Multi-parton interactions in the LHC Run 3 and beyond

Antonio Ortiz

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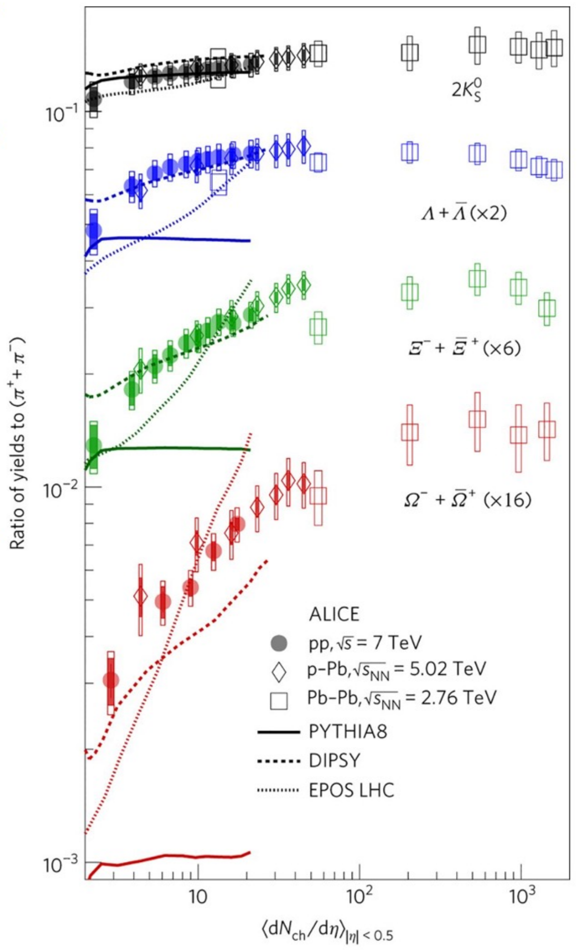
13th International workshop on Multiple Partonic Interactions at the LHC, IFT UAM/CSIC Madrid
14-18, November 2022

arXiv:2211.06093

Introduction

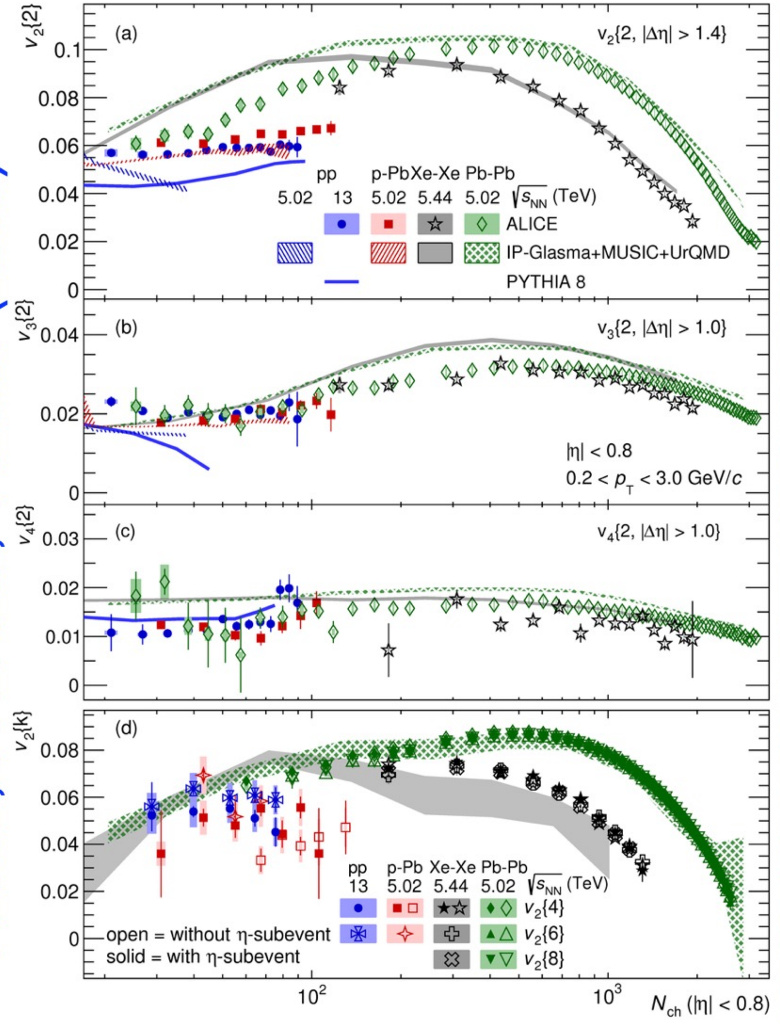
Small collision systems

ALICE, Nat. Phys. 13, 535-539 (2017)



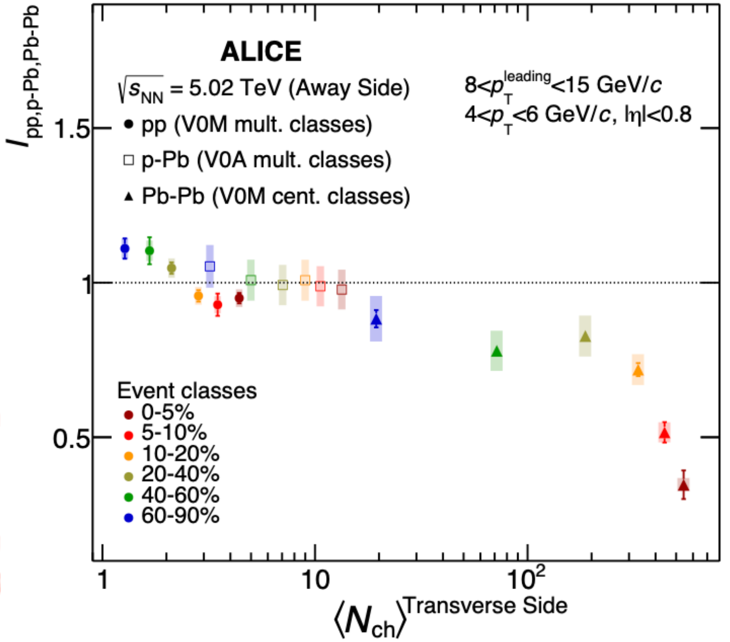
Strangeness enhancement

ALICE, PRL 123, 142301 (2019)



Collectivity

Effects at high p_T



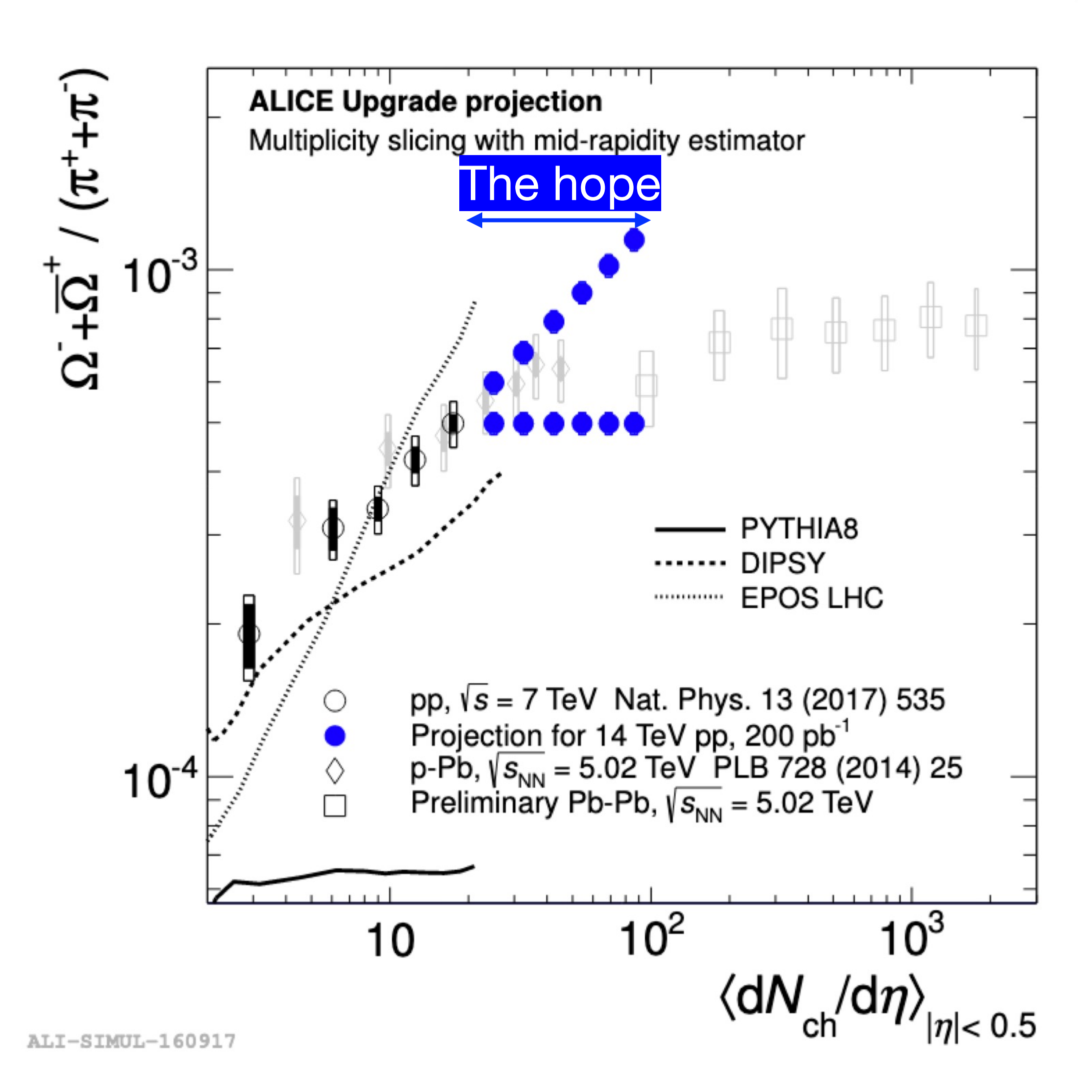
Within the limited multiplicity reach, no jet quenching effects are seen in small systems

ALICE, arXiv:2204.10157

ALICE plans for runs 3 and 4

- Study pp collisions with $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \approx 100$ (estimated energy density $\epsilon \approx 50\ \mathrm{GeV/fm^3}$ as found in central Pb–Pb collisions)
- Search for jet quenching effects
- Check whether the Ω/π ratio reaches or exceeds the thermal limit

ALICE-PUBLIC-2020-005

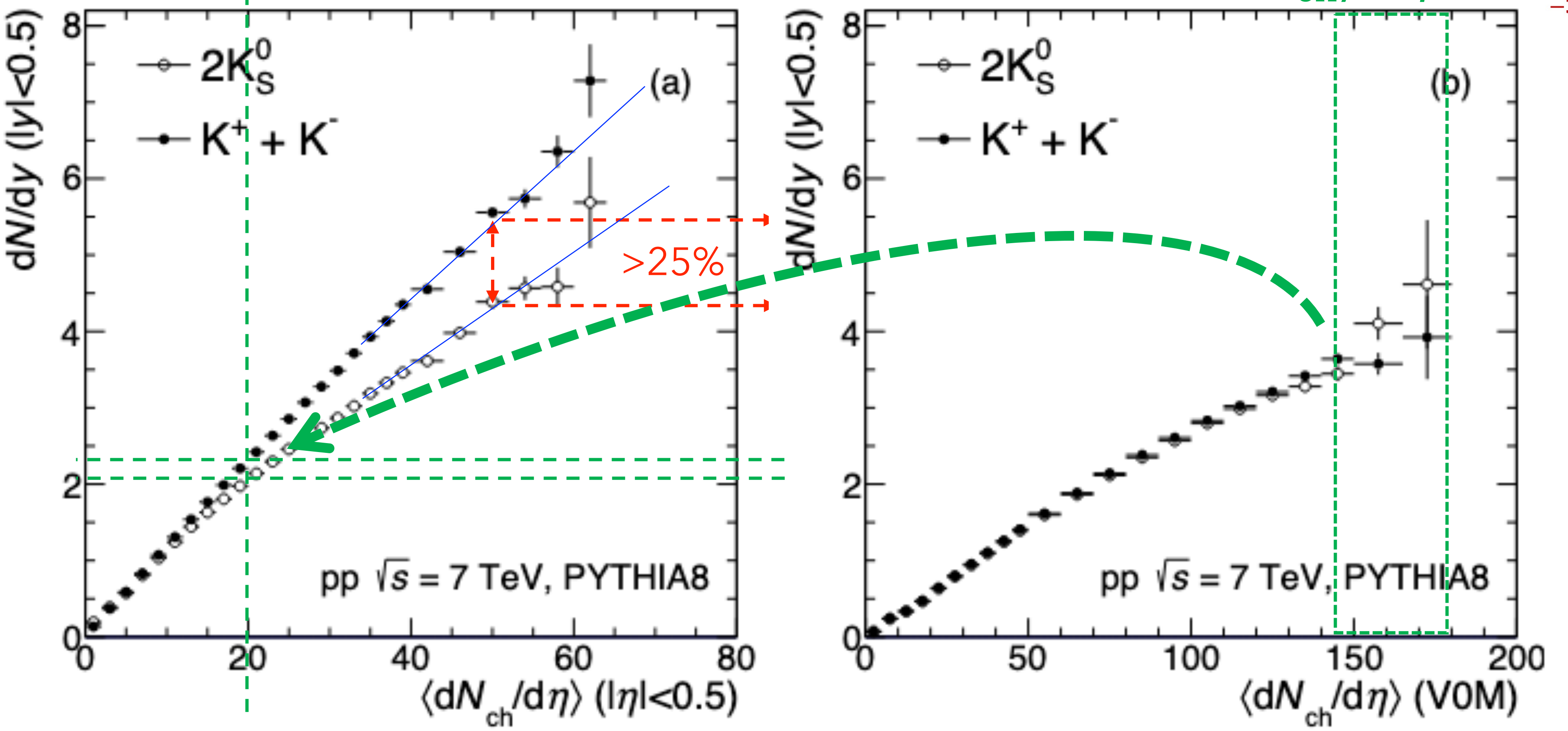


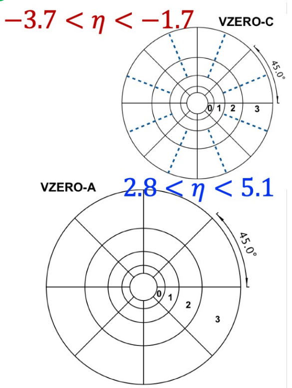
Expected issues for very HM pp collisions

Instituto de Ciencias Nucleares UNAM

[ALICE, Phys. Rev. C 99, 024906 (2019)](#)

$\mathrm{d}N_{\mathrm{ch}}/\,\mathrm{d}\eta \approx 20$





- Charged particles bias

- Better control of the biases when the multiplicity is measured in the V0 detector, but at the cost of a lower multiplicity reach ($|\eta| < 0.5$)

Selection biases II

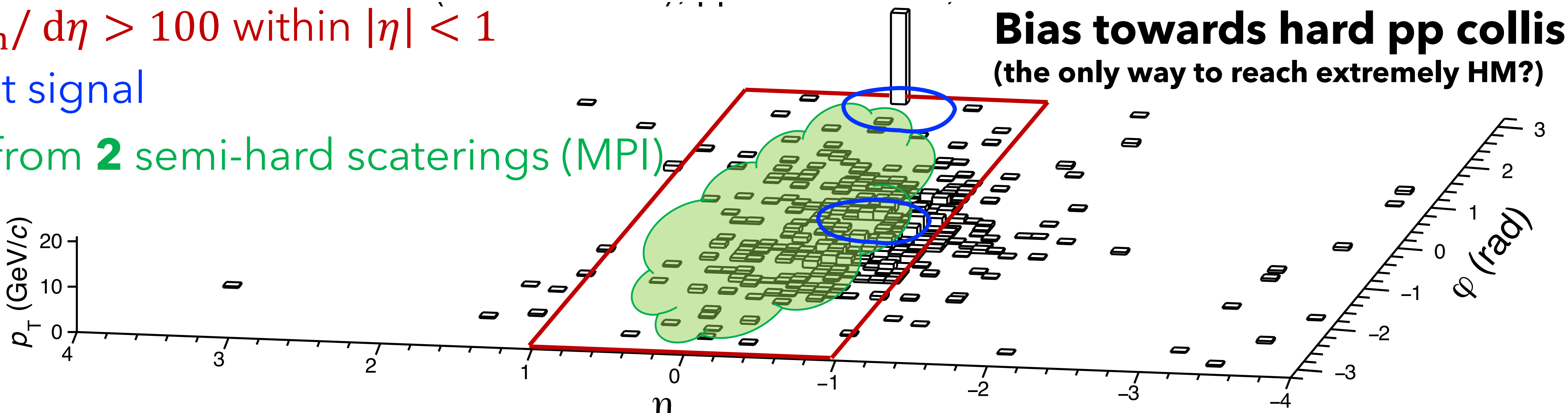
$dN_{ch}/d\eta > 100$ within $|\eta| < 1$

Dijet signal

UE from **2** semi-hard scaterings (MPI)

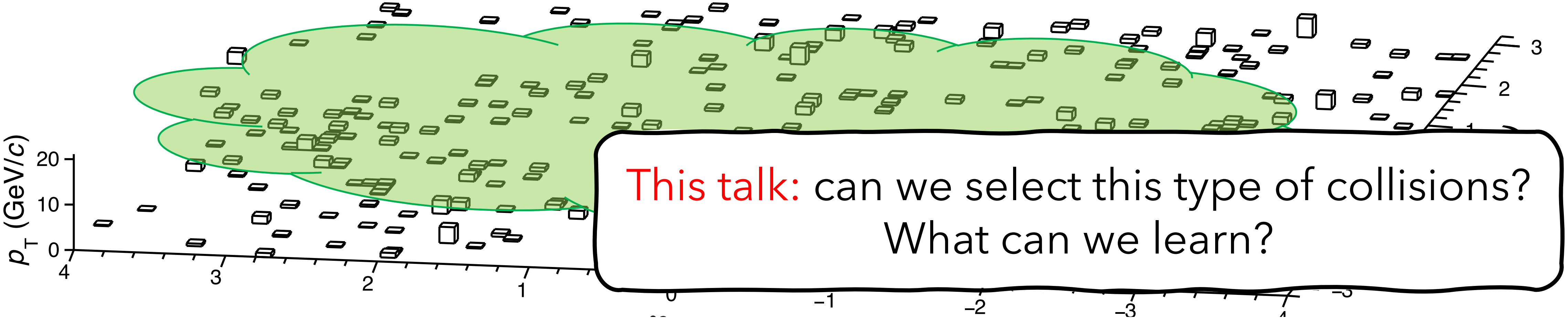
Bias towards hard pp collisions

(the only way to reach extremely HM?)



$dN_{ch}/d\eta \approx 50$ within $|\eta| < 1$

No clear dijet signal



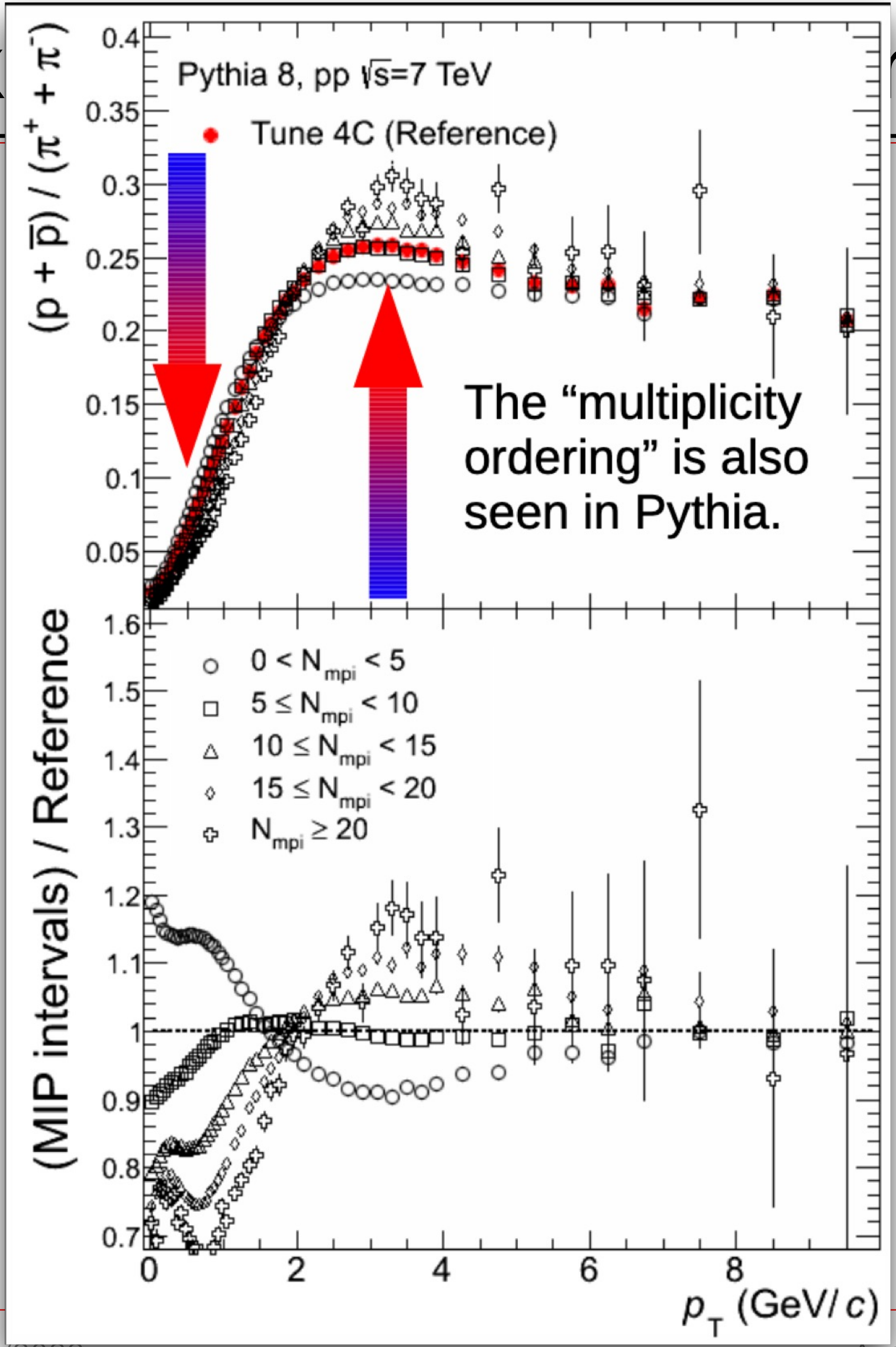
This talk: can we select this type of collisions?
What can we learn?

Isotropic pp collisions ("only UE")

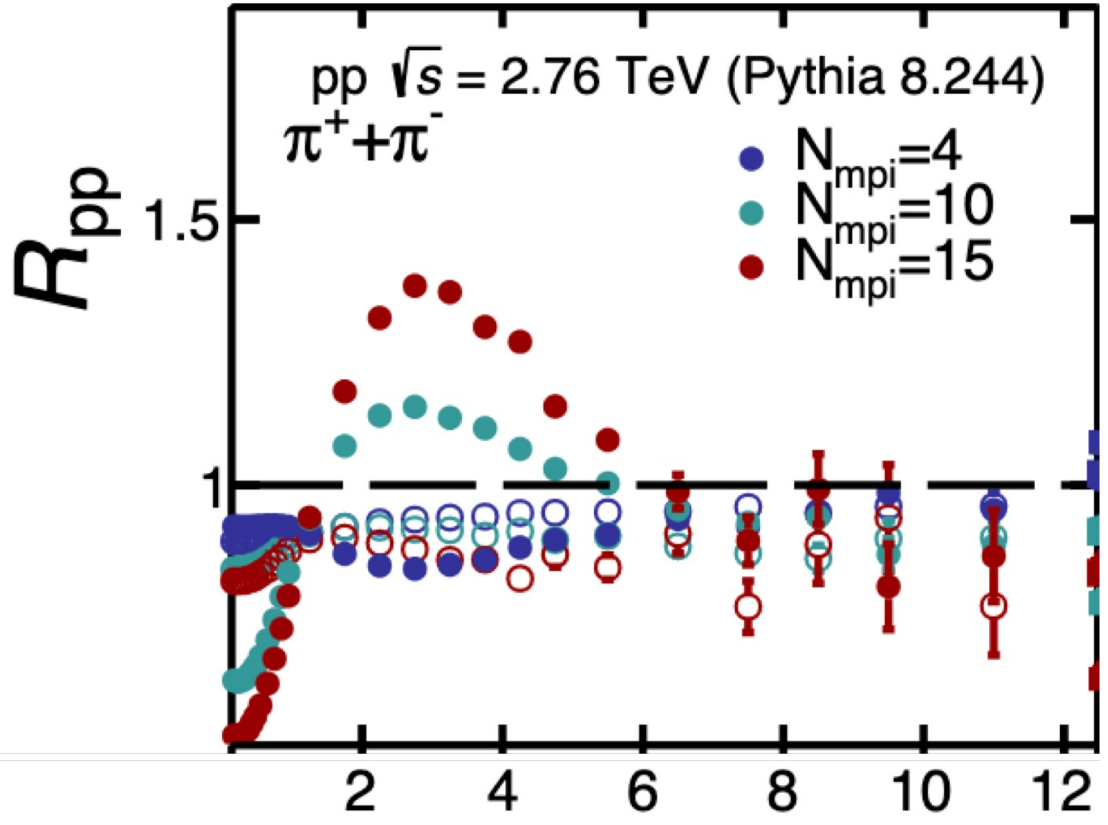
(interesting: several scaterred partons in the same collision, they must interact before the hadronization)

Ex nts with active MPI

Phys. Rev. Lett. 111, 042001 (2013)



Phys. Rev.D 102 (2020) 7, 076014

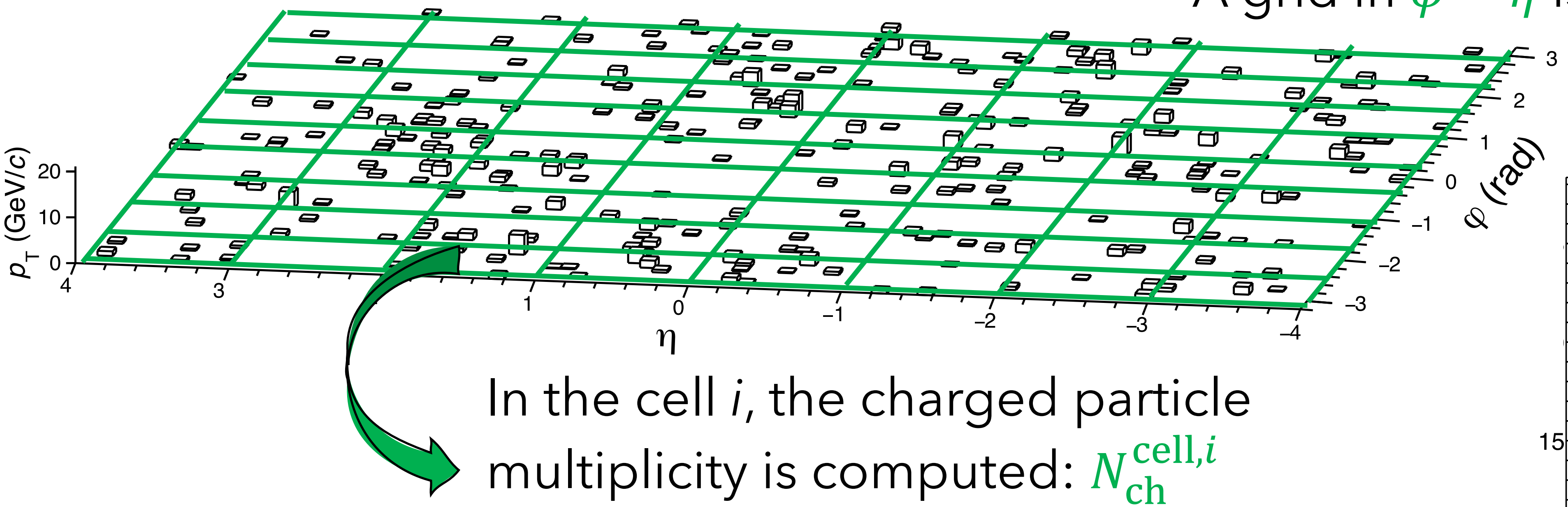


$$R_{\mathrm{pp}} = \frac{\mathrm{d}^2 N_{\mathrm{ch}}^{\mathrm{mpi}} / (\langle N_{\mathrm{mpi}} \rangle \mathrm{d}\eta \mathrm{d}p_{\mathrm{T}})}{\mathrm{d}^2 N_{\mathrm{ch}}^{\mathrm{MB}} / (\langle N_{\mathrm{mpi}}^{\mathrm{MB}} \rangle \mathrm{d}\eta \mathrm{d}p_{\mathrm{T}})}$$

Is there any way to improve the multiplicity estimator (small selection biases & high N_{ch} reach)?

In the past, I proposed transverse spherXcity to characterize high multiplicity pp collisions:
A. Ortiz, AIP Conf.Proc. 1348 (2011) 111-117; Nucl.Phys.A 941 (2015) 78-86

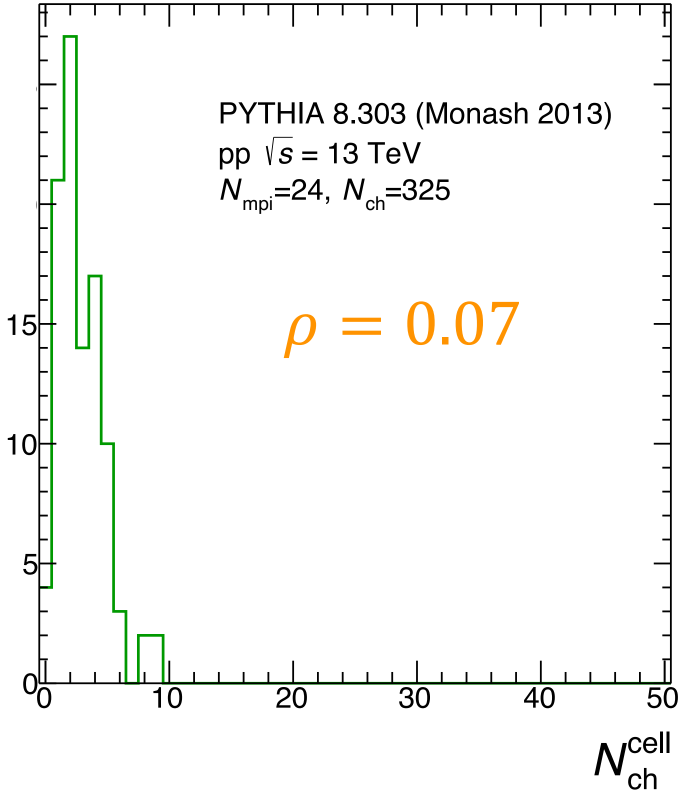
Flattenicity



A grid in $\varphi - \eta$ is built: $N_{\mathrm{cell}} = 10{\times}8$

EbE the $N_{\mathrm{ch}}^{\mathrm{cell}}$ distribution is obtained

In the cell i, the charged particle multiplicity is computed: $N_{\mathrm{ch}}^{\mathrm{cell},i}$



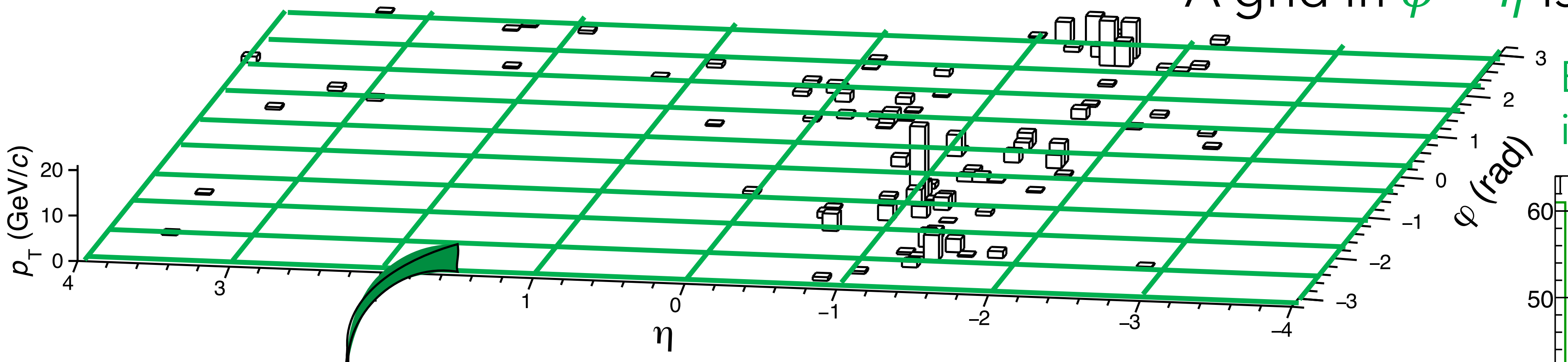
$$\rho = \frac{\sqrt{\sum_i (N_{\mathrm{ch}}^{\mathrm{cell},i} - \langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle)^2 / N_{\mathrm{cell}}^2}}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}$$

A. Ortiz et al, arXiv:2204.13733
A. Ortiz, A. Khuntia, O. Vázquez et al, arXiv:2211.06093

Events with isotropic distribution of particles (very active MPI) are expected to have small ρ values

Flattenicity

PYTHIA 8.303 (Monash 2013), pp $\sqrt{s}$ = 13 TeV, N_{mpi}=1, N_{ch}=109



A grid in $\varphi - \eta$ is built: $N_{\rm cell} = 10{\times}8$

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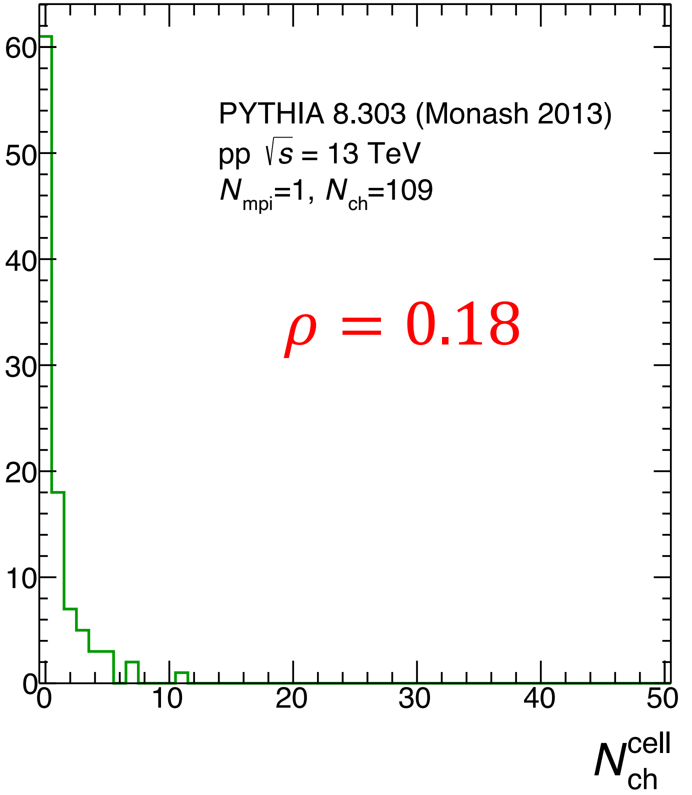


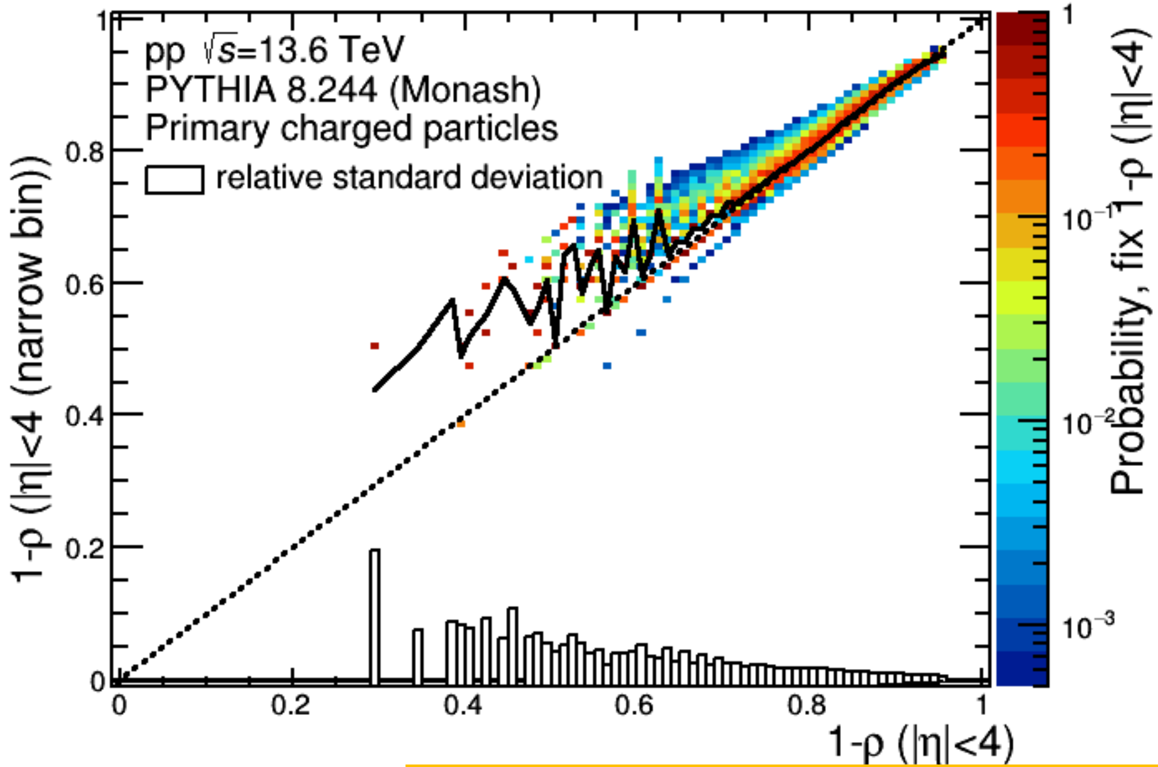
Events with jet structures are expected to have large ρ values

Stability of flattenicity (cell size)

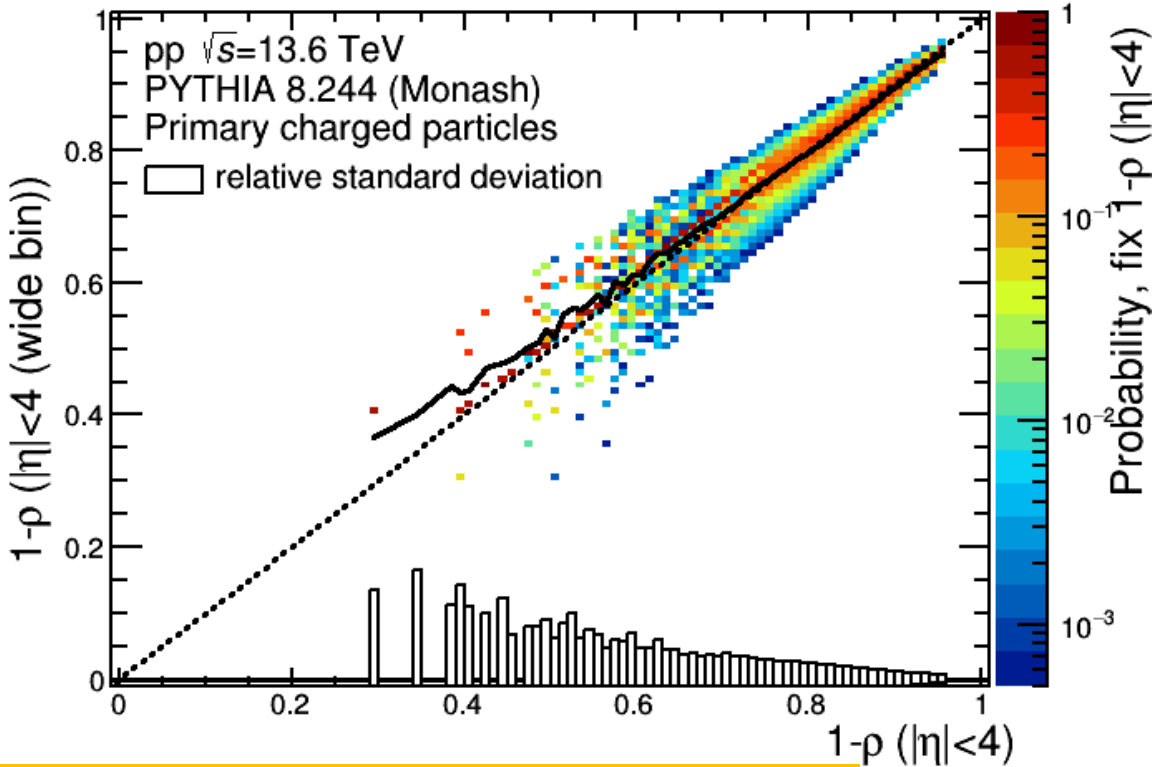
MC simulation: pp collisions at 13.6 TeV ~800 M NSD events

Reference flattenicity: cell size $0.5\times2\pi/8$ rad, $-4 < \eta < 4$

Narrow binning: $0.25\times2\pi/25$

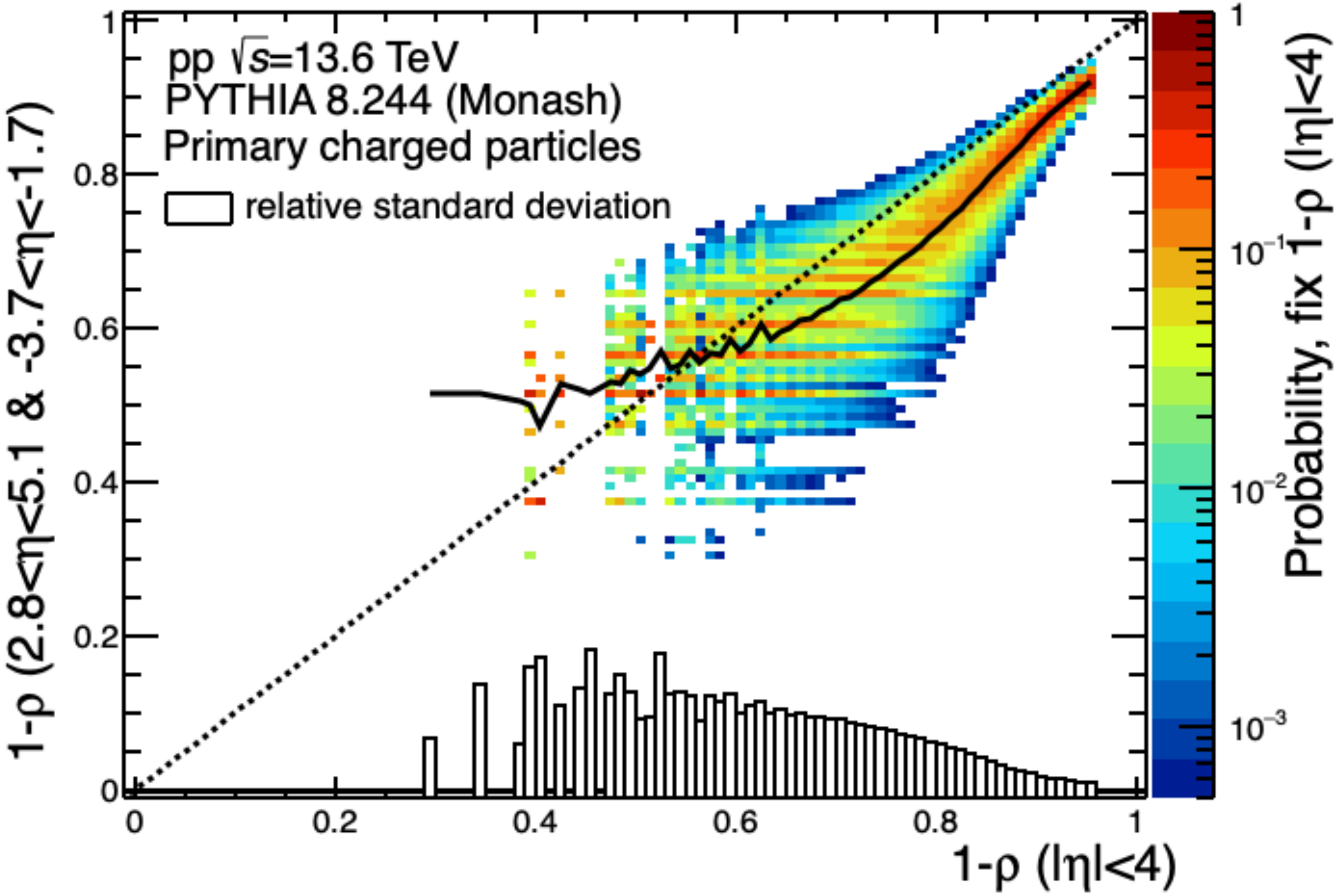


Wide binning: $1\times2\pi/6$

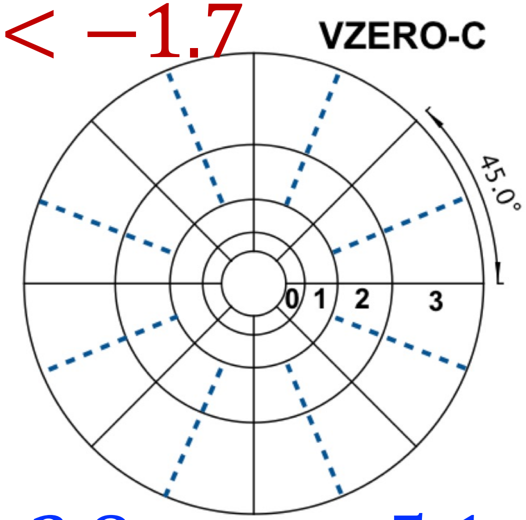


Flattenicity is very stable against variations in the cell size

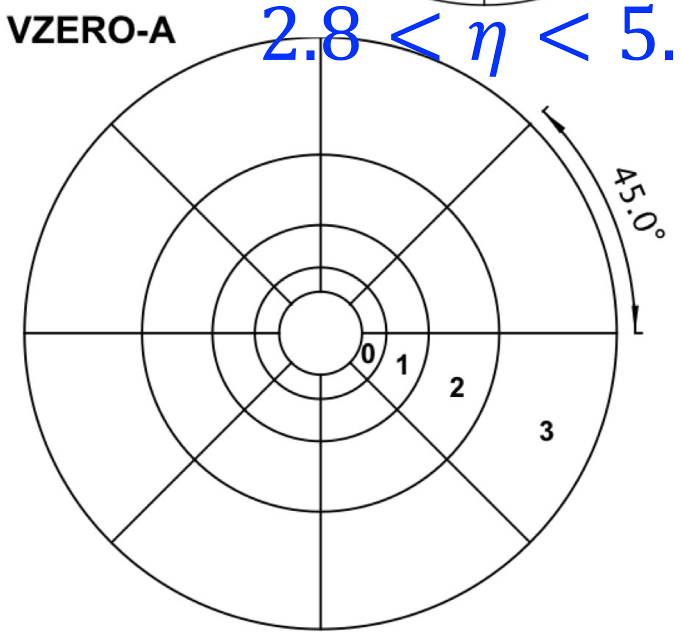
Flattenicity in the pseudorapidity covered by V0



$-3.7 < \eta < -1.7$

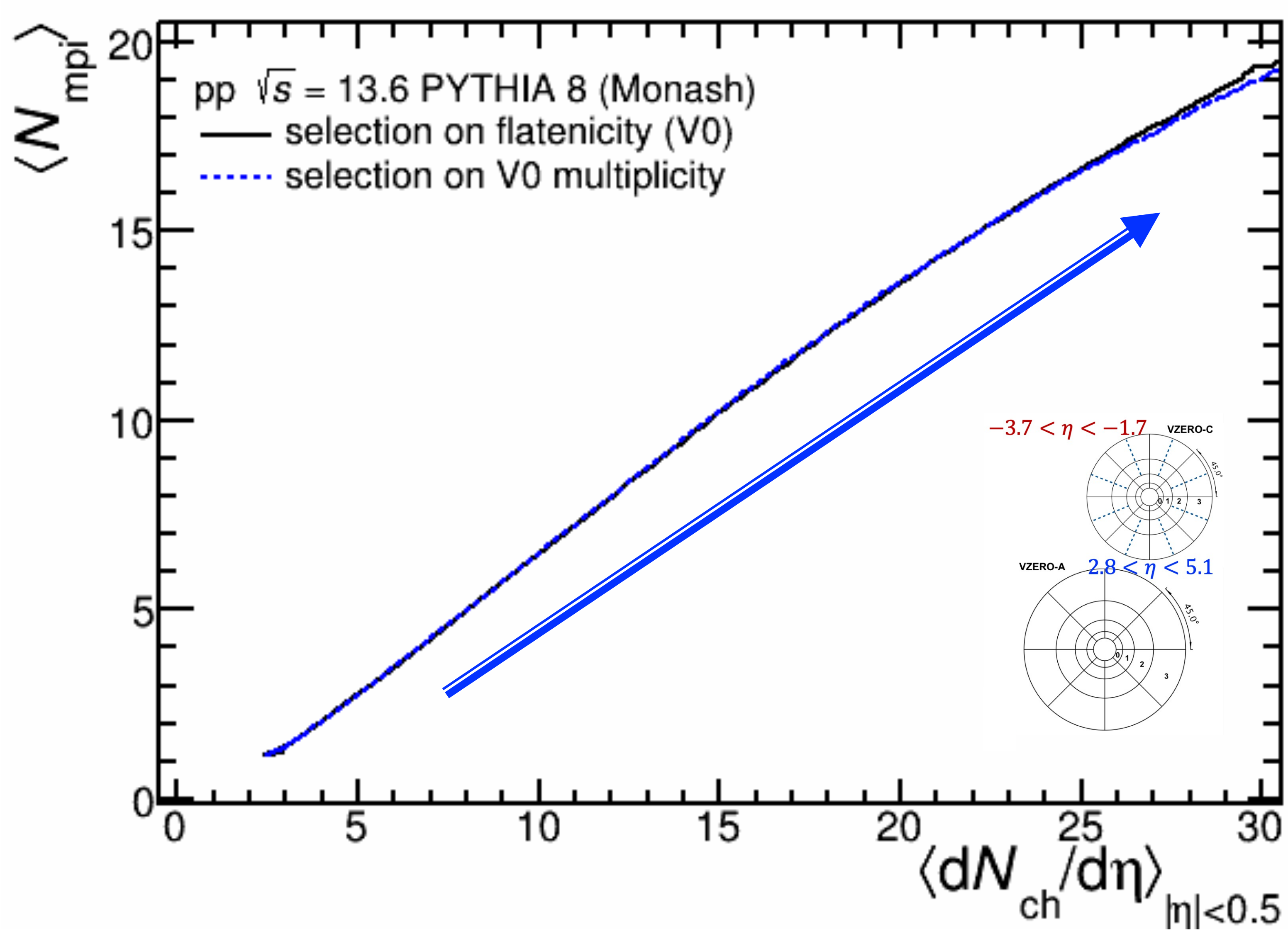


$2.8 < \eta < 5.1$



Flattenicity in V0 region: good sensitivity to the global shape

Flattenicity vs MPI and “hardness” of the coll

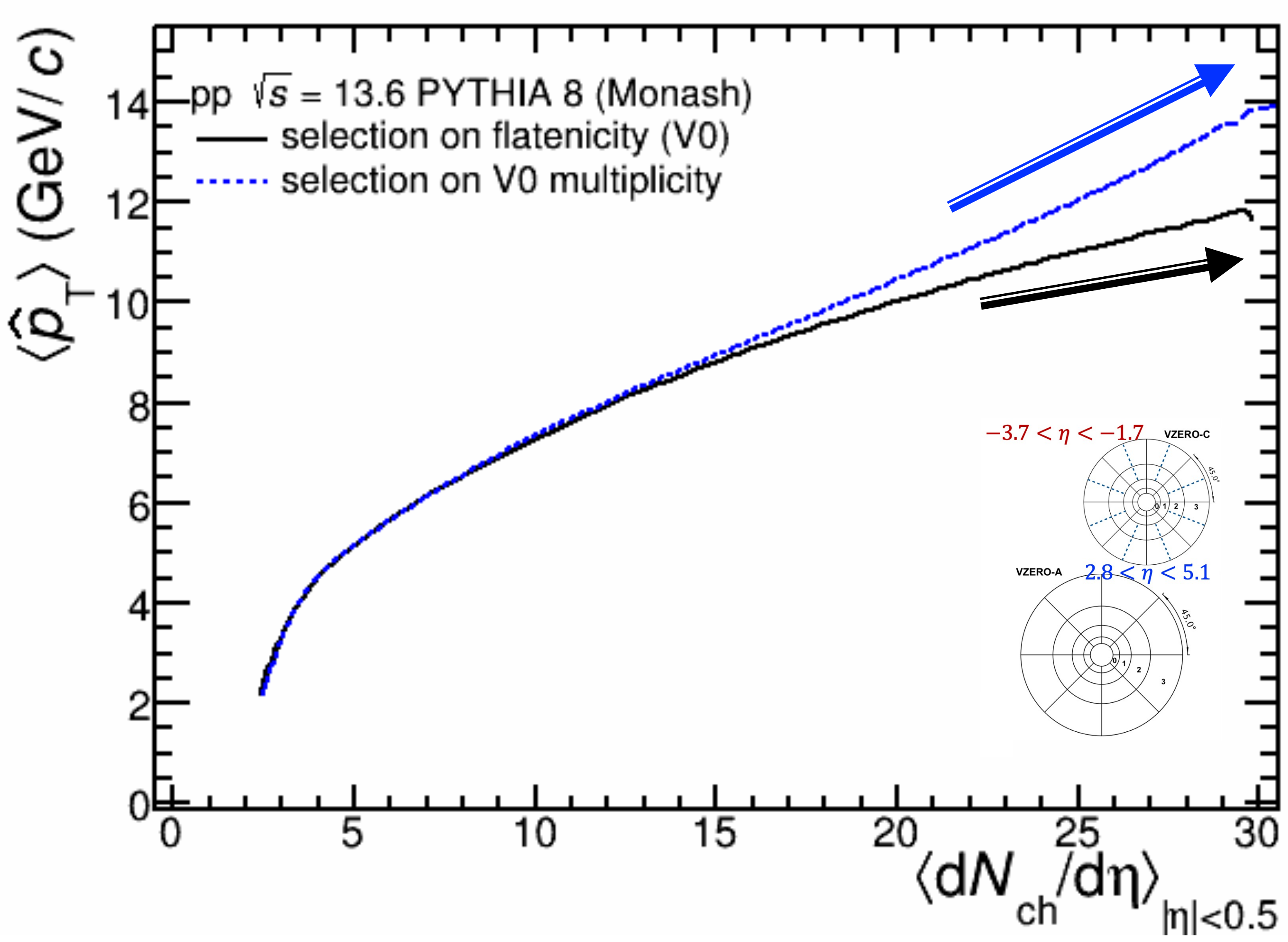


UE as a function of the average midpseudorapidity charged-particle density. Very similar correlation if the event selection is done either in multiplicity or flattenicity in the V0 region

For a similar fraction of cross section, flattenicity and multiplicity in the V0 select pp collisions with very similar charged particle densities ($|\eta| < 0.5$)

Event class	$1-\rho$	V0M
0-1%	25.0	27.1
1-5%	22.9	23.0
5-10%	18.4	18.7
10-20%	15.6	15.3

Flattenicity vs MPI and "hardness" of the coll



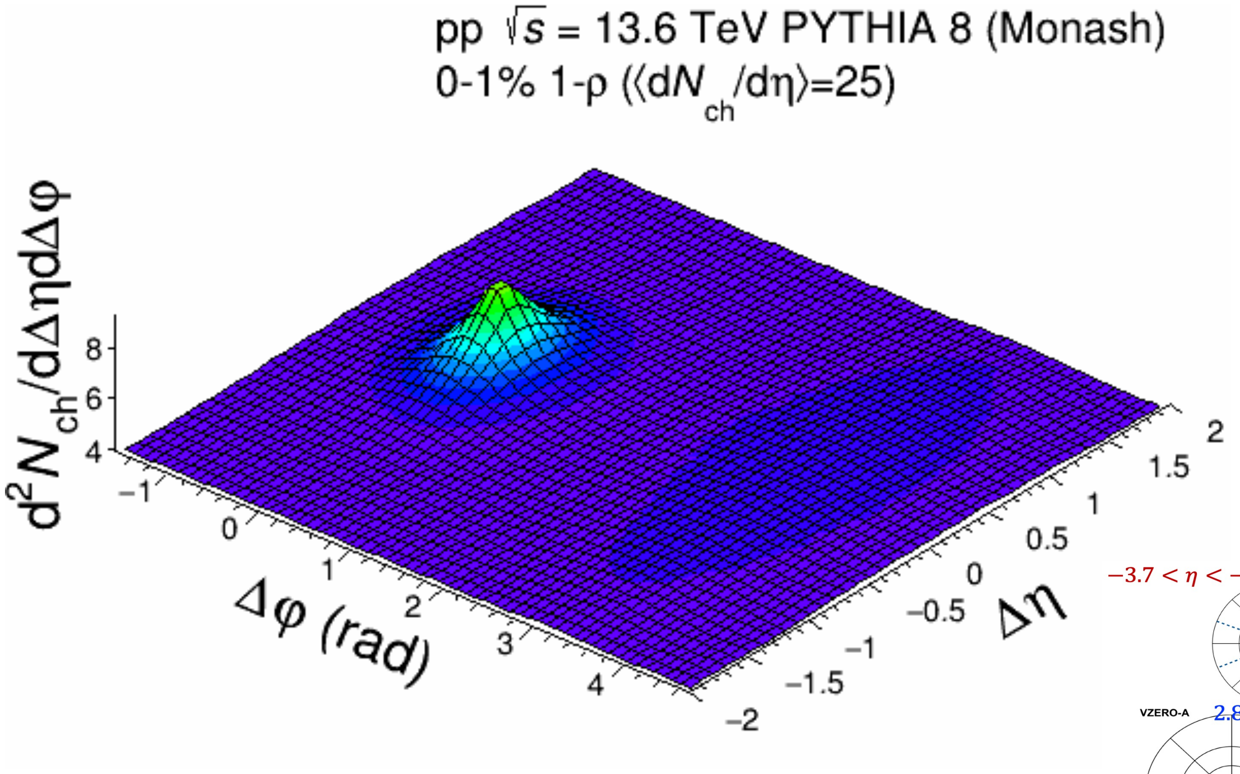
Transverse momentum of the main 2 → 2 process as a function of charged particle multiplicity at midpseudorapidity

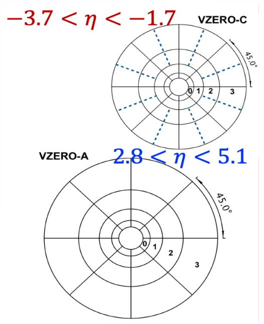
At high multiplicity, the pp collisions selected with flattenicity (V0) are harder than those selected with multiplicity (V0)

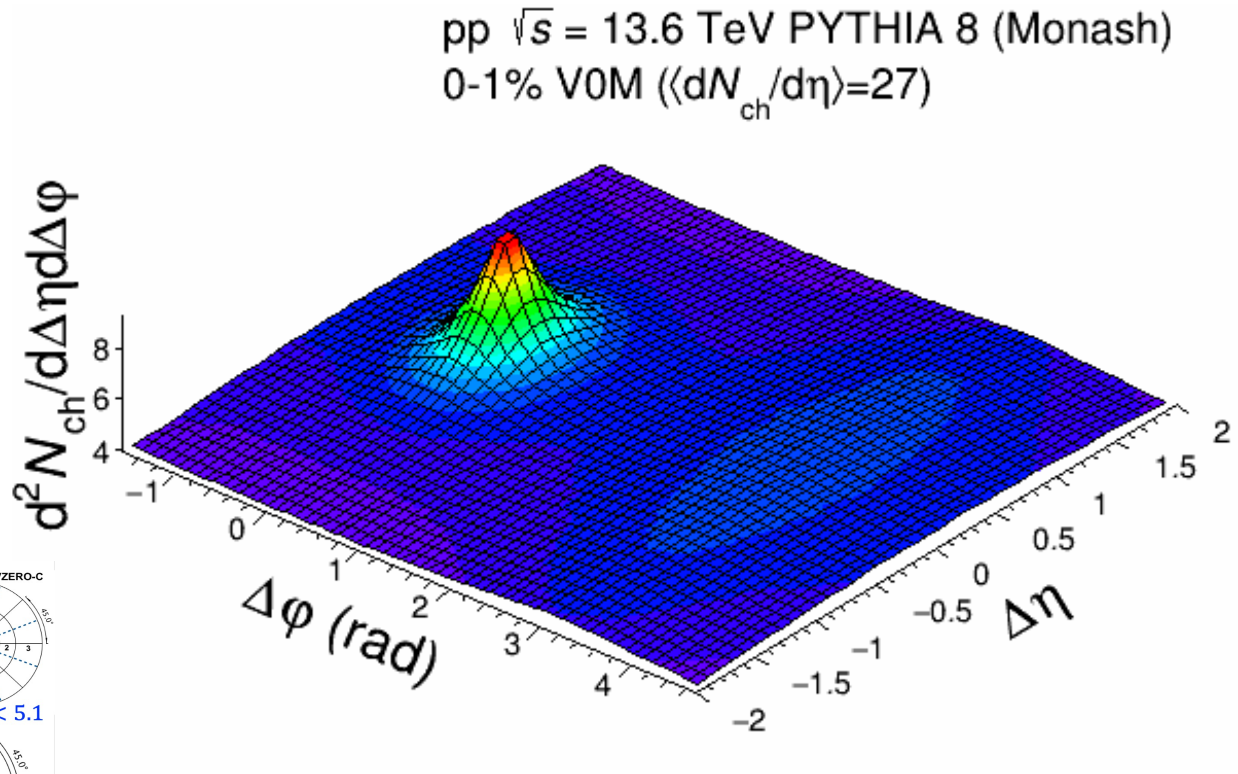
Leading particle angular correlations

Flattenicity selection

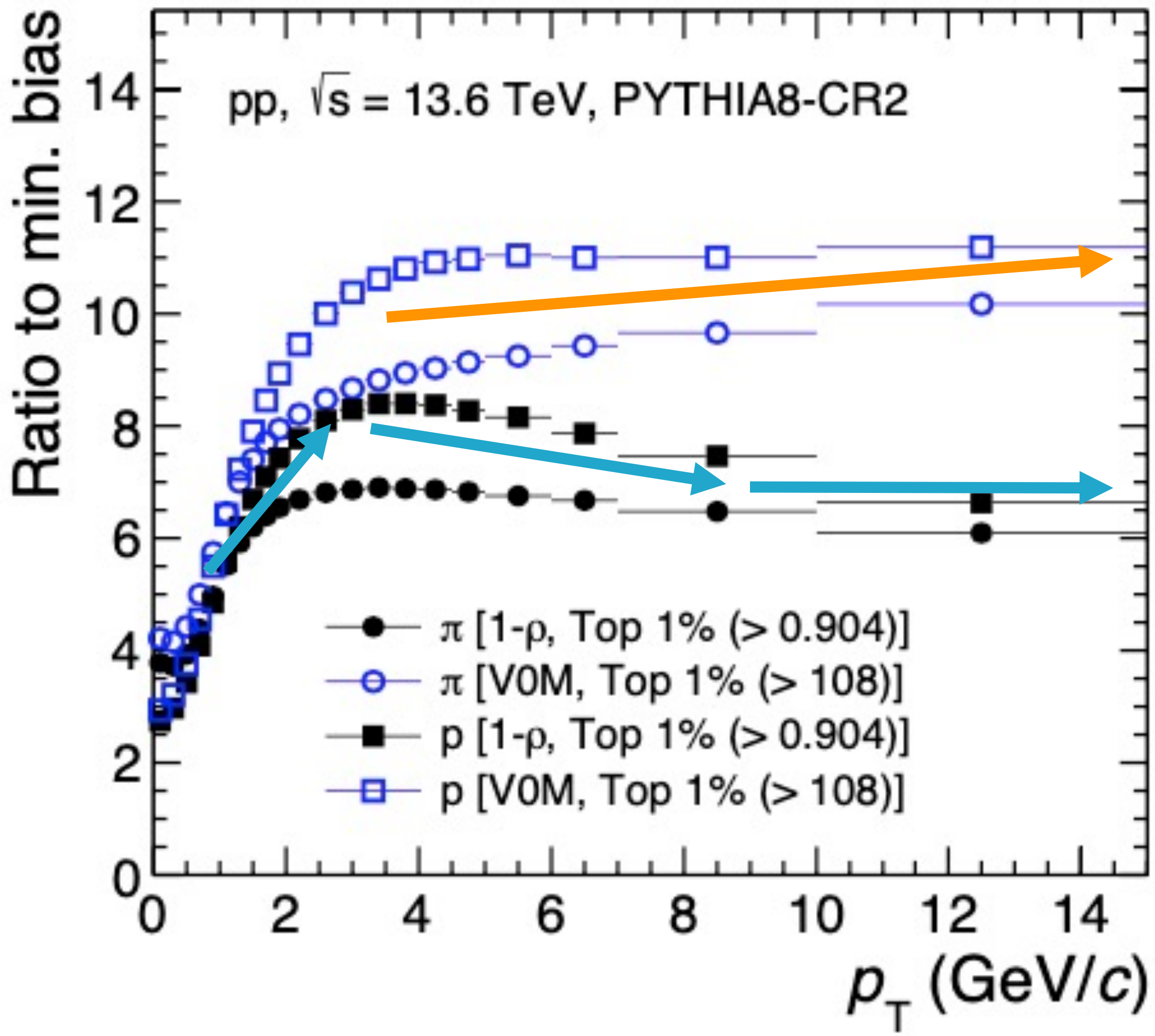
Multiplicity selection







Ratios to minimum-bias pp collisions



$$R(p_{\mathrm{T}}) = \frac{\left(\frac{\mathrm{d}^2 N_{ch}}{\mathrm{d}\eta \mathrm{d}p_{\mathrm{T}}}(p_{\mathrm{T}})\right)^{\mathrm{ev.class}}}{\left(\frac{\mathrm{d}^2 N_{ch}}{\mathrm{d}\eta \mathrm{d}p_T}(p_{\mathrm{T}})\right)^{\mathrm{MB}}}$$

High V0M multiplicity -> bias towards hard pp collisions (the pT spectrum) gets harder than that in MB pp collisions

Ratio behaves very similar to the R_{pp} factor defined before (in terms of MPI). A bum is observed at intermediate transverse momentum, the effect is mass dependent

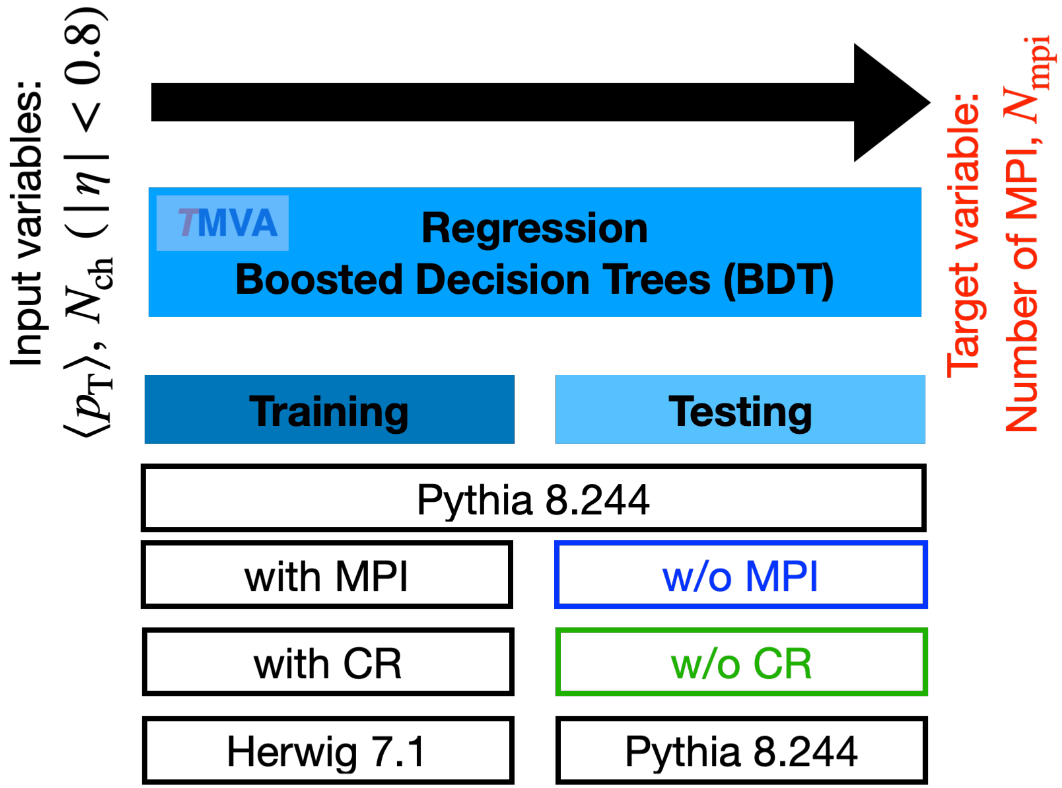
Other approach using ML

Can we infer (target variable) from a given a set of input variables?

Regression problem

We use a multivariate regression technique based on Boosted Decision Trees (BDT) with gradient boosting training, which is implemented in TMVA (arXiv:physics/0703039)

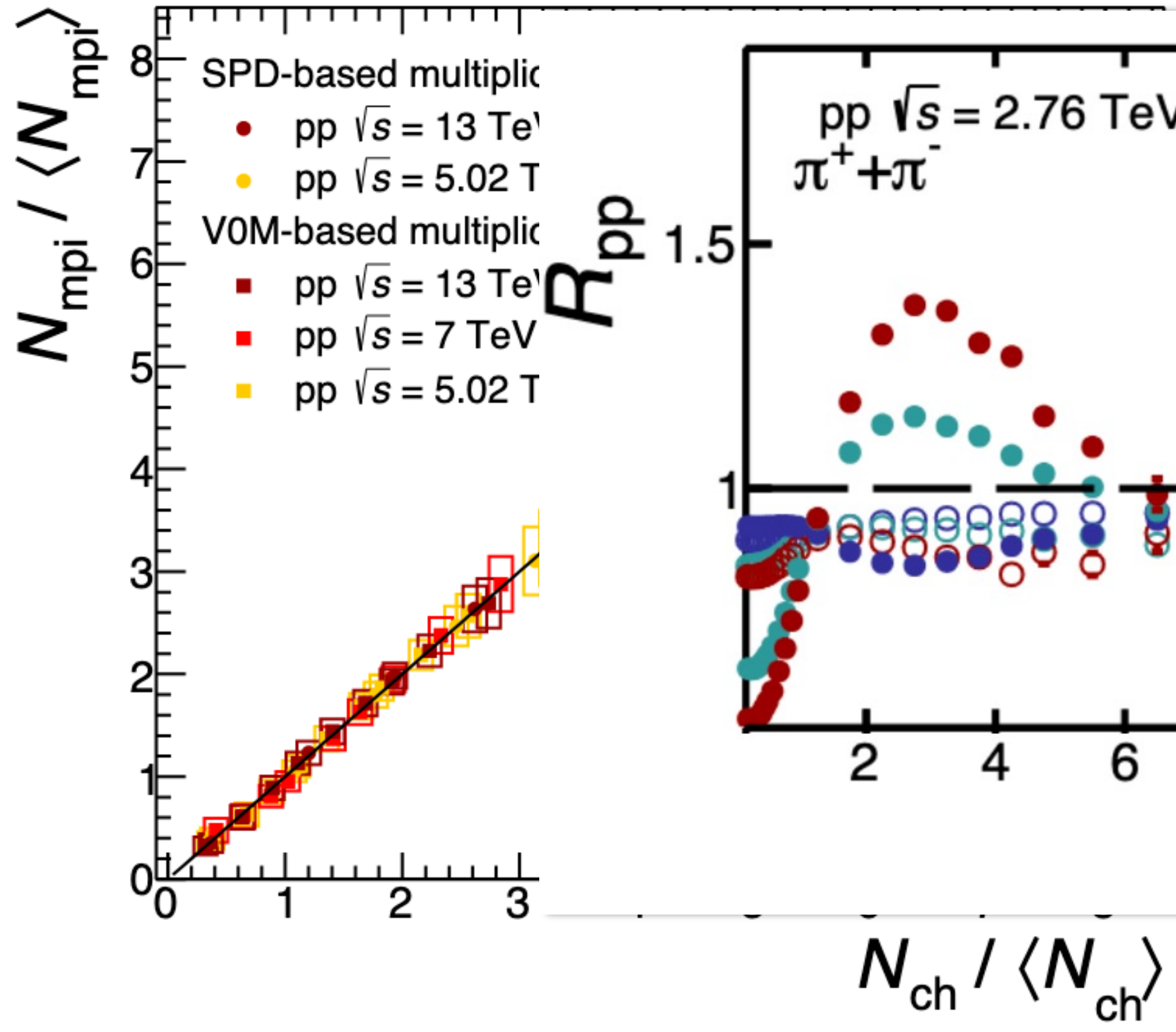
We use the existing data on p_{T} spectra as a function of multiplicity [OK for MPI studies in minimum-bias pp collisions]

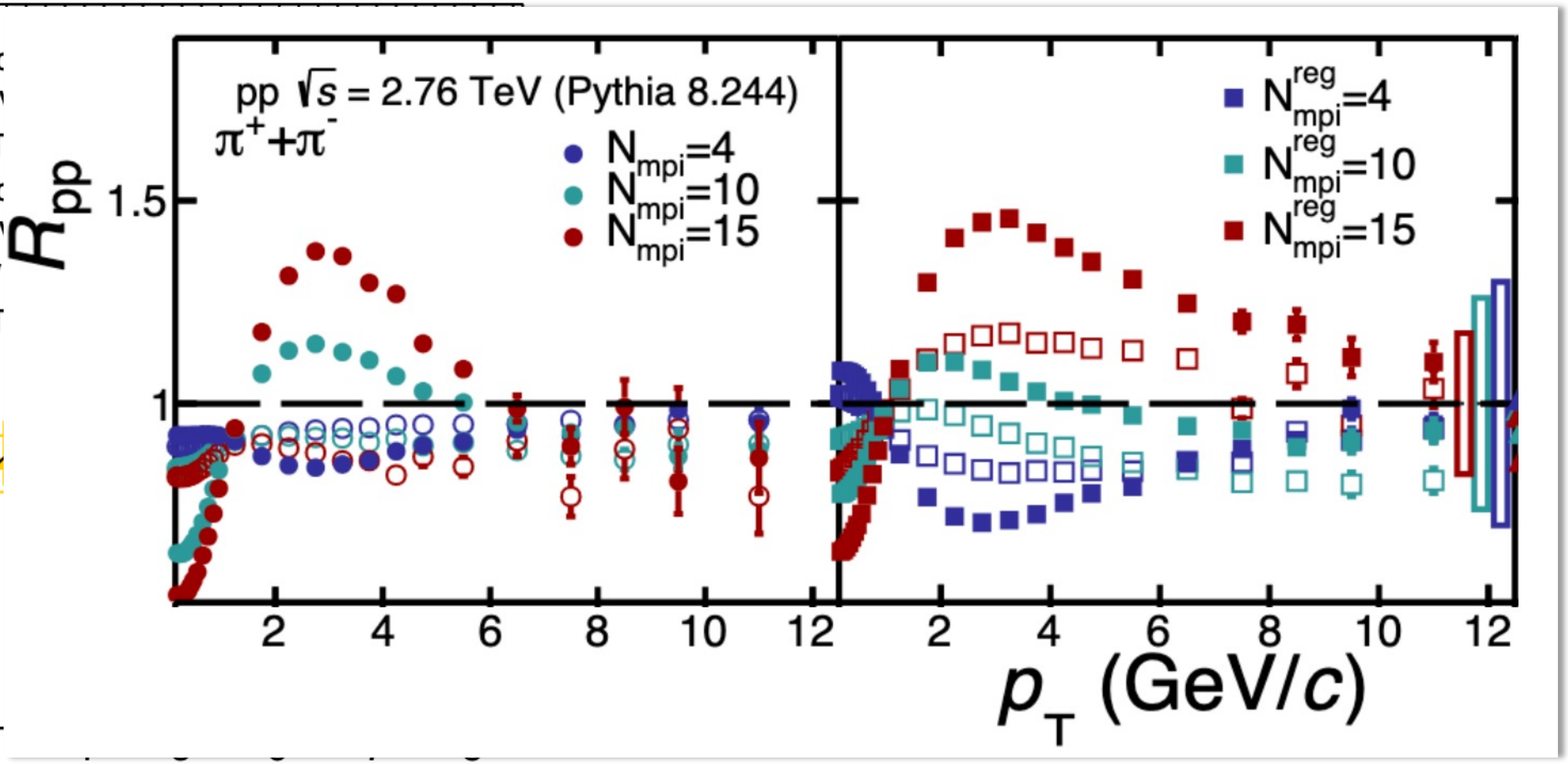


- **Input variables:** Event-by-event average p_{T} of charged particles / Multiplicity

For systematic uncertainties other set of input variables was considered: Charged particle multiplicity in the pseudorapidity region covered by VZERO detector / Transverse spherocity

Some results





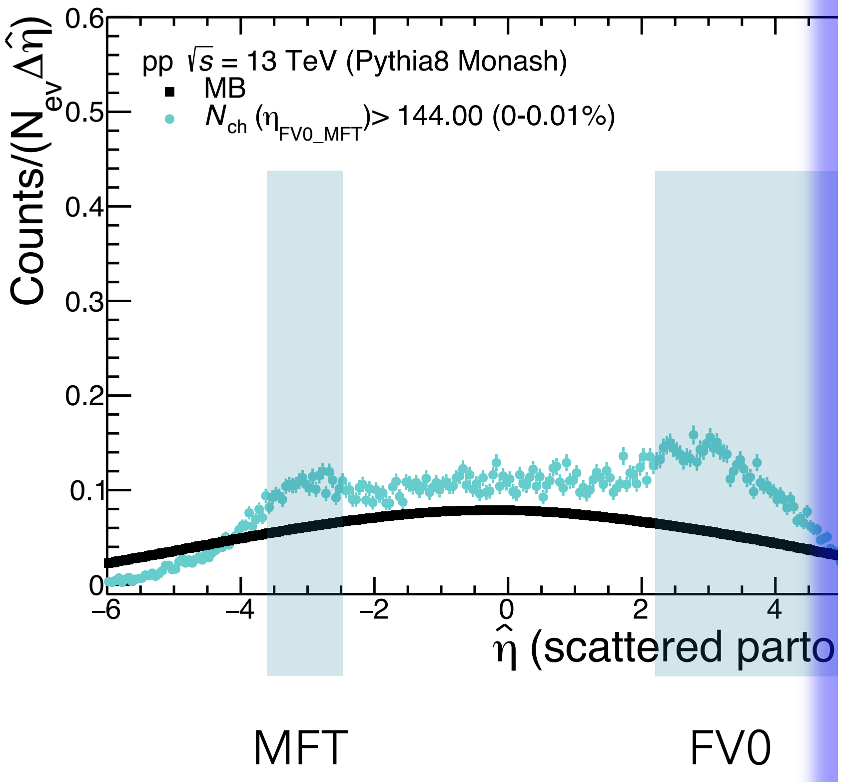
A. Ortiz et al, Phys.Rev.D 102 (2020) 7, 076014

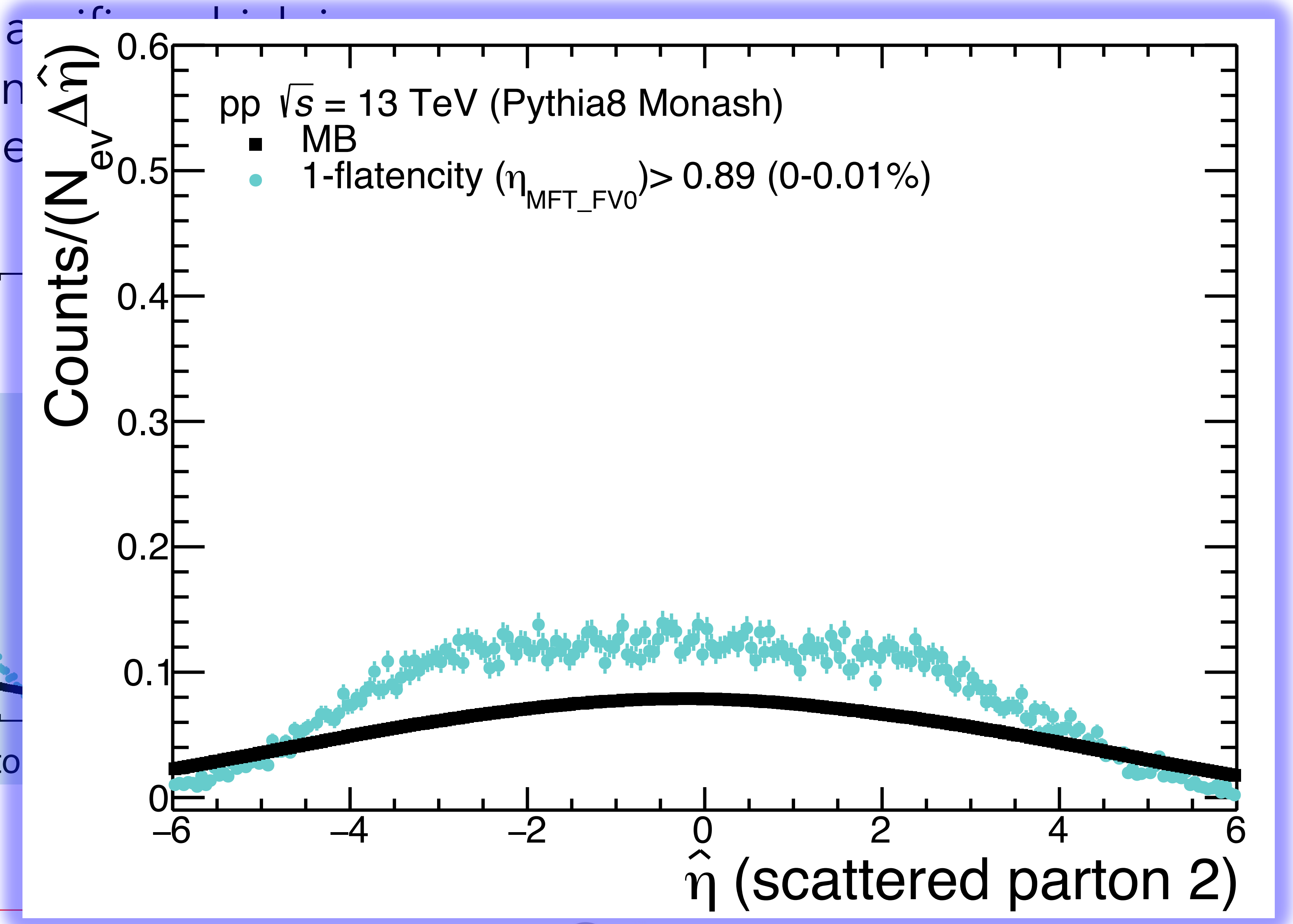
Next step: include flattenicity as input variable

A. Ortiz and E. Zepeda, Phys. G48 (2021) 8, 085014

Summary

- Flattenicity is a new event cla[…]
  more global than V0M, it can […]
  unwanted biases, it is very se[…]





Backup

First attempts to classify the events

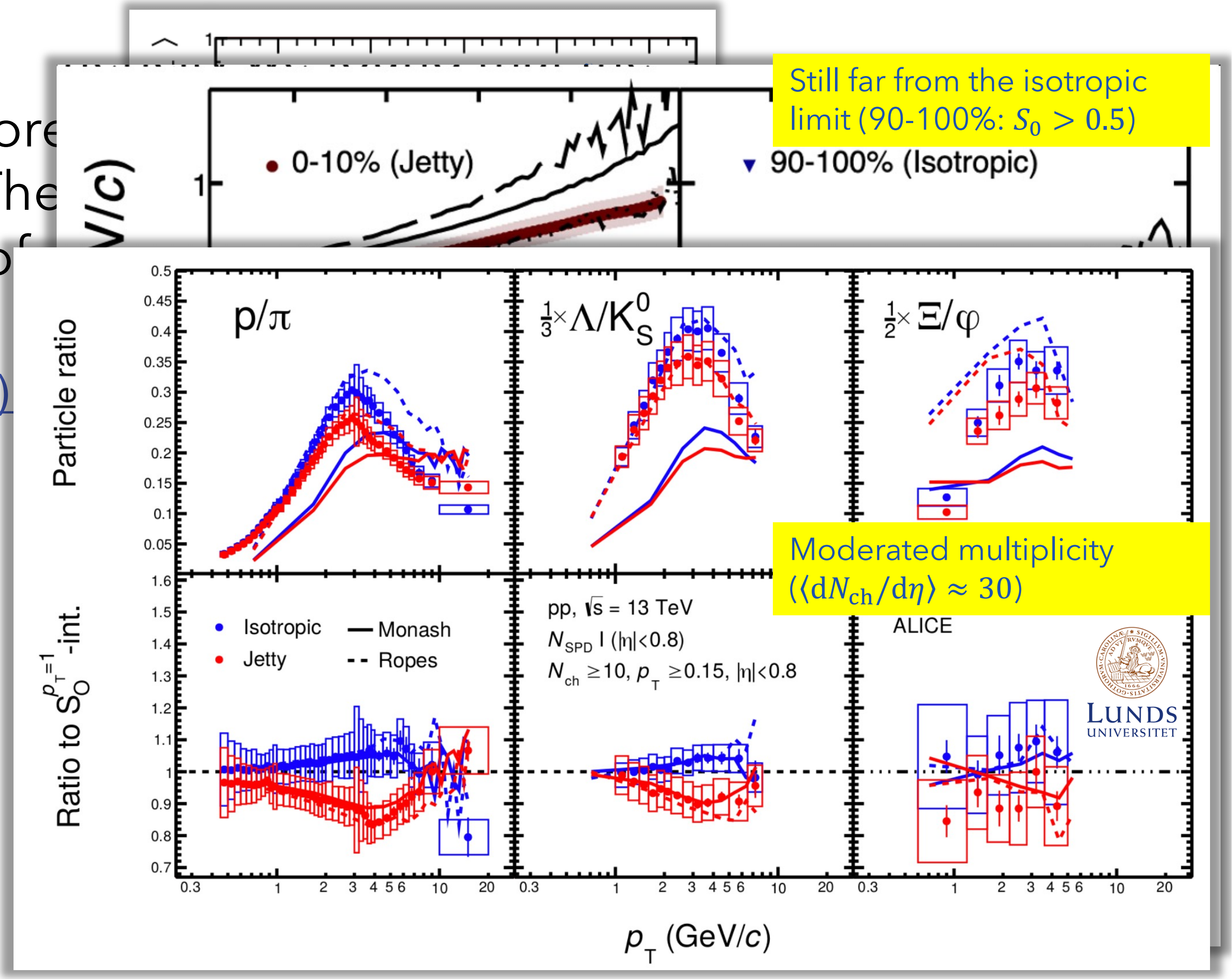
Using sphericity we found that the system created in pp collisions are more isotropic than predicted by models. The minijet analysis supports the picture of MPI in pp collisions

ALICE, EPJC 72 (2012) 2124 / JHEP 09 (2013)

Bigger $\langle p_{\mathrm{T}} \rangle$ in jetty than in isotropic events, models face difficulties to reproduce the data

ALICE, EPJC 79 (2019) no.10, 857

ID hadron production is different in jetty vs isotropic events

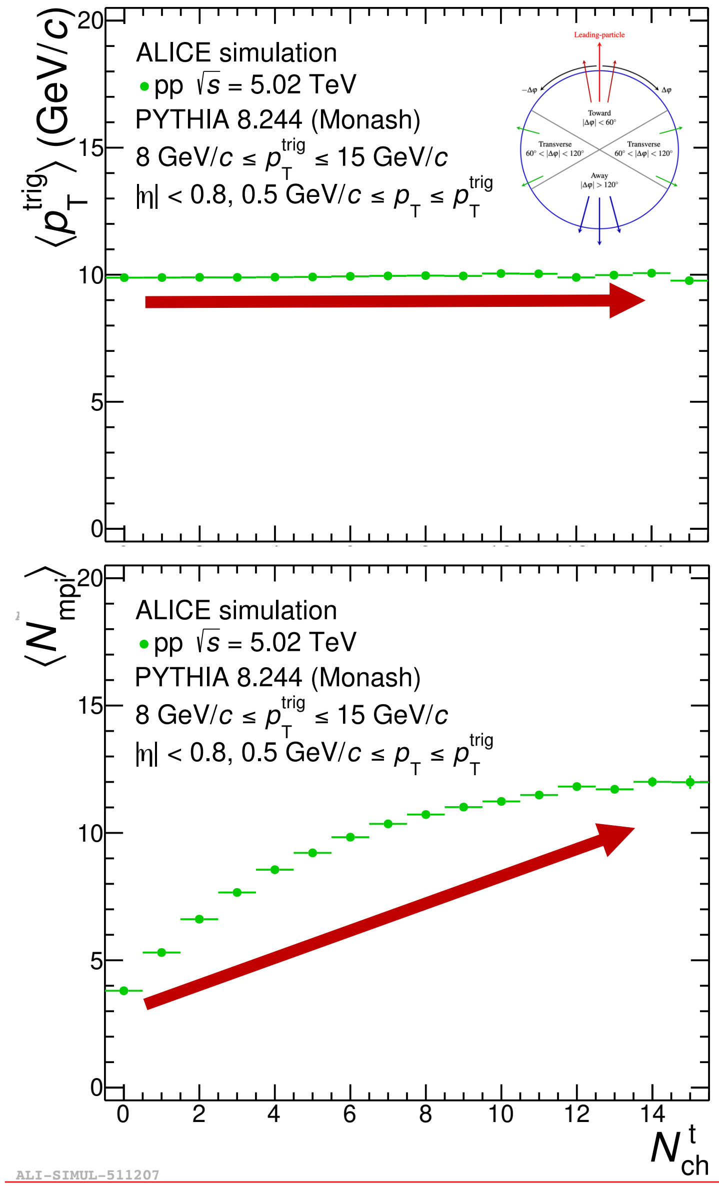


Still far from the isotropic limit (90-100%: $S_0 > 0.5$)

Moderated multiplicity ($\langle dN_{ch}/d\eta \rangle \approx 30$)

Still far from selecting pp collisions from several MPI

Extremes of UE from a different perspective

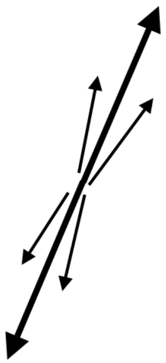


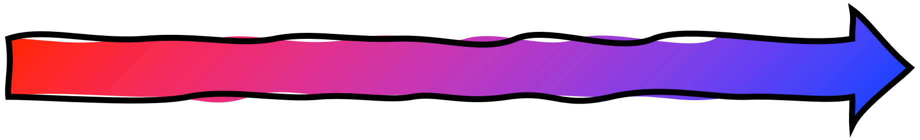
$N_{\mathrm{ch}}^{\mathrm{t}}$: multiplicity in the transvere region of the di-hadron correlations at the plateau (i.e., the $p_{\mathrm{T}}^{\mathrm{trig}}$-region where the average UE activity saturates, $p_{\mathrm{T}}^{\mathrm{trig}} > 5$ GeV/c)

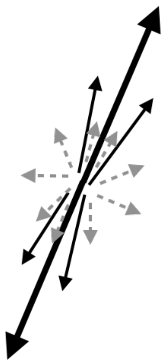
The jet-like signal is $N_{\mathrm{ch}}^{\mathrm{t}}$ independent / UE increases with $N_{\mathrm{ch}}^{\mathrm{t}}$

To exprerimentaly control the UE activity, we define the self-normalized $N_{\mathrm{ch}}^{\mathrm{t}}$:

$$R_{\mathrm{T}} \equiv \frac{N_{\mathrm{ch}}^{\mathrm{t}}}{\langle N_{\mathrm{ch}}^{\mathrm{t}} \rangle}$$



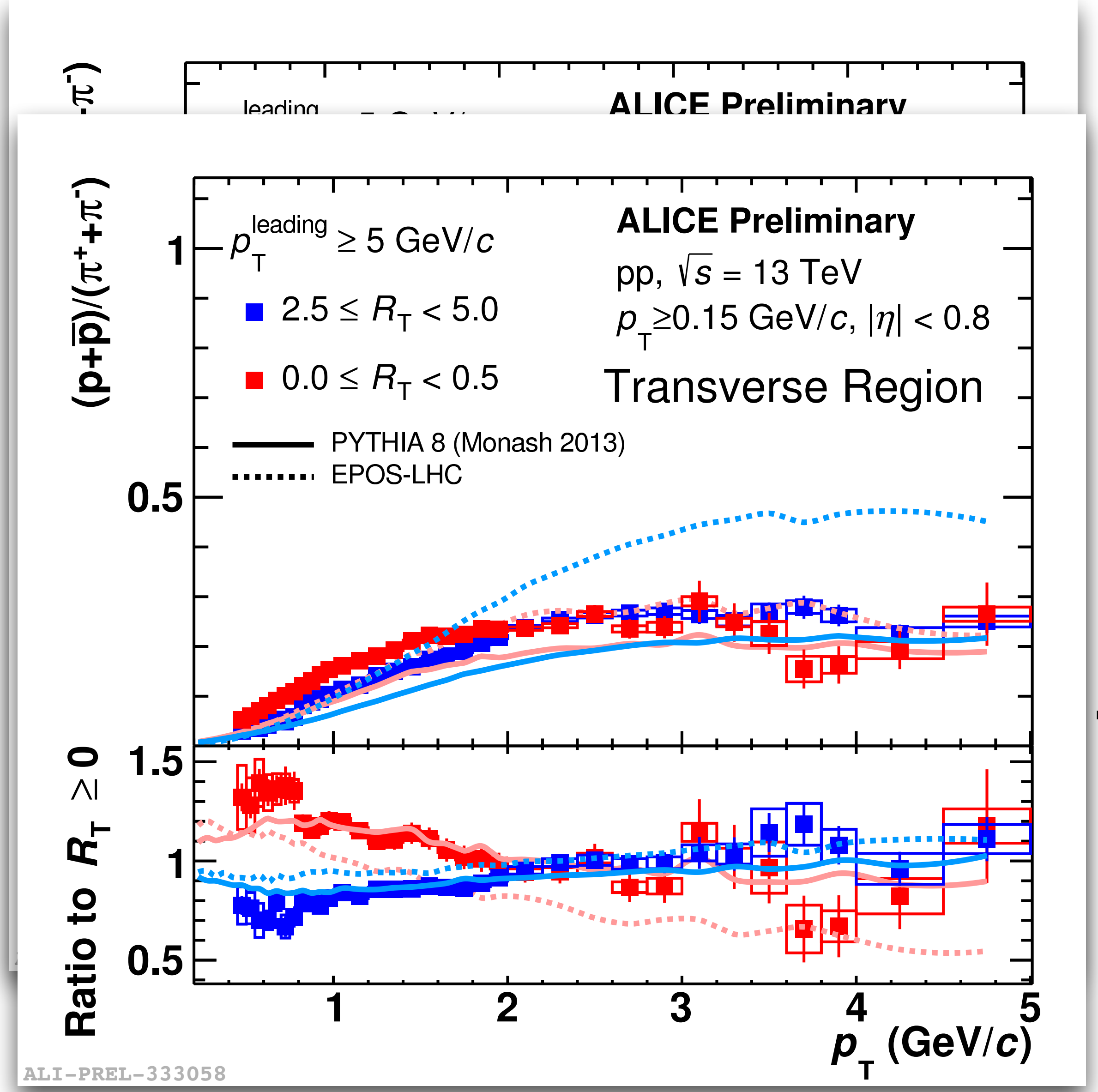


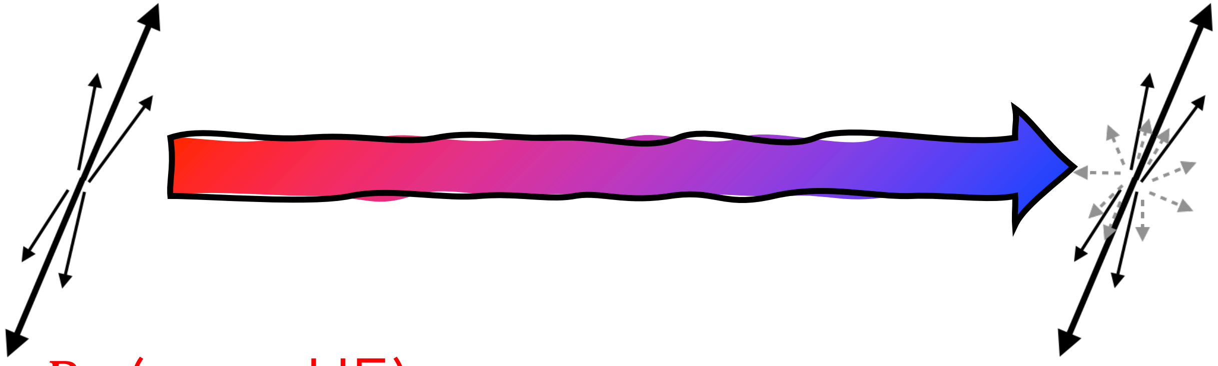


Low R_{T} (poor UE)

High R_{T} (large UE)

Particle ratios vs R_T





Low R_T (poor UE)

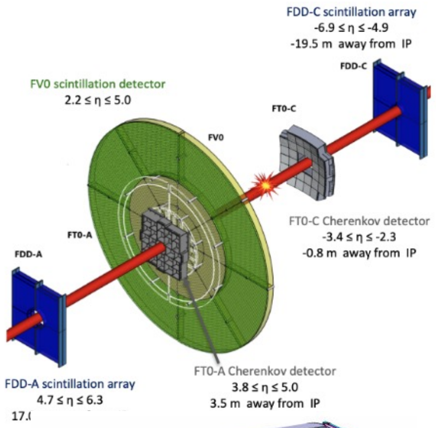
Toward region: not a surprise because we compare jet vs (jet+UE)

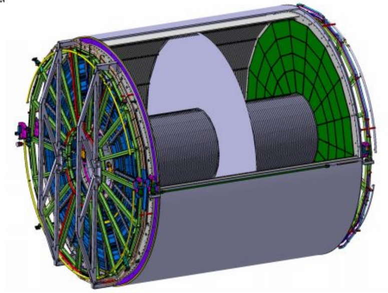
Transverse region: An enhancement of the particle ratio at intermediate pT is expected (high RT relative to low RT). We do not see it probably due to hard ISR&FSR:

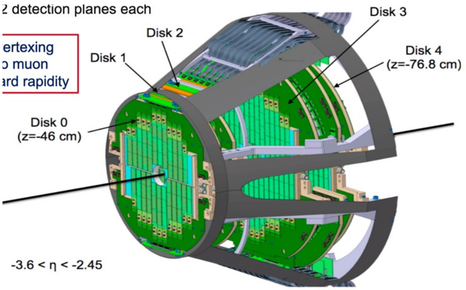
PRD 104 (2021) 1, 016017

Flattenicity forward- vs mid-pseudorapidity

Is flatenicity a global event shape?



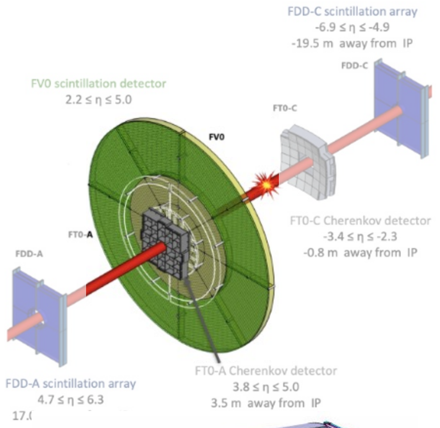


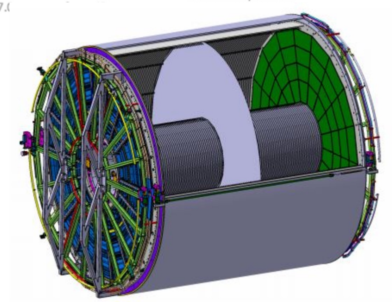


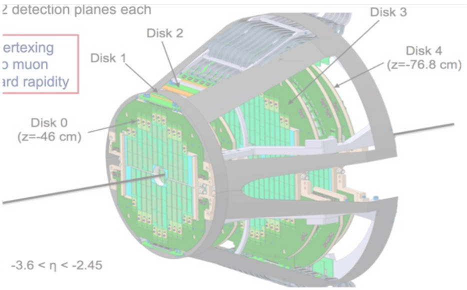
Flattenicity forward- vs mid-pseudorapidity

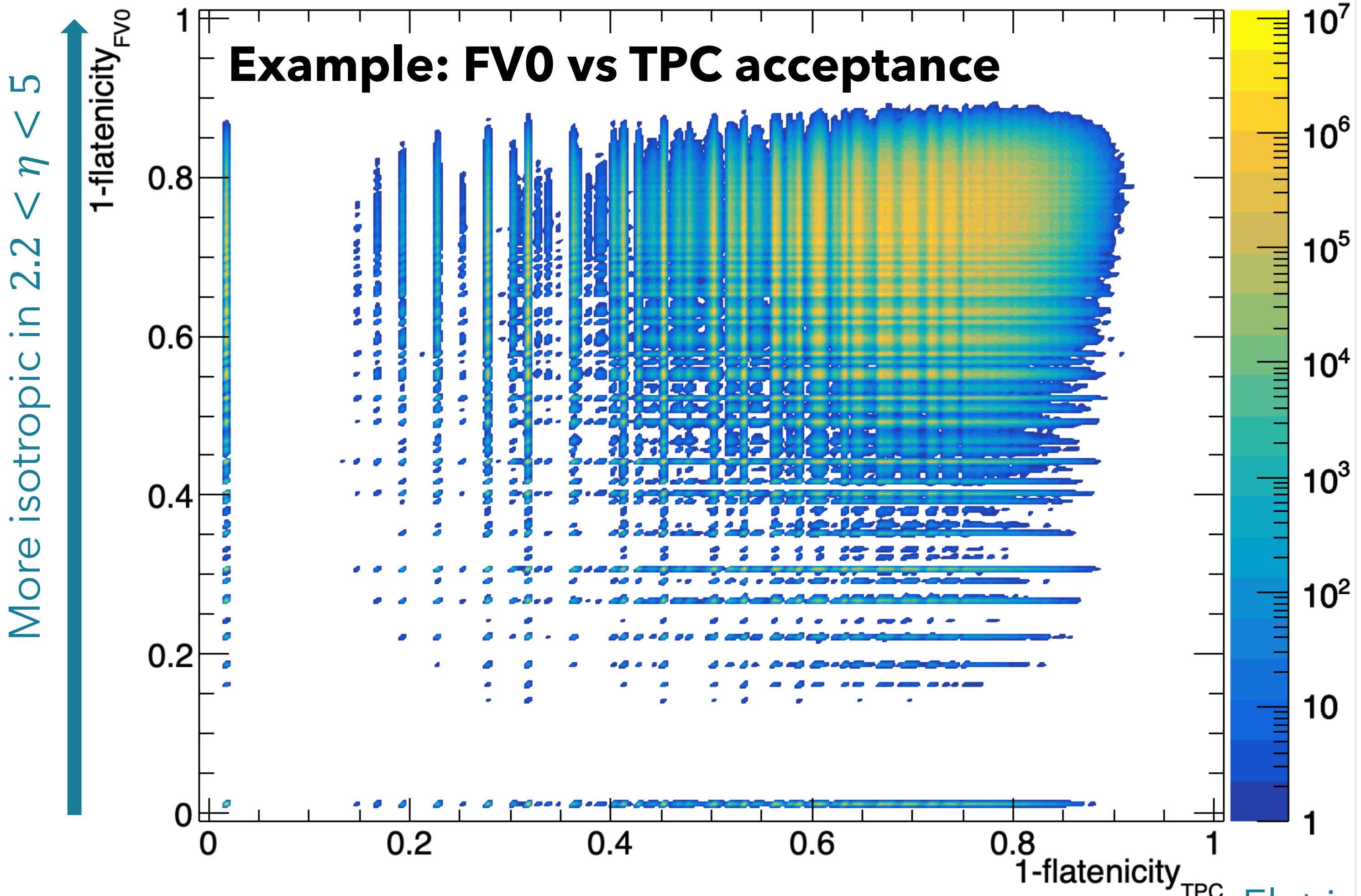
Is flatenicity a global event shape?

Pythia 8 standalone simulations, pp $\sqrt{s} = 0.9$ TeV







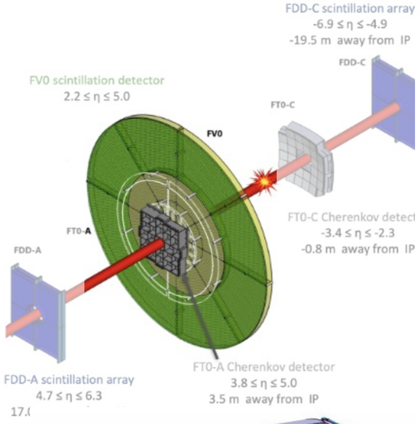


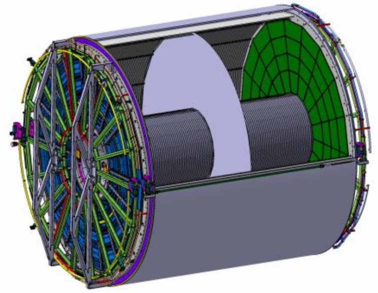
Flat in $|\eta| < 0.8$

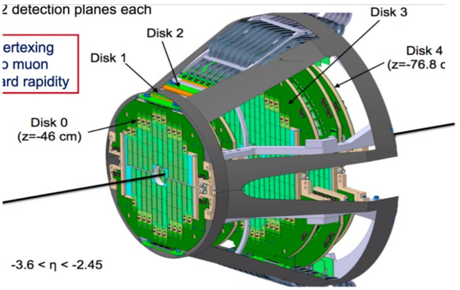
Flattenicity: biases

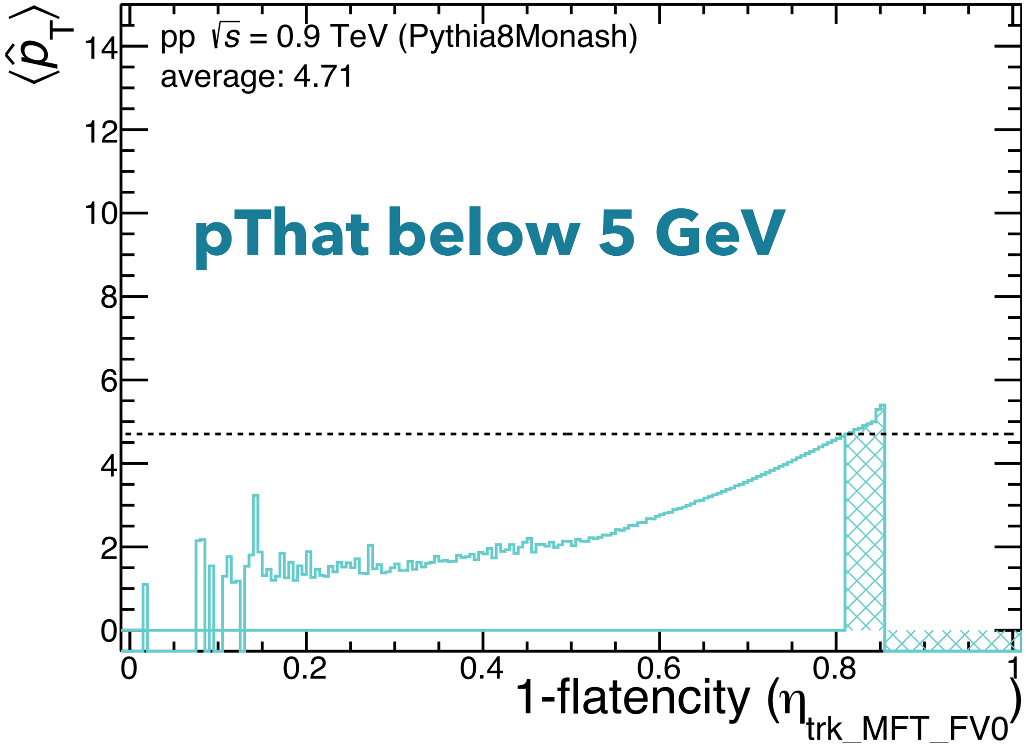
Can flatenicity help to reduce the unwanted biases?

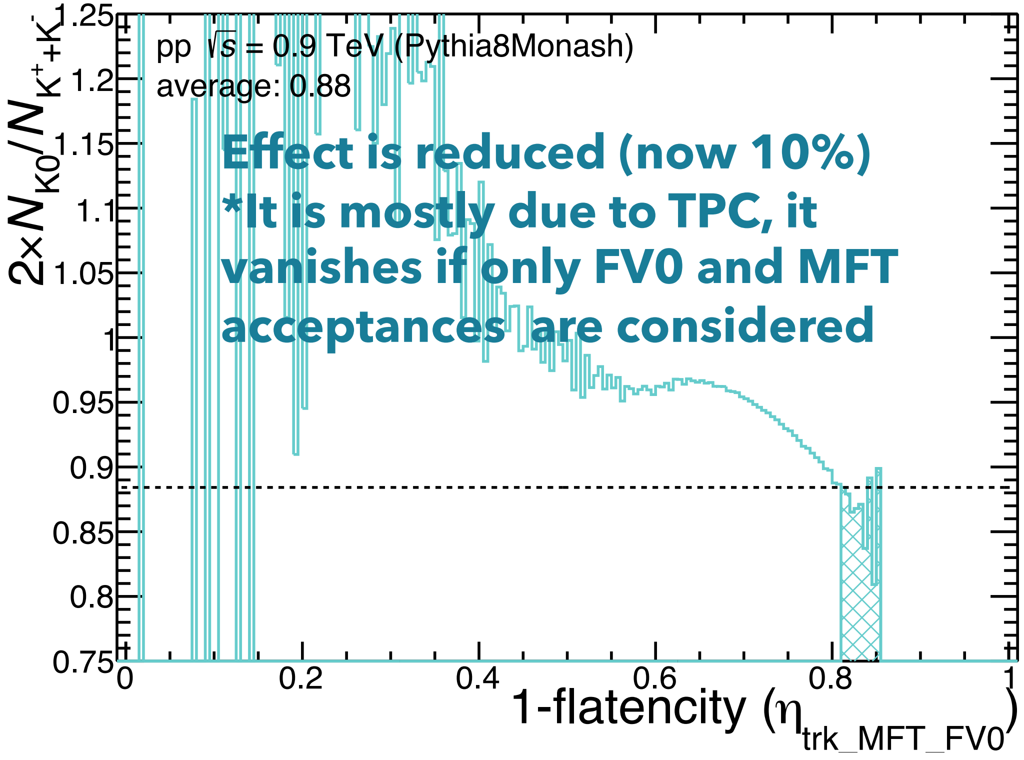
Pythia 8 standalone simulations, pp $\sqrt{s} = 0.9$ TeV









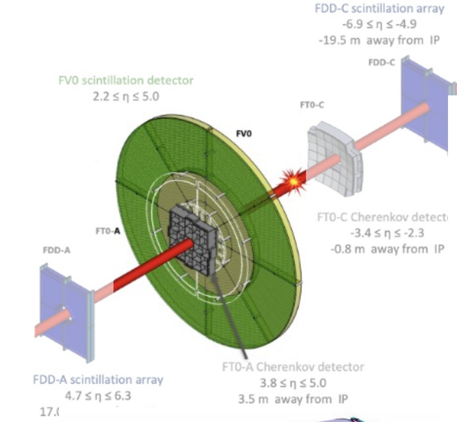


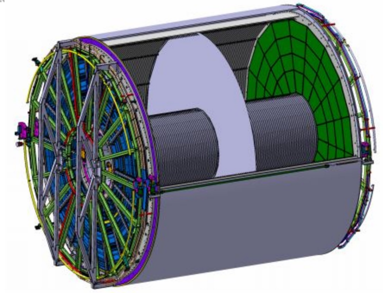
FV0 + TPC + MFT

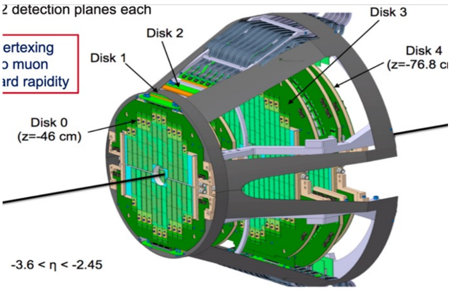
Flattenicity: multiplicity reach

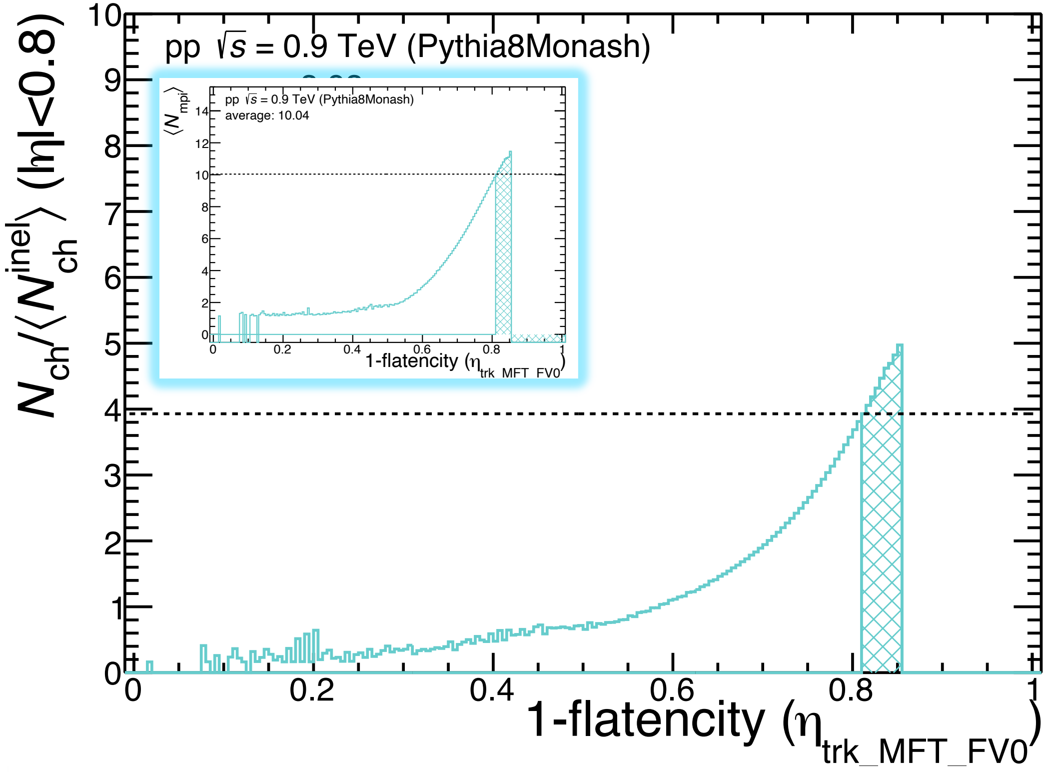
Can flatenicity help to select high multiplicity ($|\eta| < 0.8$) pp collisions?

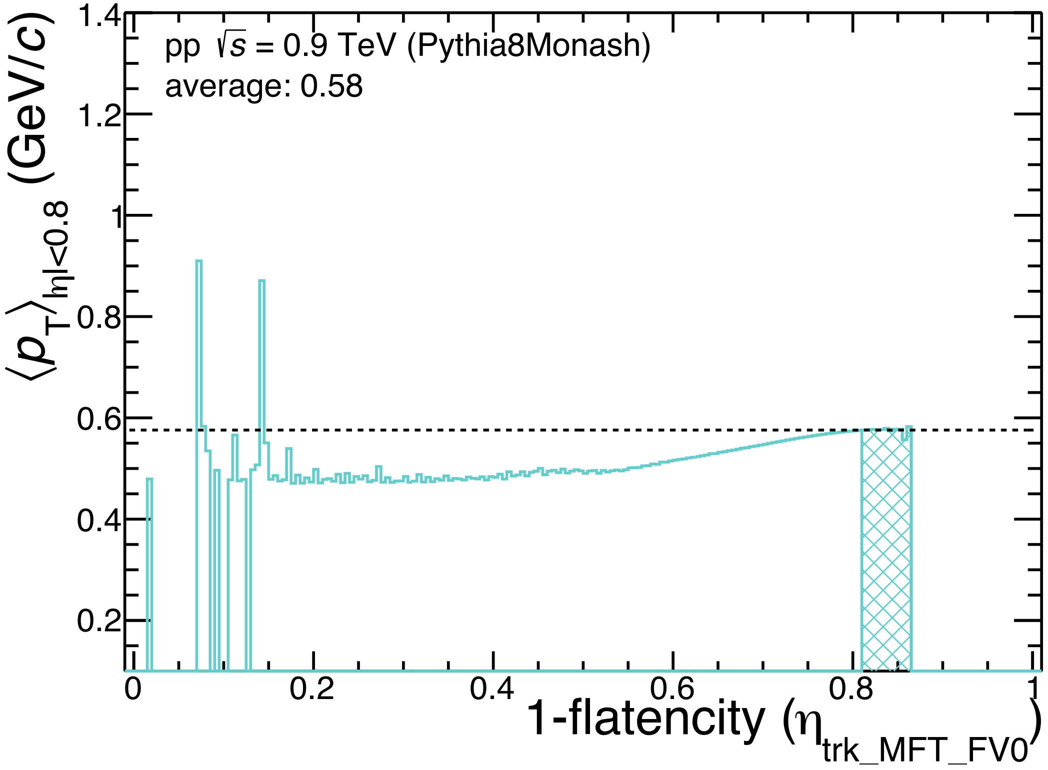
Pythia 8 standalone simulations, pp $\sqrt{s} = 0.9$ TeV





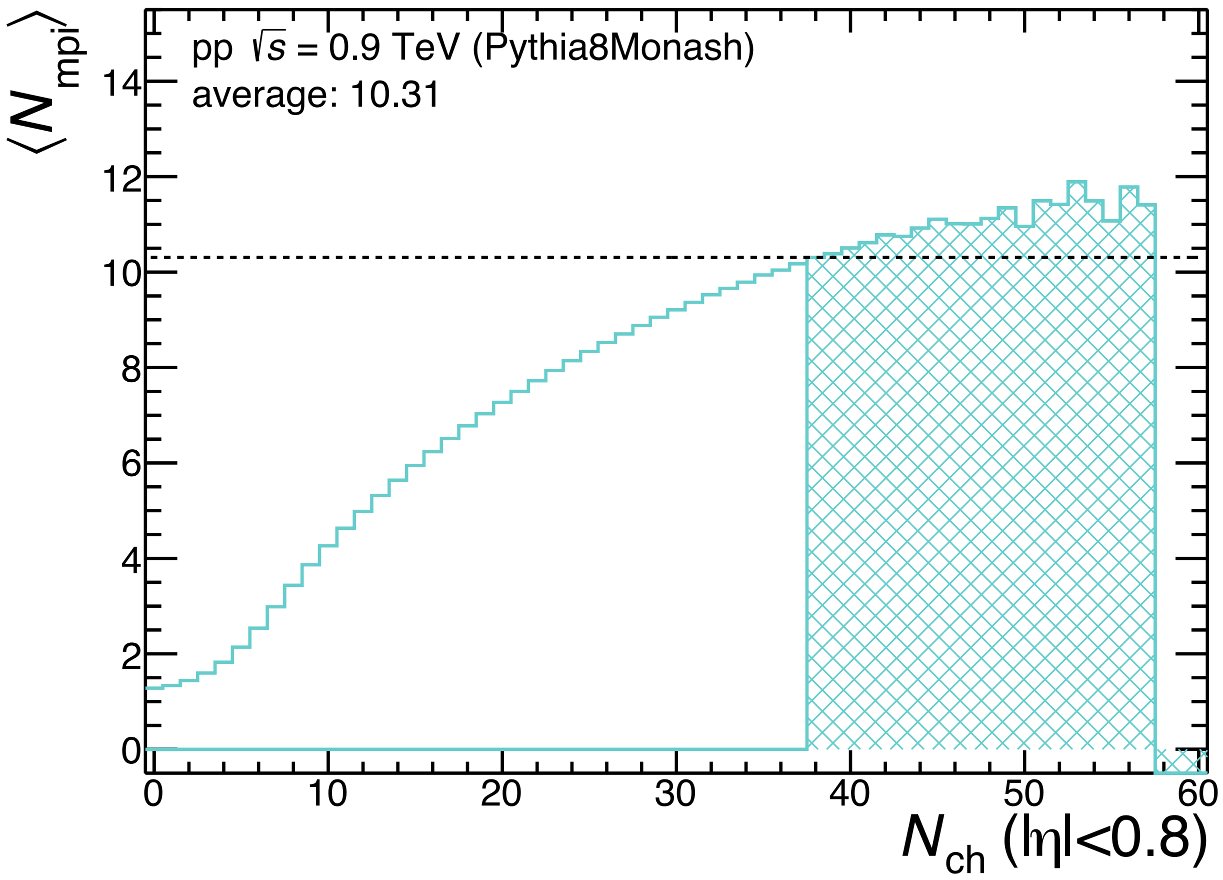




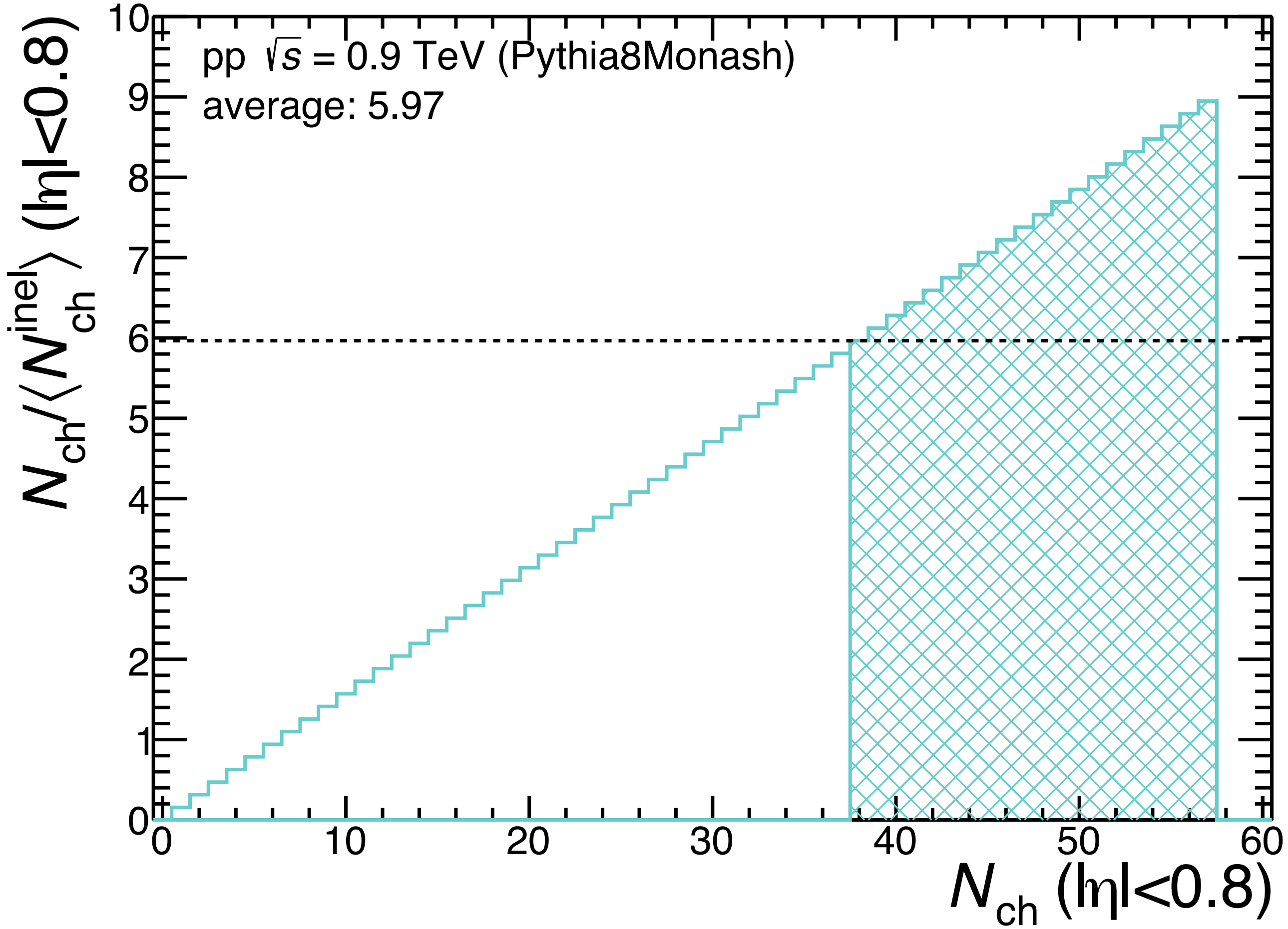


FV0 + TPC + MFT

Summary

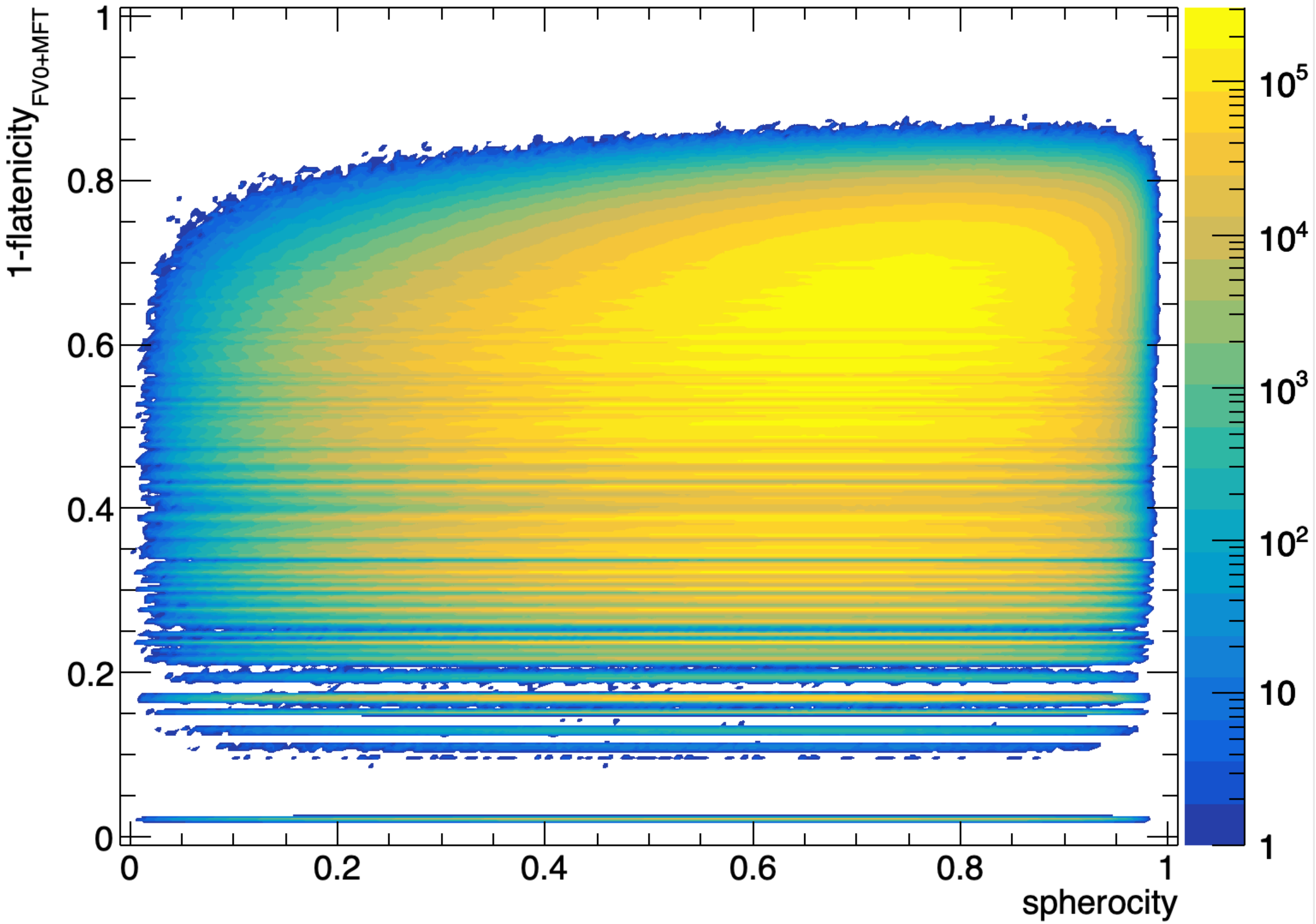


pp $\sqrt{s}$ = 0.9 TeV (Pythia8Monash)
average: 10.31
$\langle N_{mpi} \rangle$
N_{ch} (|η|<0.8)



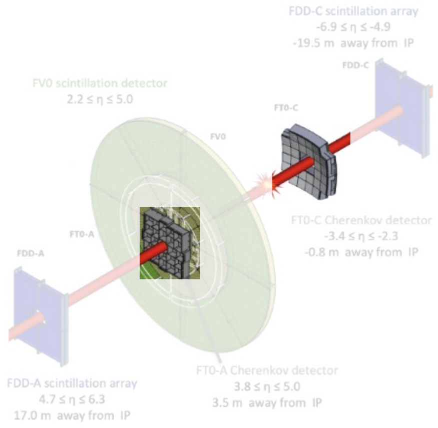
pp $\sqrt{s}$ = 0.9 TeV (Pythia8Monash)
average: 5.97
$N_{ch}/\langle N_{ch}^{inel} \rangle$ (|η|<0.8)
N_{ch} (|η|<0.8)

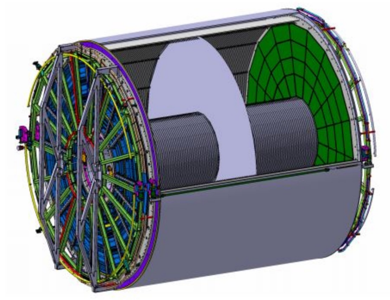
Flatenicity - vs mid-pseudorapidity spherocity

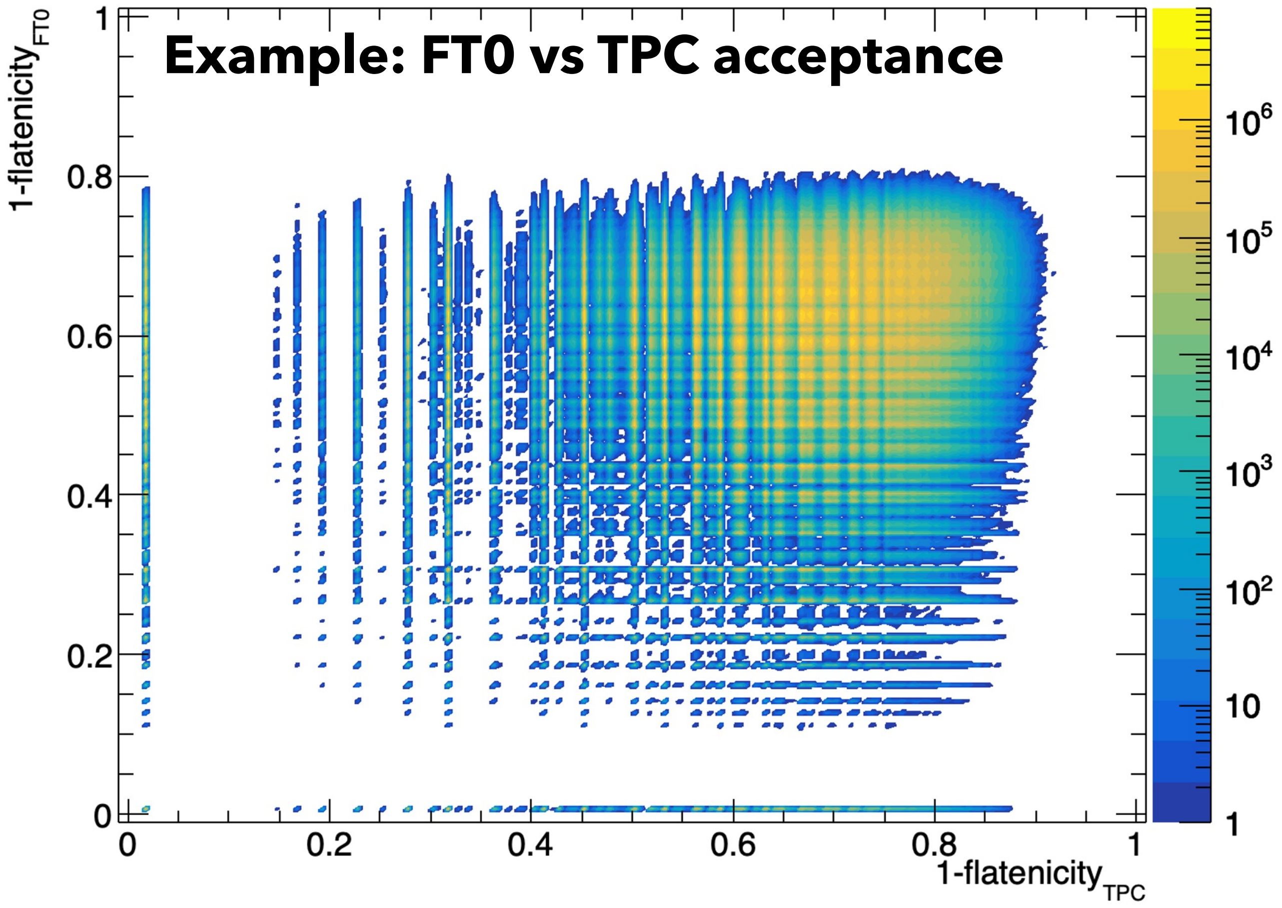


Flatenicity forward- vs mid-pseudorapidity

Pythia 8 standalone simulations, pp $\sqrt{s} = 0.9$ TeV
If one event is isotropic at forward η, is it flat at midrapidities?



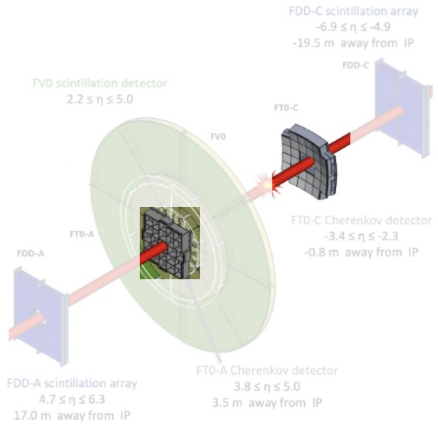


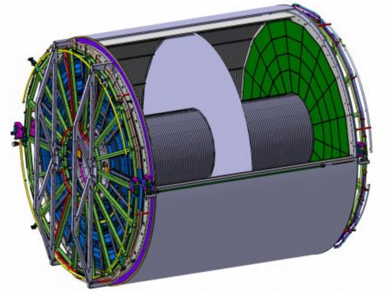


Flatenicity forward- vs mid-pseudorapidity

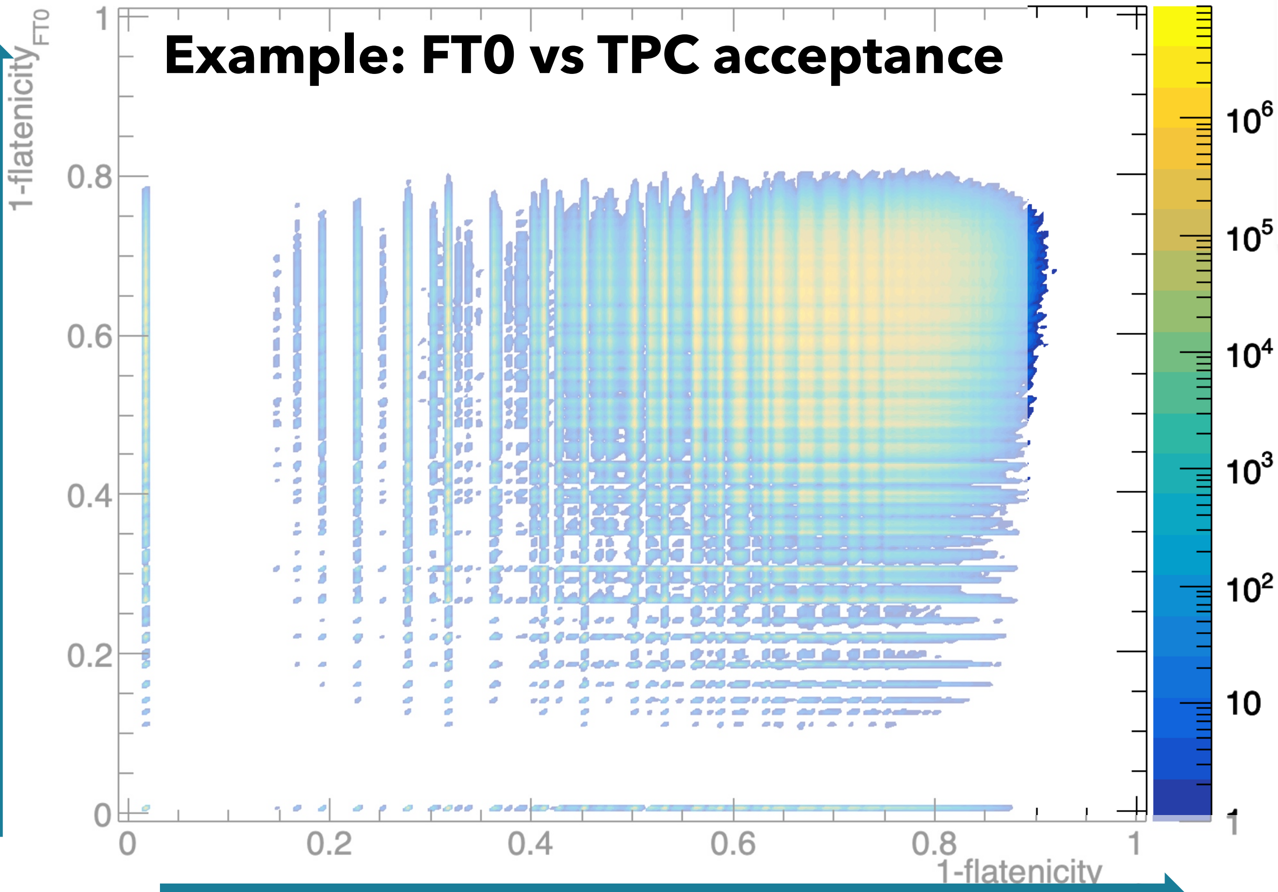
Pythia 8 standalone simulations, pp $\sqrt{s} = 0.9$ TeV

If one event is isotropic at forward η, is it flat at midrapidities?

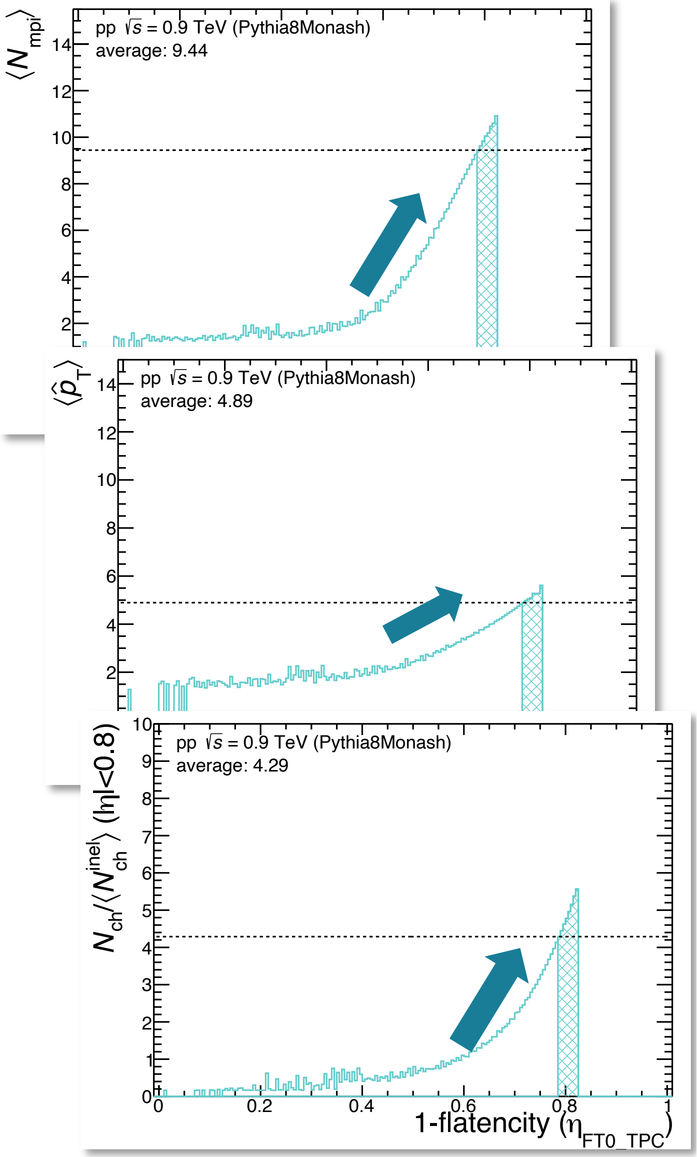




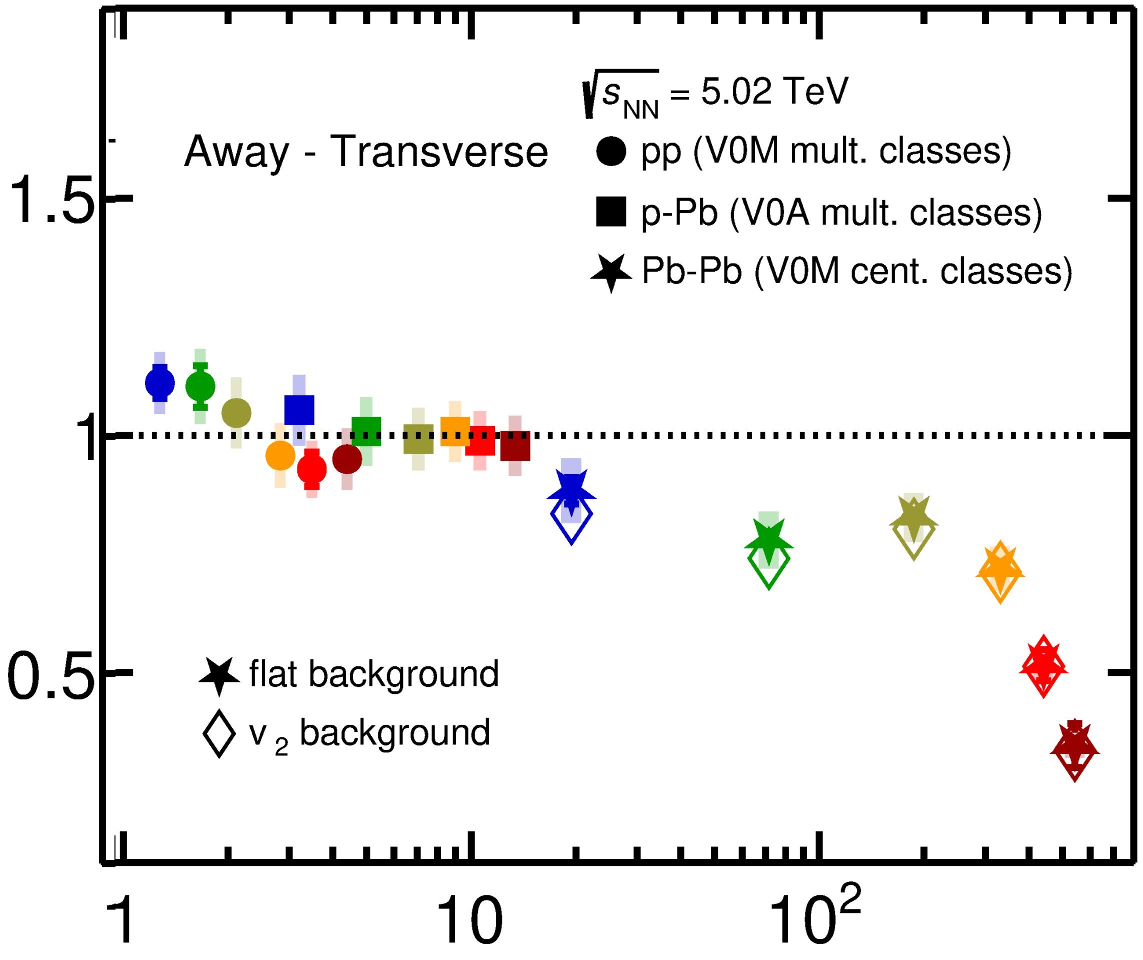
More isotropic in FT0



More isotropic in $|\eta| < 0.8$



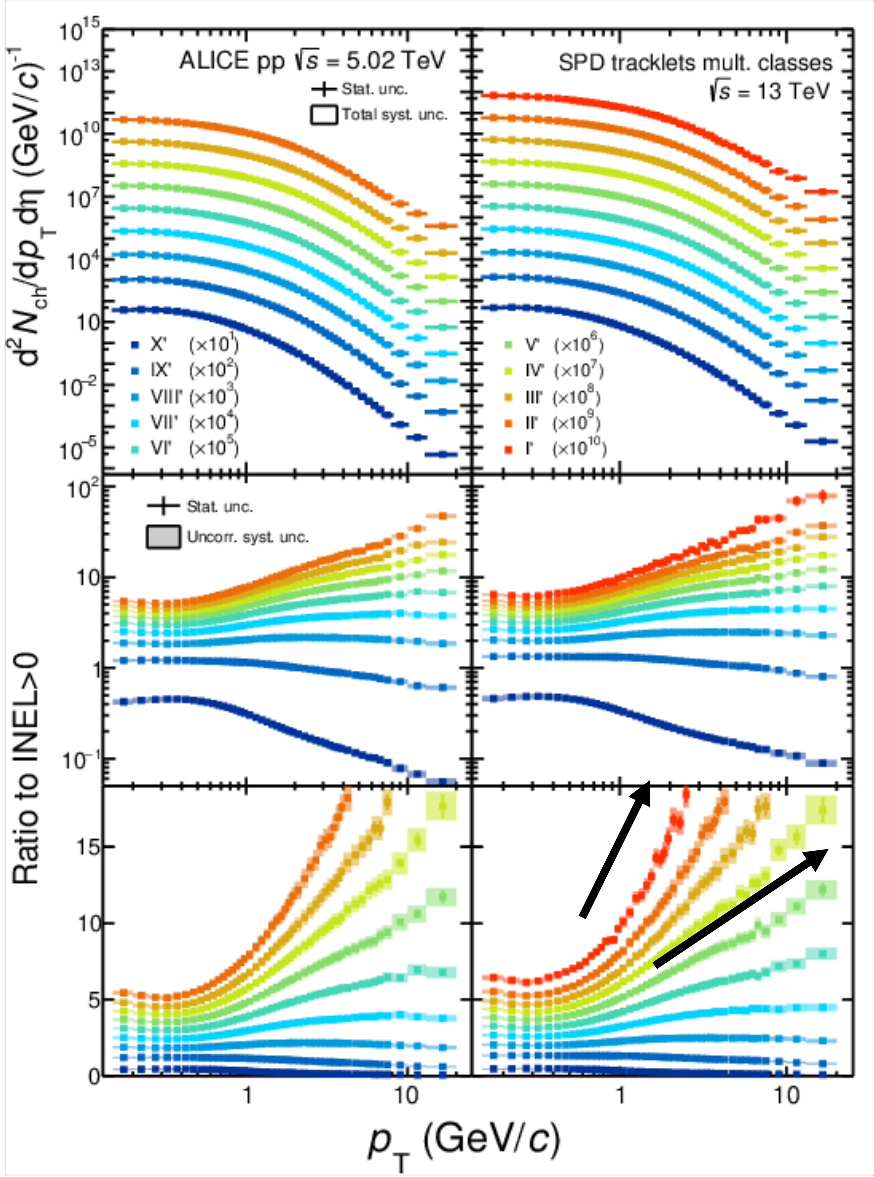
Analyses (run 2)



Search for jet quenching in small systems using two particle correlations ($5 < p_T^{trig} < 40$ GeV/c).
The high-p_T yields (4-6 GeV/c) as a function of the activity in the V0 detector were normalised to same quantity measured in minimum-bias pp collisions (similar to I_{AA})

Questions (high multiplicity):
Origin of collectivity: MPI vs QGP: enhance the sensitivity to MPI using rho (measure pT spectra vs rho in ITS2+FV0+FT0) / pT spectra vs Rtmin (ITS2)
Modifications at high pT? -> two particle correlations vs activity in (FV0+TF0)

Selections biases I

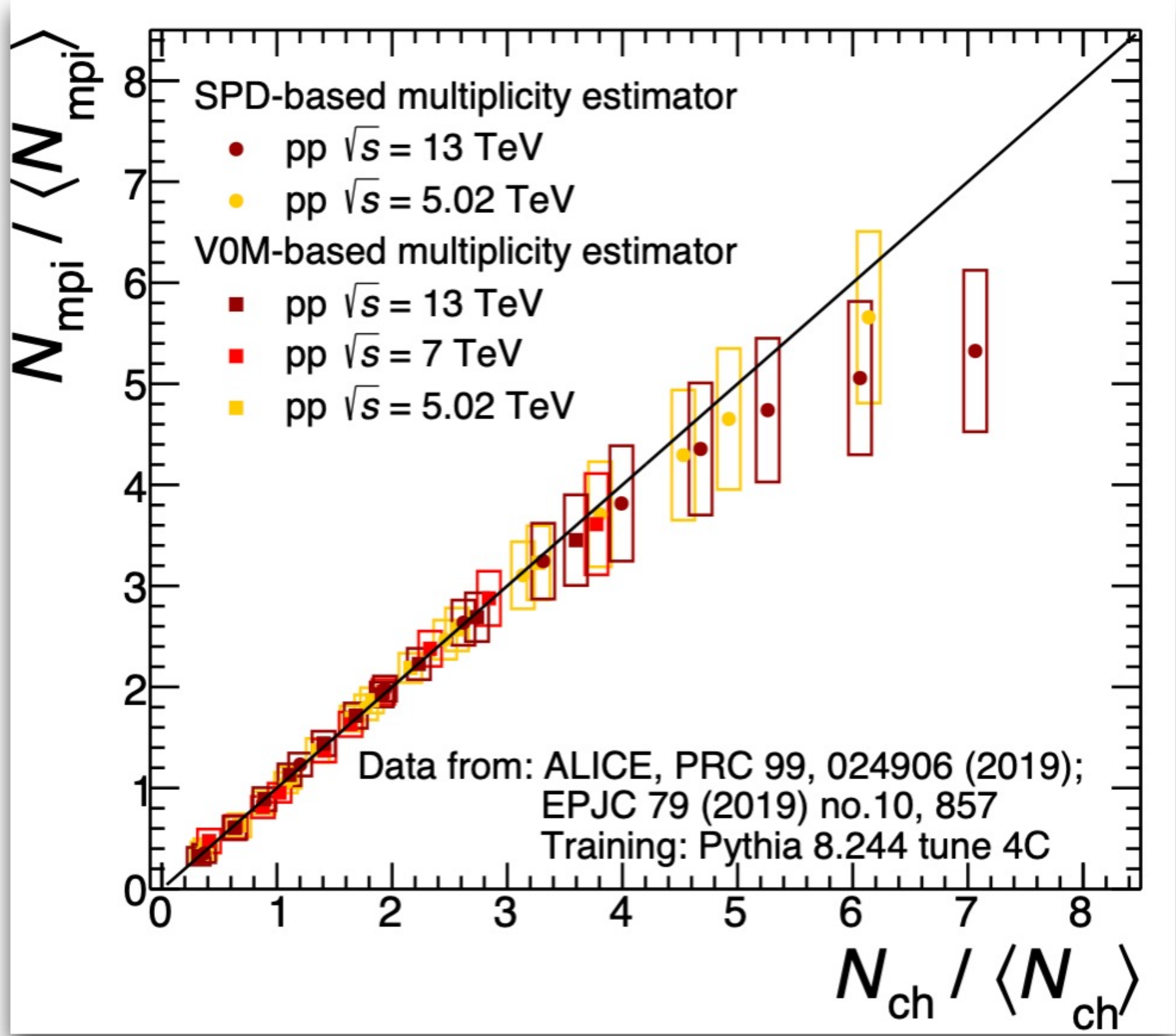


Charged particle multiplicity at mid-pseudorapidity. Very high multiplicity reach ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \geq 50$), but:

- Bias towards hard pp collisions

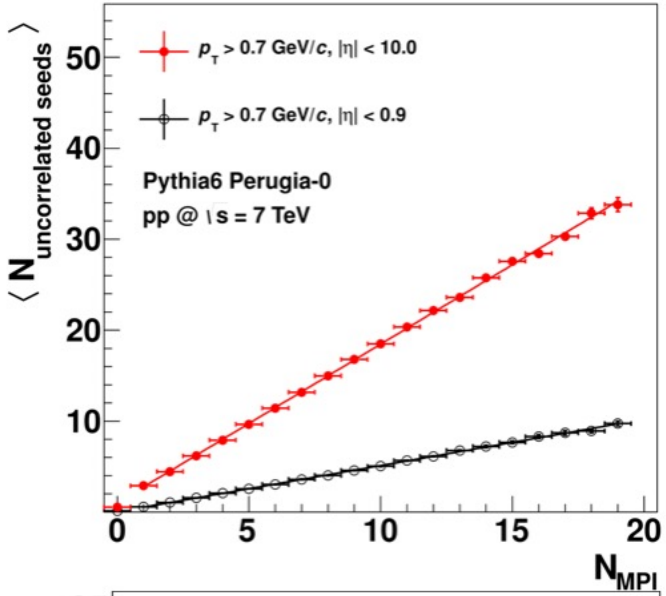
[ALICE, Eur.Phys.J. C79 (2019) no.10, 857]

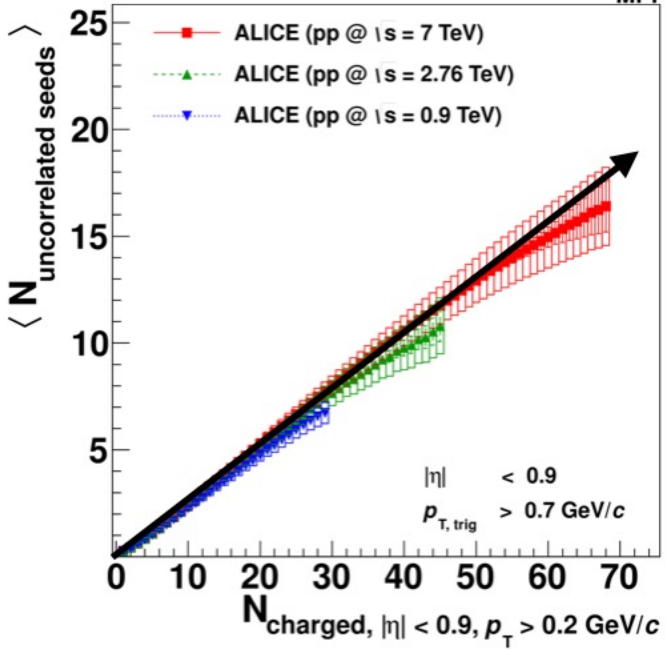
MPI from ALICE data



J. Phys. G: Nucl. Part. Phys. 48 (2021) 8, 085014

ALICE, JHEP 09 (2013) 049





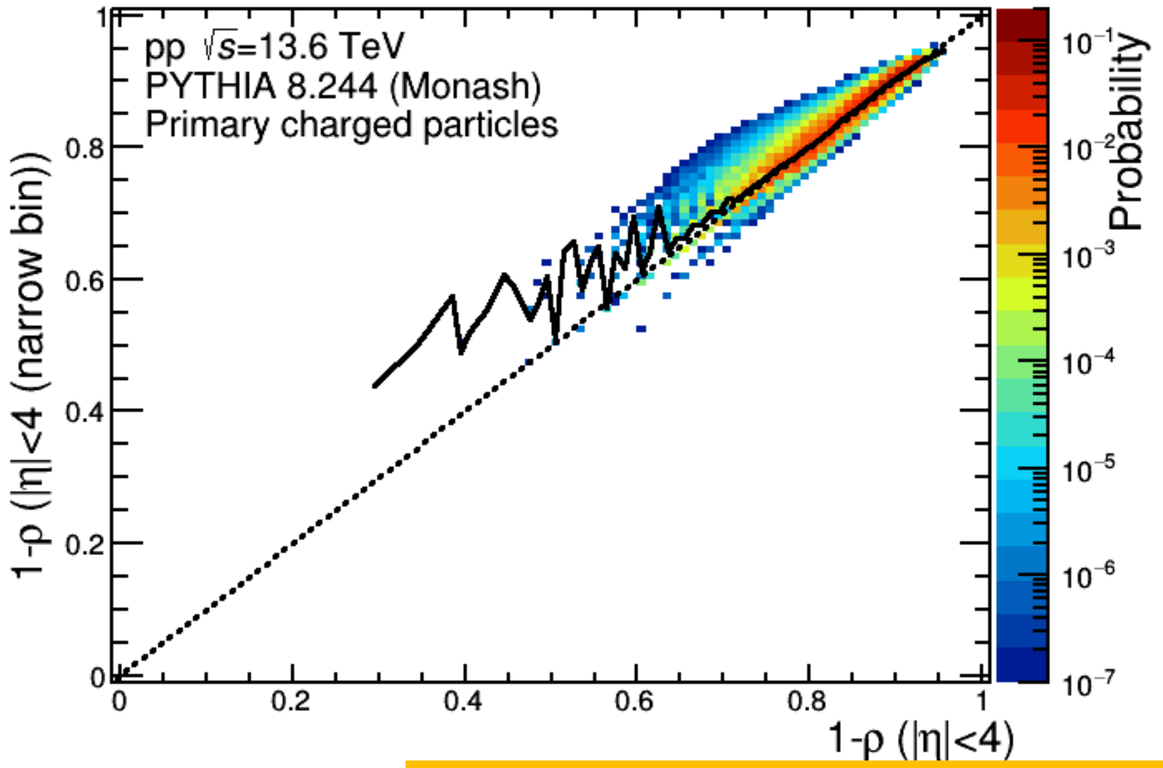
Our result is qualitatively consistent with the MPI-dedicated analysis

Stability of flattenicity (cell size)

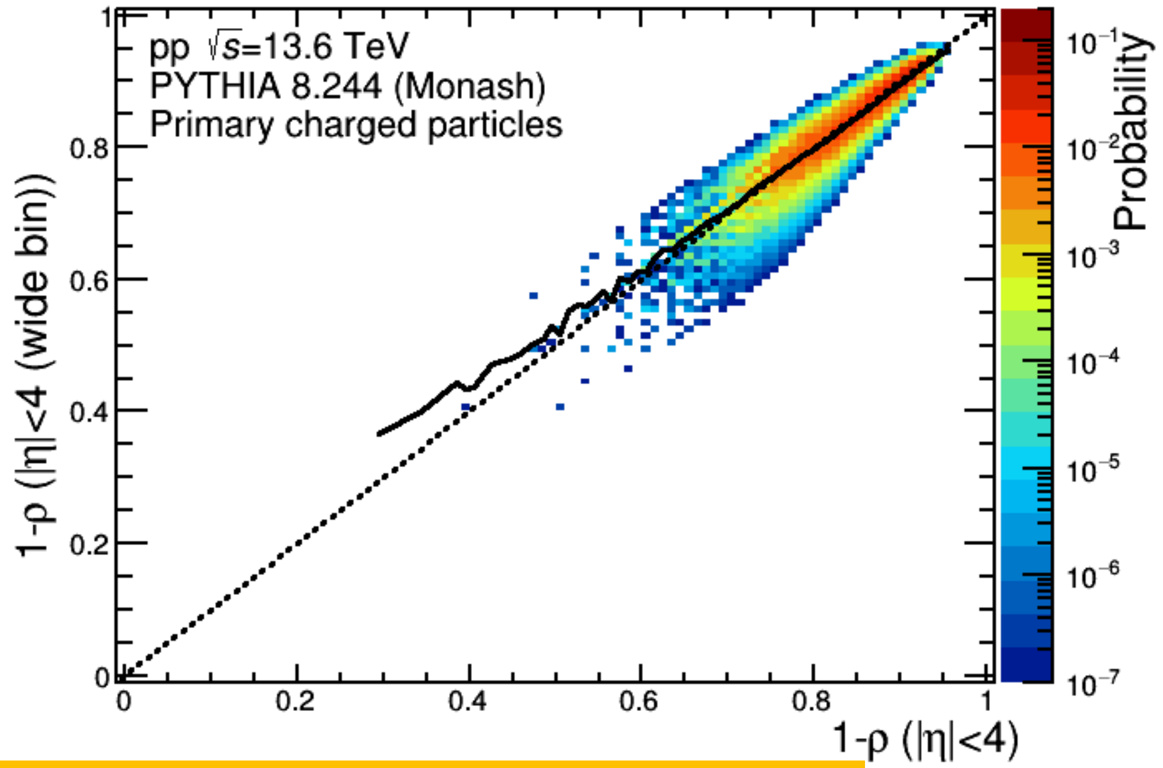
MC simulation: pp collisions at 13.6 TeV ~800 M NSD events

Reference flattenicity: cell size $0.5\times 2\pi/8$ rad, $-4 < \eta < 4$

Narrow binning: $0.25\times 2\pi/25$

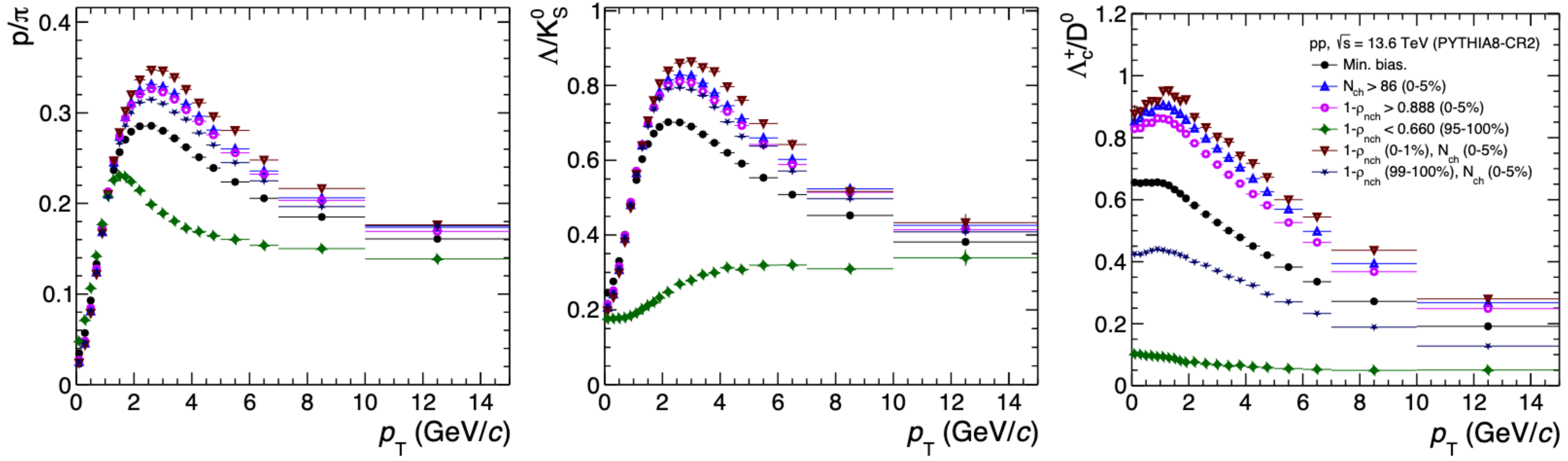


Wide binning: $1\times 2\pi/6$



Flattenicity is very stable against variations in the cell size

Particle ratios vs p_T



Larger enhancement relative to high V0M multiplicity is observed in isotropic events