Transverse spherocity dependence of light-flavor hadrons in pp collisions at $\sqrt{s}$ = 13 TeV

Rutuparna Rath

INFN Bologna, Italy

[On behalf of the ALICE Collaboration]

Istituto Nazionale di Fisica Nucleare

MESON 2023

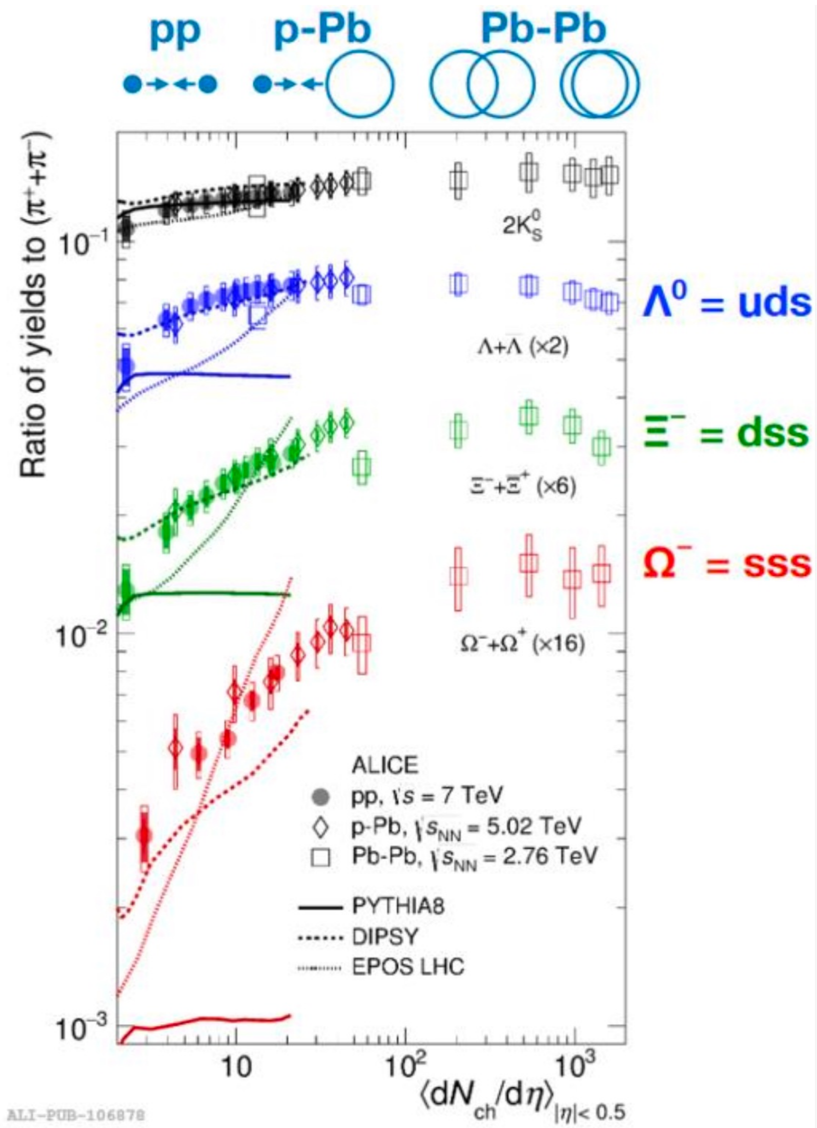
17th International Workshop on Meson Physics

22nd - 27th June 2023, Kraków, Poland

Organized by Jagiellonian University Kraków,
GSI Helmholtz Centre for Heavy Ion Research,
INFN-LNF Frascati, Institute of Nuclear Physics PAS

Motivation

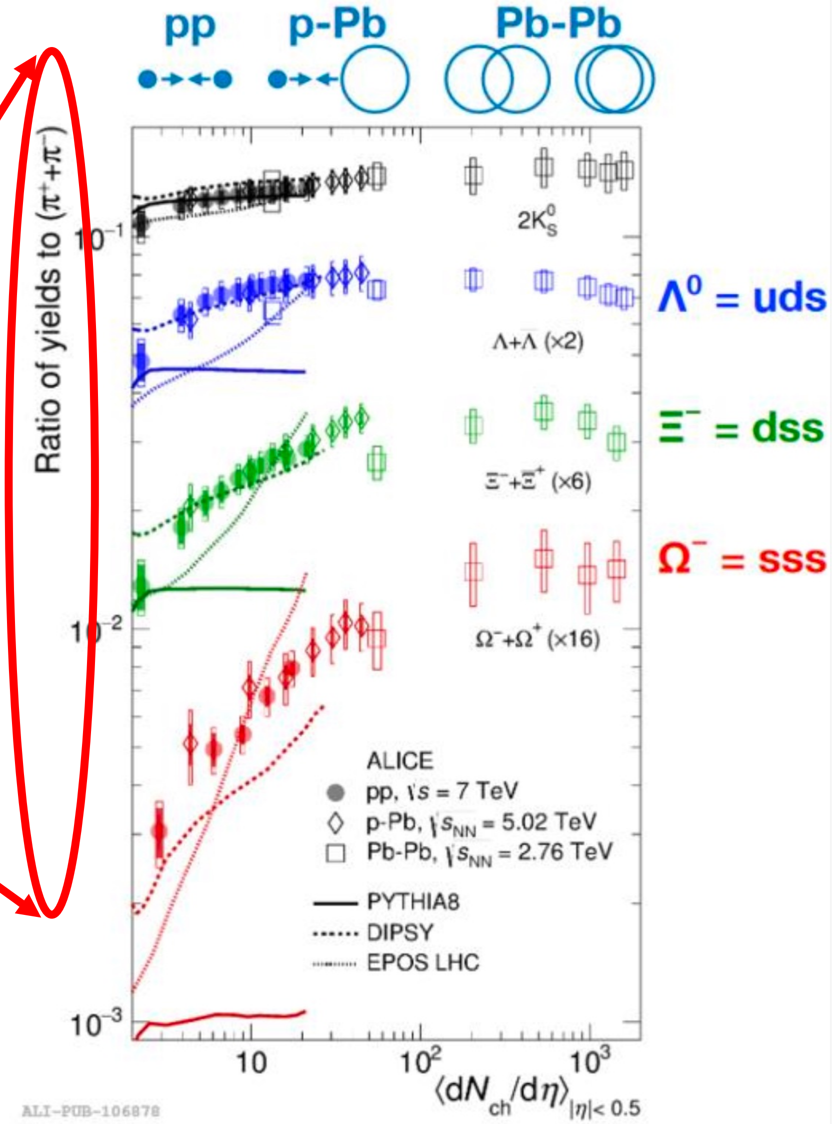
- Multiplicity-dependent study in small systems allows us to bridge the gap between minimum bias pp and peripheral heavy-ion collisions
- Light-flavor hadrons: the most abundant particles facilitate the study of the soft processes and non-perturbative regime
- The main focus of this presentation:
    - Light-flavor yield vs. event multiplicity
        - The relative yield of strange hadrons to pions (S/π)
        - The average charged-particle-multiplicity measured at midrapidity



Nature Phys 13, 535–539 (2017)

Motivation

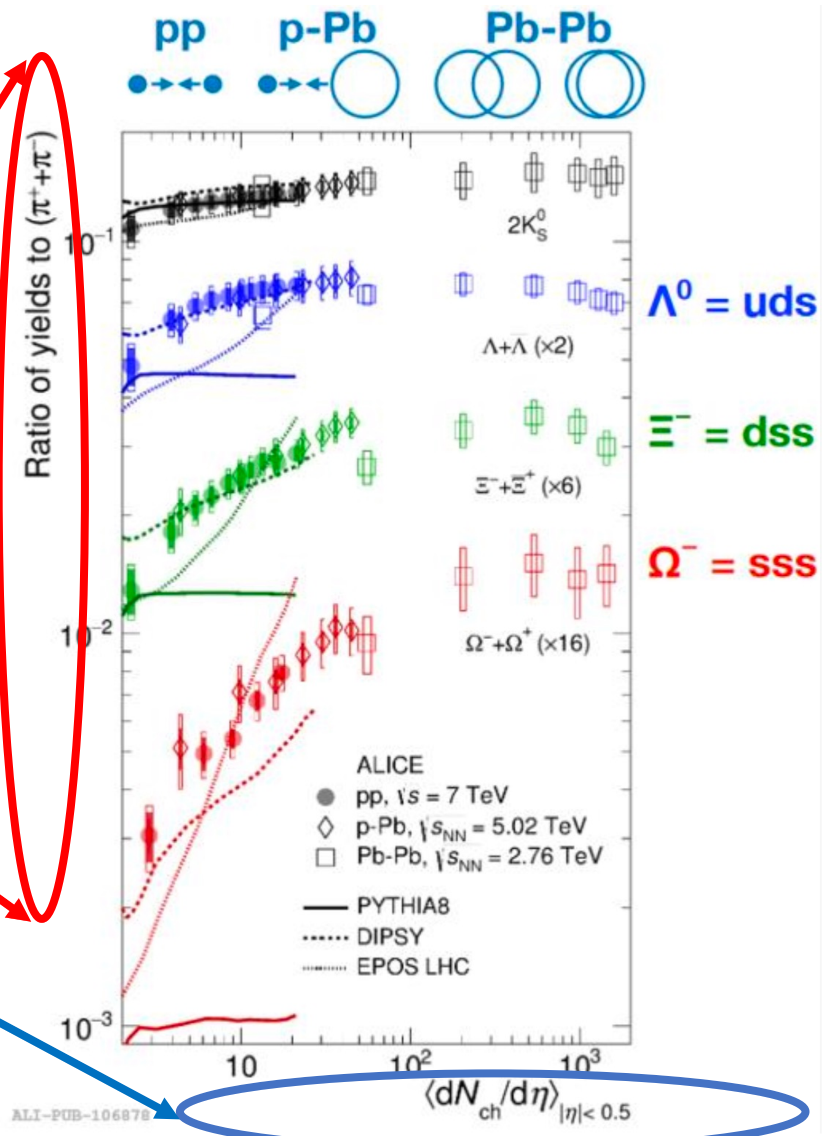
- Multiplicity-dependent study in small systems allows us to bridge the gap between minimum bias pp and peripheral heavy-ion collisions
- Light-flavor hadrons: the most abundant particles facilitate the study of the soft processes and non-perturbative regime
- The main focus of this presentation:
    - Light-flavor yield vs. event multiplicity
        - The relative yield of strange hadrons to pions (S/π)
        - The average charged-particle-multiplicity measured at midrapidity



Nature Phys 13, 535–539 (2017)

Motivation

- Multiplicity-dependent study in small systems allows us to bridge the gap between minimum bias pp and peripheral heavy-ion collisions
- Light-flavor hadrons: the most abundant particles facilitate the study of the soft processes and non-perturbative regime
- The main focus of this presentation:
  - Light-flavor yield vs. event multiplicity
    - The relative yield of strange hadrons to pions (S/π)
    - The average charged-particle-multiplicity measured at midrapidity

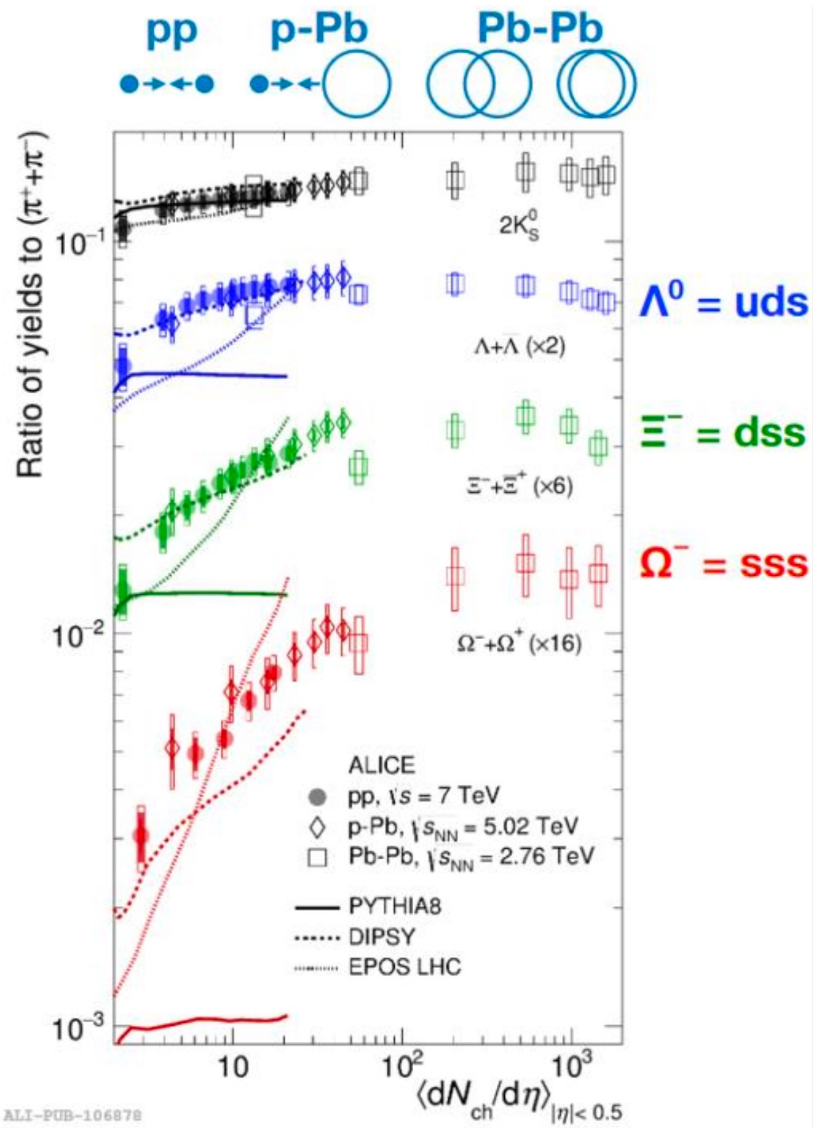


Nature Phys 13, 535–539 (2017)

Motivation

- Multiplicity-dependent study in small systems allows us to bridge the gap between minimum bias pp and peripheral heavy-ion collisions
- Light-flavor hadrons: the most abundant particles facilitate the study of the soft processes and non-perturbative regime
- The main focus of this presentation:
    - Light-flavor yield vs. event multiplicity

- In AA 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



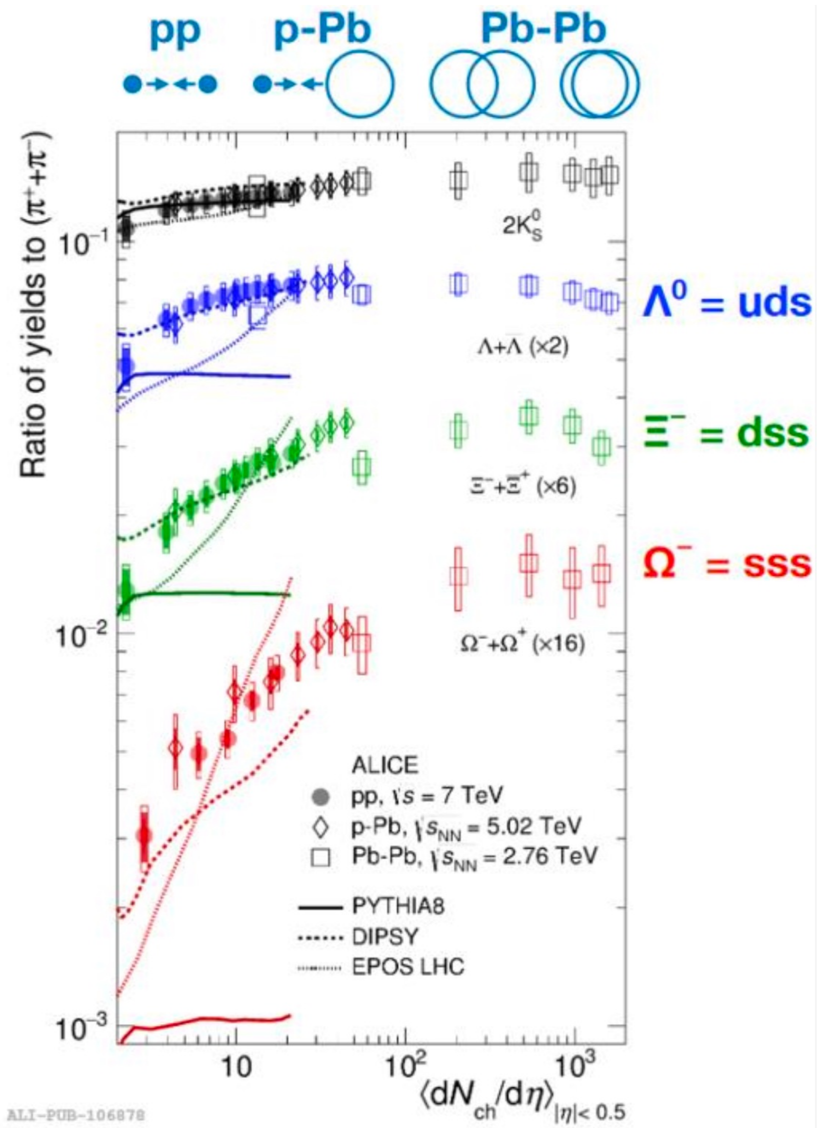
Nature Phys 13, 535–539 (2017)

Motivation

- Multiplicity-dependent study in small systems allows us to bridge the gap between minimum bias pp and peripheral heavy-ion collisions
- Light-flavor hadrons: the most abundant particles facilitate the study of the soft processes and non-perturbative regime
- The main focus of this presentation:
    - Light-flavor yield vs. event multiplicity

- In AA 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

- In such cases, we need other observables to characterize events. So, what are the possible observables?



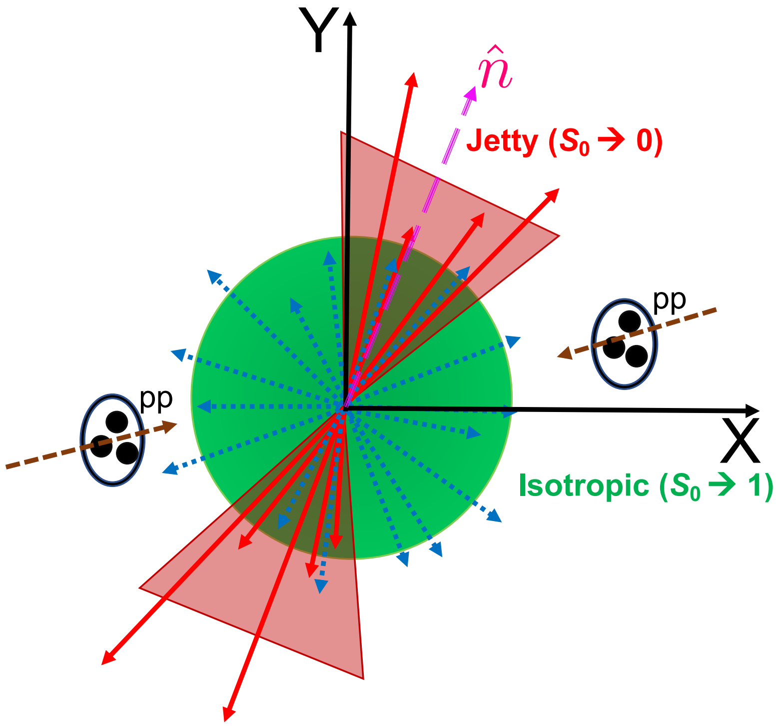
Nature Phys 13, 535–539 (2017)

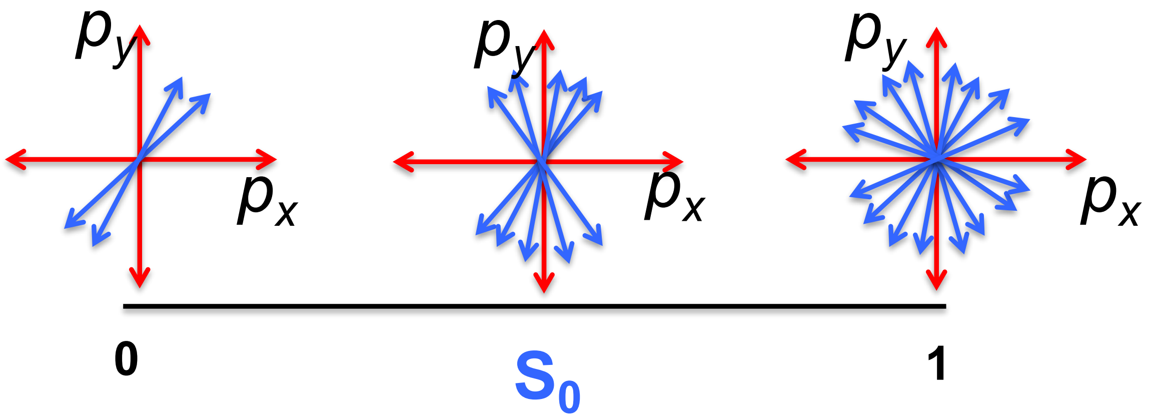
Transverse spherocity ($S_0^{p_\mathrm{T}=1}$)

- S_0 is defined using a unit vector n (n_T, 0) that minimizes

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

- S_0 can be used to disentangle the soft and hard QCD dominated process in an event





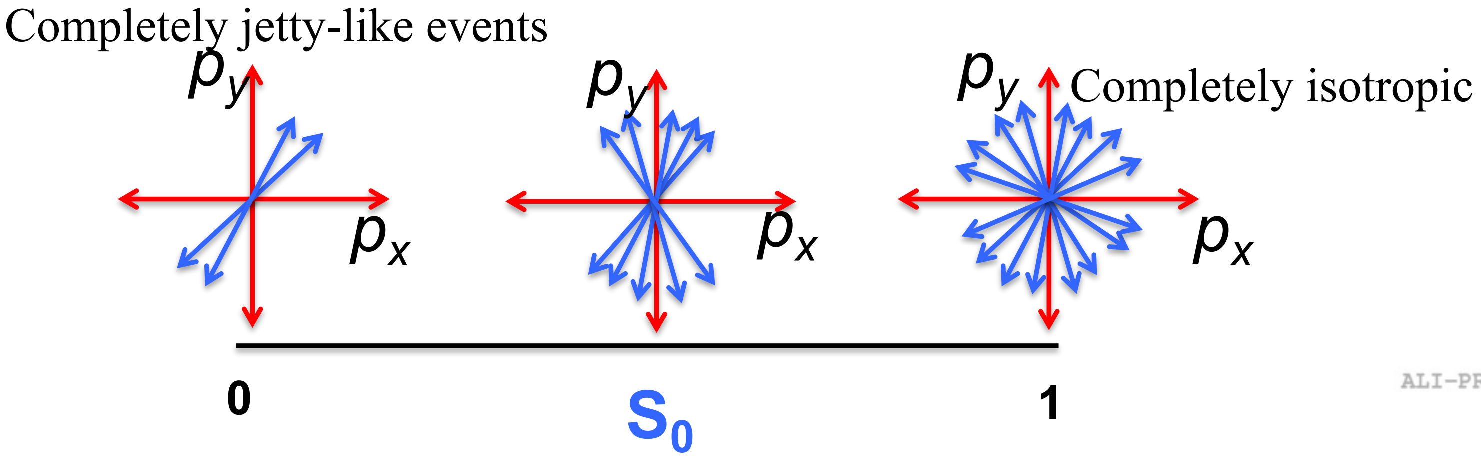
S_0 → 0 (jetty limit)
(Dominated by hard QCD processes)
S_0 → 1 (isotropic limit)
(Dominated by soft QCD processes)

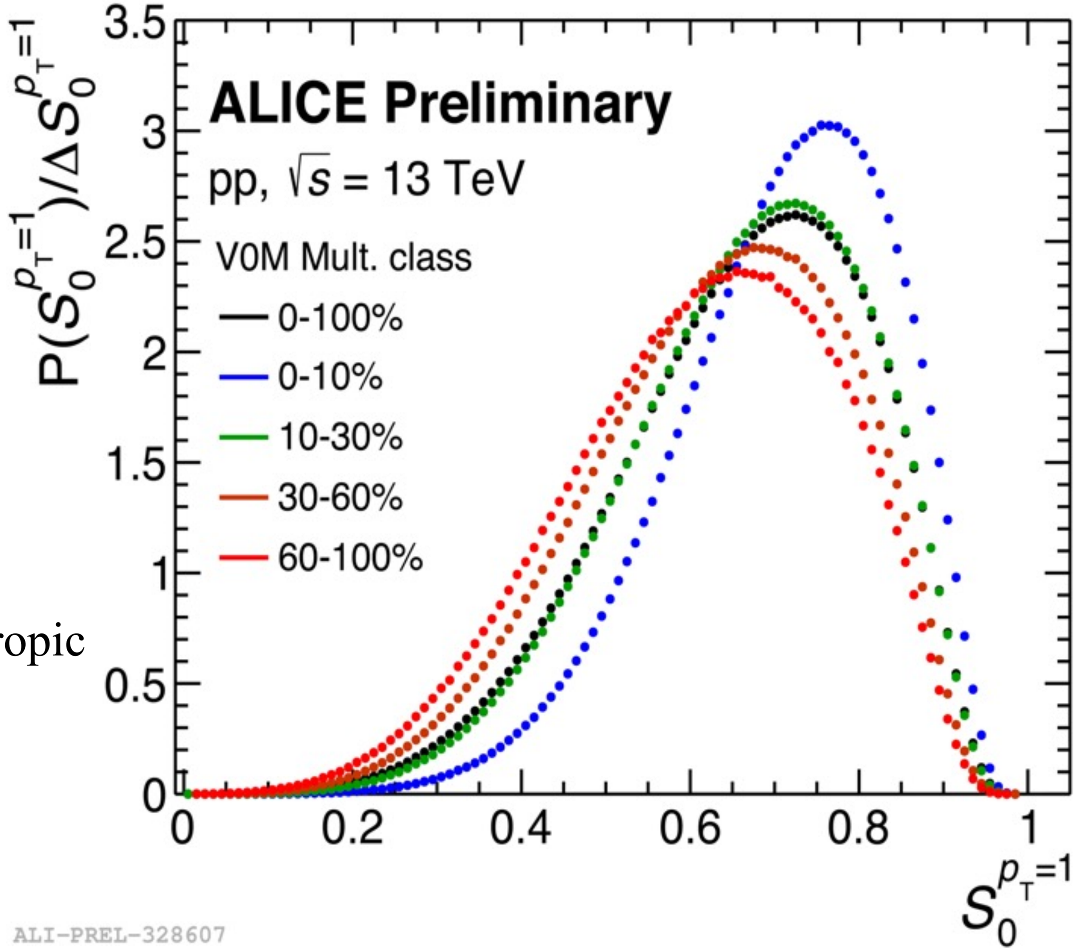
Transverse spherocity ($S_0^{p_T=1}$)

- S_0 is defined using a unit vector n (n_T, 0) that minimizes

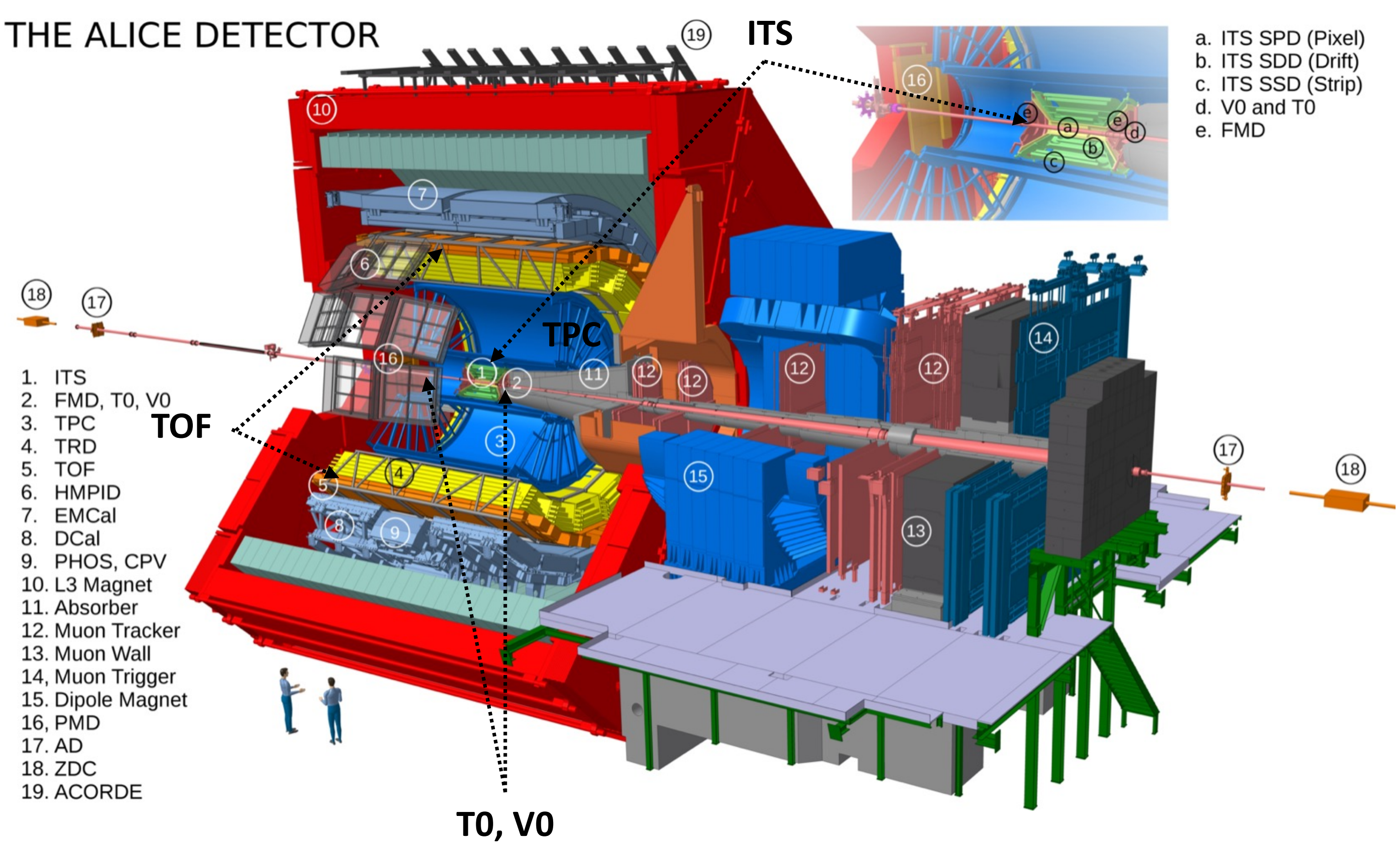
$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i \; |\hat{p}_{T_i} \times \hat{n}|}{N_{trk}} \right)^2$$

- S_0 can be used to disentangle the soft and hard QCD dominated process in an event





The ALICE detector



JINST 3, S08002 (2008)

ITS ($|\eta|<0.9$)

Trigger, vertex, tracking, PID (dE/dx)

TPC ($|\eta|<0.9$)

Tracking and vertexing, PID (dE/dx)
$\sigma_{dE/dx} \sim$ 5.5% for pp
$\sigma_{dE/dx} \sim$ 7% for Pb–Pb

TOF ($|\eta|<0.9$)

Multi-gap Resistive Plate Chambers

Time resolution ($\sigma_{TOF} \sim$ 80 ps) , PID (time-of-flight)

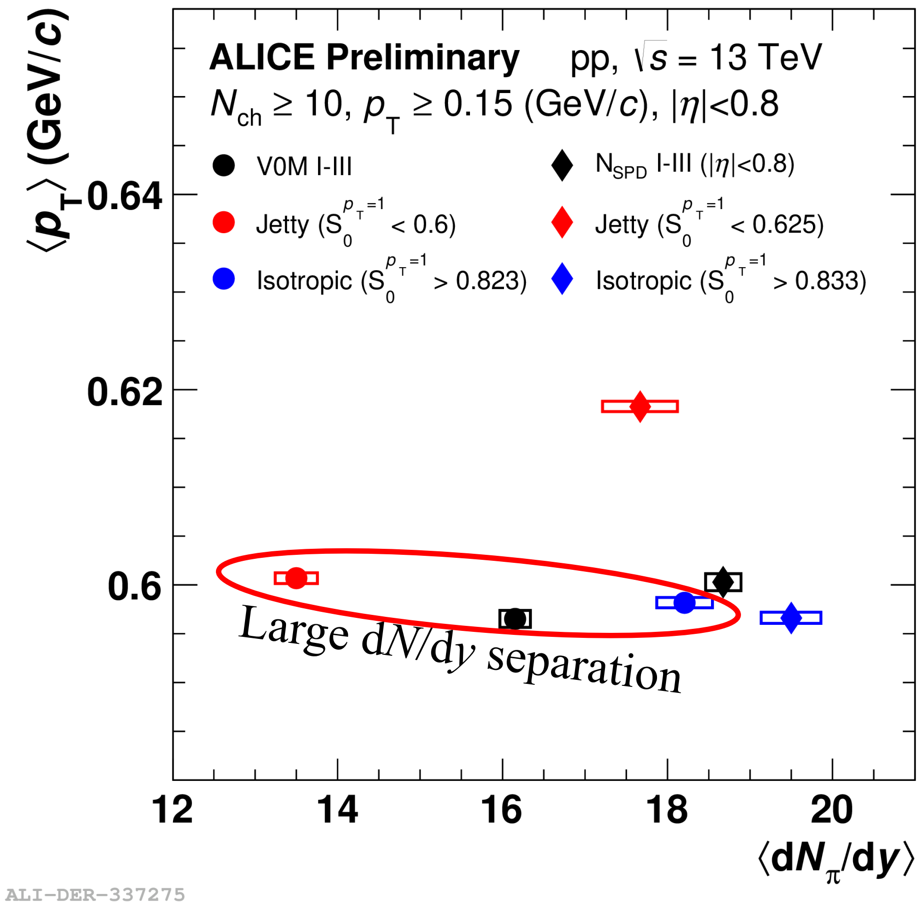
V0 (A&C)

trigger, multiplicity estimators
(Minimum Bias: 0 – 100%, High Multiplicity: 0 – 0.1%)

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

CL1: Mid-rapidity multiplicity estimator (obtained using SPD tracklets: $|\eta| < 0.8$)
V0M: Forward rapidity multiplicity estimator (obtained using V0 amplitude: $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)

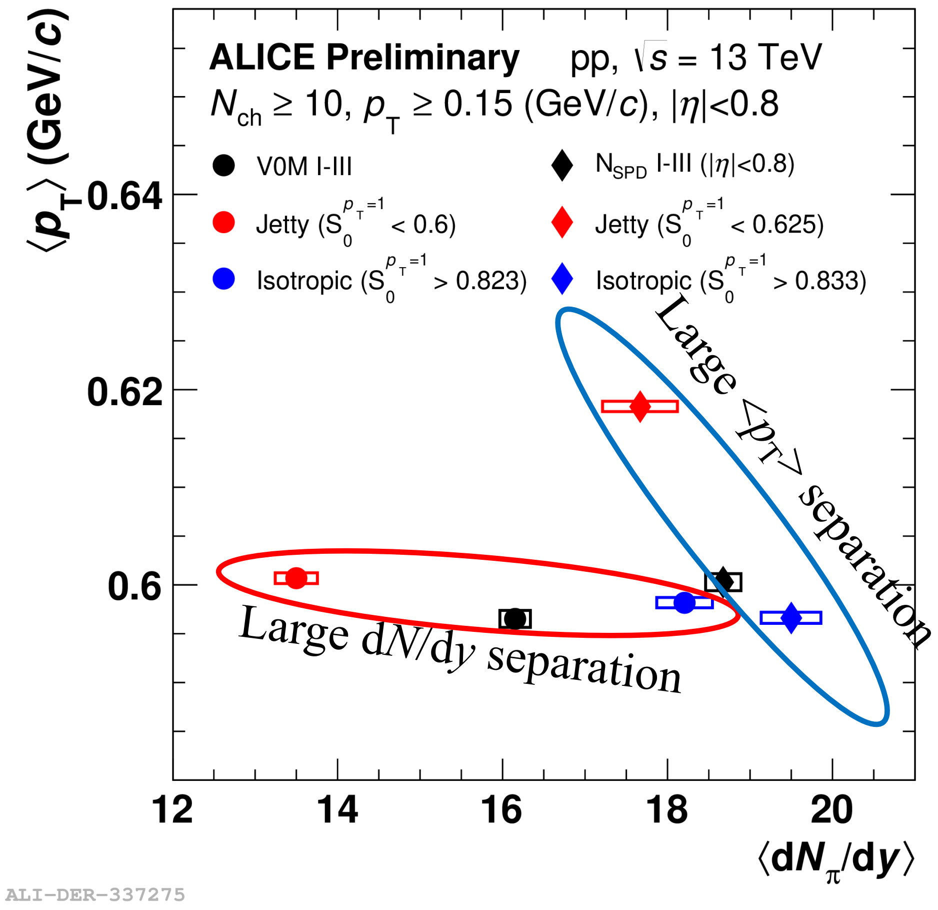
- V0M → change in <dN/dy>
- CL1 → change in $\langle p_\mathrm{T} \rangle$
- We expect a trivial correlation between spherocity and multiplicity. Due to the nature of MPIs/soft collisions
- This means that broad multiplicity range → selection on multiplicity
- This is why the main focus is CL1, where there is a significant selection of hardness



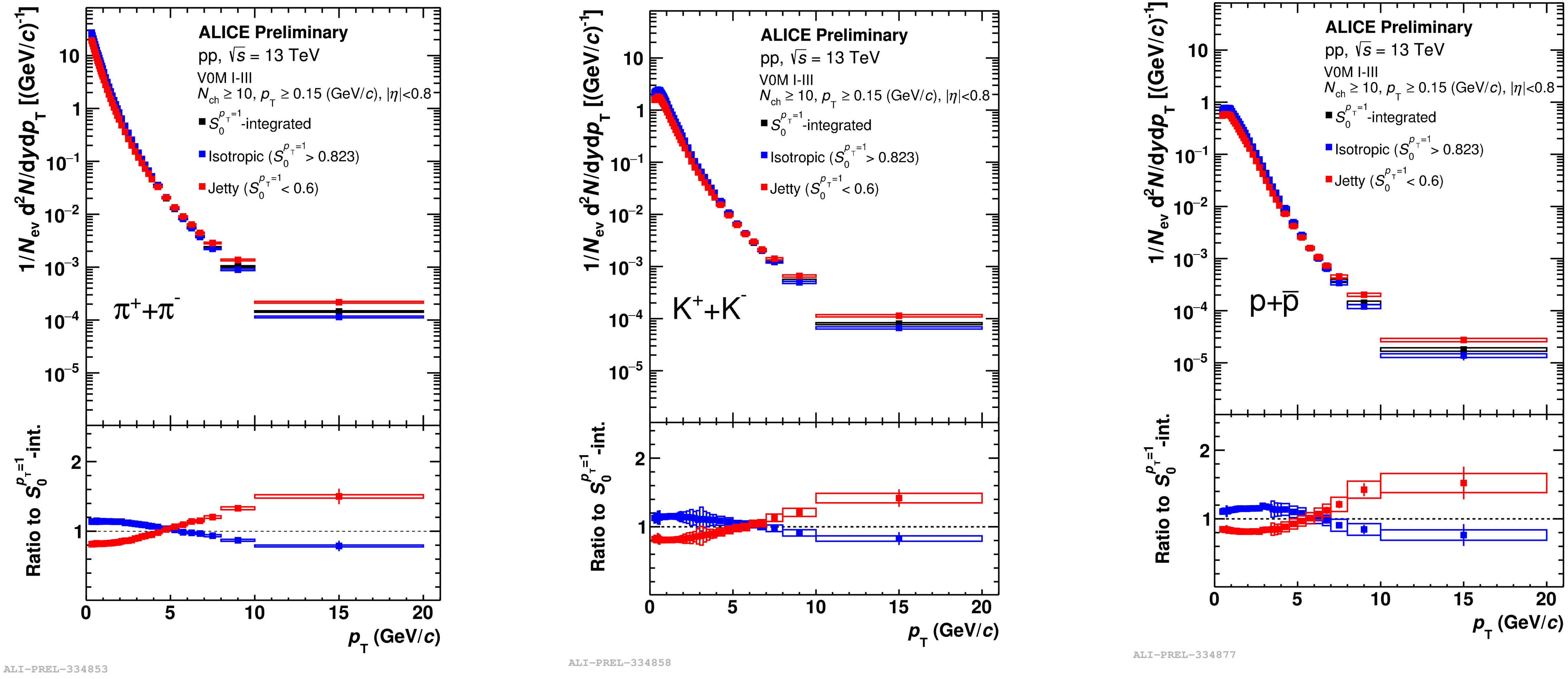
Multiplicity estimators for $S_0^{p_T=1}$ analysis

CL1: Mid-rapidity multiplicity estimator (obtained using SPD tracklets: $|\eta| < 0.8$)
V0M: Forward rapidity multiplicity estimator (obtained using V0 amplitude: $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$)

- V0M → change in <dN/dy>
- CL1 → change in <p_T>
- We expect a trivial correlation between spherocity and multiplicity. Due to the nature of MPIs/soft collisions
- This means that broad multiplicity range → selection on multiplicity
- This is why the main focus is CL1, where there is a significant selection of hardness

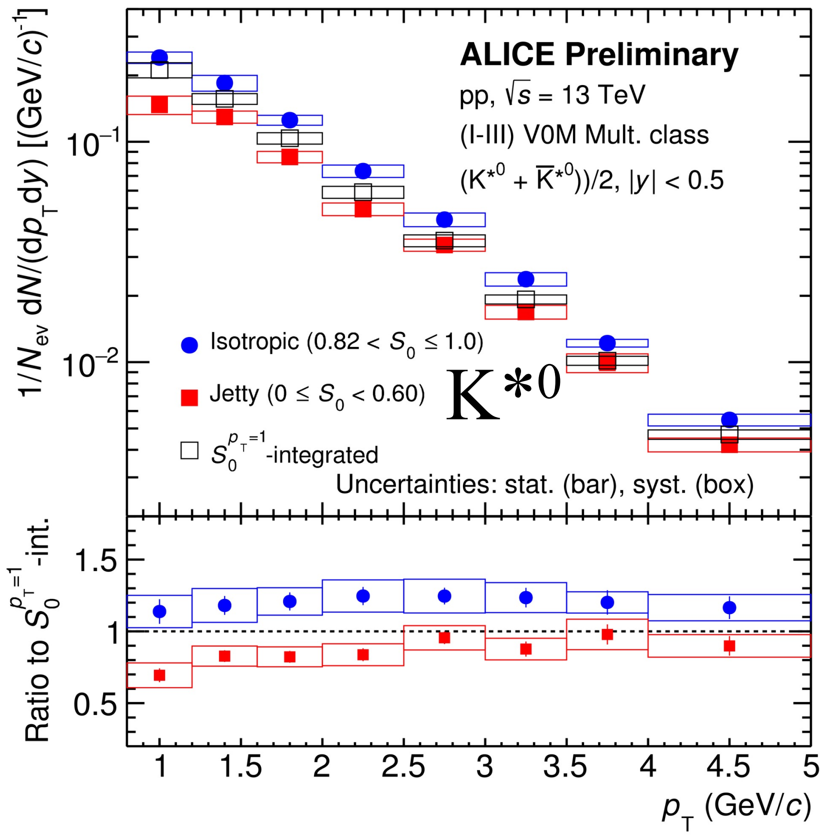


Transverse momentum spectra as a function of $S_0^{p_T=1}$ in V0M

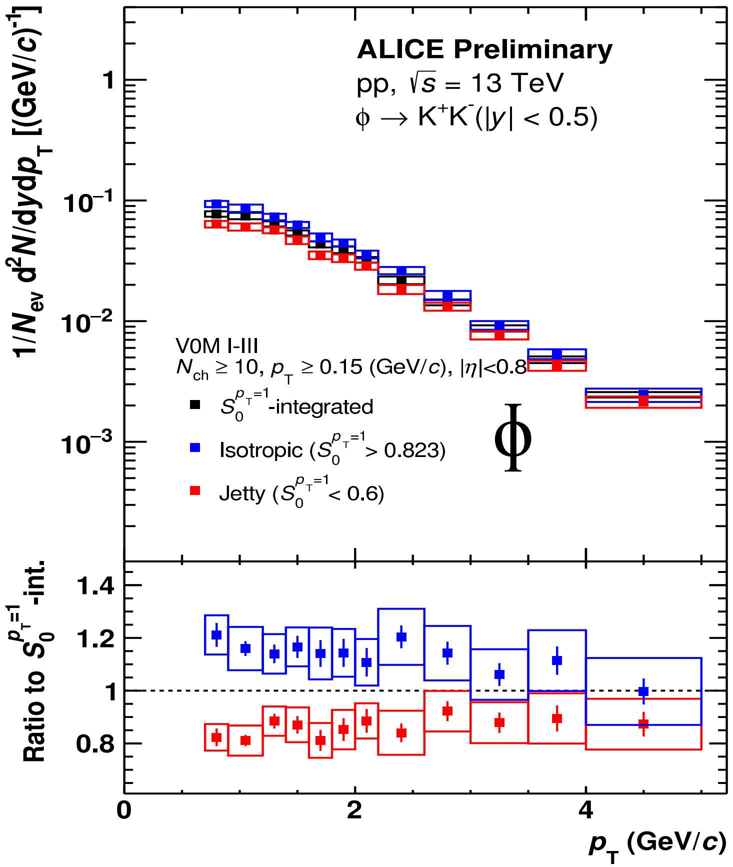


- As a function of S_0 event classes, the low-p_T region is dominated by isotropic-like events, whereas, the high-p_T region is dominated by jetty like events

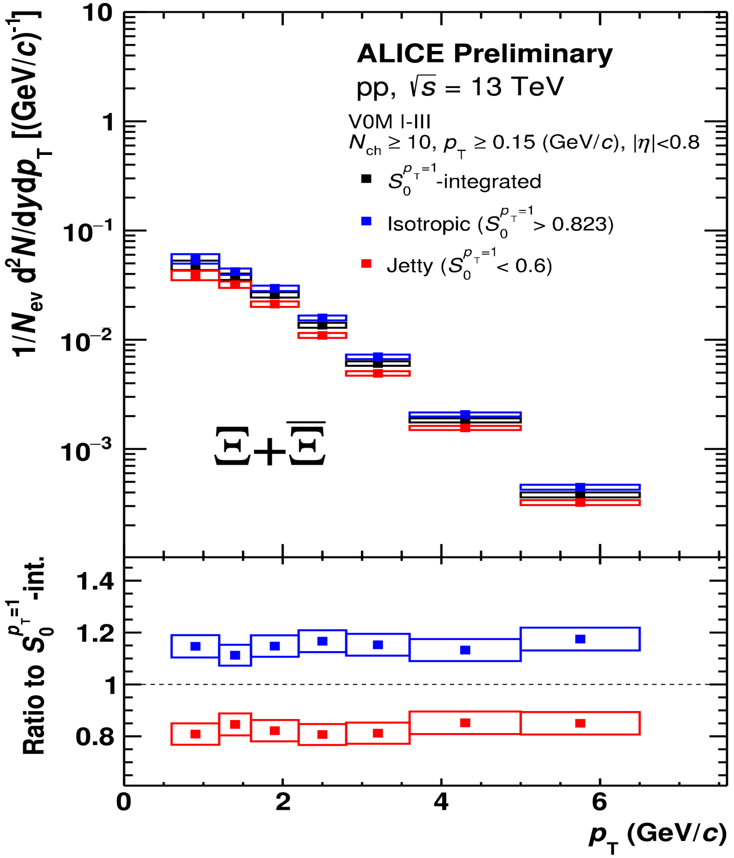
Transverse momentum spectra as a function of $S_0^{p_T=1}$ in V0M



ALI-PREL-328616



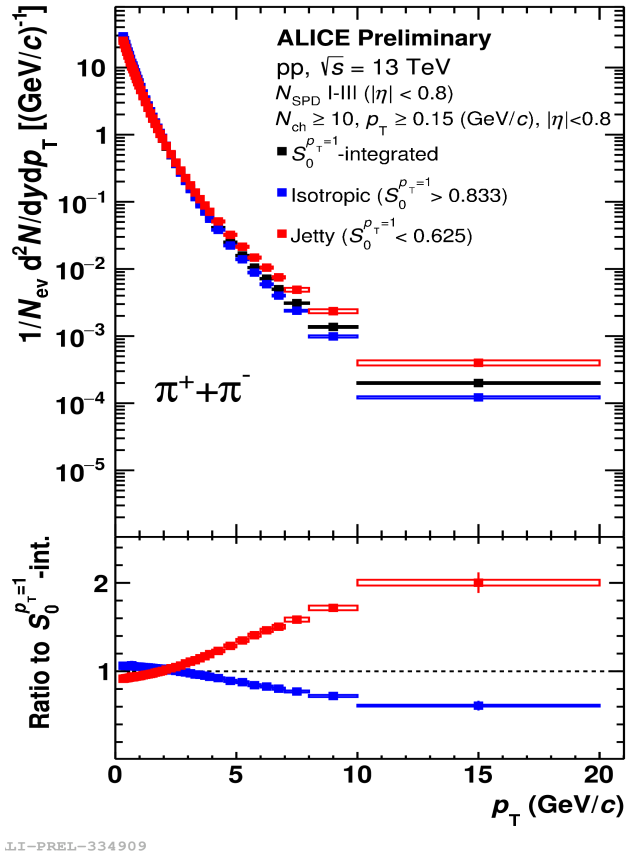
ALI-PREL-335191

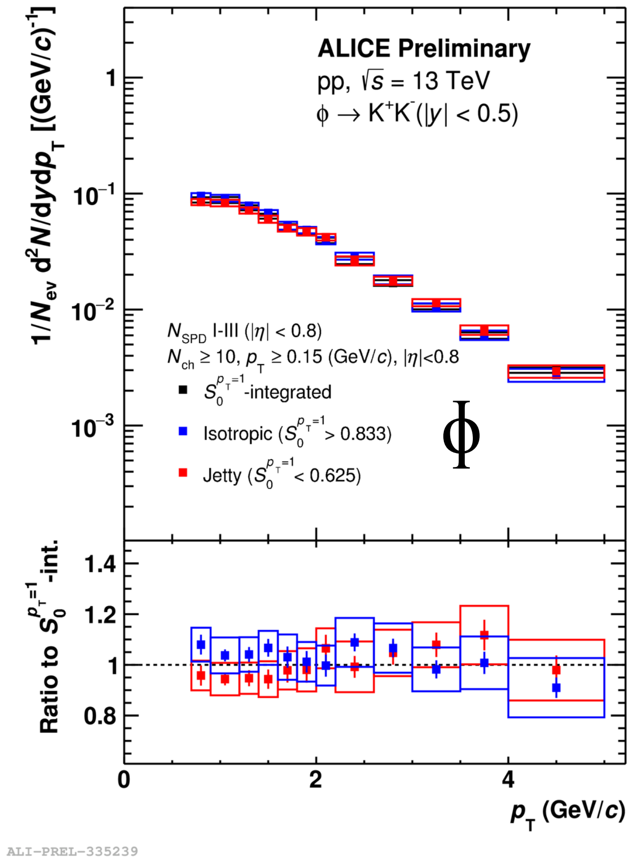


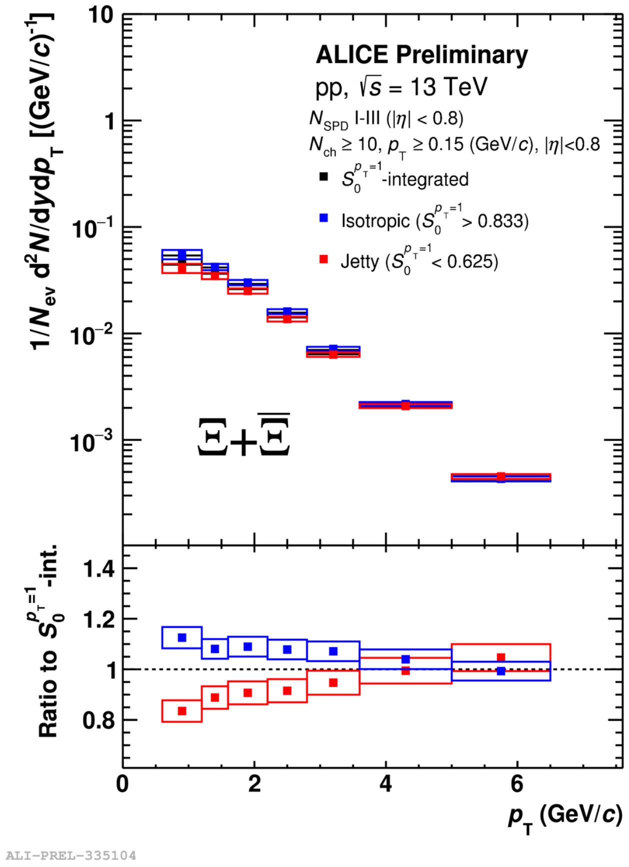
ALI-PREL-335032

- As a function of S_0 event classes, the low-p_T region is dominated by isotropic-like events, whereas, the high-p_T region is dominated by jetty-like events
- Similar dependence on event shape classes was observed across the particle species in V0M multiplicity

Transverse momentum spectra as a function of $S_0^{p_T=1}$ in CL1

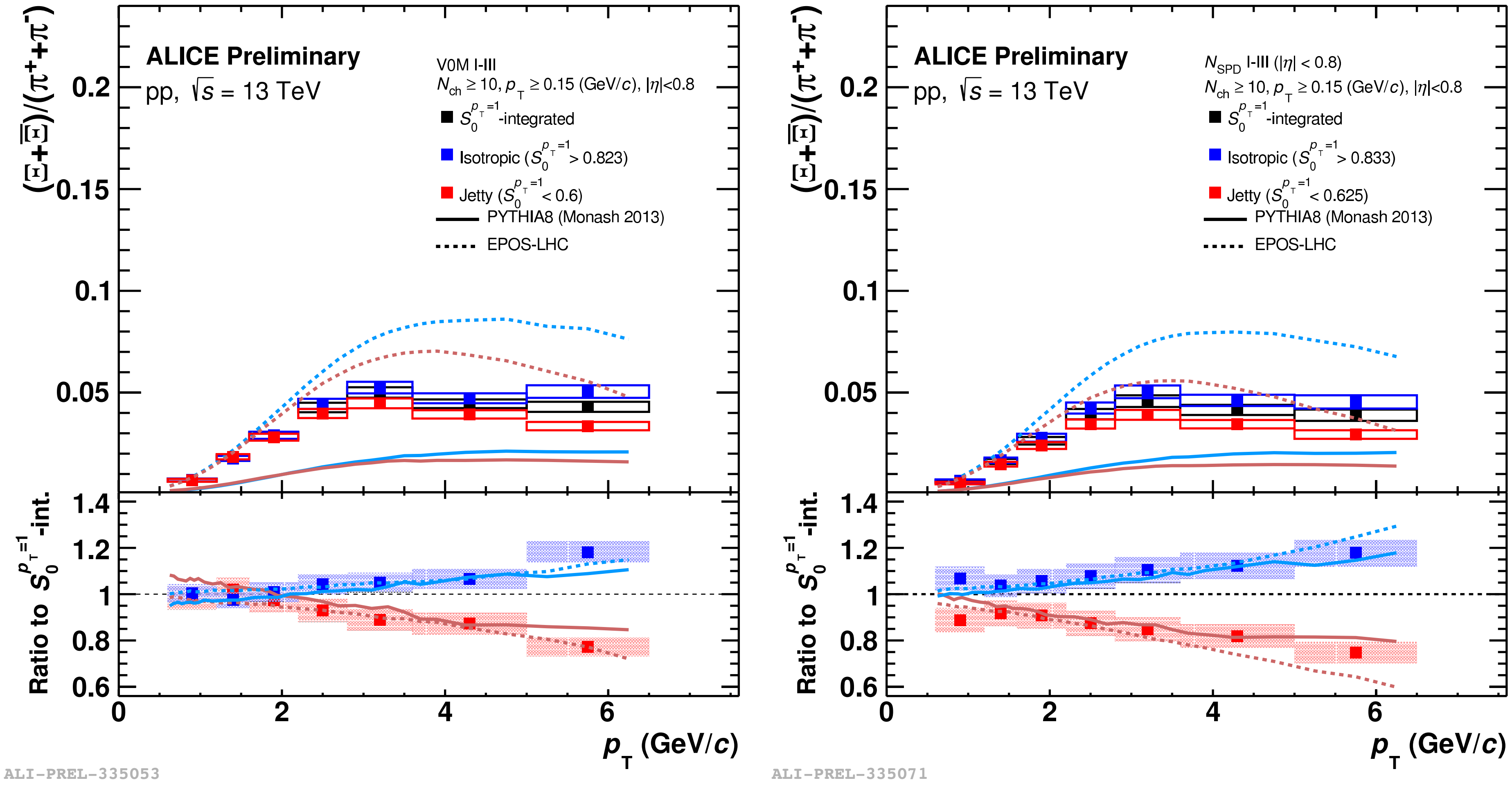






- As a function of S_0 event classes, the low-p_T region is dominated by isotropic-like events, whereas, the high-p_T region is dominated by jetty-like events
- With CL1, the crossing point for the light-flavor hadrons appear at lower p_T as compared to V0M → CL1 is more sensitive towards the hardness of the event

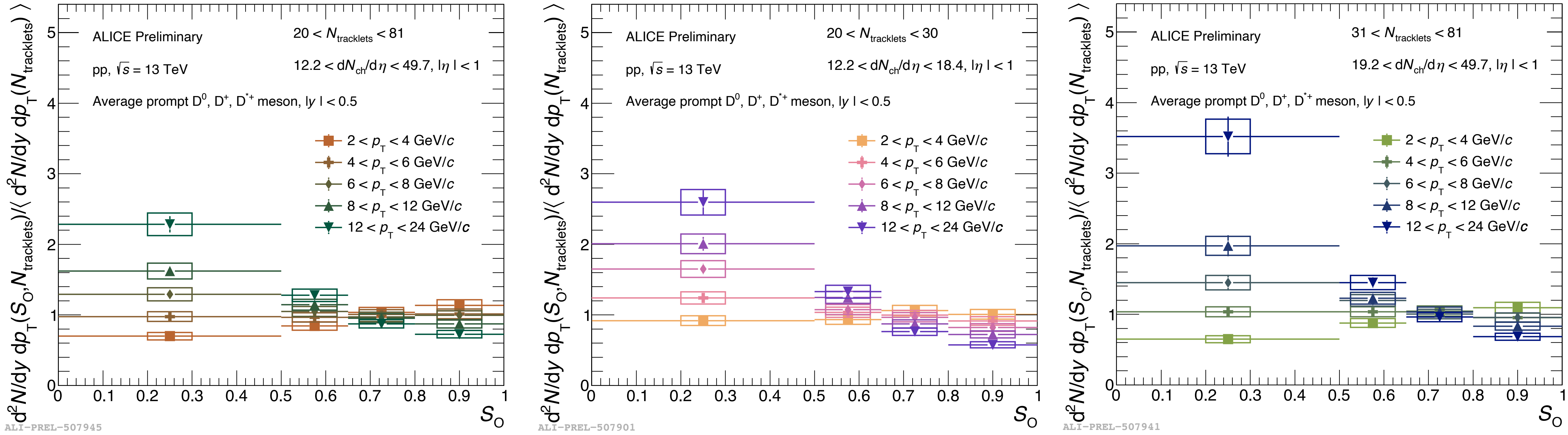
Ξ/π ratios as a function of $S_0^{p_\mathrm{T}=1}$



- 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 p_T evolution quite well, except for low- p_T

A glimpse from D-meson study as a function of $S_0^{p_\mathrm{T}=1}$



- The self-normalised yields have a decreasing shape which becomes faster with higher p_T intervals, for all the multiplicity classes considered
- It seems that the contribution of isotropic events in the production of prompt D mesons is very similar to jet-like ones for very low p_T intervals, while the latter is dominant for $p_\mathrm{T} > 6$ GeV/c

Summary and outlook

- $S_0^{p_T=1}$ can select different physics depending on the η region
- The results suggest that high-multiplicity events are primarily dominated by soft processes
- A clear event shape dependence for p_T-spectra has been observed for both V0M and reference multiplicity classes

Outlook

- A comprehensive paper on $S_0^{p_T=1}$ under preparation that includes results in the most extreme selections such as the top 0-1% in multiplicity and the top 0-10% in transverse spherocity, which is expected to be published soon

Further investigation with high statistics RUN 3 data (**Stay tuned for new results**)

Summary and outlook

- $S_0^{p_\mathrm{T}=1}$ can select different physics depending on the η region
- The results suggest that high-multiplicity events are primarily dominated by soft processes
- A clear event shape dependence for p_T-spectra has been observed for both V0M and reference multiplicity class

Outlook

- A comprehensive paper on $S_0^{p_\mathrm{T}=1}$ under preparation that includes results in the most extreme selections such as the top 0-1% in multiplicity and the top 0-10% in transverse spherocity, which is expected to be published soon

Further investigation with high statistics RUN 3 data (**Stay tuned for new results**)

THANK YOU FOR YOUR ATTENTION...

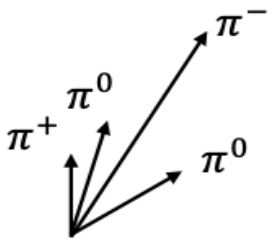
BACK UP

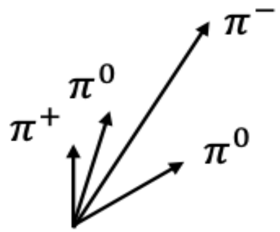
Introduction to unweighted transverse spherocity $S_0^{p_T=1}$

Spherocity Vs Unweighted Spherocity

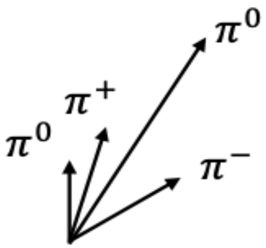
$$S_O = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \rightarrow S_O^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

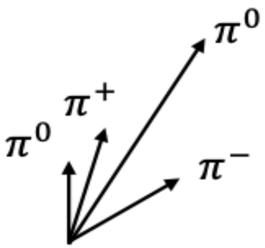
$S_{O,1}$





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





$S_{O,2}$

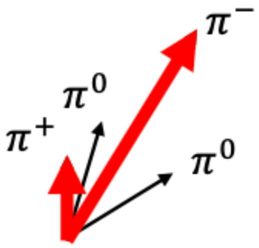
$S_{O,2}^{p_T=1}$

Introduction to unweighted transverse spherocity $S_0^{p_T=1}$

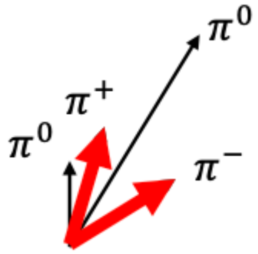
Spherocity Vs Unweighted Spherocity

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |p_T \times \hat{n}|}{\Sigma_i p_{T_i}} \right)^2 \quad \rightarrow \quad S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\hat{p}_T \times \hat{n}|}{N_{trk}} \right)^2$$

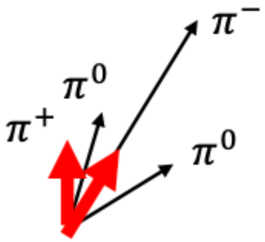
$S_{0,1}$



$S_{0,1}$ and $S_{0,2}$ will describe two completely different topologies!

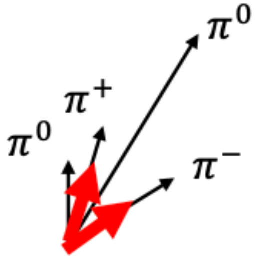


$S_{0,2}$



$S_{0,1}^{p_T=1}$

$S_{0,1}^{p_T=1}$ and $S_{0,2}^{p_T=1}$ will describe two similar topologies.



$S_{0,2}^{p_T=1}$