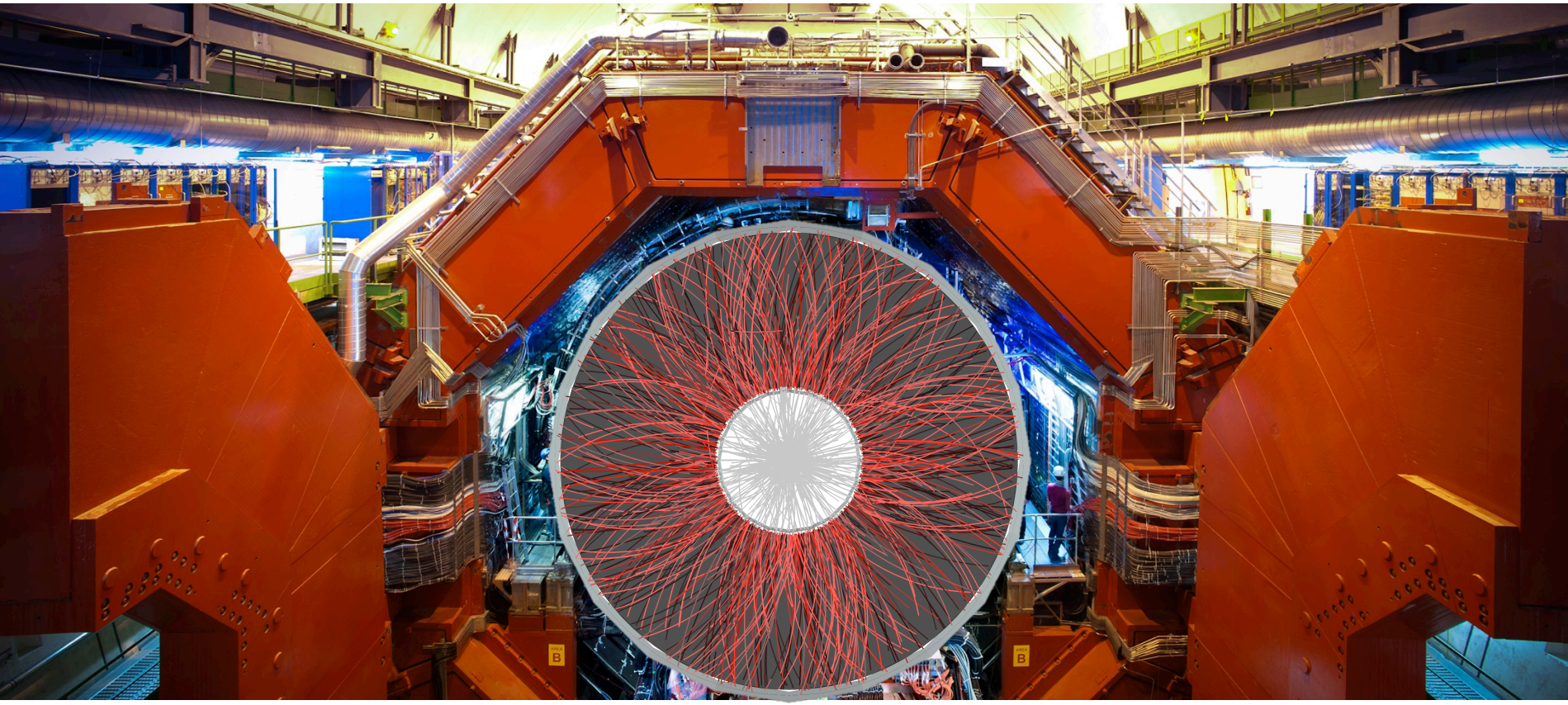
Two–particle correlations and balance functions in p–Pb and Pb–Pb collisions at LHC energies with ALICE



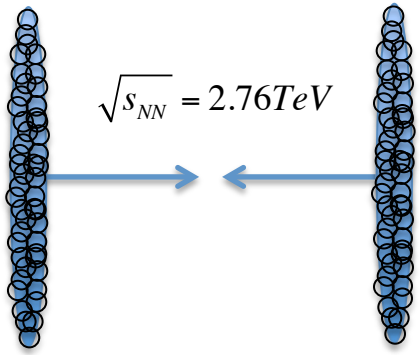
Michael Weber (University of Houston)

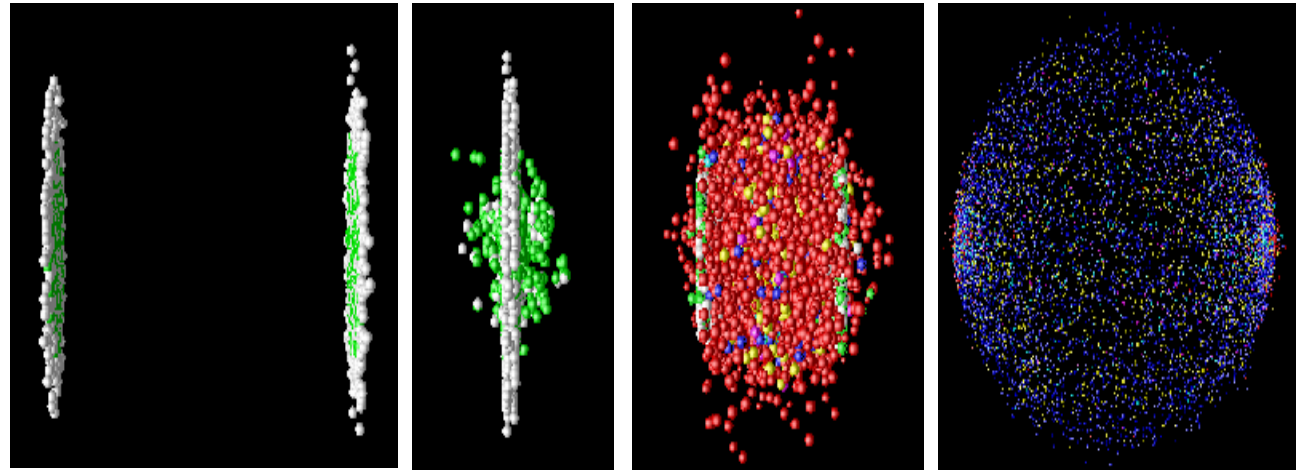
on behalf of the ALICE collaboration

EPS HEP 2013 - Stockholm, Sweden – 18.07.2013

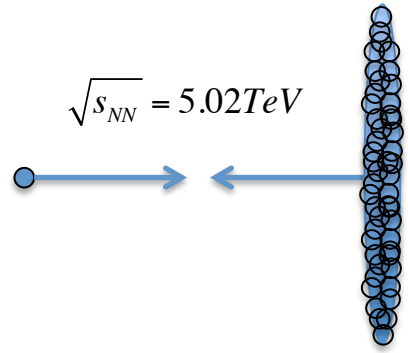
Motivation

Heavy Ion collisions (Pb-Pb) → Hot QCD matter (Quark Gluon Plasma)

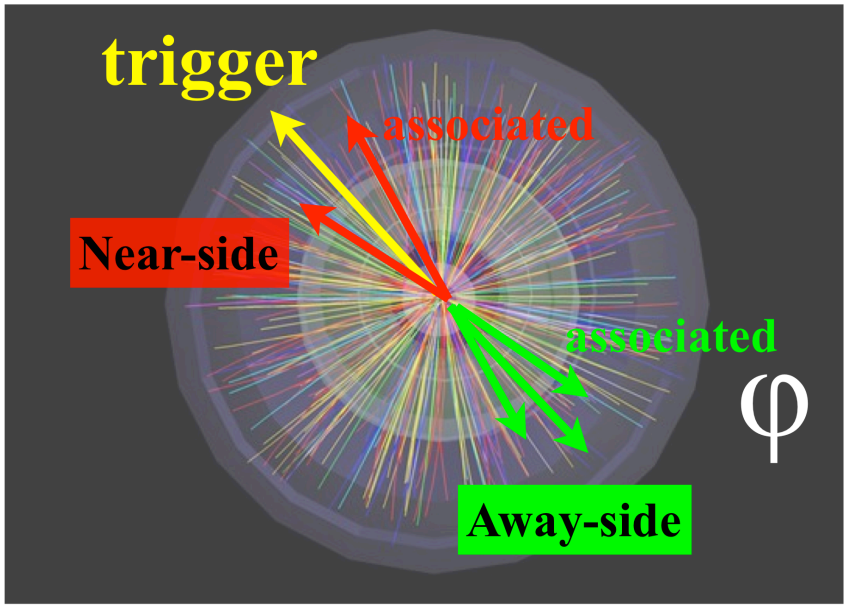


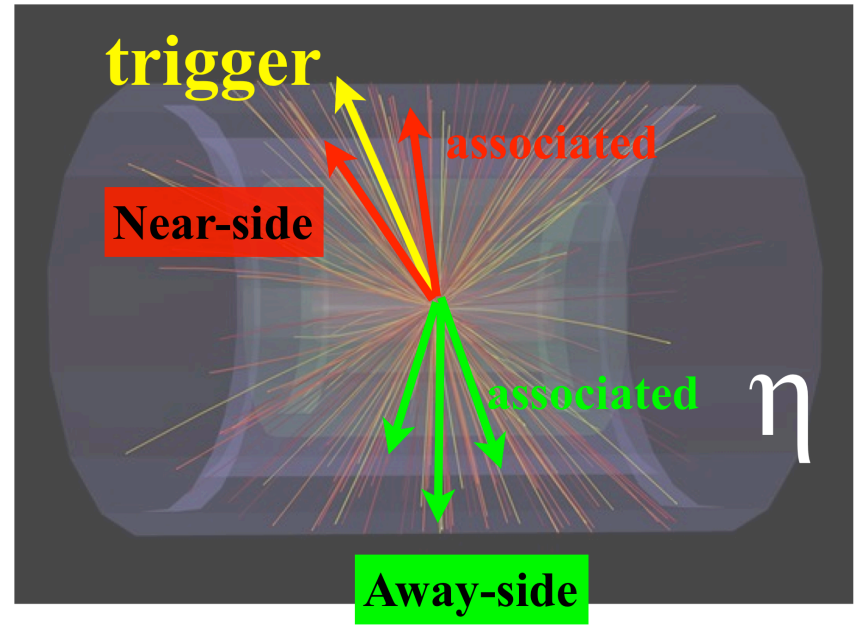


p-Pb collisions: as a reference for cold nuclear matter effects



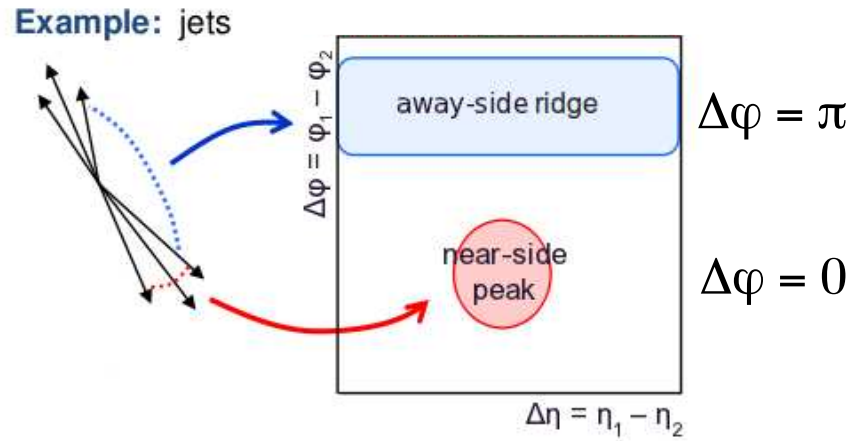
Two-particle correlations





Study the underlying mechanism and dynamics of particle production

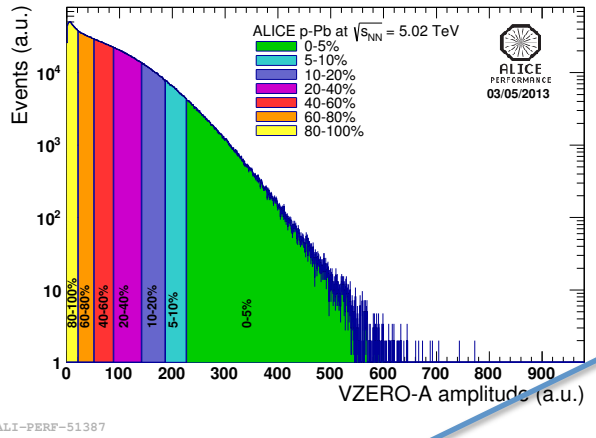
- For each trigger particle with p_T count number of associated particles with p_T, $\Delta\varphi$, $\Delta\eta$

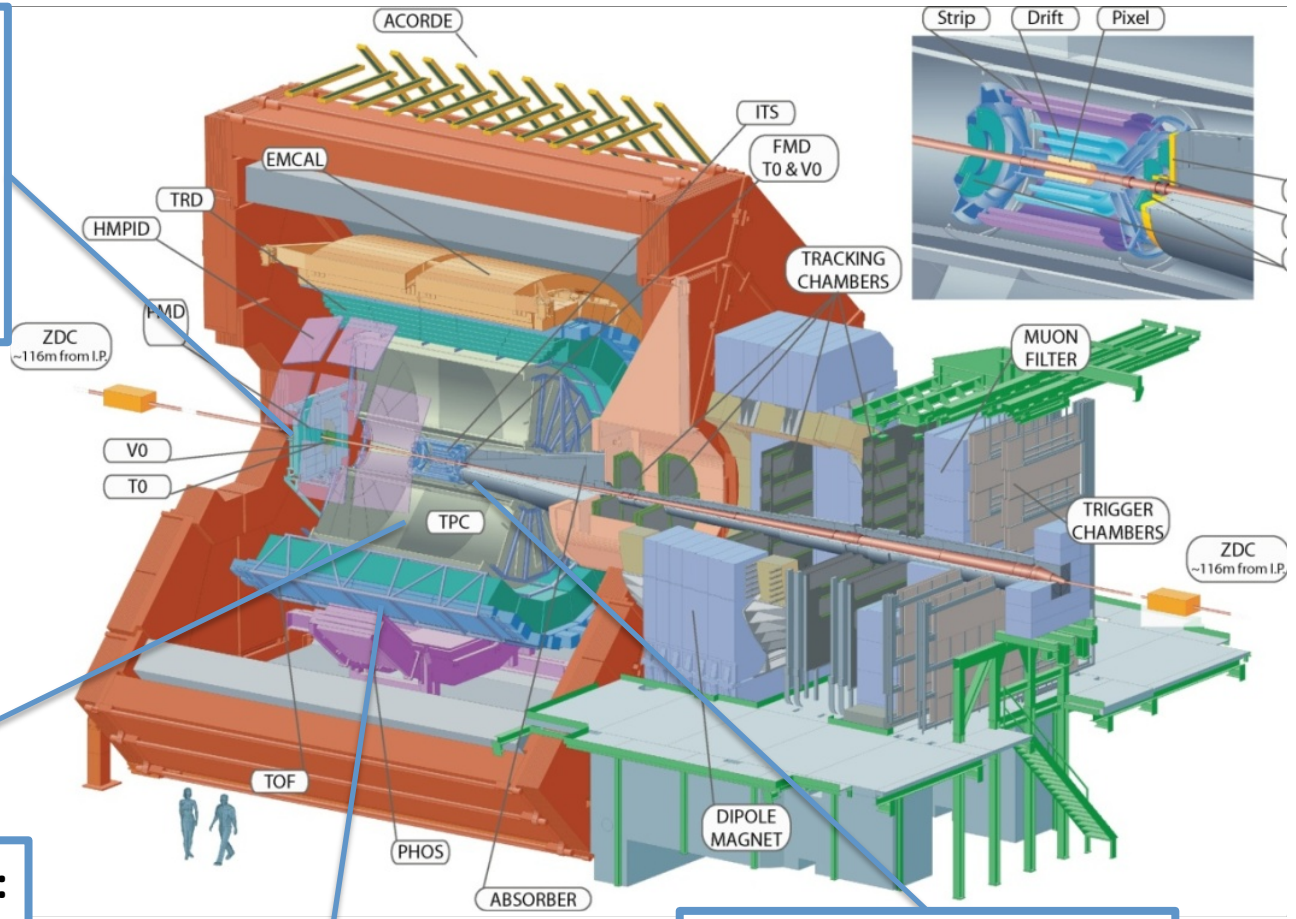


A Large Ion Collider Experiment

VZERO-A ($2.8 < \eta < 5.1$):

- Multiplicity determination
- Correlation between geometry/centrality and multiplicity is not trivial in p-Pb collisions





Time Projection Chamber:

- Vertex
- Tracking: $|\eta| < 0.8$
- PID (dE/dx)

Time Of Flight:

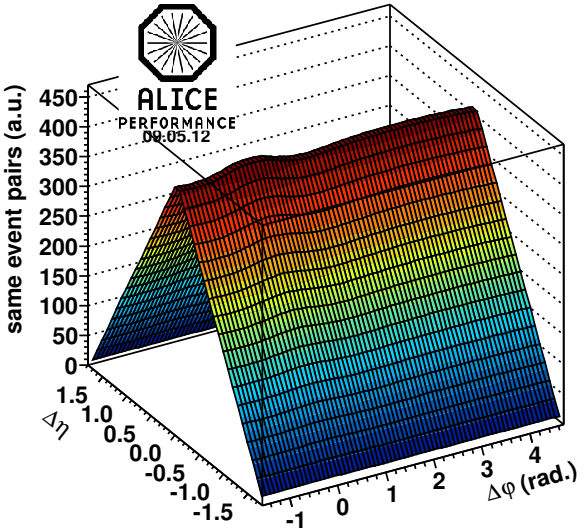
- PID (beta)

Inner Tracking System:

- Tracking
- Vertex ($|V_z| < 10$ cm)

JINST, 3 (2008), S08002
PRL, 106 (2011), 032301

Two-particle correlations (Pb-Pb)

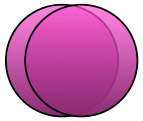


ALI-PERF-15347

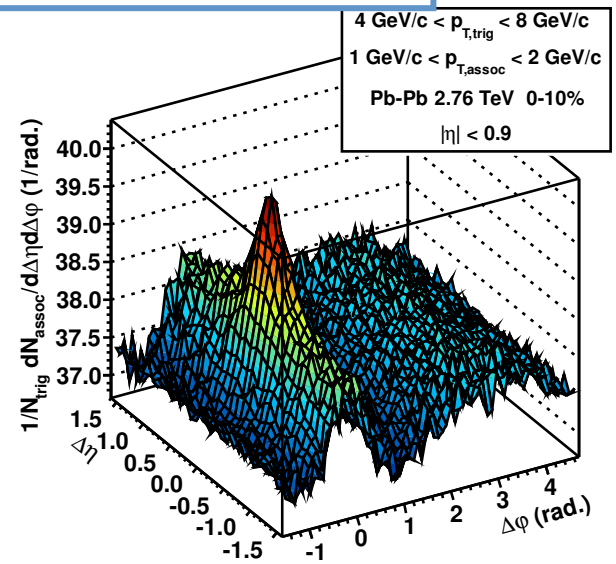
Particle pairs in same event:

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

Central Collision

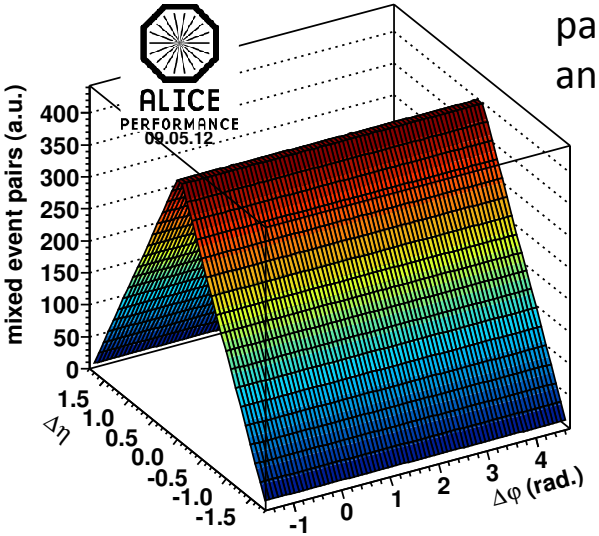


$$\frac{1}{N_{trig}} \frac{d^2 N_{assoc}}{d\Delta\eta d\Delta\varphi} = \frac{S(\Delta\eta,\Delta\varphi)}{B(\Delta\eta,\Delta\varphi)\cdot\alpha}$$



ALI-PREL-15872

Corrected for single particle efficiency and contamination

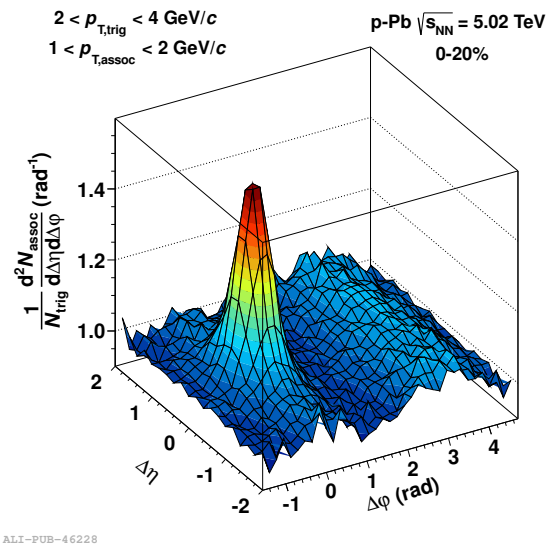


Particle pairs in mixed events:

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

"Bulk-dominated" p_T region:
- double ridge structure
- long range in $\Delta\eta$

Two-particle correlations (p-Pb)



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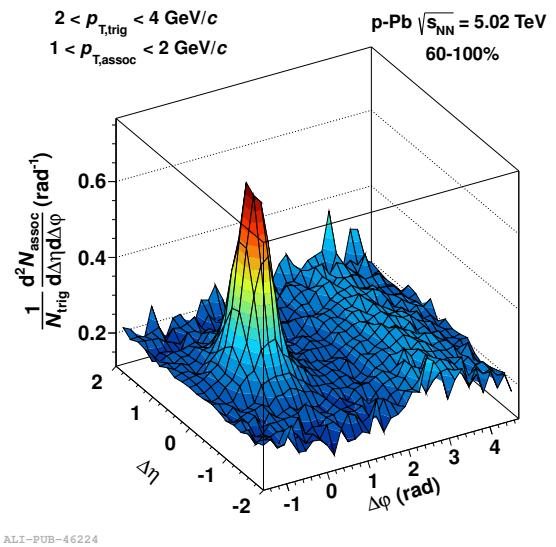

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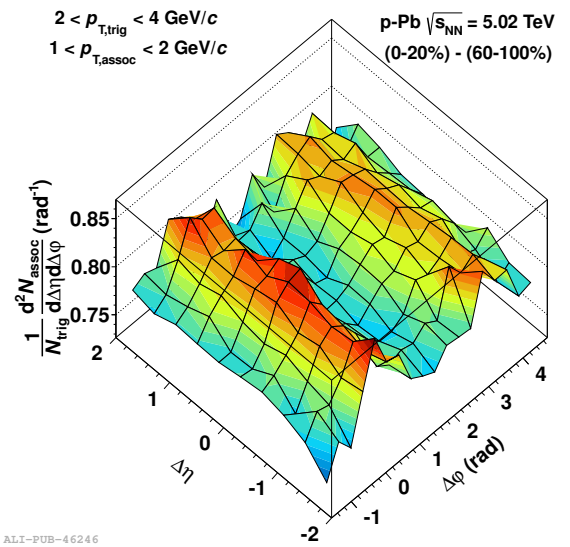


High multiplicity events
($\langle dN_{ch}/d\eta \rangle|_{|\Delta\eta|<0.5}$ = 35.84 ± 0.78)

Low multiplicity events
($\langle dN_{ch}/d\eta \rangle|_{|\Delta\eta|<0.5}$ = 6.83 ± 0.55)

Double "Ridge"

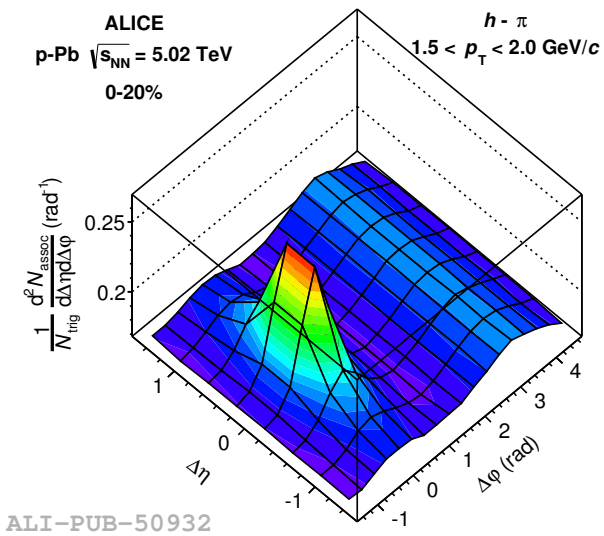
Charge dependence (Balance function)

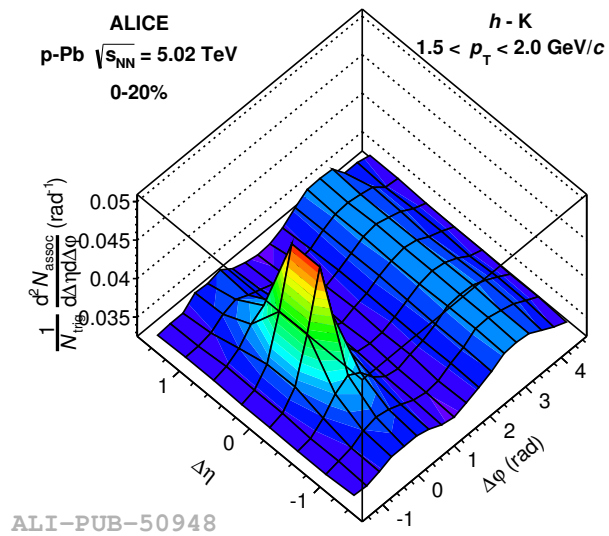
Interpretation:
- Initial state (color glass condensate)?
- Final state (hydrodynamics)?

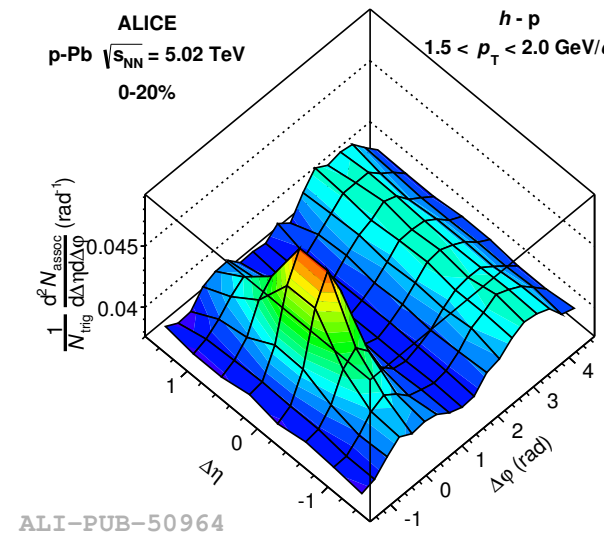
Identified Particles

PLB, 719 (2013), 29

Identified particles (p-Pb)







Correlations:

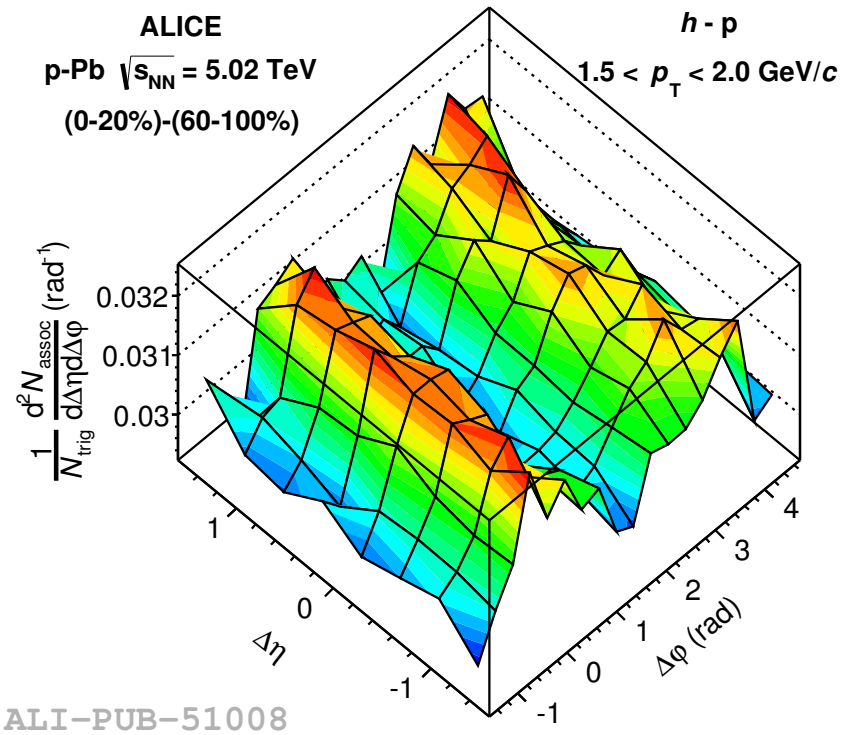
- Trigger particle = hadron
- Associated particle = pion, kaon, proton
- Symmetric p_T bins
- PID: Combine TOF (beta) and TPC (dE/dx) information
- Low (<15%) contamination from wrongly identified particles
- Cuts:

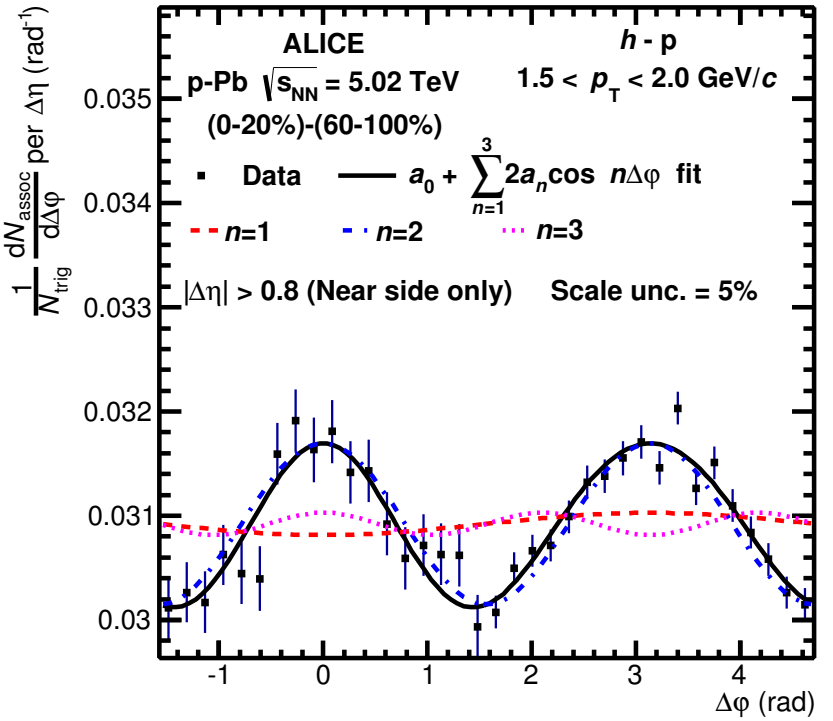
$$N^2_{\sigma,PID} = N^2_{\sigma,TPC} + N^2_{\sigma,TOF}, N_{\sigma,PID}(p_T < 0.5GeV/c) = N_{\sigma,TPC}$$

$$N_{\sigma,PID} < 3$$

arXiv:1307.3237 [nucl-ex]

Subtraction procedure



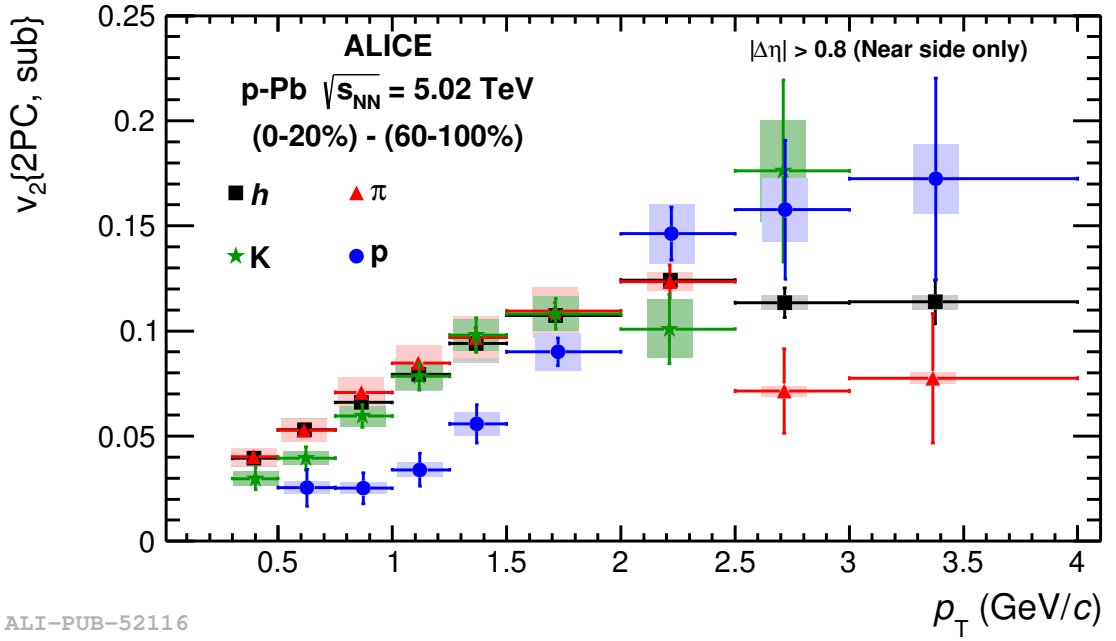


- Subtraction of Jet component via multiplicity classes: (0-20%) – (60-100%)
- Residual jet peak on near side excluded: $\Delta\eta > 0.8$ for $\Delta\varphi < \pi/2$
- Harmonic decomposition of $\Delta\varphi$ distribution:

$$a_0 + \sum_{n=1}^{3} 2a_n \cdot \cos(n \cdot \Delta\varphi)$$

arXiv:1307.3237 [nucl-ex]

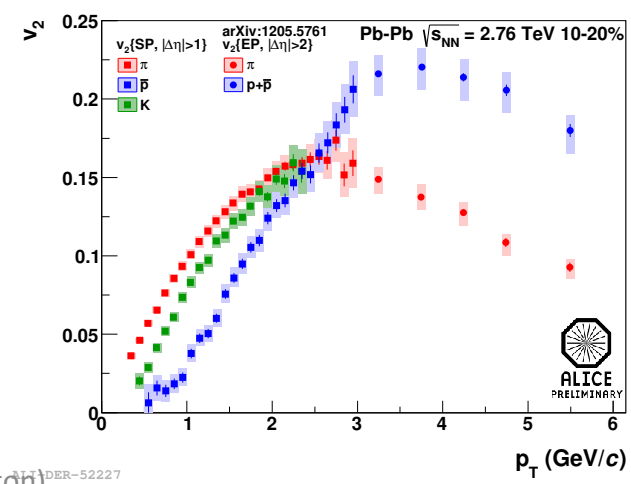
v_2 from two-particle correlations (2PC)



- Extract v_2

$$V_{2\Delta}^{h-i}\{2PC\} = a_2^{h-1} / a_0^{h-1}, i = \pi, K, p$$

$$v_2^i\{2PC\} = V_{2\Delta}^{h-i} / \sqrt{V_{2\Delta}^{h-h}}$$



- v_2{2PC,sub}: from subtraction procedure
- p_T dependence shows a mass ordering
- Qualitatively similar to Pb-Pb
- Can be described by hydrodynamic models

arXiv:1307.3237 [nucl-ex]

Balance function

Definition:

$$B(\Delta\eta,\Delta\varphi) = \frac{S(\Delta\eta,\Delta\varphi)_{US}}{B(\Delta\eta,\Delta\varphi)_{US}} - \frac{S(\Delta\eta,\Delta\varphi)_{LS}}{B(\Delta\eta,\Delta\varphi)_{LS}}$$

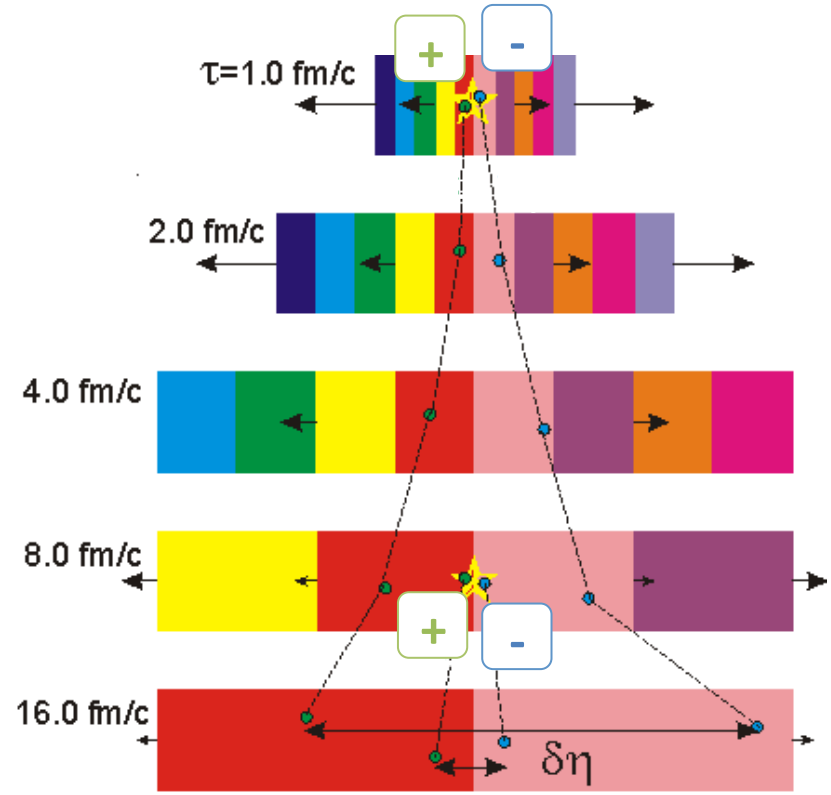
$$US = +-/-+$$

$$LS = ++/--$$

Motivation:

- Creation of balancing charges in rapidly expanding medium
- Questions:
  - What is the time ordering of the collision?
  - Can we detect different stages where charges are created?

- **Early stage creation**: larger final separation, **wider balance functions**
- **Late stage creation**: pairs more correlated, **narrower balance functions**
- **BUT: stronger flow** → pairs also more correlated, **narrower balance functions**



$$\sigma^2_{\delta y} = \sigma^2_{\delta\eta} + \sigma^2_{\text{therm}}$$

experiment

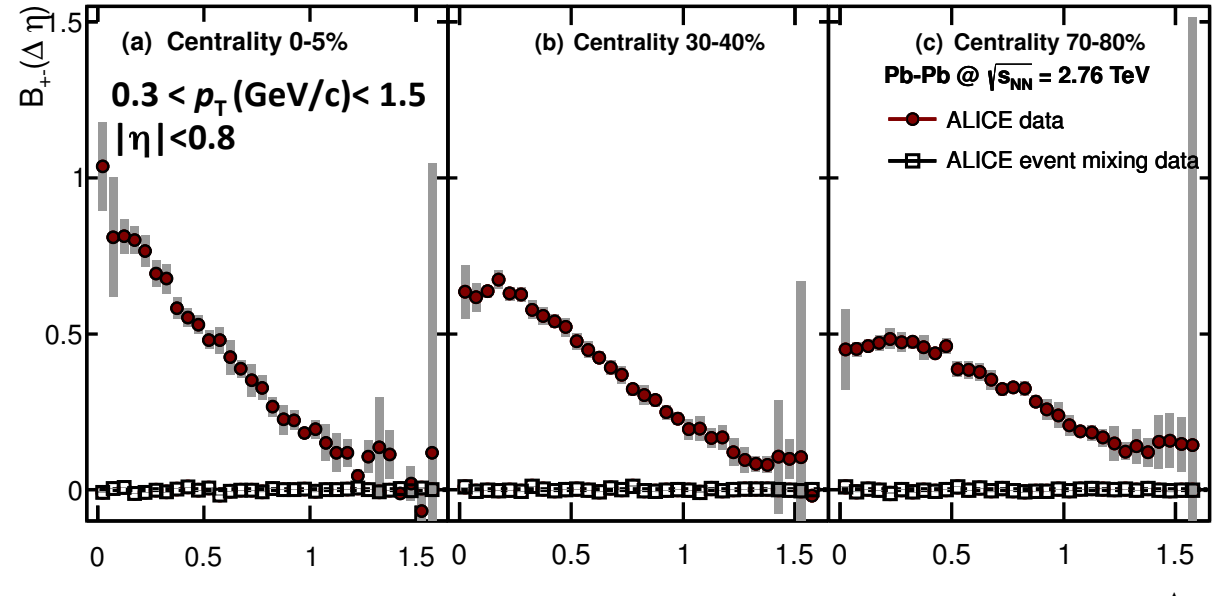
diffusive

determined by breakup temp.

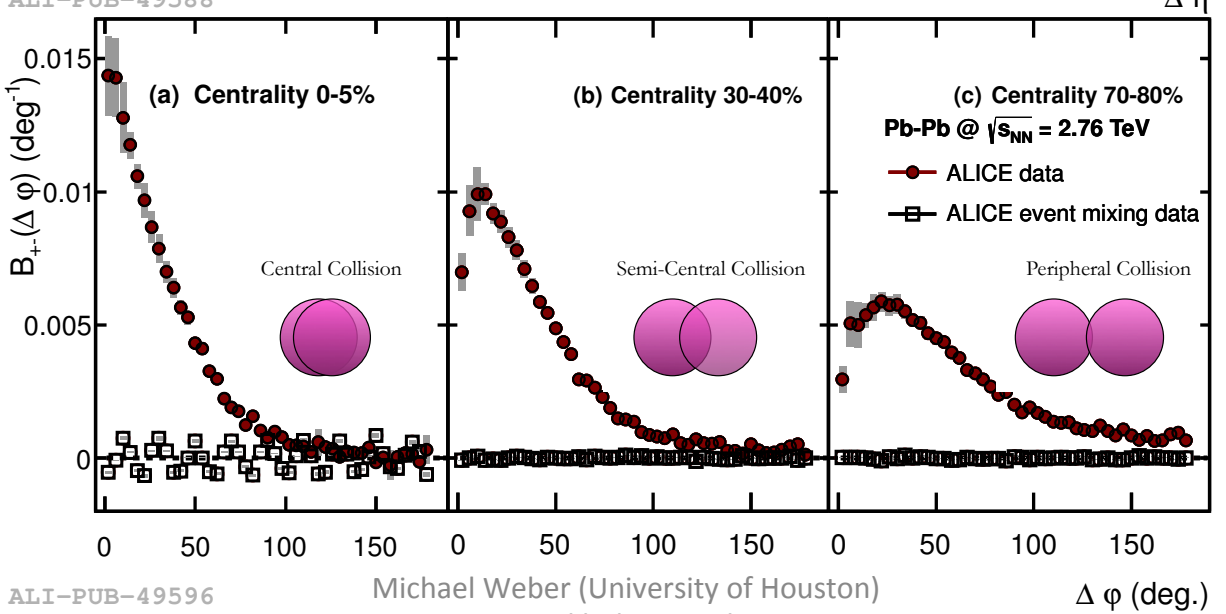
Bass, Danielewicz, Pratt, PRL 85, (2000) 2689.
Pratt, Phys. Rev. C85, (2012) 014904.

Example: Pb-Pb

Δη



Δφ

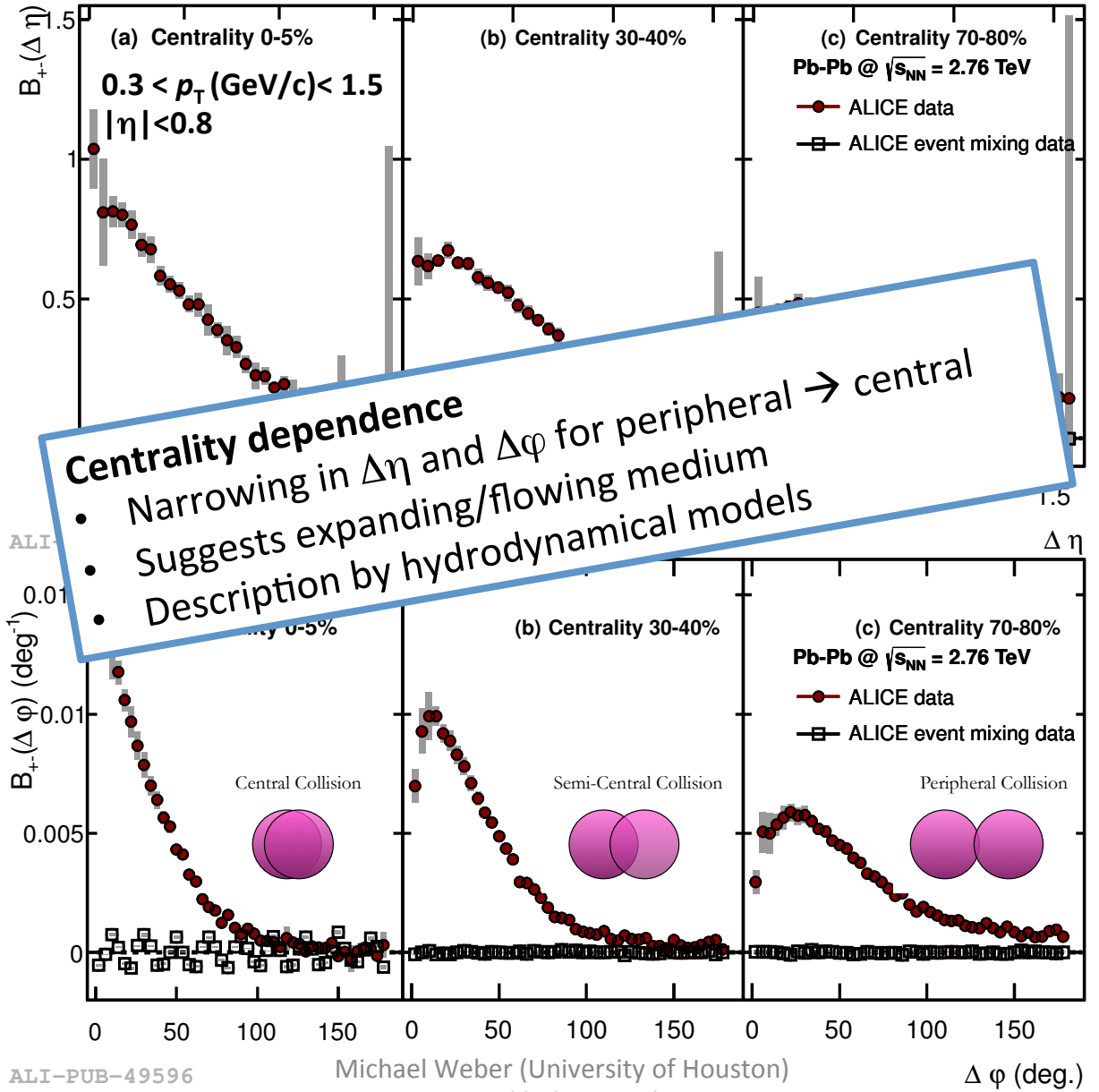


PLB, 723 (2013), 267

Example: Pb-Pb

Δη

Δφ



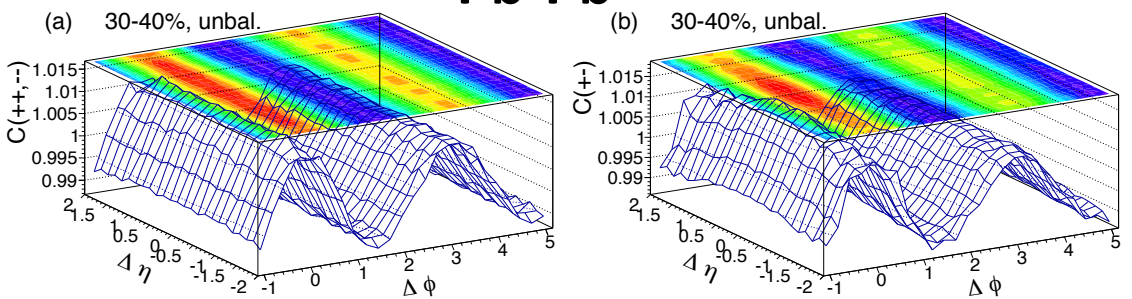
Centrality dependence

- Narrowing in Δη and Δφ for peripheral → central
- Suggests expanding/flowing medium
- Description by hydrodynamical models

PLB, 723 (2013), 267

Hydro calculations

Pb-Pb

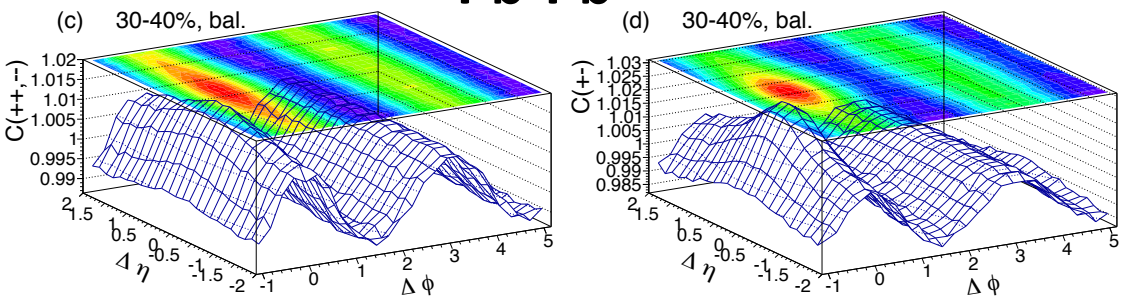


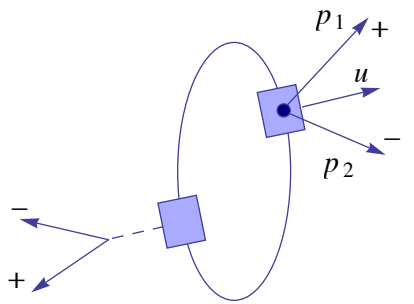
Charge dependent correlations from EbyE, 3+1 D, viscous hydro **without charge balancing**

Bozek, Broniowski, PRL, 109 (2012), 062301
Bozek, Broniowski, PLB, 718 (2013) 1557

Hydro calculations

Pb-Pb





Charge dependent correlations from EbyE, 3+1 D, viscous hydro **with charge balancing**

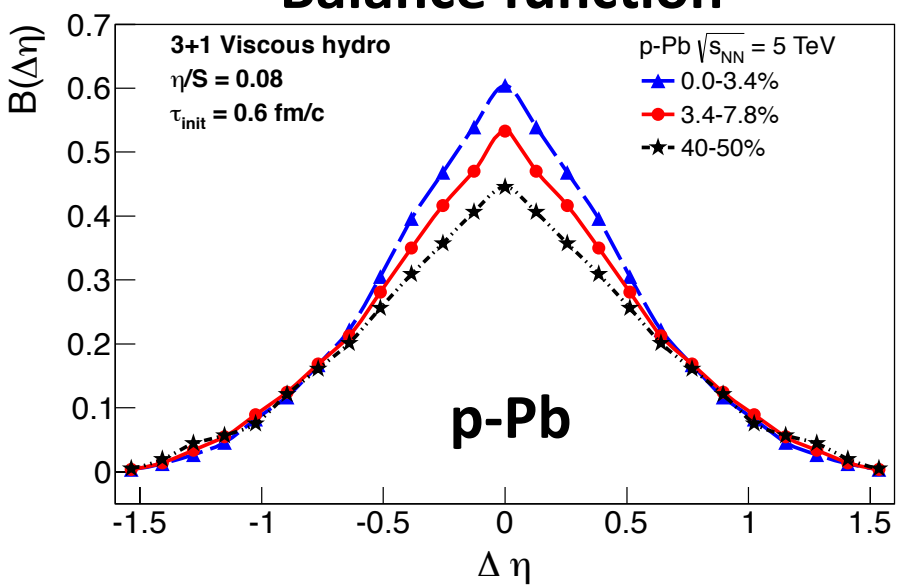
Findings:

- Pb-Pb: Charge balancing leads to a difference for LS and US pairs
- p-Pb: double ridge

Balance function:

- Centrality dependence
- Sensitivity to input parameters
- To be measured with ALICE

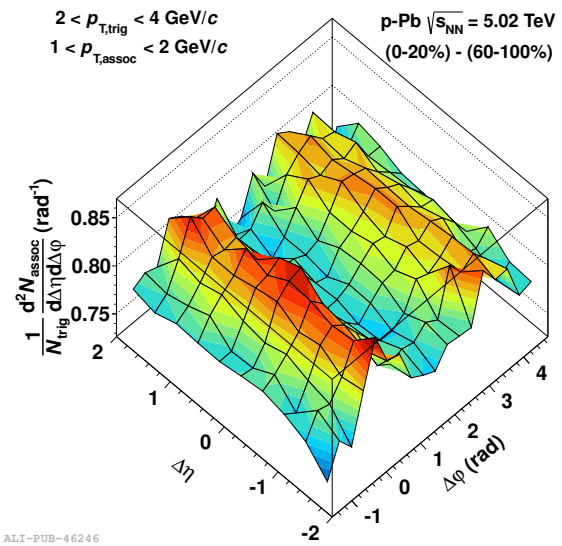
Balance function



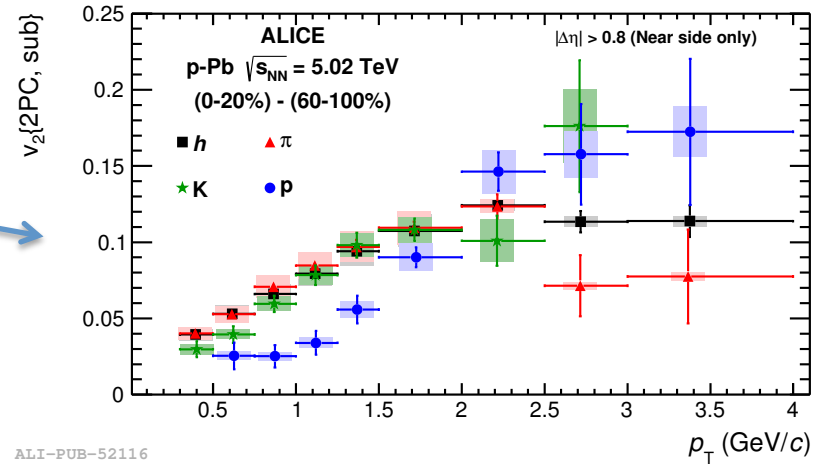
Private communication Bozek, Broniowski

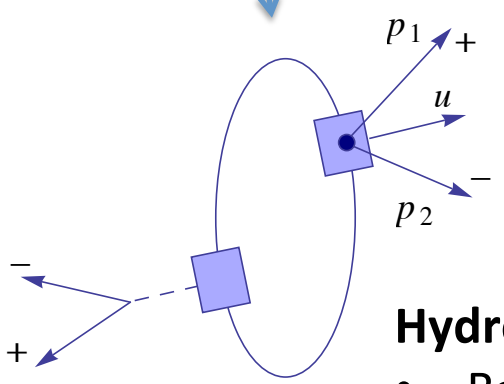
Bozek, Broniowski, PRL, 109 (2012), 062301
Bozek, Broniowski, PLB, 718 (2013) 1557

Summary



Double "Ridge" in p-Pb correlations





Identified Particles:

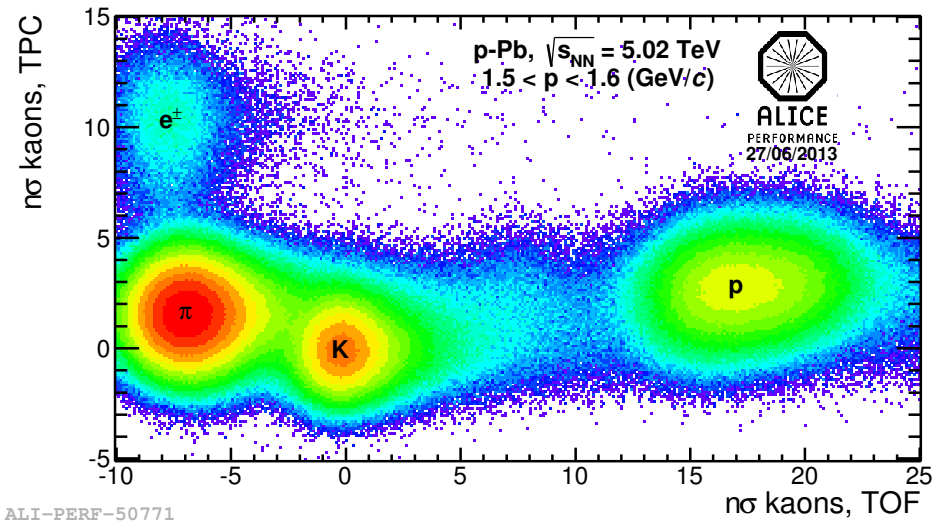
- Mass ordering
- p-Pb is not just a reference, but shows new phenomena

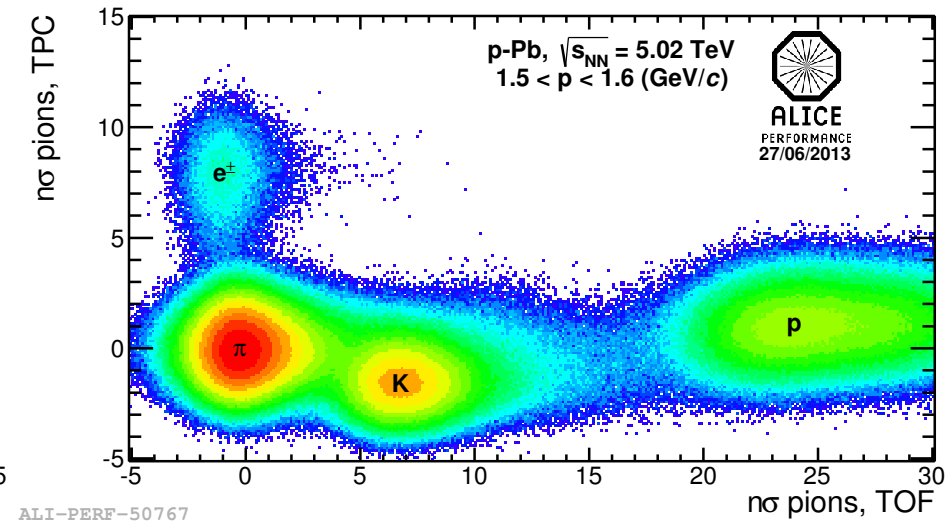
Hydro with local charge conservation?

- Balance function to be measured

Backup

Particle identification





PID:

- Combine TOF (beta) and TPC (dE/dx) information
- Cuts:

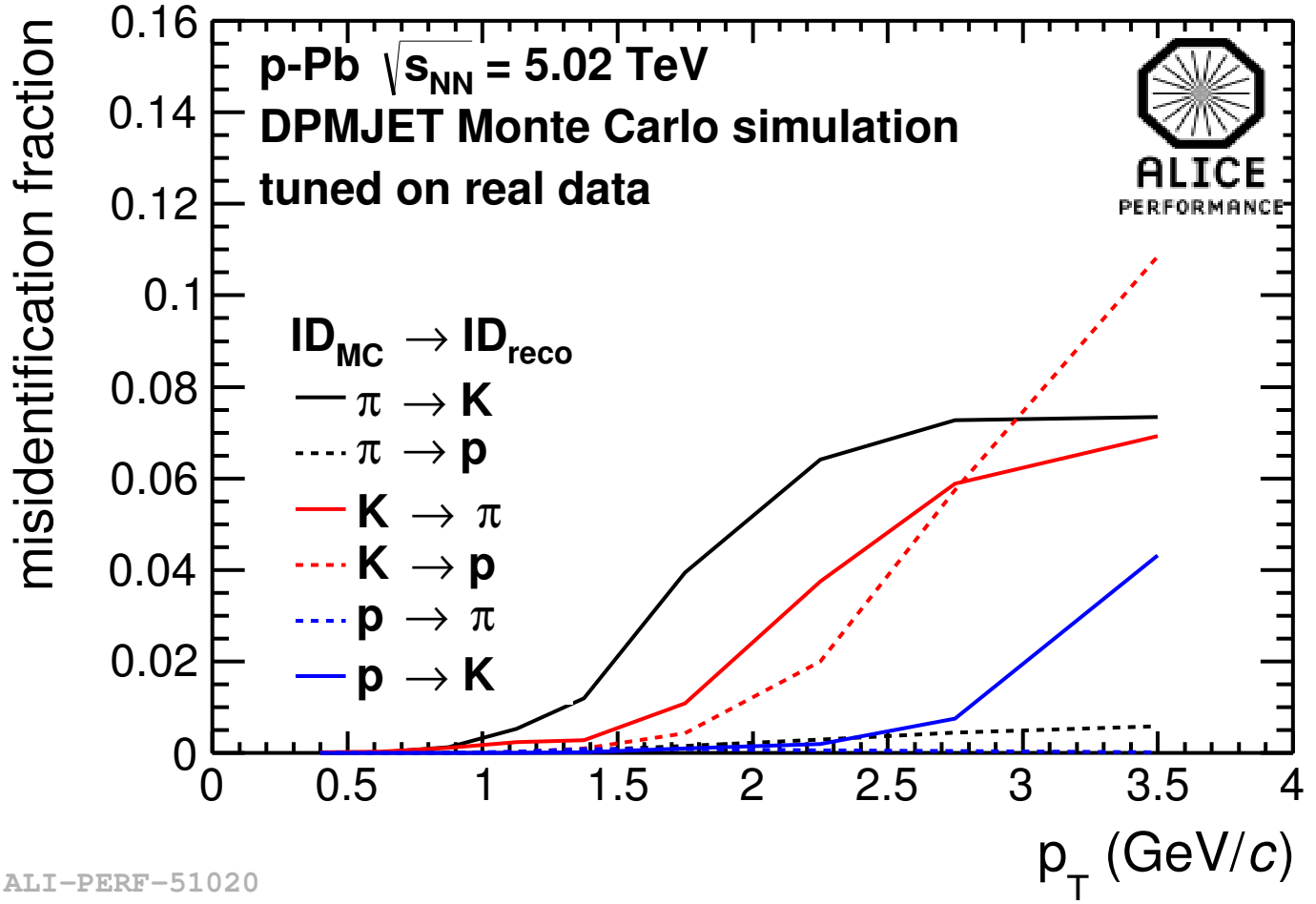
$$N^2_{\sigma,PID} = N^2_{\sigma,TPC} + N^2_{\sigma,TOF}$$

$$N^2_{\sigma,PID} < 3$$

$$N_{\sigma,PID}(p_T < 0.5GeV/c) = N_{\sigma,TPC}$$

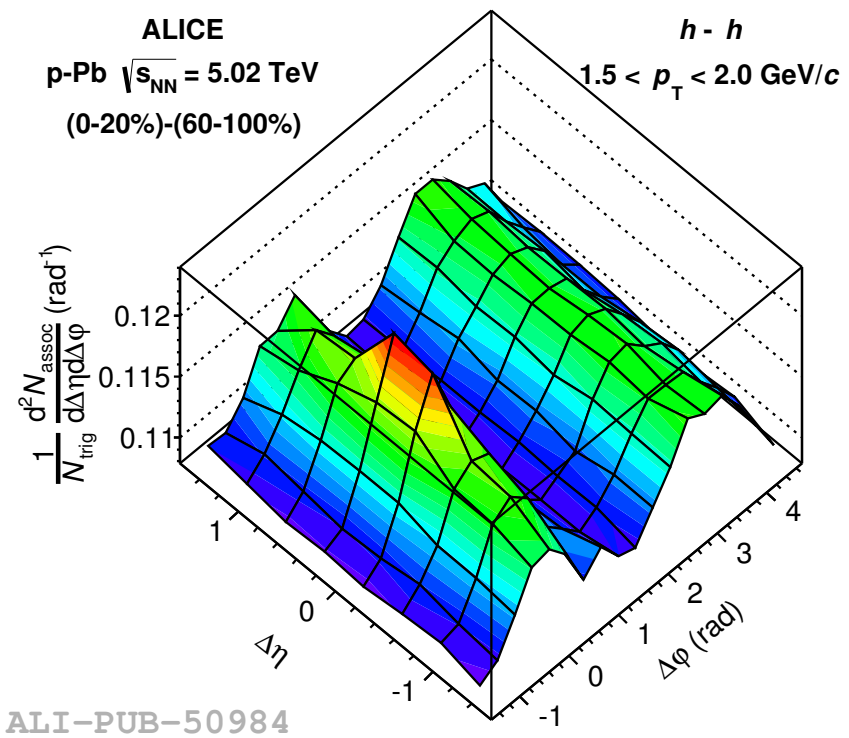
arXiv:1307.3237 [nucl-ex]

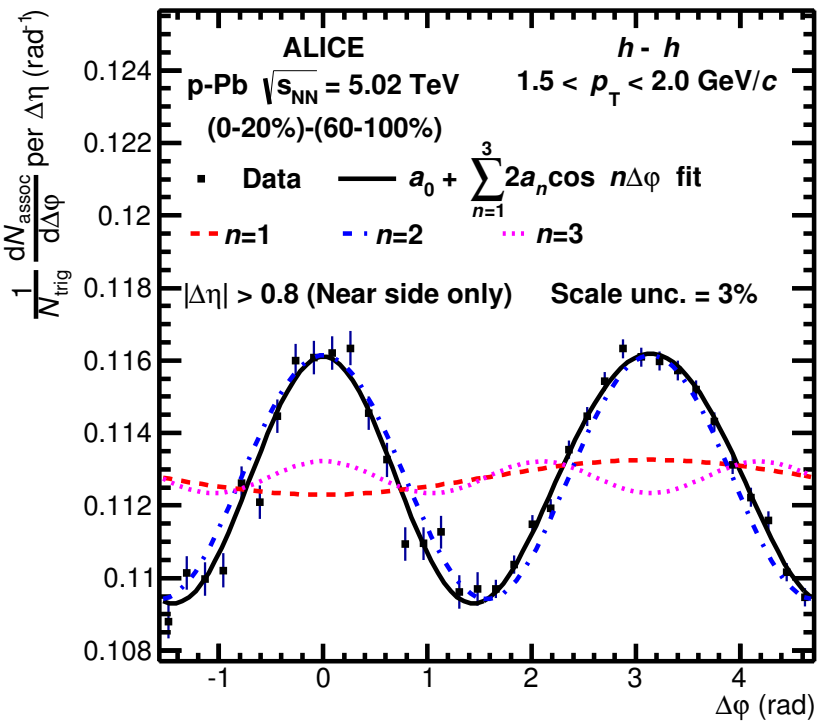
Misidentification



arXiv:1307.3237 [nucl-ex]

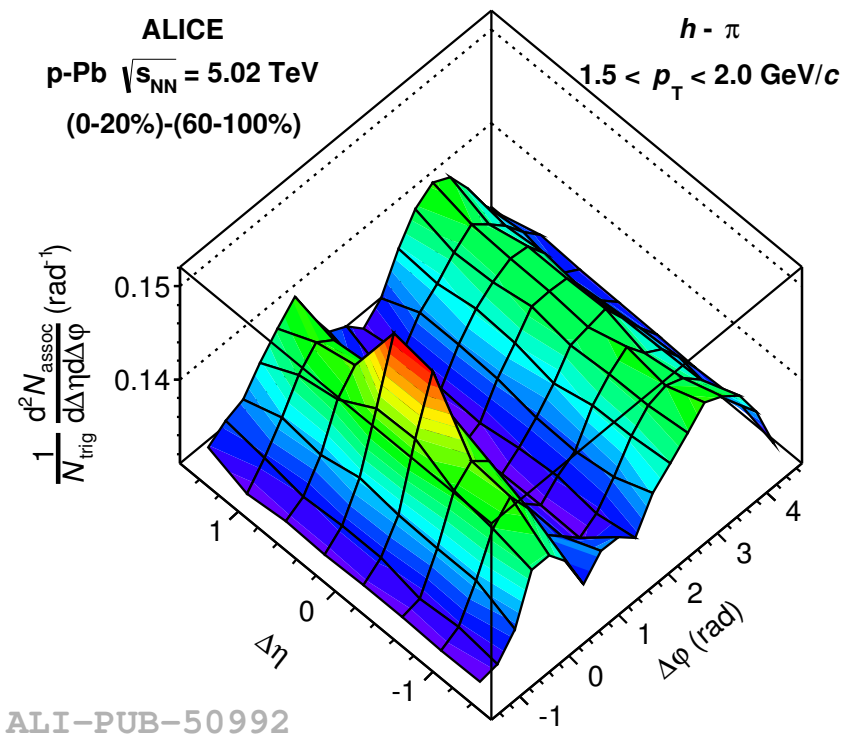
h-h correlations

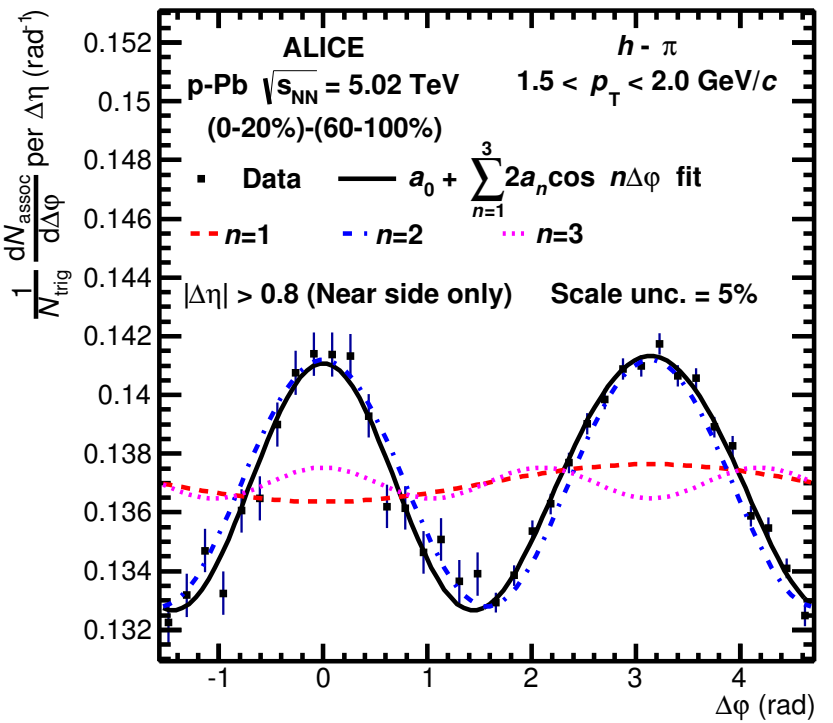




arXiv:1307.3237 [nucl-ex]

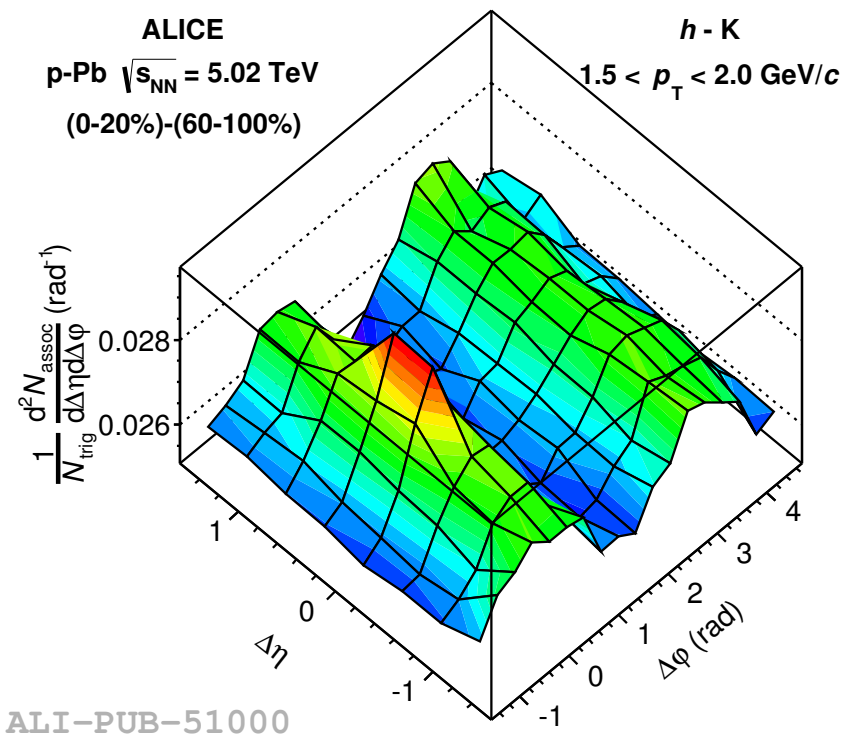
h-π correlations

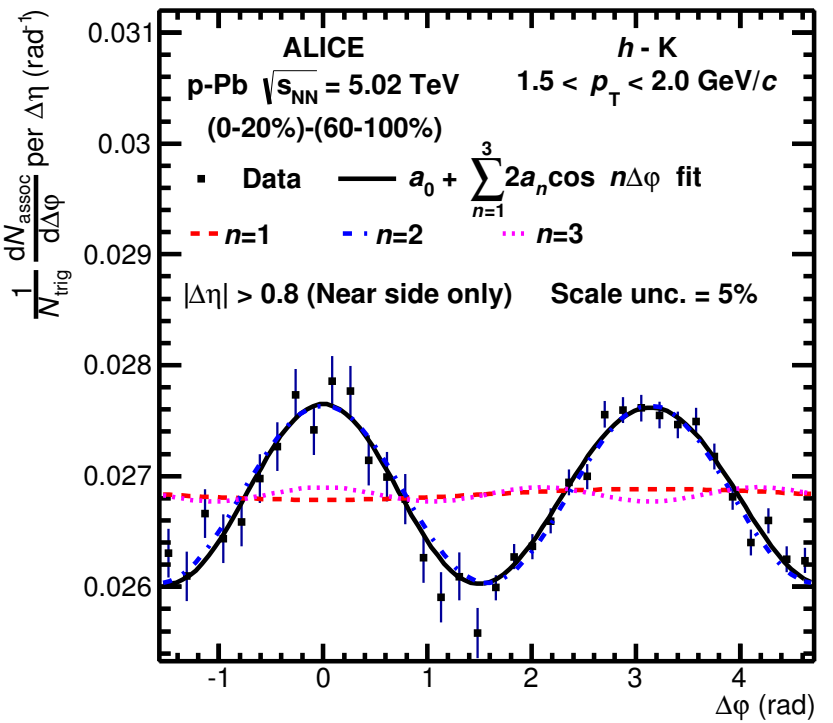




arXiv:1307.3237 [nucl-ex]

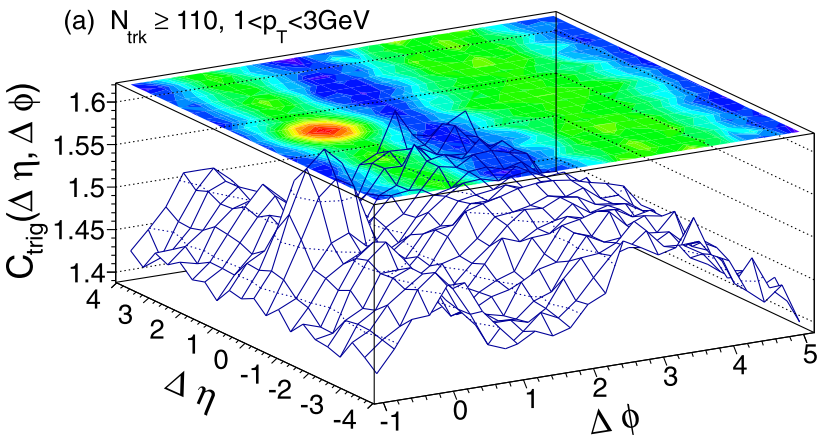
h-K correlations

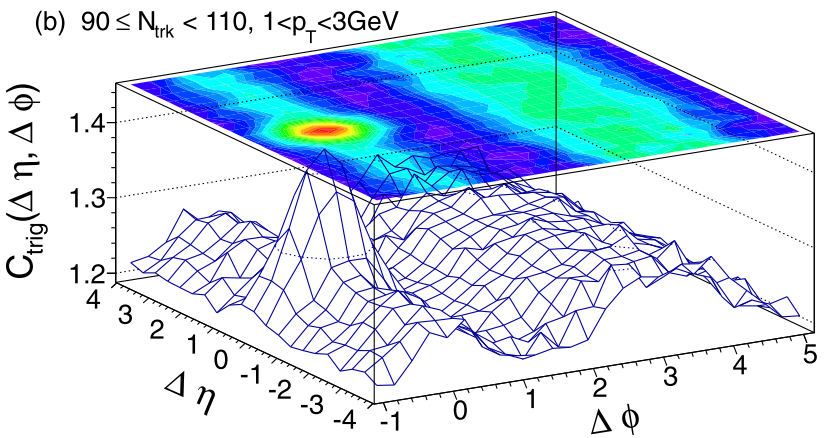


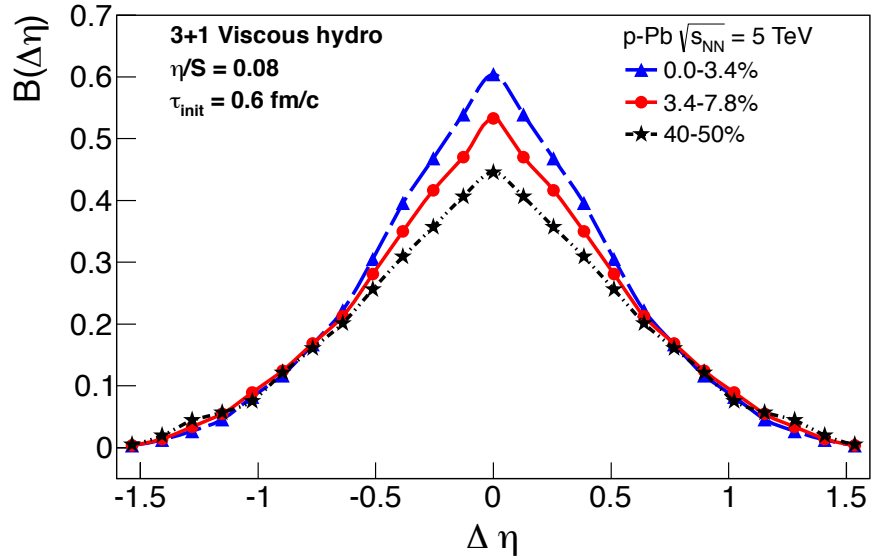


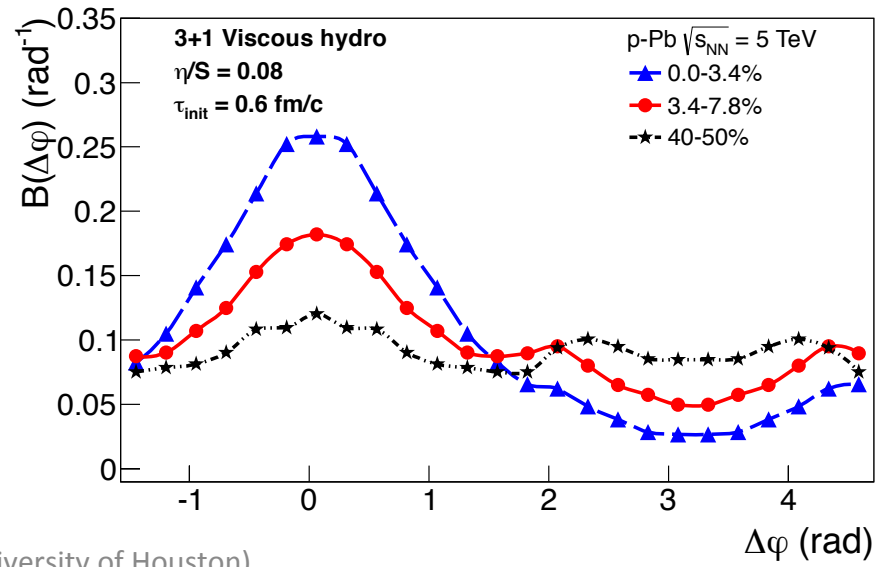
arXiv:1307.3237 [nucl-ex]

Hydro calculations









Bozek, Broniowski, PLB, 718 (2013) 1557
Private communication Bozek, Broniowski

Model comparison

HIJING:

- Charges produced early (mainly via string fragmentation)
- No collectivity e.g. radial flow

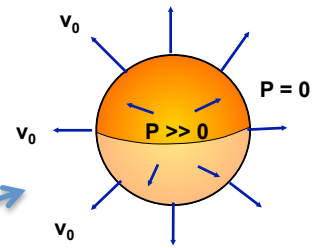
AMPT:

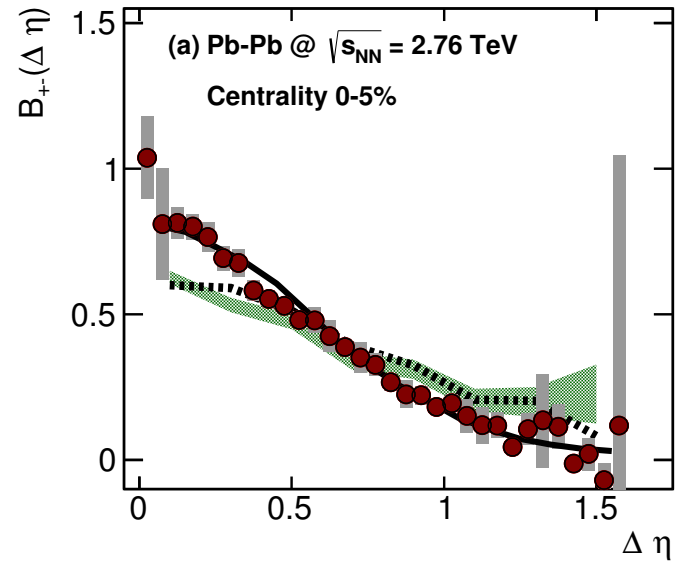
- HIJING: initial conditions
- ZPC: partonic evolution
- ART: hadronic rescattering
- Lund fragmentation
- Different flavours

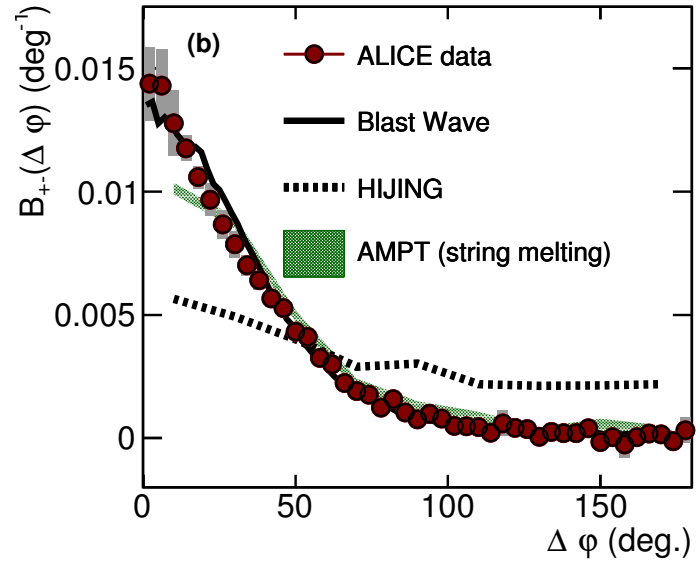
Blast Wave

- Collective motion $U_{x,y}$ in/out of reaction plane and temperature T
- Local charge conservation
- Emission of pair with initial separation at freeze-out σ_η and σ_ϕ

Radial (isotropic flow)







HIJING: *PRD 44, 3501 (1991).*
AMPT: *PRC 61, (2000) 067901,*
PRC 83, (2011) 034904.
PRC 84, (2011) 044907.
Blastwave: *PRC 85, (2012) 014904.*
PRL 108, (2012) 212301.

Centrality dependence

Measure:

- Weighted average: $\langle \Delta\eta \rangle = \frac{\sum B(\Delta\eta_i)\Delta\eta_i}{\sum B(\Delta\eta_i)}$

Data:

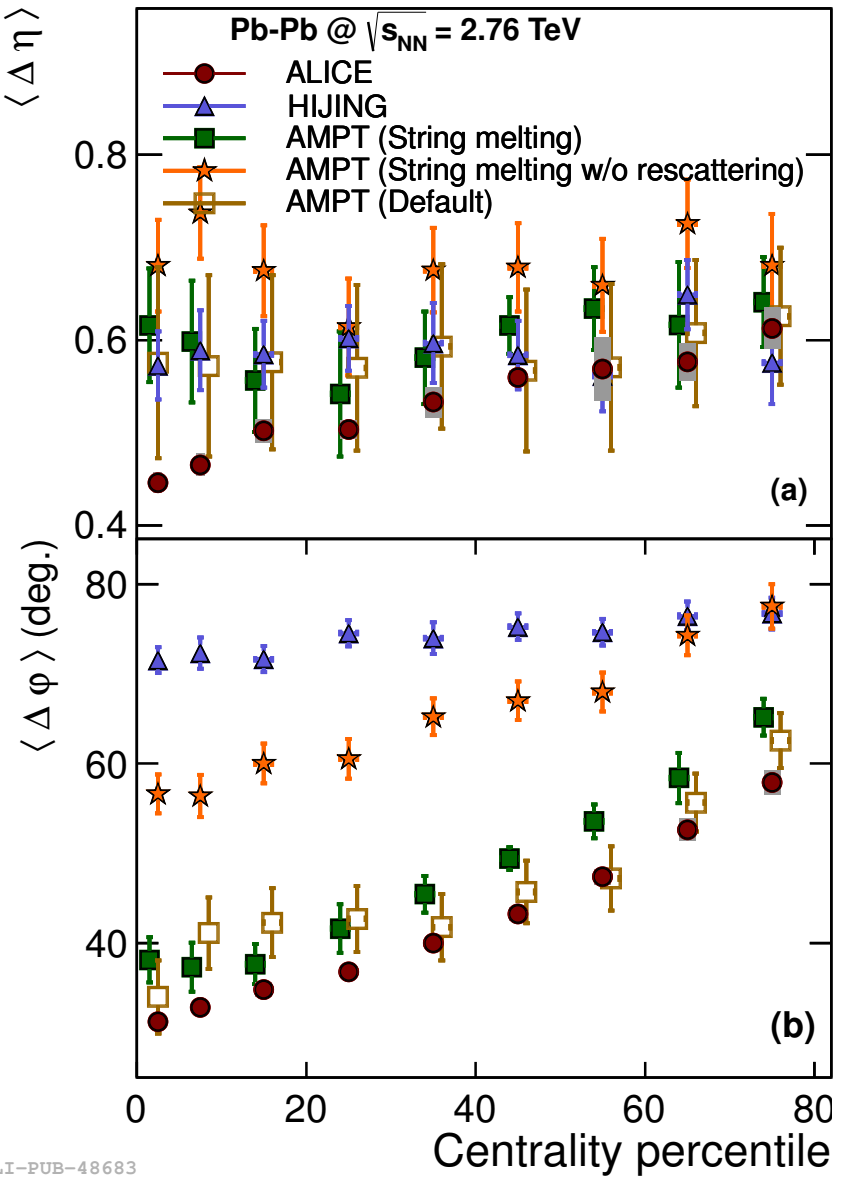
- Strong centrality dependence

HIJING:

- Charges produced early
  (mainly via string fragmentation)
- No collectivity e.g. radial flow
- Little or no centrality dependence
- Match data for most peripheral bin

AMPT:

- HIJING: initial conditions
- ZPC: partonic evolution
- ART: hadronic rescattering
- Lund fragmentation
- Different flavours
- $\Delta\eta$: Little or no centrality dependence
- Can reproduce $\Delta\varphi$



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Centrality dependence

Narrowing (peripheral to central):

$$\langle \Delta\eta \rangle = \frac{\sum B(\Delta\eta_i)\Delta\eta_i}{\sum B(\Delta\eta_i)}$$

Consistent with idea of:

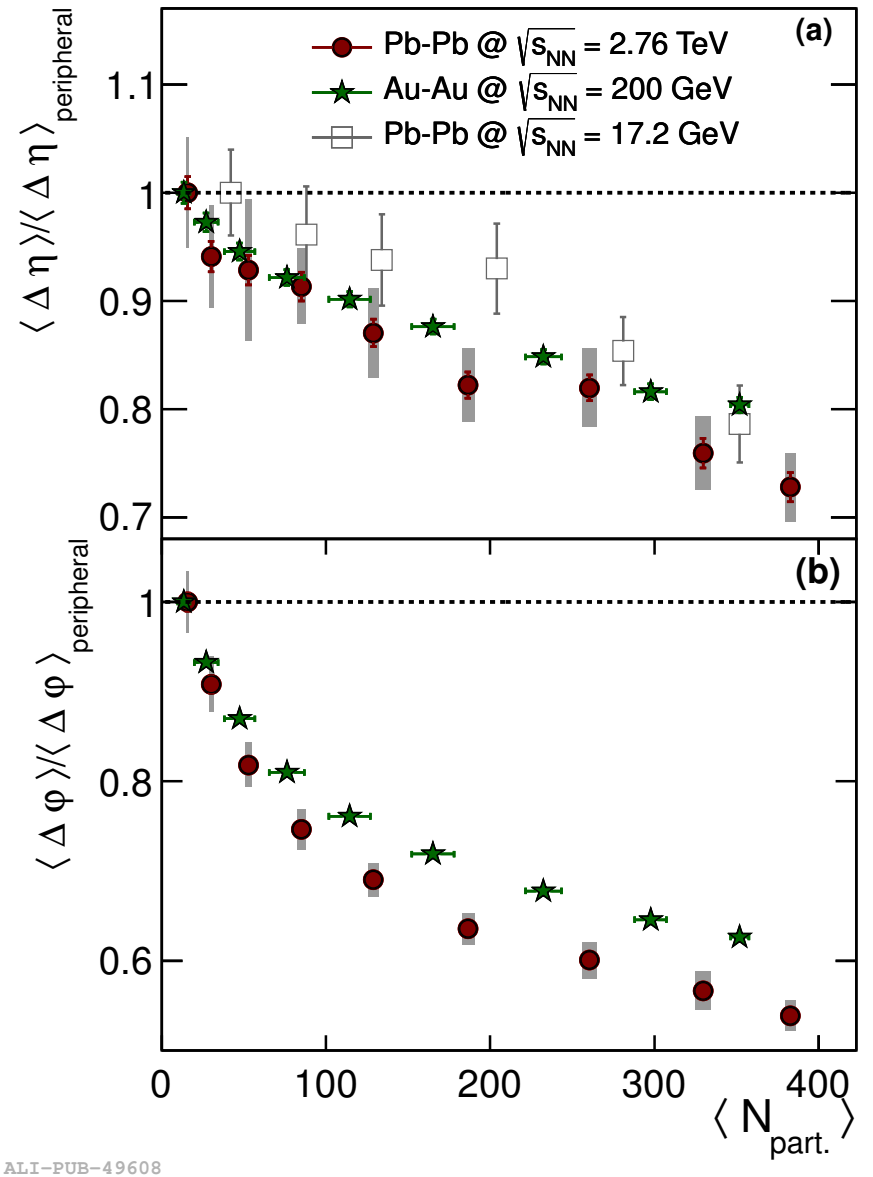
- Larger radial flow (RHIC→LHC)
- Longer–lived QGP phase and thus an even greater delayed creation of the detected charges.

BUT…

- Relative decrease:

$$\langle \Delta\eta \rangle_{CP} = \frac{\langle \Delta\eta \rangle}{\langle \Delta\eta \rangle_{peripheral}}$$

- $\langle\Delta\eta\rangle_{CP}$: seems to fall (unexpectedly?) on the same curve
- Hard to explain it in terms of late stage creation of charges



ALICE: PLB, 723 (2013), 267
NA49: PRC 71, (2005) 034903
STAR: PRC 82 (2010) 24905