Centrality Categorization for $R_{p(d)+A}$ in High-Energy Collisions

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Centrality

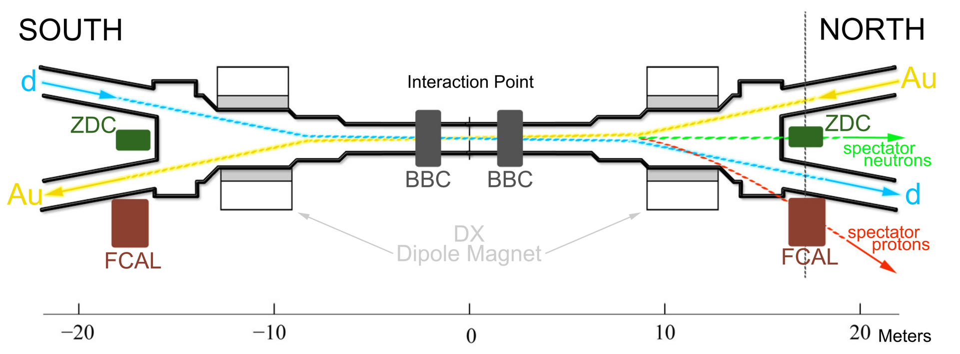

Figure 1: PHENIX uses beam beam counters (BBC's) covering the pseudorapidity range $3.0 < |\eta| < 3.9$ and zero-degree calorimeters (ZDCs) covering $|\eta| > 6$ to characterize geometry.

Centrality categories in d+Au are selected based on the summed charge measured in the BBC in the Au-going direction.

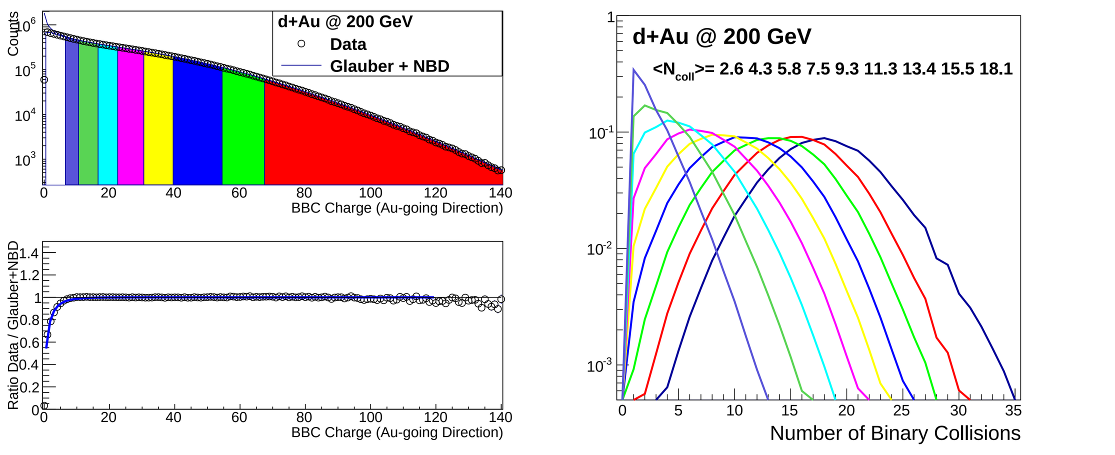

Figure 2: (Left-Top) The BBC charge distribution in d+Au collisions in the Au-going direction, shown as open circles, along with Glauber+NBD calculations, shown as histograms. (Left-Bottom) The ratio of real data to Glauber+NBD calculation. The line is a fit to the experimental trigger efficiency turn-on curve. (Right) Extracted distribution of the number of binary collisions in each of the nine centrality quantiles: 0%-5%, 5%-10%, 10%-20%, 20%-30%, 30%-40%, 40%-50%, 50%-60%, 60%-70%, and 70%-88%.

The mapping from the measured charge to geometric quantities of interest is performed using a standard MC-Glauber model. It is hypothesized that the Au-going BBC charge is proportional to the number of binary collisions in an individual d+Au collision, with fluctuations in the contribution from each binary collision described by the negative binomial distribution (NBD). The NBD parameters are fitted to the experimental charge distribution for BBC charge> 20, as shown in Figure 2. The centrality categories are determined by slicing the BBC charge distribution into bins, as in Figure 2. These same cuts can be applied to the MC-Glauber output, with the inclusion of the MB trigger efficiency in peripheral bins, to determine the distributions of quantities of interest. The N_{coll} distributions for each centrality bin are shown in Figure 2.

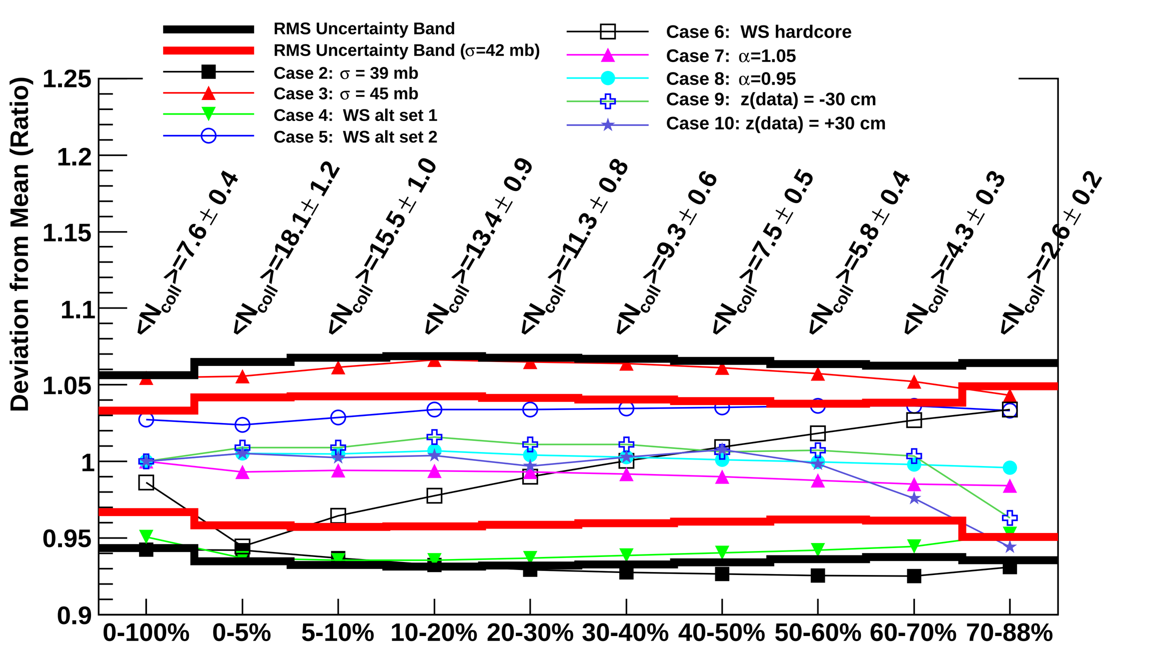

Figure 3: The variation relative to the mean N_{coll} value for variations in the input assumptions for the MC-Glauber extraction used to determine systematic uncertainties.

Cross Checks

The validity of the geometry selection method is further checked using neutron-tagged events where the spectator neutron in the d-going direction is measured by the ZDC.

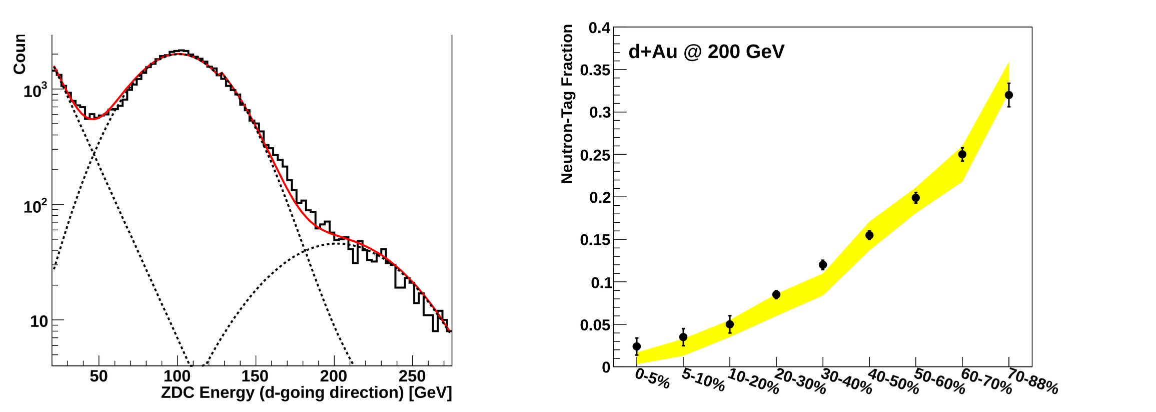

Figure 4: (Left) ZDC energy distribution in the deuteron-going direction for MB d+Au collisions. The data are well described by an exponential background component, a single spectator neutron peak, and a much smaller contribution from two neutrons due to double interactions. (Right) Data points are the measured fraction of events where there is a spectator neutron from the deuteron projectile. In comparison, the yellow band is the MC-Glauber result with systematic uncertainties.

Selecting on the single-neutron peak, the fraction of neutron-tagged events is determined for each centrality category, and shown in Figure 4. The agreement between data and calculations is good and lends confidence to the geometric modeling of the collisions.

Acknowledgments

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Bias-factor Corrections

Auto-correlations between the presence of a particular particle in the event and the Au-going multiplicity can lead to biases in the centrality measurement. Two biases are considered in d+Au events:

1. The MB trigger efficiency is larger for events with a particle produced at midrapidity[1]. This is due to the fact that the nondiffractive part of the inelastic $n+n$ collision has a larger probability for producing particles at midrapidity compared to the single and double diffractive collisions which dominantly produce particles near the beam rapidity, outside of the BBC acceptance. This bias primarily effects peripheral events, where the MB trigger is less efficient.
2. The particle multiplicity is also larger for events with a midrapidity particle[1]. This creates a bias in d+Au towards higher charge in the Au-going BBC, and thus towards larger centrality. This effect is accounted for in the MC-Glauber framework by assuming that a single binary collision in a given d+Au event has a larger NBD contribution to the Au-going BBC charge while all other binary collisions remain unmodified. From MB p+p and clock-trigger data this increase was determined to be consistent with scaling the NBD parameters μ and κ by 1.55 ± 0.23.

Table 1: Mean N_{coll} and bias-factor correction values (c) for each centrality calculated within the MC-Glauber framework from the ratio of invariant yields for a midrapidity particle calculated with and without the rescaled NBD parameters, and in HIJING.

	Glauber+NBD		HIJING	
Centrality	$\langle N_{coll}\rangle$	c	$\langle N_{coll}\rangle$	c $(1 \leqslant p_T \leqslant 5)$
0%–20%	15.1 ± 1.0	0.94 ± 0.01	15.0	0.951 ± 0.001
20%–40%	10.2 ± 0.7	1.00 ± 0.01	10.1	0.996 ± 0.001
40%–60%	6.6 ± 0.4	1.03 ± 0.02	6.3	1.010 ± 0.001
60%–88%	3.2 ± 0.2	1.03 ± 0.06	2.8	1.030 ± 0.001

[1] Similar considerations apply to events with a particle at any rapidity characteristic of nondiffractive collisions.

HIJING Study - d+Au at $\sqrt{s_{NN}} = 200$ GeV

The bias-factor corrections, and their p_T dependence are further studied using HIJING, which is found to provide a reasonable description of the bias effects observed in p+p and d+Au collisions (see [1] for details). Using the same procedure as in data, HIJING events are separated into centrality categories. The $\langle N_{coll}\rangle$ values for each centrality bin are shown in Table 1, and show good agreement with those calculated within the MC-Glauber framework.

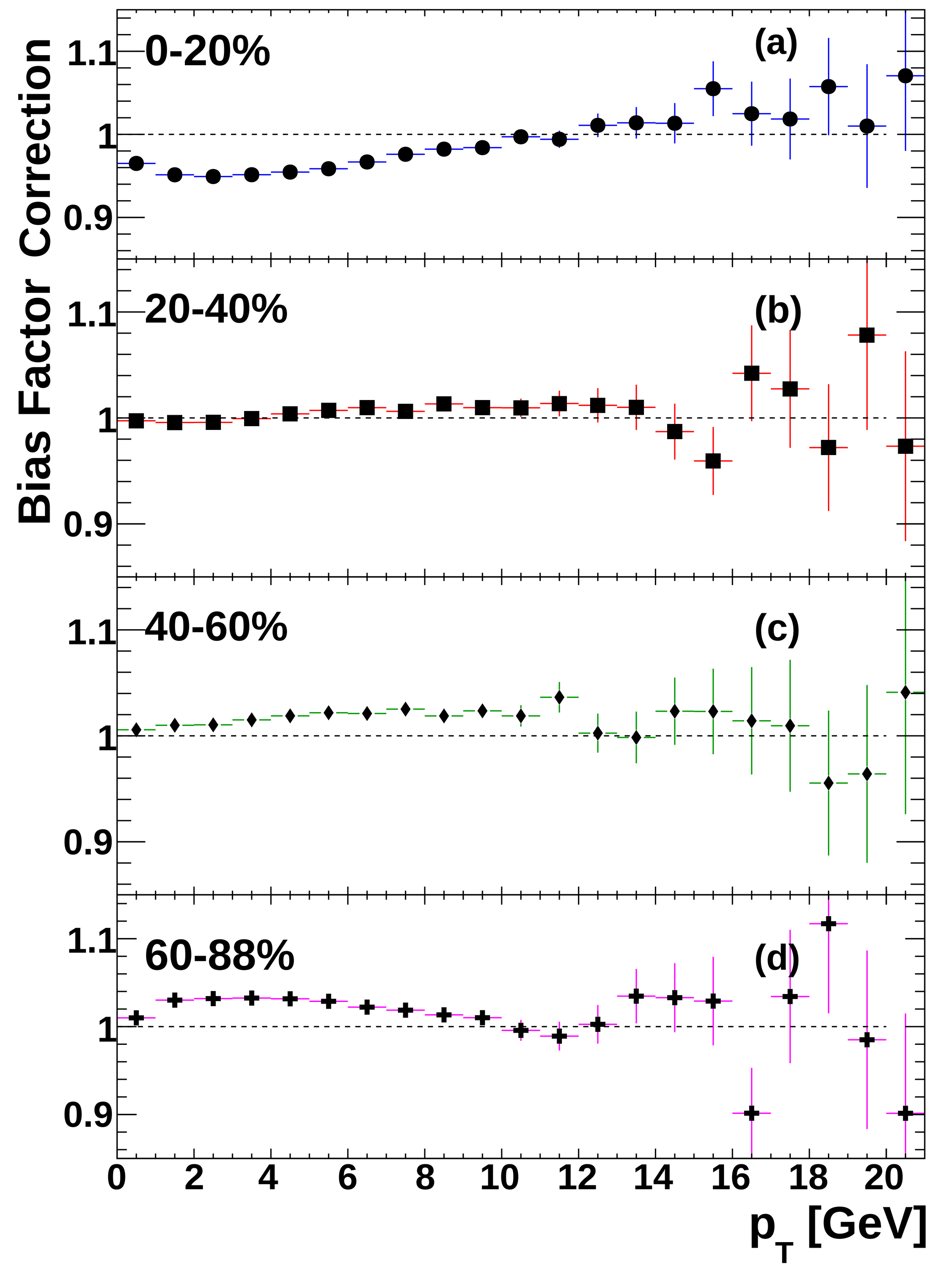

Figure 5: Bias-factor corrections as a function of p_T for HIJING d+Au events at $\sqrt{s_{NN}} = 200$ GeV.

The invariant yield of particles at midrapidity in each centrality bin can be calculated in a similar manner to the experimental data, which we call the HIJING "measured" yield. Separately, using the N_{coll} truth information, the HIJING events are sourced into the centrality bins to exactly match the N_{coll} distributions determined in the "measured" selection. This is referred to as the "truth" yield, and the only difference in the yields results from the auto-correlation between the midrapidity particle production and the multiplicity measured in the Au-going direction. Dividing the "truth" yields by the "measured" yield gives the bias-correction factors, shown as a function of p_T in Figure 5.

Bibliography

[1] A. Adare et al.
Centrality categorization for $R_{p(d)+A}$ in high-energy collisions.
2013.

[2] Michael H. Seymour and Andrzej Siodmok.
arXiv:1307.5015.

HIJING Study - p+Pb at $\sqrt{s_{NN}} = 5.02$ TeV

A similar study is performed for p+Pb collisions at $\sqrt{s_{NN}}$ =5.02 TeV.

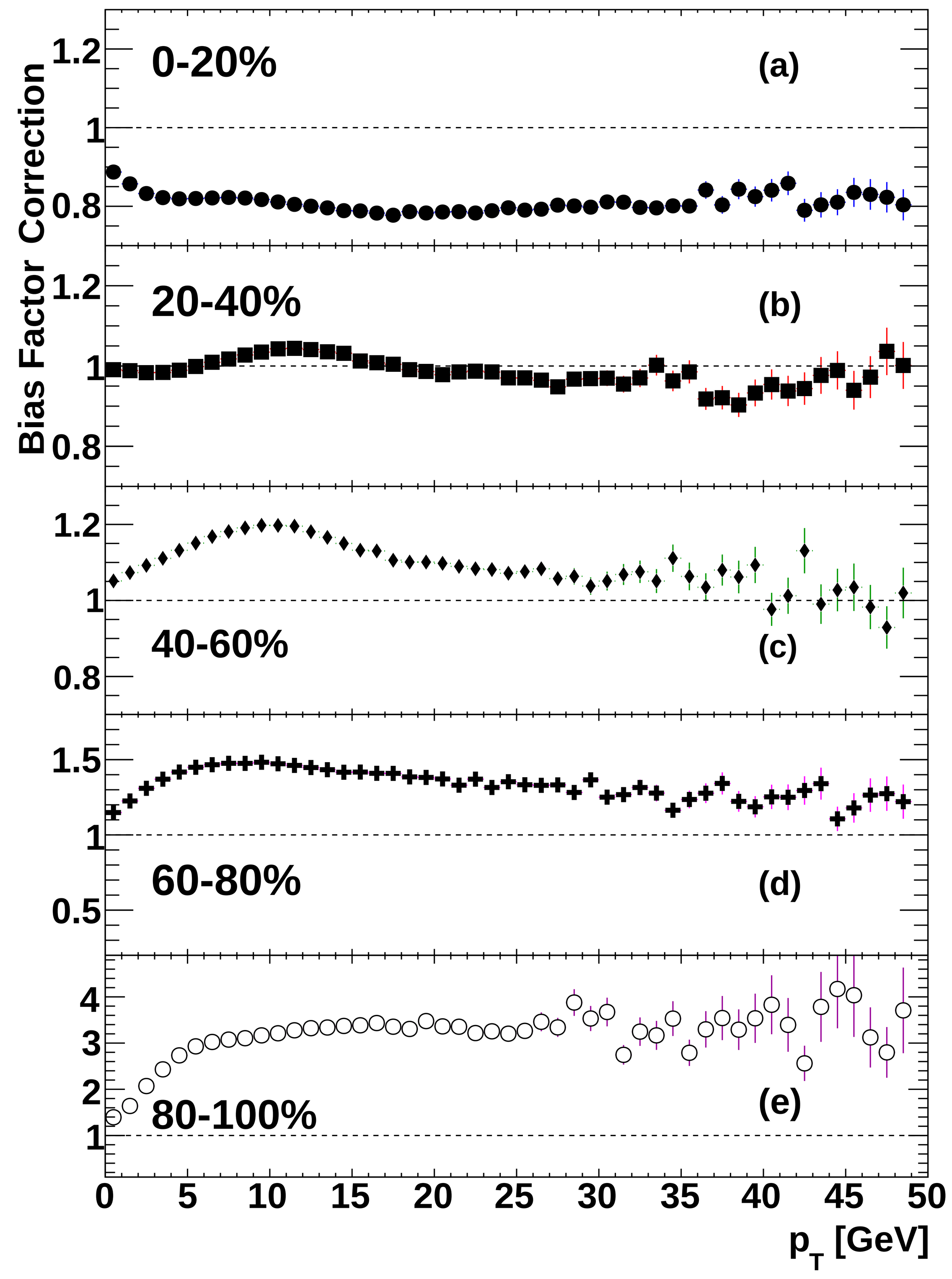

Figure 6: Bias-factor corrections as a function of p_T for HIJING p+Pb events at $\sqrt{s_{NN}}$ = 5.02 TeV.

Significantly larger bias-factor corrections are observed in p+Pb at $\sqrt{s_{NN}}$ =5.02 TeV compared to d+Au at $\sqrt{s_{NN}}$ =200 GeV.

Multiparton Interactions

The order of magnitude increase in the bias-factor corrections from 200 GeV to 5.02 TeV may be explained by multiparton interactions [2]. This effect is investigated within HIJING by counting the mean number of hard scatterings per $n-n$ binary collision, shown in Figure 7 as a function of N_{coll}. The mean value is 0.24 in d+Au at 200 GeV, but 1.36 in p+Pb at 5.02 TeV, highlighting the strong $\sqrt{s}$ dependence.

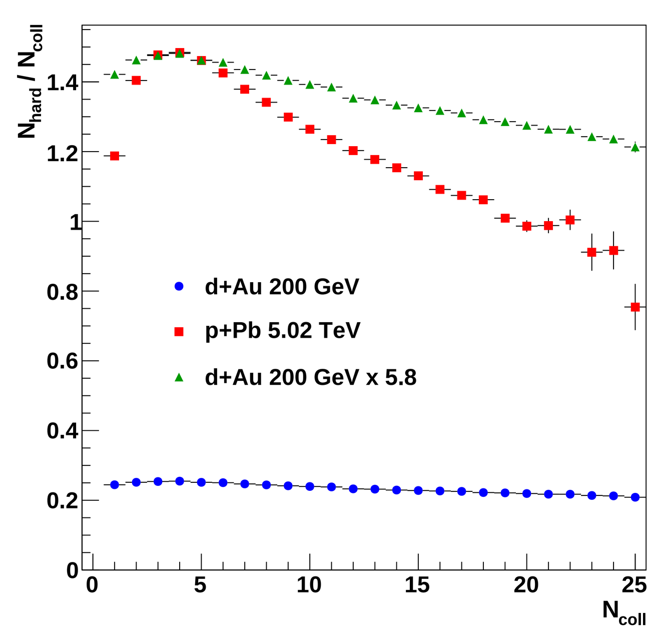

Figure 7: A comparison of the MPI effect in HIJING for d+Au and p+Pb collisions at 200 GeV and 5.02 TeV respectively.

Summary

In PHENIX, centrality is measured using the charge deposited in the BBC in the Au-going direction. Geometric quantities, such as N_{coll}, are mapped to these centrality selections using a standard MC-Glauber model, where the systematic uncertainties in the quantities are calculated by varying the MC-Glauber input parameters. Using the MC-Glauber framework, the fraction of neutron-tagged events in each centrality bin is calculated, and agrees well with the measured data.

Auto-correlations between produced particles at midrapidity and the multiplicity (and hence charge) in the Au-going direction cause bias effects that must be corrected for when calculating invariant yields. These bias-factor corrections have been calculated for d+Au at 200 GeV within the same MC-Glauber model, and are less than 5%.

The p_T dependence of the bias-correction factors are further studied using HIJING, which gives similar results for d+Au at 200 GeV as calculated from the MC-Glauber model. At RHIC energies the corrections are small with modest p_T dependence. Bias-factor corrections for p+Pb at 5.02 TeV are also calculated within the same framework, yielding corrections an order of magnitude larger than those found at 200 GeV. This increase is likely due to the significant increase in multiparton interactions at 5.02 TeV compared to 200 GeV.

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XXIV Quark Matter Darmstadt 2014