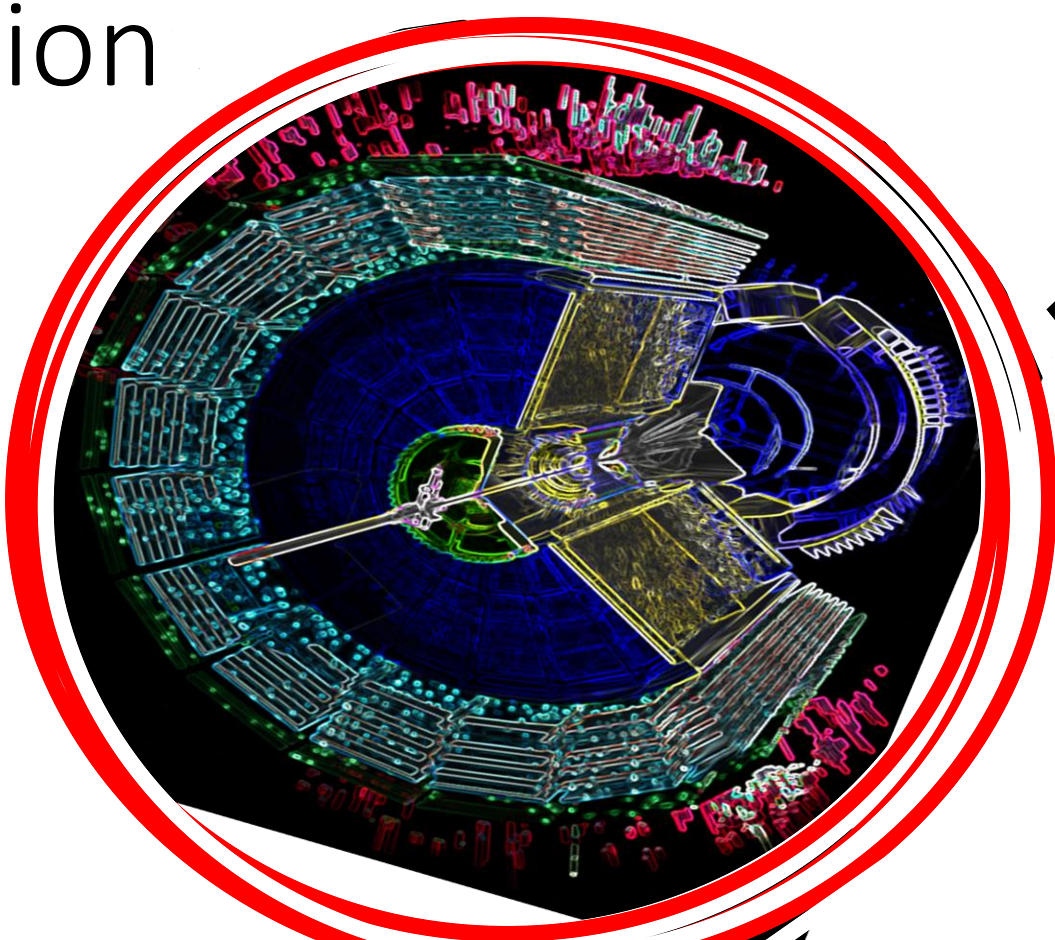
SQM 2024

The 21st International Conference on Strangeness in Quark Matter
3-7 June 2024, Strasbourg, France

ALICE

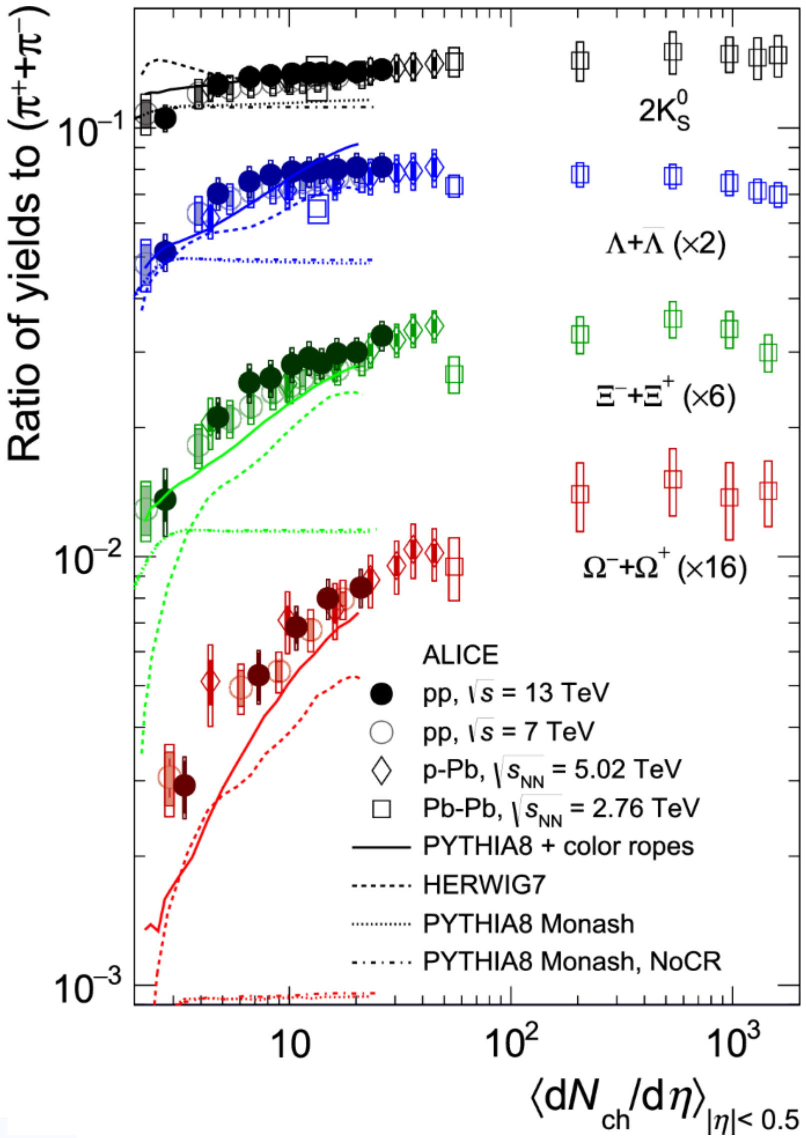
Light-flavour particle production as a function of transverse spherocity with ALICE



Adrian Nassirpour, on behalf of the ALICE Collaboration
(Sejong University, South Korea)

Motivation - Strangeness Production

- ALICE strangeness enhancement results are published in 2016
  - ➢ Out-of-the box PYTHIA 8 is incompatible with the data



Eur. Phys. J. C 80 (2020) 693 + *Nature Physics* **volume 13**, pages 535–539 (2017)

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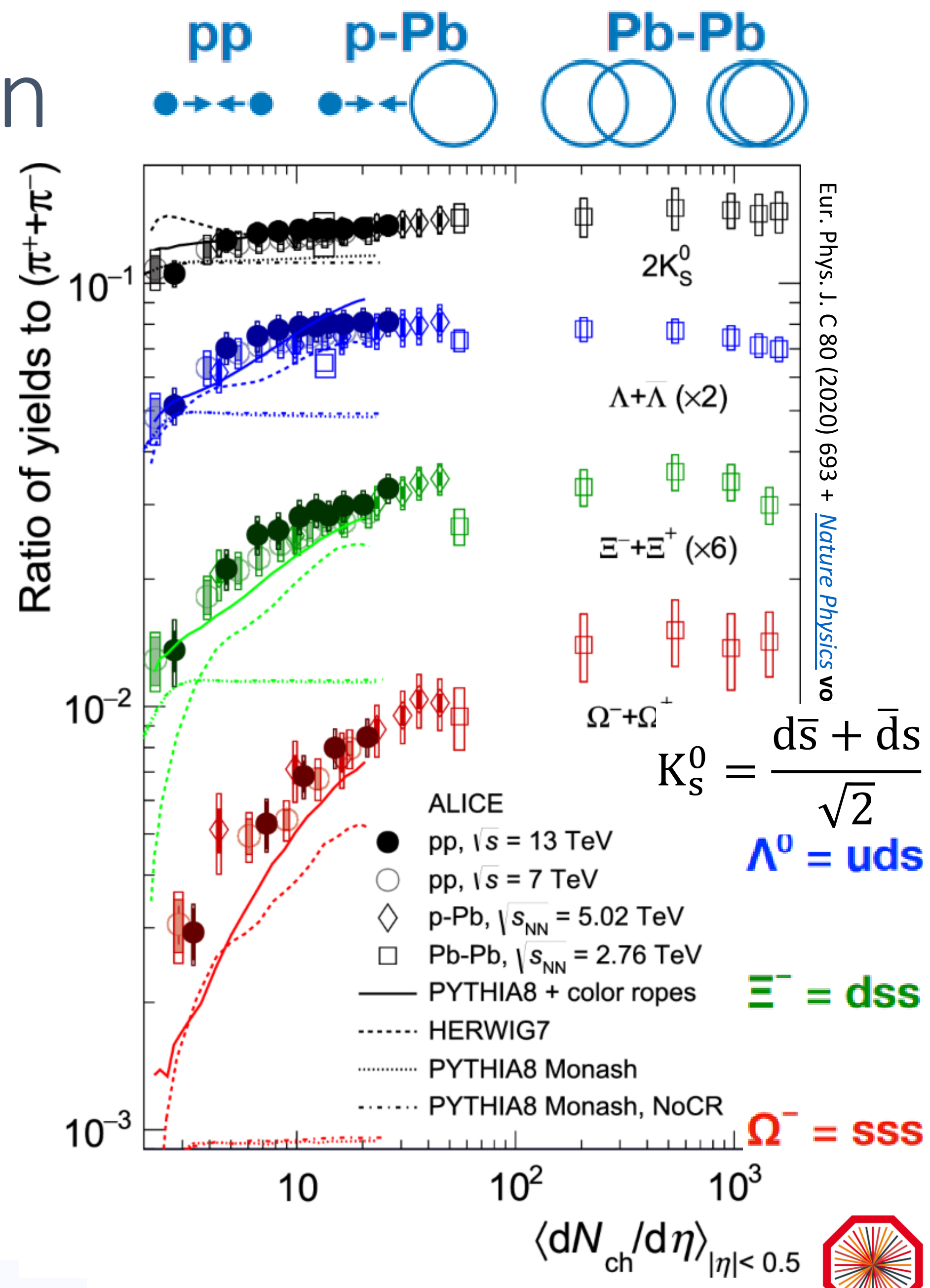

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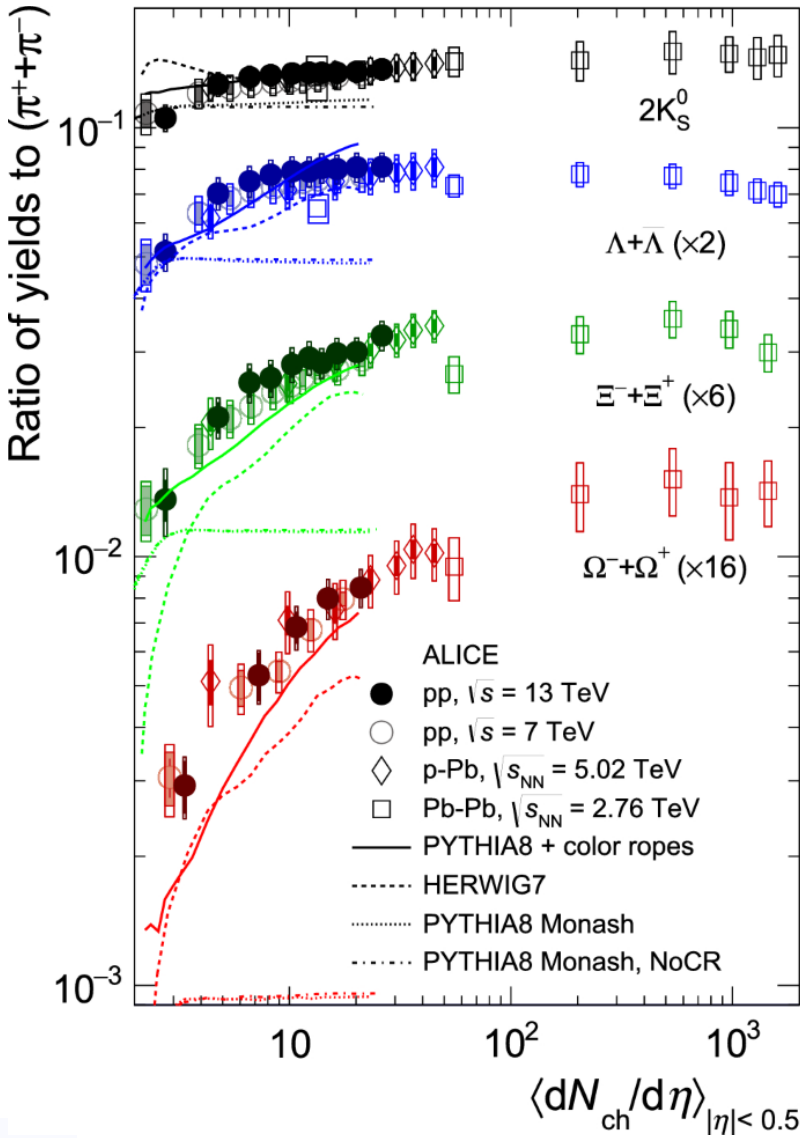
- Strangeness enhancement: historical QGP signature in heavy-ion collisions

- However, the origins of this effect are unclear in smaller systems
  - ➢ Moreover, the main fraction of enhancement is driven within pp collisions



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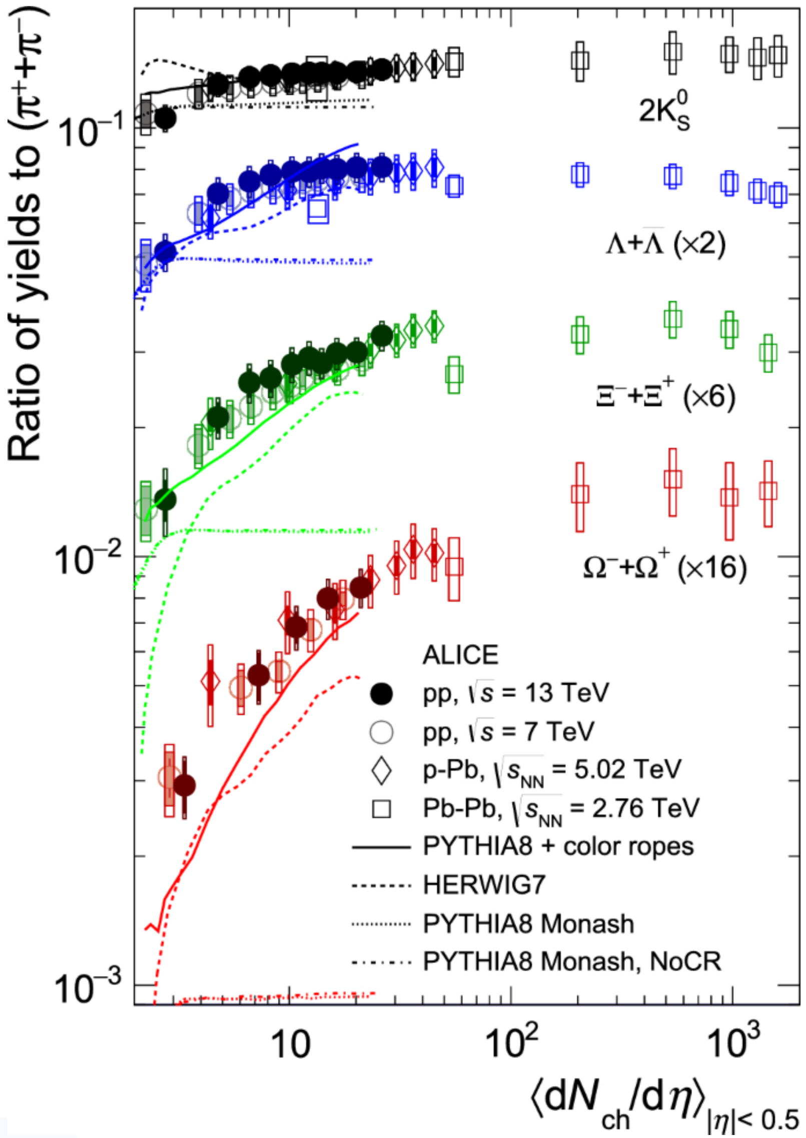
- In this context, how can we improve our understanding of strange hadron production?



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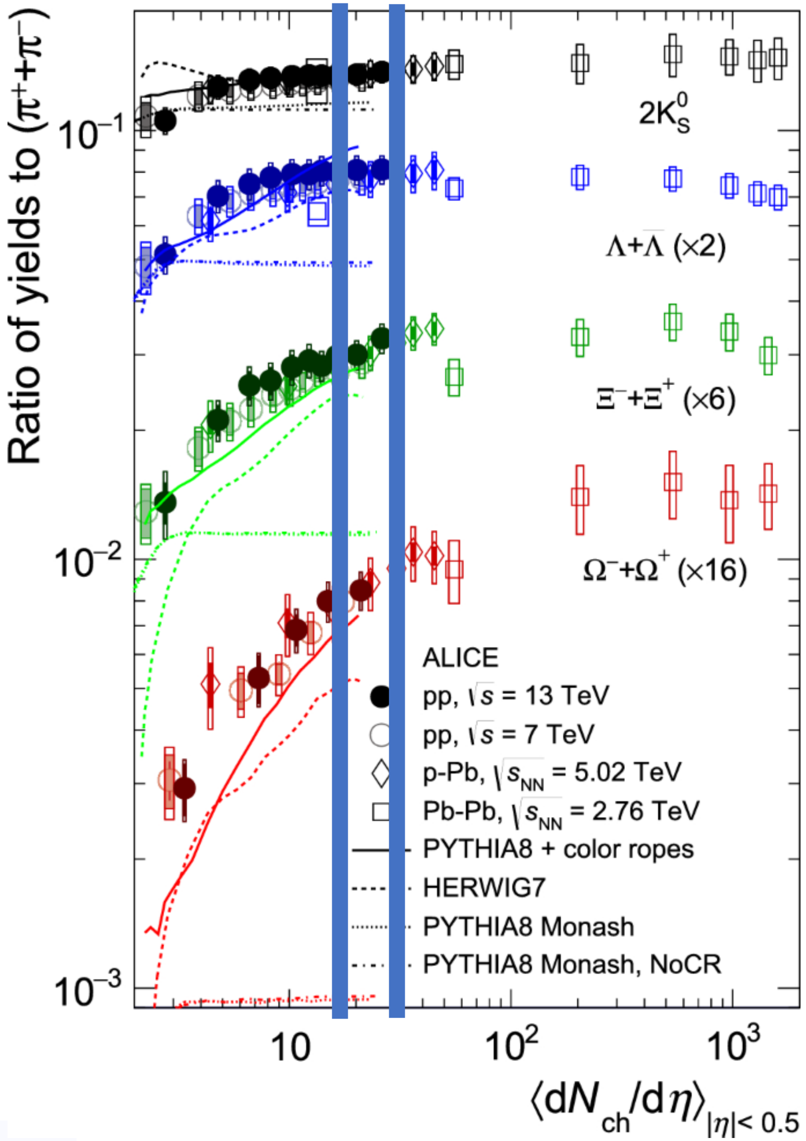
Transverse Spherocity $S_0^{p_\mathrm{T}=1}$

- Idea: classify high-multiplicity events based on event topology
  - ➢ We select top 1% multiplicity pp events, where QGP-like effects arise



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Transverse Spherocity $S_0^{p_{\mathrm{T}}=1}$

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

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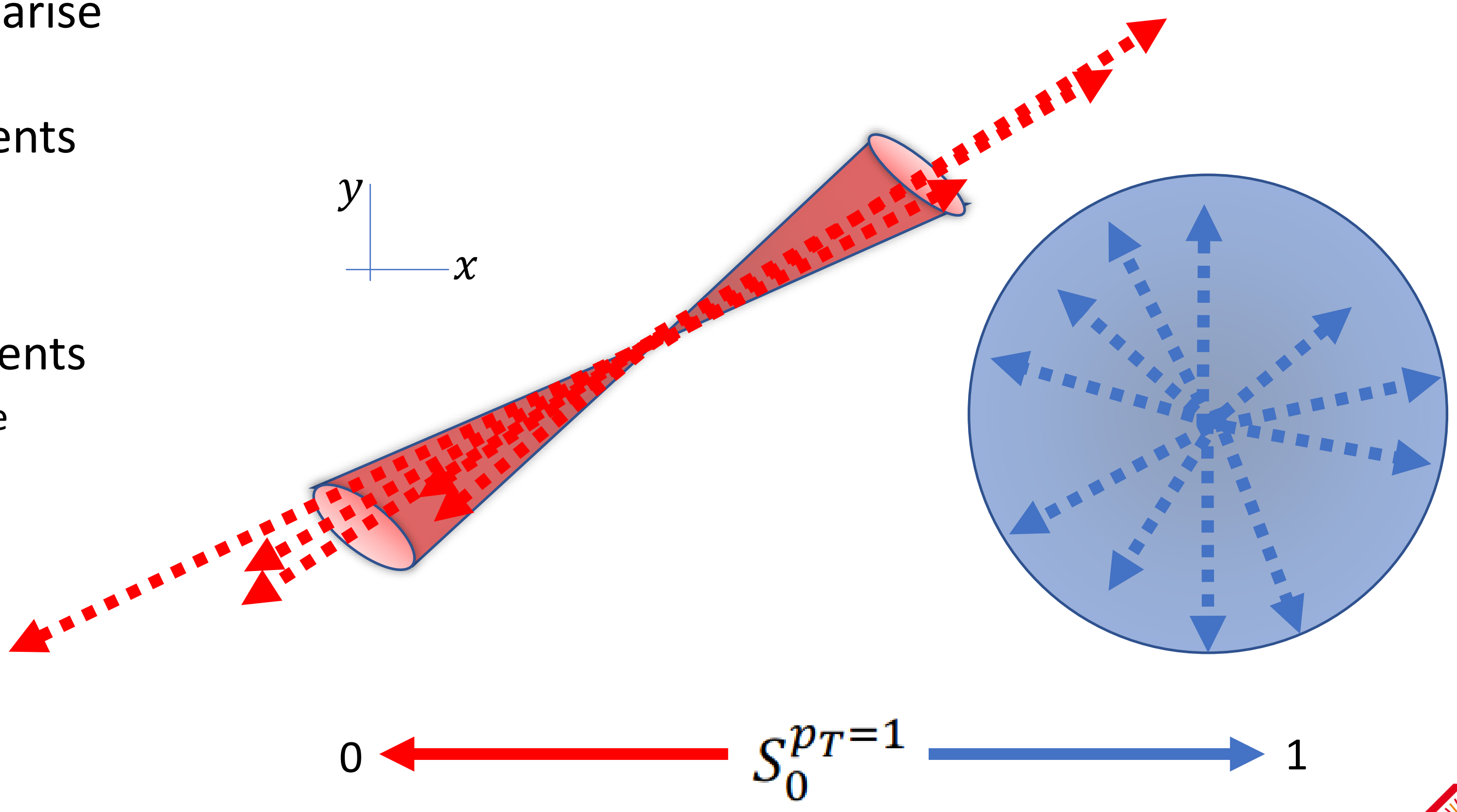
- **Jet-like:** Back-to-back "jet-like" events
  - ➢ Particle production mainly driven by hard physics

- **Isotropic:** Azimuthally isotropic events
  - ➢ Particle production driven by multiple softer collisions



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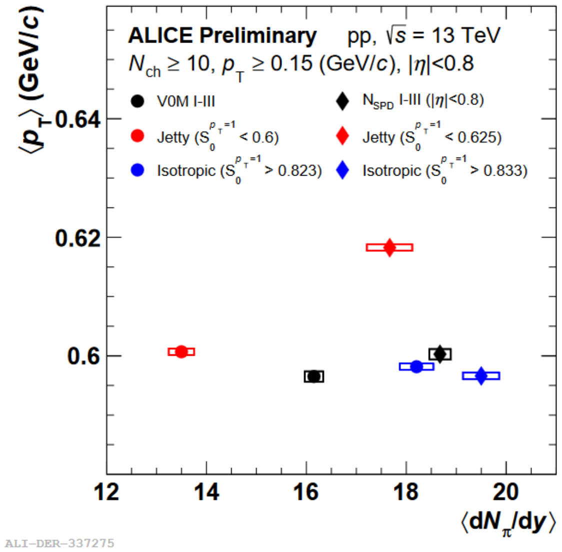
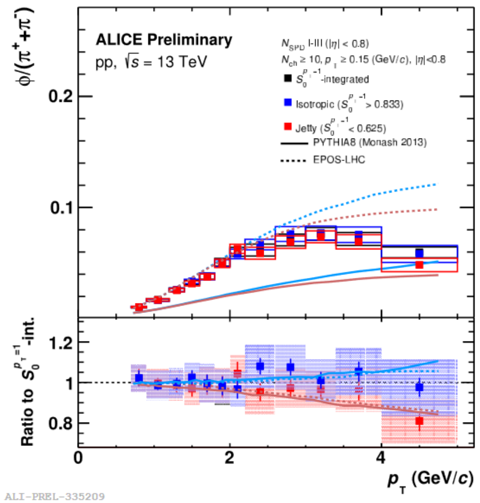
➢ Several ALICE contributions based on preliminary results...

Quark Matter 2019



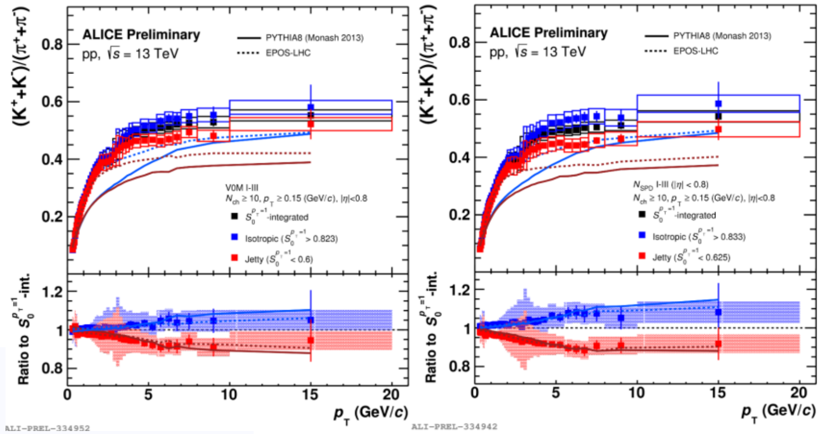
SQM 2022



MPI@LHC 2019

Forward Estimator
2.8< η <5.1 , −3.7< η <−1.7

Midrapidity Estimator
|η| <0.8



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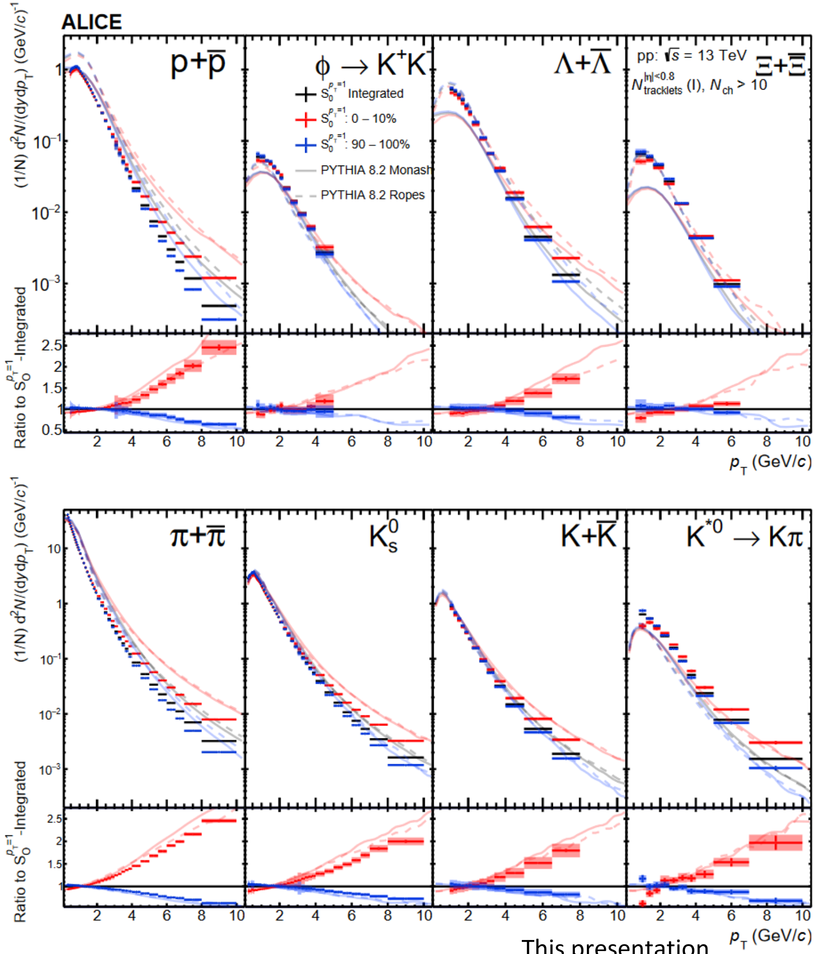
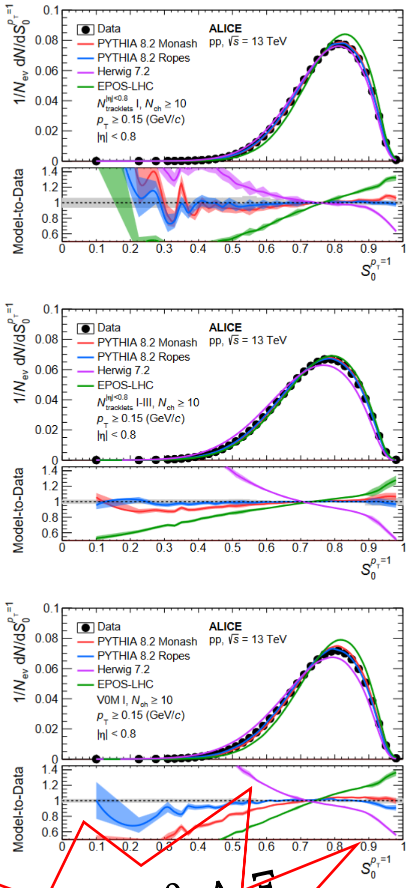
➢ Several ALICE contributions based on preliminary results...
  - ➢ Finally wrapped up in a paper,! https://doi.org/10.1007/JHEP05(2024)184

ALICE

CERN-EP-2023-215
27 September 2023

Light-flavor particle production in high-multiplicity pp collisions at $\sqrt{s} = 13$ TeV as a function of transverse spherocity





This presentation will only highlight a selection of results

$\pi, K, p, \phi, K^*, K^0, \Lambda, \Xi$
41 pages
19 figures
Wow!

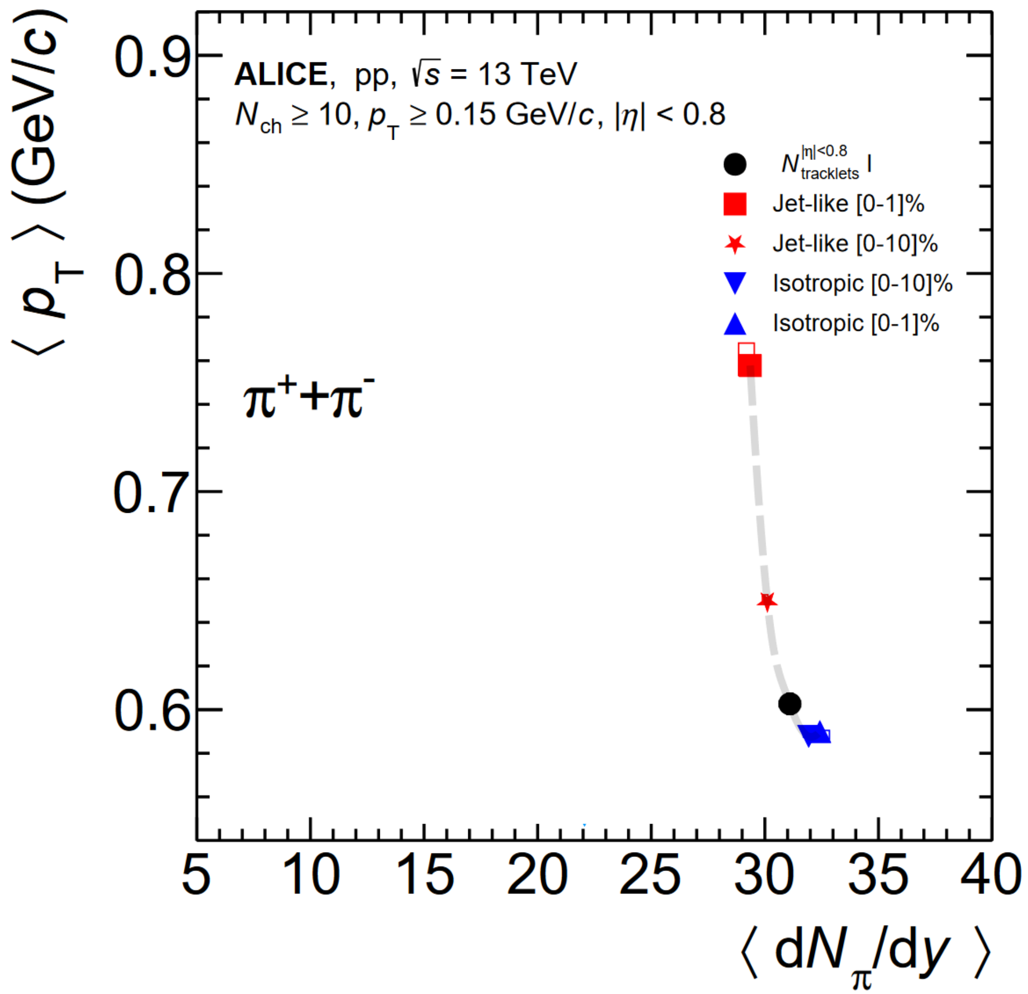
Transverse Spherocity $S_0^{p_\mathrm{T}=1}$ - Multiplicity Estimation

- When using $N_{\mathbf{tracklets}}^{|\eta|<0.8}$ in conjunction with spherocity selection, we observe:

Estimate of mid-rapidity activity

Transverse Spherocity $S_0^{p_{\mathrm{T}}=1}$ - Multiplicity Estimation

- When using $N_{\mathrm{tracklets}}^{|\eta|<0.8}$ in conjunction with spherocity selection, we observe:
  - Large shift in $< p_{\mathrm{T}} >$
  - Very small (≈10%) shift in yield



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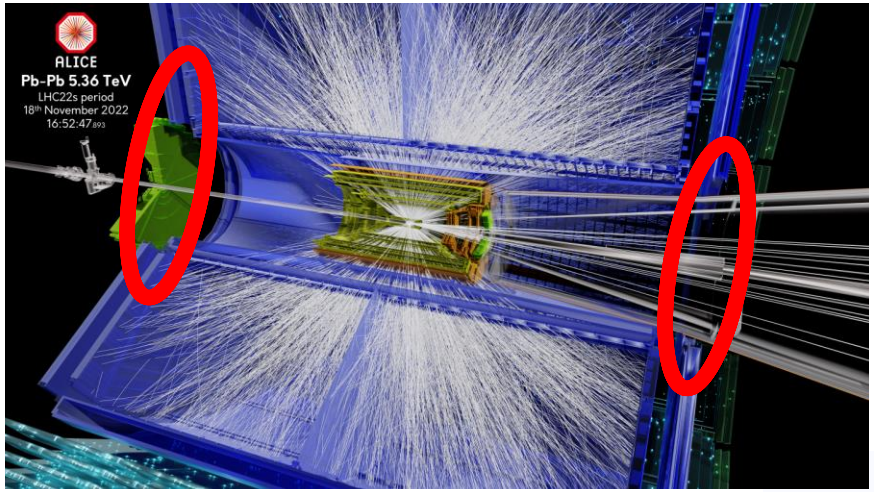
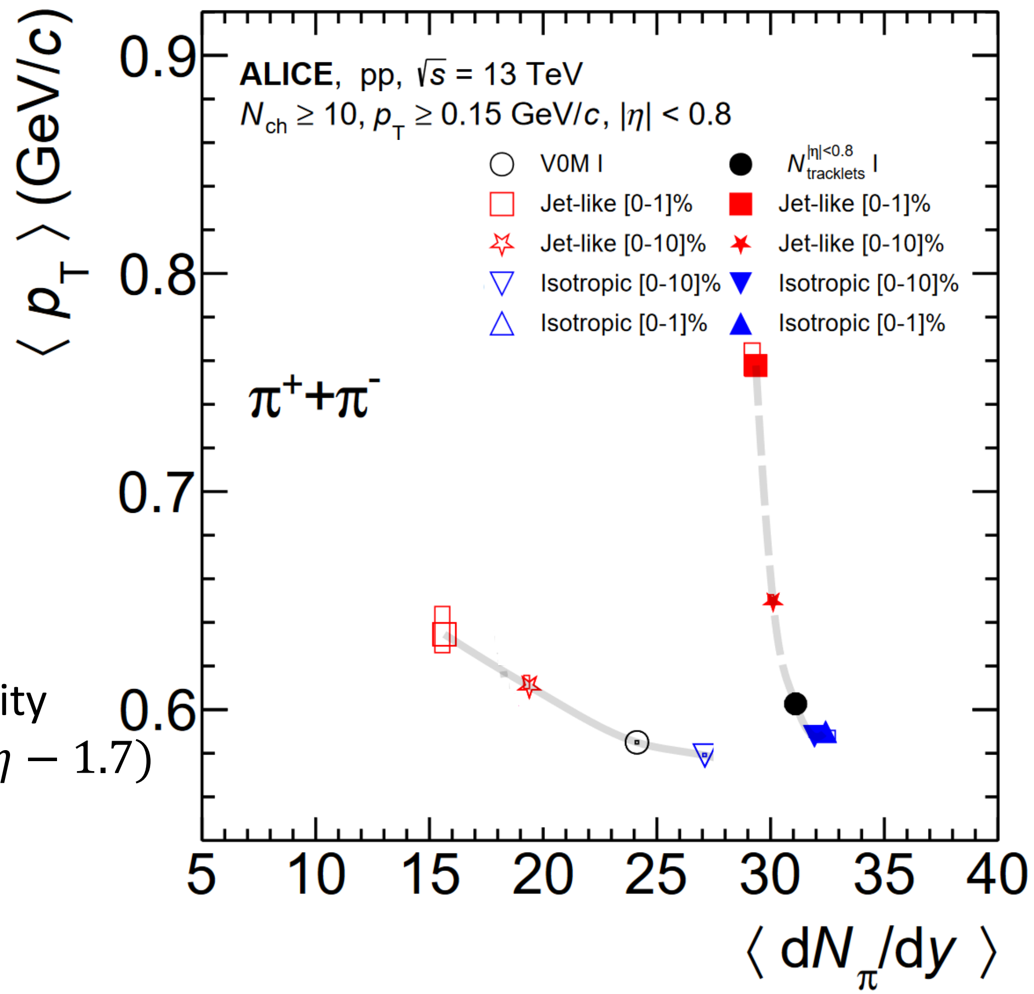


V0M: Event-class with forward-rapidity event activity $(2.8 < \eta < 5.1), (-3.7 < \eta - 1.7)$



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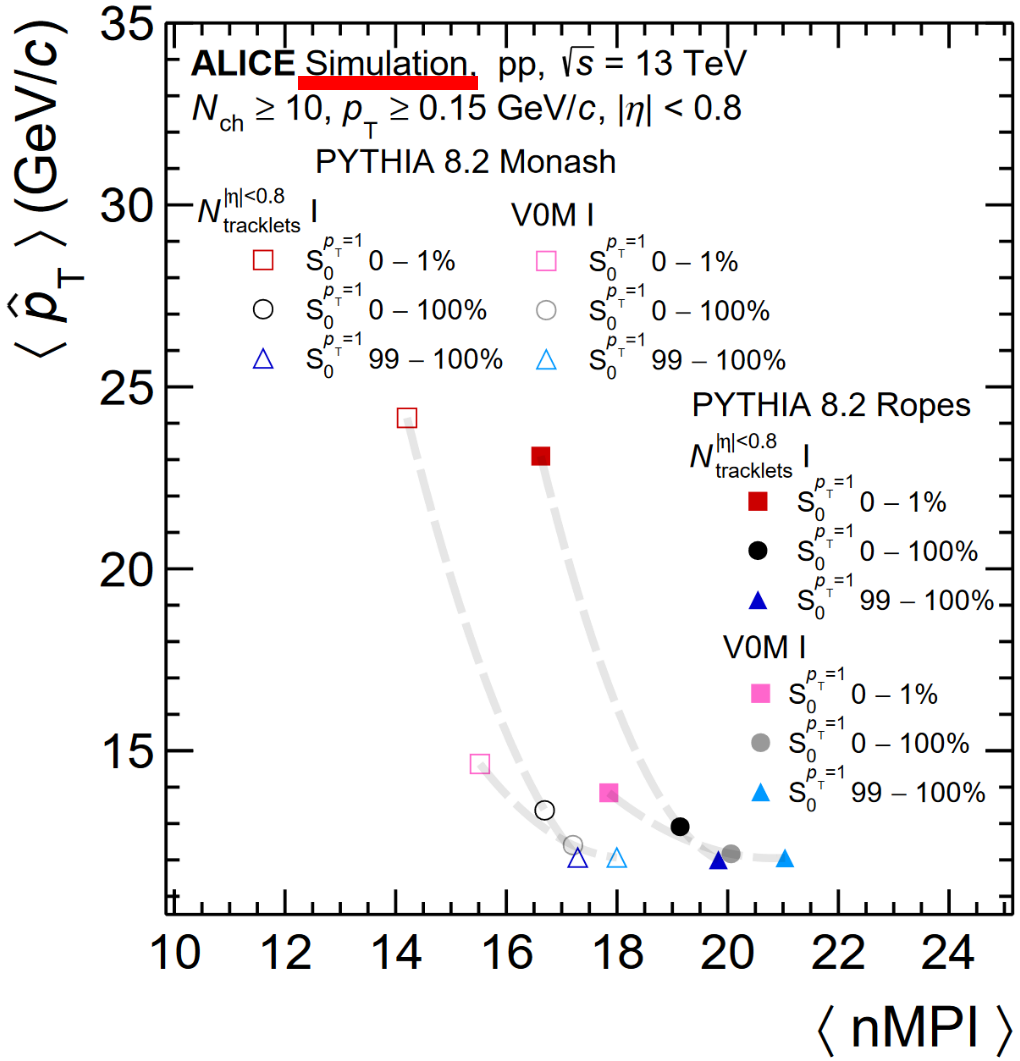
  - Autocorrelation is a feature, not a bug!
    - ➢ Normally, high-multiplicity midrapidity measurements are biased towards jets
    - ➢ However, in our case, the jet-like selection is able to capture these local fluctuations!
      - The exact two paradigms we want to contrast



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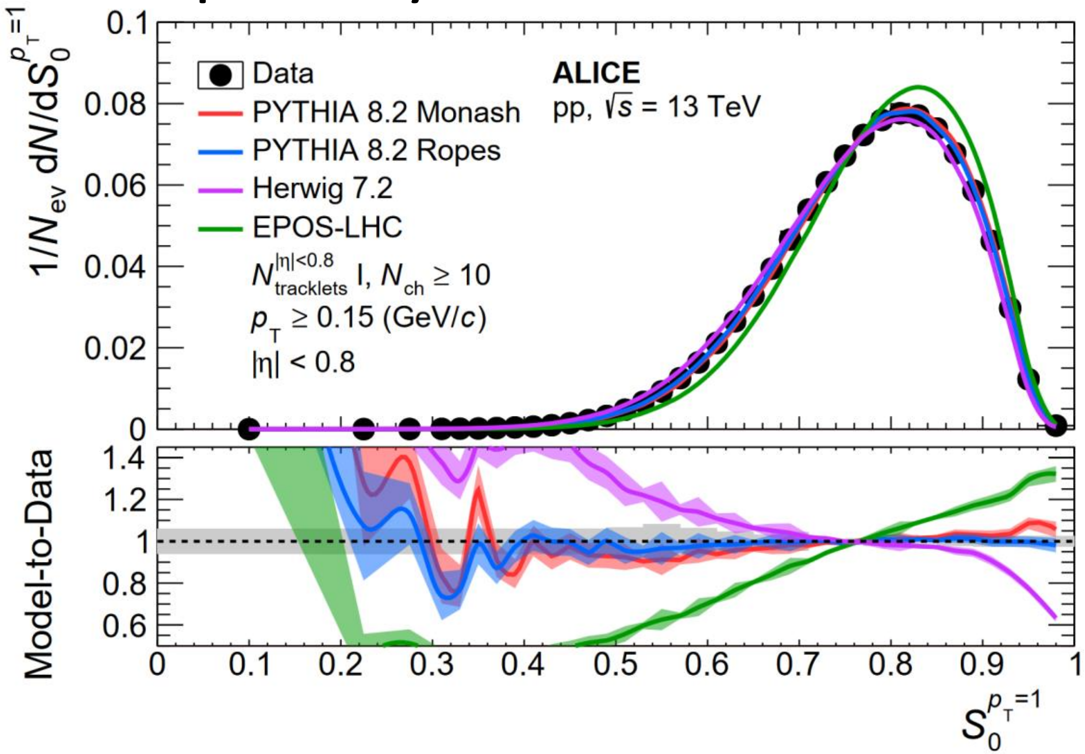
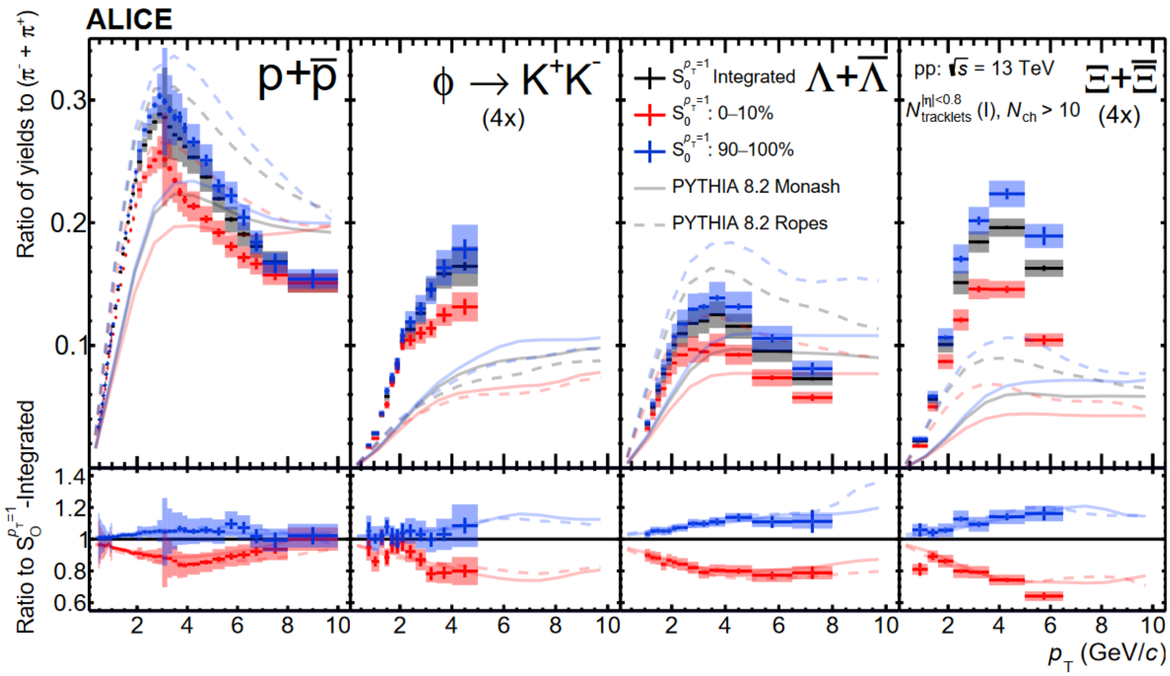


This presentation will focus on results in $N_{\mathrm{tracklets}}^{|\eta|<0.8}\ 0-1\%$

- PYTHIA is able to qualitatively predict shape of distribution observed in data
- EPOS-LHC and Herwig 7.2 showcase large deviations

Results: $S_0^{p_\mathrm{T}=1}$ X-to-π ratios

$N_{\mathrm{tracklets}}^{|\eta|<0.8}: 0-1\%\ (\mathrm{I})\ +\ S_0^{p_\mathrm{T}=1}: 0-10\%$



- Jet-like events: p_T - differential suppression of strange particles
  - Balances out at high- p_T for protons
  - Consistent suppression of strange particles

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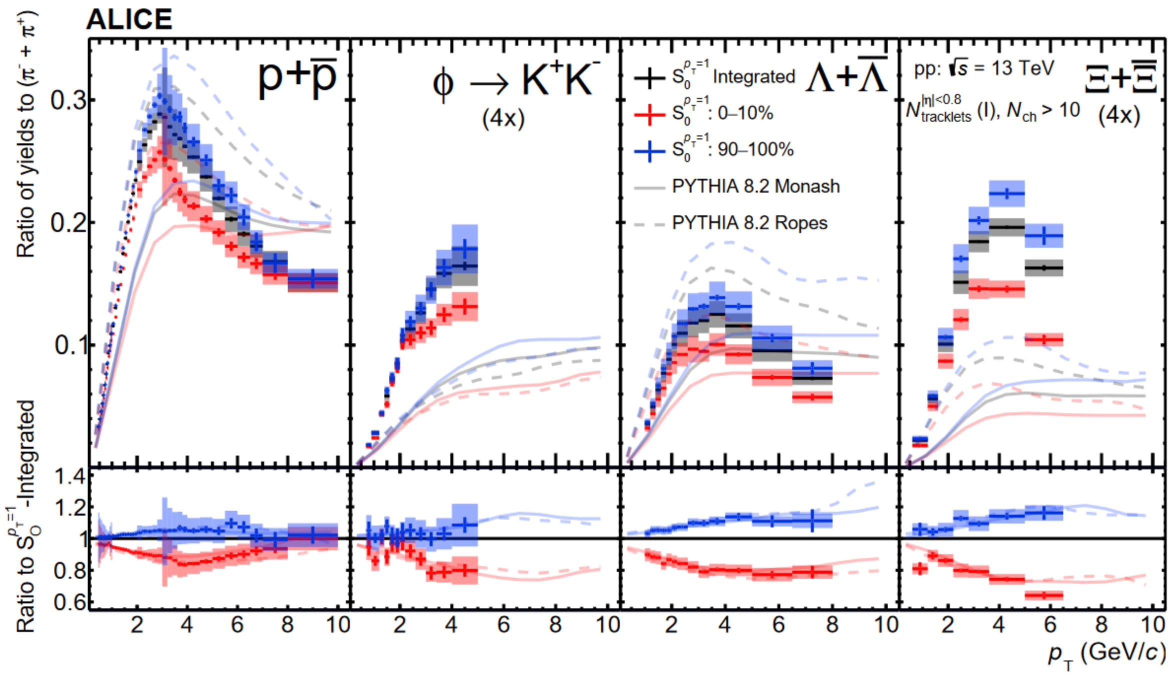
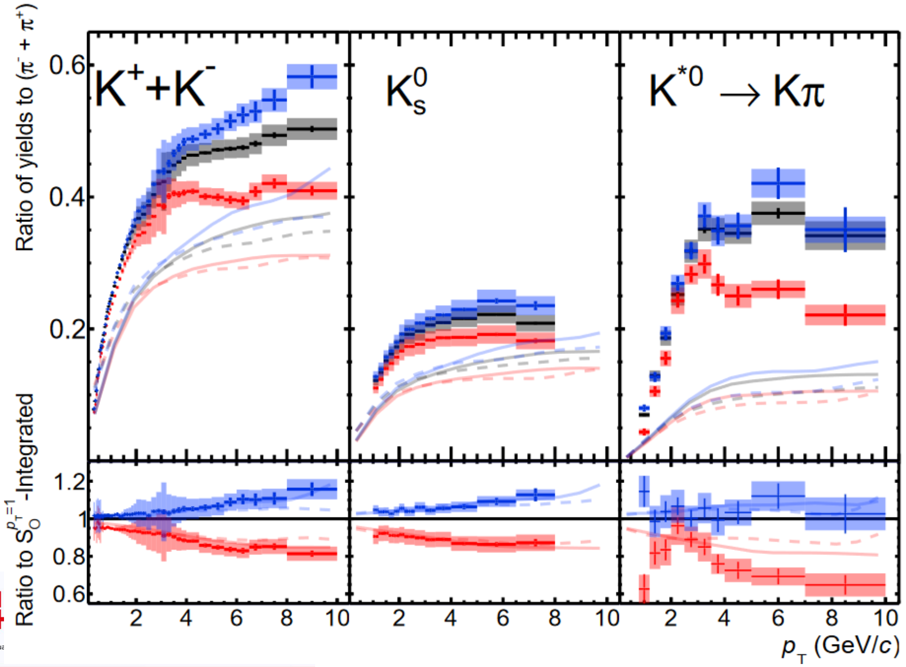
    - Also the case for presented mesons
- MC models are not able to capture absolute trends
  - ➢ However, interplay to high-multiplicity reference is generally well-described





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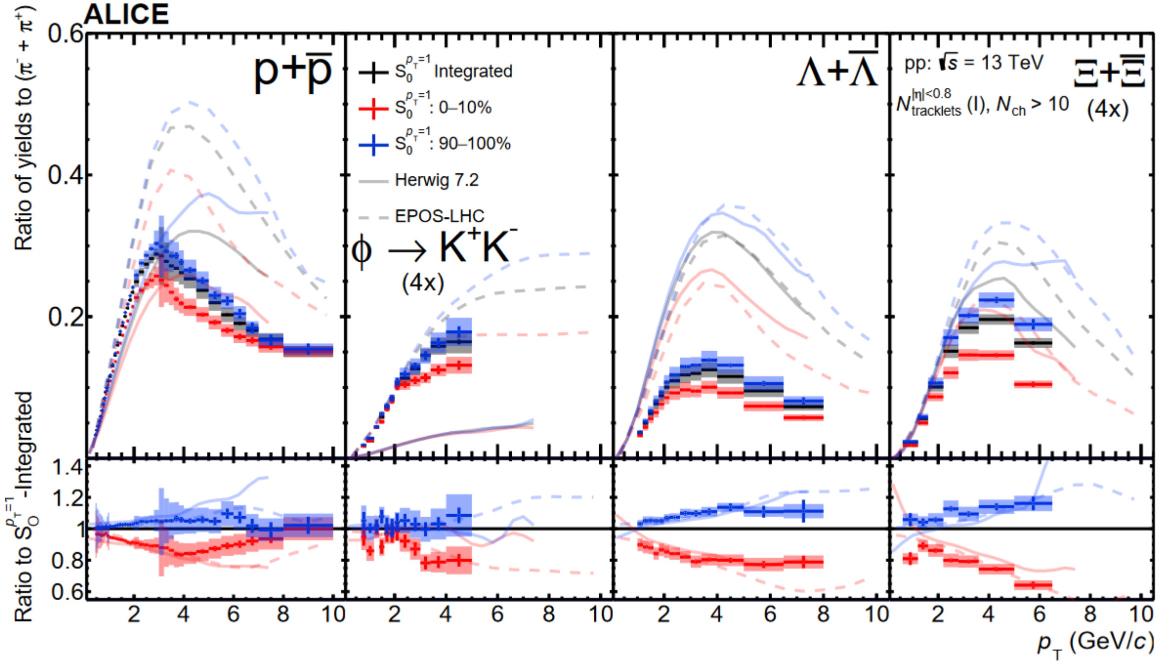

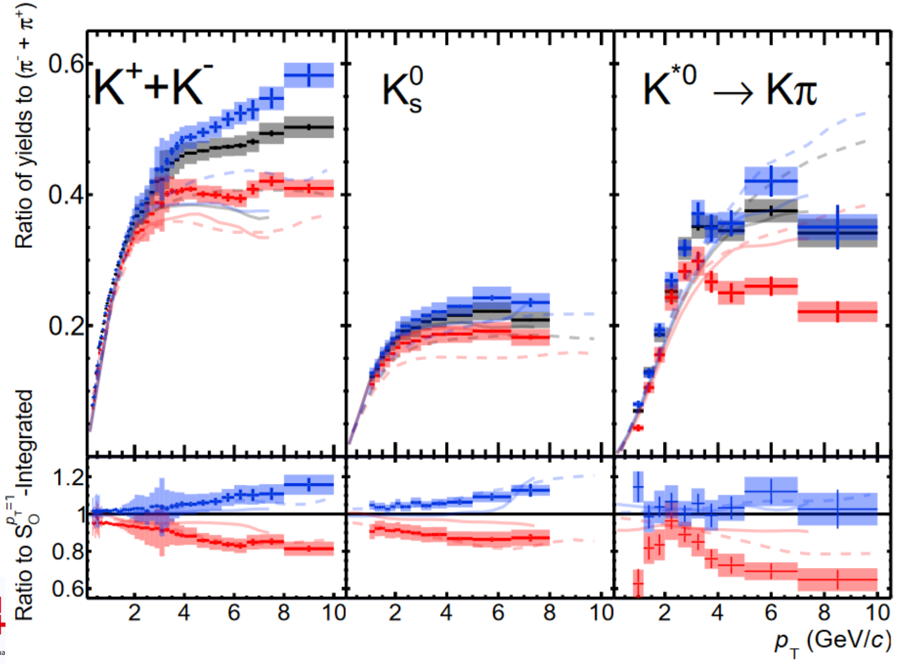

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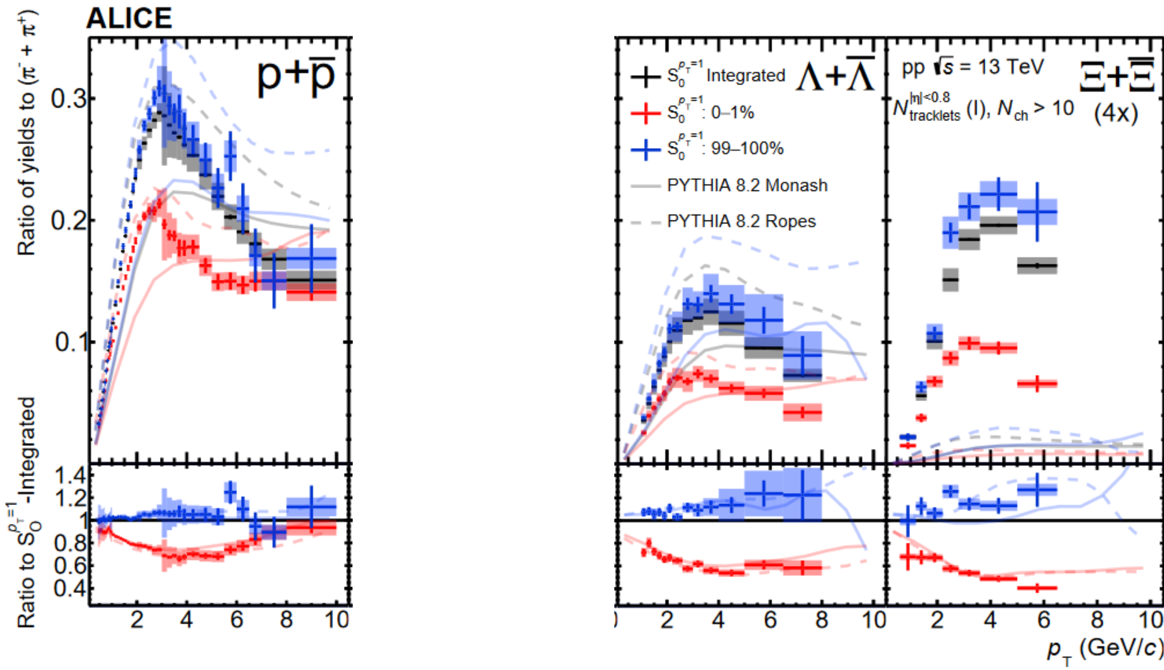

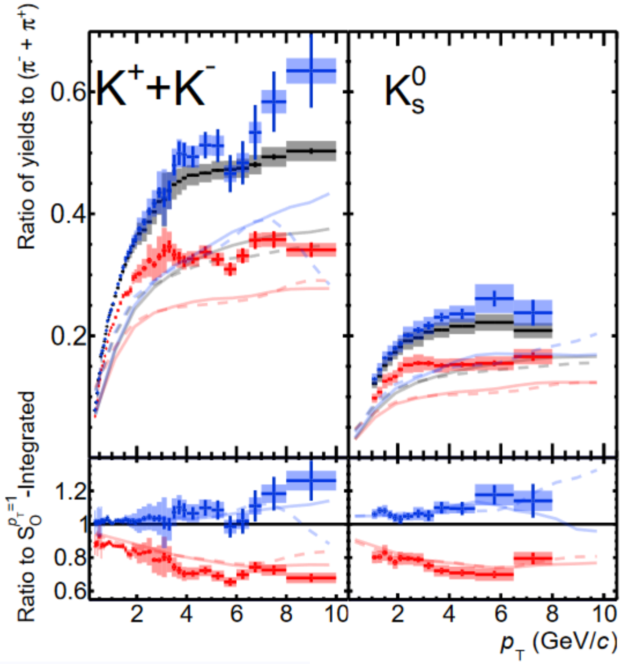

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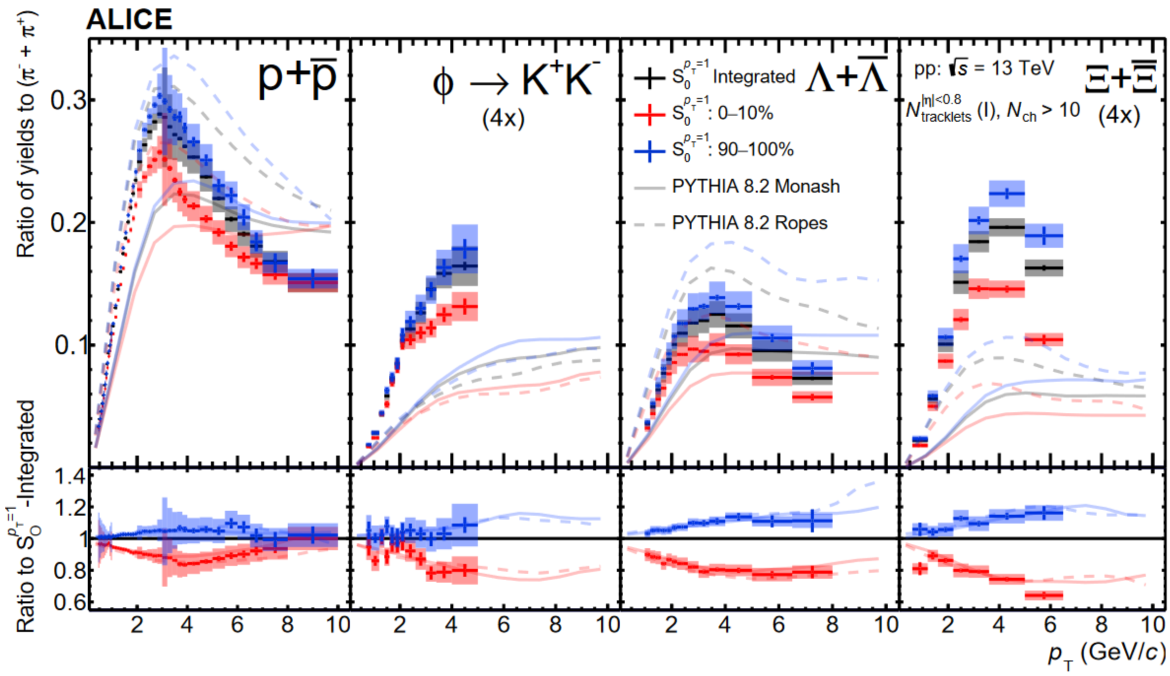

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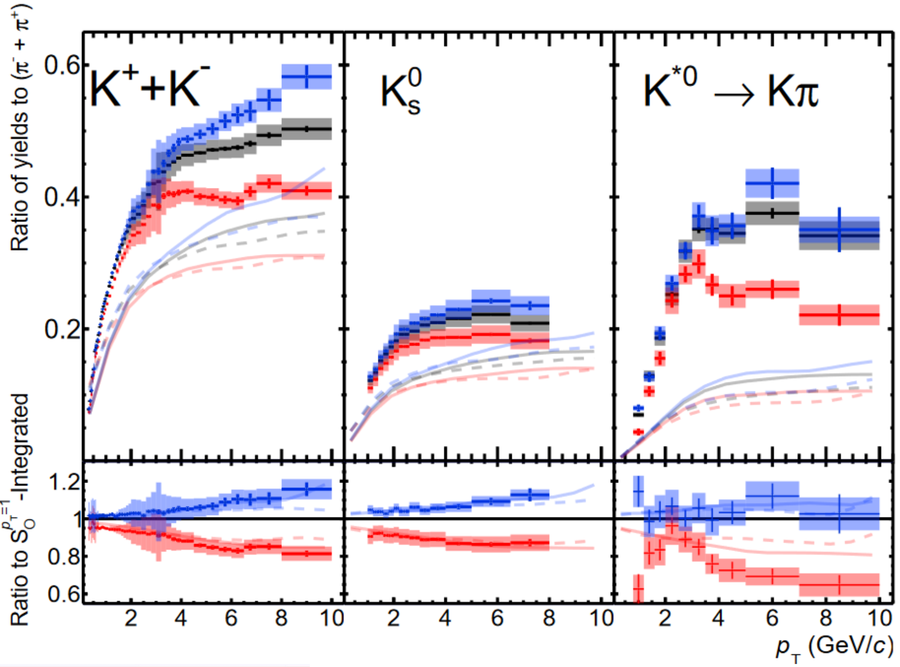

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*DOI:10.1103/PhysRevC.93.034913

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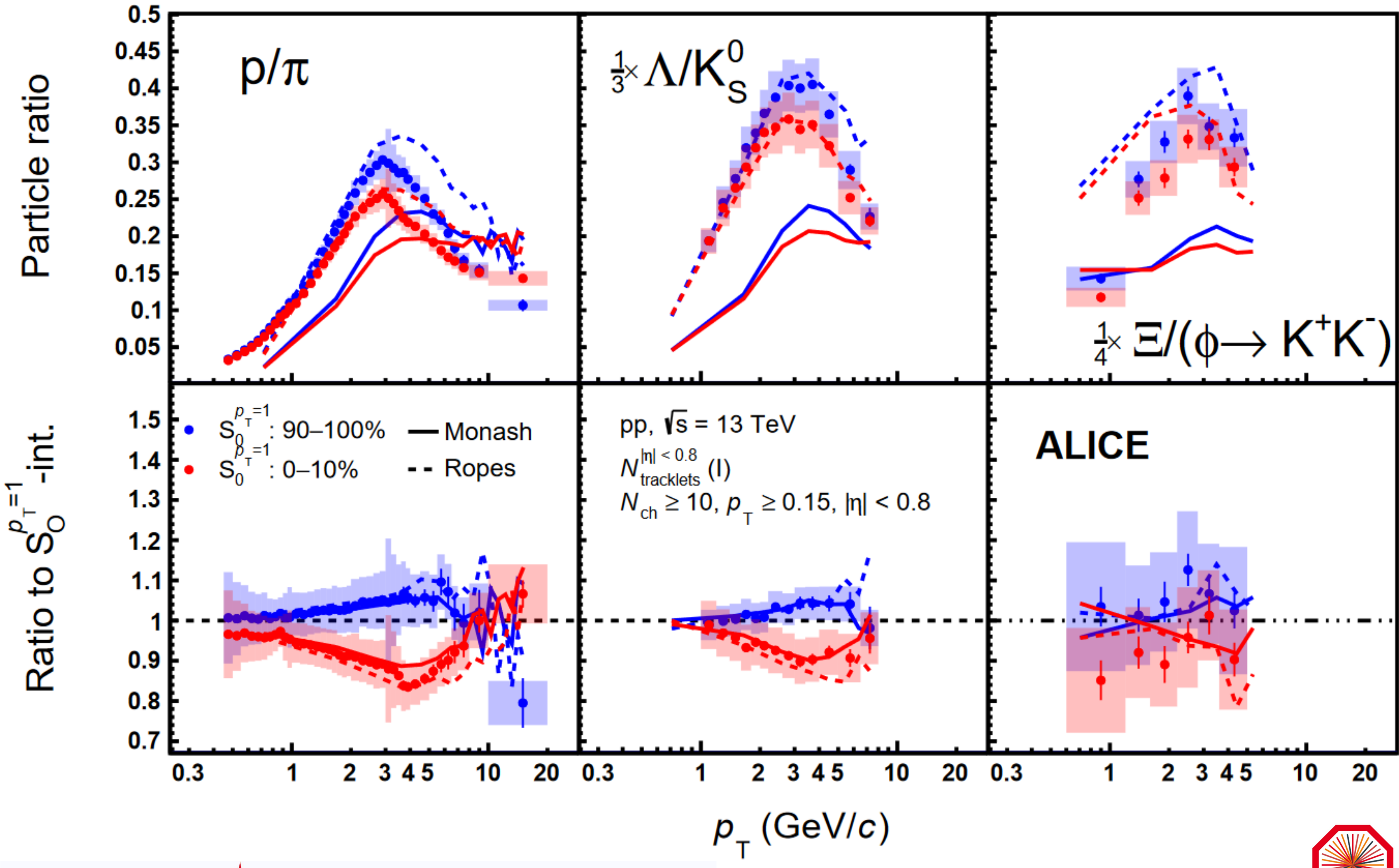
- Overall trend similar between p/π, $\Lambda/\mathrm{K}^0_{\mathrm{S}}$, and Ξ/ϕ
  - Ratios between "equivalent" strangeness content

- In the context of radial flow*:
  - ➢ Heavy baryons boosted to high- p_{T}
  - ➢ Depletion of baryons at low-p_{T} is missing



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- In the context of radial flow*:
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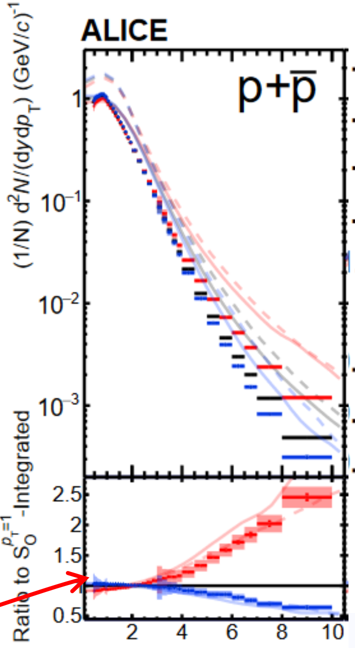
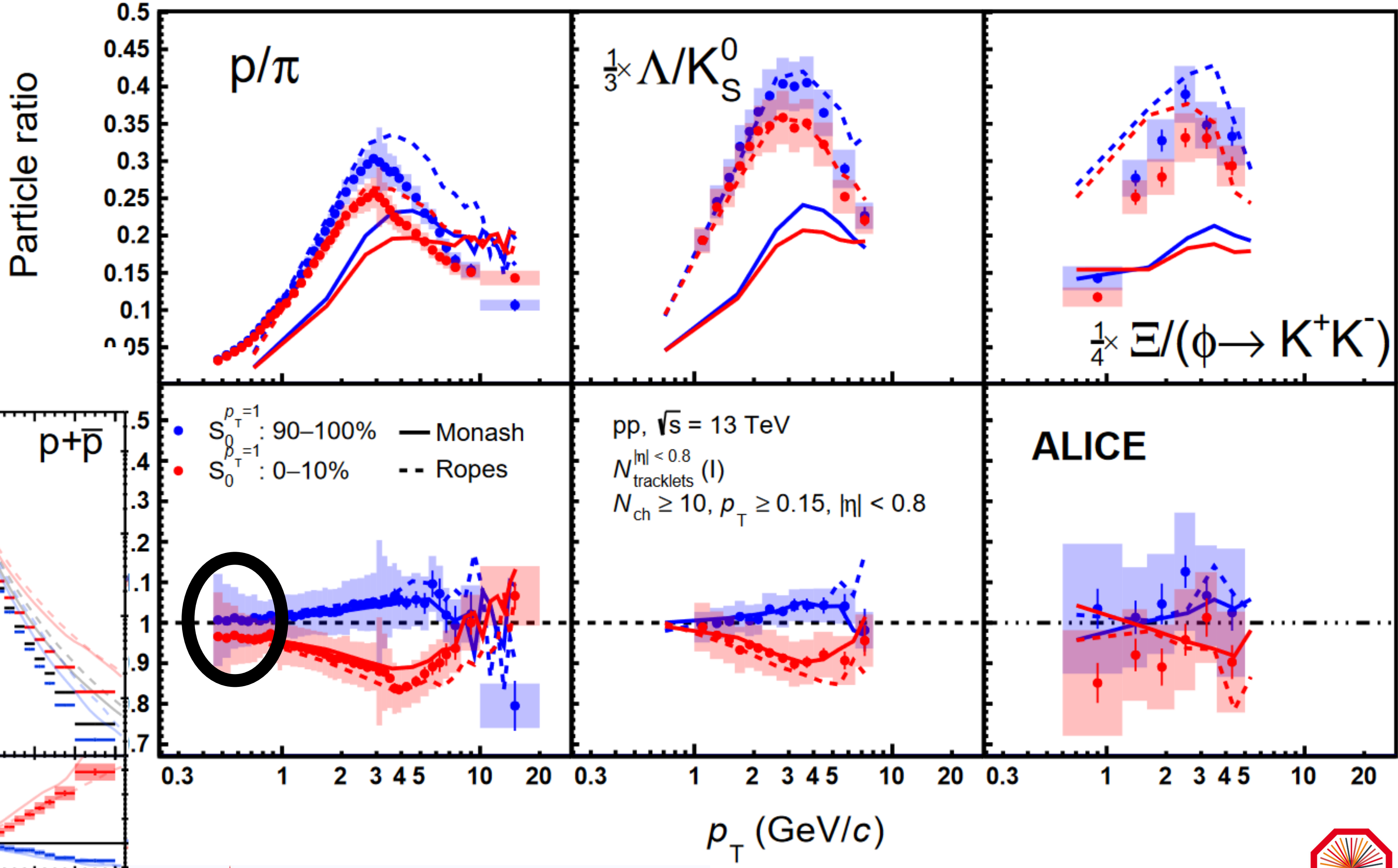
- Interplay between soft radial flow and hard suppression?
  - ➢ Counter-acting processes
  - ➢ Origin still unclear





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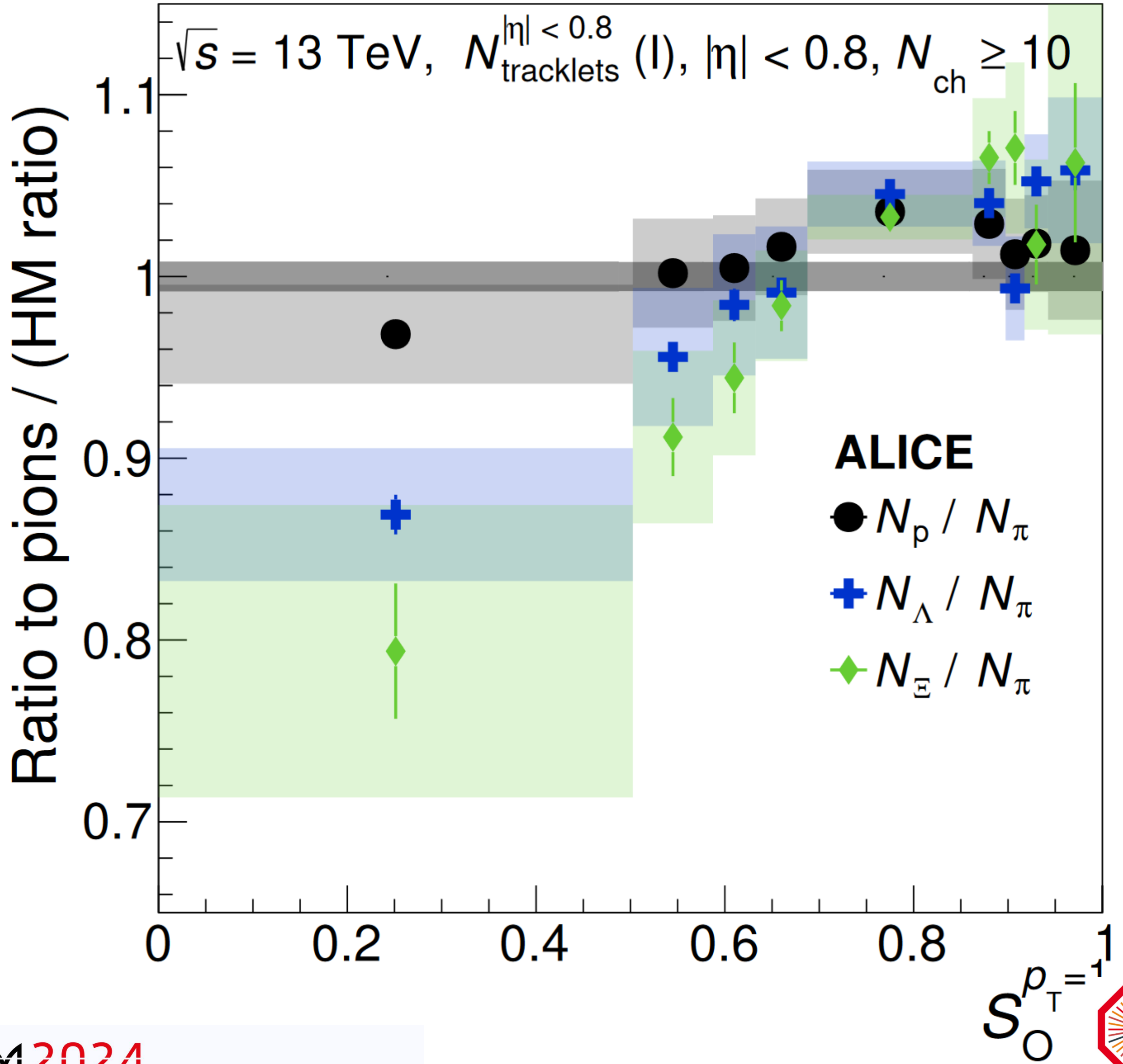
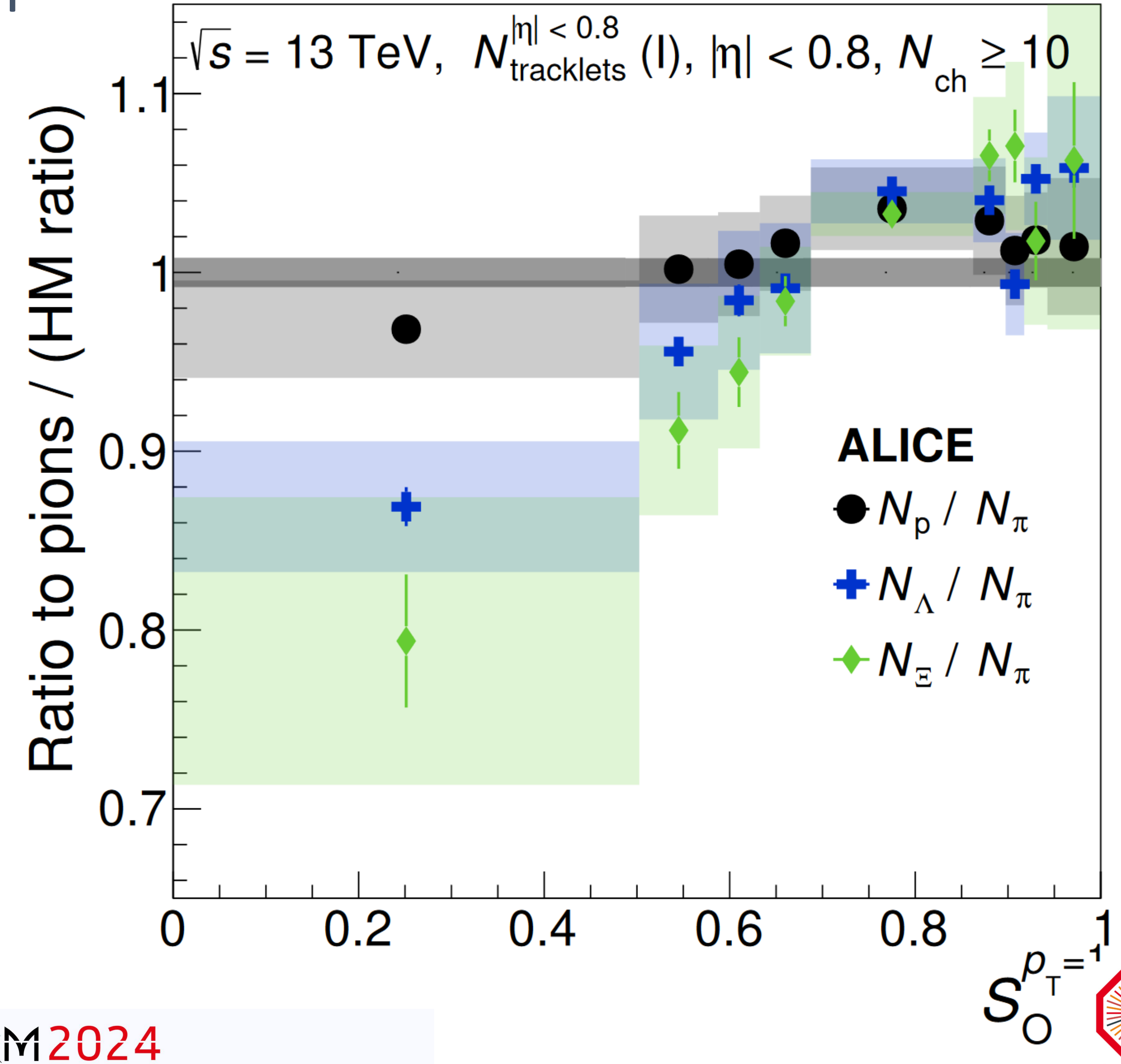
Results: $S_0^{p_T=1}$ integrated particle ratios

$$\left(\frac{dN/dp_T}{dN_\pi/dp_T}\right)_{S_O^{p_T=1}} \Big/ \left(\frac{dN/dp_T}{dN_\pi/dp_T}\right)_{\int S_O^{p_T=1}}$$



Results: $S_0^{p_\mathrm{T}=1}$ integrated particle ratios

- Significant suppression of yields in Jet-like events
  - Proton is largely unmodified
  - Approximately 20% effect for Ξ
  - Strength is ordered in strangeness



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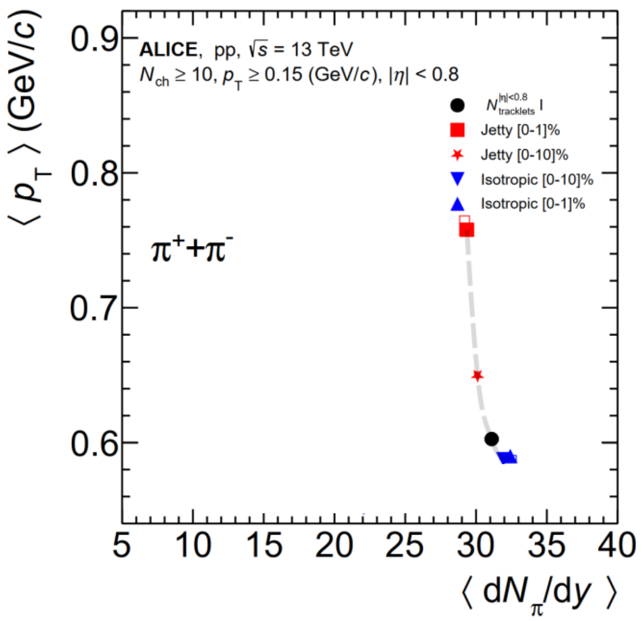

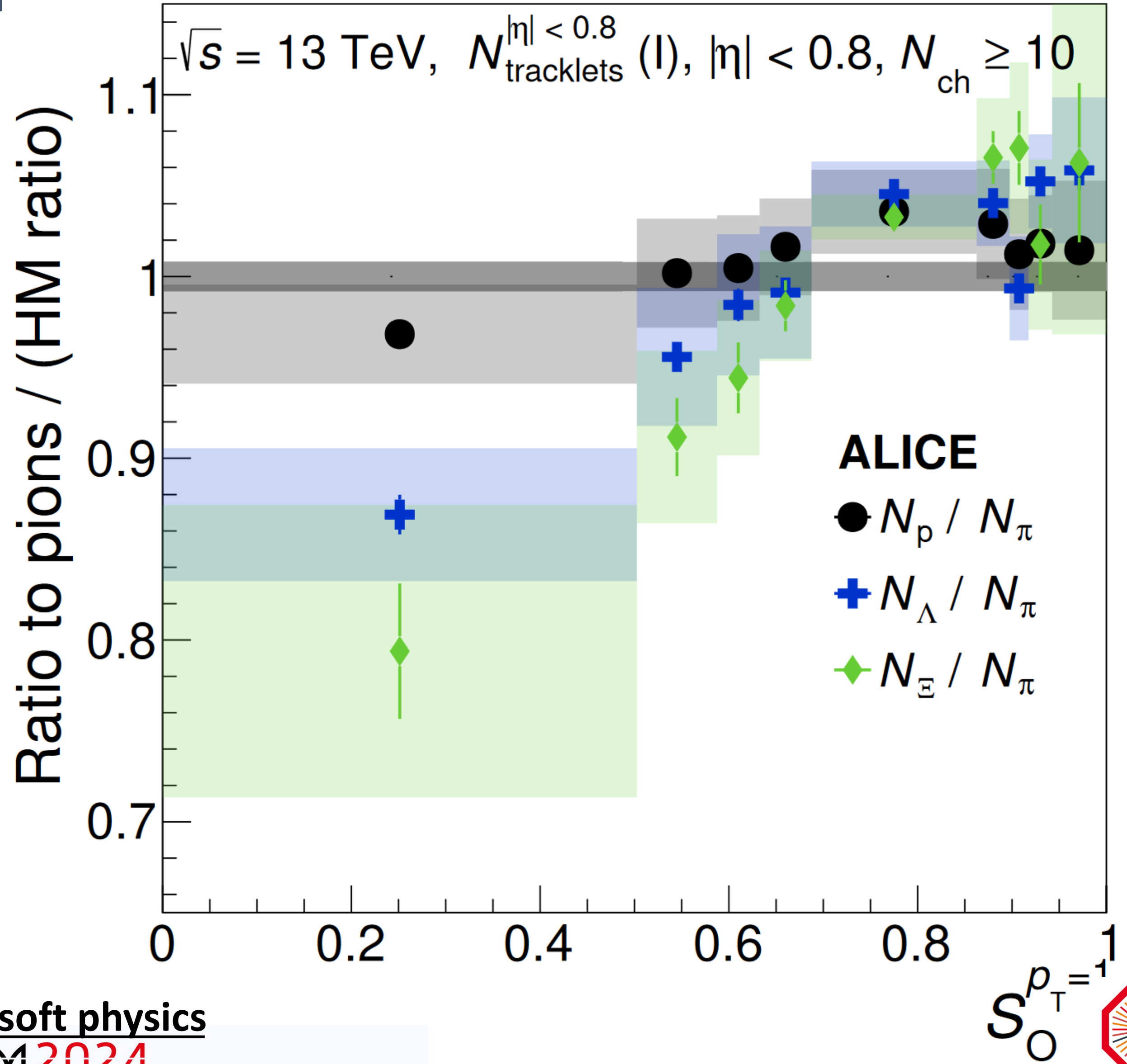

➢ Reminder: Multiplicity fluctuates at roughly 15%!

➢ **Strangeness enhancement: seemingly property of UE/soft physics**

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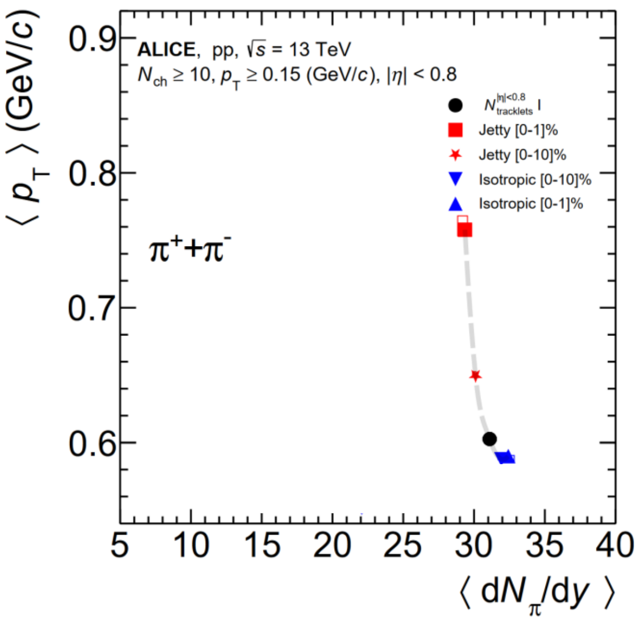

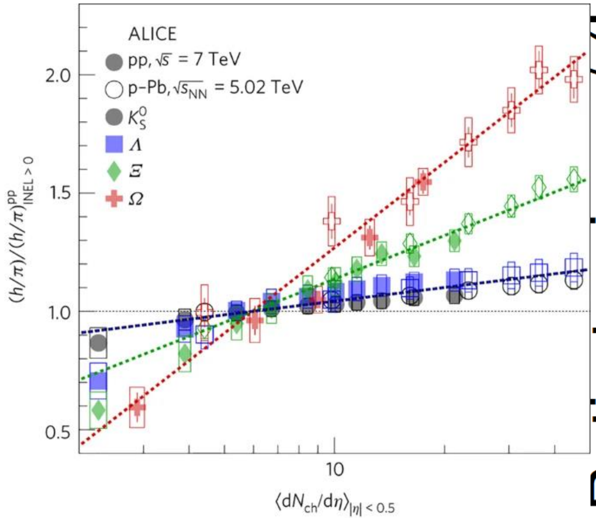

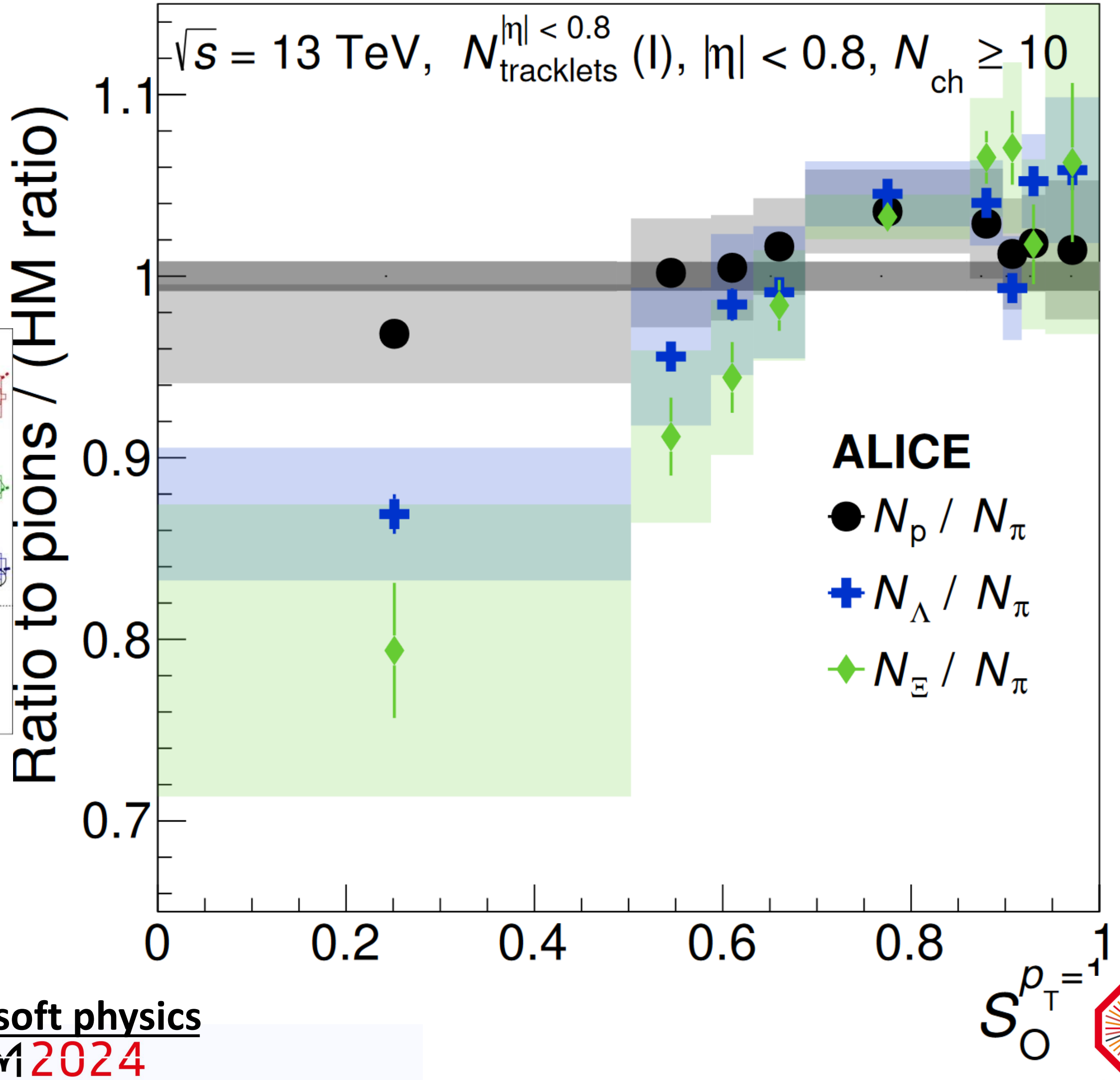

- Reminder: Multiplicity fluctuates at roughly 15%!
  - Equivalent suppression by $\langle dN/d\eta \rangle$ would require 200-300% shift in multiplicity!
- **Strangeness enhancement: seemingly property of UE/soft physics**

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- Quantitative estimate:
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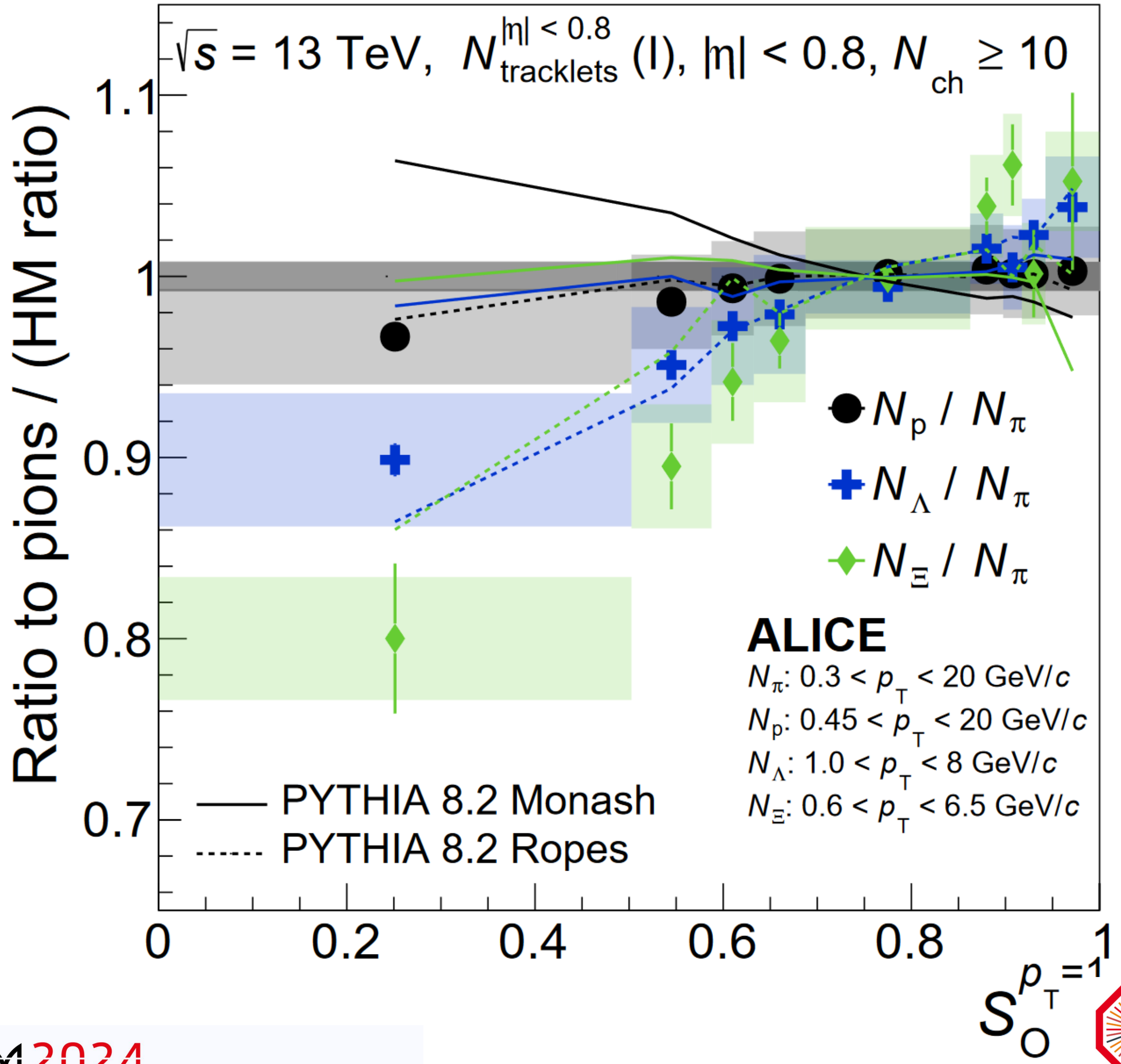
  - ➢ PYTHIA 8.2 Ropes predicts qualitative trend, but not correcting strangeness ordering



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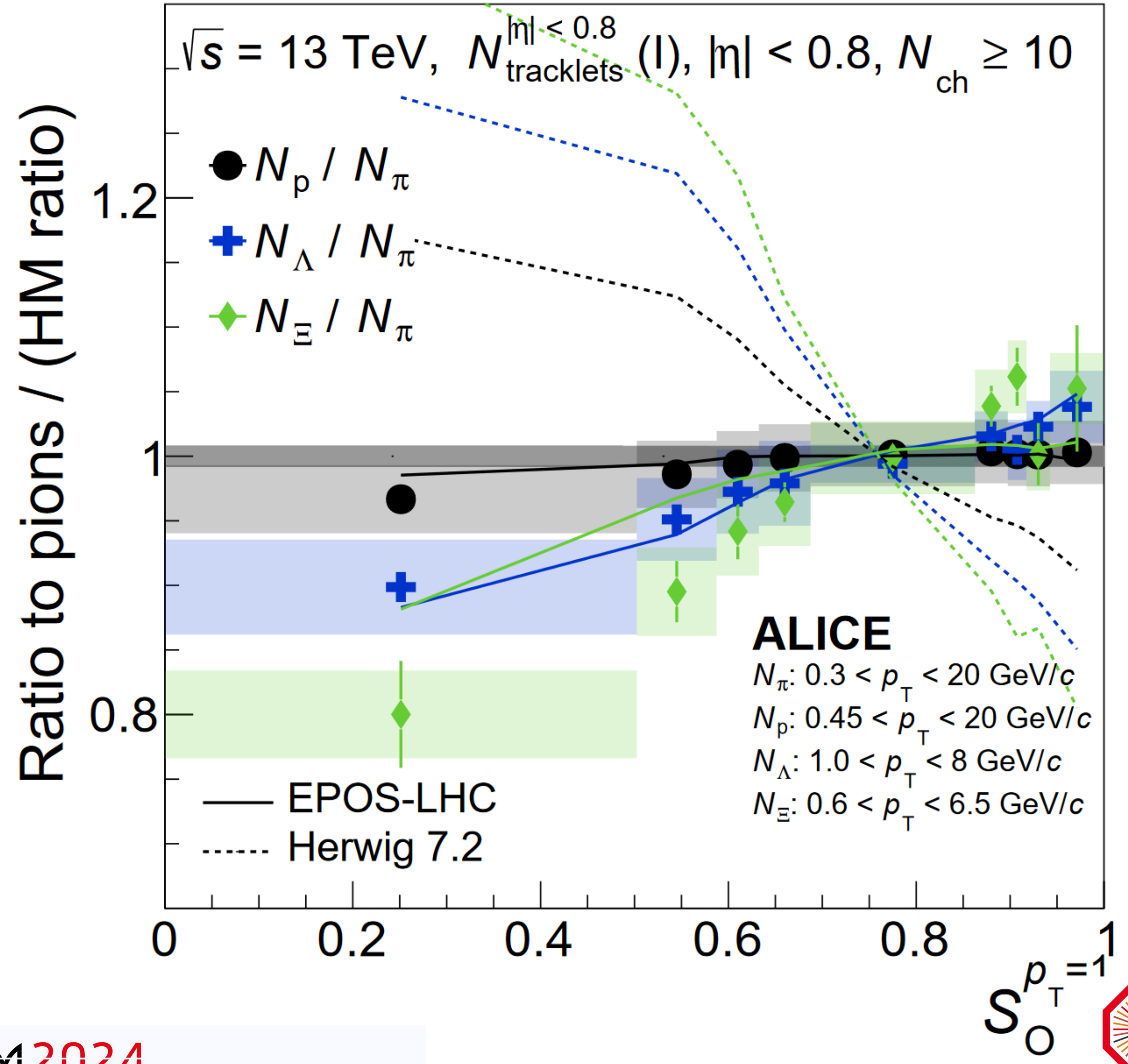
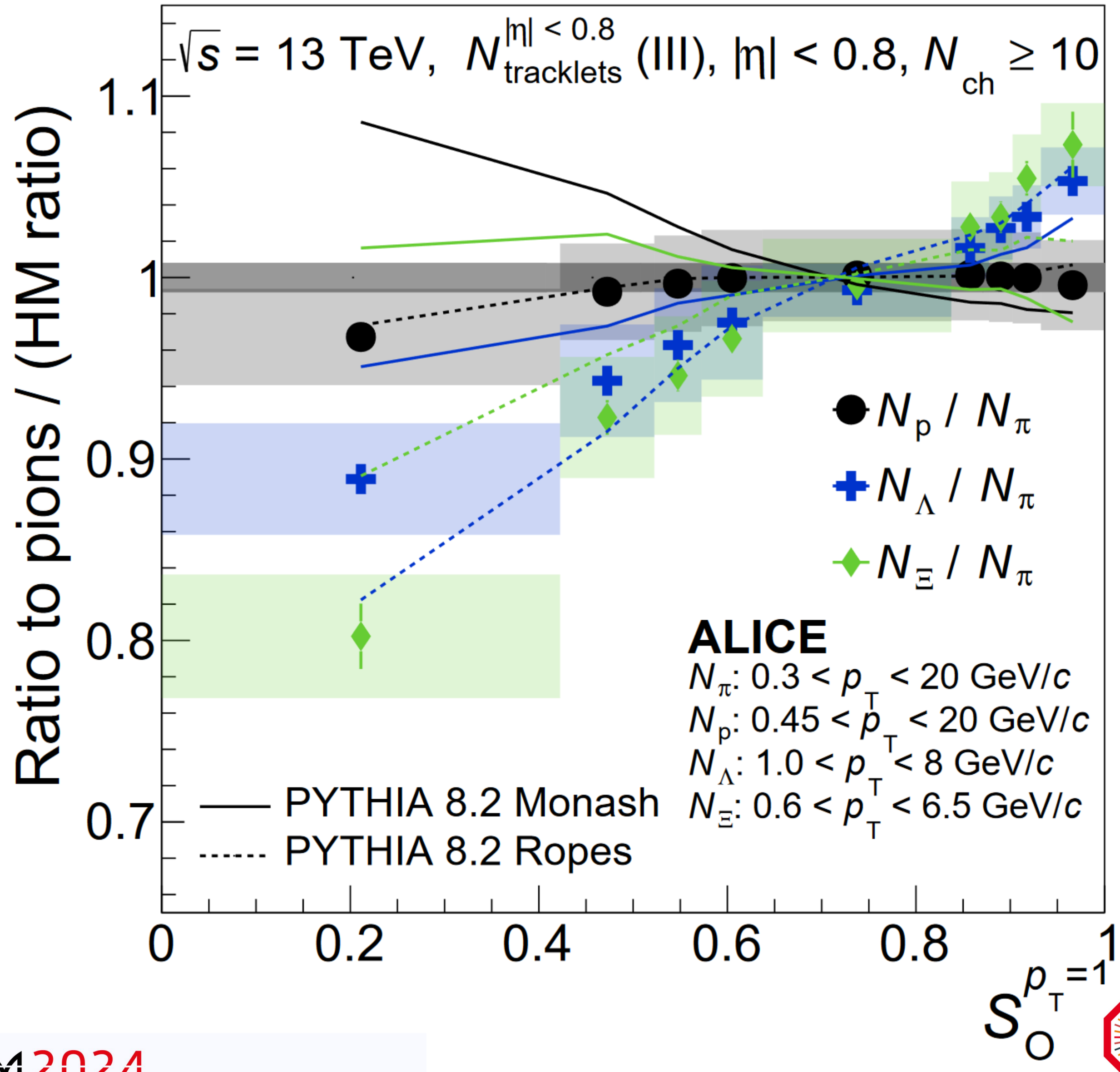
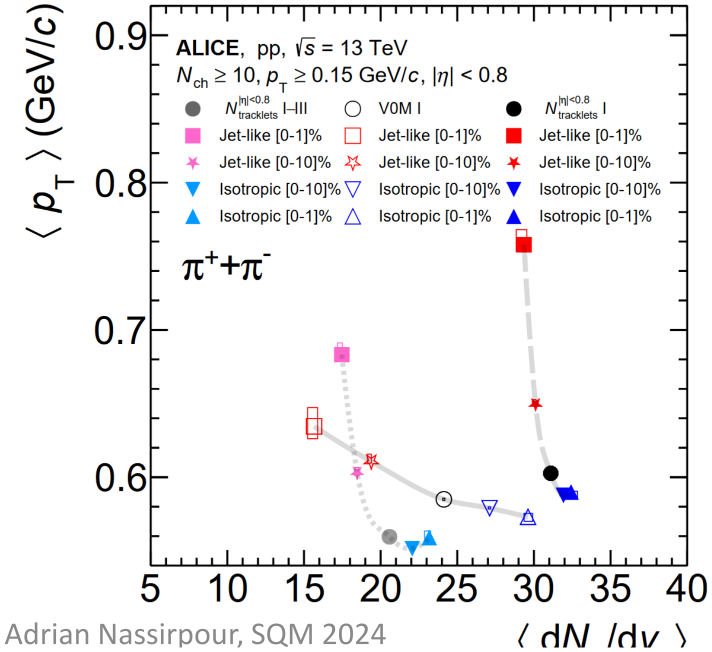
- Quantitative estimate:
  - Allows for precise MC-to-Data comparison
  - PYTHIA 8.2 Ropes predicts qualitative trend, but not correcting strangeness ordering
  - Same applies for EPOS
  - Herwig 7.2 and PYTHIA 8.2 Monash are unable to capture trends



Results: $S_0^{p_T=1}$ integrated particle ratios with broader multiplicity intevals

- From $N_{\text{tracklets}}^{|\eta|<0.8}$ $\mathbf{0-1\%}$ $\mathbf{(I)}$ to $N_{\text{tracklets}}^{|\eta|<0.8}$: $\mathbf{0-10\%}$ $\mathbf{(III)}$
  - ➢ Multiplicity constraint slightly relaxed
  - ➢ Steeper curve: quicker suppression/enhancement

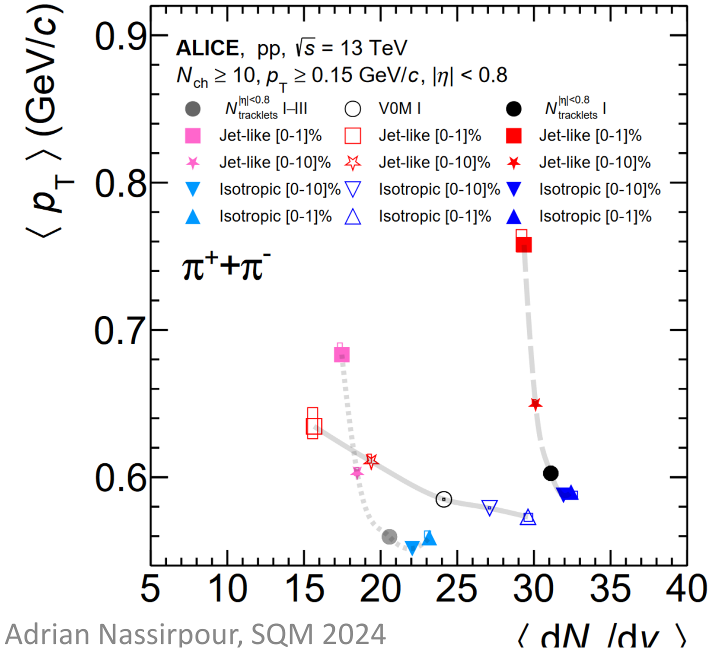


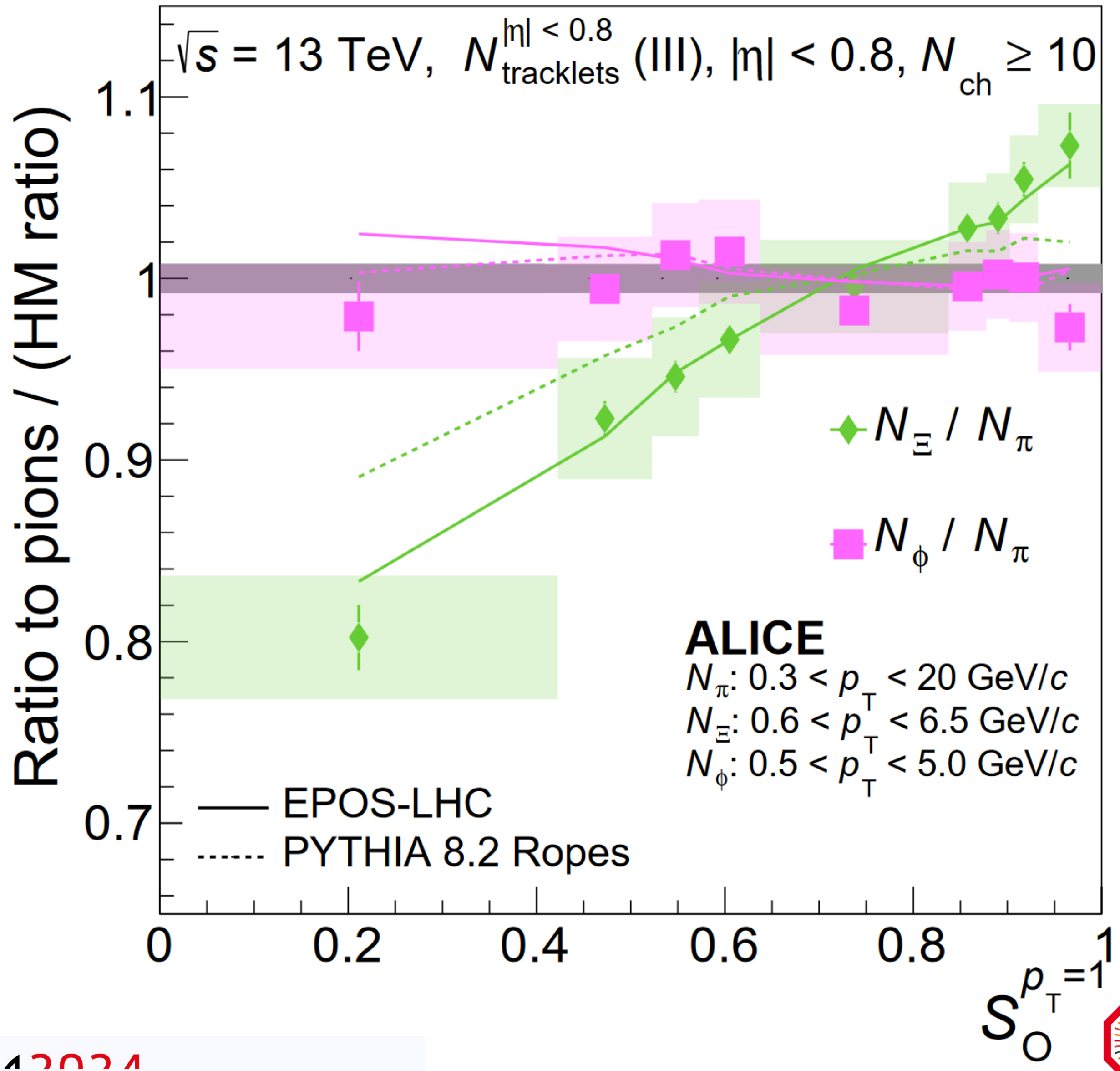


Results: $S_0^{p_T=1}$ integrated particle ratios with broader multiplicity intevals

- From $N_{\text{tracklets}}^{|\eta|<0.8}$ $\mathbf{0-1\%}$ **(I)** to $N_{\text{tracklets}}^{|\eta|<0.8}$: $\mathbf{0-10\%}$ **(III)**
  - ➢ Multiplicity constraint slightly relaxed
  - ➢ Steeper curve: quicker suppression/enhancement

➢ Allows us to probe the integrated ϕ ratio
  - ➢ In the context of $S_0^{p_T=1}$, ϕ exhibits characteristics of an (|S|=0) particle





Summary

- How homogenous are high-multiplicity pp collisions?
  - ➢ Topologies driven by soft physics are consistent with the average high-multiplicity event
  - ➢ "Jet-like" topologies seem to be clear outliers

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    at a much lower rate than the average high-multiplicity event
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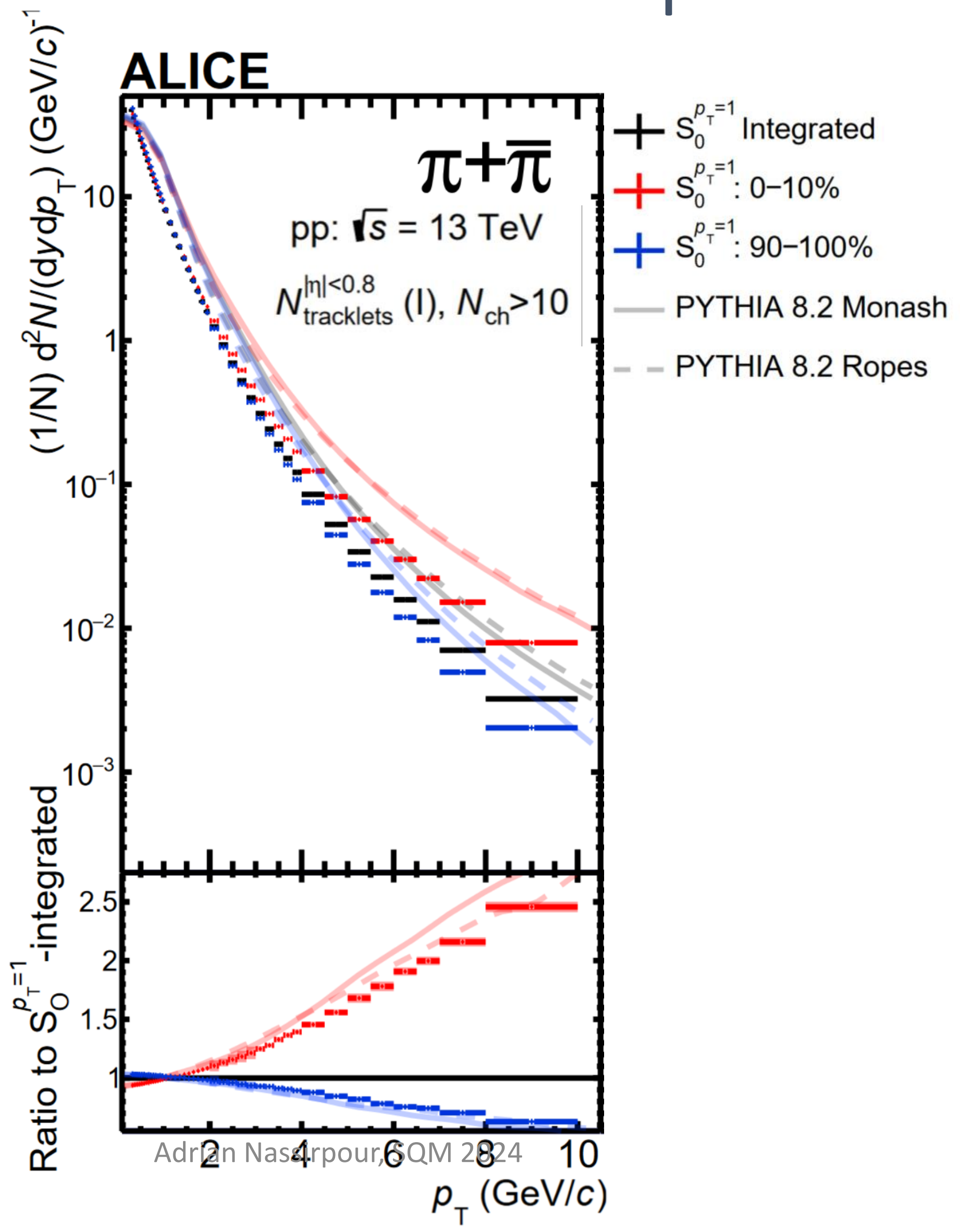
- Outlook: several new $S_0^{p_\mathrm{T}=1}$ ALICE analyses currently underway!
  - Heavy-flavor sector: Λ_c resonance and D-meson studies as a function of $S_0^{p_\mathrm{T}=1}$
  - $S_0^{p_\mathrm{T}=1}$ -dependent two-particle correlation studies

Thank you for your attention!!!

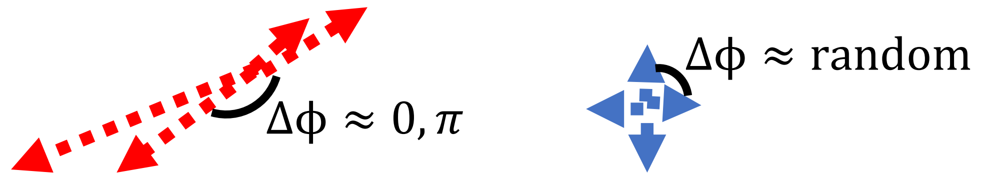
ALICE

BACKUP SLIDES

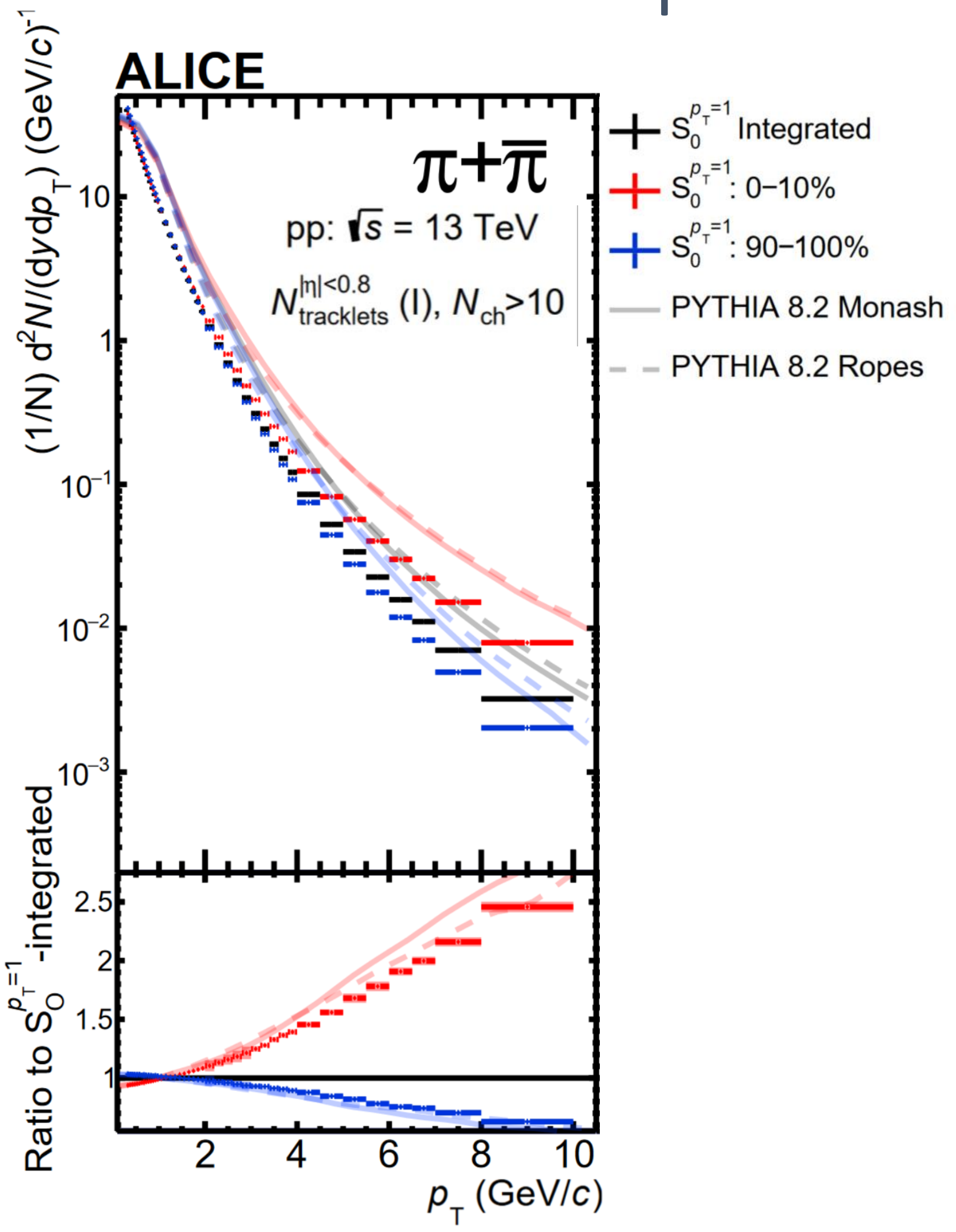
Transverse spherocity - p_T spectra



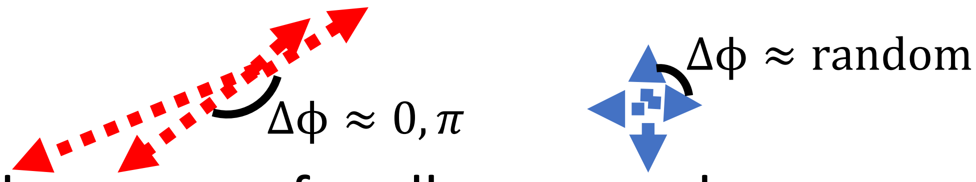
- Pion production is suppressed at low-pt, but enhanced at high-pt for jetty events
- Vice-versa for Isotropic events
- Suggests general hardening of the spectra in Jetty events



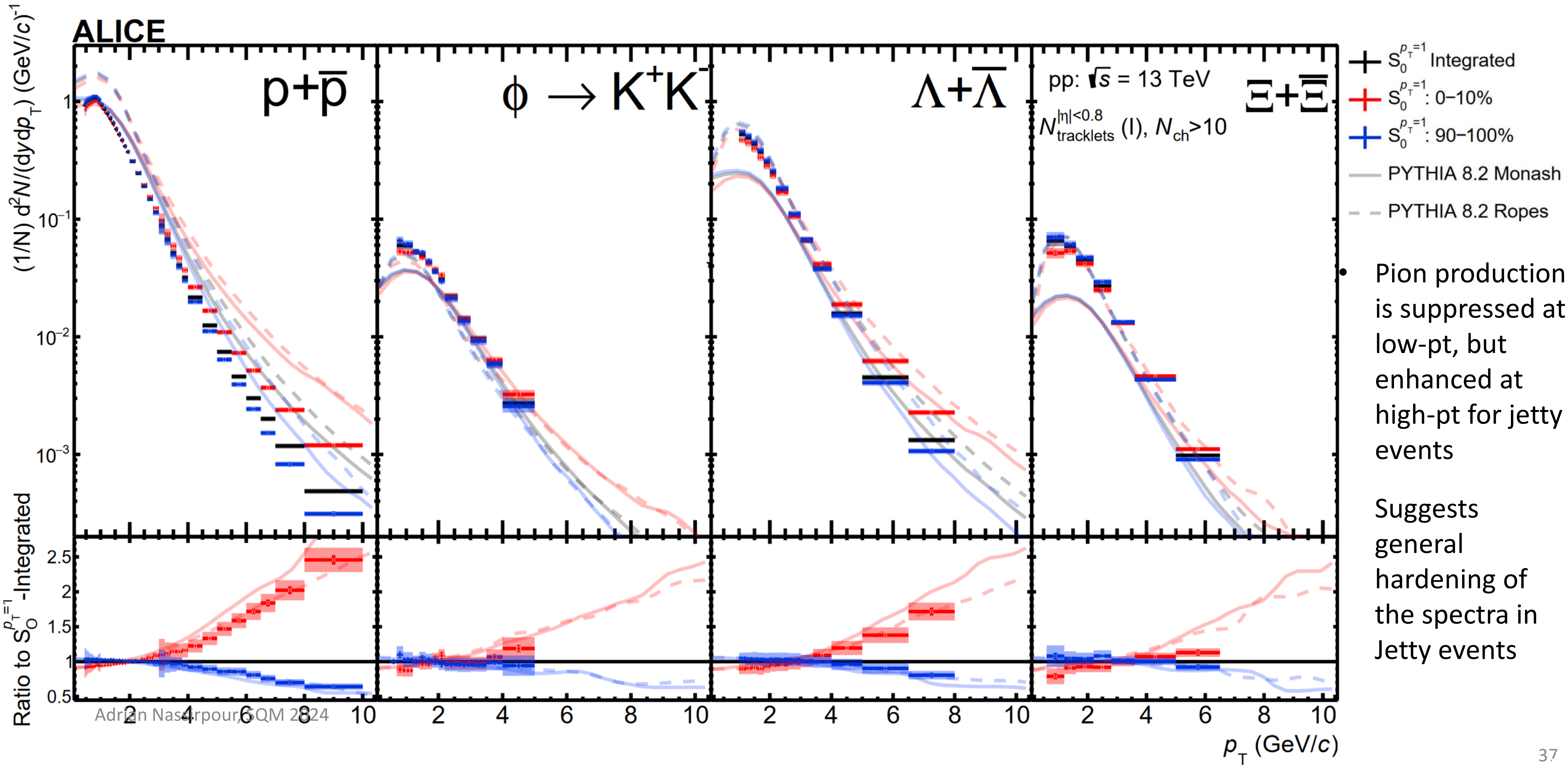
Transverse spherocity - p_T spectra



- Pion production is suppressed at low-pt, but enhanced at high-pt for jetty events
- Vice-versa for Isotropic events
- Suggests general hardening of the spectra in Jetty events
- The same trends are seen for all measured particle species



Transverse spherocity - p_T spectra



- Pion production is suppressed at low-pt, but enhanced at high-pt for jetty events

Suggests general hardening of the spectra in Jetty events

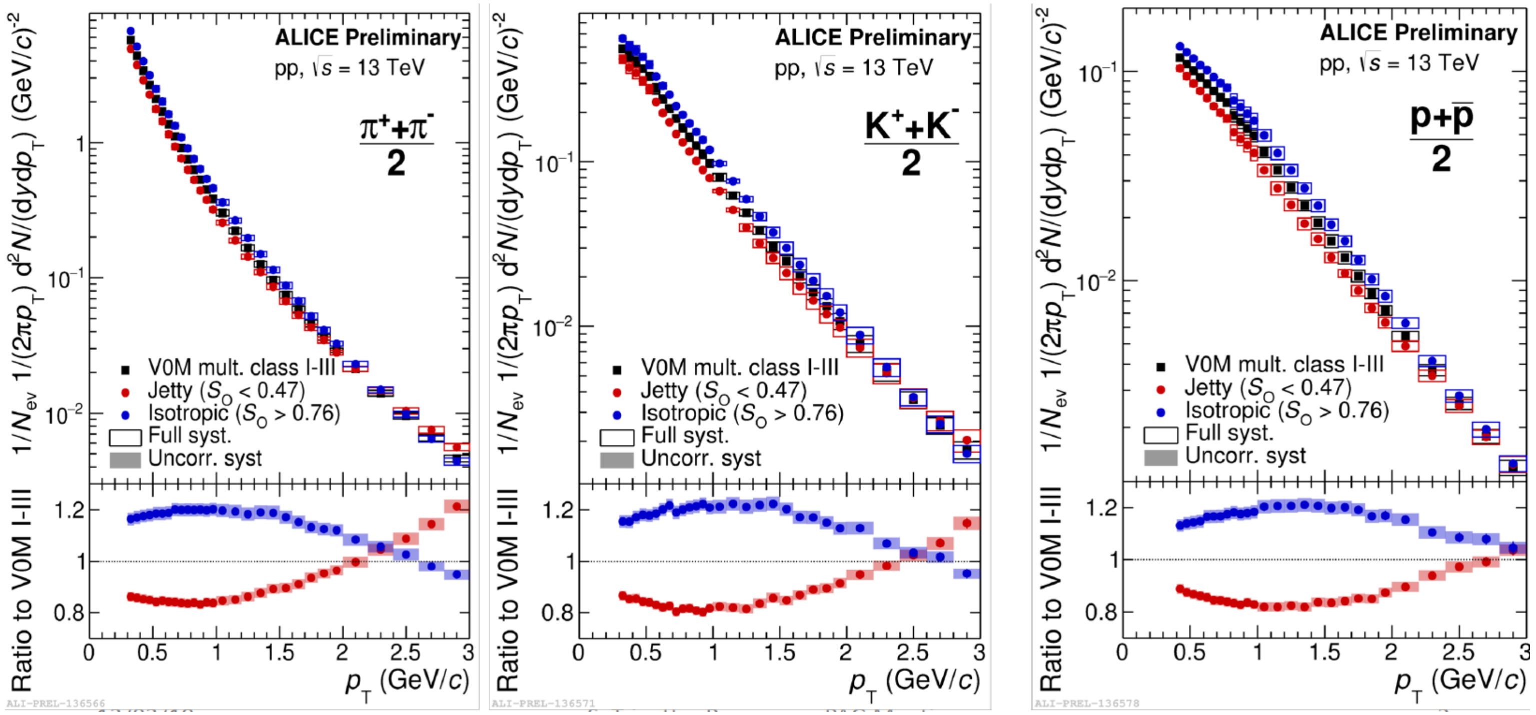
Identified Vs Unidentified Hadrons

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

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

$\times$

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



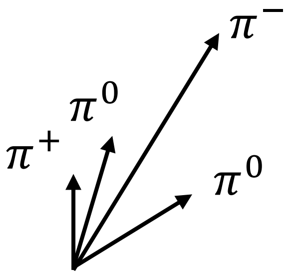
- Primary Unidentified hadrons enter both the yield extraction and S_O
- This also applies to $\pi/K/P$
- **But this does NOT apply to Ξ!**
- ϕ enters twice! $(K^+ K^-)$

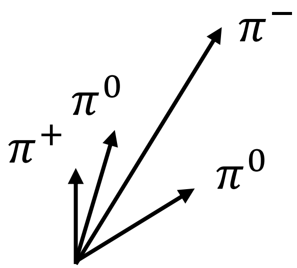
Unweighed Transverse Spherocity $S_O^{p_T=1}$

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

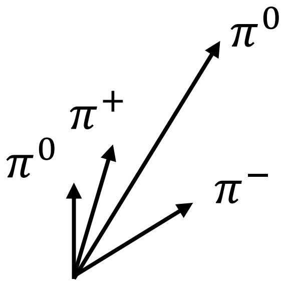
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

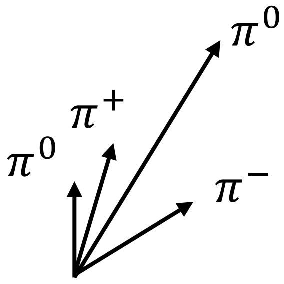
$S_{O,1}$





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





$S_{O,2}$

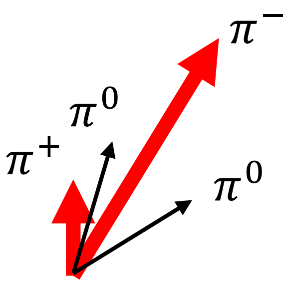
$S_{O,2}^{p_T=1}$

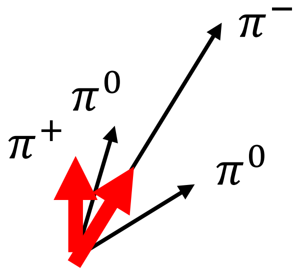
Unweighed Transverse Spherocity $S_O^{p_T=1}$

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

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

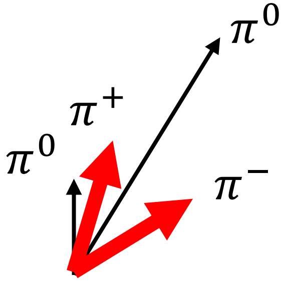
$S_{O,1}$

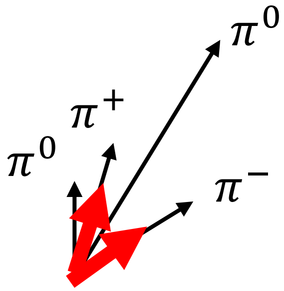




$S_{O,1}^{p_T=1}$

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





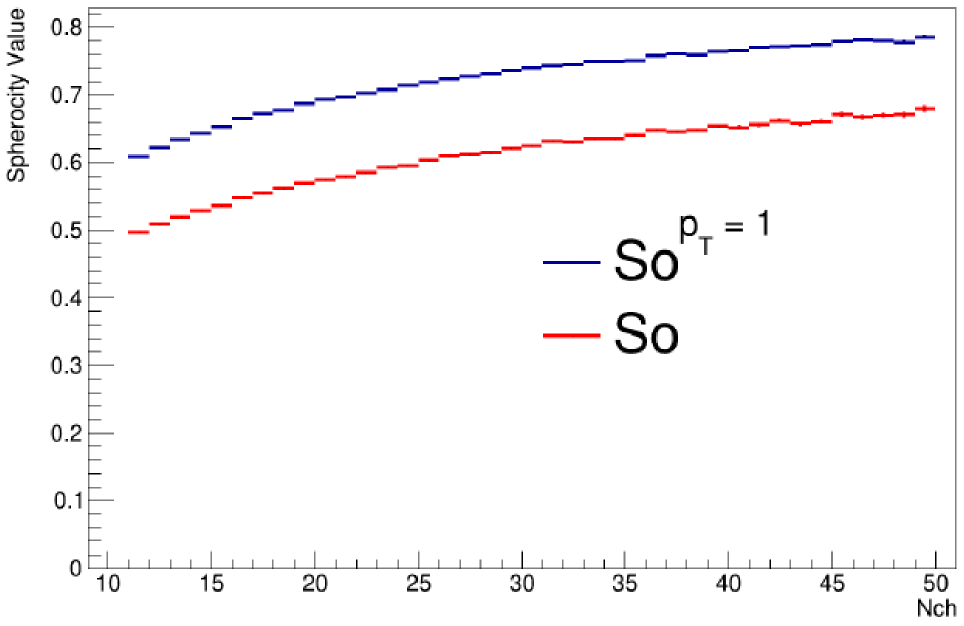
$S_{O,1}^{p_T=1}$ and $S_{O,2}^{p_T=1}$ will describe two similar topologies.

$S_{O,2}$

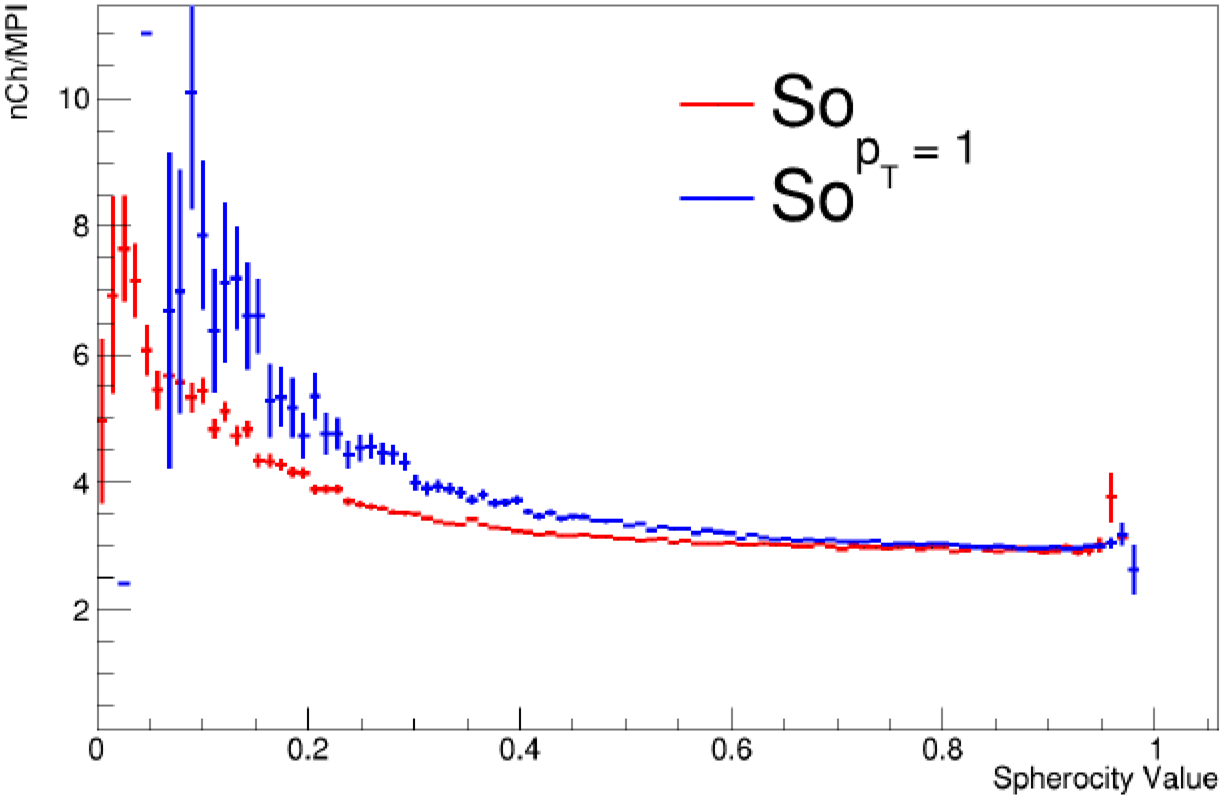
$S_{O,2}^{p_T=1}$

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

Qualitatively similar
Nch distributions

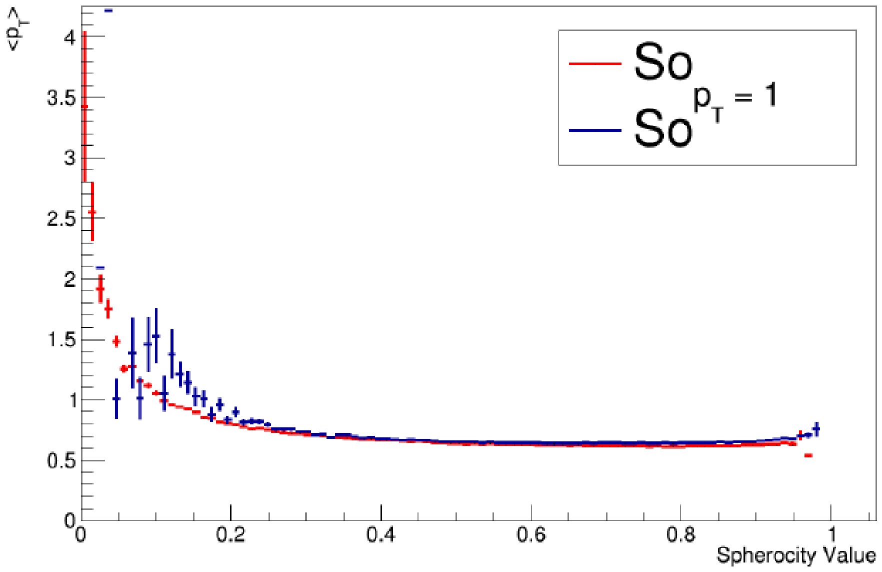


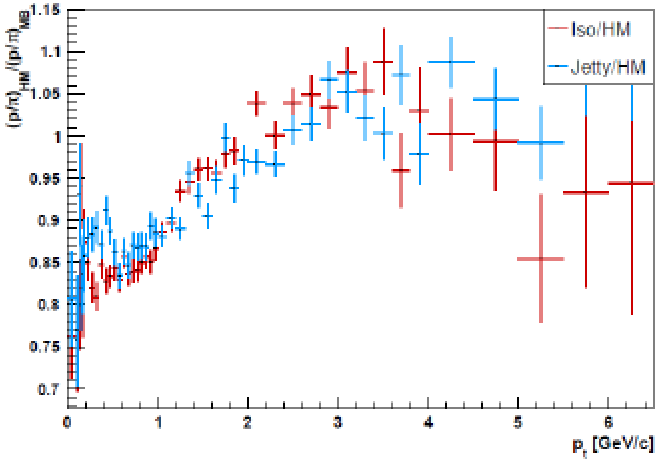
Qualtitatively similar
Nch/MPI distributions



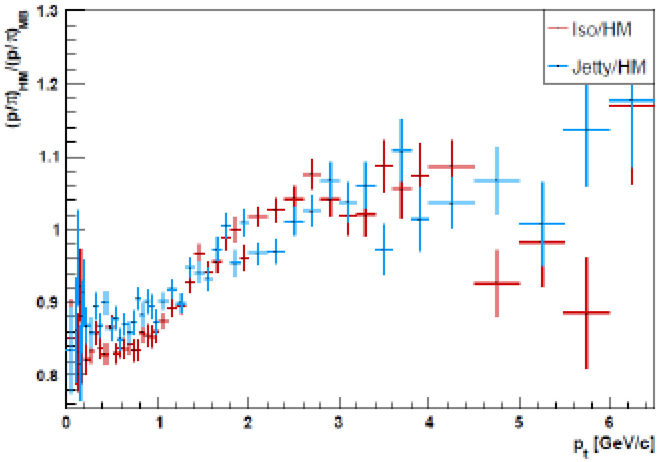
$S_O^{p_T=1}$ MC Studies - $S_O^{p_T=1}$ vs S_O

Qualtitatively similar
<p_T> distributions





(a) Spherocity

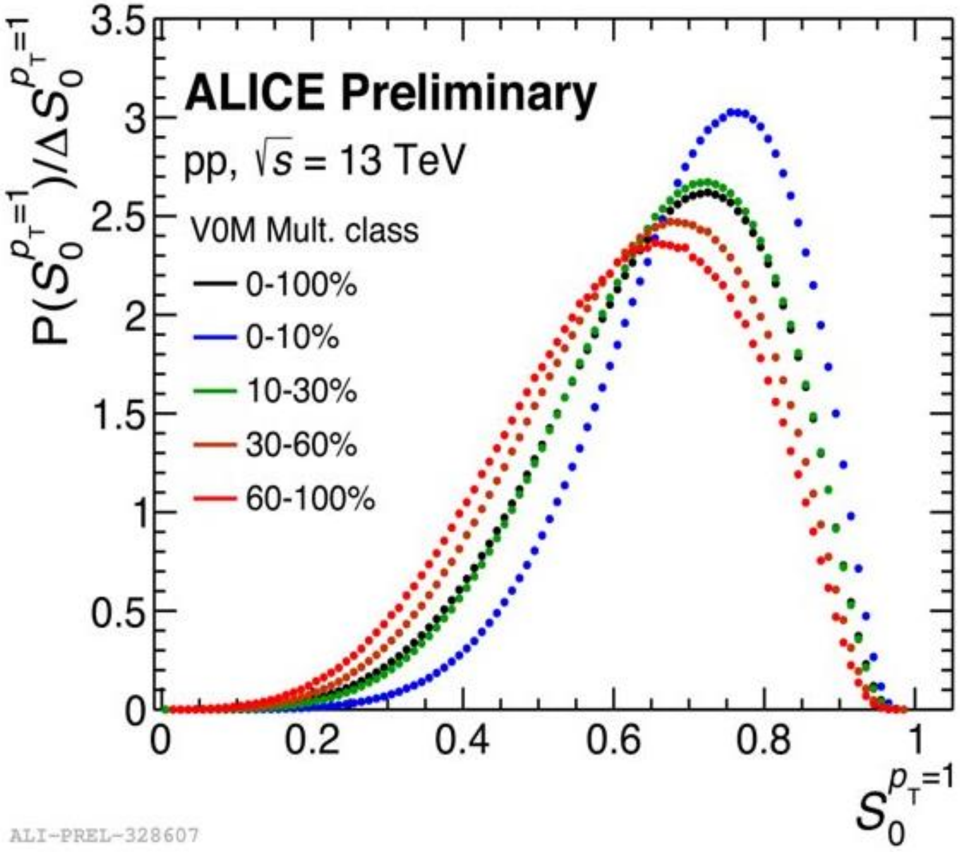


(b) Spherocity $p_T = 1$

Strangeness Enhancement in Different Topologies: Transverse Spherocity S_o

- Probing the strangeness production as a function of the azimuthal event topology.
- Disentangle event into two types:
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events.
    - Particle production driven by multiple soft collisions.

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

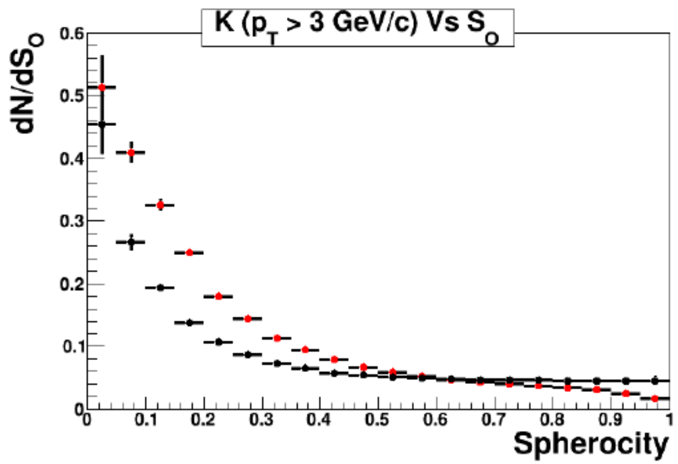


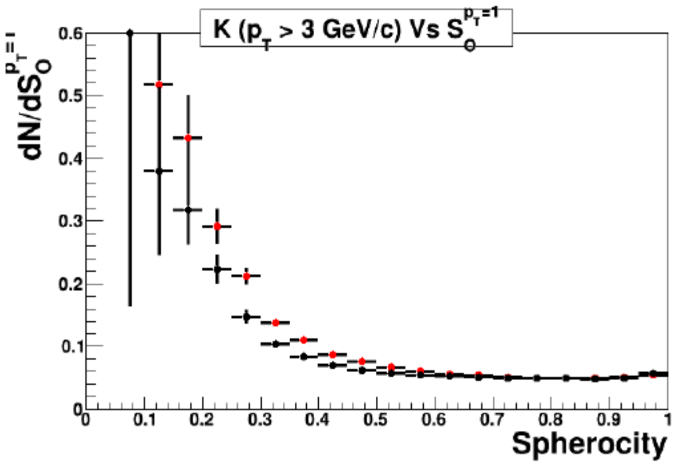
NO TRIGGER, BUT 10 NCH REQUIRMENT + TOP 10% MULTIPLICITY

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

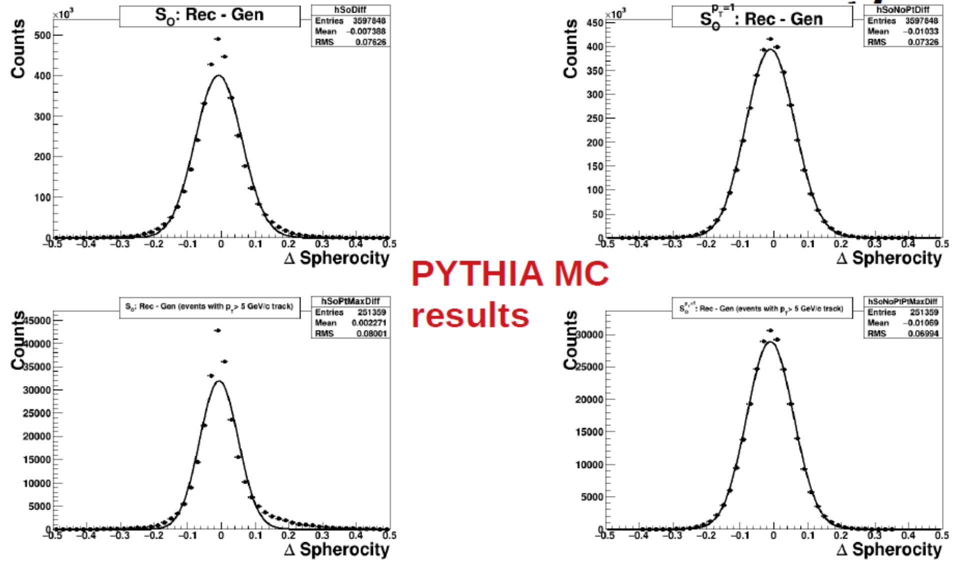
K^+ and K^0_S with p_T>3 GeV/c

PYTHIA MC results (generator level)



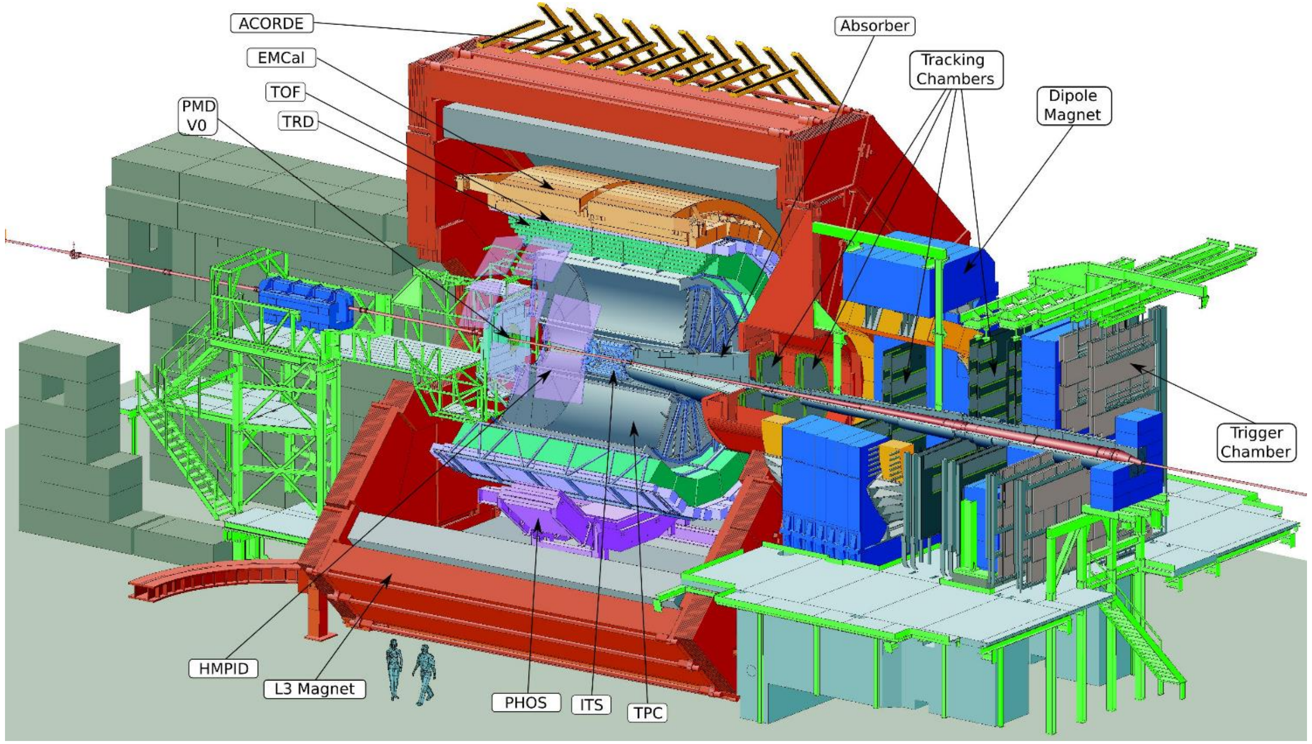


$S_{O,pT=1}$ is more "robust": all particles have same weigth



PYTHIA MC results

ALICE Detector and Rapidity Acceptance.



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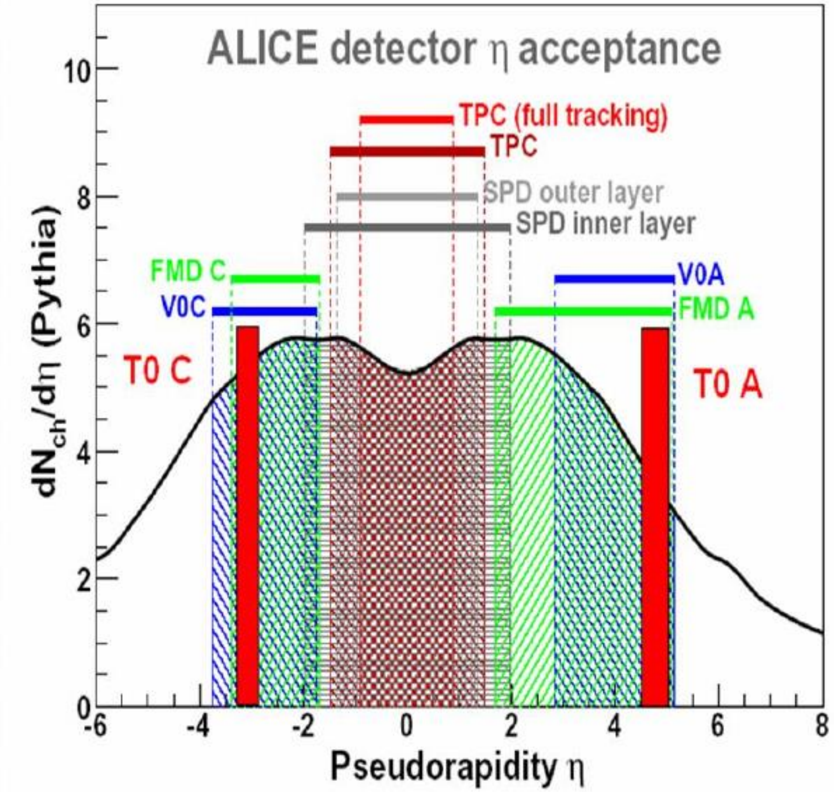

Nucl.Phys.B Proc.Suppl. 179-180 (2008) 196-201