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11th International Workshop on Multiple Partonic Interactions at the LHC
Prague, November 18-22, 2019

Instituto de Ciencias Nucleares UNAM

MC study of high multiplicity jet and UE-biased pp collisions at the LHC energies

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November 18, 2019

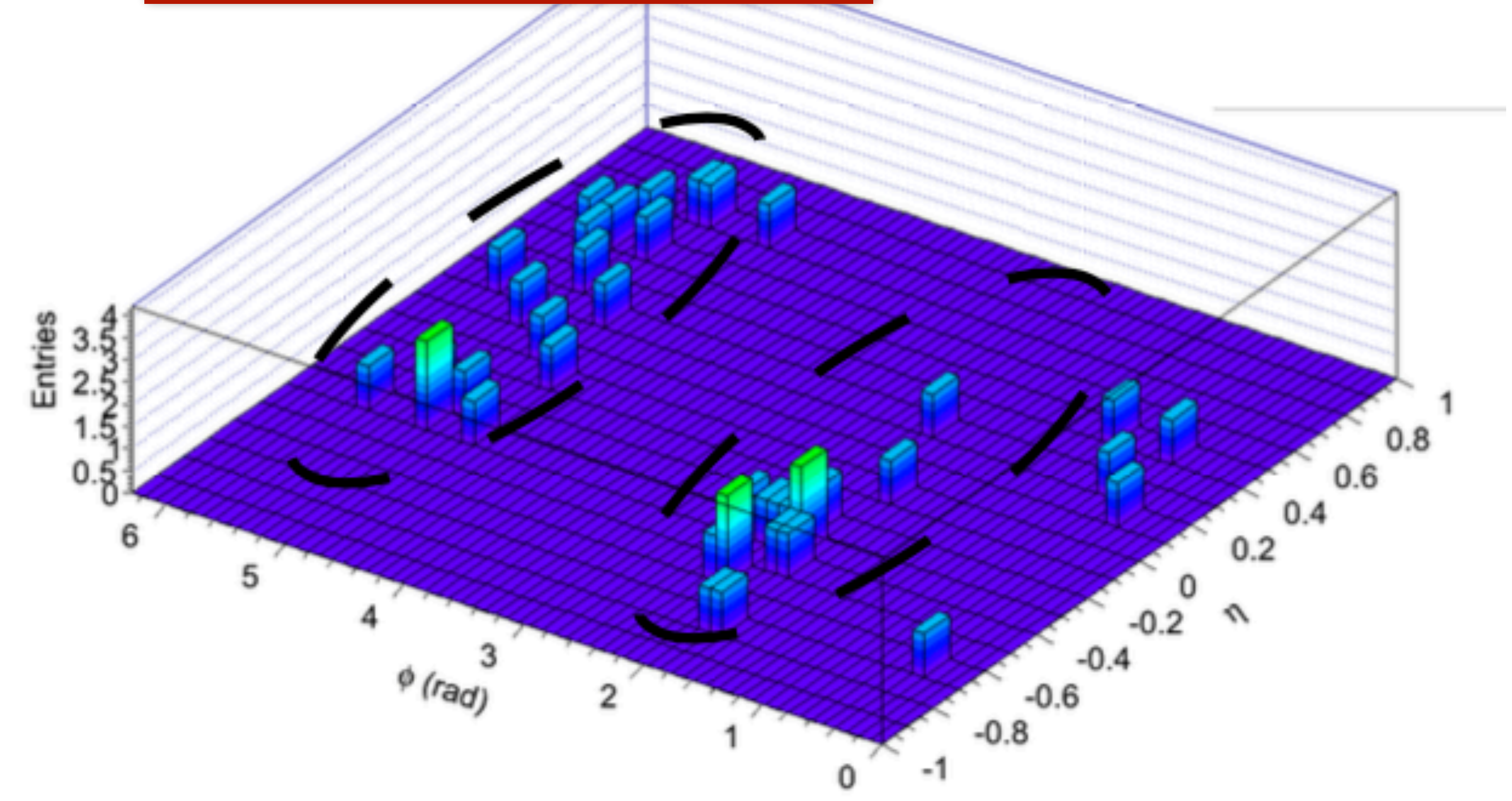
Introduction

Transverse spherocity

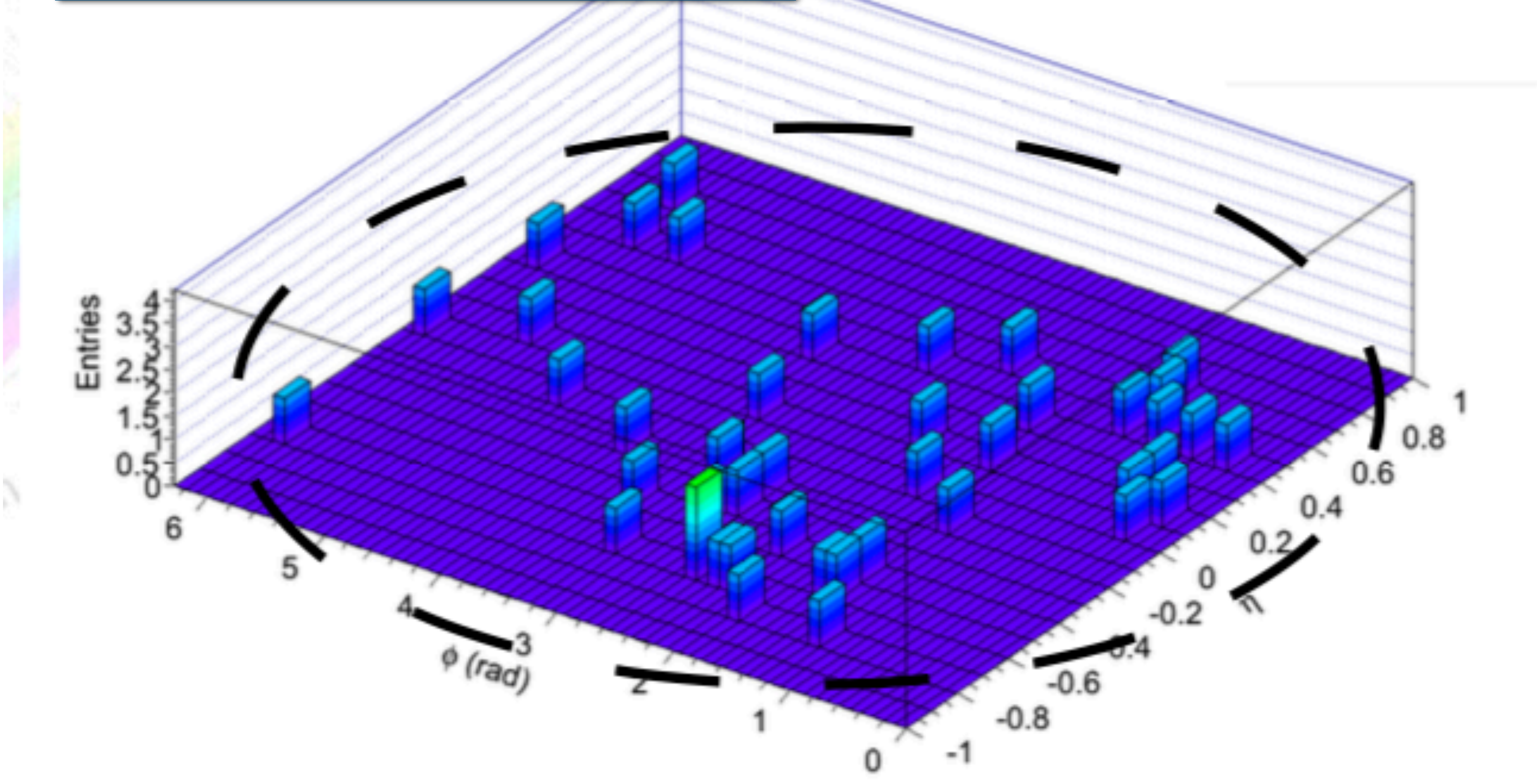
Transverse spherocity (S_0) is an event shape which measures the particle production which is perpendicular to the plane formed by the beam axis and that of the main partonic scattering (~spherocity axis, $\hat{\mathbf{n}}$)

$$S_0 = \min \frac{\pi^2}{4} \left(\frac{\sum_i |\vec{p}_{\mathrm{T},i} \times \hat{\mathrm{n}}|}{\sum_i p_{\mathrm{T}.i}} \right)^2$$

Spherocity (S_0 close to 0)



Spherocity (S_0 close to 1)



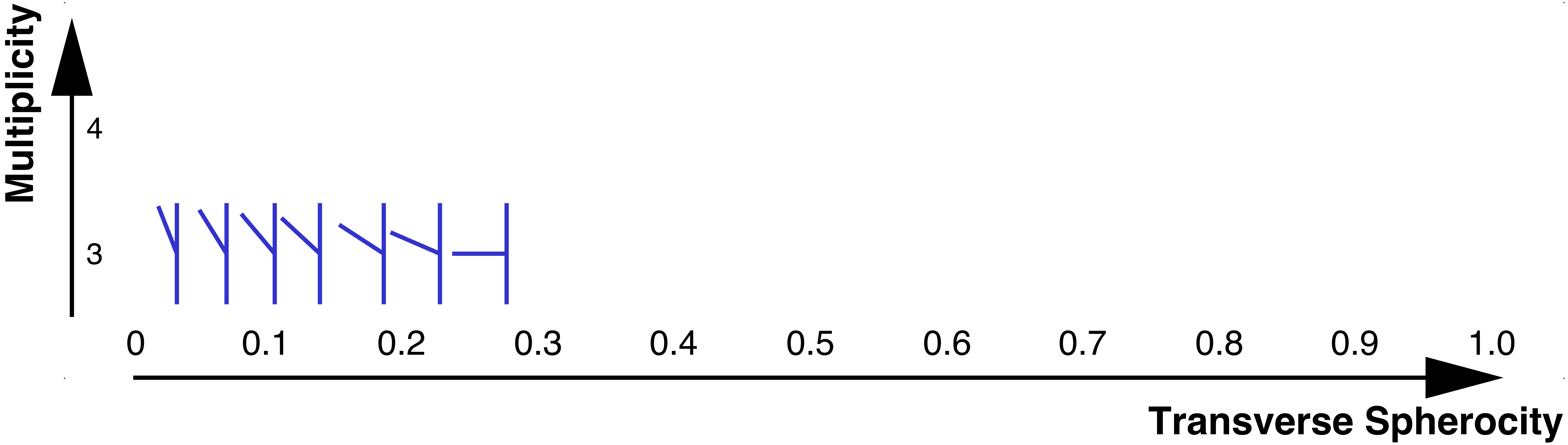
For the calculation of spherocity we consider at least three primary charged particles, $p_{\mathrm{T}} > 0.15$ GeV/c, $|\eta| < 0.8$

Several works have been reported:
Adv. Ser. Direct. High Energy Phys. 29 (2018) 343-357
Nucl. Phys. A941 (2015) 78-86
arXiv:1404.2372

Spherocity for event classification

There particles with same p_{T}

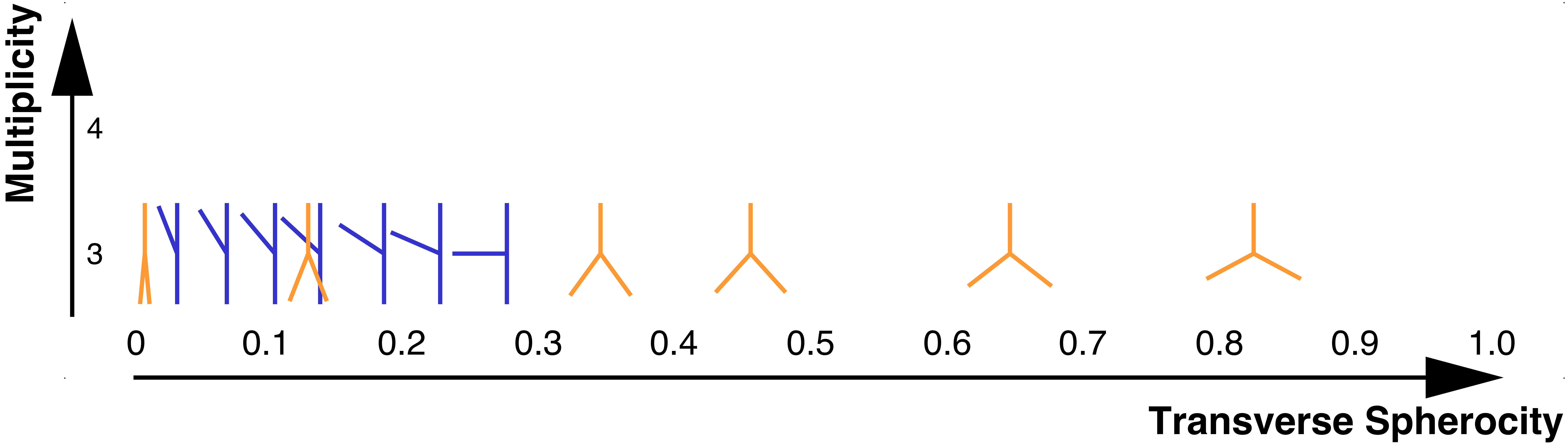
Low-spherocity values



Spherocity for event classification

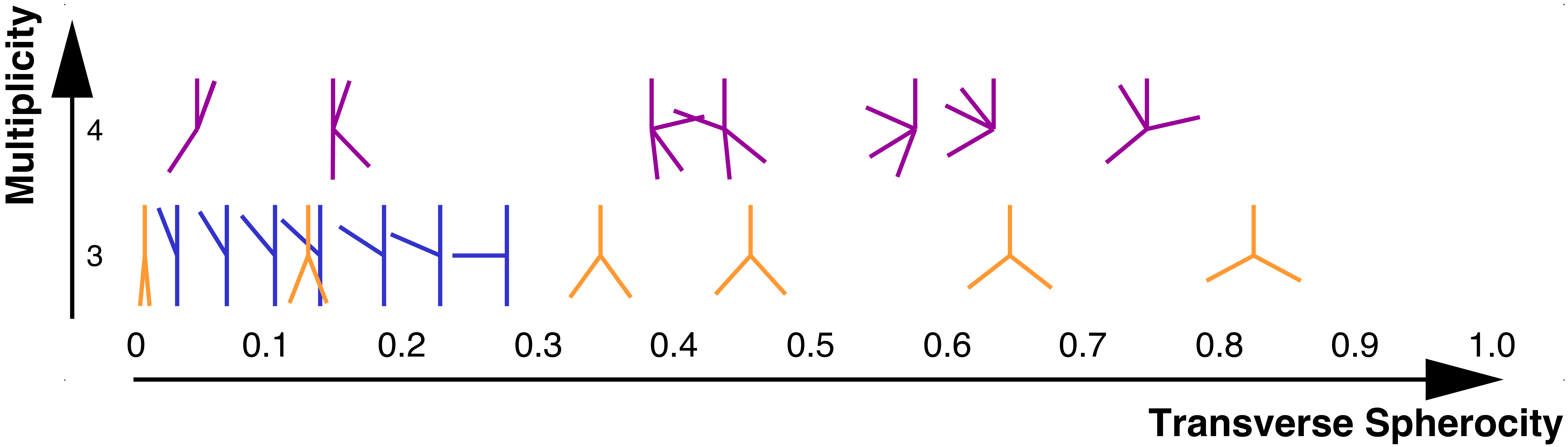
There particles with same p_{T}

Different jet topologies



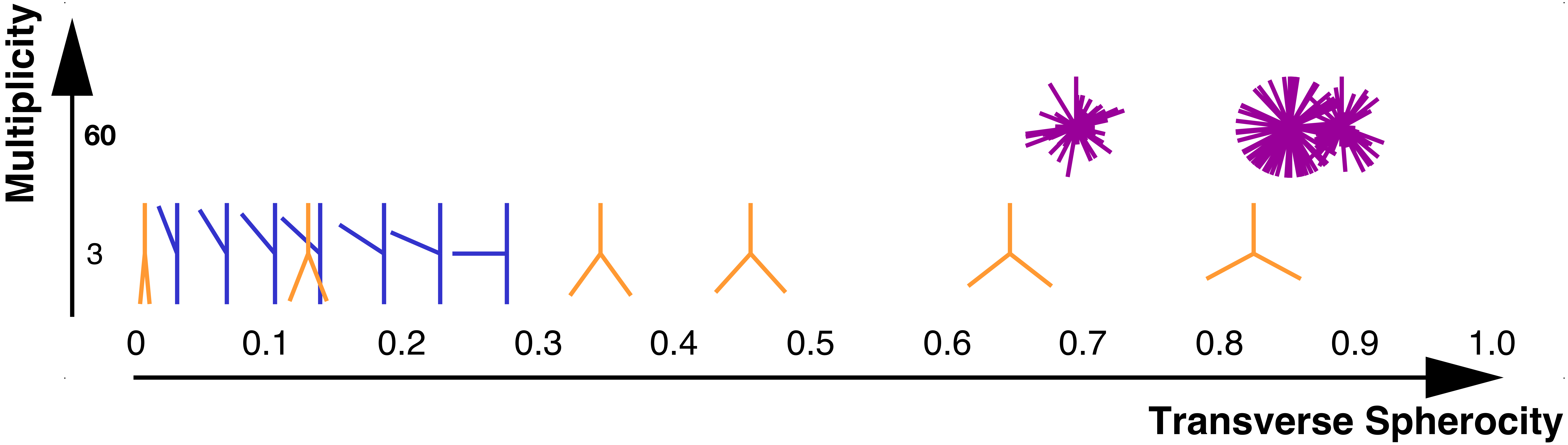
Spherocity for event classification

Four randomly distributed particles with same p_{T}



Spherocity for event classification

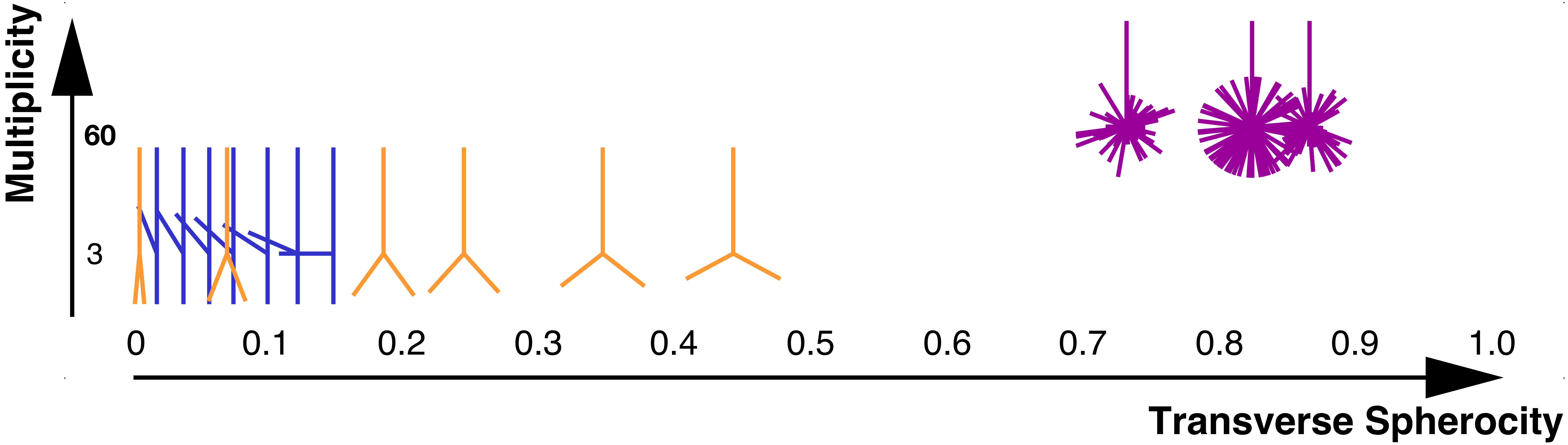
Sixty randomly distributed particles with same p_{T}
High spherocity values are reached



Spherocity for event classification

Effect of high p_{T} particles

Sixty randomly distributed particles with same p_{T}
High spherocity values are reached



Little effect for jetty events (low or high multiplicity)

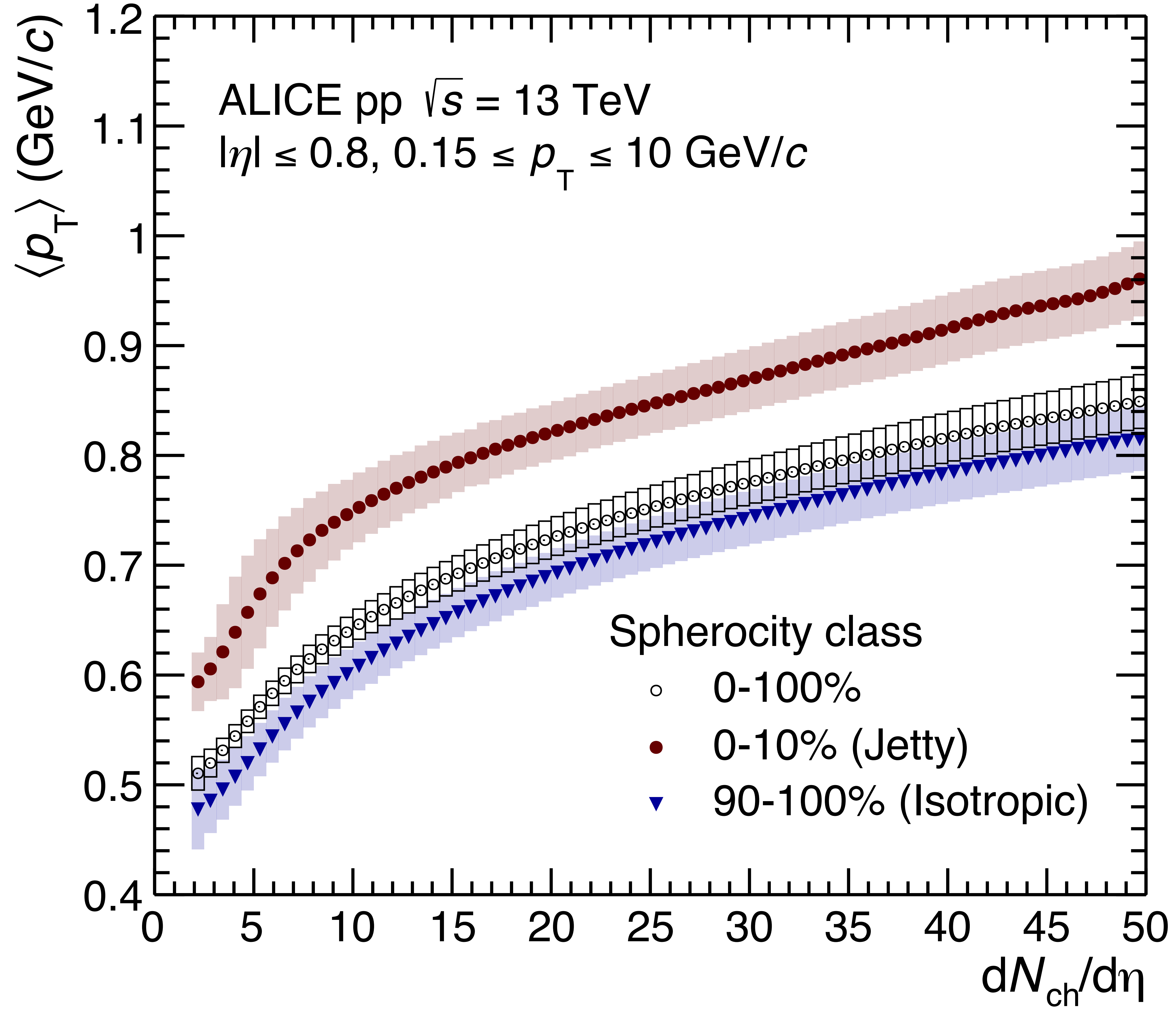
Little or no effect: events with enhanced UE activity

Spherocity is an useful tool to understand the heavy-ion like features discovered in small systems

Recent LHC results using spherocity

Motivation

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

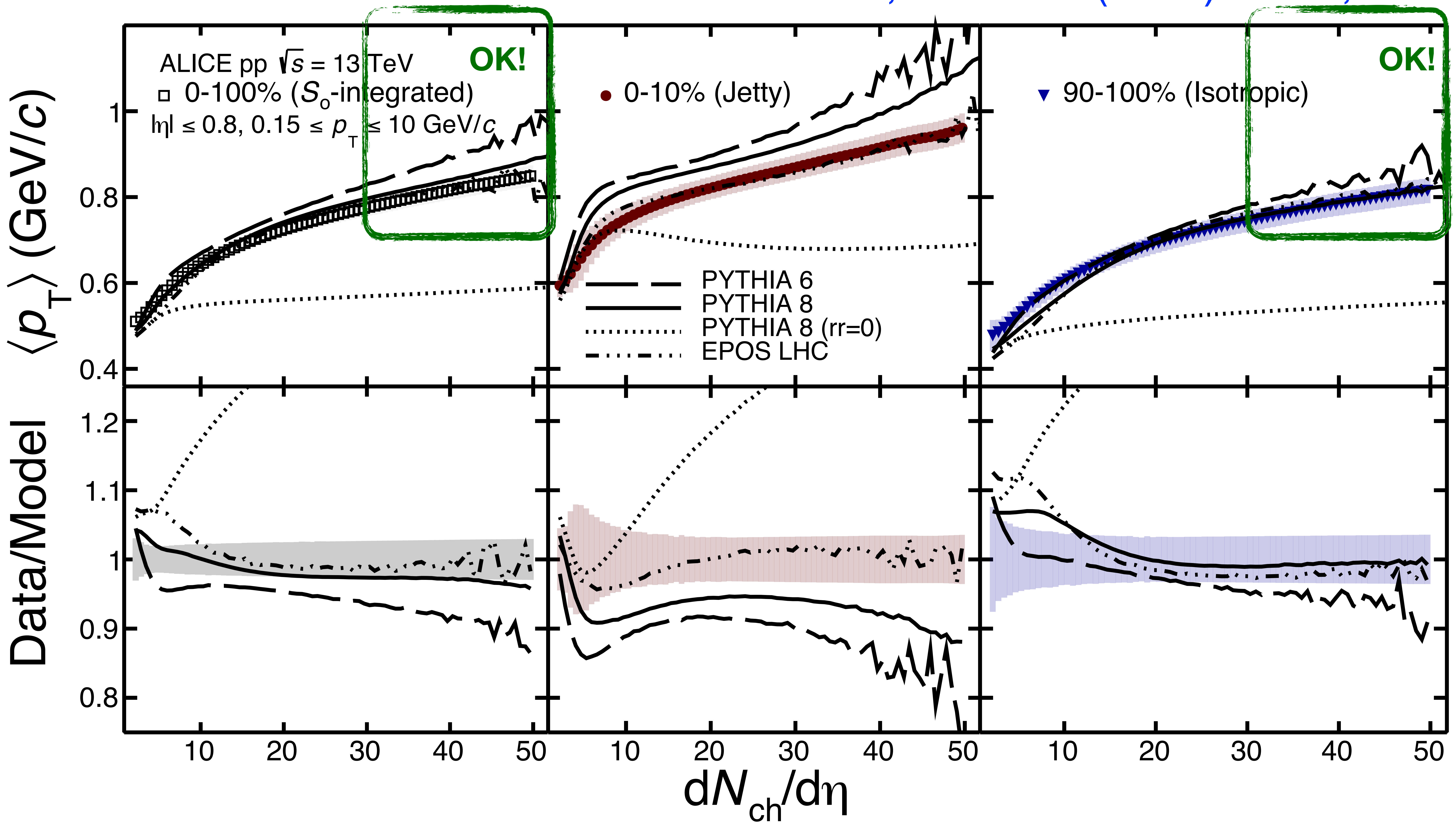


- New data on $\langle p_{\rm T}\rangle(N_{\rm ch})$ for pp collisions at $\sqrt{s} = 13$ TeV are available
- Transverse spherocity (S_0) is used to study particle production in jetty-like and isotropic events (soft/semi-hard physics)
  - The average $p_{\rm T}$ is higher in jetty-like than in isotropic events
  - For $\mathrm{d}N_{\rm ch}/\mathrm{d}\eta > 30$, $\langle p_{\rm T}\rangle$ increases at the same rate for all S_0 classes

Motivation

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

- PYTHIA 8 and 6 describe the data for "MB" and isotropic events

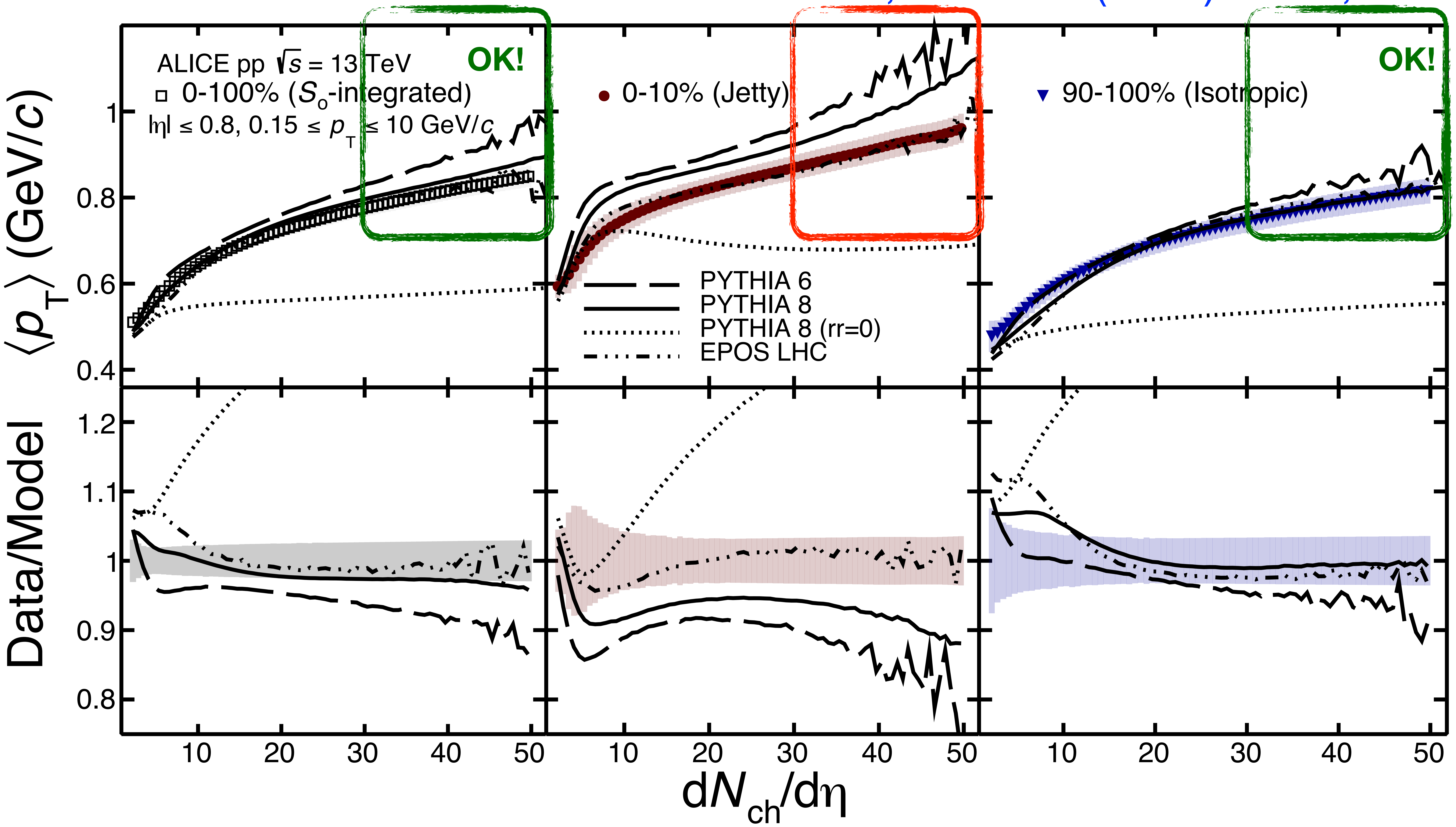


Motivation

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

- PYTHIA 8 and 6 describe the data for "MB" and isotropic events

- PYTHIA 6 and 8 predict a different behavior for high multiplicity jetty-like events: a third rise of $\langle p_{\mathrm{T}} \rangle$ at $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta > 30$



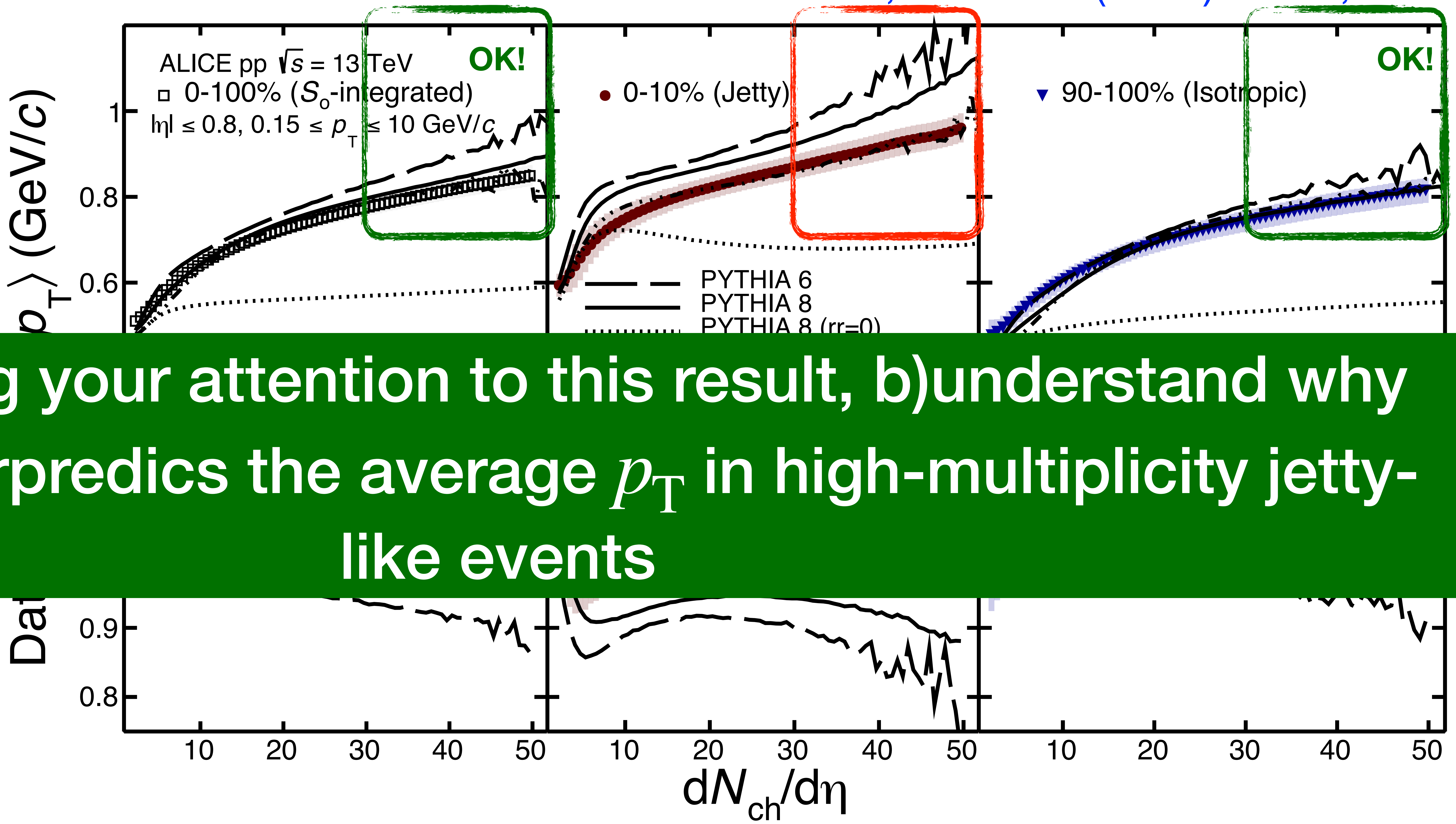
This is a surprise because we know that PYTHIA describes better hard physics than EPOS, e.g. ALICE, PRD 99 (2019) no.1, 012016 and PLB 753 (2016) 319-329

Motivation

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

- PYTHIA 8 and 6 describe the data for "MB" and isotropic events

events: a third rise of $\langle p_{\rm T} \rangle$ at $dN_{ch}/d\eta > 30$



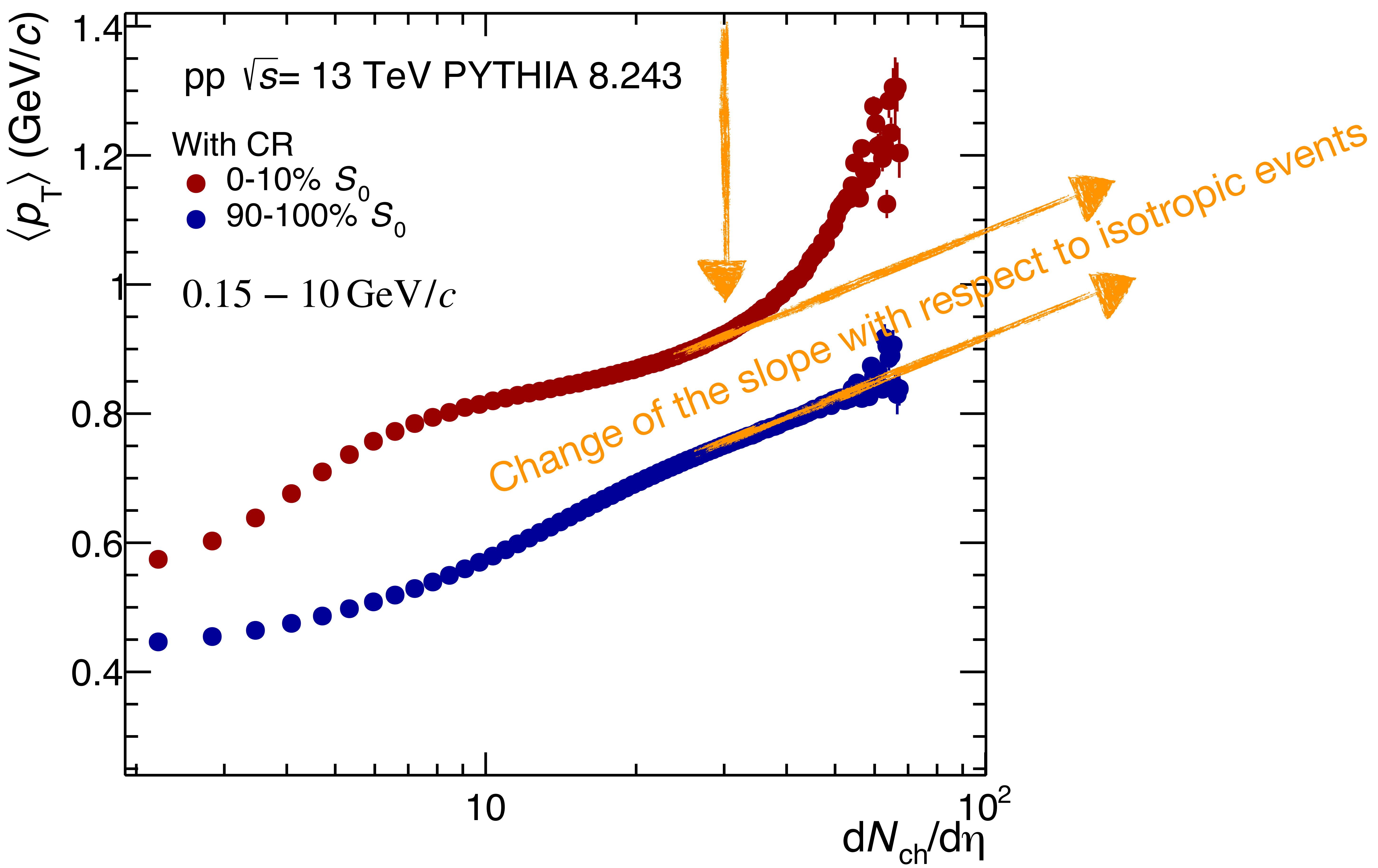
Goals: a) bring your attention to this result, b)understand why PYTHIA 8 overpredics the average $p_{\rm T}$ in high-multiplicity jetty-like events

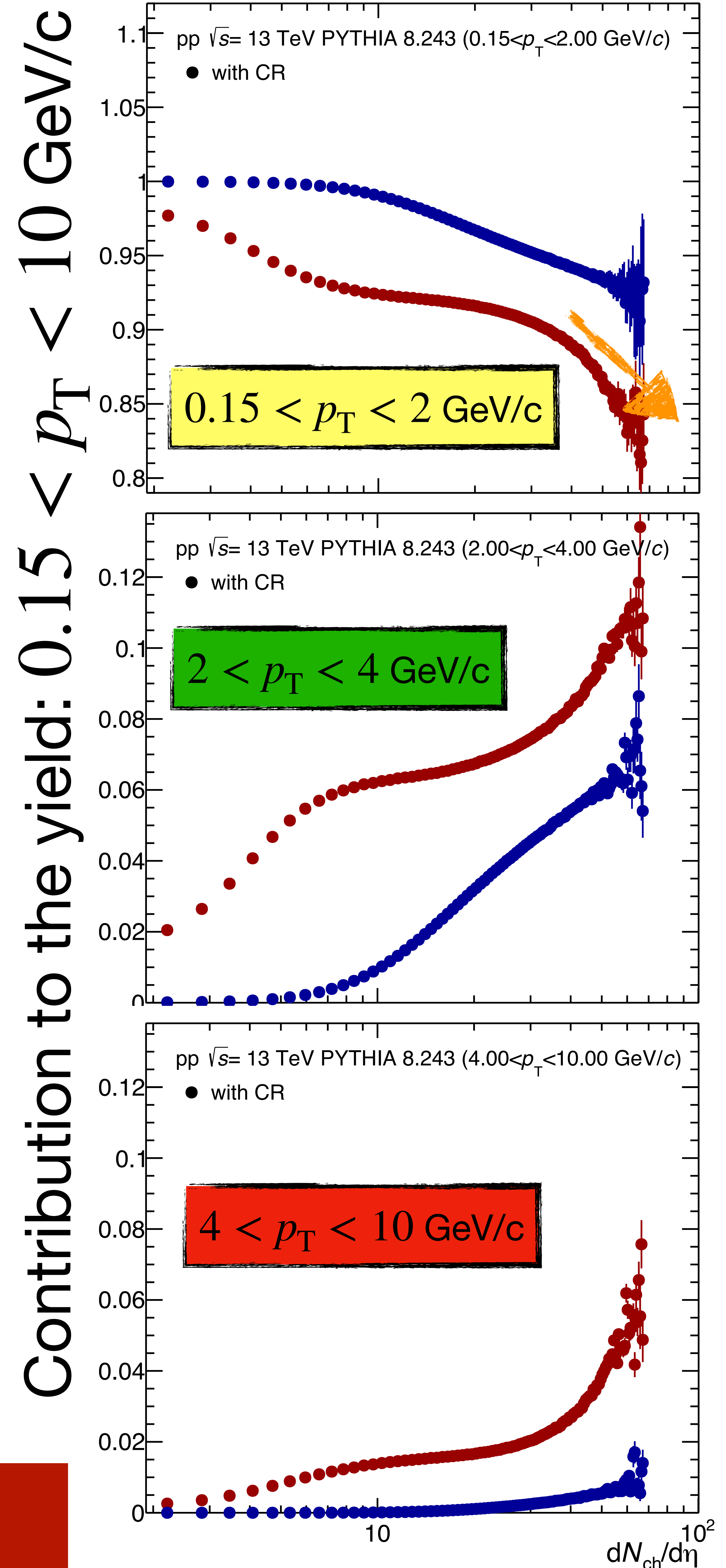
This is a surprise because we know that PYTHIA describes better hard physics than EPOS, e.g. ALICE, PRD 99 (2019) no.1, 012016, PLB 753 (2016) 319-329

Is the third rise a low- or high-p_{T} effect?

Isotropic vs jetty-like events

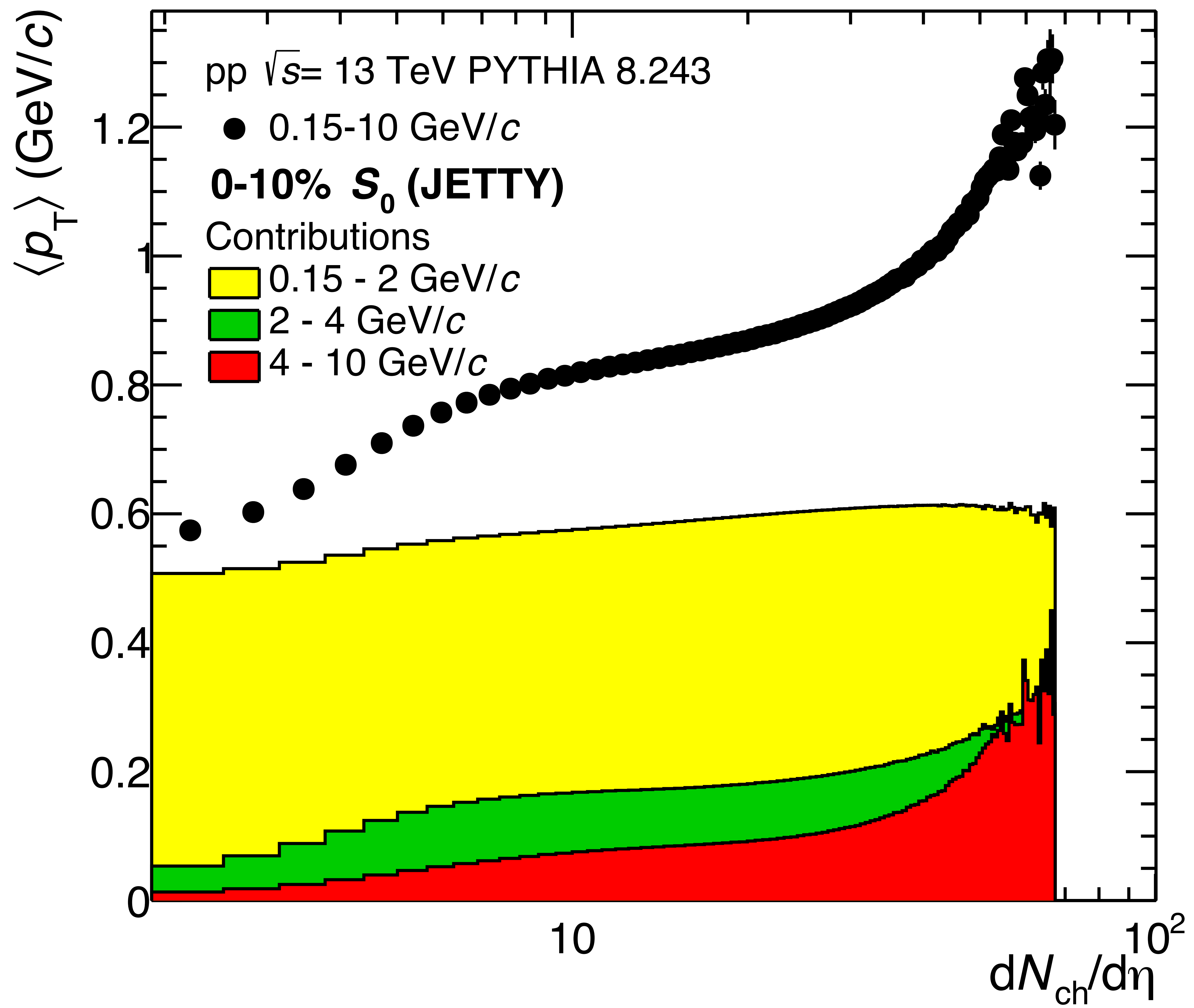
The third rise can be seen like a deviation with respect to the behavior of underlying event (characterized by isotropic events)

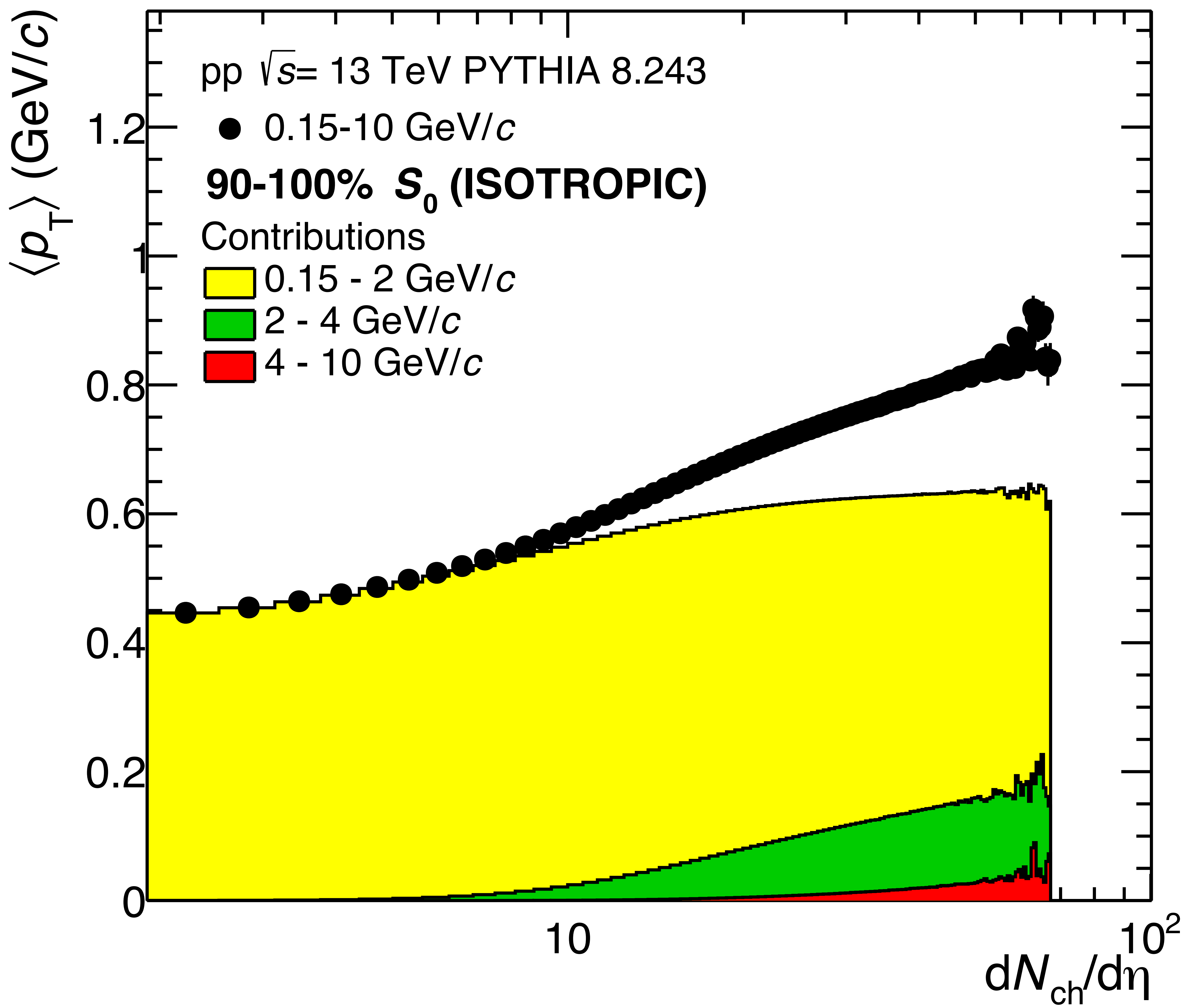




At the same $\mathrm{d}N_\mathrm{ch}/\mathrm{d}\eta$, the low-$p_\mathrm{T}$ yield is reduced (~10%)

Contributions of different p_T intervals



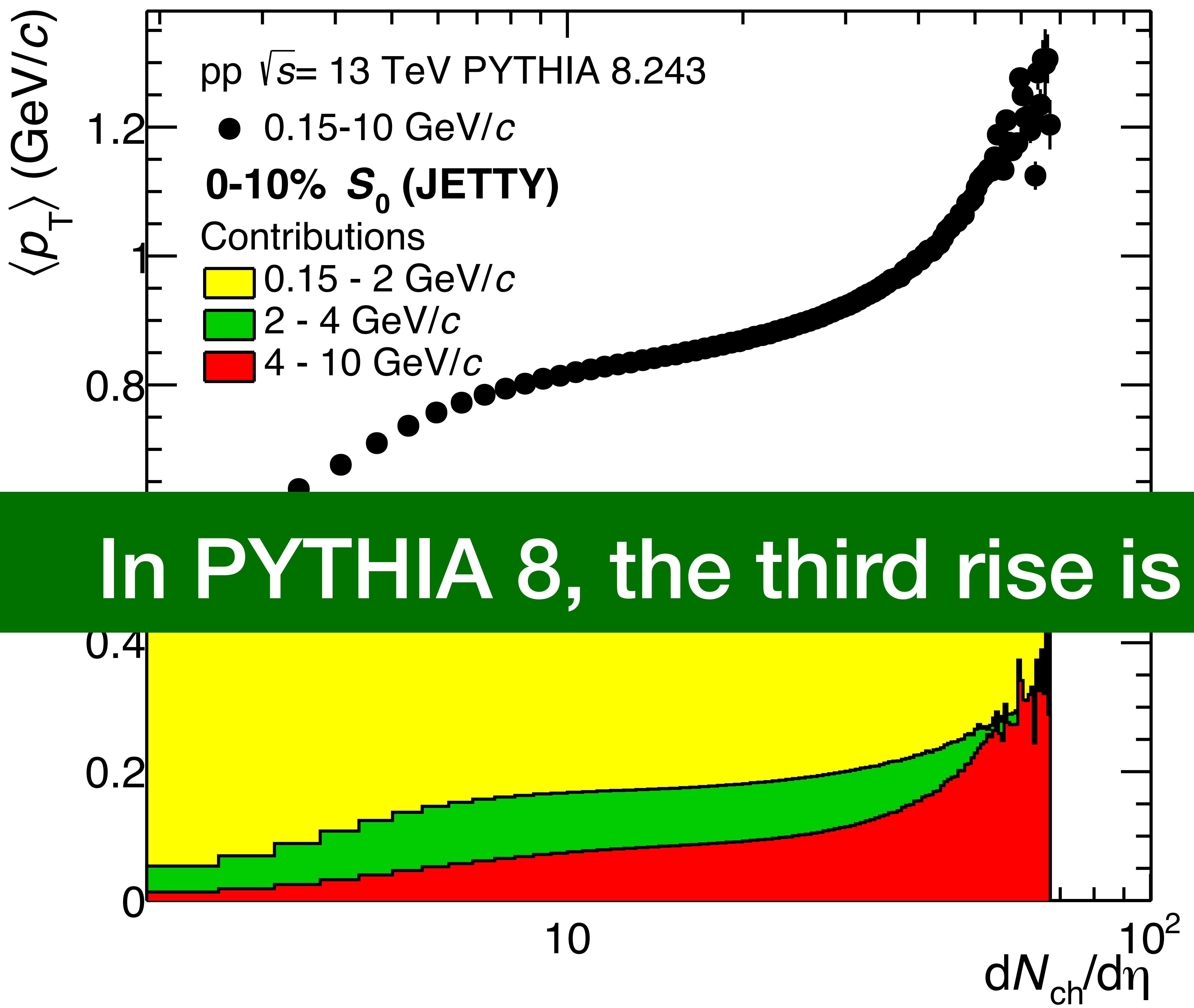


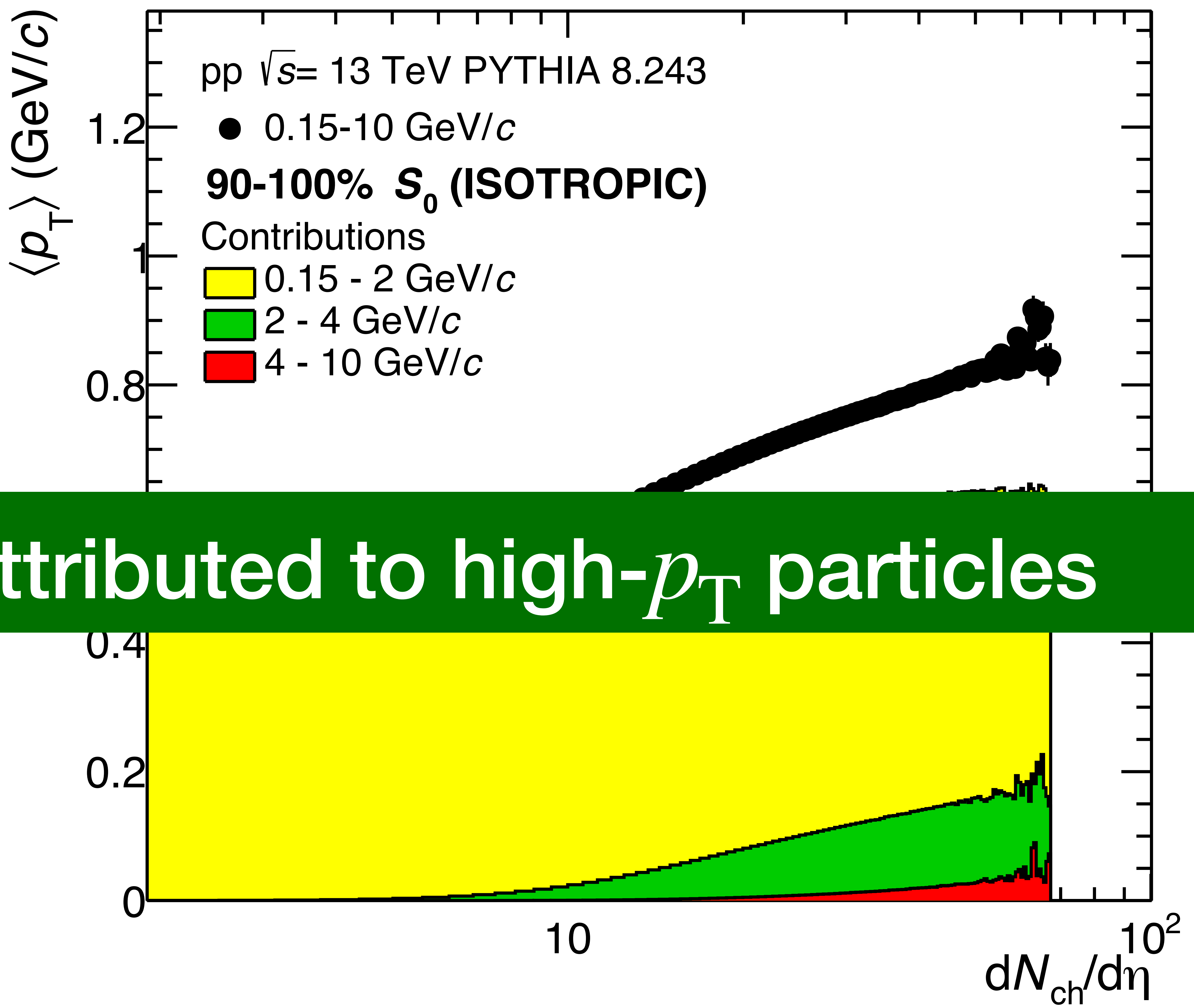
First rise driven by low-p_T particles

Third rapid rise driven by high-p_T particles

Low-p_T particles drive the average -p_T

Contributions of different p_T intervals





In PYTHIA 8, the third rise is attributed to high-p_T particles

First rise driven by low-p_T particles

Third rapid rise driven by higher-p_T particles

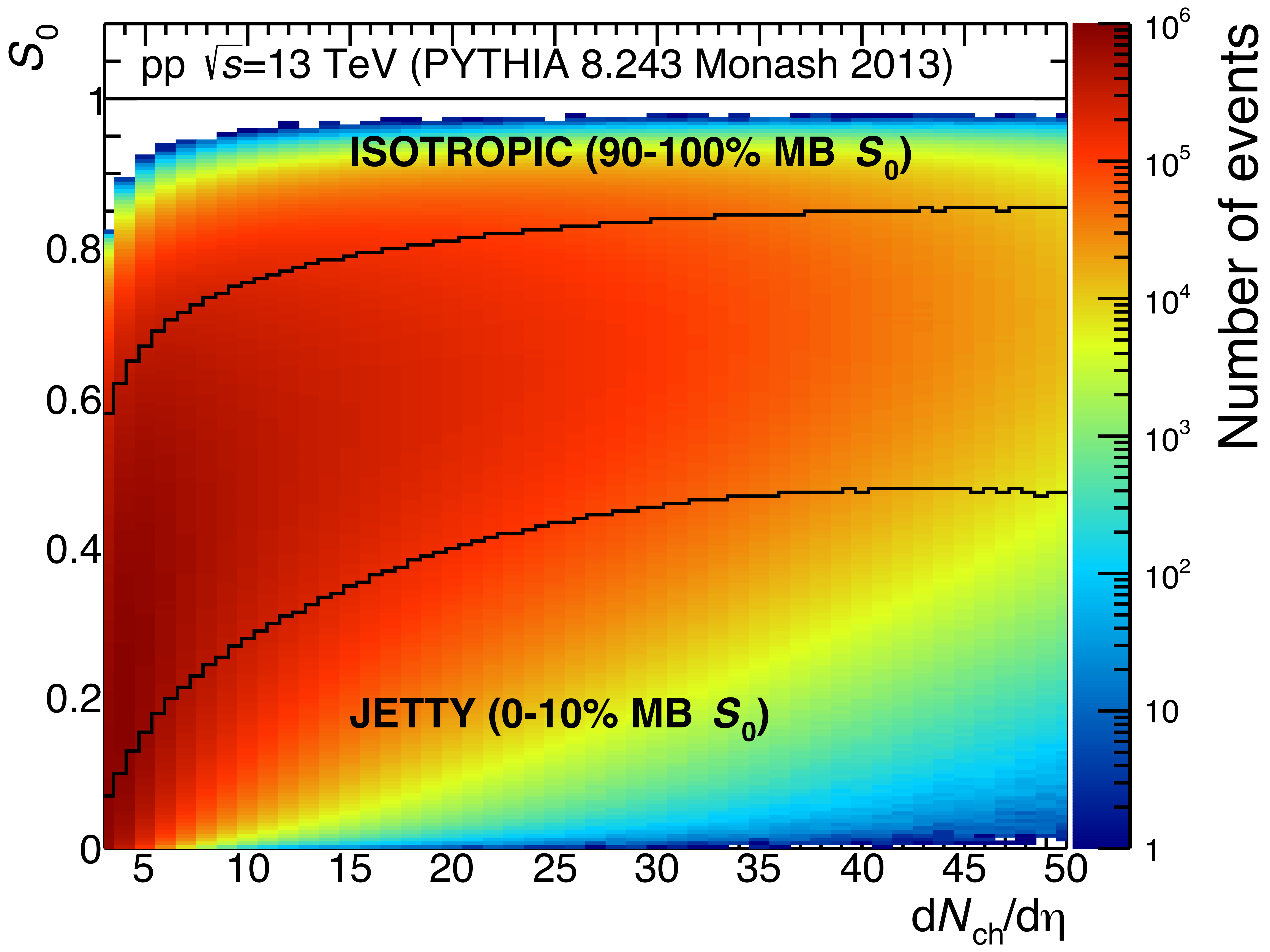
Low-p_T particles drive the average -p_T

Is the third rise also observed in the UE?

S_0 vs multiplicity (MB)

Idea:

- Select 0-10% S_0 events

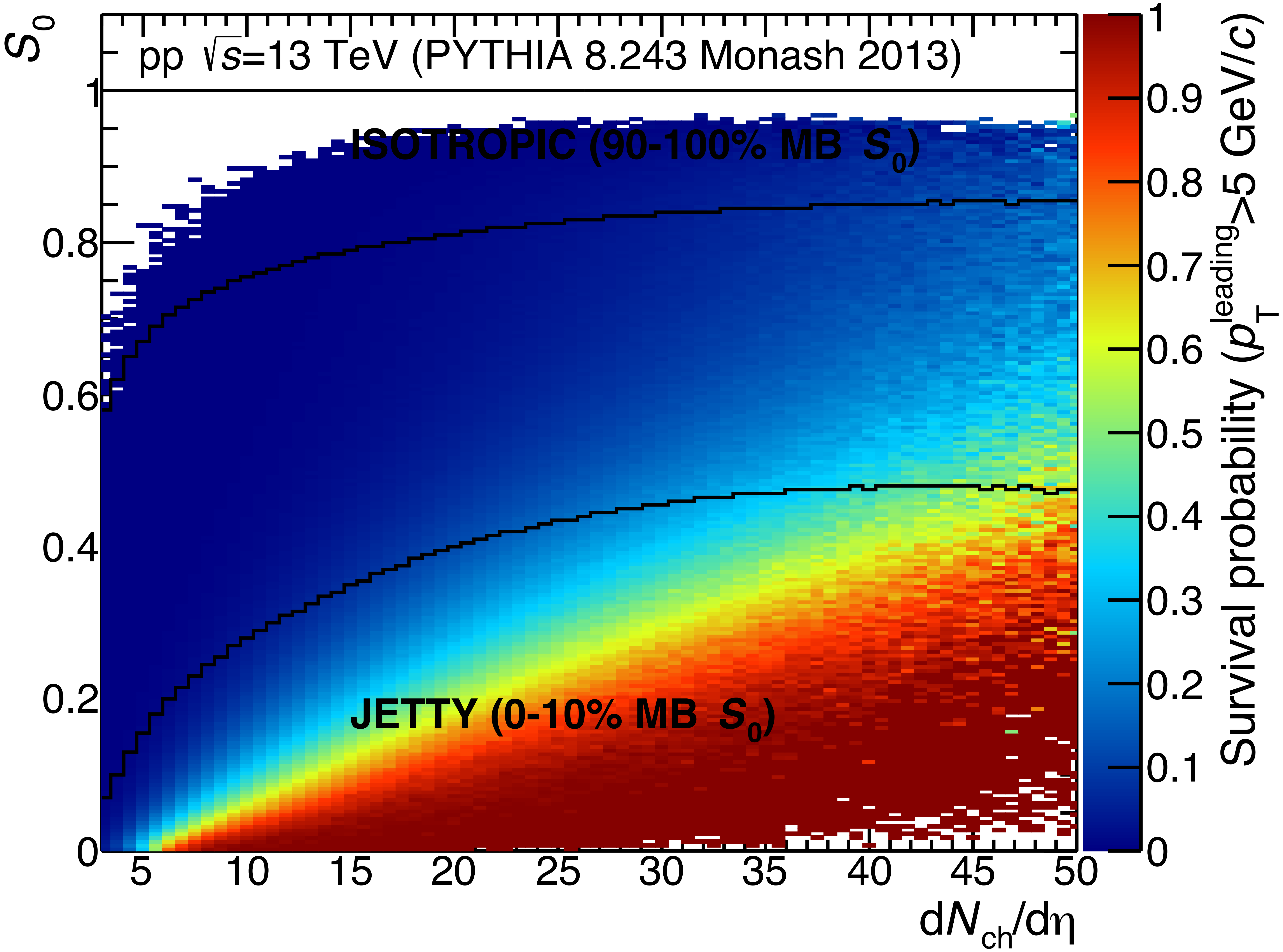


S_0 vs multiplicity (MB)

Idea:

- Select 0-10% S_0 events
- Consider only events with charged leading particle: $p_{\mathrm{T}}^{\mathrm{leading}} > 5$ GeV/c

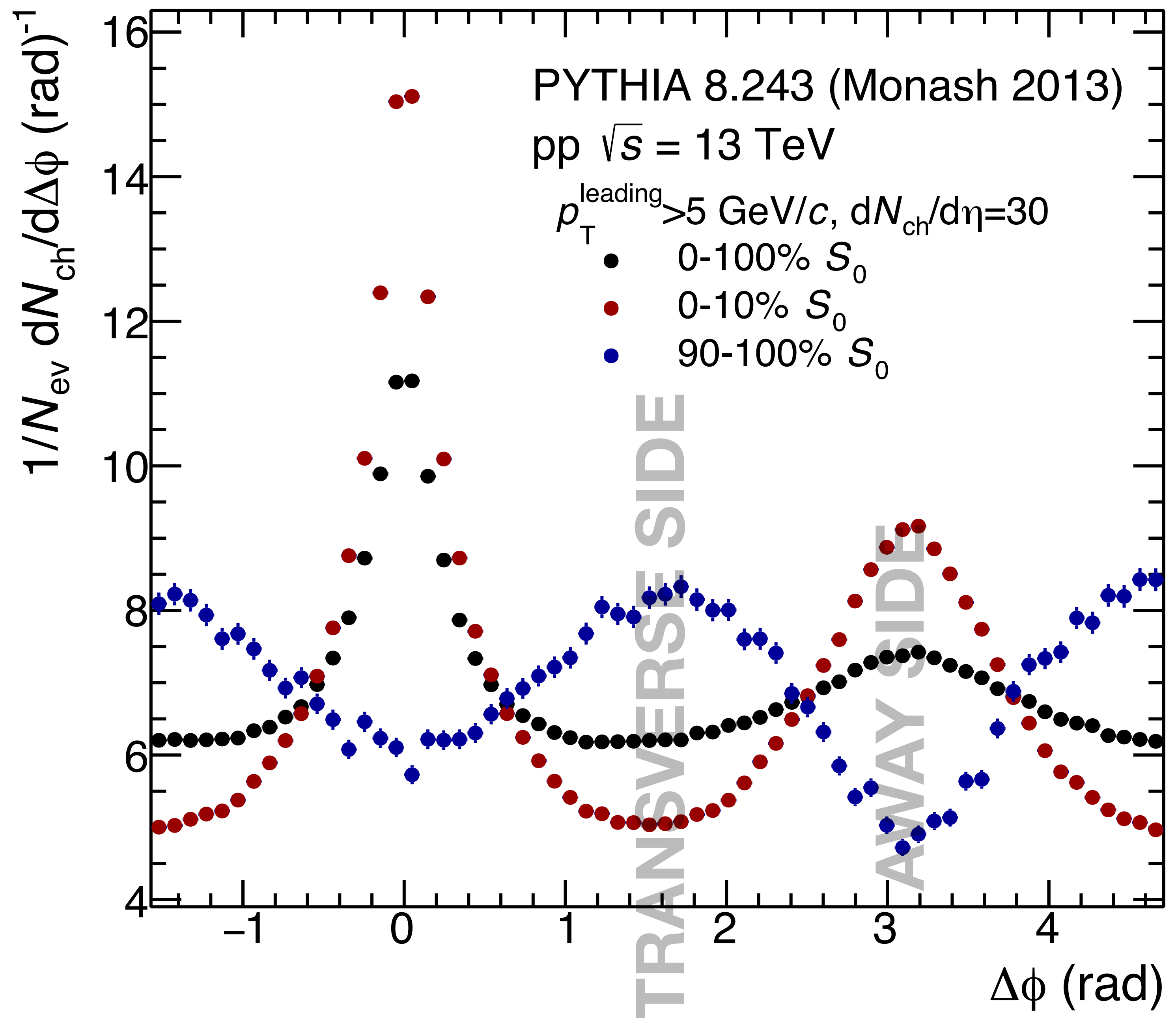
Most of the events which survive the $p_{\mathrm{T}}^{\mathrm{leading}}$ cut have low spherocity. Therefore, spherocity and R_{T} studies should produce similar results

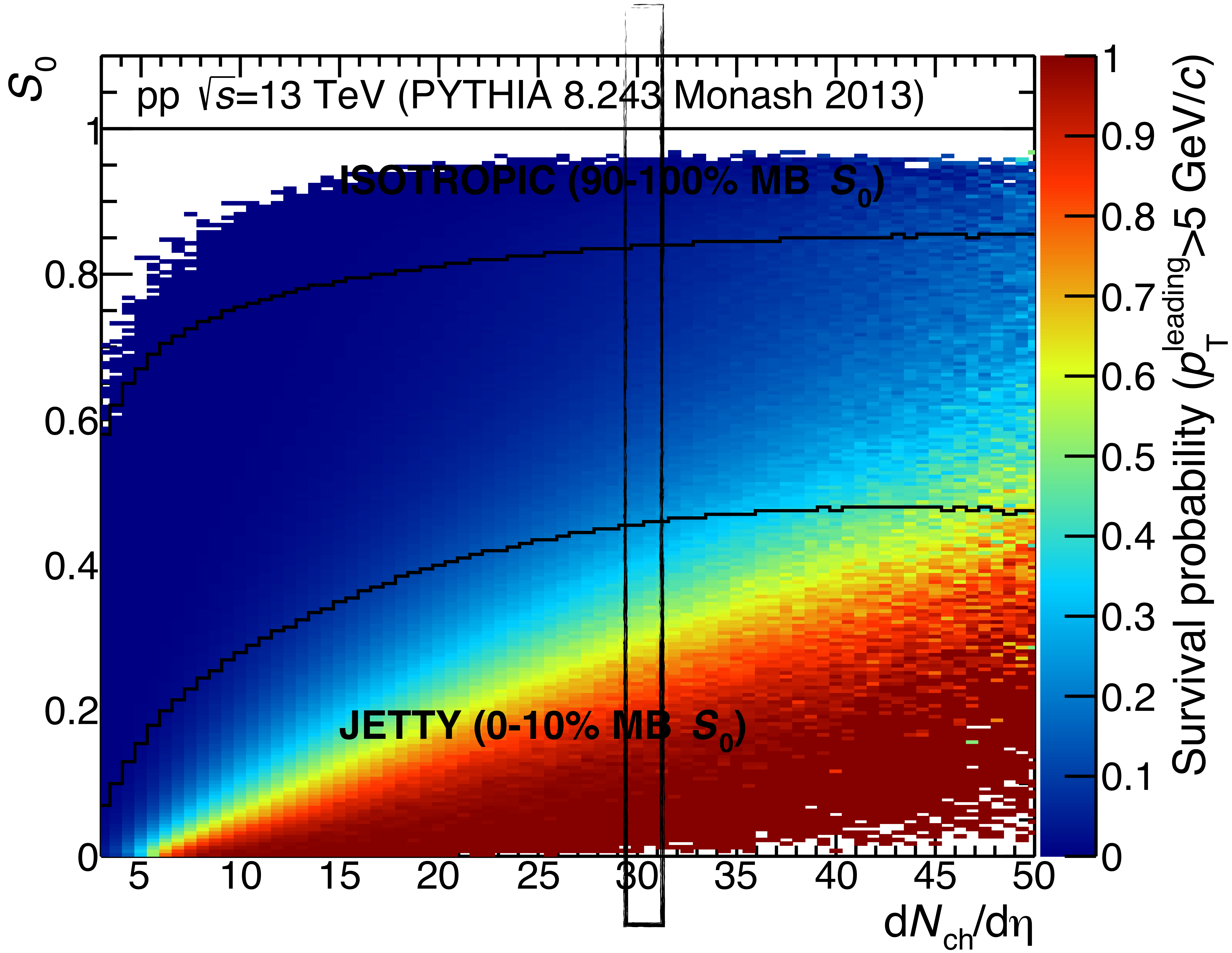


S_0 vs multiplicity (MB)

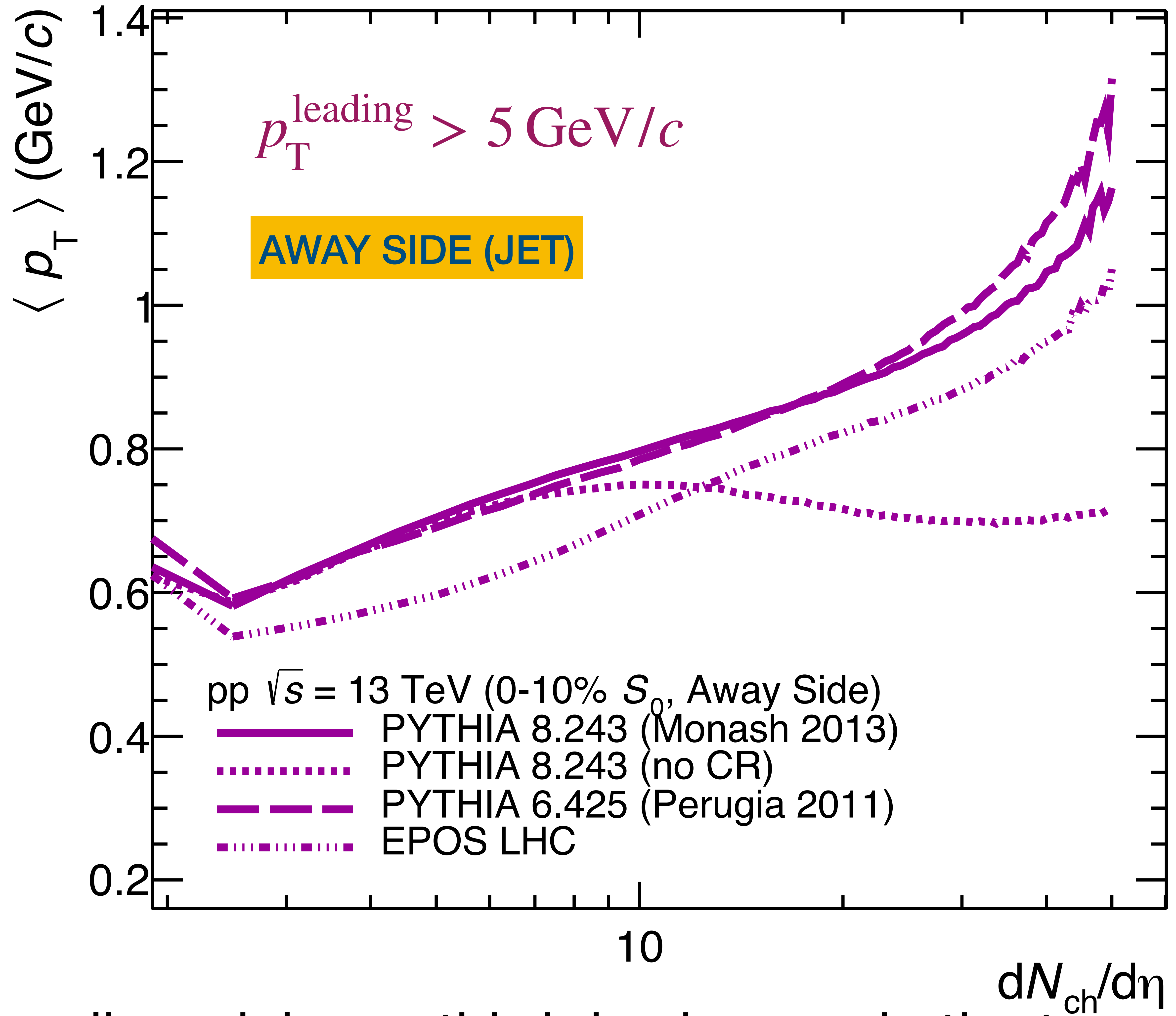
Idea:

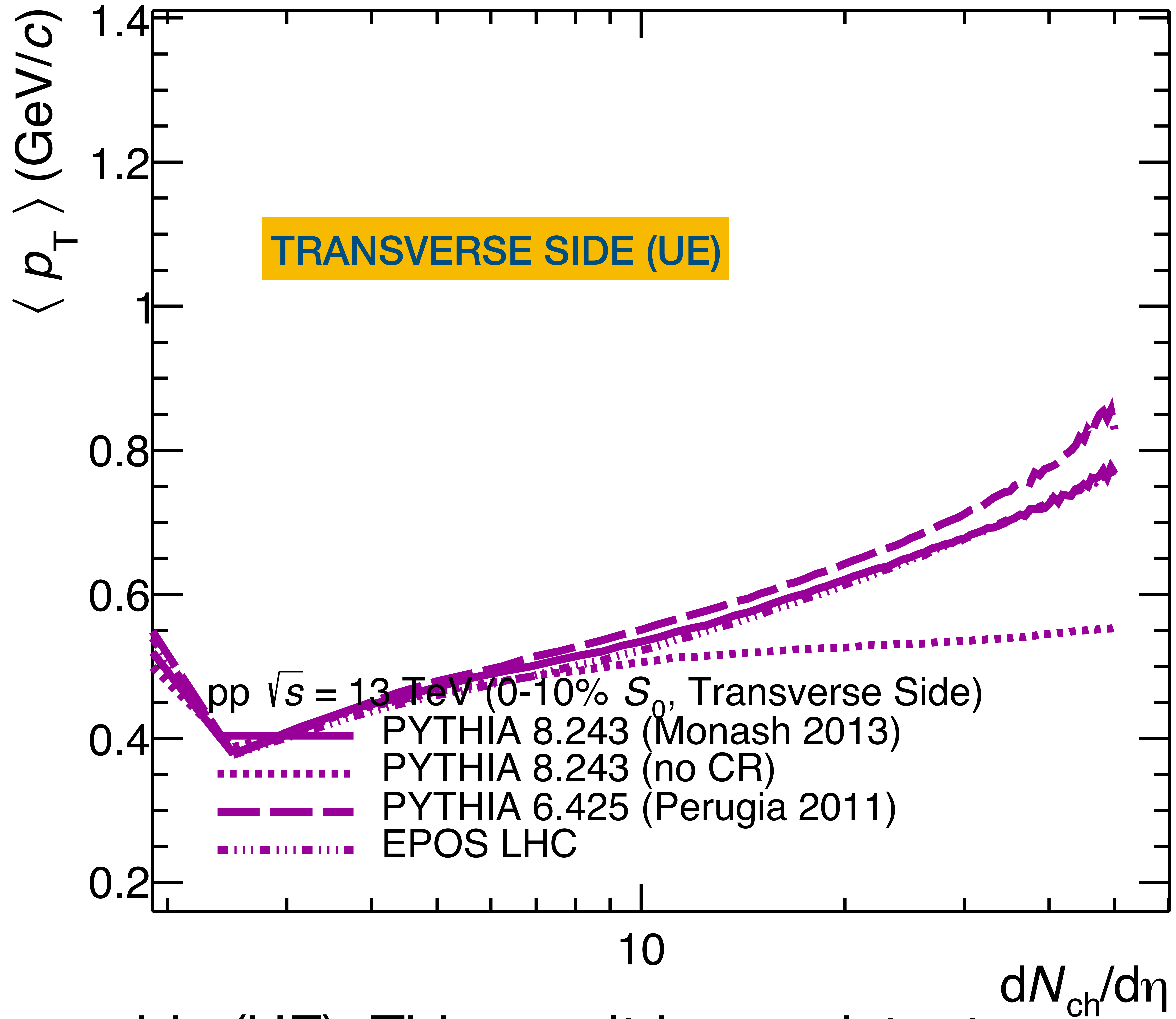
- Select 0-10% S_0 events
- Consider only events with charged leading particle: $p_{\mathrm{T}}^{\mathrm{leading}} > 5$ GeV/c
- For each multiplicity, study the leading-hadron correlations





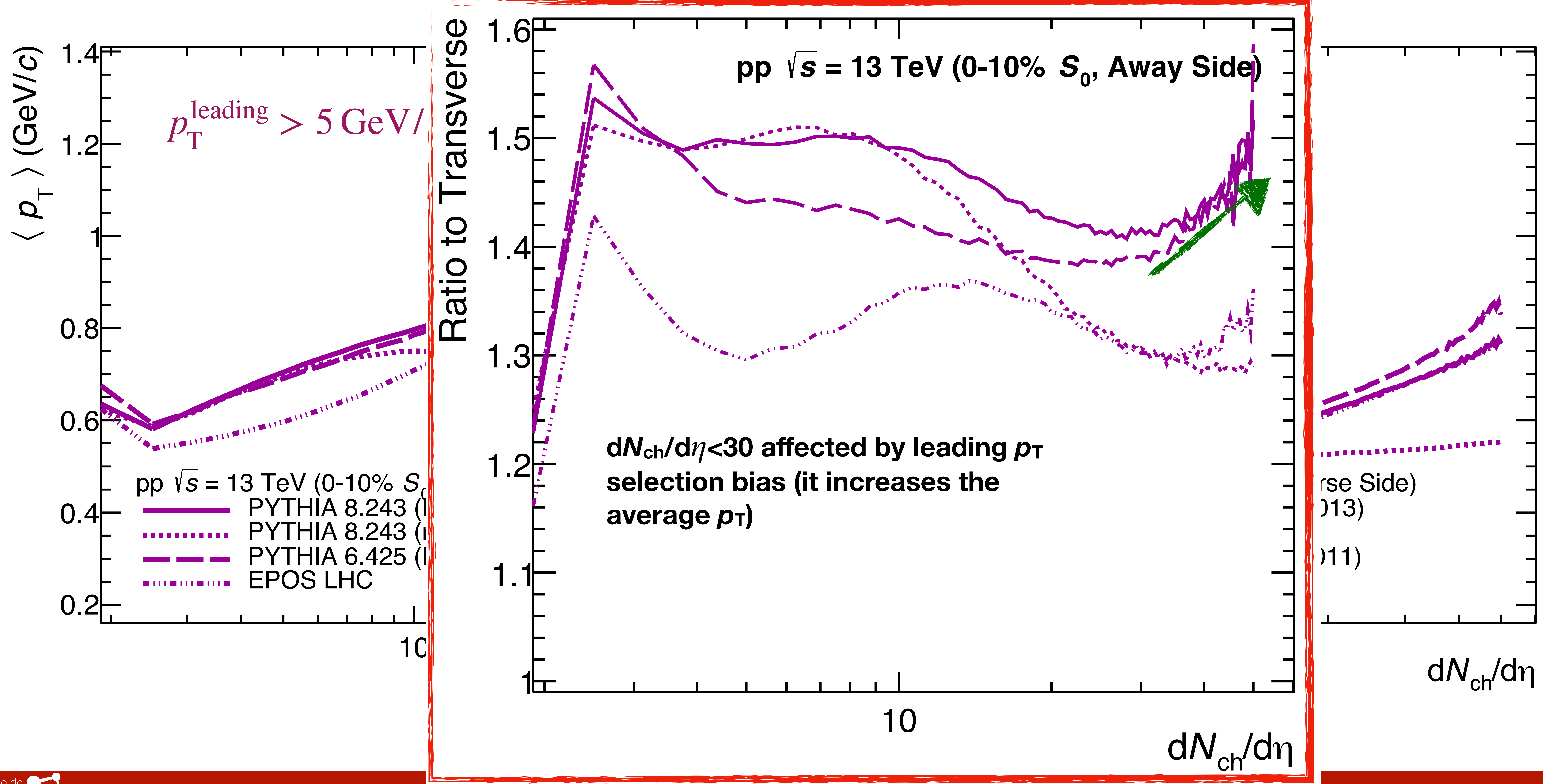
$\langle p_{\mathrm{T}}\rangle(N_{\mathrm{ch}})$: away vs transverse side for jetty-like events



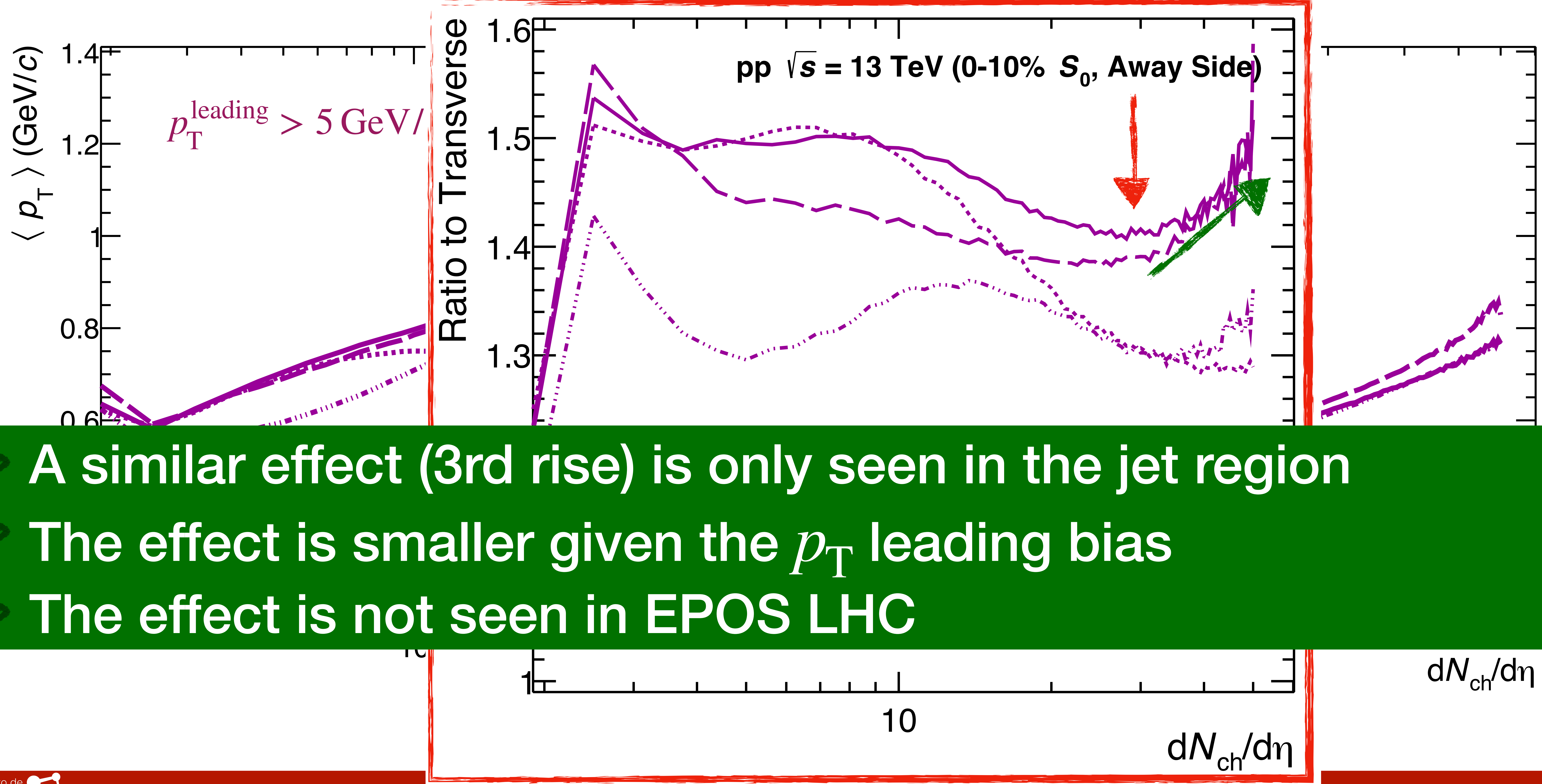


For all models: no third rise is seen in the transverse side (UE). This result is consistent with the $|\Delta\phi|$-integrated analysis: all MC agree each other for isotropic events (UE)

$\langle p_{\mathrm{T}} \rangle (N_{\mathrm{ch}})$: away / transverse side for jetty-like events



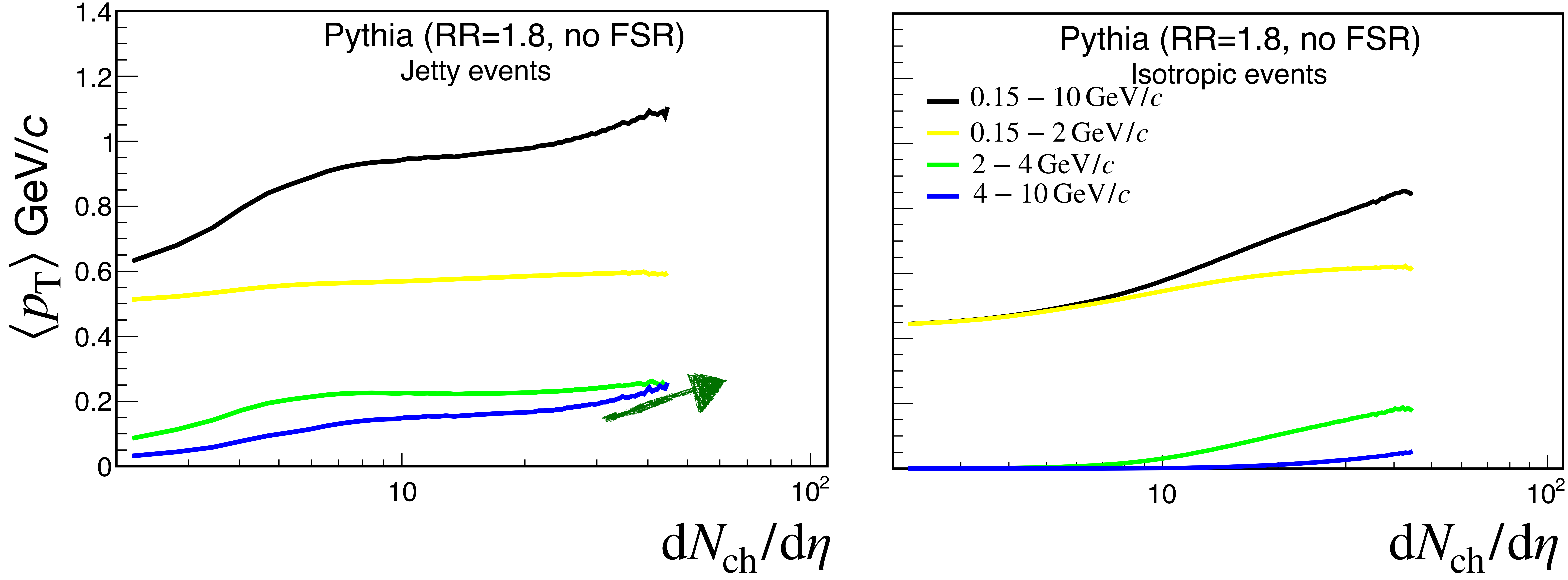
$\langle p_T \rangle (N_{ch})$: away / transverse side for jetty-like events



- A similar effect (3rd rise) is only seen in the jet region
- The effect is smaller given the p_T leading bias
- The effect is not seen in EPOS LHC

Is the third rise caused by Final State Radiation (FSR)?

PYTHIA 8 (Monash FSR off)

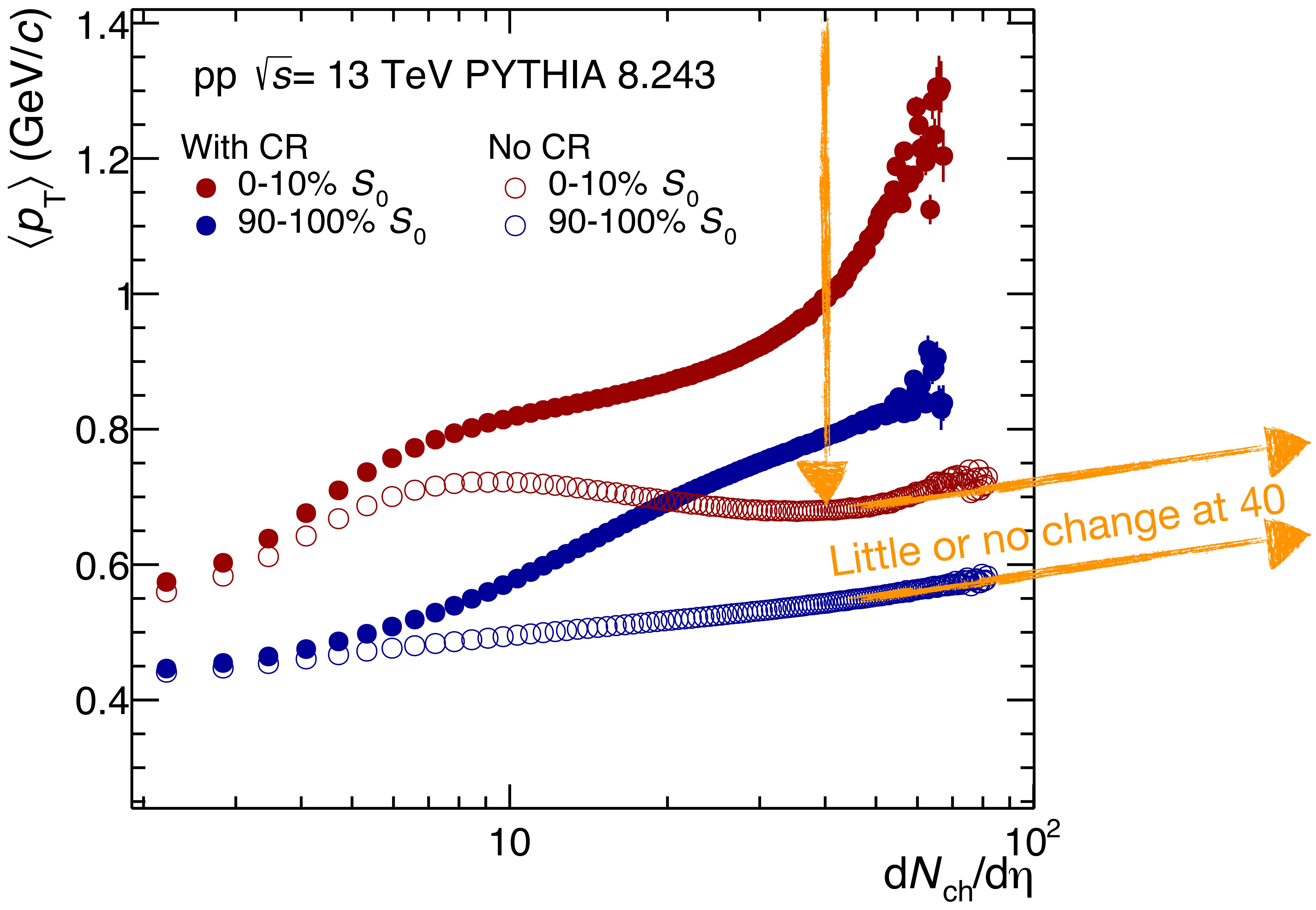


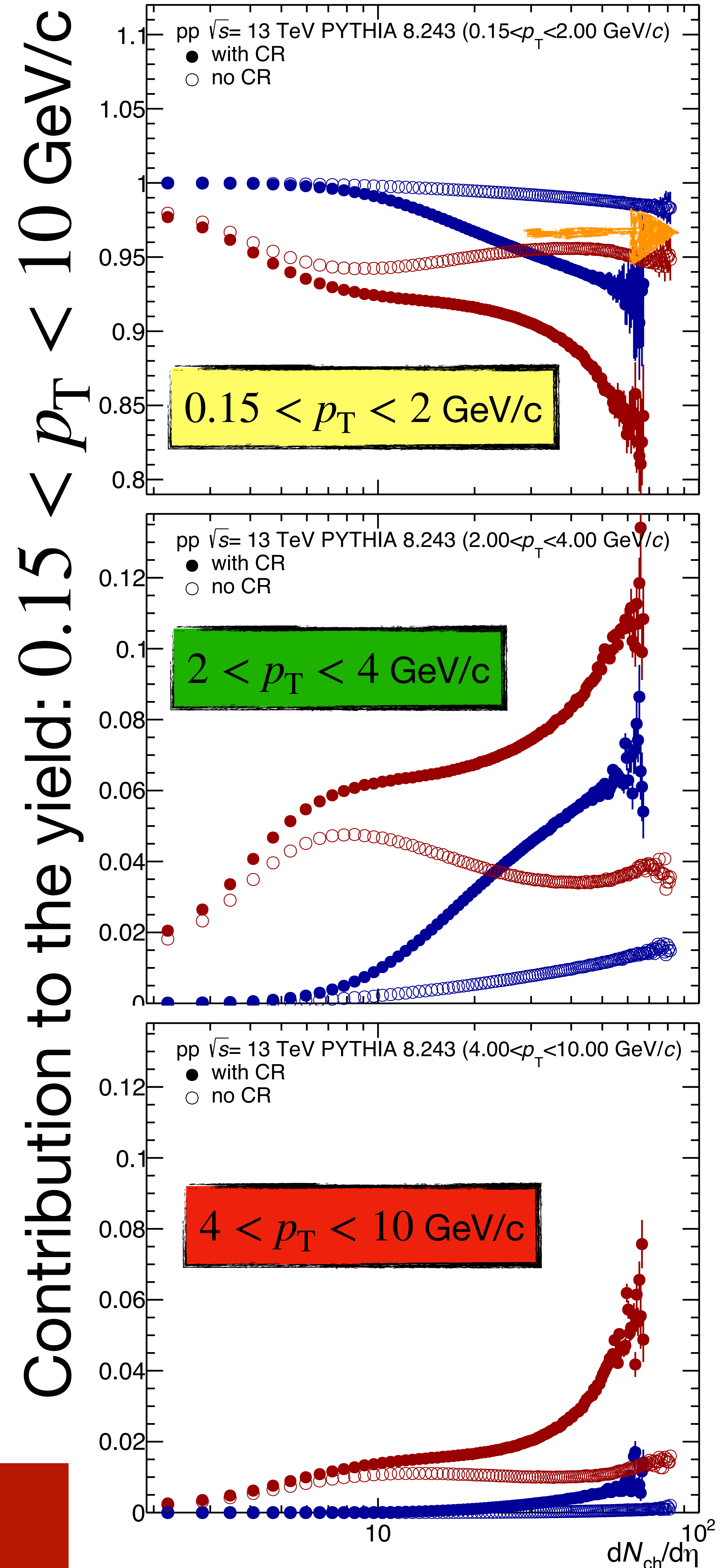
The effect (3rd rise) is still observed in simulations w/o FSR

The effect is influenced by color reconnection?

Simulations w/o CR

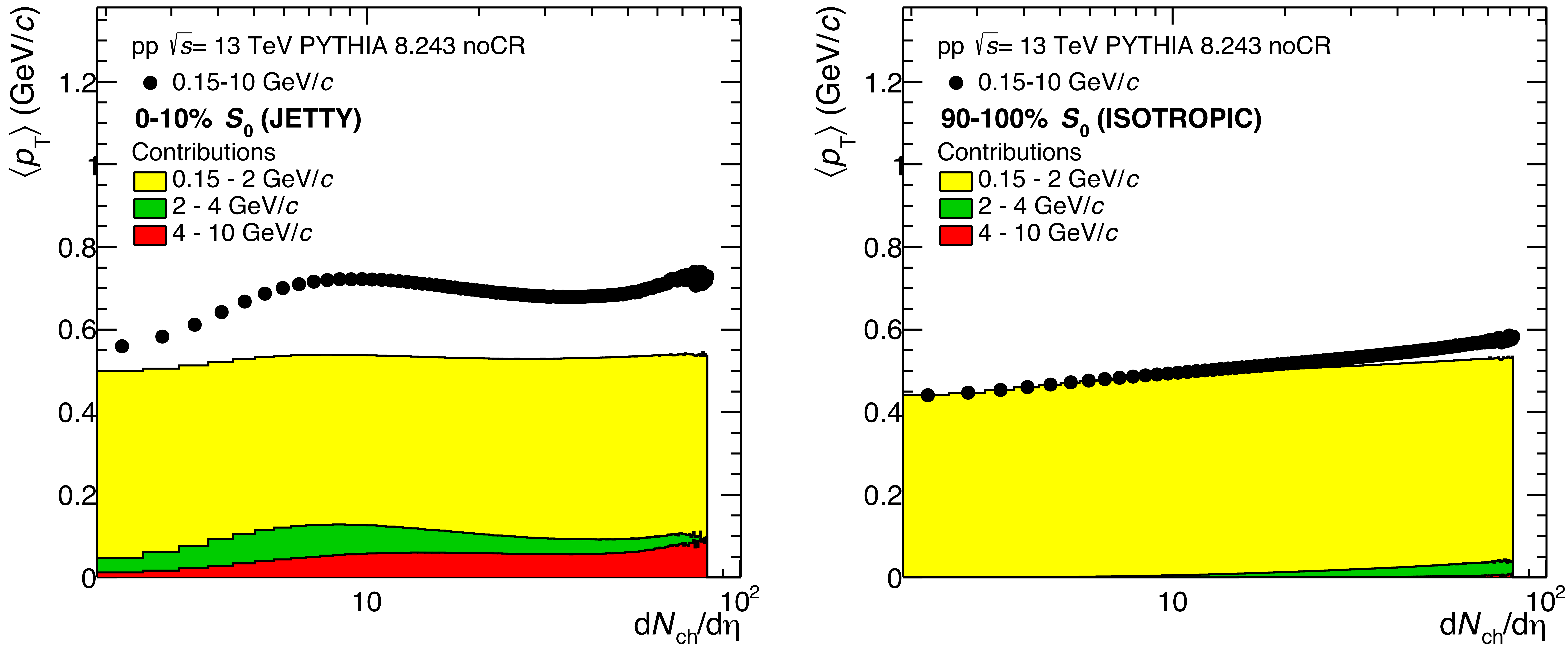
Little or no effect (3rd rise) is observed when CR is switched off





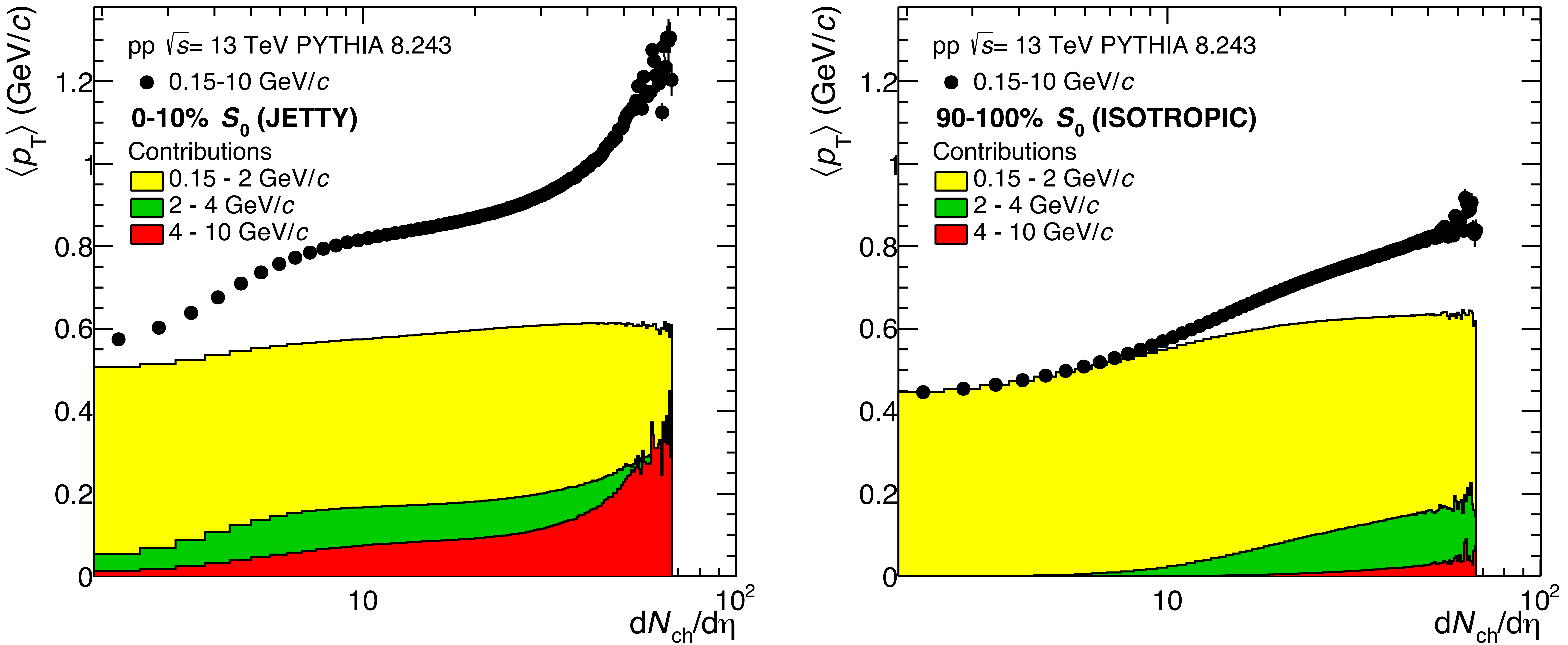
We do not see a dramatic change of the low-p_T particle yield

Contributions of different p_{T} intervals (RR=0)



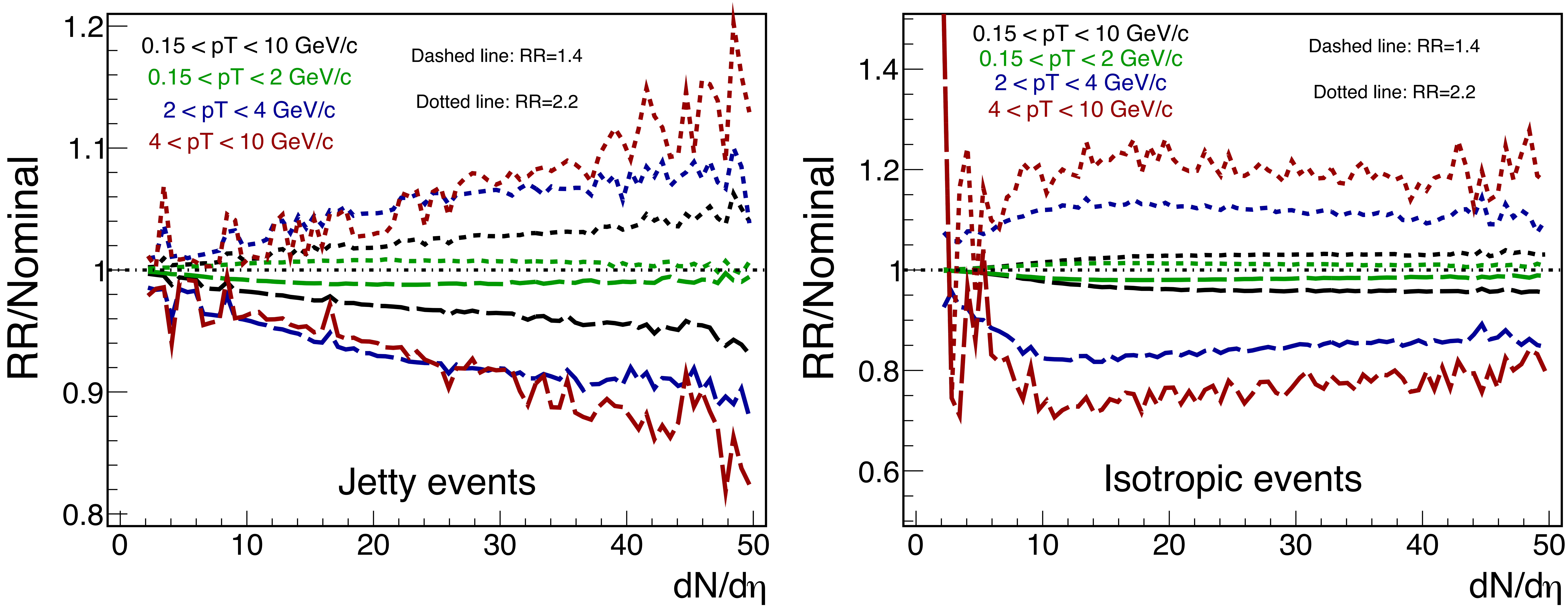
Little or no effect (3rd rise) is observed when CR is switched off. Contribution of high-p_{T} particles slightly increases with increasing multiplicity

Contributions of different p_T intervals (RR=1.8)



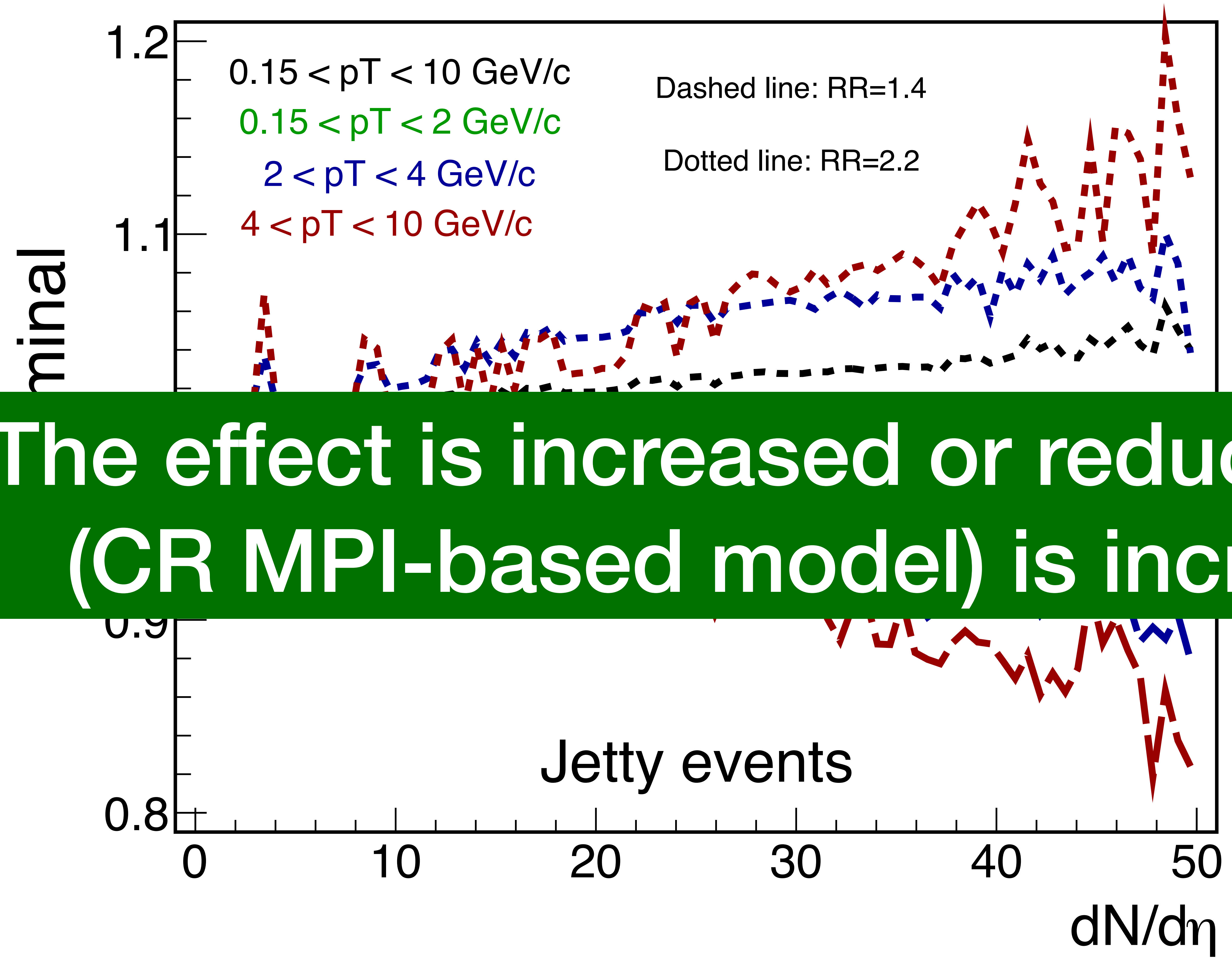
Color reconnection affects both isotropic and jetty-like events. However, the 3rd rise is only observed in jetty like events

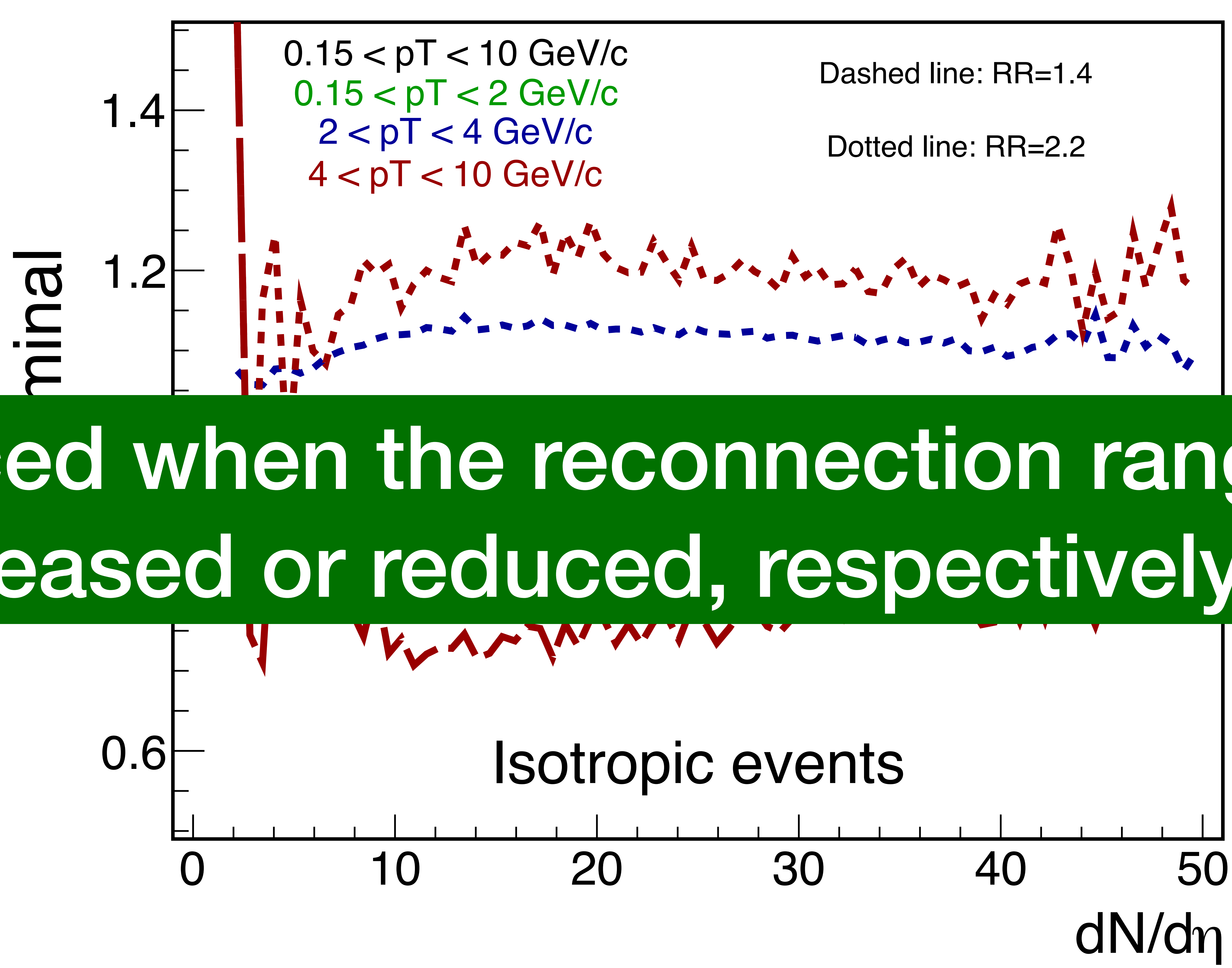
Variation of RR (1.4, **1.8**, 2.4)



High multiplicity: CR effect ($0.15 < p_{\mathrm{T}} < 10\,\mathrm{GeV}/c$) is higher for jetty-like (10%) events than for isotropic (5%) events

Variation of RR (1.4, **1.8**, 2.4)





The effect is increased or reduced when the reconnection range (CR MPI-based model) is increased or reduced, respectively

High multiplicity: CR effect ($0.15 < p_{\mathrm{T}} < 10\,\mathrm{GeV}/c$) is higher for jetty-like (10%) events than for isotropic (5%) events

Summary

- EPOS LHC describes the $\langle p_{\mathrm{T}} \rangle (N_{\mathrm{ch}})$ measured by ALICE. PYTHIA 8 gives a good description for MB and isotropic events

- PYTHIA (6 & 8) with CR gives a 3rd rise of $\langle p_{\mathrm{T}} \rangle$ ($\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta > 30$) for jetty-like events. The effect is not seen in data. This is a surprise because normally PYTHIA does a good job in describing hard physics

    - The effect is produced by high-p_{T} particles

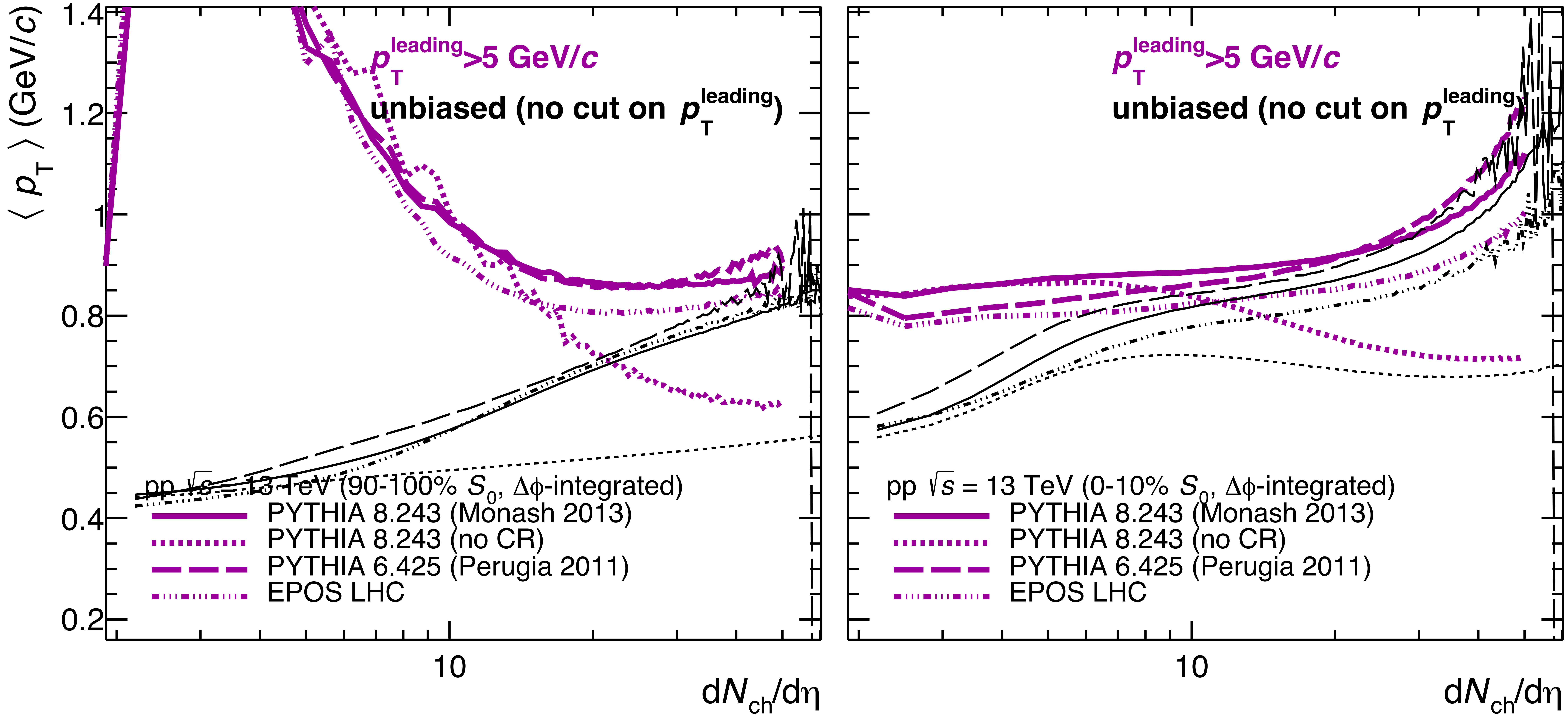
    - The effect is observed in the toward and away sides, and it is absent in the UE region. The effect is not attributed to FSR

    - The effect is connected with strong correlations between UE and jets (CR), but data are better described by models where such a correlation is weaker

- Spherocity is an excellent tool to study high multiplicity pp collisions. New data (p_{T} spectra vs N_{ch} and spherocity) will help to understand why models fail to describe the features of jetty-like events. Comparisons among pp, pA and AA collisions are in progress

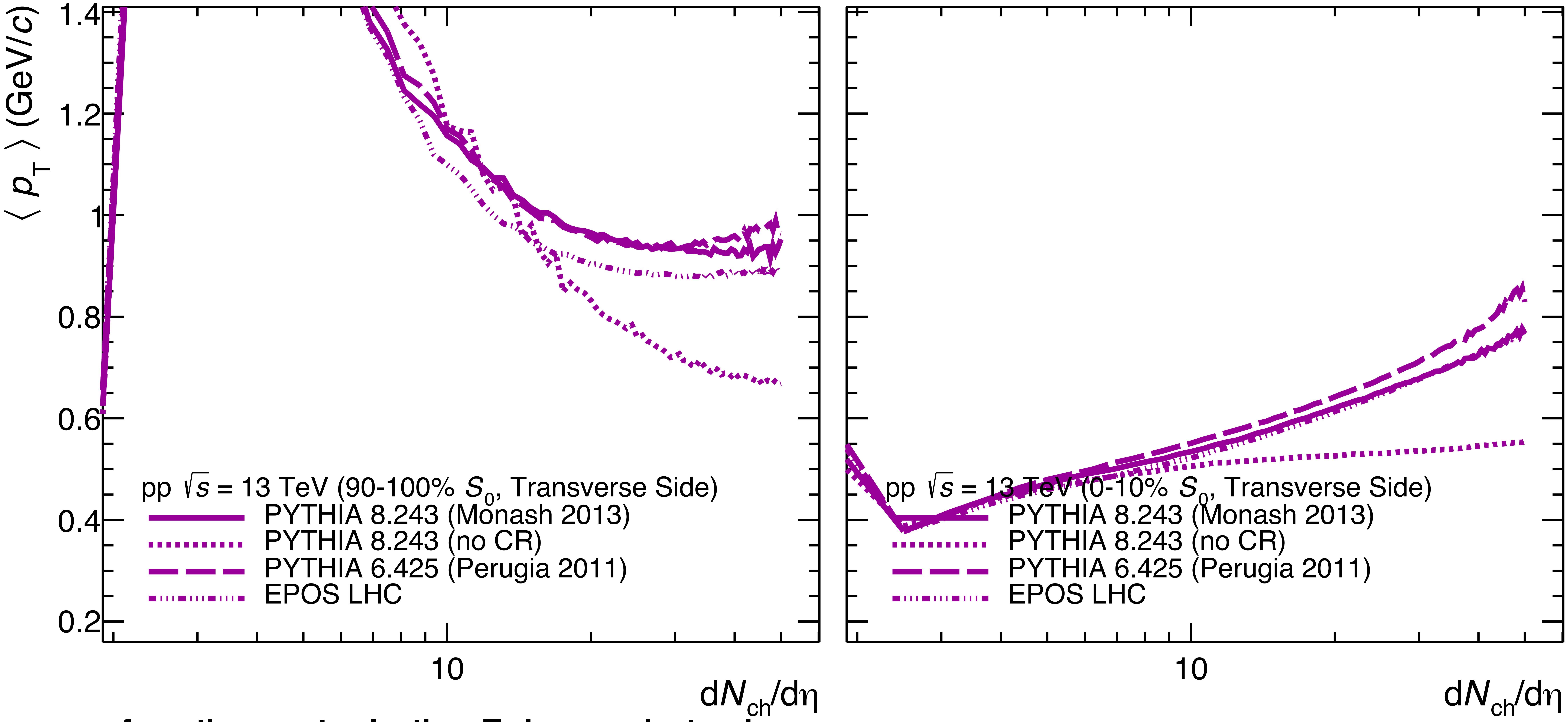
Back up

The bias comes from the event selection. To have an isotropic event with a leading above 5 GeV/c additional high particles are needed to compensate the momentum of the leading



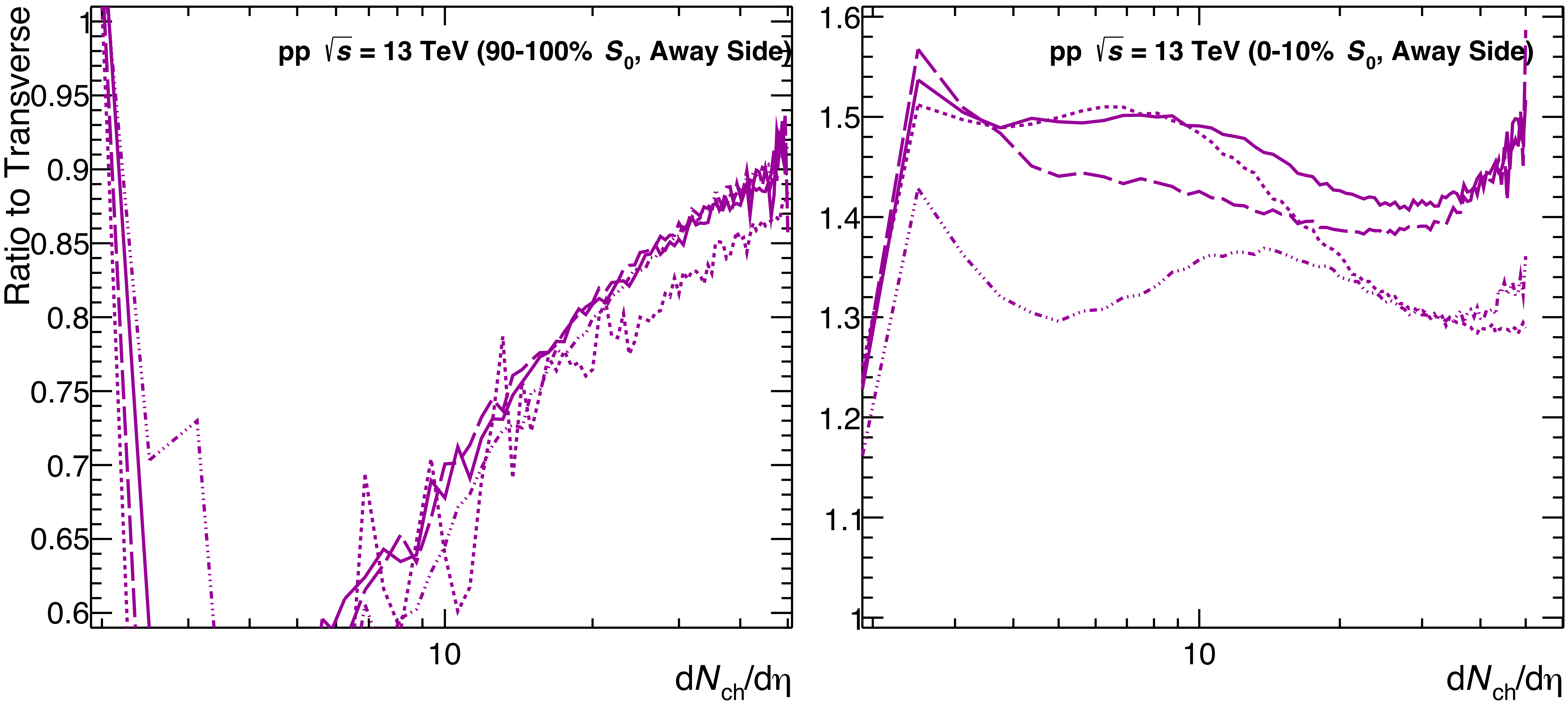
The second rise is observed in jetty events, though it seems smaller given the pT leading selection

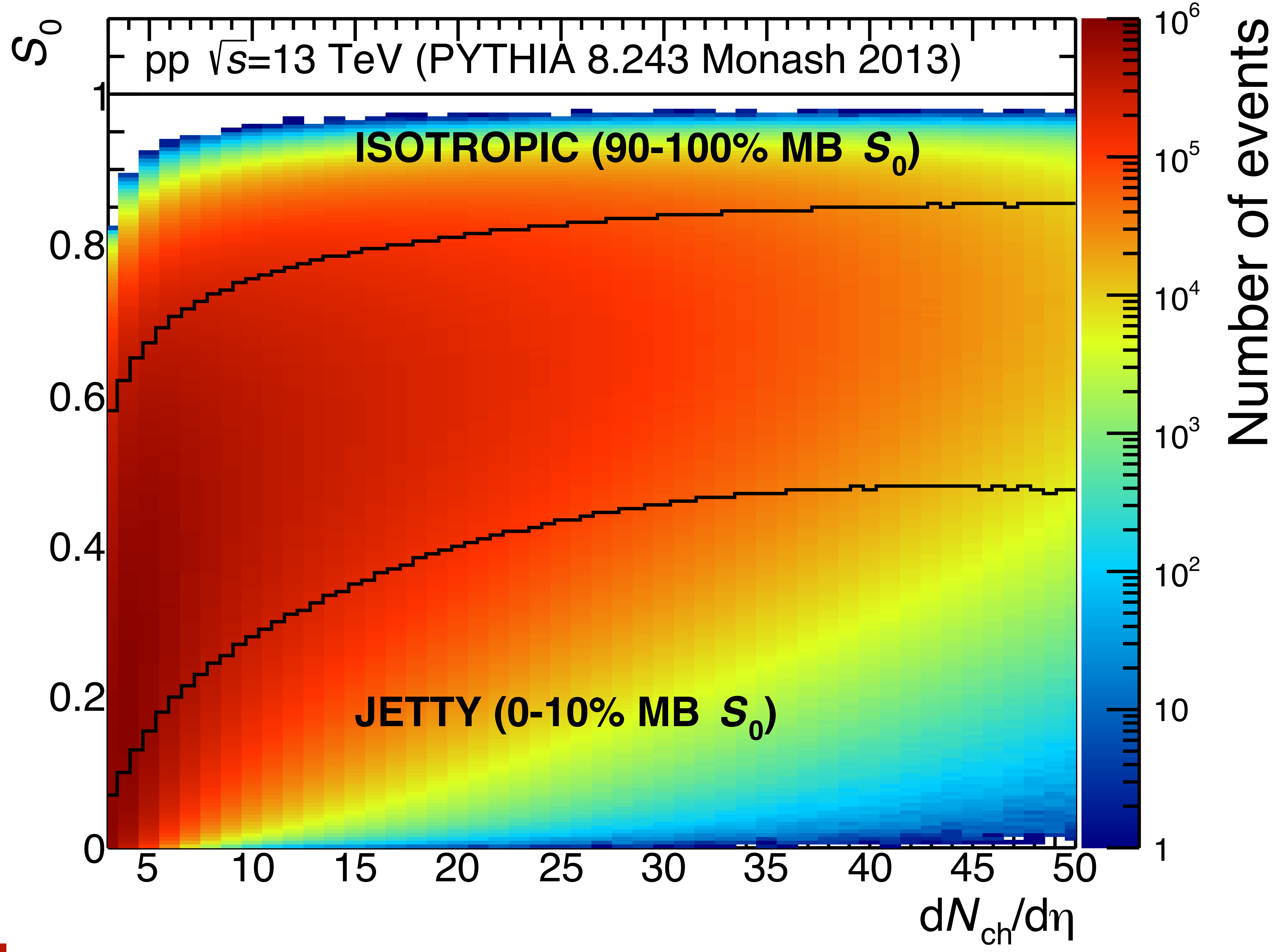
Mean pT transverse side

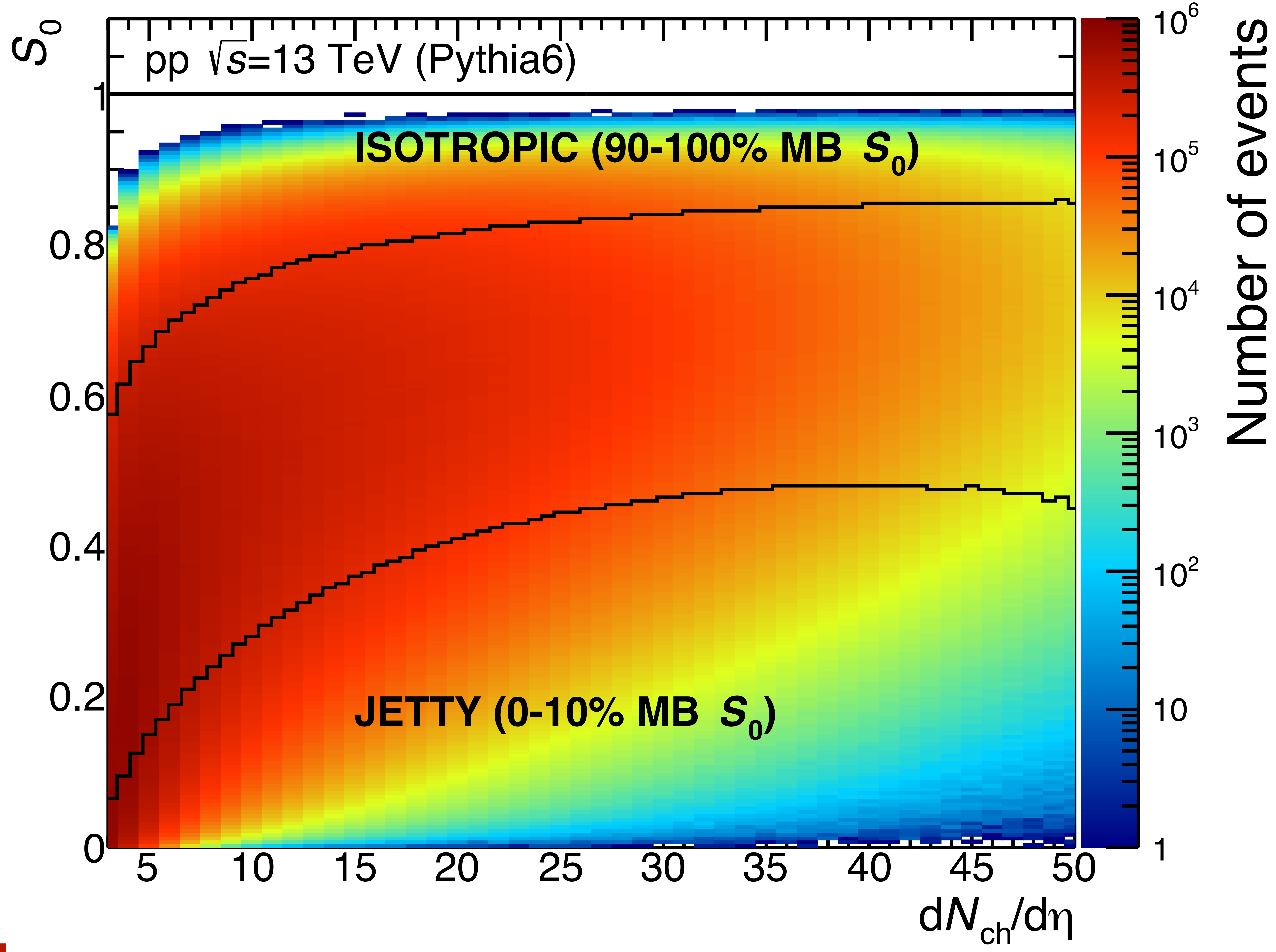


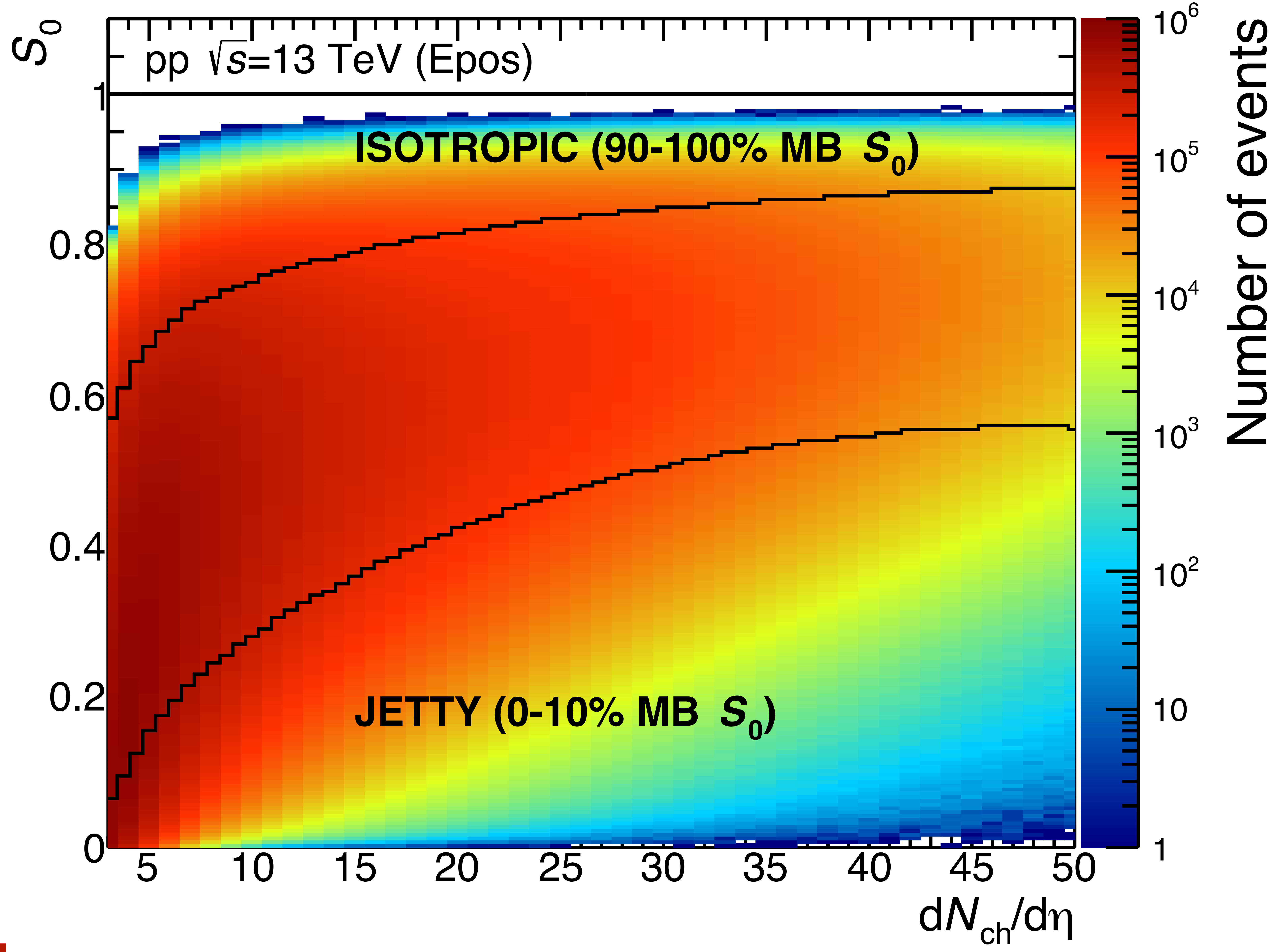
The bias comes from the event selection. To have an isotropic event with a leading above 5 GeV/c additional high particles are needed to compensate the momentum of the leading

Away to transverse

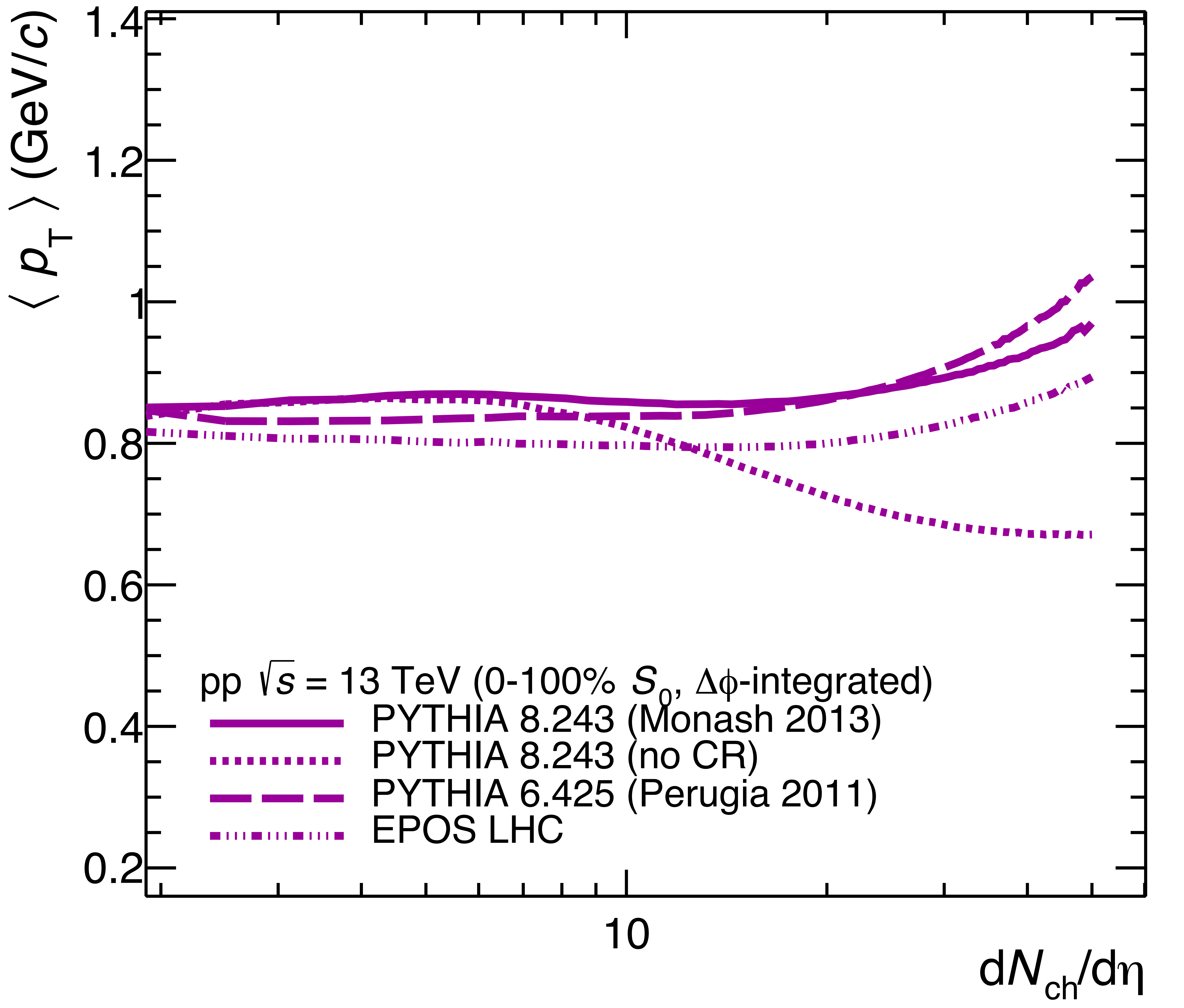



pp √s=13 TeV (PYTHIA 8.243 Monash 2013)
ISOTROPIC (90-100% MB S0)
JETTY (0-10% MB S0)
S0
dNch/dη
Number of events
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
40
45
50
1
10
10^2
10^3
10^4
10^5
10^6

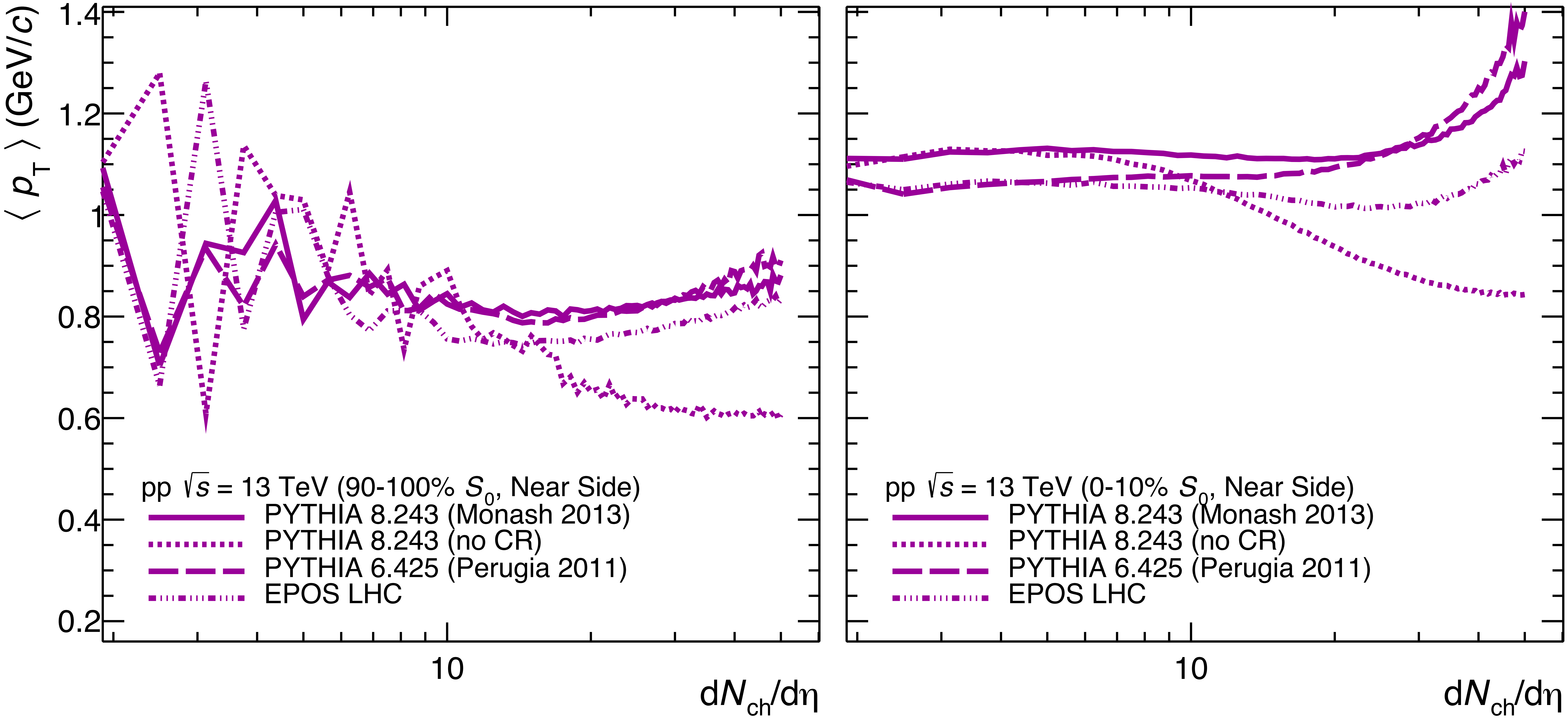

pp √s=13 TeV (Pythia6)
ISOTROPIC (90-100% MB S0)
JETTY (0-10% MB S0)
S0
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
40
45
50
dNch/dη
1
10
10^2
10^3
10^4
10^5
10^6
Number of events



pp √s=13 TeV (Epos)
ISOTROPIC (90-100% MB S0)
JETTY (0-10% MB S0)
S0
dNch/dη
Number of events
0
0.2
0.4
0.6
0.8
1
5
10
15
20
25
30
35
40
45
50
1
10
10^2
10^3
10^4
10^5
10^6

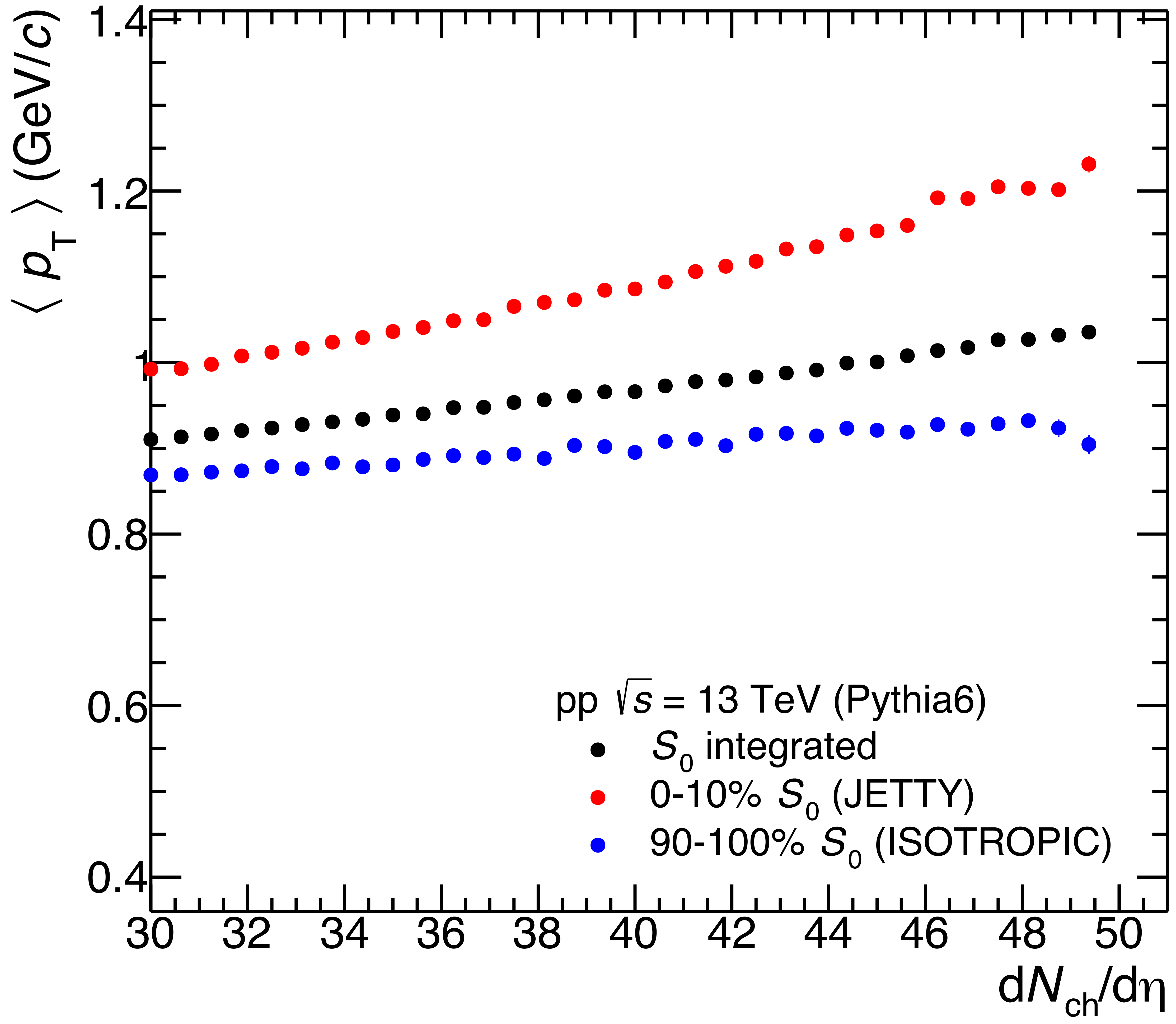


1.4
1.2
1
0.8
0.6
0.4
0.2
10
⟨ p_T ⟩ (GeV/c)
dN_{ch}/dη
pp $\sqrt{s}$ = 13 TeV (0-100% S_0, Δϕ-integrated)
PYTHIA 8.243 (Monash 2013)
PYTHIA 8.243 (no CR)
PYTHIA 6.425 (Perugia 2011)
EPOS LHC



⟨ p_T ⟩ (GeV/c)
1.4
1.2
1
0.8
0.6
0.4
0.2
10
$dN_{ch}/d\eta$
pp $\sqrt{s}$ = 13 TeV (90-100% S_0, Near Side)
PYTHIA 8.243 (Monash 2013)
PYTHIA 8.243 (no CR)
PYTHIA 6.425 (Perugia 2011)
EPOS LHC
pp $\sqrt{s}$ = 13 TeV (0-10% S_0, Near Side)
PYTHIA 8.243 (Monash 2013)
PYTHIA 8.243 (no CR)
PYTHIA 6.425 (Perugia 2011)
EPOS LHC

Effect of cut



The analysis is restricted to dN/deta>30 (seond rise)
Given the cut on pTleading, the average pT is slightly higher than that w/o such a cut
Different trends observed :
Flat for isotropic
Rapid increase for jetty events (second rise)
Difference up to 35% for the highest multiplicity

Features observed w/o cut on pTlreading are preserved

Effect of $p_T^{leading}$ cut (>5 GeV/c)

Little or no effect on Jetty-like events (low Sphero
Given that I am interested in high multiplicity ever
restrict the analysis to dN/deta>30
We use the same dining to that reported by ALICE
(based on MB events)