Exploration of Hot Partonic Matter at LHC-ALICE

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1 Introduction

The goals of high energy nuclear physics programs include: to study the *system* of elementary particles, as compared to the *processes* as in particle physics; to create and investigate the new state of matter of partons, which existed in the very early universe at $\sim 10^{-5}$ seconds after the Big Bang; and to search for a clue of the generation mechanism of hadronic mass via spontaneous chiral symmetry breaking upon confinement of quarks into hadrons.

With the ALICE experiment on the topics, along with ATLAS, CMS and LHC-b, the physics programs at the Large Hadron Collider (LHC) at CERN will provide a comprehensive understanding of strong, electro and weak forces.

2 Physics Outcomes at RHIC-PHENIX

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory started its operation in 2000, and has provided a wide variety of collision systems from $p+p$, d+Au to Au+Au, with the center-of-mass collision energy per nucleon pair ($\sqrt{s_{NN}}$) up to 200 GeV (500 GeV for $p+p$).

RHIC has been proven to be a real success, as reported in many articles, *e.g.* [1]. Properties of the newly discovered matter can be summarized as follows: the matter is *dense* to have quarks lose their kinetic energy traversing it, as observed through jet quenching or suppression of particles with high transverse momenta; it is *partonic* with degrees of freedom of quarks and gluons, as seen via scaling properties of collective motions with the number of constituent quarks in baryons and mesons, and also with color screening observed as suppression of J/Ψ; it is *strongly coupled* showing perfect fluidity, leading to hydro-dynamic behavior of collective motions; and it is apparently very *hot* and thermally radiative, with a thermal photon component observed.

3 Physics Prospects at LHC-ALICE

3.1 The ALICE Experiment at LHC

LHC is the machine of next generation to further attack the physics which RHIC has explored. It circulated the first beam on September 10, 2008, and the first collisions of $p+p$ at $\sqrt{s} = 10$ TeV are planned in October, 2009, to be followed by $p+p$ physics running and the first collisions of Pb+Pb at $\sqrt{s_{NN}} = 3.9$ TeV through the fall of 2010. It should be noted that "p"+Pb and Ar+Ar running is also scheduled in the first few years of operation of LHC, in addition to regular $p+p$ and Pb+Pb running at $\sqrt{s_{(NN)}} = 14$ and 5.5 TeV, respectively.

The ALICE experiment is the only one dedicated to and designed for physics of high energy nucleus-nucleus collisions at LHC, with more than 1,000 collaborators from 109 institutions in 31 countries (as of April, 2009). For details of ALICE, see *e.g.* [2].

3.2 Direct and Thermal Photons

Measurement of photons is an essential physics topic at LHC. They are vital probes to investigate the properties of the hot and dense matter created in high energy nucleus-nucleus collisions in many ways such as: thermal photons as a thermometer of the created fireball; HBT correlation of thermal photons to trace the space-time evolution of the system; photons from initial hard scattering of partons to look into pQCD processes and also to tag jets; as well as neutral mesons via photonic decay channels to measure the energy loss of quarks.

At LHC, the large production rate of photons up to $\sim$ 100 GeV makes them even more powerful than at lower energies. The signal to background ratio of direct photons also improves with transverse momentum and the collision energy; the number of direct photons is expected to exceed that of photons from decaying hadrons in the range of transverse momentum above $\sim$ 70 GeV/c in central Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV. In the softer regime, there still are multiple significant sources of photons beside thermal ones from deconfined partonic phase, such as photons from hadronic gas and those induced in the medium by jets. The fraction of the thermal component is expected to be at most 10%, keeping a high quality photon measurement at low to moderate transverse momentum essential, as has been so at RHIC and SPS [3].

A key issue for the feasibility of measurement of photons in the low transverse momentum region is systematic errors. ALICE has evaluated and expects its capability to measure photons with the total systematic error of $\sim$ 7% down to $\sim$ 1.5 GeV/c of transverse momentum, suggesting a good feasibility to isolate thermal photons [4].

3.3 Heavy Quarkonia

Another obvious physics topic to be further pursued at ALICE is heavy flavors. While clear suppressions of J/Ψ has been observed at SPS and RHIC, the similarity beyond the collision energies is not uniquely explained. If a possible explanation of coincidental cancellation of melting and regeneration is the correct scenario, the suppression of J/Ψ should be reduced at LHC due to a larger charm yield and hence enhanced regeneration. In case of another possible scenario that the observed suppression is only because of Ψ' and χ_c melting while J/Ψ has not been melt even at RHIC, J/Ψ at LHC may be further suppressed due to a larger energy density leading J/Ψ itself to finally disappear. The measurement at LHC is hence a key to disentangle the mechanism. Moreover Υ is not only a new but important probe at LHC to reveal the mechanism of suppression of heavy quarkonia. Comparison between Υ(1s) and Υ(2s) is of particular interest, with the former expected to disappear only at LHC and the latter to melt approximately with J/Ψ [5, 6].

ALICE has a unique advantage over the other detectors at LHC that its acceptance for heavy quarkonia extends down to zero transverse momentum and also to a large rapidity where the muon spectrometer sits. ALICE also has good invariant mass resolutions of $<$ 80 MeV in dielectron channels at the mid-rapidity in the mass region of Υ and $<$ 100 MeV for dimuons at the forward, allowing to separate the substates of Υ [4].

In a central collision of Pb+Pb at $\sqrt{s_{NN}} = 5.5$ TeV, as many as $\sim$ 5 pairs of beauty and anti-beauty quarks are expected to be produced along with $\sim$ 115 pairs of charm and anti-charm, assuming reasonable shadowing factors, allowing measurement of substates of Ψ and Υ with high statistics. In one month of Pb+Pb running at ALICE with the nominal luminosity, J/Ψ are expected to be measured up to $\sim$ 20 GeV/c and Υ(1s) and Υ(2s) up to $\sim$ 8 GeV/c with good statistics and signal to background (S/B) ratios. Ψ' may suffer from a low S/B ratio and Υ(3s) from low statistics, requiring a few runs combined to achieve good measurements [4].

4 A Key Device: ALICE Photon Spectrometer

As a key device for measurement of photons in a broad range of transverse momentum with a high precision, a photon spectrometer (PHOS) is placed at the bottom part of the central barrel of ALICE [7]. It is an electro-magnetic calorimeter array with a high energy resolution of $\sim 3\%/\sqrt{E[\mathrm{GeV}]}$ and a high granularity of $22{\times}22$ mm^2 at 4.6 m from the interaction point. PHOS consists of 17,920 channels, each with a $PbWO_4$ crystal of 180 mm or 20 radiation lengths deep and a readout system with an avalanche photo diode (APD), covering the pseudo-rapidity range from -0.12 to 0.12 and an azimuthal region of 100 degrees. The temperature of the crystals, APD's and charge sensitive preamplifiers are controlled at -25 ± 0.1 °C to enhance the light yield from the crystals and to reduce the electric noise in the APD's. PHOS also provides the ALICE experiment with level 0 and 1 trigger signals.

The ALICE group at Hiroshima University has contributed to PHOS in several ways. Expertise on $PbWO_4$ crystals and APD's has been built via unique calorimeter oriented studies of their properties, such as photon yield and decay time constants of the crystals and gain, breakdown voltage and noise of APD's as a function of temperature down to -35 °C. The research and development have played a vital role in leading PHOS to achieve the excellent energy resolution of $2.2\%/E[\mathrm{GeV}] \oplus 2.8\%/\sqrt{E[\mathrm{GeV}]} \oplus 1.3\%$ in test experiments with electron beams.

The first one of the five modules of PHOS was installed in ALICE in 2008, to be followed by two more in 2009 for the first physics operation of LHC.

5 Summary and Concluding Remarks

While RHIC has been proven to be very successful, physics of high energy nucleus-nucleus collisions has not come to the end of the story. Contrarily more interesting issues are now on stage, *i.e.* to comprehensively investigate and understand the properties of the newly created hot and dense partonic matter. The ALICE experiment at LHC, starting its operation later in 2009, is not only uniquely suitable for hard and/or heavy probes, but at the same time is opening a new ground for *soft* photonic probes with its photon spectrometer, PHOS. The experimental community in Japan in the field of physics is in full commitment to ALICE, along with to RHIC. As ALICE is a wide-purpose high energy nuclear physics experiment, it has a broad coverage of physics prospects and also a high capacity for the *unknown*. A rich harvest of physics is expected just around the corner (even in the initial p+p running).

References

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