Strangeness production in pp as a function of particle multiplicity and effective energy with ALICE

Francesca Ercolessi on behalf of the ALICE Collaboration

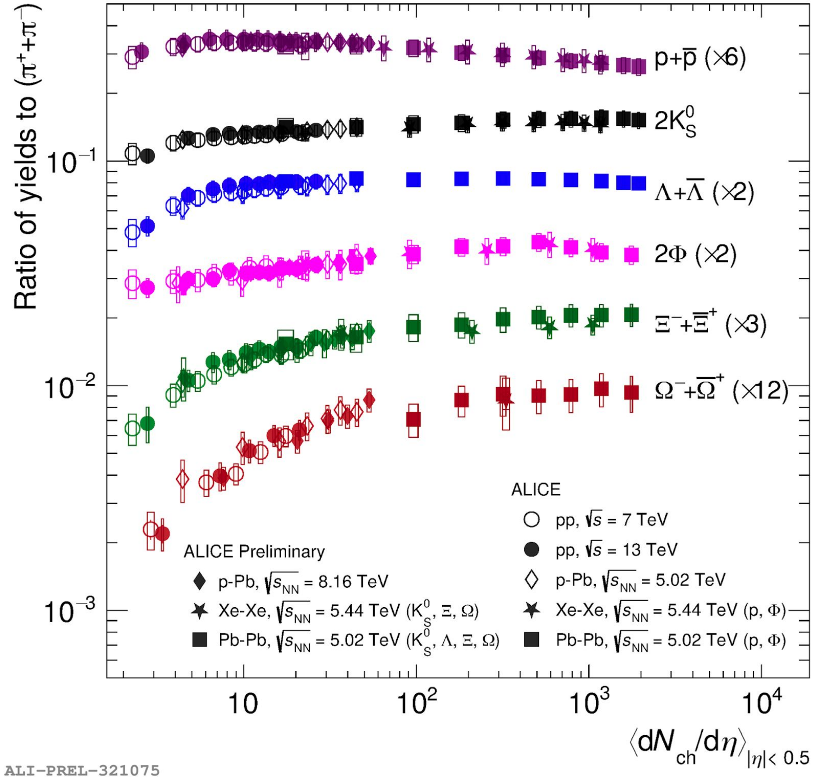
University and INFN, Bologna

ALICE

INFN
Istituto Nazionale di Fisica Nucleare

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Strangeness production across collision systems



The enhanced production of strange hadrons in heavy-ion collisions relative to pp is **expected because of QGP effects**

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

- **increases with multiplicity**
- **smoothly evolves across** different collision **systems**
- shows a **hierarchy with** the hadron **strangeness content**

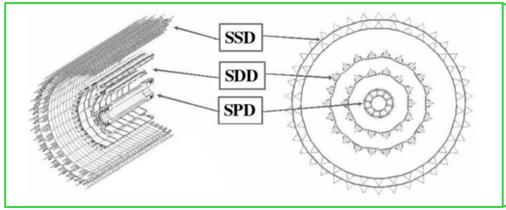
Different phenomenological **models attempt to describe this effect** but it is still not fully understood

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

ALICE at the LHC

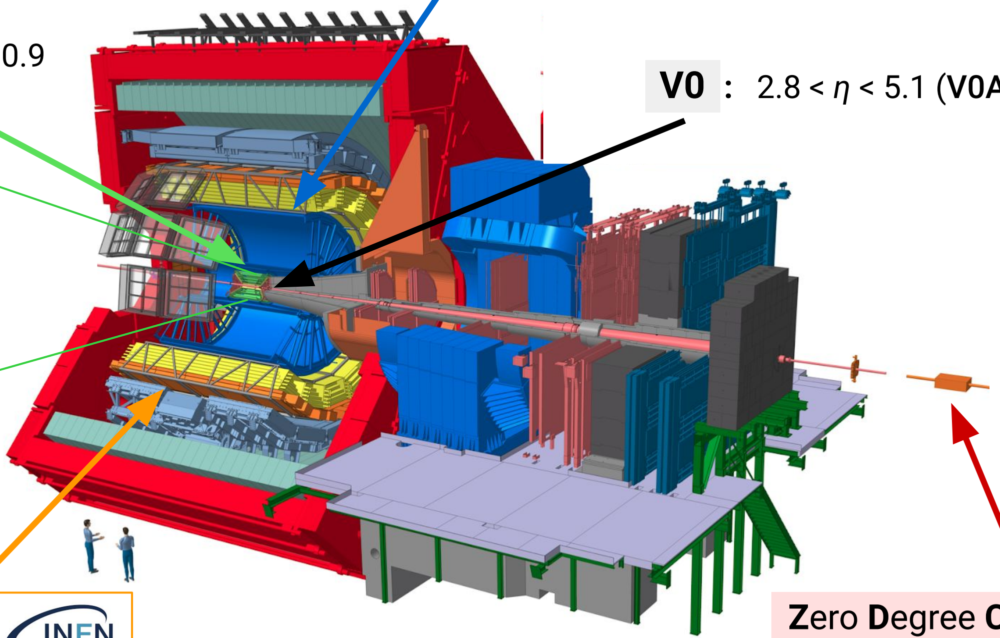
Inner Tracking System (ITS) $|\eta| < 0.9$

SPD (two innermost layers)



Time Projection Chamber (TPC) $|\eta| < 0.9$

V0 : $2.8 < \eta < 5.1$ (**V0A**), $-3.7 < \eta < -1.7$ (**V0C**)



Time Of Flight (TOF) $|\eta| < 0.9$

Zero Degree Calorimeters (ZDC)

- 112.5 m from the Interaction Point
- $|\eta| > 8.8$ (ZN), $6.5 < |\eta| < 7.4$ (ZP*)

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

Strange particle identification with ALICE

ALICE exploits **kinematical** and **geometrical** criteria to reconstruct candidates for strange hadrons

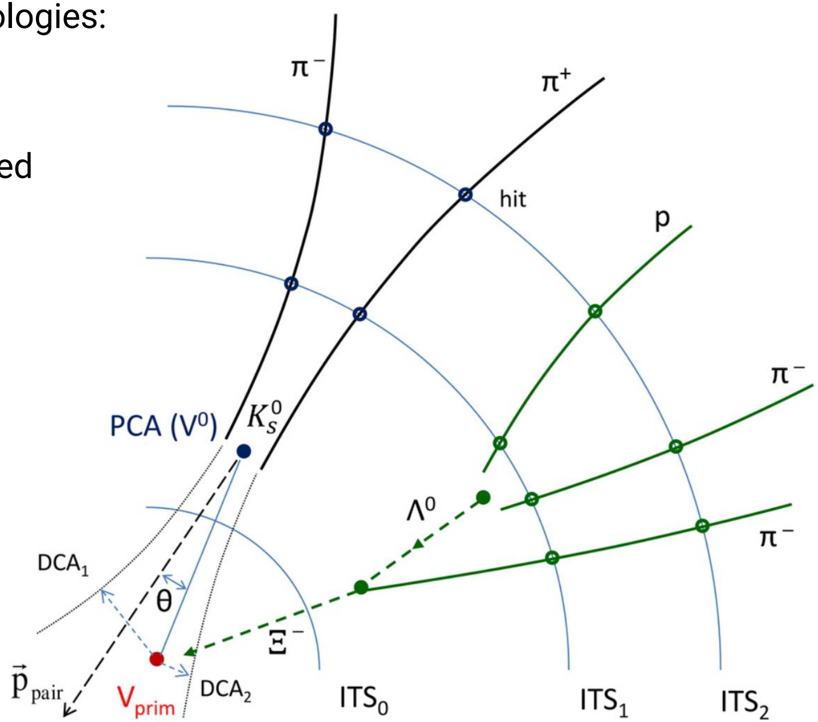
The identification of (multi-)strange baryons is based on two topologies:

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

$$\Lambda \rightarrow p + \pi^- \qquad \bar{\Lambda} \rightarrow \bar{p} + \pi^+$$

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

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



Analysis strategy

The multiplicity distribution of charged particles in pp:

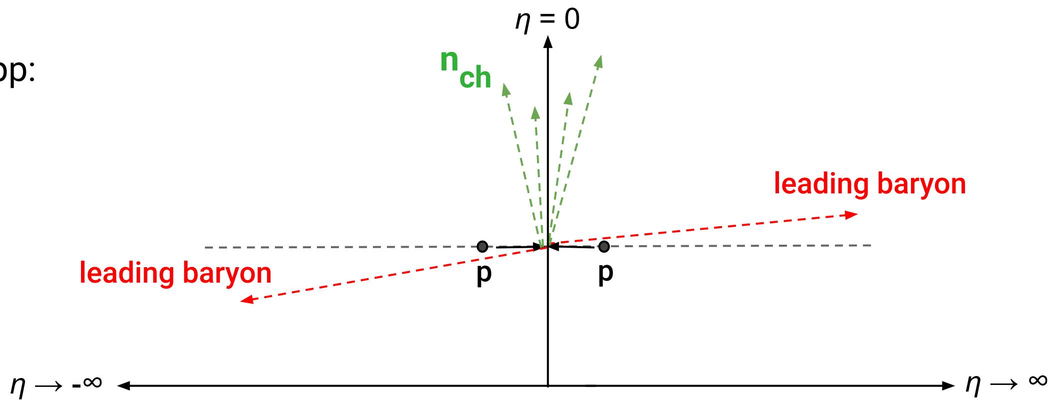
- is characteristic of the **final state** of the collision
- is strongly correlated to the **initial stage**

EFFECTIVE ENERGY

Energy available for particle production in the initial phase of the pp collision

The effective energy is reduced w.r.t. the full center of mass energy due to **forward leading baryon emission:**

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



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

Analysis strategy

The multiplicity distribution of charged particles in pp:

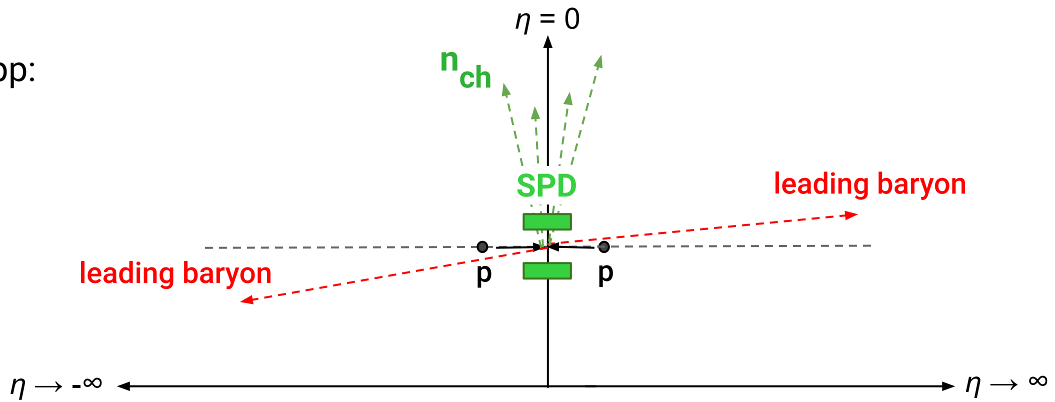
- is characteristic of the **final state** of the collision
- is strongly correlated to the **initial stage**

EFFECTIVE ENERGY

Energy available for particle production in the initial phase of the pp collision

The effective energy is reduced w.r.t. the full center of mass energy due to **forward leading baryon emission:**

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



ALICE can measure:

- the multiplicity at midrapidity through the **SPD**

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

Analysis strategy

The multiplicity distribution of charged particles in pp:

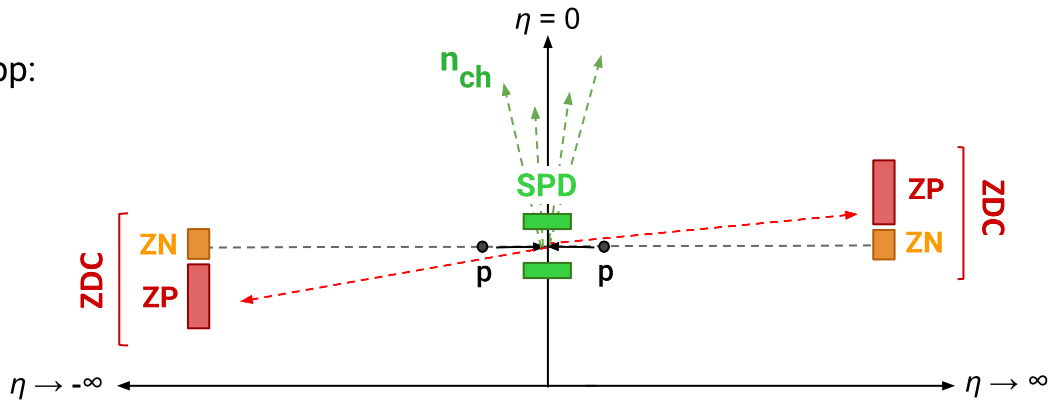
- is characteristic of the **final state** of the collision
- is strongly correlated to the **initial stage**

EFFECTIVE ENERGY

Energy available for particle production in the initial phase of the pp collision

The effective energy is reduced w.r.t. the full center of mass energy due to **forward leading baryon emission:**

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



ALICE can measure:

- the multiplicity at midrapidity through the **SPD**
- the energy of forward baryons through the **ZDC**

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

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

Analysis strategy

The multiplicity distribution of charged particles in pp:

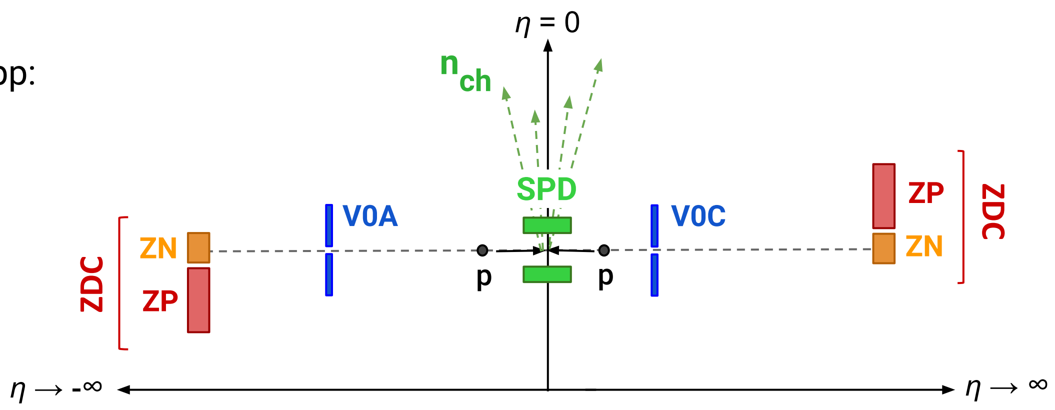
- is characteristic of the **final state** of the collision
- is strongly correlated to the **initial stage**

EFFECTIVE ENERGY

Energy available for particle production in the initial phase of the pp collision

The effective energy is reduced w.r.t. the full center of mass energy due to **forward leading baryon emission:**

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



ALICE can measure:

- the multiplicity at midrapidity through the **SPD**
- the energy of forward baryons through the **ZDC**

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

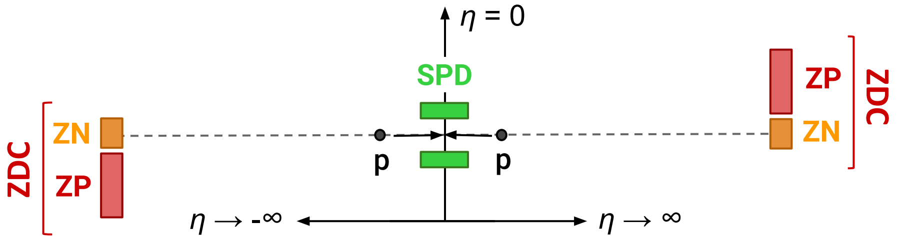
- the forward multiplicity through the **V0M** (V0A+V0C)

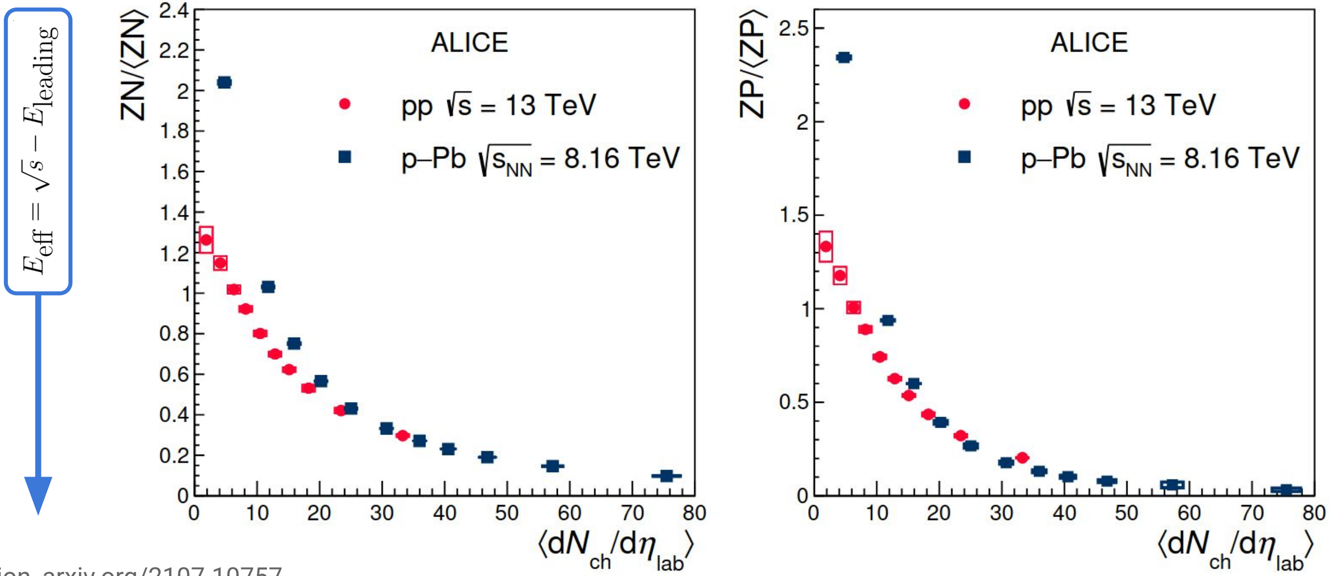
A. Akindinov et al., Eur. Phys. J. C 50, 341-352 (2007)

Multiplicity and effective energy are correlated

ALICE has measured the correlation between the leading energy and particle production at midrapidity

Forward energy **decreases with increasing** particle multiplicity produced at **midrapidity**





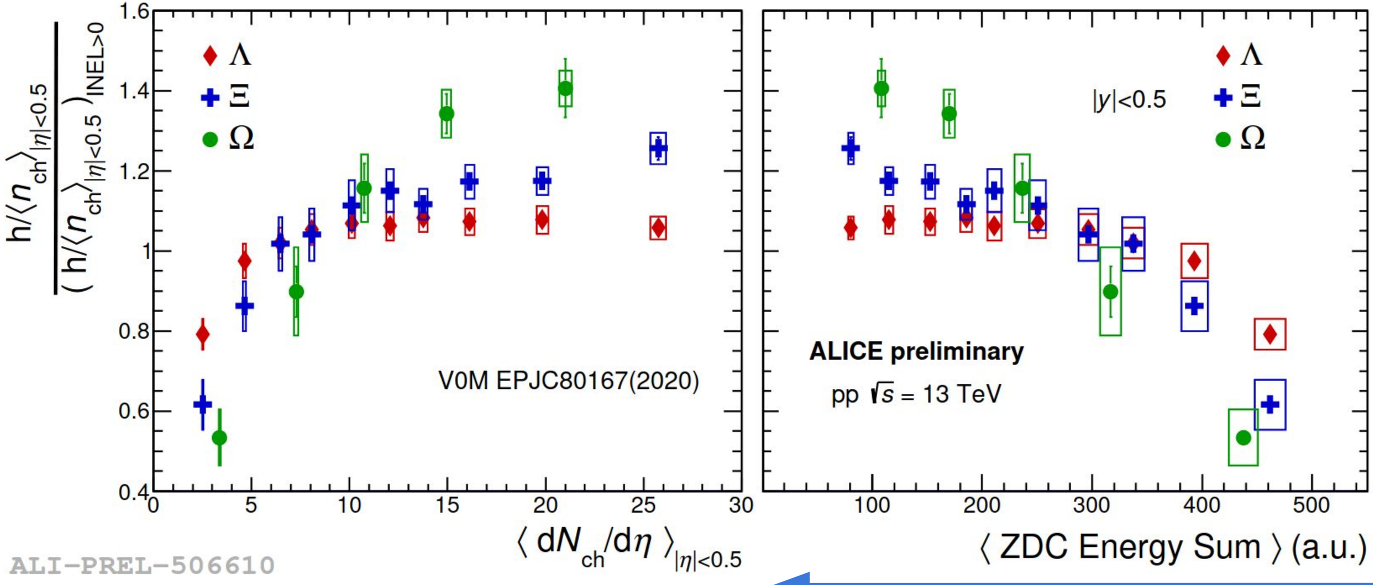
ALICE Collaboration, arxiv.org/2107.10757

Strangeness production in standalone classes

Strangeness production per charged particle (proxy for h/π):

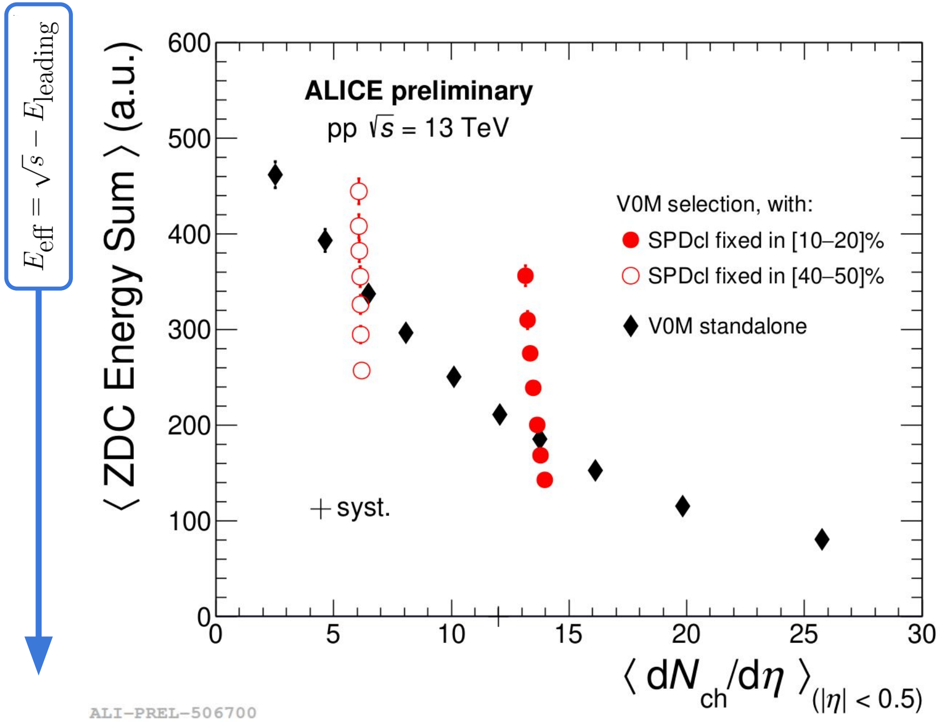
- **increases** with midrapidity multiplicity (left)
- is **anti-correlated** with ZDC energy deposits (right)

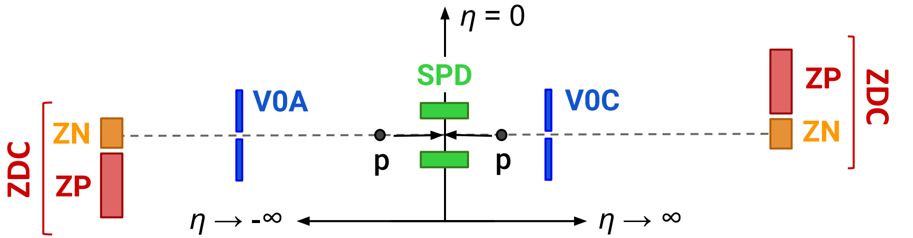
To disentangle the dependence from effective energy and multiplicity ALICE performs a **multi-differential study**



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

Multi-differential event classes

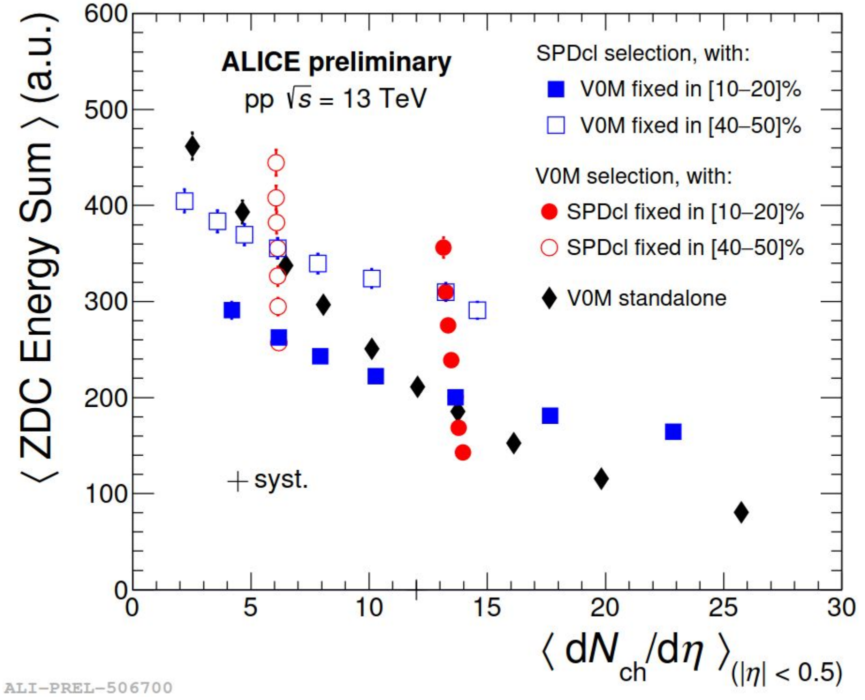


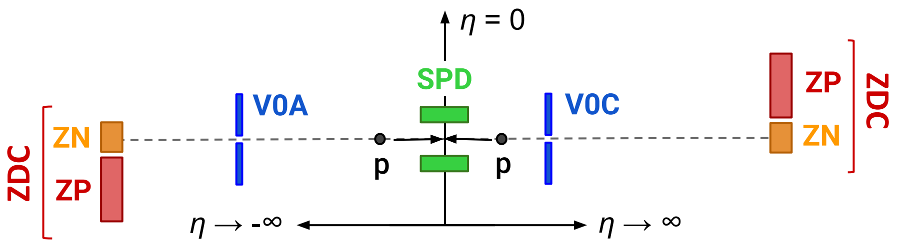


Event classes defined using V0 and SPD (clusters) information:

- ◆ **Standalone** V0 event classes
- ● ○ **Fixed multiplicity at midrapidity +** different forward energy deposits in the ZDC

Multi-differential event classes





Event classes defined using V0 and SPD (clusters) information:

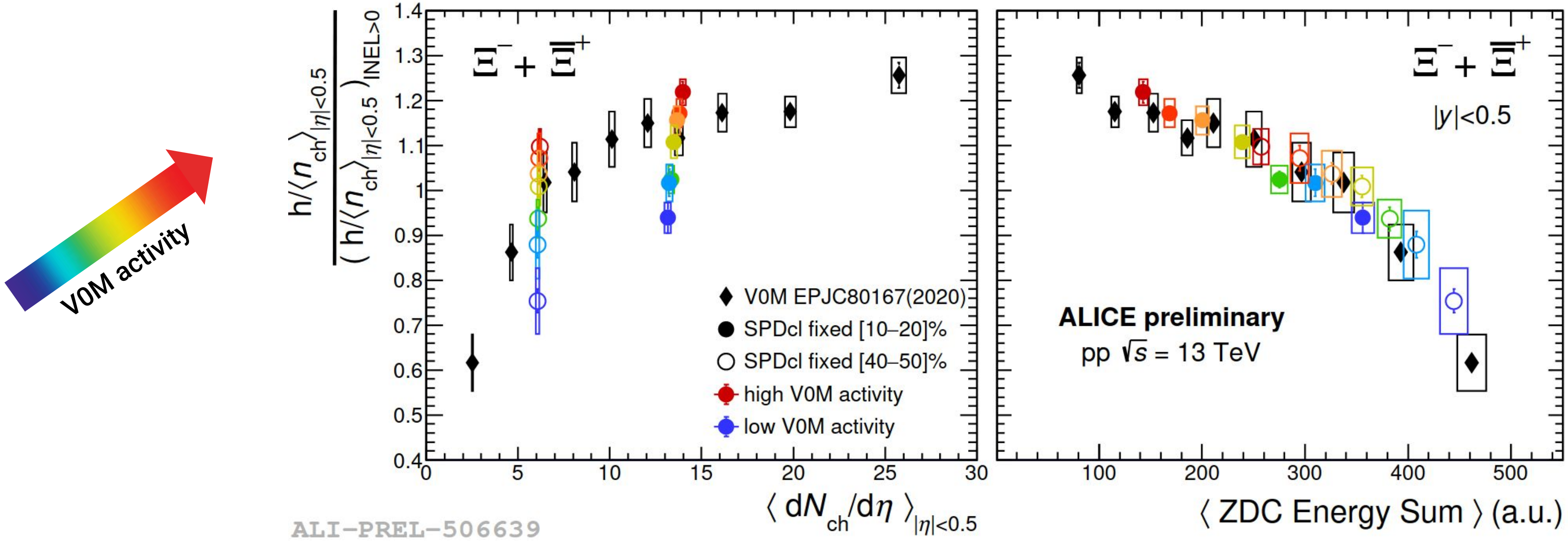
- ◆ **Standalone** V0 event classes
- ● ○ **Fixed multiplicity at midrapidity +** different forward energy deposits in the ZDC
- ■ □ **ZDC energy deposits fixed in a small range +** different multiplicity produced in the event

Strangeness production at fixed multiplicity

In events with the same charged particle multiplicity produced:

- an **increase** in Ξ production per charged particle is observed for **decreasing forward energy** detected by the **ZDC**
- scaling trends with ZDC energy are **compatible within uncertainties**

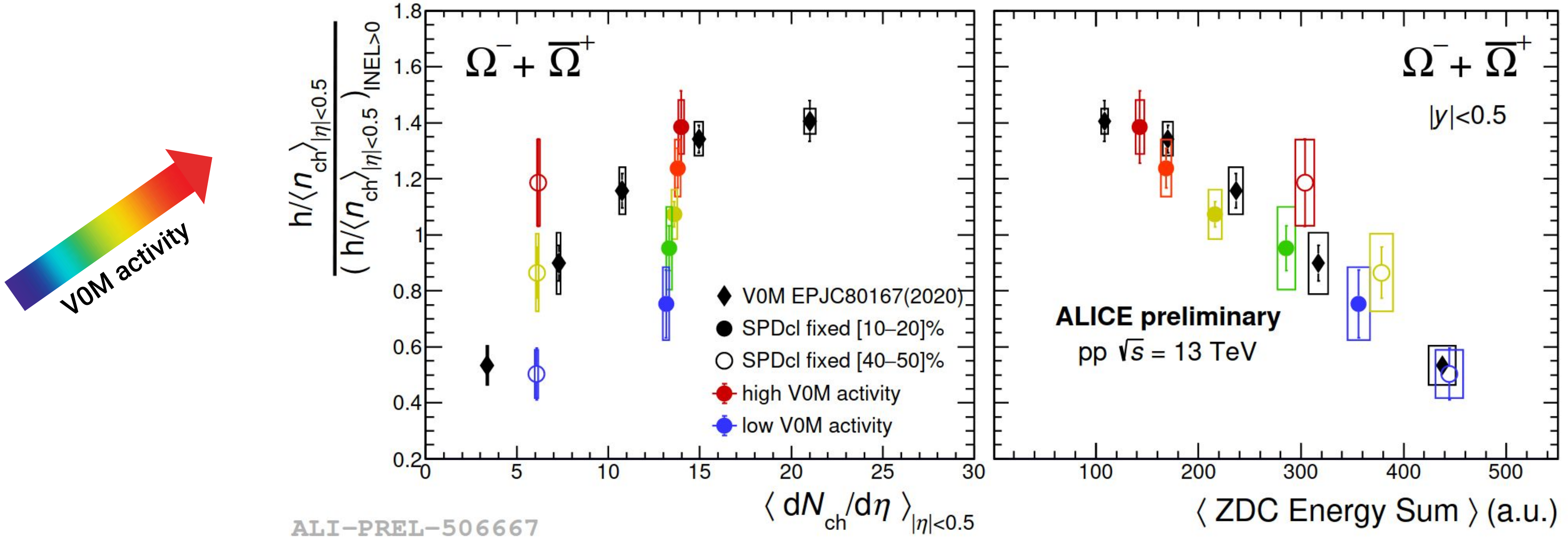
Strangeness enhancement in pp collisions was **observed for the first time at fixed** final state **multiplicity**



Strangeness production at fixed multiplicity

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

Strangeness enhancement in pp collisions was **observed for the first time at fixed** final state **multiplicity**

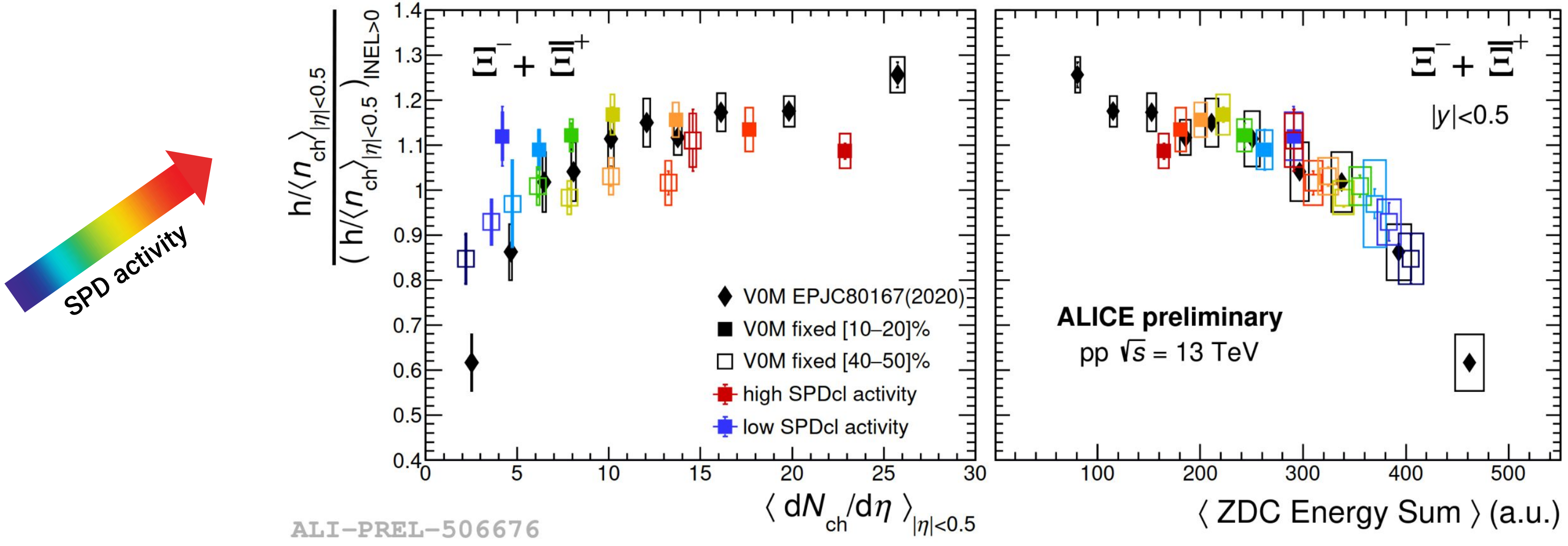


Strangeness production at fixed forward energy

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)

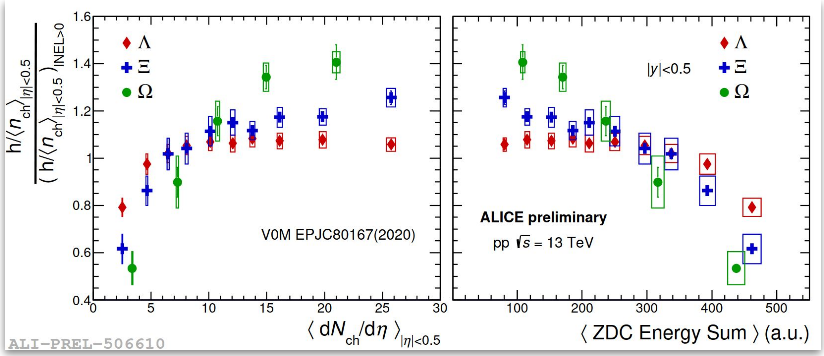
Strangeness enhancement in pp collisions is **correlated to the effective energy** (**initial stage** of the collision)



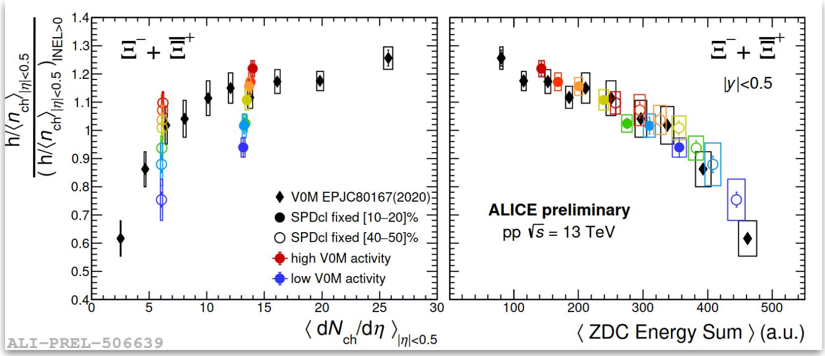
Summary

Recent ALICE results in pp collisions exploit a **multi-differential approach** to study strangeness production

The ratio of strange hadron yields to the charged particle multiplicity **increases with multiplicity** and is **anti-correlated with very forward energy** emission



Strangeness enhancement in pp collisions was **observed at fixed** final state **multiplicity at midrapidity** and shows a **strong correlation with the effective energy**, which reflects the **initial stage** of the collision



Thank you!

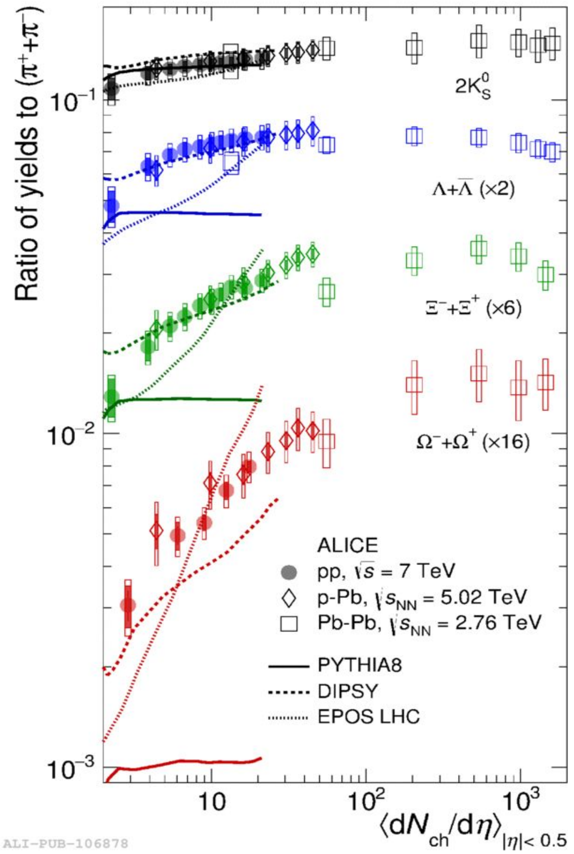
Hadrochemistry evolution in small systems

Models based on standard event generators such as:

- PYTHIA8 (**color reconnection**)
- DIPSY (**color ropes**)
- EPOS LHC (**core-corona**)

can **reproduce only qualitatively** what we see in data, but struggle quantitatively

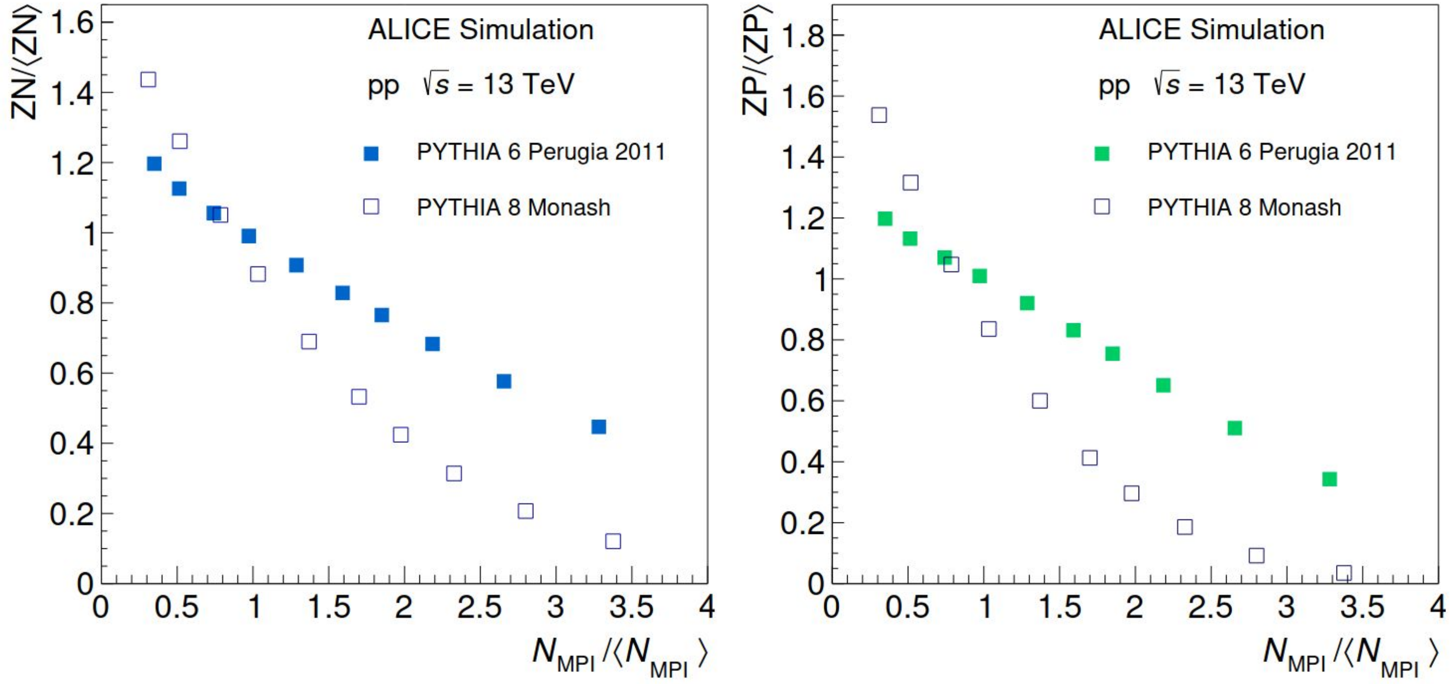
The thermal-statistical hadronization picture which describes heavy-ion collisions can be extended to smaller collision systems (**strangeness canonical suppression**)
→ **agreement with data** within uncertainties, but **not for all strange particles**



A Maldonado-Cervantes et al 2014 J. Phys.: Conf. Ser.509 012064
C. Bierlich et al., PRD 92 (2015) 094010
T. Pierog et al., arXiv:1306.0121
V. Vislavicius, A. Kalweit arXiv:1610.03001

Very forward energy emission vs MPIs

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



ALICE Collaboration, arxiv.org/2107.10757