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Jet physics in Pb-Pb collisions with ATLAS

Martin SPOUSTA[*] **for the ATLAS collaboration**
Charles University in Prague, Faculty of Mathematics and Physics
E-mail: `spousta@ipnp.troja.mff.cuni.cz`

The existing measurements of hard probes at RHIC done until now do not provide a sufficient quantitative insight to the details of energy loss of fast partons in the dense QCD medium. The majority of measurements are done using leading particles or two particle correlations. The energy range of LHC will provide a possibility to perform full jet reconstruction and to achieve high enough statistics to distinguish between differences among different theoretical predictions for energy loss. In this article, the basis of the jet reconstruction strategy in heavy ion collisions with the ATLAS detector is described. The expected accuracy of the measurement of fragmentation functions, j_T distributions and jet shapes are shown. Sensitivity of these measurements to the energy loss mechanism simulated by the PYQUEN generator is also discussed.

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[*] Speaker.

The measurements of hard probes at RHIC are insufficient to infer details of the energy loss of fast partons in the dense QCD medium. The majority of measurements are done using leading particles or two particle correlations [1]. Due to the limited p_T reach of measurements and the large soft background, these measurements suffer from biases towards jets and di-jets that escape the medium having lost little energy. These biases have made extracting true quantitative information about medium properties from the RHIC data difficult. In contrast, the high center-of-mass energy and large rates for high-p_T jets at the LHC will make full jet measurements possible over a wide range of jet energies. Particularly interesting are measurements of the fragmentation function, $D(z) = 1/N_{jet}\ \mathrm{d}N/\mathrm{d}z$ and j_T distribution, $D(j_T) = 1/N_{jet}\ 1/j_T\ \mathrm{d}N/\mathrm{d}j_T$, where z is the fraction of the longitudinal momentum of a fragment with respect to the jet axis and j_T is the transverse momentum of the fragment with respect to the jet axis. The ATLAS detector is also well suited for calorimetric measurements of energy flow inside the jet, thus jet shapes. All these measurements are expected to be modified in heavy ion collisions [7] and will provide direct information on the properties of the hot, high color charge density medium created in heavy ion collisions.

Standard jet reconstruction algorithms developed for p+p collisions at the ATLAS experiment have to be modified to take into account the underlying background of Pb+Pb collision. This background needs to be properly estimated and then subtracted. This is done prior to the cone jet reconstruction. Jet candidates in an event are found using a sliding window algorithm and regions containing these candidates are excluded from the background estimate. The layer- and η-dependent average background is then subtracted from all calorimeter cells[1]. After that, the iterative cone jet algorithm is run. For more detailed information including kT algorithm and basic jet reconstruction performance, see [2, 3, 5]. To evaluate the expected reconstruction performance in heavy ion collisions with the ATLAS detector, di-jet PYTHIA [8] events were embedded in HIJING [9] heavy ion events[2] and reconstructed using the full simulation of the ATLAS detector.

Fragmentation function and j_T

The fragmentation function and j_T distribution is built up from reconstructed tracks that match the jet. For each jet, background distributions are constructed from tracks that match HIJING particles. These background distributions are subtracted from the original distributions. After the background subtraction, a p_T-independent tracking efficiency correction of 70% [4] is applied. Upper panel of Fig. 1 compares truth fragmentation function and j_T distribution computed using charged particles and truth jets with reconstructed distributions computed using tracks. The most central HIJING collisions ($b = 2$ fm, $\mathrm{d}N/\mathrm{d}\eta = 2700$) were used for this study. The p_T cut used for particles and tracks is 2 GeV. The jet energy is between 70 GeV and 140 GeV. As one can see there is a good agreement between truth and reconstructed fragmentation function whereas some differences can be seen in the case of j_T distribution, mainly at low j_T values. This difference is due to the limited position resolution of the reconstructed jet. Since j_T measures the transversal component of the jet it is naturally quite sensitive to the jet position resolution. We can enhance the jet position resolution using position of a jet determined with smaller cone size $R = 0.2$. To use

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[1] Cells represent the segmentation of calorimeter measurements in each layer. Barrel part of the calorimeter is layered radially, end-cap part is layered longitudinally with respect to the beam axis.

[2] Simulations of Pb+Pb collisions at $\sqrt{s_{NN}} = 5.5$ TeV without quenching were used.

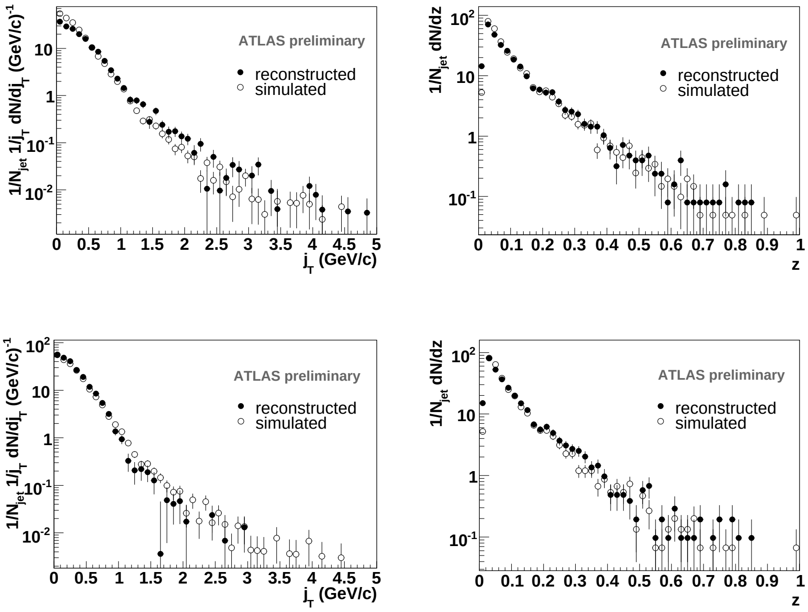

Figure 1: Upper panel: j_T and z distributions after the subtraction of background distributions and after the correction on the tracking efficiency. Truth distributions (open markers), reconstructed distributions (closed markers). Lower panel: j_T and z distributions after the additional jet position resolution correction.

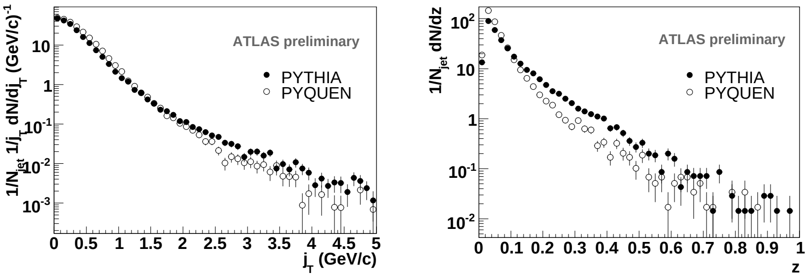

Figure 2: j_T distribution (left) and fragmentation function (right) from PYQUEN (open markers) and PYTHIA (closed markers) events.

the smaller cone size means to look only at the hard core of the jet and not to take into account the soft component of the jet which can interfere with fluctuations of the background that cannot be subtracted. Thus jets determined using the smaller cone size have better position resolution than the standard $R = 0.4$ jets. Lower panel in Fig. 1 shows the fragmentation function and j_T distribution after the additional correction on the jet position resolution. One can see that the fragmentation function remains unaffected whereas the correspondence between truth and reconstructed j_T is improved and is quite satisfactory. This reflects a good performance of the ATLAS tracking system.

In order to test our sensitivity to effects of the jet quenching, we compare $D(z)$ and $D(j_T)$ distributions from PYTHIA and b=0 fm PYQUEN [6] at the generator level (i.e. the ATLAS detector is not simulated). The result is shown in Fig. 2. As expected, the high-z fragments are

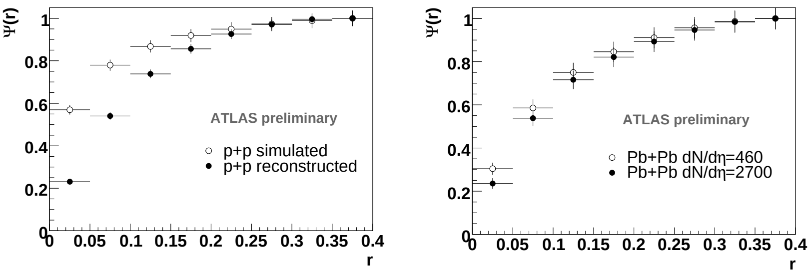

Figure 3: Left panel: Integral jet shape for reconstructed (closed) and truth (open) p+p events. Right panel: Integral jet shape reconstructed in the most central collisions (closed) and jet shape reconstructed in the most peripheral collisions (open).

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suppressed and the low-z fragments are enhanced. It is interesting to note that, contrary to other energy loss models [7], the high j_T fragments are suppressed as well. This could be due to the fact that PYQUEN quenches the radiated gluons as well. In any case, the modifications observed for both distributions are much larger than the difference between input and reconstructed distributions in Fig. 1. Thus we can conclude that ATLAS experiment has sufficient sensitivity to measure quenching of the scale comparable to that modelled by PYQUEN.

Jet shapes

A suitable variable to measure the jet energy flow at different distances r from a jet axis is the jet shape: $r = \sqrt{(\phi - \phi_{jet\ axis})^2 + (\eta - \eta_{jet\ axis})^2}$, the integral jet shape $\Psi(r, R_{cone}) = \int_0^r E_T(\rho)\mathrm{d}\rho / \int_0^{R_{cone}} E_T(\rho)\mathrm{d}\rho$, the differential jet shape $\psi(r, R_{cone}) = \mathrm{d}\Psi(r, R_{cone})/\mathrm{d}r$. Left plot in Fig. 3 shows the comparison between simulated p+p jet shapes determined using particles and reconstructed jet shapes determined using calorimeter cells. Naturally, truth jets are narrower than calorimeter jets. To evaluate the accuracy of the measurement of jet shapes in heavy ion collisions, we reconstructed jet shapes in the most central collisions ($b = 2$fm, $\mathrm{d}N/\mathrm{d}\eta = 2700$) and jet shapes in the most peripheral collisions ($b = 10$fm, $\mathrm{d}N/\mathrm{d}\eta = 460$). In both cases background subtraction have been performed. From right plot in Fig. 3 one can see that jet shapes determined in the most central collisions are in a good agreement with jet shapes determined in the most peripheral collisions. Small underestimation of the energy at low r in the most central collisions is due to the finite position resolution.

We again compare PYTHIA and PYQUEN at the generator level to see the sensitivity of jet shapes to the quenching. Fig. 4 shows differential and integral jet shapes computed for quenched and unquenched data. The modification of the energy flow can be better seen from the differential jet shape. It is visible that the energy is redistributed from the center of jet to the periphery.

Based on the results presented above we can conclude that ATLAS can perform detailed and accurate measurements of jet properties in heavy ion collisions. These measurements should provide a deeper insight into the parton energy loss mechanism.

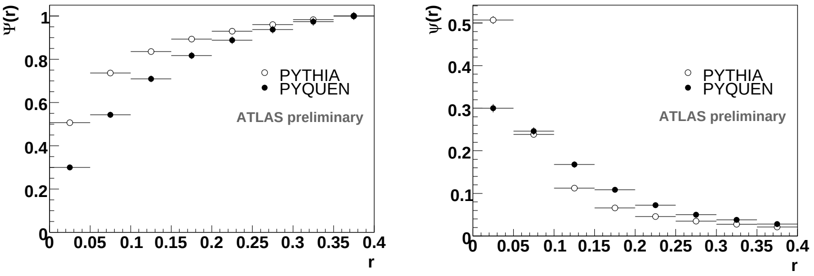

Figure 4: Integral (left) and differential (right) jet shape for PYQUEN and PYTHIA simulated events.

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