Long-range correlations in ALICE at the LHC

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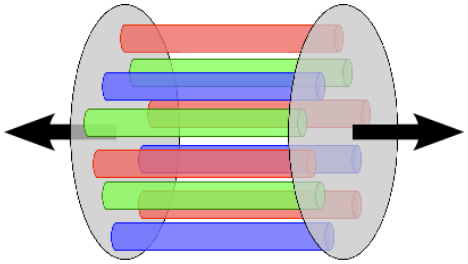
What are the sources of long-range correlations?

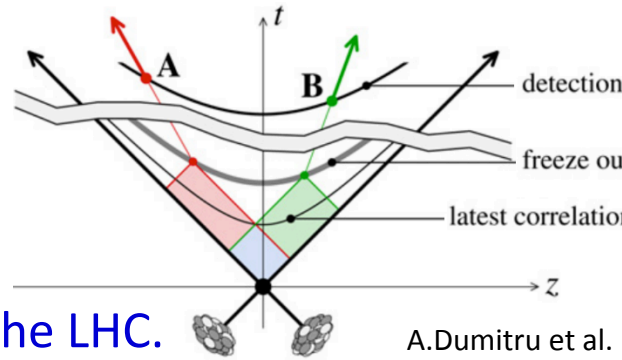
Long-range correlations (LRC)

– correlations between particles separated by pseudorapidity gap

Typically: $|\Delta\eta| > 1.0$ → suppress contribution from resonances and (mini) jets

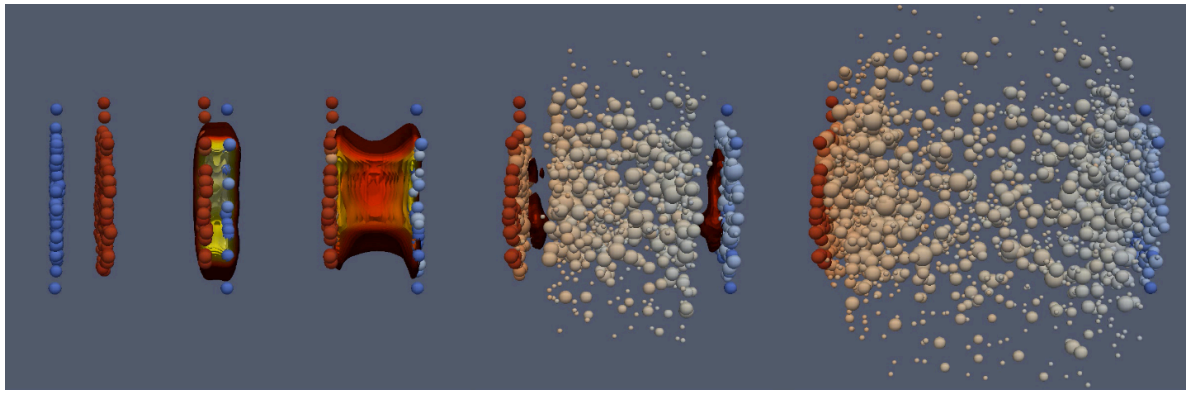
- LRC can be created only at early stages of the collision
  - geometry, interactions between strings
- can be modified by medium and final state interactions
  - hydrodynamic expansion
  - energy loss in medium
  - conservation laws





A.Dumitru et al.
Nucl. Phys. A 810 (2008) 91–108

Pb-Pb, p-Pb and pp collisions are under investigation at the LHC.



ALICE experimental setup

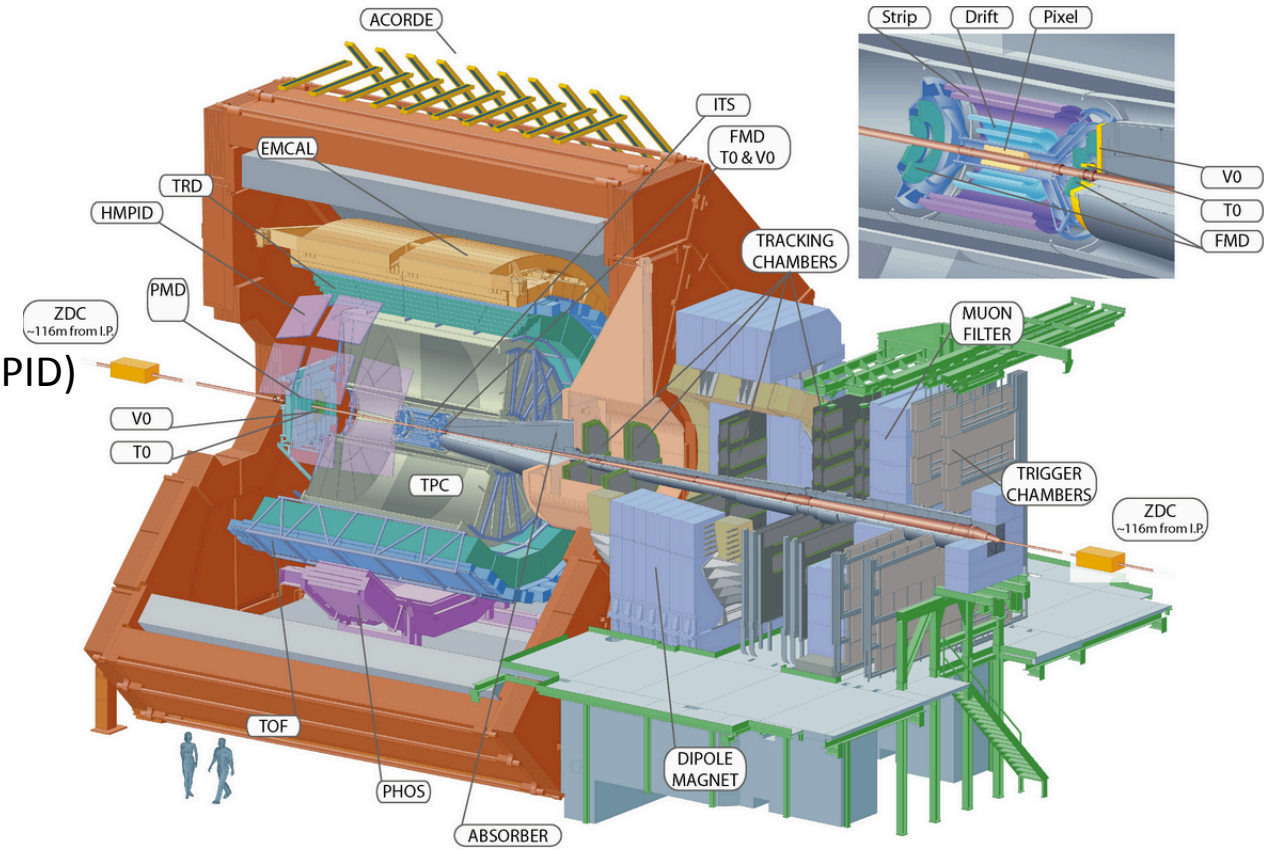
Inner Tracking System (ITS)
(-0.9<η<0.9)
Tracking + triggering

Time Projection Chamber (TPC)
(-0.8<η<0.8)
Tracking + particle identification (PID)

Time Of Flight (TOF)
(-0.8<η<0.8)
PID

VZERO detector
Two forward scintillator arrays
(-3.7<η<-1.7, 2.8<η<5.1)
centrality + triggering

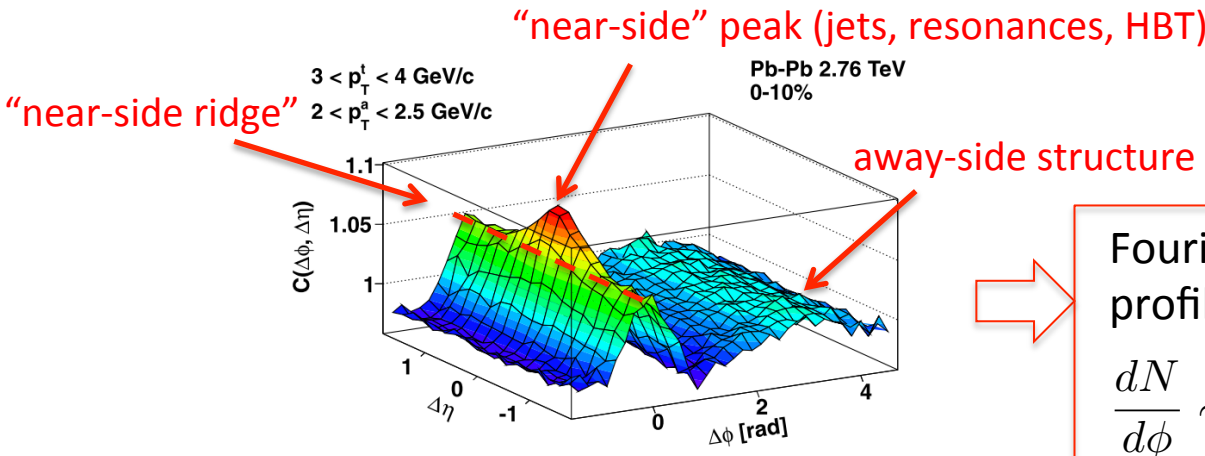
Muon Spectrometer
Tracking chambers **(-4<η<-2.5)**
Trigger chambers



- Tracking: ITS+TPC (p_T > 0.2 GeV/*c*)
- Particle identification: ITS+TPC+TOF
- Centrality estimators: VZERO, ZDC

How do we extract information about long-range correlations?

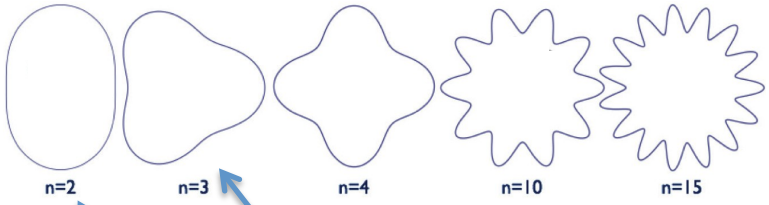
- Two-particle correlations with pseudorapidity gap



$$C(\Delta\phi,\Delta\eta) \equiv \frac{N_{\text{mixed}}}{N_{\text{same}}} \times \frac{N_{\text{same}}(\Delta\phi,\Delta\eta)}{N_{\text{mixed}}(\Delta\phi,\Delta\eta)}$$

Fourier decomposition of azimuthal profile at large Δη:

$$\frac{dN}{d\phi} \sim 1 + 2\sum_n v_n \cos[n(\phi - \Psi_n)]$$



triangular flow

elliptic flow

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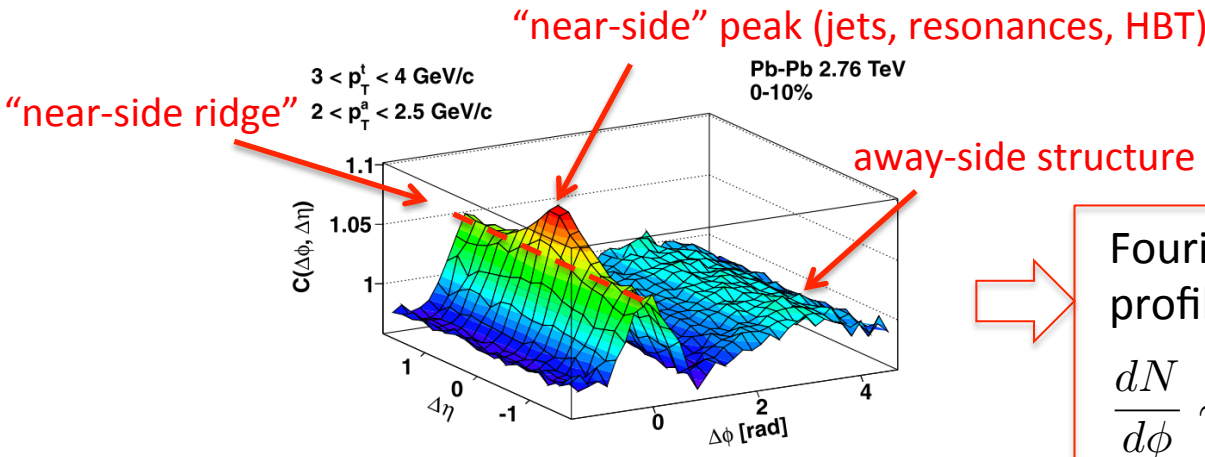

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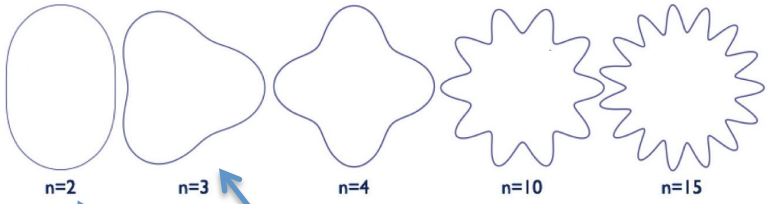


elliptic flow

triangular flow

- Multiparticle correlations

$v_2\{4\}$, $v_2\{6\}$, $v_2\{8\}$, $v_2\{\text{LYZ}, \infty\}$

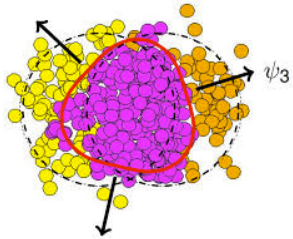
- Forward-backward correlations

$$b_{corr} = \frac{\langle n_B n_F\rangle - \langle n_B\rangle\langle n_F\rangle}{\langle n_F^2\rangle - \langle n_F\rangle^2}, \quad \langle n_B\rangle_{n_F} = a + b_{corr}\cdot n_F$$

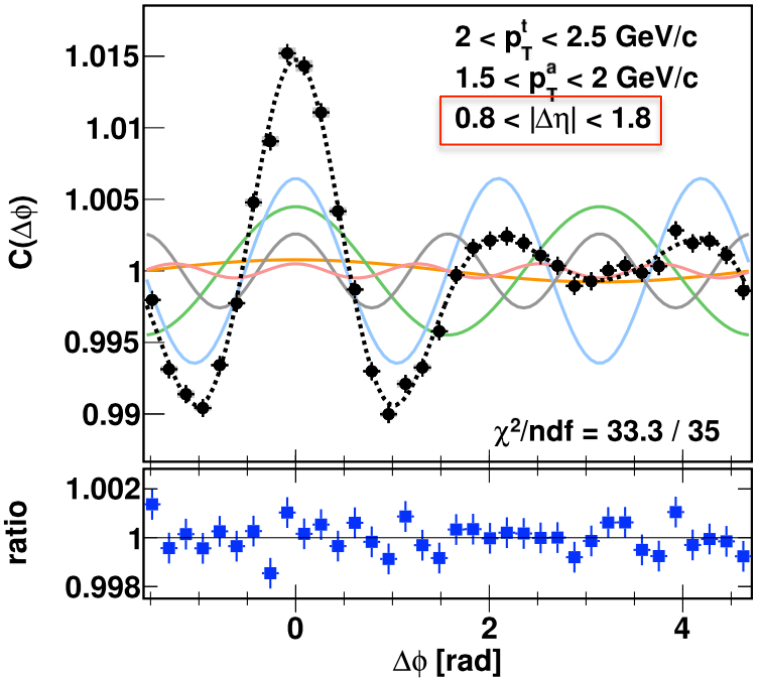
In this talk – some experimental highlights on LRC from ALICE.

Harmonic decomposition of long-range two-particle angular correlations

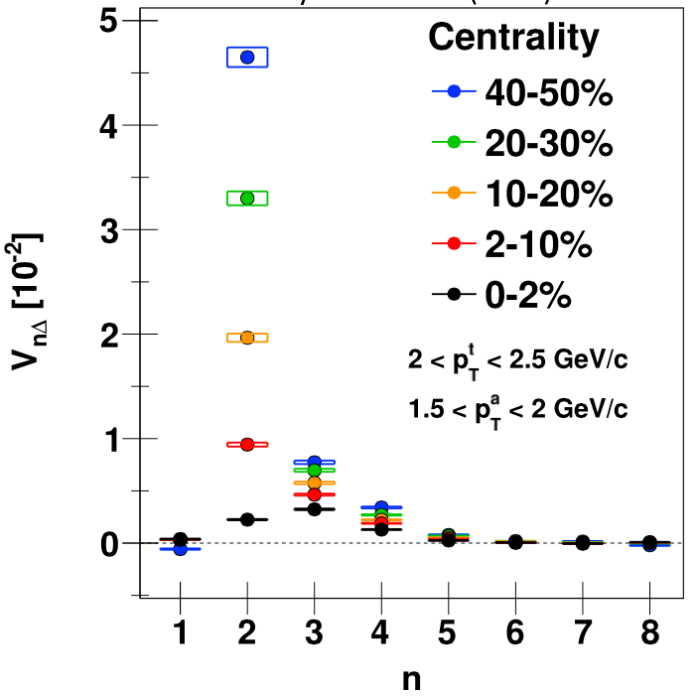
- shape of the overlap region → large elliptic flow v_2, non-zero v_4
- fluctuations of the initial energy density profile → affect v_2, produce v_3, …



Most central (0-2%) Pb-Pb collisions at 2.76 TeV:



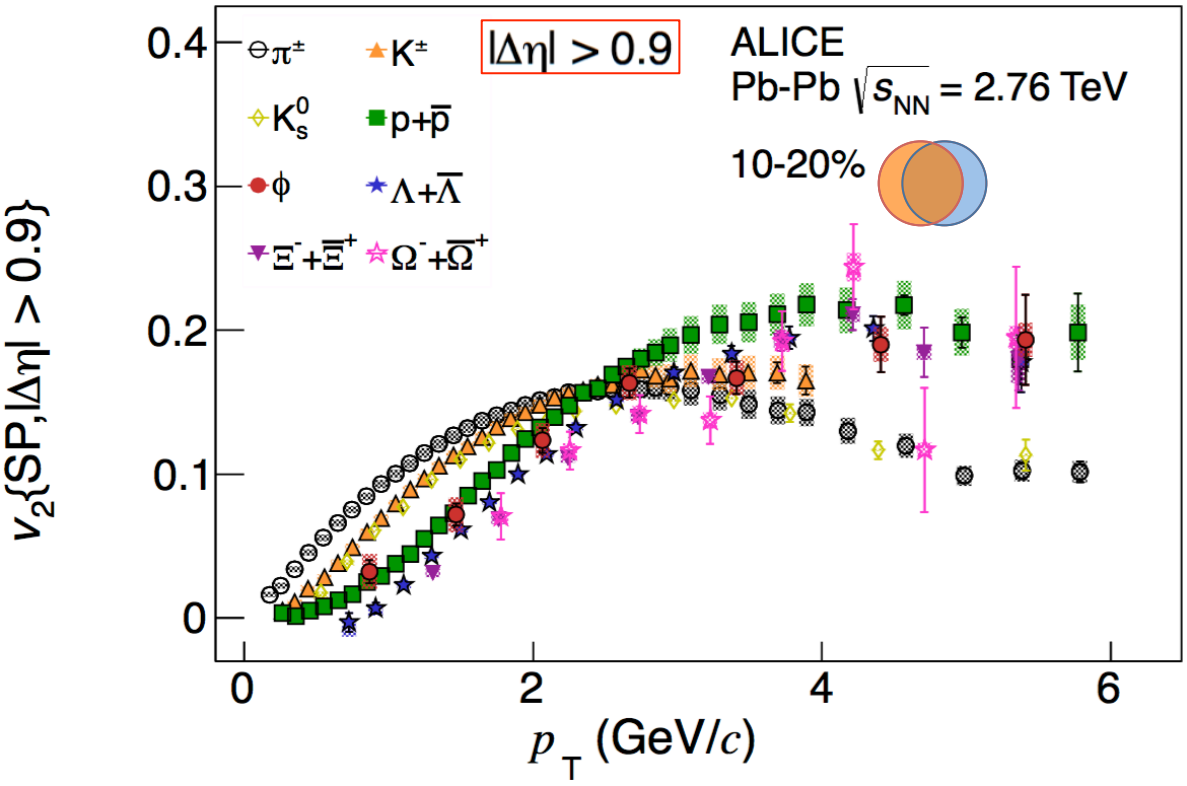
Phys Lett B 708 (2012) 249–264



"Double hump" structure – due to larger v_3 relative to v_2 in most central collisions.

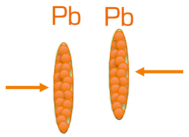
2

v_2 for **identified** particles versus p_T



ALICE

JHEP 06 (2015) 190

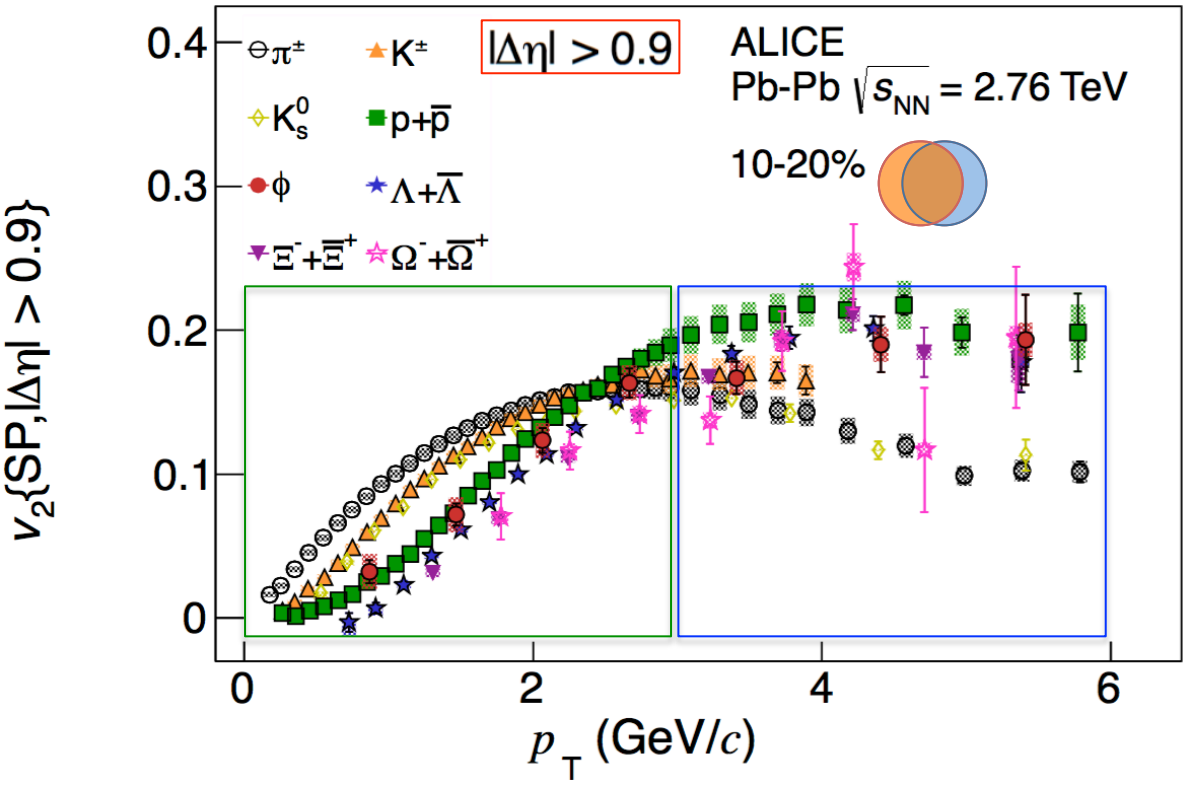


v_2 for π, $K^{\pm}$, p, K^0_s, Λ, Ξ and Ω:

- Mass ordering observed for many species
- Stronger in most central collisions → stronger radial flow
- Crossing between proton and pion v_2 around p_T~3 GeV/c
- Baryon/meson splitting persists out to high p_T

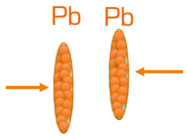
2

v_2 for **identified** particles versus p_T



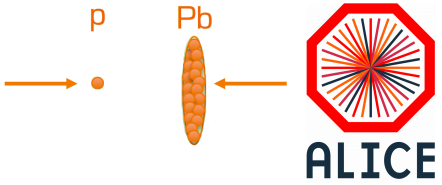
ALICE

JHEP 06 (2015) 190

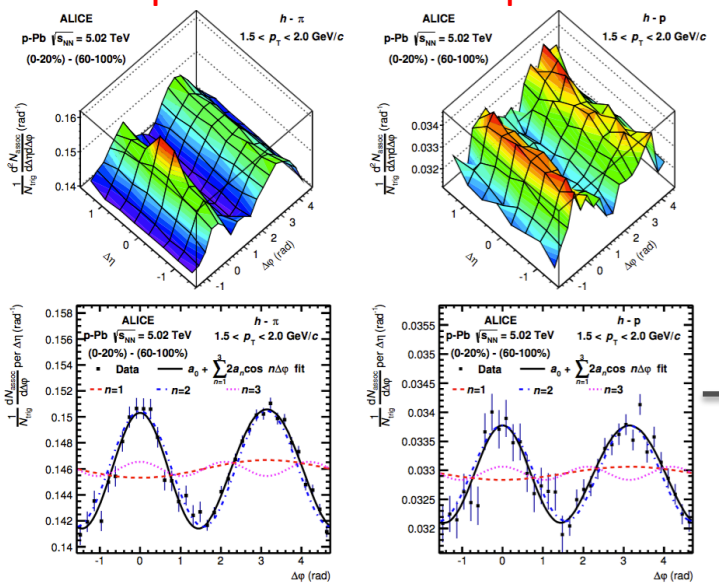


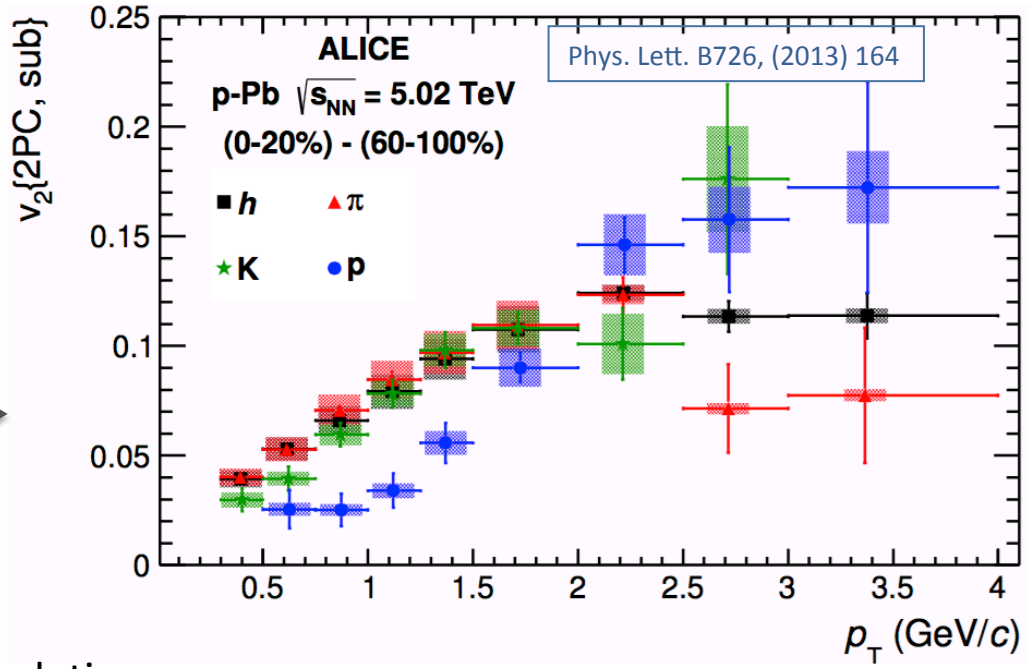
- Mass ordering at low p_T (p_T < 3 GeV/c): interplay between elliptic and radial flow
- Intermediate p_T (3 < p_T < 6 GeV/c): grouping based on type? (mesons/baryons)
  - puzzling behaviour of ϕ-meson

3 p-Pb also flows?



hadron-pions: hadron-protons:

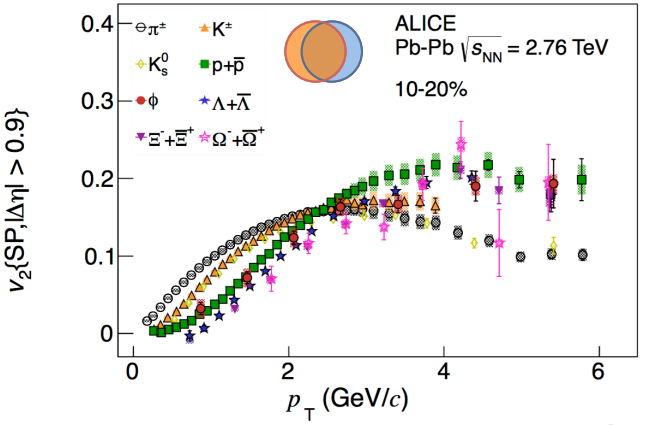




- v_2 was extracted from two-particle correlations after *subtraction* of correlations in low multiplicity events
- In high-multiplicity p–Pb collisions:
  - p_T<2 GeV/*c*: v_2 is larger for π than for protons
  - at p_T 3–4 GeV/*c*, v_2 for protons is higher than for π

Qualitatively similar picture in p-Pb as in Pb-Pb

→ Flow not only in A-A but also in smaller systems?



4 “Forward-central” two-particle correlations in p-Pb at $\sqrt{s_{NN}}$=5.02 TeV

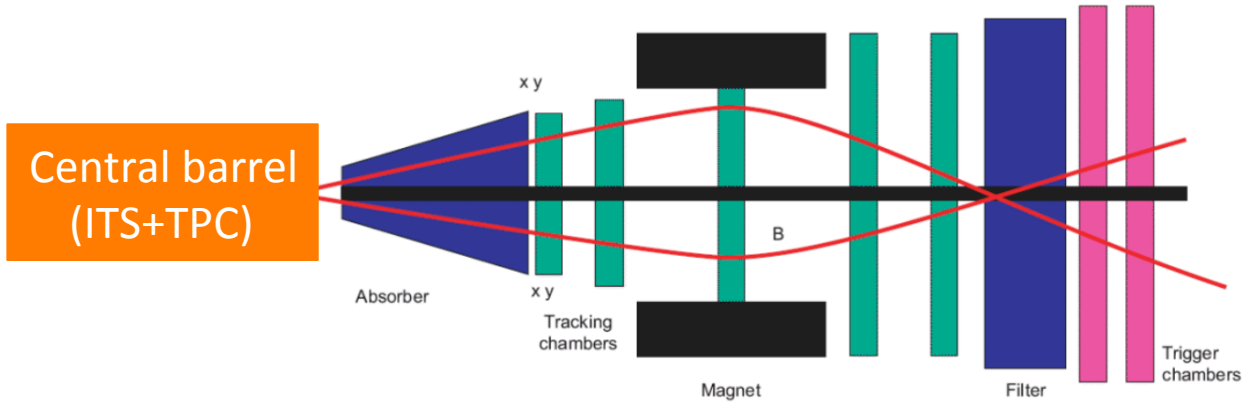
Further insight into the production mechanism of long-range correlation structures may be gained by studying their **η-dependence**.

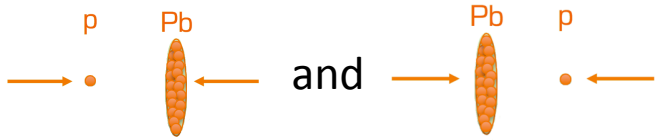
Phys. Lett. B 753 (2016) 126-139

trigger particles = inclusive **muons**: **$0.5 < p_T < 4$ GeV/c at $-4 < \eta < -2.5$**

associated particles = charged particles in ITS+TPC: **$|\eta| < 1$ at $0.5 < p_T < 4$ GeV/c**

(or “tracklets” in SPD: p_T >~ 50 MeV/c)



- Beam directions:  and

- Reconstructed muons mainly originate from weak decays of π, K and mesons from heavy flavor (HF) decays.
- Associated yield per trigger muon: $Y = \frac{1}{N_{\mathrm{trig}}} \frac{\mathrm{d}^2 N_{\mathrm{assoc}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\varphi} = \frac{S(\Delta\eta, \Delta\varphi)}{B(\Delta\eta, \Delta\varphi)}$

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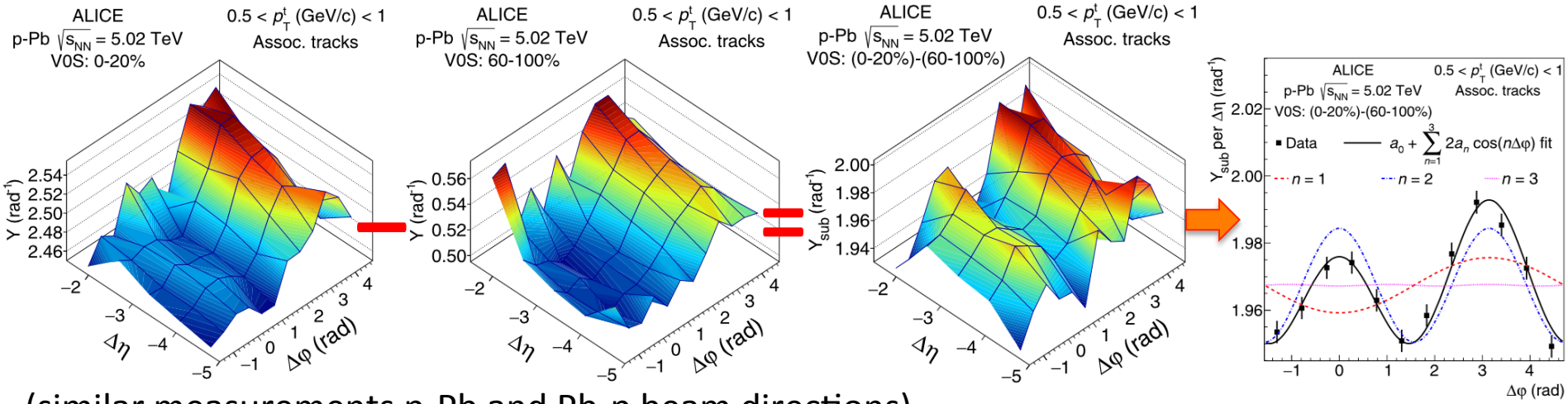
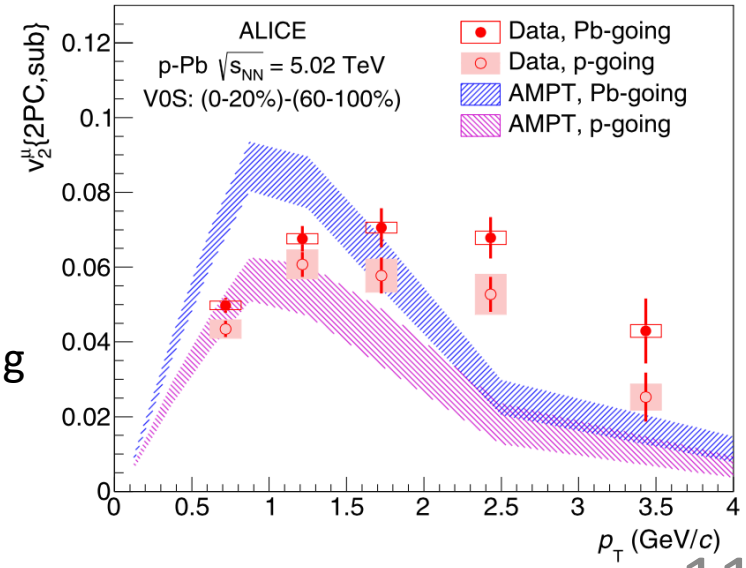


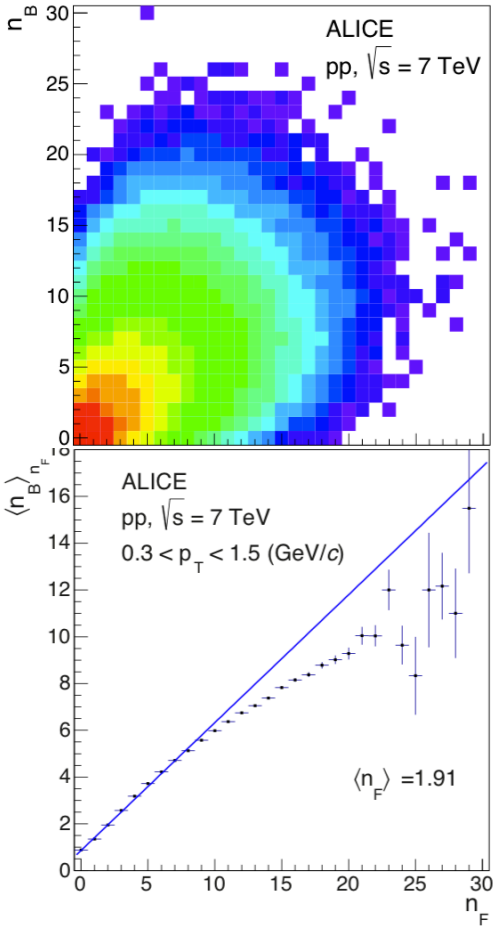
(similar measurements p-Pb and Pb-p beam directions)

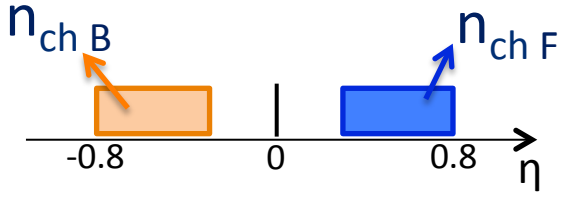
Assume factorization: $v_2^{\mu}(2\mathrm{PC},\mathrm{sub}) = V_{2\Delta}^{\mu,c} / \sqrt{V_{2\Delta}^{c,c}}$



- **ridge extends up to |Δη|=5 and |η|~4**
- it decreases from η = −1.5 to η = −5.0
- **Pb-going** coefficients **larger by 16 ± 6%** than p-going
- comparison with AMPT: similar behavior at low p_T

5 Forward-Backward multiplicity correlations in p p





Correlation strength is extracted by linear regression:

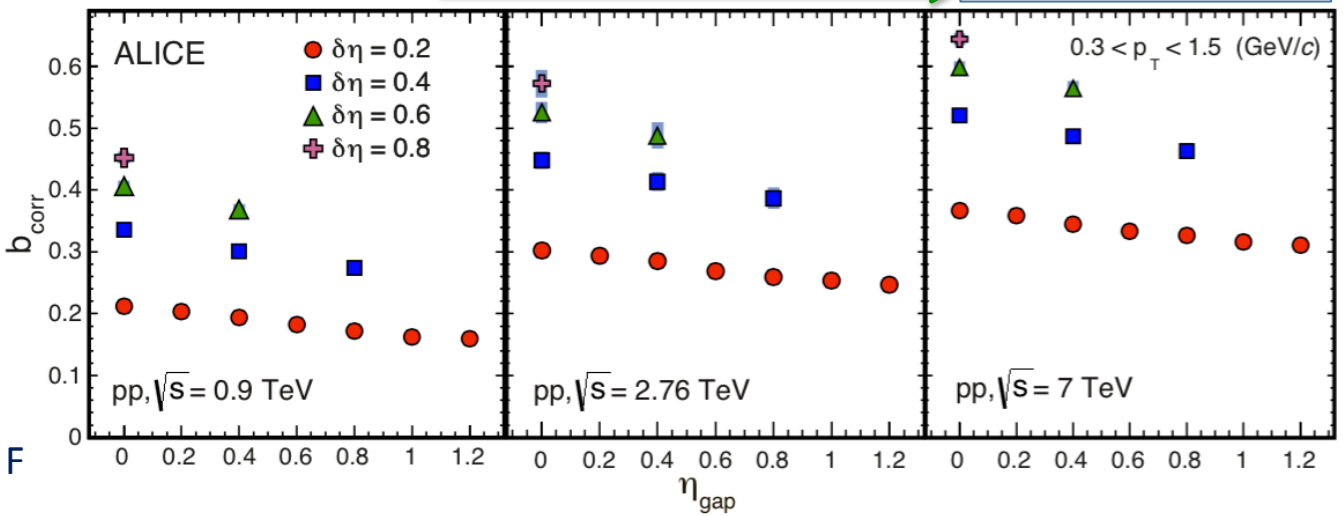
$$\langle n_B \rangle_{n_F} = a + b_{corr} \cdot n_F$$

Alternative definition:

$$b_{corr} = \frac{\langle n_B n_F \rangle - \langle n_B \rangle \langle n_F \rangle}{\langle n_F^2 \rangle - \langle n_F \rangle^2}$$

higher energy

JHEP 1505 (2015) 097

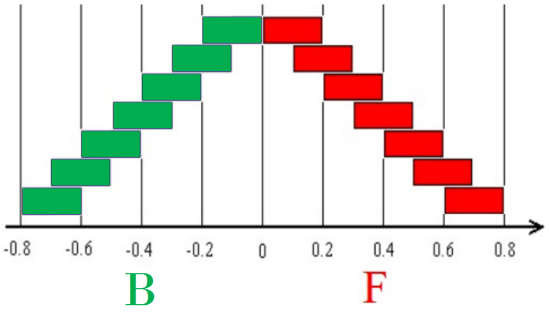


- correlation coefficient b_{corr} drops with η gap
- values of b_{corr} increase with collision energy

FB multiplicity correlations in separated η and φ windows

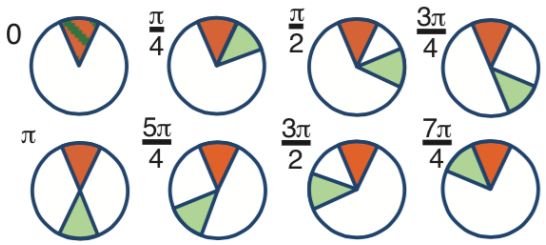
JHEP 1505 (2015) 097

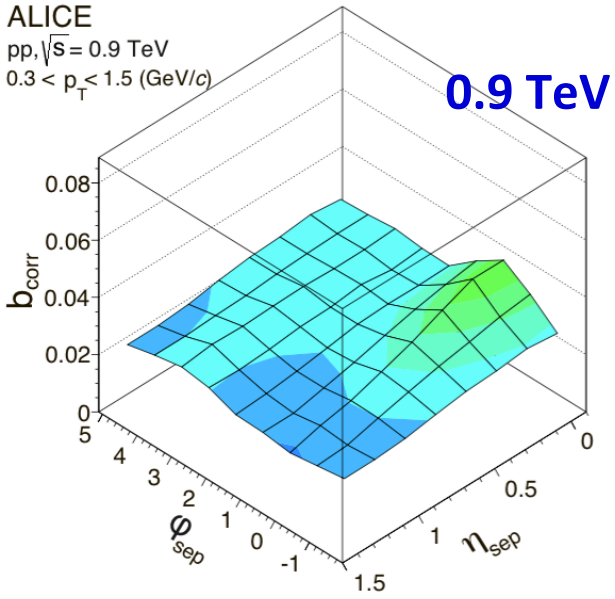
η windows

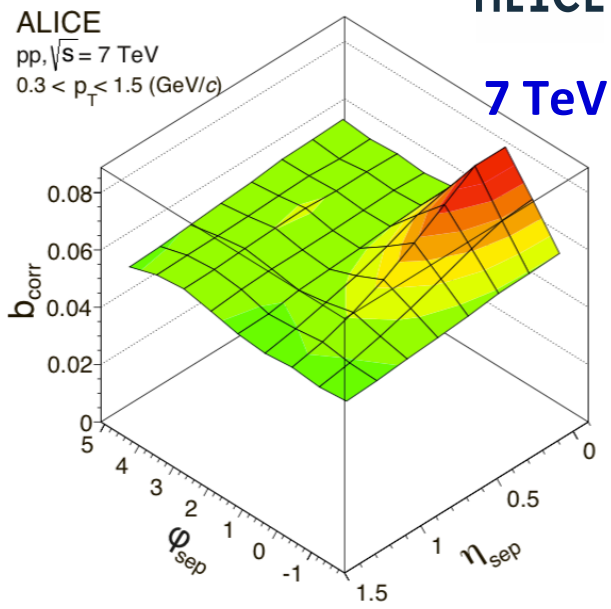


+

φ windows







δη=0.2, δϕ=π/4

Extension of FB multiplicity correlations study into *azimuthal dimension* provides additional insight into particle production mechanisms

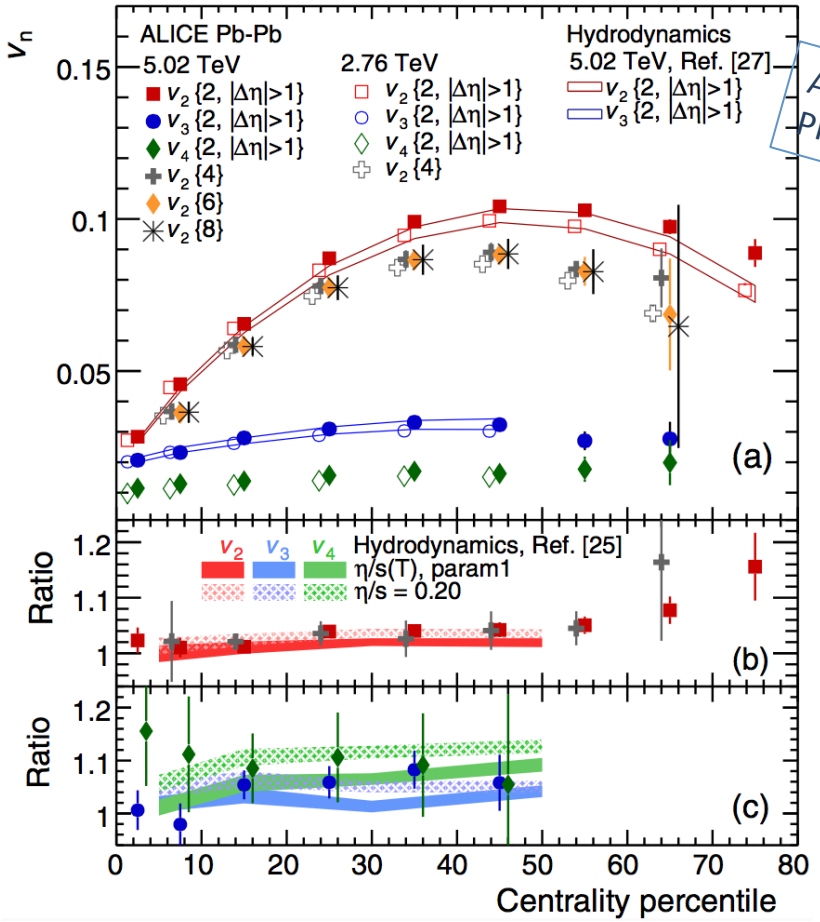
- short-range and long-range contributions are distinguishable
- non-zero plateau is observed and increases with the energy
- can be interpreted by simple model of independent particle emitters

V.V. Vechernin, *Nucl.Phys. A939 (2015) 21*, arXiv:1210.7588

Anisotropic Flow of Charged Particles in Pb-Pb at $\sqrt{s_{NN}}$=5.02 TeV

Methods: two- and multiparticle cumulants: $v_n\{2, |\Delta\eta| > 1\}$, $v_n\{4\}$, $v_n\{6\}$, $v_n\{8\}$

Integrated flow



April 1, 2016
PRL 116, 132302

- Increase in integrated flow at 5.02 *wrt* 2.76 TeV:
  v_2~ 3%, v_3~ 4%, v_4~ 10%

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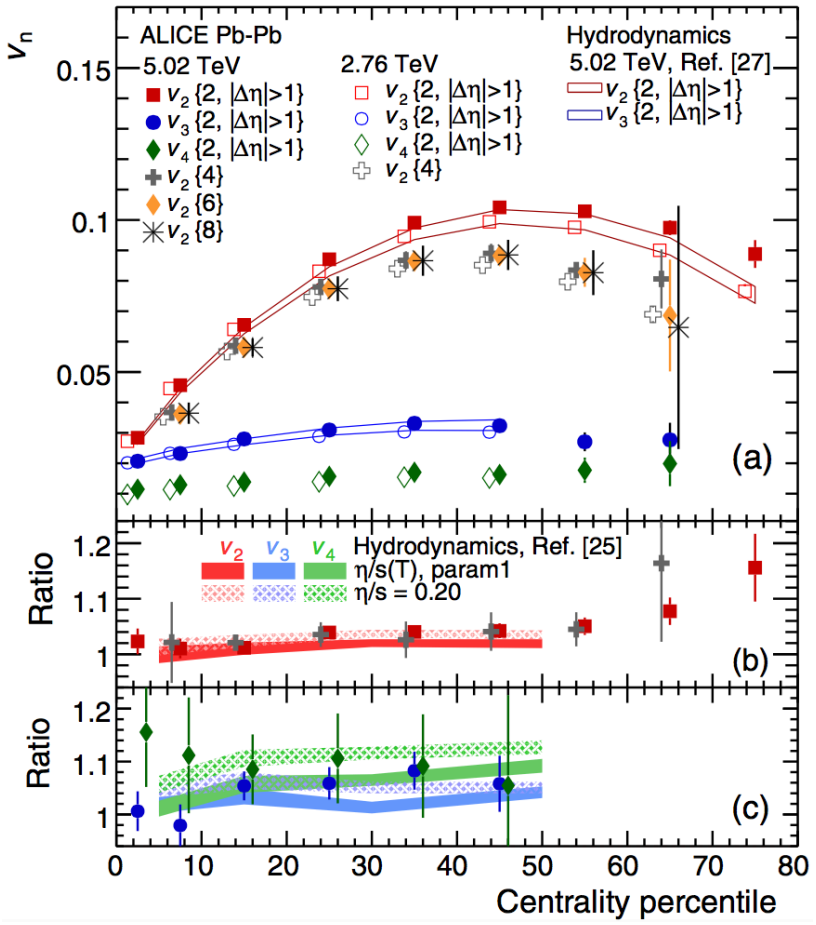

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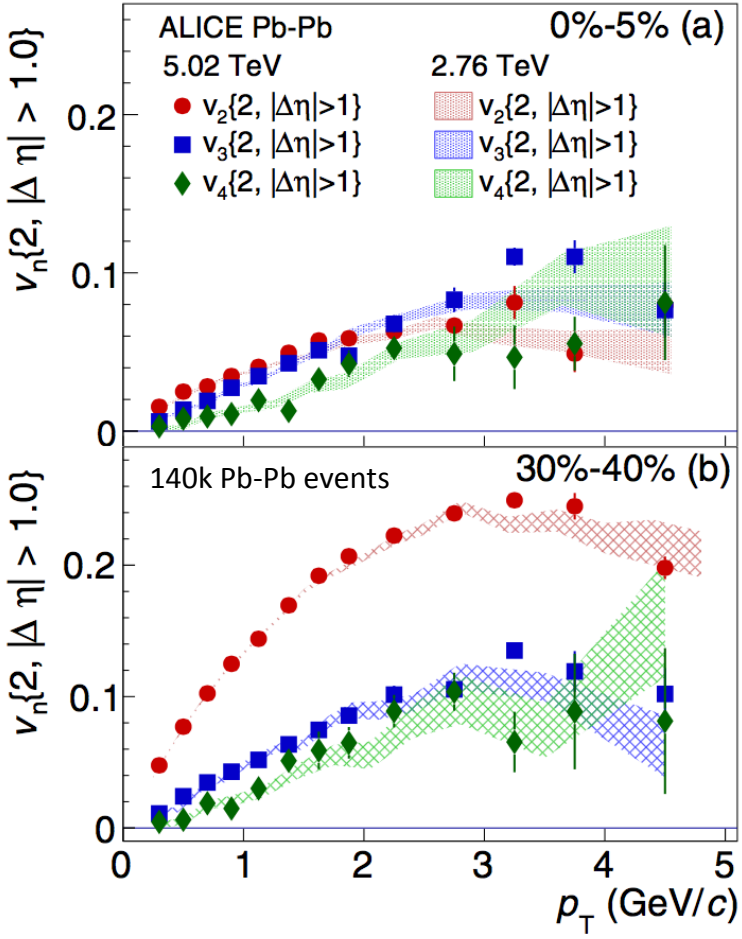
Differential flow



- Similar $v_n(p_T)$ at 5.02 and 2.76 TeV

→ Growth of integrated flow is mostly due to increase in $\langle p_T \rangle$

Summary

Long-range correlations are being studied at ALICE in pp, p-Pb, Pb-Pb by several analysis methods.

- Anisotropic flow in **Pb-Pb** with large Δη: clear **mass ordering** at low p_T<2 GeV/*c*
  → consistent with the picture of hydrodynamic expansion of the medium
- **p-Pb** collisions: similar features for v_2 and v_3 as in Pb-Pb
  → **flow in small systems**?
- Muon-hadron correlations in p-Pb: long-range double ridge **up to Δη≈ 5**
- Forward-backward correlations in **pp**: sensitivity to fluctuations in number and properties of particle sources (strings)

- Very moderate increase of anisotropic integrated flow from 2.76 to 5.02 TeV

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Many interesting results are not covered here (two-particle correlations with PID, flow measurements with D-mesons and electrons, etc.)

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- Upcoming results from LHC Run-2 (pp 13 TeV, Pb-Pb 5.02 TeV, p-Pb 5.02 and 8 TeV).

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Thank you for your attention!