SQM2022

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ALICE

Light-flavor hadron production

Adrian Nassirpour, for the ALICE Collaboration

LUNDS UNIVERSITET

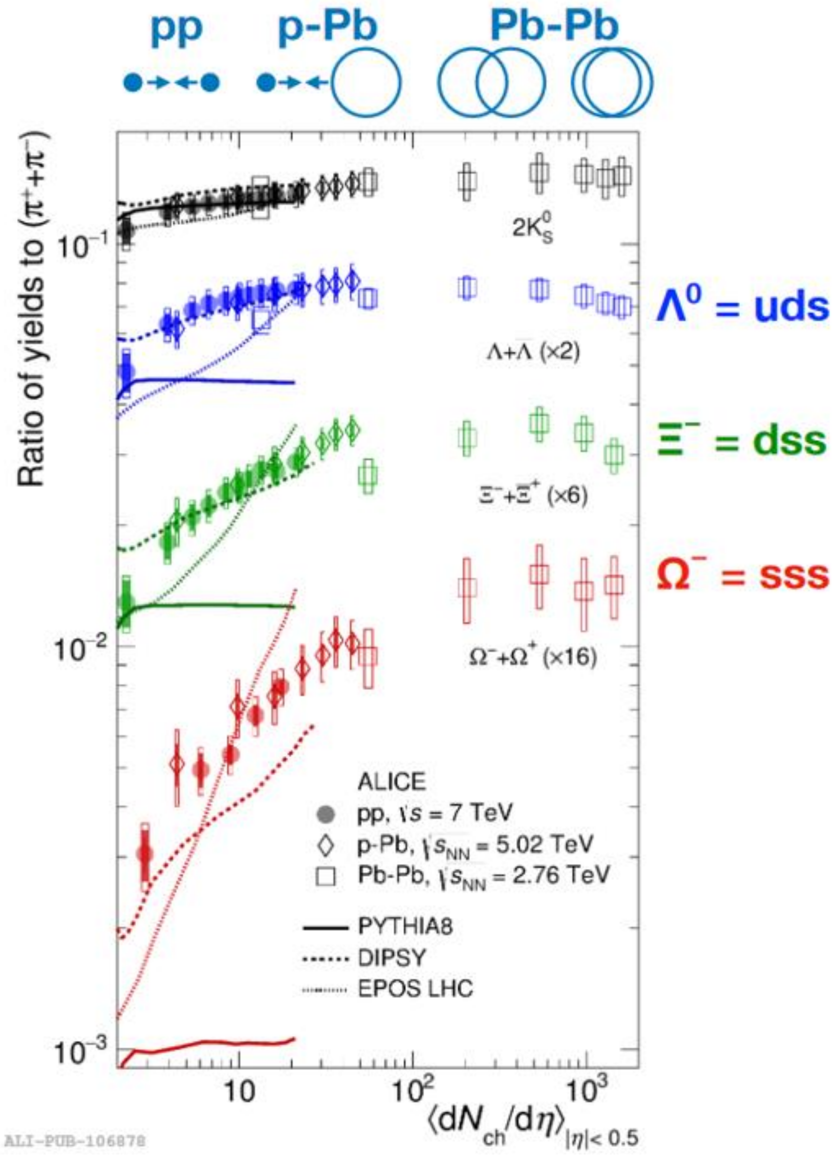
Outline

- This presentation will cover:
  - Neutral meson yields as a function of p_{T} and multiplicity
  - Light-flavor particle production as a function of Unweighted Transverse Spherocity

Light-flavor hadron production as a function of multiplicity

- Light-flavor hadrons: a key tool to study hadronization
- Main focus for this presentation:
  - Light-flavor yield vs. event multiplicity.

Nature Phys **13,** 535–539 (2017)



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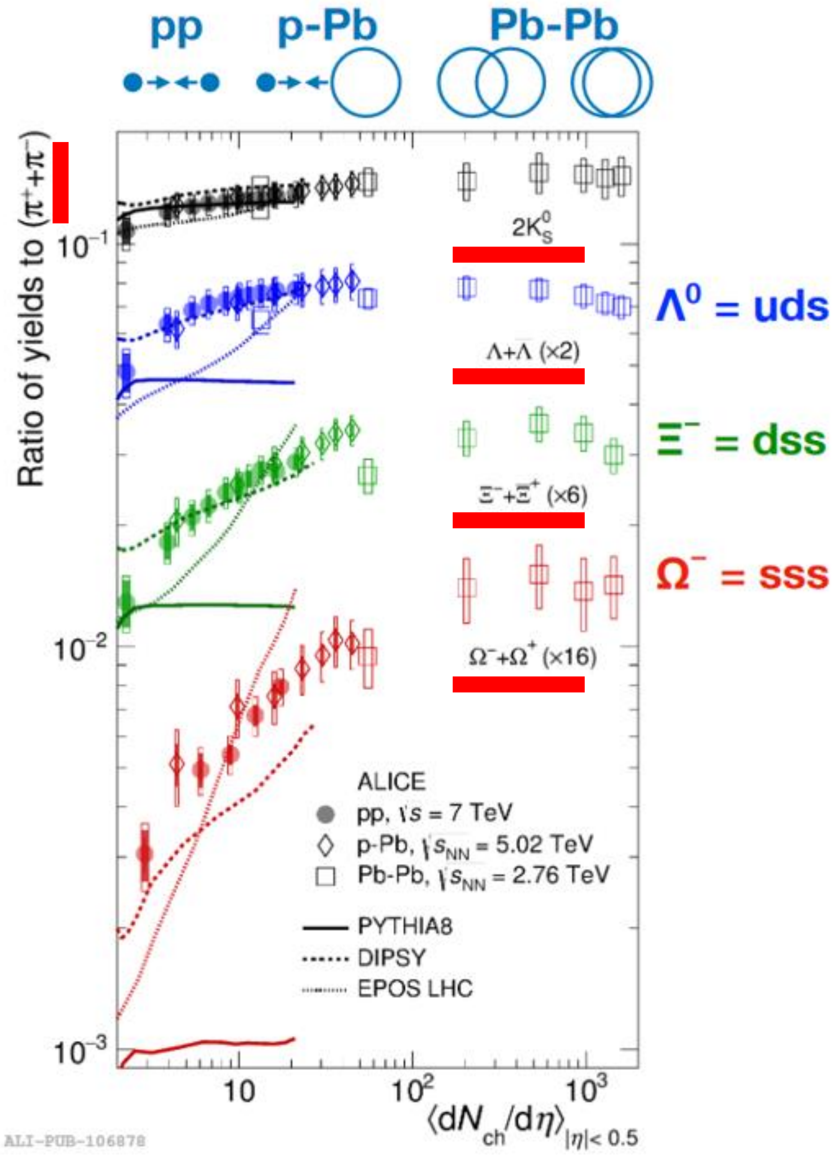

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- Relative yield of strange hadrons to pions (S/π).

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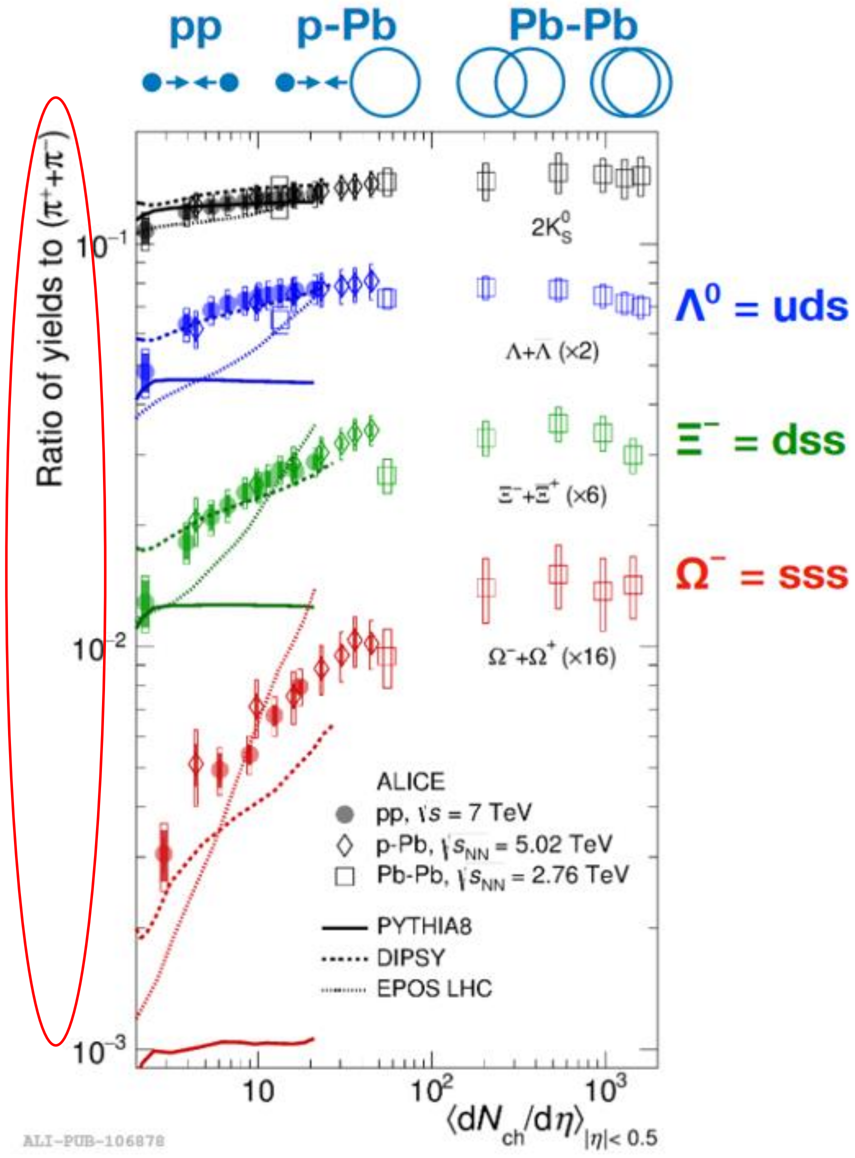

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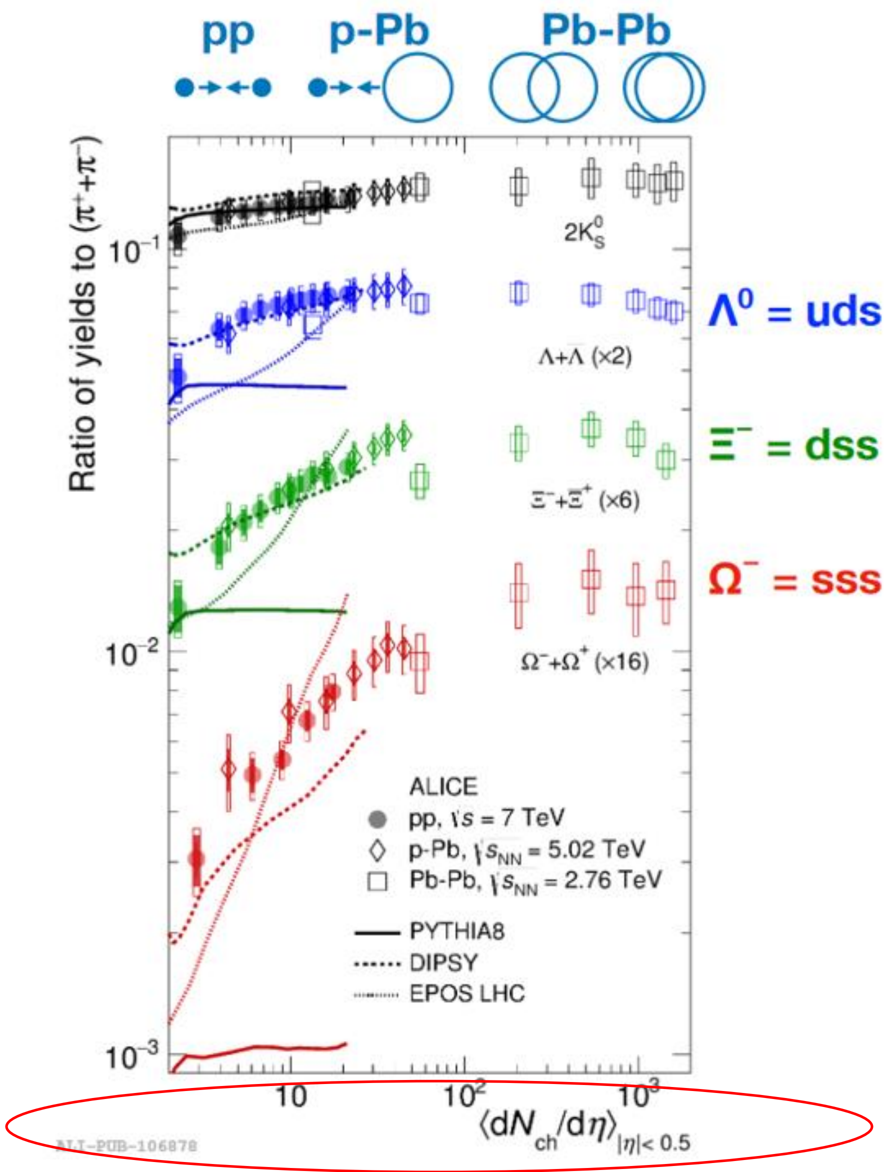

- Relative yield of strange hadrons to pions (S/π).
- The average charged particle-multiplicity measured at midrapidity.

Light-flavor hadron production as a function of multiplicity

- Light-flavor hadrons: a key tool to study hadronization
- Main focus for this presentation:
  - Light-flavor yield vs. event multiplicity.
- In A-A systems, strangeness enhancement could be interpreted as a signature of the formation of a quark–gluon plasma (QGP).
  - Unresolved if this also applies to pp collisions.

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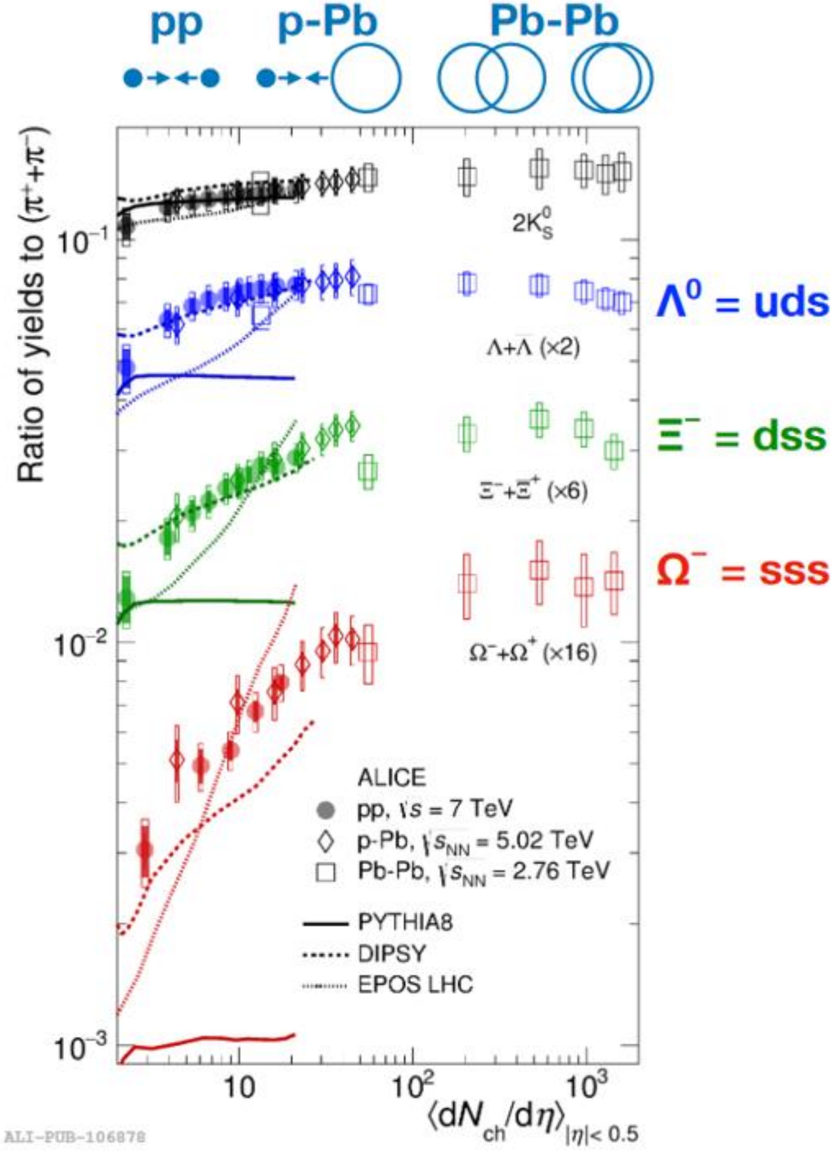

Light-flavor hadron production as a function of multiplicity

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

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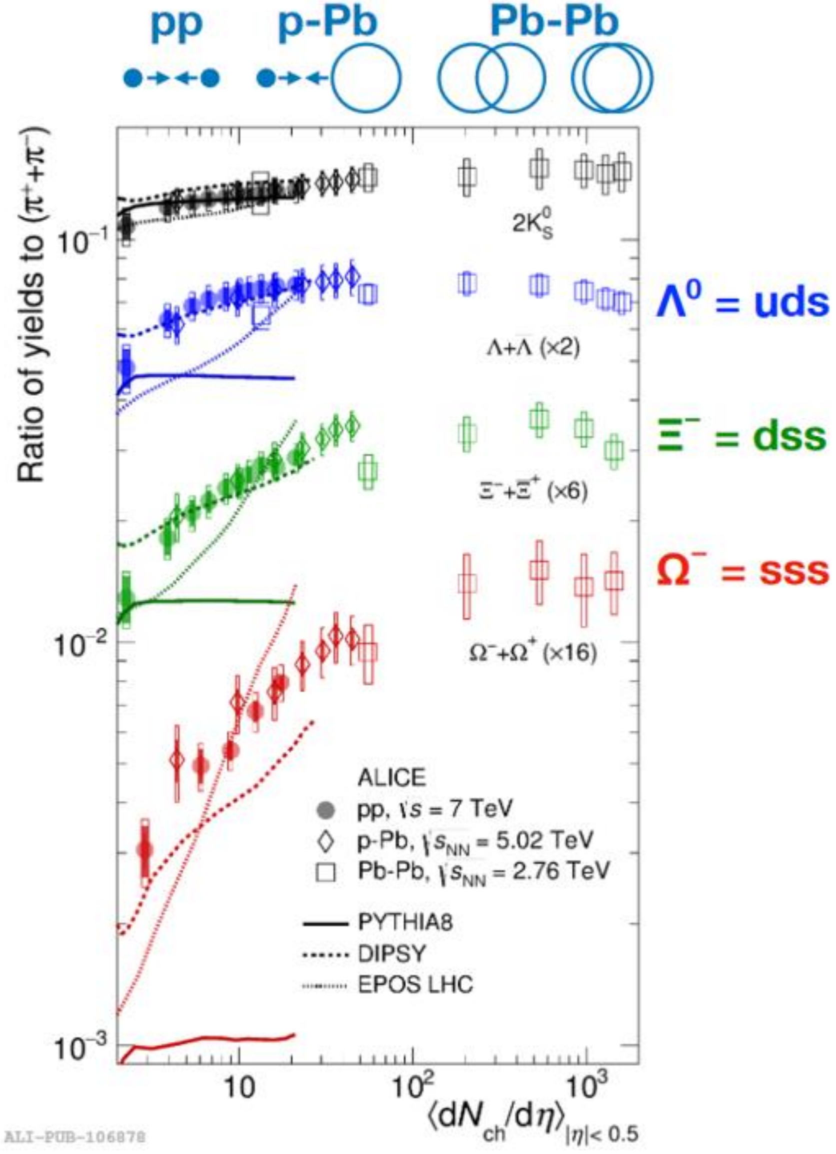

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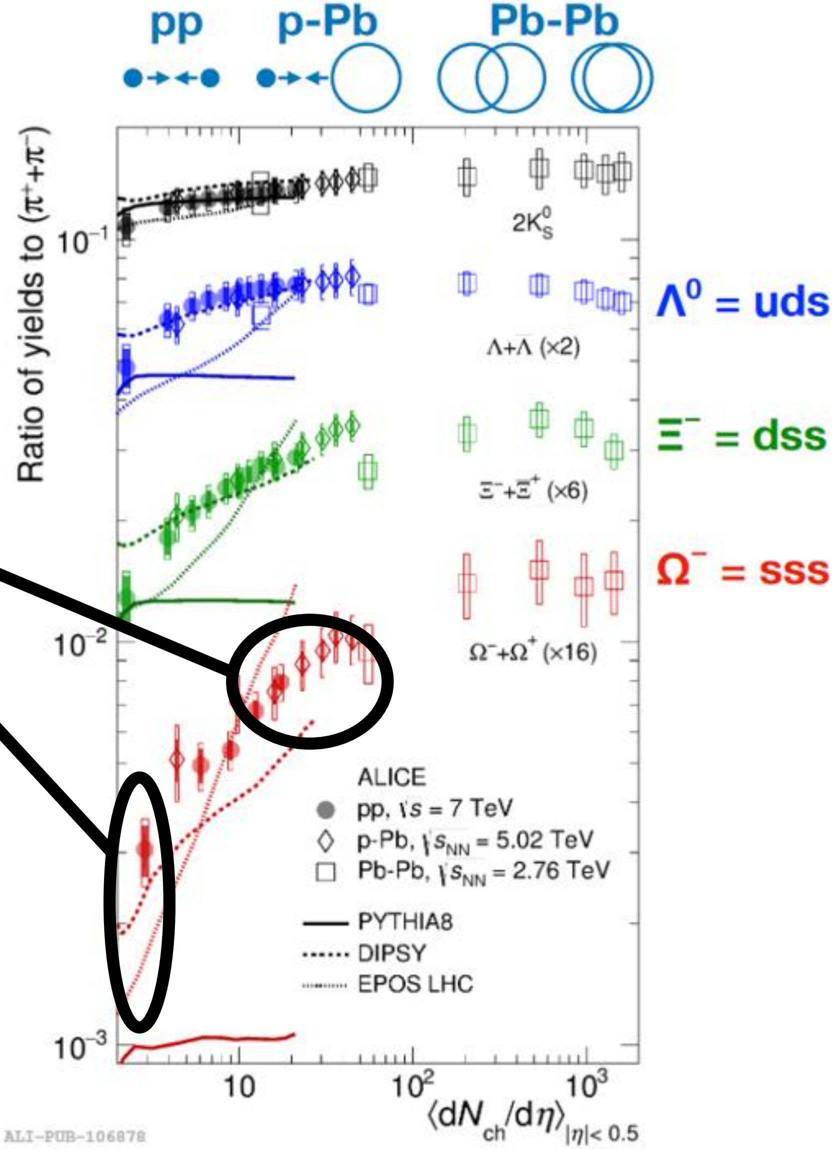

Light-flavor hadron production as a function of multiplicity

- In this context, how can we improve our understanding of light-flavor hadron production?
  - Can these events be characterized by other properties than <dN/dη> production?
  - Do ALL light-flavor particles follow the same trend?

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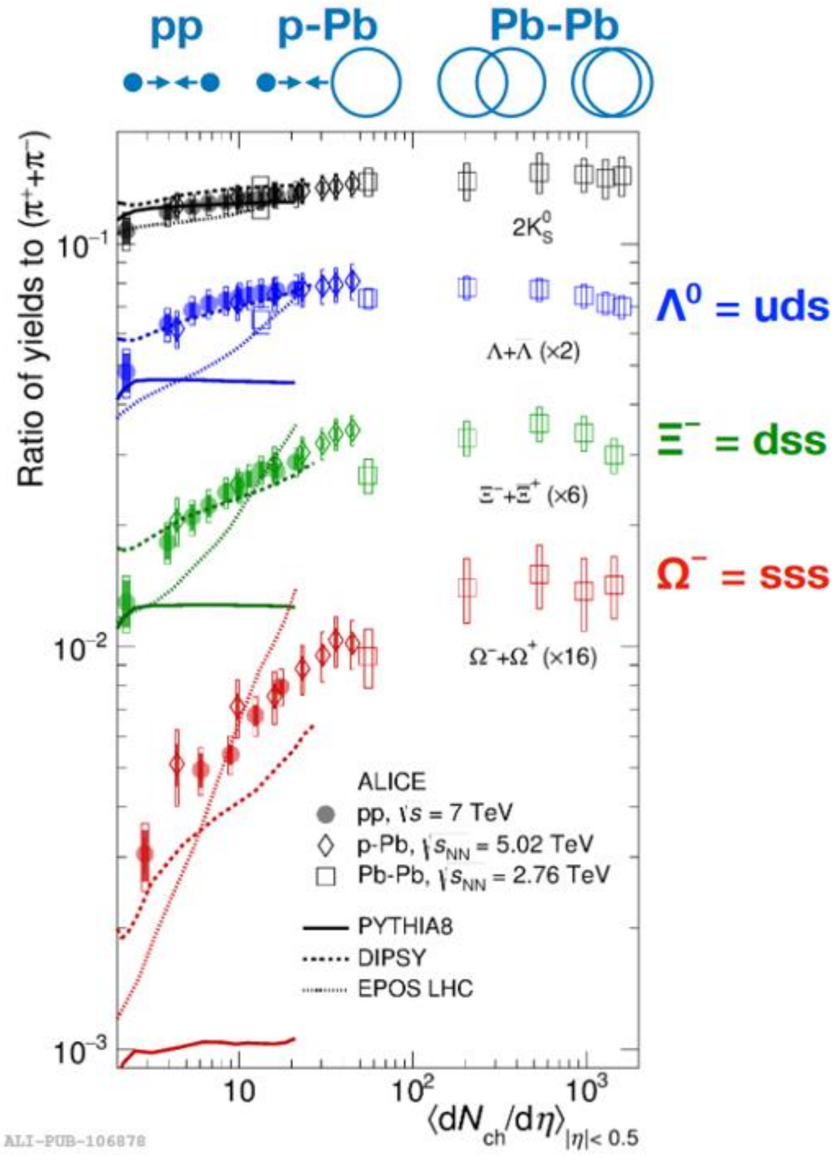
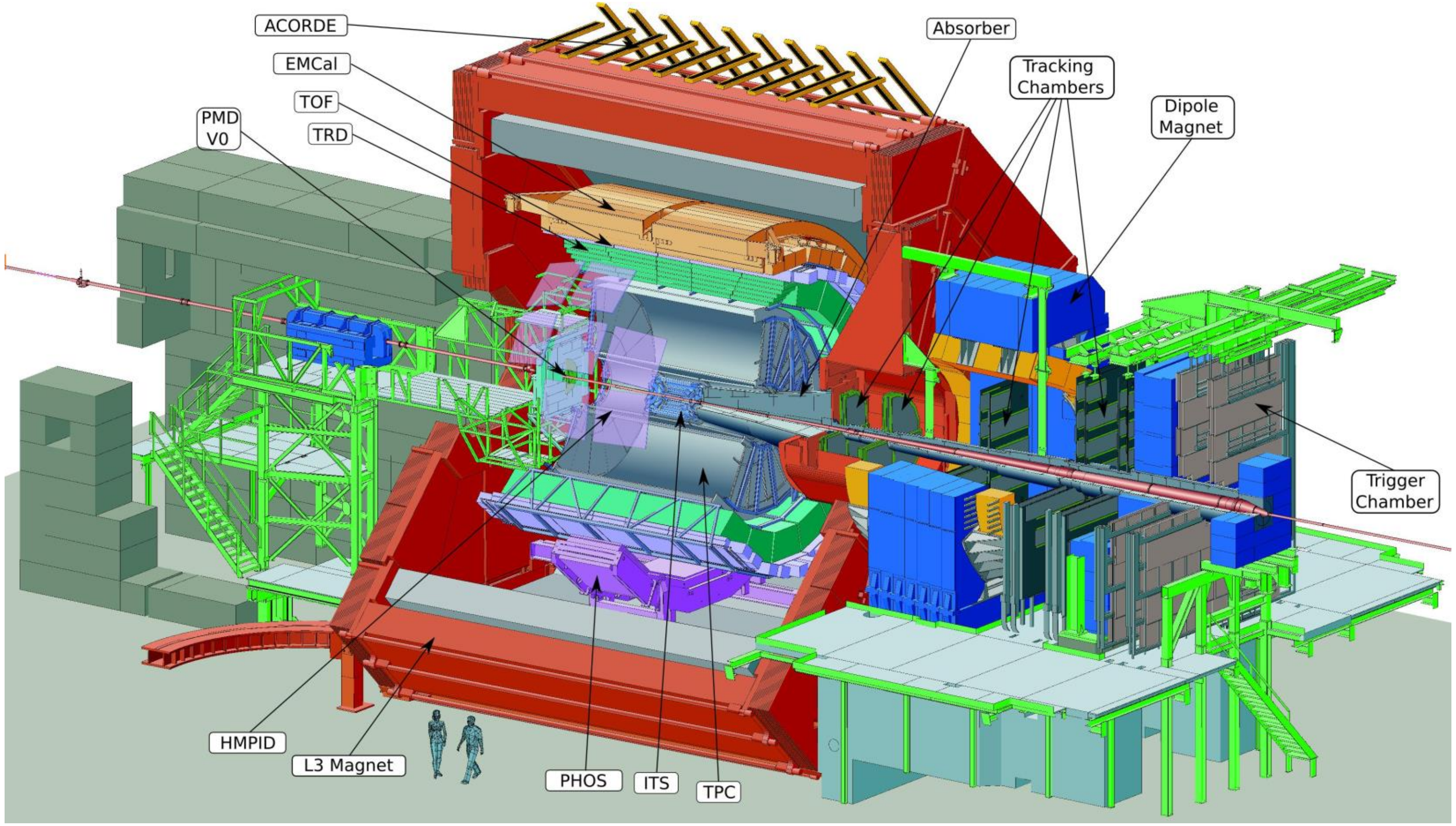


ALICE apparatus

- A large range of subdetectors are utilized in the different measurements presented here:
  - TPC
    - Track reconstruction + PID
  - ITS
    - Track reconstruction + midrapidity multiplicity
  - TOF
    - PID



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    - TPC
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    - PHOS
        - Neutral meson yield
    - EMCal
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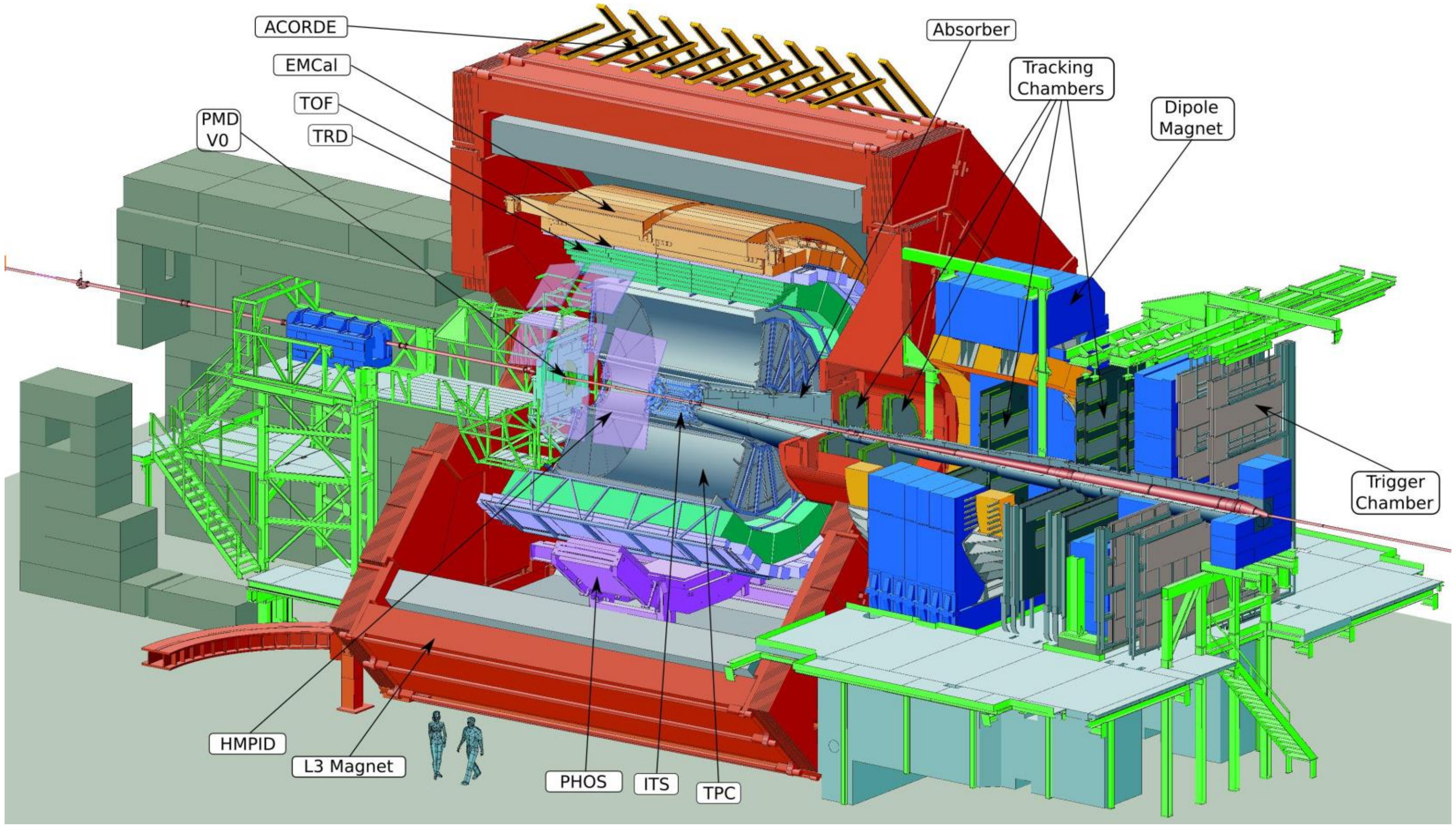

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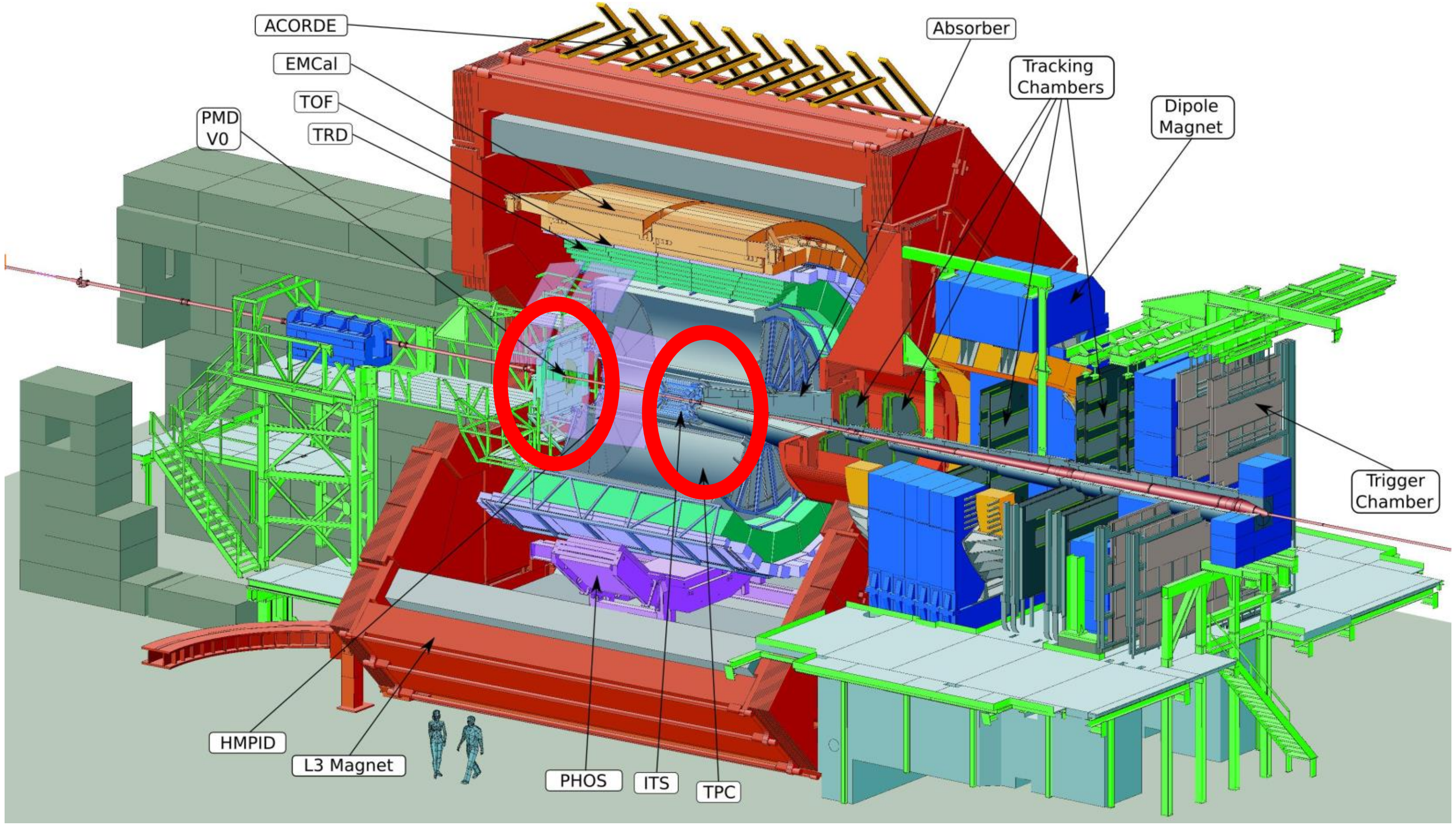
  - V0A/V0C
    - Triggering + forward-rapidity multiplicity.

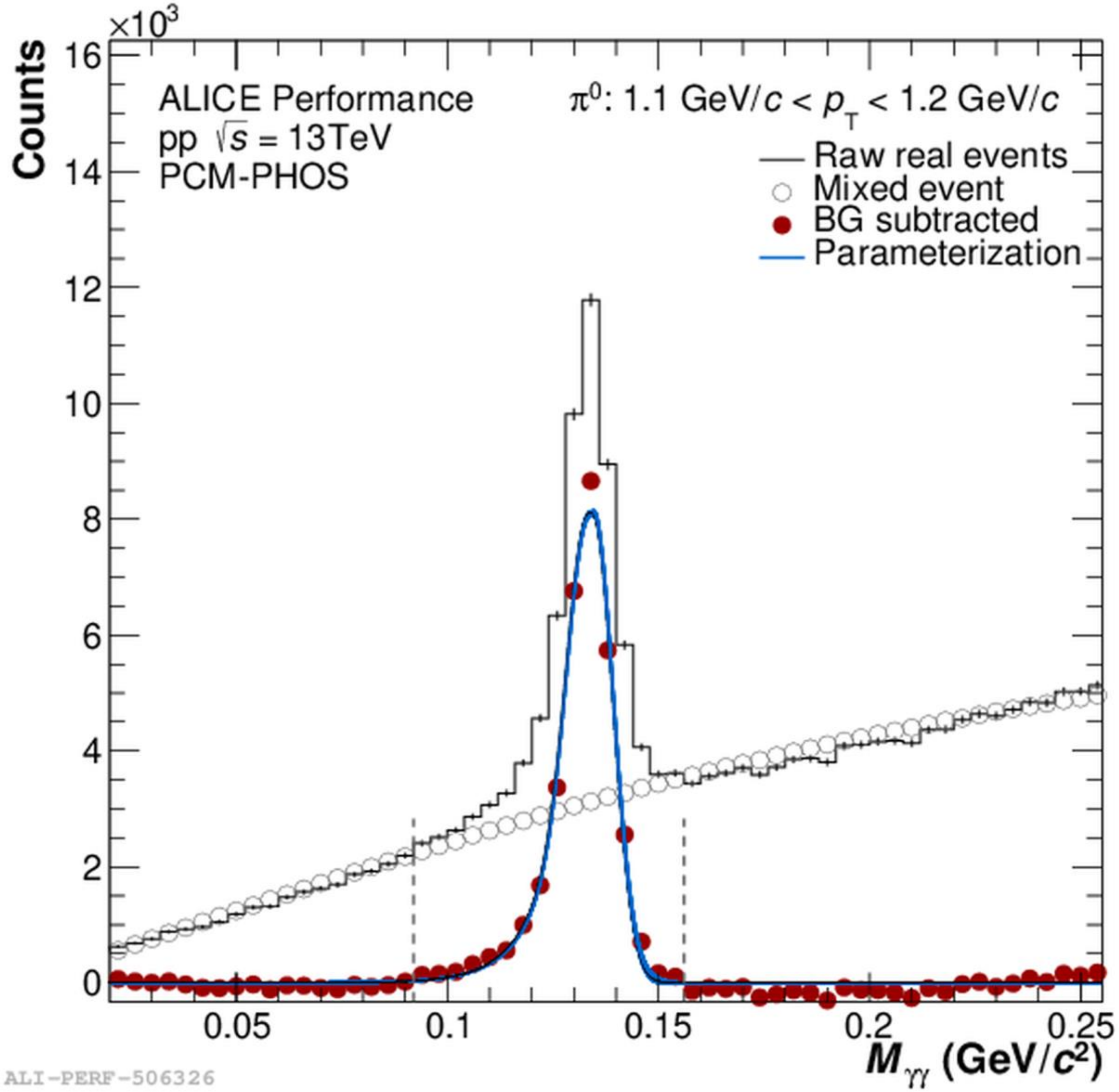


Outline

- This presentation will cover:
  - Neutral meson yields as a function of multiplicity
  - Light-flavor particle production as a function of Unweighted Transverse Spherocity

Neutral meson production: analysis details

- The η and π^0 mesons are reconstructed by calculating invariant masses of photon pairs.



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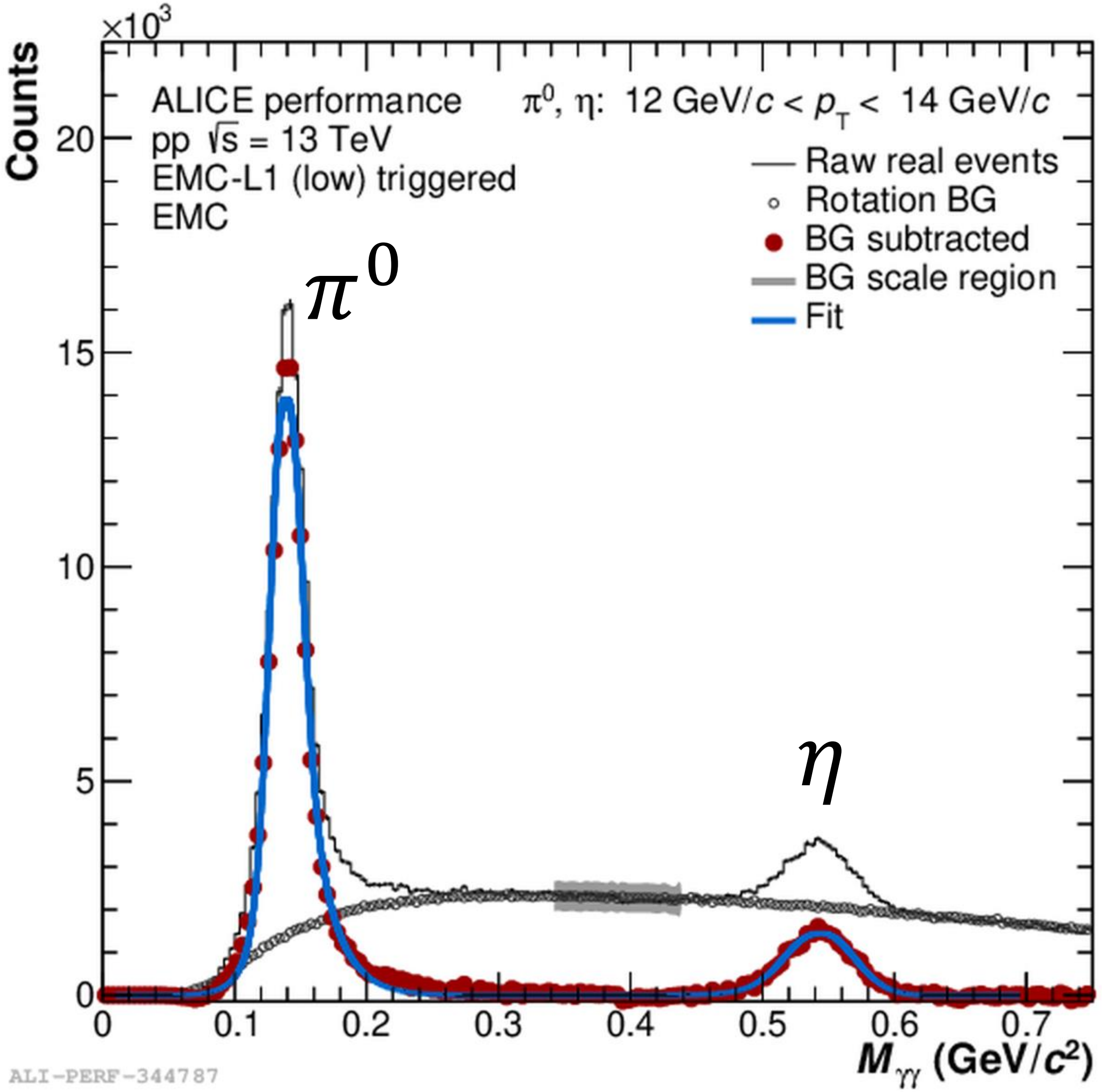
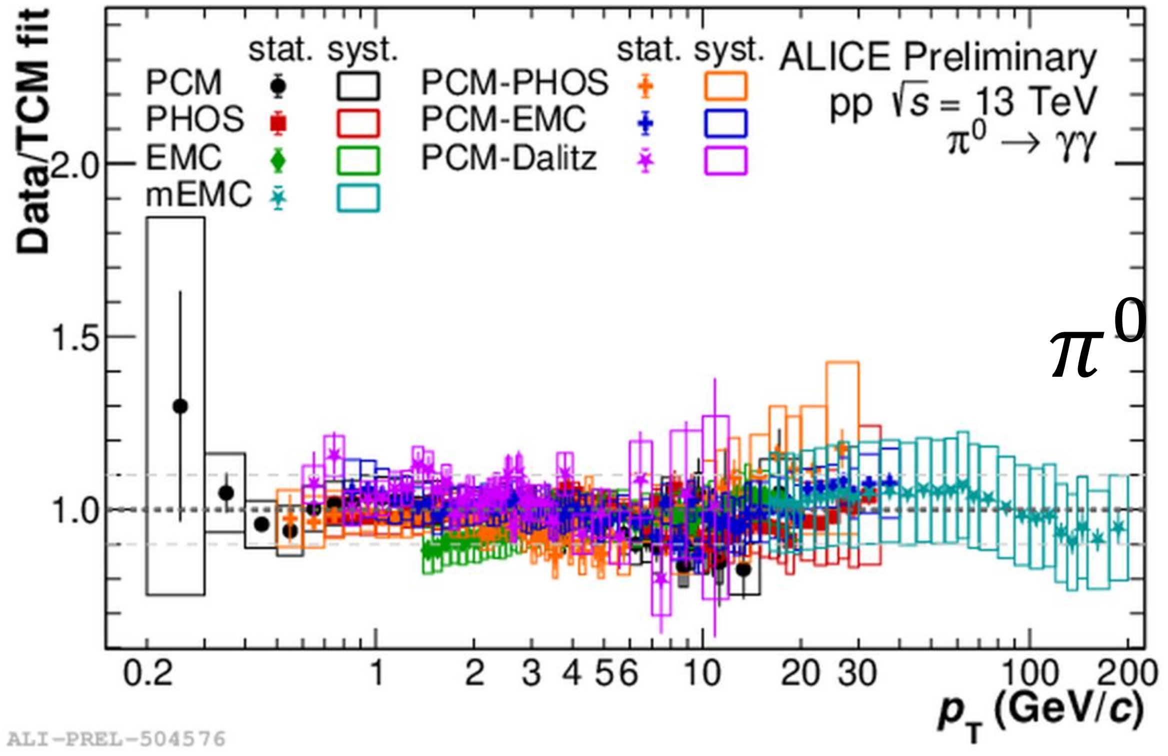
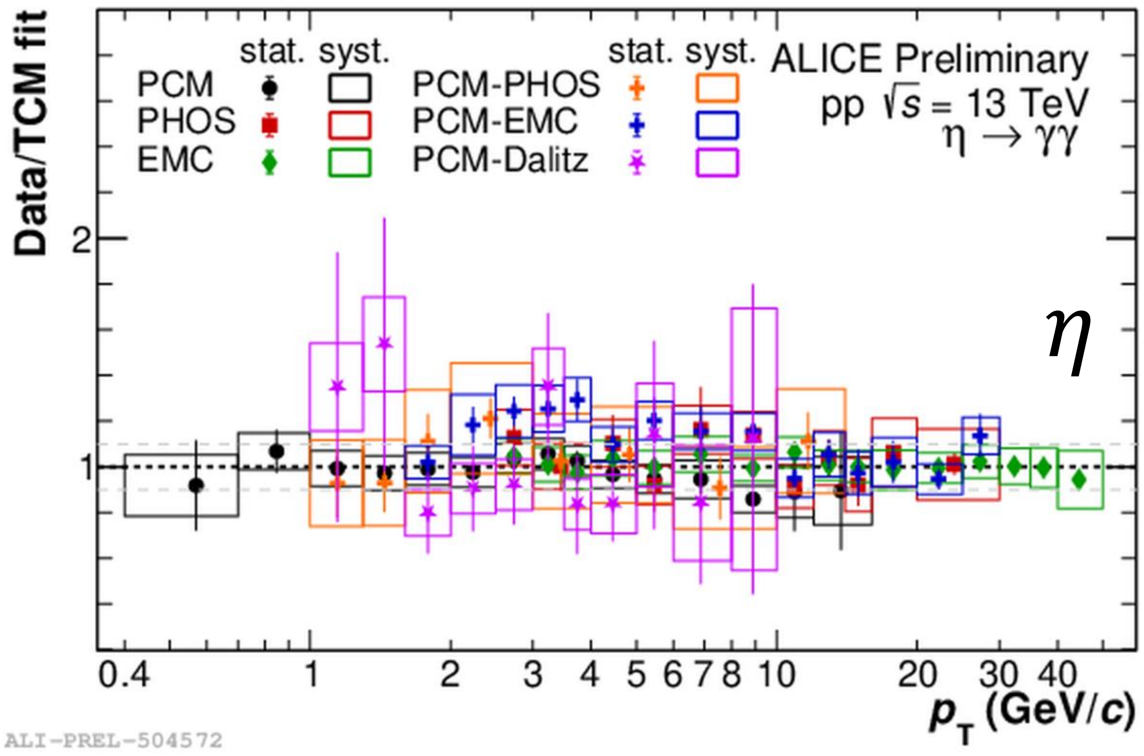


Neutral meson production: analysis details

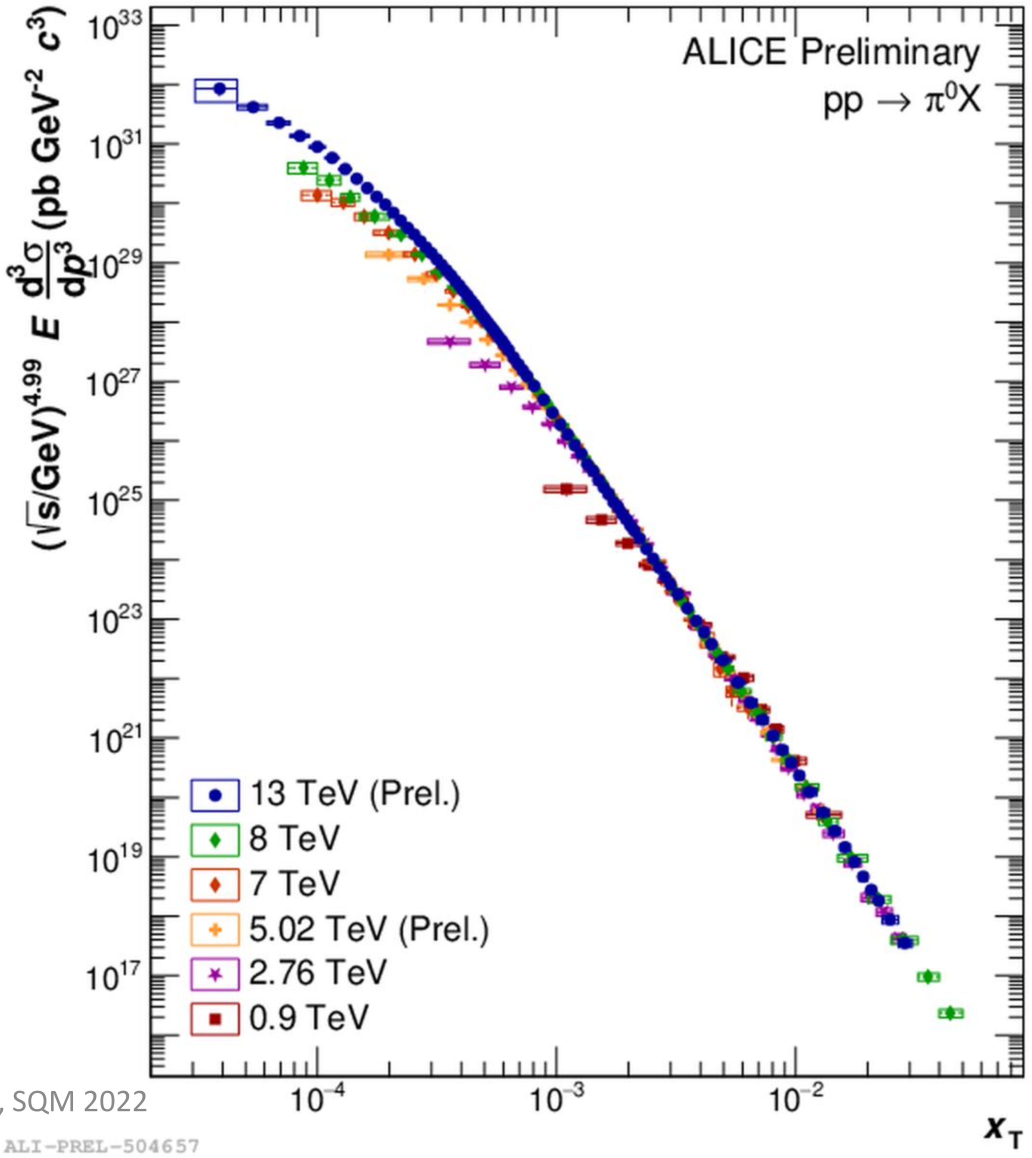
- The η and π^0 mesons are reconstructed by calculating invariant masses of photon pairs.
  - Final yield is extracted by combining subdetectors.





Neutral meson production: Results

- Indications of universal scaling as a function of collision energy.
  - $x_T = \frac{2p_T}{\sqrt{s}}$



Neutral meson production: results

- Indications of universal scaling as a function of collision energy.
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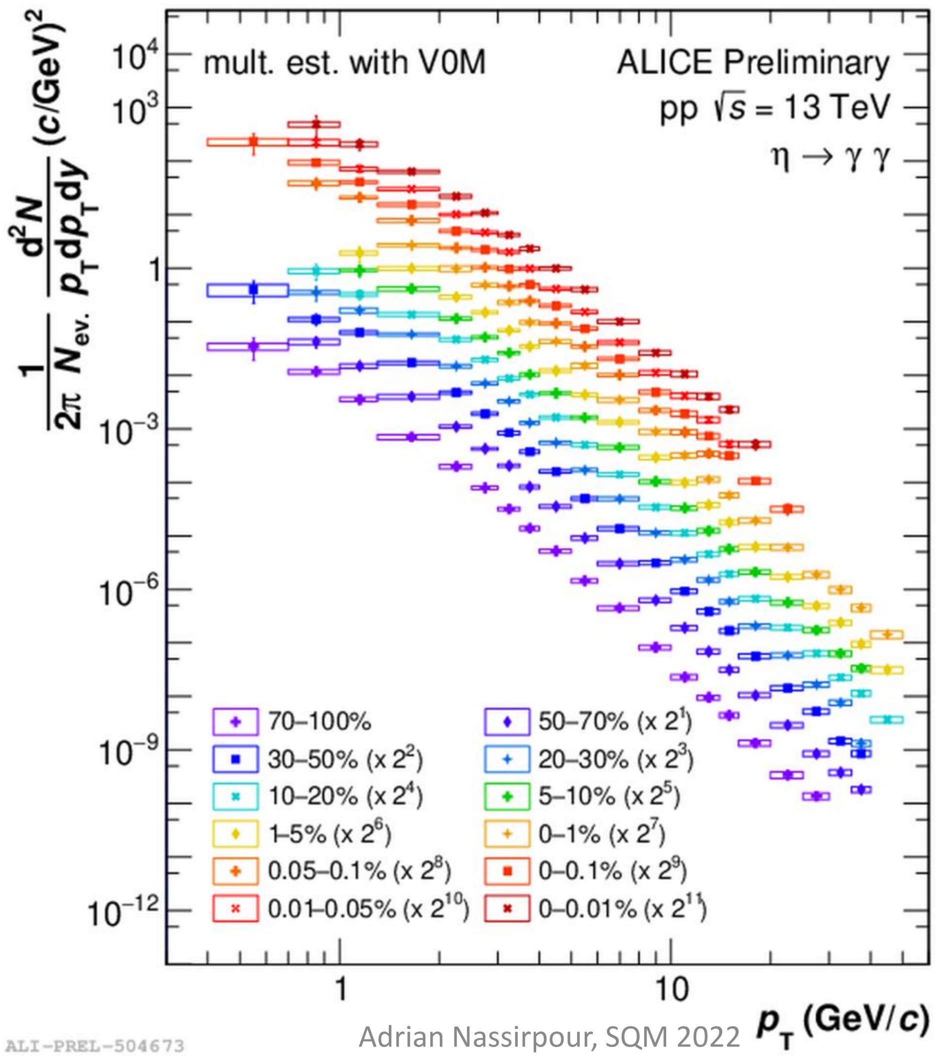
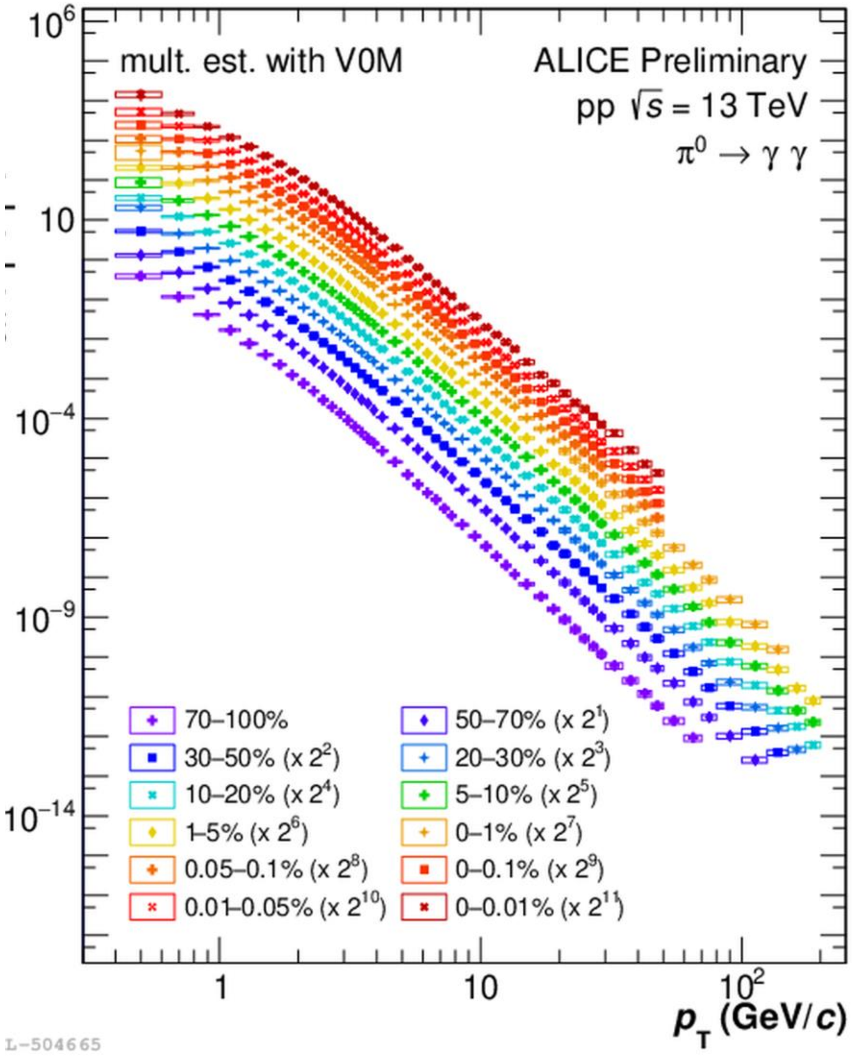
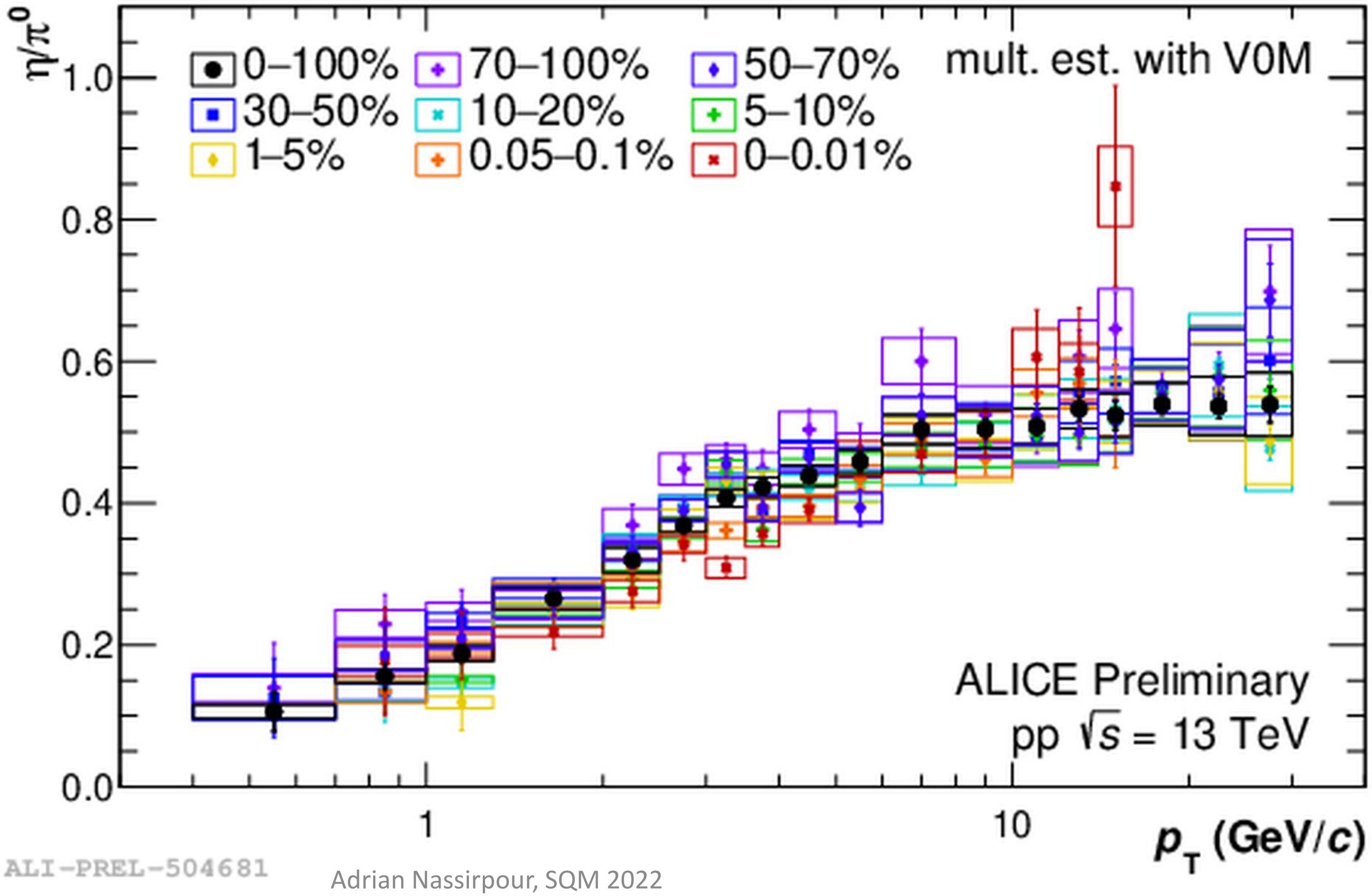
- Measurements of η and π^0 as a function of forward multiplicity





Neutral meson production: results

- New results suggests that η/π^0 is independent of multiplicity as a function of p_{T}.



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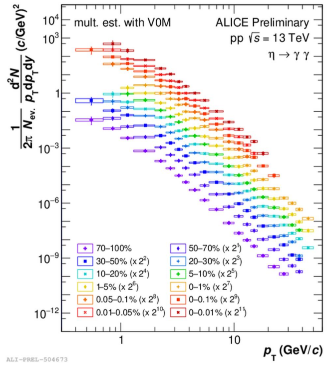
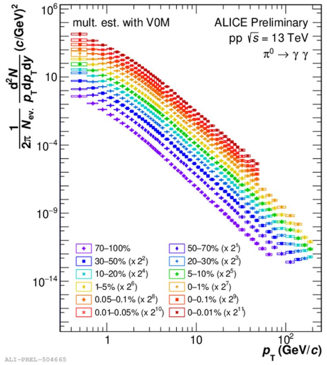
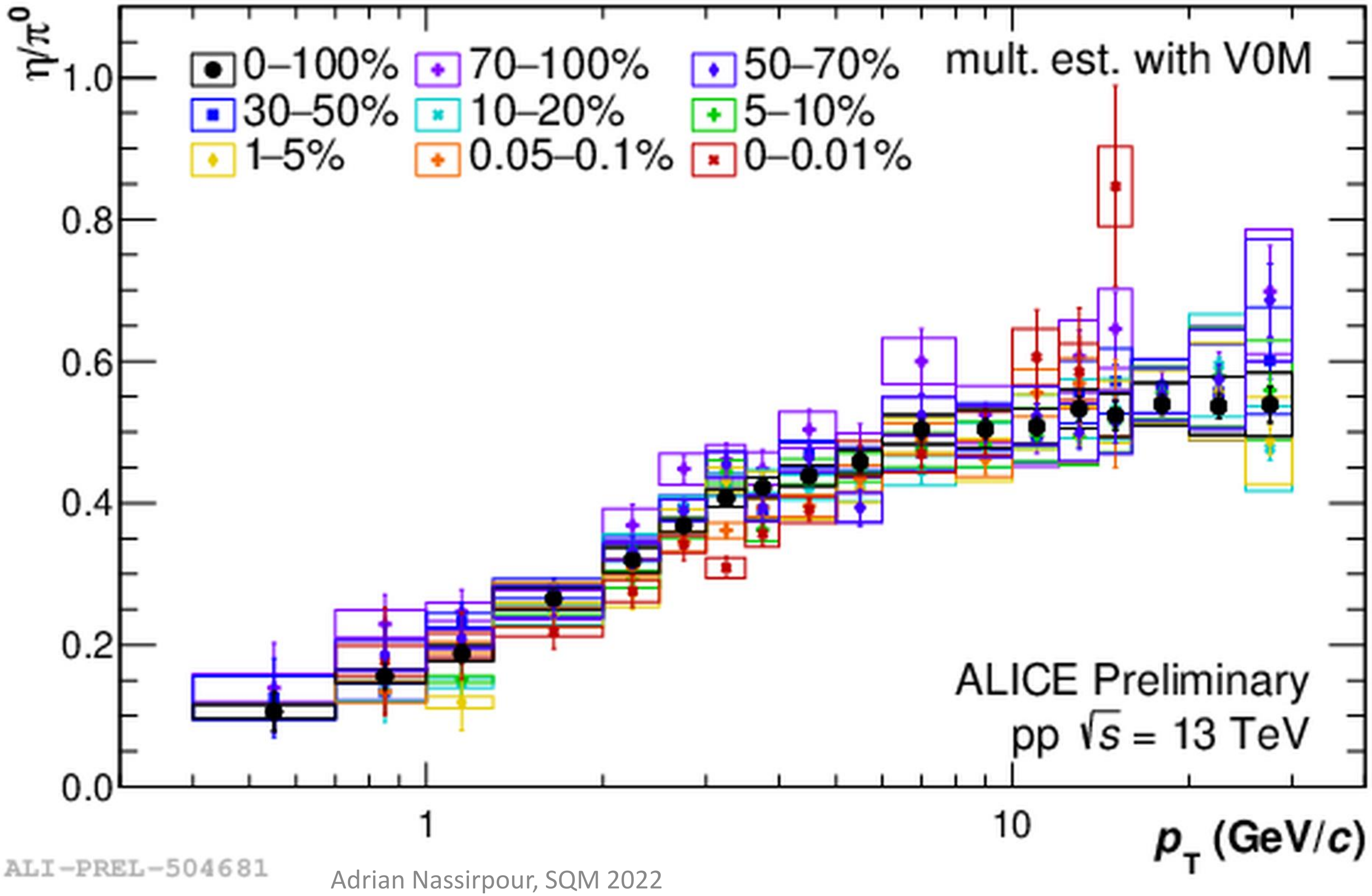


η / π^0





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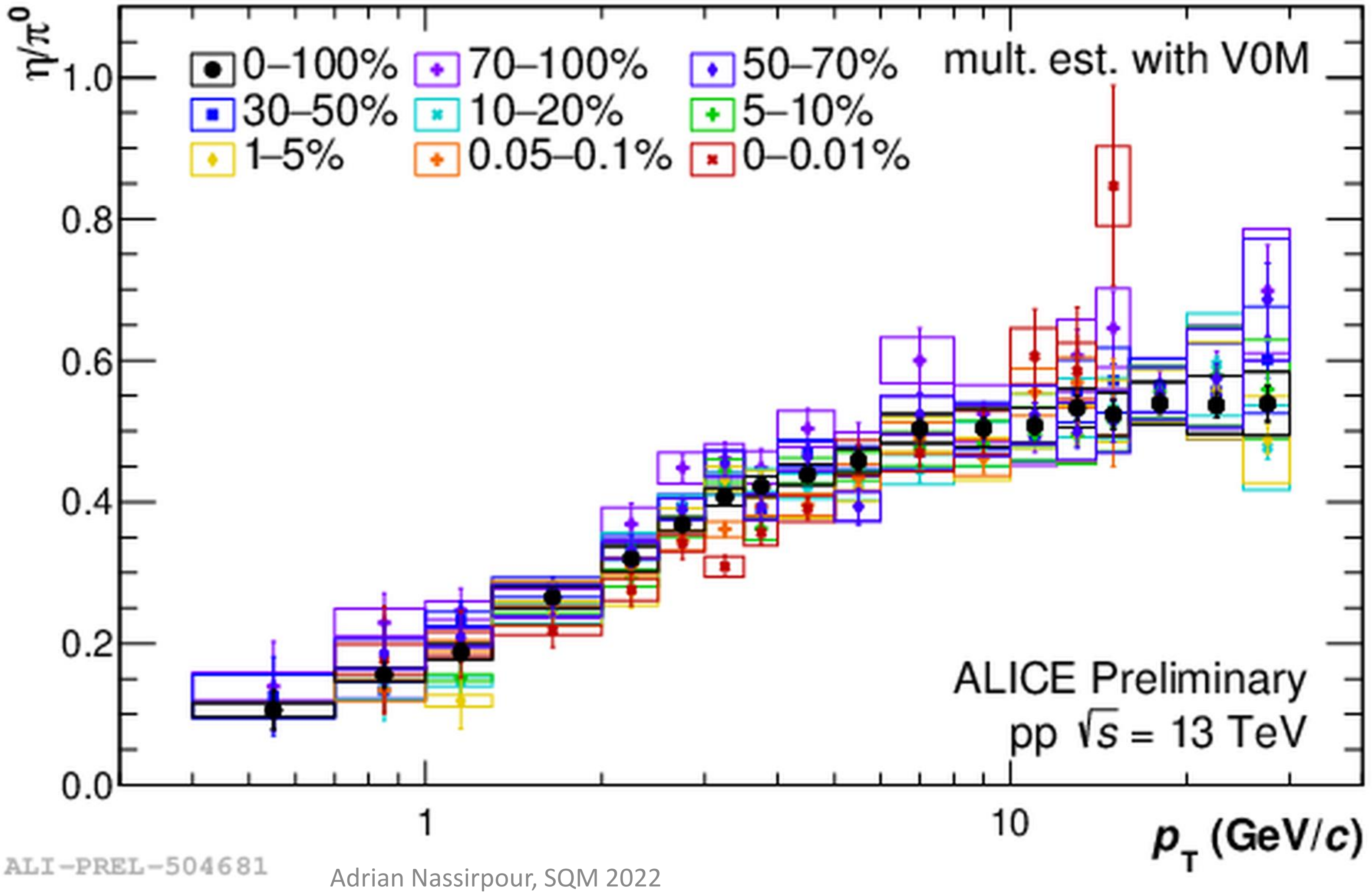
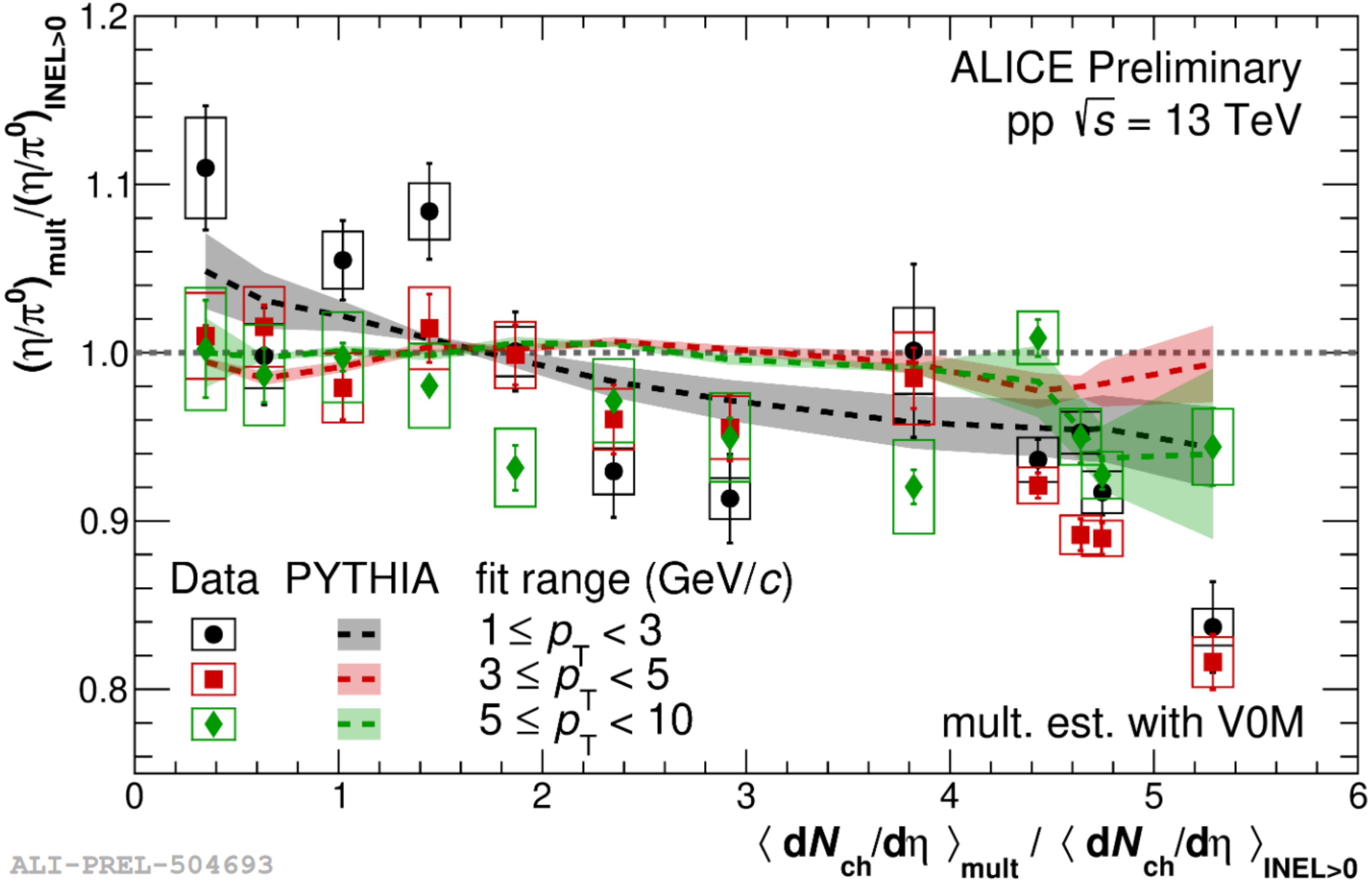


Neutral meson production: results

- New results suggests that η/π^0 is independent of multiplicity as a function of p_{T}.
  - p_{T} -differential η production is not modified even in extremely large pp multiplicities.
- p_{T} integrated double-ratio presents a suppression of η with increasing multiplicity



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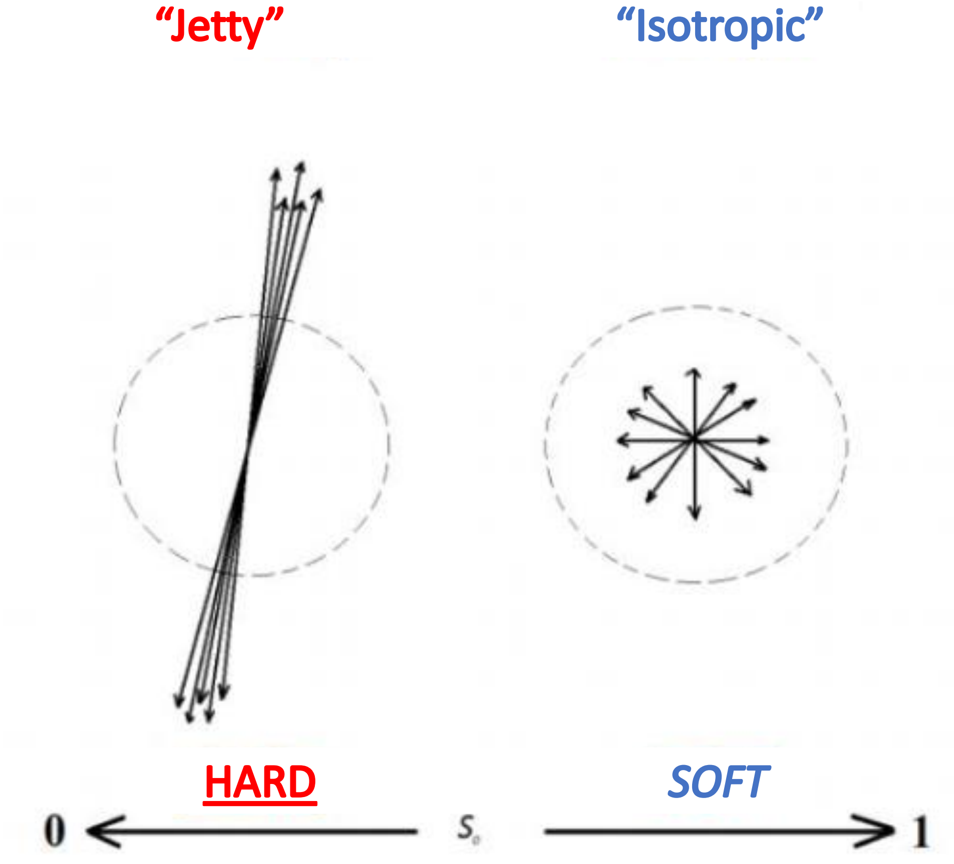
Strangeness enhancement in different topologies: Transverse Spherocity $S_0^{p_{\mathrm{T}}=1}$

- Categorize event into two types:
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard processes
  - **Isotropic:** Azimuthally isotropic events.
    - Particle production driven by multiple softer collisions.

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



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  - These categories are defined by the bottom/top 20% $S_0^{p_T=1}$ quantile.

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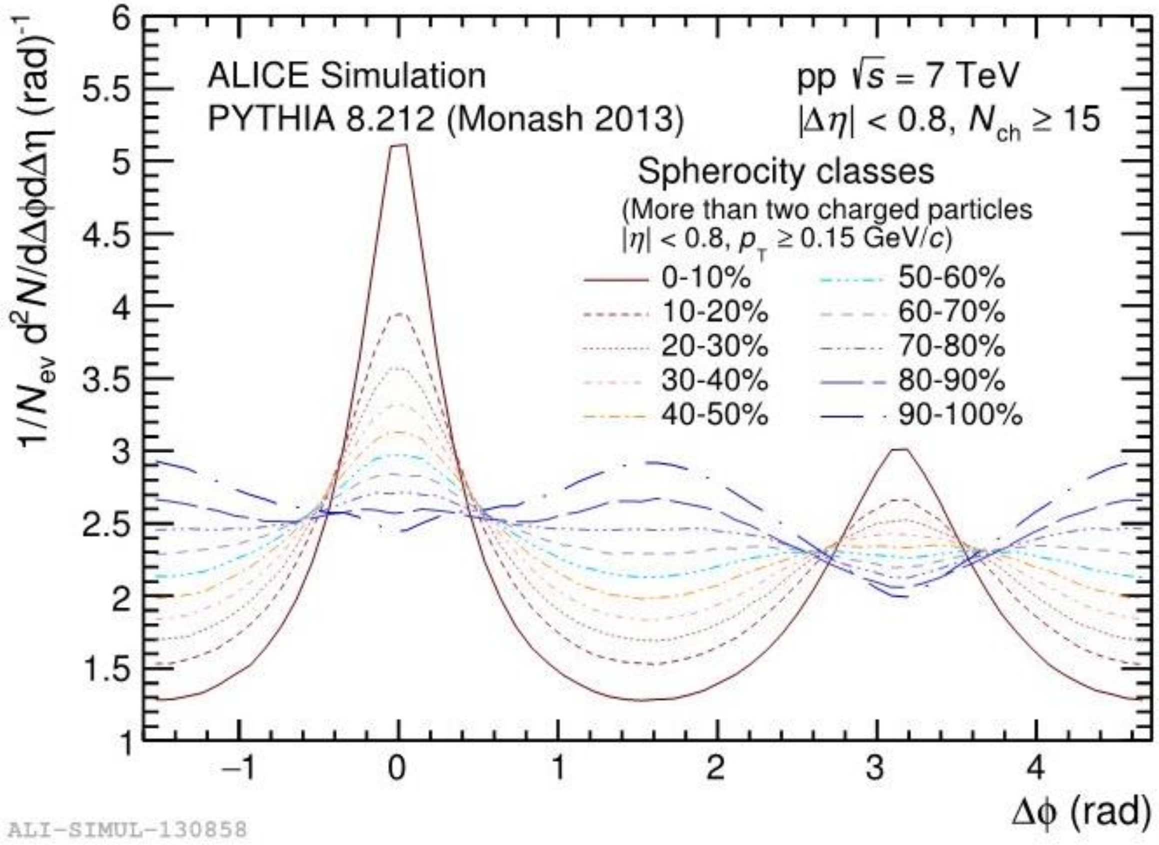
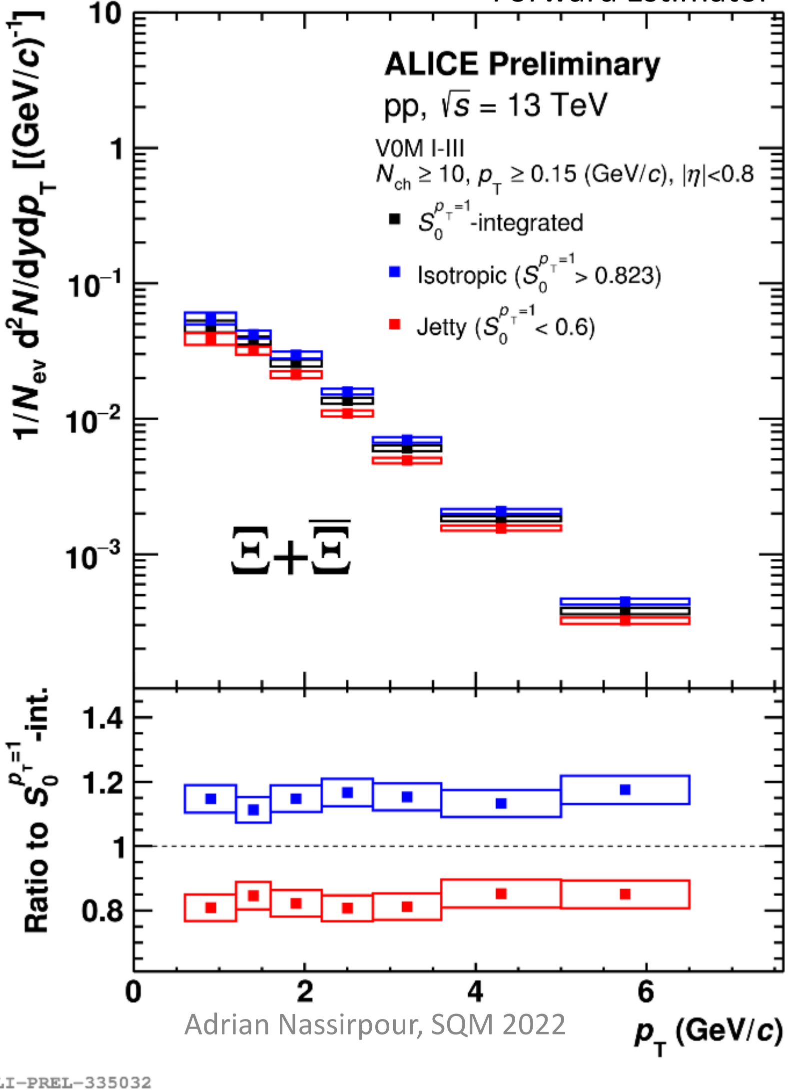


Multiplicity triggers for $S_0^{p_{\mathrm{T}}=1}$ analysis

Multiplicity (0-10%) for spectra is measured in two rapidity regions

- Forward rapidity: $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$

Forward Estimator



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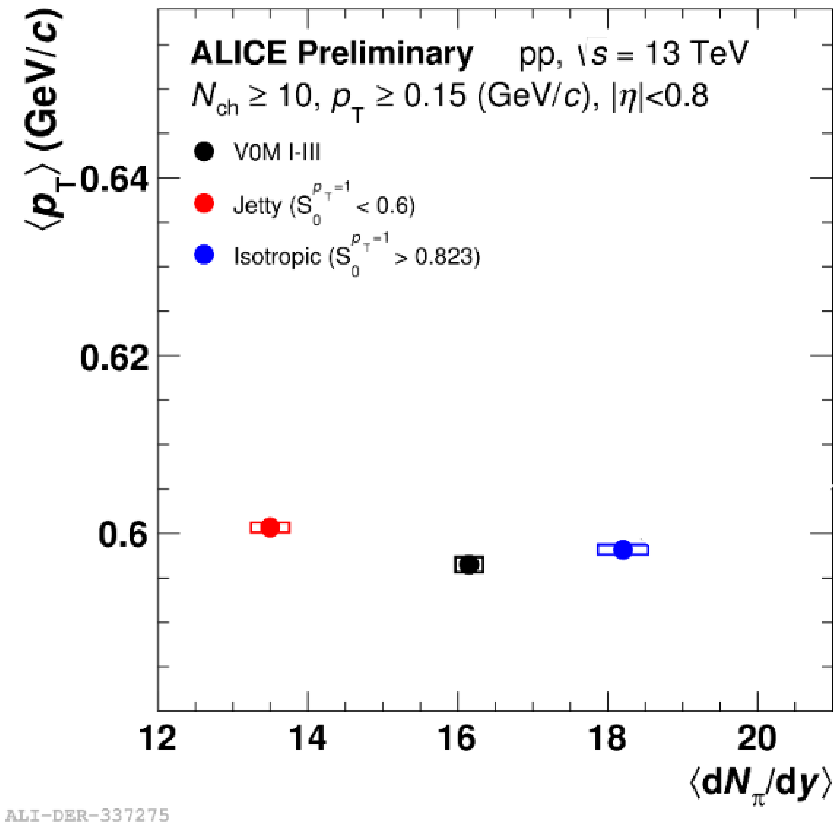

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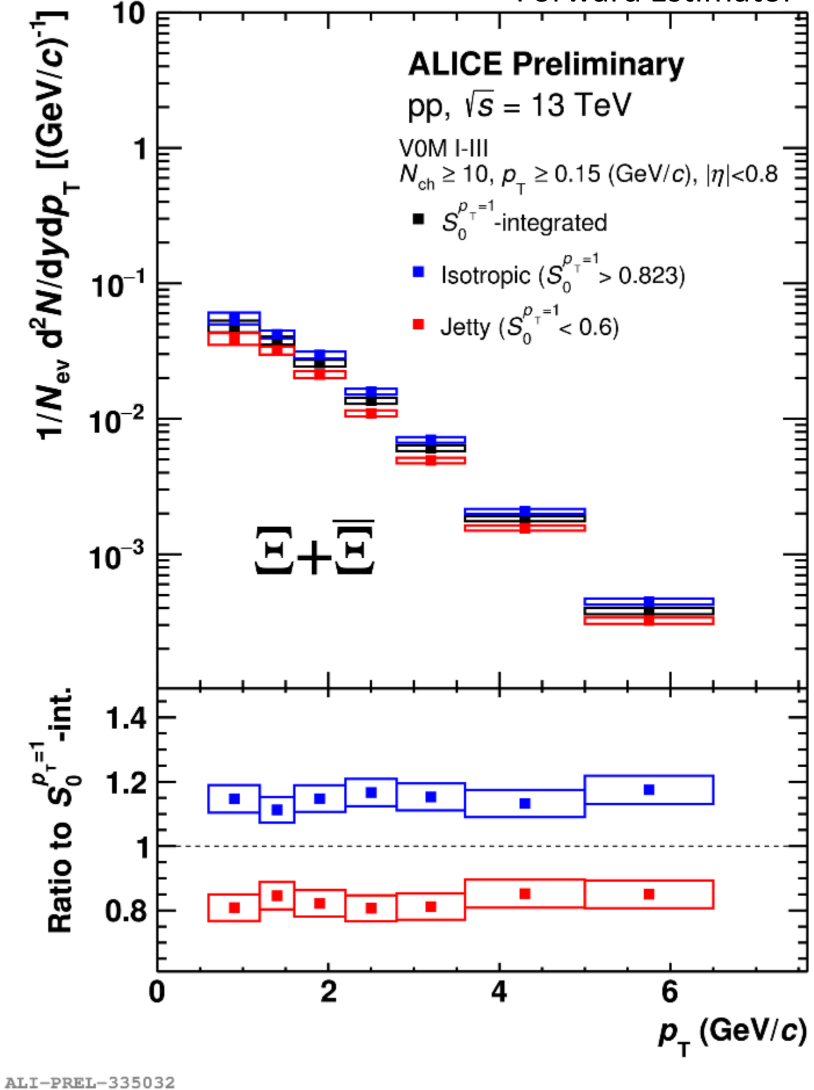

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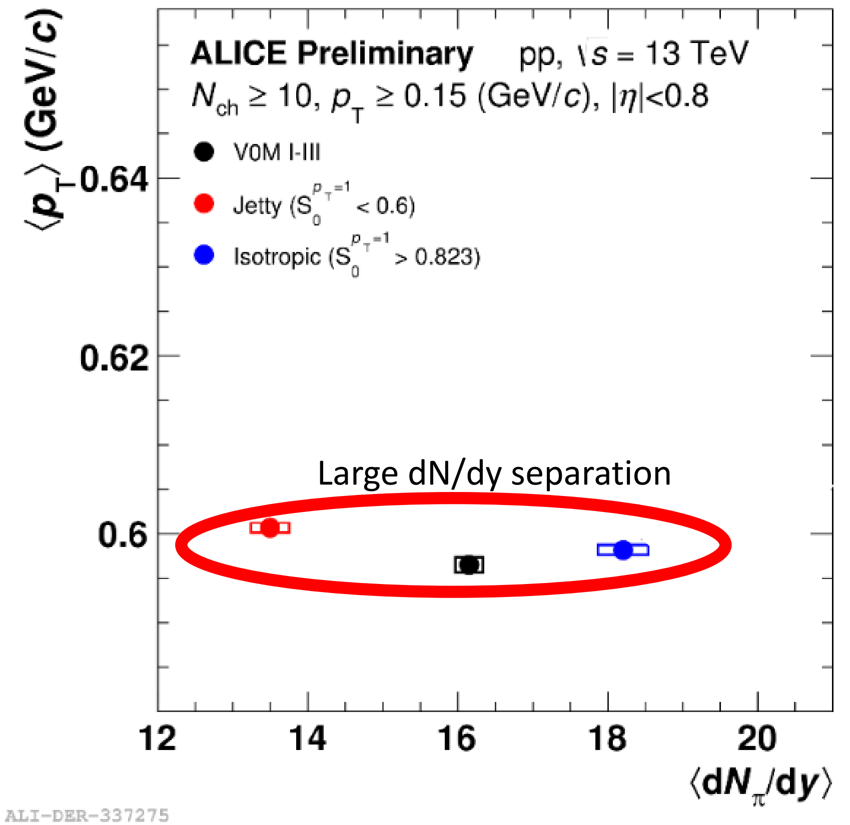

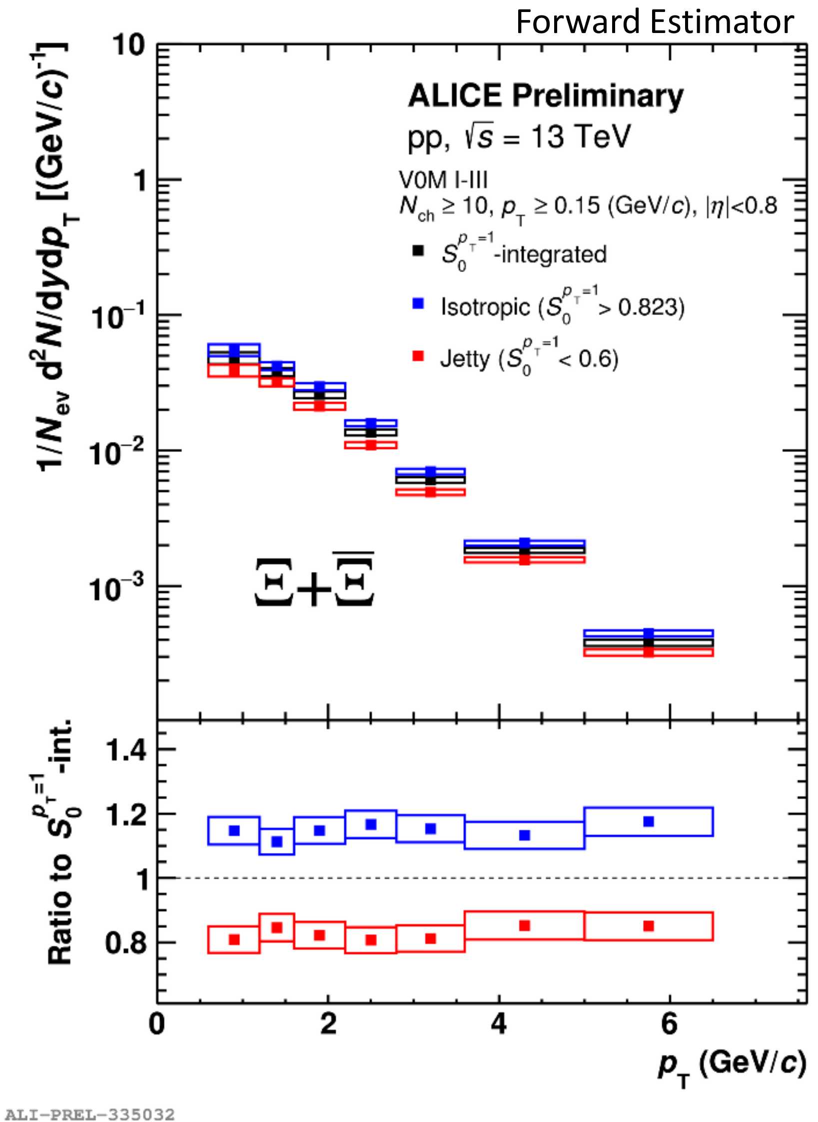

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- Forward rapidity:
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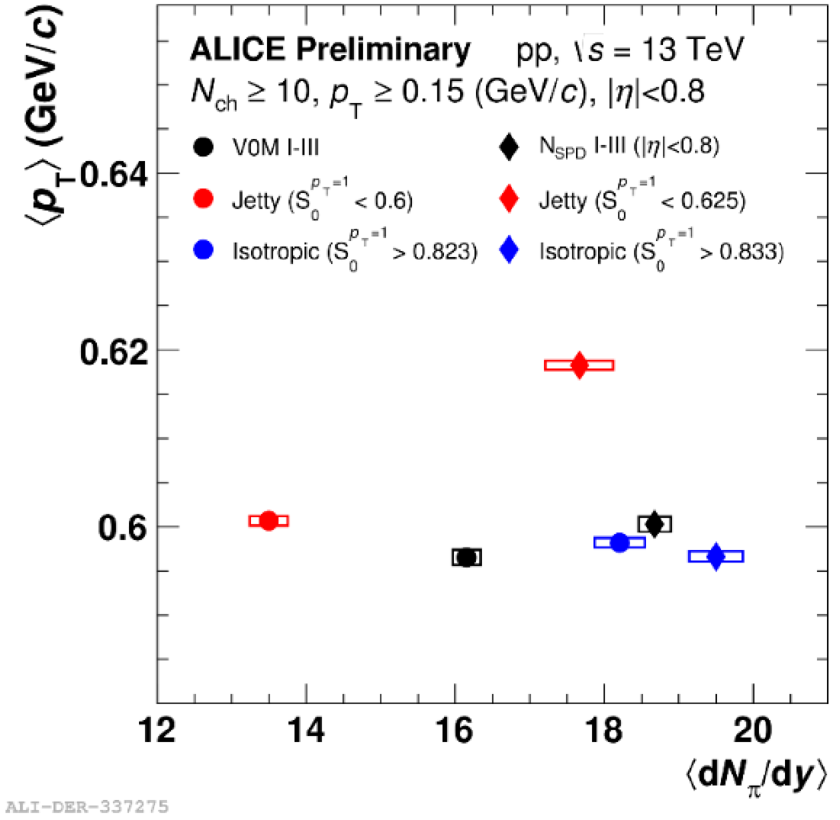
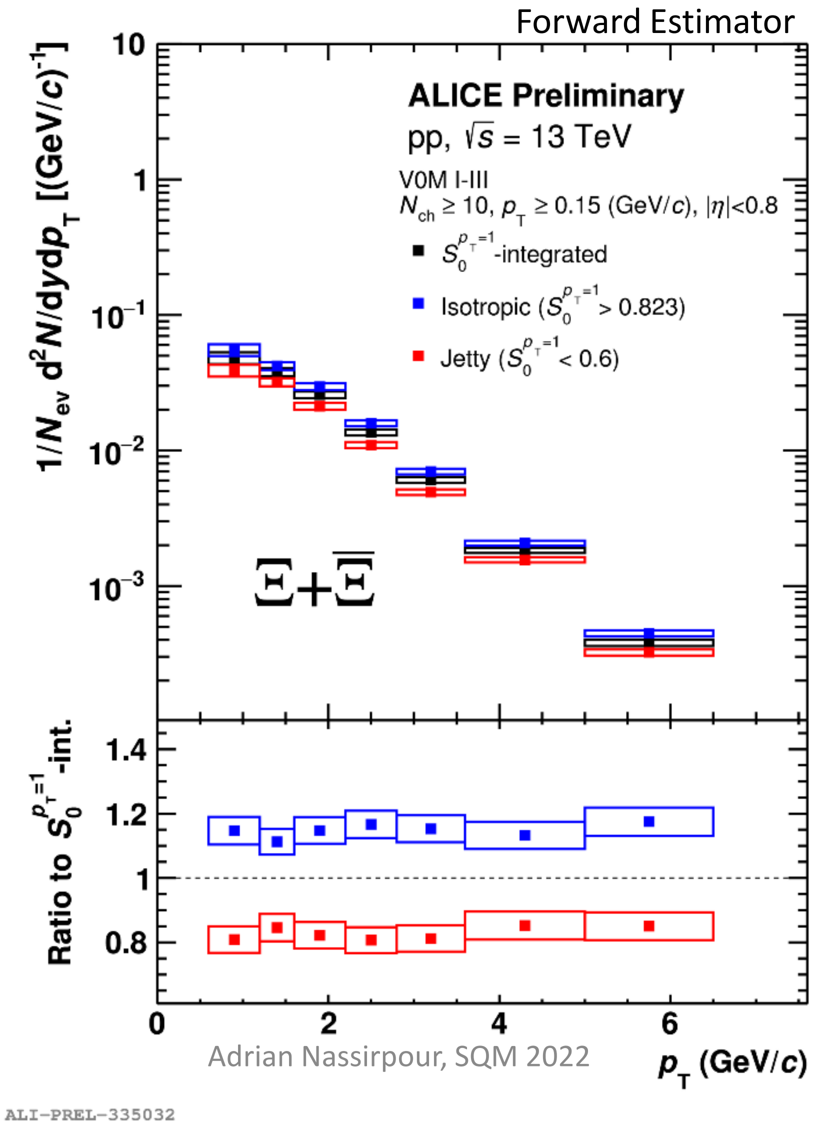
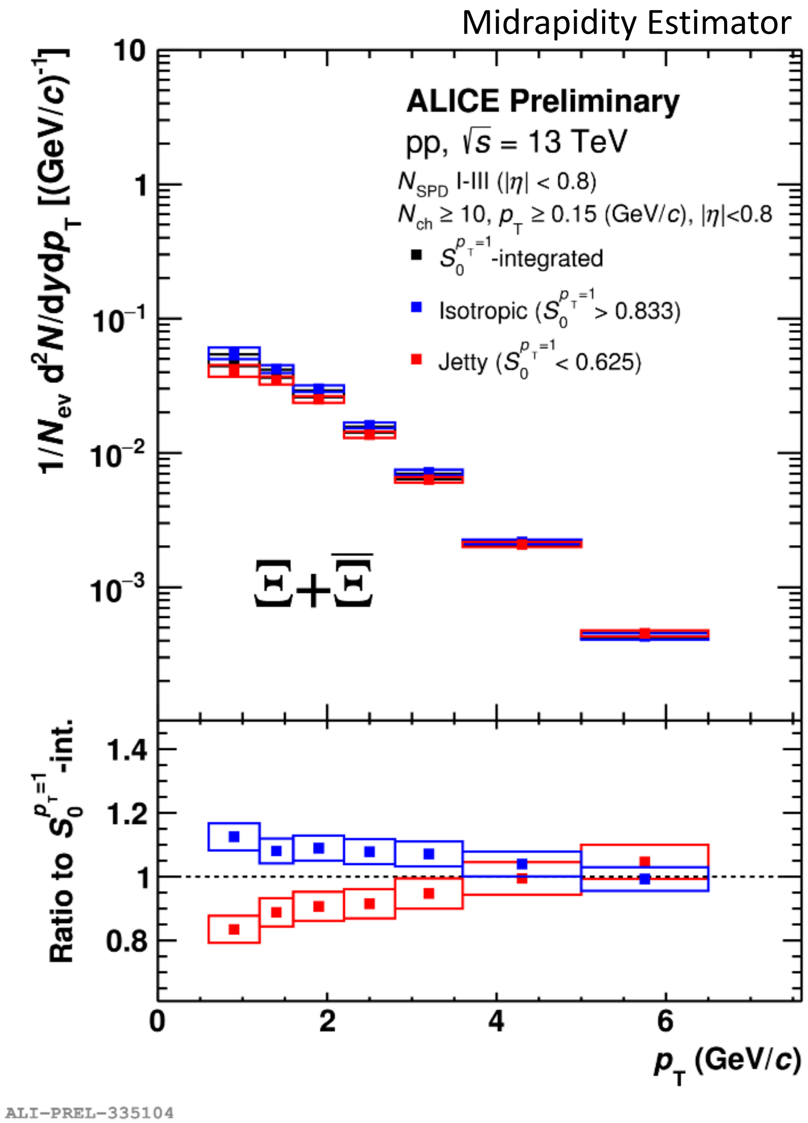
- Midrapidity: $|\eta|$ <0.8







Multiplicity triggers for $S_0^{p_T=1}$ analysis

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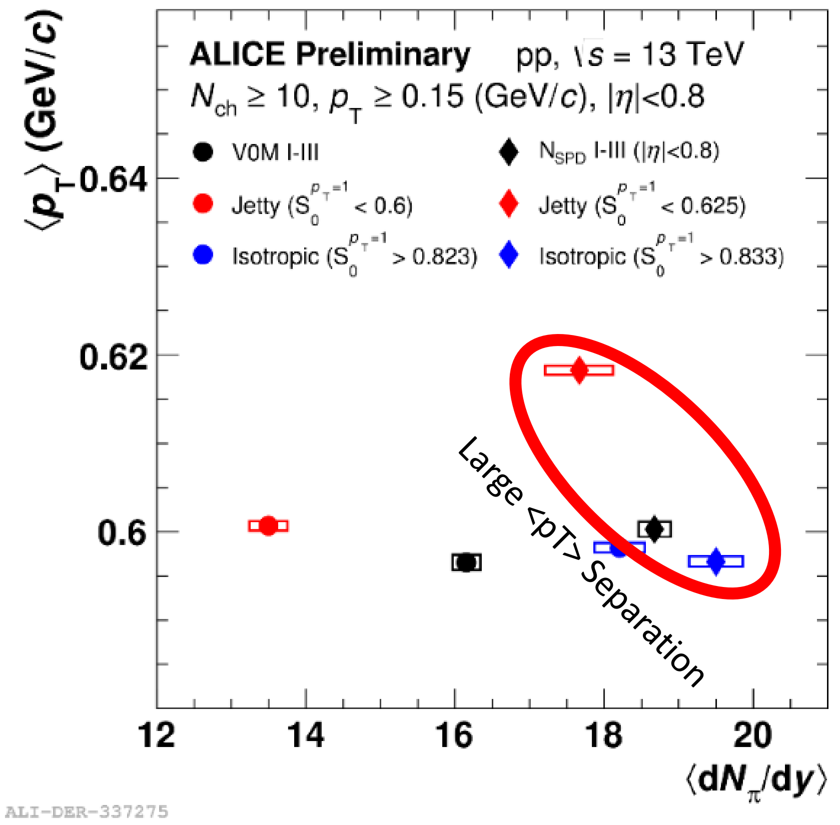
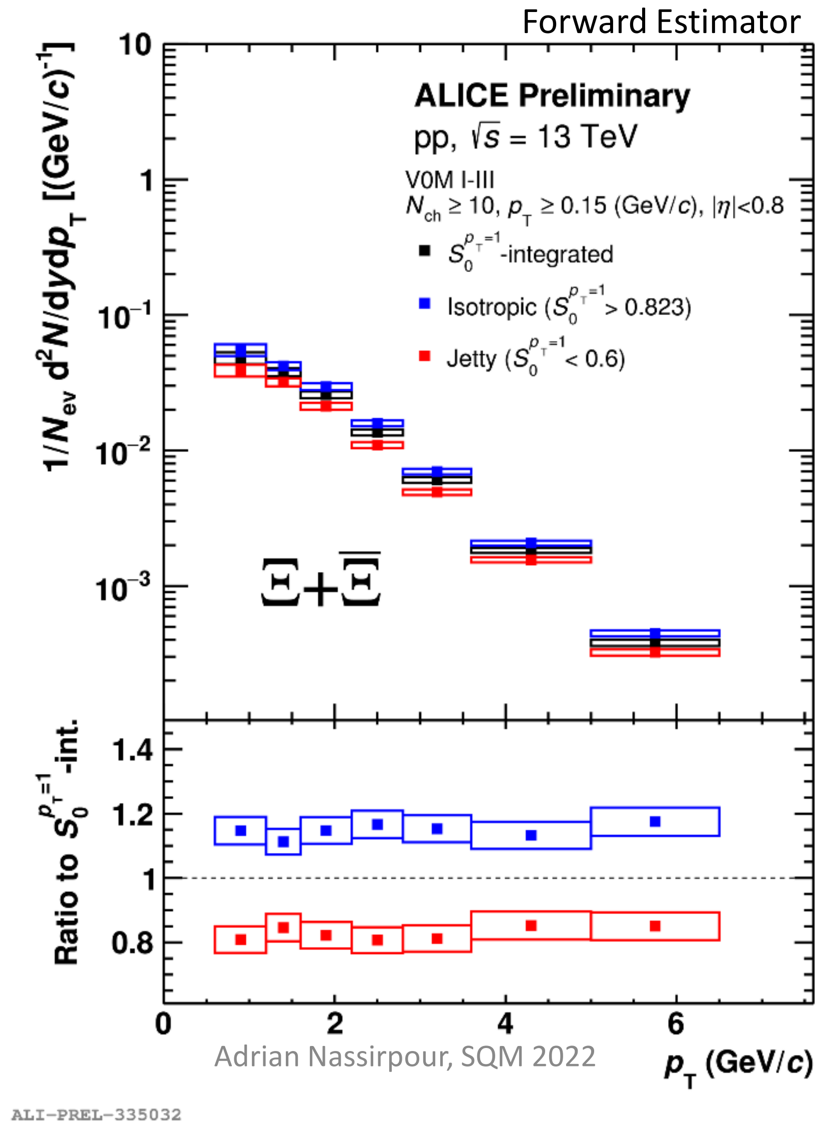
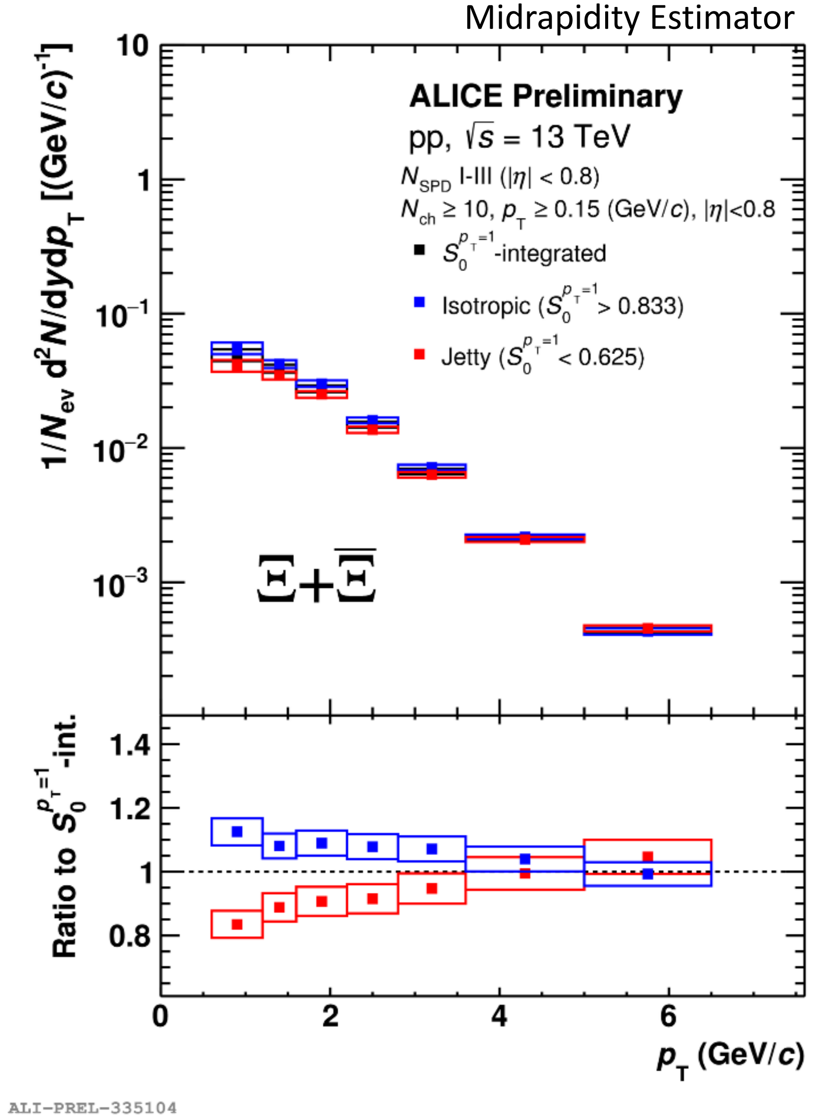
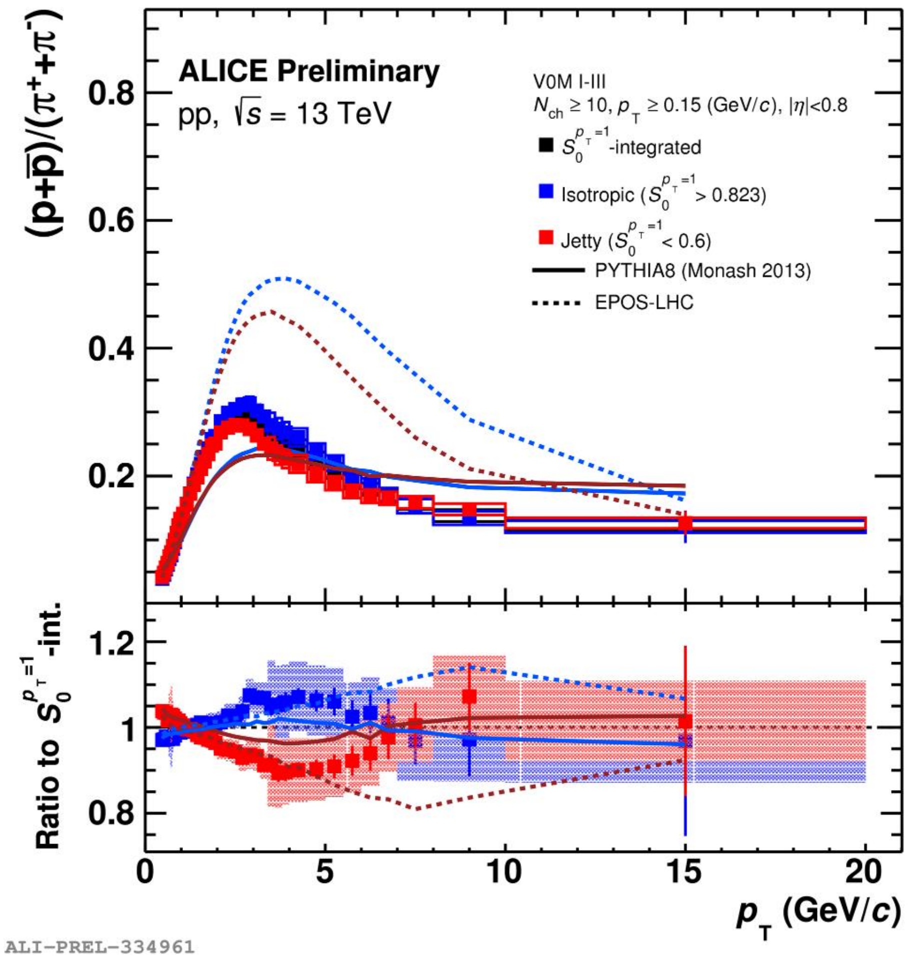






p-to-π ratios as functions of $S_0^{p_{\mathrm{T}}=1}$

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



JETTY : RED

ISOTROPIC : BLUE

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.

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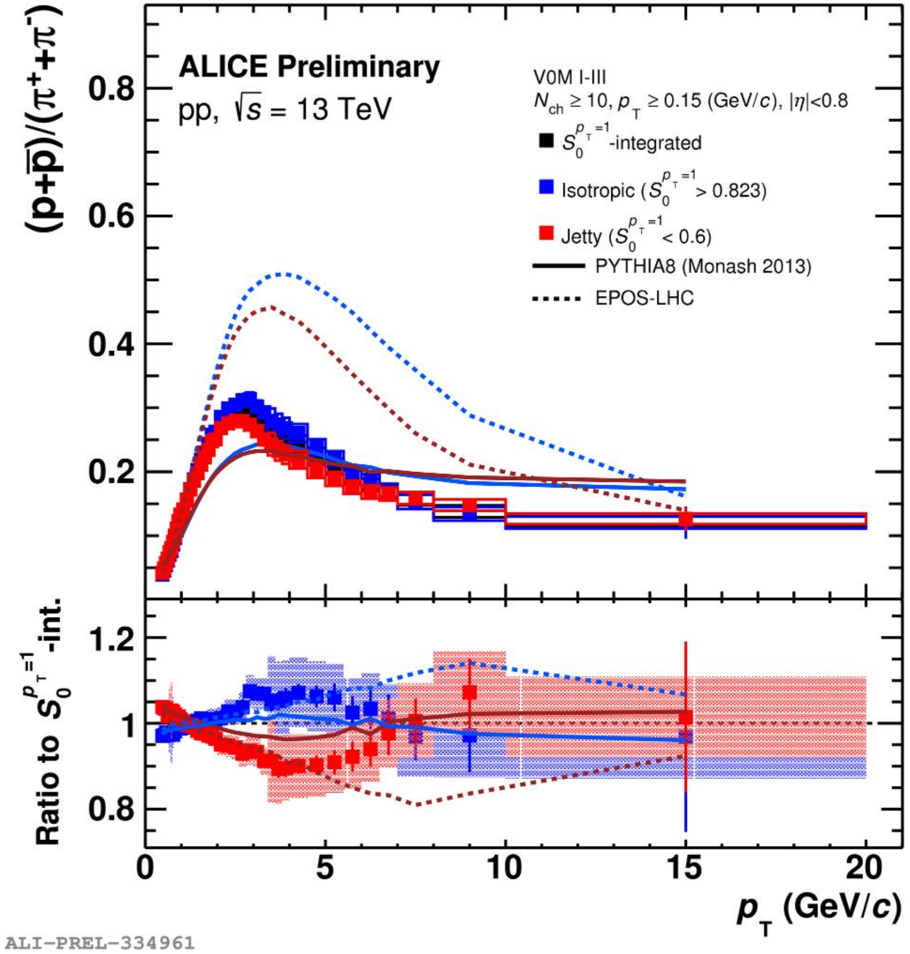
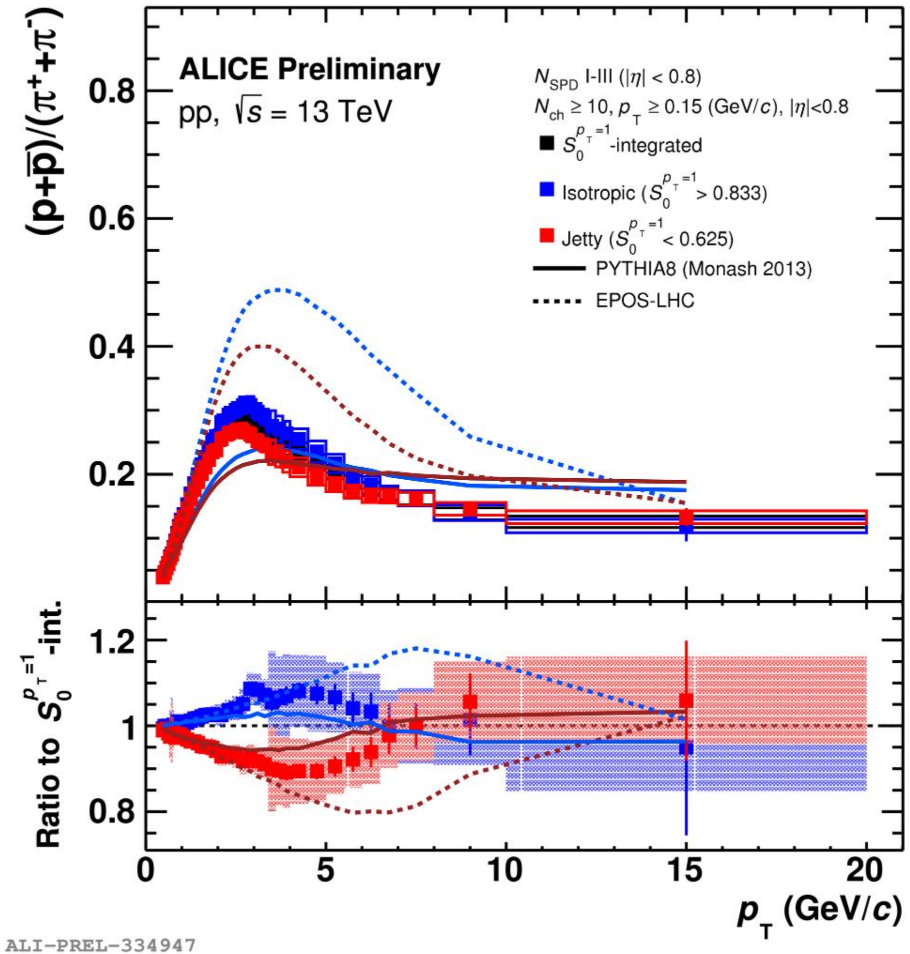


Midrapidity Estimator
$|\eta| < 0.8$



p-to-π ratios as functions of $S_0^{p_T=1}$

Forward Estimator
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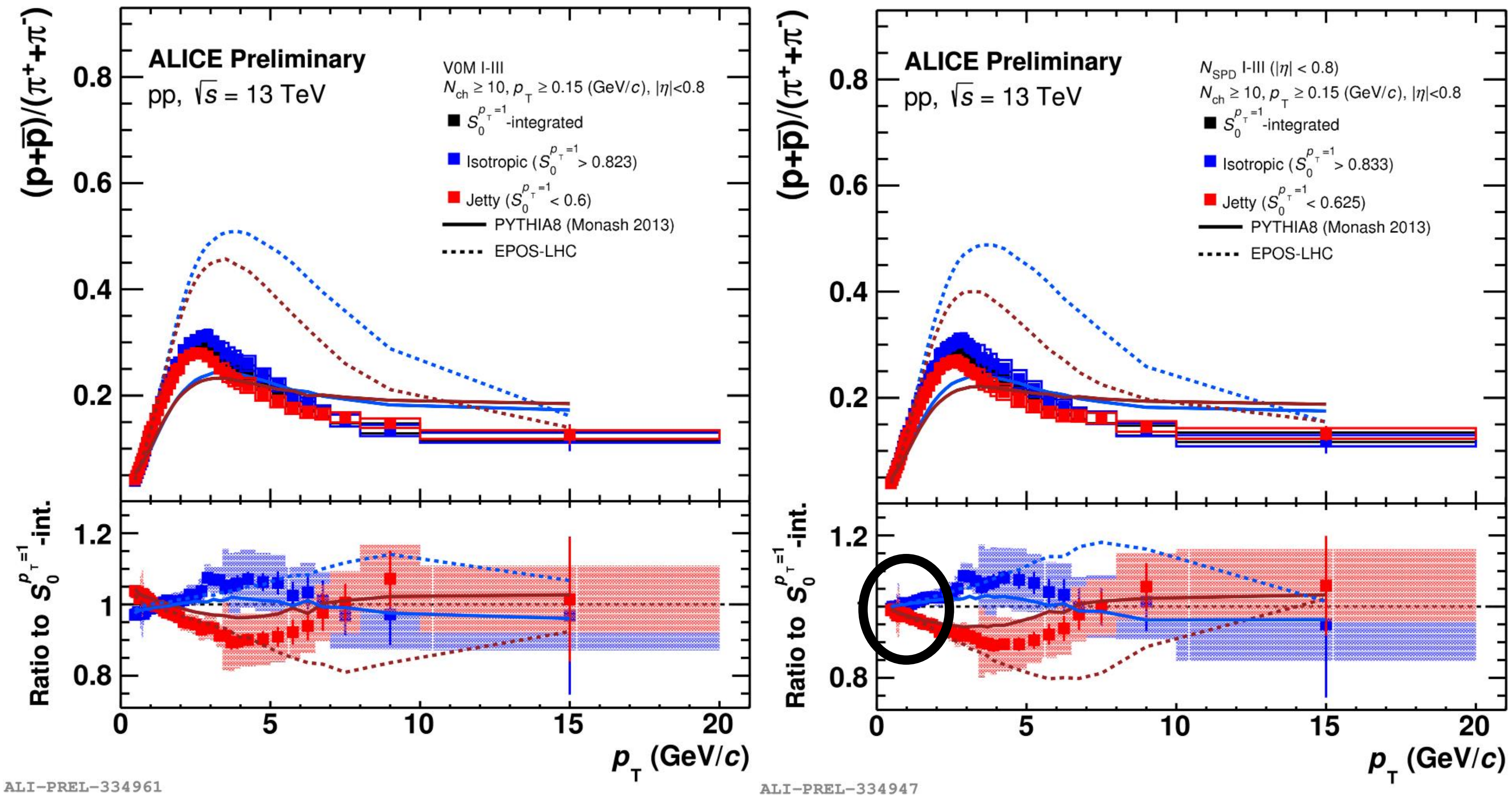

JETTY : RED

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p-to-π : shift of protons from low (high) p_{T} to high (low) p_{T} for isotropic (jetty) events.

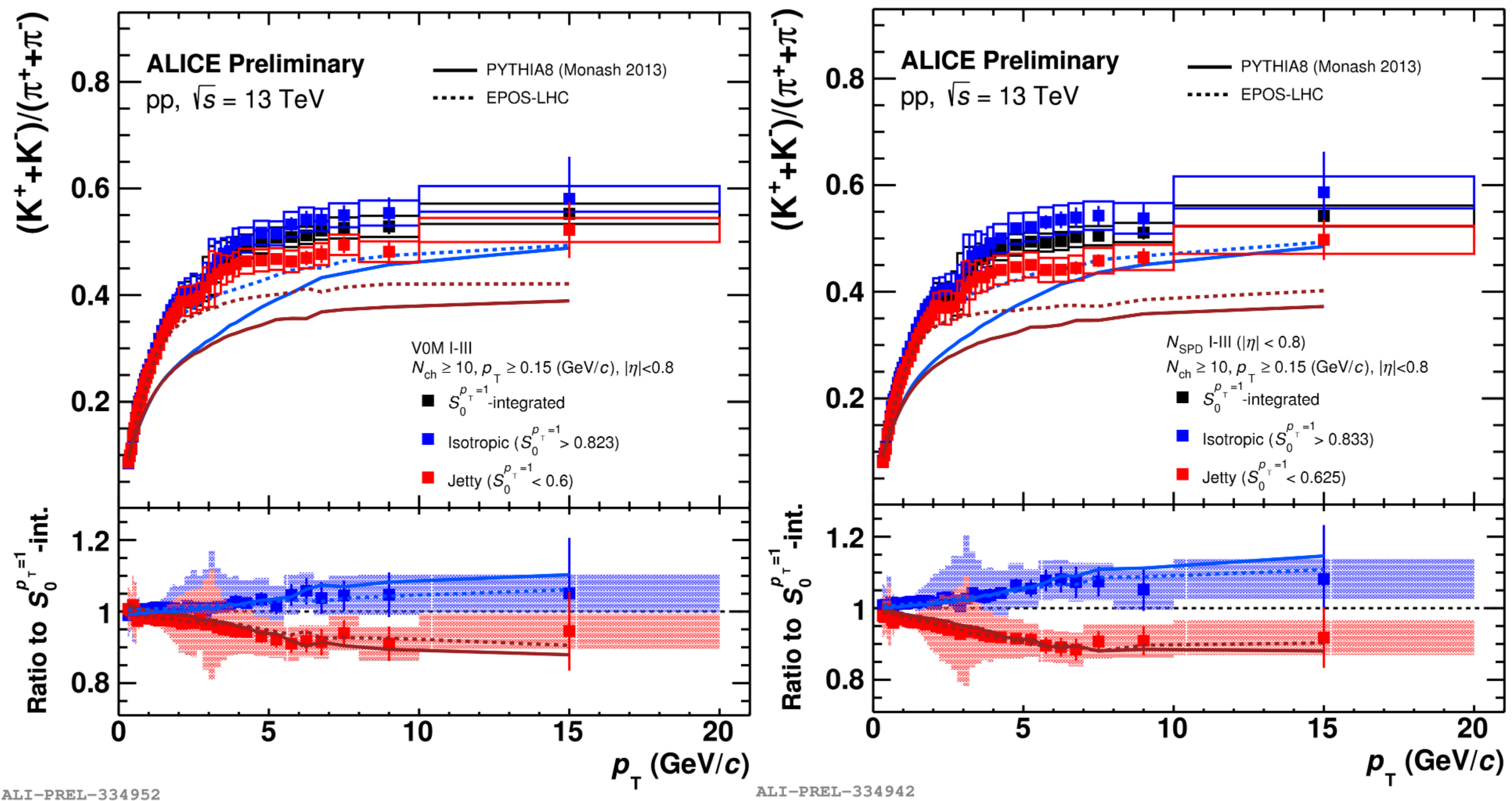
Normally associated with increase (decrease) of radial flow in large systems.

Likely competing effects between radial flow and hardening due to jet fragmentation.

K-to-π ratios as functions of $S_0^{p_T=1}$

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

Midrapidity Estimator
$|\eta|$ <0.8



JETTY : RED

ISOTROPIC : BLUE

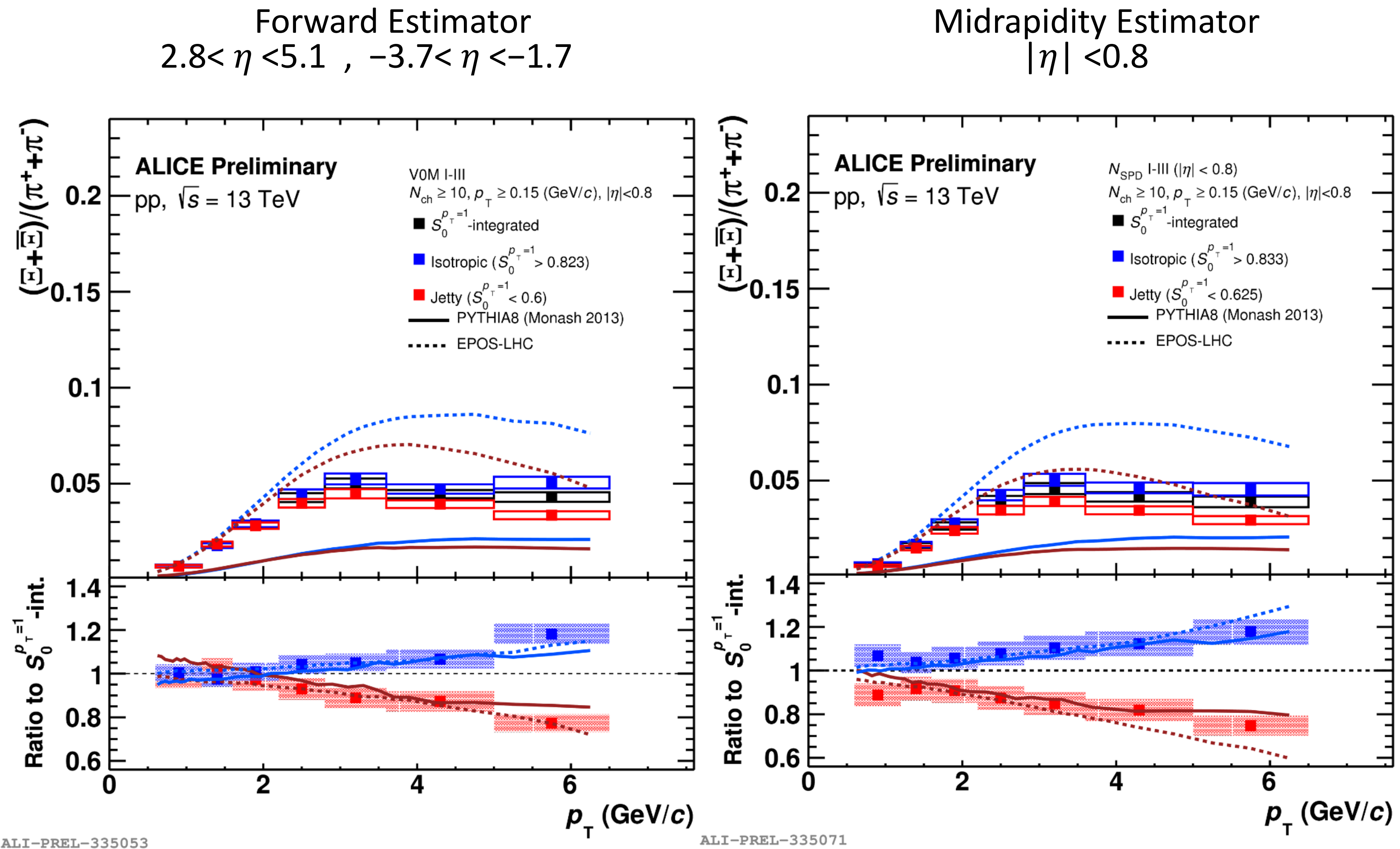
K-to-π ratio showcases a clean separation between the kaon production in Isotropic and Jetty events

Generators describe the double-ratio quite well

Ξ-to-π ratios as functions of $S_0^{p_\mathrm{T}=1}$

JETTY : RED

ISOTROPIC : BLUE



Midrapidity results suggest that one can enhance or suppress the strangeness enhancement by selecting on $S_0^{p_\mathrm{T}=1}$

Generators describe the double-ratio quite well, except for some tension at low p_T, but not the p_T evolution

ϕ-to-π ratios as functions of $S_0^{p_\mathrm{T}=1}$

JETTY : RED

ISOTROPIC : BLUE

Unlike the K and Ξ, the ϕ does not show a difference for jetty and isotropic events.

Results using different estimators are consistent within uncertainties

Forward Estimator
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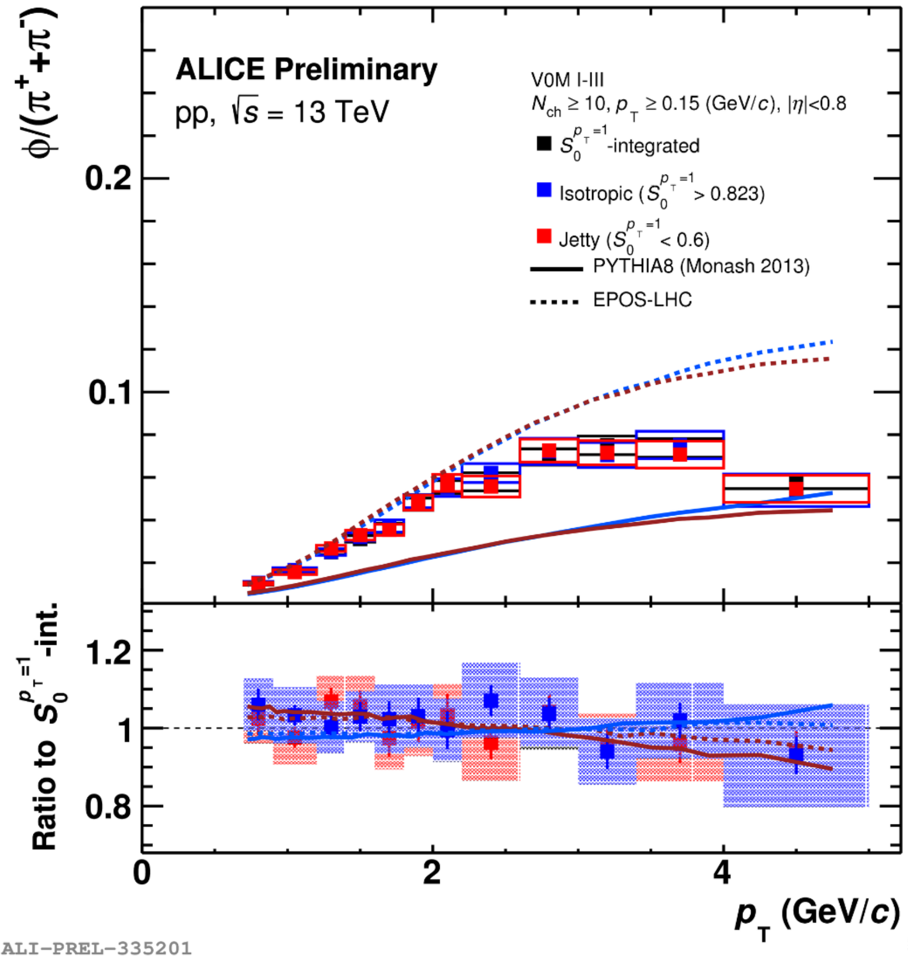

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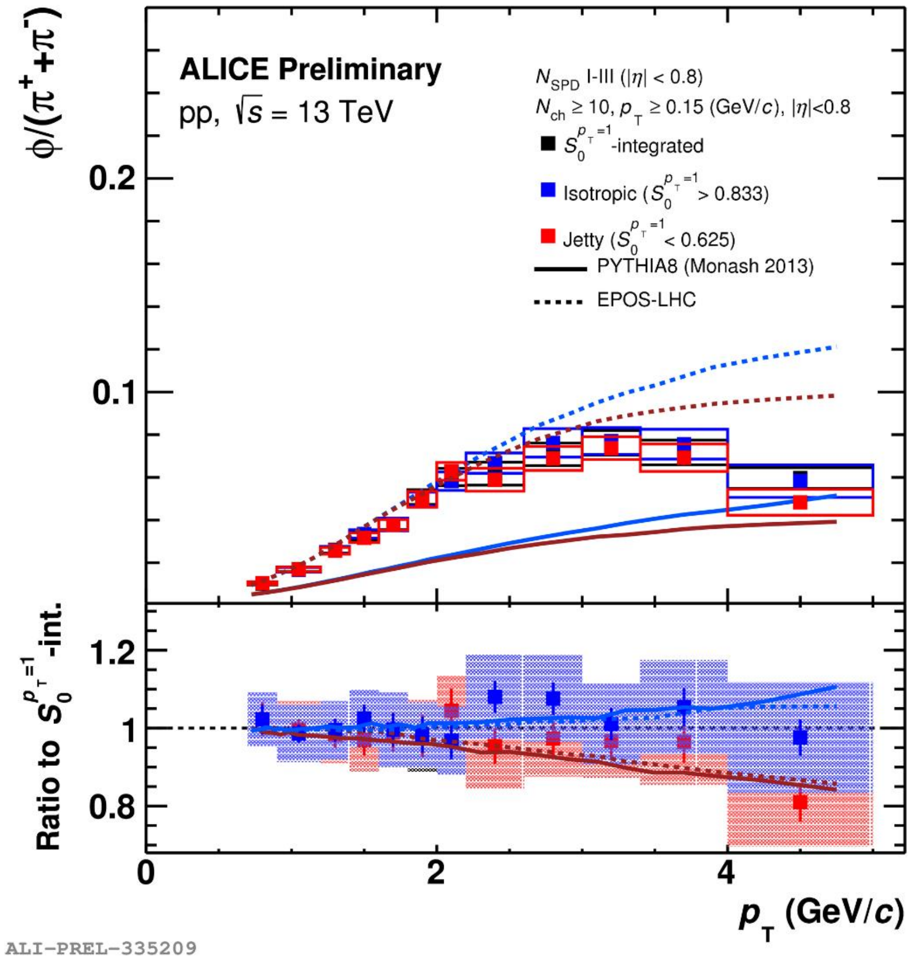

Multiplicity triggers for $S_0^{p_{\mathrm{T}}=1}$ analysis

Multiplicity (0-10%) for spectra
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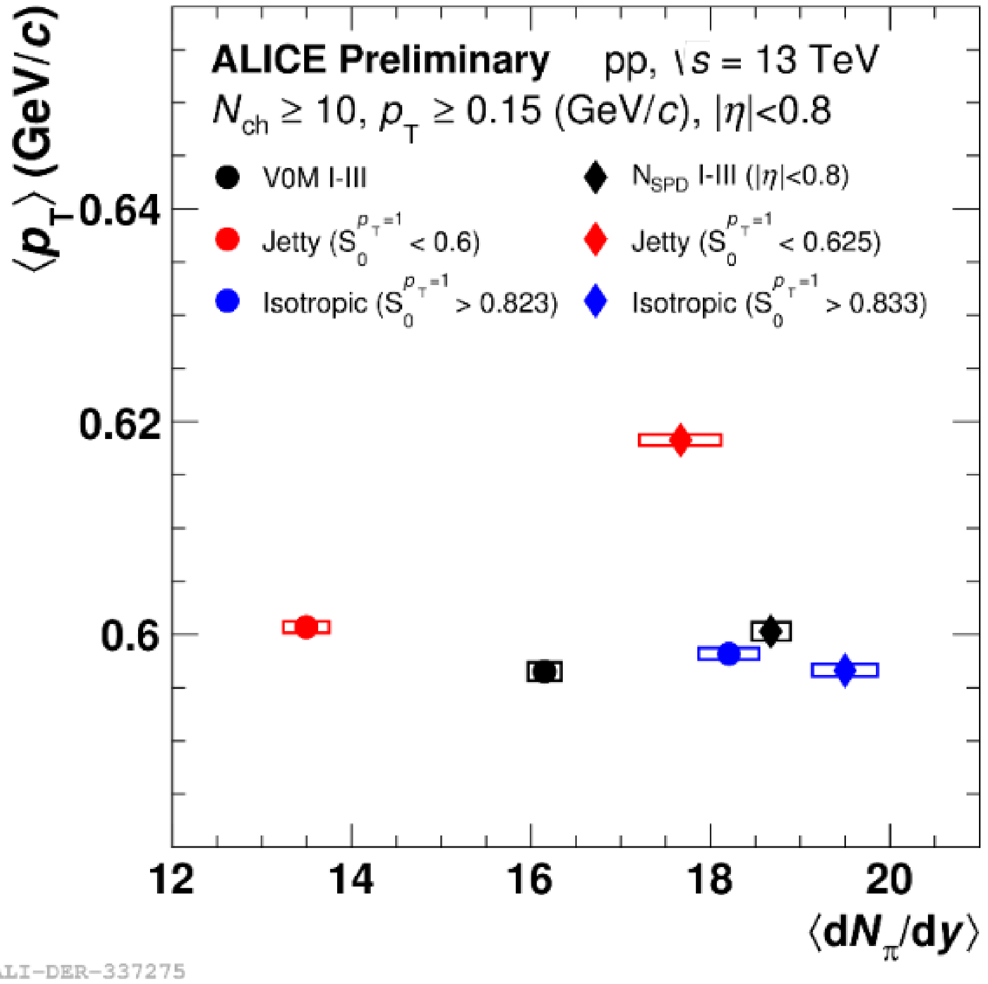
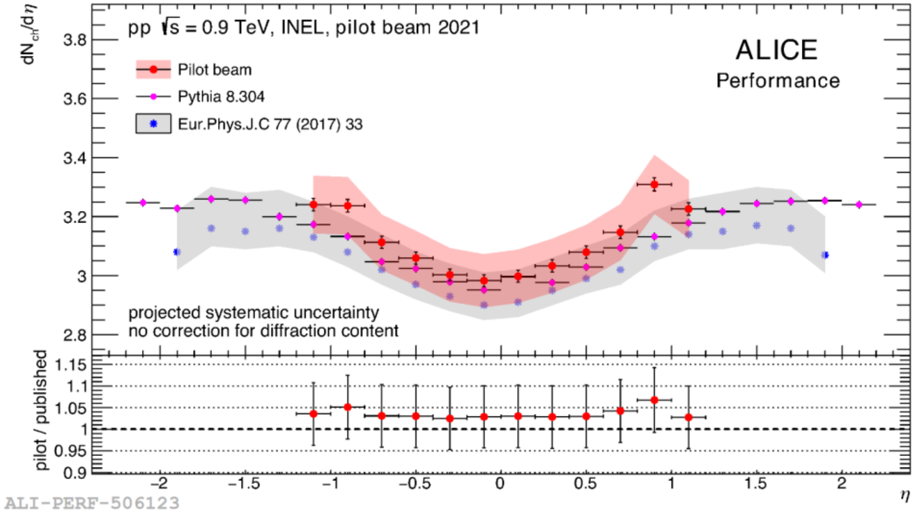
- Forward Rapidity: 2.8< η <5.1 , −3.7< η <−1.7
- Midrapidity: $|\eta|$ <0.8



- Takeaway messages:
  - The HM events are not a direct average of the Isotropic and Jetty event classes.
  - Instead, HM events are more similar to Isotropic events
  - This indicates that HM events are dominated by soft processes.

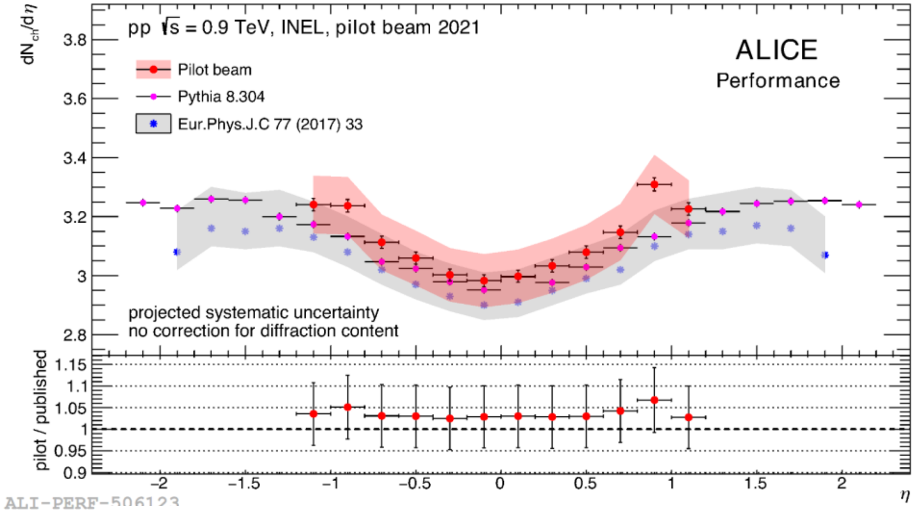
Outlook on low-multiplicity studies

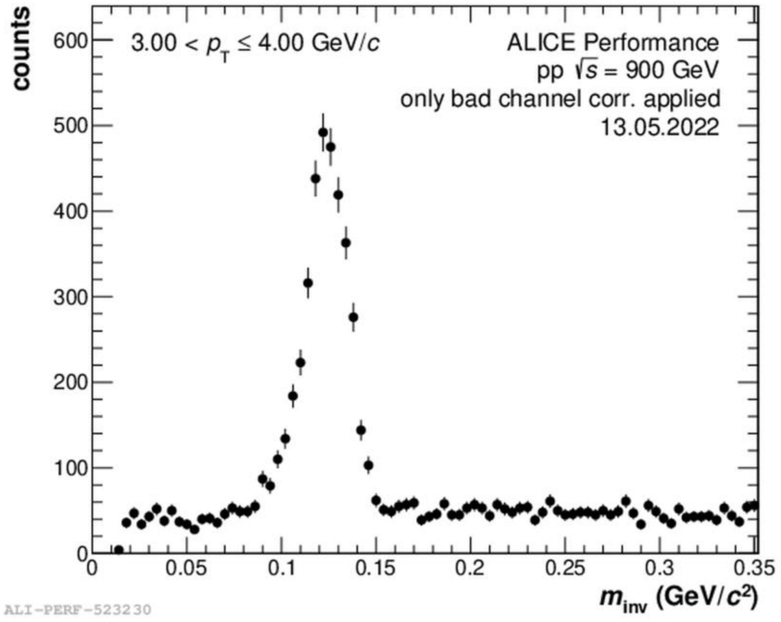
- Run 3 analyses can be utilized to measure extremely low multiplicities:
  - $< \mathrm{d}N/\mathrm{d}\eta >$



Outlook on low-multiplicity studies

- Run 3 analyses can be utilized
  to measure extremely low multiplicities:
  - $< \mathrm{d}N/\mathrm{d}\eta >$
  - Neutral mesons

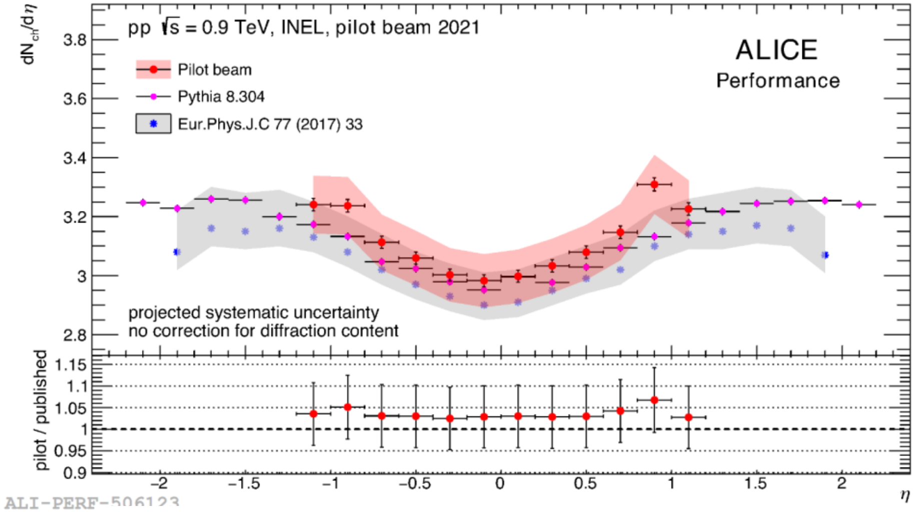


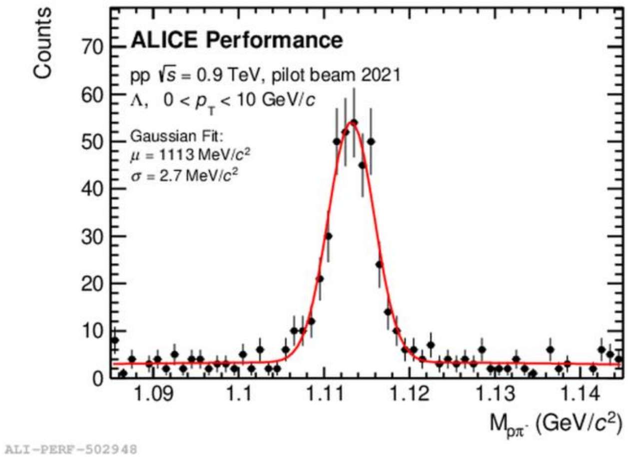


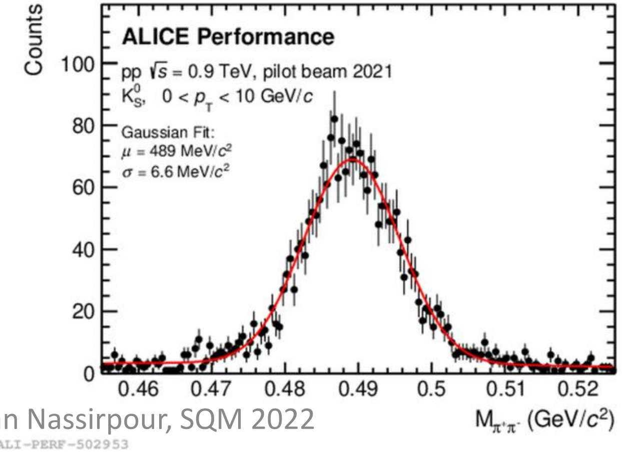
Outlook on low-multiplicity studies

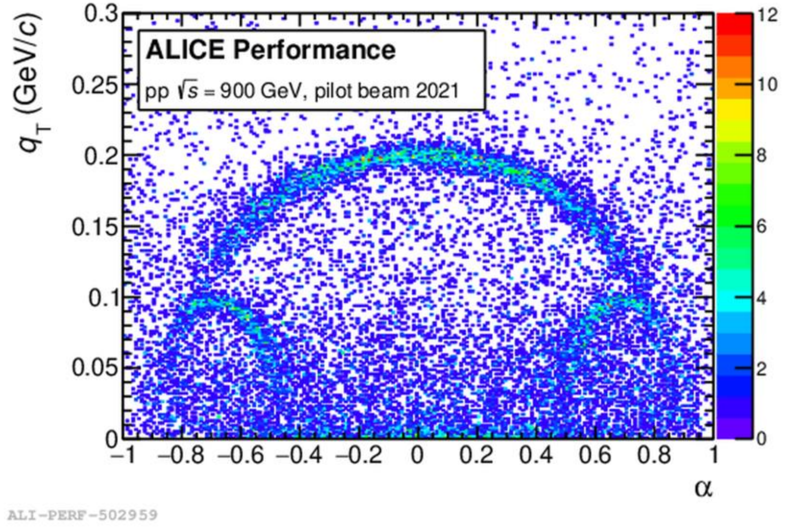
- Run 3 analyses can be utilized to measure extremely low multiplicities:
  - $< \mathrm{d}N/\mathrm{d}\eta >$
  - Neutral mesons
  - Strangeness

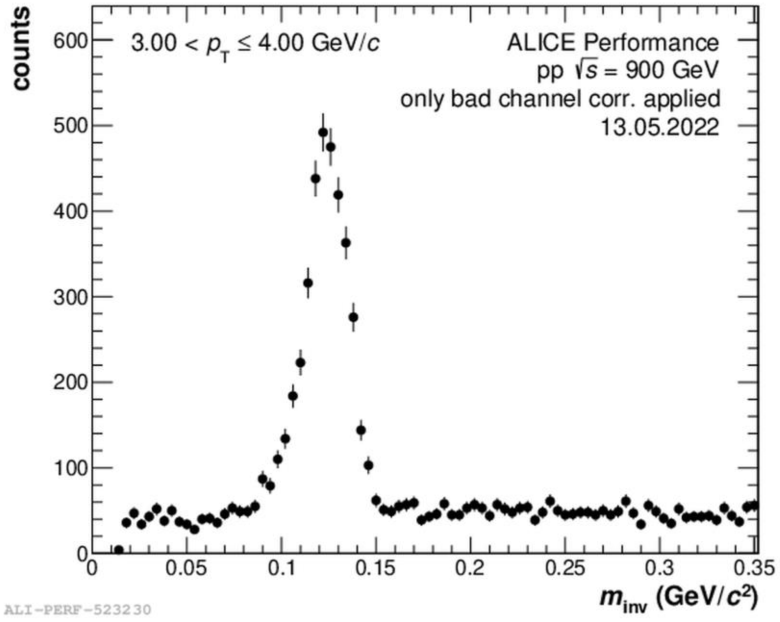
  - Analyses currently ongoing!











Summary

Neutral meson production as a function of multiplicity:

- No significant multiplicity dependence of η/π^0 as a function of p_{T}
- Integrated η/π^0 yields hint towards suppression of η at larger multiplicities

Particle Production as a function of Unweighted Transverse Spherocity:

- $S_0^{p_{\mathrm{T}}=1}$ can be used to select strangeness enhanced/suppressed events
- $S_0^{p_{\mathrm{T}}=1}$ can select different physics depending on the η region
- The results suggest that high-multiplicity events are primarily dominated by soft processes.

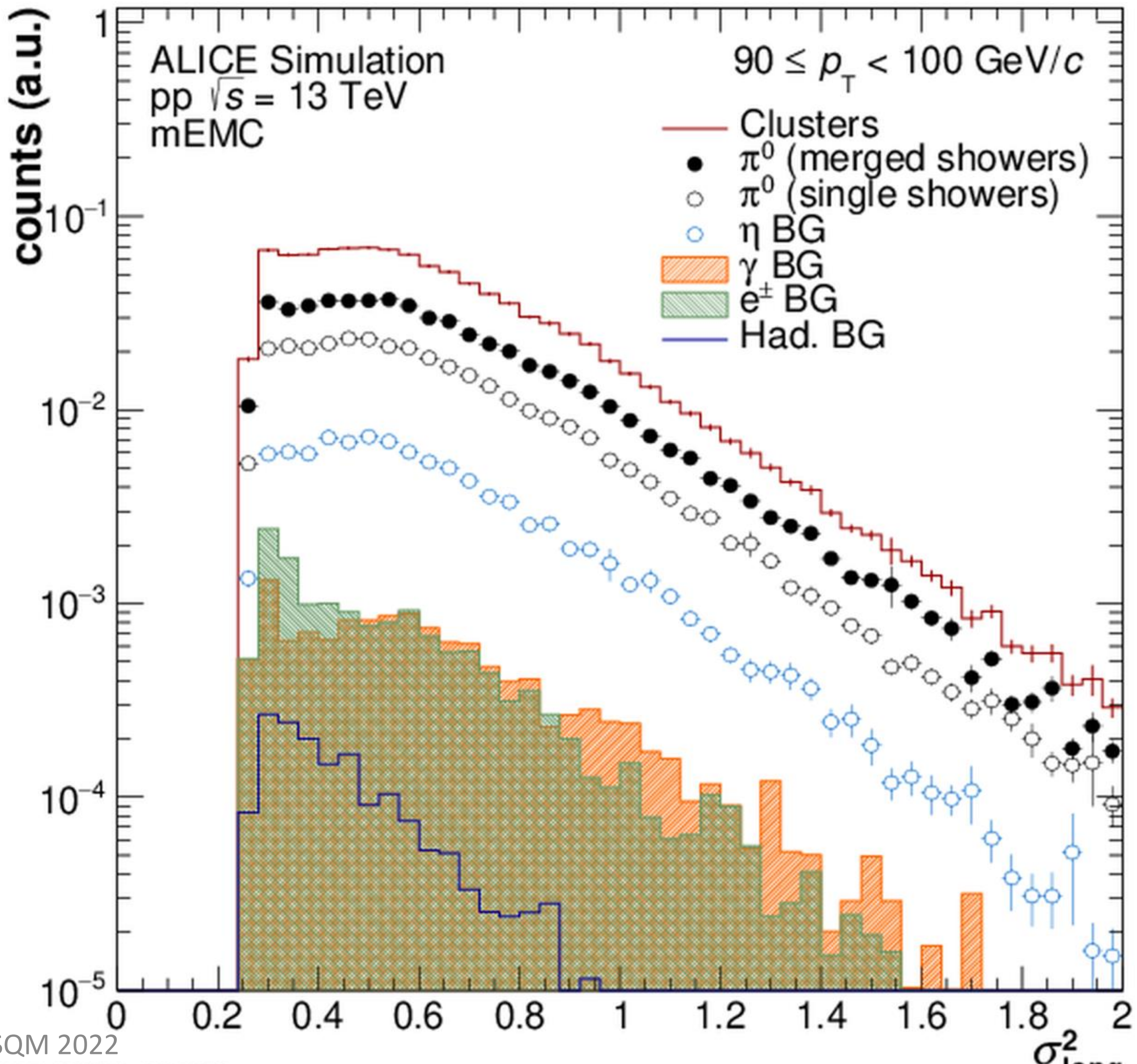
Outlook:

- Comprehensive paper on $S_0^{p_{\mathrm{T}}=1}$ under review, expected publication in the near future
- Run 3/4 will allow for differential low-multiplicity measurements

BACKUP

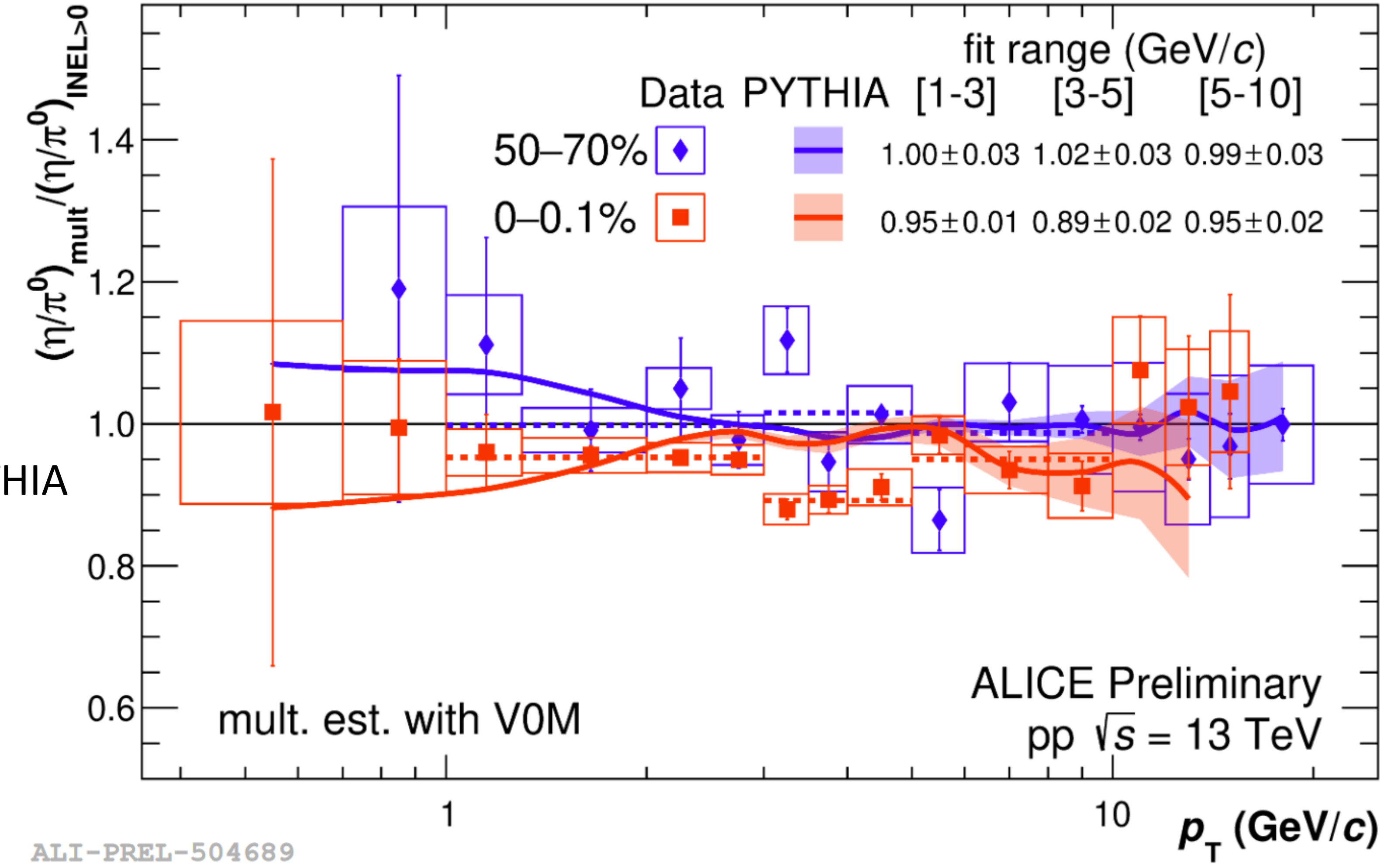
Neutral Meson Production: Analysis details

- The η and π^0 mesons are reconstructed by combining photon pairs.
  - Final yield is extracted by combining subdetectors.
- Measurements up to high-p_{T} (>50 GeV/c) using merged EMCal clusters.
  - Ensures a high π^0 purity (>70%)

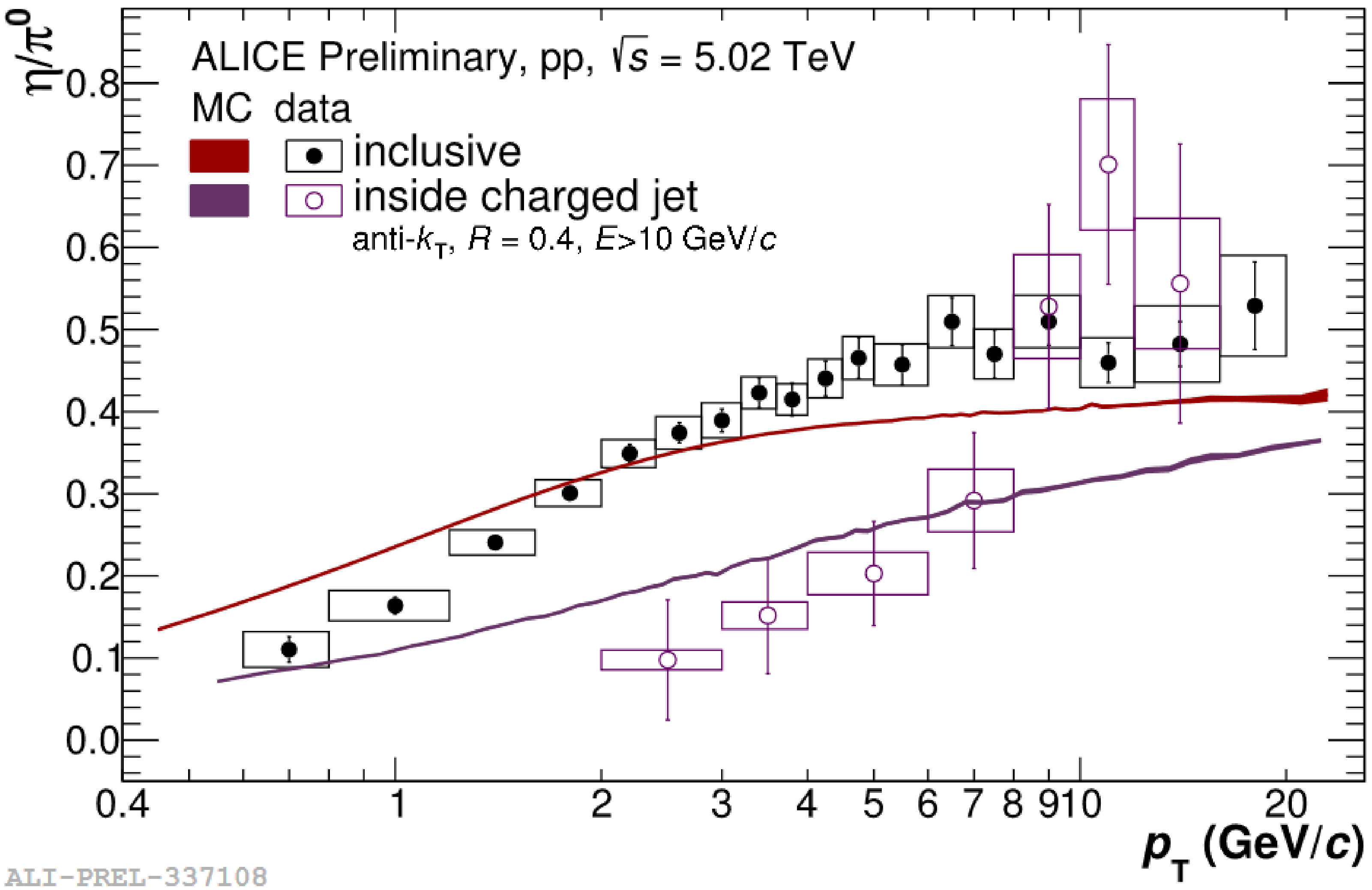


Neutral Meson Production: Results

- New results suggests that η/π^0 is independent of multiplicity as a function of p_{T}.
  - p_{T} -differential η production is not modified even in extremely large pp multiplicities.
- Double-ratio hints towards a very small effect.
  - Qualitatively well described by PYTHIA
  - Small tension at 3-5 GeV/c, could contain interesting physics.



Jet Pt Evolution



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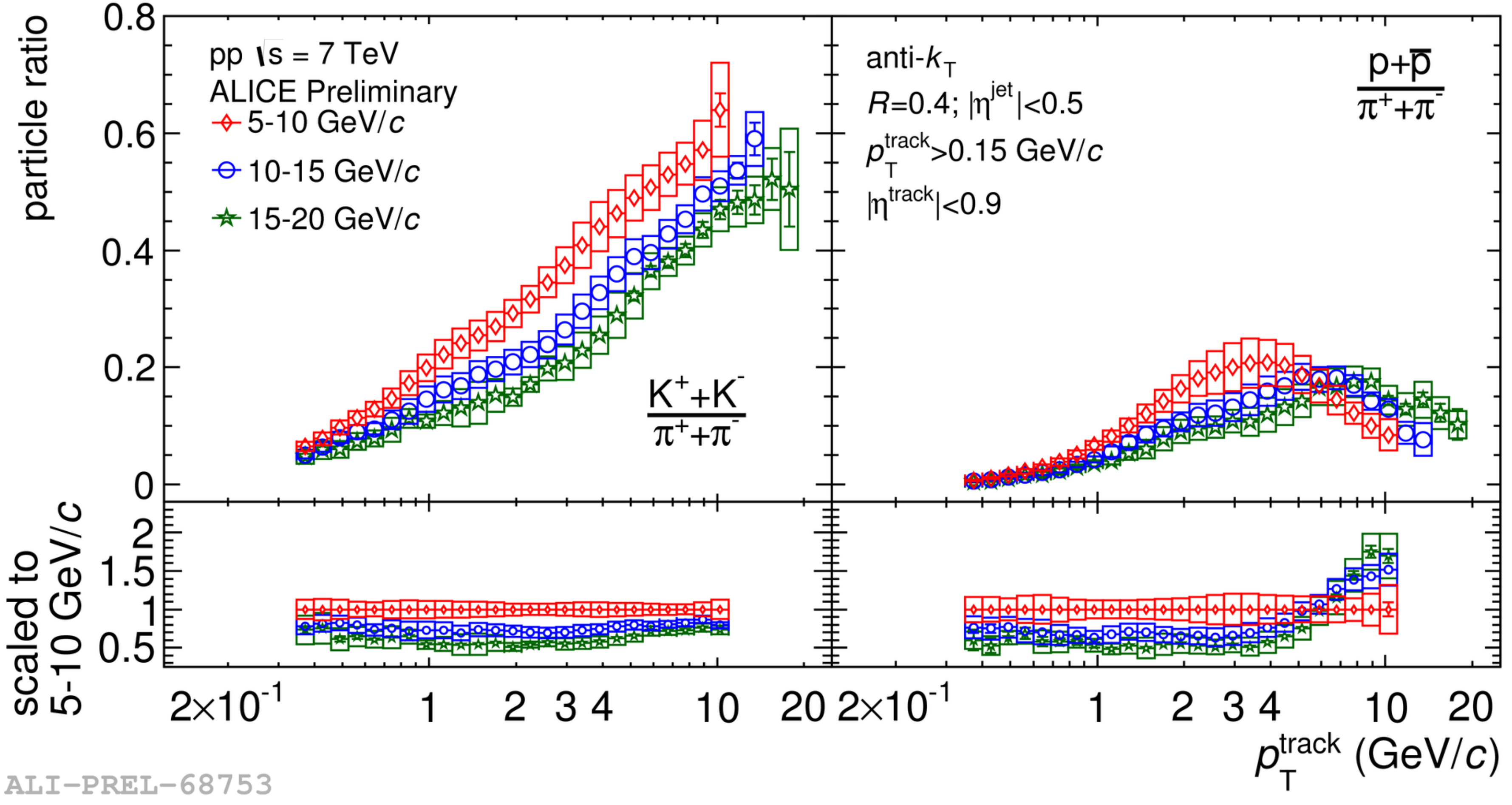
Jet Pt Evolution

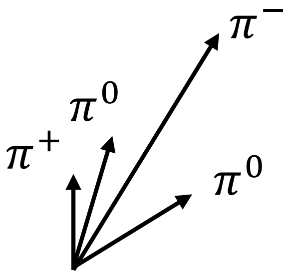


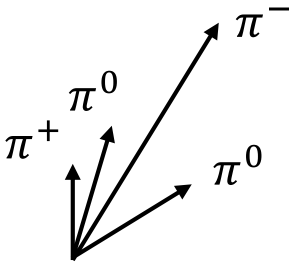
Unweighed Transverse Spherocity $S_O^{p_T=1}$

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

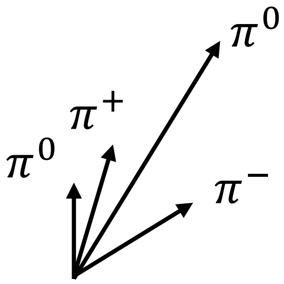
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

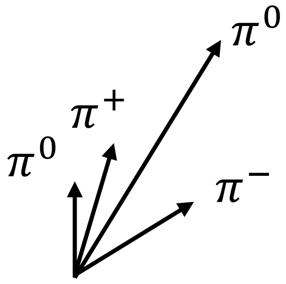
$S_{O,1}$





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





$S_{O,2}$

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

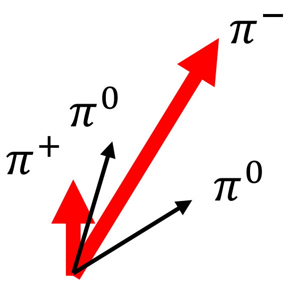
Unweighed Transverse Spherocity $S_{O}^{p_{T}=1}$

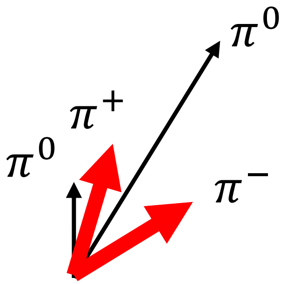
- $S_{O}^{p_{T}=1}$ is measured as S_O, but only considers the angular component.

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

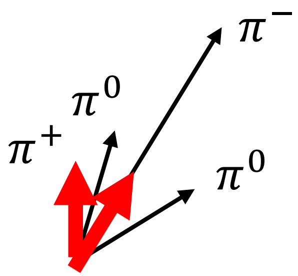
$S_{O,1}$ and $S_{O,2}$ will describe two completely different topologies!

$S_{O,1}$

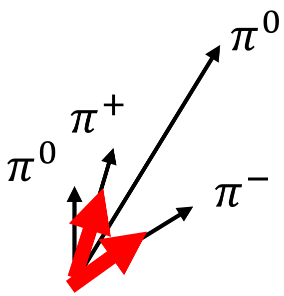




$S_{O,2}$



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



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

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

Identified Vs Unidentified Hadrons

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

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

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

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