# Light flavour hadron production as a function of event structure ($R_T$, $S_0^{p_T=1}$) in pp collisions

***New ALICE preliminary results from QM19!***


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*CLASH meeting*

*18 December 2019 Lund*

ALICE

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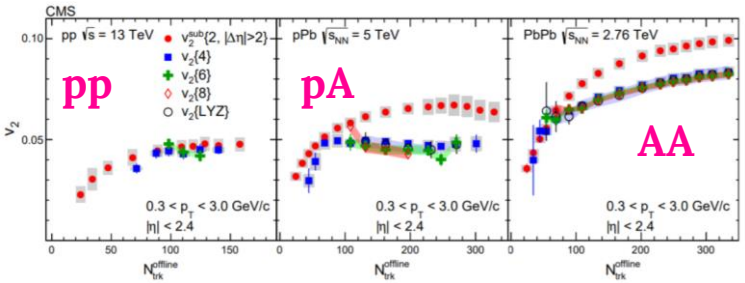
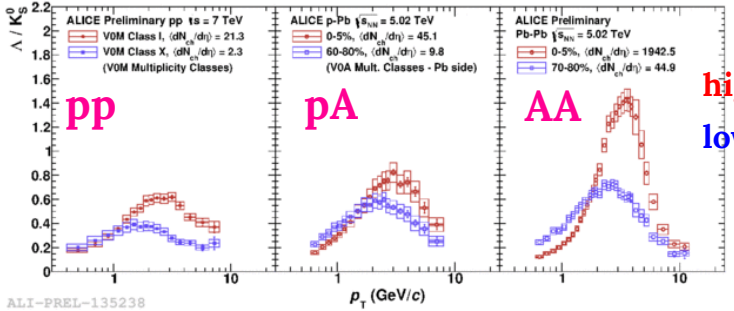
# QGP features in pp collisions

- Traditional QGP signatures also observed in pp and p-A collisions at high energies
- ***Elliptic flow***



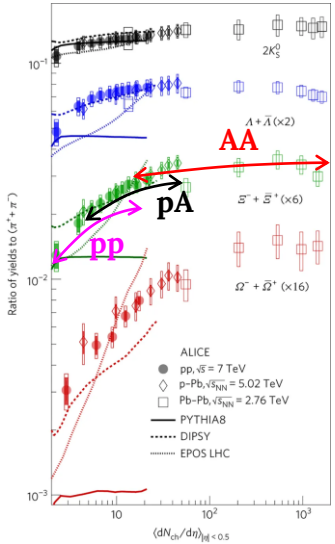

- ***Radial flow***




high mult.

low mult.

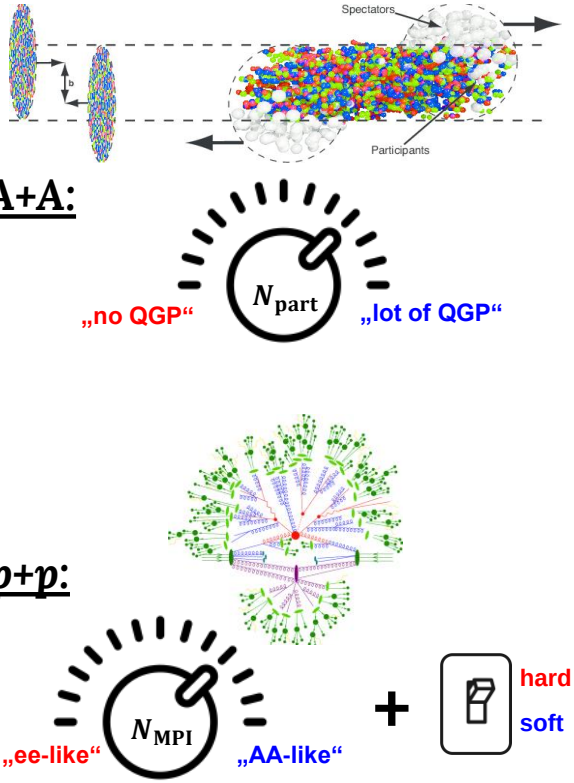
- ***Strangeness enhancement***

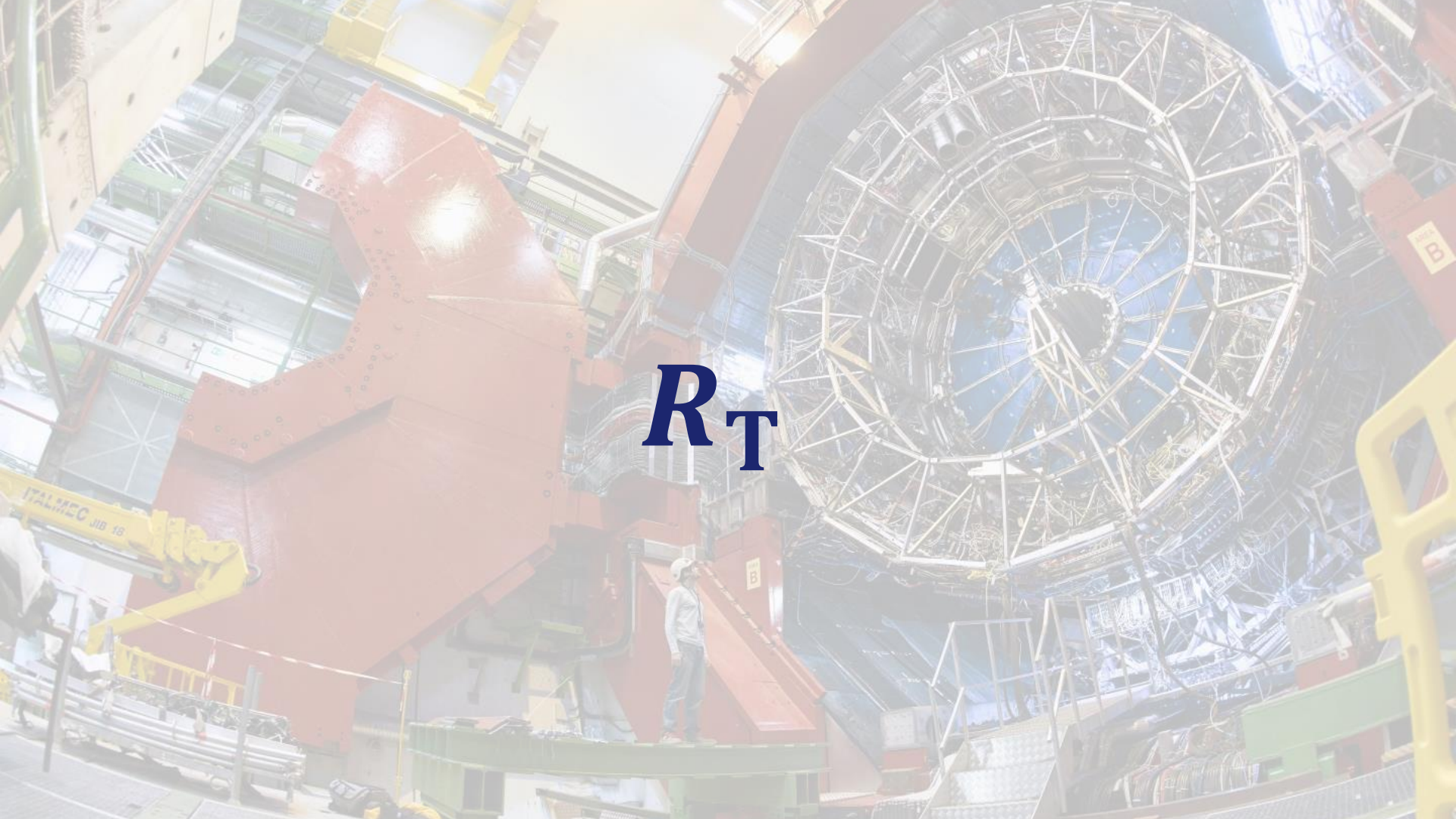



*Same trends when increasing the **multiplicity**, regardless of the system!*

# Multiplicity in pp and in AA

- Is multiplicity the driving factor for the onset and the magnitude of these QGP-like features?
- ***In A+A:***
  - multiplicity $N_{\mathrm{ch}}$ directly related to $\boldsymbol{N_{\mathrm{part}}}$
- ***In p+p:***
  - $N_{\mathrm{part}}$ is fixed to =2, sources of $N_{\mathrm{ch}}$ are more complicated!
  - $N_{\mathrm{ch}}$ comes from ~***soft*** MPI (Multiple Partonic Interactions)
  - $N_{\mathrm{ch}}$ also scales with ***hard***ness of the primary scattering!
    - Jet fragmentation
    - Hardness – impact parameter bias
- To study the underlying nature of said QGP-like features, the interesting dial is thus
  1. ***Number of MPI*** (analogous to $N_{\mathrm{part}}$)
  2. ***Hard*** ***vs.*** ***soft*** ***effect*** (different mechanisms)
- Promising test of strings- vs. hydro-based models!

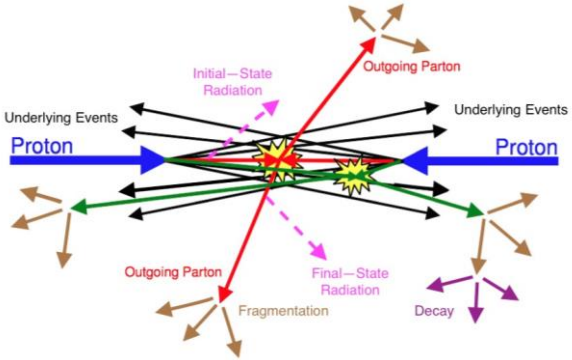


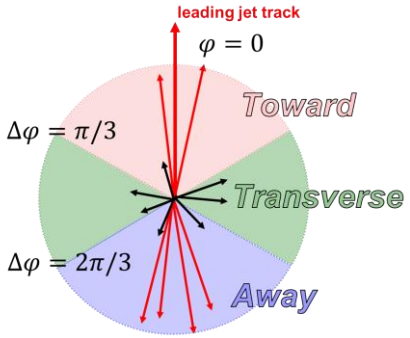


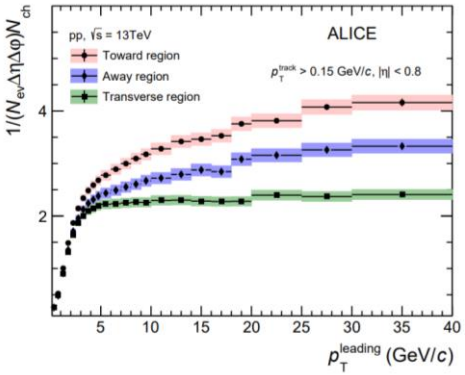

$R_T$

# Multiple Partonic Interactions (MPI)

- $N_{\mathrm{MPI}}$ – unlike $N_{\mathrm{part}}$ – is difficult to access experimentally, but doable
- With ***Underlying Event (UE)*** !
  - collection of particles NOT originating from the primary hard parton-parton scattering or the related fragmentation
  - constant particle production rate due to UE can be seen as a „jet pedestal effect“

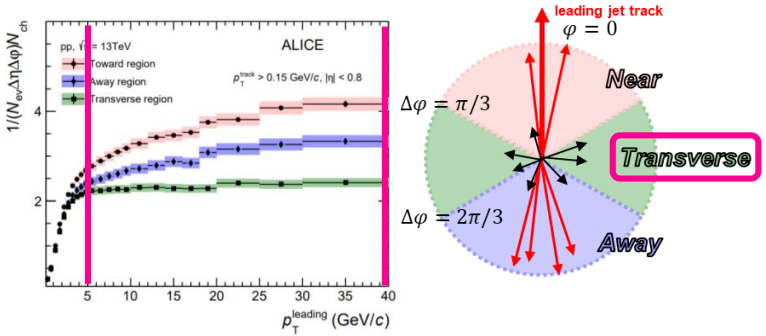


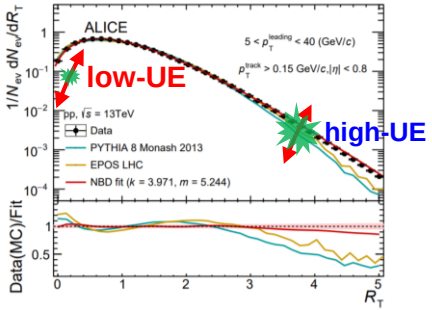

- In events with a jet $p_{\mathrm{T}}^{\mathrm{lead}} > 5$ GeV, *(fixing stoch. effects)*
  - In **Toward** and **Away** regions, $N_{\mathrm{ch}}$ scales with hardness of the jet
  - In **Transverse** region, there is a plateau *(no contributions from jet fragmentation)*
- UE activity in the Transverse is
  - isolated from and ~insensitive to the hard component of the collision
  - ***directly sensitive to*** $N_{\mathrm{MPI}}$

# Underlying event activity $R_T$

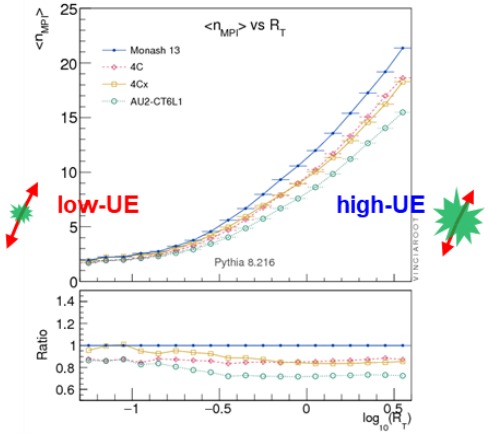



$$R_T = \frac{N_{ch}^{trans}}{\langle N_{ch}^{trans} \rangle}$$

- Self-normalised so that different collision energies and systems can be directly compared
- Proposed originally arXiv:1603.05298

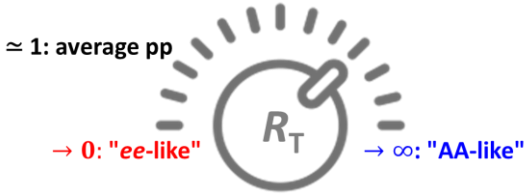



- ***Proxy for $N_{MPI}$ :***



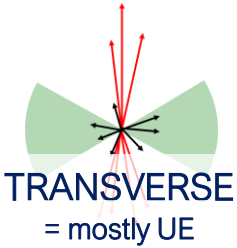

- Interesting to study identified particles vs. $R_T$
  - **$\pi$** : reference
  - **$K_S^0$ vs. $K^{\pm}$** : charge effect on the measurement (self-correlation bias)
  - **$\Lambda$ vs. p** : strangeness effect
  - **$\Xi$ vs. $\Lambda$ vs. p** : strangeness scaling effect
  - **$\phi$ vs. $\Xi$** : hidden vs. open strangeness effect

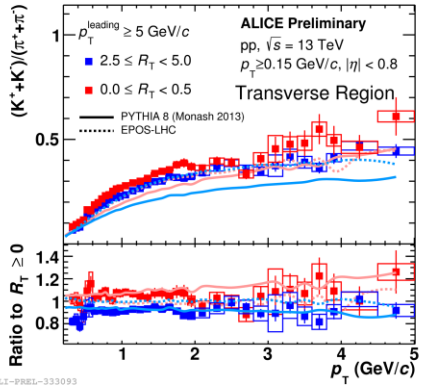
***Analyses by:***
*Omar V. , Adrian N. , Peter Ch. , myself*

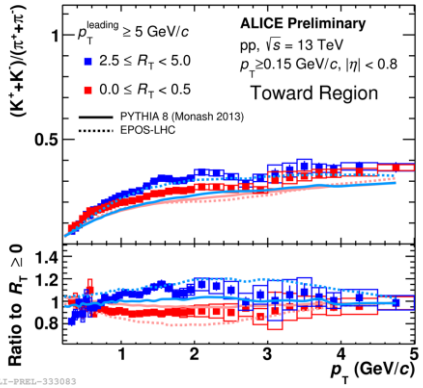


# p, K vs. $R_T$

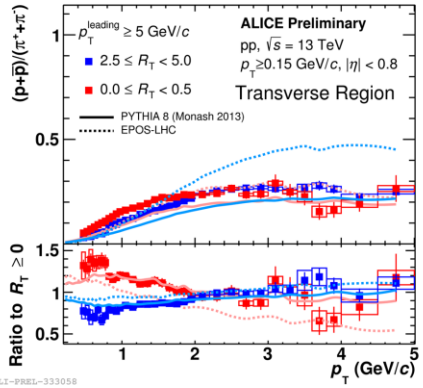
- ***Kaons:***

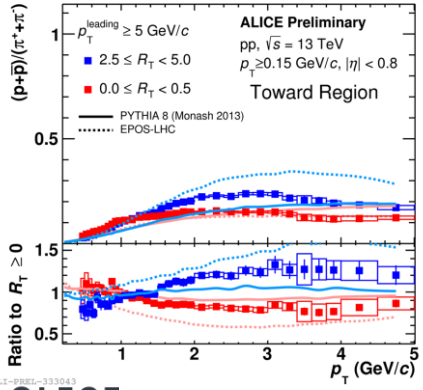


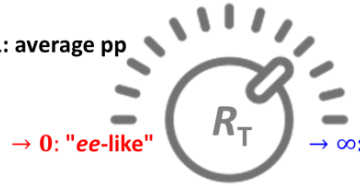

- ***Protons:***

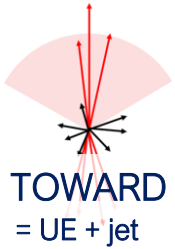



≃ 1: average pp

→ 0: "*ee*-like" → ∞: "AA-like"



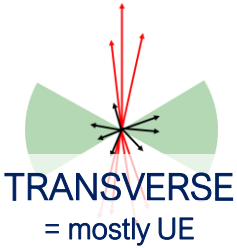

*Protons and Kaons enter the $R_T$ as primary charged tracks*

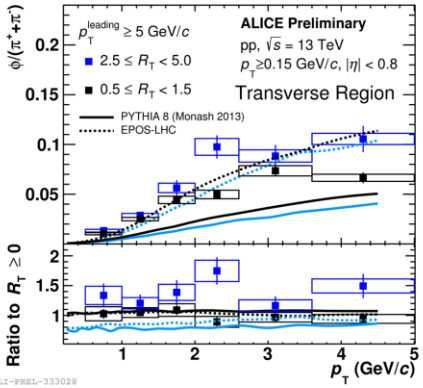
***Ratios of particle pT-spectra***

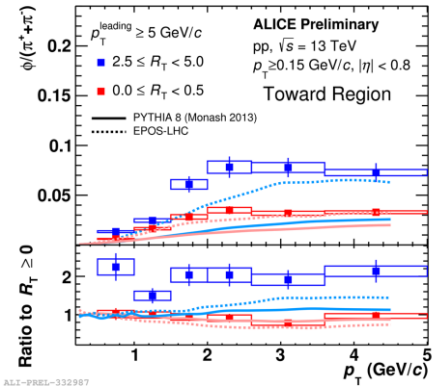
- p/$\pi$ exhibits a radial flow like behaviour in the **Toward** region

# $\Xi, \phi$ vs. $R_T$

- **Phi meson:**

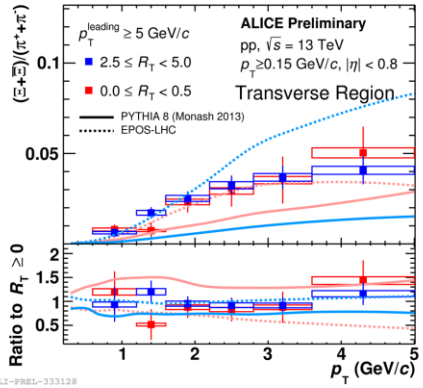


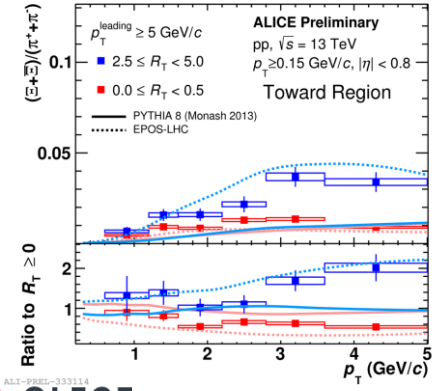




- **Xi baryon:**

***$\Lambda, K_S^0$ results are coming soon!***

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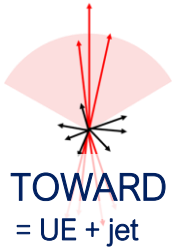


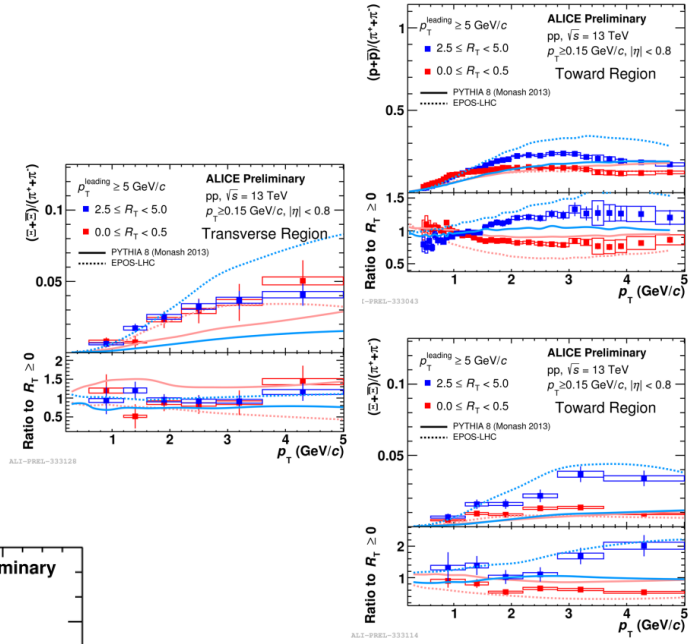

*Phi meson may enter the $R_T$ as two primary charged tracks*

***Ratios of particle pT-spectra***

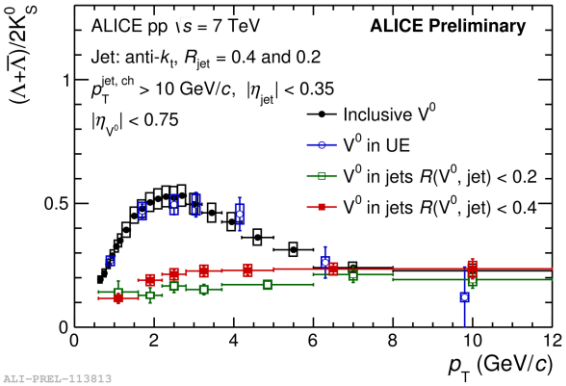
- In **Toward**, $\phi$ and $\Xi$ are enhanced w.r.t. $\pi$ as $R_T$ increases
- **$\phi$ in Transverse** is enhanced with $R_T$
- **$\Xi$ in Transverse** does not depend on $R_T$

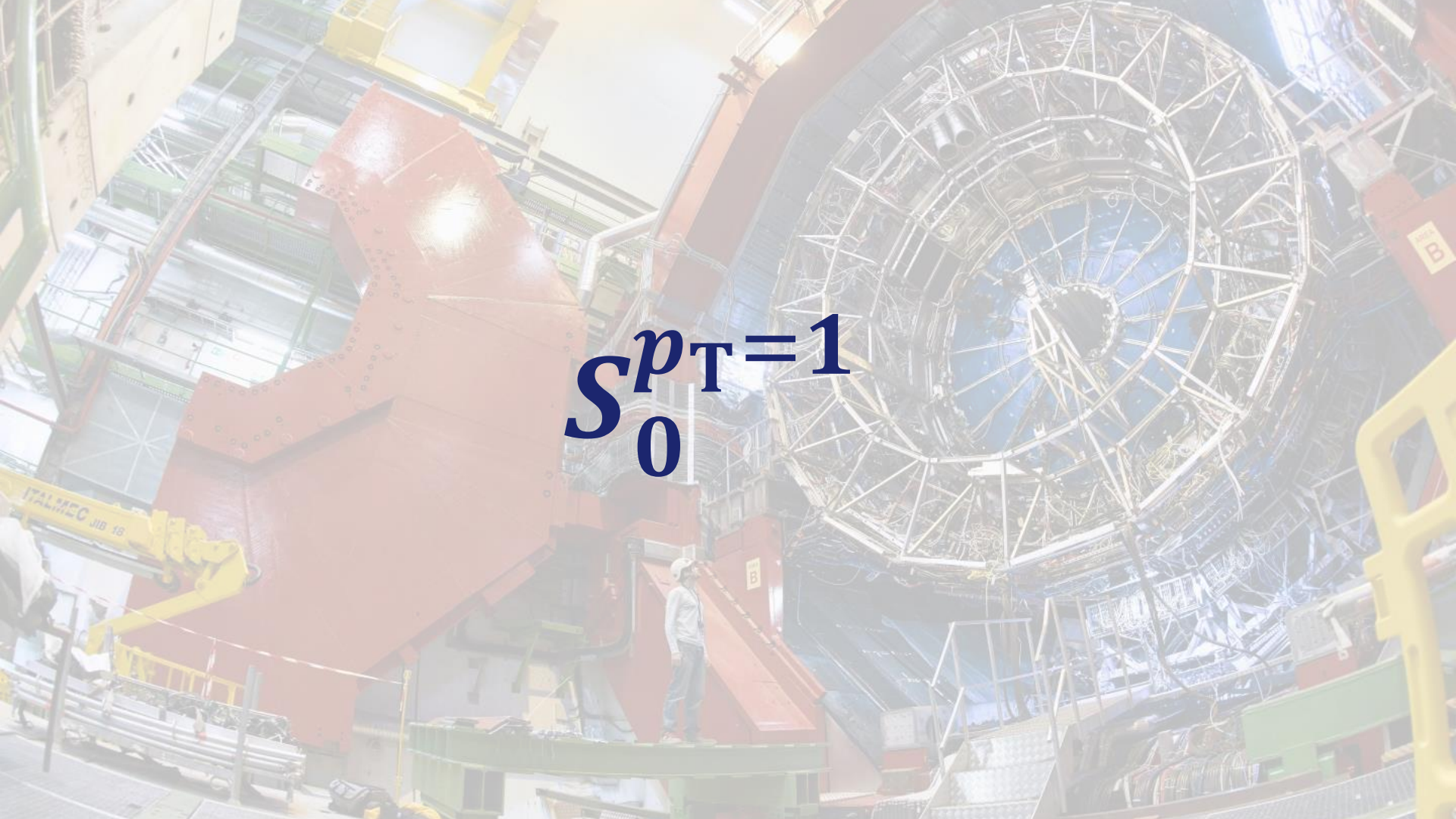
# Radial flow

- „Radial flow“-like pattern not observed in **Transverse** but observed in **Toward**
- High-$R_T$ results in Toward also converge to those in Transverse
- This suggests that the driving factor behind radial flow is not $N_{MPI}$ but rather the interplay between hard and soft
- This interplay is in the **Toward** region directly controlled by $R_T$




- This is because productions in UE (soft) and in jets (hard) look very different:

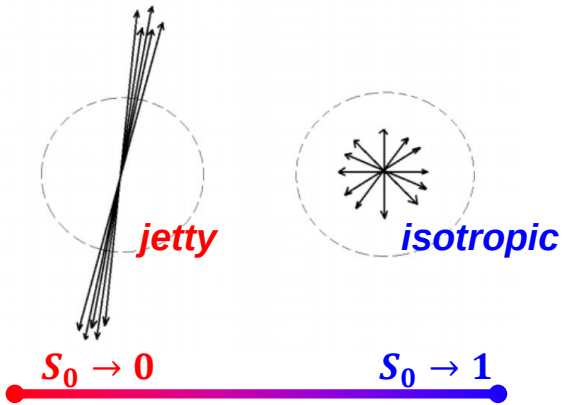


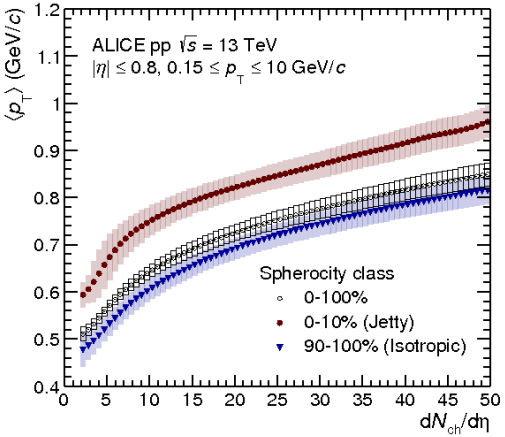

$S_0^{p_T=1}$

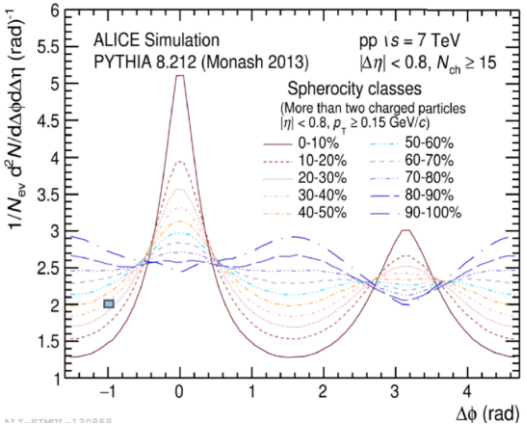
# Transverse spherocity $S_0$

- Event geometry can be used to isolate „hard“- vs. „soft“-process dominated events
  - Hadrons produced from ***hard*** scatterings typically form cone-like structured, back-to-back in azimuth
  - Hadrons from ***soft*** interactions typically isotropically distributed
- $S_0$ is a simple event geometry classifier:

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



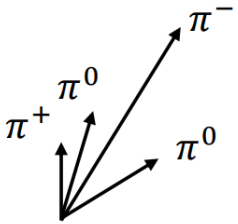

*$S_0$ and $R_T$ measurements are of a similar nature and are mutually complementary!*

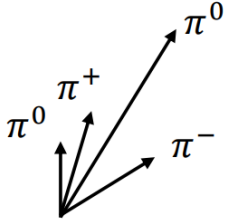
# Unweighted spherocity $S_0^{p_T=1}$

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

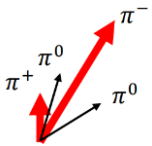
- Takes into account only angular components of the track
- Isotropic/jetty not in terms of momenta, but number of particles

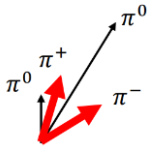
- Two examples of topologically equivalent events:

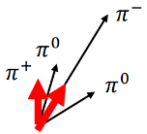


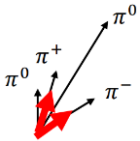




- Using a detector (only charged particles):
  - $S_0$ will be measured as two different values
  - $S_0^{p_T=1}$ will be measured as two similar values



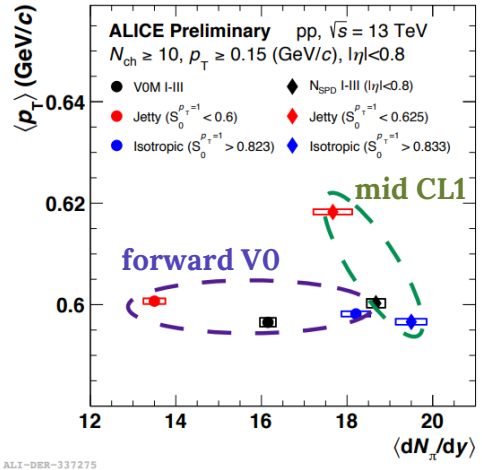

**Moreover:**
- *Neutral „jetty“ might appear as charged „isotropic“*
- *Neutral „isotropic“ might appear as charged „jetty“*

$S_0^{p_T=1}$ *also helps reduce the smearing stemming from failing to reconstruct a high-pT track*

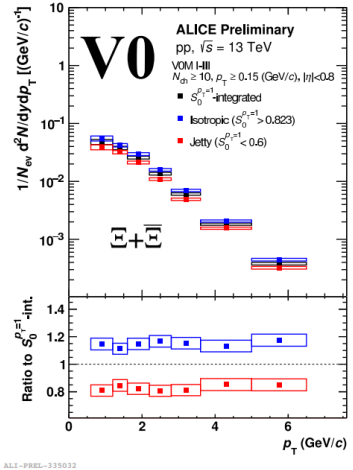
# Spherocity and multiplicity classes

- $S_0^{p_T=1}$ measurements performed in events with $N_{ch} > 10$ in 0-10% highest multiplicity events determined at
  1. forward rapidity (V0 scintillators)
  2. mid-rapidity ($N_{tracklets}$ in SPD, called CL1)
- Where we measure $N_{ch}$ changes what our spherocity classifies:

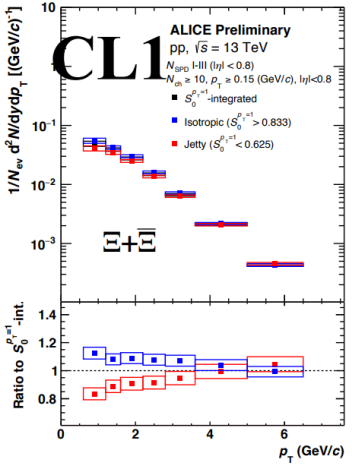
- ***With V0M, $S_0^{p_T=1}$ selects events with similar $\langle p_T \rangle$ but different multiplicity***
- ***With CL1, $S_0^{p_T=1}$ selects events with similar multiplicity but different $\langle p_T \rangle$ and thus disentangles events based on hardness***




- ***pT spectra for Xi baryon:***

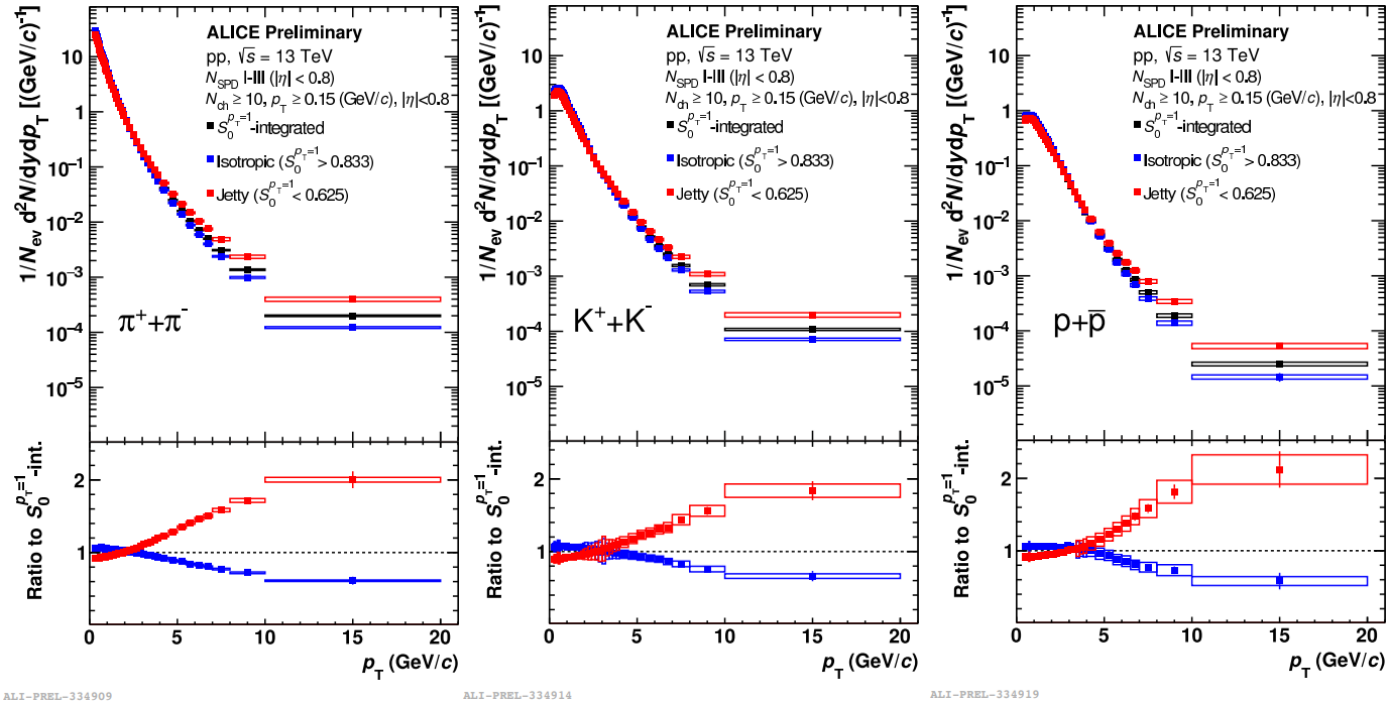


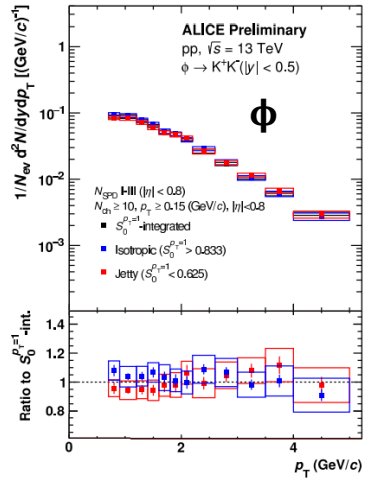

- $S_0^{p_T=1}$ selects events with similar behaviour to the integrated result

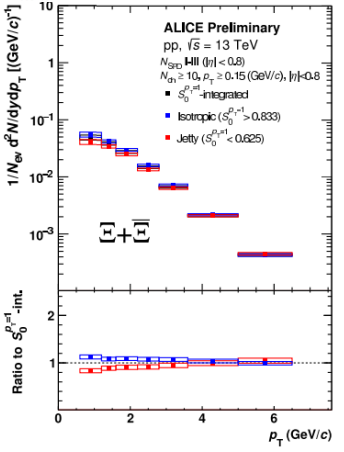



- $S_0^{p_T=1}$ selects events with different pT shape w.r.t the integrated result

# Identified pT spectra – CL1 estimator



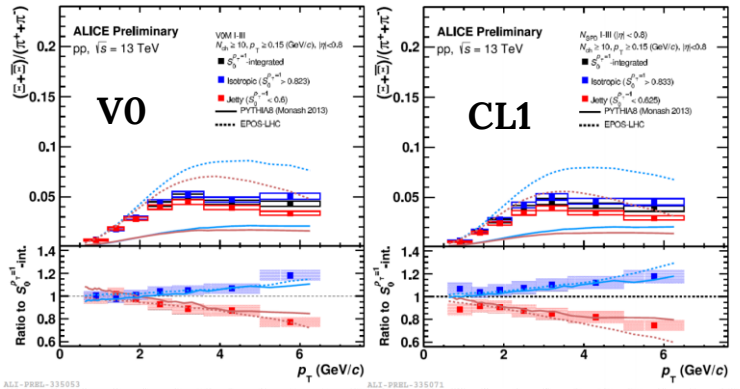



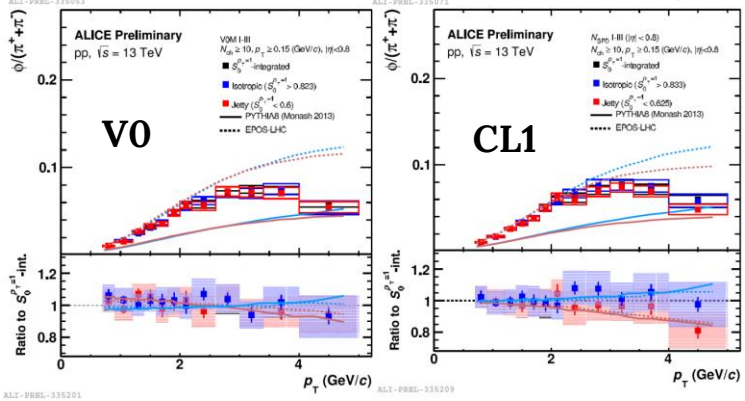

*Pions, Protons, Kaons enter the spherocity calculation*
*Phi mesons enter twice (two primary daughters)*
*Xi does not enter*

# Particle ratios – Xi, phi

- **Xi baryon:**




- **Phi meson:**




*Xi results suggest that in combination with the CL1 estimator, changing $S_0^{p_T=1}$ enhances or suppresses strangeness*
*(no crossing point)*

*Phi meson does not give a clear picture and shows no dependence on $S_0^{p_T=1}$ using both CL1 and V0*

**Models:**
- *Neither Pythia8 nor EPOS-LHC can describe the particle ratios quantitatively*
- *However, double ratios can described well by both*

# Summary

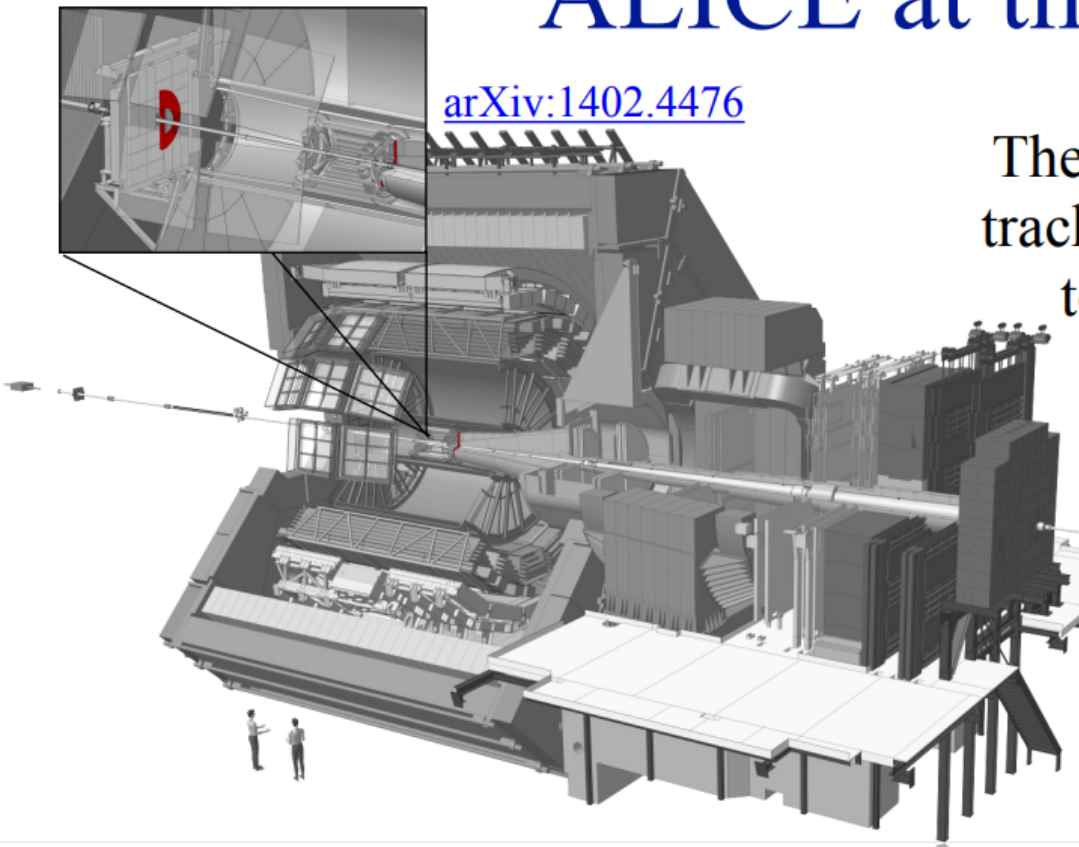
- Underlying event activity $R_{\mathrm{T}}$ can be used
  - as a proxy for $N_{\mathrm{MPI}}$ (in the Transverse region) ,
  - to control the amount of mixing between **jet**- and **UE**-related production (in the Toward region) .
  - Results hint at the fact that the driving factor behind observations of „radial flow“-like features is not $N_{\mathrm{MPI}}$ but rather the jet/UE interplay
- Unweighted spherocity $S_0^{p_{\mathrm{T}}=1}$ can be used
  - as a tool to discriminate between **soft** and **hard** physics dominated events based on the event topology, particularly in combination with high-multiplicity events determined at mid-rapidity.
  - **Isotropic** events display Ξ enhancement, **jetty** events show suppression,
  - models cannot describe the observed particle ratios.
- Results showed at
  - QM 2019 ( https://indico.cern.ch/event/792436/contributions/3533768/ and https://indico.cern.ch/event/792436/contributions/3533783/ )
  - MPI 2019 ( https://indico.cern.ch/event/816226/contributions/3603866/ and https://indico.cern.ch/event/816226/contributions/3614931/ )
  - Zimanyi Winter School 2019 (https://indico.cern.ch/event/867085/contributions/3656079/attachments/1954459/3245983/Zimanyi_talk.pdf )
- Studying events vs. the event structure seems very promising and there is still a lot of area to cover

# Thank you for your attention!

# –

# BACKUP

# ALICE at the LHC



arXiv:1402.4476

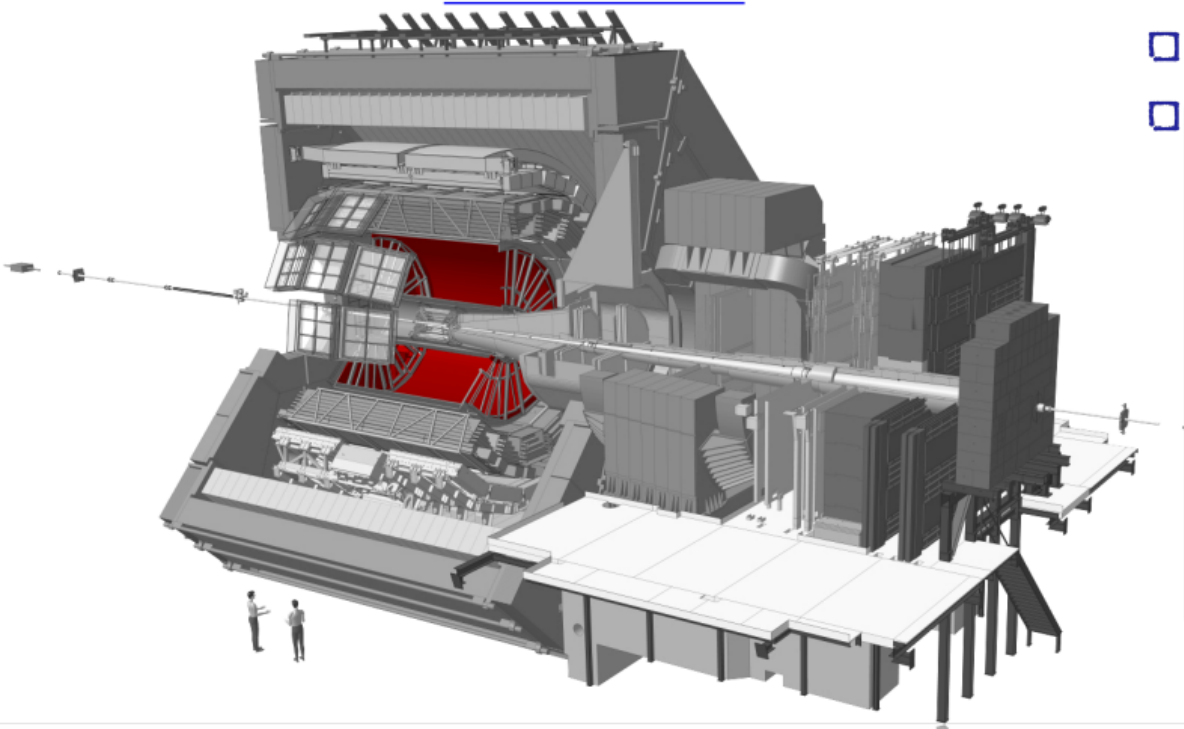
The dedicated detector at the LHC for tracking and PID from ~150 MeV/c up to 20 GeV/c in high-multiplicity environments

V0 = V0A + V0C

- Forward scintillator hodoscopes
  - V0A ($2.8 < \eta < 5.1$)
  - V0C ($-3.7 < \eta < -1.7$)
- Triggering, background suppression and multiplicity estimator in the forward region

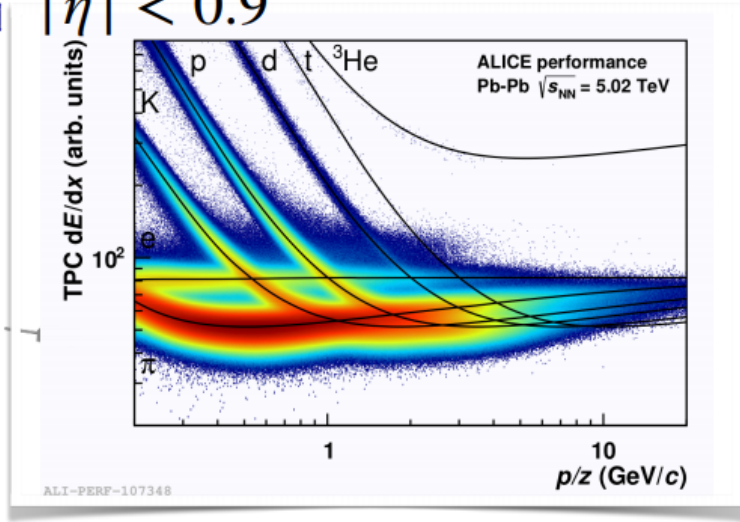
# PID with ALICE

arXiv:1402.4476



## TPC

- PID based on d$E$/d$x$
- $|\eta| < 0.9$



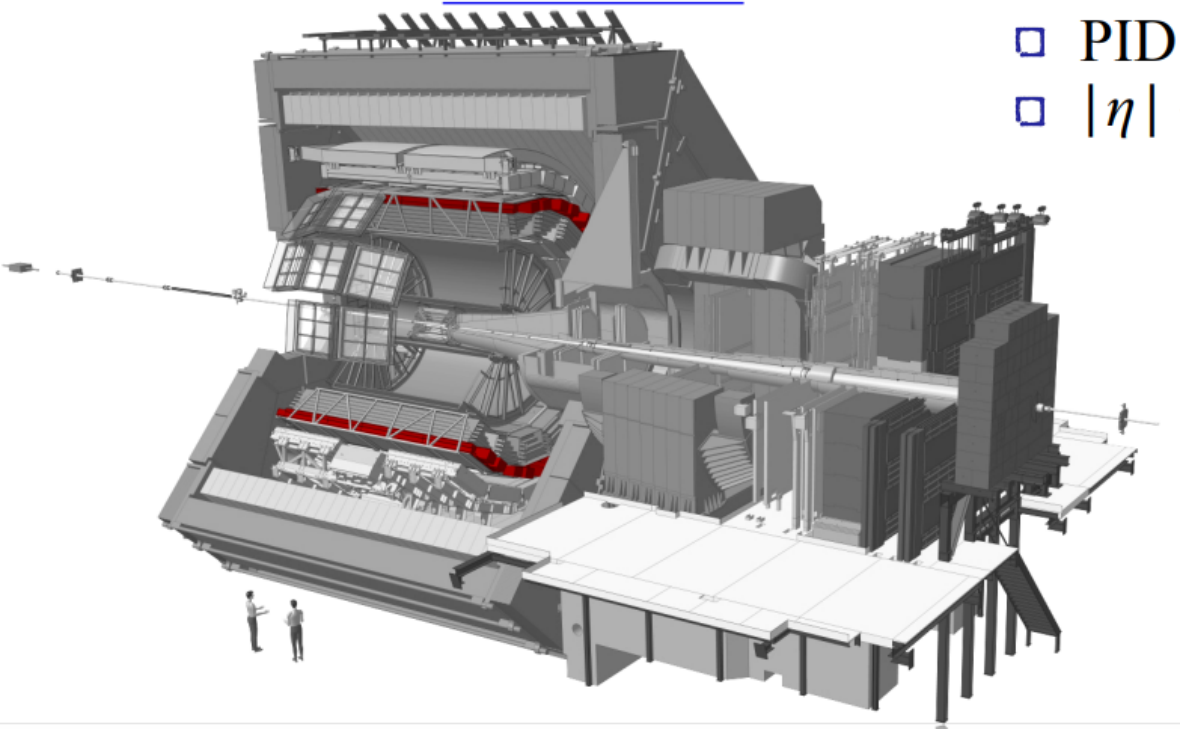

In this presentation:

$\pi$/K/p , $\phi \rightarrow K^+K^-$

$\Xi^-(\overline{\Xi}^+) \rightarrow \Lambda(\overline{\Lambda}) + \pi^-(\pi^+)$

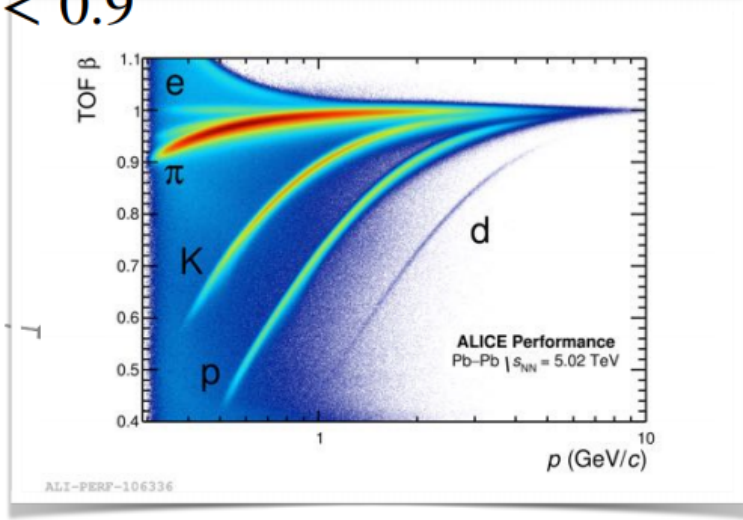
# PID with ALICE

arXiv:1402.4476



## TOF

- PID based on the Time-Of-Flight
- $|\eta| < 0.9$

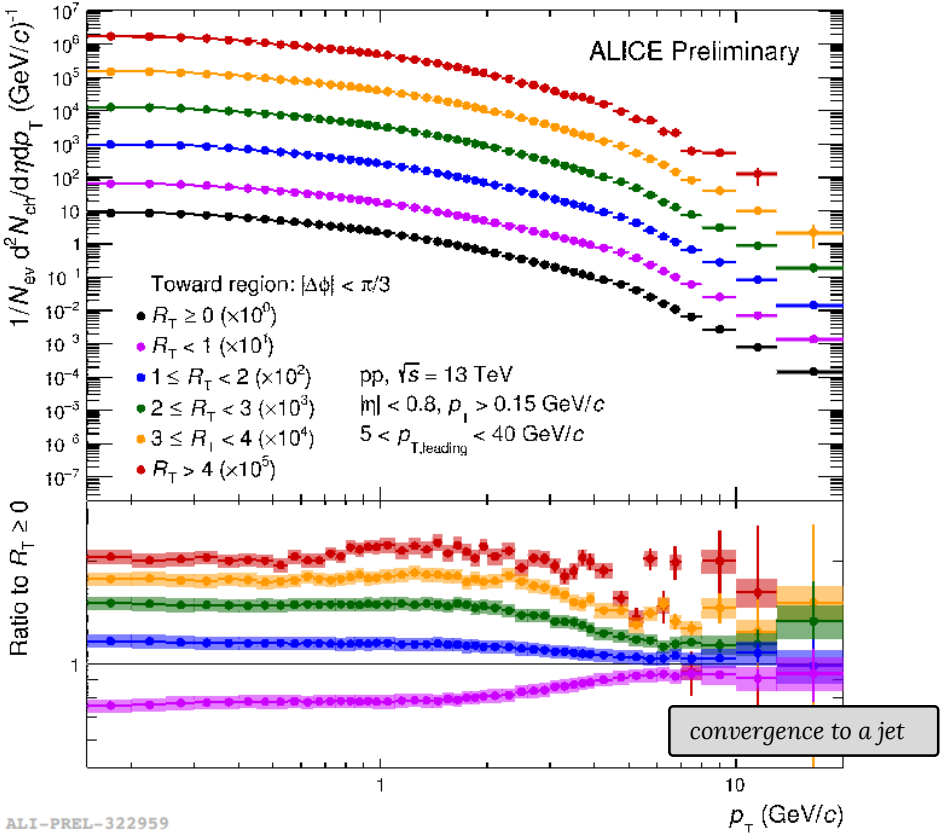


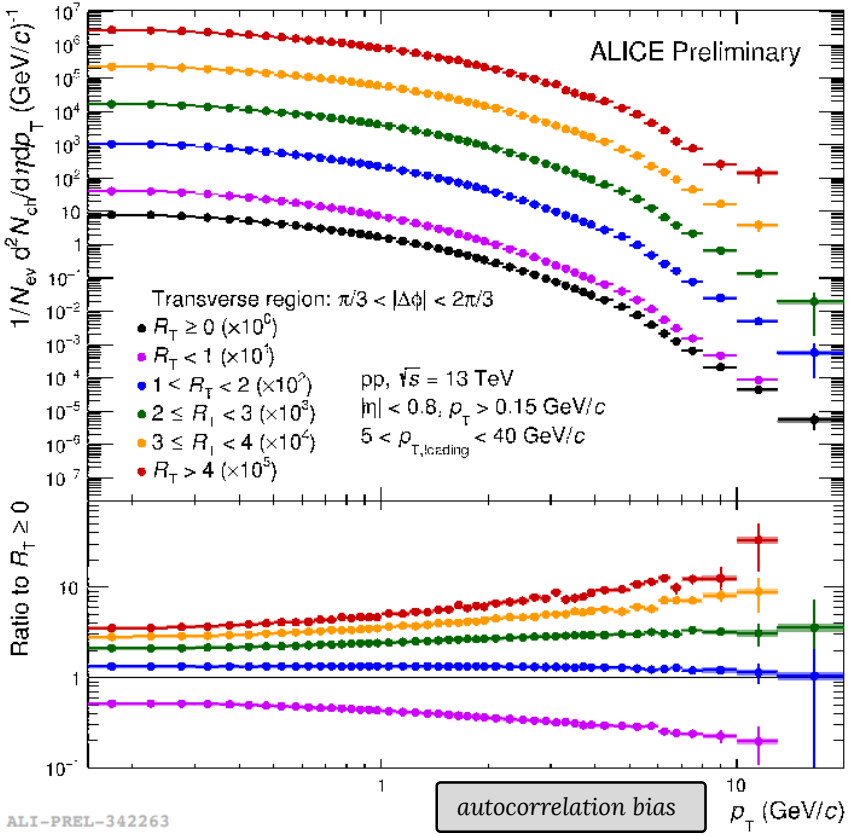

In this presentation:

$\pi/\mathrm{K}/\mathrm{p}$ , $\phi \rightarrow \mathrm{K}^{+}\mathrm{K}^{-}$

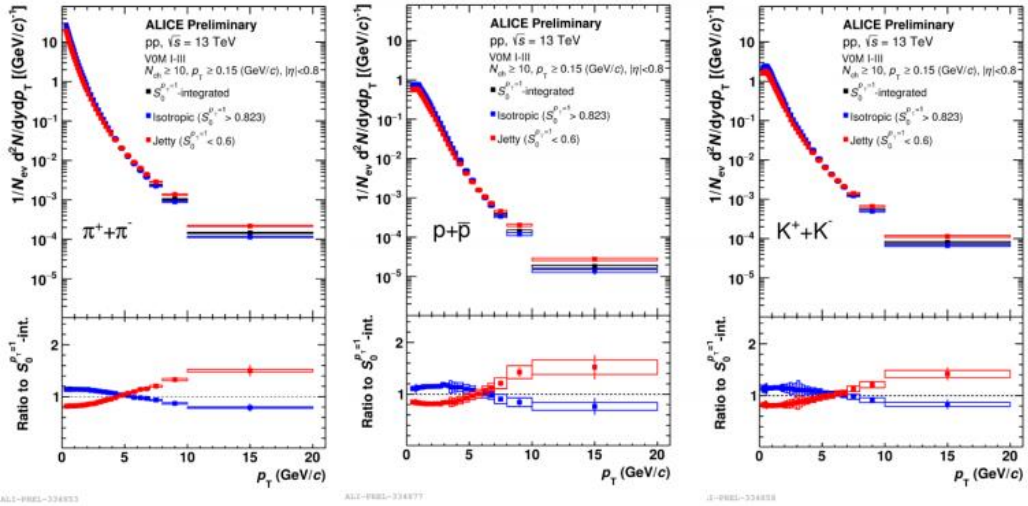
$\Xi^{-}(\overline{\Xi}^{+}) \rightarrow \Lambda(\overline{\Lambda}) + \pi^{-}(\pi^{+})$

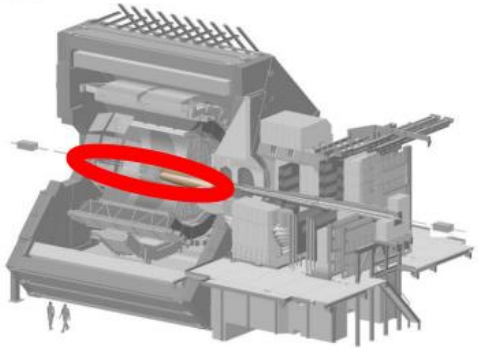
# Charged tracks vs RT



# Unweighed Transverse Spherocity $S_0^{p_T=1}$ — Results
## V0M 0 – 10%

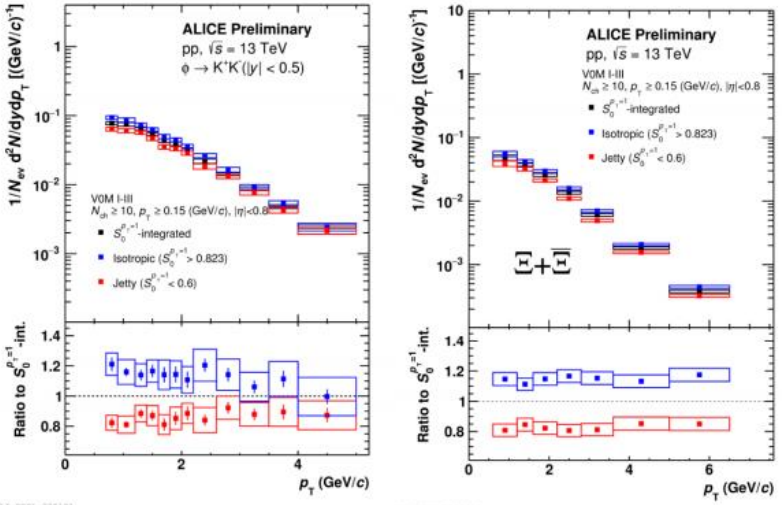


$$2.8 < \eta < 5.1$$
$$-3.7 < \eta < -1.7)$$

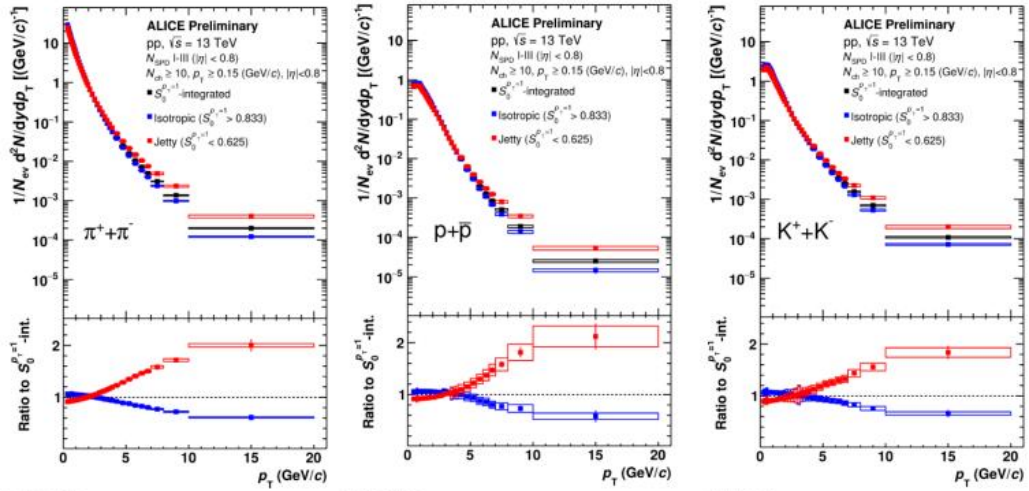
Distinct difference between Jetty and Isotropic events!

$\pi/K/P$ has distinct crossing point.
$\phi/\Xi$ seem to be more flat around unity.

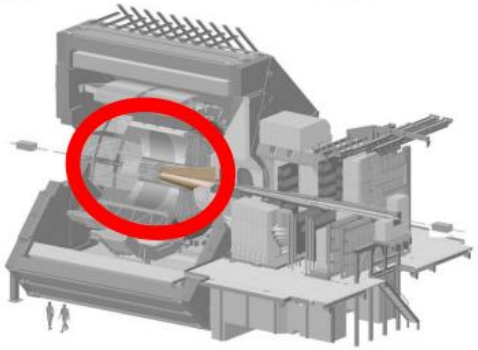


# Unweighed Transverse Spherocity $S_0^{p_T=1}$ — Results

## CL1 0 – 10%



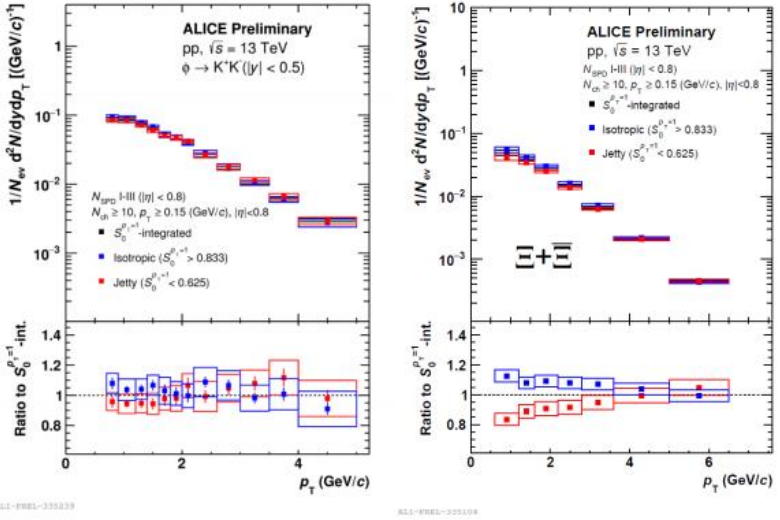

$|\eta| < 0.8$



Difference between Isotropic and Jetty are now less distinct at low $p_T$.

$\pi/K/P$ still has a crossing point.

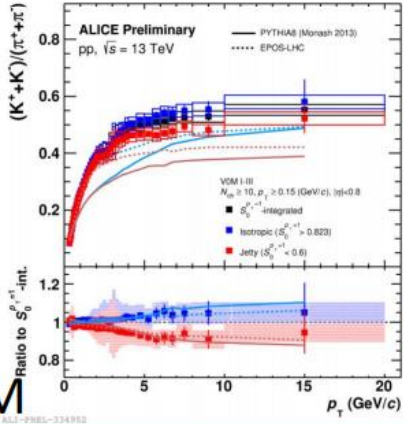
$\phi/\Xi$ converge to unity.

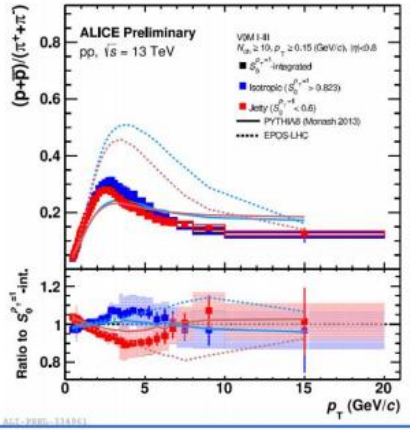


# Unweighed Transverse Spherocity $S_0^{p_T=1}$ — Results

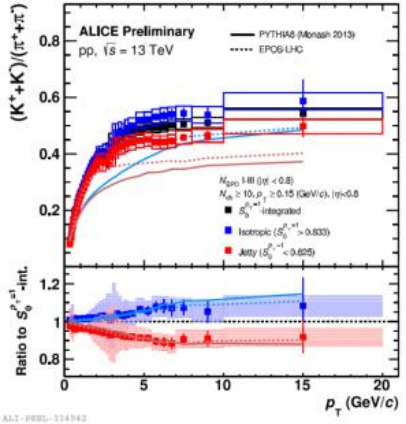
## Ratio to Pions - $K/\pi$ and $p/\pi$

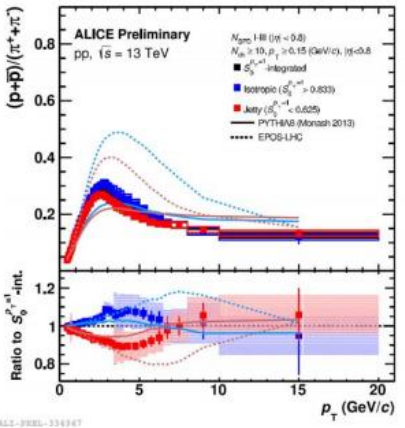
V0M




CL1




The $K/\pi$ and $p/\pi$ ratios exhibit different effects when triggering on CL1 or V0M