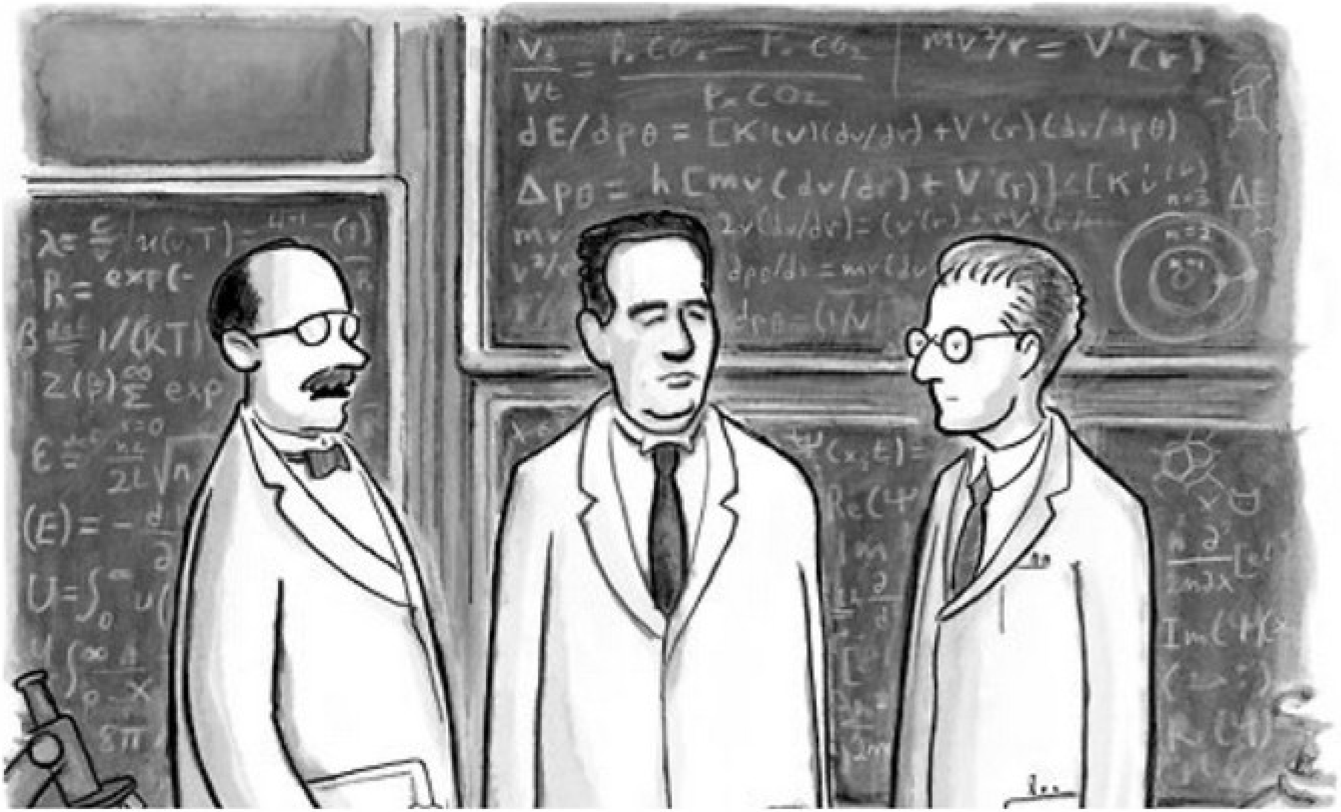


Is there collectivity in small systems? Copenhagen interpretation @
Workshop on Collectivity in Small Collision Systems

And what about parton energy loss?

C.Loizides (LBNL)
10 May 2017

2 Summary of typical HI observables

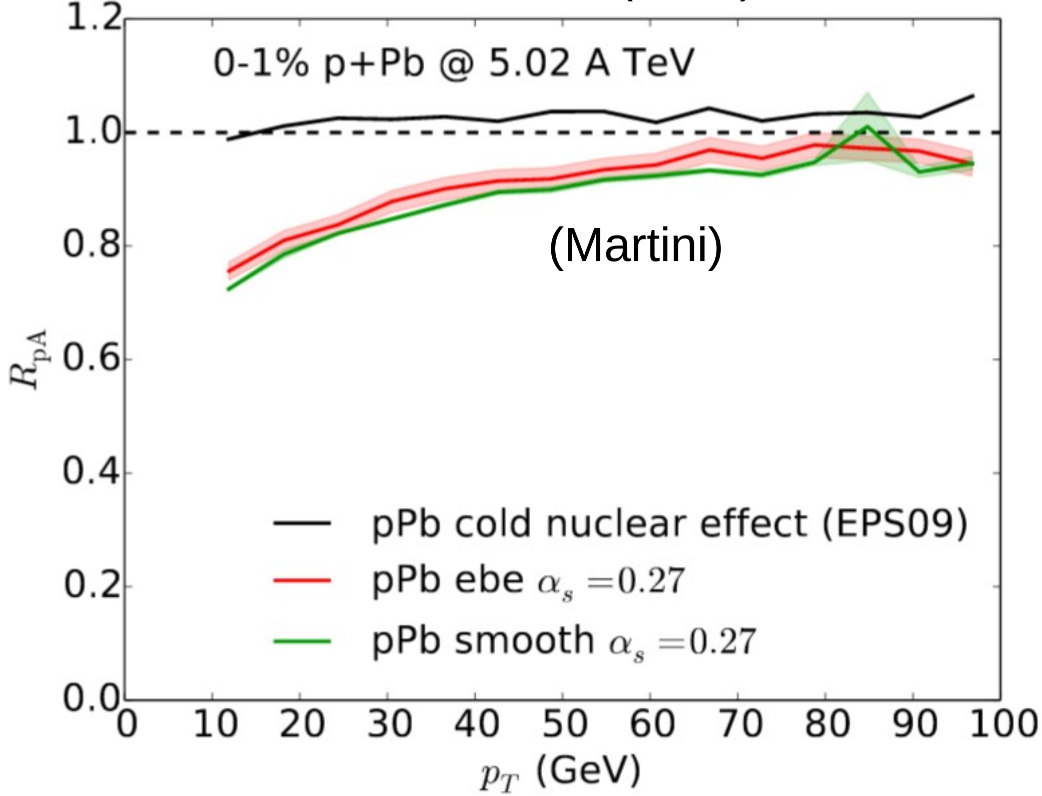
CL., arXiv:1602.09138

Observable or effect	PbPb	pPb (at high mult.)	pp (at high mult.)	Refs.
Low p_T spectra ("radial flow")	yes	yes	yes	[37–42]
Intermed. p_T ("recombination")	yes	yes	yes	[41–47]
Particle ratios Statistical model	GC level $\gamma_s^{GC} = 1$, 10–30%	GC level except Ω $\gamma_s^{GC} \approx 1$, 20–40%	GC level except Ω $\gamma_s^{C} < 1$, 20–40% [2]	[48–51] [52]
HBT radii ($R(k_T)$, $R(\sqrt[3]{N_{ch}})$)	$R_{out}/R_{side} \approx 1$ [3]	$R_{out}/R_{side} \lesssim 1$	$R_{out}/R_{side} \lesssim 1$	[53–59]
Azimuthal anisotropy (v_n) (from two part. correlations)	$v_1 - v_7$	$v_1 - v_5$	v_2, v_3	[25–27] [60–67]
Characteristic mass dependence	v_2, v_3 [4]	v_2, v_3	v_2	[67–73]
Directed flow (from spectators)	yes	no	no	[74]
Higher order cumulants (mainly $v_2\{n\}, n \geq 4$)	"$4 \approx 6 \approx 8 \approx$ LYZ" +higher harmonics	"$4 \approx 6 \approx 8 \approx$ LYZ" +higher harmonics	"$4 \approx 6$" [5]	[28, 29, 67] [75–83]
Weak η dependence	yes	yes	not measured	[83–90]
Factorization breaking	yes ($n = 2, 3$)	yes ($n = 2, 3$)	not measured	[91]
Event-by-event v_n distributions	$n = 2 - 4$	not measured	not measured	[92]
Event plane and v_n correlations	yes	not measured	not measured	[93–95]
Direct photons at low p_T	yes	not measured	not measured [6]	[96]
Jet quenching	yes	not observed [7]	not measured [8]	[97–105]
Heavy flavor anisotropy	yes	hint [9]	not measured	[106–109]
Quarkonia	$J/\psi \uparrow$, $\Upsilon \downarrow$	suppressed	not measured [8]	[110–116]

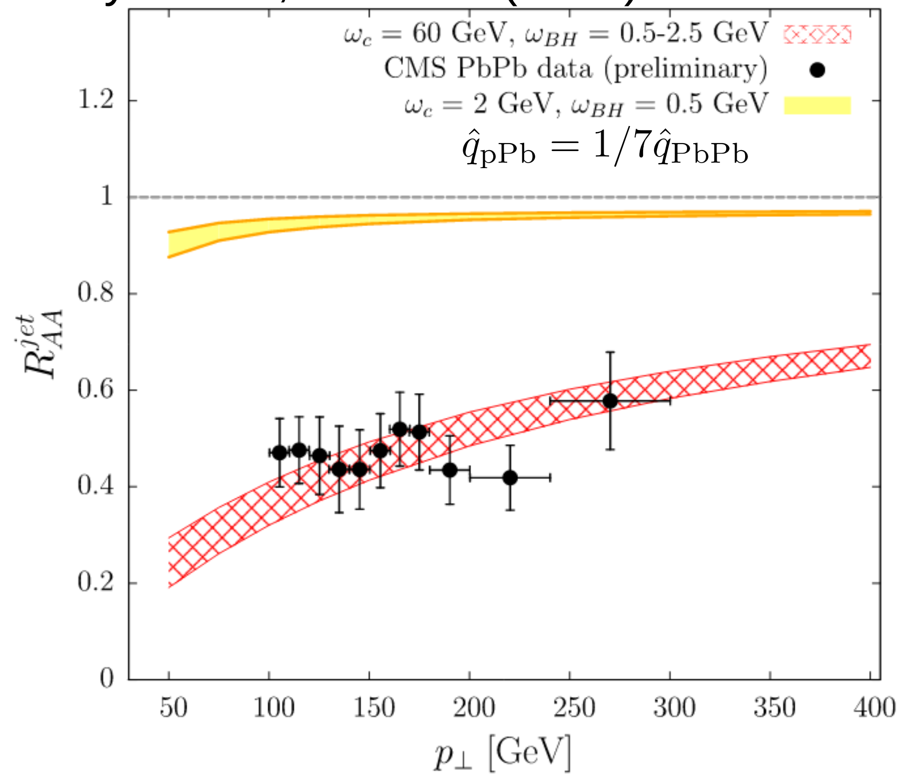
Observations qualitatively similar across systems for similar multiplicity, and can be reconciled by postulating a sQGP, even in high mult pp collisions. But no direct evidence for parton energy loss, which - even if tiny - should be there!

3 Predictions from models

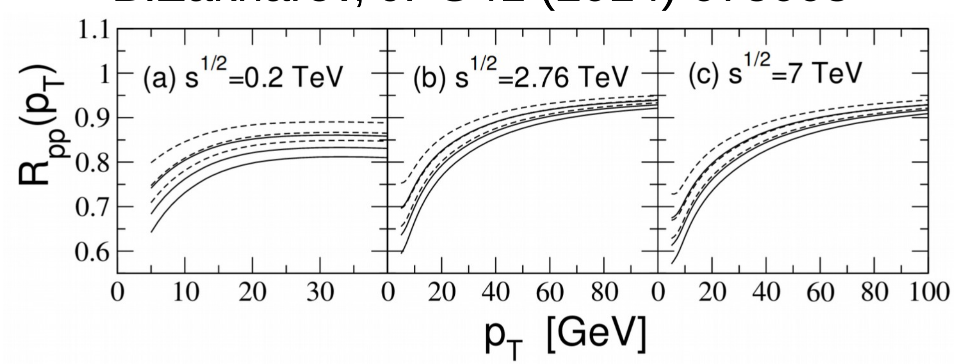
C.Shen et al., NPA956 (2016) 741



K. Tywoniuk, NPA 926 (2014) 85



B.Zakharov, JPG41 (2014) 075008



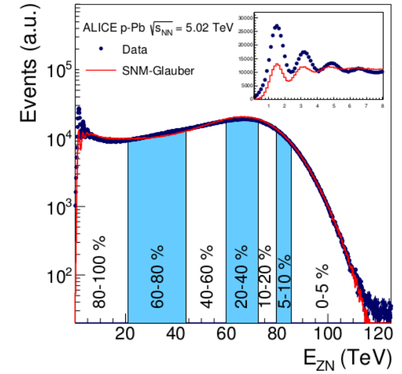
Calculations expect sizable (10-20%) suppression for "central" pPb and pp

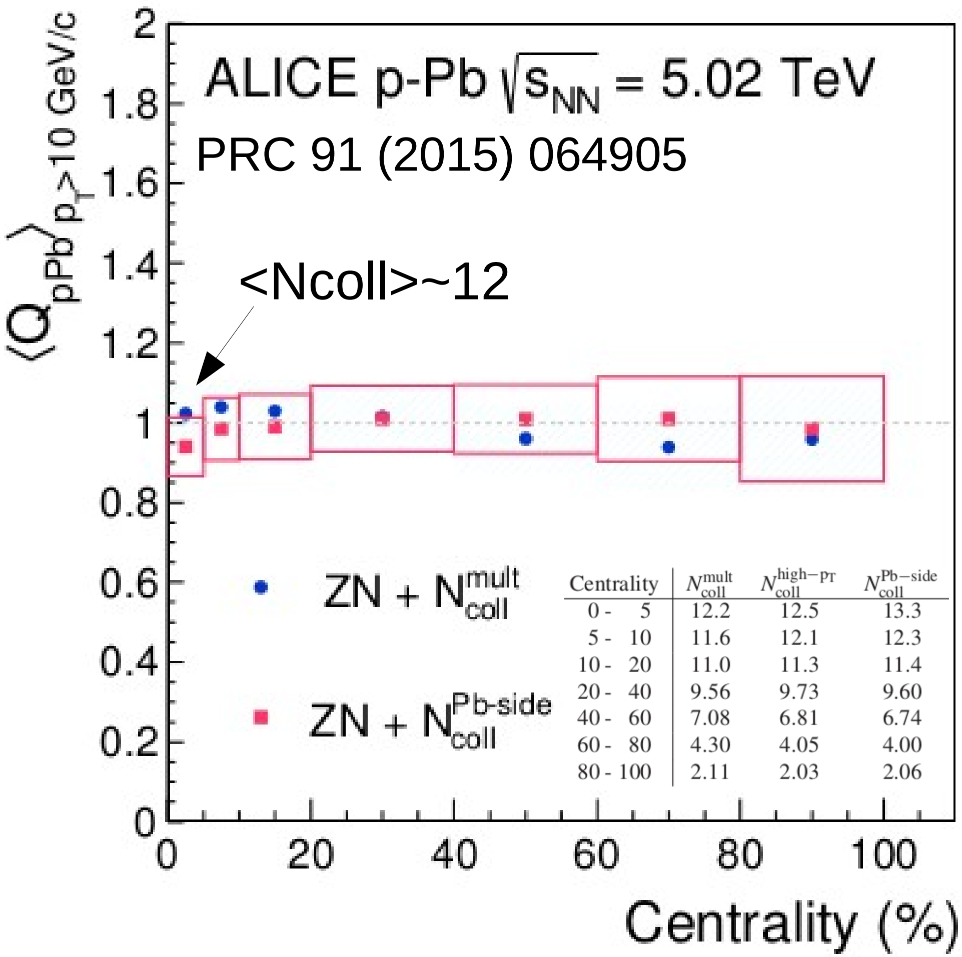
4 No modification (at low p_T, ie. x<0.1)

$$Q^{ZN}_{\mathrm{pPb}} = \frac{1}{N_{\mathrm{coll}}} \frac{\mathrm{d}N_{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}N/\mathrm{d}p_{\mathrm{T}}}$$

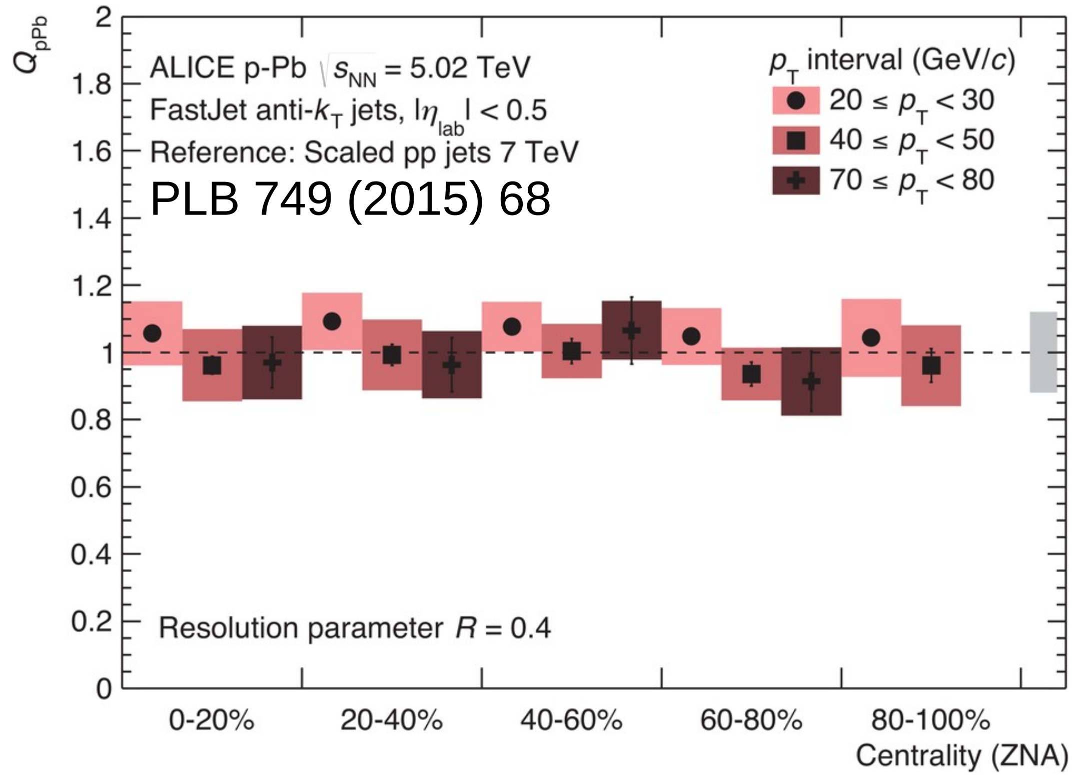
(with selection on neutron ZDC on the Pb-side and Ncoll from multiplicity assuming the wounded nucleon model)

ZN on Pb-side



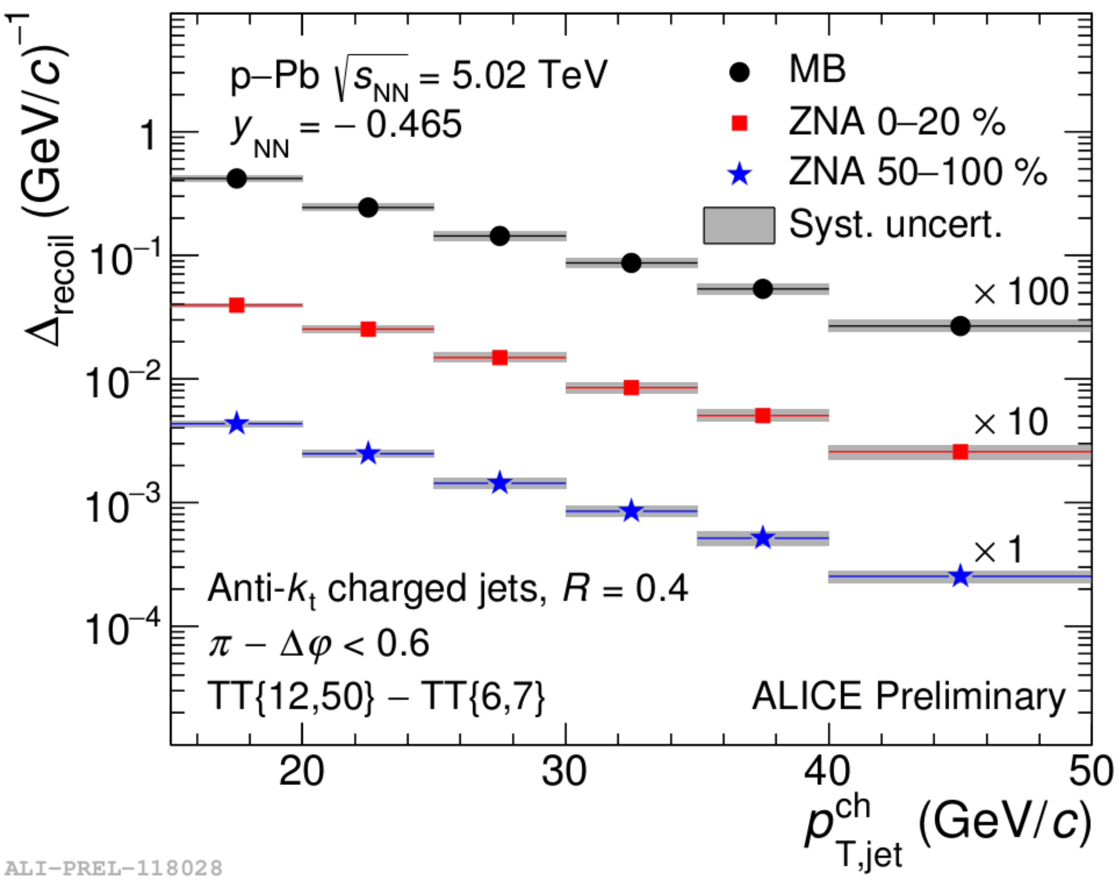


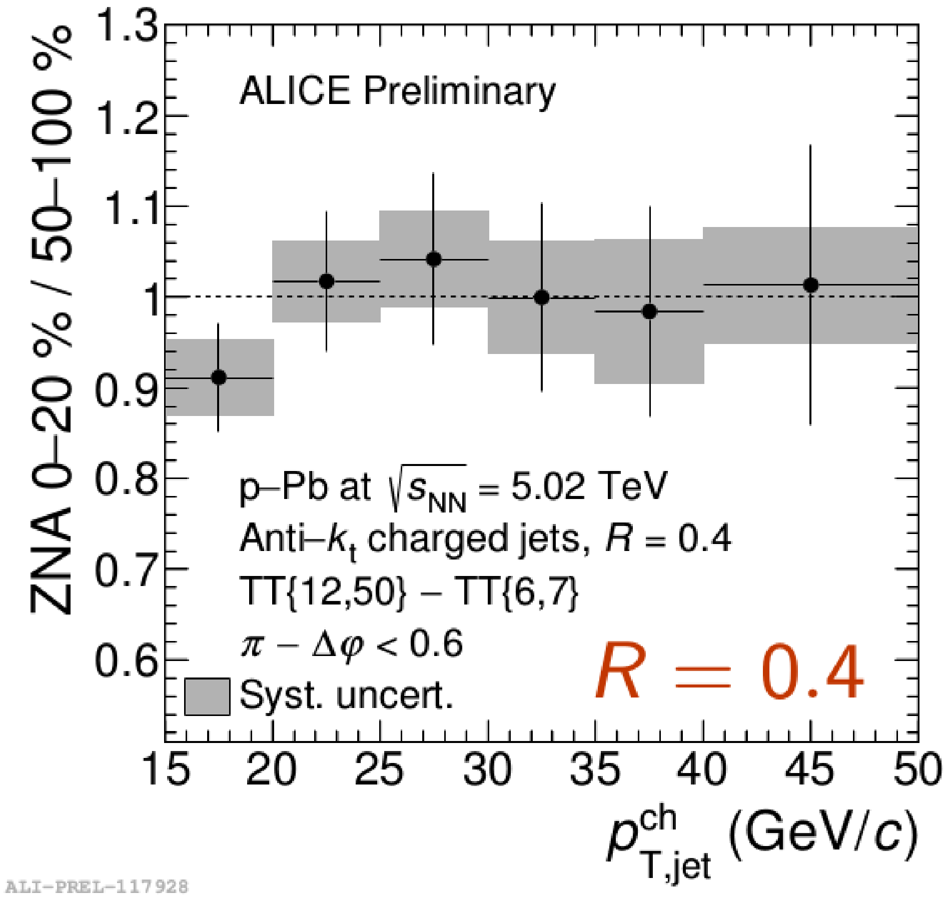
Centrality	N^{mult}_{coll}	$N^{high-p_T}_{coll}$	$N^{Pb-side}_{coll}$
0 - 5	12.2	12.5	13.3
5 - 10	11.6	12.1	12.3
10 - 20	11.0	11.3	11.4
20 - 40	9.56	9.73	9.60
40 - 60	7.08	6.81	6.74
60 - 80	4.30	4.05	4.00
80 - 100	2.11	2.03	2.06



No suppression observed

5 Hadron-jet coincidence measurement





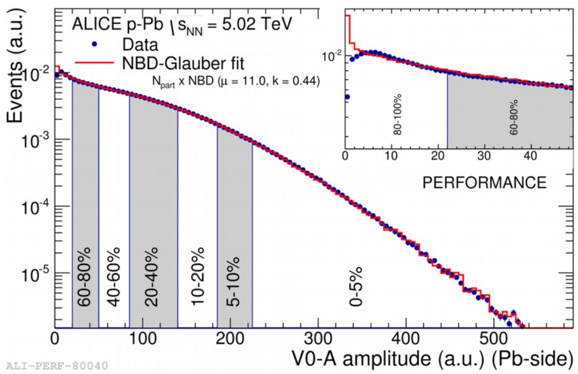
$$\Delta_{recoil} = \frac{1}{N_{trig}} \frac{d^2 N_{jet}}{d p_{T,jet}^{ch} d\eta}\bigg|_{p_{T,trig} \in TT\{12,50\}} - c_{Ref} \cdot \frac{1}{N_{trig}} \frac{d^2 N_{jet}}{d p_{T,jet}^{ch} d\eta}\bigg|_{p_{T,trig} \in TT\{6,7\}}$$

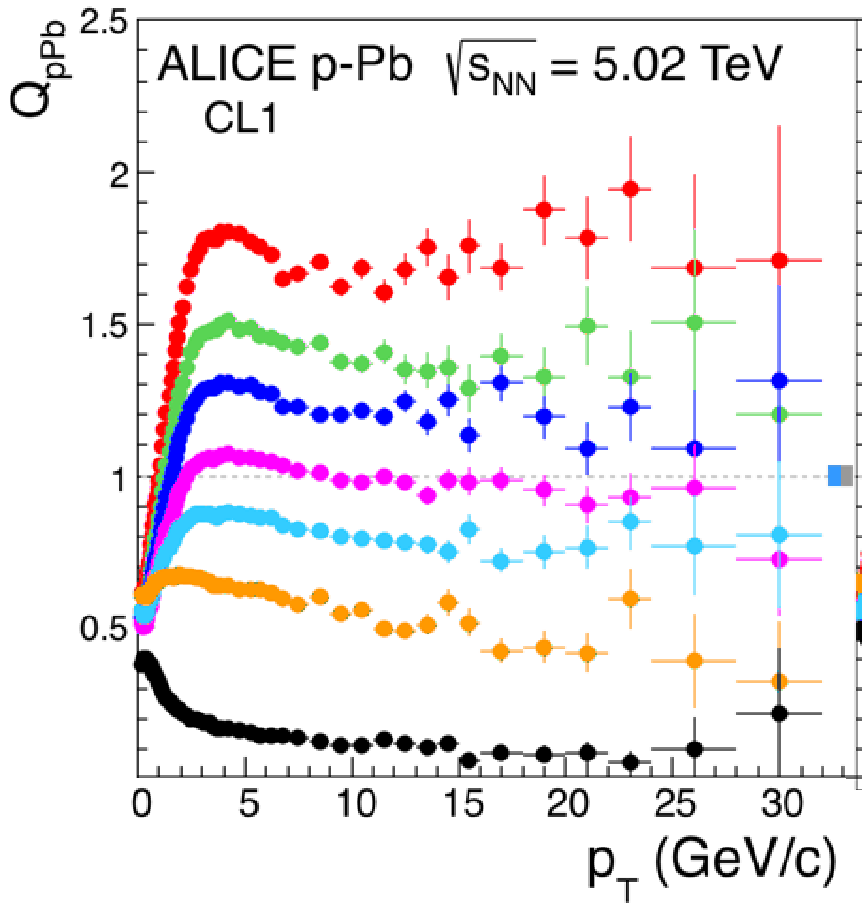
No suppression (precision will improve with large 2015 pPb data!)

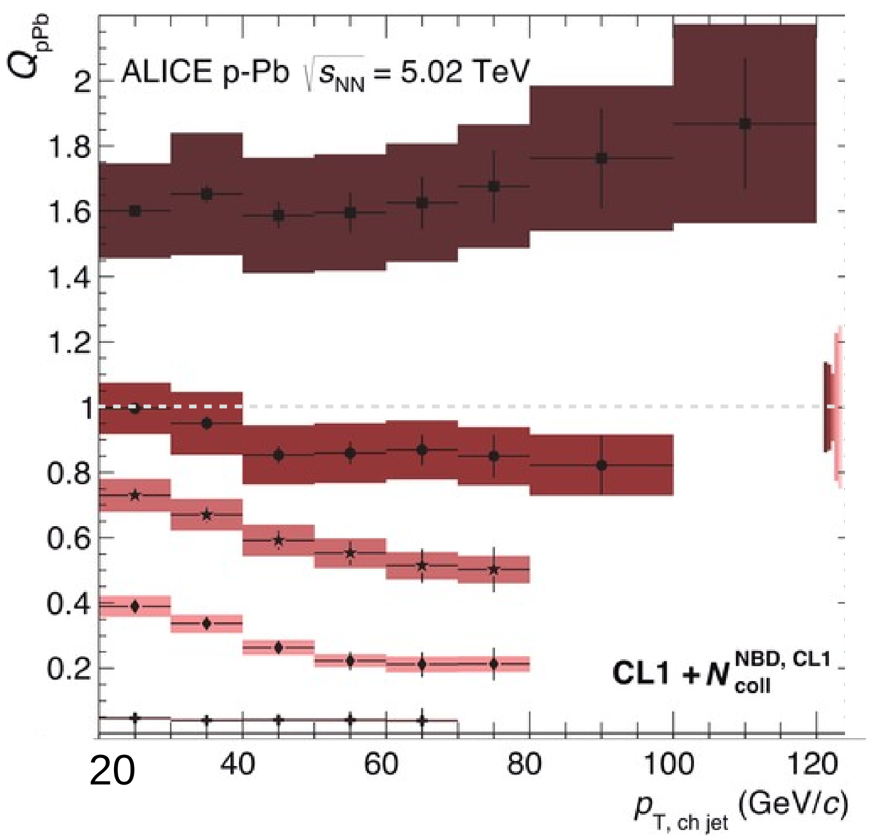
Multiplicity based selection

$$Q_{\mathrm{pPb}} = \frac{1}{N_{\mathrm{coll}}^{\mathrm{fit}}} \frac{\mathrm{d}N_{\mathrm{pPb}}/\mathrm{d}p_{\mathrm{T}}}{\mathrm{d}N/\mathrm{d}p_{\mathrm{T}}}$$

(with selection on multiplicity and Ncoll from Glauber fit)





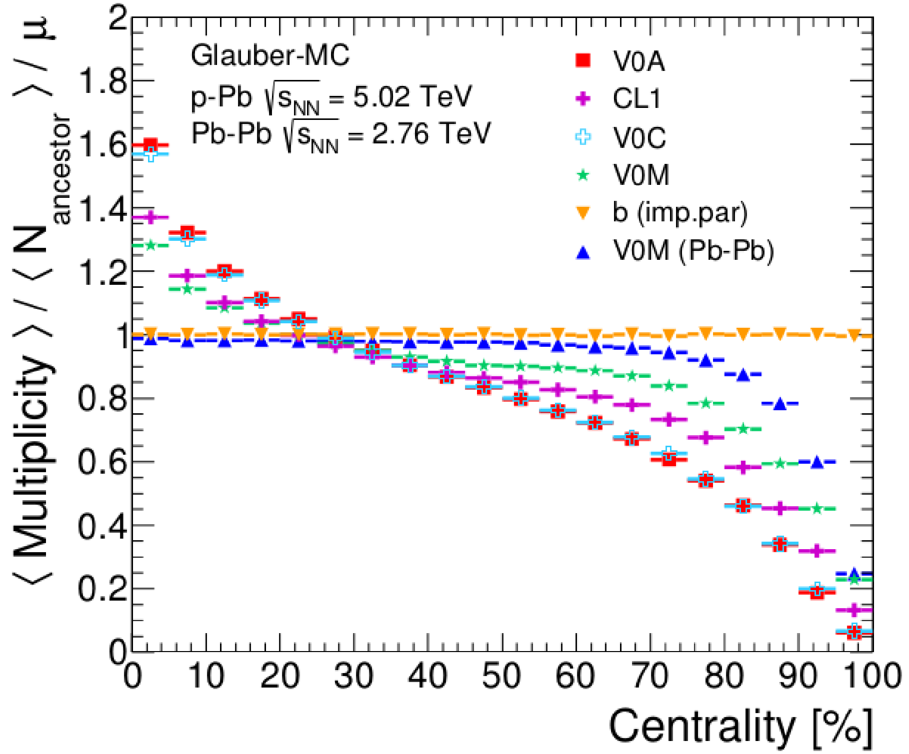


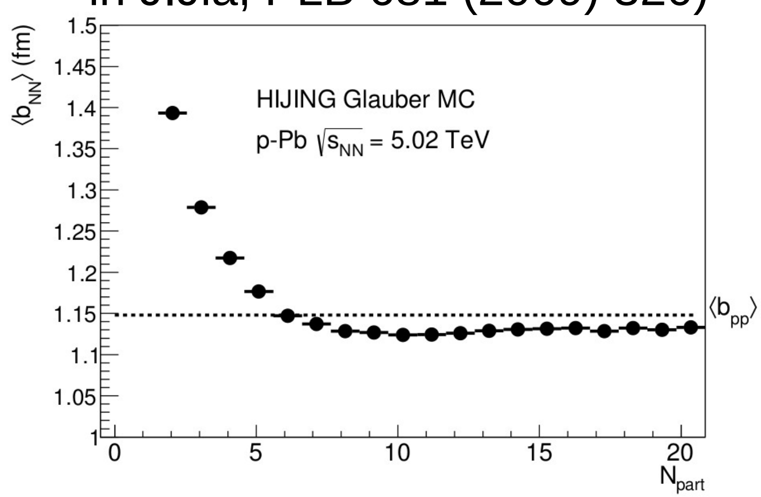
Huge effect

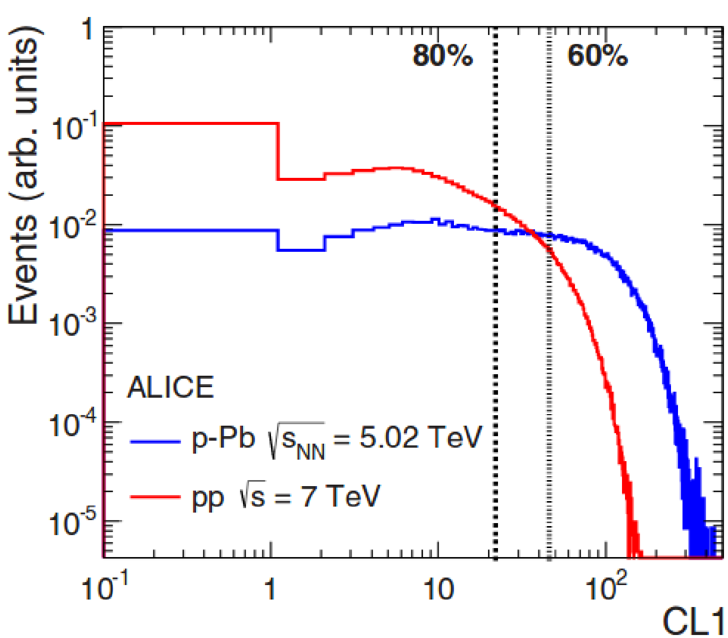
(but QpPb not necessarily one in absence of nuclear modification!)

Multiplicity based selection (2)

- Several biases are relevant
  - Multiplicity bias
    - Bias on the sources contributing to particle production
  - Jet veto bias
    - Auto-correlation between high p_T particle and soft multiplicity
  - Geometrical bias
    - Average NN impact parameter increases for peripheral collisions (explicitly discussed in J.Jia, PLB 681 (2009) 320)

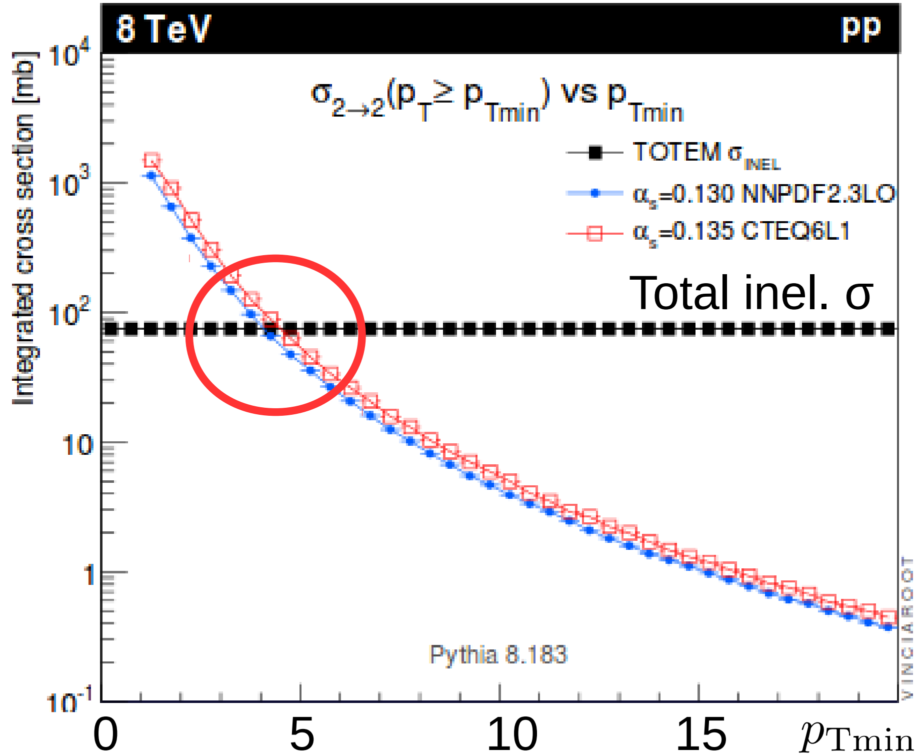






Multiple parton interactions (MPI)

Skands, arXiv:1207.2389



- Naive factorization

$$\langle n_{2\to2}\rangle = \frac{\sigma_{2\to2}}{\sigma_{tot}}$$

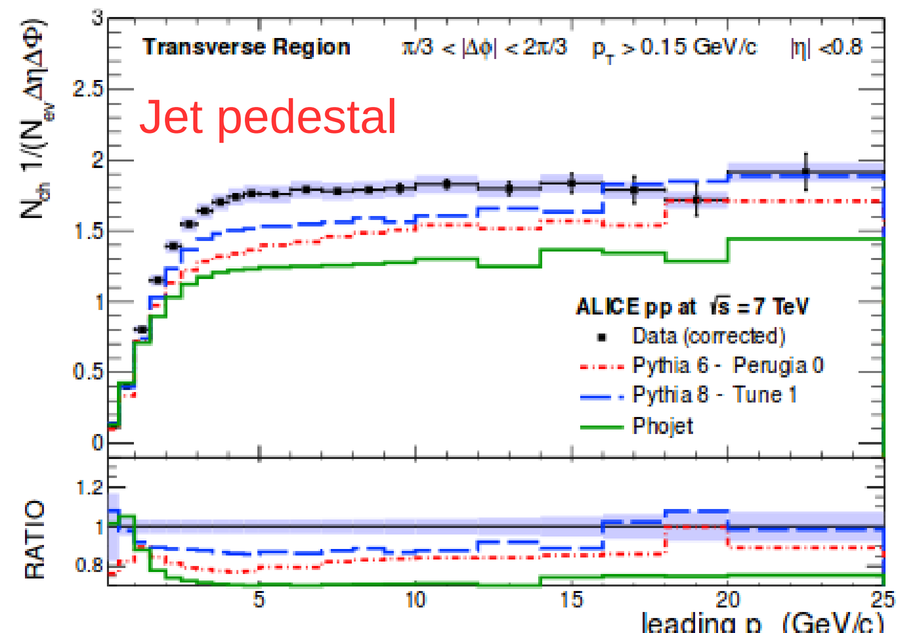
>1 at pert. scale

$$P_n = \frac{\langle n_{2\to2}\rangle^n}{n!} exp\left(-\langle n_{2\to2}\rangle\right)$$

- Realistic models (eg. PYTHIA)
  - Color screening to regularize hard cross section at low p_T
  - Cut-off at high n because of energy conservation
  - Coherence between scatters
  - Impact parameter dependence

$$n_{\mathrm{hard}}(b) = \sigma_{\mathrm{hard}} T_{\mathrm{p}}(b)$$

    - Leads to a correlation between hard and soft particles as in AA



Guidance from HIJING

PRD44 (1991) 3501

Inelasticic NN collision at b_{NN} given as

$$\sigma_{\rm inel} \propto 1 - e^{(\sigma_{\rm soft}+\sigma_{\rm hard})T_{\rm N}(b_{\rm NN})}$$

with nuclear overlap (Eikonal function)

$$T_{\rm N} \propto (\xi\mu)^3 K_3(\xi\mu) \text{ with } \xi = b_{\rm NN}/b_0$$

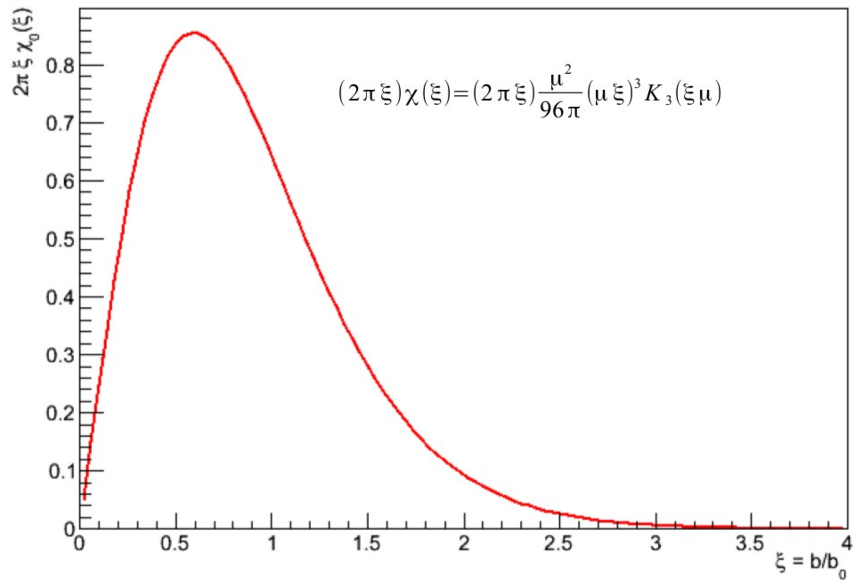
Number of hard (mpi) collisions given by

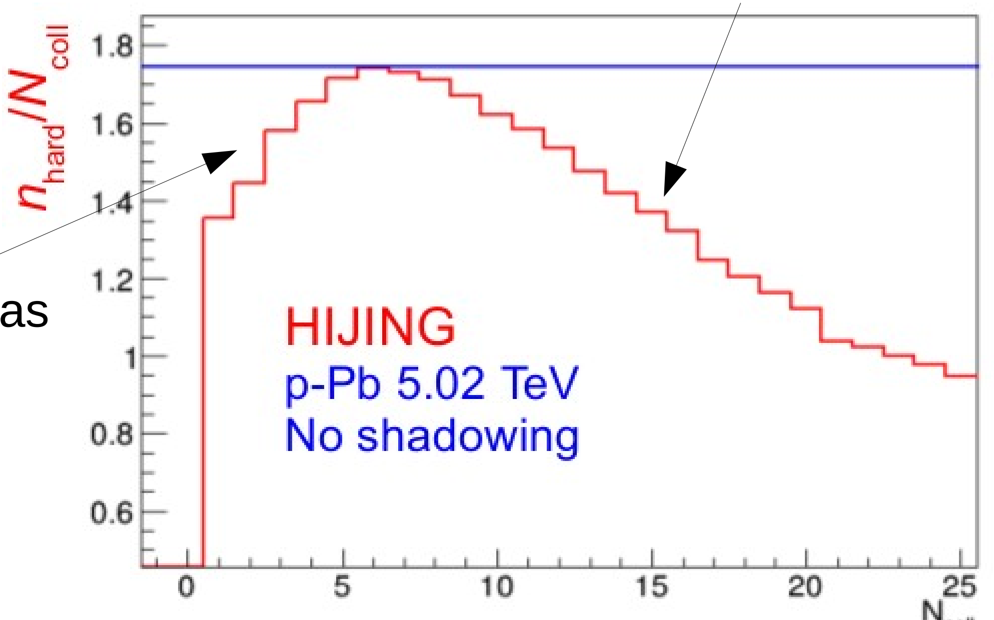
$$P(n_{\rm hard}) = \frac{\langle n_{\rm hard}\rangle^{n_{\rm hard}}}{n_{\rm hard}!} e^{-\langle n_{\rm hard}\rangle}$$

with

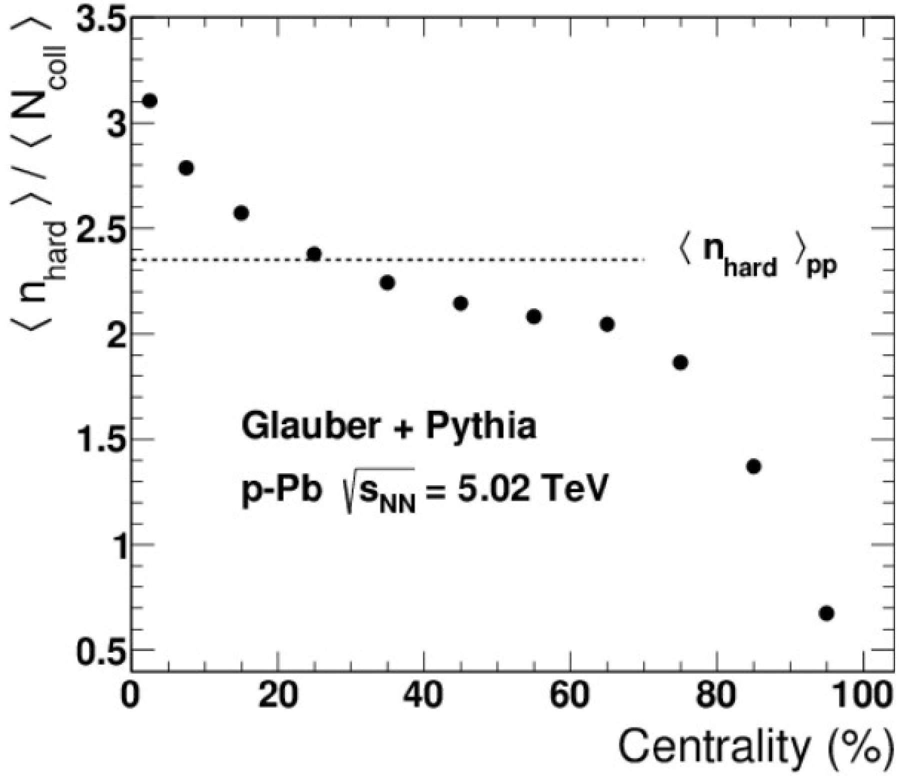
$$\langle n_{\rm hard}\rangle = \sigma_{\rm hard} T_{\rm N}$$

Eikonal function

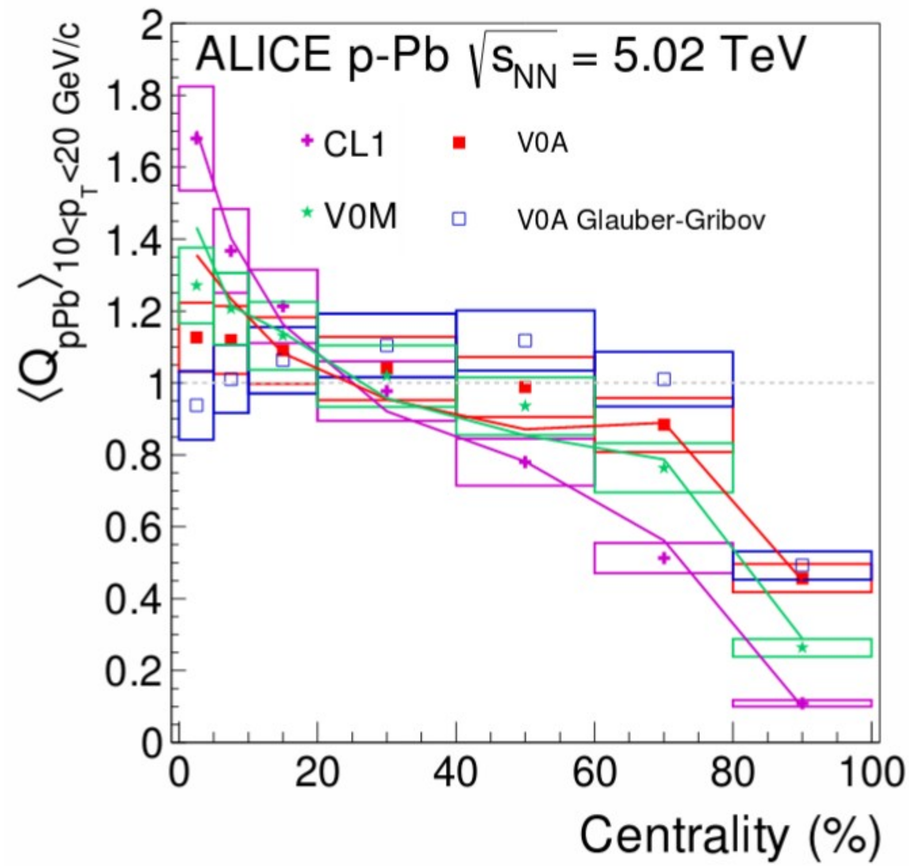




Demonstration using Glauber+Pythia



ALICE, PRC 91 (2015) 064905



G-PYTHIA:

1. For a given Glauber event, simulate Ncoll many PYTHIA pp events
2. Order events according to resulting total multiplicity (in given phase space)

Suggests, at high p_T

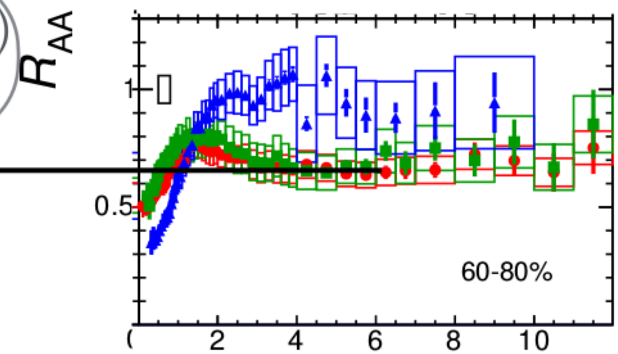
$$\langle Q_{\mathrm{pPb}} \rangle \propto \frac{N_{\mathrm{hard}}}{\mathrm{N_{coll}} \, \langle \mathrm{N^{pp}_{hard}} \rangle}$$

What about (peripheral) AA?

Dennis Perepelitsa (QM 2017)

M. Spousta (ATLAS) Tues. 12:10pm

N. Jacazio (ALICE) Wed. 4:50pm

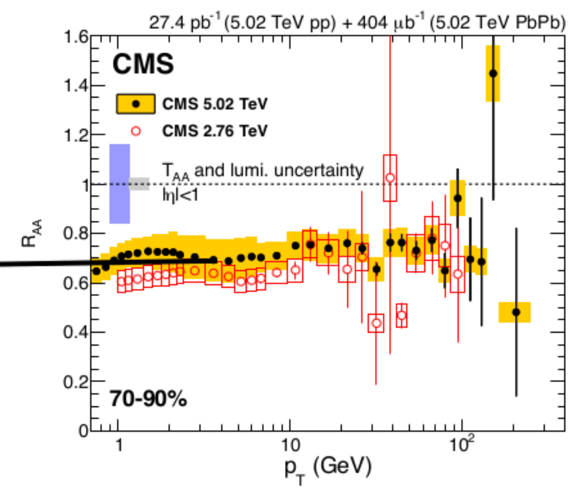


60-80% Pb+Pb, R_{AA} = 0.65

$<N_{part}>$ = 23 (ATLAS similar)

<1% *p*+Pb (0-5% in Glauber-Gribov!)

Y.-J. Lee (CMS) Monday 12:10pm

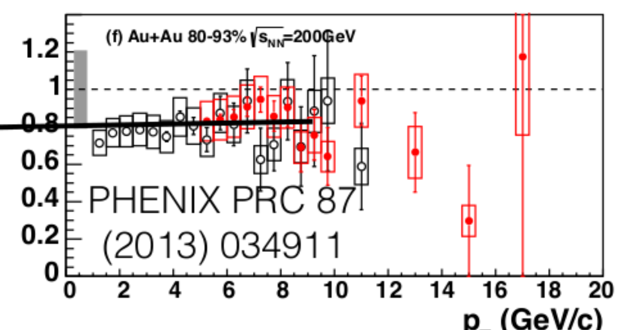


70-90% Pb+Pb, R_{AA} = 0.7

$<N_{part}>$ = 11

~20-30% *p*+Pb

S. Zharko (PHENIX) Wed. 10:40am



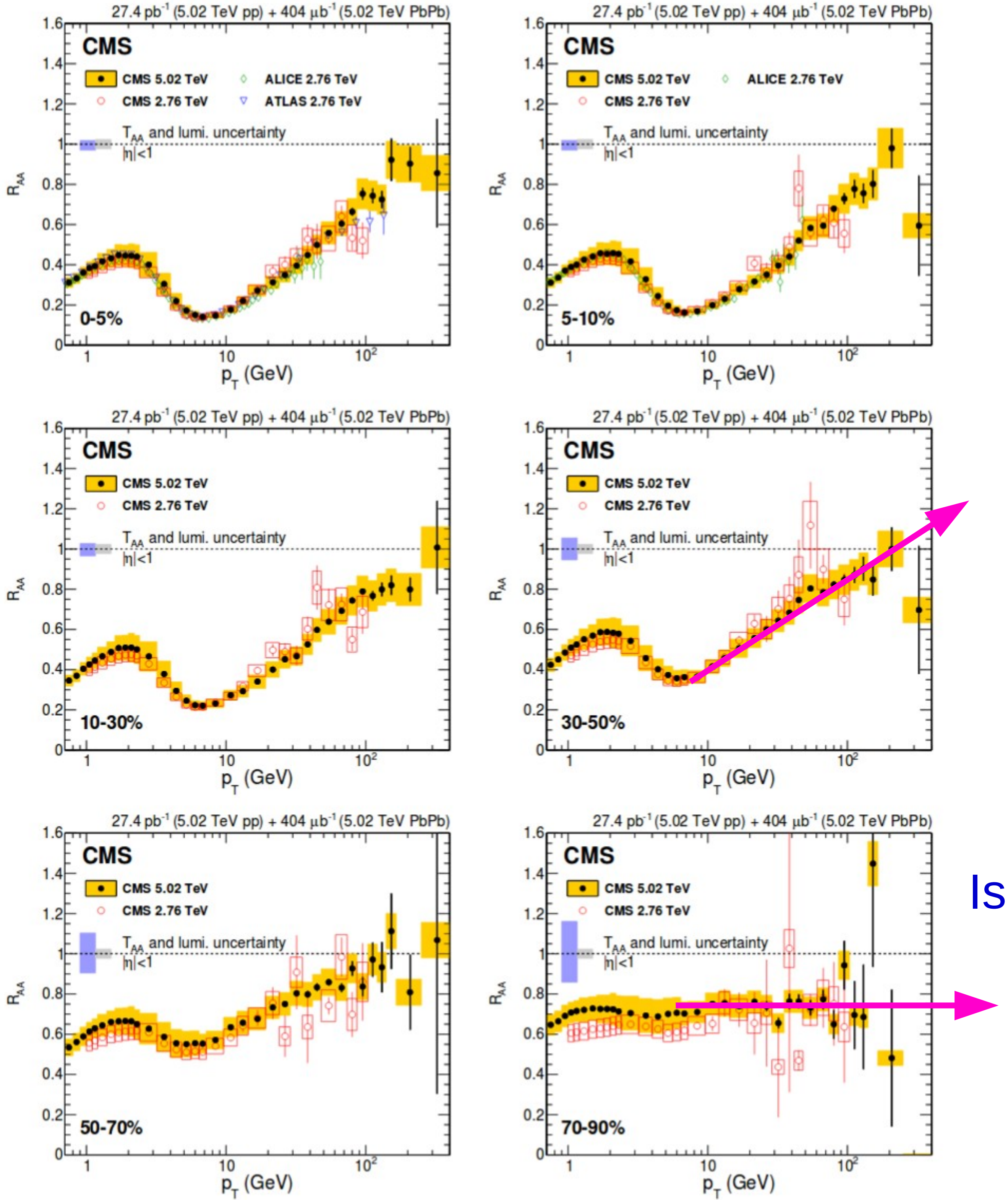
80-93% Au+Au, R_{AA} = 0.8

$<N_{part}>$ = 5

~50-70% *p*+Pb

decreasing N_{part}

JHEP 04 (2017) 039



Rising and approaching R~1!

Is it a multiplicity bias?

Seemingly constant at around R~0.8

13 Model comparison

Hijing:

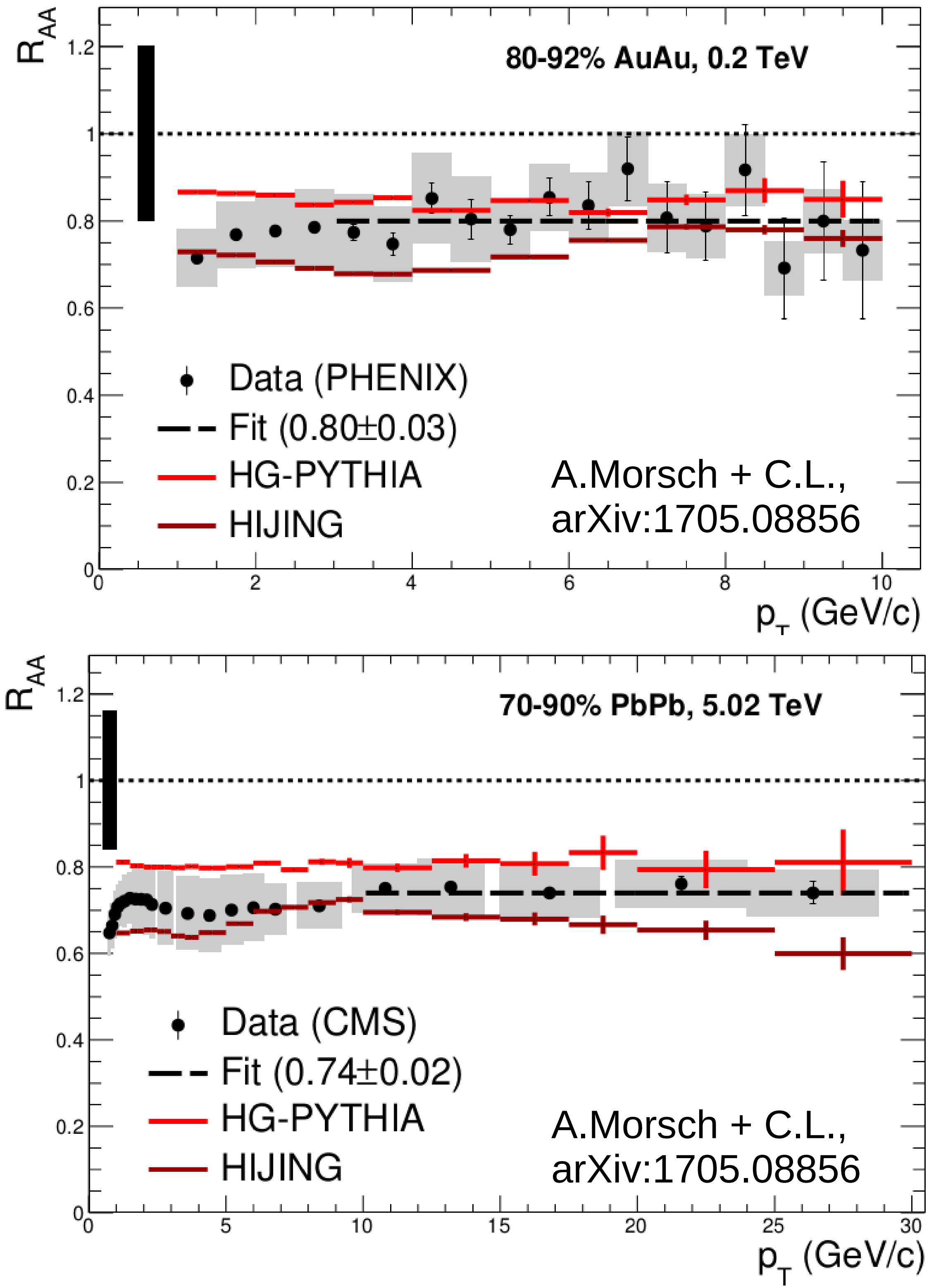
- No quenching, no shadowing, but ad-hoc momentum conservation and multiple scattering
- Does not give $R_{AA} \rightarrow 1$ at high p_T for central collisions

HG-Pythia:

- Use as HIJING nhard distribution as input but just superimpose PYTHIA (Perugia 2011) events
- Does not reproduce multiplicity

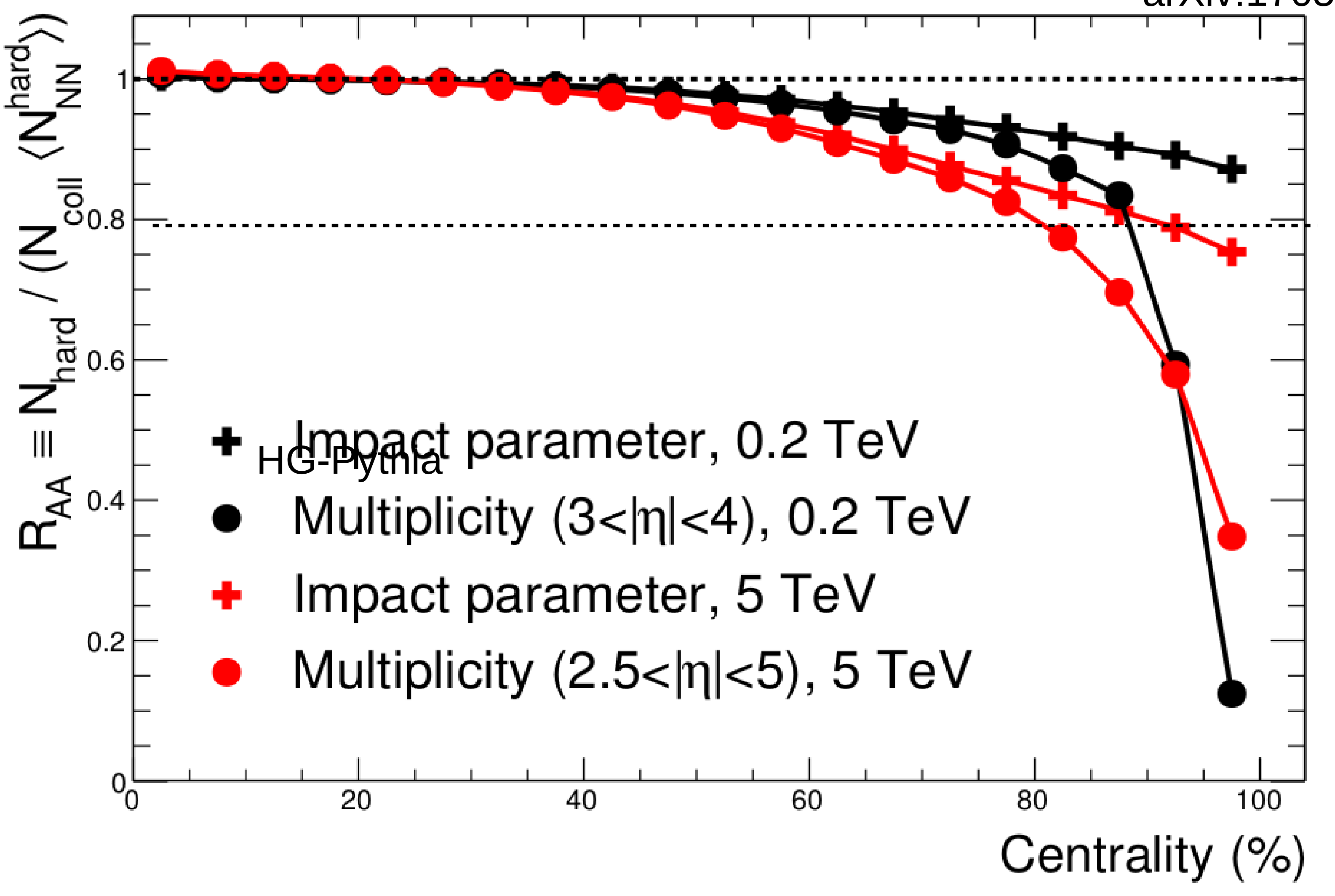
Results obtained using event ordering (slicing) for forward multiplicity (2.5<|η|<5)

Multiplicity bias can cause the apparent suppression!



Multiplicity and geometry bias effect

A.Morsch + C.L.,
arXiv:1705.08856

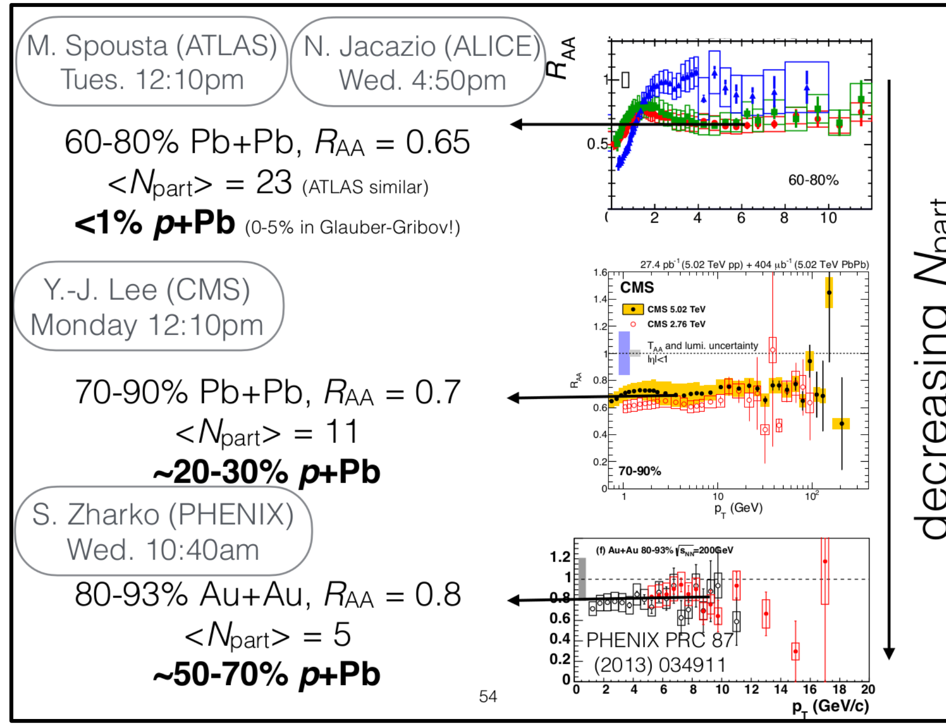


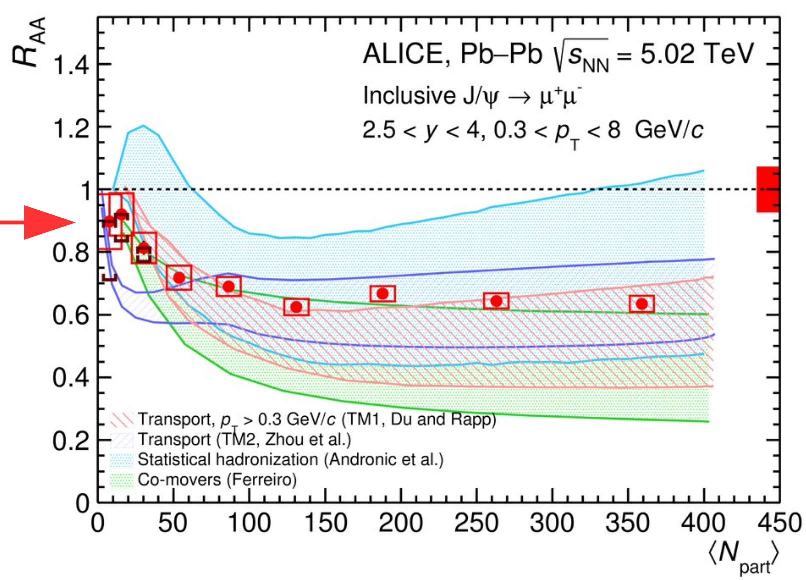
Peripheral collisions strongly affected by multiplicity bias

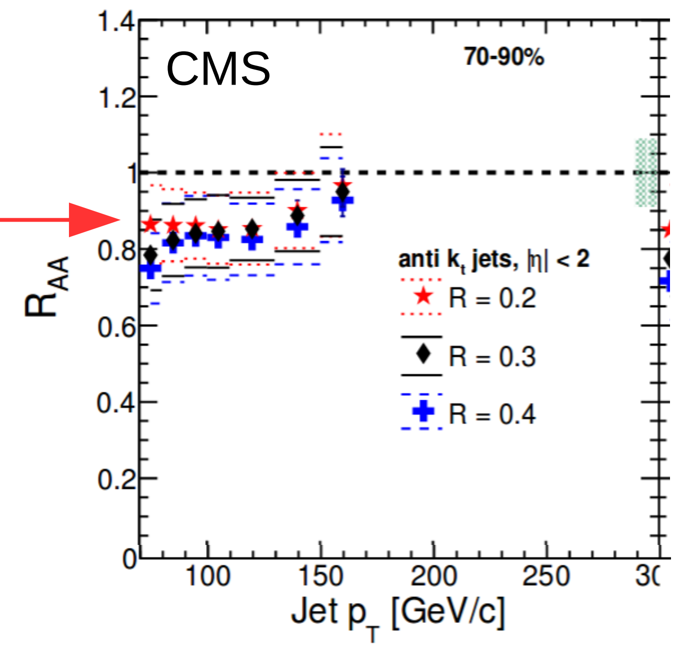
Implications

Multiplicity/geometry bias

- Toy model study suggests that apparent suppression in very (80++%) peripheral AA originates from bias
  - Relevant for all hard probes
  - Relevant at all energies (BES)
  - Beware use of R_{CP}

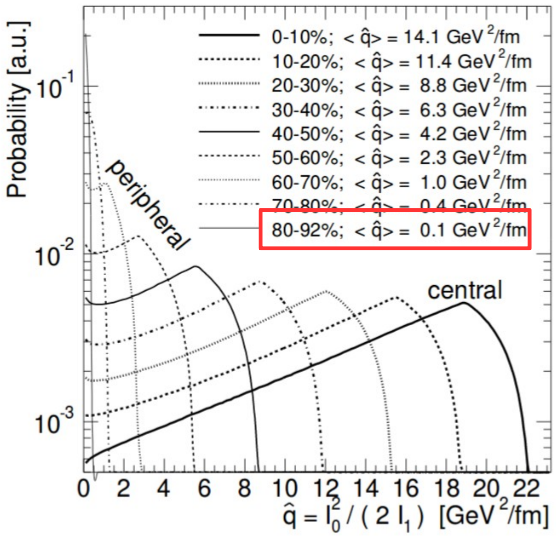


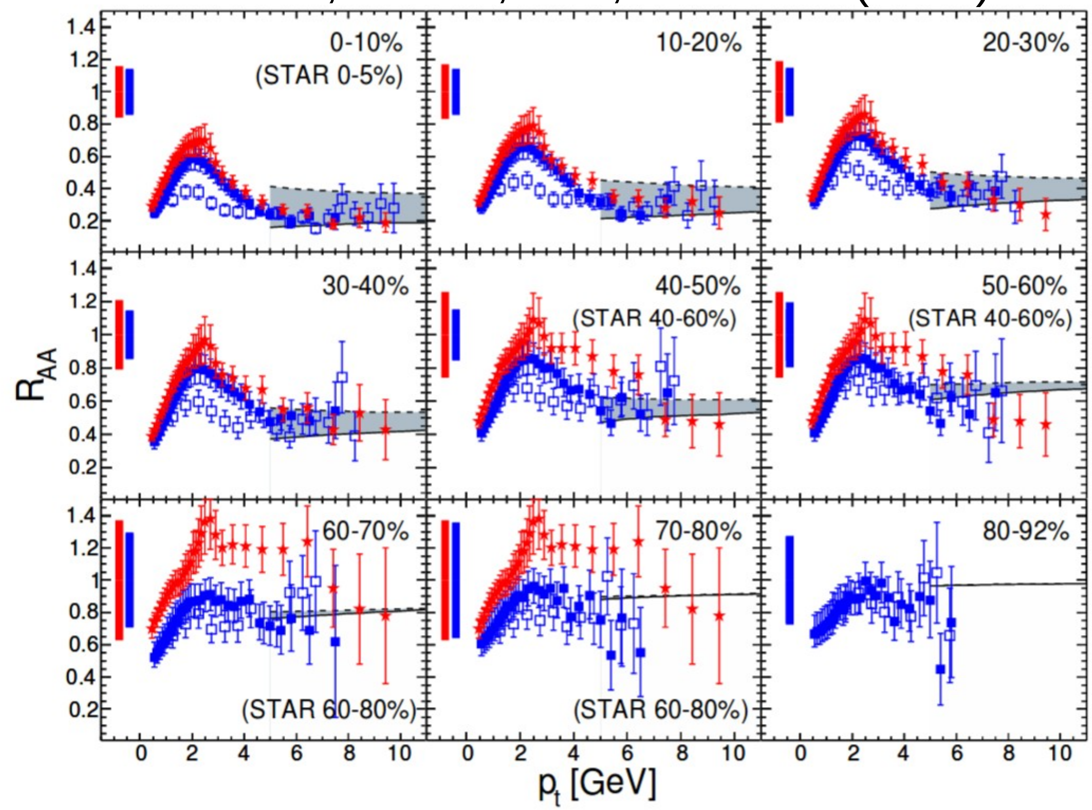


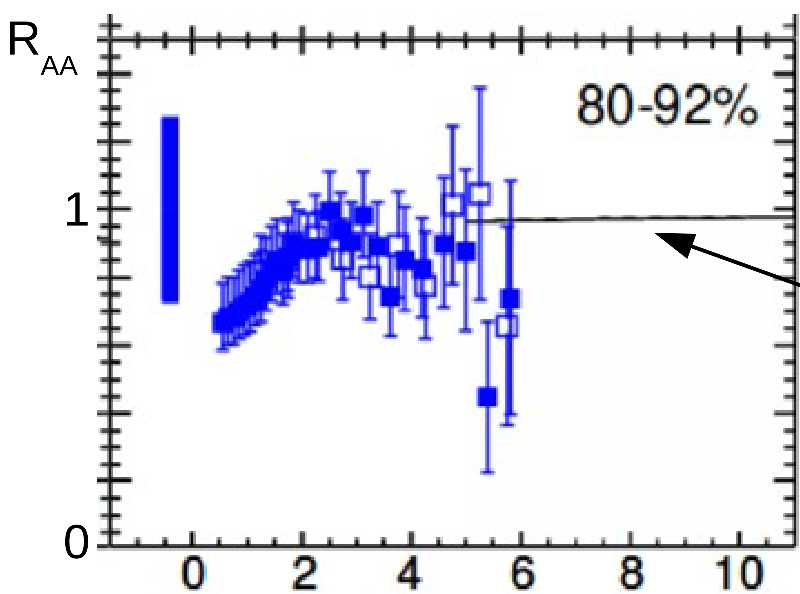


Parton quenching calculation (~2004)

A.Dainese, G.Paic, C.L., EPJC 38 (2005) 461





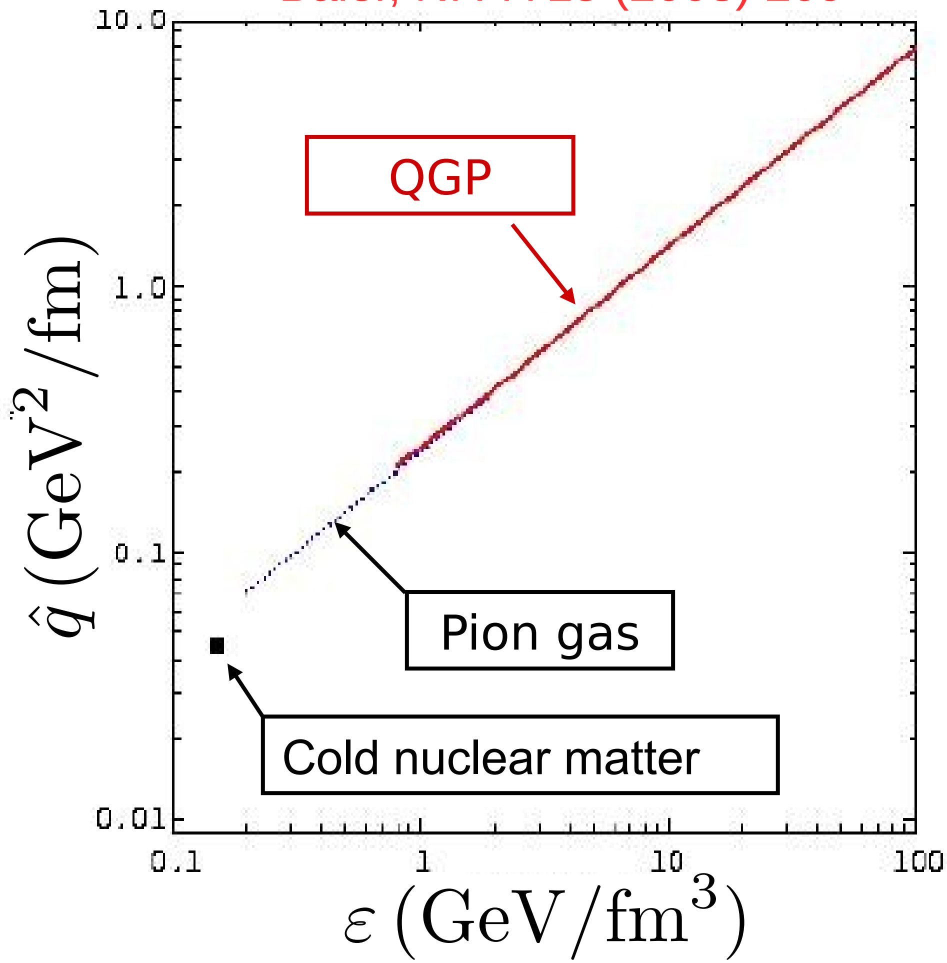


Indeed only very small suppression (3%) from (old) PQM calculation

17 Implications

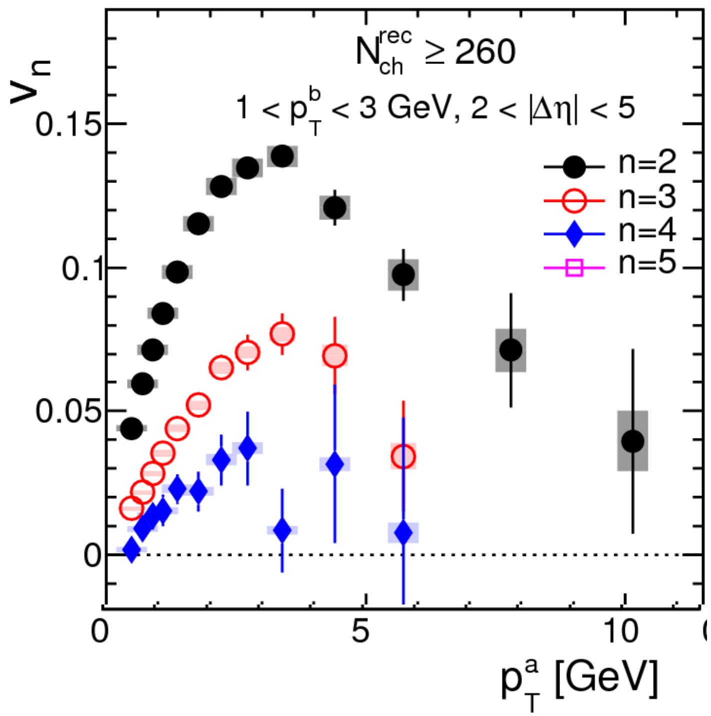
- Toy model study suggests that apparent suppression in very (80++%) peripheral AA originates from bias
  - Relevant for all hard probes
  - Relevant at all energies (BES)
  - And RCP not pp!
- Expect parton energy loss to be “continuous”
  - Natural explanation that it turns off both at multiplicities of peripheral AA (and pPb)
    - ie. be similar to that of pion gas or cold nuclear matter

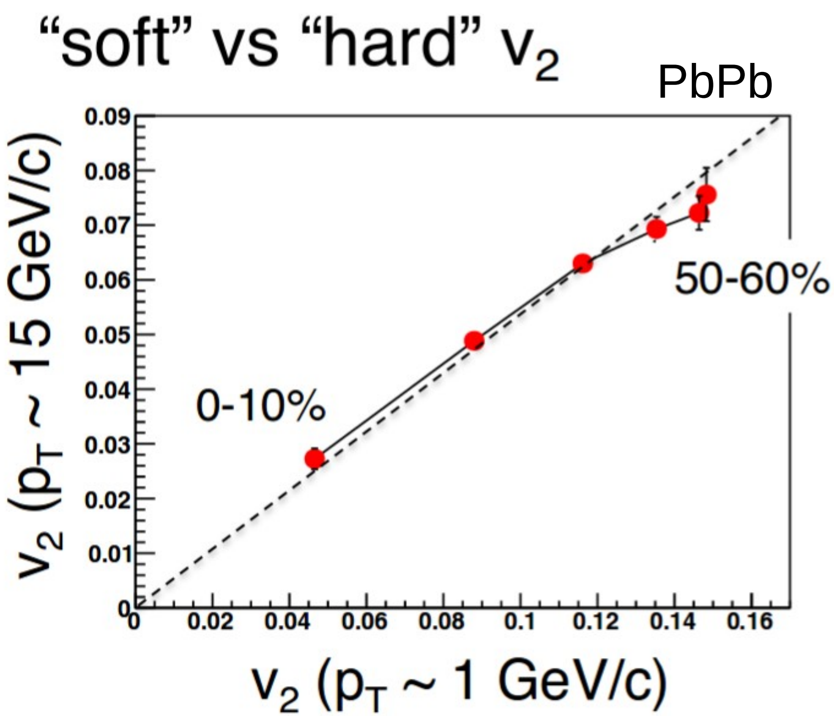
Baier, NPA 715 (2003) 209



18 What next ...

- Measure v_N in pPb (and very peripheral PbPb) to higher p_T
  - Would be good to get predictions at ~10-20 GeV from parton energy loss
- Semi-inclusive measurements
  - T_{AB} cancels
- Candle (cross section) measurement in peripheral AA
  - Difficult (needs “white” probe)
  - Hybrid centrality method?
    - Geometry bias can probably not be avoided



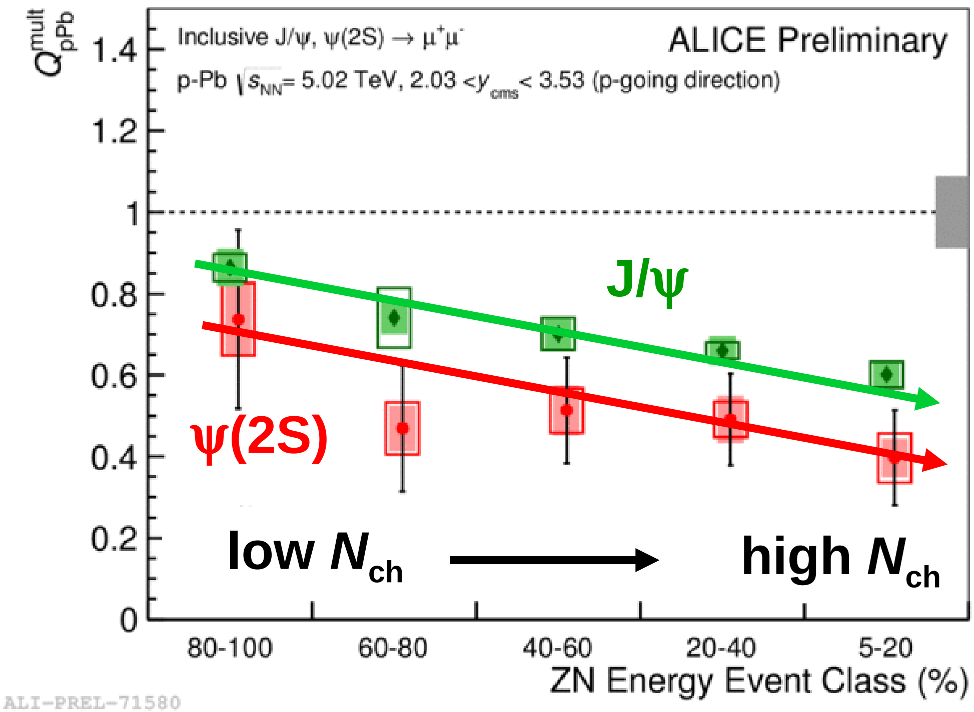


19 Extra

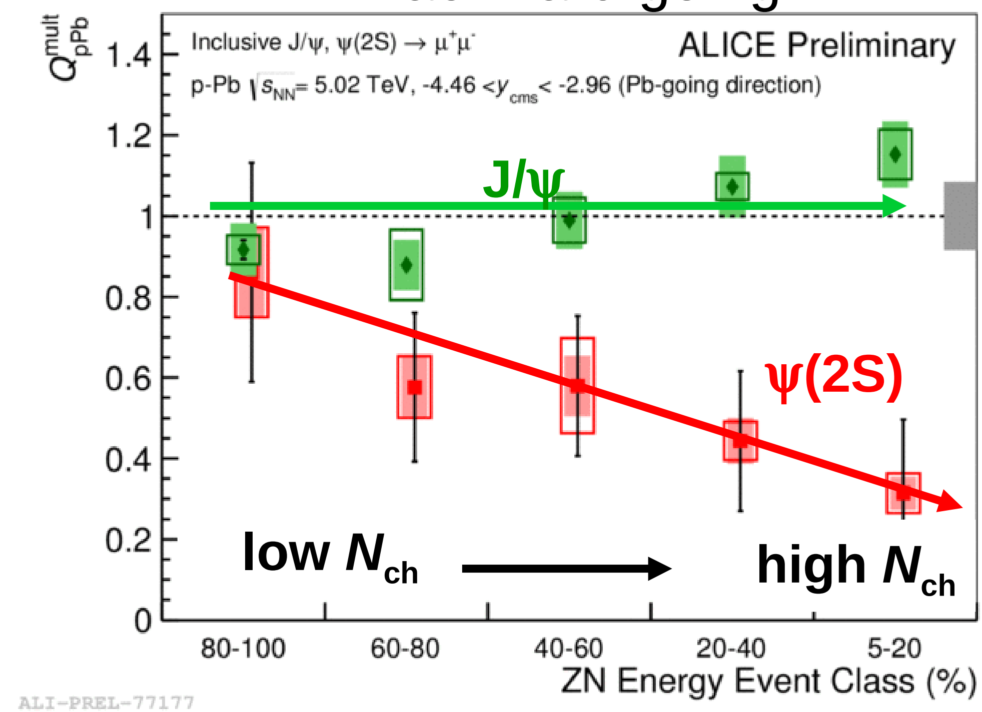
20 J/Ψ and Ψ(2S) suppression

ALICE, JHEP 06 (2016) 50

Forward going

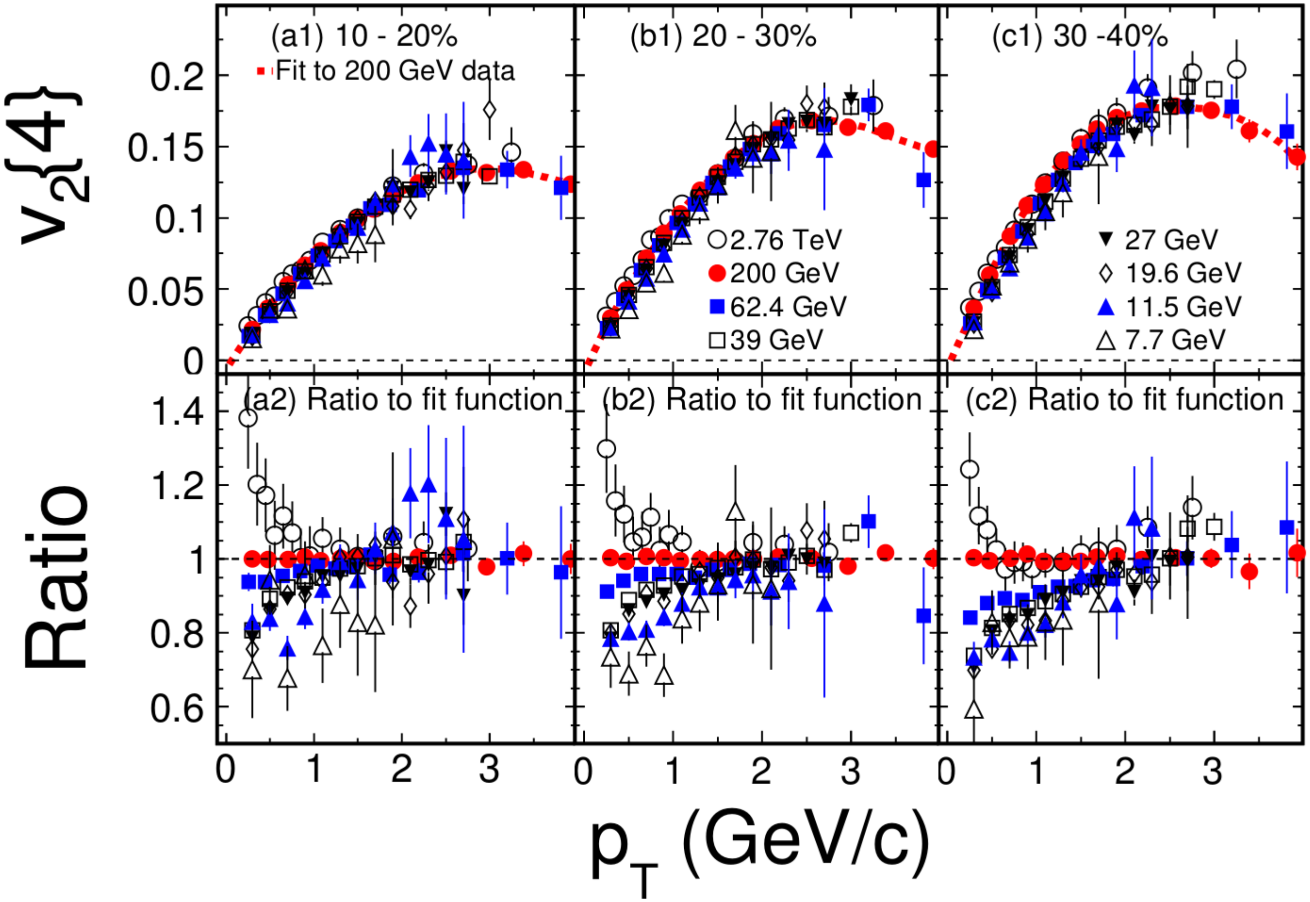


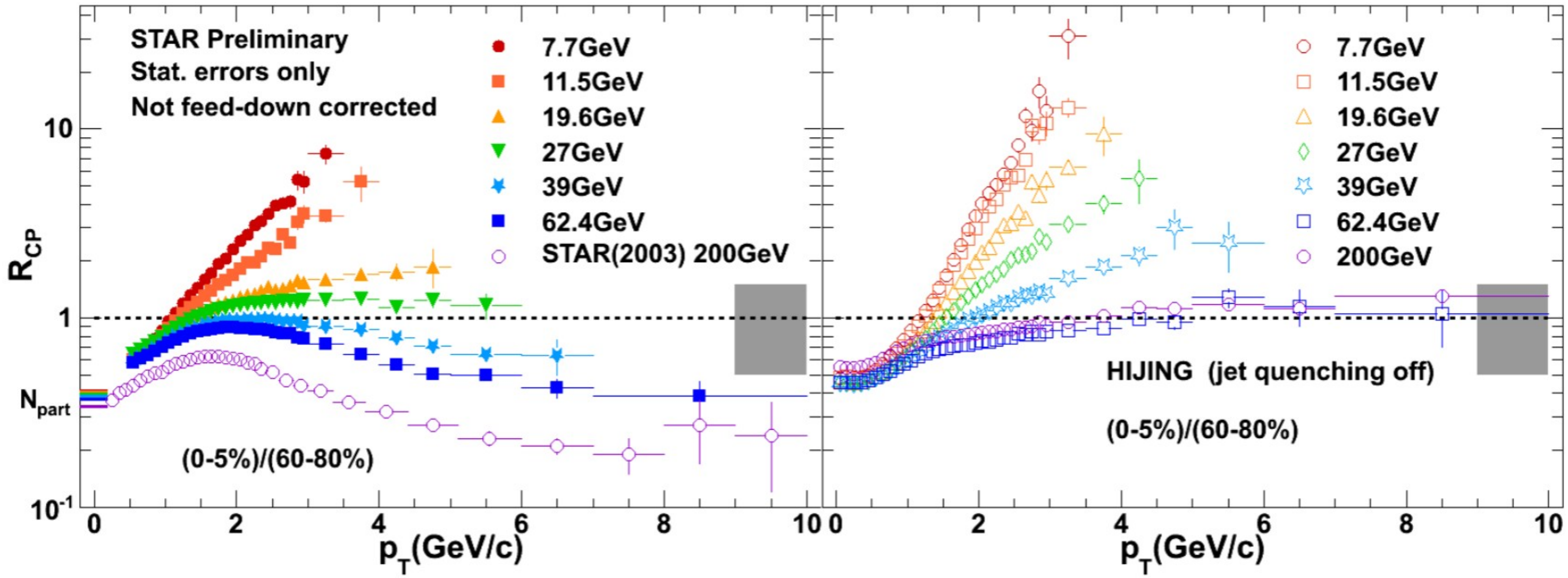
Backward going



- J/ψ → μμ: Multiplicity dependent suppression in p-going direction, and no suppression in Pb-going direction
  - Consistent with shadowing
- ψ(2S) → μμ: Multiplicity dependent suppression in both directions
  - Needs additional effect (Final state?)

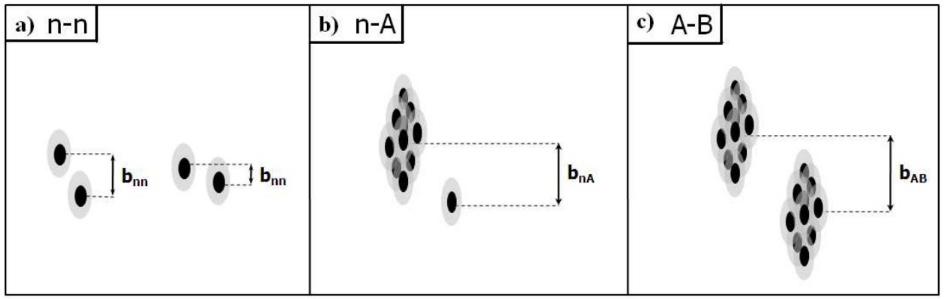
21 Energy scan





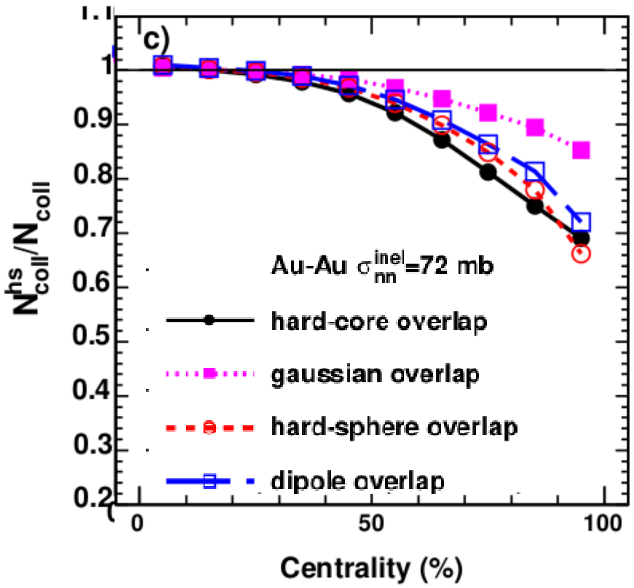
Impact parameter (geometrical) bias

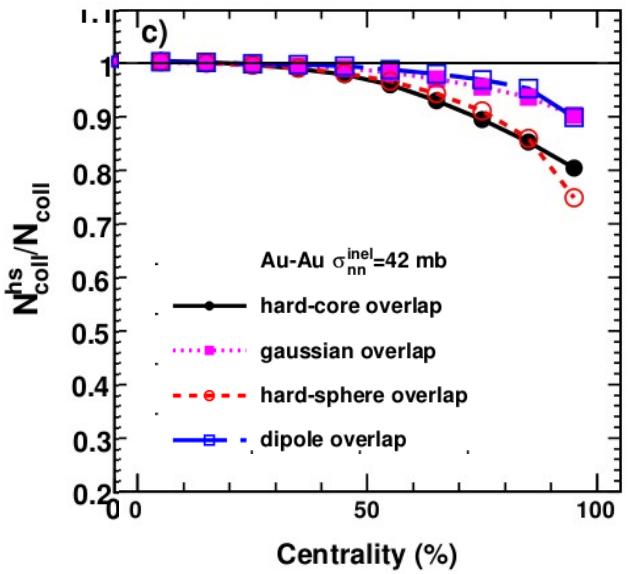
J.Jia, PLB 681 (2009) 320



$$T_{AB}(\vec{b}_{AB}) = \int d\vec{b}_A d\vec{b}_B \, T_A(\vec{b}_A) T_B(\vec{b}_B) t(\vec{b}_{AB} - \vec{b}_A + \vec{b}_B)$$
$$= \int d\vec{s} d\vec{b}_{nn} \, T_A(\vec{s}) T_B(\vec{s} - \vec{b}_{AB} + \vec{b}_{nn}) t(\vec{b}_{nn}).$$

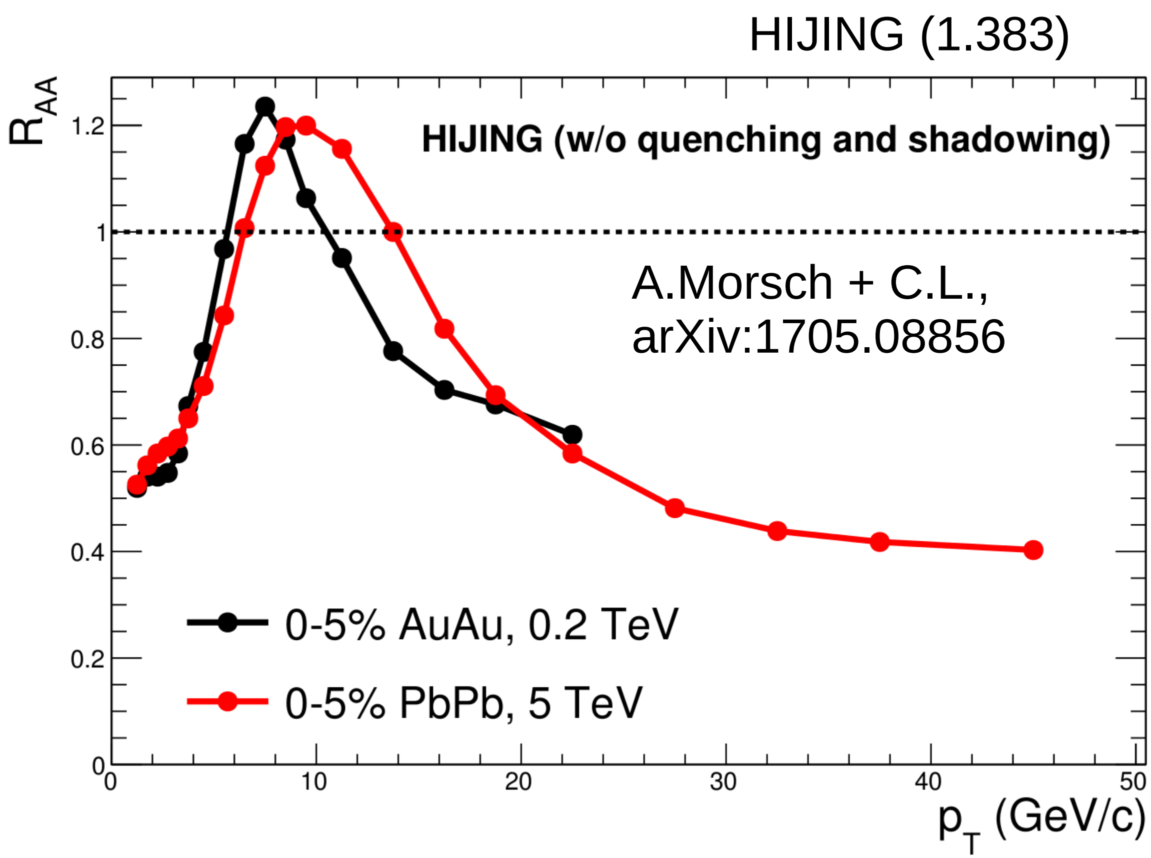
$$N_{coll} = T_{AB}\, \sigma_{NN}$$



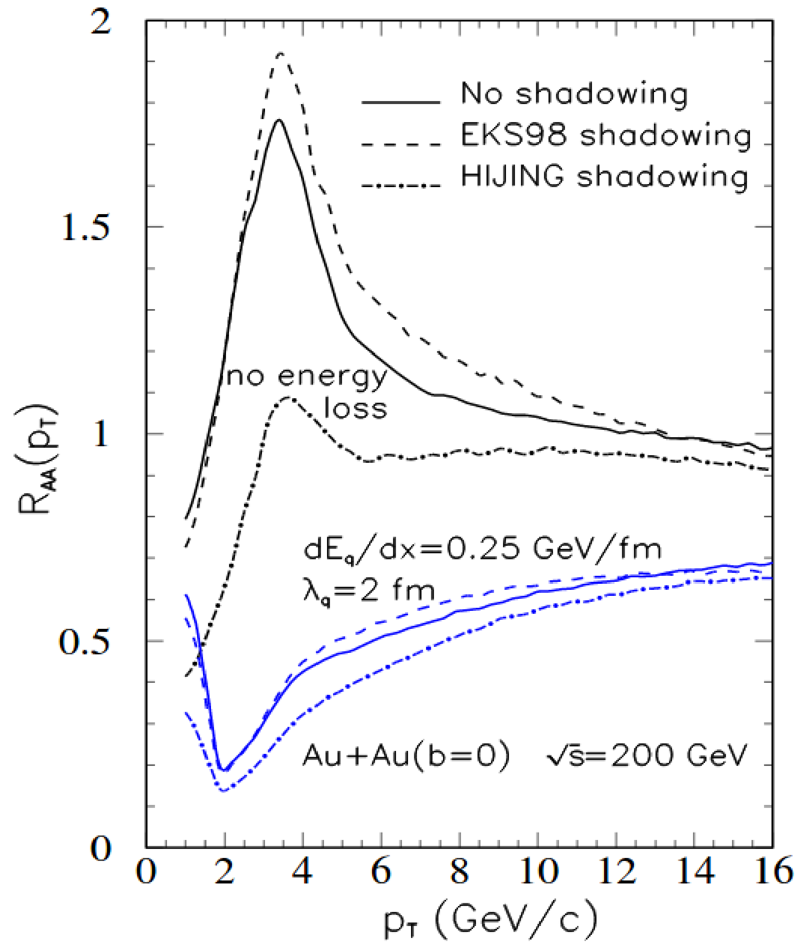


Including a impact parameter dependent nucleon-nucleon overlap function can lead to 20% variation of Ncoll for peripheral collisions

23 HIJING

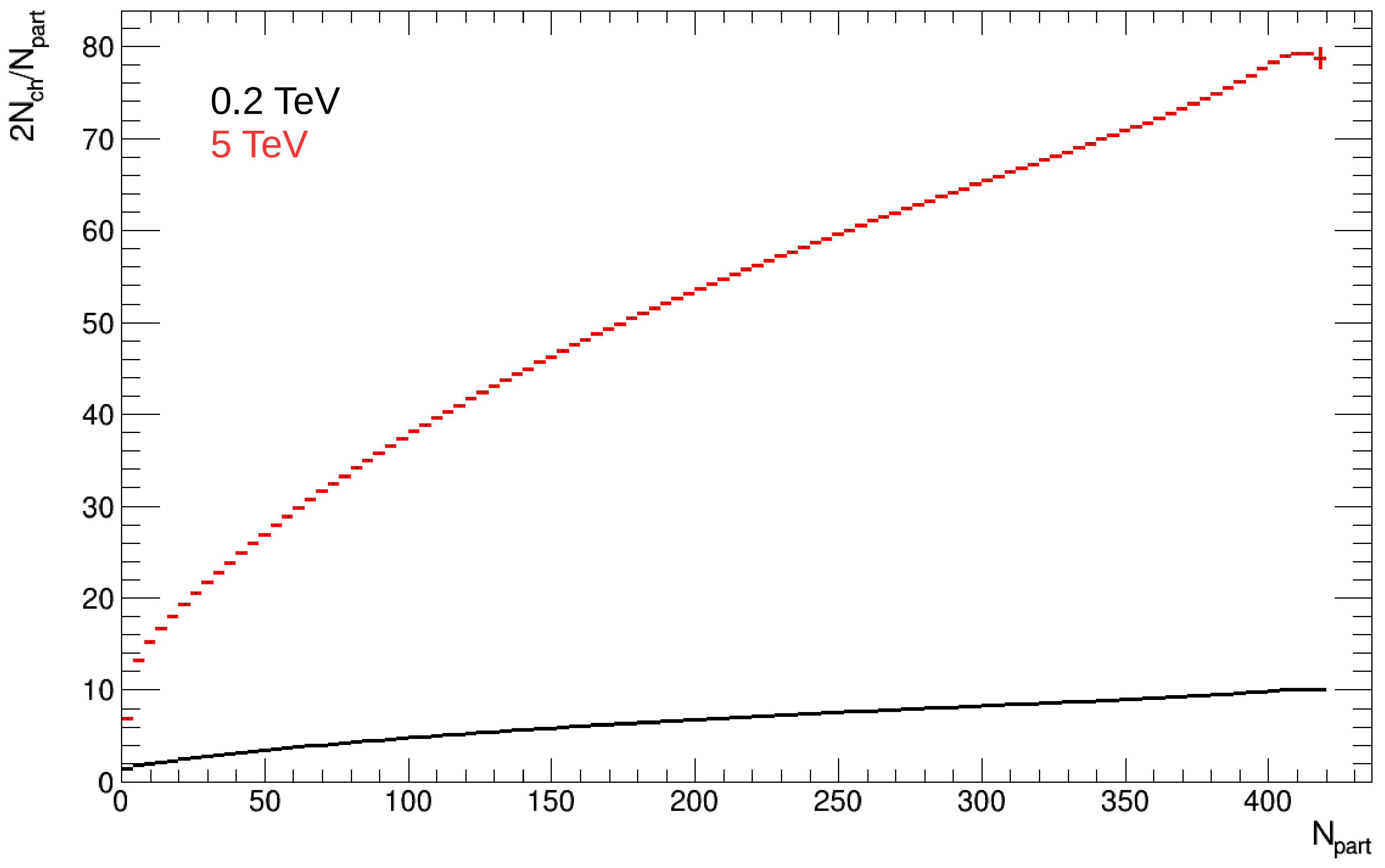


PRC 61 (2000) 064910



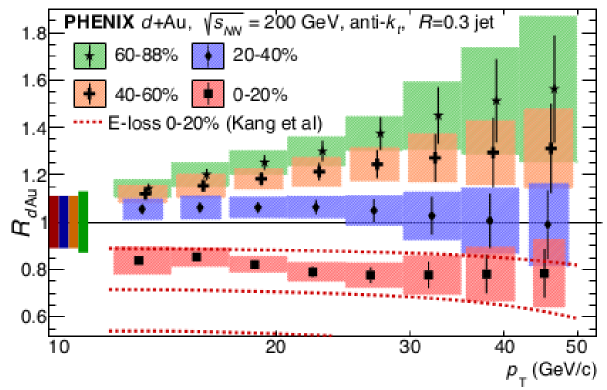
Un-understood features in central PbPb
related maybe to adhoc-momentum conservation
And multiple scattering. Does not give RAA→1 at high p_T

HG-Pythia multiplicity dependence

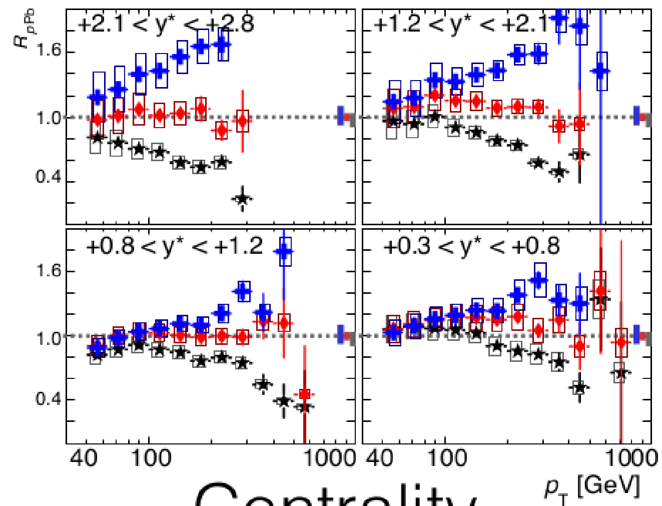


By construction, does not well scale with Npart, but rather with Nhard (or Ncoll)

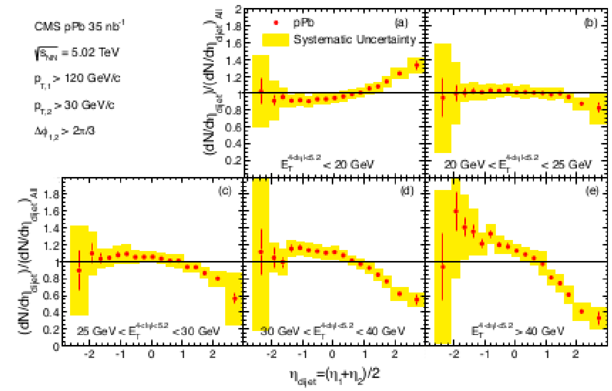
Effects at large p_T (x>0.1)



Centrality "splitting" for jets at RHIC



Centrality "splitting" for jets at LHC

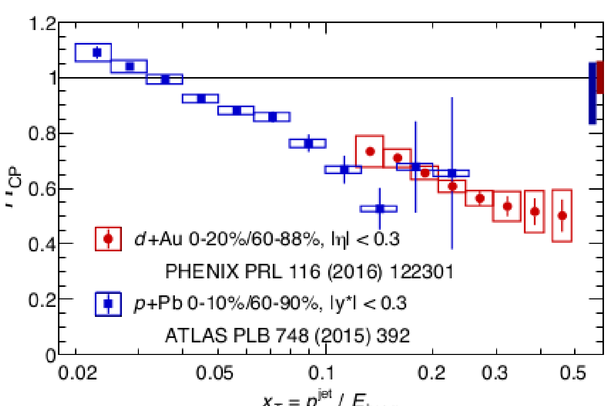


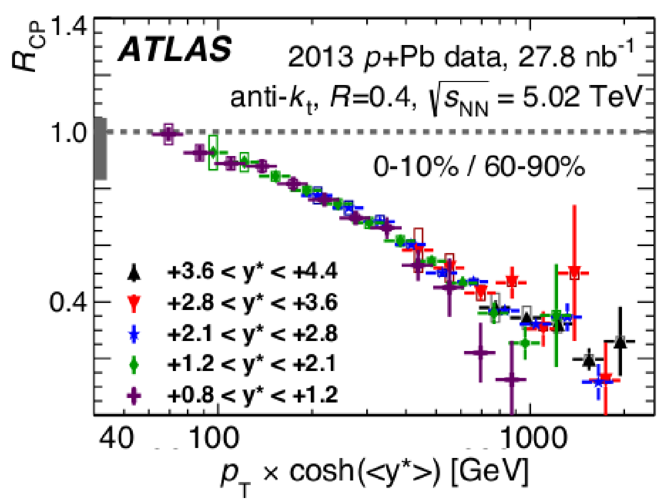
"Splitting" for dijets at large η

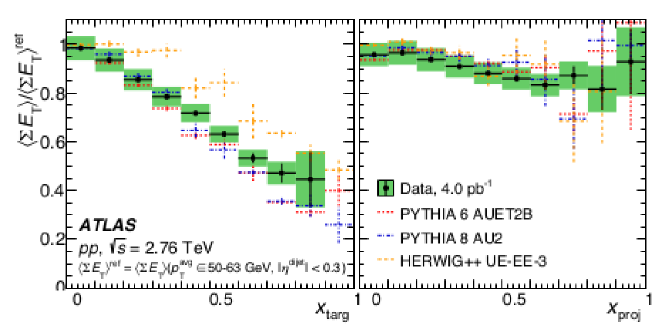
scales with x_T b/w RHIC & LHC

scales with $\boldsymbol{x_p}$ (or x_F) b/w rapidities at LHC

not trivial energy conservation

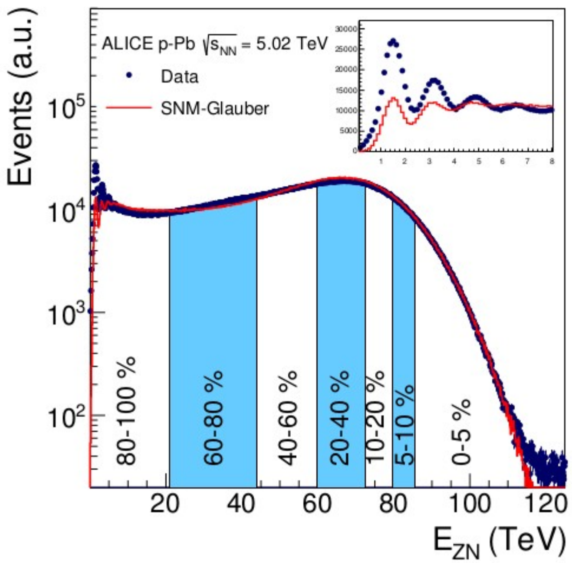






(from D.Perepelitsa, QM17)

Centrality from HYBRID method



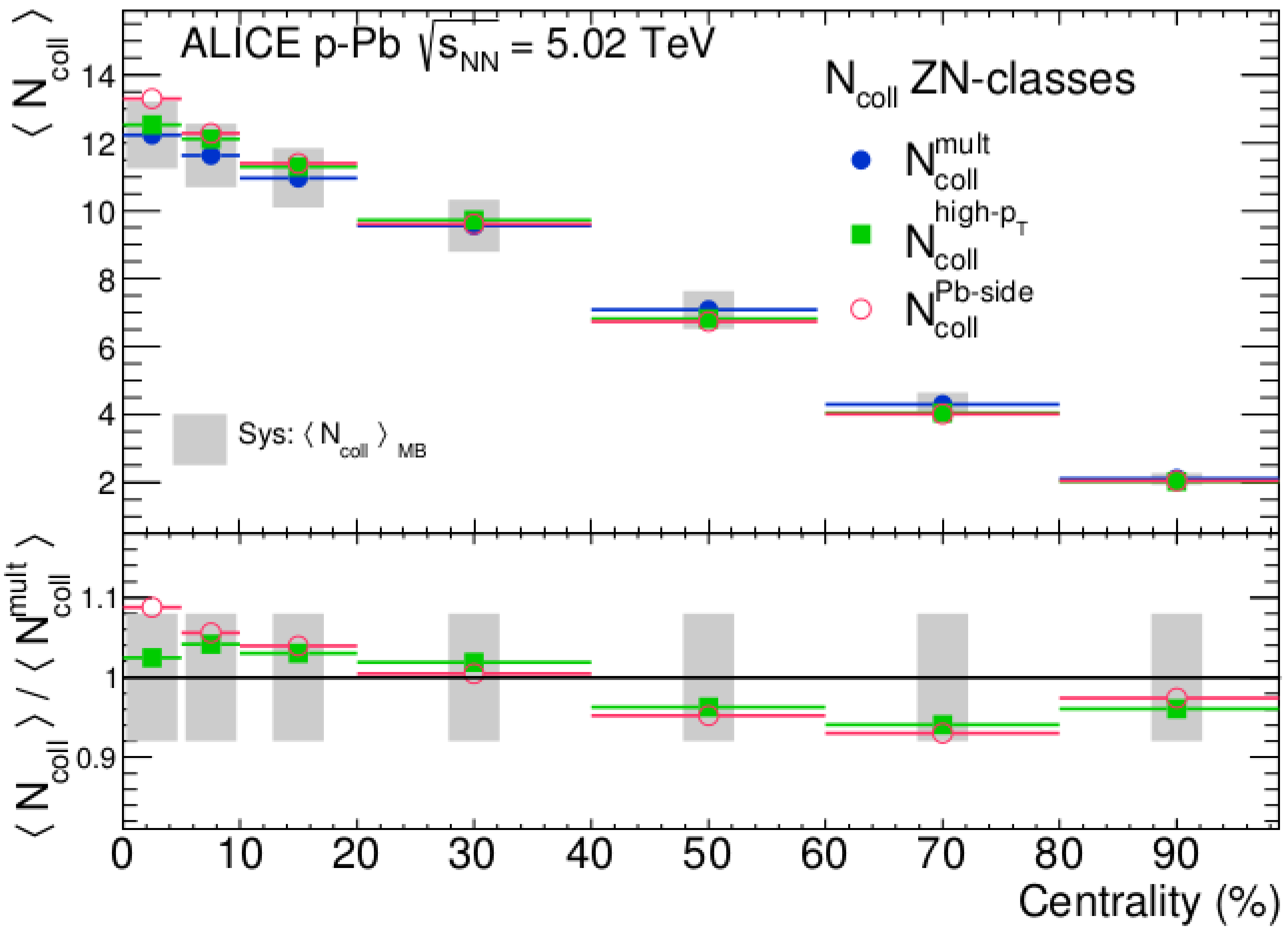
$$\langle N_{\rm coll}\rangle_i^{\rm mult} = \langle N_{\rm part}\rangle_{\rm MB}\ \frac{\langle dN/d\eta\rangle_i}{\langle dN/d\eta\rangle_{\rm MB}}\bigg|_{-1<\eta<0} - 1$$

$$\langle N_{\rm coll}\rangle_i^{\rm high\ p_T} = \langle N_{\rm coll}\rangle_{\rm MB}\ \frac{\langle Y_{10<p_T<20}\rangle_i}{\langle Y_{10<p_T<20}\rangle_{\rm MB}}$$

$$\langle N_{\rm coll}\rangle_i^{\rm Pb\,side} = \langle N_{\rm coll}\rangle_{\rm MB}\ \frac{\langle S_{\rm V0Ar1}\rangle_i}{\langle S_{\rm V0Ar1}\rangle_{\rm MB}}$$

1) Assume ZN is bias free + define centrality classes
2) Construct similar model as for the Glauber fits

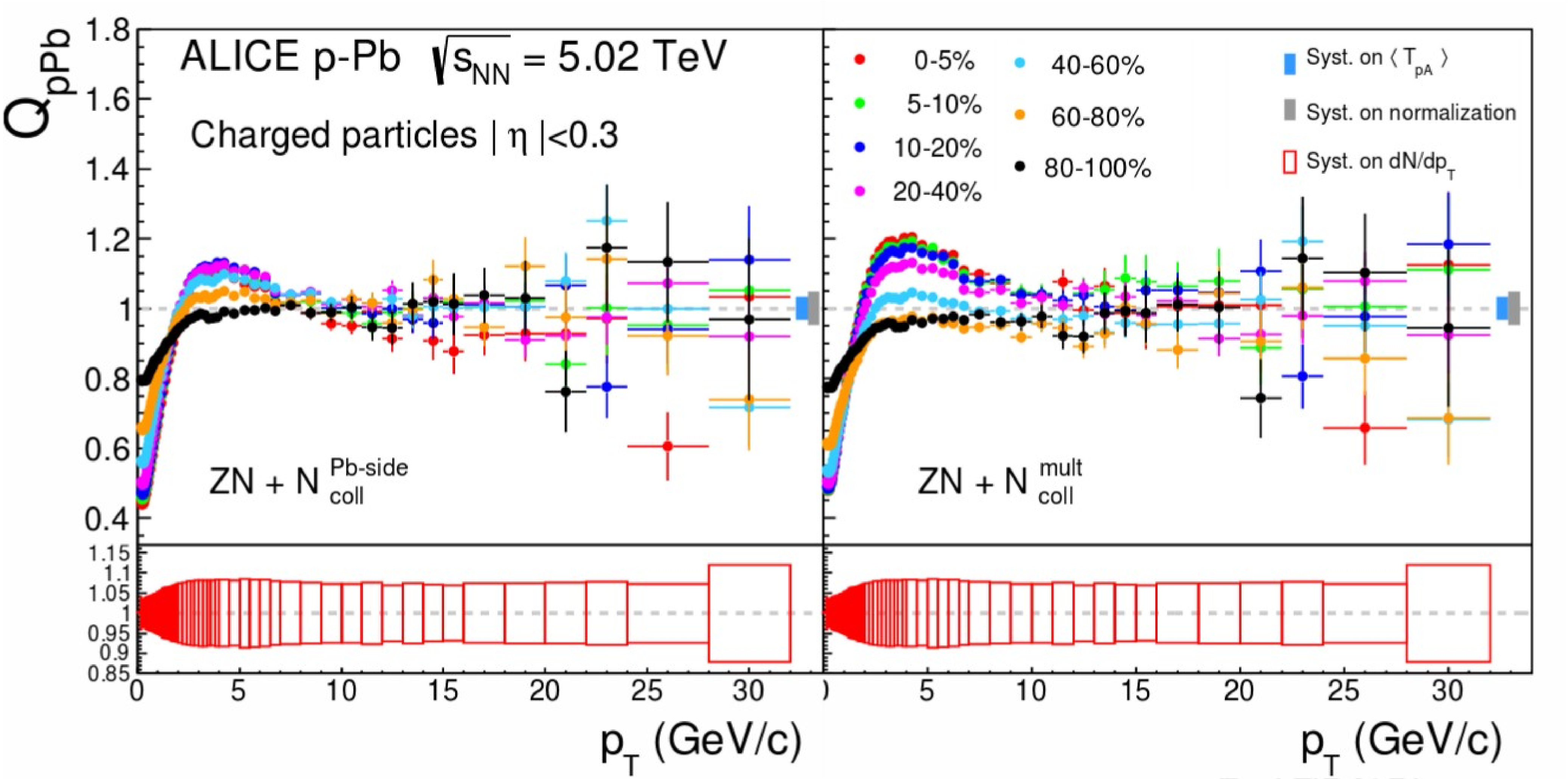
Resulting values within at most 10%



ALICE, PRC 91 (2015) 064905

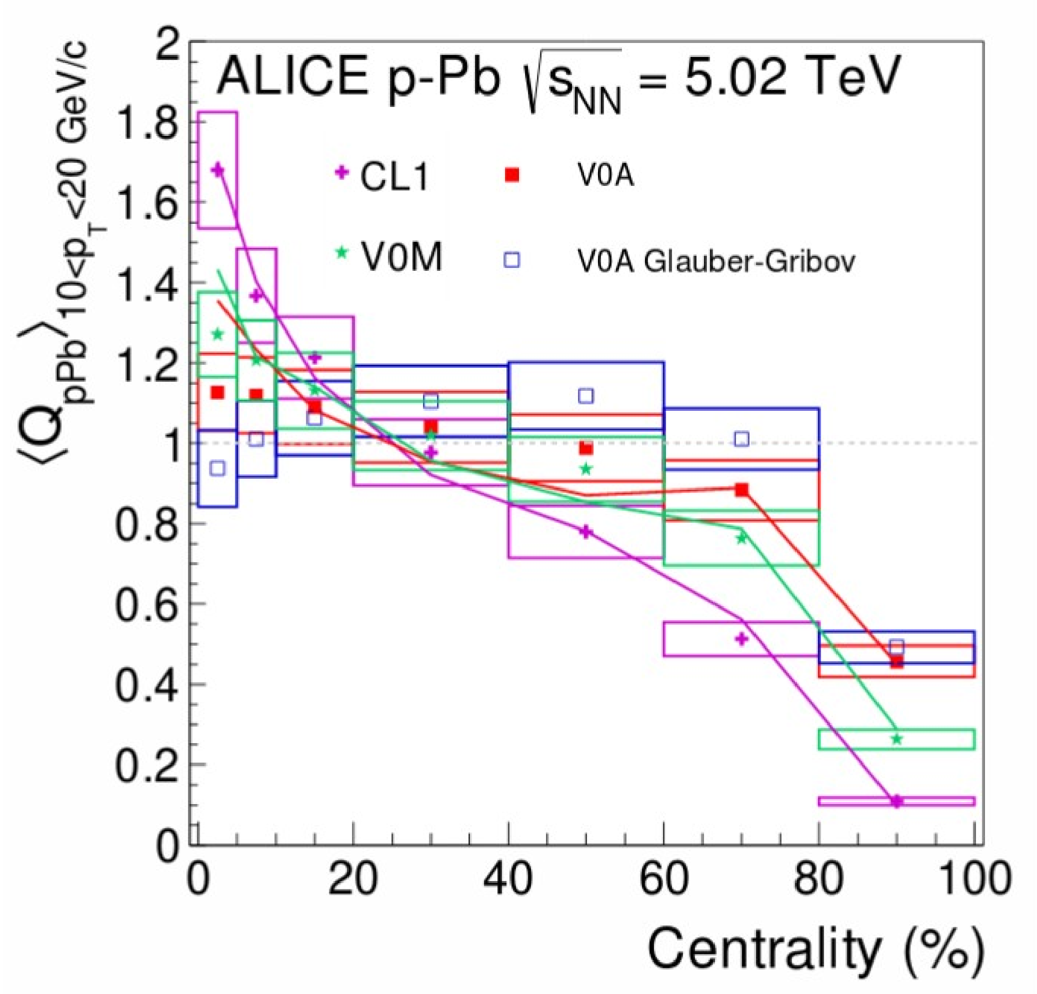
Results using the hybrid method

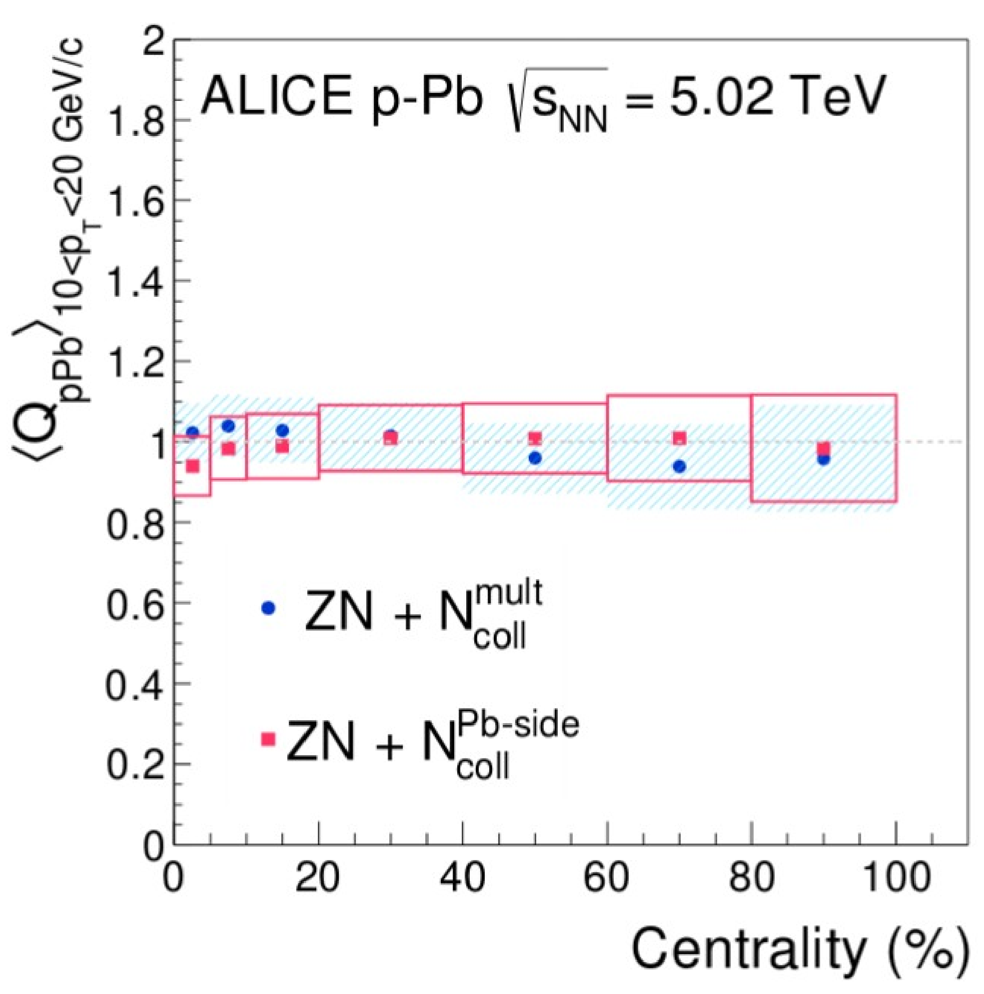
ALICE, PRC 91 (2015) 064905



Multiplicity vs ZN selection

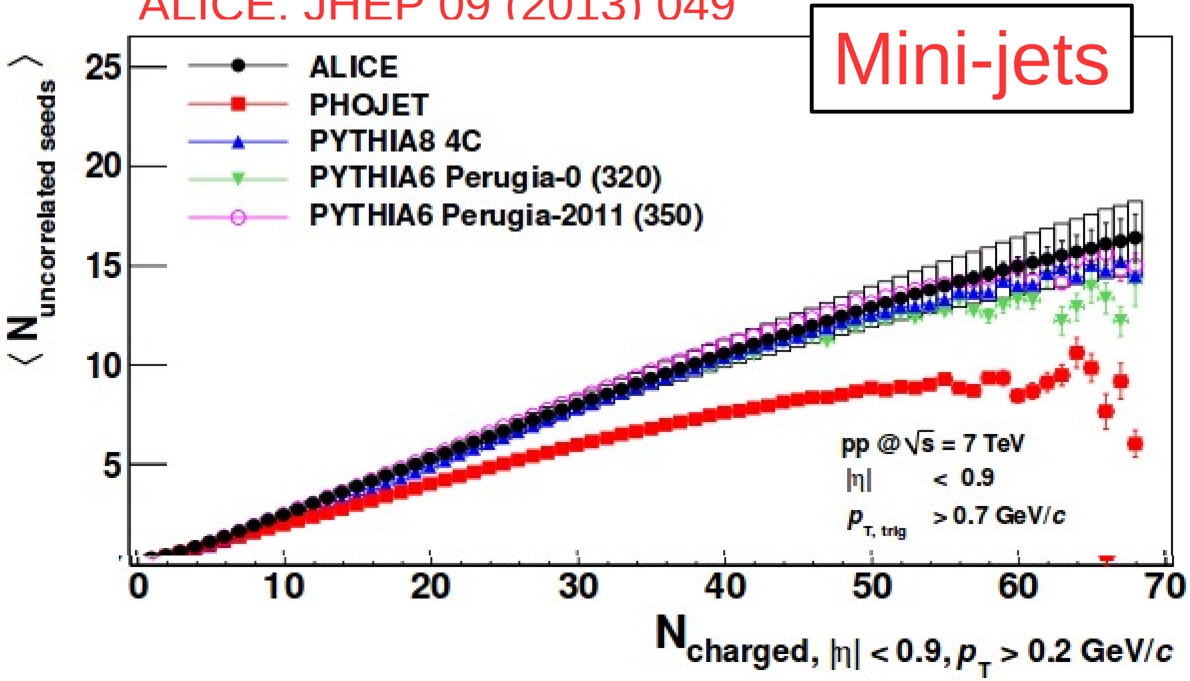
ALICE, PRC 91 (2015) 064905



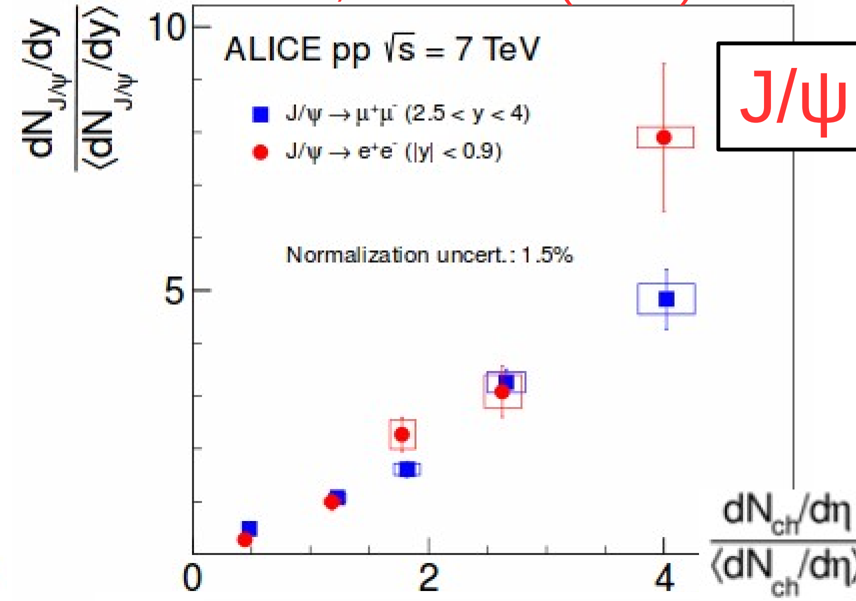


Scaling of hard probes with multiplicity

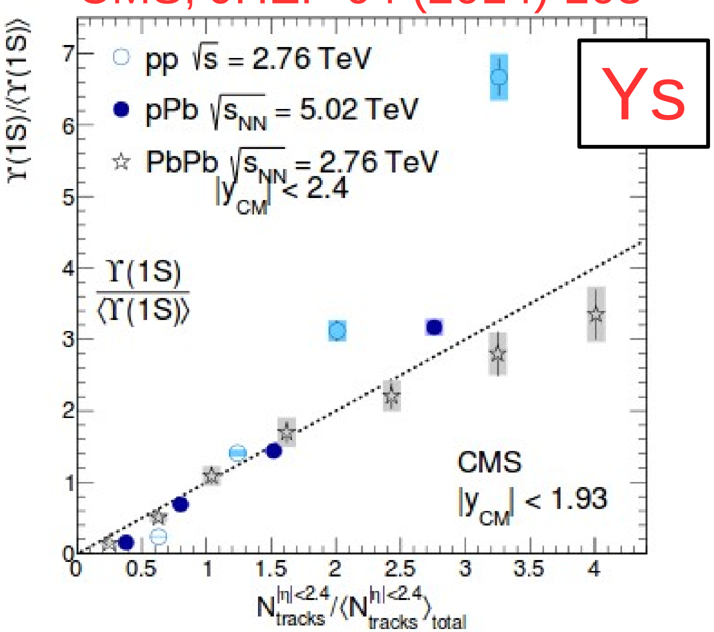
ALICE. JHEP 09 (2013) 049

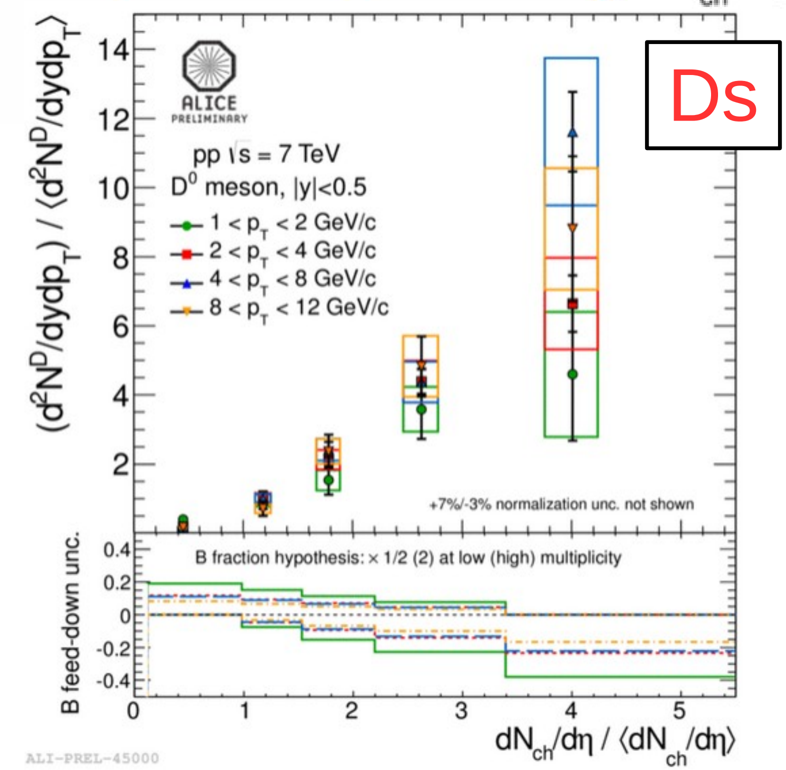


ALICE, PLB 712 (2012) 165

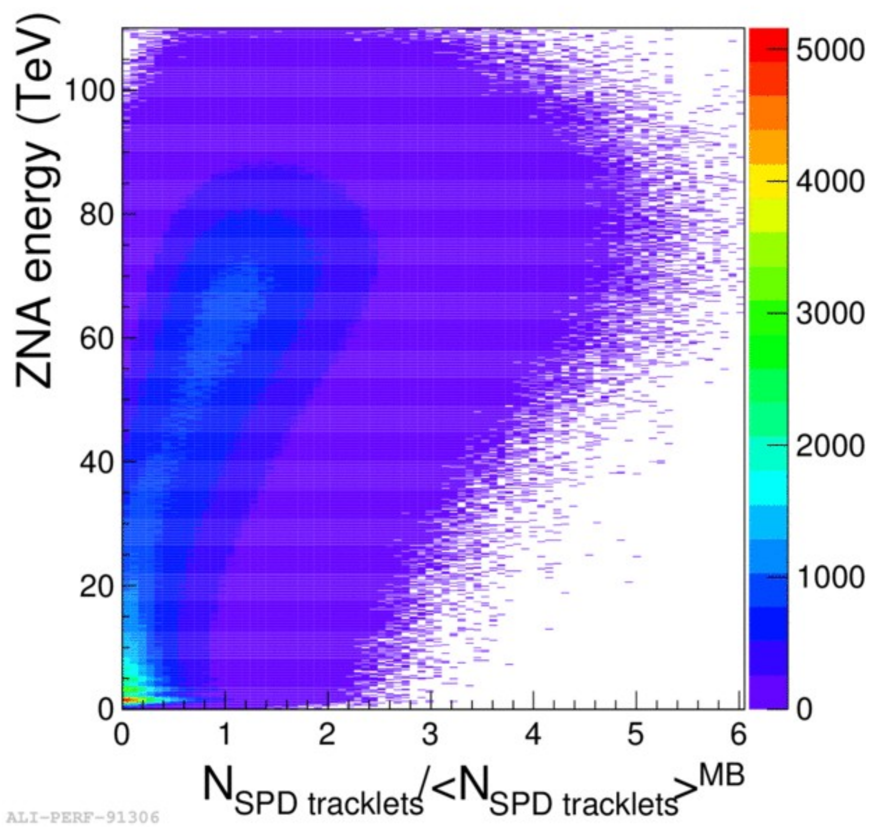


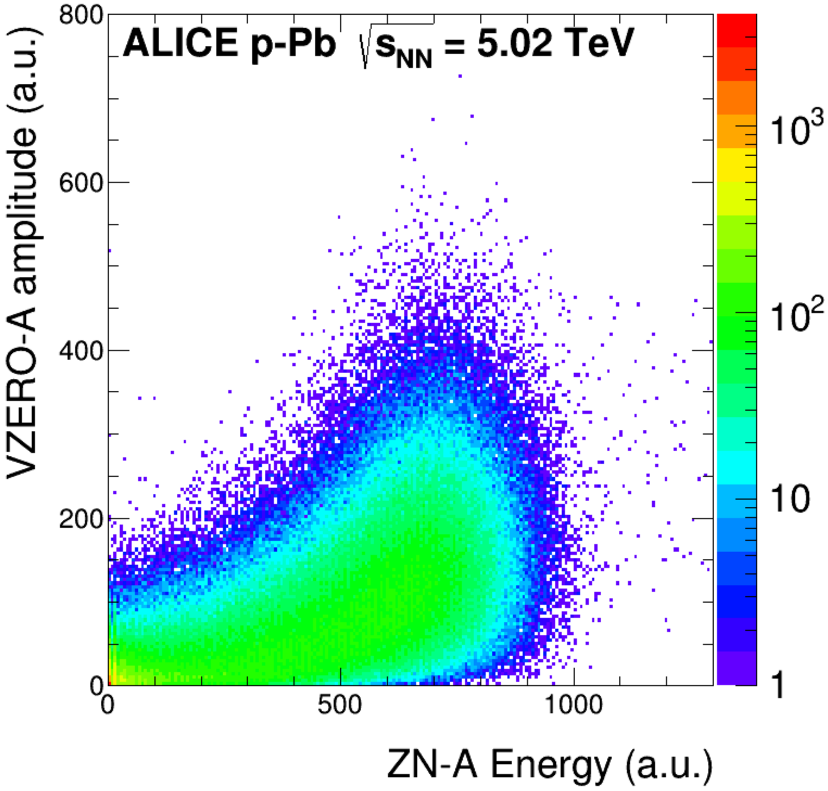
CMS, JHEP 04 (2014) 103





Correlation between ZNA and multiplicity





Elliptic flow and high pT suppression in AA

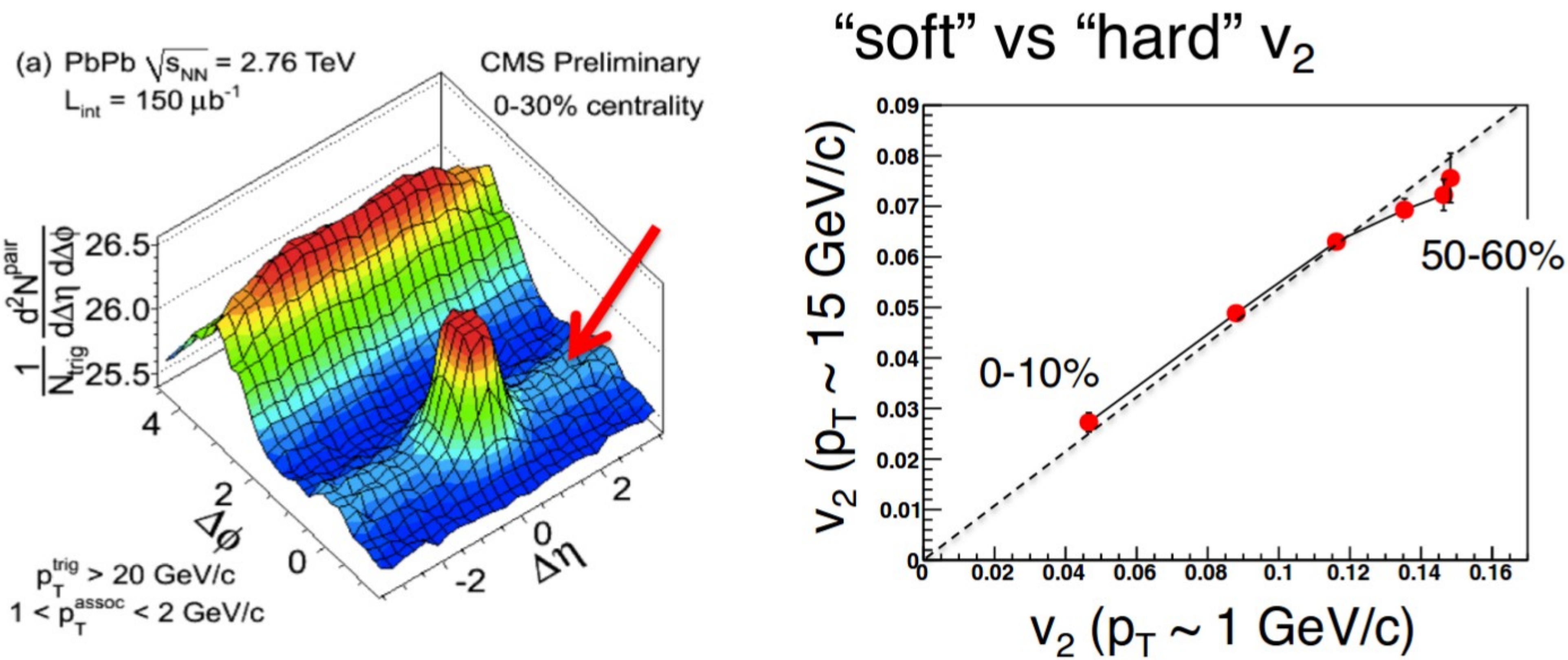


Fig. 42. Left: The 2-D $\Delta\eta$–$\Delta\phi$ correlation function for high-p_T ($> 20\,\mathrm{GeV}/c$) trigger particles in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\mathrm{TeV}$. Right: The v_2 values at high p_T ($\sim 15\,\mathrm{GeV}/c$) versus low p_T ($\sim 1\,\mathrm{GeV}/c$) for different centralities in Pb-Pb collisions.[250]

Wei, Dusling, Schenke, IJMP E25 (2016) 01, 1630002

ATLAS, PRC 90 (2014) 044906