Flow in p-Pb collisions at the LHC

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[Details: **Piotr Bożek** & WB, PRL **109** (2012) 062301, PLB 718 (2013) 1557, arXiv:1301.3314]

Signatures of sQGP

Main sigantures of sQGP in ultra-relativistic A+A collisions

- Collective flow
- Jet quenching

Flow manifest itself in harmonic components in the momentum spectra, certain features in correlation data (ridges), interferometry (femtoscopy), ...

3-stage approach

Our approach ("Standard Model of heavy-ion collisions"):
initial $\rightarrow$ hydro $\rightarrow$ statistical hadronization

- **Initial phase** - "geometric"
- **Hydrodynamics** - 3+1 D viscous event-by-event
- **Statistical hadronization**

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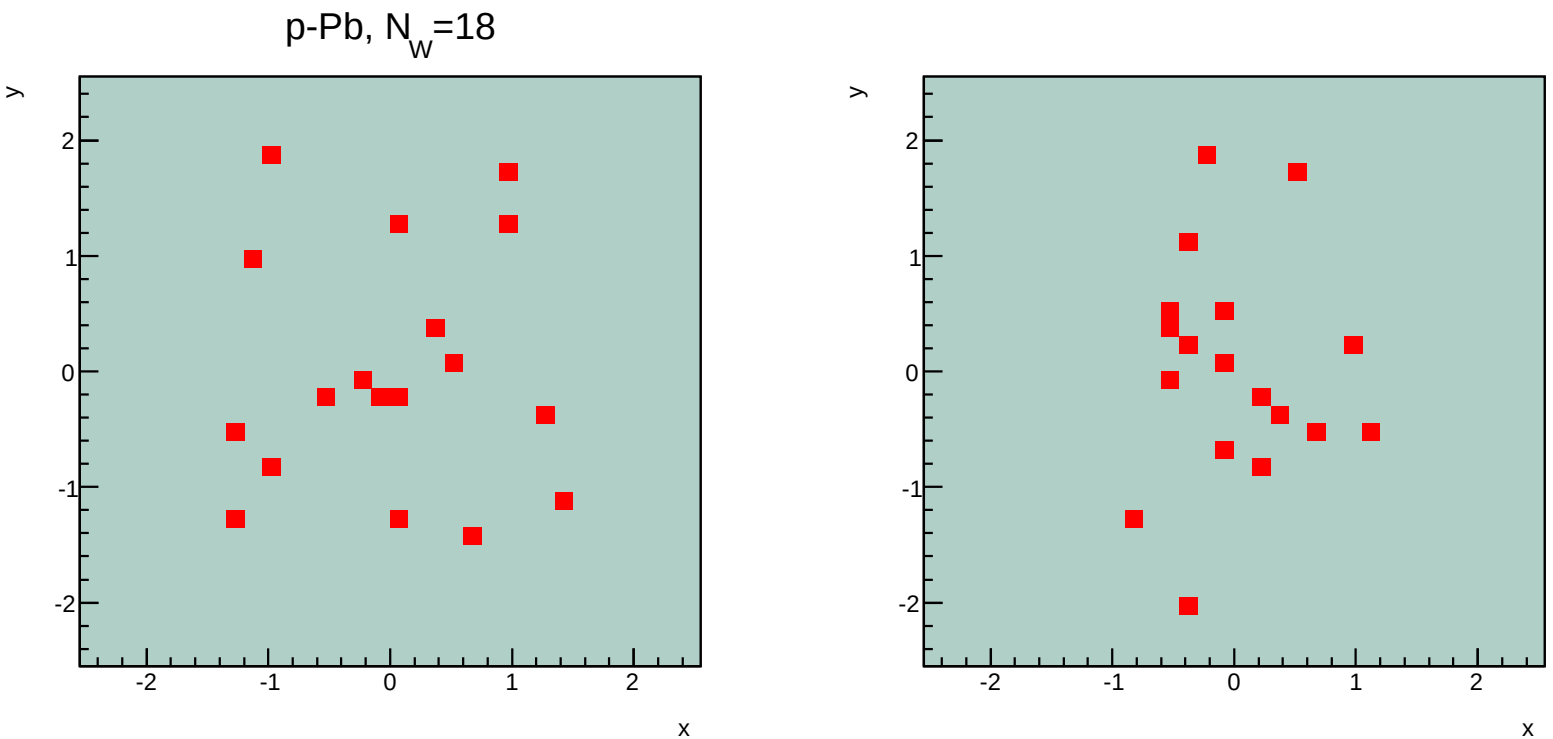
Main question: **Are the (central) p-Pb collisions hydro-like, i.e. collective?**

Initial fluctuations in the Glauber approach

Typical configuration of participant nucleons from Pb nucleus in the transverse plane generated with GLISSANDO
3% of collisions have more than 18 participants, rms ~ 1.5 fm – large!



Hydrodynamics [Bożek 2011]

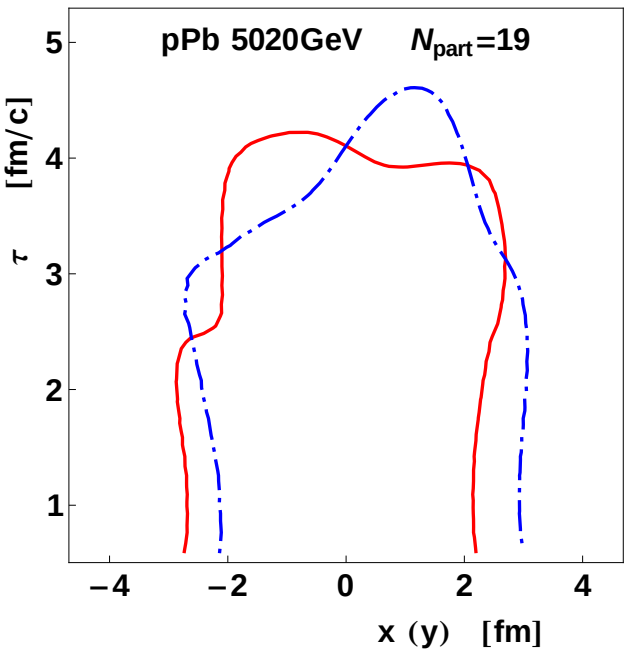
3+1D viscous event-by-event hydrodynamics

standard set of parameters:

$\tau_{\rm init} = 0.6$ fm/c, $\eta/s = 0.08$ (**shear**), $\zeta/s = 0.04$ (**bulk**), $T_f = 150$ MeV

realistic equation of state (lattice + hadron gas)

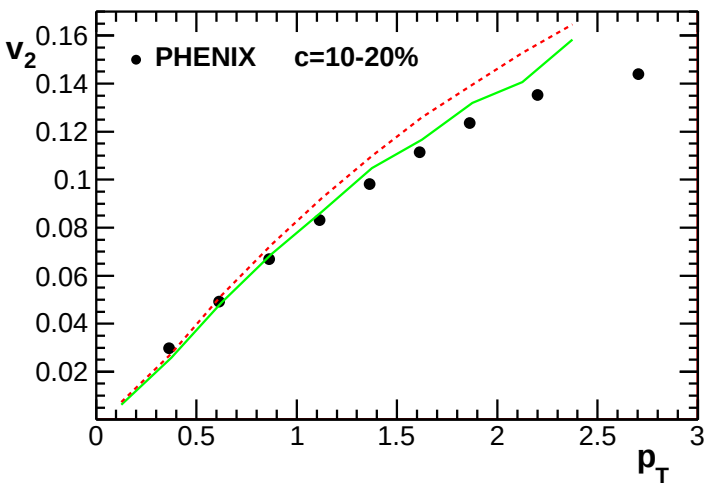
viscosity necessary for small systems

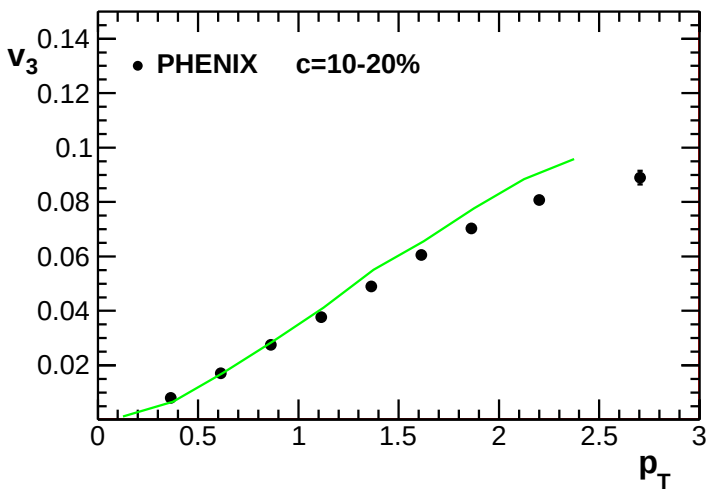


Some results for p+Pb at RHIC

[Bożek 2011]

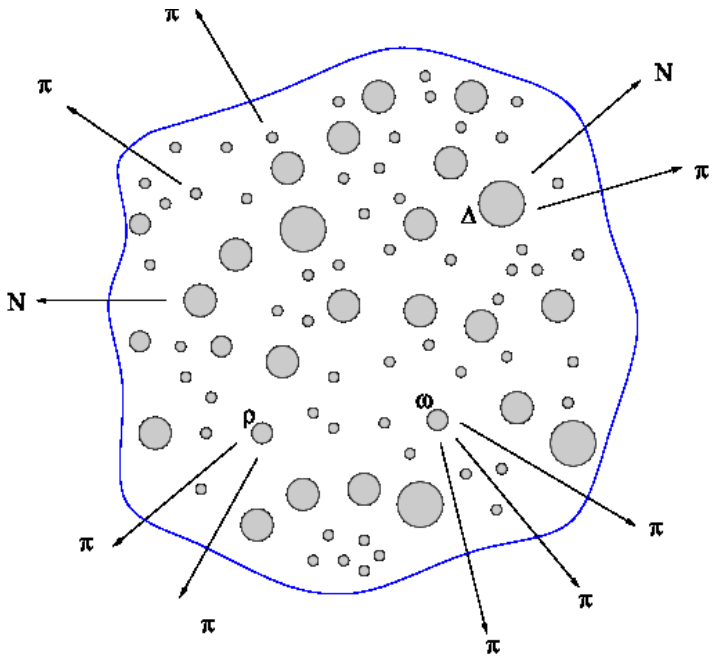
sample results → the method works for one-body observables





solid: e-by-e, dashed: averaged initial condition

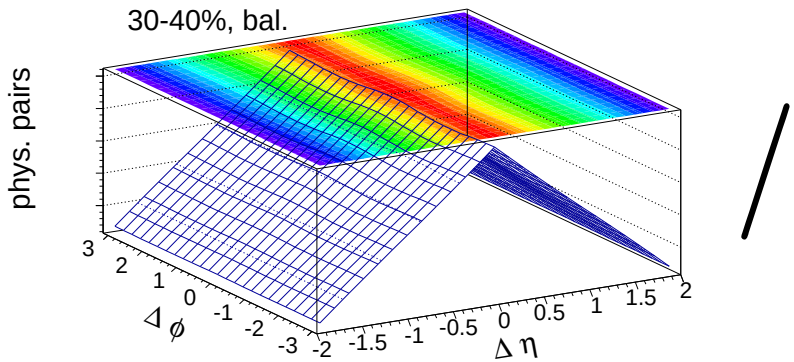
Final fluctuations

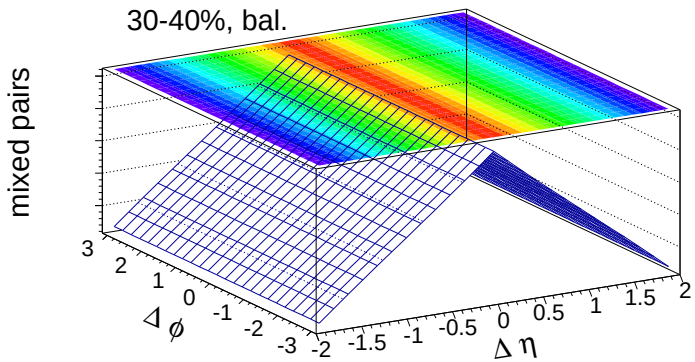


Statistical hadronization via Frye-Cooper formula + resonance decays (THERMINATOR), transverse-momentum conservation approximately imposed, charge balancing

Definition

$$C(\Delta\eta, \Delta\phi) = \frac{N^{\text{pairs}}_{\text{phys}}(\Delta\eta,\Delta\phi)}{N^{\text{pairs}}_{\text{mixed}}(\Delta\eta)}$$





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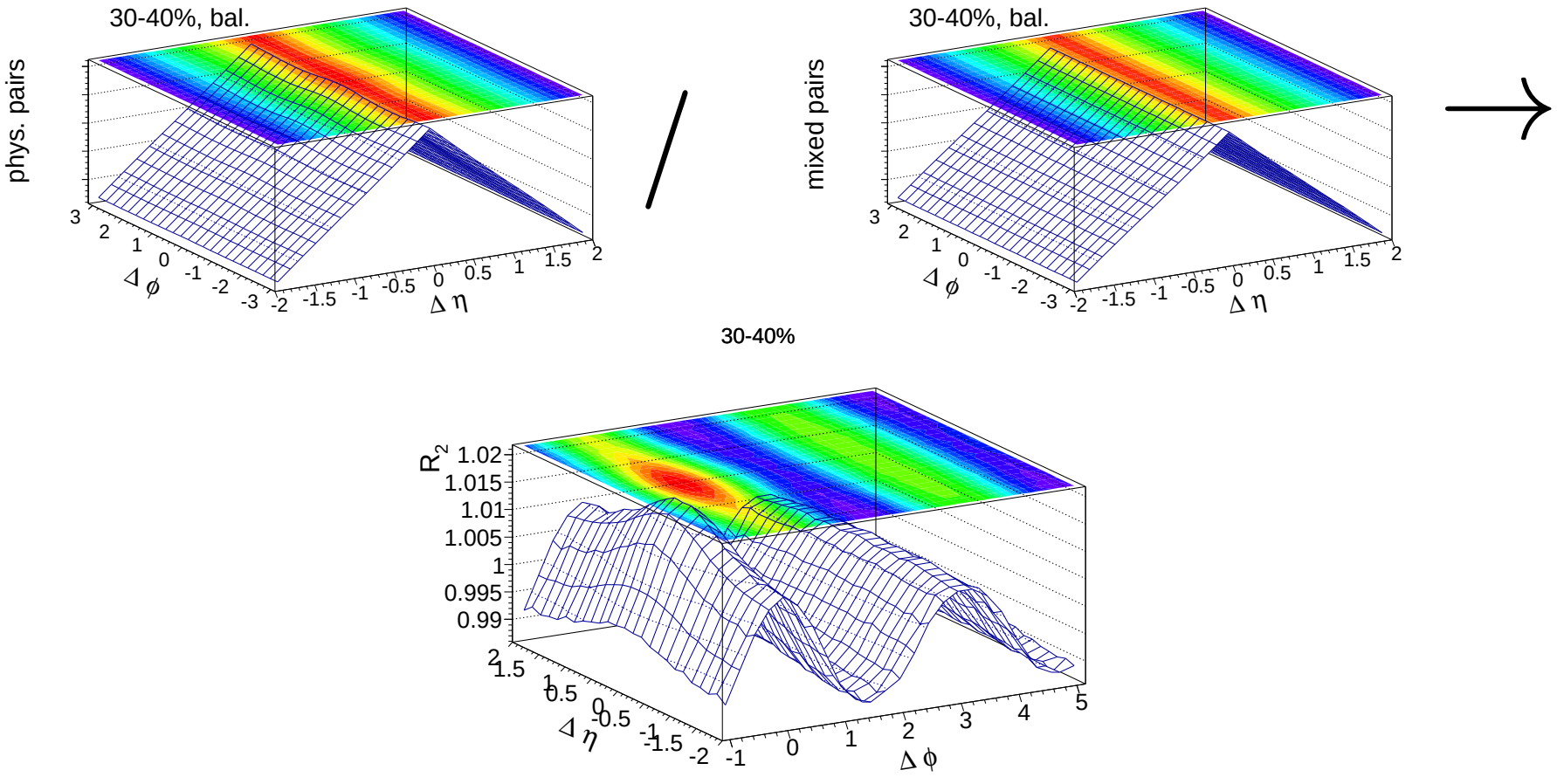
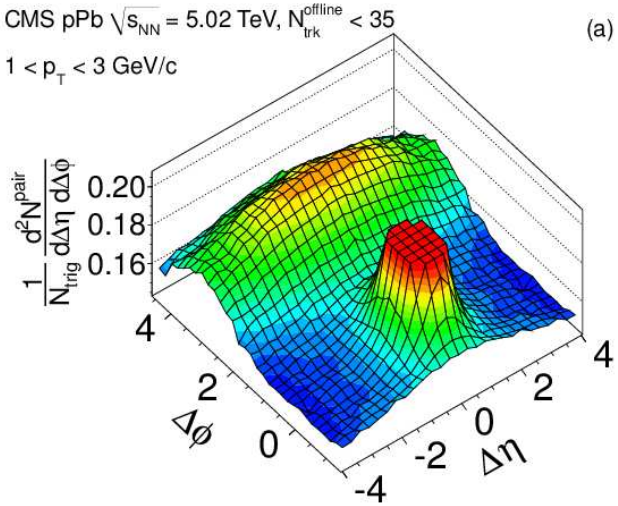
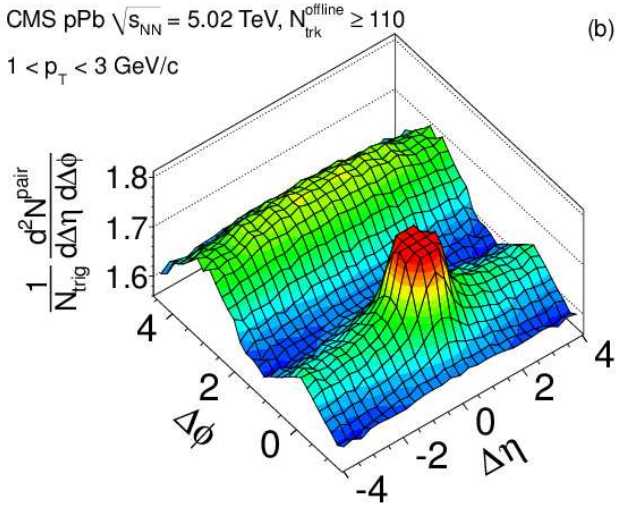


Sources of correlations

- jets $\rightarrow$ central peak (same jet), away-side ridge (back-to-back jets)
- collective harmonic flow $\rightarrow$ near- and away-side ridges
- charge balancing $\rightarrow$ central peak, shape of the near-side ridge
- resonance decays $\rightarrow$ away-side ridge
- Bose-Einstein $\rightarrow$ central peak
- Coulomb, final-state, ...

p-Pb from CMS, 5.02 TeV





(released in October 2012)
"Observation of long-range near-side angular correlations in proton-lead collisions at the LHC", CMS Collaboration

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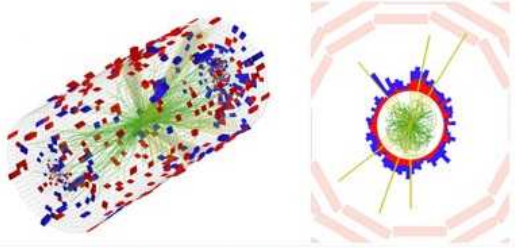
Unexpected 'ridge' seen in CMS collision data again

Oct 31, 2012 6 comments



p-Pb collision event display, CMS

The first data from proton–lead collisions at the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) at CERN include a "ridge" structure in correlations between newly generated particles. According to theorists in the US, the ridge may represent a new form of matter known as a "colour glass condensate".

This is not the first time such correlations have been seen in collision remnants – in 2005, physicists working on the Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory in New York found that the particles generated in collisions of gold nuclei had a tendency to spread transversely from the beam at very small relative angles, close to zero. A similar correlation was seen in 2010 at CMS in proton–proton collisions and then later that year in lead–lead collisions. (See image below, parts *a* and *b*.)

Observing ridges

When a graph is plotted of the fraction of particles versus the relative transverse emission angle and the relative angle to the beam axis, the correlation appears as a distinct ridge. Now, this ridge has been seen in proton–lead collisions for the first time – within a week of data collection at CMS (see image below, part *c*) (arXiv:1210.5482).

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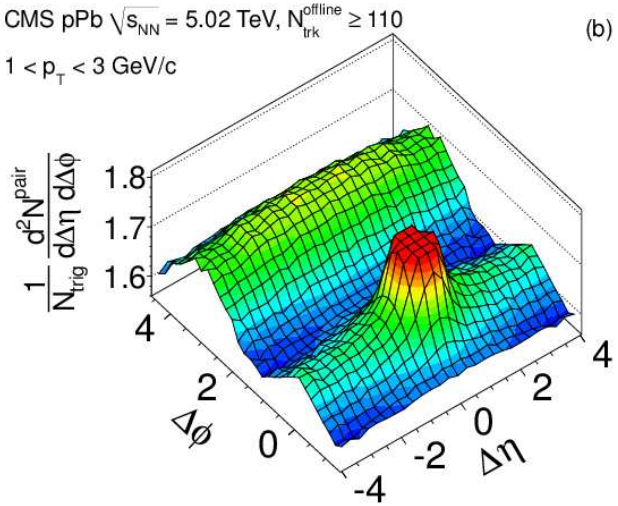
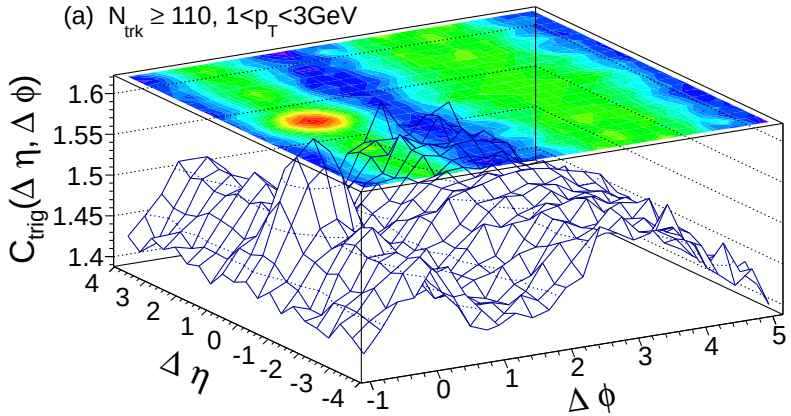
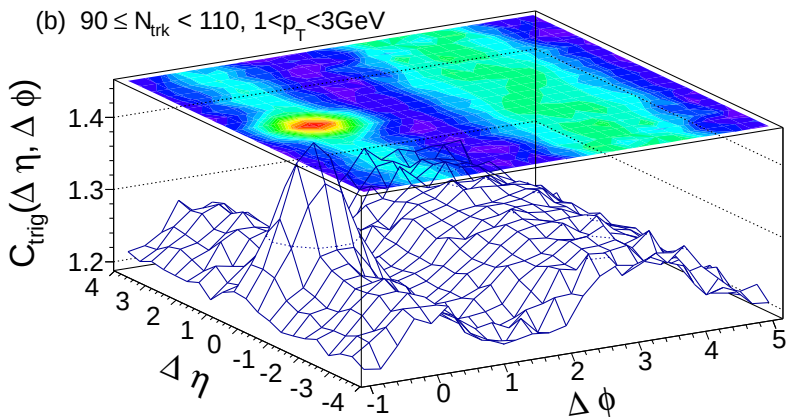
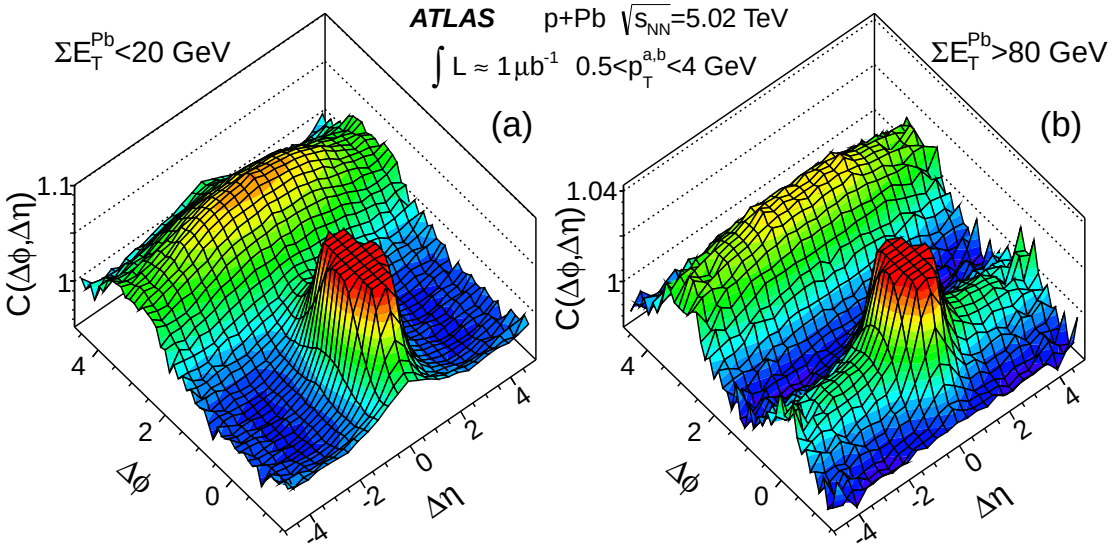
Ridge in p-Pb, CMS

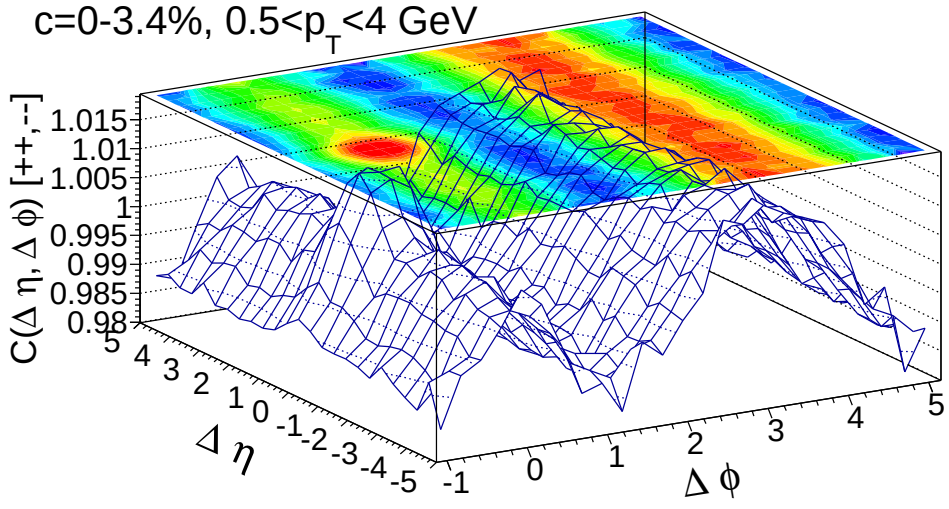






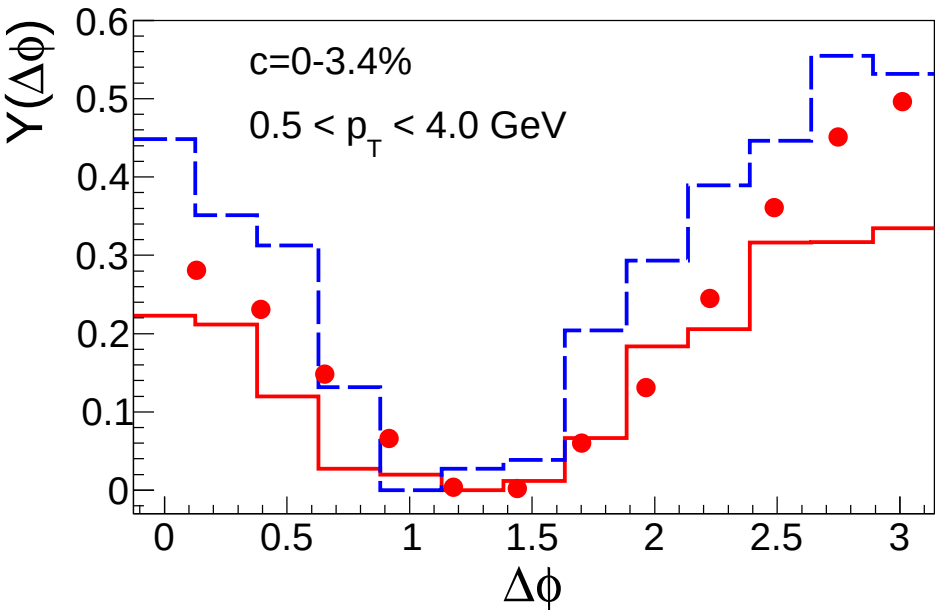
Ridge in p-Pb, ATLAS





Projection on $2 \leq |\Delta\eta| \leq 5$

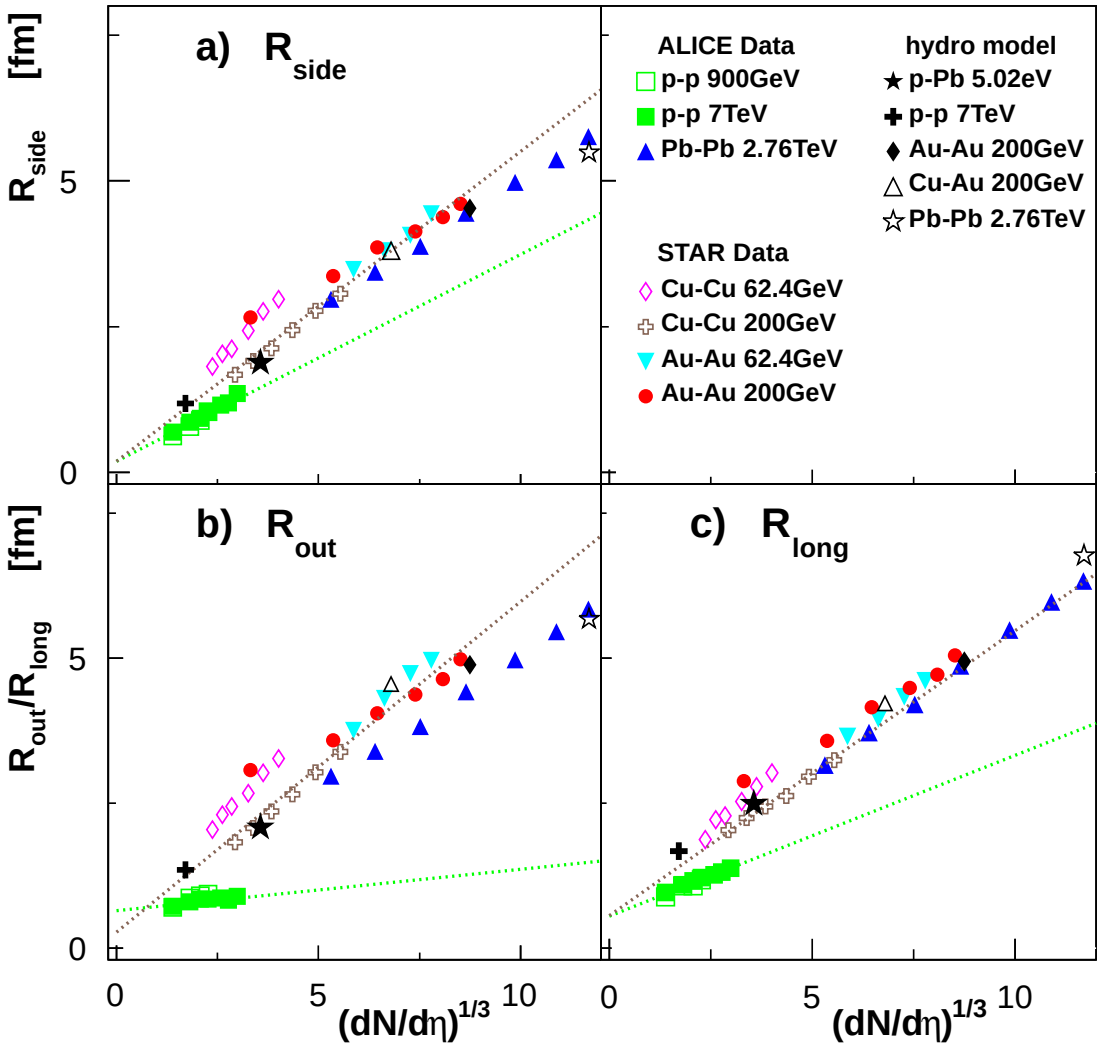
$$Y(\Delta\phi) = \frac{\int B(\Delta\phi)d(\Delta\phi)}{N} C(\Delta\phi) - b_{\mathrm{ZYAM}}$$



Two variants:
red - standard Glauber-model (sources at centers of participants)
blue - "compact" (sources at center-of mass points)

HBT radii

Interferometric radii due to Bose-Einstein correlations



Conclusions

- E-by-e hydro in semi-quantitative agreement with the (soft) data for 2-particle 2D correlations from RHIC and LHC for A-A and p-A collisions
- Hydrodynamic explanation of the same-side ridge in p-Pb

  $\rightarrow$ **collective behavior in high-multiplicity p-Pb systems**
- Hydro: interferometric radii for p-Pb on the A-A line, away from the p-p line - way to distinguish
- Data on interferometric radii for p-Pb expected shortly