Particle production as a function of charged-particle flattenicity in small collision systems with ALICE

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for the ALICE Collaboration

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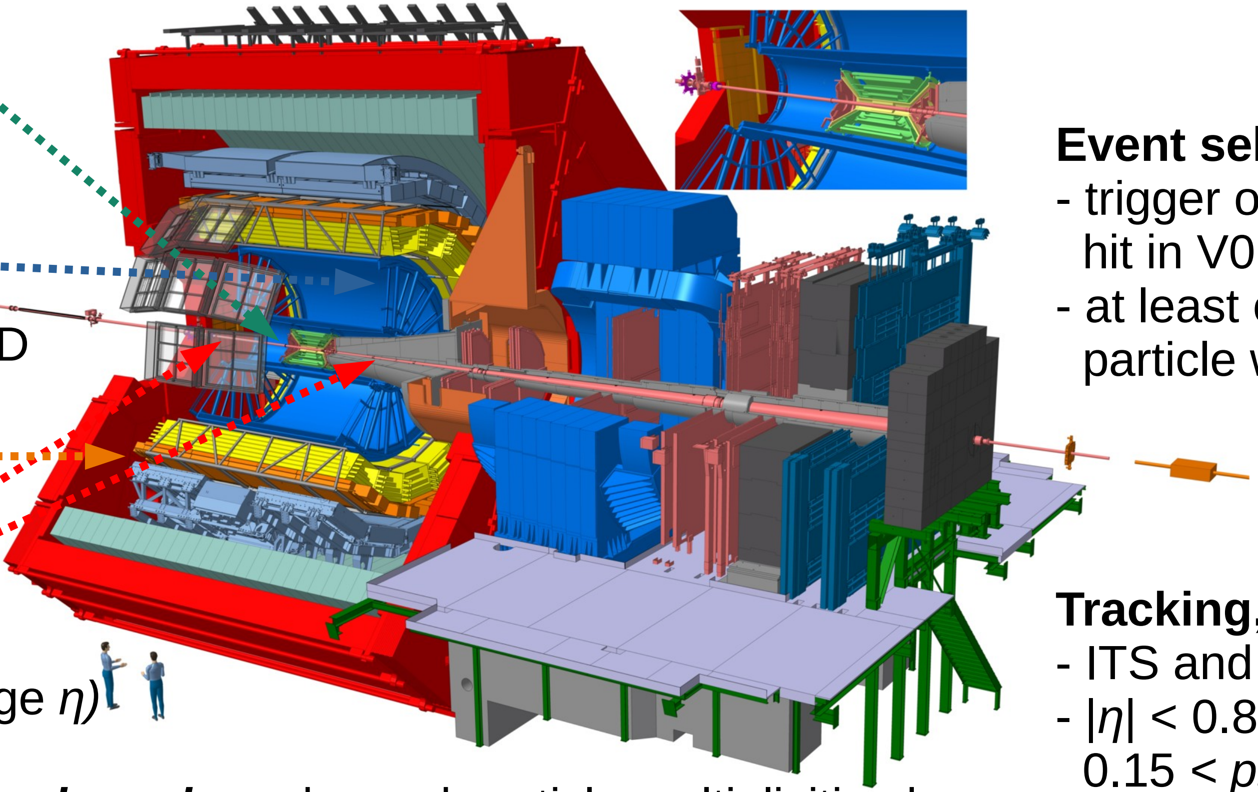
The ALICE detector (during Run 2)

Inner Tracking System
- triggering, vertexing, tracking

Time Projection Chamber
- tracking, vertex, PID

Time of Flight
- PID



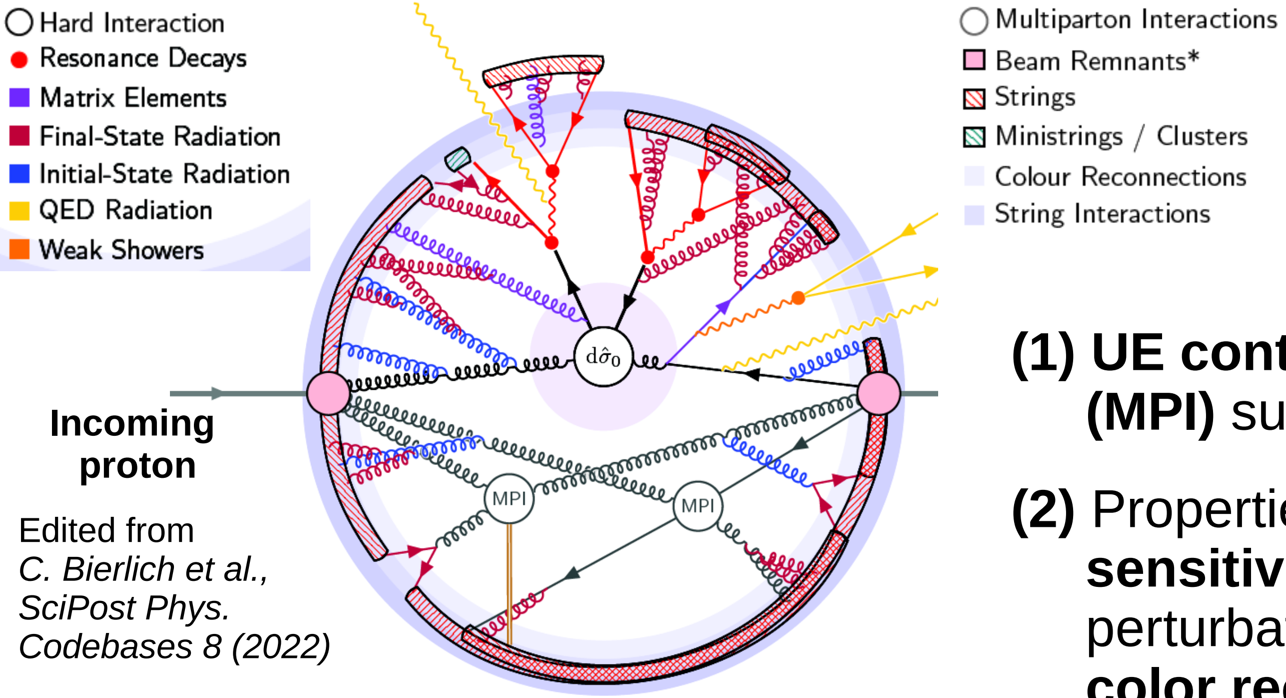
Event selection:
- trigger on at least one hit in V0 detectors
- at least one charged particle within $|\eta| < 1$

Tracking, kinematics:
- ITS and TPC tracks
- $|\eta| < 0.8$ or $|y| < 0.5$, $0.15 < p_T < 20$ GeV/c

V0 detectors (at large η)
- triggering
- ***event classification based on*** charged-particle multiplicities by measuring ***signal amplitude in V0A and V0C detectors: V0M***

Introduction

High energy pp collision:
hard parton-parton interactions and underlying event (UE) modeled by PYTHIA 8



PYTHIA 8 - Comput.Phys.Commun. 191 (2015) 159-177

Edited from
C. Bierlich et al., SciPost Phys. Codebases 8 (2022)

Main structure of a pp collision modeled by PYTHIA 8.
Hadronization not included.

(1) UE contains multiparton interactions (MPI) supported by LHC measurements

(2) Properties of the **hadronic final state**: **sensitive to** modeling of **MPI**, **and** non-perturbative final-state effects such as **color reconnection** (CR)

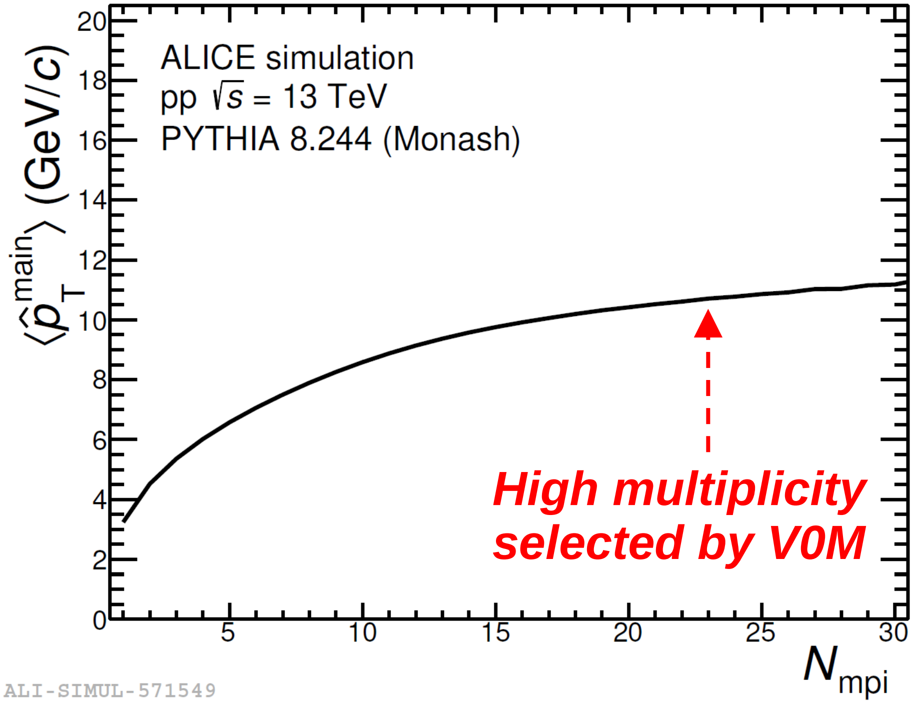
Introduction

(3) *High-multiplicity collisions*

→ **large** number of MPIs (***N*$_{\mathbf{MPI}}$**) →

→ more “central” pp collisions →

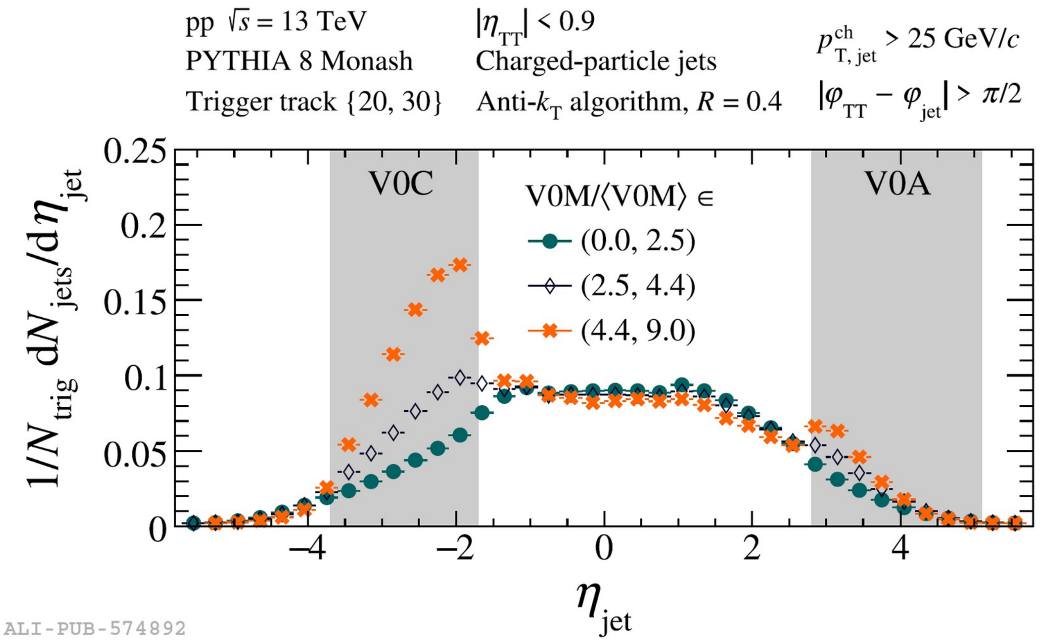
→ **high probability** to find a **high-p_T parton**



(4) *High-multiplicity class* ***selected by V0M***

→ selects pp collisions with jets in the forward pseudorapidity region →

→ **jet bias** due to local mult. fluctuations

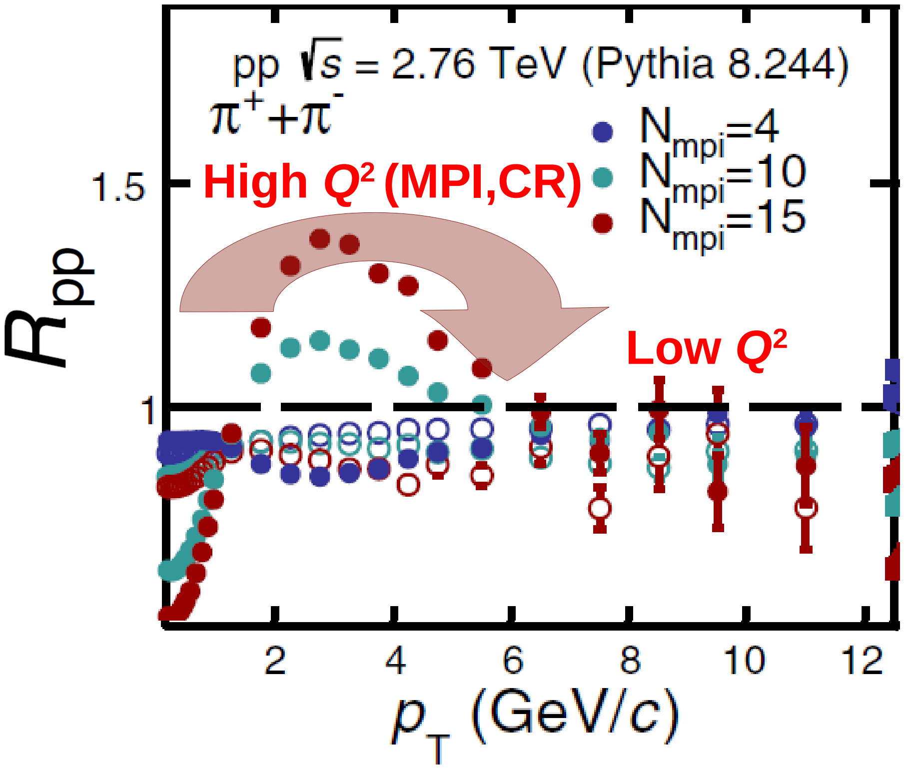


JHEP 05 (2024) 229

Motivation

Objective: study particle production using ***event shape*** observable with ***strong sensitivity to MPI, CR,*** *and* ***local multiplicity fluctuations***

A. Ortiz et al., PRD 102 (2020) 7, 076014

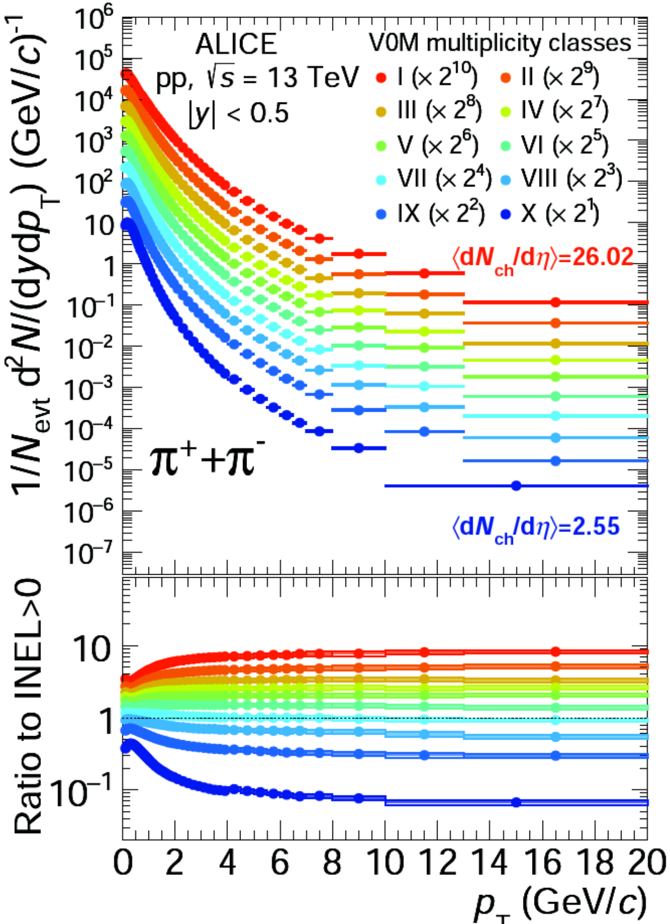


$$R_{\mathrm{pp}} = \frac{\mathrm{d}^2 N_{\mathrm{ch}}^{\mathrm{MPI\,selection}} / \langle N_{\mathrm{MPI\,selection}} \rangle \mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}{\mathrm{d}^2 N_{\mathrm{ch}}^{\mathrm{min.\,bias}} / \langle N_{\mathrm{min.\,bias}} \rangle \mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}$$

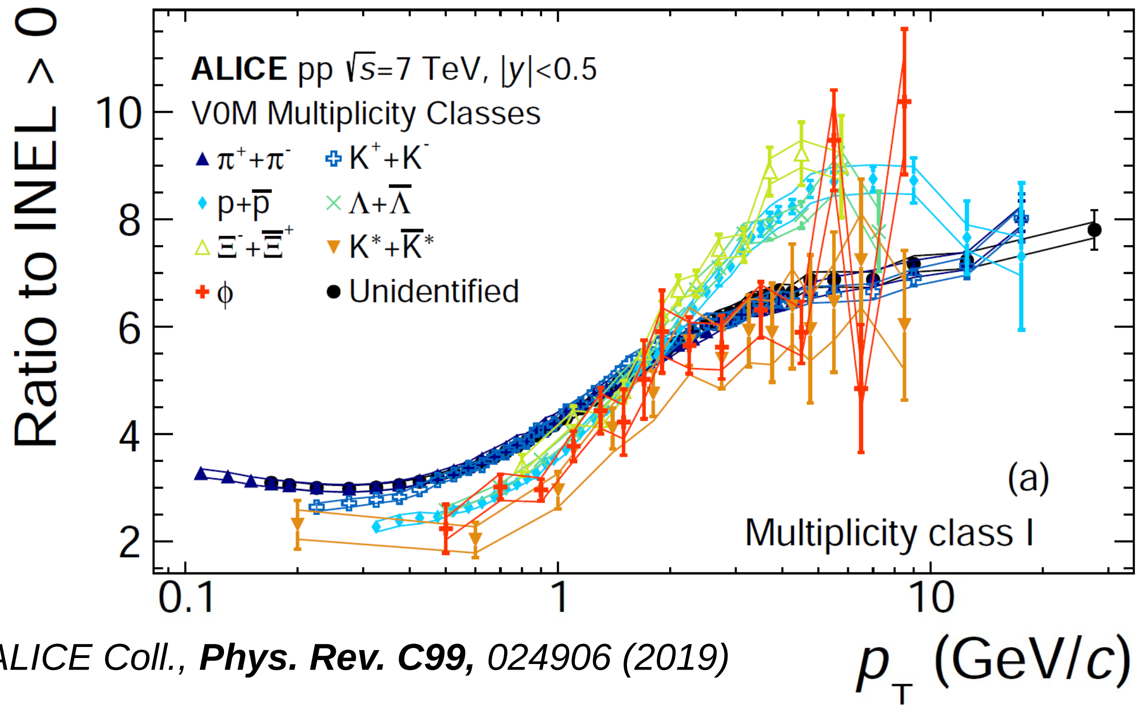
Ratio of yield in MPI-enhanced pp collisions **to yield for minimum bias** (MB) pp collisions:

- 40% increase w.r.t. the binary parton-parton scaling: “bump” structure in $1 < p_T < 6$ GeV/c
- the effect is driven by CR
- **MPI selection does not bias toward higher p_T**

Existing spectra results from ALICE



ALICE Coll., ***EPJ C 80*** *(2020) 693*



ALICE Coll., ***Phys. Rev. C99,*** *024906 (2019)*

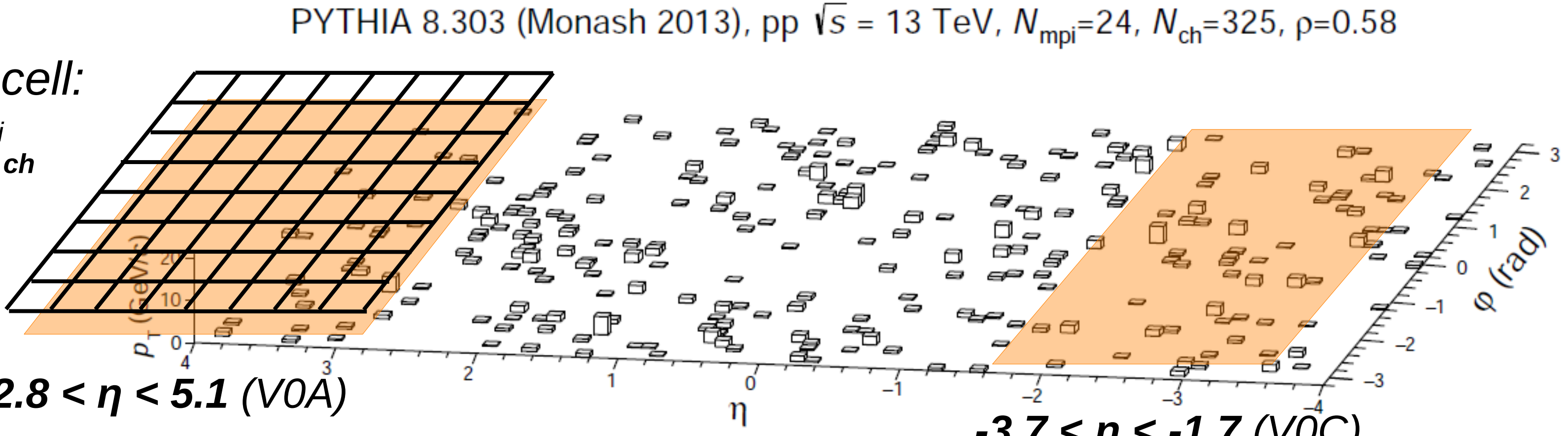
- **Selection bias toward higher p_T**
- **Explore event classifier:** sensitivity to MPI **with reduced selection bias**

Event classification with Flattenicity

- **Define a grid in *η – φ* covered by the V0 detector of ALICE:**
  2.8 < η < 5.1 (V0A) and -3.7 < η < -1.7 (V0C) and full azimuth
- *Measure charged particle multiplicity in a grid of N_{cell} (64 cells)*

i-th cell:

$N^{cell,i}_{ch}$



2.8 < η < 5.1 *(V0A)*

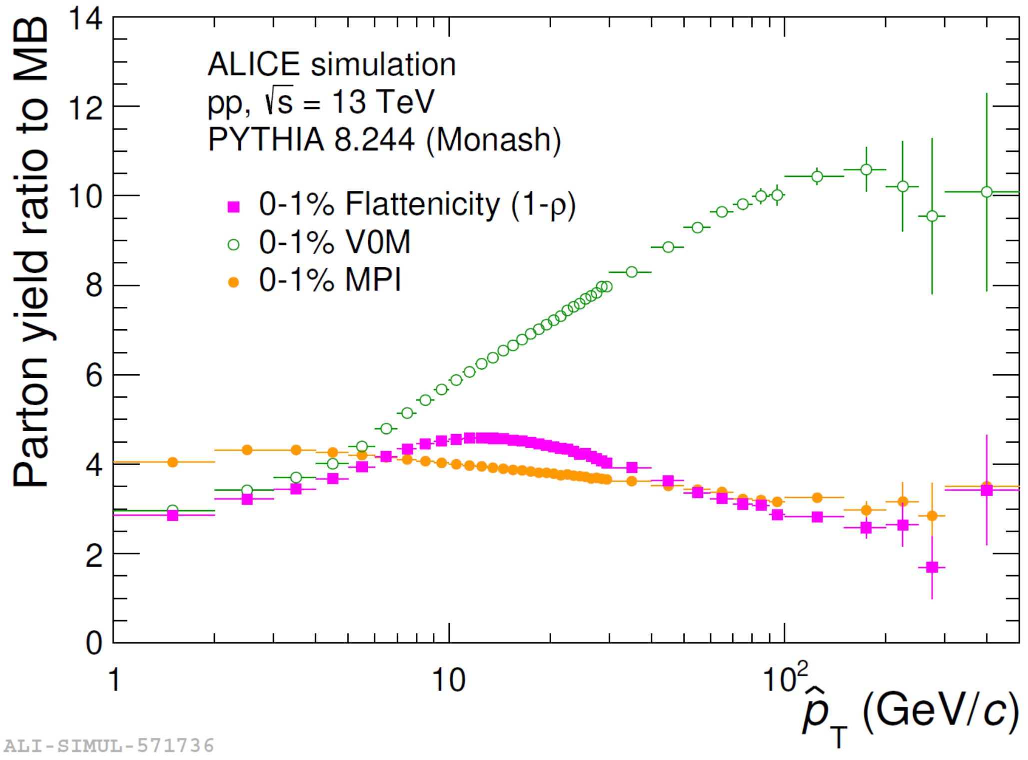
-3.7 < η < -1.7 *(V0C)*

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

- *$N^{cell,i}_{ch}$: charged-particle multiplicity in the i-th cell*
- *$\langle N_{cell,ch} \rangle$: the event-averaged $N^{cell,i}_{ch}$*
- **Define event shape Flattenicity event-by-event:**

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

High-p_T physics: V0M vs. flattenicity selection



- **Ratios of parton yields** for the events with the ***0-1% highest activity to that without any event selection:***

$$\mathrm{ratio}(\hat{p}_T) = \frac{\left.\frac{1}{N_{ev}}\frac{dN_{parton}}{d\hat{p}_T}\right|_{1\%\,\mathrm{xsec}}}{\left.\frac{1}{N_{ev}}\frac{dN_{parton}}{d\hat{p}_T}\right|_{MB}}$$

- **V0M selection:**
  → jet bias toward higher p_T

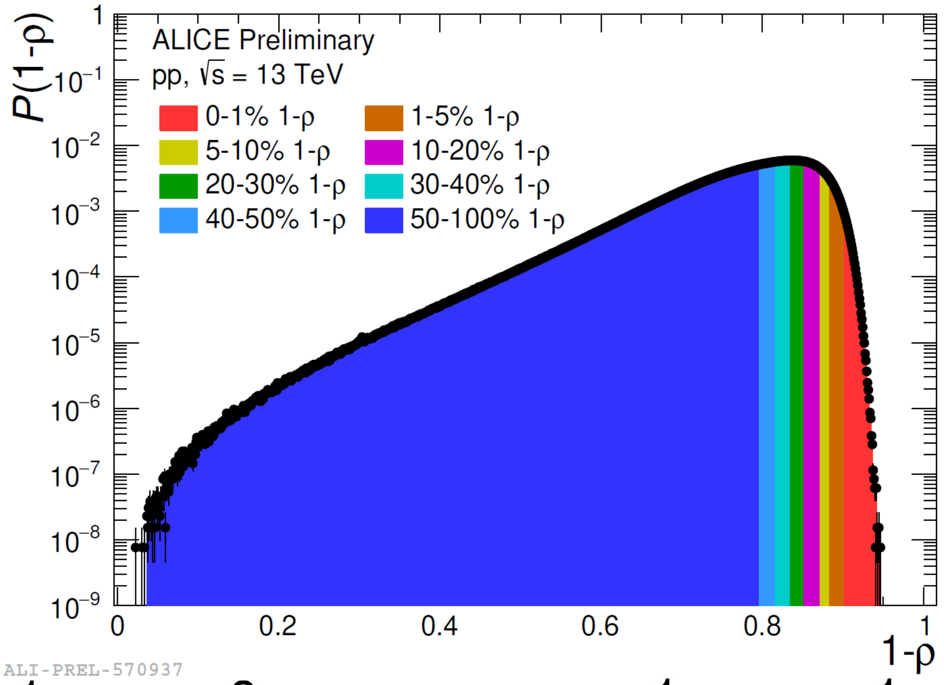
- **Flattenicity selection:**
  → similar behavior to the case of MPI toward higher p_T

Data analysis

- Data set: 2016–18 LHC pp collisions at 13 TeV, 1.6B events (integrated luminosity: 21 nb^{-1})
- **To associate** with other event shapes (e.g. Spherocity) using $1-\rho$
  Talk on Spherocity by Rutuparna Rath, 19/07/24, 08:47h
- Systematic uncertainties up to 10%

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

Low N_{MPI} **High N_{MPI}**



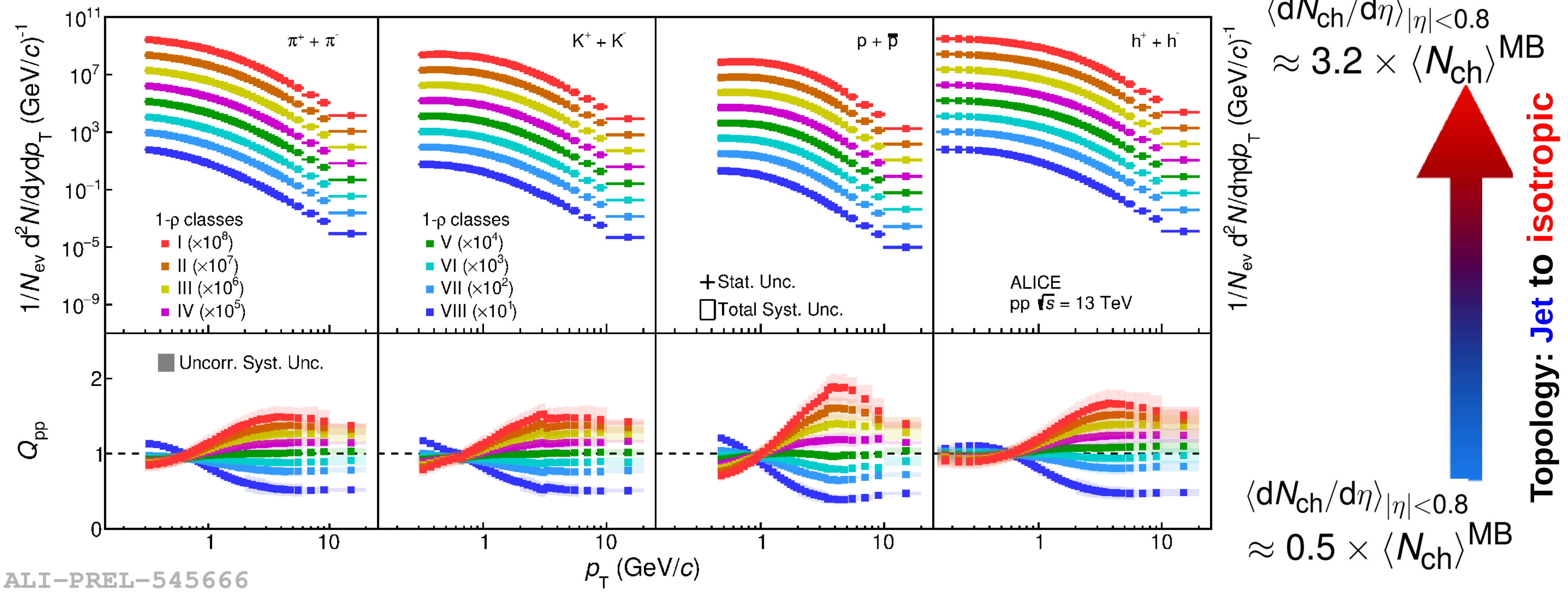
$1-\rho \to 0$

- ***large** local $N^{cell,i}_{ch}$* **fluctutations** in V0
- Jet structures

$1-\rho \to 1$

- ***small** local $N^{cell,i}_{ch}$* **fluctutations** in V0
- “Isotropic” distr. of particles

p_T spectra and Q_{pp} ratios vs. Flattenicity

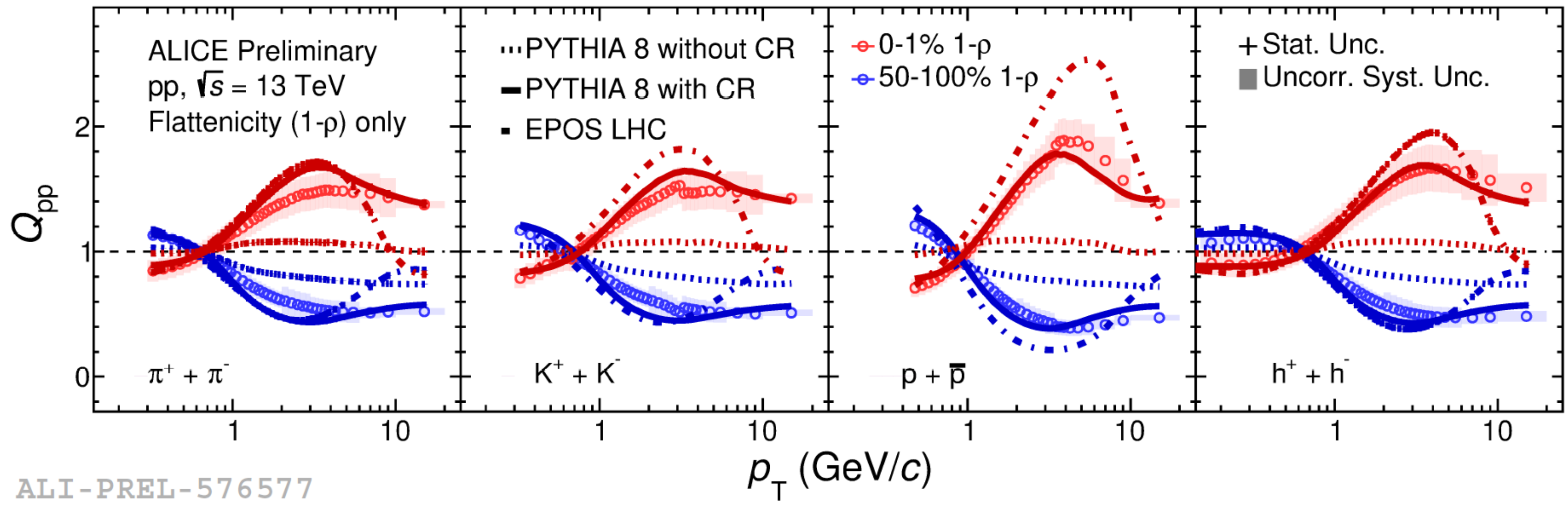


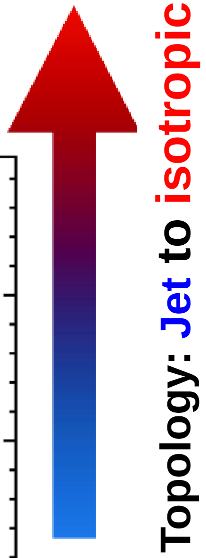
Ratio of yields to MB: $Q_{pp} = (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{1-\rho \text{ class}} / (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{\text{Minimum bias}}$

1) **Intermediate p_T:** clear **development of a peak** with increasing multiplicity (0–1% 1-ρ, class I)
2) **High p_T:** Q_{pp} approaches to unity

Q_{pp}: comparison with MC models

$$Q_{pp} = \frac{\left(\frac{d^2N/d\eta\, dp_T}{\langle dN_{ch}/d\eta \rangle}\right)^{1-\rho\text{ class}}}{\left(\frac{d^2N/d\eta\, dp_T}{\langle dN_{ch}/d\eta \rangle}\right)^{\text{Min. bias}}}$$

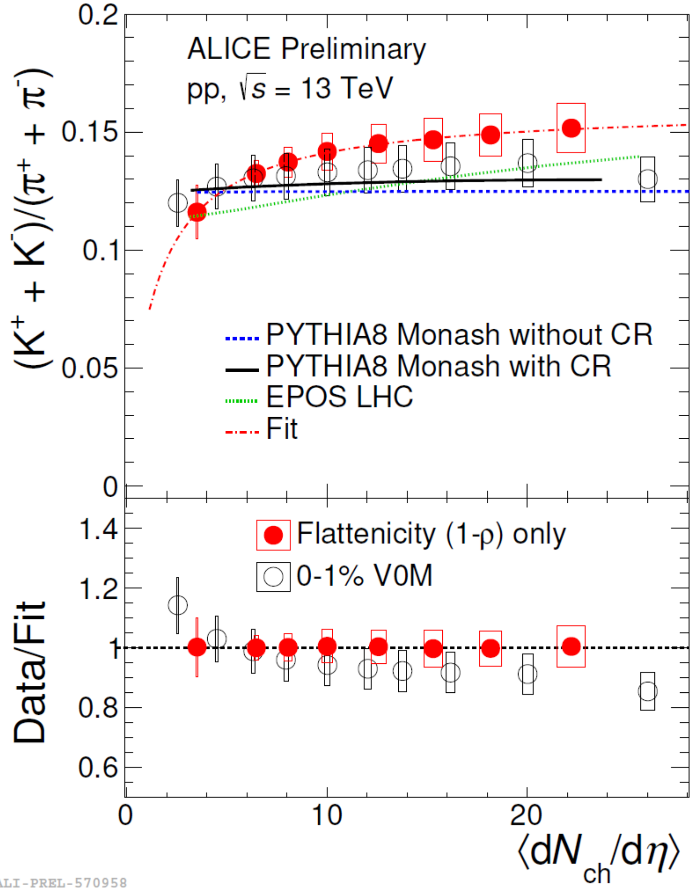


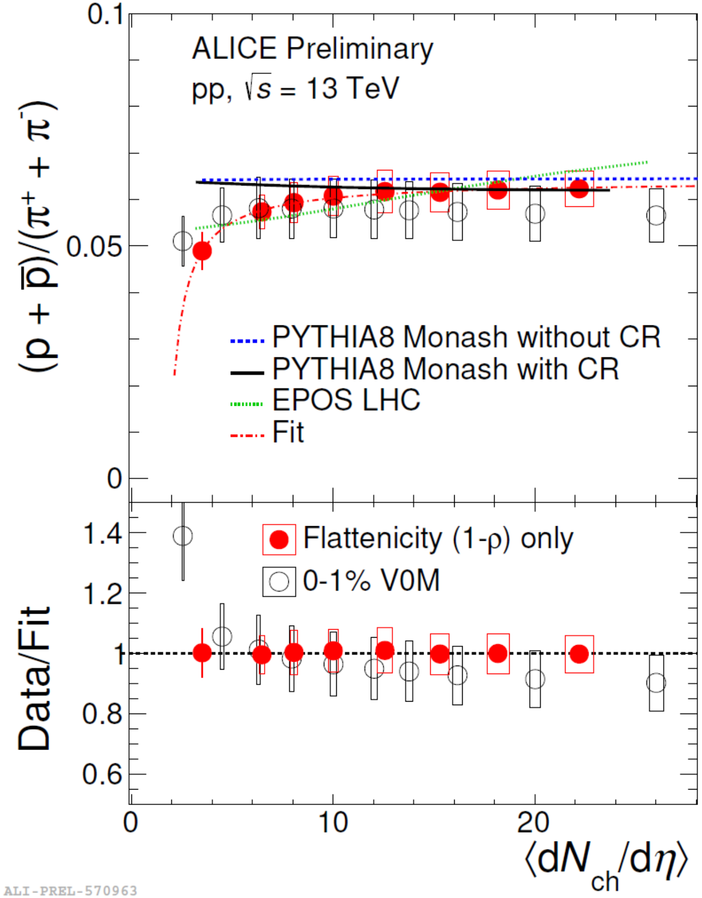


- **PYTHIA 8** Monash 2013 **with MPI and CR** effects **describes the data**; sensitive to evt. sel. due to CR
- **EPOS LHC** with **parametrized collective hydrodynamics descirbes** the data **partially** (low-to-mid p_T)

PYTHIA 8 - Comput.Phys.Commun. 191 (2015) 159-177; EPOS LHC - Phys. Rev. C 92, 034906

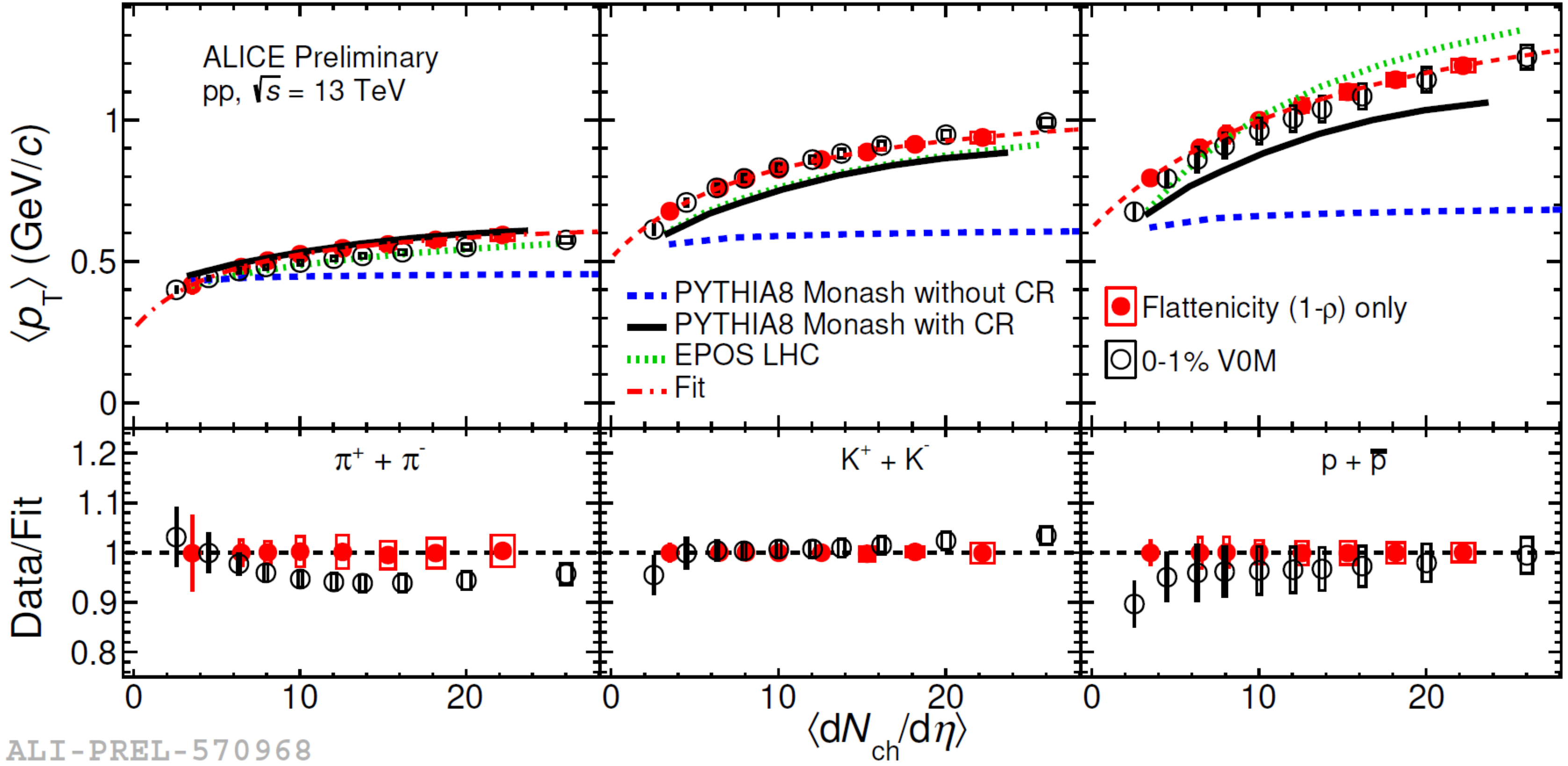
K/π and p/π particle ratios





- **K/π: Flattenicity selection → hint of a steeper increase** w.r.t. the V0M selection
  - PYTHIA 8 and EPOS LHC describe the data

Average transverse momentum

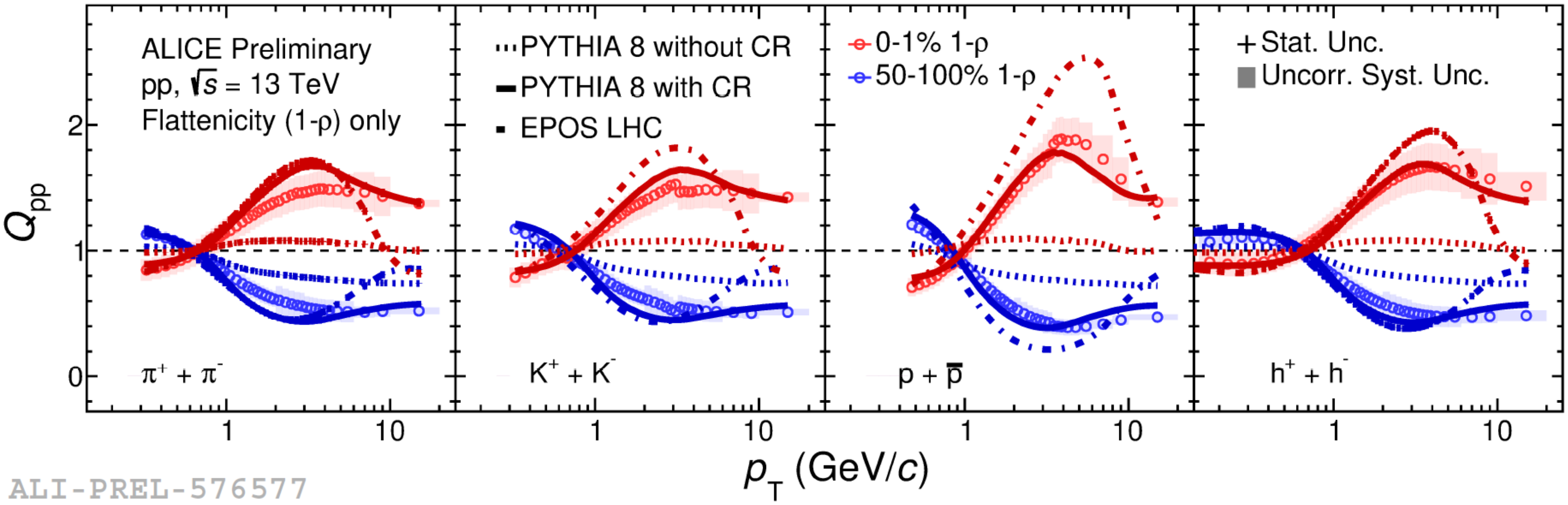


Flattenicity selection:

- **Pions indicate a hint of a steeper increase** w.r.t. the V0M selection
- Kaons and protons agree with results from V0M within uncertainties
- PYTHIA with CR and EPOS LHC describe the data qualitatively

Summary and Outlook

- Particle production is studied in pp collisions at 13 TeV using a ***new event shape observable flattenicity*** for the first time



- The ratio of event-class dependent p_T spectra to that of MB (Q_{pp}) develops a **"bump"-like structure** with increasing multiplicity that has not been observed with the "standard" event classifier V0M
- **Results are** qualitatively **described by** the **PYTHIA** model based on color strings and indicate that **flattenicity-selected events show reduced sensitivity to multijets**
- **Analysis with Run 3 pp data is in progress, stay tuned for more results!**

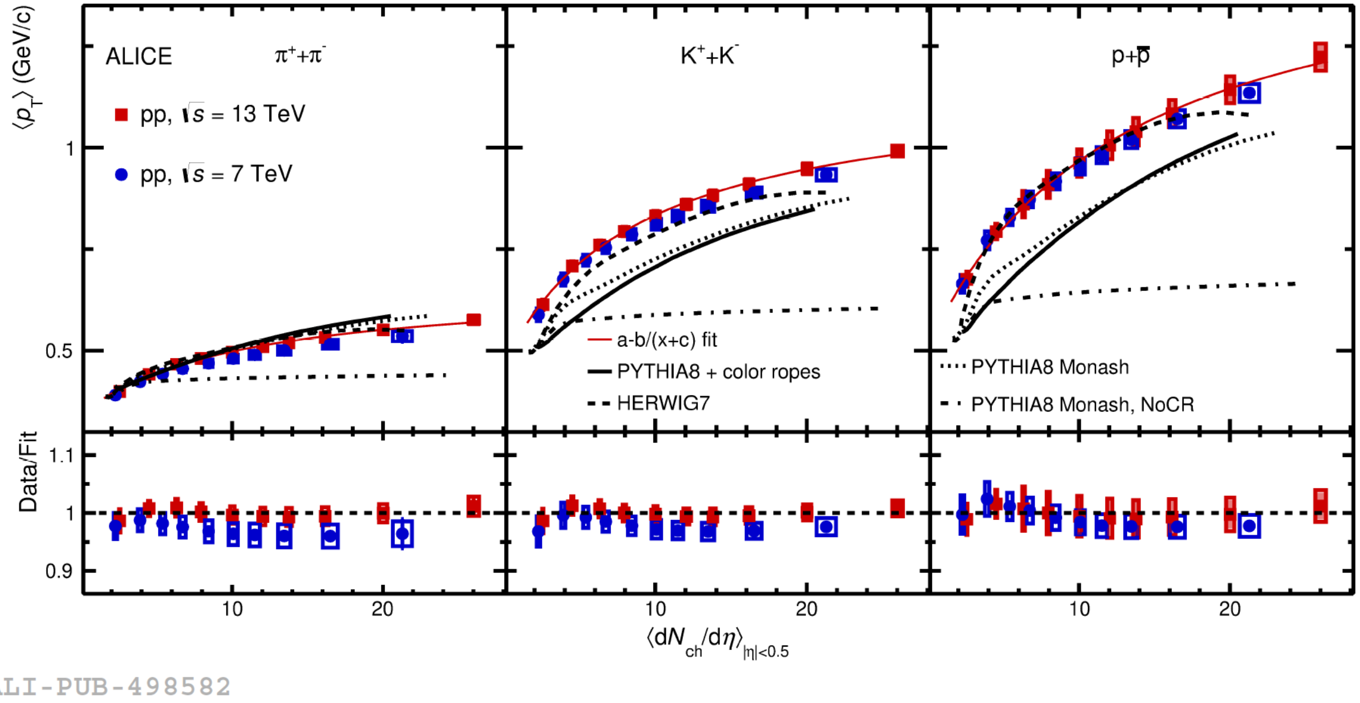
Backup

Average transverse momenta of π, K, and p as a function of charged-particle multiplicity density

CR in pp collisions with large number of MPI is particularly pronounced:

→ correlation between the average transverse momentum and charged-particle multiplicity

→ mass dependent and reminiscent of radial flow effects in heavy-ion collisions

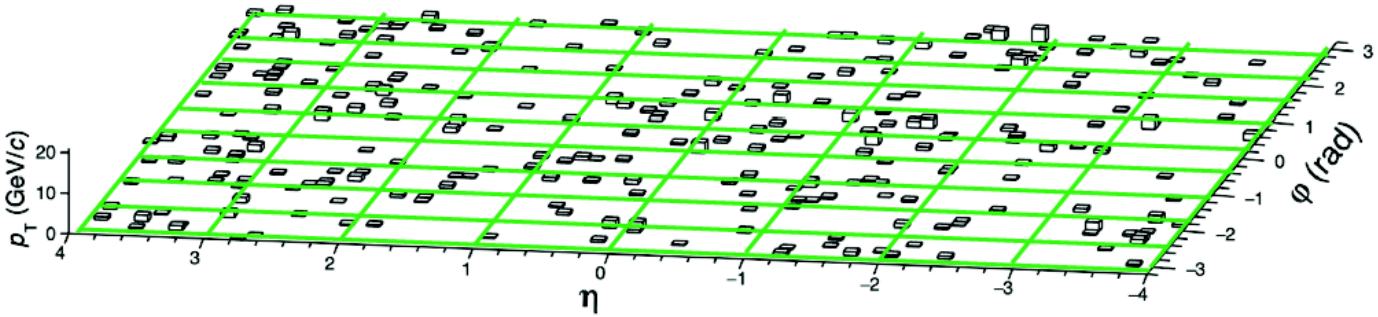


ALICE Collaboration, EPJ C 80 (2020) 693

MC studies on Flattenicity

Define a grid in the $\eta - \varphi$ plane: $N_{\mathrm{cell}} = 10 \times 8$

Phys. Rev. D 107, 076012

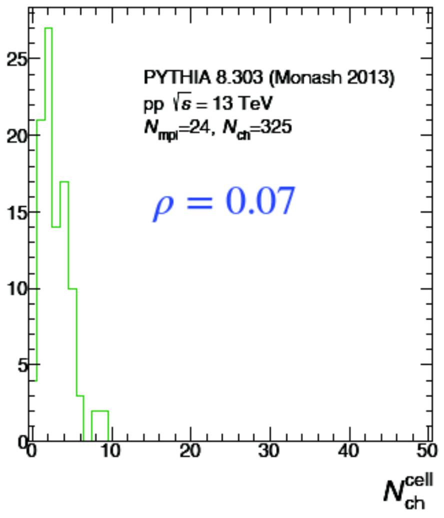


Measure the charged-particle multiplicity in the *i-th* cell: $N_{\mathrm{ch}}^{\mathrm{cell},i}$

The $N_{\mathrm{ch}}^{\mathrm{cell}}$ distribution is obtained (EbE)

For each event Flattenicity is computed:

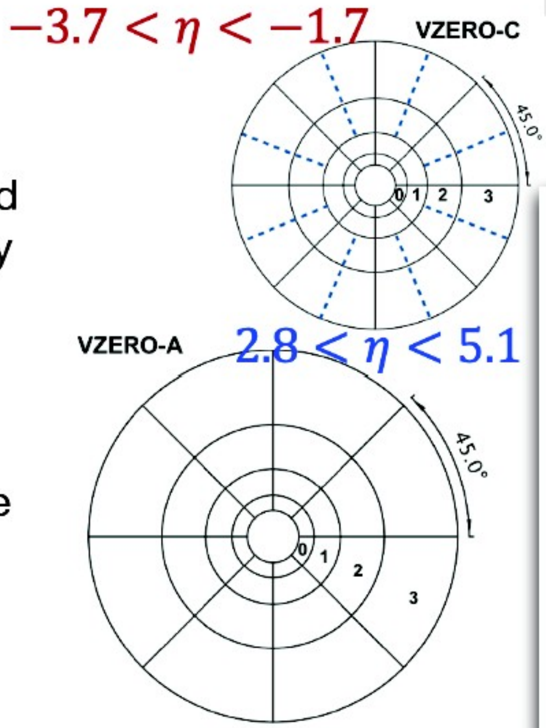
$$\rho = \frac{\sqrt{\left(N_{\mathrm{ch}}^{\mathrm{cell},i} - \langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle\right)^2 / N_{\mathrm{cell}}^2}}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}$$



Events with isotropic distribution of particles are expected to have small ρ ($\rho \to 0$)

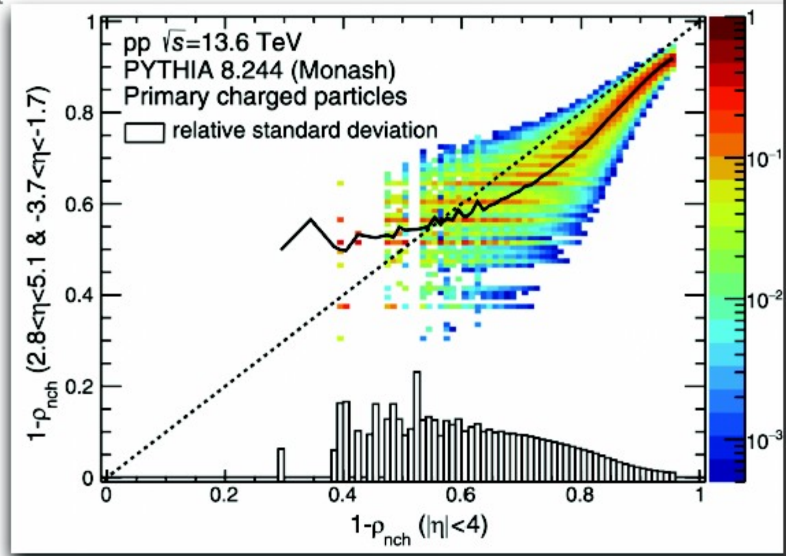
MC studies on Flattenicity

Based on MC simulations, Flattenicity measured in the pseudorapidity interval covered by the ALICE V0A and V0C detectors is strongly correlated with the shape of the events measured in eight units of pseudorapidity



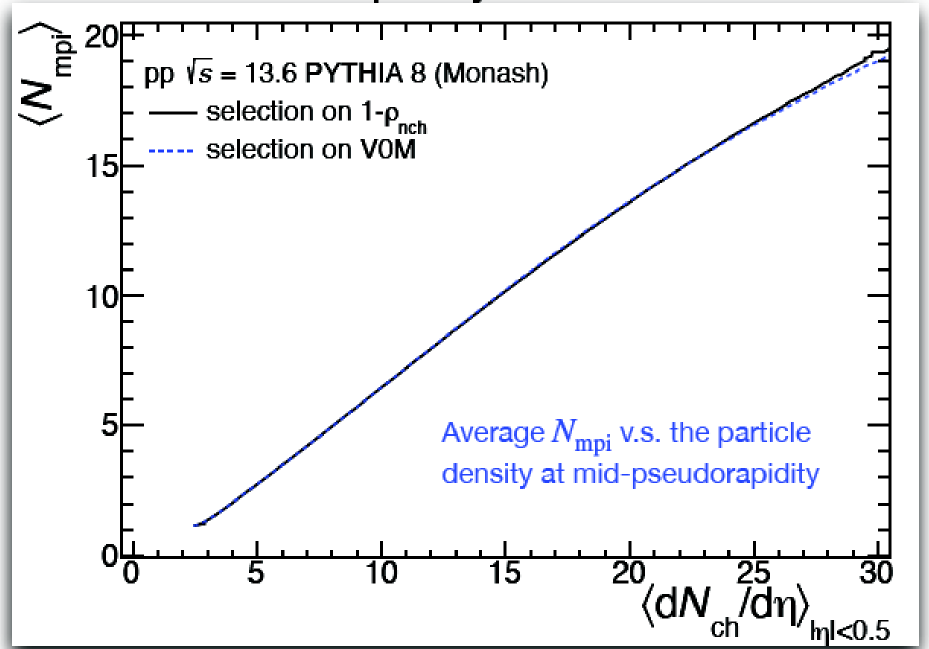
$$\rho = \frac{\sqrt{\left(N_{ch}^{cell,i} - \langle N_{ch}^{cell} \rangle\right)^2 / N_{cell}^2}}{\langle N_{ch}^{cell} \rangle}$$

Phys. Rev. D 107, 076012

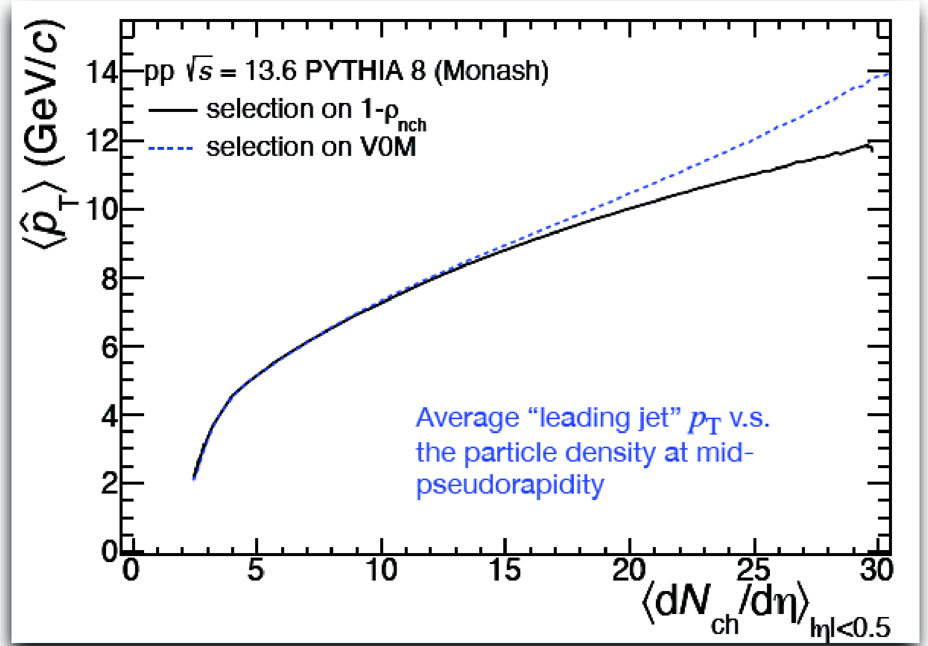


MC studies on Flattenicity

Same sensitivity to MPI as the V0M multiplicity estimator



Flattenicity selects “softer” pp collisions than the V0M estimator



Phys. Rev. D 107, 076012