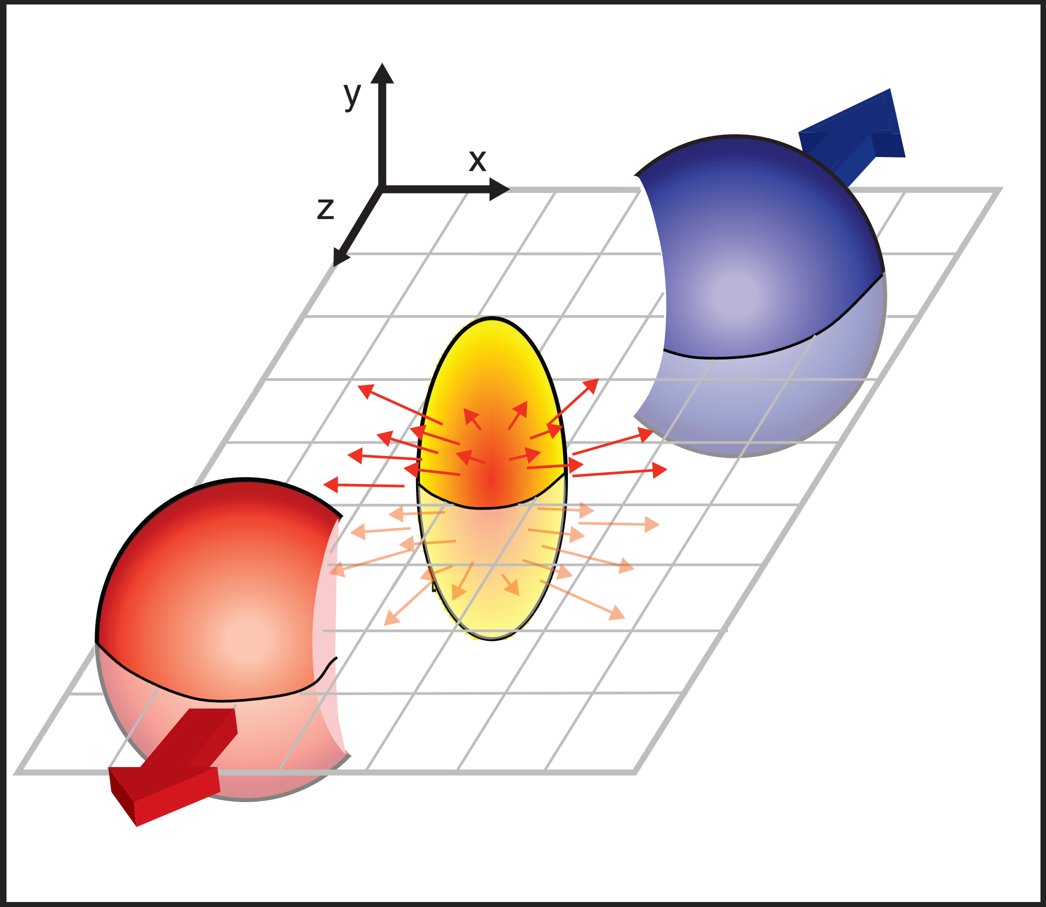
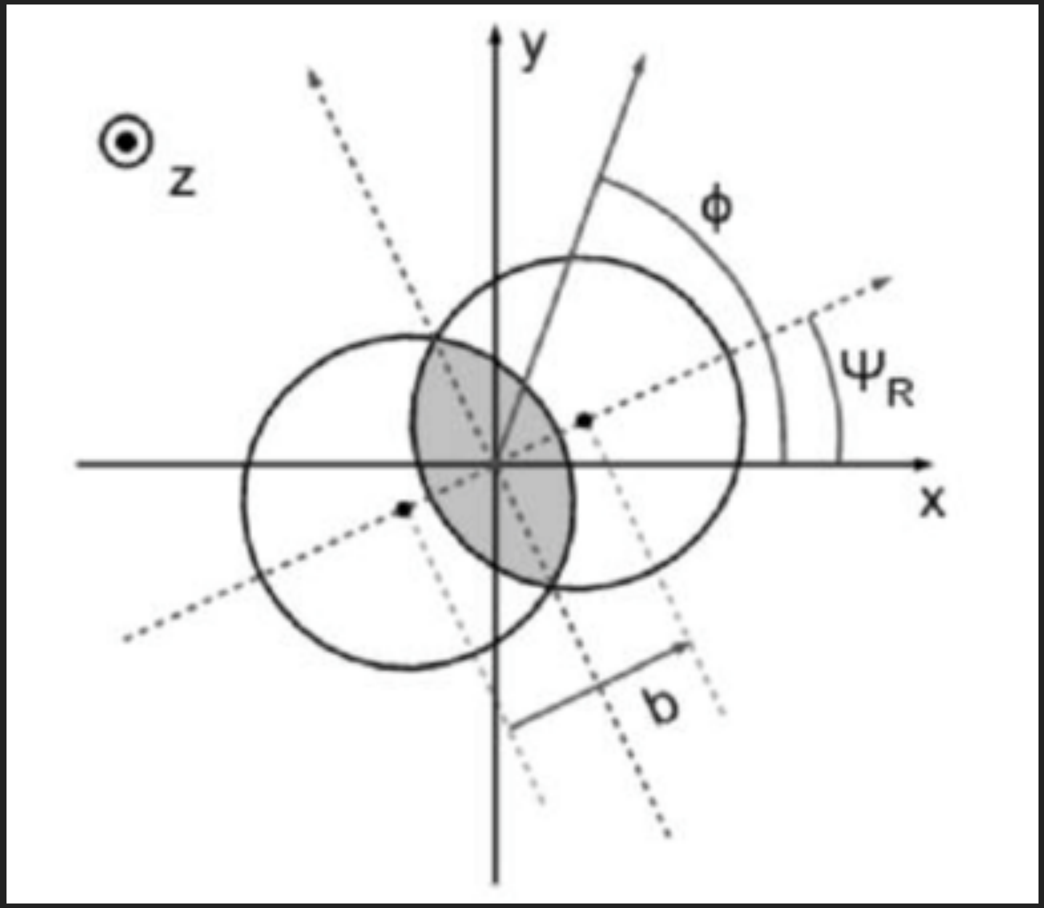
JACOPO MARGUTTI for the ALICE Collaboration - ICHEP 2016 CHICAGO

Anisotropic flow in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with ALICE

What is flow?

Anisotropic Flow: anisotropies in the azimuthal distribution of particles in momentum space.





Why does it flow?

It is commonly interpreted as the result of the hydrodynamic behaviour of strongly-interacting QCD matter:

- strongly-interacting non-spherical system
  –> anisotropic pressure –> anisotropic flow

Spatial anisotropies of the initial system are due to:

- event-by-event fluctuations
- geometry of the collision

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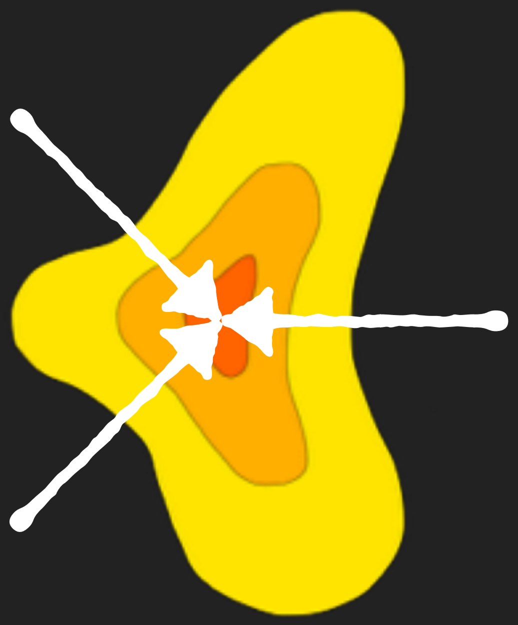
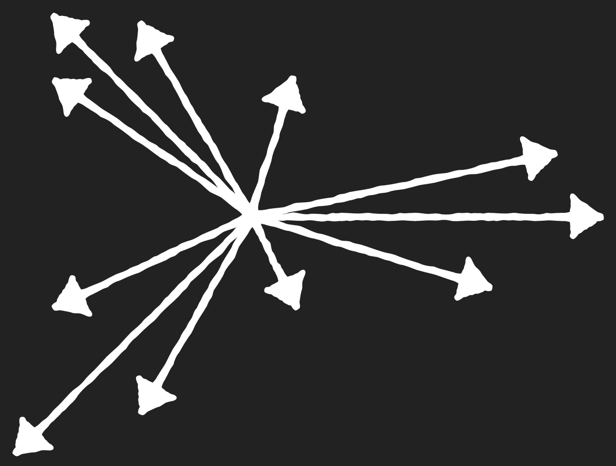


$$\rho \frac{d\vec{v}}{dt} = -\vec{\nabla} P$$

hydro



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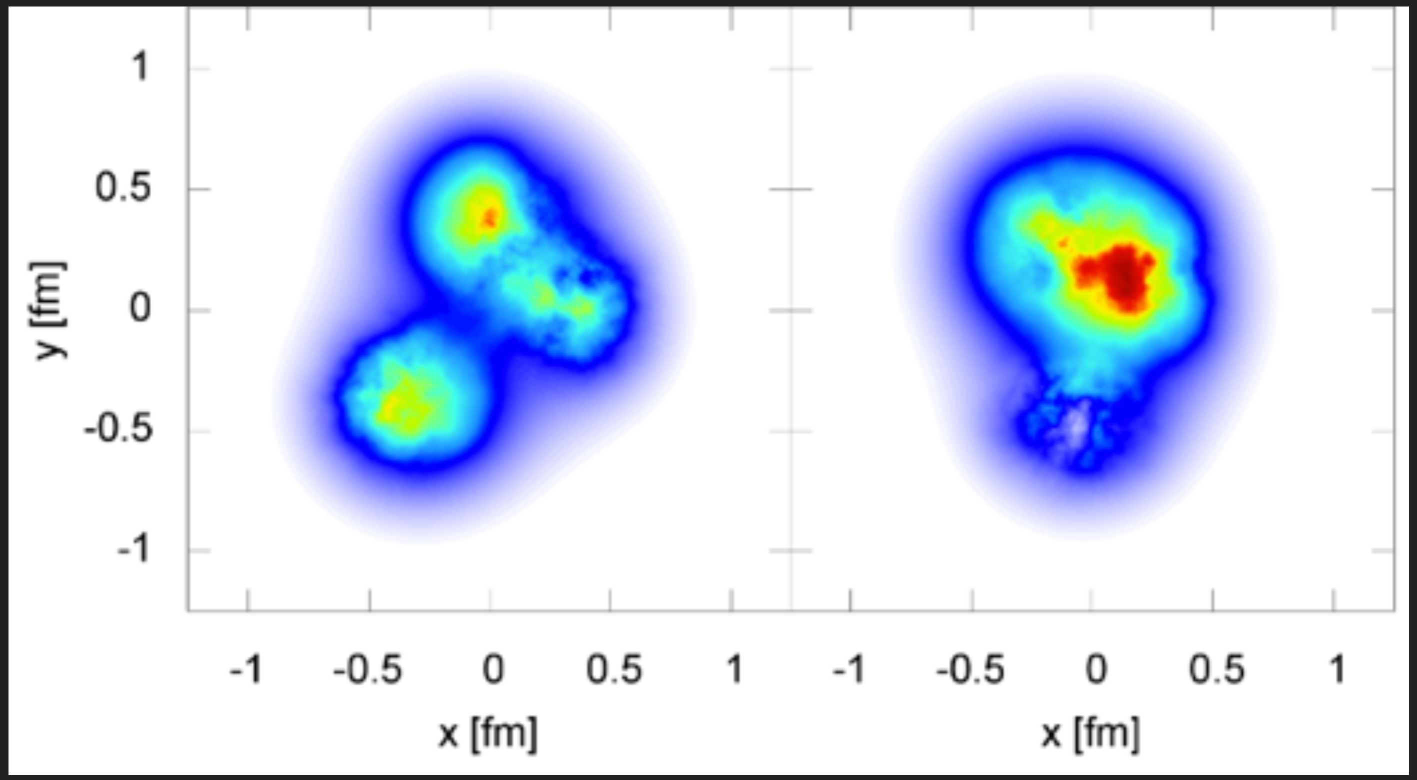
spatial anisotropies
also in p-p collisions!



H. Mäntysaari, B. Schenke, Phys. Rev. Lett. 117, 052301 (2016)

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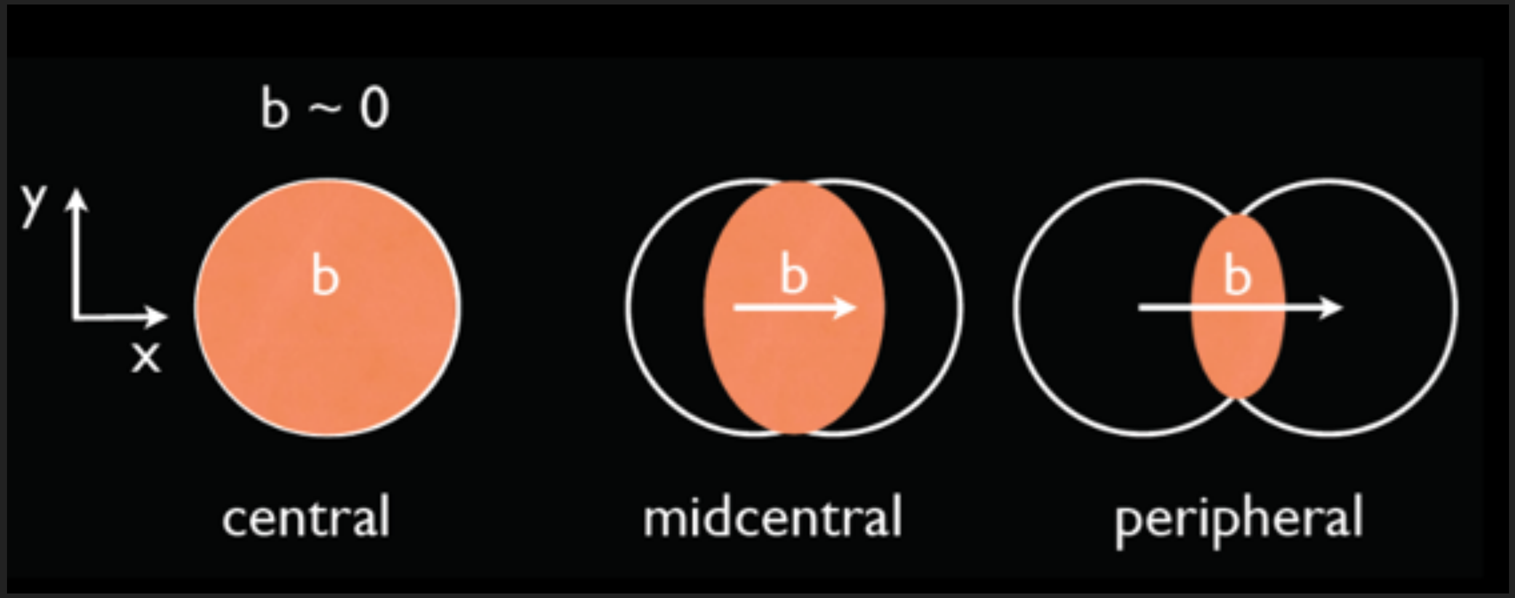

in Pb-Pb collisions, strong elliptical anisotropy, depending on centrality / impact parameter.

How does it flow?

Flow is also sensitive to:

- QCD Equation of State:
  - connects temperature, pressure and density
- transport coefficients:
  - bulk viscosity (attenuates shock waves)
  - shear viscosity (attenuates shearing flow)

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- shear viscosity over entropy density ratio (η/s) close to the theoretical lower bound: $1/4\pi$
- low η/s –> strongly coupled system
- expected to depend on temperature, not fully understood!

A new (higher) energy at the LHC

Different questions can be addressed comparing flow measurements at 2.76 TeV and 5.02 TeV, e.g.:

- what is the temperature dependence (5.02 TeV = higher temperature) of the QCD bulk properties, e.g. shear viscosity?
- do the spatial eccentricities of the initial system depend on the collision energy?

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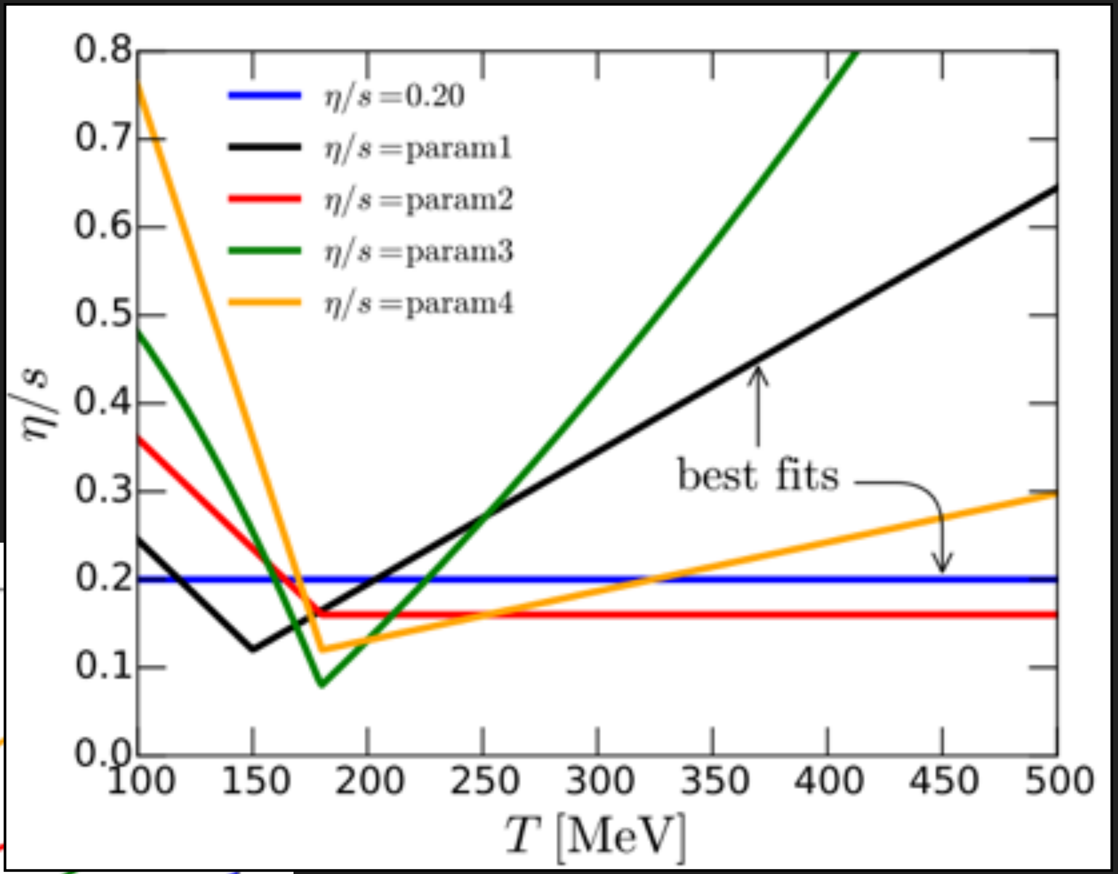

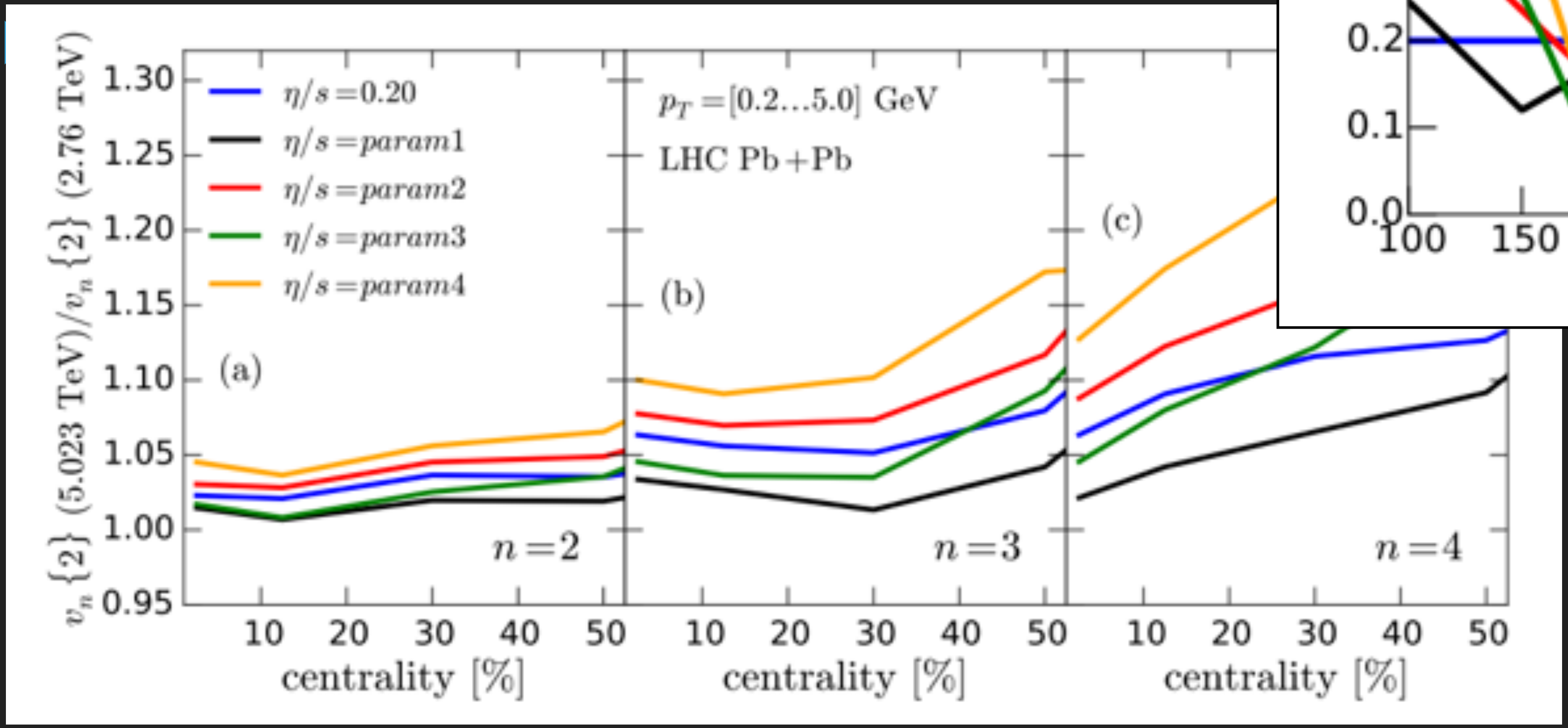

H. Niemi, K. J. Eskola, R. Paatelainen,
Phys. Rev. C 93, 024907 (2016)

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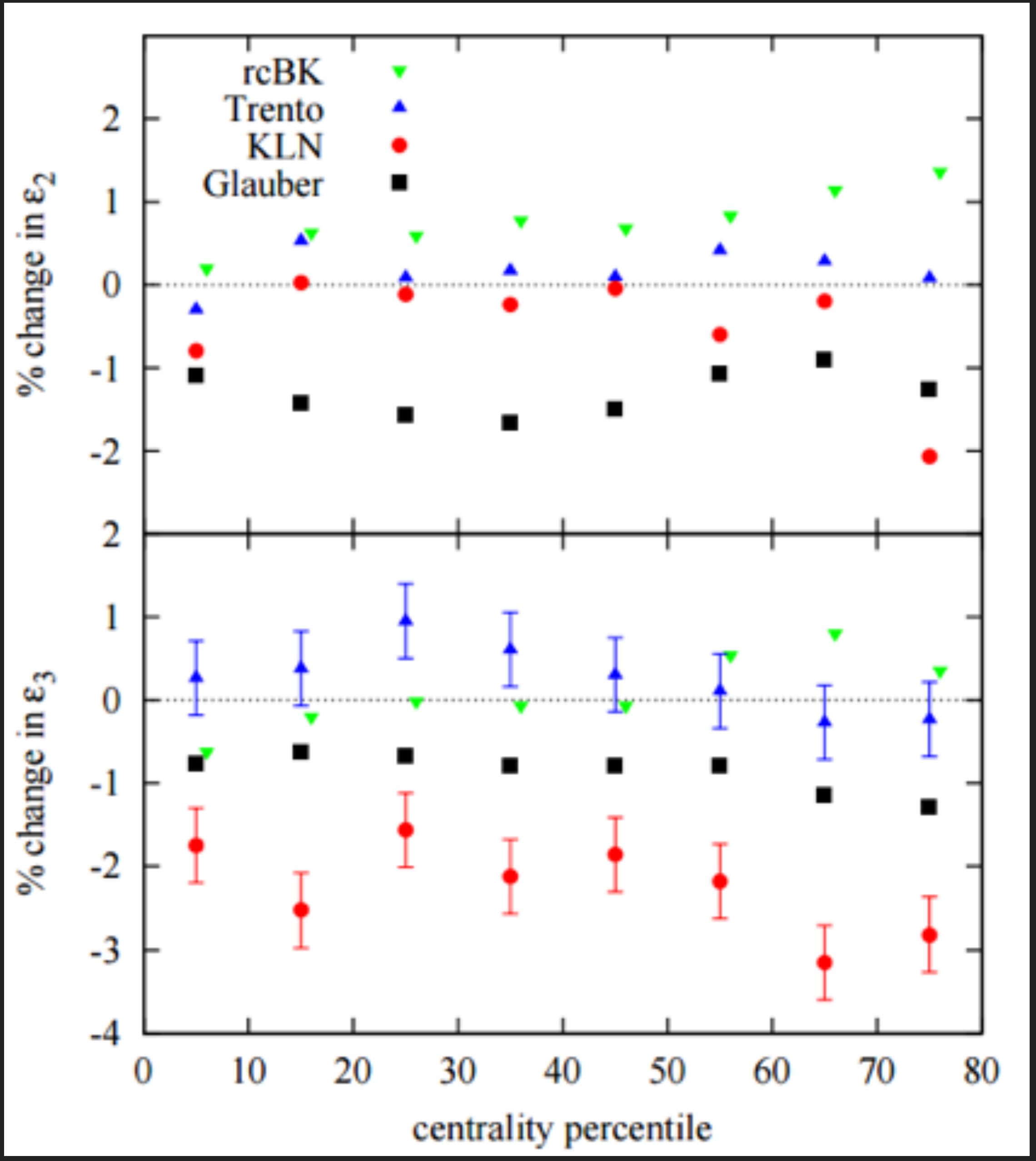
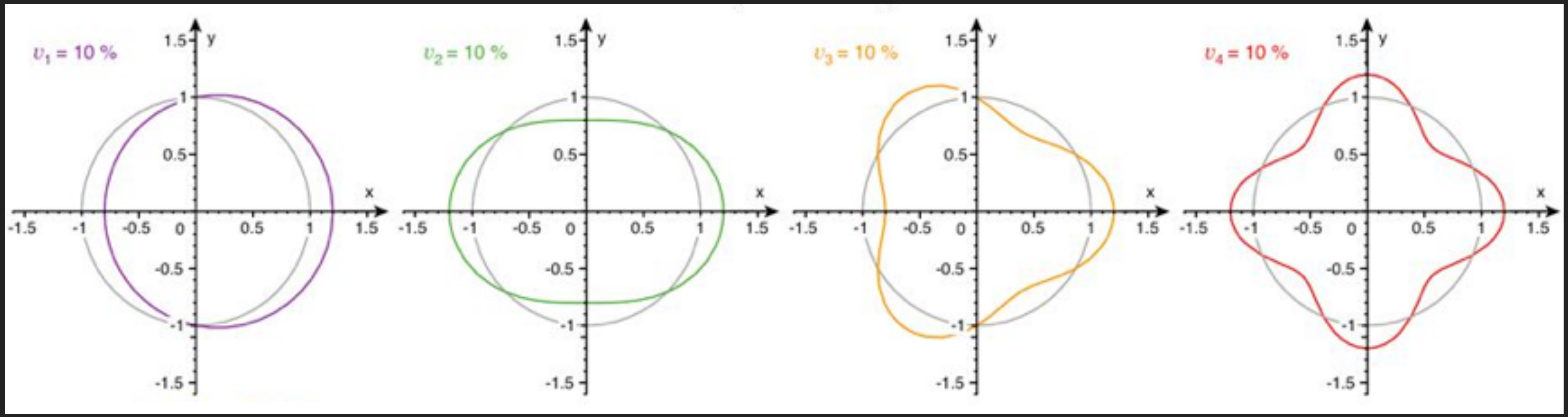


J. Noronha-Hostler, M. Luzum, and J.-Y. Ollitrault, Phys. Rev. C 93, 034912 (2016)

How do we quantify it?

Flow is quantified in terms of Fourier coefficients:

$$E\frac{d^3N}{d^3\vec{p}} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left(1+\sum_{n=1}^{+\infty}2v_n\cos(n(\varphi-\Psi_{\mathrm{RP}}))\right)$$



The different harmonics are conventionally referred to as: directed flow (v_1), elliptic flow (v_2), triangular flow (v_3), etc.

How do we measure it?

Flow is most commonly measured with multi-particle correlations*:

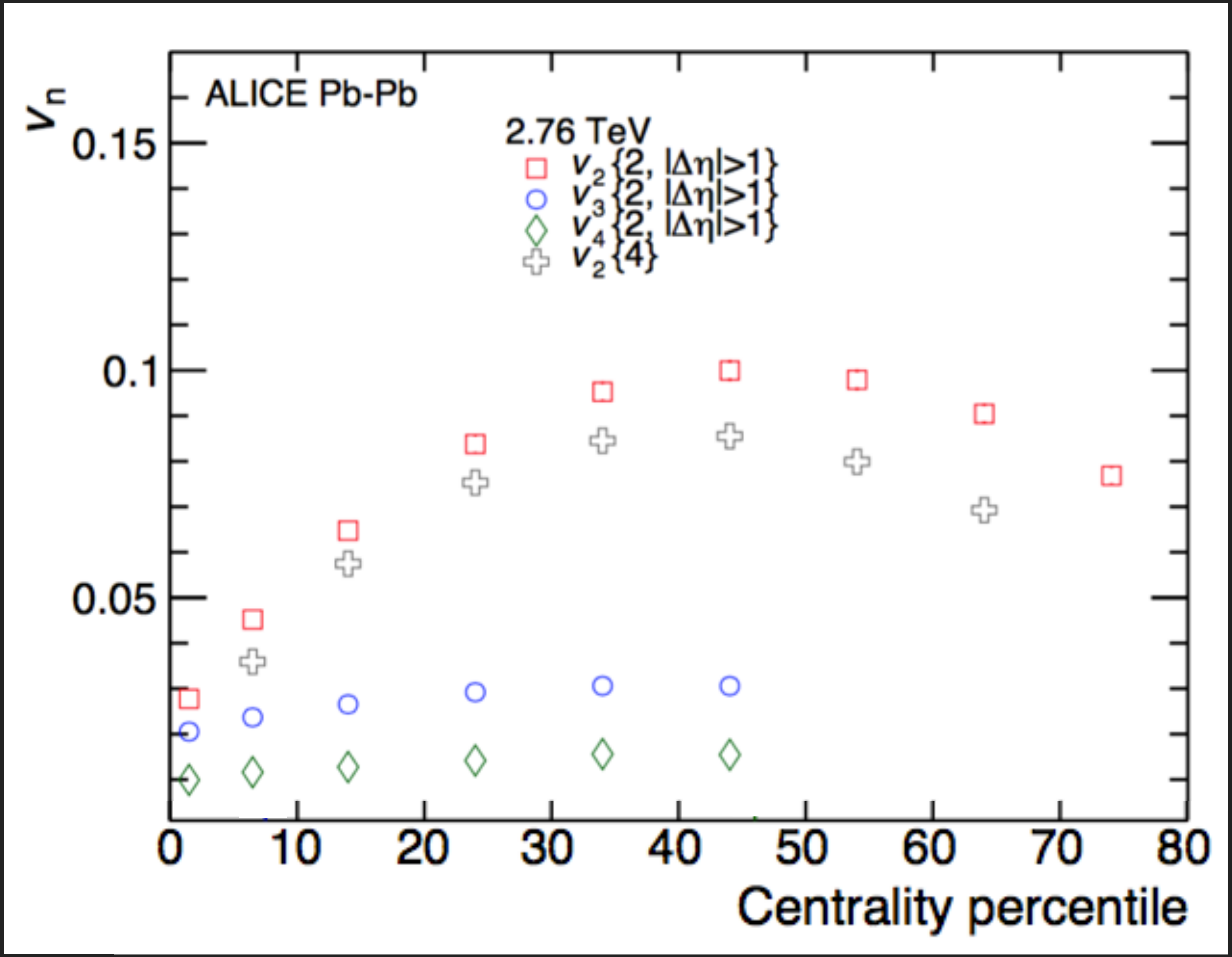
$$\langle e^{in(\varphi_1-\varphi_2)}\rangle = \langle e^{in(\varphi_1-\Psi_{\mathrm{RP}}-(\varphi_2-\Psi_{\mathrm{RP}}))}\rangle =$$
$$= \langle e^{in(\varphi_1-\Psi_{\mathrm{RP}})}\rangle\langle e^{in(\varphi_2-\Psi_{\mathrm{RP}})}\rangle = \langle v_n^2\rangle$$

from which we extract different cumulants of flow coefficients:

$$v_n\{2\} = \sqrt{\langle v_n^2\rangle}$$
$$v_n\{4\} = \sqrt[4]{2\langle v_n^2\rangle^2 - \langle v_n^4\rangle}$$

*assumption: correlations among produced particles are induced only by correlation of each particle with the reaction plane.

Results: centrality dependence



Charged particles,
$0.2 < p_T < 5$ GeV/c

Data Samples (MB events):
2.76 TeV: 12 M

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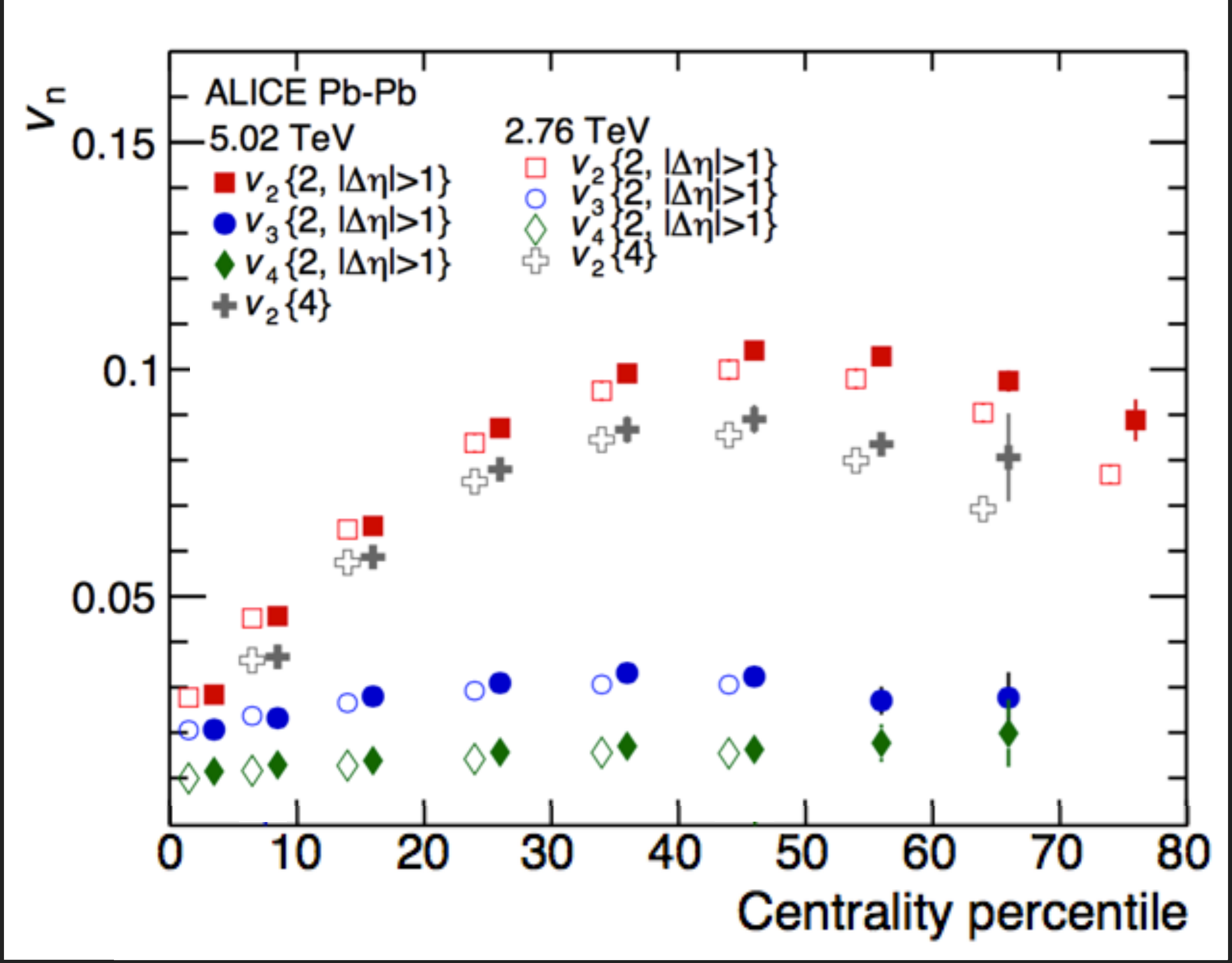

Charged particles,
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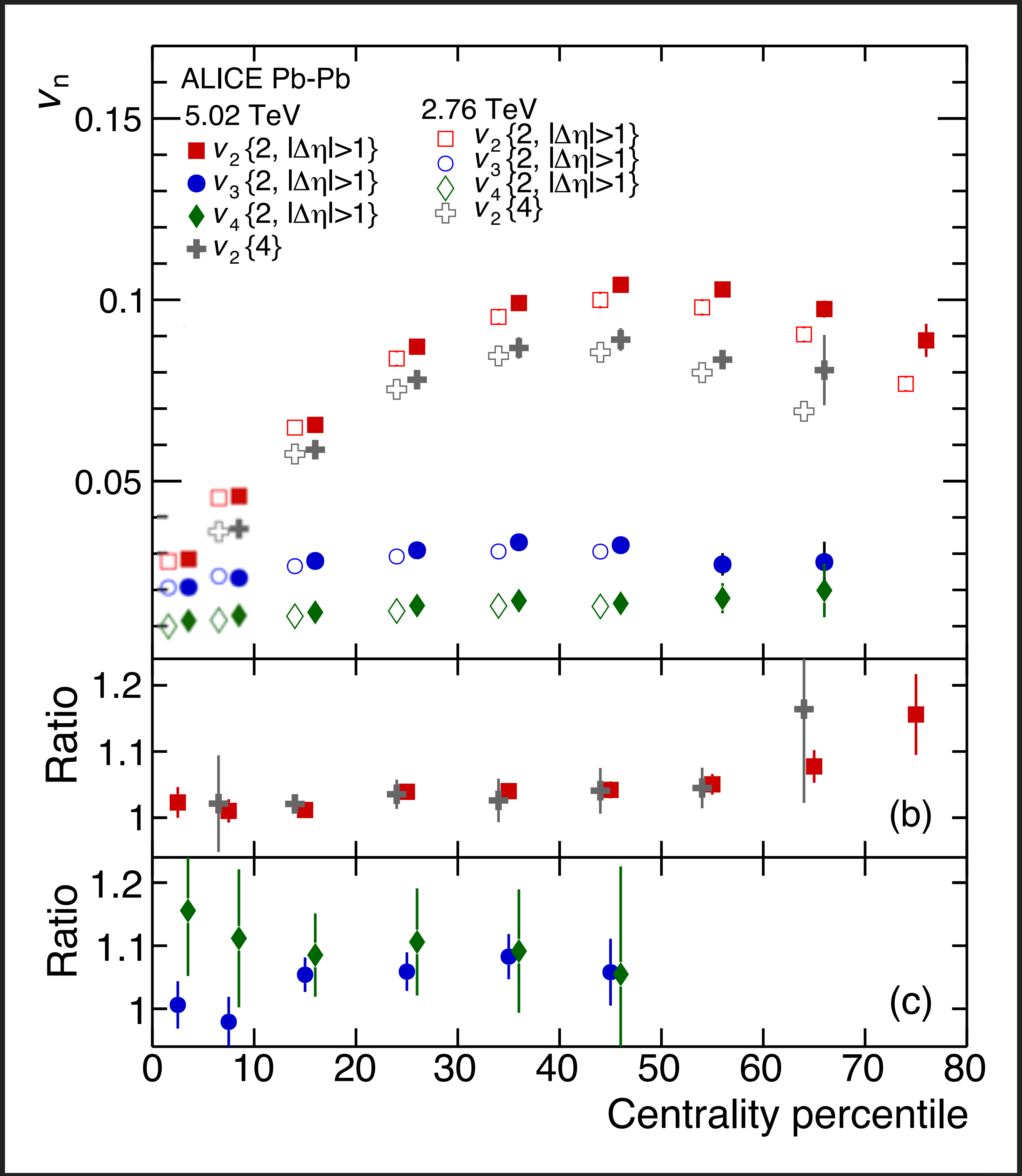
Data Samples (MB events):
2.76 TeV: 12 M, 5.02 TeV: 140 k

Results: centrality dependence



Phys. Rev. Lett. 116, 132302 (2016)

- v_2, v_3 and v_4 are found to increase by (3.0±0.6)%, (4.3±1.4)% and (10.2±3.8)%, respectively, in the centrality range 0-50%.
- No significant centrality dependence in the centrality range 0-50%, possibly different going more peripheral.

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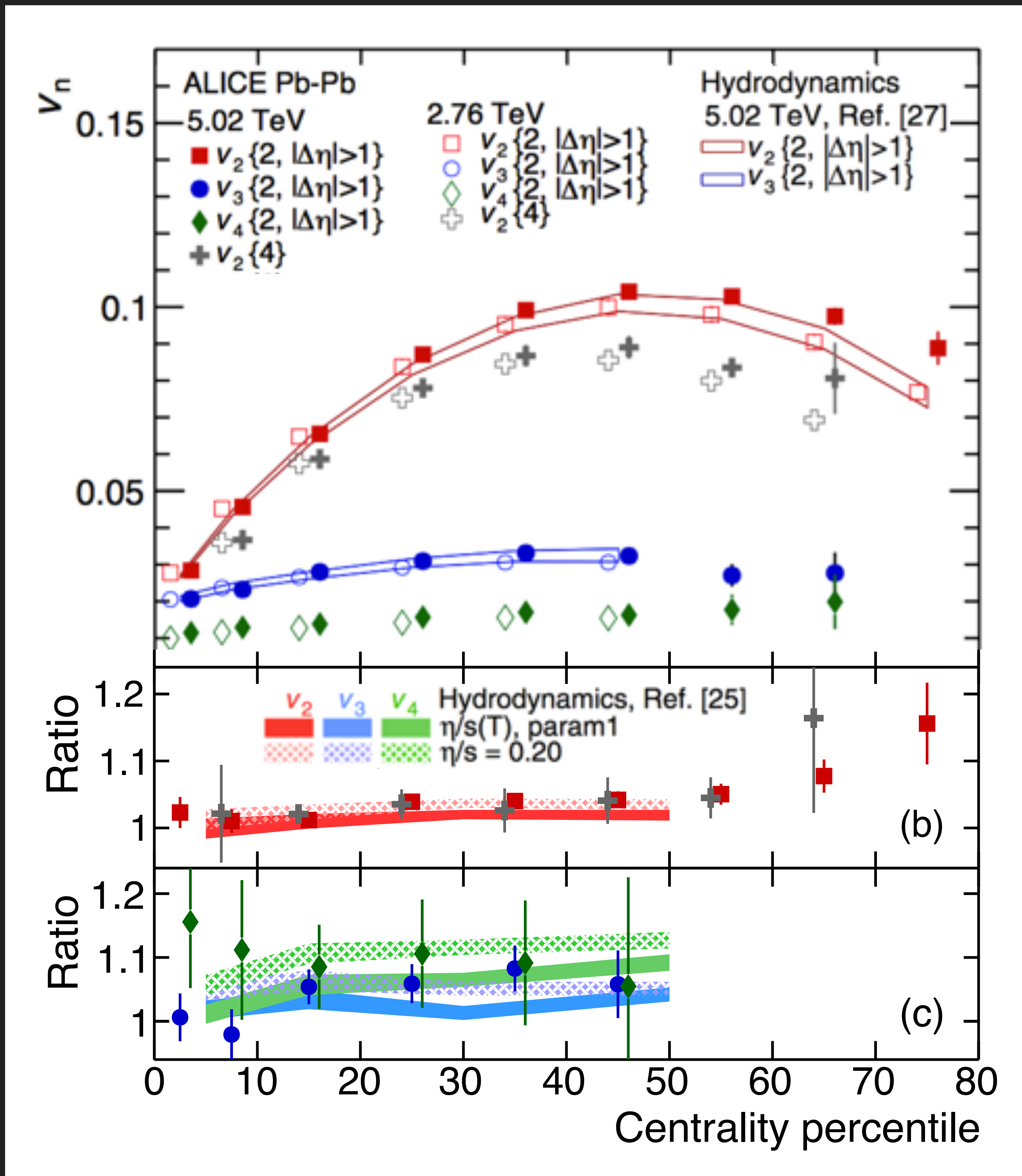

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[25] H. Niemi et al., Phys. Rev. C 93, 024907 (2016)
[27] J. Noronha-Hostler, et al., Phys. Rev. C 93, 034912 (2016)

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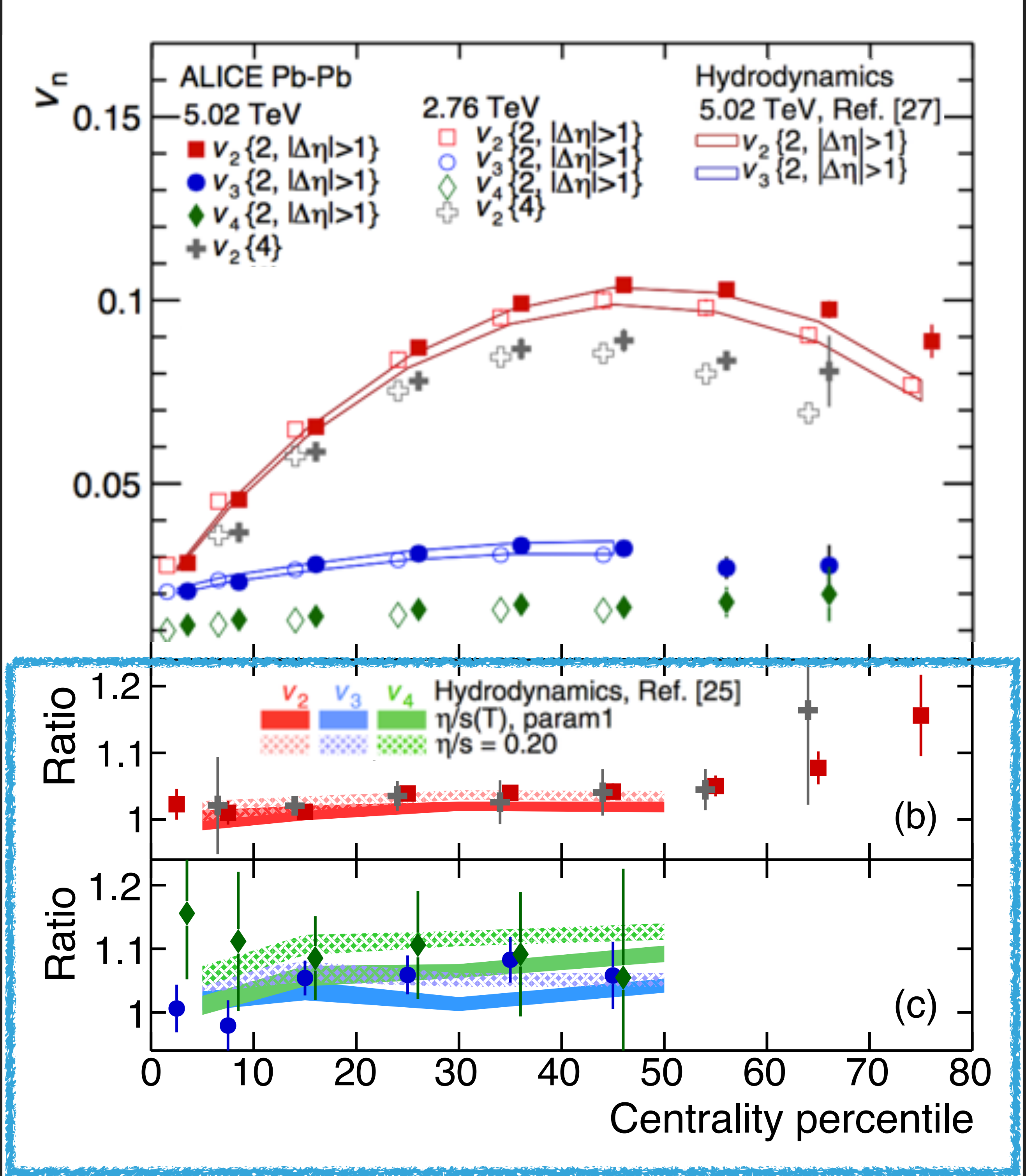

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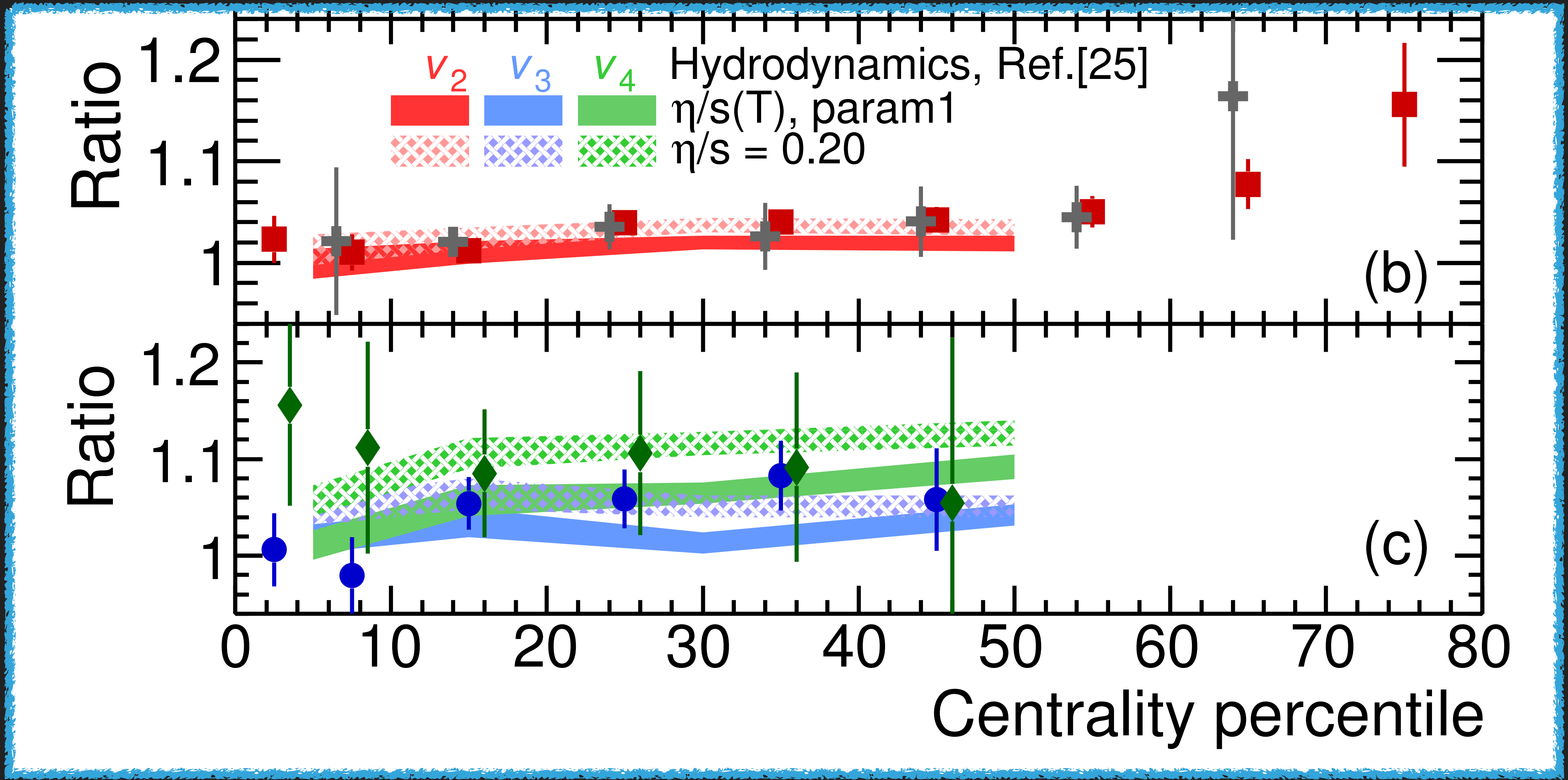


indicate no or small changes in shear viscosity to entropy density ratio (η/s) between the two energies:

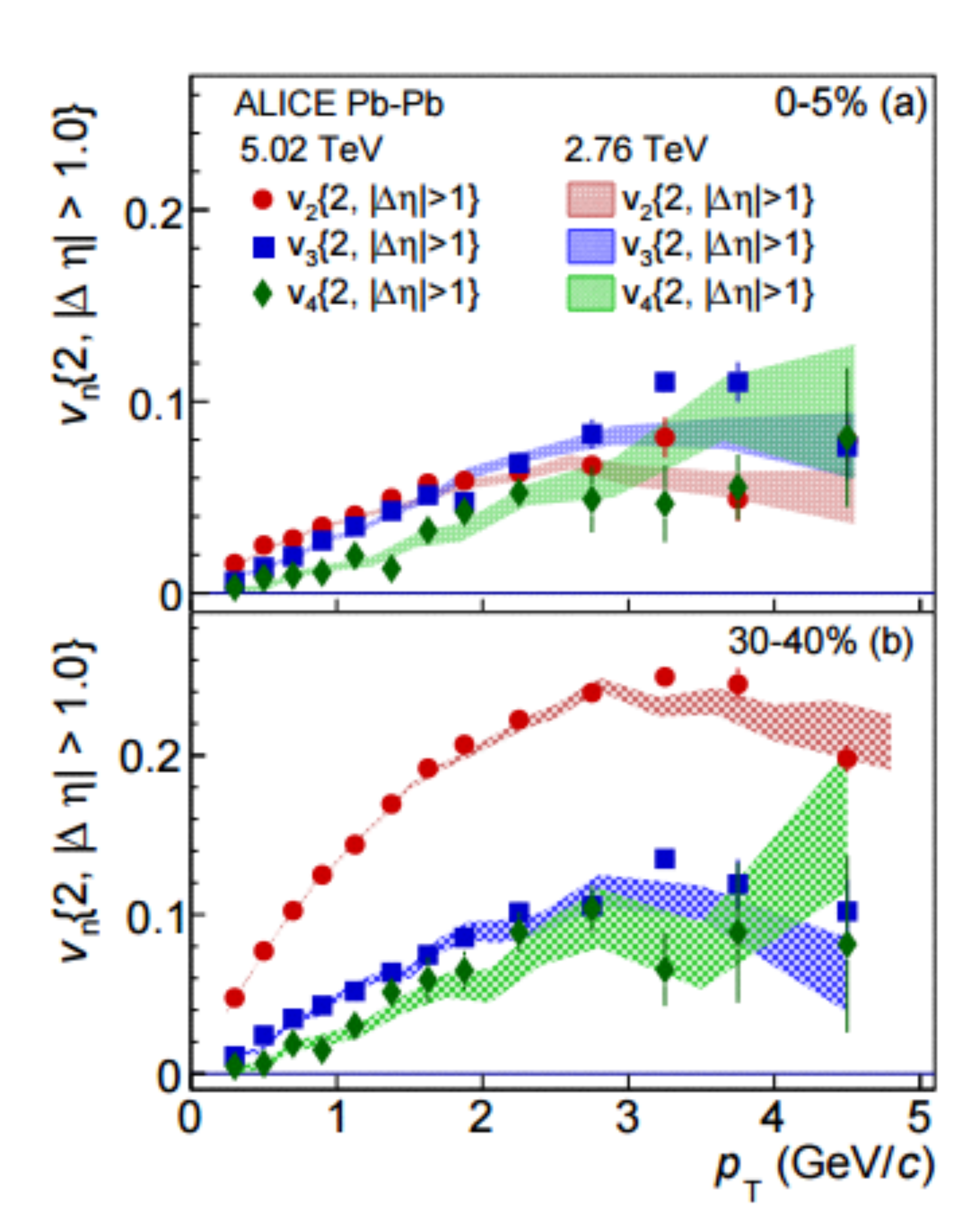
$$0 < \frac{d\,\eta/s}{d\,T} < 0.15\ [100\,\mathrm{MeV}^{-1}]$$

$$T \geq 150\,\mathrm{MeV}$$

consistent with latest findings:

J.E. Bernhard et al., arXiv:1605.03954 (2016),
H. Niemi et al., Phys. Rev. C 93, 024907 (2016).

Results: p_T dependence

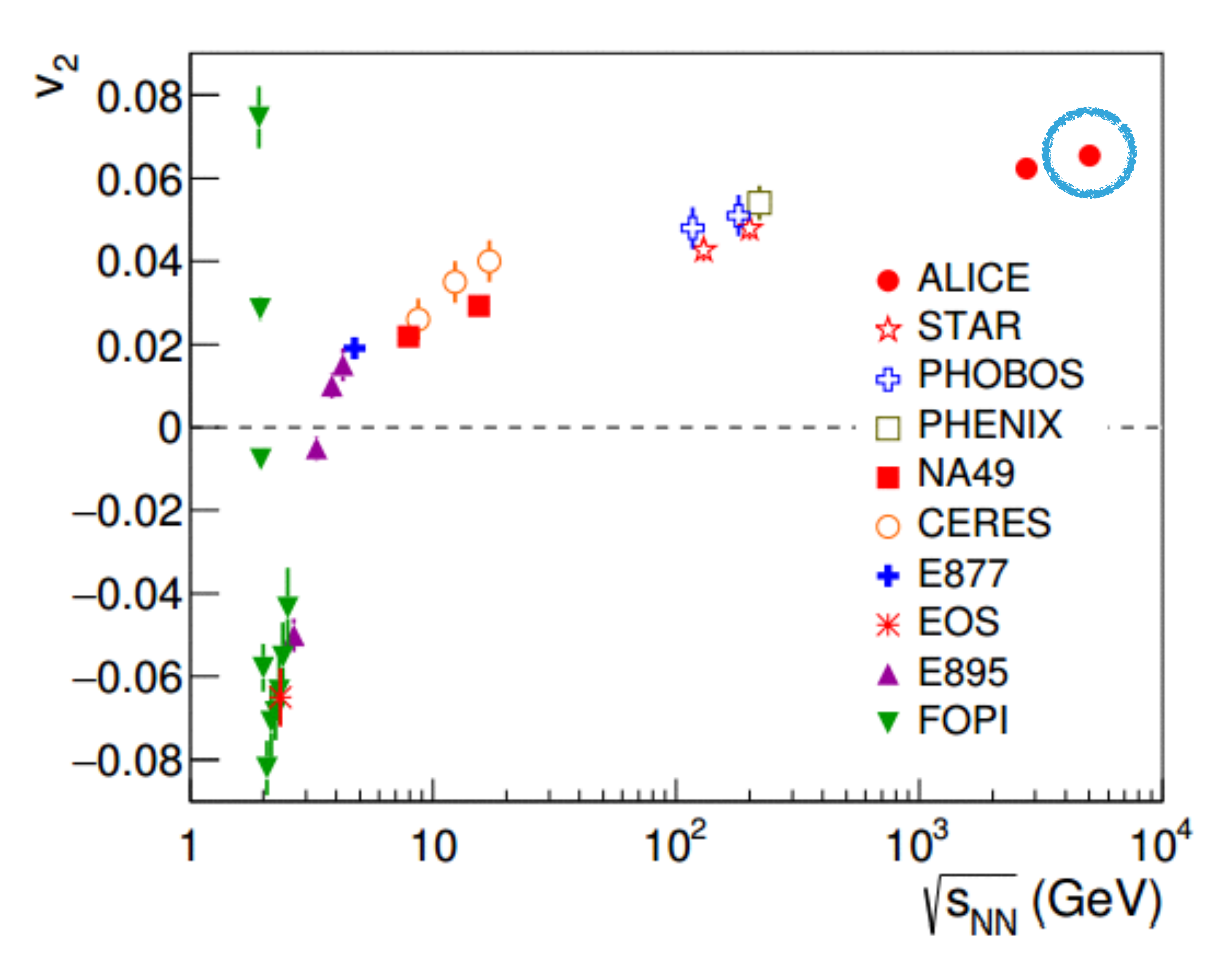


Phys. Rev. Lett. 116, 132302 (2016)

- Consistent with 2.76 TeV data: v_2 is the dominant harmonic over all p_T, except in central events (0-5%) at p_T > 2 GeV/c.
- The increase in p_T-integrated flow can thus be attributed to an increase in < p_T >, i.e. stronger radial flow at 5.02 TeV w.r.t. 2.76 TeV.

Results: energy dependence

one step forward!



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$v_2\{4\}$, cen. 20-30%

THANKS FOR THE ATTENTION!