How to better compare pp and AA data?

Antonio Ortiz

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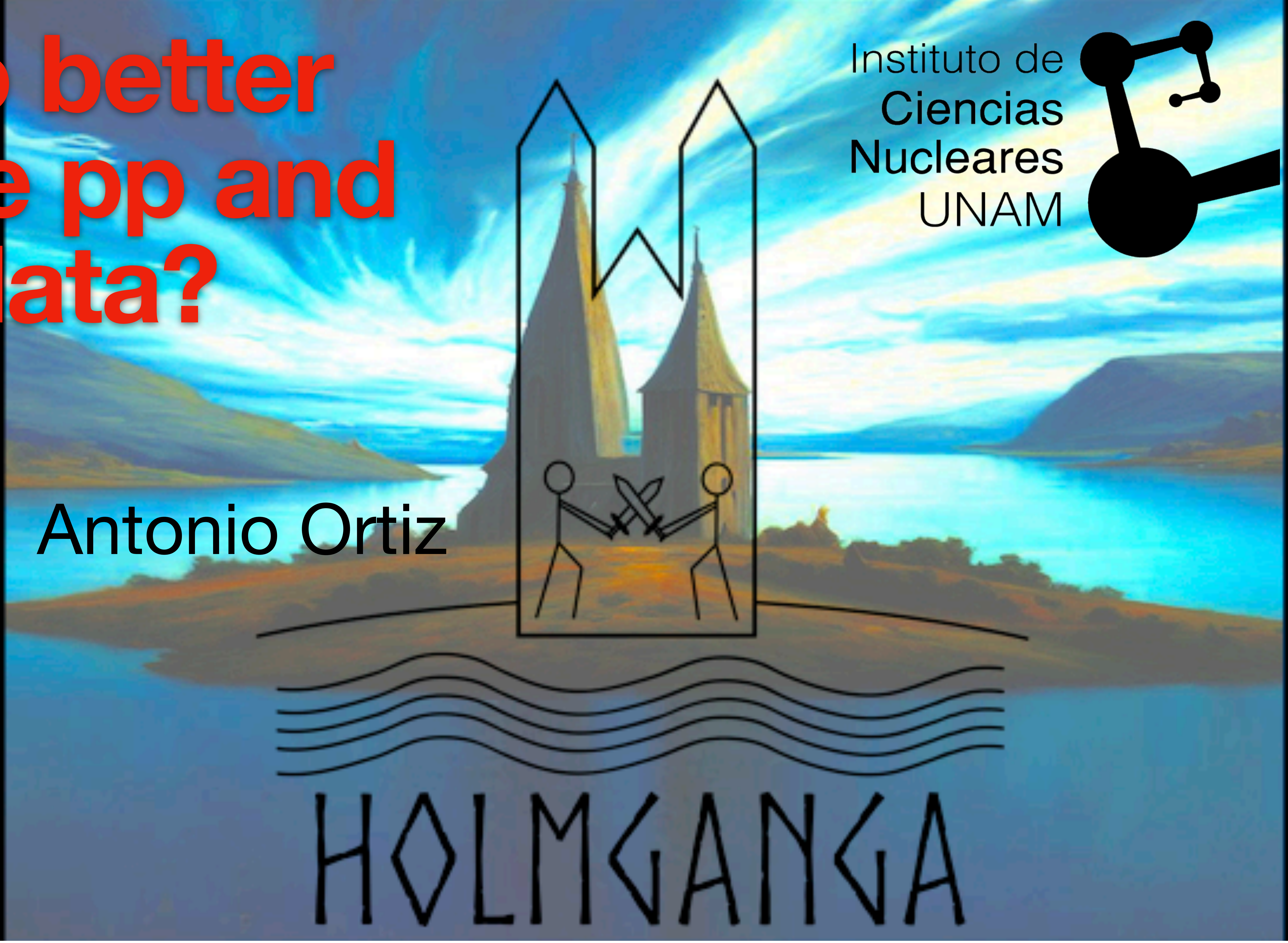

CLASH workshop 2023

Helsingborg, Sweden

Introduction

We are all interested in understanding the LHC observations in pp collisions: collective-like behaviour, charm/bottom baryon-to-meson ratios and similarities with the light flavour sector, strings vs QGP scenarios, … BUT there are some basic questions that we have not fully addressed, their answers may be important to understand the data

Introduction

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We are all interested in understanding the LHC observations in pp collisions: collective-like behaviour, charm/bottom baryon-to-meson ratios and similarities with the light flavour sector, strings vs QGP scenarios, … BUT there are some basic questions that we have not fully addressed, their answers may be important to understand the data

- What type of pp collisions should we compare with heavy-ion collisions (HIC)?
- How can we tag those pp collisions (event classifiers)
- Do we understand the bias of the different classifiers explored so far?
- How are they correlated?
- Are our data biased in the same way as MC?

What type of pp collisions should we compare with HIC?

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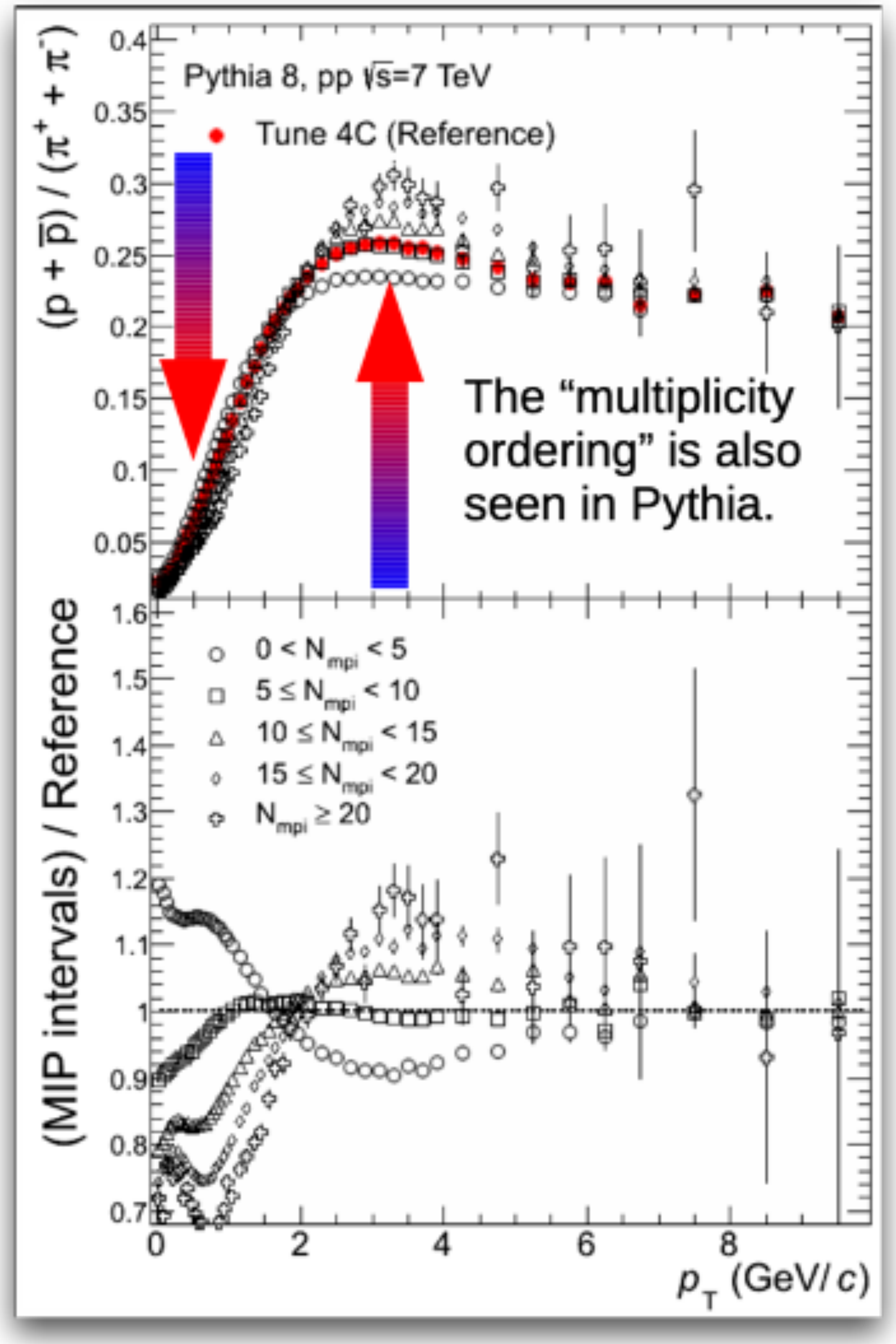
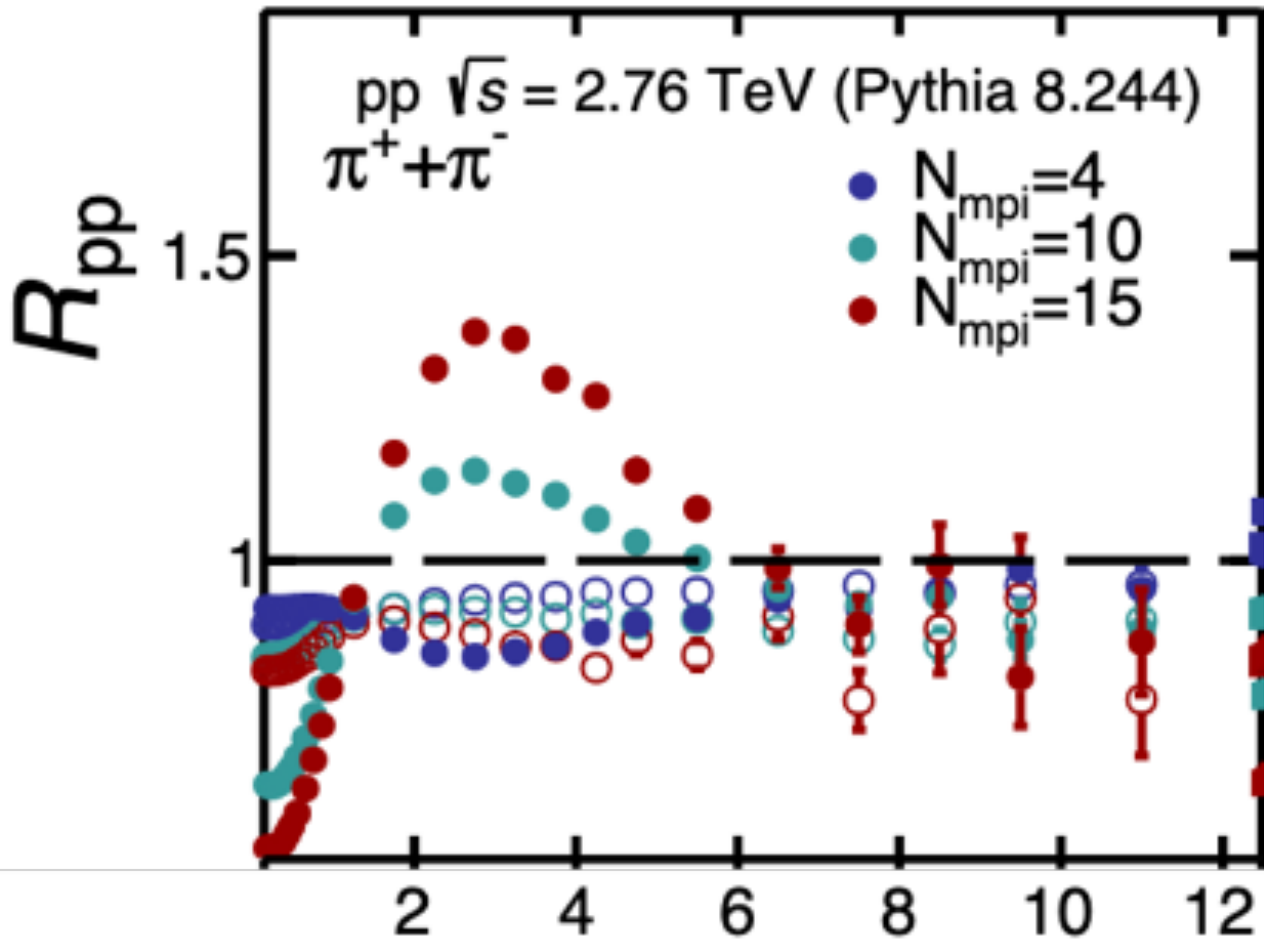
- Collisions with several "soft" parton-parton scatterings seems like the most natural candidates. Example using Pythia (MPI + CR)

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





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

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

How can we tag those pp collisions?

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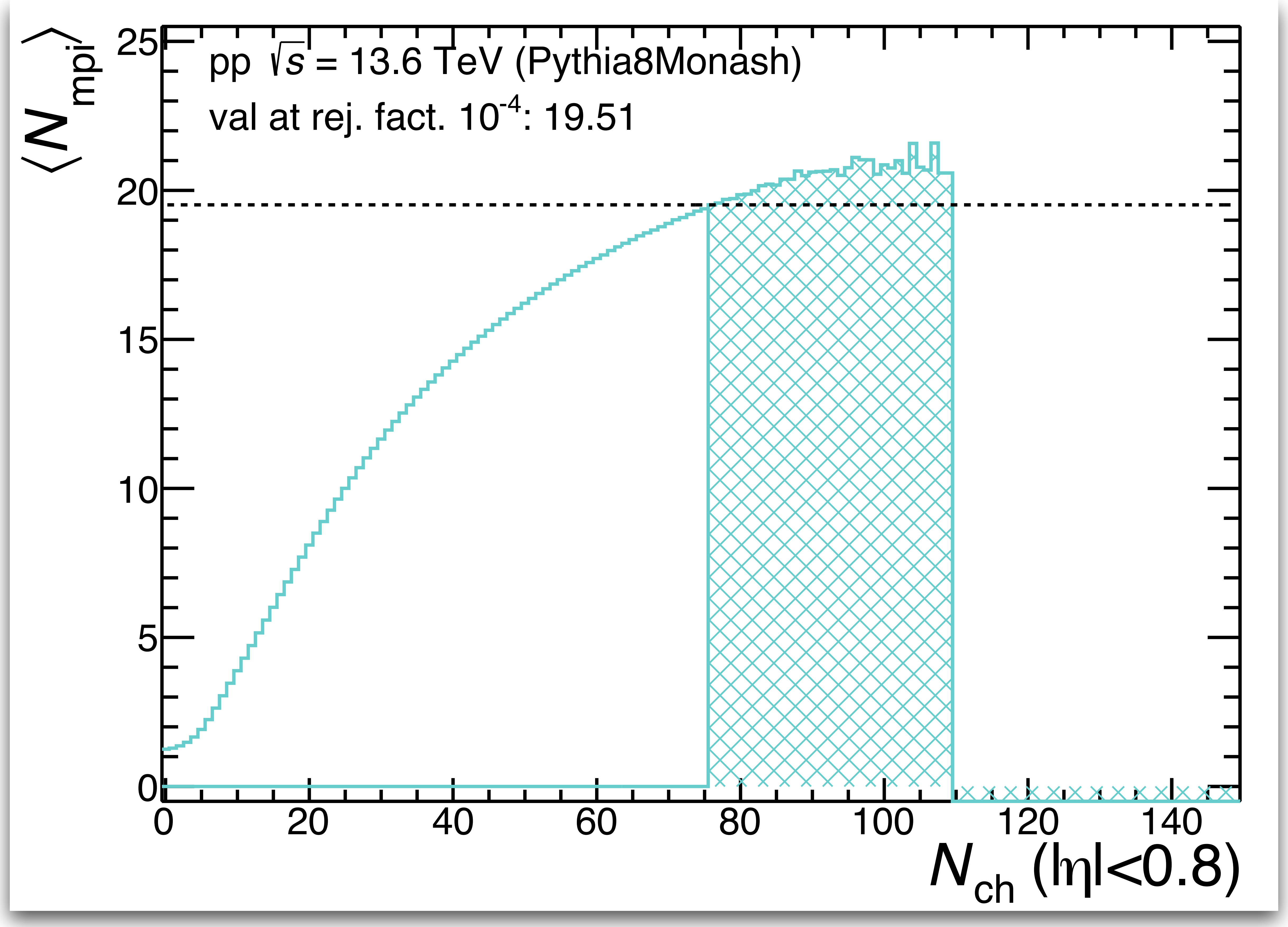
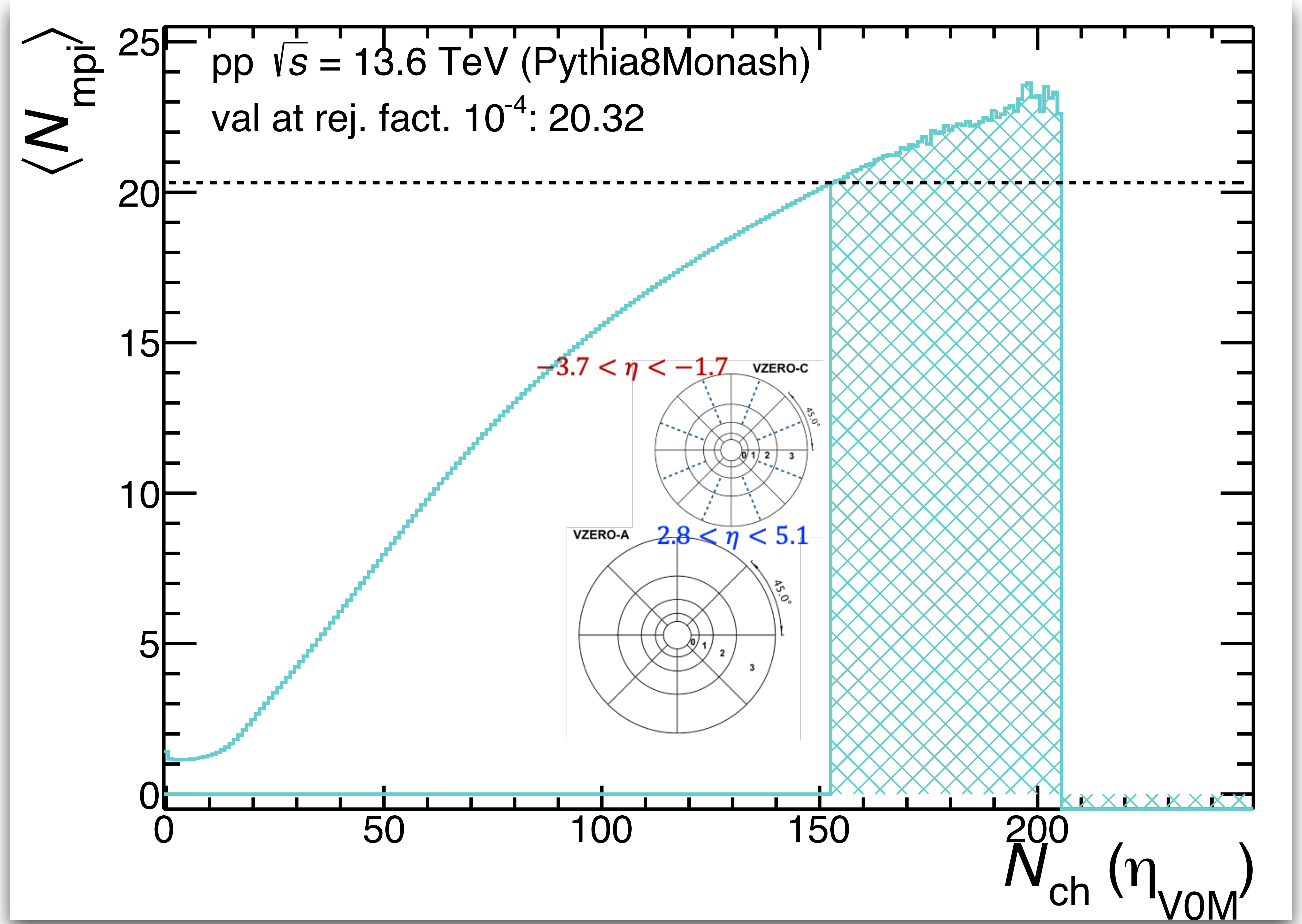
Particle multiplicity seems to be a good candidate, example:



Track multiplicity ($|\eta| < 0.8$)



Multiplicity in the forward direction (V0M):

$-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$

Do we understand the bias of the different classifiers?

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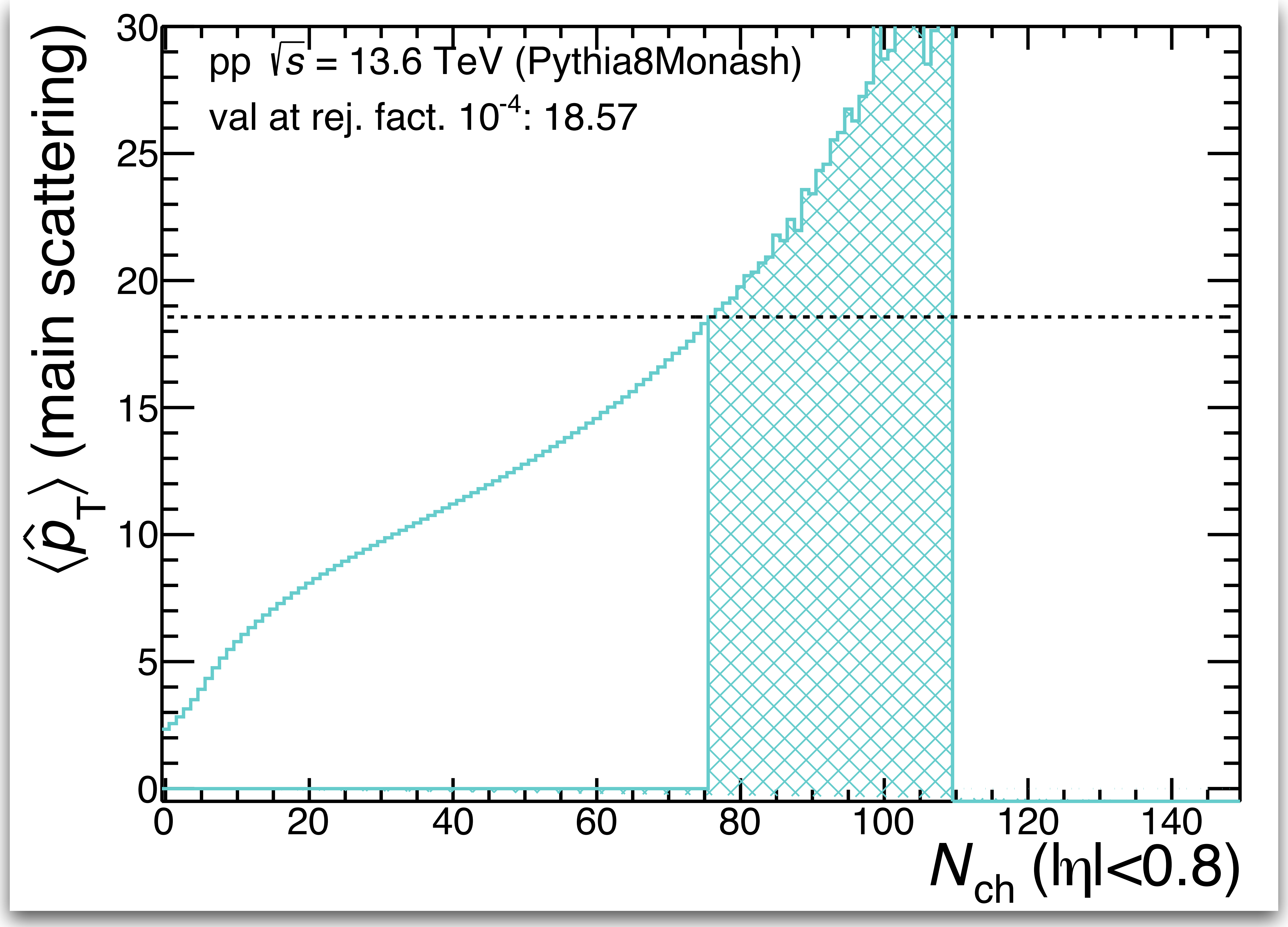
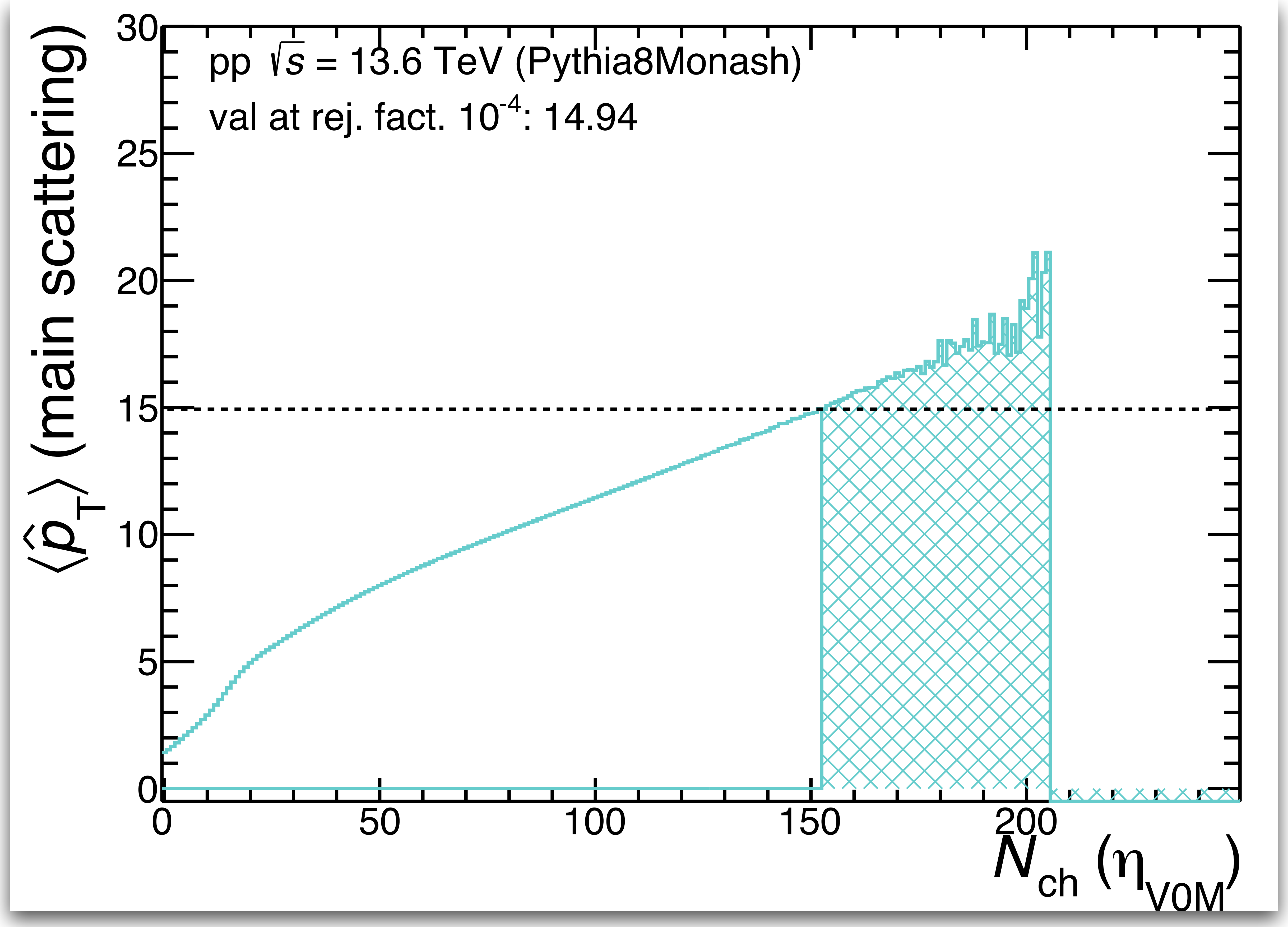
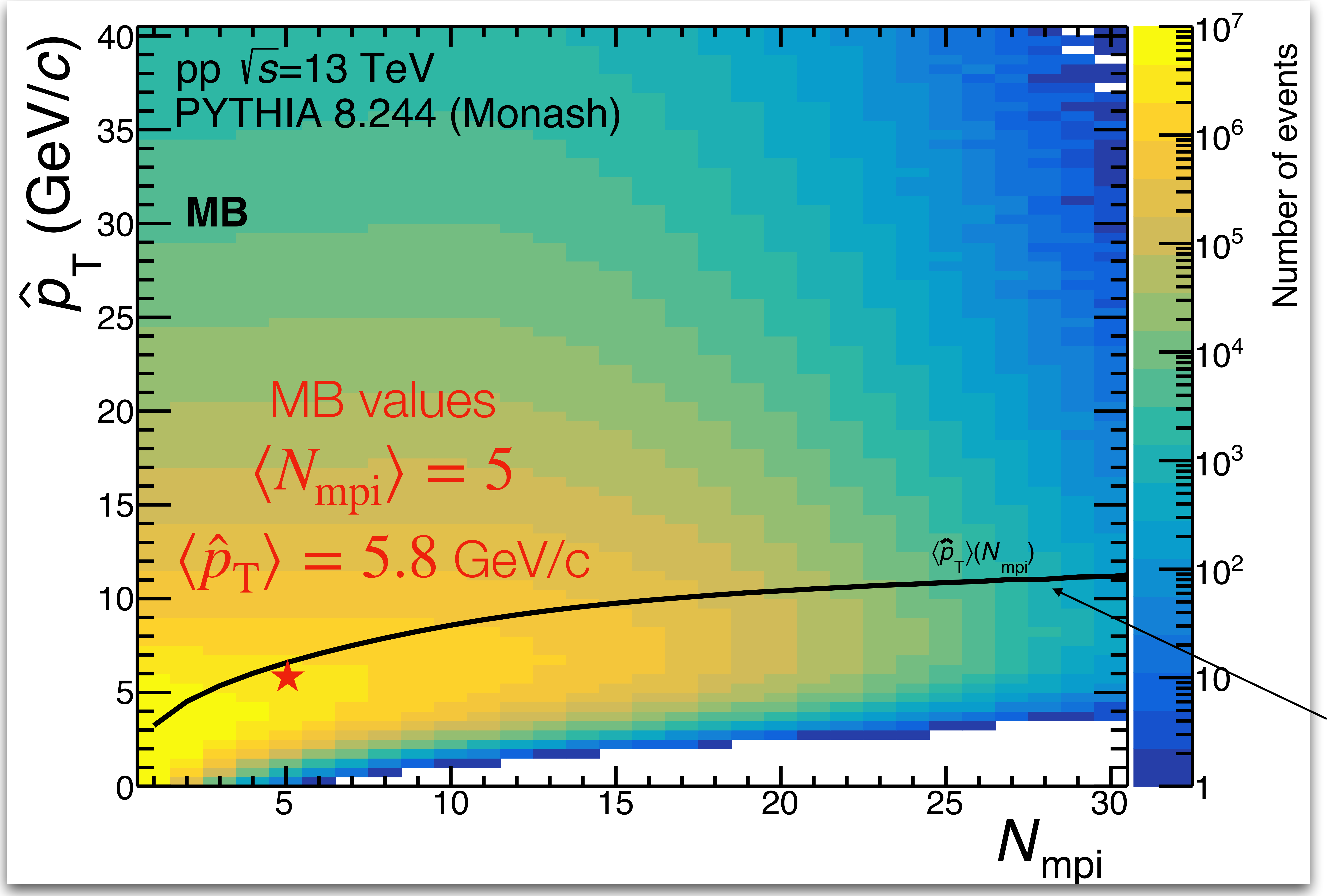
Example: strong sensitivity to MPI but bias towards hard pp collisions. The effect is stronger for the mid-pseudorapidity multiplicity estimator





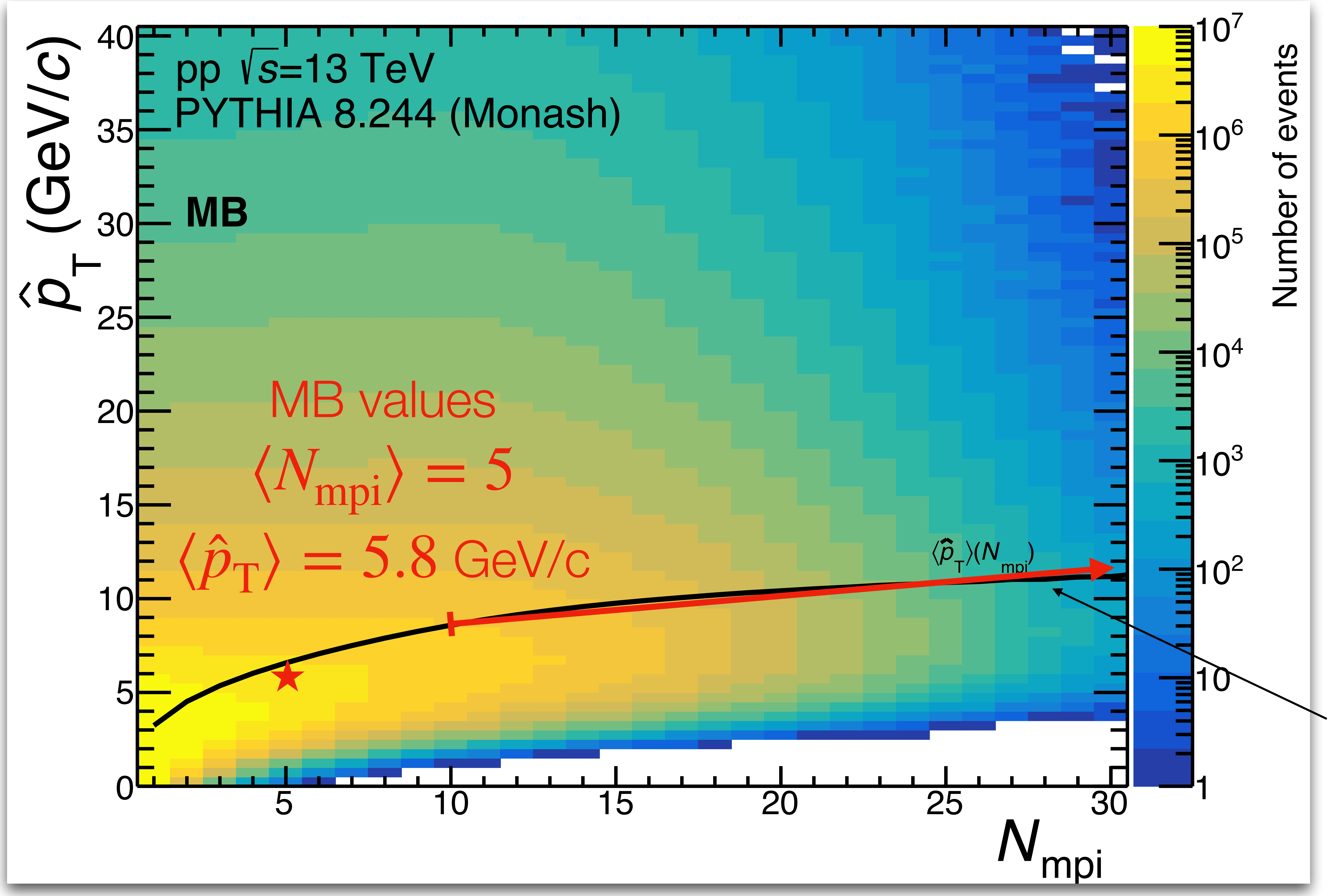
V0M seems to be more convenient, in addition no bias in the ratio charged-to-neutral particles

Understanding the different event classifiers



MB pp collisions:
The solid line represents the unbiased correlation (our goal) between jet $p_{\rm T}$ and $N_{\rm mpi}$

Understanding the different event classifiers



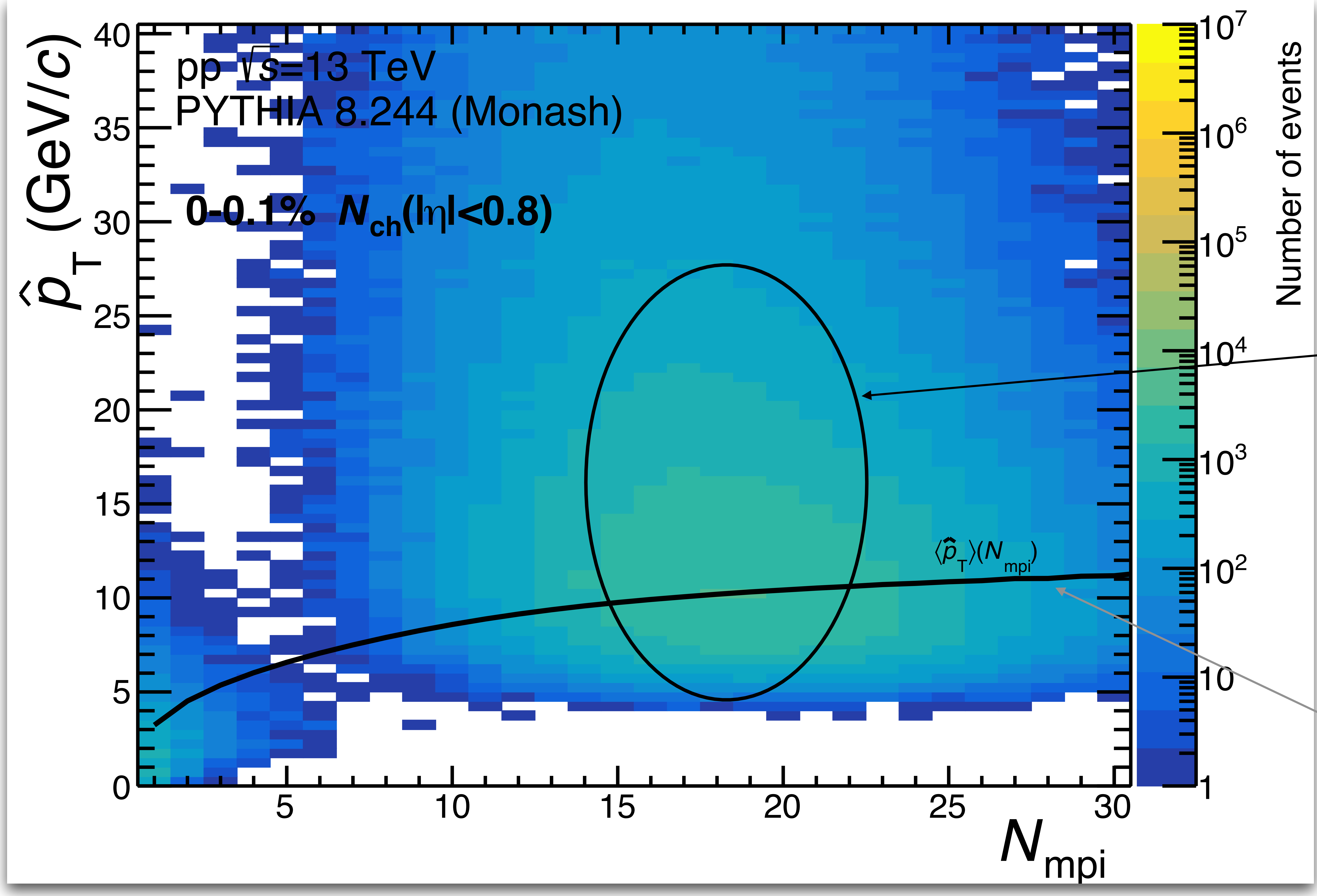
A factor 3 increase in MPI: $N_{\rm mpi} = 10$ to $N_{\rm mpi} = 30$

$\rightarrow$

small increase in $\hat{p}_{\rm T}$: (~30%)

MB pp collisions:
The solid line represents the unbiased correlation (our goal) between jet $p_{\rm T}$ and $N_{\rm mpi}$

High-multiplicity selector N_{ch}



0-0.1% N_{ch}:
Primary charged particles
$|\eta| < 0.8$, $p_T > 0$ GeV/c

$\sigma_{\hat{p}_T} - \sigma_{N_{mpi}}$:
Correlation ellipse

MB pp collisions:
The solid line represents the unbiased correlation (our goal) between jet p_T and N_{mpi}

High-multiplicity selector (efficiency)

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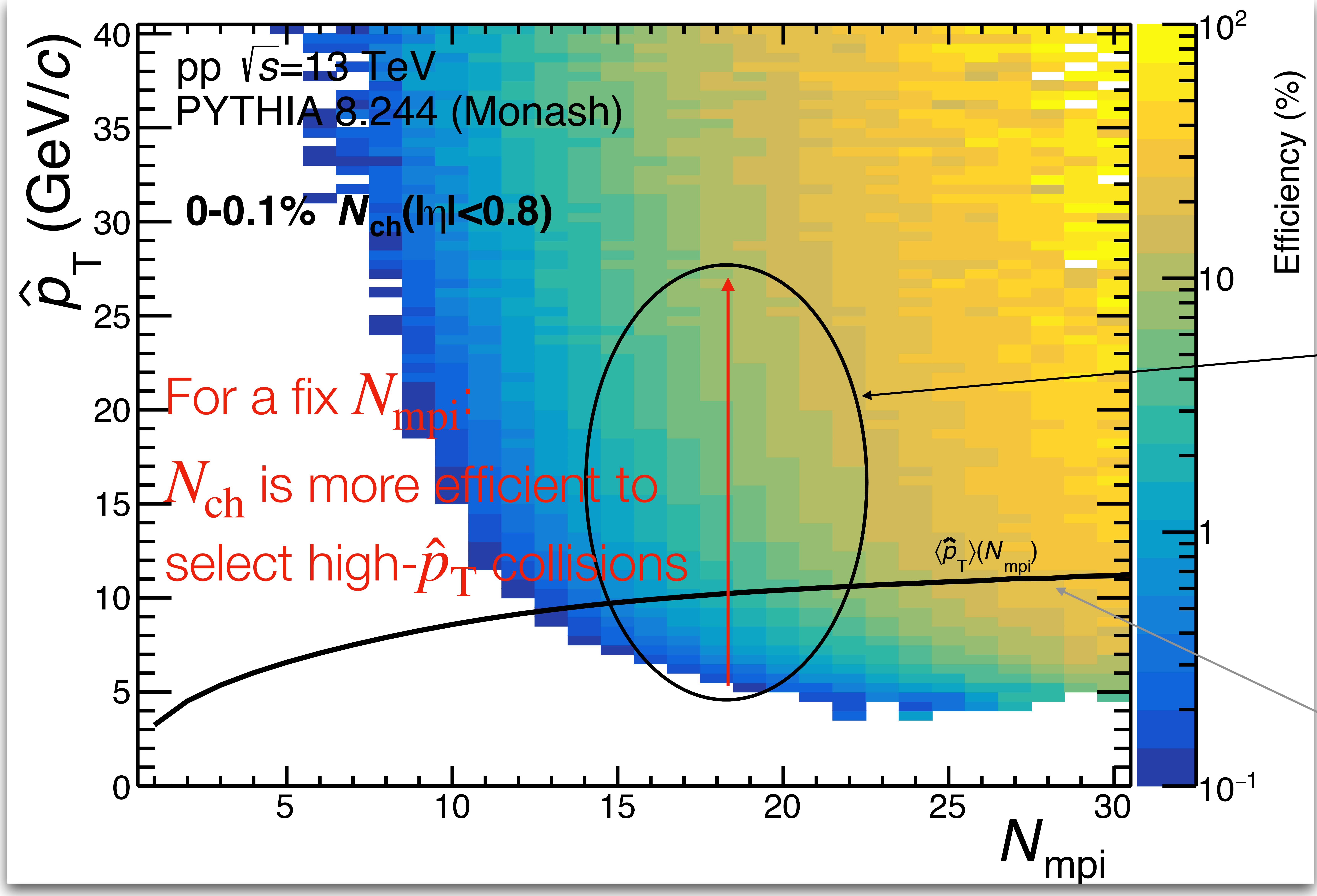

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Primary charged particles
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$\sigma_{\hat{p}_{\rm T}} - \sigma_{N_{\rm mpi}}$:
Correlation ellipse

MB pp collisions:
The solid line represents the unbiased correlation (our goal) between jet $p_{\rm T}$ and $N_{\rm mpi}$

Efficiency: $N_{ch} \rightarrow$ V0M

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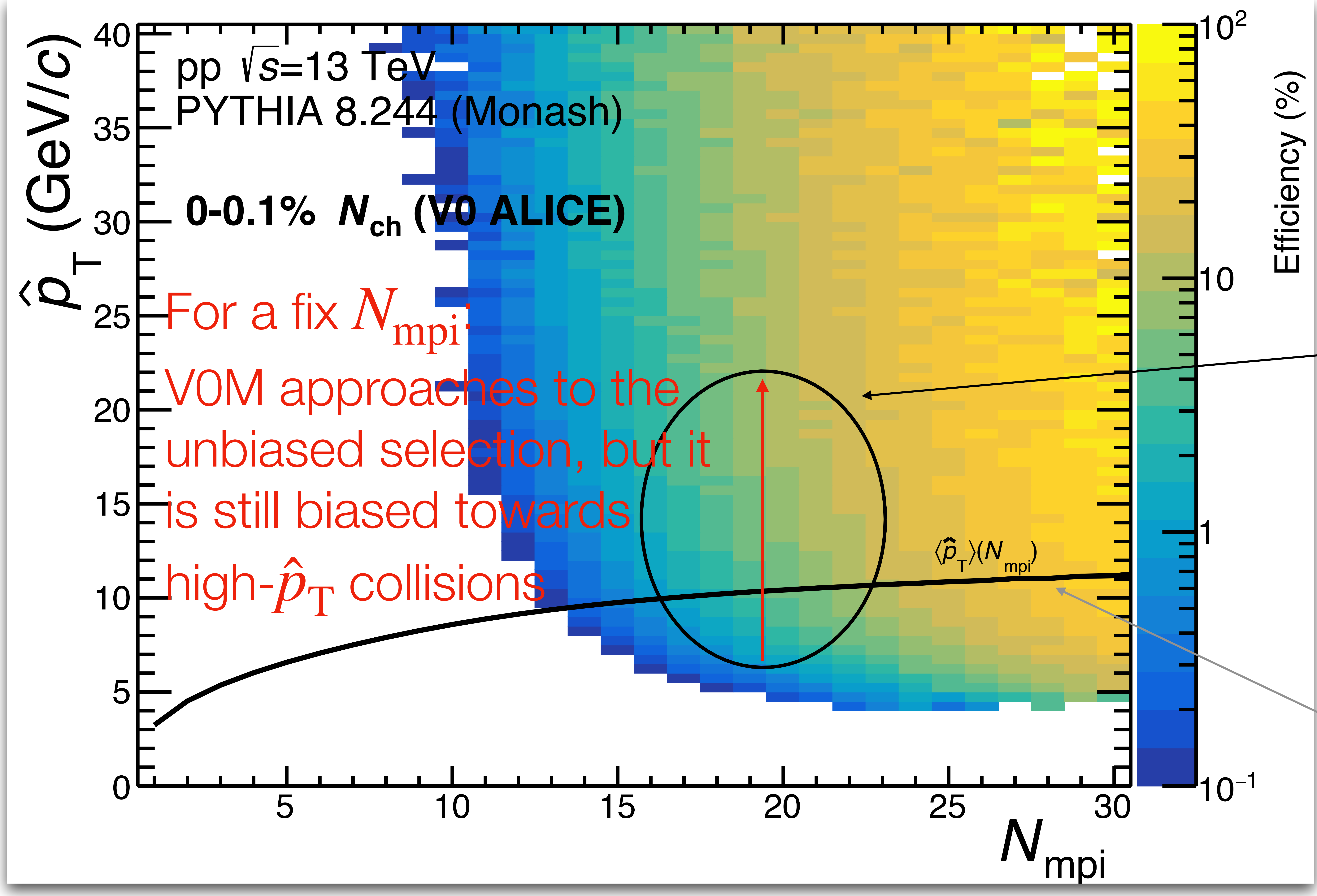

0-0.1% V0M:
Primary charged particles ($p_T > 0$ GeV/c) in the ALICE V0 acceptance

$\sigma_{\hat{p}_T} - \sigma_{N_{mpi}}$:
Correlation ellipse (narrower area than with N_{ch})

MB pp collisions:
The solid line represents the unbiased correlation (our goal) between jet p_T and N_{mpi}

Efficiency: N_{ch} → V0M → flattenicity

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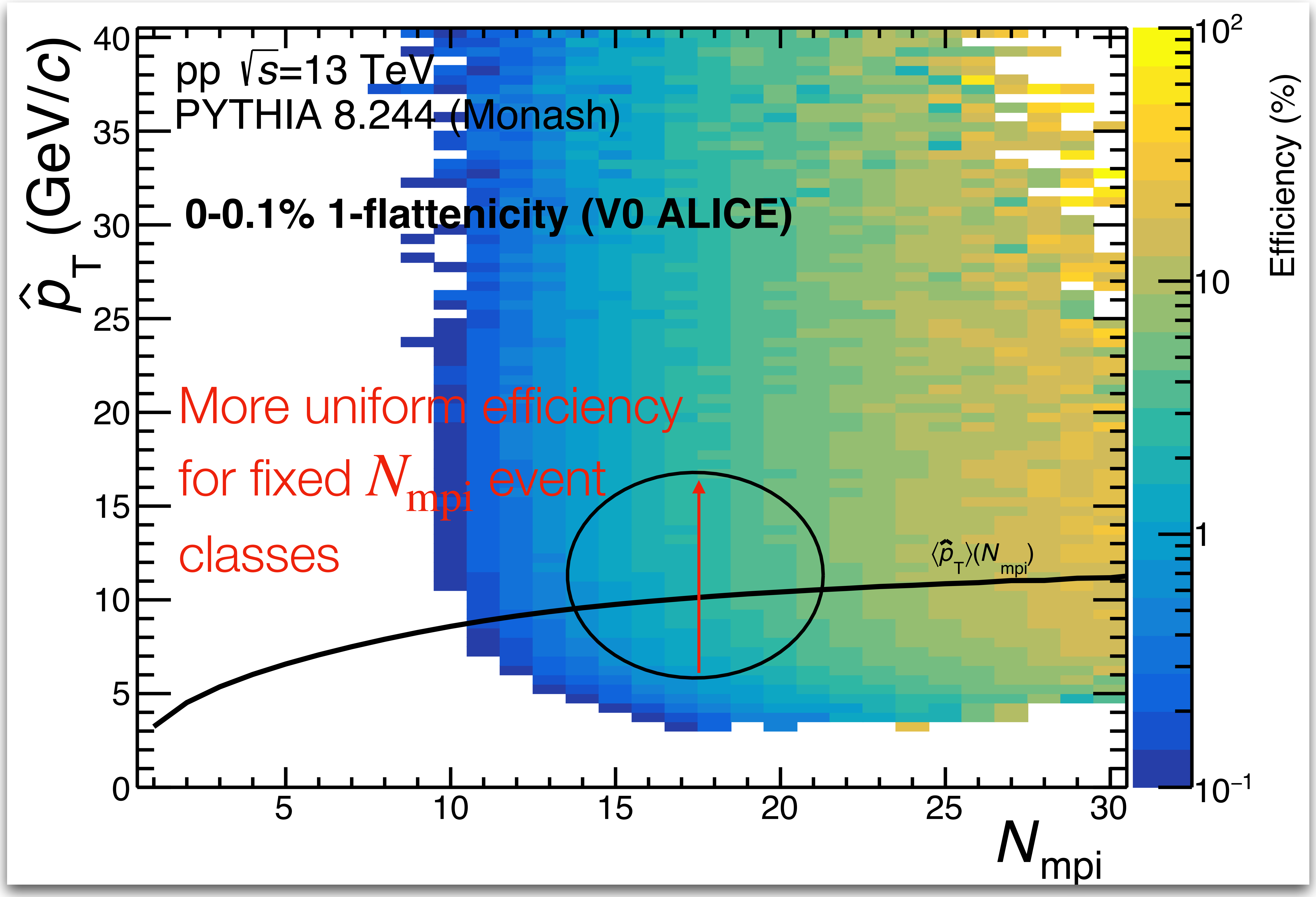
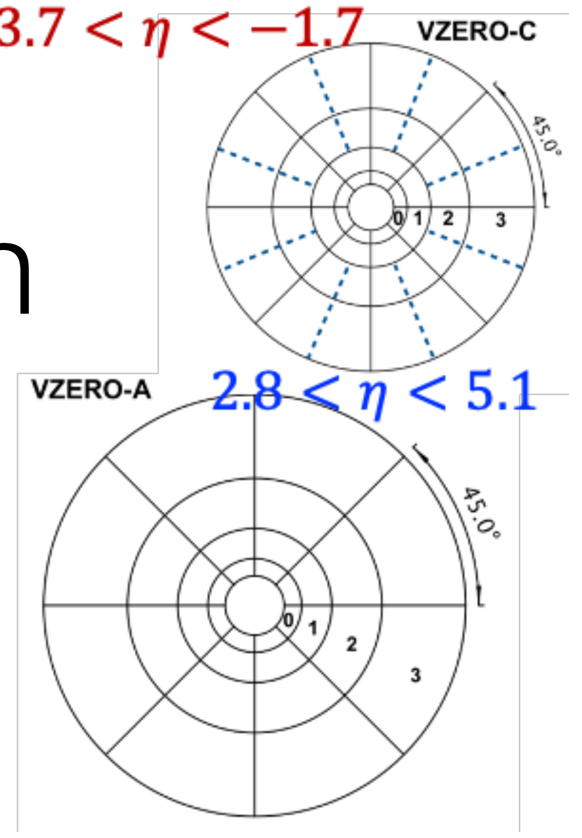


Calculated in the region cover by the V0 detector and using N_{ch} instead of p_T

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

The normalisation to N_{cell} allows flattencity to stay within 0-1



[A. Ortiz et al., PRD 107 (2023) 7, 076012]

Biases at work! V0M vs flattenicity selections

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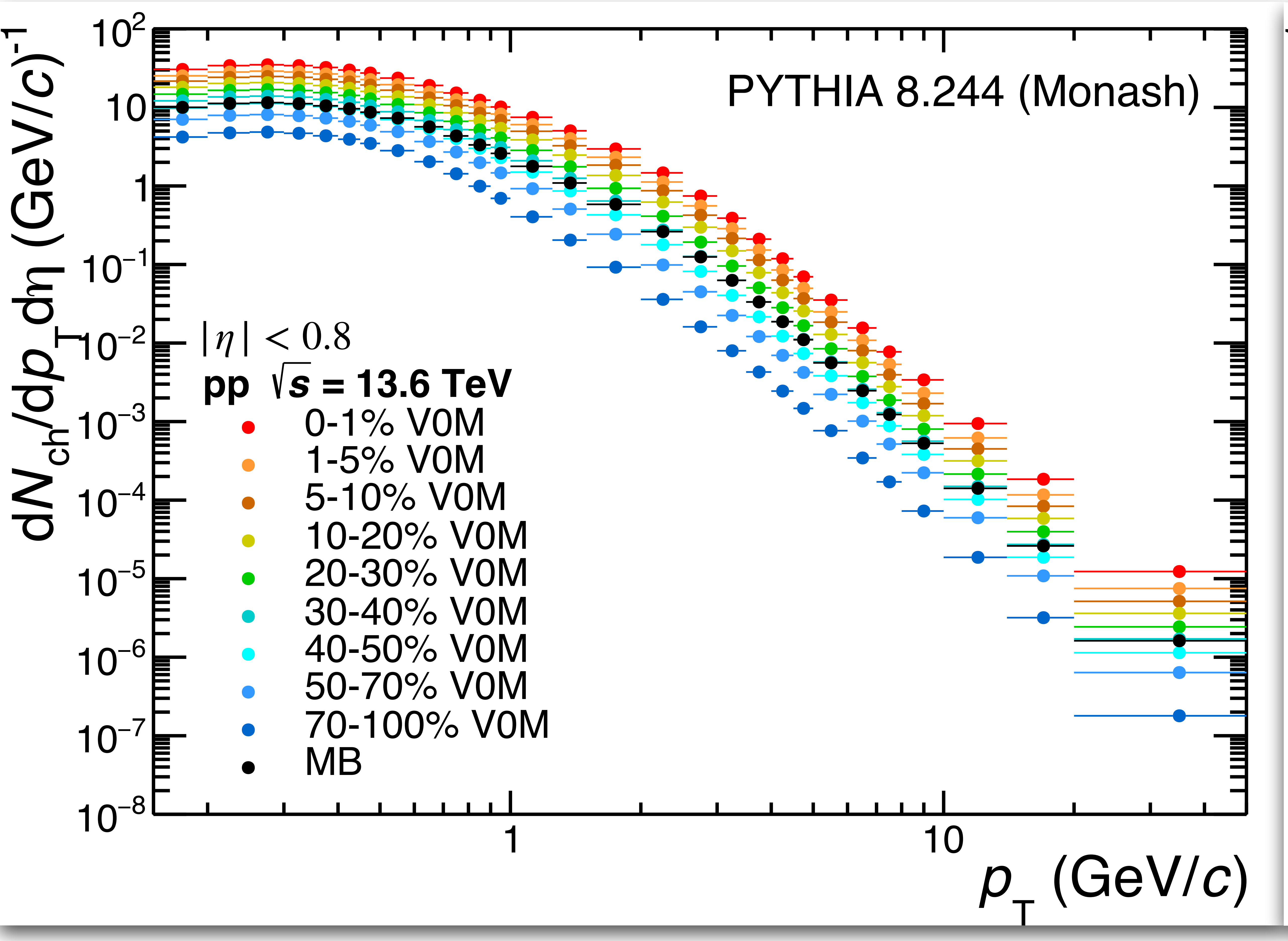
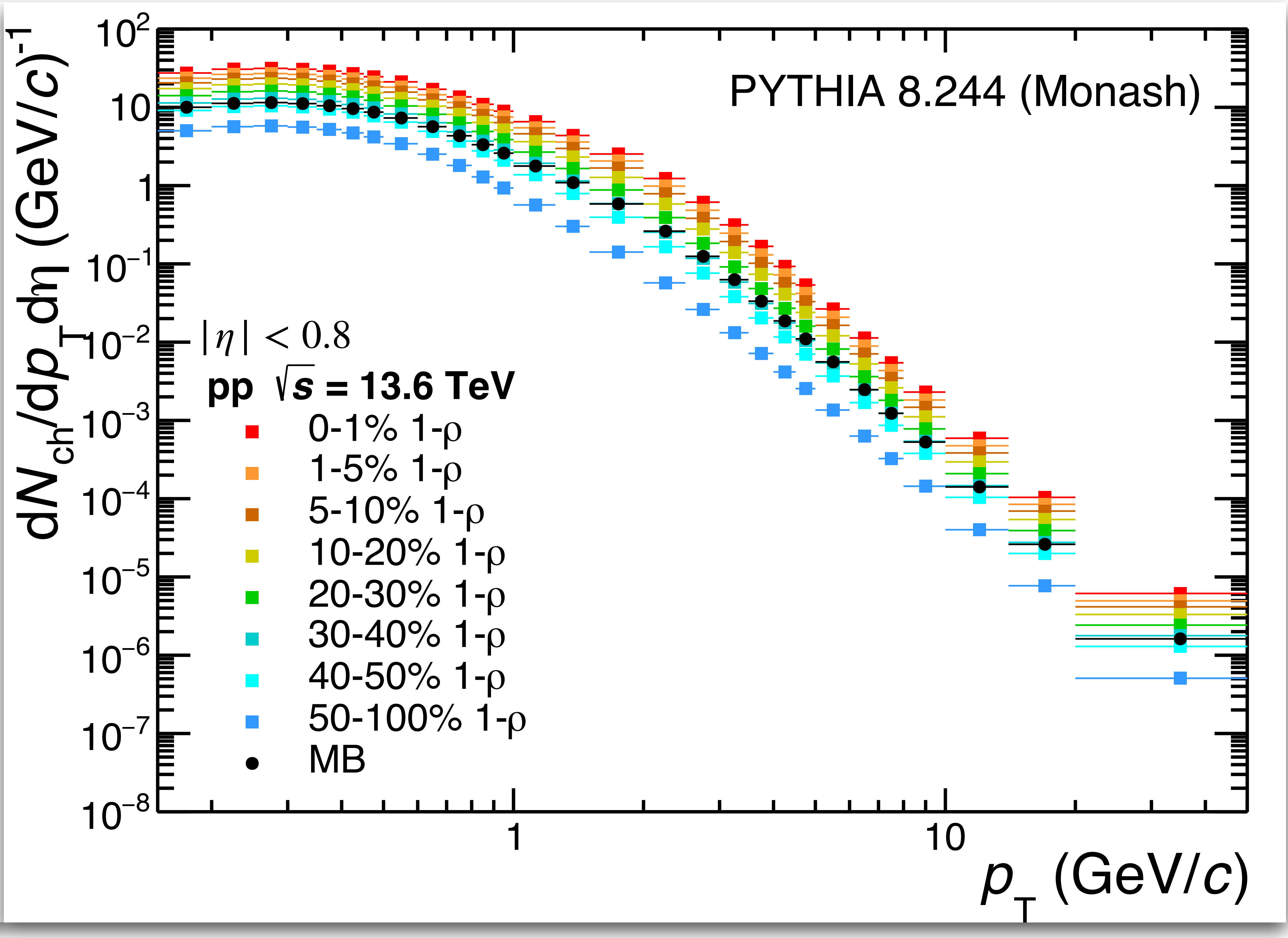
Selection based on V0M



Selection based on flattenicity



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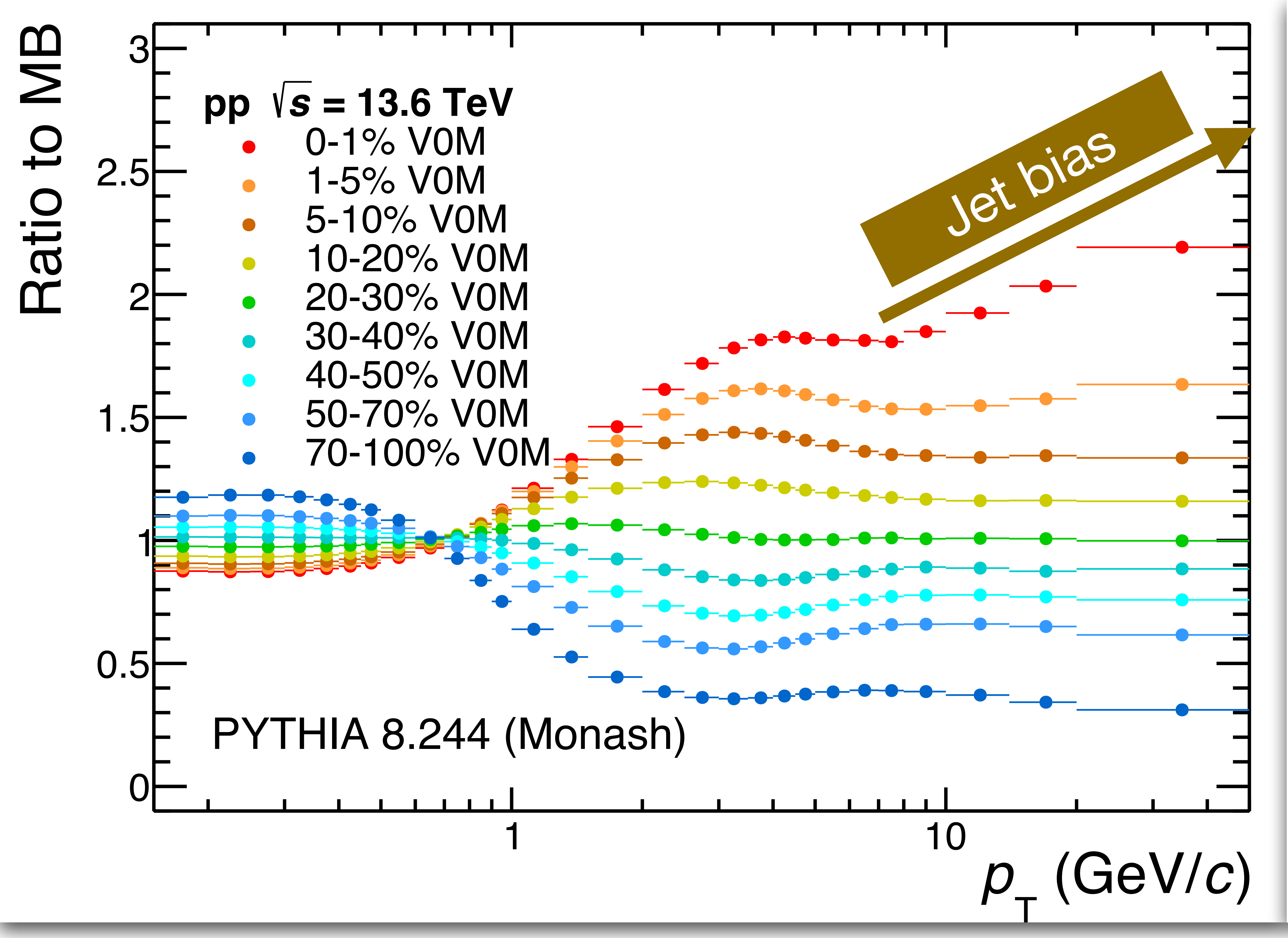

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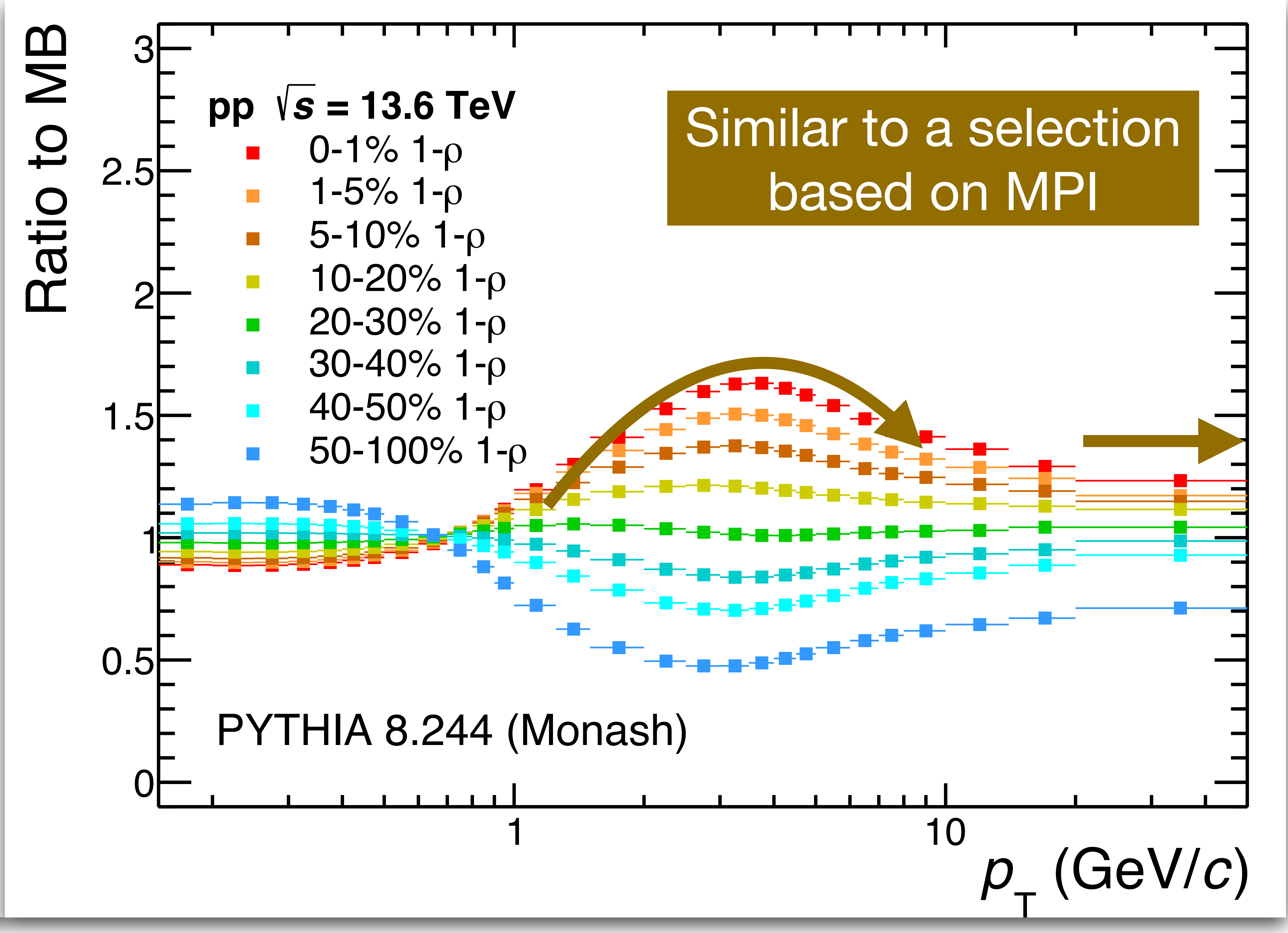

How are the different classifiers related to each other?

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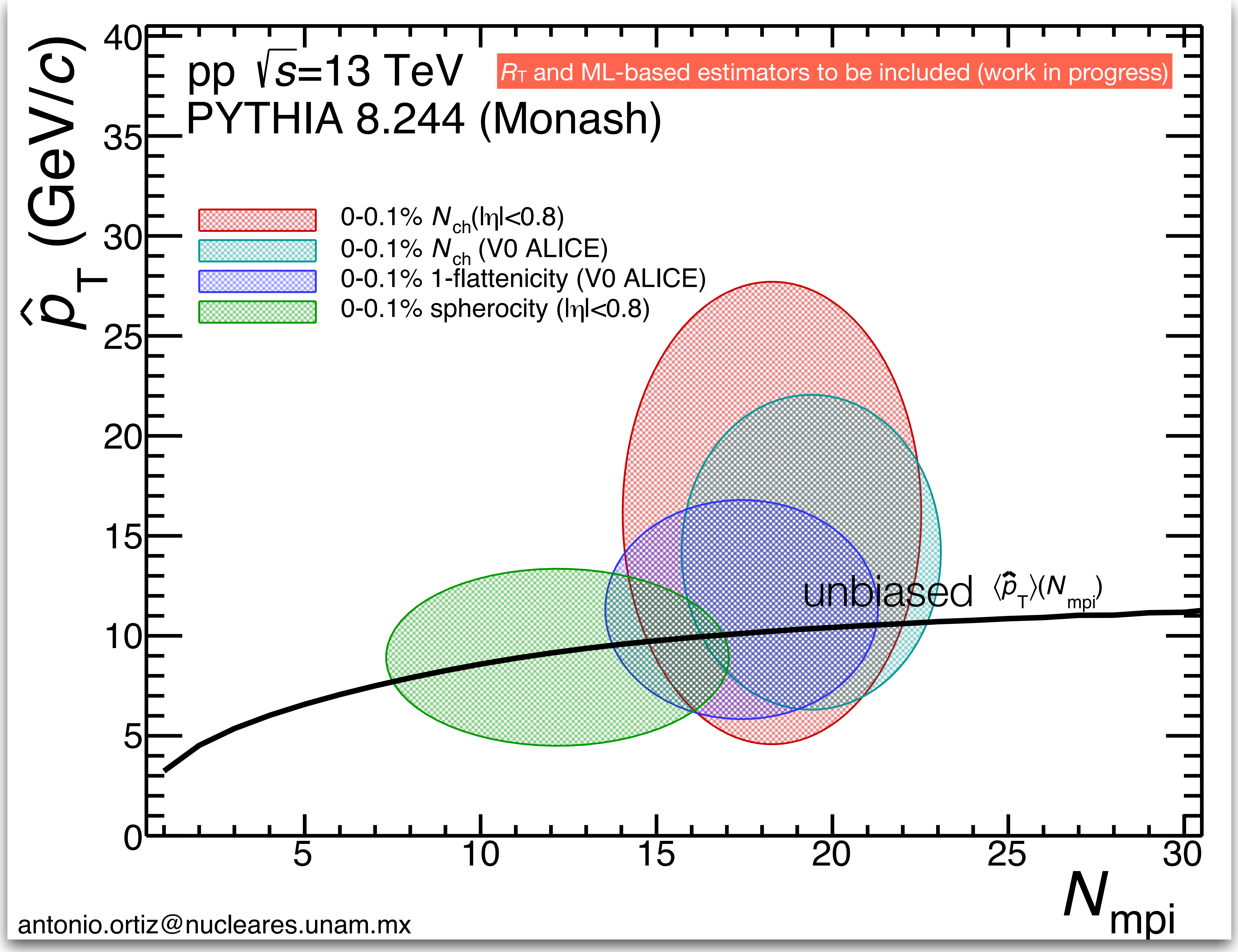

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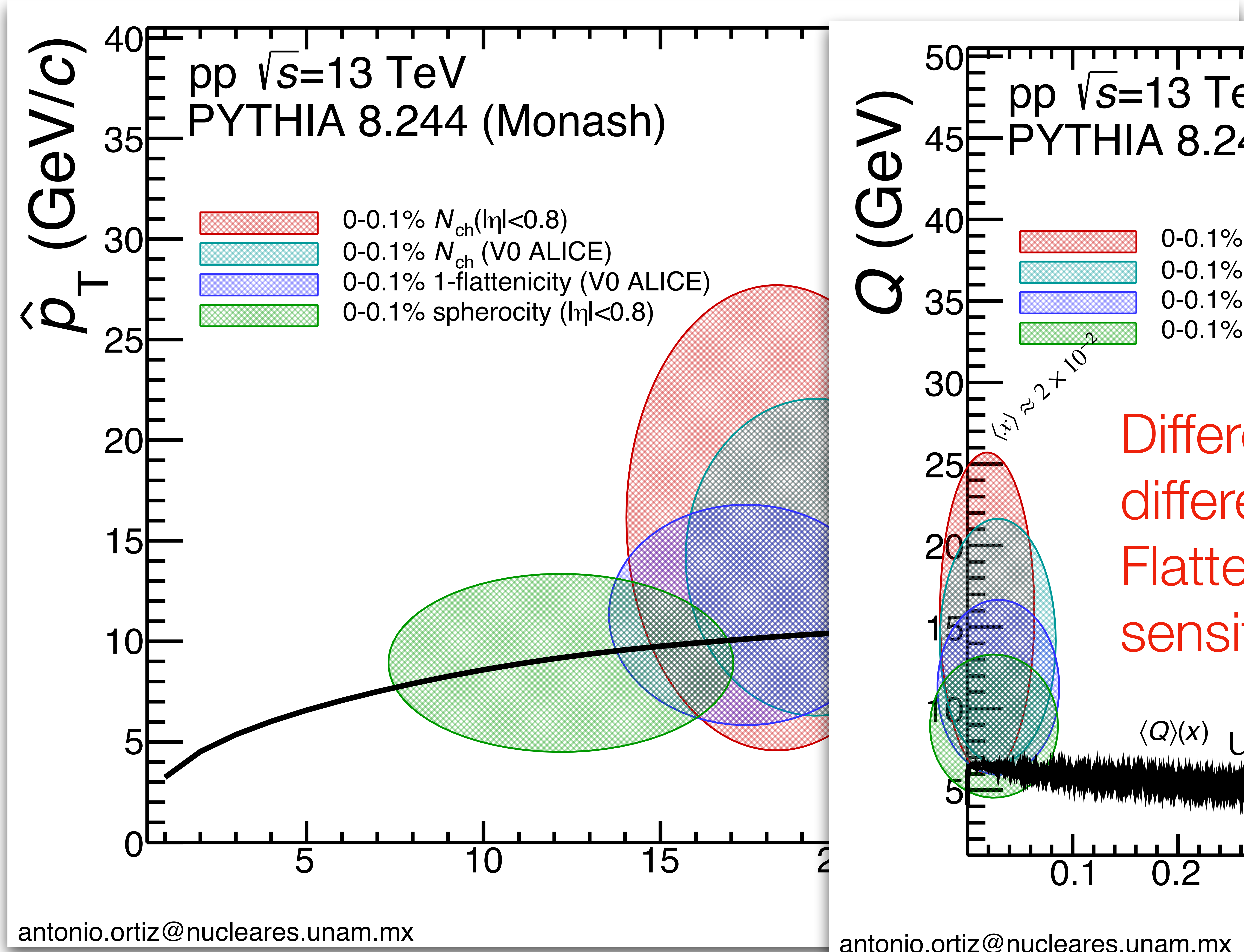
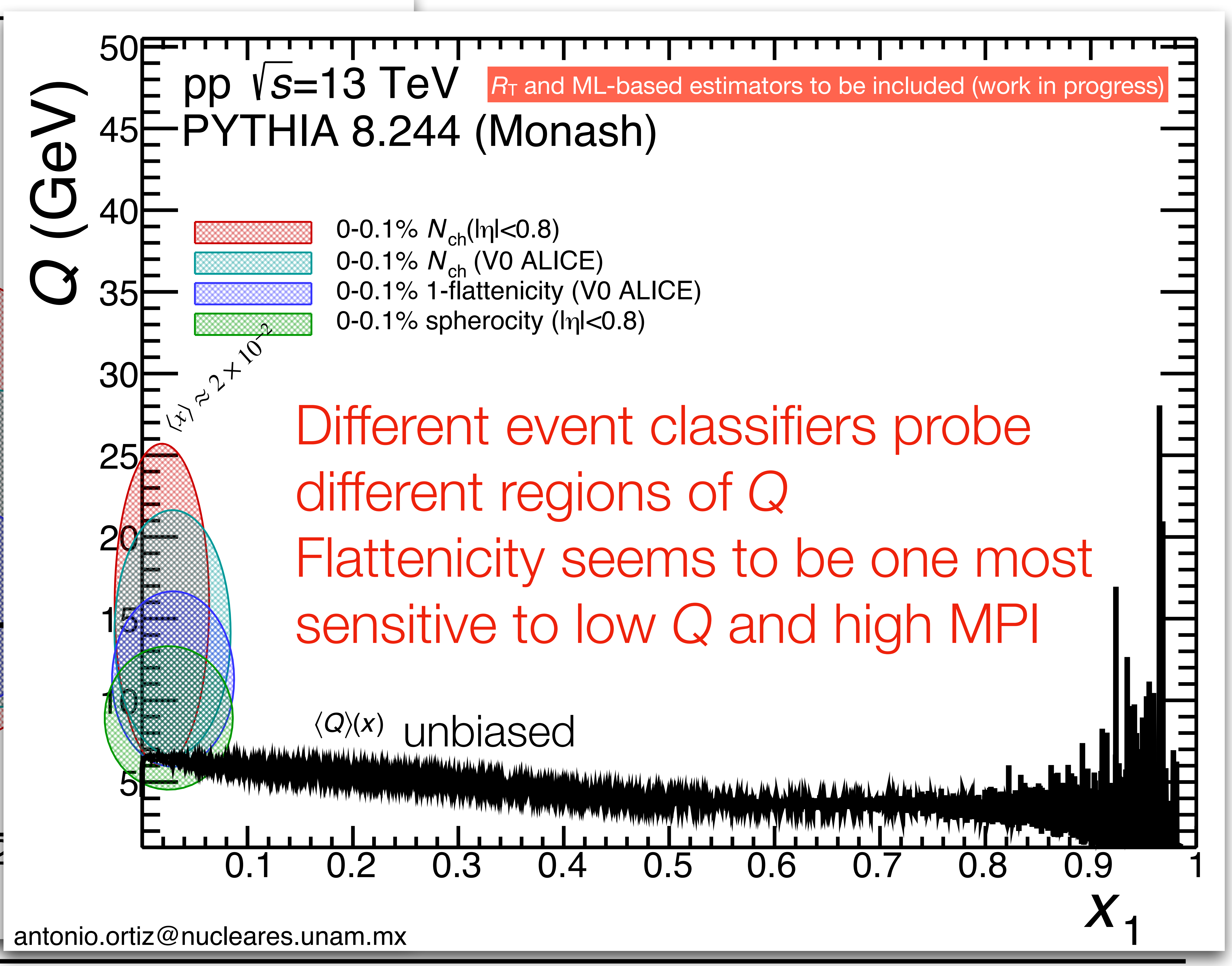




Different event classifiers probe different regions of Q

Flattenicity seems to be one most sensitive to low Q and high MPI

Take home message

- What type of pp collisions should we compare with heavy-ion collisions (HIC)?
  Events with large MPI activity but with "jet bias" well under control

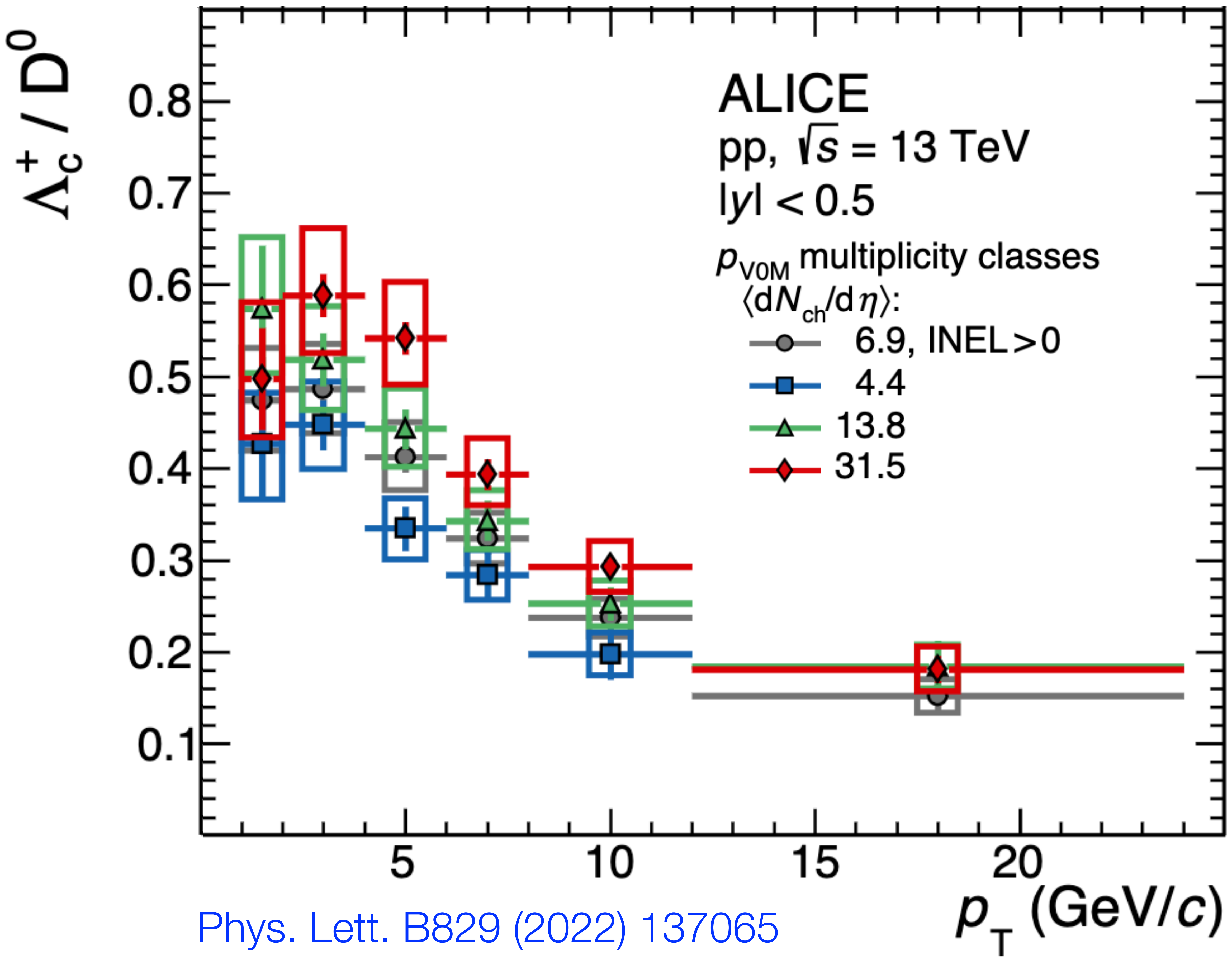
- How can we tag those pp collisions (event classifiers)
  Several options in the market, flattenicity seems like one of the most promising

- Do we understand the bias of the different classifiers explored so far? How are they correlated?
  MC studies like the one presented today need to be performed (see e.g. a study for R_T; G. Bencedi, A. Ortiz, A. Paz, PRD 104 (2021) 1, 016017)

- Are our data biased in the same way as MC?
  Probably not at the same level, but this need to be understood
  Multi-experiment effort would be important
  Common strategy (perhaps one outcome of this workshop?)

Backup

Particle ratios vs Nch



Phys. Lett. B829 (2022) 137065

Do we understand the bias of the different classifiers?

Example: strong sensitivity to MPI but bias towards hard pp collisions

Spherocity selector (efficiency)

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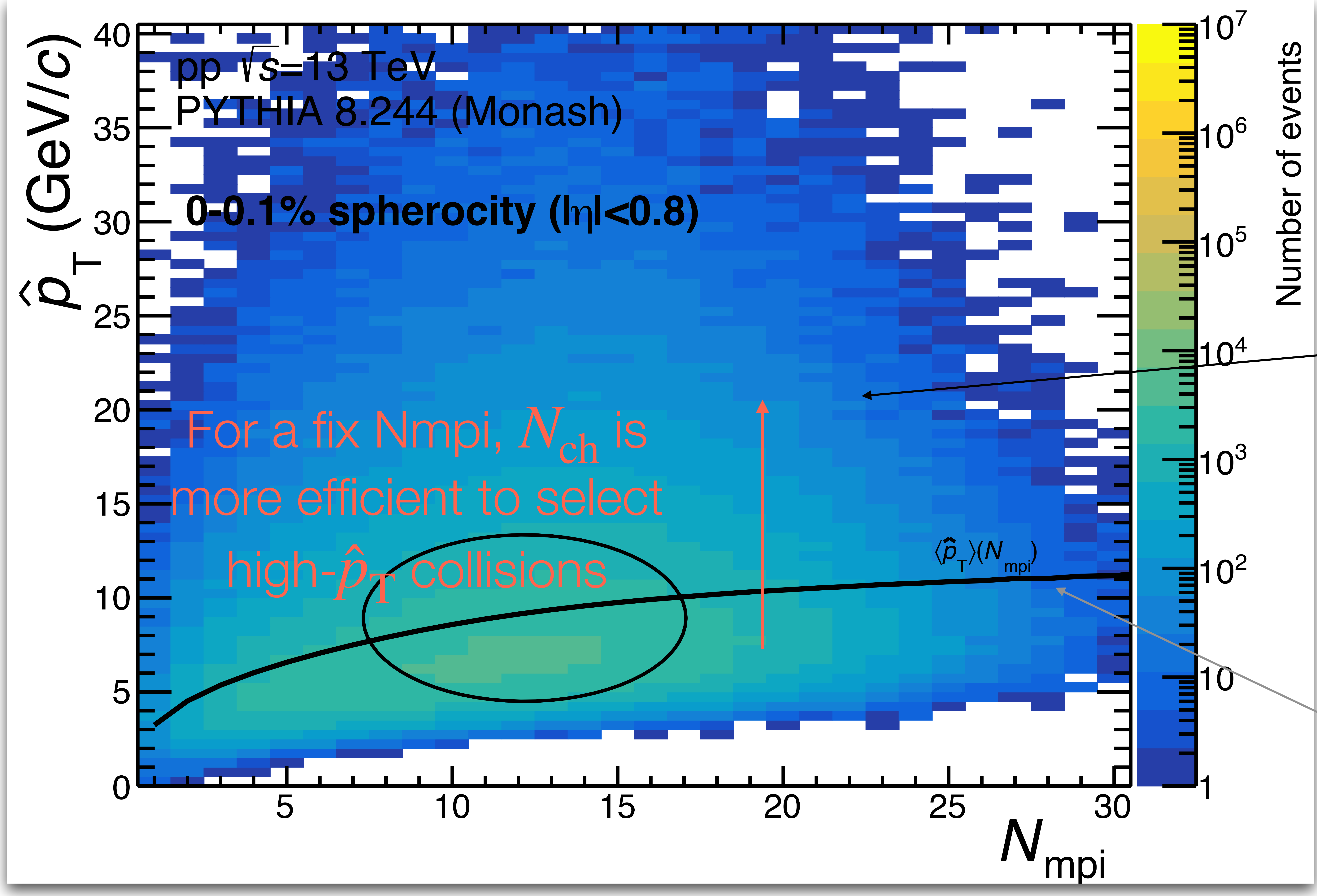

0-0.1% $N_{\rm ch}$:
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Existing "R_{pp}" results as a function of N_{ch}

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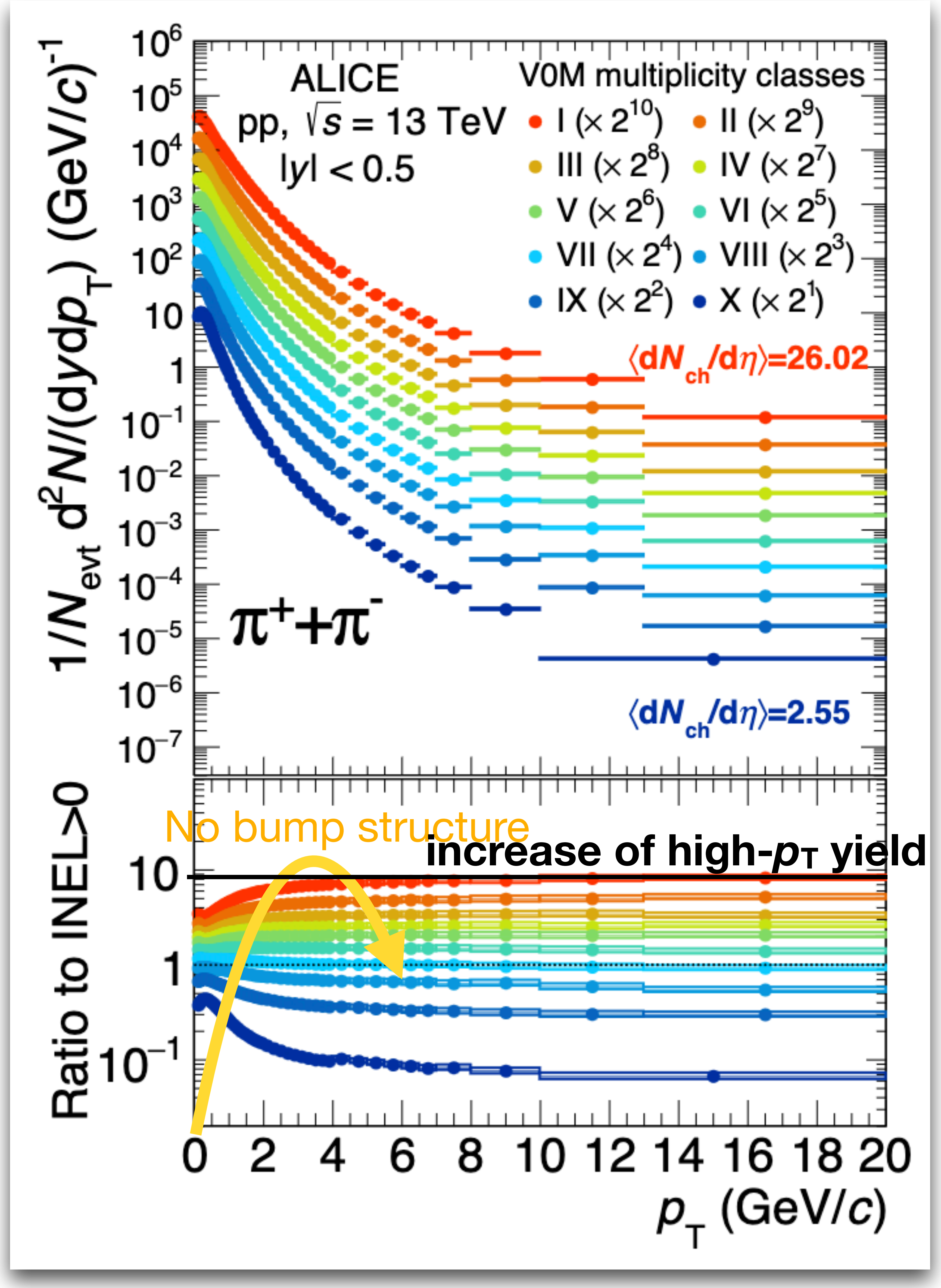
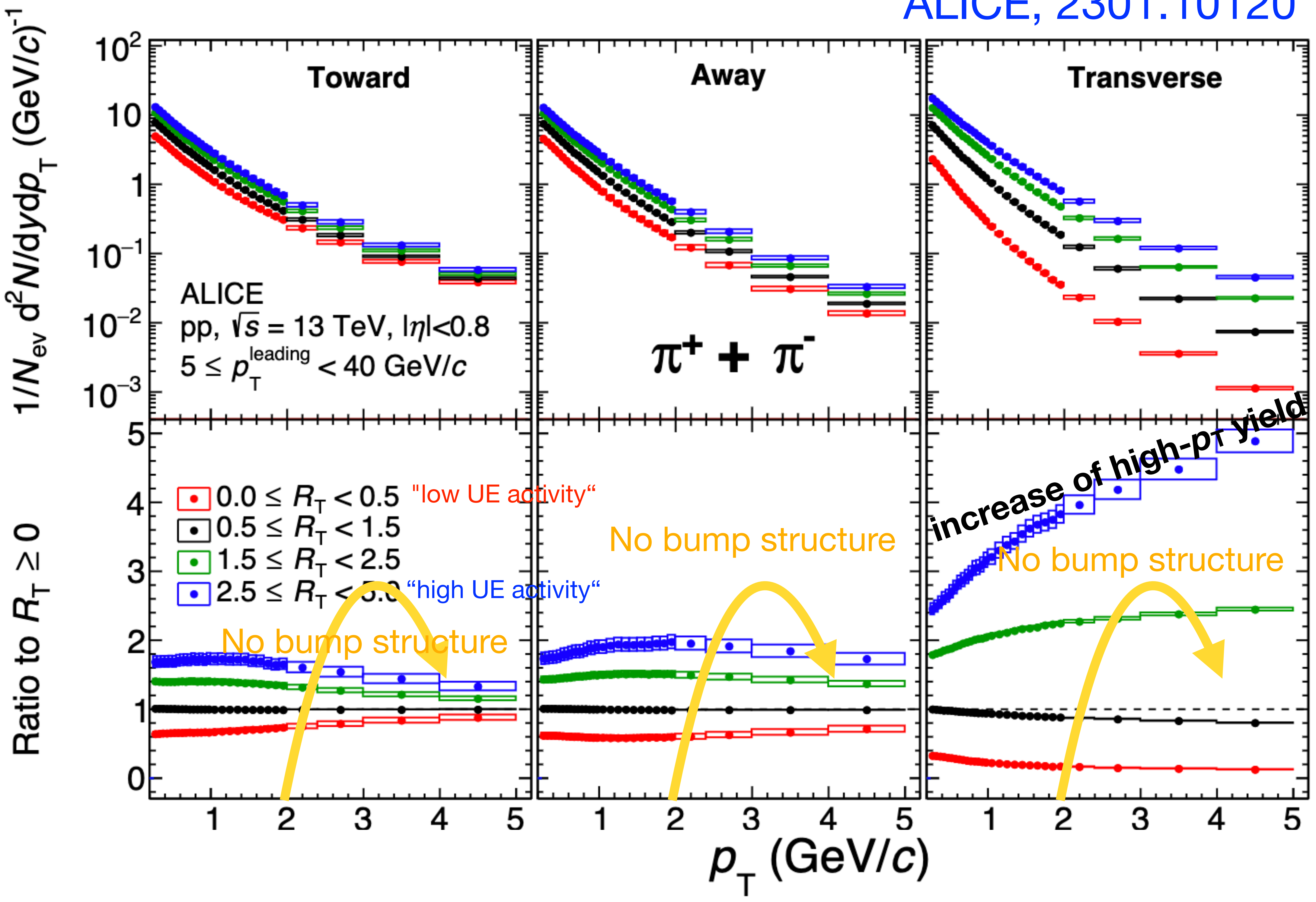


ALICE, EPJC 80 (2020) 693

ALICE, 2301.10120



How can we increase the sensitivity to MPI?

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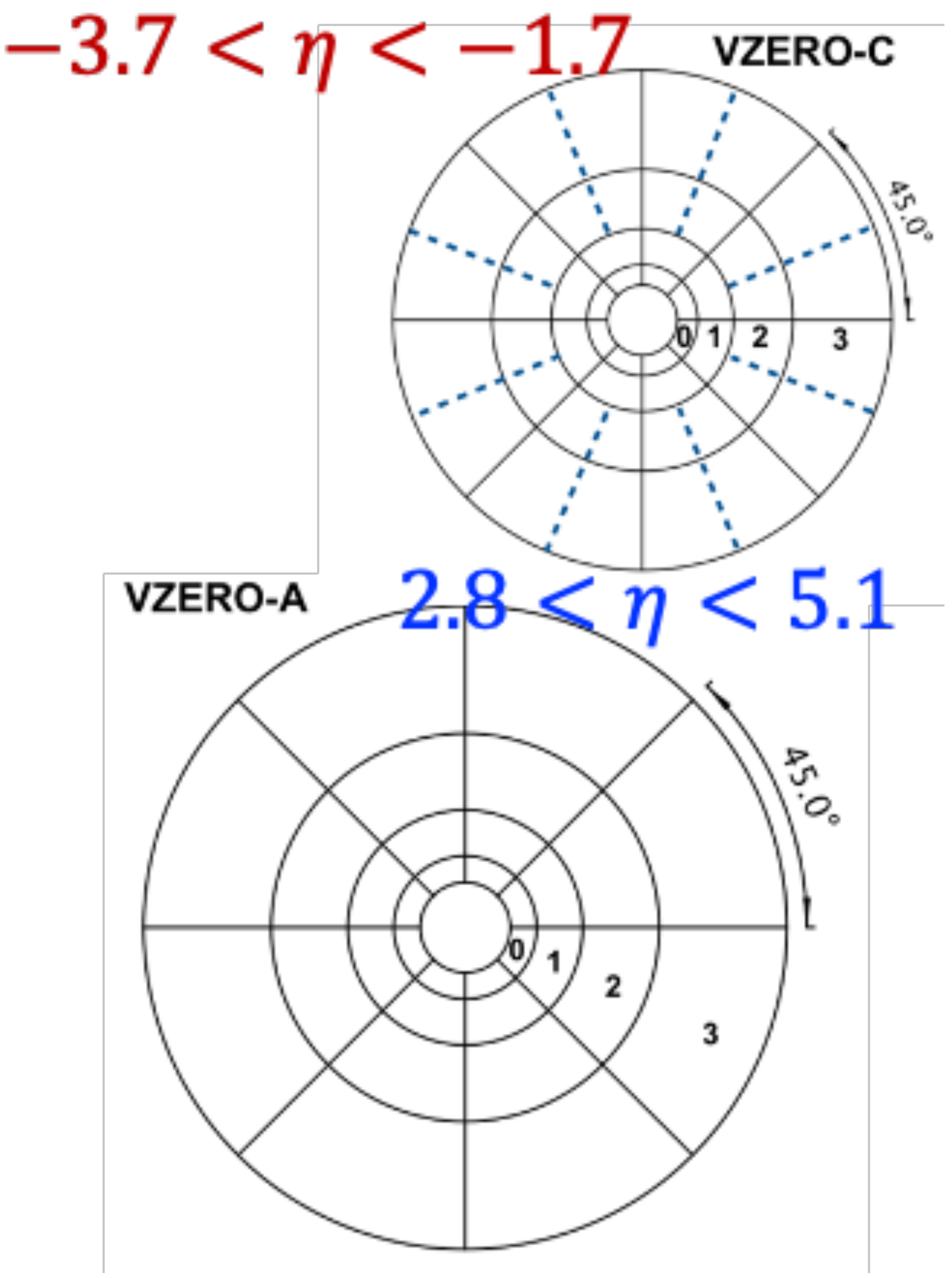
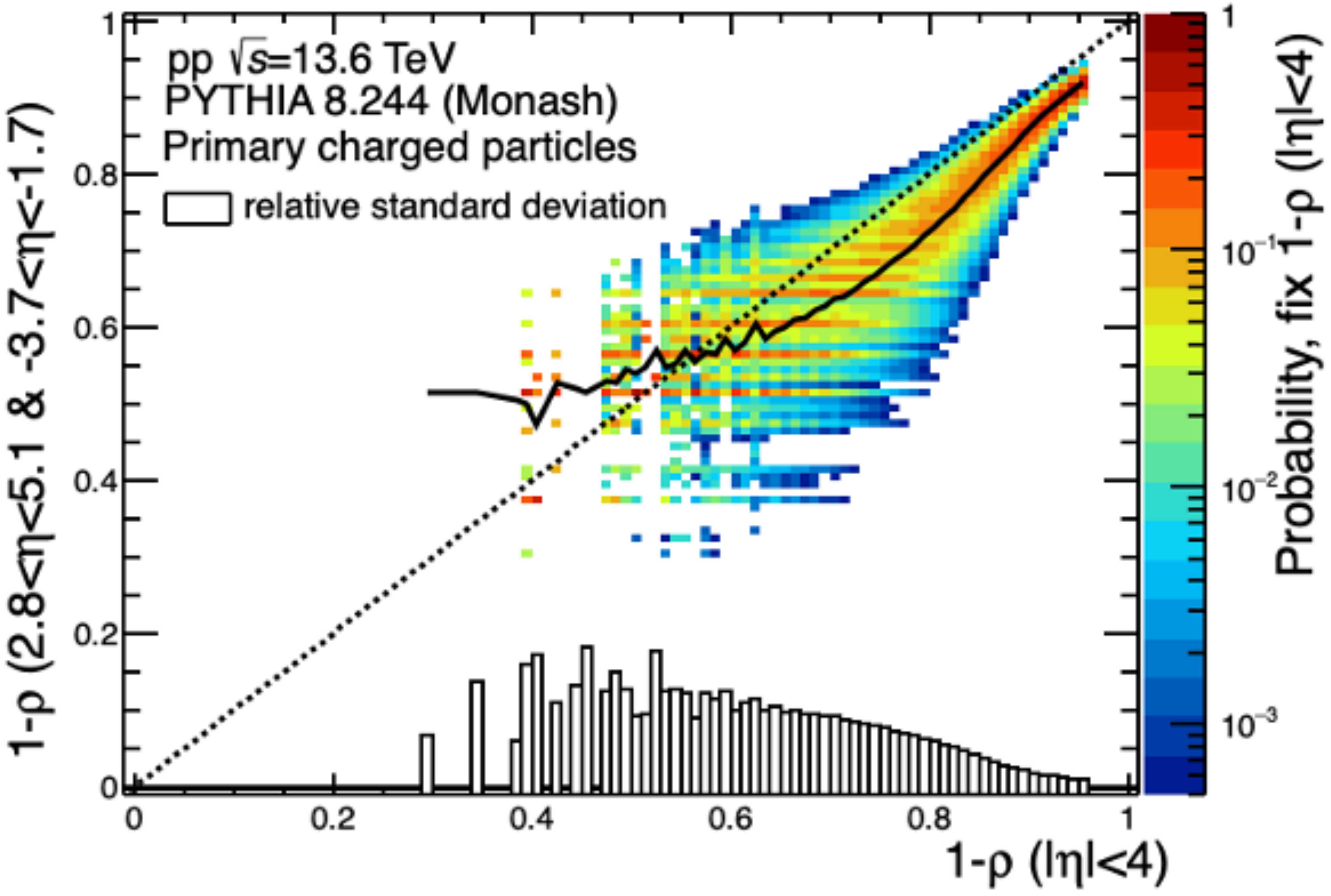


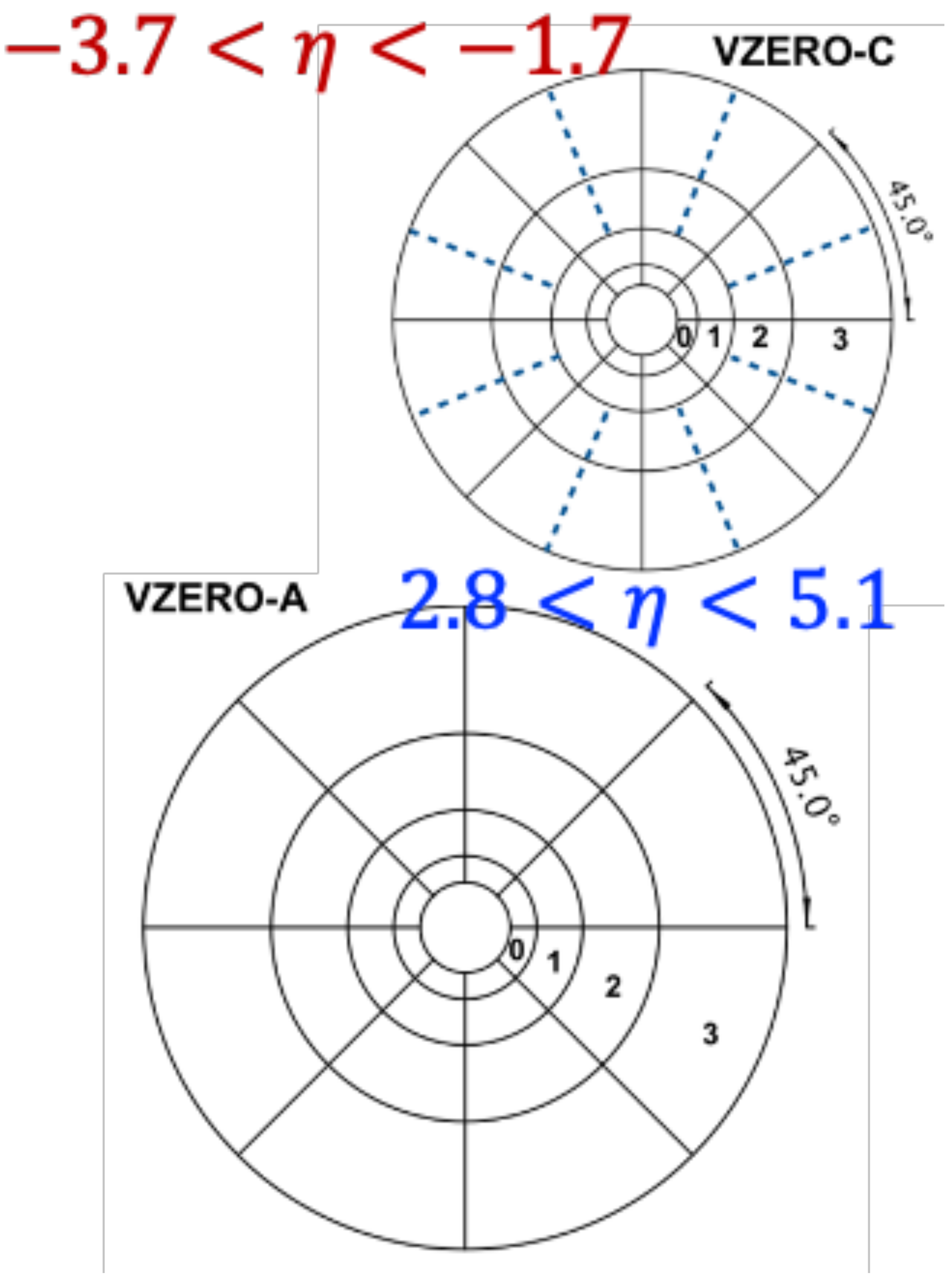
- Flattenicity definition:

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

- Based on MC simulations, flattenicity in the pseudorapidity interval covered by ALICE V0A and V0C detectors is strongly correlated with the global shape of the event



Flattenicity



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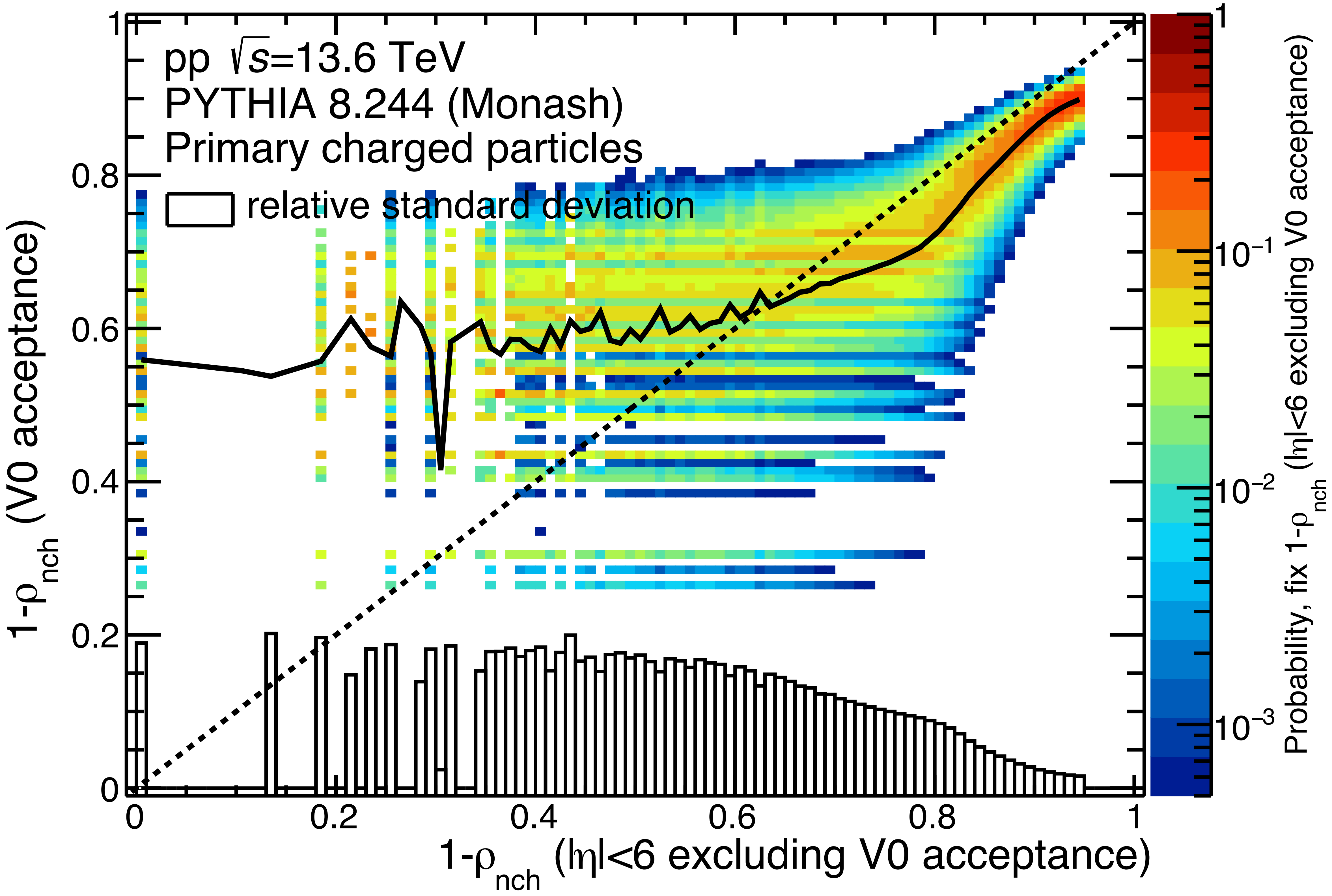

Andreas' request: check the correlation excluding the V0 acceptance

Sensitivity of flattenicity to MPI

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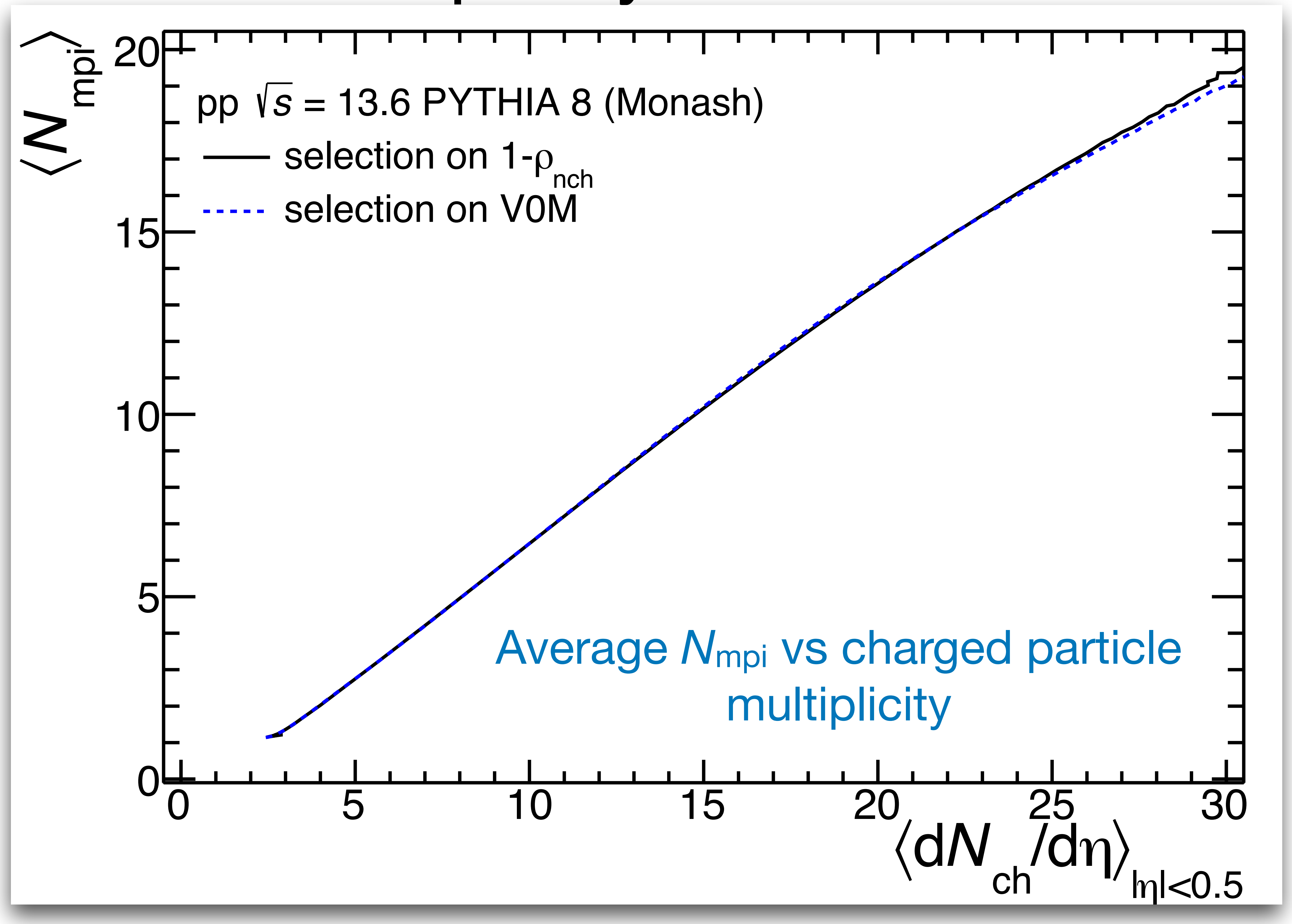
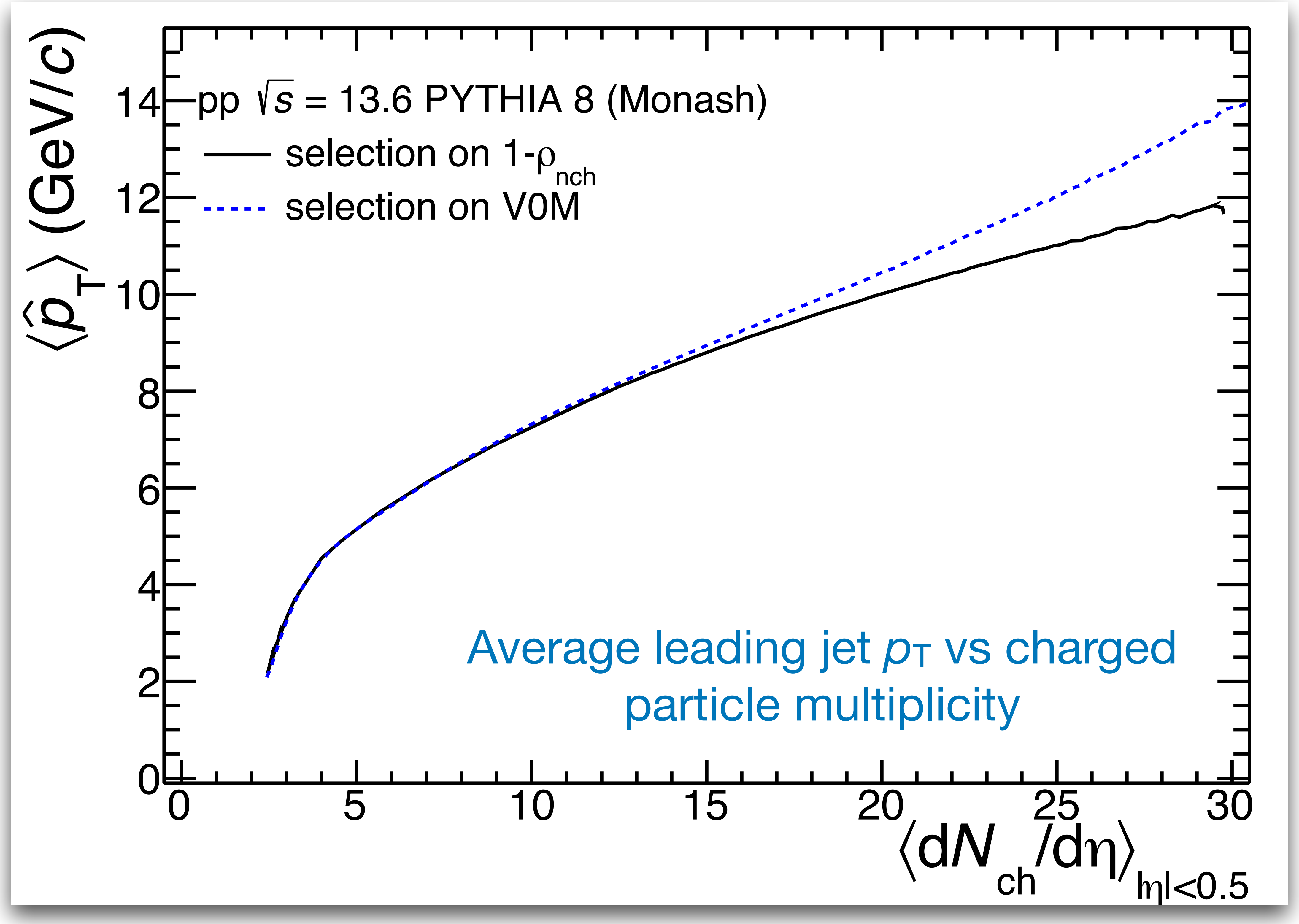
- Same sensitivity to MPI as the V0M multiplicity estimator

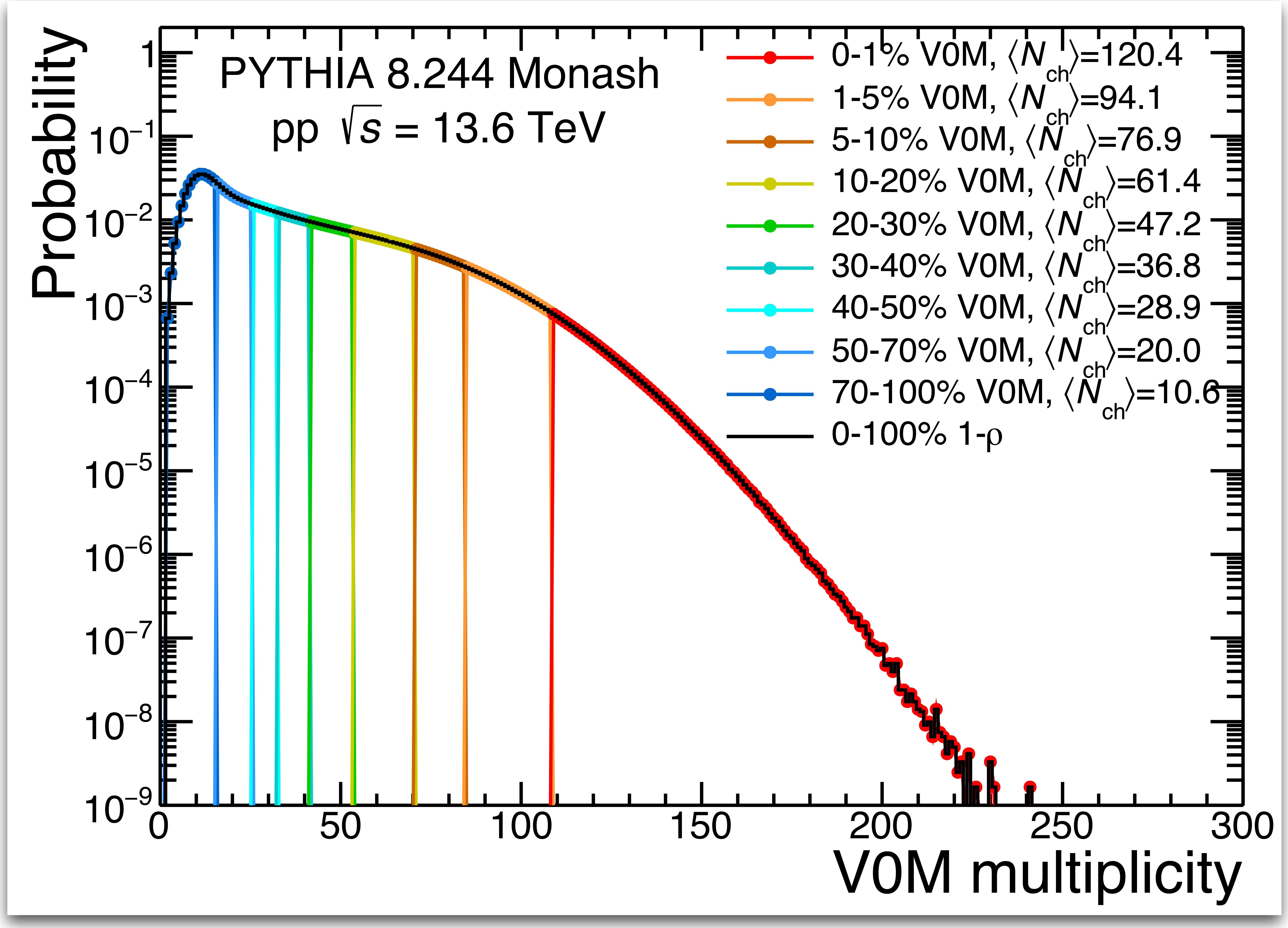


- Flattenicity selects "softer" pp collisions than the V0M estimator



See A. Ortiz, A. Khuntia, O. Vázquez, S. Tripathy, G. Bencédi, S. Prasad and F. Fan, "Unveiling the effects of multiple soft partonic interactions in pp collisions at 13.6 TeV using a new event classifier" to appear in Phys. Rev. D [2211.06093]

V0M event classes



V0M event classes

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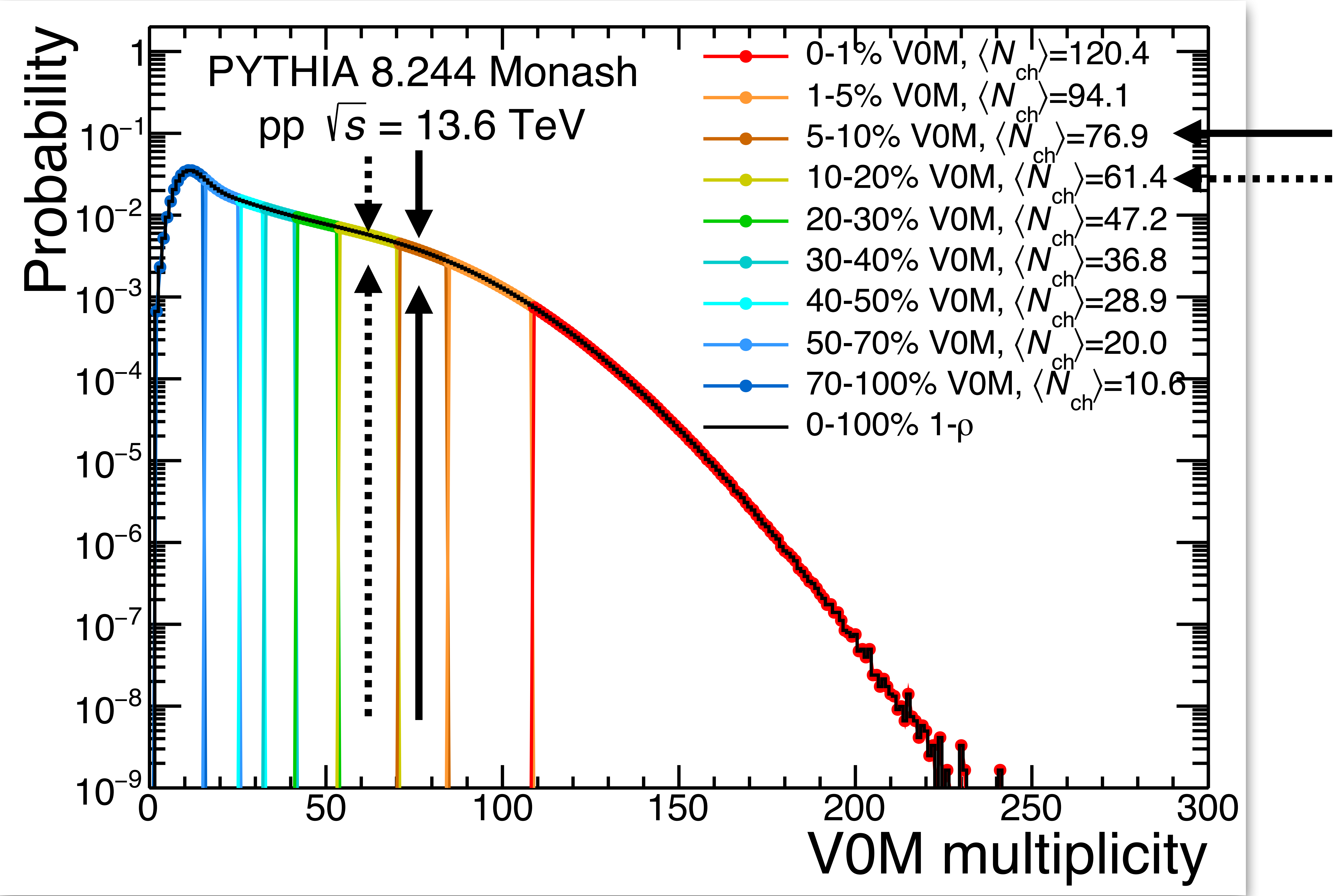
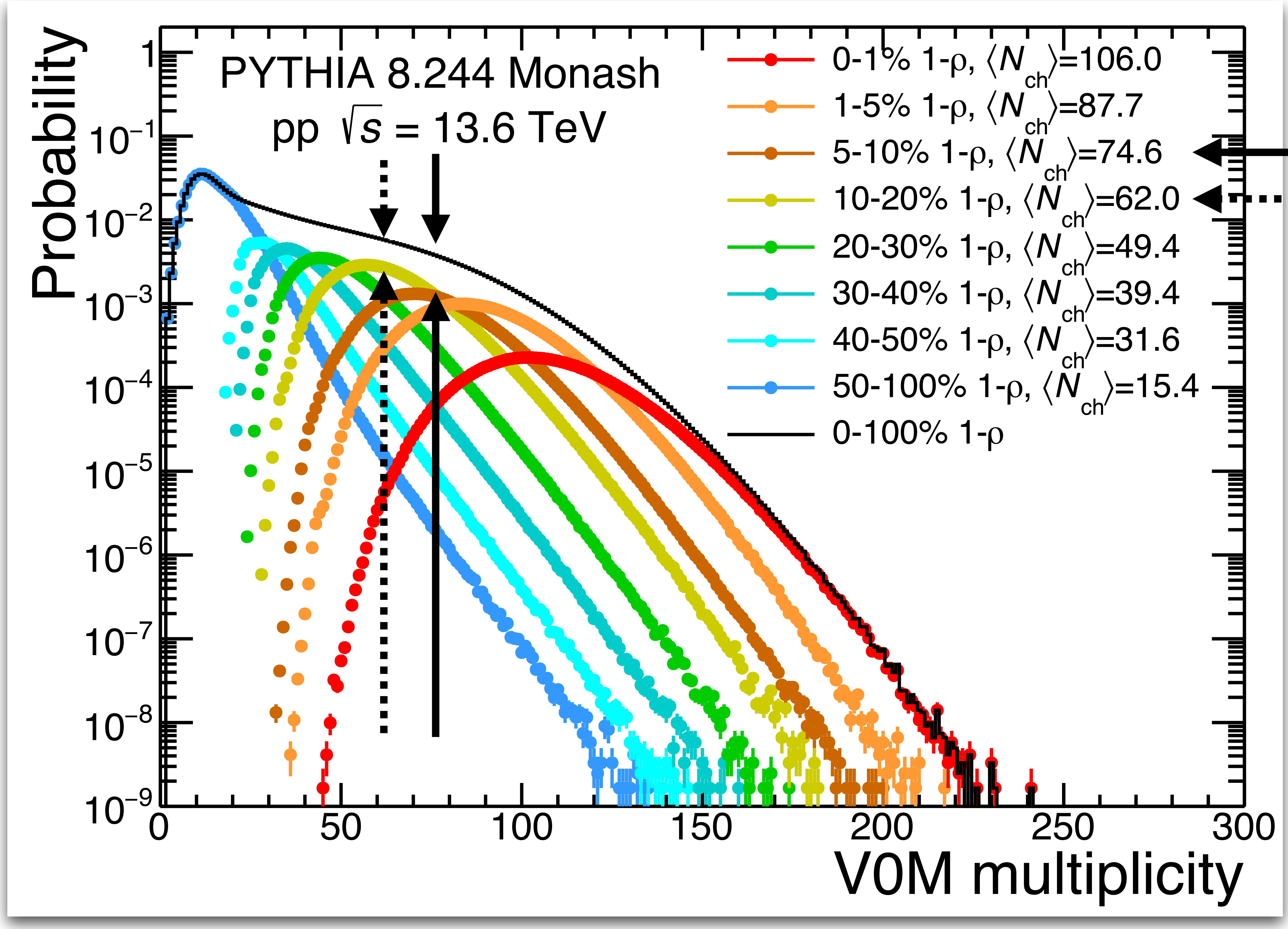


Flattenicity event classes

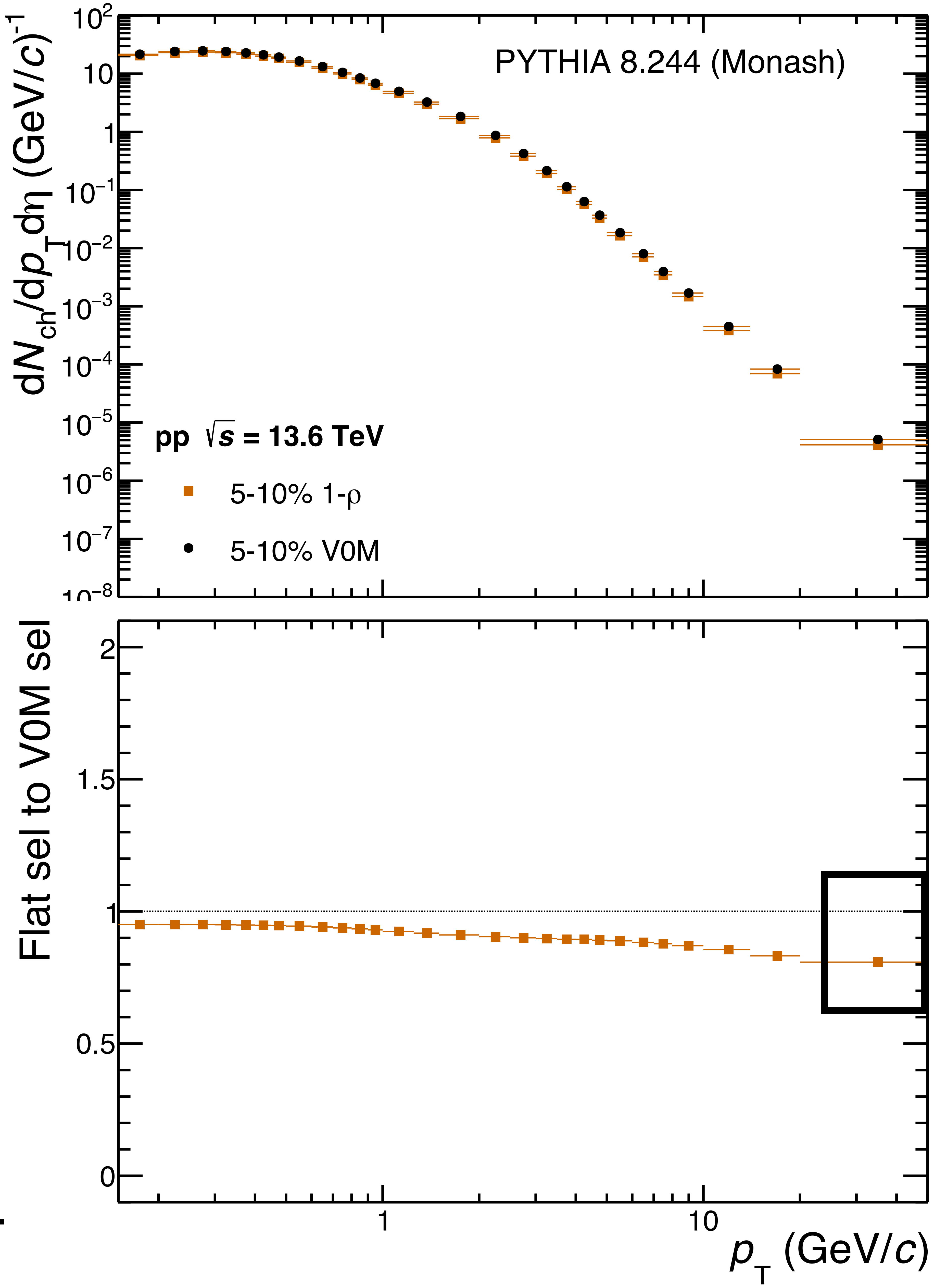


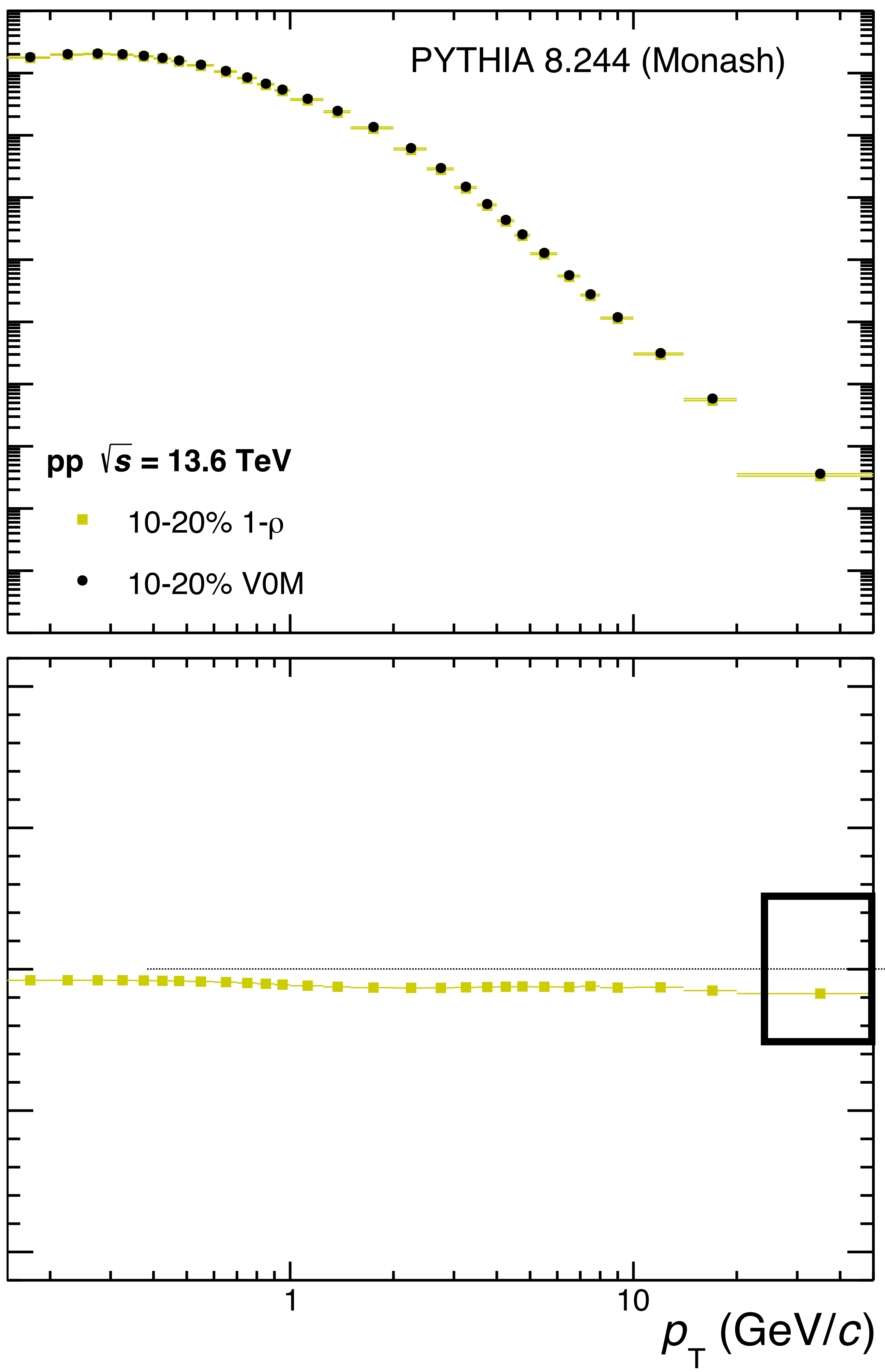
Diference wrt V0M: ~3%

Diference wrt V0M: ~1%

Event classes with similar <Nch>

Diference in V0M mult: ~3%
Difference at high p_T: >15%





Diference in V0M mult: ~1%
Difference at high p_T: >5%

High-p_T yield

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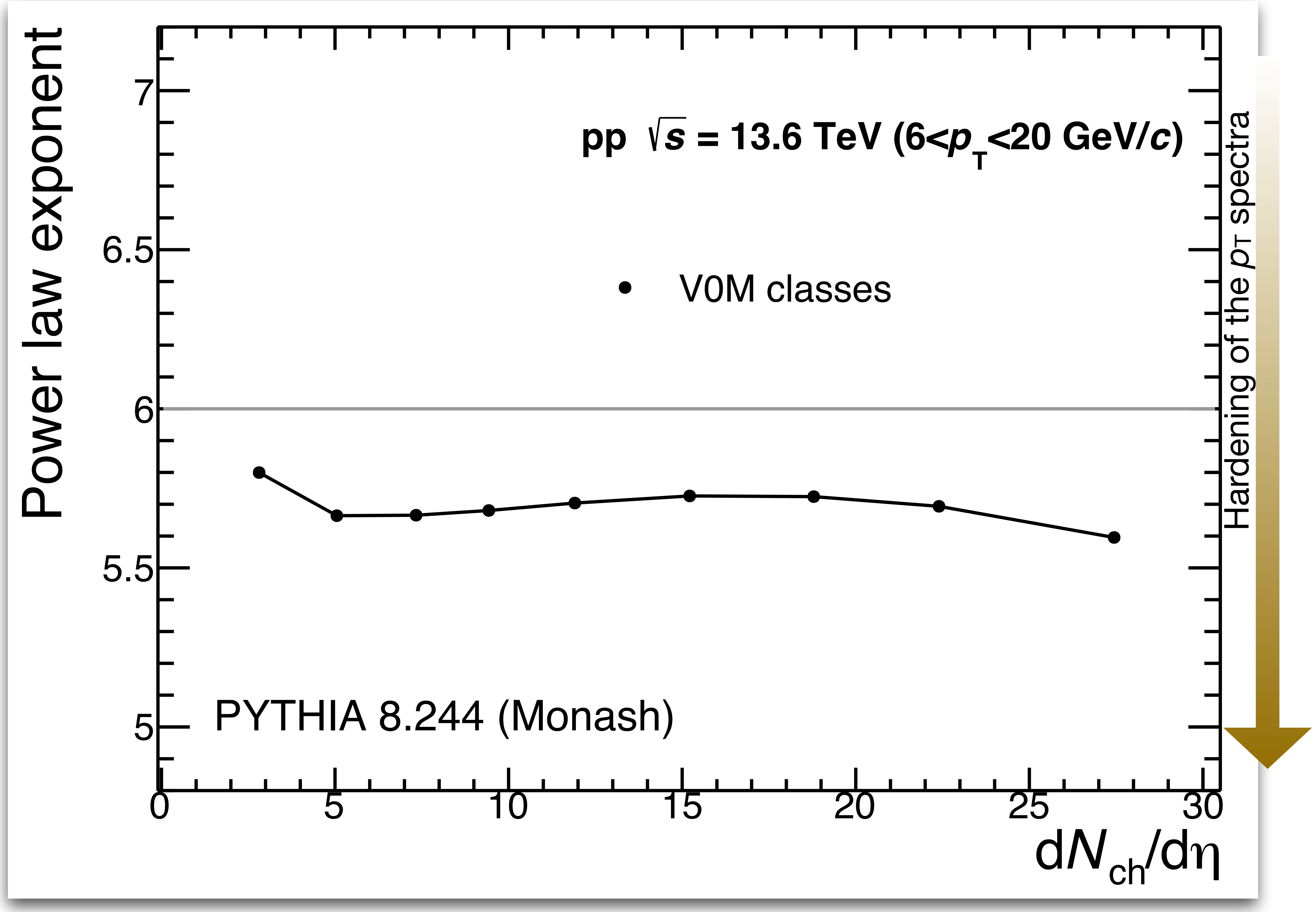
Selection based on V0M



High-p_T yield

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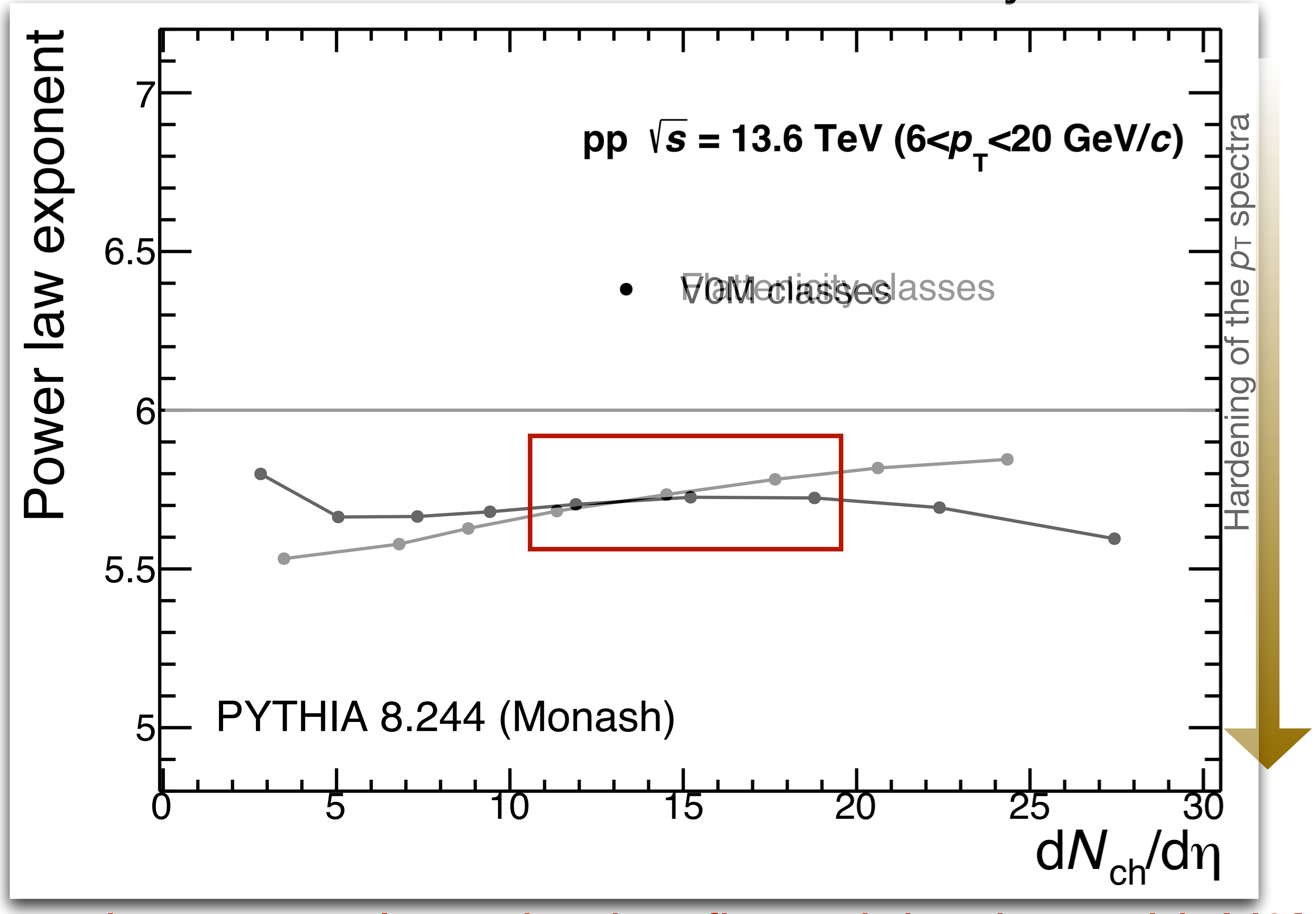
Selection based on flattenicity



Softer interactions are selected using flattenicity than with V0M multiplicity

Double differential analysis

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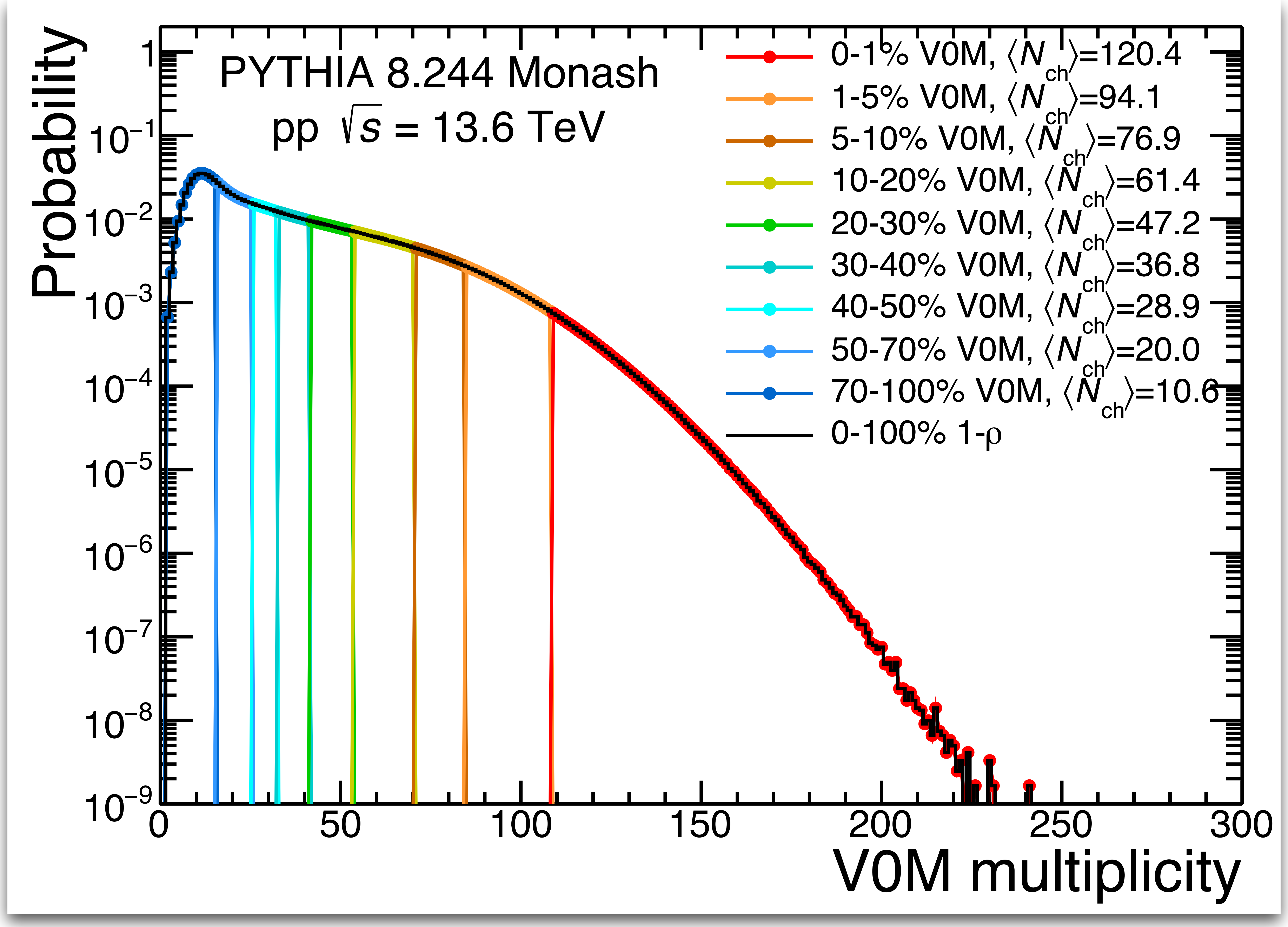
Selection based on V0M



Double differential analysis

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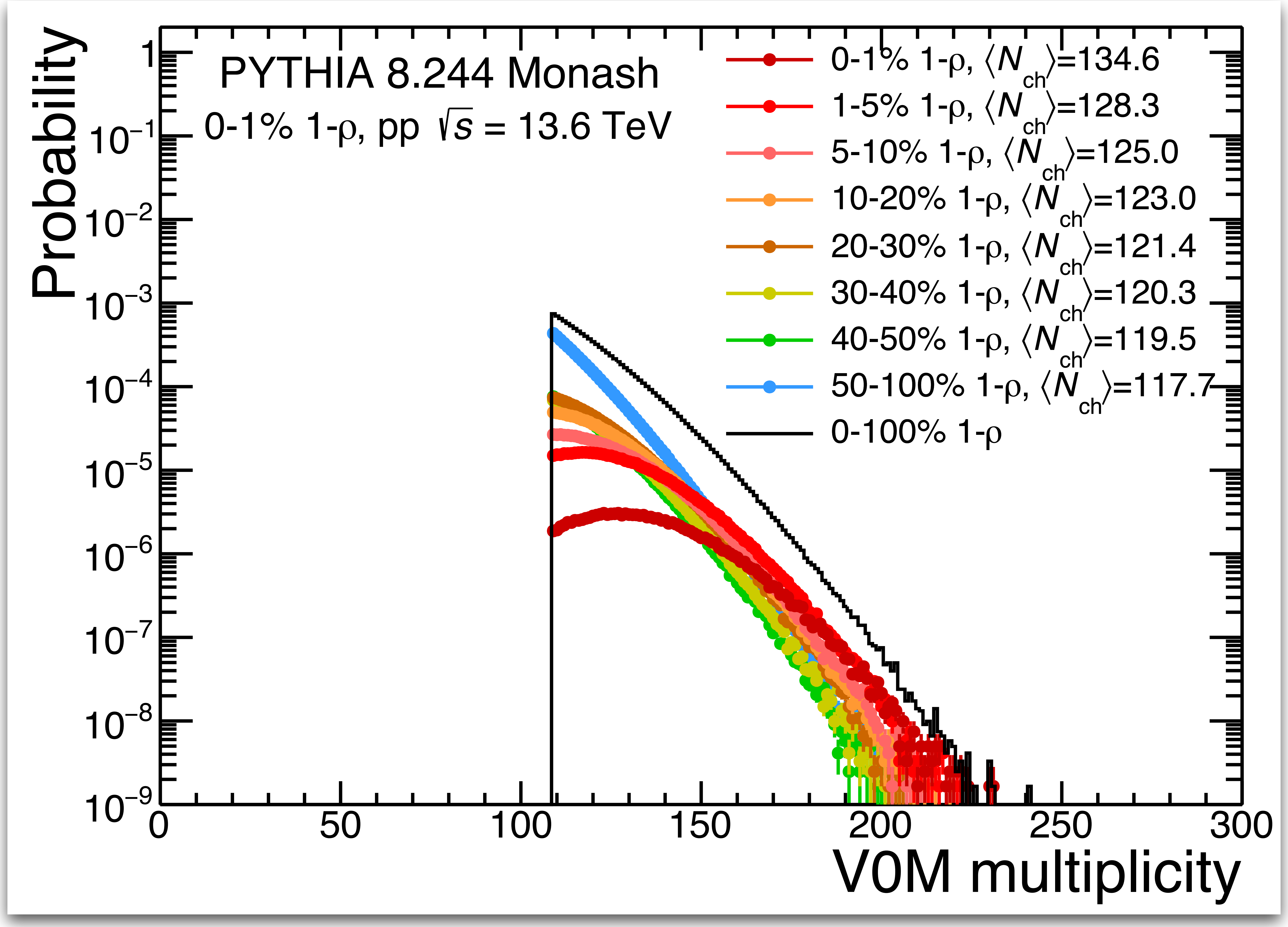
Selection based on V0M + flattenicity (example 0-1% V0M)

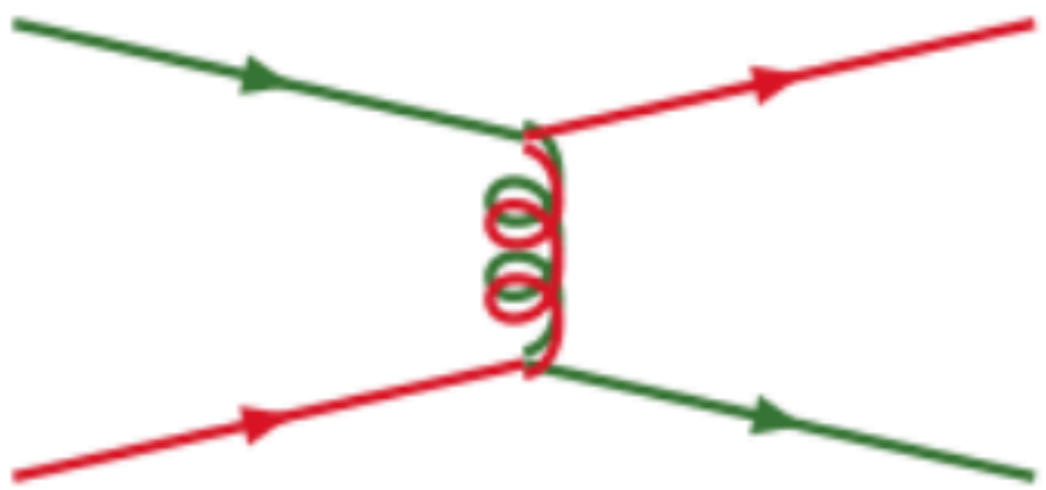


High flattenicity events (0-1% 1-ρ) do not correspond to the highest multiplicity class. Instead, flattenicity exhibit a modest multiplicity dependence

Multiparton interactions MPI

At high energies, the leading order cross-section for $2 \rightarrow 2$ parton scatterings with momentum transfer $Q > Q_{\rm min} \gg \Lambda_{\rm QCD}$ exceeds the total pp cross-section at a range of $Q_{\rm min}$-values where perturbative QCD is applicable (at LHC, $Q_{\rm min} \approx 4$ GeV/*c*) [T. Sjöstrand and M. Zijil Phys. Rev. D36 (1987)]

T. Sjöstrand, 6th MPI @ LHC Workshop



Integrate QCD $2 \rightarrow 2$

$\mathrm{qq}' \rightarrow \mathrm{qq}'$

$\mathrm{q\bar{q}} \rightarrow \mathrm{q}'\mathrm{\bar{q}}'$

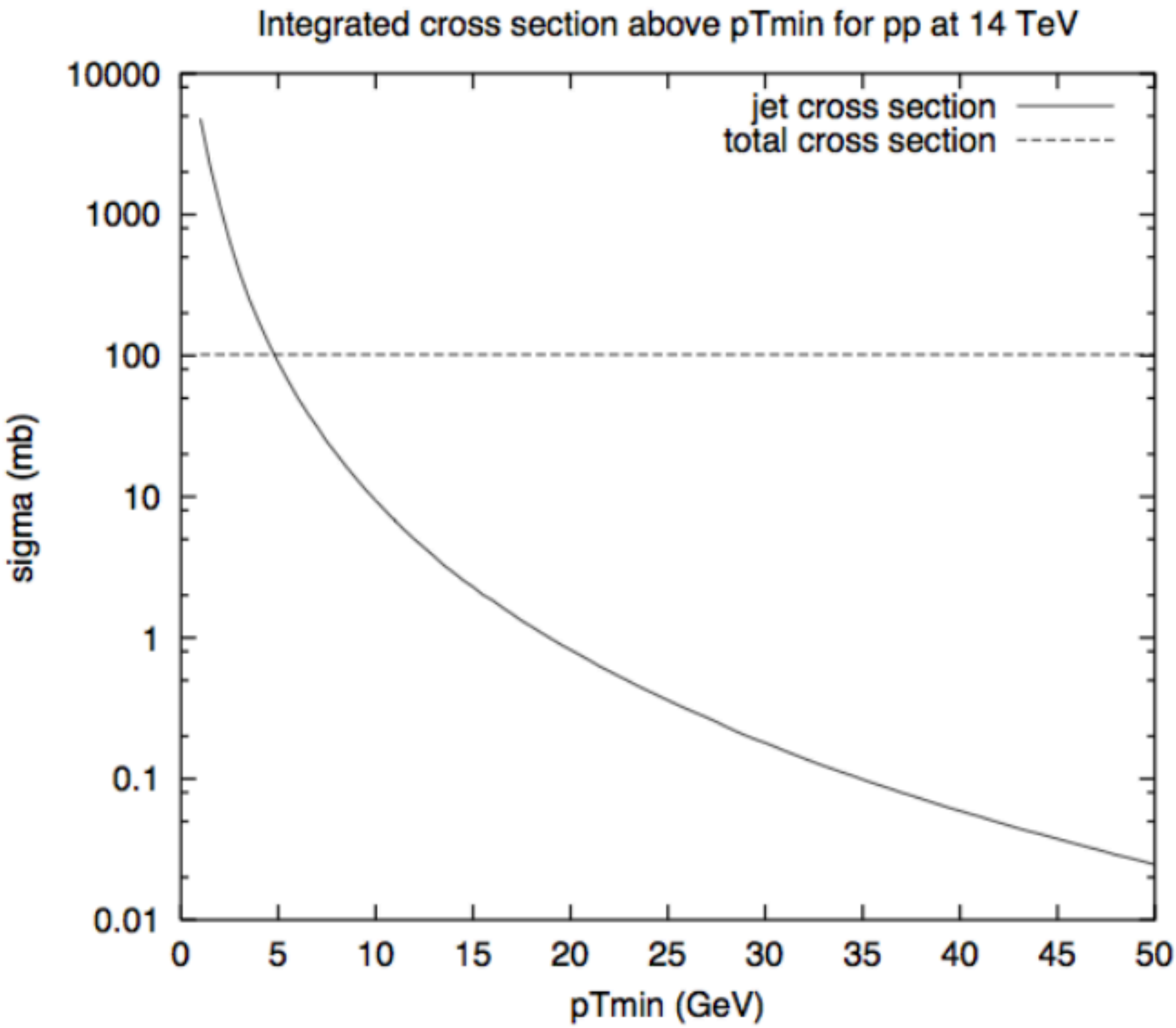
$\mathrm{q\bar{q}} \rightarrow \mathrm{gg}$

$\mathrm{qg} \rightarrow \mathrm{qg}$

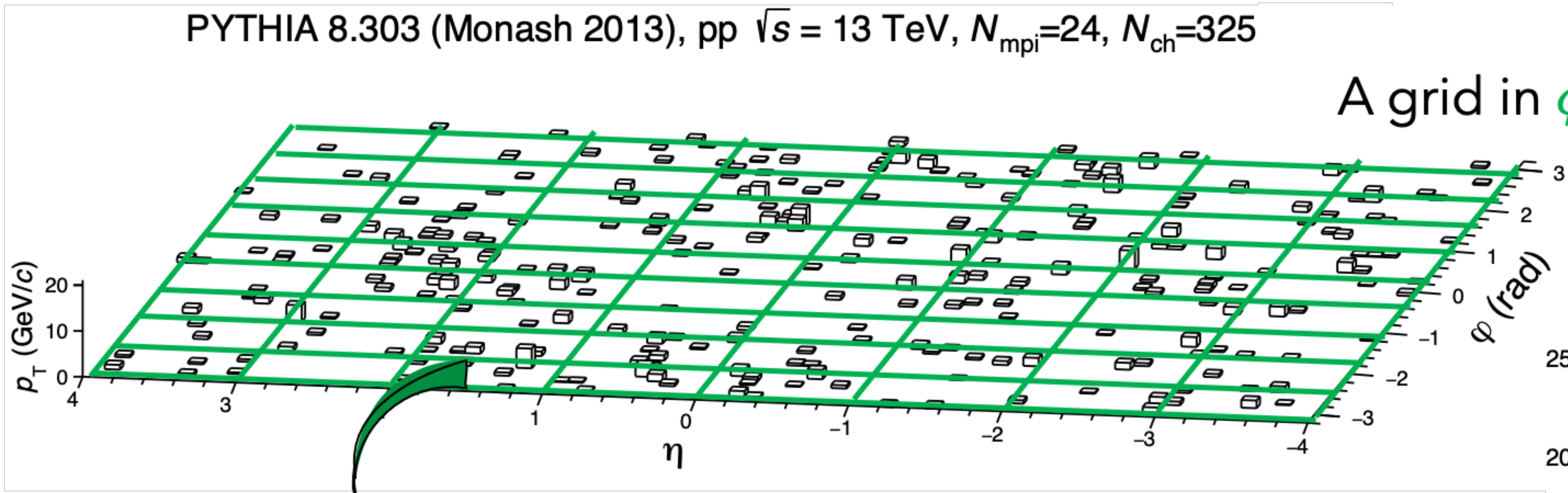
$\mathrm{gg} \rightarrow \mathrm{gg}$

$\mathrm{gg} \rightarrow \mathrm{q\bar{q}}$

(with CTEQ 5L PDF's)

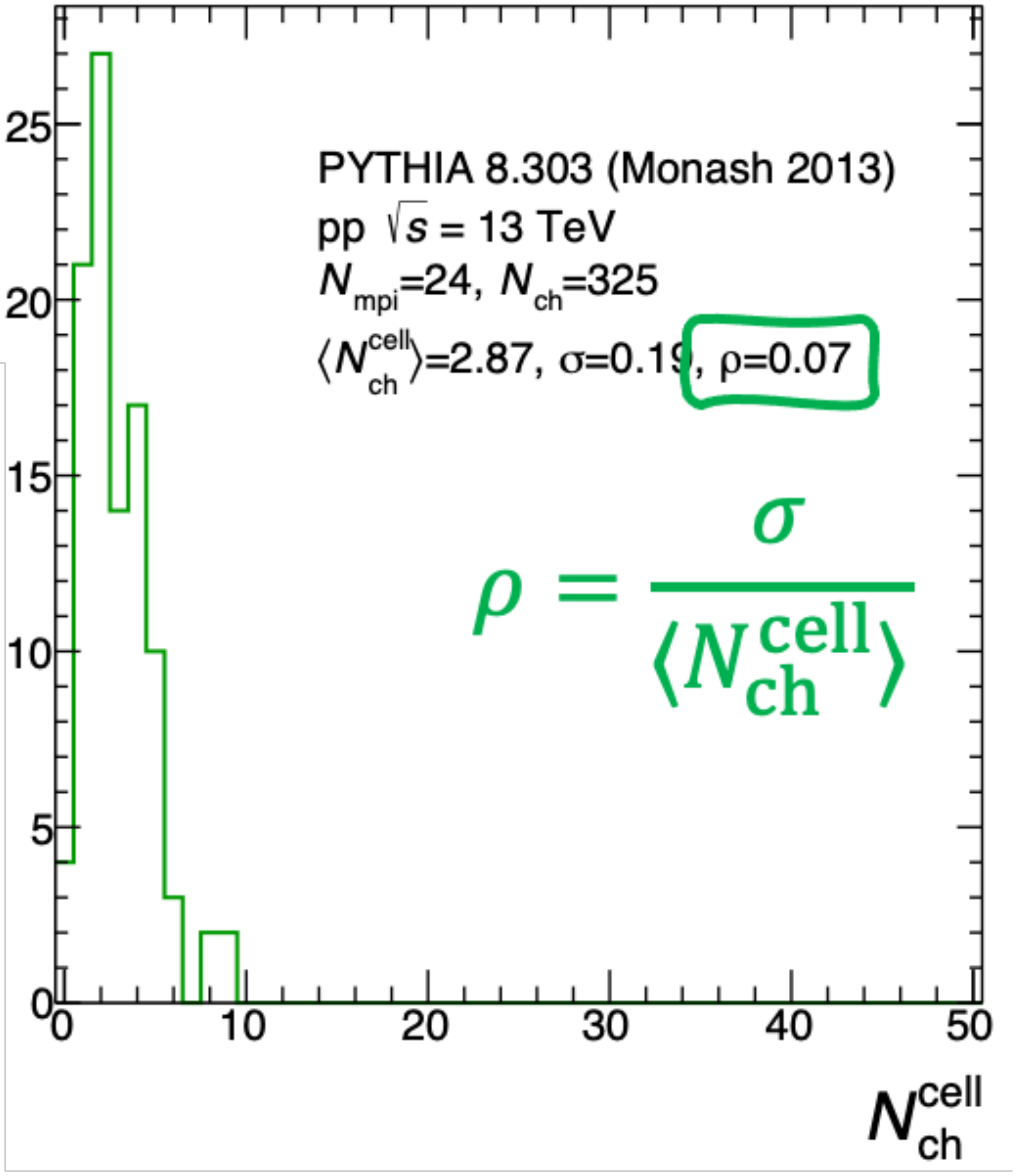


Flattenicity



A grid in $\varphi - \eta$ is built: 10×8

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



$$\rho = \frac{\sigma}{\langle N_{\mathrm{ch}}^{\mathrm{cell}} \rangle}$$

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

Events with several minijets (very active MPI) are expected to have small ρ values

MPI

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At high ene
order cross
$2 \rightarrow 2$ part
with momer
$Q > Q_{\min}$
the total pp
range of Q_{r}
perturbative
applicable (
GeV/*c*) [T. S
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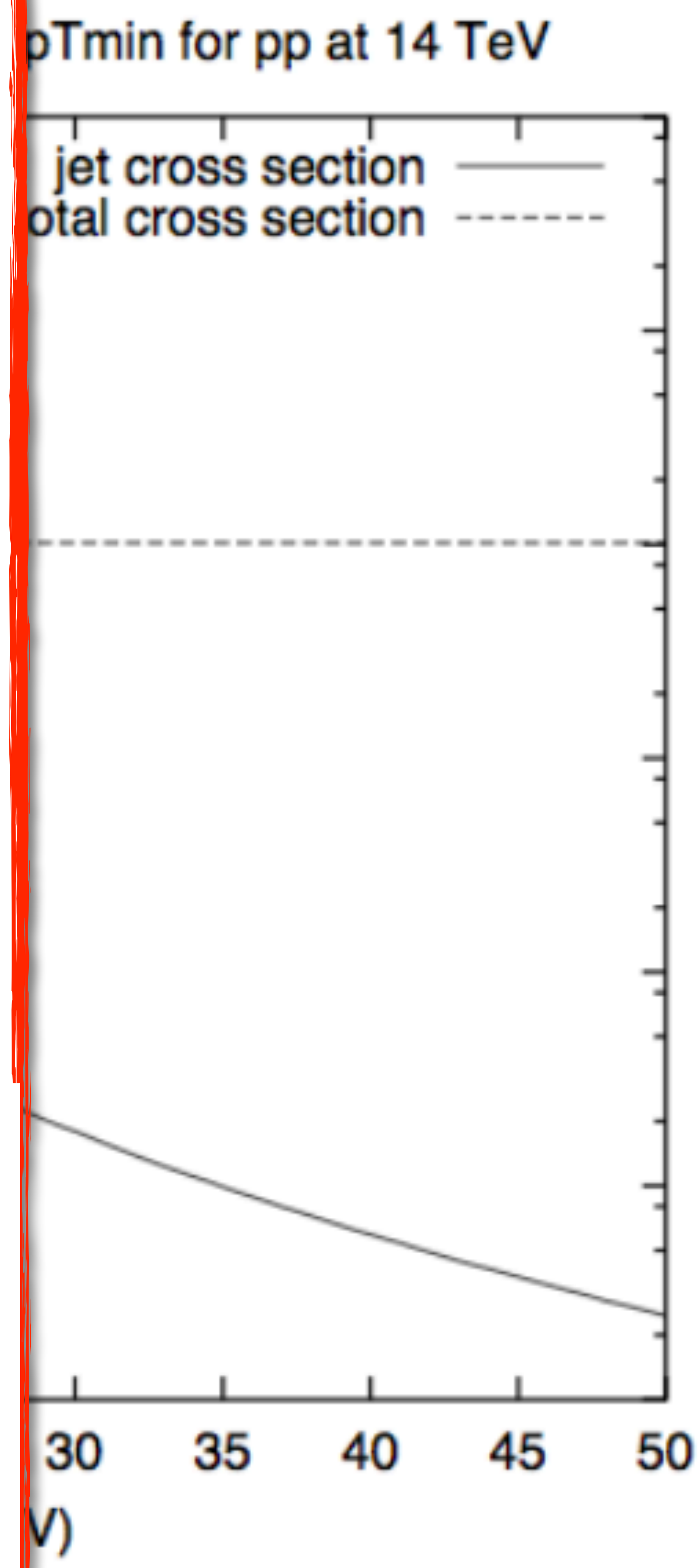
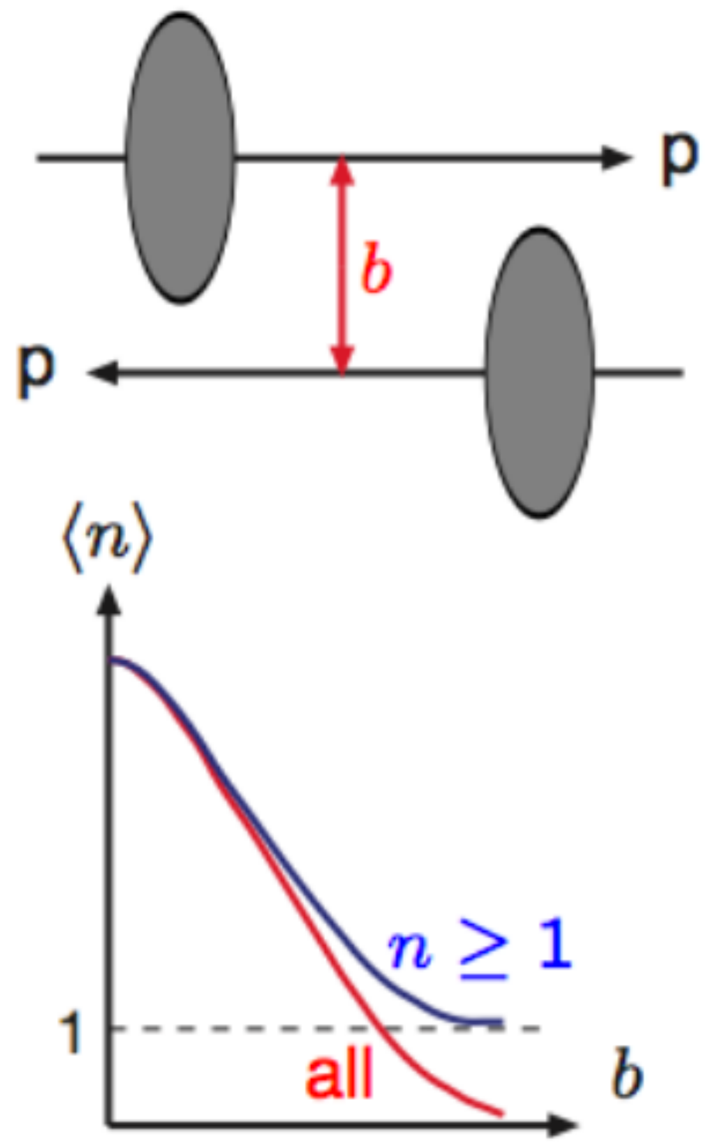
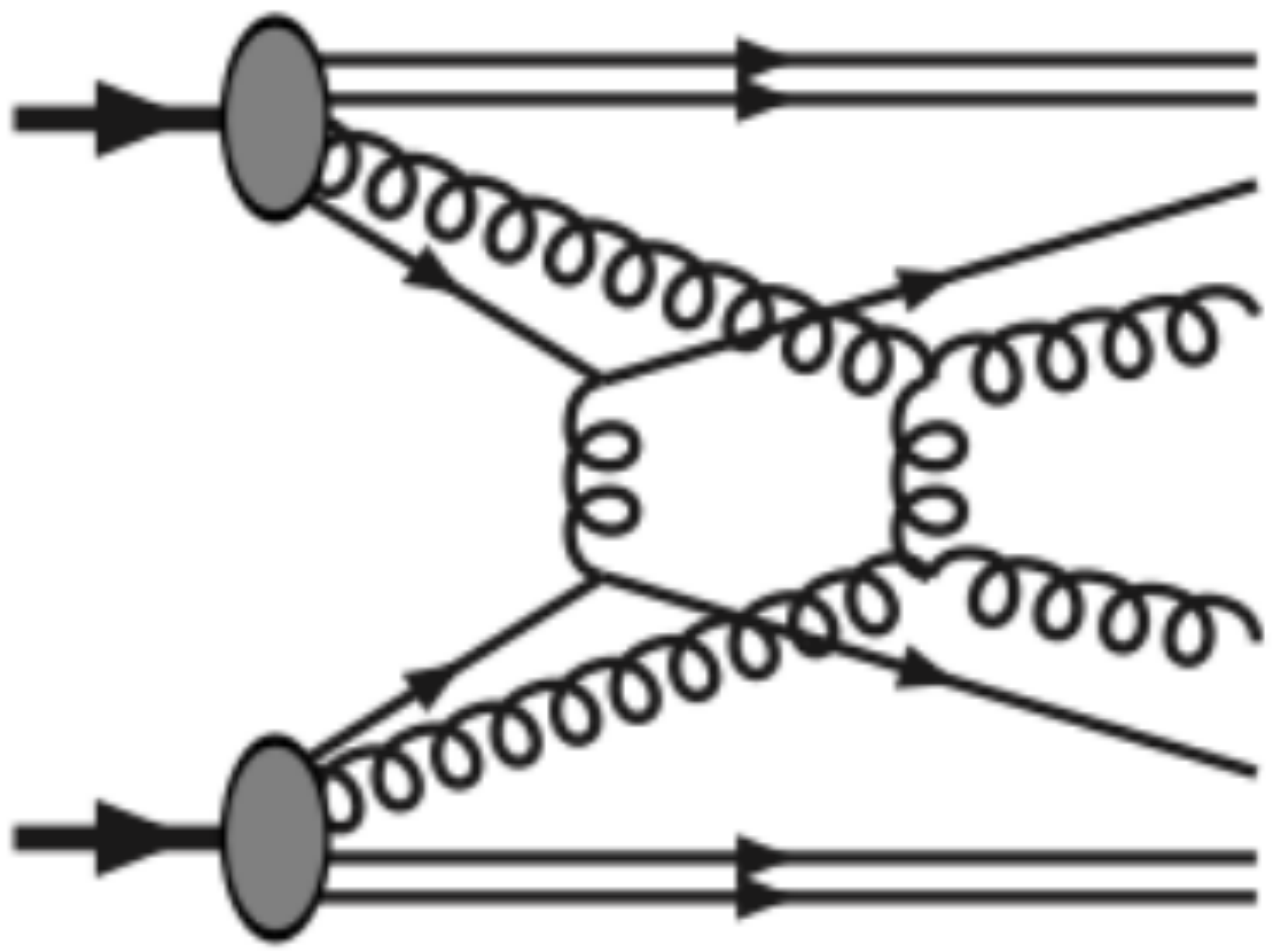


Interpretation: Many partonic scatterings per event: (MPI)

- MPI is a logical consequence of the composite nature of protons



- In event generators like Pythia, an impact parameter dependence is considered



Overlap of protons during encounter is

$$\mathcal{O}(b) = \int \mathrm{d}^3\mathbf{x}\,\mathrm{d}t\; \rho_1(\mathbf{x}, t)\, \rho_2(\mathbf{x}, t)$$

where ρ is (boosted) matter distribution in p, e.g. Gaussian or more narrow peak.

T. Sjöstrand, ISAPP 2018