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ICHEP 2022

41st International Conference on High Energy Physics

New insights into strangeness production in pp collisions with ALICE at the LHC

Francesca Ercolessi on behalf of the ALICE Collaboration

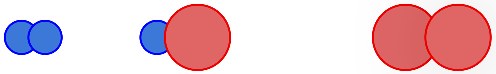
University and INFN Bologna

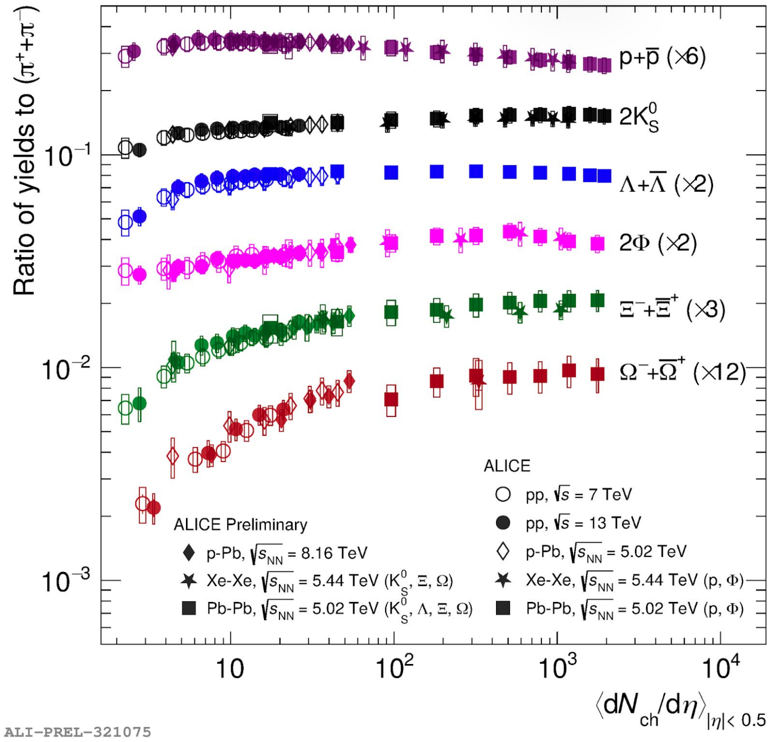
ALICE

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

INFN Istituto Nazionale di Fisica Nucleare

Strangeness production across collision systems





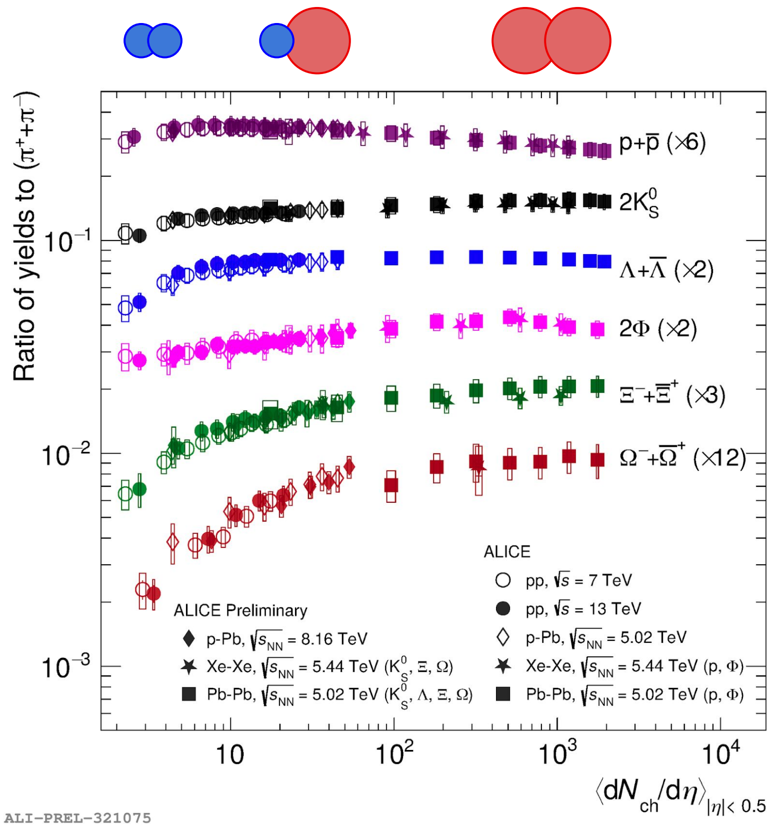
Strangeness enhancement was one of the first proposed signatures of **QGP** formation in heavy-ion collisions

ALICE observed that the ratio of strange to non-strange hadron yields (*h/π*):

- **increases with** midrapidity **multiplicity**
- **smoothly evolves across** different collision **systems**
- shows a **larger enhancement** for particles with larger **strangeness content**

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

Strangeness production across collision systems



Latest ALICE results in pp collisions address some fundamental questions

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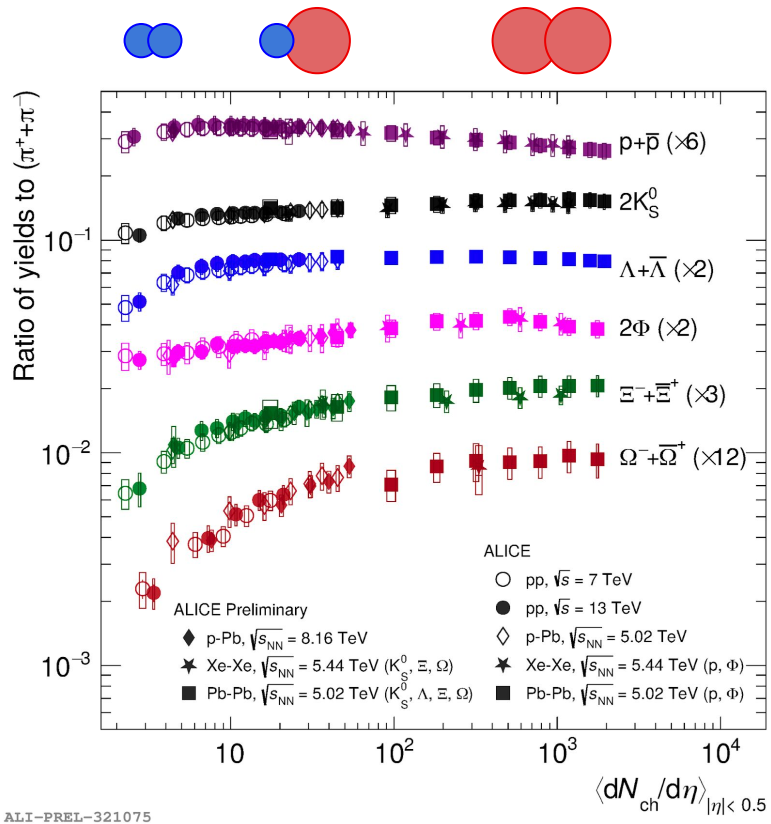

ALI-PREL-321075

Latest ALICE results in pp collisions address some fundamental questions

? Does strangeness production depend only on final state particle multiplicity, or **is it also correlated to the initial stage of the collision**?

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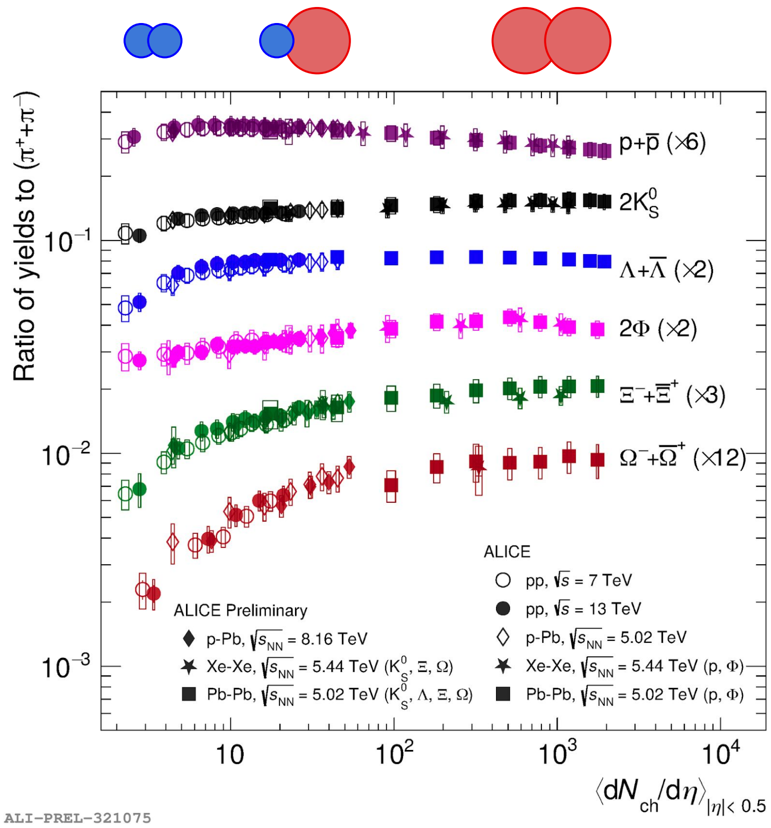
Strangeness production across collision systems



Latest ALICE results in pp collisions address some fundamental questions

? Does strangeness production depend only on final state particle multiplicity, or **is it also correlated to the initial stage of the collision**?

? Is strangeness **mainly produced** in **hard processes**, such as jets, or **out-of-jet processes**?

Nature Phys 13, 535-539 (2017)
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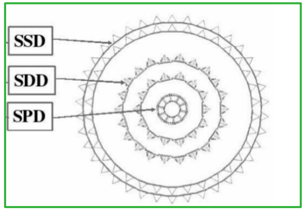
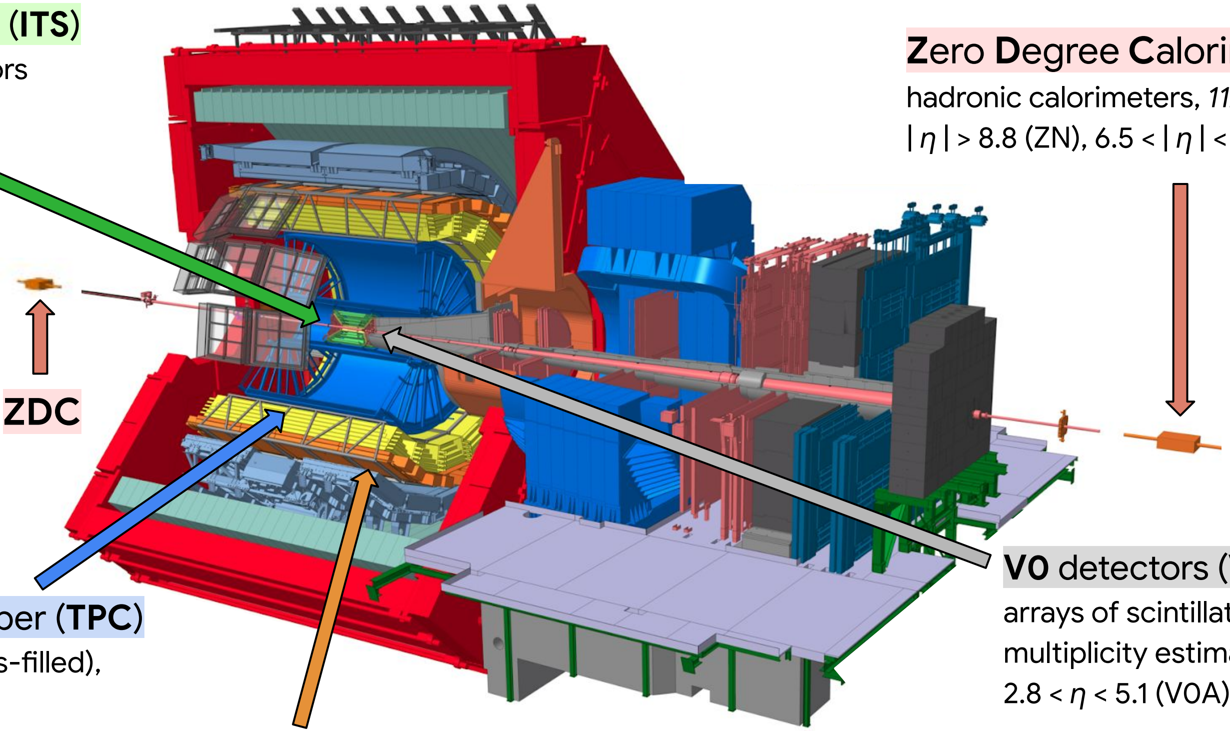
ALICE: A Large Ion Collider Experiment

Inner **T**racking **S**ystem (**ITS**)

six layers of silicon detectors (SPD, SDD, SSD), tracking, triggering, vertexing



ZDC



Zero **D**egree **C**alorimeters (**ZDC**)

hadronic calorimeters, *112.5* m from the IP

$|\eta| > 8.8$ (ZN), $6.5 < |\eta| < 7.4$ (ZP*))

Time **P**rojection **C**hamber (**TPC**)

main tracking detector (gas-filled), vertexing, PID (dE/dx)

Time **O**f **F**light (**TOF**)

PID via Time-Of-Flight technique

V0 detectors (**V0A** and **V0C**)

arrays of scintillators, triggering, multiplicity estimators

$2.8 < \eta < 5.1$ (V0A), $-3.7 < \eta < -1.7$ (V0C)

*considering LHC beam optics ZP acceptance for protons is $7.0 < |\eta| < 8.7$

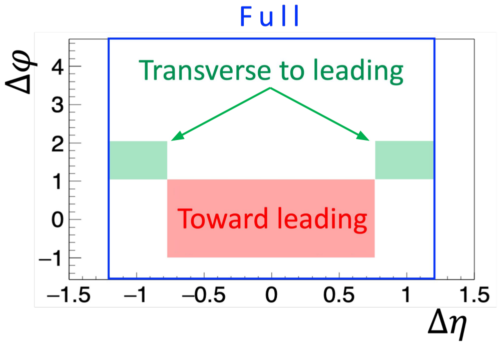
Strange-hadron correlation studies

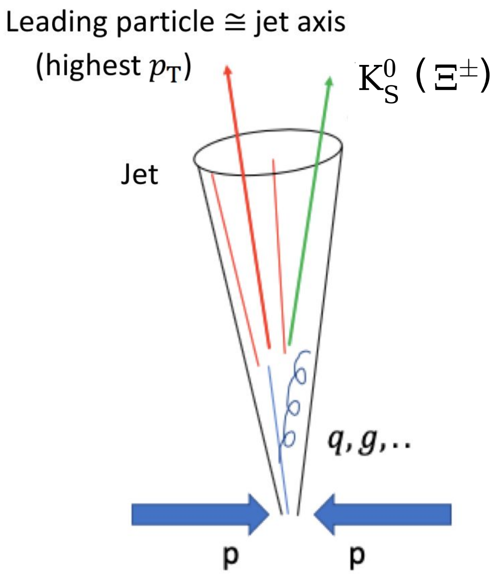
ANGULAR CORRELATION METHOD

1) **Trigger particle** as a proxy for the **jet axis** (p_T > 3 GeV/c)
2) Identification of **associated particles** (strange hadrons)
3) **Angular correlation** between trigger and associated particles

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

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





From identified pions and protons ALICE reconstructs K^0_S via *V0* decay topology and $\Xi^\pm$ via *cascade* decay topology

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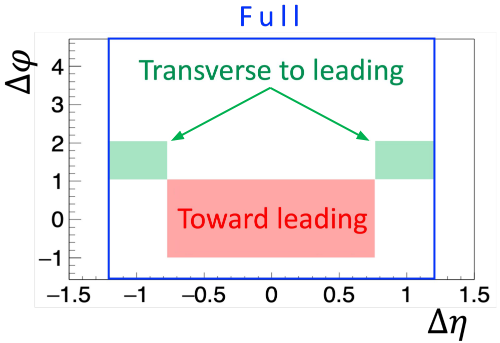
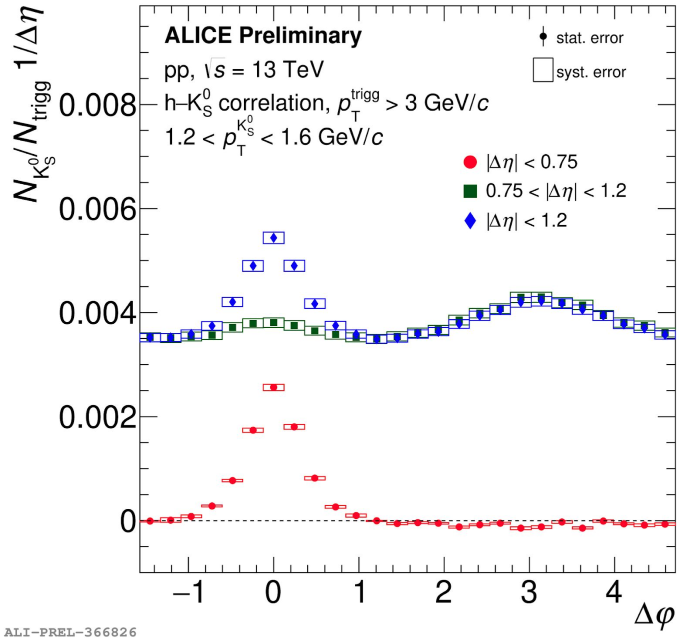
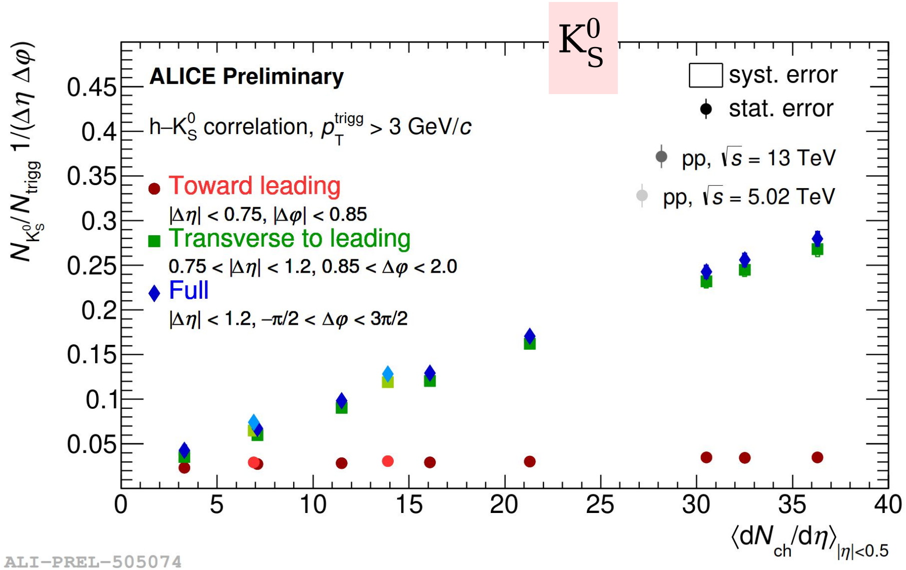




Toward leading = Full − Transverse to leading

Strangeness production in and out-of jets

- The **full yield** and the **transverse to leading yield** **increase** with multiplicity
- The **toward leading yield** shows a **weak** multiplicity dependence
  → **transverse to leading** production w.r.t. **toward leading** production **increases** with multiplicity
- **No dependence** on the **centre-of-mass energy** is observed



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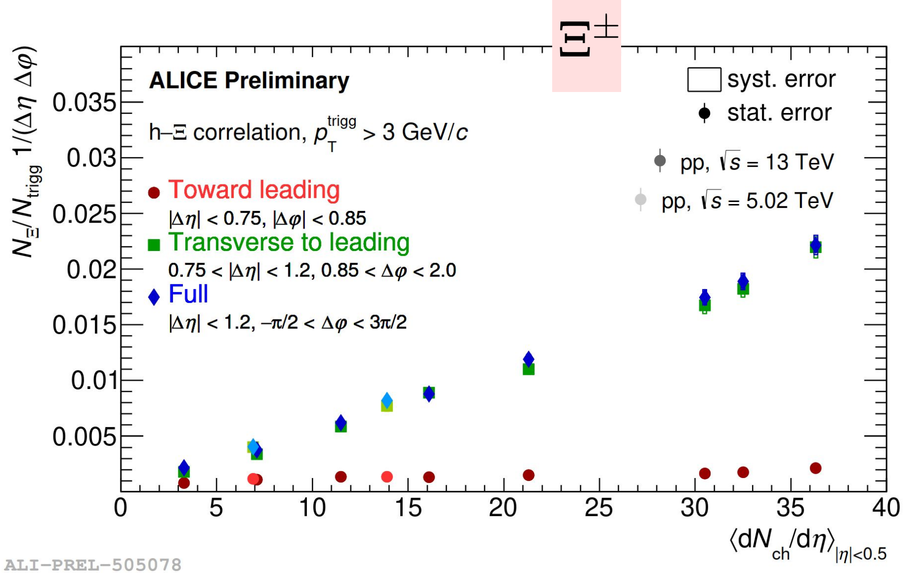

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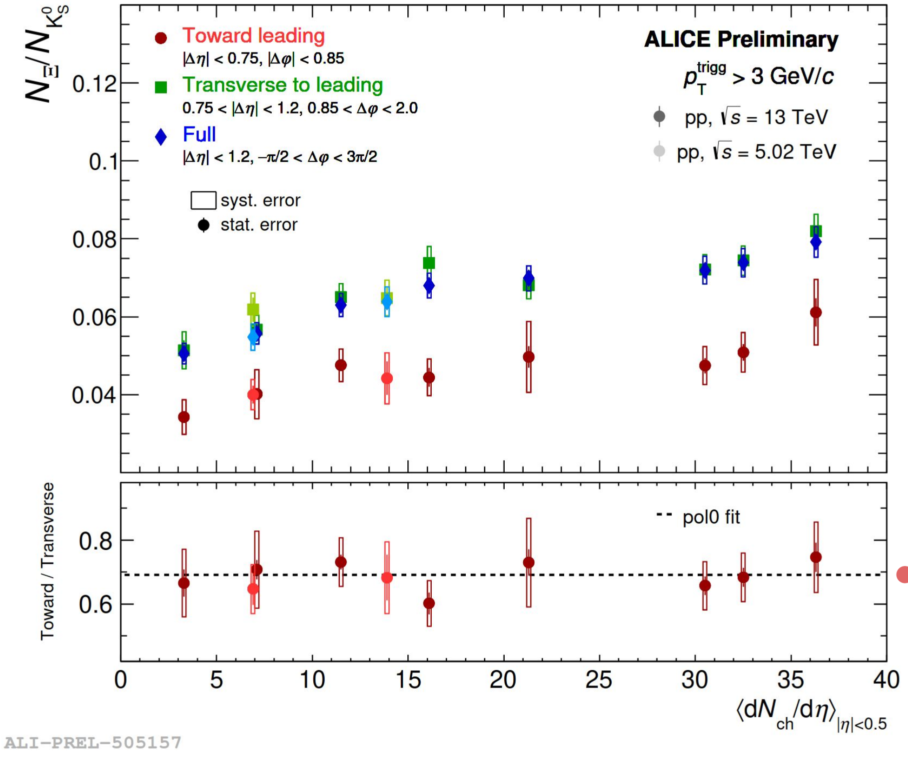
Strangeness enhancement in and out-of jets



$\Xi^{\pm}/K^0_S$ **full yield ratio** **increases with multiplicity**

→ larger strangeness content of $\Xi^{\pm}$ w.r.t. K^0_S

The **transverse to leading** ratio **increases with multiplicity** and is **compatible** with the **full** ratio **within uncertainties**

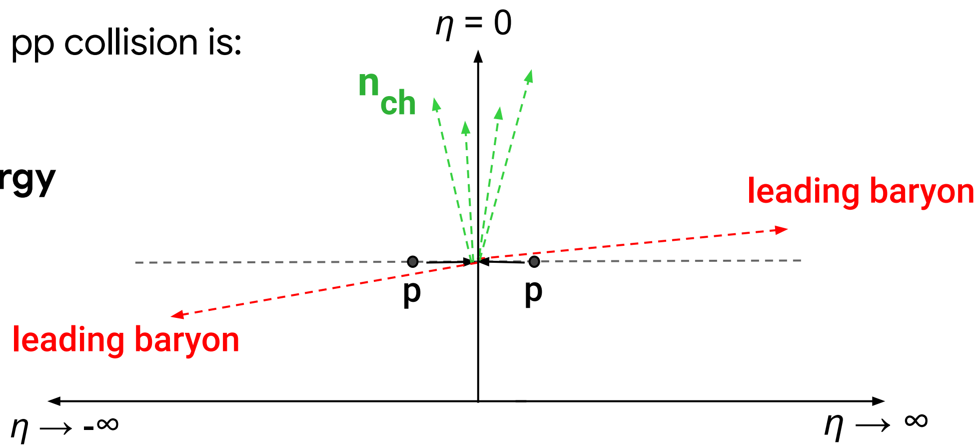
The **toward leading** ratio is **lower**

Compatible increase with multiplicity in the **toward leading** ratio w.r.t. the **transverse to leading** ratio

The concept of effective energy

The **charged-particle multiplicity** produced in a pp collision is:

- characteristic of the **hadronic final** state
- strongly correlated to the **initial effective energy**



EFFECTIVE ENERGY

energy available for particle production in the **initial stages** of the pp collision

$E_{\mathrm{EFF}} < \sqrt{s}$ due to **leading baryon emission** at forward rapidity

A. Akindinov et al., Eur. Phys. J. C 50, 341-352 (2007)

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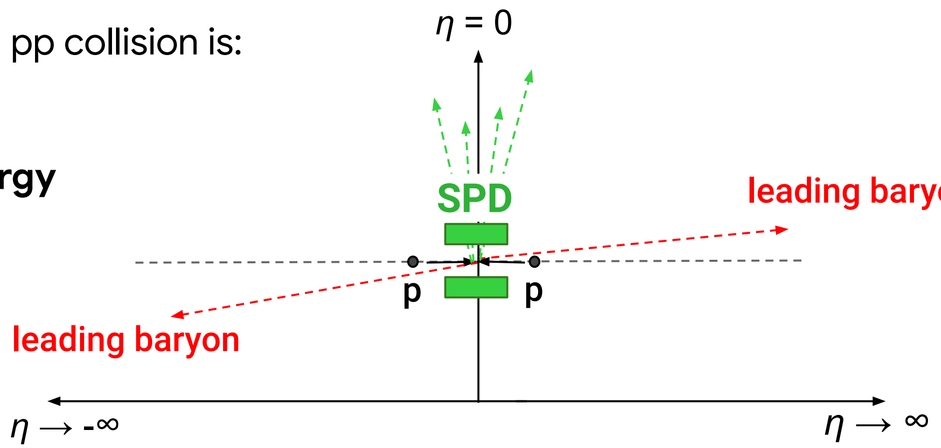

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ALICE can measure:

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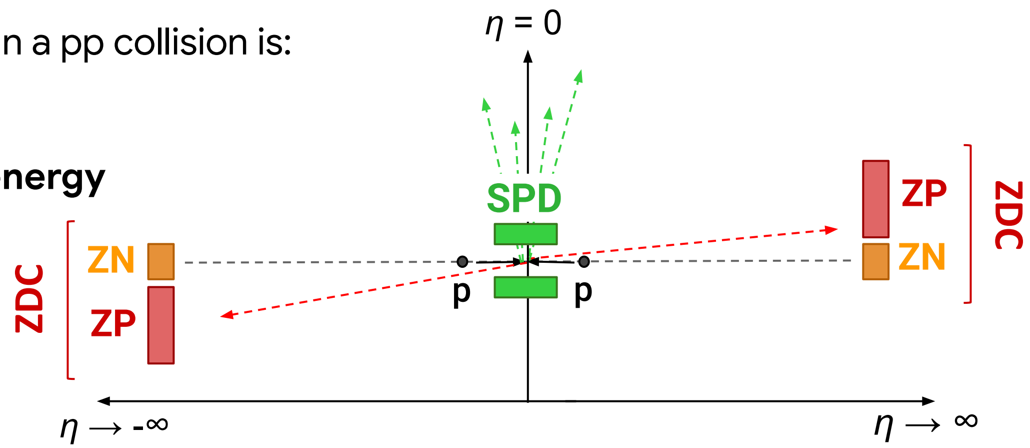

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$$E_{\mathrm{eff}} = \sqrt{s} - E_{\mathrm{leading}} \simeq \sqrt{s} - E_{\mathrm{ZDC}}$$

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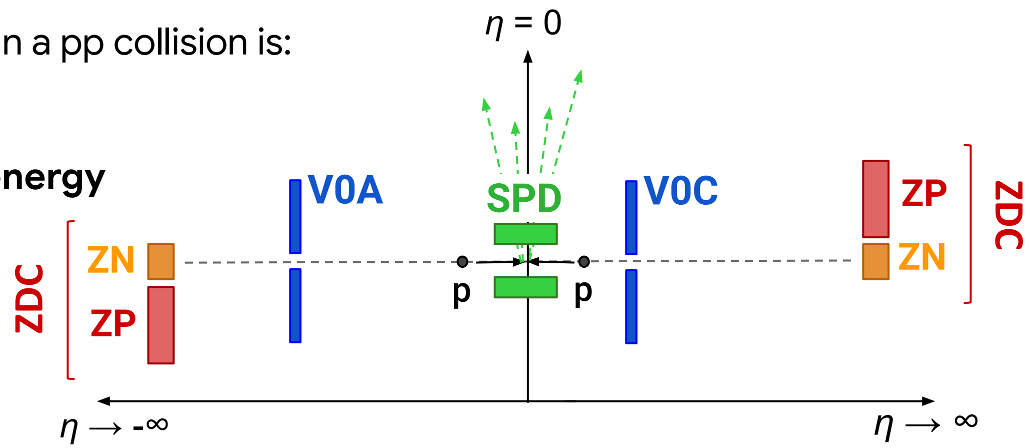

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$$E_{\mathrm{eff}} = \sqrt{s} - E_{\mathrm{leading}} \simeq \sqrt{s} - E_{\mathrm{ZDC}}$$

- multiplicity (**V0M** = V0A+V0C)

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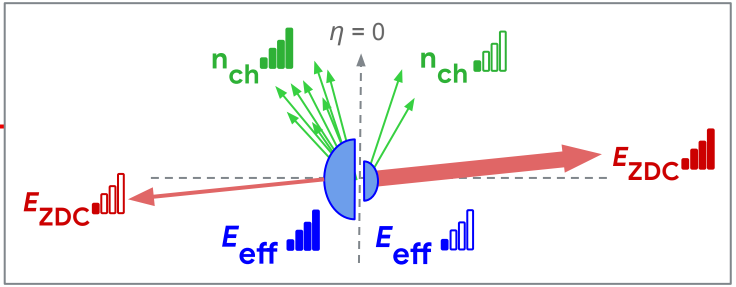
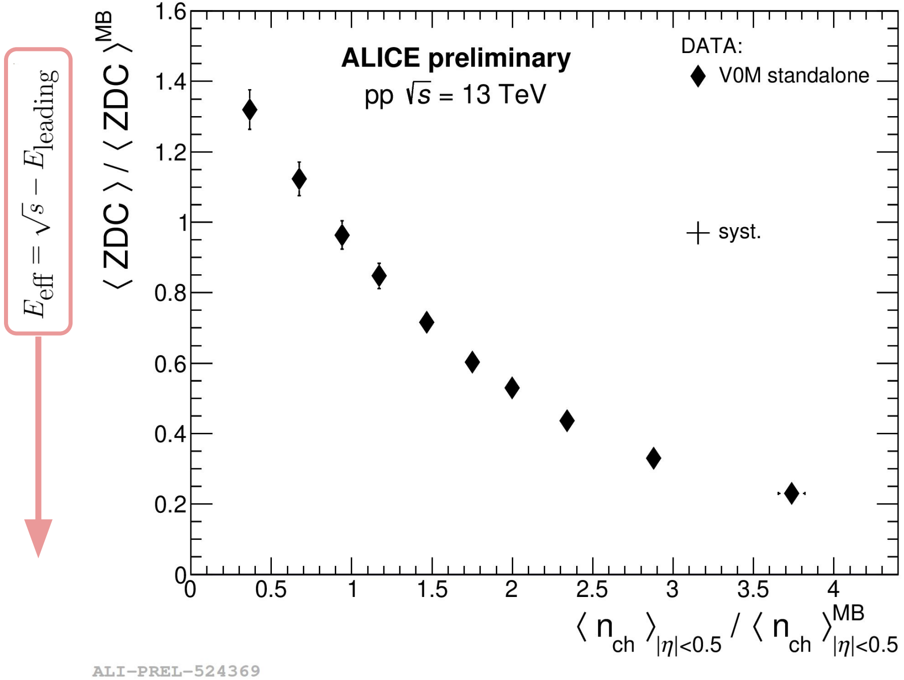
Leading energy vs multiplicity



The **forward energy decreases with** increasing particle **multiplicity** produced at **midrapidity**



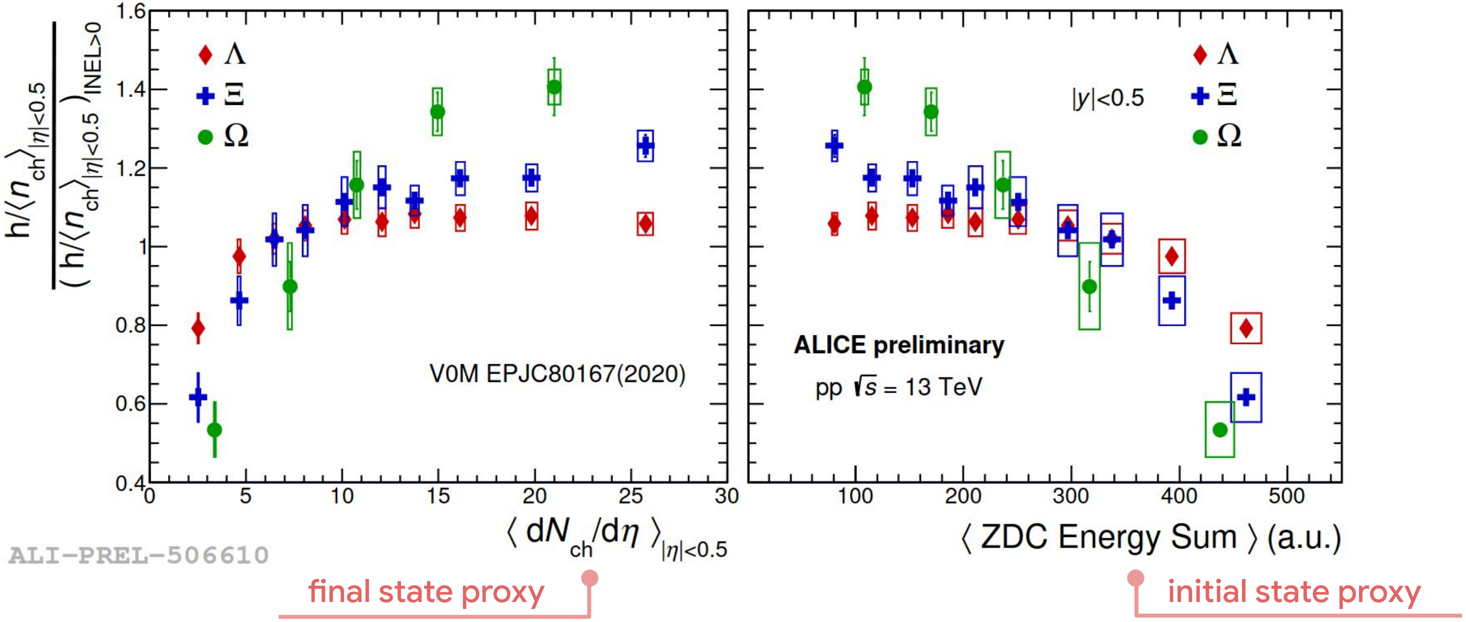
- **Standalone** V0 event classes

ALICE Collaboration arxiv.org/2107.10757

Strangeness in single-differential classes

Strangeness production per charged particle:

- **increases** with **midrapidity multiplicity** (left)
- is **anticorrelated** with the **ZDC energy** (right)



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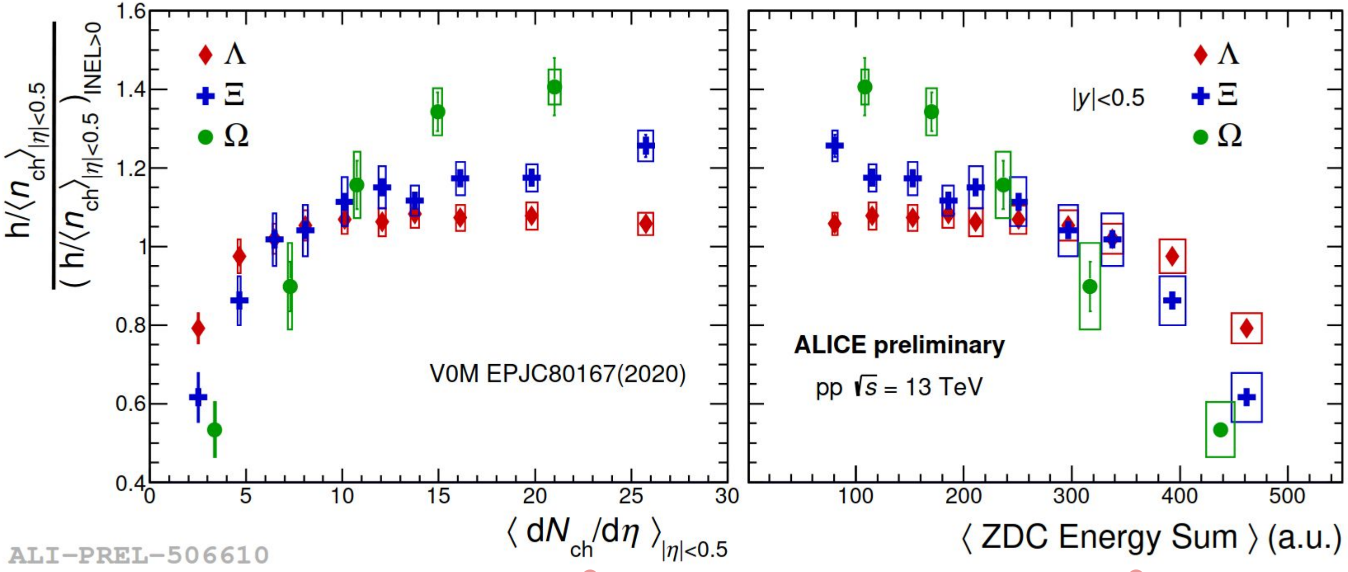
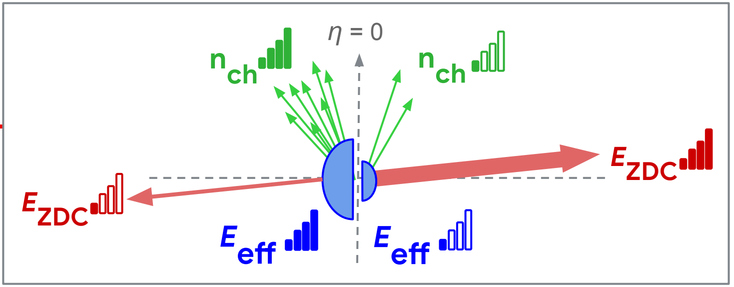
Can we **disentangle** the dependence on effective energy and multiplicity?



final state proxy

initial state proxy

Multi-differential event classes



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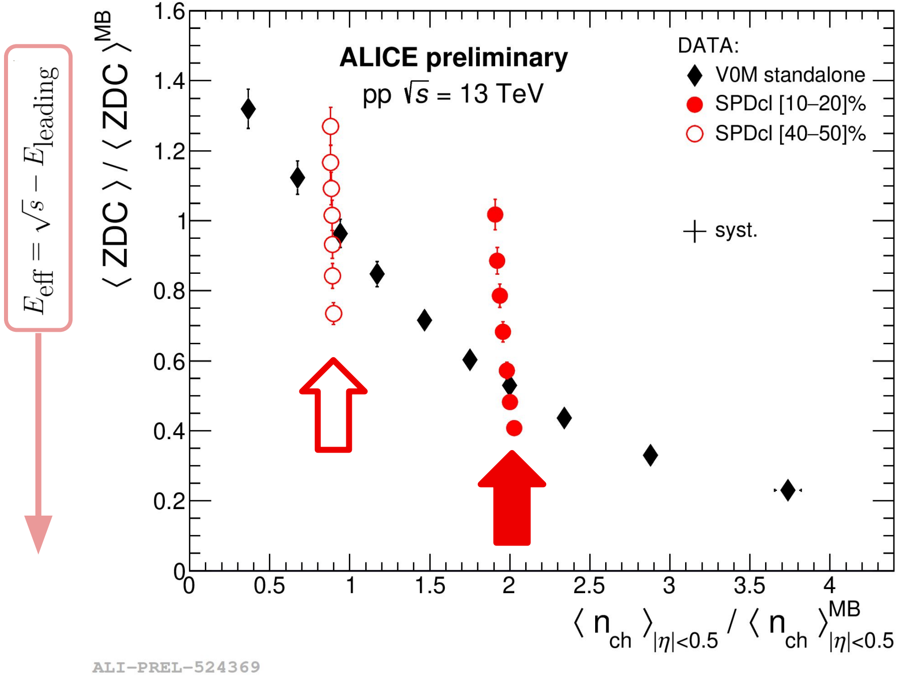
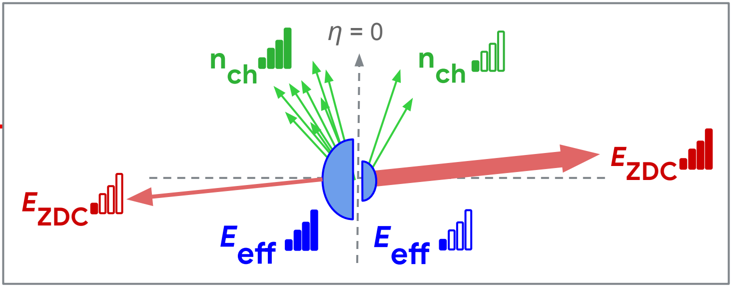


◆ **Standalone** V0 event classes

Event classes defined using V0 and SPD (clusters):

● ○ **Fixed multiplicity** at midrapidity + different forward energy deposits in the ZDC

Multi-differential event classes



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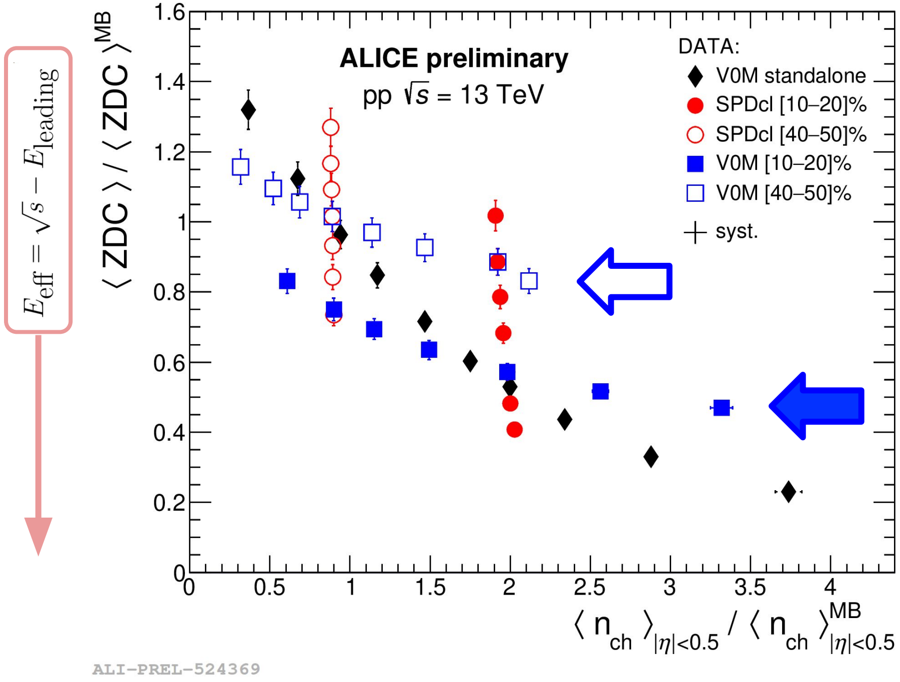


◆ **Standalone** V0 event classes

Event classes defined using V0 and SPD (clusters):

● ○ **Fixed multiplicity** at midrapidity + different forward energy deposits in the ZDC

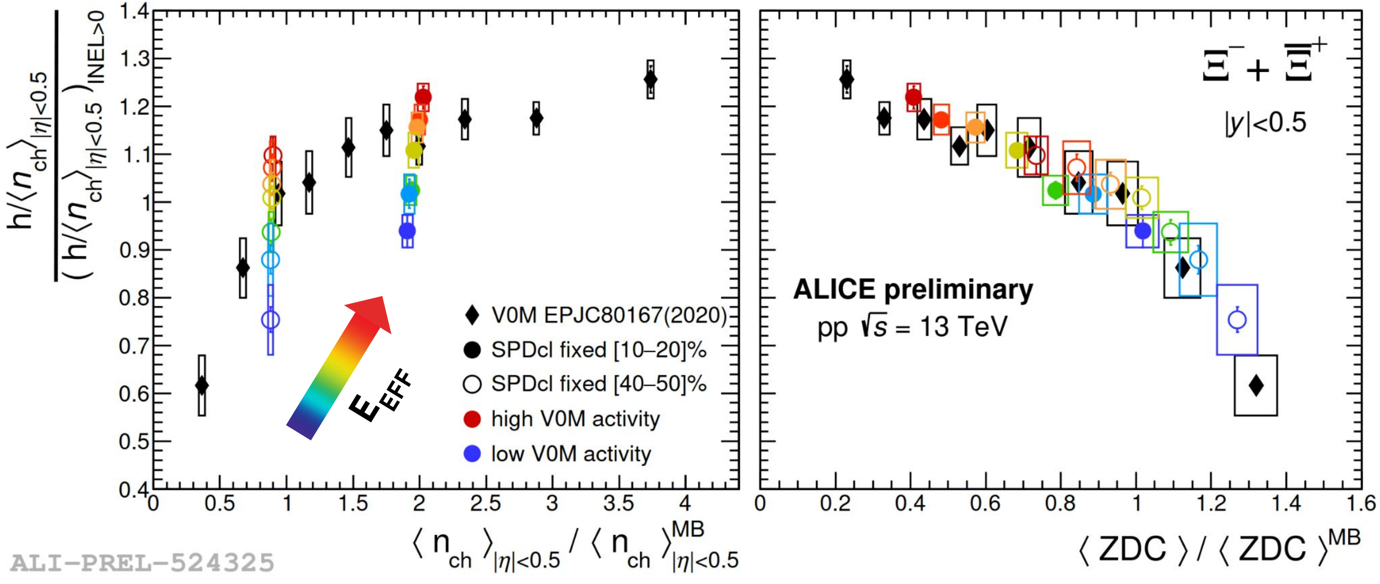
■ □ **ZDC energy fixed in a small range** + different multiplicity produced in the event

* New comparison with Pythia tunes in backup!

Strangeness production at fixed multiplicity

In events with the same particle multiplicity produced:

- **increase** in Ξ production per charged particle is observed for **decreasing forward energy** (ZDC)
- scaling trends with ZDC energy are **compatible within uncertainties**



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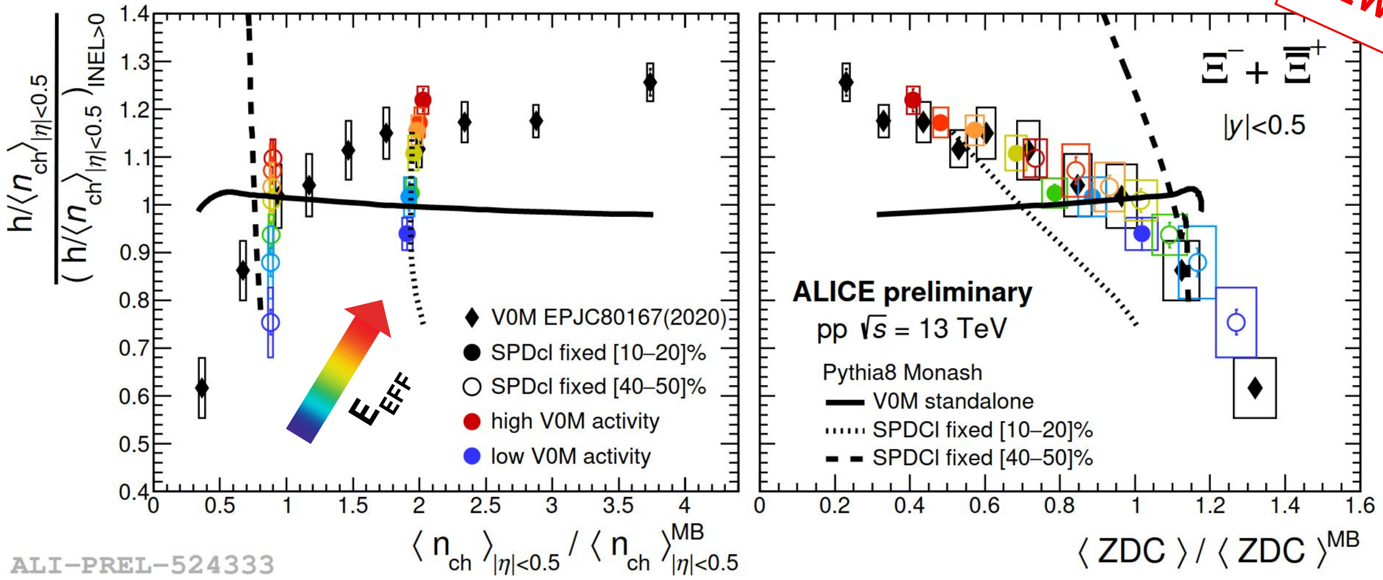
NEW!



The **Pythia Monash 2013** tune **fails to reproduce** the results

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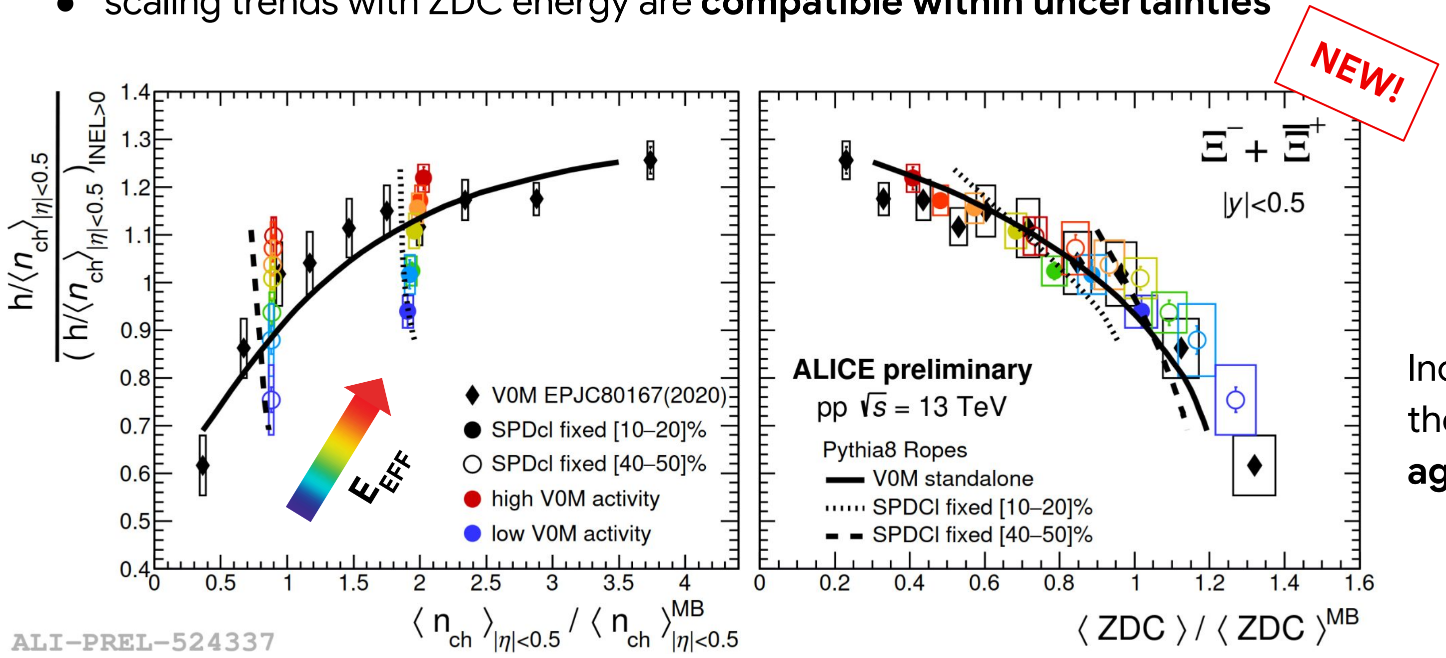
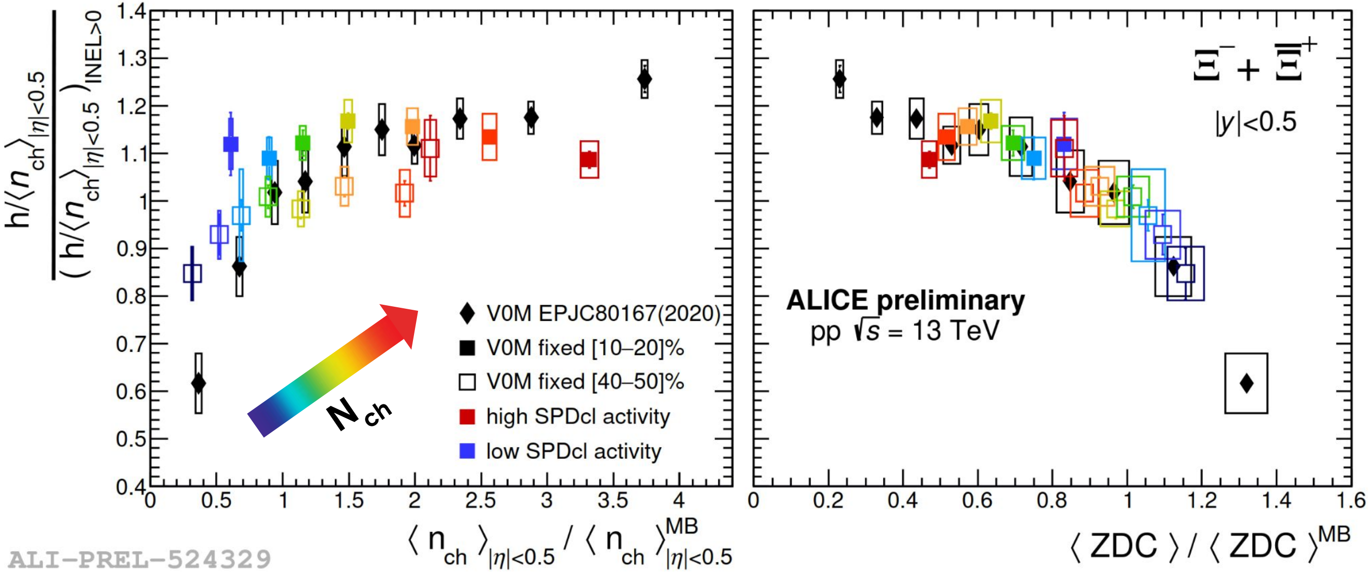


Including **Color Ropes** in the model **improves the agreement** with data

Strangeness production at fixed forward energy

In events with ZDC energy deposits fixed in a small range:

- strangeness **enhancement with multiplicity is reduced** (left)
- within the small ZDC energy range, scaling **trends** are **compatible** within uncertainties (right)



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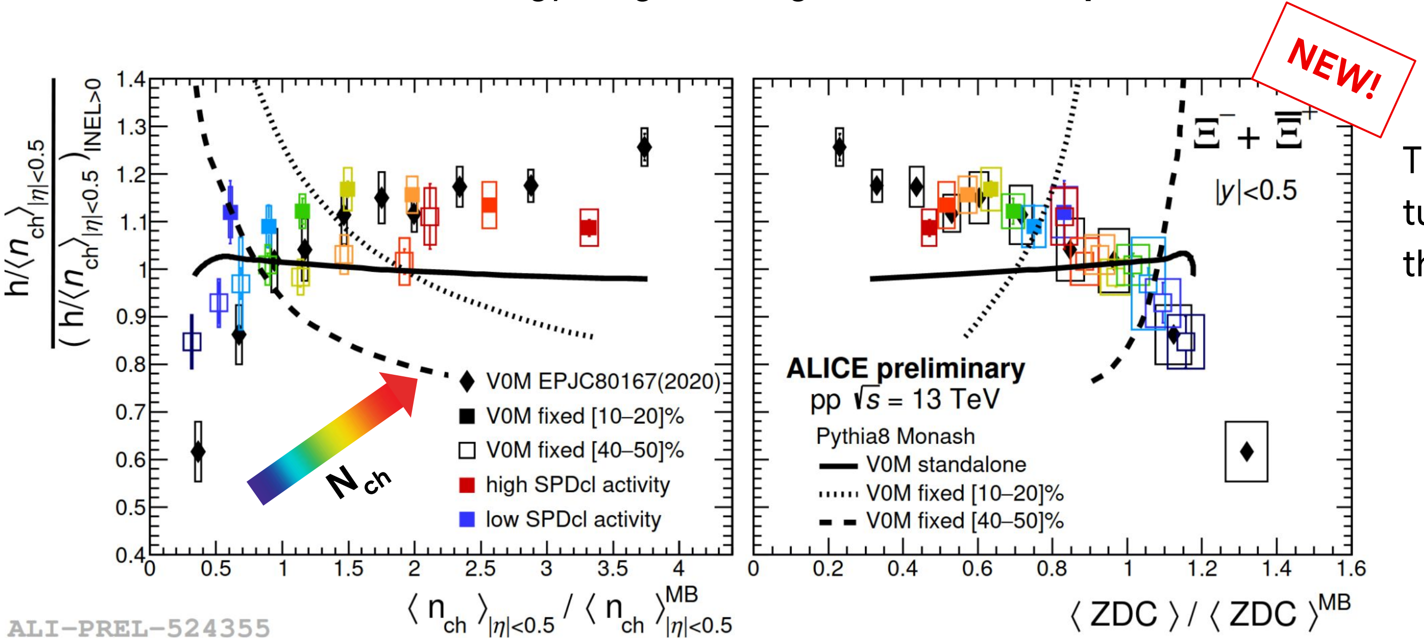

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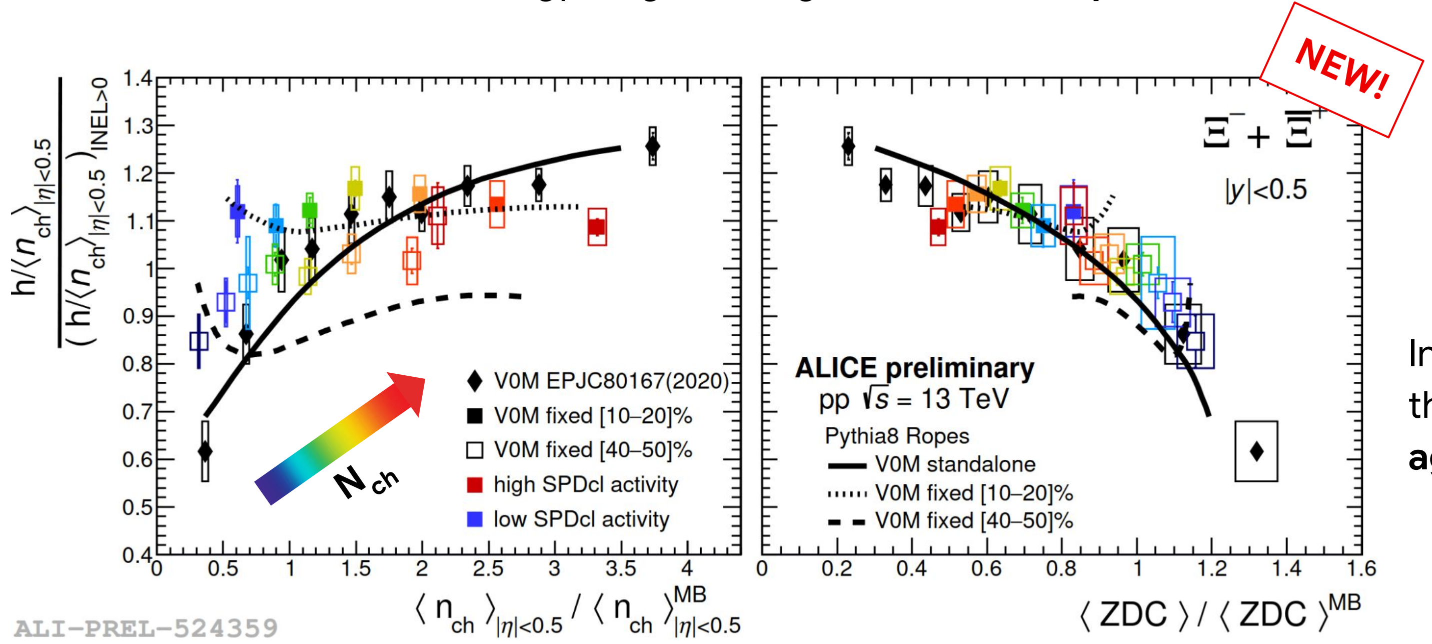

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Summary

Studying the relative contribution of hard and out-of jet processes to strangeness production:

- **transverse to leading processes** give the **dominant contribution** to strangeness production
- **strangeness enhancement** with multiplicity is observed in **toward** and **transverse to leading** processes

Summary

Studying the relative contribution of hard and out-of jet processes to strangeness production:

- **transverse to leading processes** give the **dominant contribution** to strangeness production
- **strangeness enhancement** with multiplicity is observed in **toward** and **transverse to leading** processes

Strangeness enhancement in pp collisions:

- was **observed** at **fixed midrapidity multiplicity**
- shows a **strong correlation with the effective energy** (initial stage)

Pythia Monash tune **does not** reproduce the results, a **better agreement** is achieved when **Color Ropes** are included in the model

Thank you!

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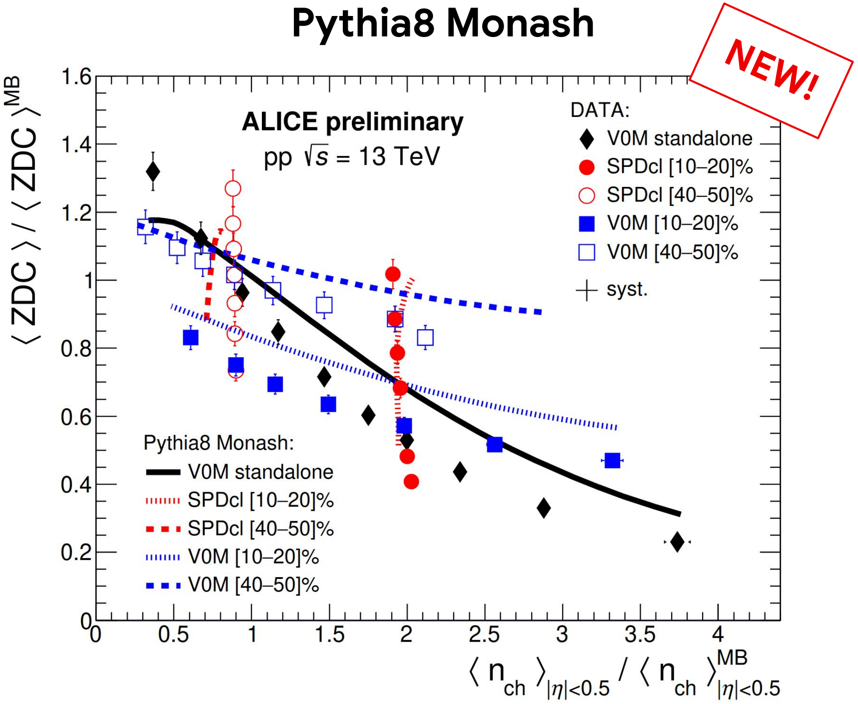
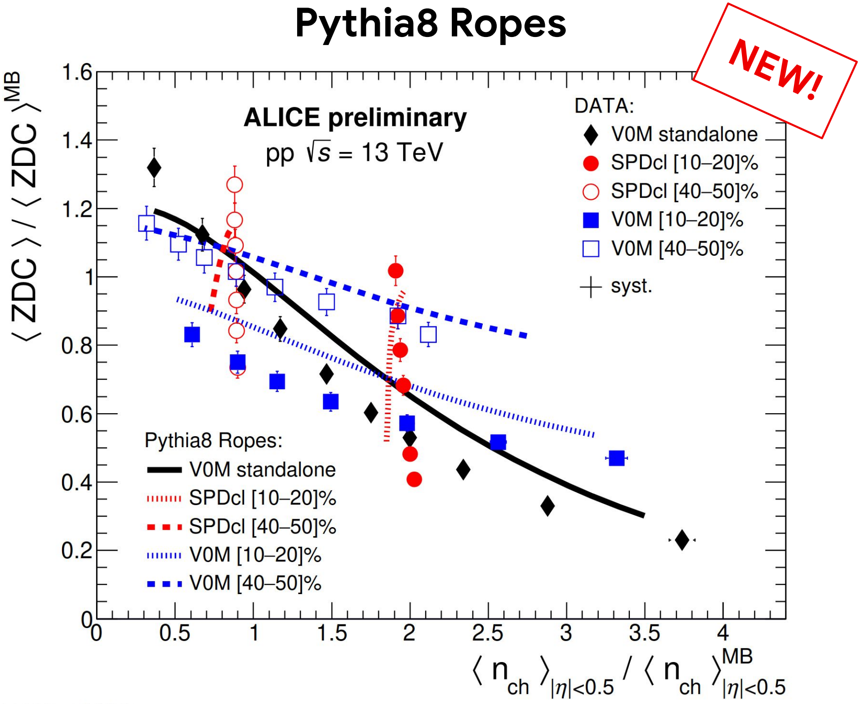
Multi-differential classes in Pythia

Pythia8 Monash



ALI-PREL-524373

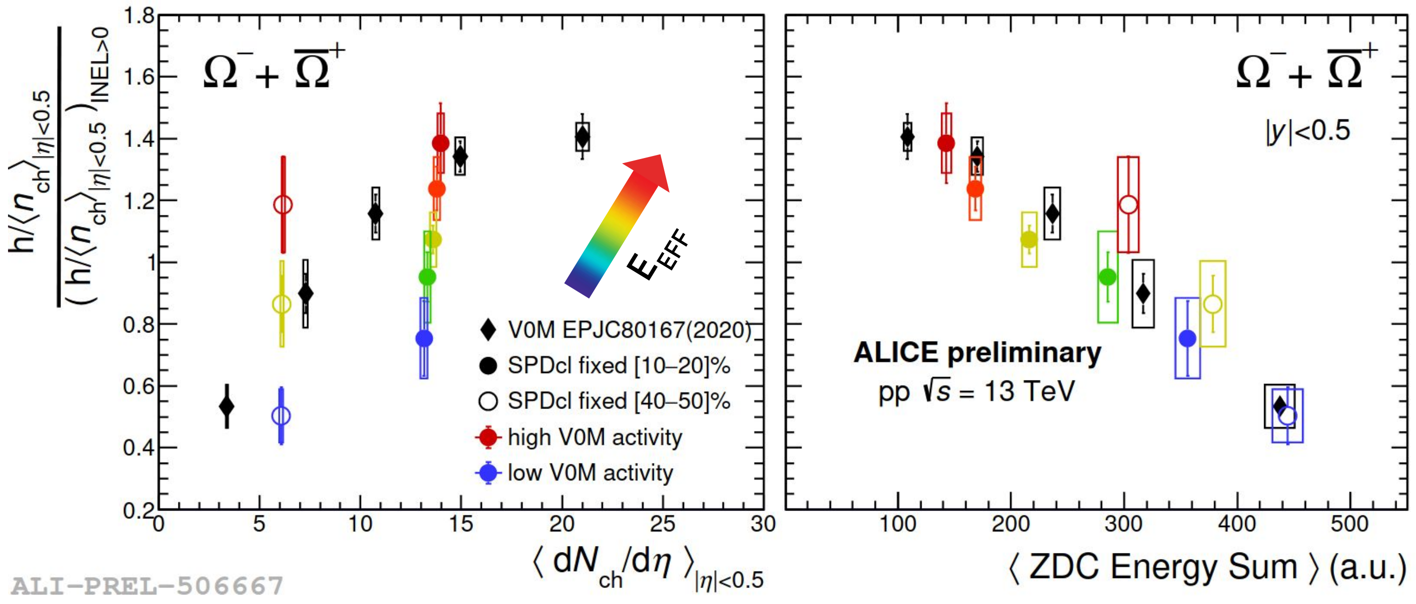
Pythia8 Ropes



ALI-PREL-524377

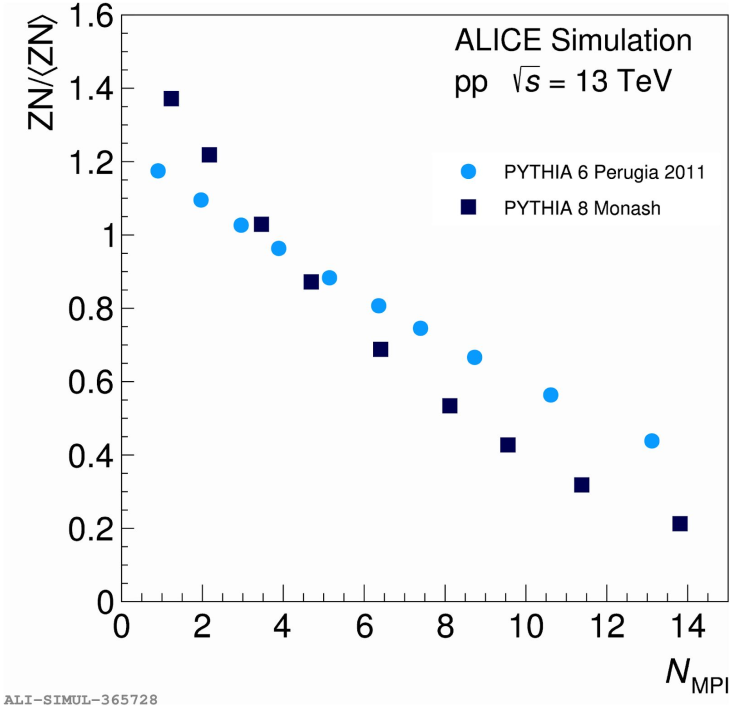
Strangeness production at fixed multiplicity

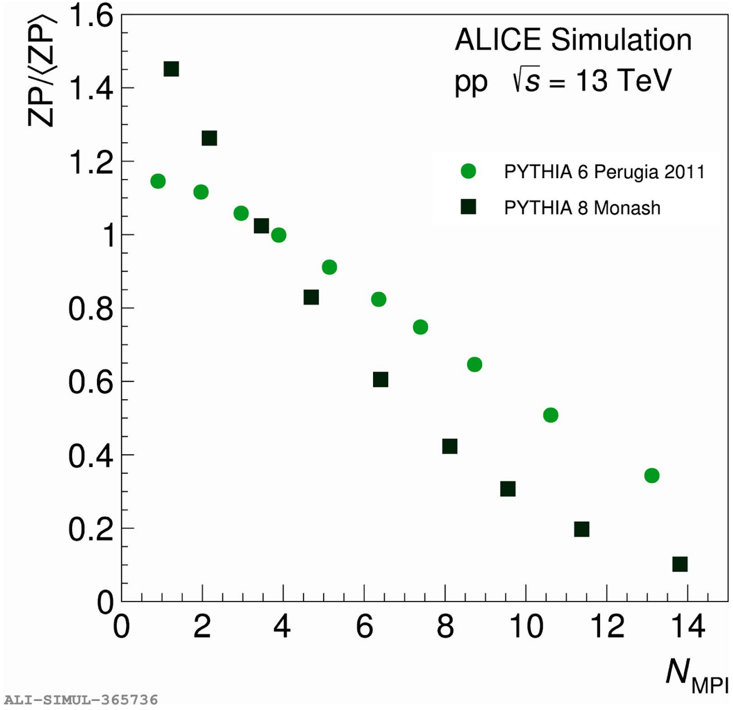
Similar results are obtained for the Ω baryon (higher strangeness content)



Very forward energy vs number of MPIs

Inverse dependence of very forward energy as a function of the number of MPIs observed in Pythia



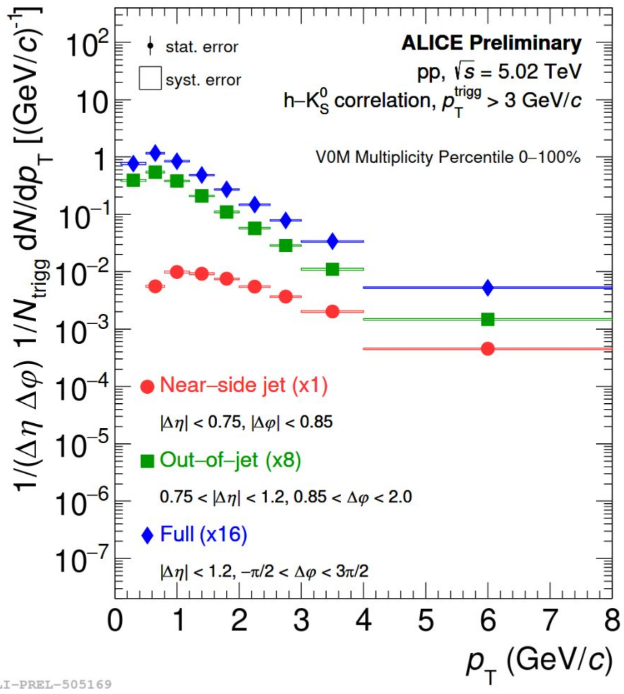


ALICE Collaboration, arxiv.org/2107.10757

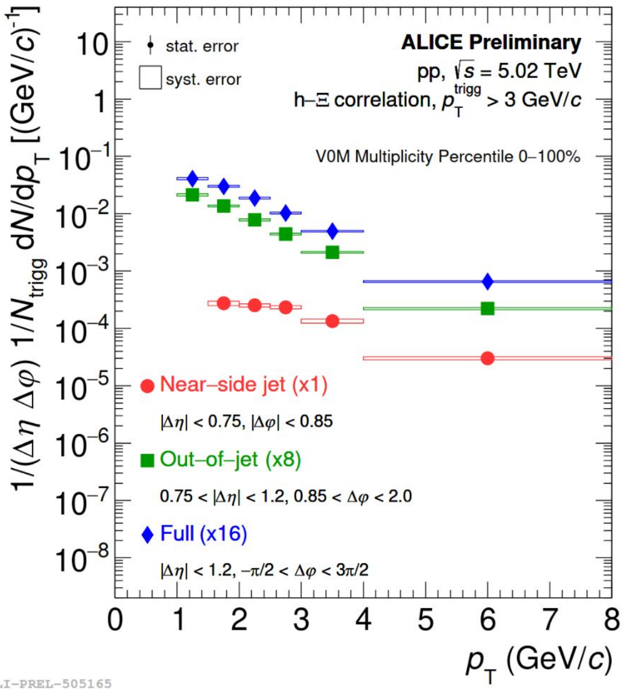
Near-side jet, out-of-jet and full p_T spectra

Spectra of strange hadrons produced **in jets** are **harder** than spectra of those produced **out-of jets**
The same feature is observed at different centre-of mass energies and for different event classes

K^0_S

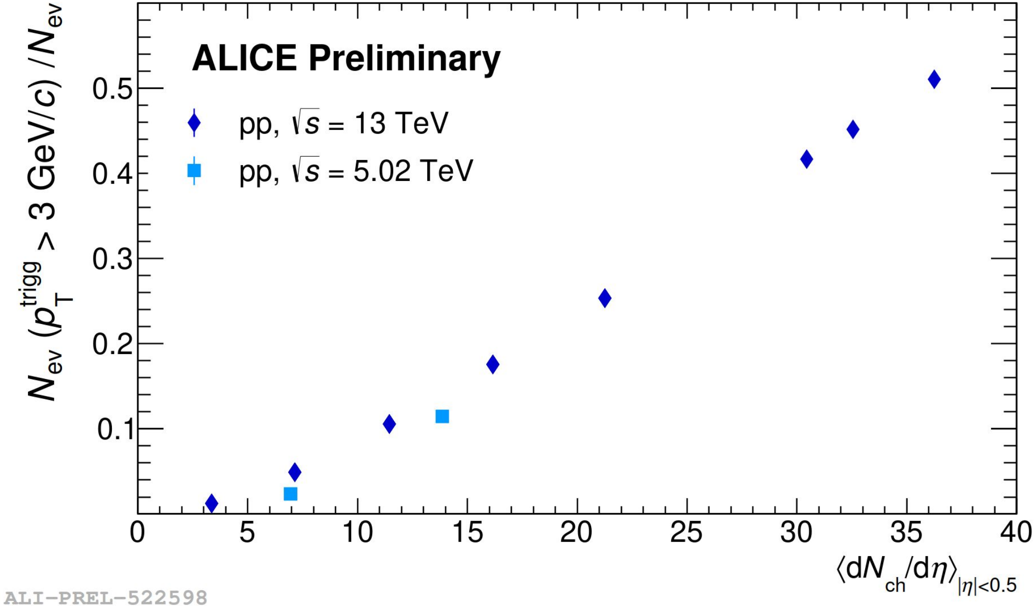


$\Xi^{\pm}$



Events with a trigger particle vs multiplicity

The fraction of events with a trigger particle with p_T > 3 GeV/*c* increases with the multiplicity of charged particles and is larger at higher centre-of mass energy



ALI-PREL-522598

Strange hadron identification with ALICE

Kinematical and **geometrical** criteria are used to reconstruct candidates for strange hadrons

Identification of (multi-)strange baryons is based on two topologies:

- **V^0** → neutral particle decaying weakly into a pair of charged particles (V-shaped decay)

$$K^0_S \rightarrow \pi^+ + \pi^-$$

$$\Lambda \rightarrow p + \pi^-$$

- **Cascade** → charged particle decaying weakly into a V^0 + charged particle

$$\Xi^- \rightarrow \Lambda + \pi^-$$

$$\bar{\Xi}^+ \rightarrow \bar{\Lambda} + \pi^+$$