Soft physics at

Quark Matter Annecy 2011

Jean-Yves Ollitrault, IPhT Saclay
Heavy-ion seminar, IPN Orsay, July 26

Outline

- Multiplicity
- Hadron chemistry
- Particle spectra
- Correlations and flow

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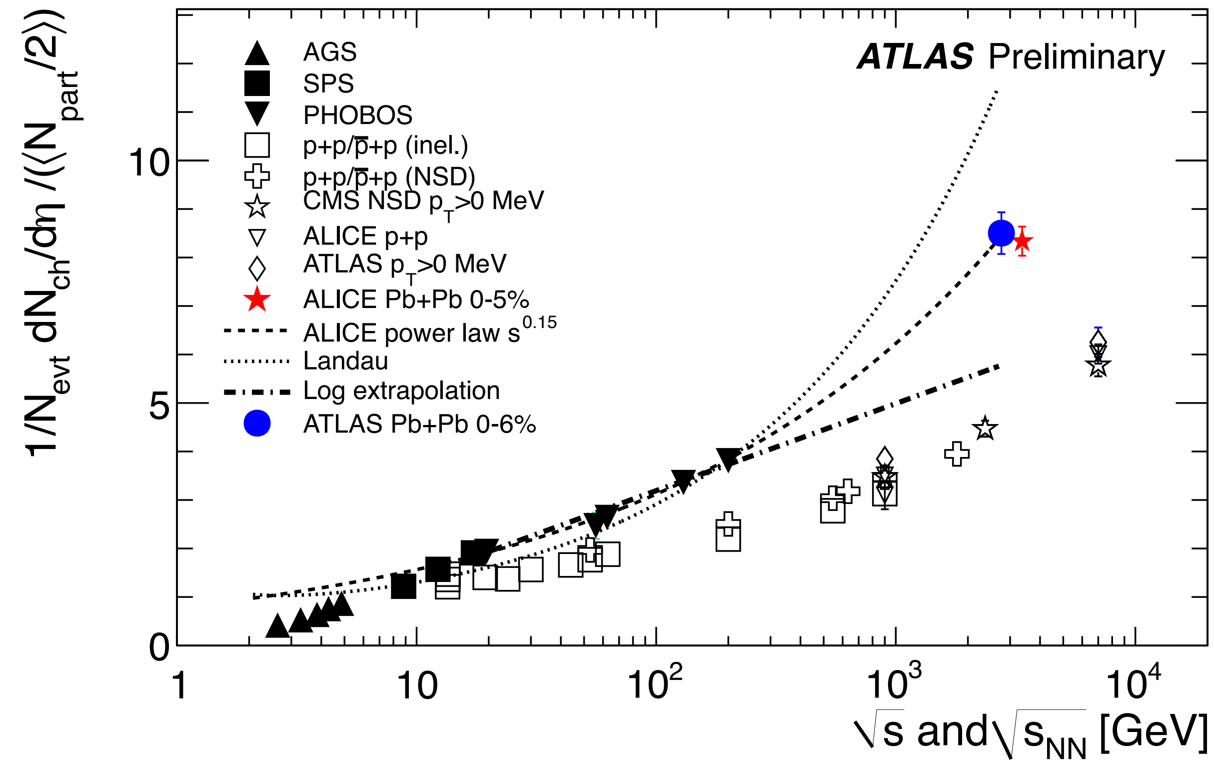
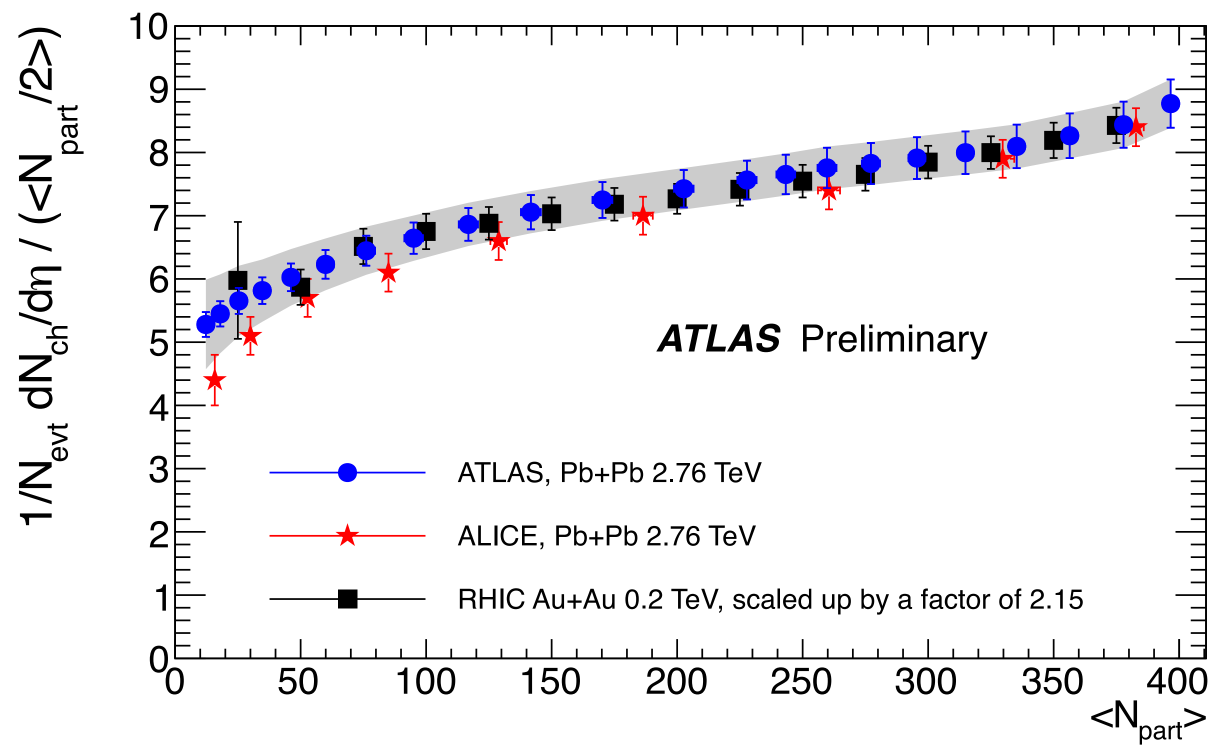
Charged particle multiplicity





Pixel "tracklets" in solenoid-off data, to measure down to p_T>0

Yield per participant pair increases by factor of two relative to RHIC, in agreement with ALICE measurement

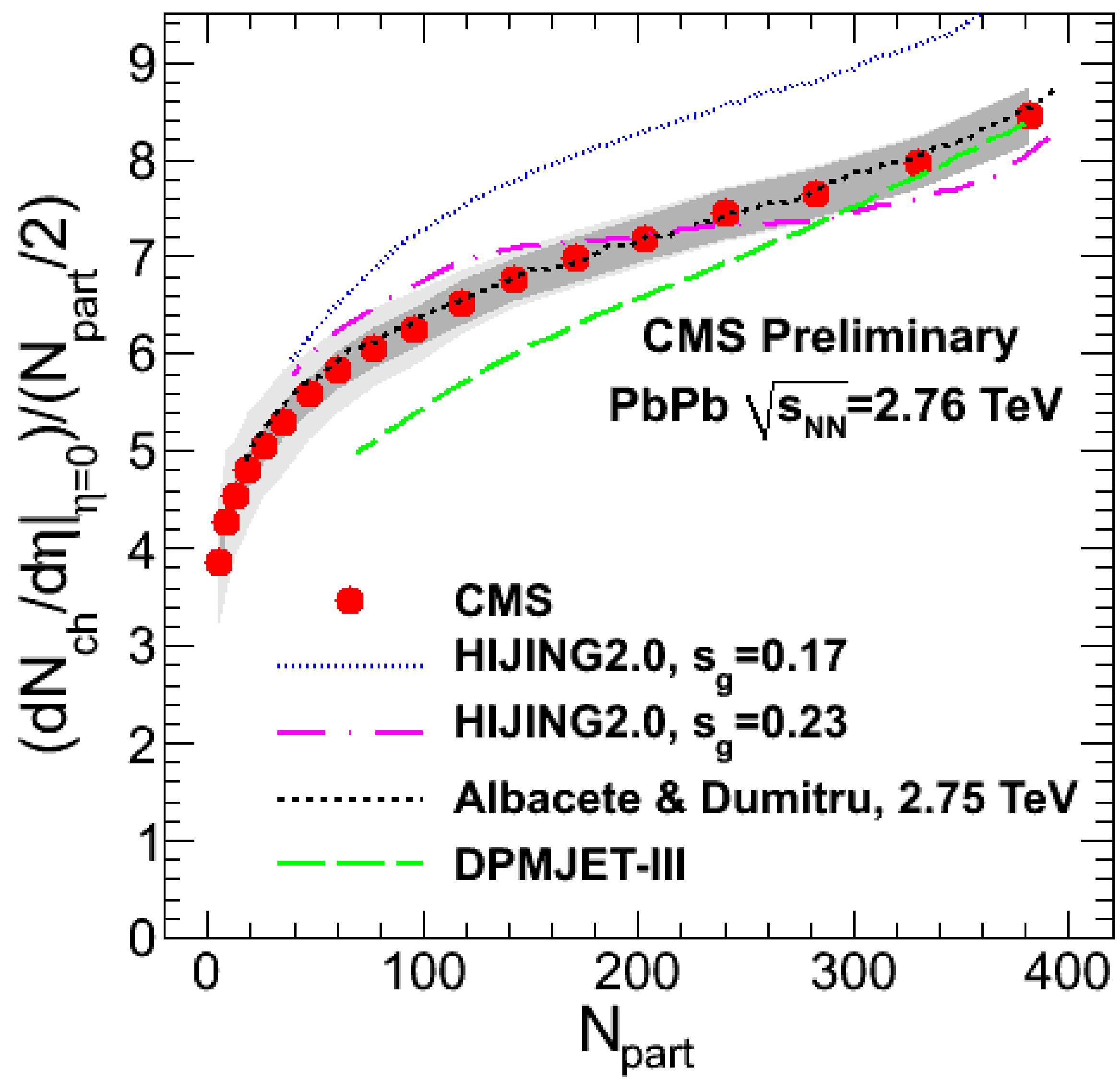
Similar centrality dependence to that found at RHIC (which itself was similar to top SPS energies):

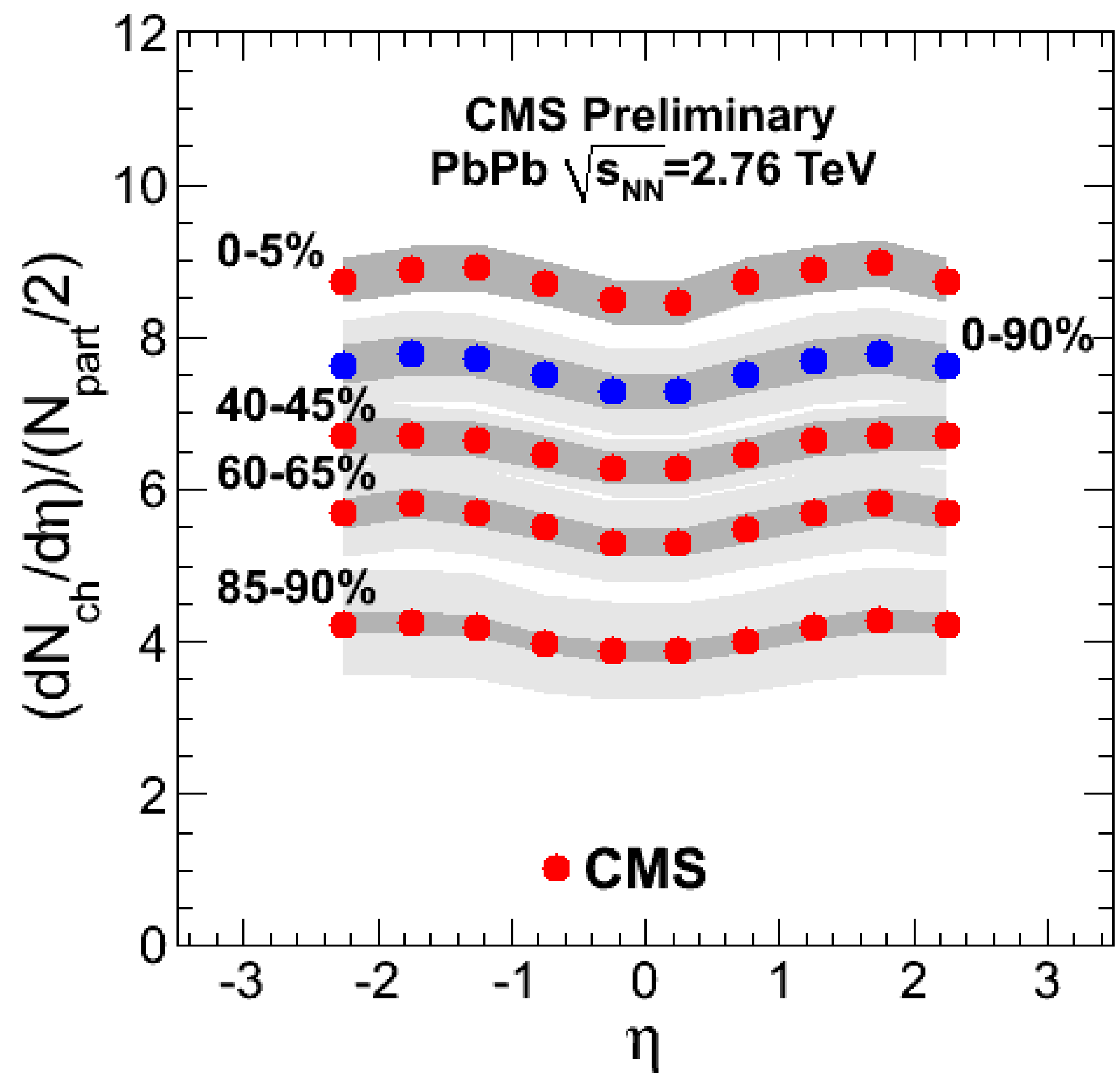
Confirmation of what appears to be a robust scaling feature in HI

for details, see talk by Yujiao Chen (4pm Mon.)

Charged particle multiplicity

- Uses pixel tracker and two methods
- Data taken with no magnetic field, B=0T
- Trigger with 99% efficiency, 1% UPC contamination





- Central multiplicity $dN_{ch}/d\eta = 1610 \pm 55$ for 0–5% centrality

K. Krajczar (TODAY), M. Malek (poster)

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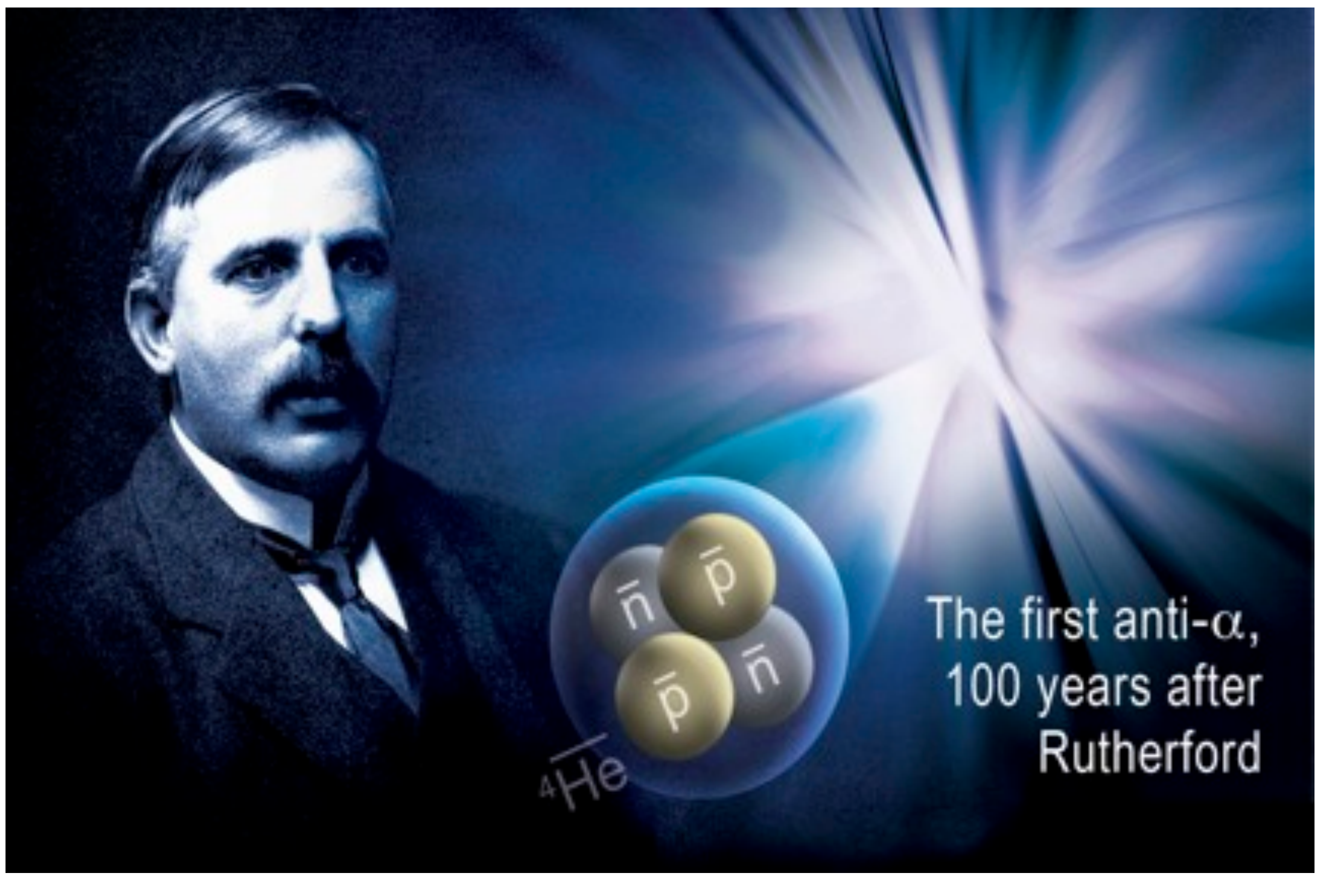
Observation of the antimatter Helium-4 (anti-α) nucleus



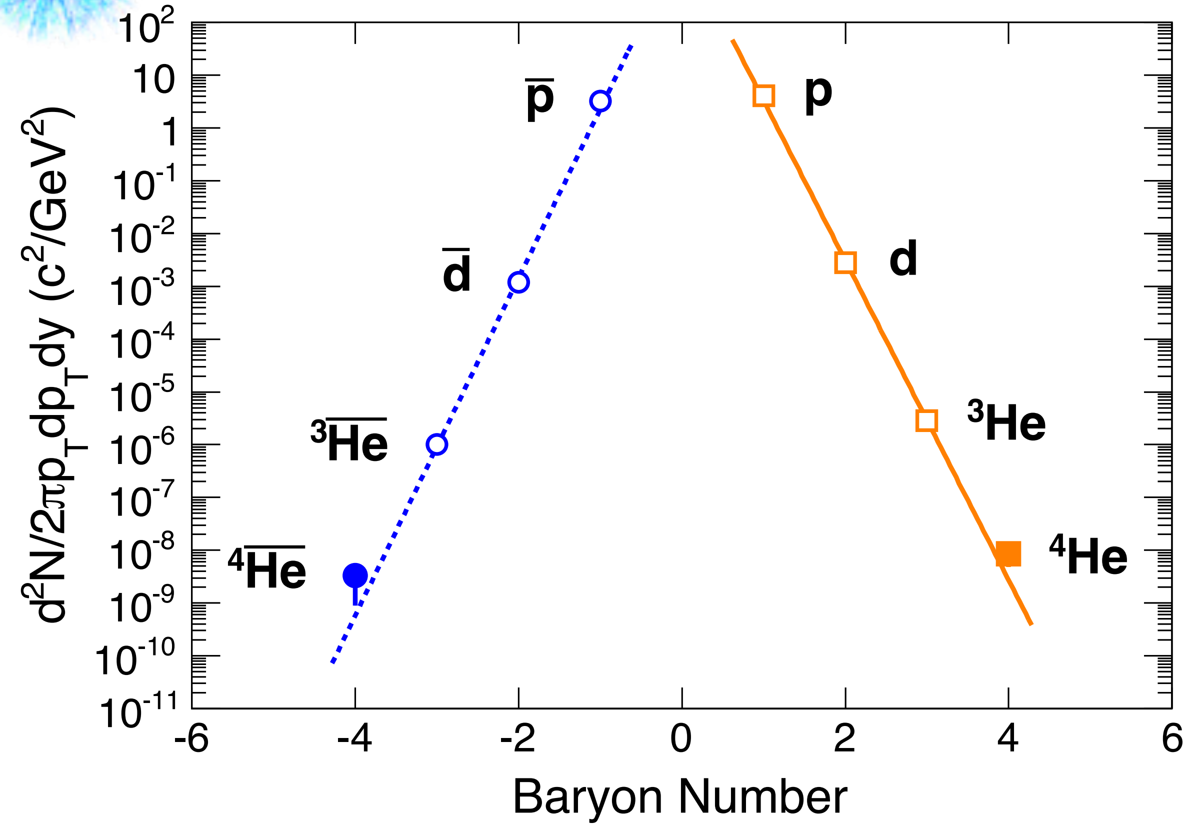
arXiv:1103.3312v2
DOI: 10.1038/nature10079
Nature Vol 473,(2011) 353-356

Liang Xue[a,b]
for the STAR Collaboration

[a]Brookhaven National Laboratory
[b]Shanghai Institute of Applied Physics

- **Introduction & Motivation**
- **Evidence of the observation of $^4\overline{He}$**
- **Quality check for $^4\overline{He}$**
- **$^4\overline{He}$ invariant yields**
- **Summary**

$^4\overline{\mathrm{He}}$ invariant yields



Particle ratios:

– **Measured:**

$^4\mathrm{He}/^3\mathrm{He}$ ~ (3.0±1.3(stat))×10^{-3}
$^4\overline{\mathrm{He}}/^3\overline{\mathrm{He}}$ ~ (3.2±2.3(stat))×10^{-3}

– **Statistical model:**

$^4\mathrm{He}/^3\mathrm{He}$ is ~ 3.1x10^{-3}
$^4\overline{\mathrm{He}}/^3\overline{\mathrm{He}}$ is ~ 2.4x10^{-3}

Andronic, A. et al., Phys. Lett. B 697, 203 (2011)

- An exponential trend is predicted by both coalescence and statistical model.
- Production rate reduce by 1.6×10^3 (1.1×10^3) for each additional anti-nucleon (nucleon) added to the anti-nucleus (nucleus).
- The yield of the stable antimatter nucleus next in line (B = -6) is predicted to be down by a factor of 2.6x10^6 compared to $^4\overline{\mathrm{He}}$ and is beyond the reach of current accelerator technology.

$$E_A \frac{d^3N_A}{d^3p_A} \propto B_A \left(E_p \frac{d^3N_p}{d^3p_p}\right)^A$$

$$E_A \frac{d^3N_A}{d^3p_A} = \frac{gV}{(2\pi)^3} E e^{-m_p A/T}$$

R. Scheibl. PRC 59:1585, (1999)

E. Schnedermann. PRC 48, (1999), 2462

(Schukraft plenary)

the (anti)proton anomaly

- **pp:** Thermus thermal fit rather poor (wasn't this better for pp at lower energies ??)
- **K/π** grows slightly from pp value

(Schukraft plenary)

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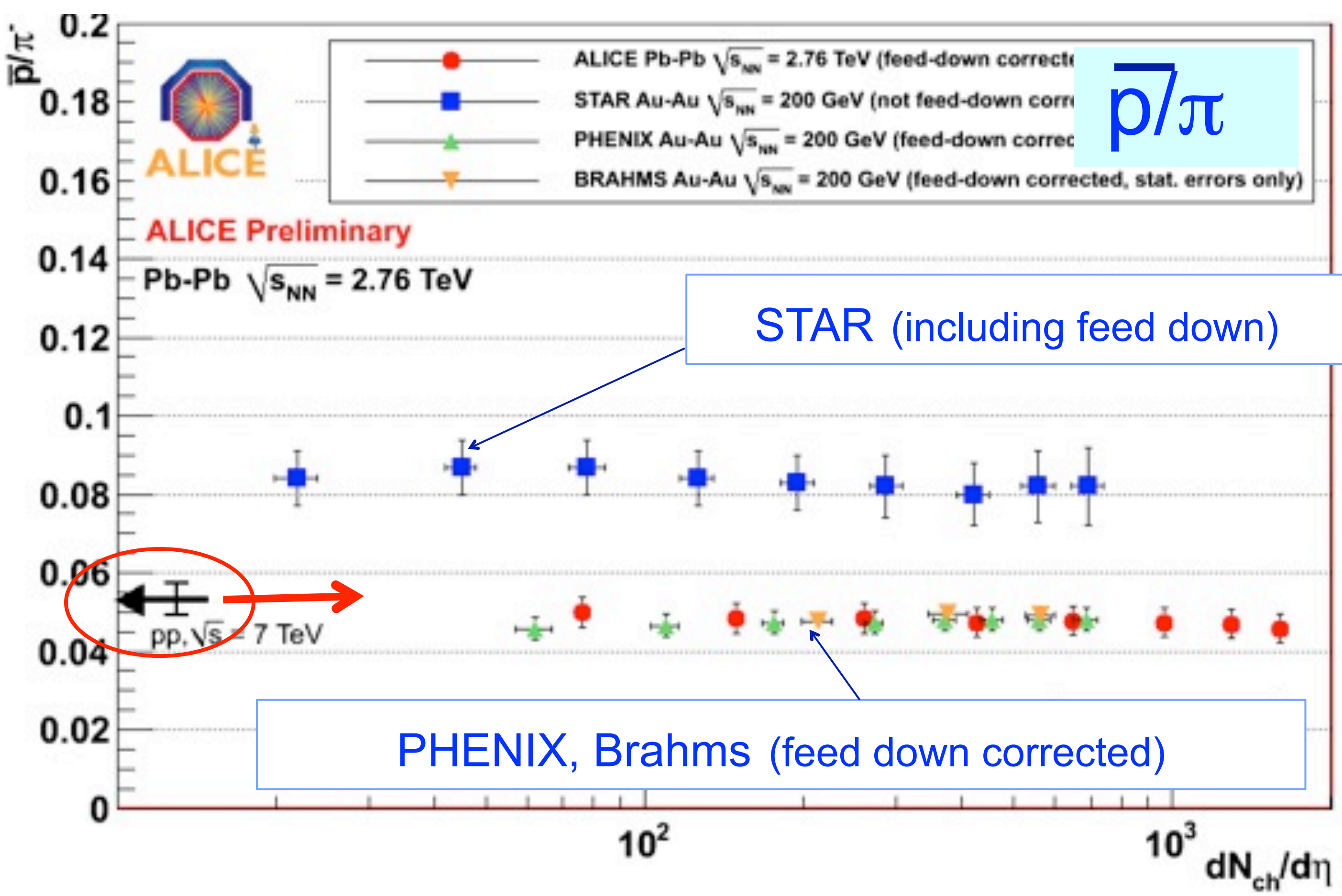
- **K/π** grows slightly from pp value
- **p/π** ≈ like pp



(Schukraft plenary)

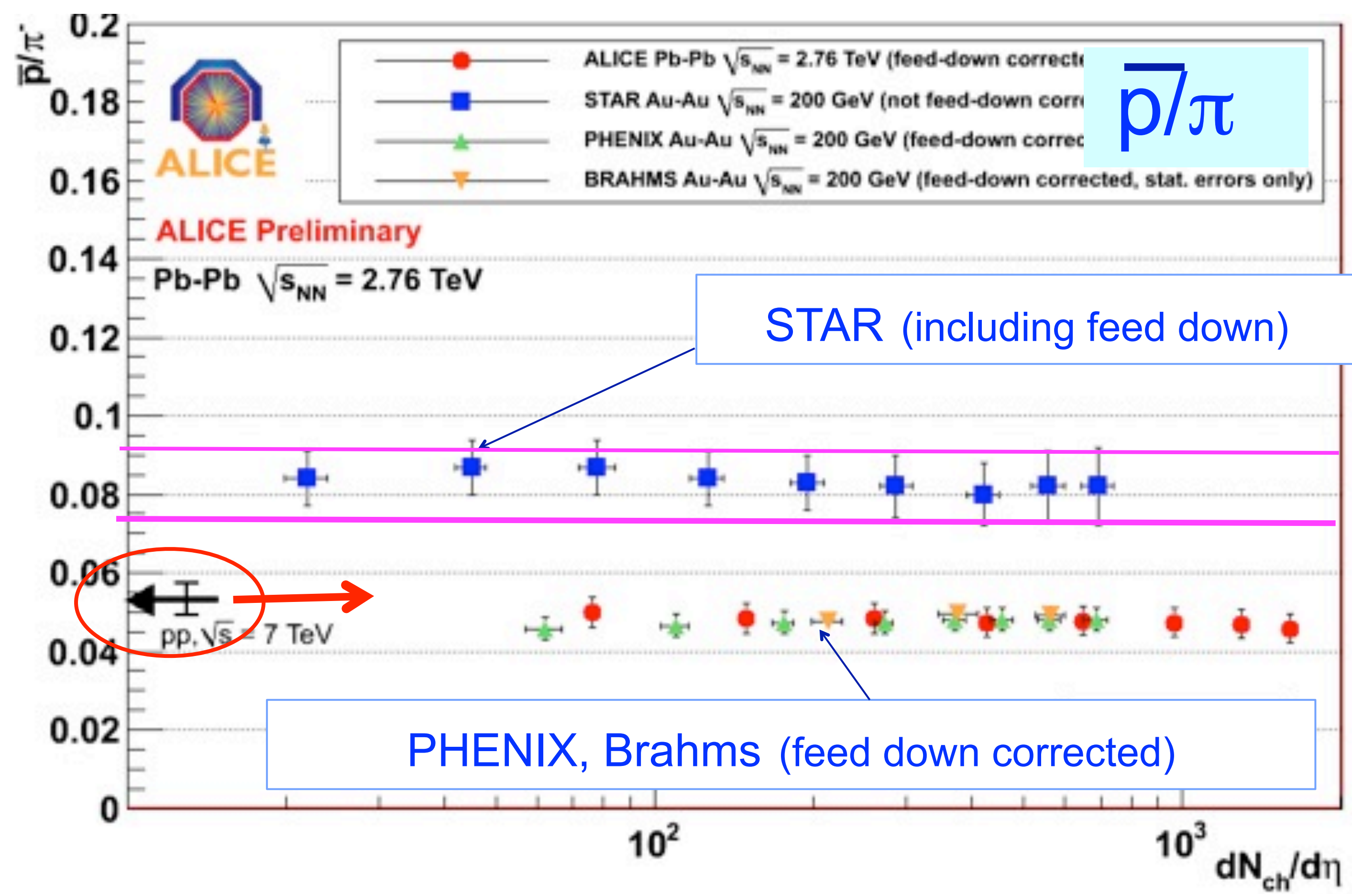
the (anti)proton anomaly

- **pp:** Thermus thermal fit rather poor
 (wasn't this better for pp at lower energies ??)
- **K/π** grows slightly from pp value
- **p/π** ≈ like pp

Pb: p/π off by factor > 1.5 from predictions !

but very compatible with RHIC !!

Before we can conclude anything we need more particle species..



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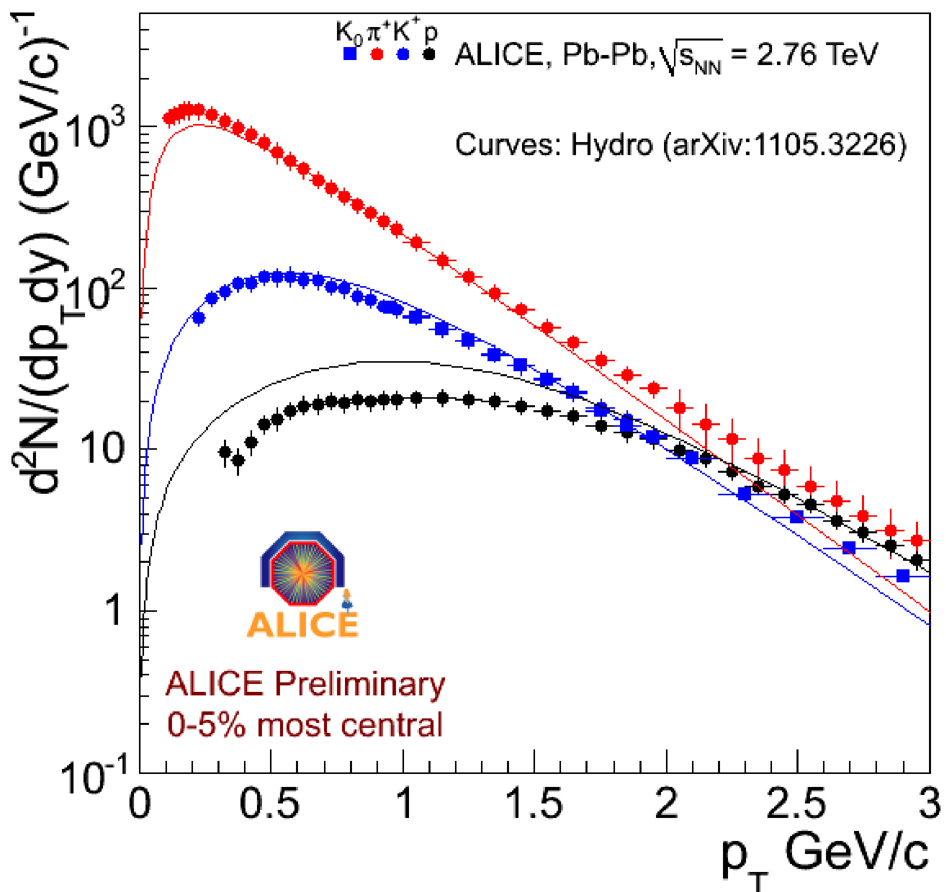
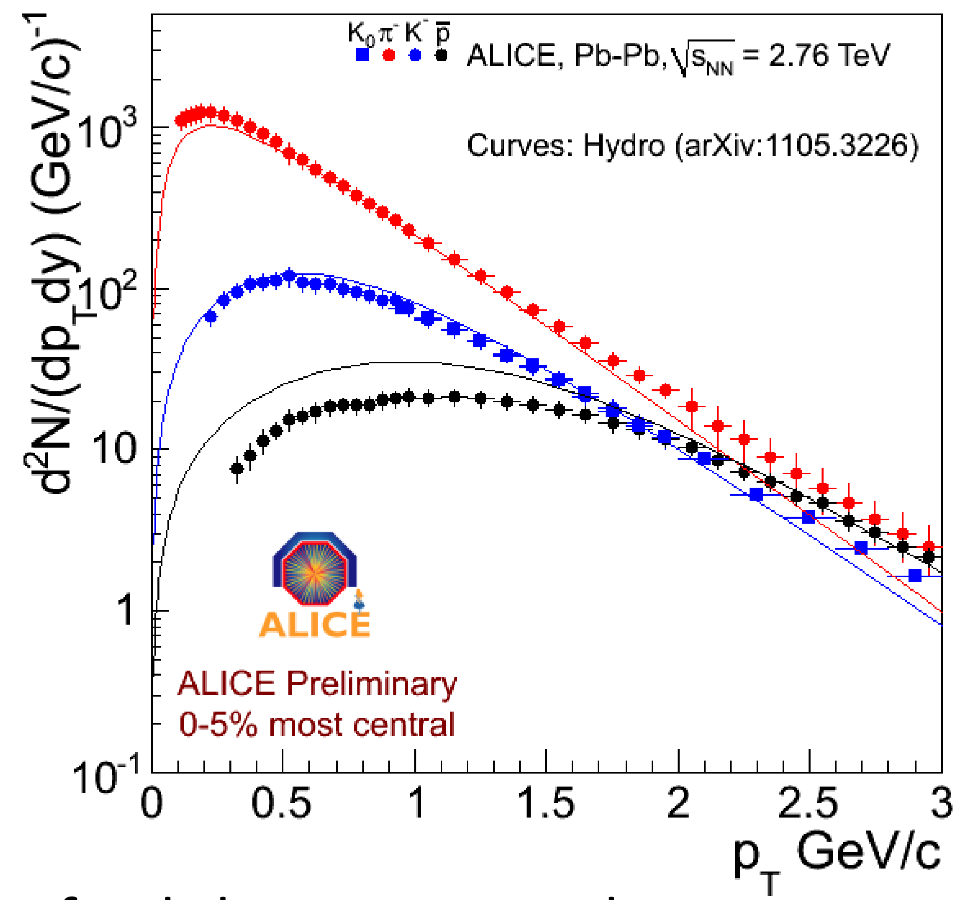
(Michele Floris, plenary)

positive



negative



At RHIC: STAR proton data generally not feed-down corrected.

Large feed down correction

➔ Consistent picture with feed-down corrected spectra

At LHC: ALICE spectra are feed-down corrected

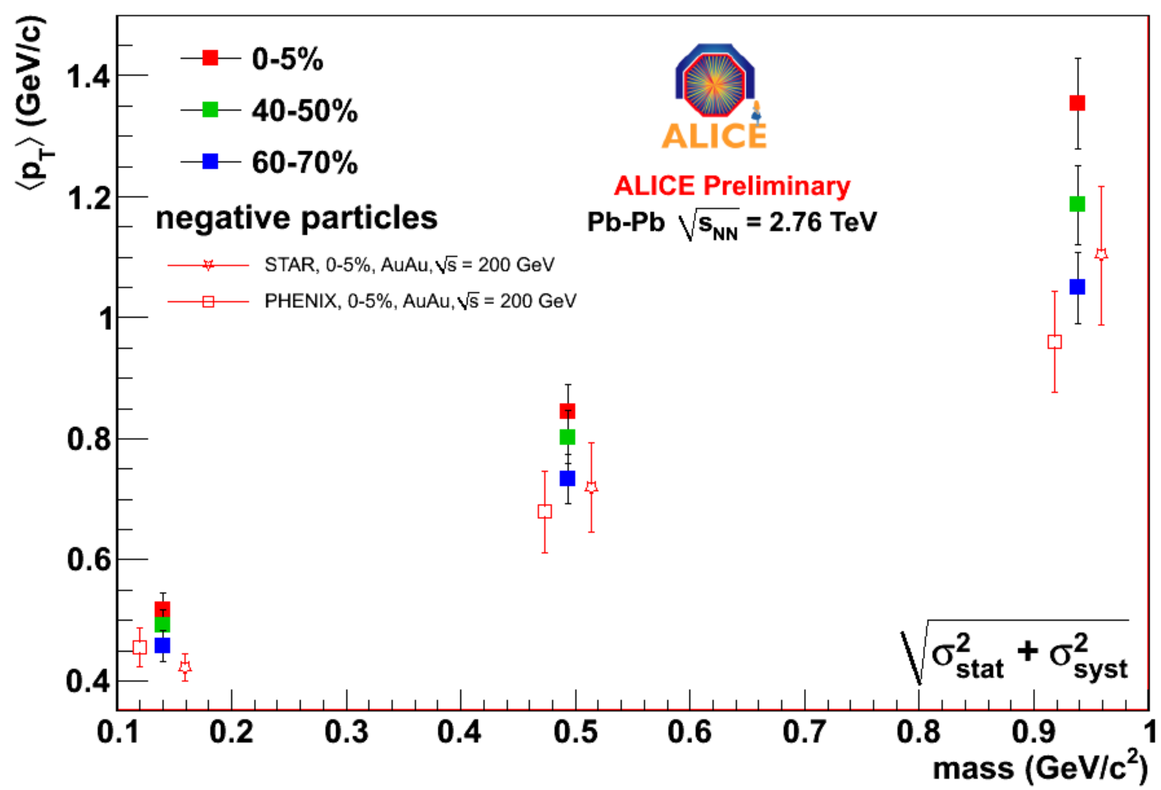
- Harder spectra, flatter p at low pt
- Strong push on the p due to radial flow?

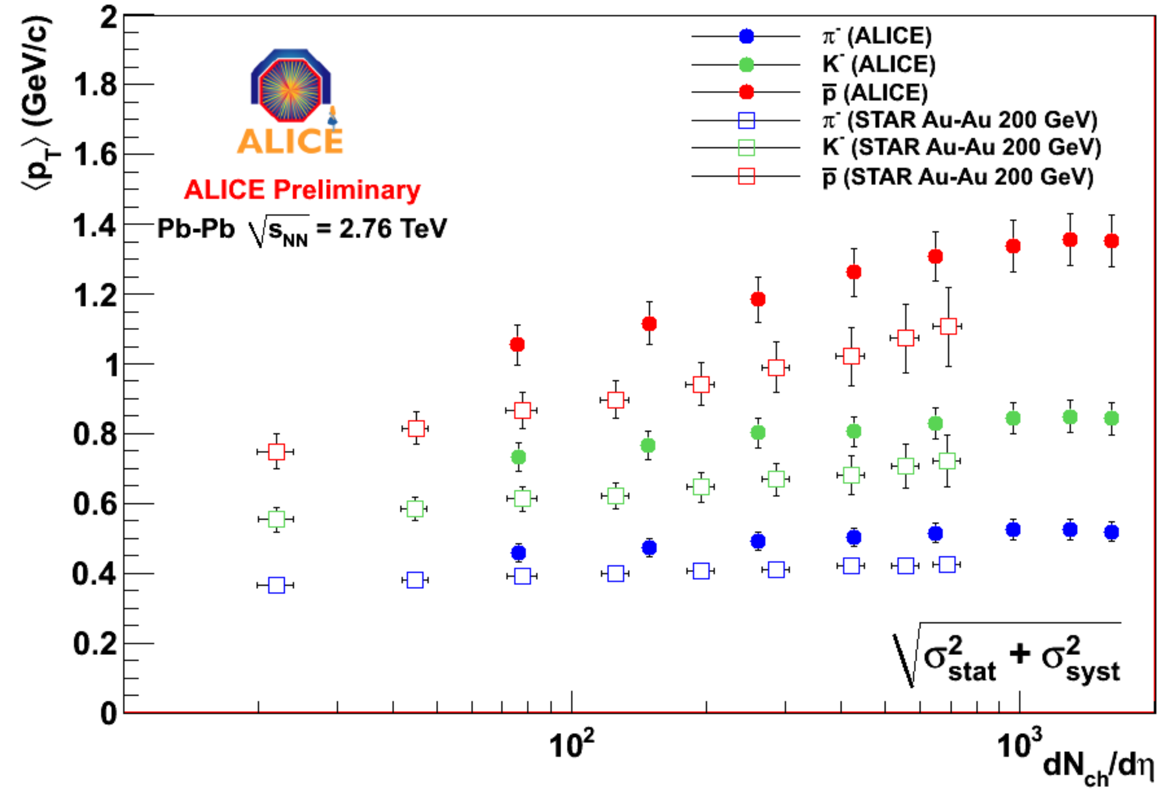
STAR, PRL97, 152301 (2006)

STAR, PRC 79 , 034909 (2009)

PHENIX, PRC69, 03409 (2004)

(Michele Floris, plenary)





Mean p_T increases linearly with mass

Higher than at RHIC (harder spectra, more flow?)

For the same dN/dη higher mean p_T than at RHIC

Density increases by 2.15 from RHIC to LHC

Mean pt of pions (~T) increases only by 10%: soft equation of state

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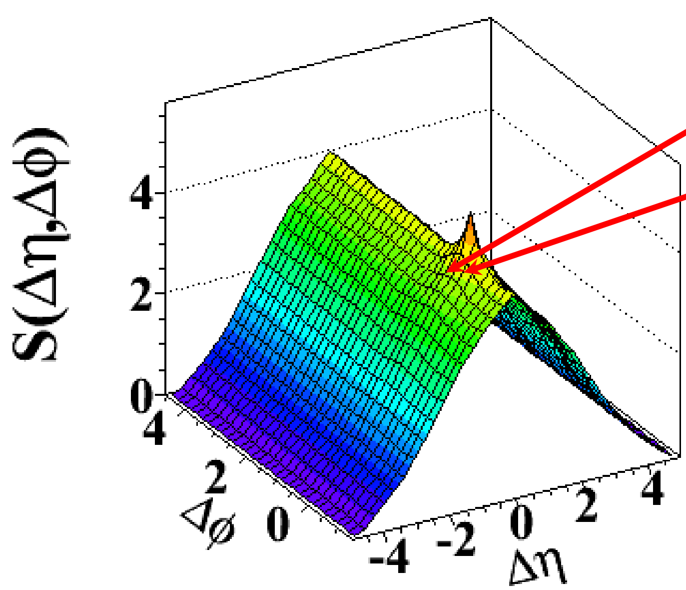
Dihadron correlation technique in CMS

Particle 1: trigger
Particle 2: associated

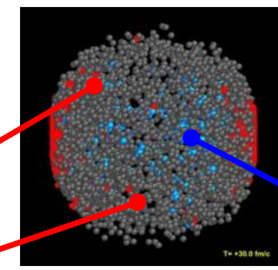
Signal distribution:

$$S(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\varphi}$$

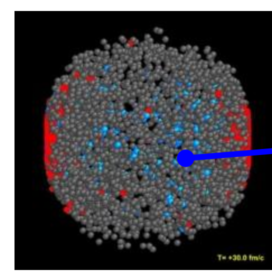


same event pairs

Event 1

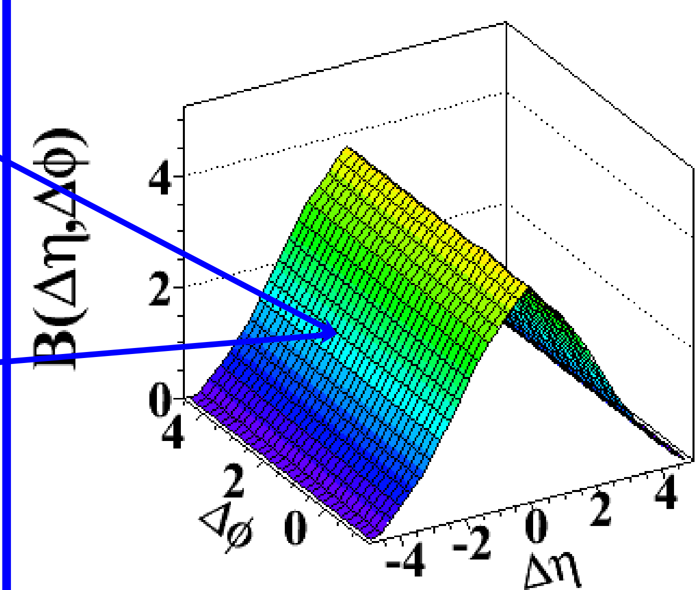


Event 2



Background distribution:

$$B(\Delta\eta,\Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\varphi}$$



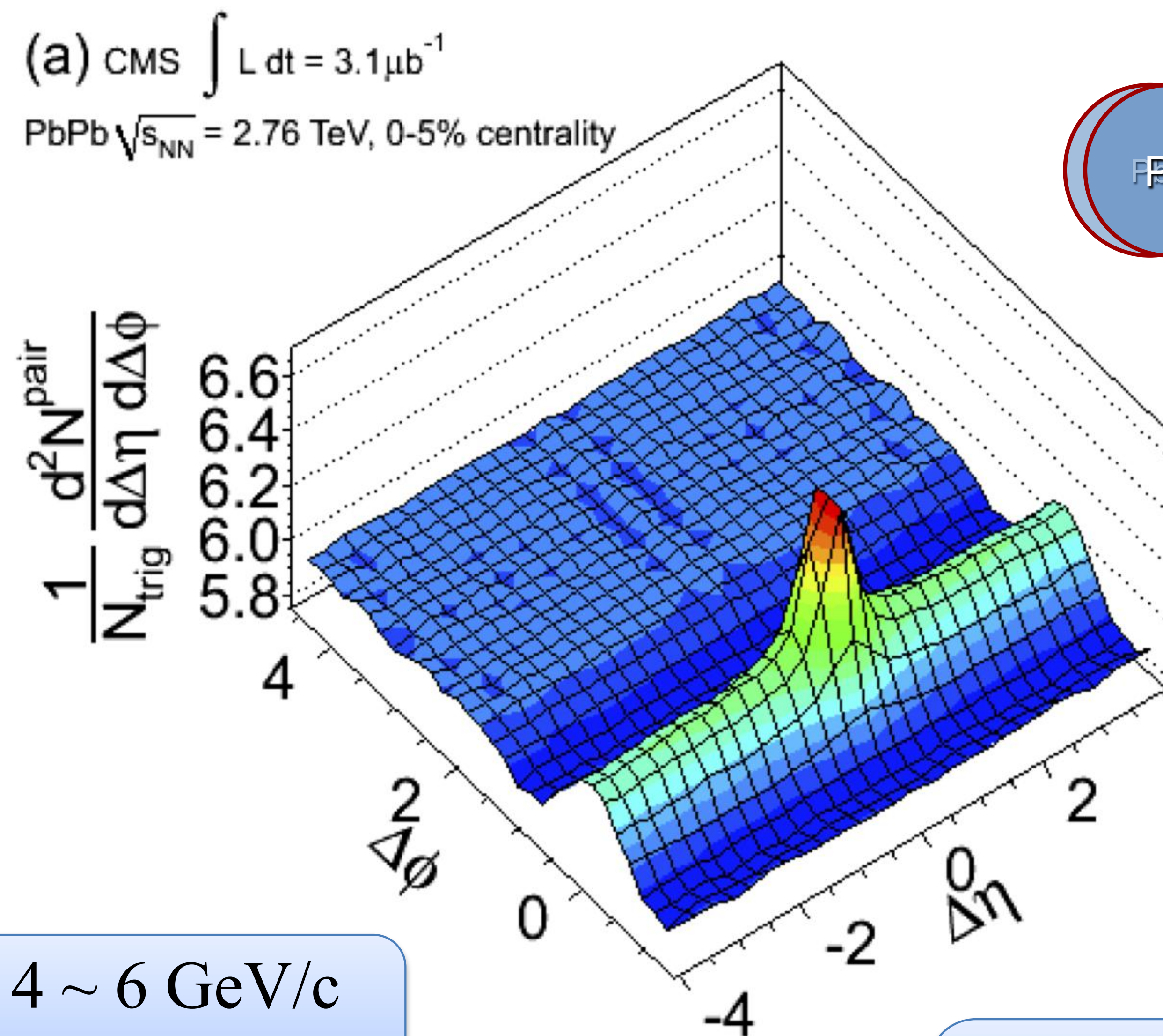
mixed event pairs

$\Delta\eta = \eta^{assoc} - \eta^{trig}$
$\Delta\phi = \phi^{assoc} - \phi^{trig}$

Associated hadron yield per trigger:

$$\frac{1}{N_{trig}} \frac{d^2N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

Heavy-ion "ridge" at LHC



0-5% most central

arXiv:1105.2438

p_T^{trig} : 4 ~ 6 GeV/c
p_T^{assoc}: 2 ~ 4 GeV/c

Associated hadron yield per trigger:

$$\frac{1}{N_{trig}} \frac{d^2N^{pair}}{d\Delta\eta d\Delta\phi} = B(0,0) \times \frac{S(\Delta\eta,\Delta\phi)}{B(\Delta\eta,\Delta\phi)}$$

See talk by Jeremy Callner (05/24, 3:20pm)

Flow vs. non-flow correlations

(Adare parallel)

Collective effects

Flow-related effects imply correlation through a plane of symmetry ψ_n.

Flow-dominated correlations should factorize:

$$\langle \cos n\Delta\varphi \rangle = \langle \cos n(\varphi_{trig} - \varphi_{assoc}) \rangle$$
$$= \langle \cos n(\varphi_{trig} - \psi_n) \rangle \langle \cos n(\varphi_{assoc} - \psi_n) \rangle$$
$$= v_n(p_{Ttrig})\, v_n(p_{Tassoc})$$

Pair coefficients are just products of familiar single-particle v_ns.

Jet-related effects

A few energetic particles are highly correlated by fragmentation, but not directly through ψ_n.

Caveat: there can be indirect correlations, i.e. length-dependent quenching.
Would be largest w.r.t. ψ_2 since it reflects the collision geometry.

The collectivity relation

$$\langle \cos n\Delta\varphi \rangle \stackrel{?}{=} v_n(p_{Ttrig})\, v_n(p_{Tassoc})$$

is a quantitative hypothesis that can be tested!

Global fit of 2-particle Fourier moments

Find best $v_n(p_T)$

Fit <cos nΔφ> for all p_T bins simultaneously

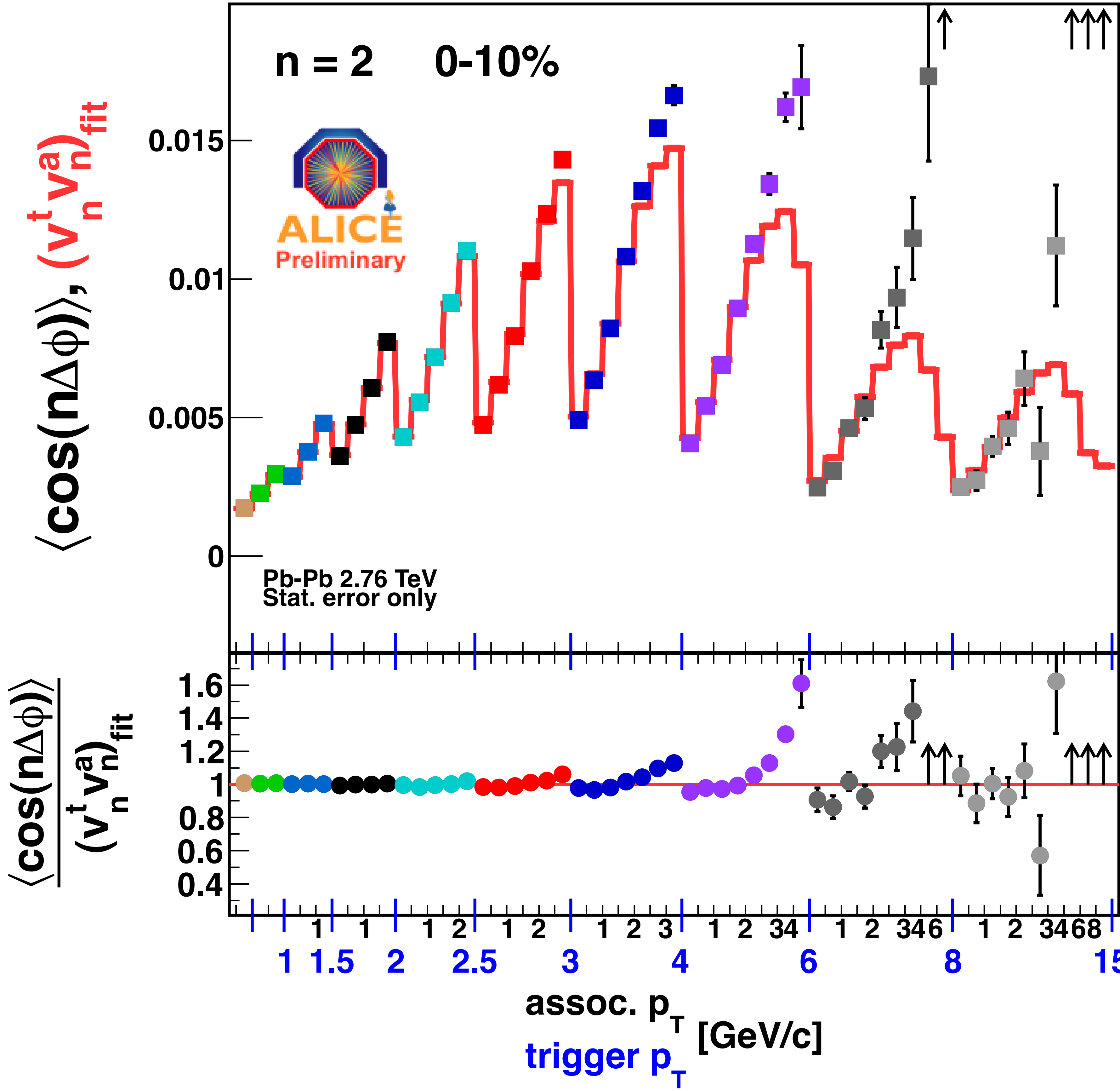
Fit function: $V_{n\Delta} = v_n^t \, v_n^a$.

Fit breaks at high p_T, where jets dominate.

Key idea

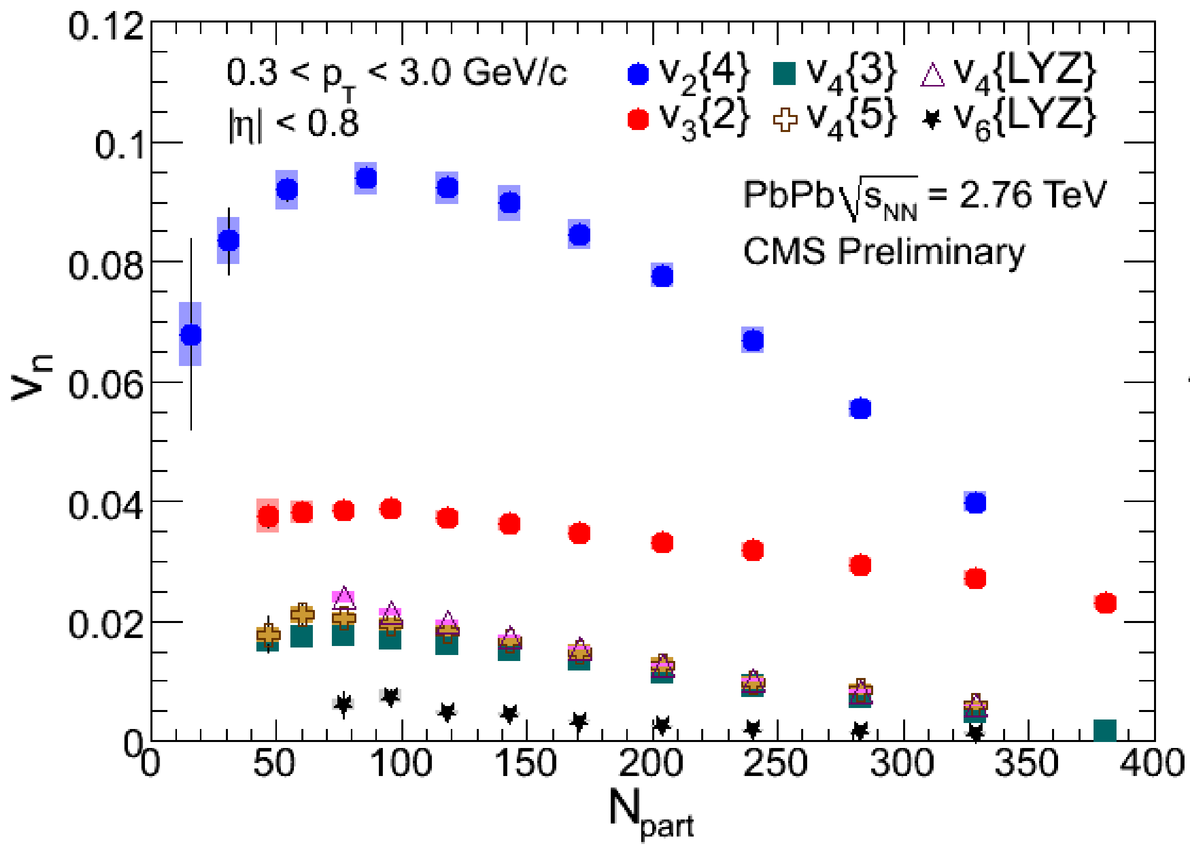
If fit matches data
suggests flow-type correlations

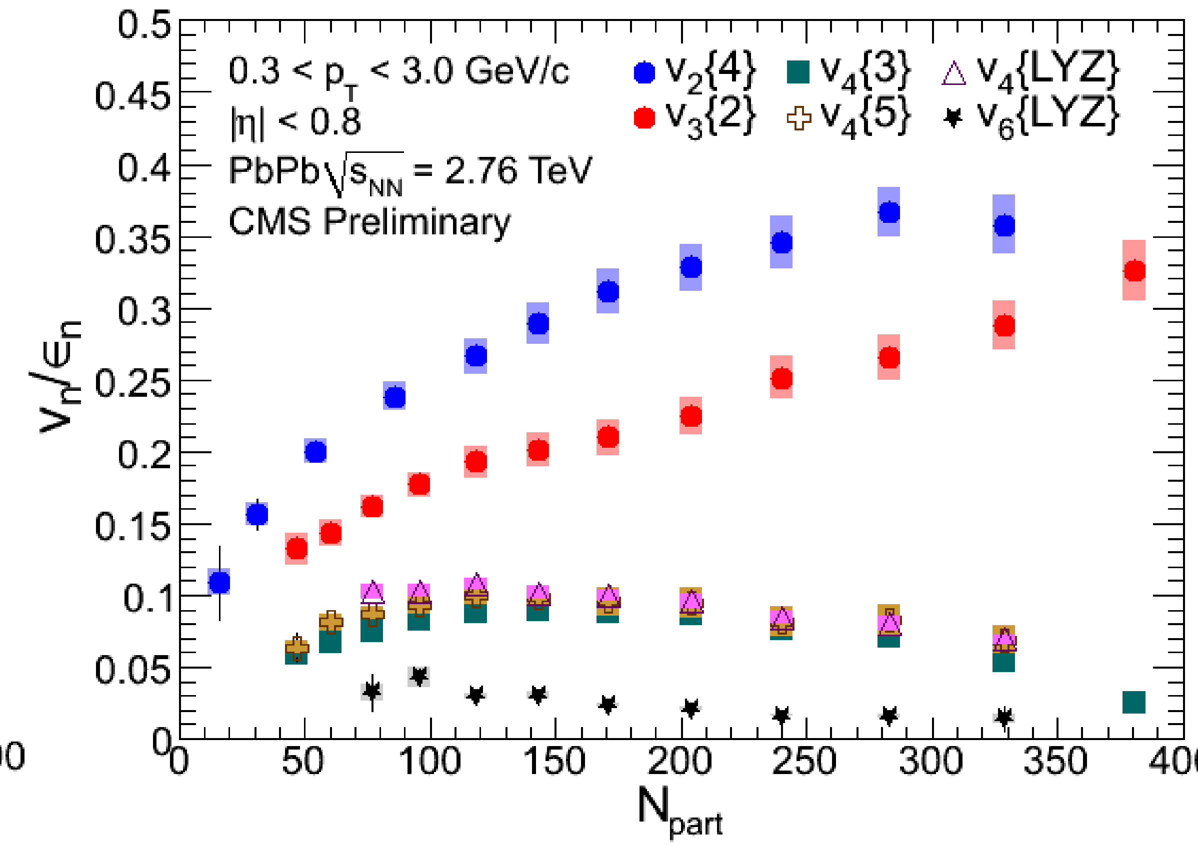
If fit diverges
collective description less appropriate.



Transition between cases follows clear trends.

The full harmonic spectrum

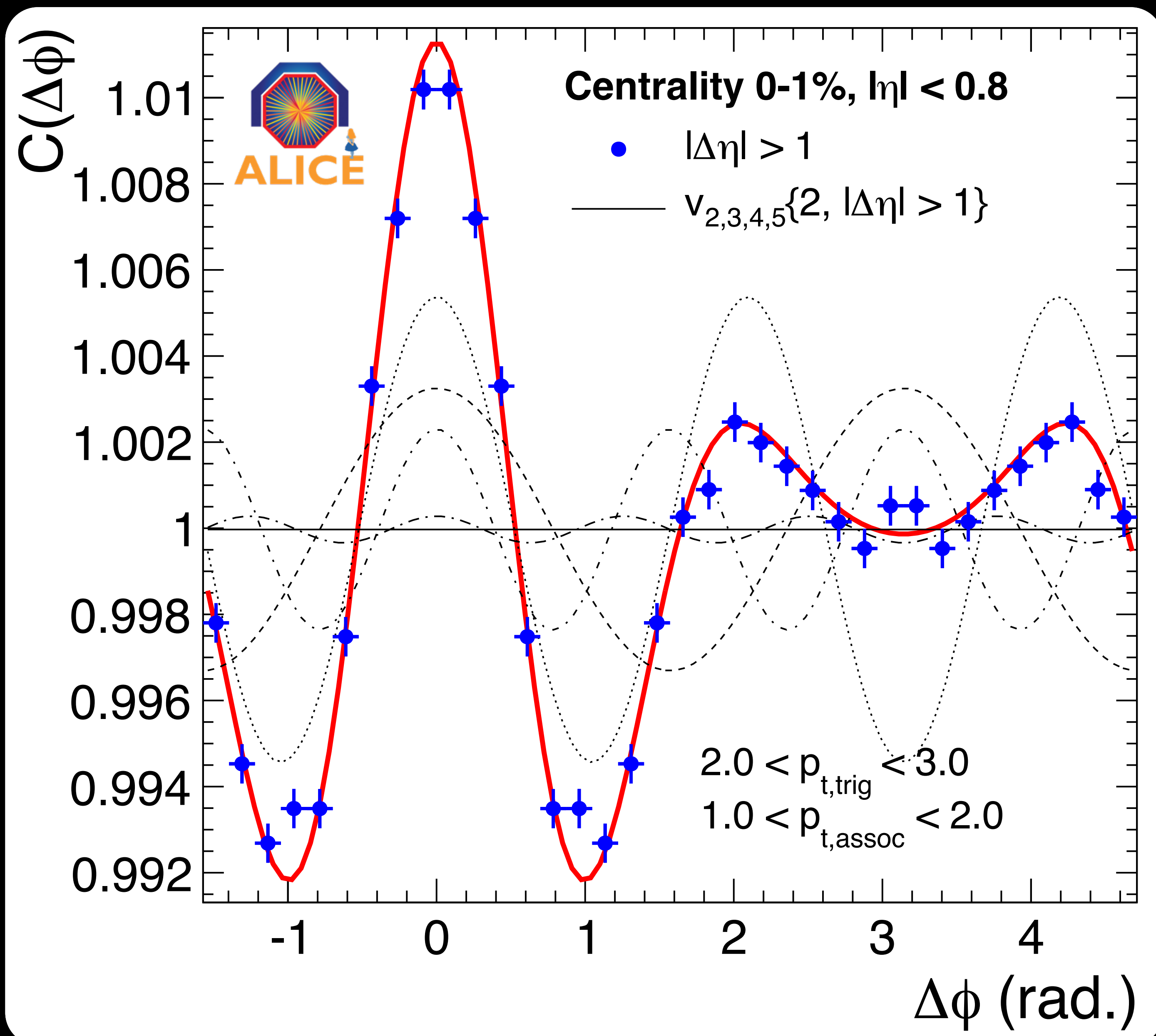




- v_n vs N_{part} shows different trends:
  - even harmonics have similar centrality dependence:
    - decreasing → 0 with increasing N_{part}
  - v_3 has weak centrality dependence, finite for central collisions

Other Harmonics

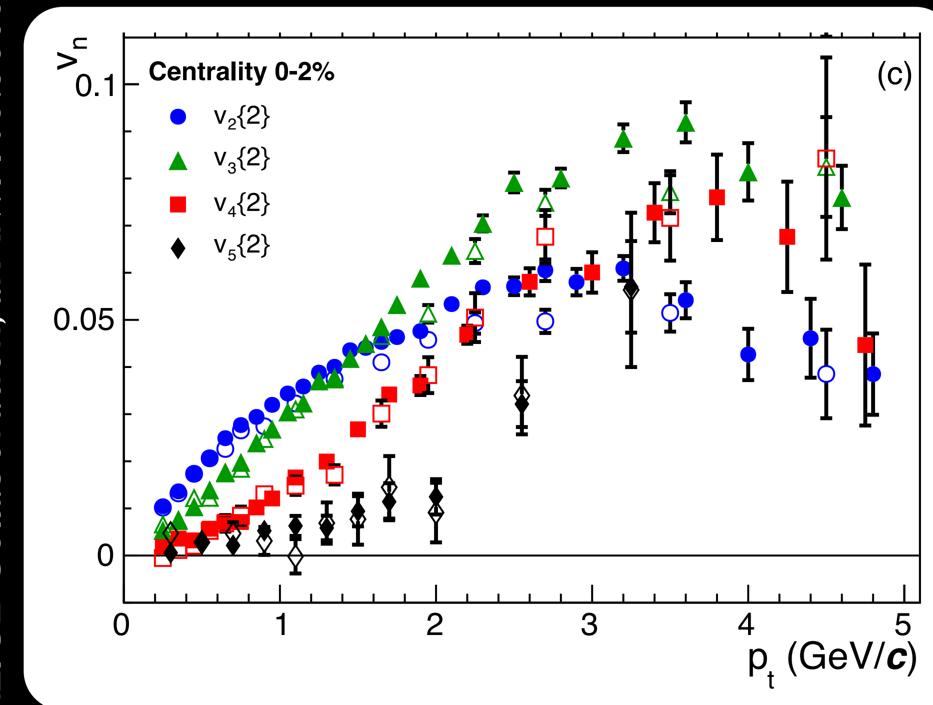
ALICE Collaboration, arXiv:1105.3865



see presentations J-F. Grosse-Oetringhaus and A. Adare

$$C(\Delta\phi) \equiv \frac{N_{\rm mixed}}{N_{\rm same}} \frac{{\rm d}N_{\rm same}/{\rm d}\Delta\phi}{{\rm d}N_{\rm mixed}/{\rm d}\Delta\phi}$$

ALICE Collaboration, arXiv:1105.3865

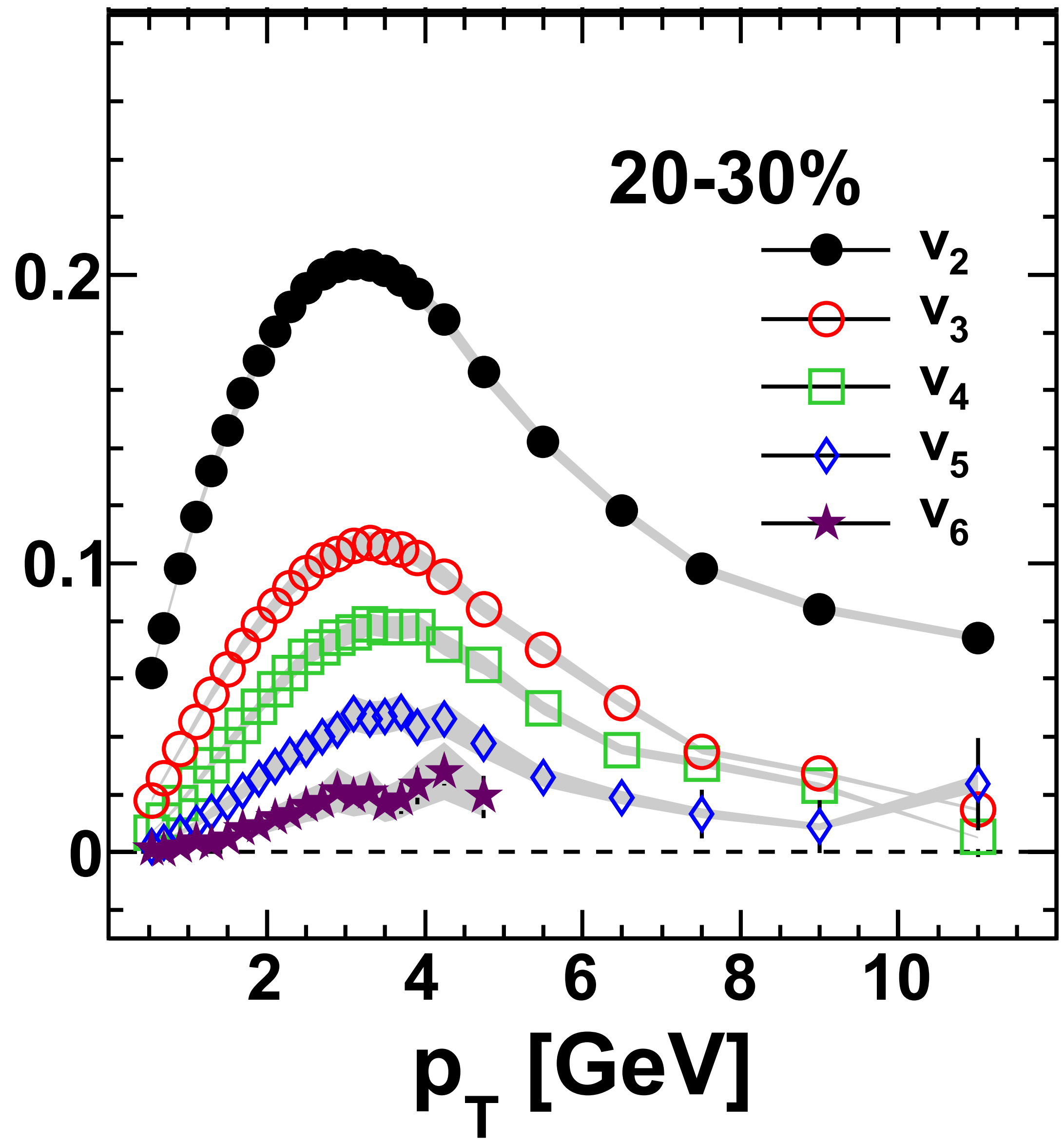


We observe a doubly-peaked structure in the azimuthal correlation function opposite to the trigger particle before the subtraction of v_2

The red line shows the sum of the measured anisotropic flow Fourier coefficients. Those flow coefficients give a natural description of the observed correlation structure

(J. Jia @ ATLAS, plenary)

v_n(n=2-6) vs p_T (0.5-12 GeV)

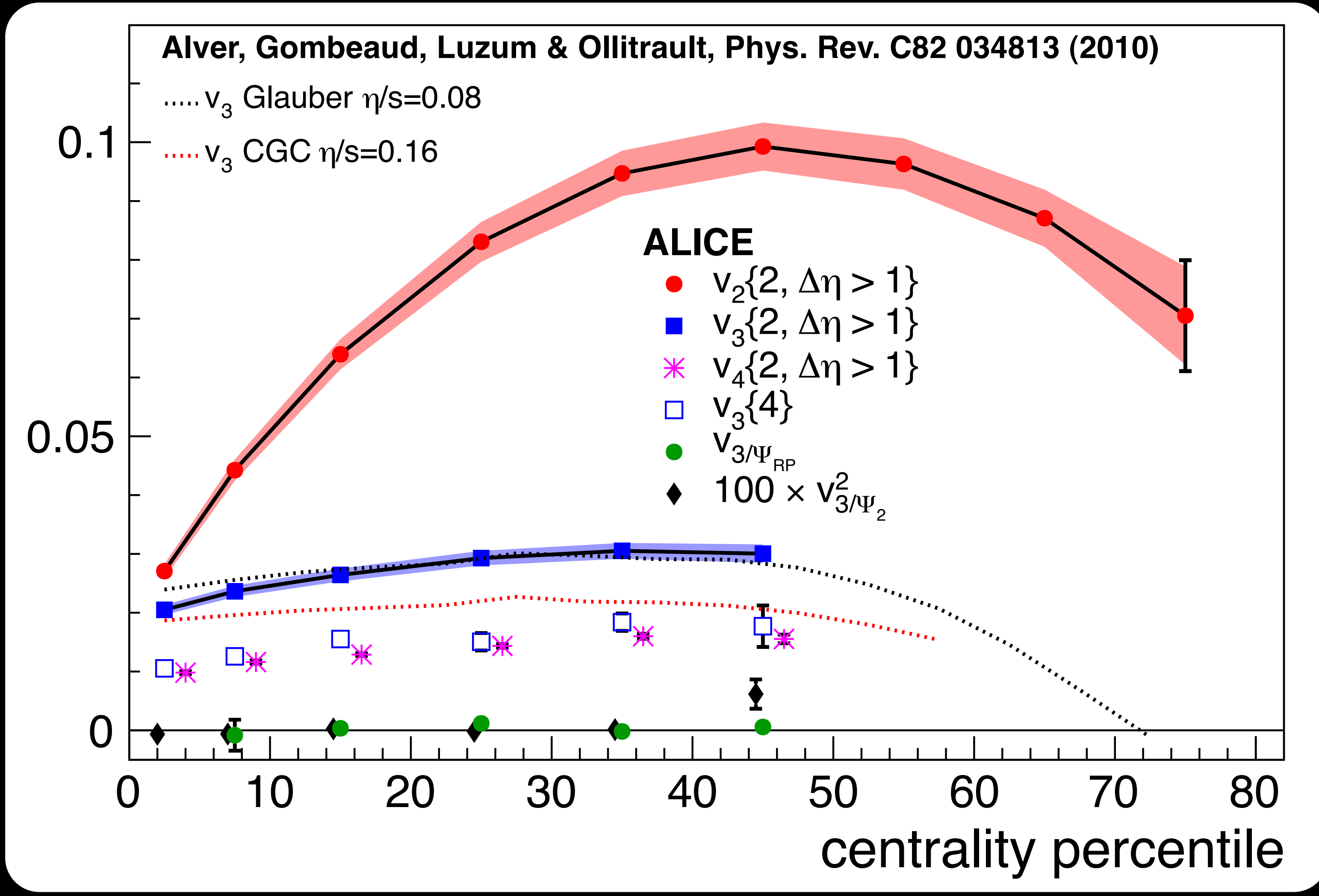


Similar p_T dependence for all n: rise to 3-4 GeV, then falls

Triangular Flow

We observe significant v_3 which compared to v_2 has a different centrality dependence

The centrality dependence and magnitude are similar to predictions for MC Glauber with η/s=0.08 but above MC-KLN CGC with η/s=0.16

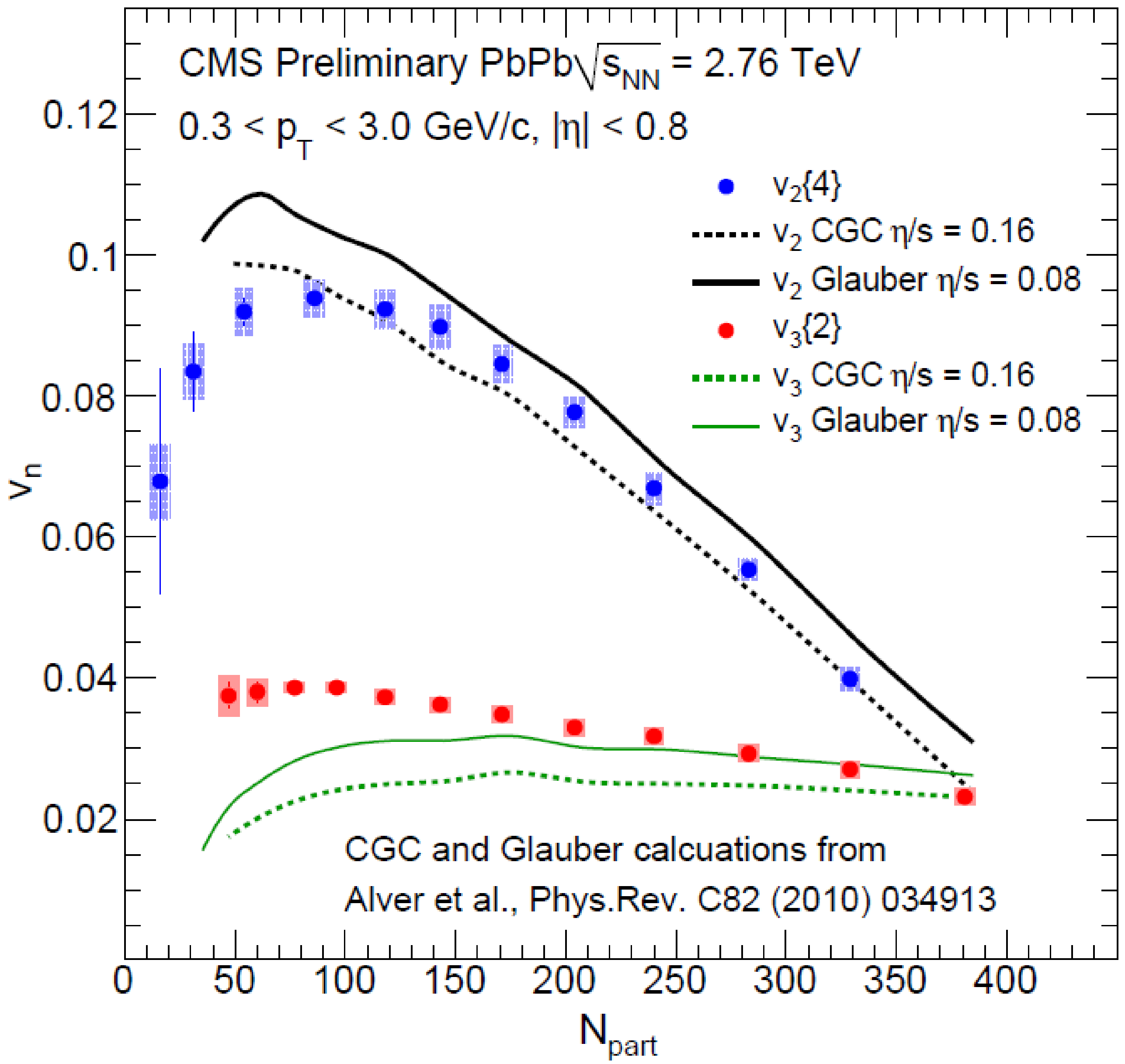


ALICE Collaboration, arXiv:1105.3865

The v_3 with respect to the reaction plane determined in the ZDC and with the v_2 participant plane is consistent with zero as expected if v_3 is due to fluctuations of the initial eccentricity

The $v_3\{2\}$ is about two times larger than $v_3\{4\}$ which is also consistent with expectations based on initial eccentricity fluctuations

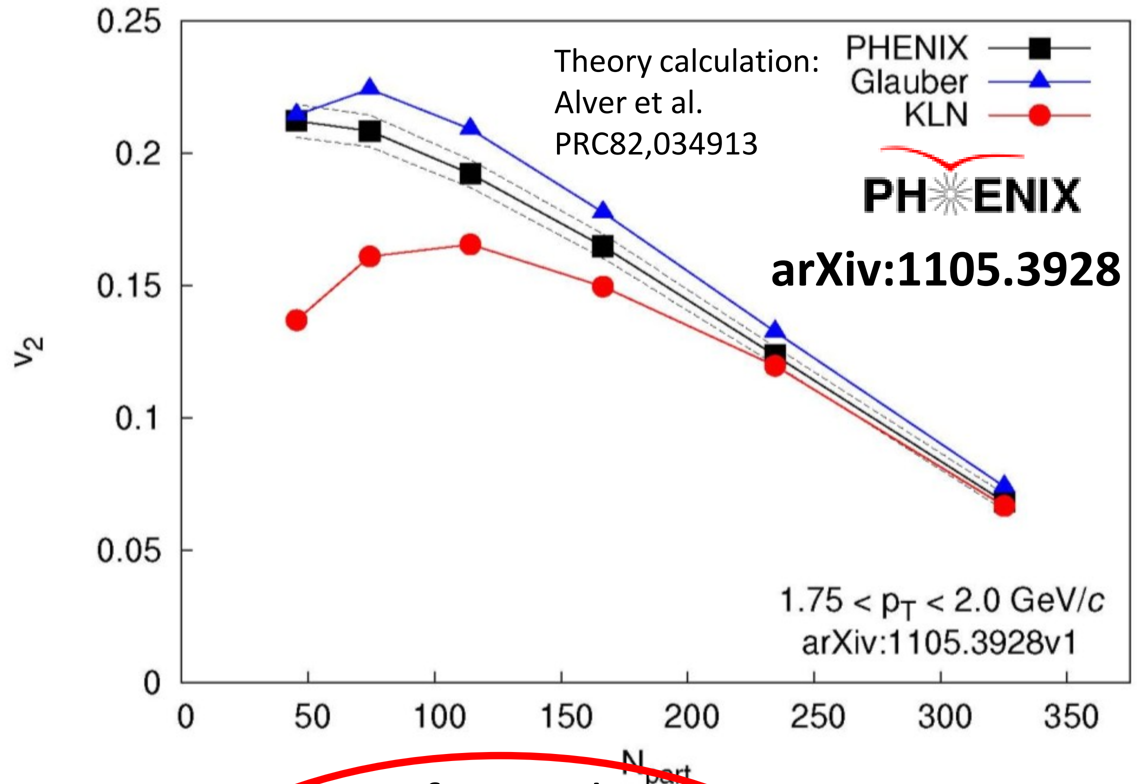
v_2 and v_3 vs N_{part} : Comparison to hydro



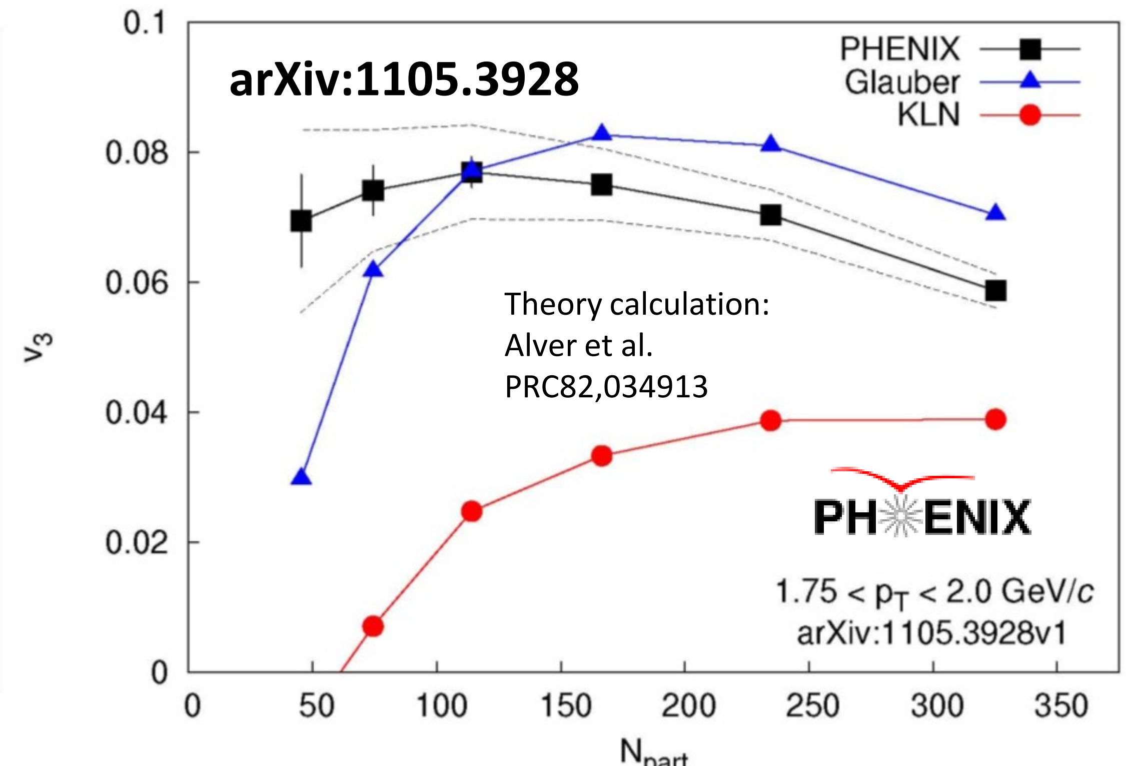
Qualitative agreement with the data
Further tuning/studies are needed for quantitative comparison
On the experiment side: better control of non-flow effects will be explored

v_3 disentangles initial state and η/s

v_2 described by Glauber and CGC



v_3 described only by Glauber



Lappi, Venugopalan, PRC74, 054905
Drescher, Nara, PRC76, 041903

favored

- Glauber
  - Glauber initial state
  - $\eta/s = 1/4\pi$

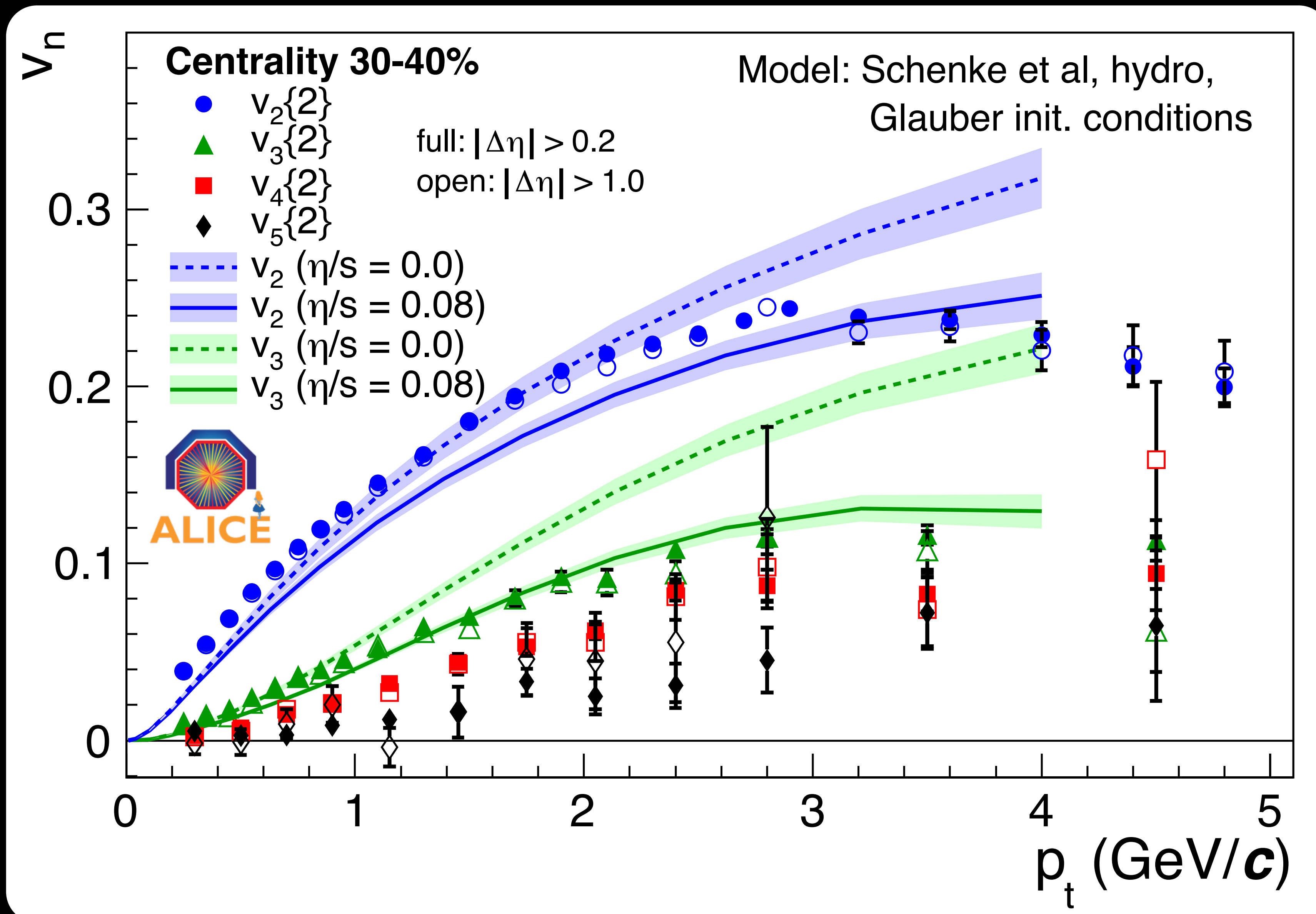
← Two models →

- MC-KLN
  - CGC initial state
  - $\eta/s = 2/4\pi$

Stefan Bathe for PHENIX, QM2011

Plenary: S. Esumi, Tue
Parallel: R. Lacey (v3, jet shape) Mon

Other Harmonics



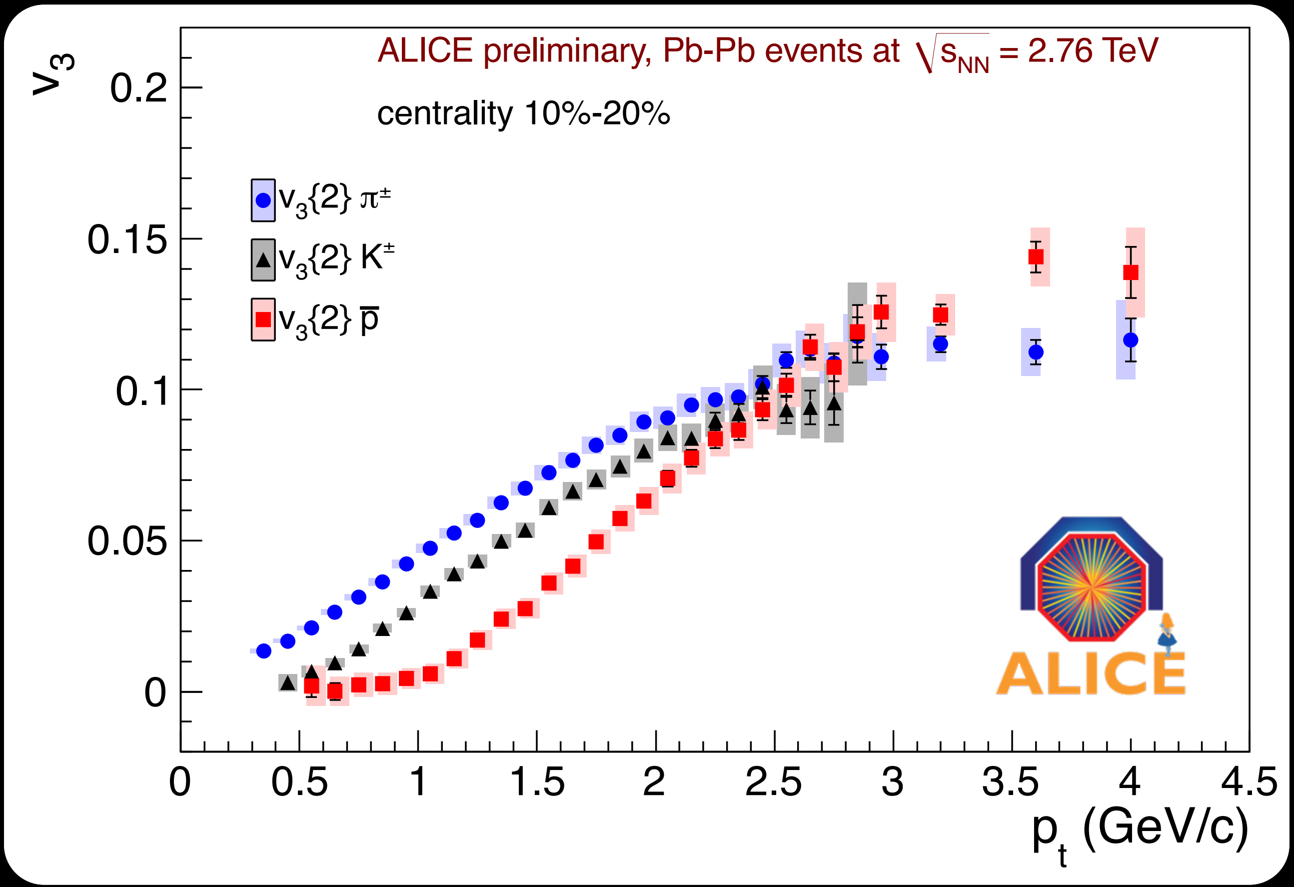
ALICE Collaboration, arXiv:1105.3865

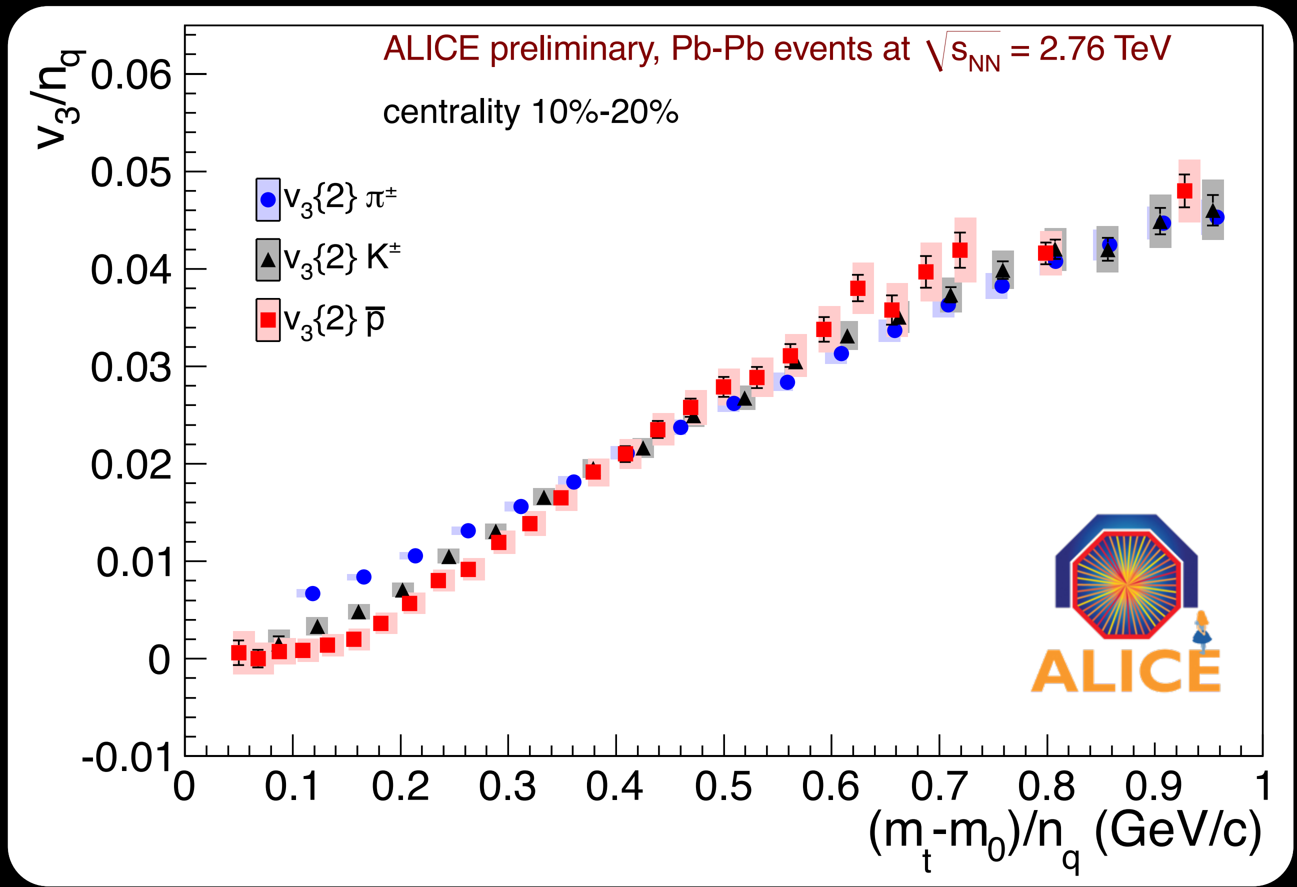
see presentation A. Bilandzic

The overall dependence of v_2 and v_3 is described

However there is no simultaneous description with a single η/s of v_2 and v_3 for Glauber initial conditions

Triangular Flow





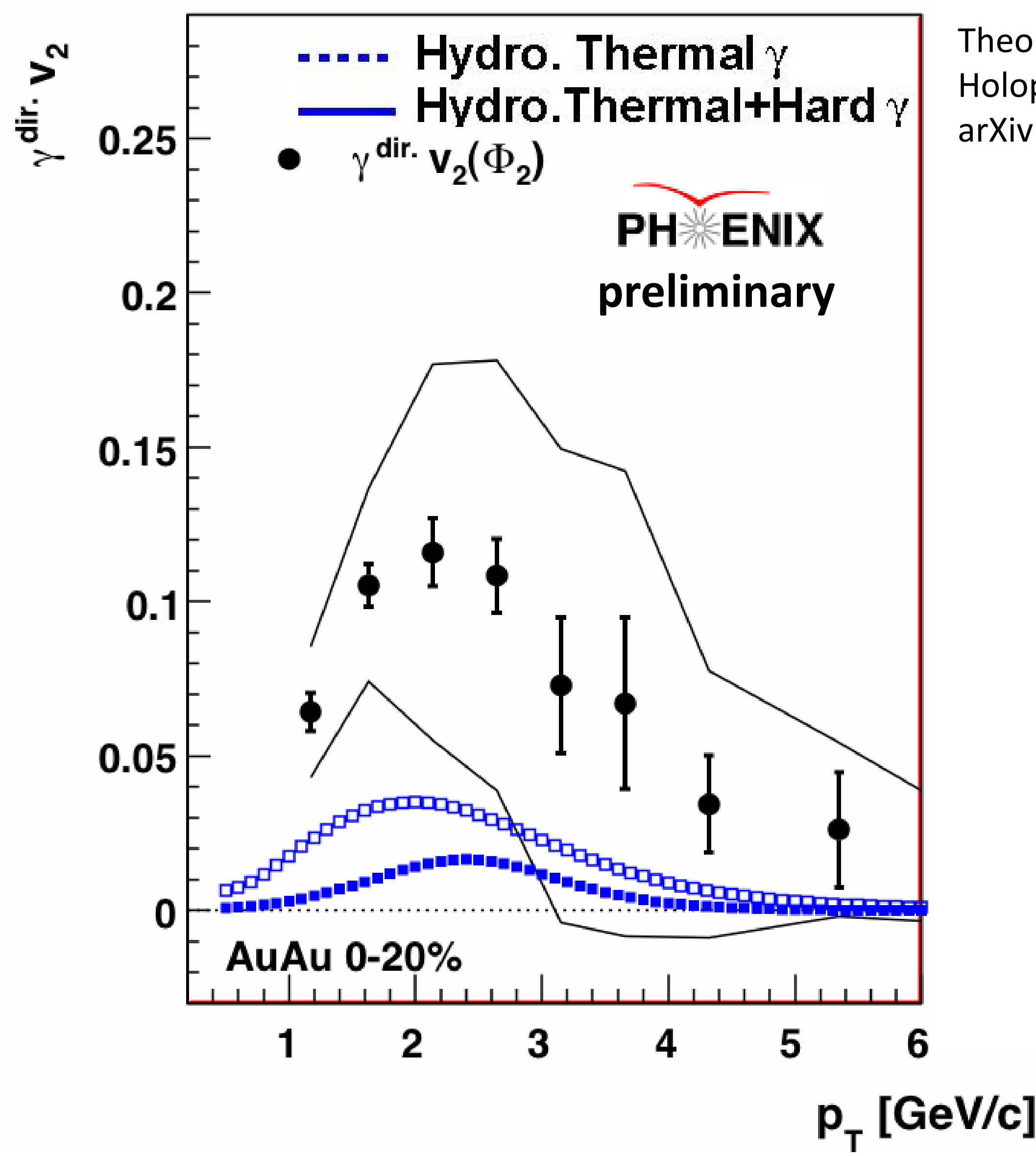
see presentation M. Krzewicki

The behavior of v_3 as function of p_t for pions, Kaons and protons shows the same features as we already observed for v_2

(we observe the mass splitting and, in addition, the crossing of the pions with protons at intermediate p_t, which for v_2 was considered as a signature for coalescence/recombination)

Theory Comparison: Direct Photon v_2

13



Stefan Bathe for PHENIX, QM2011

Theory calculation:
Holopainen, Räsänen, Eskola
arXiv:1104.5371v1

- Models under-predict direct photon v_2
- Measurement further constrains T_i and τ_i
- Challenge to theorists

Plenary: S. Esumi (flow), Tue
Parallel: E. Kistenev (direct photons) Thu

Conclusions

- Correlations up to p_t~5 GeV compatible with just initial fluctuations + flow: soft physics is gaining ground!
- Not only v_2, but also higher harmonics: v_3, v_4, v_5 measured
- v_1 from fluctuations not yet measured
- These new measurements constrain models of initial state: more theory needed.