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Prospects for identified leading particle correlation at LHC and in ALICE

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Azimuthal di-hadron correlations play important role in the characterization of the medium created in heavy-ion collisions at RHIC. Moreover, as a novel phenomenon, strong modification of the away-side correlation is observed in Au+Au with respect to p+p collisions. Below the exclusive jet reconstruction threshold at LHC, leading particle correlations will provide access to the regime where hard scatterings and bulk medium properties can be simultaneously studied. Leading particle correlations can be extended to very low transverse momenta via the tracking and particle identification capabilities of ALICE, to the coalescence and hydrodynamic domains. In preparation for the first p+p and Pb+Pb collisions of LHC, we present prospects on leading particle correlations with identified particles in ALICE.

High-pT physics at LHC
March 23-27 2007
University of Jyväskylä, Jyväskylä, Finland

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PoS(LHC07)027

1. Introduction

Awaiting for the startup of the next generation particle and heavy-ion physics experiments at the Large Hadron Collider (LHC), we review few selected results from the Relativistic Heavy Ion Collider (RHIC), where heavy-ion collisions at 200 GeV c.m.s. energy provide the most suitable environment, up to now, to study the strongly interacting matter under extreme temperature and energy density. At RHIC, in central Au+Au collisions strong suppression of large transverse momentum (un)identified charged hadrons is observed with respect to peripheral Au+Au, p+p or d+Au collisions [1, 2]. This suppression is referred as jet quenching and extends to large transverse momenta ($p_T \sim$ 15-20 GeV/c). Furthermore, in azimuthal di-hadron correlations strong modification of the away-side correlation is seen in Au+Au with respect to p+p collisions [3, 4], followed by similar observations even at SPS energies [5]. Extending the azimuthal di-hadron correlations to pseudo-rapidity as well, on the near-side, long range pseudo-rapidity correlation appears as shown in Fig. 4. In the so called intermediate transverse momentum region ($2< p_T < 6$ GeV/c) enhancement of baryon production is observed in mid-central, central Au+Au collisions with respect to p+p collisions [7, 8]. These measurements highlight the importance of the intermediate p_T region

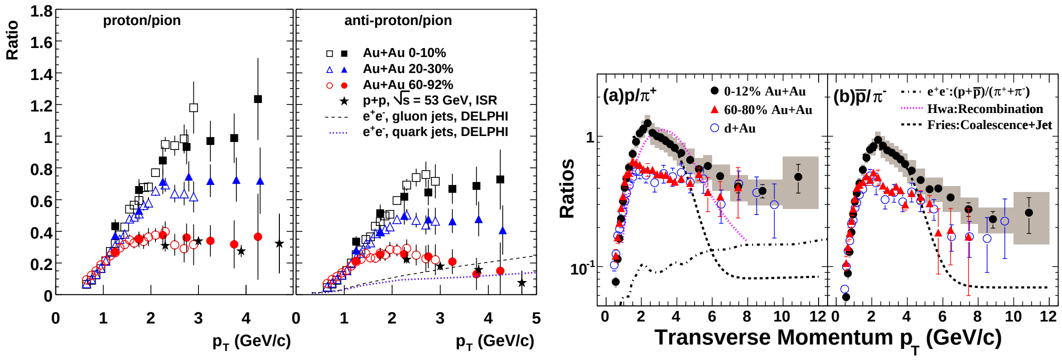

Figure 1: $p(\overline{p})/\pi^{\pm}$ ratios measured by PHENIX [7] and STAR [8].

where one can investigate to the interaction between the hard probes and the bulk matter created in heavy-ion collisions.

2. Review of RHIC results

2.1 Particle spectra and ratios

Majority of the particles emitted in heavy-ion collisions appear in the low transverse momentum region: $p_T < 2$ GeV/c. This region was extensively studied in AGS and SPS experiments, measurements at higher transverse momenta were limited by beam energy. At RHIC, the transverse momentum range of identified particles is extended to high-$p_T \sim 5$ GeV/c [7] and later up to $p_T \sim$ 12 - 15 GeV/c [8]. Experimental results and theoretical calculations suggest distinction of three p_T regions: bulk, intermediate and high p_T. The bulk region ($p_T < 2$ GeV/c) seems to be driven by the thermal properties of the matter created in heavy-ion collisions. In the high$-p_T$ (6 GeV/c $< p_T$) region particle measured particle spectra are well described by pQCD calculations. Baryon

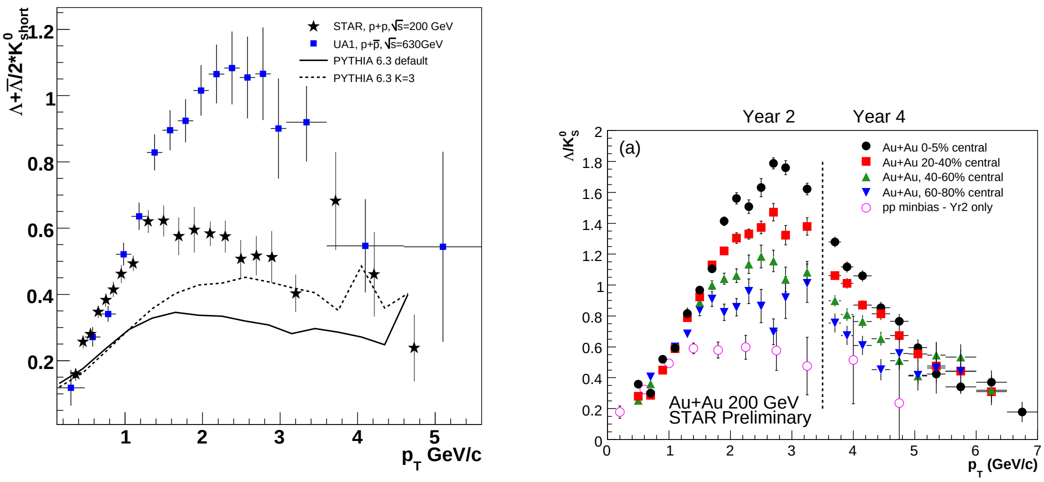

Figure 2: Λ/K^0_S ratios measured in p+p and Au+Au collisions [9].

production is significantly enhanced and the baryon/meson ratio reaches 1 in most central Au+Au collisions at 200 GeV as shown in Fig. 1. Expectations of particle production from elementary collisions, quark and gluon jets and recombination/coalescence mechanisms are also shown [7, 8]. Similar enhancement is observed in strange particle production as shown in Fig. 2, however results from p+p collisions show clear collision energy dependence. Coalescence-recombination models quantitatively agree with results on particle spectra (R_{AA}), particle ratios (eg. $\overline{p}/\pi$, Λ/K^0_S) and elliptic flow in the intermediate p_T region.

2.2 Azimuthal di-hadron correlations at mid- and forward-rapidities

While full jet reconstruction only became available recently at RHIC, hard processes are studied via high-p_T particle production and their (azimuthal) correlation with lower momentum particles. These measurements revealed significant suppression of high-p_T hadrons and the disappearance of the away-side jet in central Au+Au collisions [1, 2]. Fig. 3 shows a systematic measurement of azimuthal di-hadron correlations by STAR, where the away-side is significantly broadened with respect to proton-proton collisions and the near-side remains unchanged [10]. The broadening and the modification of the away-side correlation and the presence of long range $\Delta\eta$ correlation on the near-side lead to various theoretical explanations. Models based on the assumption of flow deflected jets, large angle gluon radiation [11, 12], conical flow induced by shock waves in the medium (Mach cones) [13, 14] and Cerenkov radiation [15, 16] provide alternative descriptions of azimuthal di-hadron correlations.

Extended measurements of the near-side peak in wide $\Delta\eta$ reveal enhancement in the near-side correlated yield extending up to $|\Delta\eta| \sim 1.5$ in Au+Au collisions, as shown in Fig. 4, which is commonly referred as the ridge [6, 17]. Two particle correlation measurements at low transverse momenta ($p_T < 2$ GeV/c) without trigger particle also show long range correlation in $\Delta\eta$, above the flow modulated background [18]. There are many competing theories to describe the long range $\Delta\eta$ correlations: coupling of induced radiation to the longitudinal flow [19], turbulent color

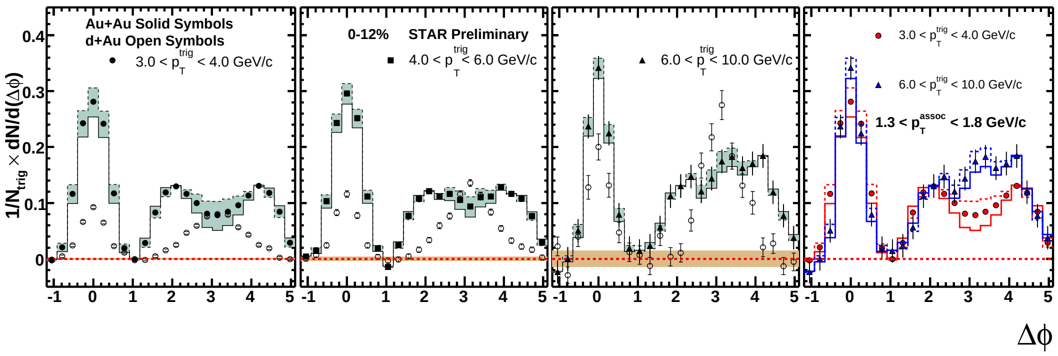

Figure 3: Azimuthal di-hadron distributions are shown for different trigger particle selections [10].

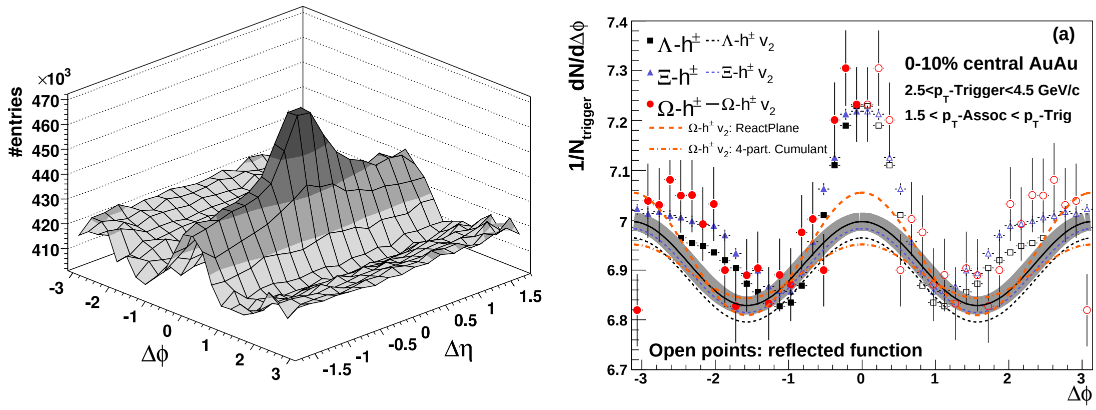

Figure 4: Raw $\Delta\eta \times \Delta\phi$ correlation function in Au+Au collisions [6] and strange, multi-strange - charged hadron correlations in central (0-10%) Au+Au collisions [25].

fields [20], anisotropic plasma [21] and the interplay of jet-quenching and strong radial flow [22]. Recombination of locally thermal enhanced partons due to partonic energy loss also provide a ridge like signal [23]. Up to now, STAR has the unique opportunity to fully characterize the properties of the long range $\Delta\eta$ correlations. Figure 4 also shows strange and multi-strange hadron triggered azimuthal di-hadron correlations measured by STAR above the flow background. Clear near-side correlation is shown in contrast to coalescence/recombination expectations for Ω, however recently a new solution is suggested [24]. The jet (peak) and the bulk (shoulder structure) is separated and the extracted correlated yields are shown in Fig. 5. The correlated jet yield is increasing, while the ridge yield seems to level off with increasing trigger p_T [25]. The ridge is considered the response of the medium to the traversing hard partons/jets. The properties of the peak structure are jet like while the shoulder like structure is similar to the bulk.

STAR has reported measurements in p+p, d+Au and Au+Au collisions from the forward rapidity region utilizing its Forward Time Projection Chambers [26] (FTPCs). Extension of the azimuthal di-hadron correlation measurements to large rapidities have the possibility to explore modifications of away-side correlations and the possible existence of long range correlations on the near side by the bulk response. In these measurements, the high-p_T trigger particles are se-

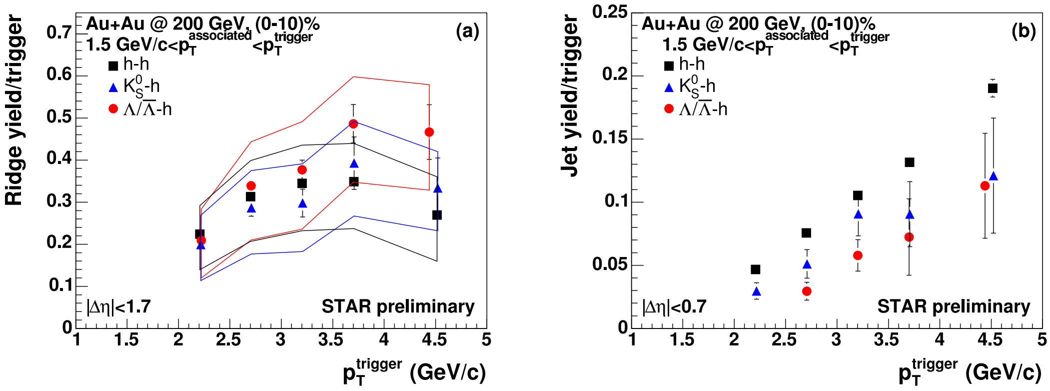

Figure 5: Jet and ridge yields as a function of trigger p_T in central (0-10%) Au+Au collisions [25].

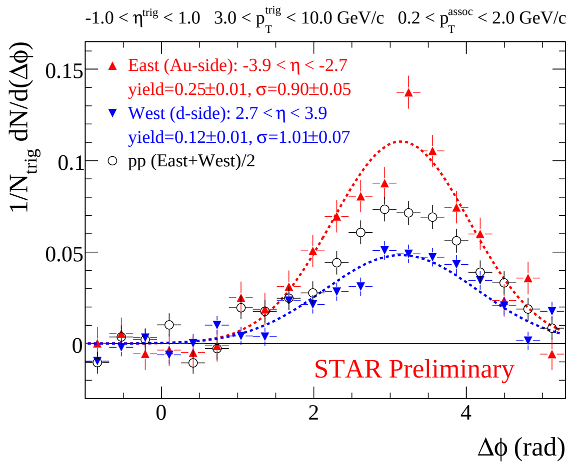

Figure 6: Correlation functions for pseudo-rapidity averaged p+p and pseudo-rapidity selected d+Au collision [29].

lected in the STAR Time Projection Chamber (TPC): $|\Delta\eta| < 1$, while the associated particles are selected in the FTPCs: $2.7 < |\Delta\eta| < 3.9$. These selections introduce a minimum 1.7 pseudo-rapidity gap and are possibly sensitive to small-x gluon and large-x quark hard scattering [27], while azimuthal di-hadron correlations with the selection of the trigger particle and the associated particles at mid-rapidity address gluon-gluon hard scatterings at RHIC energies [28]. Figure 6 shows the two particle distributions in p+p and d+Au collisions [27, 29] at forward rapidities. In d+Au collisions the outgoing *d* and *Au* sides are shown separately, while the p+p results are averaged over positive and negative pseudo-rapidities. The near-side correlation is consistent with zero both for p+p and d+Au collisions. On the away-side a factor of 2 suppression of the d-side yield is observed with respect to the Au-side. The p+p results are situated between the d- and Au-side. The suppression of the d-side yield is in qualitative agreement with the Color Glass Condensate (CGC) picture [30], which predicts suppression of small-x gluons in the Au nucleus. However, the reduction of the

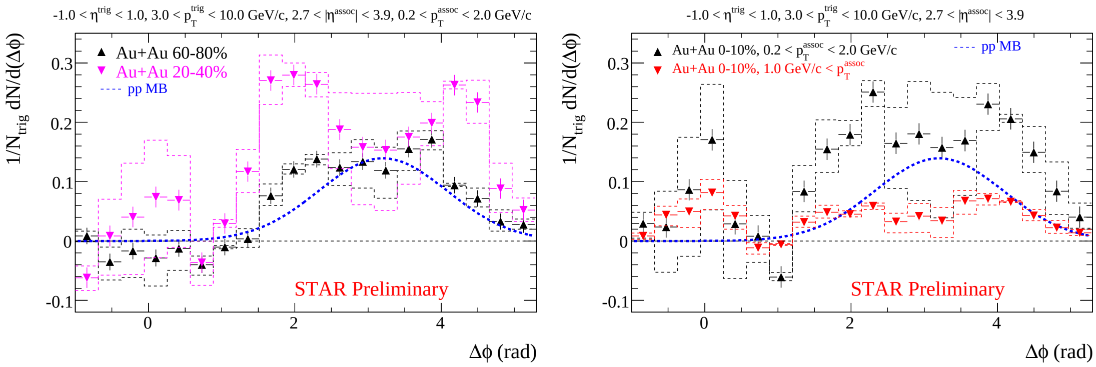

Figure 7: Corrected $\Delta\phi$ correlation functions in Au+Au collisions compared to p+p collisions [29].

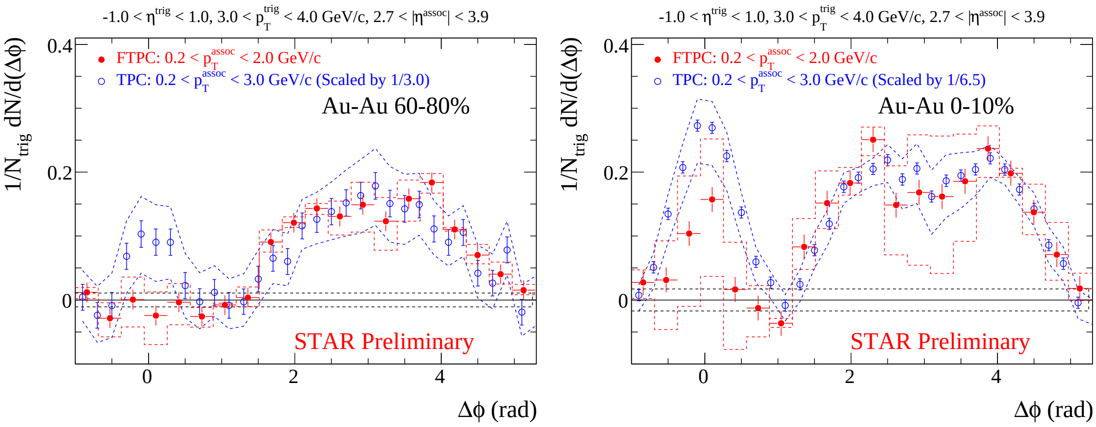

Figure 8: Comparison of azimuthal di-hadron correlation functions from mid- and mid-forward rapidities peripheral and central Au+Au collisions [29].

d-side yield may arise from the energy degradation of the d-side quarks due to multiple scattering in the Au nucleus. Gluon anti-shadowing [31] and the EMC effect [32] would enhance the d-side yield relative to the Au-side [27, 29]. Figure 7 shows the mid- forward-rapidity azimuthal correlations for different centralities and associated p_T ranges in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, which can be regarded as the extension of Fig. 4 to large pseudo-rapidities. In peripheral and mid-peripheral Au+Au collisions the near-side correlations for $0.2 < p_T^{assoc} < 2$ GeV/c are consistent with zero within the systematic uncertainties. For the most central (0-10%) Au+Au dataset two associated p_T ranges are selected. The near-side correlations for $0.2 < p_T^{assoc} < 2$ GeV/c are consistent with zero within the systematic uncertainties. However, the central data at high associated p_T, with the reduced systematic uncertainty, are suggestive of non-zero correlation on the near-side. This result indicates that long range $\Delta\eta$ correlations, first observed in $\Delta\eta < 2$ [6], may extend out to $\Delta\eta \sim 4$ in the FTPCs [29].

In mid- forward-rapidity correlations, broadening of the away-side correlation shapes is observed in Au+Au collisions with respect to p+p as shown in Fig. 7. The broadening is present for each centrality, such as at mid-rapidity [10], however the away-side yield at forward-rapidity is a factor of 3 - 6.5 smaller [29]. Figure 8 shows the comparison of the azimuthal correlations measured at forward rapidity (with the scaled down yield) and at mid-rapidity as shown eg. in Fig 3. The away-side correlation shapes measured in the STAR-TPC and FTPCs are identical within the systematic uncertainties. This might suggests similar apparent energy loss at mid- and forward-rapidities, however the interplay of the physical processes might be different.

3. Prospects for LHC

The LHC will deliver 14 TeV proton-proton collisions and 5.5 TeV Pb+Pb collisions at high luminosity. Among the LHC experiments, ALICE has strong capabilities in particle identification, down to $p_T \sim 200$ MeV/c due to the low magnetic field (0.2-0.5T) and the material budget. Particle identification is achieved by the combination of the ALICE sub-detectors: ITS, TPC, TOF, TRD and HMPID and the more specified EMCAL and PHOS [33].

In the first run, LHC will deliver proton-proton collisions, which are not only baseline for heavy-ion measurements but represent essential physics to contrast with theoretical expectations. There are many questions left open in proton-proton and heavy-ion physics at RHIC for the concise interpretation. At LHC energies the azimuthal di-hadron correlations will benefit from the enhanced cross-section of large-Q^2 processes, but the uncorrelated background which appears in the combinatorial background will also increase. ALICE carried out a feasibility study on azimuthal di-hadron correlations (leading particle correlations) in simulated unquenched and quenched HIJING Pb+Pb events at $\sqrt{s_{NN}}$ = 5.5 TeV, with a choice of trigger and associated particle selection to be able to compare to RHIC results [34]. Trigger bias has to be properly addressed and the γ - charged hadron correlation provide good solution, however limited in the lower transverse momentum region [35]. Azimuthal di-hadron correlations in $\Delta\eta$ x $\Delta\phi$ and 3-particle correlations are not yet address in feasibility studies, which will be important to repeat and extend them to identified correlations to gain more insights to the interaction of hard scattered partons and the bulk.

4. Summary

Selected review of RHIC results are presented, focusing on particle production azimuthal di-hadron correlations in the intermediate transverse momentum region. Two particle correlations in $\Delta\phi$ and $\Delta\eta$ are important tools to investigate and characterize the interaction of the hard probes and the medium created in heavy-ion collisions. Combined measurement of single particle and correlated yields might help to disentangle the physics processes and provide solid baseline to contrast with theoretical expectations.

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