Role of MPI in Heavy Ion Collisions

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12th MPI at LHC

12th International workshop on Multiple Partonic Interactions at the LHC

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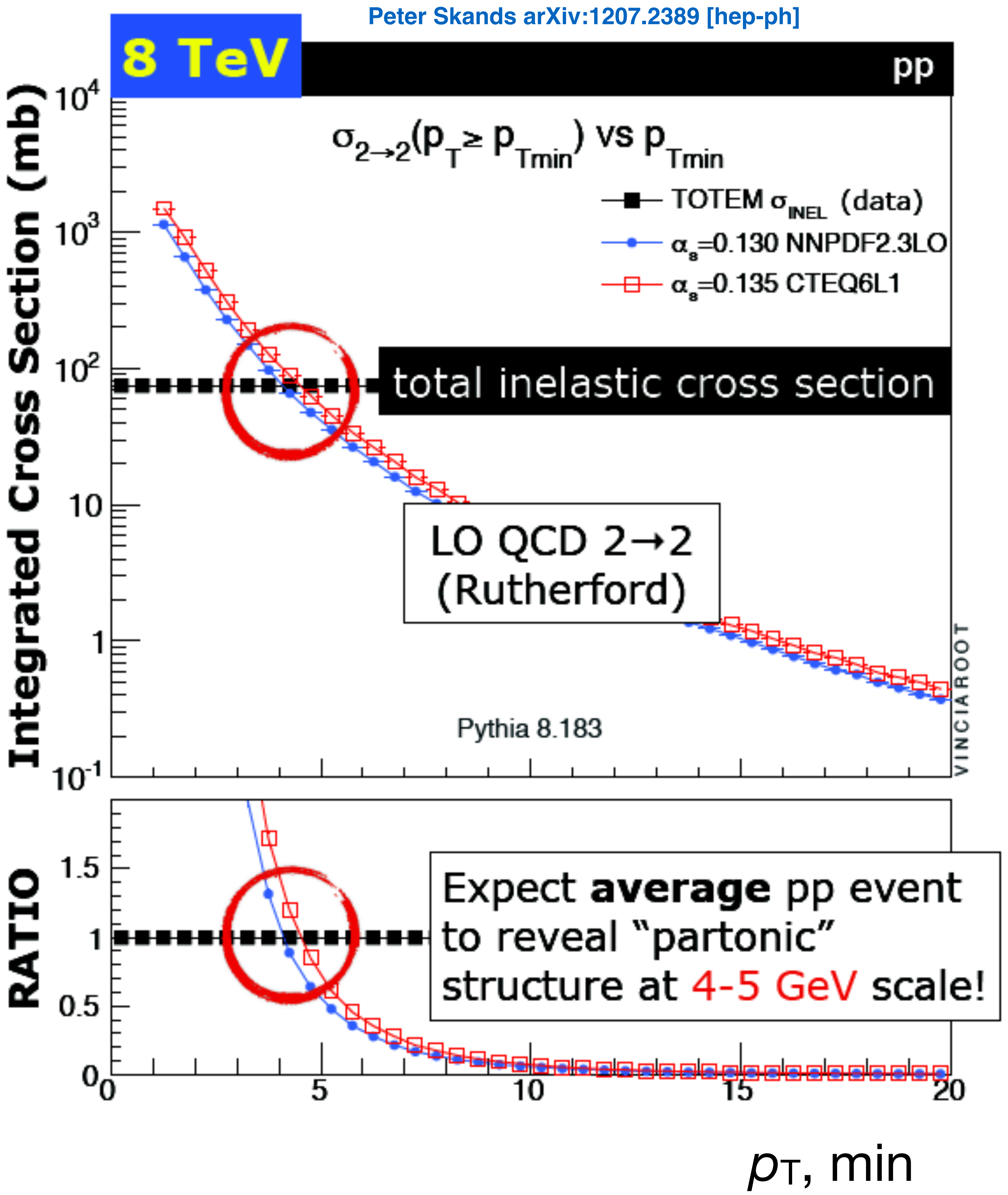
What can we learn about MPIs in Heavy-Ion collisions?

- → What can we learn about Heavy-Ion collisions from MPI?
- Help to define a reference compared to which we can observe genuine medium effects
  - Main reason:
    MPI provide connection between bulk observables (e.g. multiplicity, ..) to rare processes
    - in pp these “hard-soft” correlation provide important constraints on MPI models …

pp: hard-soft correlations

Integrated hard cross-section
above cut-off $p_{T\mathrm{min}}$



$\sigma_{2\to2} \gg \sigma_{\mathrm{tot}}$

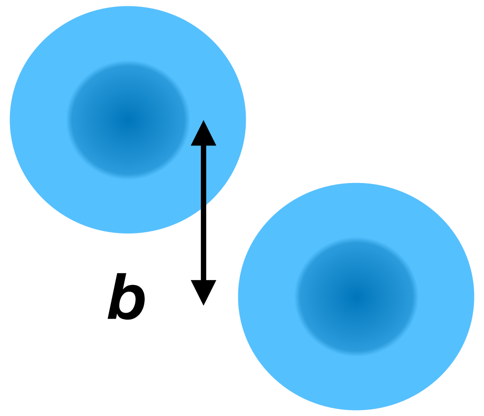
large per event yields at perturbative scales

$\sigma_{2\to2} \ll \sigma_{\mathrm{tot}}$

rare processes

simplest model ...

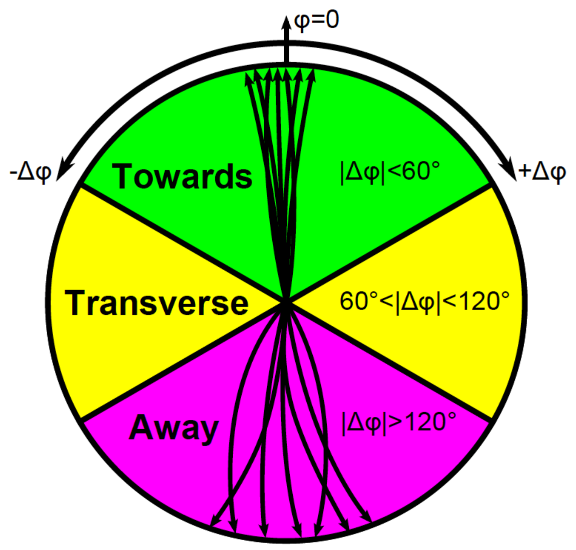
$$n_{\mathrm{MPI}} \approx \sigma_{2\to2}/\sigma_{\mathrm{tot}}$$

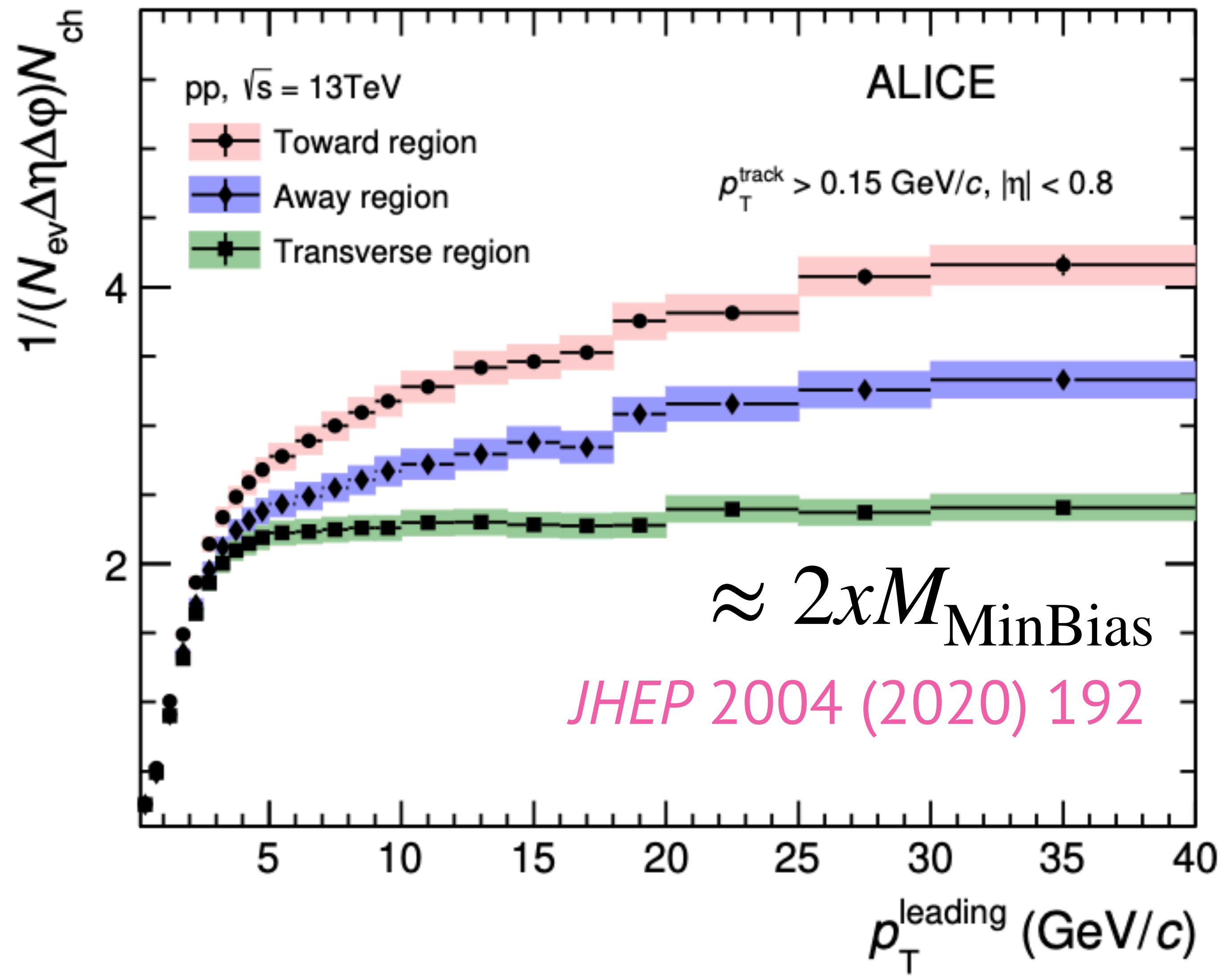


$$n_{\mathrm{MPI}} = T_{\mathrm{pp}}(b)\sigma_{2\to2}$$

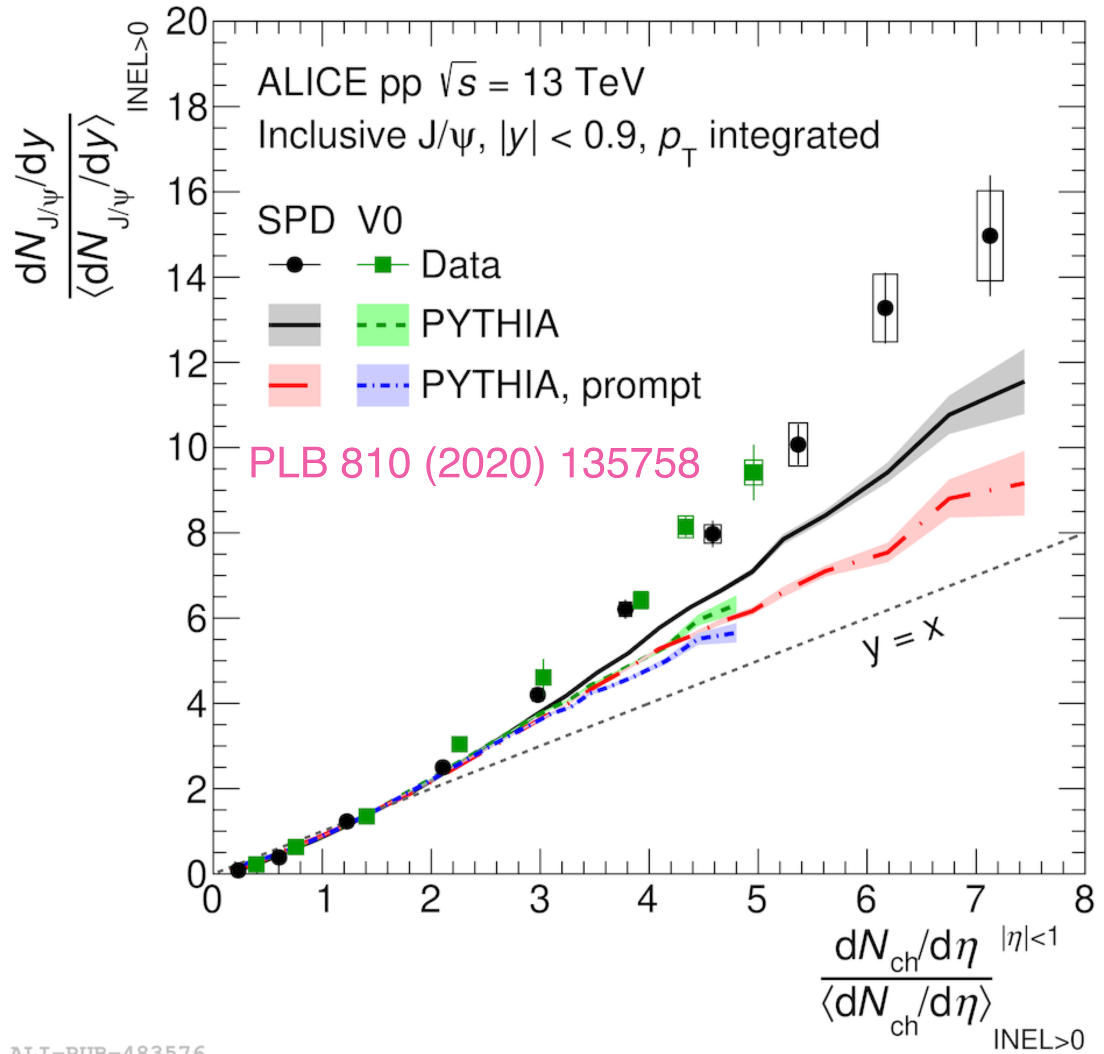
- no way to select *b*
- but it can be biased

select high-p_T → small *b*, increased multiplicity





select high-*M* → small *b*, increased hard yield

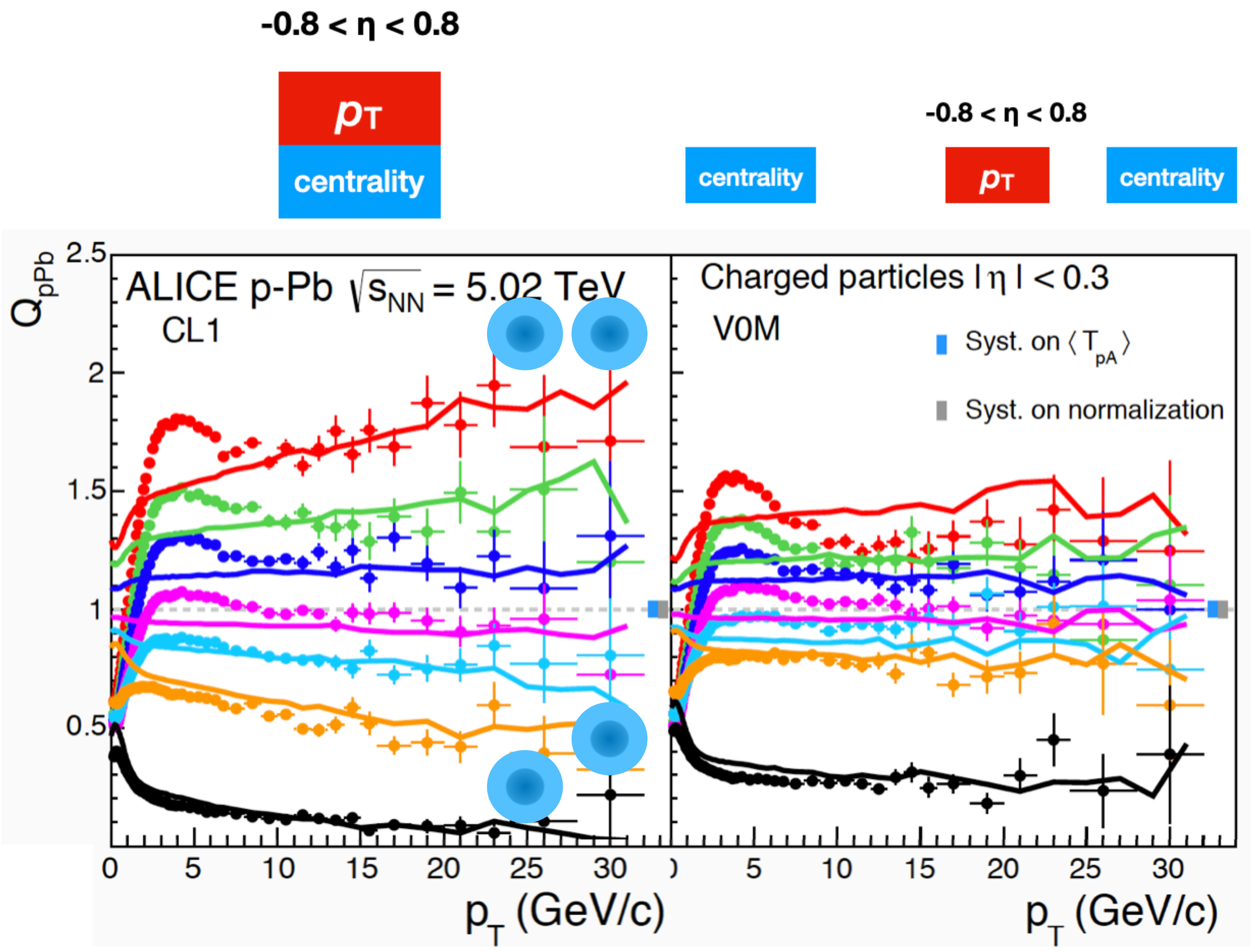


MPI in pPb

- n_{MPI} → Number of nucleon-nucleon binary collisions (N_{coll})
    - Glauber fit to multiplicity or summed energy distributions
    - N-N collision treated as minimum bias collisions
    - Large deviations of nuclear modification factors from unity.
- Explanation:
    - N-N collisions are not unbiased in centrality bins
    - pp hard-soft correlations transferrable to pPb
- pp impact parameter biased by
    - pure phase space factor in Glauber
    - multiplicity selection
- Improved "incoherent" reference obtained by including these effects
- Alternative explanation: Glauber-Gribov pp cross-section fluctuations
    - effectively similar since both models introduce additional fluctuations

nuclear modification factor:

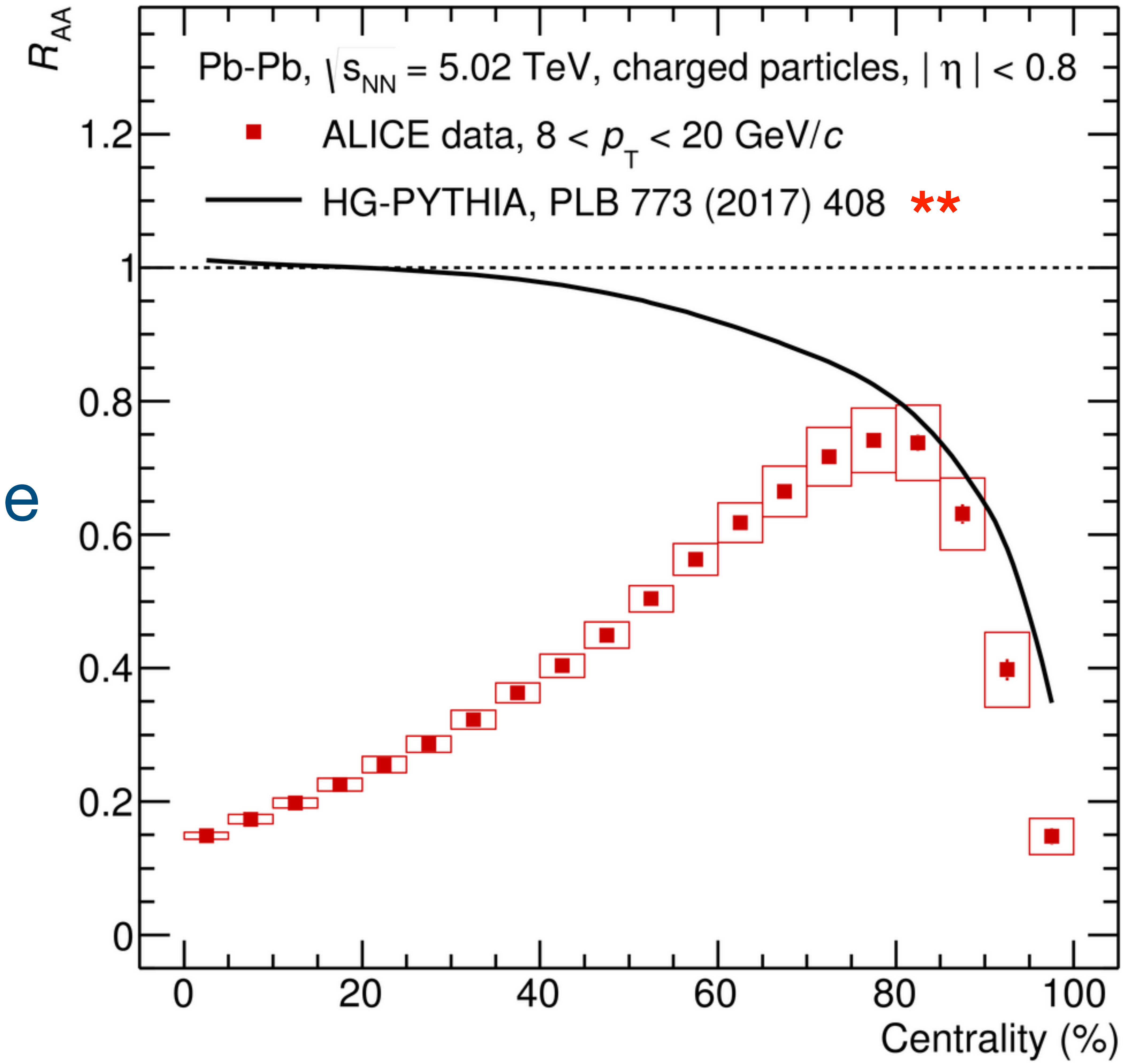
$$Q_{\mathrm{pPb}}(p_{\mathrm{T}};\mathrm{cent}) = \frac{\mathrm{d}N^{\mathrm{pPb}}_{\mathrm{cent}}/\mathrm{d}p_{\mathrm{T}}}{\langle N^{\mathrm{Glauber}}_{\mathrm{coll}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} = \frac{\mathrm{d}N^{\mathrm{pPb}}_{\mathrm{cent}}/\mathrm{d}p_{\mathrm{T}}}{\langle T^{\mathrm{Glauber}}_{\mathrm{pPb}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$



Phys. Rev. C 91 (2015) 064905

… in Pb-Pb

- Claims about quenching in peripheral collisions were made …
    - similar biases need to be considered
- Region below 80% not well constrained due to possible real quenching effects.



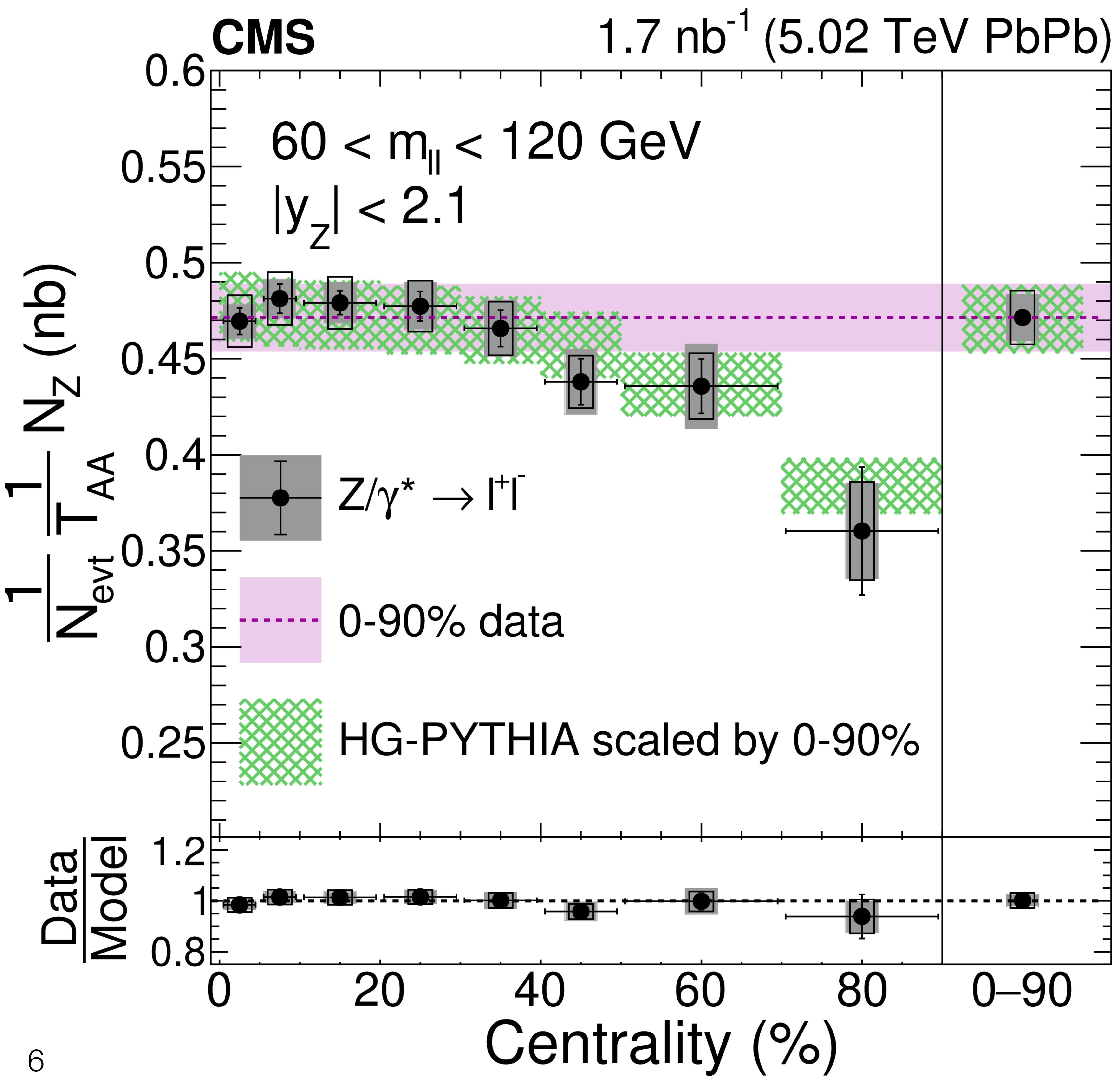
** HG-PYTHIA used to give credit to the original MPI-Glauber implementation in HIJING. In HIJING itself the MPI effects are masked by other nuclear effects.

C Loizides, AM, Physics Letters B, Volume 773, 2017, pp. 408-411

Centrality dependent Z production in PbPb

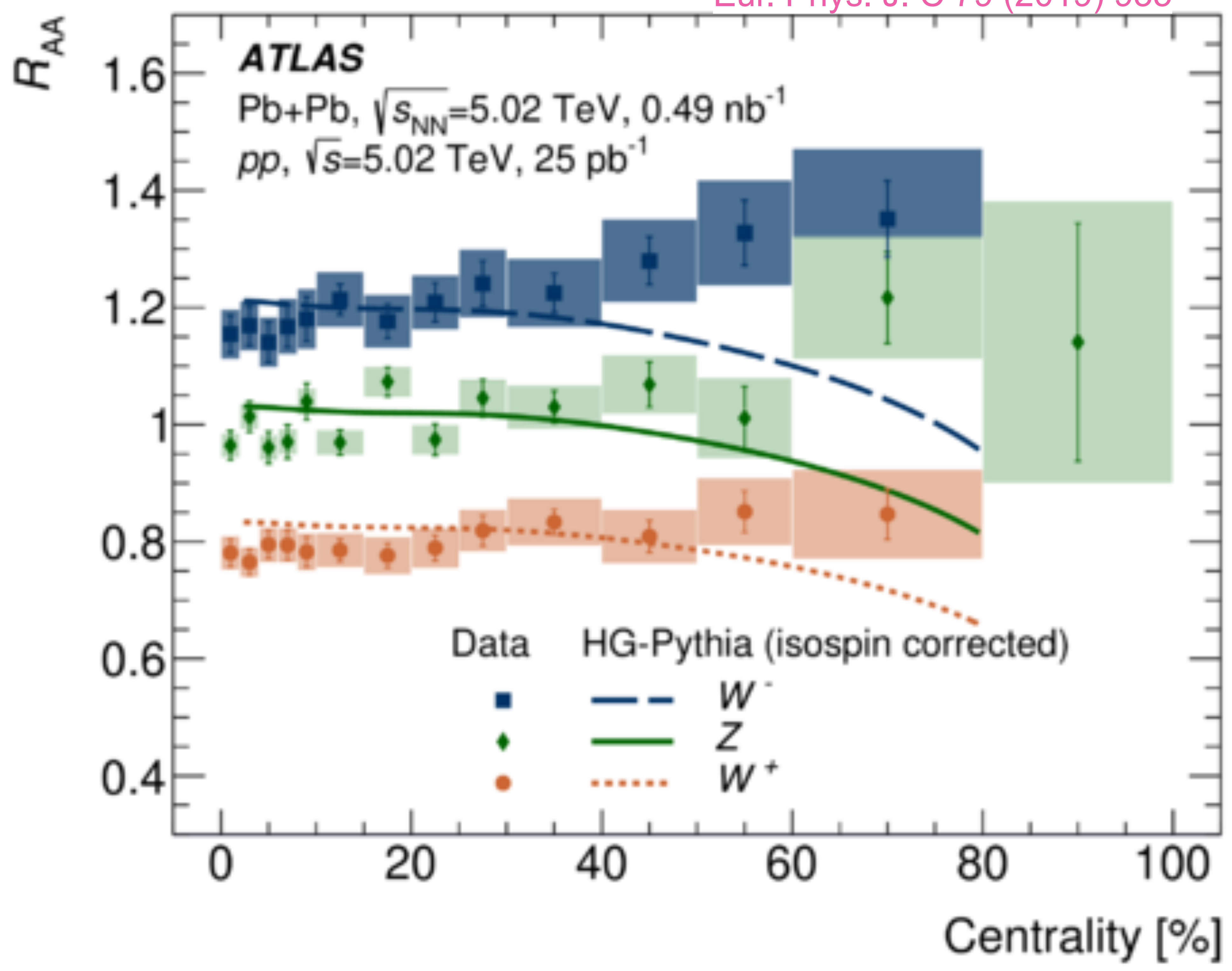
- No quenching expected for Z
  - “calibrates” the Glauber reference

Phys. Rev. Lett. 127 (2021) 102002

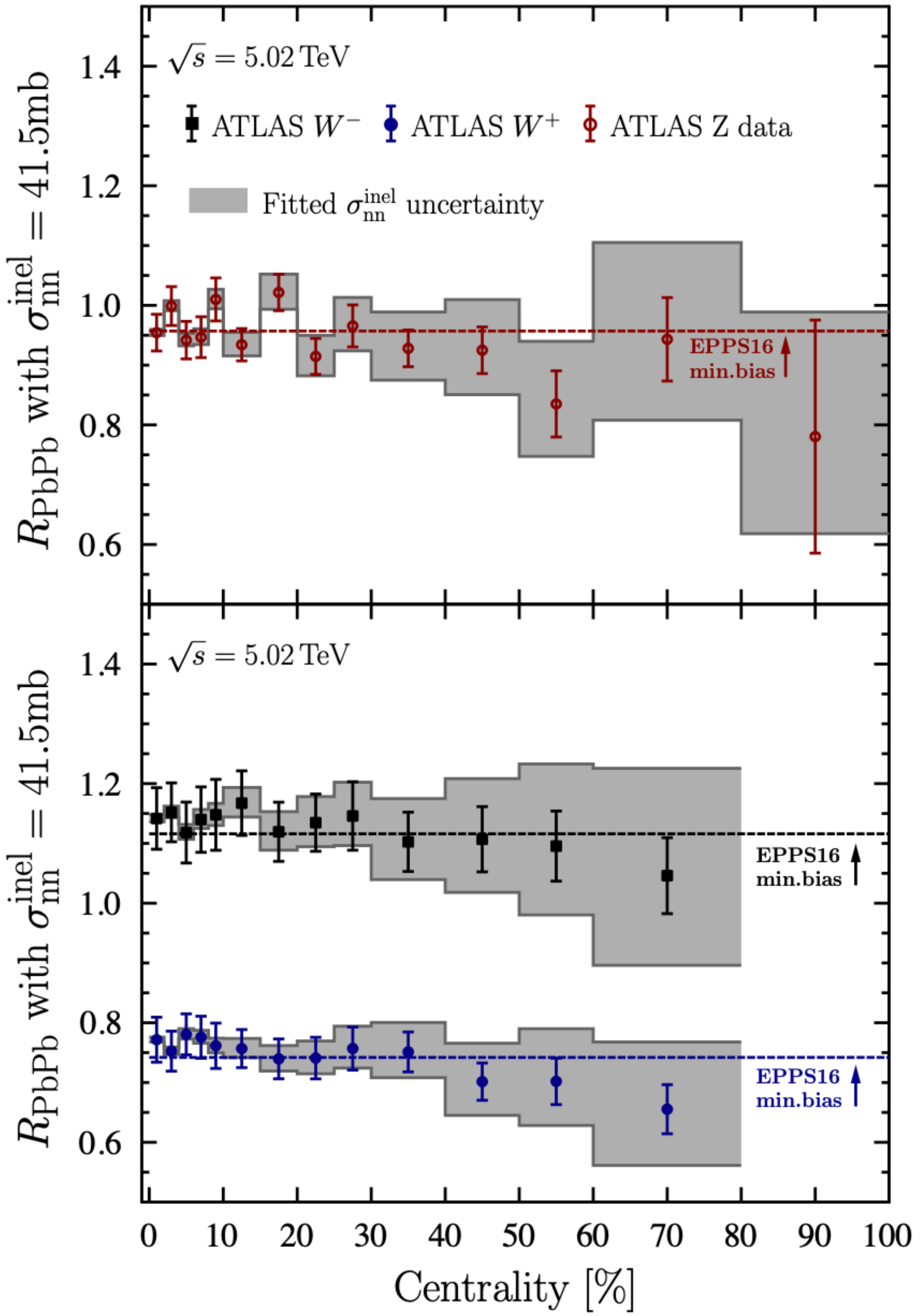


Centrality dependent W/Z production in PbPb

Phys. Lett. B 802 (2020) 135262
Eur. Phys. J. C 79 (2019) 935



KJ Eskola et al., Phys. Rev. Lett. **125**, (2020) 212301



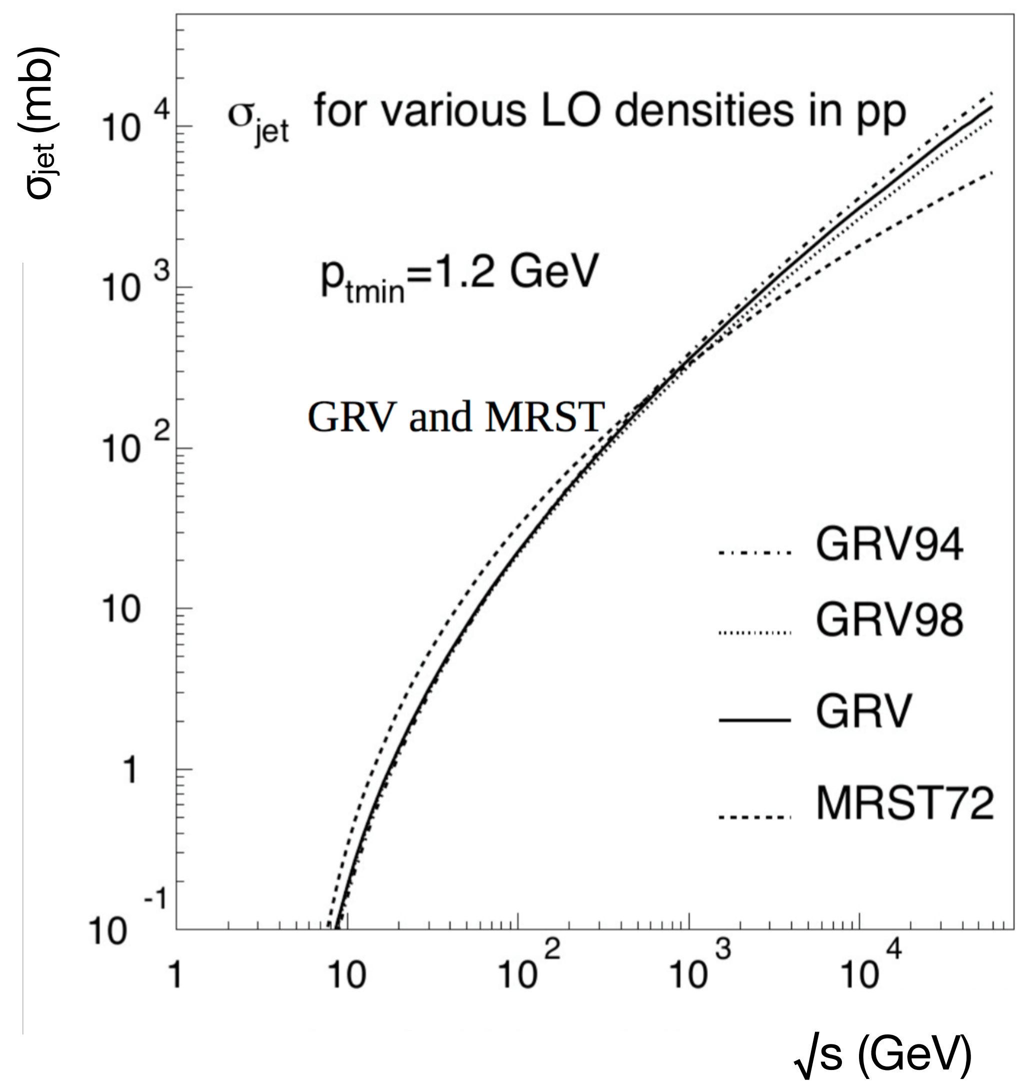
- Strong tension between CMS and ATLAS results
  - Centrality determination still a challenge !!
- Eskola et al. : Shadowing of inelastic pp cross section
  - reduced from 70 mb to 41.5 mb in Glauber to explain ATLAS results
  - corresponds to 30% reduction of proton radius!

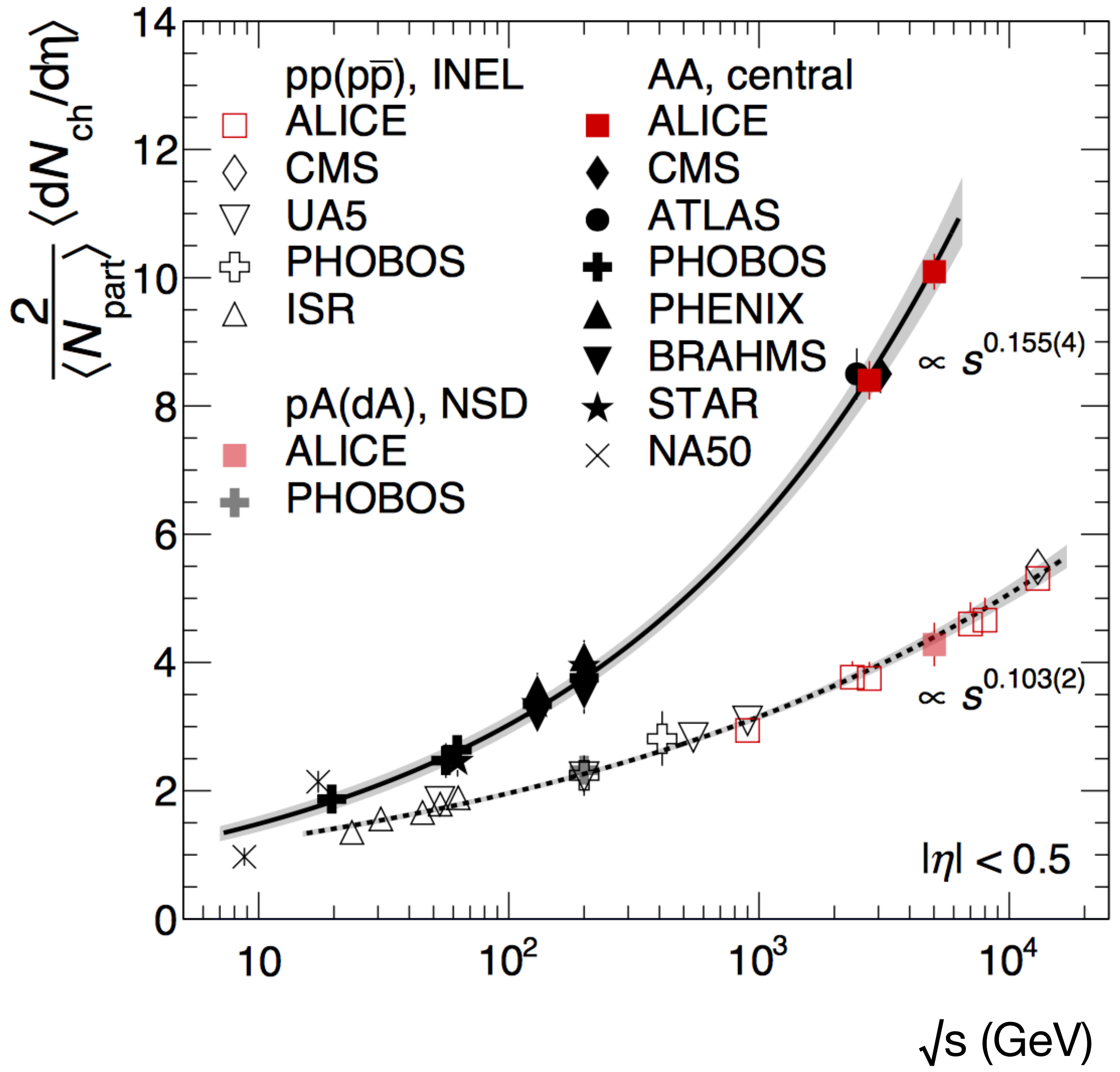
Limits of the model

- MPI model of independent scatterings has limits for low p_T and low $\sqrt{s}$
  - $p_T \gg \Lambda_{QCD}$ for pQCD
  - factorisation breaks for large $n_{2\to 2}$ in area $1/p_T^2$
  - Implemented in PYTHIA by regularising the pQCD hard cross-section at low p_T

σ_{hard} x 10^5

pp: N_{ch} x 4 AA: x10





$\sqrt{s}$ = 10 - 10 TeV

Energy dependence in PbPb

- Centrality dependence of mid-rapidity multiplicity
- *S*-shape consistent with "hard+soft scaling"

$$fN_{\mathrm{part}} + (1-f)N_{\mathrm{coll}}$$

  - But shape almost energy independent!
- Simple explanation for this geometric scaling ?
- Higher $\sqrt{s}$ would provide additional lever-arm.