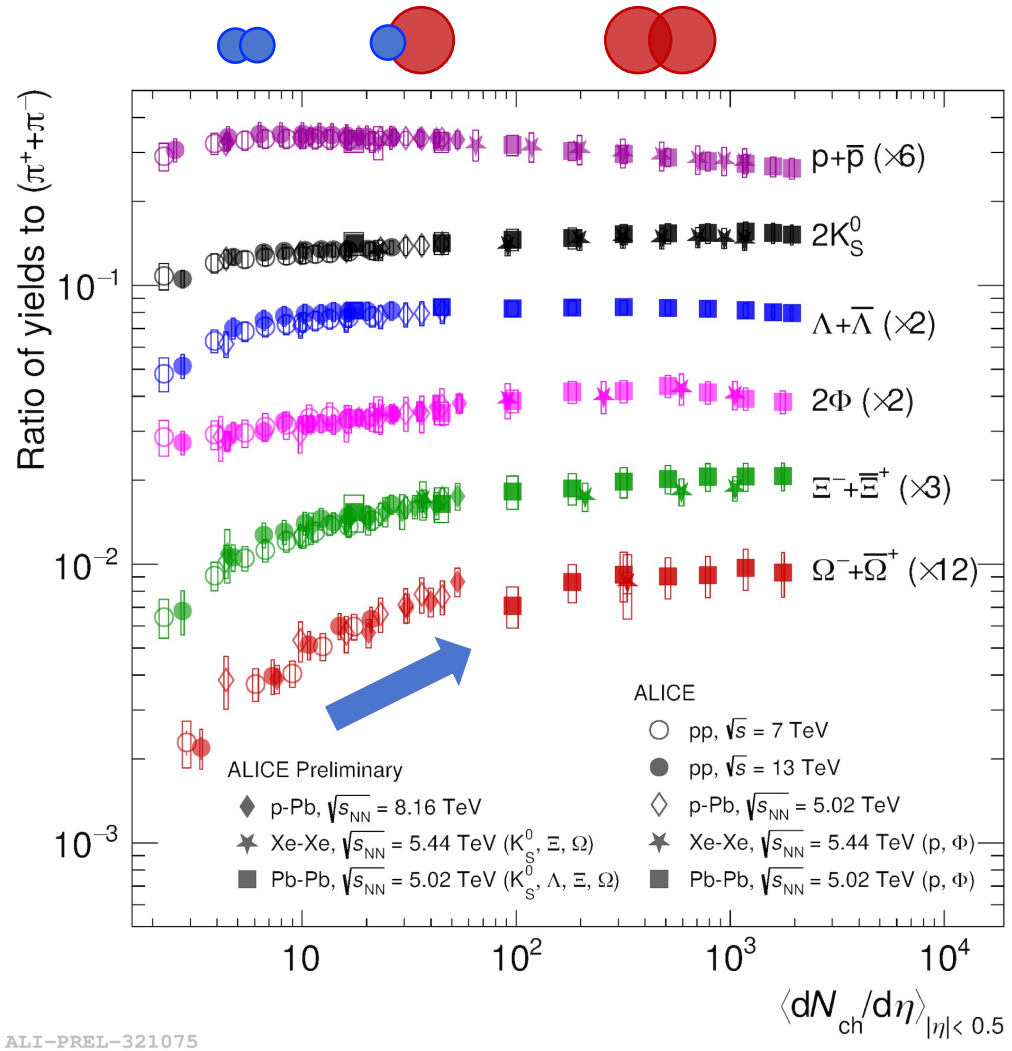
ALICE search for the collective origin of strangeness enhancement

Chiara De Martin on behalf of the ALICE Collaboration

University and INFN - Trieste

Physics motivation

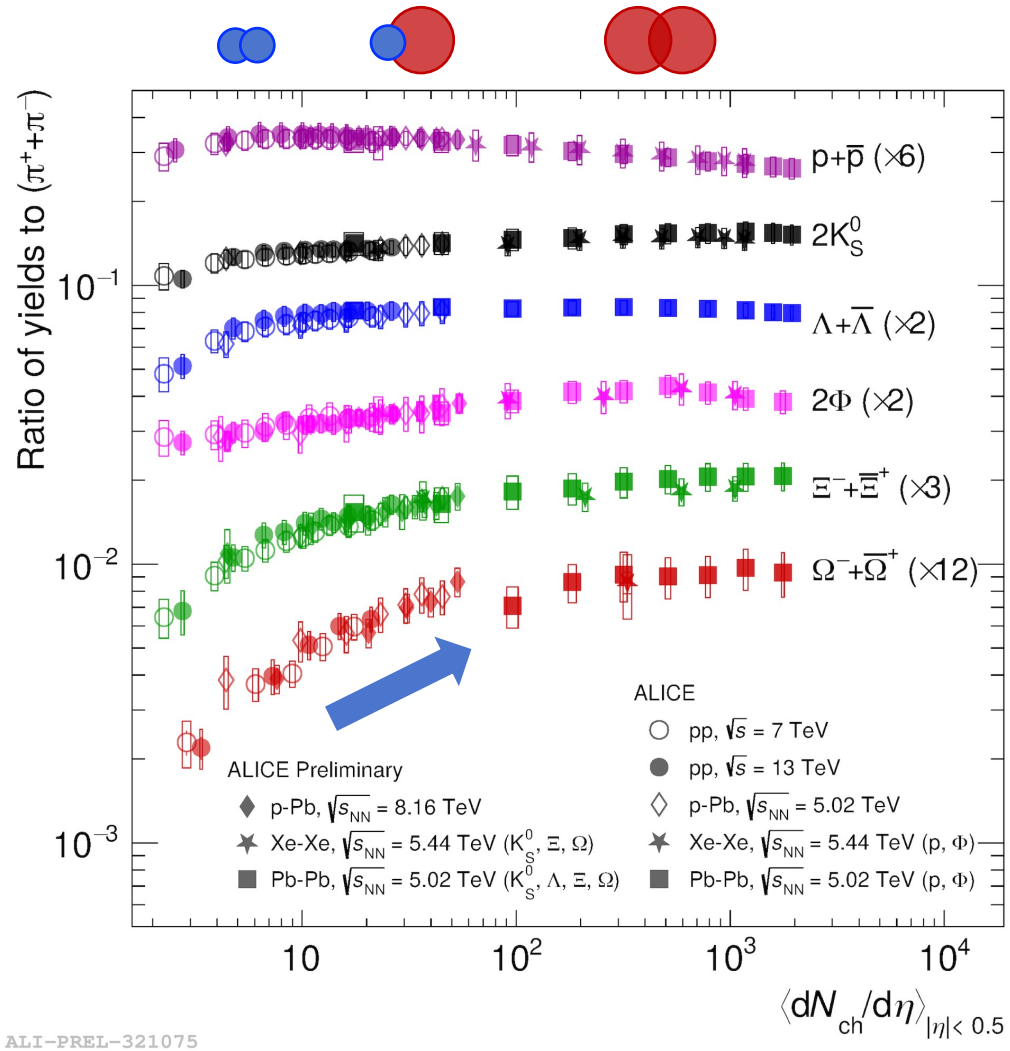


Strangeness enhancement:
The ratio between (multi-)strange hadron yields and pion yields is enhanced in heavy-ion collisions with respect to minimum bias pp collisions

- Smooth evolution with the multiplicity of charged particles across different collision systems (pp, p-Pb, Pb-Pb)
- No dependence on the collision energy at the LHC
- The enhancement is larger for particles with larger strangeness content ($\Omega > \Xi > \Lambda \sim K^0_S$)

Nature Phys 13, 535–539 (2017)
Eur.Phys.J.C 80, 167 (2020)

Physics motivation



Strangeness enhancement:
The ratio between (multi-)strange hadron yields and pion yields is enhanced in heavy-ion collisions with respect to minimum bias pp collisions

- Is strangeness enhancement in pp collisions correlated only with final state particle multiplicity, or do initial stage effects play a role?
- Is strangeness enhancement in pp collisions related to hard processes, such as jets, to out-of-jet processes, or to both?

Nature Phys 13, 535–539 (2017)
Eur.Phys.J.C 80, 167 (2020)

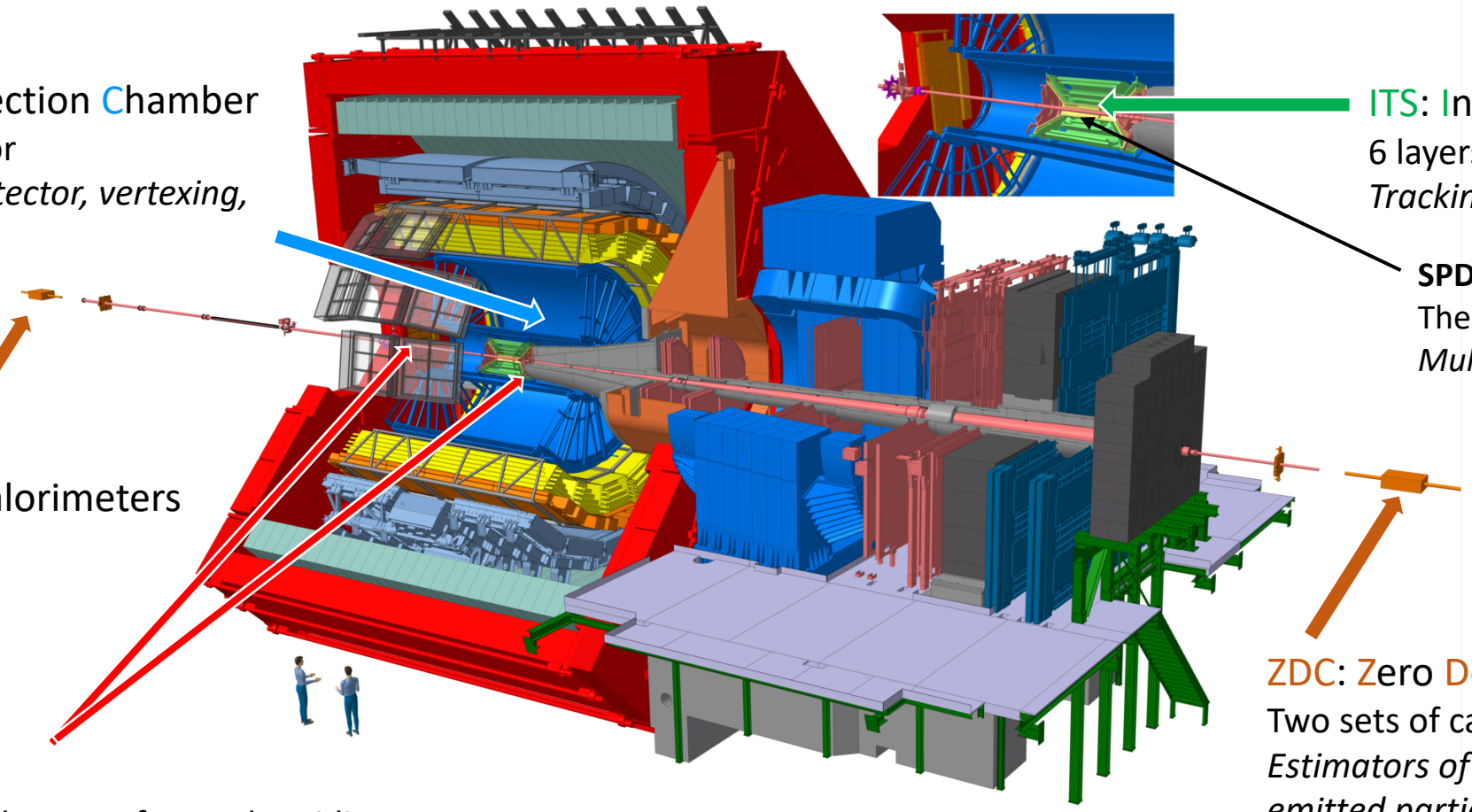
→ See also Francesca Ercolessi poster (Session 1 T14_1)

ALICE at the LHC

TPC: Time Projection Chamber
Gas-filled detector
Main tracking detector, vertexing, PID (dE/dx)

ITS: Inner Tracking System
6 layers of silicon detectors
Tracking, triggering, vertexing

SPD: **S**ilicon **P**ixel **D**etector
The first 2 layers of the ITS
Multiplicity estimators

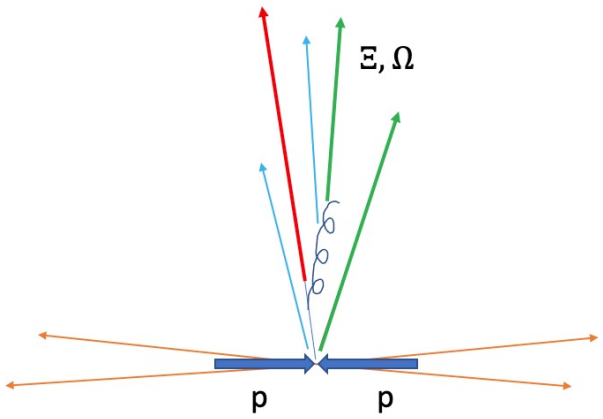


ZDC:
Zero Degree Calorimeters

V0A and V0C
Arrays of scintillators at forward rapidity
Triggering, multiplicity estimators

ZDC: Zero Degree Calorimeters
Two sets of calorimeters at forward rapidity
Estimators of energy deposits of forward emitted particles

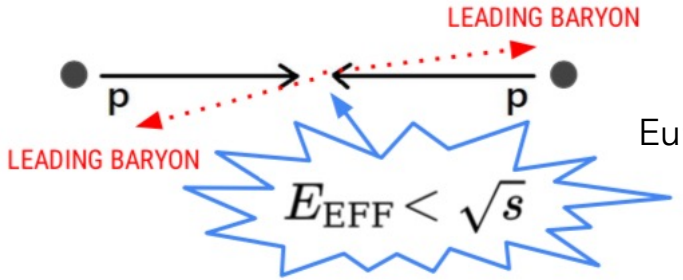
Strangeness production as a function of effective energy



The concept of effective energy in pp collisions

- The energy available in an event for particle production is only a fraction of the centre-of-mass energy, because of the leading baryon effect

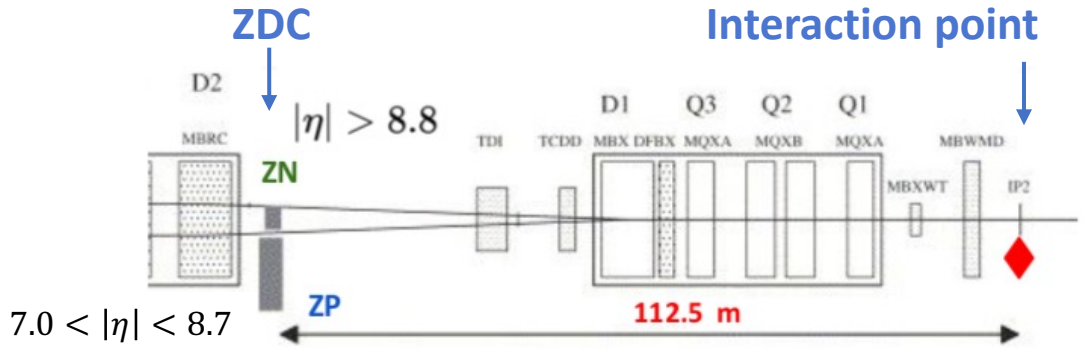
Leading baryon effect:
high probability of emitting baryons with high longitudinal momentum in the forward direction



Eur.Phys.J.C 50, 341-352 (2007)

- ALICE estimates the event effective energy from the measurement of the energy deposited in the forward calorimeters (ZDCs):

$$E_{\mathrm{EFF}} \backsimeq \sqrt{s} - \langle \mathrm{ZDC\ energy\ sum} \rangle$$

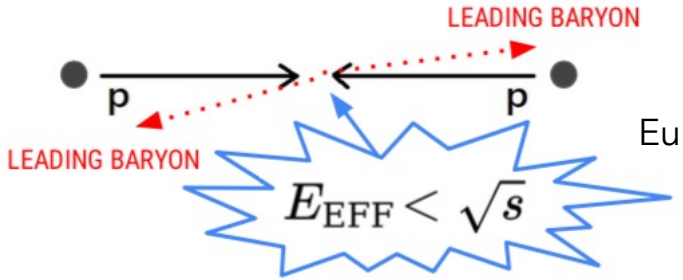


https://arxiv.org/abs/2107.10757

The concept of effective energy in pp collisions

- The energy available in an event for particle production is only a fraction of the centre-of-mass energy, because of the leading baryon effect

Leading baryon effect:
high probability of emitting baryons with high longitudinal momentum in the forward direction

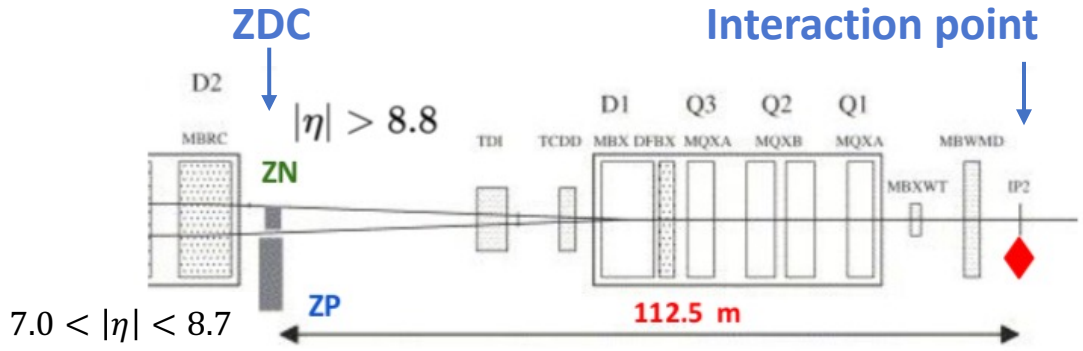


Eur.Phys.J.C 50, 341-352 (2007)

- ALICE estimates the event effective energy from the measurement of the energy deposited in the forward calorimeters (ZDCs):

$$E_{\mathrm{EFF}} \backsimeq \sqrt{s} - \langle \mathrm{ZDC\ energy\ sum} \rangle$$

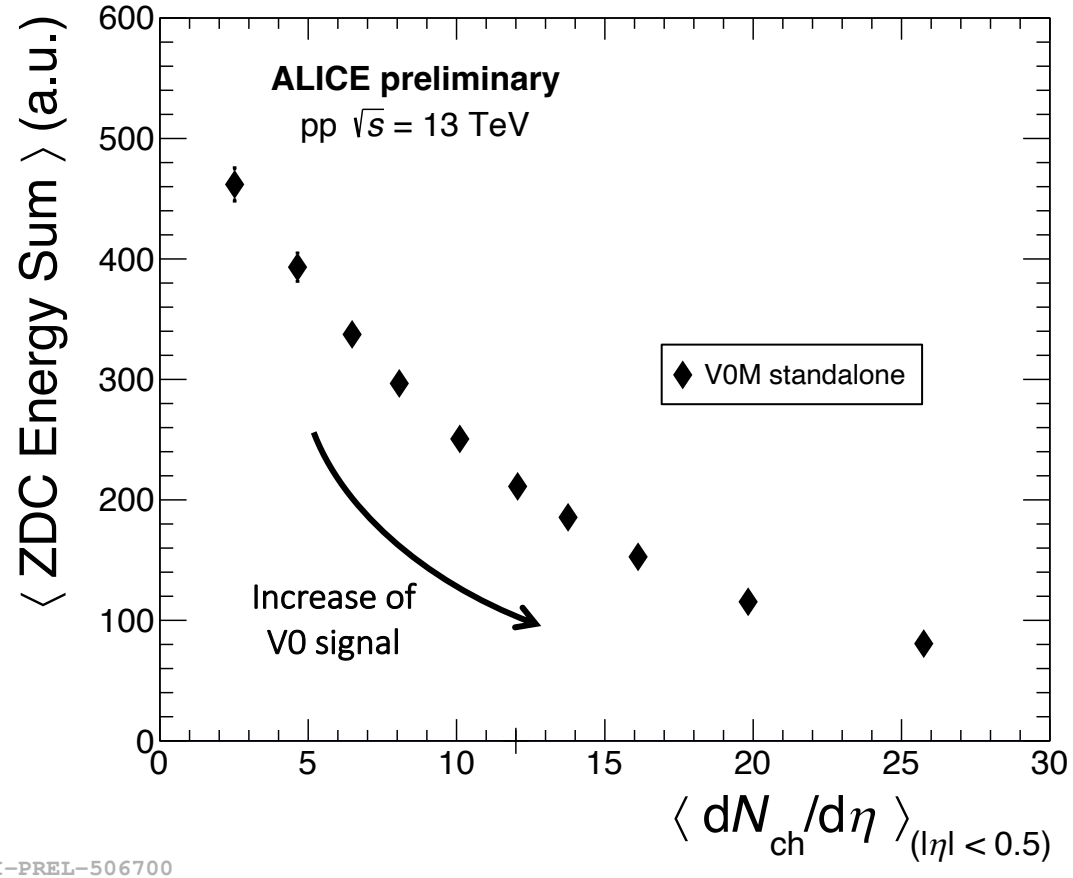
Is strangeness production correlated with the effective energy, which is connected with the initial stage of the collision?



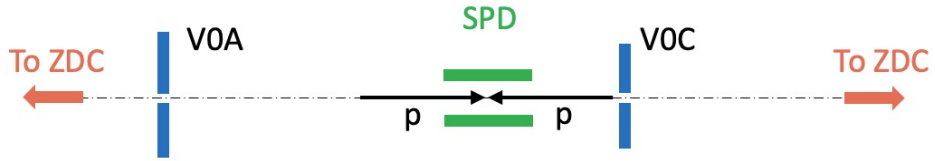
https://arxiv.org/abs/2107.10757

Multiplicity and effective energy are correlated

NEW!



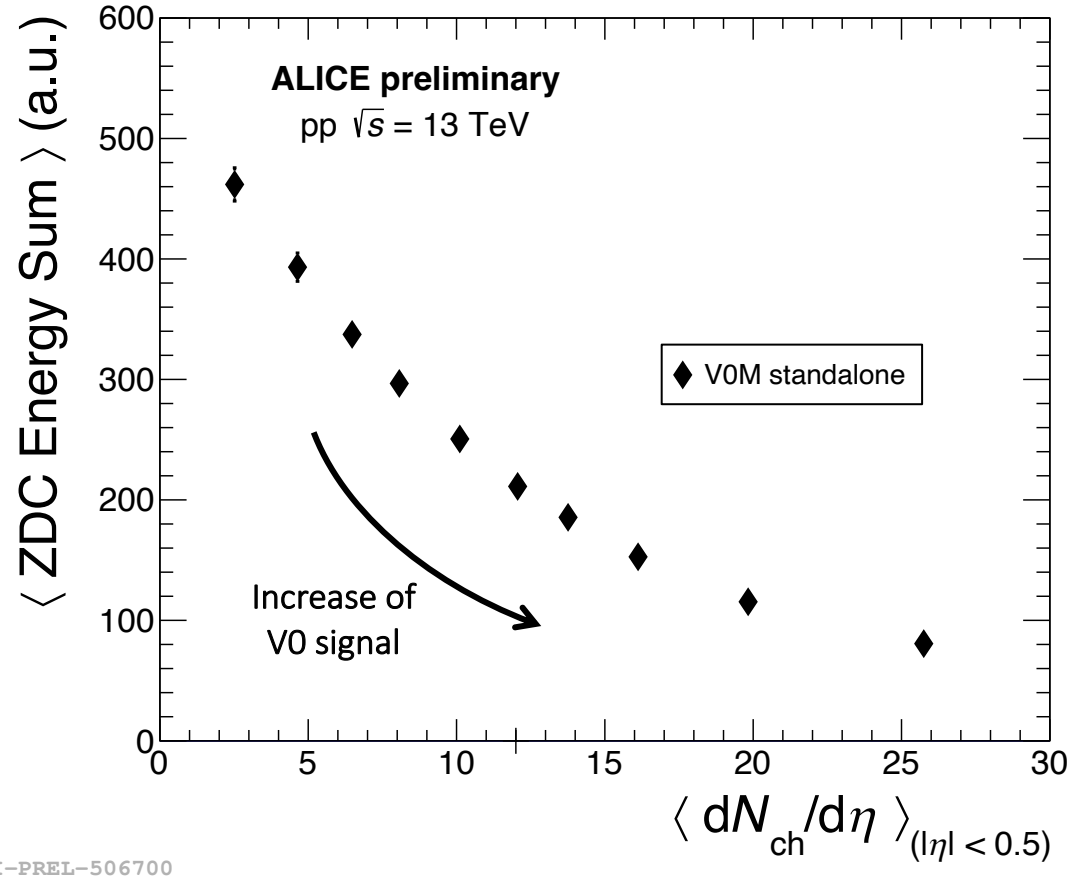
ALI-PREL-506700



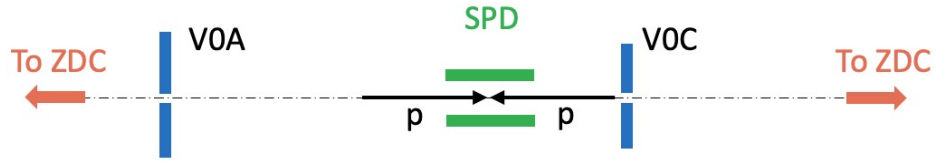
- V0M standalone classes:
  - Percentile classes based on signal amplitude in V0 detectors
  - Show a strong **correlation** between **effective energy** and **multiplicity at midrapidity**

Multiplicity and effective energy are correlated

NEW!



ALI-PREL-506700



♦ V0M standalone classes:

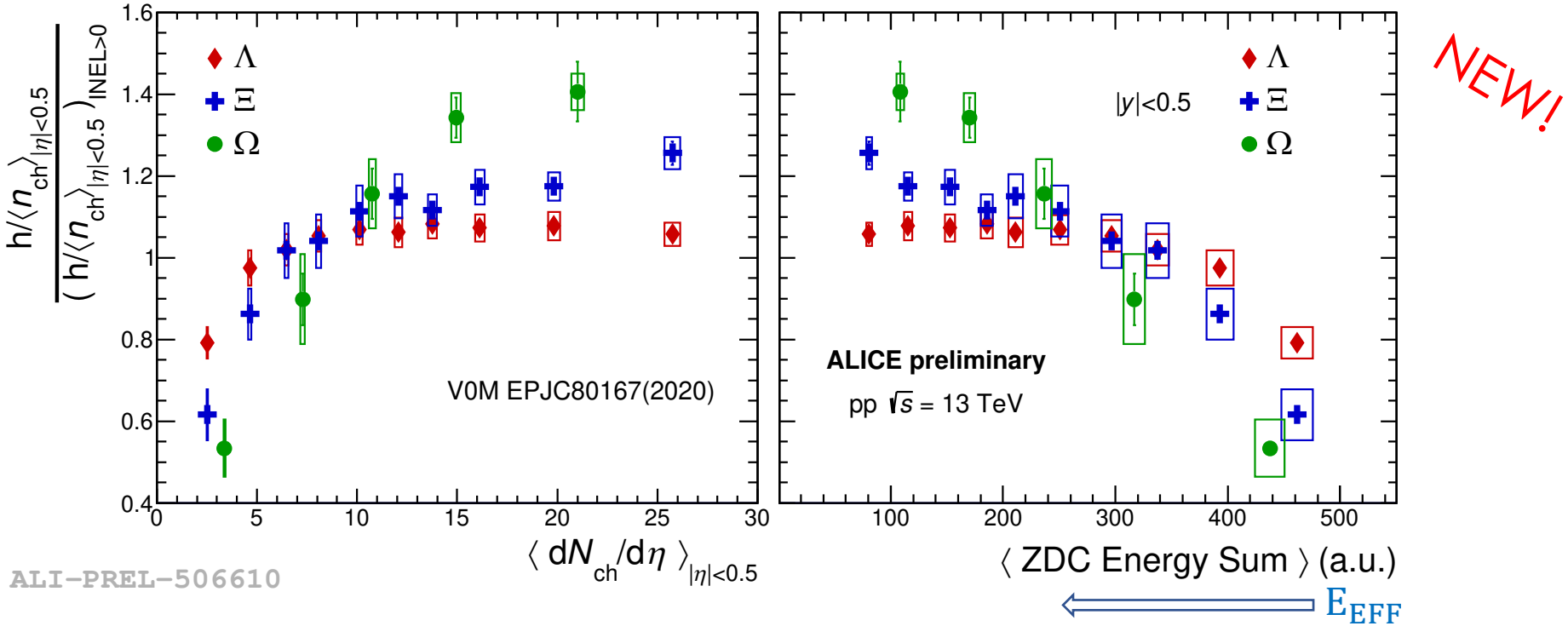
- Percentile classes based on signal amplitude in V0 detectors
- Show a strong **correlation** between **effective energy** and **multiplicity at midrapidity**

The analysis of **strangeness production in V0M classes does not allow to disentangle** the multiplicity dependence from the effective energy dependence

Strangeness production in V0M classes

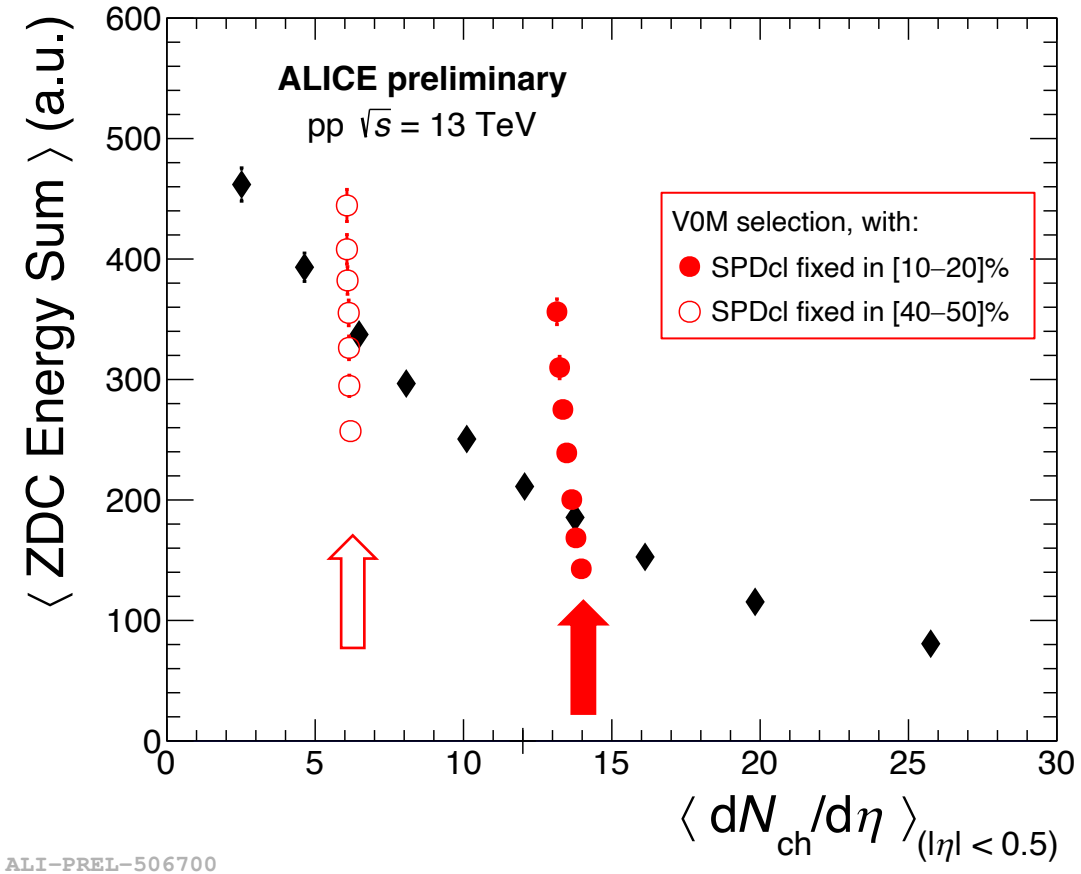
- The yields of strange hadrons normalised to the charged particle multiplicity:
  - **increase** with the **multiplicity at midrapidity** (the well known strangeness enhancement!)
  - **decrease** with the **ZDC energy sum**

→ Multi-differential analysis needed to disentangle effective energy from multiplicity dependence

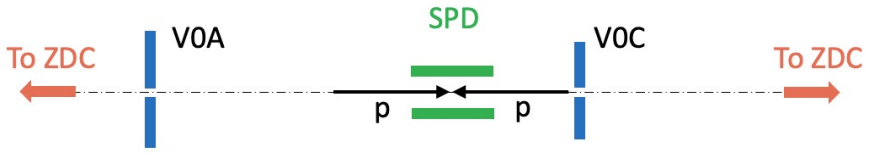


Disentangle multiplicity and effective energy

NEW!



ALI-PREL-506700



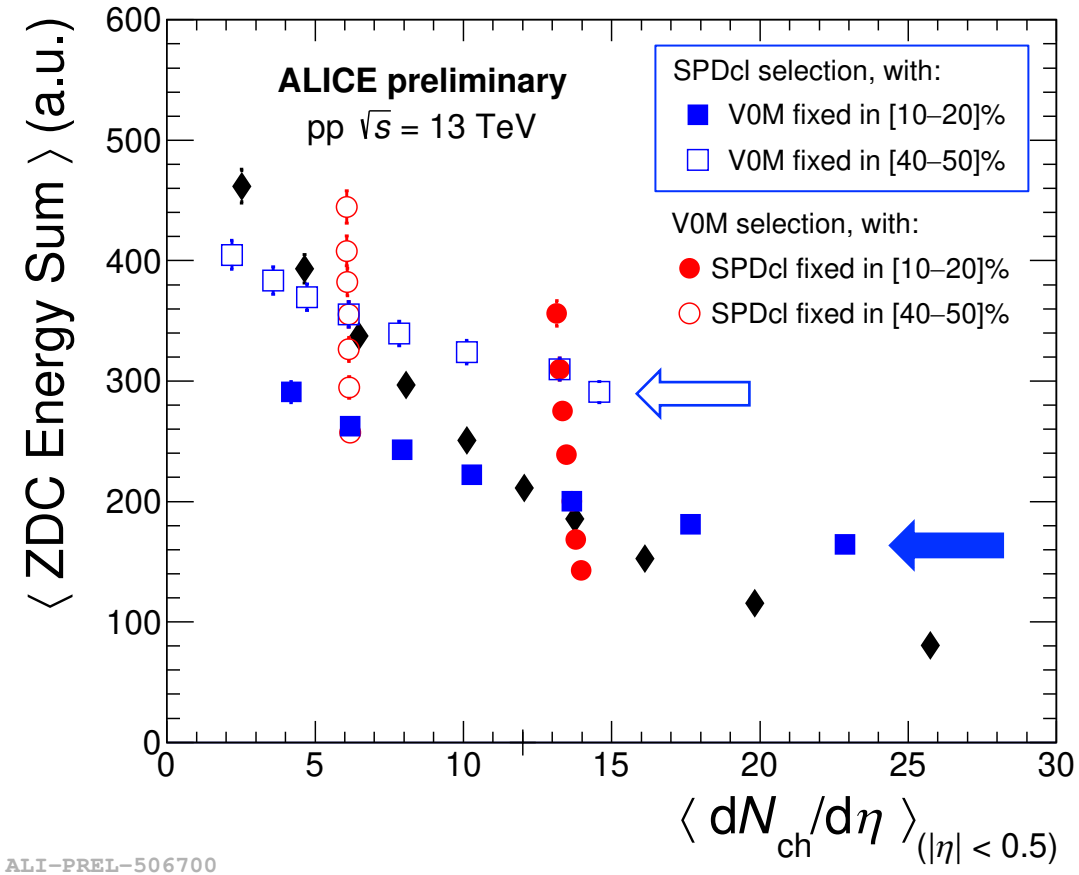
SPD classes:
Percentile classes based on the number of clusters in the SPD ($|\eta| < 0.8$)

○ ● SPD class fixed + V0M selections:

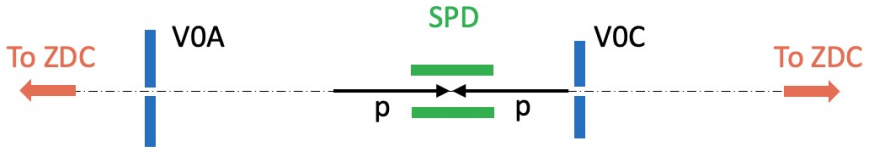
Fix the multiplicity at midrapidity and vary the effective energy

Disentangle multiplicity and effective energy

NEW!



ALI-PREL-506700



SPD classes:
Percentile classes based on the number of clusters in the SPD ($|\eta| < 0.8$)

○ ● SPD class fixed + V0M selections:

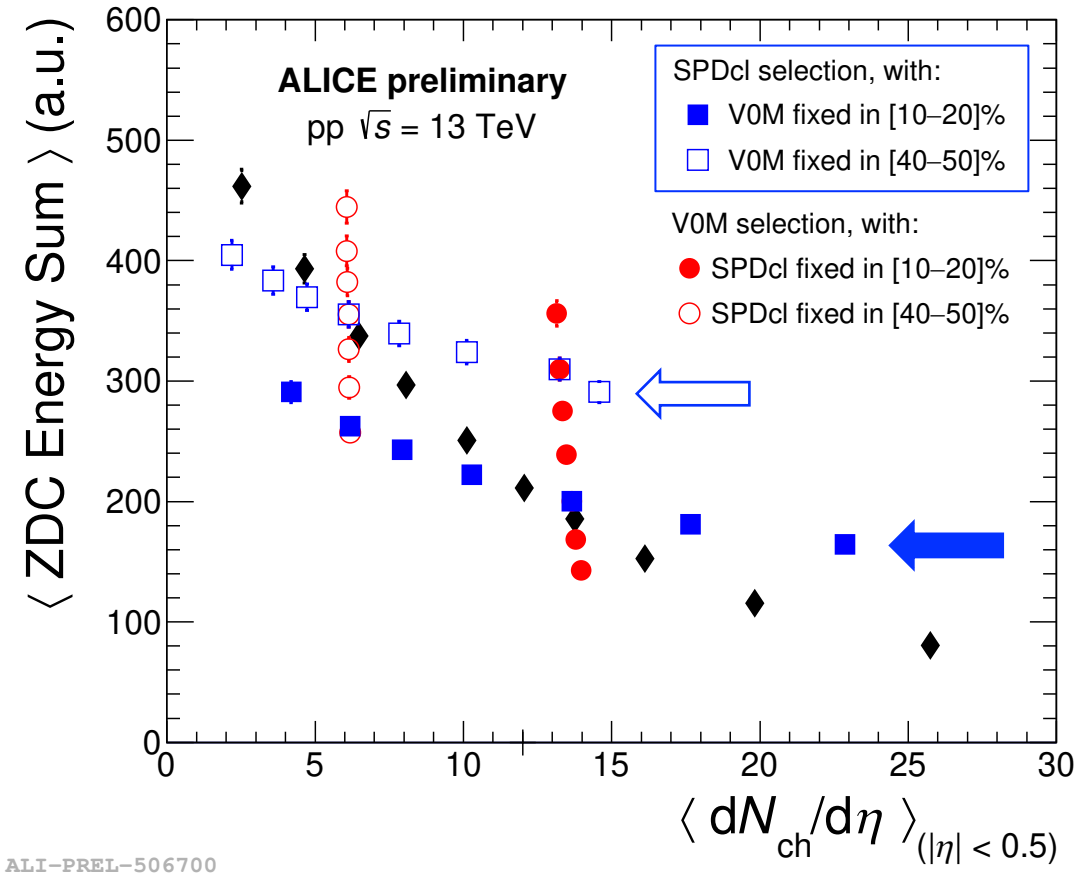
Fix the multiplicity at midrapidity and vary the effective energy

□ ■ V0M class fixed + SPD selections:

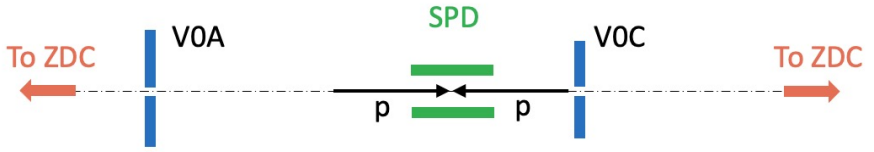
Reduce the span of the effective energy and vary the multiplicity at midrapidity

Disentangle multiplicity and effective energy

NEW!



ALI-PREL-506700



SPD classes:
Percentile classes based on the number of clusters in the SPD ($|\eta| < 0.8$)

○ ● SPD class fixed + V0M selections:

Fix the multiplicity at midrapidity and vary the effective energy

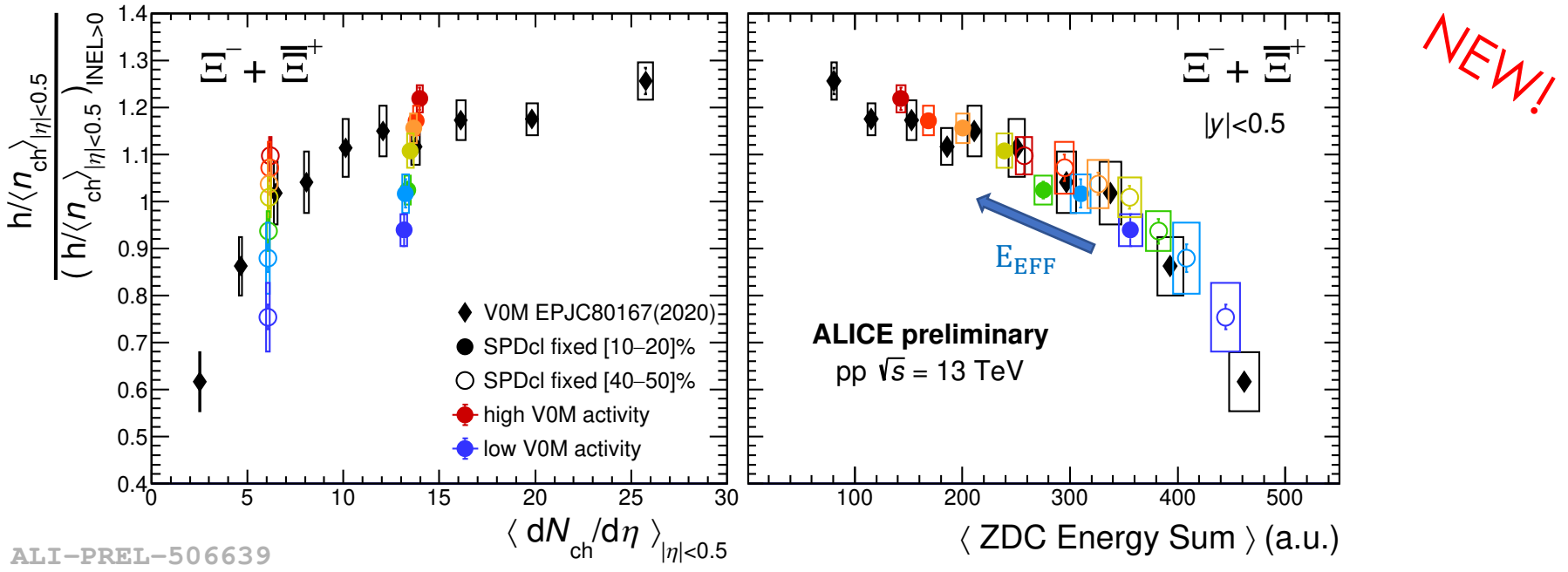
□ ■ V0M class fixed + SPD selections:

Reduce the span of the effective energy and vary the multiplicity at midrapidity

A **multi-differential analysis in combined V0M and SPD classes** allows to disentangle the effective energy and the multiplicity at midrapidity

Disentangle multiplicity and effective energy

$\Xi^{\pm}$ yield normalised to the charged particle multiplicity, fixing the multiplicity at midrapidity:



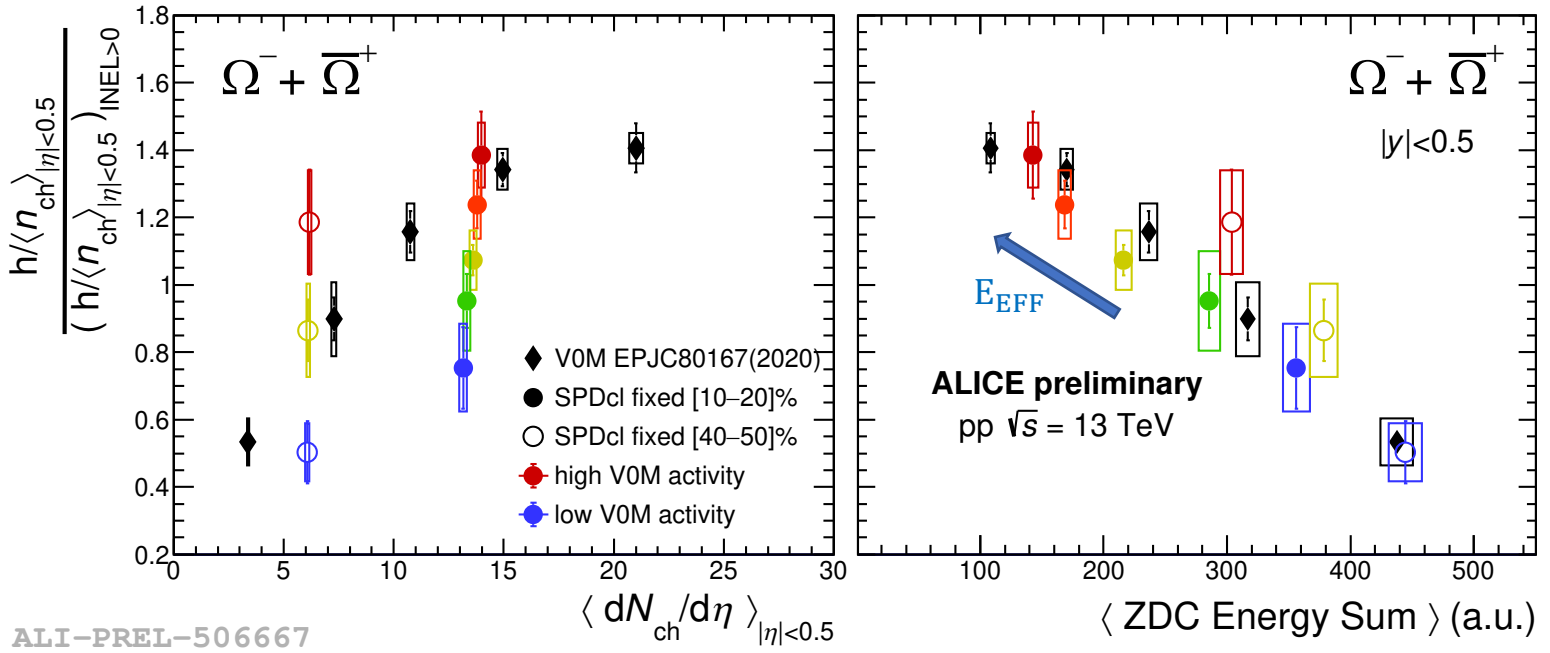
NEW!

- Strangeness enhancement with effective energy is observed also when the multiplicity at midrapidity is fixed
- Compatible trends with effective energy between the V0M standalone and the double differential analysis

→ Effective energy plays an important role in determining the production of strange hadrons

Disentangle multiplicity and effective energy

$\Omega^{\pm}$ yield normalised to the charged particle multiplicity, fixing the multiplicity at midrapidity:



NEW!

- Similar results obtained for the triple strange baryon $\Omega^{\pm}$

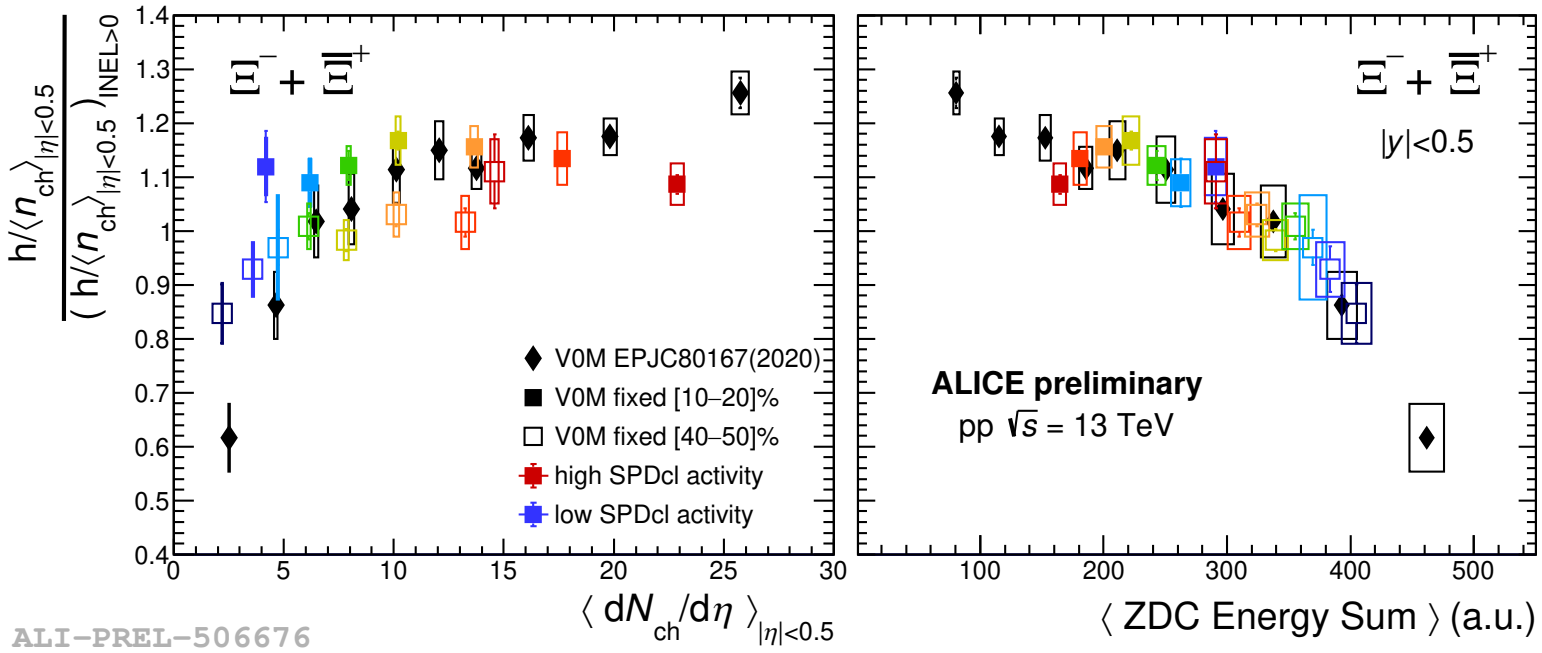
→ Effective energy plays an important role in determining the production of strange hadrons

Disentangle multiplicity and effective energy

$\Xi^{\pm}$ yield normalised to the charged particle multiplicity, reducing the effective energy span:

Larger E_{EFF}

Smaller E_{EFF}

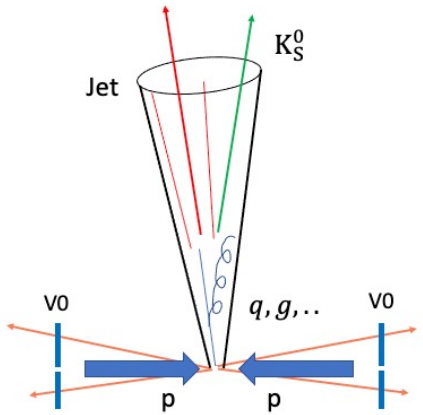


NEW!

- When the effective energy is constrained, the strangeness enhancement with multiplicity is reduced

→ Effective energy plays an important role in determining the production of strange hadrons

Angular correlations for in-jet and out-of-jet studies of strange hadron production



Correlations of high-p_{T} charged hadrons with strange particles

The angular correlation method:

1. Selection of the trigger particle (~jet axis): the charged primary particle with the highest p_{T} and $p_{\mathrm{T}} > 3$ GeV/c

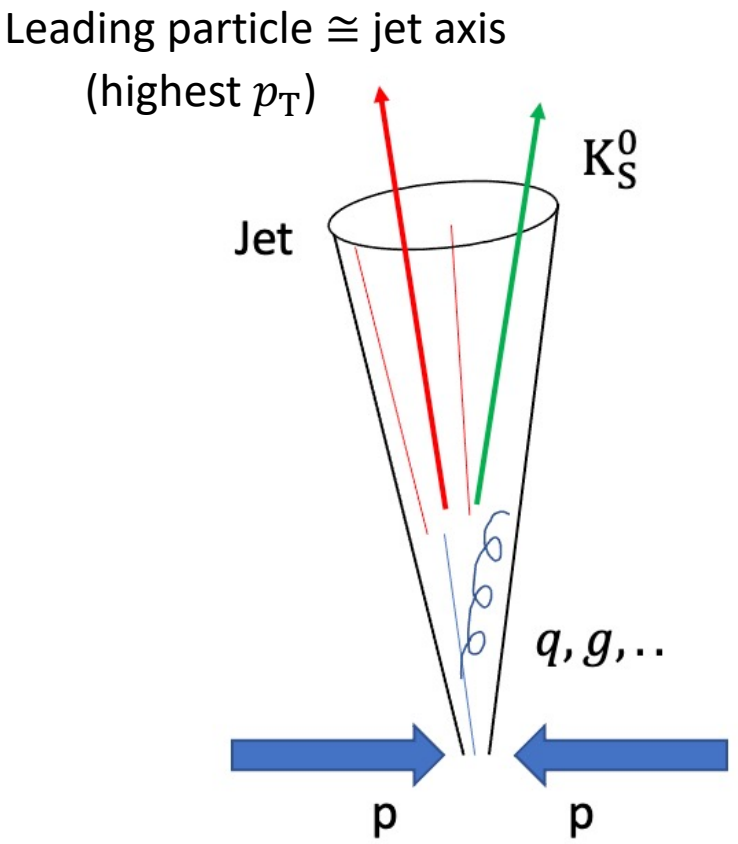
2. Identification of strange hadrons (associated particles)

3. Angular correlation between trigger and associated particles is calculated

$$\Delta\varphi = \varphi_{Trigg} - \varphi_{Assoc}$$

$$\Delta\eta = \eta_{Trigg} - \eta_{Assoc}$$

φ: azimuthal angle
η = - ln (tan(θ/2))
θ: polar angle



Correlations of high-p_{T} charged hadrons with strange particles

The angular correlation method:

1. Selection of the trigger particle (~jet axis): the charged primary particle with the highest p_{T} and $p_{\mathrm{T}} > 3$ GeV/c

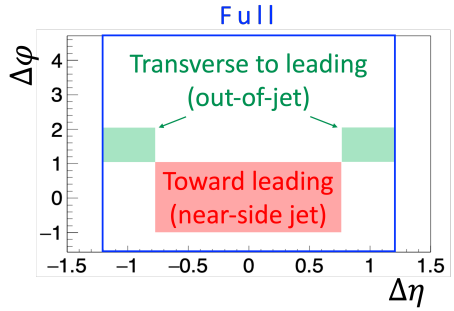
2. Identification of strange hadrons (associated particles)

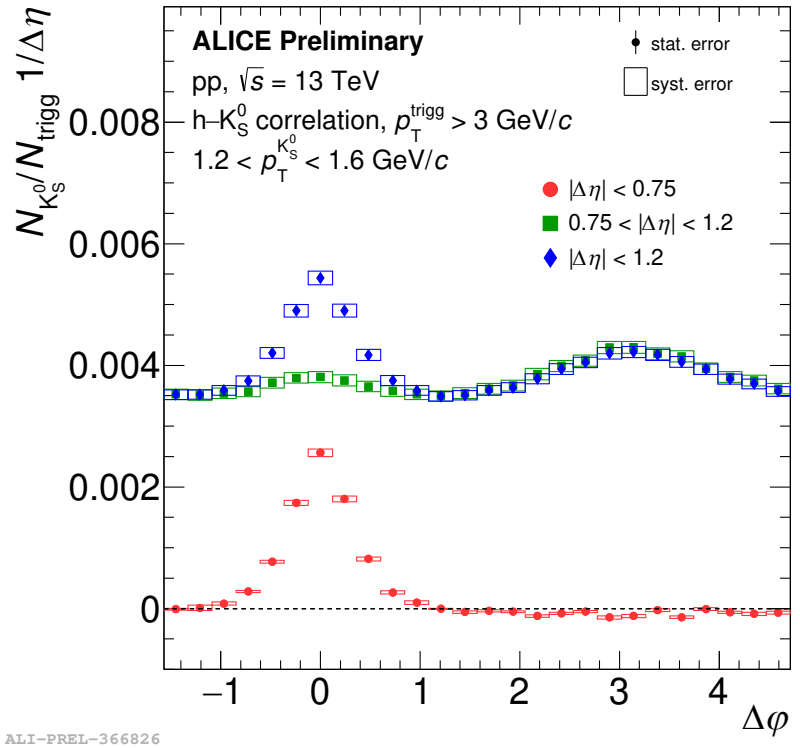
3. Angular correlation between trigger and associated particles is calculated

$$\Delta\varphi = \varphi_{Trigg} - \varphi_{Assoc}$$

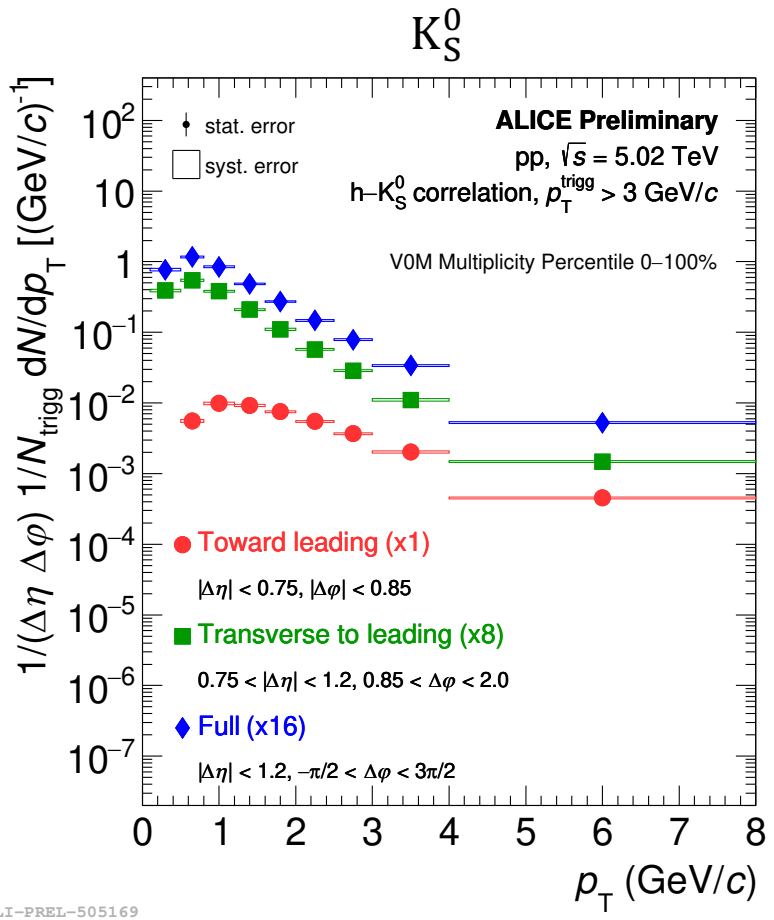
$$\Delta\eta = \eta_{Trigg} - \eta_{Assoc}$$

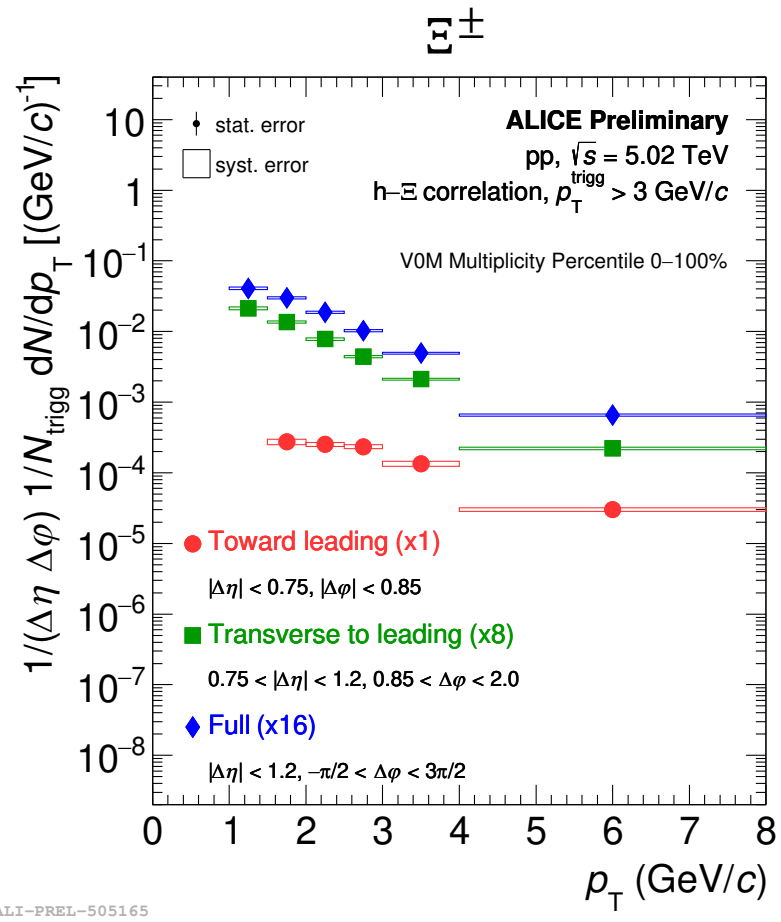
φ: azimuthal angle
η = - ln (tan(θ/2))
θ: polar angle





Near-side jet, out-of-jet and full p_T spectra of K^0_S and $\Xi^{\pm}$

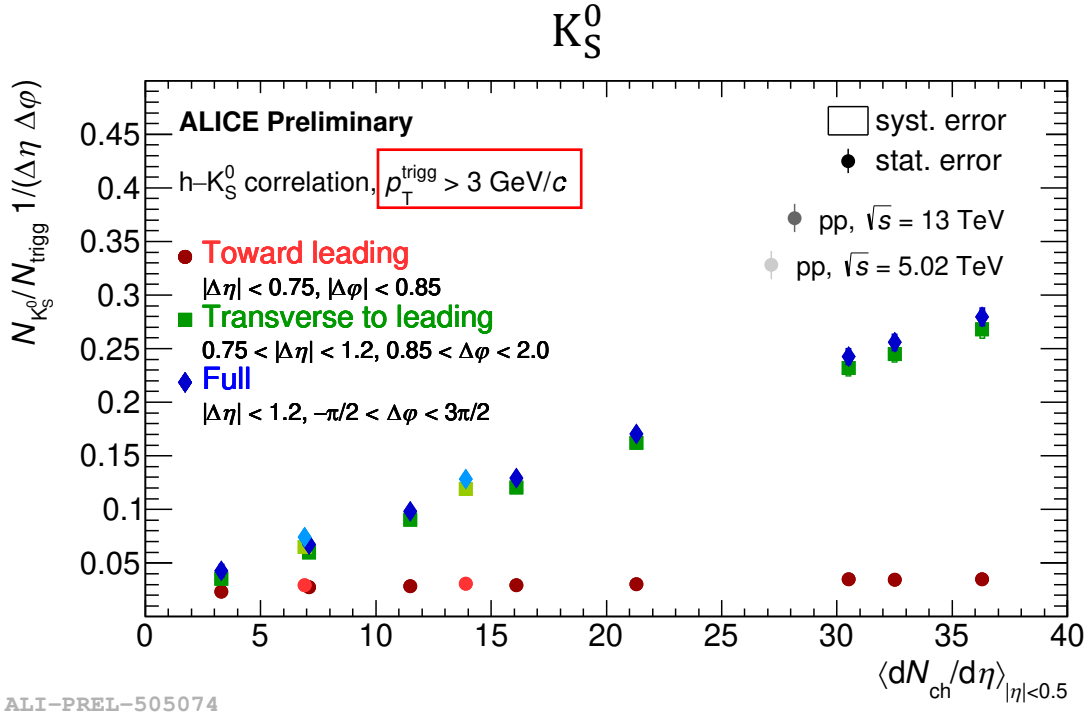


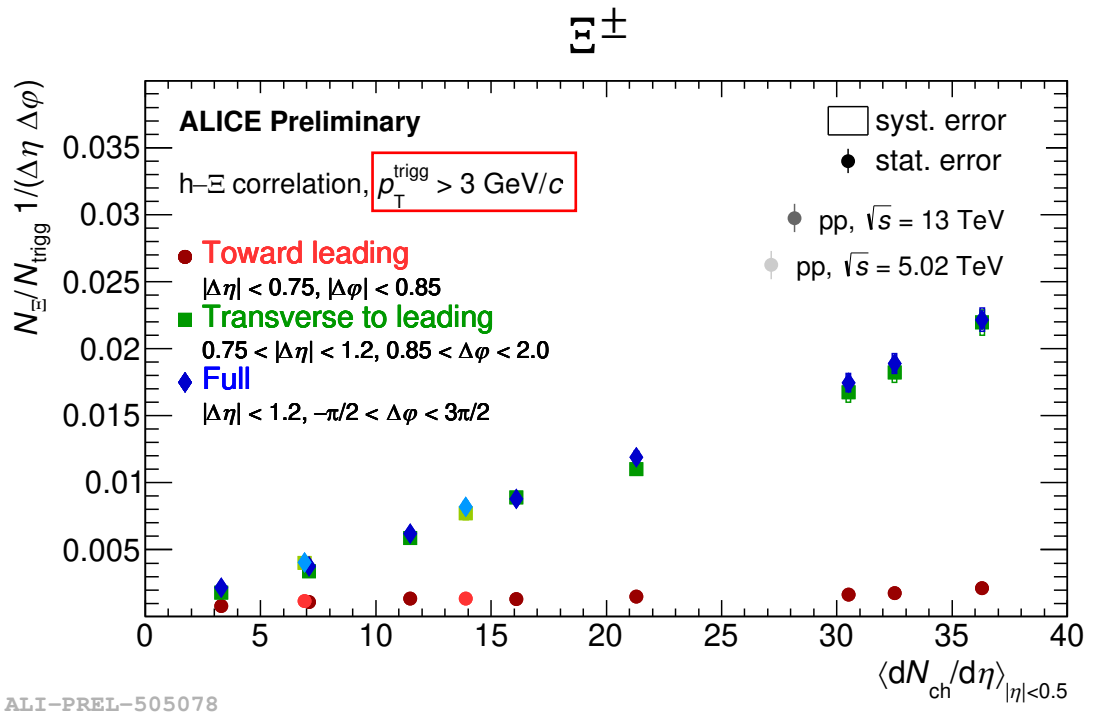


NEW!

- Spectra of K^0_S ($\Xi^{\pm}$) produced in jets are harder than spectra of K^0_S ($\Xi^{\pm}$) produced out of jets
- Same feature observed in different V0M multiplicity classes and different centre-of-mass energies

Near-side jet, out-of-jet and full yields of strange hadrons vs multiplicity



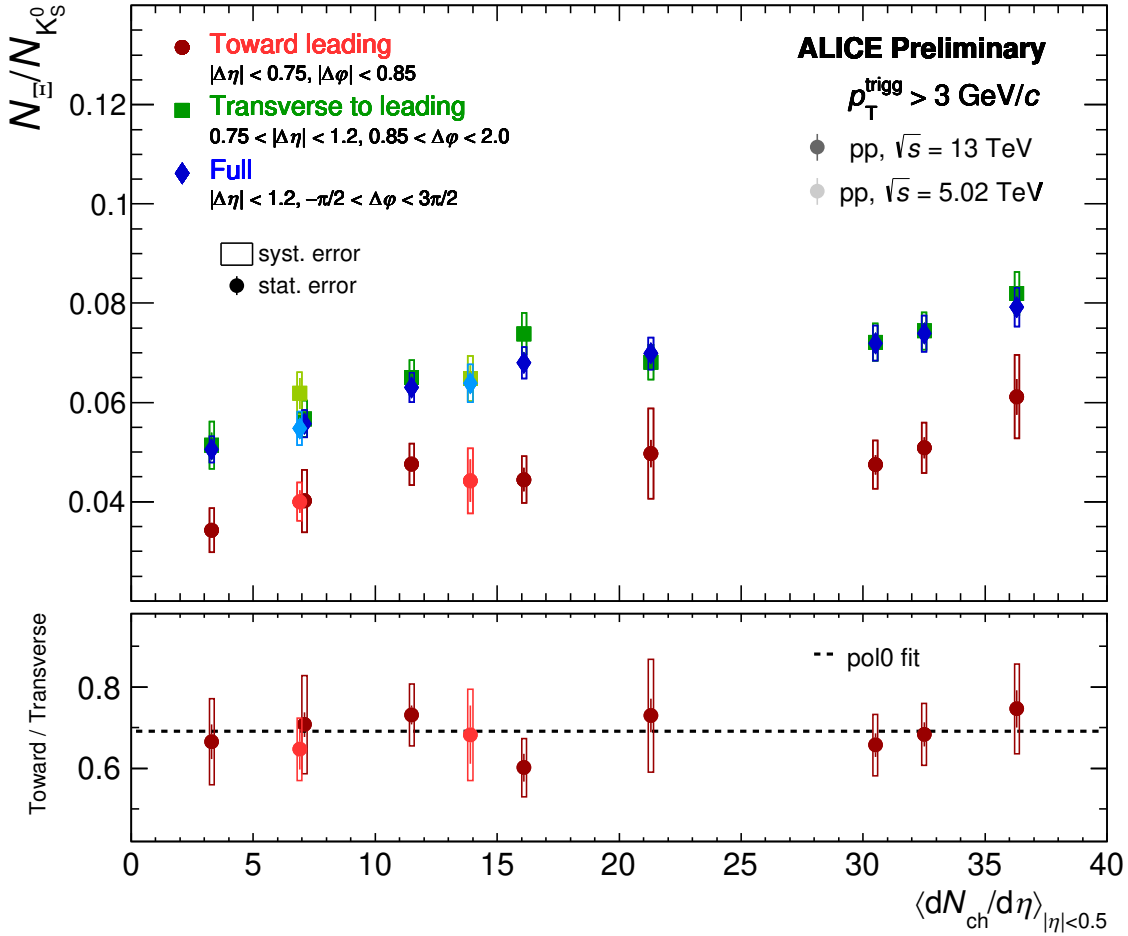


NEW!

- Both the full yield and the out-of-jet yield increase with the multiplicity
- Very mild to no evolution with multiplicity of the near-side-jet yield
- The yields show no dependence on the centre-of-mass energy

→ The contribution of out-of-jet production relative to near-side jet production increases with multiplicity

Strangeness enhancement in jets and out of jets

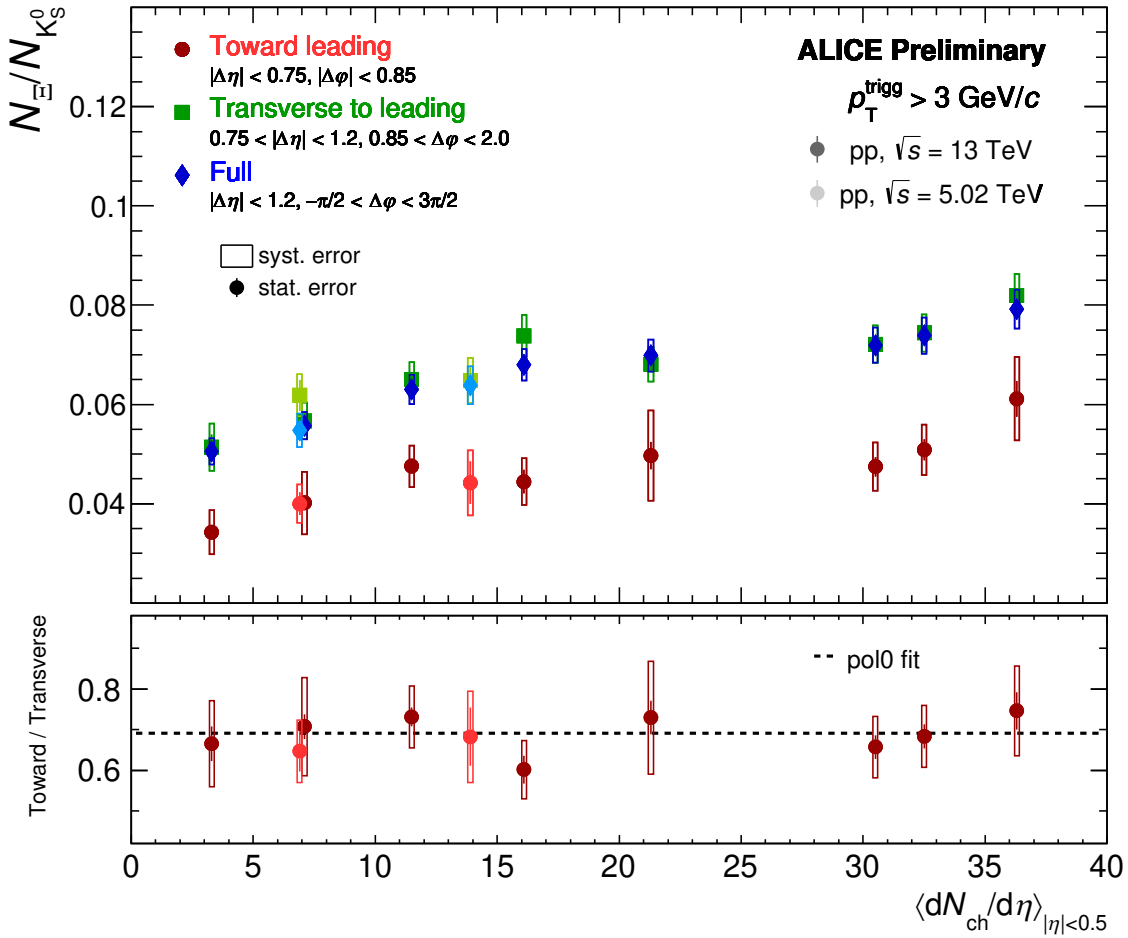


NEW!

- The strangeness enhancement in the ratio of full yields is attributed to the larger strangeness content of Ξ ($|S| = 2$) with respect to K^0_S ($|S| = 1$)
- The out-of-jet Ξ/K^0_S yield ratio **increases with the multiplicity** and is compatible with the ratio of full yields
- The near-side jet yield ratio is **smaller** than the out-of-jet one

- The near-side jet and out-of-jet Ξ/K^0_S yield ratios show **compatible increase** with multiplicity

Strangeness enhancement in jets and out of jets



ALI-PREL-505157

NEW!

→ Out-of-jet processes give the **dominant contribution** to the Ξ/K^0_S full yield ratio in pp collisions

→ The near-side jet and out-of-jet Ξ/K^0_S yield ratios show **compatible increase with multiplicity**

Summary

Do initial stage effects play a role in the strangeness enhancement observed in pp collisions?

→ Even at fixed multiplicity at midrapidity strangeness enhancement is strongly correlated with the effective energy, which is connected to the initial stage of the collision

Is strange hadron production in pp collisions dominated by out-of-jet processes or by hard interactions?

→ Out-of-jet processes give the dominant contribution to strange particle production and strangeness enhancement with multiplicity is observed in out-of-jet processes

Summary

Do initial stage effects play a role in the strangeness enhancement observed in pp collisions?

→ Even at fixed multiplicity at midrapidity strangeness enhancement is strongly correlated with the effective energy, which is connected to the initial stage of the collision

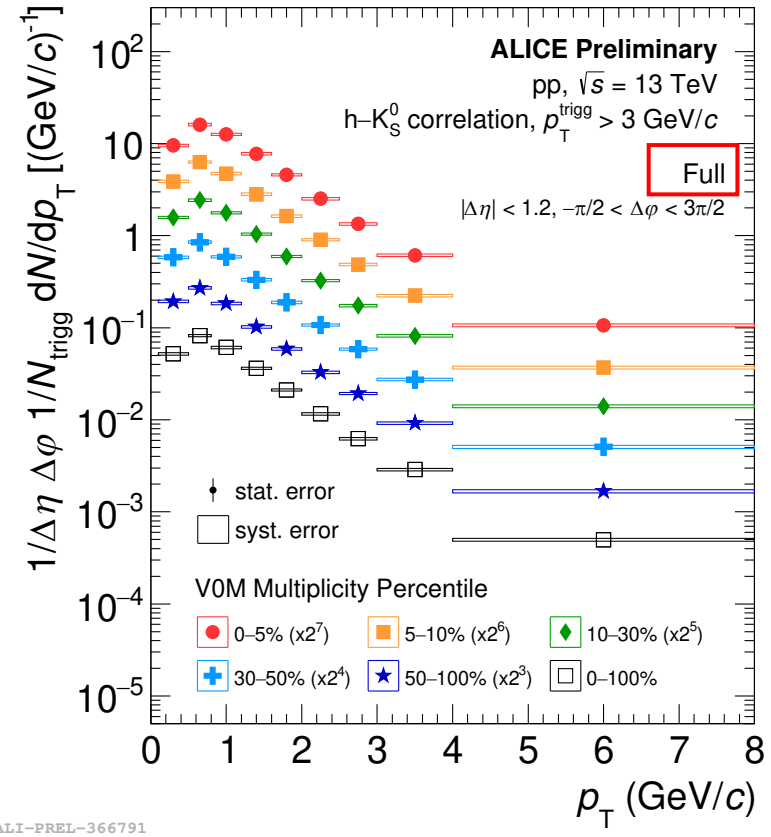
Is strange hadron production in pp collisions dominated by out-of-jet processes or by hard interactions?

→ Out-of-jet processes give the dominant contribution to strange particle production and strangeness enhancement with multiplicity is observed in out-of-jet processes

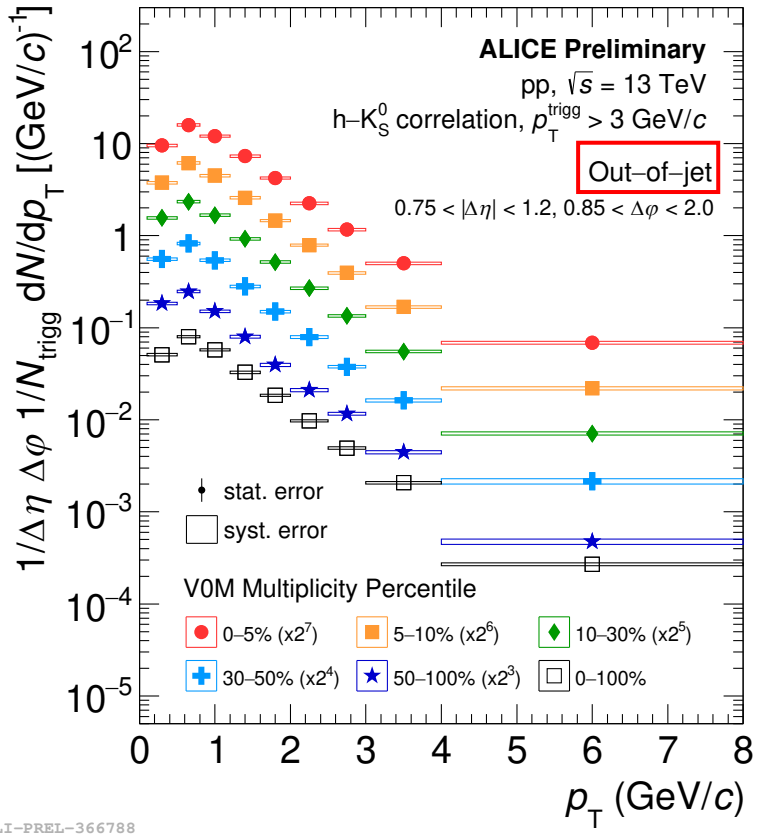
- Further multi-differential studies to explore the correlation between the effective energy and the relative contribution of in-jet and out-of-jet processes can help shed light on the origin of strangeness enhancement in pp collisions
- Studies of strangeness production in pp collisions will profit from the large amount of data which will be collected during Run 3 (e.g. x3000 increase of $\Omega^{\pm}$ for in- and out-of-jet analysis)

Backup

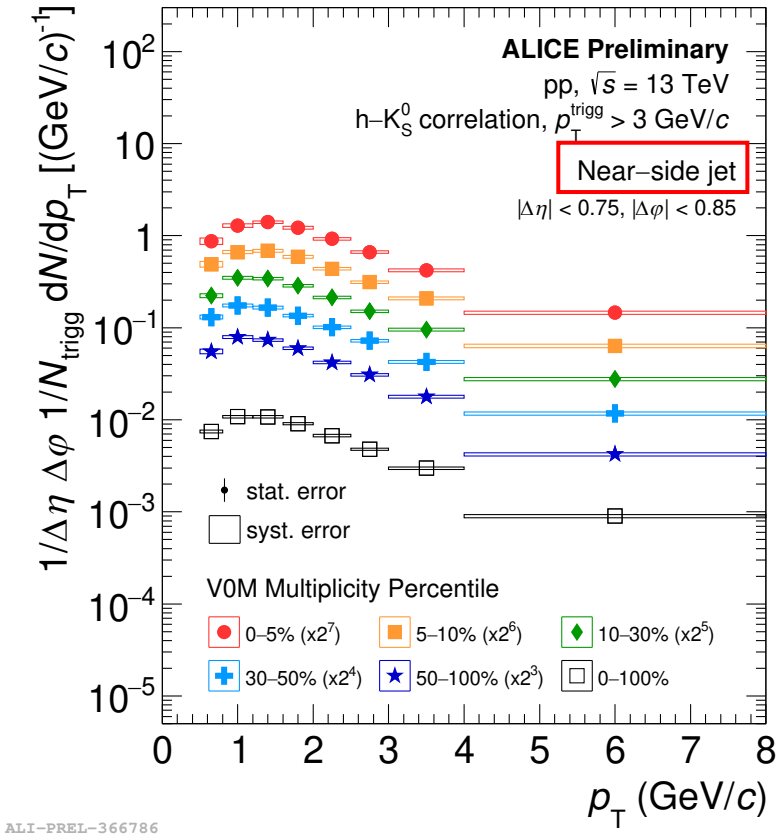
Near-side jet, out-of-jet and full p_{T} spectra of $\mathrm{K}^0_{\mathrm{S}}$



ALI-PREL-366791



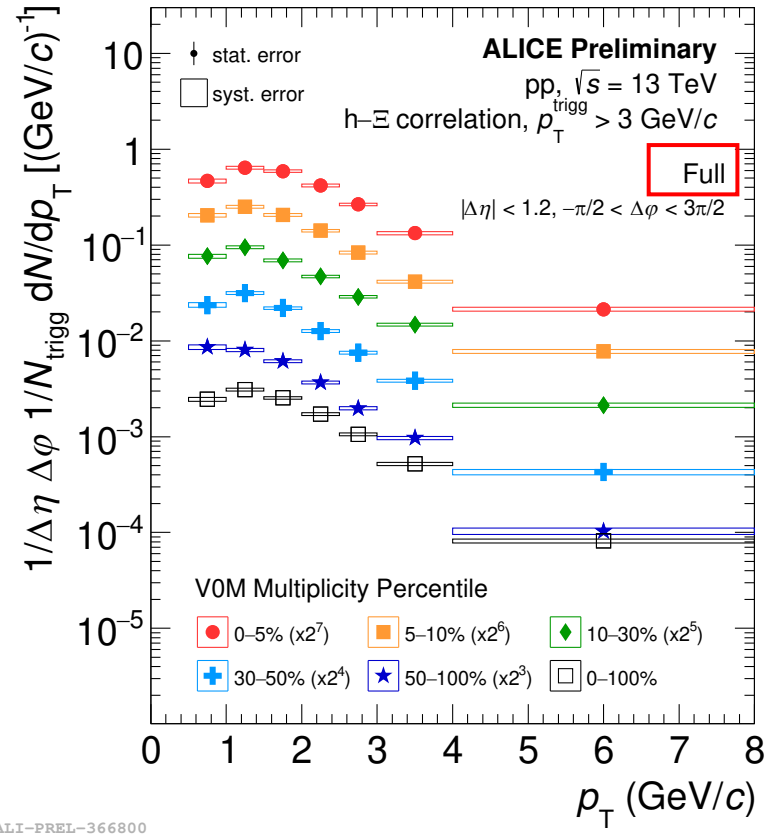
ALI-PREL-366788

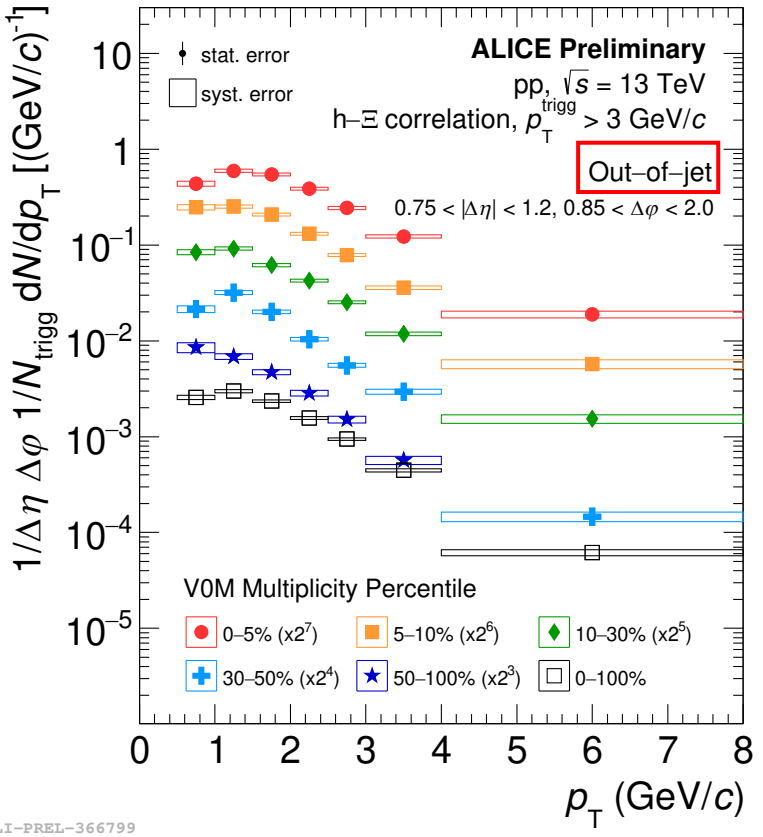


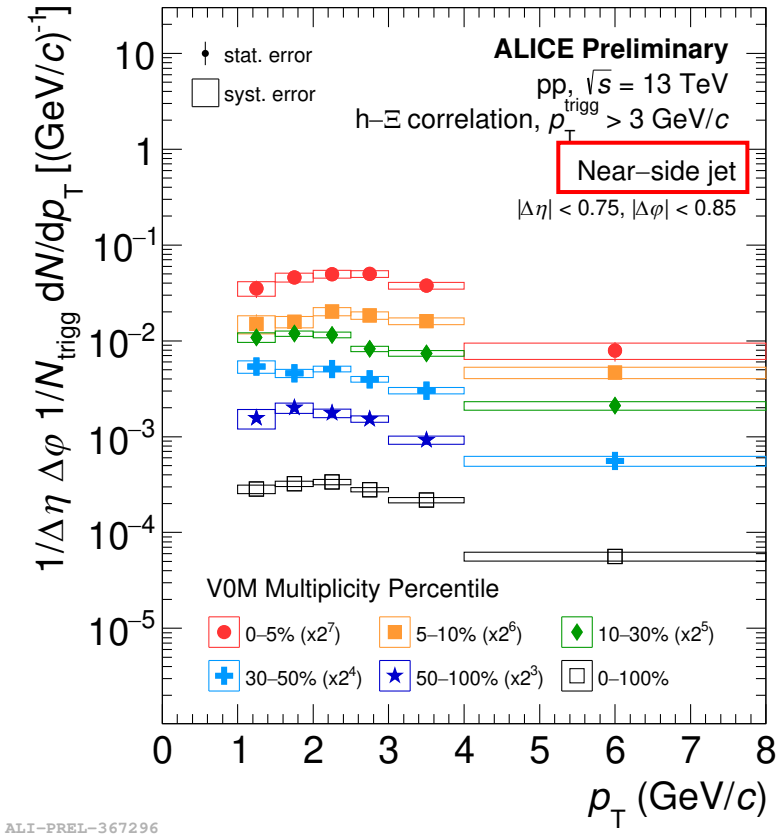
ALI-PREL-366786

Spectra of $\mathrm{K}^0_{\mathrm{S}}$ produced in jets are harder than spectra of $\mathrm{K}^0_{\mathrm{S}}$ produced out of jets

Near-side jet, out-of-jet and full p_{T} spectra of $\Xi^{\pm}$

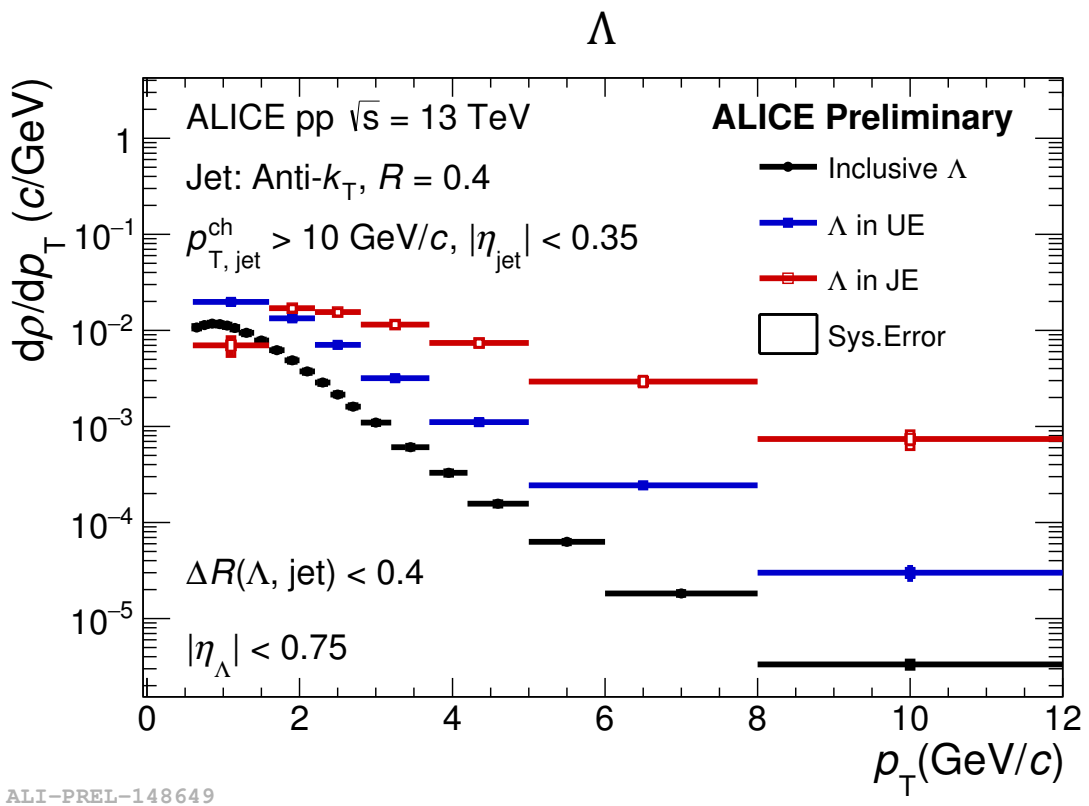


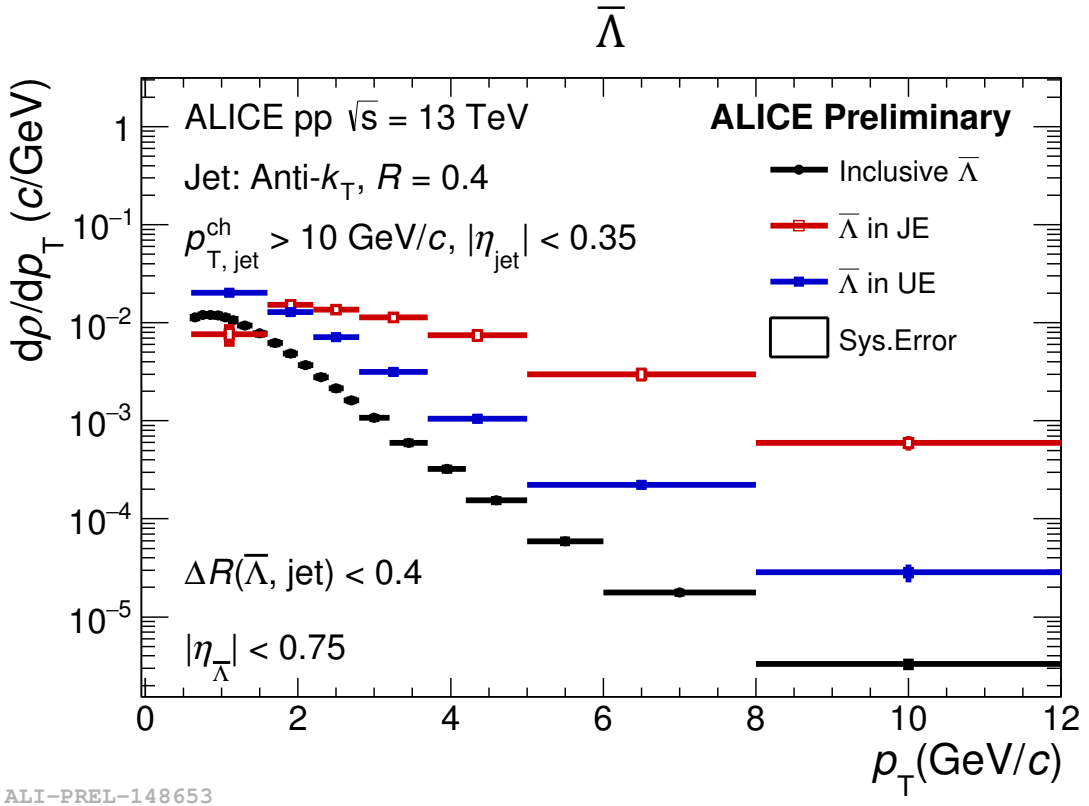




Spectra of $\Xi^{\pm}$ produced in jets are harder than spectra of $\Xi^{\pm}$ produced out of jets

Strange particle production in and out of jets

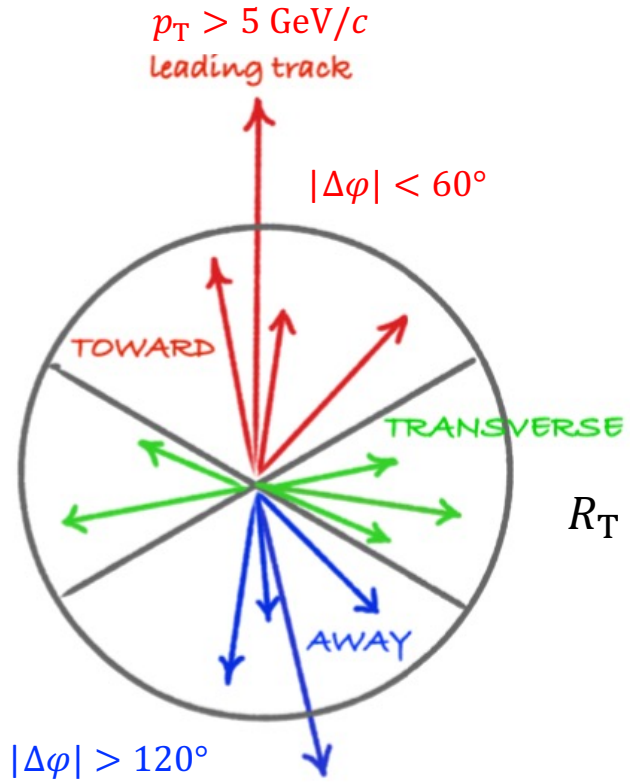




- The spectra of Λ and $\overline{\Lambda}$ in jets are harder than in the UE

R_{T} : particle production in the Underlying Event

R_{T} measures the multiplicity of tracks in a transverse region with respect to the leading track
i.e. the multiplicity related to the underlying event (UE)

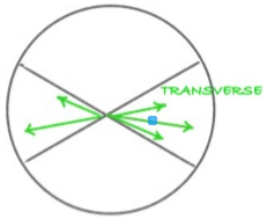


$$R_{\mathrm{T}} = \frac{N_T}{\langle N_T \rangle}$$

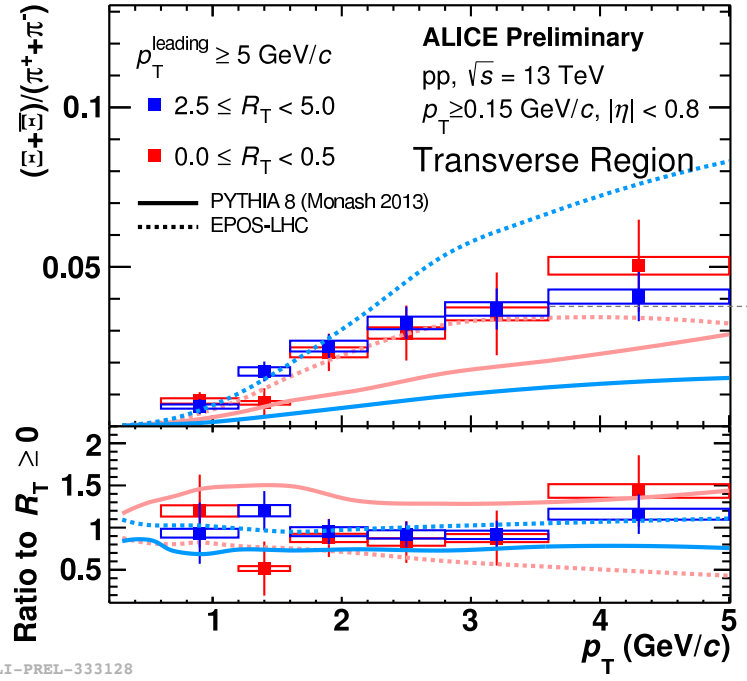
Topological classification of pp events:
Toward region (jet + UE)
Transverse region (UE)
Away region (recoiling jet + UE)

Studies of strange hadron production vs R_{T} in the different regions provide insight into strangeness enhancement

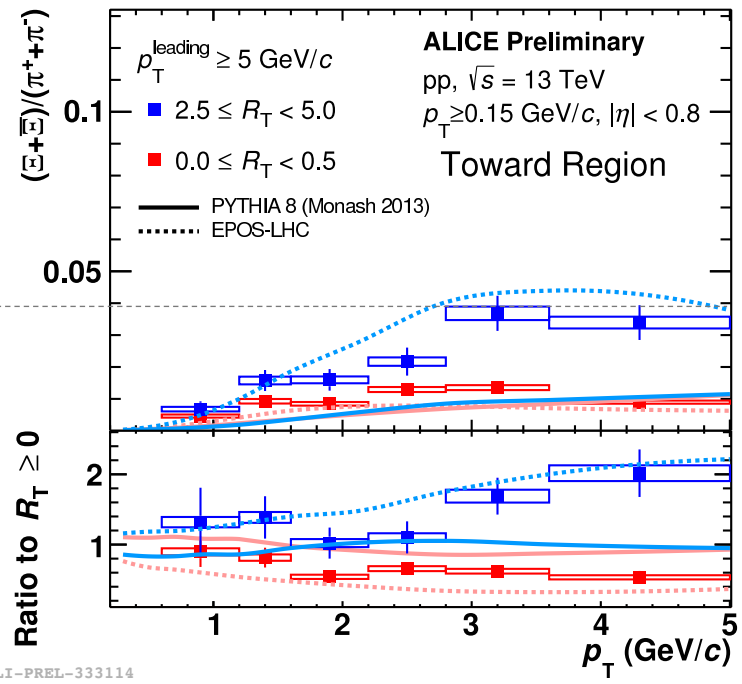
$\Xi^{\pm}$ production vs R_{T}

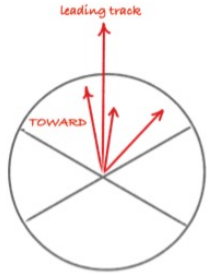


UE



Jet + UE





Ξ/π does not depend on R_{T} in the Transverse Region (UE)

Ξ/π increases with R_{T} in the Toward Region (Jet + UE), approaching the values of the Transverse Region

$\rightarrow \Xi/\pi$ higher in the UE than in the jet