Flow
selected topics

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Czech Technical University in Prague

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EVROPSKÁ UNIE
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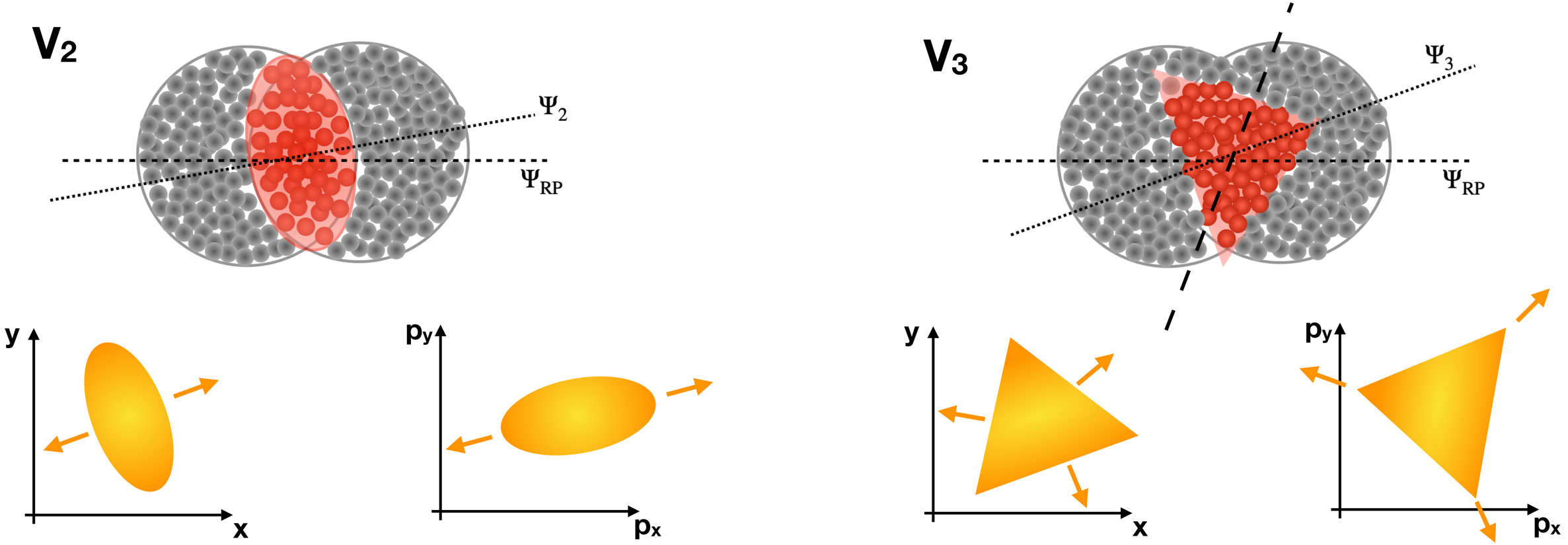
MINISTERSTVO ŠKOLSTVÍ, MLÁDEŽE A TĚLOVÝCHOVY

Introduction

flow vector $$V_n = v_n e^{in\Psi_n}$$

flow magnitude

flow angle: azimuth of V_n in momentum space



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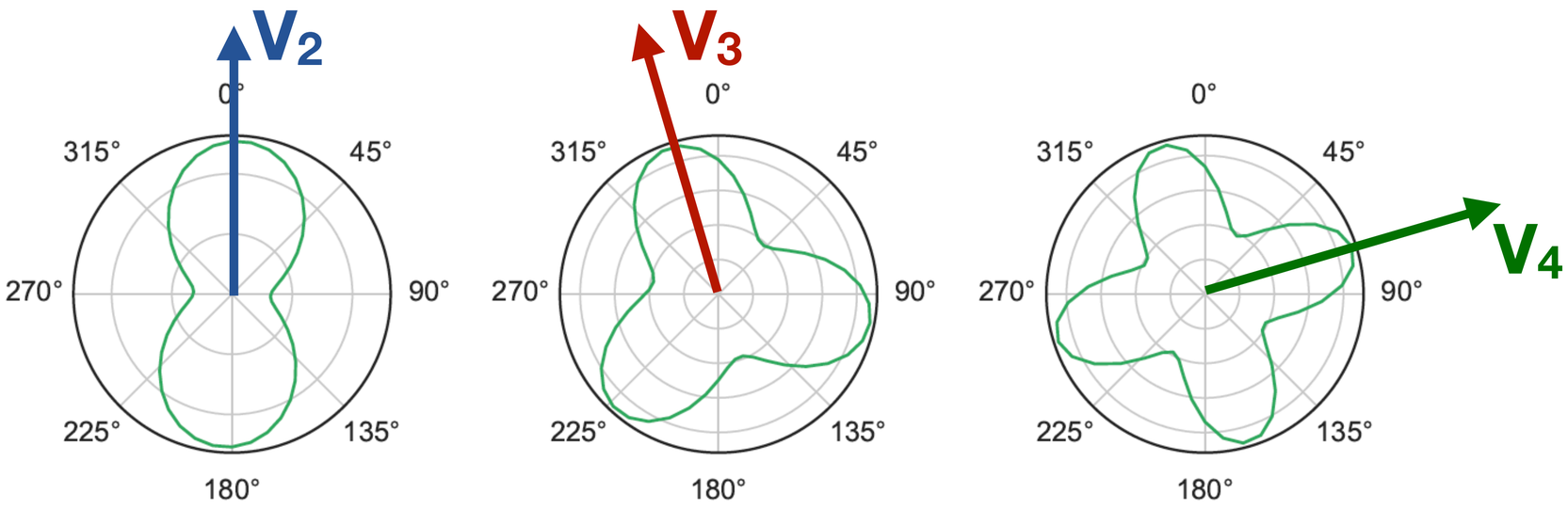

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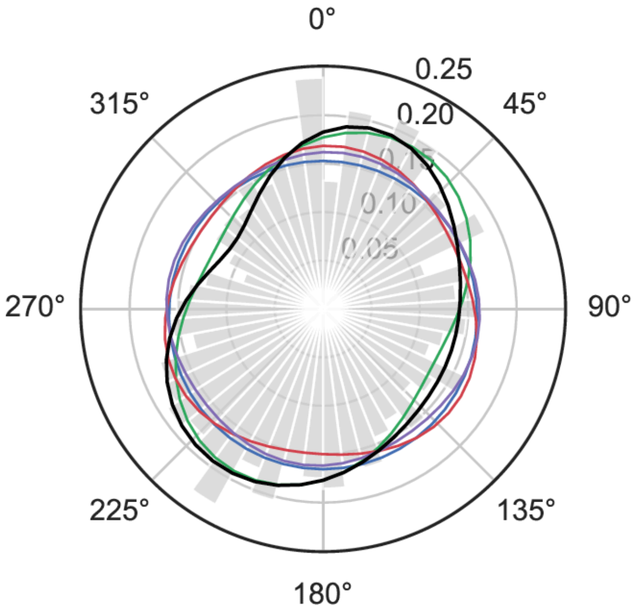

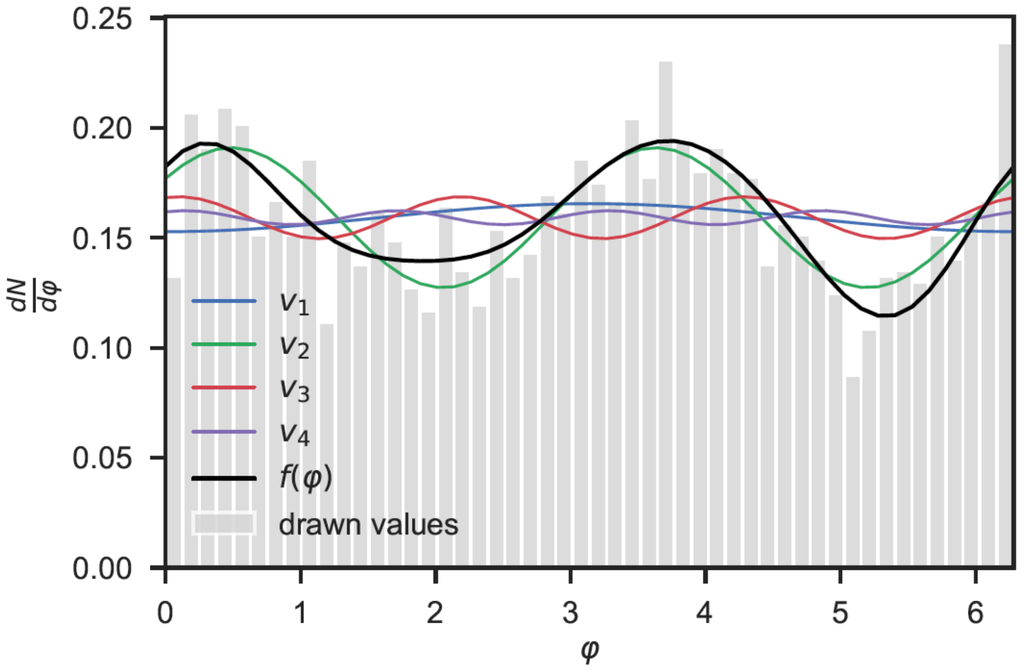

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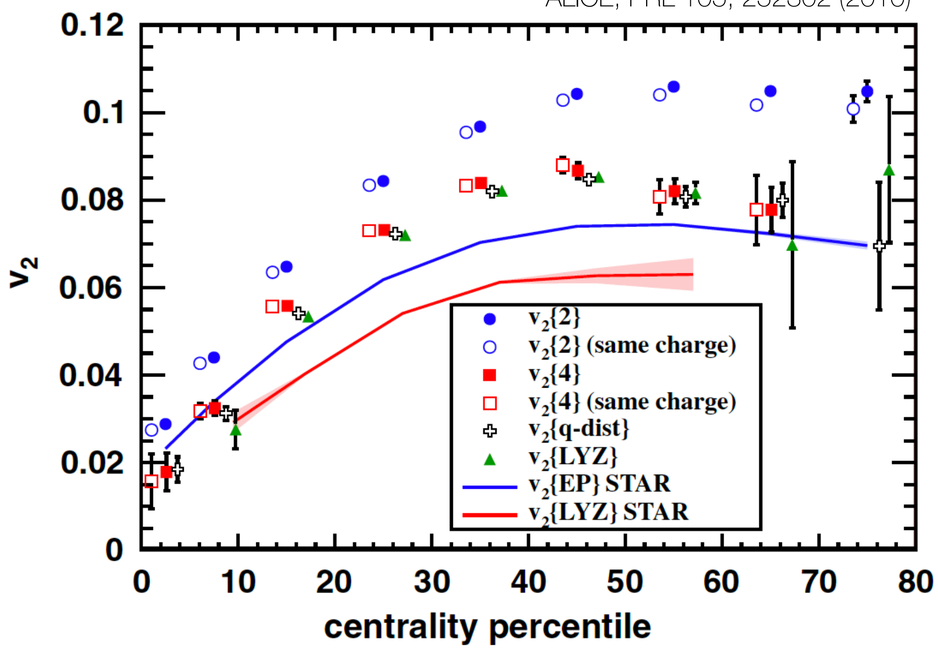
- As a function of:
  - centrality
  - p_T
  - pseudorapidity η
  - different collision systems

ALICE, PRL 105, 252302 (2010)



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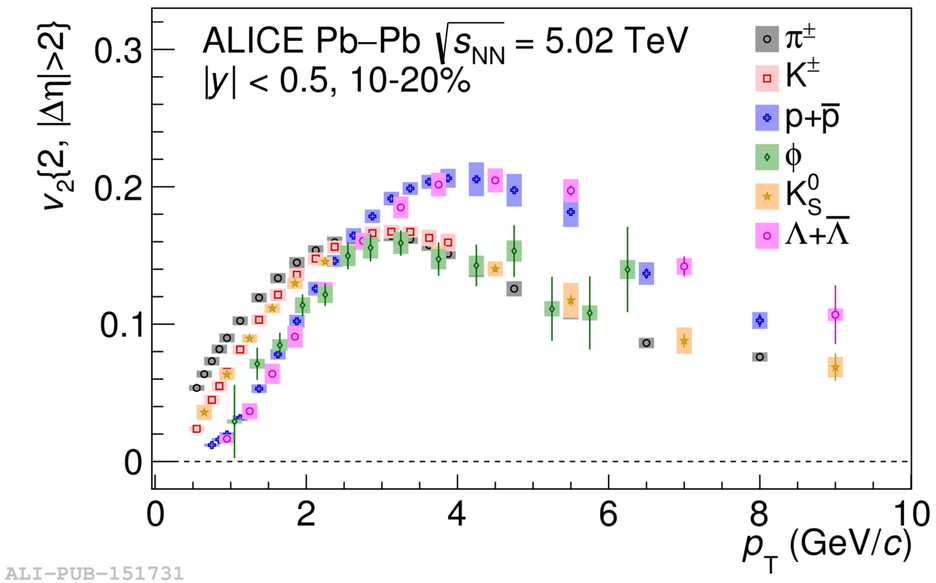

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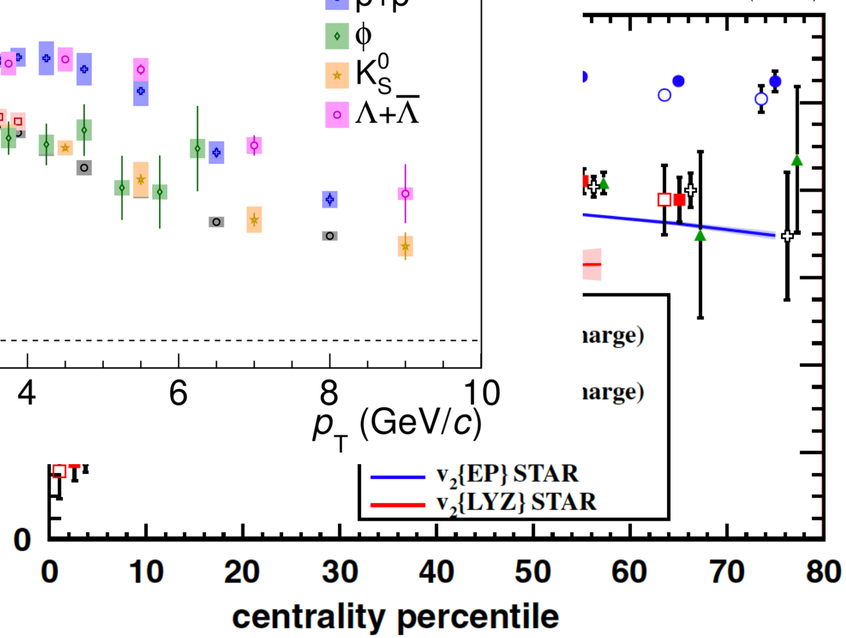

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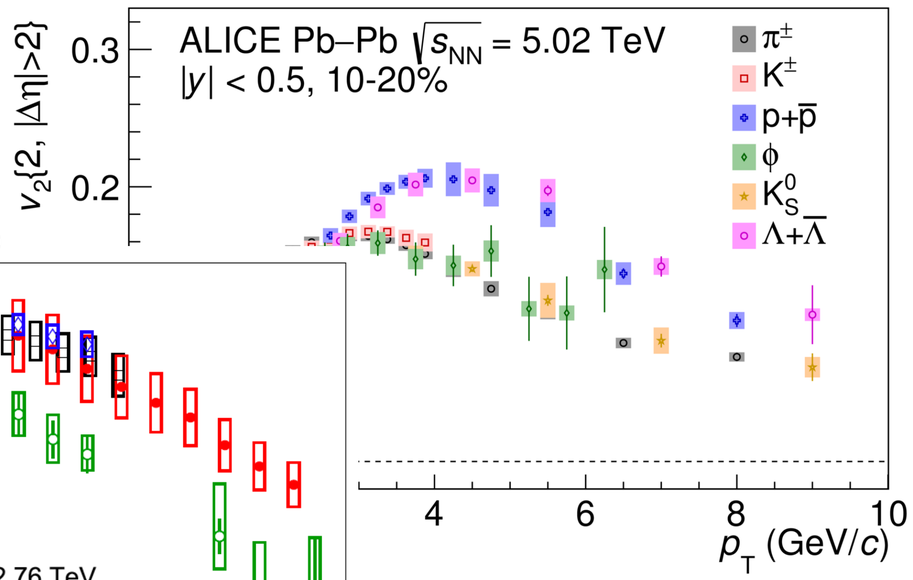
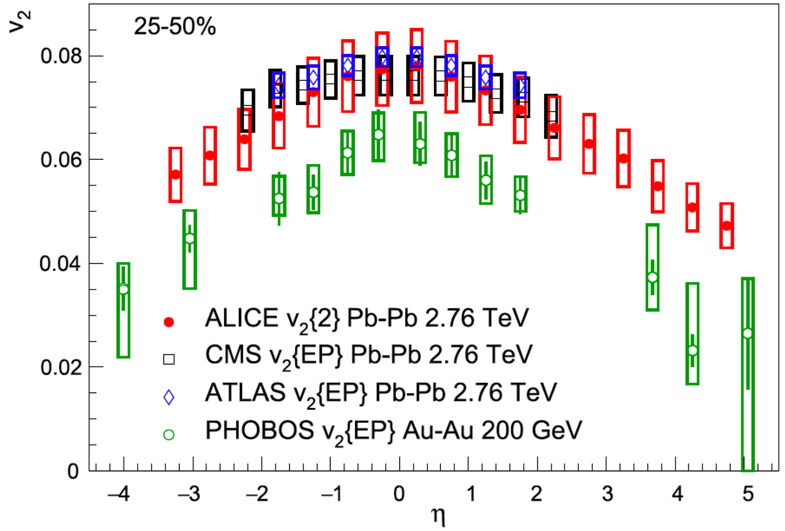


ALICE, PLB 762, 376 (2016)



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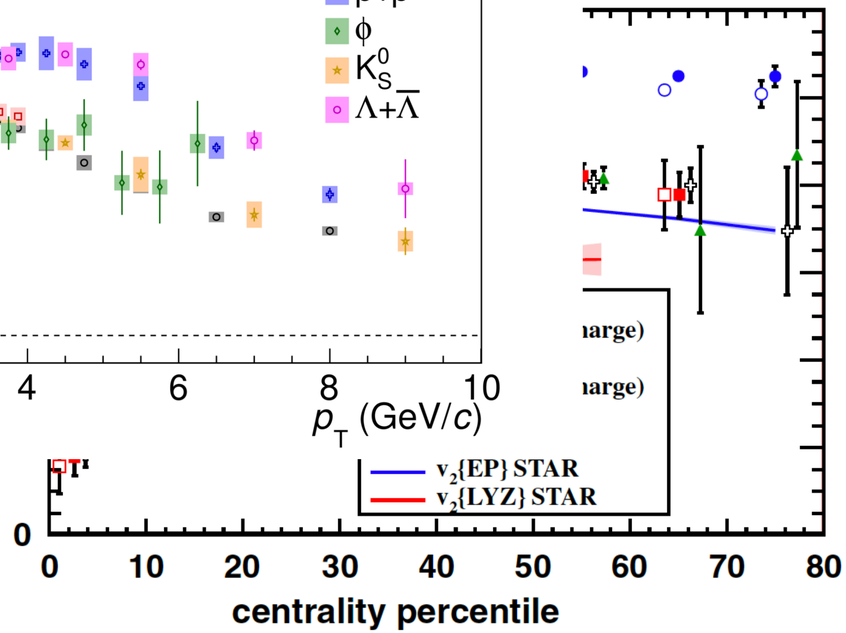

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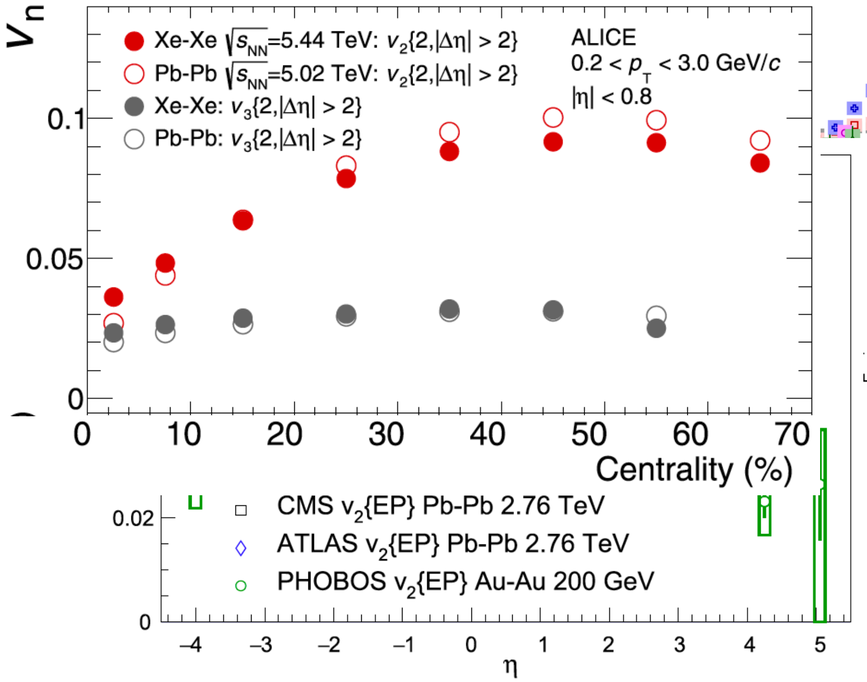
ALICE, PLB 784, 82 (2018)



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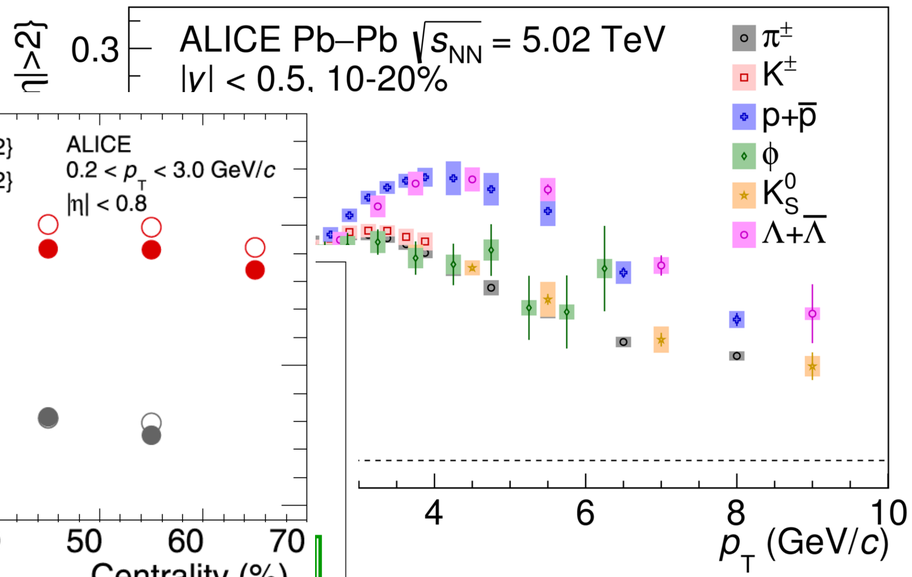

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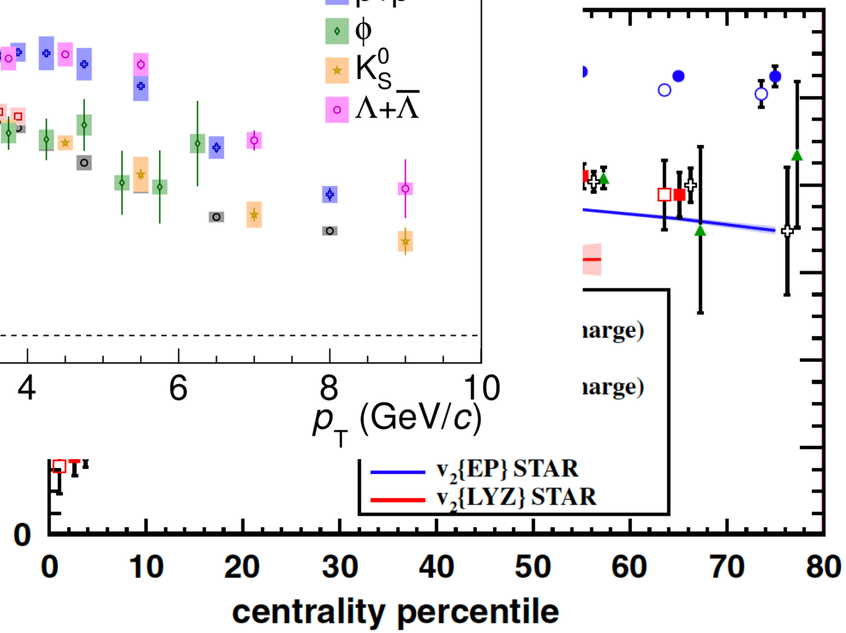
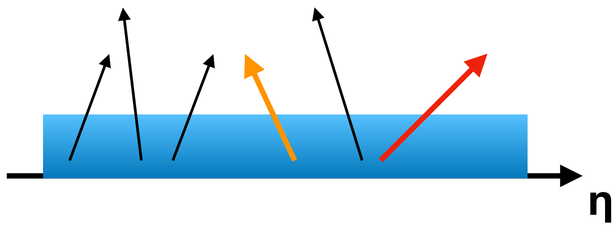


How we measure flow

$$v_n = \langle \cos \mathrm{n}(\varphi - \Psi_\mathrm{n}) \rangle$$



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$$\langle\langle 2 \rangle\rangle = \langle\langle \cos \mathrm{n}(\varphi_1 - \varphi_2) \rangle\rangle = \langle \mathrm{v}_\mathrm{n}^2 \rangle$$

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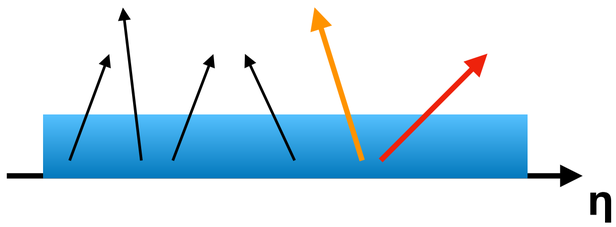

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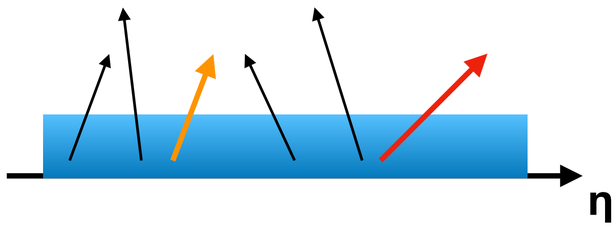

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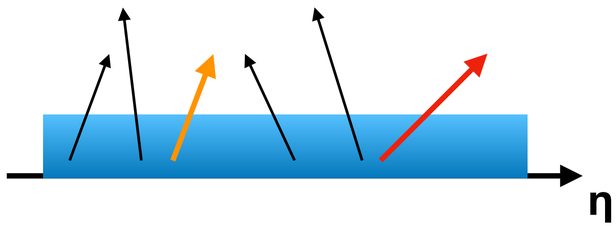

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- And correlations of higher orders ….

$$\langle\langle 4 \rangle\rangle = \langle\langle \cos \mathrm{n}(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4) \rangle\rangle = \langle \mathrm{v}_\mathrm{n}^4 \rangle$$

$$v_n\{4\} = \sqrt[4]{2\langle\langle 2 \rangle\rangle^2 - \langle\langle 4 \rangle\rangle}$$

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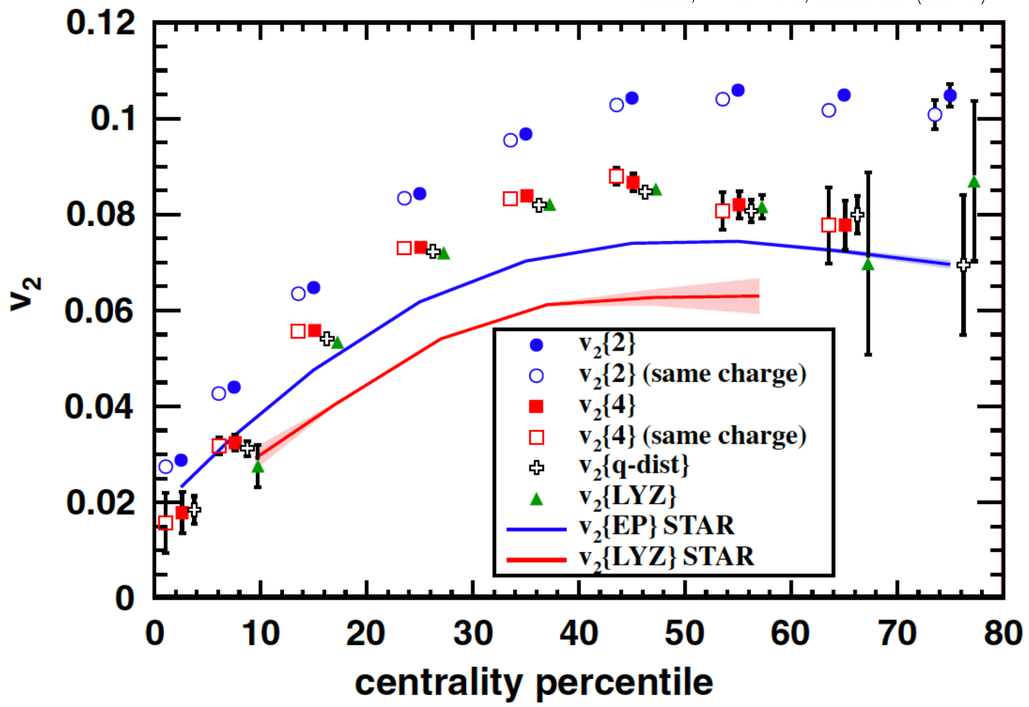

Flow in small systems

- Collisions of small systems with large multiplicities surprisingly exhibit flow-like patterns, only seen in AA collisions and understood as a manifestation of collective flow of a hot and dense medium
  - Investigated via measurements of azimuthal correlations (similarly as in AA collisions)

See talk of Daniel Mihatsch @ 11:20

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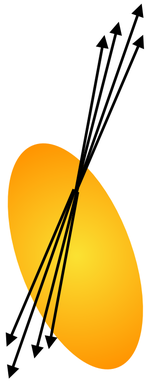

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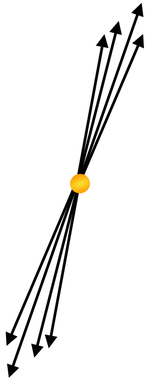

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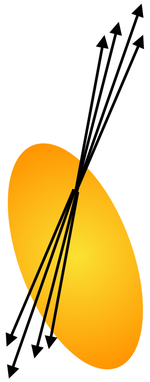

can we still safely do correlations ?

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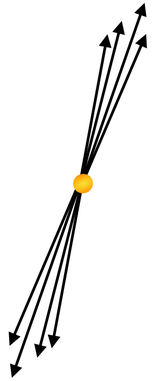
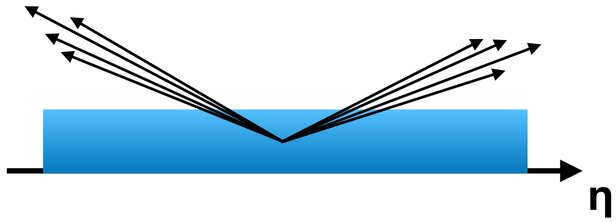


Subevent method

$$\langle \cos n(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4) \rangle$$



we include whole jet in correlations

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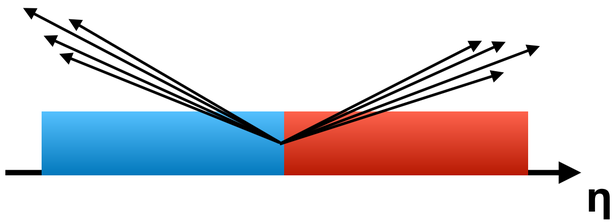

we do not correlate particles from the same jet cone
but we still correlate particles from opposite jet cones

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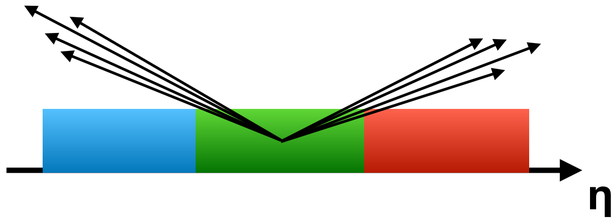

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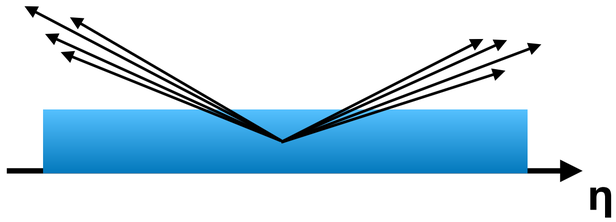

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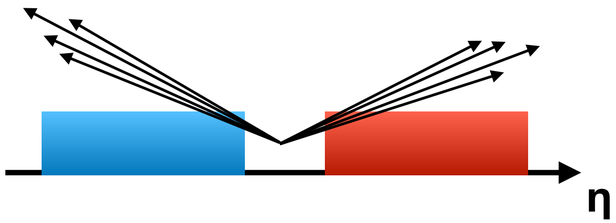

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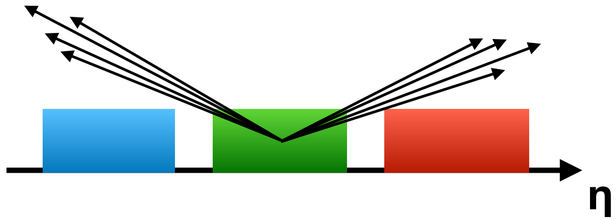

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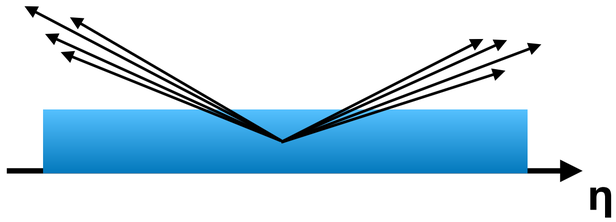

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the larger the η gap, the better suppression of non-flow

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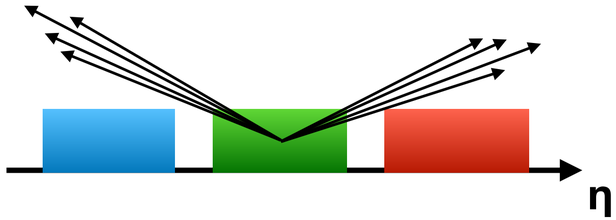

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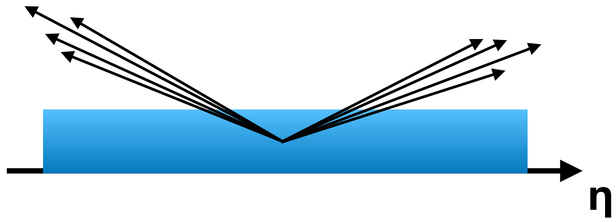

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Not necessarily true

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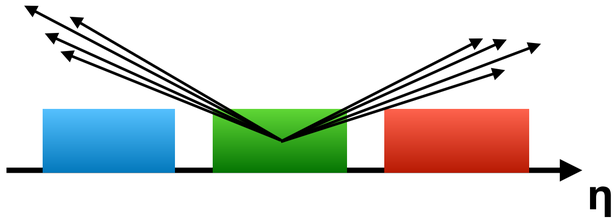

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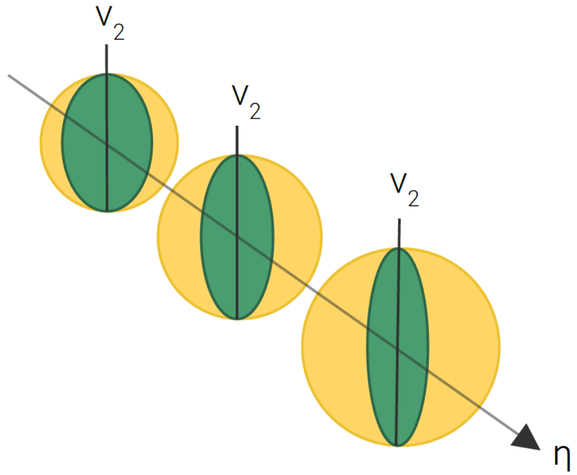
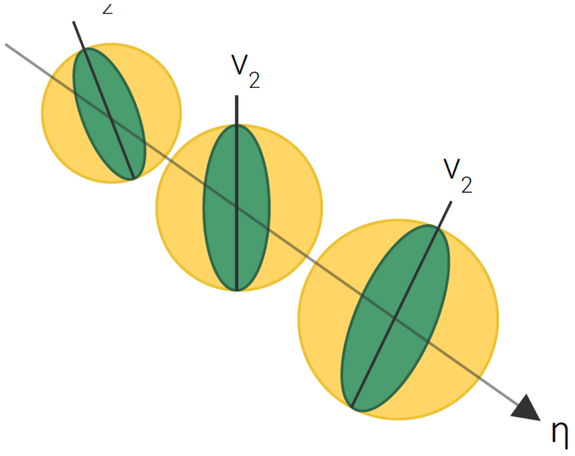
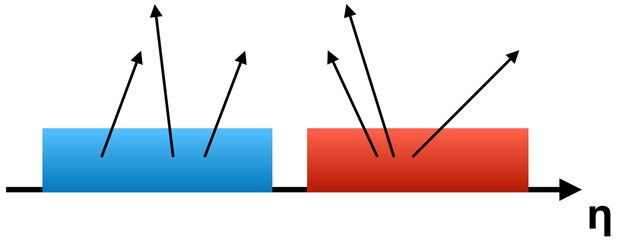
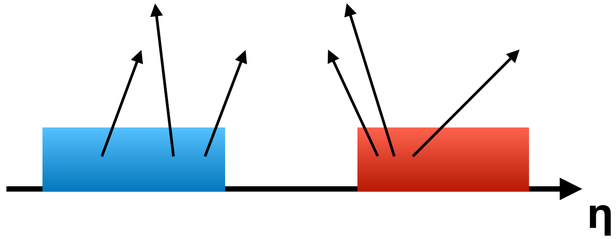




- Flow vector fluctuates in p_T and η
  - Flow magnitude fluctuations
  - Flow angle fluctuations
- Fluctuations in η (=longitudinal fluctuations) pose a danger to the subevent method



<u>small η gap:</u>
large non-flow
small decorrelation



<u>large η gap:</u>
small non-flow
large decorrelation

Flow vector decorrelations

- Interesting measurements due to their link to the event-by-event fluctuations of the initial energy density (distribution of the participating nucleons in the initial overlap region)
  - Found by hydrodynamic calculations

- Interesting measurements for theorists
  - Allows to constrain 3D modelling of the evolution of a heavy-ion collision

Flow vector decorrelations

η - dependent flow vector fluctuations

$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$

measures relative flow angle fluctuations

$$r_n(\eta^a,\eta^b) = \frac{\langle v_n(-\eta^a)v_n(\eta^b)\cos\{n[\Psi_n(-\eta^a)-\Psi_n(\eta^b)]\}\rangle}{\langle v_n(\eta^a)v_n(\eta^b)\cos\{n[\Psi_n(\eta^a)-\Psi_n(\eta^b)]\}\rangle}$$

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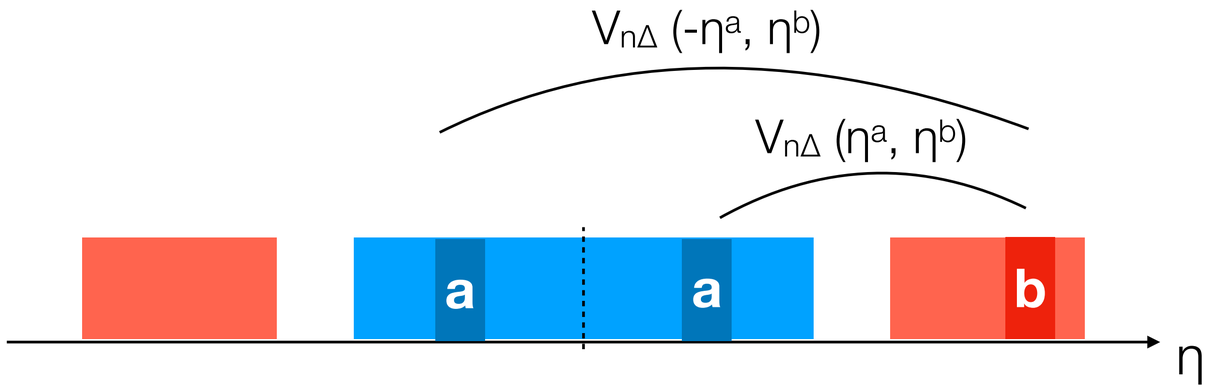
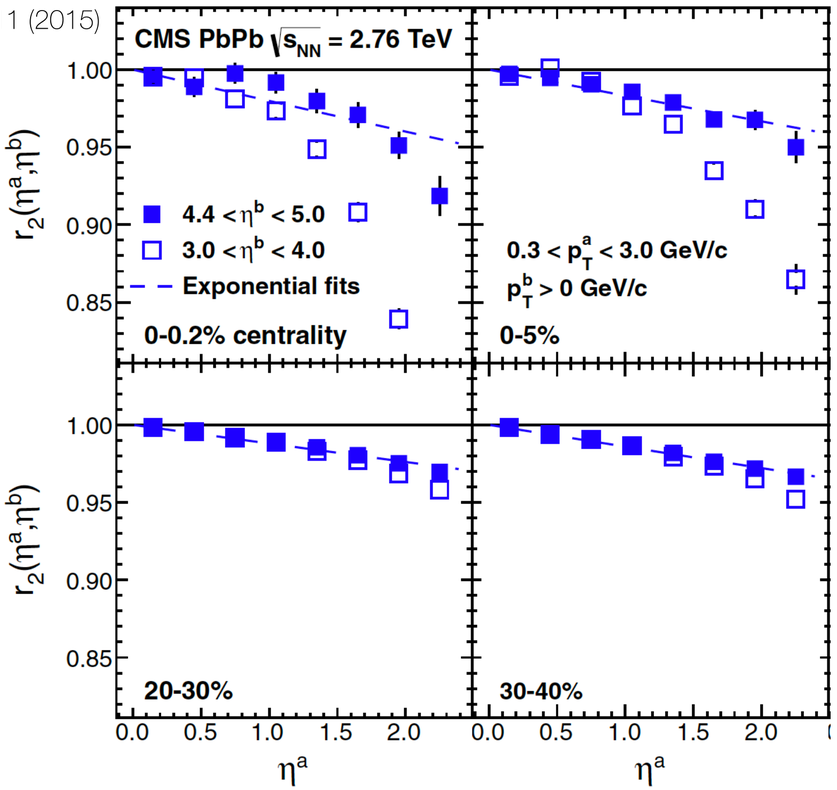


Flow vector decorrelations

CMS, PRC 92, 034911 (2015)



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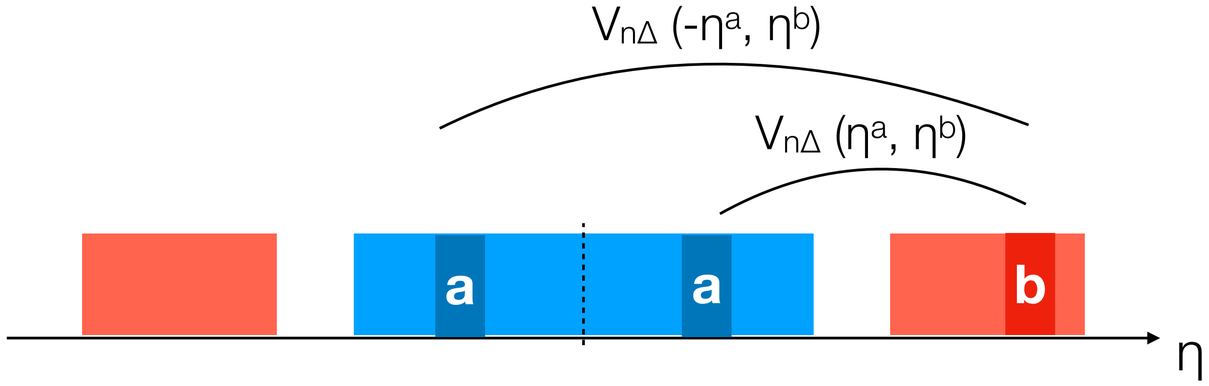

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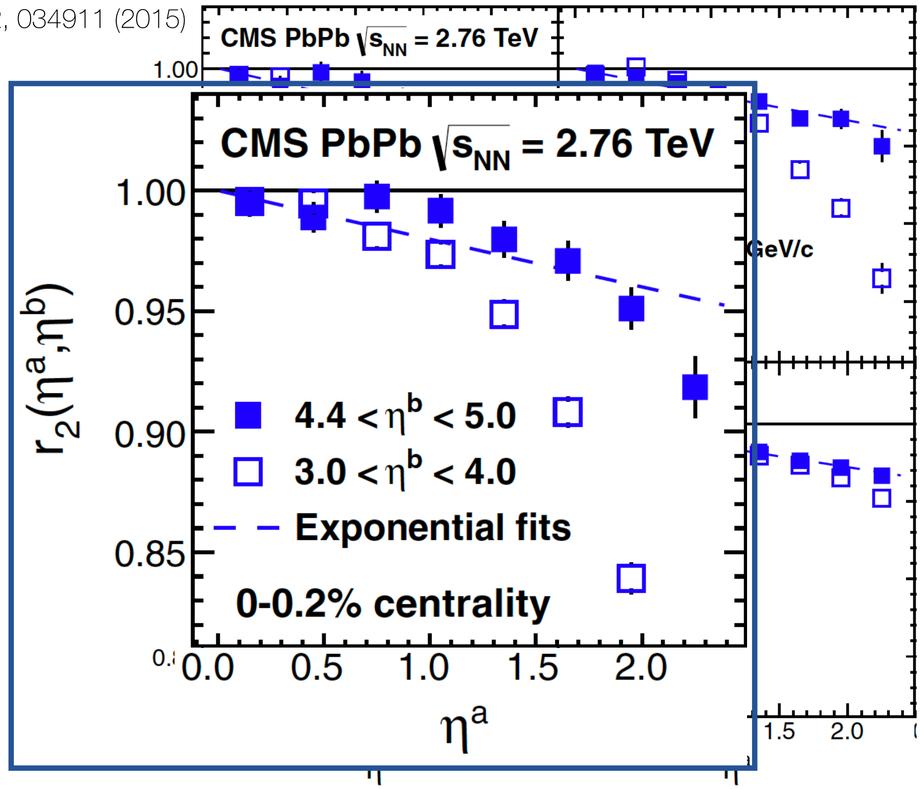
CMS, PRC 92, 034911 (2015)



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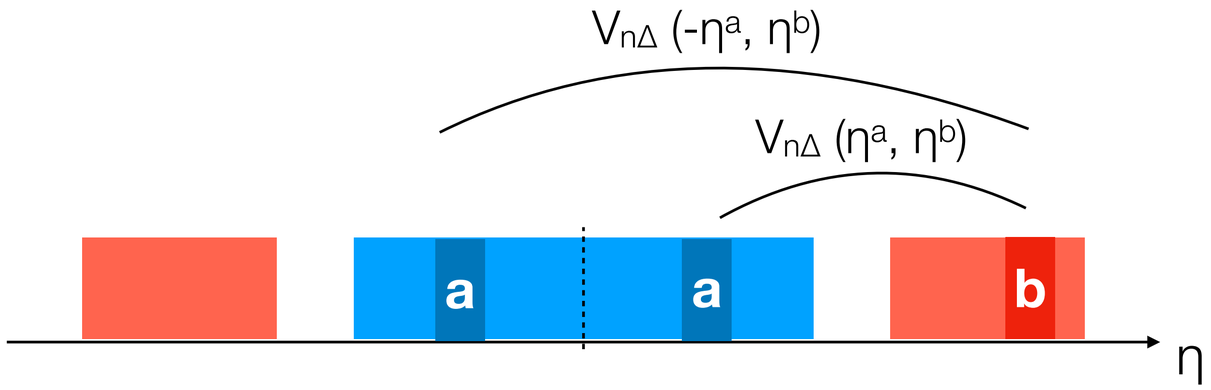
$$r_n(\eta^a,\eta^b) \equiv \frac{V_{n\Delta}(-\eta^a,\eta^b)}{V_{n\Delta}(\eta^a,\eta^b)}$$

measures relative flow angle fluctuations

$$r_n(\eta^a,\eta^b) = \frac{\langle v_n(-\eta^a)v_n(\eta^b)\cos\{n[\Psi_n(-\eta^a)-\Psi_n(\eta^b)]\}\rangle}{\langle v_n(\eta^a)v_n(\eta^b)\cos\{n[\Psi_n(\eta^a)-\Psi_n(\eta^b)]\}\rangle}$$

$r_n = 1$ … no fluctuations $\Psi_n(\eta^a) = \Psi_n(\eta^b)$

$r_n < 1$ … fluctuations $\Psi_n(\eta^a) \neq \Psi_n(\eta^b)$



Decorrelations in small systems

- It is desirable to measure such observables in small systems

- If they indeed develop a hydrodynamic flow, then they should also exhibit flow vector decorrelations
  - We would expect stronger decorrelation because small systems are dominated by initial state fluctuations rather than the overall geometry

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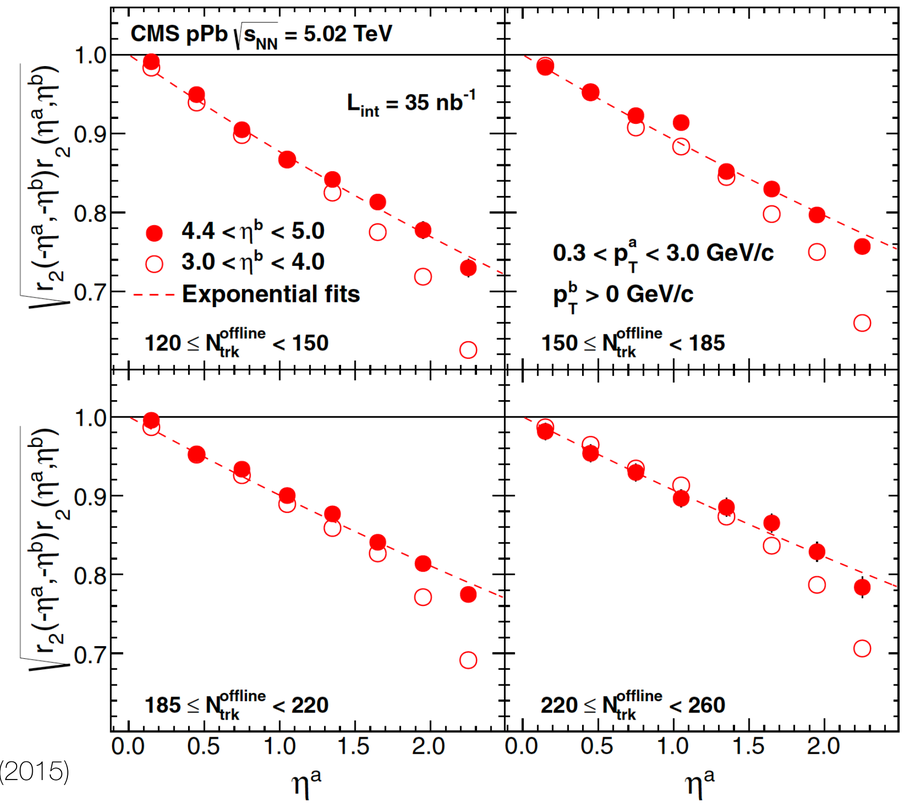
- So far only measured by CMS in p-Pb collisions

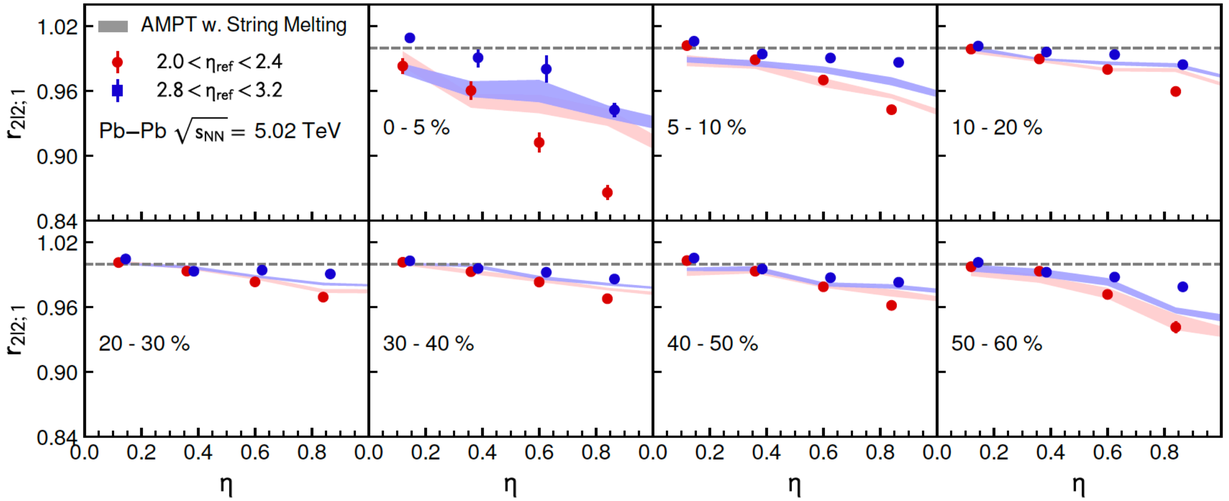


CMS, PRC 92, 034911 (2015)

Flow vector decorrelations with MFT?

What we already measured

- ALICE measured this using the “old” detector set-up in Pb-Pb collisions (paper in preparation now)
  - Used the TPC + FMD, which didn’t have tracking, measurements were affected by large contamination from secondaries



What we could measure in the future

- Decorrelations in AA collisions using the new MFT detector
- Decorrelations in small systems (including pp ?)

Summary

- Stay tuned for the (hopefully) exciting new results in Run 3 :)

Subevent method

$$\langle \cos n(\varphi_1 + \varphi_2 - \varphi_3 - \varphi_4) \rangle$$

$\langle \cos n$

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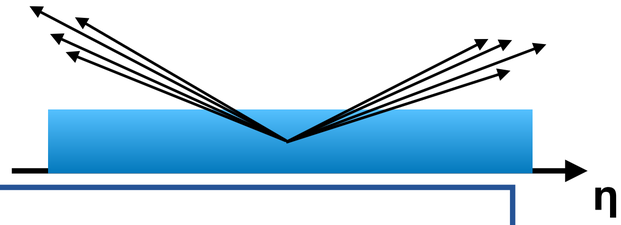

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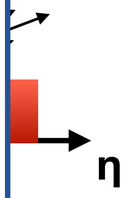
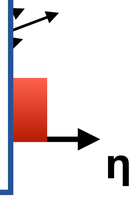
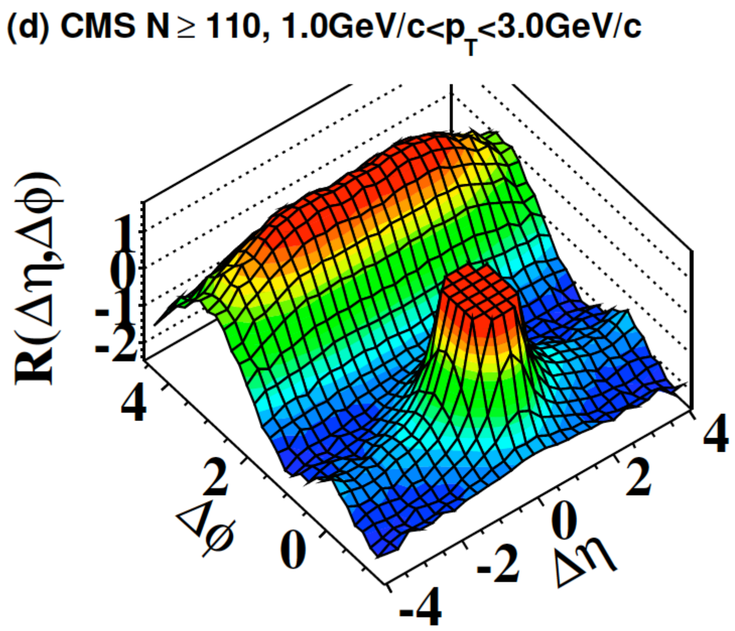


same jet cone
posite jet cones



Side note



This eta gap is **not** the same
as in di-hadron correlation measurements

Di-hadron correlations (left):
eta separation between two particles

Subevent method:
eta separation between two detector regions

we do not correlate particles from the same jet cone
nor from opposite jet cones

Flow vector decorrelations

p_T - dependent flow vector fluctuations

$$r_n\left(p_{\mathrm{T}}^a, p_{\mathrm{T}}^b\right) \equiv \frac{V_{n\Delta}\left(p_{\mathrm{T}}^a, p_{\mathrm{T}}^b\right)}{\sqrt{V_{n\Delta}\left(p_{\mathrm{T}}^a, p_{\mathrm{T}}^a\right) V_{n\Delta}\left(p_{\mathrm{T}}^b, p_{\mathrm{T}}^b\right)}}$$

$$r_n\left(p_{\mathrm{T}}^a, p_{\mathrm{T}}^b\right) = \frac{\left\langle v_n\left(p_{\mathrm{T}}^a\right) v_n\left(p_{\mathrm{T}}^b\right) \cos\left\{n\left[\Psi_n\left(p_{\mathrm{T}}^a\right) - \Psi_n\left(p_{\mathrm{T}}^b\right)\right]\right\}\right\rangle}{\sqrt{\left\langle v_n^2\left(p_{\mathrm{T}}^a\right)\right\rangle \left\langle v_n^2\left(p_{\mathrm{T}}^b\right)\right\rangle}}$$

$r_n = 1$ … no fluctuations $\Psi_n(p_T^a) = \Psi_n(p_T^b)$

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Flow vector decorrelations

ALICE, JHEP 09, 032 (2017)

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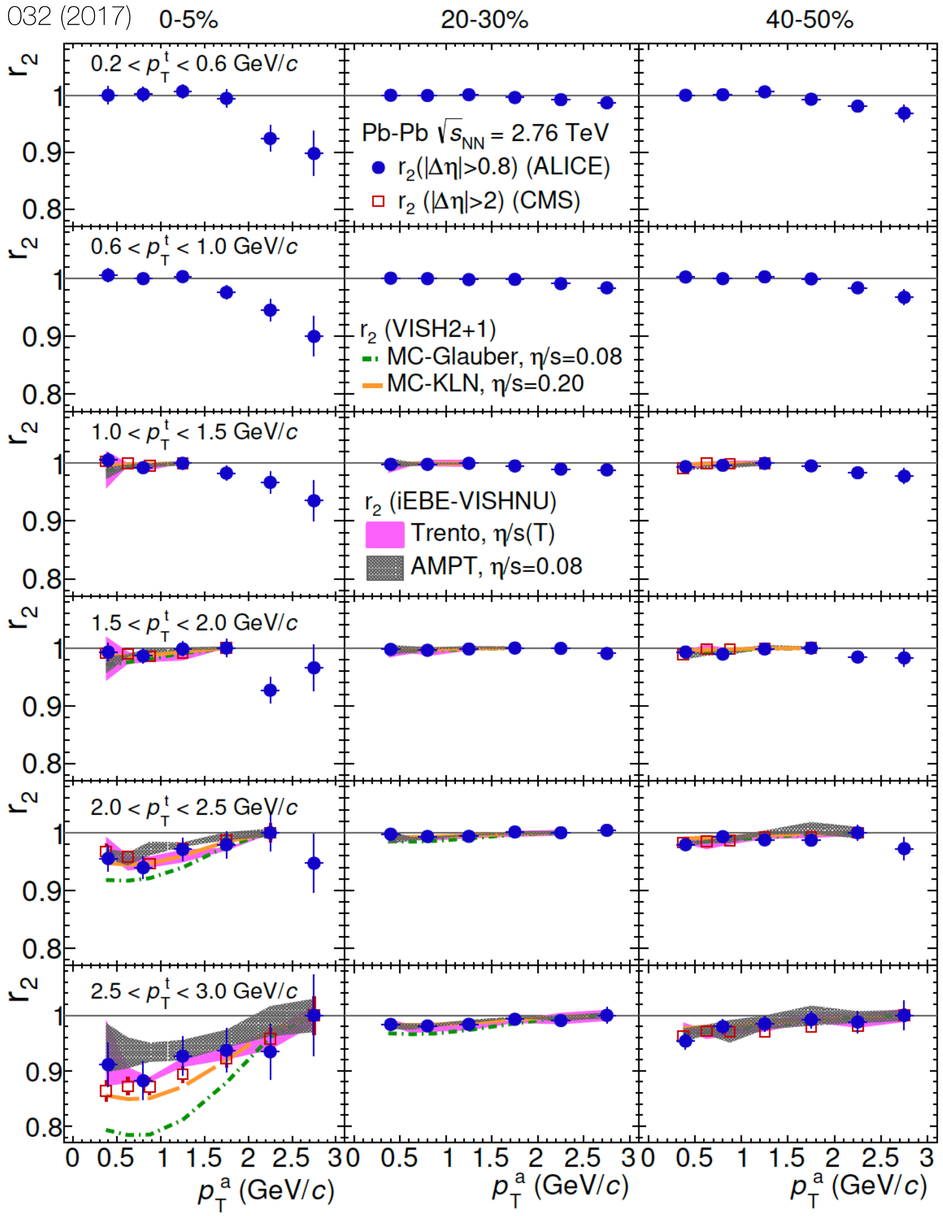

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