New results on multiplicity and event shape dependence of particle production in pp collisions

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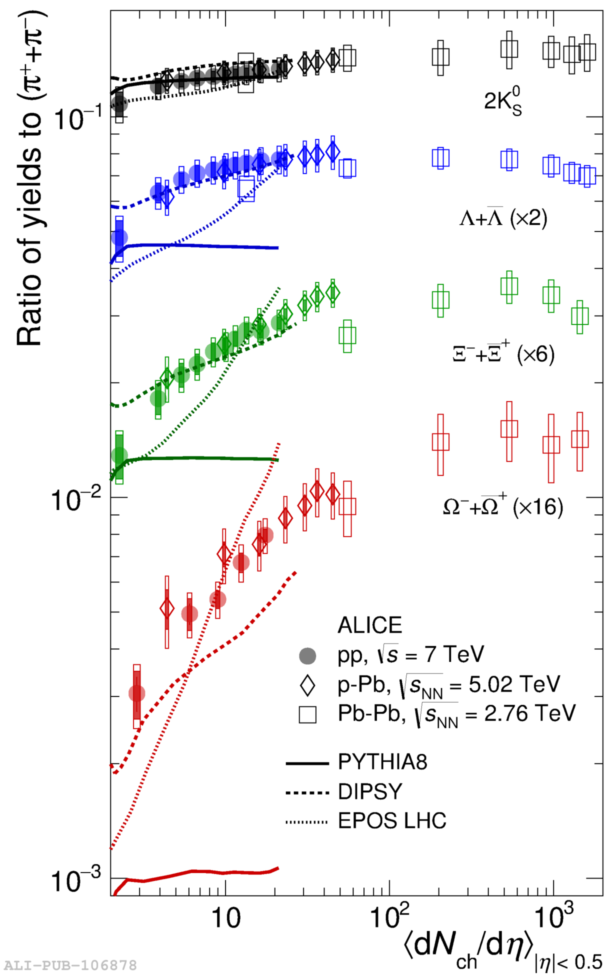
Outline

- **Motivation**
- **Event Shapes with transverse spherocity**
- **$\langle p_T \rangle$ as a function of charged particle multiplicity and spherocity**
- **Identified particle spectra and ratios as a function of spherocity**
- **Summary**

Motivation

Strangeness Enhancement



ALICE, NP13,535-539 (2017)

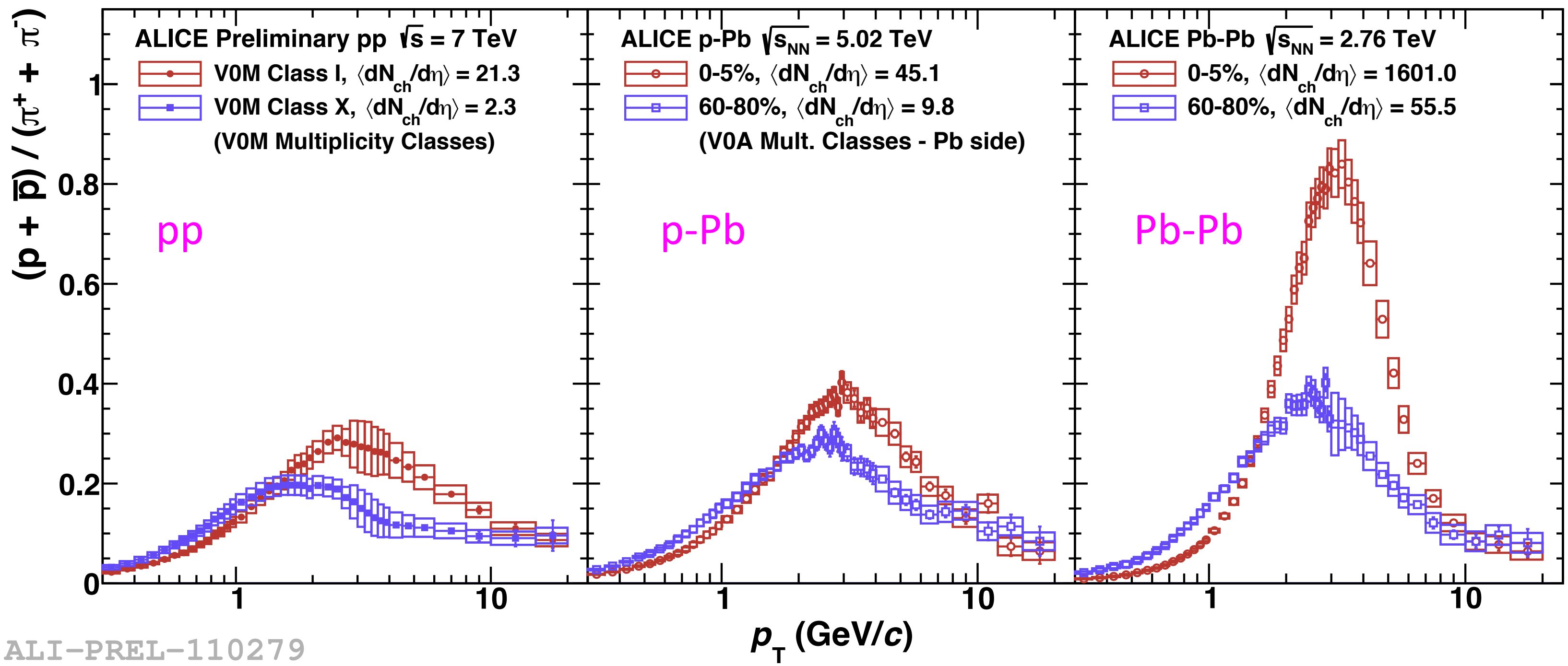
- **Smooth evolution of particle ratios across different colliding systems as a function of <dN_{ch}/dη>.**
- **The observed enhancement increases with strangeness content.**
- **Such behavior cannot be reproduced by any of the MC models commonly used for pp collisions.**

New tools to study the High-Multiplicity events are needed.

Motivation

- Similar features of particle production in pp, p-Pb and Pb-Pb

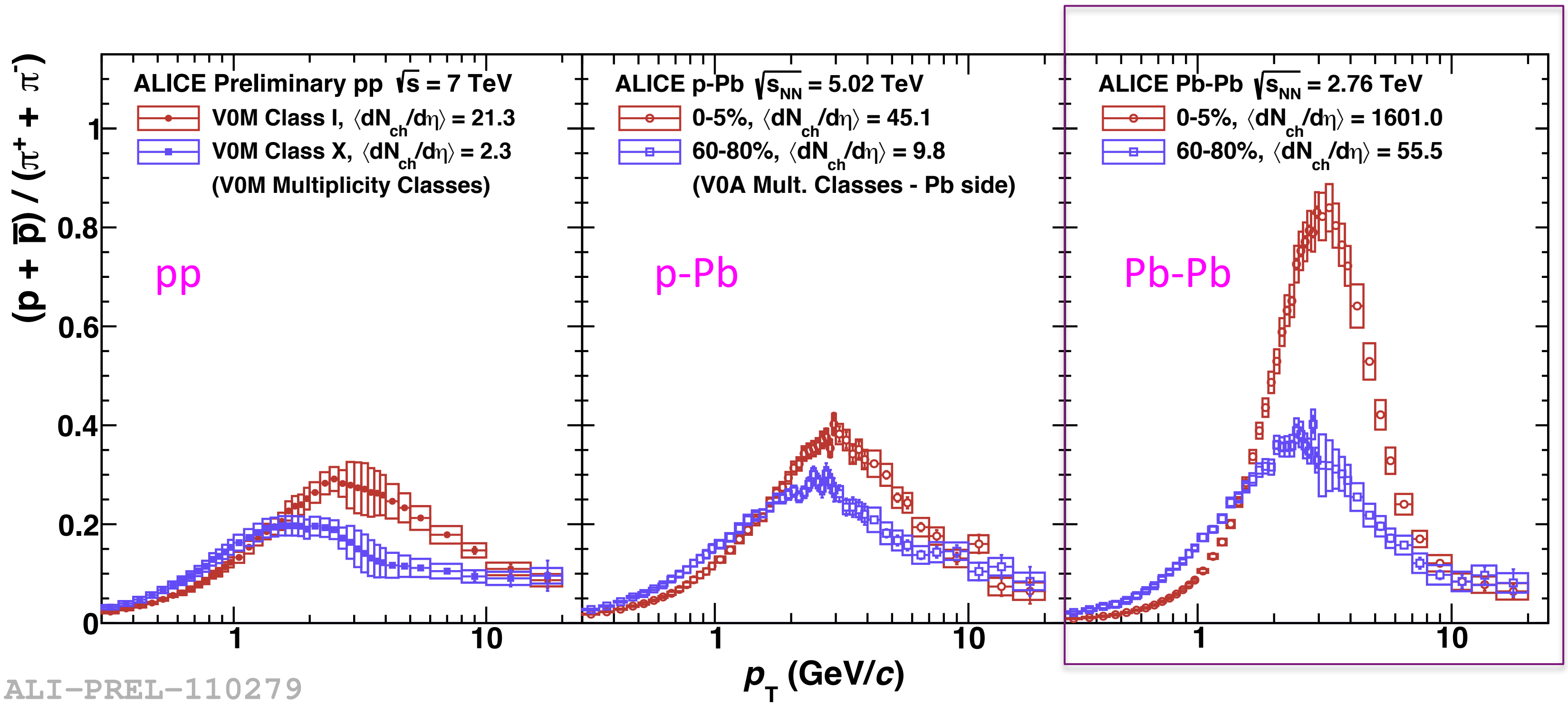
See N. Sharma's talk, 10:20 Wednesday 13



proton-to-pion ratio

Motivation

- Similar features of particle production in pp, p-Pb and Pb-Pb
- Modification of ratios for heavy-ion collisions can be explained by coalescence, radial flow etc.



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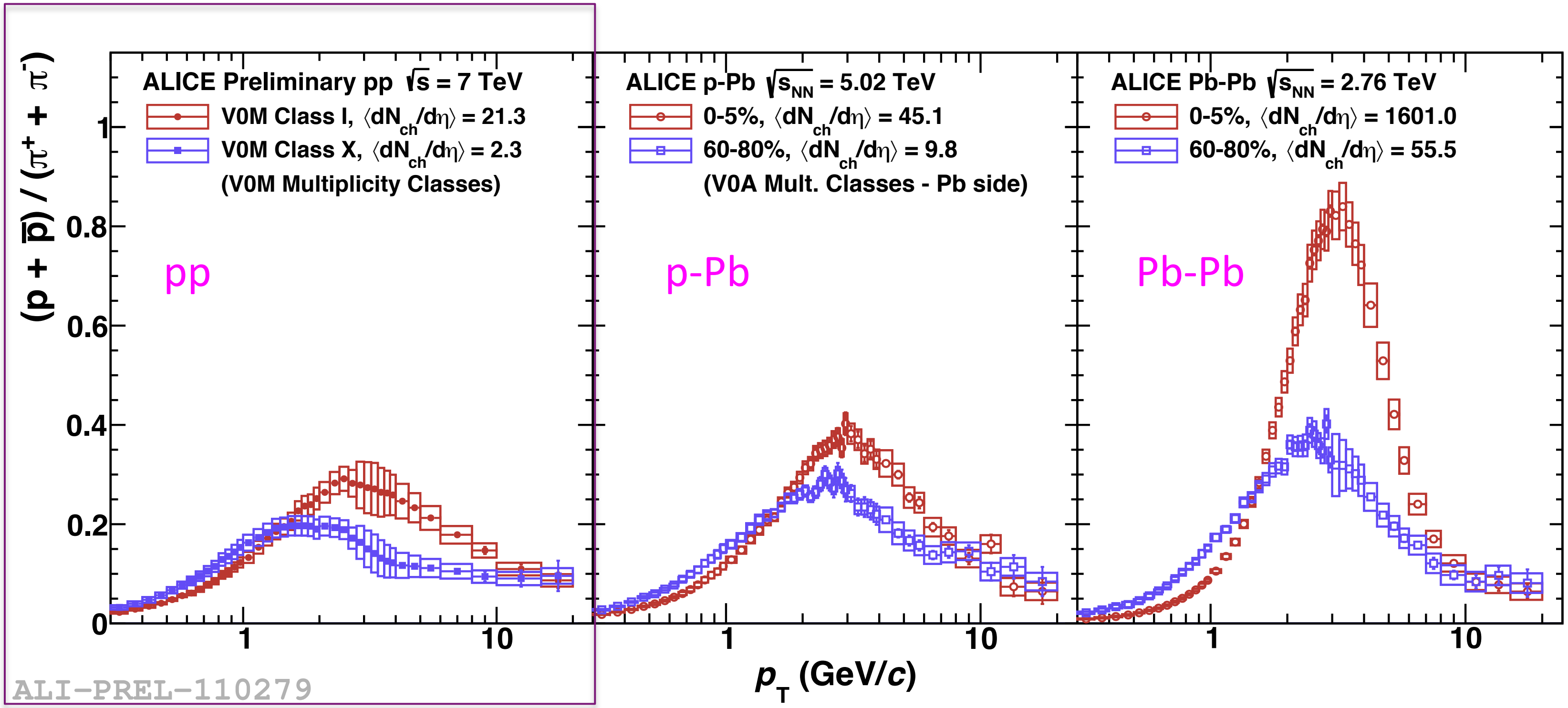
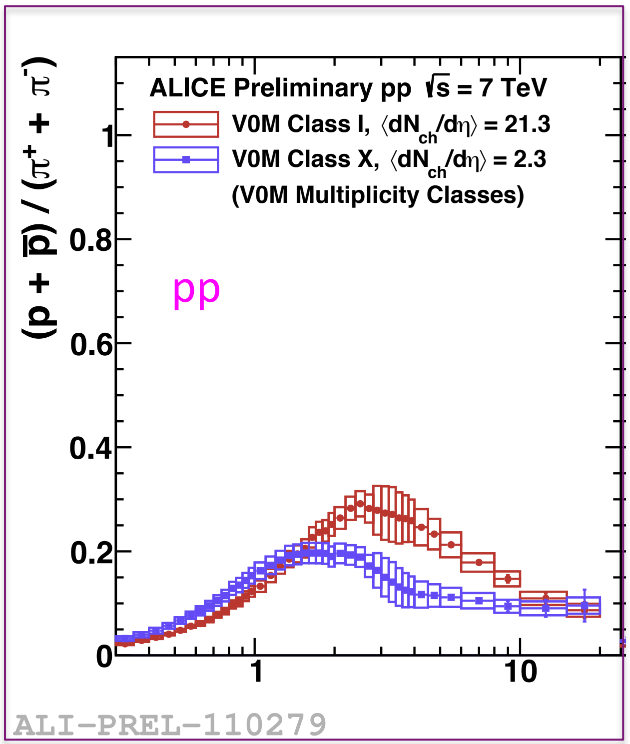
- Similar features are observed in pp and p-Pb collisions.

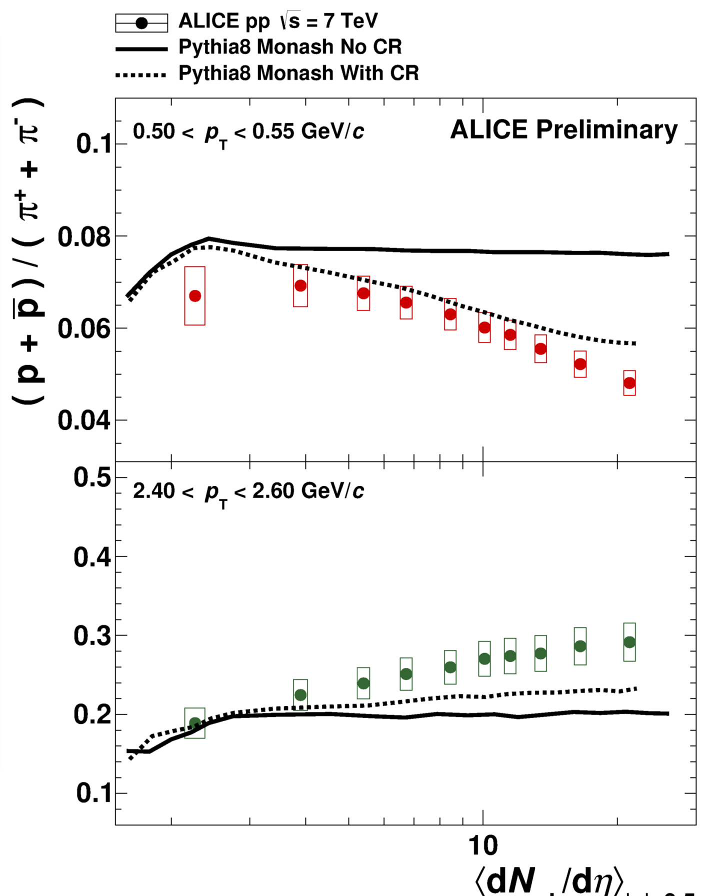


proton-to-pion ratio

Motivation

- Similar features of particle production in pp, p-Pb and Pb-Pb
- Modification of ratios for heavy-ion collisions can be explained by coalescence, radial flow etc.
- Similar features are observed in pp and p-Pb collisions.
  - Can be qualitatively explained by QCD-like effects. (e.g. color reconnection)





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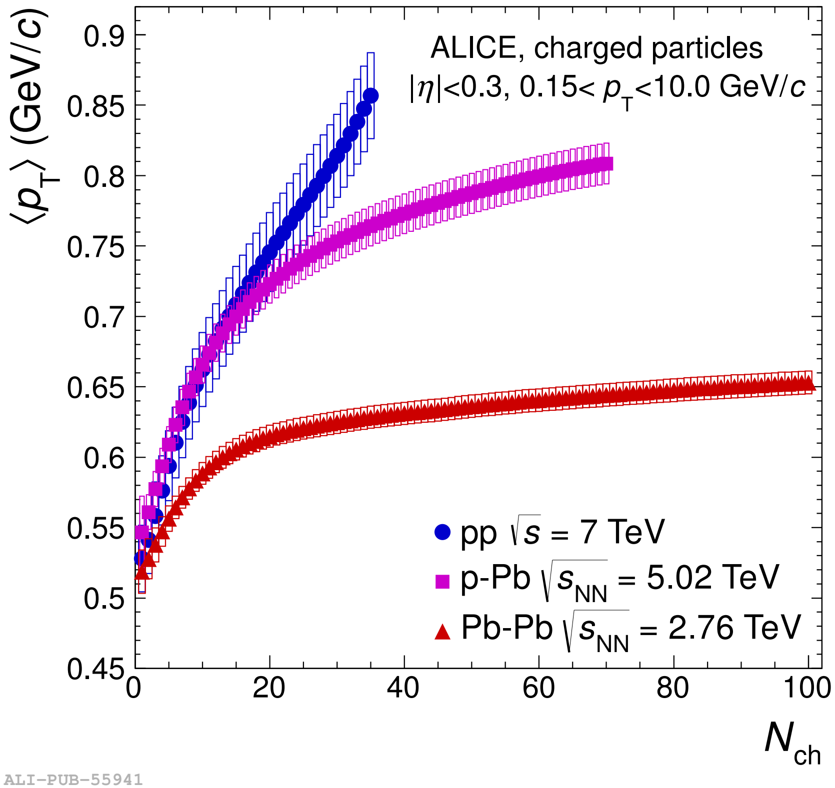
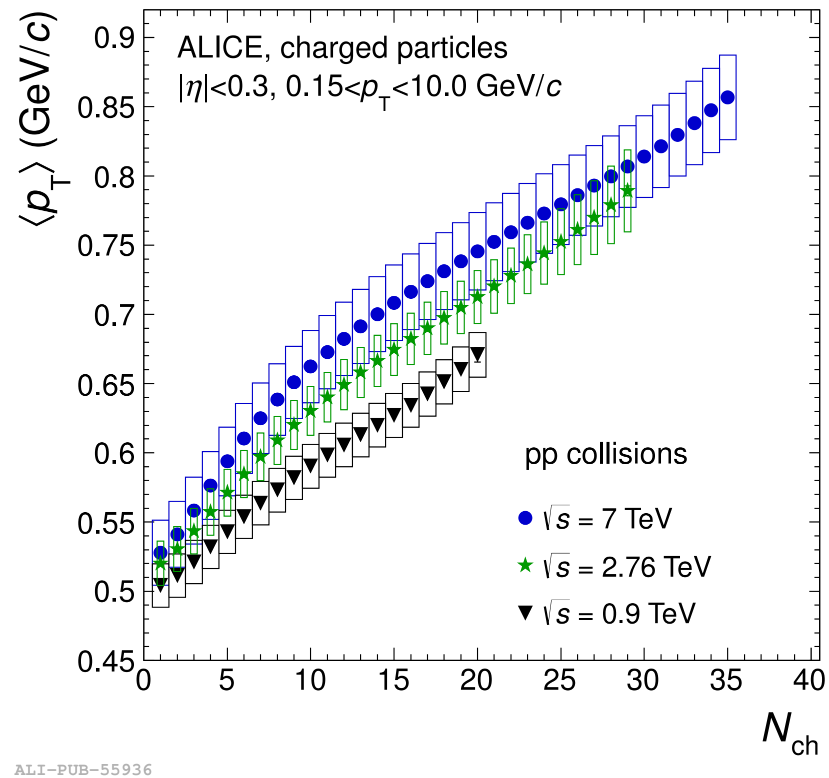
Motivation(contd.)





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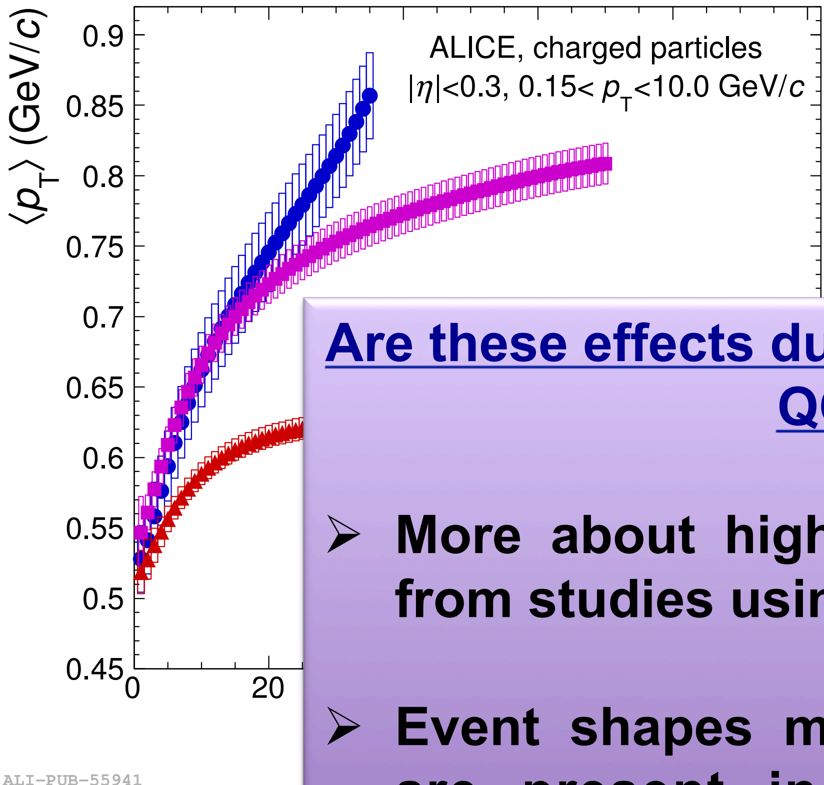
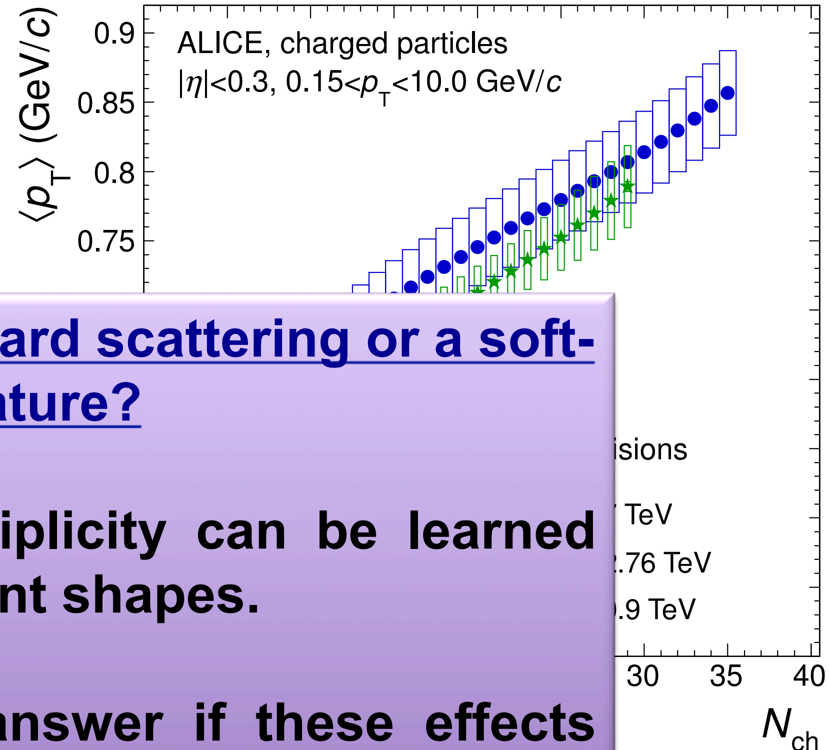
- **<p_T> exhibits steep rise as a function of charged particle multiplicity.**
- **Slope in pp collisions is larger (even at different energíes) than p-Pb and Pb-Pb collisions.**

Motivation(contd.)





Are these effects due to hard scattering or a soft-QCD feature?

- **More about high multiplicity can be learned from studies using event shapes.**
- **Event shapes might answer if these effects are present in both hard and soft-QCD dominated collisions.**

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n of charged particle multiplicity.

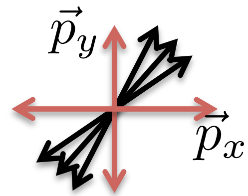
- Slope in pp collisions is larger (even at different energíes) than p-Pb and Pb-Pb collisions.

Transverse Spherocity

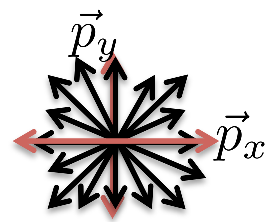
Spherocity is defined for a unit vector $\hat{n} = (n_x, n_y, 0)$

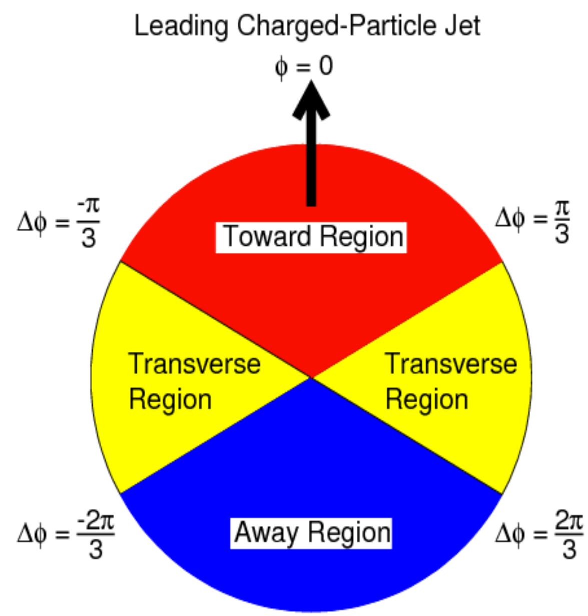
such that $$S_o = \frac{\pi^2}{4} \min_{\hat{n}=(n_x,n_y,0)} \left(\frac{\sum_i |\vec{p}_{Ti} \times \hat{n}|}{\sum_i p_{Ti}} \right)^2$$

Jetty (pencil like): $S_o \rightarrow 0$



Isotropic (spherically symmetric): $S_o \rightarrow 1$





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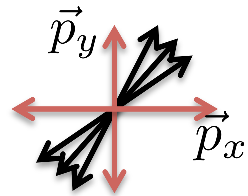

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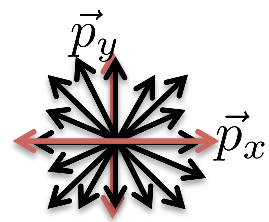
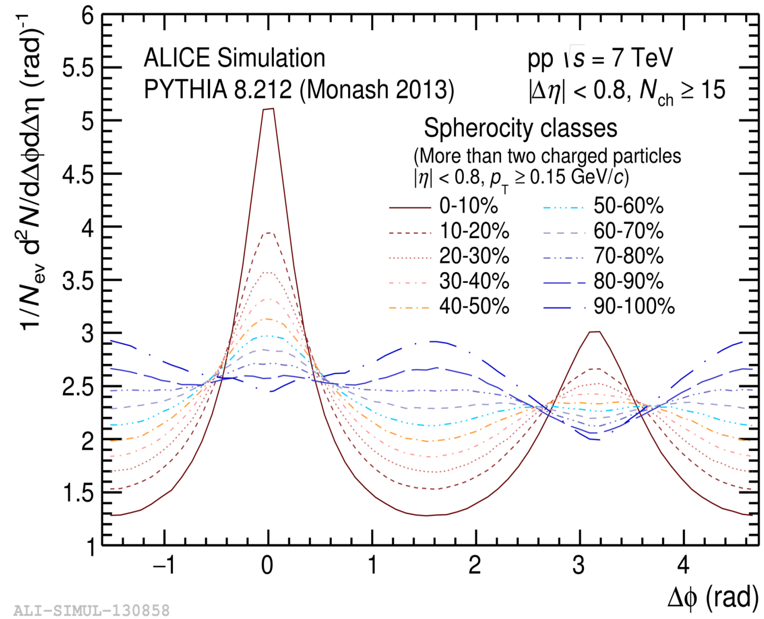
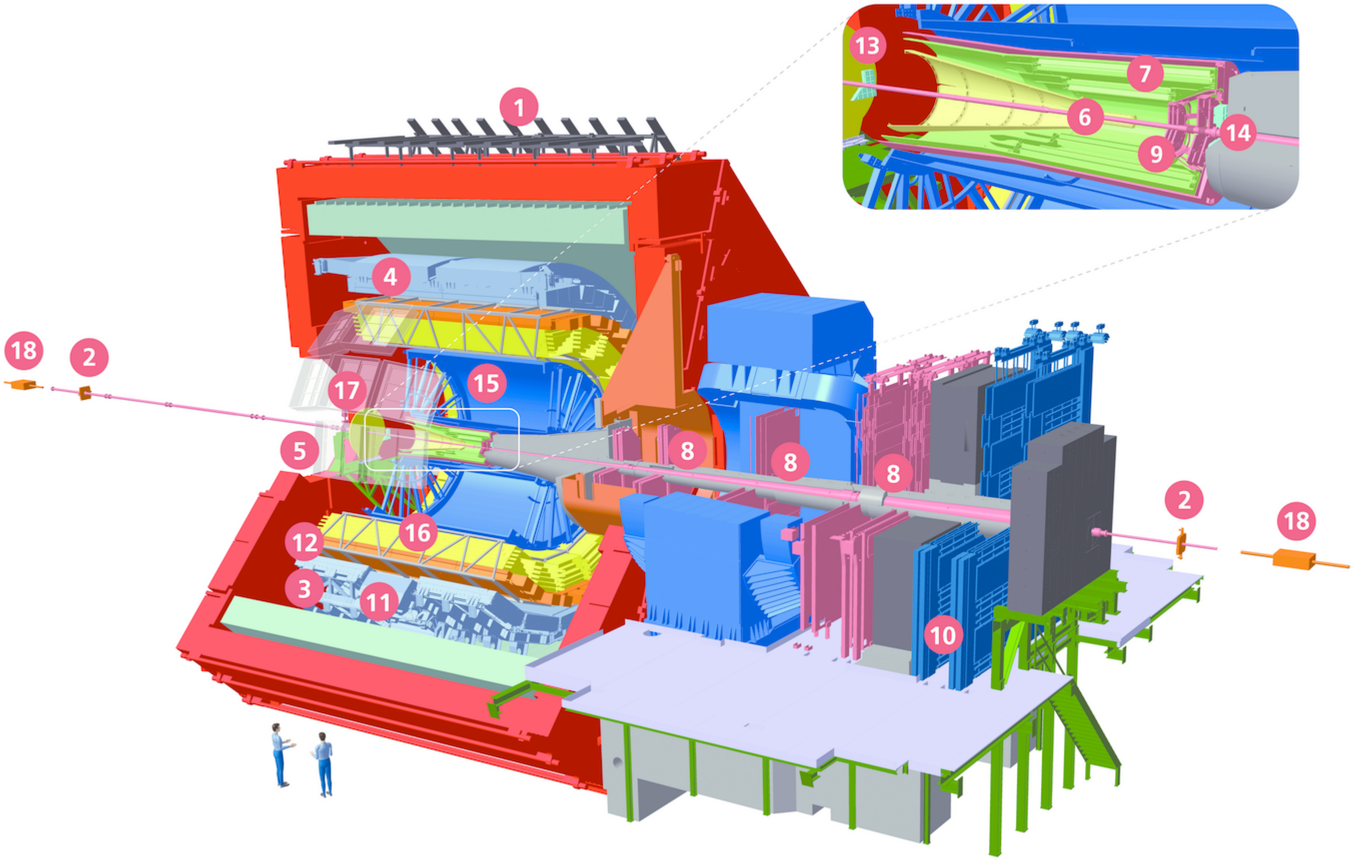




- Spherocity can help to discriminate hard and soft processes.
  - Jetty: back-to-back structure, indication of hard QCD
  - Isotropic: enhanced UE, soft QCD (MPI ?)

ALICE Detectors

ALICE
A JOURNEY OF DISCOVERY



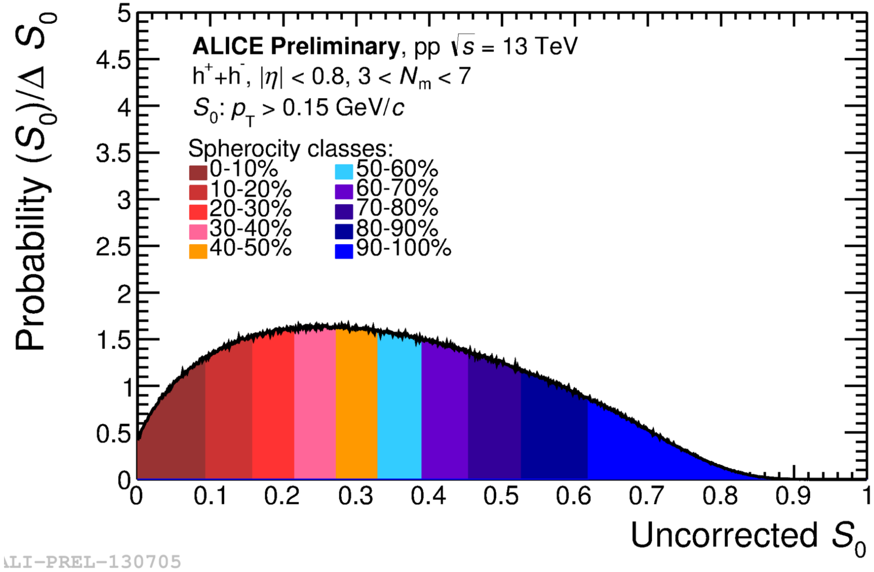
1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

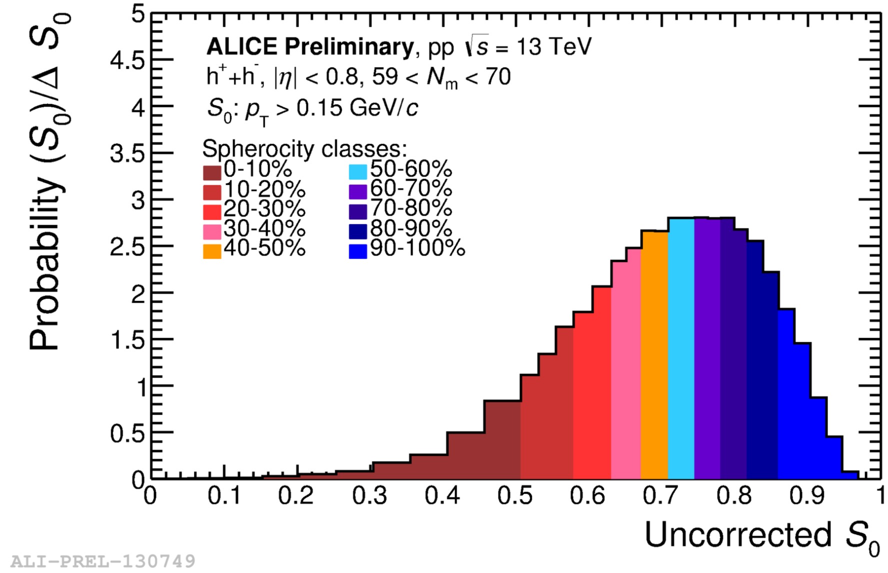
For this analysis:

- **V0 : trigger and event activity estimator**
- **ITS: tracking and vertex**
- **TPC: tracking and PID**
- **TOF: PID**

Spherocity classes

- Multiplicity selection: charged particle tracks in $|\eta| < 0.8$
- Spherocity is calculated requiring more than 2 tracks ($p_T > 0.15$ GeV/c, $|\eta| < 0.8$)





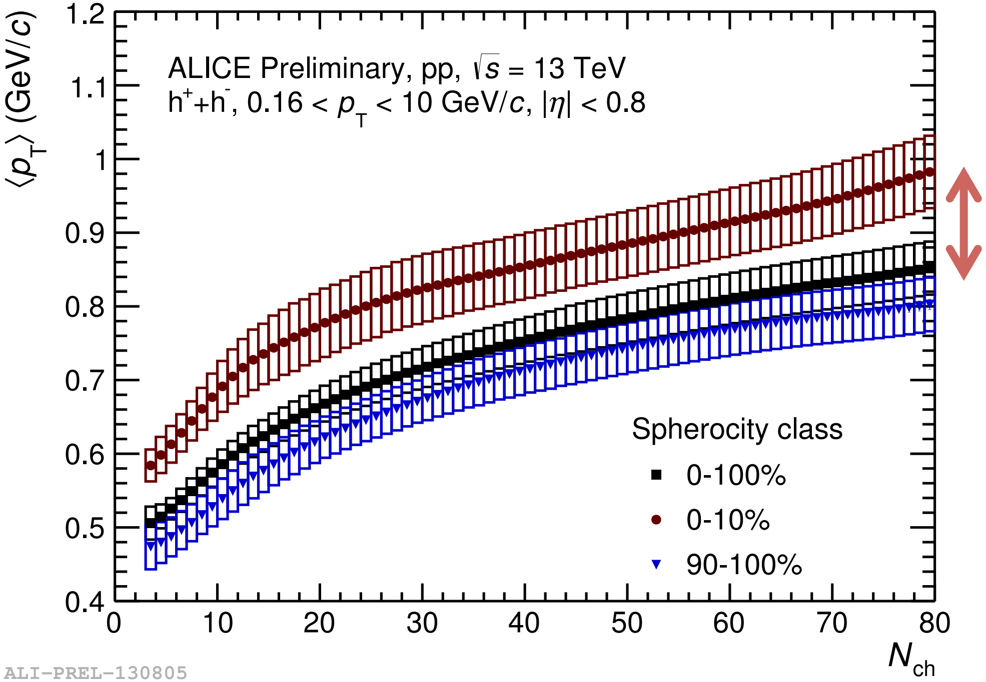
The events were classified according to their spherocity percentile, the most jetty (isotropic) events are represented by the 0-10% (90-100%) class.

$\langle p_T \rangle$ as a function of charged particle multiplicity and spherocity

$\langle p_T \rangle$ as a function of multiplicity and spherocity

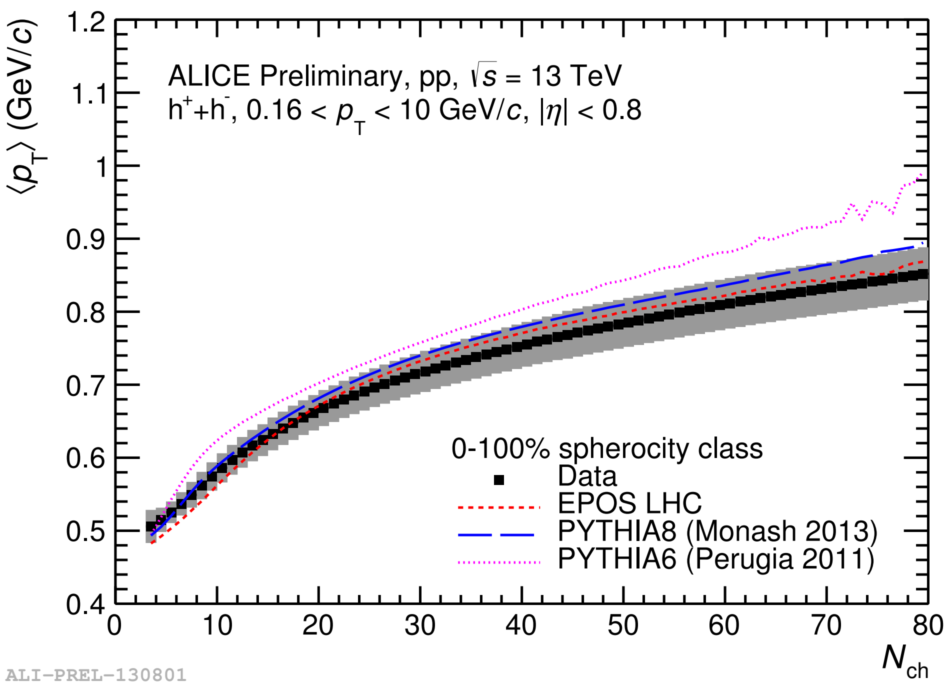
- **At high multiplicity the rise of $\langle p_T \rangle$ is steeper in jetty events than that observed in the inclusive case (spherocity integrated)**

- **As a function of spherocity:**
  - **Jetty: systematically higher $\langle p_T \rangle$ and larger slope**
  - **Isotropic: lower $\langle p_T \rangle$, smaller slope**



$\langle p_T \rangle$ as a function of multiplicity and spherocity

- **Inclusive (spherocity integrated):**
- **PYTHIA 6 overestimates $\langle p_T \rangle$.**
- **PYTHIA 8 consistent with data (requires CR to regulate UE).**
- **EPOS LHC consistent with data.**



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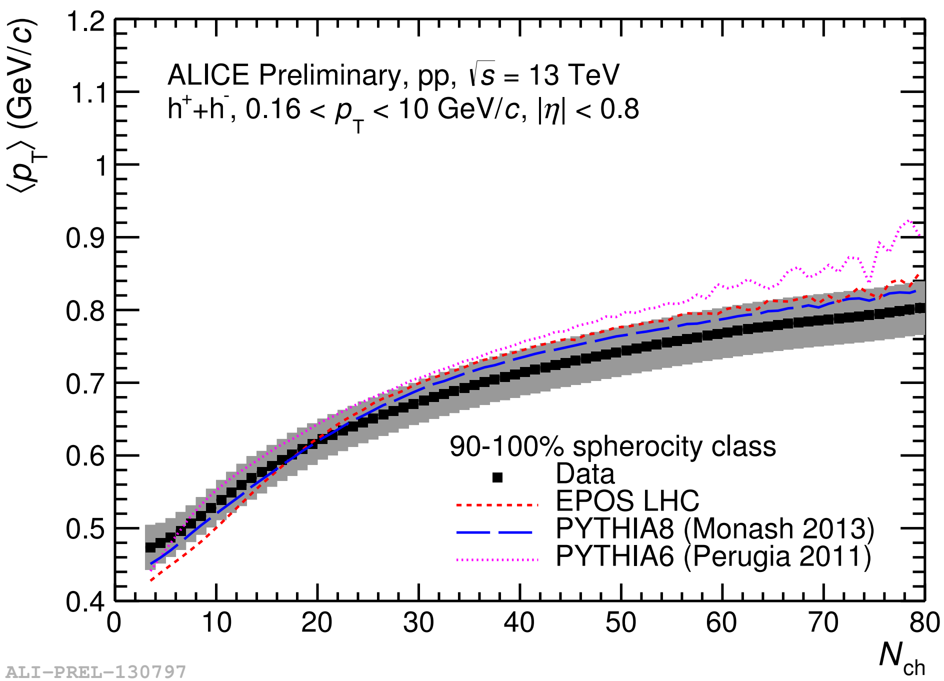
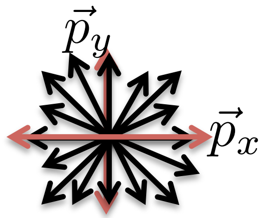
- **Better agreement with models. (EPOS LHC and PYTHIA 8 consistent with data within systematic uncertainties)**
- **Slightly underestimated at low N_{ch} by EPOS LHC.**





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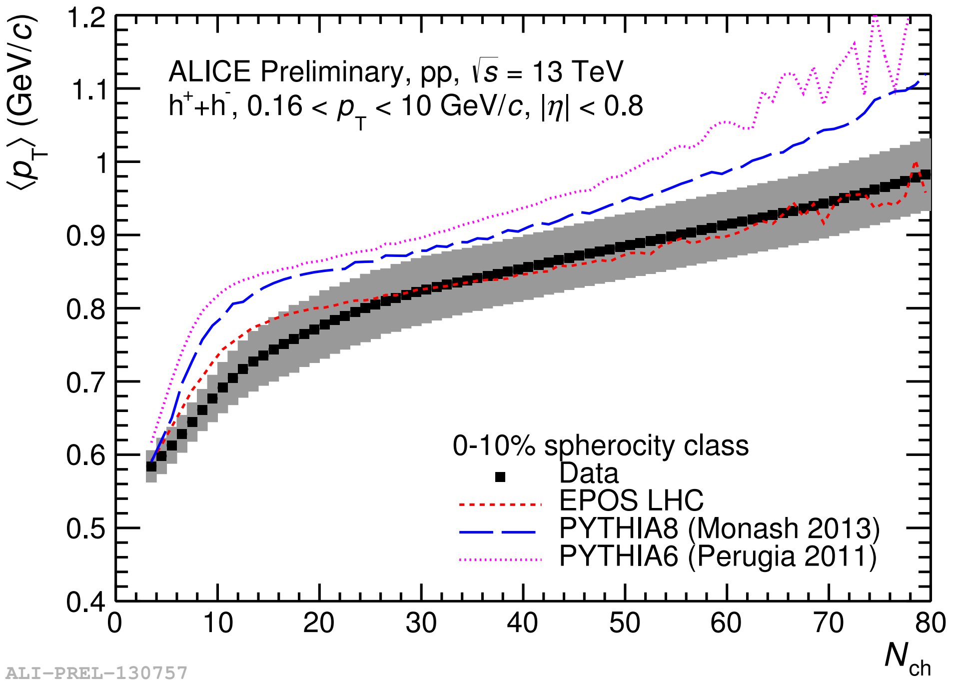
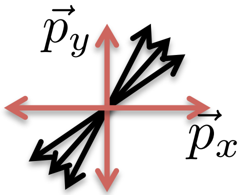
- **Jetty:**
- **PYTHIA 6 and 8 overestimate the data. (less UE or too many jets) --> input for MC tuning**
- **EPOS LHC overestimates at low N_{ch}.**

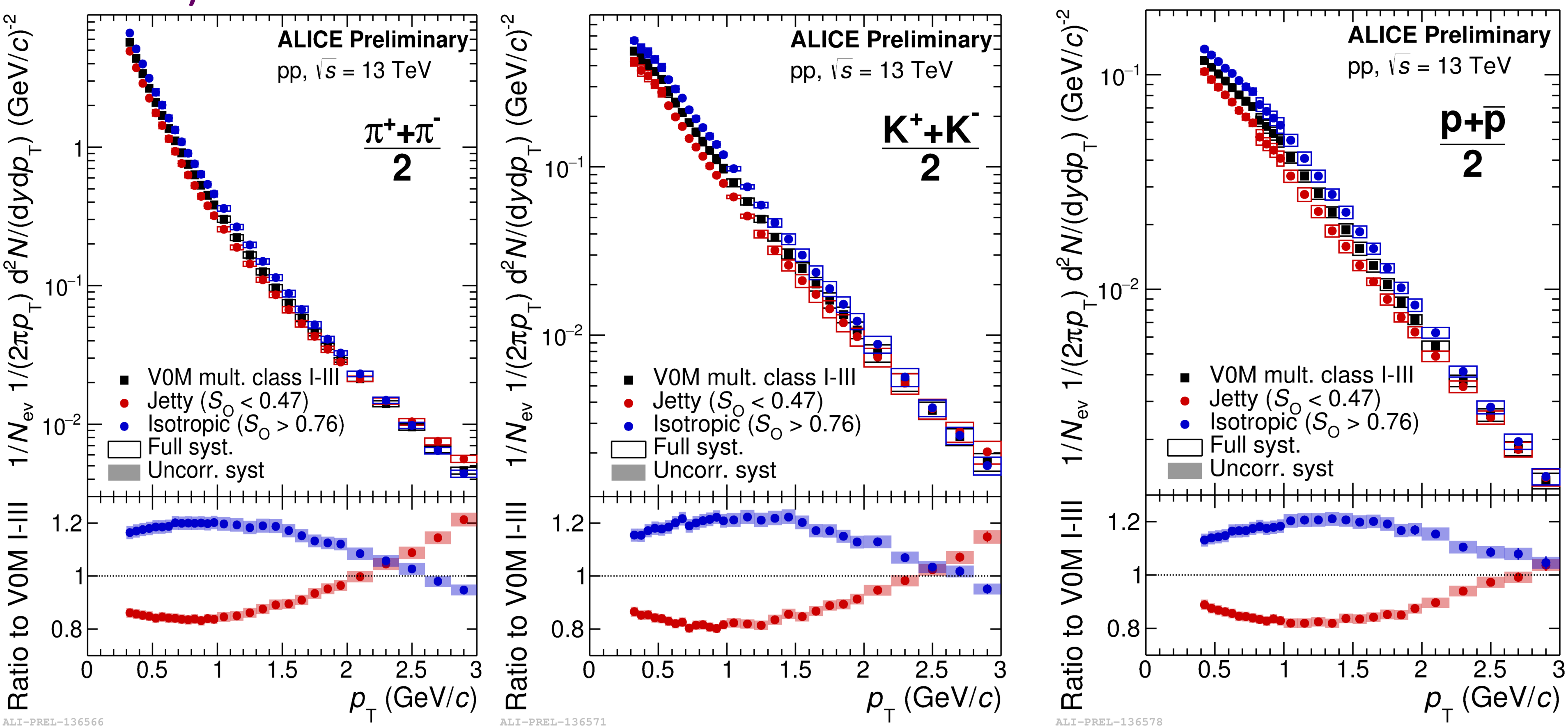




Identified particle spectra and ratios as a function of spherocity

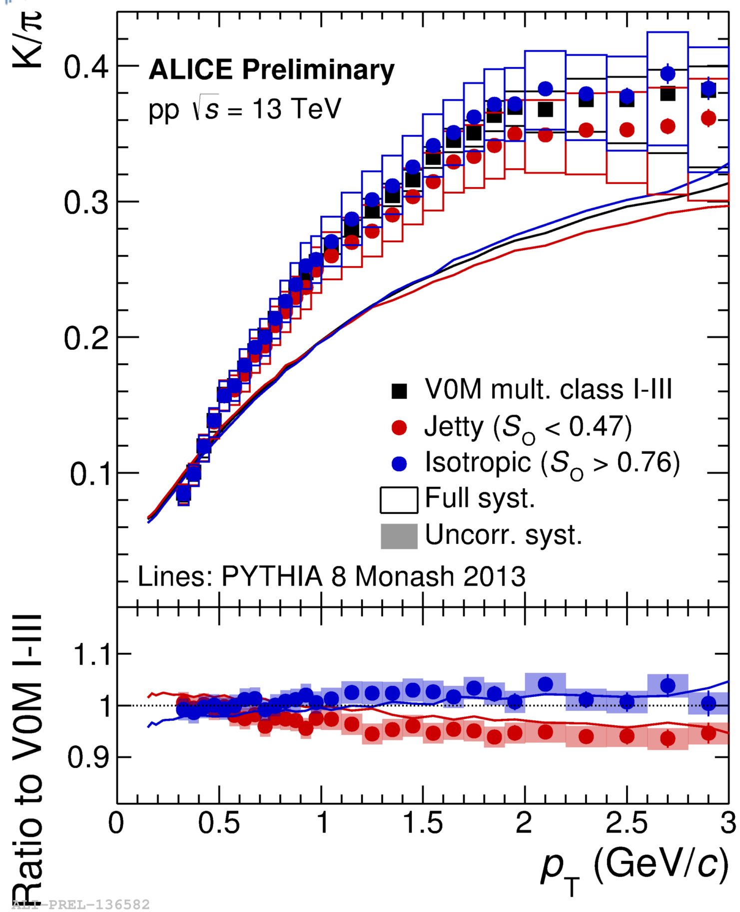
Identified particle spectra as a function of spherocity

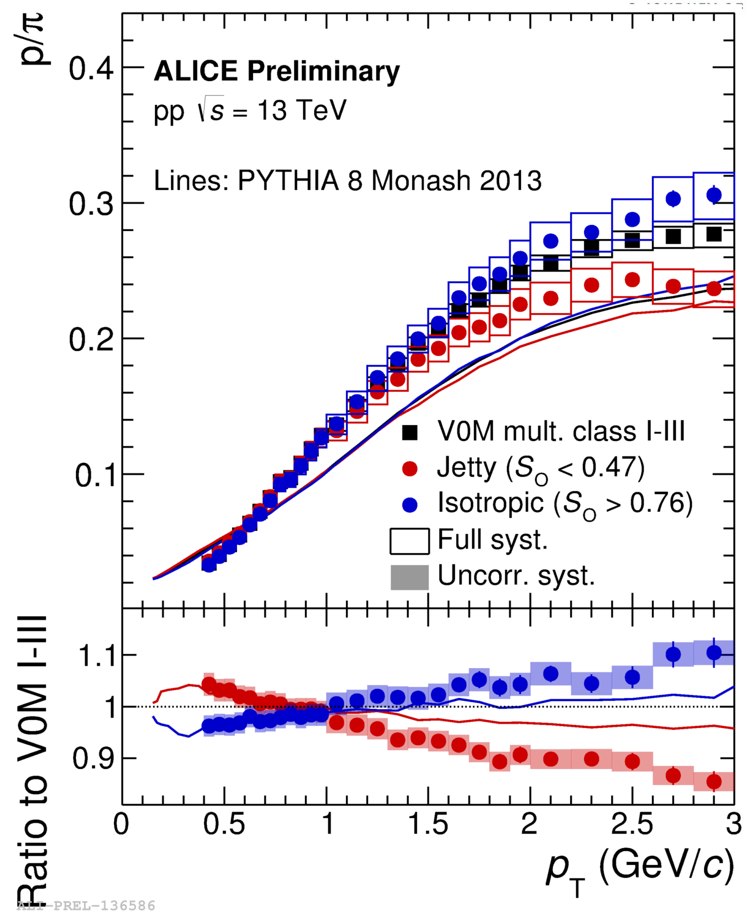
- **Spectral modifications with spherocity.**
- **The hardening at low p_T is larger in isotropic events confirms an origin of it from the bulk production.**
- **Mass dependence of crossing of the ratios. (Flow-like effects more pronounced in isotropic events?)**



≈0-10% V0M

Identified particle ratios as a function of spherocity





- **In isotropic events the proton-to-pion ratio exhibits a depletion (enhancement) for p_T<1 GeV/*c* (p_T>1 GeV/*c*) with respect to jetty events. (not reproduced by MC !)**

≈0-10% V0M

Summary

- **Event shapes are important tools to understand the origin of the phenomena newly discovered in high multiplicity pp collisions as they can be used to understand soft-hard interplay.**

- **Spherocity is a useful tool to discriminate events dominated by hard and soft processes and can help to better identify role played by MPI in high multiplicity events.**

- **<p_T> evolution with charged particle multiplicity is more pronounced in jetty events as compared to isotropic.**

- **The hardening at low p_T is larger in isotropic events confirms an origin of it from the bulk production.**

- **Evolution of K/π and p/π ratios as a function of spherocity also studied and compared with PYTHIA.**

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- Event shapes are important tools to understand the origin of the phenomena newly discovered in high multiplicity pp collisions as they can be used to understand soft-hard interplay.

- Spherocity is a useful tool to discriminate events dominated by hard and soft processes and can help to better identify role played by MPI in high multiplicity events.

Thank you for your attention

- $\langle p_T \rangle$ evolution with charged particle multiplicity is more pronounced in jetty events as compared to isotropic.

- The hardening at low p_T is larger in isotropic events confirms an origin of it from the bulk production.

- Evolution of K/π and p/π ratios as a function of spherocity also studied and compared with PYTHIA.