ISMD 2021

Multi-differential studies to explore strangeness enhancement in pp with ALICE at the LHC

Francesca Ercolessi on behalf of the ALICE Collaboration

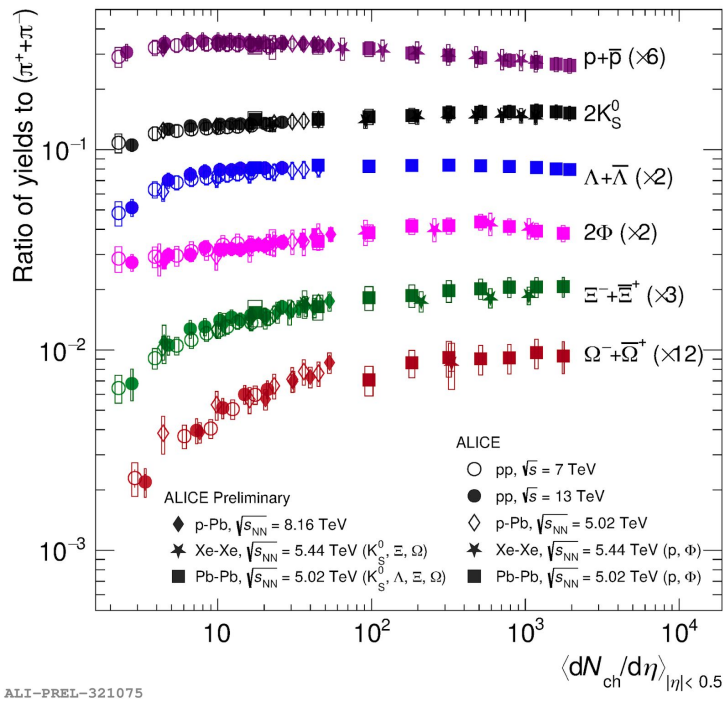
University and INFN Bologna

ALICE

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA A.D. 1088

INFN Istituto Nazionale di Fisica Nucleare

Strangeness production across systems and energies



ALICE has measured the ratio of strange to non-strange hadron yields (**h/π**) across multiplicities, collision systems and energies

→ **increases across multiplicities**

→ **smoothly evolves across different collision systems**

→ **no dependence on collision energy for similar multiplicities**

→ **enhancement is larger for particles with larger strangeness content**

$$E(\Omega) > E(\Xi) > E(\Lambda)$$

Different phenomenological models attempt to describe this effect but it is still not fully understood

ALICE Collaboration, Nature Phys 13, 535–539 (2017)
ALICE Collaboration, Eur. Phys. J. C80, 167 (2020)

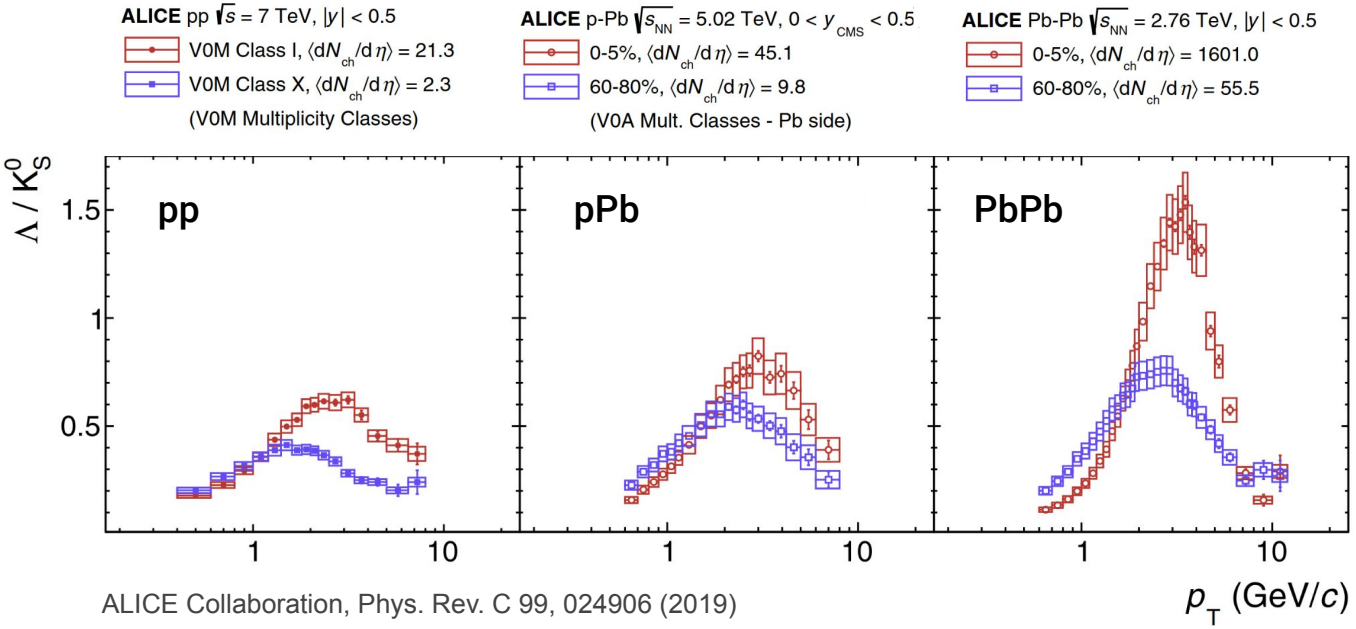
Spectral modification from large to small systems

Enhancement of Λ/K^0_S ratio at $p_T \sim 3$ GeV/c

→ Observed in **different collision systems** (pp, pPb and PbPb)

→ **Larger effect** in collisions characterised by a **larger charged particle multiplicity**

Hints of collective phenomena in small systems?

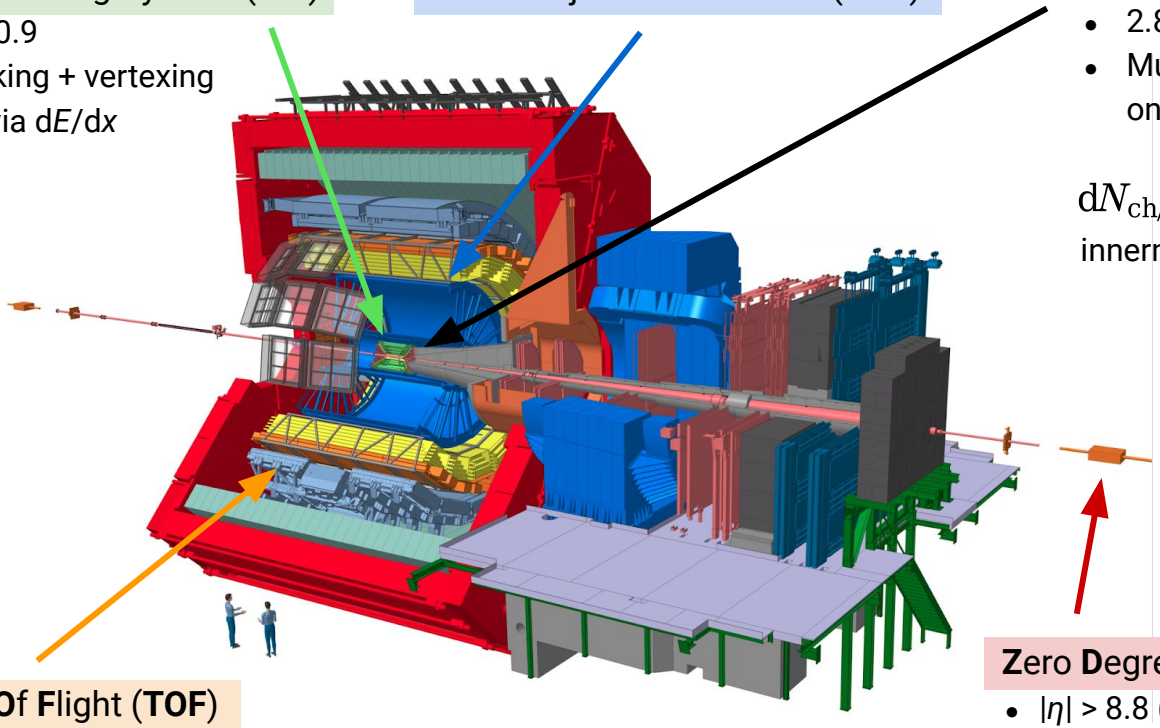


ALICE Collaboration, Phys. Rev. C 99, 024906 (2019)

ALICE at the LHC

Inner Tracking System (ITS) and **Time Projection Chamber (TPC)**

- $|\eta| < 0.9$
- Tracking + vertexing
- PID via dE/dx



V0

- $2.8 < \eta < 5.1$ (V0A), $-3.7 < \eta < -1.7$ (V0C)
- Multiplicity percentile classes based on the V0 signal amplitude

$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ is measured using **SPD** (two innermost layers of the **ITS**) in $|\eta| < 0.5$

Time Of Flight (TOF)

- $|\eta| < 0.9$
- PID via Time-Of-Flight technique

Zero Degree Calorimeters (ZDC)

- $|\eta| > 8.8$ (ZN), $6.5 < |\eta| < 7.4$ (ZP)
- Energy percentile classes based on the energy deposits of forward emitted particles

Strange particle 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)

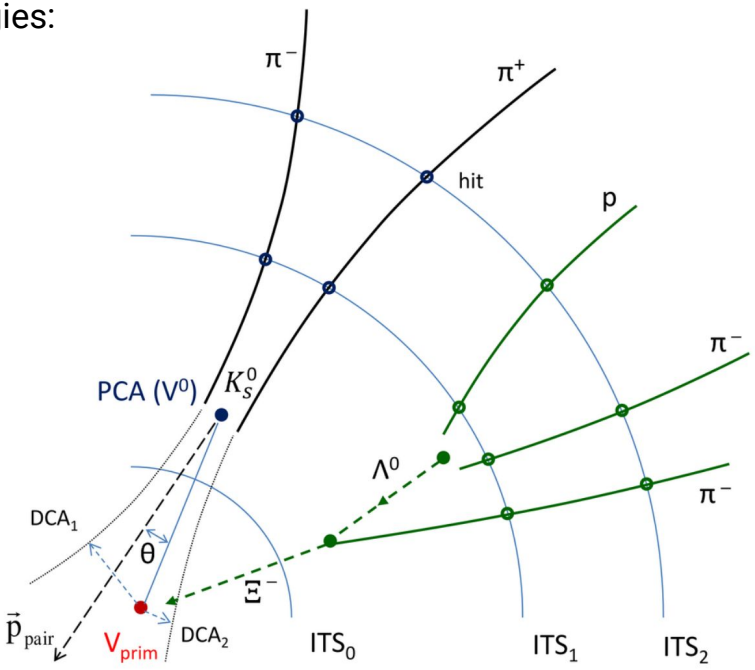
$$K^0_S \rightarrow \pi^+ + \pi^-$$

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

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

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

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



Strangeness production in and out of jets in pp collisions

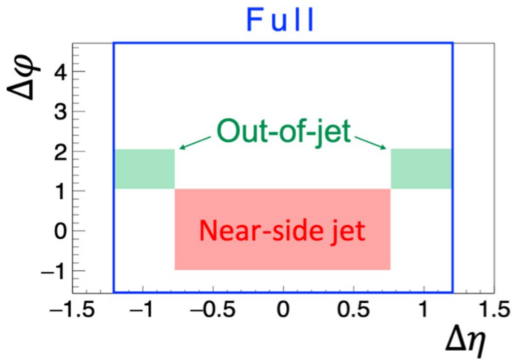
Strange hadron correlation studies

Angular correlation method:

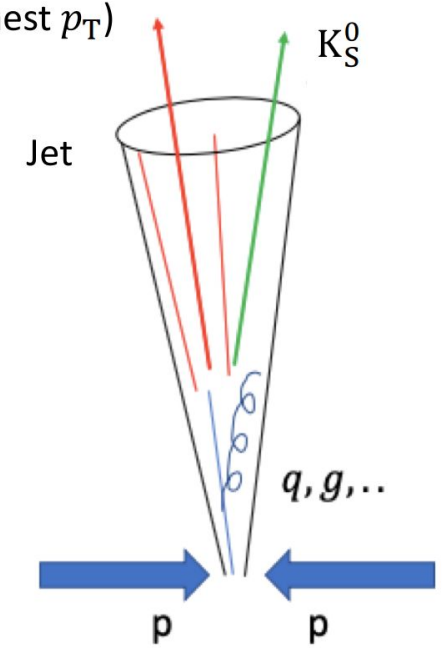
1. Selection of the **trigger particle** as a proxy for the **jet axis**:
   → the charged primary particle with the highest p_T (p_T > 3 GeV/c)
2. Identification of **associated particles** (strange hadrons)
3. **Angular correlation** between trigger and associated particles:

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

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



Leading particle ≅ jet axis
(highest p_T)



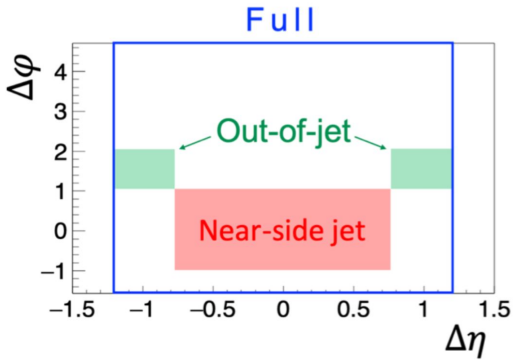
Strange hadron correlation studies

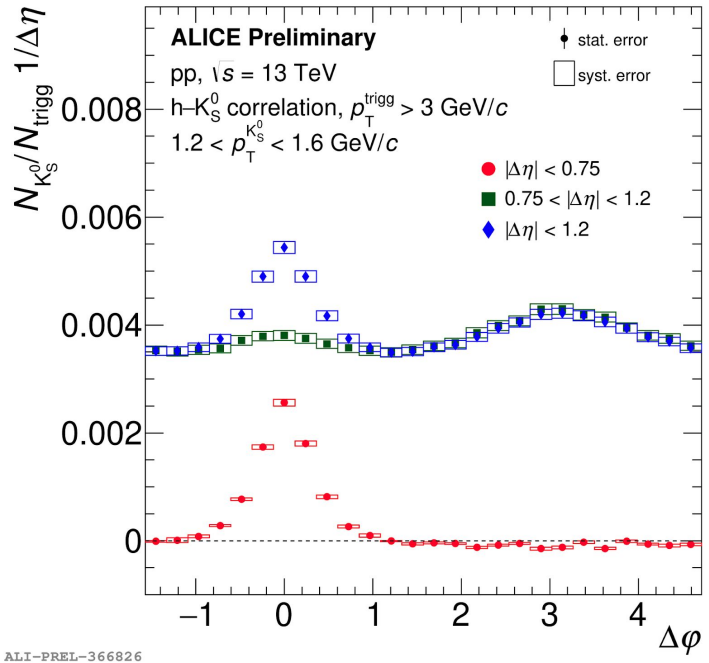
Angular correlation method:

1. Selection of the **trigger particle** as a proxy for the **jet axis**:
   → the charged primary particle with the highest p_T (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





near-side jet = full – out-of-jet

Strangeness production in and out-of-jet vs multiplicity

The **full** and **out-of-jet** yields increase with multiplicity

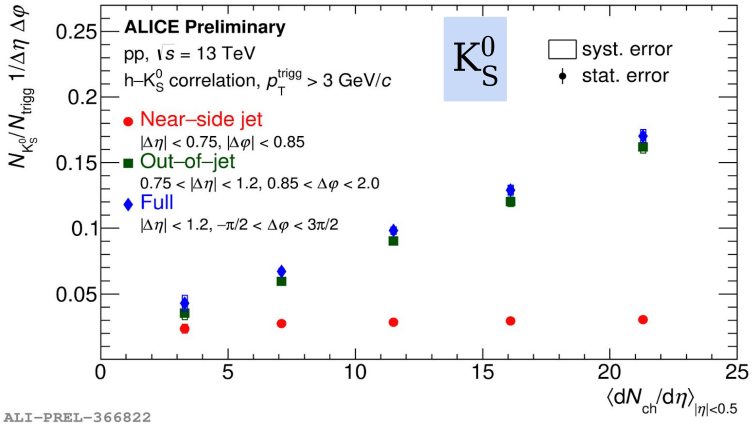
The **near-side-jet** yields show a very mild dependence on multiplicity

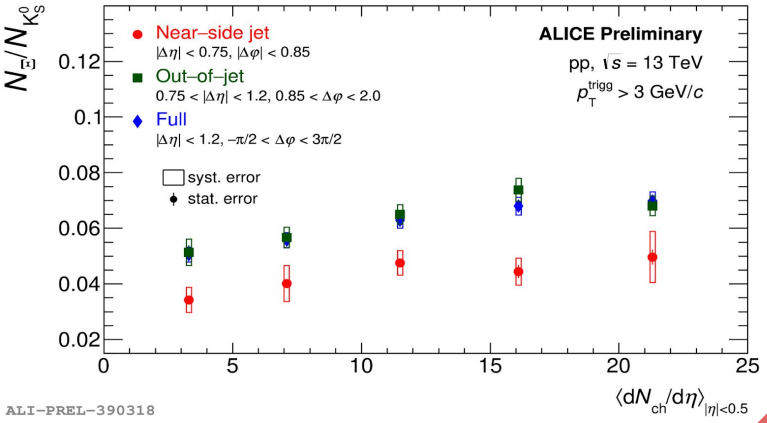
$\Xi^{\pm}/\mathrm{K}^{0}_{\mathrm{S}}$ yield ratio are consistent with the observation that **strangeness enhancement is larger for particles with larger strangeness content**

$\Xi^{\pm}/\mathrm{K}^{0}_{\mathrm{S}}$ **full** and **out-of-jet** yield ratio increases with multiplicity

$\Xi^{\pm}/\mathrm{K}^{0}_{\mathrm{S}}$ **near-side-jet** yield ratio shows a hint of increase with multiplicity

Out-of-jet processes are the dominant contribution to the full yield ratio





Strange particle dynamics in and out of jets

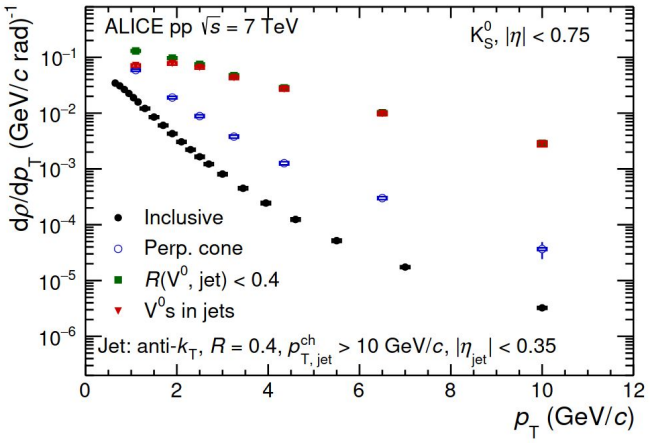
p_T spectra **in jet** are harder than in the **UE** → observed for Λ as well

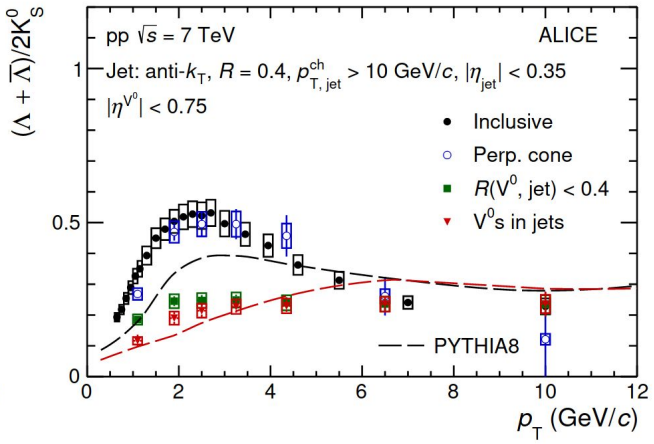
Different p_T dependence of Λ/K^0_S ratios **in jet** and in the **UE**:

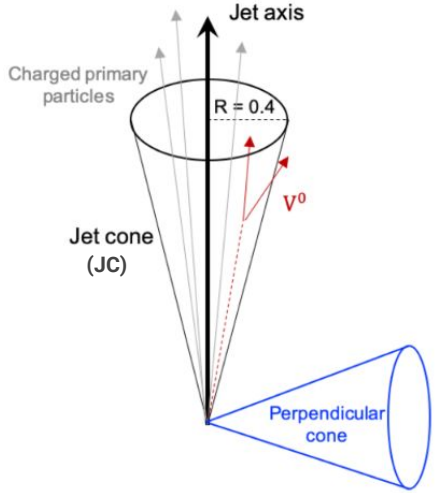
→ the **inclusive** and **UE** ratios are compatible (peak at p_T ~ 3 GeV/c)

→ the effect is much suppressed **in jets**

- **Jet cone (JC)**
  - → R(strange hadron, jet) < 0.4
  - → jet finder algorithm: anti -k_T
- **Underlying Event (UE)**
  - → strange hadrons in perpendicular cone
- **In jet production = JC - UE**







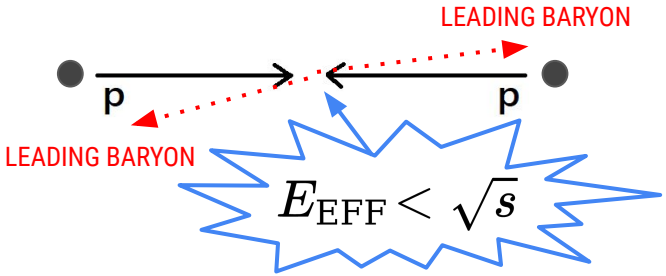
UNDERLYING EVENT (UE)

arXiv:2105.04890 [nucl-ex]

Initial and final state effects on strangeness production in pp collisions

Exploiting the concept of effective energy in pp

High probability to emit baryons in the forward direction with high longitudinal momenta called **leading effect**



Effective energy available for particle production reduced in pp

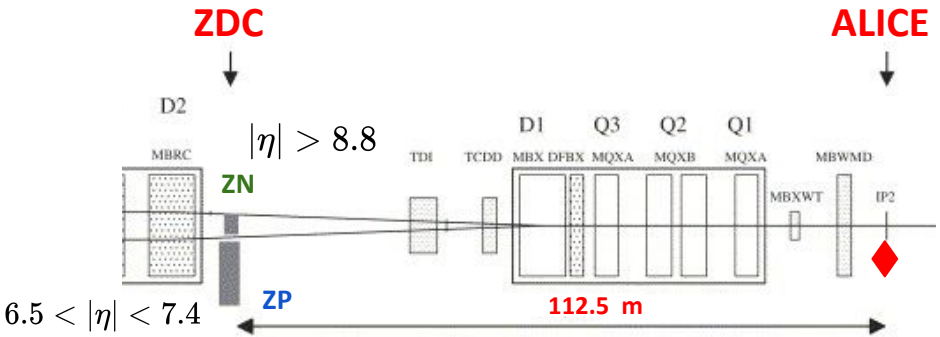
$$E_{\mathrm{EFF}} < \sqrt{s}$$

ALICE can measure the energy of forward baryons through the **ZDC**

$$E_{\mathrm{EFF}} = \sqrt{s} - E_{|\eta|>8}$$

Recent results exploit V0 and ZDC detectors to classify events in **multiplicity** and **effective energy** classes

Explore initial and final state effects on particle production

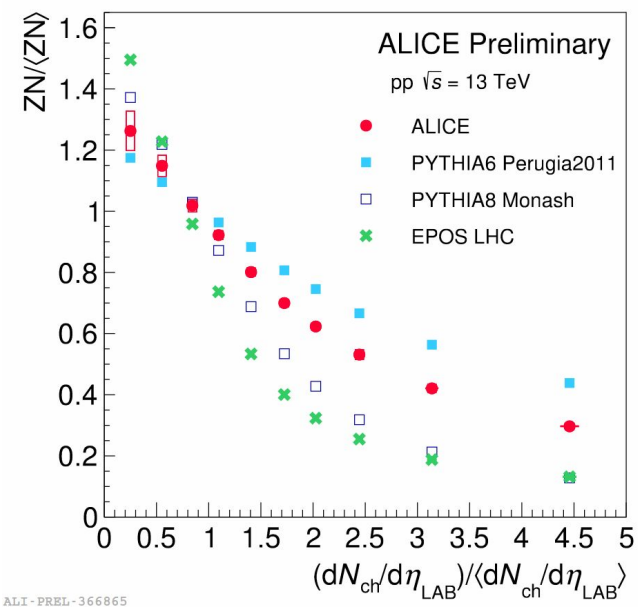


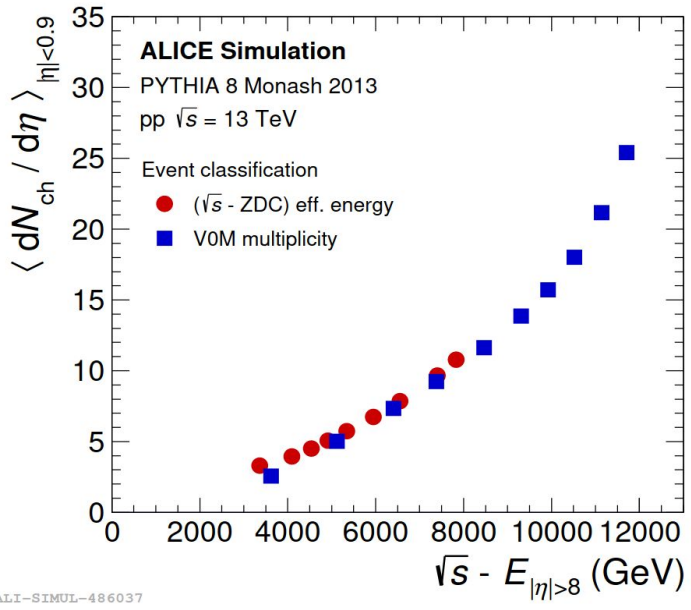
Effective energy and multiplicity correlation

Data and MC simulations confirm effective energy and multiplicity are correlated

- data show **forward energy decreases with increasing particle multiplicity at midrapidity**
  → standard generators describe the overall pattern, but are not able to quantitatively reproduce the experimental results

- simulation shows that **V0** and **ZDC** based event classes have **sensitivity to both multiplicity and effective energy**



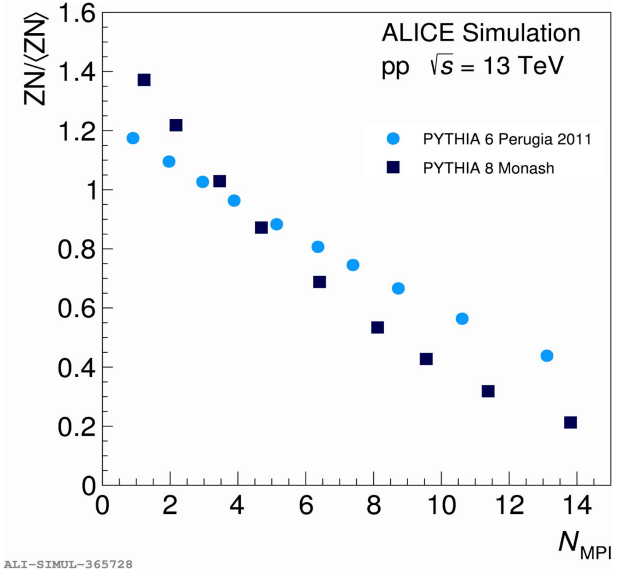


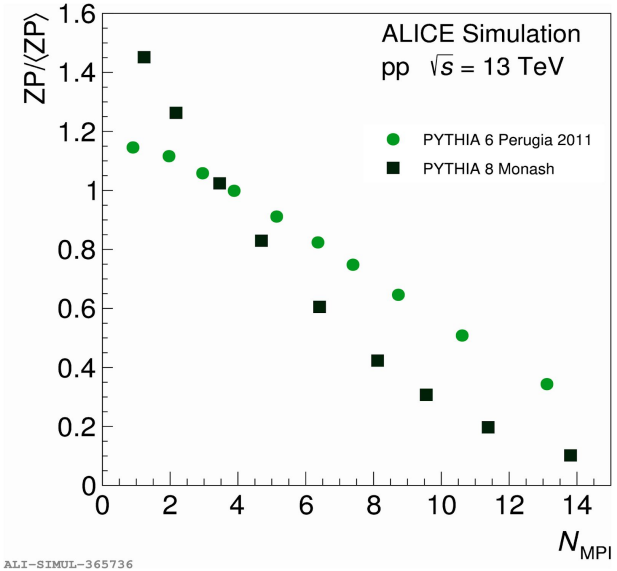
Very forward energy emission and MPIs

The very forward energy emission can be compared with models including **Multiple Parton Interactions (MPI)**

→ observed anticorrelation of **MPIs** with forward energy detected by the **ZDC,** different slopes due to different treatment of MPIs in the two generators

→ the pattern resembles the observed dependence on charged-particle multiplicity at midrapidity





Strangeness production in multiplicity and energy classes

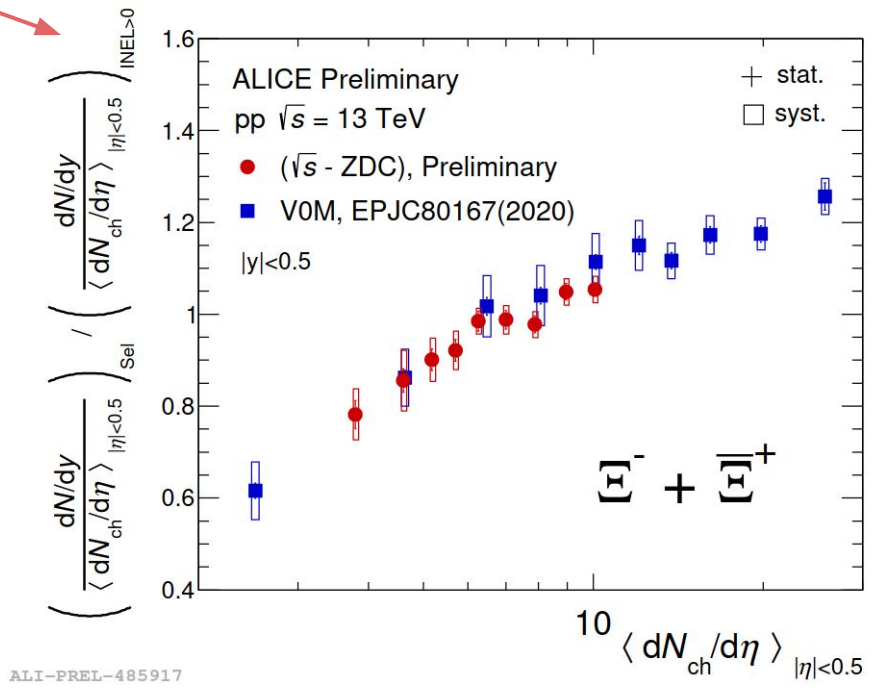
(self-normalized) ratio of $\Xi^{\pm}$ yields to the average charged particle multiplicity (in INEL>0) with multiplicity selected through **V0** and **ZDC**

→ strange particle production increases with multiplicity **independent** of the estimator used to classify events

→ clear **correlation** among **V0** and **ZDC** based event classes

Standalone analyses are **not able to disentangle initial and final state effects**

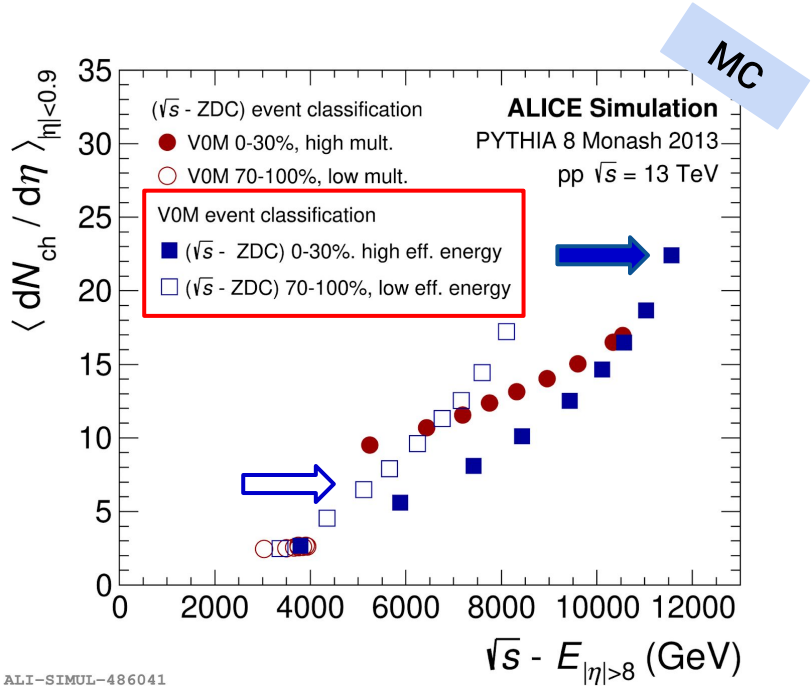
Definition of combined classes could help discriminate



Disentangle initial and final state effects

Ratio of $\Xi^{\pm}$ yields over the average charged particle multiplicity in **multiplicity** classes fixing the effective energy to:

- High effective energy → $(\sqrt{s} - \mathrm{ZDC})$ 0-30%
- Low effective energy → $(\sqrt{s} - \mathrm{ZDC})$ 70-100%



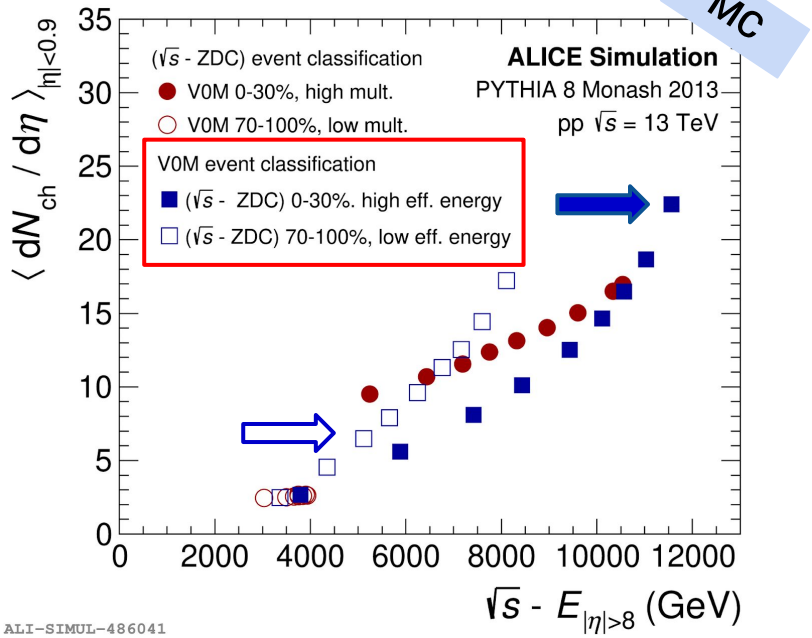
Disentangle initial and final state effects

Ratio of $\Xi^{\pm}$ yields over the average charged particle multiplicity in **multiplicity** classes fixing the effective energy to:

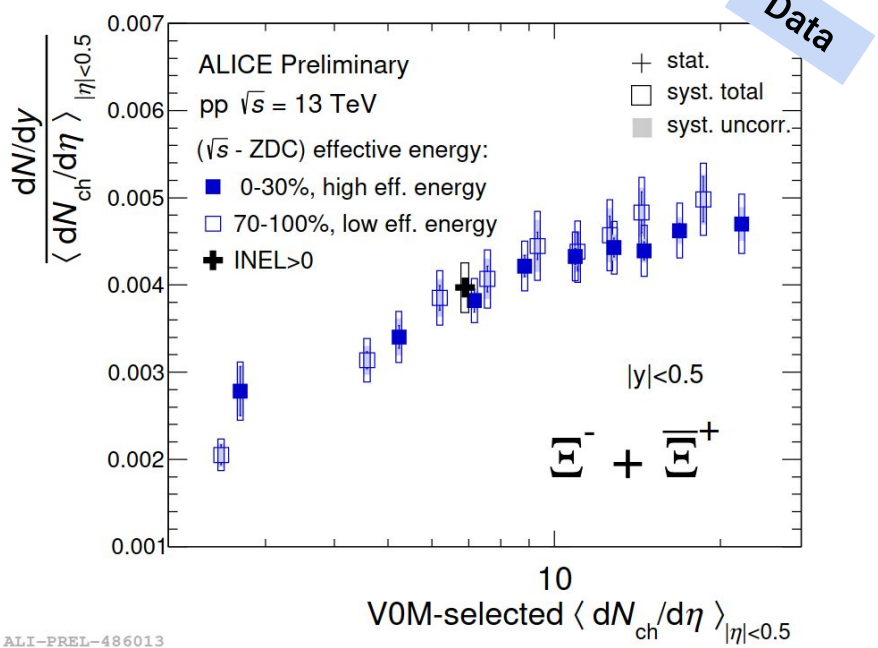
- High effective energy → $(\sqrt{s} - \mathrm{ZDC})$ 0-30%
- Low effective energy → $(\sqrt{s} - \mathrm{ZDC})$ 70-100%

Strangeness enhancement with multiplicity independent of the selection in effective energy

MC



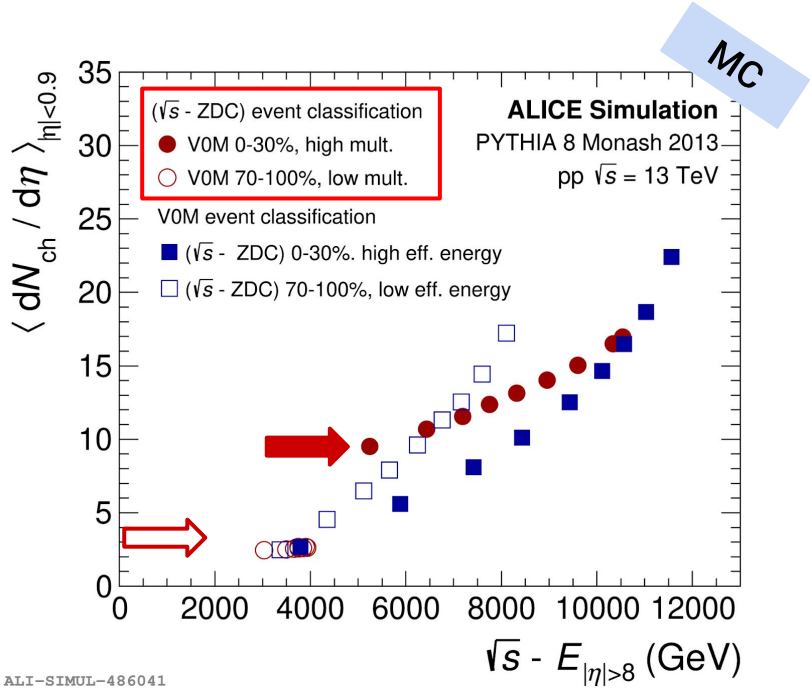
Data



Disentangle initial and final state effects

Ratio of $\Xi^{\pm}$ yields over the average charged particle multiplicity in **effective energy** classes fixing the multiplicity to:

- High multiplicity → V0M 0-30 %
- Low multiplicity → V0M 70-100%



ALI-SIMUL-486041

Disentangle initial and final state effects

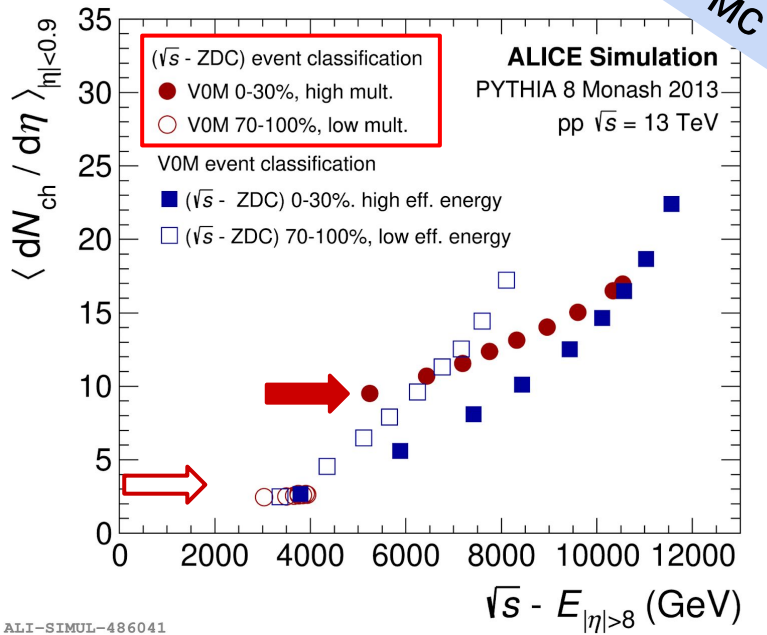
Ratio of $\Xi^{\pm}$ yields over the average charged particle multiplicity in **effective energy** classes fixing the multiplicity to:

- High multiplicity → V0M 0-30 %
- Low multiplicity → V0M 70-100%

→ no strangeness enhancement vs effective energy estimator

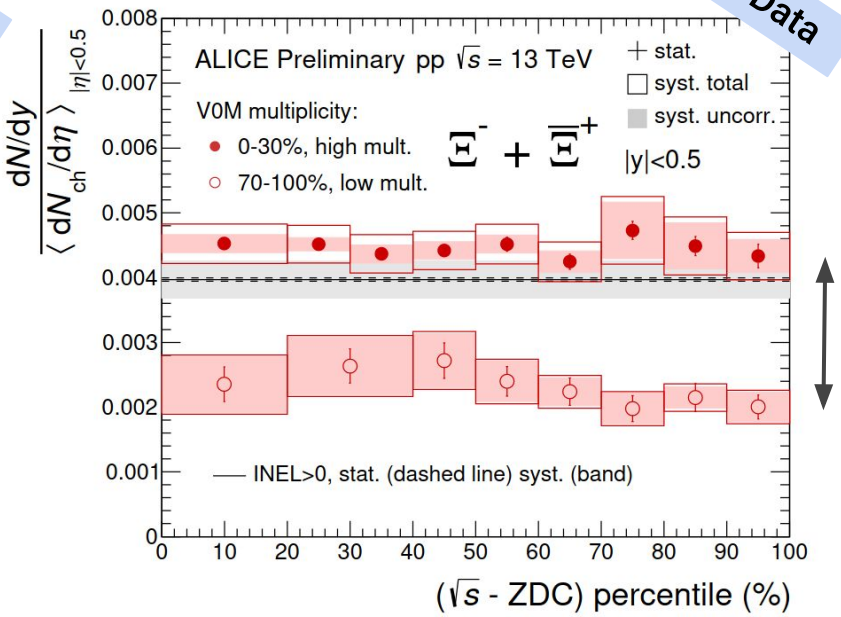
→ final-state multiplicity is the driving factor

MC



ALI-SIMUL-486041

Data



ALI-PREL-486021

Summary

The relative contribution of **hard** and **soft** processes to strangeness production in pp can be studied through techniques involving two-particle correlations and full jet reconstruction:

→ results suggest **soft processes are the dominant contribution to strange particle production**

Measurement of very forward energy with the ZDC is an interesting probe for the initial stages of the collision being **anti-correlated with the final particle multiplicity produced at midrapidity as well as to MPIs**

Initial and **final** state effects on strange particle production can be studied through **multi-differential analyses**:

→ **preliminary results suggest no significant role of effective energy on strangeness enhancement, confirming the strong connection to the final particle multiplicity**