Event activity, direct photons and photon/hadron ratios in asymmetric collisions

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Introduction

Asymmetric collisions (like p/d+A), initially meant as straightforward control experiments to set a baseline against which A+A collisions, and the QGP formed in them can be tested, started to offer surprising physics insights on their own in the past decade. Long-range correlations in pseudorapidity, azimuthal anisotropies similar to those seen in A+A have been observed in p/d+A as well, were nuclear modification factors at high p_T reminiscent of "jet quenching" in the QGP formed in A+A. "If it looks like a duck, swims like a duck, quacks like a duck, it probably **is** a duck." Is QGP indeed formed in p/d+A (or even p+p)? We are agnostic about this, but argue that apparent jet suppression (or enhancement!) should not be part of this discussion, not the least because as we understand it today, it depends on pathlength of partons traversing the QGP, and even if droplets of QGP are formed in p/d+A, and exhibit genuine flow, they are way too small to cause substantial energy loss. Two other known issues are that – contrary to A+A – the suppression in "central" p/d+A does not saturate with increasing p_T (R_{pA} keeps decreasing monotonically), and the counter-intuitive enhancement in "peripheral" collisions keeps increasing (see Fig. 1).

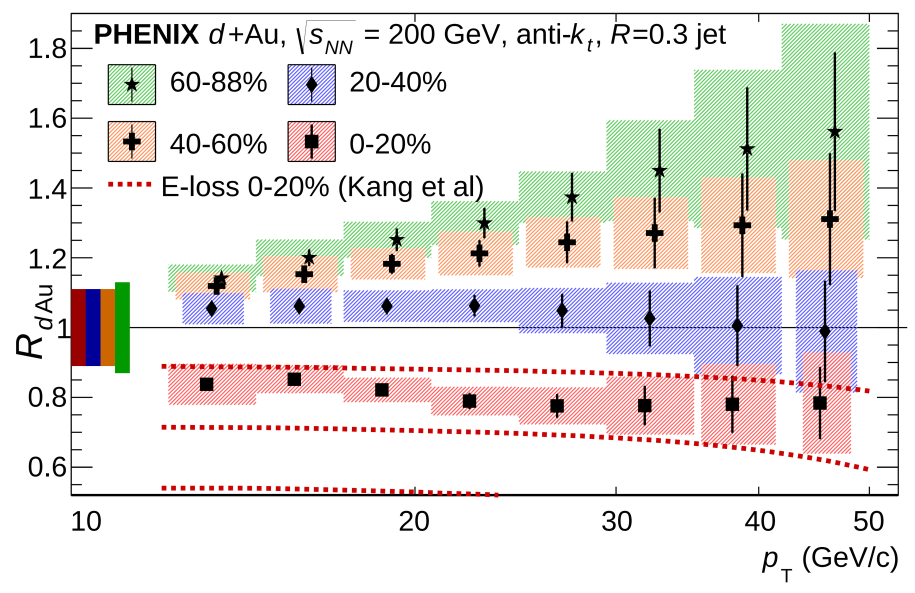

Figure 1: Jet R_{dAu} at RHIC for various centralities. Figure taken from [PRL **116**, 122301 (2016)].

Event activity vs collision geometry

Traditionally collision geometry has been calculated based on the Glauber model, connecting it to observables with the assumption that "the majority of the initial state NN collisions will be analogous to MB pp collisions with small perturbation from much rarer hard interactions" (Annu. Rev. Nucl. Part. Sci. **57**, 205-243 (2007)). Glauber himself wrote about the validity of his approach, that it "is only adequate for ... small angle scattering" without large momentum transfer. The issue is well demonstrated in Fig 2 for pp collisions: as the highest p_T observed at mid-rapidity increases, soft particle production at high rapidities (the usual input to establish centrality) is gradually depleted.

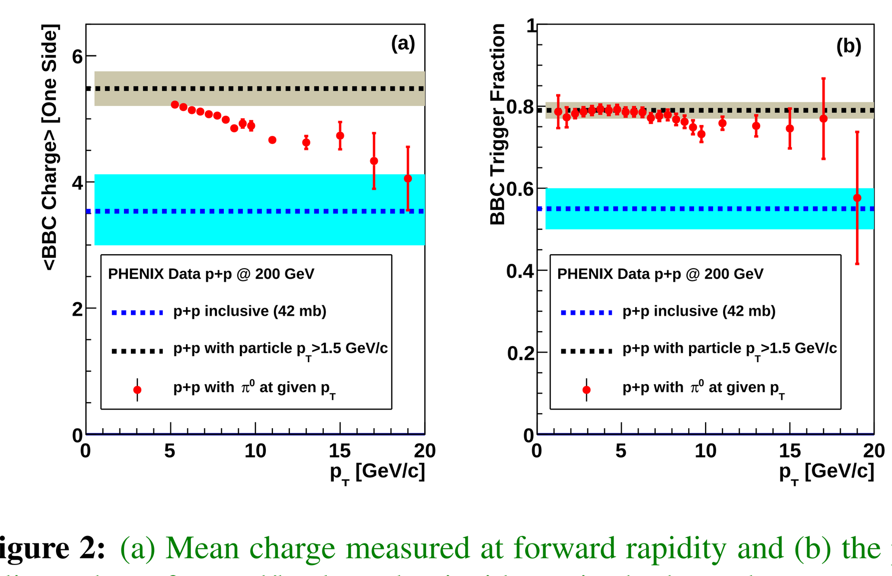

Figure 2: (a) Mean charge measured at forward rapidity and (b) the probability to have forward/backward coincidence in the beam-beam counters as a function of the highest p_T observed at mid-rapidity at RHIC. Figure taken from [PRC **90**, 034902 (2014)].

A similar problem is present in asymmetric (small-on-large) collisions, as demonstrated in Figs. 3 and 4: in presence of a high p_T hadron trigger at mid-rapidity event-activity in the forward region is strongly biased with respect to the distribution in average (minimum bias) events (PLB **783** (2018) 95-113). The two measures of event activity are neutrons in the zero degree calorimeter (ZNA) and charged particles in a forward scintillator array (V0A).

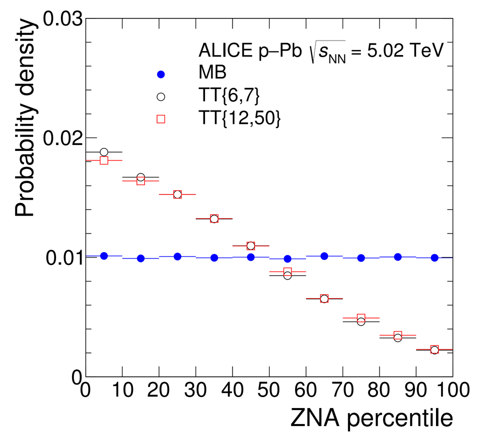

Figure 3: Distribution of event activity in the zero degree calorimeter in presence of a high p_T hadron trigger at mid-rapidity. Figure taken from PLB **783** (2018) 95-113.

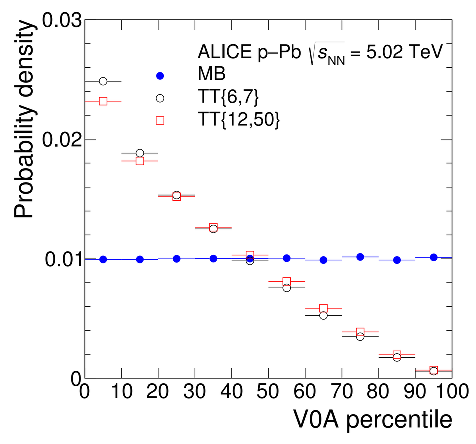

Figure 4: Distribution of event activity in the forward scintillator in presence of a high p_T hadron trigger at mid-rapidity. Figure taken from PLB **783** (2018) 95-113.

Connecting collision geometry to soft, bulk observables via the Glauber-model was recently questioned even in very peripheral A+A collisions (PLB **773**, (2017) 408-411), primarily because of the 20-25% suppression seen even in the most peripheral Au+Au (PHENIX) and PbPb (CMS) collisions. In Fig. 5 a recent calculation of the effect of geometry and event selection biases on R_{AA} is shown.

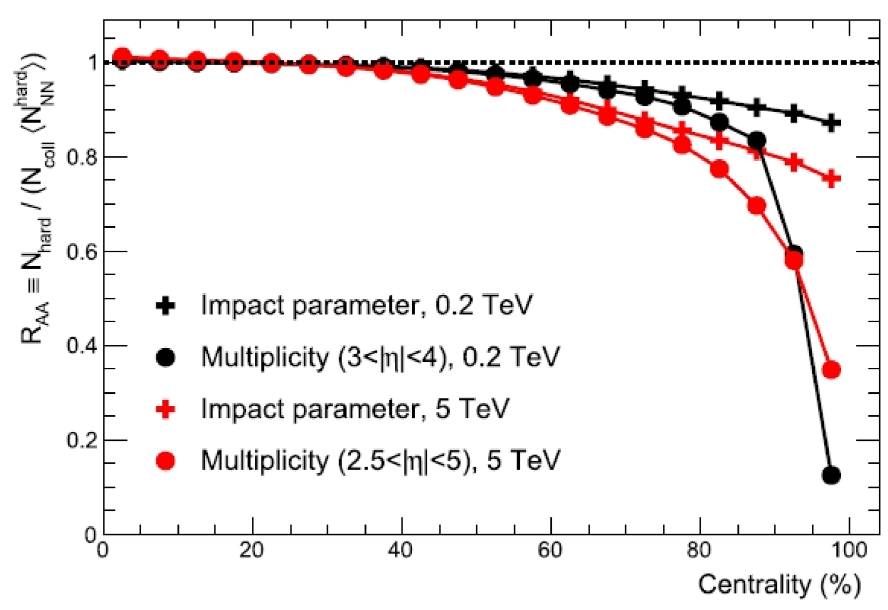

Figure 5: Normalized R_{AA} versus centrality for AuAu and PbPb collisions at 200 GeV and 2 TeV, respectively. Figure taken from PLB **773**, (2017) 408-411.

In PRC **97**, 054904 (2018) it is pointed out that in p/d+Au "the puzzling enhancement seen in peripheral events at RHIC and the LHC, as well as the suppression seen in central events at the LHC are possibly due to mis-binning of central and semi-central events, containing a jet, as peripheral events... partonic correlations built out of simple energy conservation are responsible for such an effect". An illustration of these calculations is shown in Fig. 6.

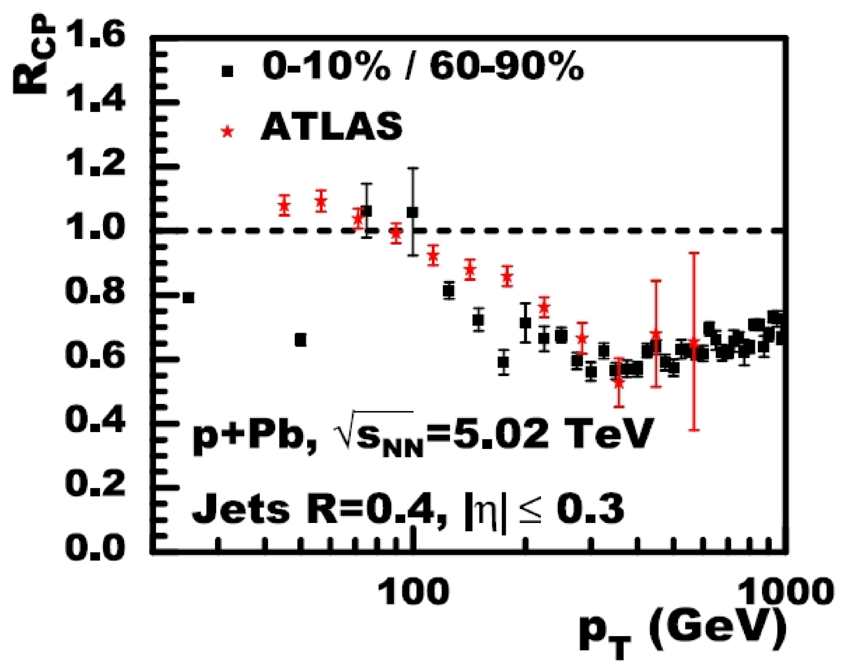

Figure 6: Ratio of the nuclear modification factor of jets produced in pPb collisions at the LHC, compared to a model emphasizing energy conservation over color transparency effects. Figure taken from PRC **97**, 054904 (2018).

High p_T photons to the rescue?

The production of high p_T direct photon in p+p is well understood and described by NLO pQCD (see Fig. 7); the majority of them comes from high momentum transfer $2 \to 2$ processes.

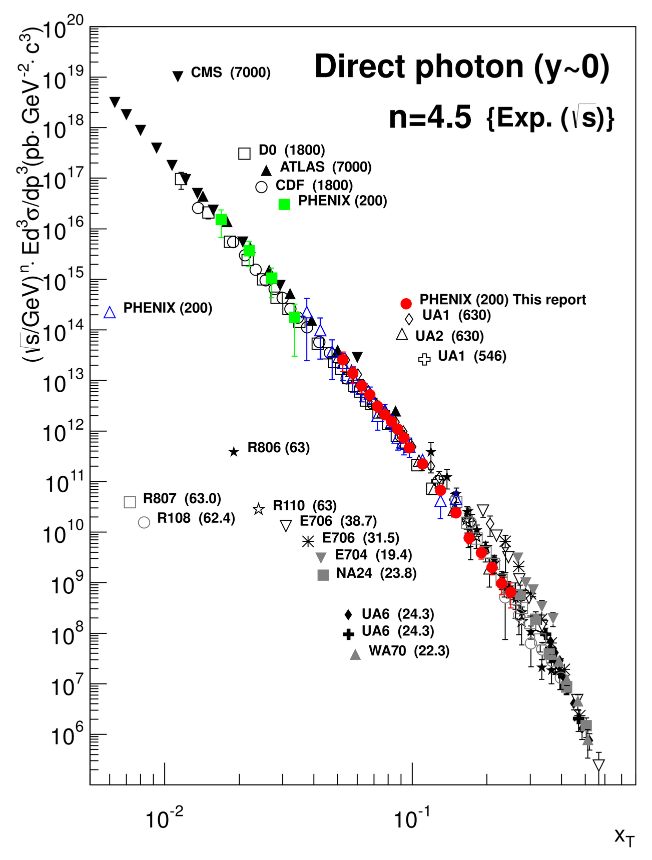

Figure 7: Various direct photon cross-section measurements in p+p and p+$\bar{p}$ collisions versus x_T. Figure taken from PRD **86**, 072008 (2012).

In A+A collisions, high transverse momentum (p_T) direct photons are penetrating probes: once produced (at the rate consistent with the binary NN collisions), they leave the collision region virtually unaffected, even if a hot, dense partonic medium was formed. This is also the reason why direct photons are immune to the suppression observed for high p_T hadrons and jets in heavy ion collisions.

The nuclear modification factor of high p_T photons is unity in Au+Au collisions if the p+p yields are scaled by the number of nucleon-nucleon collisions calculated from the Glauber-model (PRL **109**, 152302 (2012), also see Fig. 8.

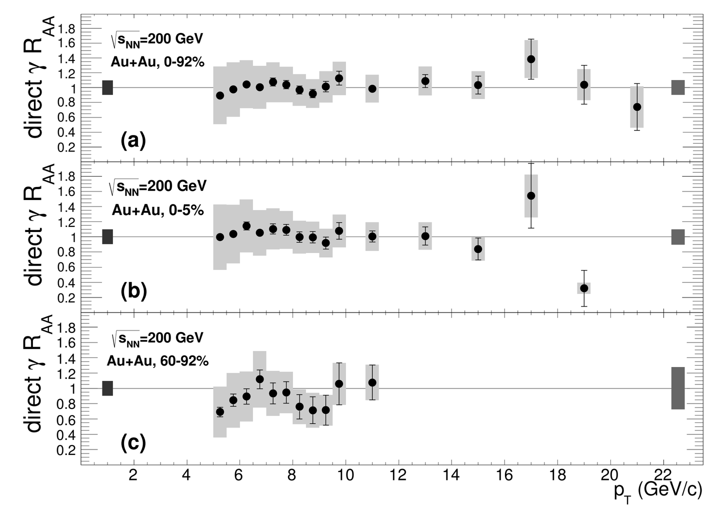

Figure 8: Direct photon nuclear modification factor in different centralities for 200 GeV Au+Au collisions. Figure taken from [PRL **109**, 152302 (2012)].

We assume that high transverse momentum direct photons are a "standard candle" for initial hard scattering, and, per extension, for collision geometry not only for p+p and A+A, but also for small-on-large collisions. If true, comparing the centrality dependence of direct photon and hadron production in p+Au is a robust test of the applicability of the Glauber model in such systems.

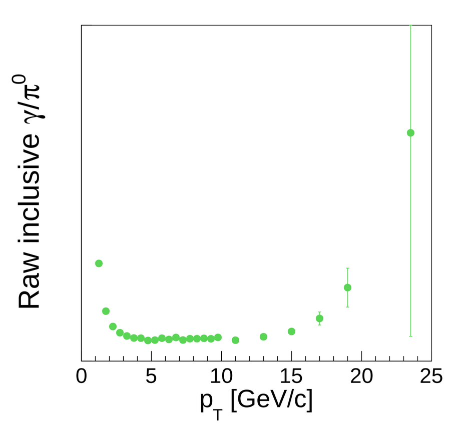

Figure 9: Example γ/π^0 ratio in p+p collisions.

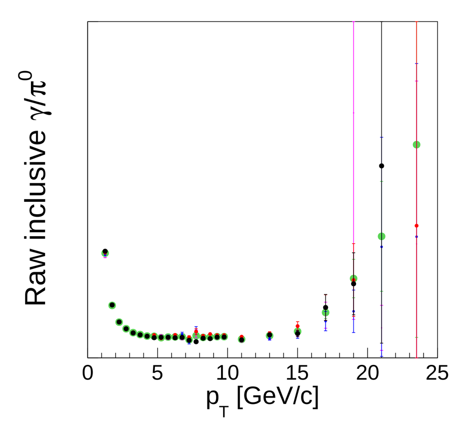

Figure 10: Example γ/π^0 ratios in p+A collisions, different centralities.

The most straightforward way to do this comparison is to form the γ/π^0 ratios, since jets and high p_T photons are formed in the similar/same processes, and photons are immune to final state effects. If the same centrality definition is applied, these ratios are independent of any (even p_T-dependent) centrality bias. For instance if those ratios turn out to be similar in various centralities, then the apparent enhancement or suppression in the nuclear modification factor of inclusive hadrons/jets is due to an event selection bias. (Illustration from a toy model is shown in Figs. 9 and 10.)

In summary, since high p_T photons are the standard candle of hard scattering, they should be the (event class defining) reference for other high p_T observables (PoS(INPC2016)345).