PROCEEDINGS OF SCIENCE

Heavy Ion physics in ATLAS and CMS

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We will present the capabilities of the ATLAS and CMS experiments to explore the heavy-ion physics programme offered by the CERN Large Hadron Collider (LHC). The collisions of lead nuclei at energies $\sqrt{s_{NN}}$ = 5.5 TeV, will probe quark and gluon matter at unprecedented values of energy density. The prime goal of this research is to study the fundamental theory of the strong interaction (QCD) in extreme conditions of temperature, density and low parton momentum fraction. The current paper will give an overview of the potential of ATLAS and CMS to carry out a set of representative Pb-Pb measurements.

These include "bulk" observables, like charged hadron multiplicity, low p_{T} inclusive hadron identified spectra and elliptic flow – which provide information on the collective properties of the system; as well as perturbative processes, such as quarkonia, heavy-quarks, jets, γ-jet, and high p_{T} hadrons — which yield "tomographic" information of the hottest and densest phases of the reaction.

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1. Introduction

The study of the fundamental theory of strong interaction (QCD) in extreme conditions of temperature, density and the parton momentum fraction (low-x) is the motivation for the previous, ongoing and future heavy–ion experiments. The heavy–ion program in ATLAS and CMS is strongly motivated by the J/ψ anomalous suppression discovered at Super Proton Synchrotron(SPS) and several new phenomena observed at the Relativistic Heavy Ion Collider (RHIC). The top list of evidences at RHIC [1] includes lower hadron multiplicity than expected (possible saturation of the gluon density), the constituent quark number scaling of the elliptic flow and momentum spectra, strong interaction of high p_T hadrons with the dense matter and a significant suppression of the J/ψ, similar to the one seen at the SPS, accompanied with more suppression of J/ψ's in forward than in the central region. The LHC plans to collide Pb nuclei at $\sqrt{s_{NN}} = 5.5$ TeV which is 28 times higher than the highest energy available at RHIC. According to our current understanding the regime accessible at LHC will be characterized by the following properties - an initial state dominated by high-density (saturated) parton distribution with relevant range of parton momentum fraction x as low as 10^{-5} with a characteristic saturation momentum, $Q_s^2 \simeq 5-10$ GeV^2 [2]; copious production of hard probes (jets, high-p_T hadrons, heavy-quarks, quarkonia); large yields of the weakly interacting perturbative probes (direct photons, dileptons, Z^0 and $W^\pm$ bosons) [3].

2. ATLAS and CMS detectors

Both ATLAS and CMS are general purpose detectors designed to explore the physics at the TeV energy scale. Both detectors have tracker, muon system, calorimeters with full azimuth angle and wide pseudorapidity coverage. The tracker covers $|\eta| < 2.5$ for both detectors. Muon chambers are extended up to ± 2.4 in CMS and ± 2.7 in ATLAS. Electromagnetic (ECAL) and hadronic (HCAL) calorimeters cover $|\eta| < 3.2$ in ATLAS and $|\eta| < 3$ in CMS. Both detectors are equipped with forward calorimeters (FCAL in ATLAS and HF in CMS) up to $\eta = \pm 5$. From $\eta = \pm 5.5$ and up to $\eta = \pm 6$ ATLAS has the additional Lucid detector and CMS has CASTOR calorimeter in pseudorapidity range $5 < |\eta| < 6.7$. Zero degree calorimeters are located with $|\eta| > 8$ both in ATLAS and CMS systems. A detailed description of ATLAS and CMS detectors can be found in Ref. [4]. We have the unique possibility to cross-check measurements done in the same phase space but using different types of detectors.

3. Bulk ("hydro") measurements in A-A collisions

3.1 Charged particle multiplicity

The charged particle multiplicity per unit of rapidity at mid-rapidity is related to the produced entropy density in the Pb-Pb collisions and fixes the global properties of the produced medium. Extrapolations from SPS to RHIC energies gave essential overestimation relative to the measured multiplicity at RHIC. This evidence gives rise to the Color Glass Condensate (CGC) approaches which effectively take into account a reduced initial number of scattering centers in PDFs and reproduces results from RHIC. The expected hadron multiplicities at midrapidity in the frame of CGC model is much lower ($dN/d\eta|_{\eta=0}$ =2000) than the $dN/d\eta|_{\eta=0}$ =8000 predictions before

RHIC results. Both ATLAS and CMS assume the first day measurement of the charged particle multiplicities by two methods: hit counting in pixel detectors accomplished with *dE/dx* cut and tracklets with vertex constraint. The comparison of the reconstructed multiplicity with hits counting and generated one is presented in Fig. 1 for ATLAS detector and in Fig. 2 for CMS detector.

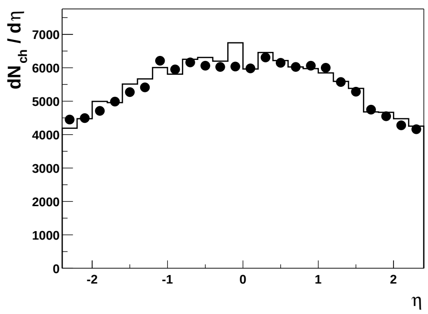

Figure 1: Comparison of the original distribution of primary simulated tracks (histogram) to the estimate obtained from the reconstructed hits in layer 1 of the Si pixel tracker (points) for ATLAS detector.

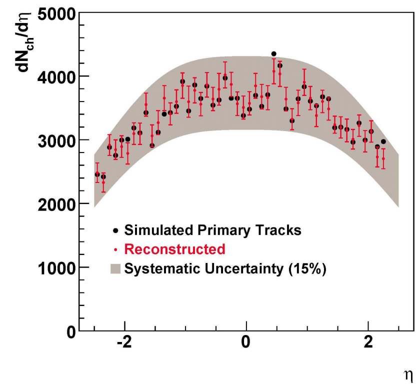

Figure 2: Comparison of the original distribution of primary simulated tracks (black large points) to the estimate obtained from the reconstructed hits in layer 1 of the Si pixel tracker (red smaller points) with statistical error bars, the grey band indicates a somewhat conservative systematic uncertainty of Ref. [3] for CMS detector.

3.2 Low-p_T hadron spectra

Measurements of hadron momentum spectra and ratios at low p_T are the important tool to determine the amount of collective radial flow and the thermal and chemical conditions of the final (freeze-out) state of reaction. The CMS has developed a special low p_T tracking algorithm with the possibility of particle identification by correlating energy loss, *dE/dx*, and the momentum of track, p, in Si-pixels and strips. The inclusive hadron spectra can be measured up to $p \simeq 1$ GeV/c for pions and kaons and up to 2 GeV/c for protons (Fig. 3).

3.3 Elliptic flow

The initial state in A-A collisions with non-zero impact parameter is characterized by an anisotropic distribution in coordinate space. In collective system, the initial space anisotropy translates into a final elliptical asymmetry in momentum space with respect to reaction plane because the pressure gradient is larger for directions parallel to the smallest dimension of the ellipse. The elliptic flow parameter, v_2 is defined as the second harmonic coefficient of the fitted Fourier series function for the azimuthal distribution of hadrons with respect to the reaction plane. The comparison of the experimental data on v_2 with hydrodynamical calculations reveals that the produced matter behaves like perfect fluid close to the hydrodynamical limit expectations for a fully thermalized system [3]. Both ATLAS and CMS will provide measurements of v_2 parameter. The resolution of the event plane determination for CMS is shown in Fig. 4. The dependence of v_2 parameter on

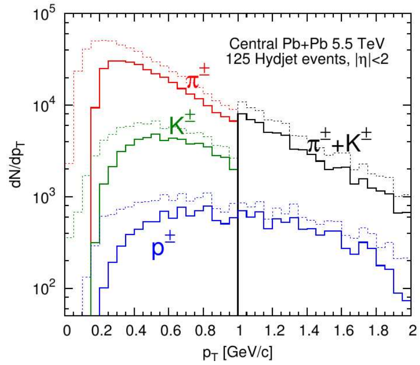

Figure 3: Low-p_T spectra of generated hadrons (dotted line) and the reconstructed hadrons (solid lines). Simulation was done for central Pb-Pb events at $\sqrt{S_{NN}}$ =5.5 TeV.

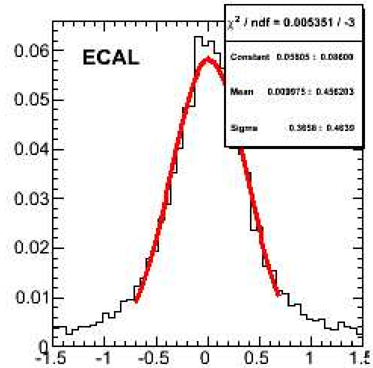

Figure 4: The reaction plane resolution estimated with the CMS electromagnetic calorimeter

the momentum of track is presented in Fig. 5 for ATLAS and in Fig. 6 for CMS for two different parameterization of elliptic flow included in the input generator.

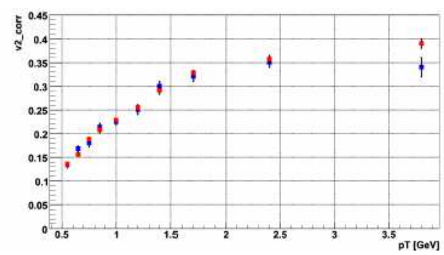

Figure 5: Dependence of the reconstructed v_2 parameter on the p_T of track for ATLAS [5]. Elliptic flow was included in HIJING [7] according to Ref. [6]

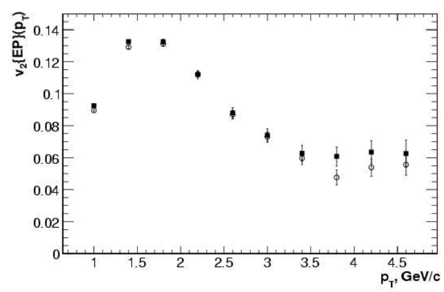

Figure 6: The dependence of the reconstructed v_2 parameter on the p_T of track for CMS. Elliptic flow was included in HYDJET [8]

4. Hard ("tomographic") probes of dense QCD matter

Hard probes (particles with large transverse momentum and/or high mass) are of crucial importance for several reasons: (i) they originate from parton scattering with large momentum transfer Q^2 and are directly coupled to the fundamental QCD degrees of freedom; (ii) their production timescale is short, allowing them to propagate and potentially be affected by the medium; (iii) their cross-sections can be theoretically predicted with pQCD.

4.1 Jets and high-p_T hadrons production

One of the major discoveries at the RHIC is the hadron suppression at relatively high p_T, i.e. jet quenching effect. This effect is visible with the p_T dependence of the nuclear modification factor, R_{AA} which is defined by the ratio of particle yield in heavy-ion collisions to the binary collisions scaled yield in p+p collisions. The expected spectrum of high-p_T hadrons obtained for minbias events (without High Level Trigger) is shown in Fig. 7 for ATLAS detector. The reach for the p_T dependence of R_{AA} function using sample of events selected with High Level Trigger is shown in Fig. 8 for CMS [3].

New hard probes are available at the LHC, such as jet production, and boson-tagged (γ,Z^0) jet production. To investigate jet quenching in a full set of available signatures ATLAS and CMS developed jet, high-p_T tracks and photon reconstruction in the high occupancy conditions in detector [3],[9]. The ratio of the reconstructed quenched fragmentation function to the unquenched one is presented in Fig. 9 in comparison with Monte-Carlo (MC) truth [10] for the integrated luminosity of 0.5 nb^{-1}.

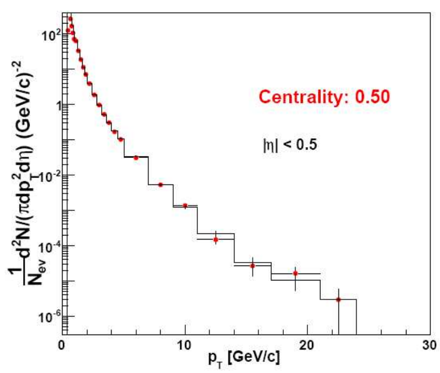

Figure 7: Charged particle p_T spectrum expected for Pb-Pb collisions at 5.5 TeV for a nominal integrated luminosity of 0.5 nb^{-1} using the minbias sample (ATLAS).

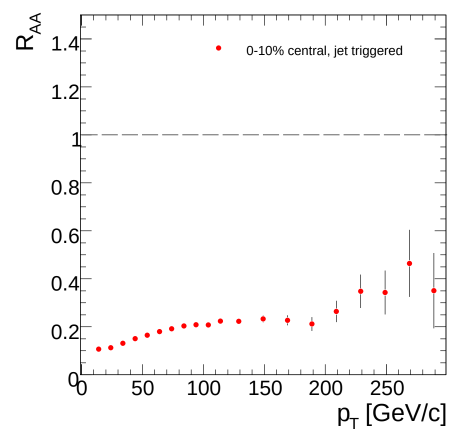

Figure 8: Expected statistical reach for the nuclear modification function, $R_{AA}(p_T)$ for inclusive charged hadrons in central Pb-Pb collisions generated with HYDJET [8] for a nominal integrated luminosity of 0.5 nb^{-1} for data triggered on high-p_T jets (CMS).

4.2 Quarkonium production

The study of heavy-quark bound states in high energy A-A collisions was proposed as a sensitive probe of the thermodynamical properties of the produced medium in [11]. The recent lattice calculations predict the step-wise suppression of the J/ψ and Υ families because of the different melting temperature for each $Q\bar{Q}$ state [12]. At the LHC Υ family will be available with large statistics for the first time. Unlike the J/ψ family the botomonium family will be less affected by the recombination process due to less amount of $b\bar{b}$ compared to $c\bar{c}$ pairs in A-A collisions.

The dimuon mass distribution for J/ψ together with the invariant mass spectra of opposite–sign muon pairs in J/ψ mass range is presented in Fig. 10 for ATLAS detector [13]. The dimuon spectra for J/ψ and Υ family obtained with CMS detector [3] are shown in the Figs. 11, 12. The mass resolution in Υ mass range is 125 MeV/c^2 for ATLAS detector. The mass resolution for Υ is about 54 MeV/c^2 for CMS barrel and it worsens to 90 MeV/c^2 if endcap detectors are included. For

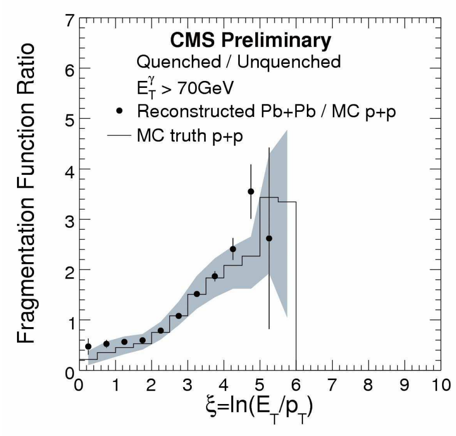

Figure 9: The ratio of the reconstructed quenched fragmentation function to the unquenched one (filled circles) is compared with the Monte-Carlo truth (solid histograms) for the integrated luminosity of 0.5 nb^{-1} (CMS).

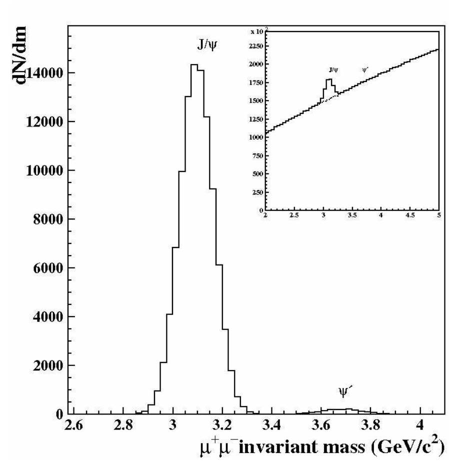

Figure 10: The J/ψ mass distribution and invariant mass spectra of opposite sign muon pairs in J/ψ mass range (ATLAS).

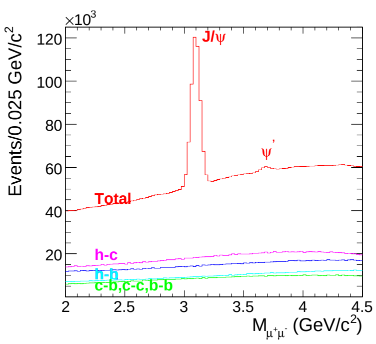

Figure 11: Invariant mass spectra of opposite–sign muon pairs in J/ψ mass range with $dN_{ch}/d\eta|_{\eta=0} = 2500$ with both muons in $|\eta| < 2.5$ (CMS detector)

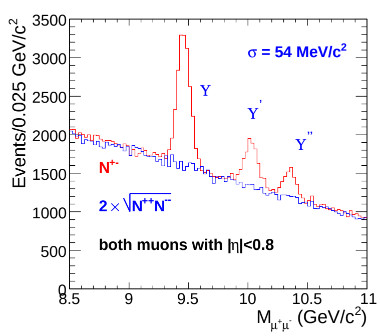

Figure 12: Invariant mass spectra of opposite–sign muon pairs in Υ mass range with $dN_{ch}/d\eta|_{\eta=0} = 2500$ with both muons in $|\eta| < 0.8$ (CMS detector)

J/ψ, mass resolution is 100 MeV/c^2 for ATLAS and 35 MeV/c^2 for CMS in full η range. Around 20 Kevents of Υs and a few hundreds ($\simeq$200) kevents of J/ψs is expected in 0.5 nb^{-1}.

5. Summary

The excellent capabilities of ATLAS and CMS give the unique possibility of measuring both soft and hard probes of the dense medium state, such as multiplicity, soft and hard spectra of charged particles, photons, jets, quarkonia and some other probes (ultra-peripheral collisions,dihadron and dijet correlations,HBT) that are not covered in the current paper. The similar $p_T - \eta$ acceptance of ATLAS and CMS detectors allows to cross-check measurements done with different technologies.

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