Centrality bias from correlations between hard processes and the *NN* underlying event

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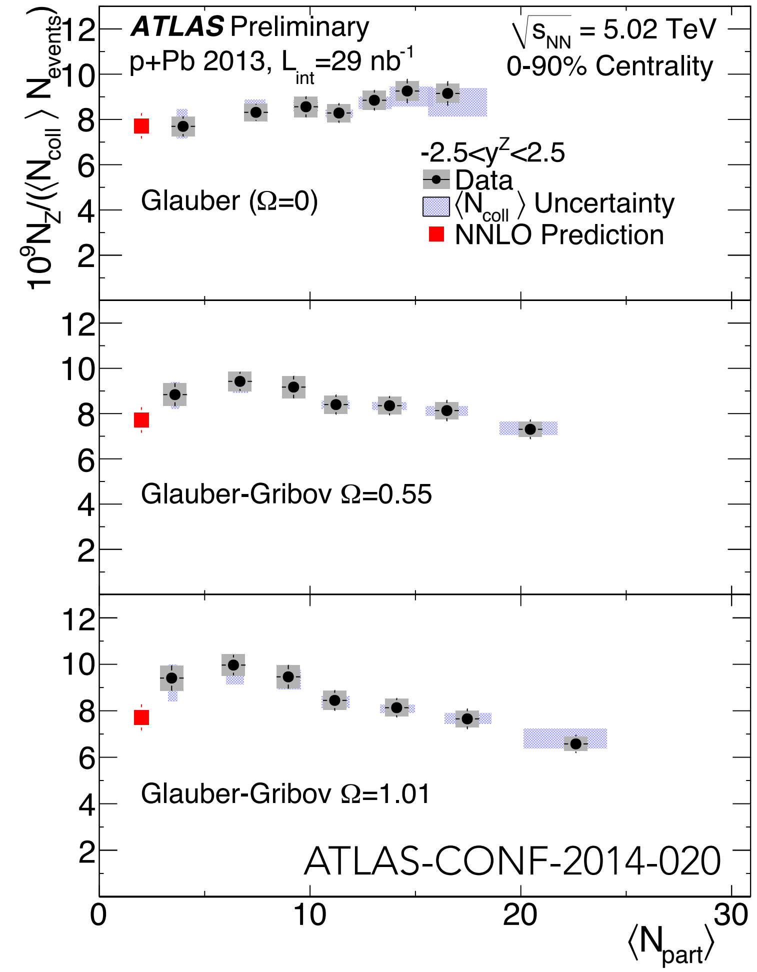
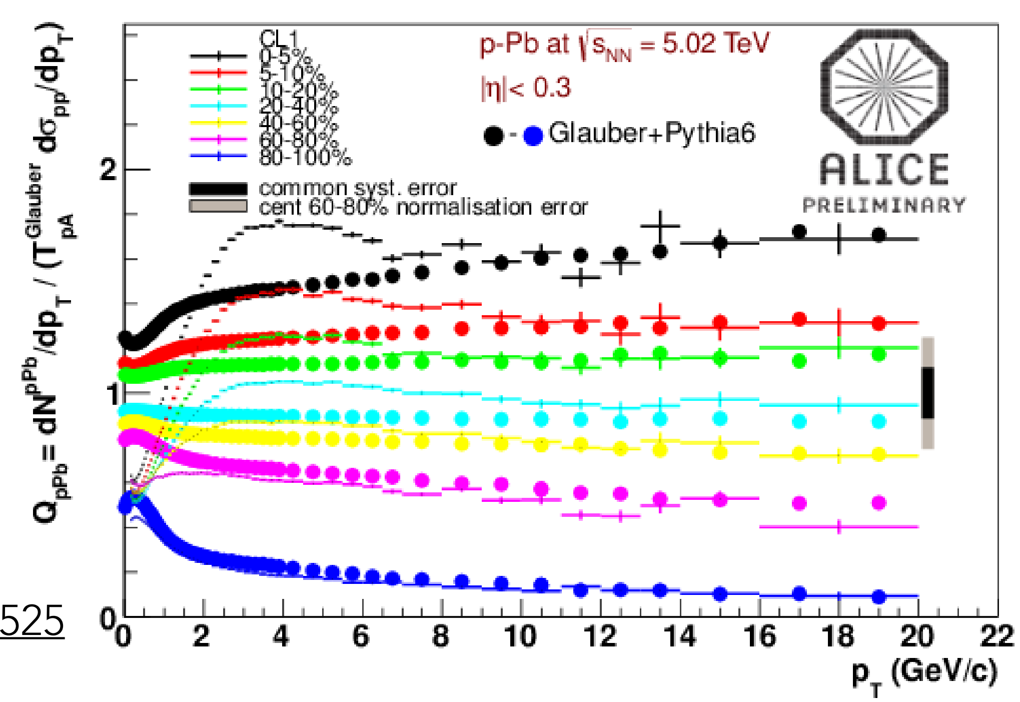
Challenge of centrality-dependent measurements in p+Pb

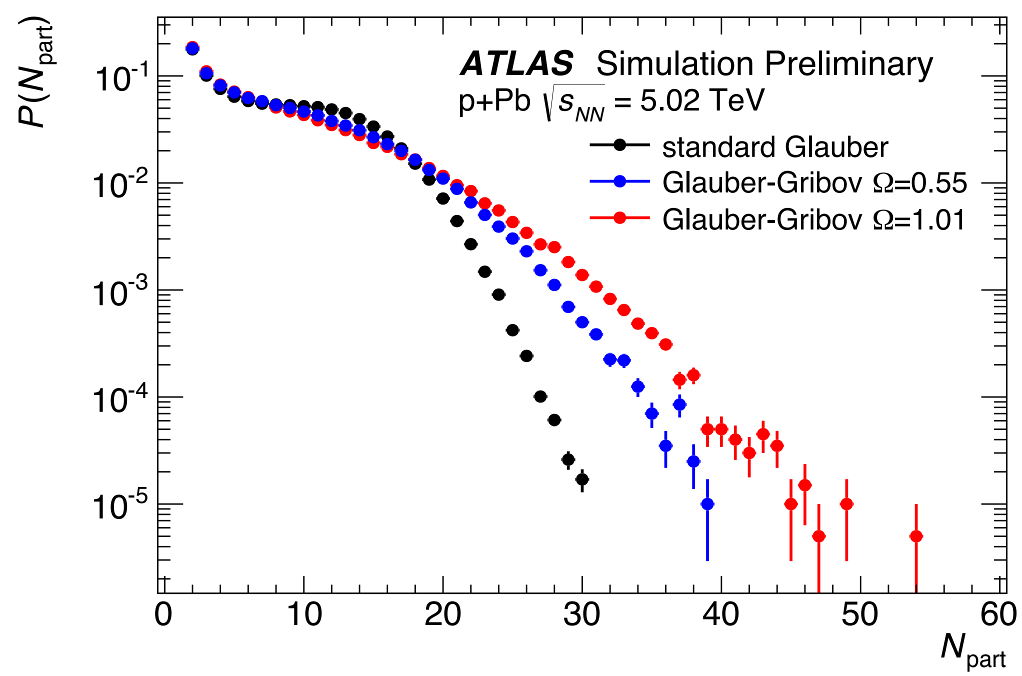
- It has been noticed by all collaborations that the standard methodology of dividing p+A events into centrality intervals does not easily lead to scaling of hard processes N_{coll}
- ATLAS noticed Z's not scaling — applied simple "shift" correction based on difference between E_T distributions in Z and non-Z events
- ALICE has systematically characterized biases for different detectors, and modeled them with toy models based on Glauber & PYTHIA



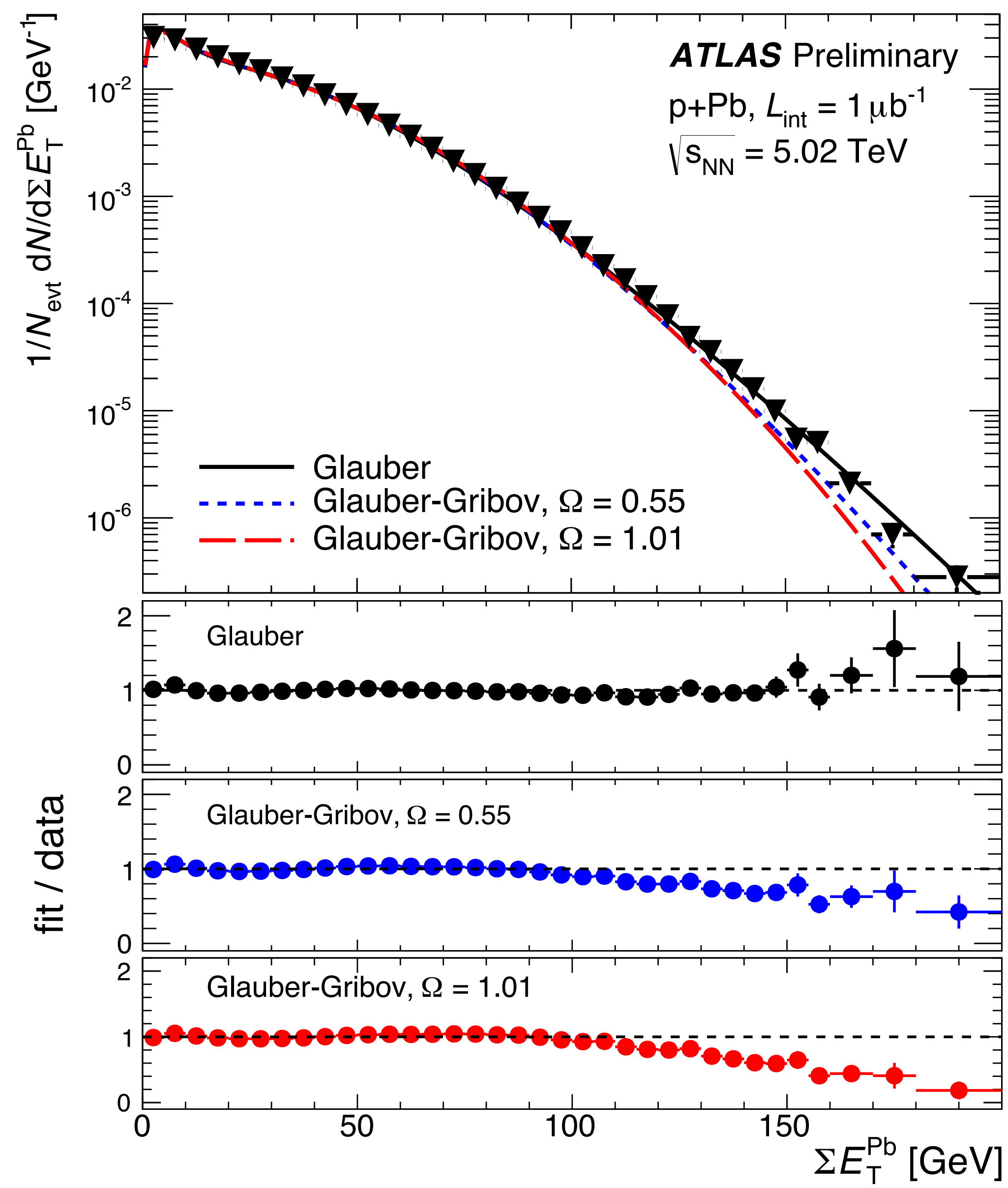


Morsch, http://arxiv.org/abs/1309.5525

Centrality estimates in p+Pb

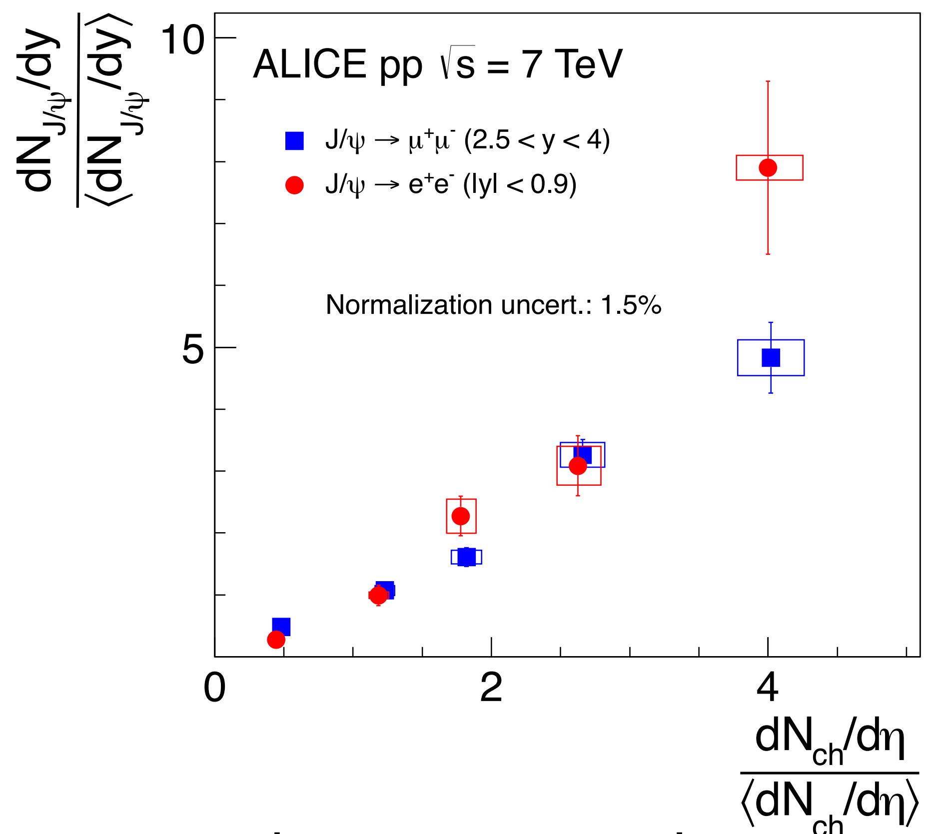


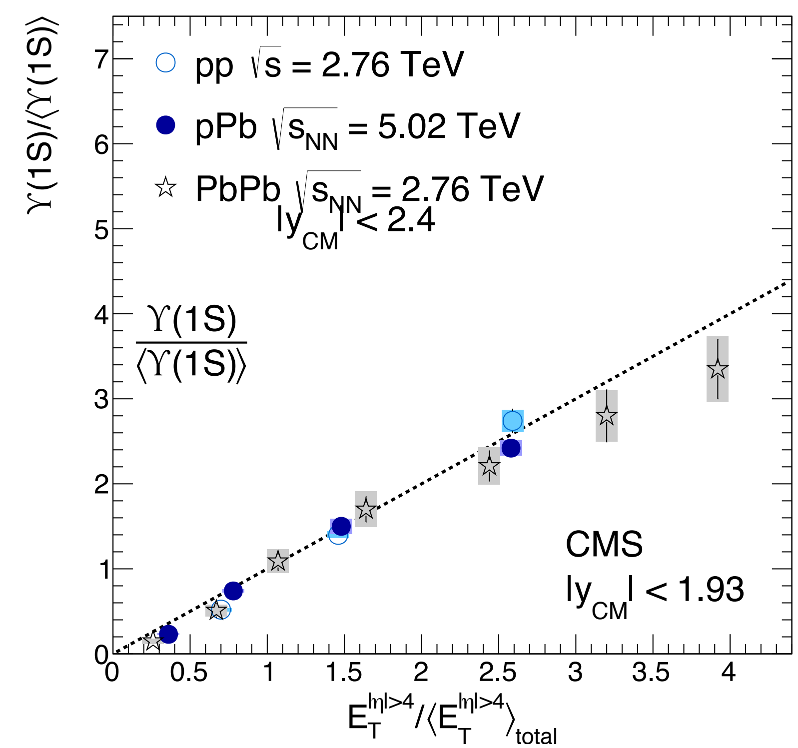
We typically perform fits to measured E_T or N_{ch} distributions, assuming a convolution of an underlying *pp* distribution (modulo non-linear terms) with the Glauber geometry.

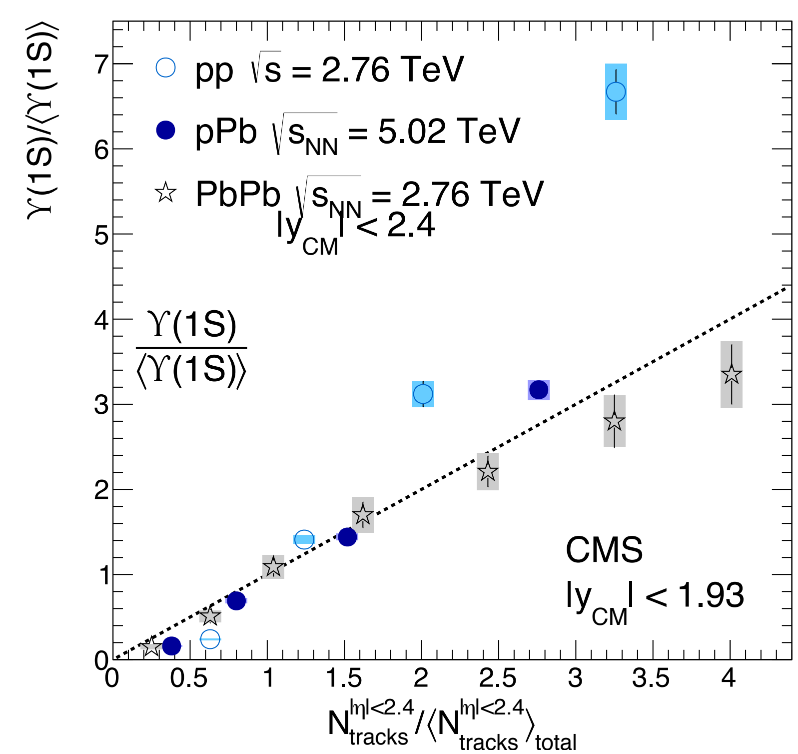


We typically do not assume that the *pp* E_T or N_{ch} distribution depends on the object being measured.

Centrality scaling in pp and p+Pb



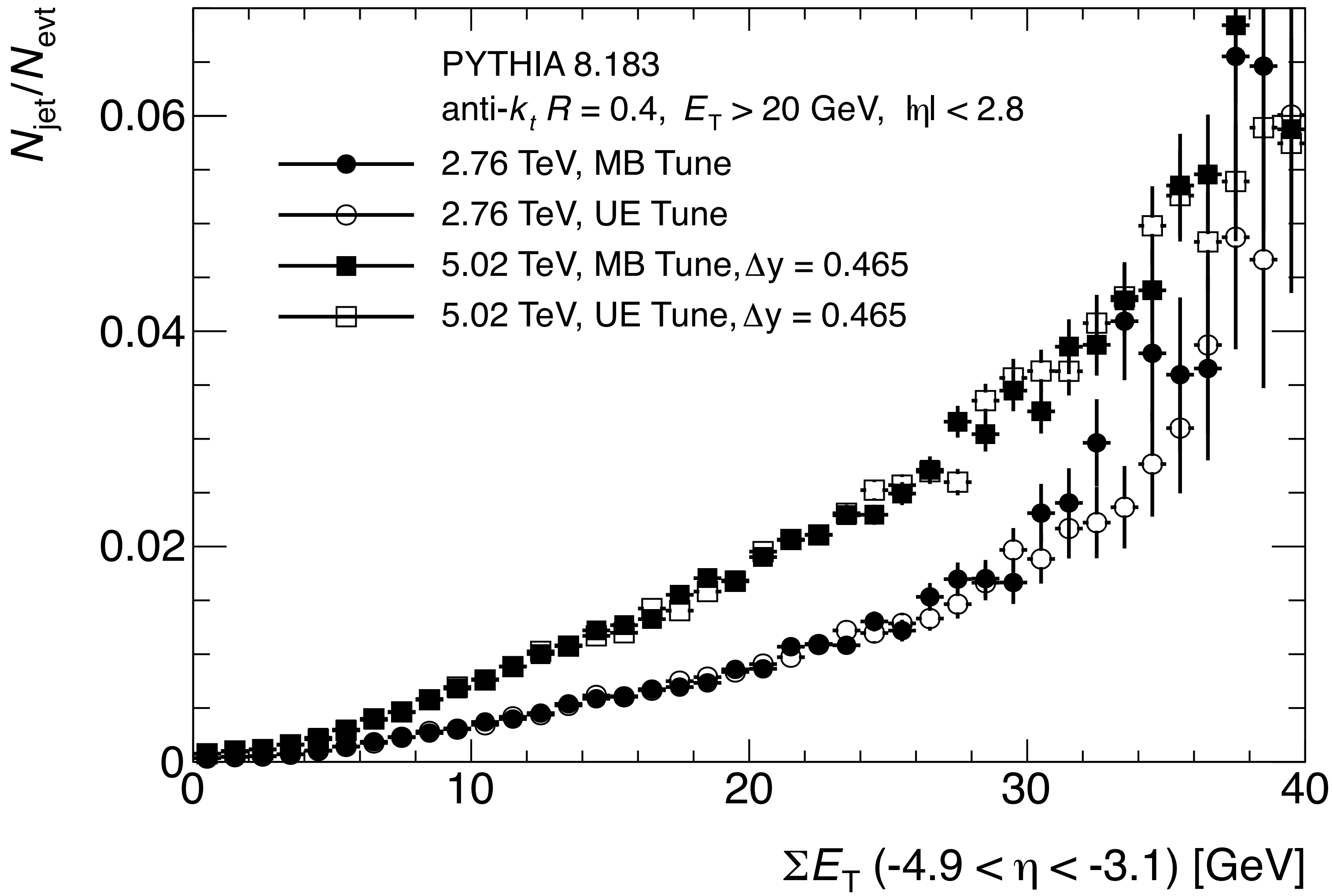




Quarkonia production in p+p & p+Pb follow surprisingly linear trends when parametrized by UE activity: interpreted in terms of MPI

Jet yields vs. E_T from PYTHIA

arxiv:1412.0976



Just to see if such behavior is in PYTHIA, measured yield per event as a function of a forward ET sum: not perfectly linear, but strong correlation.

Primary relationship: $\langle Y_{\mathrm{hard}}(E_T) \rangle \propto E_T$.

Centrality model

- Assume each NN collisions is sampled from a Gamma distribution

$$P_{NN}(E_{\mathrm{T}}^{j}) = \Gamma(E_{\mathrm{T}}^{j}; k, \theta)$$
$$\equiv \left(E_{\mathrm{T}}^{j}\right)^{k-1} \exp\left(-E_{\mathrm{T}}^{j}/\theta\right) \Big/ \Gamma(k)\theta^{k},$$

- For fixed N_{coll}, sample N_{coll} times and include contribution from the incident proton

$$E_{\mathrm{T}} \equiv \left(\sum_{j=1}^{N_{\mathrm{coll}}} E_{\mathrm{T}}^{j}\right) + E_{\mathrm{T}}^{\mathrm{evt}(p)}$$

- Full distribution is convolution over N_{coll} of

$$P_{N_{\mathrm{coll}}}(E_{\mathrm{T}}) = \Gamma(E_{\mathrm{T}}; N_{\mathrm{coll}}k, \theta) \oplus \Gamma(E_{\mathrm{T}}; k^{\mathrm{evt}}, \theta)$$

Three models: UCM and PCM

- Uncorrelated model (UCM)

$$Y_j = C, \qquad Y_{N\mathrm{coll}}(E_{\mathrm{T}}) = \sum_{j=1}^{N_{\mathrm{coll}}} Y_j = C N_{\mathrm{coll}}$$

- Partially correlated model (PCM)

$$Y_j = C\left(E_{\mathrm{T}}^j + E_{\mathrm{T}}^{j(p)}\right)\Big/ 2k\theta \qquad Y_{N\mathrm{coll}}(E_{\mathrm{T}}) = \frac{C}{2k\theta}\sum_{j=1}^{N_{\mathrm{coll}}}\left(E_{\mathrm{T}}^j + E_{\mathrm{T}}^{j(p)}\right)$$

PCM reflects the fact that the E_T produced by the proton on each nucleon could be different in each collision: however, choose a single E_T value from the proton for the centrality

E_T here is a "general" centrality signal: either transverse energy (e.g. ATLAS) or charge (e.g. PHENIX)

Three models: VCM

- Variably correlated model (VCM): integrate out the fluctuations from the proton and one finds:

$$Y_j = C\left(E_{\mathrm{T}}^j \middle/ k\theta + 1\right) \middle/ 2$$

- The constant weakens the correlation between the yield and the underlying event. Can generalize this to:

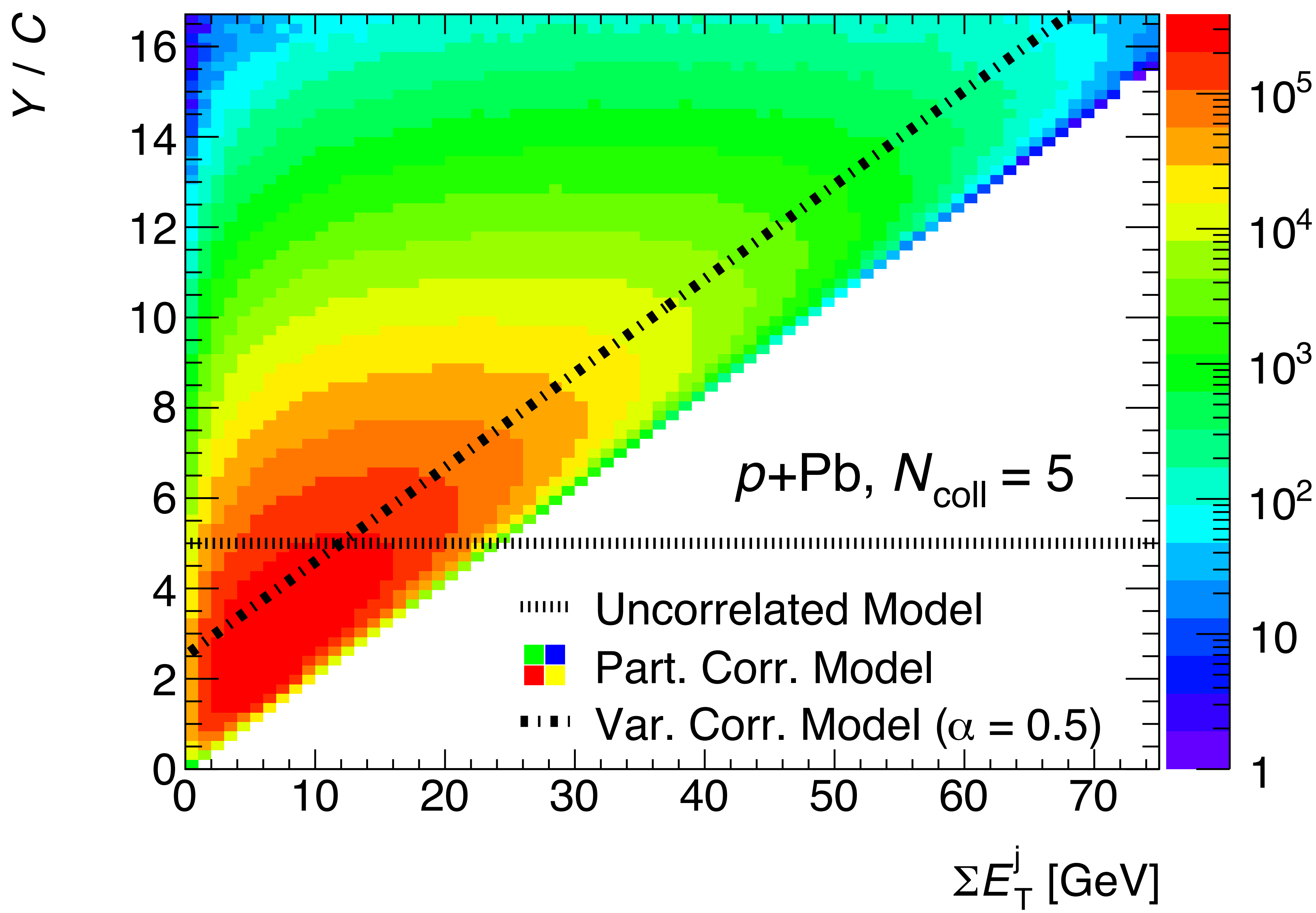
$$Y_j = C\left(\alpha\, E_{\mathrm{T}}^j \middle/ k\theta + (1-\alpha)\right)$$

$$Y_{N\mathrm{coll}}(E_{\mathrm{T}}) = C\left(\alpha \sum_{j=1}^{N_{\mathrm{coll}}} E_{\mathrm{T}}^j / k\theta + (1-\alpha) N_{\mathrm{coll}}\right)$$

In this approach, PCM = VCM for α=0.5

We use this to assign a conservative error to the bias factors, by varying α from 0.25 to 0.75

3 models, illustrated



Fixed N_{coll}=5, and just "N_{coll}" part of centrality observable

Key features of model

- This model does not try and modify the single collision which produces a hard process

- It says that the yield per collision is correlated with the UE
  - Neither that the UE somehow influences the hard process
  - Nor that the hard process increases the UE

- Natural in an MPI scenario where both the hard process and the UE are correlated with the NN overlap
  - Jia, Frankfurt et al

Application to experimental data

Measured hard process yield involves 3 distributions:
N_{coll} distribution from Glauber (geometry),
E_T distribution per collision (centrality model),
Correlation of yield with underlying UE (Y):

$$\mathcal{Y}\left[\ Y_{\mathrm{Ncoll}}(E_{\mathrm{T}});E_{\mathrm{T}}^{\mathrm{min}},E_{\mathrm{T}}^{\mathrm{max}}\ \right]=$$

$$\sum_{N\mathrm{coll}}\int_{E_{\mathrm{T}}^{\mathrm{min}}}^{E_{\mathrm{T}}^{\mathrm{max}}} dE_{\mathrm{T}} P(N_{\mathrm{coll}}) P_{N\mathrm{coll}}(E_{\mathrm{T}}) Y_{N\mathrm{coll}}(E_{\mathrm{T}})$$

The modified yield due to correlation is then defined as:

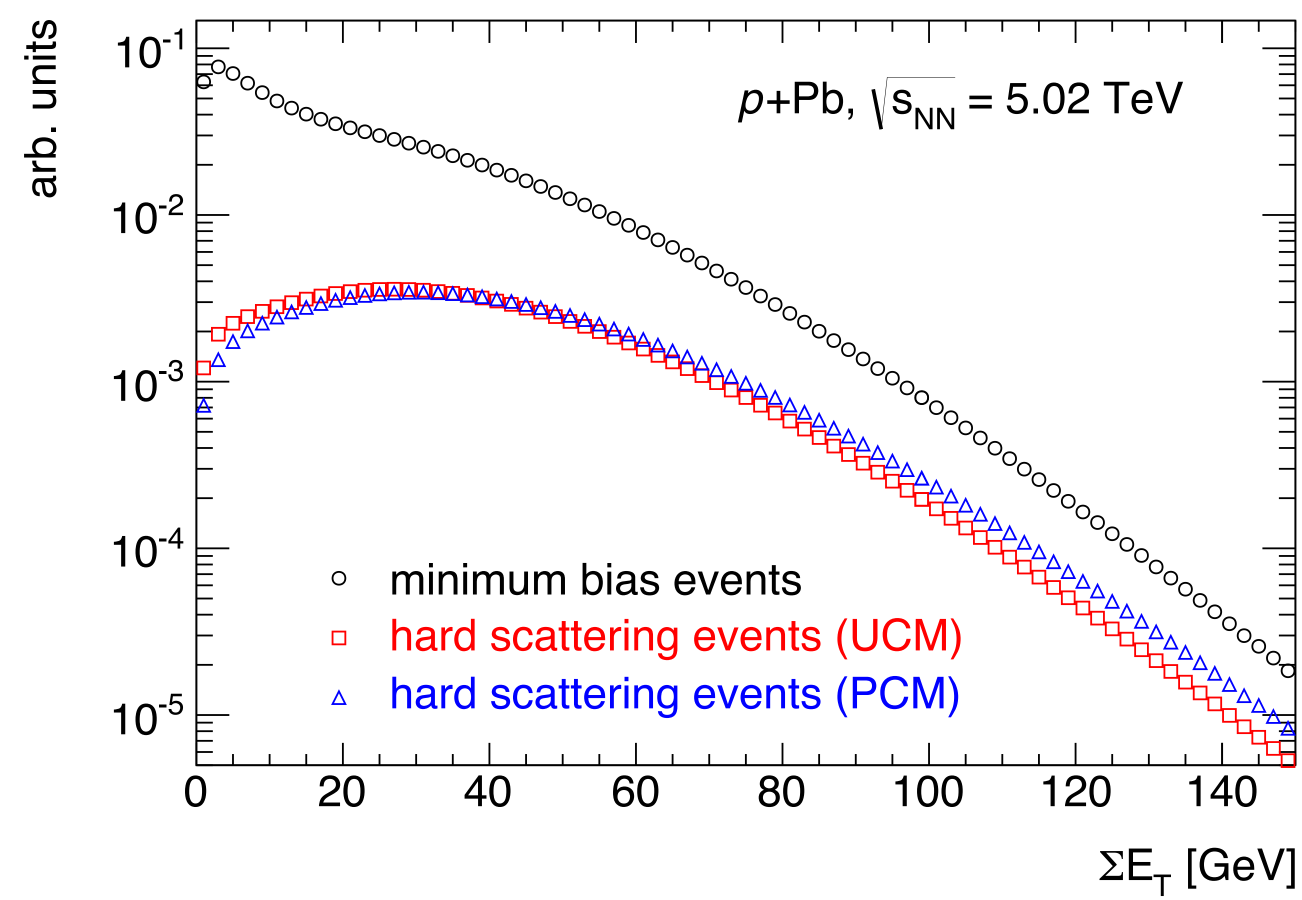
$$\rho=\mathcal{Y}\left[\ Y_{\mathrm{Ncoll}}(E_{\mathrm{T}})\ \right]/\ \mathcal{Y}\left[\ CN_{\mathrm{coll}}\ \right]$$

ATLAS case

- Based on ATLAS centrality bins used in several p+Pb results (multiplicity, jets, Z's)

- In ATLAS , Gamma function parameters depend on Npart
  - $k(N_{part}) = k_0 + k_1(N_{part}-2)$
    - k0 = 1.39, k1 = 0.425 —> k_{evt} = 0.965
  - $\Theta(N_{part}) = 3.41 + 1.3\ \ln(N_{part}-1)$

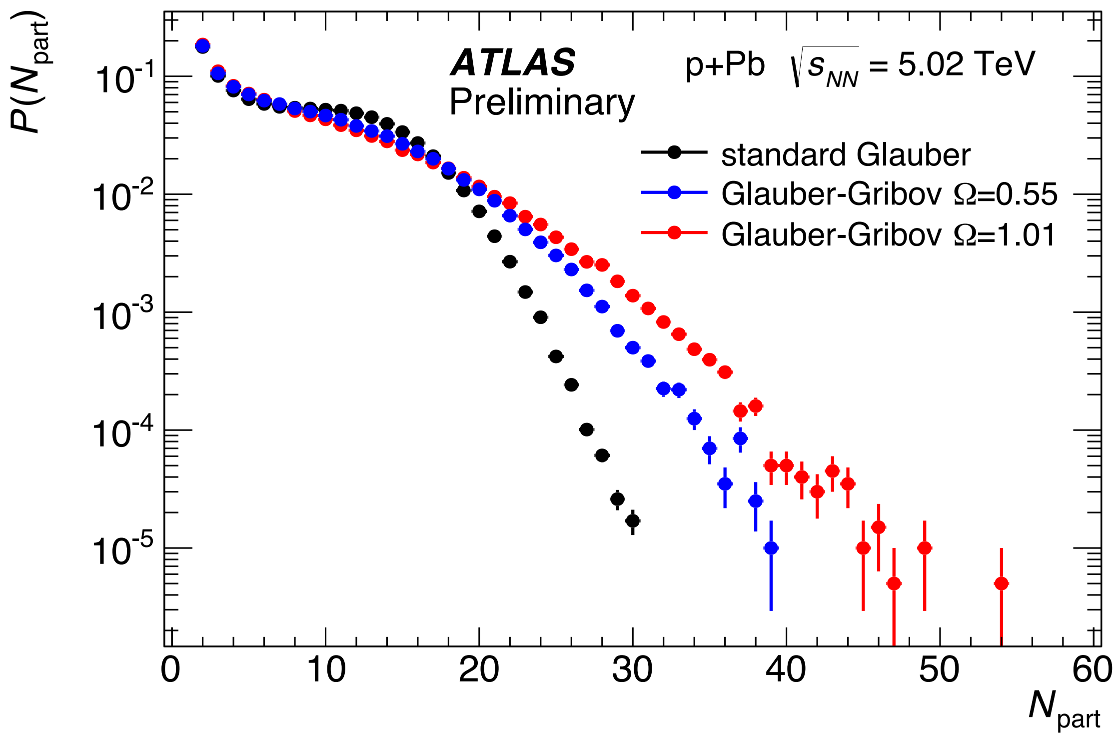
- Cuts applied exactly as in ATLAS paper



Glauber, σ_{NN}=70 mb, 10k events per N_{coll}

Corrections for ATLAS

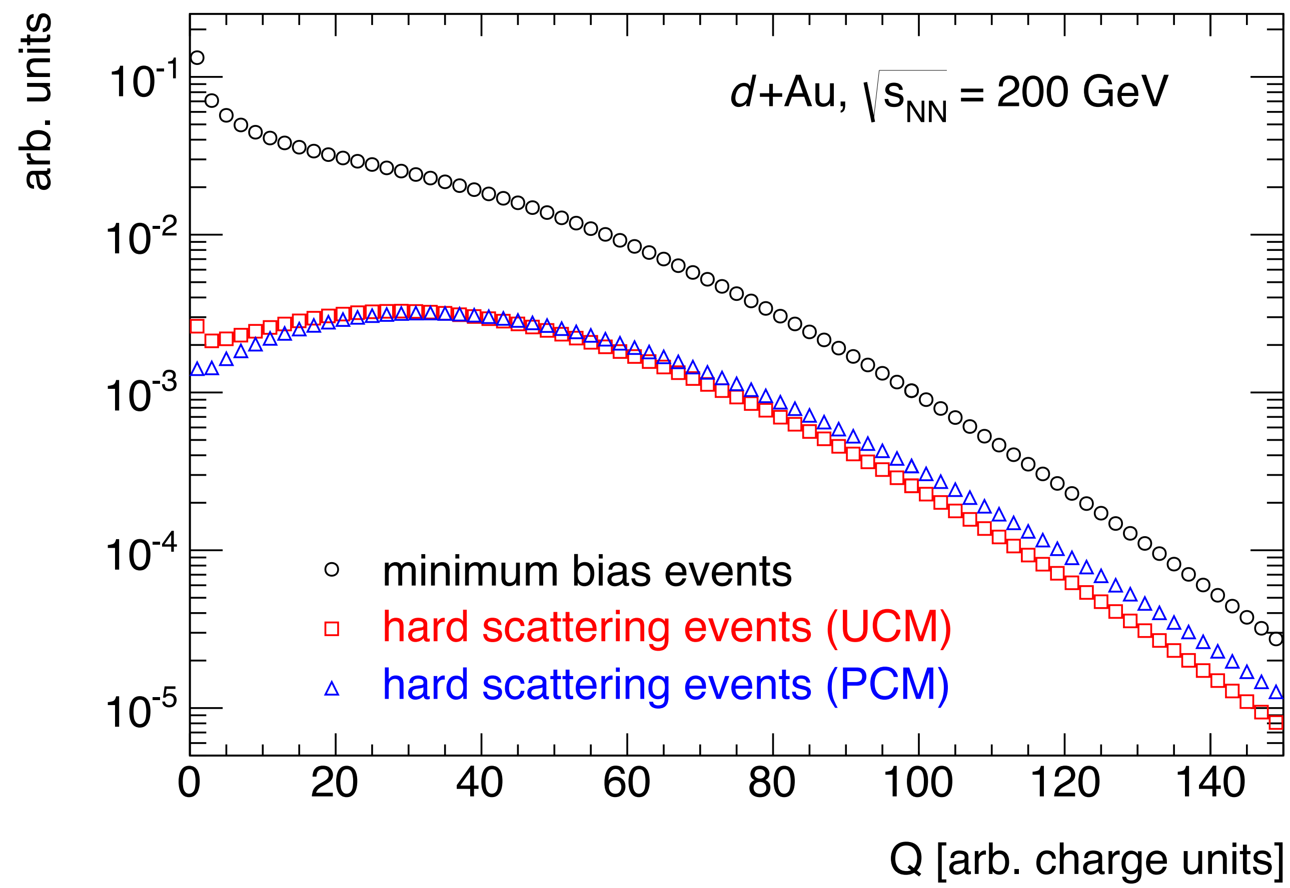
- Calculated in PCM for default Glauber, and Glauber-Gribov color fluctuation models (used by ATLAS)
- 10-20% deviations from unity for default Glauber
- Bias factors become smaller with increasing cross section fluctuations
  - Decreasing steepness at high N_{part}



	p+Pb 5.02 TeV		
centrality	ρ (default)	ρ ($\Omega = 0.55$)	ρ ($\Omega = 1.01$)
0–10%	1.20 ± 0.10	1.09 ± 0.04	1.07 ± 0.03
10–20%	1.06 ± 0.03	1.03 ± 0.02	1.03 ± 0.01
20–30%	1.00 ± 0.01	1.00 ± 0.01	1.01 ± 0.01
30–40%	0.96 ± 0.02	0.98 ± 0.01	0.99 ± 0.01
40–60%	0.91 ± 0.04	0.96 ± 0.02	0.97 ± 0.02
60–90%	0.82 ± 0.07	0.87 ± 0.06	0.88 ± 0.06

PHENIX case

- PHENIX uses charge Q in beam-beam counters (BBC)
    - Assumed to scale linearly with N_{coll}
- NBD has parameters μ=3.03, **κ**=0.46
- Bias factors from PCM compared with results from PHENIX (arXiv:1310.4793)
    - Similar in magnitude and consistent within (large) uncertainties



	d+Au 200 GeV	
centrality	ρ	1/BF (PHENIX)
0–20%	1.15 ± 0.07	1.06 ± 0.01
20–40%	0.99 ± 0.01	1.00 ± 0.01
40–60%	0.92 ± 0.04	0.97 ± 0.02
60–88%	0.82 ± 0.09	0.86 ± 0.06

D. Perepelitsa & PAS, arxiv:1412.0976

Summary

- We have developed a simple framework for calculating centrality biases in p+Pb/d+Au, based on existing centrality frameworks
- Based on positive (linear) correlation in *NN* collisions between hard process yield and the centrality observable, which reflects the underlying event activity
- 3 models shown: no correlation, partial correlation, and variable correlation
    - In general, overall level of correlation found to be more important than the stochastic fluctuations.
- Bias factors extracted for ATLAS and PHENIX frameworks
    - However, framework is general and adaptable to other environments