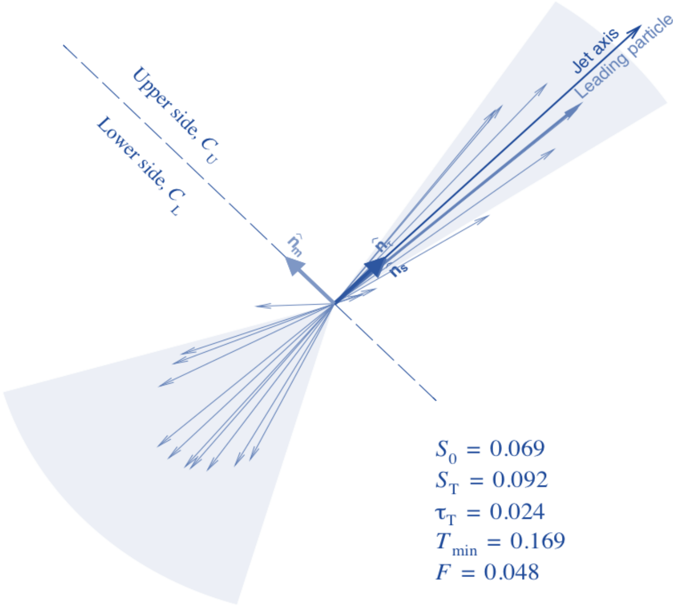

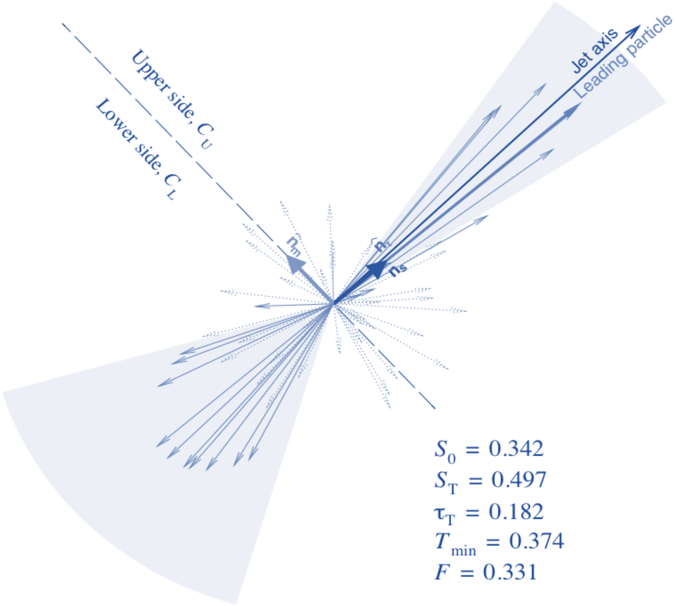

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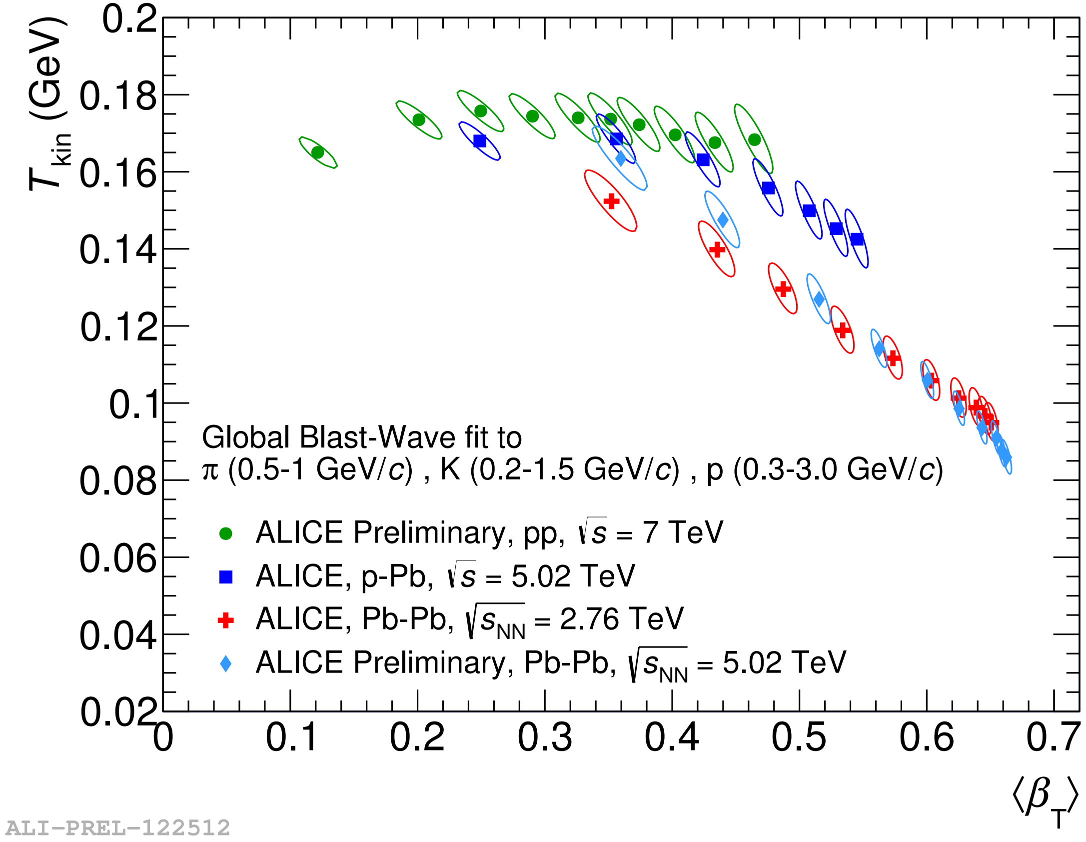
Isolating the new physics using Spherocity

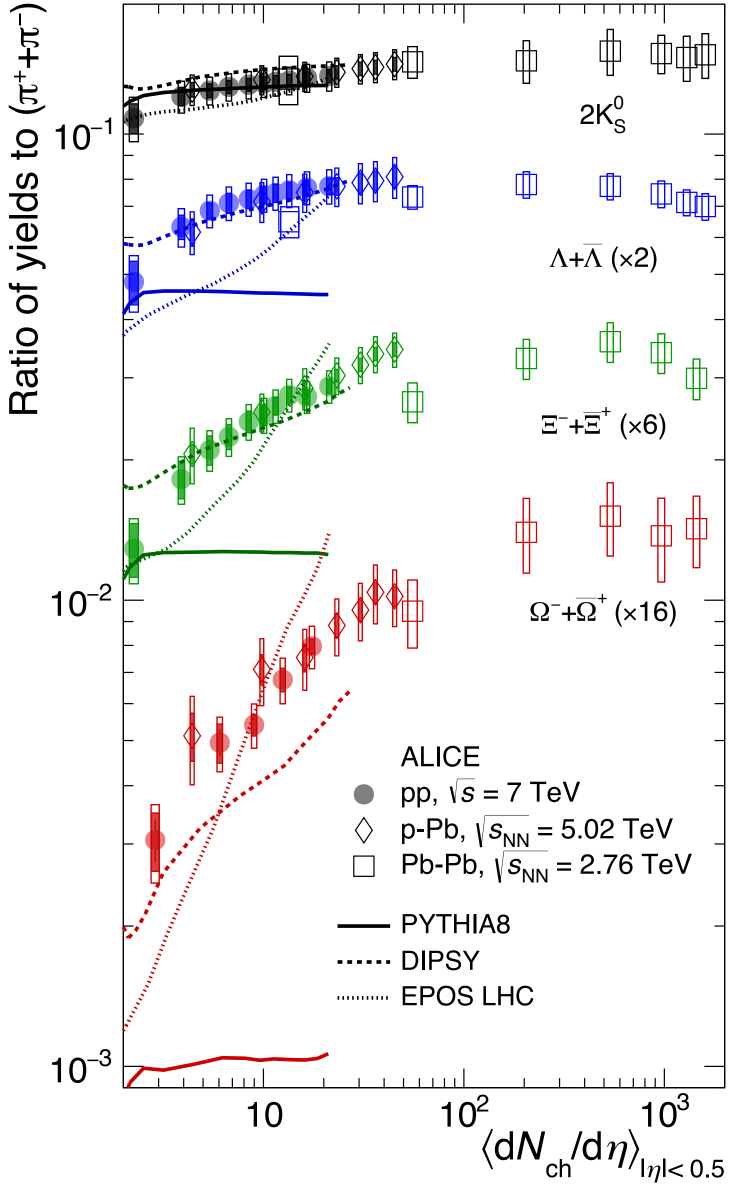
Antonio Ortiz
work in collaboration with Gyula Bencedi

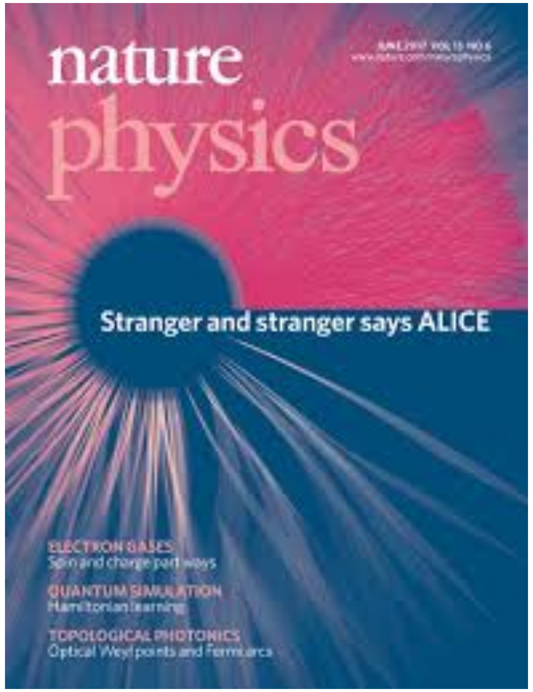
Seminar, Institute for Particle and Nuclear Physics, Wigner RCP Hungarian Academy of Sciences
June 29, 2017

The particle production in small systems (pp and pA) is very similar to that from heavy-ion collisions where we know that the strongly-interacting Quark-Gluon-Plasma (sQGP) is formed



Radial flow in pp collisions



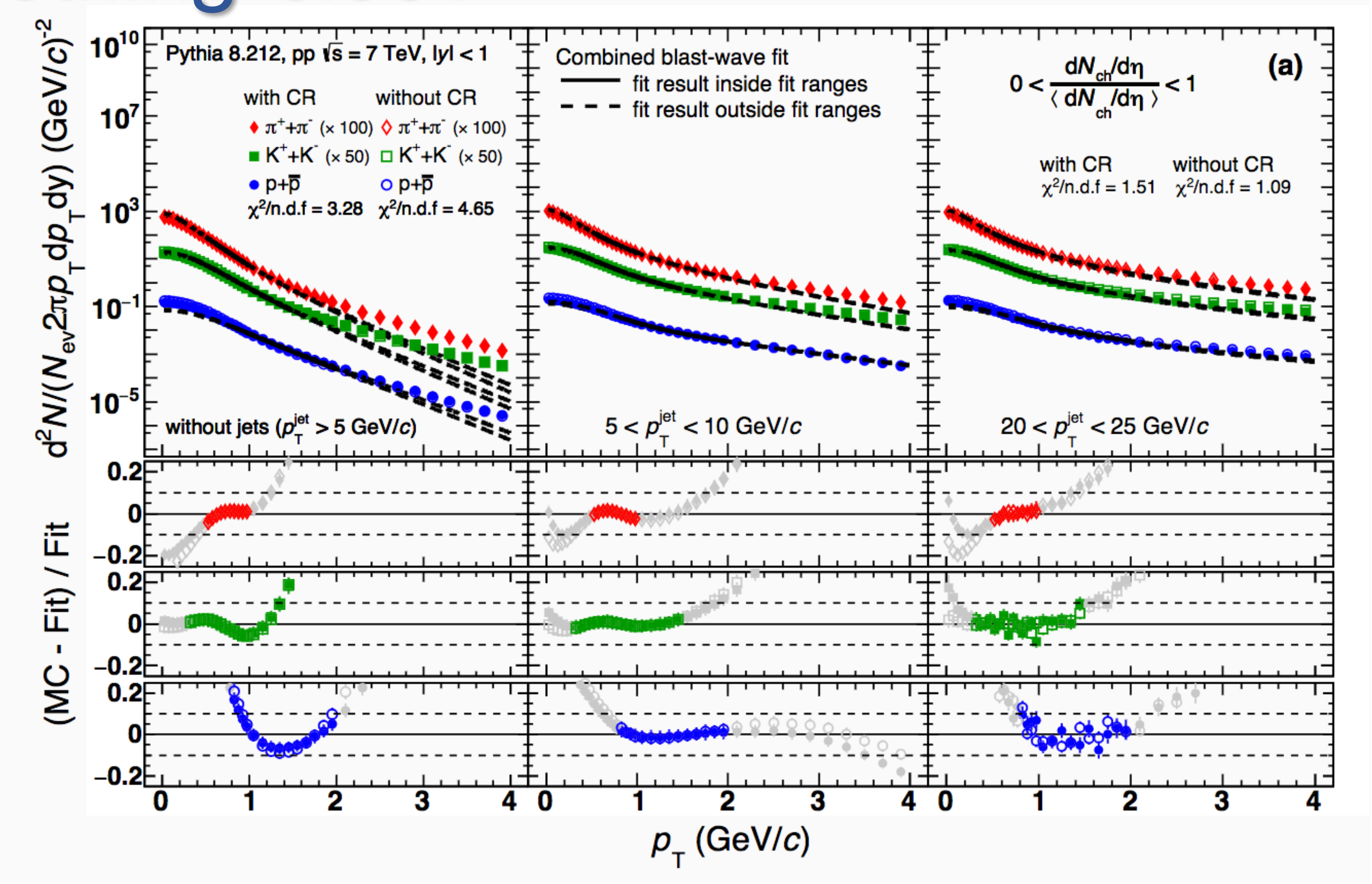


Strangeness enhancement in pp collisions

sQGP or something else?

For example, color reconnection and jets produce flow-like patters

G. Bencedi et al., J. Phys. **G44** (2017) 065001



Outline

- What are the event shape variables?
  - Transverse spherocity (S_0)
- Event selection using S_0: features of the non-isotropic and isotropic events
- Double differential analysis using mid-rapidity charged multiplicity (N_{ch}) and S_0
  - Underlying event (UE) and jet isolation (PYTHIA 8.212)
  - Core-corona separation (EPOS 3.117*)
- First results on $\langle p_T \rangle$ vs N_{ch} using ALICE data
- Summary

* Thanks to Klaus for providing EPOS 3.117. Albeit, this is not the most updated versions of the generator, it allows to check the ideas presented here.

Event shapes

- Several studies using event shapes were performed in e^+e^- annihilation processes
  - Extraction of the energy dependence of α_S JADE, EPJC **1** (1998) 461
  - Jet studies G. Hanson et al., PRL **35** (1975) 1609
  - Gluon discovery (e.g. MARK-J, PRL **43** (1979) 830)
  - Correction due to hadronization effects S. Kluth et al., EPJC **21** (2001) 19
- At hadron colliders pQCD calculations are available for a vast number of event shapes (e.g. A. Banfi et al., JHEP **06** (2010) 038)
  - QCD has been extensively tested in the perturbative regime, e.g.
    - CMS, PLB **722** (2013) 238; ATLAS EPJC **72** (2012) 2211; CDF, PRD **83** (2011) 112007
- For the soft regime few measurements have been reported for hadron colliders, allowing to test the phenomenological models, e.g.
  - ALICE, EPJC **72** (2012) 2124; ATLAS, PRD **88** (2013) 032004
- In this talk, I will discuss other possibilities for the soft regime

Transverse spherocity

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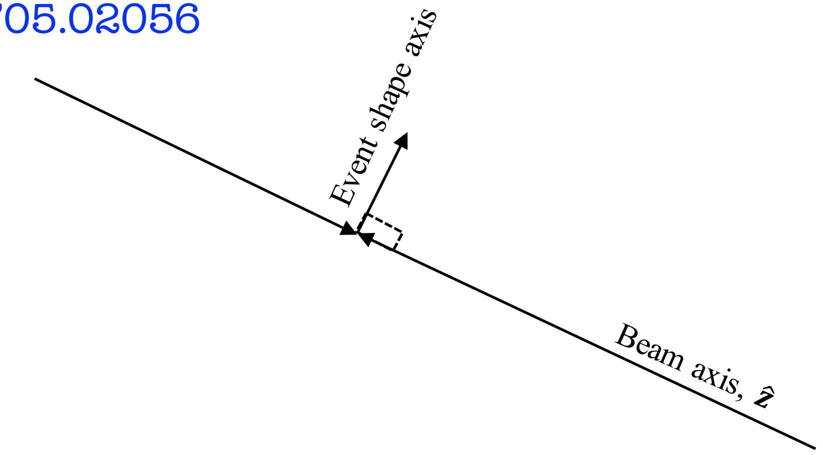
- “Event shapes measure the geometrical properties of the energy flow in QCD events and, notably, its deviation from that expected based on pure lowest order partonic predictions” A. Banfi et al., JHEP **1006** (2010) 038
- At hadron colliders, the event shape axis is searched in the plane perpendicular to the beam axis
- Then, the radiation perpendicular to the plane formed by the main hard scattering (≈event shape axis) and the beam axis would be sensitive to soft physics

arXiv:1705.02056



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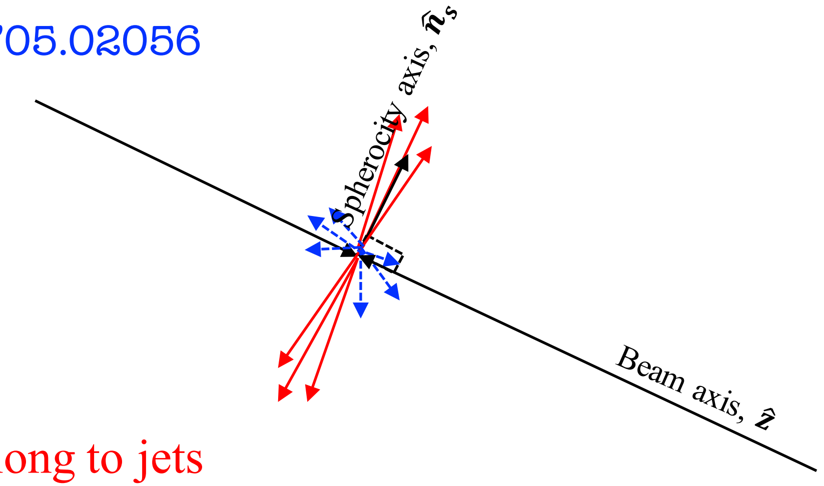

$p_{\rm T}$'s belong to jets
$p_{\rm T}$'s belong to UE

By definition, transverse spherocity is sensitive to soft physics

$$S_0 \equiv \frac{\pi^2}{4} \min_{\hat{n}_s} \left(\frac{\sum_i^{N_{\rm ch}} |\vec{p}_{{\rm T},i} \times \hat{n}_s|}{\sum_i^{N_{\rm ch}} p_{{\rm T},i}} \right)^2$$

(events with more than 2 charged particles within $|\eta|<0.8$ and $p_{\rm T}>0.15$ GeV/c)

Transverse spherocity

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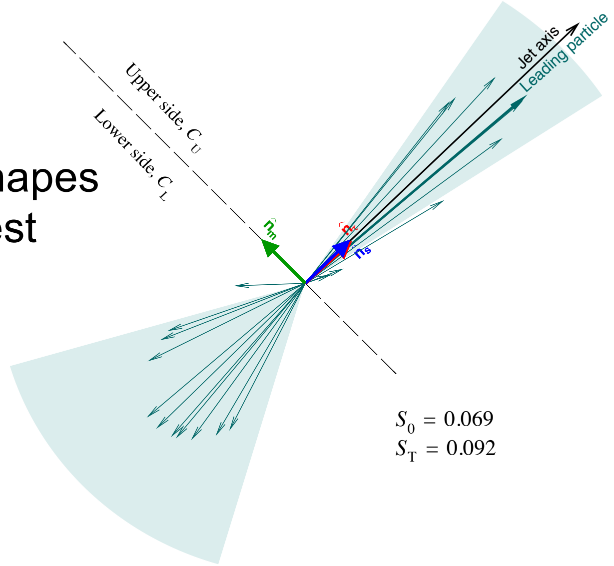
Dijet
By definition, the event shapes go to zero or to their lowest value



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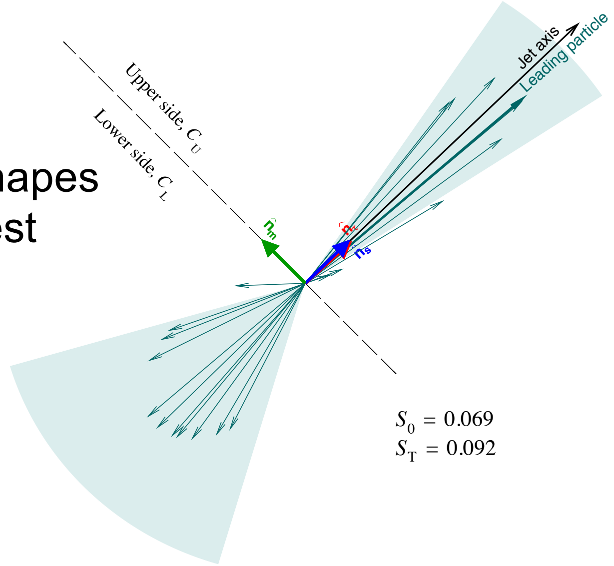
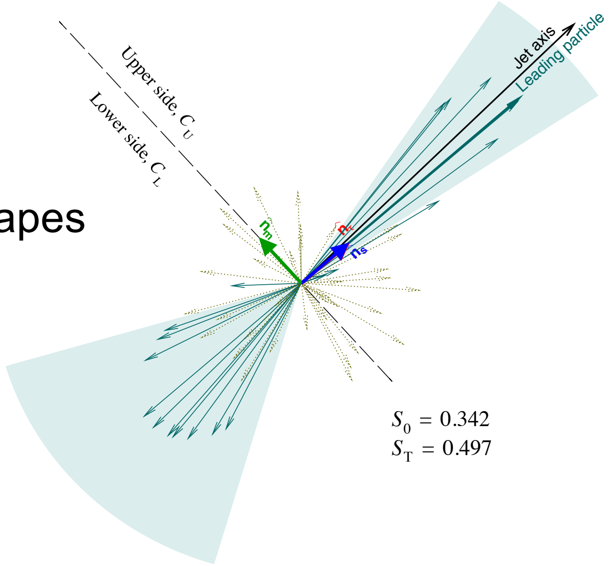


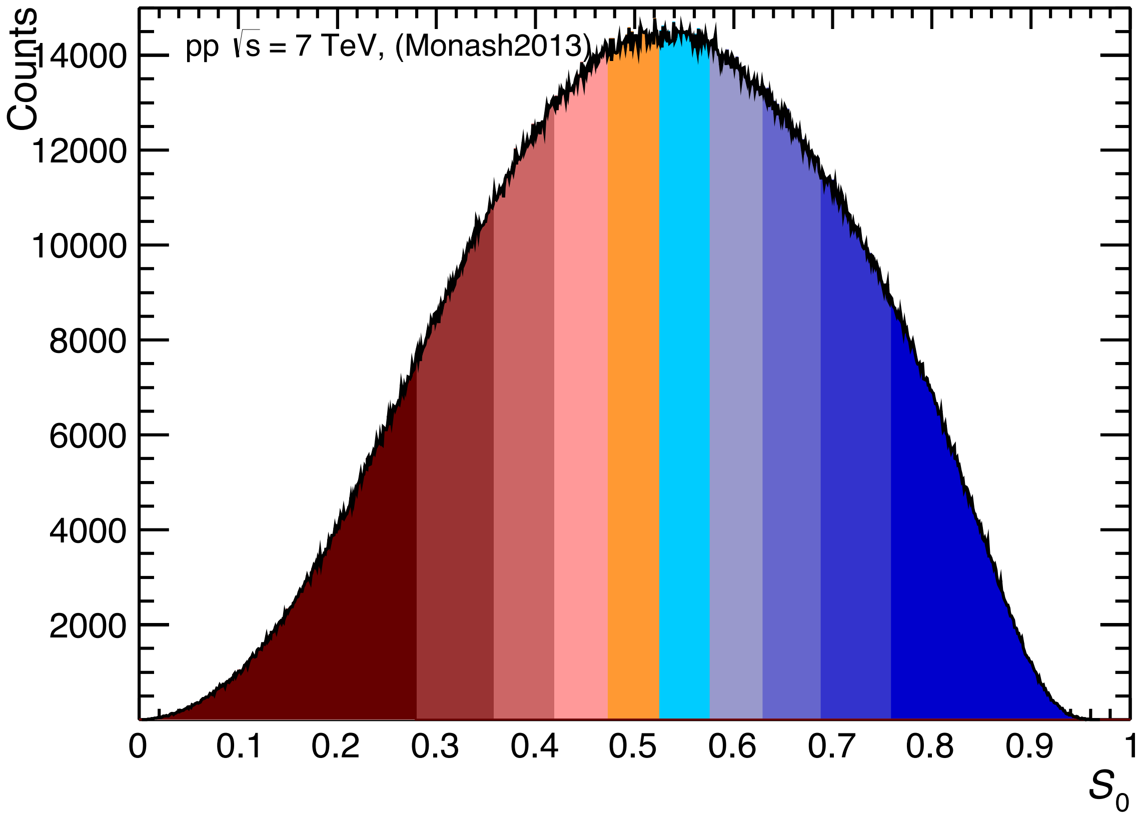
Dijet + UE
Overall, the event shapes increase their values



Event features: low – high S_0

Simulations: INEL pp collisions at $\sqrt{s}$ = 7 TeV, PYTHIA 8.212

- In this exercise we chose events with more than 15 charged particles ($|\eta|<0.8$)



The analysis is performed using spherocity percentiles

- 10% for each event class

Event features: low – high S_0

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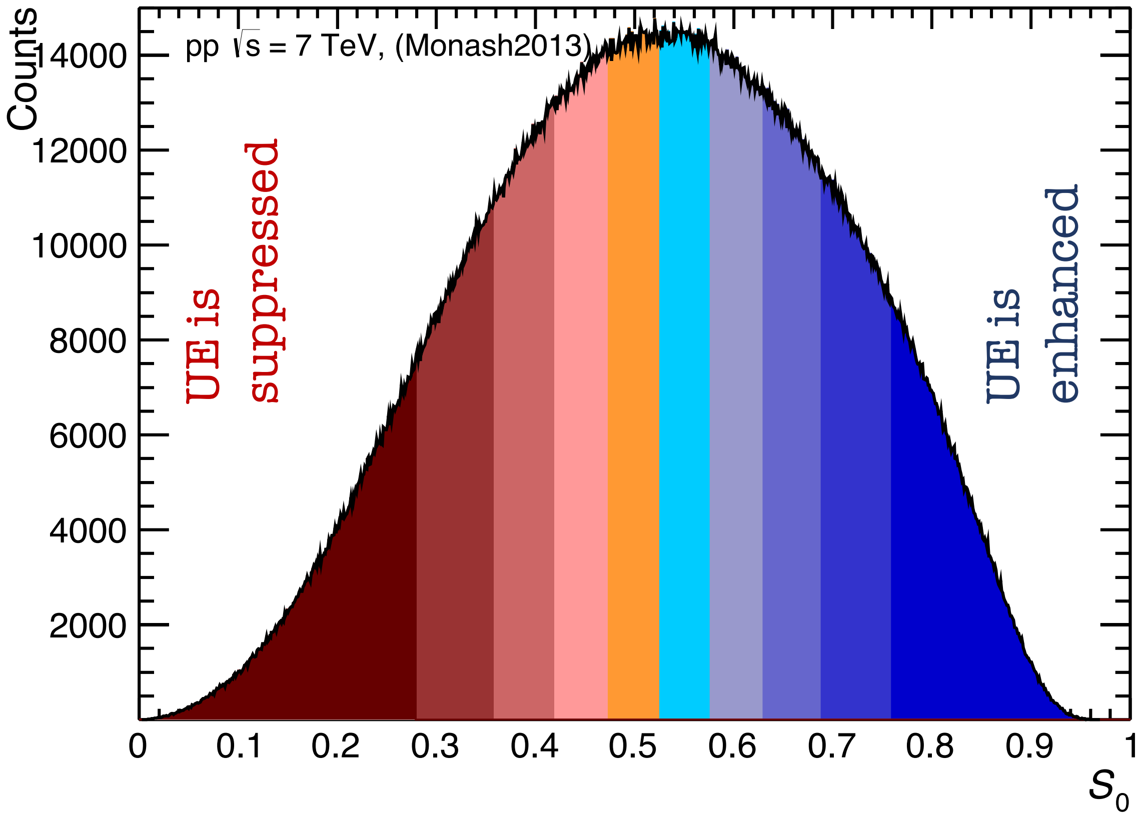
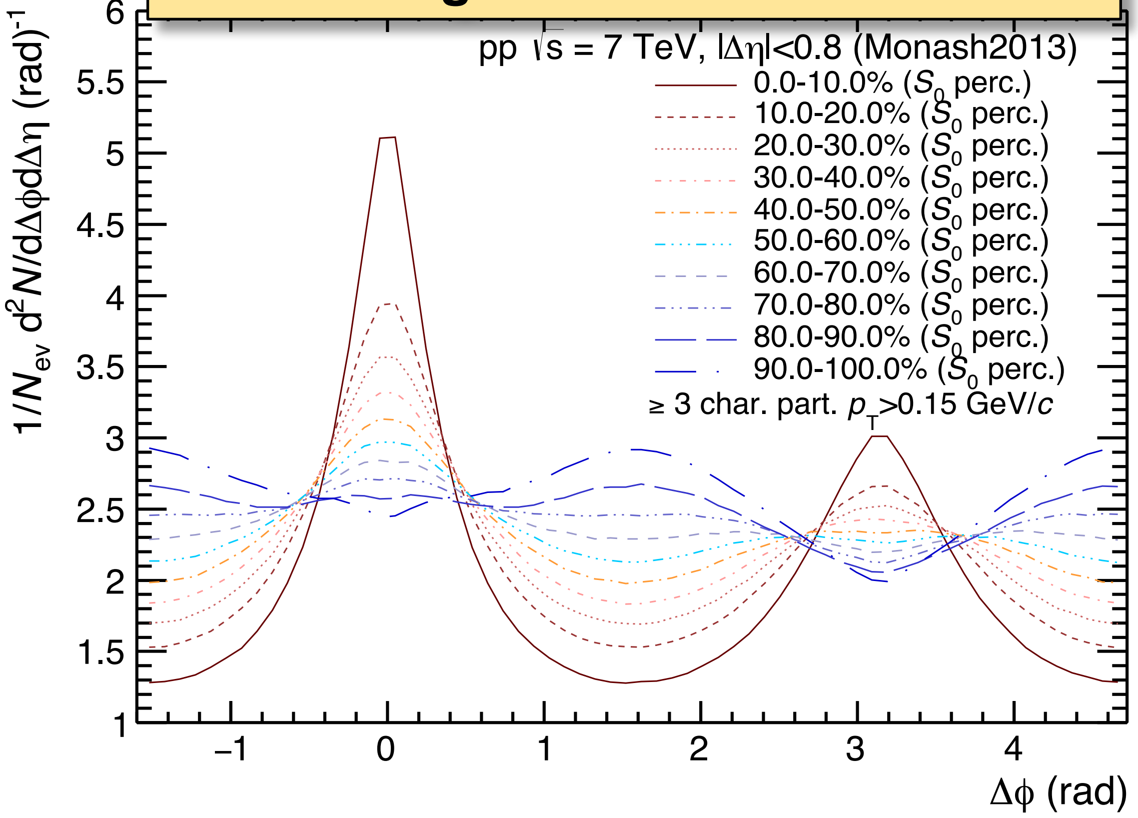


Leading-hadron correlations



EPJC **62** (2009) 535, also studied by Vytautas Vislavicius

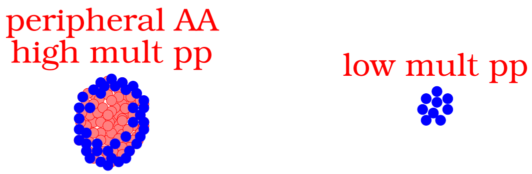
Simulations using EPOS 3

Secondary interactions

Core-corona procedure (for pp, pA, AA)

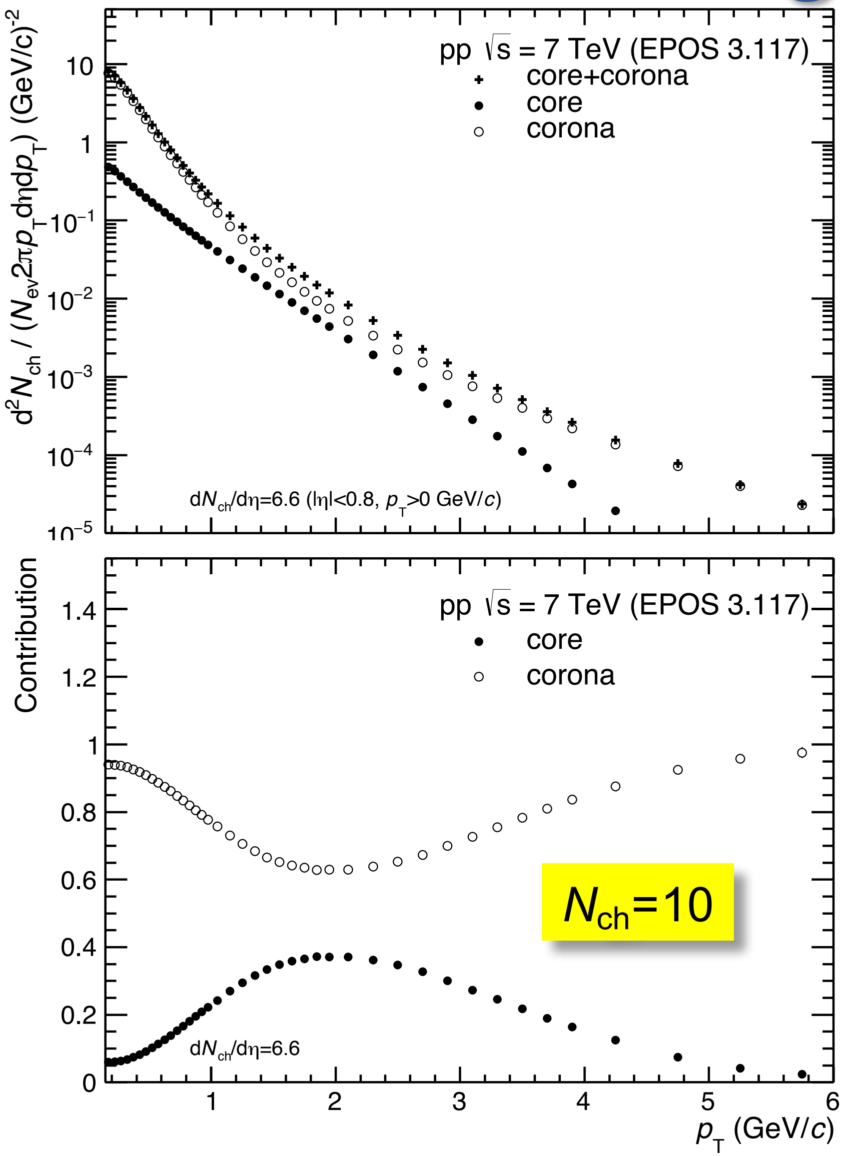
(Many) Pomerons => parton ladders => flux tubes (kinky strings)

String segments with high pt escape => **corona**,
the others form the **core** = initial condition for hydro
depending on the local string density



core => hydro => statistical decay ($\mu = 0$)
corona => string decay

Simulations using EPOS 3



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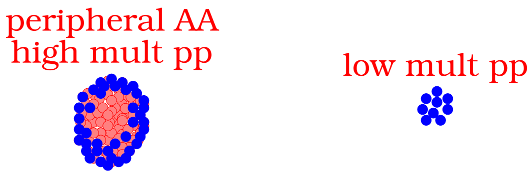

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p_T spectra vs S_0 (N_{ch}=10)

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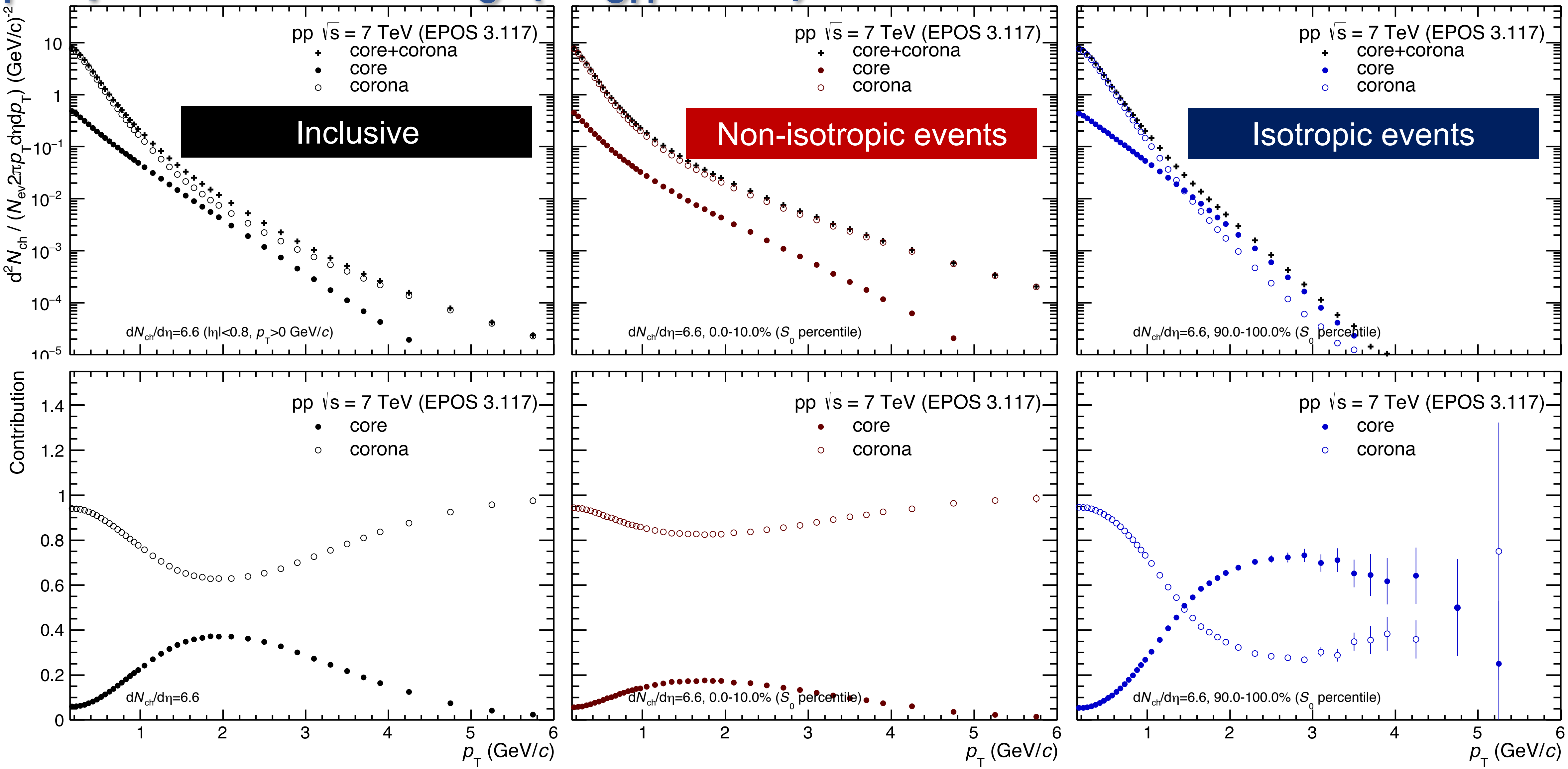
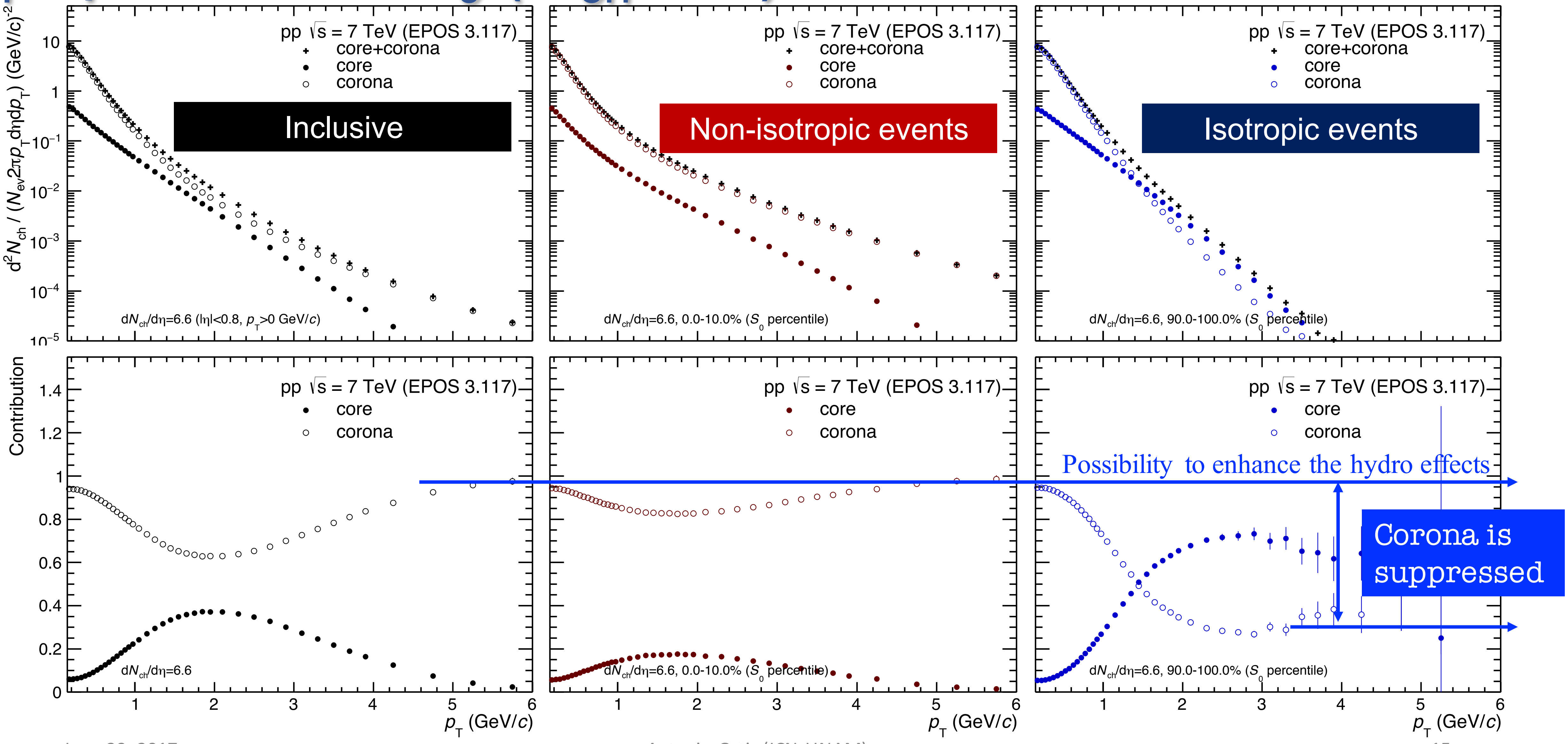


p_T spectra vs S_0 (N_{ch}=10)



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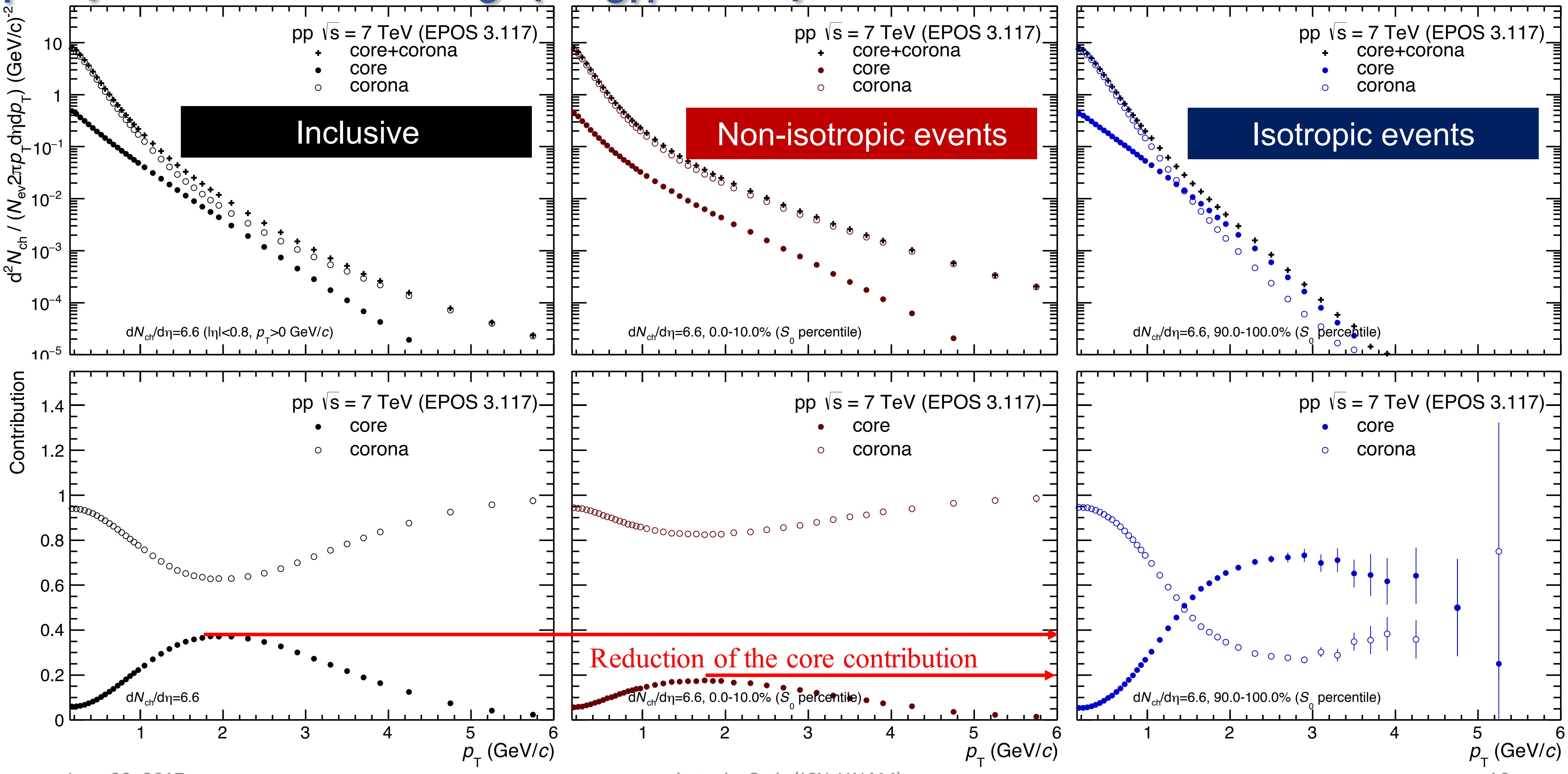

p_T spectra vs S_0 (N_{ch}=64)

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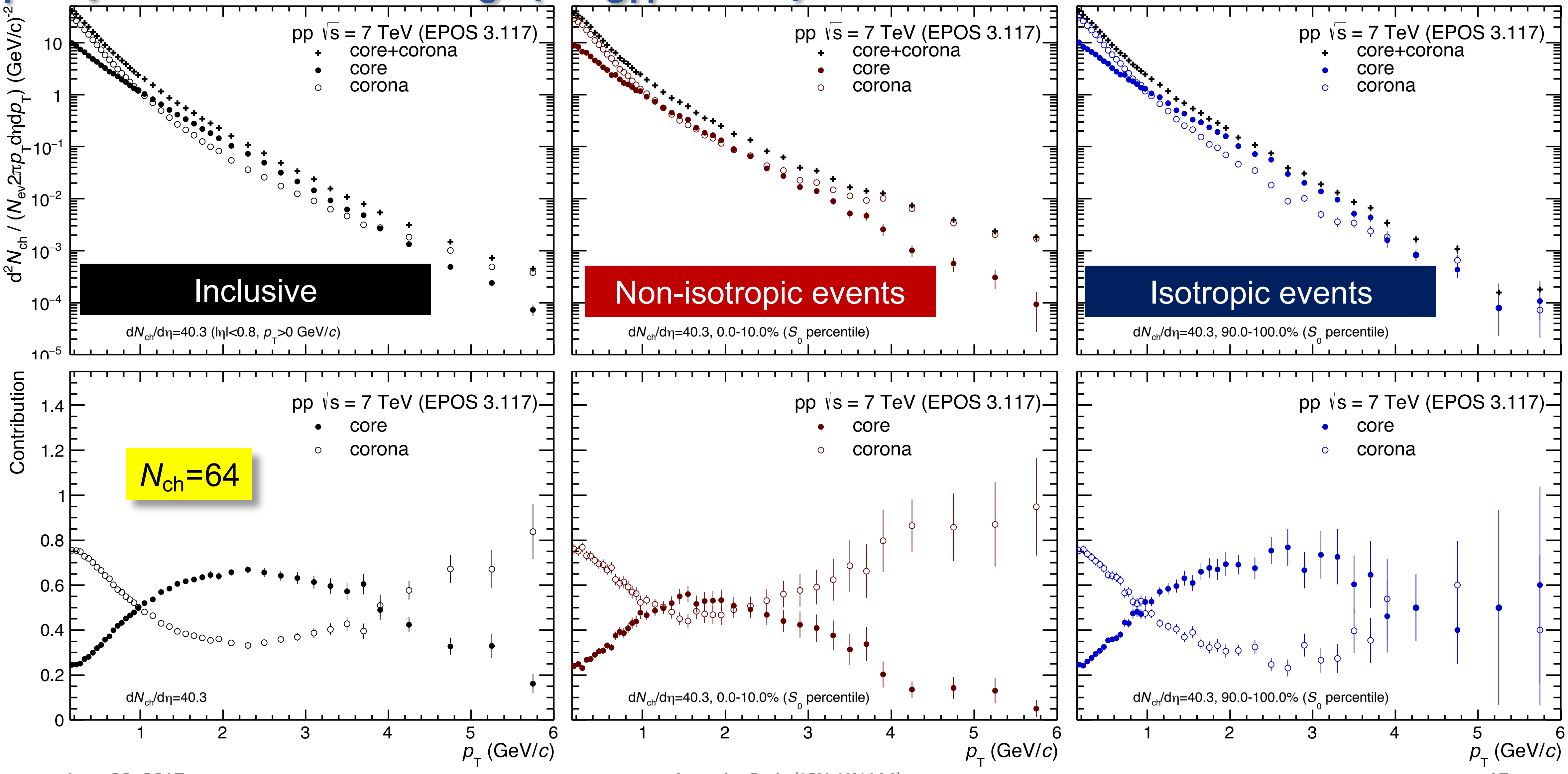

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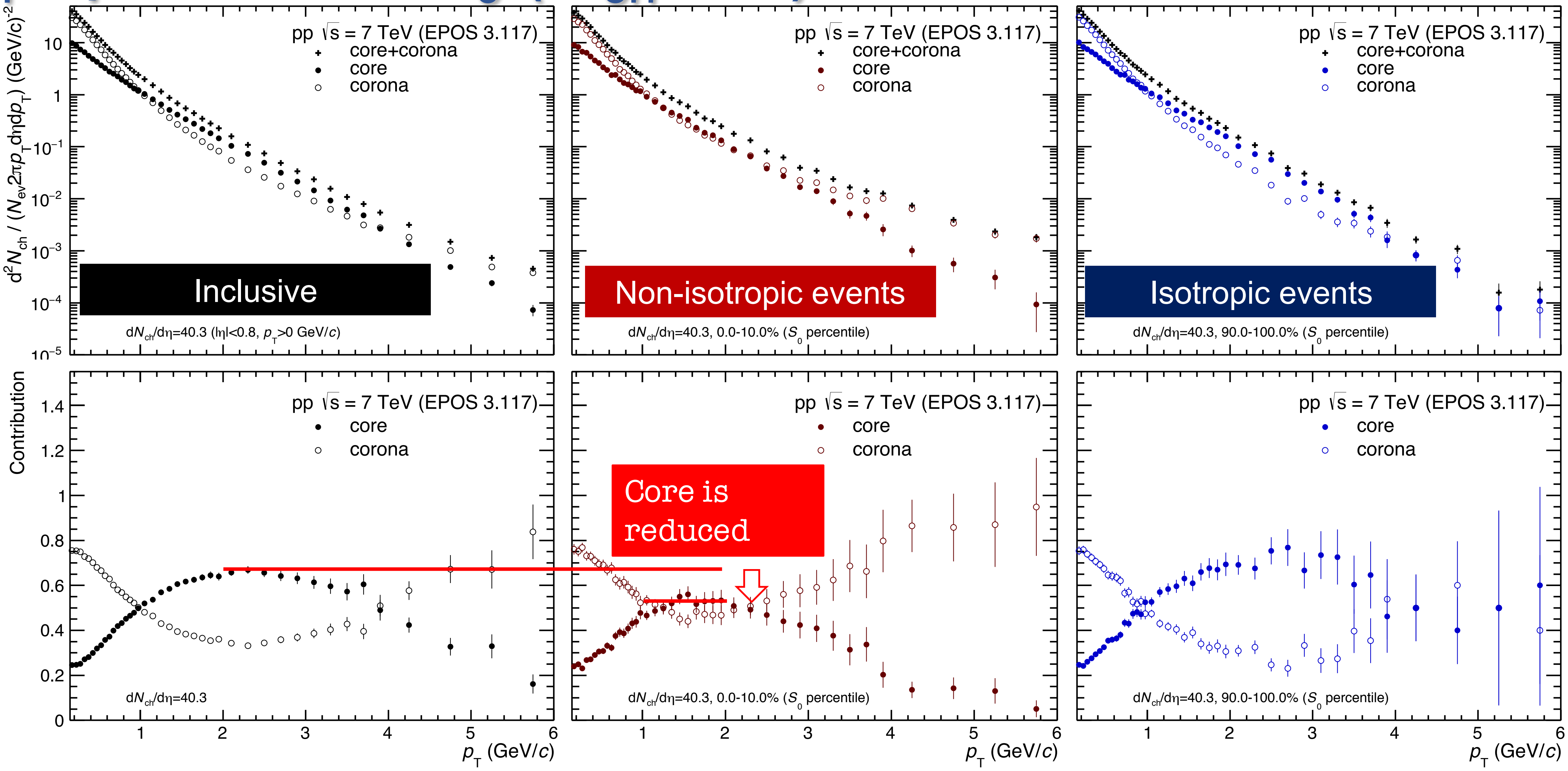
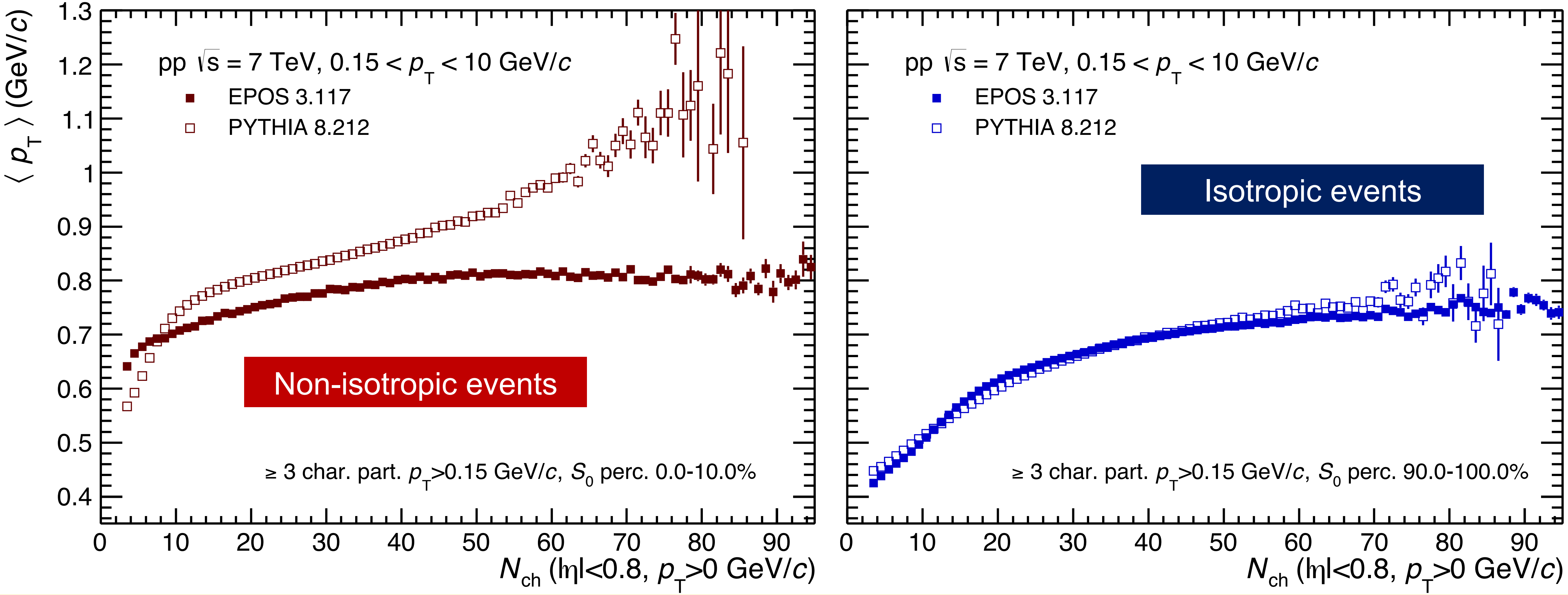


EPOS vs PYTHIA ($\langle p_{\rm T}\rangle$ vs $N_{\rm ch}$)



Within uncertainties, PYTHIA 8 and EPOS (LHC) describe well the inclusive data: ALICE, PLB **727** (2013) 371

Adding S_0, differences between EPOS and PYTHIA are found

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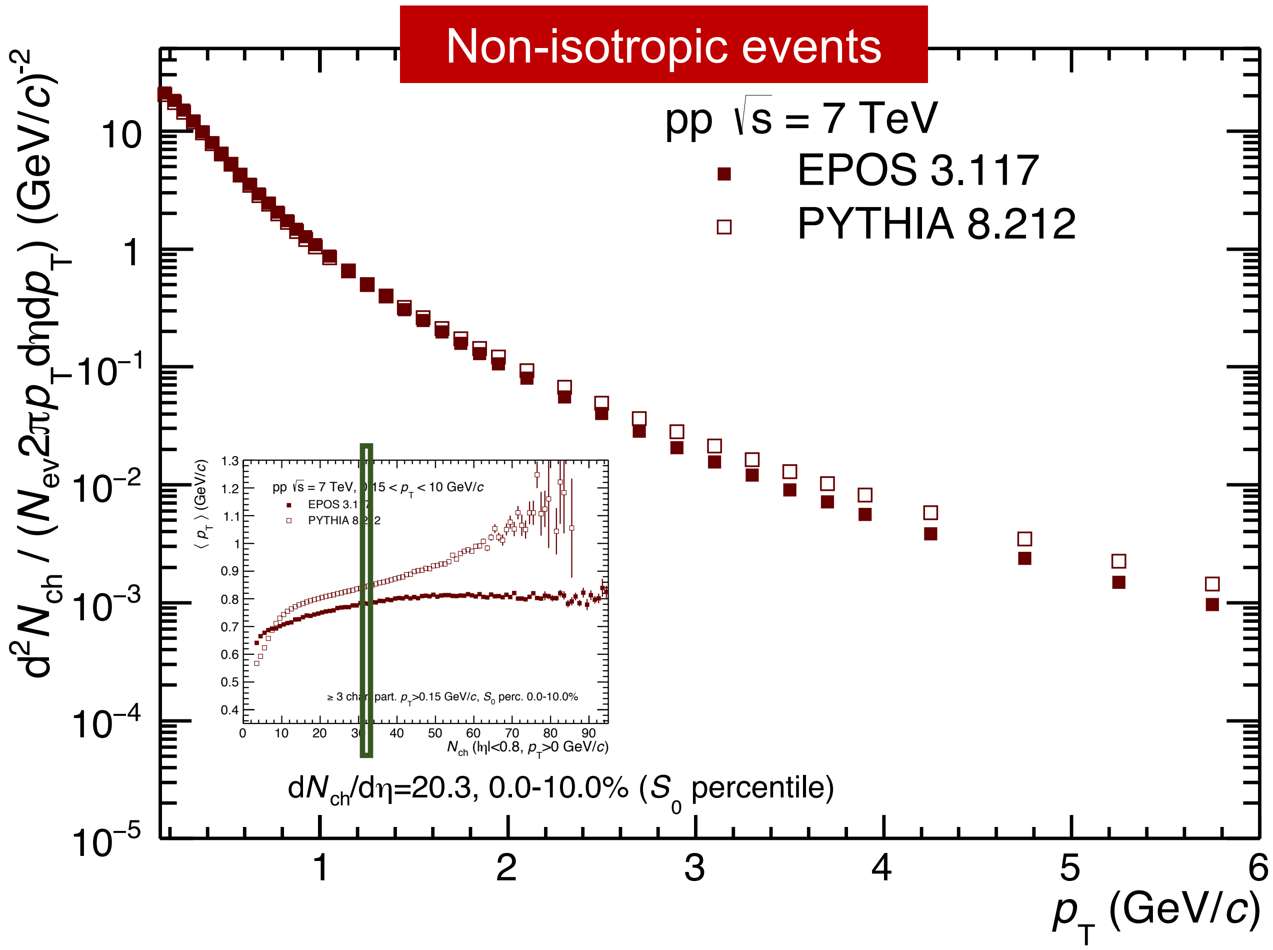
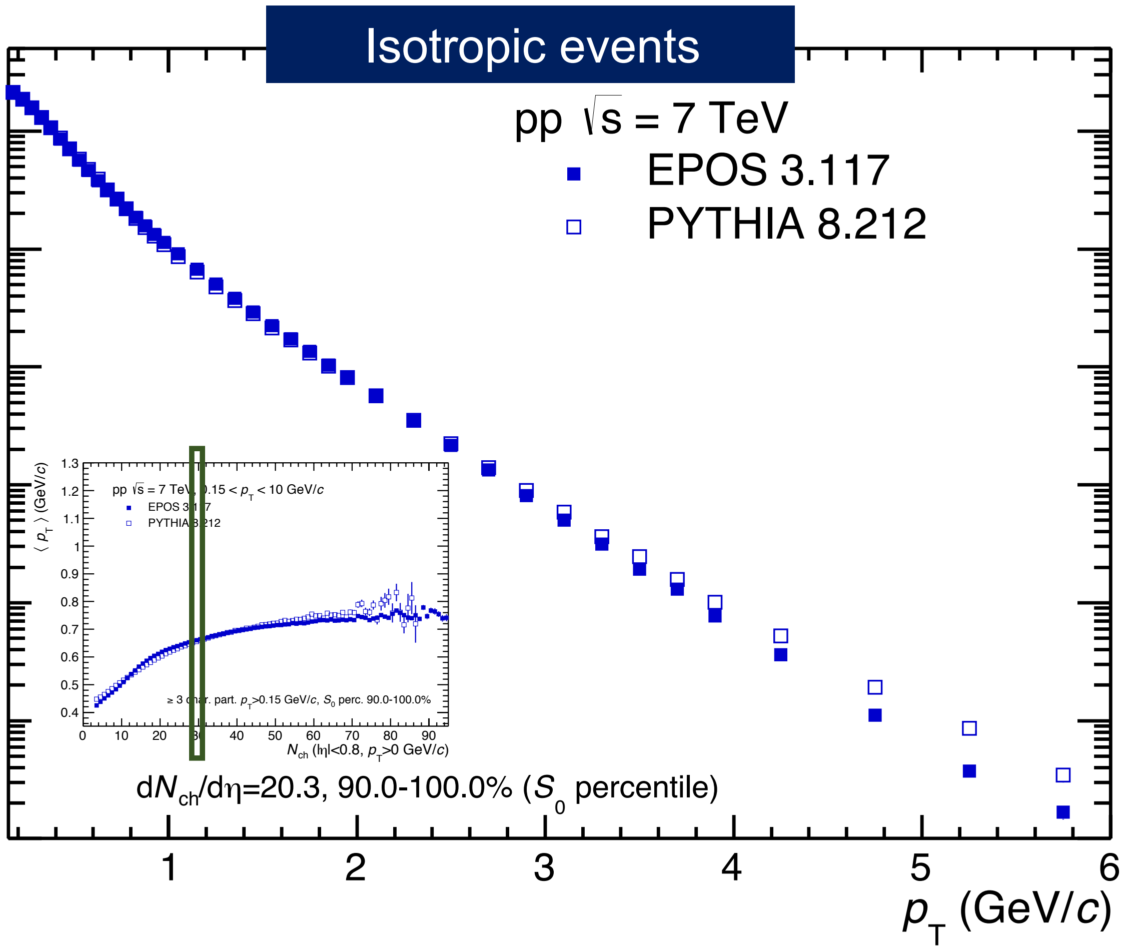
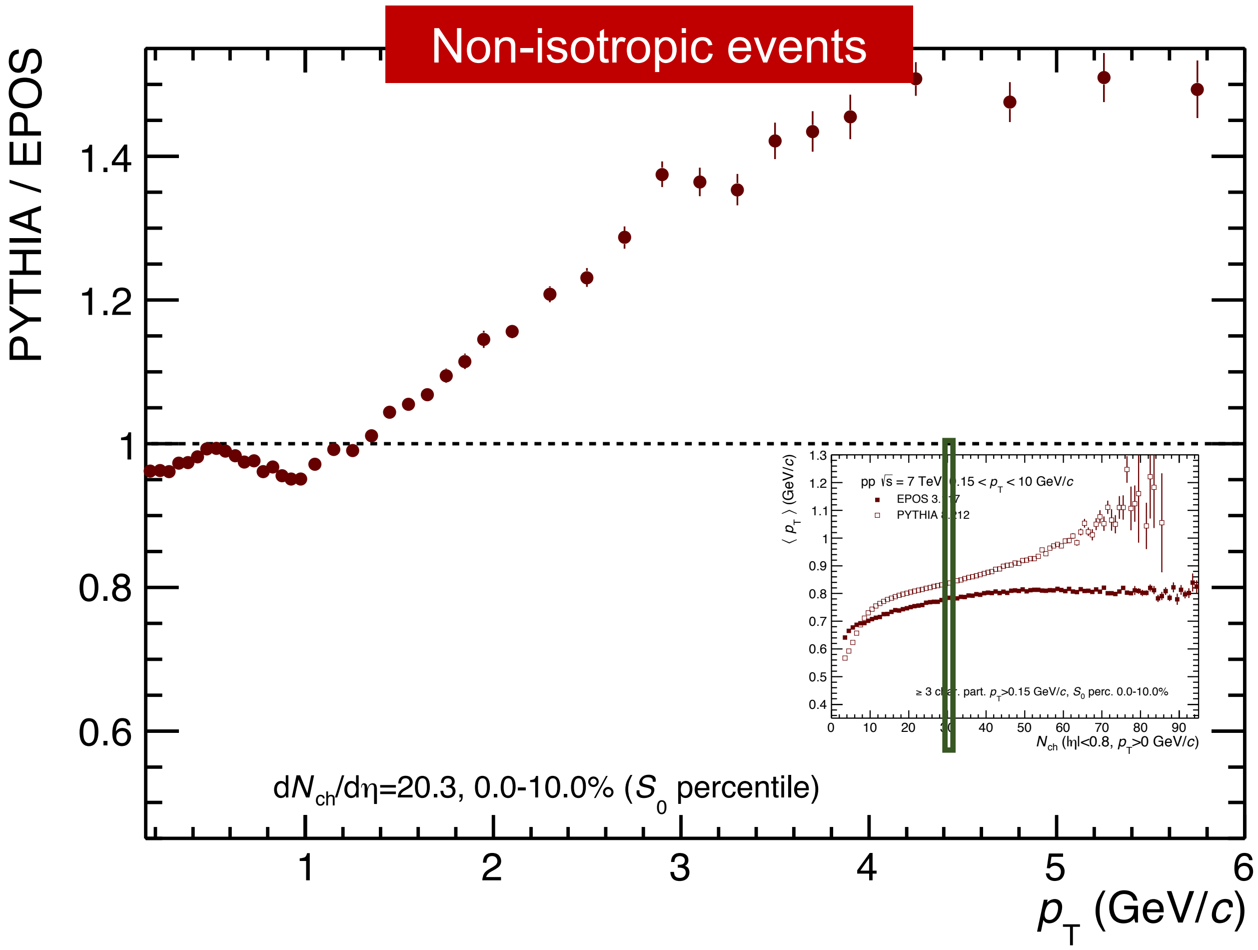
EPOS vs PYTHIA ($N_{ch} = 32$)

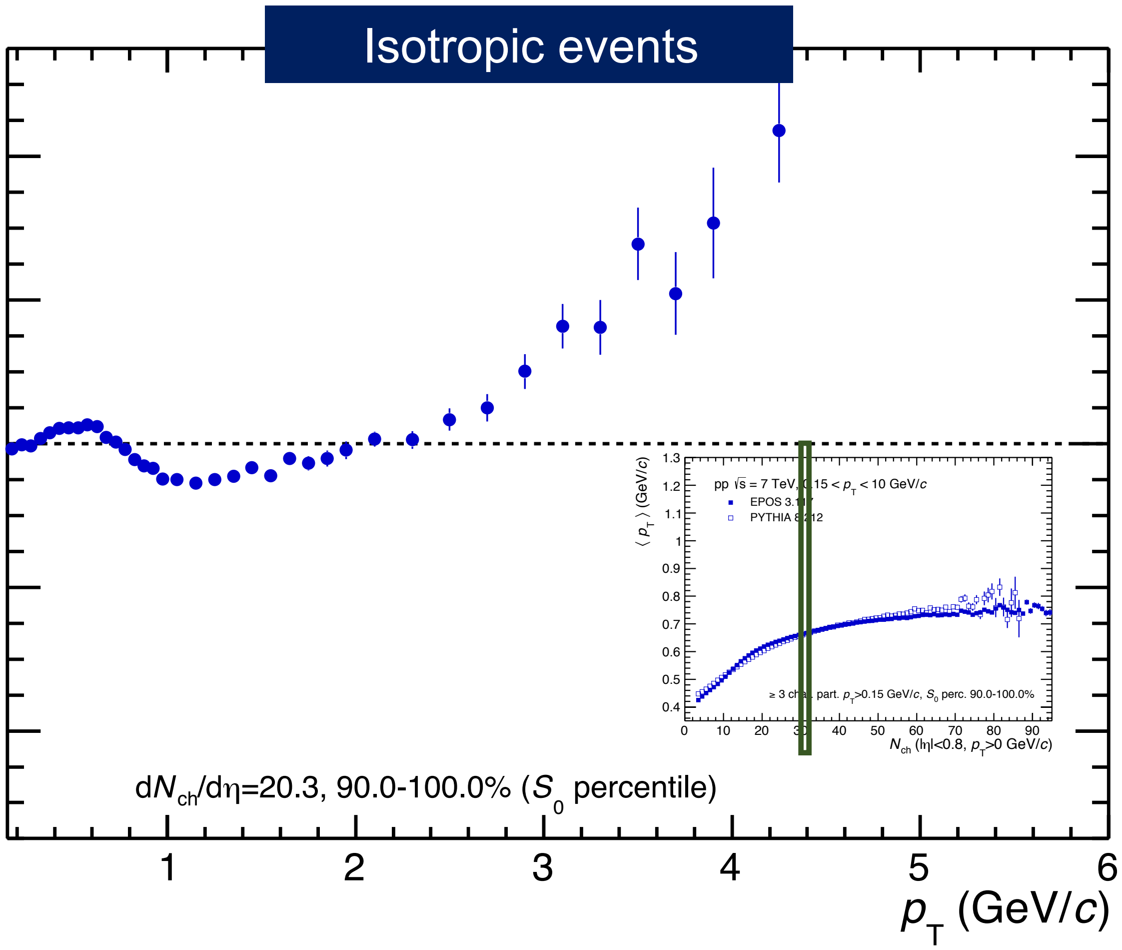




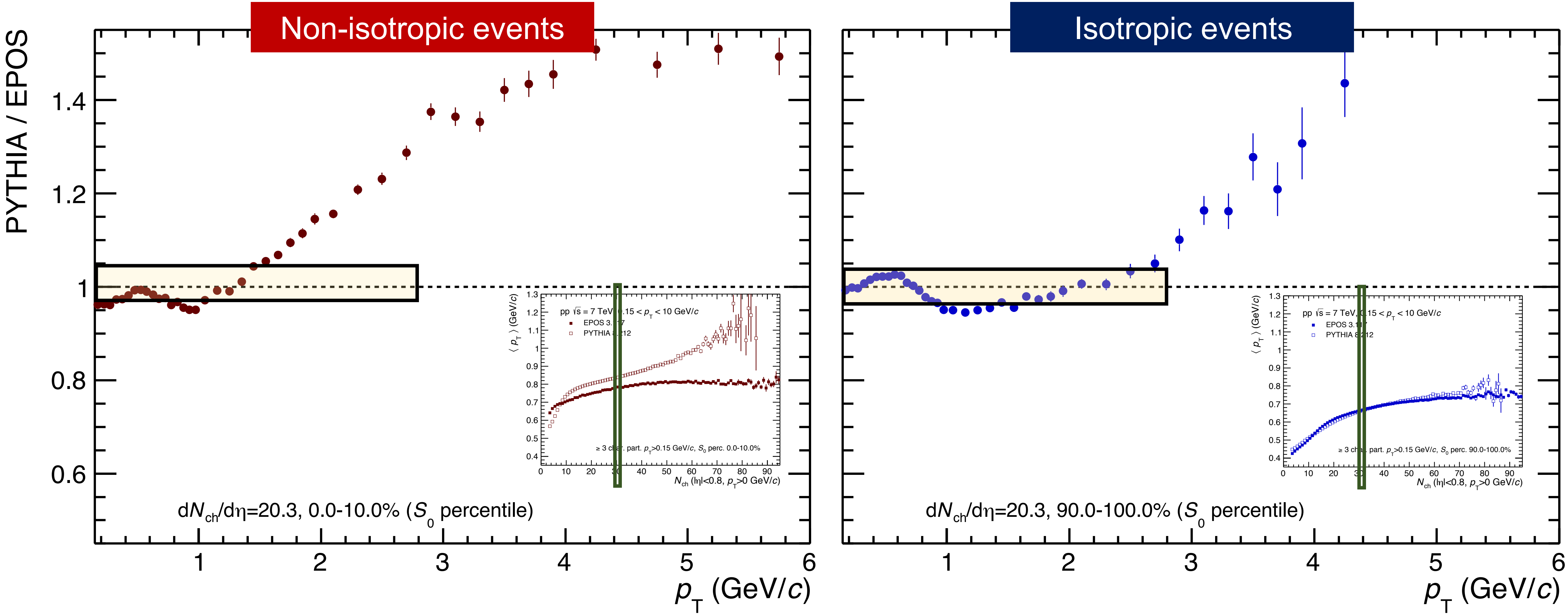
N_{ch} = 32, Main difference is observed for non-isotropic events, p_T > 1.5 GeV/c

EPOS vs PYTHIA ($N_{\mathrm{ch}} = 32$)



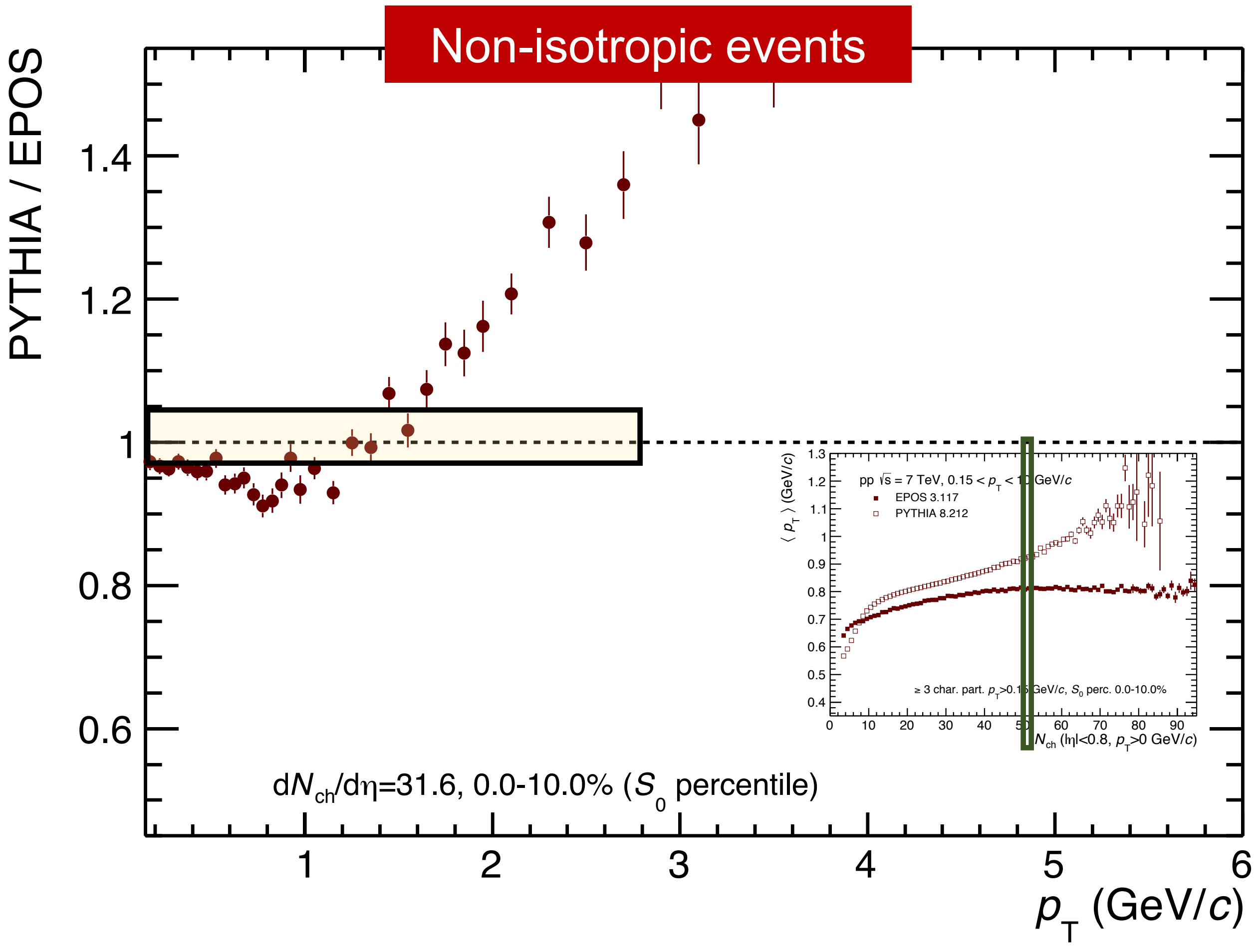


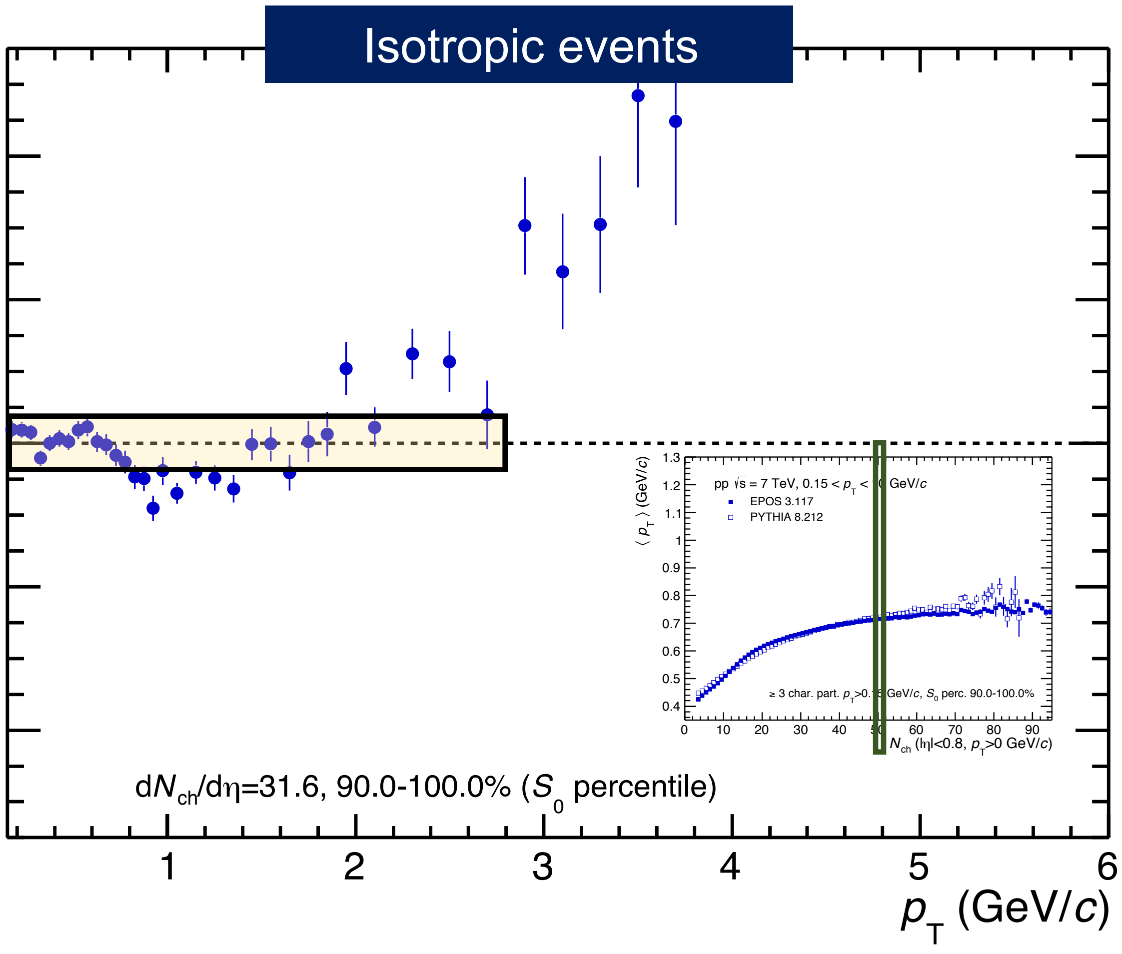
EPOS vs PYTHIA ($N_{\mathrm{ch}} = 32$)



For isotropic events the models agree within 5% for p_{T}<2.5 GeV/c. This produces the roughly same $\langle p_{\mathrm{T}} \rangle$

EPOS vs PYTHIA ($N_{\mathrm{ch}} = 50$)





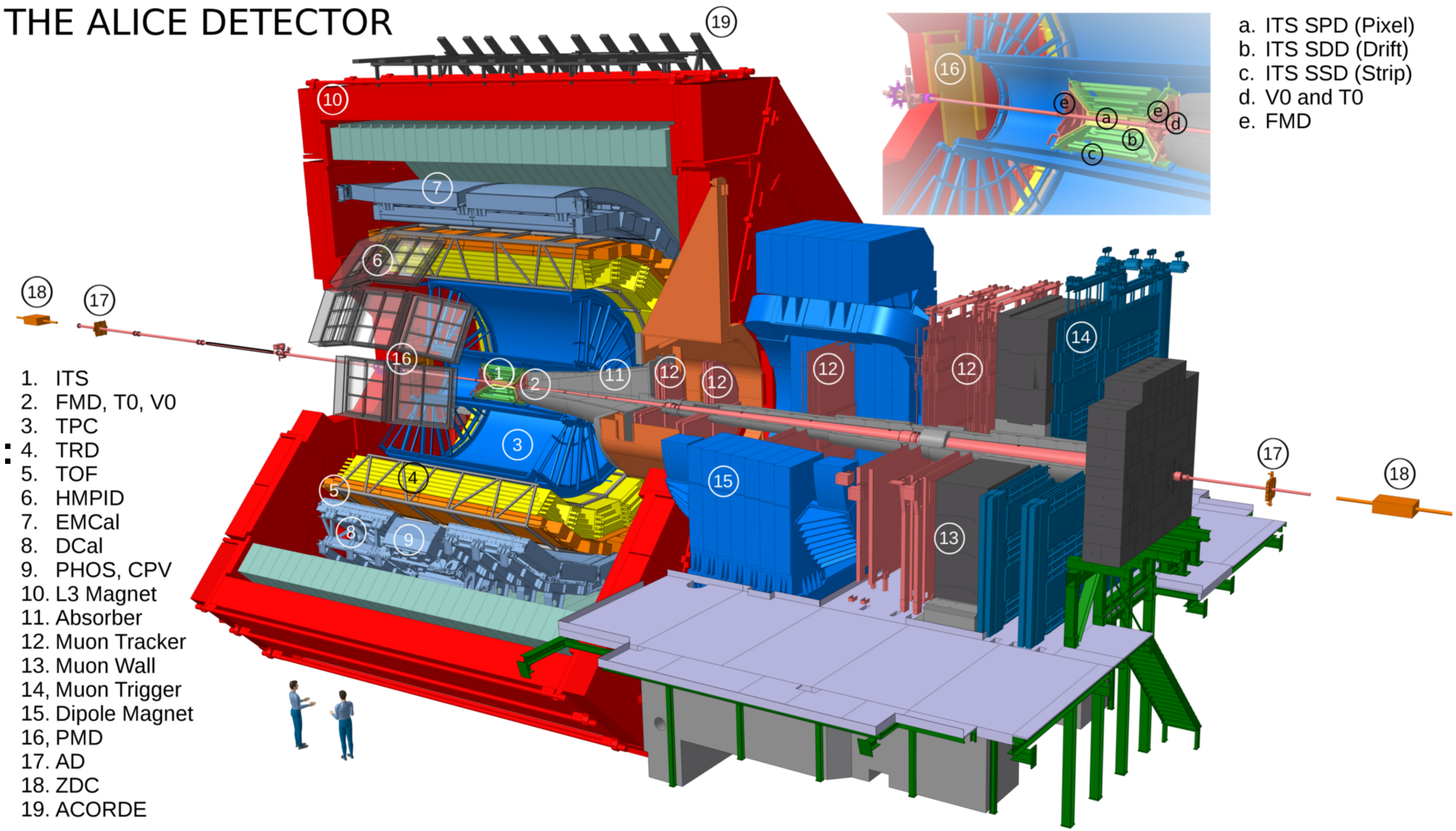
The $\langle p_{\mathrm{T}} \rangle$ vs N_{ch} using different p_{T} intervals (0.15-1.5, 1.5-3.0, 3.0-10) should give the same effect

First measurements in ALICE

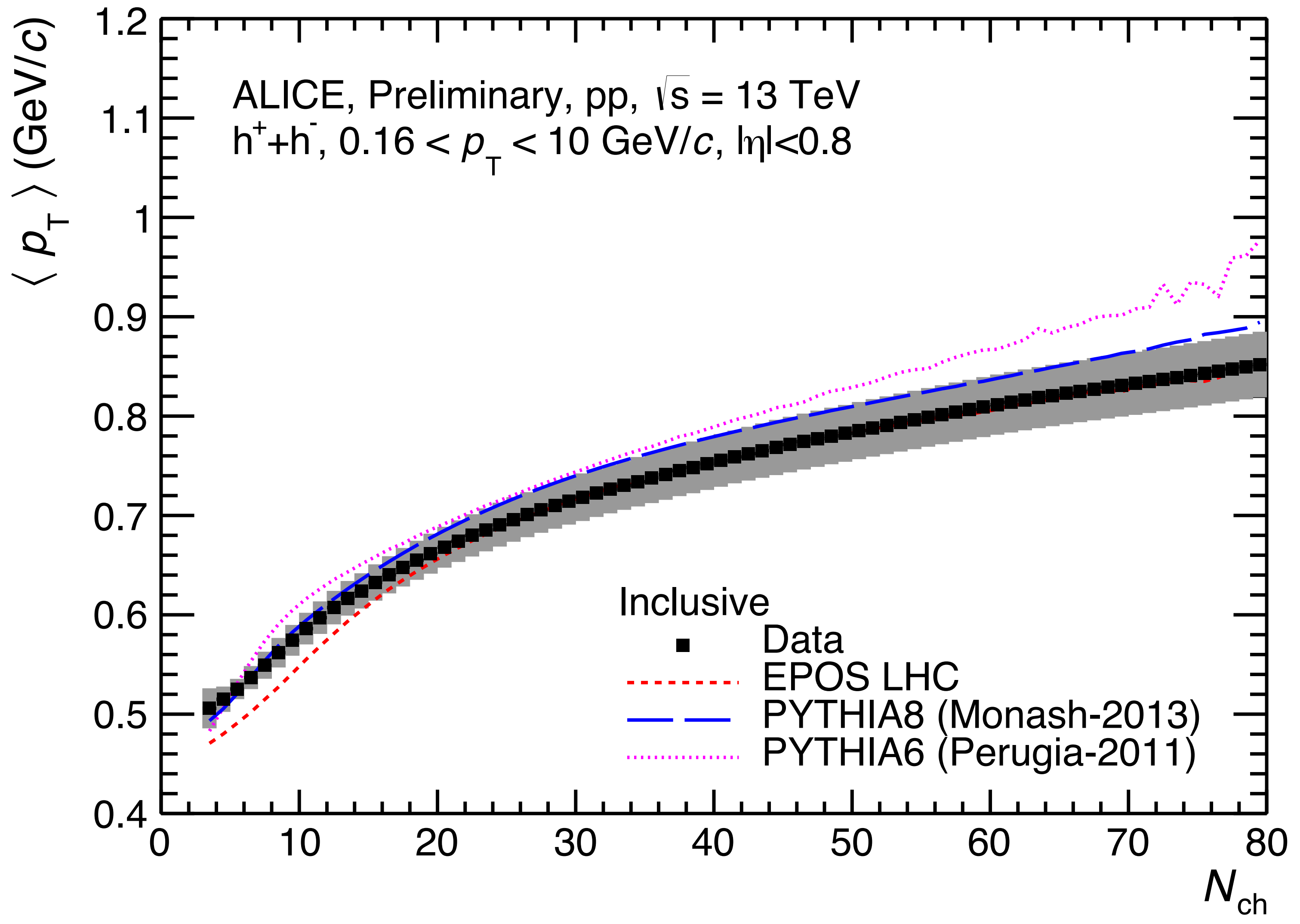
MB trigger:
VZERO detector: two scintillator arrays at asymmetric positions

Vertex reconstruction:
SPD detector

Tracking:
Time Projection Chamber: 90 m^3, $Ar\text{-}CO_2$ (88-12%) gas mixture



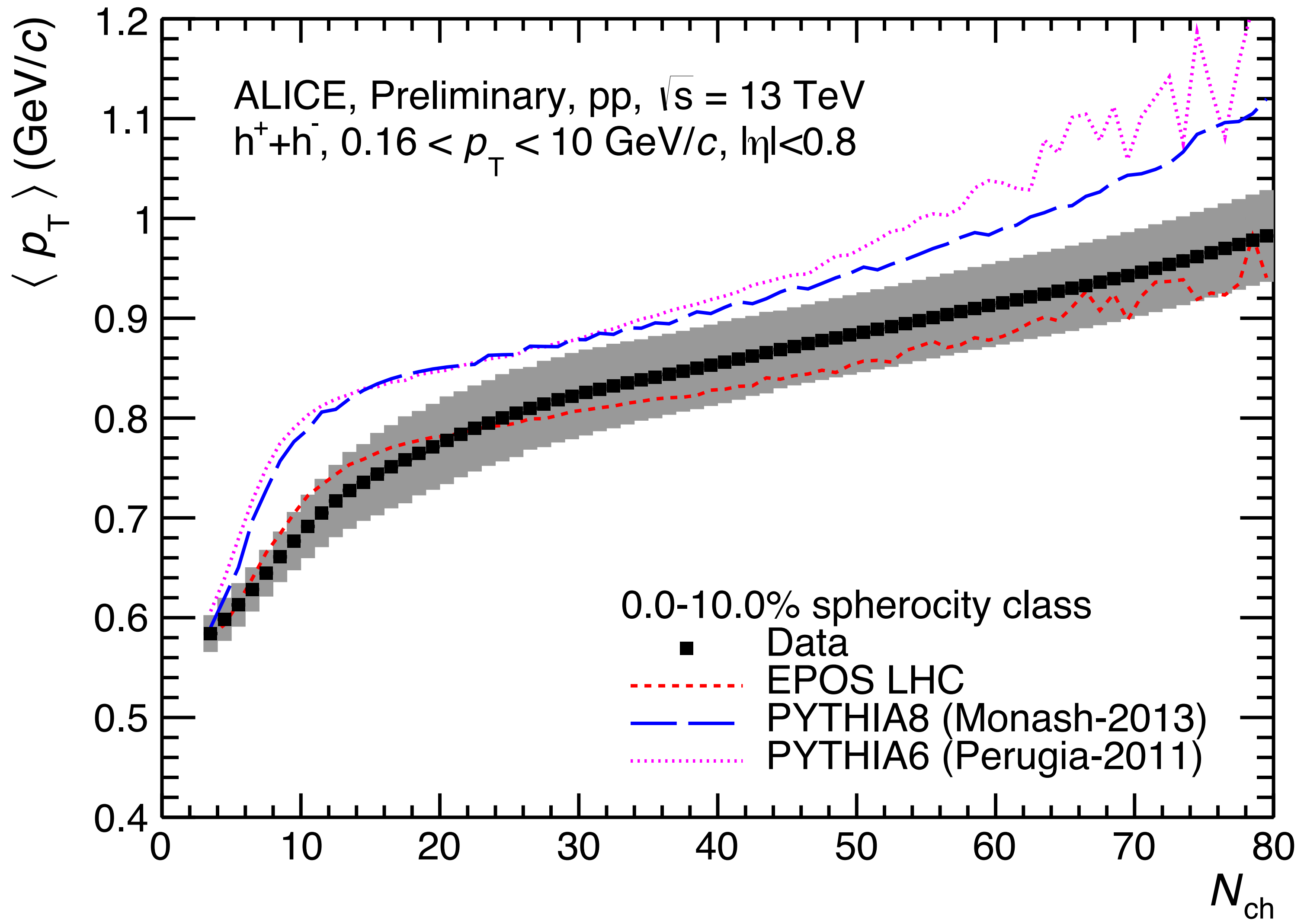
ALICE results

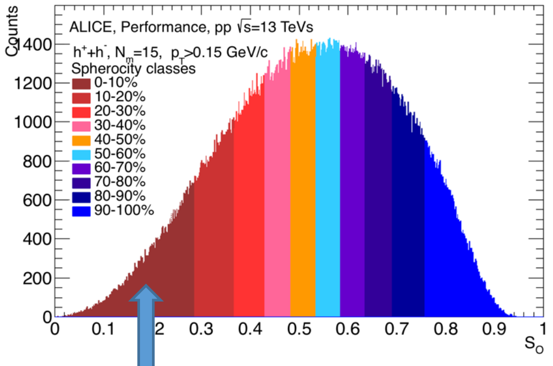


Fully corrected meant p_T vs multiplicity

- <p_T> was measured using global tracks (TPC+ITS): $|\eta|<0.8$
- Multiplicity was measured counting tracks (TPC) and tracklets (ITS). It was corrected by detector effects: $|\eta|<0.8$, $p_T > 0$ GeV/c
- Systematic uncertainties include contributions from: MC non-closure (method), model dependence, track cuts, tracking efficiency

ALICE results





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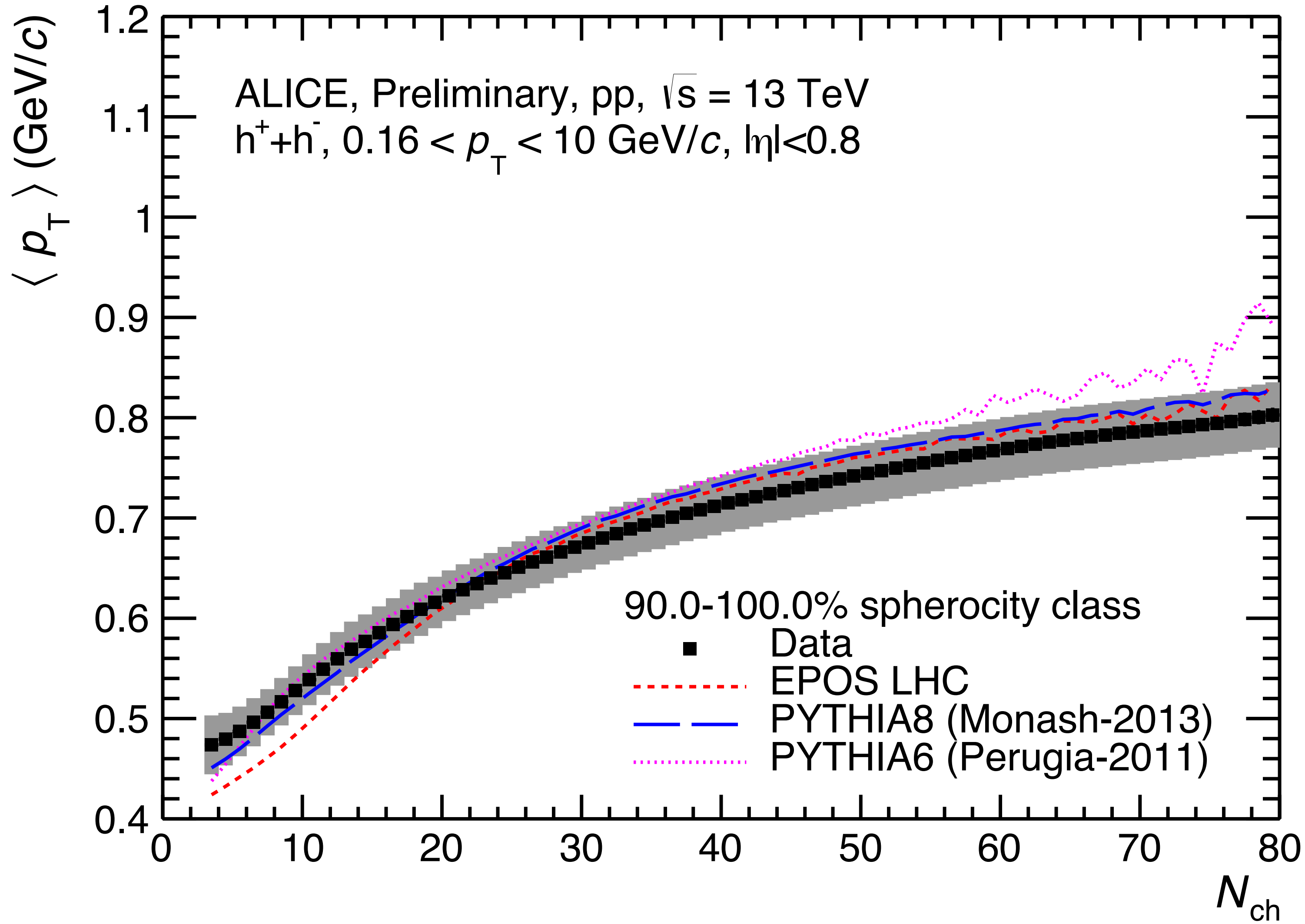
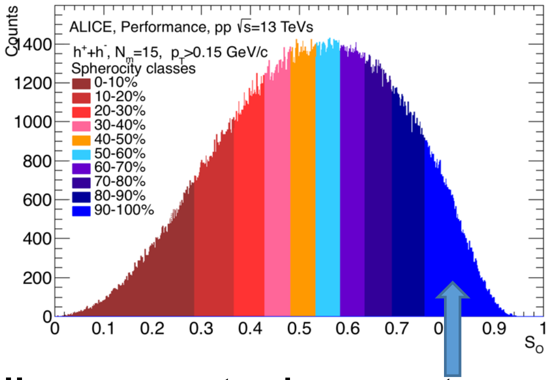
- Transverse spherocity was measured using global tracks. Events are required to have more than two tracks with $p_T > 0.15$ GeV/c and within $|\eta|<0.8$.

Color reconnection modifies the low p_T particle production if a low p_T system is merged with other of a harder scale

ALICE results





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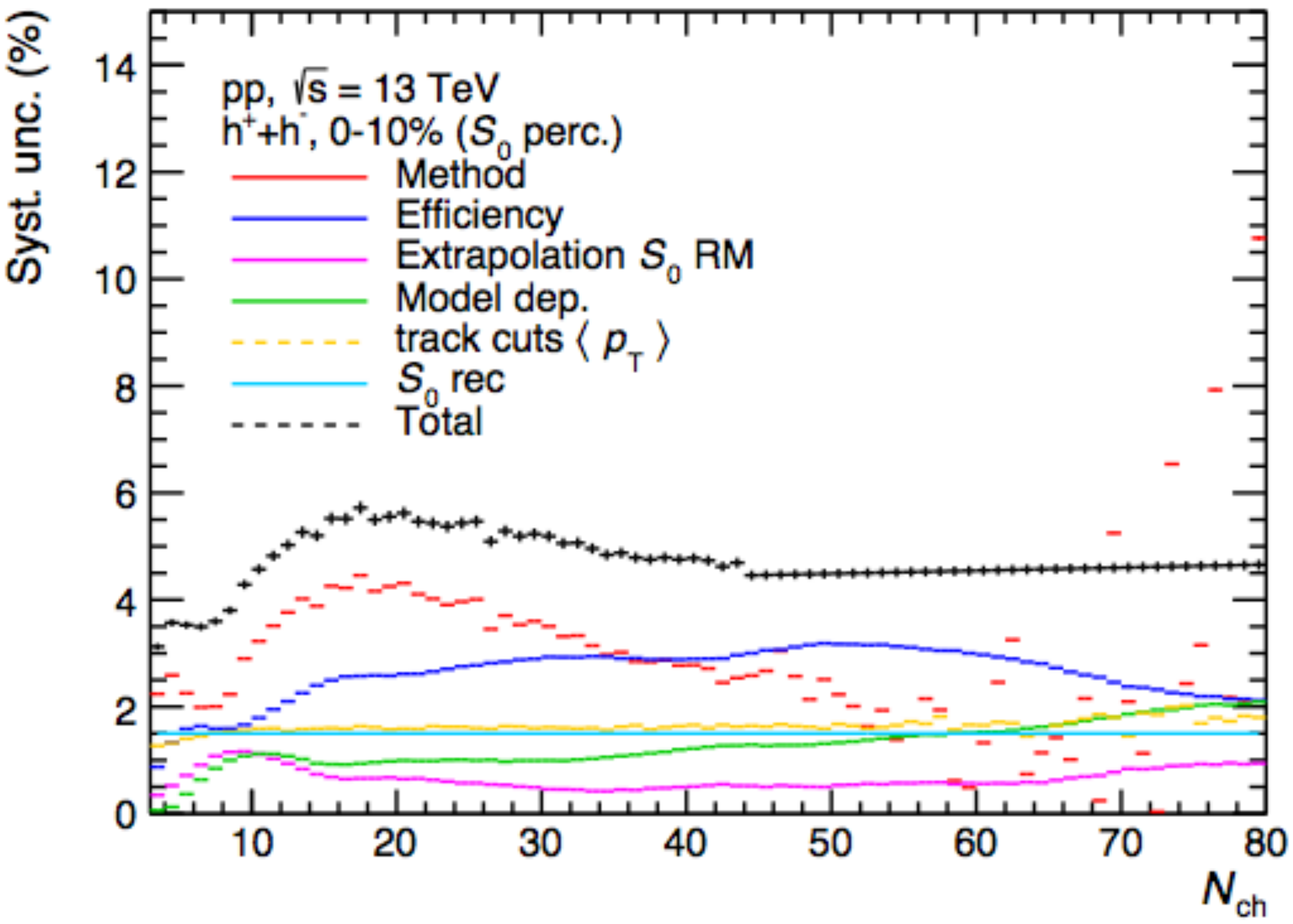
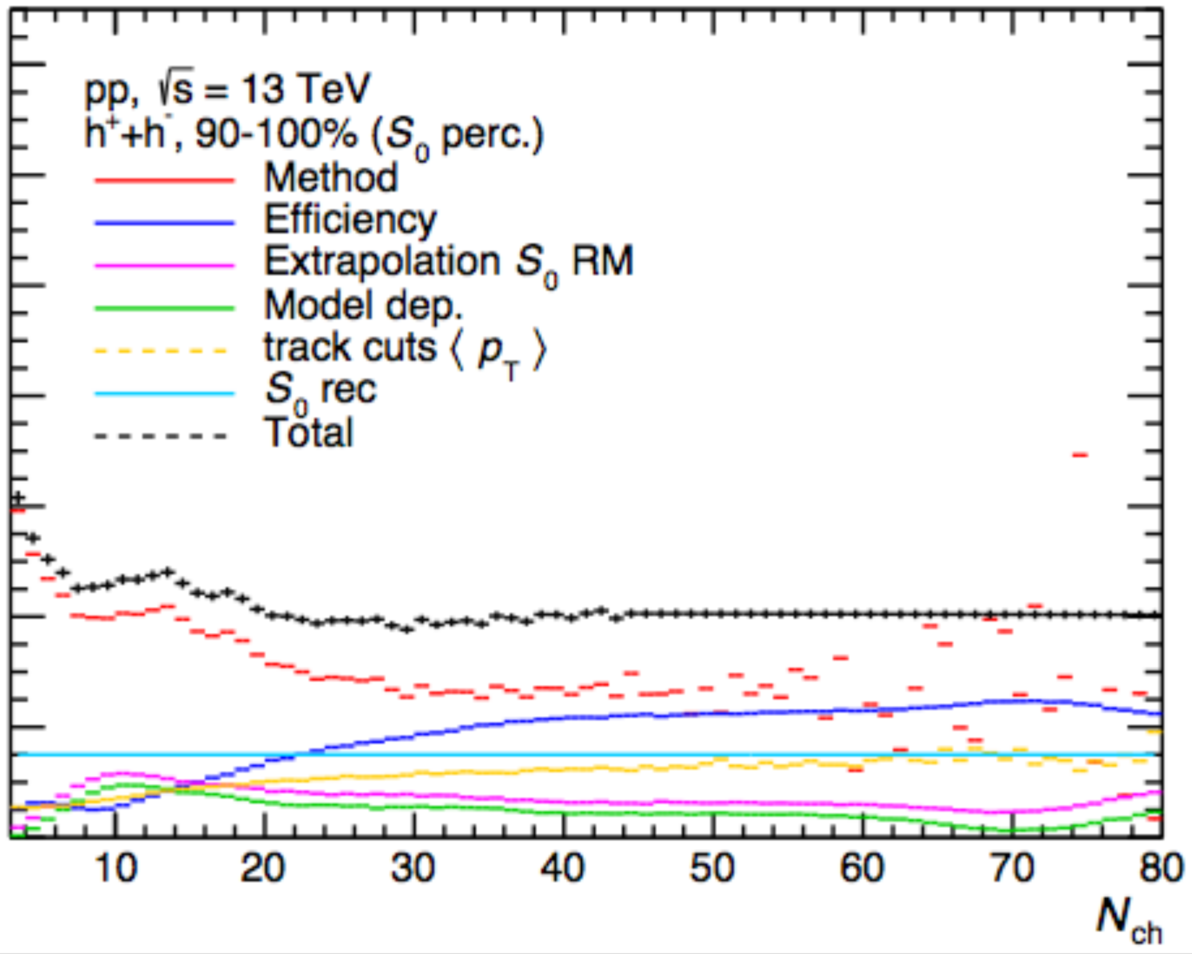
Models describe better the isotropic events than the inclusive (spherocity integrated) ones.

Systematic uncertainties





Inclusive vs S_0 dependent $\langle p_T \rangle$

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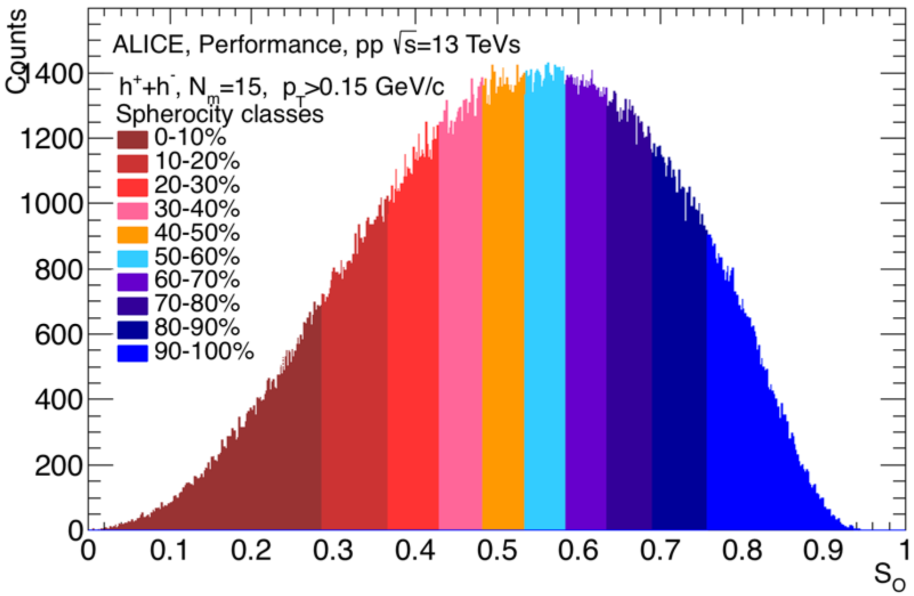
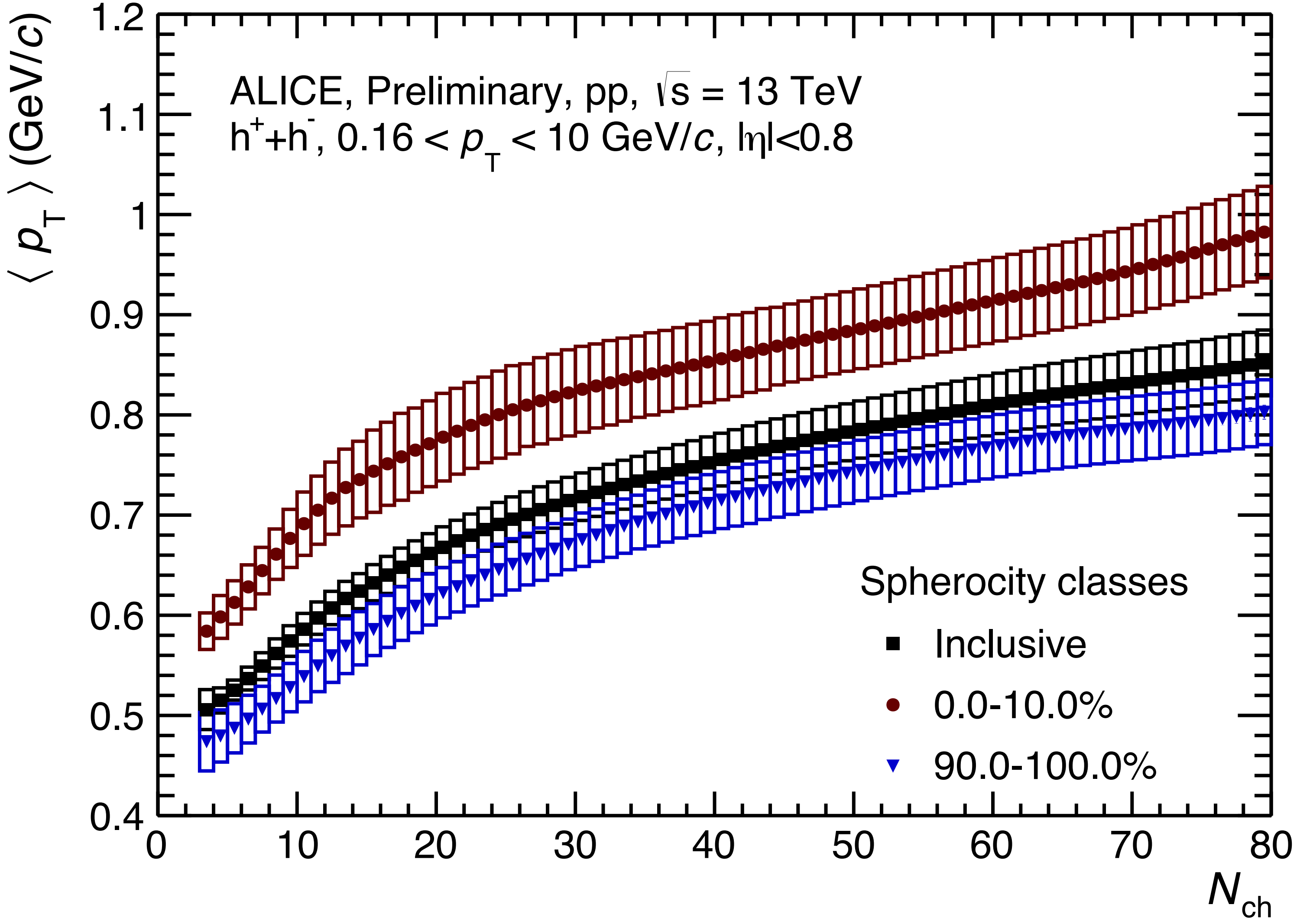
This new tool allows the study of the pp collisions in such a way that the core contribution can be controlled (enhanced or suppressed). Many things can be done using particle identification. For example, if EPOS 3 is right, then we must observe strangeness enhancement even in low multiplicity events





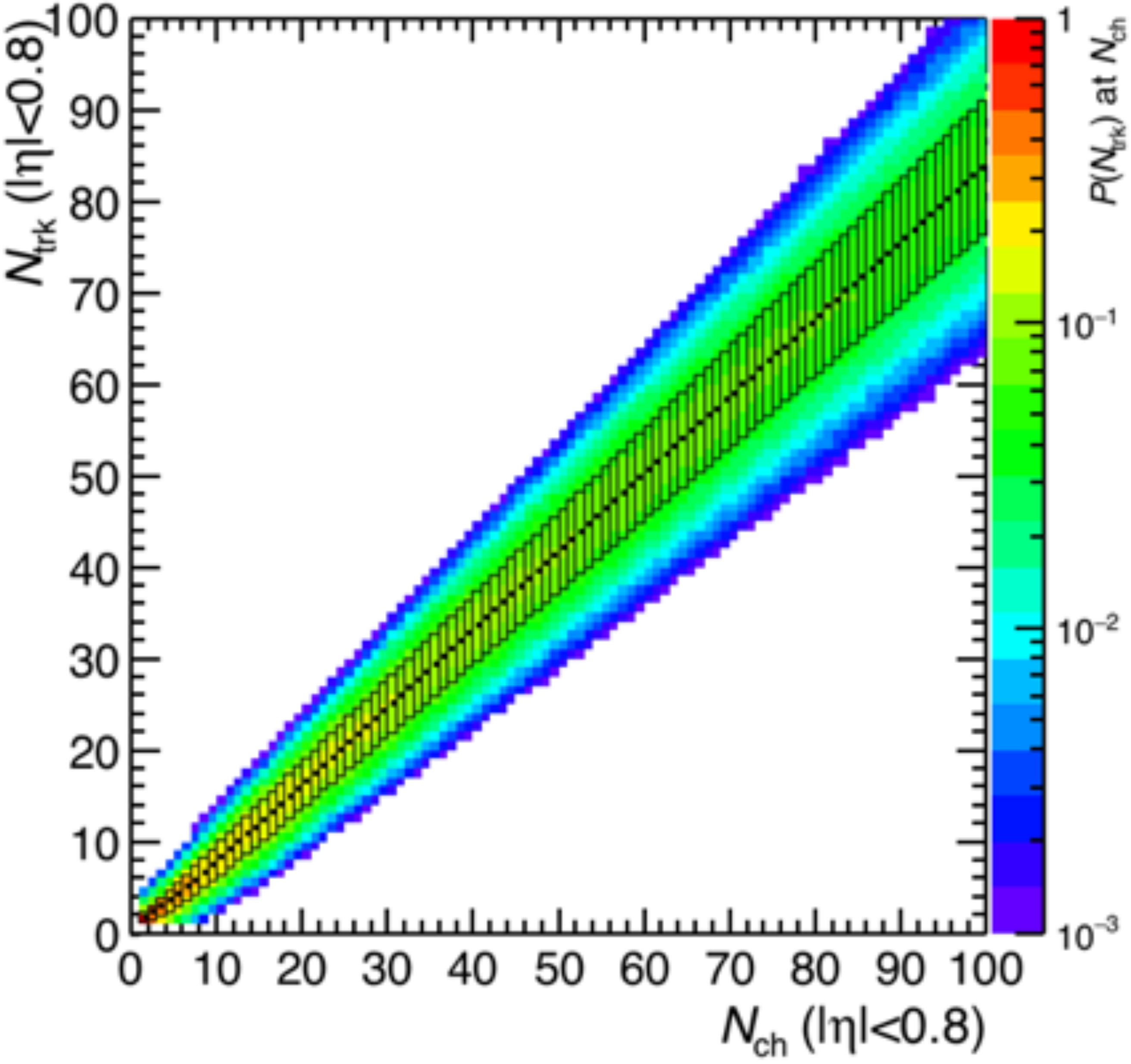
Summary

- A new tool (spherocity) was introduced in order to isolate the new physics (sQGP?) in small systems

- The double differential analysis shown here allows to test the models where underlying event (or core contribution) is enhanced or suppressed with respect to the multiplicity dependent case

- The first results of ALICE applying spherocity have been presented
  - The average p_T exhibits a steeper rise with N_{ch} going from isotropic (90-100%) to non-isotropic (0-10%) events
  - The largest tension between data and PYTHIA (6 and 8) is observed for non-isotropic events, where color reconnection can affect the low p_T part of the spectrum due to the presence of a hard parton
  - This can be used to study the soft-hard interaction

Backup



Detector response

$$\langle p_{\mathrm{T}}\rangle(N_{\mathrm{ch}}) = \sum_{\mathrm{m}} \langle p_{\mathrm{T}}\rangle(N_{\mathrm{m}}) R(N_{\mathrm{ch}}, N_{\mathrm{m}})$$

Analysis vs $\sqrt{s}$: e.g. multiplicity distributions

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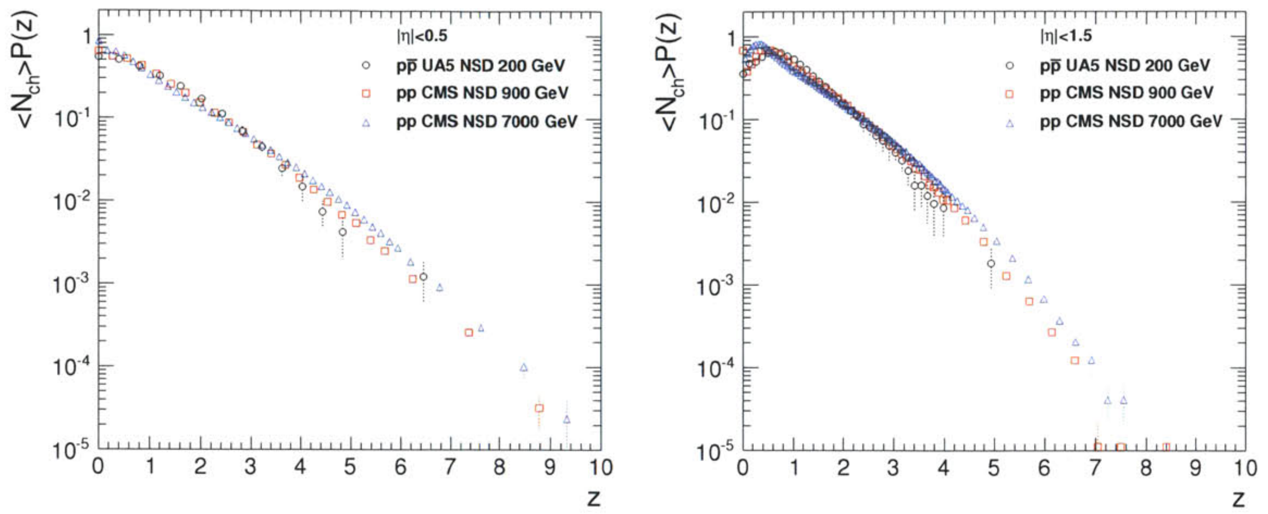

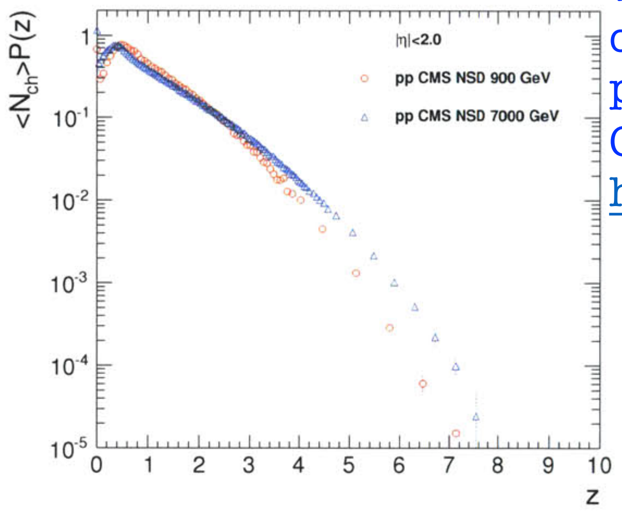

Yen-Jie Lee, Ph. D. thesis, "Measurement of charged-hadron multiplicity in proton-proton collisions at the LHC with the CMS detector", http://hdl.handle.net/1721.1/68876

- KNO scaling is broken when large pseudorapidity intervals are considered
- What does the transverse spherocity analysis tell us?

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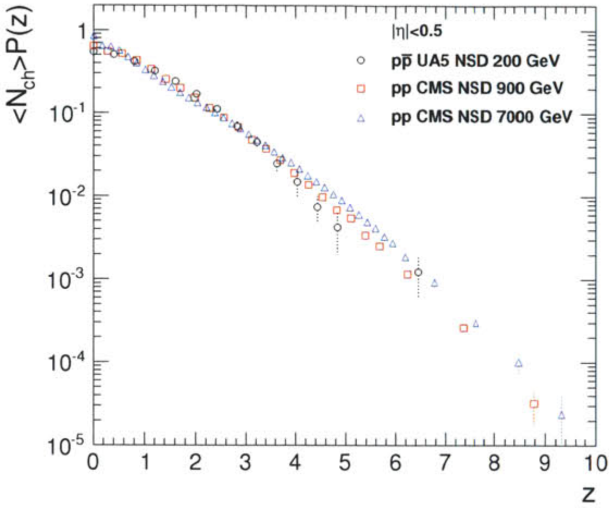

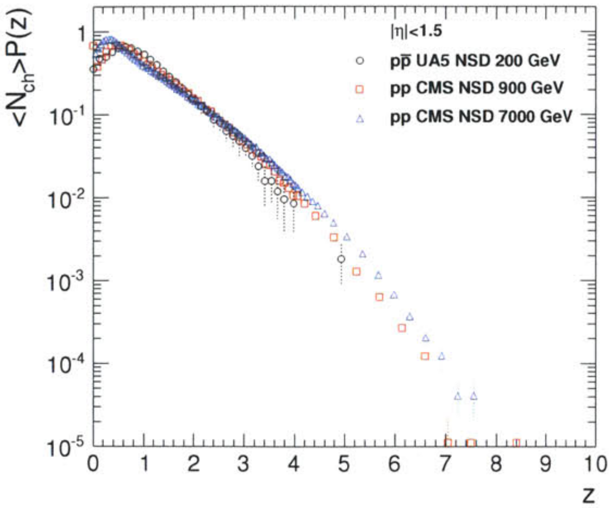

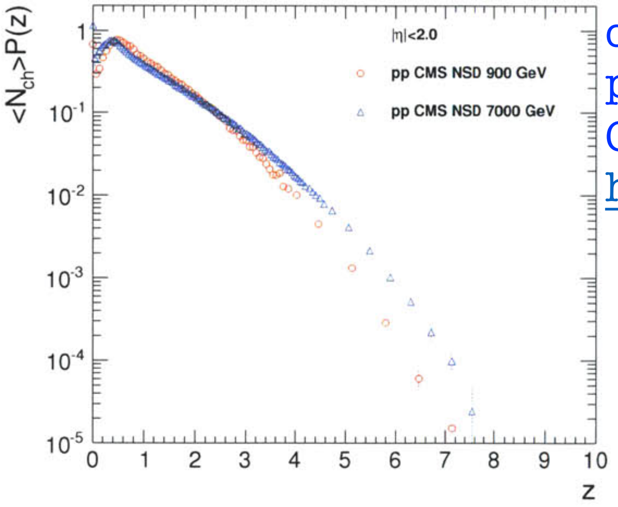

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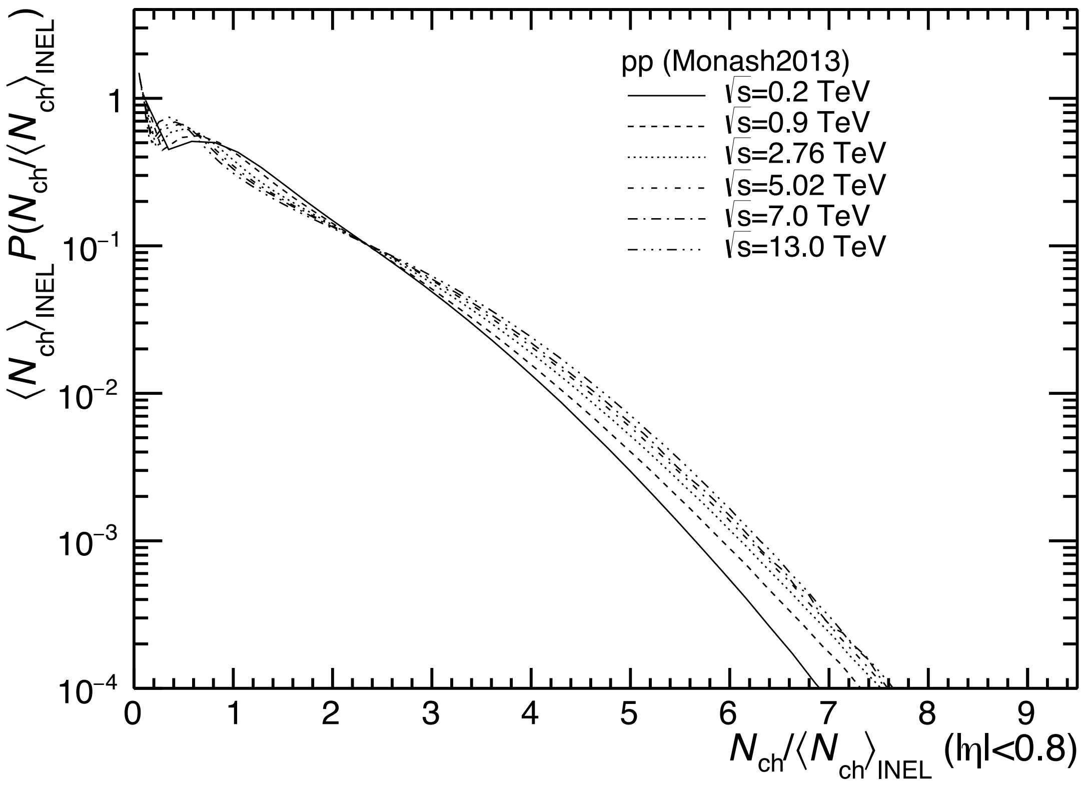
- ❑ What does the transverse spherocity analysis tell us?

Simulations using PYTHIA 8.212 tune Monash 2013

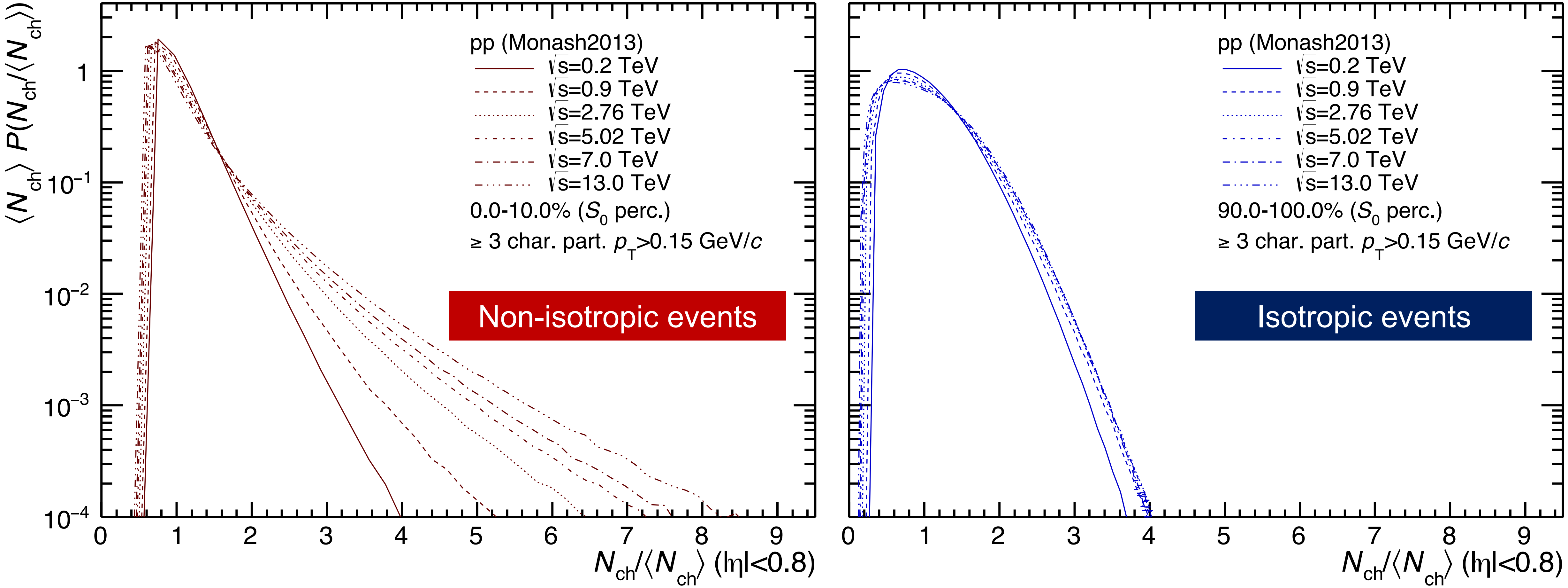
T. Sjöstrand et al., Comp. Phys. Comm. **191** (2015) 159

P. Skands et al., EPJ **C74** (2014) 3024



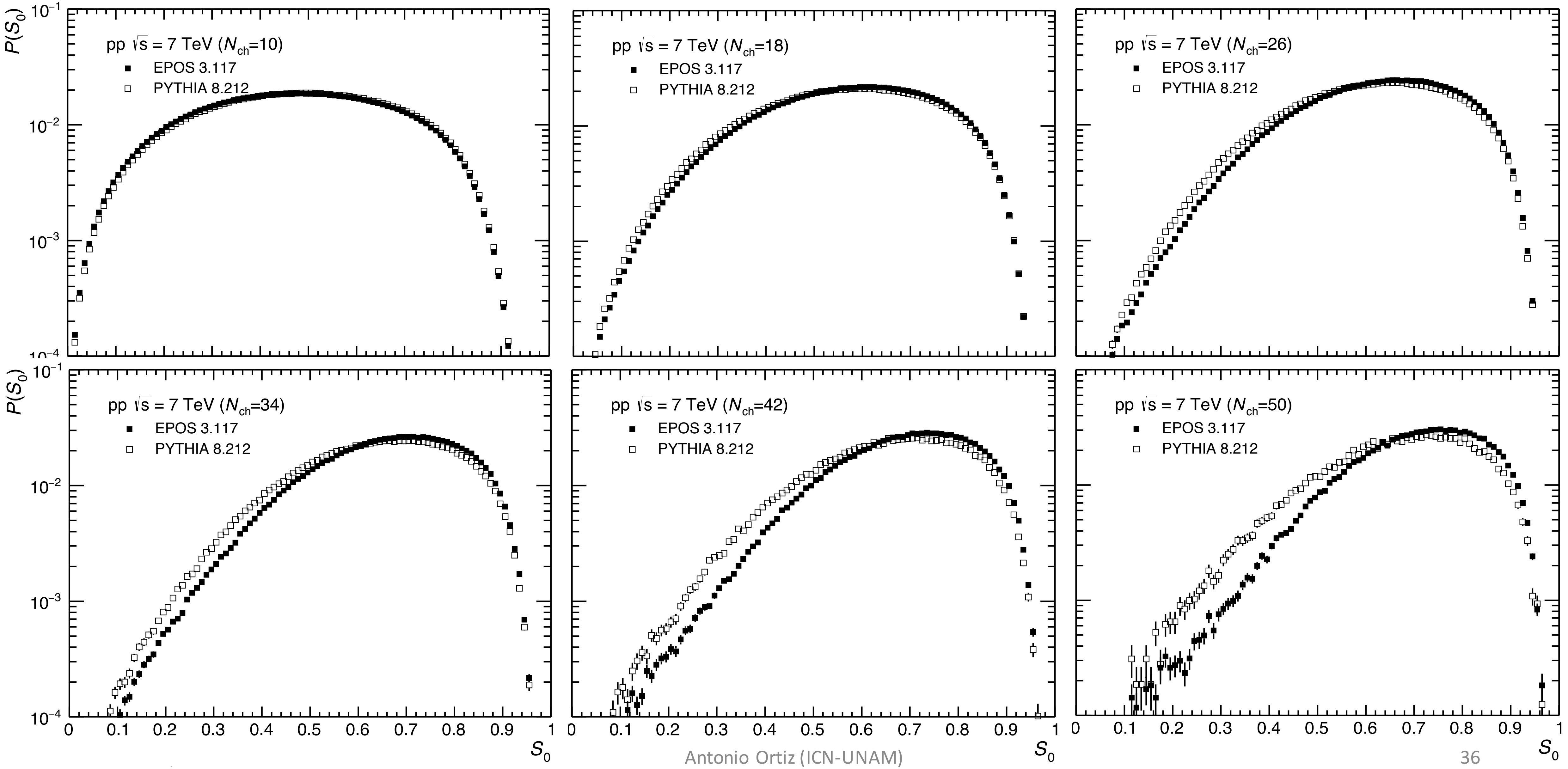
PYTHIA 8.212 reproduce the KNO breaking

Multiplicity distributions

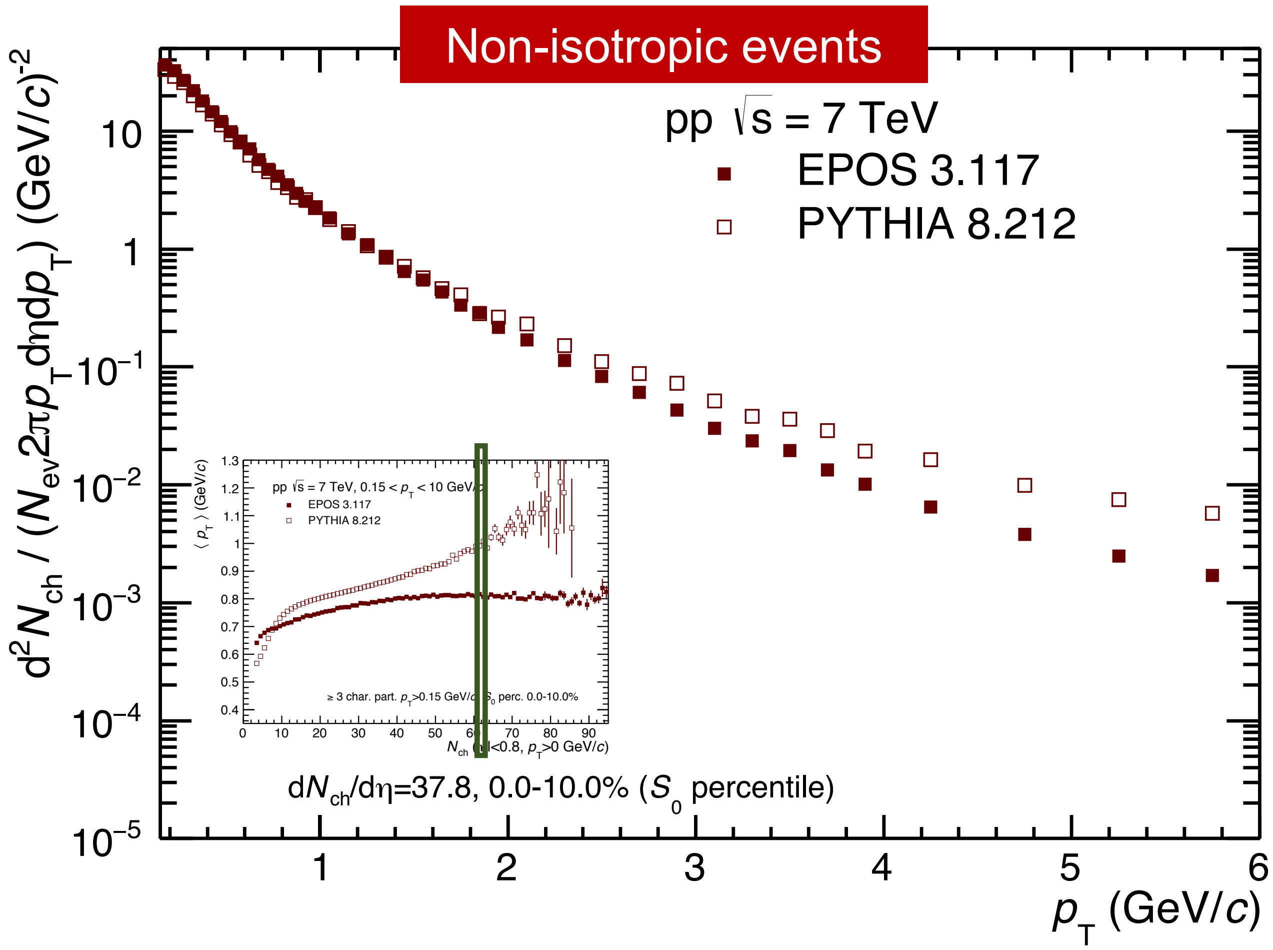


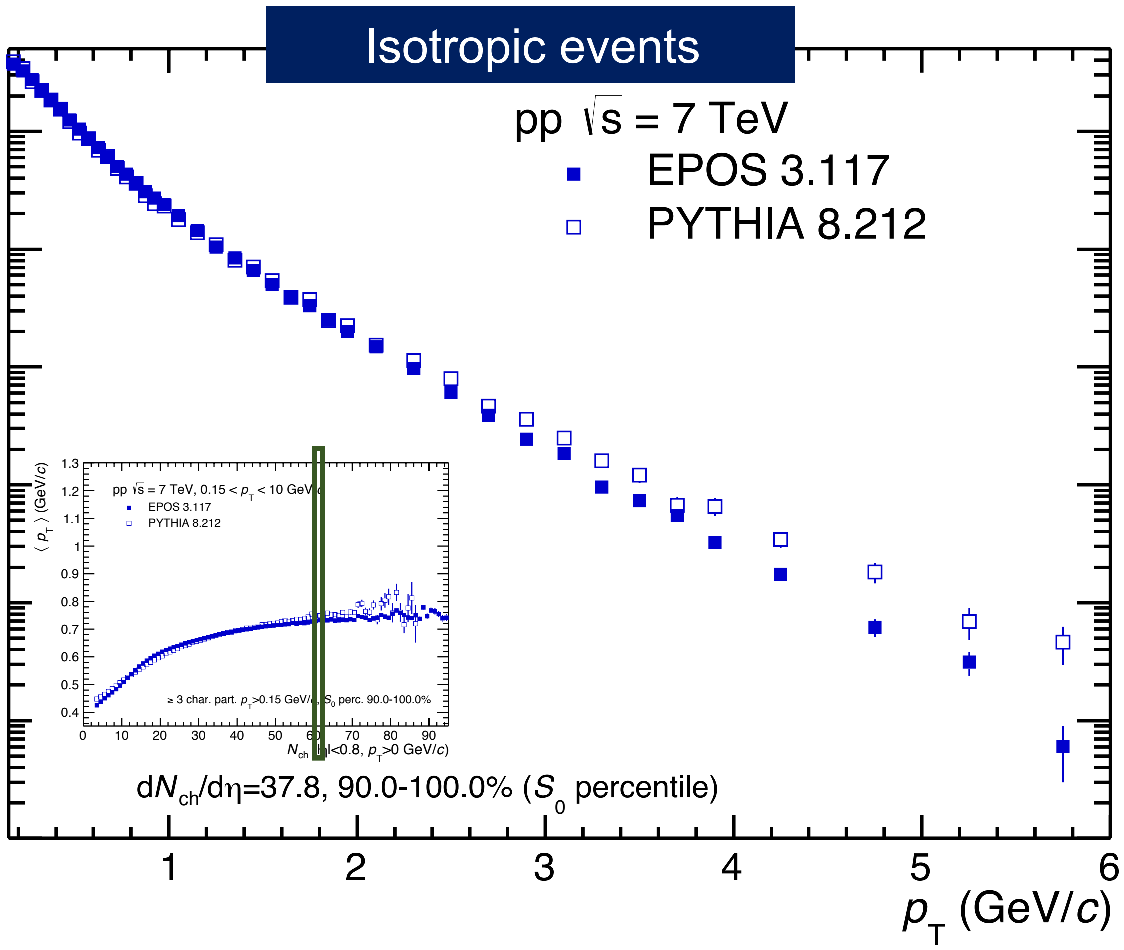
*Normalization to the corresponding mean multiplicity
Multiplicity scaling is observed in isotropic events (enhanced UE)

Epos vs Pythia (S_0 spectra vs N_{ch})

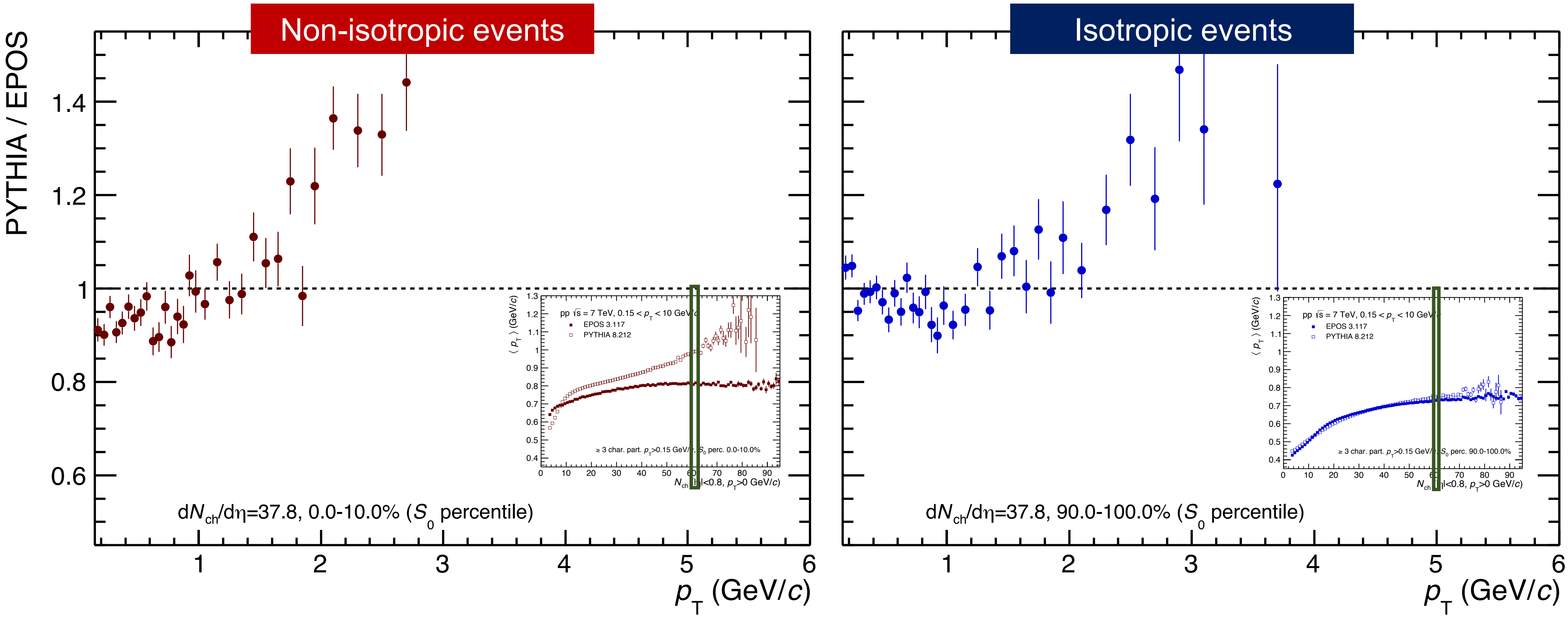


Epos vs Pythia (p_T spectra vs N_{ch})





Epos vs Pythia (p_T spectra vs N_{ch})



Leading-hadron correlations