Angular Correlations with ALICE

- **Muon-hadron correlations (p-Pb)**
- **Event shape engineering (Pb-Pb)**
- **Identified particle femtoscopy (Pb-Pb)**

Jan Fiete Grosse-Oetringhaus, CERN

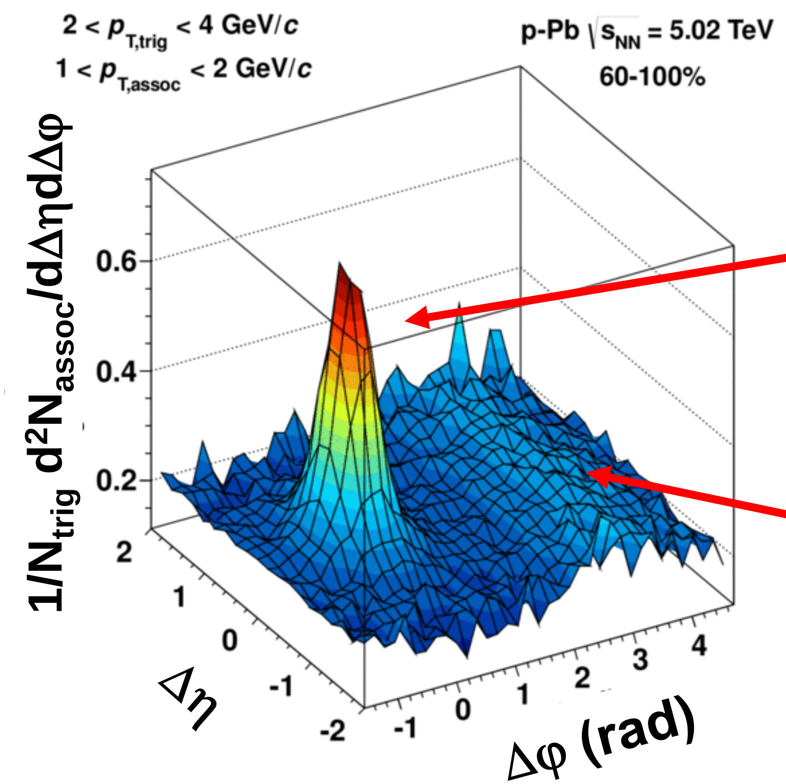
for the ALICE collaboration

EPS-HEP, Vienna

23.07.15

p-Pb

Typical Two-Particle Correlation



$2 < p_{T,trig} < 4$ GeV/c
$1 < p_{T,assoc} < 2$ GeV/c
40% lowest multiplicity p-Pb

Near-side jet
+ resonances, ...
($\Delta\varphi \sim 0$, $\Delta\eta \sim 0$)

Away-side jet
($\Delta\varphi \sim \pi$, elongated in $\Delta\eta$)

As you probably know, there is more…

ALICE, PLB719 (2013) 29

here: $\eta = \eta_{lab}$

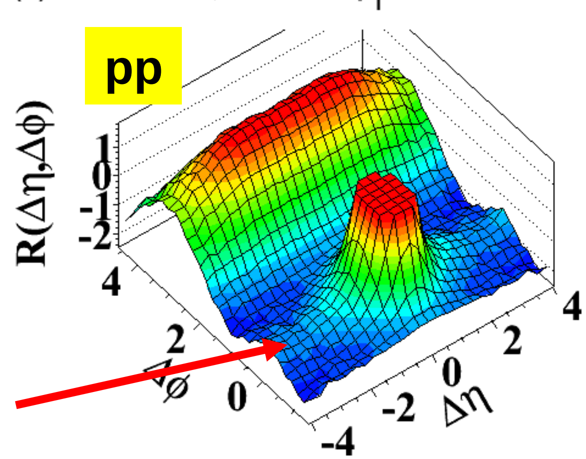
pp
p-Pb
Pb-Pb

here: $\eta = \eta_{lab}$

The Near-Side Ridge

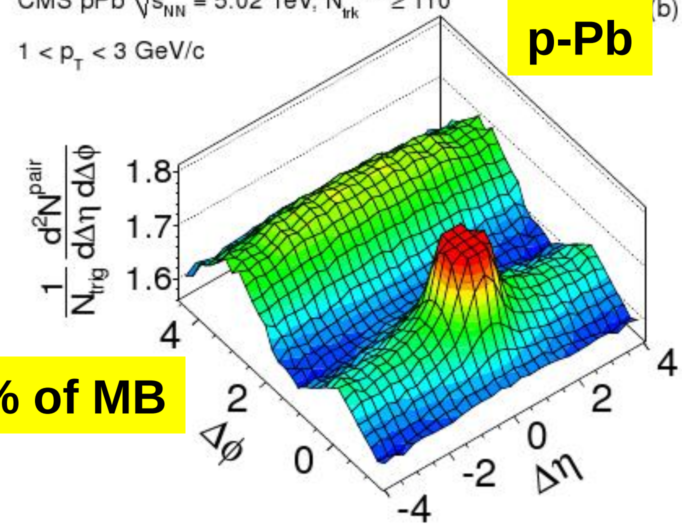
- Observed in high-multiplicity pp collisions
- Well known feature from Pb-Pb collisions (→ collective flow)
- Somehow expected in p-Pb, still surprising, in particular the amplitude

0.0005% of MB



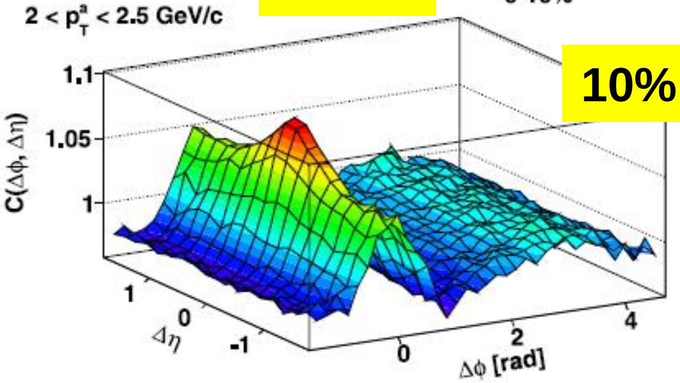
CMS, JHEP09(2010)091

$N_{offline,trk}$ > 110



3.1% of MB

CMS, PLB718 (2013) 795



10% of MB

ALICE, PLB708 (2012) 249

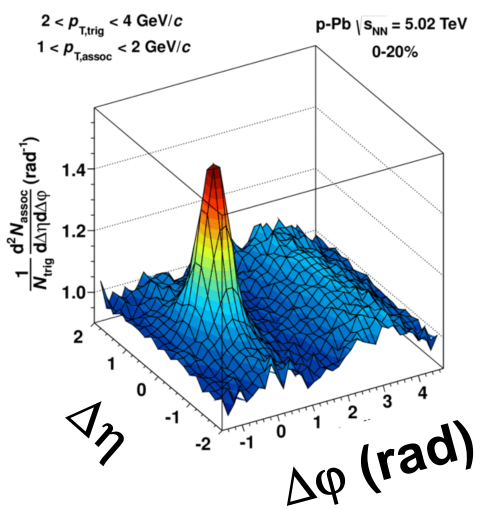
p-Pb

here: $\eta = \eta_{lab}$

The Double Ridge

- Subtraction to "isolate" ridge from jet
  - No ridge seen in 60-100% and similar to pp

0-20% **60-100%**



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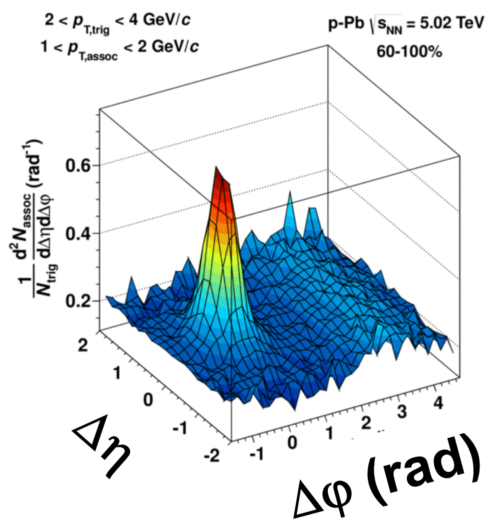

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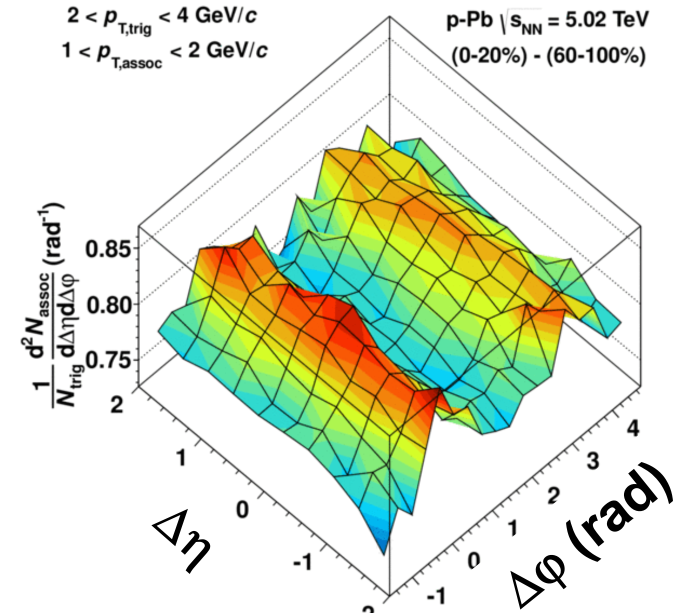
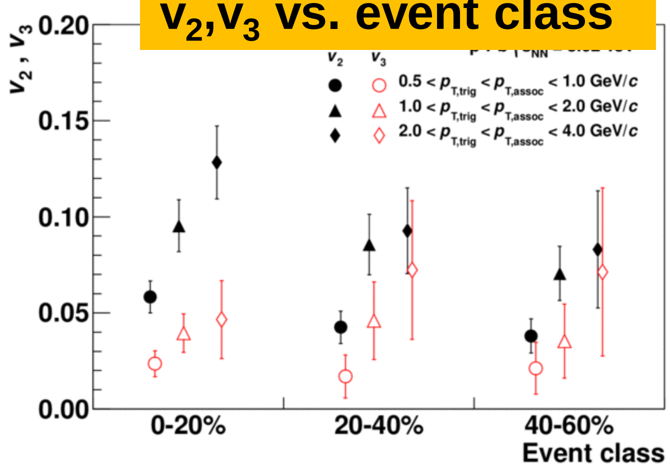


Two ridges !

Quantified by Fourier coefficients v_n of the $\Delta\varphi$ distribution

v_2,v_3 vs. event class

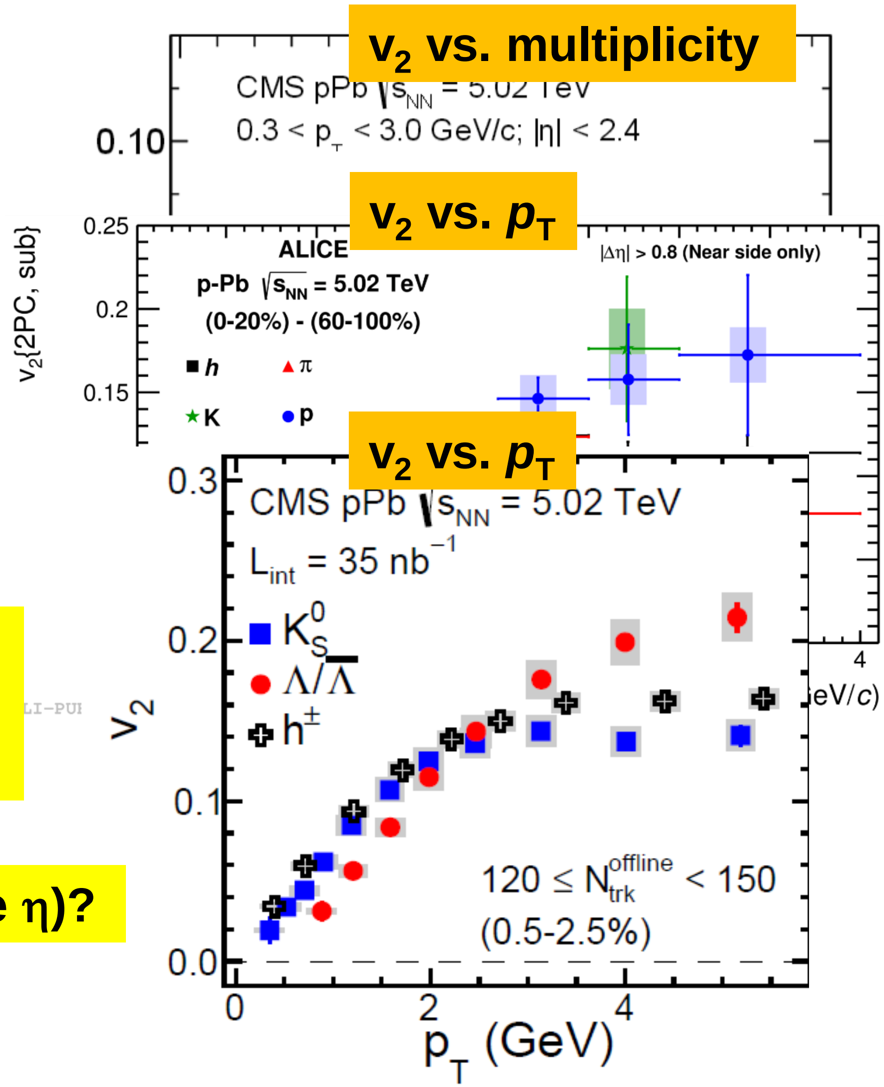


ALICE, PLB719 (2013) 29

Quantification of Ridges

p-Pb

- v_n coefficients
  - Significant v_2 and v_3
- Multi-particle correlation
  - $v_2\{4\} = v_2\{6\} = v_2\{8\}$
- Particle species dependence
  - Mass ordering of $v_2\{p\}$ and $v_2\{\pi\}$
  - Similar for K and Λ



Features reminiscent of Pb-Pb collisions → strong hints that similar effects at play in p-Pb and Pb-Pb collisions

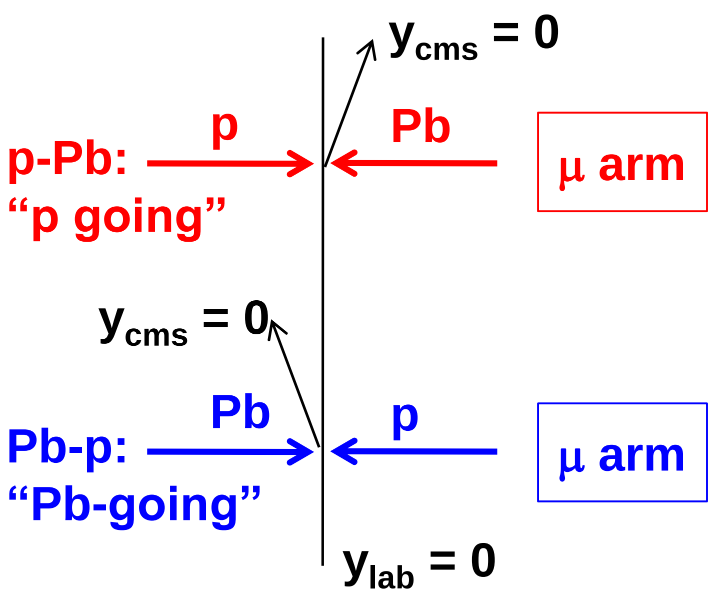
What happens in the forward region (large η)?

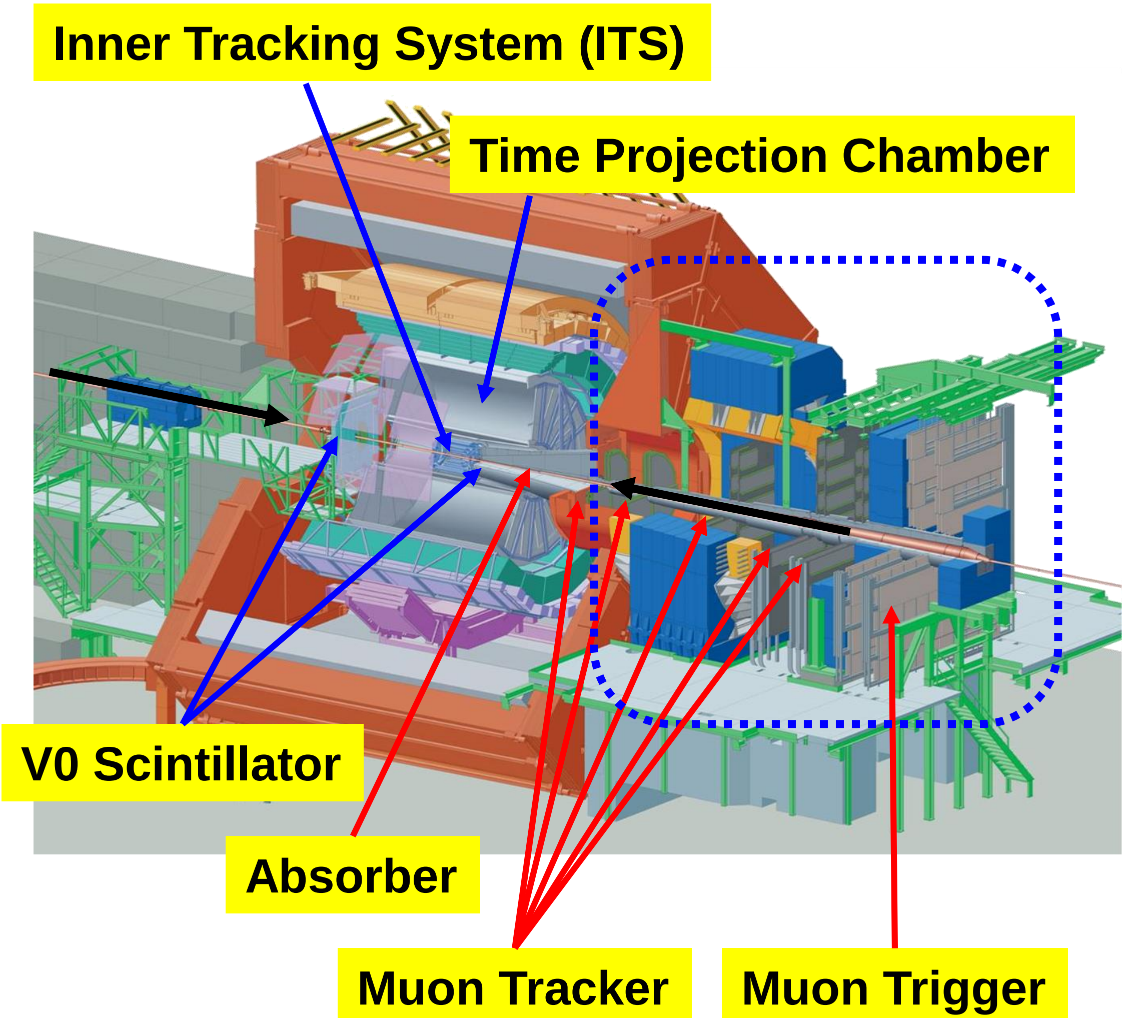
PRL110, 182302 (2013)
PLB 726 (2013) 164

arXiv:1502.05382
PLB 742 (2015) 200

p-Pb Collisions in ALICE

- $\sqrt{s_{NN}}$ = 5.02 TeV
- $y_{lab} - y_{cms} = \pm 0.465$
- L_{int} = 5 – 5.8 nb^{-1}
- One sided muon arm
- Beam configurations:

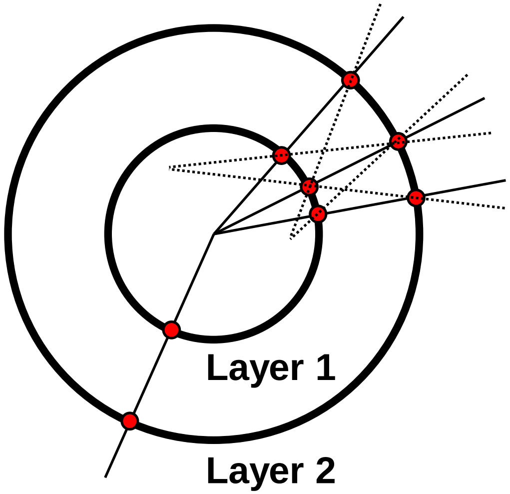




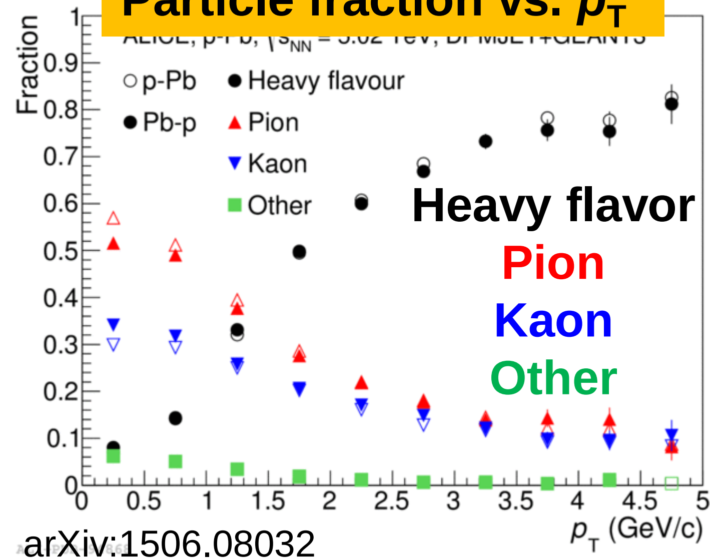
p-Pb

Forward-Central Correlations

- Hadrons at mid rapidity ($|\eta| < 1.0$) and forward inclusive muons ($-4 < \eta < -2.5$)
- Tracklets
  - Straight line using first two layers of ITS
  - $\langle p_T \rangle \sim 0.75$ GeV/c
  - Cross-checked with reconstructed tracks (lower statistics)
- Inclusive muons
  - Composition varies as a function of p_T
  - Higher p_T: dominated by heavy flavour
- Sample split into multiplicity classes (V0, $2.8 < \eta < 3.9$ and $-3.7 < \eta < -2.7$)
  - Symmetric for both beam configurations
  - 0-20% = high multiplicity | 60-100% low multiplicity



Particle fraction vs. p_T



arXiv:1506.08032

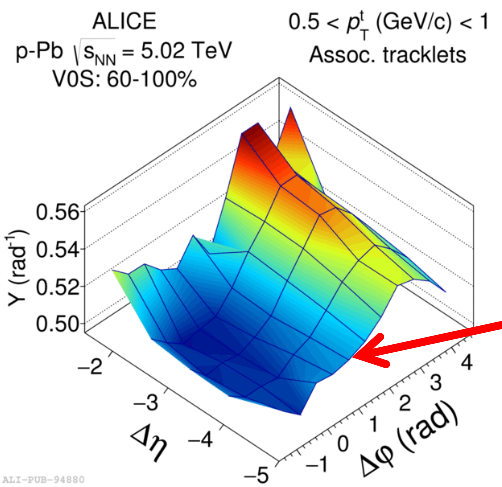
p-Pb

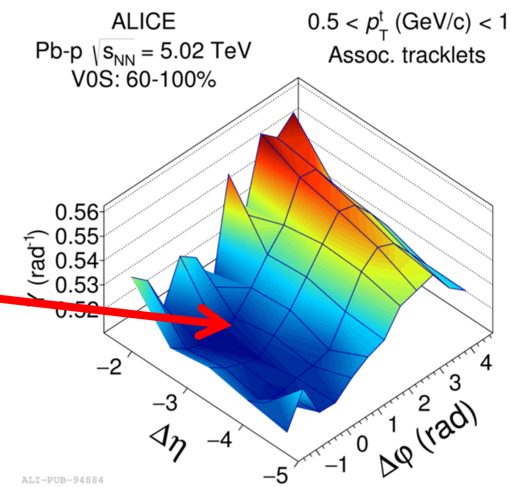
Correlations

$$Y = \frac{1}{N_{trig}} \frac{d^2 N_{assoc}}{d\Delta\varphi d\Delta\eta}$$

p-going direction | **Pb-going direction**

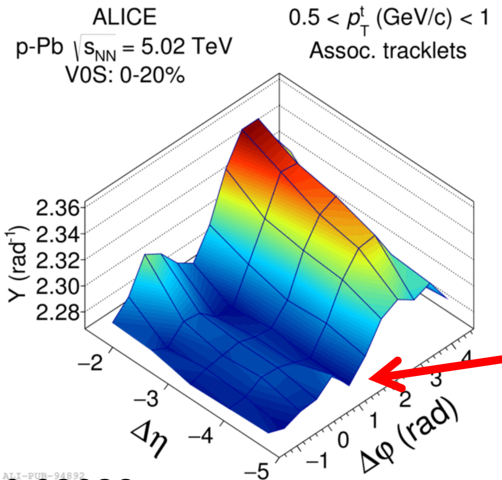
60-100%

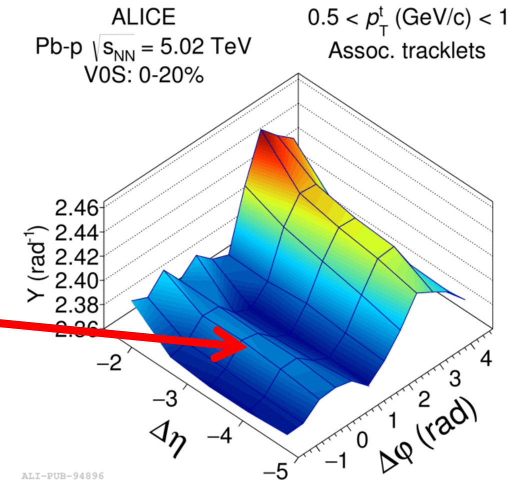




No ridge in low multiplicity

0-20%





Ridge in high multiplicity

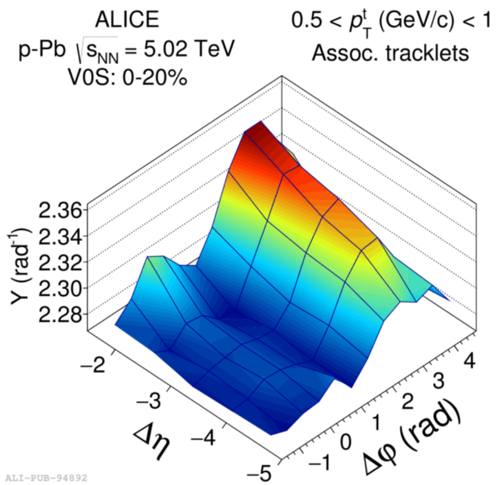
Near-side ridge extends out to Δη ~ 5 (and η ~ ±4)

arXiv:1506.08032

Subtraction

déjà vu…

0-20%



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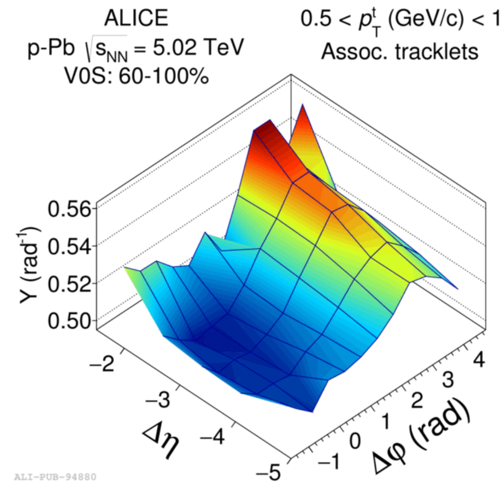
60-100%



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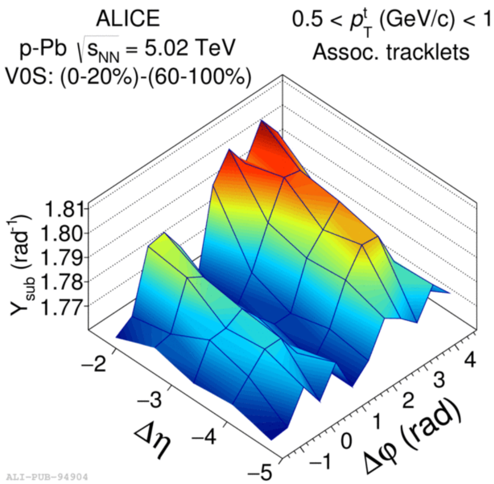
arXiv:1506.08032

p-Pb

Subtracted Correlations

p-going direction



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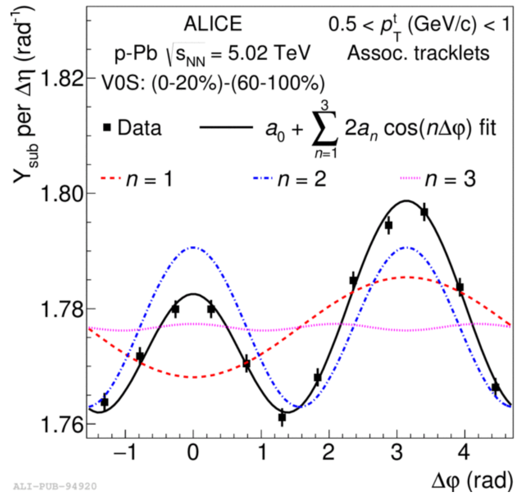


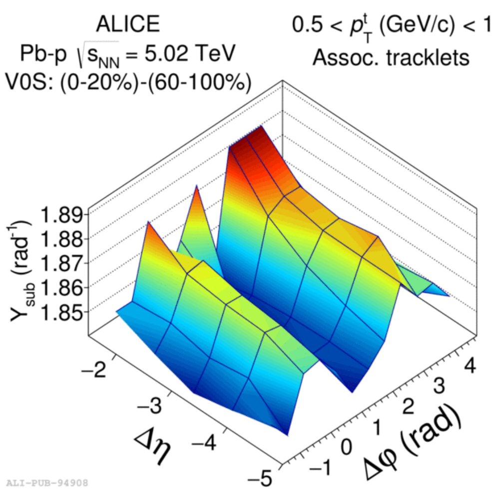
Double ridge in both beam directions

n = 1

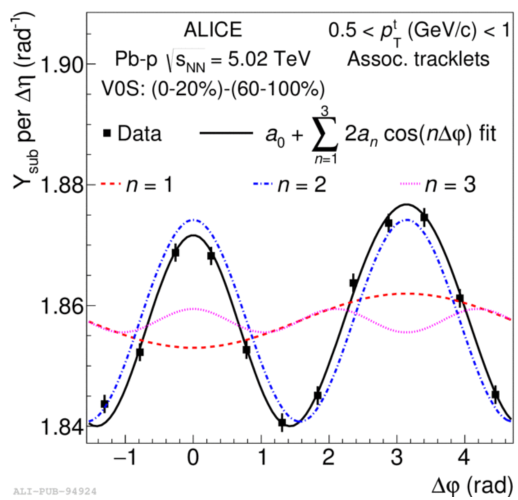
n = 2

n = 3

Pb-going direction



→



2nd coefficient dominates

arXiv:1506.08032

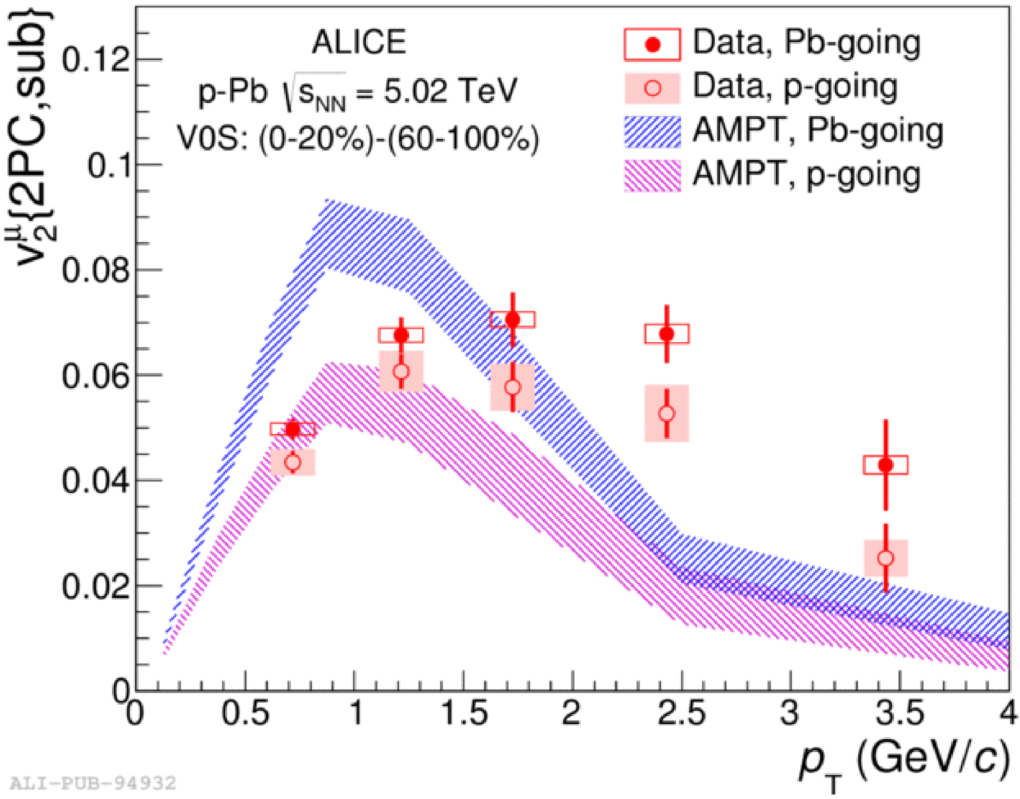
p-Pb

v_2

- Calculate inclusive μ v_2 (factorization)

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

- p-going < Pb-going (16% difference)
- AMPT (for inclusive μ)
  - Similar trend
- For p_T > 2 GeV/c heavy flavour > 60%
  - v_2^{HF}(AMPT) ~ 0
  - v_2^{HF} (data) > 0? or different particle composition?

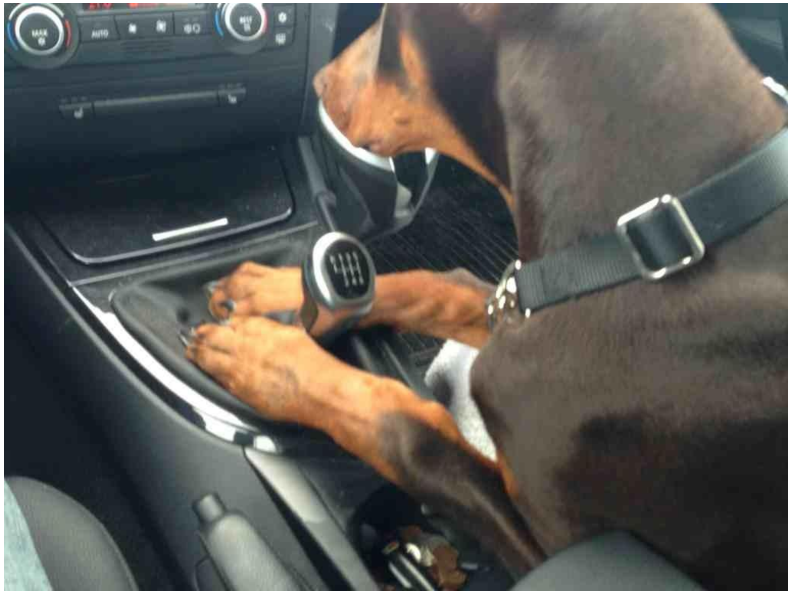


arXiv:1506.08032

ALICE

After discussing potential collective effects in small systems

let’s shift gears…

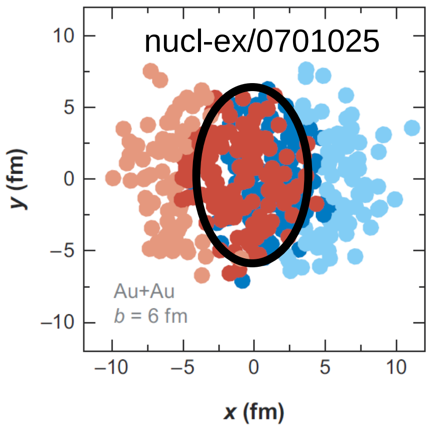


… and have a look at news about collectivity from Pb-Pb

Pb-Pb

Event Shape Engineering

- Large event-by-event variation of v_n
- Final-state v_2 correlated with initial-state eccentricities ε_2 (hydro with small η/s)
- Proposed by Schukraft, Timmins, Voloshin (PLB719 (2013) 394)
  - Split events by event-by-event v_2 (Q vector)
- Q vector from 2 different detectors
  - TPC in $|\eta| < 0.4$ → q_2^{TPC}
  - V0C ($-3.7 < \eta < -1.7$) → q_2^{V0C}
- Event studied in $0.5 < |\eta| < 0.8$
  - p_T spectra
  - v_2 (scalar product method)



$$q_2 = \frac{|Q_2|}{\sqrt{M}}$$

$$|Q_2| = \sqrt{Q_{2,x}^2 + Q_{2,y}^2}$$

$$Q_{2,x} = \sum \cos 2\varphi_i$$

$$Q_{2,y} = \sum \sin 2\varphi_i$$

M no. of particles

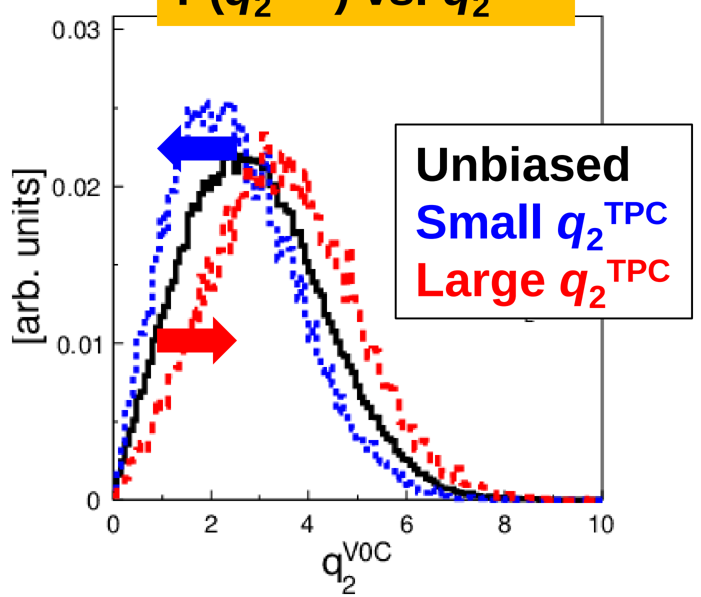
arXiv:1507.06194

Pb-Pb

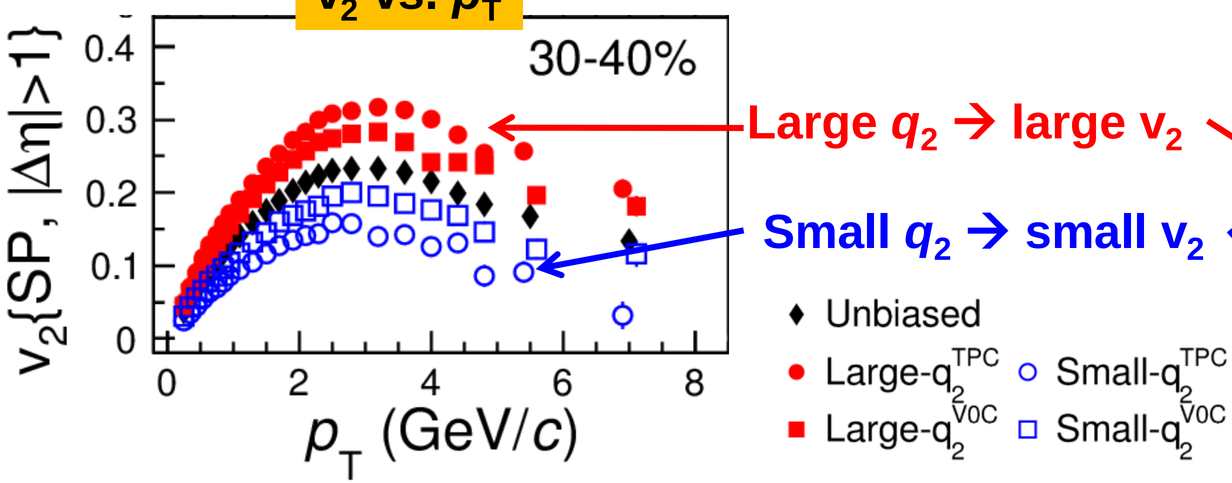
q_2 Selection

- Does the selection work?
  - Select on q_2^{TPC} → check q_2^{V0C}
- v_2 changes p_T independent
  - q_2^{TPC} vs. q_2^{V0C} → selection bias

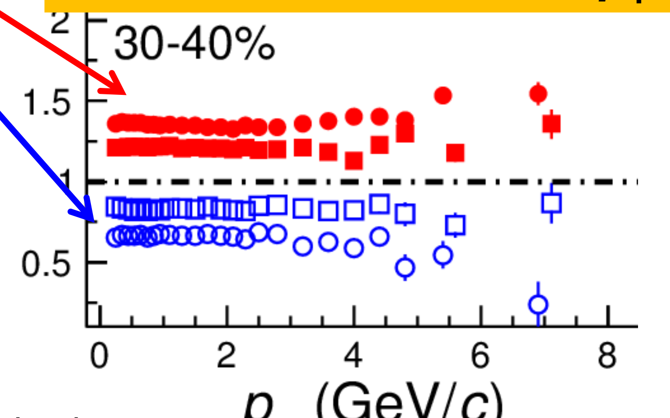
P(q_2^{V0C}) vs. q_2^{V0C}



v_2 vs. p_T



Selected / Inclusive vs. p_T



q_2 selects global event property

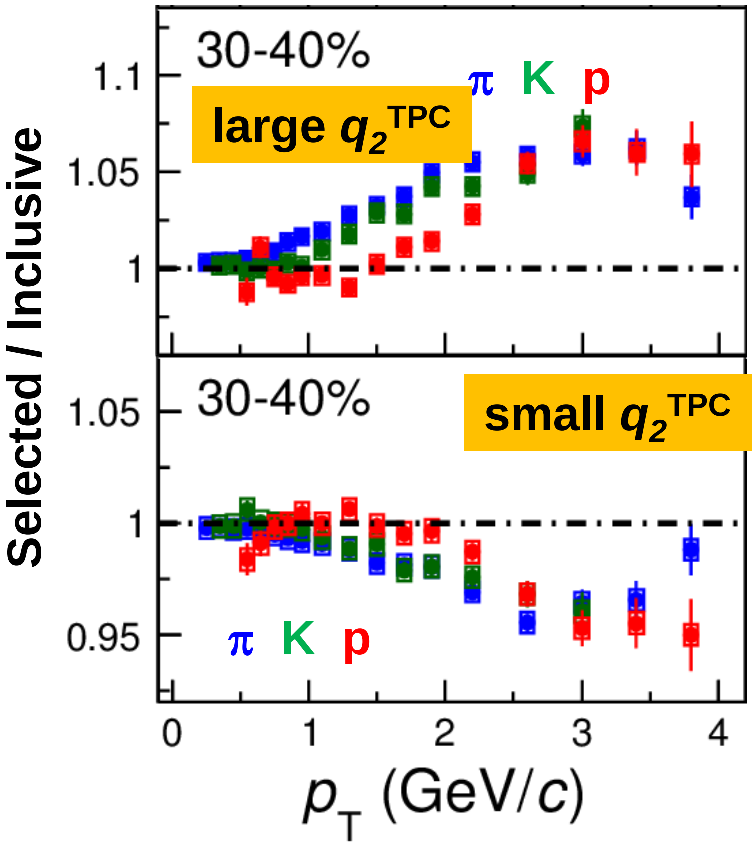
(all centralities in backup)

arXiv:1507.06194

Pb-Pb

p_T Spectra

- p_T spectra for π, K, p
- Change observed with q_2 selection
  - p_T dependent effect
  - Harder spectra for large q_2
  - Softer spectra for small q_2
  - Magnitude depends on mass
- Events with large q_2 have also larger radial flow?



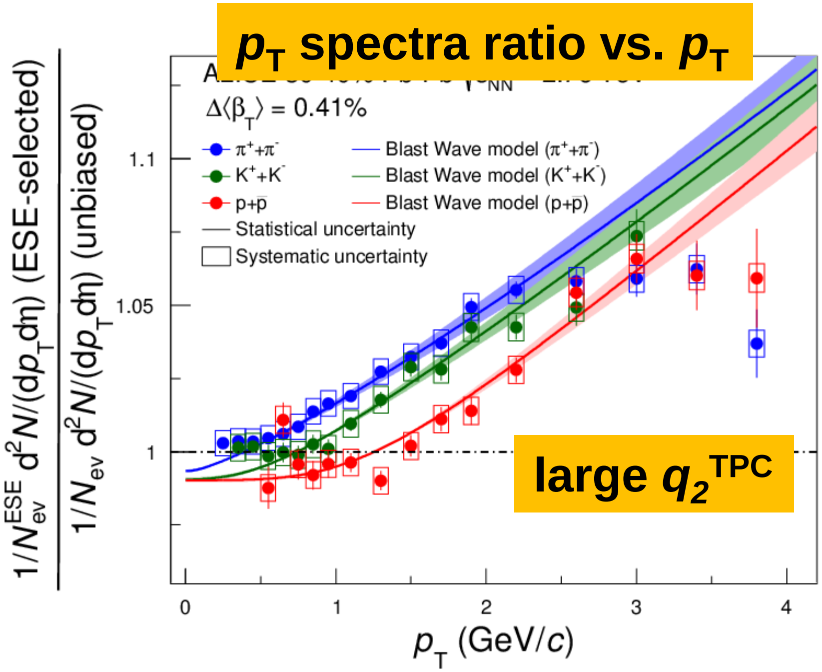
Let's test this question…

arXiv:1507.06194

Pb-Pb

Blast-Wave Fit

- Quantification of radial flow
  - Reproduce basic features of hydro-dynamic modeling
  - Main parameters expansion velocity β_T and temperature T
- Quantify change of spectra
  - Fixed T, allow change of β_T
  - β_T is 0.41%±0.03% larger than inclusive in the large q_2 selection
  - β_T is 0.22%±0.03% smaller than inclusive in the small q_2 selection



q_2 vector (→ eccentricity) correlated with radial flow (→ pressure gradient)

Blast-Wave: PRC 48, 2462 (1993)

arXiv:1507.06194

Pb-Pb

Femtoscopic radii for π, K, p

Advertisement

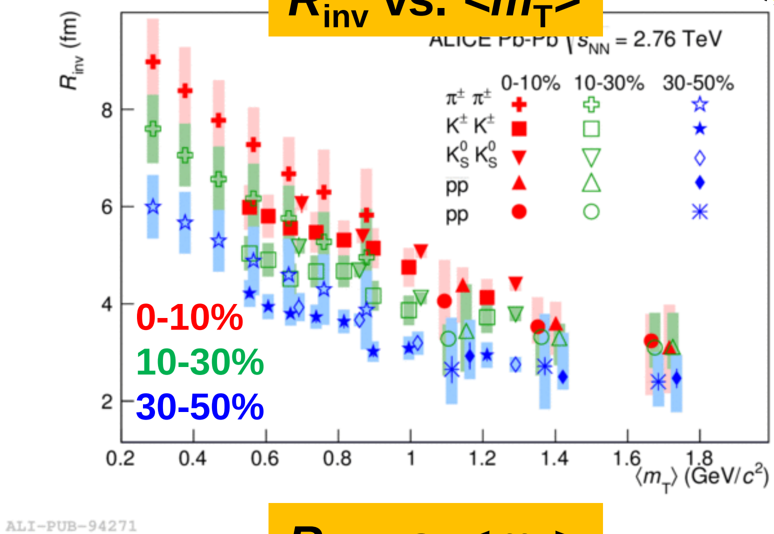
- Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
- 1D radii separate for π, $K^{\pm}$, K^0, pbar, p pairs
- Monotonic decrease with increasing pair transverse mass

Approximate m_T scaling for K and p

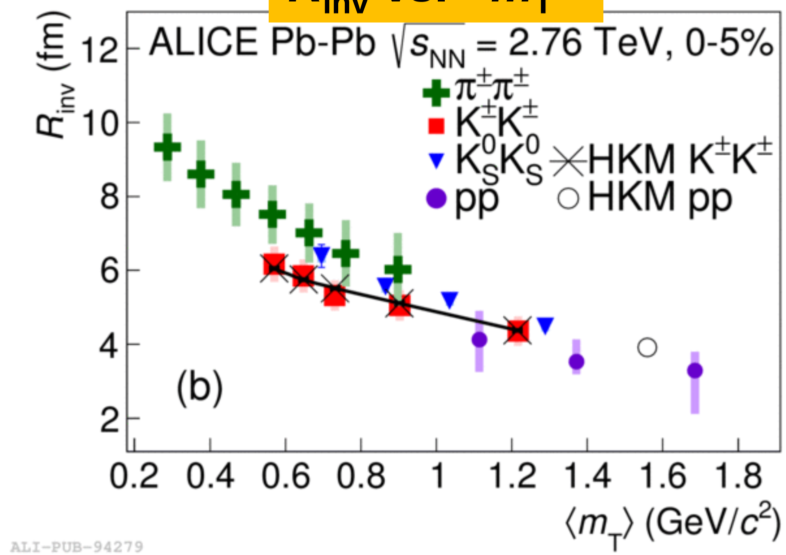
- Can be described by hydro with hadronic phase (HKM model)
  - HKM: ideal hydro, gradual decoupling (hydrokinetic), UrQMD

Hadronic phase important

R_{inv} vs. <m_T>



R_{inv} vs. <m_T>



ALICE paper: arXiv:1506.07884
HKM: Nucl.Phys. A929 (2014) 1

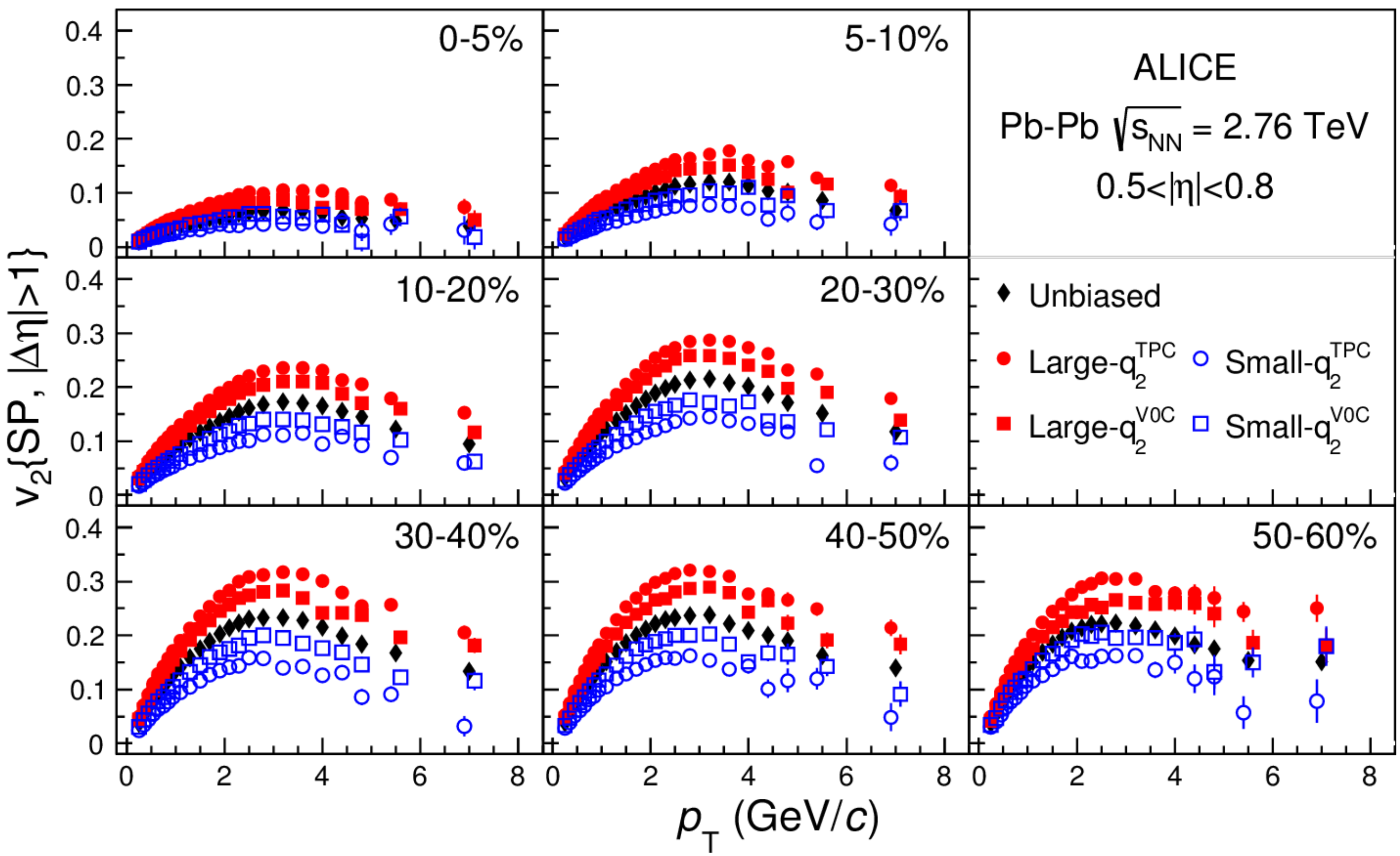
Summary

- Muon-hadron correlations at forward rapidities in p-Pb
  - Double ridge extends over 10 units of pseudorapidity
  - Inclusive muon v_2 larger on Pb-going side than p-going side
  - AMPT comparison suggests HF $v_2 > 0$ or different particle composition

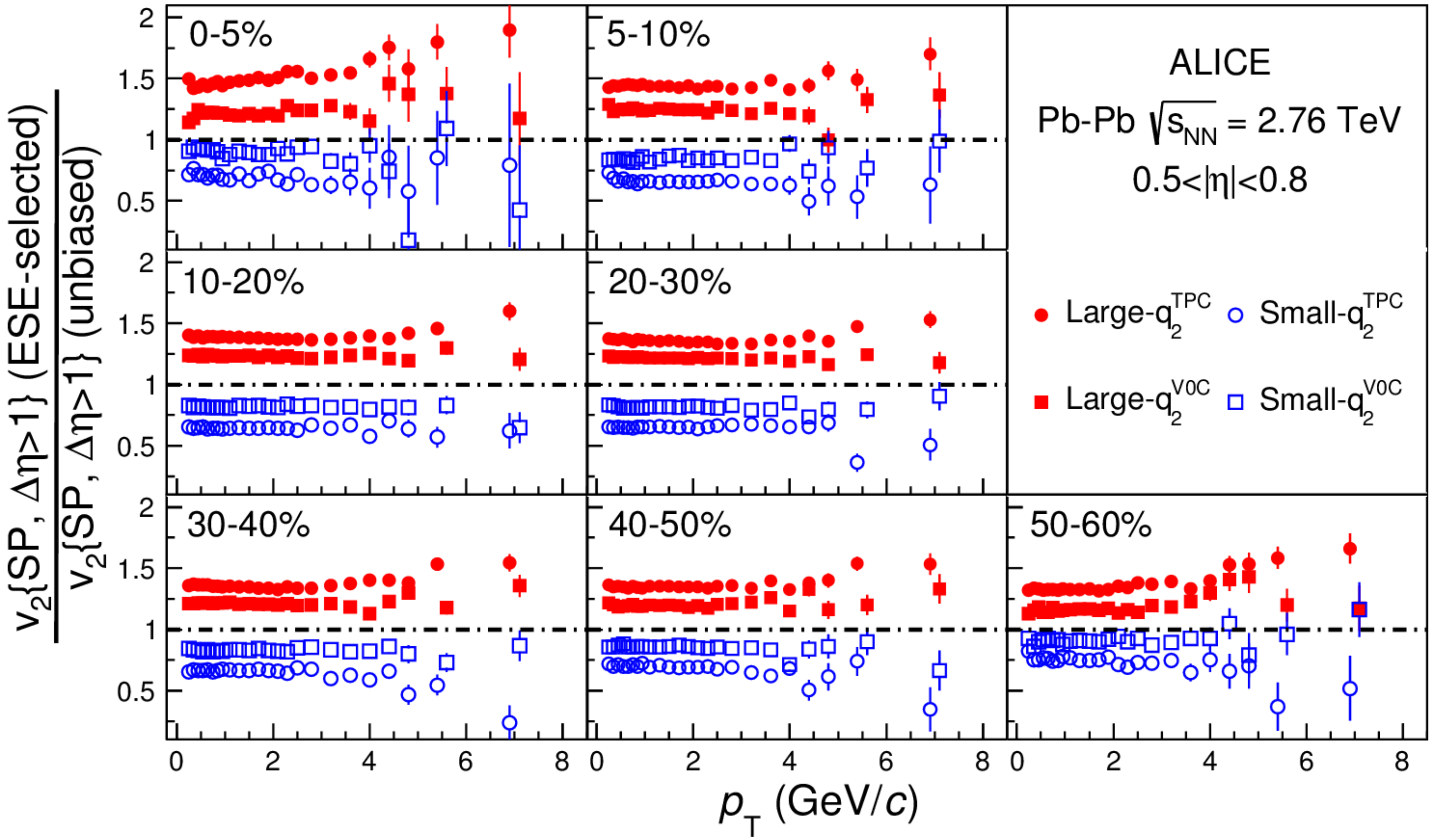
- Event Shape Engineering in Pb-Pb
  - Divide event sample based on event-by-event q vector
  - q vector shown to be a global event property
  - Initial state 2nd order eccentricity and pressure gradients correlated

Results constrain the role of initial state and hydrodynamic expansion in the modeling of p-Pb and Pb-Pb collisions

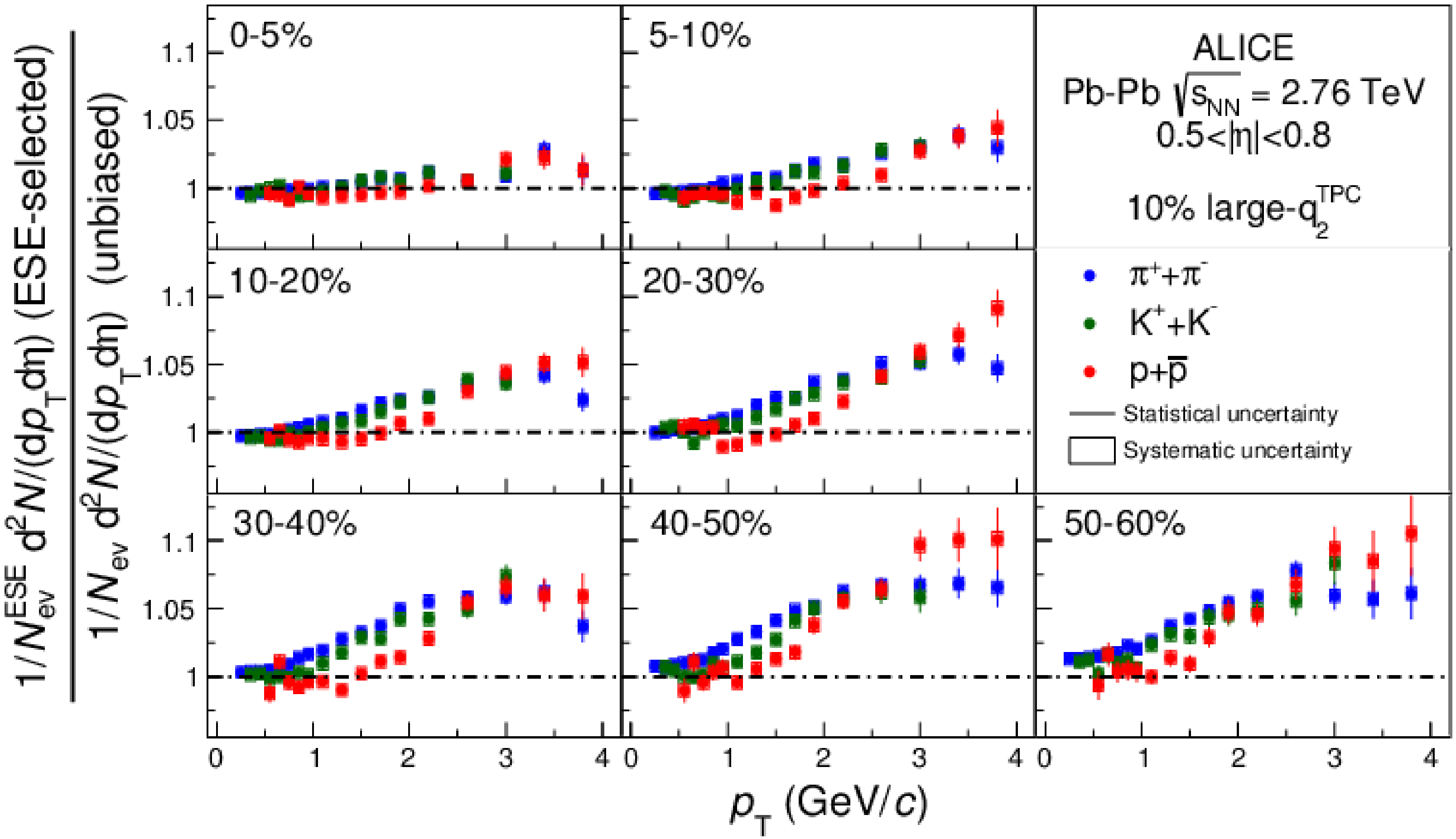
Backup



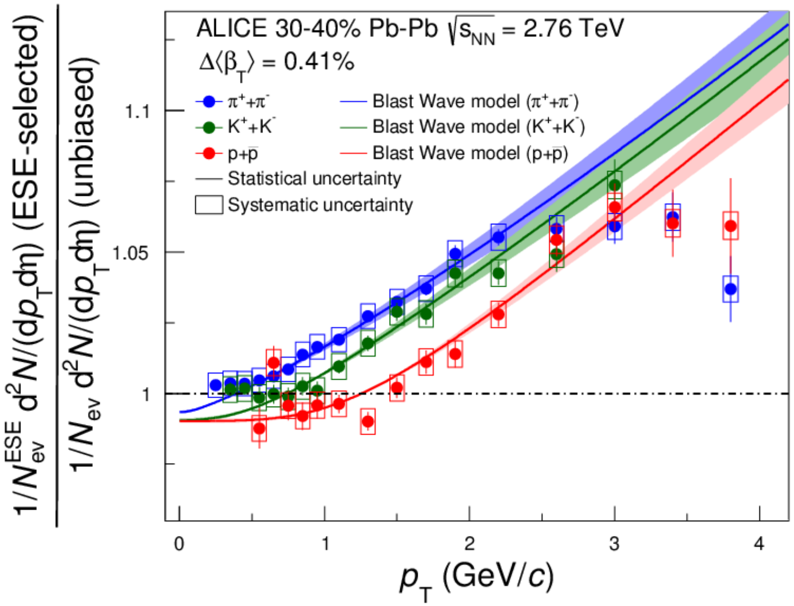
0-5%
5-10%
ALICE
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.5<|η|<0.8
10-20%
20-30%
Unbiased
Large-q_2^{TPC}
Small-q_2^{TPC}
Large-q_2^{V0C}
Small-q_2^{V0C}
30-40%
40-50%
50-60%
$v_2\{SP, |\Delta\eta|>1\}$
p_T (GeV/c)

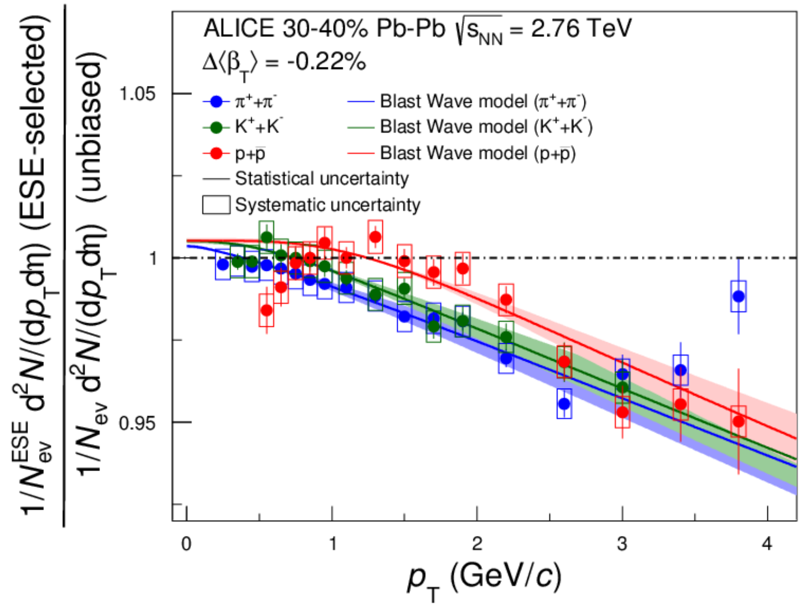


0-5%
5-10%
ALICE
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.5<|η|<0.8
10-20%
20-30%
Large-q_2^{TPC}
Small-q_2^{TPC}
Large-q_2^{V0C}
Small-q_2^{V0C}
30-40%
40-50%
50-60%
$v_2\{SP, \Delta\eta>1\}$ (ESE-selected) / $v_2\{SP, \Delta\eta>1\}$ (unbiased)
p_T (GeV/c)



ALICE
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
0.5<|η|<0.8
10% large-q_2^{TPC}
$\pi^+ + \pi^-$
$K^+ + K^-$
$p + \bar{p}$
Statistical uncertainty
Systematic uncertainty
0-5%
5-10%
10-20%
20-30%
30-40%
40-50%
50-60%
p_T (GeV/c)
$\frac{1/N_{ev}^{ESE}\, d^2N/(dp_T d\eta)\ (\text{ESE-selected})}{1/N_{ev}\, d^2N/(dp_T d\eta)\ (\text{unbiased})}$


ALICE 30-40% Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$\Delta\langle\beta_T\rangle$ = 0.41%
$\pi^+ + \pi^-$
$K^+ + K^-$
$p + \bar{p}$
Blast Wave model ($\pi^+ + \pi^-$)
Blast Wave model ($K^+ + K^-$)
Blast Wave model ($p + \bar{p}$)
Statistical uncertainty
Systematic uncertainty
$1/N_{ev}^{ESE}\, d^2N/(dp_T d\eta)$ (ESE-selected)
$1/N_{ev}\, d^2N/(dp_T d\eta)$ (unbiased)
p_T (GeV/c)


ALICE 30-40% Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
$\Delta\langle\beta_T\rangle$ = -0.22%
$\pi^+ + \pi^-$
$K^+ + K^-$
$p + \bar{p}$
Blast Wave model ($\pi^+ + \pi^-$)
Blast Wave model ($K^+ + K^-$)
Blast Wave model ($p + \bar{p}$)
Statistical uncertainty
Systematic uncertainty
$1/N_{ev}^{ESE}\, d^2N/(dp_T d\eta)$ (ESE-selected)
$1/N_{ev}\, d^2N/(dp_T d\eta)$ (unbiased)
p_T (GeV/c)