

FCPPL-CSC PhD proposal - 2015

Thesis title: Open heavy-flavour measurements via muons in proton-proton and Lead-Lead collisions with the ALICE detector at the CERN-LHC

Type of proposed PhD diploma: French Chinese French & Chinese **X** (tick correct answer)

French host laboratory: Laboratoire de Physique Corpusculaire, CNRS/IN2P3, UMR6533, 24 Avenue des Landais, BP 80026, F-63171 AUBIERE

Chinese laboratory (if applicable): Institute of Particle Physics (IOPP), Central China Normal University (CCNU), Key Laboratory of Quark & Lepton Physics, MoE, Luoyu Road 152, Wuhan 430079, China

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Planned date of start of stay in French lab: 01/11/2015

Planned duration of stay in French lab (months): 36 (or 24), under discussion

Expected date of thesis defense: November 2018

Detailed description of the thesis subject:

The aim of ultra-relativistic heavy-ion collisions is to pin down the nuclear equation of state by studying the properties of nuclear matter under extreme conditions of temperature and pressure. The ultimate goal is to study the deconfinement of the hadron constituents in the so-called Quark-Gluon Plasma (QGP). This phase of matter is a prediction of Quantum ChromoDynamics (QCD) i.e. the theory of the strong interaction. It is believed that the Universe was made of a QGP a few microseconds after the Big Bang and that a QGP could be present in the core of neutron stars. The heavy-ion collision experimental program has started in the eighties at the Super Proton Synchrotron (SPS) at CERN and has then been pursued since 2000 at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven. With a nucleus-nucleus center-of-mass energy nearly 14 times larger than that reached at RHIC, the Large Hadron Collider (LHC) at CERN has been offering, since 2009, a totally new environment for systematic studies of the QGP. A Large Ion Collider Experiment (ALICE) is the unique LHC experiment dedicated to the study of heavy-ion collisions. The ALICE collaboration consists of 1550 physicists from 151 institutes in 37 countries. The detector is made of a central barrel, a small forward angle muon spectrometer and a set of detectors for event characterization and triggering.

Amongst the various probes of the QGP, heavy quarks (charm and beauty) are of particular interest since, due to their large masses, they are mainly produced in hard scattering processes at the early stages of the heavy-ion collision and subsequently interact with the strongly-interacting medium formed in the collision. Open heavy-flavour particles are sensitive to the density of this medium through heavy quark in-medium energy loss mechanism. This effect is usually studied by means of the so-called nuclear modification factor: $R_{AA}(p_T) = (dN_{AA}/dp_T) / (\langle T_{AA} \rangle d\sigma_{pp}/dp_T)$ where $\langle T_{AA} \rangle$ is the average nuclear overlap function corresponding to the considered collision centrality class; dN_{AA}/dp_T and $d\sigma_{pp}/dp_T$ are the transverse momentum (p_T) production yield and cross-section (σ) in nucleus-nucleus (AA) and proton-proton (pp) collisions. According to QCD, quarks should lose less energy than gluons when passing through the medium. This is due to the colour-charge of gluons which is higher than that of quarks. In addition, heavy quarks are expected to lose less energy than light quarks due to the "dead-cone" effect. This colour-charge and mass-dependence of parton energy loss should therefore result in the following R_{AA} hierarchy: $R_{AA}^\pi < R_{AA}^D < R_{AA}^B$. First measurements have been performed and published (see below) with the data taken with the ALICE detector during the LHC Run1. In the LHC Run 2, the higher beam energy and luminosity will allow better

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precision measurements over a broader p_T range. It will also make possible to build “double” ratios of R_{AA} ($R_{AA}(\text{heavy flavours})/R_{AA}(\text{light flavours})$ and $R_{AA}(\text{beauty})/R_{AA}(\text{charm})$) which will allow to investigate in detail the features of in-medium parton energy loss. On the other hand, the study of heavy-flavour particle azimuthal anisotropy and the measurement of their elliptic flow can provide insight on the degree of thermalization of charm and beauty quarks in the medium and on the heavy-flavour hadronization mechanism at low p_T and intermediate p_T , respectively. In the high p_T region, the elliptic flow can constrain the path-length dependence of the in-medium parton energy loss. This is complementary to the study of parton energy loss. Here again, the larger statistics which will become available with the LHC Run 2 data will allow to extend the measurements done with the LHC Run 1 data at higher p_T .

Heavy flavours are measured in ALICE in the charm hadronic decay channels and in the semi-electronic decay channel at mid-rapidity and, in the semi-muonic decay channel at forward rapidity.

The topic of the PhD thesis is the study of the heavy-flavour production in proton-proton (pp), and lead-lead (Pb-Pb) collisions via single muons measured with the ALICE muon spectrometer. A particular emphasis will be placed on the measurements in the high p_T region.

The manuscript will be organized in 6 chapters: 1) Introduction, 2) Heavy-flavour production as a probe of the QGP, 3) The ALICE experiment at the LHC, 4) Measuring heavy-flavours with the ALICE muon spectrometer, 5) Results and comparison to model predictions, 6) Conclusion. The first chapter consists of a general overview of heavy-ion collisions and QCD phase transitions. The second chapter presents the motivations for measuring heavy-flavours and their relevance for studying the QGP. In these two first chapters a comprehensive summary of the theoretical background and of the main experimental results obtained so far will be presented. Chapter three gives an overview of the ALICE experiment with a detailed description of the muon spectrometer. The ALICE data recording and analysis strategy are presented in chapter four. It includes the performance of the muon spectrometer for measuring the heavy-flavour production and the strategy followed at different steps of the analysis chain i.e. data reduction, background subtraction, acceptance x efficiency correction, normalization, estimation of systematic uncertainties etc. Finally, results are presented in chapter five. They are discussed and compared to other experimental measurements and to model predictions. A summary and the conclusions are given in the last chapter.

The results obtained will be regularly presented in various meetings of the ALICE collaboration, as well as in international conferences and workshops, and then published.

Candidates' requested qualifications: The candidate is already identified: Zuman Zhang from CCNU Wuhan. Zuman Zhang has already spent few months at LPC Clermont-Ferrand for his Master-I and Master-II trainings. He has all requested qualifications for the proposed PhD and has already started to get familiar, during his Master trainings, with the physics case and the ALICE data analysis tools.

Tentative timeline of the PhD preparation

[Detail content and duration of the various phases of the PhD work]

The PhD work will consist in participating to data taking with the ALICE detector at CERN. Then, the candidate will have to analyze the data, subtract the background and apply acceptance and efficiency corrections and normalization factors, and estimate the systematic uncertainties. The final results (production cross section, nuclear modification factor and elliptic flow) will be interpreted and compared to other experimental results and predictions from different models.

Below is a rough estimate of the timeline.

November 2015 - December 2015: participation in Pb-Pb data taking with the ALICE detector at CERN; first data analysis;

January 2016 - summer 2017: Participation in proton-proton data taking with the ALICE detector at CERN; analysis of pp and Pb-Pb data; presentation of the results in meetings of the ALICE collaboration;

Summer 2017: Presentation of the results in summer conferences;

Summer 2017 - December 2017: finalization of the analyses and writing of the publication;
December 2017: Participation in Pb-Pb data taking with the ALICE detector at CERN;
January 2018 – October 2018: analysis of the 2017 Pb-Pb run and writing of the PhD manuscript.
November 2018: PhD defense.

Publications related to the PhD subject: The 3 publications below are the result of the PhD of our former student from (Xiaoming Zhang) who has defended his PhD on May 2012. Two other publications on similar topics are being prepared. One of them is the result of the work of our actual student (Shuang Li). Both PhD theses are co-tutorship Wuhan - Clermont-Ferrand.

- B. Abelev et al. (The ALICE collaboration), Production of muons from heavy flavor decays at forward rapidity in pp and Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, **Phys. Rev. Lett. 109 (2012) 112301**
- B. Abelev et al. (The ALICE collaboration), Heavy flavour decay muon production at forward rapidity in proton-proton collisions at $\sqrt{s} = 7$ TeV, **Phys. Lett. B 708 (2012) 265**
- R. Averbeck, N. Bastid, Z. Conesa del Valle, P. Crochet, A. Dainese, X. Zhang, Reference heavy flavour cross sections in pp collisions at $\sqrt{s} = 2.76$ TeV, using a pQCD-driven \sqrt{s} -scaling of ALICE measurements at $\sqrt{s} = 7$ TeV, **arXiv:1107.3243 [hep-ph]**

Conference proceedings related to the PhD subject:

- N. Bastid for the ALICE collaboration, Heavy-flavour and quarkonium measurements with ALICE XI International Conference on hyperons, charm and beauty hadrons, Birmingham, UK, July 2014, **Journal of Physics: Conference Series 556 (2014) 012020**
- S. Li for the ALICE collaboration, Heavy-flavour nuclear modification factor at forward and backward rapidity in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE at the LHC XXIV international conference on ultra-relativistic nucleus-nucleus collisions (Quark Matter), Darmstadt, Germany, May 2014
To be published in Nucl. Phys. A
- S. Li for the ALICE collaboration, Nuclear modification factor and elliptic flow of muons from heavy-flavour decays in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE 6th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions (Hard Probes), Cape Town, South Africa, Nov. 2013
To be published in Nucl. Phys. A
- X. Zhang for the ALICE collaboration, Nuclear modification factor and elliptic flow of muons from heavy-flavour decays and muon elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV Strangeness in Quark Matter 2013 (SQM), Birmingham, UK, July 2013
Journal of Physics: Conference Series 509 (2014) 012045
- X. Zhang for the ALICE collaboration, Nuclear modification factor of muons from open heavy-flavour decays and single muon elliptic flow at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE 23th International conference on ultra-relativistic nucleus-nucleus collisions (Quark Matter), Washington, USA, August 2012
Nucl. Phys. A 904 (2013) 977c
- N. Bastid for the ALICE collaboration, Heavy-flavour and quarkonium measurements in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV with ALICE Heavy Ion Collisions in the LHC Era, Quy Nhon, Vietnam, July 2012
Journal of Physics: Conference Series 422 (2013) 012014

- P. Crochet for the ALICE collaboration, Heavy flavour production measurements with ALICE at the CERN-LHC
16th International Conference In Quantum Chromodynamics (QCD), Montpellier, France, July 2012
Nucl. Phys. B 234 (2013) 325
- P. Crochet, Heavy flavour production measurements at the CERN-LHC
XLI International Symposium on Multiparticle Dynamics (ISMD), Miyajima Island, Hiroshima, Japan, Sept. 2011
Progress of Theoretical Physics Supplement 193 (2012) 89
- N. Bastid for the ALICE collaboration, Quarkonium and heavy flavour physics in pp and Pb--Pb collisions with the ALICE muon spectrometer at the LHC
International Workshop on Early Physics with Heavy-Ion Collisions at LHC, Bari, Italy, July 2011
AIP Conf. Proc. 1422 (2012) 153
- X. Lopez for the ALICE collaboration, Heavy flavour production in the semi-muonic channel in pp and Pb--Pb collisions measured with the ALICE experiment
Strangeness in Quark Matter (SQM), Cracow, Poland, Sept. 2011
Acta Phys. Polon. Supp. 5 (2012) 297
- X. Zhang for the ALICE collaboration, Heavy flavour production cross section in the semi-muonic channel at forward rapidity in pp collisions at 7 TeV and measurement of its nuclear modification factor in Pb--Pb collisions at 2.76 TeV with ALICE
22th International conference on ultra-relativistic nucleus-nucleus collisions (Quark Matter), Annecy, France, May 2011
Journal of Physics G: Nuclear and Particle Physics 38 (2011) 124067
- X. Zhang for the ALICE collaboration, Heavy flavour physics with the ALICE muon spectrometer at the LHC
XLIX International Winter Meeting on Nuclear Physics, Bormio, Italy, Jan. 2011
Pos (Bormio 2011) 030
- N. Bastid for the ALICE collaboration, Quarkonium and heavy flavour physics with the ALICE muon spectrometer at the LHC
International Conference on Hyperons, Charm and Beauty Hadron, Perugia, Italy, June 2010
Nucl. Phys. B (Proc. Suppl.) 210-211 (2011) 53
- X. Zhang, L. Manceau, N. Bastid, P. Crochet, S. Grigoryan, D.C. Zhou for the ALICE collaboration, Measurement of (di)muons from heavy flavour decay in pp collisions at 14 TeV with ALICE at the LHC
5th International conference on quarks and nuclear physics, Beijing, China, August 2009
Chinese Physics C 34-9 (2010) 1538

ALICE Internal notes related to the PhD subject:

- X. Zhang, N. Bastid, P. Crochet
Measurement of the elliptic flow of muons from heavy-flavour decays at forward rapidity in Pb--Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV
ALICE-ANA-2013-921 (2013)
- S. Li, X. Zhang, Z. Zhang, N. Bastid, P. Crochet
Production of muons from heavy-flavour decays at forward rapidity in p--Pb and Pb--p collisions at $\sqrt{s} = 5.02$ TeV
ALICE-ANA-2013-920 (2013)
- L. Manceau, X. Zhang, N. Bastid, P. Crochet, S. Grigoryan and D. Zhou
Performance of the ALICE muon spectrometer for the measurement of the B-hadron and D-hadron production cross sections in pp collisions at $\sqrt{s} = 14$ TeV via single muons
ALICE-INT-2011-xxx (2011)
- L. Manceau, X. Zhang, N. Bastid, P. Crochet, S. Grigoryan and D. Zhou

Performance of the ALICE muon spectrometer for the measurement of the B-hadron and D-hadron production cross sections in pp collisions at $\sqrt{s} = 14$ TeV

ALICE-INT-2010-004 (2010)