UNIVERSITÁ DEGLI STUDI DI TRIESTE
– Dipartimento di Fisica –
VERBALE N.34 del
DEL COLLEGIO DEI DOCENTI
DELLA SCUOLA DI DOTTORATO IN FISICA

Il giorno 13 novembre 2012 alle ore 11, presso il Dipartimento di Fisica dell'Università, sede di via Valerio, 2, aula C, si è riunito, regolarmente convocato, il Collegio dei Docenti. Presiede il Prof. Paolo Camerini. Sono presenti:

	Università di Trieste Dipartimento di:		presente	assente	assente giustif.
– Componenti effettivi:					
1. ARFELLI Fulvia	RC	Fisica	…	…	X
2. BENATTI Fabio	RC	Fisica	…	…	X
3. BORGANI Stefano	PA	Fisica	X	…	…
4. BOSISIO Luciano	PA	Fisica	X	…	…
5. CAMERINI Paolo	PA	Fisica	X	…	…
6. CANTATORE Giovanni	PA	Fisica	X	…	…
7. DELLA RICCA Giuseppe	RC	Fisica	…	…	X
8. FRANCIOSI Alfonso	PO	Fisica	X	…	…
9. GIRARDI Marisa	RC	Fisica	X	…	…
10. GREGORIO Anna	RC	Fisica	X	…	…
11. LANCERI Livio	PO	Fisica	X	…	…
12. LONGO Renata	PA	Fisica	X	…	…
13. MARDIROSSIAN Fabio	PO	Fisica	…	…	X
14. MARTIN Anna	PA	Fisica	…	…	X
15. MATTEUCCI M. Francesca	PO	Fisica	X	…	…
16. MILOTTI Edoardo	PA	Fisica	…	…	X
17. MODESTI Silvio	PO	Fisica	X	…	…
18. PARMIGIANI Fulvio	PO	Fisica	X	…	…
19. PERESSI Maria	PA	Fisica	X	…	…
20. RUI Rinaldo	PO	Fisica	X	…	…
21. SENATORE Gaetano	PO	Fisica	…	…	X

Il Presidente, constatato il numero legale dei componenti effettivi del Collegio intervenuti, apre la riunione alle ore 11:10.

1. Approvazione OdG
2. Comunicazioni del Direttore.
3. Comunicazioni dei membri del Collegio.
4. Approvazione del Verbale n. 33.
5. Assegnazione posti e borse di dottorato per il XXVIII ciclo
6. Delibera sulla positiva conclusione dell'anno accademico 2012 per i dottorandi del XXV ciclo e richieste di proroga.
7. Ammissione all'esame finale dei dottorandi del XXV ciclo.
8. Approvazione referee esterni.
9. Nomina delle commissioni per l'esame finale del dottorato: proposte e delega al Direttore.
10. Delibera sulle date dell'esame finale: delega al Direttore.
11.Selezione dei dottorandi: istituzione di una commissione per l'elaborazione di proposte.

12. Attività seminariale dei dottorandi: istituzione di una commissione per l'elaborazione di proposte.
13. Pratiche studenti.
14. Varie ed eventuali.

1. **Approvazione OdG.**
L'ordine del giorno è approvato all'unanimità.

2. **Comunicazioni del Direttore.**

Si è concluso il concorso ordinario per il XXVIII ciclo: 18 candidati hanno passato la selezione.
I seminari di fine anno dei dottorandi si terranno nei giorni 4/5 dicembre per l'ultimo anno (in concomitanza alla riunione Consiglio Scientifico), e nei giorni 22-26 novembre per l'area "struttura della materia", 29 novembre per l'area "astro", 30 novembre per l'area "Nucleare e subnucleare".

3. **Comunicazioni dei membri del Collegio.**

Non ci sono comunicazione dei membri del collegio.

4. **Approvazione del Verbale n. 33.**

Il Verbale n. 33 viene approvato, esclusi gli assenti al precedente collegio.

5. **Assegnazione posti e borse di dottorato per il XXVIII ciclo**

Viene presa in esame la graduatoria relativa alla selezione ordinaria e le opzioni per cui e' stata verificata la competenza. Si discute relativamente al fatto che non viene più richiesta ai candidati una graduatoria nelle borse opzionate. La prof.ssa Matteucci chiede che il prossimo anno risulti da bando più chiaro ai candidati che può venir loro assegnata una qualsiasi delle borse opzionate. Viene approvata l'assegnazione delle borse secondo il prospetto qui sotto.

cognome	nome	TOT	libera	INFN	INAF	Sincro	Borsa assegnata
FERRARI	EUGENIO	110.0				Sincro	**D9 FEL**
CAROLLO	FEDERICO	109.0	libera	INFN			**D7 INFN**
ESPOSITO	MARTINA	107.5	libera	INFN		Sincro	**M1 UniTS**
PANIZON	EMANUELE	105.0	Libera				**M2 UniTS**
GOZ	DAVID	101.0	Libera		INAF		**M3 UniTS**
ALBA	PAOLO GIUSEPPE	99.5	libera	INFN			**M4 UniTS**
OMICIUOLO	LUCA	98.0	Libera			Sincro	**D8 Sincro**
PIVIDORI	MARCO	97.0	Libera				**M5 UniTS**
PUGLISI	ARMANDO	96.5	libera	INFN	INAF		**D10 INAF**
UMER	TOMO	95.0	libera	INFN			
MUNINI	RICCARDO	94.5	libera	INFN			
FEDON	CHRISTIAN	94.0	libera	INFN			
PARISI	ALESSANDRO	93.5	libera	INFN			
GASBARRI	GIULIO	93.0	libera	INFN			
SIKORSKY	TOMAS	92.0	Libera				
CASOLARI	FRANCESCO	91.0	Libera			Sincro	
ANNUNZIATELLA	MARIANNA	87.0	Libera		INAF		
STELLA	CARLO	85.5	libera	INFN		Sincro	

Questo punto dell'ordine del giorno viene redatto, letto ed approvato seduta stante.

6. **Delibera sulla positiva conclusione dell'anno accademico 2012 per i dottorandi del XXV ciclo e richieste di proroga.**

Tutte le relazioni di fine anno sono state ricevute entro i tempi richiesti. Vengono lette ed approvate singolarmente le relazioni (vedi All.1)di:
Dorigo (Vitale/Zanetti), Montanino (Cossutti/Della Ricca), Lea (Camerini,Piano), Lopez (Longo), Novelli (Parmigiani/Fausti), Olivieri (Morgante), Vattakunnel (Matteucci/Tozzi), Capogrosso (Parmigiani/Malvestuto), Mohammadi (Parmigiani/Tromba).

Si esamina la richiesta di proroga per Argentieri, presentata dal supervisore dott. Fabio Benatti. Il Collegio approva l'estensione per un anno a maggioranza (con un astenuto).

Si esamina la richiesta di proroga per Contini presentata dal supervisore Gabriella De Lucia. Interviene Borgani che completa le informazioni. Il Collegio approva l'estensione per un anno maggioranza con un astenuto.
Questo punto dell'ordine del giorno viene redatto, letto ed approvato seduta stante.

7. **Ammissione all'esame finale dei dottorandi del XXV ciclo.**

In base all'esame delle relazioni di fine anno e dei riassunti delle tesi (vedi All. 2) , si delibera l'ammissione all'esame finale dei seguenti dottorandi del XXV: Dorigo, Montanino, Lea, Lopez, Novelli, Olivieri , Vattakunnel , Capogrosso e Mohammadi.

Questo punto dell'ordine del giorno viene redatto, letto ed approvato seduta stante.

8. **Approvazione referee esterni.**

Si approvano i referee secondo la tabella sottostante (I e II nome della tabella, il terzo essendo approvato come possibile sostituto). Si delega altresì il Direttore a nominare dei sostituti in caso di rinuncia.

DOTTORANDO		**CYCLE**	**Referee1**	**Referee2**	**Ref. 3**	Titolo ricerca
OLIVIERI Giorgia	Morgante	**XXV**	Prof. Maurizio Canepa Dipartimento di Fisica Università di Genova	Prof. Gvido Bratina Vice rector for research, University of Nova Gorica,	Dr. Deborah Prezzi Università di Modena	Organic Electronic Devices: Investigation of the Electronic Transport Properties at the Molecular Level
Capogrosso Valentina	Parmigiani	**XXV**	Andrea Damascelli damascelli@physics.ubc.ca	Mario Cuoco mario.cuoco@spin.cnr.it	Federico Boscherini (UNIBO)	Dimensionality and ordering effects on the electronic structure of low dimensional strongly correlated electron transition metal oxides.
Novelli Fabio	Parmigiani / Fausti	**XXV**	Dr Adolfo Avella: avella@sa.infn.it	Dr. Ra'anan I.Tobey: r.i.tobey@rug.nl	Dr. Simon Wall: wall@fhi-berlin.mpg.de	In search of selective excitations for studying out-of-equilibrium properties in strongly correlated electron systems and high temperature superconductors.
MOHAMMADI Sara	Tromba / Parmigiani	**XXV**	Prof. Josef Kaiser Brno University of Technology - Faculty of Mechanical Engineering - Institute of Physical	Dr.ssa Alessia Cedola CNR - Istituto di Fotonica e Nanotecnologi ROMA	Giacomo Ceccone Joint Research Centre - ISPRA Establishment 21020 VARESE	Bio-medical X-ray imaging with Synchrotron Radiation: study and implementation of algorithms related to

			Engineering	Email: cedola@ifn.cnr.it	Email: giacomo.ceccone@jrc.it	phase sensitive techniques
LOPEZ Frances Caroline	Longo Renata	**XXV**	Roberto Bellotti (Bari) Roberto Bellotti <Roberto.Bellotti@ba.infn.it>	Roberto Cirio (to), <cirio@to.infn.it>	valeria Rosso	Single photon counting system for mammography with synchrotron radiation
DORIGO Mirco	Zanetti / Vitale	**XXV**	Pierluigi Campana LNF Pierluigi.Campana@lnf.infn.it	Franco Simonetto Univ.Padova franco.simonetto@pd.infn.it	Batignani	Search for New Physics in the B0_s--> J/Psi phi and B0_s-->phi phi Decays at CDF
MONTANINO Damiana	Cossutti / Della ricca	**XXV**	Prof. Attilio Andreazza (Universita` degli Studi di Milano and INFN, Sezione di Milano); Attilio.Andreazza@cern.ch	Dr. Maarten Boonekamp (IRFU/CEA Saclay, France) Maarten.Boonekamp@cern.ch	Markus Elsing	Study of the associated production of a Z boson and jets in pp collisions at sqrt(s) = 7 TeV at CMS
LEA Ramona	Camerini, Piano	**XXV**	Josef Pochodzalla Institut fuer Kernphysik Universitaet Mainz pochodza@kph.uni-mainz.de	Prof. Dr. Laura Fabbietti Physik Department E12, Techn. Univ. Muenchen; Laura.Fabbietti@ph.tum.de	Prof. Aldo Zenoni, univ. Brescia zenoni@bs.infn.it	Study of hypernuclei production in Pb-Pb collisions at √sNN = 2.76 TeV with the ALICE experiment at the LHC

9. Nomina delle commissioni per l'esame finale del dottorato: proposte e delega al Direttore.

Il Direttore propone una commissione mista Astro/Nucleare/Fisica-Medica. Si propone: dott. Monaco (Supplente Mezzetti), prof. Andreazza e prof. Cirio. Supplenti: prof. Simonetto, prof. Bellotti. Si delibera altresì di far esaminare da questa commissione la dottoranda Sara Mohammadi.
Si delega altresì il Direttore a nominare dei sostituti in caso di rinuncia.
Commissione: prof. Avella, prof. Canepa, prof. Comelli (presidente); supplenti prof. Parmigiani, prof. Gvido Bratina, Prof. Federico Boscherini.

Si da' delega al Direttore per nominare un altro supplente.

Questo punto dell'ordine del giorno viene redatto, letto ed approvato seduta stante.

10. Delibera sulle date dell'esame finale: delega al Direttore.

Il Consiglio delega il Direttore.
Questo punto dell'ordine del giorno viene redatto, letto ed approvato seduta stante.

11. Selezione dei dottorandi: istituzione di una commissione per l'elaborazione di proposte.

Seguendo la discussione di una precedente riunione del Collegio sul tema delle modalità di reclutamento e attrattività del dottorato verso l'esterno, si sono manifestate alcune candidature per una commissione istruttoria sul tema: Senatore, Lanceri, Borgani e Camerini. Il Collegio approva a maggioranza.

12. **Attivita' seminariale dei dottorandi: istituzione di una commissione per l'elaborazione di proposte.**

Su stimolo del Consiglio Scientifico, ci si pone l'obiettivo di organizzare attività seminariali affinché i dottorandi sviluppino migliori capacità di comunicazione. Il Direttore suggerisce che sia la commissione didattica ad istruire eventuali proposte, con l'aiuto dei colleghi che si occupano dei seminari (dott.ssa Gregorio). Il Consiglio approva.

13. **Pratiche studenti.**

Non ci sono pratiche studenti.

14. **Varie ed eventuali.**

Non ci sono varie ed eventuali..

La seduta si chiude alle ore 13:00.

IL PRESIDENTE
Prof. P. Camerini

IL SEGRETARIO
Dr. A. Gregorio

ALLEGATO 1

End-of-cycle Report

Candidate: Mirco Dorigo
Advisors: Dr. Anna Maria Zanetti, Dr. Marco Rescigno
University supervisor: Dr. Lorenzo Vitale

Doctoral School of Physics of the University of Trieste
XXV Entrance, 2010–2012

Research activity

My research activity during the PhD course has been conducted entirely with the INFN group of Trieste working in the Collider Detector at Fermilab (CDF) experiment, under the supervision of Dr. Anna Maria Zanetti (INFN Trieste) and Dr. Marco Rescigno (INFN Roma I). The CDF experiment is a collaboration of about 600 physicists from more than 50 institutions in 12 countries. The detector is a large, multipurpose solenoidal magnetic spectrometer surrounded by 4π projective calorimeters and fine-grained muon detectors that ended operations in September 2011. It measured energy, momentum and mass of a broad range of final-state particles produced in 1.96 TeV proton-antiproton collisions provided by the Tevatron collider.

Over the course of the first year, I have continued the work on the $B_s^0 \to \phi\phi$ decay started the year before with my Master degree's project on the first measurement of the polarization amplitudes of this decay mode. The $B_s^0 \to \phi\phi$ decay belongs to the class of decays of pseudoscalar mesons into two vector particles. They feature a rich dynamics that involves three different decay amplitudes corresponding to the polarization states allowed by angular momentum conservation. In the standard model, the quark-level $b \to s$ *penguin* process, which is a higher-order flavor-changing transition, dominates the amplitude. This provides an opportunity to indirectly access new physics through this channel, if exchange of new virtual massive particles occurs. Some deviations from theory expectations were indeed observed in similar channels. Explanations involving either new physics models or improved calculations within the standard model were proposed. Additional experimental information in B_s^0 penguin-dominated decays help distinguishing the various solutions.

The core of the polarization measurement is a simultaneous fit to the mass and the angular distributions of the final state particles from a signal of about 300 events. In the finalization of the measurement I have evaluated the biases in the measurement

due to the sculpting of the decay-time distribution induced by the trigger and carried out the calculation of all the systematic uncertainties of the measurement. I gave the first public presentation of the results (Moriond QCD 2010 [A5]) which include the best measurement of the $B_s^0 \to \phi\phi$ branching ratio, and the first measurement of the $B_s^0 \to \phi\phi$ polarization amplitude, showing a significantly suppressed longitudinal polarization. I reported them also at the CKM workshop 2010 [A4] and directly contributed to the corresponding Letter in *Physical Review* [1].

The $B_s^0 \to \phi\phi$ decay is predicted to exhibit tiny, if any *CP* violation. A measurement of nonzero *CP*-violating asymmetries would indicate physics beyond the standard model. After the completion of the polarization measurement, I've devised an original method to measure *CP*-violating asymmetries with our small signal sample of $B_s^0 \to \phi\phi$ decays. In close collaboration with phenomenologists (Prof. J. Rosner, Prof. D. London, Dr. A. Datta) I've constructed new observables that make *CP* violation accessible in $B_s^0 \to \phi\phi$ decays even with small samples and have now been adopted also by LHCb in their $B_s^0 \to \phi\phi$ analysis. I have included the new observables in a maximum likelihood fit and measured them for the first time, obtaining no evidence for *CP* violation. The analysis was approved in March 2011 and I presented the results at the 2011 BEAUTY conference [A3]. These are published in *Physical Reviews Letters* [1].

While completing the $B_s^0 \to \phi\phi$ measurement, in the second year of my PhD course I've gradually moved my research interests toward the final CDF measurement of *CP* violation in B_s^0 mixing using the $B_s^0 \to J/\psi\phi$ decays. Particle-antiparticle oscillations of the B_s^0 meson proceed through loop transitions where possible new particles or couplings can compete with the standard model ones yielding observable contributions. The *CP*-violating phase of the B_s^0–$\bar{B}_s^0$ mixing amplitude is particularly promising since it is predicted to be very small in the standard model. A non-standard model enhancement of the phase also decreases the decay width difference between the light and heavy mass eigenstates of the B_s^0 meson, $\Delta\Gamma_s$. The time-evolution of the $B_s^0 \to J/\psi\phi$ decays where the flavor of the bottom-strange meson is identified at production is the most effective probe of the phase and of the width difference.

In 2010, CDF had just released the measurement based on a subsample of the available data. I've joined the small group that aimed at conducting the final update of the measurement using the whole data set. The crux of the measurement is a multivariate likelihood fit to the time-evolution of $B_s^0 \to J/\psi\phi$ decays that exploits advanced techniques for statistically separating the signal from backgrounds and distinguishing the B meson's flavor at production (neural networks, particle identification, flavor tag-

ging techniques, etc.). Along with another student I was the reference person in CDF for this analysis and I had control on each individual step of the work, from selection of the data and control samples, to generation of simulated samples, to development of the fit and the study of its features, to the final extraction of the results with their systematic uncertainties. We extended the previously-finalized analysis to a sample doubled in size and we introduced several improvements in the analysis technique, such as a new calibration of the tagging, and an original, accurate determination of previously-neglected physics background that mimic signal.

One of my specific tasks was the development of a previously-unavailable realistic simulation of the $B_s^0 \to J/\psi K^+K^-$ decays complete with the whole resonant substructure. This built confidence in the determination of the contamination from S-wave decays in the main analysis, which is important since discrepancies among experiments are observed for this quantity. Similarly, another specific responsibility I had was an auxiliary simultaneous fit of the K^+K^- and $J/\psi K^+K^-$ mass distributions to independently determine the S-wave fraction and check the main fit's result. In this study the full resonance structure of the $B^0 \to J/\psi K\pi$ decays is included for the first time and it contribute with a sizable background due to mis-identification of the pion as a kaon. The contamination from mis-identified B^0 decays is found to be significantly larger than typically derived assuming only P-wave B^0 decays and, if neglected, could mimic a larger K^+K^- S-wave component than present.

During this analysis, I was co-supervisor of the master student Lucia Grillo, who was in charge of validating the quality of the new data, studying the sample composition in terms of trigger selections and doing some control checks of the main fit result with the measurement of the $\Delta\Gamma_s$ assuming no CP violation.

I presented the preliminary results, approved in early 2012, at the 2012 Moriond QCD conference and at the 2012 ICHEP conference [A2, A1]. The results feature improved confidence intervals for the B_s^0 mixing phase that are second in precision only to LHCb and agree with the standard model expectation. The measurements of the B_s^0 lifetime, width difference, and polarization amplitudes are among the most precise available to date and show consistency with expectations and determinations from other experiments. A Letter documenting these results is published by *Physical Review Letters* [2].

During my PhD, I've served in CDF operations for a total of forty-five 8-hours shifts in the three-people crew of the control room directly responsible for the data acquisitions process and monitoring of the detector stability.

Teaching experience

May–Oct 2011 Co-supervisor of student Lucia Grillo (University of Trieste) on the master's degree thesis "Measurement of B_s^0 lifetime, decay width difference and polarization amplitudes of the $B_s^0 \to J/\psi\phi$ decays at CDF".

Jul–Aug 2010 Tutor of Fermilab summer student Gabriele Bertoli (University of Trieste) within the DOE/INFN Summer Exchange Program at Fermilab (USA).

Attended schools

XXI giornate di studio sui rivelatori May 10–13, 2011, Villa Gualino, Torino;

69th Scottish Universities Summer School in Physics Aug 19 – Sept 1, 2012, St. Andrews (United Kingdom).

Plan of studies

Introduzione ai metodi Bayesiani (Prof. E. Milotti), 16 hours;

Test sperimentali del Modello Standard (Dr. F. Cossutti), 16 hours;

Electroweack and Strong Interactions (Prof. S. Petcov and Prof. G. Martinelli, SISSA), 50 hours.

Conference talks

36th International Conference on High Energy Physics talk on *CDF results on CP violation in hadronic B decays*, Jul 4–11, 2012, Melbourne (Australia);

47th Rencontres de Moriond, QCD and High Energy Interactions talk on *Recent heavy flavor results from the Tevatron*, Mar 10–17, 2012, La Thuile (Italy);

13th International Conference on B-Physics at Hadron Machines talk on *Suppressed B_s^0 decays at CDF*, Apr 4–8, 2011, Amsterdam (The Netherlands);

6th International Workshop on the CKM Unitarity Triangle talk on *Charmless and Penguin Decays at CDF*, Sept 6–10, 2010, University of Warwick (United Kingdom);

45th Rencontres de Moriond, QCD and High Energy Interactions talk on *Measurements of the masses, lifetimes and decay modes of hadrons at Tevatron*, Mar 13–20, 2010, La Thuile (Italy).

Publications

As a member of the CDF Collaboration's default authors list I am co-author of about 90 papers (see `http://inspirehep.net/search?p=author%3AM.Dorigo.1` for complete list). In the following, I list the ones for which I actively participated giving a direct contribution – public papers have been inserted in the U-GOV catalogue.

Journals Paper

[1] T. Aaltonen *et al.* (CDF Collaboration), *Measurement of Polarization and Search for CP Violation in $B_s^0 \to \phi\phi$ Decays*, Phys. Rev. Lett. **107**, 261802 (2011) [arXiv:1107.4999 (hep-ex)].

[2] T. Aaltonen *et al.* (CDF Collaboration), *Measurement of the Bottom-Strange Meson Mixing Phase in the Full CDF Data Set*, Phys. Rev. Lett. **109**, 171802 (2012) [arXiv:1208.2967 (hep-ex)].

Conference Proceedings

[A1] M. Dorigo (for the CDF Collaboration), *CDF results on CP violation in hadronic B decays*, (2012), in preparation, for the 36th International Conference on High Energy Physics.

[A2] M. Dorigo (for the CDF and D0 Collaborations), *Recent heavy flavor results from the Tevatron*, (2012) [arXiv:1205.3899 (hep-ex)], for the 47th Rencontres de Moriond, QCD and High Energy Interactions.

[A3] M. Dorigo (for the CDF Collaboration), *Suppressed B_s^0 Decays at CDF*, (2011) [arXiv:1105.4437 (hep-ex)], for the 13th International Conference on B-Physics at Hadron Machines.

[A4] M. Dorigo (for the CDF Collaboration), *Charmless and Penguin Decays at CDF*, (2010) [arXiv:1012.4738 (hep-ex)], for the 6th International Workshop on the CKM Unitarity Triangle.

[A5] M. Dorigo (for the CDF and D0 Collaborations), *Measurements of the masses, lifetimes and decay modes of hadrons at Tevatron*, (2010) [arXiv:1005.2564 (hep-ex)], for the 45th Rencontres de Moriond, QCD and High Energy Interactions.

CDF Public Note

[B1] M. Dorigo *et al.*, *Measurement of B_s^0 Mixing Phase in $B_s^0 \to J/\psi\phi$ Decays Using the Full Run II Data Sample*, CDF Note 10778 (2012).

[B2] M. Dorigo *et al.*, *Measurement of Triple Products Asymmetries of the $B_s^0 \to \phi\phi$ Decay*, CDF Note 10424 (2011).

[B3] M. Dorigo *et al.*, *Measurement of the Polarization Amplitudes of the $B_s^0 \to \phi\phi$ Decay*, CDF Note 10120 (2010).

CDF Internal Note

[C1] M. Dorigo *et al.*, *An Updated Measurement of the CP-Violating Phase β_s in 9.6 fb^{-1} of Data*, CDF Internal Note 10722 (2012).

[C2] M. Dorigo *et al.*, *Study of Triple Products in the $B_s^0 \to \phi\phi$ Decay*, CDF Internal Note 10416 (2011).

[C3] M. Dorigo *et al.*, *Measurement of the Polarization Amplitudes of the $B_s^0 \to \phi\phi$ Decay*, CDF Internal Note 10073 (2010).

Trieste, November 8, 2012

Ph.D. student: Damiana Montanino

Ph.D. School of Physics XXV Cycle (IV School Cycle) End-of-cycle report

The research activity carried out during these years covers different sectors. During the first year it was focused on the characterization of minijets and minijet pairs as pattern of Multiple Parton Interactions (MPIs) in proton-proton collisions at LHC with the CMS detector. This process is believed to be of fundamental importance for the description of the hadron interactions and in particular for the comprehension of the Underlying Event, that describes the part of the event that cannot be directly attributed to the hardest parton-parton interaction. The parton level cross section predicts the maximum for transverse momenta tend to zero, therefore these phenomena are observed principally at low energy scale, where it is not possible to use the perturbative QCD in order to formulate theoretical predictions. Phenomenological models are needed for the description of these processes, which must be compared to the data in order to be checked and improved.

This study used the 900 GeV data collected by the CMS experiment in the 2010 and a part of those at 7 TeV, exploiting minijets (jets with very low transverse momenta) obtained by tracks, chosen due to the optimum resolution of the tracking system of CMS. A set of observables complementary to the ones used by the traditional analysis of the Underlying Event was studied, following analyses performed in the past by the UA1 Collaboration. The results obtained from the data were compared with different Monte Carlo samples in order to reject some models and understand which of them describe better the analysed events.

From the second year the doctoral activity was related to the study carried out in the thesis, the characterization of the associated production of a Z boson and jets (Z+jets) in proton-proton collisions at LHC with the CMS detector.

Initially a study of the calibration of the electromagnetic calorimeter (ECAL) of CMS was performed, as part of the activities to understand in detail the detector response. The problem taken into account was the energy containment. Given a photon that hits the calorimeter, the energy associated to the object is the one measured in a particular cluster (3×3 crystals). The fraction of energy not contained in the range was studied as a function of the energy and pseudo-rapidity of the photon in order to construct functions that could correct the results for this effect. This study was performed considering neutral pions (π^0) decaying in two photons and comparing the reconstructed energy with information from the Monte Carlo truth. Finally the obtained results were tested exploiting the reconstructed invariant mass of the boson pairs and comparing the variation of the peak of the distribution with the expected

value of π^0 mass.

A dedicated study regarding electrons was then carried on, in preparation for their use as signature for the Z boson selection. In the framework of the CMS analysis it is possible to use different algorithms to reconstruct the electrons, optimized in particular scenarios. Hence a point of particular interest was the choice of the electron reconstruction algorithm to consider.

The standard method gives origin to the set called GSF Electrons, and starts from the production of calorimeter deposits followed by the Gaussian Sum Filter (GSF) algorithm, a specialized reconstruction for tracks with sizable energy losses. The alternative method is based on Particle Flow algorithm, a global event description which uses the combined information provided by all CMS sub-detectors, as ECAL energy deposits or track segments, for an optimal determination of the direction, energy and type of all the stable particles in the event, as electrons, muons, photons, charged hadrons and neutral hadrons.

The results obtained with the two methods were analysed in order to evaluate the best procedure for the Z boson reconstruction. The electrons resulting with the different algorithm and with the Monte Carlo truth were compared. Also the Z boson obtained by the two kinds of electrons was taken into account, observing how the invariant mass varied in different conditions.

The remaining part of the doctoral activity was focused on the characterization of Z+jets events reconstructed in CMS; this analysis is part of a more general publication in course of preparation. This study provides an important Standard Model (SM) test, a detector commissioning ground through physics, and last but not least a powerful probe for new phenomena.

In the context of the SM, the study of jets produced in association with Z allows for tests of perturbative QCD (pQCD) calculations. The leading order (LO) and next-to-leading order (NLO) predictions are in good agreement with data, but the latter, available for Z+n jets, with n up to 4, are only known with a precision varying from 10% up to 30%, due to uncertainties on the parton distribution functions and on the perturbative nature of the calculations.

The Z+jets production is an important background in searches on supersymmetry, in Higgs and Dark Matter signatures, and for studies of the top quark. Many extensions of the SM predict new particles with electroweak couplings that decay into SM gauge bosons accompanied by jets.

This study used the 7 TeV data collected by the CMS experiment in the 2011 using jets and vector bosons detected through their decays into electron-positron pairs. The corresponding total integrated luminosity was estimated to be about 4.89 fb^{-1}.

The strategy for the selection of the events was to first look for a Z boson. The presence of a pair of well-identified and isolated high energy electrons was required as signature of the boson decay. In the analysis, several different observables were considered. The differential jet rate cross section was measured, as well as the transverse momentum p_T and pseudo-rapidity η distributions for the four highest transverse momentum jets. The distribution of the scalar sum of jet transverse momenta H_T was also measured as a function of the jet multiplicity.

Hence the jet reconstruction had a main role in the definition of the results. The

jets considered in the study were reconstructed using a sequential clustering algorithm. Quality cuts were applied to reduce the contamination from the underlying events and to provide good jet identification and good noise jet rejection.

The final distributions were obtained applying efficiency corrections and deconvolving the detector effects from the physics ones by means of the unfolding procedure. The associated systematic uncertainties represented an important aspect to deal with, and involved in particular the definition and the counting of jets. The dominant experimental uncertainties were caused by the jets energy corrections that could modify the measured number of these hadronic objects. Other important sources of systematics effects were given by the unfolding method, the evaluation of the efficiencies, the contribution from the pile-up and the background subtraction. The results were compared with pQCD theoretical predictions at leading order, extracted from two different models, Madgraph plus Pythia6 and Sherpa. An overall good agreement was globally found on all the analysed observables, considering the large uncertainties on the predictions due to the choice of the parton density functions and the scale of the interaction.

List of publications:

- **"Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, or at least 3 b-quark jets in 7 TeV pp collisions using the variable alphaT"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.8115 [hep-ex]

- **"Search for a non-standard-model Higgs boson decaying to a pair of new light bosons in four-muon final states"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.7619 [hep-ex]

- **"Measurement of the sum of WW and WZ production with W+dijet events in pp collisions at $\sqrt{s} = 7$ TeV"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.7544 [hep-ex]

- **"Search for heavy quarks decaying into a top quark and a W or Z boson using lepton + jets events in pp collisions at $\sqrt{s} = 7$ TeV"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.7471 [hep-ex]

- **"Measurement of the inelastic proton-proton cross section at $\sqrt{s} = 7$ TeV"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.6718 [hep-ex]

- **"Search for pair production of third-generation leptoquarks and top squarks in pp collisions at $\sqrt{s} = 7$ TeV"**
  S. Chatrchyan *et al.* [CMS Collaboration].
  arXiv:1210.5629 [hep-ex]

- **"Observation of Long-Range Near-Side Angular Correlations in Proton-Proton Collisions at the LHC"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1009.4122 [hep-ex]
  10.1007/JHEP09(2010)091
  JHEP **1009**, 091 (2010)

- **"CMS Tracking Performance Results from early LHC Operation"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1007.1988 [physics.ins-det]
  10.1140/epjc/s10052-010-1491-3
  Eur. Phys. J. C **70**, 1165 (2010)

- **"First Measurement of the Underlying Event Activity at the LHC with $\sqrt{s} = 0.9$ TeV"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1006.2083 [hep-ex]
  10.1140/epjc/s10052-010-1453-9
  Eur. Phys. J. C **70**, 555 (2010)

- **"Measurement of the charge ratio of atmospheric muons with the CMS detector"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1005.5332 [hep-ex]
  10.1016/j.physletb.2010.07.033
  Phys. Lett. B **692**, 83 (2010)

- **"Measurement of Bose-Einstein correlations with first CMS data"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1005.3294 [hep-ex]
  10.1103/PhysRevLett.105.032001
  Phys. Rev. Lett. **105**, 032001 (2010)

- **"Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at sqrt(s) = 7 TeV"**
  V. Khachatryan *et al.* [CMS Collaboration].
  arXiv:1005.3299 [hep-ex]
  10.1103/PhysRevLett.105.022002
  Phys. Rev. Lett. **105**, 022002 (2010)

PhD Student: Ramona Lea

XXV Ciclo di Dottorato – IV Ciclo delle Scuole

End of cycle report

During my PhD I′ve worked within the Trieste group of the ALICE experiment. ALICE (A Large Ion Collider Experiment) is an experiment presently being performed at LHC (Large Hadron Collider) at CERN which studies a wide range of physics topics by colliding ultra relativistic heavy ions as well as protons.

The topic of my thesis is the study of the production of light hypernuclei in ultra-relativistic heavy-ion collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

Ultra relativistic heavy-ion collisions offer a unique opportunity for understanding the strong interaction of strange hadrons. In the collision a huge number of strange hadrons is produced and the ***s*** quark created during the collision carries information of the initial system.

In this context hyperons interactions are key to understand the phase structure of QCD at large densities and the interior of compact stars.

In the heavy-ion collision hyperon-baryon bound systems, called hypernuclei, can be produced. Hypernuclear physics offers a direct experimental way to study hyperon-nucleon (**YN**) and hyperon-hyperon (**YY**) interactions.

It is possible to discriminate two distinct mechanisms for hypercluster formation in heavy ion collisions. First, the absorption of hyperons in the spectator fragments of non central heavy ion collisions; alternatively, they can emerge from the hot and dense fireball region of the reaction. In this scenario the cluster is formed at, or shortly after,the (chemical-)freeze out of the system. According to thermal and coalescence models, (anti)(hyper)nuclei production scales with A, so systems with A=3 are predicted to be the most probable to be produced in ultra relativistic heavy-ion collisions.

The hypertriton, ${}^{3}_{\Lambda}H$, is the lightest known hypernucleus and is formed by a proton, a neutron and a Λ. ${}^{3}_{\Lambda}H$ decays mesonically into the following channels:

(1) ${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$

(2) ${}^{3}_{\Lambda}H \rightarrow {}^{3}H + \pi^{0}$

(3) ${}^{3}_{\Lambda}H \rightarrow d + p + \pi^{-}$

(4) ${}^{3}_{\Lambda}H \rightarrow d + n + \pi^{0}$

The study of the production of ${}^{3}_{\Lambda}H({}^{3}_{\bar{\Lambda}}\bar{H})$ detected via its decay ${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$ (${}^{3}_{\bar{\Lambda}}\bar{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$) using ALICE is the main topic presented in my thesis.

The study presented in the thesis is based on the statistics collected by the ALICE experiment during 2010 and 2011 data taking. The 2010 statistics is composed of about 14 millions of

minimum-bias[1] events, while the 2011 statistics is composed by 22 million of central[2], 20 million of semi-central[3] and about 1.5 million on minimum bias events.

The main detector used in the analysis is the Time Projection Chamber (TPC) of ALICE. The ALICE TPC is the main detector used for global tracking and allows the particle identification via the specific energy loss ($\mathrm{d}E/\mathrm{d}x$).

First of all, I have studied the particle identification using the specific energy loss ($\mathrm{d}E/\mathrm{d}x$). Both daughter tracks of ${}^{3}_{\Lambda}\mathrm{H}({}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}})$ (i.e., pion and helium-3), can be clearly identified using the TPC. Once the daughter tracks have been identified, it was possible to reconstruct the hypertriton signal candidates by identifying secondary vertices.

Signal extraction is based on the study of the invariant mass spectrum of $({}^{3}\mathrm{He},\pi^{-})({}^{3}\overline{\mathrm{He}},\pi^{+})$. In the analysis two types of background have been studied. The first one is the ″like - sign" method which consists in the combination of two tracks with the same sign (i.e. $[{}^{3}\mathrm{He} + \pi^{+}]$or $[{}^{3}\overline{\mathrm{He}} + \pi^{-}]$), and the second is the combined fit (third degree polynomial function for the background and a Gaussian for the signal) of the invariant mass spectrum. From the invariant mass spectrum fit it is possible to extract mean $\boldsymbol{\mu}$, width $\boldsymbol{\sigma}$, raw yield and significance of the signal.

The efficiency evaluation is based on the study of Monte Carlo productions ″anchored" to the data by using Hjiing (a heavy-ion simulator) with hypertriton signal injected.

I have been responsible of the introduction of hypernuclei in the AliRoot framework, and I took care of the quality checks of those Monte Carlo simulations.

I have studied the (anti)hypertrion efficiency estimation as a function of several variables, like the transverse momentum, the proper lifetime, the momentum of the daughters tracks and the pseudorapidity of the $({}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}})^{3}_{\Lambda}\mathrm{H}$, and I made several systematics studies.

To extract the 2010 and 2011 yield I have studied two different procedures. 2010 statistics allows to extract only an integrated p_{T} yield: the method used to extract the corrected yield is based on two 2-d histograms (Invariant Mass vs p_{T}) for Signal+Background $({}^{3}\mathrm{He} + \pi^{-})$(S+B) and Background $({}^{3}\mathrm{He} + \pi^{+}$, Like-Sign background)(B). By their subtraction ((S+B)-B) is possible to get the Signal (S). Correcting the S histogram for p_{T} efficiency will provide the integrated yield.

2011 statistics allow to divide the ${}^{3}_{\Lambda}\mathrm{H}$ invariant mass spectrum in 3 p_{T} bins ([2-4],[4-6] and [6-10] GeV/c) and the acceptance correction analysis can be performed directly on the signal.

Each p_{T} bin is corrected for the corresponding efficiency so it has been possible to obtain a spectrum vs p_{T}.

The same analysis have be performed separating ${}^{3}_{\Lambda}\mathrm{H}$ from ${}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$. The two spectra show a similar yield for ${}^{3}_{\Lambda}\mathrm{H}$ and ${}^{3}_{\bar{\Lambda}}\overline{\mathrm{H}}$.

1 Minimum-bias events have a centrality between 0 and 100 %
2 Central events have a centrality between 0 and 10 %
3 Semi-central events have a centrality between 10 and 70 %

To evaluate the strangeness population factor [$S_3=({}^3_\Lambda H + {}^3_{\bar\Lambda}\bar{H})/({}^3He + {}^3\overline{He}) / (\Lambda/p)$], which is a good representation of the local correlation between baryon number and strangeness, the study of the ${}^3He$ (${}^3\overline{He}$) yield is needed. I have evaluate the corrected yield by using the 2011 data and I studied the related systematic errors.

Using the 2011 data set has also been possible to extract the lifetime of ${}^3_\Lambda H$. The total invariant mass spectrum has been divided into 3 $c\tau$ bins and an estimation on the ${}^3_\Lambda H$ mean lifetime has been provided.

I have reported regularly the results of my work during the Physics Analysis Group (PAG) meeting dedicated to Strangeness held every week at CERN, and during Physics Working Group (PWG) meeting, held every month at CERN. Results have also being reported during the ALICE Physics Week held in Jyvaskyla, (Finland, 29th August – 2nd September 2011).
In addition, the results have been reported in three international conferences:

- Strangeness in Quark Matter (SMQ2011) – Cracow, Poland, 18th -24th September 2011;
- 2nd European Nuclear Physics Conference (EunPC) - Bucharest, Romania , 17th -21th September 2012;
- XI International Conference on Hypernuclear - Barcelona, Spain, 1st - 5th October, 2012 ;

and at the

- XCVII Congress of the Italian Society of Physics (SIF) - L'Aquila (26th – 29th September 2011).

During the 2011 Pb-Pb data taking, I joined the ITS QA Task Force, a special group of analysis formed to check in "real time" reconstructed data and I've written some tasks useful for Quality Assurance (QA) analysis. I have took several QA shift, reporting the results during the weekly ALICE-QA meetings.

Plan of studies

Attended Courses:

- F. Cossutti (INFN), Test sperimentali del Modello Standard, 16 ore
- P. Camerini, Fisica sperimentale con Kaoni di bassa energia, 12 ore
- S. Dalla Torre (INFN), Rivelatori a gas di particelle ionizzanti e rivelatori RICH, 15 ore
- V. Bonvicini (INFN), Rivelatori al silicio ed elettronica di lettura, 16 ore.
- E. Milotti, Introduzioni ai metodi Bayesiani, 16 ore
- P. Schiavon, Metodi di fit e filtro di Kalman, 10 ore.

Passed Exams:

- S. Dalla Torre (INFN), Rivelatori a gas di particelle ionizzanti e rivelatori RICH (Oral exam);
- A. Milotti, Introduzione ai metodi Bayesiani (Seminar);
- P. Camerini, Fisica sperimentale con Kaoni di bassa energia (Seminar and oral exam);
- F. Cossutti (INFN), Test sperimentali del Modello Standard (Seminar and oral exam);
- V. Bonvicini (INFN), Rivelatori al silicio ed elettronica di lettura (Seminar and oral exam);
- P. Schiavon, Metodi di fit e filtro di Kalman (Oral exam).

Attended PhD Schools:

- XX Giornate di studio sui rivelatori, Centro congressi di Villa Gualino, Torino, 23-26 February 2010;
- VII Seminario sul Software per la fisica Nucleare, Subnucleare e Applicata, Alghero, 31 May - 4 June 2010;
- 4th Summer School on Physics of LHC School: Theoretical and Experimental Aspects, Martignano (Lecce), 14-19 June 2010;
- IV scuola per utenti INFN della GRID, INFN-CNAF Bologna 21-24 February 2011.

Attended conferences

- Strangeness in Quark Matter, 18-24 September 2011 Polish Academy of Arts and Sciences, Cracow, Poland;
- XCVII Congresso Nazionale Società Italiana di Fisica, L'Aquila 26-30 Settembre 2011;
- 2nd European Nuclear Physics Conference (EunPC) - Bucharest, Romania , 17th -21th September 2012;
- XI International Conference on Hypernuclear - Barcelona, Spain, 1st - 5th October, 2012 ;

Publications

- **Hypernuclei Production in Pb–Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE at LHC.**
  Ramona Lea for the ALICE Collaboration.
  Proceedings of the conference HYP2012, Barcelona Spain.

- **Light Hypernuclei Production in Pb–Pb Collisions at $\sqrt{s_{NN}}$=2.76 TeV with ALICE at LHC.**
  Ramona Lea for the ALICE Collaboration.
  Proceedings of the conference SQM2011, Cracow, Poland.
  Acta Physica Polonica B Proceedings Supplement vol. 5 (2012) page 599

- **Neutral pion and η meson production in proton-proton collisions at $\sqrt{s}$ = 0.9 TeV and 7 TeV.**
  ALICE Collaboration, Physics Letters B717 (2012), pp. 162-172.

- **Harmonic decomposition of two-particle angular correlations in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.**
  ALICE Collaboration, Physics Letters B708 (2012), pp. 249-264.

- **Underlying Event measurements in pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV with the ALICE experiment at the LHC.**
  ALICE Collaboration, JHEP 1207 (2012), pp. 116.

- **Light vector meson production in pp collisions at $\sqrt{s}$ = 7 TeV.**
  ALICE Collaboration, Physics Letters B710 (2012), pp. 557-568.

- **Particle-yield modification in jet-like azimuthal di-hadron correlations in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.**
  ALICE Collaboration, Physics Review Letters 108, 092301 (2012).

- ***J*/psi polarization in pp collisions at $\sqrt{s}$=7 TeV.**
  ALICE Collaboration, Physics Review Letters 108 (2012) 082001.

- **Measurement of charm production at central rapidity in proton-proton collisions at $\sqrt{s}$ = 7 TeV.**
  ALICE Collaboration, JHEP 01 (2012) 128.

- **Femtoscopy of pp collisions at $\sqrt{s}$=0.9 and 7 TeV at the LHC with two-pion Bose-Einstein correlations.**
  ALICE Collaboration, Physics Review D 84, 112004 (2011).

- **Transverse sphericity of primary charged particles in minimum bias proton-proton collisions at $\sqrt{s}$=0.9, 2.76 and 7 TeV.**
  ALICE Collaboration, Eur. Phys. J. C (2012) 72:2124.

- **K^0s-K^0s correlations in 7 TeV pp collisions from the LHC ALICE experiment.**
  ALICE Collaboration, Physics Letters B 717 (2012) pp. 151-161

- **Measurement of charm production at central rapidity in proton - proton collisions at $\sqrt{s}$ = 2.76 TeV.**
  ALICE Collaboration, JHEP 01 (2012) 128.

- **Production of muons from heavy flavour decays at forward rapidity in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, Physics Review Letters 109, 112301 (2012).

- **Suppression of high transverse momentum prompt *D* mesons in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, JHEP 9 (2012) 112.

- **Multi-strange baryon production in pp collisions at $\sqrt{s} = 7$ TeV with ALICE.**
  ALICE Collaboration, Physics Letters B 712 (2012) 309.

- ***J*/psi Production as a Function of Charged Particle Multiplicity in pp Collisions at $\sqrt{s} = 7$ TeV.**
  ALICE Collaboration, Physics Letters B712 (2012) 165-175.

- ***J*/psi suppression at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, Physics Letters 109, 072301 (2012).

- **Measurement of Event Background Fluctuations for Charged Particle Jet Reconstruction in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, JHEP 03 (2012) 053.

- **Heavy flavour decay muon production at forward rapidity in proton-proton collisions at $\sqrt{s} = 7$ TeV.**
  ALICE Collaboration, Physics Letters B 708 (2012) 265.

- **Production of pions, kaons and protons in pp collisions at $\sqrt{s} = 900$ GeV with ALICE at the LHC.**
  ALICE Collaboration, Eur.Phys.J.C 71(6): 1655, 2011

- **Higher harmonic anisotropic flow measurements of charged particles in Pb-Pb collisions at 2.76 TeV.**
  ALICE Collaboration, Physics Review Letters 107, 032301 (2011).

- **Strange particle production in proton-proton collisions at $\sqrt{s} = 0.9$ TeV with ALICE at the LHC.**
  ALICE Collaboration, Eur. Phys. J. C 71 (3), 1594 (2011).

- **Two-pion Bose-Einstein correlations in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, Physics Letters B696 (4): 328-337, 2011.

- **Centrality dependence of the charged-particle multiplicity density at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, Phys. Rev. Lett. 106, 032301 (2011).

- **Elliptic flow of charged particles in Pb-Pb collisions at 2.76 TeV.**
  ALICE Collaboration, Phys. Rev. Lett. 105, 252302 (2010).

- **Suppression of Charged Particle Production at Large Transverse Momentum in Central Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**

ALICE Collaboration, Phys. Lett. B 696 (2011) 30-39

- **Charged-particle multiplicity density at mid-rapidity in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.**
  ALICE Collaboration, Phys. Rev. Lett. 105, 252301 (2010).

Trieste, 09/12/12

Il dottorando
Ramona Lea

Il Responsabile
Prof. Paolo Camerini

Student : LOPEZ, Frances Caroline M.
CYCLE : XXV
Supervisor : Prof. Longo, Renata

In the period of the PhD program, the student was involved with the development of a new read-out system of the PICASSO (Phase Imaging for Clinical Application with Silicon detector and Synchrotron radiatiOn) in collaboration with SYRMEP group coming from the University of Trieste, Instituto Nazionale di Fisica Nucleare sez di Trieste and the detector group of the Swiss Light Source of Paul Scherrer Institut. One of the aims of the project is to supply an in-house detector development needed by the on-going clinical mammography research at the SYRMEP beamline at ELETTRA.

PICASSO is a digital detector that comprises a linear array of microstrip sensors that are oriented oriented "edge-on", ie it's strips are aligned in parallel to the incoming beam. It is coupled with MYTHEN II ASICs operating in single photon counting mode. Its active area of the system developed during this thesis encompasses the whole height and width of the beam at the clinical station of the SYRMEP beamline where phase-contrast may be carried out. The clinical mammographic program at the SYRMEP beamline demands that the the read-out is fast , keeping in mind the huge amount of data that has to transferred and processed in real-time. With this task, the student was involved with the detector upgrade that includes the change of controllers of the detector capable of meeting the constraints in speed for clinical studies.

In year 1, the student attended in-house courses offered by the Physics Department of the university. These includes courses in detectors, medical imaging and synchrotron applications. Also in this period, the student was also introduced to the current demands with the new controllers of the detectors that were under development. Computer languages necessary to program its operation and architecture were learned. These includes C, C++, Root, VHDL - hardware description language, Linux and Microcontroller operating systems. In this year, a two month stay was carried out with the Detector Group of Paul Scherrer Institut to understand the operations of the MYTHEN detector system and to perform preliminary tests on the new controller under development.

In the second year, the new software architecture and firmware was completed for a single PICASSO controller . Tests were carried out on its front end electronics, analog as well as digital components and the overall performance of the electronics. Collaborative work remained with the Detector Group of the Swiss Light Source in this year. Two visits to their laboratory to perform further tests with the PICASSO detector were done. Also, initial results with the new PICASSO architecture were communicated to the detector community as an oral presentation at the 13th International Workshop on Radiation Imaging Detectors at ETH Zurich, Switzerland.

The PICASSO detector was brought to the SYRMEP beamline to test its imaging capabilities. Images were taken to the experimental and clinical stations of SYRMEP. In these runs, the signal-to noise-ratio, contrast and spatial resolution were evaluated together with the dose delivered to

standard mammographic phantoms, simulating image acquisition with patients. Further, the student and the detector under development was involved in imaging studies where novel techniques on coded-apertures were used.

PICASSO detector, in its final configuration is composed of four layers grouped in two pairs, each controlled by separate controllers. Effort was given on the synchronization of the two controllers of the detector this year, concurrent with the testing with the fourth and last layer of PICASSO. The whole assembly will be tested at the beamline on 16-20 November. The planarity of all the layers will be evaluated. The alignment of the four layers may be adjusted by using the screws on the lateral sides of the detector frames. The gaps among sensors will also be checked. Ideally, minimal or zero gap should exist between the top sensor of both detector couples. The same should be true for the bottom sensors. Synchronization of the two controllers of the detector will be tested with the beam concurrent with image reconstruction putting into consideration the inherent time delay between the two.

Publications

Munro PRT*, Rigon L, Ignatyev K, Lopez FC, Dreossi D, Speller RD and Olivo A. A quantitative non-interferometric x-ray phase contrast imaging technique Optics Express (in press, 2012)

Lopez, FC*, Rigon L, Longo R, Arfelli F, Bergamaschi A, Chen RC, Dreossi D, Schmitt, B, Vallaza E, Castelli E 2011 *Development of a fast read-out system of a single photon counting detector for mammography with synchrotron JINST* ***6*** *C12031* doi:10.1088/1748-0221/6/12/C12031 *inserted in UGOV

Oral Presentation

Lopez, FC*, Rigon L, Longo R, Arfelli F, Bergamaschi A, Chen RC, Dreossi D, Schmitt, B, Vallaza E, Castelli E 2011 *Development of a fast read-out system of a single photon counting detector for mammography with synchrotron* 13th International Workshop of Radiation Imaging Detectors

Longo, R*, Arfelli F, Dreossi D, Lopez FC, Quai E, Quaia E, Tromba G, Castelli E (2011) *Misura in vivo del coefficiente di attenuazione lineare della mammella* VII Congresso Nazionale Assosazione Fisica Medica 13-16 Settembre 2011 Catanzo, Italy

Poster Presentation

Lopez FC*, Rigon L, Arfelli F, Bergamaschi A, Chen RC, Dreossi D, Longo M, Schmitt B, Vallazza E, Castelli E and Longo R "The PICASSO detector at the clinical mammography facility of the SYRMEP beamline: preliminary results" 7th Medical Applications of Synchrotron Radiation Workshop 17-20 October 2012 Shanghai, China

Longo R*, Arfellli F, Dreossi D, Lopez FC, Quai E, Quaia E, and Tromba G "In vivo measurements of the breast linear attenuation coefficient" 7th Medical Applications of Synchrotron Radiation Workshop 17-20 October 2012 Shanghai, China

Longo M*, Rigon L, Arfelli F, Chen RC, Lopez FC, Olivo A, Munro P, and Longo R "A quantitative study of coded-aperture based X-ray phase contrast imaging with synchrotron radiation" V Alpe-Adria Medical Physics Meeting 3-5 May 2012 Trieste Italy

Lopez,FC* , Rigon L, Longo R, Arfelli F, Bergamaschi A, Chen RC, Dreossi D, Schmitt, B, Vallaza E, Castelli E. (2011) "*PICASSO: En route to digital detection for mammography with synchrotron radiation"* Secondo Convegno Conguinto SILS-SISN, XIX Convegno Nazionale SILS, XXII Convegno Nazionale SISN Trieste, Italy 1-3 September 2011 (One of the winners : Best poster, Young Researcher's Award)

International / National Schools:

1) School on Synchrotron and Free-Electron-Laser Sources and their Multidisciplinary Applications (International Center for Theoretical Physics Trieste 26 April - 7 May 2010)
2) International School of Trigger and Data Acquisition (La Sapenza, Rome 9-16 February 2011)
3) Rivelatori ed Elettronica per Fisica delle Alte Energie, Astrofisica, Applicazioni Spaziali e Fisica Medica (INFN Laboratori Nazionali di Legnaro, 12-13 April 2011)
4) Joint ICTP-IAEA Advanced Courcse in Mammography (International Center for Theoretical Physics 3-7 October 2011)
5) Monte Carlo Radiation Transport and Associated Needs for Medical Applications (International Atomic Energy Agency/ICTP 17-28 October 2011)

Periods outside Italy for collaborative work

1) Paul Scherrer Institute Villigen, Switzerland. Worked on PICASSO detector readout system in collaboration with Swiss Light Source Detector Group. (October - November 2010)
2) Paul Scherrer Institut, Villigen, Switzerland. Worked on PICASSO detector readout system in collaboration with Swiss Light Source Detector Group. (11 July - 15 July 2011)
3) Paul Scherrer Institut Villigen, Switzerland. Worked on PICASSO detector readout system in collaboration with Swiss Light Source Detector Group. (04 December – 10 December 2011)

In-house courses (120 hours/80 hours)

1) Caratteristiche generali dei rivelatori - 72 hours
2) Metodi in Immagine in Fisica Medica – 48 hours

2012 end of cycle report of Fabio Novelli, Ph.D. student XXV cycle

Supervisor Prof. Fulvio Parmigiani

Co-Supervisor Dr. Daniele Fausti

May 2010 – December 2010

Time-resolved studies of topological insulators by Angle Resolved Photo-Emission Spectroscopy (ARPES).

Topological insulators are a class of crystals which are electrical insulators in the bulk but their surface is metallic and allows a flow of electrons with definite spin. The first material of this type has been measured in 2006 (Zhang et al., Science 314, 1757-1761) in a quantum well system realized at the interface between the semiconductors HgTe and CdTe. Recently the research activity concentrated on the growth of Bi2Se3 and Bi2Te3, which are semiconductors with a gap of few hundreds meV and a simple band structure.

In the first few months of my Ph.D. I studied Bi2Se3 crystals with different doping by means of

- Time-resolved ARPES, equipped with both an hemispherical electron analyzer and a two-dimensional Time-of-Flight (ToF) electron analyzer and uses either a helium source (21.2 eV) or a pulsed laser source
- Spin-resolved ARPES, equipped with a Mott-ToF in order to resolve the spin components

2011

Ultra-fast time-resolved spectroscopy of strongly correlated materials.

I developed a tabletop TeraHertz pump – broadband optical probe setup to study and possibly drive (D.Fausti et al., Science 331, 189, 2011) photo-induced phase transformations in high temperature superconductors.

In order to produce a **broadband optical probe** we used super-continuum white light generation in a sapphire crystal. We performed a 800 nm pump & broadband probe temperature-study of YVO_3 to test the acquisition electronics and develop a suitable procedure for data analysis.

YVO_3 is a case-study among **transition metal oxides**, since it shows an interesting variety of phase-transitions upon cooling. Its optical bands are directly related to the orbital, magnetic and electronic degrees of freedom but their interpretation is controversial. Performing reflectivity measurements in the time and frequency domains, we demonstrated that the two lowest lying optical transitions (at hν=1.8 eV and hν=2.4 eV) belong to the same band, while the lower binding energy one is interpreted as a Hubbard exciton, i.e. a nearly bound state stabilized by a kinetic energy drop that we are able to quantify. Moreover, we rationalize the non-thermal long-living (>

1 ns) metastable phase as spin disorder, and suggest that the material can be used as an ultrafast magnetic switch (F.Novelli et al., PRB 86, 165135, 2012).

The most efficient way to produce **TeraHertz pump** pulses in a tabletop setup is the "tilted wavefront generation"(J.Hebling et al., J. Opt. Soc. Am. B 25, B6, 2008). At first I get accustomed with THz spectroscopy by realizing a "TeraHertz time-domain" (THz-TDS) setup to study the optical properties of a material at very low energies (1 THz ≈ 4 meV). Afterwards we measure the evolution of the TeraHertz transmission of silicon after pumping with ultra-short 800 nm pulses with a "Time-Resolved TeraHertz" (TRTS) setup. At this stage both optical rectification in a ZnTe crystal and four wave mixing in plasma were used to generate "weak" THz pulses from a Ti:Sa laser source. We performed a series of optical/THz pump – THz probe measurements on $CuGeO_3$, the only non-organic Spin-Peierls system known so far, both in-house and at the FEL of Dresden. Then we collect reflection and transmission spectra of a Pnictide superconductor. Through all these experiences I acquired the skills needed to realize a setup based on the novel generation technique of tilted wave front in $LiNbO_3$. This technique reaches efficiencies exceeding 10^{-4} and THz pulses with more than 100 nJ of energy corresponding to a fluence higher than 10 $\mu J/cm^2$ were obtained. With this setup we studied the optical response of GaAs.

In the **Franz-Keldysh effect** an electric field perturbs the optical properties of a semiconductor in an energy region across the gap. By pumping with ultrashort single-cycle pulses of THz radiation we detected the dynamical Franz-Keldysh effect in GaAs and, moreover, a novel saturation regime for strong THz field is revealed (in preparation).

2012

In search of selective excitations for studying out-of-equilibrium properties in strongly correlated electron systems and high temperature superconductors.

In transition metal oxides the electronic, magnetic and lattice correlations are responsible for exotic and intriguing physical properties such as colossal magneto-resistance and high-temperature superconductivity. Time-domain spectroscopy offers a unique tool to disentangle the different players in the game. Furthermore, it can be used to induce non-thermal transitions in condensed matter. In particular, by tailoring of the pump pulses, it is possible to drive a condensate into the desired physical state by a selective excitation.

During my PhD we developed an ultrafast laser-based pump-probe spectroscopic tool which combines broad-band optical probes in the 1-3 eV range and ultra-short pulses with high intensity either at optical or THz frequencies (1 THz is about 4 meV).

In 2012 I performed broadband-probe optical-pump time-domain reflectivity measurements on the Mott-insulator La_2CuO_4 and on optimally doped thin films of superconducting $YBa_2Cu_3O_{7-\delta}$. Moreover, THz-pump experiments on $YBa_2Cu_3O_{7-\delta}$.

In order to address the pump-wavelength dependence of the frequency and time-domain response of cuprates we studied the parent compound La_2CuO_4. Here, I demonstrated that the pump effect cannot be treated as a simple perturbation of the system, as completely different dynamics are revealed when the pump pulses are at lower or higher energies with respect to the charge-transfer gap at 2 eV. This evidence forces to review all the interpretations on time-resolved data on HTSC (in preparation).

I studied thin films of optimally doped $YBa_2Cu_3O_{7-\delta}$ with 800nm-pump and 400-1200nm probe and revealed an anomalous enhancement of a Ba vibrational mode upon entering the superconducting state. I demonstrate that the spectral distribution of the coherent phonon detected in the time-domain is heavily affected when the condensate melts non-adiabatically as a consequence of high fluence excitation. The details of the mechanism leading to such an effect are under investigation, but oscillations of the superconducting gap or structural deformations seems suitable candidates (in preparation).

I performed preliminary measurements on $YBa_2Cu_3O_{7-\delta}$ and show that pumping above or below the superconducting gap results in a different optical response of the material in the time-domain. This can be rationalized if the optical response is associated to quasi-particles piled up in antinodal points of the superconducting gap.

Fabio Novelli's plan of studies, Ph.D. student XXV cycle

Classes:

- Corso estivo "Energia per il domani: fonti rinnovabili, idrogeno e risparmio energetico", Giugno-Luglio 2010, Sesto - Prof. Fermeglia, 25 hours
- Advanced Imaging and Spectromicroscopy methods for chemical and structural characterization of micro- and nano-materials - Prof. Kiskinova, 15 hours
- Noisy Channels and Quantum Communication - Prof. Romano, 20 hours
- Molecular self-assembling and nanostructures - Prof. Morgante, 20 hours

Schools and workshops:

- XV Training Course in the Physics of Strongly Correlated Systems (Vietri sul Mare, Italy), 4/10/2010-15/10/2010
- The new generation in strongly correlated electron systems NGSCES 2012 (Portoroz, Slovenia), 25/6/2012-29/6/2012

  Oral presentation: "*THz pump white light probe time domain spectroscopy*"
- Innovations in Strongly correlated Electronic Systems: School and Workshop (Trieste, Italy) 6/8/2012-17/8/2012

  Poster:"*Hubbard exciton revealed by time-domain optical spectroscopy*"

Papers:

- "Ultrafast optical spectroscopy of the lowest energy excitations in the Mott insulator compound YVO_3: Evidence for Hubbard-type excitons"

  F. Novelli, et al. PHYSICAL REVIEW B 86, 165135 (2012) (in U-GOV as of 07/11/2012)
- "Quantum memory effects in bulk GaAs detected by pump-probe THz spectroscopy"

  F.Novelli, et al. in preparation
- "Disentangling the charge transfer dynamics in La_2CuO_4 by selective excitations"

  F.Novelli, et al. in preparation
- "Resonant and activated phonons detected by superconductivity quenching in optimally doped $YBa_2Cu_3O_{7-\delta}$"

  D.Fausti, **F.Novelli**, et al. in preparation

Summary of the PhD activities
Student: Giorgia Olivieri

BEAMTIMES AT *ELETTRA* SYNCHROTRON (Trieste)

- *August 2010- "*Analysis of C60-based *ball and socket* semiconductors interfaces" at ALOISA beamline
  Achievements: Organic solar cells have depended heavily of C60 and related derivatives for electron transporting and donating functionalities. A new family of contorted electron donating materials which form a socket that demonstrates a bulk co-crystal with C60, have been synthesized. The hypothesis that this contortion enhances device performance has been tested using XPS, NEXAFS and RPES.
- *November 2010*- "Study of the electronic levels of an organic semiconducting crystal" at ALOISA beamline
  Achievements- 4-hydroxycyanobenezene (4HCB) is a dipolar conjugated molecule which is the base constituent of very interesting semiconducting single crystals. 4HCB films have been successfully deposited Au(110) surface. Both the monolayer and the thick film have been characterized by means of XPS, NEXAFS and RPES. In the monolayer the molecules are adsorbed on the surface with one preferential geometry, while in the multilayer the molecular orientation does not have preferential directions. In both phases a molecule-molecule interaction has been observed.
- *June 2011*- "Exciton dissociation at the interface between C60/C70 and highly contorted hexabenzocoronene derivatives for solar cell applications" at ALOISA beamline
  Achievements: Following the first set of experiments on the *ball and socket* system, new interfaces comprising highly contorted hexabenzocoronene materials and both C60 and C70 have been tested to examine their electronic interaction.
- *August 2011*- "Molecular spectroscopy of 4-hydroxycyanobenzene" at GasPhase beamline
  Achievements- The electronic structure of 4HCB molecule in its gas phase has been fully characterized.
- *March 2012*- "Study of the electronic levels of organic semiconducting single crystals" at ALOISA beamline
  Achievements- 4HCB single crystals growth in solution have been inserted in the measuring chamber and both XPS and NEXAFS have been successfully performed on it. Due to beam damaging the RPES could not have been measured.

EXTERNAL COLLABORATIONS

- *October-December 2011-* Joint programme in the context of the CEI (Central European Initiative) University Network: Advanced Materials and nanosystems for ICT. (Dept. of Physics, University of Ljubljana, Slovenia)
  Project- Analysis of the ResPES and NEXAFS data taken on the *c*-HBC/C60 ball-and-socket system.

- *June-October 2012-* Visiting student at CLUE (Columbia Laboratory for Unconventional Electronics) laboratory, Columbia University, New York.
  Project- Realization and optimization of organic tandem solar cells with graphene used as recombination layer.

LIST OF ATTENDED SCHOOLS

- "HERCULES 2011", Grenoble from 02/27/2011 to 03/30/2011
- "Summer school on atomistic simulation techniques for material science, nanotechnology and biophysics", SISSA, Trieste from 07/11/2011 to 07/29/2011

LIST OF ATTENDED CLASSES

- "Advanced imaging and spectromicroscopy methods for chemical and structural characterization of micro- and nano-materials" M. Kiskinova (15 h)
- "Applicazioni chimiche della simmetria molecolare" P. Decleva (32 h)
- "Molecular self-assembling and nanostructures" A. Morgante, L. Casalis, L. Pasquato (20 h)
- "Spettroscopie di fotoemissione e spettromicroscopie" A. Baraldi (25 h)

CONFERENCES AND WORKSHOPS

- IOM-CNR Workshop, Trieste, Italy 30/09/2010-01/10/2010
- SINFO (Surfaces, Interfaces and Functionalization Preocesses in Organic Compounds and Applications) Workshop, June 2012, Parma, Italy
  Poster: "*Investigation of 4HCB molecule by synchrotron based techniques"*
- XX SILS (Italian Synchrotron Radiation Society) Conference, July 2012, Cosenza, Italy
  Poster: "*Investigation of 4HCB molecule by synchrotron based techniques"*
- *SPIE Optics + Photonics, San Diego, USA, 12-16/08/2012*

PUBLICATIONS

- "Donor-acceptor shape matching drives performance in photovoltaic", Schiros T., Kladnik G., Prezzi D., Ferretti A., Olivieri G., Cossaro A., Floreano L., Verdini A., Schenck C., Cox M., Gorodetsky A., Plunkett K., Delongchamp D., Nuckolls C., Morgante A., Cvetko D., Kymissis I.
  Submitted
- "Investigation of 4HCB molecule by synchrotron based techniques" Olivieri G. *et al.*
  In preparation

Dottorato di Ricerca in Fisica
presso INAF – Osservatorio Astronomico di Trieste
Relazione di fine A.A. 2011/2012 (Quarto Anno)

The cosmic star formation rate: Observational measures and modelization

Ph.D Thesis, Shaji Vattakunnel

Ph.D. Student: Shaji Vattakunnel
Supervisors: Francesca Matteucci (DAUT), Paolo Tozzi (INAF-OA Trieste)

Scientific Activity Star formation is one of the key element for understanding galaxy composition and evolution. My Ph.D. Thesis is devoted to the study of the cosmic star formation history and star forming galaxies, both from an observational and from a theoretical point of view.

A multiwavelength approach to the identification of star forming galaxies at high redshift is crucial to obtain a bias-free measure of the star formation rate. Instantaneous star formation in a given galaxy can be estimated through the measure of a tracer related to the emission of young, massive, short-lived stars. However, most of the star formation tracers are affected by strong uncertainties. It must be stressed that it is possible to identify star forming regions only in local galaxies due to the limited angular resolution, while for distant galaxies we must rely on the total galaxy emission. My scientific work is then mainly focused on two bands not affected by absorption, the X-ray and radio bands. The X-ray emission is mostly associated to the High-Mass X-ray binaries, promptly formed with the high mass stellar population, while the radio emission is due to the thermal bremsstrahlung emission from HII clouds associated to star forming regions. However, these two observable have their own observational complexities. X-ray emission can be contributed also by Low-Mass X-ray Binaries, which is proportional to the integrated star formation history rather than the instantaneous one, by the presence of hot gas and, most important, by the presence of a central Active Galactic Nuclei (AGN). Radio emission can be contaminated as well by the presence of a radio AGN. Disentangling the signature of star formation from other contributions at high redshift is difficult due to the limited angular resolution in both bands (which can be at best 1 arcsec). It is not possible to identify star forming regions in distant galaxies, so that the instantaneous star formation rate must be derived from a unique measure for the entire galaxy.

To address this issue I am using the deepest data available, in one of the most observed region of the sky, the Chandra Deep Field South (CDFS). The radio VLA survey of the Extended Chandra Deep Field South, along with the deep and medium-deep X-ray coverage, allow me to explore the capability of tracing the past cosmic star formation history using the combination of the deepest X-ray and radio data.

During the **first year** of my PhD, my scientific work was mainly focused on data reduction and analysis in the X-ray and radio bands. Then I cross-correlated the X-ray

sources with the sources detected in the radio band, in order to find all radio objects with an X-ray counterpart. The positional match was then refined with a visual inspection of the optical counterpart of each source. Therefore I obtained three source samples: one of objects detected in both X-ray and radio bands, and two of sources detected only in radio or X-ray band.

In the **second year** of my PhD, I updated the X-ray with the newest 4Ms Chandra observation of the CDFS, and updated the calibration of the 250 ks exposure of the E-CDFs area (flanking the deepest CDFS field). A full spectral analysis of the identified X-ray counterparts of the VLA sources, supported by optical measure of the redshift for the majority of them, allowed me to characterize their X-ray properties, and to provide a robust classification in terms of AGN and star forming galaxies.

In the **third year** of my PhD, I updated the X-ray with the newest CDFS catalog and calibration, and improved the spectral analysis and classification. The identification of the sources dominated by emission associated to star forming processes was done through many criteria based both on radio and X-ray emission: low unabsorbed X-ray luminosity in hard band L_X(2-10 keV), low intrinsic absorption N_H, no evidence of Fe emission line, no X-ray timing variability at 97% level of confidence, low X-ray to optical ratio Log(F_X/F_{opt}), low radio power $L_{1.4GHz}$, no radio variability at a 3 σ confidence level, high radio slope α_R, measured between 1.4 GHz and 5 GHz, no evidence in radio image of FR I or FR II morphology. It can be noticed that X-ray criteria alone are able to screen almost the 98% of AGNs, unlike radio criteria which barely select the 43% of them. Therefore we can use with confidence the same criteria on the objects detected only in X-ray band, while we expect an higher AGN contamination in the radio-only sample.

After having identified the sources dominated by emission associated to star forming processes, we are able to evaluate the radio-X-ray correlation and estimate the instantaneous star formation rate for all of them.

Our results are summarized as follows:

- Among the 268 sources with both radio and X–ray detections, 43 ($\sim$16%) are consistent with being powered by star formation processes in both bands. Among the sources detected only in the X-ray or the radio band, we select 70 and 111 star forming candidates, respectively;

- We find that for the sources detected in both bands the $L_X - L_R$ relation is well fitted with a slope close to 1: $Log(L_{2-10keV}) = (1.04 \pm 0.05) \times Log(L_{1.4GHz}) + (17.68 \pm 1.15)$. The fit which includes X-ray upper limits, treated with censored data analysis, is consistent with the previous relation;

- Assuming a linear slope in the $L_X - L_R$ relation and splitting our sample in low and high redshift bins, we find no evolution in redshift;

- We find that the $L_X - L_R$ relation shows a significant scatter. We estimate its intrinsic component to be 0.4 dex, possibly due to a contribution to X-ray luminosity unrelated to the instantaneous SFR;

- Finally we compute relation between SFR and X-ray luminosity in the 2-10 keV band: $SFR = (1.40 \pm 0.32) \times L_{2-10keV}\ 10^{-40}$ $M_{\odot}$/yr. The comparison of these data with models of chemical evolution allows us to explore the nature of the SFG galaxies. The SFRs we measure in our deep narrow survey span a wide range from normal spirals like the Milky Way or M31, to starburst like M82, up to strong starburst typical of bulges and spheroids in formation.

The strong correlation of SFR with the hard X-ray luminosity in our high-z galaxy sample shows that X-ray surveys can provide a powerful and independent tool in measuring the instantaneous SFR in distant galaxies. However, our data also indicates that the complex physics behind the X-ray and radio emission associated to star formation, may introduce significant scatter between L_X and SFR.

In the **fourth year** of my PhD, I modelled starburst-like galaxies making use of chemical evolution models. The model consists of a one-zone model where the galaxy is formed by infall of primordial gas (no metals). The gas forms stars, which in turn pollute the interstellar medium (ISM) with newly created elements the interstellar. We assume that the new elements are mixed instantaneously but we do not adopt the instantaneous recycling approximation. Supernovae (SNe) release part of their energy in the ISM and, if the thermal energy of the gas so heated is higher than the binding energy of the gas, winds develop expelling mostly metals. I varied four parameters (infall mass, star formation efficiency (ν), number of bursts and wind efficiency) and the initial mass function (IMF), and constrained them with observational data. Comparison with SFR, SNrate and metallicity from both local galaxies (M82) and high redshift galaxies, leads to the following results:

- The high z starbursts are only massive galaxies. Low mass starbursts can be observed only in the local universe;

- A bursting scenario with short and highly efficient SF is more conceivable in reproducing the observed SFR and chemical abundances;

- Winds are produced only with high SF efficiencies ($\nu > 10$ Gyr^{-1}) due to the potential well of the galaxy;

- The comparison of the models with the local starburst M82 shows that the galaxy is in a high efficient and short bursting phase ($\nu > 1$ Gyr^{-1}) and that an IMF different from Salpeter better reproduces the data;

- Only bursting models with strong efficiency reach the high star formation observed in high z starburst galaxies. This suggests the we observe only the short bursting phases of the galaxies, being the quiescent period below the flux limit, but for local galaxies.

Corsi (first year):

1. Cosmic Structure Formation (16 hours) (passed)
   Prof. Stefano Borgani
2. X-ray Astronomy (8 hours) (passed)
   Prof. Paolo Tozzi
3. Stellar Nucleosynthesis and Chemical Evolution (10 hours) (passed)
   Prof.ssa Maria Francesca Matteucci
4. Stellar feedback and galaxy evolution (10 hours) (passed)
   Dott. Simone Recchi (Universita' Statale di Vienna)
5. Evoluzione chimica e fotometrica delle galassie (40 hours) (passed)
   Prof.ssa Maria Francesca Matteucci

Schools:
First year:

Summer School Novicosmo 2009: Highlights in Astrophysics.

Second year:

National PhD School of Astrophysics Francesco Lucchin 2010: *The Infrared Universe: the Herschel and Alma eras.*

Talks:
First year:

Student talk in the Summer School Novicosmo 2009: *Faint and Extragalactic Sources: Star Formation and Nuclear Activity.*

Report of Summer School Novicosmo 2009.

End of the first year seminar: *Star Formation and Nuclear Activity at high redshift.*

Second year:

Journal Club OATS: *Star Formation and Nuclear Activity of Faint and Extragalactic Sources.*

Talk in the National Congress AGN9 2010: *The VLA Survey of the Chandra Deep Field South: X-ray Properties of Radio Sources.*

Third year:

Journal Club OATS: *Report of PhD School "Francesco Lucchin" 2010: IR Surveys - from the dust to the galaxy populations.*

Fourth year:

Talk in the National Congress AGN10 2012: *Results from the VLA-E–CDFS Survey: X-ray Properties of Radio Sources.*

Publications:

Vattakunnel et al. 2011: *The Radio - X–ray relation as a star formation indicator: Results from the VLA–E-CDFS Survey.*

Bonzini et al. 2012: *The sub-mJy radio population of the E-CDFS: Optical and IR Counterpart Identification.*

PhD Progress Report for Sara Mohammadi

Contact details: sara.mohammadi@elettra.trieste.it
XXV-cycle, Physics Department, Trieste University
Supervisors: *Giuliana Tromba, Fulvio Parmigiani*

Bio-medical X-ray imaging with Synchrotron Radiation: study and implementation of algorithms related to phase-sensitive techniques

This report summarizes my Ph.D. research progress from January 2010 to November 2012. As stated in my previous reports, the goal of my Ph.D. research is to optimize the application of phase retrieval methods for different phase-contrast imaging situations.
My research methodology consists of three phases. The first part concerned experimental activity carried out at the SYRMEP beamline of Elettra and focused on using phase contrast imaging for different purposes of research in the life science. The second phase was dedicated to the study and implementation of algorithms related to phase-sensitive techniques. During the third and final phase, I analyzed the two most-applied single-distance phase-retrieval approaches and outlined derivations, approximations and assumptions of each one. The details of these steps, in chronological order, are summarized below.

Motivation

Since the discovery of X-rays, absorption has been the dominant principle of image formation in X-ray Radiography. However, a wide range of bio-medical samples demonstrates very weak absorption contrasts [Momose et al., 2001]. Phase contrast imaging increases the sensitivity in the hard X-ray region and provides substantially enhanced contrast, especially for low-Z samples [Schmahl et al., 1998, Sayre et al., 1995, Nugent et al., 1996]. Phase contrast imaging helps to reduce the radiation dose delivered to the sample under investigation: this is a very important issue for *in vivo* studies [Arfelli et al., 1998].
Whilst a majority of the experimental research on X-ray phase contrast imaging is ongoing we now know that phase contrast imaging has an important role to play in areas such as medical diagnostic imaging [Bravin et al., 2002; Lewis, 2004] and materials characterization [Schenk et al., 2005; Mayo et al., 2002a]. The motivation of this thesis is to optimize the application of phase retrieval algorithms for different phase-contrast imaging situations considering their applicability for different studies. Retrieving phase information from intensity distribution enables us to obtain important qualitative information directly from the phase retrieved images, as well as quantitative data about the internal composition of the sample [Momose et al., 1996].

First Year

For my PhD thesis I had the opportunity to work at the SYRMEP beam line of Elettra, where novel phase contrast imaging techniques are used for many research fields of life and material science [Abrami et al., 2004]. Due to my participation to several experiments at the SYRMEP beam line, I gained some knowledge in computed micro-tomography (mCT), micro-radiography and practical experimental skill in using the different imaging set-ups, from sample preparation to data reconstruction and analysis.
I concentrated on the in-line X-ray phase contrast imaging, also known as “propagation-based technique”. Its set-up is identical to the one for the conventional absorption-based imaging except that we increase the sample-to-detector distance and also the X-ray source is sufficiently spatially coherent [Matsuo et al.

2004]. For data treatment and quantitative analysis, I worked with some commercial software packages, such as ImageJ [ImageJ 2012], Image Pro Plus [Image Pro Plus 2012] and VGStudio [VGStudio 2012]. I got some skills also working with programs for computed tomography reconstructions based on filtered back projection algorithms (SYRMEP-Tomo-Project (STP)). I also proposed some improvements for handling the reconstructions of large number of samples. I learnt to use CT program, an improvement of STP including single distance phase retrieval algorithms developed by R.Chen [Chen et al. 2012].

Second year

In the second year, I made a thorough field-study over the phase-sensitive imaging techniques with the classification and comparison of the different approaches. My study focused on the implementations of these algorithms to microCT studies in biomedical research.

In particular, I started considering the CT program which uses the non-iterative phase-retrieval algorithm based on Born approximation proposed by Gureyev et al. [2004], designed for low-Z and homogeneous materials. Recently this code has been developed for being applied also to quasi-homogeneous objects [Chen et al., 2012]. The second approach I used was the so–called "ANKAphase" [Weitkamp et al., 2011] that processes phase contrast radiographs by utilizing the single-distance non-iterative phase-retrieval algorithm proposed by Paganin et al. [2002].

I applied these algorithms to different case studies varying the experimental conditions and image parameters, then I compared the results with the ones obtained using the conventional standard back projection approach.

I showed that, for low absorption samples, the application of phase retrieval methods brought to a great enhancement in the contrast between the different sample phases, and I also achieved more accurate quantitative analysis. As expected, the results for high absorption samples were not satisfying. In these cases the images after phase retrieval were blurred and missing the tiniest details information. After these results, we decided to focus mainly on low absorption samples and improve the images and methods.

As analysis skills, I learnt the basics of IDL-programming-language and some knowledge about quantitative analysis by using Pore3d [Brun et. al, 2010], a dedicated software developed for mCT dataset analysis. Furthermore I started to work with XTRACT [XTRACT, 2012], an image analysis and processing software toolkit developed by CSIRO that includes various phase retrieval algorithms.

Third year

I analyzed three different phase-retrieval methods to evaluate their effectiveness and applicability limits for different imaging situations and improve them. In particular I applied the non-iterative phase-retrieval algorithm based on Born approximation [Chen et al., 2012] and the "transport-of-intensity (TIE) algorithm" [Paganin et al., 2002] on single-distance mCT data of multi-material objects included in XTRACT package. Then a double-distance algorithm based on TIE equation, called TIE2R, [XTRACT, 2012] has compared with the single-distance algorithms.

We implemented the single-distance algorithms on different samples, such as lung tissue, foams, seeds, scaffolds, renal stones and defined test objects. We evaluated the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) for area and edge signals, respectively. In all cases the CNR values are significantly improved by applying these algorithms. We were also able to reduce the scattering contributions and achieve higher CNR values by increasing the sample-to-detector distances. We showed that both algorithms extremely increase the edge SNR values by decreasing the positive and negative

peaks across the edges. We proved that the edge noises are lower for longer sample-to-detector distances due to a smoothing effect of the reconstruction. Using phase retrieval algorithms, the edges tiny details are less defined than in the original phase contrast image because of blurring, but, on the final analysis, this is not significant since data are rendered and segmented more efficiently. Among all the studied cases, the best result regards the phase retrieval imaging of an asthmatic mice model, where we obtained high resolution images showing both morphological and functional information at the same time.

In order to analyze the TIE double-distance algorithm (TIE2R), we scanned a multi-material object at two different sample-to-detector distances. We obtained results were not satisfying. Indeed the main drawback of this approach concerns the high-accuracy requirements for the experimental set-up and the beam stability. These conditions were not satisfied in our experimental set-up.

Publications:

Sara Mohammadi, Rongchang Chen, Christian Dullin, Marjana Regvar, Giuliana Tromba, "*Application of phase-sensitive techniques to Biological samples with different absorption levels*", 4th ITSR Workshop on Imaging Techniques with Synchrotron Radiation, Bordeaux, France, September 2011 (Oral Presentation).

Stefano Pesaro, Kevin Prince, Giuliana Tromba, Sara Mohammadi, Renato Ceccherelli, Giacomo Rossi, "*Study of dystrophic versus physiological wing feathers of the common swift using phase contrast imaging and histological evaluation*", 1st International Conference on Avian, Herpetological, Herpetological and Exotic Mammal Medicine, Wiesbaden, Germany, April 2013 (Abstract accepted).

Christian Dullin, Simeone dal Monego, Emanuel Larsson, Sara Mohammadi, Andrea Lorenzon, Chiara Garrovo, Stefania Biffi, Giuliana Tromba, "*Functional phase contrast CT imaging in an asthma mouse model, utilizing barium labeled alveolar macrophages*", Second International Symposium on Bio-Medical Applications of X-Ray Phase Contrast Imaging, Garmisch-Partenkirchen, Germany, Jan 2013 (Abstract accepted).

Andre P Almeida, Doctoral Student; Liebert P Nogueira; Regina C Barroso; Marcos Colaço; Andrea Mantuano; Delson Braz; Sara Mohammadi; Giuliana Tromba; Simone C Cardoso; Eloi S Garcia; Marcelo S Gonzalez; Patricia Azambuja, *"Phase contrast Micro-computed tomography for comparison of reconstructed slices of Rhodnius prolixus with and without phase retrieval technique"*, J. Radiation Physics and Chemistry, September 2012 (Submitted).

"SR μ-tomography reconstructions of wheat (Triticum aestivum) seeds reveal X-ray translucent vacuoles within aleurone cells and specific reticulate networks of seed coats", M. Regvar, et al. (in preparation)

"Evaluation of phase retrieval techniques to improve x-ray phase contrast imaging in pre-clinical lung disease models", J. Synchrotron Rad (in preparation).

"Three dimensional detection and staging of morphological alterations in different pre-clinical asthma mouse models utilizing phase contrast x-ray lung imaging" (in preparation).

Schools, Workshops and Advanced courses:

1. School on Synchrotron and Free-Electron Laser sources and their Multidisciplinary Applications, International Centre for Theoretical Physics (ICTP), Trieste, Italy, 26 April to 7 May 2010.
2. XVIIIth European Synchrotron Radiation Light Source Workshop, Elettra, Trieste, Italy, 25 and 26 November 2010.
3. Santaló's Summer School on Mathematical Models in Image Processing and Computer Vision, Santander, Spain, 8 to 12 August 2011.
4. 4th ITSR Workshop on Imaging Techniques with Synchrotron Radiation, Bordeaux, France, 24 to 27 September 2011.

5. Courses taken:

Course Title	Teacher	Status	Hours
Metodi in Immagine in Fisica Medica	R. Longo	Exam passed	48
Metodi di trattamento delle immagini	M. Messerotti	Exam passed	72
Applicazioni della radiazione di sincrotrone	G. Paolucci	Exam is missed*	72

* This course was out of PhD program. However, in order to be familiar with the subject and improve my background, I attended it as optional course.

Chapter and Section outline of my dissertation

Chapter 1: Introduction

Phase sensitive imaging
Phase retrieval

Chapter 2: Phase contrast imaging

Properties of X-ray
    Absorption coefficient and refractive index
Intensity and phase distribution
Propagation-based imaging
    Mathematical basis for propagation-based phase contrast
Phase retrieval method
    Single-distance algorithm
        Phase retrieval in TIE approach
        Phase retrieval in Born approximation approach
    Multi-distance algorithm

Chapter 3: Experimental implementation and methods

X-ray sources
X-ray tubes
Synchrotron radiation facilities
The SYRMEP beamline at Elettra

Experimental setup
Image acquisition
Image processing
    Slices reconstruction
    Pore3d software
Contrast-to-noise and Signal-to-noise ratio

Chapter 4: Quantitative analysis of Propagation-based phase contrast imaging

Experimental methods
    Test phantom
    Biological samples

Chapter 5: Comparison of the phase retrieval algorithms

Absorption and phase-shift cross-sections
SNR_area and SNR_edge
Conclusion

Postgraduate Research Proposal

As my postgraduate research, I applied for TRIL (Training and Research in Italian Laboratories) program at ICTP, Trieste, Italy. The activity during this program will be mainly concentrated in two directions: i) study and application of double distance phase retrieval algorithms for multi elemental samples; ii) new applications of single distance phase retrieval algorithms to new scientific cases.

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Candidate: Valentina Capogrosso

XXV Ph.D. cycle

Supervisor Prof. F. Parmigiani, Co-supervisor: Marco Malvestuto

End-of-cycle report

During the three years of Ph.D., my research activity focused on a particular class of strongly correlated-electron materials, whose dimensionality is the most defining material parameter. With my Ph.D. project I deepened into some physical properties of these materials by means of core-levels spectroscopies such as **resonant x ray emission (RXES)** and **static and time-resolved x ray absorption (XAS)**. Most part of the measurements have been carried out at the beamline BACH (Beamline for Advanced diCHroism) and at the Time-Resolved X-ray spectroscopy (T-ReX) laboratory at the Elettra light source facility in Trieste. Part of my Ph.D. has been also dedicated to the modelling of these systems by means of ***ab-initio* LDA+U** calculations (WIEN2k code).

The first experimental activity has been the exploit of the capabilities of the newly developed experimental setup for time-resolved XAS experiments available at BACH. The apparatus, which was under commissioning during the first year of my Ph.D. activity, is based on a variable repetition rate Ti:sapphire laser (pump pulse) synchronized with the ~ 500 MHz X-ray photon pulses (probe pulses). The surface semiconductor-metal transition in crystalline germanium has been photoinduced. The main results are reported in Rev. Sci. Instrum. 82, 123109 (2011).

The following experimental activities focused on two case-study systems: the layered $Sr_{n+1}Ru_nO_{3n+1}$ (n=1,2,3) family and the single layered half-doped $Pr_{0.5}Ca_{1.5}MnO_4$ (hd-PCMO). Both these systems exhibit fascinating phenomena intimately related to a complicated interplay between the crystal lattice, spin, charge, and orbital degrees of freedom, where crystal dimensionality plays a crucial role.

The layered $Sr_{n+1}Ru_nO_{3n+1}$ (n=1,2,3) have emerged as an important family of perovskites because of the unexpected and unprecedented evolution from anisotropic ferro- or metamagnetic behavior of $Sr_4Ru_3O_{10}$ (n=3) dependent on the direction of the magnetic field, enhanced Pauli paramagnetism close to magnetic order of $Sr_3Ru_2O_7$ (n=2) and, finally, to low-temperature superconductivity in Sr_2RuO_4 (n=1).
Although numerous studies have been reported on the structural and magnetic properties of these compounds, the evolution of the occupied and unoccupied electronic structures were not investigated in detail. Thus, the dependence of electronic structures and the hybridization of O 2p states have been investigated by combining polarization dependent O K (2p-1s transition) XAS and RXES spectroscopies.
A parallel activity has been the participation to an experiment carried out at the Soleil synchrotron at the DEIMOS beamline. In this experiment we measured the **magnetic circular and linear dichroism (XMCD and XMLD)** on the magnetic phases of $Sr_4Ru_3O_{10}$. The data analysis is still going on.

hd-PCMO exhibits a charge-orbital ordering (CO-O) transition at a remarkably high T_{CO}, slightly above room temperature, accompanied by an orthorhombic structural distortion, where the strongly correlated Mn e_g charge carriers order onto separate

crystallographic sub-lattices (charge-ordered state) with a specific orbital character (orbital ordered state). Furthermore, hd-PCMO also displays an anomalous lattice response at temperatures 20K above the Neél temperature T_N, which is associated to an unexpected spin-lattice coupling.

Since a study of the PCMO unoccupied electronic states was lacking, temperature dependence measurements by **XAS linear dichroism (XLD)** have been performed at the O-K and Mn-L_3 thresholds in order to elucidate the role of Mn 3d - O 2p orbital topology. The experimental data, supported by *ab-initio* LDA+U, shed light on the charge redistribution and p-DOS changes at the CO-O and antiferromagnetic (AFM) transitions. The results obtained show that the competitive interplay between the local atomic distortion, necessary for accomodating the CO-ordering, and the charge dynamics of the hopping mechanism regulates the orbital state of the charge carriers.

Furthermore, on the basis of theoretical studies that predict the formation of transient "hidden" orbital and structural phases by optical stimulation, we have studied the unoccupied DOS of the optically induced metastable state in PCMO by means of time resolved XAS, which offers a unique tool to measure site and symmetry projected DOS of metastable states in matter.

Tr-XAS measurements at the O-K edge have been carried out by means of the novel experimental apparatus. The time evolution of the XAS lineshapes across the optically photoinduced CO-O transition results different respect to the adiabatic XAS measurements, demonstrating the existence of a photoinduced "hidden phase" in PCMO, whose nature is still unknown.

Exams:

- "Spectroscopies" by Prof. Parmigiani and Prof. Baldereschi;

- "Photoemission Spectroscopy and Spectromicroscopy" by Prof. Baraldi;

- "Advanced Imaging and Spectromicroscopy methods for chemical and structural characterization of micro- and nano-materials" by Prof.ssa Kiskinova.

- "Condensed Matter 1" by Prof.ssa Peressi *.

All the exams of the approved study plan have been successfully taken.

*Since during my under graduate studies my curriculum was focused on nuclear physics course, I attended this course on Condensed Matter, but I did not take the exam.

List of attended schools & conferences:

- "**Workshop dell'Istituto Officina dei Materiali (CNR-IOM)**", September 30th-October 1st 2010, Area Science Park Campus Padriciano, Trieste. Presentation of a poster entitled: "Time Resolved and Surface-Science X-ray absorption magnetic circular dichroism (XMCD) experiments @ beamline BACH and T-Rex lab: present and future

status";

- "**National Seminar on Innovative Detectors**", October 18-22th 2010, Area Science Park Campus Padriciano, Trieste;

- Participation to the **"Joint US-CERN-Japan-Russia School on Synchrotron Radiation & Free Electron Lasers"**, April 2011, Erice, Italy.

- Participation to the **"Workshop MagDyn2011: Magnetization dynamics using pulsed X rays techniques around SOLEIL and X-FEL's"**, 28th-29th June 2011, Soleil synchrotron, Saint Aubin (France). Presentation during the **poster session** of a poster entitled: **"Time Resolved Soft x-ray Absorption Spectroscopy @ Elettra in multi-bunch mode".**

- Participation to the **"School on Synchrotron Radiation: Fundamentals, Methods and Applications"**, 5th-15th September 2011, Duino Castle (Trieste).

- Participation to the **Workshop** "**Mama: multifunctional materials and nanoscale phenomena probe and theory**", March 2012, Vietri sul Mare (Salerno). Presentation during the **poster session** of a poster entitled: " Static and dynamical XAS study of electronic and structural phase transitions in $Pr_{0.5}Ca_{1.5}MnO_4$".

Publications:

- L. Stebel, M. Malvestuto, **V. Capogrosso** et al., **"Time-resolved soft x-ray absorption setup using multi-bunch operation modes at synchrotrons",** Rev. Sci. Instrum. 82, 123109 (2011); doi: 10.1063/1.3669787, inserted in the U-GOV catalogue.

- **V. Capogrosso,** M. Malvestuto, et al., **"Effects of charge-orbital order-disorder phenomena on the unoccupied electronic states in the single layered half doped $Pr_{0.5}Ca_{1.5}MnO_4$",** to be submitted to Phys. Rev. B.

- M. Malvestuto, **V. Capogrosso**, et al., "**Resonant X-ray emission study of the $Sr_{n+1}Ru_nO_{3n+1}$ (n=1,2,3) family: role of the apical and planar oxygen sites**", in preparation.

ALLEGATO 2

Search for New Physics in the $B_s^0 \to J/\psi\phi$ and $B_s^0 \to \phi\phi$ Decays at CDF

Candidate: Mirco Dorigo

Advisors: Dr. Anna Maria Zanetti, Dr. Marco Rescigno

Doctoral School of Physics of the University of Trieste

XXV Entrance, 2010–2012

We present the search for physics beyond the standard model (SM) through the measurement of *CP* violation in two decays of the B_s^0 meson, the $B_s^0 \to J/\psi\phi$ and the $B_s^0 \to \phi\phi$ decays, using data collected by the Collider Detector at Fermilab (CDF) in proton-antiproton collisions provided by the Tevatron collider at the center-of-mass energy of 2 TeV.

The time-evolution of the $B_s^0 \to J/\psi\phi$ decays where the flavor of the B_s^0 meson is identified at production is the most effective probe of the *CP*-violating phase of the B_s^0–$\bar{B}_s^0$ mixing amplitude, $2\beta_s$ [1]. B_s^0–$\bar{B}_s^0$ oscillations proceed through highly suppressed transitions, where possible new particles or couplings can compete with the SM ones, yielding observable discrepancies from expectations. The phase of the mixing amplitude is particularly sensitive to such additional contributions, since it is predicted to be very small in the SM. A non-SM enhancement of the mixing phase also decreases the decay width difference between the light and heavy mass eigenstates of the B_s^0 meson, $\Delta\Gamma_s$. The thesis reports the measurement of β_s, $\Delta\Gamma_s$, the mean lifetime of heavy and light B_s^0 mass eigenstates, τ_s, and the angular momentum composition of the signal sample, using the final data set collected by CDF which comprises about 11 000 $B_s^0 \to J/\psi\phi$ decays. The crux of the measurement is a multivariate likelihood fit that exploits advanced techniques for statistically separating the signal from the background components and distinguishing the B_s^0 meson's flavor at production. We find $-0.06 < \beta_s < 0.30$ at the 68% C.L. in agreement with the SM expectation, $\Delta\Gamma_s = 0.068 \pm 0.026(\text{stat}) \pm 0.009(\text{syst})\,\text{ps}^{-1}$ and $\tau_s = 1.528 \pm 0.019(\text{stat}) \pm 0.009(\text{syst})\,\text{ps}$. The measurements of the B_s^0 lifetime, width difference, and polarization amplitudes are among the most precise available to date and show consistency with expectations and determinations from other experiments. The results are published in *Physical Reviews Letters* [2].

The $B_s^0 \to \phi\phi$ decay proceeds in the SM through a higher-order quark flavor-changing transition. Similar to the tree-dominated $B_s^0 \to J/\psi\phi$, the $B_s^0 \to \phi\phi$ decay is sensitive to mixing-induced *CP* violation in the interference of the decays with and without flavor oscillations. In addition, the $B_s^0 \to \phi\phi$ can probe *CP* violation in the decay as well. Being the decay amplitude dominated by the same coupling of the mixing amplitude in the SM, the $B_s^0 \to \phi\phi$ decay is predicted to exhibit tiny, if any *CP* violation. The thesis presents an original method to measure two *CP*-violating asymmetries, $\mathcal{A}_u$ and $\mathcal{A}_v$, that are sensitive to both mixing-

induced and decay-induced *CP* violation, even with a small signal sample. Since they are expected to vanish in the SM, a measurement of nonzero values of such asymmetries would indicate physics beyond the SM [3]. Using a dataset of about 300 signal events, we include the asymmetries in a maximum likelihood fit and measure them for the first time. We find $\mathcal{A}_u = (-0.7 \pm 6.4(\text{stat}) \pm 1.8(\text{syst}))\%$ and $\mathcal{A}_v = (-12.0 \pm 6.4(\text{stat}) \pm 1.6(\text{syst}))\%$, which are statistically consistent with the no *CP* violation hypothesis. The measurement is published in *Physical Reviews Letters* [4].

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[4] T. Aaltonen *et al.* (CDF Collaboration), *Measurement of Polarization and Search for CP Violation in $B_s^0 \to \phi\phi$ Decays*, Phys. Rev. Lett. **107**, 261802 (2011) [arXiv:1107.4999 (hep-ex)].

CANDIDATE FRANCES CAROLINE LOPEZ
CYCLE 25
PROPOSED TITLE Single photon counting system for mammography with synchrotron radiation
SUPERVISOR Prof. Renata Longo

SUMMARY

During the period of the PhD program, the candidate was involved with the development of the final version of a detector named PICASSO (Phase Imaging for Clinical Application with Silicon detector and Synchrotron radiatiOn) under the supervision of the SYRMEP group composing members from the Physics Department of the University of Trieste and INFN Section of Trieste, with the participation of Swiss Light Source Detector Group. This project is aimed to help address the detection and data acquisition needs of clinical facility of the SYRMEP beamline, where mammography and imaging research is currently being performed.

The detector is based on Silicon microstrip sensors that operates in single-photon counting mode on "edge-on" configuration. Its design encompasses the whole width and height of the beam at a distance where phase-contrast imaging may be performed. The detector has modular electronics, each coupled with 12 MYTHEN II frontend ASICs from by Paul Scherrer Institute. Our previous prototypes had smaller active area and number of channels, with relatively long dead time between frame acquisitions. With this new design, it requires only less than 150 microseconds to read all ASICs in parallel at 16-bit dynamic range. This fast system is capable of imaging a standard breast in 20 seconds, hence optimal for a continuous scan design structure. The configuration of the mammography set-up at our beamline requires a read-out that is fast, keeping in mind the bulky data that has to be transported and processed in real time, including issues on radiation dose delivered in-vivo. The contribution of the candidate was concentrated on a new read out system capable of meeting the constraints in speed for clinical studies.

In the period of the program, a new software architecture and firmware were developed with the assistance and in collaboration with the SLS Detector Group of Paul Scherrer Institute in line with the change of detector controllers. Tests include front-end electronics, analog and digital component tests and overall performance of its electronics.

PICASSO was brought to the Elettra for testing to evaluate its imaging capabilities. In particular, signal-to-noise ratio, contrast, and spatial resolution were evaluated concurrent with the dose given to the standard mammographic phantoms being imaged at both the experimental and the radiological stations of the SYRMEP beamline. Phase contrast methods were tested using the prototype under development. Further, this version of the detector was also used in pioneering imaging experiments during the program.

The last part of the program concludes with the testing of the recently assembled four layers

of PICASSO, which constitute the detector's final configuration. This system is controlled by two separate controllers, and final evaluation on how images are reconstructed with the inherent time delay between the two are under evaluation.

Bio-medical X-ray imaging with Synchrotron Radiation: study and implementation of algorithms related to phase-sensitive techniques

PhD Thesis by *Sara Mohammadi*
XXV-cycle, Physics Department, Trieste University
Supervisors: *Giuliana Tromba, Fulvio Parmigiani*
October, 2012

Phase-contrast X-ray imaging is an invaluable tool in medical diagnostics and biological sciences. It provides images where both absorption and refraction contribute. For quantitative analysis of these images, the phase needs to be retrieved numerically. There are many phase-retrieval methods available.
My thesis aims to optimize the application of phase retrieval methods for different phase-contrast imaging situations. A quantitative comparison between phase contrast and phase retrieved images is also performed on some selected examples.

We analyzed the two most-applied single-distance phase-retrieval approaches and outlined derivations, approximations and assumptions of each one. We implemented these algorithms on experimental data collected at the SYRMEP beam-line of Elettra, Italy. In particular, we used the algorithms called "phase-attenuation-duality Born" and "transport-of-intensity (TIE)" for different absorption level materials such as lung tissue, foams, seeds, scaffolds, renal stones and defined test objects. It is demonstrated that both algorithms work very well for low absorption materials, which is the case of most biological samples. The results for high absorption samples may not be well satisfying. In these cases the image after phase retrieval is deformed and also missing a lot of details information and sharpening in the contour.

We evaluated the contrast-to-noise ratio (CNR) and signal-to-noise ratio (SNR) for area and edge signals, respectively. The CNR values are significantly improved by applying these phase retrieval algorithms. We were also able to reduce the scattering contributions and achieve higher CNR values by increasing the sample-to-detector distance. We showed that both algorithms extremely increase the edge SNR values by decreasing the positive and negative peaks across the edges. We proved that the edge noises are lower for longer sample-to-detector distances due to a smoothing effect of the reconstruction. Using phase retrieval algorithms, the edges tiny details are less defined than in the original phase contrast image because of blurring, but, on the final analysis, this is not significant since data are rendered and segmented more efficiently.
Among all the studied cases, the best result regards the phase retrieval imaging of an asthmatic mice model, where we obtained high resolution images showing both morphological and functional information at the same time.

Ph.D. student: Damiana Montanino

Ph.D. School of Physics – XXV Cycle (IV School Cycle)

Study of the associated production of a Z boson and jets in pp collisions at sqrt(s) = 7 TeV at CMS

The analysis carried out in this thesis is focused on the characterization of the associated production of a Z boson and jets (Z+jets) in proton-proton collisions at LHC with the CMS detector. This study provides an important Standard Model (SM) test, a detector commissioning ground through physics, and last but not least a powerful probe for new phenomena.
In the context of the SM, the study of jets produced in association with Z allows for tests of perturbative QCD (pQCD) calculations. The leading order (LO) and next-to-leading order (NLO) predictions are in good agreement with data, but the latter, available for Z+n jets, with n up to 4, are only known with a precision varying from 10% up to 30%, due to uncertainties on the parton distribution functions and on the perturbative nature of the calculations.
The Z+jets production is an important background in searches on supersymmetry, in Higgs and Dark Matter signatures, and for studies of the top quark. Many extensions of the SM predict new particles with electroweak couplings that decay into SM gauge bosons accompanied by jets.
This study has used the 7 TeV data collected by the CMS experiment in the 2011 using jets and vector bosons detected through their decays into electron-positron pairs. The corresponding total integrated luminosity is estimated to be about 4.89 fb^{-1}.
In the framework of the CMS analysis it is possible to use different algorithms to reconstruct the electrons, optimized for specific scenarios. The standard method gives origin to the set called GSF Electrons, and starts from the production of calorimeter deposits followed by the Gaussian Sum Filter (GSF) algorithm, a specialized reconstruction for tracks with sizable energy losses. The alternative method is based on Particle Flow algorithm, a global event description which uses the combined information provided by all CMS sub-detectors, as ECAL energy deposits or track segments, for an optimal determination of the direction, energy and type of all the stable particles in the event, as electrons, muons, photons, charged hadrons and neutral hadrons. The results obtained with the two methods are compared in order to evaluate the best procedure for the Z boson reconstruction and the Particle Flow electrons were chosen.
The selection of the analysed events is based on the research of the Z boson. The presence of a pair of well-identified and isolated high energy electrons is required as signature of the boson decay. The jets, considered in the study, are

reconstructed using a sequential clustering algorithm. Quality cuts are applied to reduce the contamination from the underlying events and to provide good jet identification and good noise jet rejection. An important aspect is the correction for the pile-up due to the high luminosity conditions. Both the variables used for the electrons selection and the jet energy need to be corrected due to the bias produced by the presence of particles coming from additional interactions.

In this work several different observables are considered. The differential jet rate cross section is measured, as well as the transverse momentum p_T and pseudo-rapidity η distributions for the four highest transverse momentum jets. The distribution of the scalar sum of jet transverse momenta H_T is also measured as a function of the jet multiplicity.

All the distributions are corrected for the efficiency of the trigger, selection, reconstruction and isolation criteria calculated with the Tag&Probe method. It is a data-driven procedure based on the selection of a well-known resonance, which exploits its decay in the pair of particles that are under study. Applying this method to measure efficiencies for data and simulation, it is possible to extract the data-to-simulation scale factors, which provide corrections for differences between data and Monte Carlo. Using these factors, the background can be estimated from the Monte Carlo predictions.

In order to be able to compare the results with the theoretical expectations, the detector effects must be deconvolved from the physics phenomenon. This procedure, known as unfolding, allows to obtain distributions at particle level, that reflect the event configuration before the interaction with the detector. Two different methods are considered in order to cross-check the results and to estimate a systematic error of the procedure.

The study of the production of vector bosons with jets suffers from uncertainties associated with the definition and the counting of jets. The dominant experimental uncertainties are caused by the jets energy corrections that can modify the measured number of these hadronic objects. Other important sources of systematics effects are gived by the unfolding method, the evaluation of the efficiencies, the contribution from the pile up and the background subtraction.

The final results are presented showing a direct comparison with pQCD theoretical predictions at leading order, extracted from two different models, Madgraph plus Pythia6 and Sherpa. An overall good agreement is globally found on all the analysed observables, considering the large uncertainties on the predictions due to the choice of the parton density functions and the scale of the interaction.

Student: OLIVIERI

Organic Electronic Devices:
Investigation of the Electronic Transport Properties at the Molecular Level

- *Chapter 1*

The first chapter is dedicated to the description of the ALOISA beamline present at the synchrotron facility in Trieste and of the wide range of complementary experimental techniques available on it. I highlight among the others, the three spectroscopic techniques I have been using to analyze the systems presented in the next chapters. In particular I recall the principles of the X-ray Photoemission Spectroscopy (XPS) and the Near-edge X-ray Absorption Fine structure Spectroscopy (NEXAFS) with which one can probe respectively the filled and empty molecular states, extracting both electronic and structural information. I then explain the Resonant Photoemission Spectroscopy (RPES) and how it can be used to measure the charge transfer time between molecules adsorbates and substrate or between two different molecules. This technique is based on core-level excitation and decay and is complementary to the pump-probe technique, with an intrinsic timescale coming from the lifetime of core-hole. The shortness of this timescale, in the order of femtoseconds, gives this approach a unique place in the study of electron transfer dynamics. Moreover it has the advantage of atomic specificity as it involves the excitation of core electrons.

- *Chapter 2*

This chapter is dedicated to the study of the electronic properties of the 4-hydroxycyanobenzene (4HCB) molecule and how they change passing from the gas phase to the solid state. The 4HCB molecule belong to the class of organic semiconductors single crystals (OSSC) and it has been demonstrated that it forms millimeter sized single crystals with strong anisotropic transport properties along the three crystallographic axes. The high purity, absence of defects and long range structural order of the OSSCs make 4HCB a suitable system to investigate the charge transport mechanism in organic semiconductors. In particular, for this molecule, the main issue is how the macroscopic anisotropic properties can be related to the electronic structure of the molecule and what is the role that the two functional groups (hydroxyl and cyano) attached to the central benzene core play in the transport mechanism.

To achieve this goal I used a combination of three different spectroscopic techniques (XPS, NEXAFS and RPES) together with theoretical *ab-initio* calculations that have been especially helpful considering the lack of literature references for this system. I started measuring the XPS, NEXAFS and RPES on the different molecular edges (namely carbon, nitrogen and oxygen) in gas phase. The XPS from the C1s supported by a DFT simulation of the same, allowed me to find the energetic hierarchy of all the inequivalent carbon atoms present in the molecule. I used then the information from the core levels to study the molecular empty states (LUMOs) probed by the NEXAFS. Once again the combination of experimental evidences and DTF simulation of the unoccupied molecular orbitals, permitted me to assign all the transition from the core to the LUMO levels typical of a NEXAFS spectrum.

After the full electronic characterization of the molecule in the gas phase I studied the interaction of the 4HCB monolayer with two different gold surfaces, namely Au(111) and Au(110), to model the behavior at the interface between the organic active layer and the metal electrodes. Comparing the gas phase with the solid state spectra I can conclude that the 4HCB poorly interacts with the gold surfaces, the strongest interaction being that between the cyano group and the more reactive sites of the Au(110).

On the other side the deposition of a thick film on a Au substrate well resembles the bulk properties of

4HCB single crystal. Beside the standard characterization, the quenching of the HOMO resonances in the solid state with respect the same resonances in the gas phase gives insight on the molecular interaction inside the crystal. In particular I found that the cyano group play a fundamental role in the charge transport being the resonances on the N-edge much more attenuated than the same on the C-edge.

- *Chapter 3*

Herein are presented three organic heterojunction systems made up coupling three different hexabenzocoronene (HBC) molecules, namely flat-HBC (f-HBC), contorted-HBC (c-HBC) and dibenzotetrathienocoronene (DBTTC) with the fullerene (C60).
When HBCs and C60 molecules are deposited one on the top of the other, a donor/acceptor (D/A) interface is formed and so these systems can be used as active layer in organic photovoltaic devices. Moreover, due to their shape complementarity, both the c-HBC/C60 and DBTTC/C60 interfaces show a supramolecular self-assembled nanostructure in which the C60 molecules are interwoven between the well ordered structure of the donor material. It has been shown that this supramolecular order drives a large increase in the solar cell power conversion efficiency compared to the f-HBC/C60 system in which the flat geometry of the HBC does not match the C60 shape.
I studied the detailed morphology of these bilayer systems exploiting the synchrotron based spectroscopic techniques. In particular I performed the NEXAFS dichroism study on both the pristine films and the coupled systems to see how the HBCs pristine orientation changes when the molecules interact with the C60. While the dichroism analysis of the donor type molecules is straightforward and the C60 film, due to its molecular geometry, does not present any NEXAFS dichroism, the NEXAFS analysis of the bilayer films presents several issues. In order to be able to get the structural information from the heterojunction interfaces, I applied a new model that take into account many different effects, among which the most prominent ones are the attenuation of the signal coming from the two layers and the possible intermixing of the pure phases.
This study reveals that for all the systems there is a change of the HBCs tilt angle passing from the pristine films to the bilayer systems even if this effect is less significant for the f-HCB while it is much stronger for both the c-HCB and DBTTC systems. Moreover while the f-HBC/C60 can be well approximated with a pure bilayer system, the other two systems present a non negligible intermixed phase at the interface.
Finally with the core-hole clock spectroscopy the charge transfer rates at the D/A interface have been calculated. The results are in agreement with the morphological evidences and clearly show an enhanced exciton dissociation rate for the systems in which the shape complementarity drives a supramolecular assembly.

- *Chapter 4*

This last section is, unlike the others, dedicated to the fabrication and characterization of actual organic electronic devices, in particular bilayer heterojunction solar tandem cells. The tandem structure is made up of two standard solar cells connected in series via a recombination layer. The series connection leads the increase of the open circuit voltage that in turn causes an increasing of the cell efficiency. The active part of my cells is the organic heterojunction Subphtalocyanine/C60 that has been shown to have an higher efficiency compared to the more used CuPc/C60 heterojunction. I focused my attention on the study of the recombination layer concluding that the best solution for it is a combination of Ag nanoclusters with a thin film of MoO_3. Apart for the scientific results, in this chapter I would like to address all the issue related with the fabrication and characterization of the organic electronic devices.

Candidate: Valentina Capogrosso

XXV cycle Ph.D. thesis summary

Supervisor Prof. F. Parmigiani, Co-supervisor: Marco Malvestuto

Title: ***Dimensionality and ordering effects on the electronic structure of low dimensional strongly correlated electron transition metal oxides.***

Summary

In the vast scenario of strongly correlated-electron materials transition-metal oxides have attracted enormous interest because of their interesting physical properties, including for example, superconductivity in cuprates and colossal magnetoresistance in manganites. In particular, my interest was directed to a particular class of materials, whose dimensionality is the most defining material parameter.

With my Ph.D. project I deepened into some physical properties of these materials by means of core-levels spectroscopies such as **resonant x ray emission** (RXES) and **static and time-resolved x ray absorption** (XAS). All the measurements have been carried out at the beamline BACH (Beamline for Advanced diCHroism) at the Elettra light source facility in Trieste.

The experimental activities focused on two case-study systems: the single layered half-doped $Pr_{0.5}Ca_{1.5}MnO_4$ (hd-PCMO) and the layered $Sr_{n+1}Ru_nO_{3n+1}$ (n=1,2,3) family. Both these systems exhibit fascinating phenomena intimately related to a complicated interplay between the crystal lattice, spin, charge, and orbital degrees of freedom, where crystal dimensionality plays a crucial role.

hd-PCMO exhibits a charge-orbital ordering (CO-O) transition at a remarkably high T_{CO}, slightly above room temperature, accompanied by an orthorhombic structural distortion, where the strongly correlated Mn e_g charge carriers order onto separate crystallographic sub-lattices (charge-ordered state) with a specific orbital character (orbital ordered state). Furthermore, hd-PCMO also displays an anomalous lattice response at temperatures 20K above the Neél temperature T_N, which is associated to an unexpected spin-lattice coupling.

Since a study of the PCMO unoccupied electronic states was lacking, temperature dependence measurements by XAS linear dichroism (XLD) have been performed at the O-K and Mn-L_3 thresholds in order to elucidate the role of Mn 3d - O 2p orbital topology. The experimental data, supported by ab-initio LDA+U, shed light on the charge redistribution and p-DOS changes at the CO-O and antiferromagnetic (AFM) transitions. The results obtained show that the competitive interplay between the local atomic distortion, necessary for accomodating the CO-ordering, and the charge dynamics of the hopping mechanism regulates the orbital state of the charge carriers.

Furthermore, on the basis of theoretical studies that predict the formation of transient "hidden" orbital and structural phases by optical stimulation, we have studied the unoccupied DOS of the optically induced metastable state in PCMO by means of time resolved XAS, which offers a unique tool to measure site and symmetry projected DOS of metastable states in matter.
Tr-XAS measurements at the O-K edge have been carried out by means of a novel experimental apparatus available at BACH, which is based on a variable repetition rate Ti:sapphire laser (pump pulse) synchronized with the ~ 500 MHz X-ray photon pulses (probe pulses). The time evolution of the XAS lineshapes across the optically photoinduced CO-O transition results different respect to the adiabatic XAS measurements, demonstrating the existence of a photoinduced "hidden phase" in PCMO, whose nature is still unkown.

The layered $Sr_{n+1}Ru_nO_{3n+1}$ (n=1,2,3) have emerged as an important family of perovskites because of the unexpected and unprecedented evolution from anisotropic ferro- or metamagnetic behavior of $Sr_4Ru_3O_{10}$ (n=3) dependent on the direction of the magnetic field, enhanced Pauli paramagnetism close to magnetic order of $Sr_3Ru_2O_7$ (n=2) and, finally, to low-temperature superconductivity in Sr_2RuO_4 (n=1).
Although numerous studies have been reported on the structural and magnetic properties of these compounds, the evolution of the occupied and unoccupied electronic structures were not investigated in detail. Thus, the dependence of electronic structures and the hybridization of O 2p states have been investigated by combining polarization dependent O K (2p-1s transition) XAS and RXES spectroscopies.

A section of the chapter 2 is dedicated to illustrate a newly developed experimental setup for time-resolved XAS experiments by exploiting the multibunch time structure of a synchrotron storage ring. By exploiting the capabilities of this setup, the surface semiconductor-metal transition in crystalline germanium has been photoinduced and the complete set of data discussed in chapter 4.

The outline of my Ph.D. thesis is the following. The first chapter introduces the reader into the orbital physics and the electronic phase transitions in layered strongly correlated electronic compounds. The experimental tools, including an excursus on the spectroscopic techniques and the description of the experimental apparatus, are reviewed in chapter 2. Chapter 3 is dedicated to the DFT and LDA+U theories and to the details of the modeling of the PCMO system. Chapter 4 is divided into three sections, including the case of PCMO, the photoinduced surface semiconductor-metal transition in crystalline germanium and the case of the Ruddlesden-Popper series of Sr Ruthenates. In the concluding chapter the future perspectives of this work are presented.

Fabio Novelli

XXV cycle Ph.D. thesis summary

Supervisor Prof. F. Parmigiani, Co-supervisor Dr. D. Fausti

Title: **In search of selective excitations for studying out-of-equilibrium properties in strongly correlated electron systems and high temperature superconductors**

In transition metal oxides the electronic, magnetic and lattice correlations are responsible for exotic and intriguing physical properties such as colossal magneto-resistance and high-temperature superconductivity (HTSC). Time-domain spectroscopy offers a unique tool to disentangle the different players. Furthermore, it can be used to induce non-thermal transitions in condensed matter. In particular, by tailoring of the pump pulseswhile using probe pulses suitable to detect the pump effects, it is possible to drive a condensate into the desired physical state by a selective excitation.

During my PhD we developed an ultrafast laser-based pump-probe spectroscopic tool which combines broad-band optical probes in the 1-3 eV range and ultra-short pulses with high intensity either at optical or THz frequencies (1 THz is about 4 meV).

The first few chapters of my thesis introduce the state of the art, the experimental techniques, and the static and the models we used to study the differential optical properties of solids. The following chapters are dedicated to the materials investigated: we performed broadband-probe optical-pump time-domain reflectivity measurements on Mott-Insulators (YVO_3 and La_2CuO_4) and superconductors ($YBa_2Cu_3O_{7-d}$), and THz-pump experiments on GaAs and $YBa_2Cu_3O_{7-d}$.

YVO_3 is a case-study among transition metal oxides, since it shows an interesting variety of phase-transitions upon cooling. Its optical bands are directly related to the orbital, magnetic and electronic degrees of freedom but their interpretation is controversial. Performing reflectivity measurements in the time and frequency domains, we demonstrated that the two lowest lying optical transitions (at hν=1.8 eV and hν=2.4 eV) belong to the same band, while the lower binding energy one is interpreted as a Hubbard exciton, i.e. a nearly bound state stabilized by a kinetic energy drop that we are able to quantify. Moreover, we rationalize the non-thermal long-living (> 1 ns) metastable phase as spin disorder, and suggest that the material can be used as an ultrafast magnetic switch (F.Novelli et al., accepted PRB).

In order to address the pump-wavelength dependence of the frequency and time-domain response of cuprates we studied the parent compound La_2CuO_4. Here, we demonstrated that the pump effect cannot be treated as a simple perturbation of the system, as completely different dynamics are revealed when the pump pulses are at lower or higher energies than the charge-

transfer gap (2 eV). This evidence forces to review all the interpretations on time-resolved data on HTSC (in preparation).

We studied thin films of optimally doped $YBa_2Cu_3O_{7-d}$ with 800nm-pump and 400-1200nm probe and revealed an anomalous enhancement of a Ba vibrational mode upon entering the superconducting state. We demonstrate that the spectral distribution of the coherent phonon detected in the time-domain is heavily affected when the condensate melts non-adiabatically as a consequence of high fluence excitation. The detailed mechanisms are under investigation, but oscillations of the superconducting gap or structural deformations seems suitable to explain the effects (in preparation).

An electric field perturbs the optical properties of a semiconductor in an energy region across the gap. This is the Franz-Keldysh effect. By pumping with ultrashort single-cycle pulses of THz radiation we detected the dynamical Franz-Keldysh effect in GaAs and, moreover, a novel saturation regime for strong THz field is revealed (in preparation).

We performed preliminary measurements on $YBa_2Cu_3O_{7-d}$ and show that pumping above or below the superconducting gap results in a different optical response of the material in the time-domain. This can be rationalized if the optical response is associated to quasi-particles piled up in antinodal positions of the Brillouin zone.

In conclusion, I have performed a series of transient reflectivity and transmission experiments on transition metal oxides and demonstrated that selective excitations are indeed possible, and moreover useful physical information can be obtained by tuning the energy of the pump pulses. Nonetheless, extreme caution must be undertaken in rationalizing time-resolved laser-based optical data when the effect of the pump is treated as simple ultrafast heating.

XXV cycle of the Doctoral School of Physics of the University of Trieste

Study of hypernuclei production in Pb-Pb collisions with the ALICE experiment at the LHC

Candidate: Ramona Lea
Supervisors: Prof.Paolo Camerini, Dott. Stefano Piano

Thesis Summary

The subject of the present PhD thesis is the study of the production of light hypernuclei in ultra-relativistic Pb-Pb collisions with the ALICE (A Large Ion Collider Experiment) experiment, one of the four major experiments at the LHC (Large Hadron Collider).
The main physics goal of the ALICE experiment is the investigation of the properties of the strongly interacting matter in high energy density (> 10 GeV/fm^3) and high temperature (~ 0.2 GeV) conditions. According to the lattice Quantum Chromo Dynamics (QCD) calculations, under these conditions (*i.e.* high temperature and large energy density) hadronic matter undergoes a phase transition to a "plasma" of deconfined quarks and gluons (Quark Gluon Plasma, QGP).

In the first chapter of the thesis a general introduction to the the heavy-ion physics will be given. Then the main quantities related to QGP formation (i.e. *probes*) will be described. Finally the most important results obtained at SPS, RHIC and LHC experiments will be shown and discussed.

In the second chapter a short description of the LHC and its experimental conditions will be reported and an overview of the ALICE experiment will be given. A description of the different detectors, together with the apparatus performances during the data taking, will be described; in addition a description of the computing framework will be given.

The third chapter will be devoted to an introduction to hypernucler physics. First of all, an overview of the hypernuclei production at low energy will be given. Then the focus will be moved to hypernuclei production in heavy ion collisions: the main theoretical models of the hypermatter production will be discussed as well as the predictions on the expected production yields.

The fourth chapter is devoted to the description of the analysis method used to identify the (anti)hypertriton production in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV with the ALICE experiment via its mesonic decay ${}^{3}_{\Lambda}H \rightarrow {}^{3}He + \pi^{-}$ (${}^{3}_{\bar{\Lambda}}\bar{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$).
In the beginning of the chapter the analysis technique used for particle identification and for the determination of secondary vertices will be described. Moreover, a detailed description of the background estimation and signal extraction methods will be discussed.
At the end, the results on the production yield of (anti)hypertriton will be shown and the estimation of the hypertriton lifetime will be provided, together with the systematic errors discussion and evaluation.

Finally, in the last chapter, the present experimental results will be compared with published relevant results and with the most recent theoretical findings. Moreover, the measurement of the "Strangeness Population Factor" [$S_3 = {}^{3}_{\Lambda}H/{}^{3}He/(\Lambda/p)$] at the LHC energies will be provided. This quantity is a valuable tool to probe the nature of dense matter created in high-energy heavy-ion collisions and to validate theoretical models.

Dottorato di Ricerca in Fisica
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Thesis summary

The cosmic star formation rate: Observational measures and modelization

Ph.D Thesis, Shaji Vattakunnel

Ph.D. Student: Shaji Vattakunnel
Supervisors: Francesca Matteucci (DAUT), Paolo Tozzi (INAF-OA Trieste)

My Ph.D. Thesis is devoted to the study of the cosmic star formation history and star forming galaxies, both from an observational and from a theoretical point of view. Star formation is one of the key element for understanding galaxy composition and evolution. A multiwavelength approach to the identification of star forming galaxies at high redshift is crucial to obtain a bias-free measure of the star formation rate. Instantaneous star formation in a given galaxy can be estimated through the measure of a tracer related to the emission of young, massive, short-lived stars. However, most of the star formation tracers are affected by strong uncertainties. It must be stressed that it is possible to identify star forming regions only in local galaxies due to the limited angular resolution, while for distant galaxies we must rely on the total galaxy emission. My scientific work is then mainly focused on two bands not affected by absorption, the X-ray and radio bands. The X-ray emission is mostly associated to the High-Mass X-ray binaries, promptly formed with the high mass stellar population, while the radio emission is due to the thermal bremsstrahlung emission from HII clouds associated to star forming regions. However, these two observable have their own observational complexities. X-ray emission can be contributed also by Low-Mass X-ray Binaries, which is proportional to the integrated star formation history rather than the instantaneous one, by the presence of hot gas and, most important, by the presence of a central Active Galactic Nuclei (AGN). Radio emission can be contaminated as well by the presence of a radio AGN. Disentangling the signature of star formation from other contributions at high redshift is difficult due to the limited angular resolution in both bands (which can be at best 1 arcsec). It is not possible to identify star forming regions in distant galaxies, so that the instantaneous star formation rate must be derived from a unique measure for the entire galaxy.

To address this issue I am using the deepest data available, in one of the most observed region of the sky, the Chandra Deep Field South (CDFS). The radio VLA survey of the Extended Chandra Deep Field South, along with the deep and medium-deep X-ray coverage, allow me to explore the capability of tracing the past cosmic star formation history using the combination of the X-ray and radio data.

In the E–CDFS area, we have two sets of X–ray data obtained with *Chandra*. The most important is a 4 Ms exposure observation resulting from the coaddition of 54 individual *Chandra* ACIS–I exposures from October 1999 to July 2010 with centers

spaced within a few arcsec from α =3:32:28.80, $\delta = -27$:48:23 (J2000). To ensure a uniform data reduction, we follow the same procedure adopted in previous works using the most recent release of *Chandra* calibration files (CALDB 4.4). The 4 Ms observation is at present time the deepest X-ray survey of the sky and reaches on-axis flux limits of $\approx 9.1 \times 10^{-18}$ and $\approx 5.5 \times 10^{-17}$ ergs cm^{-2} s^{-1} for the soft [0.5-2.0 keV] and hard [2-8 keV] bands, respectively (Xue et al. 2011). The 4 Ms main X-ray source catalog by Xue et al. (2011) includes 740 X-ray sources and is used as the initial source input list. We removed 8 uncertain objects because we do not have positive aperture photometry for them in our data. The catalog we use, therefore, contains 732 sources. A further X-ray data set is the shallower $\sim$ 250 ks coverage of the square region of 0.28 deg^2 centered on the 4 Ms field. The E–CDFS consists of 9 observations of 4 partially overlapping quadrants, 2 for each of the first three fields and 3 for the last one. We applied the same data reduction procedure used for the CDFS-4 Ms. The original catalog by Lehmer et al. (2005) contains 762 sources. We remove 9 detections because we do not have positive aperture photometry for them in our data reduction. The catalog we use, therefore, contains 753 sources.

For radio data we consider the new VLA program which provides deep, high resolution 1.4 GHz imaging across the full E–CDFS, consisting of a six-pointing mosaic of 240 h spanning 48 days of individual 5 h observations. The image covers a region of 34'.1 $\times$ 34'.1 of the full E–CDFS at a rms sensitivity of 7.5 μJy per 2.8" $\times$ 1.6" beam, with the rms reaching 7.2 μJy per beam in the central 30'. Here we use two catalogs: a very deep one including all the sources with S/N $>$ 4 (1571 sources) is used when cross matching with X-ray detections. A more conservative catalog at S/N $>$ 5 is used to investigate the properties of radio sources without X-ray counterparts. This catalog includes 940 sources which shrinks to 879 single sources after identifying the multiple components.

Finally we make use of the spectroscopic surveys and optical identification (Bonzini et al. 2012) to obtain spectroscopic or photometric redshifts for the majority of our X-ray sources.

We combine the X-ray and radio information for our sources by cross-correlating the radio catalog at $S/N > 4$ with the X-ray catalogs. An X–ray source is considered a candidate counterpart of a radio source if their separation is less than $3\sigma_d$, where $\sigma_d^2 = \sigma_r^2 + \sigma_X^2$. The σ_r and σ_X are the *rms* error of the radio and X–ray positions. In the case of multiple identifications, we simply choose the X-ray candidate counterpart with a smaller separation. We estimate the false matching rate due to random associations by generating a set of radio catalogs and match them with the X-ray catalogs in CDFS and E-CDFS separately. We repeat this procedure 1000 times and find an average random contamination of 3 spurious associations in the CDFS-4 Ms and 8 in the E-CDFS area not covered by the CDFS-4 Ms survey. Therefore, we proceed with a refinement of the X-ray–radio cross correlation through a simple visual inspection of the optical images (mostly observed by HST and WFI) for all the candidate counterparts. To summarize, after a careful inspection of the X-ray, radio and optical images we have:

- 268 radio sources with X-ray counterparts: 152 from the CDFS catalog and 116 from the E–CDFS catalog;
- 693 radio sources from the $S/N > 5$ catalog without X-ray counterparts;
- 1084 X-ray sources (in the CDFS-4 Ms and in the E-CDFS catalogs) not associated with any radio source.

Our goal is to identify sources powered by star formation in the radio and X-ray bands. A full spectral analysis of the identified X-ray counterparts of the VLA sources, supported by optical measure of the redshift for the majority of them, allowed me to characterize their X-ray properties, and to provide a robust classification in terms of AGN and star forming galaxies. The identification of the sources dominated by emission associated to star forming processes was done through many criteria based both on radio and X-ray emission, here summarized:

- low unabsorbed X-ray luminosity in hard band L_X(2-10 keV)
- low intrinsic absorption N_H
- no evidence of Fe emission line
- no X-ray timing variability at 97% level of confidence
- low X-ray to optical ratio $\mathrm{Log}(F_X/F_{opt})$
- low radio power $L_{1.4GHz}$
- no radio variability at a 3 σ confidence level
- high radio slope α_R, measured between 1.4 GHz and 5 GHz
- no evidence in radio image of FR I or FR II morphology

It can be noticed that X-ray criteria alone are able to screen almost the 98% of AGNs, unlike radio criteria which barely select the 43% of them. Therefore we can use with confidence the same criteria on the objects detected only in X-ray band, while we expect an higher AGN contamination in the radio-only sample. After having identified the sources dominated by emission associated to star forming processes, we are able to evaluate the radio-X-ray correlation and estimate the instantaneous star formation rate for all of them.

Our results are summarized as follows:

- Among the 268 sources with both radio and X–ray detections, 43 ($\sim$16%) are consistent with being powered by star formation processes in both bands. Among the sources detected only in the X-ray or the radio band, we select 70 and 111 star forming candidates, respectively;

- We find that for the sources detected in both bands the $L_X - L_R$ relation is well fitted with a slope close to 1: $Log(L_{2-10keV}) = (1.04 \pm 0.05) \times Log(L_{1.4GHz}) + (17.68 \pm 1.15)$. The fit which includes X-ray upper limits, treated with censored data analysis, is consistent with the previous relation;

- Assuming a linear slope in the $L_X - L_R$ relation and splitting our sample in low and high redshift bins, we find no evolution in redshift;

- We find that the $L_X - L_R$ relation shows a significant scatter. We estimate its intrinsic component to be 0.4 dex, possibly due to a contribution to X-ray luminosity unrelated to the instantaneous SFR;

- Finally we compute relation between SFR and X-ray luminosity in the 2-10 keV band: $SFR = (1.40 \pm 0.32) \times L_{2-10keV}\ 10^{-40}$ $M_\odot$/yr. The comparison of these data with models of chemical evolution allows us to explore the nature of the SFG galaxies. The SFRs we measure in our deep narrow survey span a wide range from normal spirals like the Milky Way or M31, to starburst like M82, up to strong starburst typical of bulges and spheroids in formation.

The strong correlation of SFR with the hard X-ray luminosity in our high-z galaxy sample shows that X-ray surveys can provide a powerful and independent tool in measuring the instantaneous SFR in distant galaxies. However, our data also indicates that the complex physics behind the X-ray and radio emission associated to star formation, may introduce significant scatter between L_X and SFR.

The second part of the thesis is devoted to the theoretical modelling of starburst-like galaxies making use of chemical evolution models. The model consists of a one-zone model where the galaxy is formed by infall of primordial gas (no metals). The gas forms stars, which in turn pollute the interstellar medium (ISM) with newly created elements the interstellar. We assume that the new elements are mixed instantaneously but we do not adopt the instantaneous recycling approximation, i.e. stellar lifetimes are taken into account in detail. Supernovae (SNe) release part of their energy in the ISM and, if the thermal energy of the gas so heated is higher than the binding energy of the gas, winds develop expelling mostly metals.

Four parameters play a fundamental role in the model: the infall mass, the star formation efficiency (ν), number of bursts and wind efficiency (λ). Moreover we changed the initial mass function (IMF). Even if the Salpeter IMF is the most commonly used in literature, some past works pointed out that starbursts could have less low-mass star than the locally observed IMF. Therefore we constrained the models with the observed data. Comparison with SFR, SNrate and metallicity from both local galaxies (M82) and high redshift galaxies, leads to the following results:

- The high z starbursts are only massive galaxies. Low mass starbursts can be observed only in the local universe;

- A bursting scenario with short and highly efficient SF is more conceivable in reproducing the observed SFR and chemical abundances;

- High SF efficiencies ($\nu > 10$ Gyr^{-1}) produce efficient and metal-enriched winds, that expel an important fraction of mass;
- The comparison of the models with the local starburst M82 shows that the galaxy is in a high efficient and short bursting phase ($\nu > 1$ Gyr^{-1}) and that an IMF different from Salpeter better reproduces the data;
- Only bursting models with strong efficiency reach the high star formation observed in high z starburst galaxies. This suggests the we observe only the short bursting phases of the galaxies, being the quiescent period below the flux limit, but for local galaxies.