A Large Ion Collider Experiment

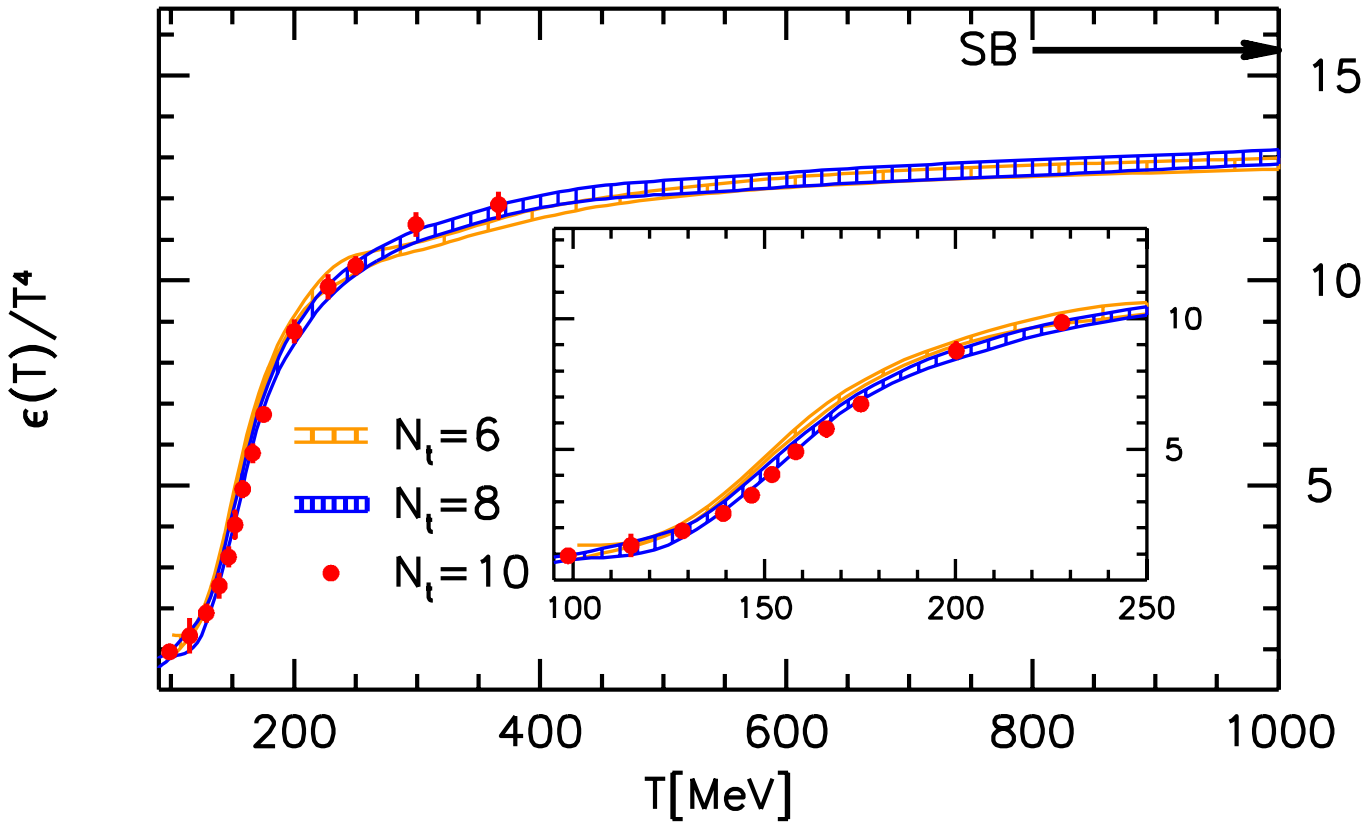
European Organisation for Nuclear Research

UNIVERSITY of HOUSTON

Azimuthal flow results from ALICE

Anthony Timmins for the ALICE Collaboration

Heavy-ion collisions and the QGP



Phys. Lett. B478 (2000) 447-455

JHEP 1011 (2010) 077

- Heavy-ion collisions deposit large energy in small volume
  - ✓ Nuclear matter "melts"
  - ✓ Quarks & gluons begin to become deconfined ➢ Quark Gluon Plasma (QGP)

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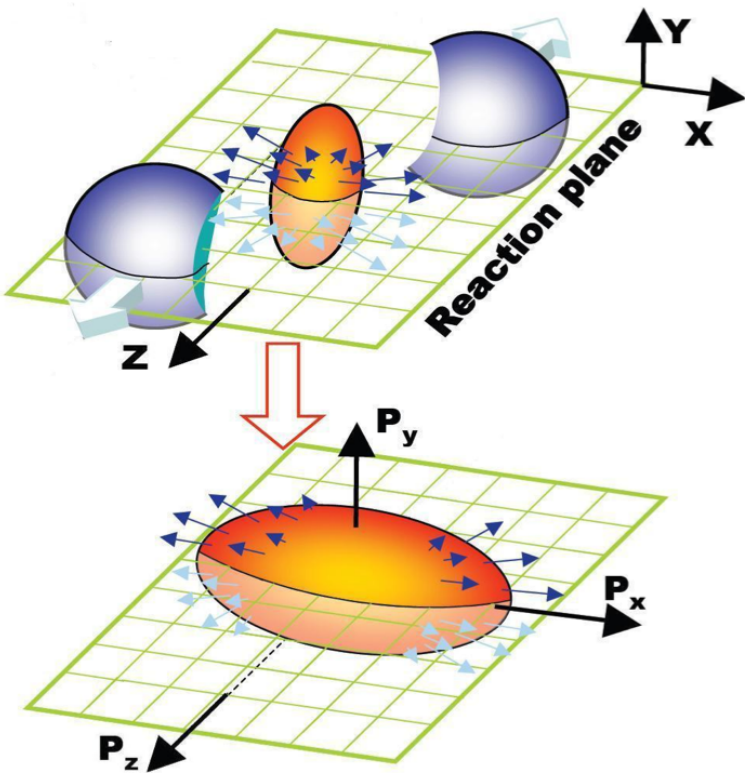
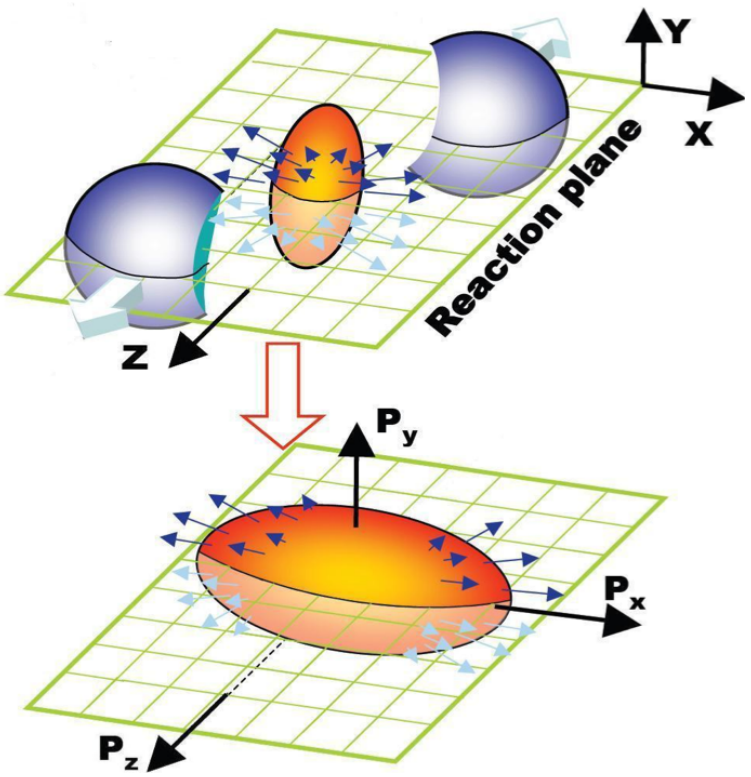
Azimuthal flow

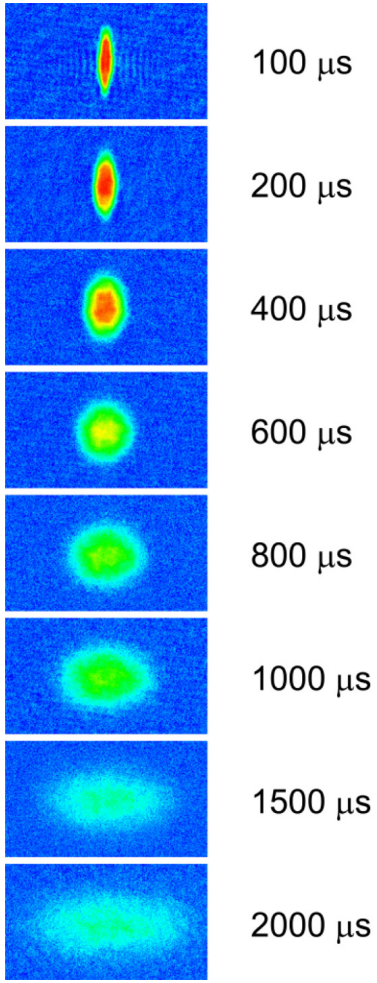


- Spatial anisotropies in the initial QGP state converted to momentum anisotropies
  - ✓ Known as “azimuthal flow”
  - ✓ Magnitude sensitive to details of initial state and transport properties of QGP

Azimuthal flow

Science Dec 13 2002 2179-2182





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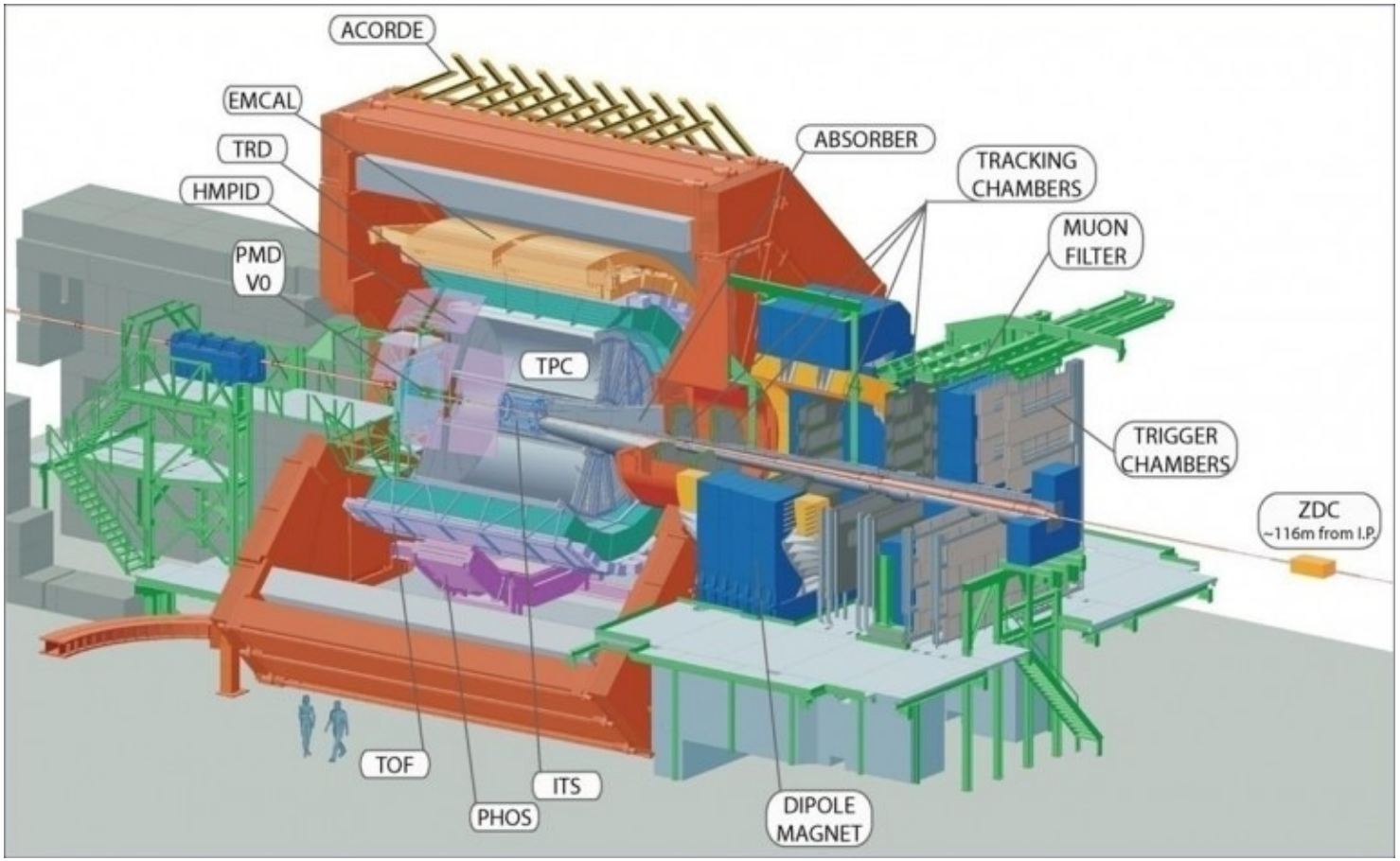
The ALICE detector and heavy-ion data



- Run 1 (2010-2013)
  - ✓ Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
  - ✓ p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- Run 2 (2015-)
  - ✓ **Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV**
  - ✓ p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

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How is azimuthal flow measured?

- Azimuthal particle distribution can be represented by Fourier series:

$$\frac{dN}{d\varphi} \propto 1 + 2\sum_{n=1}^{\infty} \mathrm{v}_n cos(n(\varphi - \psi_n))$$

- Coefficients v_n reflect magnitude of n^{th} order flow

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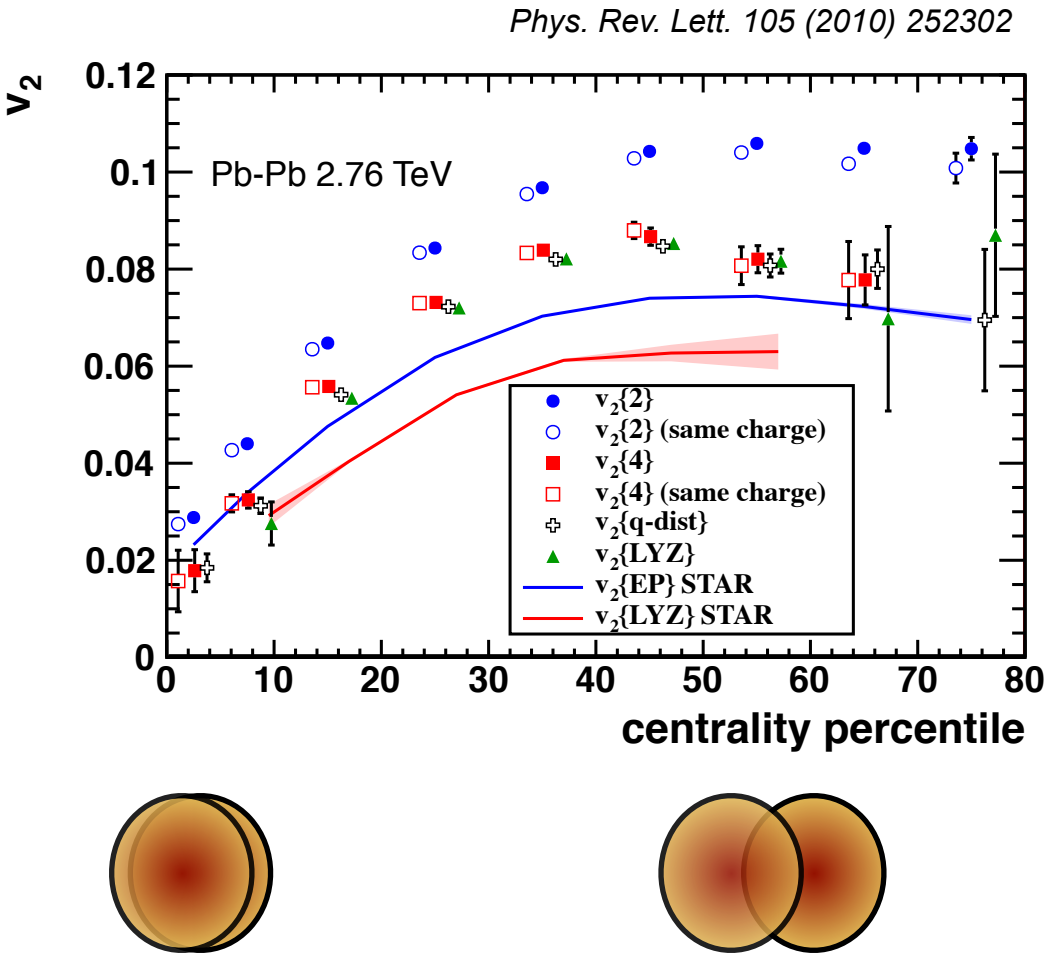

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- Coefficients v_n reflect magnitude of n^{th} order flow

- Second order (elliptic flow) typically the largest coefficient due to overlap geometry

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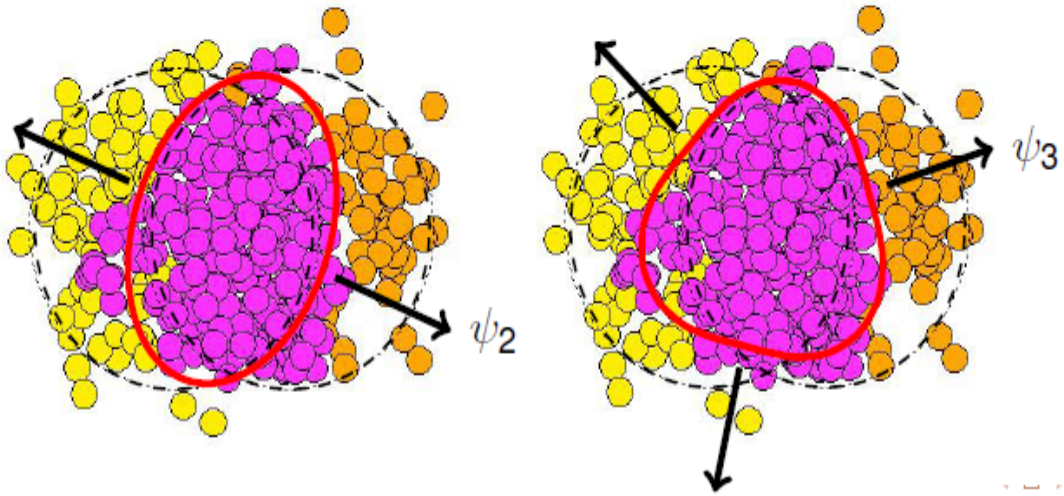
Other flow harmonics & differential studies

- Higher order flow harmonics e.g v_3, v_4
  - ✓ Can be generated from initial state fluctuations
  - ✓ More suppressed by finite η/s



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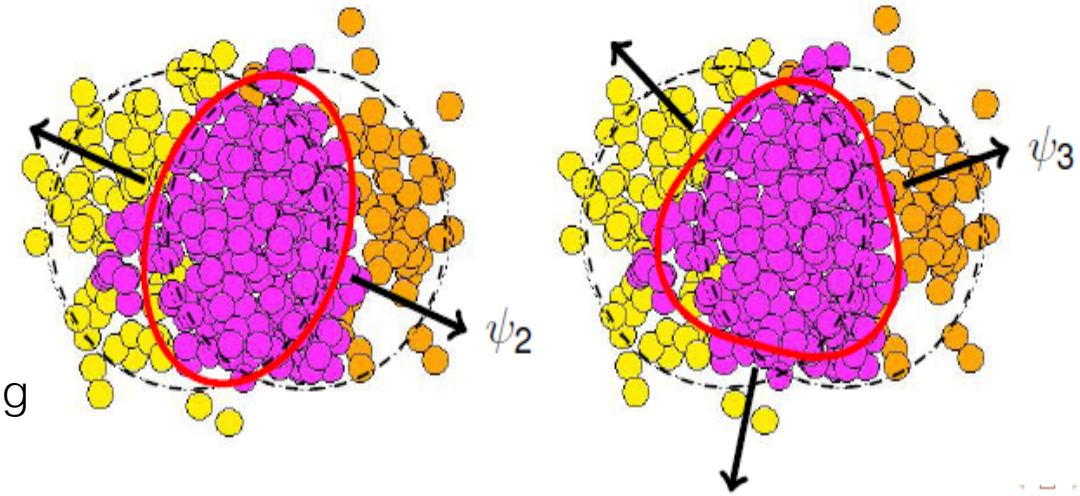
  - ✓ Transverse momentum (p_T) dependence shows mass splitting
  - ✓ Splitting due to radial flow



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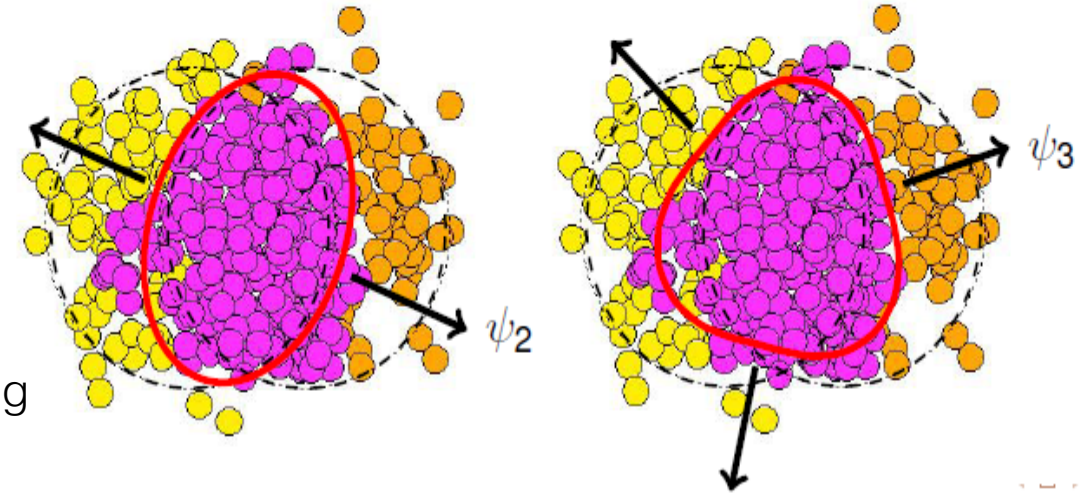

- Particle dependence of flow
  - ✓ Transverse momentum (p_T) dependence shows mass splitting
  - ✓ Splitting due to radial flow

- Correlations between different order harmonics
  - ✓ Generated from both initial state and medium response
  - ✓ Some are highly sensitive to η/s

Elliptic, trianglar, and quadrangular flow

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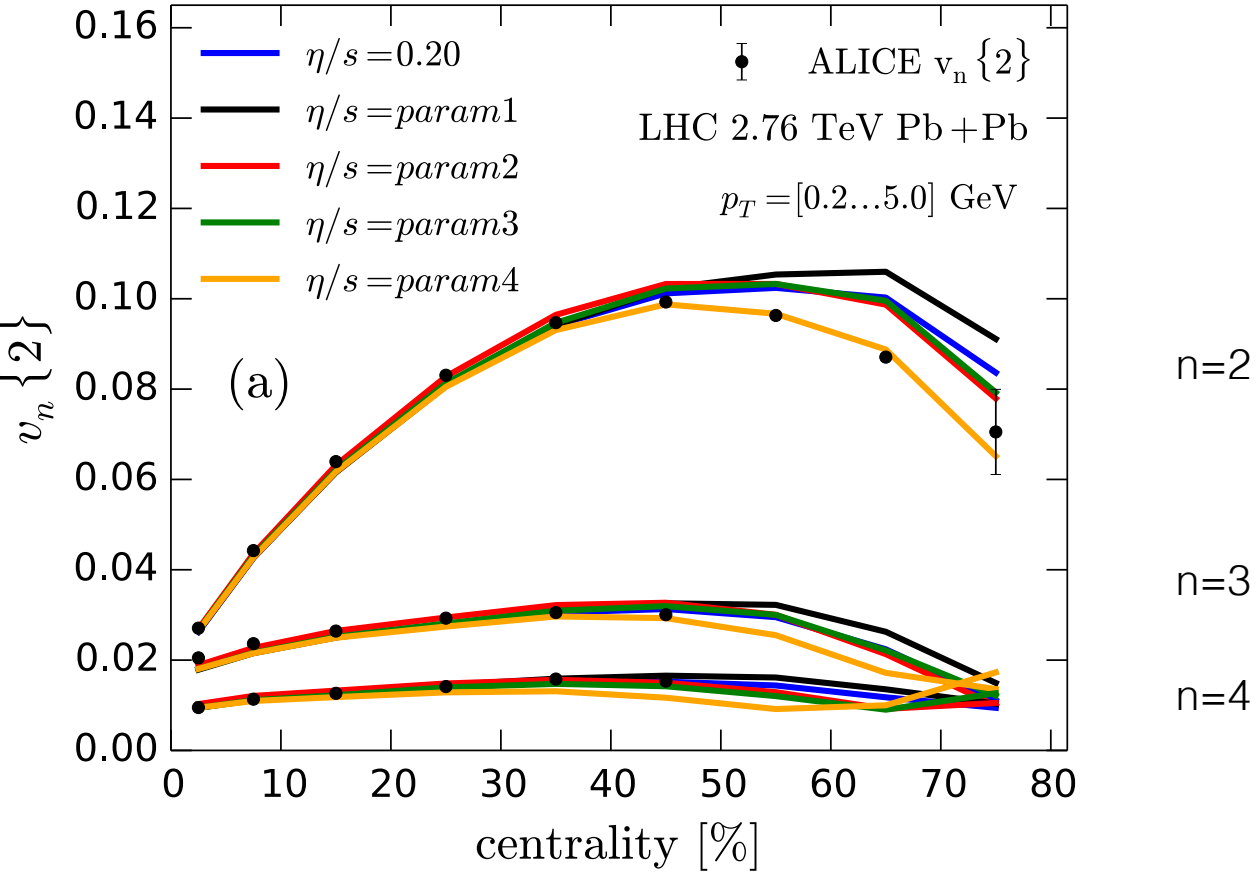
PRL 107 (2011) 032301
arXiv:1505.02677



- Hydrodynamic calculations used to investigate QGP's shear viscosity/entropy (η/s)
  - ✓ Lower bound conjectured to be 1/4π in ads/CFT
  - ✓ Comparisons to flow harmonics indicate QGP has η/s close to 1/4π

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Identified particle flow

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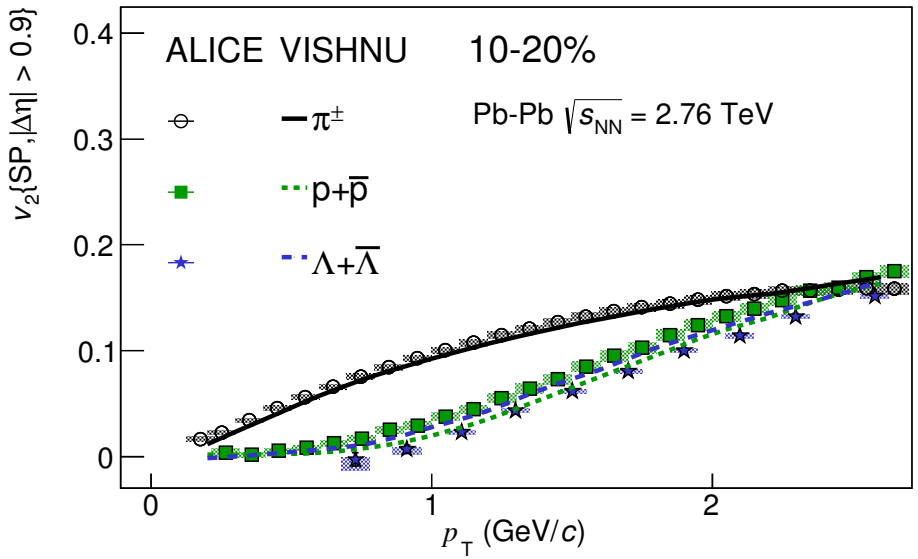
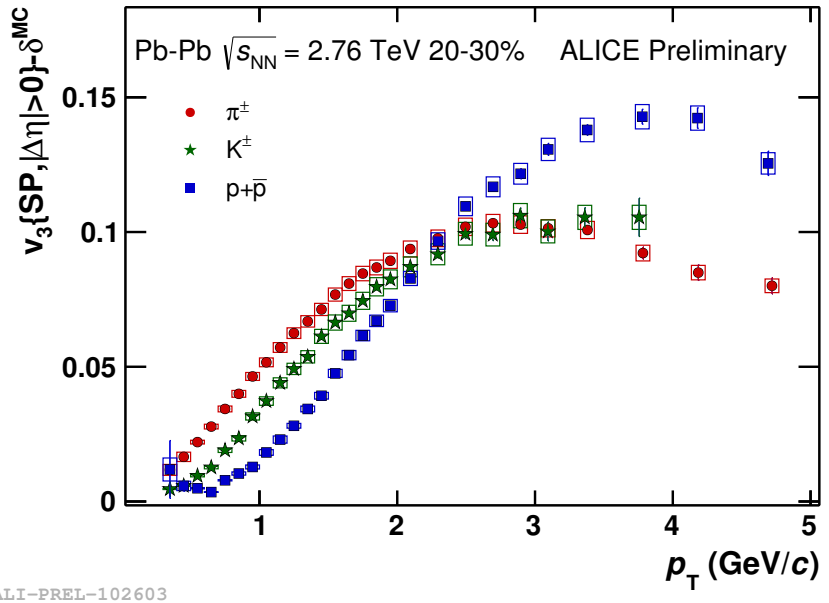
JHEP 06 (2015) 190



ALI-PUB-82888



ALI-PREL-102603

- ALICE has excellent particle identification capabilities
  - ✓ Mass splitting indeed observed for
  - ✓ Provide further constraints for hydrodynamical calculations

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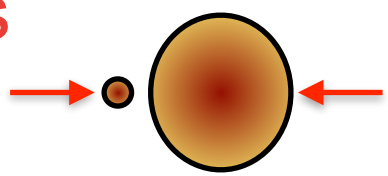
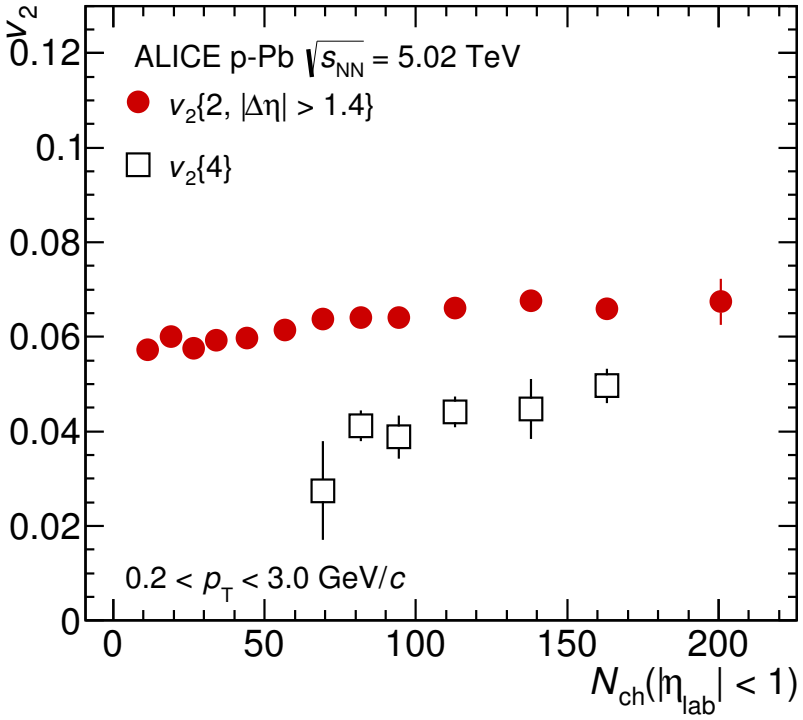
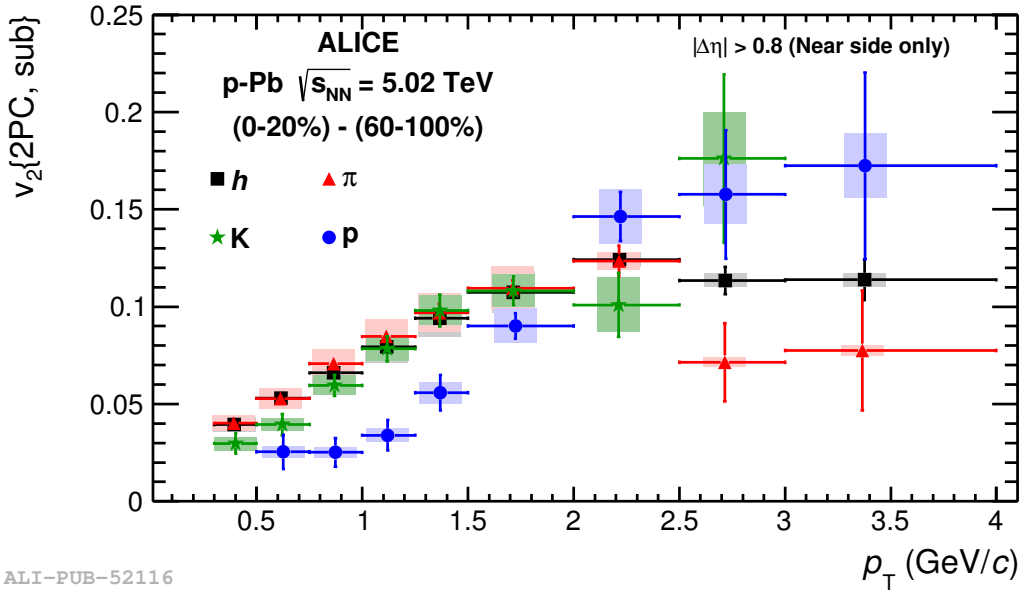
Evidence of azimuthal flow in light systems



PRC 90 (2014) 054901



PLB 726 (2013) 164–177



- Azimuthal "flow" signals also observed in high multiplicity p-Pb collisions
  - ✓ Does this mark the onset of QGP creation?
  - ✓ What other mechanisms can generate flow?

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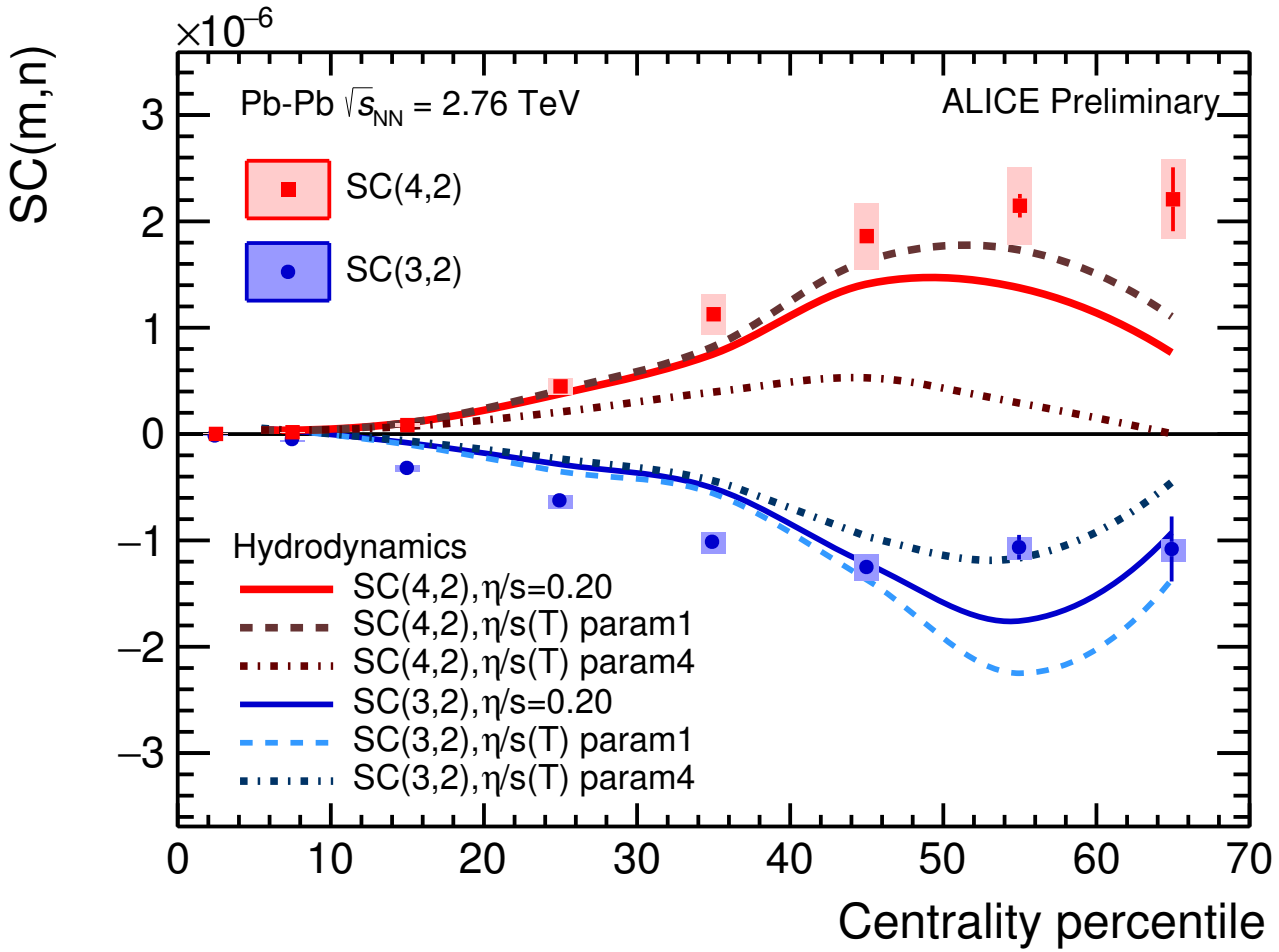
Correlations between different flow harmonics



ALI-PREL-96671

- SC(m,n) measures covariance between v_m^2 and v_n^2
  - ✓ Negative correlations between n=2 & n=3, positive for n=2 & n=4
  - ✓ Sensitive tool to constrain temperature dependence of η/s

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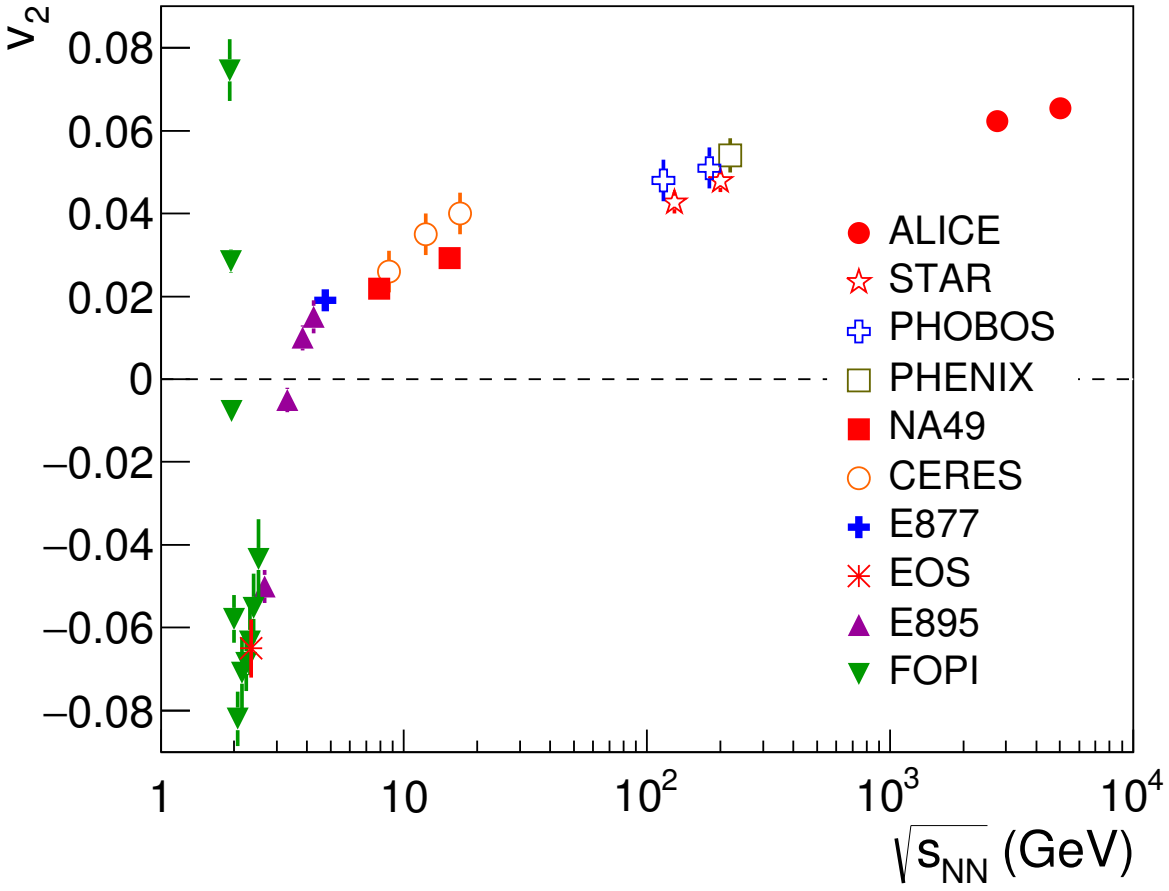
New Pb-Pb 5.02 TeV results



arXiv:1602.01119

- ~4% increase going from 2.76 to 5.02 TeV for v_2
  - ✓ Small event sample used for 5.02 TeV
  - ✓ Increase consistent with hydrodynamic predictions (PRC 93 (2016) 014912 & arXiv:1511.06289)

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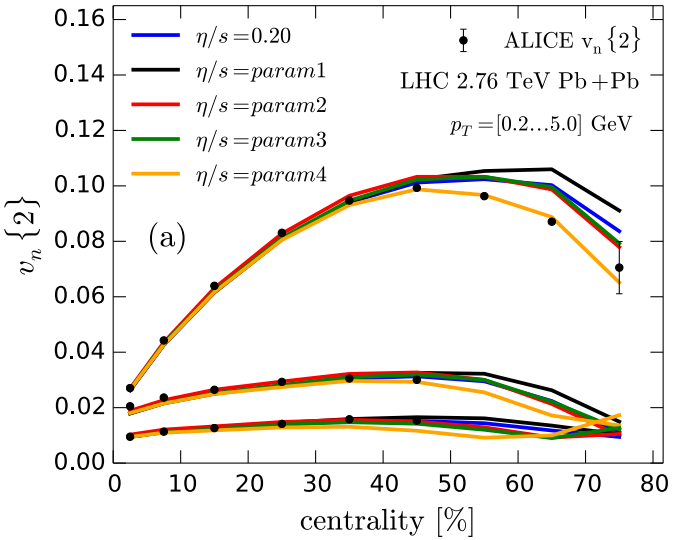
Summary and outlook

1. Comprehensive set of azimuthal flow measurements from ALICE
   - ✓Strong constraints on Quark Gluon Plasma (QGP) properties

2. Comparisons to hydro calculations indicate QGP has very small viscosities
   - ✓Close to conjectured lower bound, almost perfect fluid made at the LHC



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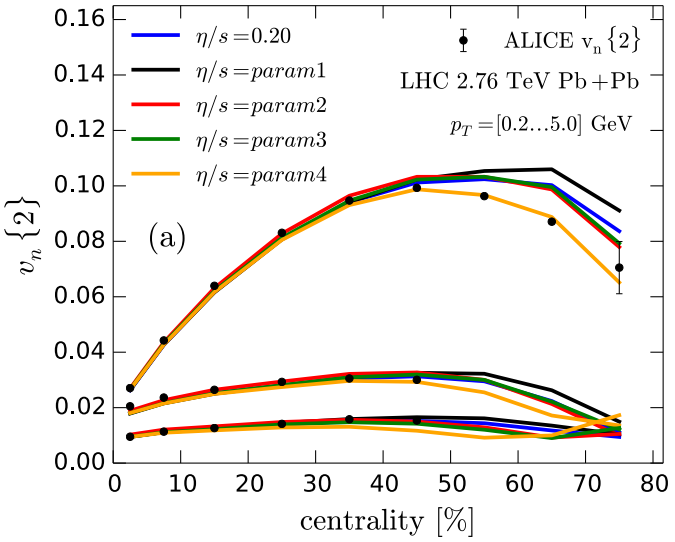
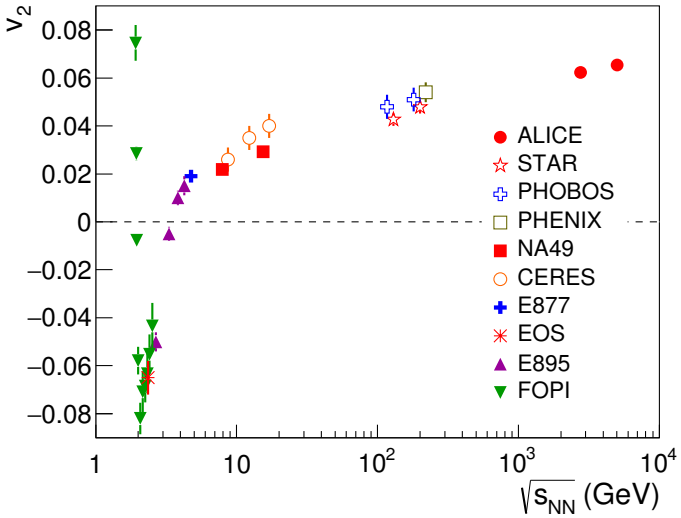
3. First azimuthal flow results from 5.02 TeV shown
   - ✓10x more events compared to 2.76 TeV expected, further improvements in accuracy to come…





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