Measurement of azimuthal anisotropy of charged particles in Pb+Pb collisions with the ATLAS detector

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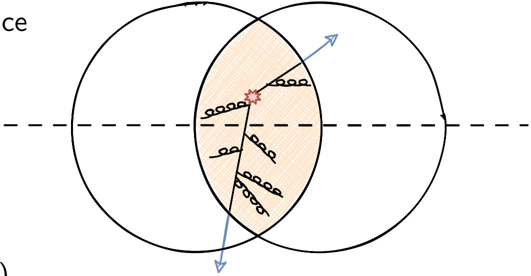
motivation

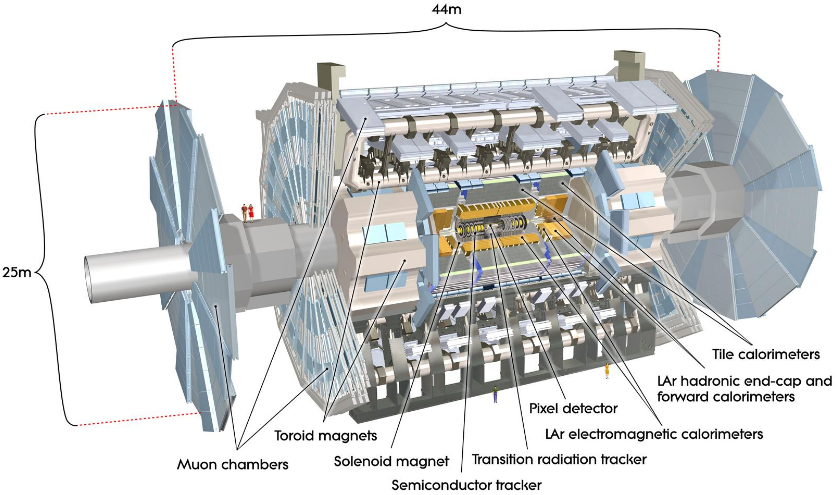
- partons traversing quark-gluon plasma lose energy
- measuring such loss provides information about the short-distance interactions with QGP
- this loss also depends on the path of a parton;
  path depends on the initial geometry of colliding nuclei
- azimuthal anisotropies of high-p_{T} particles is useful for studying path-length dependence of the energy loss
- at low p_{T}, azimuthal anisotropies are present due to the hydrodynamic flow of the QGP



$$\frac{dN}{d\phi} \approx 1 + \sum_{n=1}^{\infty} v_n \cos\left(n(\phi - \Psi_n)\right)$$

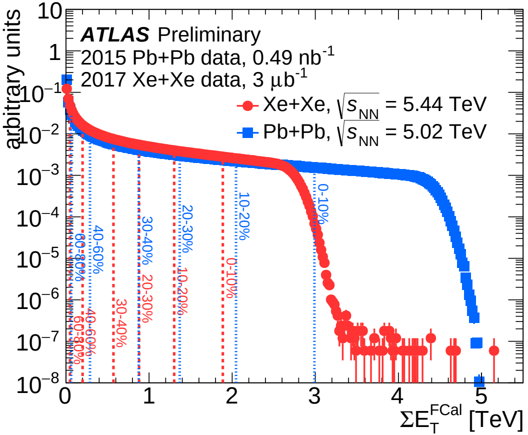
ATLAS detector

- tracker: $|\eta| < 2.5$
- EM and hadronic calorimeters: $|\eta| < 3.2$
- forward calorimeters: $3.1 < |\eta| < 4.9$ used for centrality
- muon spectrometers: $|\eta| < 2.7$
- ZDC: $|\eta| > 8.3$



centrality in Pb+Pb collisions

- centrality based on energy deposited in both sides of the Forward Calorimeter ($3.1 < |\eta| < 4.9$)
- pile-up events in heavy-ion collisions are removed from the analysis
- $\langle N_{\mathrm{part}} \rangle$ – number of participating nucleons
- $\langle N_{\mathrm{coll}} \rangle$ – number of binary nucleon–nucleon collisions
- $\langle T_{\mathrm{AA}} \rangle = \langle N_{\mathrm{coll}} \rangle / \sigma_{NN}$



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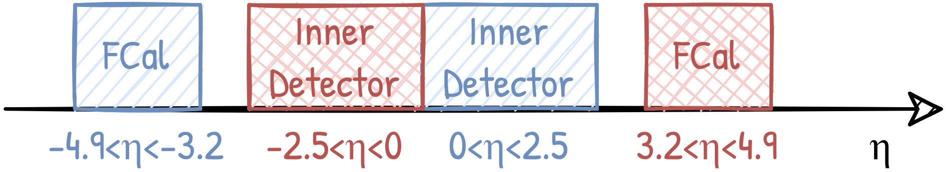
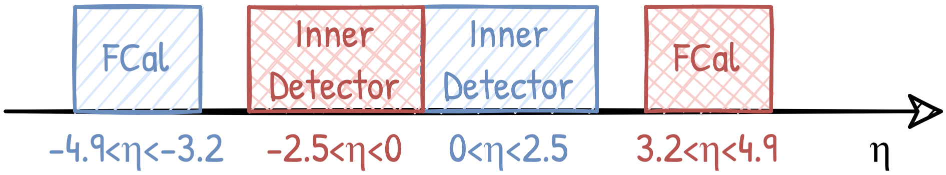
azimuthal anisotropies: scalar product method



- measured tracks from the Inner detector are correlated with measured energy in FCal
  - tracks from *positive* side of ID are correlated with energy from *negative* side of FCal
  - tracks from *negative* side of ID are correlated with energy from *positive* side of FCal
- large pseudo-rapidity gap $\eta_{gap} > 3.2$ suppresses non-flow contribution
  - resonance decay, particles from the same jet, particles from a di-jet, ...

azimuthal anisotropies: scalar product method



- for each track or calorimeter cell, we define a flow vector:

$$q_{n,j} = \mathrm{e}^{in\phi_j}$$

- for one side of FCal, we define an average flow vector:

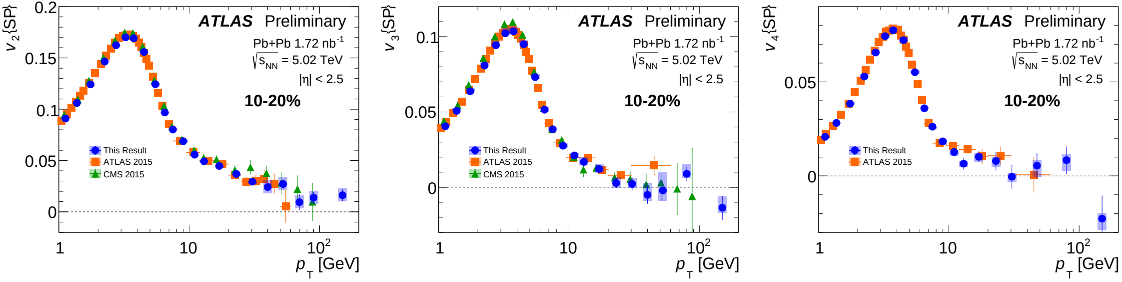
$$Q_n = \frac{1}{\sum_j w_j} \sum_j w_j q_{n,j}$$

- flow harmonics, v_n, are then:

$$v_n\{SP\} = \mathfrak{Re} \frac{\langle q_{n,j} Q_n^{N|P*} \rangle}{\sqrt{Q_n^N Q_n^{P*}}}$$

flow harmonics: p_T dependence

- using Pb+Pb data recorded in 2018
- consistent with previous results, however precision is higher
- strong dependence on p_T



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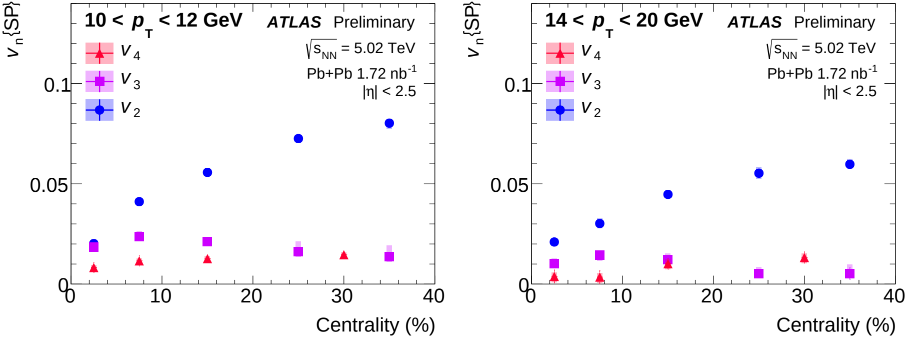
flow harmonics: centrality dependence

- $10 < p_{\mathrm{T}} < 20$ GeV
- strong centrality dependence for v_2
- weak centrality dependence for v_3 and v_4



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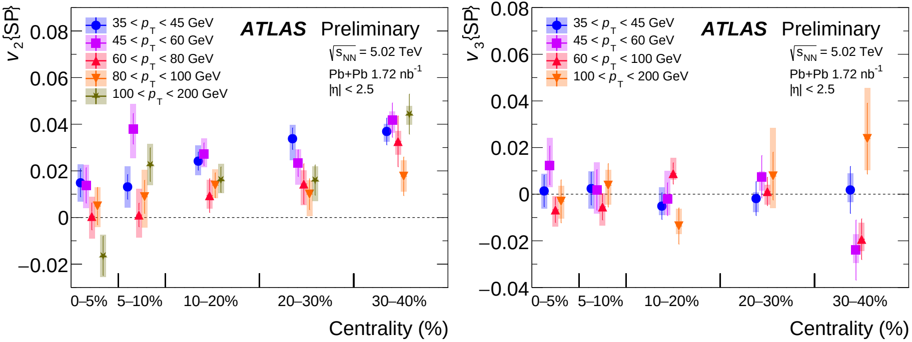
flow harmonics: high-p_T dependence

- $35 < p_T < 200$ GeV
- v_2 decreases with p_T, particularly at mid-centrality
- v_3 is consistent with zero



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flow harmonics: outline

What if we would like to have more precise measurement at **high p_T**?

- wait for a new publication *Azimuthal anisotropies of charged particles with high transverse momentum in Pb+Pb collisions at 5.02 TeV with the ATLAS detector at the LHC*
  - more statistic due to partial event building
  - using also multi-particle cumulant method
  - on arXiv by end of the next week, will be submitted to PRC

What if we would like to have more precise measurement at **low p_T**?

- convince CERN IT department to give us more CPU cores
- make track reconstruction faster

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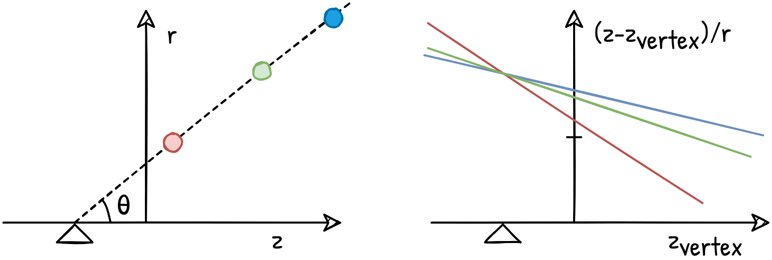
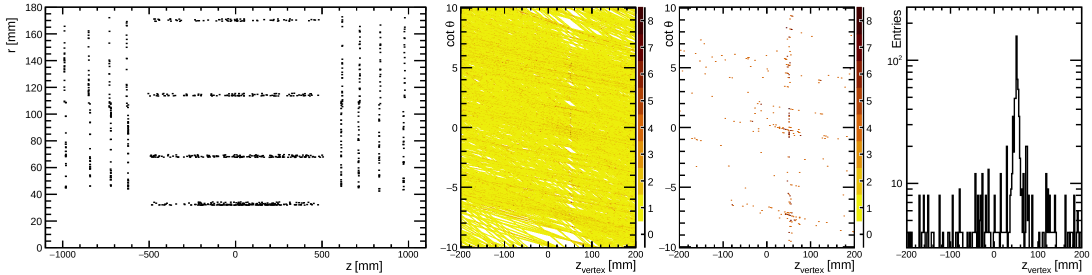
Hough transform

- speed up track reconstruction by rejecting track seeds that don't point to the vertex
- use Hough transform to get vertex position from spacepoints - no tracks needed!

- a track has some angle θ and originates at z_{vertex}
- apply Hough transform, so each spacepoint become a line
- instead of θ, we use $\cot(\theta) = (z - z_{vertex})/r$
- filter out points where not enough lines cross each other
- make a projection of the remaining points to the z_{vertex}



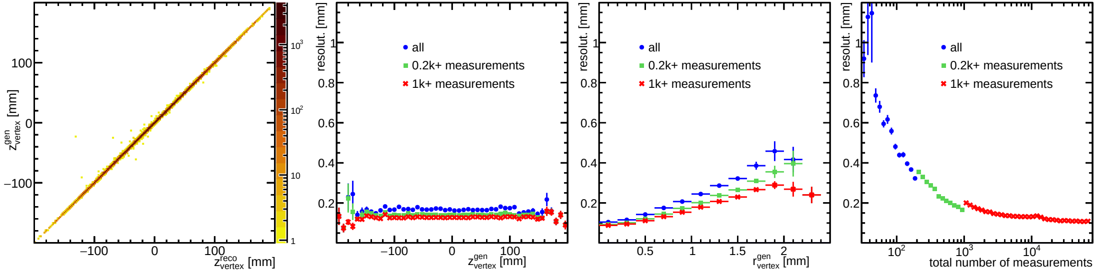
- using OpenData Detector - a simplified version of ITk (ATLAS tracker for Run 4)
- working on implementation in ACTS
  $\rightarrow$ this tracking framework will be used by ATLAS in Run 4



arXiv:2410.14494

resolution

- resolution is σ of $\left|z^{gen}_{vertex} - z^{reco}_{vertex}\right|$
- always assuming $x_{vertex} = 0\,\text{mm}$, $y_{vertex} = 0\,\text{mm}$
- tuning of various parameters necessary
- resolution good enough to reject a significant portion of track seeds



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summary

- measured azimuthal anisotropies of charged hadrons at high p_{T}
  - v_n values reach maxima at 3–5 GeV for all centralities
  - positive v_2 up to high p_{T}
  - v_3 consistent with zero for $p_{\mathrm{T}} \gtrsim 20$ GeV
- provides valuable input for the MC models
- publication with even better statistics will be released soon
- these and all other ATLAS results

  → **https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults**

- presented method to improve track reconstruction
  - useful for reconstruction of high-multiplicity events, such as Pb+Pb collisions
- will be hopefully used in Run 4

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