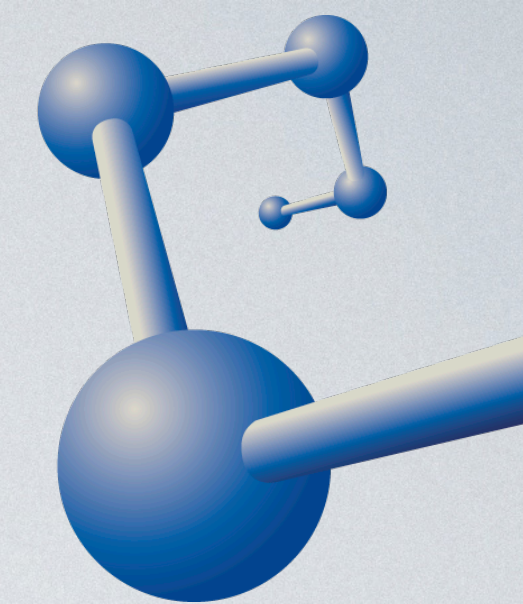




# XXXIV Reunión anual de la división de particulares y campos de la SMF (Departamento de Física Cinvestav IPN, Mexico)

Instituto de  
Ciencias  
Nucleares  
UNAM



## Topological studies of light-flavor hadron production in small collision systems with ALICE at the LHC

Sushanta Tripathy

On behalf of ALICE collaboration

### Outline:

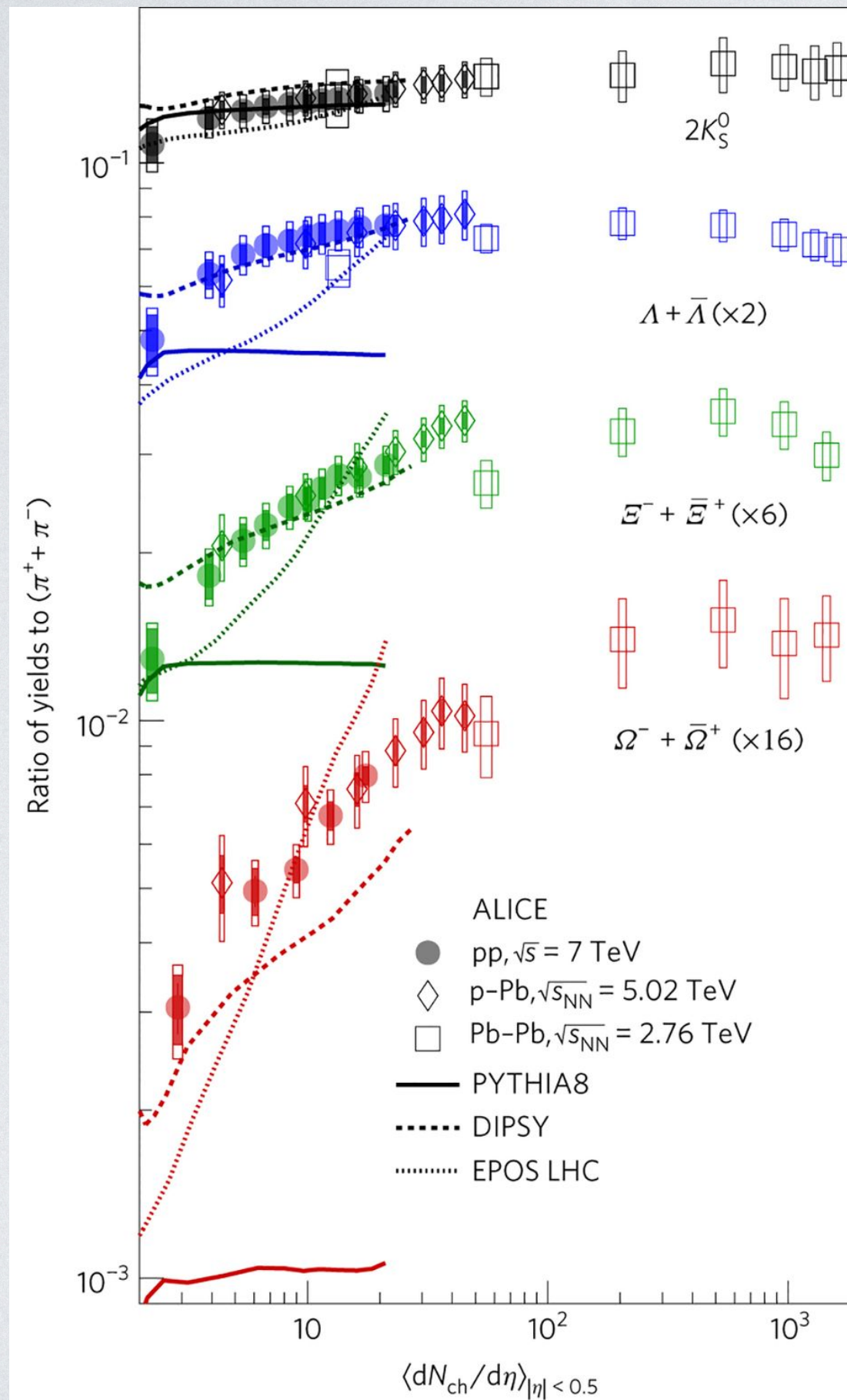
- Introduction and Motivation
- Event shape observables
  - Transverse sphericity
  - Relative transverse activity classifier
- Light-flavor hadron production as a function of event shape observables
- Search for jet quenching effects in small collision systems
- Summary



# Introduction and Motivation

- Measurements at the LHC have revealed that small collision systems exhibit **collective-like** behavior, formerly thought to be achievable only in heavy-ion collisions, where the data support the formation of QGP.

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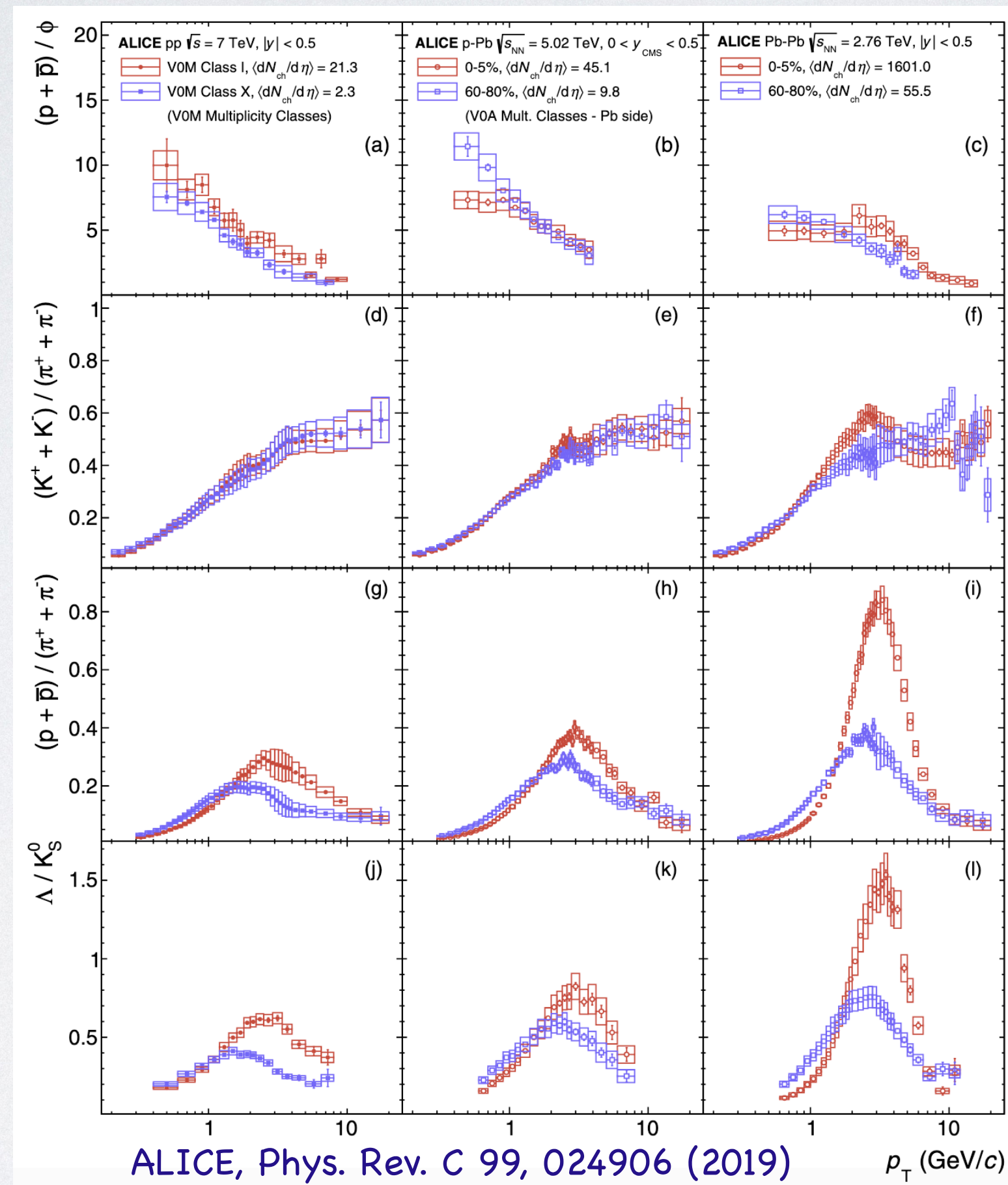
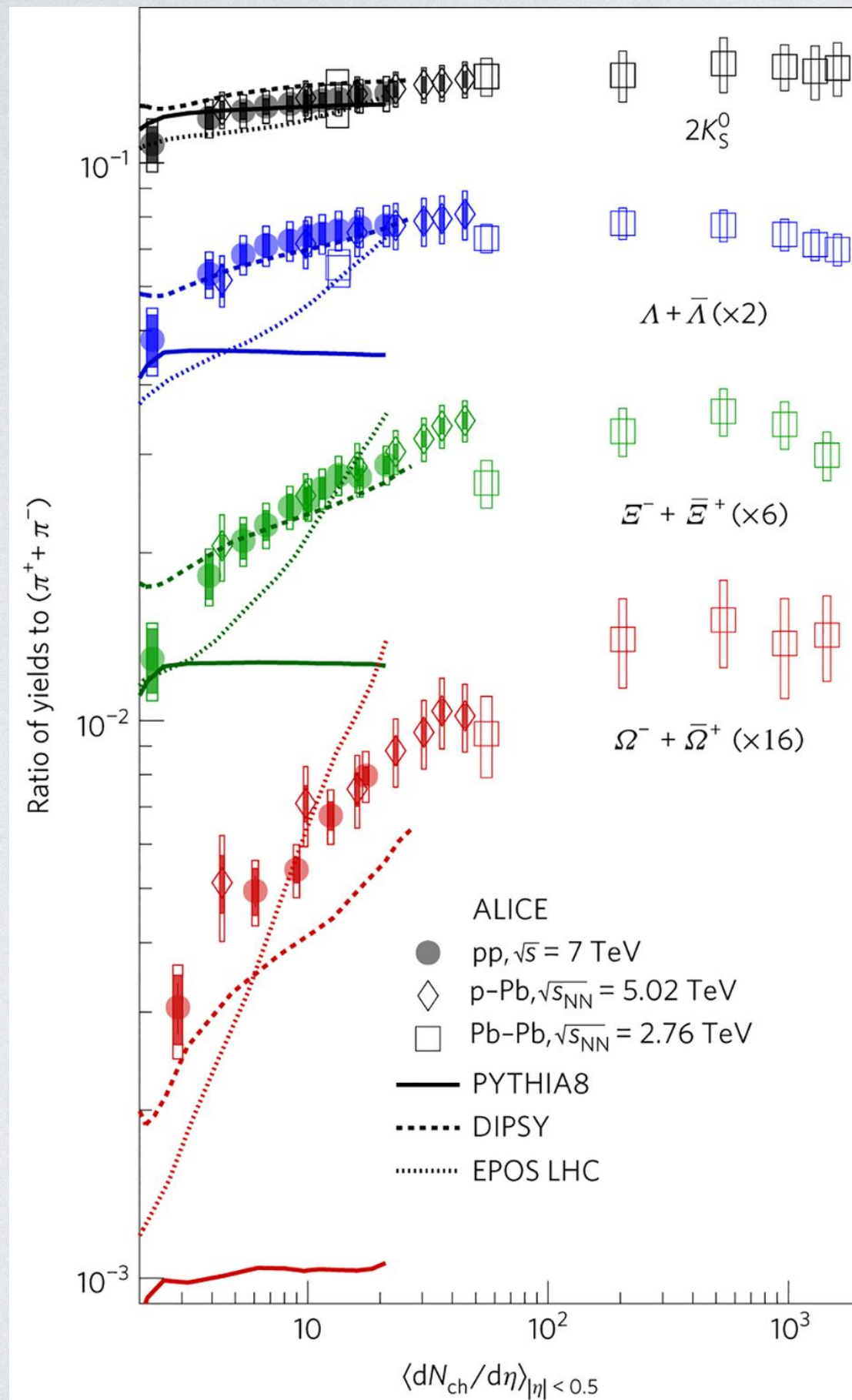


ALICE, Nature Physics 13, 535-539 (2017)

Strangeness enhancement in high multiplicity pp and p-Pb are similar to Pb-Pb collisions

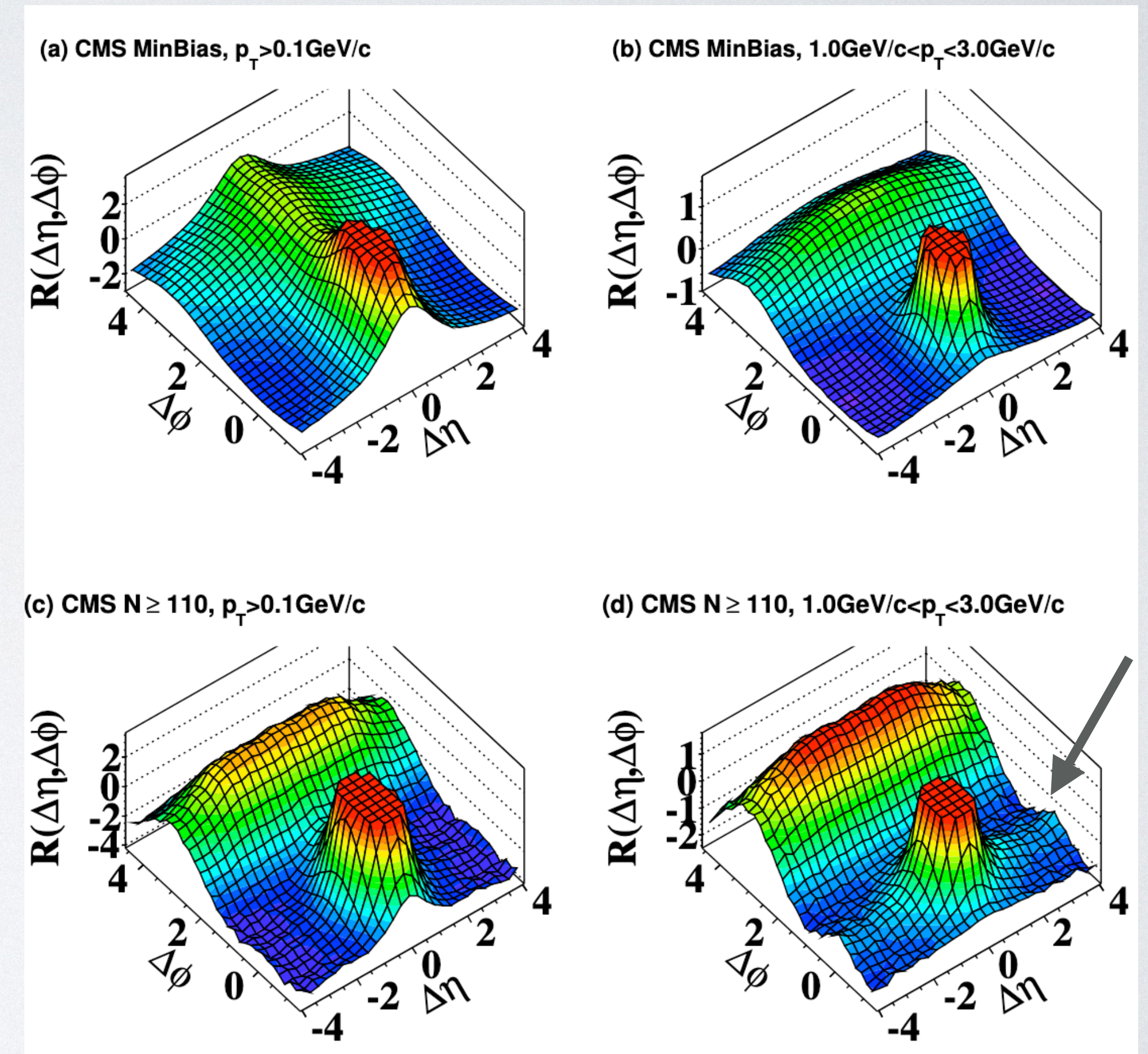
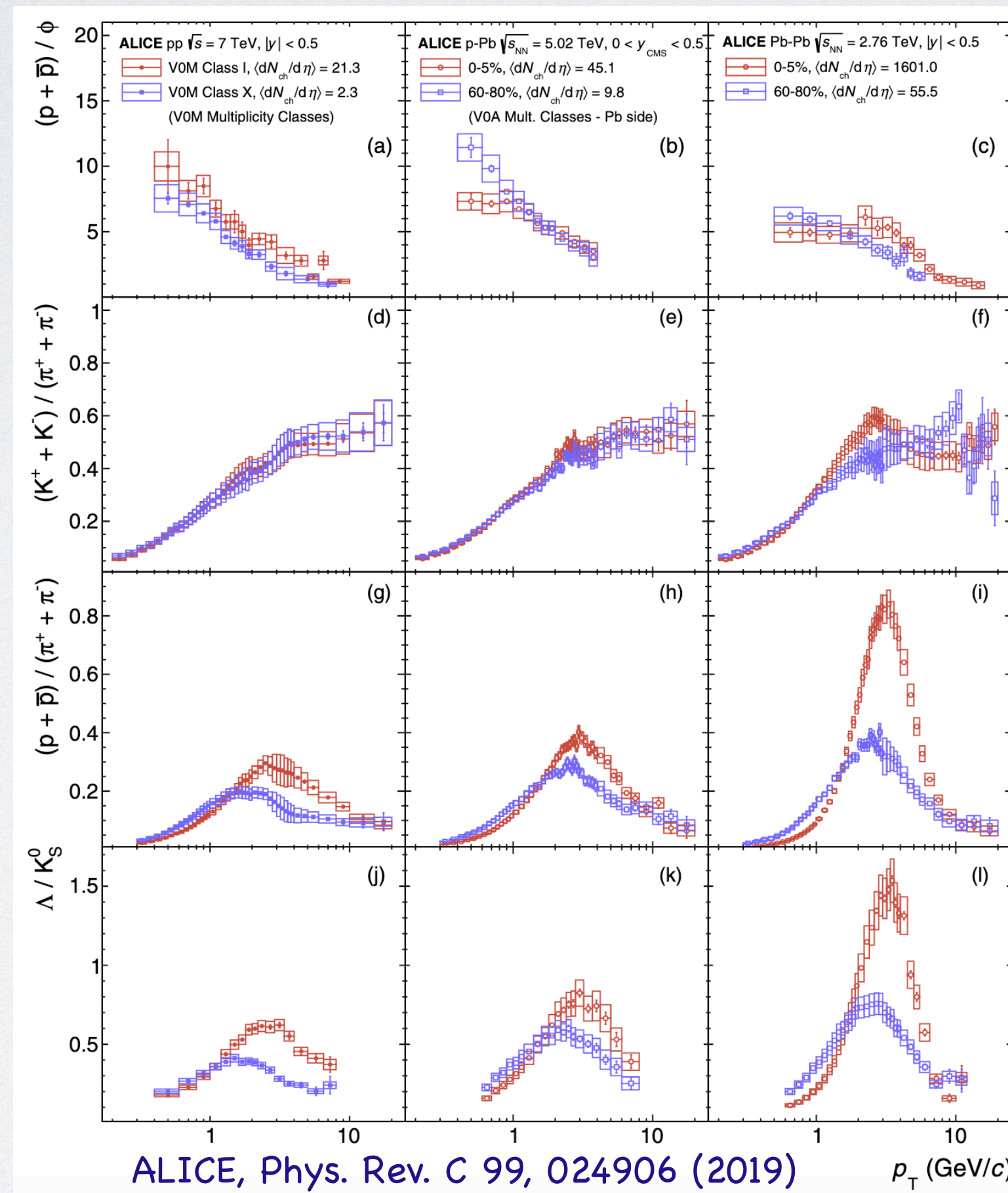
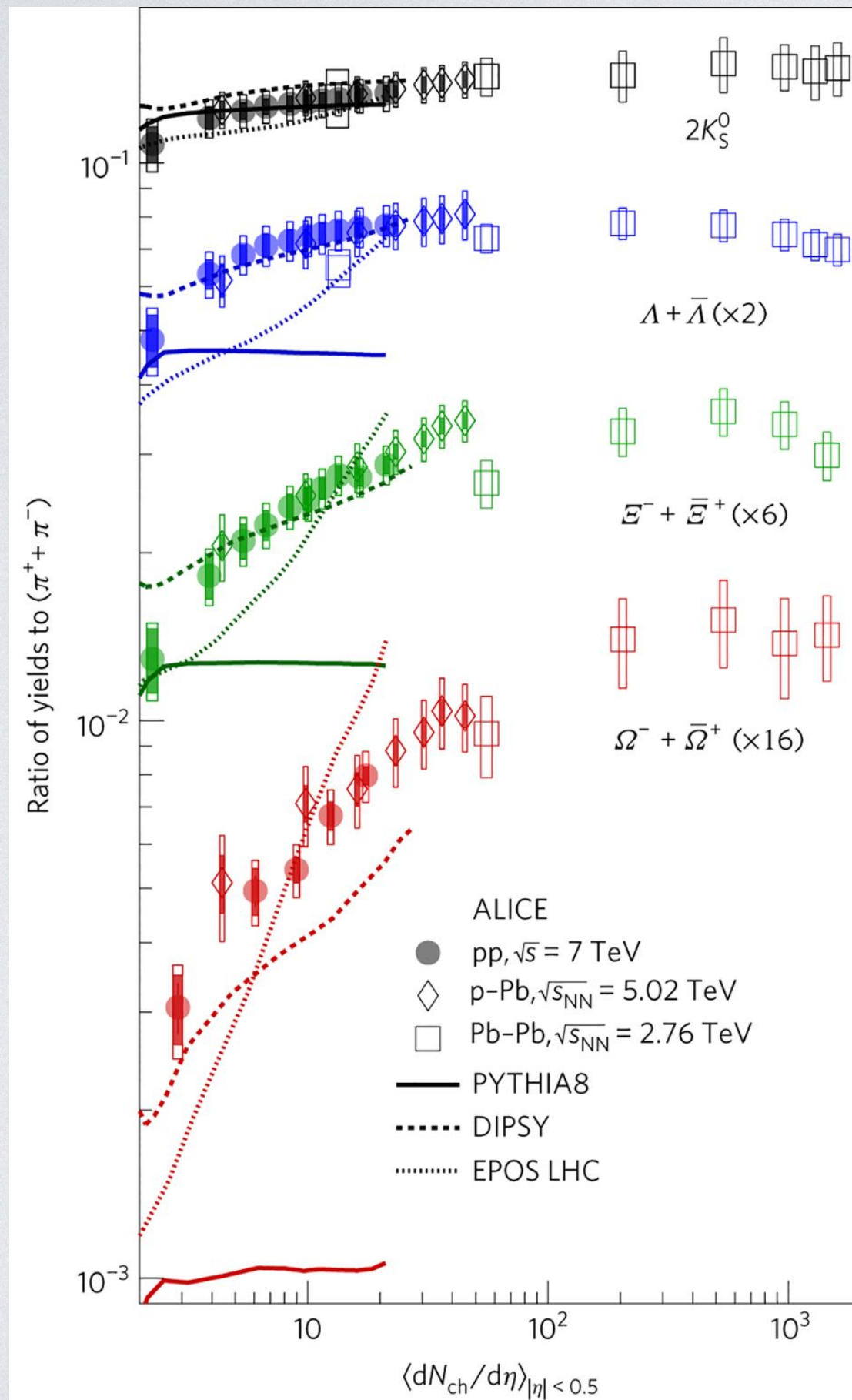
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CMS, JHEP 1009:091,2010

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Similar features of baryon to meson ratios in pp, p-Pb and Pb-Pb collisions

Observation of ridge structure in high-multiplicity pp collisions: a feature seen in heavy-ion collisions possibly due to collectivity



# Introduction and Motivation

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- Traditionally, small collision systems are used as a **baseline** for the study of possible formation of QGP in heavy-ion collisions.



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- The origin of the **collective-like behavior in small systems** is still unclear. To understand this let us discuss the following scenario in this talk.
  - **Isolating different physics regime (soft and hard physics)**
  - **Test with microscopic (strings) and macroscopic (driven by hydrodynamics) models**



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  - **Isolating different physics regime (soft and hard physics)**
  - **Test with microscopic (strings) and macroscopic (driven by hydrodynamics) models**
- To understand the small collision systems, the following multi-differential measurements are discussed here.
  - **Identified particle production as a function transverse spherocity in high multiplicity pp collisions**
  - **Un-identified and Identified particle production as a function of relative transverse activity classifier ( $R_T$ ) and search for jet quenching effects in small collision systems**

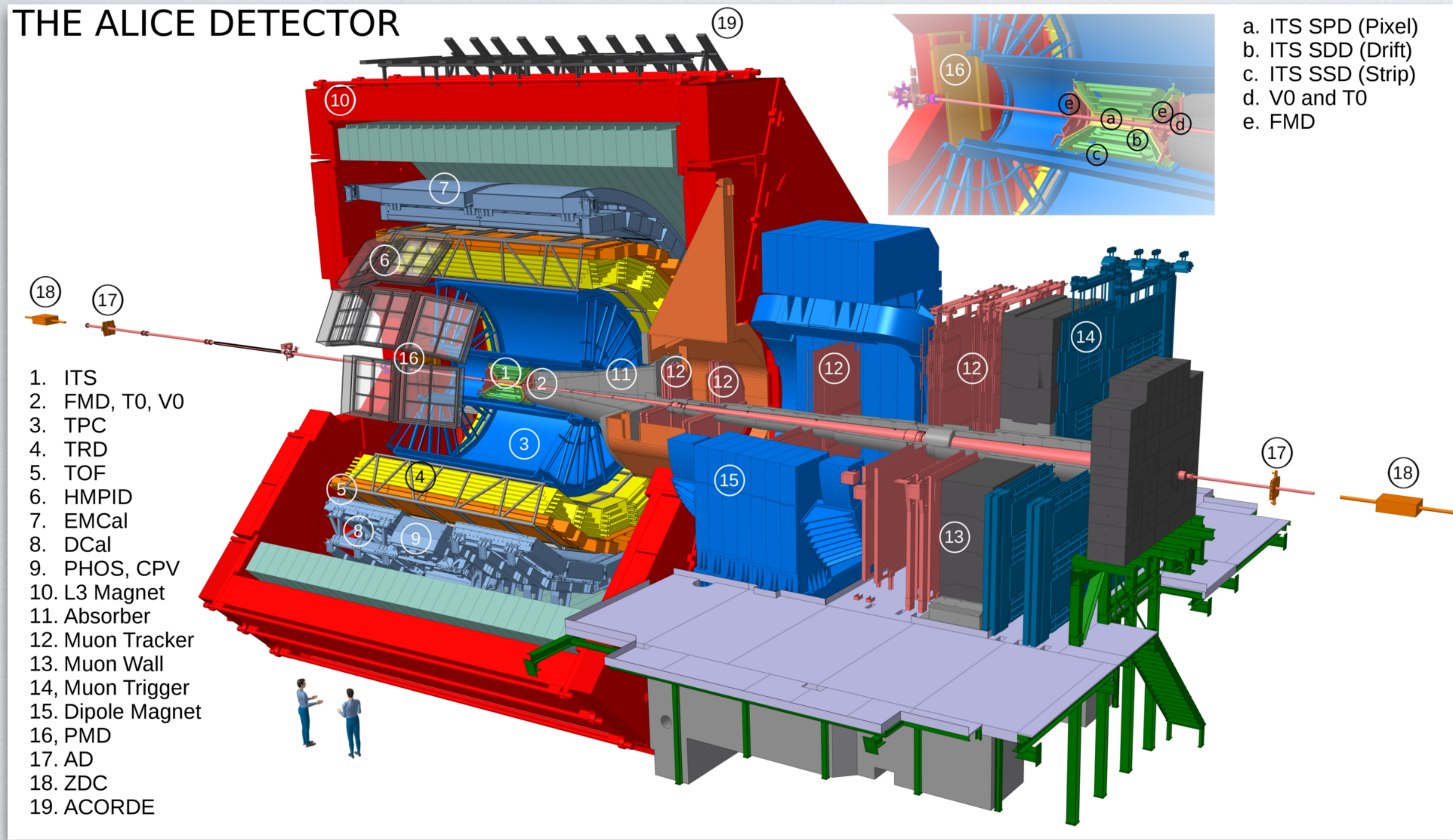


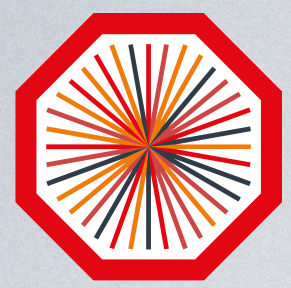
ALICE

# The ALICE detector

- ALICE has collected data for pp, p-Pb, Xe-Xe and Pb-Pb collisions at several center of mass energies.
- In order to improve the momentum resolution, tracks are accepted only in the range  $|\eta| < 0.8$  with  $p_T > 0.15$  GeV/c.

## THE ALICE DETECTOR



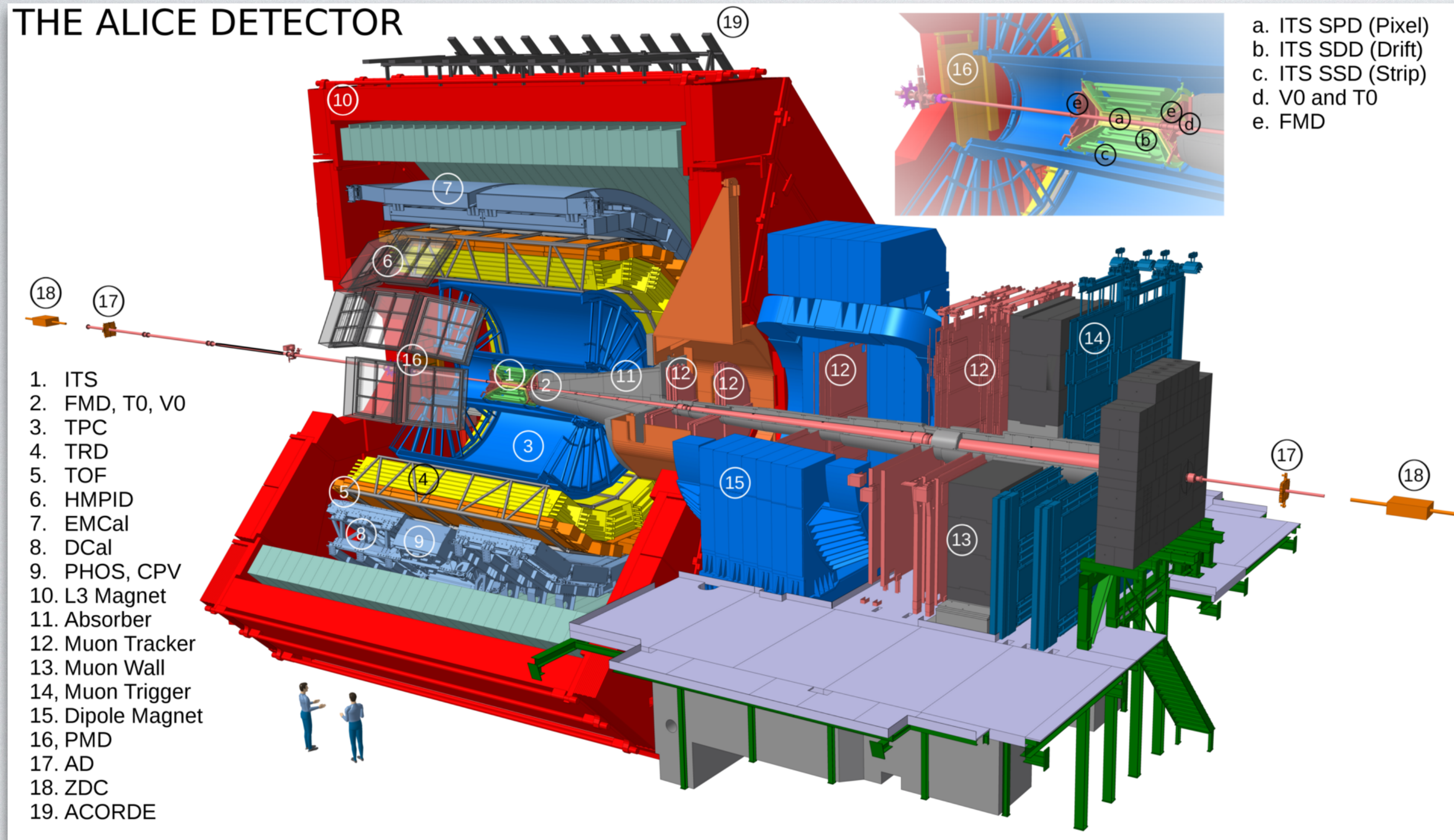


ALICE

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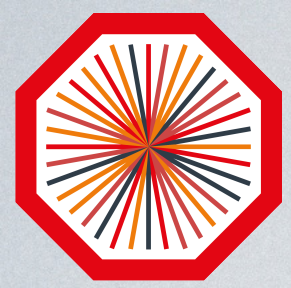
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## THE ALICE DETECTOR



### Detectors used for this analysis

- **The Inner tracking system (ITS)**
  - Trigger, tracking, vertex
  - Multiplicity estimator (CL1-mid rapidity)
- **The Time Projection Chamber (TPC)**
  - Tracking and PID (dE/dx)
- **The Time-Of-Flight detector (TOF)**
  - PID through particle time of flight
- **V0-A and V0-C detectors**
  - Trigger
  - Multiplicity estimator (V0M-forward rapidity)

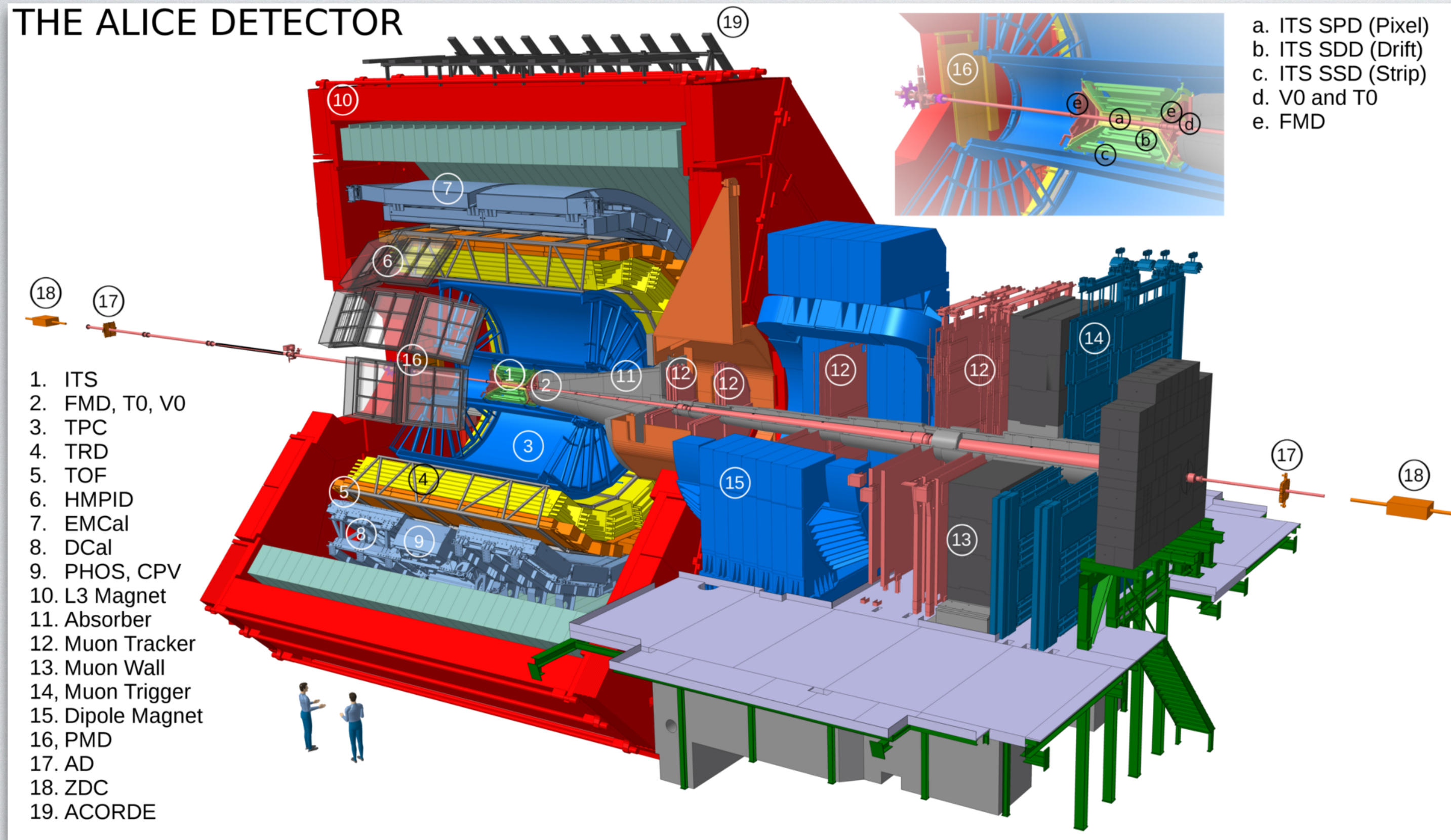


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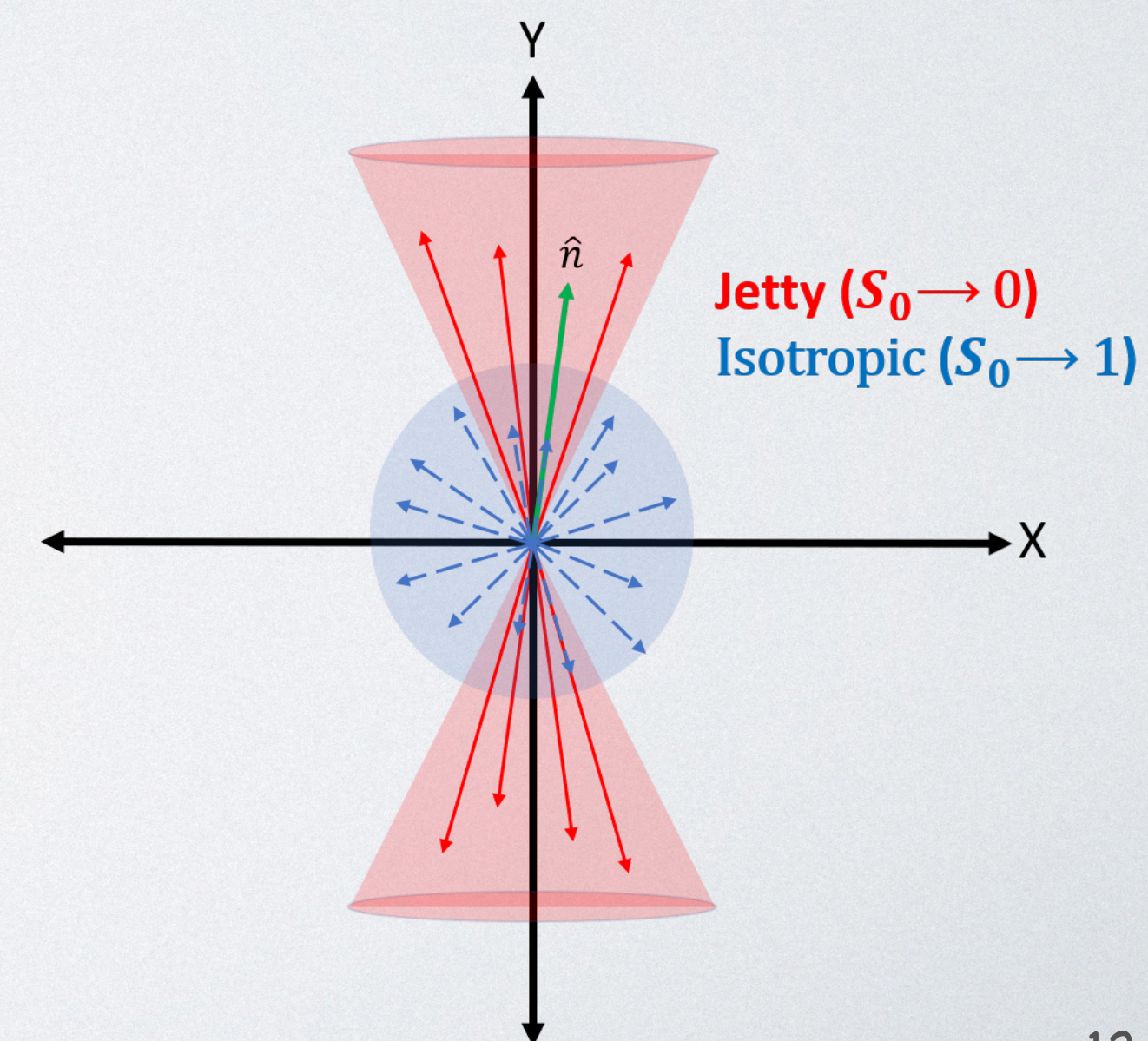


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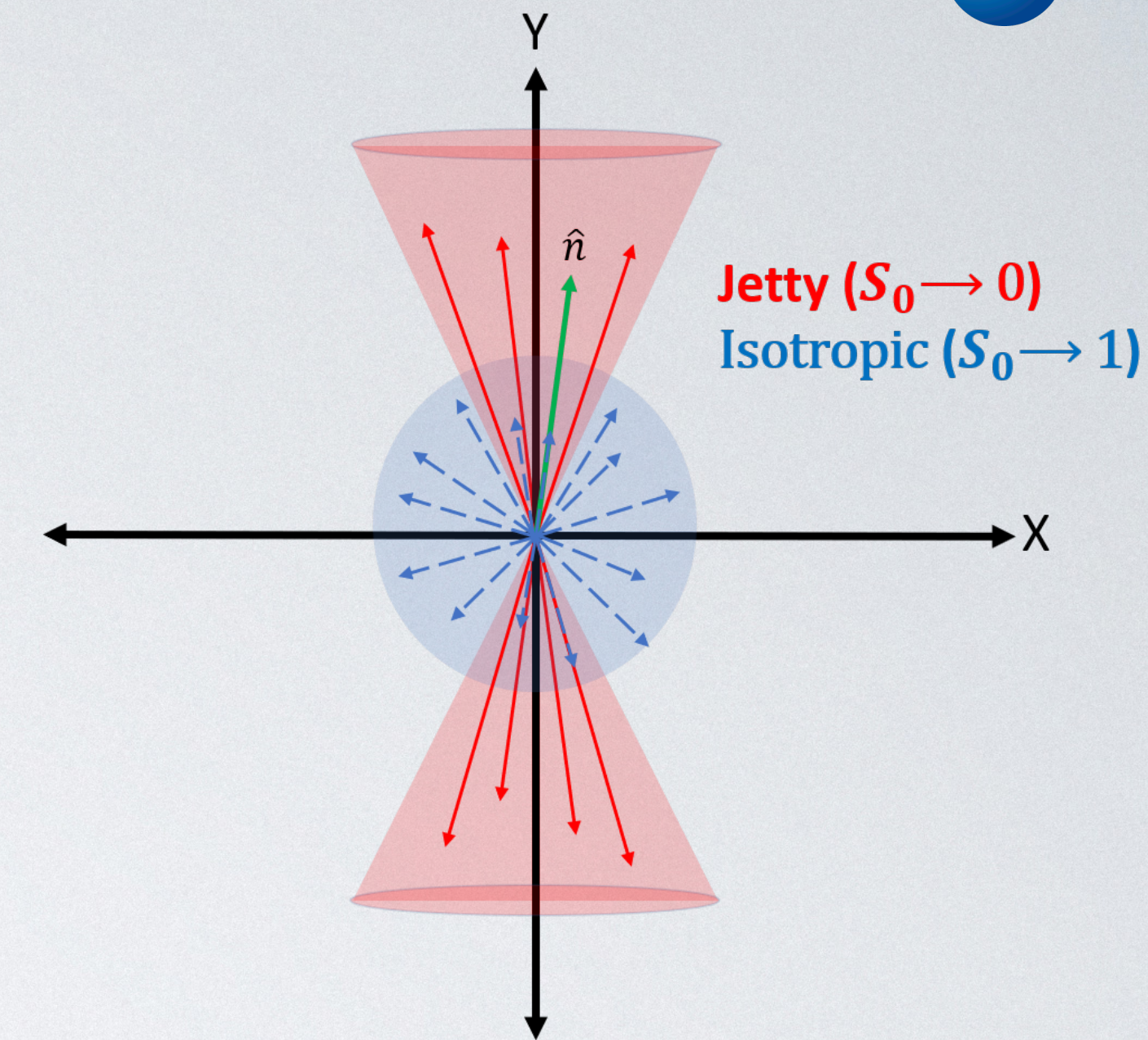
- Transverse sphericity analysis includes results from both V0M and CL1 multiplicity estimators:
  - particle production using CL1 estimator is more sensitive to auto-correlations
  - slicing events based on V0M and measuring particle production in mid-rapidity is more robust against auto-correlations.

# Identified particle production as a function of transverse spherocity



# Event shape observables: Transverse Spherocity

- Transverse Spherocity discriminates between hard and soft processes.
  - **Jetty**: Back-to-back structure, indication of hard QCD ( $S_0 \rightarrow 0$ )
  - **Isotropic**: enhances underlying events, soft QCD ( $S_0 \rightarrow 1$ )



$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left( \frac{\sum_i |\vec{p}_{Ti} \times \hat{n}|}{\sum_i p_{Ti}} \right)^2$$

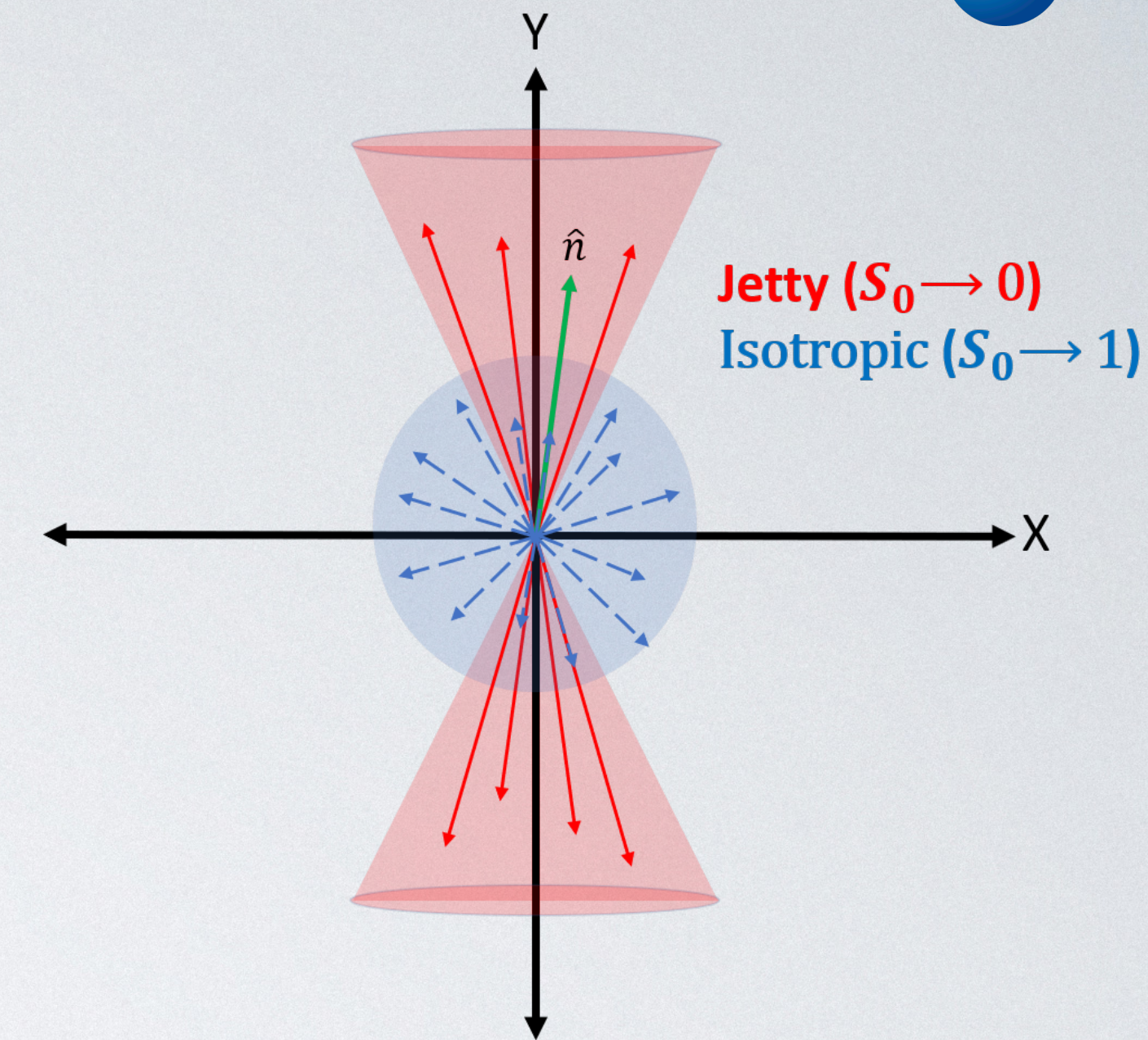
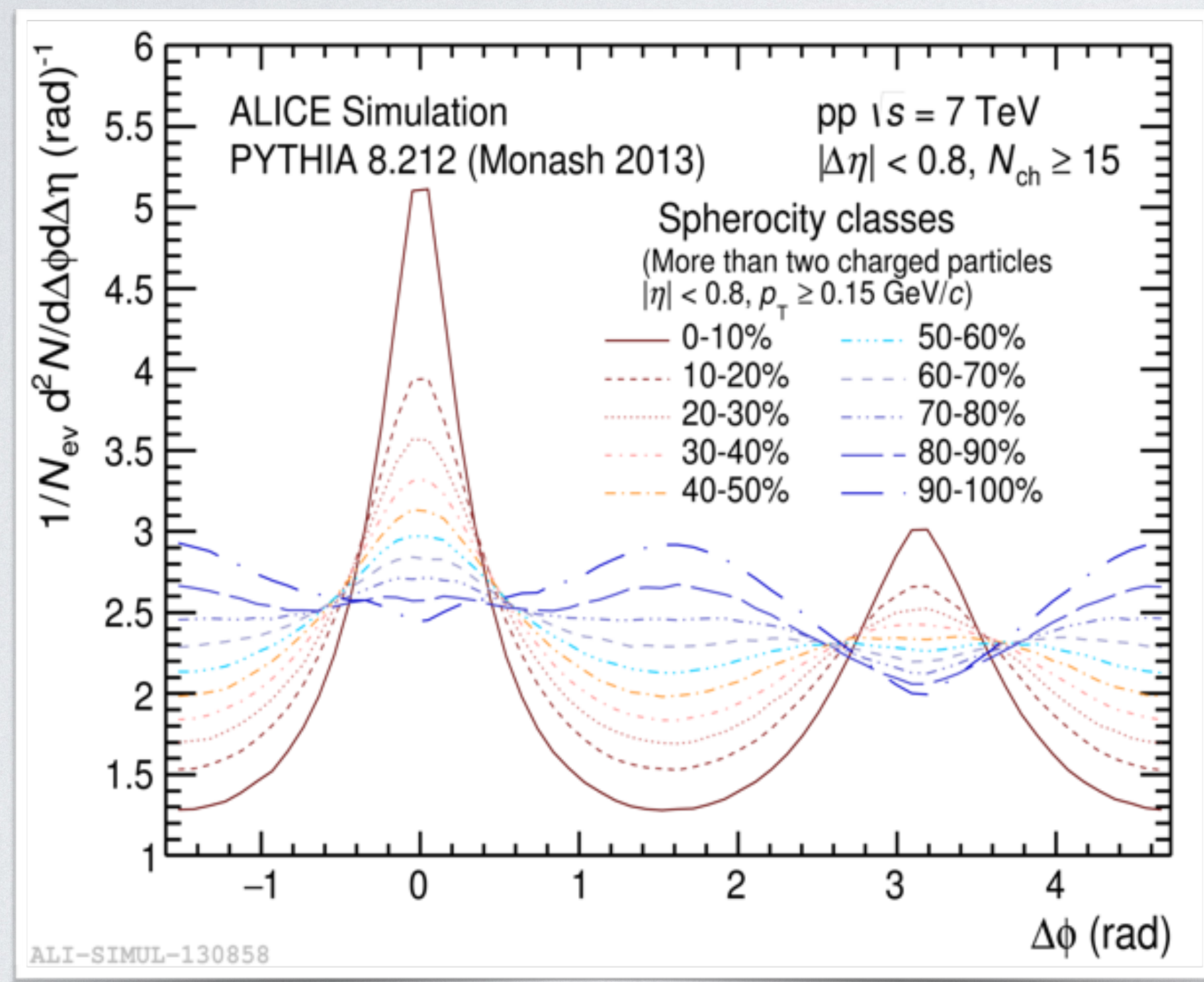
A. Ortiz, Adv.Ser.Direct.High Energy Phys. 29 (2018) 343.

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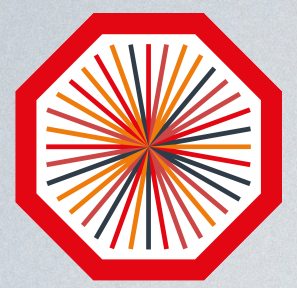


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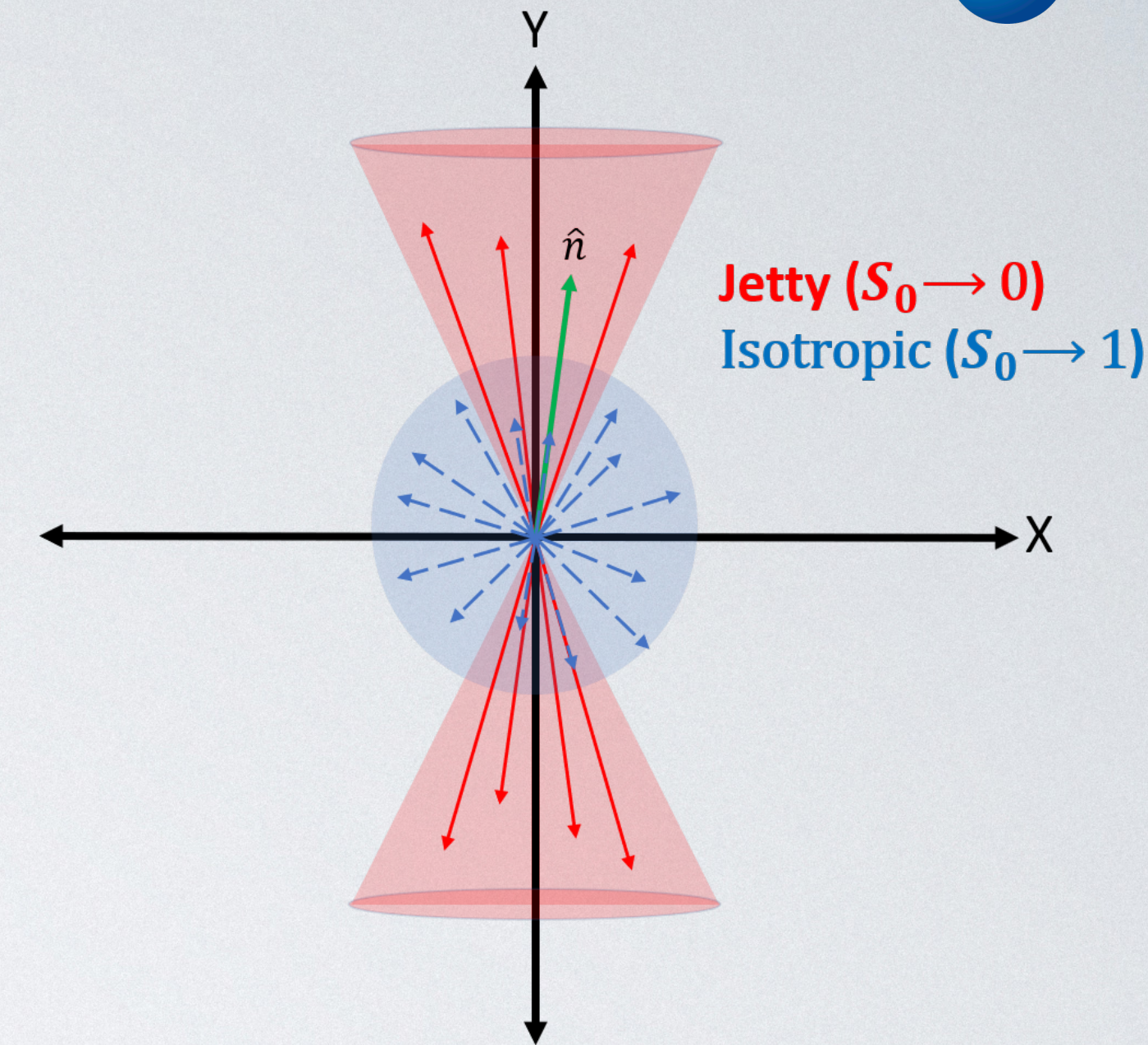
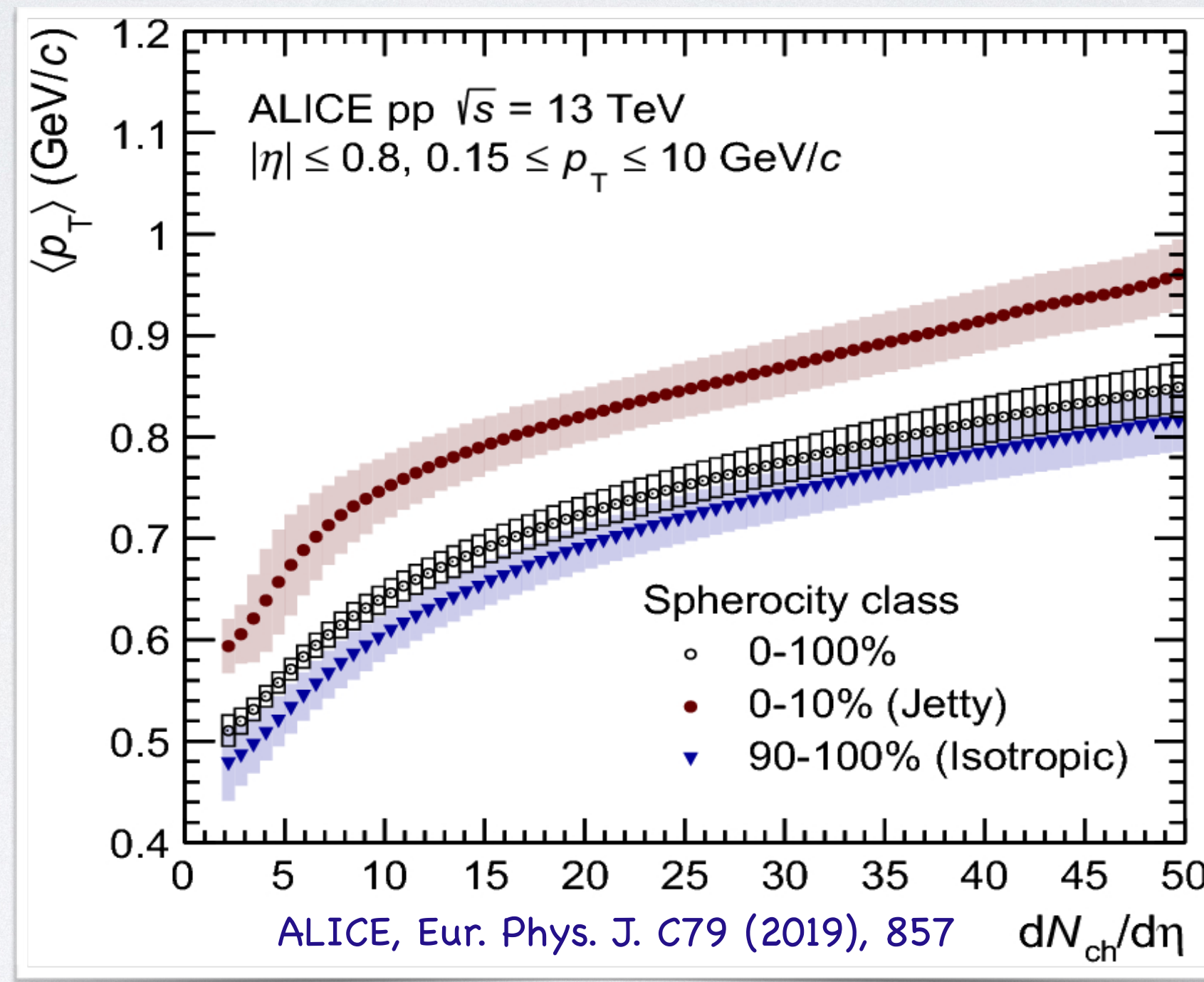
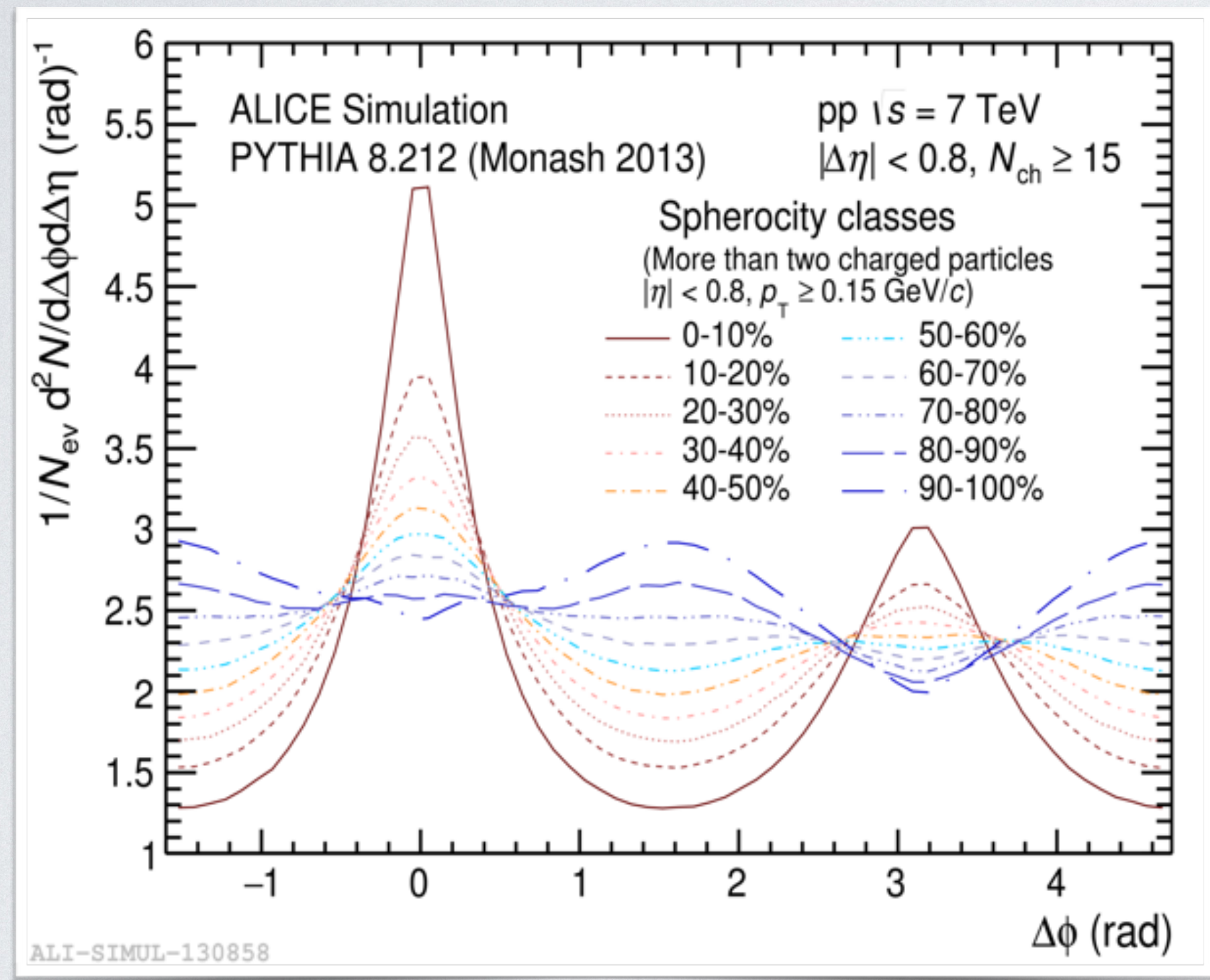
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ALICE

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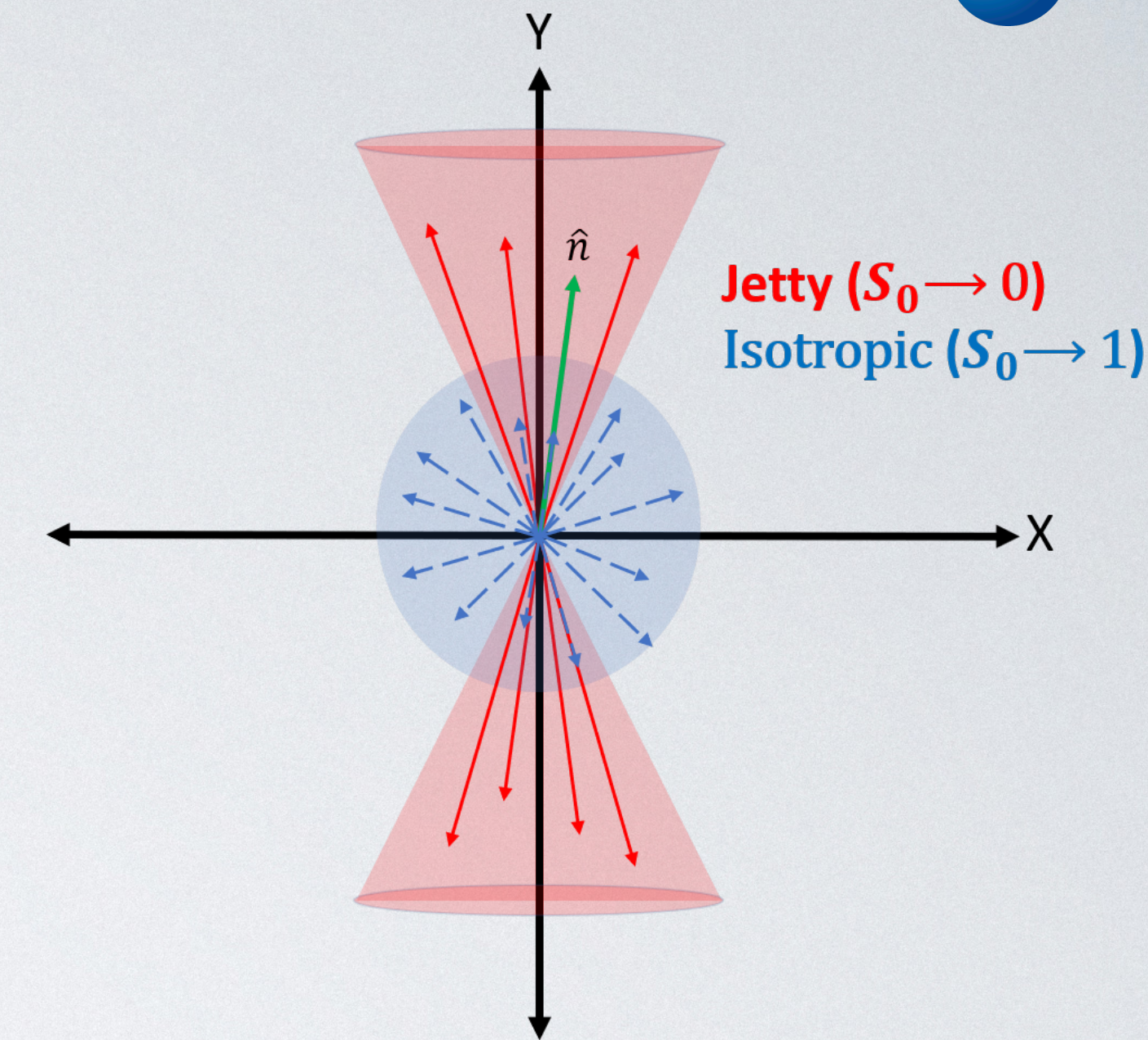
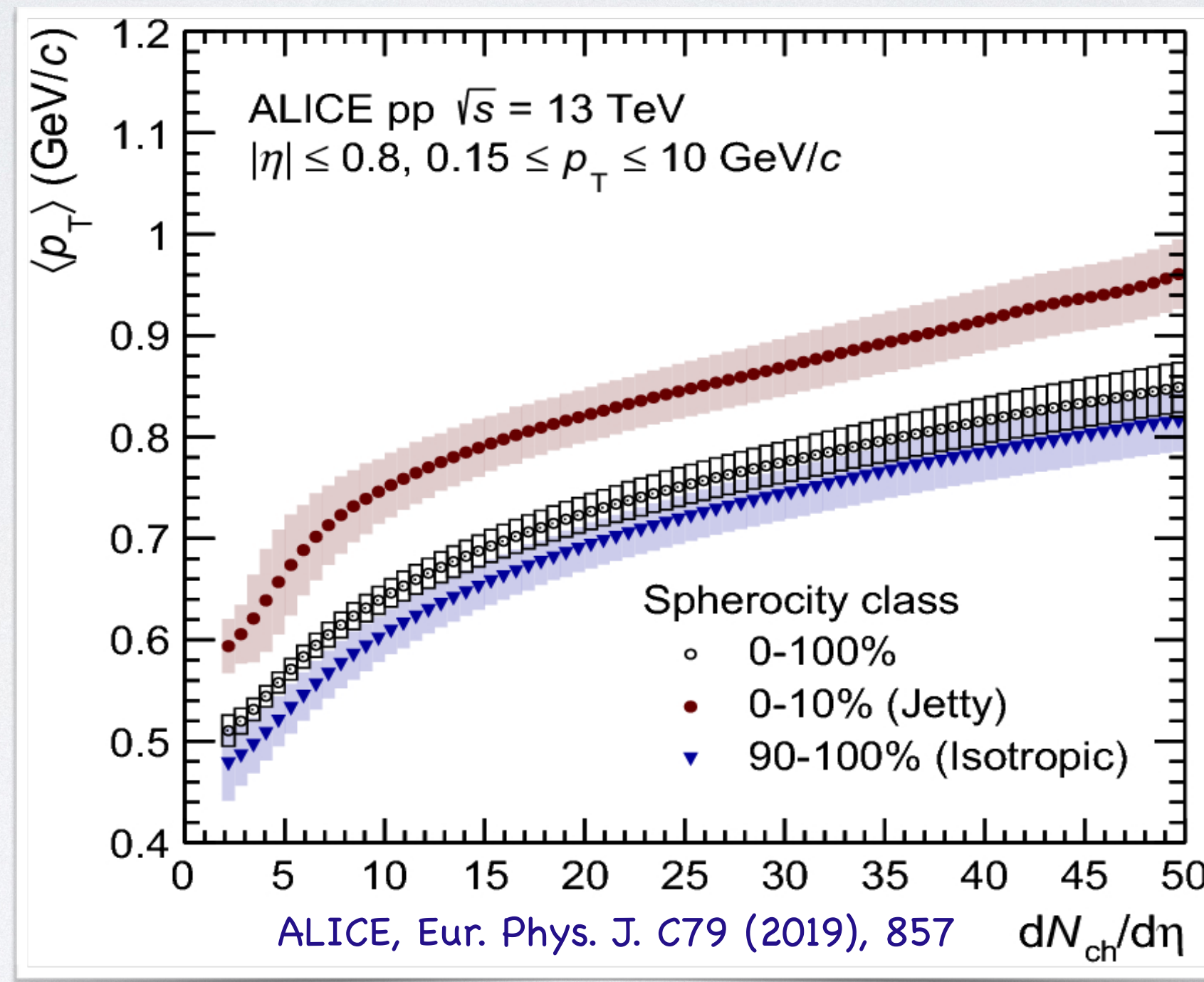
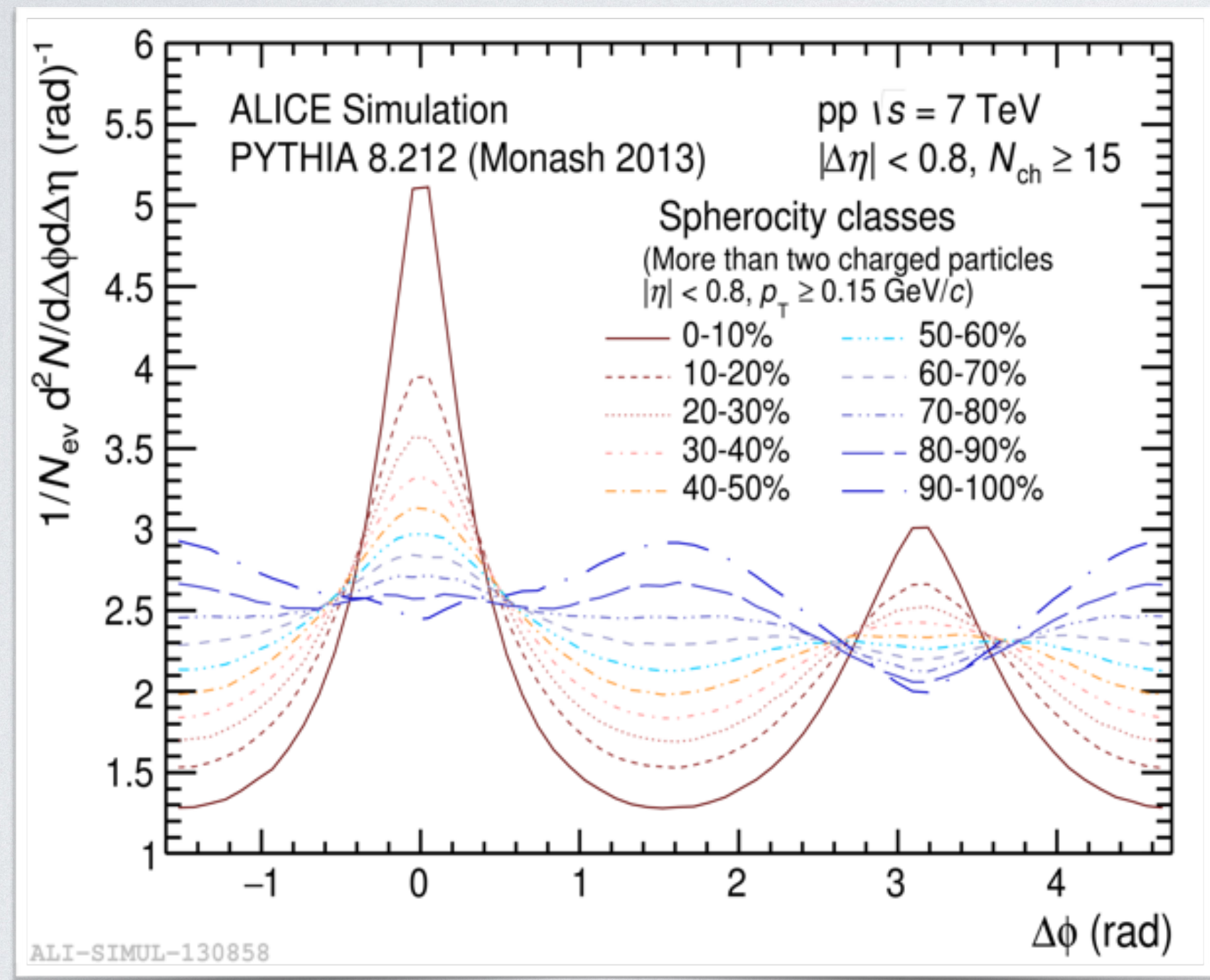
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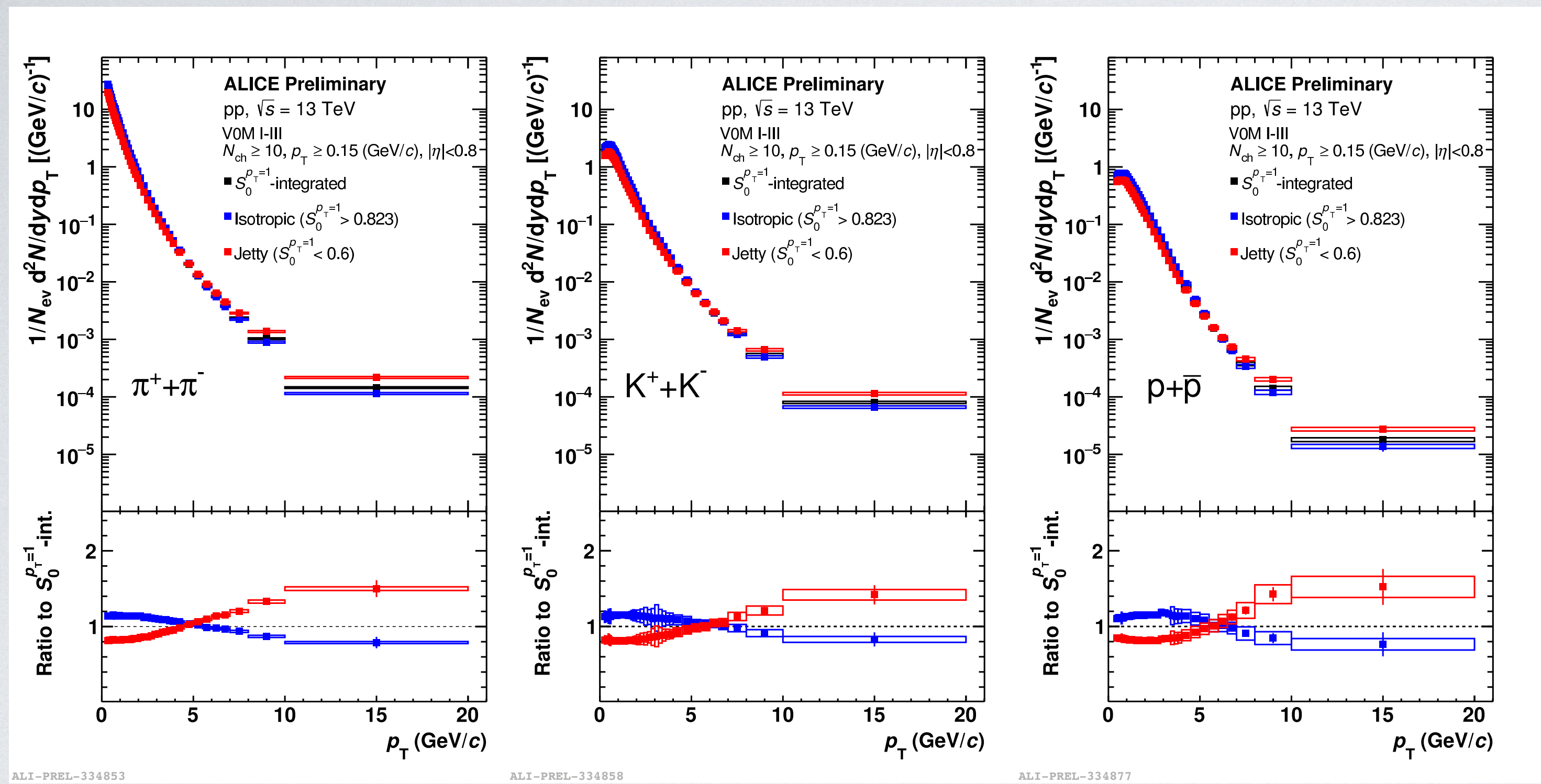


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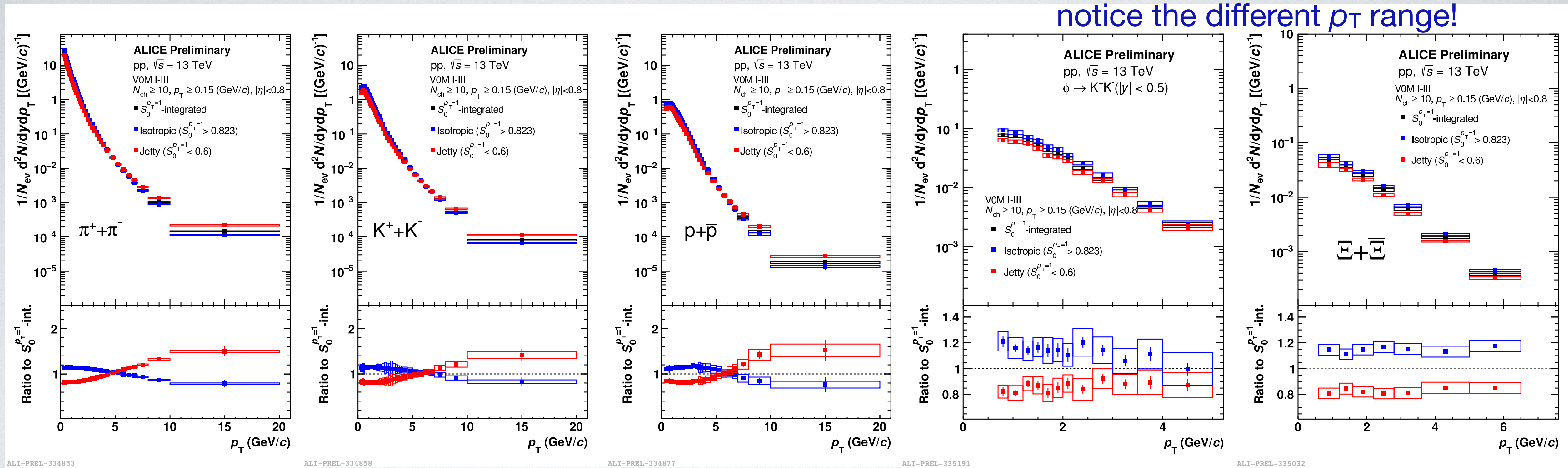
$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left( \frac{\sum_i |\hat{p}_{Ti} \times \hat{n}|}{N_{trk}} \right)^2$$

Unweighted transverse sphericity  
(Only the angular component is considered)

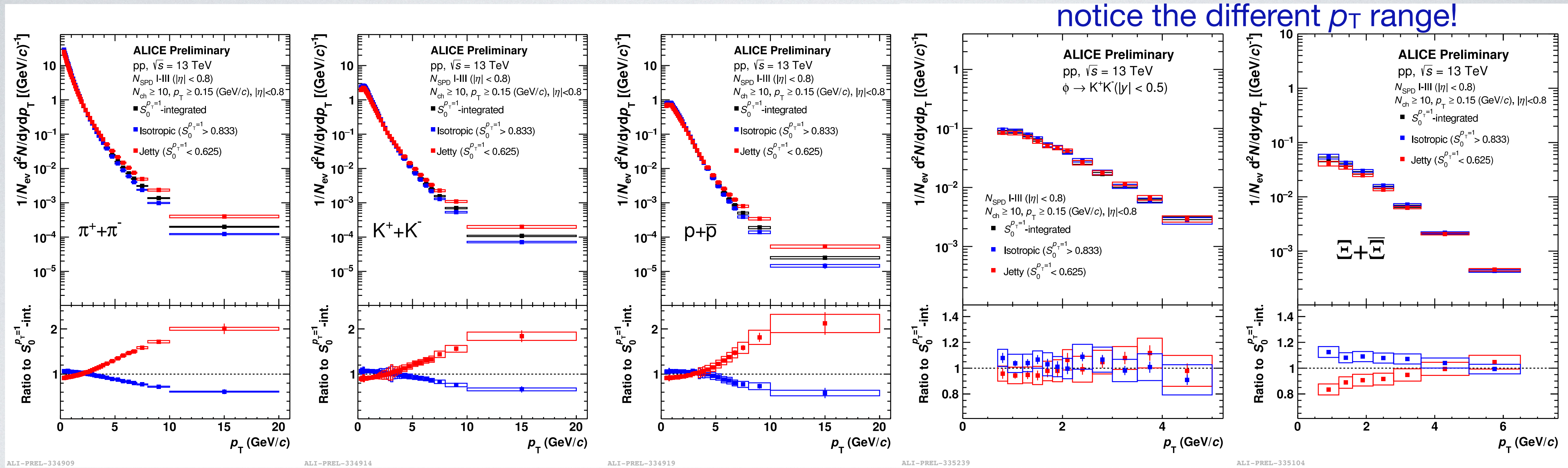
- Selecting events based on  $S_0$  affects neutral and charged hadrons differently.
- To study the neutral particles such as  $K_S^0, \phi, \Lambda, \Xi$  etc., the  $S_0$  estimator had to be modified (details in backup)



- Clear dependence of  $p_T$  spectra on  $S_0^{p_T=1}$  and in the lower panel, the isotropic and jetty events have distinct crossing points for pions, kaons and protons.



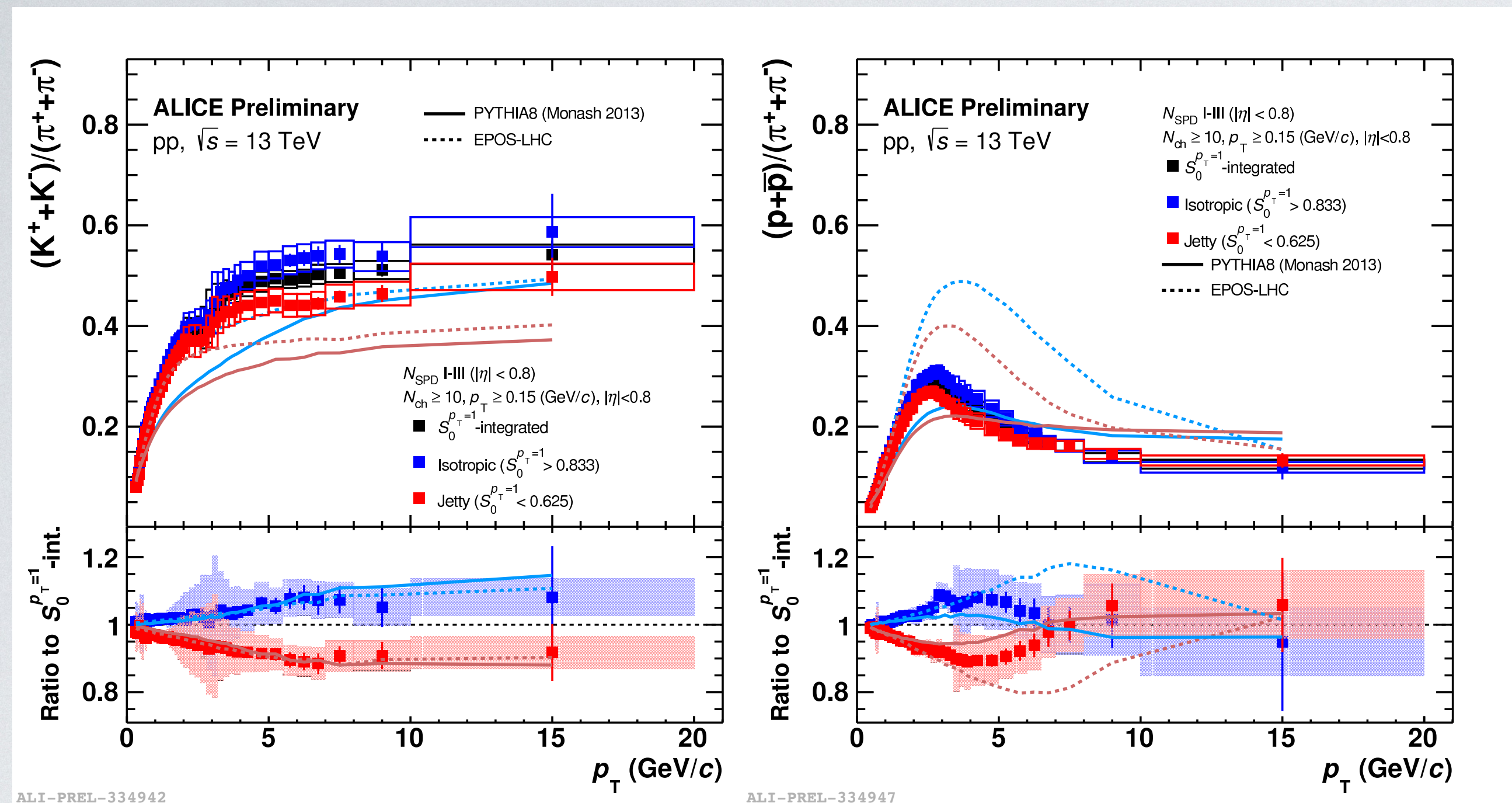
- Clear dependence of  $p_T$  spectra on  $S_0^{p_T=1}$  and in the lower panel, the isotropic and jetty events have distinct crossing points for pions, kaons and protons.
- $\phi$  and  $\Xi$  appear to be more flat around unity (notice the different  $p_T$  range!) and the crossing points are not seen in the measured momentum range.



- In the lower panels for pions, kaons and protons, the particle production from jetty events dominates from a lower- $p_T$  bin when compared to V0M estimator.
- $\Xi$  appear to be converging to unity and  $\phi$  does not show spherocity dependence in the measured  $p_T$  range.

The V0M-triggered isotropic and jetty events have larger multiplicity difference while the CL1-triggered events disentangle soft and hard events more accurately in small multiplicity gap.

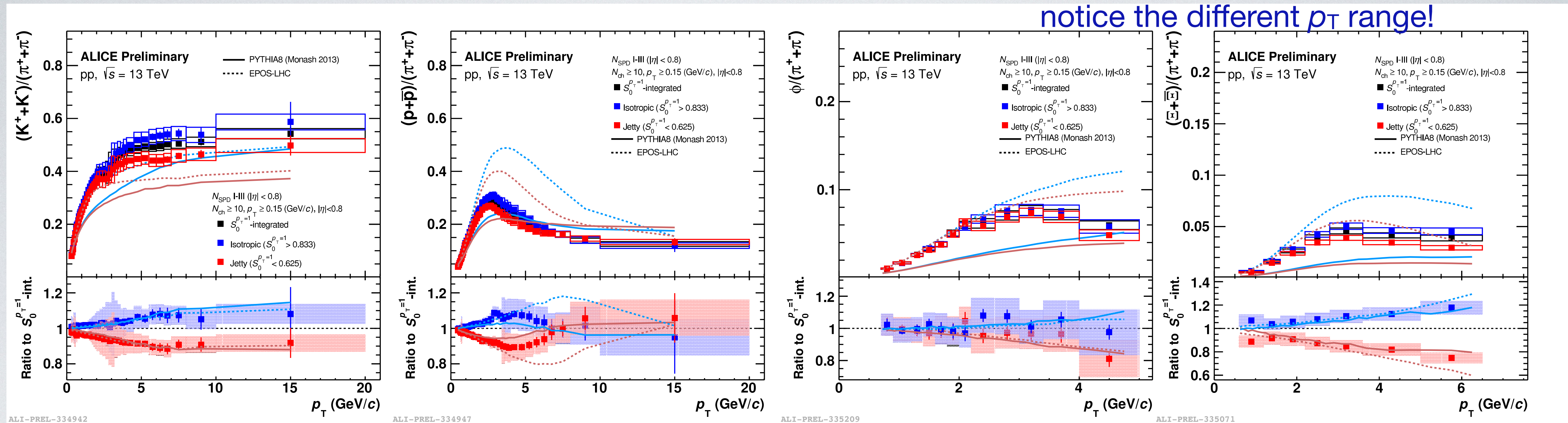
$N_{SPD}$  (CL1) estimator



- Ratio to pions, show a general softening and hardening of isotropic and jetty events, respectively.

In general, the particle ratios are not described by PYTHIA8 and EPOS-LHC. However, they seem to explain the double ratios accurately.

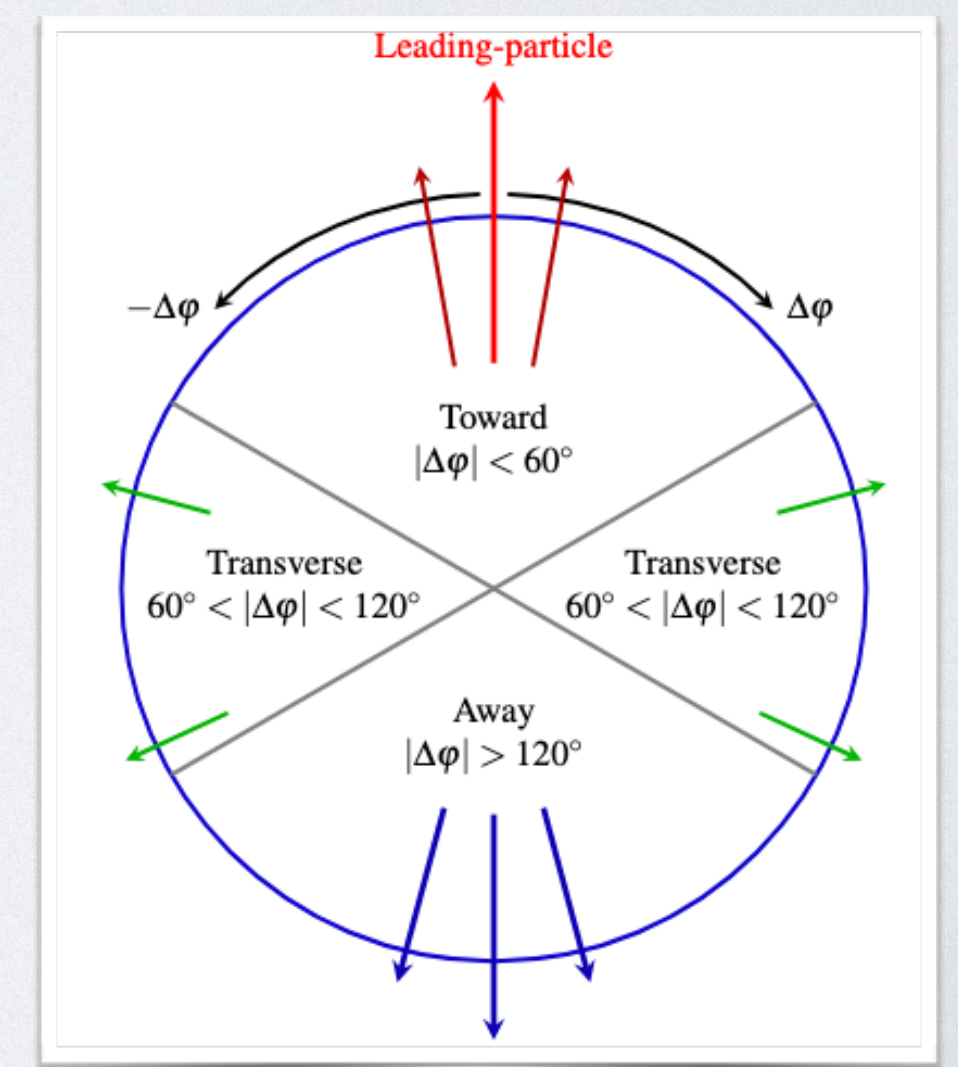
$N_{SPD}$  (CL1) estimator



- Ratio to pions, show a general softening and hardening of isotropic and jetty events, respectively.
- $\phi/\pi$  ratio: No significant dependence on sphericity unlike other particles.
- $K/\pi$  and  $\Xi/\pi$  ratios suggest that, one can enhance or suppress the strangeness enhancement by selecting on transverse sphericity.

In general, the particle ratios are not described by PYTHIA8 and EPOS-LHC. However, they seem to explain the double ratios accurately.

# Identified particle production as a function of Relative transverse activity classifier ( $R_T$ )

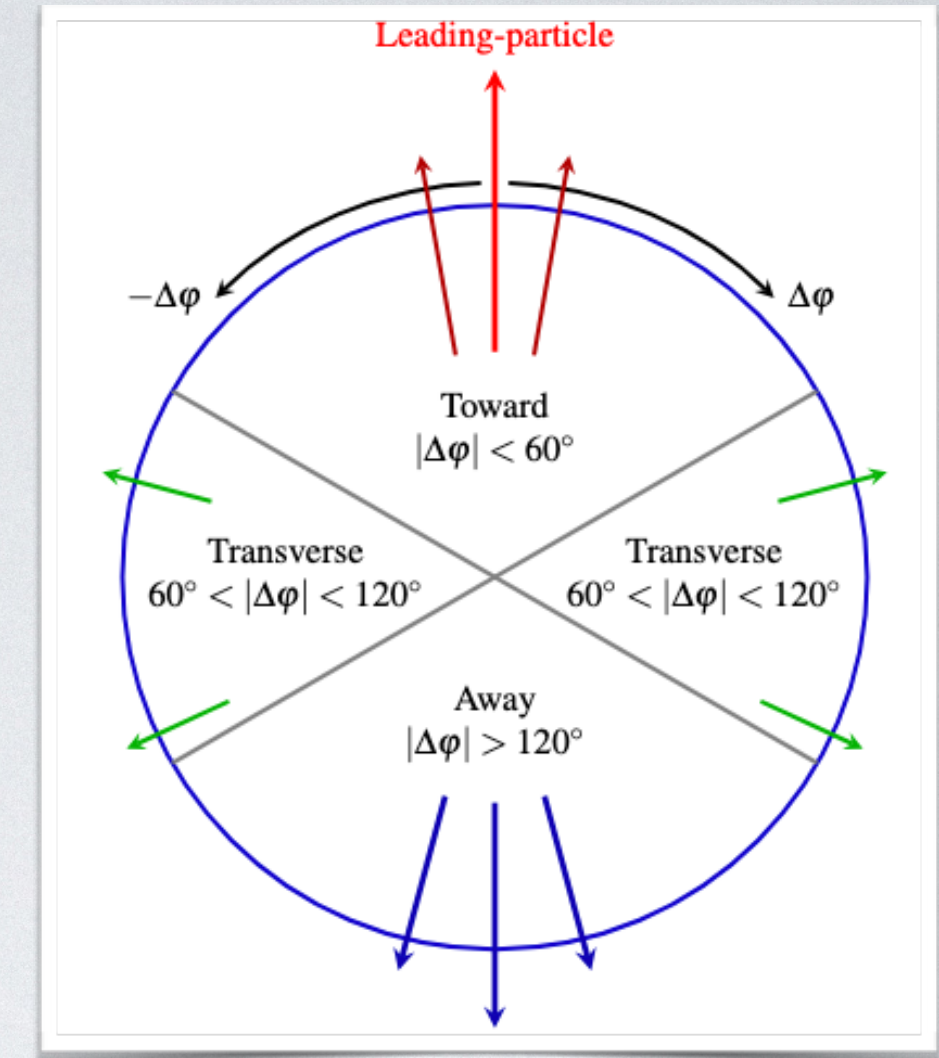




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# Event shape observables: Relative transverse activity classifier ( $R_T$ )

- $R_T = N_{ch}^{TS} / \langle N_{ch}^{TS} \rangle$ , where  $N_{ch}^{TS}$  is the charged particle multiplicity in the transverse region.
- Using  $R_T$ , one can vary the magnitude of underlying events (UE) and study the particle production.  $R_T \rightarrow 0$  : Events with less UE. They are expected to be compatible with the results from jetty-like events based on transverse sphericity.



P. Skands et. al., Eur. Phys. J. C76 (2016) 299.

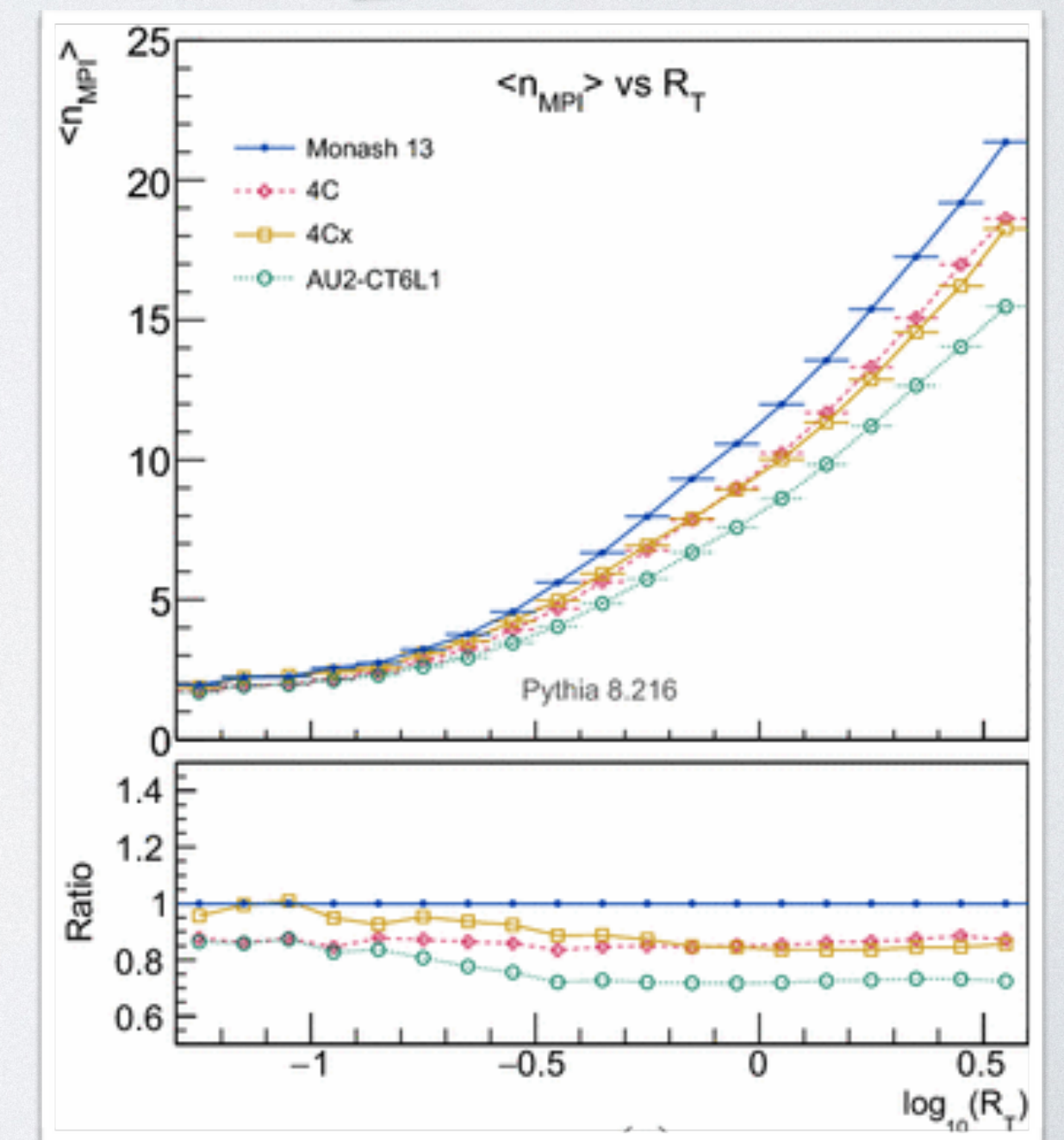
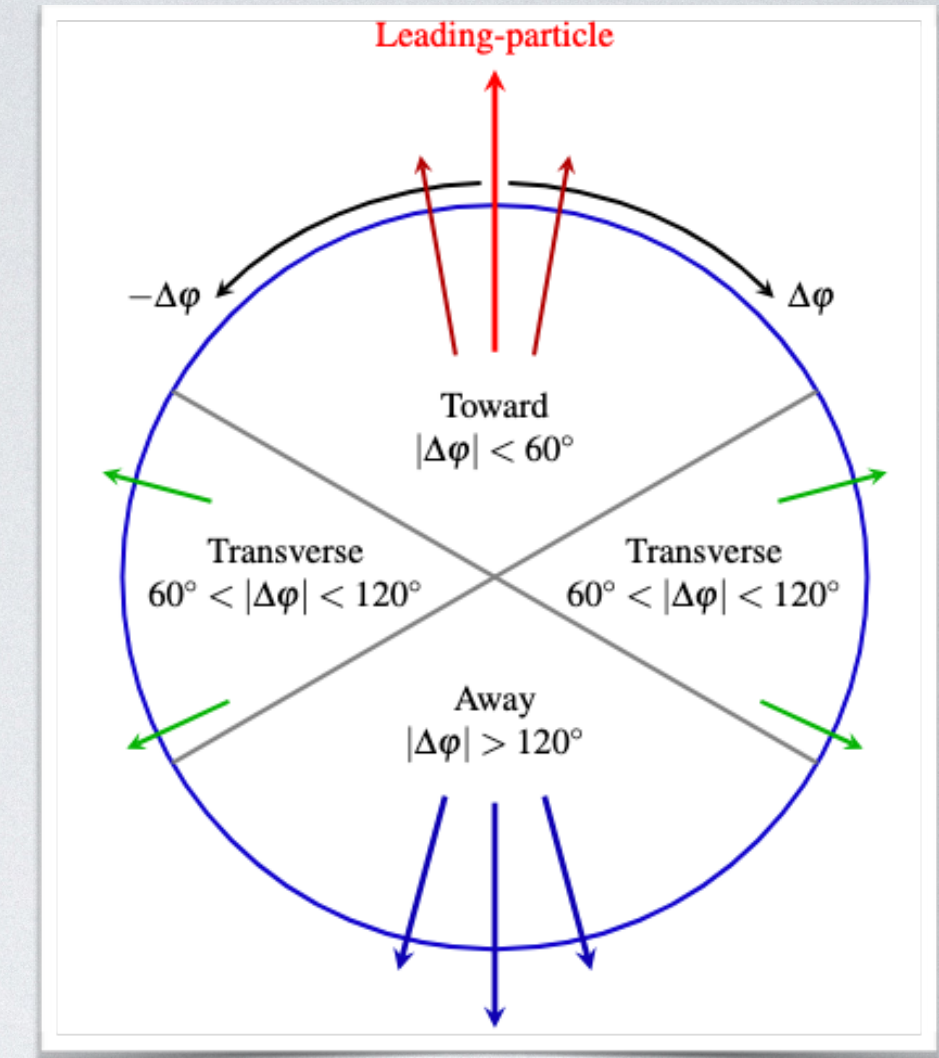
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- It is an useful tool to study:
  - Collective effects in events with low and high transverse activity
  - Events as a function of varying multi-partonic interactions (MPIs)
  - Interplay between soft and hard interactions
  - Auto-correlation effects

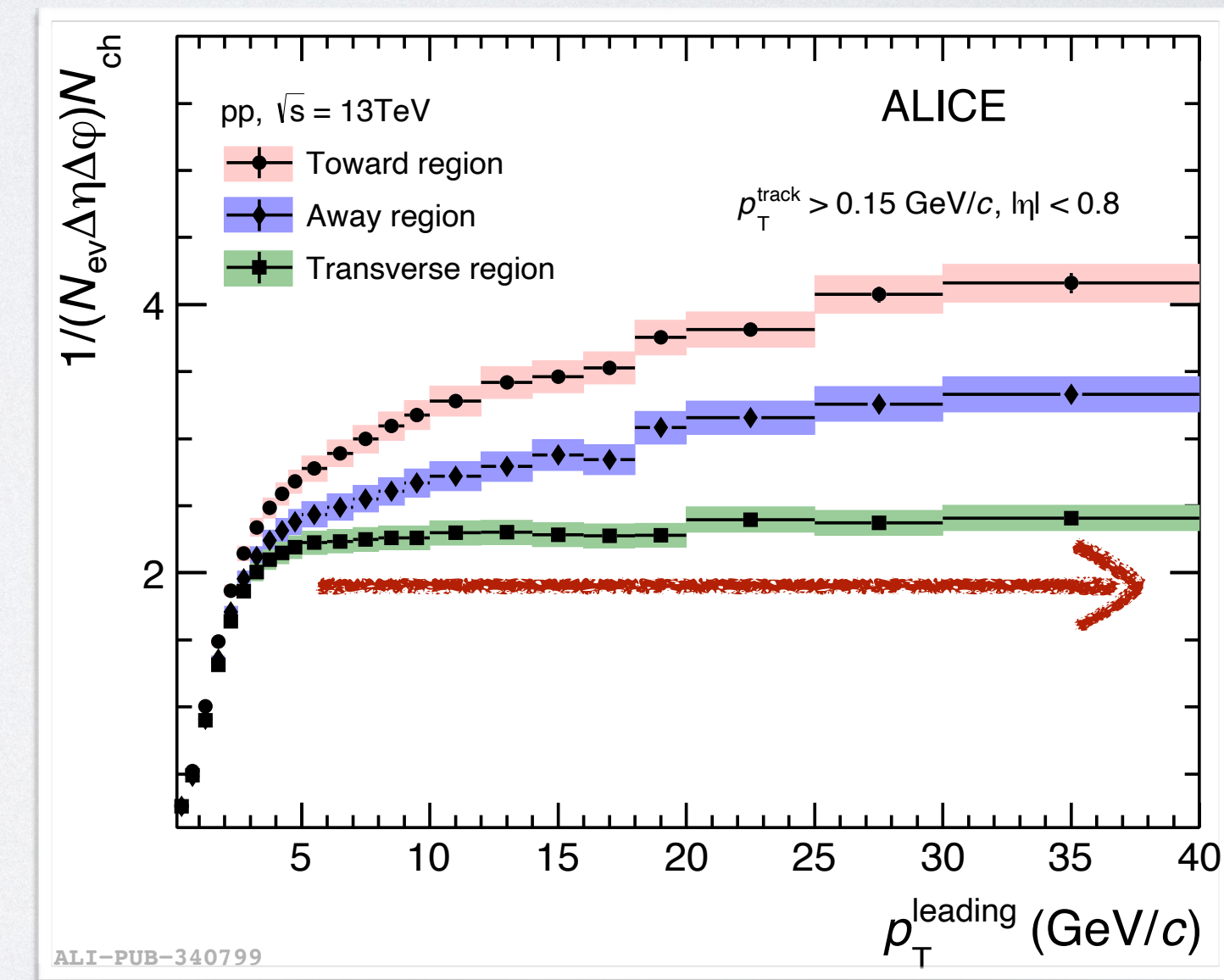
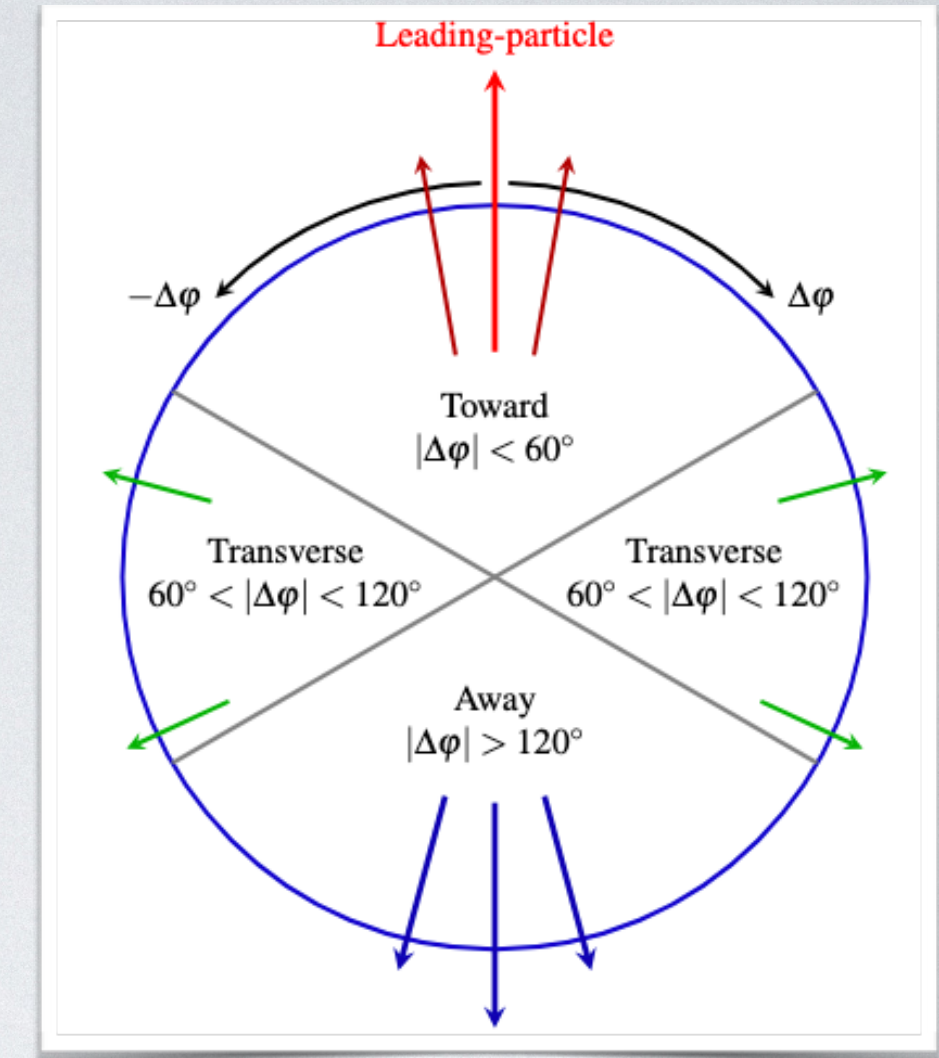


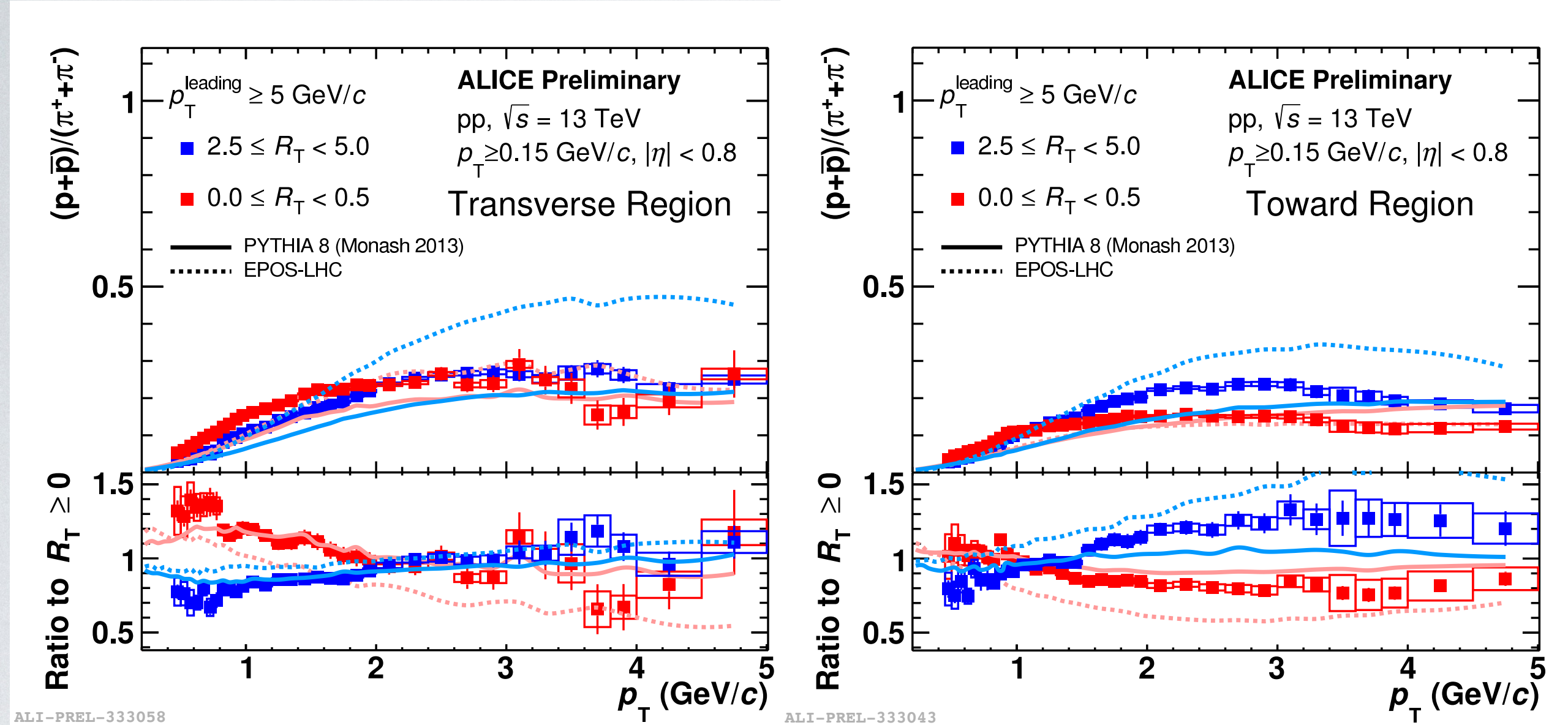


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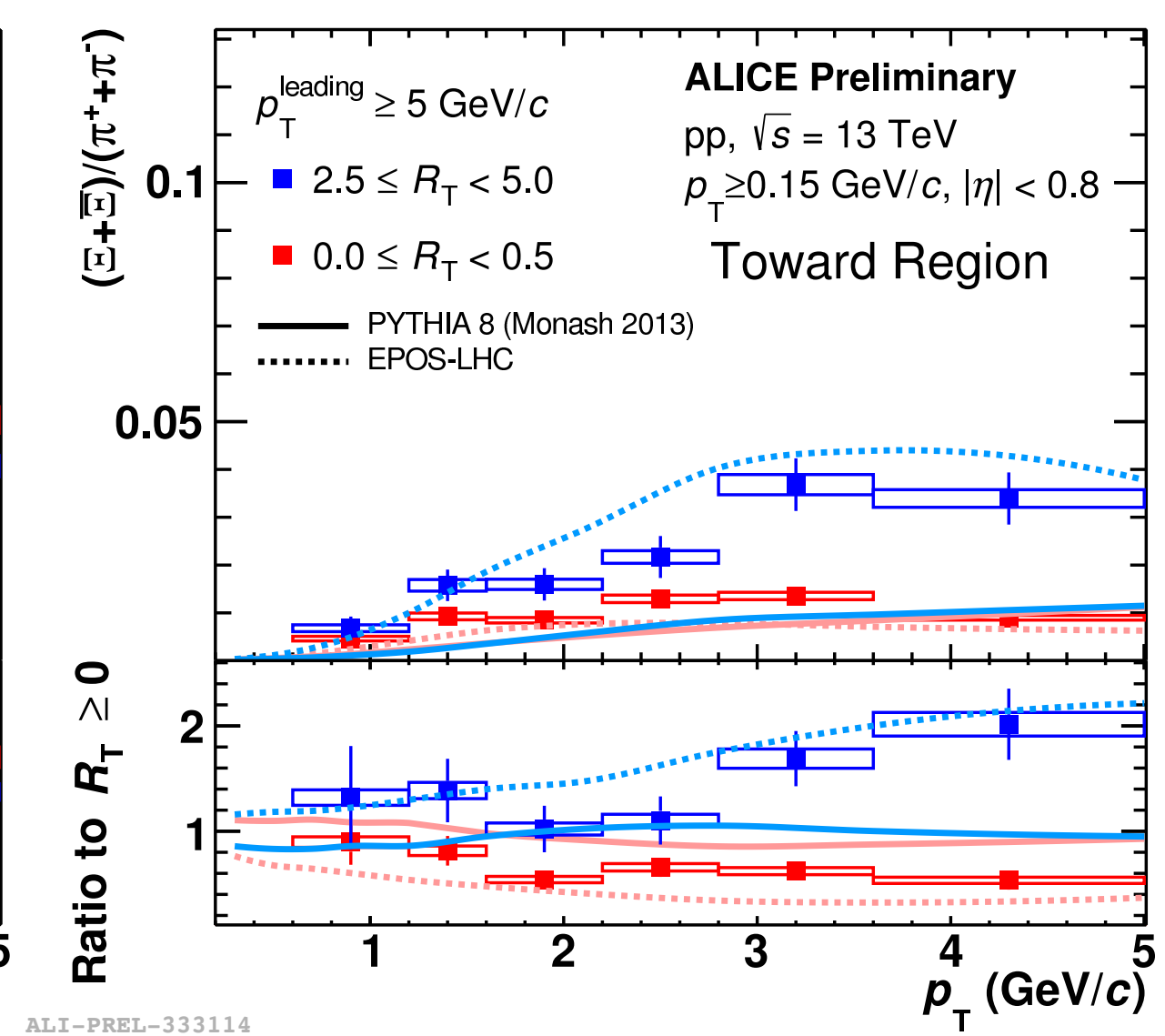
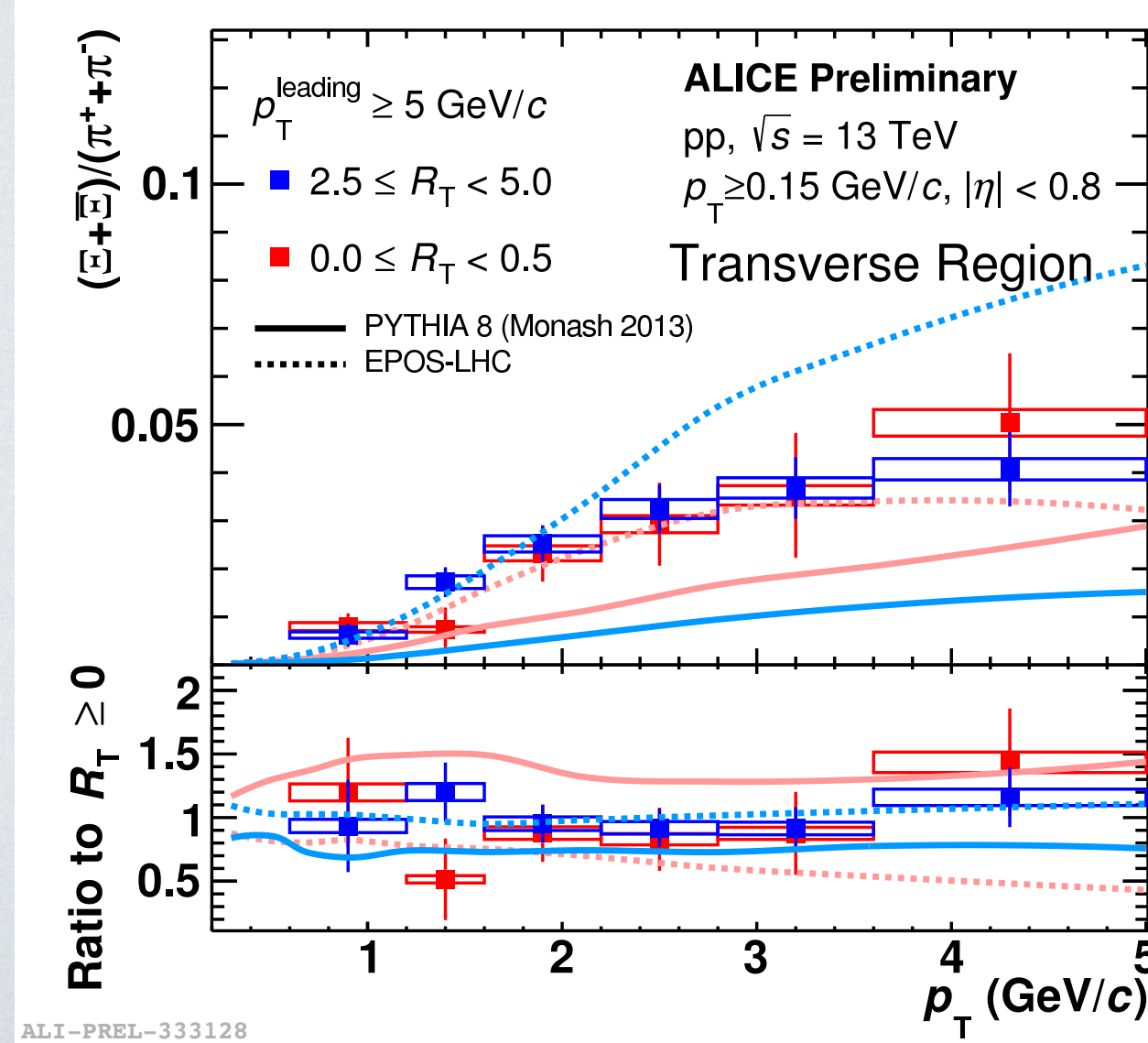
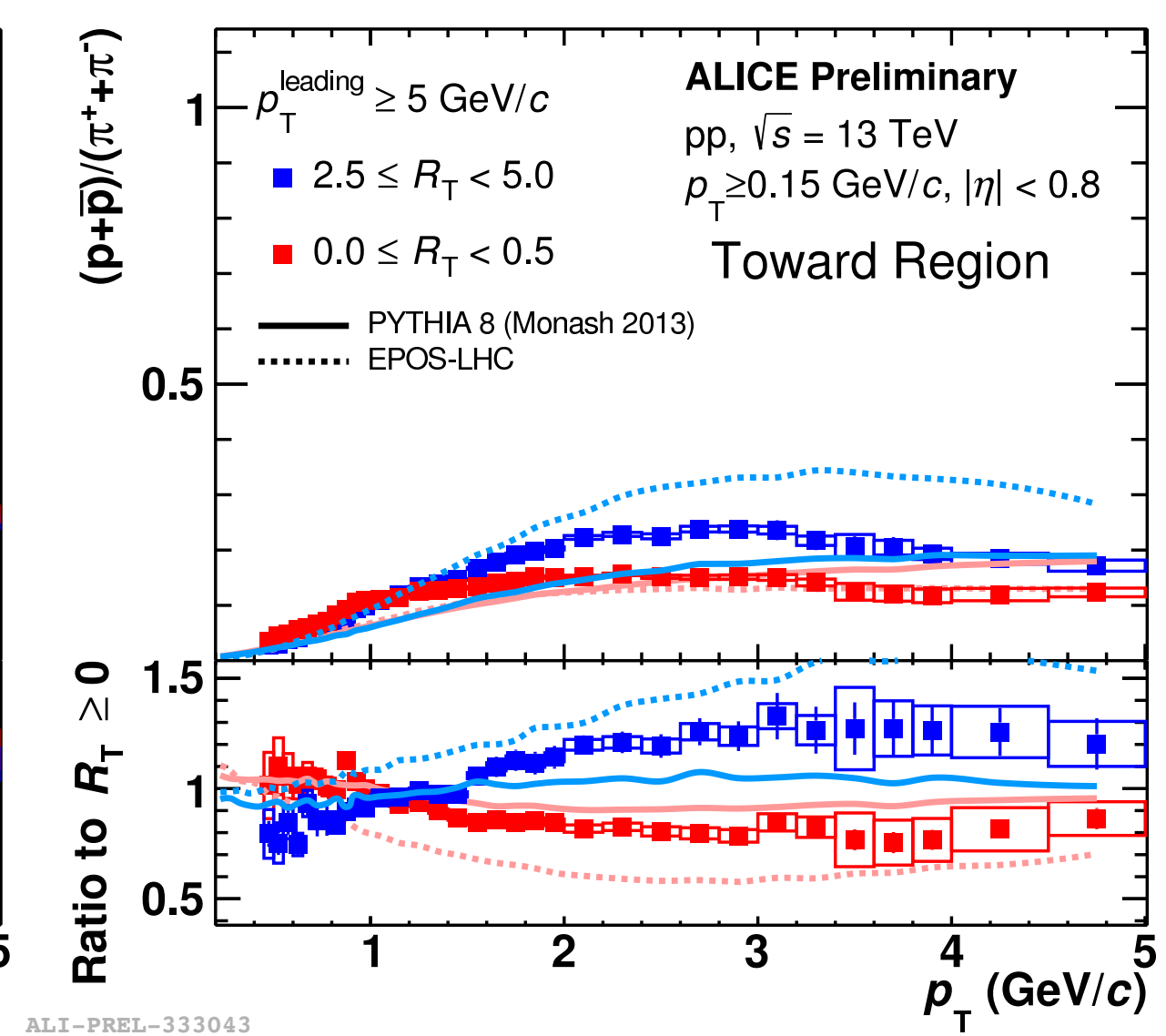
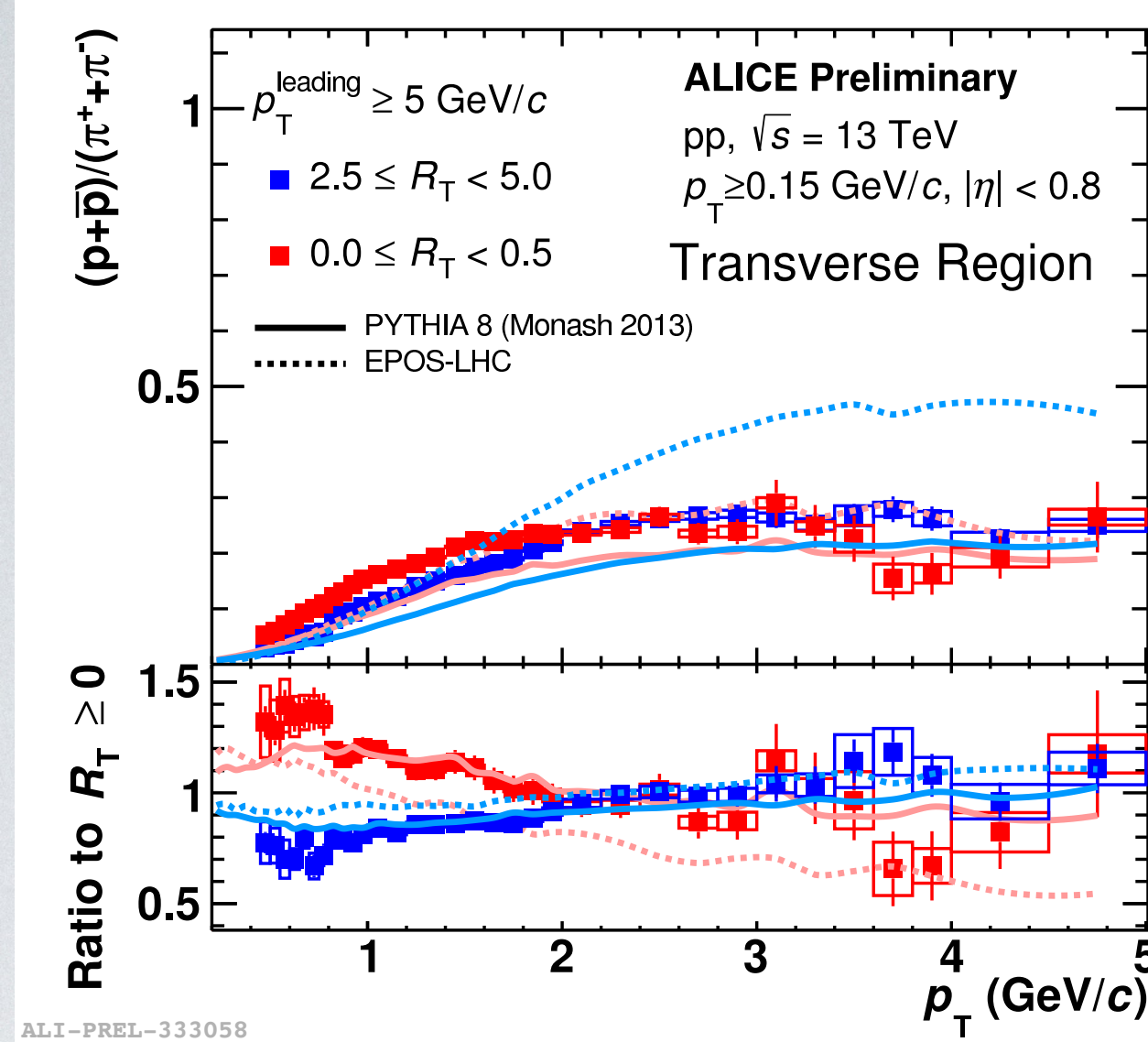
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- It is an **useful tool** to study:
  - Collective effects in events with low and high transverse activity
  - Events as a function of varying multi-partonic interactions (MPIs)
  - Interplay between soft and hard interactions
  - Auto-correlation effects
- A  $p_T$  cut for the leading particle is required to ensure a hard process
  - For **identified particle analysis**:  $p_T^{\text{leading}} > 5 \text{ GeV}/c$  (particle production in transverse region is relatively stable in this range)
  - For **un-identified charged particle analysis**:  $8 < p_T^{\text{leading}} < 15 \text{ GeV}/c$  (this hard cut reduces the flow effects, required for searches for jet quenching effects)

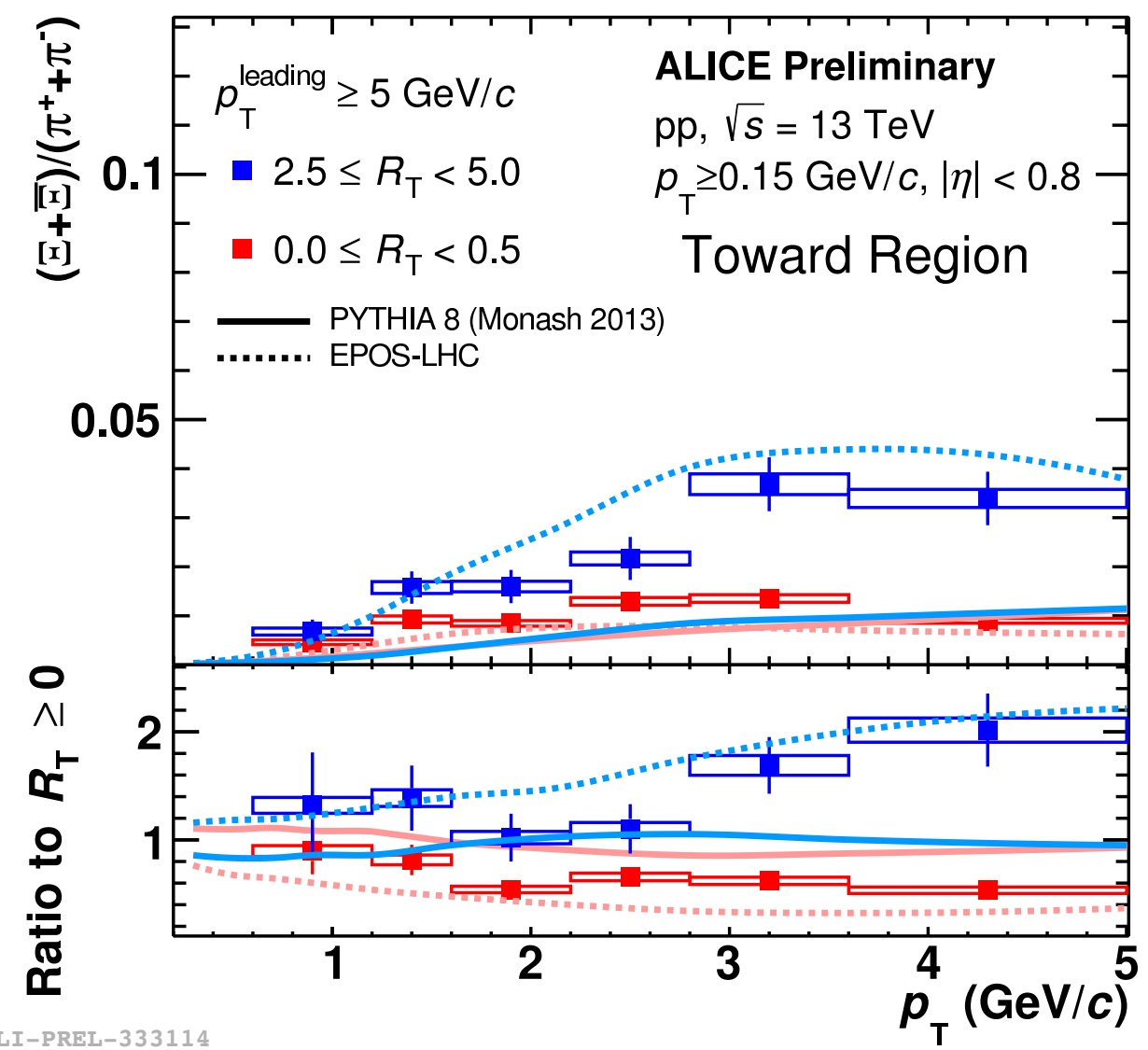
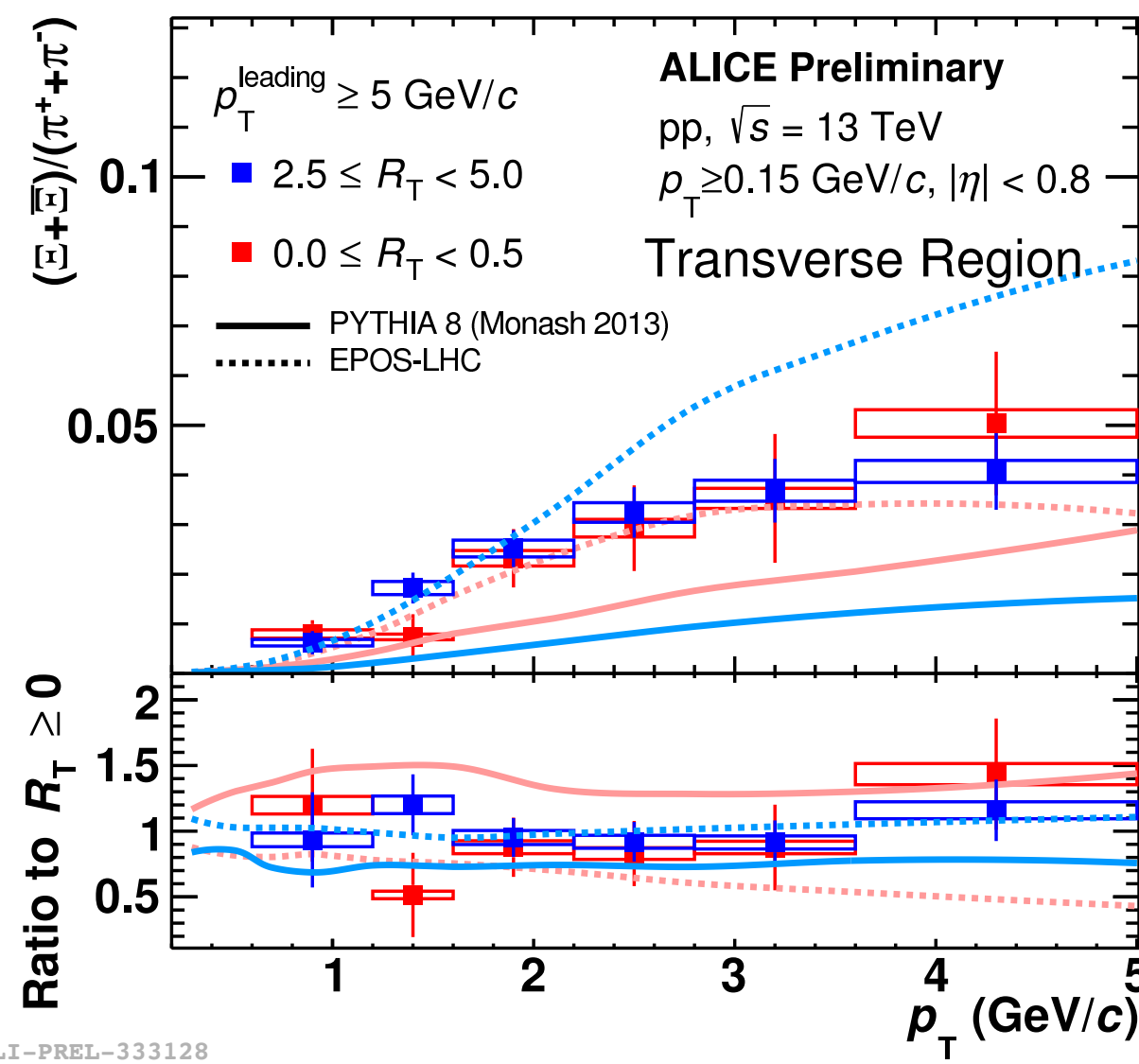
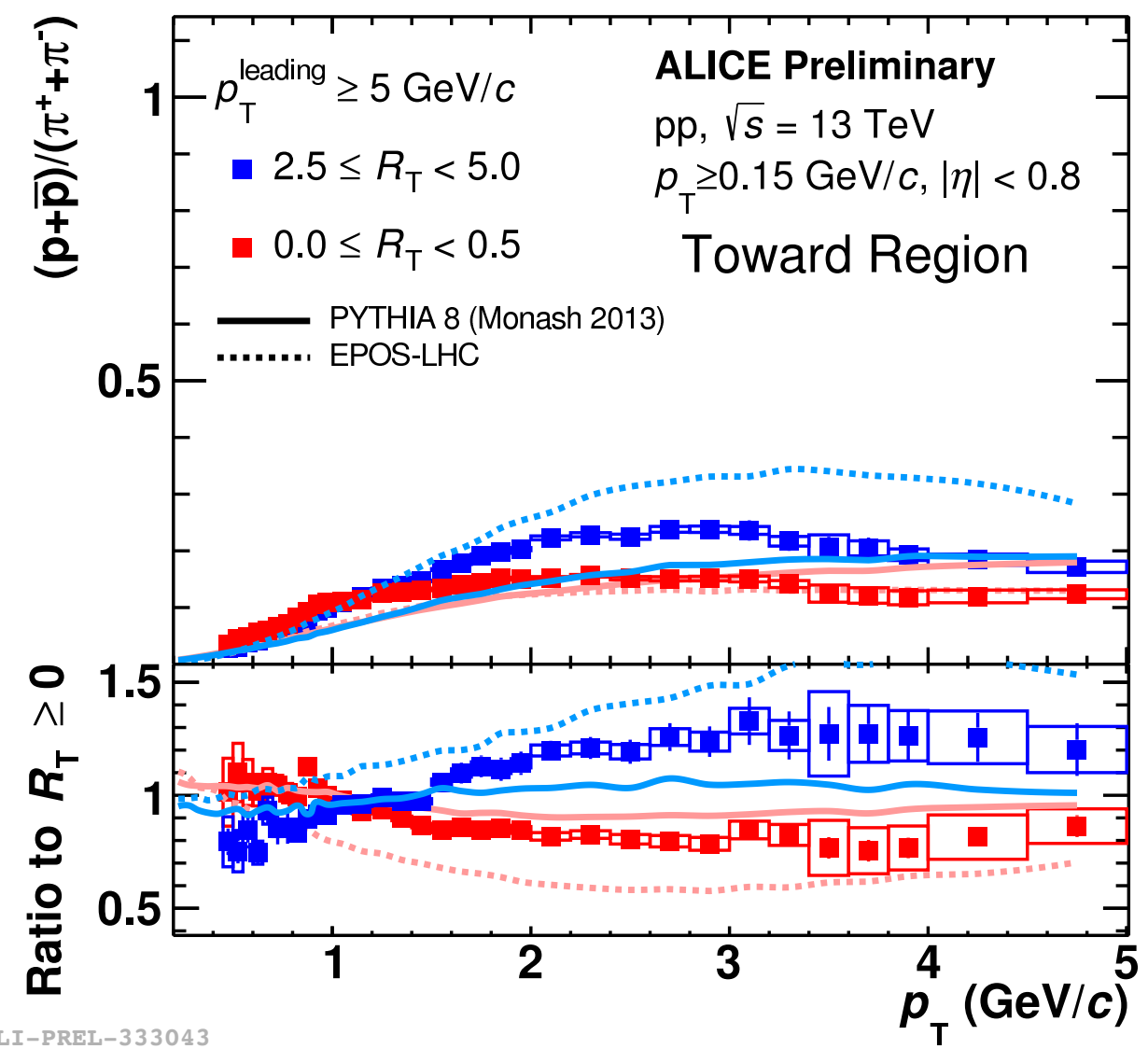
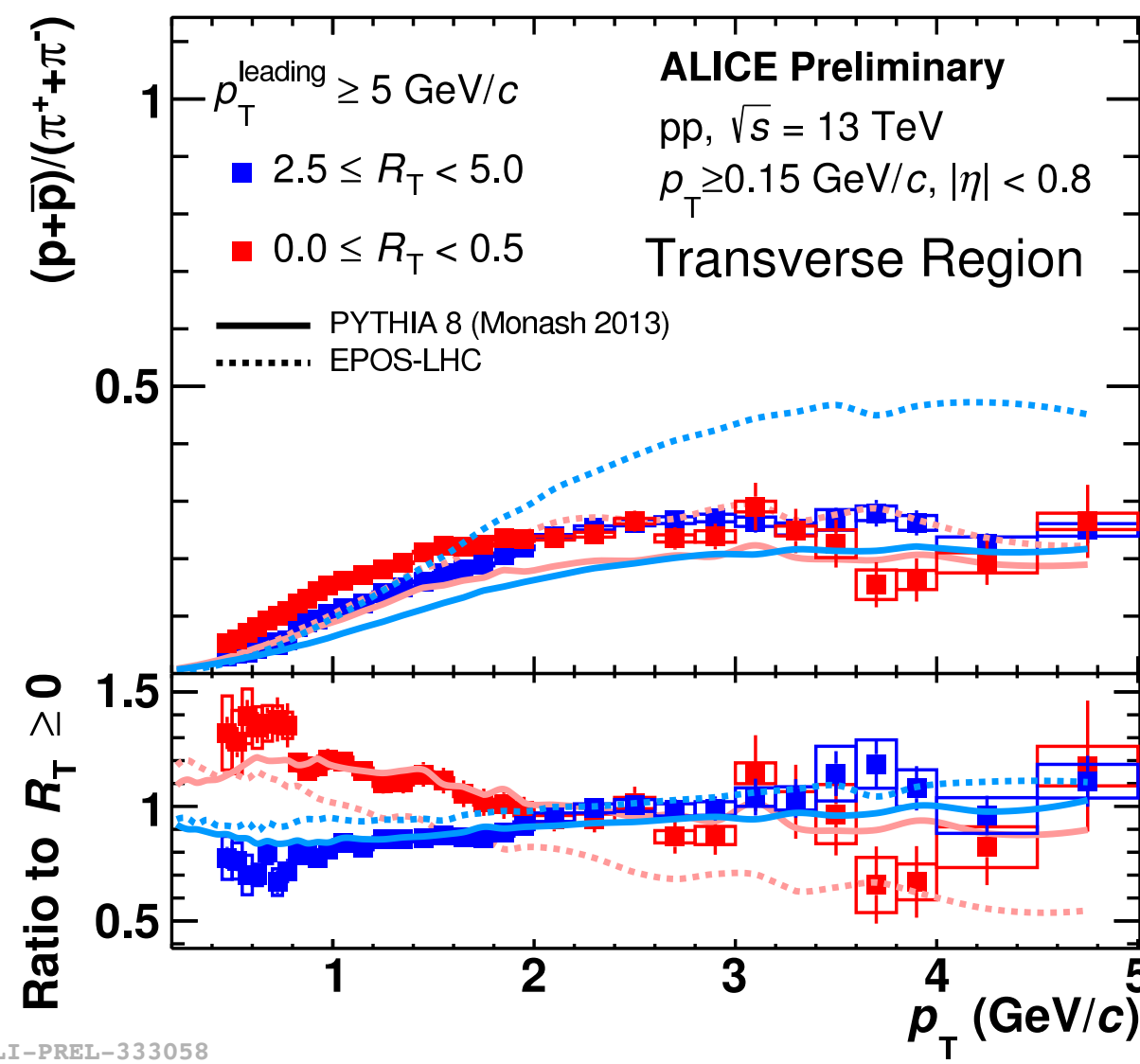




- $p/\pi$  ratio:
  - Radial flow-like features in both the regions. However, this feature is stronger in the Transverse region.
  - Low- $R_T$  trend is somewhat described by models. However, both of them fail to describe the high- $R_T$  trend.



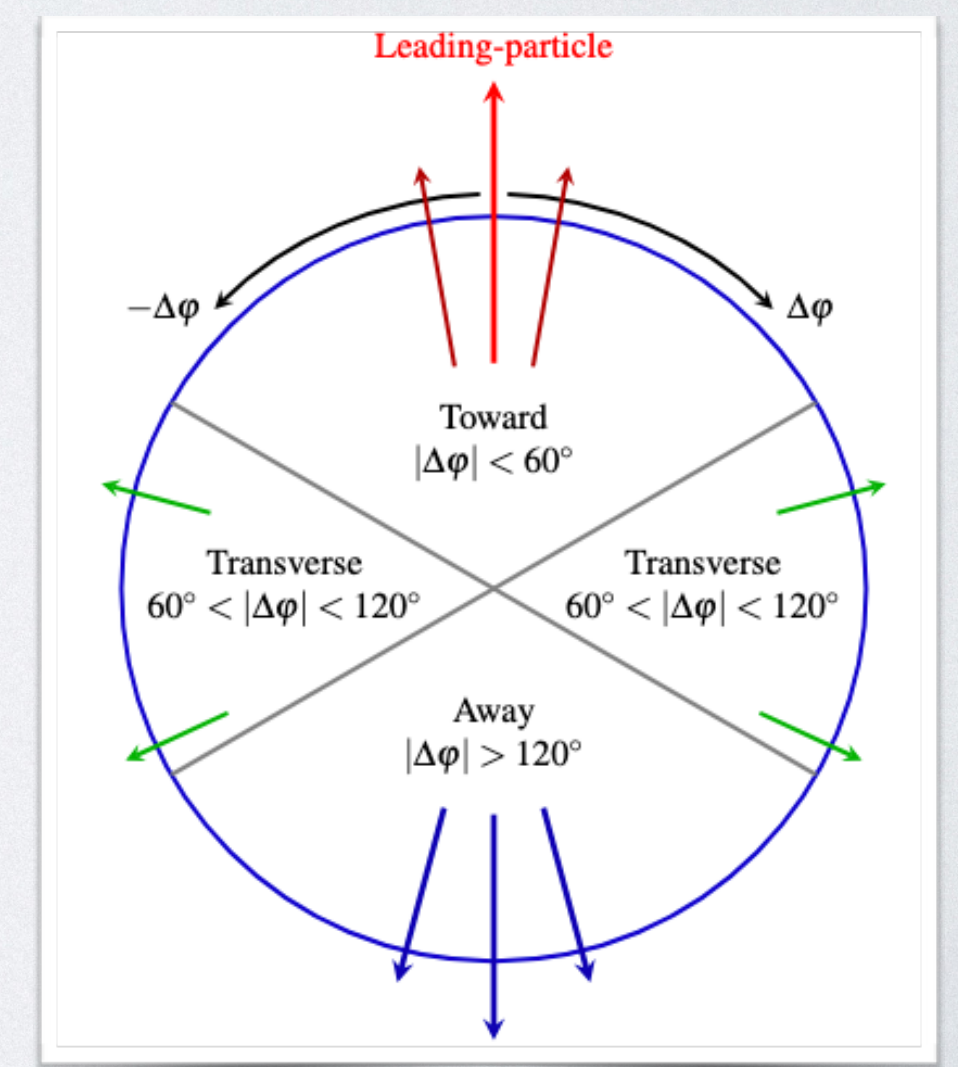
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    - high- $R_T$  toward region approaches the results in Transverse region.
    - In general, EPOS-LHC does better than PYTHIA8.
- The ratios suggest that the radial flow-like feature is also present in pp, and seems to be produced by the interplay between the jet and UE component

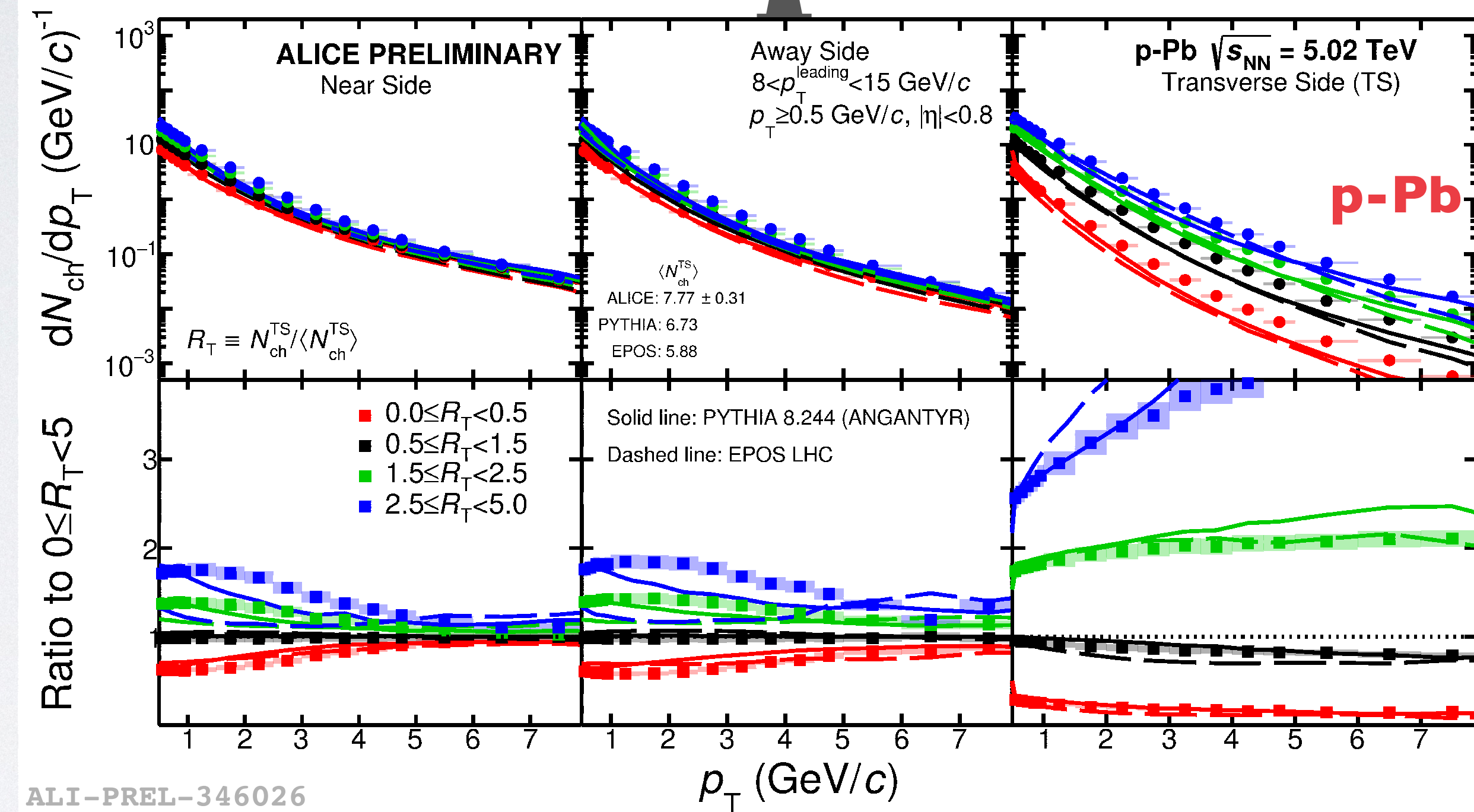
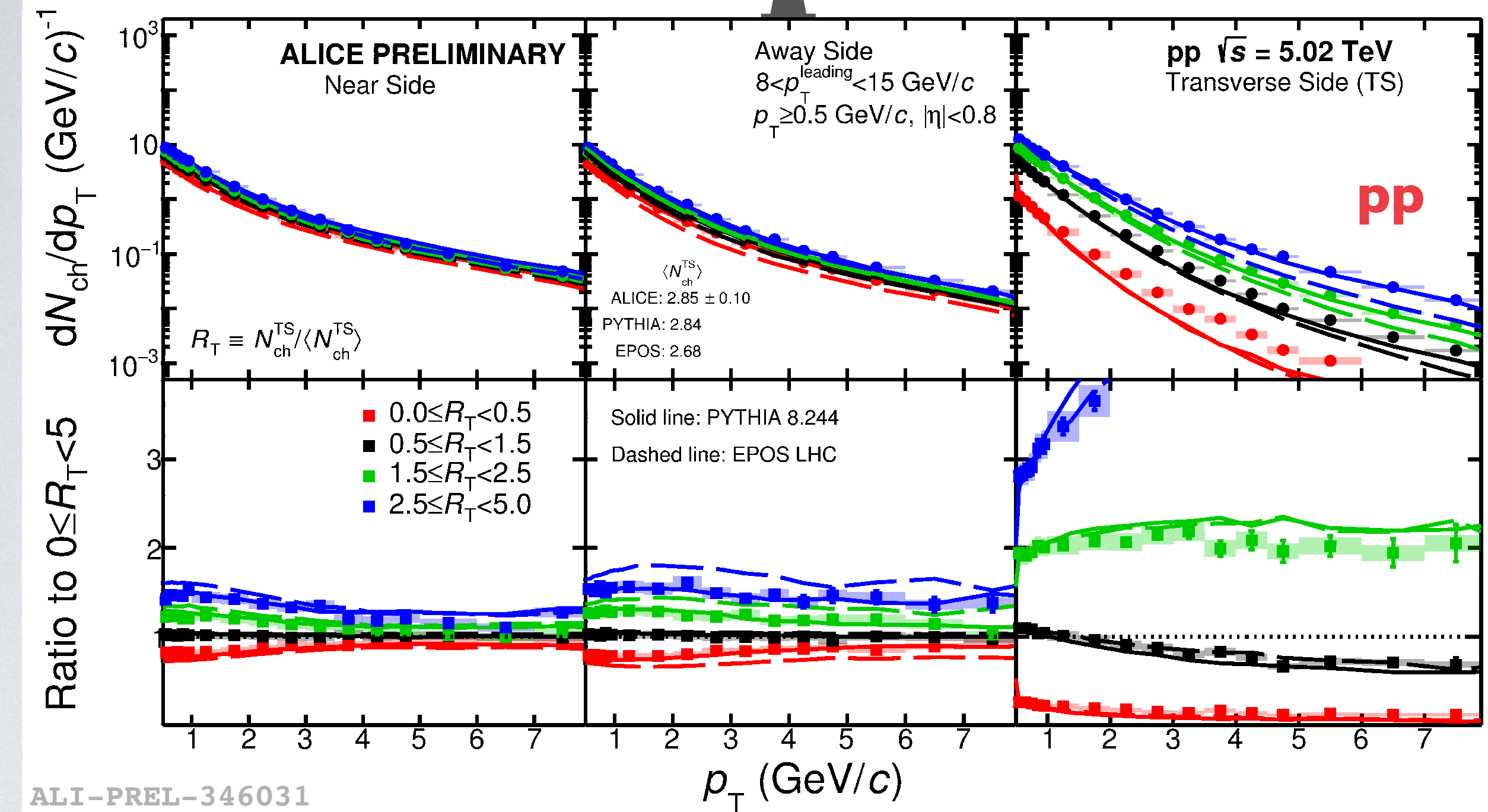


# System size dependence of particle production as a function of $R_T$ : an attempt to unveil jet quenching in pp collisions



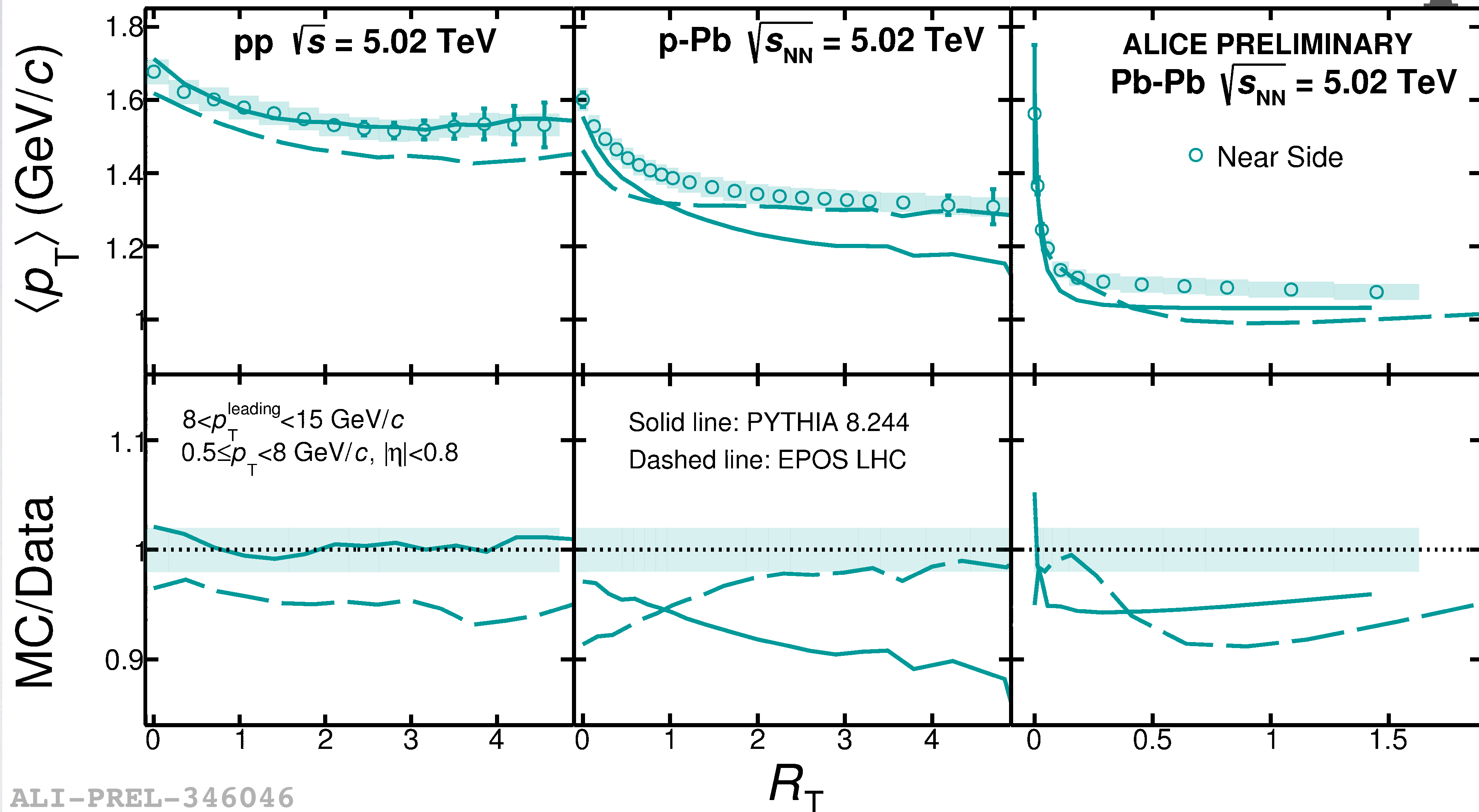
NEW

NEW

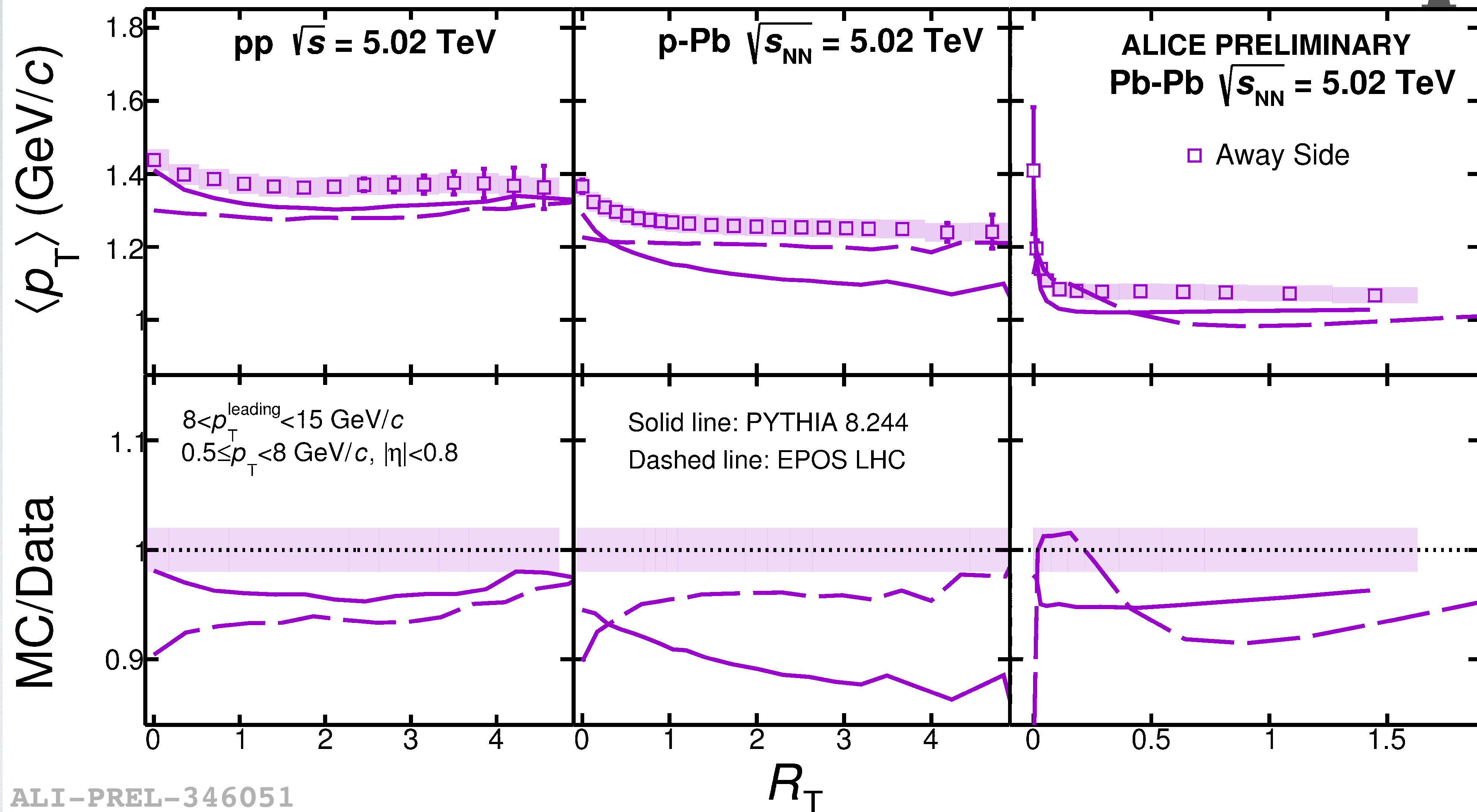


- Similar trend of  $p_T$  spectra in transverse side for pp and p-Pb collisions. The rise of the ratio to the  $0 < R_T < 5$   $p_T$  spectra is less steep for p-Pb collisions.
- Near and away side high- $p_T$  yields are nearly independent. However, at low- $p_T$ , the  $R_T$  dependence is bigger for p-Pb collisions than that in pp collisions.

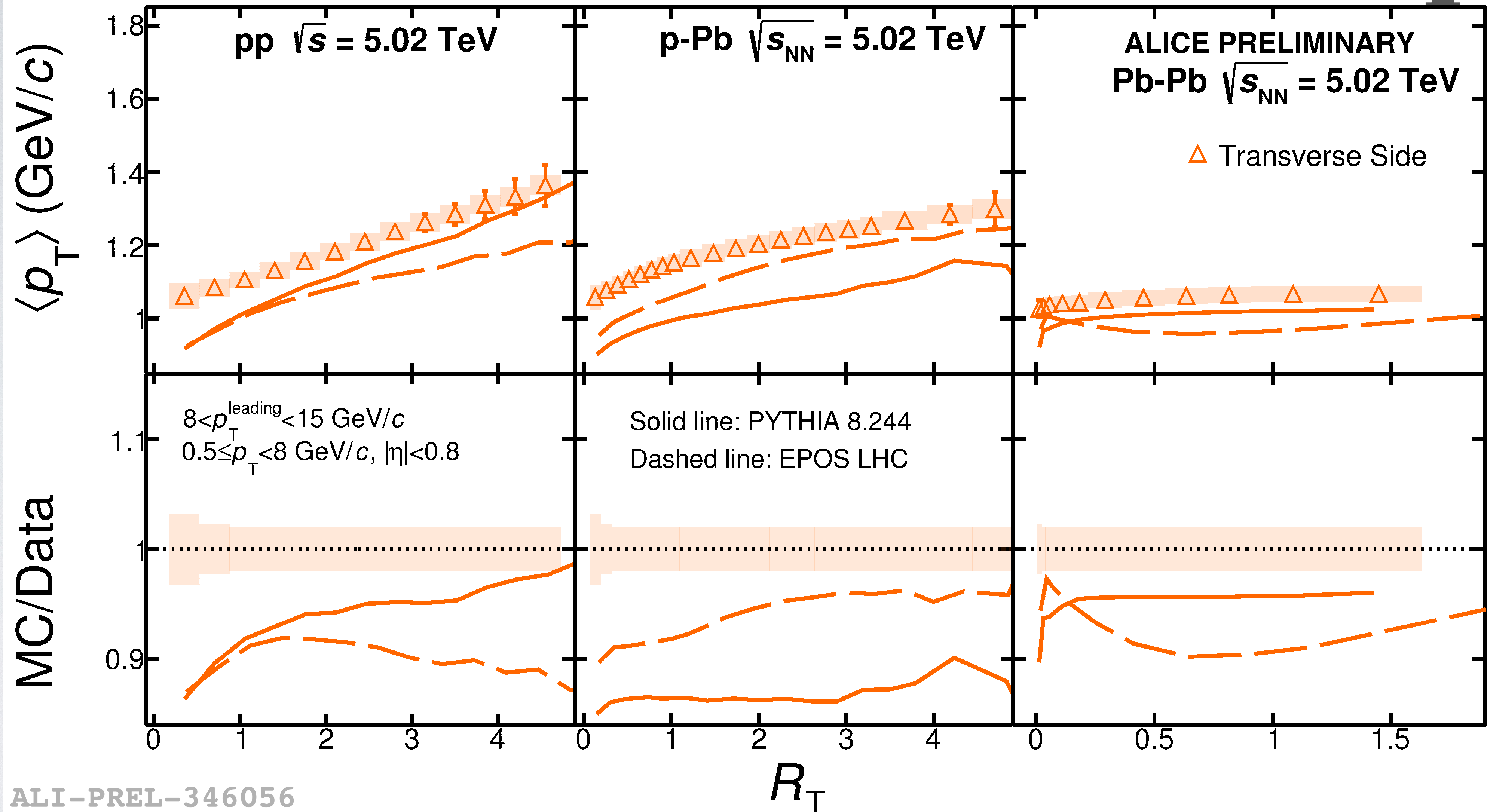
Both PYTHIA 8.244 (ANGANTYR) and EPOS-LHC models describe data qualitatively for both collision systems. However, the quantitative disagreement is quite significant, especially in near and away sides.



- Slight decrease at low  $R_T$  and remains nearly flat afterwards.
- Models deviate 10-15 % from the data for the  $\langle p_T \rangle$  across different collision systems.



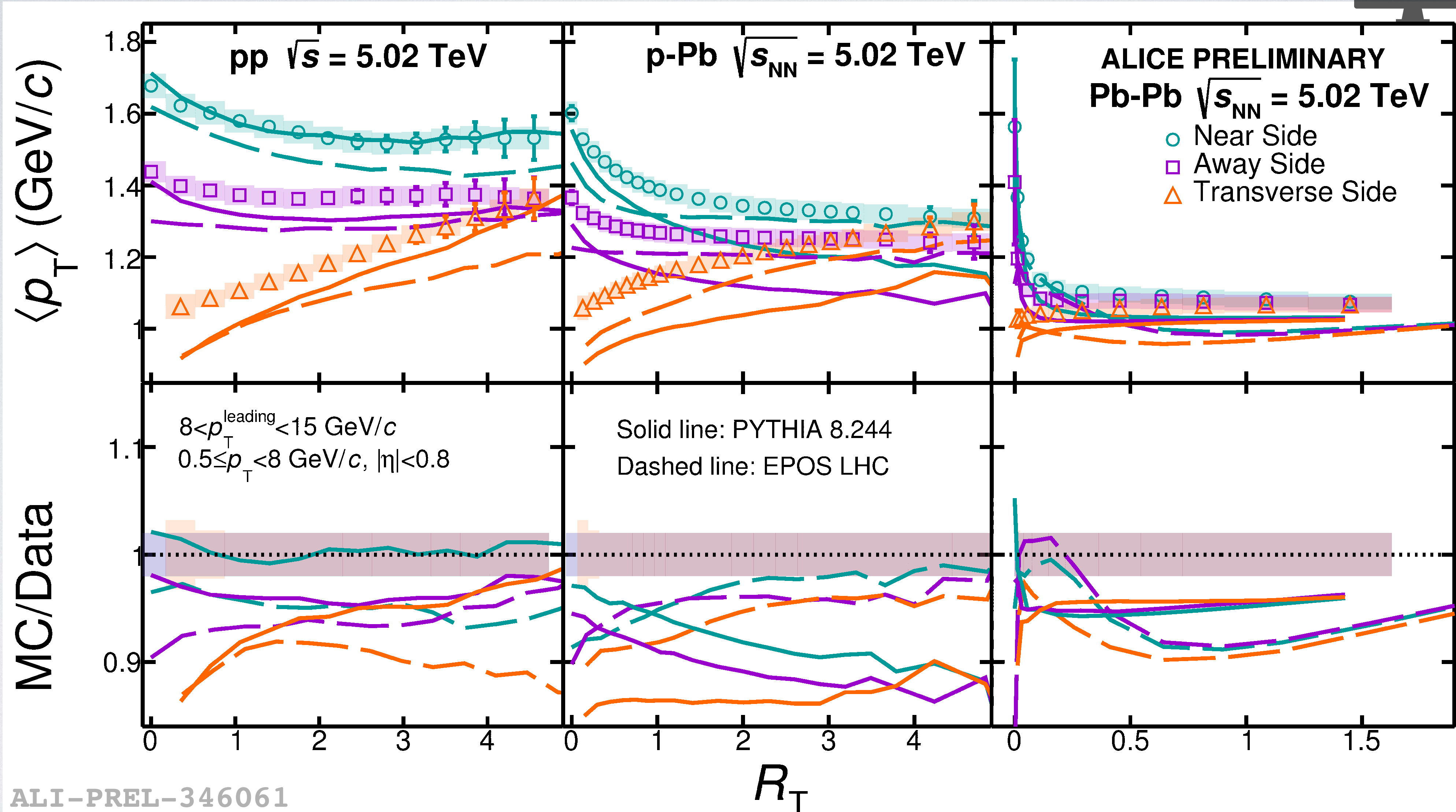
- Slight decrease at low  $R_T$  and remains nearly flat afterwards.
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- $\langle p_T \rangle$  increases with increasing  $R_T$ .
- Models deviate 10-15 % from the data for the  $\langle p_T \rangle$  across different collision systems.

# Mean transverse momentum

NEW

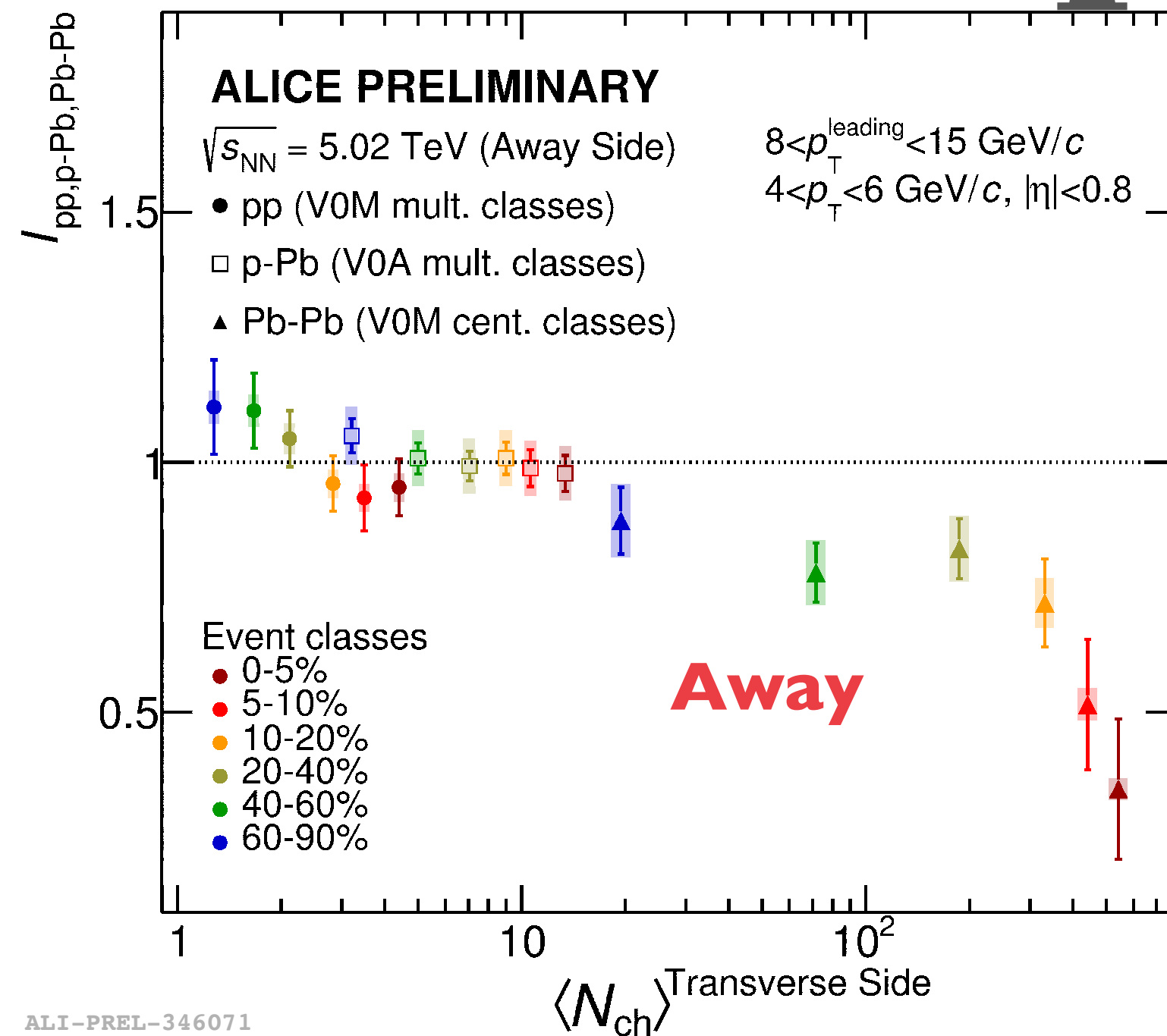
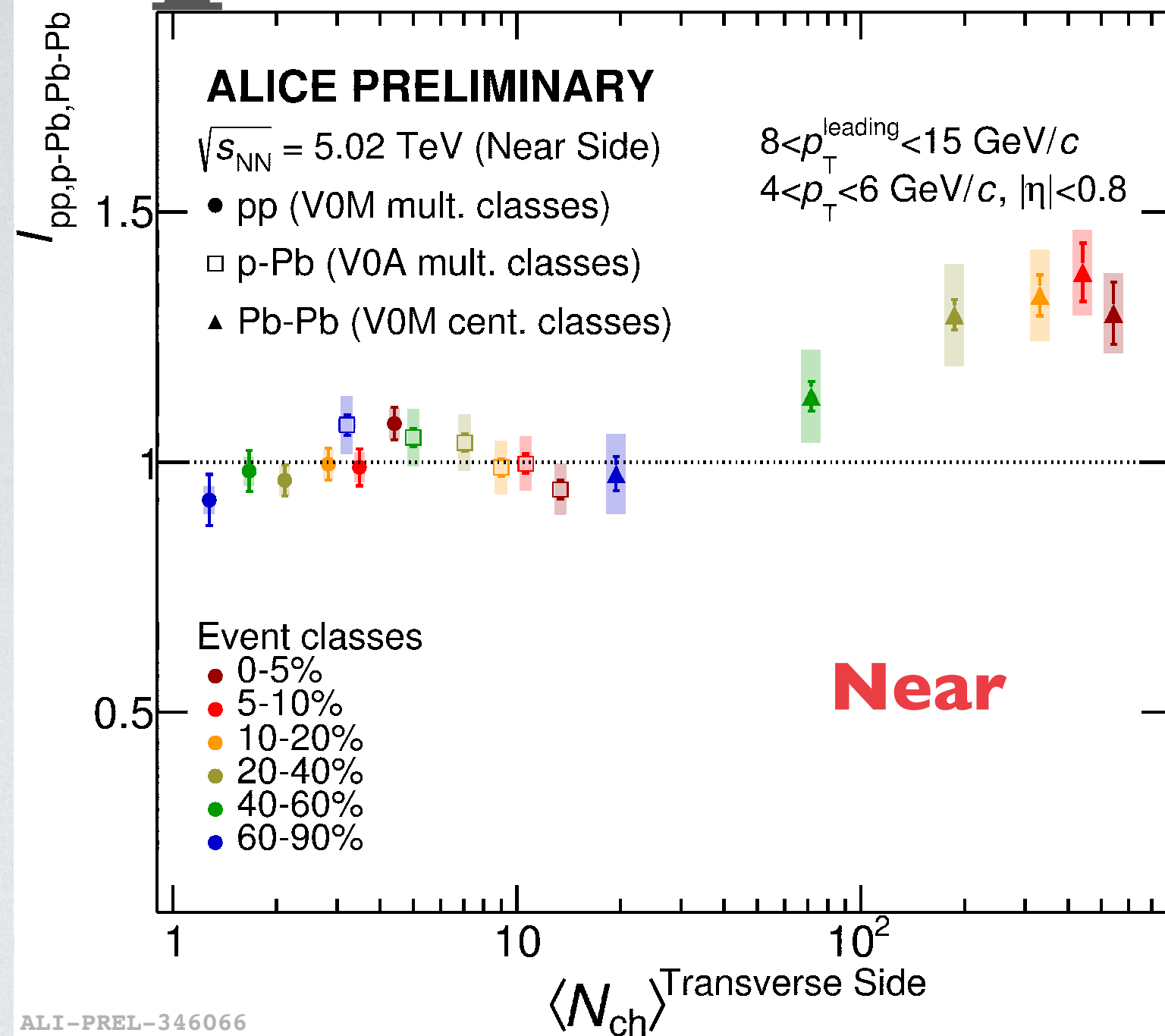


- We see contribution of jets dominates in low- $R_T$  while the  $\langle p_T \rangle$  approach to a similar value for topological regions.

$$I_{pp,p-Pb,Pb-Pb} = \frac{Y_{pp,p-Pb,Pb-Pb} - Y_{TS}^{pp,p-Pb,Pb-Pb}}{Y_{pp \text{ min.bias}} - Y_{TS}^{pp \text{ min.bias}}}$$

NEW

NEW

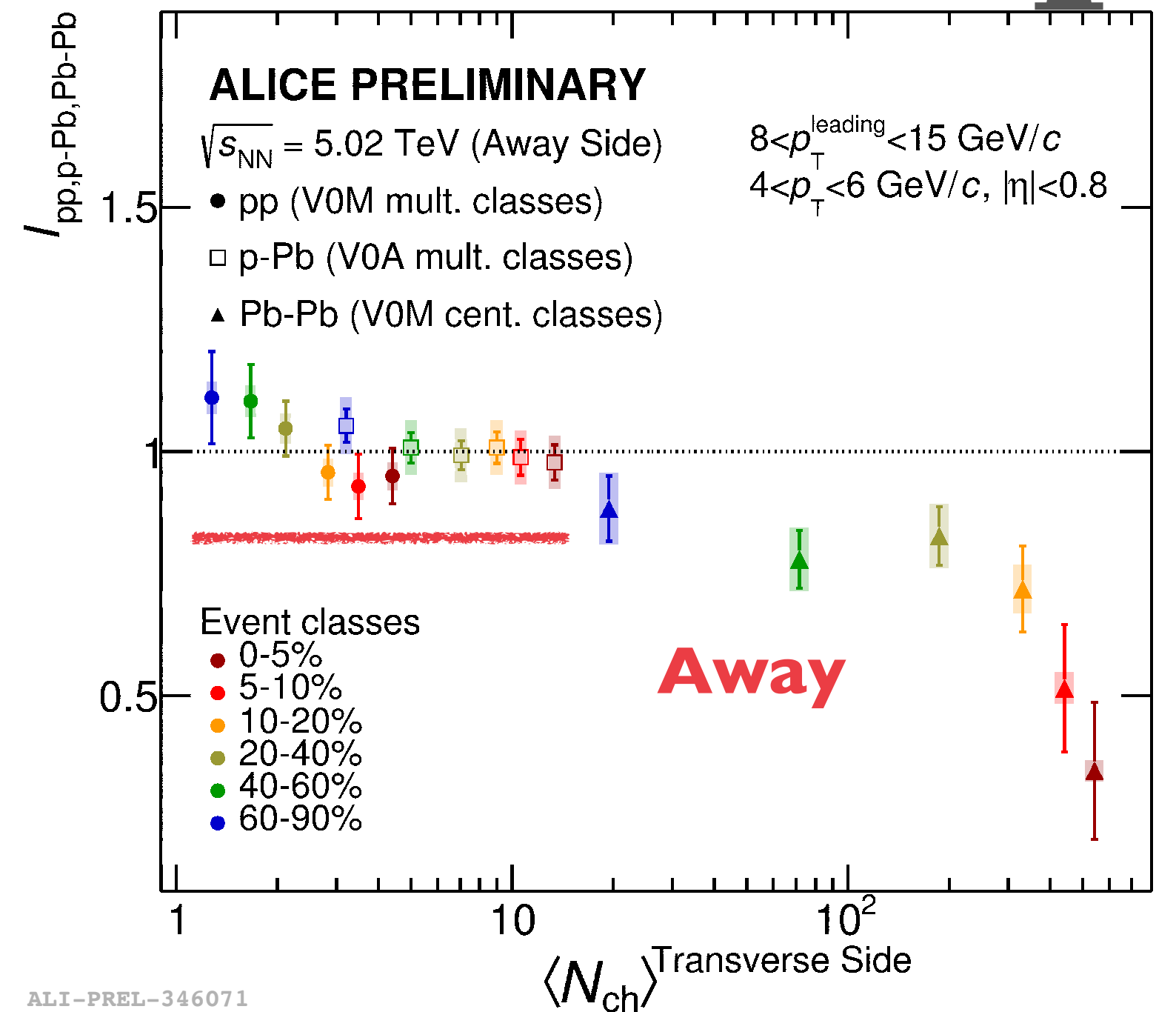
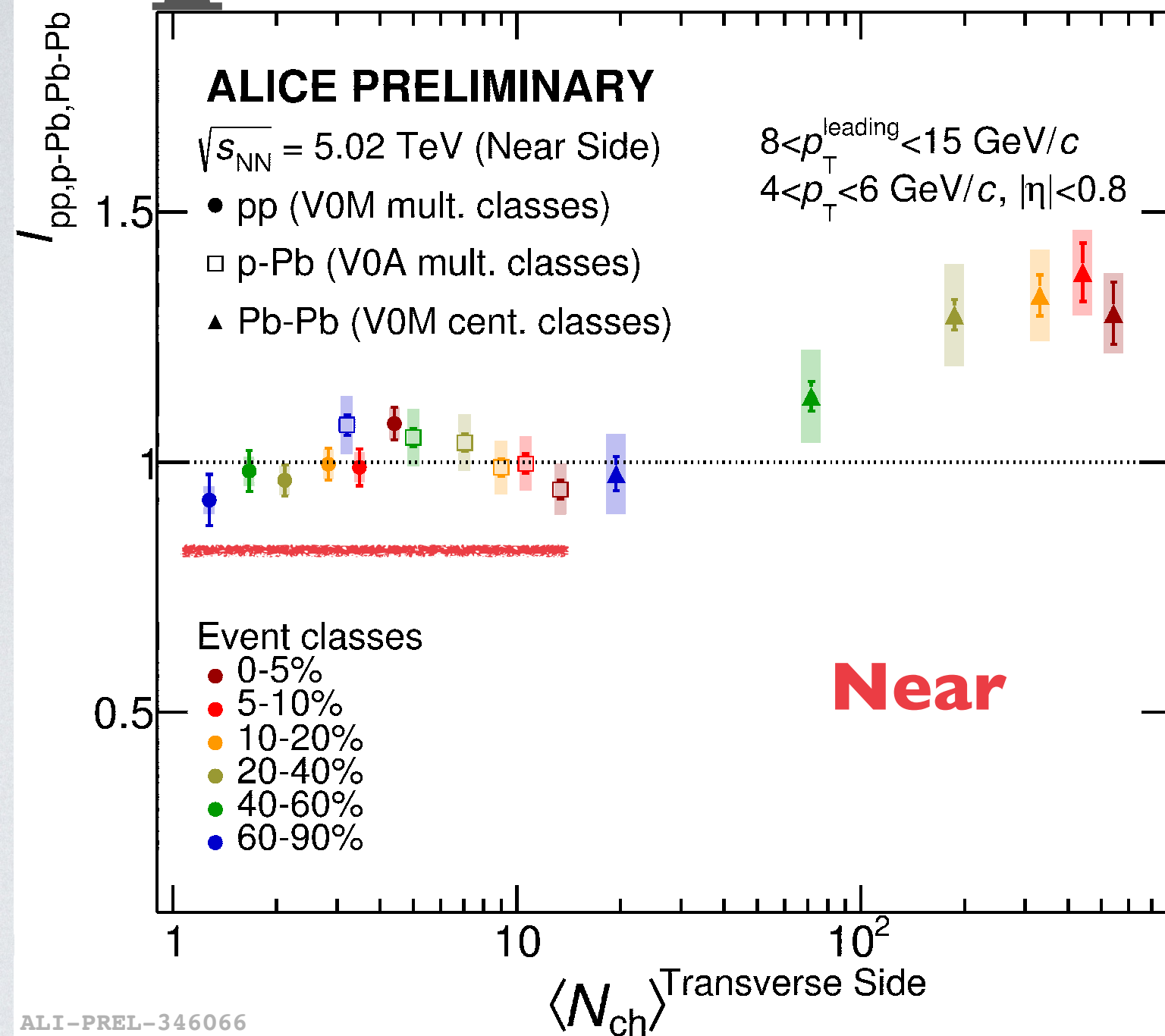


- $I_{pp,p-Pb,Pb-Pb}$  is sensitive to medium effects. The suppression in away side would indicate the presence of jet quenching.
- The trend for most peripheral and central Pb-Pb collisions are compatible with the ALICE  $I_{AA}$  results for  $\sqrt{s_{NN}} = 2.76$  TeV (ALICE, Phys. Rev. Lett. **108** (2012) 092301).

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NEW

NEW



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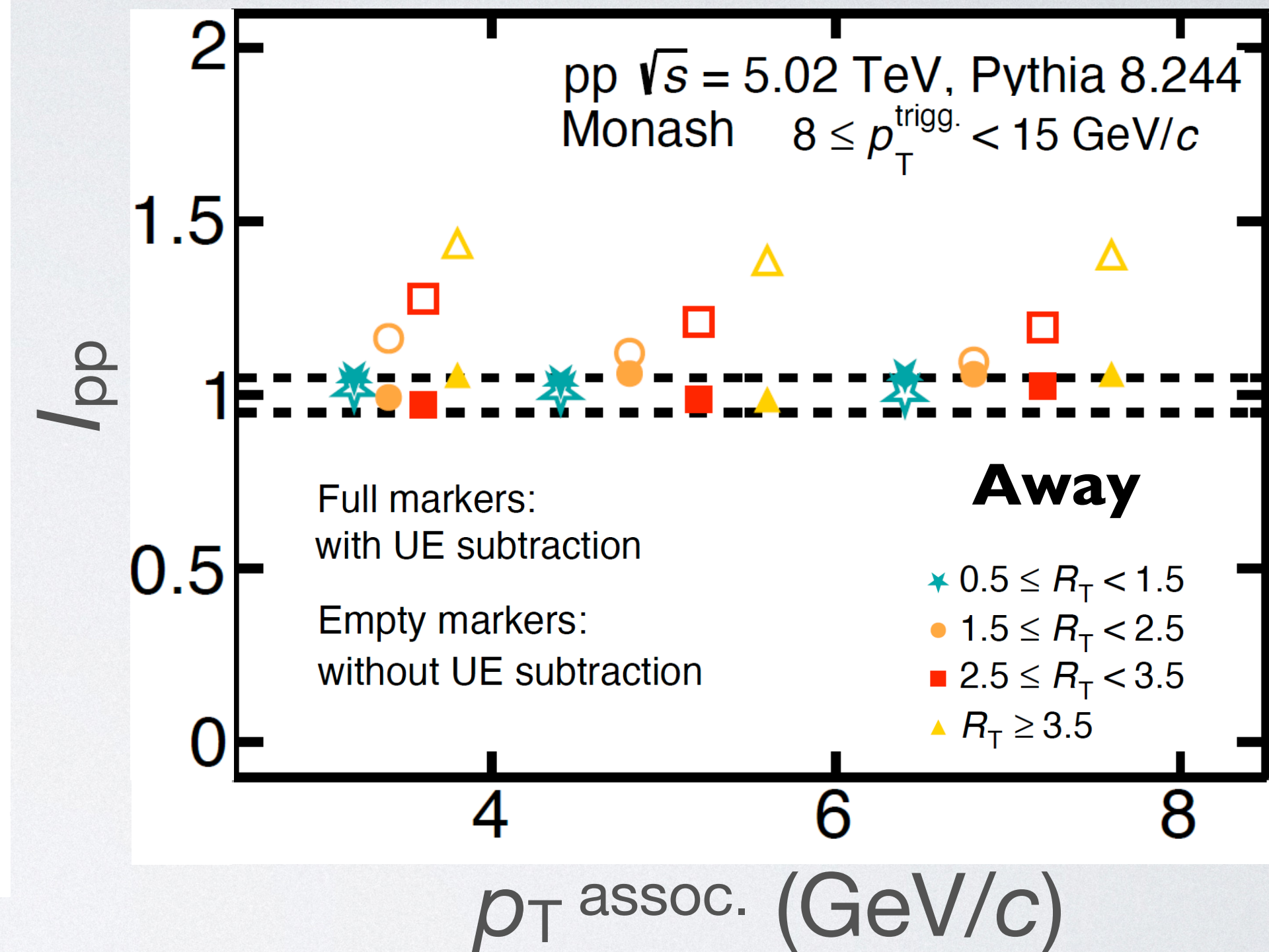
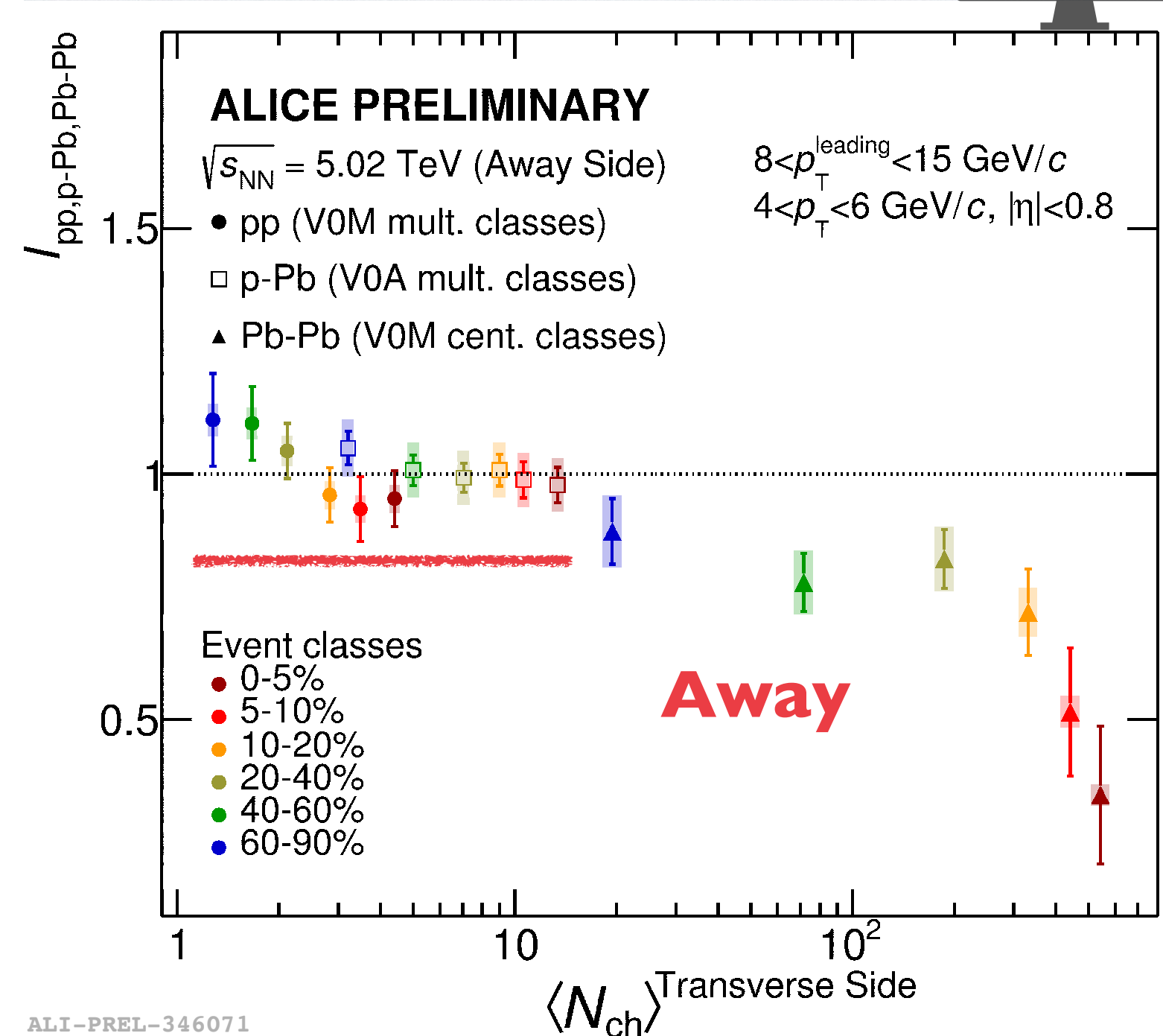
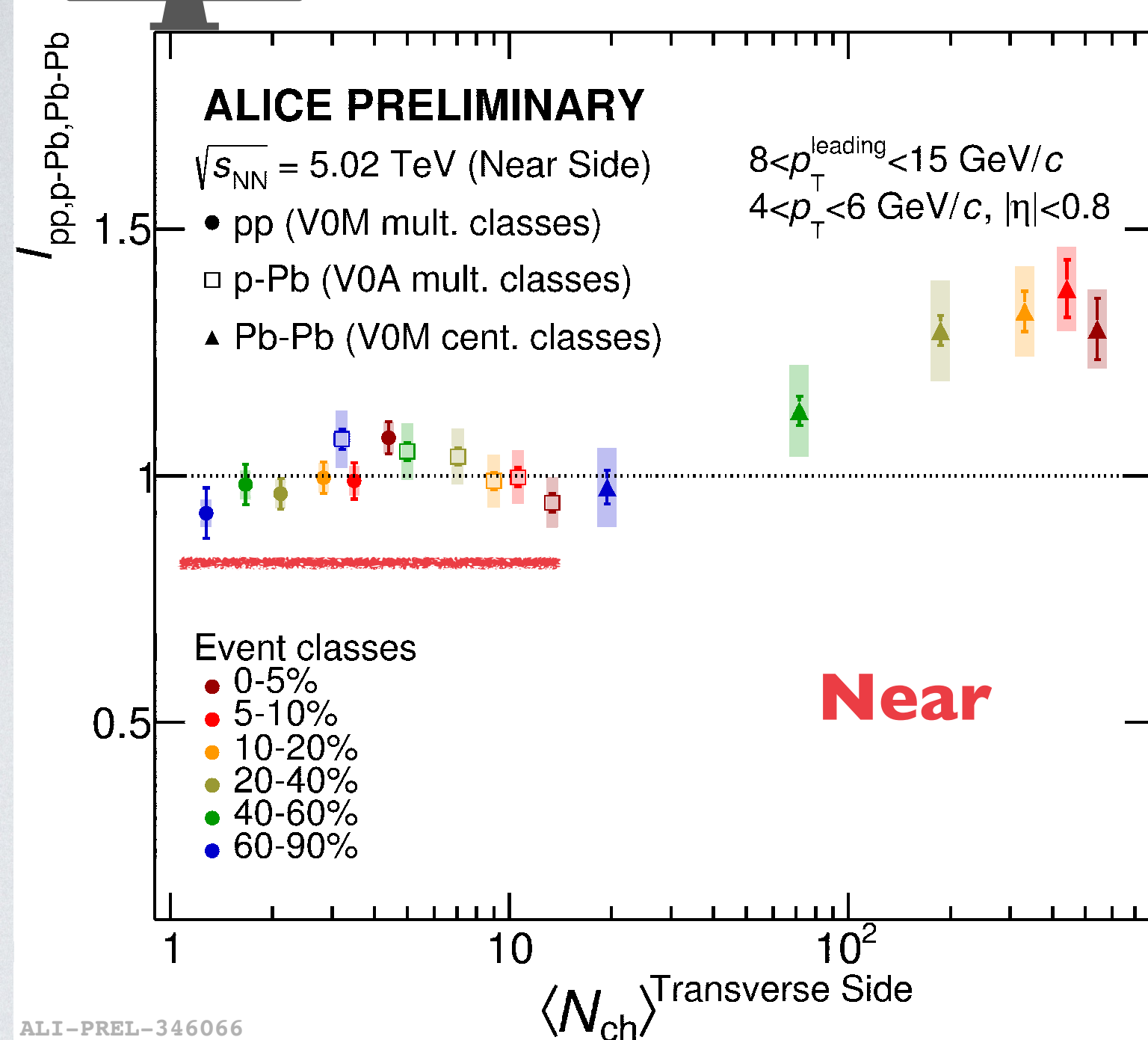
In contrast to Pb-Pb collisions, no enhancement (suppression) of  $I_{pp,p-Pb,Pb-Pb}$  is seen for NS (AS) in pp and p-Pb collisions. Based on these results, **no hint of jet quenching in small systems is observed.**

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NEW

NEW

A. Ortiz, S. Tripathy and G. Benedi, [arXiv:2007.03857](https://arxiv.org/abs/2007.03857) [hep-ph]



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Predictions from Pythia 8 (Monash tune) is consistent with data

- Using event shape observables like the Transverse spherocity and the Relative transverse activity classifier, one can **vary the magnitude of underlying events**.
  - Clear dependence of light flavor particle production is observed as a function of **event shape observables**.
- **Transverse spherocity** allows one to distinguish jetty and isotropic events while using the **Relative transverse activity classifier**, one can vary the amount of underlying events and study the final state particle production.
- The comparison of the data with models like PYTHIA8 and EPOS-LHC, will help to **constrain the models**.
- In contrast to Pb-Pb collisions, no enhancement (suppression) of  $I_{pp,p-Pb}$  is seen for Near (Away) side in pp and p-Pb collisions. Based on these results, **no hint of jet quenching in small systems is observed**.

*Thank you for your attention!*

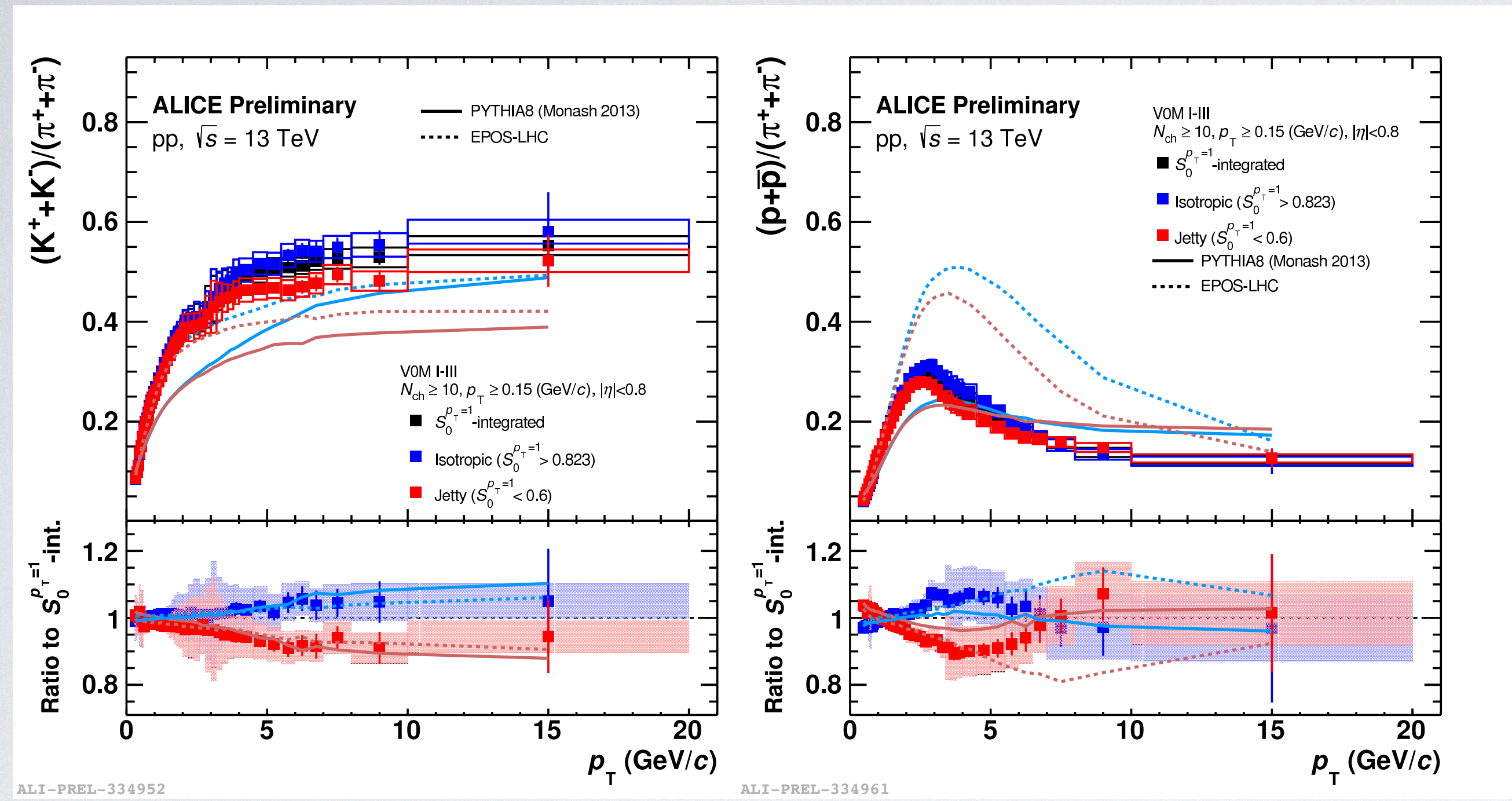


# Back-up



# Identified particle ratios as a function of $S_0^{p_T=1}$ in high-multiplicity pp collisions at 13 TeV

VOM estimator



- $K/\pi$  and  $p/\pi$  ratios: the ratios to  $S_0^{p_T=1}$ -integrated events highlight the radial flow-like features.

In general, the particle ratios are not described by the models like PYTHIA8 and EPOS-LHC. However, they seem to explain the double ratios accurately.

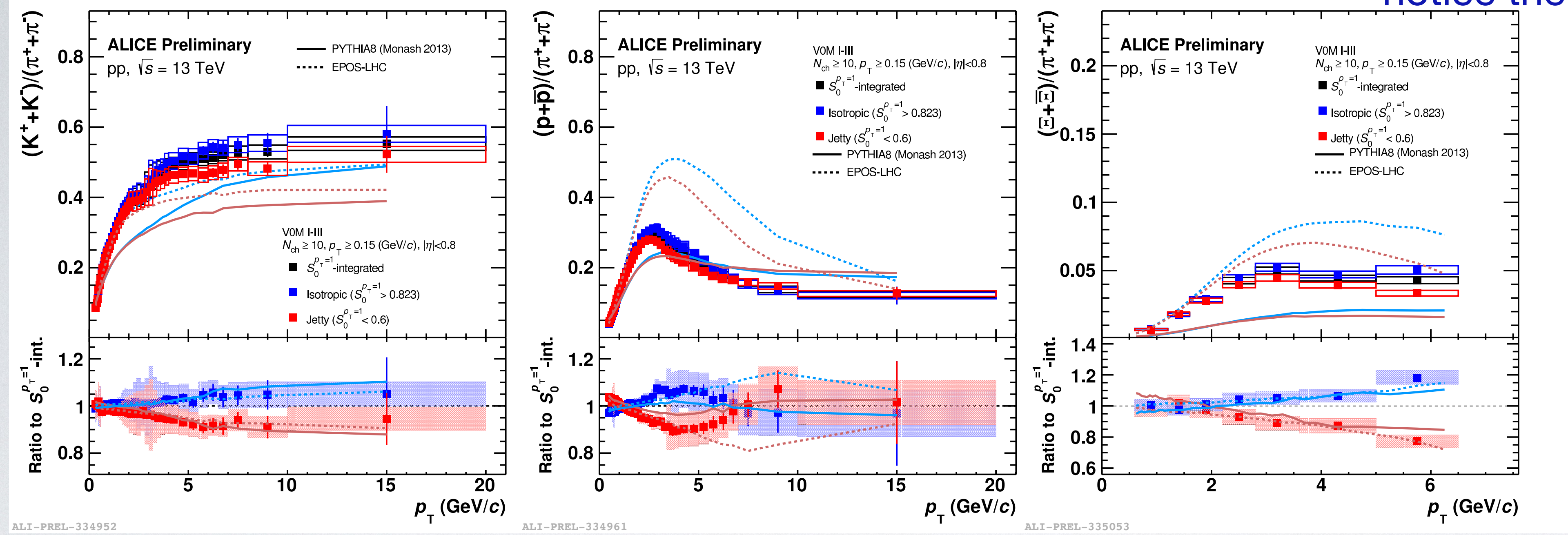


ALICE

VOM estimator

# Identified particle ratios as a function of $S_0^{p_T=1}$ in high-multiplicity pp collisions at 13 TeV

notice the change in  $p_T$  range!



- $K/\pi$  and  $p/\pi$  ratios: the ratios to  $S_0^{p_T=1}$ -integrated events highlight the radial flow-like features.
- $\Xi/\pi$  ratio: show a crossing point in the double ratio.

In general, the particle ratios are not described by the models like PYTHIA8 and EPOS-LHC. However, they seem to explain the double ratios accurately.

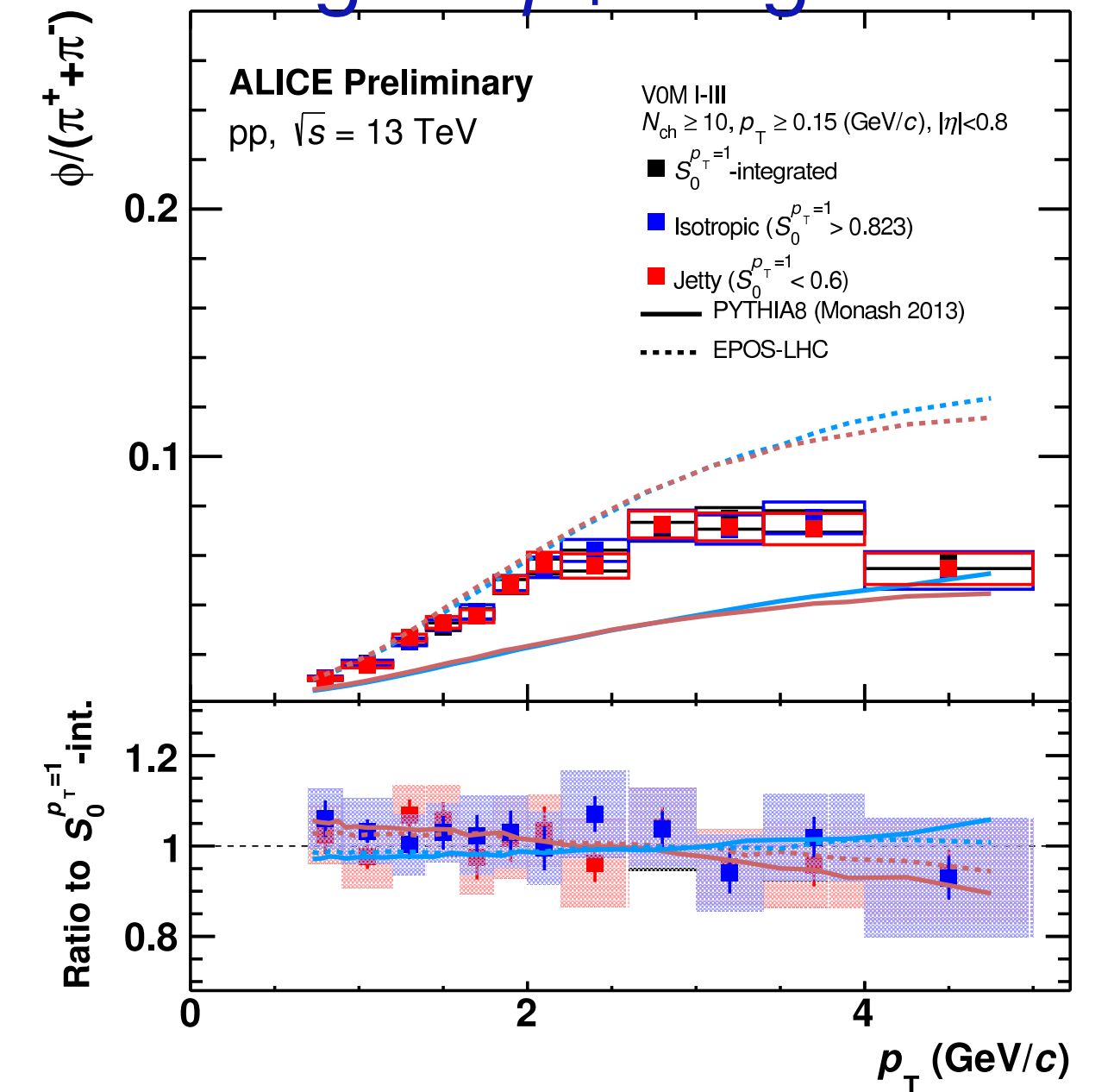
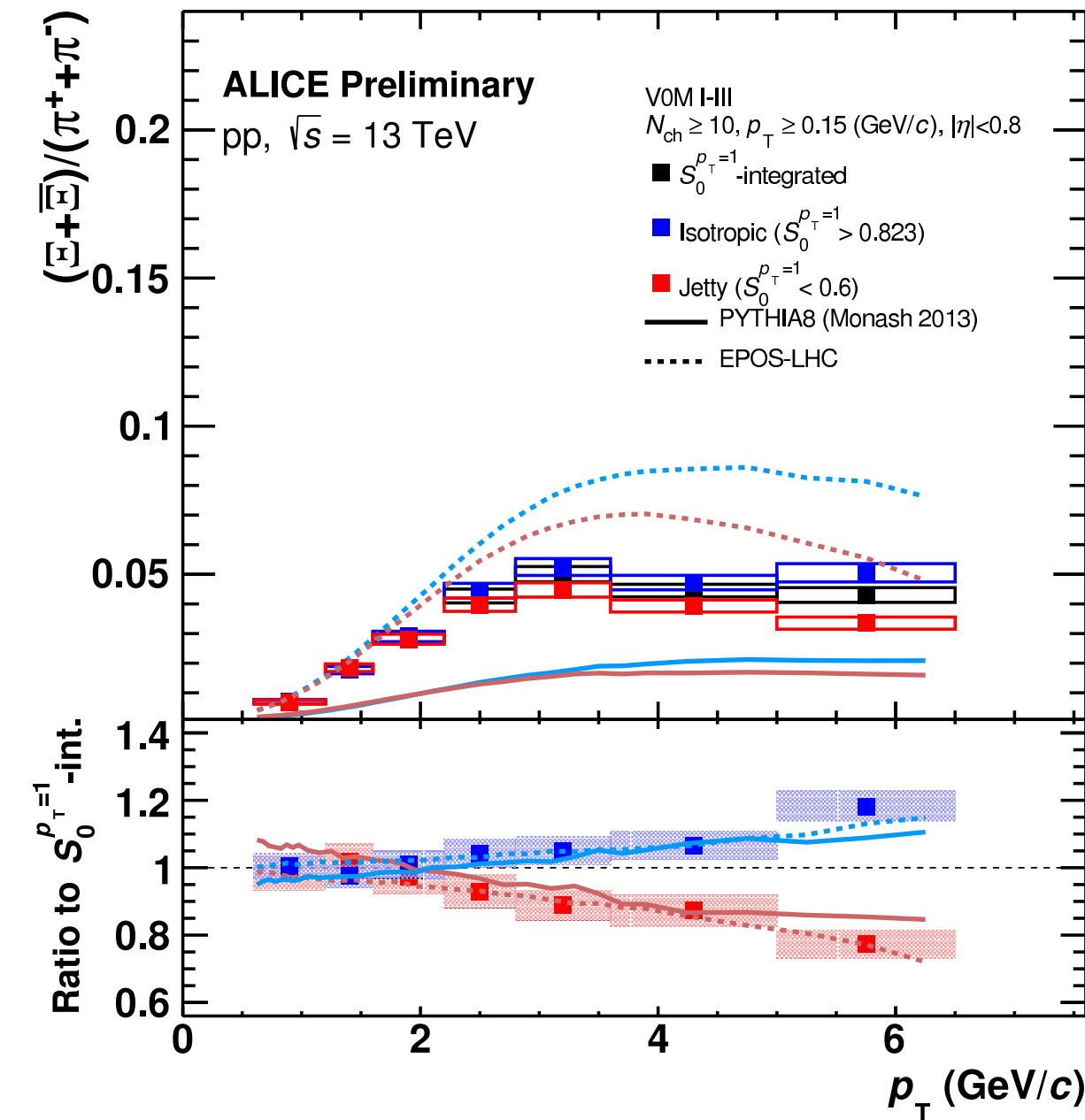
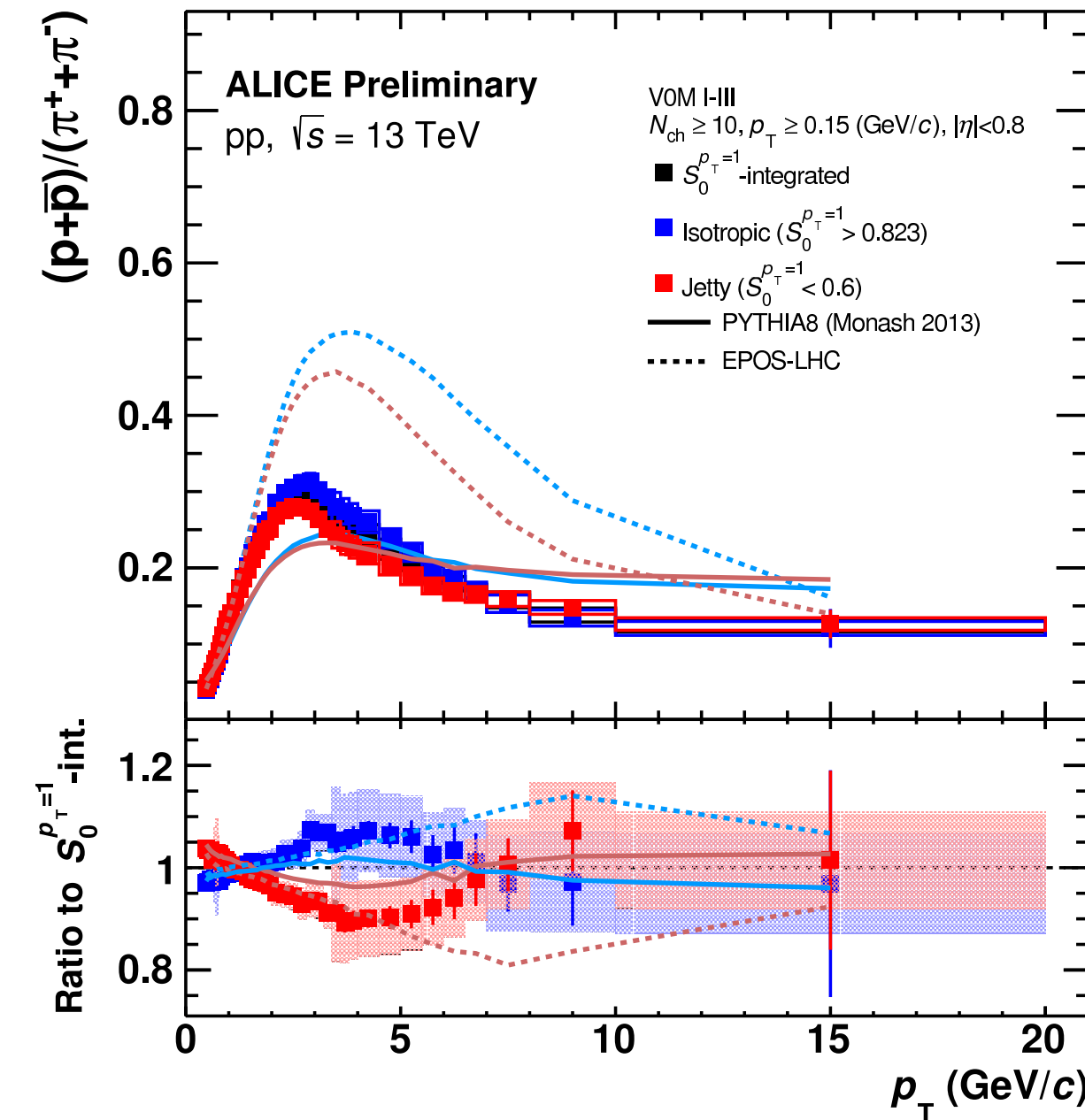
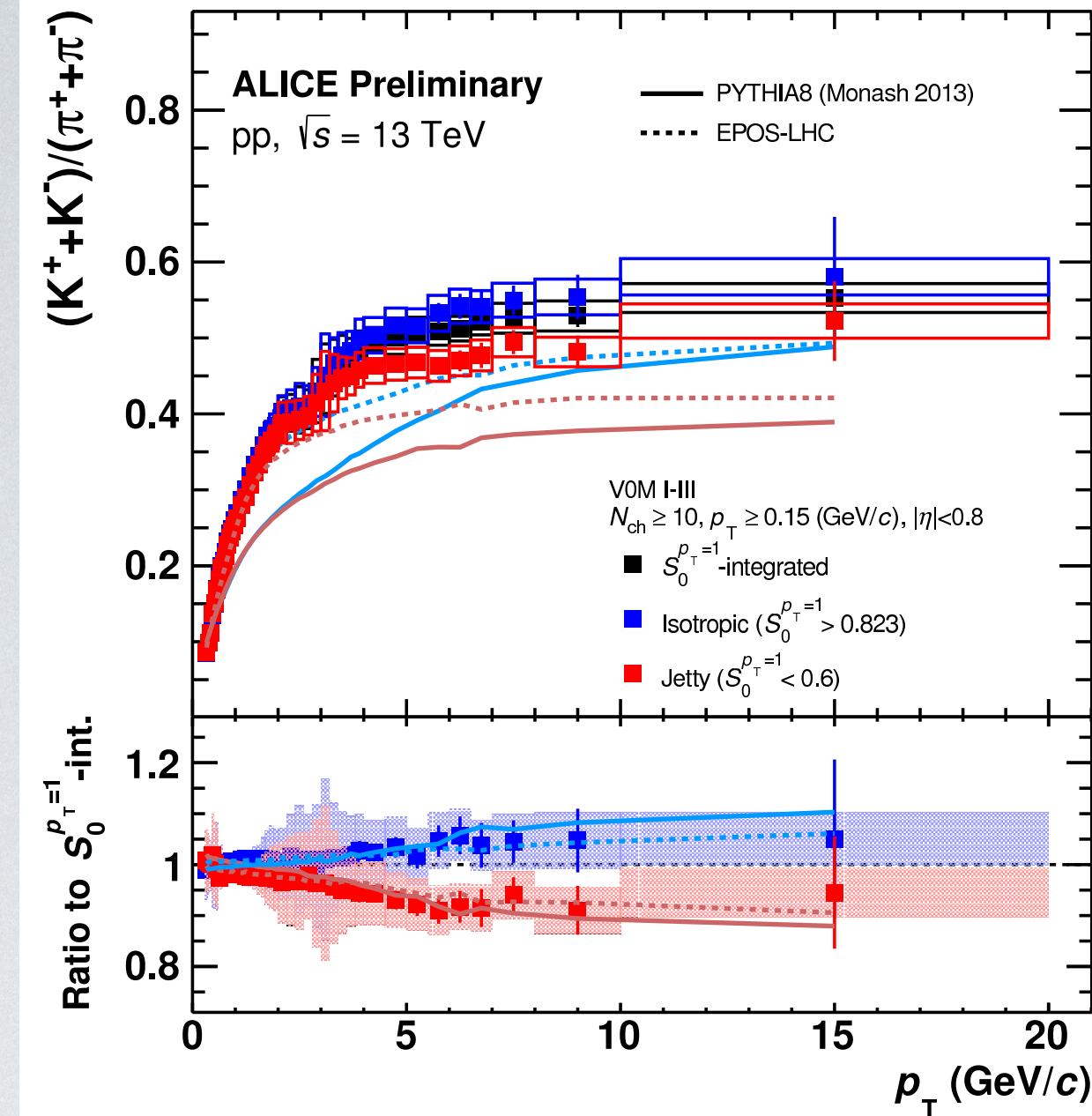


ALICE

VOM estimator

# Identified particle ratios as a function of $S_0^{p_T=1}$ in high-multiplicity pp collisions at 13 TeV

notice the change in  $p_T$  range!



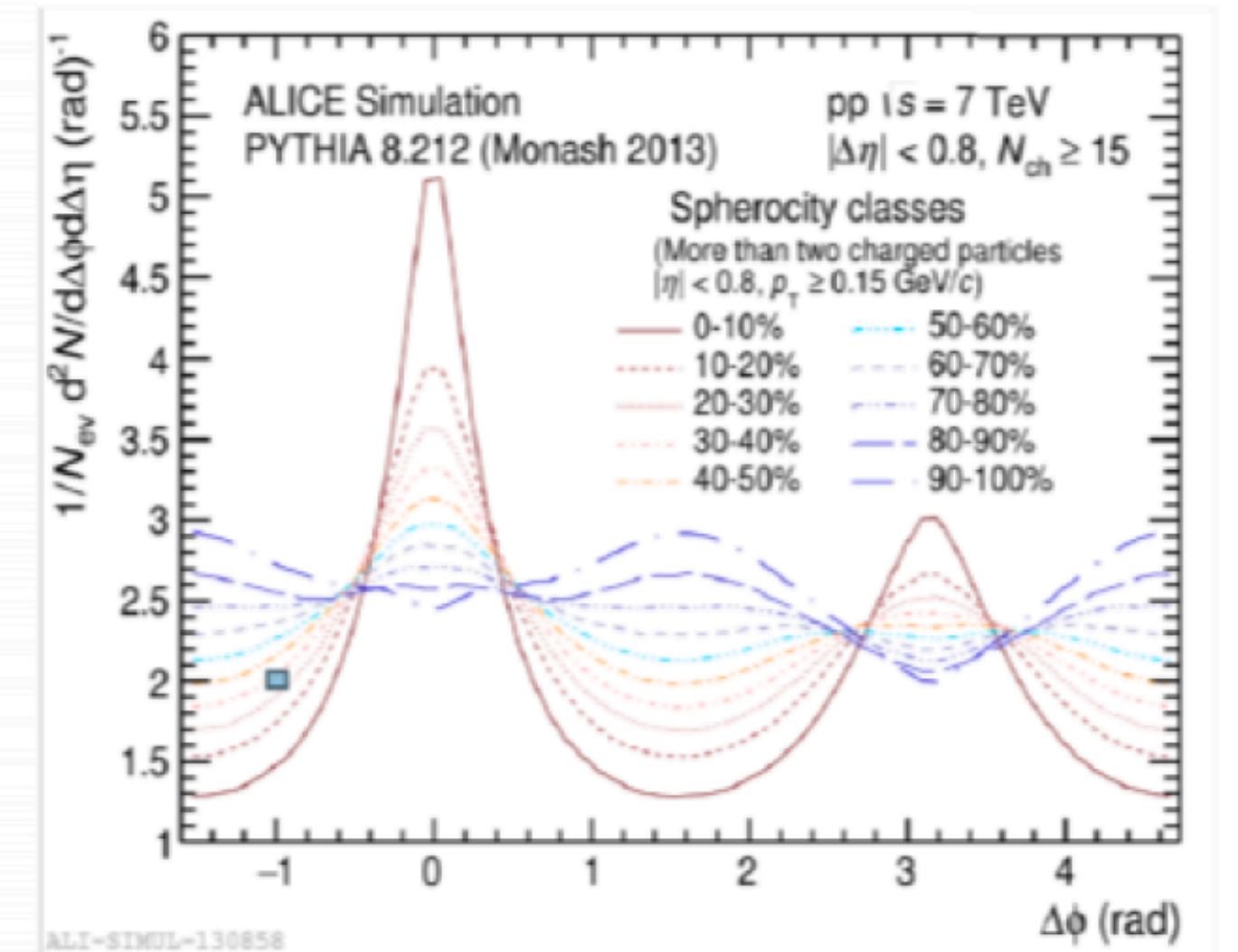
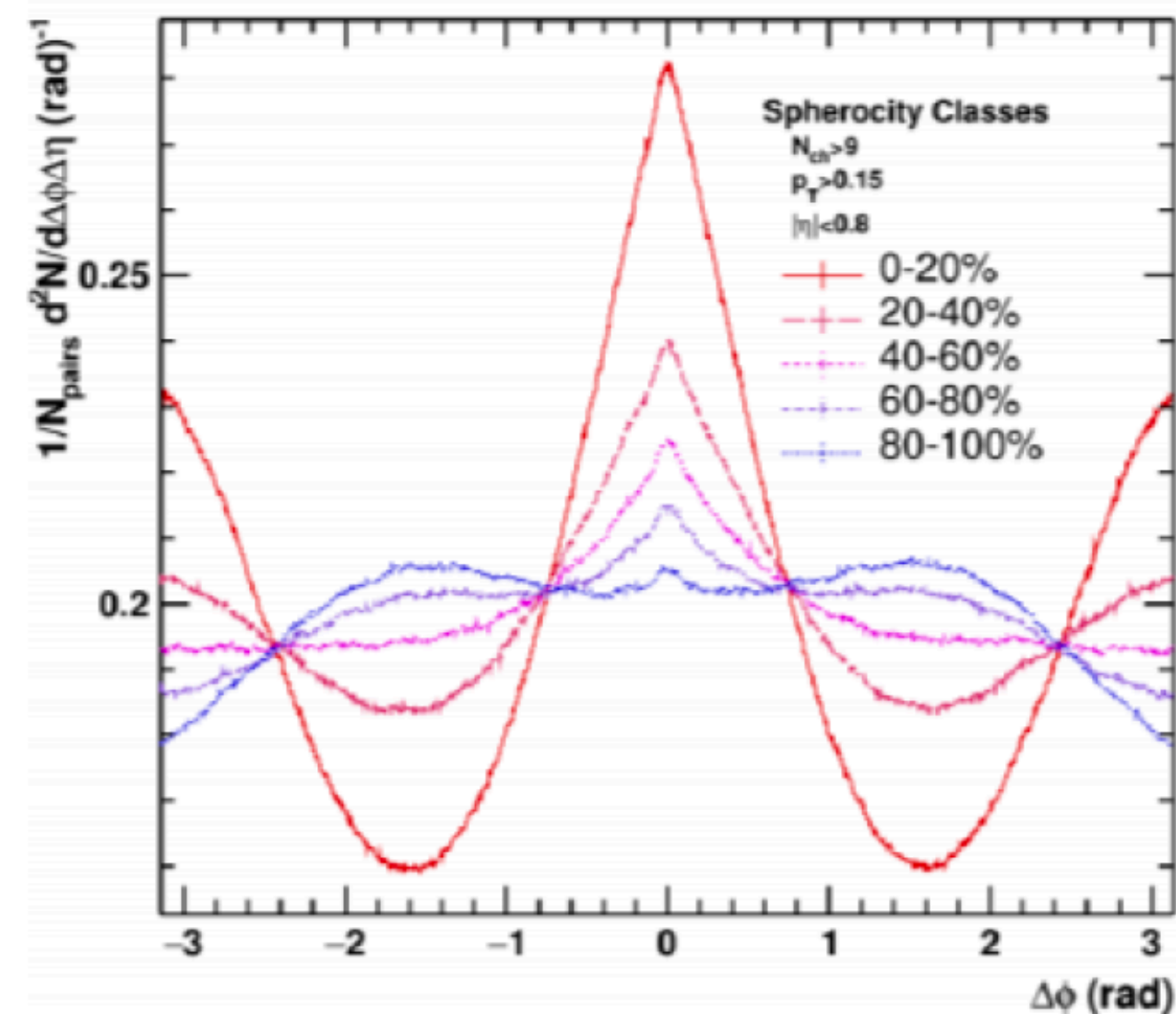
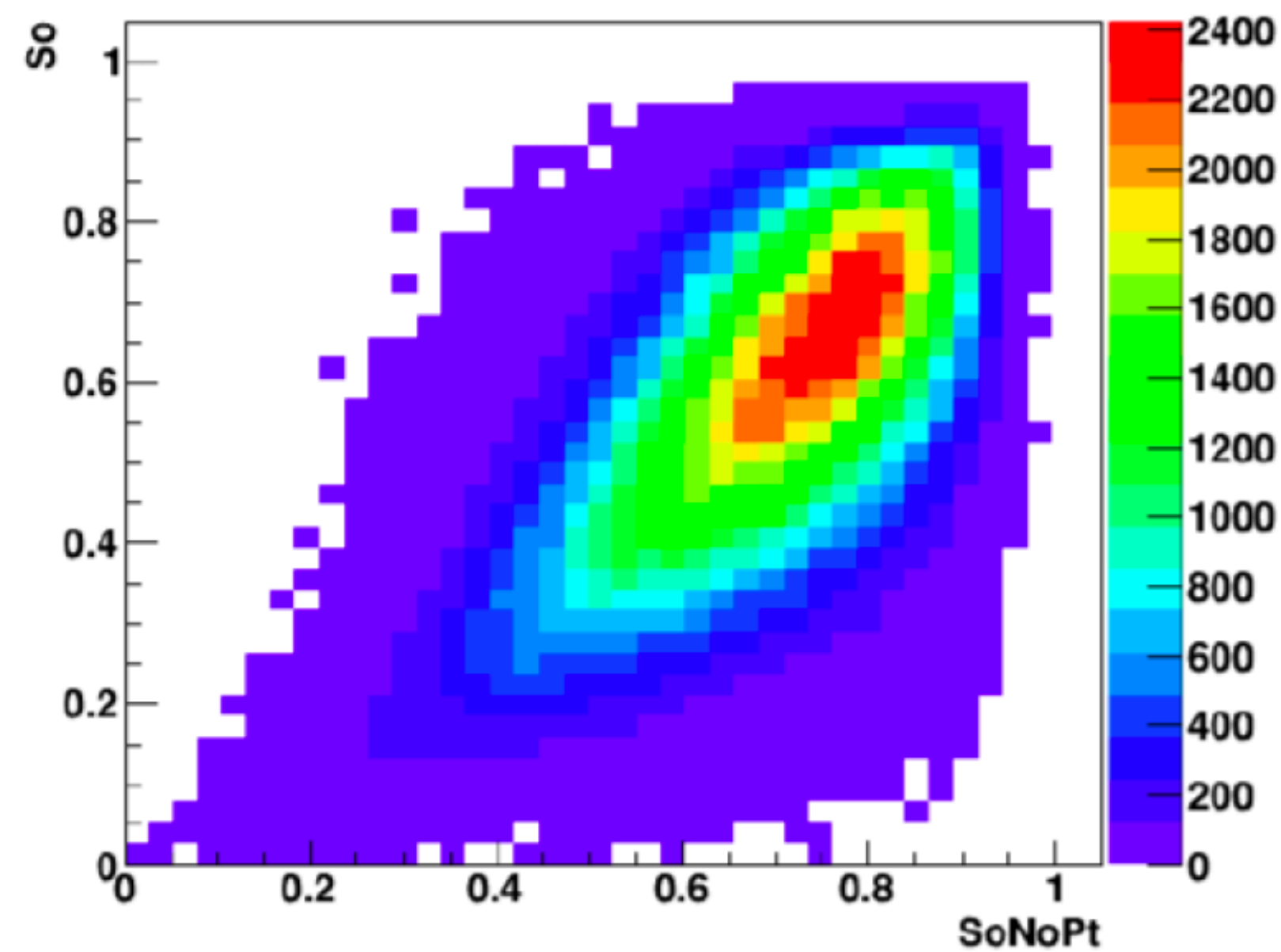
- $K/\pi$  and  $p/\pi$  ratios: the ratios to  $S_0^{p_T=1}$ -integrated events highlight the radial flow-like features.
- $\Xi/\pi$  ratio: show a crossing point in the double ratio.
- $\phi/\pi$  ratio: No significant dependence on spherocity unlike other particles.

In general, the particle ratios are not described by the models like PYTHIA8 and EPOS-LHC. However, they seem to explain the double ratios accurately.

# $S_0^{p_T=1}$ MC Studies - $S_0^{p_T=1}$ vs $S_0$

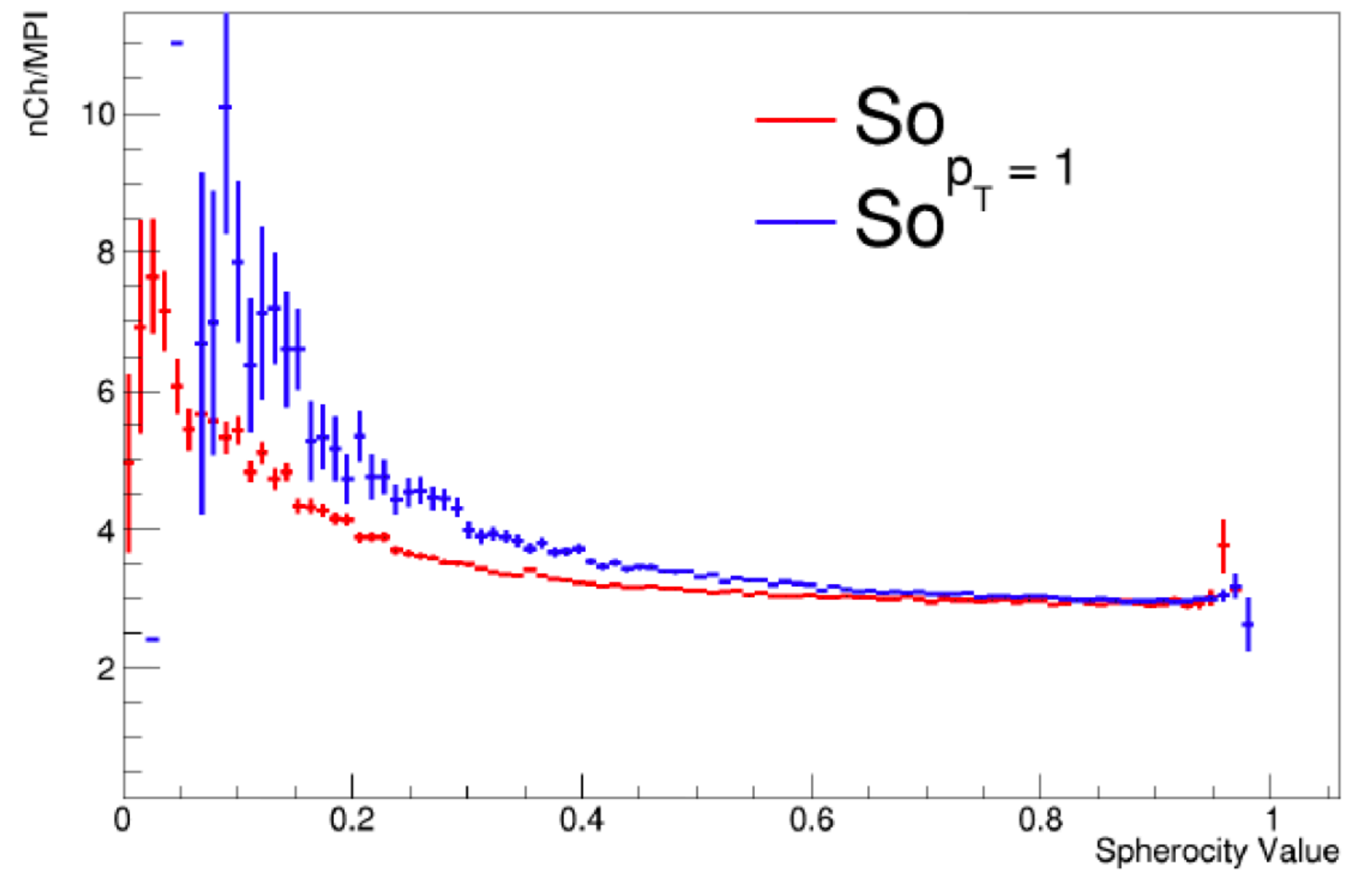
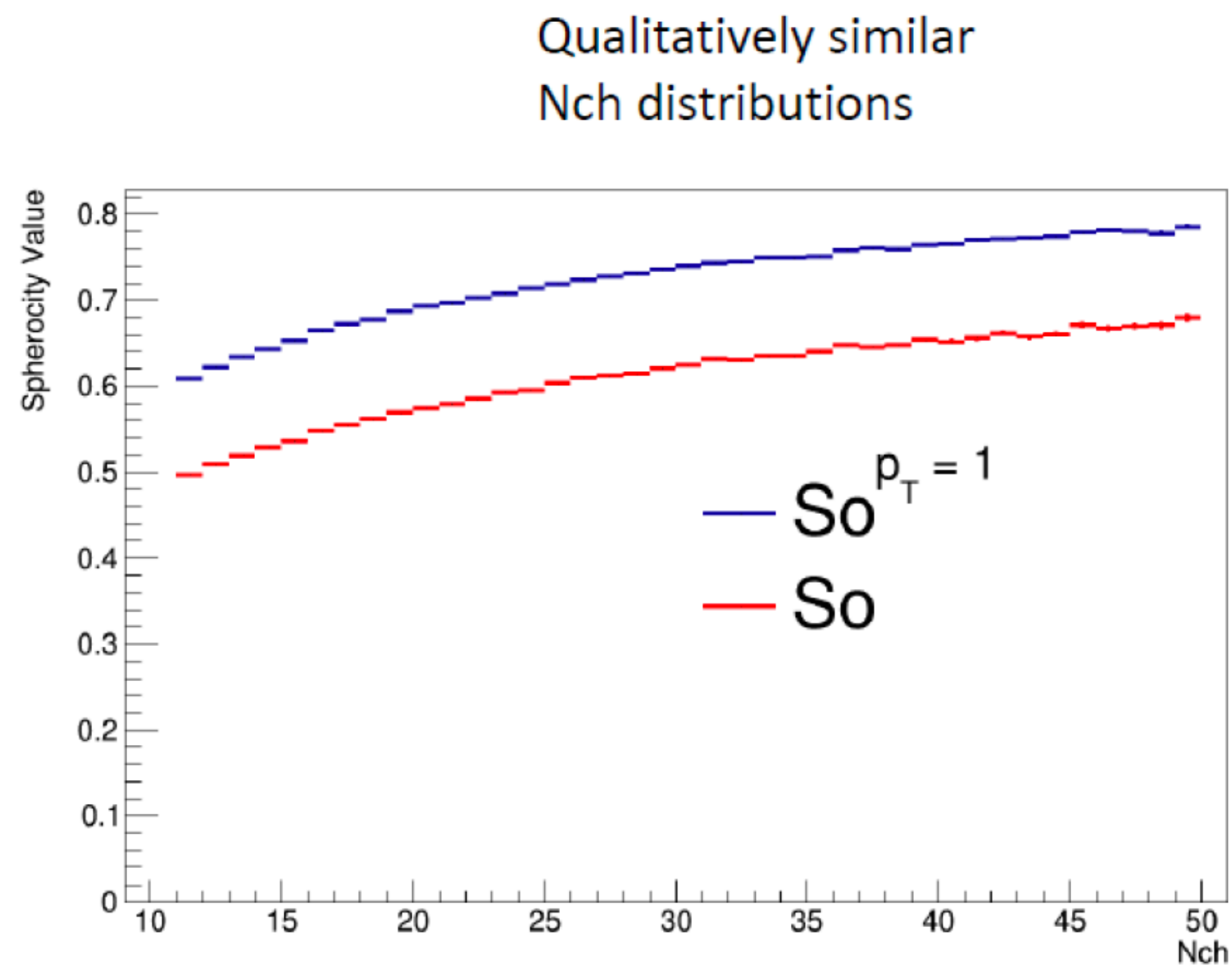
Correlation matrix between  $S_0^{p_T=1}$  and  $S_0$  linear with an initial offset.

So:SoNoPt {nCh>10}



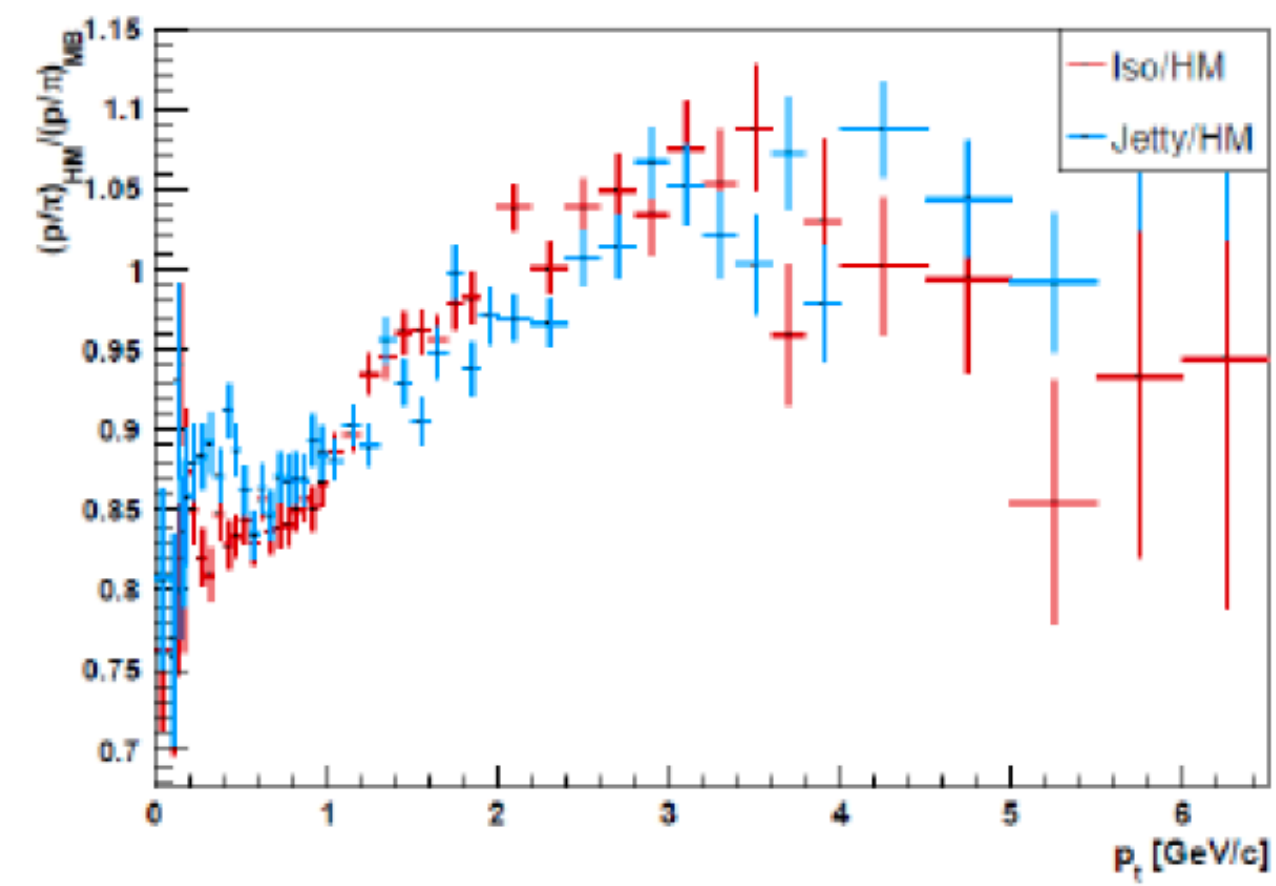
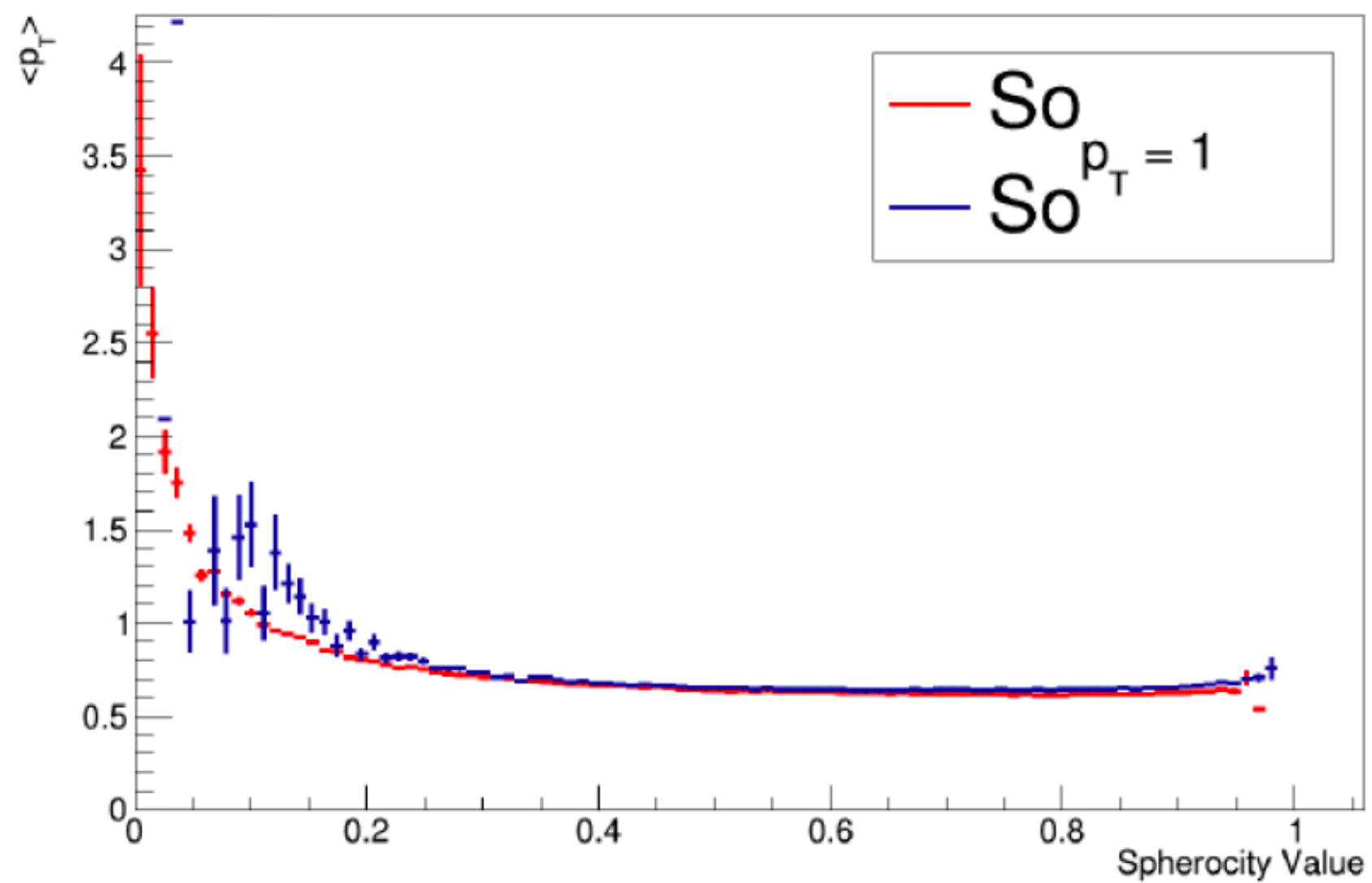
# $S_0^{p_T=1}$ MC Studies - $S_0^{p_T=1}$ vs $S_0$

Qualitatively similar Nch/MPI distributions

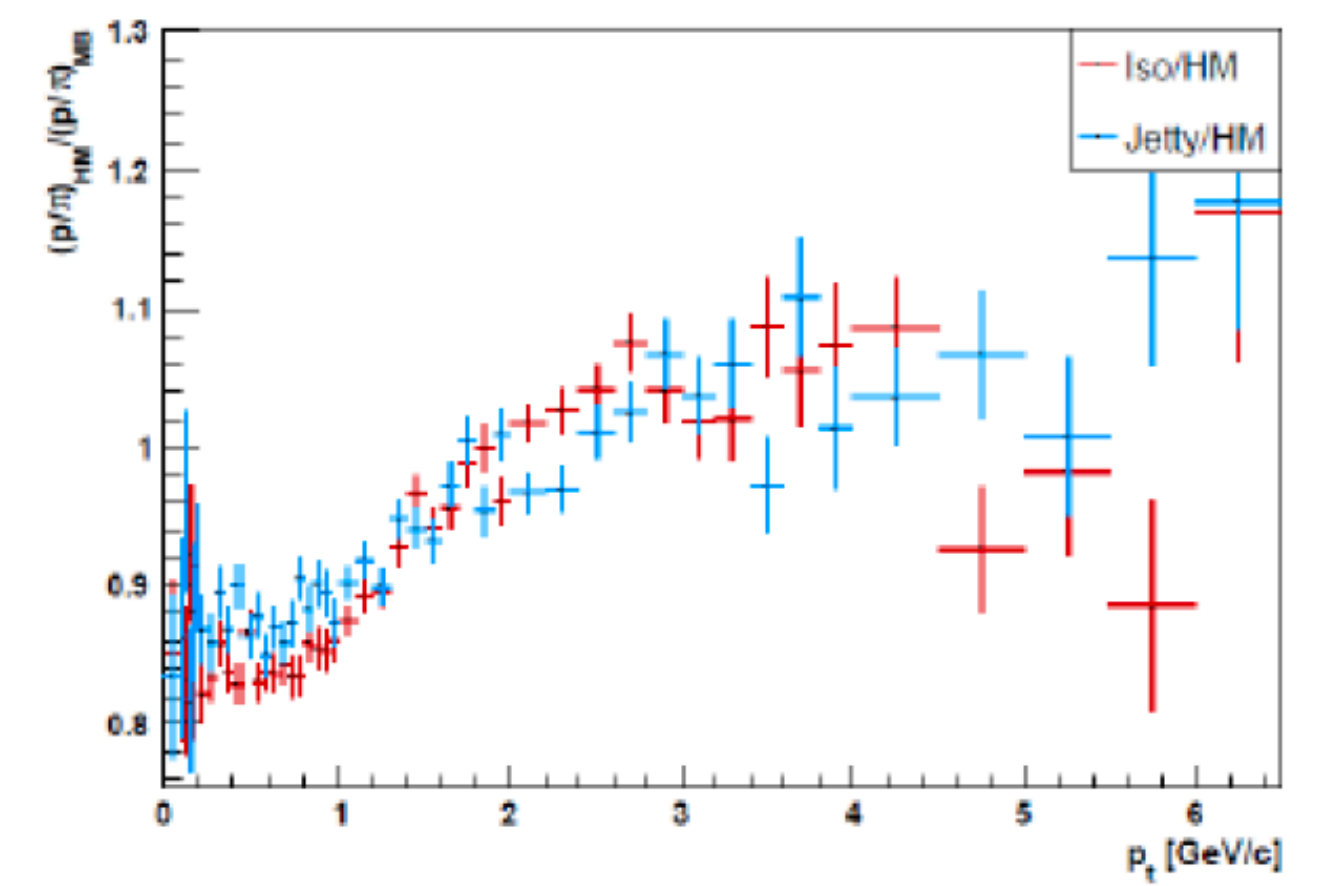


# $S_0^{p_T=1}$ MC Studies - $S_0^{p_T=1}$ vs $S_0$

Qualitatively similar  
 $\langle p_T \rangle$  distributions



(a) Sphericity



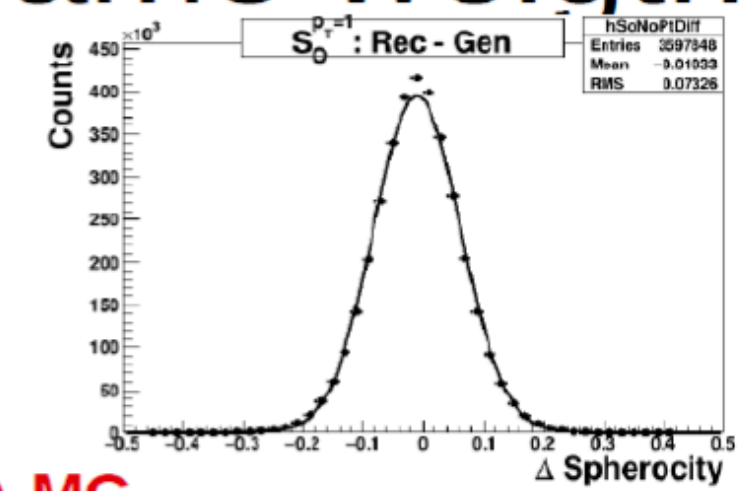
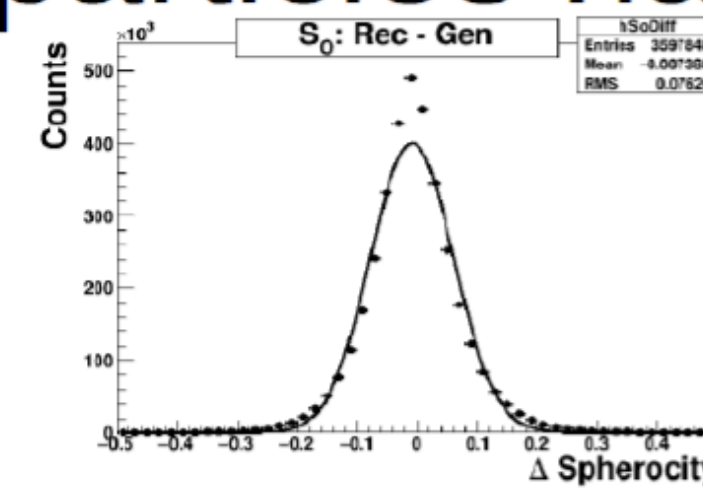
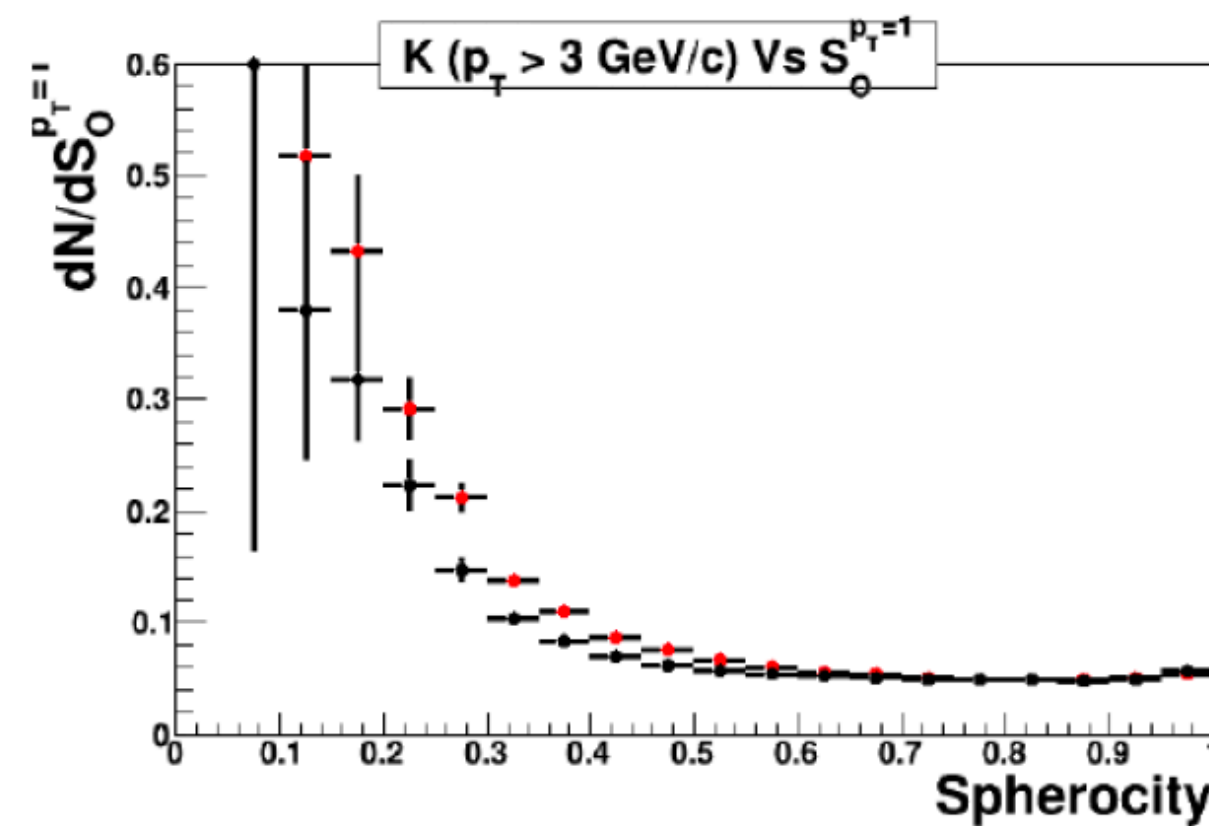
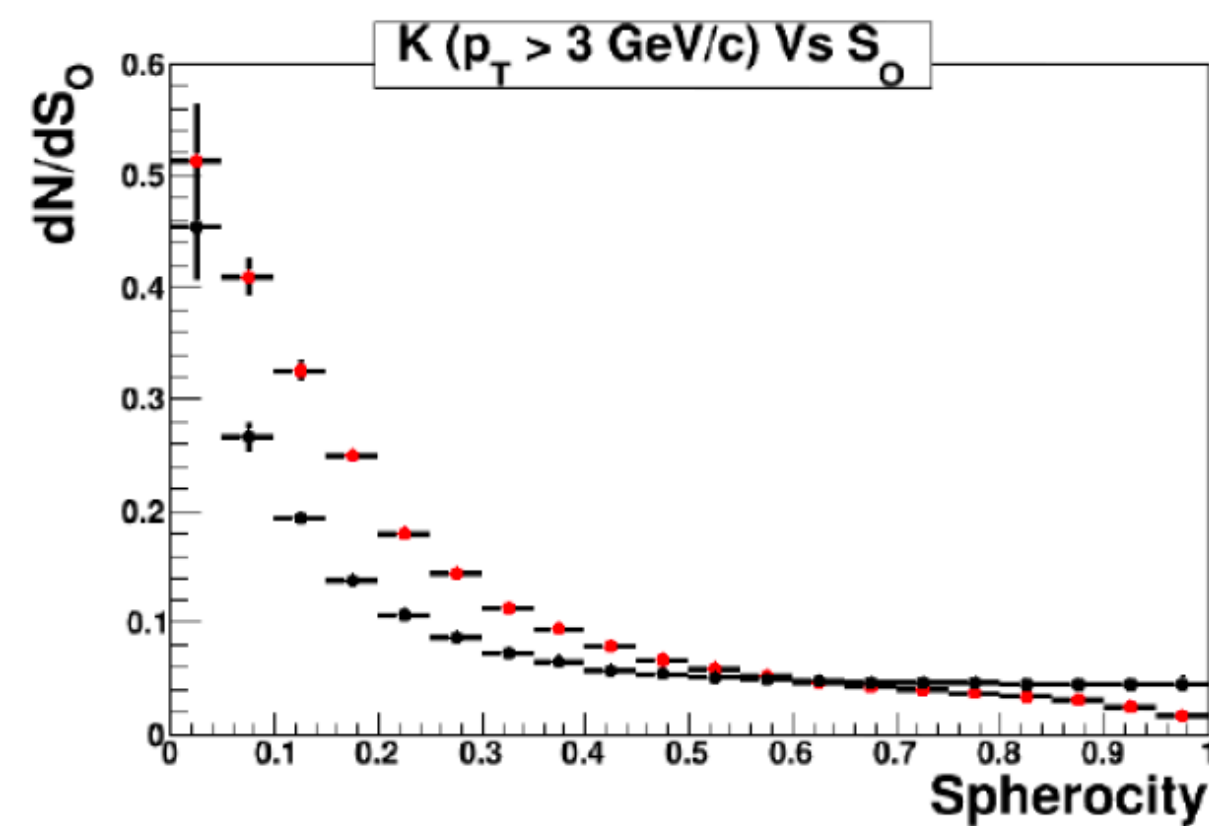
(b) Sphericity  $p_T = 1$

# $S_0^{p_T=1}$ MC Studies – Charged Vs Neutral

$K^+$  and  $K^0_s$  with  $p_T > 3$  GeV/c

$S_{0,pT=1}$  is more “robust”: all particles have same weight

PYTHIA MC results (generator level)



PYTHIA MC results

