Heavy ions at the LHC: lessons from the first data

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Heavy ions at the LHC:
Lessons from the first data

"A discussion of the first results from the 2010 heavy ion run of the LHC, with an assessment of their theoretical implications."

- Soft physics
  - multiplicity of charged particles
  - anisotropic flow
  - femtoscopy
- Hard probes
  - high transverse momentum particles
  - J/ψ, Z^0...

... and a few provocative statements for the upcoming discussions!

Heavy ions at the LHC: Lessons from the first data

"... an assessment of their theoretical implications."

- Intrinsic theoretical implications:
  - anisotropic flow (ALICE)
  - jet suppression (ATLAS & CMS)

  ☞ hot and dense system with emerging collective behavior!

- Implications for models / theories popular at RHIC

  Comparison of the first LHIC data with pre-LHC predictions within models that reproduce RHIC data...

... and a few provocative statements for the upcoming discussions!

Heavy ions at the LHC: Lessons from the first data

- Implications for models / theories popular at RHIC

What does it mean when a model that reproduces RHIC data fails to properly account for LHC results?

- … that some new phenomenon plays a role at $\sqrt{s_{NN}}$ = 2.76 TeV, but was negligible at 200 GeV and below?
- … or that the success of the model at RHIC energies reflected some careful tuning of parameters, without which no fit to the data would have been possible, because a key physical ingredient had been forgotten?

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Charged hadron multiplicity

Day 1 at the Large Heavy-Ion Collider… Fantastic news!

PRL **105,** 252301 (2010) PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

Charged-Particle Multiplicity Density at Midrapidity in Central Pb-Pb Collisions at $\sqrt{s_{NN}} = 2.76$ TeV

K. Aamodt *et al.**
(ALICE Collaboration)
(Received 19 November 2010; published 13 December 2010)

The first measurement of the charged-particle multiplicity density at midrapidity in Pb-Pb collisions at a center-of-mass energy per nucleon pair $\sqrt{s_{NN}} = 2.76$ TeV is presented. For an event sample corresponding to the most central 5% of the hadronic cross section, the pseudorapidity density of primary charged particles at midrapidity is $1584 \pm 4(\mathrm{stat}) \pm 76(\mathrm{syst})$, which corresponds to $8.3 \pm 0.4(\mathrm{syst})$ per participating nucleon pair. (…)

The jump in $\sqrt{s_{NN}}$ from 200 GeV to 2.76 TeV does bring its surprises!

Charged hadron multiplicity

$$\frac{\mathrm{d}N_{\rm ch}}{\mathrm{d}\eta} = 1584 \pm 4(\text{stat}) \pm 76(\text{syst}) \text{ at } \sqrt{s_{NN}} = 2.76 \text{ TeV for } \langle N_{\rm part}\rangle = 381,$$

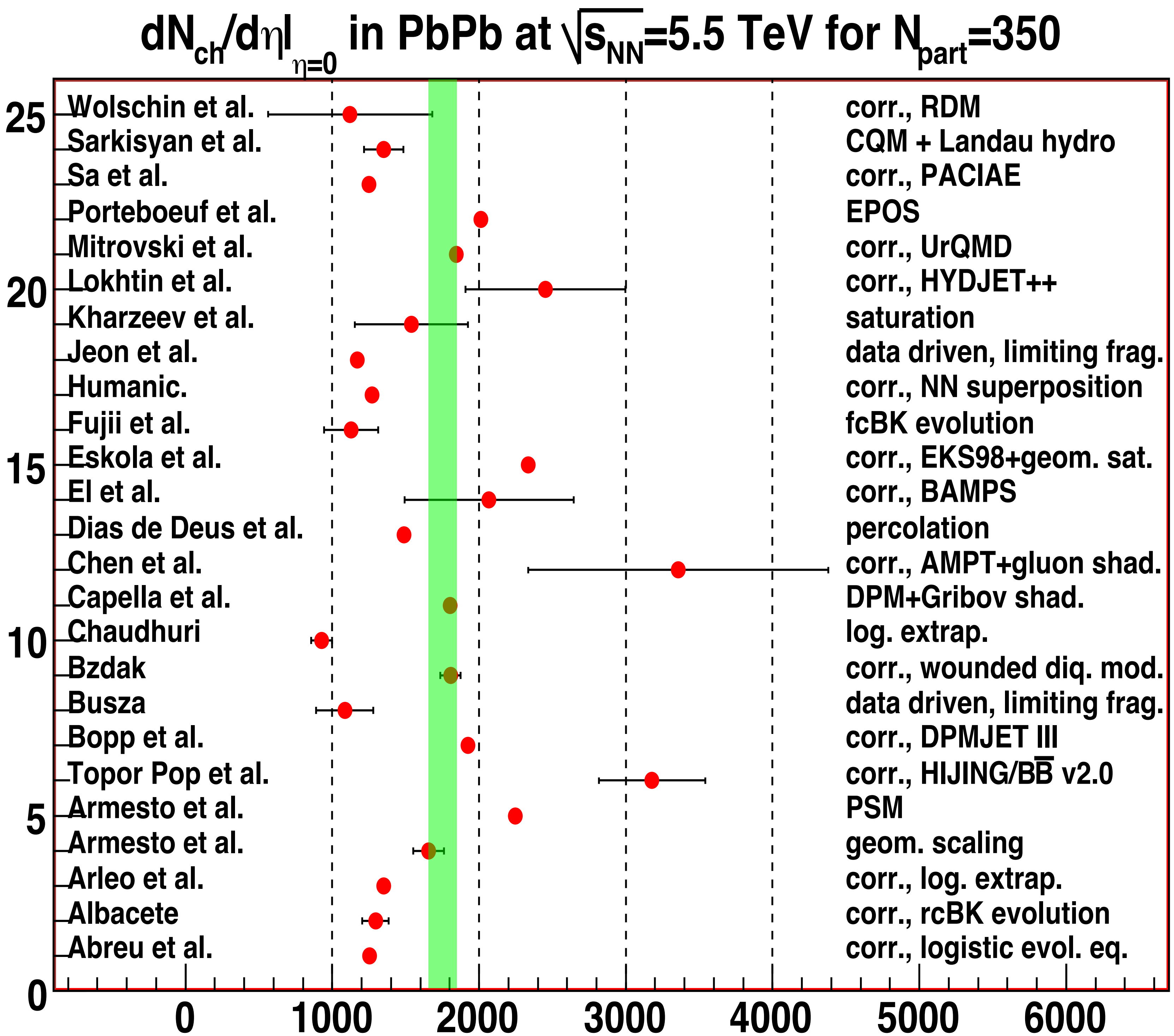
with a center-of-mass energy dependence $\propto s_{NN}^{0.15}$.

$$\rightsquigarrow \frac{\mathrm{d}N_{\rm ch}}{\mathrm{d}\eta} \approx 1760 \pm 86 \text{ at } \sqrt{s_{NN}} = 5.5 \text{ TeV for } \langle N_{\rm part}\rangle = 350$$

(hopefully measured in 201?)

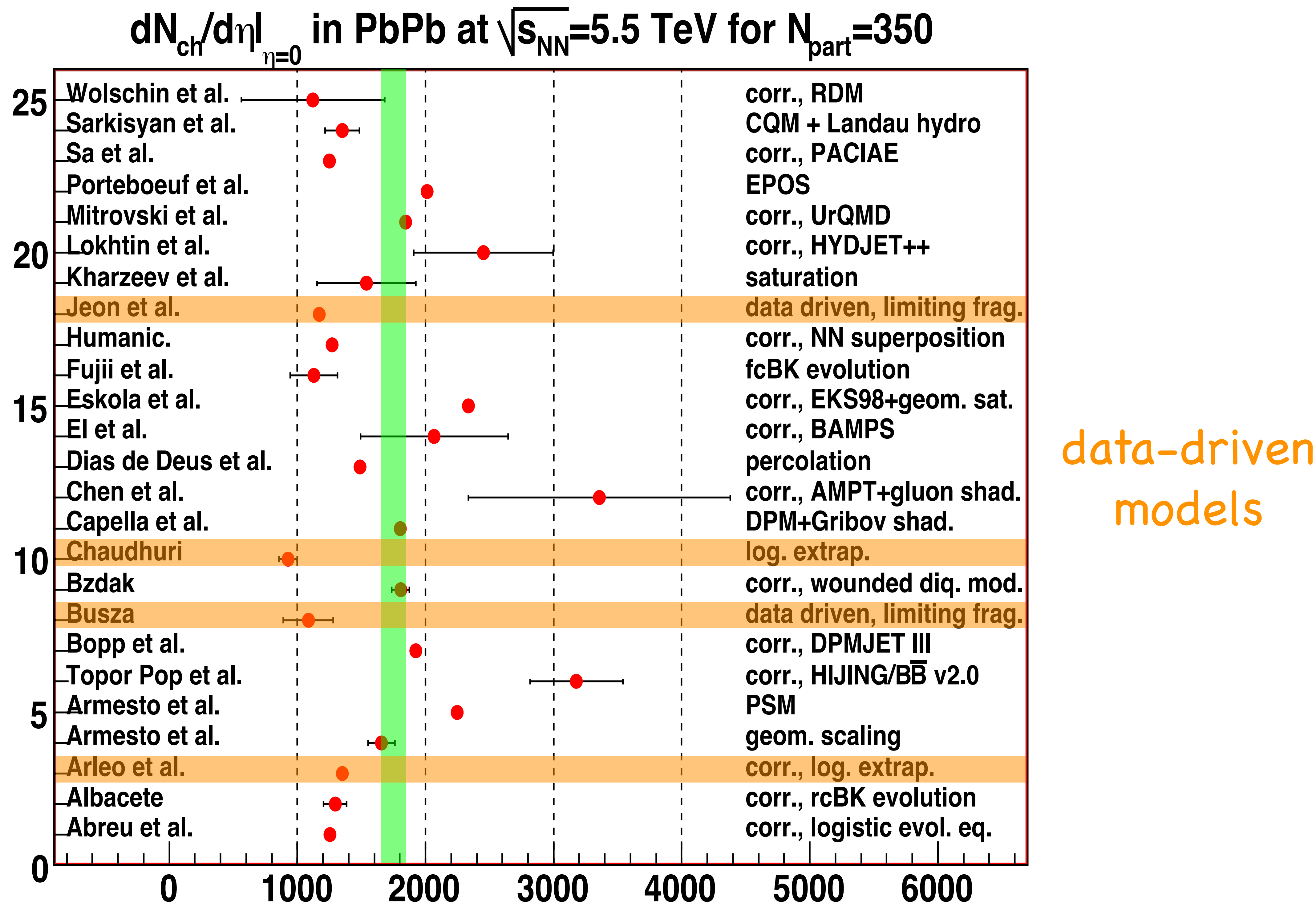
… to be compared with predictions "extrapolating" RHIC results!

Charged hadron multiplicity



corrections & compilation by N.Armesto in Quark Gluon Plasma IV

Charged hadron multiplicity



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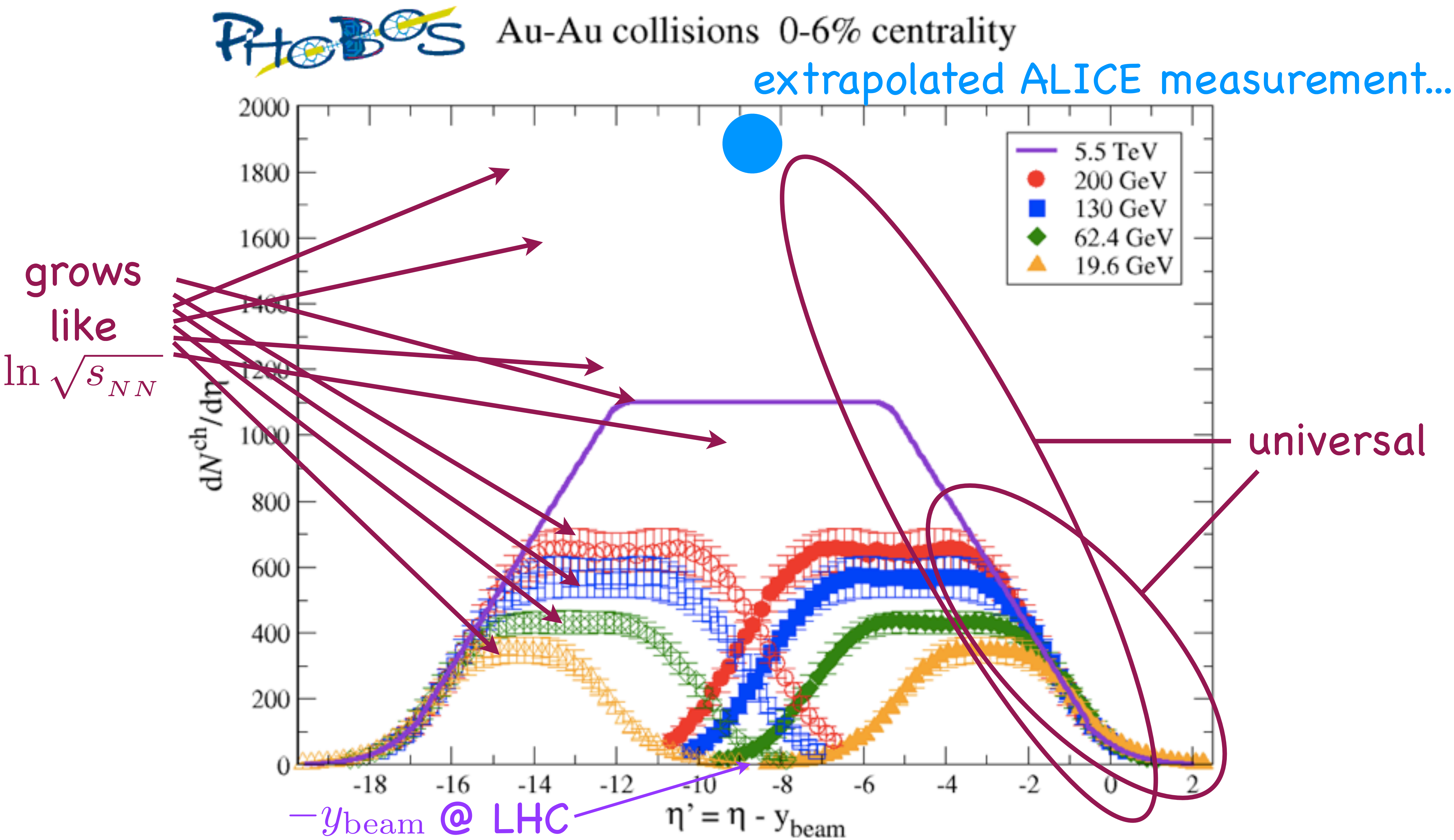
Charged hadron multiplicity

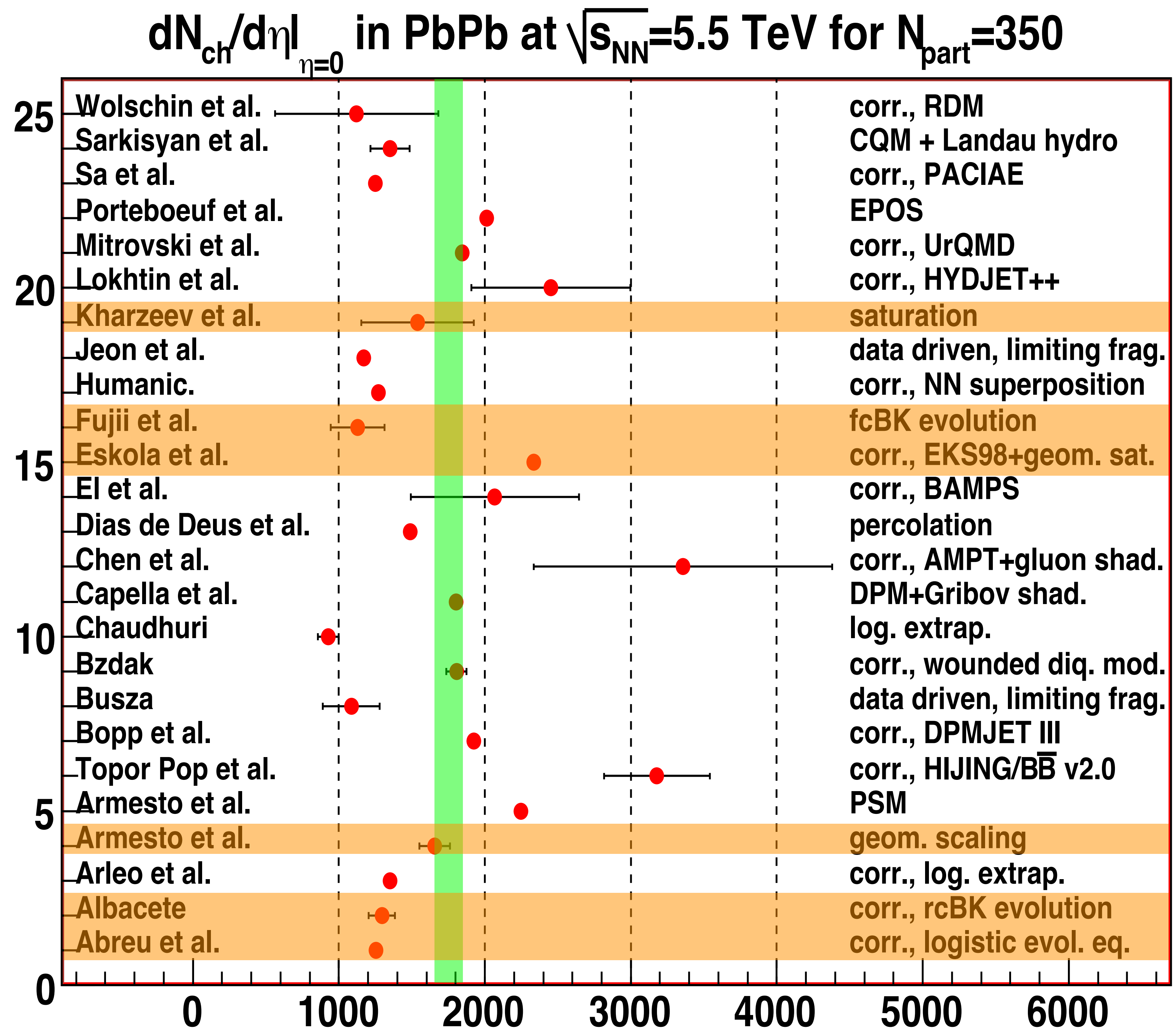


We boost everything to the rest frame of one nucleus ("projectile")

☞ "limiting fragmentation"

Busza 2004

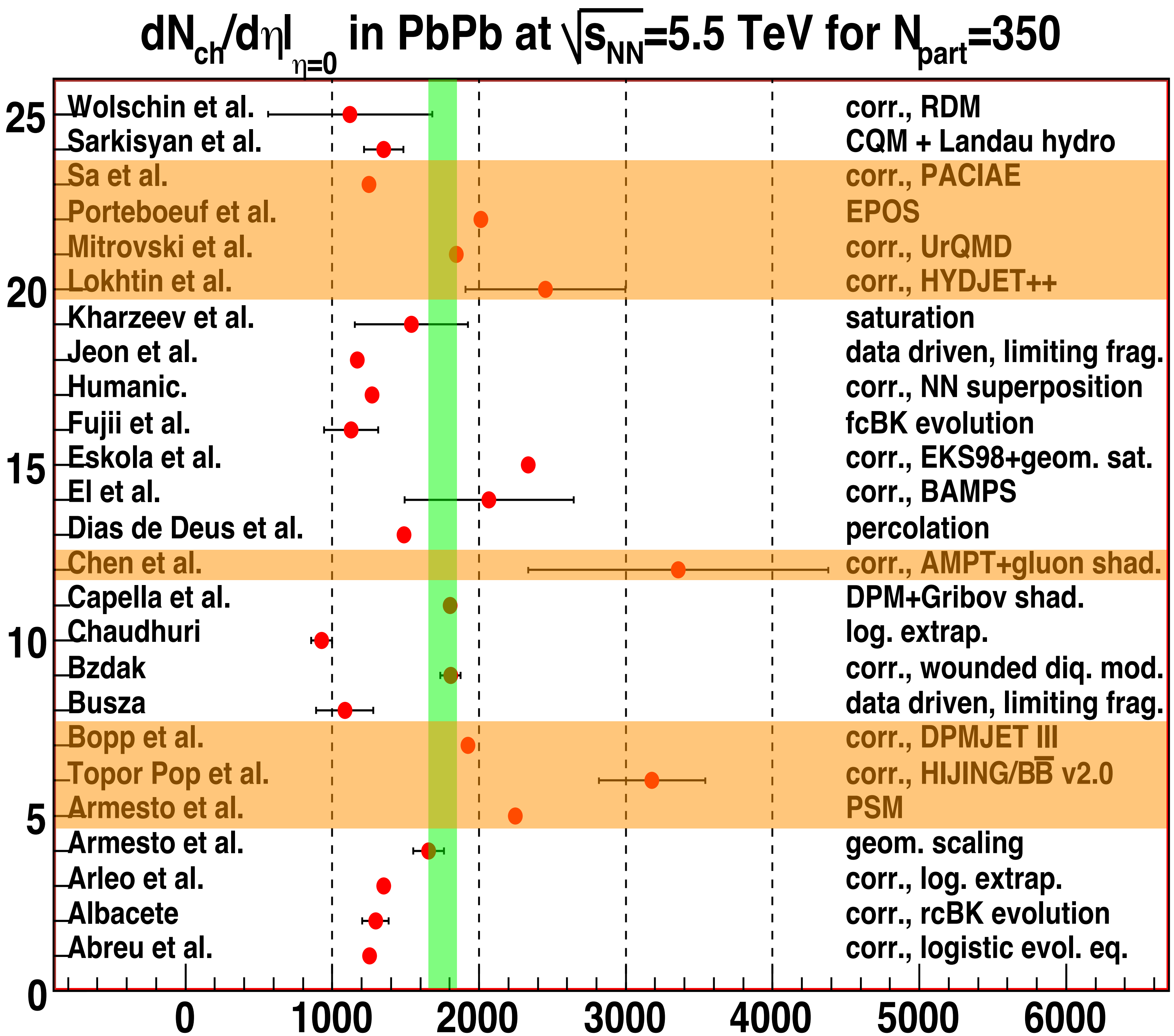
Charged hadron multiplicity



models based on saturation

corrections & compilation by N.Armesto in Quark Gluon Plasma IV

Charged hadron multiplicity



Monte-Carlo simulations (+ successful LHC-tuned Hijing 2.0)

corrections & compilation by N.Armesto in Quark Gluon Plasma IV

Charged hadron multiplicity

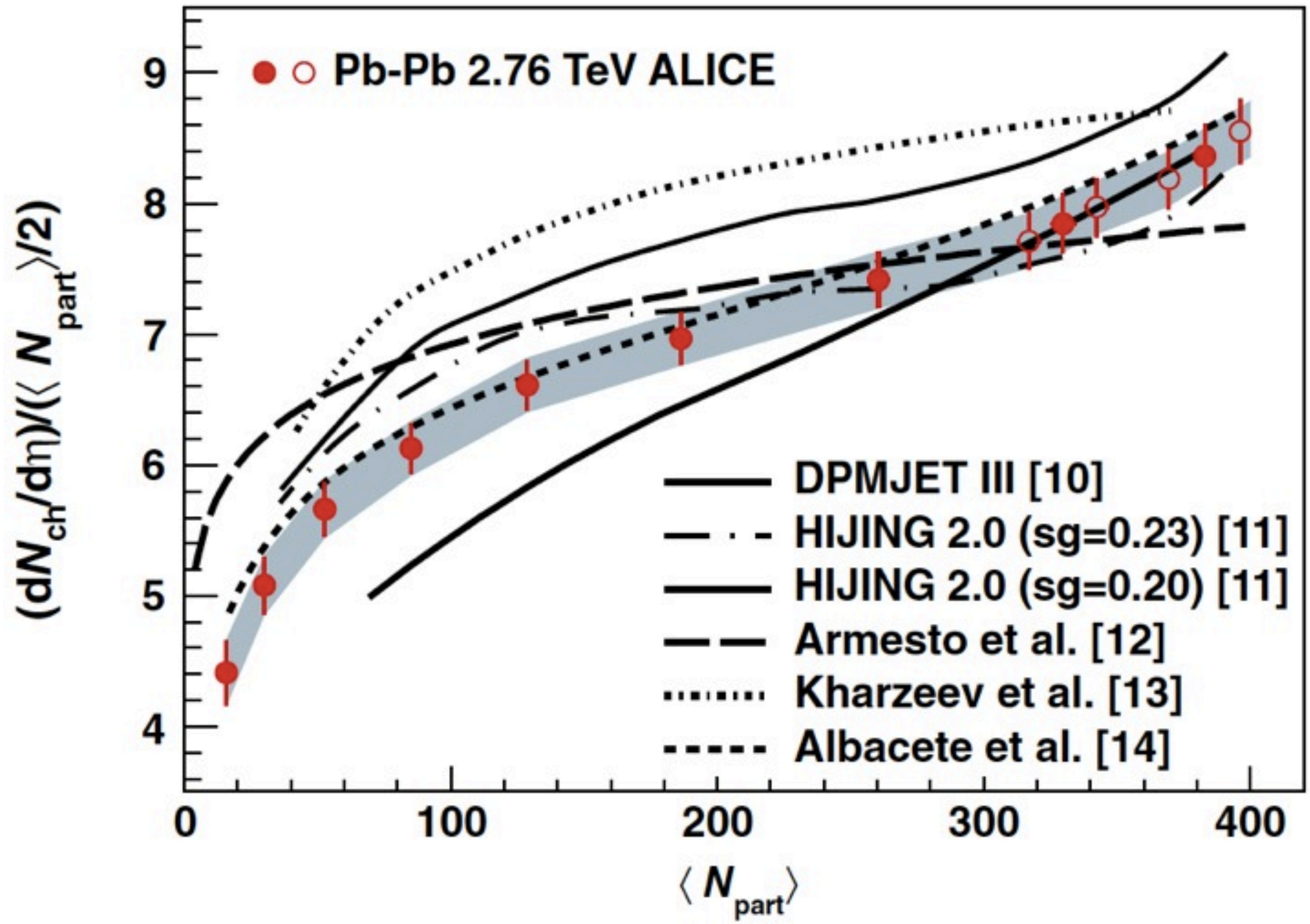
What do we learn from a single number?

- "Naive", data-driven predictions are (way) off!

  GOOD!

  Any "structureless" continuation of RHIC trends would have been boring ("Do you **really** need to inject Pb nuclei in our collider?")... and hard to explain theoretically ($\ln\sqrt{s_{NN}}$ growth?)

Charged hadron multiplicity: centrality dependence



ALICE, PRL **106** (2011) 032301

Charged hadron multiplicity: centrality dependence

- Strikingly similar to the centrality dependence measured at RHIC at $\sqrt{s_{NN}}$ = 200 GeV!

  ☞ no new ingredient needed for model builders who wish to reproduce RHIC & LHC data.

  ☞ mostly driven by geometry?

- Monte-Carlo simulations are (again) quite successful.

  (but at what price? how do you motivate impact parameter-dependent gluon shadowing with such a huge effect?)

- Saturation-based models do a good to excellent job as well.

Charged hadron multiplicity: centrality dependence

Saturation-based models do a good to excellent job...

... yet they missed the overall magnitude (by ca. 30–40%).

Is this really an issue? NO!

☞ Saturation-based models make predictions for initial-state gluons, while the measured multiplicity is that of hadrons in the final state.

A multiplicative K–factor for the mapping of partons onto hadrons is rather to be expected:

Need for an increase of the number of d.o.f. / entropy.

But how comes the K–factor was not predicted?

Well, perhaps saturation was less important at RHIC than thought?

Charged hadron multiplicity: a possibility

Baier, Mueller, Schiff & Son 2001, 2002, 2011

Bottom-up scenario:

- saturation of the gluon density in the incoming nuclei
- these gluons thermalize ("bottom-up") ⇝ natural increase in the number of (mostly soft) gluons

☞ factor 3 at RHIC energies, 1.4 at LHC...

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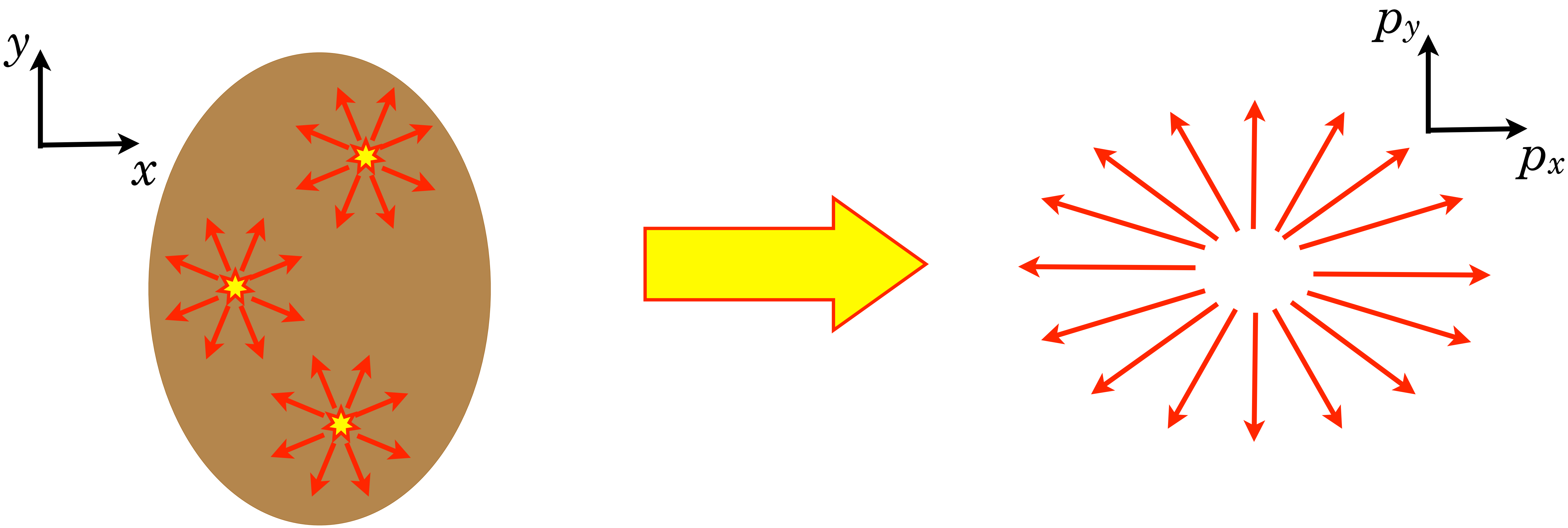
Anisotropic (transverse collective) flow

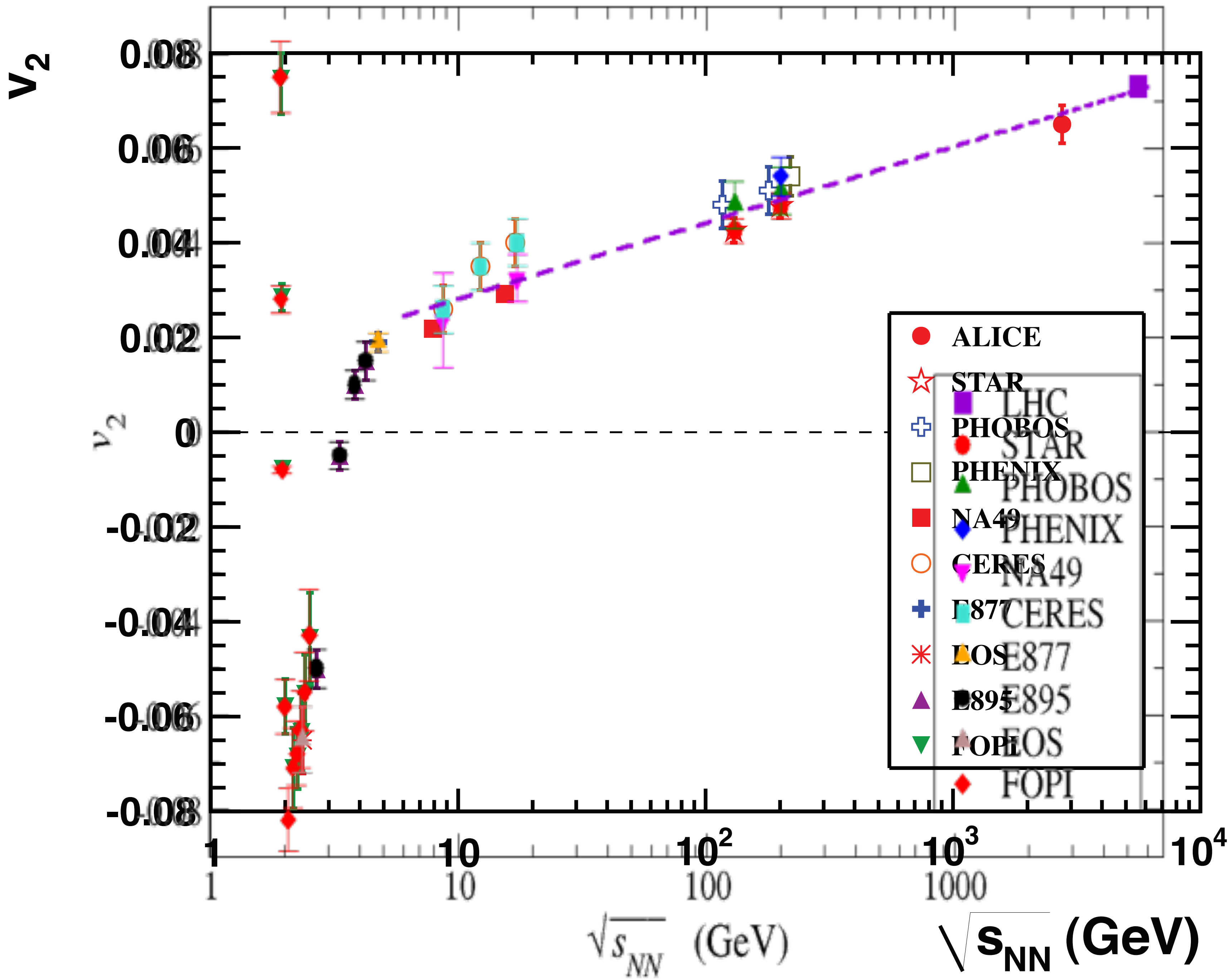
In non-central nucleus-nucleus collisions, the initial spatial asymmetry of the overlap region in the transverse plane is converted by particle rescatterings into an anisotropic transverse-momentum distribution of the outgoing particles: anisotropic flow ☞ v_1, v_2, v_3, v_4...



Non-trivial "emerging" collective behavior: each invidual N-N collision has no knowledge of the impact parameter of the Pb-Pb collision.

large v_2 signals large collectivity!

Anisotropic (collective) flow



ALICE, PRL **105** (2010) 252302

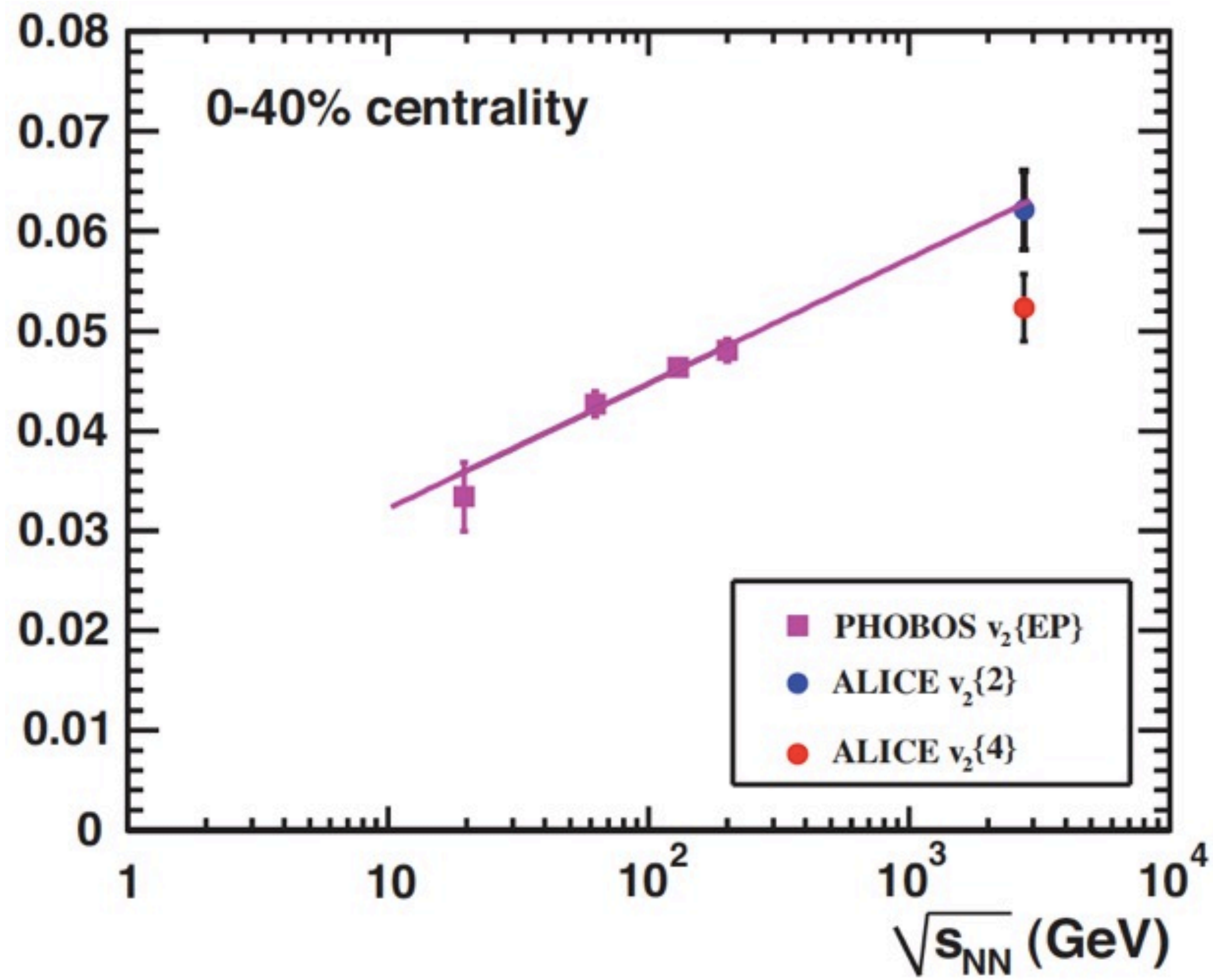
N.B. & Wiedemann 2007

large v_2 signals large collectivity!

trivial?

Anisotropic (collective) flow

More accurate comparison (with similar centrality classes and careful averaging...)



R.Snellings, arXiv:1102.3010

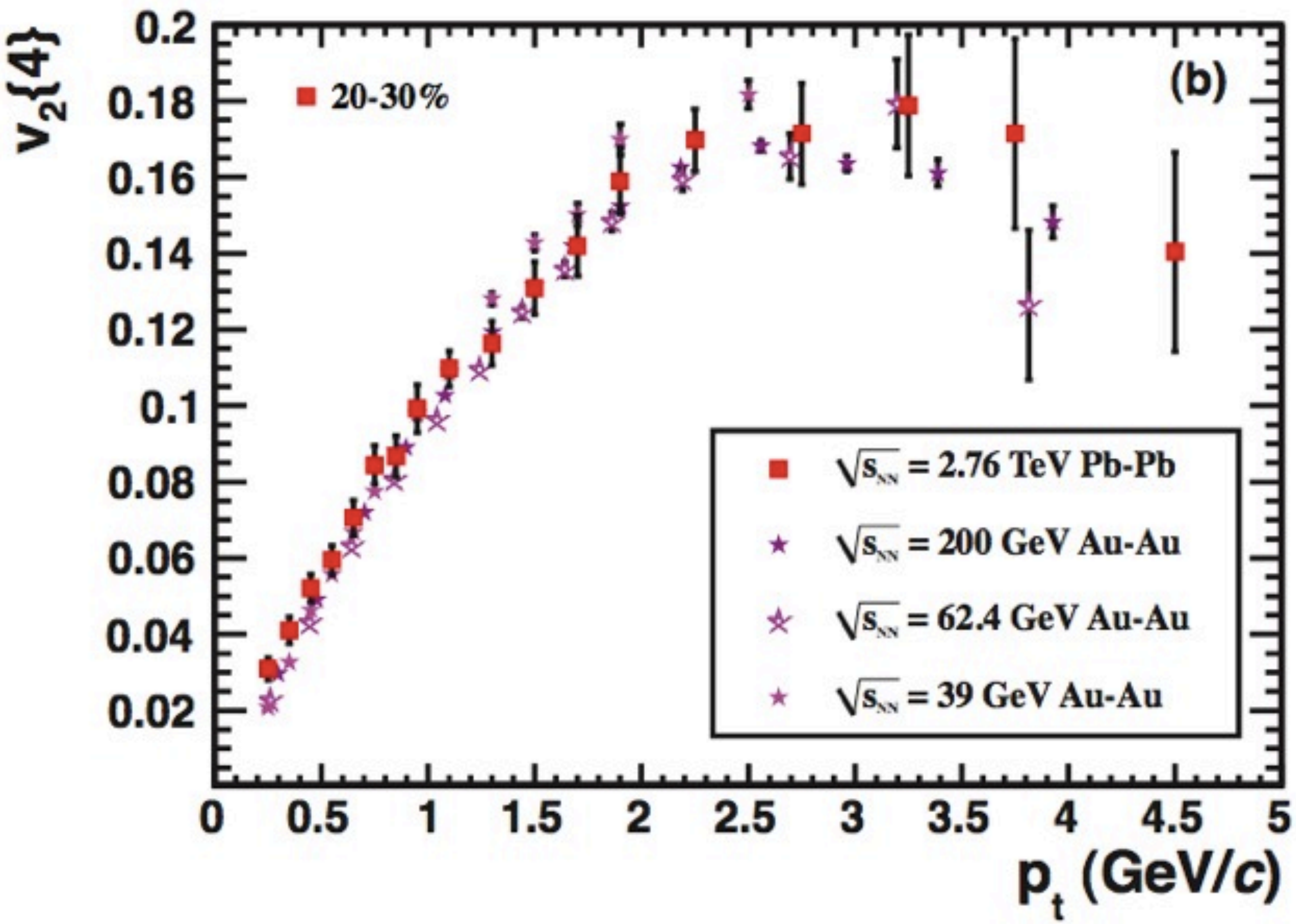
Anisotropic (collective) flow

Increase of average v_2 by 30%...

- "trivial" for a guy with a ruler: linear ln $\sqrt{s_{NN}}$ rise; (so what?)
- evidence(?) for decreasing Knudsen number (Kn $\approx 1/N_{\text{rescatt.}}$);
- embarrassing for supporters of ideal fluid dynamics at all costs;
- can be accommodated in viscous fluid dynamics(?) and / or hybrid models, under the proviso that dissipative effects were present and not negligible at RHIC.

Caveat: average v_2 depends on many ingredients (momentum spectra, initial spatial eccentricity...) irrespective of more dynamical aspects.

Anisotropic (collective) flow



R.Snellings, arXiv:1102.3010

$v_2(p_T)$ (almost) identical from $\sqrt{s_{NN}}$ = 39 GeV to 2.76 TeV

☞ initial eccentricity cannot change by much (or compensating effects?)

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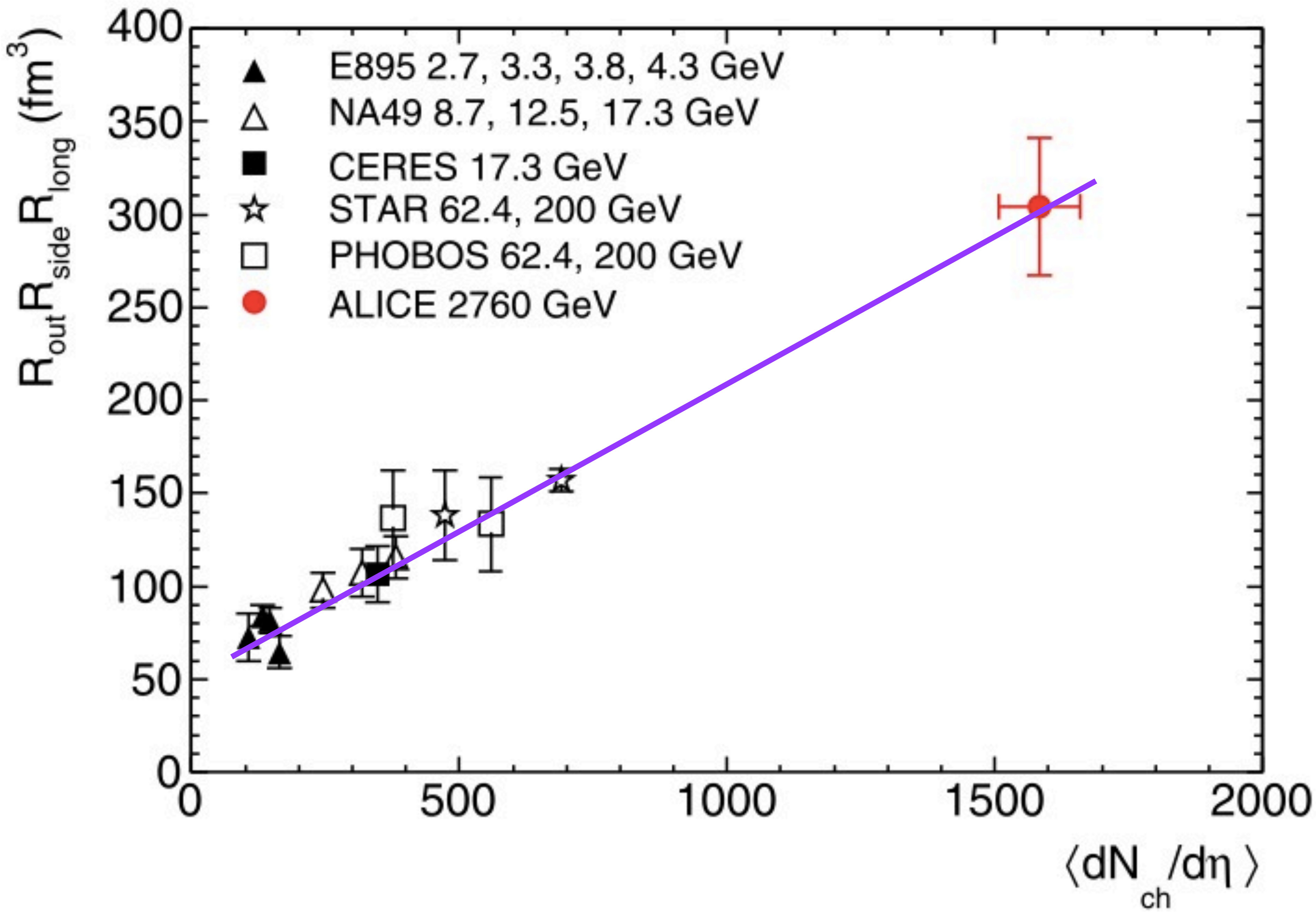
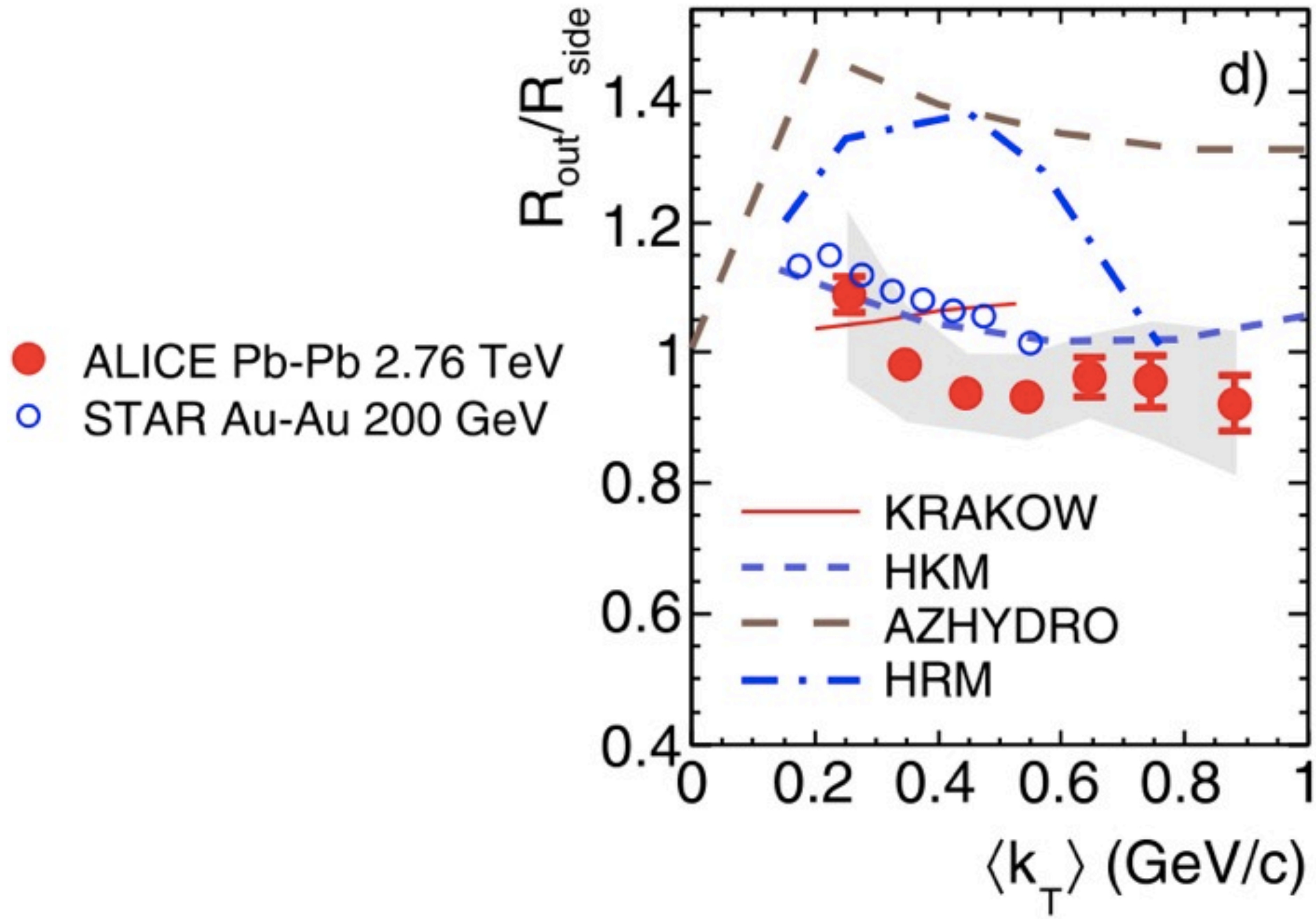
Femtoscopy



ALICE, PLB **696** (2011) 328

Volume increases linearly with charged multiplicity... Nice! unexpected?

Femtoscopy



ALICE, PLB **696** (2011) 328

Is the decreasing $R_{\rm out}/R_{\rm side}$ evidence for decreasing Knudsen number?

Gombeaud, Lappi, Ollitrault 2009

Soft physics: a biased summary

- We have evidence for a collectively evolving medium, which lives longer and expands to a larger size than at lower energies.

undisputed?

- Trends for elliptic flow and HBT radii can be explained in a picture of increasing average number of rescatterings per particle (decreasing Knudsen number) with respect to RHIC.

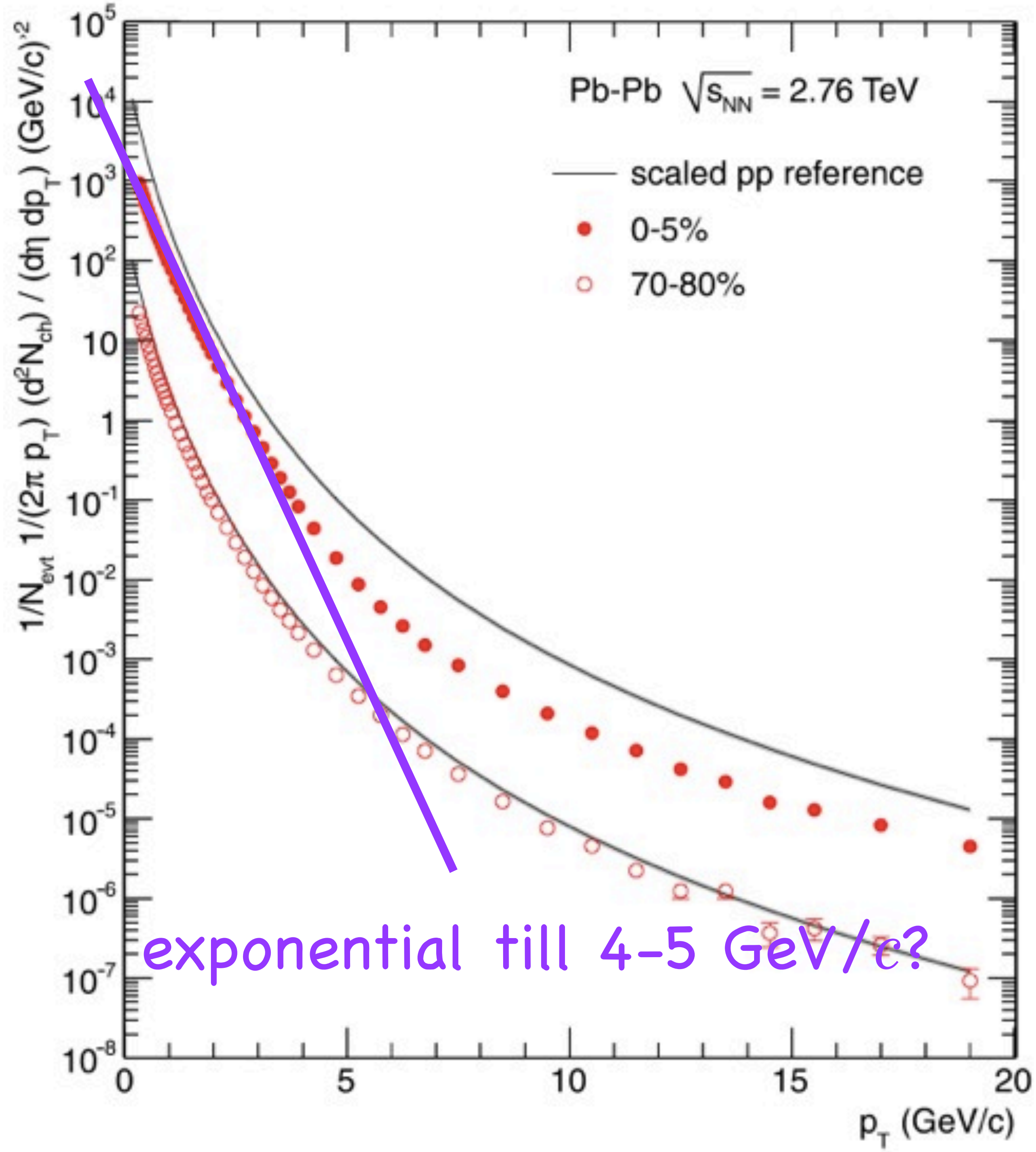
i.e., sizable dissipation at RHIC, significantly less at LHC?

entropy increase is welcome!

- Some features of the "initial state" seem to survive the evolution identically at RHIC and LHC, while others are washed out.

what drives the charged particle multiplicity?

Soft physics: where does it end?



ALICE, PLB **696** (2011) 30

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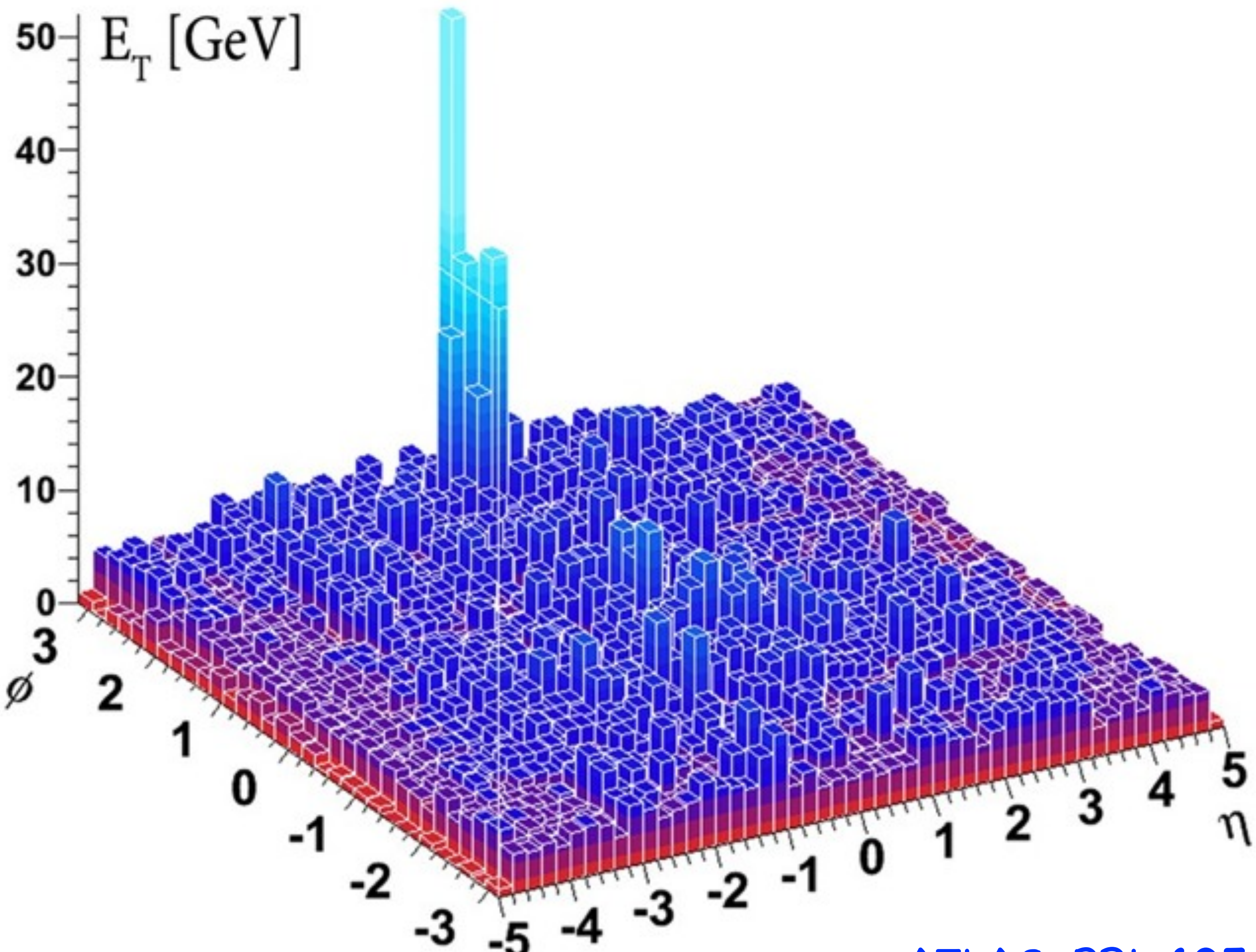
High-p_T particles

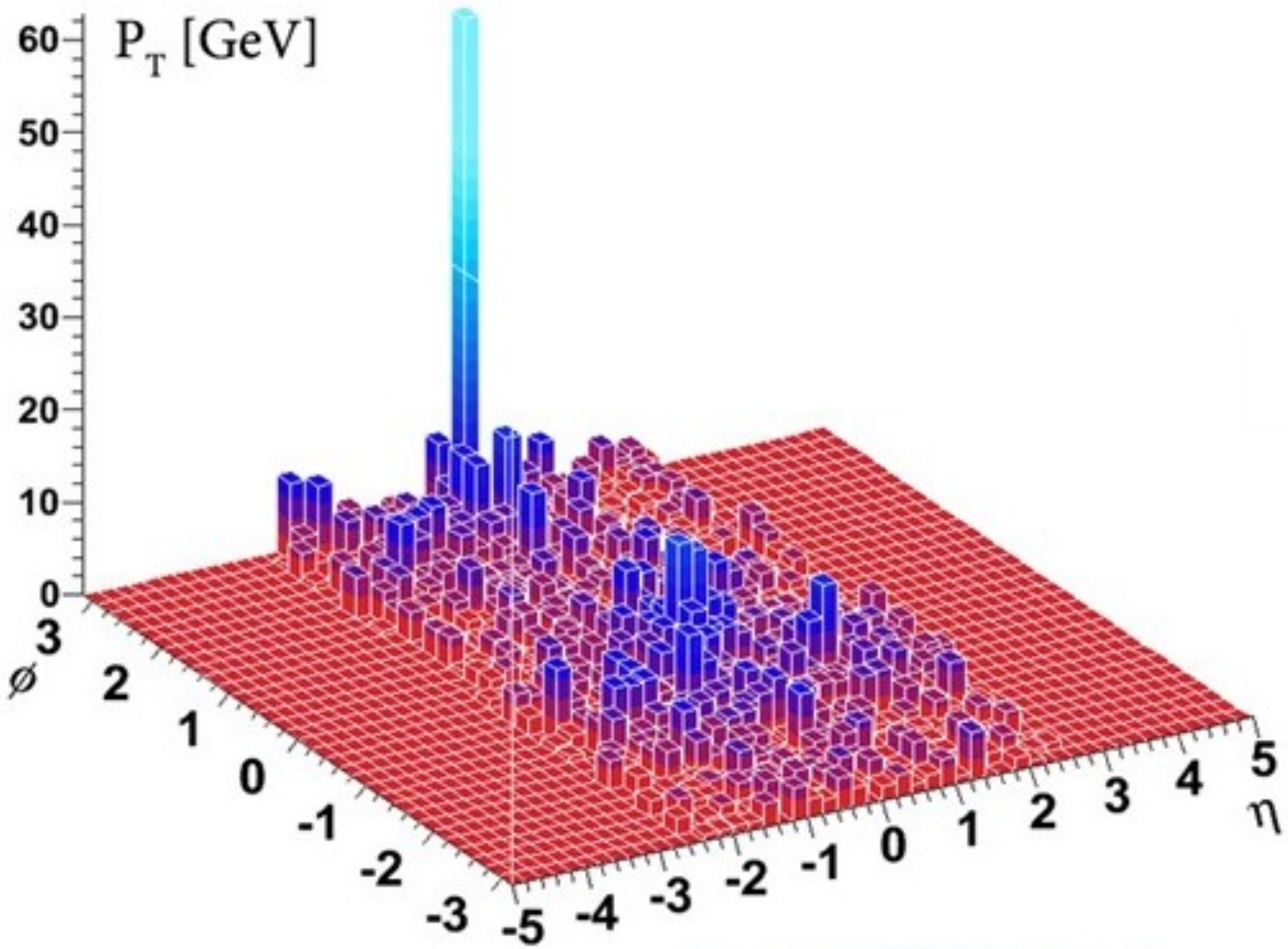
From: ATLAS & CMS heavy-ion groups
To: pp-only practitioners
Subject: We have a dense medium in our detectors!



ATLAS, PRL **105** (2010) 252303

High-p_T particles

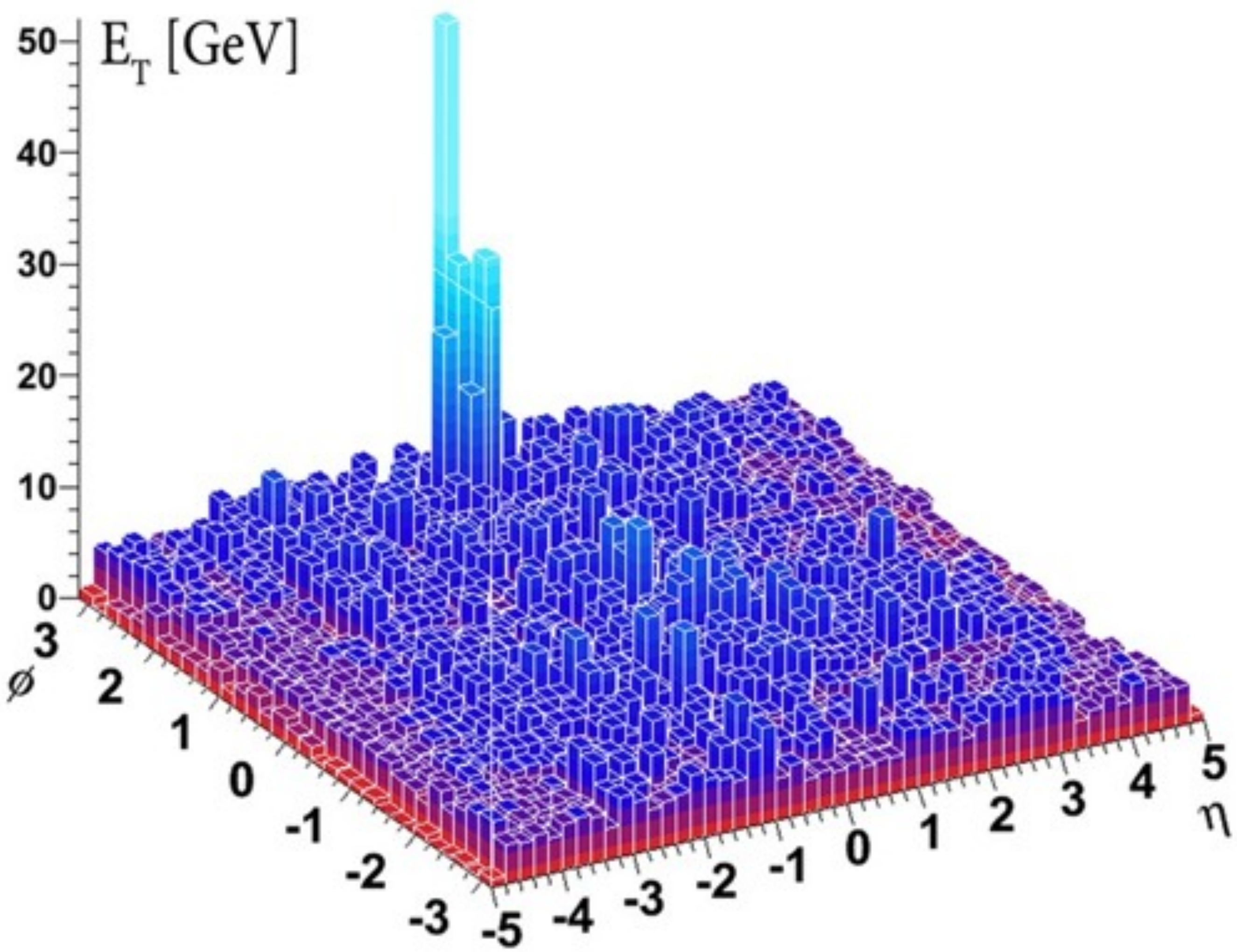
We have a dense medium in our detectors!

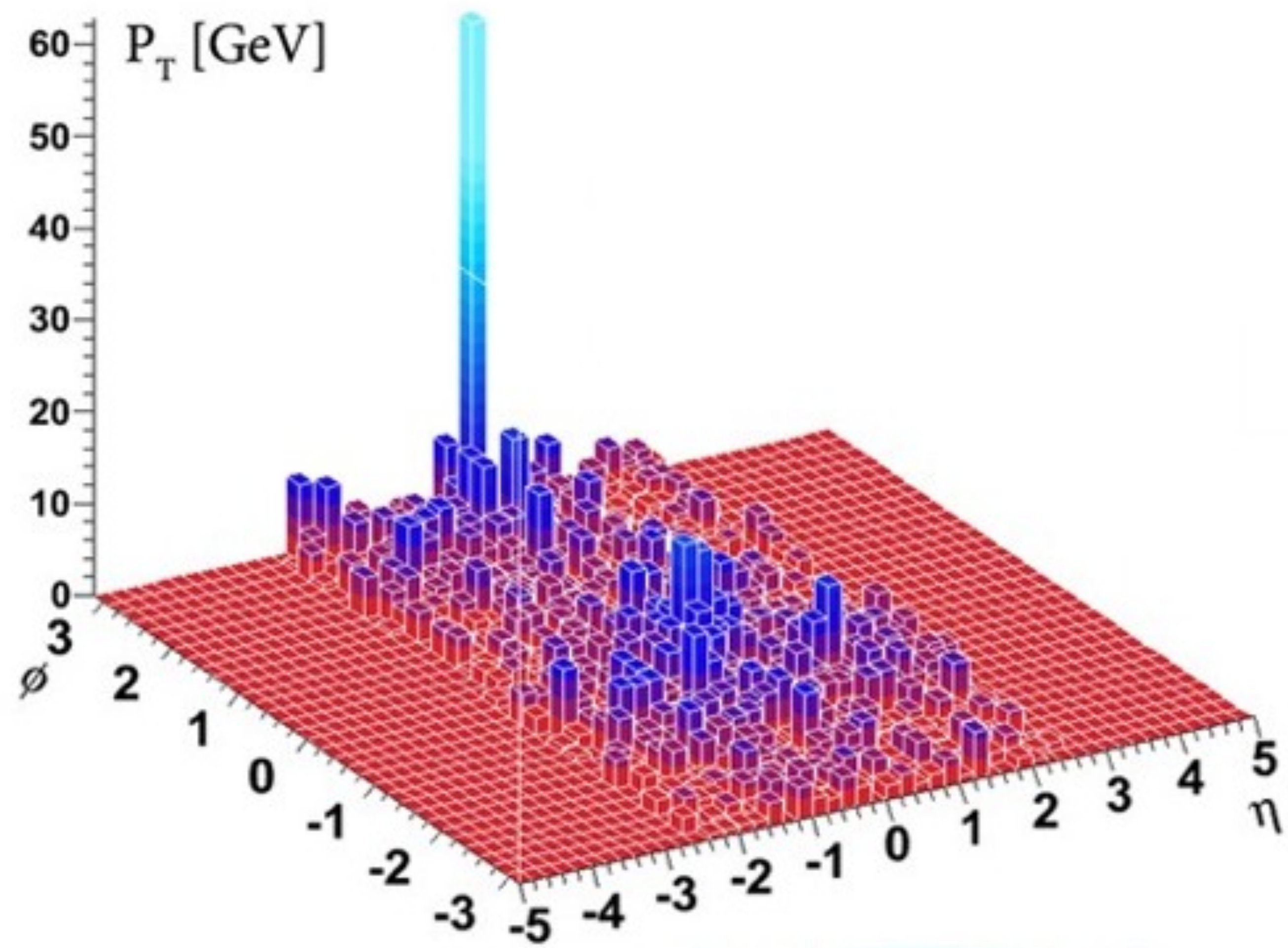


... and it redistributes transverse momentum (p_T is still conserved!)

ATLAS, PRL **105** (2010) 252303

High-p_T particles





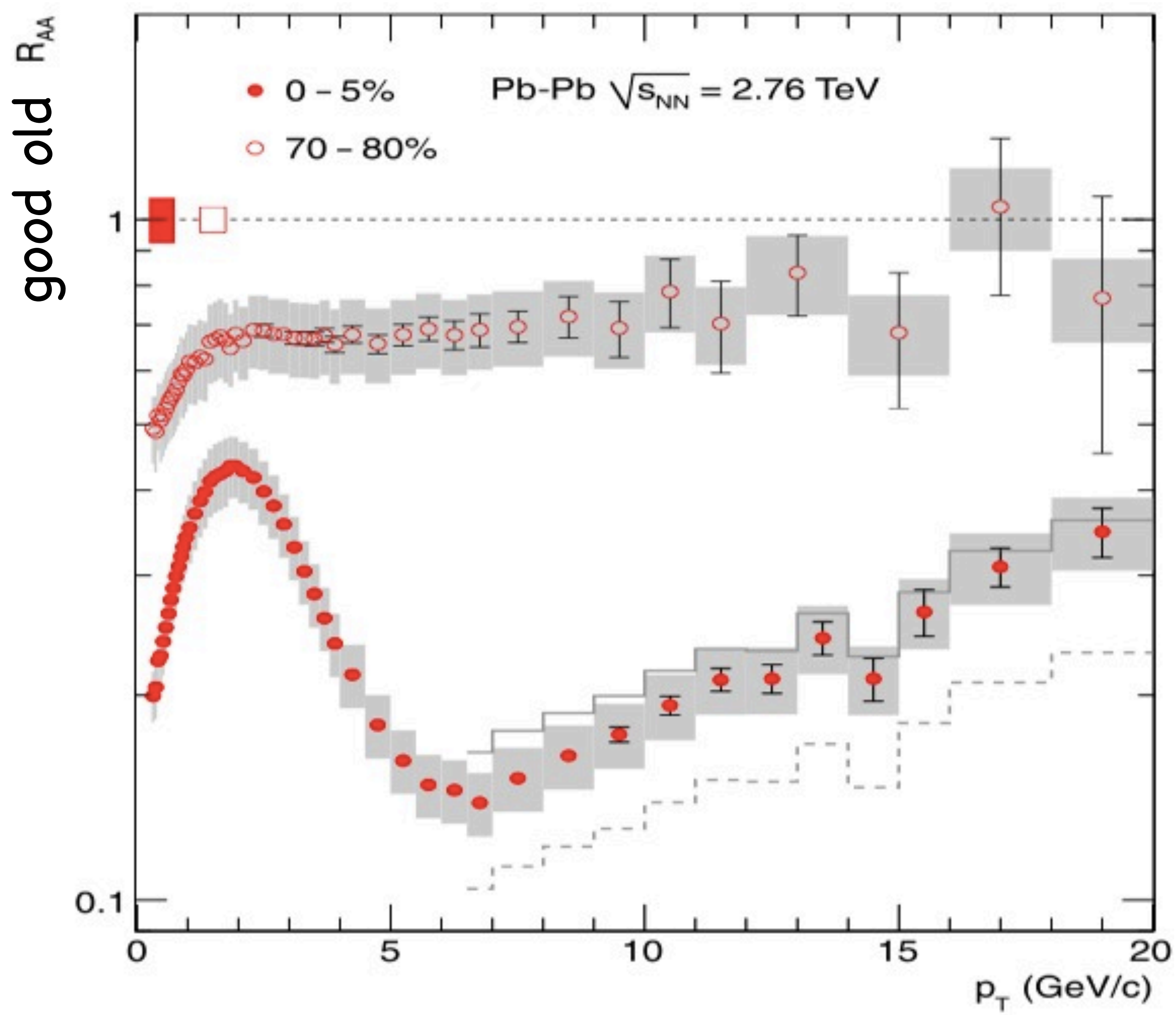
Gorgeous lego plots!

But can we do **quantitative** physics with that?

Not yet... (not your fault!)

Not-so-soft particles

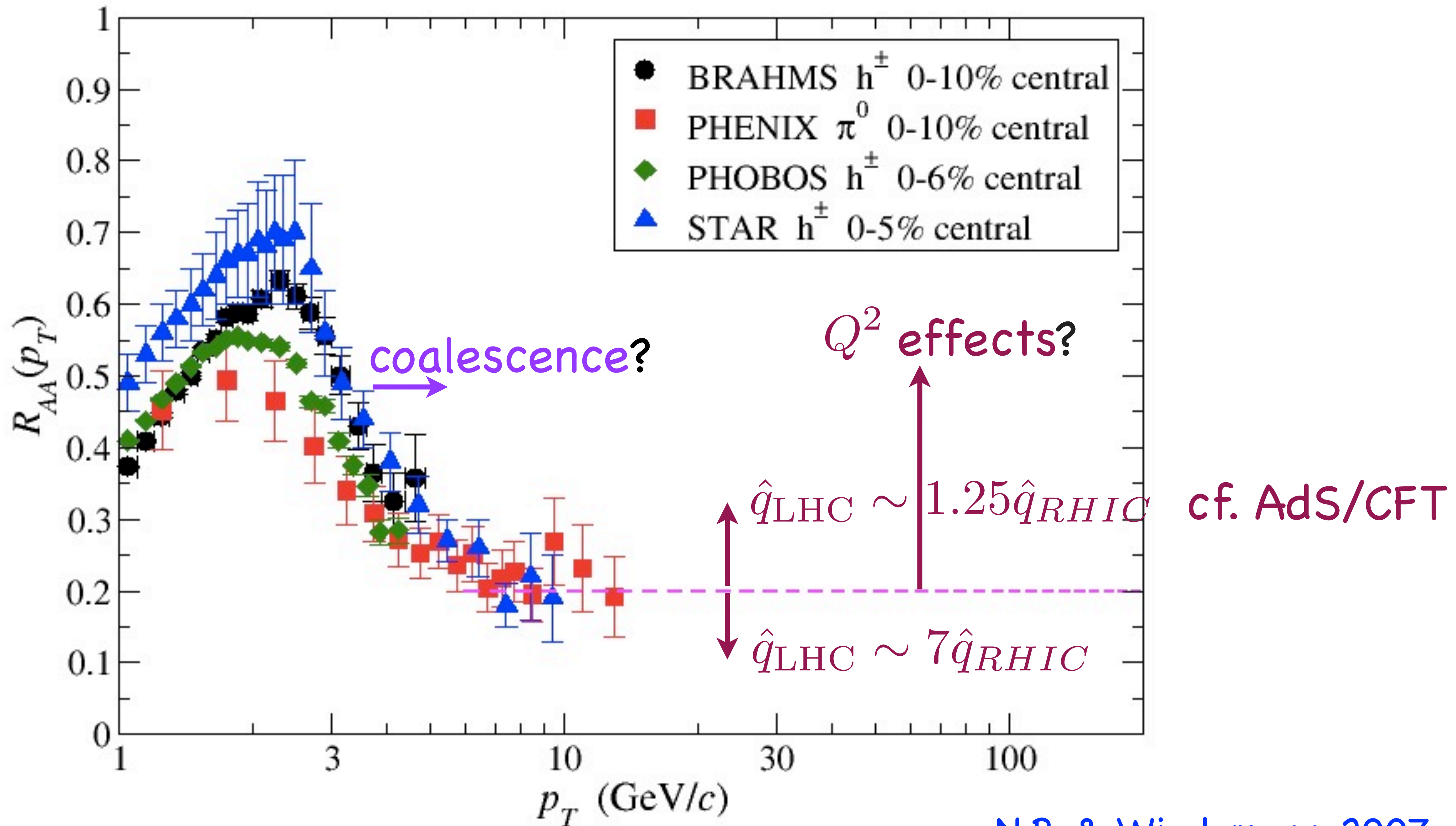
(sorry, calorimeters are hard to compete with...)



Well, in central collisions, this is not flat above 6 GeV/c!

ALICE, PLB **696** (2011) 30

High-p_T particles



N.B. & Wiedemann 2007

Well, in central collisions, the ALICE R_{AA} is not flat above 6 GeV/c...
but any conclusion would be premature!

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… full of promises for the future.

Hard probes: short summary

- "Statistics too low for any quantitative statements" (P.Steinberg)

- Signals embedded in dynamical medium, whose influence needs to be folded in for quantitative comparisons.

- Theorists should clearly think on the "jet" level, rather than only on leading particles.