p(d)A Wrap-up

Particle Production and Nuclear Modification Factors

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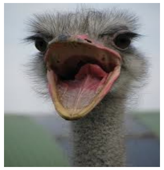
Study of p(d)-A Collisions ...

- Field developed from
  - necessary but somewhat boring control-experiment to study cold nuclear effects and to establish a baseline for A-A
  - to surprises at RHIC
    - ex. suppression of away-side correlations
      - onset of saturation ?
  - to discoveries
    - double ridge, elliptic flow
- New challenges



  - Is medium in p-A A-A like or has A-A properties of cold nuclear matter ?
  - Some unexpected correlations of hard probes with event activity (seen also in pp)
  - Centrality problematic at the LHC

Nuclear modification factor

$$R^{X}_{pA}(p_T) = \frac{\mathrm{d}N^{pA}_{X}/\mathrm{d}p_T}{N_{coll}\,\mathrm{d}N^{pp}_{X}/\mathrm{d}p_T}$$

(equivalently for dA)

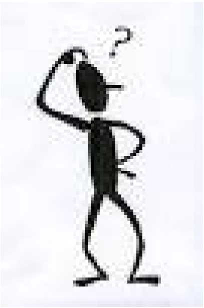
$$\frac{\mathrm{d}\sigma^{pA\rightarrow X}}{\mathrm{d}p_T} \propto f_i^p(x_1, Q^2) \circ f_j^A(x_2, Q^2) \circ \sigma^{ij\rightarrow k}(x_1, x_2, p_T/z, Q^2) \circ D_{k\rightarrow X}(z, Q^2) \circ FS\,effects$$

- In absence of strong final state effects, R_{pA} provides information about nuclear modifications of *the parton density function.*

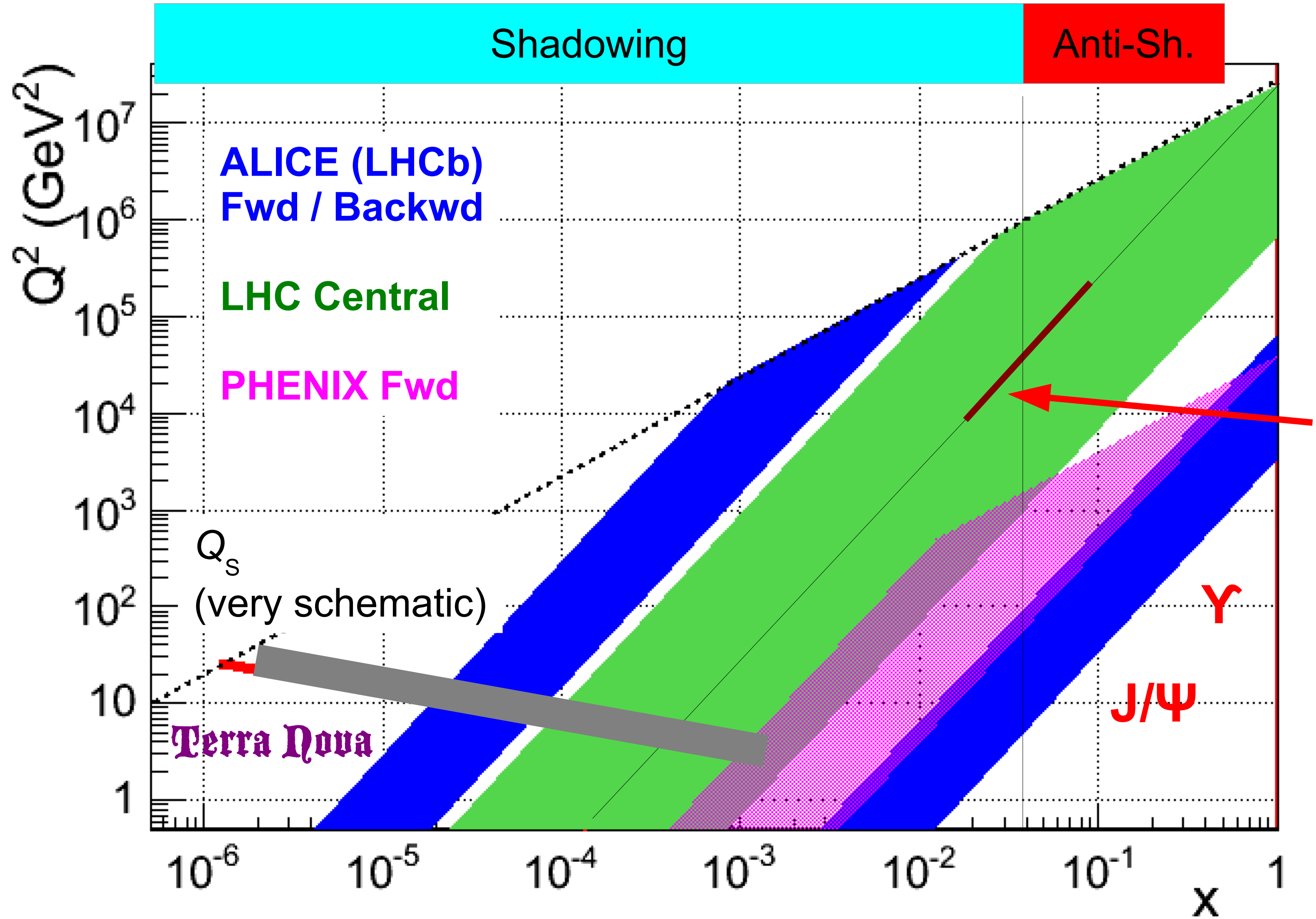
- In addition to the hard process studied ..

At LHC, expect > N_{coll} semi-hard scatterings per p-Pb collisions (in pp $\sigma_{hard} > \sigma_{tot}$) !
Bulk of particle production and hard process might be correlated.

$$f_i^p(x_1, Q^2; x_{1,1}, Q_1^2, x_{1,2} Q_2^2, ...)$$



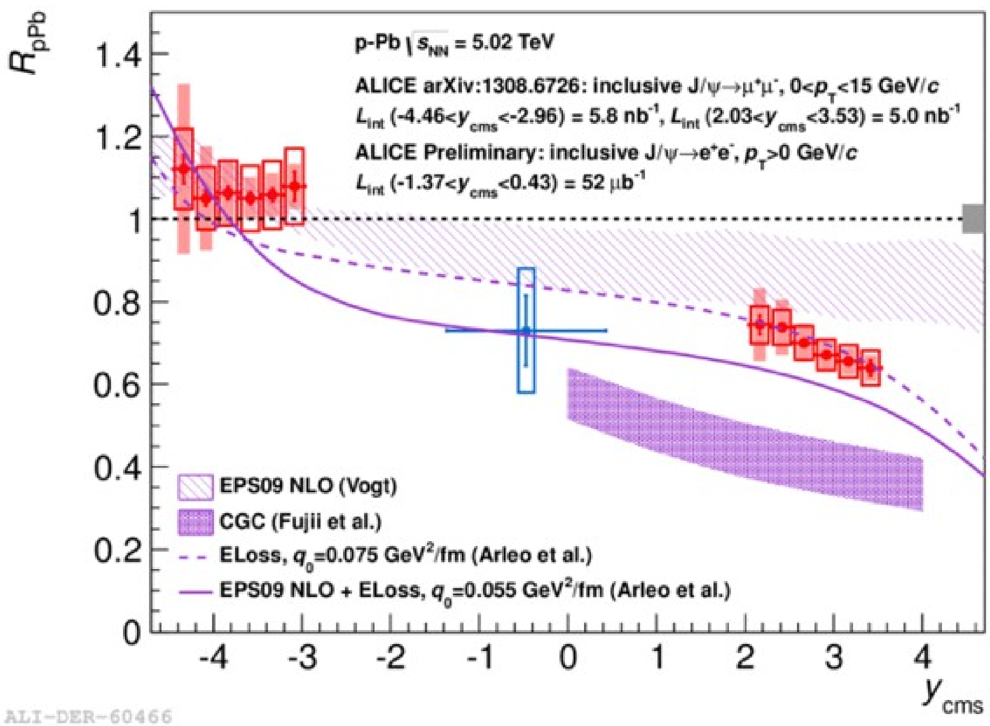
Mappa Mundi in Umbram

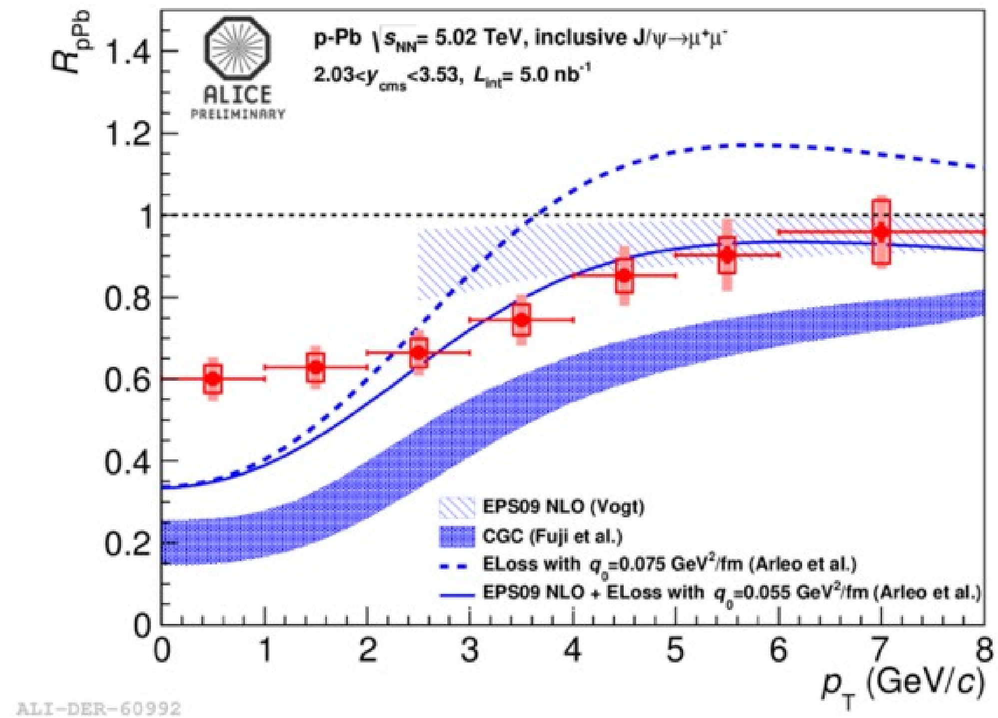


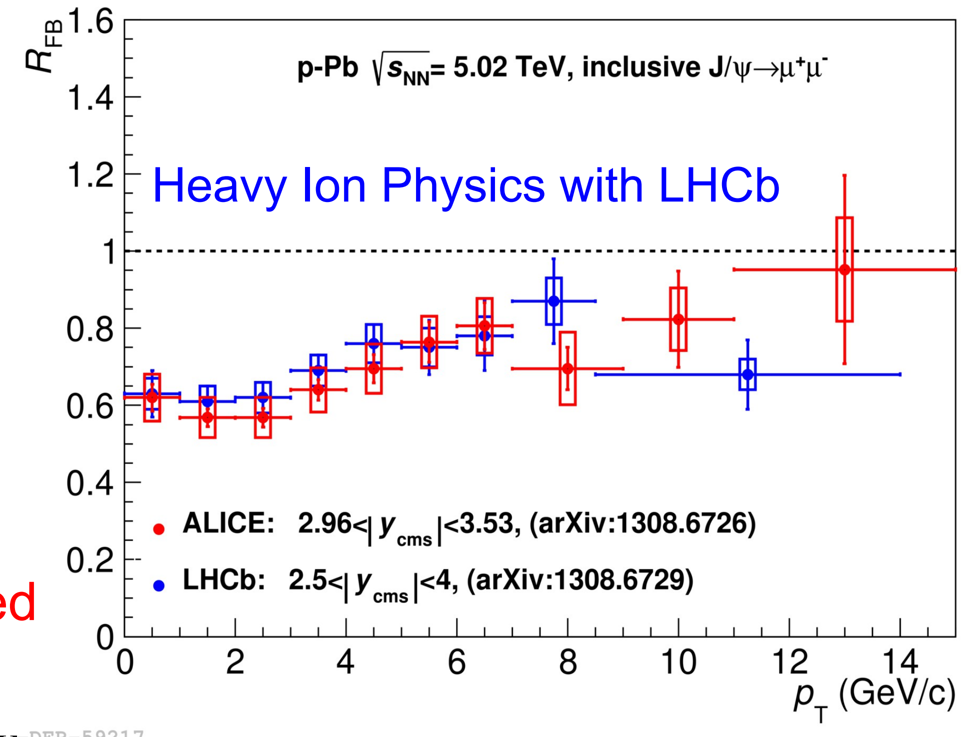
Hic sunt leones

Possibility to approach saturation scale in perturbative region.
Most of measurement performed in shadowing region.

J/ψ p-Pb at LHC (5020 GeV)

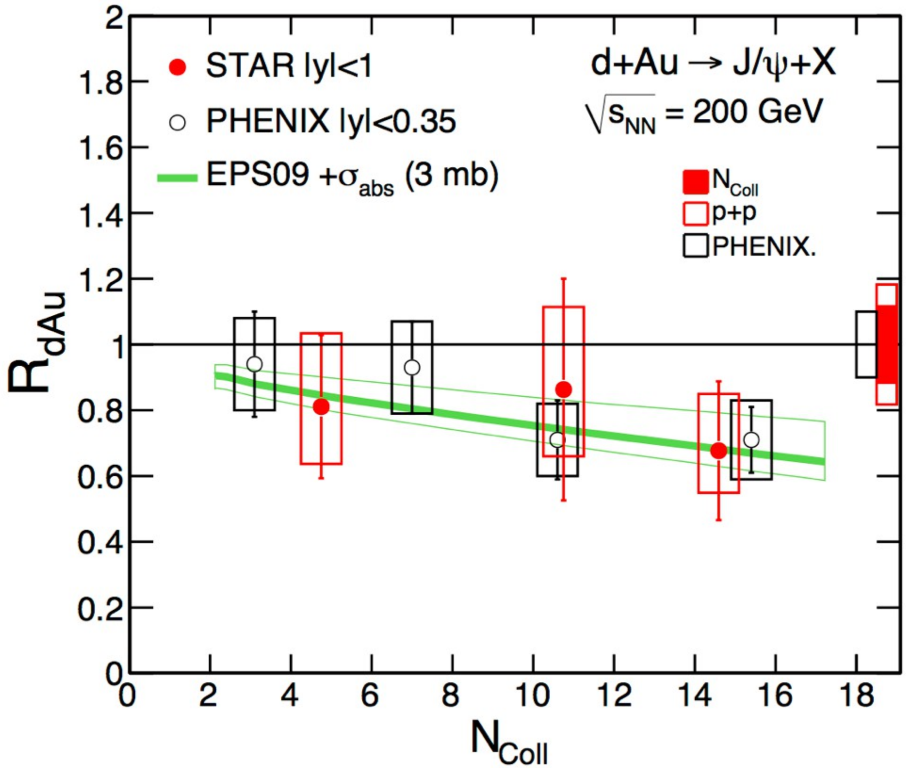


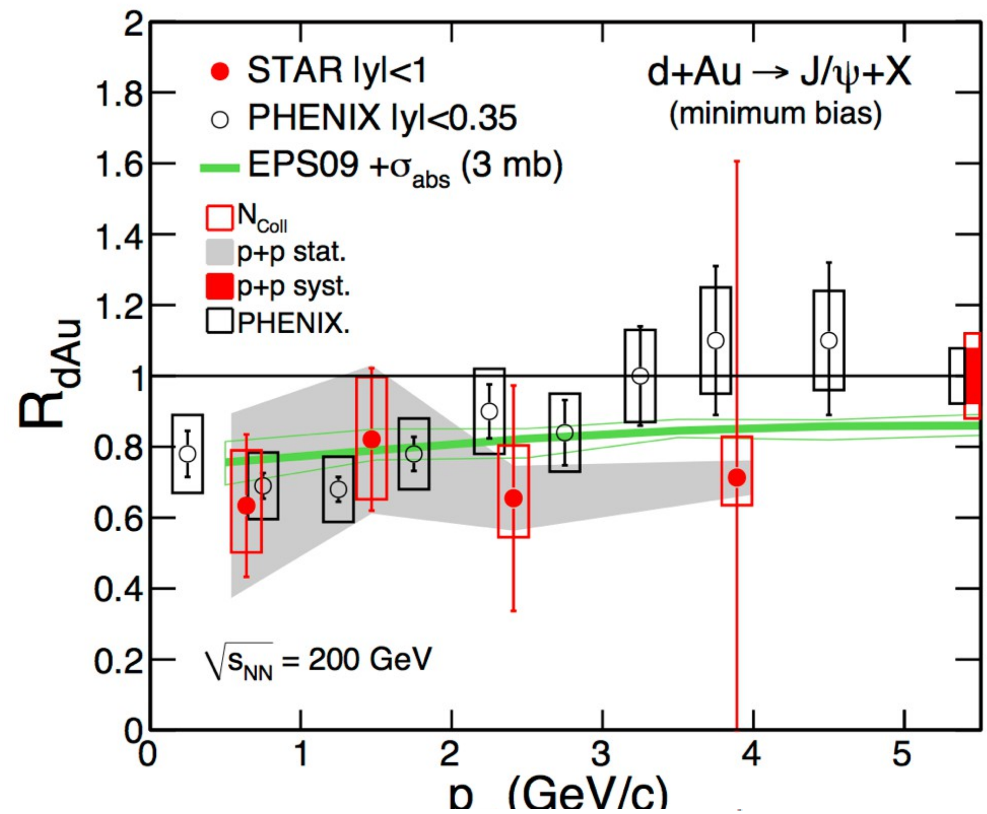




- Shadowing at lower bound of EPS0
- Indications that final state effects play a role
- Under-predict R_{pPb} at low p_T
- No feed-down suppression (Ψ' and χ_c) included

J/ψ d+Au RHIC (200 GeV) central rapidity



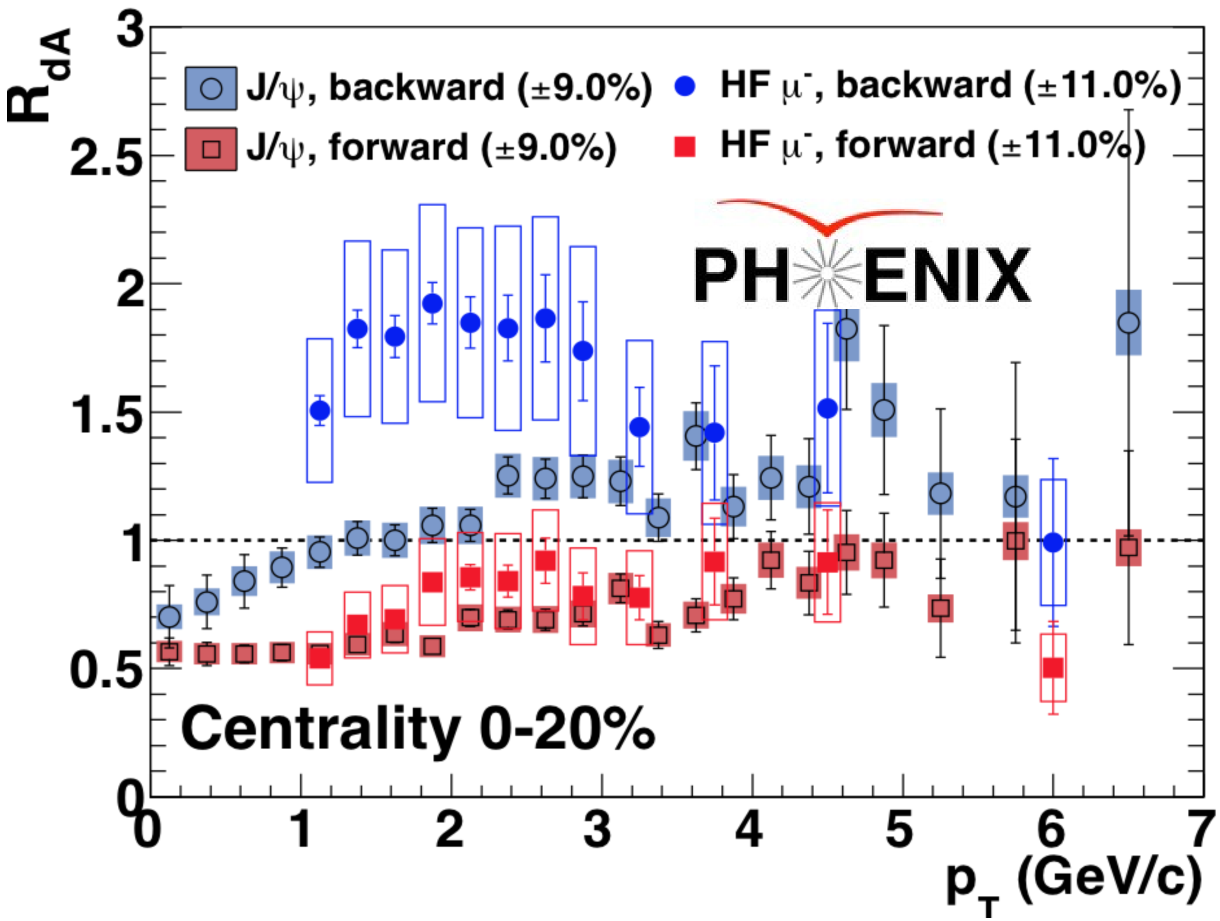


E.Eskola, H.Paukkunenea and C.Salgo, Nucl. Phys. A 830, 599 (2009) R.Vogt, Phys. Rev. C 81, 044903 (2010)

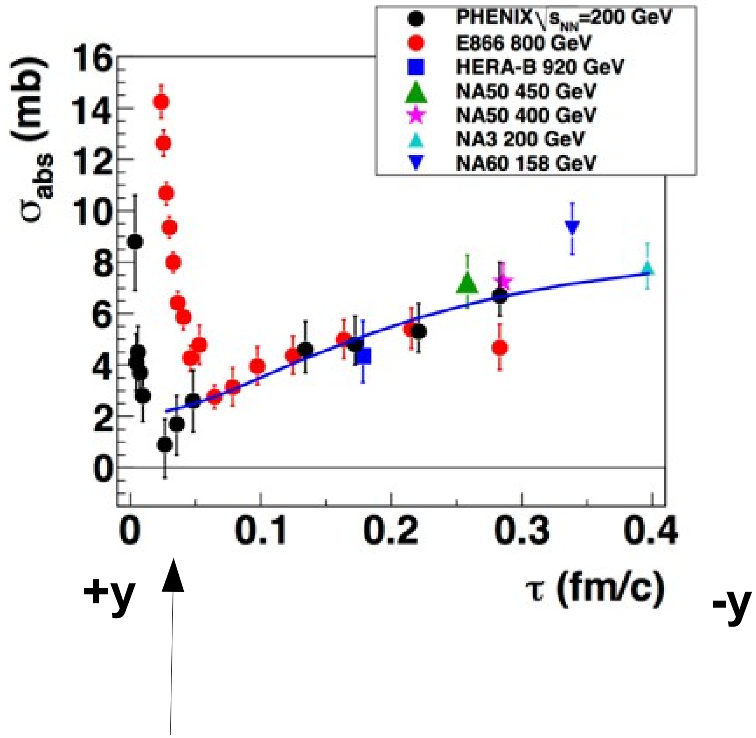
RHIC results in better agreement with models when J/ψ nuclear absorption included. (EPS09 nuclear modification of pdf + EPS09)

Absorption increases if expanding meson stays long time in the medium => backward direction.

J/ψ and Heavy Flavor Leptons at RHIC d+Au forward vs backward rapidity



Phys.Rev. C87 (2013) 054910



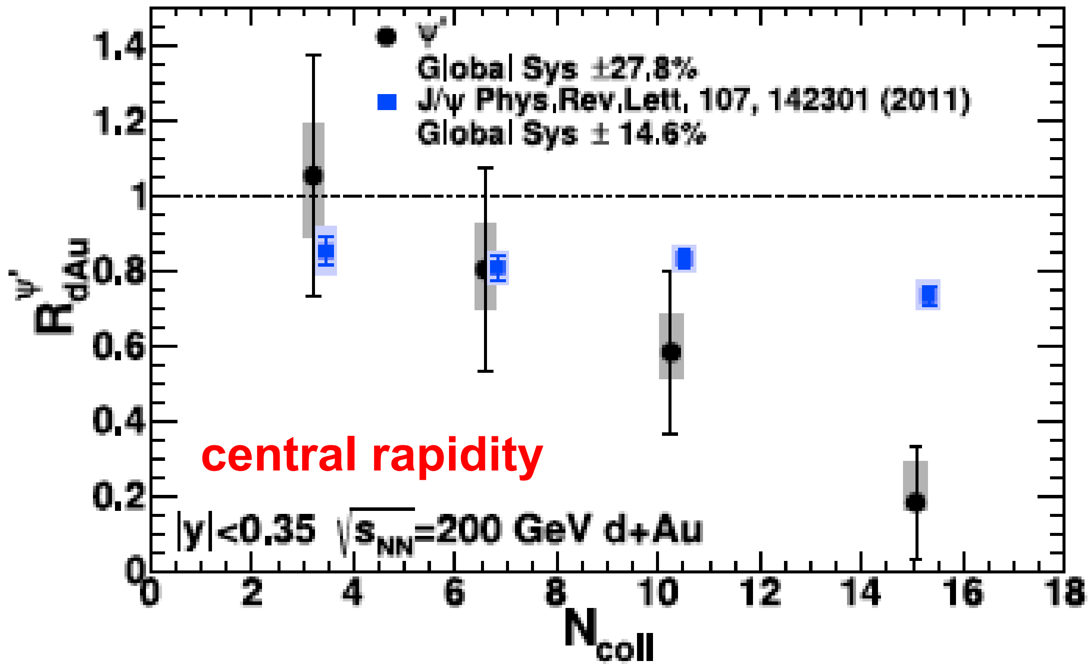
bound state formation time

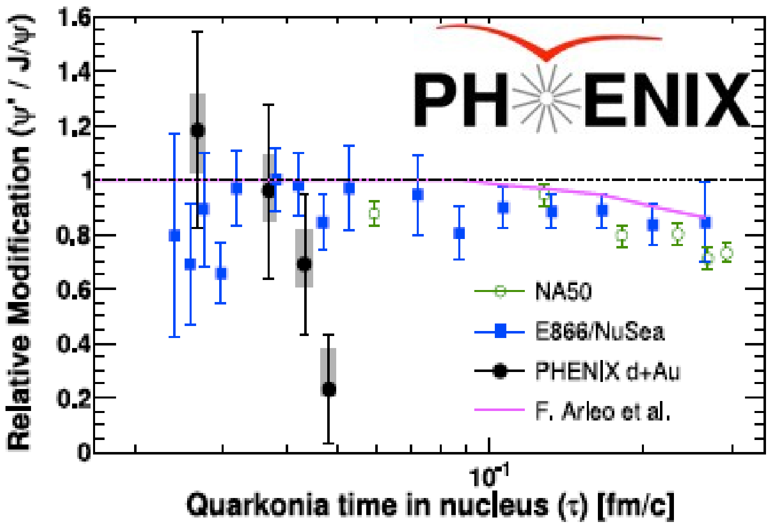
- J/ψ yield in backward direction smaller than underlying charm yield. Consistent with break-up of color-neutral charm pair expending in the medium.
- Different physics in forward rapidity, short time in medium (energy loss of colored dipole).

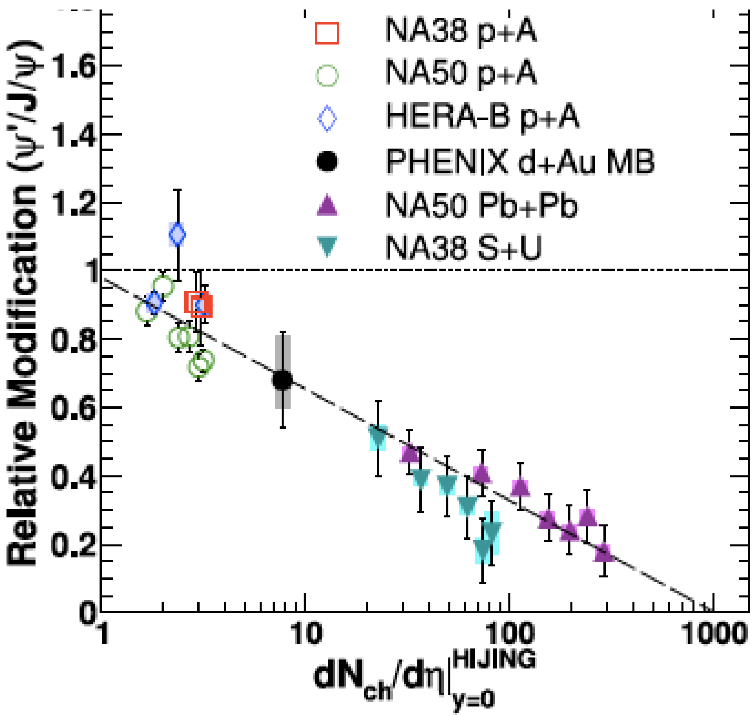
Can ψ' tell more ?
Short τ, should behave like J/ψ

ψ' at RHIC Strong indication for final state effects

PHENIX: arXiv: 1305.5516, PRL in press





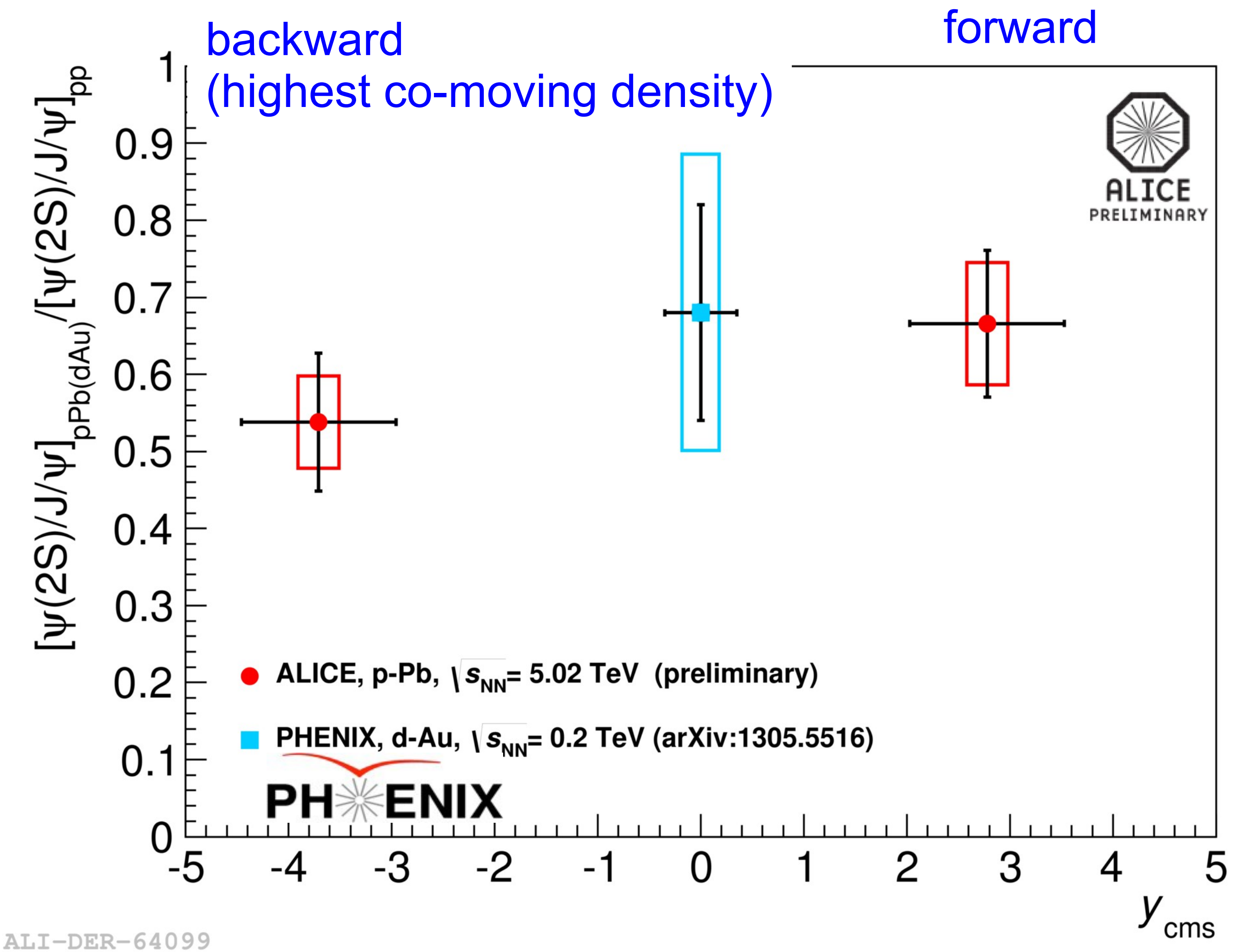


- Stronger suppression of ψ' wrt J/ψ at high N_{coll}
- No break-up of colorless expanding meson (does not distinguish between the two states, time in medium too short)

-Suppression energy dependent but scales with multiplicity: Hot medium effects ?

- Fwd/Bkwd measurement essential: ALICE can ..

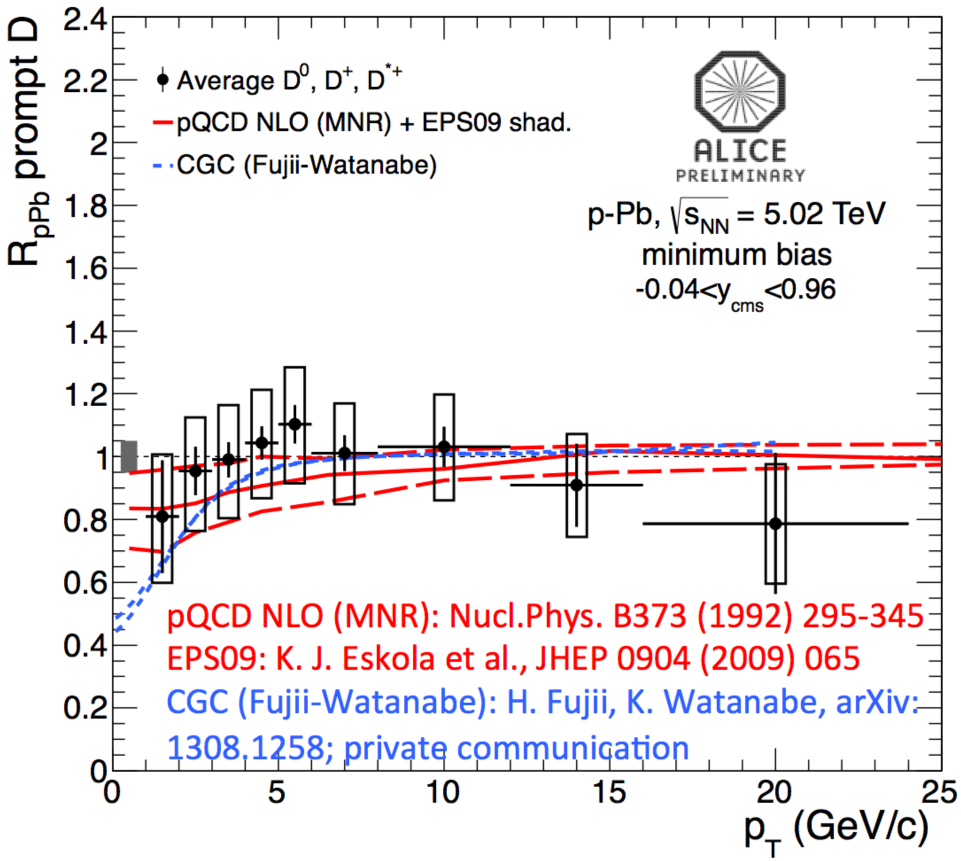
ψ' Suppression at LHC p-Pb: Forward compared to backward rapidity

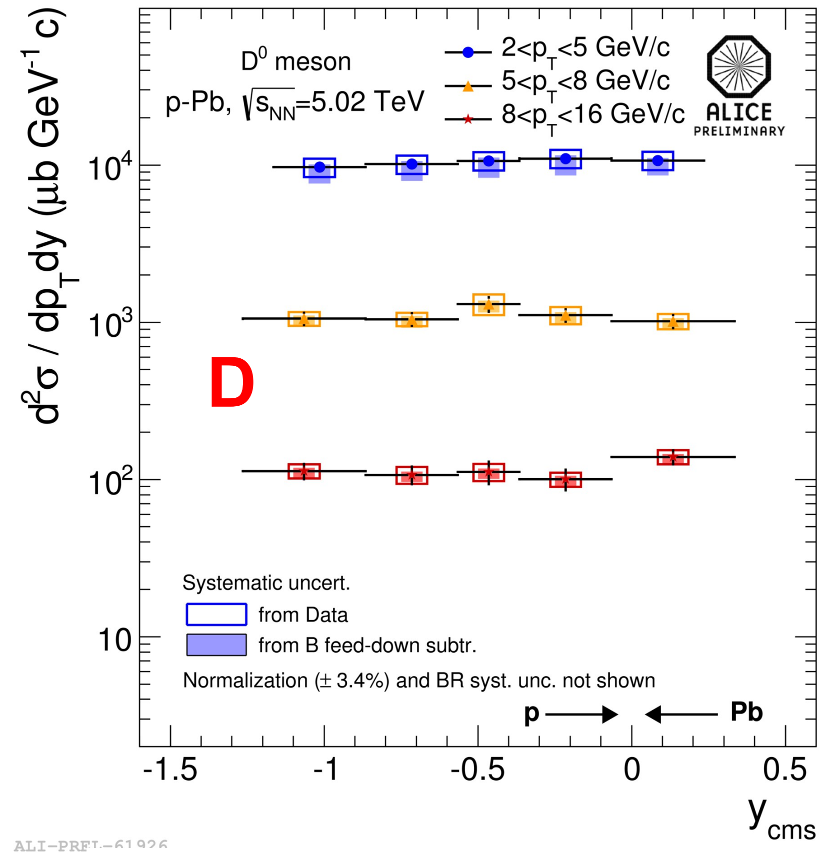


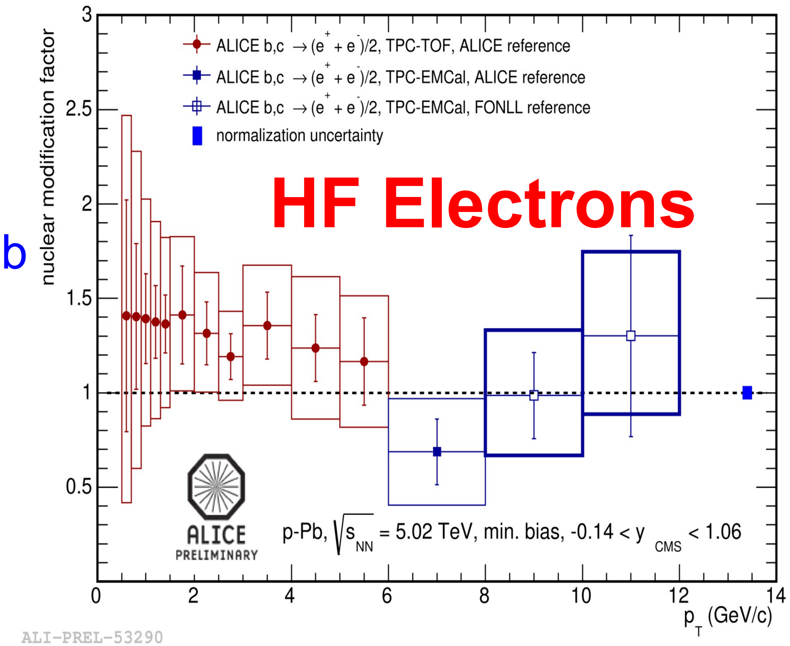
20% difference between forward and backward suppression
Qualitatively consistent with break-up by co-moving medium.
But also strong suppression in forward direction.

Also quantitatively ?

Heavy Flavor in p-Pb at LHC

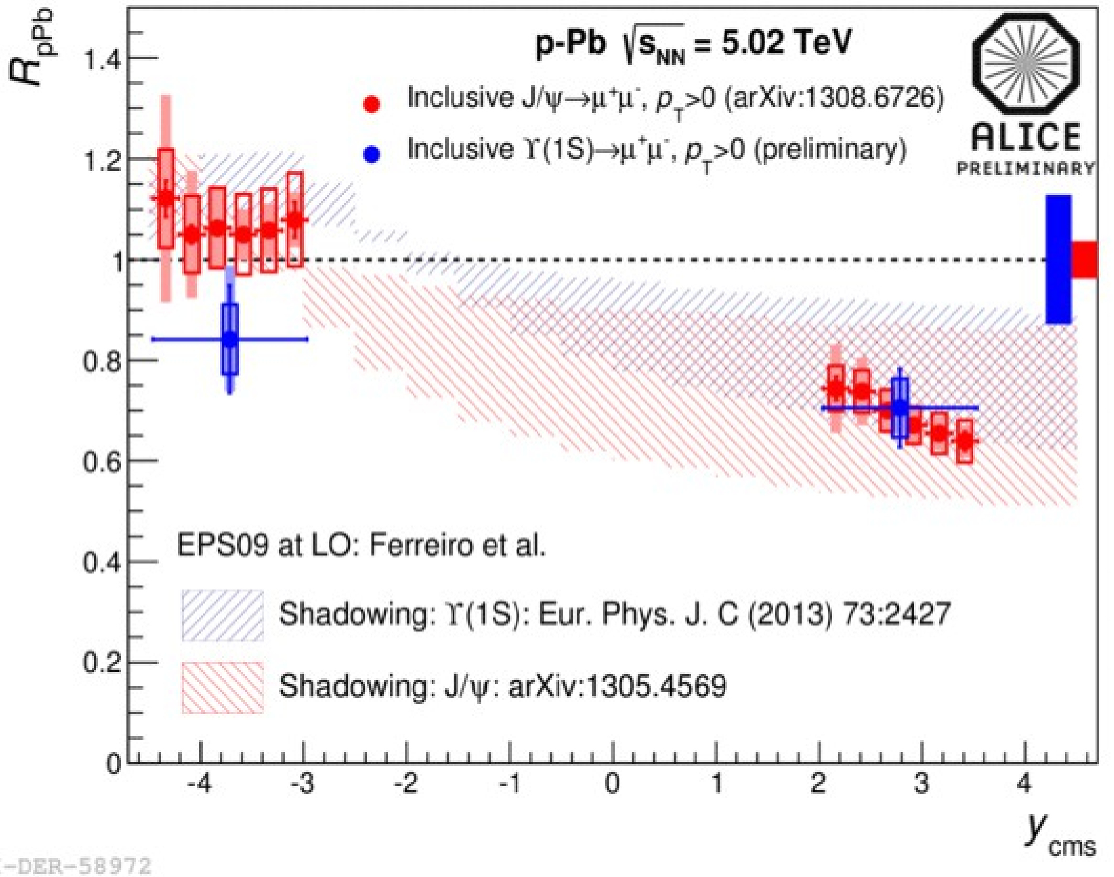






- R_{pPb} consistent with unity, observed suppression in Pb-Pb is final state effect.
- However v_2 structure seen in e-h correlations (double ridge)
- Responsible process may also influence HF R_{pPb} at low p_T

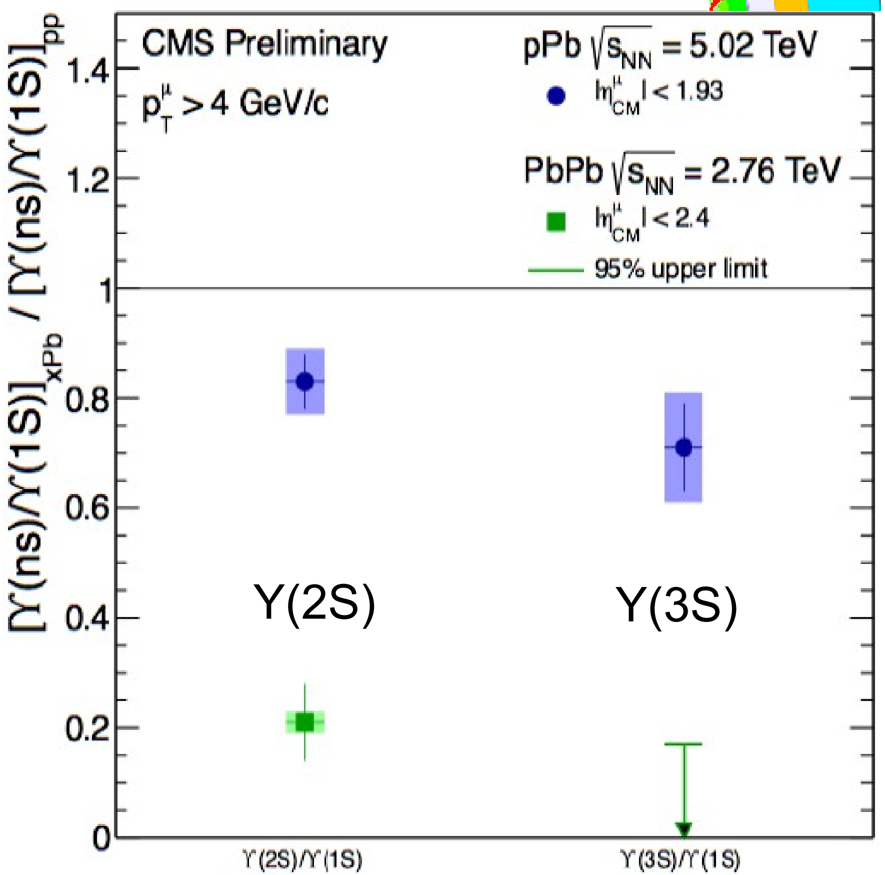
Q^2(J/ψ) x 10: The ϒ-Family

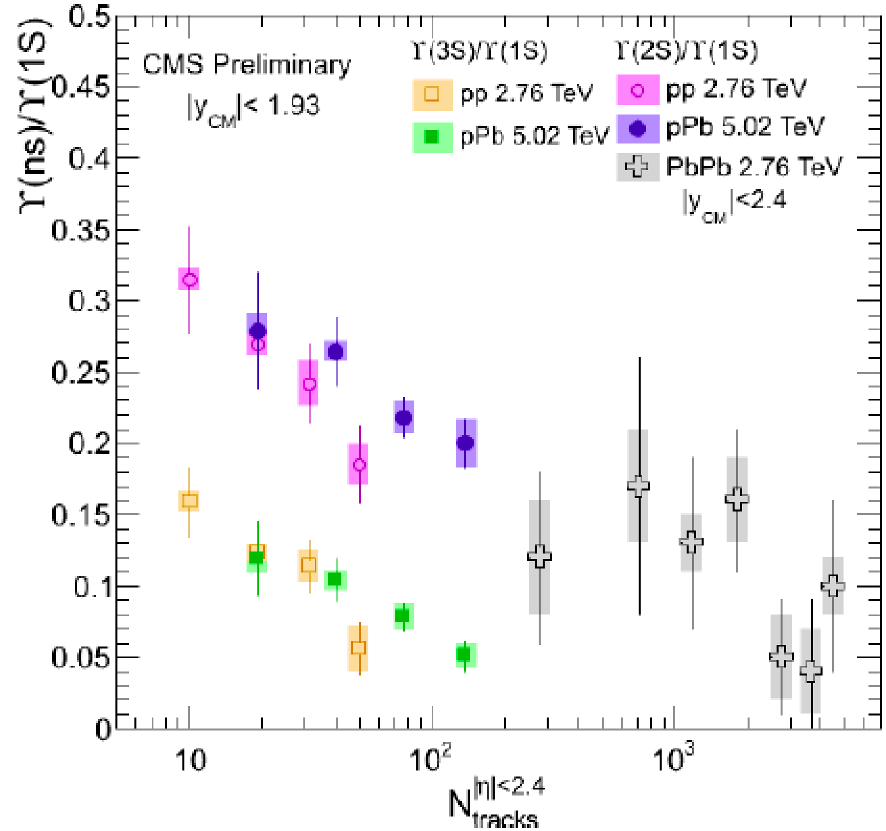


Expect more anti-shadowing and less shadowing.
Some tension wrt to EPS09 expectation, however, large uncertainties.

Q^2(J/ψ) x 10: The ϒ-Family

- Strong additional suppression of ϒ(2S), ϒ(3S) wrt ϒ(1S)
  - despite similar Q^2
- Final state effects ?

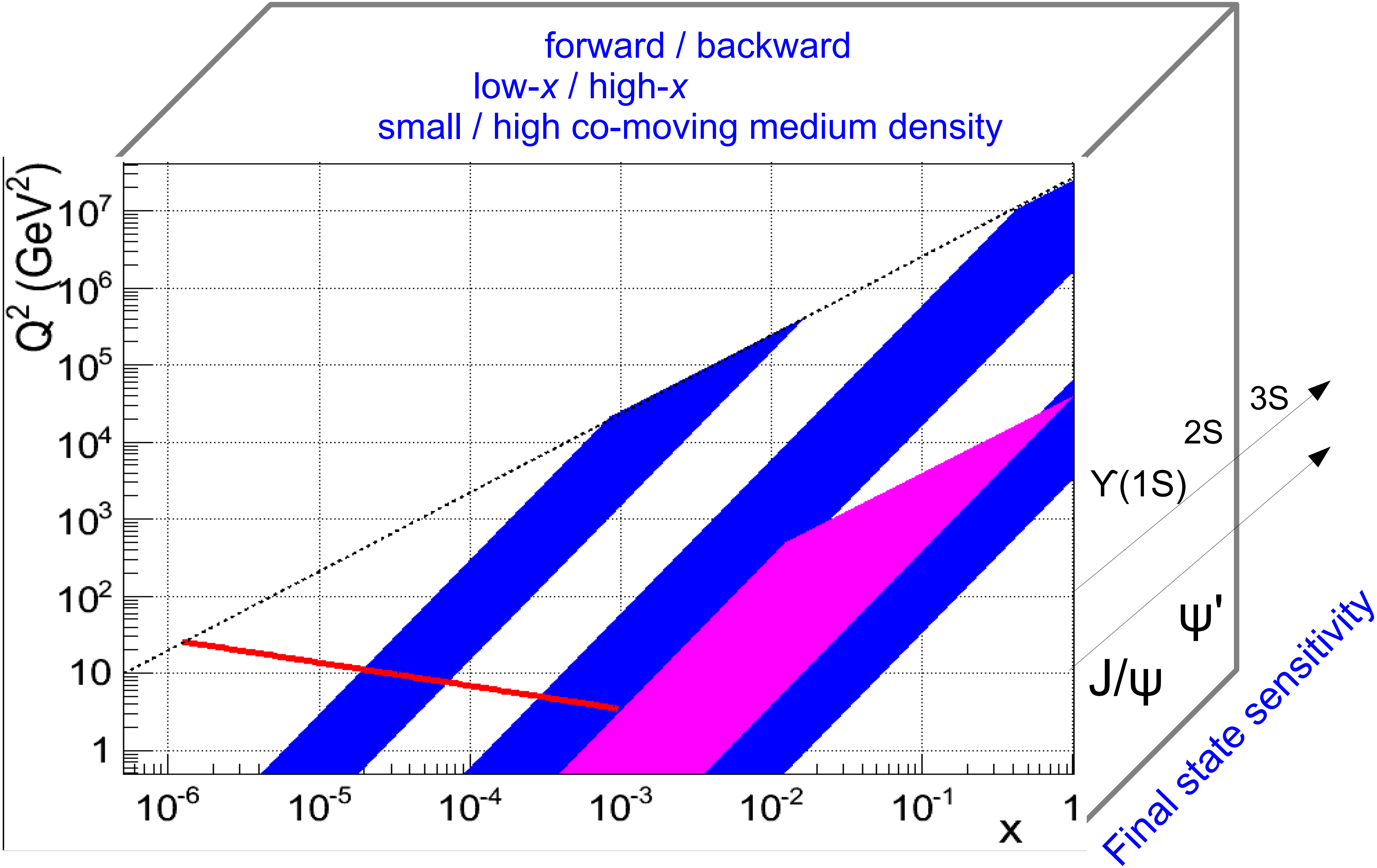




Multiplicity Scaling !
Nothing new in Pb-Pb ?

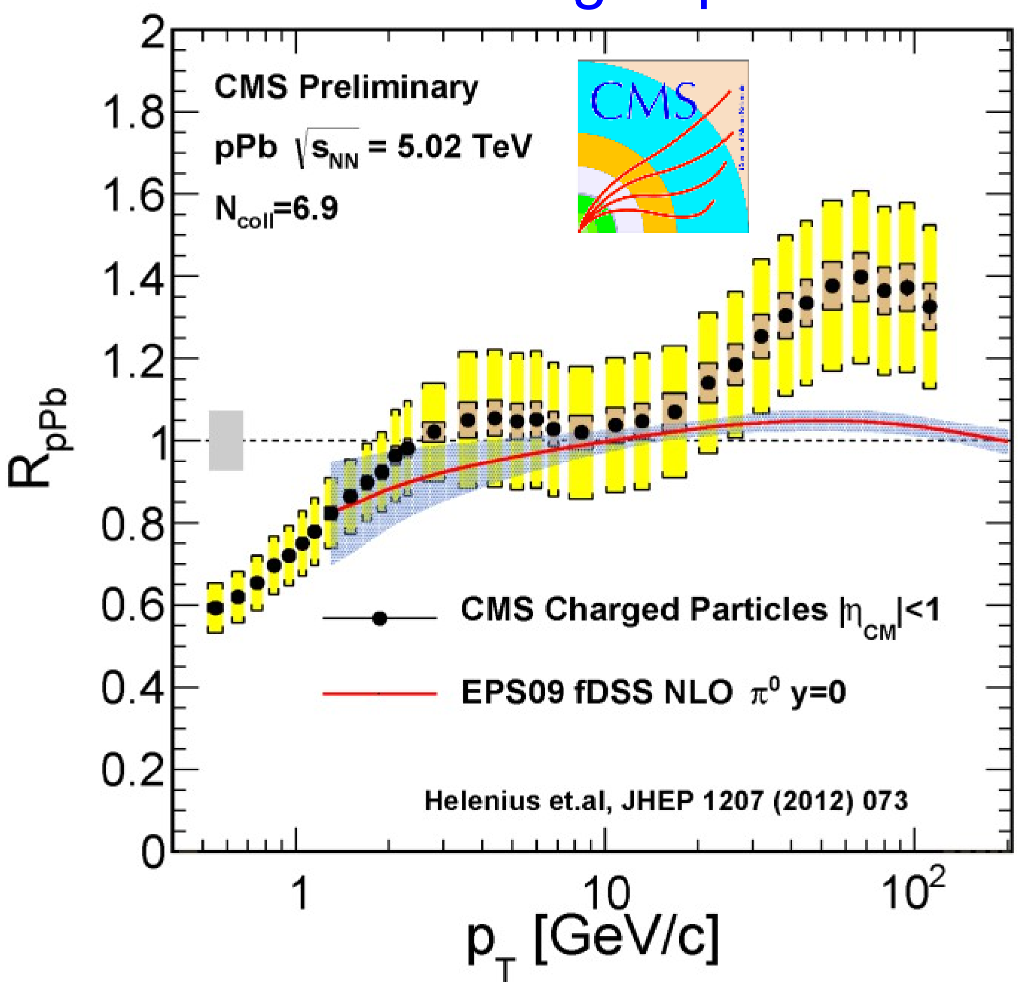
High multiplicity pp collisions are strongly biased.
Optimistic view: something new to learn about Y(1S)/Y(2S)/Y(3S) production mechanisms.
Study Y-h angular correlations !

Mappa Mundi en Umbram: extra dimensions



Stronger than expected anti-shadowing ?

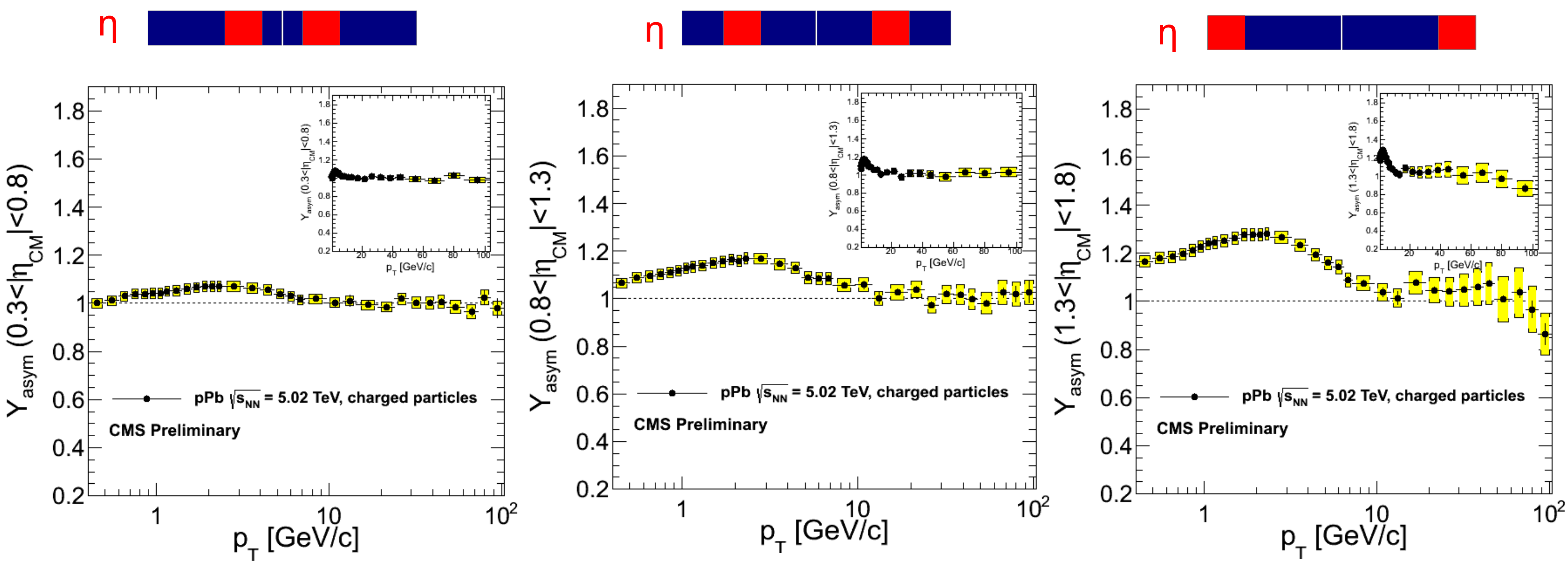
Inclusive charged particles



x = 0.02-02
$Q^2 \sim 10^4 - 10^5$ GeV^2

- Completely unexpected
- Confirmation by other experiments needed
- So far, not seen in jet R_{pPb}

Forward / Backward Asymmetry

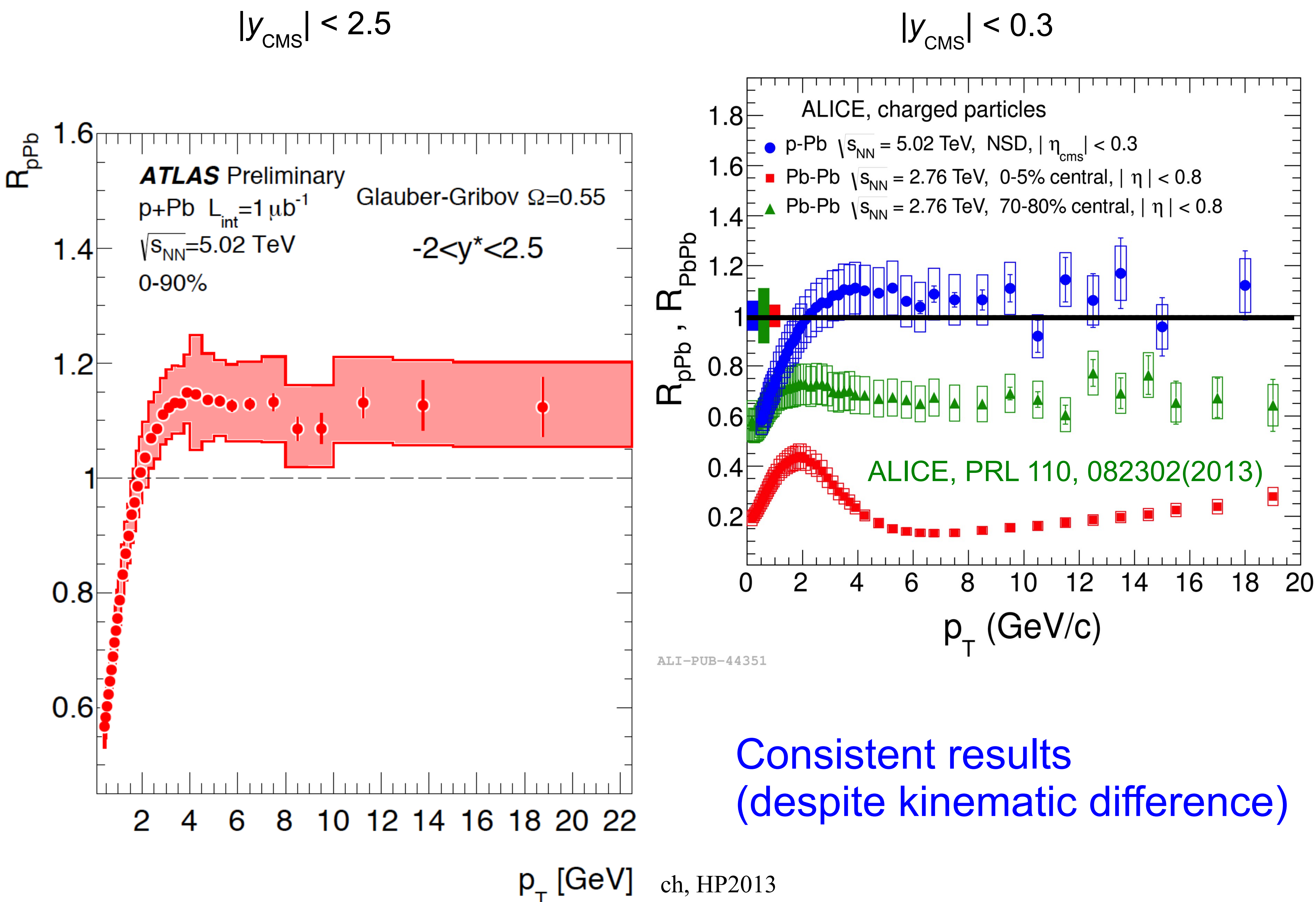


$$Y_{asym} = \frac{d^2 N_{ch} / dp_T \, d\eta_{\text{Pb-going}}}{d^2 N_{ch} / dp_T \, d\eta_{\text{p-going}}}$$

Asymmetry located in the low-p_T part.

Increases with rapidity gap.

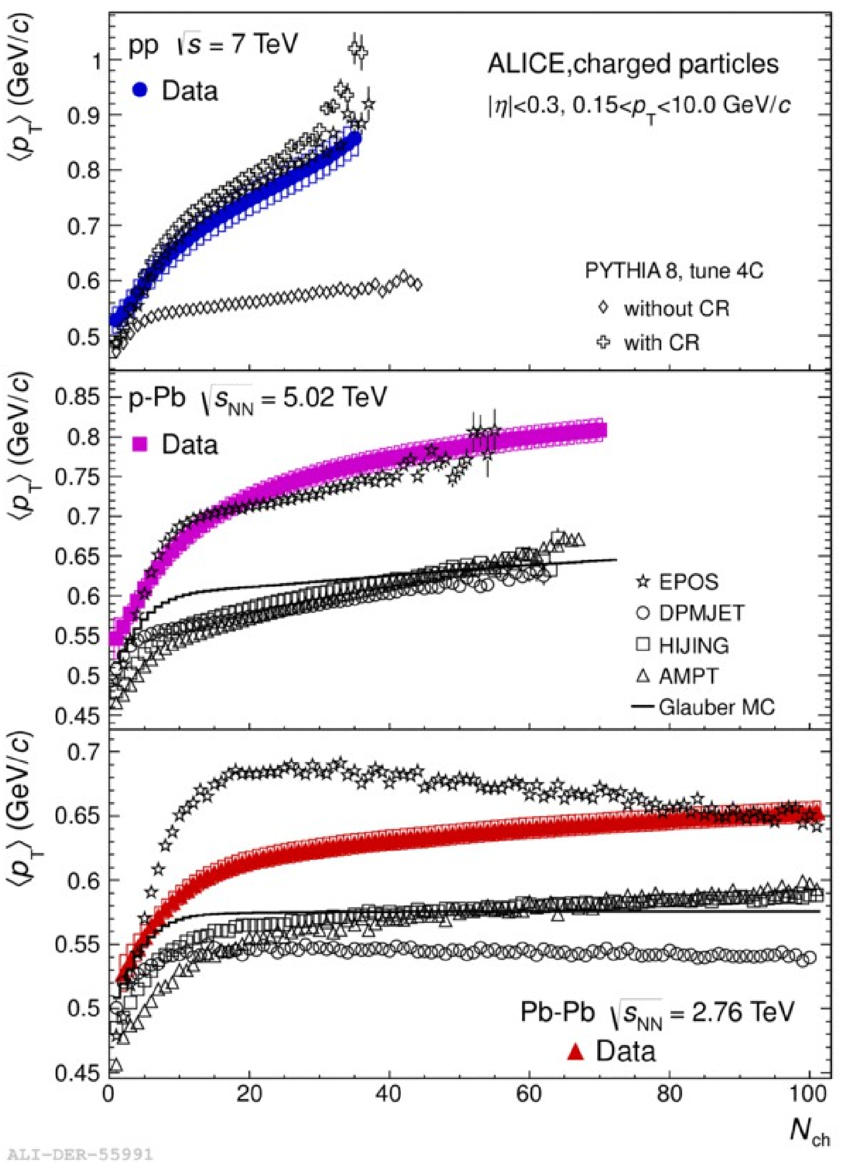
Inclusive charged hadron R_{pPb}

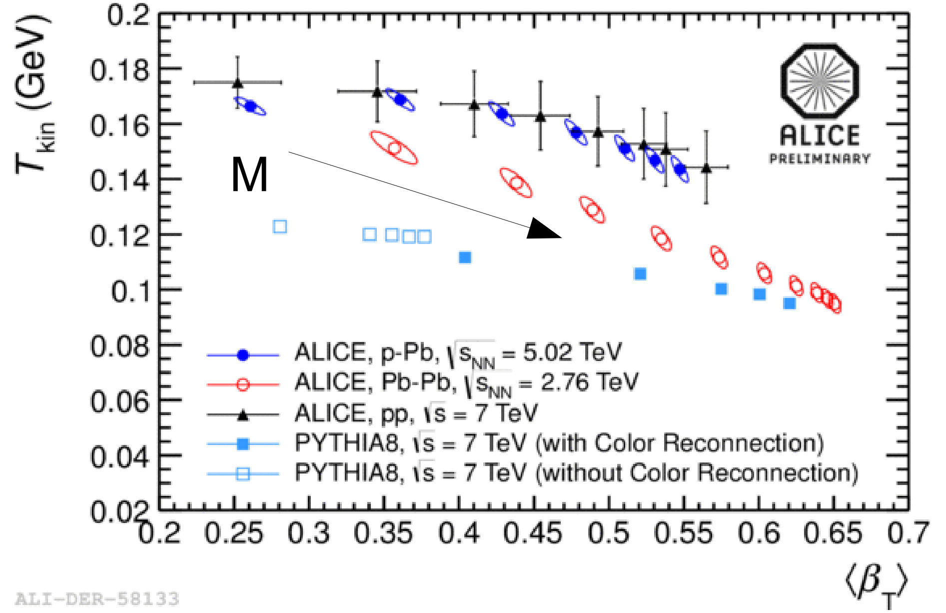


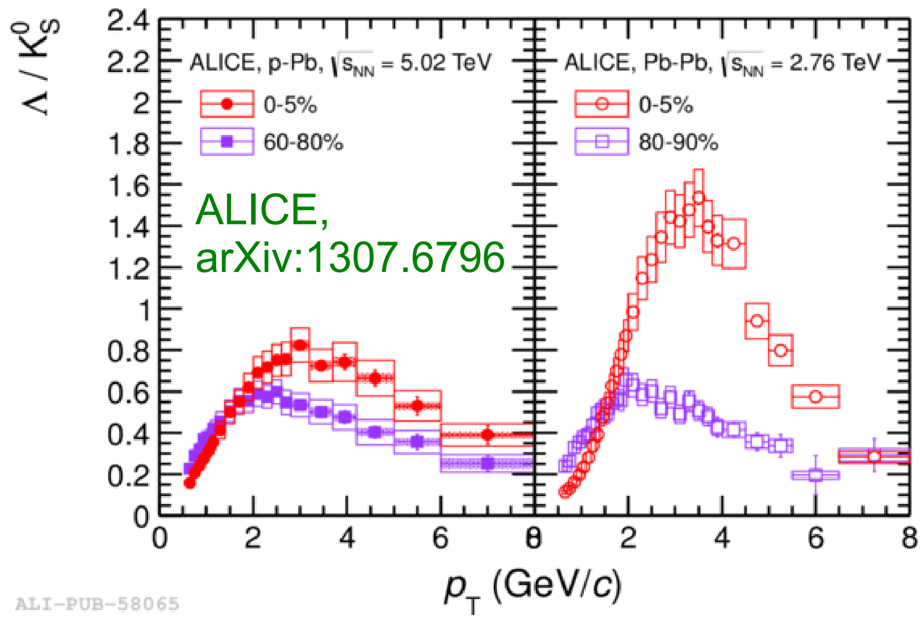
Consistent results
(despite kinematic difference)

 ch, HP2013

Multiplicity dependent studies







Indication collective flow in high multiplicity p-Pb
or Color reconnections = coherent effects between strings = some form of collectivity

Scaling of Hard Processes at LHC

$$R_{\mathrm{pA}}^{MB}(p_T)=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_T}{\langle T_{\mathrm{pA}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_T}=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_T}{\langle N_{\mathrm{coll}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_T}$$

$$\langle N_{\mathrm{coll}}\rangle=208\,\sigma_{\mathrm{pN}}/\sigma_{\mathrm{pA}}=6.9 \text{ with}$$

$$\langle T_{\mathrm{pPb}}\rangle=\langle N_{\mathrm{coll}}\rangle/\sigma_{\mathrm{pN}}=208/2100\,\mathrm{mb}^{-1}=0.098\,\mathrm{mb}^{-1}$$

How to perform centrality dependent binary scaling ?

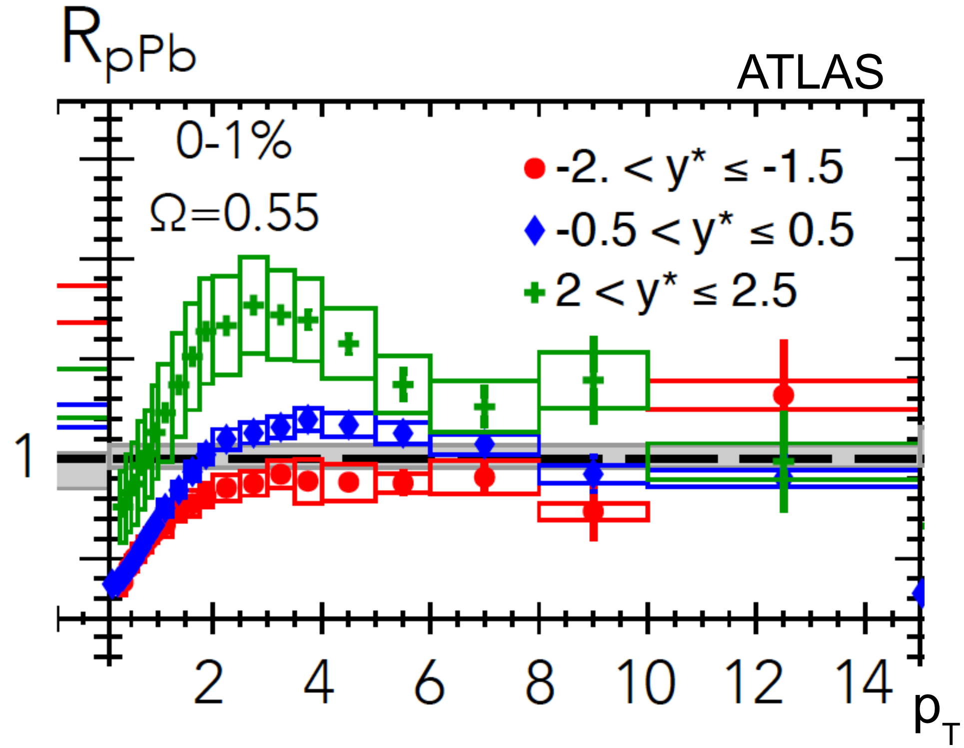
$$R_{\mathrm{pA}}^{\mathrm{cent}}(p_T)=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_T}{\langle T_{\mathrm{pA}}^{\mathrm{cent}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_T}=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_T}{\langle N_{\mathrm{coll}}^{\mathrm{cent}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_T}$$

- N_{coll} determination using forward multiplicity or energy.
- Challenges
  - How to determine N_{coll} (Glauber MC + which particle production model) ?
  - Range of N_{coll} small wrt fluctuations within centrality classes
    - Fluctuations means always possible bias
  - Particle production at LHC dominated by multiple semi-hard scatterings.
    - Used to measure centrality = autocorrelation = possible biases

N_{coll} Fluctuations
Two apparently diametrical strategies

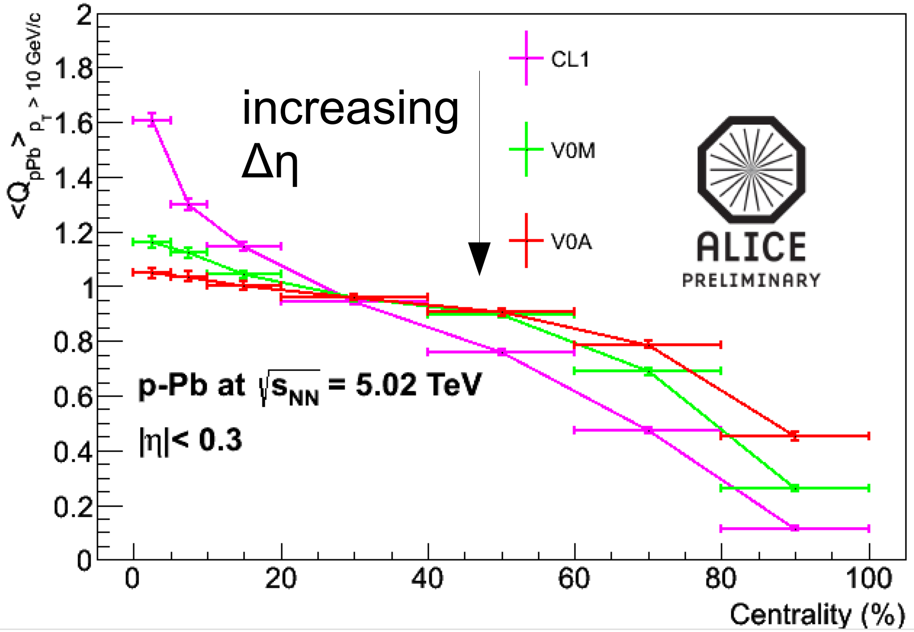
- ALICE: Multiplicity fluctuations are consequence of convolution of N_{coll} and number of parton scatterings (MPI) in each p-N collision
  - Poissonian fluctuations of number of PI event-to-event
  - Multiplicity slicing leads to bias on number of hard scatterings
  - Bias small at lower $\sqrt{s}$ and large rapidity gap between centrality estimator and measurement
- ATLAS: True N_{coll} distribution obtained from Glauber with fluctuating proton size (Glauber-Gribov)
  - Gaussian fluctuations of cross-section event to event
  - Effects for high centrality sensitive to unknown Glauber -Gribov parameter.
  - Small $\sqrt{s}$-dependence

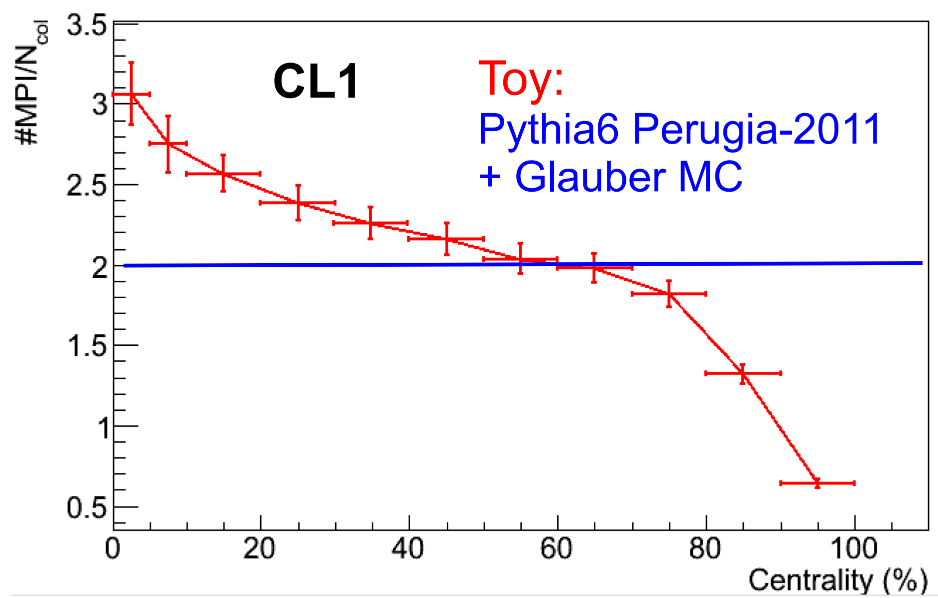
C-Estimator – p_T-Measurement rapidity gap



Centrality Estimator:
Energy in 3.2 < η < 4.9

ALICE interpretation:
Biased, not yet an R_{pPb} measurement





Fluctuations from σ to Ω

X.N. Wang and M. Gyulassy, nucl-th/9502021

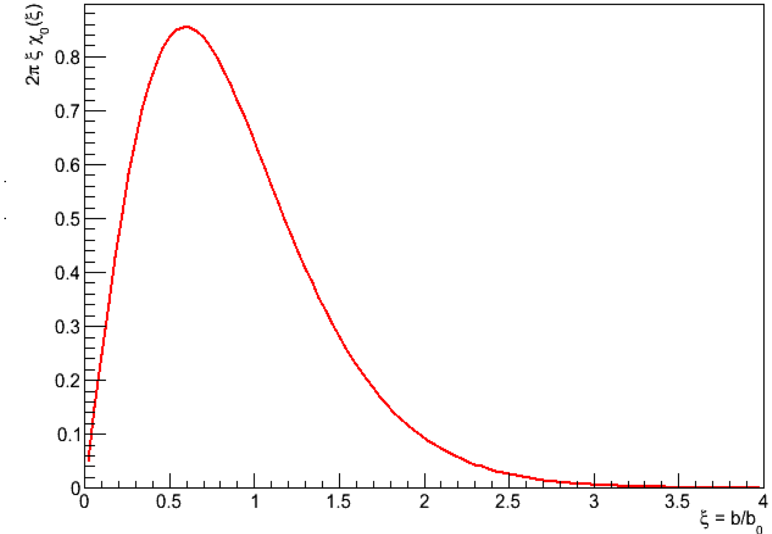
$$T_N(b) = 2\frac{\chi_0(b,s)}{\sigma_{soft}}$$

$$d\sigma_{inelastic} = \pi\, db^2[1-\exp(-2\chi(b,s))] = \pi\, db^2[1-\exp(-(\sigma_{soft}+\sigma_{hard})T_N(b,s))]$$

$$\langle n_{\mathrm{hard}}\rangle(b_{\mathrm{NN}}) = \sigma_{\mathrm{hard}}\, T_{\mathrm{N}}(b_{\mathrm{NN}})$$

Counts fluctuate !

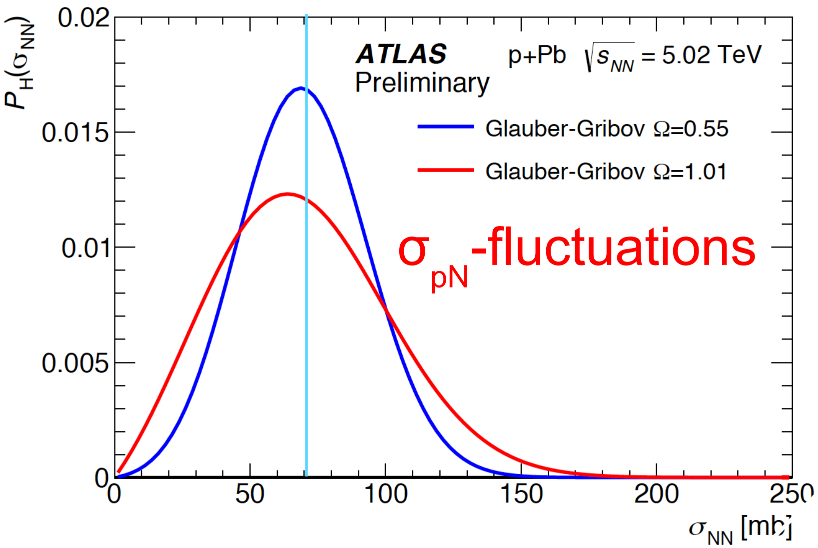
$$p_i(b_{\mathrm{NN}}) = \frac{\langle n_{\mathrm{hard}}\rangle^i}{i\,!}\exp(-\langle n_{\mathrm{hard}}\rangle)$$



(similar approach used in PYTHIA)

Geometrical fluctuations described by overlap function (eikonal) T_N.

Cross-section itself does not fluctuate (since = *flux* (db^2) *x probability*).



Only a question of terminology ?

At LHC $\sigma_{hard} >> \sigma_{tot}$

$\Omega \leftrightarrow \sigma_{hard}$??

Andreas Morsch, HP2013

No summary
Just a few thoughts ...

- Strong final state (medium-) effects seen for Ψ'/J/ψ, Υ(2S), Υ(3S) / Υ(1S)
  - Time in nucleus/medium expected to be very short, before meson has formed
  - What mechanism can do this ?

- Scaling with multiplicity seen,
  - also in pp !
- Unexpected large enhancement at high Q^2 and x for inclusive charged particles measured by CMS
- Need for better understanding of multiplicity dependent particle production in pp and p-Pb
- Study interplay between soft and hard processes
- Centrality determination in p-Pb is still an unresolved issue
  - Continue open discussions between experiments and with theorists