# Multi-parton interactions in pp collisions using charged-particle flattenicity with ALICE


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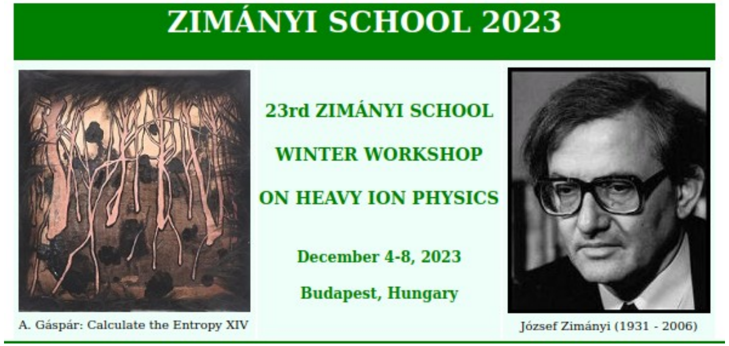
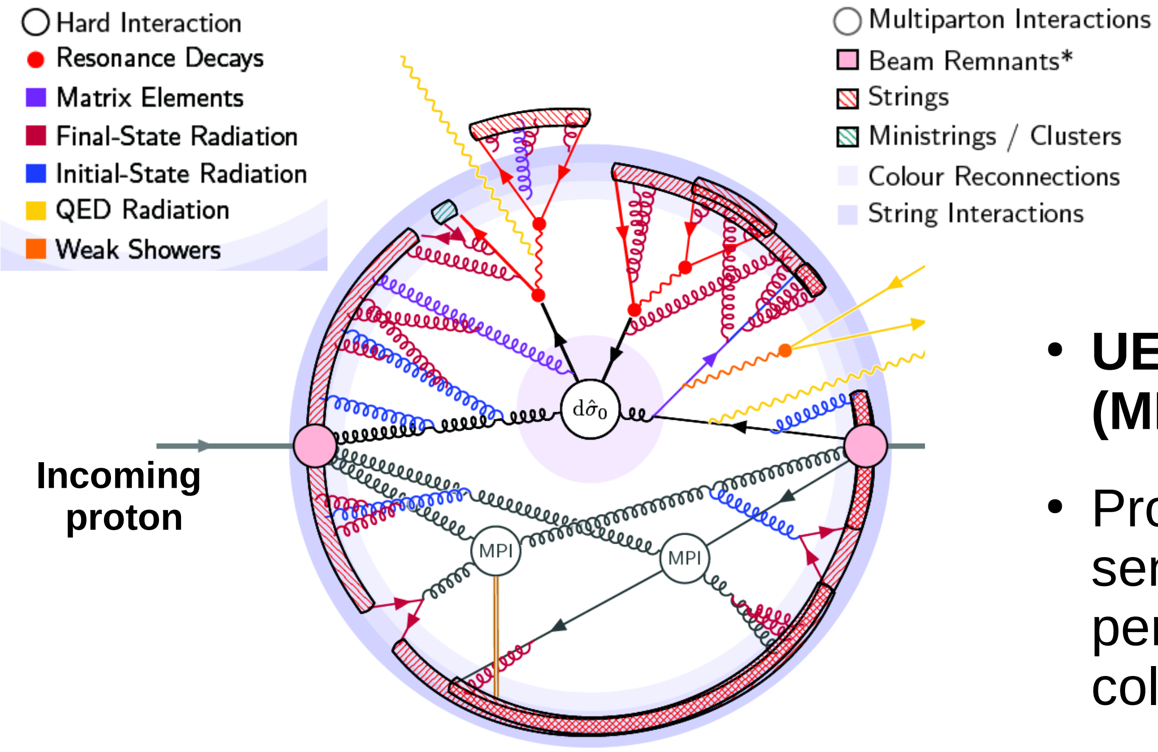




*Suppored by Hungarian National Research, Development and Innovation Office (NKFIH) under contracts OTKA PD143226, FK131979, K135515, and 2021-4.1.2-NEMZ_KI-2022-00018 / 11223-23*

# Introduction

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




Main structure of a pp collision modeled by PYTHIA.
Hadronization not included.
Edited from *C. Bierlich et al., SciPost Phys. Codebases 8 (2022)*

- **UE contains multi-parton interactions (MPI)** supported by LHC measurements
- Properties of the hadronic final state: sensitive to modeling of MPI, and non-perturbative final-state effects such as color reconnection (CR)

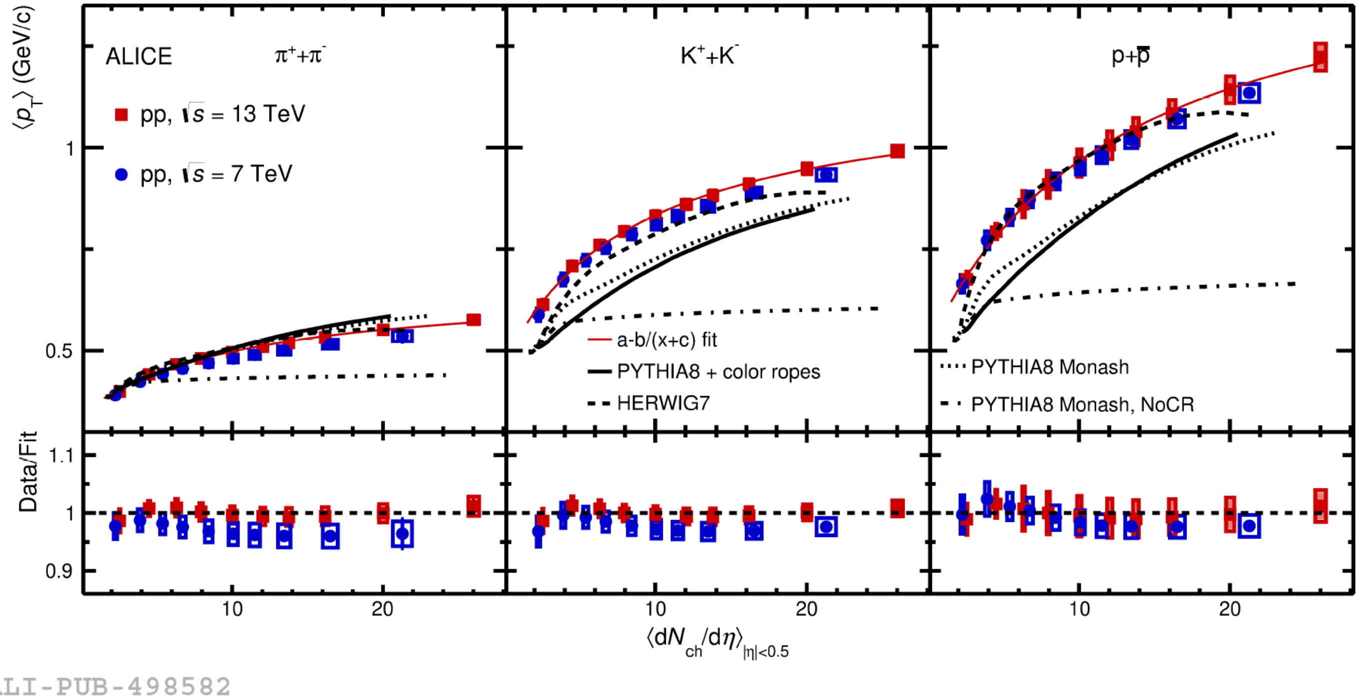
# Introduction

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

**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

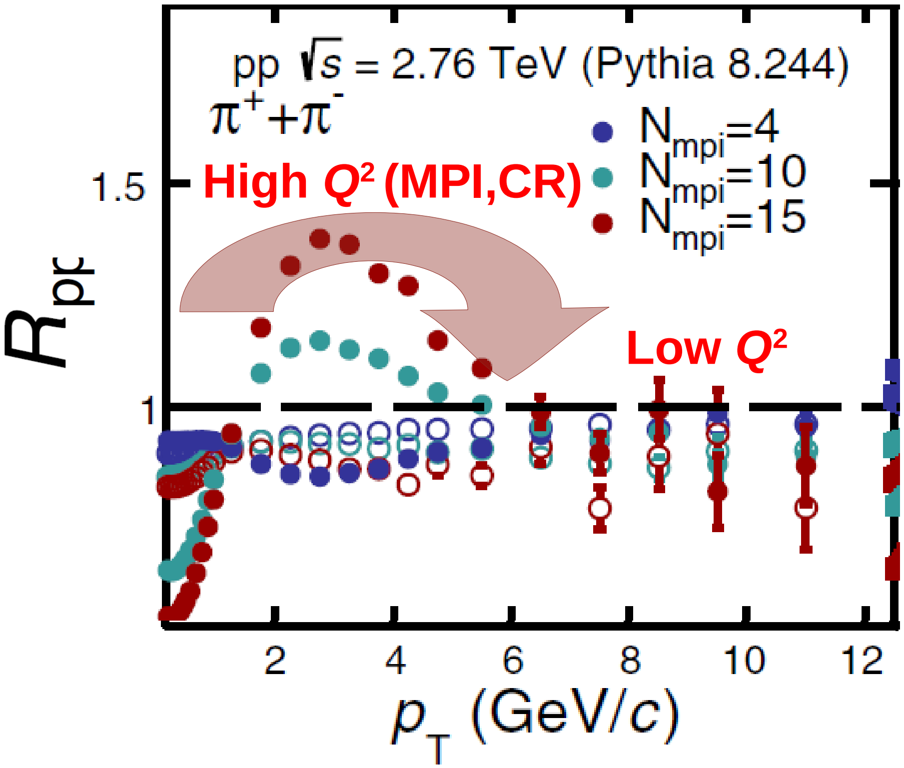



*ALICE Collaboration, **EPJ C 80** (2020) 693*

# Motivation

***Objective:*** study particle production using event shape observable with strong sensitivity to “soft” MPI and CR effects

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




$$R_{pp} = \frac{d^2N_{ch}^{mpi}/(\langle N_{mpi}\rangle d\eta dp_T)}{d^2N_{ch}^{MB}/(\langle N_{mpi}^{MB}\rangle d\eta dp_T)}$$

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

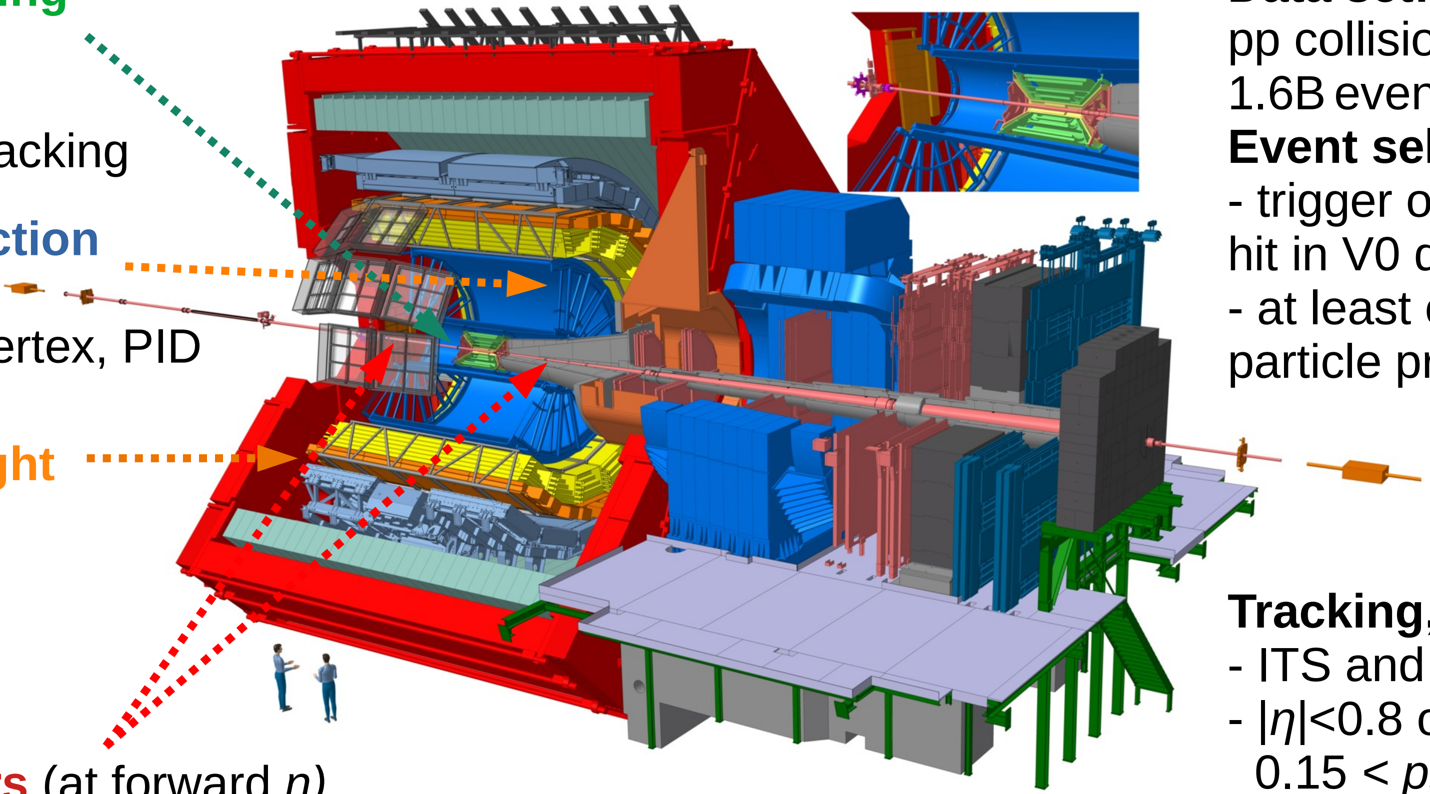
- 40% increase w.r.t. the binary parton-parton scaling: “bump” structure in $1 < p_T < 6$ GeV/$c$
- the effect is driven by CR
- MPI selection does not bias the high-$p_T$ yield

# The ALICE detector (during Run 2)

**Inner Tracking System**
- triggering, vertexing, tracking

**Time Projection Chamber**
- tracking, vertex, PID

**Time of Flight**
- PID



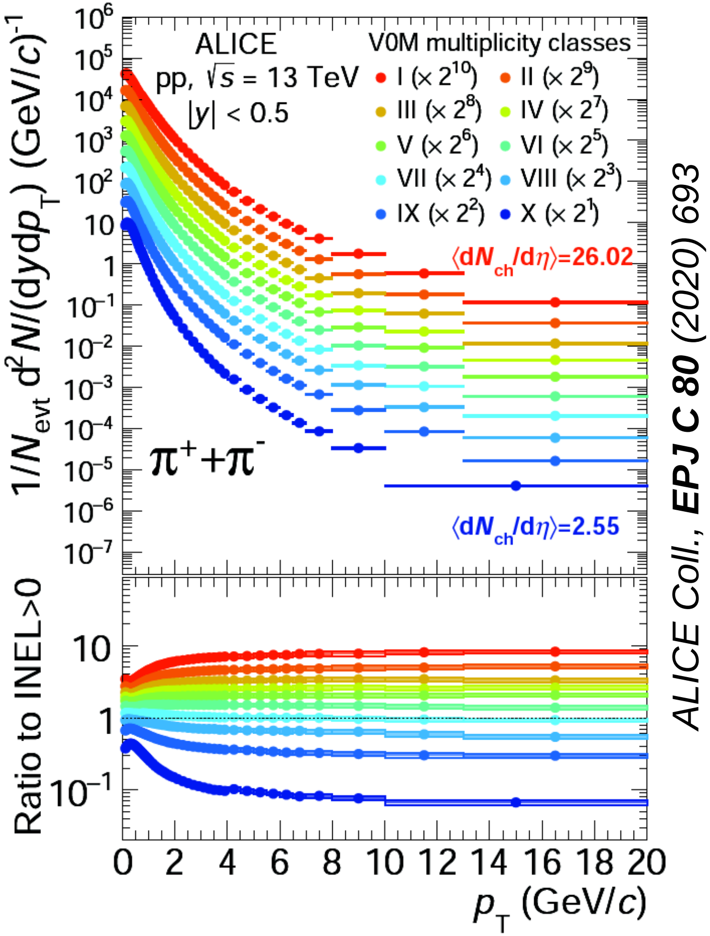
**Data set:** 2016–18 LHC pp collisions at 13 TeV, 1.6B events

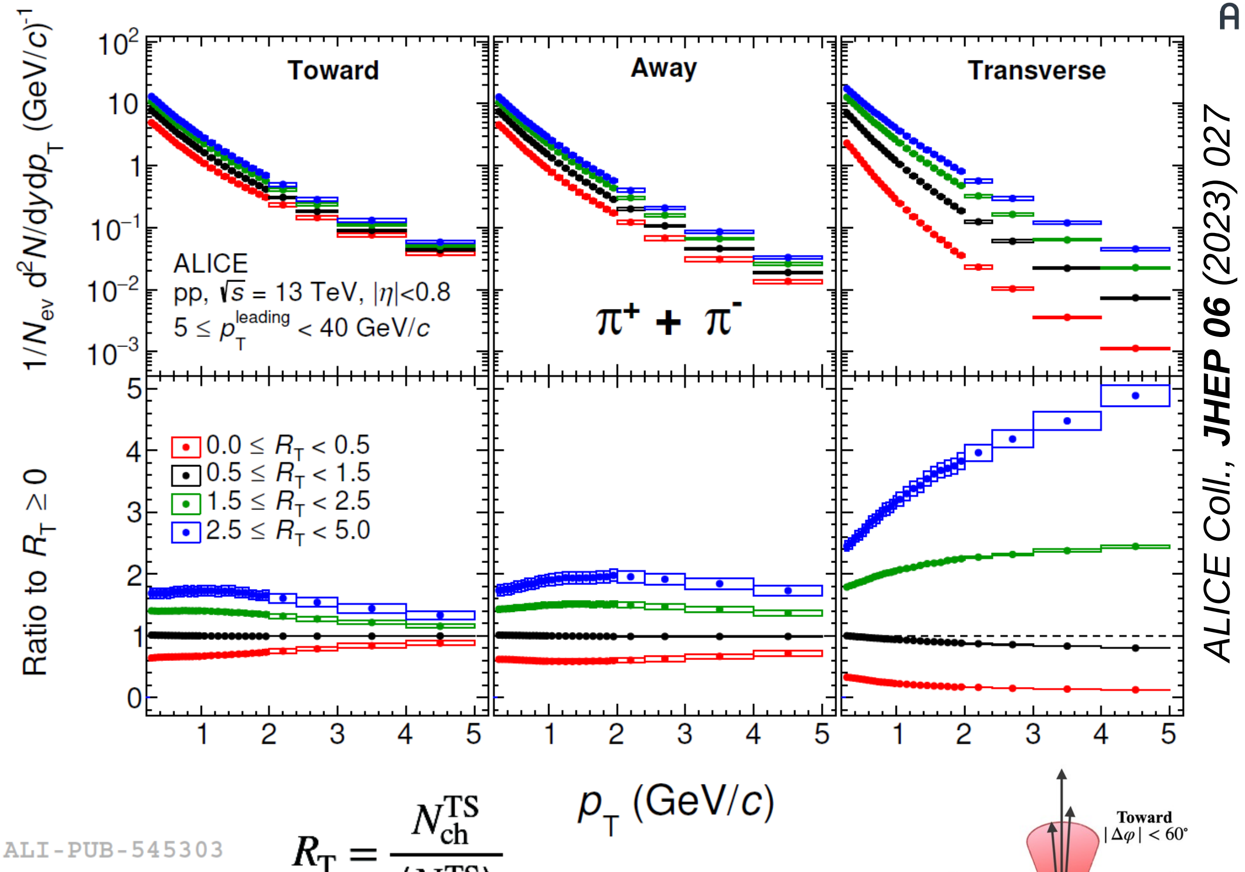
**Event selection:**
- trigger on at least one hit in V0 detectors
- at least one charged particle produced in $|\eta|<1$

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

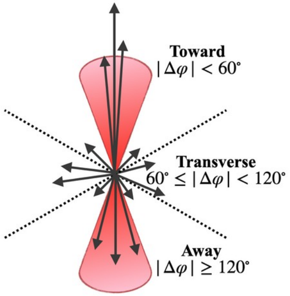
**V0 detectors** (at forward $\eta$)
- triggering
- ***event classification based on*** charged-particle multiplicites by measuring ***signal amplitude in V0A and V0C detectors: V0M***

# Existing spectra results from ALICE




$$R_{T} = \frac{N_{ch}^{TS}}{\langle N_{ch}^{TS} \rangle}$$

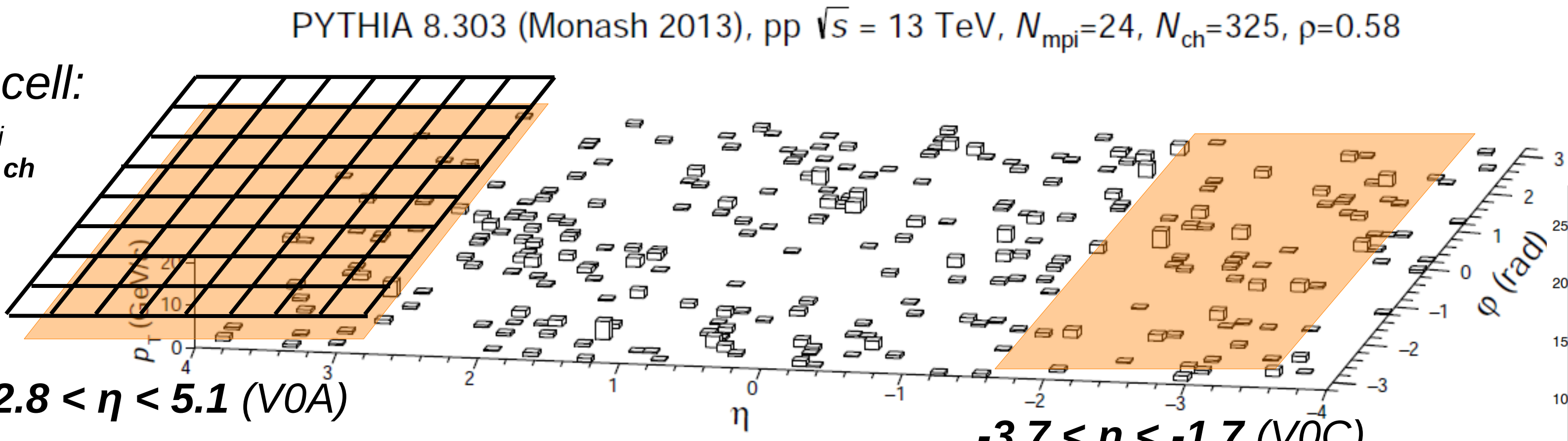



- No “bump” structure seen in any of these measurements → selection bias
- Explore event classifier: sensitivity to MPI with reduced selection bias

# Event classification with Flattenicity

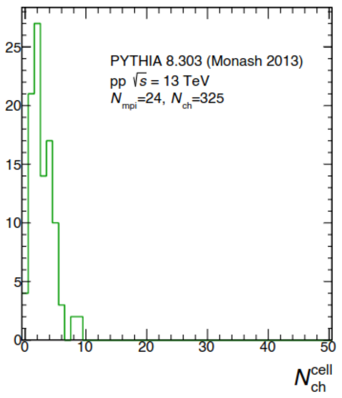
- **Define a grid in *η – φ covered by the V0 detector of ALICE:***
  *2.8 < η < 5.1 (V0A) and -3.7 < η < -1.7 (V0C) and full azimuth*
- *Measure charged particle multiplicity in a grid of $N_{cell}$ (64 cells)*

*i-th cell:* $N^{cell,i}_{ch}$




**2.8 < η < 5.1** *(V0A)*

***-3.7 < η < -1.7*** *(V0C)*




- $N^{cell,i}_{ch}$*: charged-particle multiplicity in the i-th cell*
- $\langle N_{cell,ch} \rangle$ *: the event-averaged* $N^{cell,i}_{ch}$
- **Define event shape Flattenicity[1] event-by-event:**

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


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

# Event classification with Flattenicity

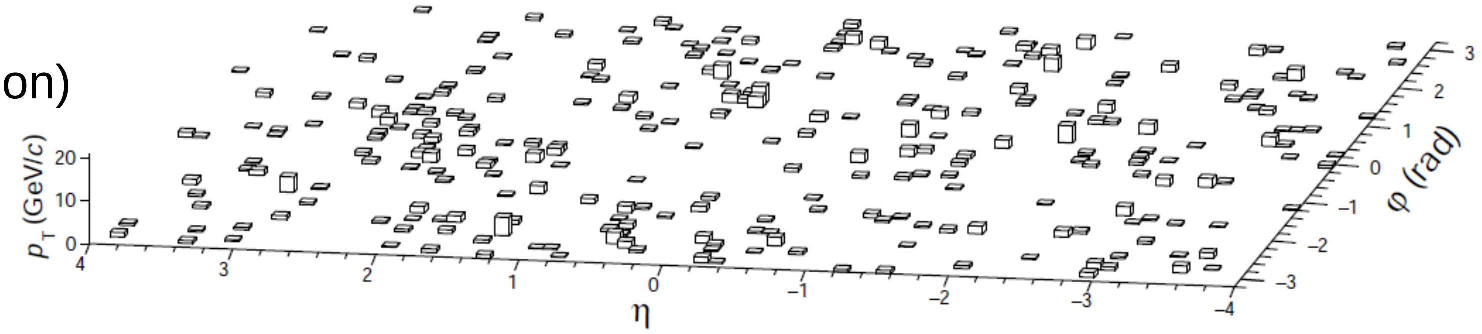
**To associate** with other event shapes (e.g. Spherocity) using $1-\rho$

***A)*** $1-\rho \rightarrow 1$:

**multi-minijet topology**

(“soft” pp collision)

PYTHIA 8.303 (Monash 2013), pp $\sqrt{s}$ = 13 TeV, $N_{mpi}$=24, $N_{ch}$=325

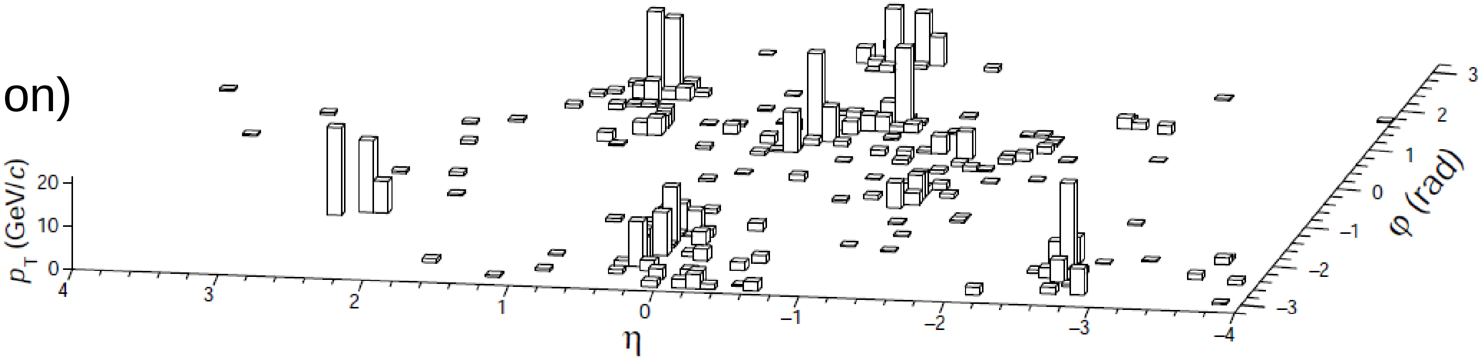



***B)*** $1-\rho \rightarrow 0$:

**multi-jet topology**

(“hard” pp collision)

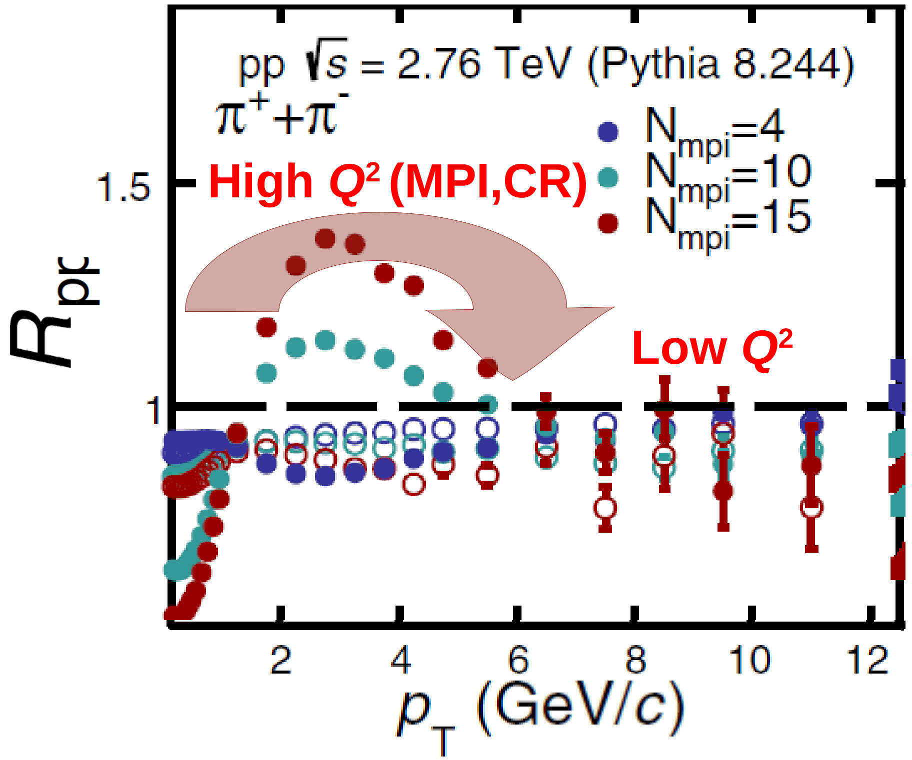
PYTHIA 8.303 (Monash 2013), pp $\sqrt{s}$ = 13 TeV, $N_{mpi}$=1, $N_{ch}$=235




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

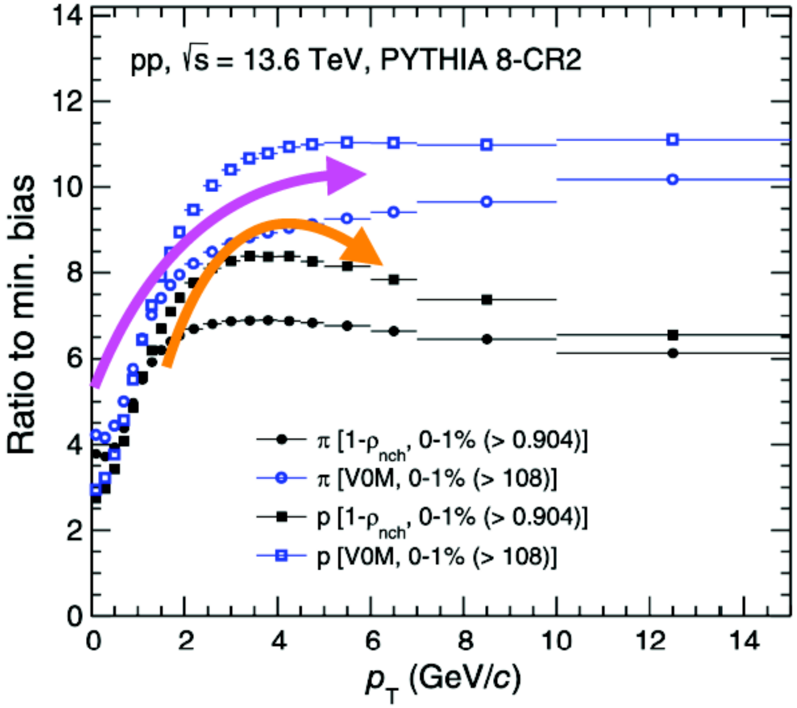
# Effects of Flattenicity selection from PYTHIA8 simulations

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



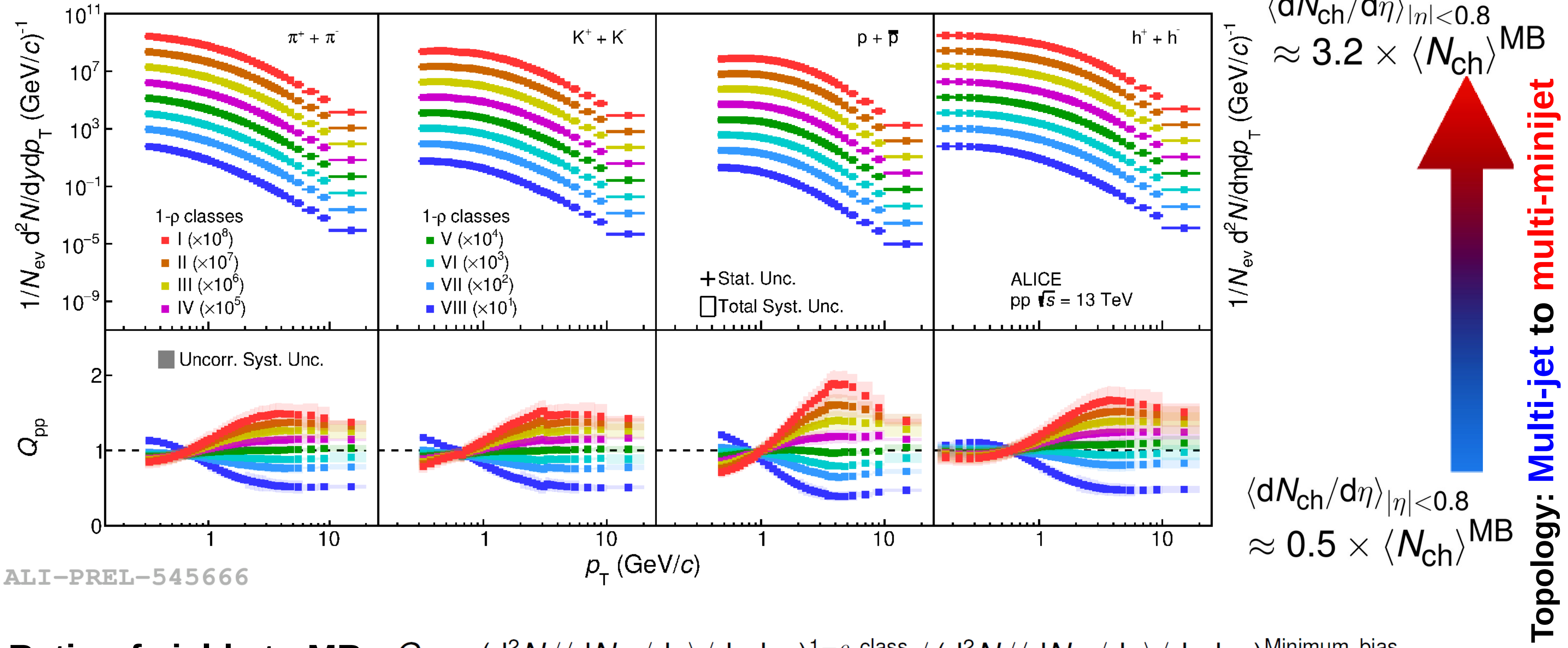

- Sensitivity to selection on MPI
- high-pT yield is not biased

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




- Selection using $1 - \rho$ shows "bump" structure
- Reduced bias towards hard physics

# $p_T$ spectra and $Q_{pp}$ ratios vs. Flattenicity



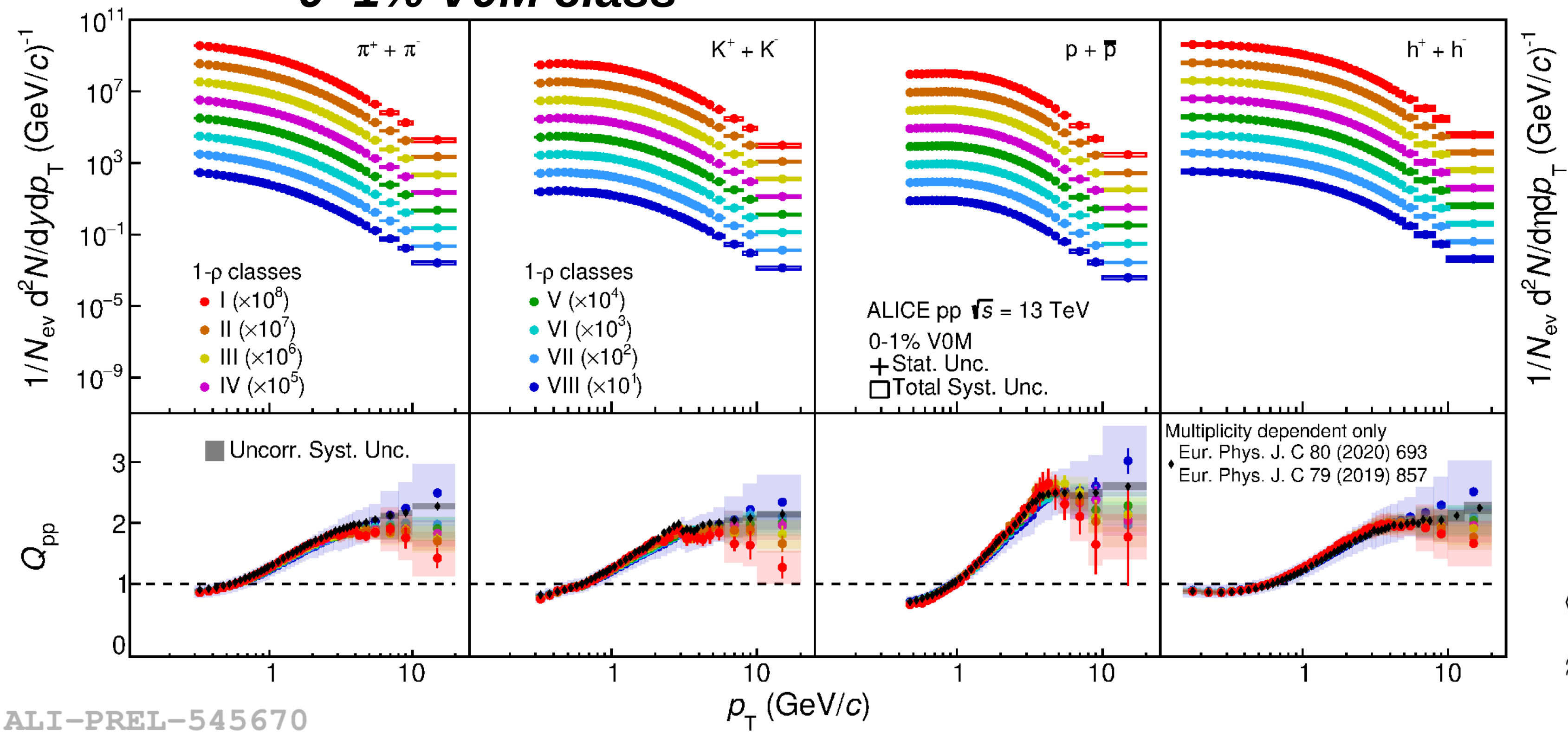

**Ratio of yields to MB:** $Q_{pp} = (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{1-\rho\ \text{class}} / (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{\text{Minimum bias}}$

1) **"Bump" structure:** clear development of a peak for **isotopic events** (flattenicity class (I), 0–1% 1-ρ)
2) **Mass dependency:** maximum of the peak shows a mass-dependent ordering

New preliminary

# $p_T$ spectra and $Q_{pp}$ ratios vs. Flattenicity and V0M

***0–1% V0M class***




$\langle dN_{ch}/d\eta\rangle_{|\eta|<0.8} \approx 4.5 \times \langle N_{ch}\rangle^{MB}$

$\langle dN_{ch}/d\eta\rangle_{|\eta|<0.8} \approx 3.4 \times \langle N_{ch}\rangle^{MB}$

**Topology: Multi-jet to multi-minijet**

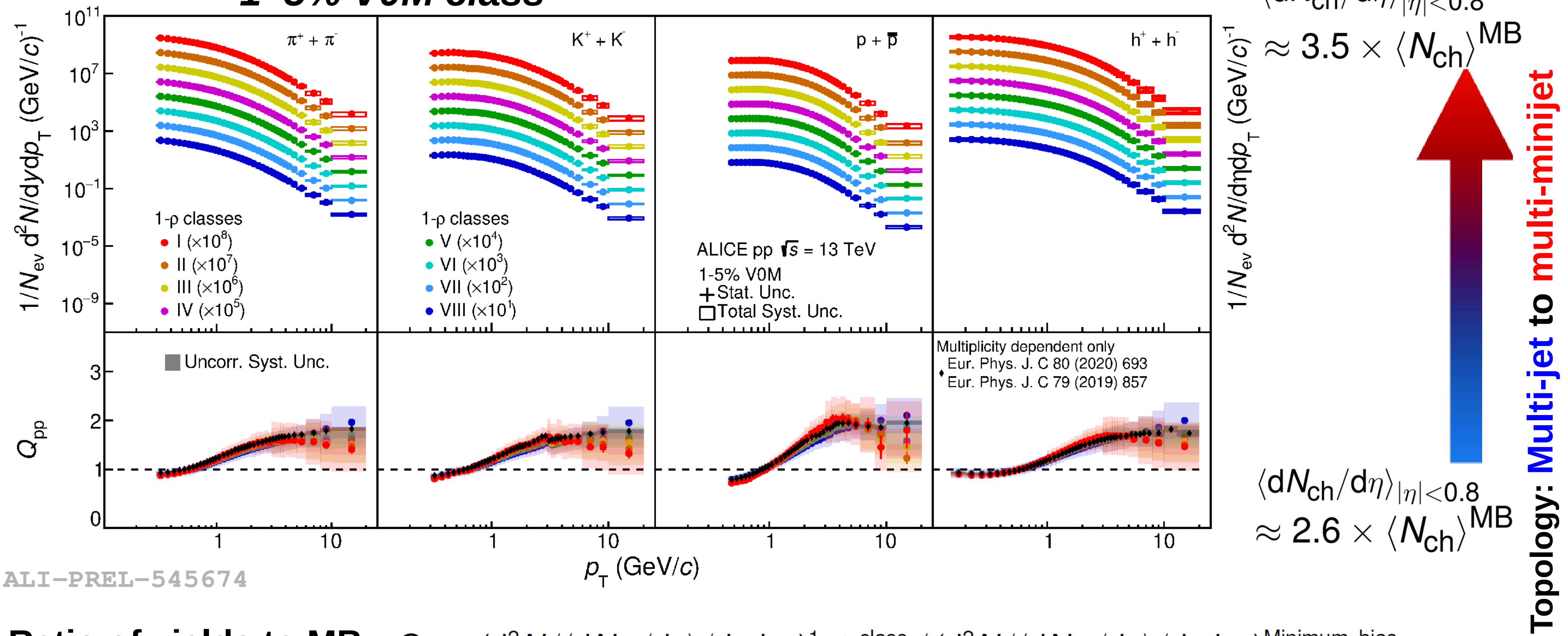
**Ratio of yields to MB:** $Q_{pp} = (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{1-\rho\ \text{class}} / (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{\text{Minimum bias}}$

1) "Bump" structure: clear development of a peak for isotopic events (flattenicity class (I), 0–1% 1-ρ)
2) Mass dependency: maximum of the peak shows a mass-dependent ordering
**3) Reduced selection bias:** due to flattenicity selection with increasing multiplicity (not seen for V0M-only)

New preliminary

# $p_T$ spectra and $Q_{pp}$ ratios vs. Flattenicity and V0M

## 1–5% V0M class



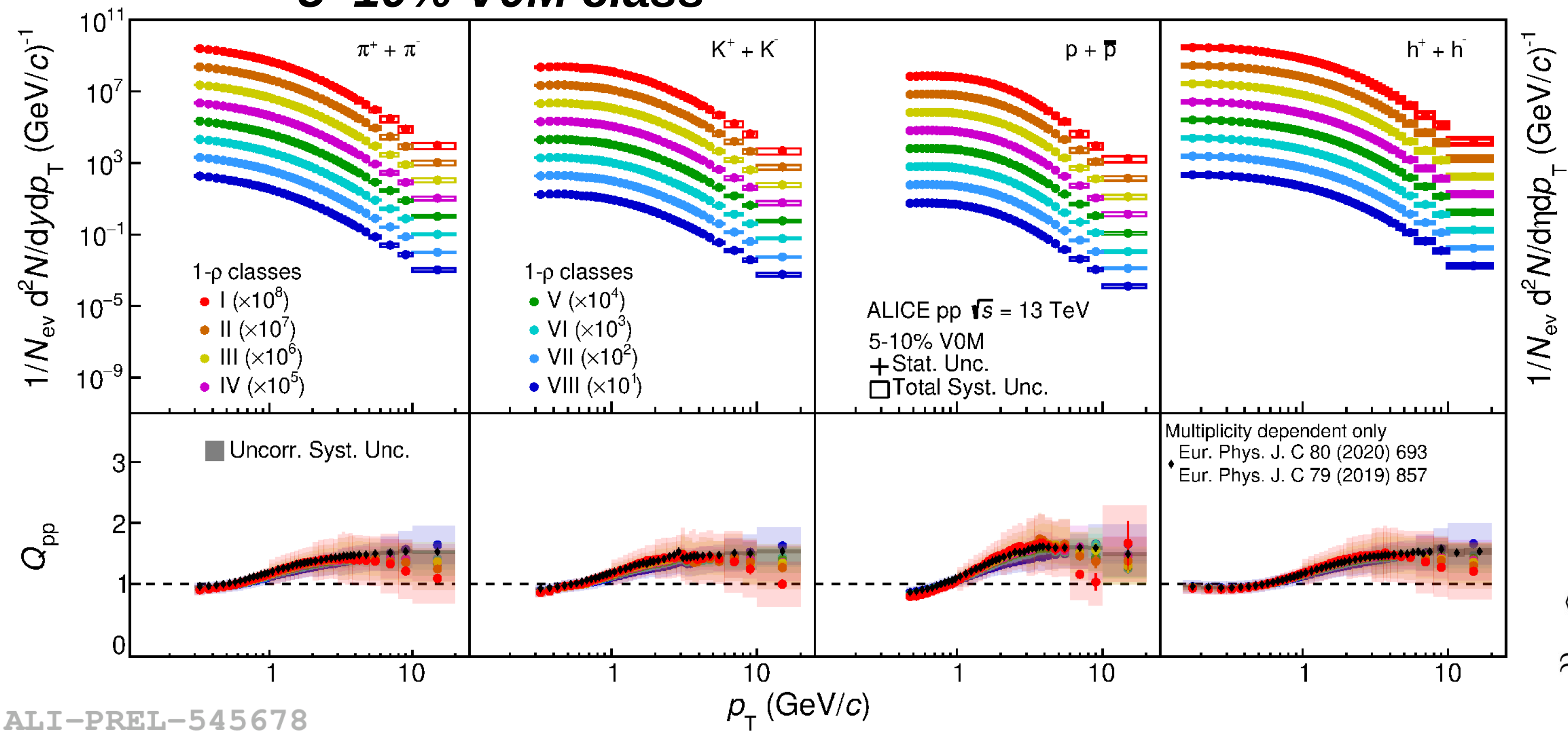

**Ratio of yields to MB:** $Q_{pp} = (d^2N/\langle dN_{ch}/d\eta \rangle/d\eta dp_T)^{1-\rho\ \text{class}} / (d^2N/\langle dN_{ch}/d\eta \rangle/d\eta dp_T)^{\text{Minimum bias}}$

1) Gradual decrease of “bump” structure with decreasing V0M multiplicity
2) Mass ordering of the peak and reduced jet bias effects are less pronounced w.r.t 0-1% V0M class

**New preliminary**

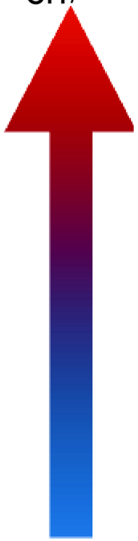
# $p_T$ spectra and $Q_{pp}$ ratios vs. Flattenicity and V0M

***5–10% V0M class***




ALICE

$\langle dN_{ch}/d\eta\rangle_{|\eta|<0.8} \approx 2.9 \times \langle N_{ch}\rangle^{MB}$



$\langle dN_{ch}/d\eta\rangle_{|\eta|<0.8} \approx 2.1 \times \langle N_{ch}\rangle^{MB}$

**Topology: Multi-jet to multi-minijet**

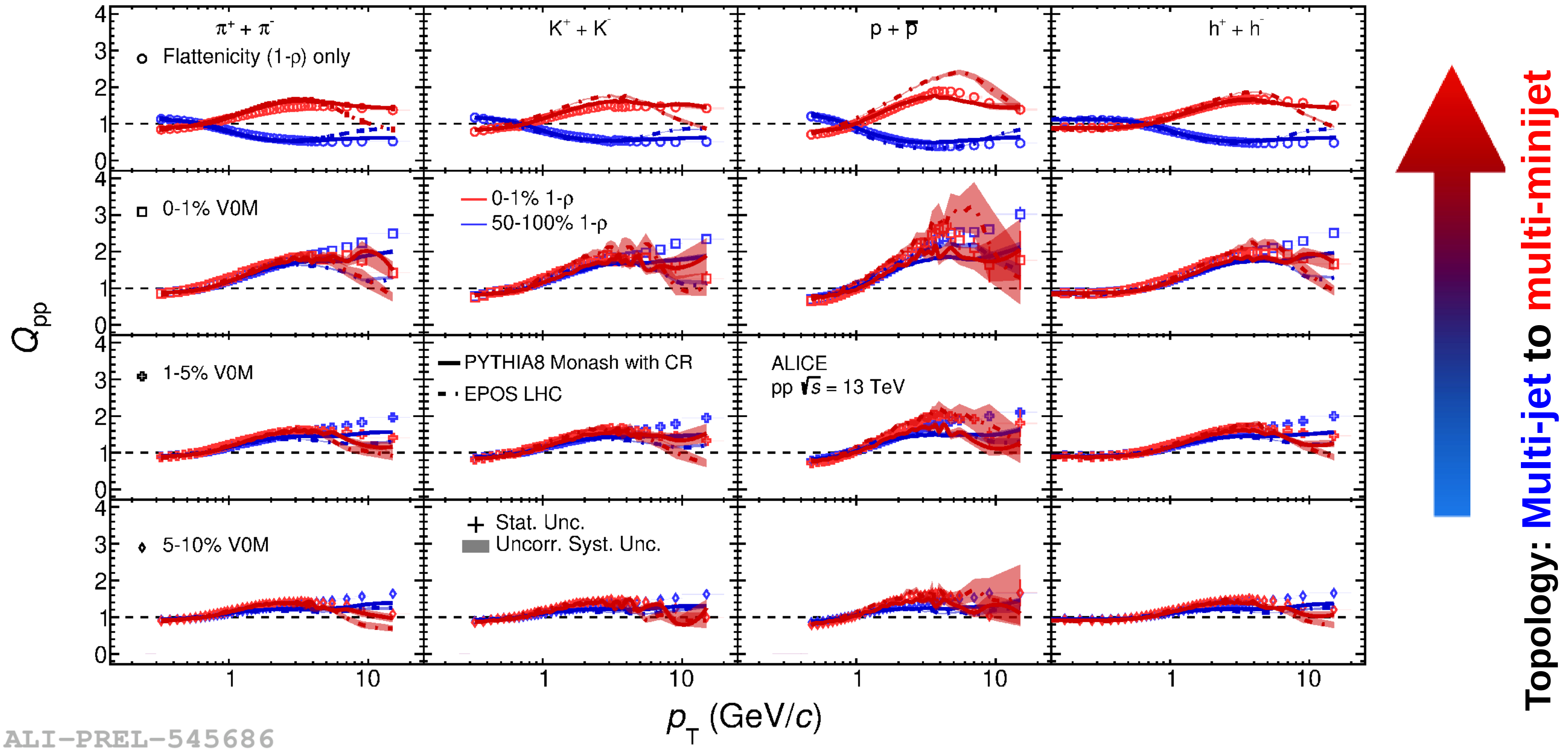
**Ratio of yields to MB:** $Q_{pp} = (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{1-\rho\ \text{class}} / (d^2N/\langle dN_{ch}/d\eta\rangle/d\eta dp_T)^{\text{Minimum bias}}$

1) Gradual decrease of "bump" structure with decreasing V0M multiplicity
2) Mass ordering of the peak and reduced jet bias effects are less pronounced w.r.t 0-1% V0M class

**New preliminary**

# Comparison with MC models (incl. detector effects) $Q_{pp}$ ratios vs. Flattenicity and V0M

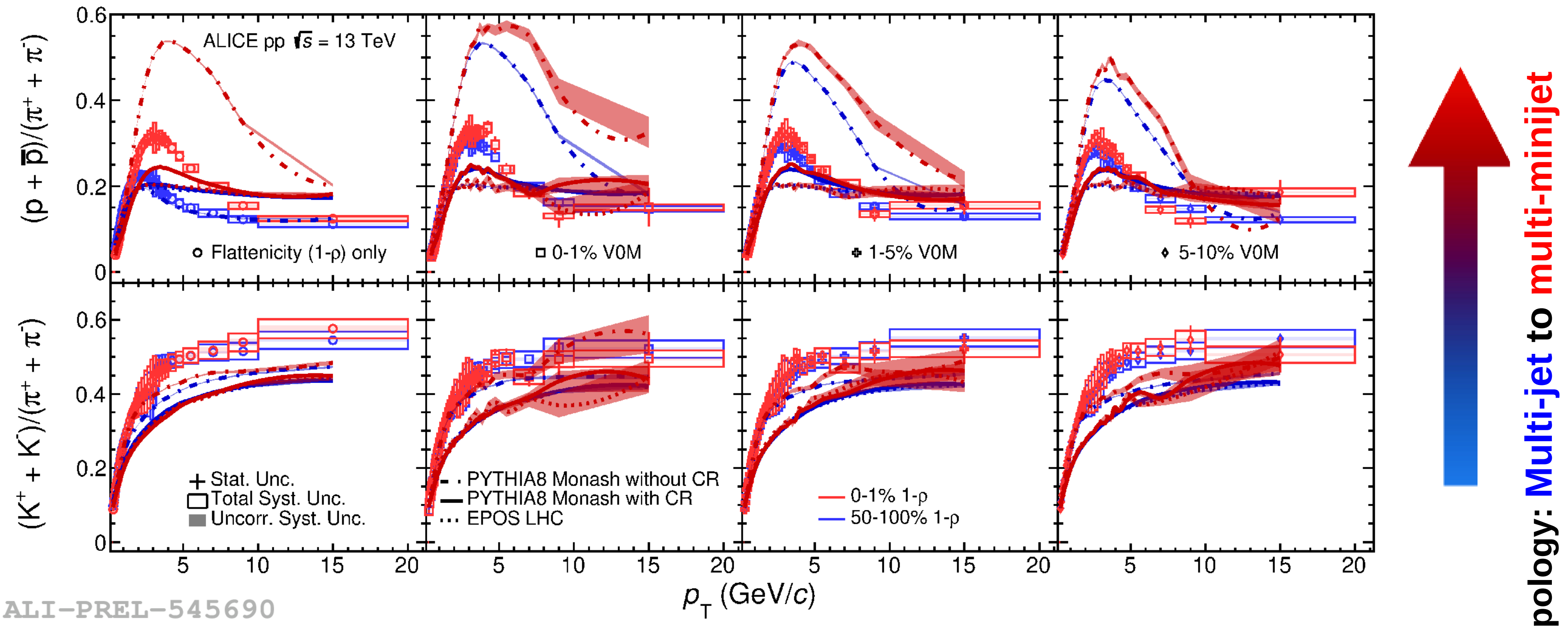
$$Q_{pp} = \frac{\left(\frac{d^2N/d\eta dp_T}{\langle dN_{ch}/d\eta\rangle}\right)^{1-\rho\ \text{class}}}{\left(\frac{d^2N/d\eta dp_T}{\langle dN_{ch}/d\eta\rangle}\right)^{\text{Min. bias}}}$$




1) **PYTHIA 8** Monash 2013 with MPI and CR effects describes the data; sensitive to evt. sel. due to CR
2) **EPOS LHC** descirbes the data partially (low-to-mid $p_T$); opposite trend seen w.r.t. PYTHIA8 at high $p_T$

New preliminary

# Double-differential study of K/π and p/π




- **K/π ratio:** do not change with flattenicity and V0M mult.; models follow this trend qualitatively
- **p/π ratio:**
  - sensitive to flattenicity-only selection, which is described by PYTHIA8 (with CR)
  - worst description by the models at the highest multiplicity (0–1% V0M) event class

# Summary and outlook

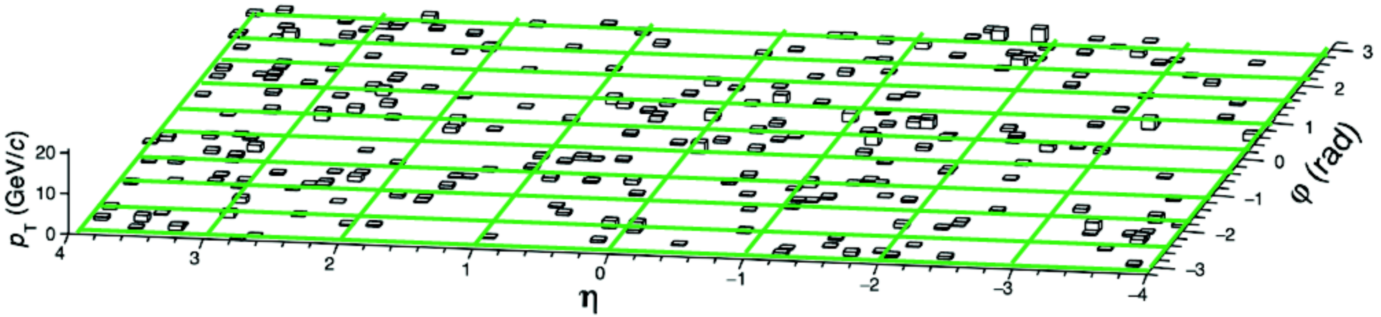
- Particle production is studied in pp collisions at 13 TeV using the ***new event shape observable flattenicity*** for the first time
- Double-differential measurement of (un)identified $p_T$ spectra in flattenicity and V0M multiplicity event classes is performed
- For **isotropic events**, the ratio of event-class dependent $p_T$ spectra to that of MB, ($Q_{pp}$) develops a **"bump"-like structure** with increasing multiplicity that is mass dependent
- Results indicate that Flattenicity-selection is
  - sensitive to soft particle production, as suggested by MC event generators
  - less sensitive to a (jet-) bias from high-$p_T$ processes
- PYTHIA8 (Monash2013) describes quantities studied in flattenicity classes
- **Outlook:**
  - More results are coming, ***paper in preparation***
  - Measurements with ALICE Run 3 data are ongoing

# Backup

# MC studies on Flattenicity

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

Phys. Rev. D 107, 076012



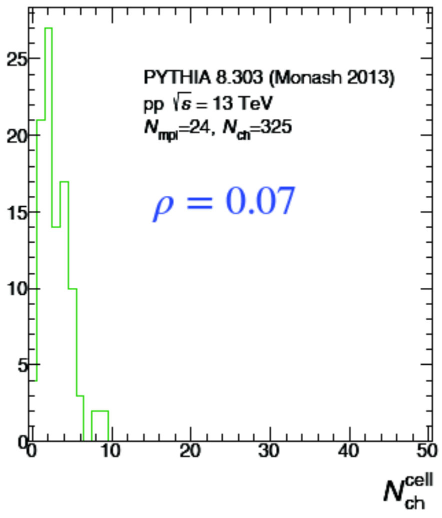

Measure the charged-particle multiplicity in the *i-th* cell: $N_{\rm ch}^{{\rm cell},i}$

For each event Flattenicity is computed:

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

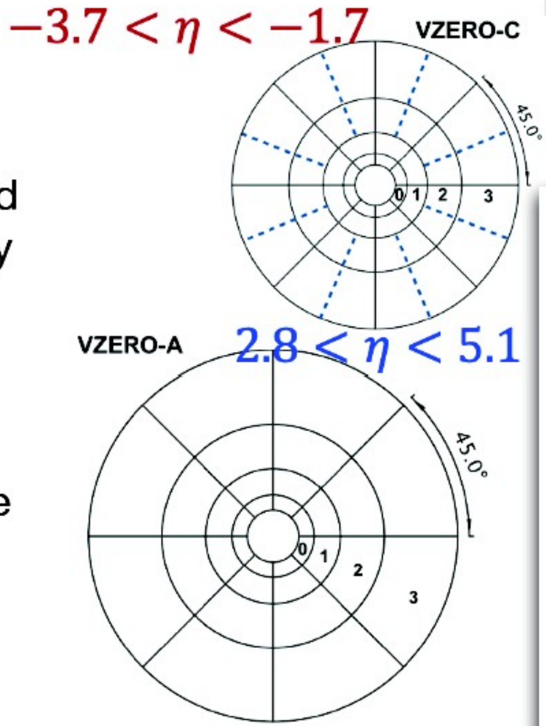
Events with isotropic distribution of particles are expected to have small $\rho$ ($\rho \to 0$)

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



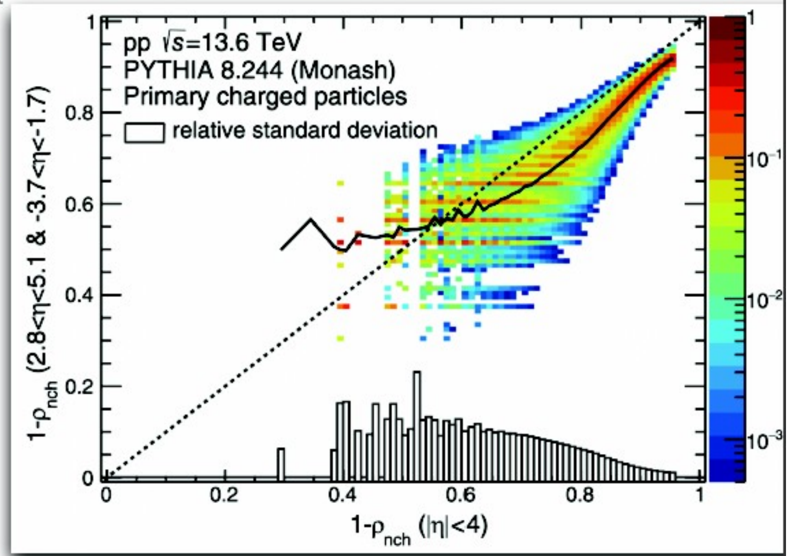
# MC studies on Flattenicity

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



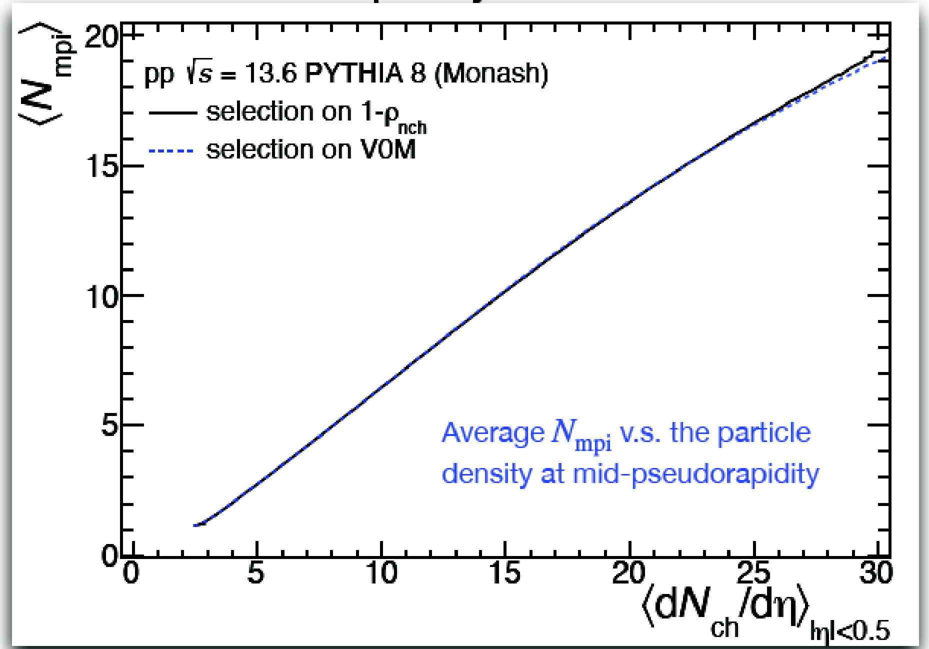

$$\rho = \frac{\sqrt{\left(N_{\mathrm{ch}}^{\mathrm{cell},i} - \langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle\right)^2 / N_{\mathrm{cell}}^2}}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}$$

Phys. Rev. D 107, 076012

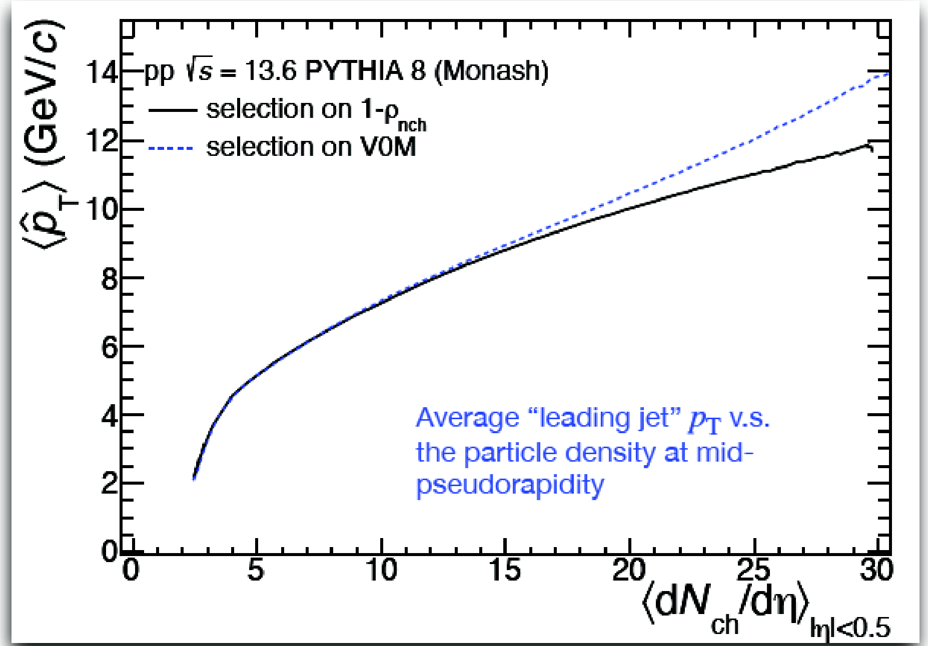


# MC studies on Flattenicity

Same sensitivity to MPI as the V0M multiplicity estimator




Flattenicity selects "softer" pp collisions than the V0M estimator




Phys. Rev. D 107, 076012