Two-particle number balance functions in pp collisions at $\sqrt{s} = 13.6$ TeV using event-shape engineering

16th **Regular Conference of the Physics Academy of North East (PANE 2026)**

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Research Scholar and DST–INSPIRE Fellow

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Outline of the presentation

1. Introduction and Motivation
2. Charge Balance Function: A Probe of Local Charge Conservation
3. Event Shape Engineering
4. Simulation and event selection details
5. 2D Distributions of $B(\Delta\eta, \Delta\phi)$
6. Projection and Width Extraction
7. 1D Projections of B
8. Flattenicity Dependence of Charge Balance Function Widths
9. Summary and Conclusions

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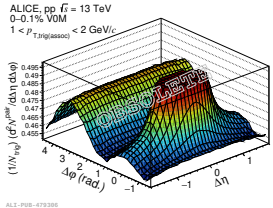

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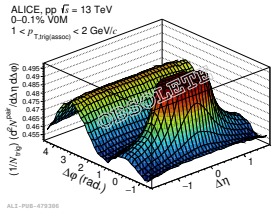

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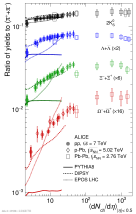

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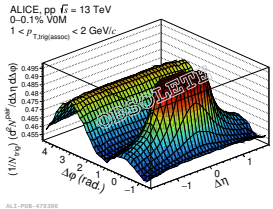

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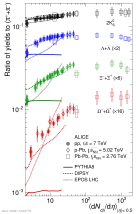

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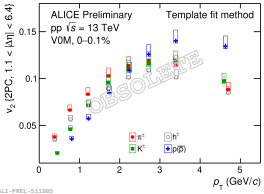

Collective behaviour (v_2)

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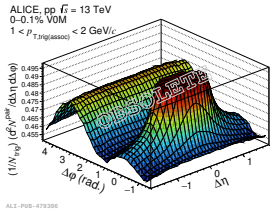

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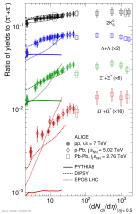

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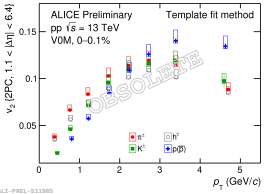


Collective behaviour (v_2)

What drives these phenomena in small collision systems?



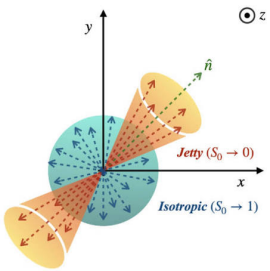
Research Motivation

Previous studies

- Transverse spherocity: jet-like vs. isotropic events [Behera *et al.*, Phys. Rev. D 114, 036025 (2026)]
- Relative transverse activity (R_T) [Roy *et al.*, arXiv:2602.19566 [hep-ph]]

Why Flattenicity?

- Sensitive to particle-density fluctuations in both η and φ.
- Provides a complementary view of event topology beyond azimuthal information alone.



Flattenicity provides aditional dimension:

Explore how charge-balancing correlations depend on **spatial distribution and topology of particle production**

Charge Balance Function: Understanding Charge Conservation

Electric charge is conserved in every microscopic partcile-production process.

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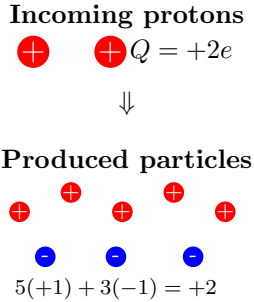

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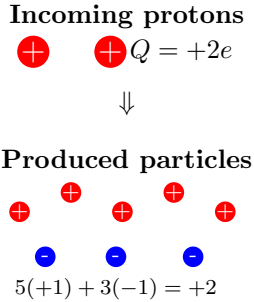
What does the balance function give us?

The charge balance function quantifies the conditional probability of finding a balancing charge associated with a given charged particle.



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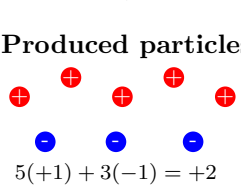
Incoming protons





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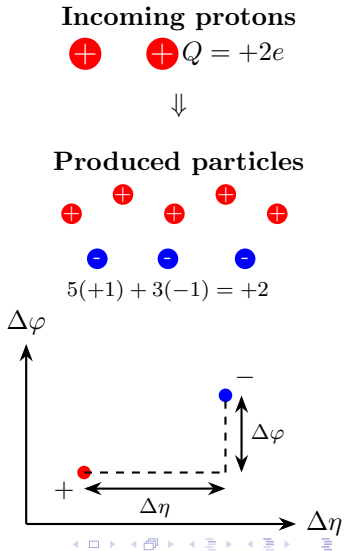

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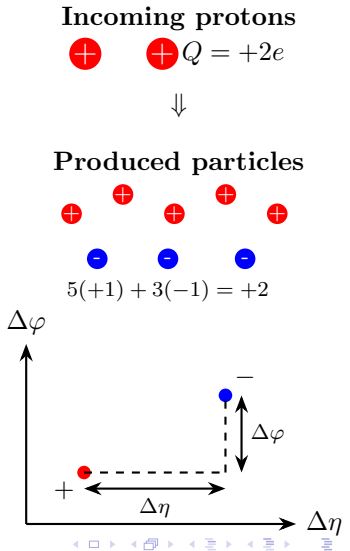
Their relative separation carries information about particle production.



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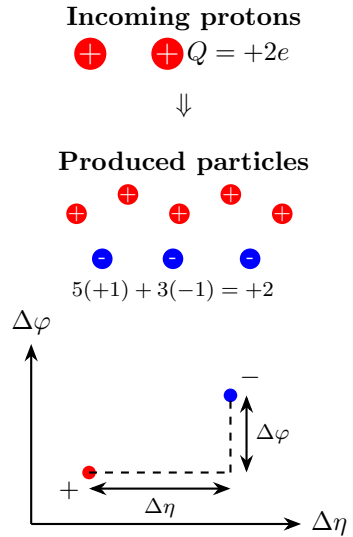
$$B(\Delta\eta, \Delta\varphi) = \frac{1}{2}\left[C_2^{(+,-)} + C_2^{(-,+)} - C_2^{(-,-)} - C_2^{(+,+)}\right] \quad (1)$$



Charge Balance Function

Balance Function

$$B = \frac{1}{2}\left[C_2^{(+,-)} + C_2^{(-,+)} - C_2^{(-,-)} - C_2^{(+,+)}\right]$$

$$\frac{1}{N_{\text{trig}}}\frac{d^2N_{\text{pair}}}{d\Delta\eta\, d\Delta\phi} = C_2(\Delta\eta, \Delta\phi) = M(0,0)\frac{S(\Delta\eta, \Delta\phi)}{M(\Delta\eta, \Delta\phi)}$$

[Phys. Rev. D 114, 036025 (2026)]

- Probes local charge conservation
- Sensitive to time of hadronization and diffusion
- Width reflects the separation of balancing charge pairs

$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{trig}}}\frac{d^2N^{\text{same}}}{d\Delta\eta\, d\Delta\phi}$$

$$M(\Delta\eta, \Delta\phi) = \frac{1}{N_{\text{trig}}}\frac{d^2N^{\text{mix}}}{d\Delta\eta\, d\Delta\phi}$$

$S(\Delta\eta, \Delta\phi)$ = normalized signal event distribution
$M(\Delta\eta, \Delta\phi)$ = normalized mixed event distribution
$M(0,0)$ = mixed event yield when both particles are emitted in nearly the same direction

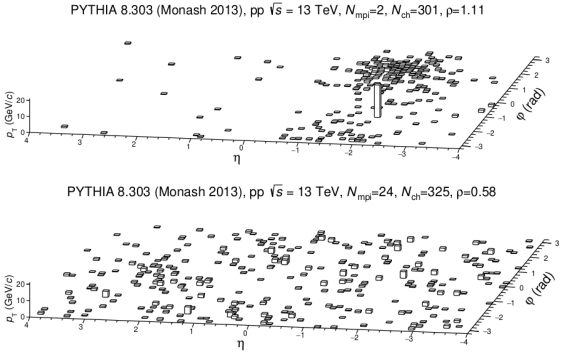
Event Shape Engineering

Event classification: Flattenicity

- Flattenicity ($\rho_{\rm nch}$), proposed by Ortiz *et al.*, classifies events according to event topology beyond charged-particle multiplicity.
- Reduces bias toward hard processes while remaining sensitive to multijet and MPI activity
- Quantifies multiplicity fluctuations across transverse cells

$$\rho_{\rm nch} = \frac{\sqrt{\sum_i \left(N_{\rm ch}^{{\rm cell},i} - \langle N_{\rm ch}^{\rm cell}\rangle\right)^2 / N_{\rm cell}^2}}{\langle N_{\rm ch}^{\rm cell}\rangle}$$

- **Isotropic events:** $1-\rho_{\rm nch} \to 1$ **; Jet-like events:** $1-\rho_{\rm nch} \to 0$



[arXiv:2204.13733 [hep-ph]]

PYTHIA 8 Simulation and Event Selection

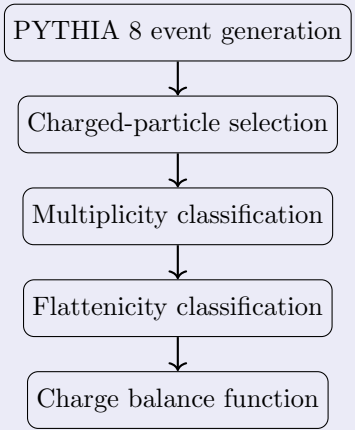
Event Generation

- Event generator: `PYTHIA 8.315`
- Collision system: pp
- Centre-of-mass energy: $\sqrt{s} = 13.6$ TeV
- Monash 2013 tune
- Colour Reconnection & MPI-based ($RR = 1.8$)
- Non-diffractive inelastic collisions

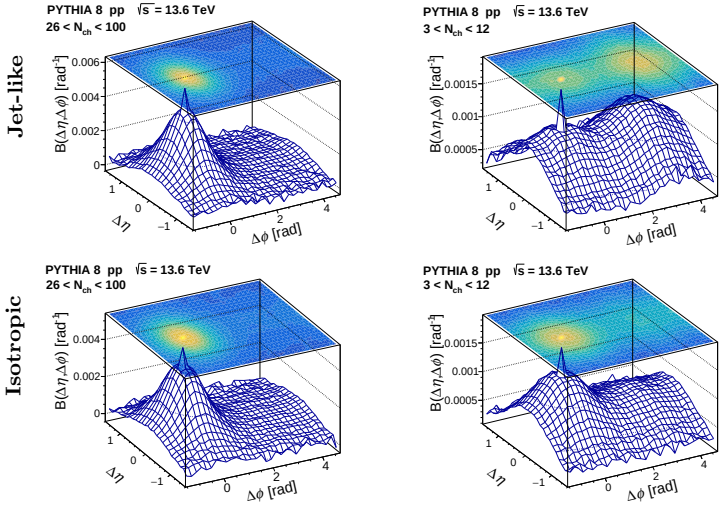
Selection criteria

- Final-state charged particles
- $0.2 < p_{\mathrm{T}} < 5.0$ GeV/c
- $|\eta| < 0.8$

Analysis Procedure



2D Distributions of $B(\Delta\eta, \Delta\phi)$:



- Pronounced **near-side peak at** $(\Delta\eta, \Delta\phi) \approx (0, 0)$ observed for both event classes, **indicating strong short range charge correlation**
- A broad **away-side correlation around** $\Delta\phi \approx \pi$ is present in all multiplicity classes and becomes **relatively more visible at lower multiplicities indicating** .

Projection and Width Extraction

Projection Procedure

- Two-dimensional observable:

$$B(\Delta\eta, \Delta\phi)$$

- Projection onto $\Delta\eta$:

$$-\frac{\pi}{2} \leq \Delta\phi \leq \frac{\pi}{2}$$

- Projection onto $\Delta\phi$:

$$-1.0 \leq \Delta\eta \leq 1.0$$

- Projected distributions are used to quantify the correlation width.
- Narrower widths indicate stronger localization of balancing pairs.

RMS Width

$$\sigma = \left[\frac{\sum_i O(\Omega_i)\, \Omega_i^2}{\sum_i O(\Omega_i)} \right]^{1/2}$$

where

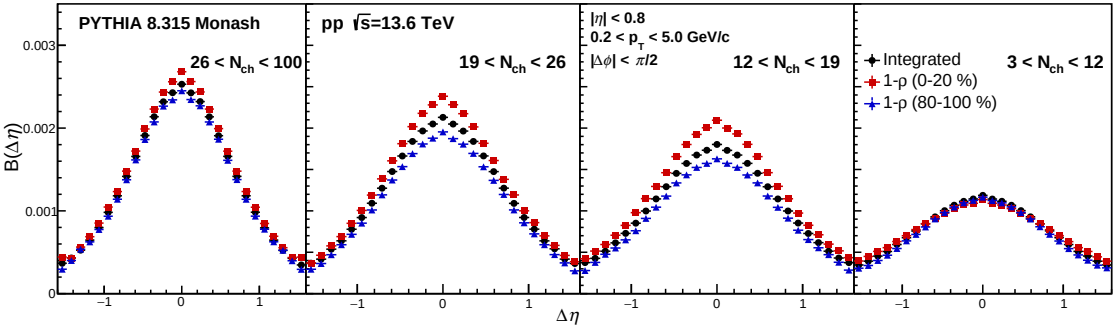
$$O(\Omega_i) = B(\Omega_i)$$

$$\Omega = \Delta\eta \text{ or } \Delta\phi.$$

Comparison

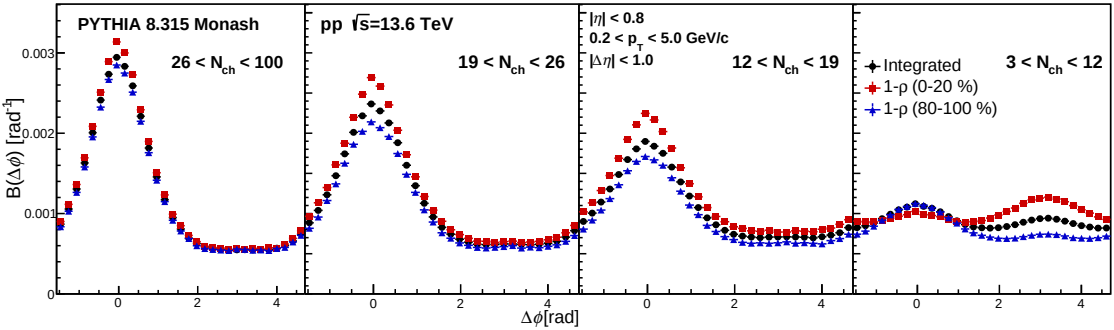
Extracted RMS widths are compared for different flattenicity classes.

1D projections: $B(\Delta\eta)$



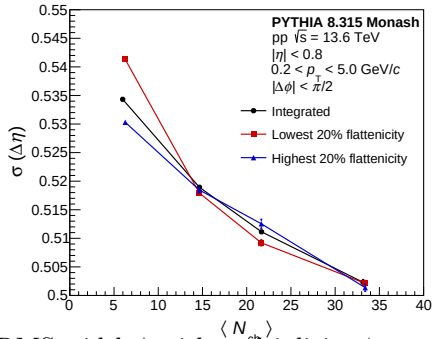
- A pronounced peak at $\Delta\eta = 0$ indicate **strong short-range charge correlations**.
- Peak magnitude decreases with decreasing charged-particle multiplicity, reflecting weaker charge correlations.
- **Jet-like events** exhibit stronger charge correlations than **Isotropic-like events**, with the flattenicity dependence becoming weaker at lower multiplicities.

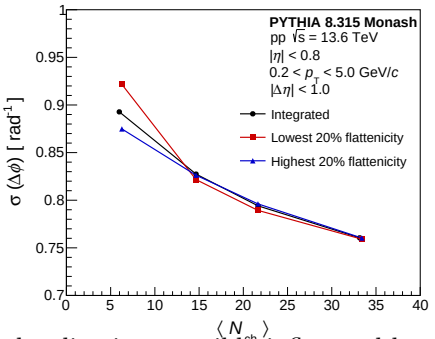
1D projections: $B(\Delta\phi)$



- Pronounced near-side peaks at $\Delta\phi = 0$ indicate strong short-range charge correlations.
- The away side peak at $\Delta\phi = \pi$ magnitide becoming more prominent at lower multiplicity classes, associated with approximately **back-to-back particle (dijet) production**
- **Jet-like events** exhibit stronger charge correlations than **Isotropic-like events**.

Flattenicity Dependence of Charge Balance Function Widths





- RMS width ↓ with multiplicity ↑ ⇒ stronger charge localization; possibly influenced by changing **MPI and CR** contributions (PYTHIA 8).
- Jet-like events exhibit narrower $\sigma(\Delta\eta)$ than isotropic events.
- Flattenicity has only a weak effect on $\sigma(\Delta\phi)$.

Flattenicity exhibit a clear modification of the balance function width, demonstrating the influence of event topology on charge balancing.

Summary and Conclusions

- The charge balance function exhibits a pronounced near-side peak, indicating strong short-range charge correlations.
- The correlation strength increases with charged-particle multiplicity, accompanied by a narrowing of the balance-function distributions.
- Jet-like events exhibit stronger near-side charge correlations than isotropic events, with the flattenicity dependence becoming weaker at lower multiplicities.
- Jet-like events show narrower $\sigma(\Delta\eta)$, whereas the flattenicity dependence of $\sigma(\Delta\phi)$ is relatively weak.

Main message

Flattenicity provides an additional handle to investigate the dependence of charge-balance correlations spatial distribution of particle production in (η, ϕ) space.

For further reading: arXiv:2610.26058 [hep-ph]

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