Measurement of charged jet spectrum and v_2 in Pb-Pb collisions at 5.36 TeV with ALICE

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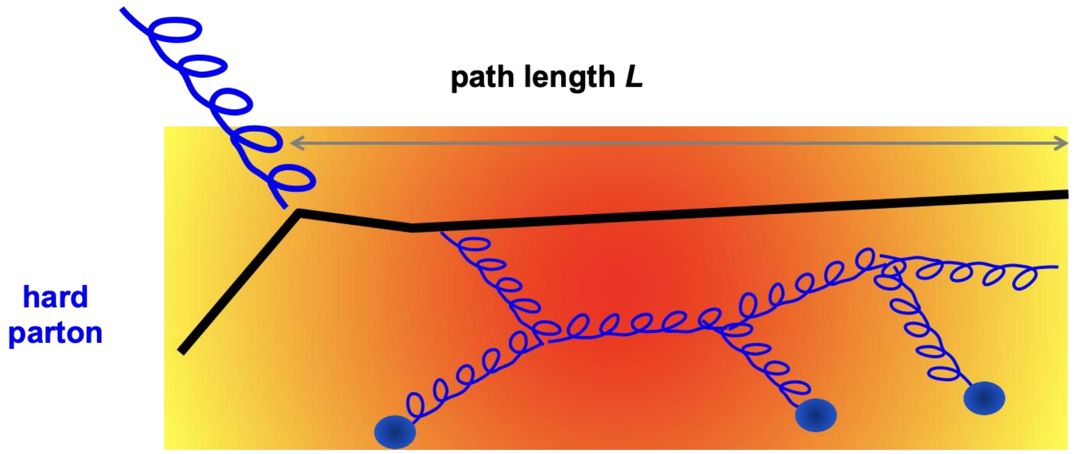
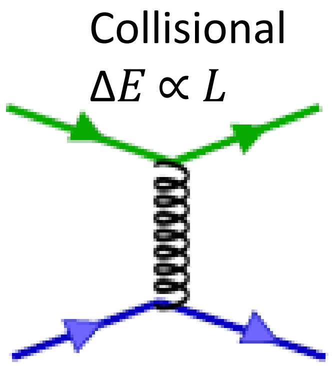
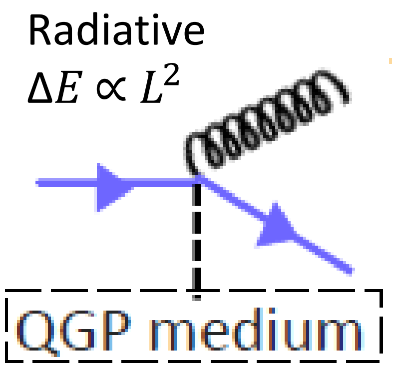
In the QGP, high-energy partons lose energy while traversing the medium.

- This energy loss is predicted to depend on the path length through the QGP.
- Observing a correlation between energy loss and path length would provide crucial insight into the underlying mechanisms.

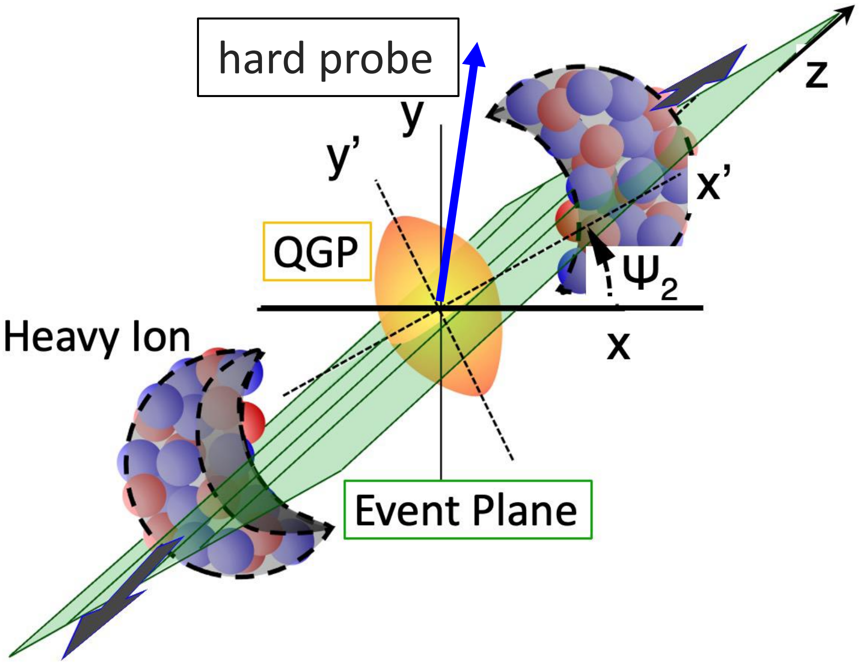






Jet v_2 quantifies the azimuthal anisotropy of jet yields and serves as a key observable to probe this path-length dependence.

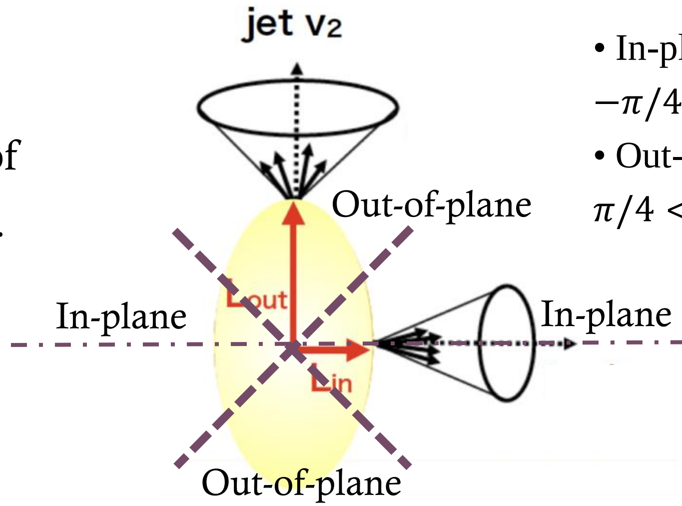
Observables



- The interaction region created in the collision has an initial spatial anisotropy
- Which is converted into a momentum anisotropy of the emitted particles due to the pressure gradients

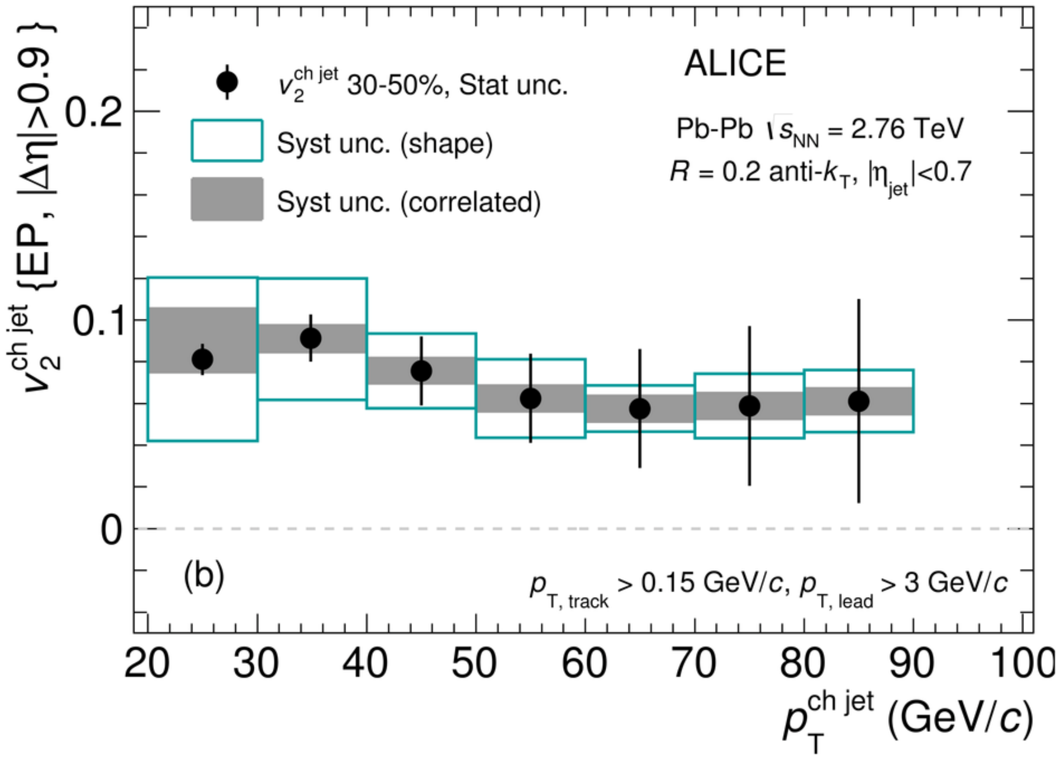
$$E\frac{d^3N}{d\varphi} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}\left\{1 + \sum_{i=1}^{\infty} v_n \cos[n(\varphi - \Psi_n)]\right\}$$

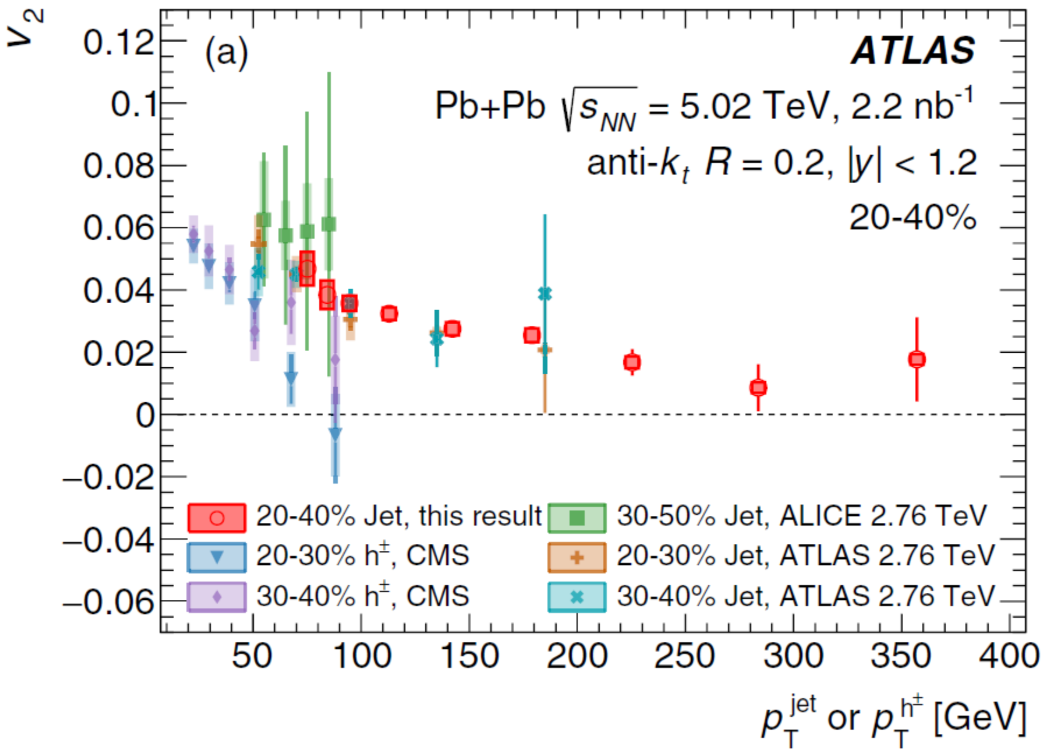
$$v_2 = \langle \cos[2[\varphi - \Psi_2]] \rangle$$



- In-plane:
  $-\pi/4 < \varphi < \pi/4$, $3\pi/4 < \varphi < 5\pi/4$
- Out-of-plane:
  $\pi/4 < \varphi < 3\pi/4$, $5\pi/4 < \varphi < 7\pi/4$

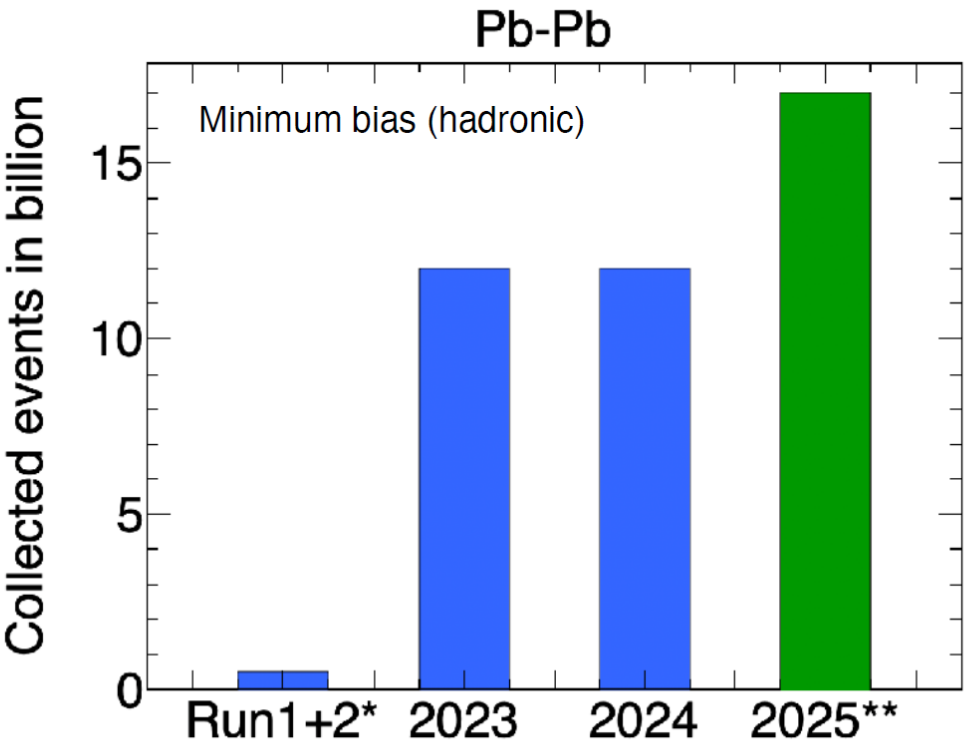
- Elliptic flow (v_2): quantifies the azimuthal anisotropy of jet (or particle) yields with respect to the reaction plane.
  - ➢ Low p_T: participation in collective motion and thrmalization of heavy quarks
  - ➢ High p_T: path-length dependence of energy loss

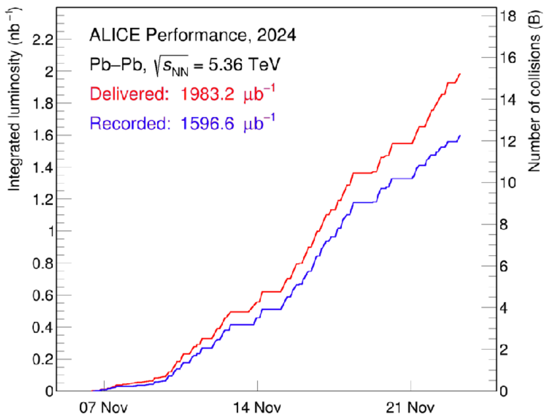


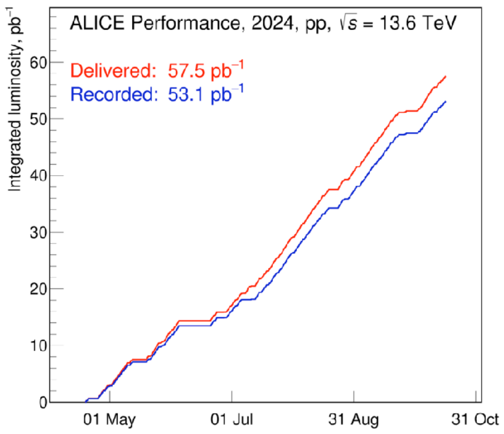


- The systematic uncertainties in the ALICE results are large
- The overlap is limited.

The current measurements at LHC shows positive jet v_2 but with poor precision, especially ALICE results







Overall data taking efficiency:

- pp: 92% physics ready
- Pb-Pb: 81% physics ready

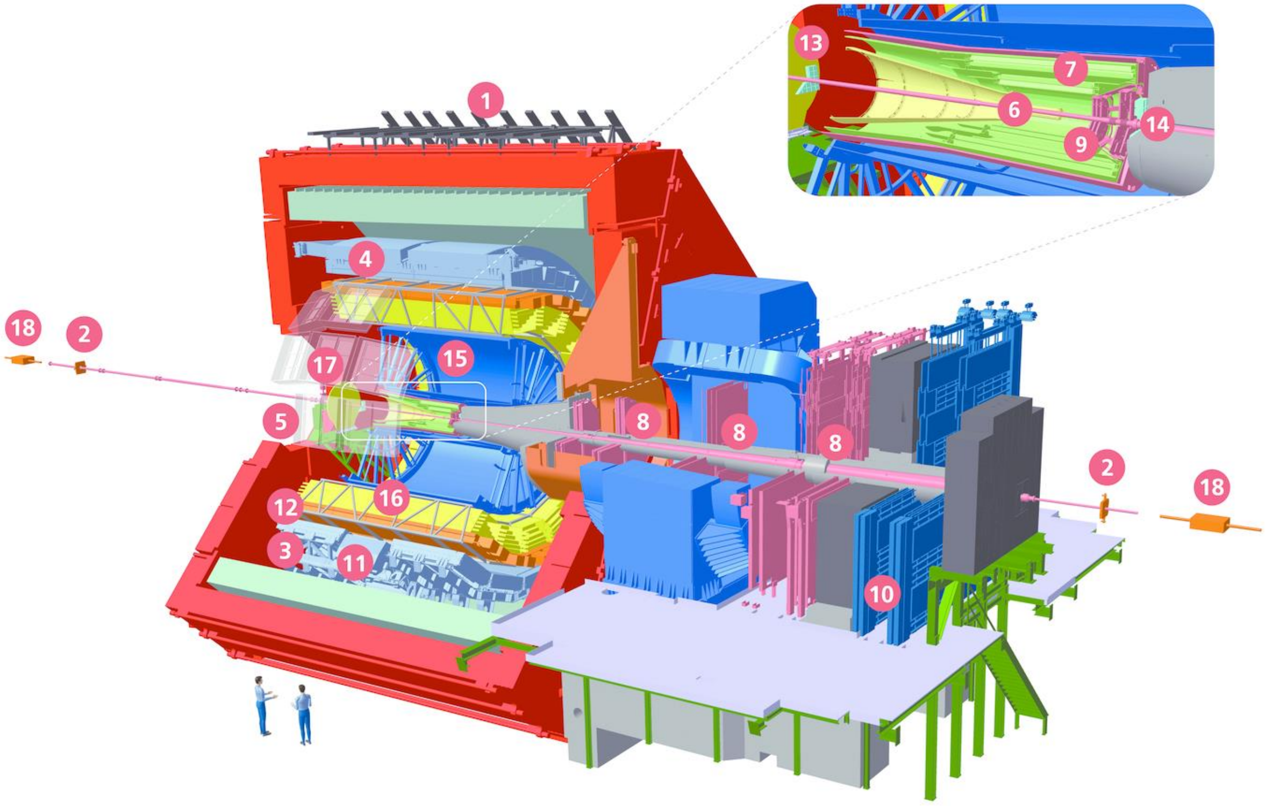
- Excellent PID capabilities.
- Reconstruction of particles down to low momenta.
- ITS2: pointing resolution of ~35 μm (at 1 GeV/c)
- MFT: Vertexing in forward direction.
- GEM-TPC: high rates up to 50 kHz in Pb-Pb with continuous readout.

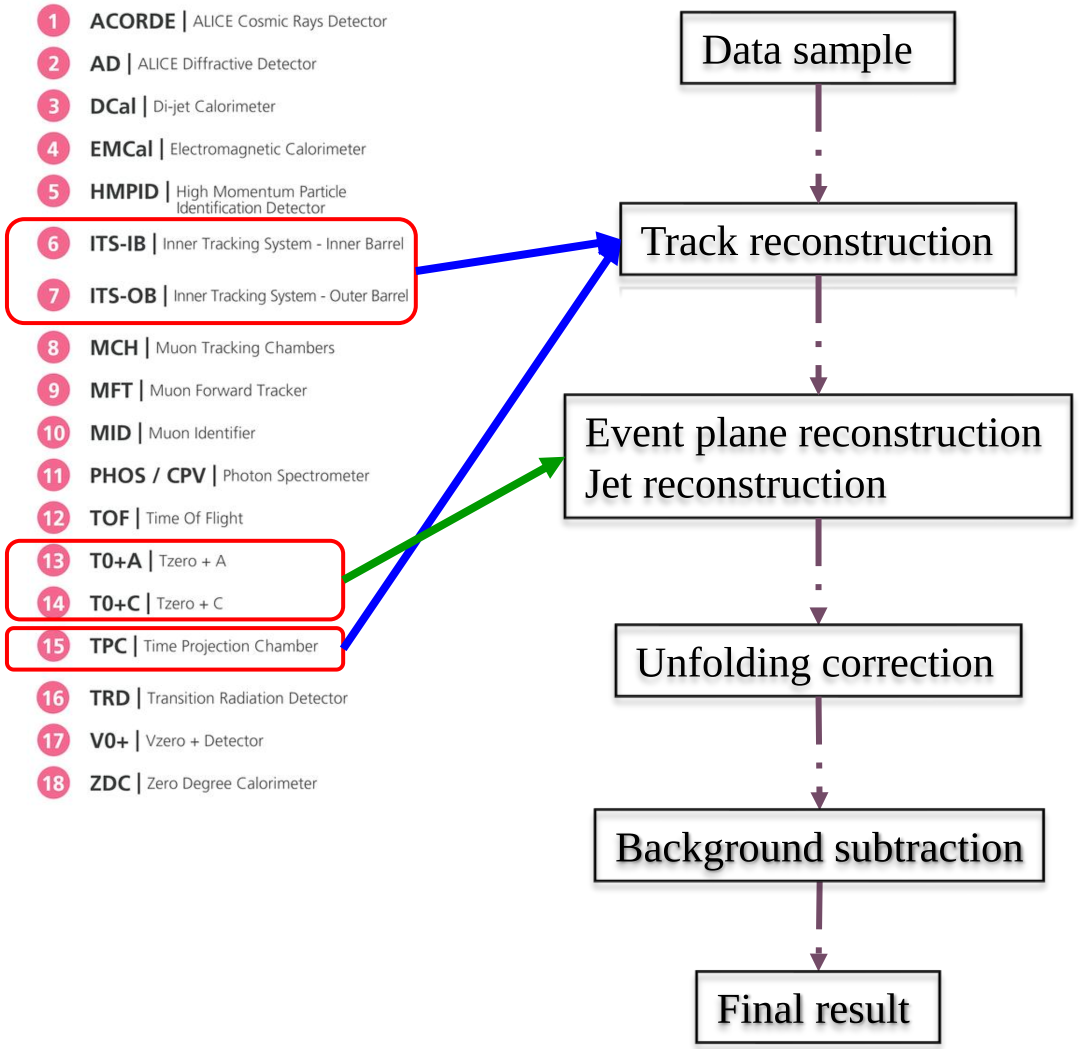
Continuous readout significantly enhances data-taking capabilities but also brings several challenges (pile-up,)

Occupancy cut

- Suppress pile-up and non-physical background
- Improve the estimation of background density
- Enhance the reliability of jet reconstruction

ALICE Detector in Run 3





- 2023 Pb-Pb collisions, 5.36 TeV (497.1 TB)
- Track reconstruction by ITS and TPC
- Event plane reconstruction by T0A and T0C

Event Plane determination

- Event plane constructed by Q-vector :

$$\Psi_{\mathrm{EP,n}} = 1/n * \arctan\left(Q_{n,y}/Q_{n,x}\right)$$

$$Q_{n,x} = \sum_i \omega_i \sin(n\varphi_i),\ \ Q_{n,x} = \sum_i \omega_i \sin(n\varphi_i)$$

ω_i: gain equalization, φ_i: Track angle, n: Fourier order

- Event plane resolution was determined by 3-sub-event method:

$$\mathcal{R}_2 = \langle \cos[2(\Psi_{\mathrm{EP,2}} - \Psi_2)] \rangle$$

- The Event Plane distribution should be flat after Q-vector corrections.

➢ Recentered:

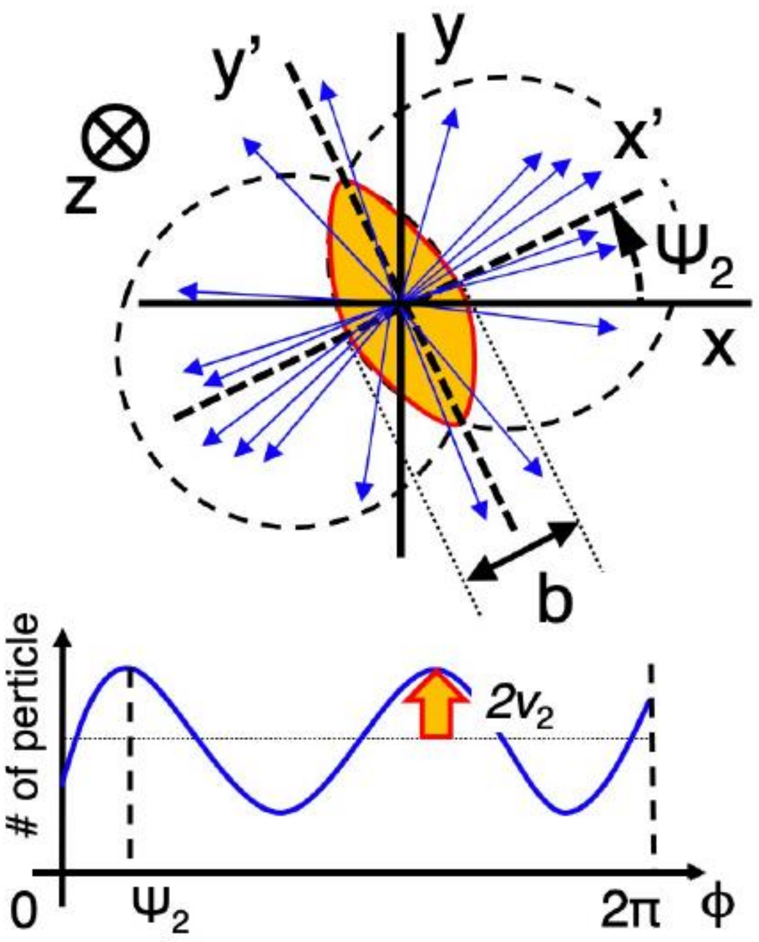
Adjusts the event plane's position to align with the true event center.

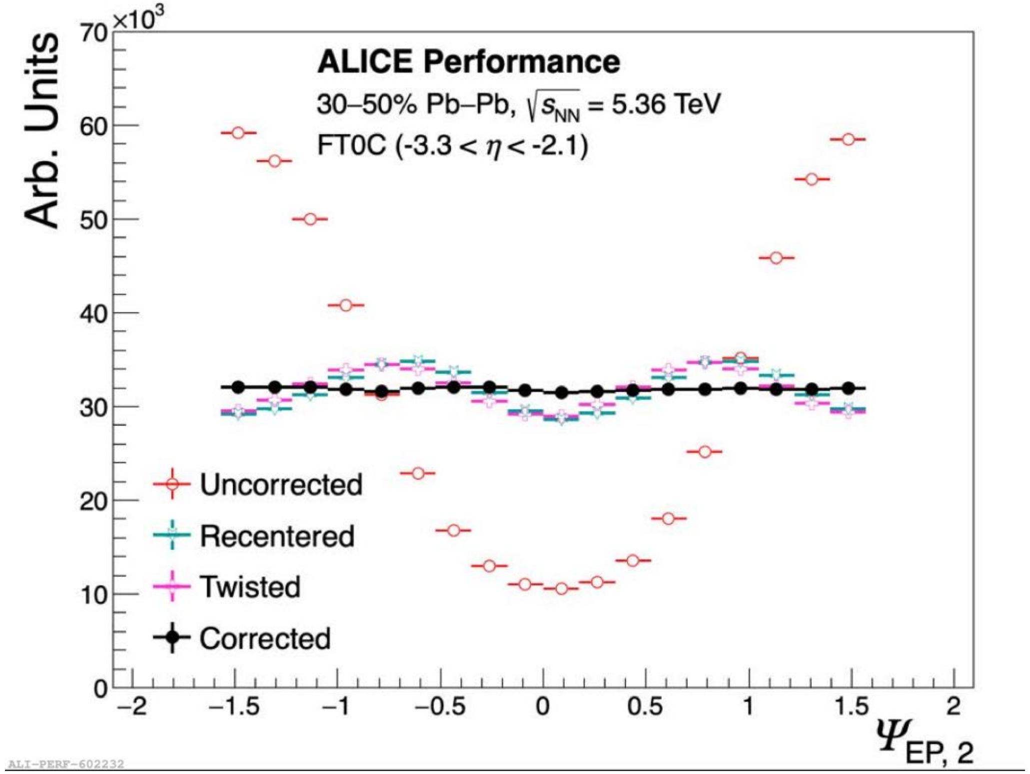
➢ Twisted:

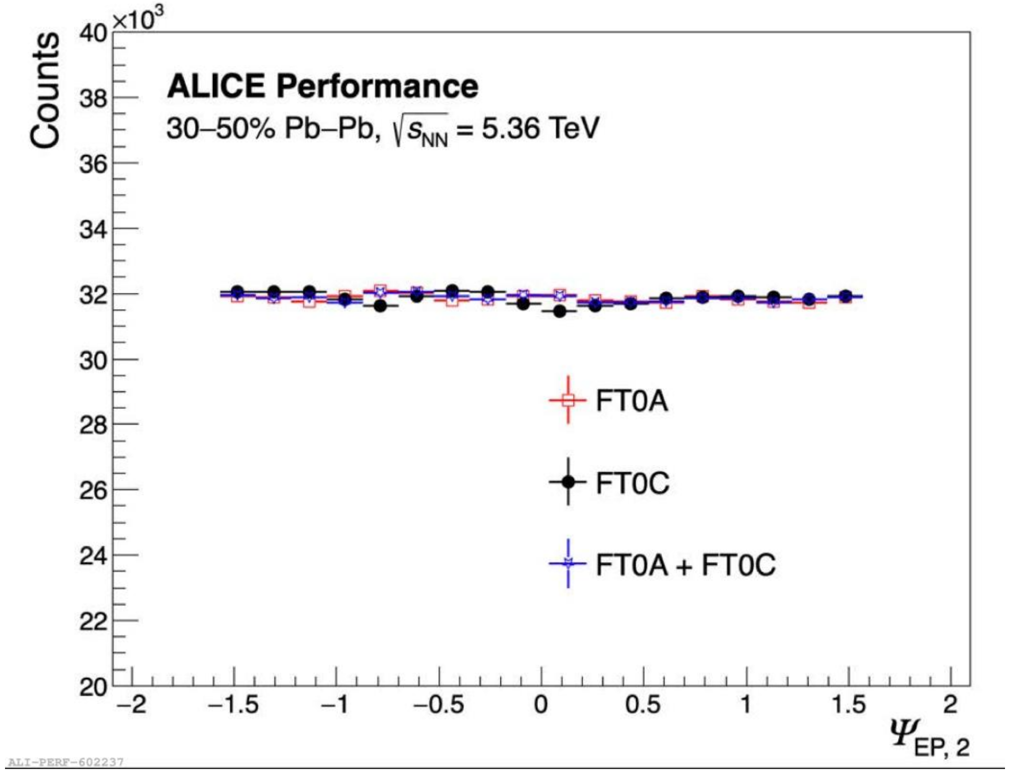
Accounts for possible rotational effects caused by detector asymmetry or other factors.

➢ Corrected:

Corrects possible deformations in the event plane to restore symmetry.





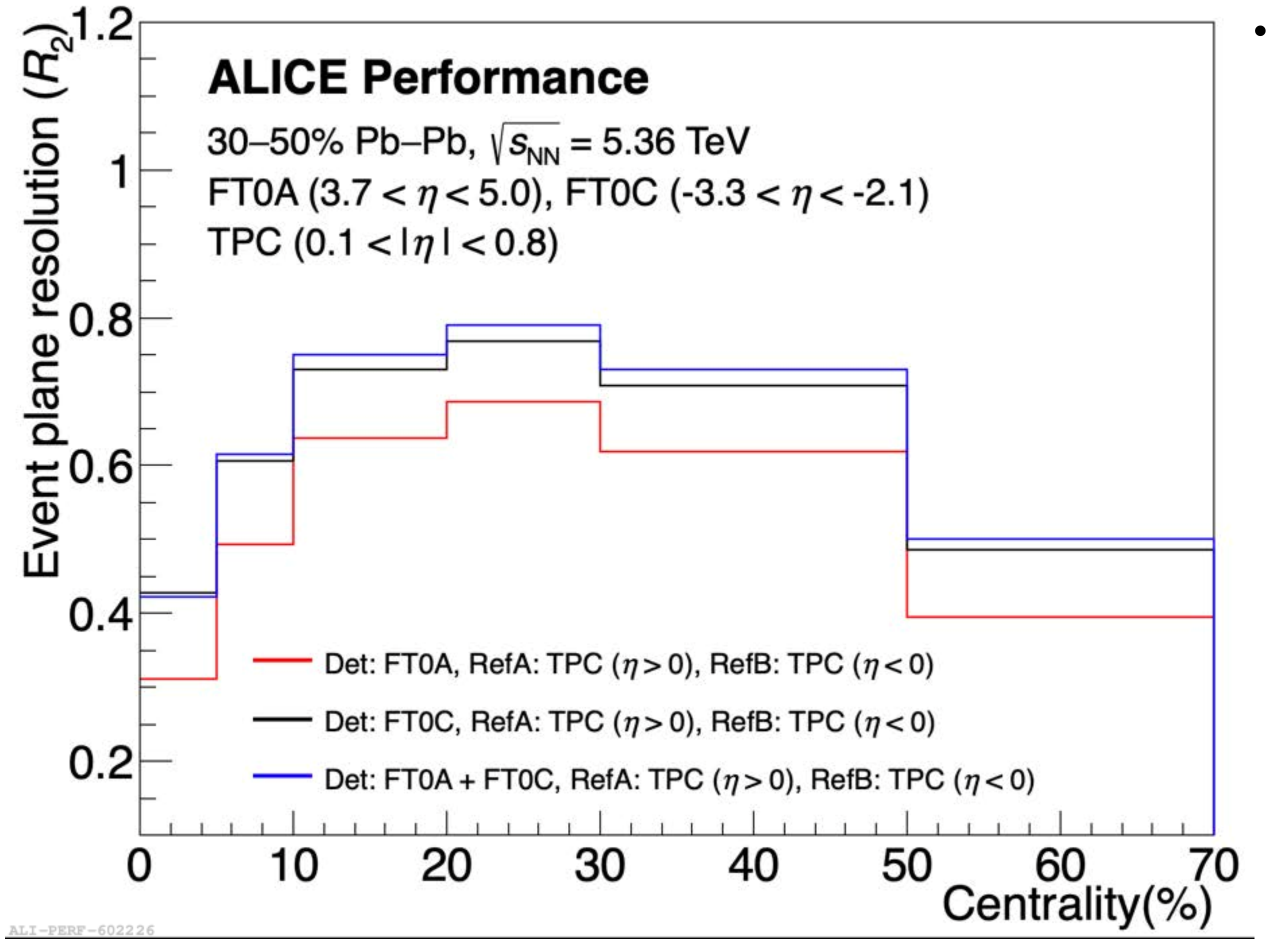


- Flow vector from detector measurement:

$\Psi_{EP,2} = 1/2 * \arctan(Q_{2,y}/Q_{2,x})$

- The distribution that has become flat after full steps correction for different detectors FT0A, FT0C and FT0M.

Event Plane Resolution



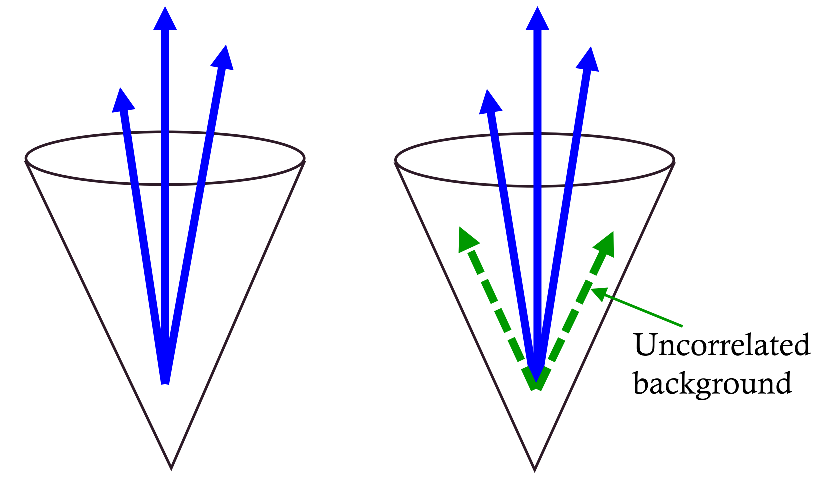
- Obtain event plane resolution using 3-sub-event method

Detector:	
FT0C(-3.3 < η < -2.1)	Reference:
FT0A(3.7 < η < 5.0)	TPC (η > 0)
FT0M(combined A & C sides)	TPC (η < 0)

$$\mathcal{R}_2 = \langle \cos[2(\Psi_{\mathrm{EP},2} - \Psi_2)] \rangle$$

$$\mathcal{R}_2 \approx \sqrt{\frac{\langle \cos[2(\Psi^{\mathrm{Det}}_{\mathrm{EP},2} - \Psi^{\mathrm{RefA}}_{\mathrm{EP},2})] \rangle \ \langle \cos[2(\Psi^{\mathrm{Det}}_{\mathrm{EP},2} - \Psi^{\mathrm{RefB}}_{\mathrm{EP},2})] \rangle}{\langle \cos[2(\Psi^{\mathrm{RefA}}_{\mathrm{EP},2} - \Psi^{\mathrm{RefB}}_{\mathrm{EP},2})] \rangle}}$$

- The event plane resolution peaks at around 80% for the 20-30% centrality class, decreasing for both more central and more peripheral collisions.



The jet we want The jet we get

In heavy-ion collisions, a huge number of particles are produced.

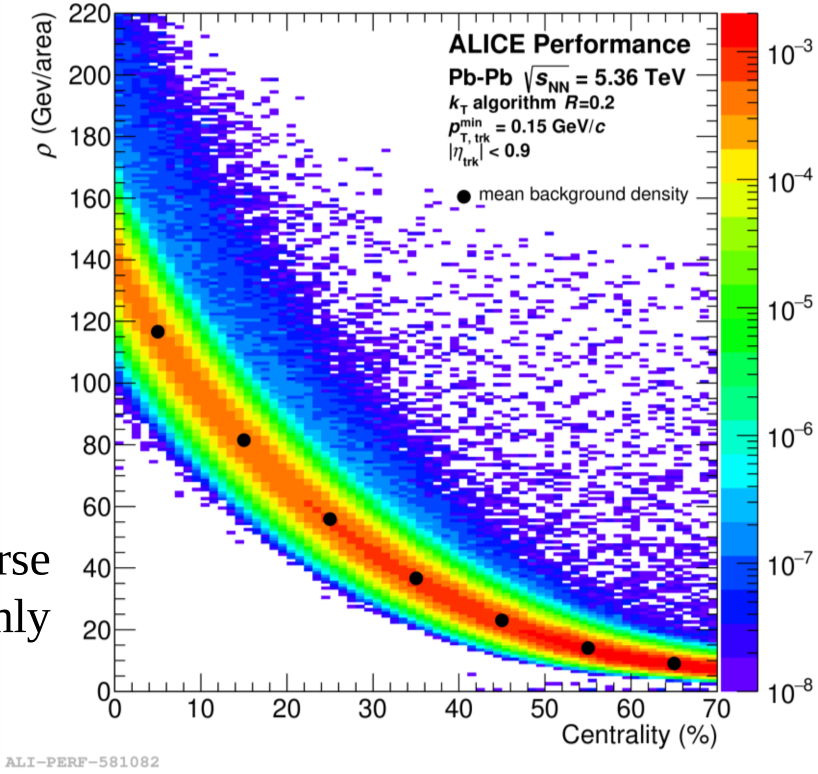
- Signal jets are reconstructed with the background particles.
- Estimate background p_T density (ρ) except for jet area to subtract the background from the signal jets

k_T clustering is used to estimate the event-by-event median background density, ρ , which is defined as:

$$\rho = median\{\frac{p_{T,k_t}}{A_{k_t}}\}$$

$p_{T,\,k_t}$: transverse momentum of all k_t cluster

A_{k_t}: area in (η, ϕ)-plane for all kt cluster



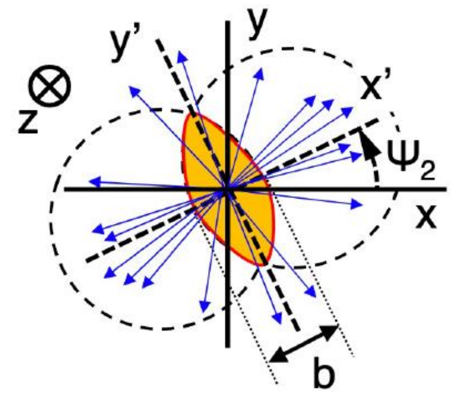
Area-based method:
Removes the event-wise median background contribution to the jet transverse momentum by estimating the background p_T density and assuming it is uniformly distributed across the jet area.

$$p_{T,jet}^{sub} = p_{T,jet}^{raw} - \rho * A_{jet}$$

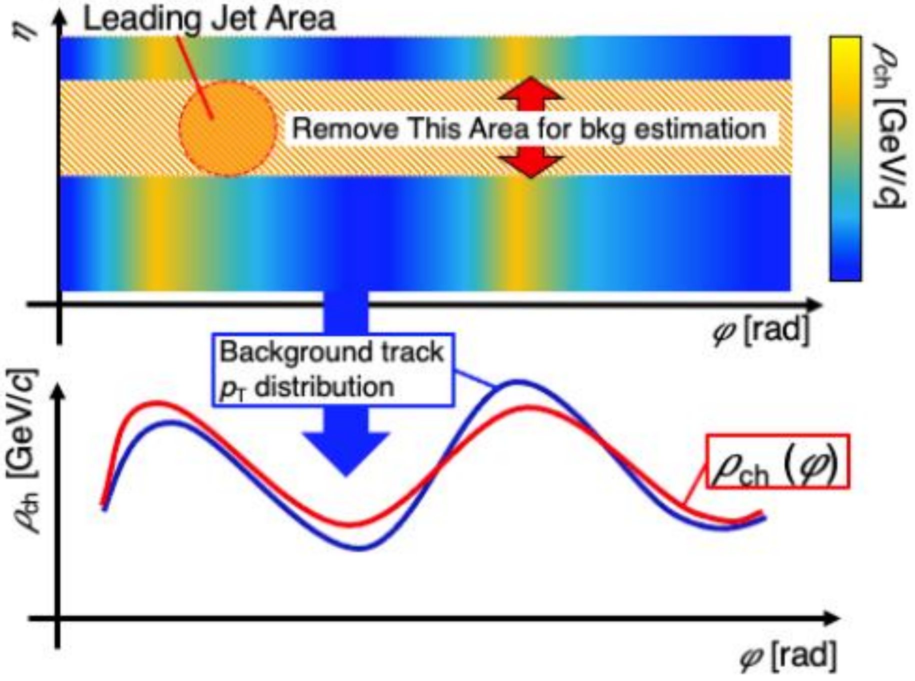
Background subtraction for jet measurements (as function of φ)

The soft particle background for jets is not uniform for azimuthal angle (φ).

- The background calculation should take the φ dependency into account.

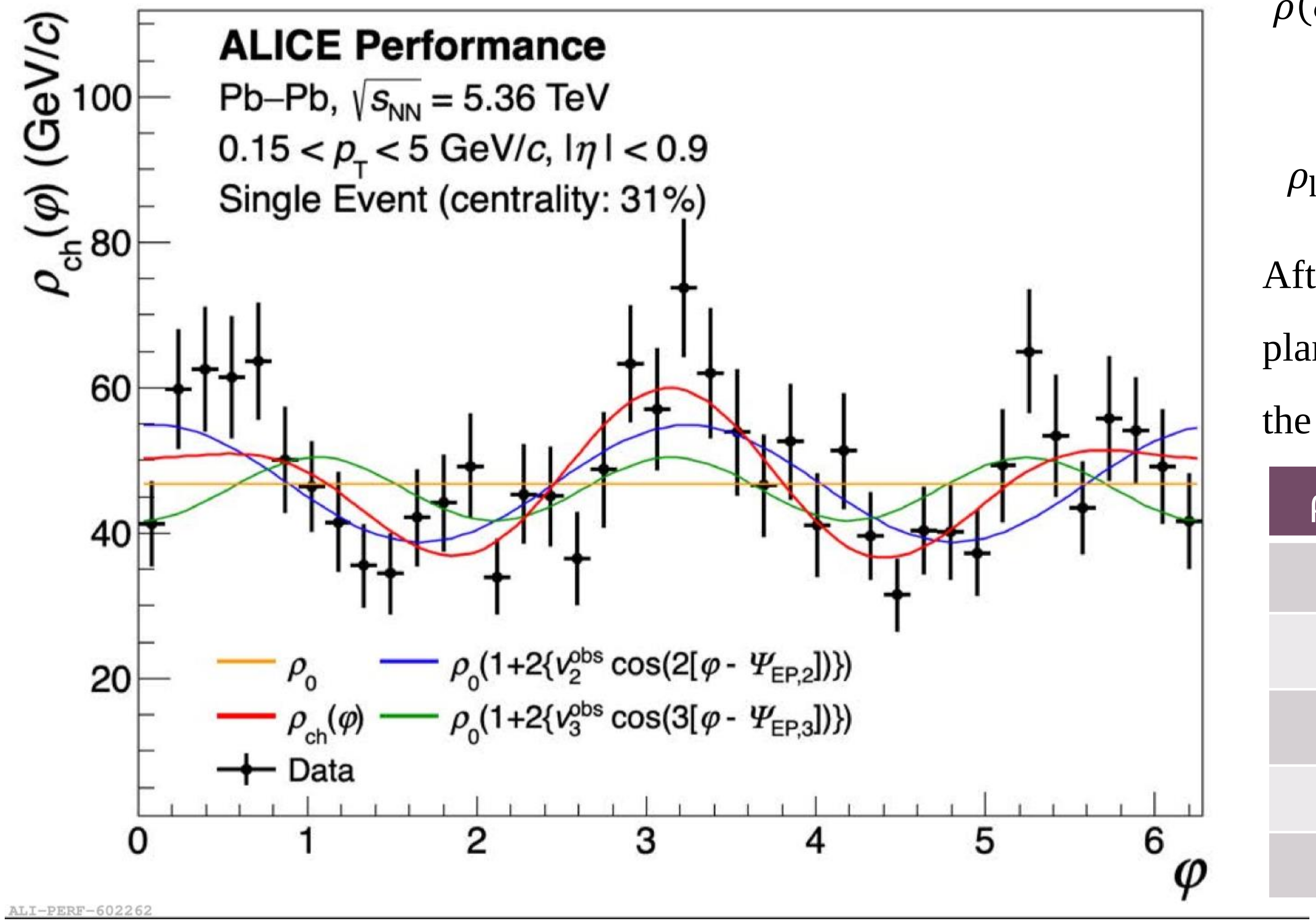


The local rho is estimated using tracks except the leading jet eta region.



In this analysis, a following equation is used

- $p_T^{corr} = p_T^{raw} - \rho_{local} * A$
- $\rho(\varphi) = \rho_0 \times (1 + 2\{v_2^{obs}\cos(2[\varphi - \Psi_{EP,2}]) + v_3^{obs}\cos(3[\varphi - \Psi_{EP,3}])\})$
  - $\Psi_{EP,2}$ and $\Psi_{EP,2}$ could get in "Event plane reconstruction"
  - ρ_0, v_2^{obs}, v_3^{obs} are fitting value.



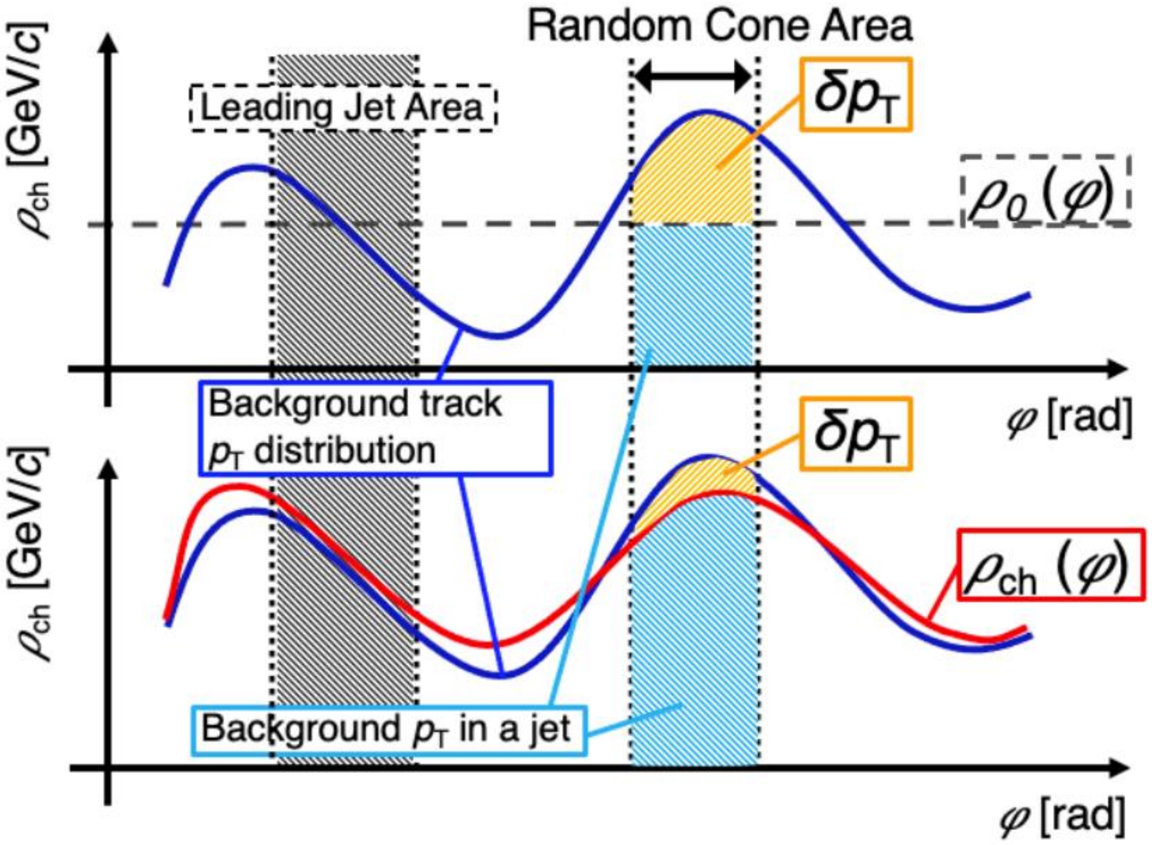
$$\rho(\varphi) = \rho_0 \times (1 + 2\{v_2^{\text{obs}}\cos(2[\varphi - \Psi_{\text{EP},2}]) + v_3^{\text{obs}}\cos(3[\varphi - \Psi_{\text{EP},3}])\})$$

$$\rho_{\text{local}}(\varphi) = \frac{\langle\rho\rangle}{2R\rho_0}\int_{\varphi-R}^{\varphi+R}\rho(\varphi)d\varphi$$

After reconstructing the second and third-order event planes (EP2 and EP3), these were used as inputs for the fit.

$\rho(\varphi)$ Fitting Parameter	**Value**
ρ_0 (fit) = par[0]	47.164 ± 1.132
v_2^{obs} (fit) = par[1]	0.0849 ± 0.016
v_3^{obs} (fit) = par[3]	-0.050 ± 0.017
X^2/NDF	1.089
p-value	0.327

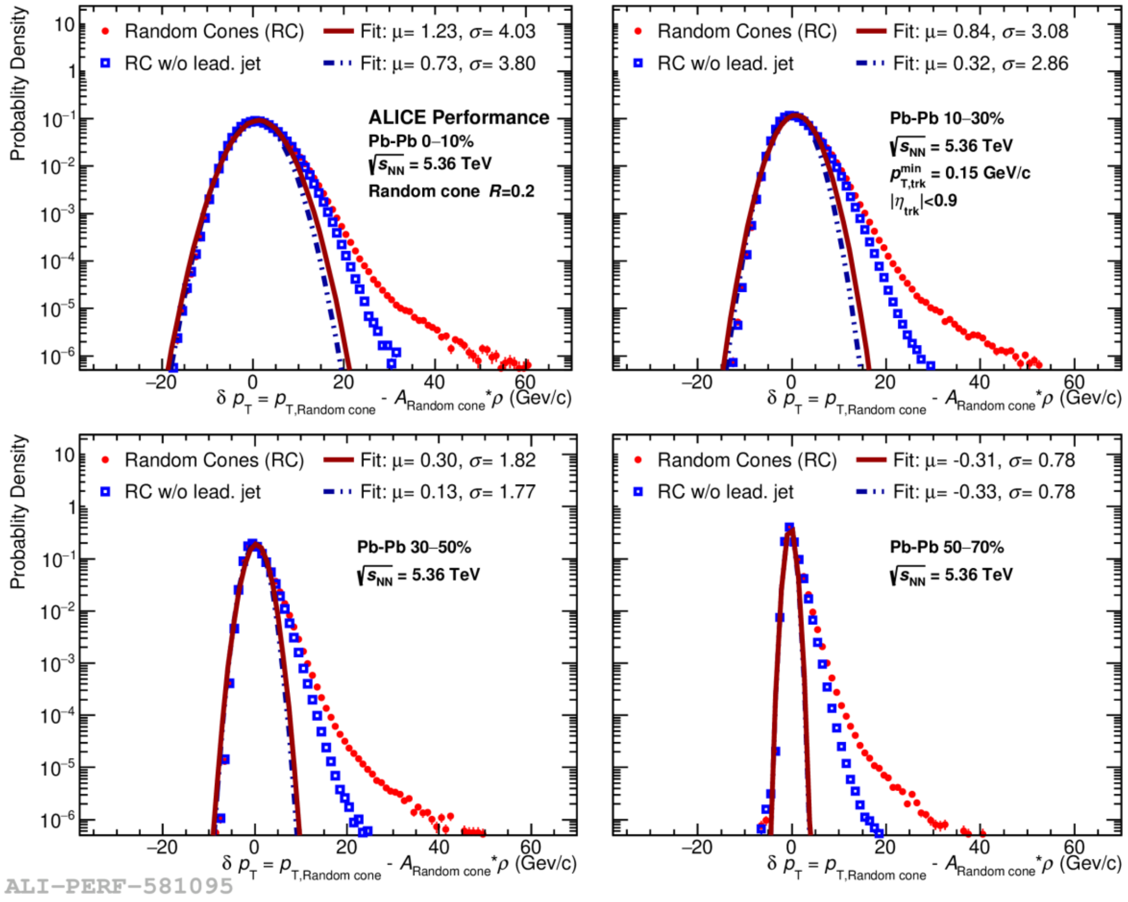
The background can fluctuate in different regions of the collision. We investigate these differences by evaluating the differences in local and event-wise background density.



- We expect the local rho's δp_T should be smaller than the median one.
- Median ρ shows strong φ-dependence in background estimation
- Local ρ reduces the φ-dependence significantly

The Random cone is created once per event except the leading jet region.

Background fluctuations



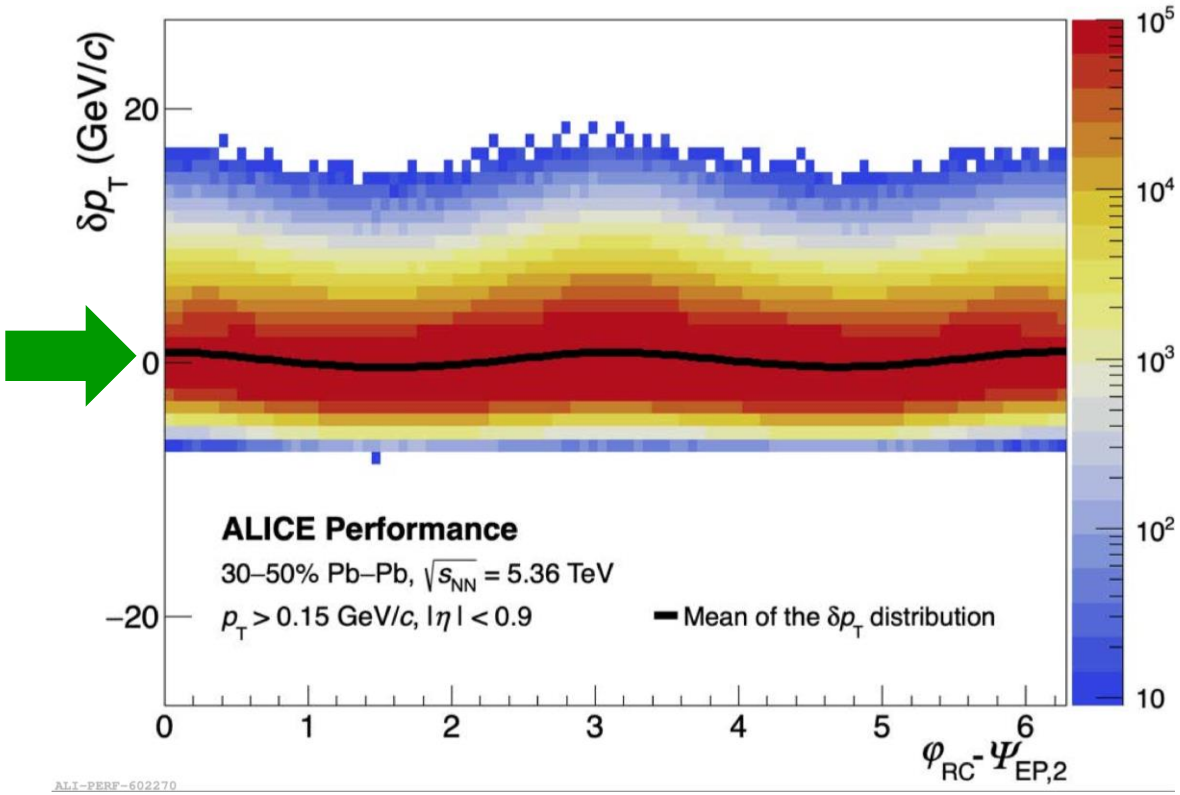
Random-Cone method: $\delta p_{\mathrm{T}} = \sum_i p_{\mathrm{T},i}^{\mathrm{track}} - \langle\rho\rangle \cdot A$

$p_{\mathrm{T},i}$: transverse momentum of tracks in cone

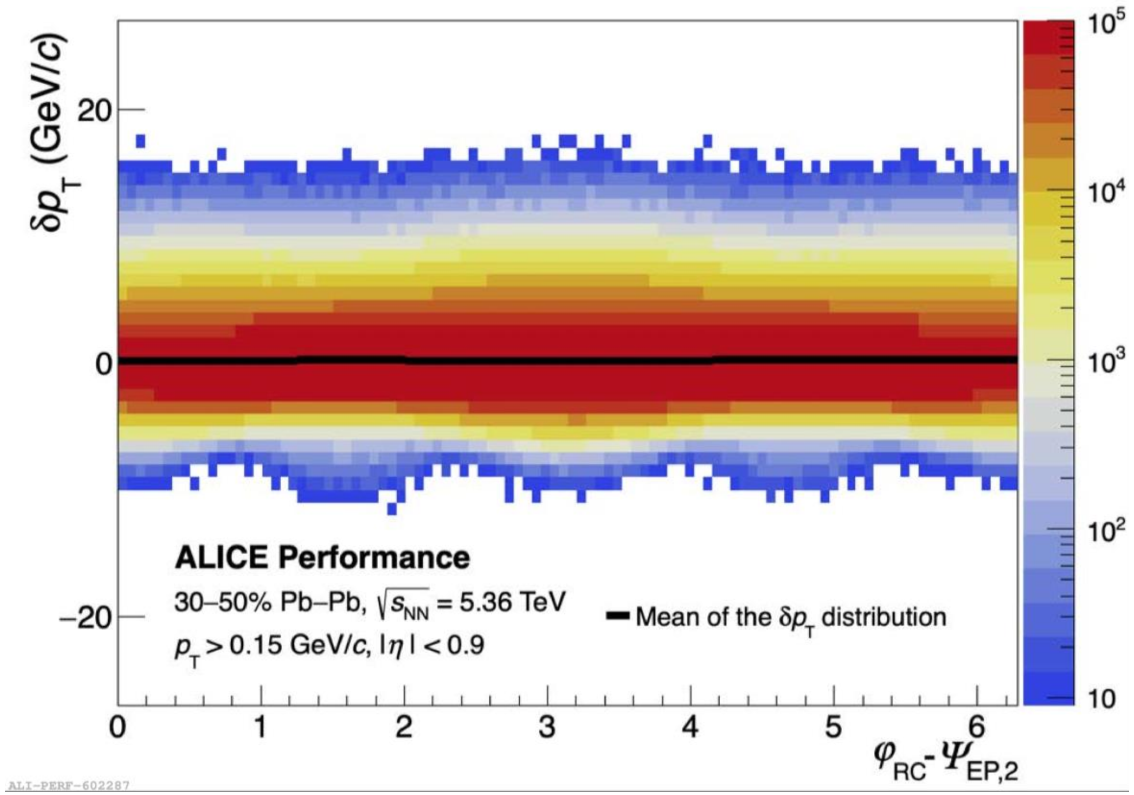
Random R=0.2 cones are reconstructed in each event with and without leading jet

- Excluding the leading jet region helps suppress upward fluctuations in the background estimation. The right-hand-side tail, originating from real jets, is significantly reduced.

Background fluctuation from different background estimation



$\langle\rho\rangle$ subtraction: Background fluctuations depend on φ

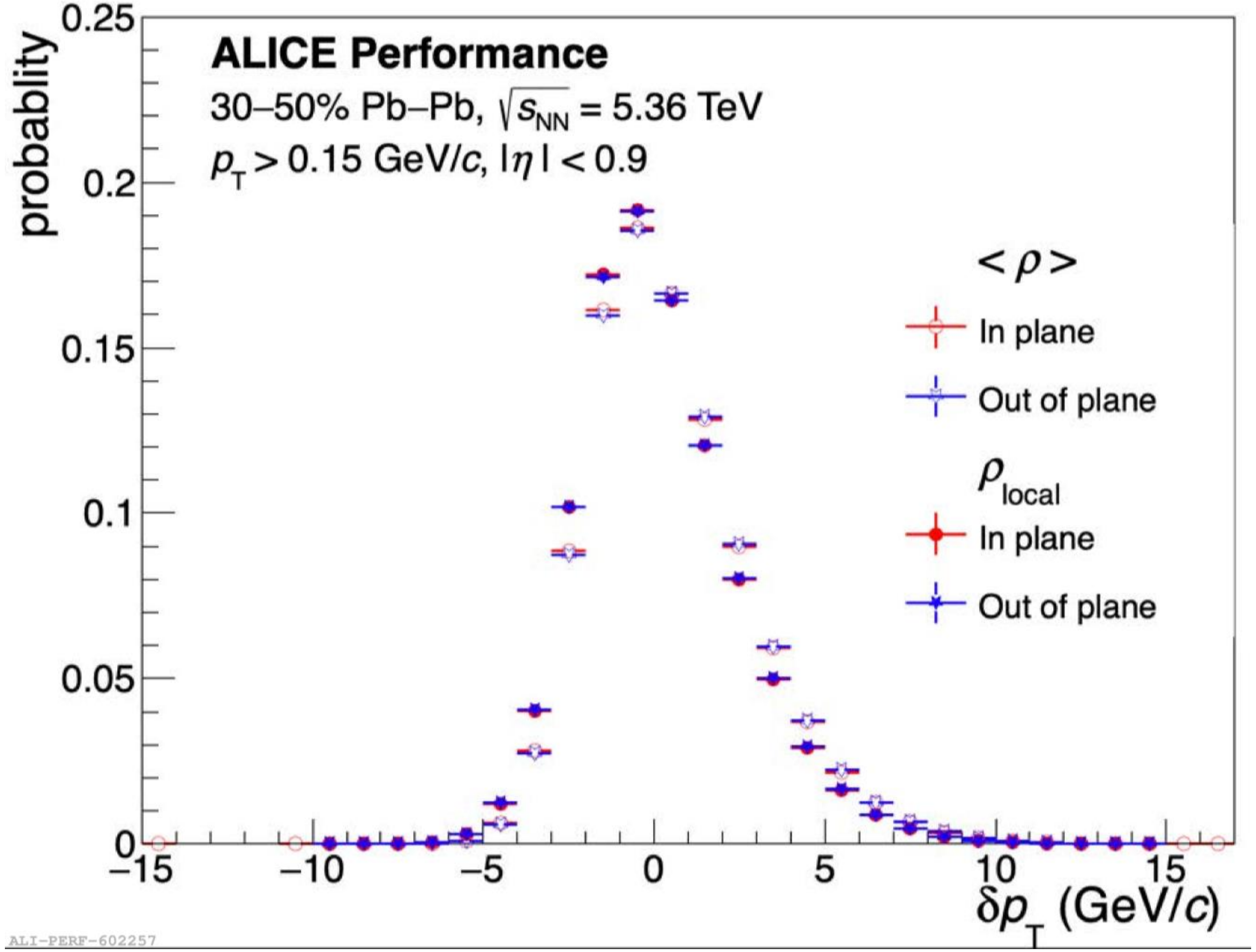


ρ_{local} subtraction: Accounts for φ dependence

- $\delta p_{\mathrm{T}} = \sum_i p_{\mathrm{T},i}^{\mathrm{track}} - \rho_{\mathrm{local}}(\varphi) \cdot A$
- $\delta p_{\mathrm{T}} = \sum_i p_{\mathrm{T},i}^{\mathrm{track}} - \langle\rho\rangle \cdot A$
- $\rho_{\mathrm{local}}(\varphi) = \frac{\langle\rho\rangle}{2R\rho_0}\int_{\varphi-R}^{\varphi+R} \rho_{\mathrm{ch}}(\varphi)d\varphi$

➢ With $\langle\rho\rangle$ subtraction, the fluctuation shows φ dependence, while using ρ_{local} the φ dependence fluctuation disappears.

Background distribution use different background subtraction



- Projection region:

  in-plane: $-\pi/4 < \varphi < \pi/4$,

  $3\pi/4 < \varphi < 5\pi/4$

  out-of-plane: $\pi/4 < \varphi < 3\pi/4$,

  $5\pi/4 < \varphi < 7\pi/4$

- The projected δp_{T} distribution are consistent when using ρ_{local}

- A small φ dependence is found when using $\langle\rho\rangle$ for subtraction

Unfolding correction

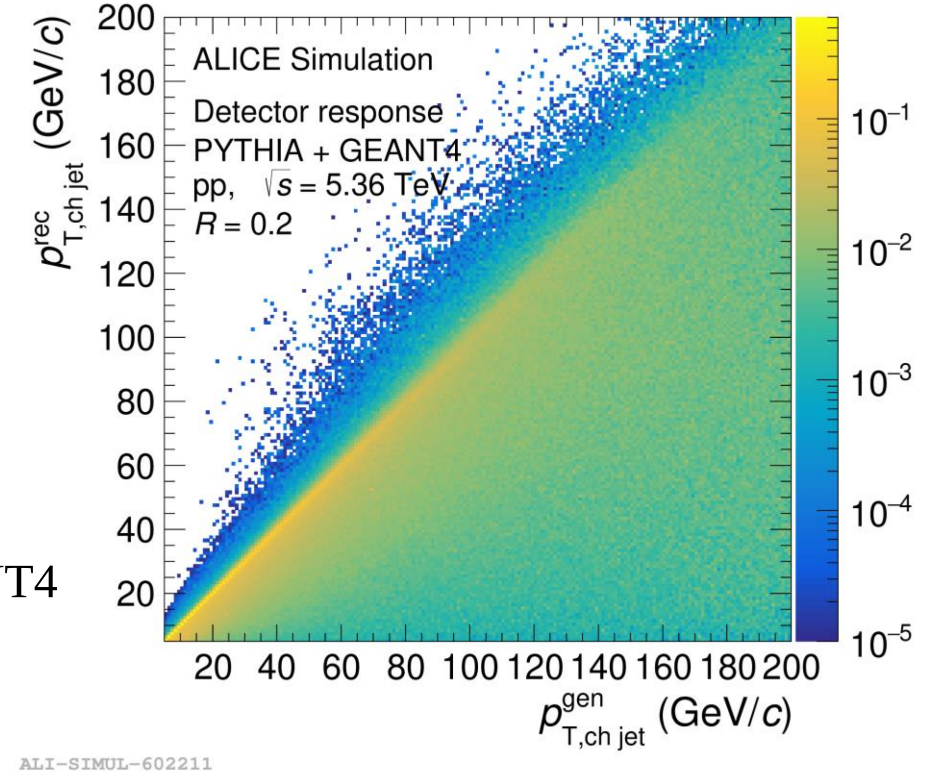
- Unfolding is used to correct the distortion and smearing of the jet p_{T} caused by limited detector resolution and background fluctuations
- To obtain the true jet from the reconstructed jet, unfolding is performed as shown equation:

$$p_{\mathrm{T,jet}}^{\mathrm{truth}} = R^{-1} p_{\mathrm{T,jet}}^{\mathrm{rec}}$$

R is the combined response matrix, formed by multiplying the detector and background fluctuation matrices.

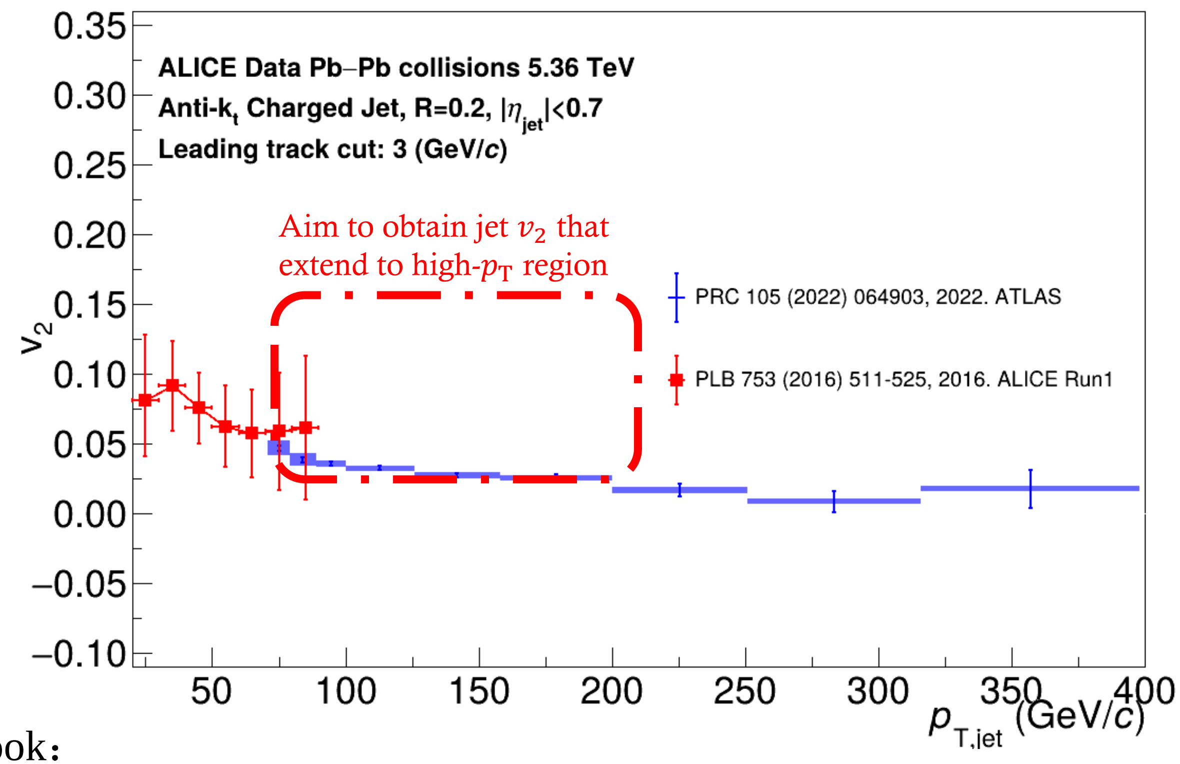
$$R = R_{\mathrm{det}} \otimes R_{\mathrm{fluc}}$$

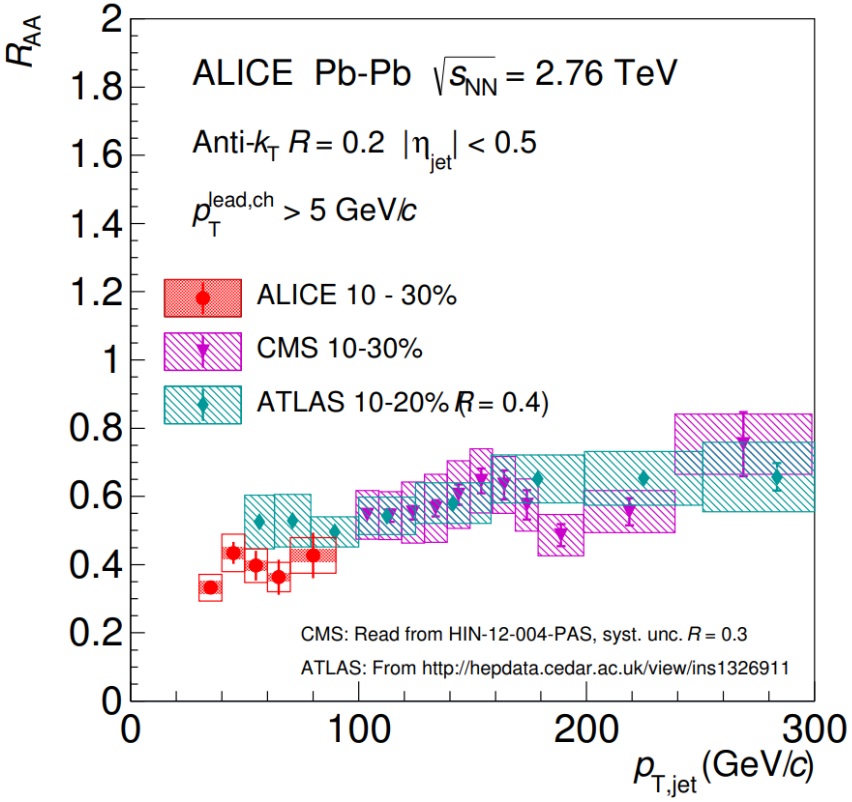
- The detector response matrix is obtained from PYTHIA + GEANT4 simulations of pp collisions under Pb–Pb conditions. It will be further smeared to reflect Pb–Pb detector effects.



➢ Next step: combine this response matrix with background-fluctuations matrix in order to perform unfolding to get the truth-level jet spectra.

Summary and Outlook





Outlook：

- Measure the charged-particle jet spectrum in Pb–Pb collisions during Run 3 to increase the overlap with ATLAS's RAA results.
- Fully unfolded physical results is on the way.
- Further study the impact of background on jet analyses by embedding jets from Monte-Carlo simulations into real minimum-bias Pb-Pb Data.
- In jet v2 analysis will use different detector combinations for EP resolution and incorporate into systematics study.

Thanks for your attention