An introduction to my research activities

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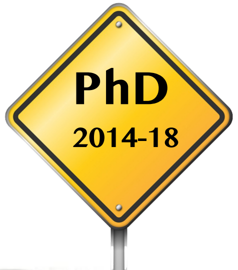
ALICE

My journey so far…

Indian Institute of Technology, Indore (India)



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Indian Institute of Technology, Indore (India)

PhD
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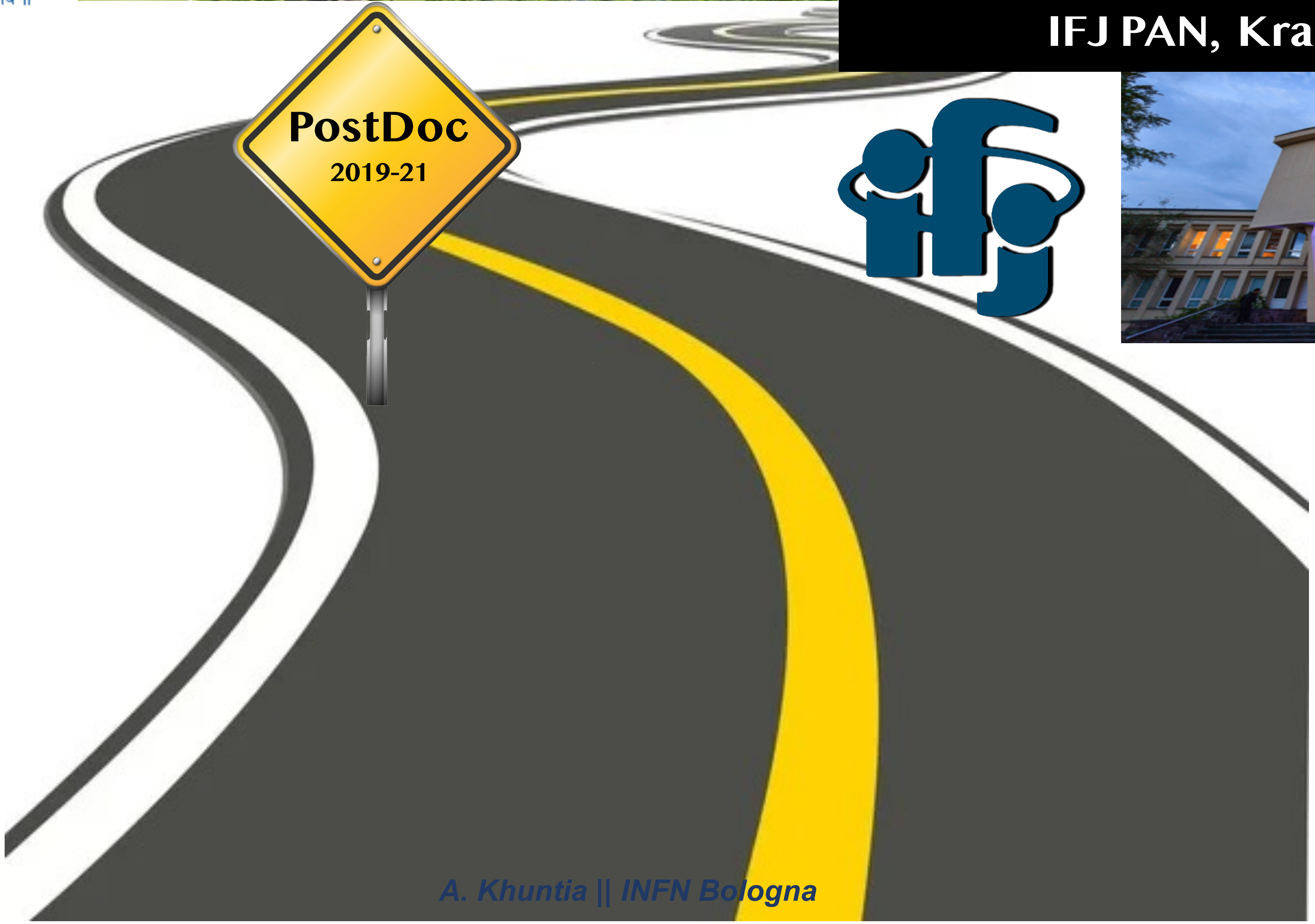

My journey so far…

Indian Institute of Technology, Indore (India)

PhD
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IFJ PAN, Krakow (Poland)

PostDoc
2021-23

Czech Technical University in Prague (CR)

PostDoc
2019-21

My experience in a nutshell

- Resonance production in small collision system to probe the hadronic phase

- Event shape dependence of particle production to understand the QGP-like effects in small collision systems

  - ✓ Transverse spherocity (S_{O})
  - ✓ Relative transverse activity classifier (R_{T})
  - ✓ Charged particle flattenicity (ρ)

- Azimuthal anisotropy in coherent ρ^0 photoproduction in ultra-peripheral collisions (UPCs)

- Contribution to the development of simulation, digitization, reconstruction and QC of the FV0 and FDD

My experience in a nutshell

- Resonance production in small collision system to probe the hadronic phase

- Event shape dependence of particle production to understand the QGP-like effects in small collision systems

  - ✓ Transverse spherocity (S_{O})
  - ✓ Relative transverse activity classifier (R_{T})
  - ✓ **Charged particle flattenicity (ρ)**

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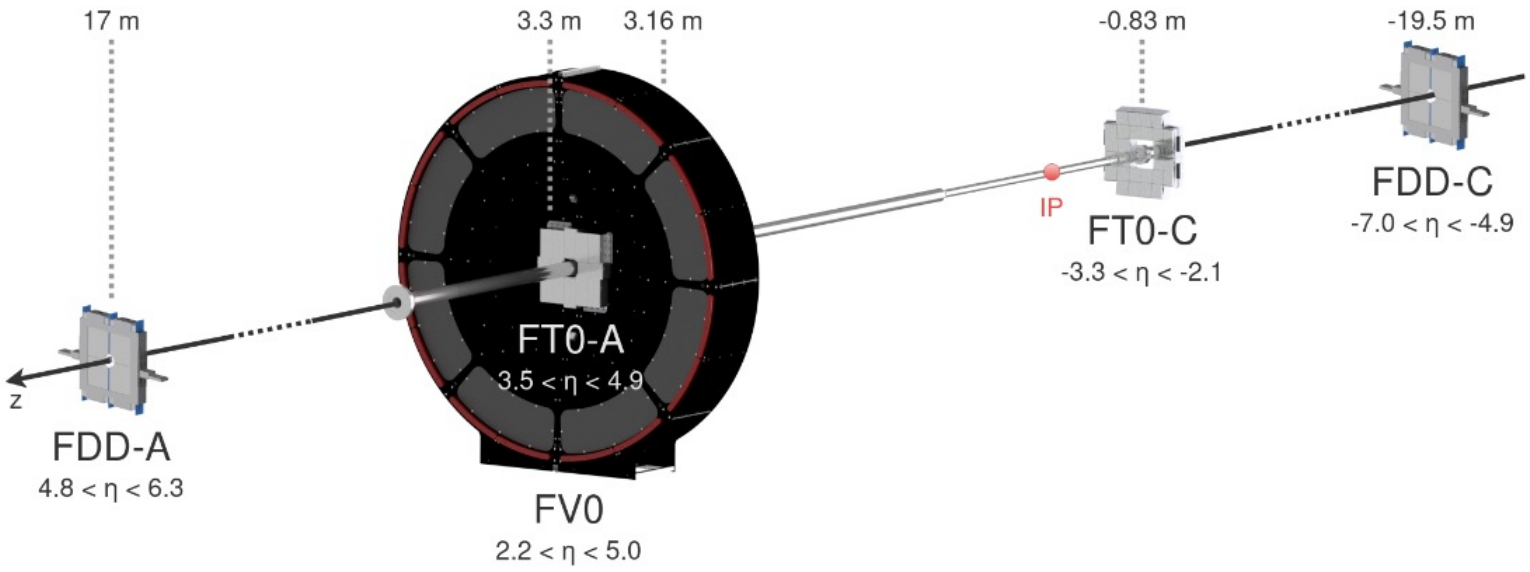
- **Contribution to the development of simulation, digitization, reconstruction and QC of the FV0 and FDD**

Fast Interaction Trigger (FIT)

FIT delivers:

- Minimum latency interaction trigger (< 425 ns)
- Vertex position
- Determine centrality/multiplicity
- Precise collision time for TOF-based particle identification
- Luminosity and background monitoring
- Veto for ultra-peripheral collisions

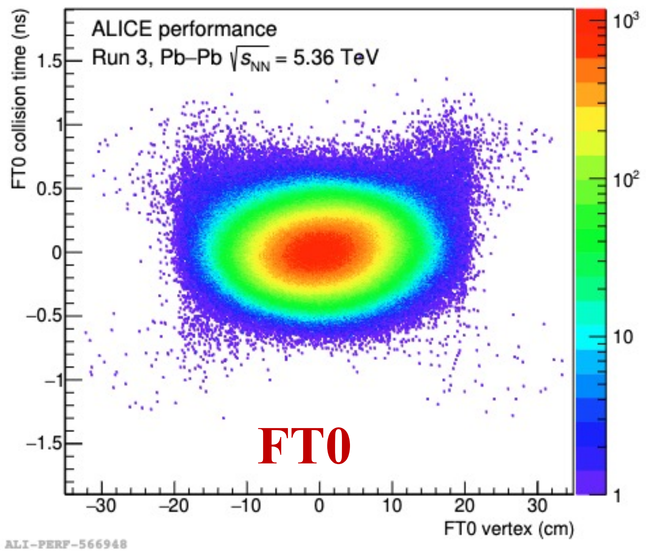
FIT = FT0 + FV0 + FDD

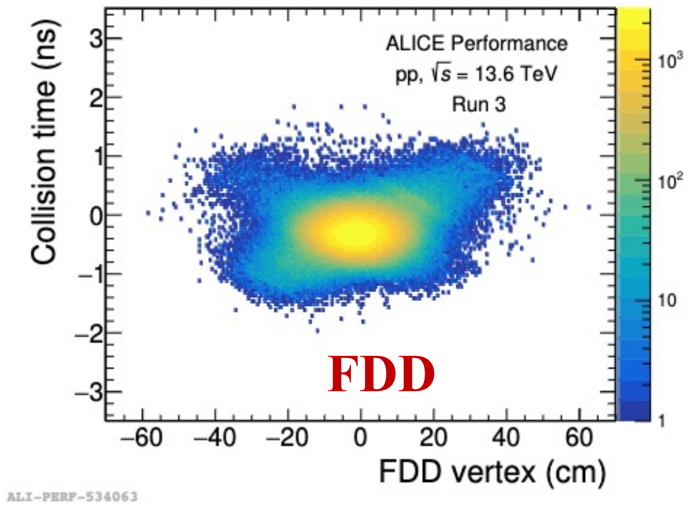


Contributed to the simulation, digitization, reconstruction and QC for the FV0 and FDD (2020-2023)

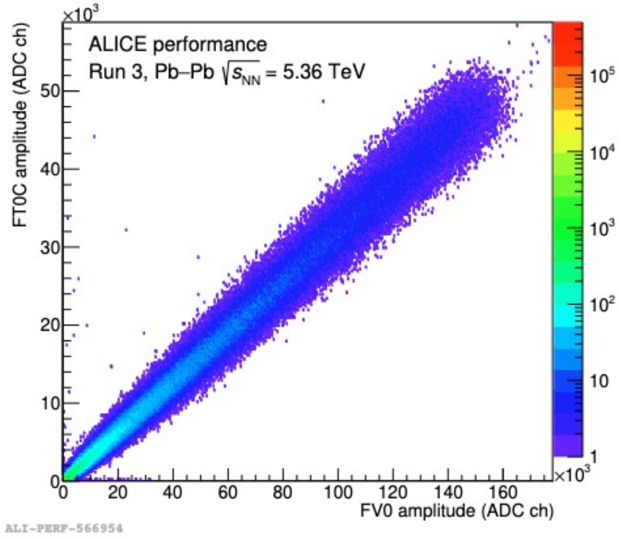
FIT performance

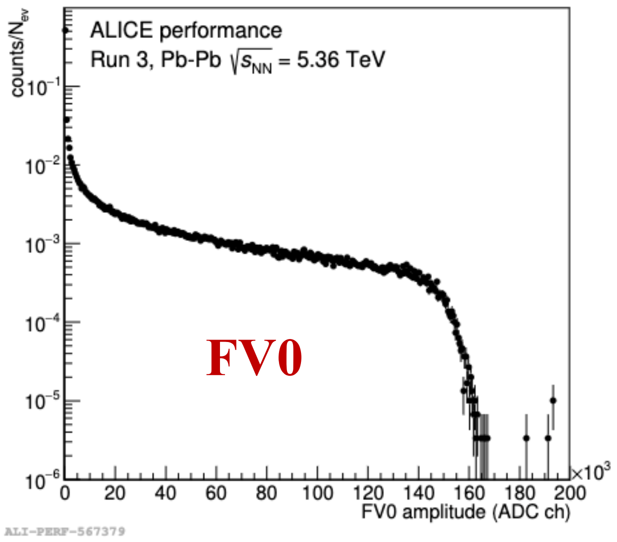
Good vertex and collision time from FT0 and FDD





Very good correlation of amplitudes between the FT0C and FV0

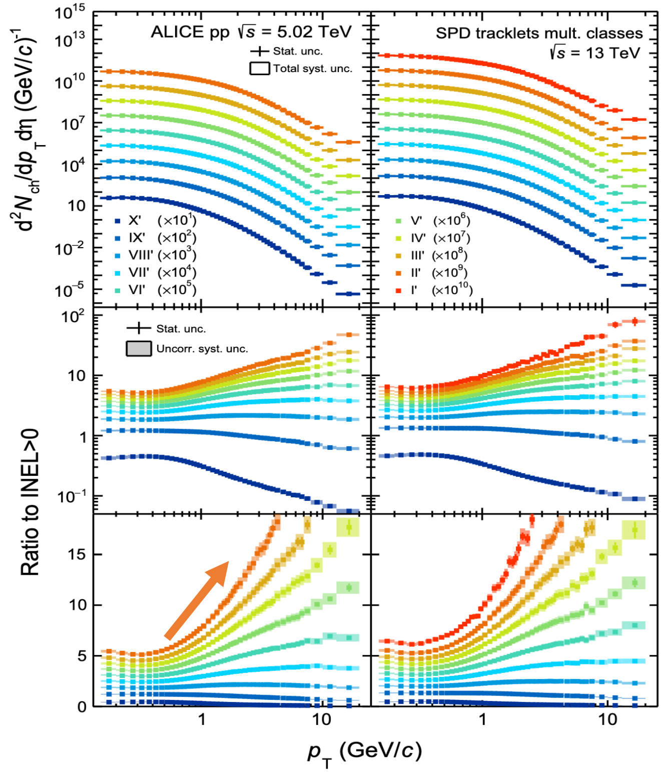




Particle production with event shape variables

Small system at the LHC energies

- High multiplicity events have significant bias towards hard physics processes



ALICE, Eur. Phys. J. C 79, 857 (2019)

Ratio of yield in MPI-enhanced pp collisions to yield in minimum bias (MB) pp collision

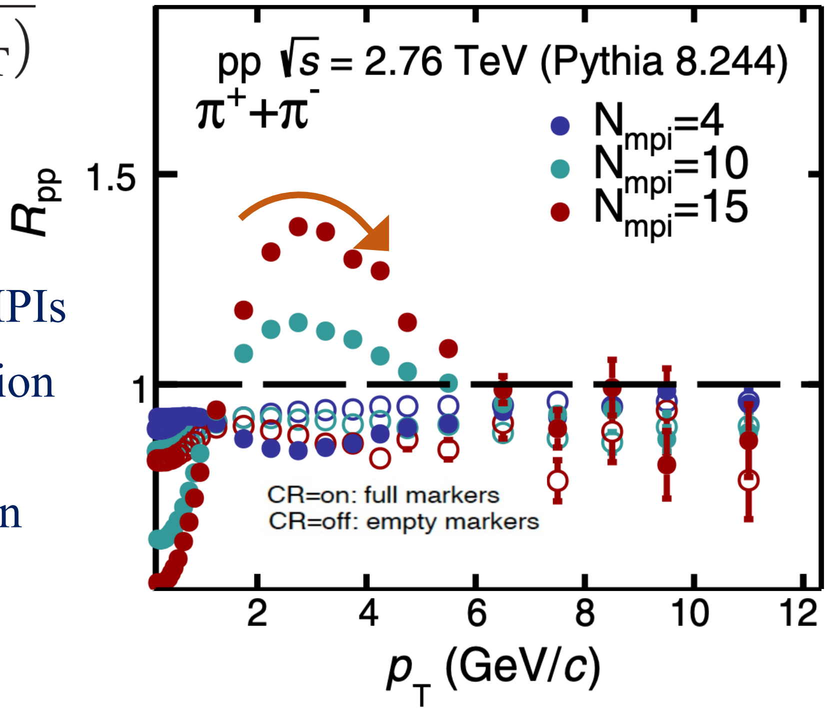
$$R = \frac{d^2N_{\pi}^{mpi}/(\langle N_{mpi}\rangle dy dp_T)}{d^2N_{\pi}^{MB}/(\langle N_{mpi,MB}\rangle dy dp_T)}$$

→ At intermediate p_T, a "bump" structure in events with higher MPIs

→ Only seen with Color Reconnection (CR)

→ High p_T yield does not depend on the selection with MPIs

A. Ortiz, A. Paz et al., Phys. Rev. D 102, 076014 (2020)



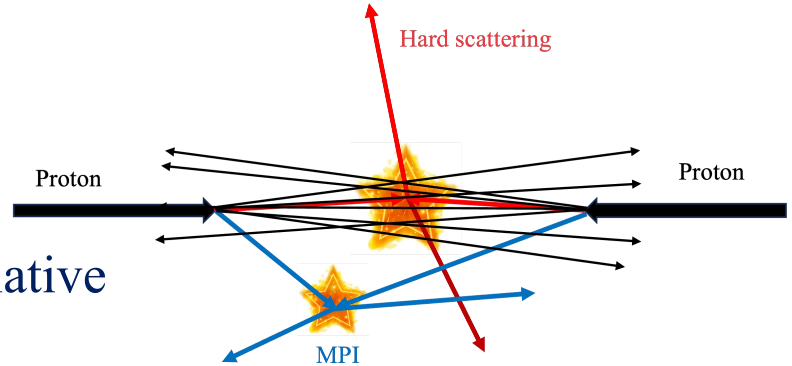
In such cases, we need other observables to characterize event's sensitivity to MPI with reduced selection bias

What are the possible observables?

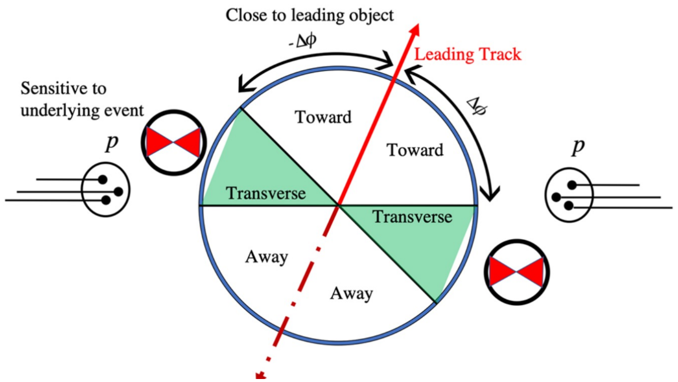
Underlying event in small collision system

- In pp the underlying event (UE) is defined as the set of particles which do not originate from the primary hard parton-parton scattering

  - ➢ MPIs, initial- and final-state radiation (ISR/FSR), beam remnants



P. Palni, A. Khuntia et al, Eur. Phys. J. C 80 (2020)

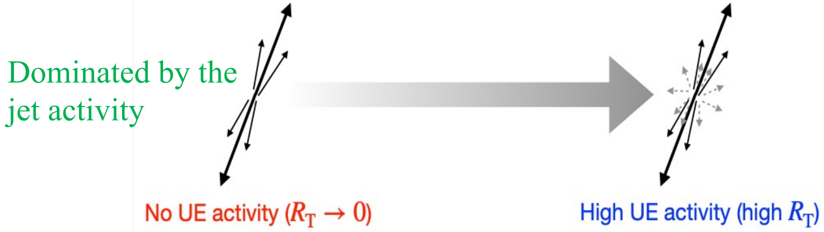


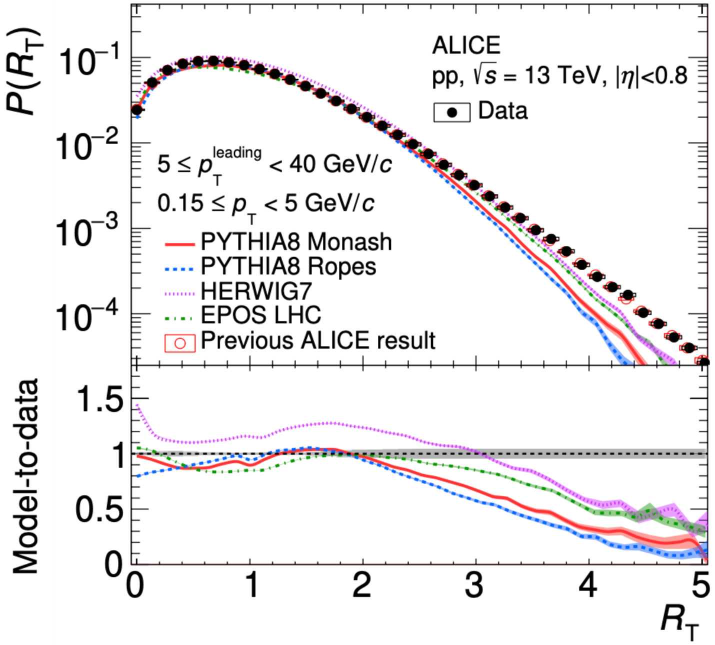
- The UE activity is quantified using the relative transverse activity classifier, R_T

$$R_T = \frac{N_T}{\langle N_T \rangle}$$

where N_T is the charged-particle multiplicity in the transverse region per event and $\langle N_T \rangle$ is the average value over all the analysed events

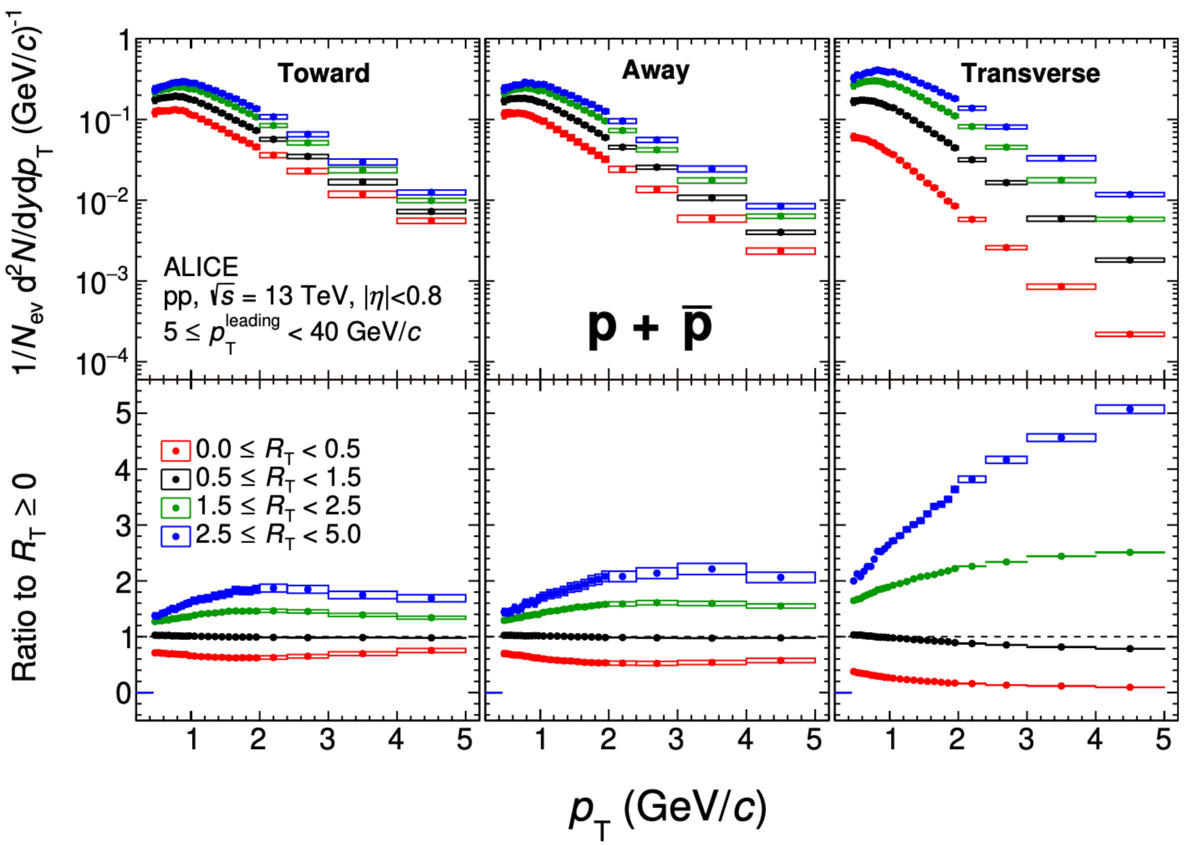
- R_T helps to control the UE contributions in an event



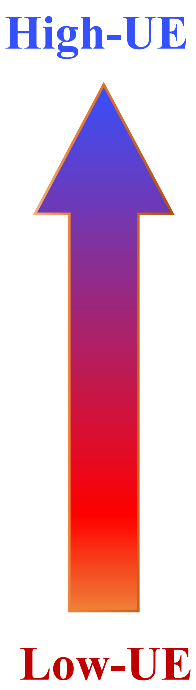


ALICE, JHEP 06, 027 (2023)

Selection with R_T: p_T-spectra



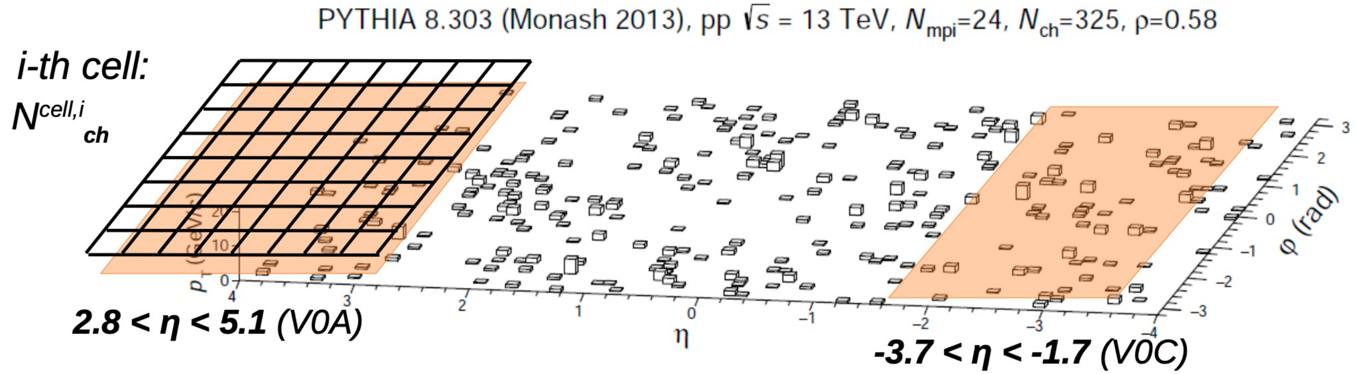
ALICE, JHEP 06, 027 (2023)

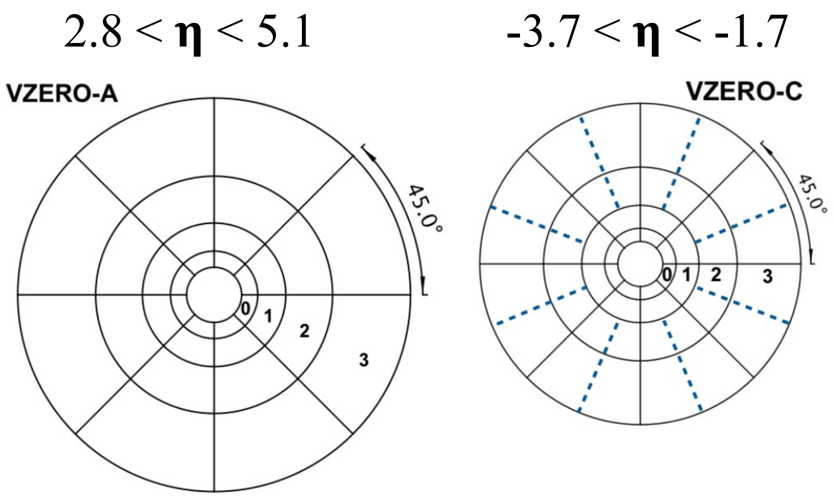


- Depletion of low-p_T particles with increasing R_T and mild dependence at high p_T for toward and away regions → Possibly a feature of radial flow
- The spectra harden with increasing UE activity at high p_T in the transverse region → Possibly due to a selection bias (contribution from multi-jet topologies)

Flattenicity(ρ): Event classification

- It is sensitive to soft particle production and can separate the multi-jet topology from multi-minijet one
- Define a grid in η – φ space covered by the V0 detector of ALICE
  - ➢ $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C) and full azimuth
- Measure charged particle multiplicity in a grid of N_{cell} (64 cells)





A. Ortiz et. al, Rev. Mex. Fis. Suppl. 3 (2022) 4, 040911

ALICE, JINST 8 P10016 (2013)

Flattenicity(ρ) is defined event-by-event :

$$\rho = \frac{\sqrt{\sum_i (N_{\text{ch}}^{\text{cell},i} - \langle N_{\text{ch}}^{\text{cell}} \rangle)^2 / N_{\text{cell}}^2}}{\langle N_{\text{ch}}^{\text{cell}} \rangle}$$

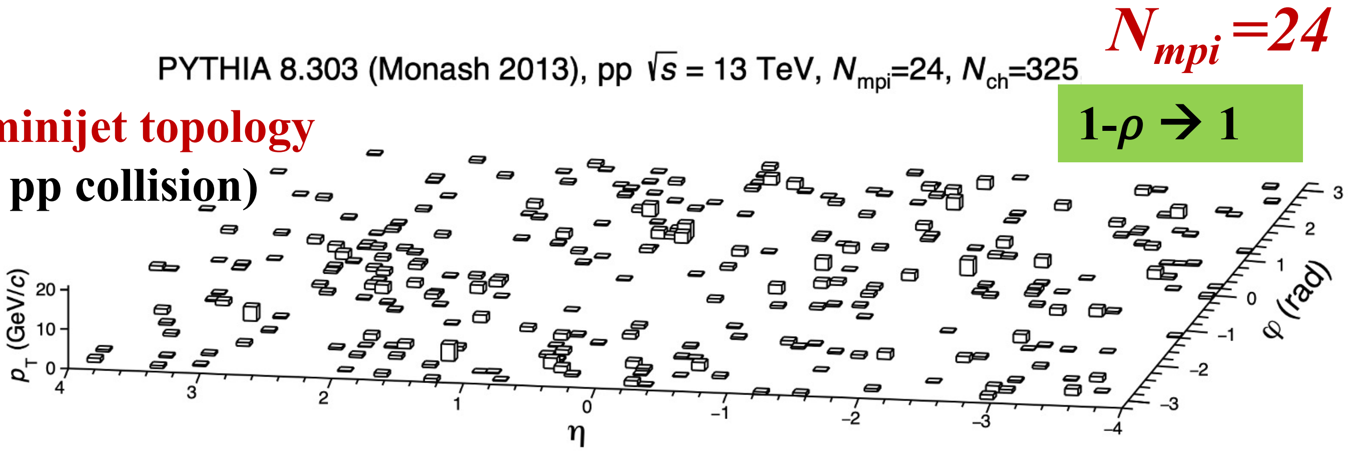
$N^{\text{cell,i}}_{\text{ch}}$: Charged-particle multiplicity in the i-th cell

$\langle N^{\text{cell}}_{\text{ch}} \rangle$: Event-average of $N^{\text{cell,i}}_{\text{ch}}$

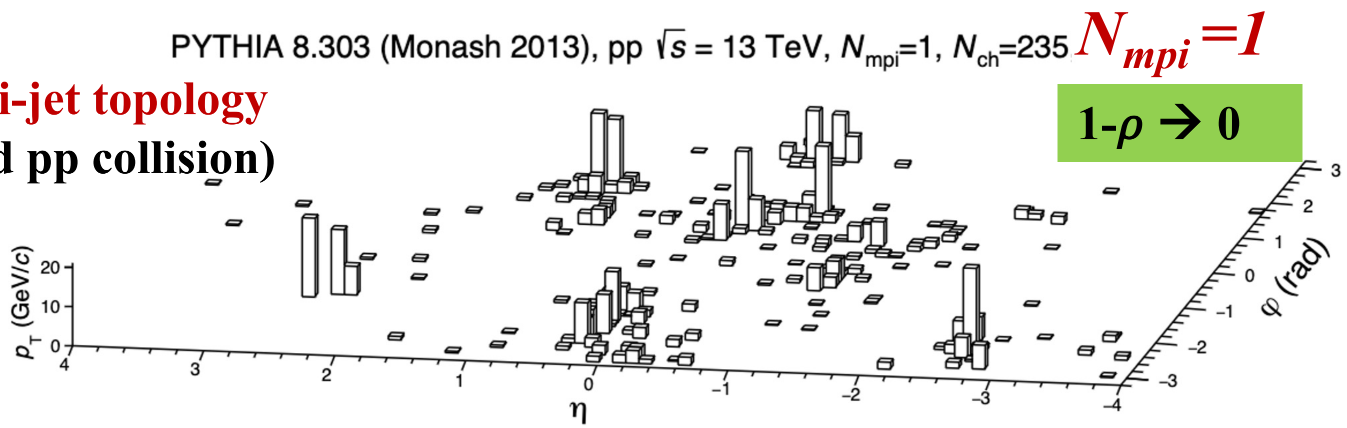
Flattenicity(ρ): Event Classification

Events having similar charged particle multiplicity with different MPIs

Multi-minijet topology
(soft pp collision)



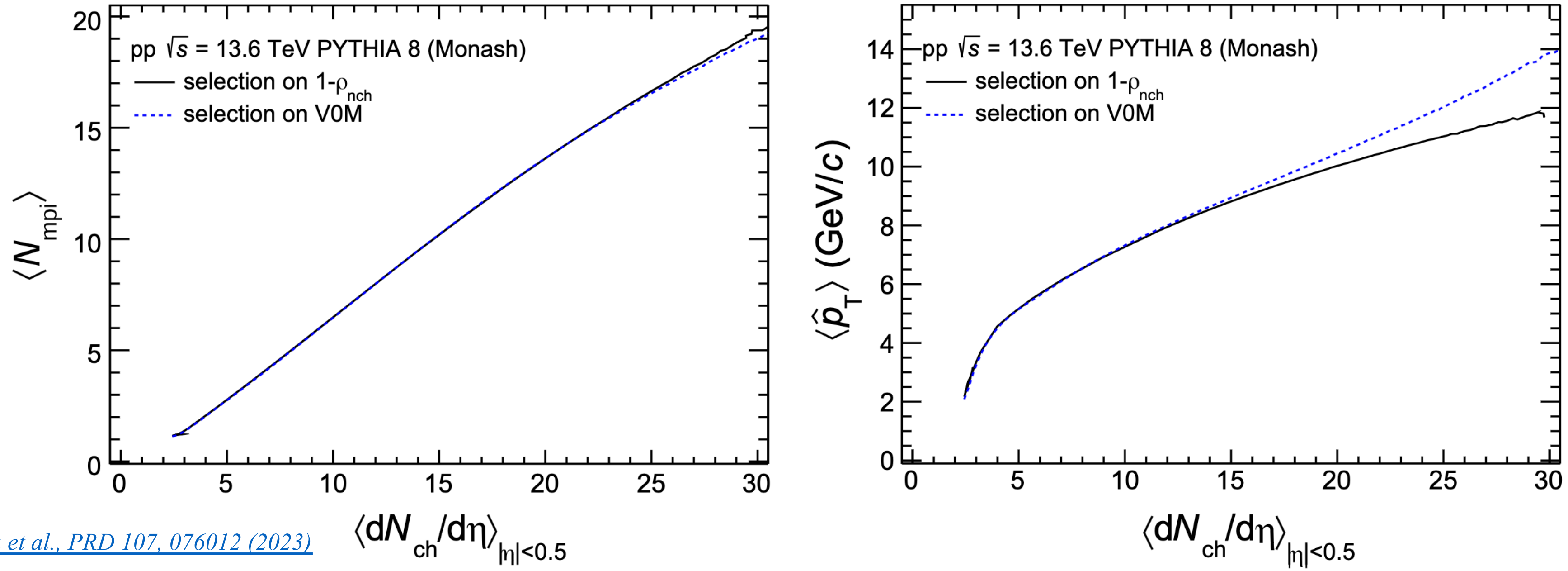
Multi-jet topology
(Hard pp collision)



- Events originate from pp collisions, where several semi-hard scatterings occur within the same pp collision, 1-ρ →1
- For multi-jet topology, 1-ρ →0
- Flattenicity seems to be robust to discriminate the multi mini-jet topology from multi-jet one

Event Selection: Flattenicity (ρnch) Vs. V0M

- Average number of multi-partonic interactions increases with the increase of the event activity estimator (V0M multiplicity or $1-\rho$)

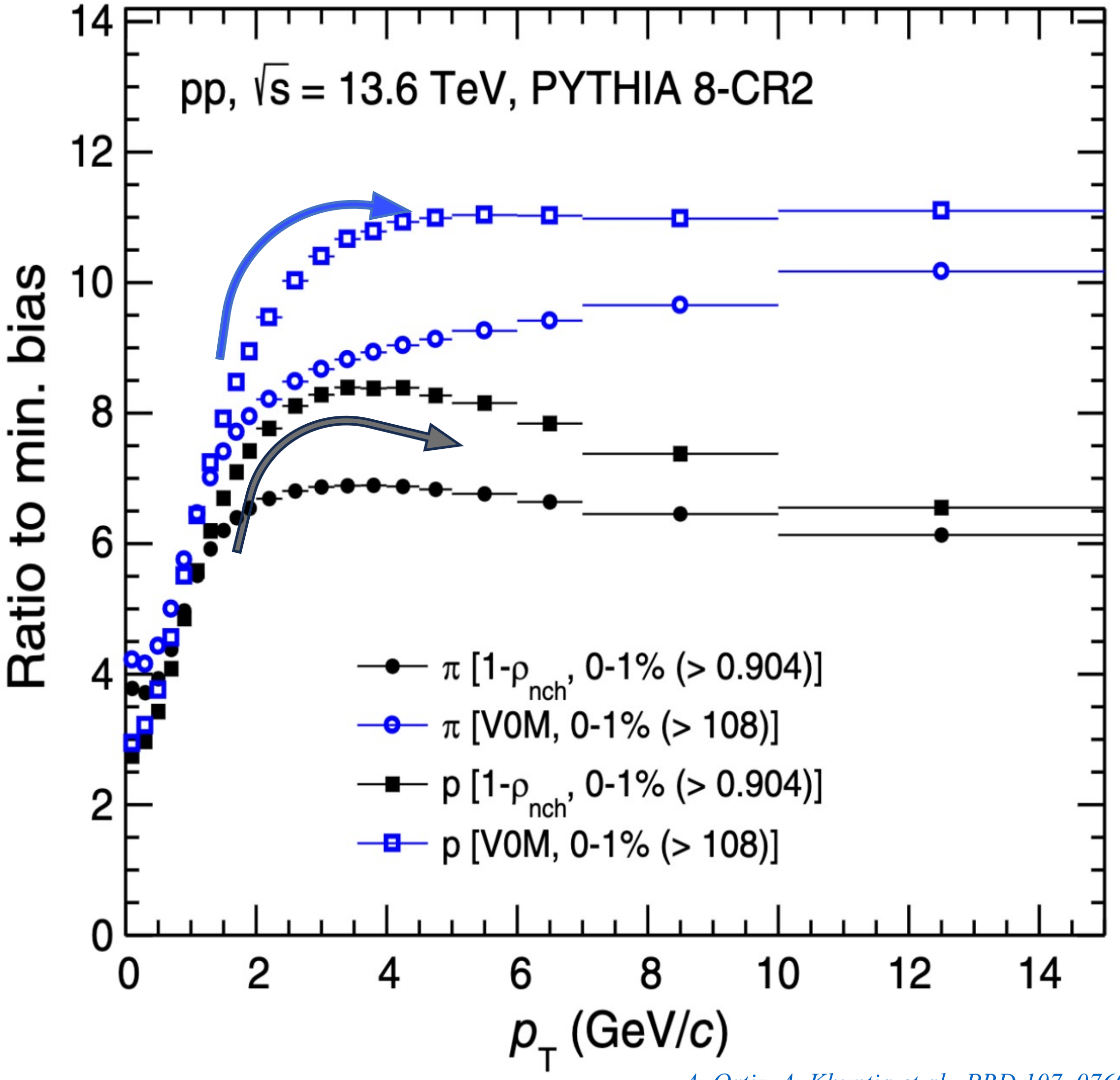


A. Ortiz, A. Khuntia et al., PRD 107, 076012 (2023)

- V0M selects event with higher $\langle \hat{p}_{\mathrm{T}} \rangle$ with the charged-particle density than that observed for the selection based on flattenicity
- V0M and flattenicity are nearly equally sensitive to MPI, but flattenicity reduces the bias towards hard pp collisions

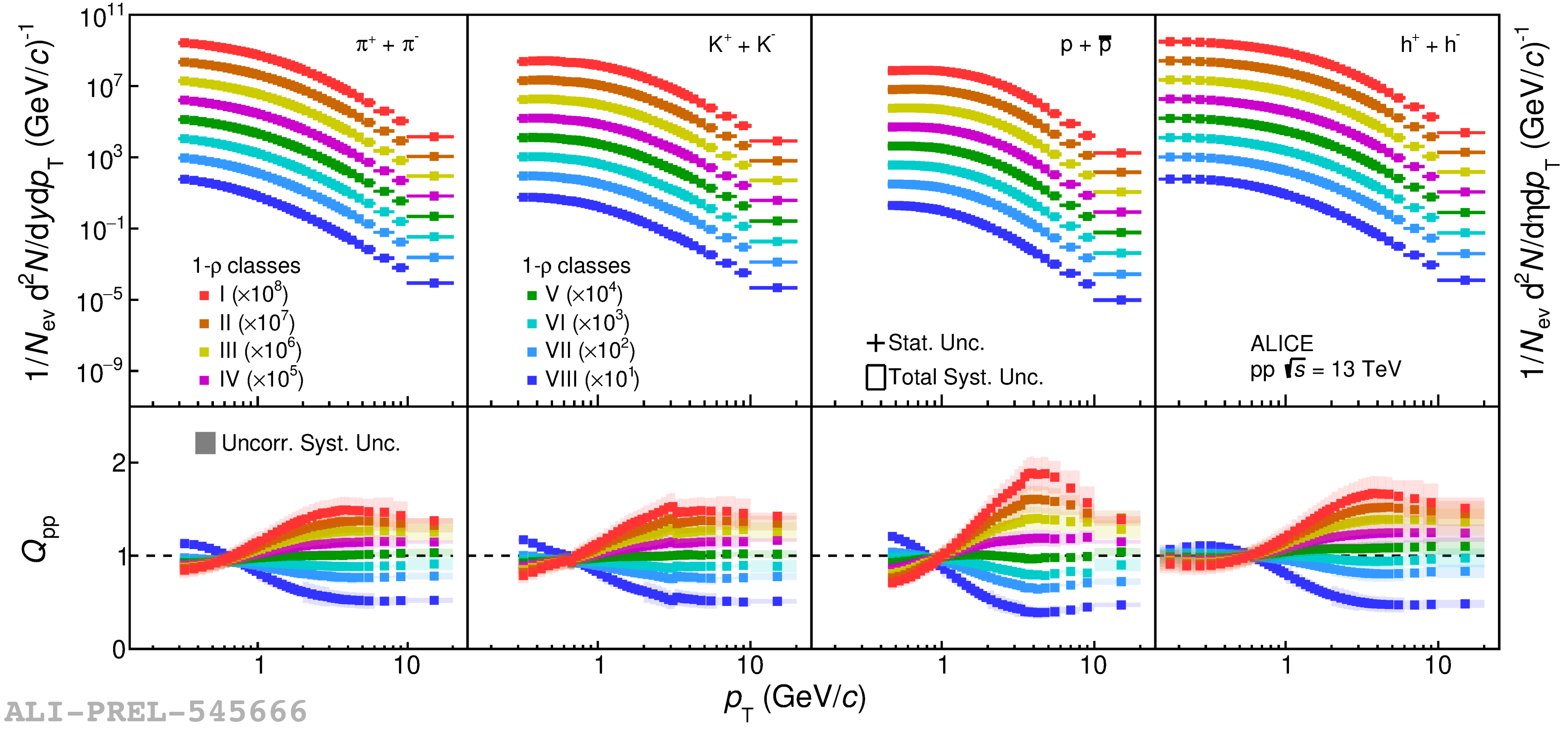
Flattenicity (ρ): Ratio to min. bias.

- Observation of a bump structure at intermediate transverse momentum based on $1-\rho$ selection
- Not observed for events selected based on V0M charged particle multiplicity
- Reduced bias towards hard physics



A. Ortiz, A. Khuntia et al., PRD 107, 076012 (2023)

p_T spectra and Qpp ratios Vs. flattenicity



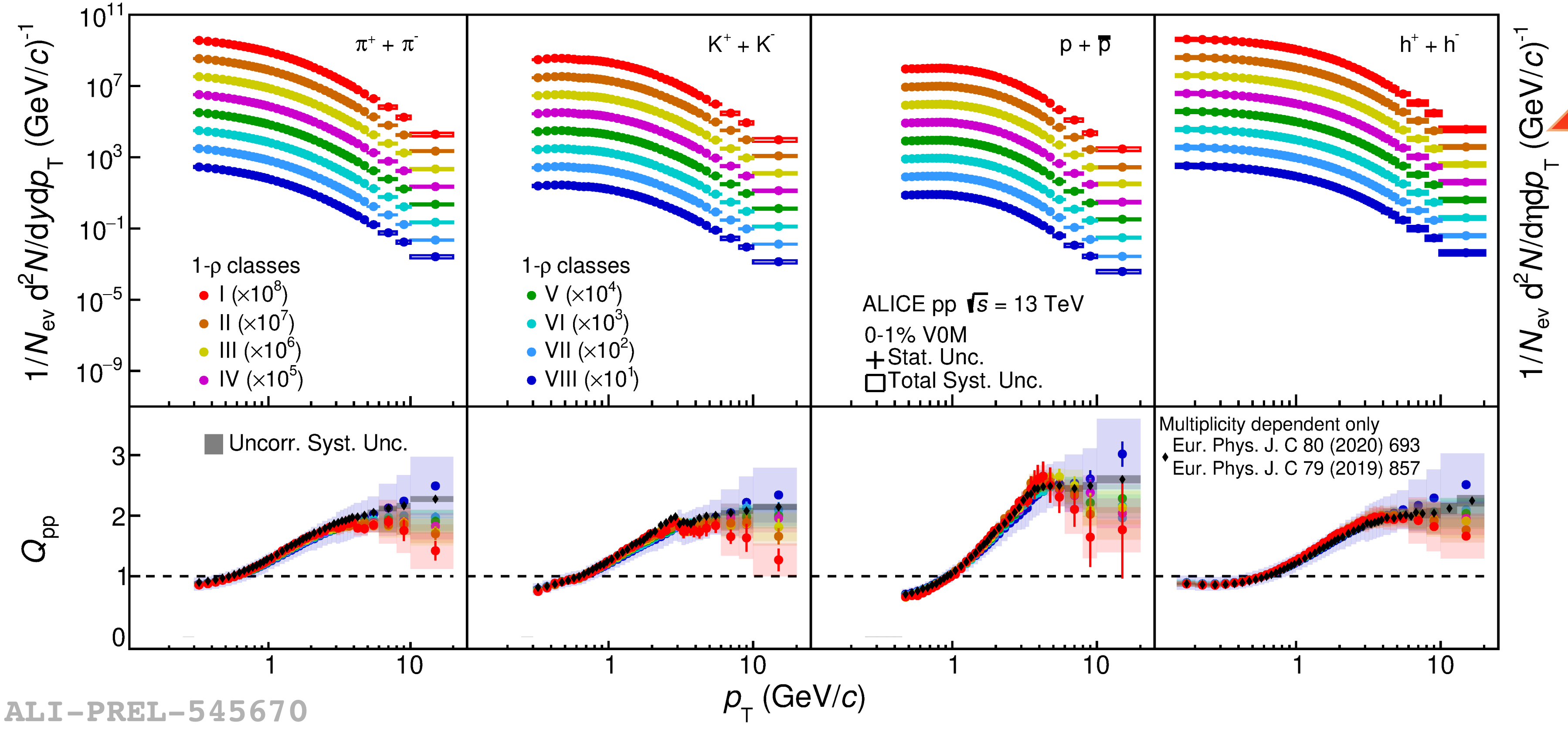
ALI-PREL-545666

Flattenicity only

$$Q_{pp} = \left(\mathrm{d}^2 N / \langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle / \mathrm{d}\eta \mathrm{d}p_T\right)^{1-\rho\ \text{class}} / \left(\mathrm{d}^2 N / \langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle / \mathrm{d}\eta \mathrm{d}p_T\right)^{\text{Minimum bias}}$$

- Clear development of a peak structure (“bump”) for isotopic events
- The strength of the bump structure shows a mass dependency

p_T spectra and Qpp ratios Vs. flattenicity + V0M (0-1%)



V0M (0-1%)
+
Flattenicity

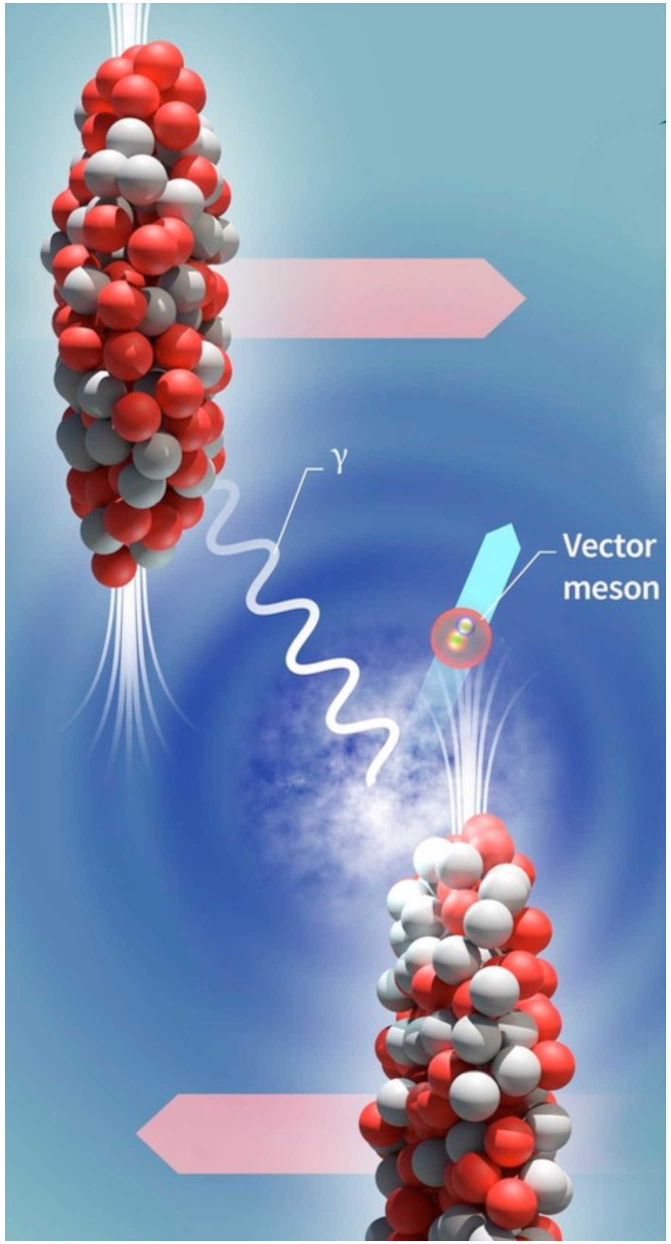
$$Q_{pp} = (\mathrm{d}^2N/\langle \mathrm{d}N_{ch}/\mathrm{d}\eta\rangle/\mathrm{d}\eta\mathrm{d}p_T)^{1-\rho\ \text{class}} / (\mathrm{d}^2N/\langle \mathrm{d}N_{ch}/\mathrm{d}\eta\rangle/\mathrm{d}\eta\mathrm{d}p_T)^{\text{Minimum bias}}$$

- Clear development of a peak structure ("bump") for isotopic events
- The strength of the bump structure shows a mass dependency
- Reduced selection bias: flattenicity selection with increasing multiplicity (not seen for V0M-only)

Measurement of azimuthal anisotropy in coherent ρ^0 photoproduction in ultra-peripheral Pb–Pb collisions with ALICE

https://alice-publications.web.cern.ch/node/9523 (ALICE CR1)

Coherent photoproduction



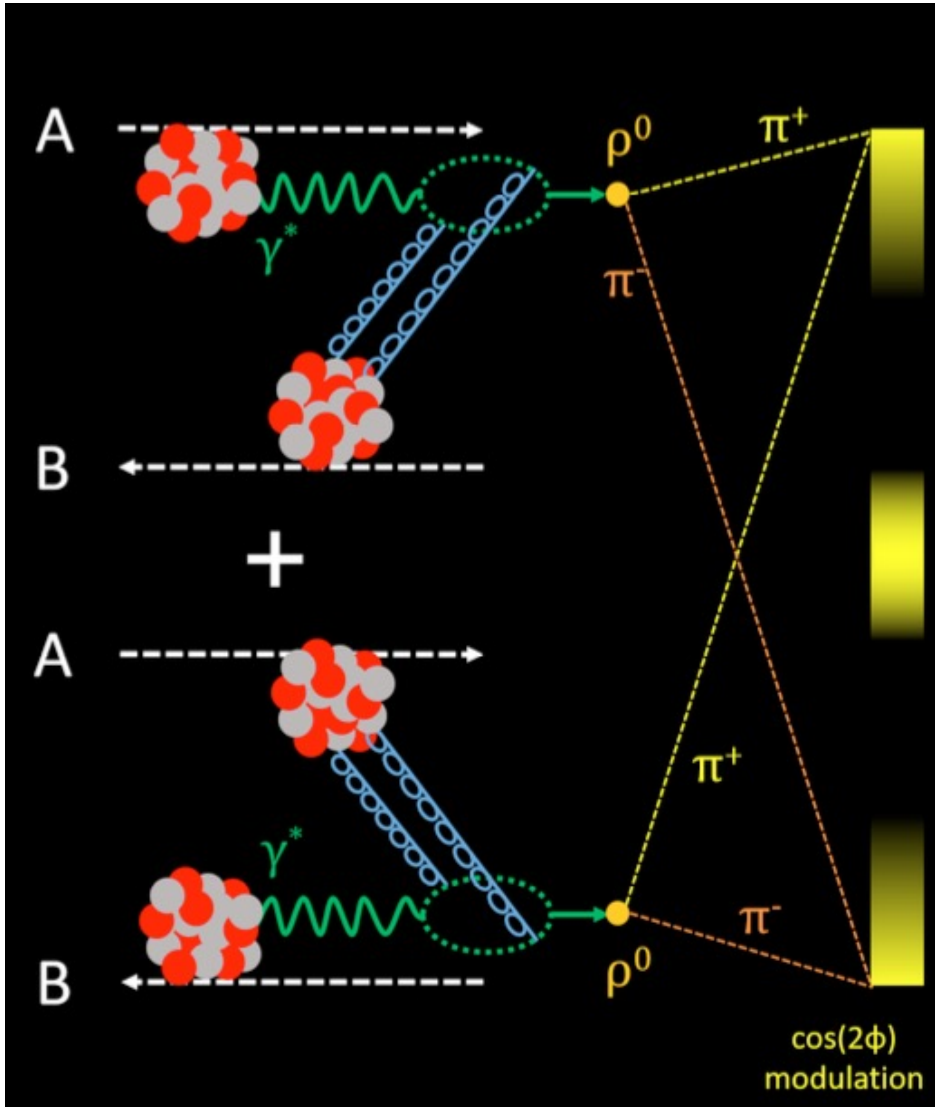
- **UPCs:** impact parameter *b* greater than the sum of the radii of the colliding nuclei
  → Purely hadronic interactions highly suppressed

- Clear signal: $\rho_0 \rightarrow \pi^+\pi^-$ at midrapidity (otherwise empty detector)

- UPCs with independent electromagnetic dissociation → nuclear break-up with emission of forward neutrons

- The EM fields of the nuclei are highly Lorentz contracted → exchanged photons are linearly polarized along *b*

Azimuthal anisotropy



Each nucleus can act as the source of the photon or as the target in the interaction

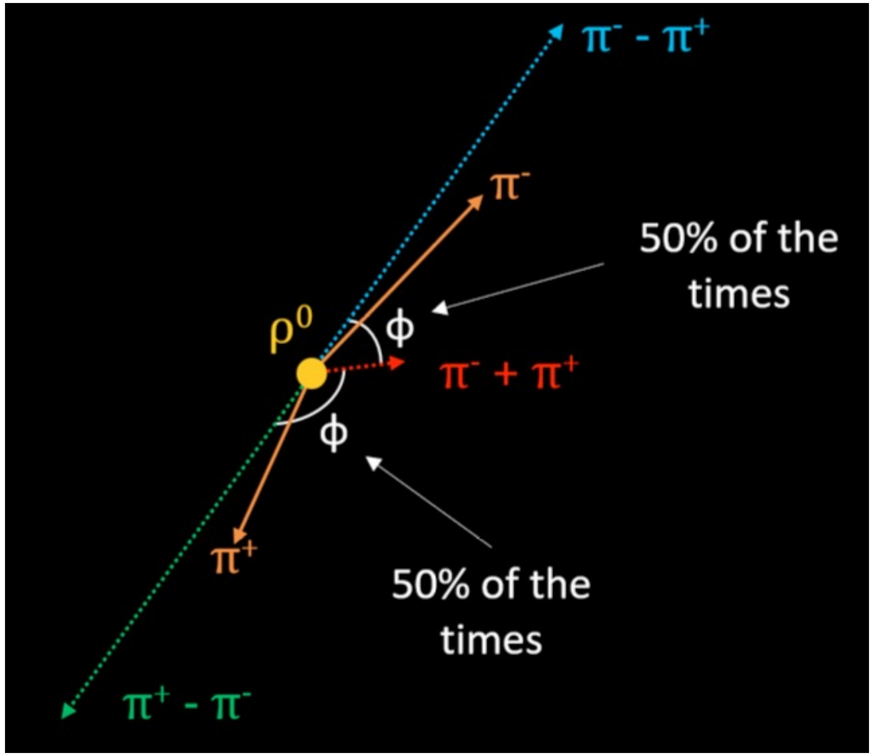
→ two indistinguishable amplitudes contribute to the cross-section

Interference between the amplitudes

$$\sigma(p_{\mathrm{T}}, b, y=0) = \left| \ A(p_{\mathrm{T}}, b) - A(p_{\mathrm{T}}, b) \ e^{i\,\vec{p}\cdot\vec{b}} \ \right|^2$$

- Correlation between ρ^0 momentum and polarization (aligned along *b*) → preserves the anisotropy
- ρ^0 is short lived: $c\tau << b$ → decay length too short for amplitudes to overlap
- Interference involves the pions, which need to be emitted in an entangled state

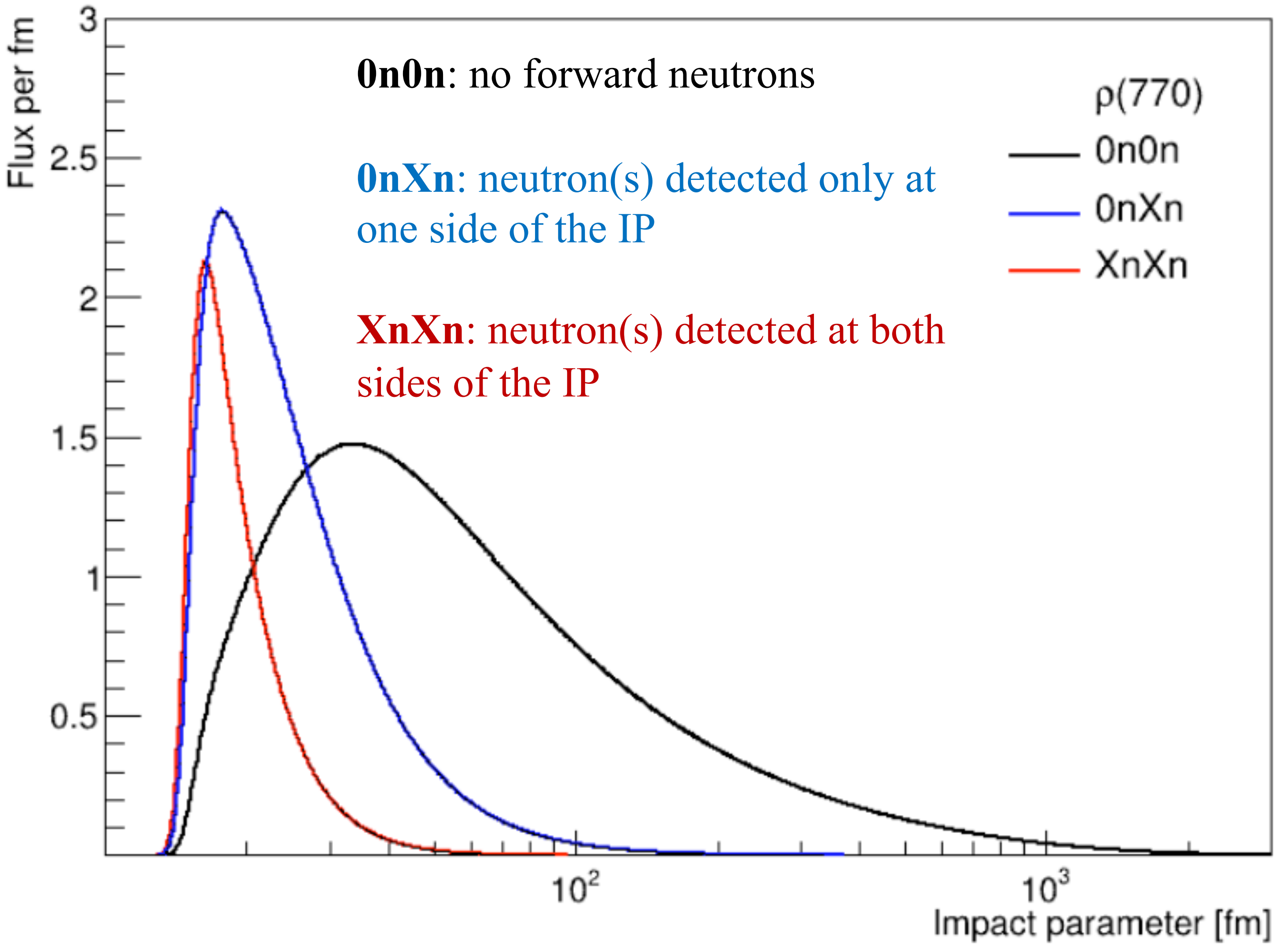
Definitions



φ = azimuth angle between p+ and p-

p± = $\pi_1 \pm \pi_2$

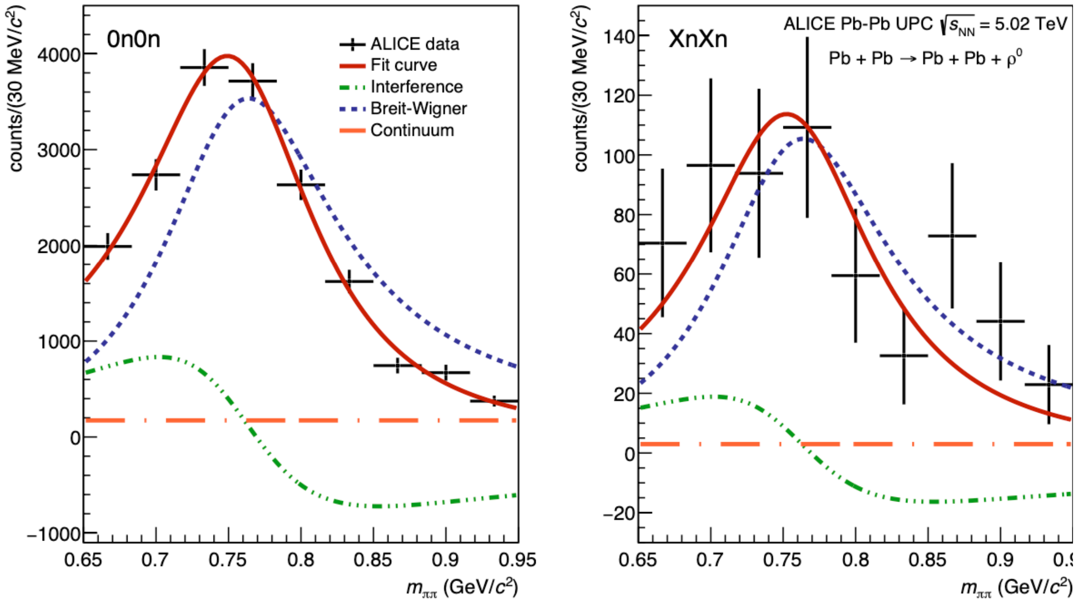
π_1 (π_2) = 4-momentum of track 1(2), randomly assigned to the positive and negative tracks



Neutron emission probability decreases with the impact parameter ***b***

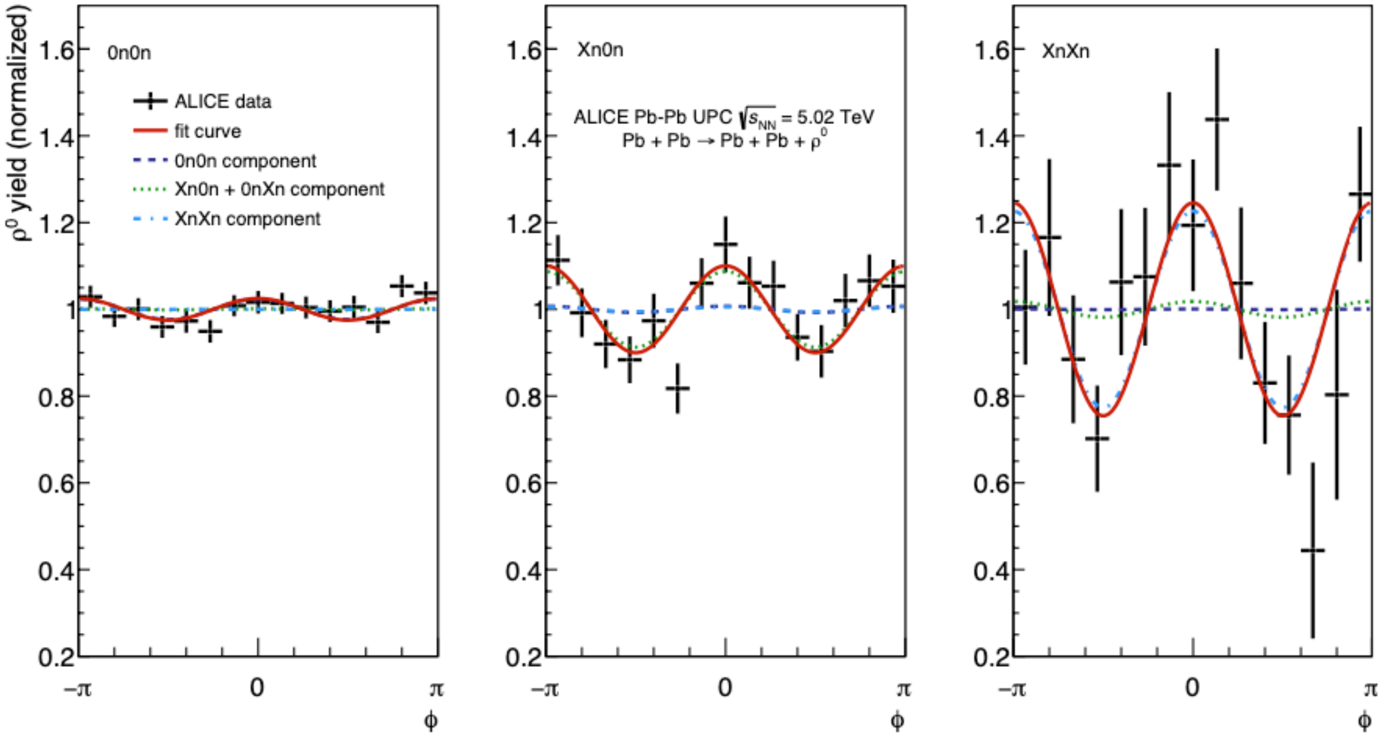
→ different neutron emission classes corresponds to different average values of ***b***

What we measure?



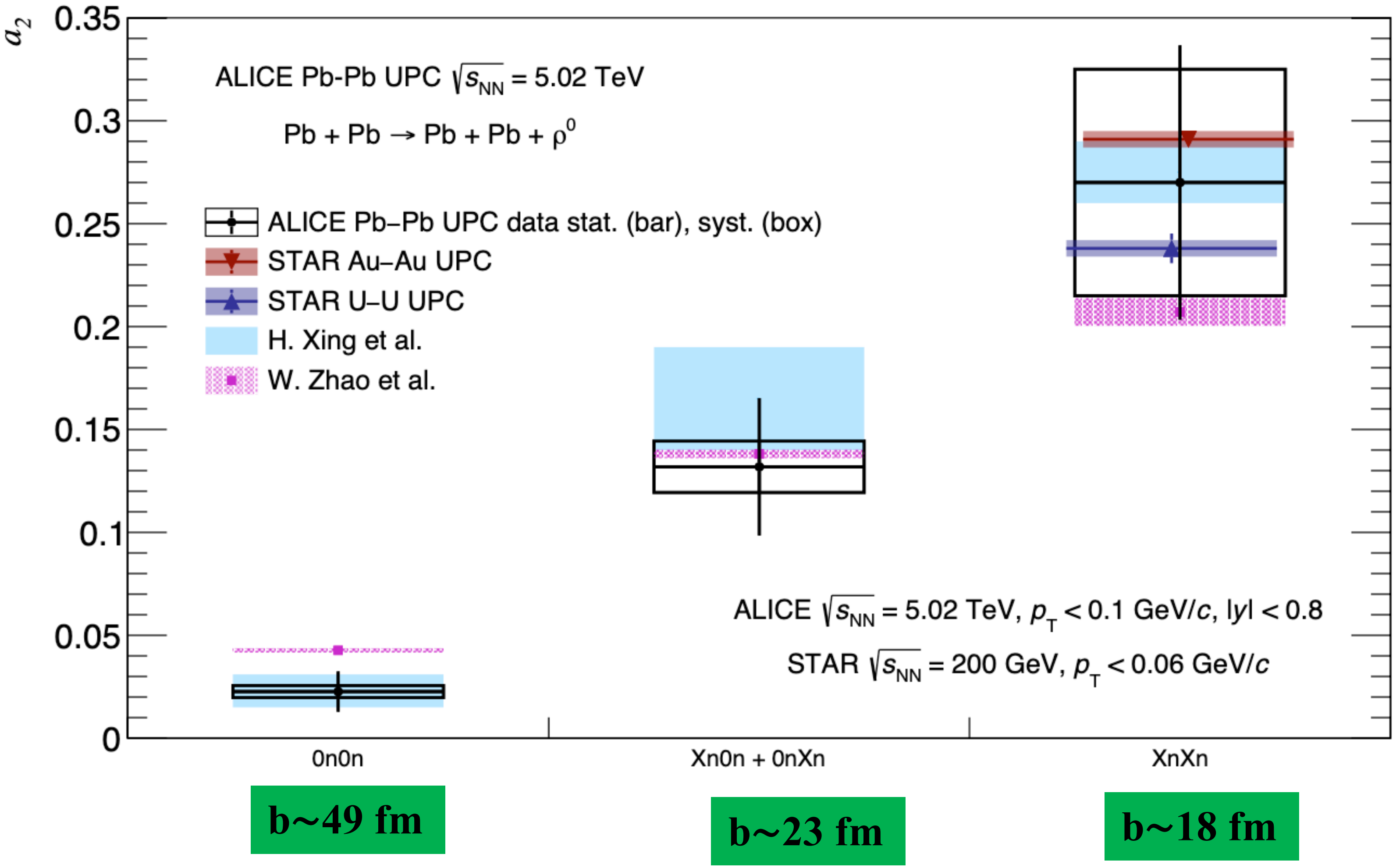
The corrected mass spectra in each φ bin are fitted using the Söding model:

$$dN/dm_{\pi\pi} = |A \cdot BW_\rho + B|^2$$



The modulation is very different in different neutron emission classes

First results on azimuthal anisotropy in UPCs



- **First measurement of the azimuthal anisotropy of the ρ^0 yield as a function of the impact parameter (b)**
- The modulation strength strongly increases as *b* decreases →

XnXn > Xn0n > 0n0n

Summary

- ✓ In the transverse region, for higher R_T (> 2.5), the activity gets biased towards multi-jet final states

- ✓ Event selection based on flattenicity could distinguish multi mini-jet and multi-jet topologies

  → Observation of "bump" like structure at intermediate p_T for isotropic events in pp collisions, which is a feature of MPIs

  → Flattenicity together with high multiplicity pp collisions could shed light on searching jet quenching signals in small collision systems

- ✓ We measured for the first time the azimuthal anisotropy of the ρ^0 yield as a function of the impact parameter

  → The effect varies by more than one order of magnitude as a function of b

Outlook:

- Working on nuclei-hadron correlation ($\Delta\eta$, $\Delta\phi$) study using the afterburner
- Analyzing dRICH test beam data for the ePIC

Publications:

1. Unveiling the effects of multiple soft partonic interactions in pp collisions at s =13.6 TeV using a new event classifier. Antonio Ortiz, Arvind Khuntia, Omar Vázquez Rueda, Sushanta Tripathy, Gyula Bencédi, Suraj Prasad, and Feng Fan. **Phys. Rev. D 107, 076012 (2023)**
2. $K^*(892)^0$ and φ(1020) in pp collisions at 5.02 TeV; *S. Acharya*.....Arvind Khuntia... et al: **Phys. Rev. C 106, 034907 (2022)**
3. Investigating heavy-flavor vs light-flavor puzzle with event topology and multiplicity in proton+proton collisions at $\sqrt{s}$ = 13TeV using PYTHIA8: S. Deb, R. Sahoo, D. Thakur, S. Tripathy and A. Khuntia: **J. Phys. G 48, 095104 (2021)**
4. Event Shape Engineering and Multiplicity dependent Study of Identified Particle Production in proton+proton Collisions at $\sqrt{s}$ = 13 TeV using PYTHIA:, Arvind Khuntia, Sushanta Tripathy, Ashish Bisht, Raghunath Sahoo: **J. Phys. G 48, 035102 (2021)**
5. Evolution of strange and multi-strange hadron production with relative transverse multiplicity activity in underlying event: Prabhakar Palni, Arvind Khuntia, Paolo Bartalini: **Eur. Phys. J. C 80, 919 (2020)**
6. $K^*(892)^0$ and phi(1020) production at mid-rapidity in pp collisions at $\sqrt{s}$ = 8 TeV: S. Acharya…..Arvind Khuntia… et al: **Phys. Rev. C 102, 024912 (2020)**
7. A Baseline Study of the Event-Shape and Multiplicity Dependence of Chemical Freeze-Out Parameters in Proton-Proton Collisions at $\sqrt{s}$ = 13 TeV Using PYTHIA8: R. Rath, A. Khuntia, S. Tripathy and R. Sahoo: **MDPI Physics 2, 679 (2020)**

Publications:

8. Event shape and Multiplicity dependence of Freeze-out Scenario and System Thermodynamics in Proton+Proton Collisions at $\sqrt{s}$ = 13 TeV: S. Tripathy, A. Bisht, R. Sahoo, A. Khuntia and M. P. S.: **Adv. High Energy Phys., 2021, 8822524 (2021)**
9. Event multiplicity, transverse momentum and energy dependence of charged particle production, and system thermodynamics in pp collisions at the Large Hadron Collider: Rutuparna Rath, Arvind Khuntia, Raghunath Sahoo, Jean Cleymans: **J. Phys. G 47, 055111 (2020)**
10. Radial Flow and Differential Freeze-out in Proton-Proton Collisions at the LHC $\sqrt{s}$ = 7 TeV at the LHC : Arvind Khuntia, Himanshu Sharma, Swatantra Kumar Tiwari, Raghunath Sahoo, Jean Cleymans: **Eur. Phys. J. A, 55, 3 (2019)**
11. Effect of Hagedorn States on Isothermal Compressibility of Hadronic Matter formed in Heavy-Ion Collisions: From NICA to LHC Energies: A. Khuntia, S. K. Tiwari, P. Sharma, R. Sahoo and T. K. Nayak: **Phys. Rev. C 100, 014910 (2019)**
12. Non-Extensive Statistics in Free-Electron Metals and Thermal Effective mass: A. Khuntia, Gayatri. Sahoo, R. Sahoo, D. P. Mahapatra and N Barik: **Physica A 523, 852 (2019)**
13. Multiplicity Dependence of Non-extensive Parameters for Strange and Multi-Strange Particles in Proton- Proton Collisions at $\sqrt{s}$ = 7 TeV at the LHC: Arvind Khuntia, Sushanta Tripathy, Raghunath Sahoo, Jean Cleymans: **Eur. Phys. J. A53, 103 (2017)**
14. Radial Flow in Non-Extensive Thermodynamics and Study of Particle Spectra at LHC in the Limit of Small (q-1): Trambak Bhattacharyya, Jean Cleymans, Arvind Khuntia, Pooja Pareek, Raghunath Sahoo: **Eur. Phys. J. A 52, 30 (2016)**
15. Speed of Sound in Hadronic matter using Non-extensive Tsallis Statistics: Arvind Khuntia, Pragati Sahoo, Prakhar Garg, Raghunath Sahoo, Jean Cleymans: **Eur. Phys. J. A 52, 292 (2016)**

Thank you for your attention!!!