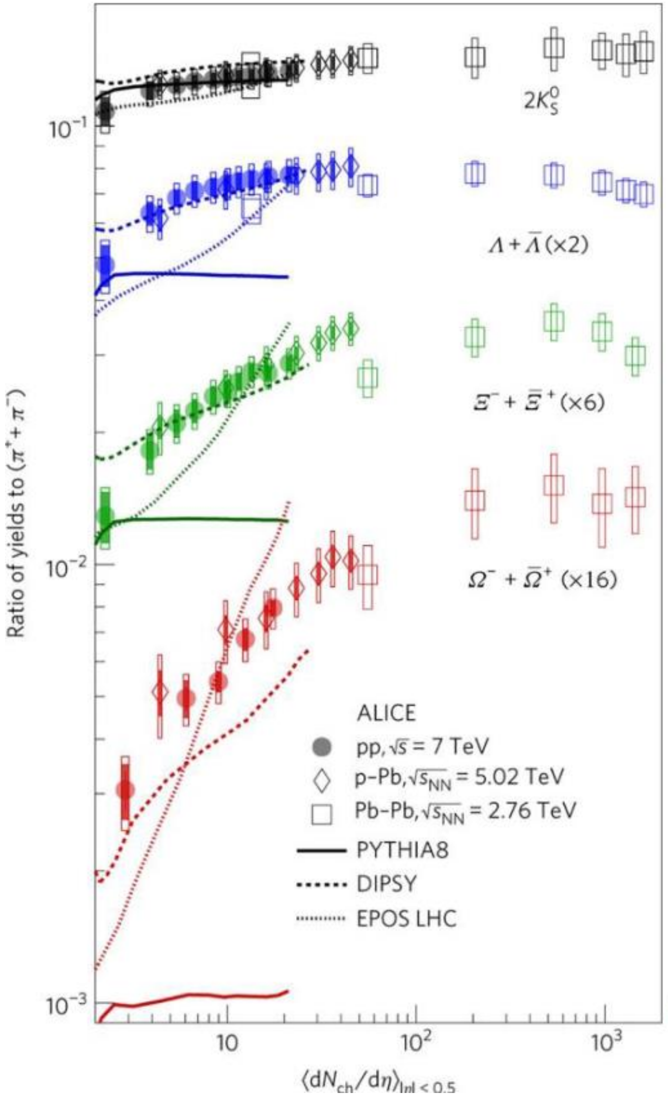
New Multi-Differential Measurements of strangeness production in small systems with ALICE at the LHC

Adrian Fereydon Nassirpour
On Behalf of The ALICE Collaboration

Introduction: The CLASH Project

- Experimental observations have found collective-like behavior in pp & p-Pb collisions.



Nature Physics 13, 535-539 (2017)

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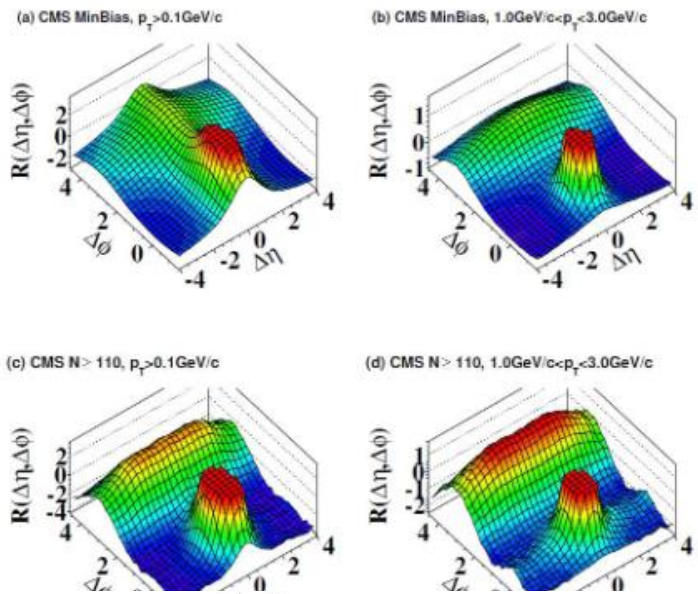

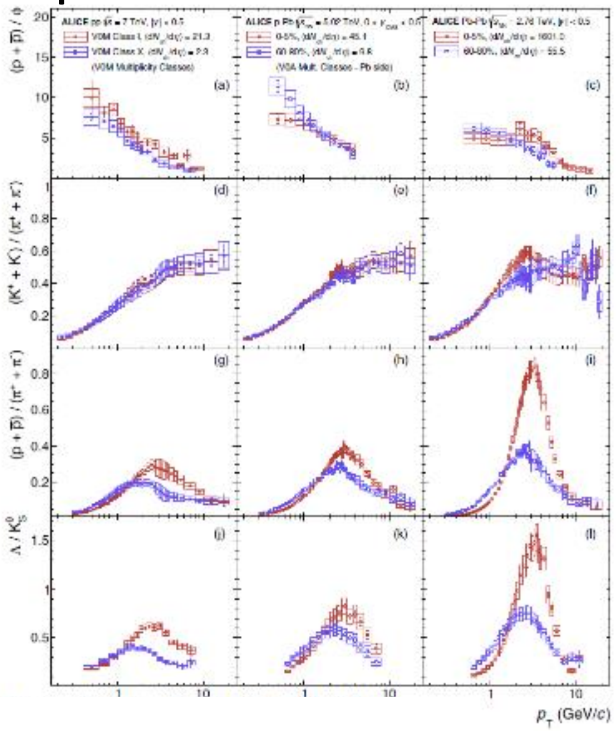

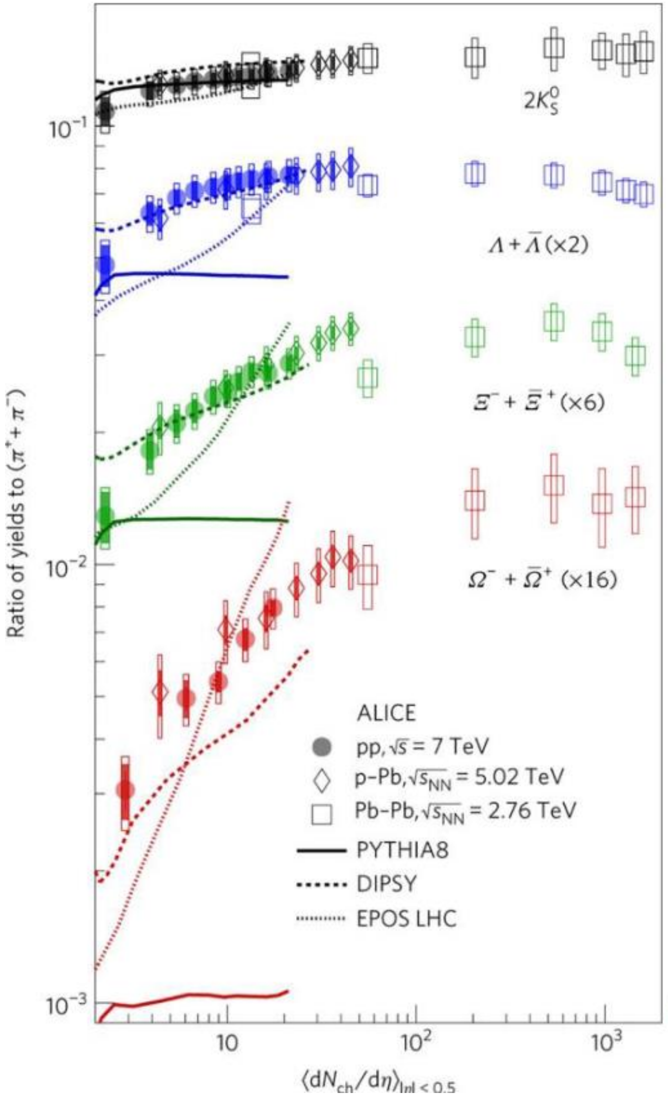

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(CMS): JHEP 1009:091,2010

Phys. Rev. C 99, 024906 (2019)

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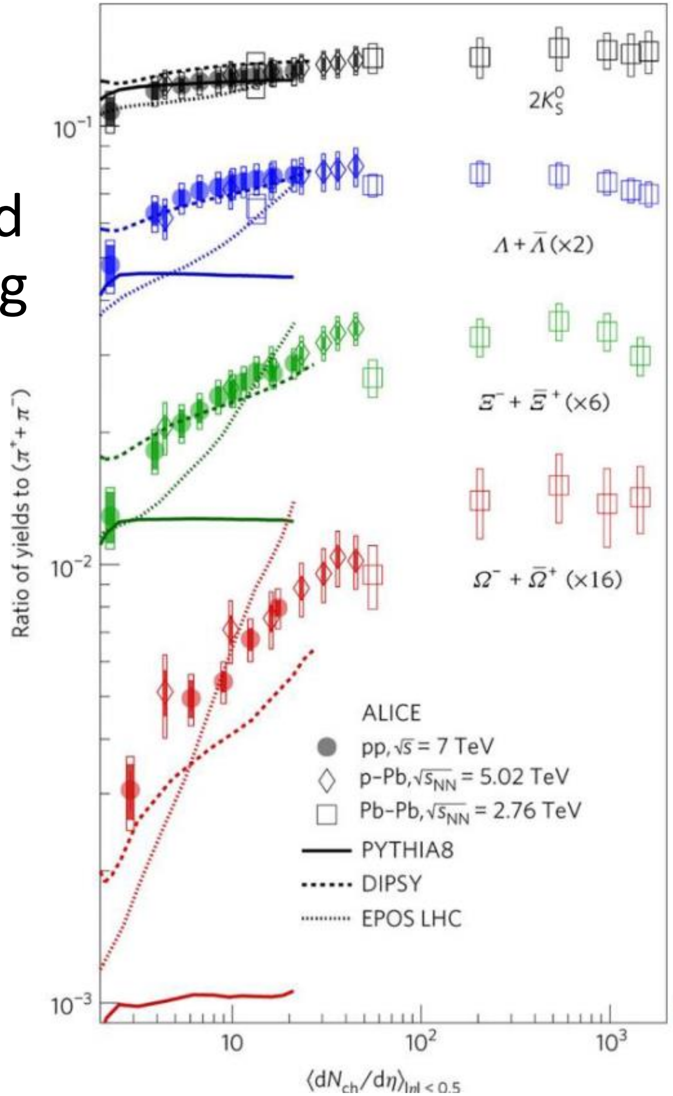

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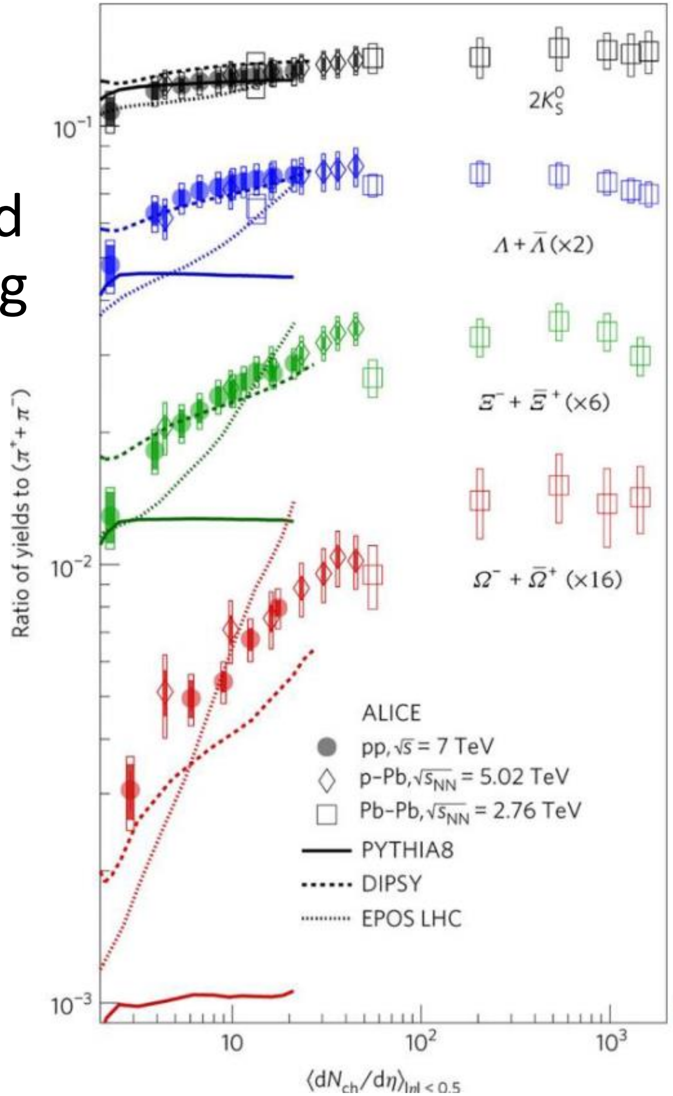
- In A-A systems, the same observations are interpreted as signatures of the formation of a strongly interacting medium, the Quark-Gluon Plasma (QGP).
- Unresolved if the system created in pp collisions is large and long-lived enough to form a QGP.



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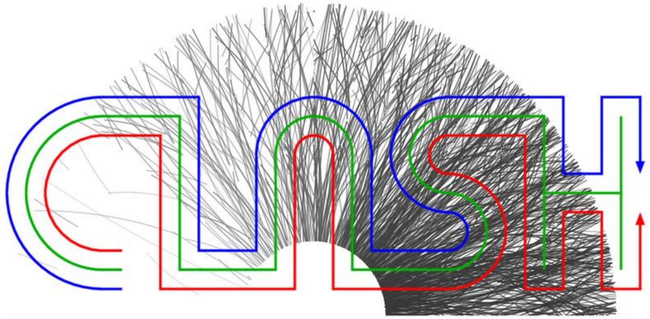

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PYTHIA/Angantyr Developments:
Color Ropes, String Shoving, etc..

Lund Theory

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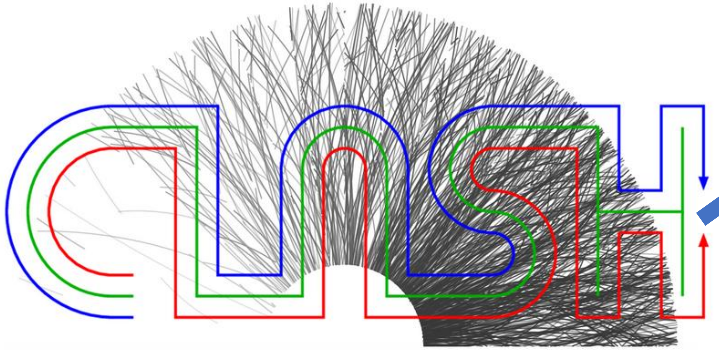

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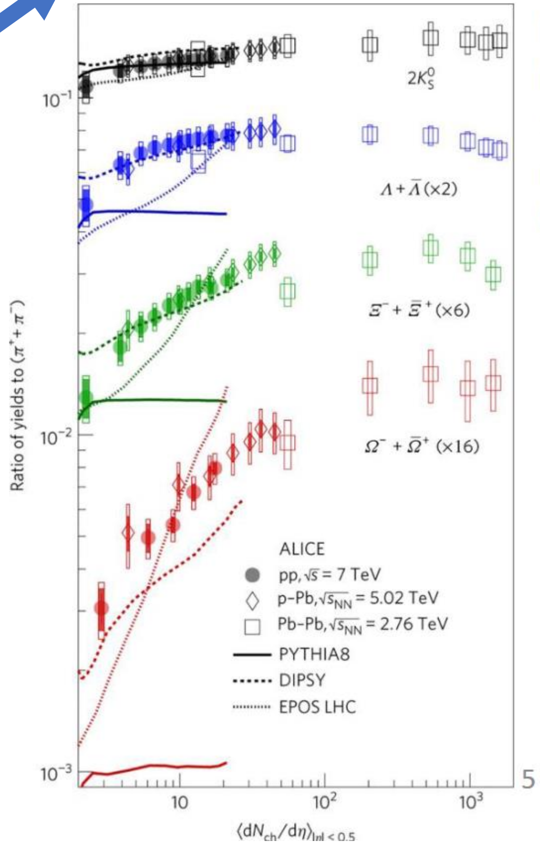

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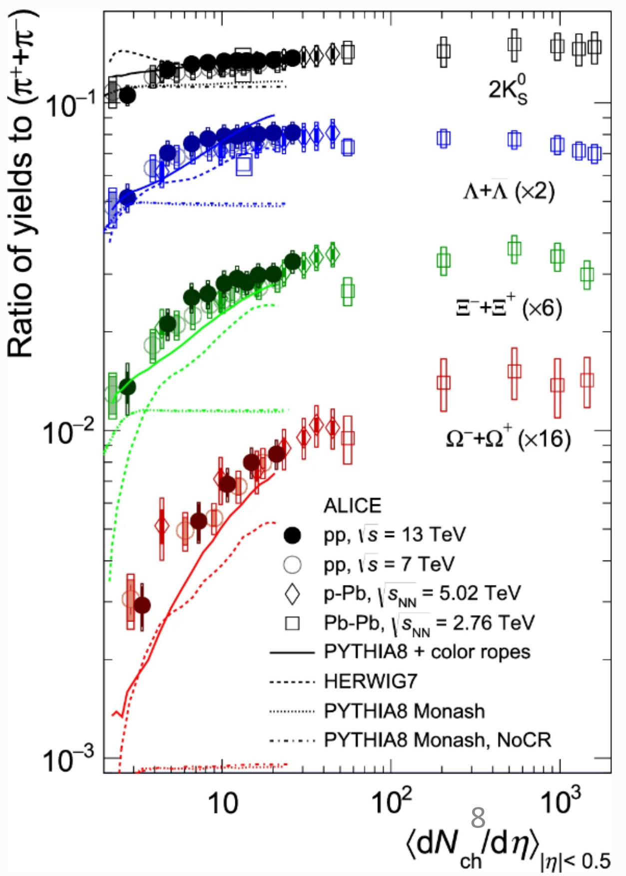

Knut and Alice Wallenberg Foundation

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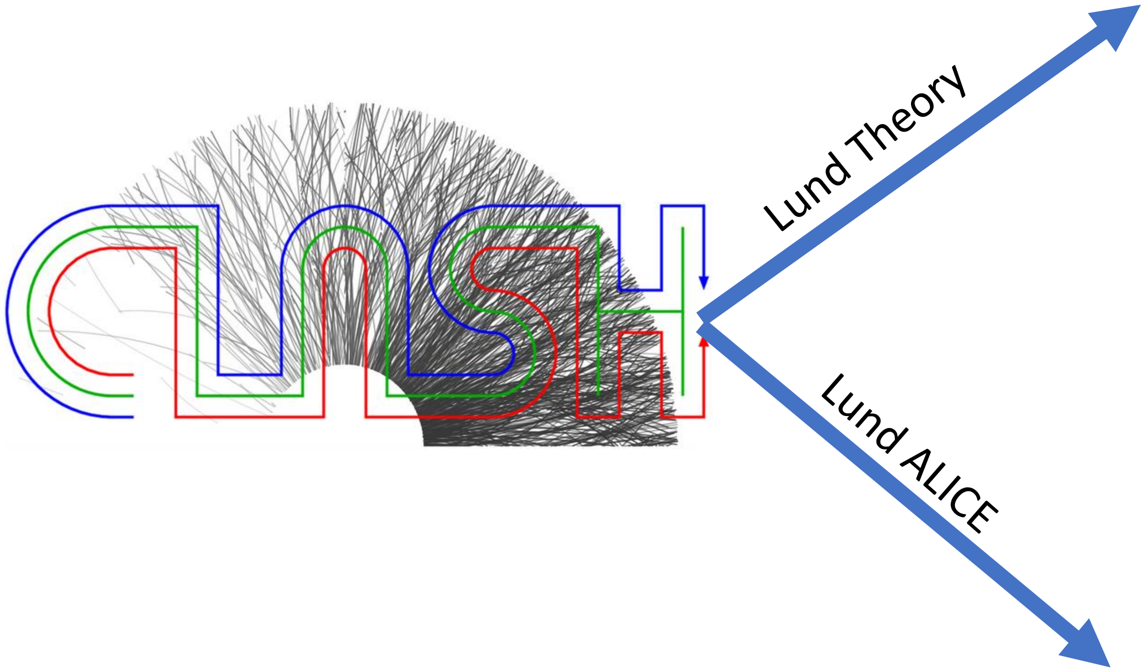

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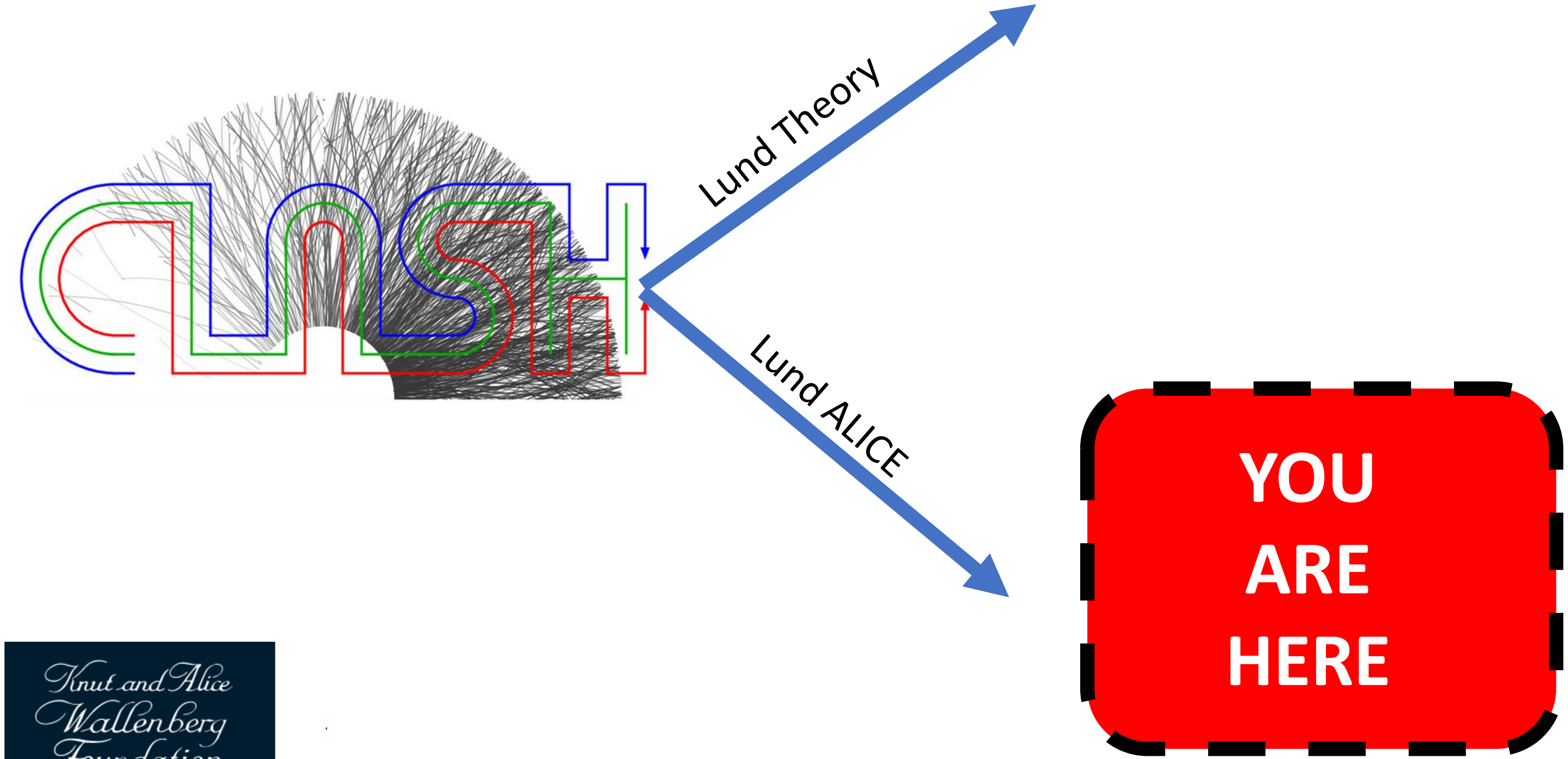

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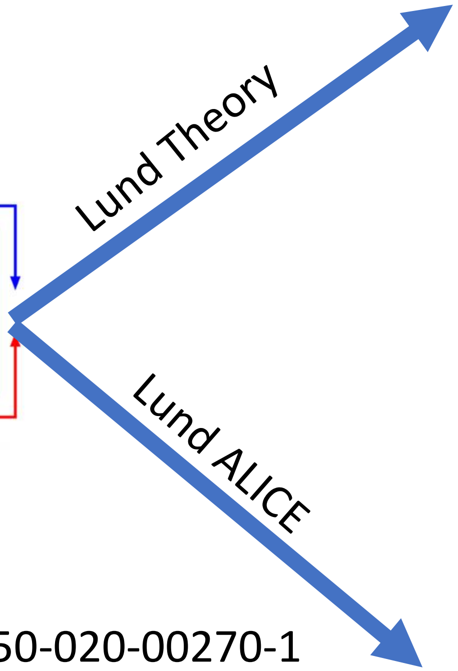

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CLASH Workshop paper:
https://doi.org/10.1140/epja/s10050-020-00270-1

Introduction: Isolating Hard & Soft Physics

- How do we pinpoint the underlying mechanisms of collective behavior and strangeness enhancement?
  - Can we isolate the different physics regimes (soft vs hard)?
  - Can we test pp (strings) vs A-A (hydro) ideas?

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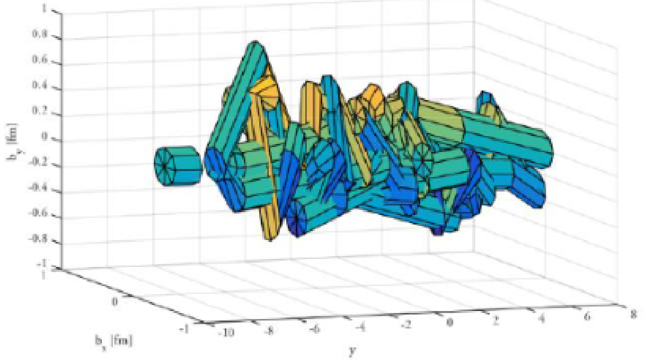
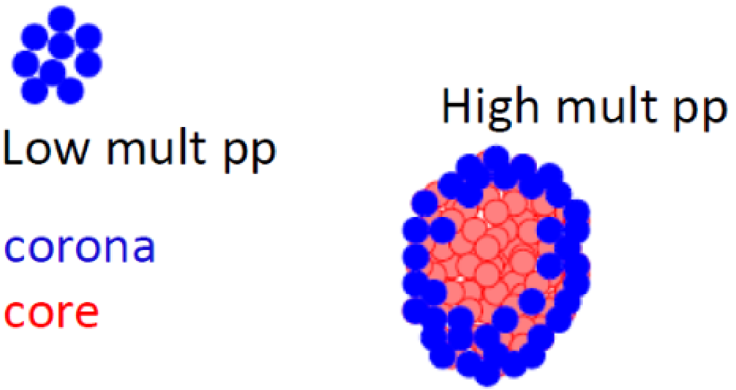
Microscopic vs Macroscopic



Picture from C. Bierlich
(string radii ~3.5 times too small!)



Pictures from K. Werner

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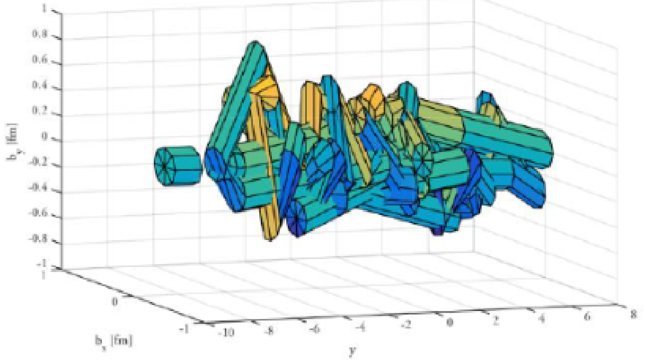

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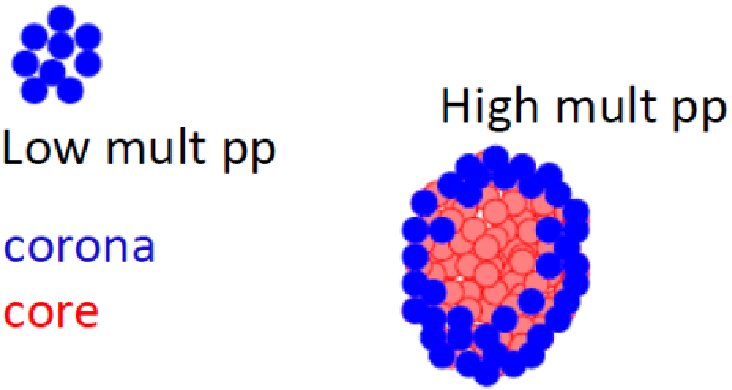

Pictures from K. Werner

How are strange quarks produced in the collision?

Canonical suppression?

Are ”collective effects” a signature of the QGP?

Can effects be reproduced by string-like models?

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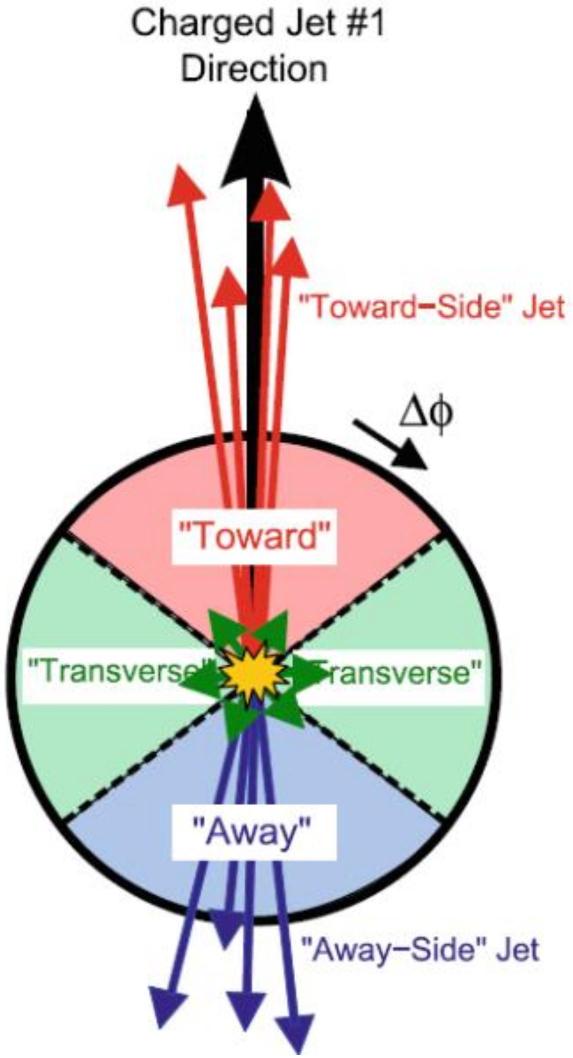
- I will present three new observables from ALICE that can provide differential insight:
  - **R_T: Particle Production as a function of the Underlying Event (UE).**
  - **$\Xi - \pi/K$ angular correlations to trace strangeness production.**
  - (In Backup) $S_0^{p_T=1}$: Particle Production for different event topologies at the same dN/dη

R_T: Particle Production as a function of the Underlying Event (UE)

1

- 5 GeV trigger particle is required to ensure hard scattering.
- Event is sliced into different sectors:



Eur. Phys. J. C62 (2009), 237

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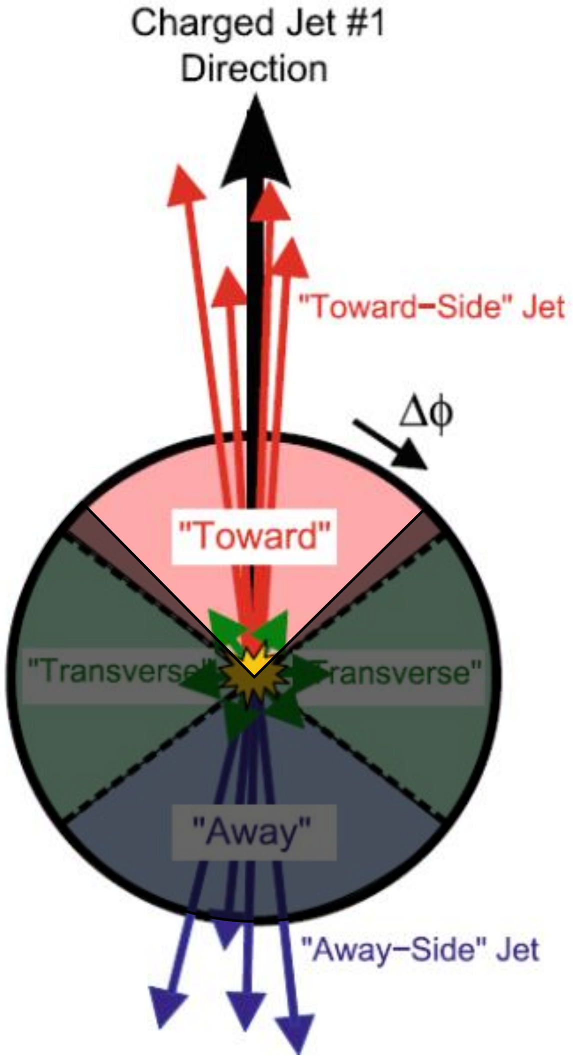

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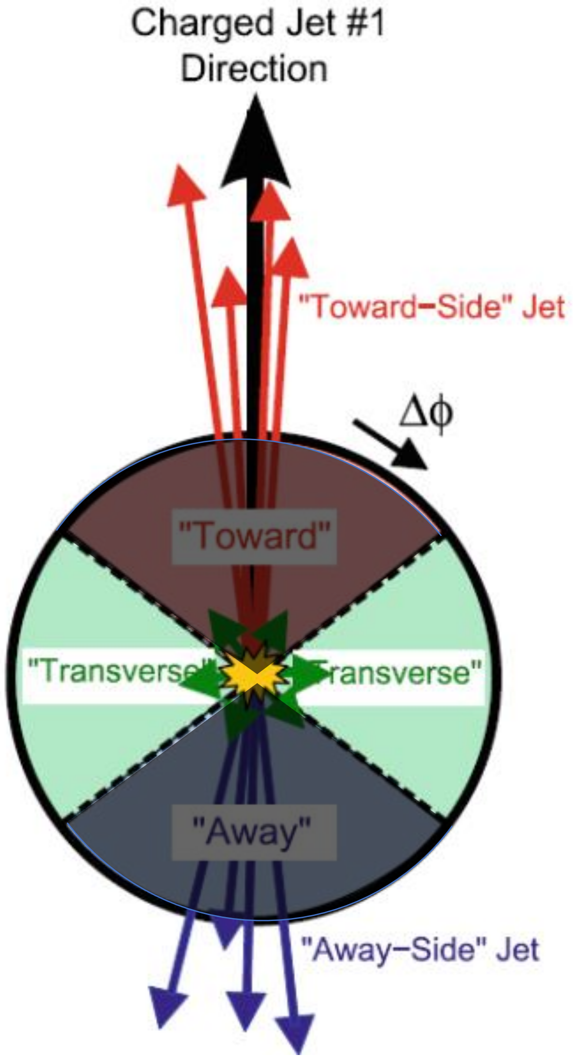

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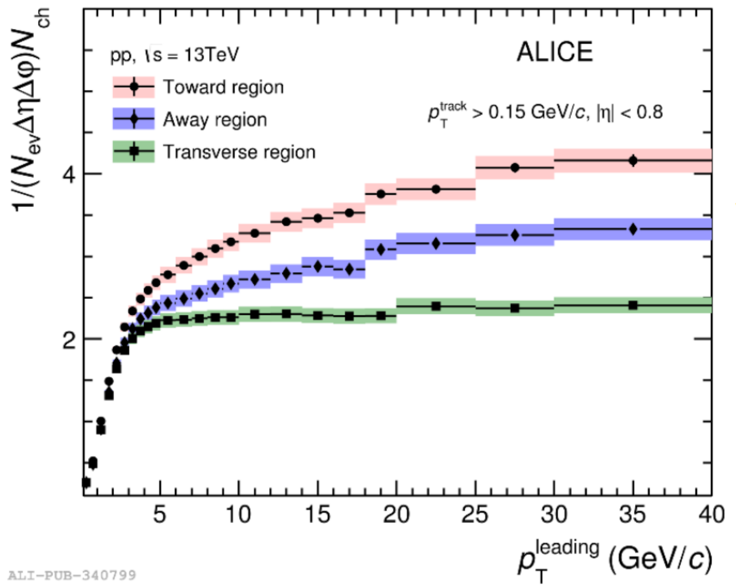

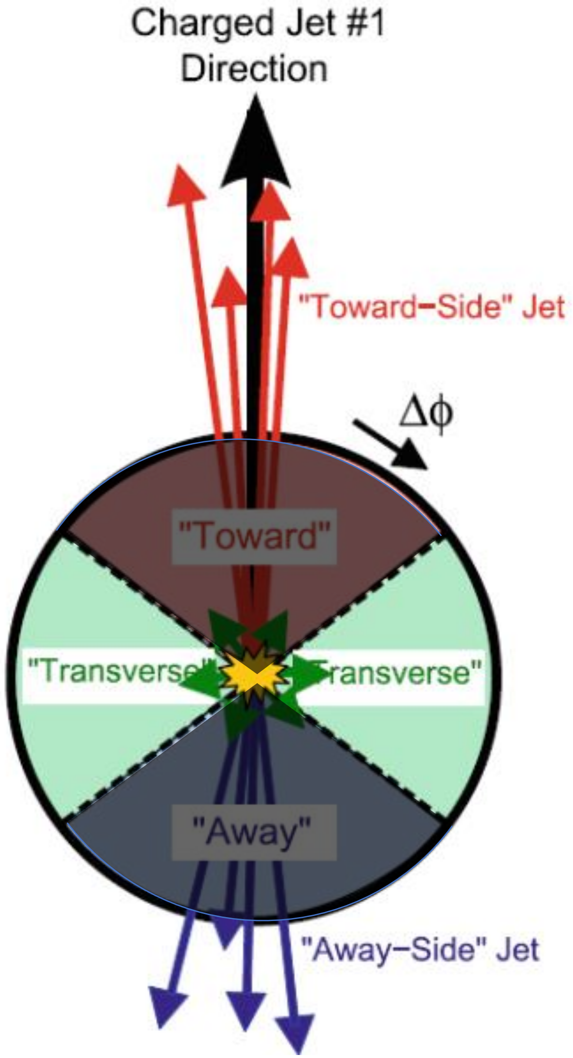

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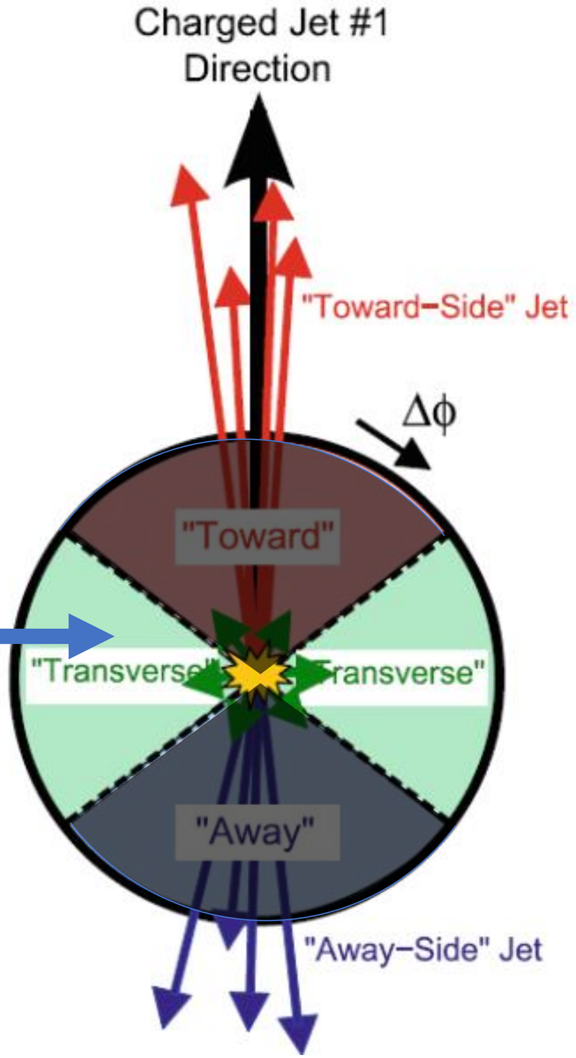
- $R_T = \frac{N_T}{<N_T>}$

(Number of measured tracks here)



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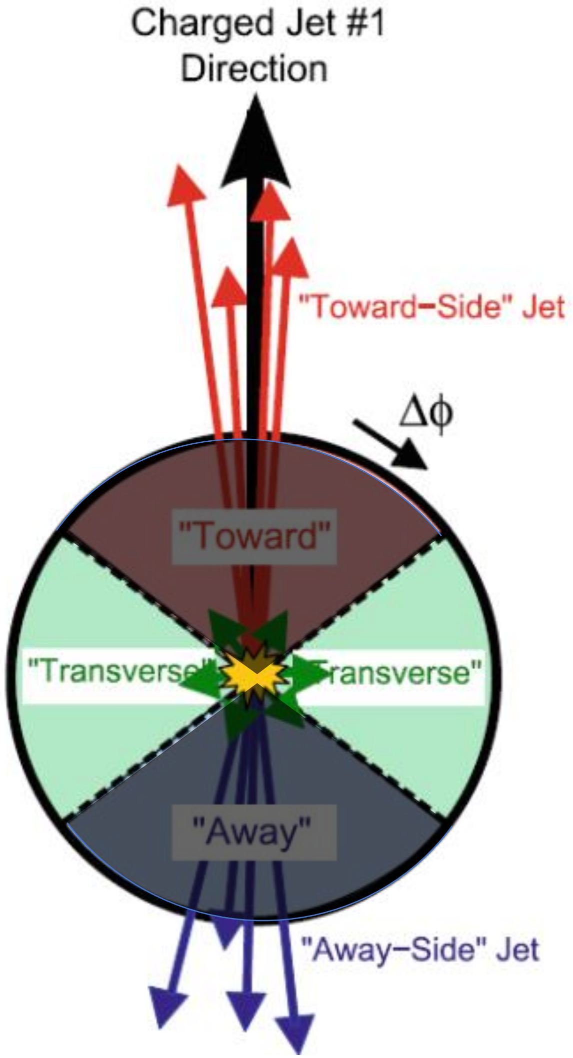
Gives some control over the UE



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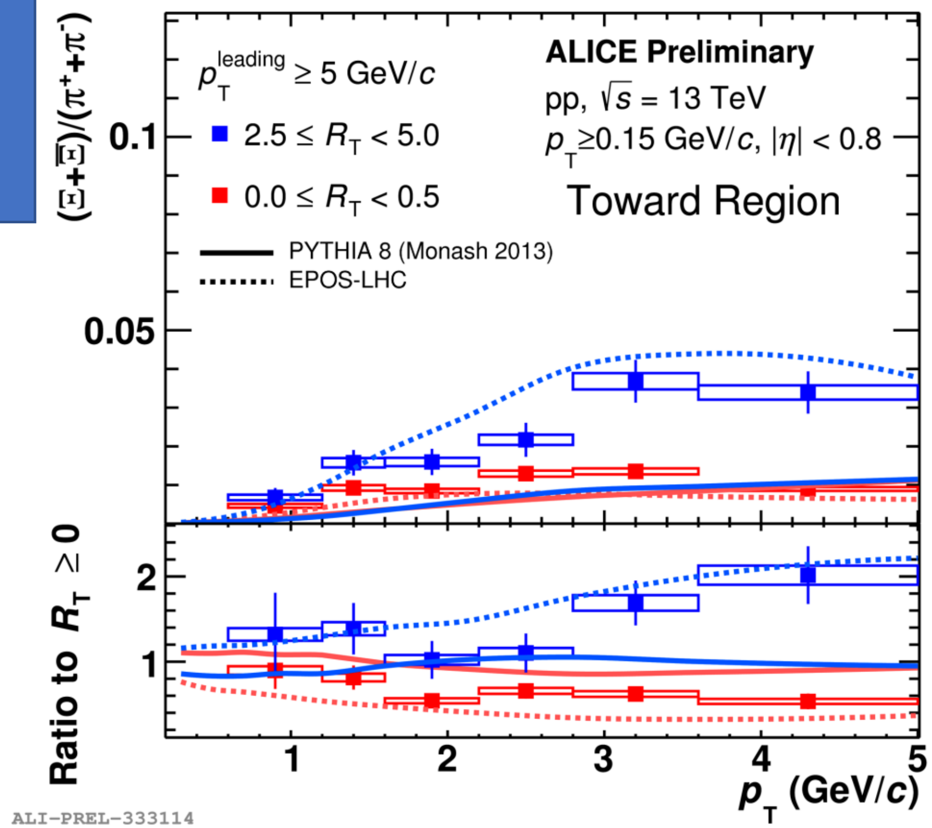
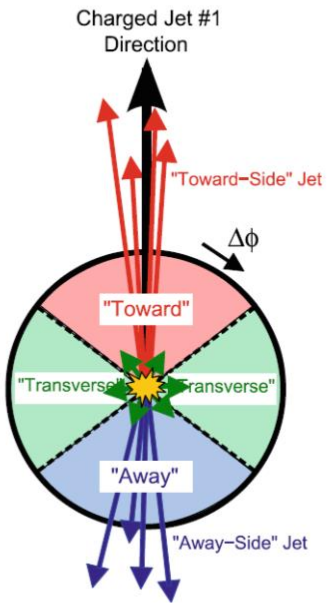
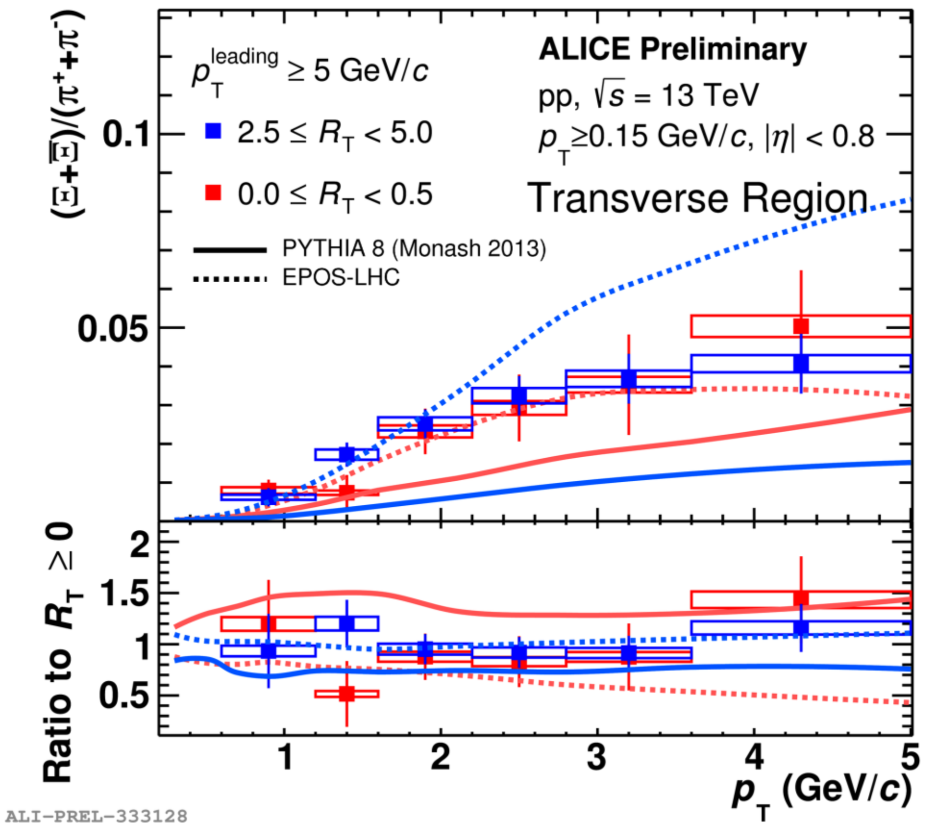
Ξ-to-π Ratios as a Function of R_T

1







- Ξ-to-π vs R_T: flat in Transverse region, approaches Transverse limit in Toward region
- PYTHIA only describes low-R_T Toward production (*ee*-like jet component)
- EPOS-LHC describes high-R_T in the Towards region, but not Transverse Region

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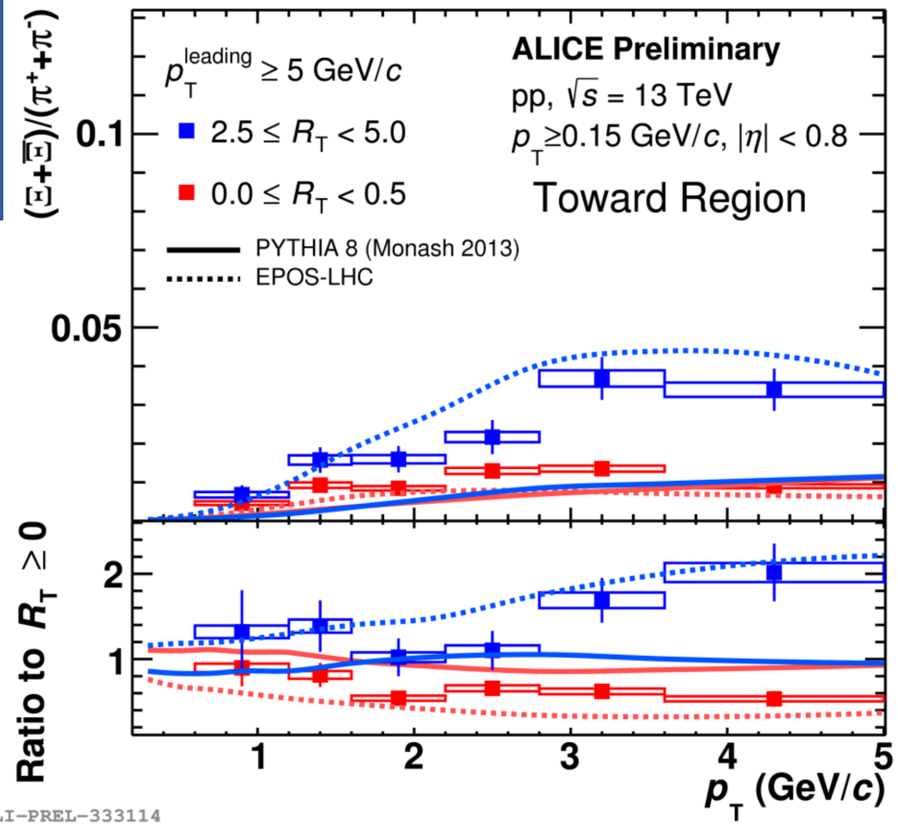

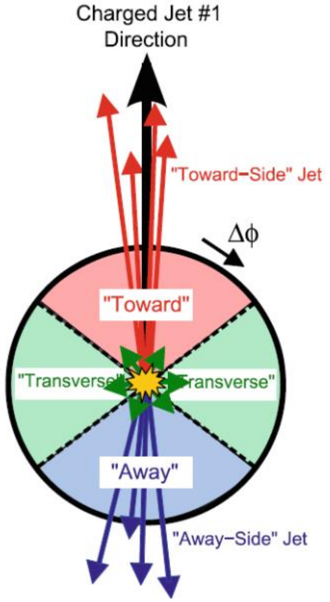

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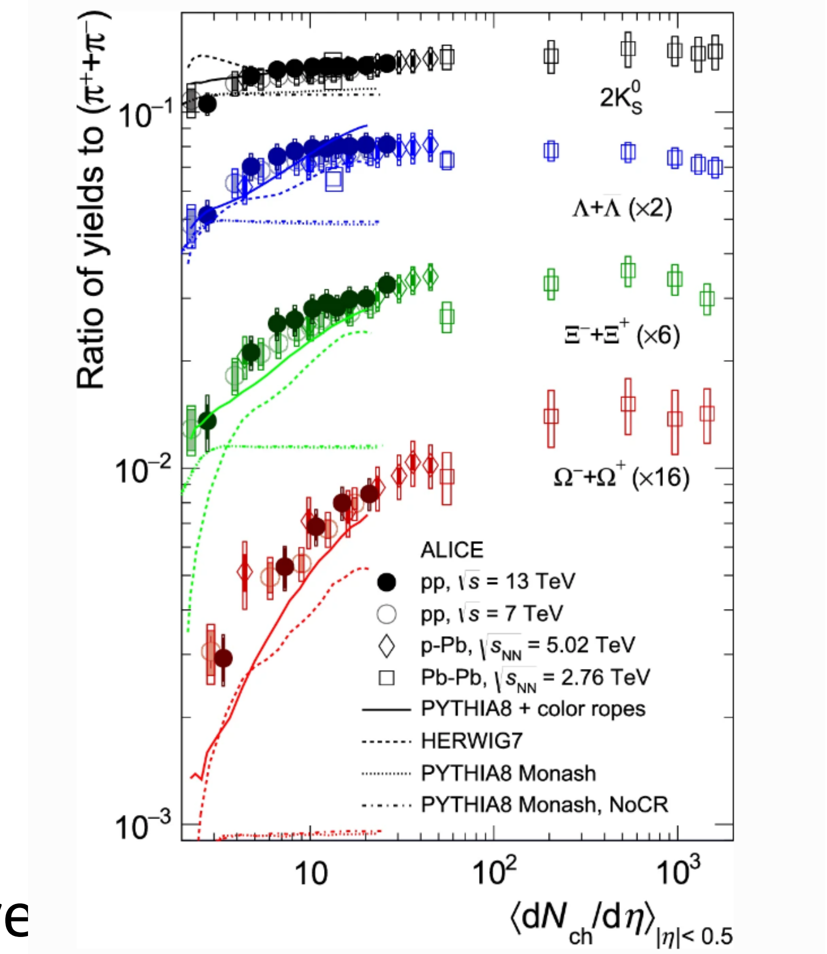

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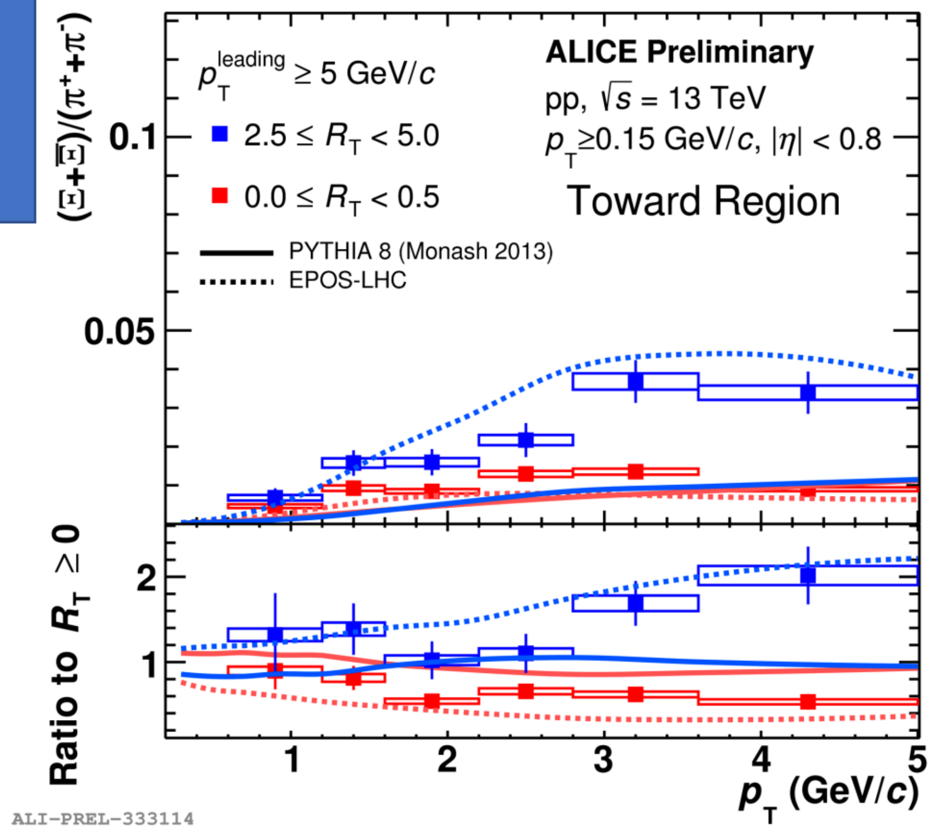

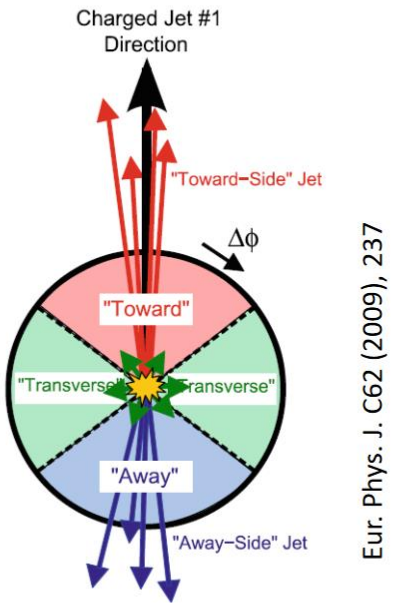

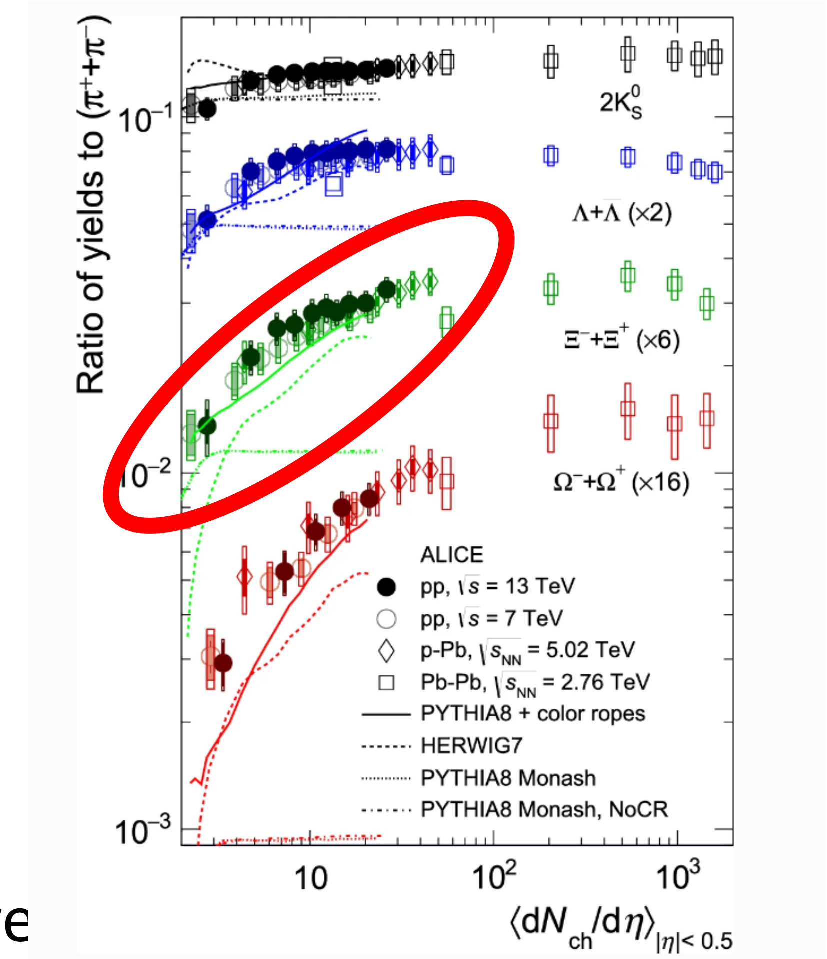

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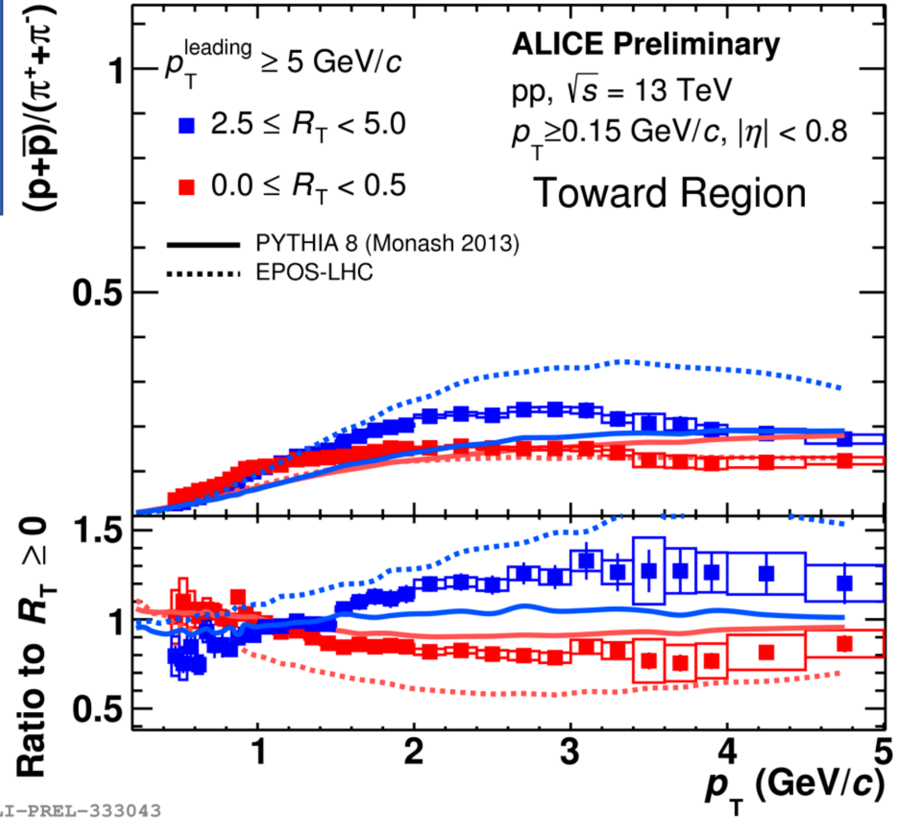
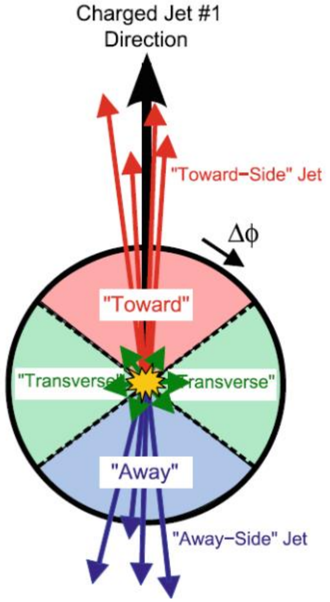
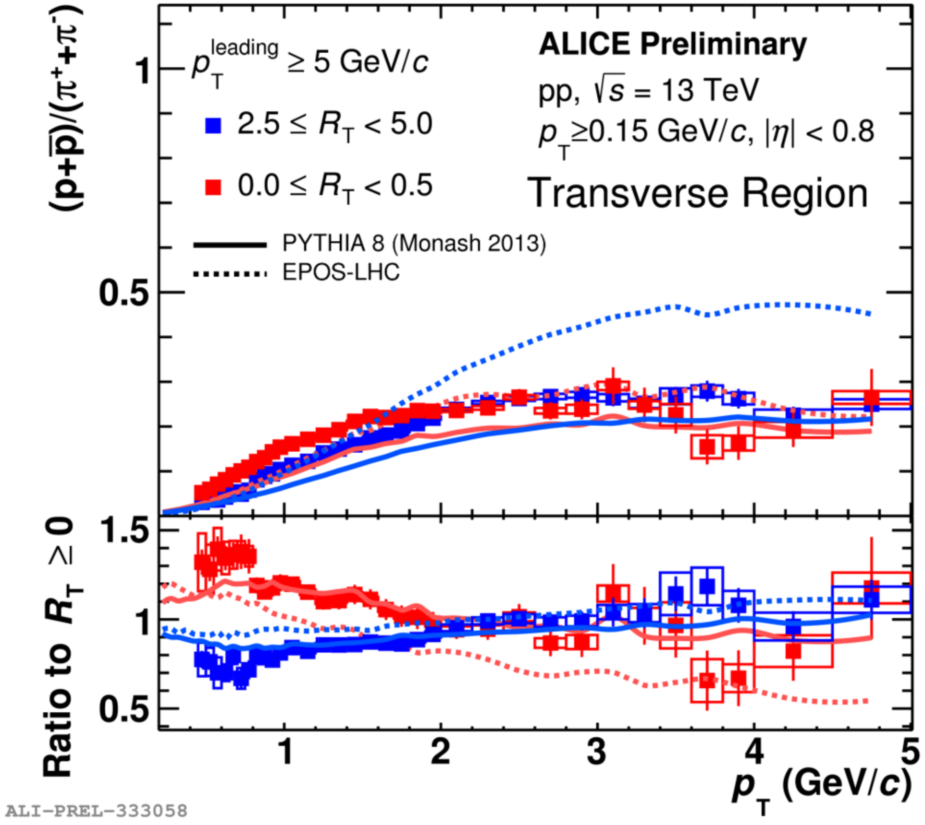






- Similar to the Ξ, the Toward values are approaching the Transverse limit
- p-to-π ratio in the Toward region displays an increasing(decreasing) trend at low(high) p_{T}, with increasing R_T
- Modification or proton yield in Transverse for low- p_{T} with increasing R_T, but little to no dependence on R_T at high p_{T}.

$\Xi - \pi/K$ Angular Correlations

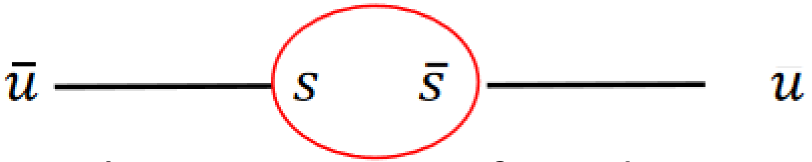
2

- $\Xi - \pi$ can shed light on the microscopic picture of light-flavor hadron production.

MICRO
(PYTHIA)

- Quark flavor conserved locally
  - Hadron correlations directly reflect this.

  Example of simple s-breaking:



- Natural consequence of Lund strings:
  - **If Ξ is produced, there will be an enhancement of associated strangeness production in close rapidity and azimuthal angle.**

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MACRO
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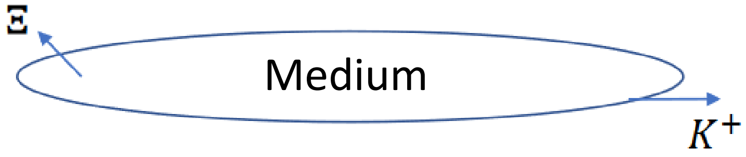
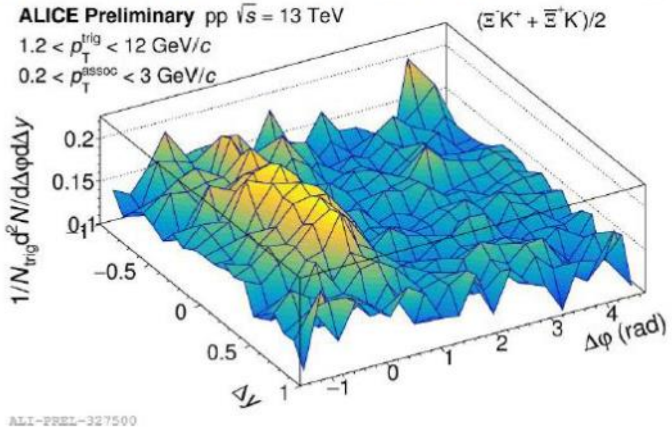
- Hadron flavor calculated using a grand canonical ensemble
  - Conserves strangeness globally



- **No strict constraint on associated strangeness production when a multi-strange particle is produced.**

$\Xi - \pi/K$ Angular Correlations

Opposite sign (OS), e.g., $\Xi^-/ssd - K^+/\bar{s}d$



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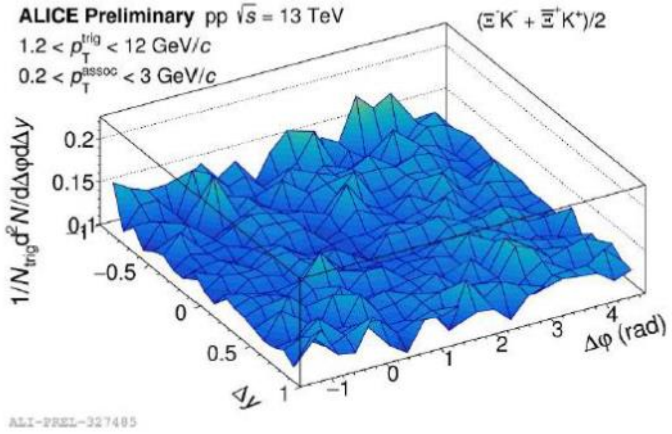

- Two-particle correlation function between opposite and like-sign $\boldsymbol{\Xi}$–$\boldsymbol{K}^{\pm}$.

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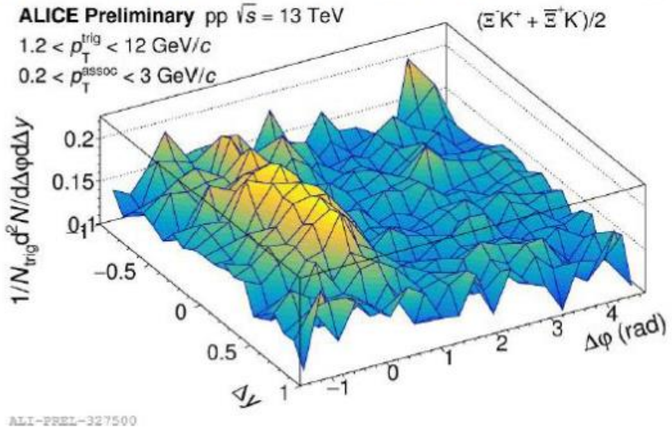

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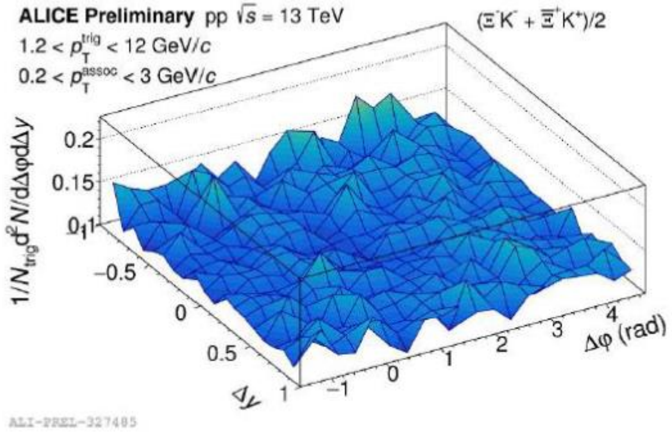

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  - Flat behavior, small away-side ridge.
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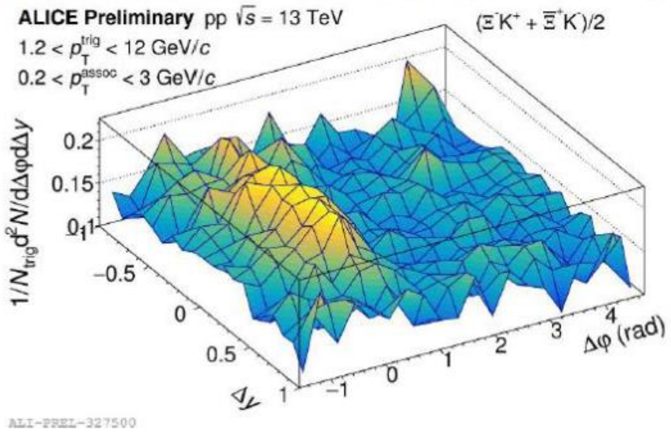

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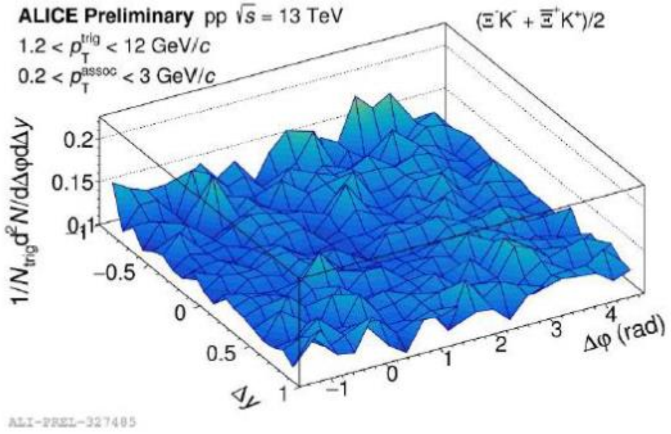

- Two-particle correlation function between opposite and like-sign Ξ–$K^{\pm}$.
  - Flat behavior, small away-side ridge.
  - Same strangeness quantum number.
- Opposite-sign channel (OS) has a very clear peak close in phase-space

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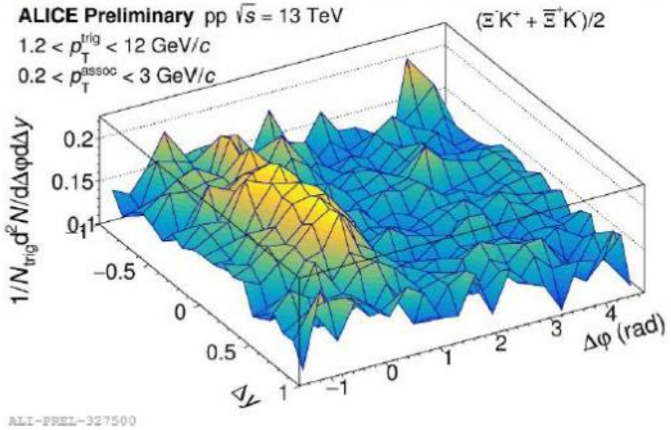

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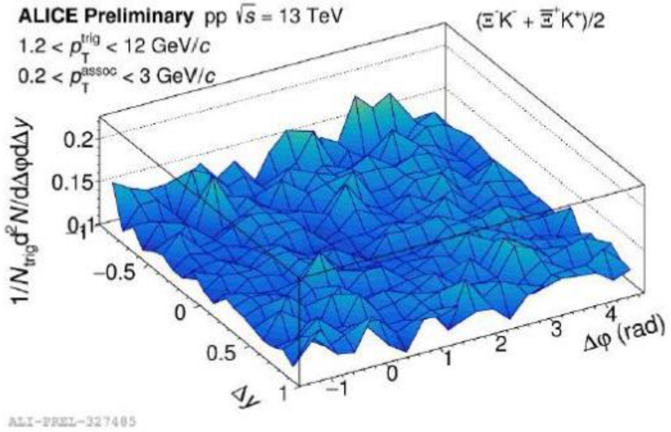

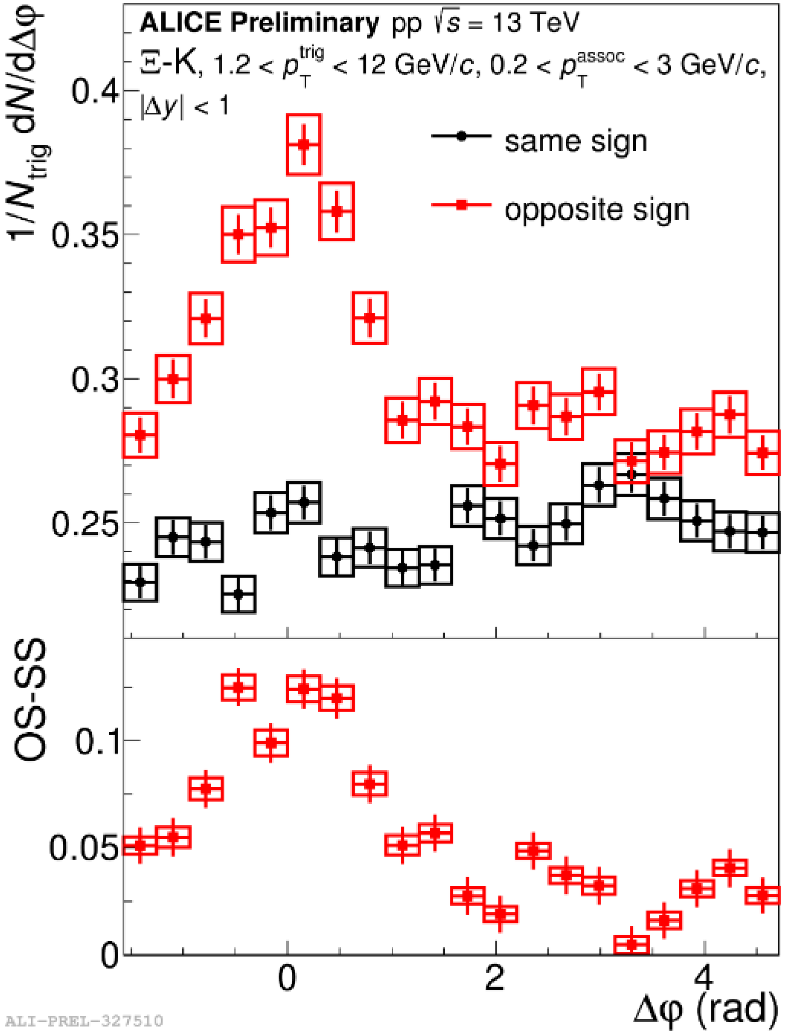

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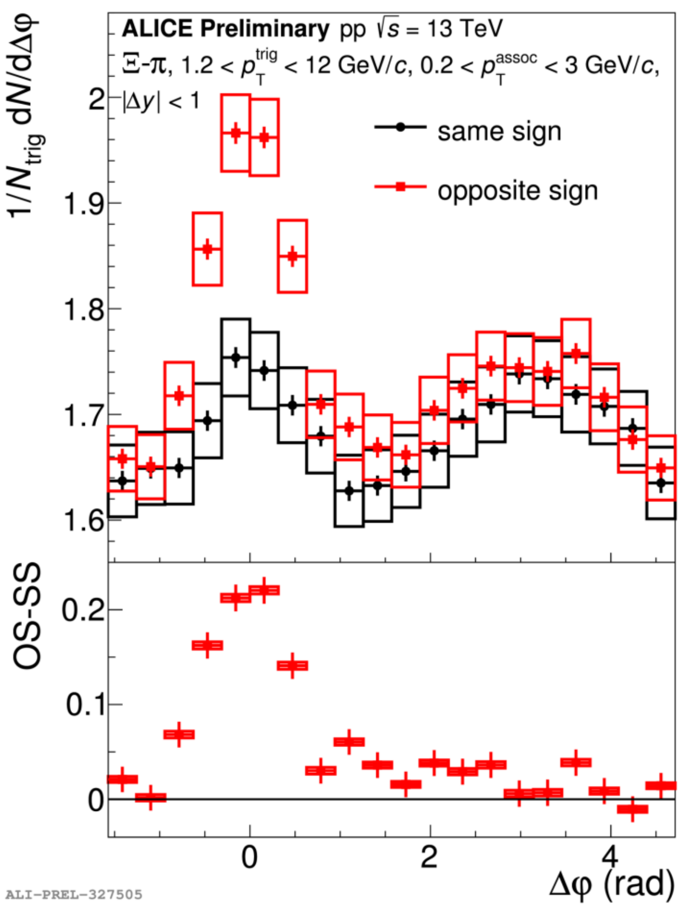
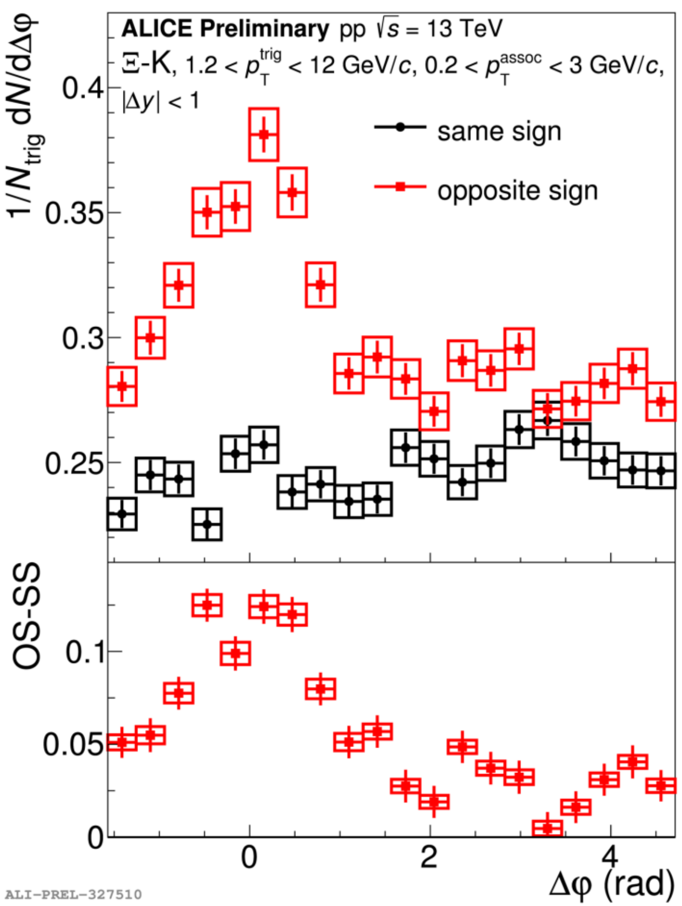
$\Xi - \pi$



$\Xi - K$



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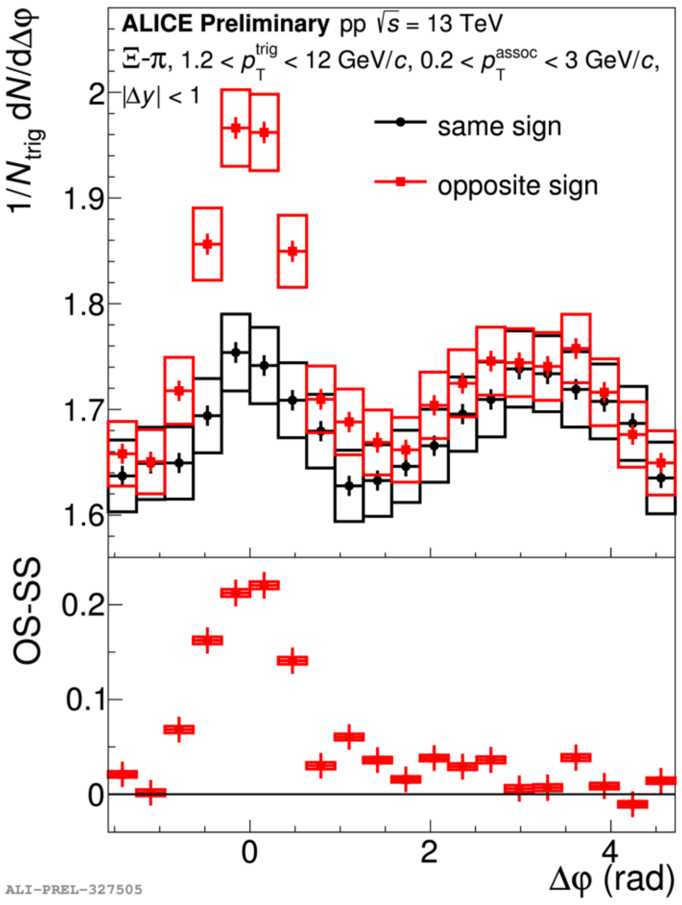

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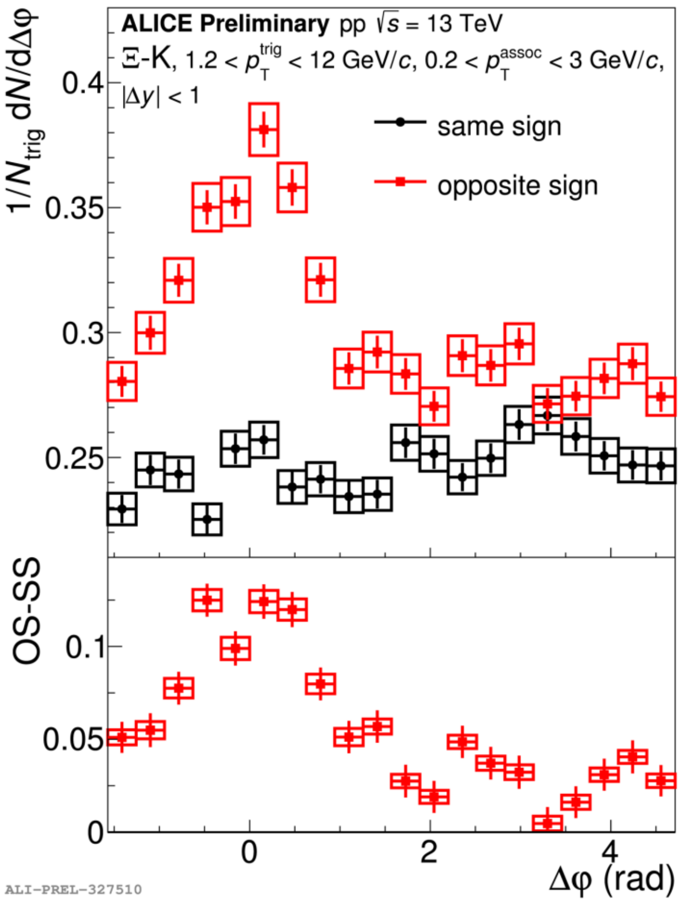
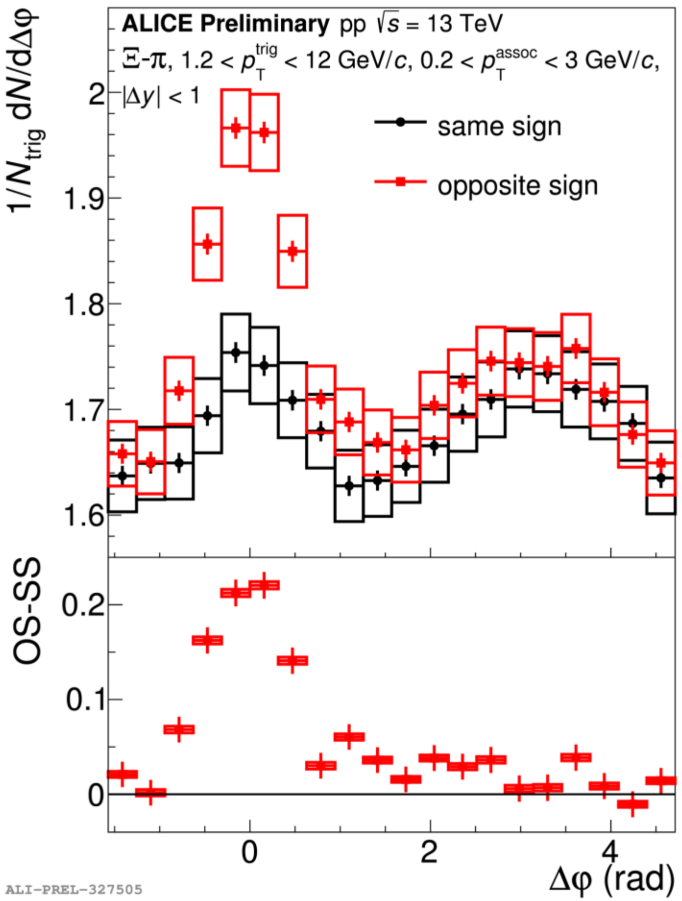


- $\Xi - \pi$:
  - Correlation at near $\Delta\phi$: minijet correlations & jet fragmentation.

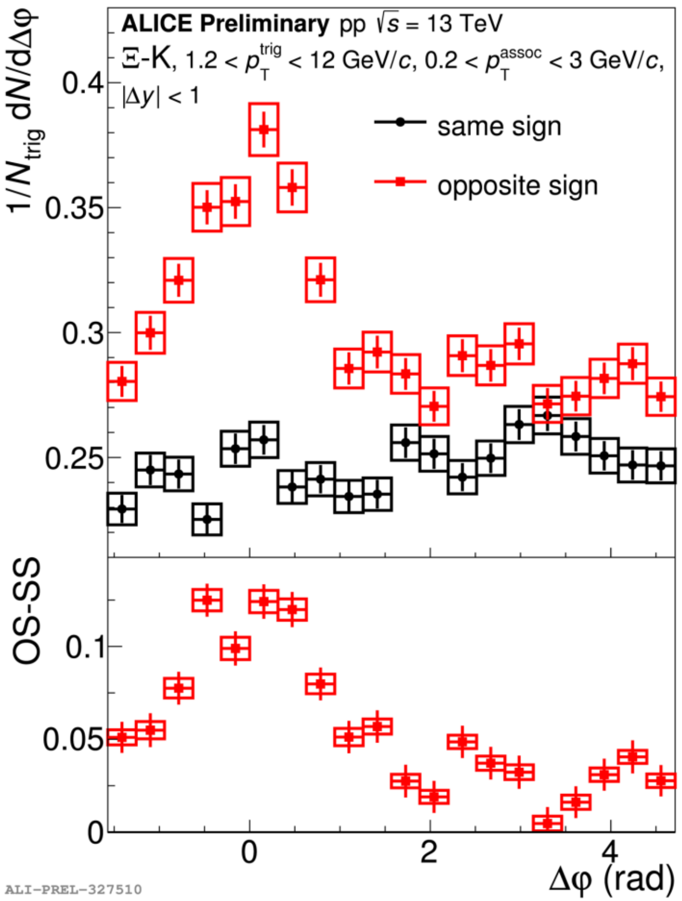
$\Xi - \pi/K$ Angular Correlations

2

$\Xi - \pi$



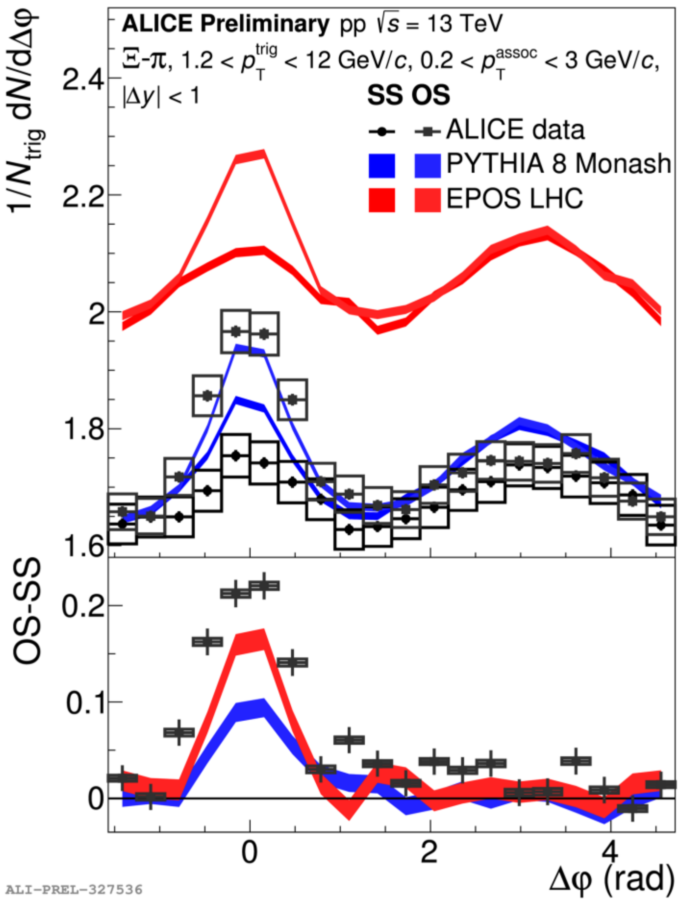
$\Xi - K$



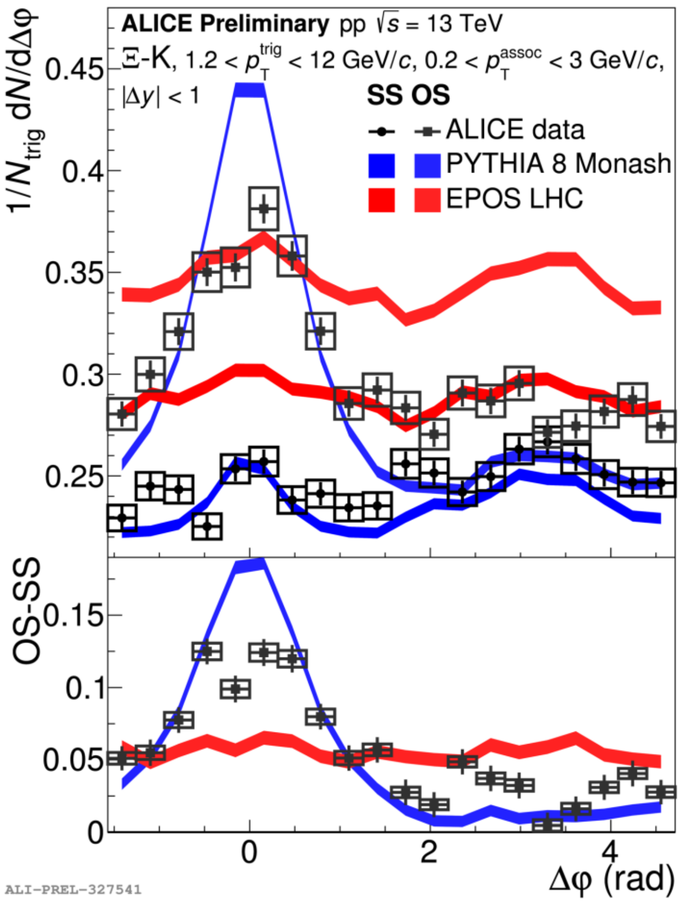
- $\Xi - \pi$:
  - Correlation at near $\Delta\phi$: minijet correlations & jet fragmentation.
- $\Xi - K$:
  - Strong OS correlation near $\Delta y, \Delta\phi \approx 0$
  - Potential evidence for some decorrelations

$\Xi - \pi/K$ Angular Correlations Model Comparison

$\boldsymbol{\Xi - \pi}$



$\boldsymbol{\Xi - K}$



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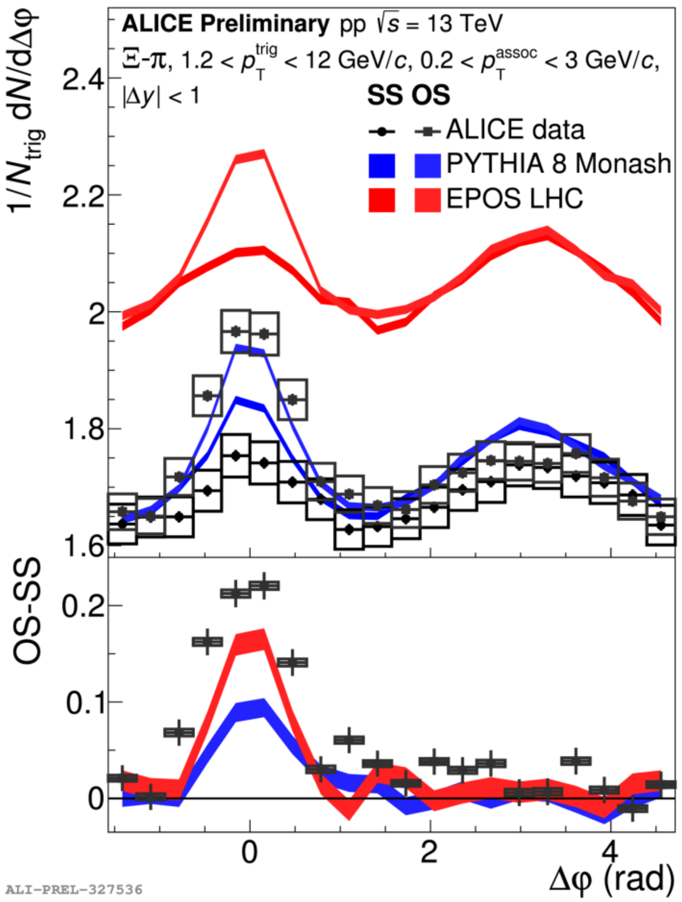
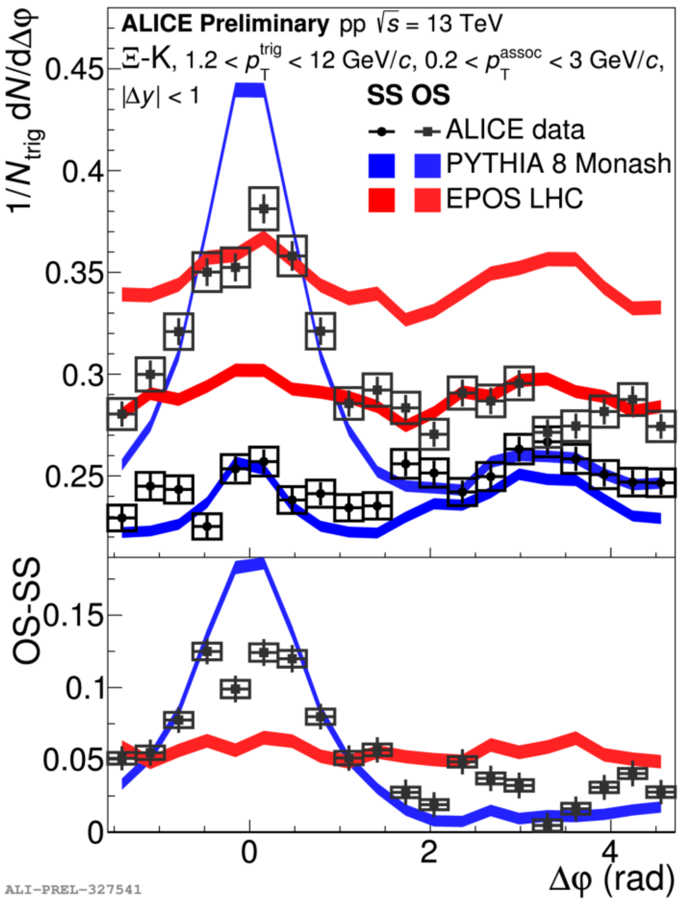


$\Xi - K$



- $\Xi - \pi$:
  - PYTHIA good at describing correlation; overestimates OS-SS imbalance.
  - EPOS overestimates correlation, but describes OS-SS imbalance fairly well.

$\Xi - \pi/K$ Angular Correlations Model Comparison

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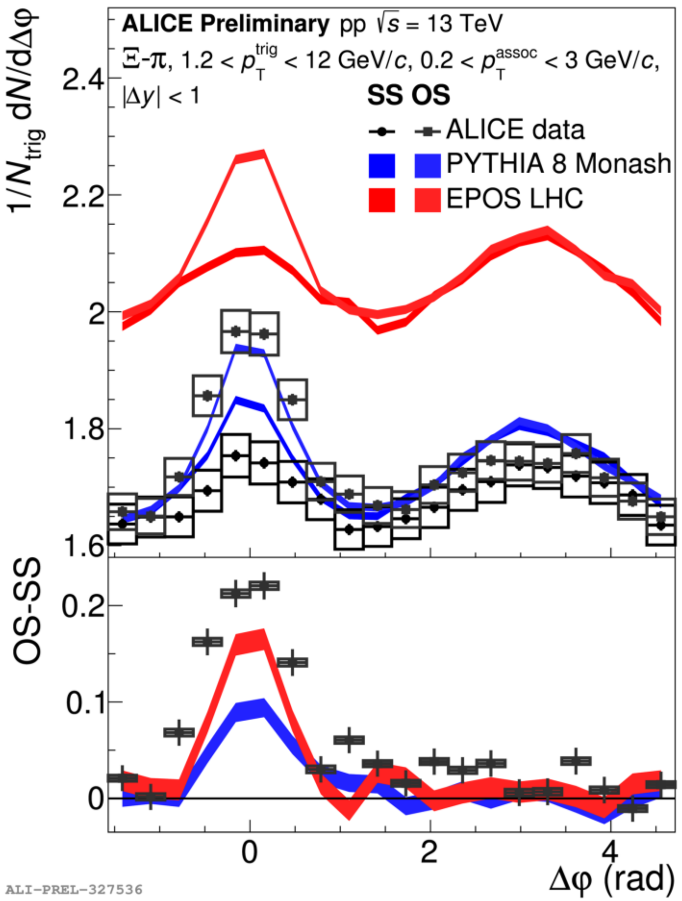
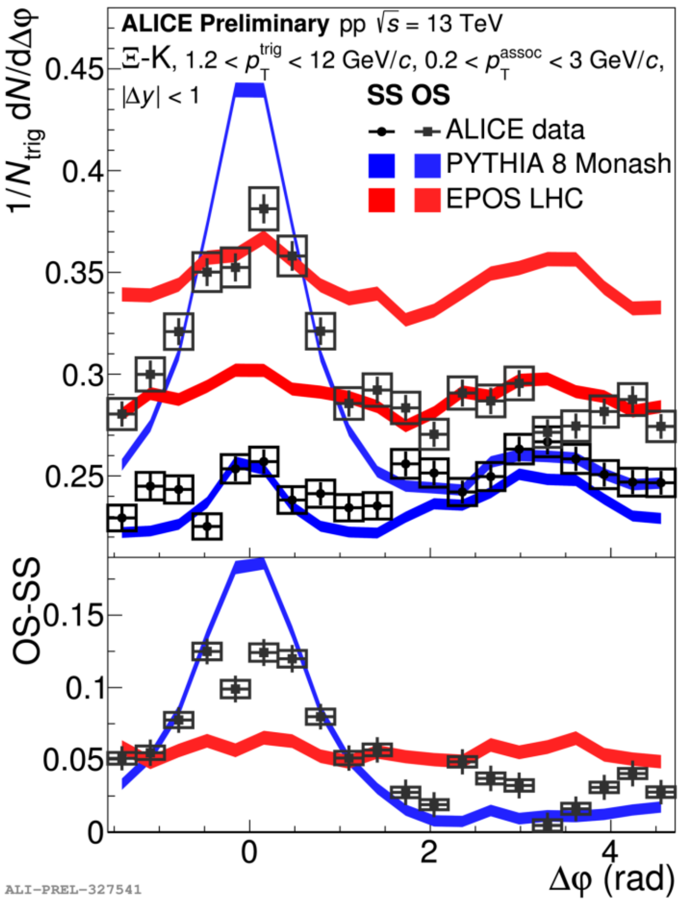


$\Xi - K$



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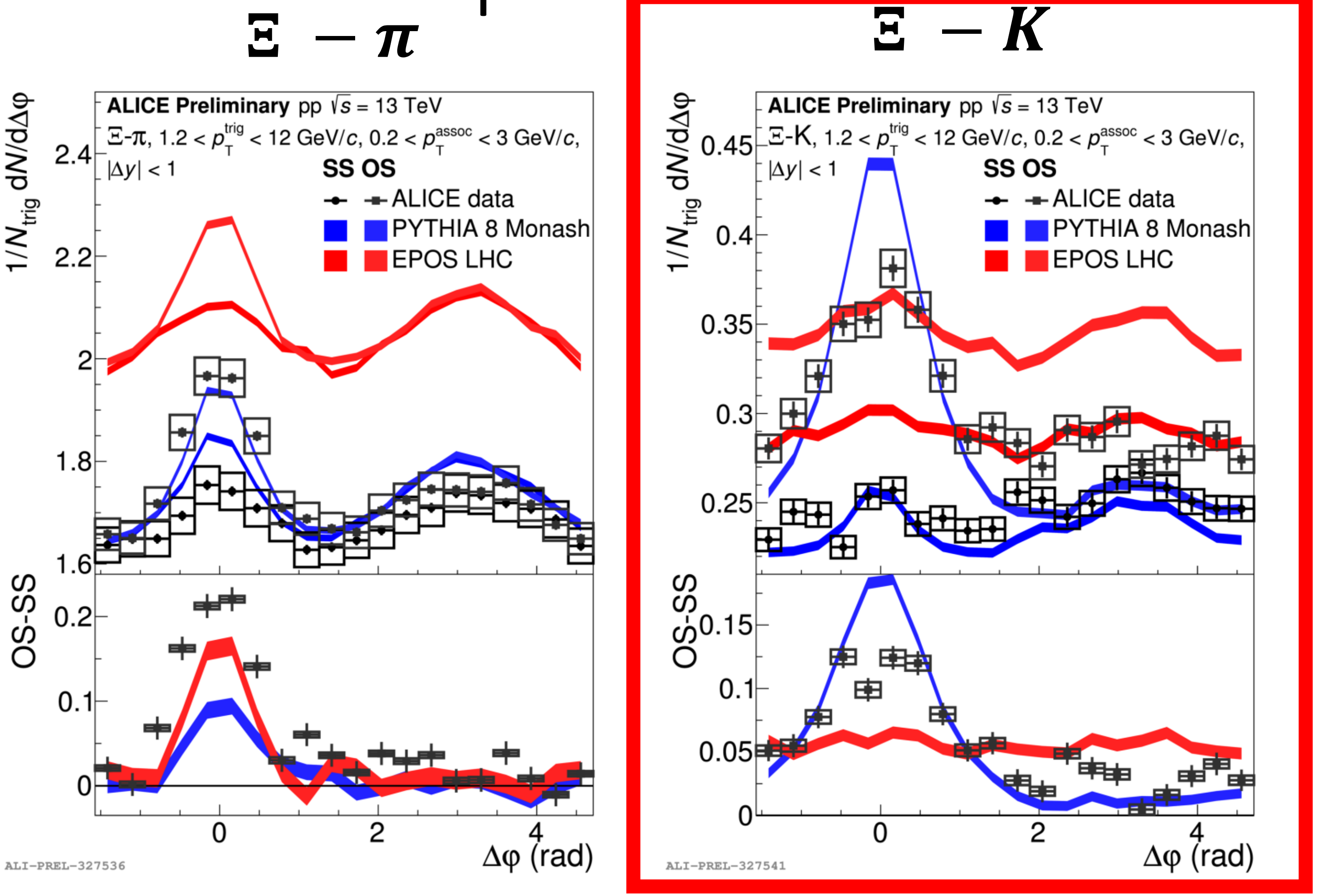
  - Almost complete decorrelation of strangeness in EPOS.

$\Xi - \pi/K$ Angular Correlations Model Comparison

2



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Ξ −h correlations has huge potential to constrain the strangeness production mechanism

Summary

- These three new ALICE measurements presented here can give insight into strangeness production in small systems, while also benchmarking recently developed tools that can hopefully be of interest in small systems.

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Thank you for your time!

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- $S_0^{p_T=1}$: Particle Production across different topologies at the same dN/dη
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BACKUP

$S_0^{p_T=1}$: Particle Production across different topologies at the same dN/dη

3

- Unw. Transverse Spherocity $S_0^{p_T=1}$ is used to separate different event topologies

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}} \right)$$

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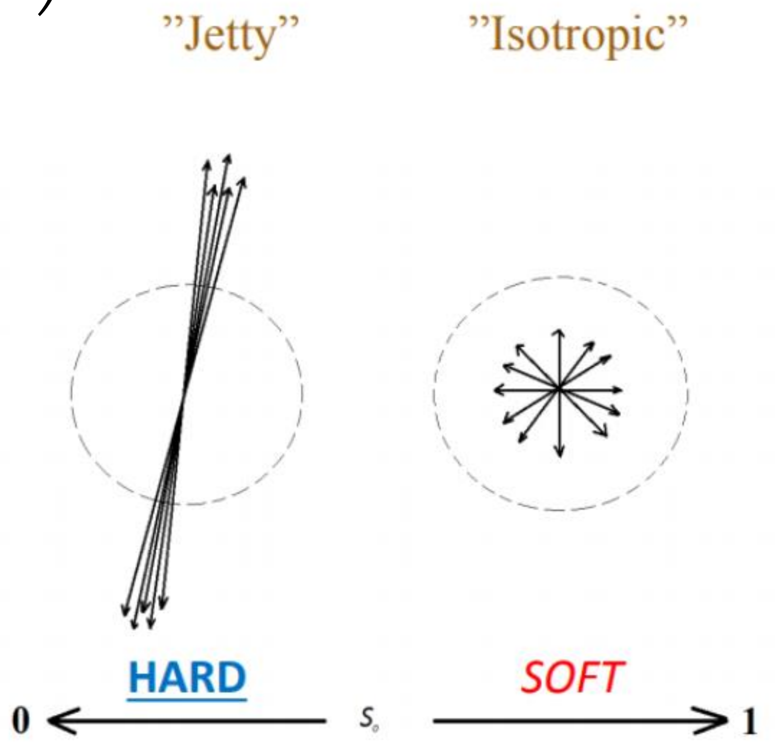

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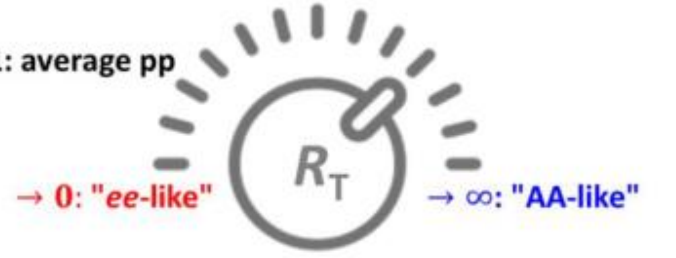
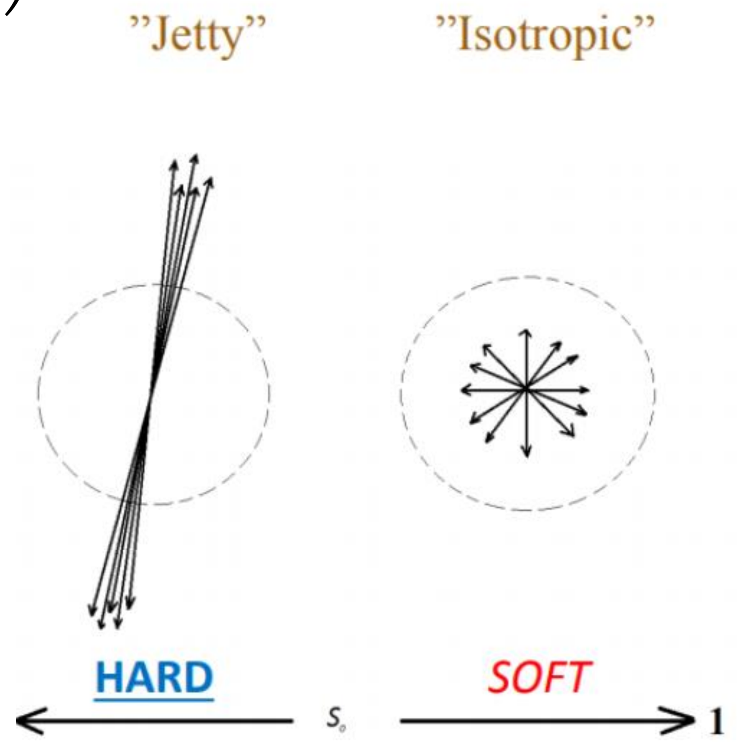




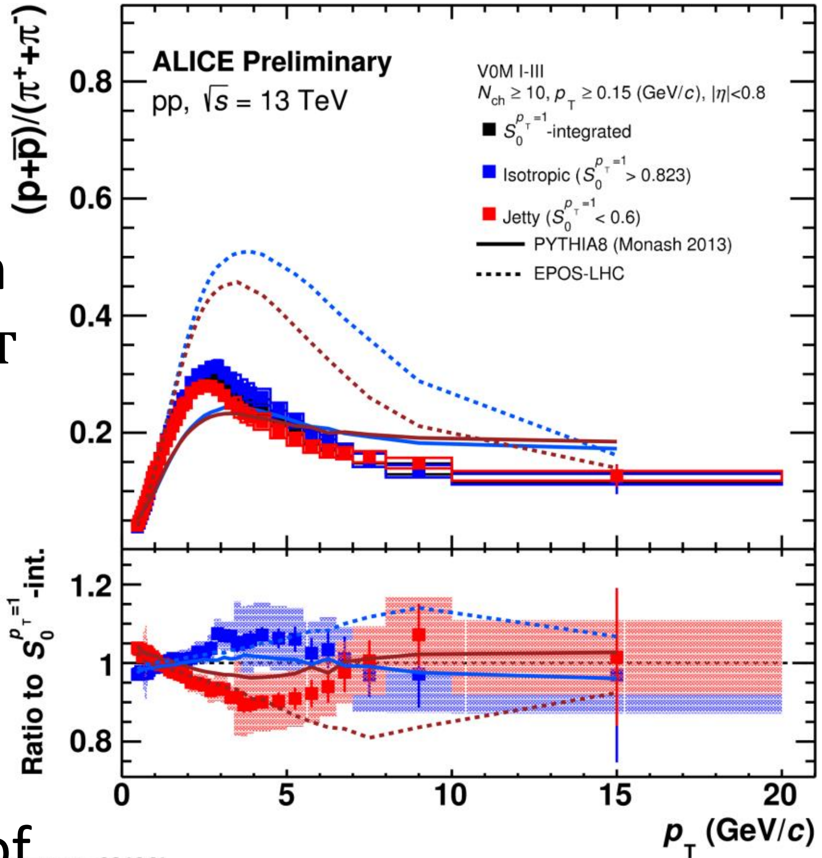
NO TRIGGER, BUT 10 NCH REQUIREMENT
+ TOP 10% MULTIPLICITY

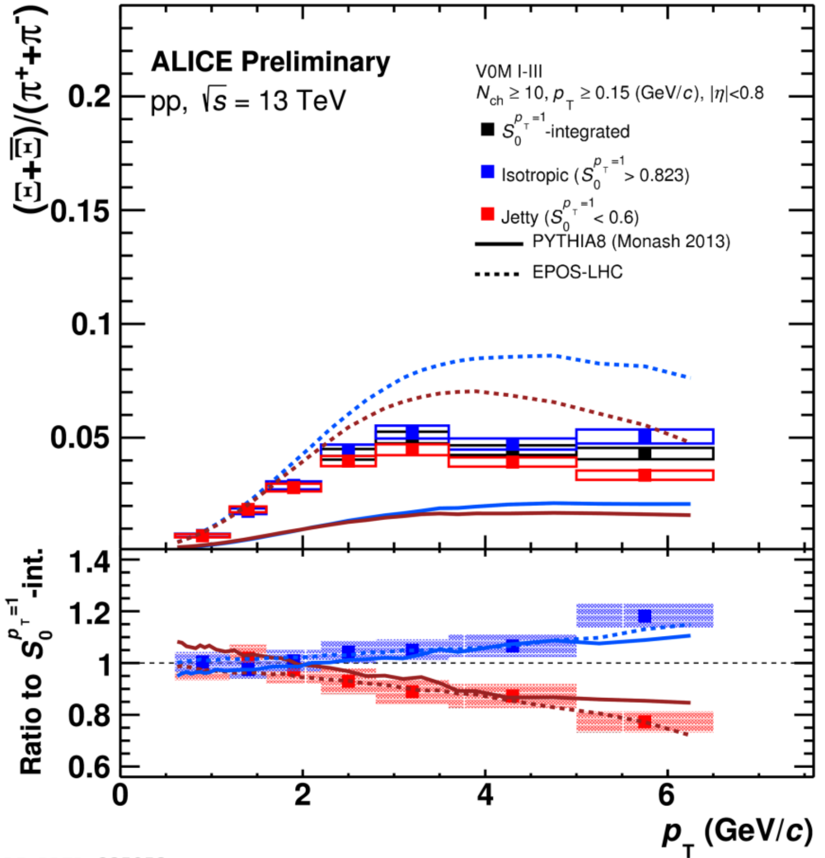
p-to-π and Ξ-to-π Ratios as Functions of $S_0^{p_\mathrm{T}=1}$

3

- p-to-π : shift of protons from low (high) p_T to high (low) p_T for isotropic (jetty) events.

  Normally associated with increase (decrease) of radial flow in large systems.





- Ξ-to-π: Increase (decrease) of Ξ production at intermediate p_T in isotropic (jetty) topologies

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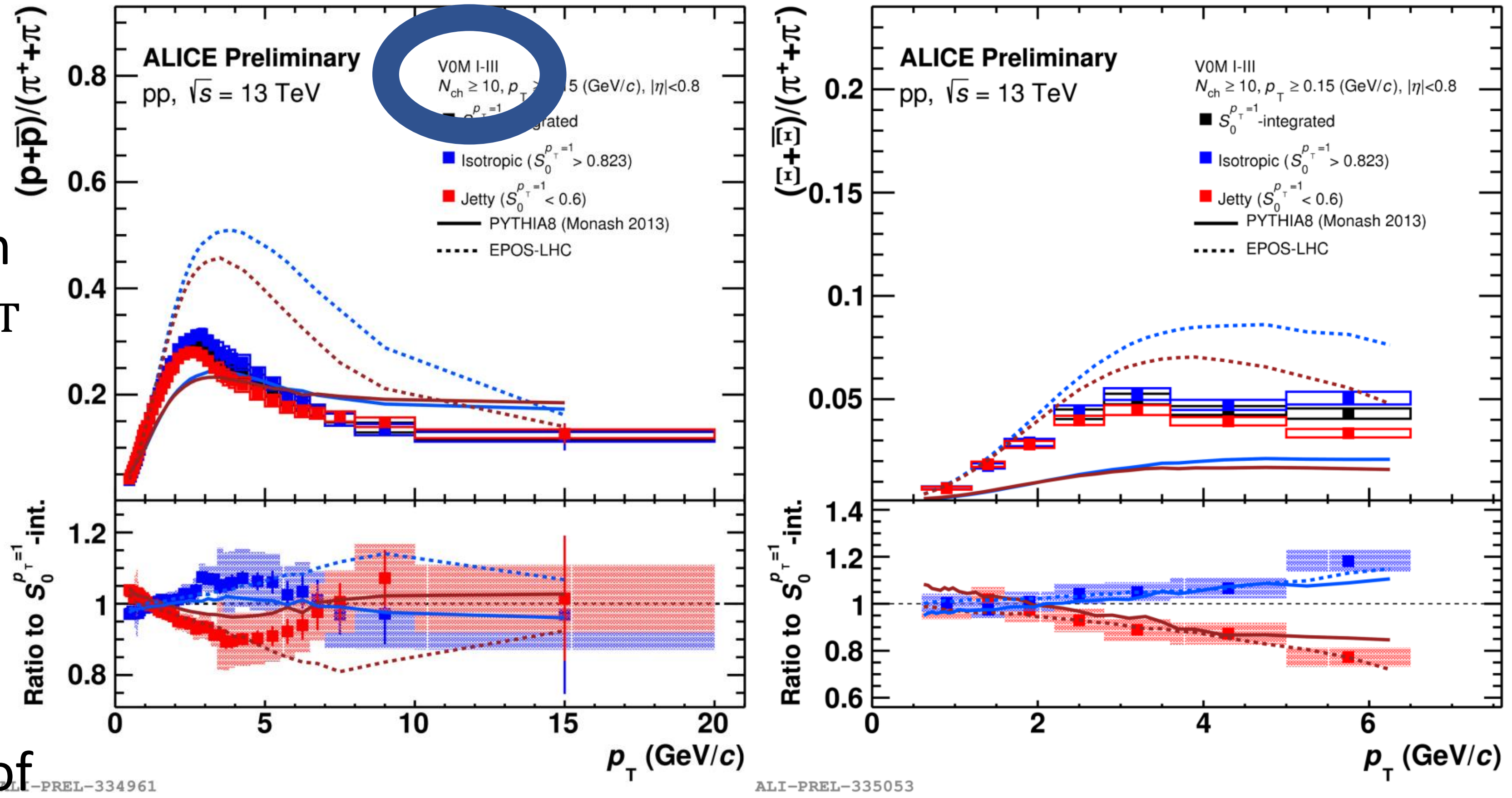
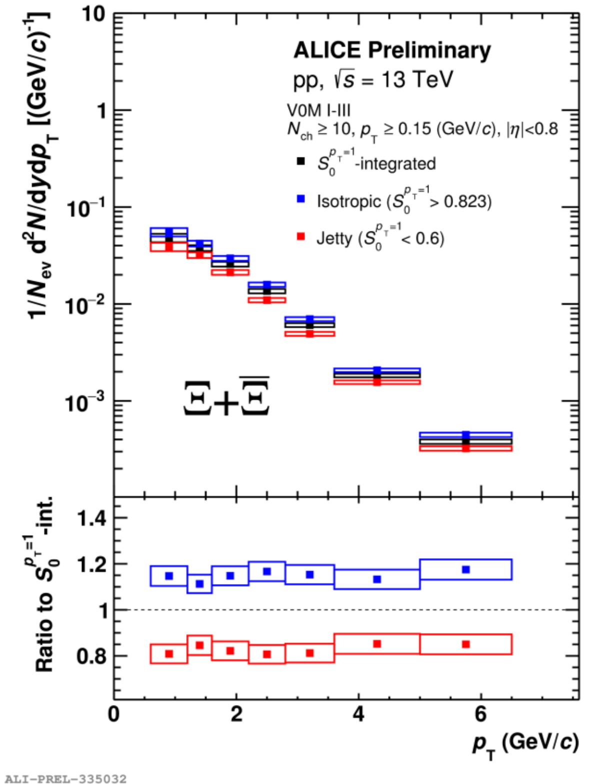
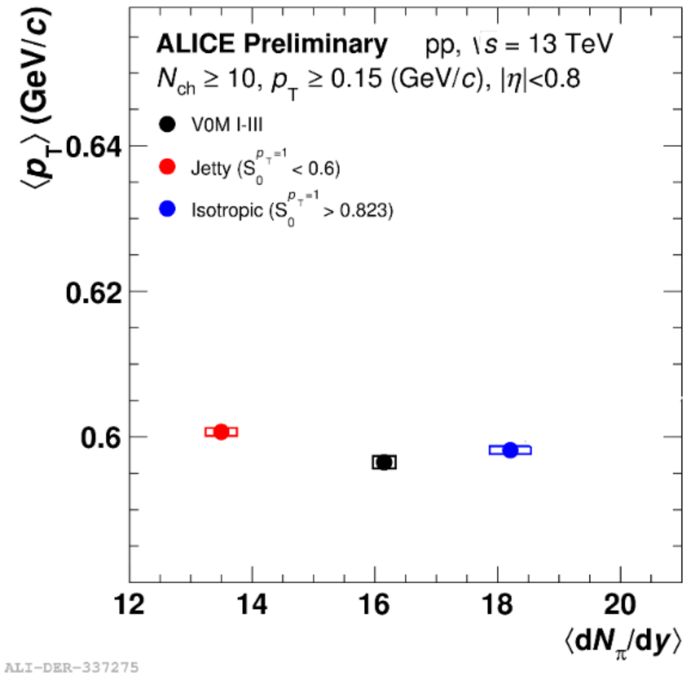


Multiplicity Triggers for $S_0^{p_T=1}$ Analysis

- V0M (V0A+V0C) is a forward multiplicity estimator $(2.8 < \eta < 5.1) + (-3.7 < \eta < -1.7)$
  - V0M triggered S_0 events differ in multiplicity, but have similar <pT>.

Forward Estimator





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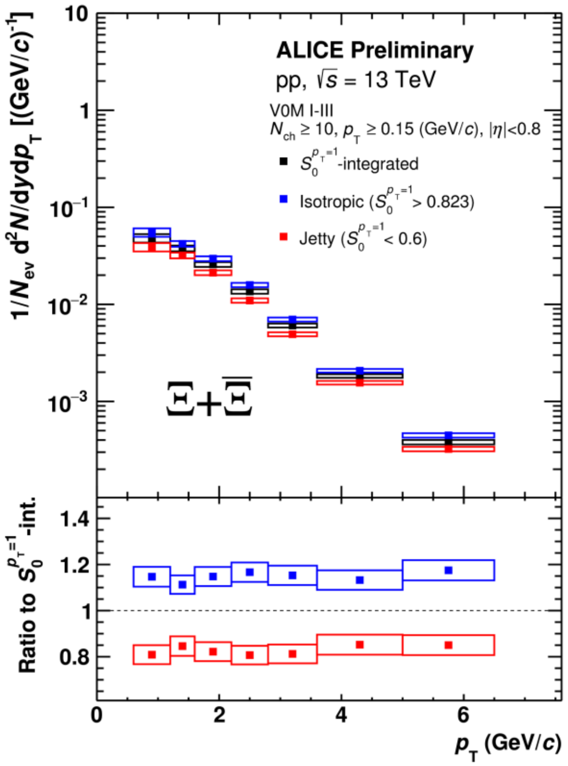
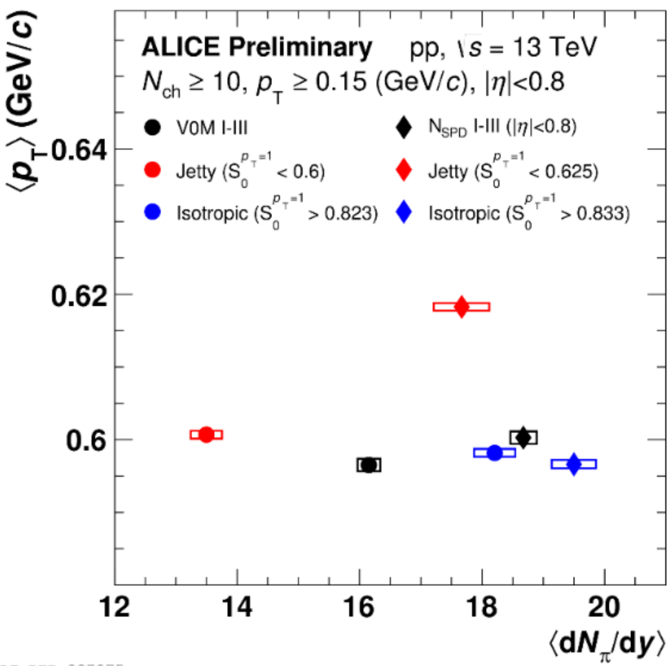
  - V0M triggered S_0 events differ in multiplicity, but have similar <pT>.
- CL1 is a mid-rapidity multiplicity estimator ($|\eta| <0.8$)
  - CL1 triggered S_0 events have a much smaller multiplicity difference, disentangle events based on hardness.

Forward Estimator

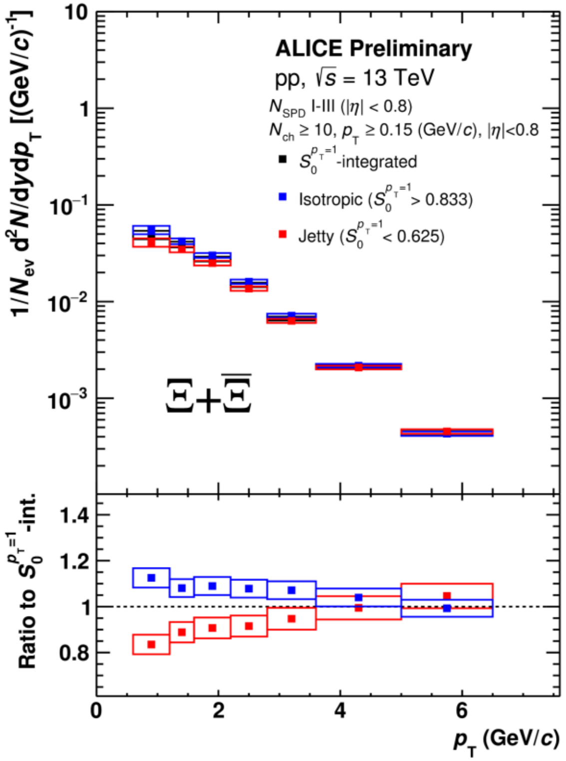


ALI-PREL-335032



ALI-DER-337275

Mid-Rapidity Estimator

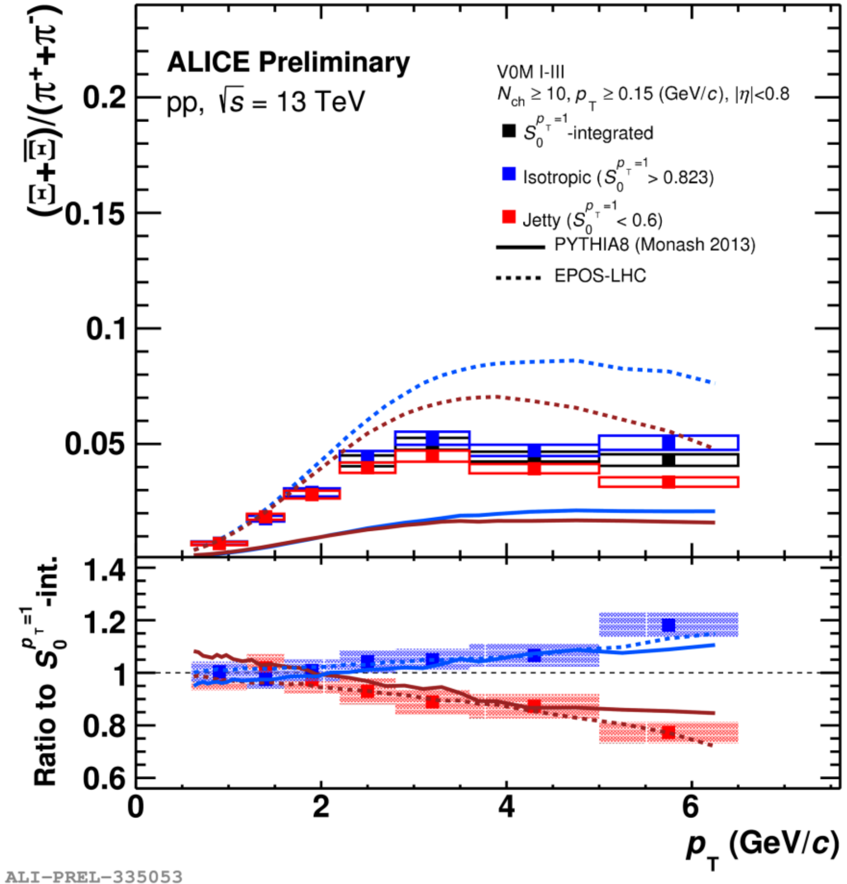


ALI-PREL-335104

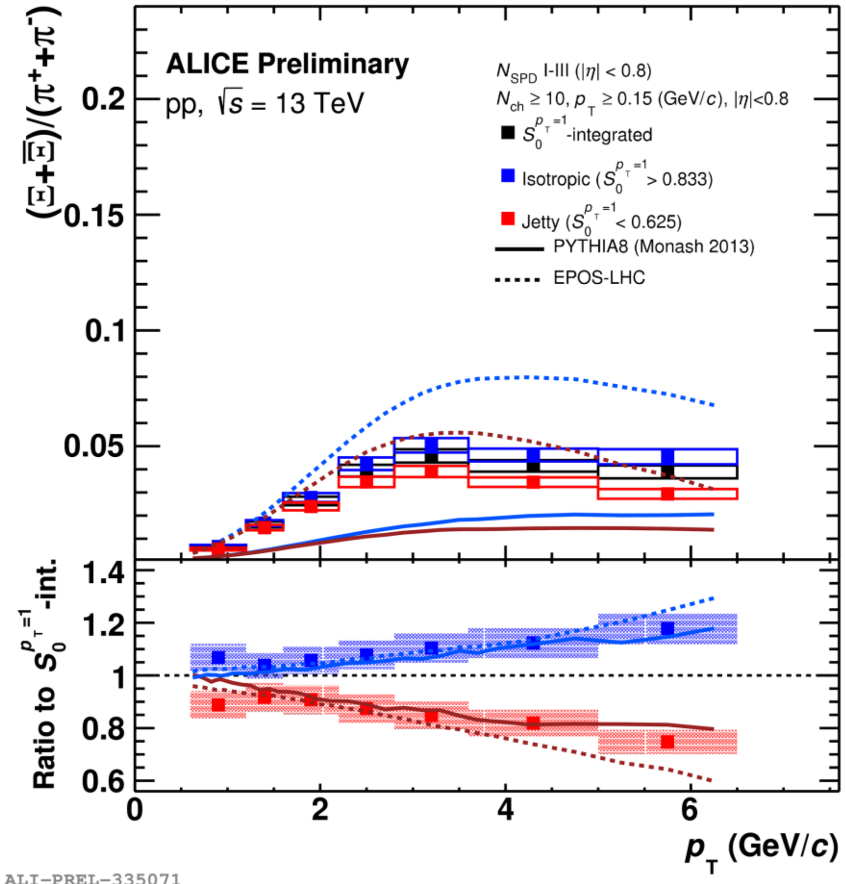
Ξ-to-π Ratios as Functions of $S_0^{p_T=1}$ for Different Multiplicity Estimators

3

(2.8< η <5.1)
(−3.7< η <−1.7)



(|η| <0.8)



Mid-Rapidity results suggest that one can enhance or suppress the strangeness enhancement by selecting on S_0.

Ξ-to-π Ratios as Functions of $S_0^{p_T=1}$ for Different Multiplicity Estimators

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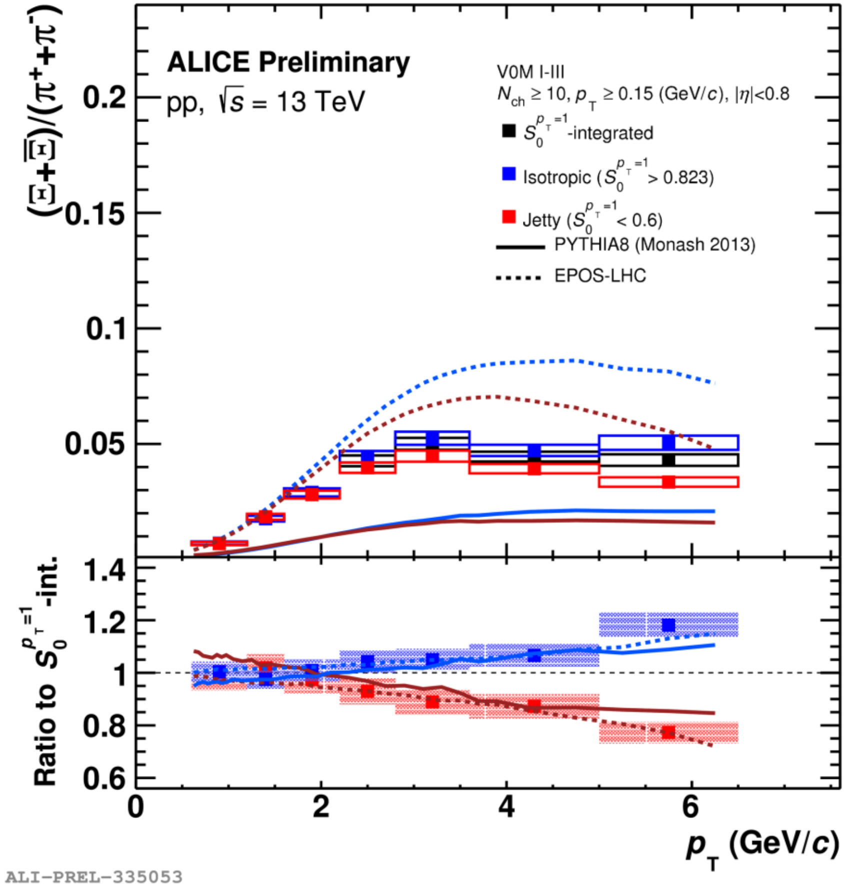

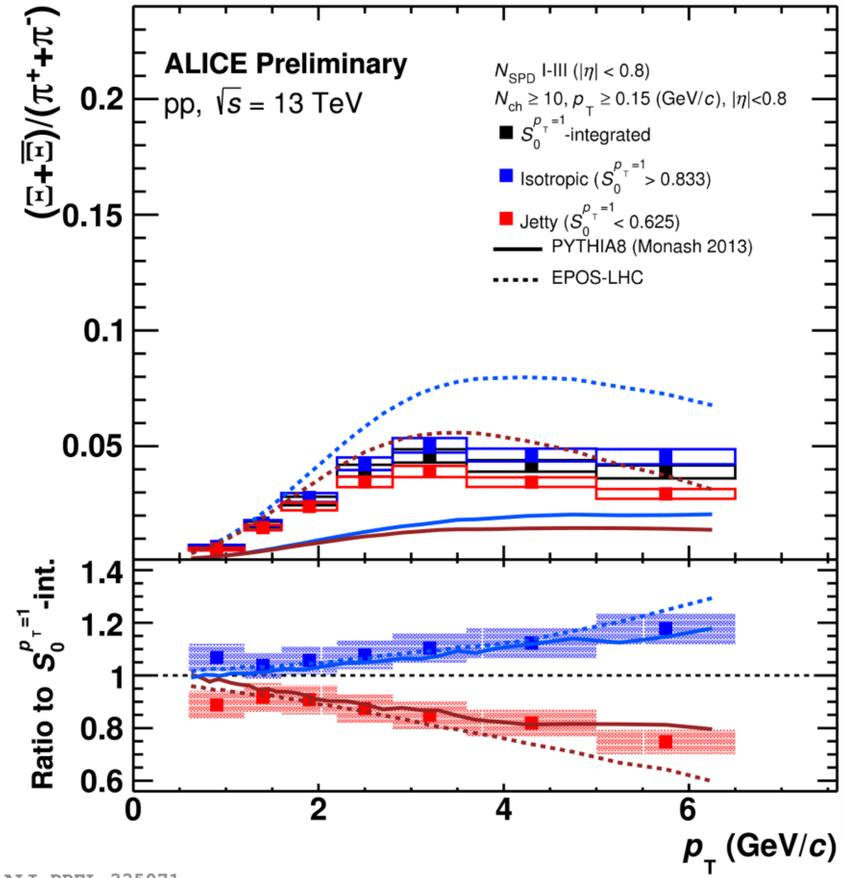

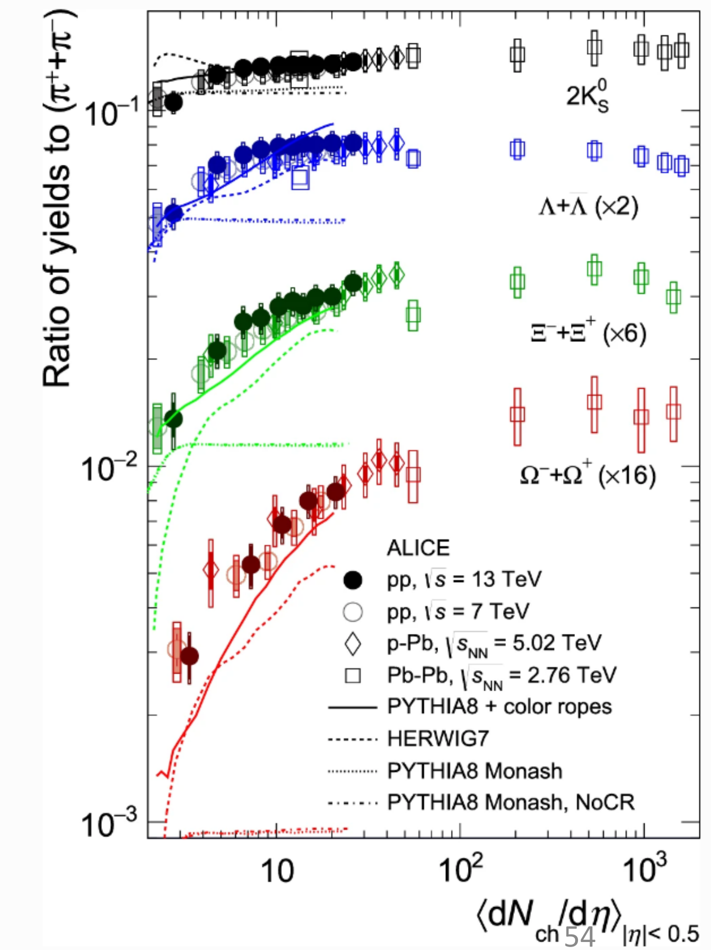

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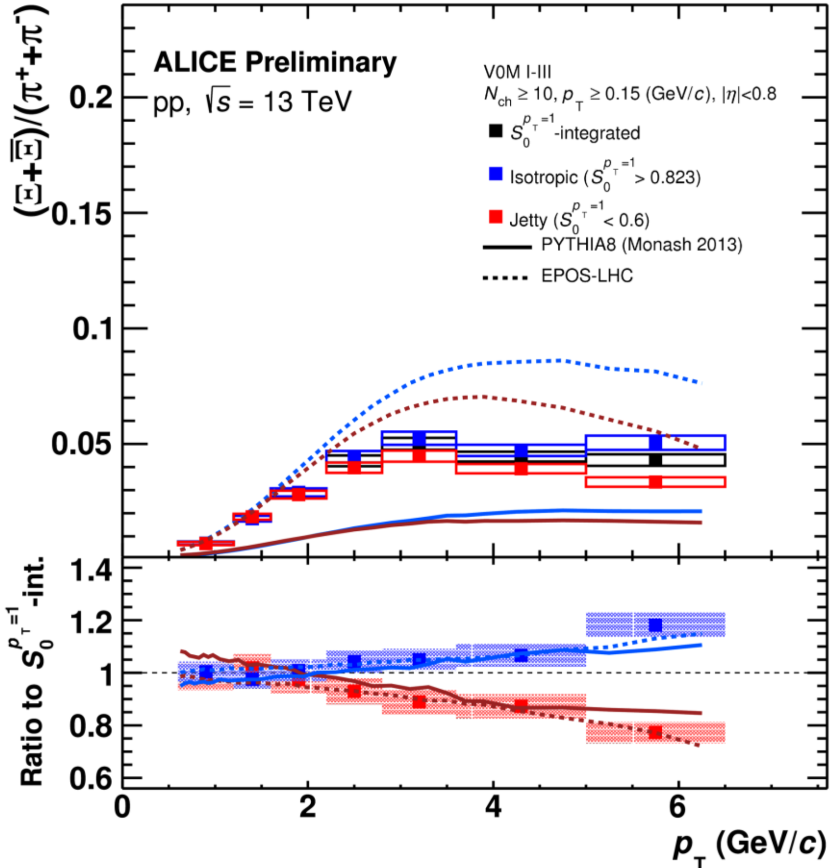
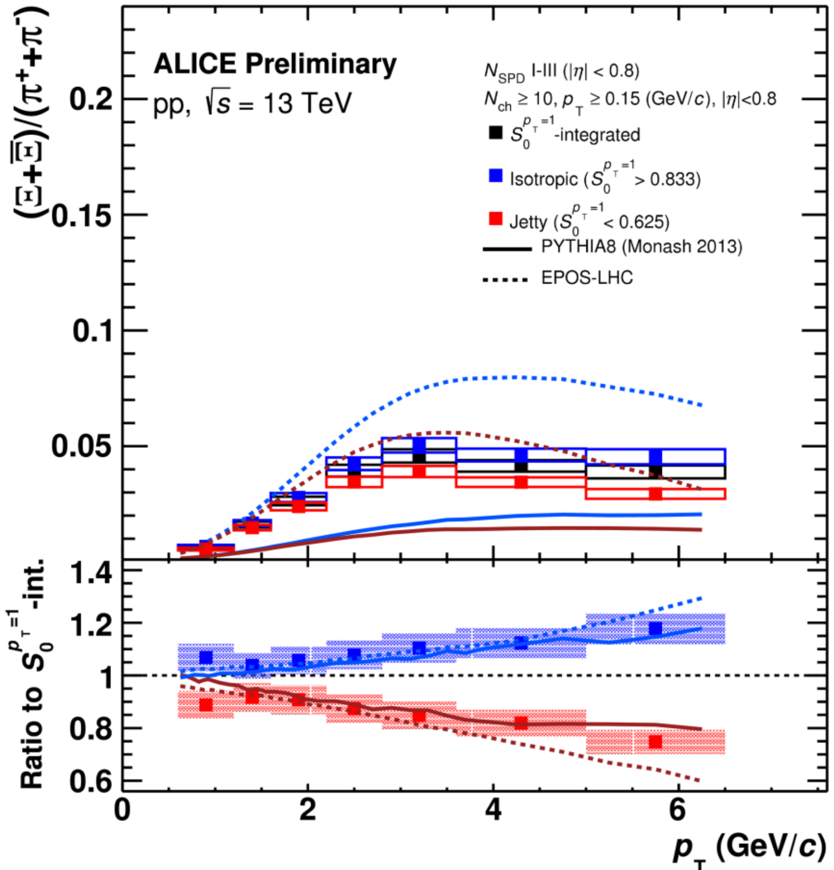


ALI-PREL-335053



ALI-PREL-335071

Mid-Rapidity results suggest that one can enhance or suppress the strangeness enhancement by selecting on S_0.

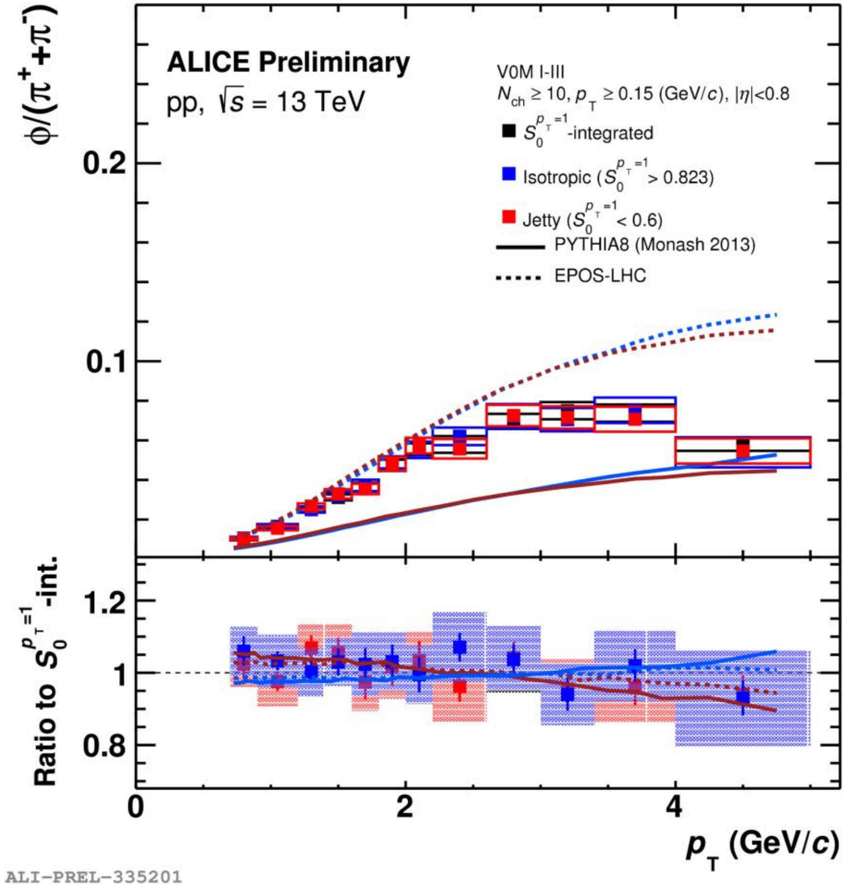
The generators do not describe the p_{T} evolution.

Generators describe the double-ratio quite well, except for some tension at low p_T.

ϕ-to-π Ratios as Functions of $S_0^{p_T=1}$ for Different Multiplicity Estimators

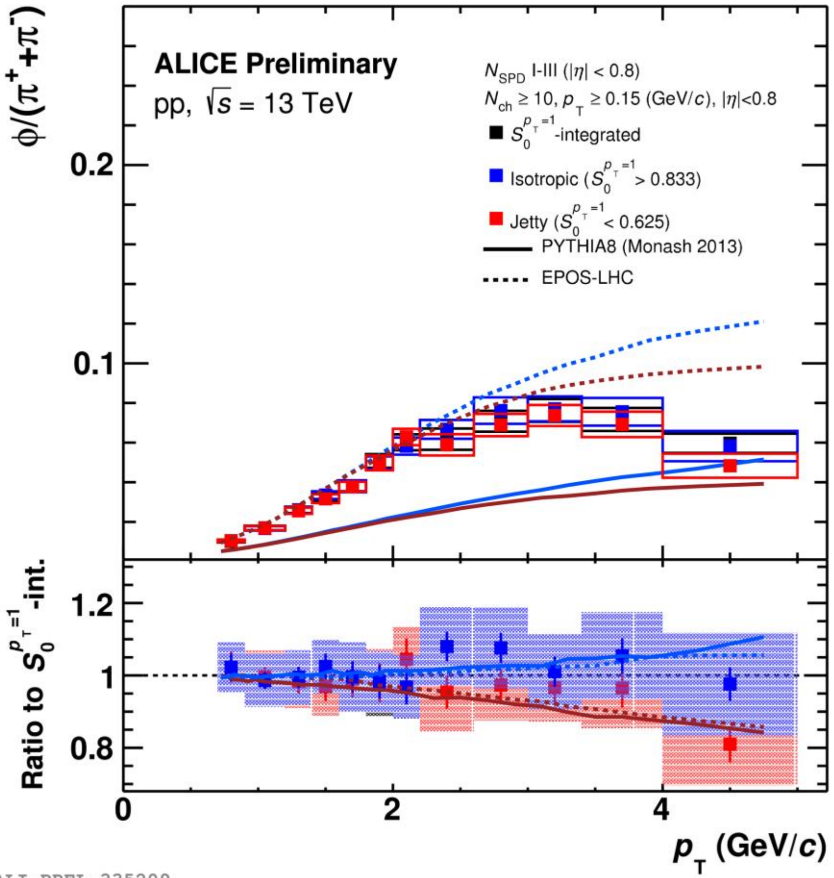
3

(2.8< η <5.1)
(−3.7< η <−1.7)



ALI-PREL-335201

(|η| <0.8)



ALI-PREL-335209

Unlike the p/Ξ, the ϕ does not give a clear picture.

There seems to be no significant difference of ϕproduction in Jetty or Isotropic events.

There is also no difference between V0M and CL1 triggered events.

S_0 : Particle Production across different topologies at the same dN/dη

- Transverse Spherocity S_0 is used to separate different event topologies

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2$$

- $S_0 \rightarrow 0$ Describes events with jet-like topologies
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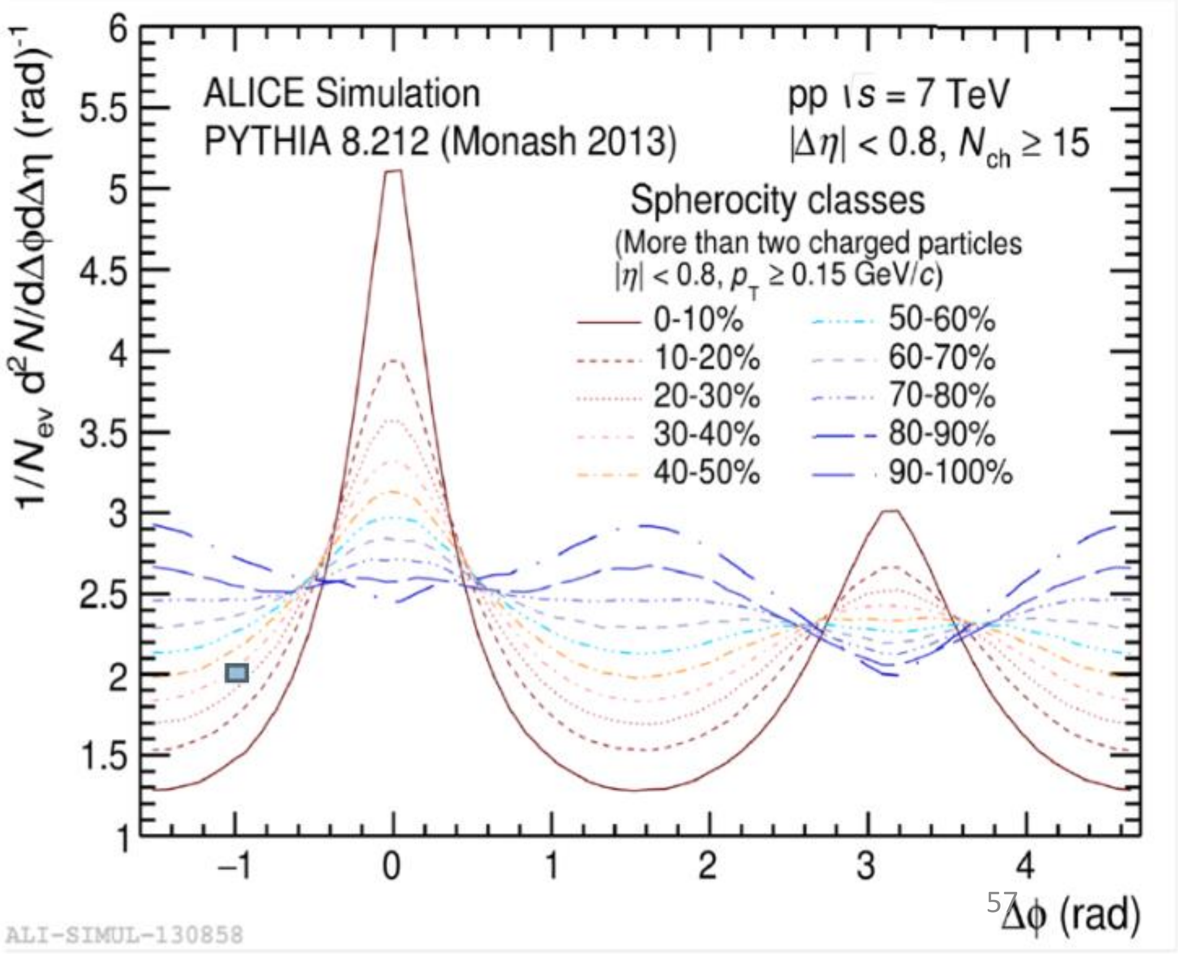
NO TRIGGER, BUT 10 NCH REQUIREMENT



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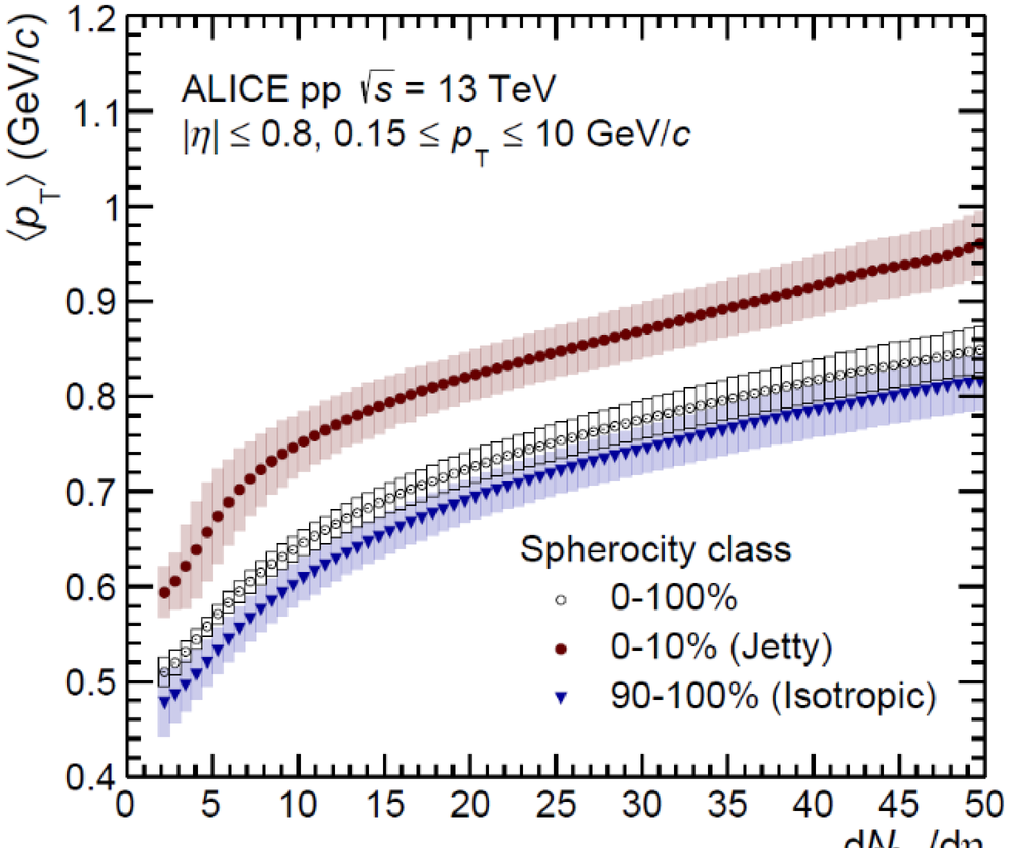
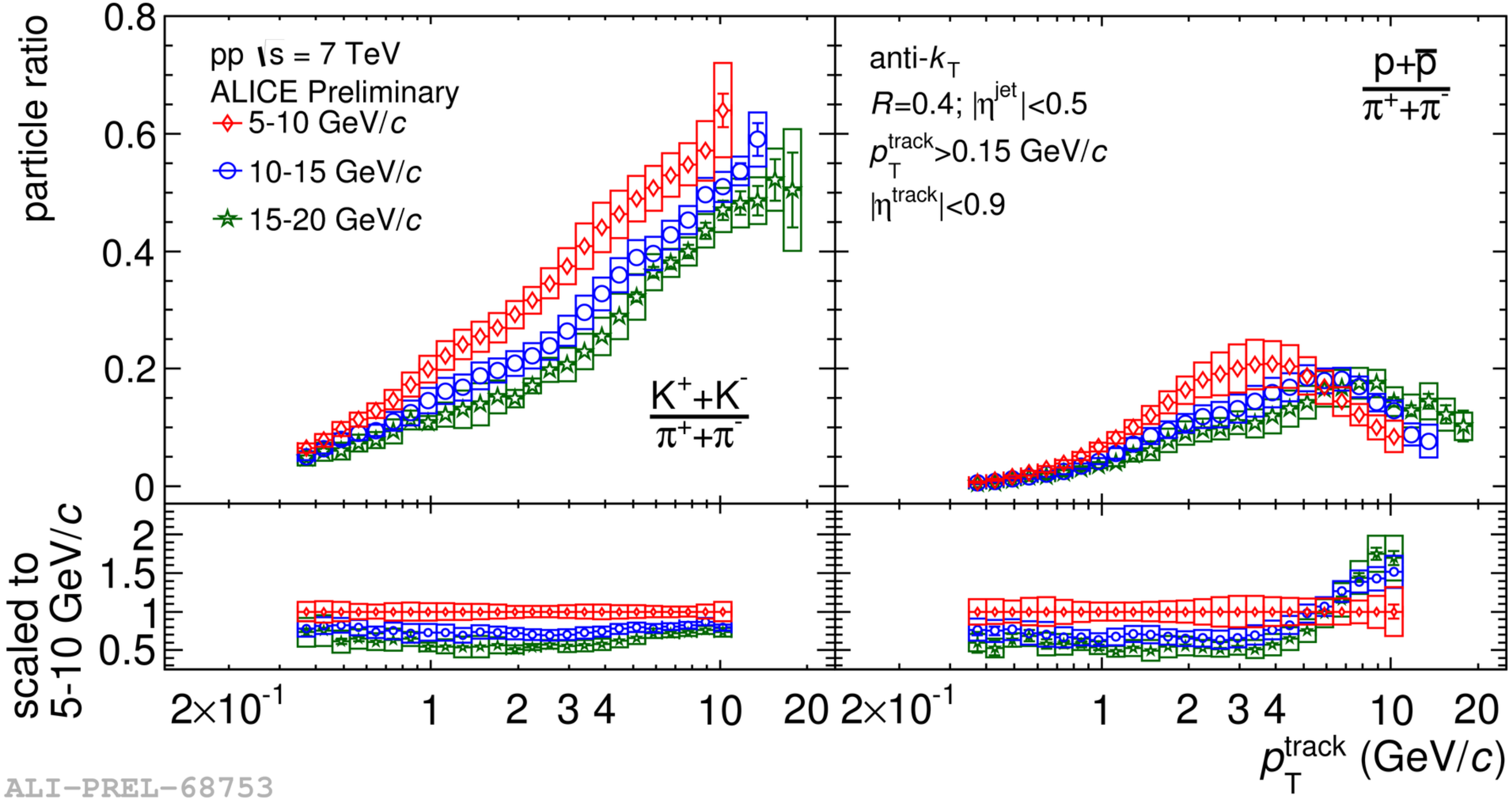


arXiv:1905.07208

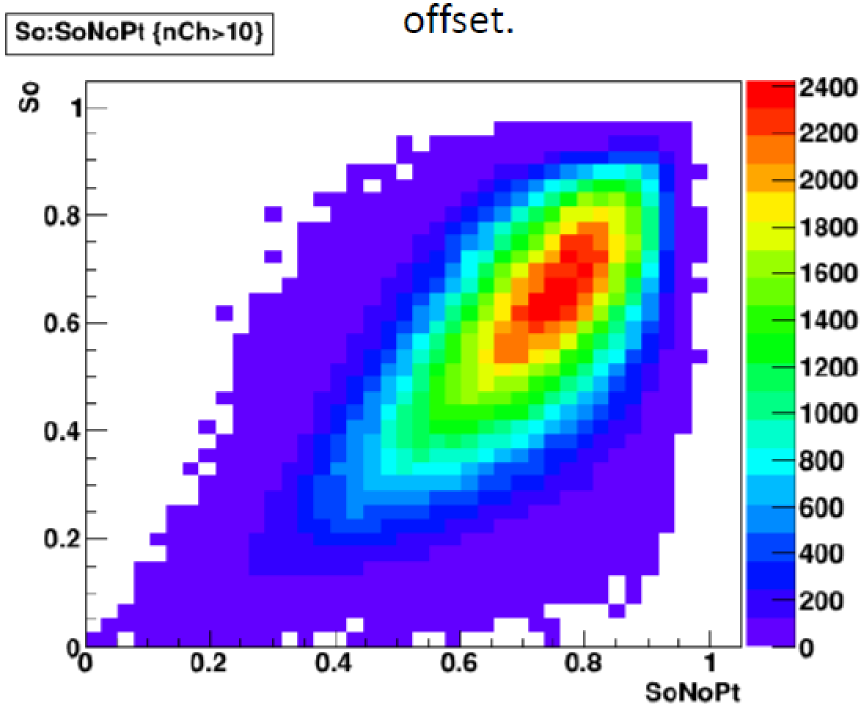
NO TRIGGER, BUT 10 NCH REQUIREMENT

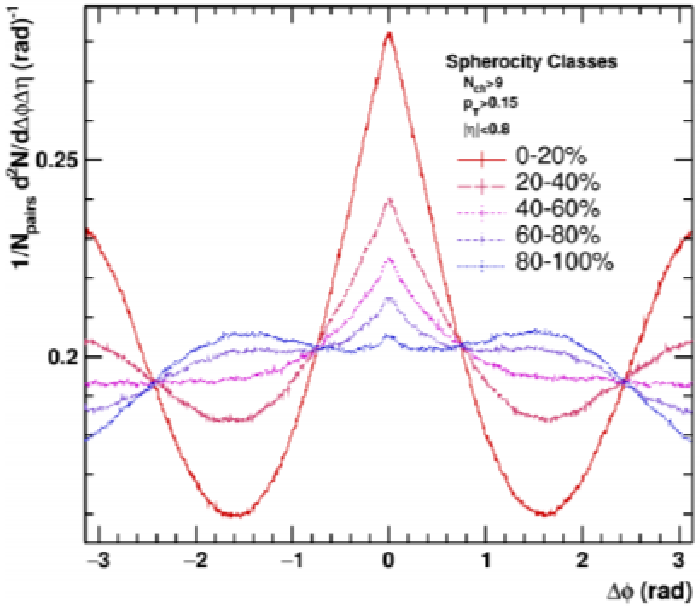
Jet Pt Evolution

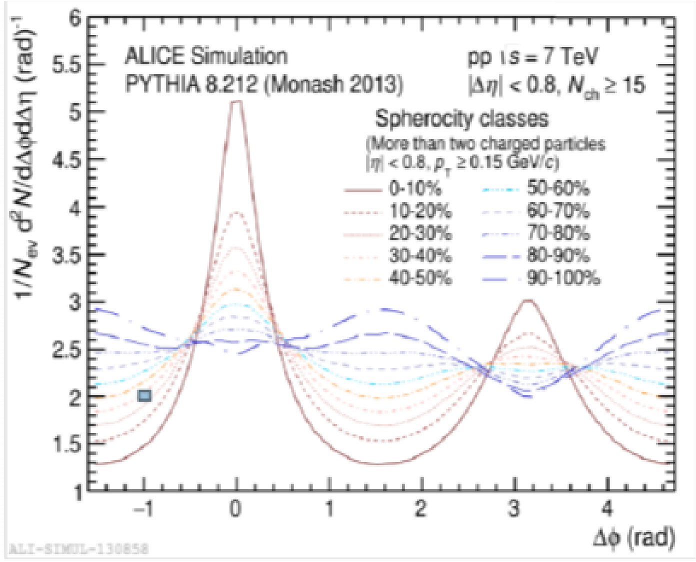


$S_O^{p_T=1}$ MC Studies - $S_O^{p_T=1}$ vs S_O

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







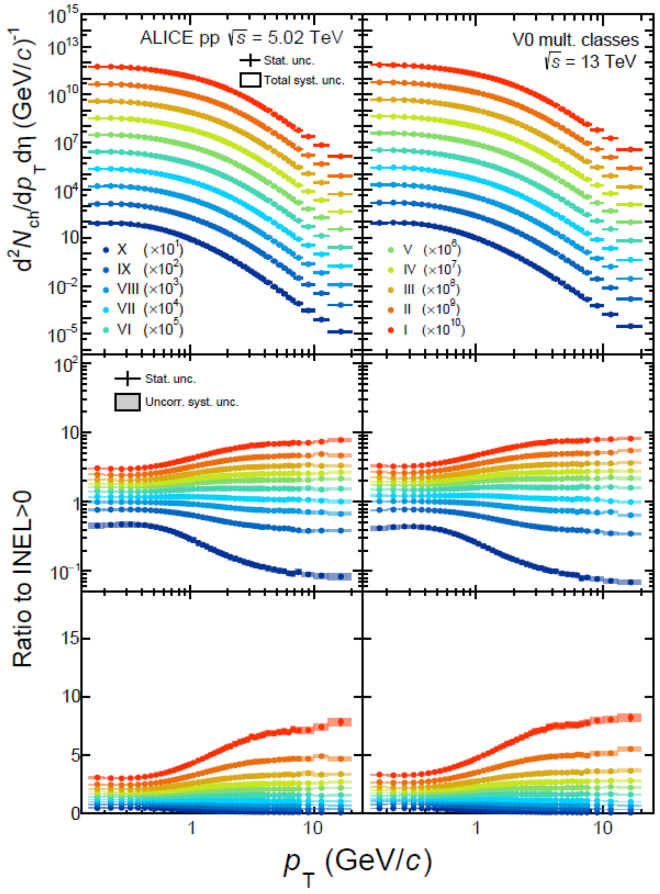
Identified Vs Unidentified Hadrons

- There is a non-trivial difference in the S_O measurement for Identified and Unidentified hadrons

arXiv:1905.07208

N_{ch}

Events require at least 10 (3) charged primary tracks.



$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2$$

- Primary Unidentified hadrons enter both the yield extraction and S_O

Identified Vs Unidentified Hadrons

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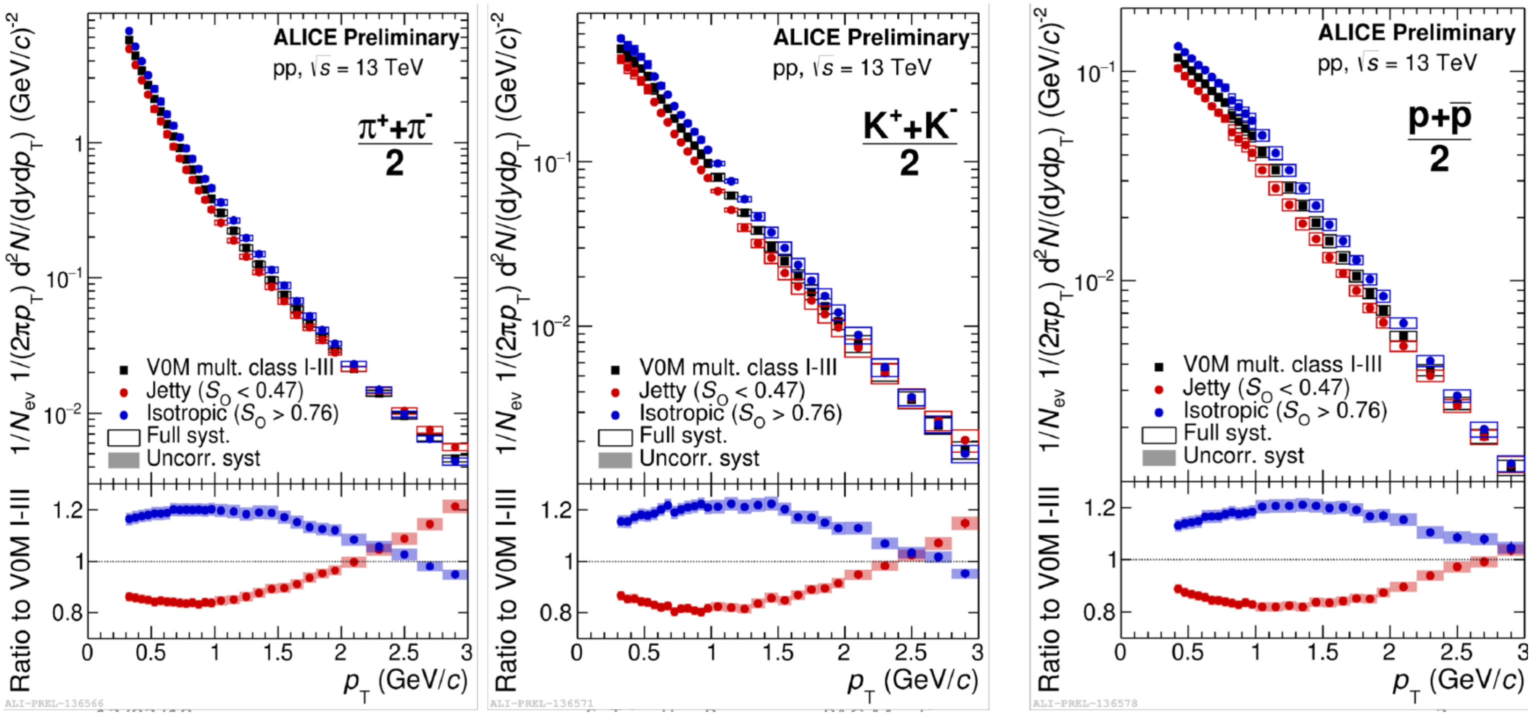
$$\pi/K/\mathrm{p}/N_{\mathrm{ch}}$$

$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2$$

- Primary Unidentified hadrons enter both the yield extraction and S_O
- This also applies to $\pi/K/P$



Identified Vs Unidentified Hadrons

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Ξ

$\pi/K/\mathrm{p}/N_{\mathrm{ch}}$

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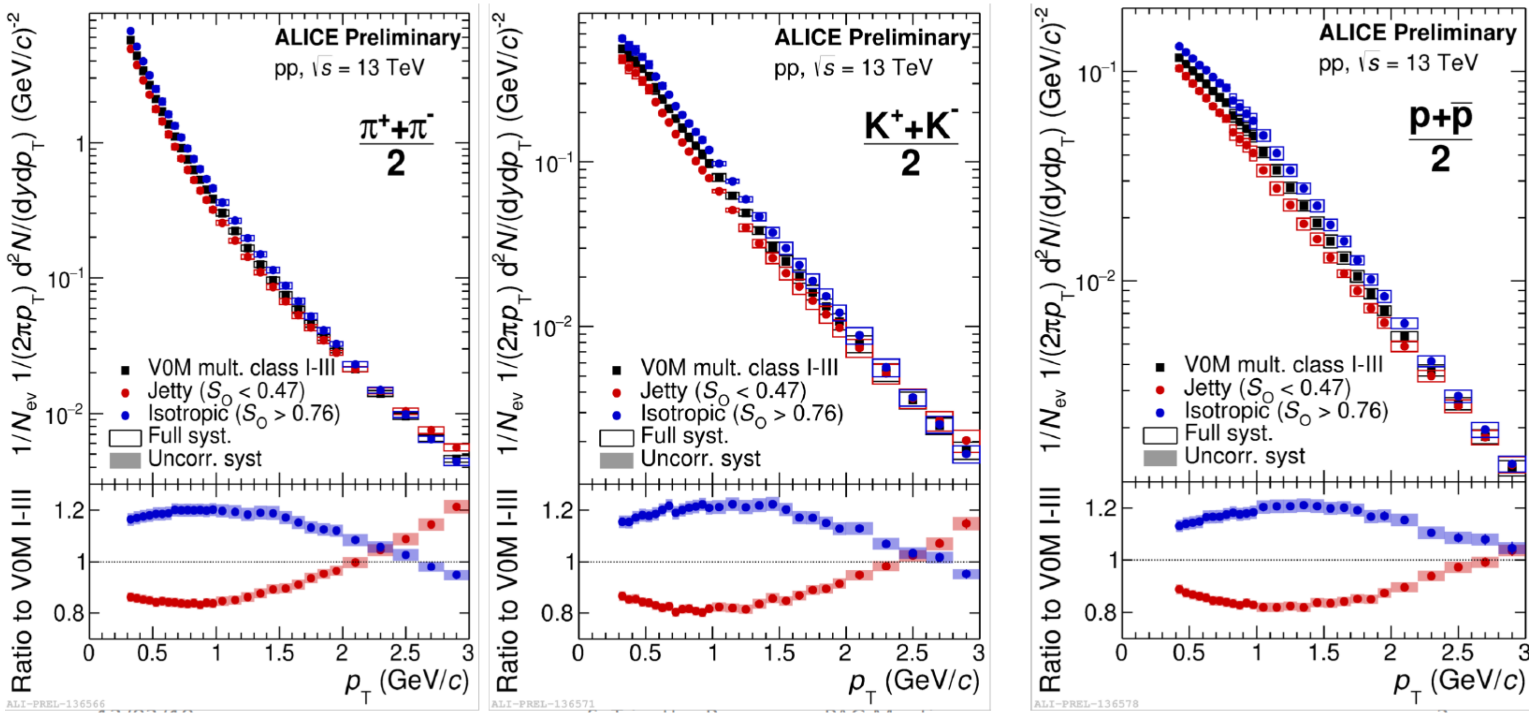
- Primary Unidentified hadrons enter both the yield extraction and S_O
- This also applies to $\pi/K/P$
- **<u>But this does NOT apply to Ξ!</u>**



Identified Vs Unidentified Hadrons

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ϕ Ξ $\pi/K/\mathrm{p}/N_{\mathrm{ch}}$

$\times$

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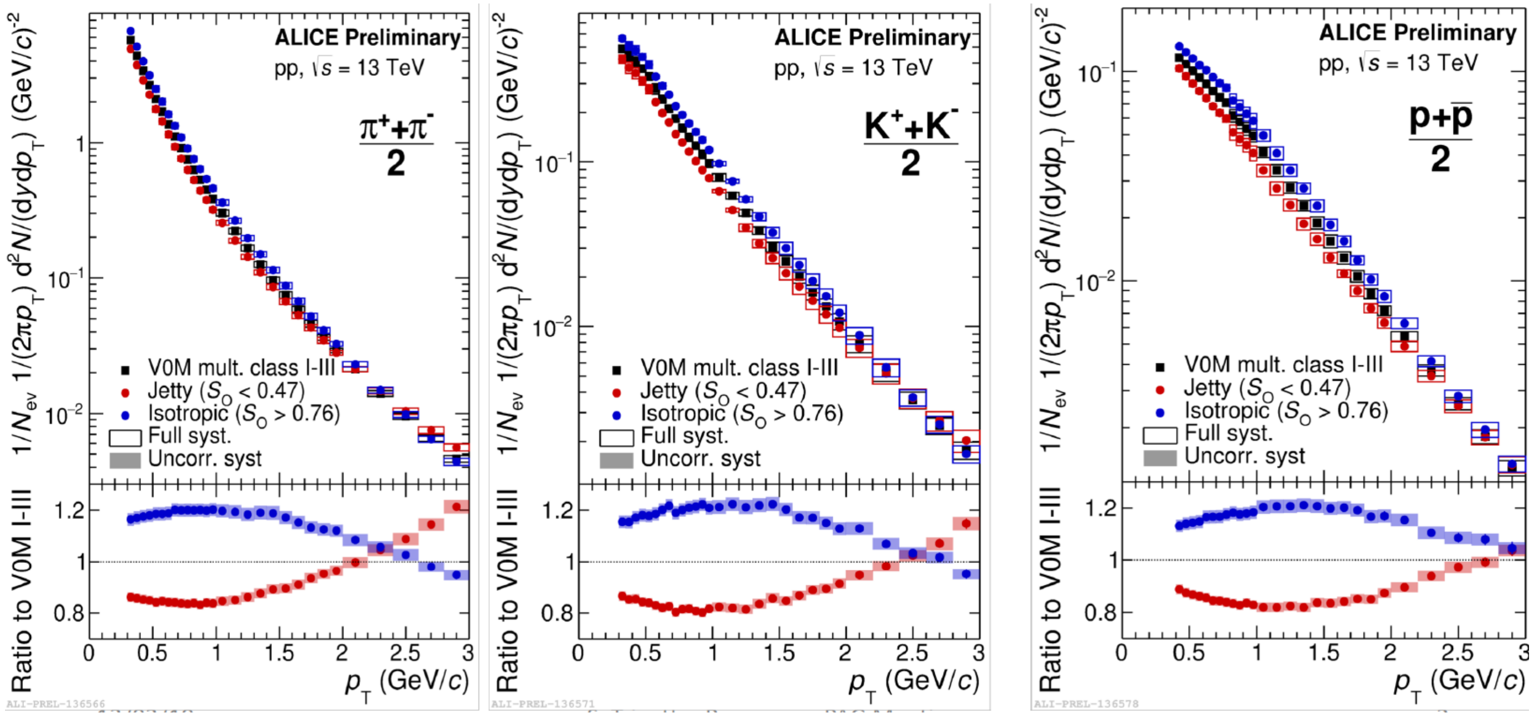
- Primary Unidentified hadrons enter both the yield extraction and S_O
- This also applies to $\pi/K/P$
- **But this does NOT apply to Ξ!**
- ϕ enters twice! $(K^+ K^-)$



Unweighed Transverse Spherocity $S_O^{p_T=1}$

- $S_O^{p_T=1}$ is measured as S_O, but only considers the angular component.

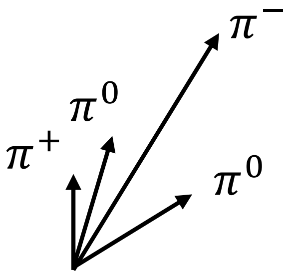
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

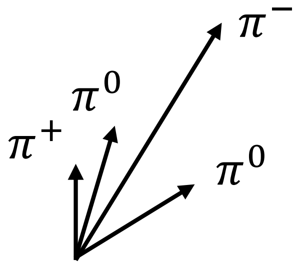
Unweighed Transverse Spherocity $S_O^{p_T=1}$

- $S_O^{p_T=1}$ is measured as S_O, but only considers the angular component.

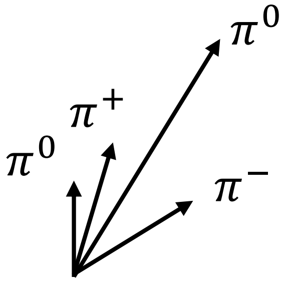
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

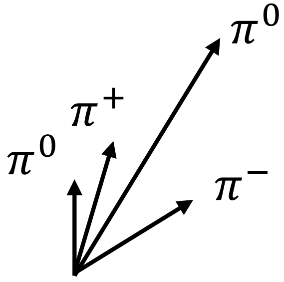
$S_{O,1}$





$S_{O,1}^{p_T=1}$





$S_{O,2}$

$S_{O,2}^{p_T=1}$

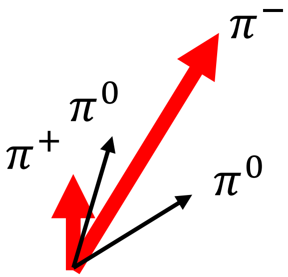
Unweighed Transverse Spherocity $S_O^{p_T=1}$

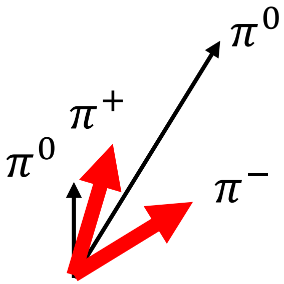
- $S_O^{p_T=1}$ is measured as S_O, but only considers the angular component.

$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

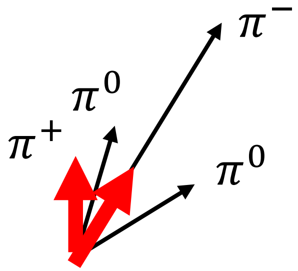
$S_{O,1}$ and $S_{O,2}$ will describe two completely different topologies!

$S_{O,1}$



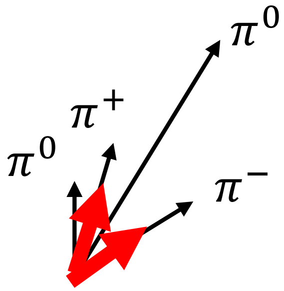


$S_{O,2}$



$S_{O,1}^{p_T=1}$

$S_{O,1}^{p_T=1}$ and $S_{O,2}^{p_T=1}$ will describe two similar topologies.

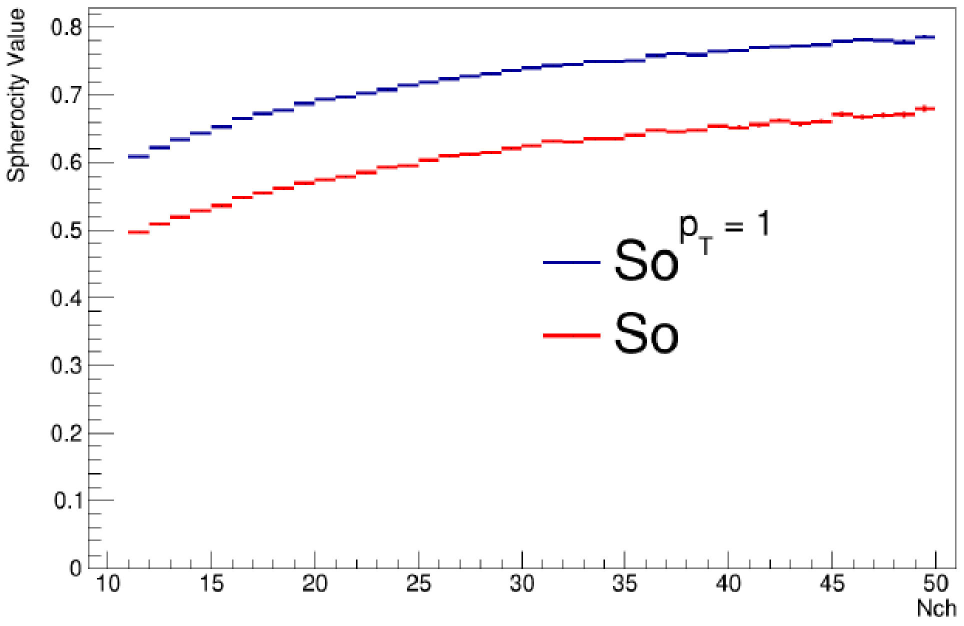


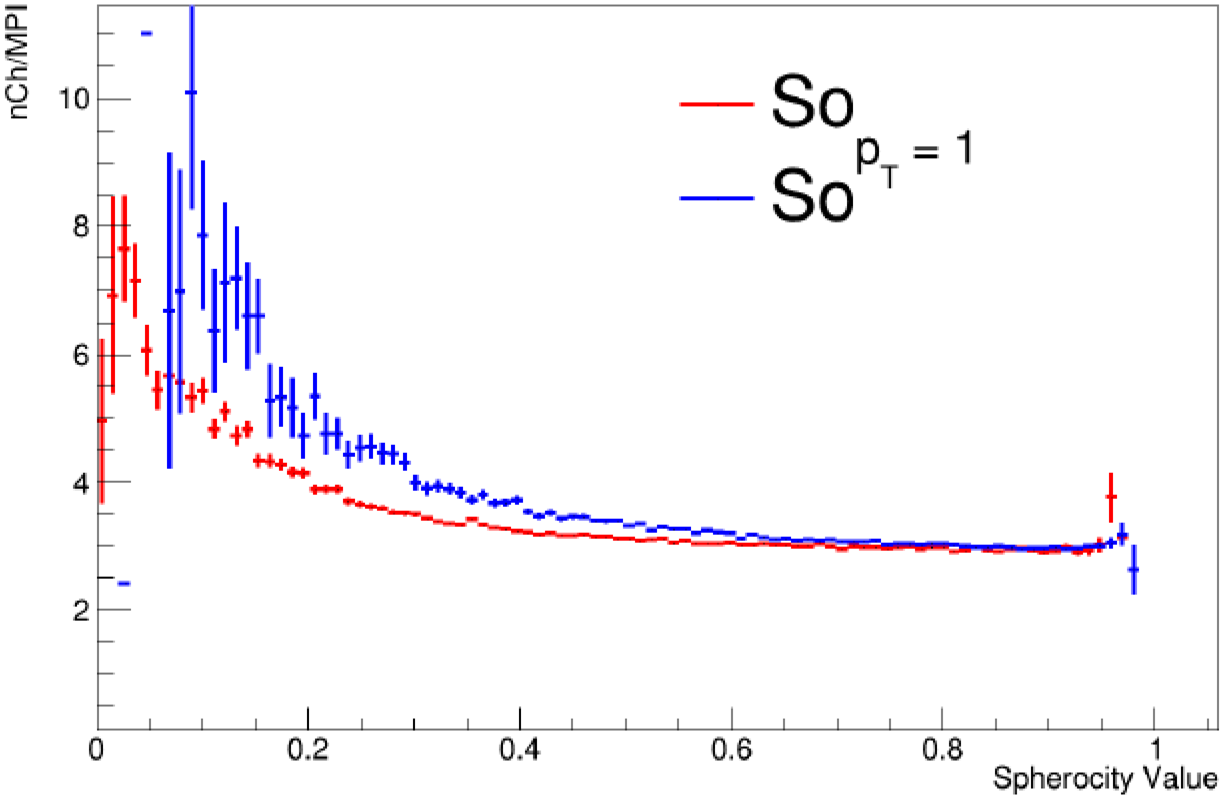
$S_{O,2}^{p_T=1}$

$S_O^{p_T=1}$ MC Studies - $S_O^{p_T=1}$ vs S_O

Qualtitatively similar
Nch/MPI distributions

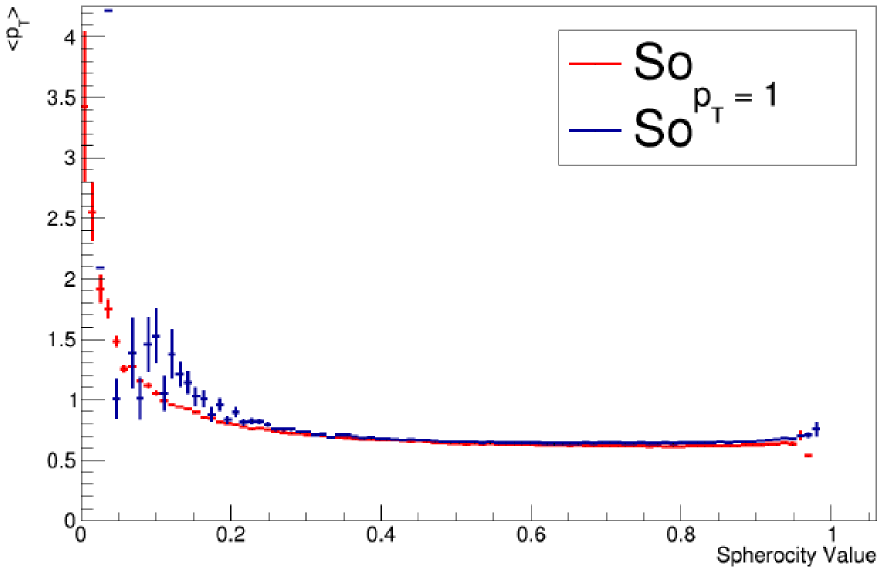
Qualitatively similar
Nch distributions

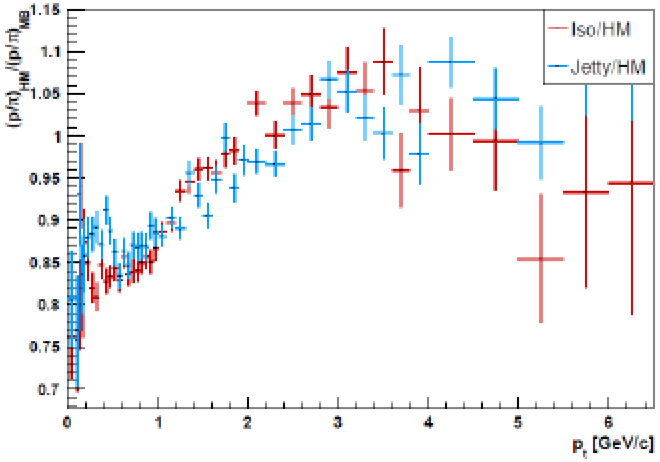




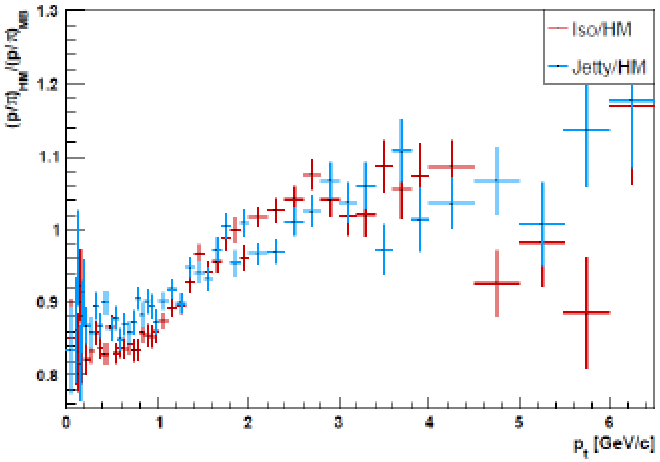
$S_O^{p_T=1}$ MC Studies - $S_O^{p_T=1}$ vs S_O

Qualtitatively similar
$\langle p_T \rangle$ distributions





(a) Spherocity

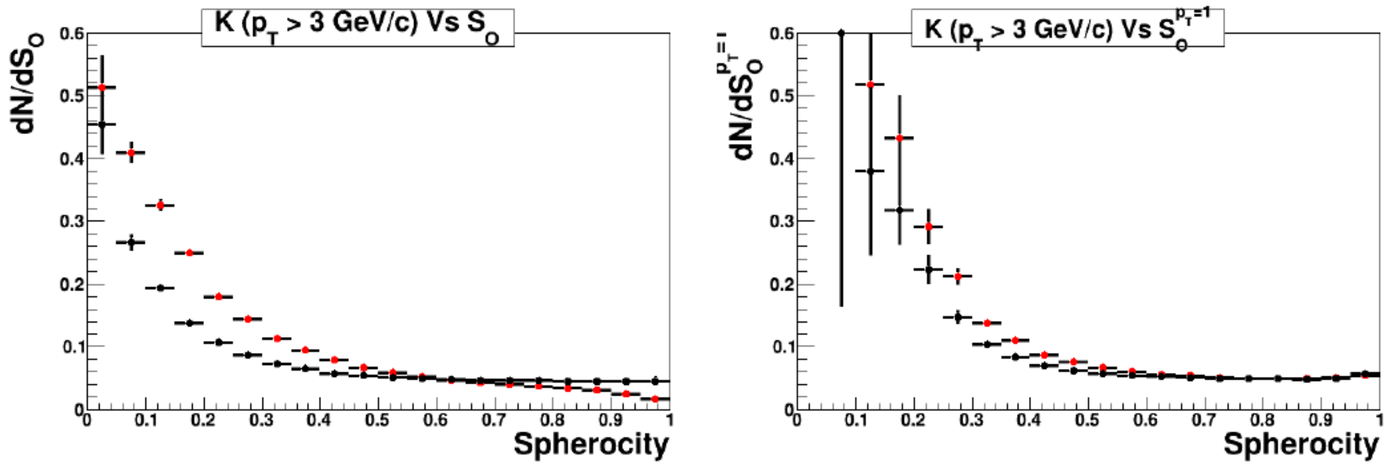


(b) Spherocity $p_T = 1$

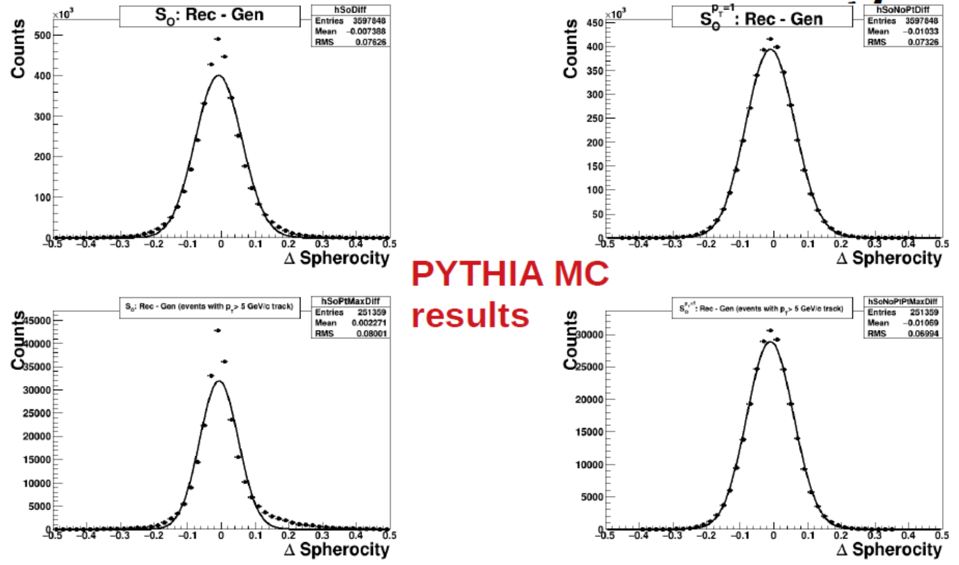
$S_O^{p_T=1}$ MC Studies – Charged Vs Neutral

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

PYTHIA MC results (generator level)



$S_{O,pT=1}$ is more "robust": all particles have same weigth



PYTHIA MC results

Backup: Correlations

- Correlation function: $\mathbb{C}(\Delta\eta, \Delta\varphi) = \frac{1}{N_{\text{pairs}}} \frac{\mathrm{d}^2 N_{\text{pairs}}}{\mathrm{d}\Delta\eta \mathrm{d}\Delta\varphi}$, number of pairs is normalised to unity
- Per-trigger yield: $\mathbb{Y}(\Delta y, \Delta\varphi) = \frac{1}{N_{\text{trig}}} \frac{\mathrm{d}^2 N_{\text{trig-assoc pairs}}}{\mathrm{d}\Delta y \mathrm{d}\Delta\varphi}$, normalised to number of triggers

Same sign:

Opposite sign:

- Balance function:
  $\mathbb{B}(\Delta y, \Delta\varphi) = \frac{1}{2}\left(\mathbb{Y}_{(+,-)} + \mathbb{Y}_{(-,+)} - \mathbb{Y}_{(+,+)} - \mathbb{Y}_{(-,-)}\right)$