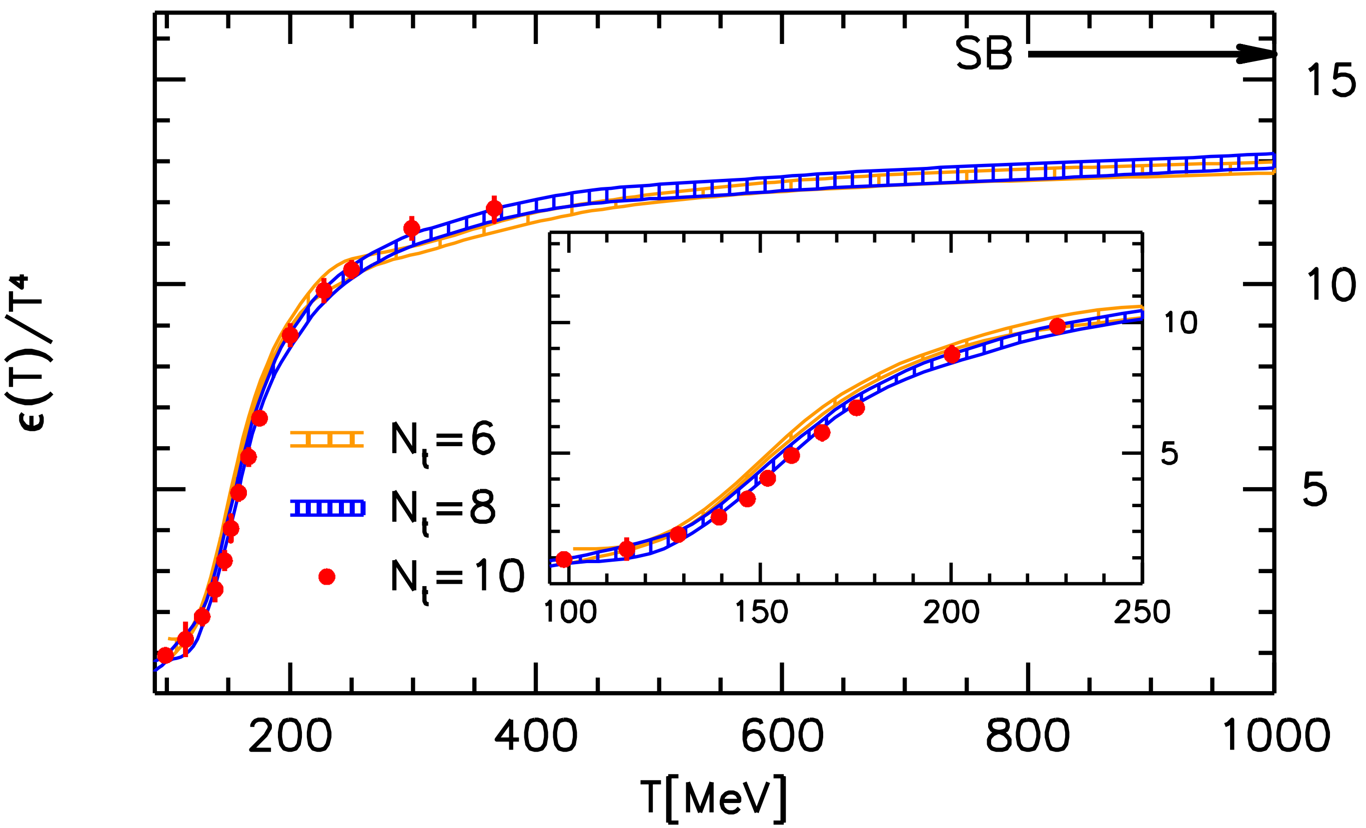
Selection of highlights from heavy-ion programs at the LHC

Anthony Timmins

The 2nd international conference on particle physics and astrophysics

Heavy-ion collisions and the QGP

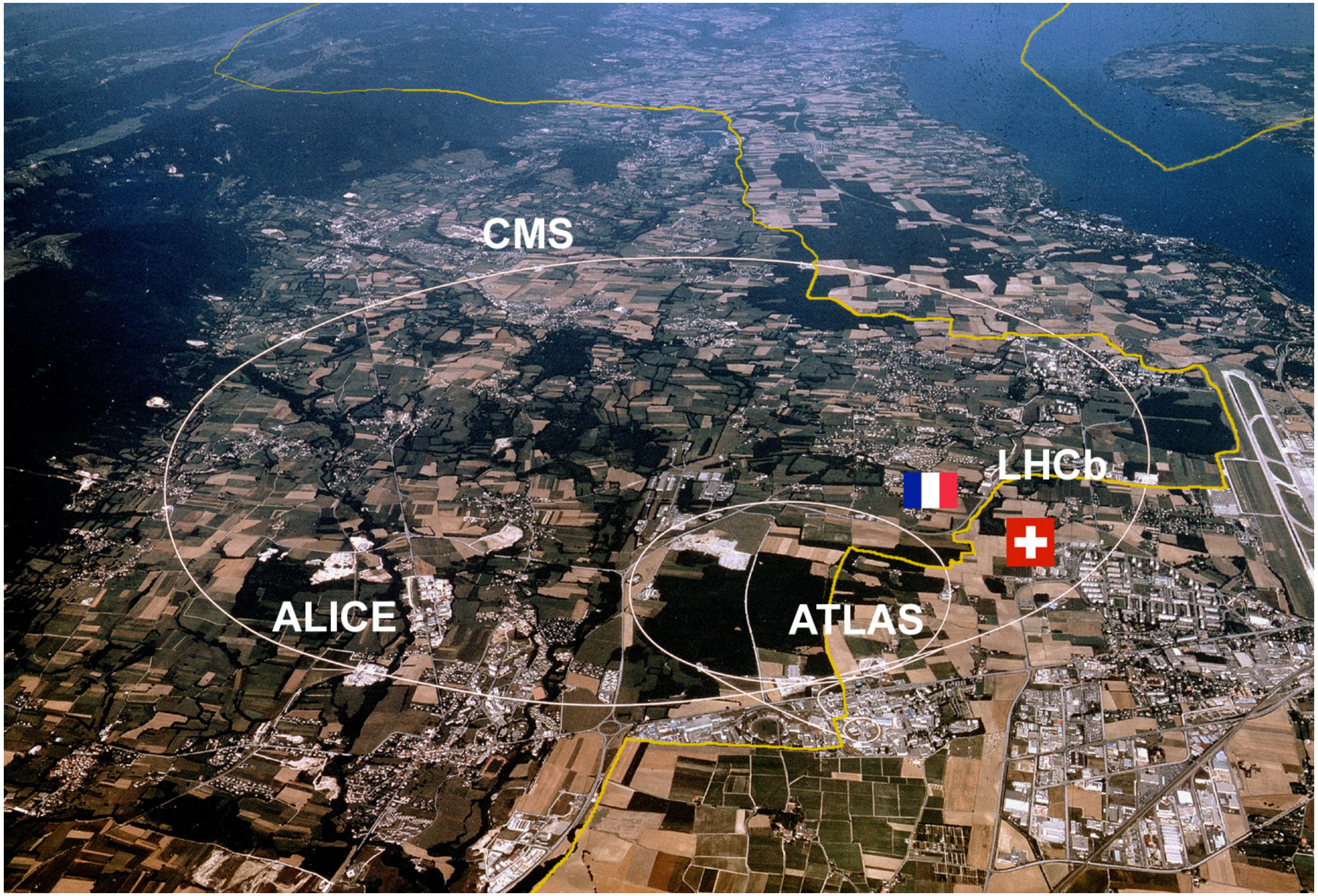


Phys. Lett. B478 (2000) 447-455

JHEP 1011 (2010) 077

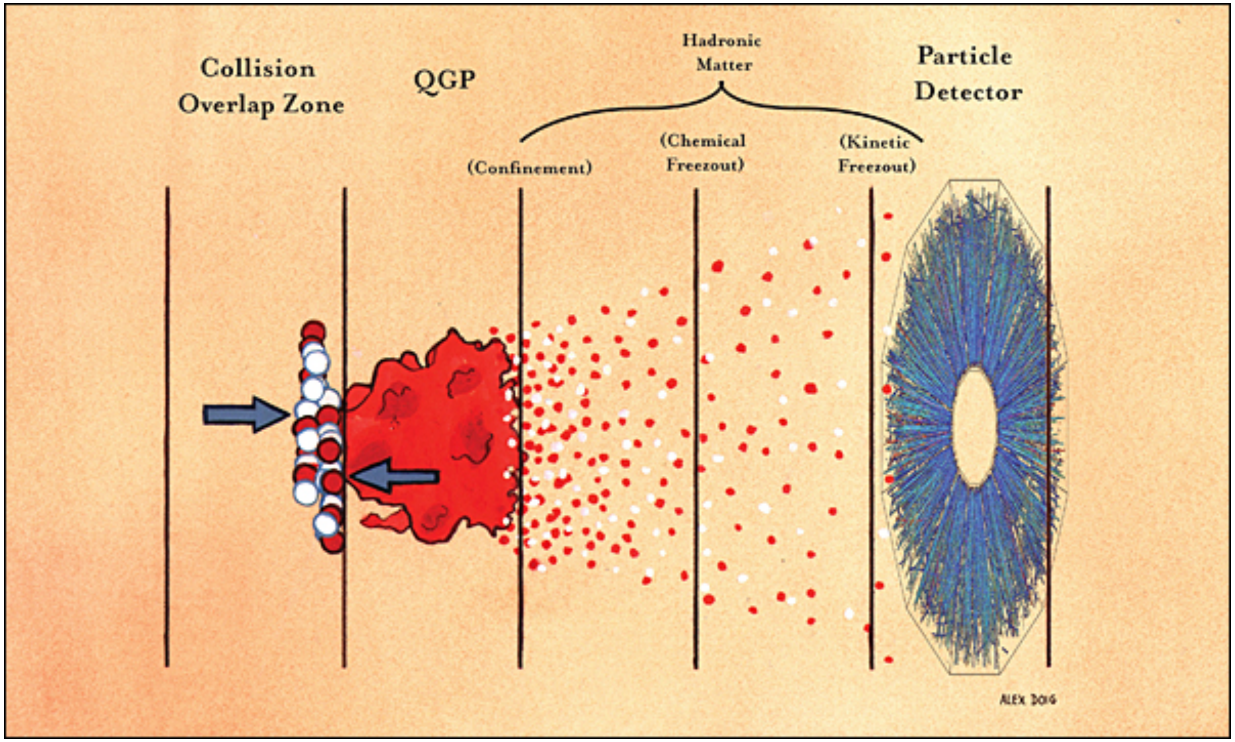
- Heavy-ion collisions deposit large energy in small volume
  - ✓ Nuclear matter "melts"
  - ✓ Quarks & gluons begin to become deconfined ➢ Quark Gluon Plasma (QGP)

Heavy-ion program at the LHC



- Run 1 (2010-2013)
  - ✓ Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
  - ✓ p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- Run 2 (2015-2018)
  - ✓ Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
  - ✓ p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV

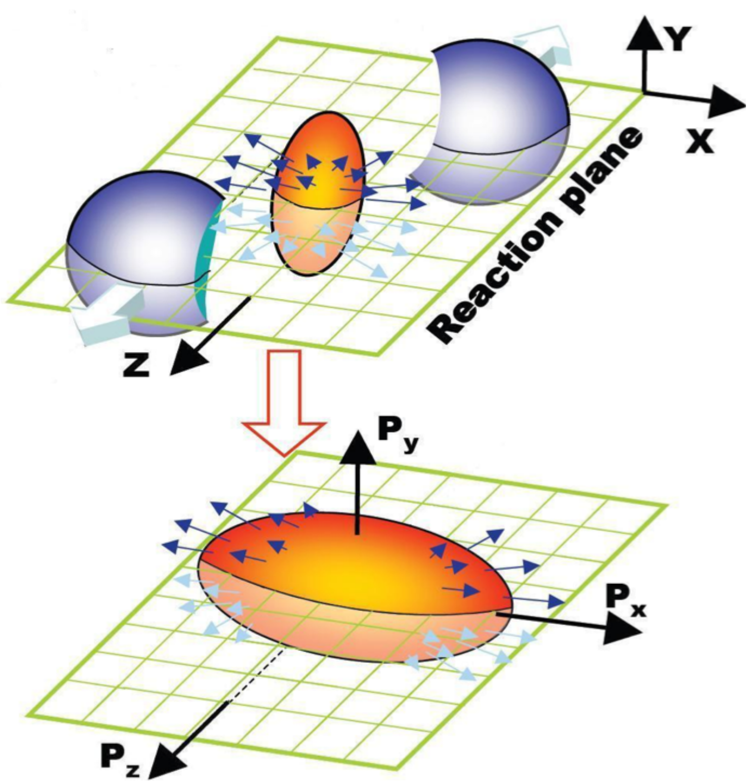
Understanding properties of the QGP

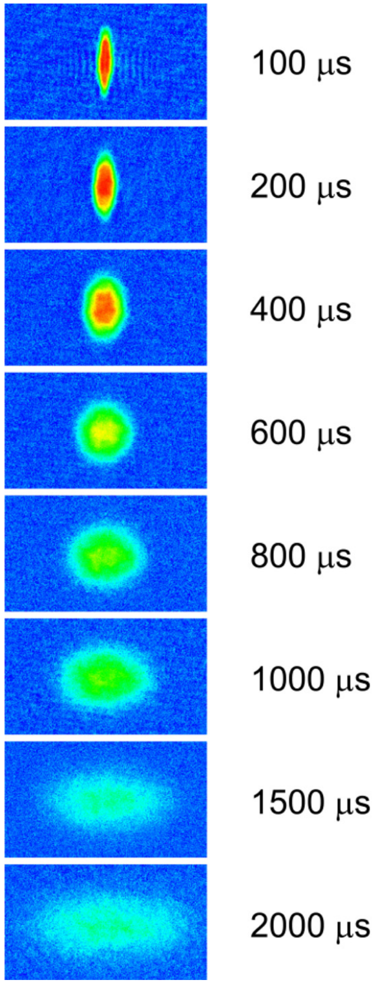


- Collisions at LHC provide high temperatures and longest lasting system
- Measurements often grouped into two categories
  - ✓ Soft probes: Azimuthal flow
  - ✓ Hard Probes: Modification of jets in the medium

Azimuthal flow

Science Dec 13 2002 2179-2182

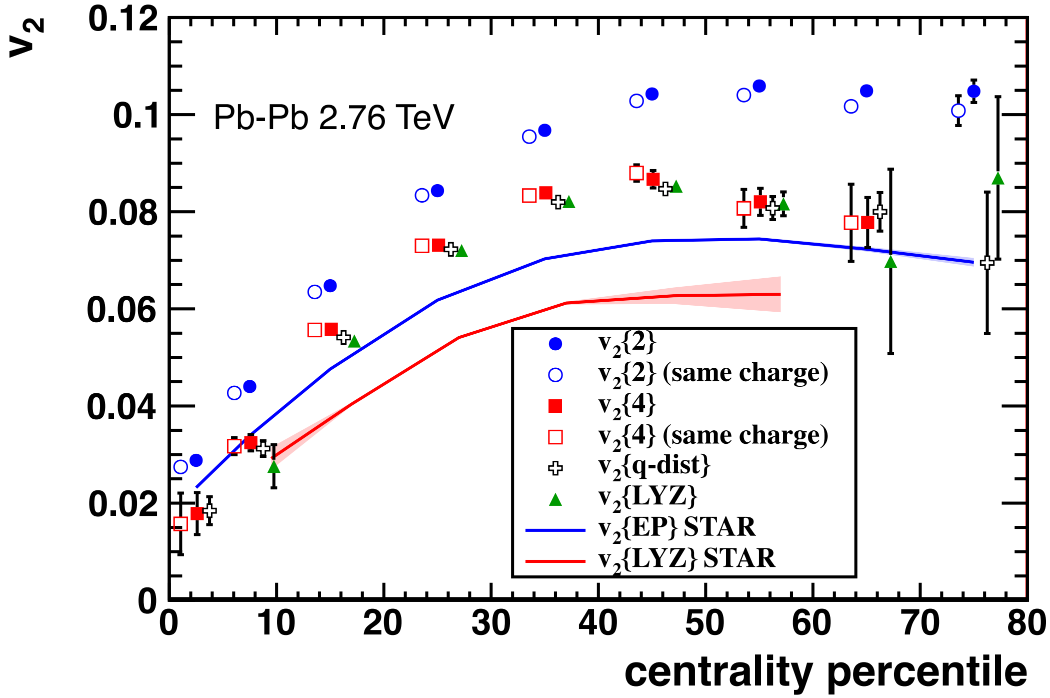


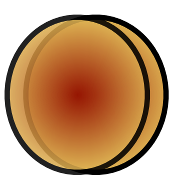


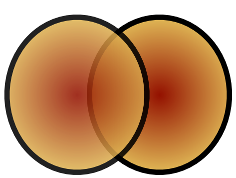
- Spatial anisotropies in the initial QGP state converted to momentum anisotropies
  - ✓ Known as “azimuthal flow”
  - ✓ Magnitude sensitive to details of initial state and transport properties of QGP

How is azimuthal flow measured?

Phys. Rev. Lett. 105 (2010) 252302







- Azimuthal particle distribution can be represented by Fourier series:

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

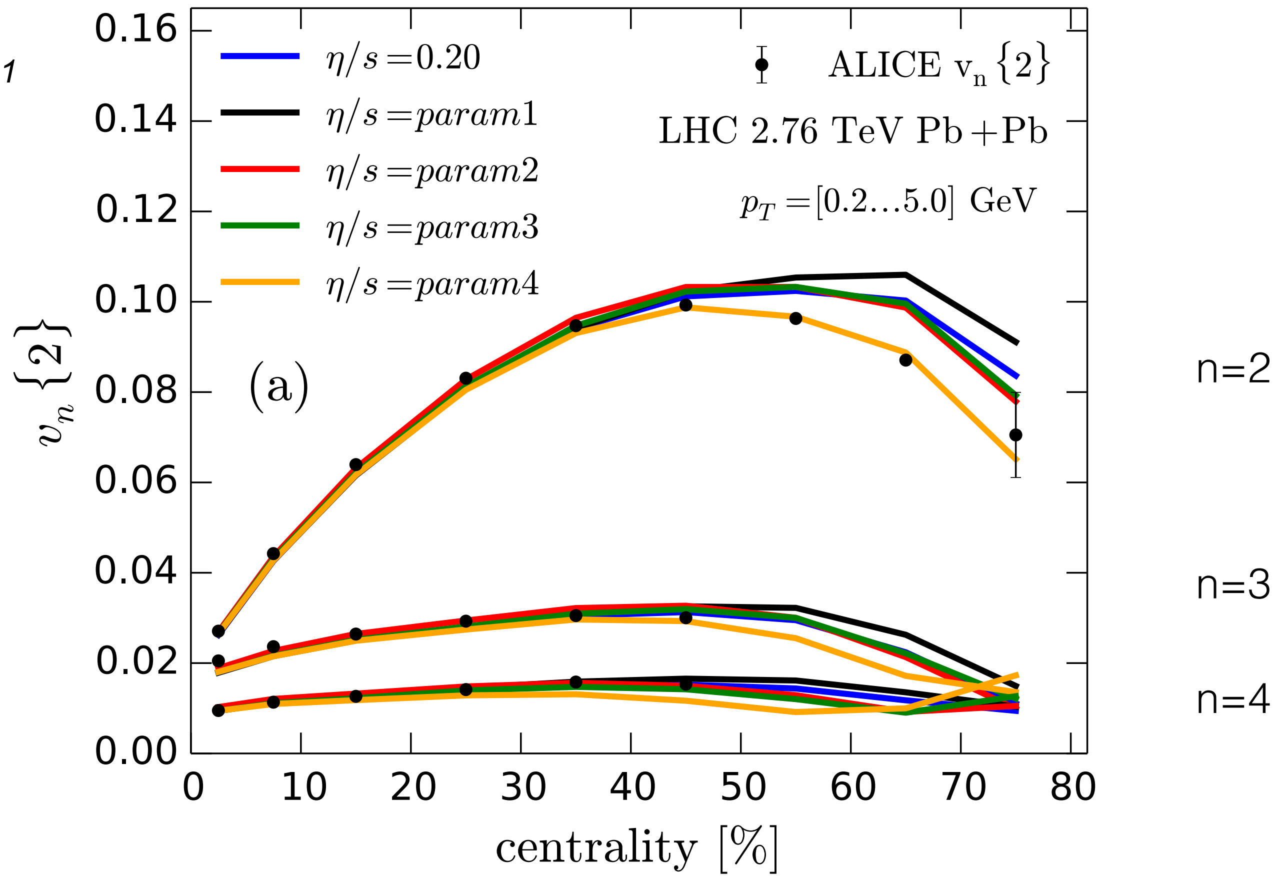
- Coefficients v_n reflect magnitude of n^{th} order flow

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

Elliptic, trianglar, and quadrangular flow

PRL 107 (2011) 032301

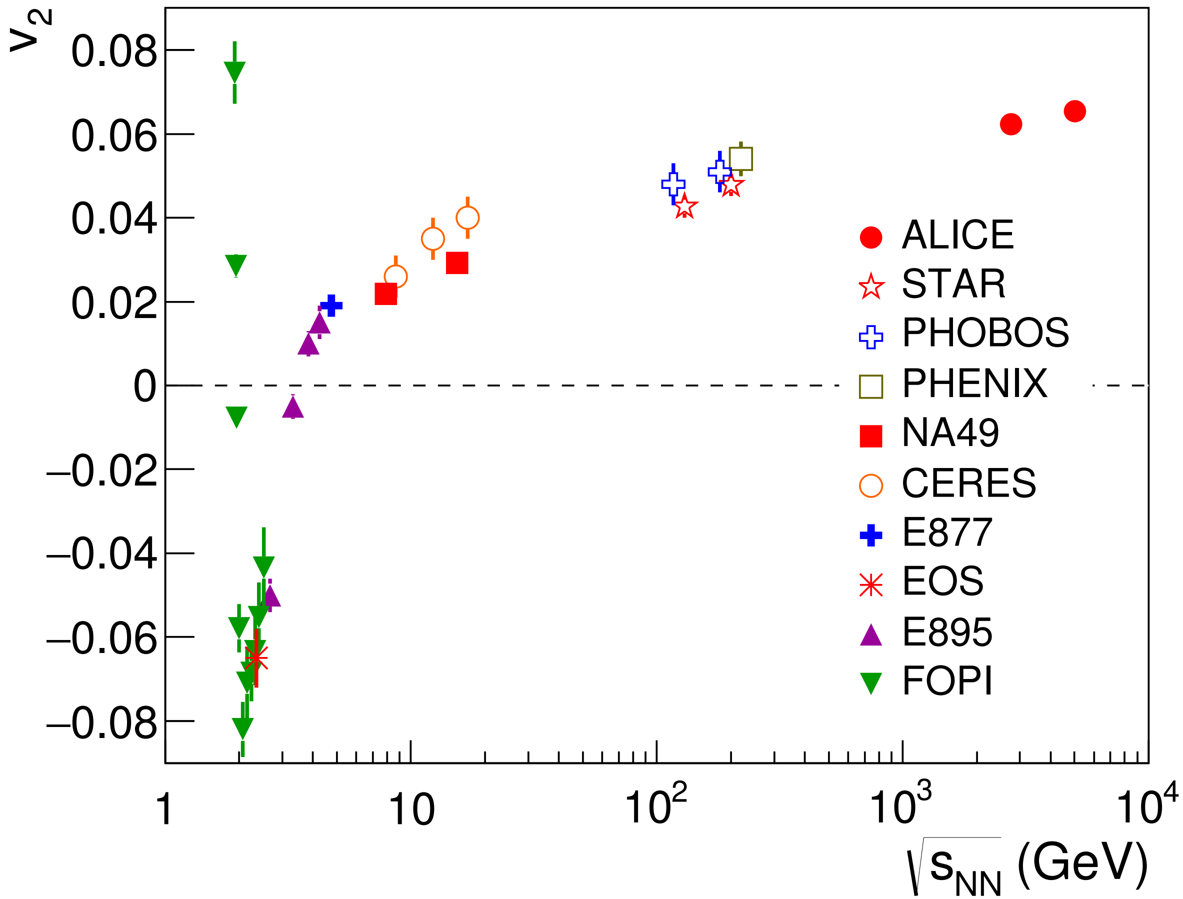
arXiv:1505.02677



- 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

UNIVERSITY of HOUSTON

Pb-Pb 5.02 TeV results



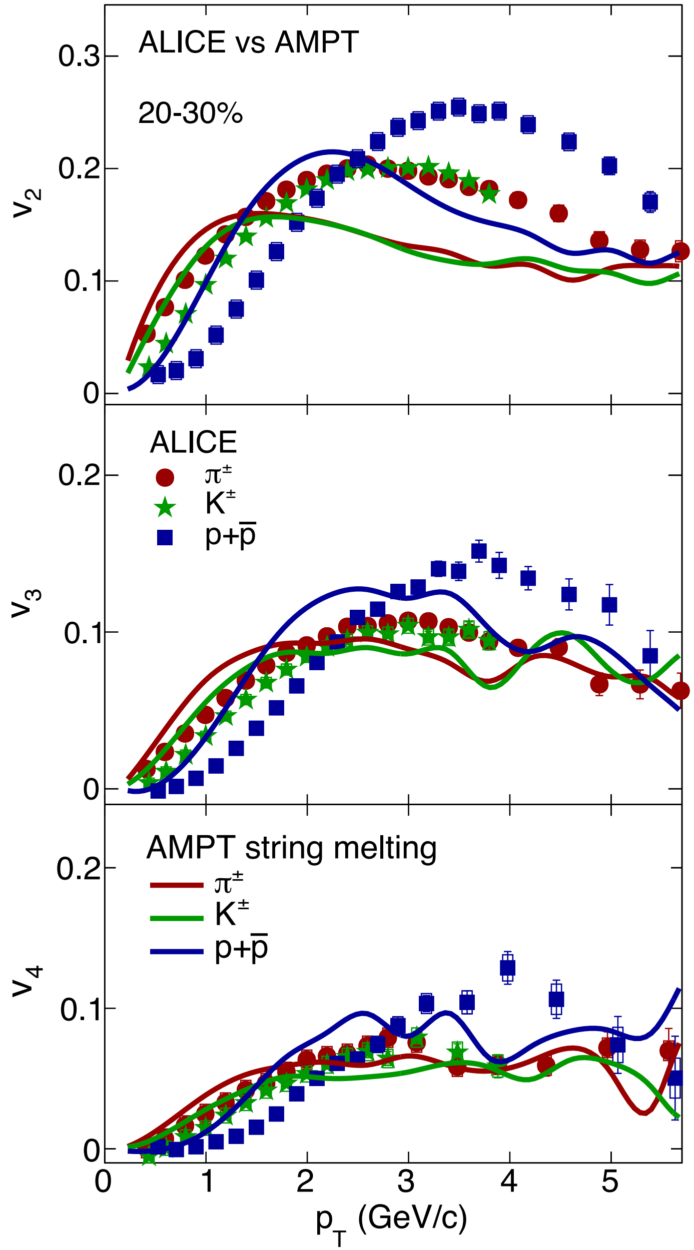
PRL 116 (2016) 132302

- ~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)

Identified particle flow

UNIVERSITY of HOUSTON

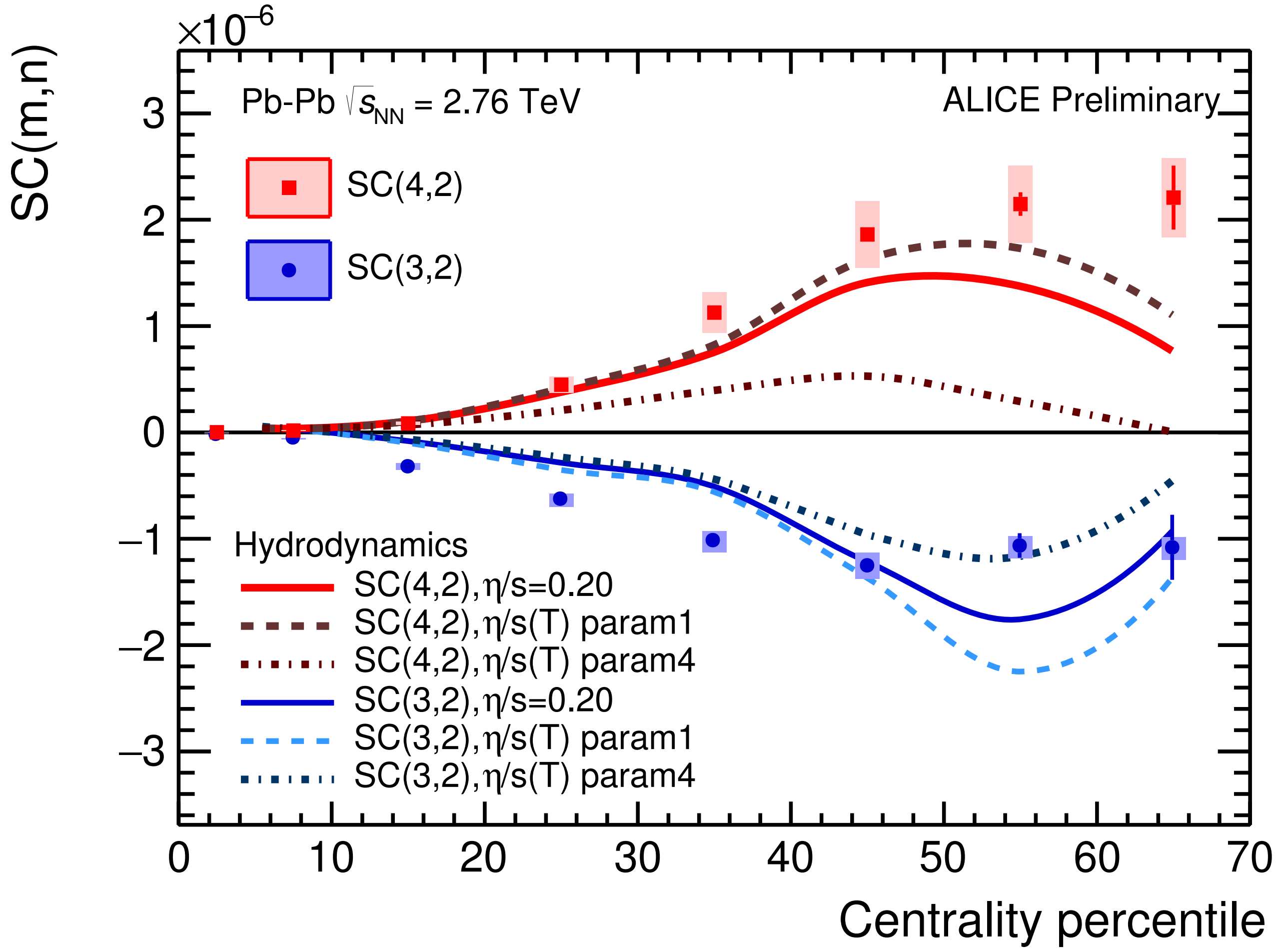
- Mass splitting observed due to common radial flow velocity
- Provide further constraints for hydrodynamical calculations…



arXiv:1606.06057

Parallel Talk: I. Altsybeev

Correlations between different flow harmonics



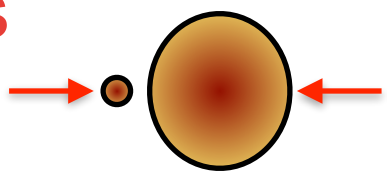
ALI-PREL-96671

Parallel Talk: A. Bilandzic

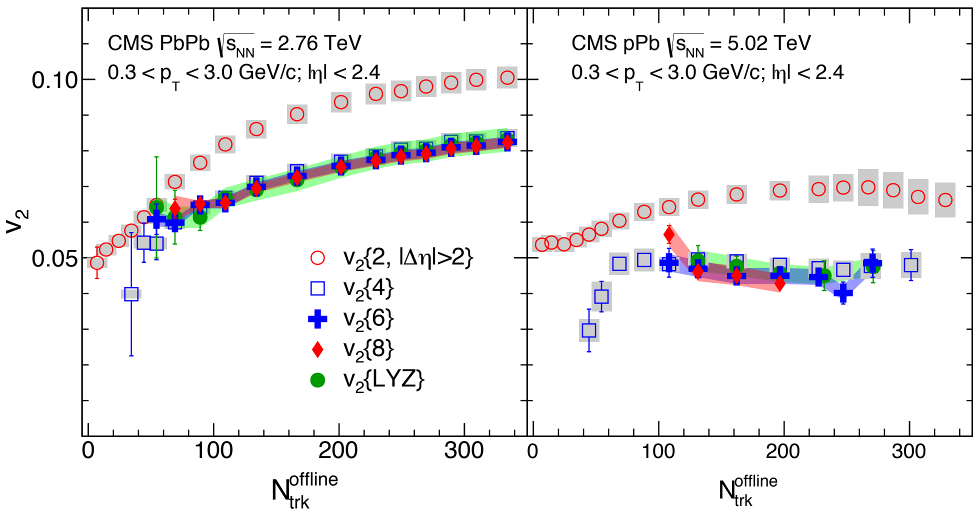
- SC(m,n) measures covariance between v_m^2 and v_n^2
  - ✓ Negative correlations between n=2 & n=3, positive for n=2 & n=4
  - ✓ Sensitive tool to constrain temperature dependence of η/s

UNIVERSITY of HOUSTON

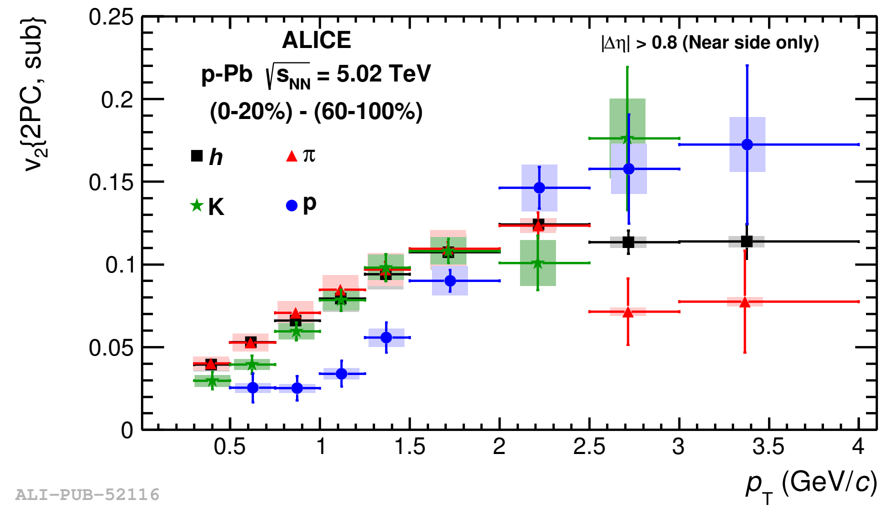
Evidence of azimuthal flow in light systems



PRL 115 (2015) 012301



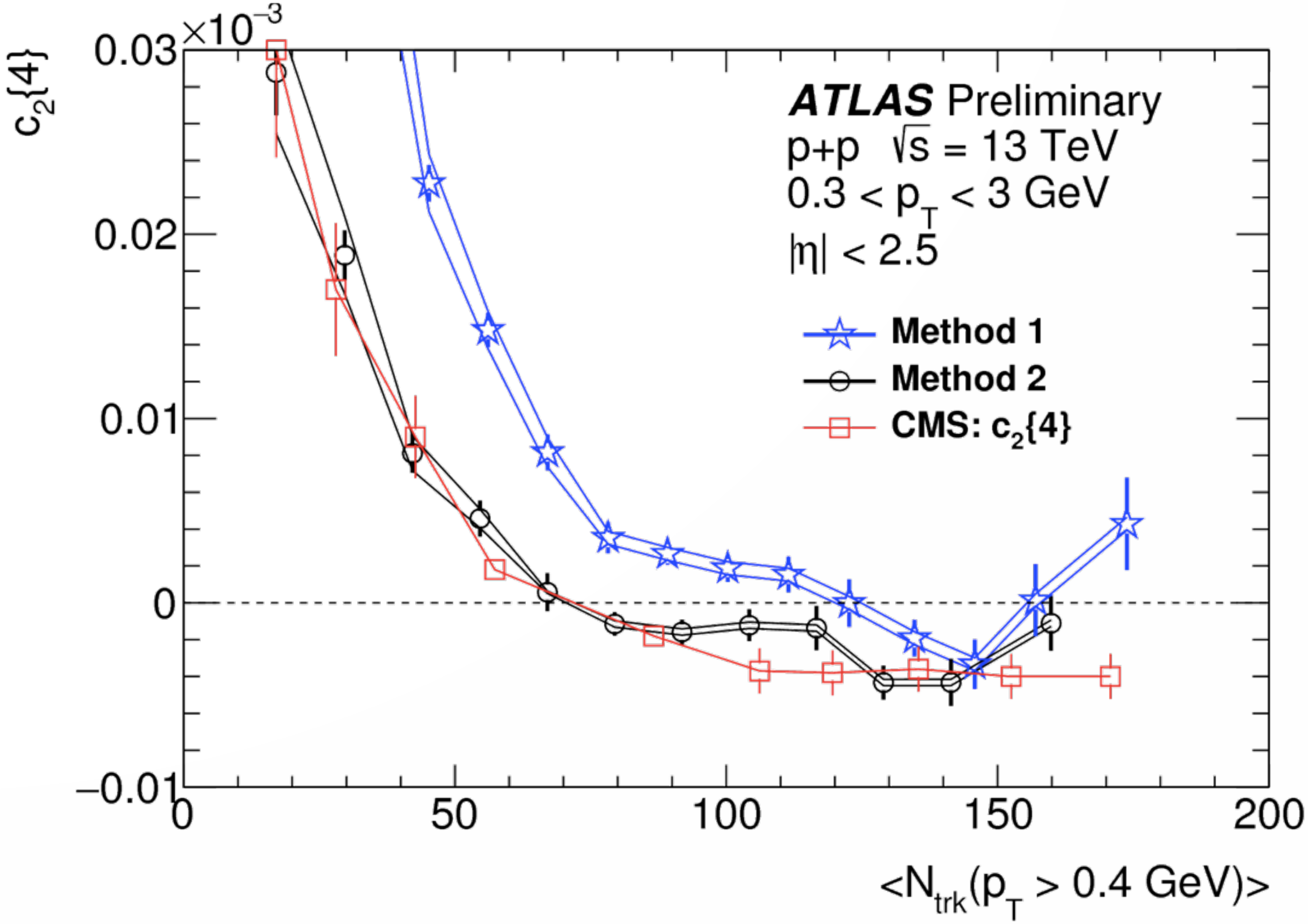
PLB 726 (2013) 164–177



Parallel Talks: A. Toia and I. Altsybeev

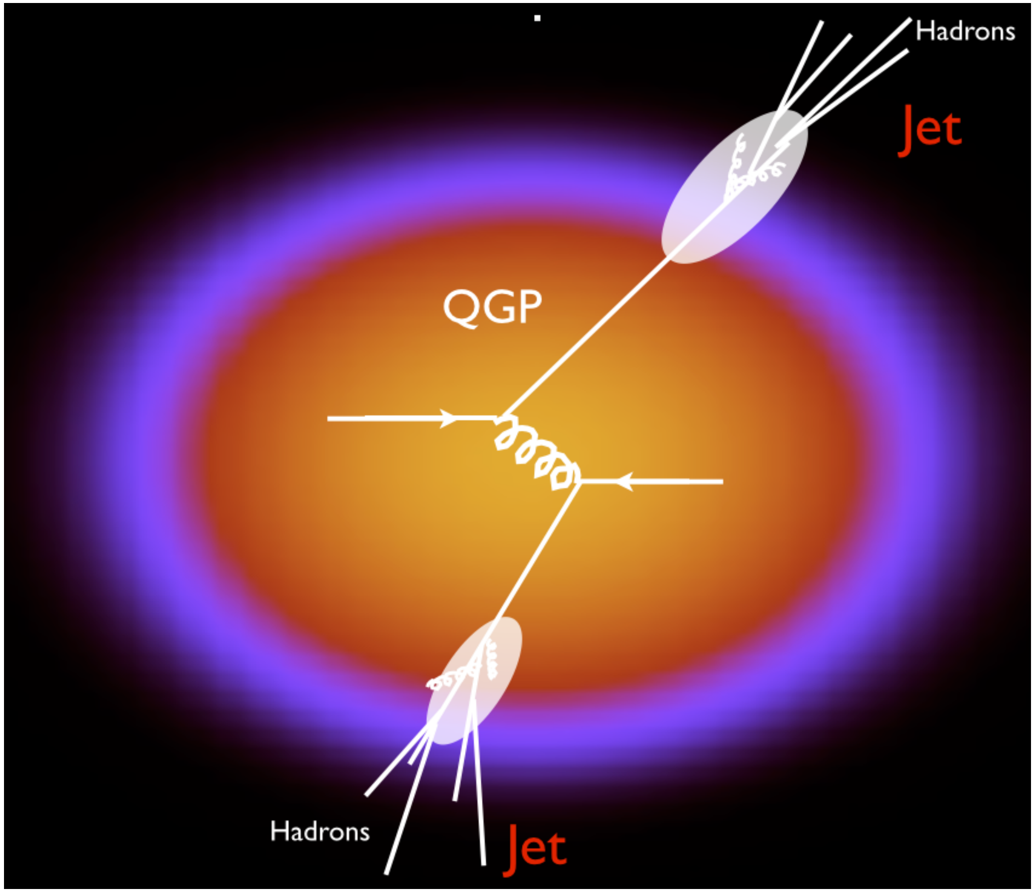
- Azimuthal "flow" signals also observed in high multiplicity p-Pb collisions
  - ✓ Does this mark the onset of QGP creation?
  - ✓ What other mechanisms can generate flow?

What happens in pp collisions?



- Negative $c_2\{4\}$ signals multiple particle correlations :
  - ✓ Results from ATLAS and CMS inconsistent

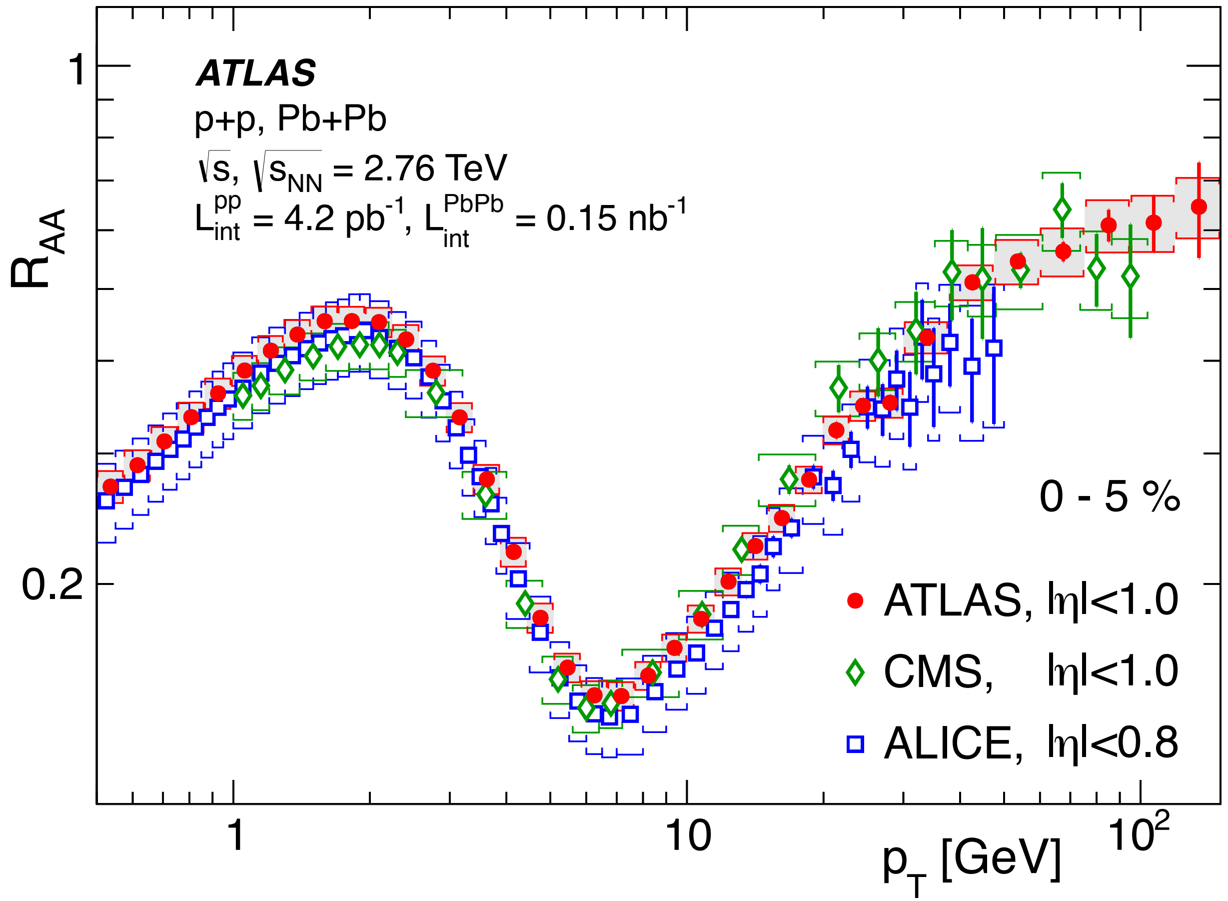
Hard probes



- High p_T partons produced in initial stages of heavy-ion collisions
  - ✓ Will be influenced differently in QGP compared vacuum.
  - ✓ Modification with medium often calculable in QCD

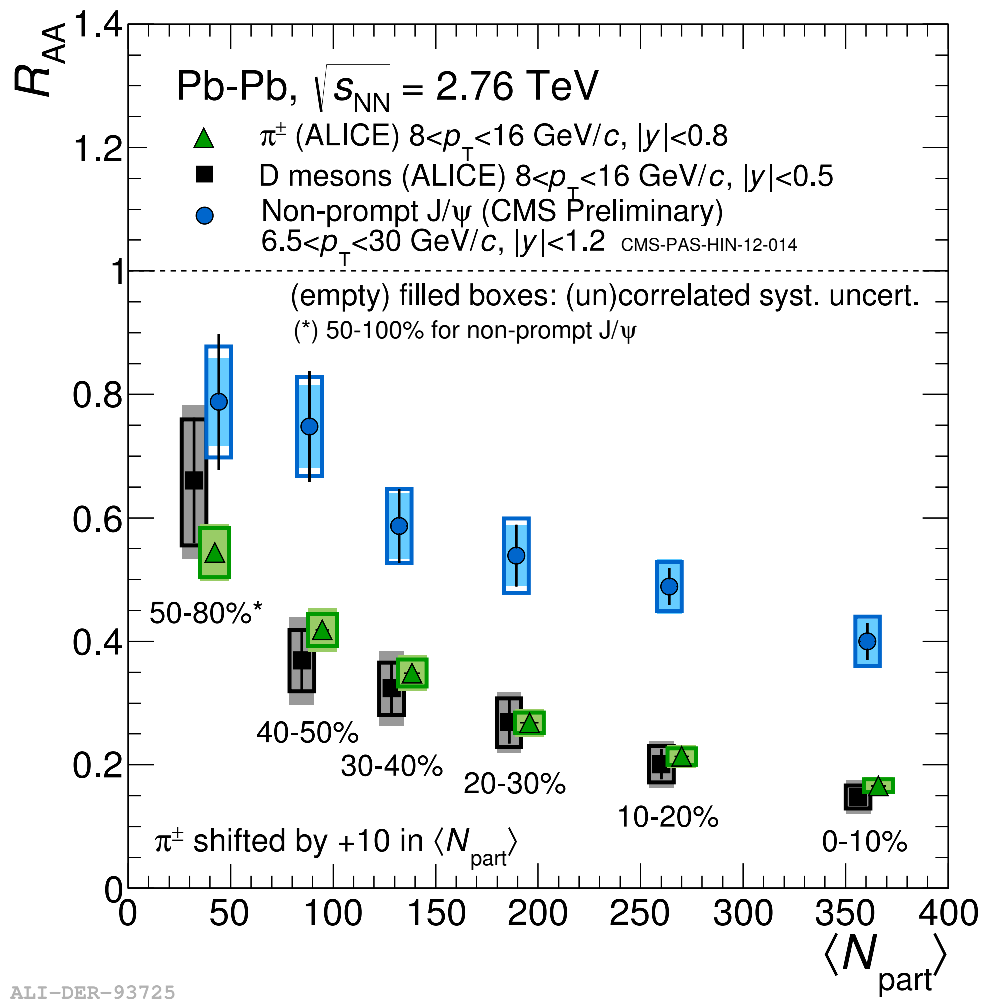
Nuclear modification factor (R_{AA})

JHEP09 (2015) 050



- Defined as charged hadron yield in Pb-Pb collisions / yield in pp collisions
  - ✓ Suppression at high p_T linked to jet quenching

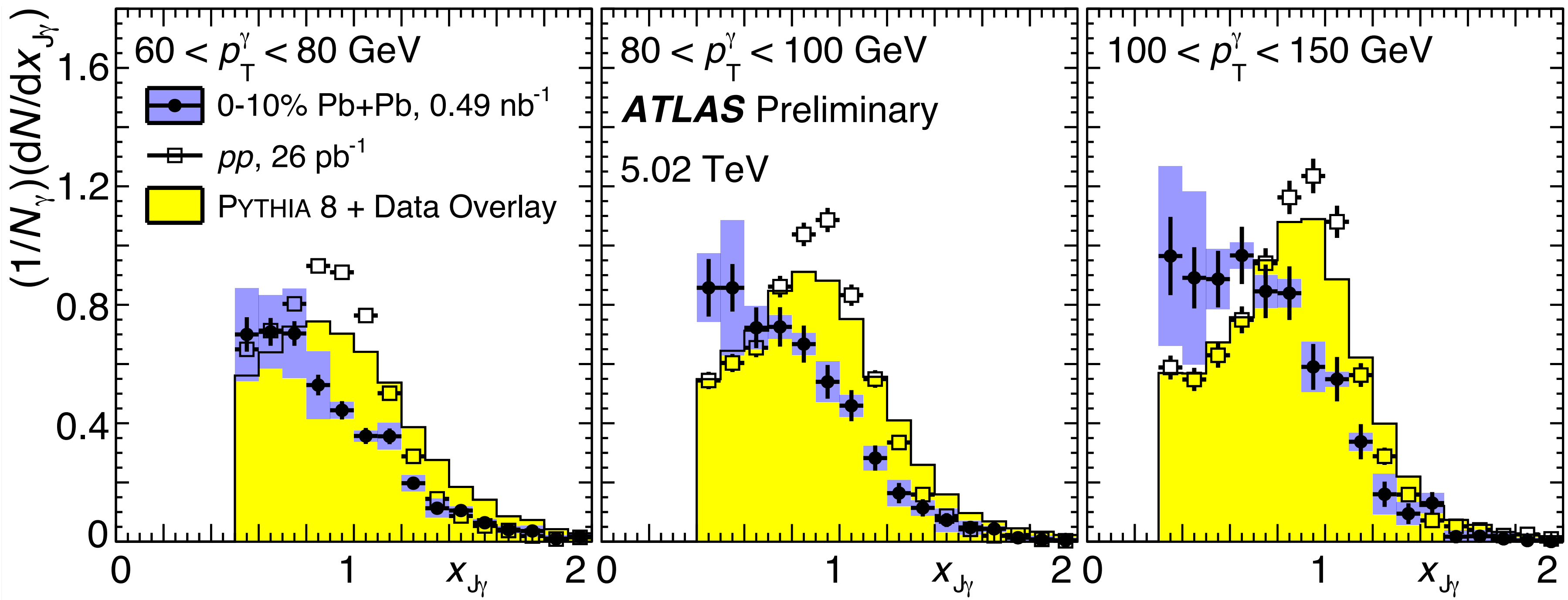
Mass dependence of R_{AA}



JHEP 1511 (2015) 205

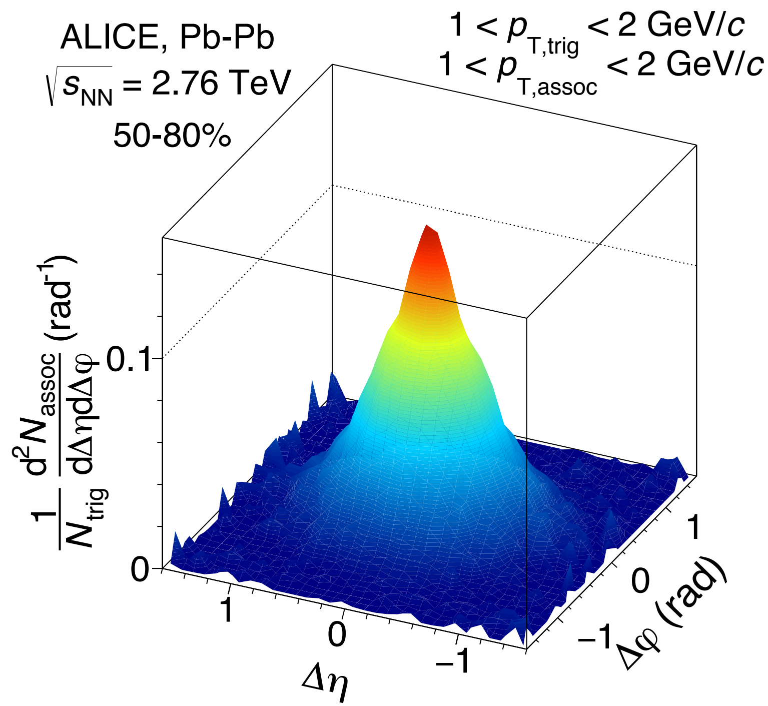
- Heavier charm particles less suppressed
  - Colour-charge dependence of parton energy loss?

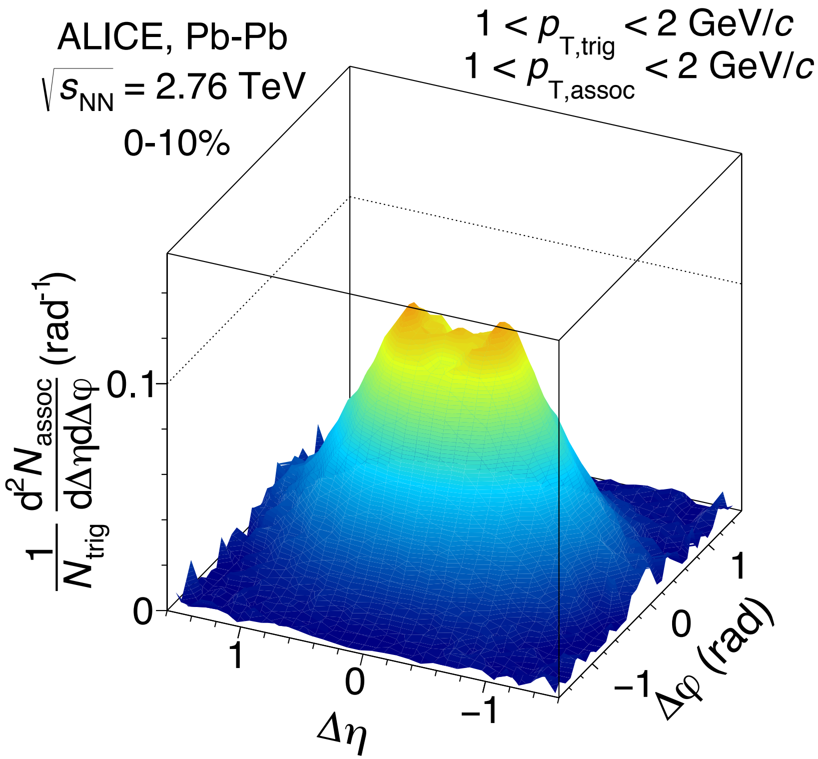
Gamma-jet correlations



- Gamma-jets produced in hard processes: $x_{J\gamma} = p_T(\text{jet})/\ p_T(\gamma)$
  - ✓ Photons not influenced by QGP
  - ✓ Jet momentum shifted to lower values in Pb-Pb collisions

Evolution of the jet-peak

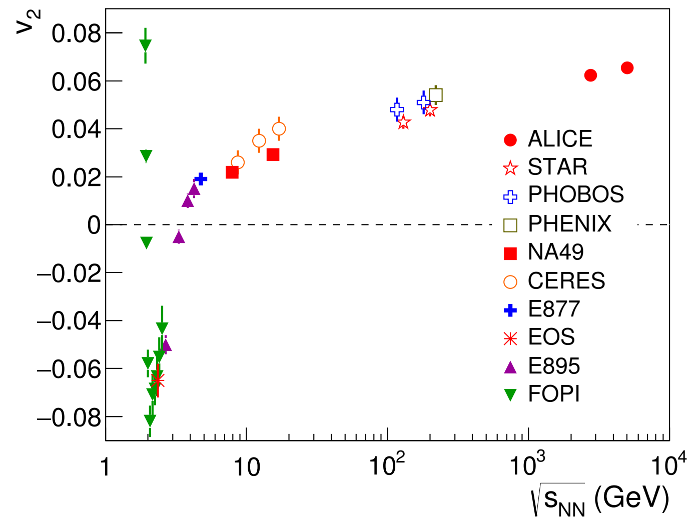




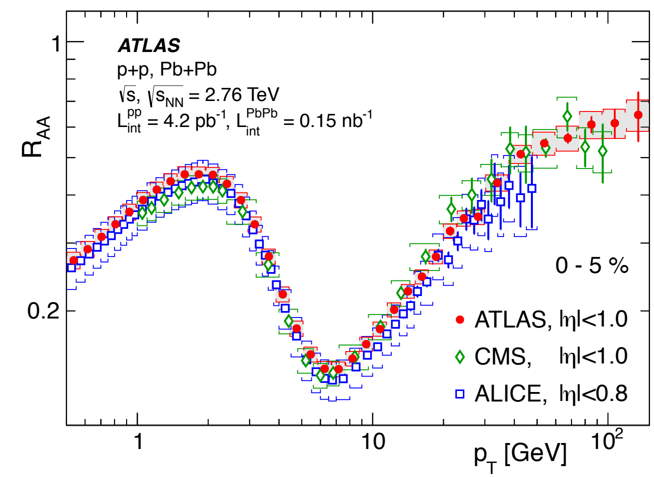
- Di-hadron correlations help examine jet peak
  - ✓ Jet peak broadens in central Pb-Pb collisions
  - ✓ Demonstrates medium also influences jet fragments

Summary

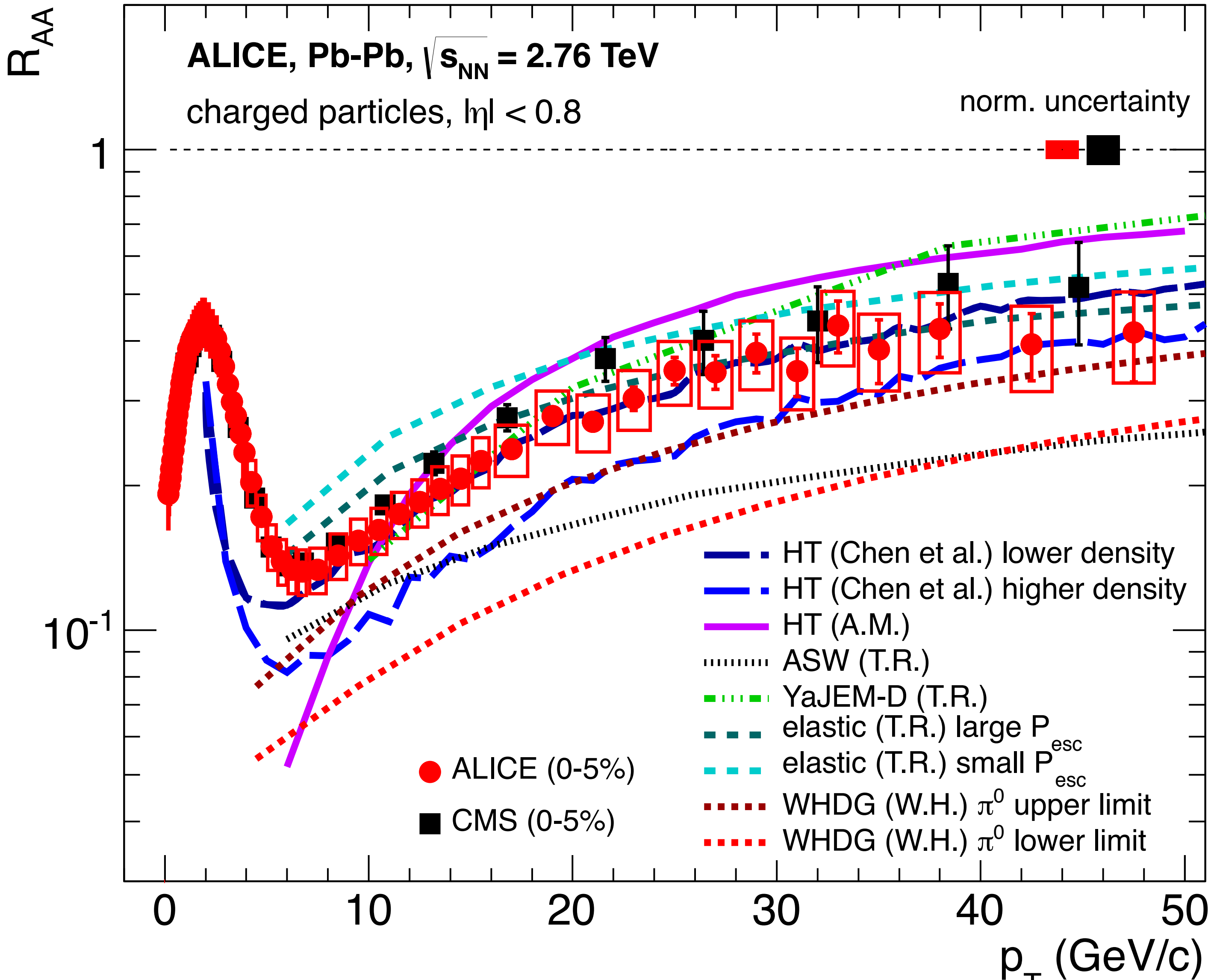
1. Measurements of azimuthal flow indicate QGP has very small viscosities
   - ✓Close to conjectured lower bound, almost perfect fluid made at the LHC
   - ✓Evidence of collectively in small systems



2. Strong jet medication seen at LHC energies
   - ✓R_{AA} drops to ~0.15 and has mass dependance
   - ✓Jet fragments clearly altered by the medium



Backup


ALICE, Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
charged particles, |η| < 0.8
norm. uncertainty
R_{AA}
1
10^{-1}
0
10
20
30
40
50
p_T (GeV/c)
ALICE (0-5%)
CMS (0-5%)
HT (Chen et al.) lower density
HT (Chen et al.) higher density
HT (A.M.)
ASW (T.R.)
YaJEM-D (T.R.)
elastic (T.R.) large P_{esc}
elastic (T.R.) small P_{esc}
WHDG (W.H.) π^0 upper limit
WHDG (W.H.) π^0 lower limit