Scalar product and event plane methods for measurements of the azimuthal anisotropy in Pb+Pb and Xe+Xe collisions with the ATLAS detector at the LHC

Klaudia Burka, on behalf of the ATLAS Collaboration
Institute of Nuclear Physics PAN, Cracow, Poland

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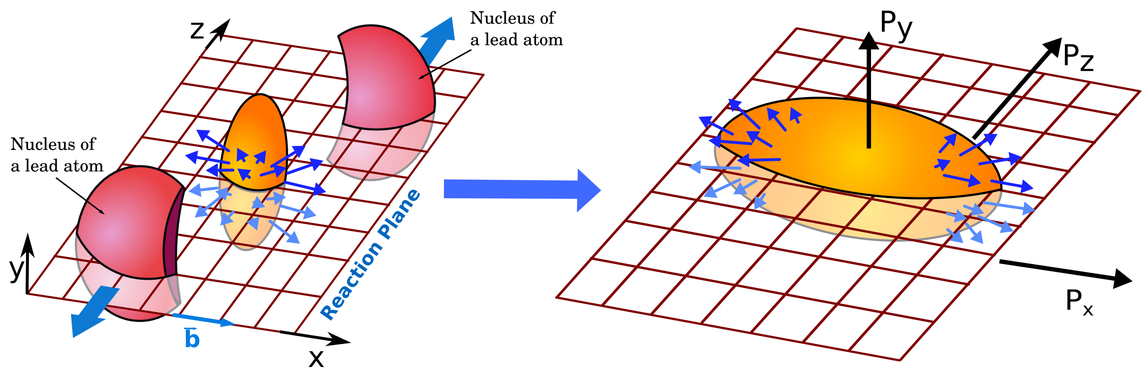
ABSTRACT

Measurements of the azimuthal anisotropy of charged particles in heavy-ion collisions are sensitive to properties of the quark-gluon plasma, in particular its dependence on initial conditions, transport coefficients and time evolution. The presented measurements are based on $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV Pb+Pb and $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV Xe+Xe data collected by the ATLAS detector in 2015 and 2017, respectively. The elliptic flow and higher-order Fourier coefficients (v_2 - v_7) are presented in a wide range of transverse momenta and collision centrality in both collision systems. The results are compared to the $v_n(p_{\mathrm{T}})$ values measured in recent $\sqrt{s_{\mathrm{NN}}} = 5.44$ TeV Xe+Xe collisions.

ANIZIMUTHAL ANISOTROPY IN HEAVY ION COLLISIONS

Signatures of QGP:

collective expansion (radial flow, elliptic flow, ...), jet quenching, etc.



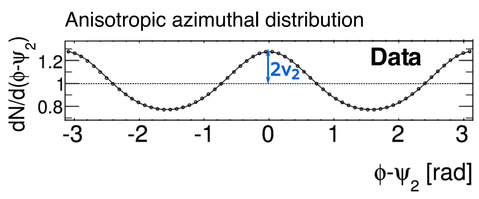
Initial spatial anisotropy → **Momentum space anisotropy**

Particle azimuthal distribution:

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

(v_n: flow harmonics)

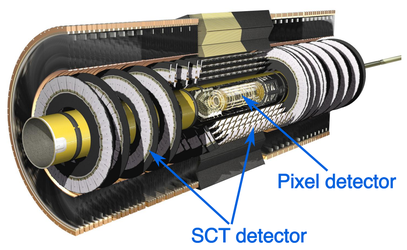
Ψ_n - reaction plane angle



- Azimuthal anisotropy results from different pressure gradients in different spatial directions
- v_2 - elliptical shape of the collision zone
- Higher order v_n - initial spatial fluctuations
- Non-zero v_n measured up to n=6
  (ATLAS: Phys.Lett.B 707 (2012) 330-348;
  Phys.Rev.C86 (2012) 014907)

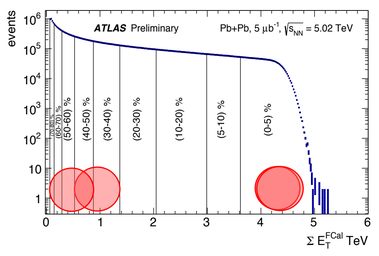
ATLAS DETECTOR → v_n MEASUREMENT

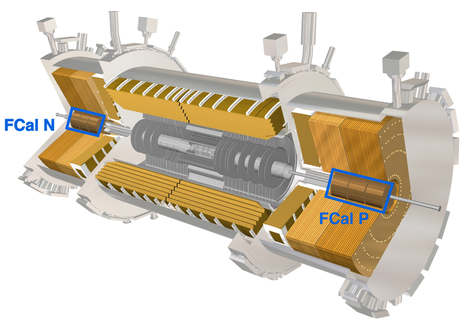
- 2015: Pb+Pb 5.02 TeV, 0.49 nb^{-1}
  - Total luminosity sampled by minimum - bias triggers: 22 $\mu\mathrm{b}^{-1}$
- 2017: Xe+Xe 5.44 TeV, 3 $\mu\mathrm{b}^{-1}$



- **Inner Dectector** (Pixel + SCT)
  Flow measurement is based on charged tracks reconstructed in ID
  - $|\eta| < 2.5$
  - 2π ϕ acceptance
  - $p_{\mathrm{T}} > 0.5$ GeV

- **Forward Calorimeter** ($3.1 < |\eta| < 4.9$)
  - Event plane angles are measured using FCal → Ψ_n^N and Ψ_n^P
  - Centrality definition

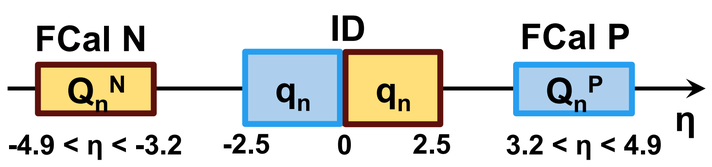




SCALAR PRODUCT (SP) METHOD

- **Flow vector**

$$Q_n = |Q_n| e^{in\Psi} = \frac{1}{S}\sum_j q_{n,j} = \frac{1}{S}\sum_j w_j e^{in\phi_j}$$

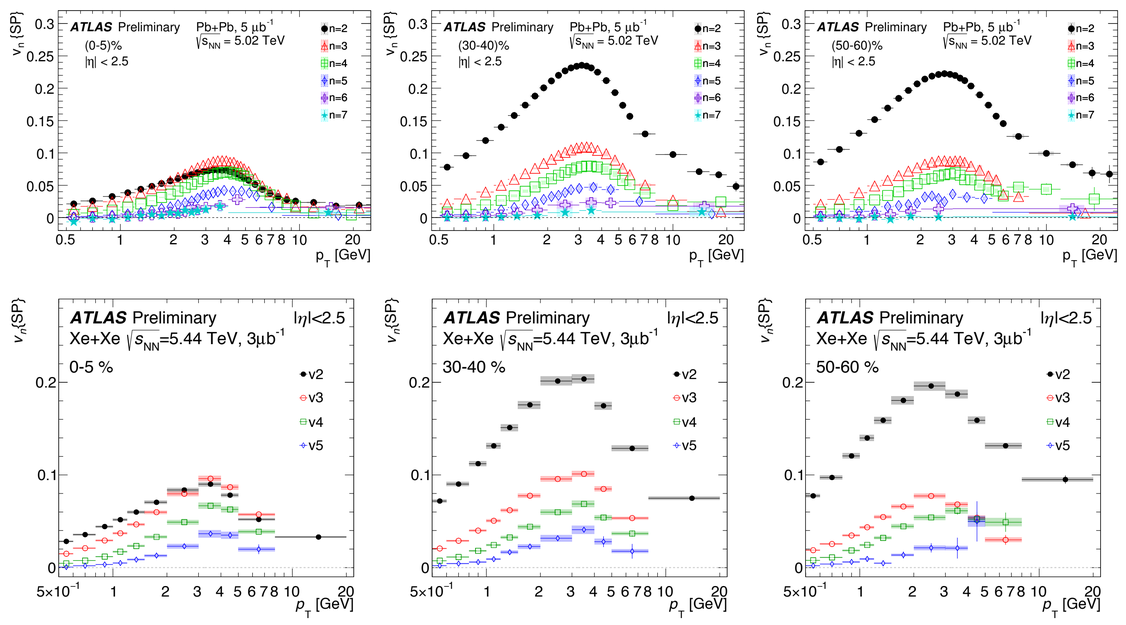


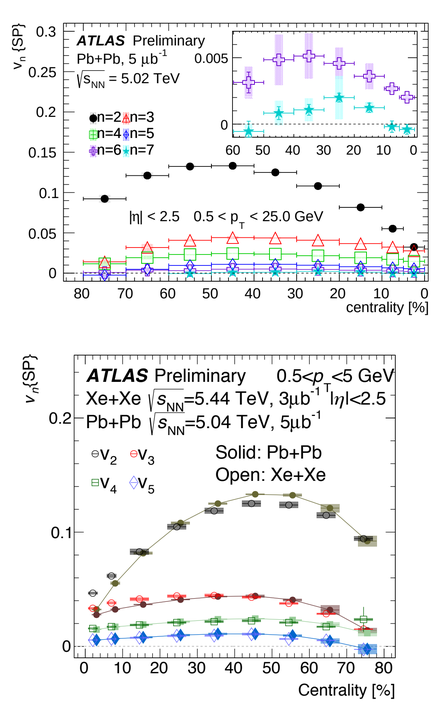
- Flow vectors are measured in sub-events
  - **ID** → sum over charged tracks, S
  - **FCal N** and **FCal P** → sum over calorimeter towers
- Final formula:

$$v_n\{SP\} = \frac{\langle |q_{n,j}||Q_n^{N|P}|\cos[n(\phi_j - \Psi_n^{N|P})]\rangle}{\sqrt{\langle |Q_n^N||Q_n^P|\cos[n(\Psi_n^N - \Psi_n^P)]\rangle}}$$

- Large eta gap ($|\eta| > 3.2$) to suppress short-range correlations
- **Scalar Product:** unambiguous measurement of v_n → always $\langle\sqrt{v_n^2}\rangle$
- Standard **Event Plane** method used to compare to results obtained at lower energy as well to other experiments

RESULTS





- Flow harmonics measured for n = 2-7
- All centrality intervals show:
  - Rapid rise of $v_2(p_{\mathrm{T}})$ up to $p_{\mathrm{T}} \sim 3$ GeV
  - Decrease out to 7-8 GeV
  - Weak p_{T} - dependence above 9-10 GeV
- The biggest asymmetry observed in mid-central collisions (30-50%)
  - elliptic flow is dominant asymmetry, except for the most central bin 0-5%
- v_2 is dominant and remains positive at high p_{T}
- v_n are comparable between the Xe+Xe [1] and Pb+Pb [2]
  - the flow related to the initial geometry rather than to the number of sources in the initial state
  - A difference for most central collisions indicate larger asymmetries in Xe+Xe collisions.

[1] ATLAS-CONF-2018-011, [2] ATLAS-CONF-2016-105

SUMMARY

- The azimuthal anisotropy of charged particles in Pb+Pb collisions at 5.02 TeV was studied in wide p_{T} ($0.5 < p_{\mathrm{T}} < 20$ GeV) and centrality (0-80%) ranges.
- The first ATLAS measurement of flow harmonics, v_n, obtained with Xe+Xe collisions at 5.44 TeV is presented.
- Significant values of the second-order harmonic, v_2, persist up to $p_{\mathrm{T}} = 20$ GeV, in both Pb+Pb and Xe+Xe systems.
- The flow in heavy ion collisions shows stronger dependence on the initial geometry rather than on the number of sources

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