

From average yields to event-by-event probability: a comprehensive journey through strangeness production with ALICE

Sara Pucillo^{1,2}

Niels Bohr Institute
University of Copenhagen
Invited seminar, 28/05/2026



1. Università degli Studi di Salerno



2. INFN Napoli



Istituto Nazionale di Fisica Nucleare
SEZIONE DI NAPOLI
Gruppo Collegato di Salerno



- **Physics motivations**
 - strange hadron production in high-energy hadronic collisions
 - strangeness hadronization models
 - higher precision results in pp and Pb–Pb collisions at 5.02 TeV from ALICE Collaboration ([arXiv:2511.10306](#), [arXiv:2511.10360](#))
- **New Run 3 results in OO and pp collisions at 5.36 TeV from ALICE Collaboration**
- **New observable: (multi-) strange particle multiplicity distributions ([arXiv:2511.10413](#))**
 - multiple strange hadron production yields vs multiplicity
 - yield ratios





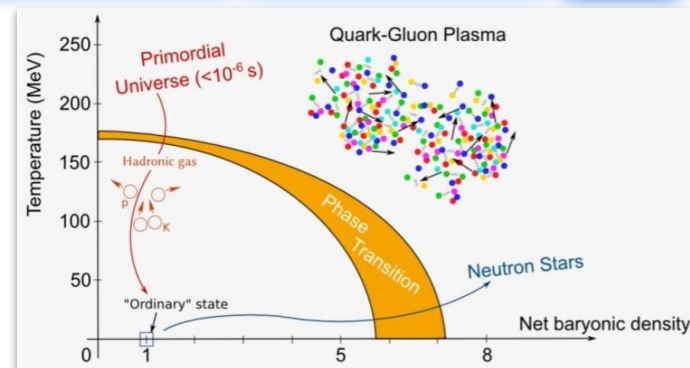
- **Physics motivations**
 - strange hadron production in high-energy hadronic collisions
 - strangeness hadronization models
 - higher precision results in pp and Pb–Pb collisions at 5.02 TeV from ALICE Collaboration ([arXiv:2511.10306](#), [arXiv:2511.10360](#))
- New Run 3 results in OO and pp collisions at 5.36 TeV from ALICE Collaboration
- New observable: (multi-) strange particle multiplicity distributions ([arXiv:2511.10413](#))
 - multiple strange hadron production yields vs multiplicity
 - yield ratios





From QCD a phase transition is expected ($T \sim 160$ MeV, $\mu_B = 0$ [1]) from hadronic matter to a deconfined state of **quarks and gluons**: quark-gluon plasma (QGP)

Experimentally → ultrarelativistic heavy-ion collisions: **ALICE** (A Large Ion Collider Experiment)



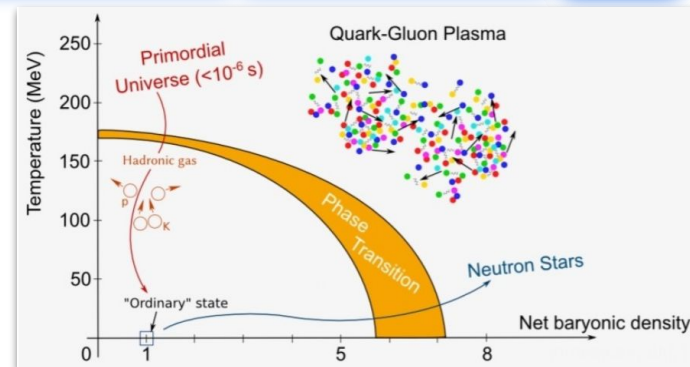
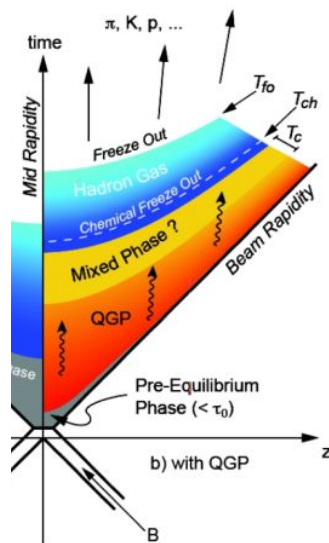
[1] C.Gale, S.Jeon, B.Schenke, arxiv.org/1301.5893





From QCD a phase transition is expected ($T \sim 160$ MeV, $\mu_B = 0$ [1]) from hadronic matter to a deconfined state of **quarks and gluons**: quark–gluon plasma (QGP)

Experimentally → ultrarelativistic heavy-ion collisions: **ALICE** (A Large Ion Collider Experiment)



- “Fireball” in local thermal equilibrium that expands hydrodynamically: partonic degrees of freedom
- chemical freeze-out: hadrons are formed
- kinetical freeze-out: all particles cease to interact

Short lifetime ($\tau \sim 10^{-23}$ s) of the QGP: **no direct detection** → characterization from the determination of the properties and modifications of final-state observables

Historical QGP signatures include **hadrochemistry** → measurement of relative abundances of produced particle species





Hadrochemistry: measurement of **relative abundances of produced particle species**

Strange quarks are not part of the valence content of the initial colliding systems: they are newly produced during the collision → **strangeness is a sensitive probe of particle production and hadronization**



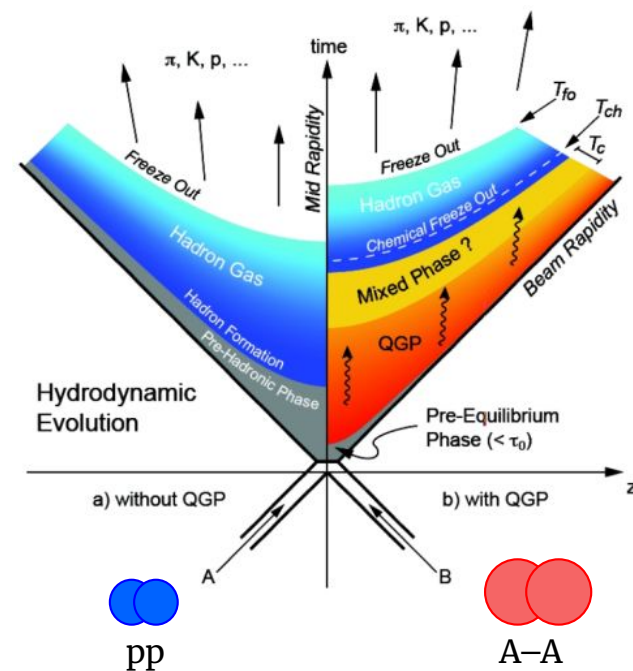


Hadrochemistry: measurement of **relative abundances of produced particle species**

Strange quarks are not part of the valence content of the initial colliding systems: they are newly produced during the collision → **strangeness is a sensitive probe of particle production and hadronization**

Strangeness enhancement: **relative abundance of particles containing strange quarks is expected to be higher in AA collisions than in pp interactions**

- historically proposed **signature of QGP formation**
([Rafelski J., Müller B., Phys.Rev.Lett. 48, 1066 \(1982\)](#))
 - lower Q-value for $s\bar{s}$ relative to $H_s H_{\bar{s}}$ formation
 - faster equilibration in partonic medium



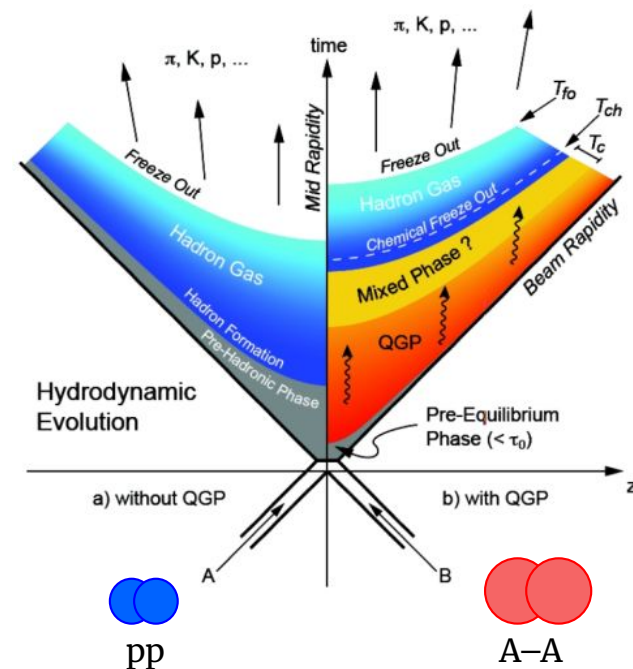


Hadrochemistry: measurement of **relative abundances of produced particle species**

Strange quarks are not part of the valence content of the initial colliding systems: they are newly produced during the collision → **strangeness is a sensitive probe of particle production and hadronization**

Strangeness enhancement: **relative abundance of particles containing strange quarks is expected to be higher in AA collisions than in pp interactions**

- historically proposed **signature of QGP formation**
([Rafelski J., Müller B., Phys.Rev.Lett. 48, 1066 \(1982\)](#))
 - lower Q-value for $s\bar{s}$ relative to $H_s H_{\bar{s}}$ formation
 - faster equilibration in partonic medium
- similar enhancement patterns can also arise from **statistical models**
(e.g. [Vislavicius V., Kalweit A., arxiv.org/1610.03001](#))
 - canonical suppression** in small systems
 - incomplete equilibrium** of strangeness





Hadrochemistry: measurement of **relative abundances of produced particle species**

Strange quarks are not part of the valence content of the initial colliding systems: they are newly produced during the collision → **strangeness is a sensitive probe of particle production and hadronization**

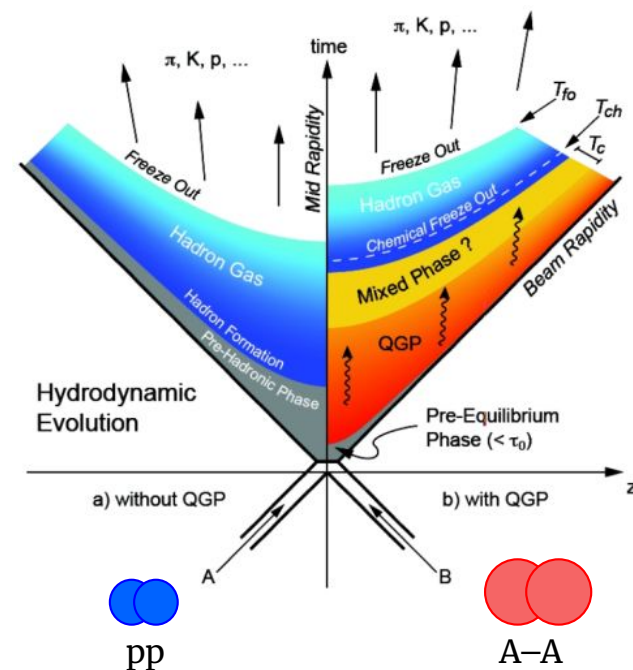
Strangeness enhancement: **relative abundance of particles containing strange quarks is expected to be higher in AA collisions than in pp interactions**

- historically proposed **signature of QGP formation**
([Rafelski J., Müller B., Phys.Rev.Lett. 48, 1066 \(1982\)](#))
 - lower Q-value for $s\bar{s}$ relative to $H_s H_{\bar{s}}$ formation
 - faster equilibration in partonic medium
- similar enhancement patterns can also arise from **statistical models**
(e.g. [Vislavicius V., Kalweit A., arxiv.org/1610.03001](#))
 - canonical suppression** in small systems
 - incomplete equilibrium** of strangeness

TAKE HOME MESSAGE

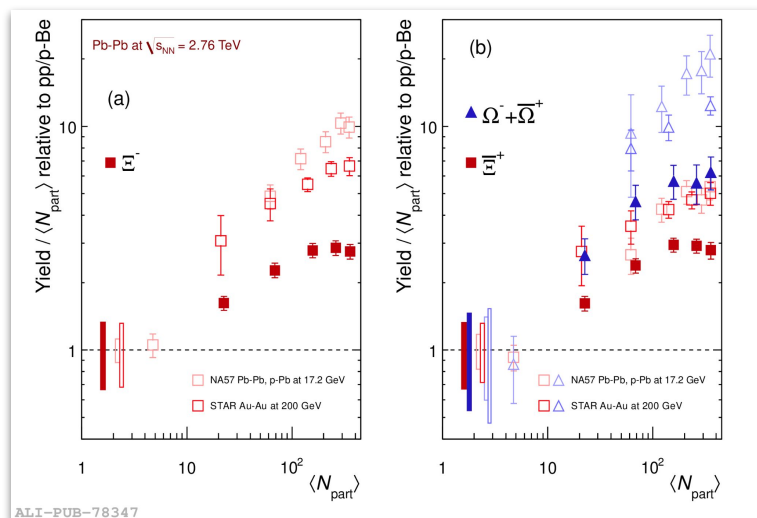
QGP $\implies$ (foreseen) altered chemical composition

QGP $\nleftarrow$ altered chemical composition





Strangeness enhancement (SE): experimentally observed at CERN SPS [2-4], BNL RHIC [5] and CERN LHC [6, 7]



- **strangeness production enhanced** in large systems with respect to small ones
- enhancement increases with the strangeness content
- **energy hierarchy problem:** ratio larger for lower energy collisions

[2] WA97 Coll., [Phys. Lett. B 449 \(1999\) 401–406](#)

[3] NA49 Coll., [Phys. Lett. B 538 \(2002\) 275–281](#)

[4] NA57 Coll., [J. Phys. G 37 \(2010\) 045105](#)

[5] STAR Coll., [Phys. Rev. C 77 \(2008\) 044908](#)

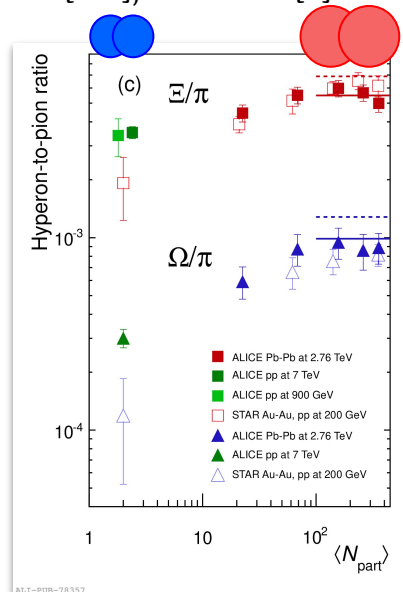
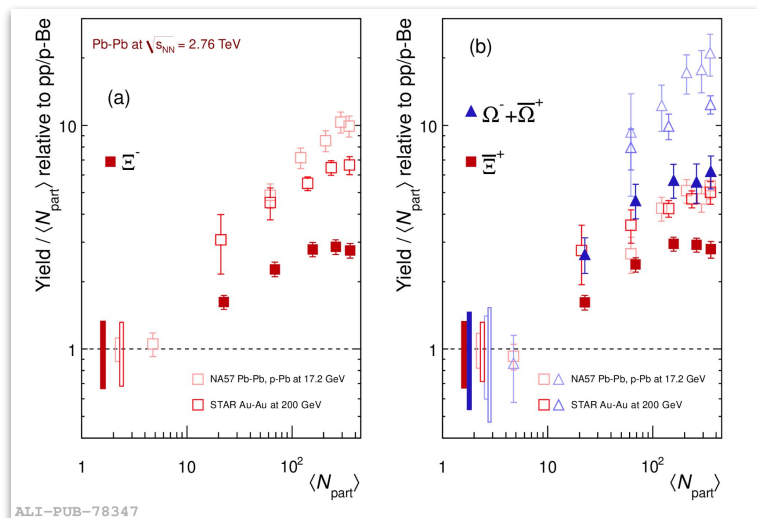
[6] ALICE Coll., [Phys. Lett. B 728 \(2014\) 216–227](#)

[7] ALICE Coll., [arXiv:2511.10360](#) (NEW!)





Strangeness enhancement (SE): experimentally observed at CERN SPS [2–4], BNL RHIC [5] and CERN LHC [6, 7]



Ratio of the yield of the particle under study to that of pions at the same $\sqrt{s}$

- strangeness production rate in AA is higher than in small collision systems
- strangeness production rate in AA collisions is constant
 - match predictions from statistical models

- **strangeness production enhanced** in large systems with respect to small ones
- enhancement increases with the strangeness content
- **energy hierarchy problem:** ratio larger for lower energy collisions

strangeness production in small systems depends on the energy $\rightarrow$ small systems cannot be used as a reference

[2] WA97 Coll., [Phys. Lett. B 449 \(1999\) 401–406](#)
 [3] NA49 Coll., [Phys. Lett. B 538 \(2002\) 275–281](#)
 [4] NA57 Coll., [J. Phys. G 37 \(2010\) 045105](#)

[5] STAR Coll., [Phys. Rev. C 77 \(2008\) 044908](#)
 [6] ALICE Coll., [Phys. Lett. B 728 \(2014\) 216–227](#)
 [7] ALICE Coll., [arXiv:2511.10360 \(NEW!\)](#)





Statistical Hadronization Models

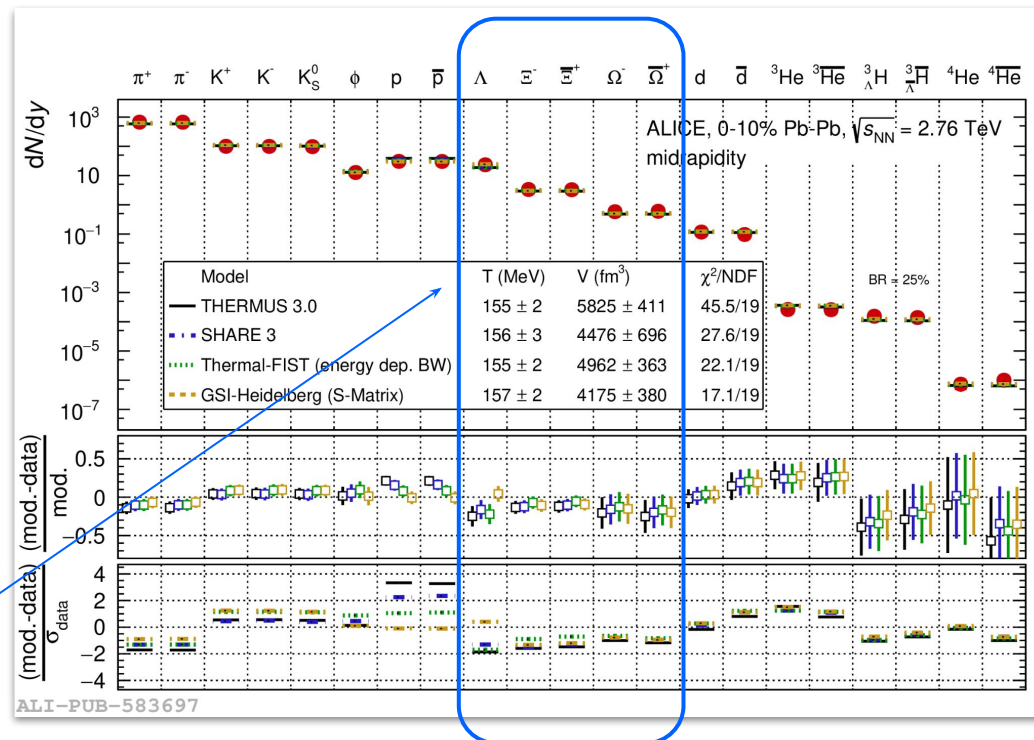
- **hadronization is modeled as the statistical emission of hadrons from an excited source**, described as an ideal gas of hadrons and resonances in thermal and chemical (non-interacting) equilibrium
- large systems: **grand-canonical ensemble**
- thermal parameters: T, V, μ (μ_Q, μ_B, μ_S)
 - extracted from a fit to the experimental data





Statistical Hadronization Models

- **hadronization is modeled as the statistical emission of hadrons from an excited source**, described as an ideal gas of hadrons and resonances in thermal and chemical (non-interacting) equilibrium
- large systems: **grand-canonical ensemble**
- thermal parameters: T, V, μ (μ_Q, μ_B, μ_S)
 - extracted from a fit to the experimental data
- **yields are reproduced well over 9 orders of magnitude, including strange particles**



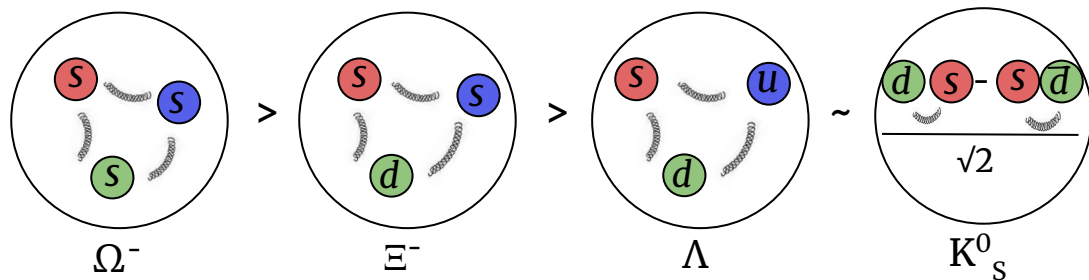
ALICE Coll., [Eur. Phys. J. C 84, 813 \(2024\)](#)



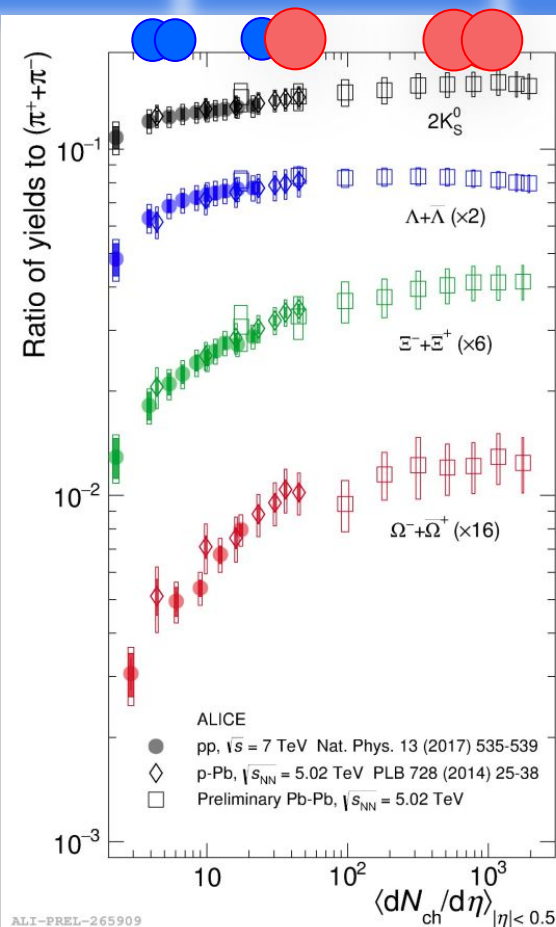


ALICE observed that the ratio of strange to non-strange hadron yields (h/π) [8, 9]:

- **increases with mid-rapidity multiplicity**
- **evolves independently on the different energies and colliding systems**
 - the origin of this effect is unexpected and unclear in smaller systems
- shows a **hierarchy with the hadron strangeness content**



ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)



$|S| = 1$

$|S| = 1$

$|S| = 2$

$|S| = 3$



[8] ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)

[9] ALICE Coll., [Eur. Phys. J. C 80 \(2020\) 2, 167](#)



ALICE observed that the ratio of strange to non-strange hadron yields (h/π) [8, 9]:

- increases with mid-rapidity multiplicity
- evolves independently on the different energies and colliding systems
 - the origin of this effect is unexpected and unclear in smaller systems
- shows a hierarchy with the hadron strangeness content

TAKE HOME MESSAGE

UNIVERSALITY

from the multiplicity information alone the chemical composition of the created system can be inferred

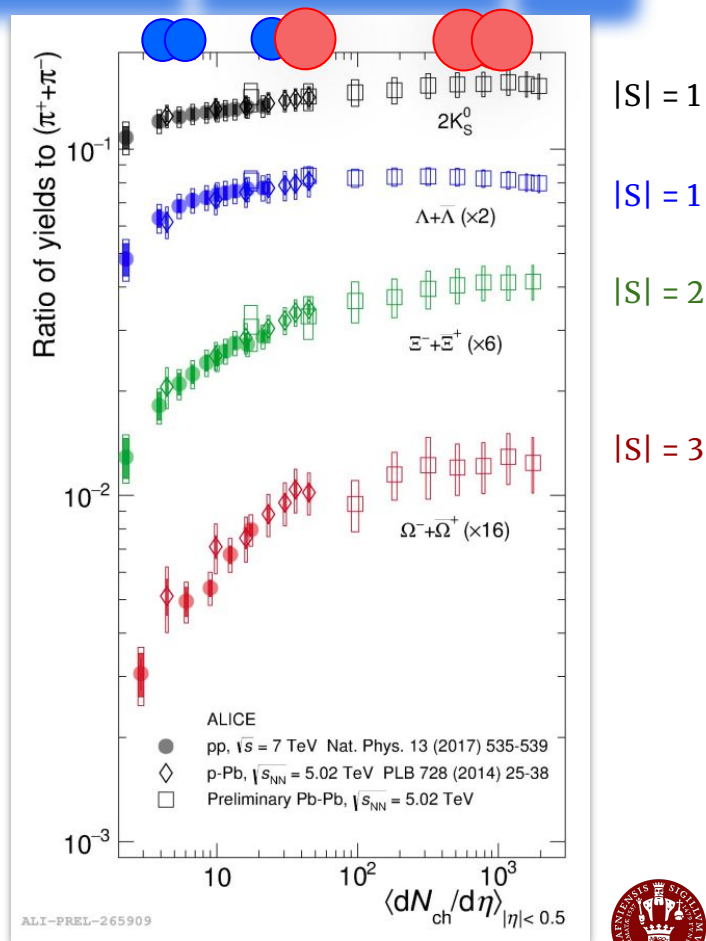
Ω^-

Ξ^-

Λ

K_S^0

ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)



[8] ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)

[9] ALICE Coll., [Eur. Phys. J. C 80 \(2020\) 2, 167](#)





ALICE observed that the ratio of strange to non-strange hadron yields (h/π) [8, 9]:

- increases with mid-rapidity multiplicity
- evolves independently on the different energies and colliding systems
 - the origin of this effect is unexpected and unclear in smaller systems
- shows a hierarchy with the hadron strangeness content

TAKE HOME MESSAGE

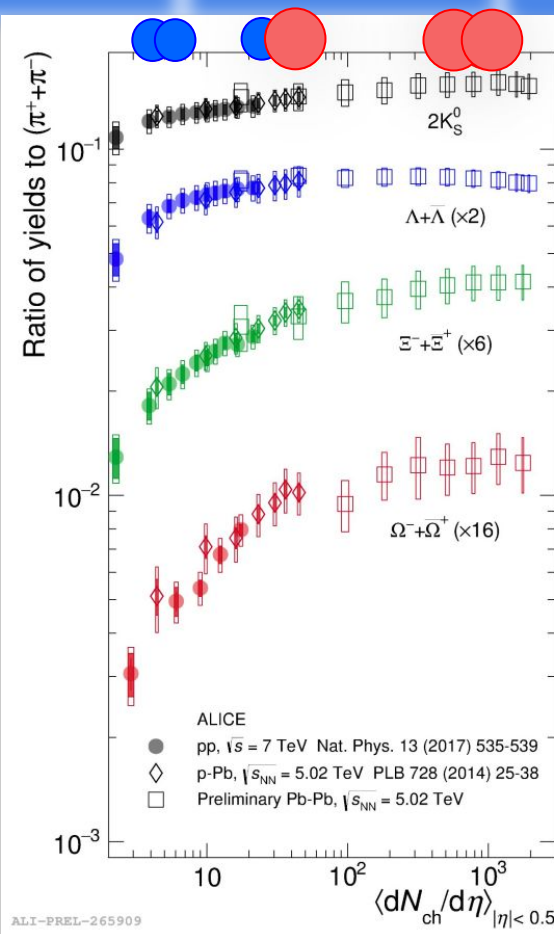
UNIVERSALITY

from the multiplicity information alone the chemical composition of the created system can be inferred

Ω^-

Is there a way to coherently describe particle production across collision systems?

ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)



$|S| = 1$

$|S| = 1$

$|S| = 2$

$|S| = 3$

[8] ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)

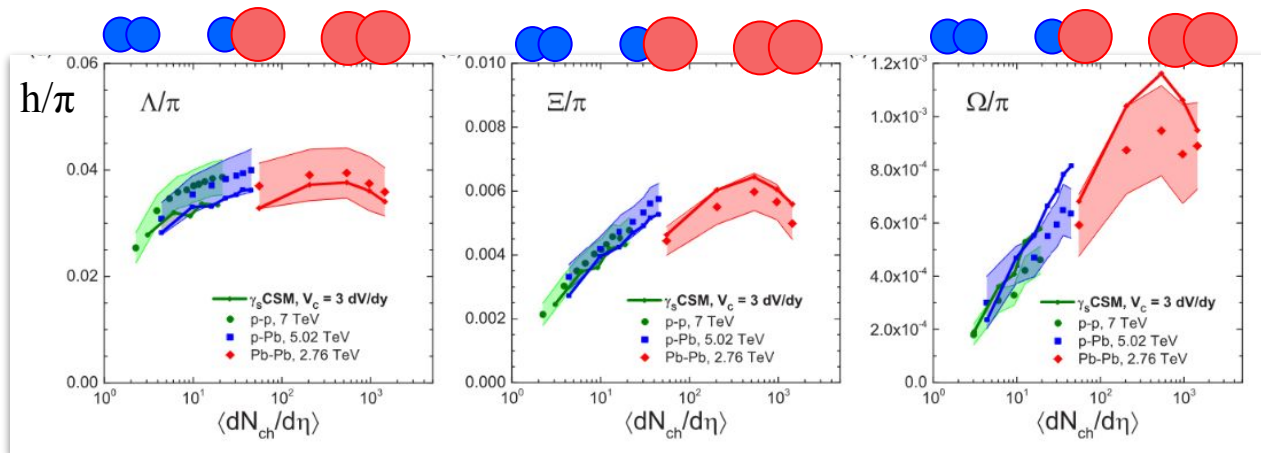
[9] ALICE Coll., [Eur. Phys. J. C 80 \(2020\) 2, 167](#)





- **Canonical suppression of strangeness (CSM)**

- extension of statistical models to small systems $\rightarrow$ conservation of the strange quantum number must be enforced locally
 - constraints on the phase space available for particle production
- introduce a strangeness saturation parameter γ_s
 - account for incomplete thermalization of strange quarks



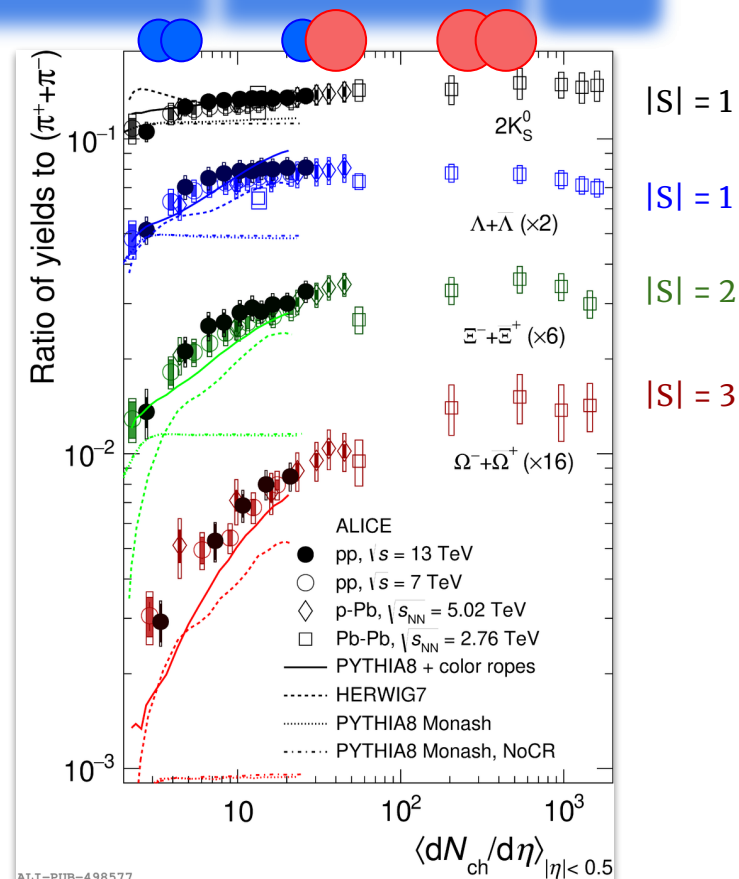
- Moving from Pb-Pb to pp: observed decrease in the strangeness production interpreted as a **suppression effect** due to the canonical conservation of strangeness

Vovchenko, V, et al., [Phys. Rev. C 100, 054906 \(2019\)](#)



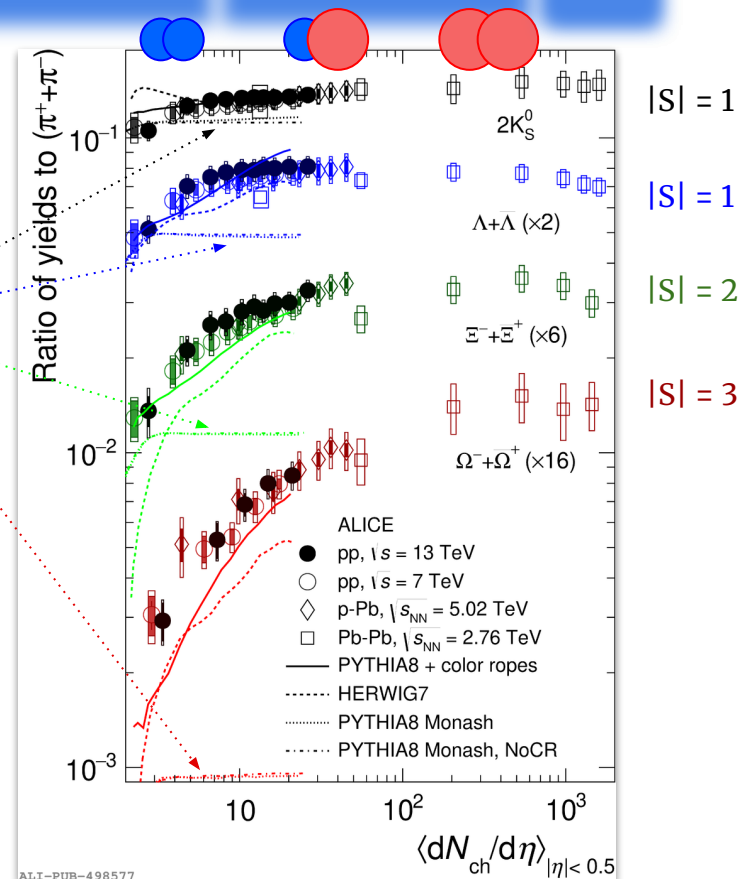


- [Pythia 8](#): linear parametrization of the QCD interaction potential at large distances (Lund string model)
 - confined color fields $\rightarrow$ “string”





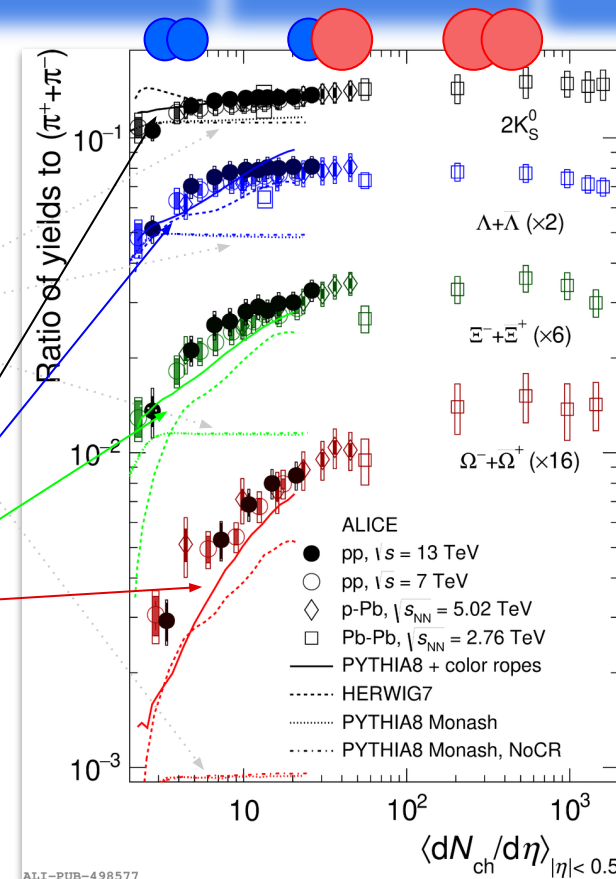
- [Pythia 8](#): linear parametrization of the QCD interaction potential at large distances (Lund string model)
 - confined color fields $\rightarrow$ “string”
- [Pythia 8 Monash](#): baseline of in-vacuum hadronization
 - hadron formation: string breaking
 - multiplicity dependence of particle production: multiple parton-parton interactions (MPI) + effective interaction among strings (CR)





- [Pythia 8](#): linear parametrization of the QCD interaction potential at large distances (Lund string model)
 - confined color fields → “string”
- [Pythia 8 Monash](#): baseline of in-vacuum hadronization
 - hadron formation: string breaking
 - multiplicity dependence of particle production: multiple parton-parton interactions (MPI) + effective interaction among strings (CR)
- [Pythia 8 QCD-CR Ropes](#): newest version
 - hadron formation: overlapping strings (color-rope)
 - multiplicity dependence of particle production: MPI + sophisticated CR

enhanced production rate of strange particles



$|S| = 1$

$|S| = 1$

$|S| = 2$

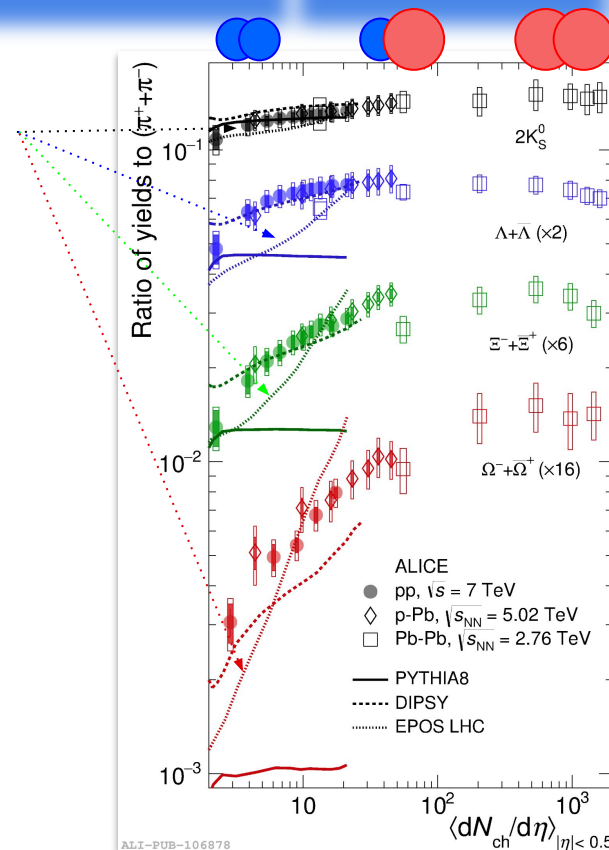
$|S| = 3$





- EPOS LHC: double regime scenario

- core $\rightarrow$ high energy density (statistical hadronization)
- corona $\rightarrow$ in-vacuum hadronization (string fragmentation)
- multiplicity dependence of particle production: different relative importance of core and corona across multiplicity



$|S| = 1$

$|S| = 1$

$|S| = 2$

$|S| = 3$

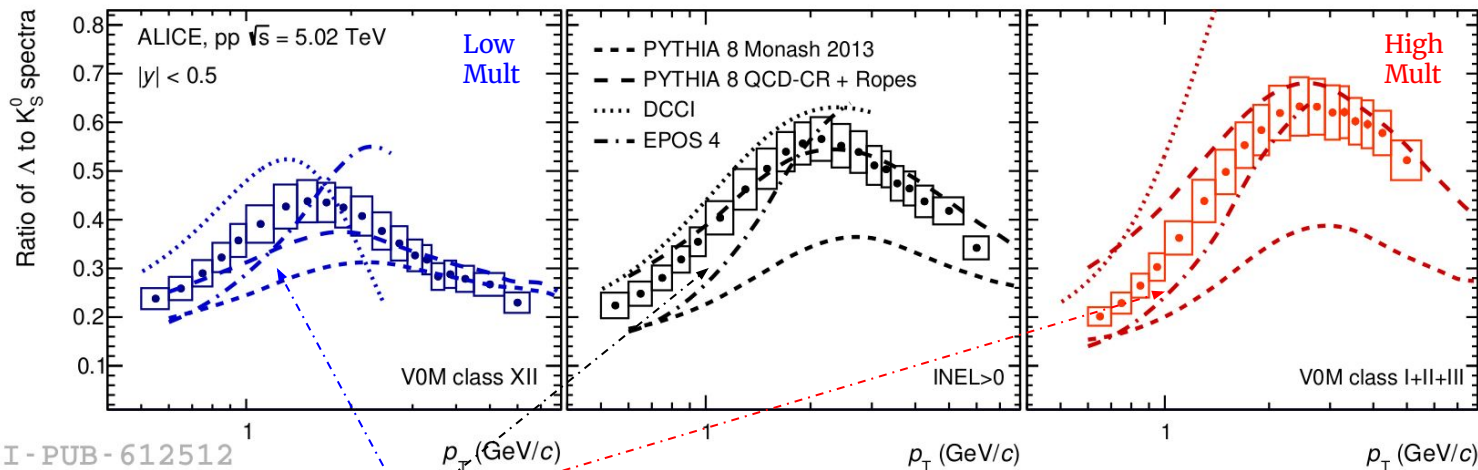
ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)





- **EPOS LHC: double regime scenario**

New paper !



ALICE largest and most precise dataset in pp collisions: strangeness production at $\sqrt{s} = 5.02$ TeV

ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306)

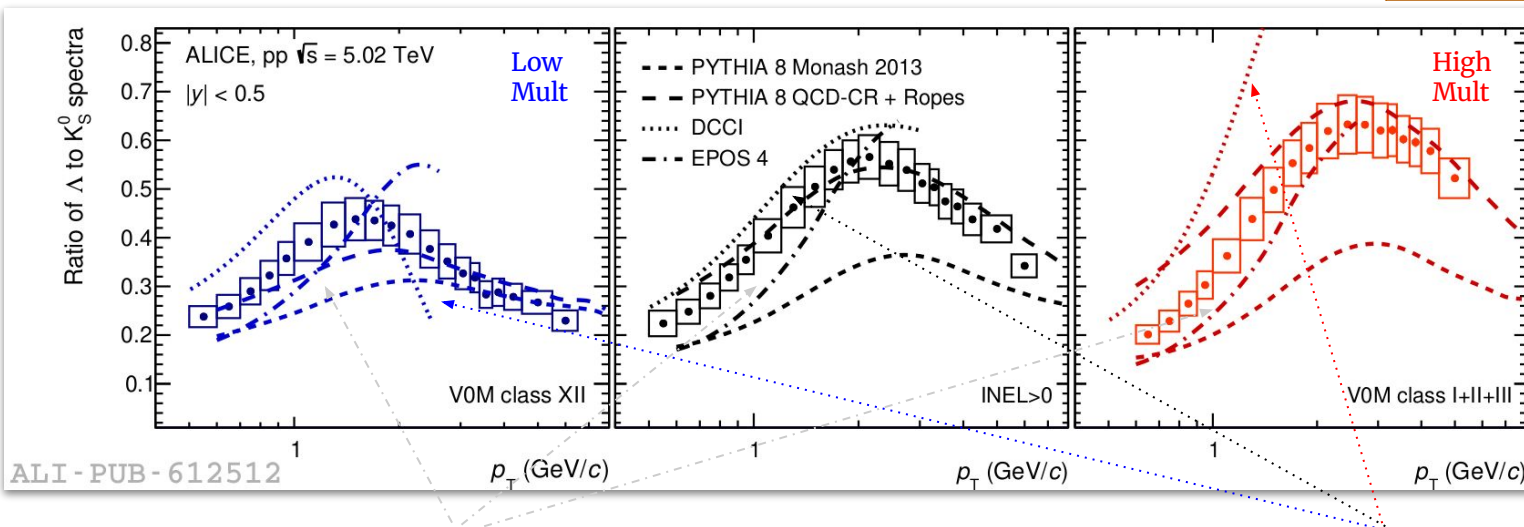
- **EPOS 4: modified hadronization in high-multiplicity environments (core)**
 - core $\rightarrow$ statistical hadronization + **hydrodynamic** expansion
 - corona $\rightarrow$ string fragmentation
 - multiplicity dependence of particle production: saturation effects and collective expansion





- EPOS LHC: double regime scenario

New paper !



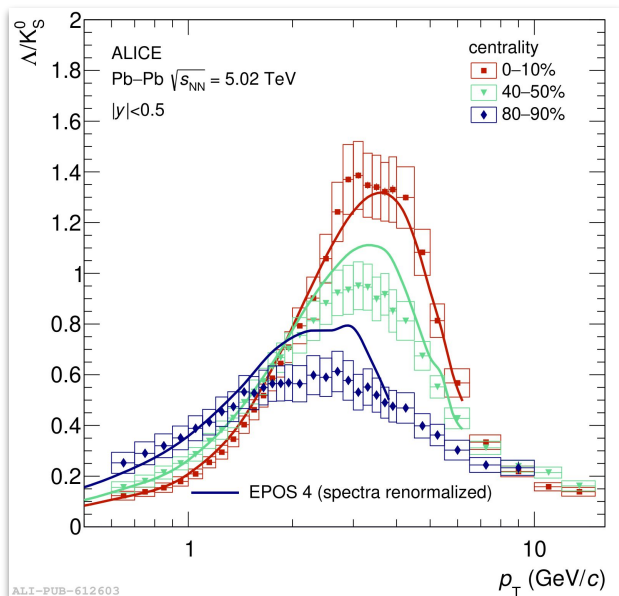
ALICE largest and most precise dataset in pp collisions: strangeness production at $\sqrt{s} = 5.02$ TeV

ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306)

- EPOS 4: modified hadronization in high-multiplicity environments (core)
 - core $\rightarrow$ statistical hadronization + **hydrodynamic** expansion
 - corona $\rightarrow$ string fragmentation
 - multiplicity dependence of particle production: saturation effects and collective expansion

- DCCI: state of the art core-corona approach
 - **evolution of the system is dynamic**
 - hadronization: in vacuum (using PYTHIA) or using the Cooper-Frye formula from core droplets



**New paper !**ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360)

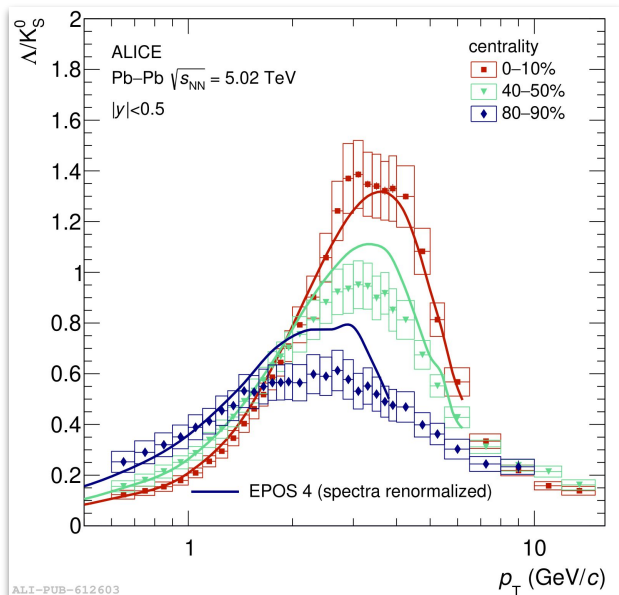
- Peak shifts to higher p_T with increasing multiplicity (stronger radial flow for baryons)
- [EPOS 4](#) describes central collisions; agreement worsens at intermediate/high p_T in semi-central and peripheral collisions → hydrodynamic expansion



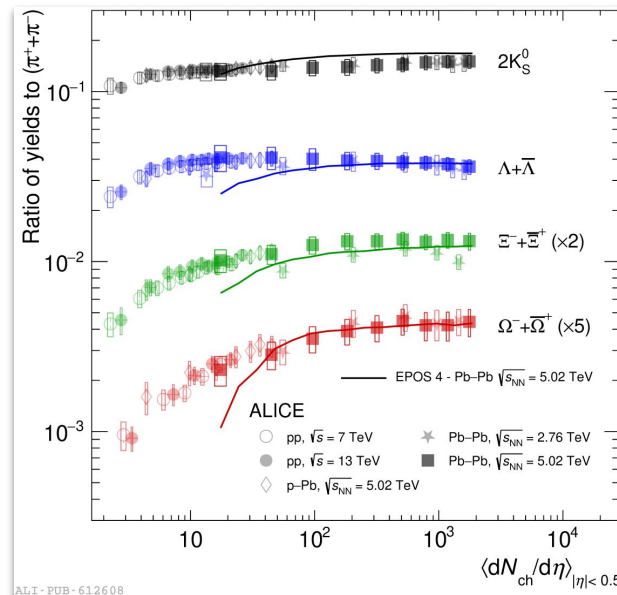


ALICE largest and most precise dataset in Pb–Pb collisions: strangeness production at $\sqrt{s} = 5.02$ TeV

New paper !



- Peak shifts to higher p_T with increasing multiplicity (stronger radial flow for baryons)
- **EPOS 4** describes central collisions; agreement worsens at intermediate/high p_T in semi-central and peripheral collisions $\rightarrow$ **hydrodynamic expansion**



- **EPOS 4** describes the evolution of h/π in Pb–Pb $\rightarrow$ recent tuning of core–corona mechanism is responsible SE
- qualitative agreement, despite remaining quantitative tensions

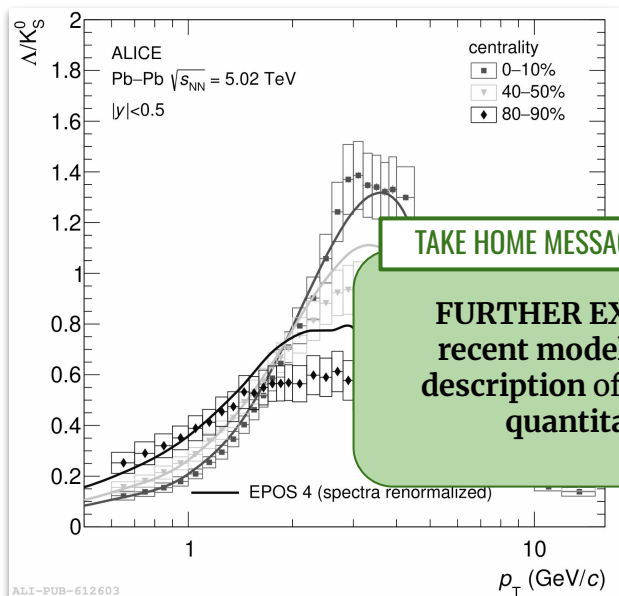
ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360)





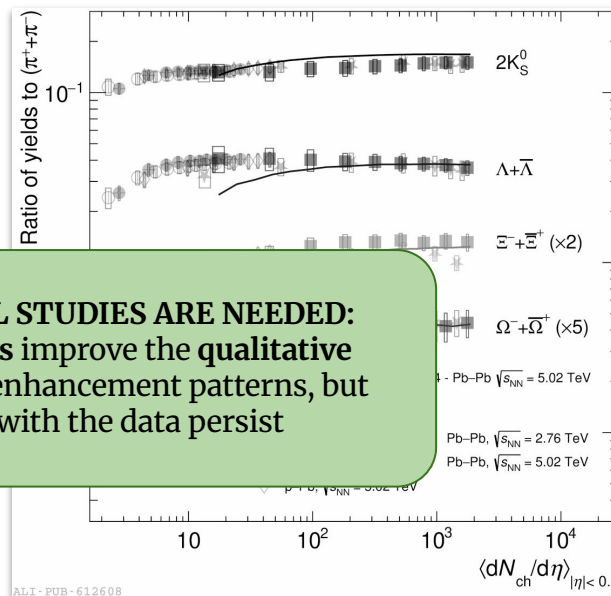
ALICE largest and most precise dataset in Pb–Pb collisions: strangeness production at $\sqrt{s} = 5.02$ TeV

New paper !



TAKE HOME MESSAGE

FURTHER EXPERIMENTAL STUDIES ARE NEEDED:
recent model developments improve the **qualitative**
description of strangeness-enhancement patterns, but
quantitative tensions with the data persist



ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360)



- Peak shifts to higher p_T with increasing multiplicity (stronger radial flow for baryons)
- EPOS 4 describes central collisions; agreement worsens at intermediate/high p_T in semi-central and peripheral collisions → hydrodynamic expansion

- EPOS 4 describes the evolution of h/π in Pb–Pb → recent tuning of core–corona mechanism is responsible SE
- qualitative agreement, despite remaining quantitative tensions



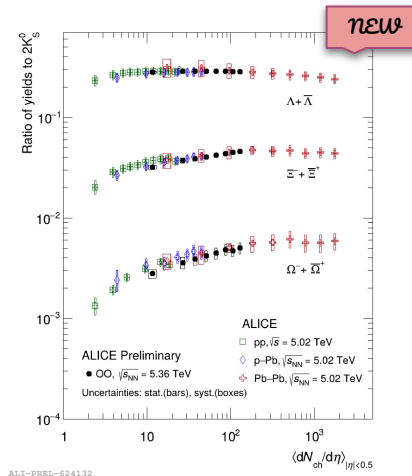


- **Physics motivations**
 - strange hadron production in high-energy hadronic collisions
 - strangeness hadronization models
 - higher precision results in pp and Pb–Pb collisions at 5.02 TeV from ALICE Collaboration ([arXiv:2511.10306](#), [arXiv:2511.10360](#))
- **New Run 3 results in OO and pp collisions at 5.36 TeV from ALICE Collaboration**
- **New observable: (multi-) strange particle multiplicity distributions** ([arXiv:2511.10413](#))
 - multiple strange hadron production yields vs multiplicity
 - yield ratios





- **Build a bridge from small to large systems** → investigate the strangeness production in light-ion collisions
 - Preliminary approved results in OO collisions at 5.36 TeV, next step investigate also p-O and Ne-Ne collisions



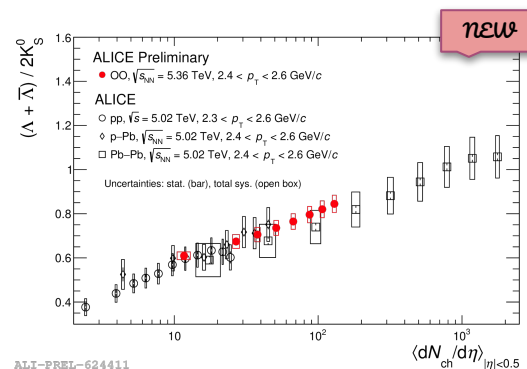
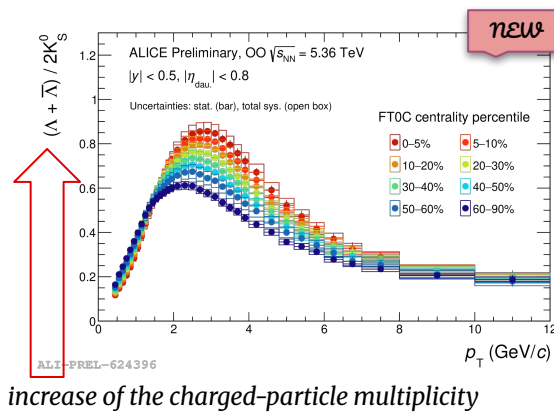
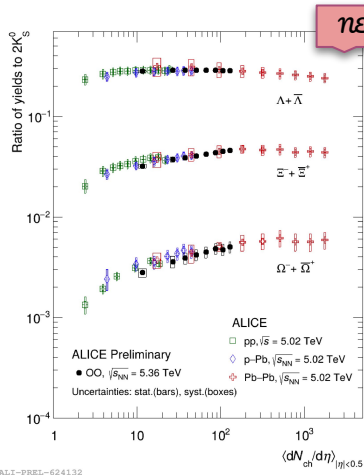
Particle yields: OO results are consistent with the smooth, multiplicity-driven evolution of strange-hadron production observed across colliding systems

ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306) (NEW!)
ALICE Coll., [Phys.Lett.B 728 \(2014\) 25-38, 2014](https://arxiv.org/abs/2511.10360)
ALICE Coll., [Phys.Lett.B 758 \(2016\) 389-401, 2016](https://arxiv.org/abs/2511.10360)
ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360) (NEW!)





- Build a bridge from small to large systems → investigate the strangeness production in light-ion collisions
 - Preliminary approved results in OO collisions at 5.36 TeV, next step investigate also p-O and Ne-Ne collisions



Particle yields: OO results are consistent with the smooth, multiplicity-driven evolution of strange-hadron production observed across colliding systems

Baryon-to-meson p_T spectra ratios

- increase at intermediate p_T across all centrality classes
 - convergence at high p_T across all centrality classes
- interplay of hydrodynamic expansion and coalescence
- across collision systems at fixed p_T : Λ/K^0_s evolves smoothly with the charged-particle multiplicity

ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306) (NEW!)

ALICE Coll., [Phys.Lett.B 728 \(2014\) 25-38, 2014](https://arxiv.org/abs/2511.10306)

ALICE Coll., [Phys.Lett.B 758 \(2016\) 389-401, 2016](https://arxiv.org/abs/2511.10306)

ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10306) (NEW!)



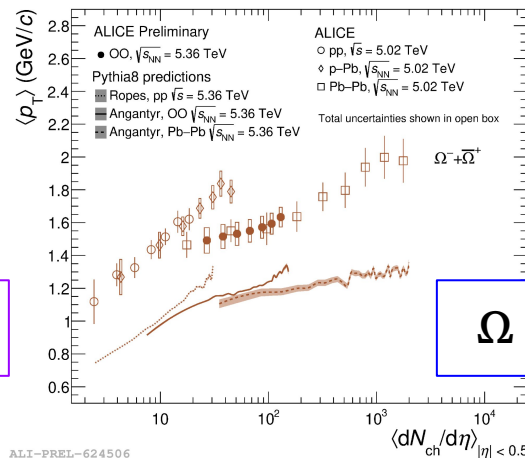
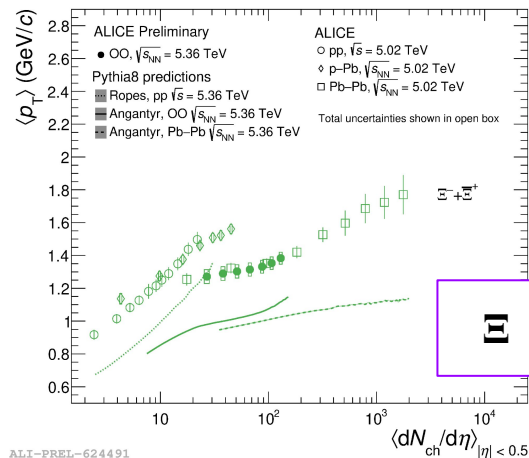
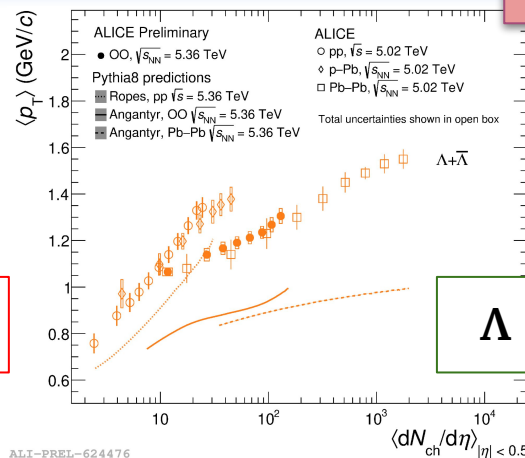
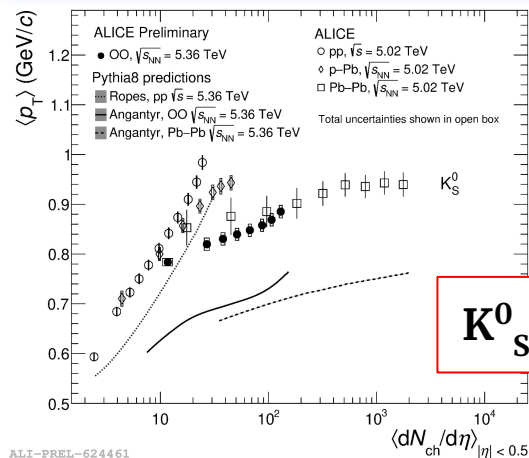


new



$\langle p_T \rangle$ evolution with multiplicity

- clear multiplicity dependence for all particles
- small and large collision systems show a visible discontinuity
- OO results follow the Pb–Pb like evolution
 - multiplicity comparable to small systems
 - spectral hardening closer to large systems
- Model comparison:
 - None of the model ([Pythia8 Angantyr](#) for OO and Pb–Pb, [Pythia8 Ropes](#) for pp) simultaneously describes the trend and magnitude over the full multiplicity range → [EPOS 4](#) simulations are ongoing



ALICE Coll., [arXiv:2511.10306](#) (NEW!)

ALICE Coll., [Phys.Lett.B 728 \(2014\) 25–38, 2014](#)

ALICE Coll., [Phys.Lett.B 758 \(2016\) 389–401, 2016](#)

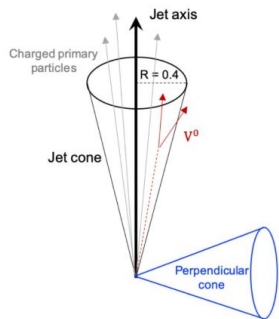
ALICE Coll., [arXiv:2511.10360](#) (NEW!)

NBI seminar - 28/05/2026

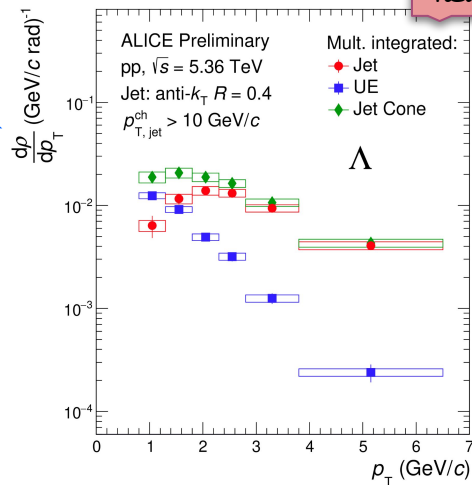




- Build a bridge from small to large systems → investigate the strangeness production in light-ion collisions
 - Preliminary approved results in OO collisions at 5.36 TeV, next step investigate also p-O and Ne-Ne collisions
- Find other properties than a difference in $\langle dN_{ch}/d\eta \rangle$
 - Connection of **strangeness production with the presence of jets** → preliminary approved results for VOs in pp collisions at 5.36 TeV, next step investigate also cascades and pp at 13.6 TeV



$$\frac{d\rho}{dp_T} = \frac{1}{N_{ev}} \times \frac{1}{A_{acc}} \times \frac{dN}{dp_T}$$



p_T differential density: the spectra in **jets** are harder than in the **UE**

Analogous in Run 2 measurement at 13 TeV
ALICE Coll., [JHEP 07 \(2023\) 136](https://arxiv.org/abs/2301.136)

- Charged-particle jet reconstructed using the anti- k_T algorithm with jet $p_T > 10$ GeV/c
- **Jet cone (JC)**: R (strange hadron, jet) < 0.4
- **Underlying Event (UE)**: strange hadrons in perpendicular cone (PC)
- **In Jet production (JE)** = JC - PC

ALI-PREL-626744

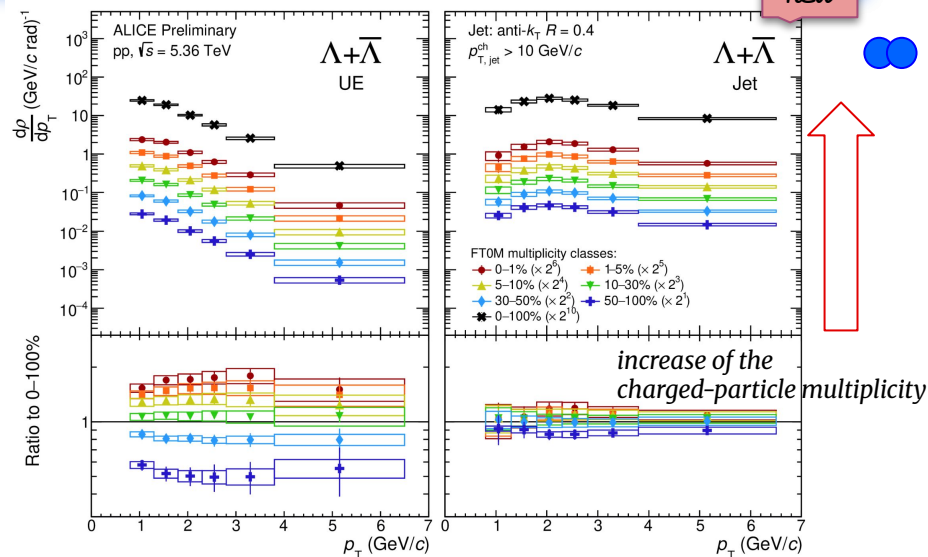




What is the sensitivity of strangeness production in- and out-of-jets to the event activity?

First measurement of the p_T differential density vs multiplicity

- **UE:** hardening of the p_T spectra with event multiplicity → similar to inclusive measurement
- **In Jet:** the effect is **suppressed** → spectral shapes and yields are consistent across multiplicity classes



ALI-PREL-626747

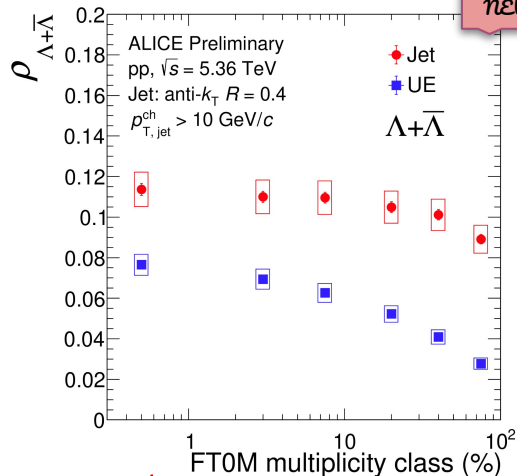




What is the sensitivity of strangeness production in- and out-of-jets to the event activity?

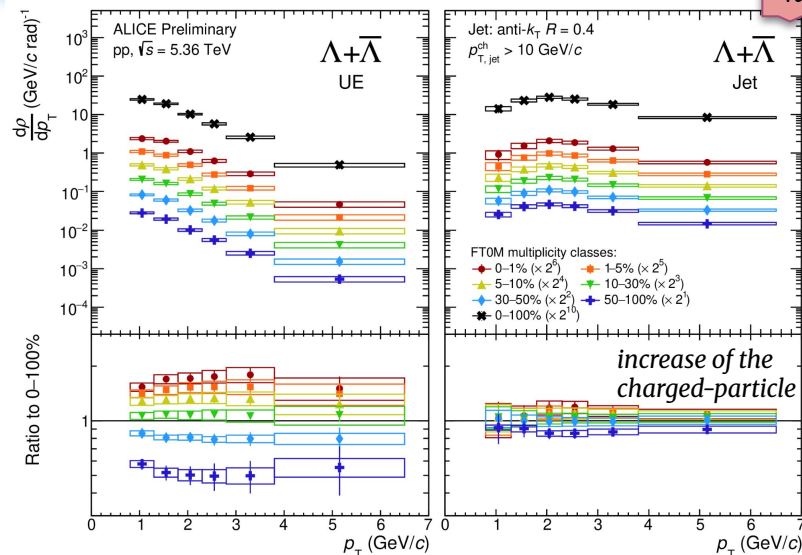
First measurement of the p_T differential density vs multiplicity

- **UE:** hardening of the p_T spectra with event multiplicity $\rightarrow$ similar to inclusive measurement
- **In Jet:** the effect is **suppressed** $\rightarrow$ spectral shapes and yields are consistent across multiplicity classes



ALI-PREL-626751

increase of the charged-particle multiplicity



ALI-PREL-626747

First measurement of the p_T integrated yields vs multiplicity

- Strangeness evolution with multiplicity is primarily driven by the UE
- The total production becomes dominated by the jet component in events with a jet $p_T > 10$ GeV/c

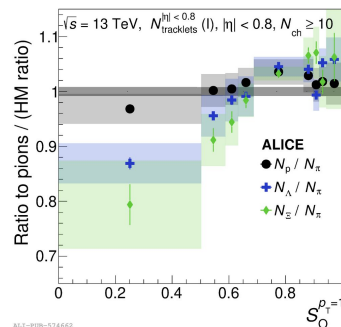




- Build a bridge from small to large systems → investigate the strangeness production in light-ion collisions
 - Preliminary approved results in OO collisions at 5.36 TeV, next step investigate also p-O and Ne-Ne collisions
- Find other properties than a difference in $\langle dN_{ch}/d\eta \rangle$
 - Connection of strangeness production with the presence of jets → preliminary approved results for VOs in pp collisions at 5.36 TeV, next step investigate also cascades and pp at 13.6 TeV

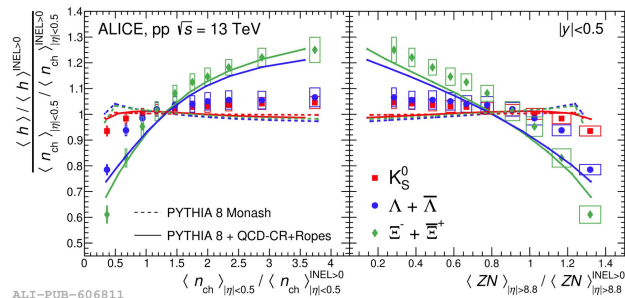
- Classification via the shape of the event (sphericity)

ALICE Coll., [JHEP 2024 \(2024\) 184](#)



- Tentative connection of SE to global event properties (effective energy)

ALICE Coll., [JHEP 03 \(Mar., 2025\) 29](#)

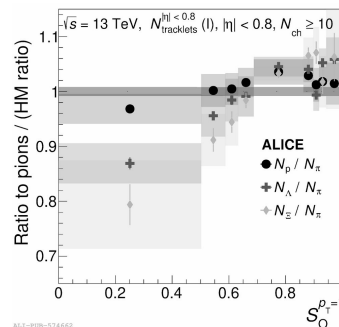




- Build a bridge from small to large systems → investigate the strangeness production in light-ion collisions
 - Preliminary approved results in OO collisions at 5.36 TeV, next step investigate also p-O and Ne-Ne collisions
- Find other properties than a difference in $\langle dN_{ch}/d\eta \rangle$
 - Connection of strangeness production with the presence of jets → preliminary approved results for VOs in pp collisions at 5.36 TeV, next step investigate also cascades and pp at 13.6 TeV

- Classification via the shape of the event (sphericity)

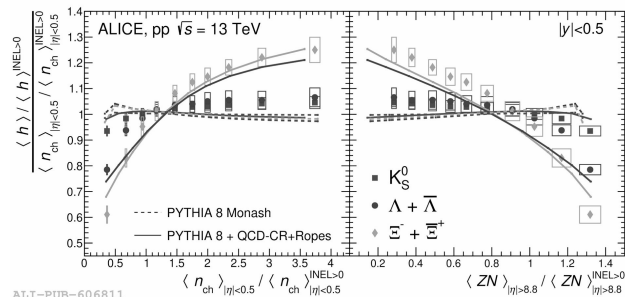
ALICE Coll., [JHEP 2024 \(2024\) 184](#)



- Tentative connection of SE to global event properties (effective energy)

ALICE Coll., [JHEP 03 \(Mar., 2025\) 29](#)

- Test available models to higher order observables
 - Measure the (multi-)strange particle multiplicity distribution



ALICE-PUB-606811





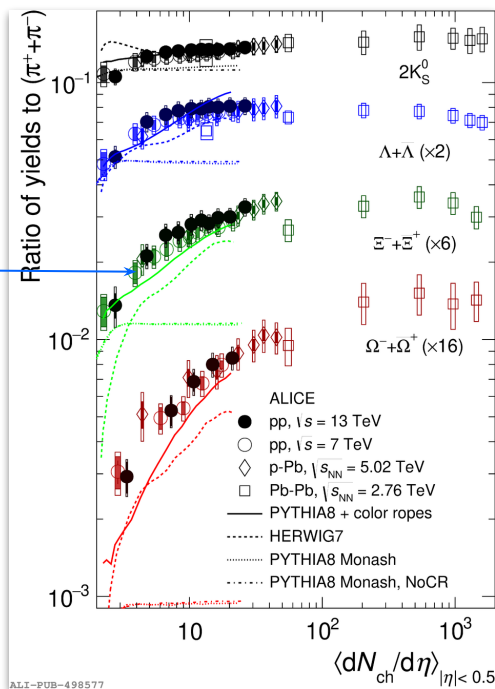
- **Physics motivations**
 - strange hadron production in high-energy hadronic collisions
 - strangeness hadronization models
 - higher precision results in pp and Pb–Pb collisions at 5.02 TeV from ALICE Collaboration ([arXiv:2511.10306](#), [arXiv:2511.10360](#))
- **New Run 3 results in OO and pp at 5.36 TeV from ALICE Collaboration**
- **New observable: (multi-) strange particle multiplicity distributions ([arXiv:2511.10413](#))**
 - multiple strange hadron production yields vs multiplicity
 - yield ratios





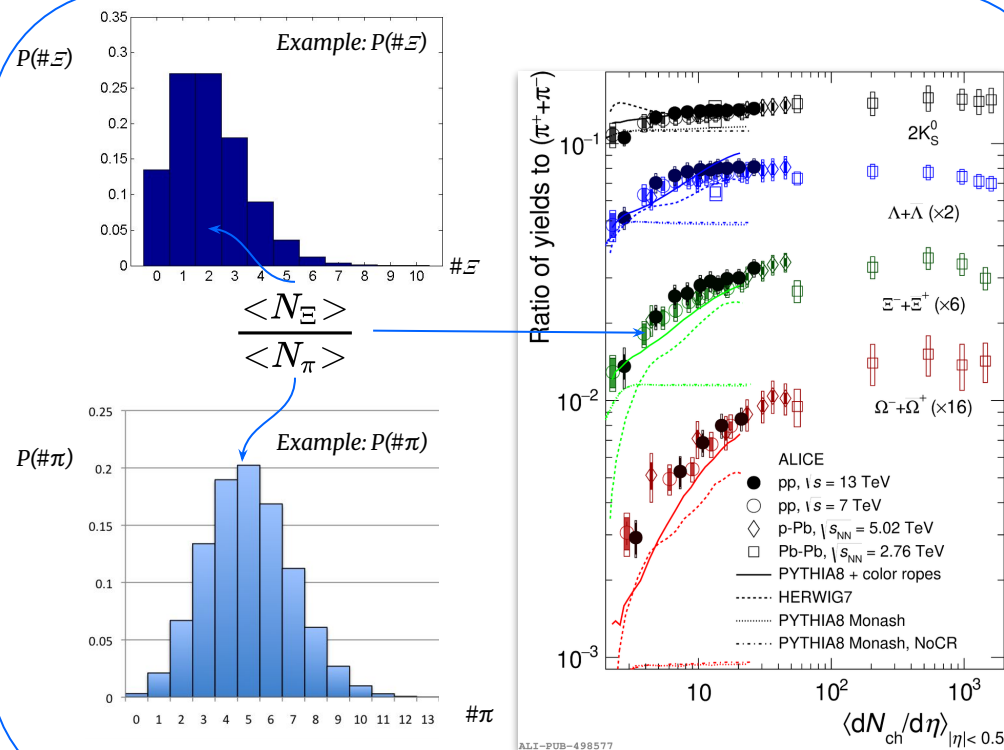
Published results: analysis of the number of strange particles in a given set of events → **average value of production rate**

$$\frac{\langle N_{\Xi} \rangle}{\langle N_{\pi} \rangle}$$





Published results: analysis of the number of strange particles in a given set of events → average value of production rate



More insightful information on the strangeness production: (multi-)strange particle multiplicity distribution

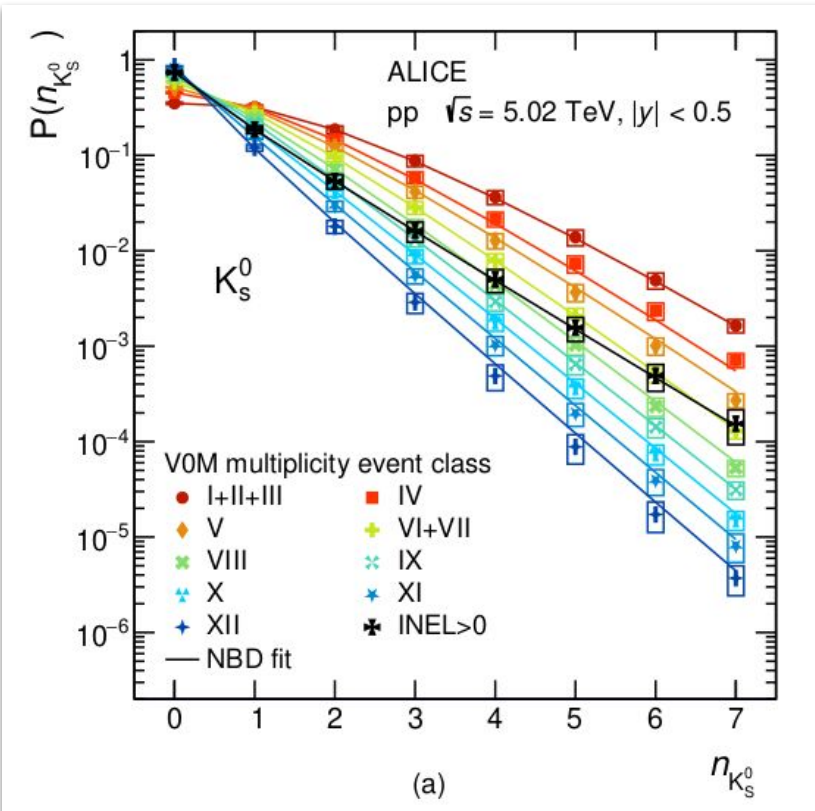
- extend beyond the average of the distribution
- new test bench for production mechanisms, probing events with a large imbalance between strange and non-strange content
- powerful tool for MC tuning





Probability to produce n particles of a given species per event

New paper !



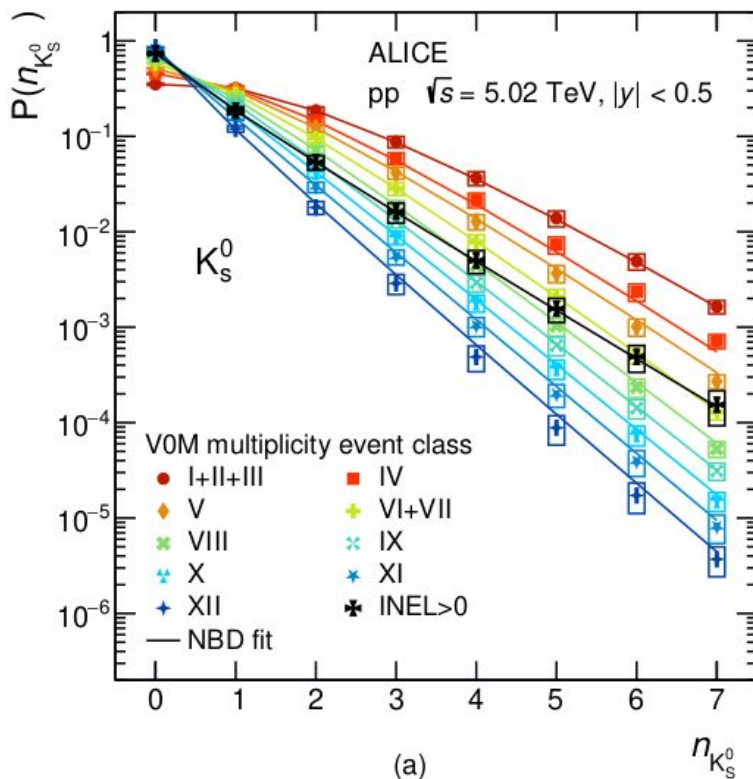
First measurement of the probability to produce n particles of a given species per event $P(n_s)$ for different selection in the event multiplicity





Probability to produce n particles of a given species per event

New paper !



First measurement of the probability to produce n particles of a given species per event $P(n_s)$ for different selection in the event multiplicity

- for $n_s > 0$, $P(n_s)$ increases with multiplicity

increase of the charged-particle multiplicity





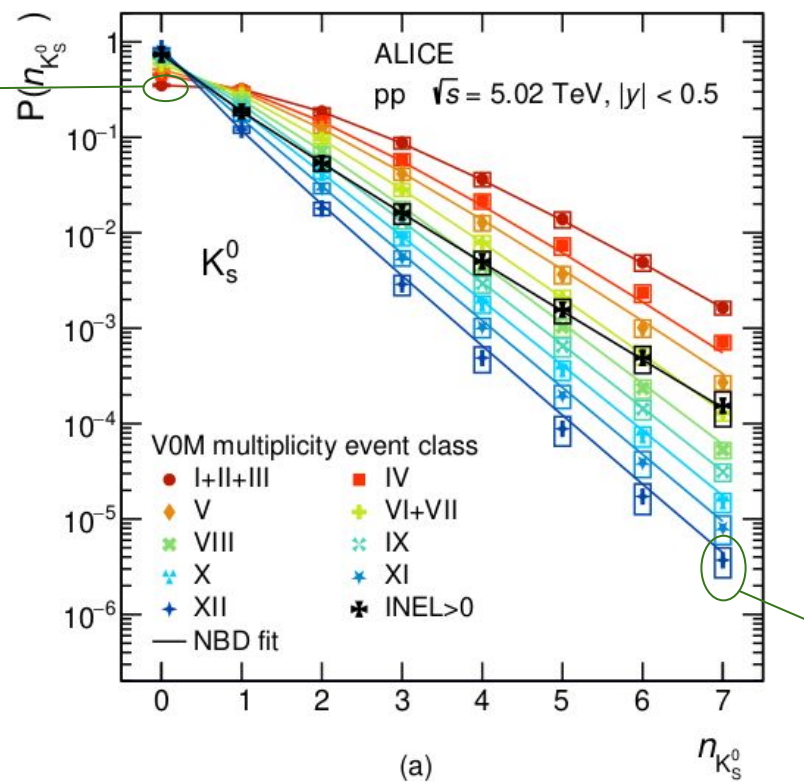
Probability to produce n particles of a given species per event

New paper !



First measurement of the probability to produce n particles of a given species per event $P(n_s)$ for different selection in the event multiplicity

- for $n_s > 0$, $P(n_s)$ increases with multiplicity
- spanning across large ranges of strange/multiplicity variations, all the way to very “extreme” situations (e.g. 7 K_s^0 at low average charged-particle multiplicity, 0 K_s^0 at high average charged-particle multiplicity)



increase of the charged-particle multiplicity

7 K_s^0 /ev
 $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5} \sim 3$

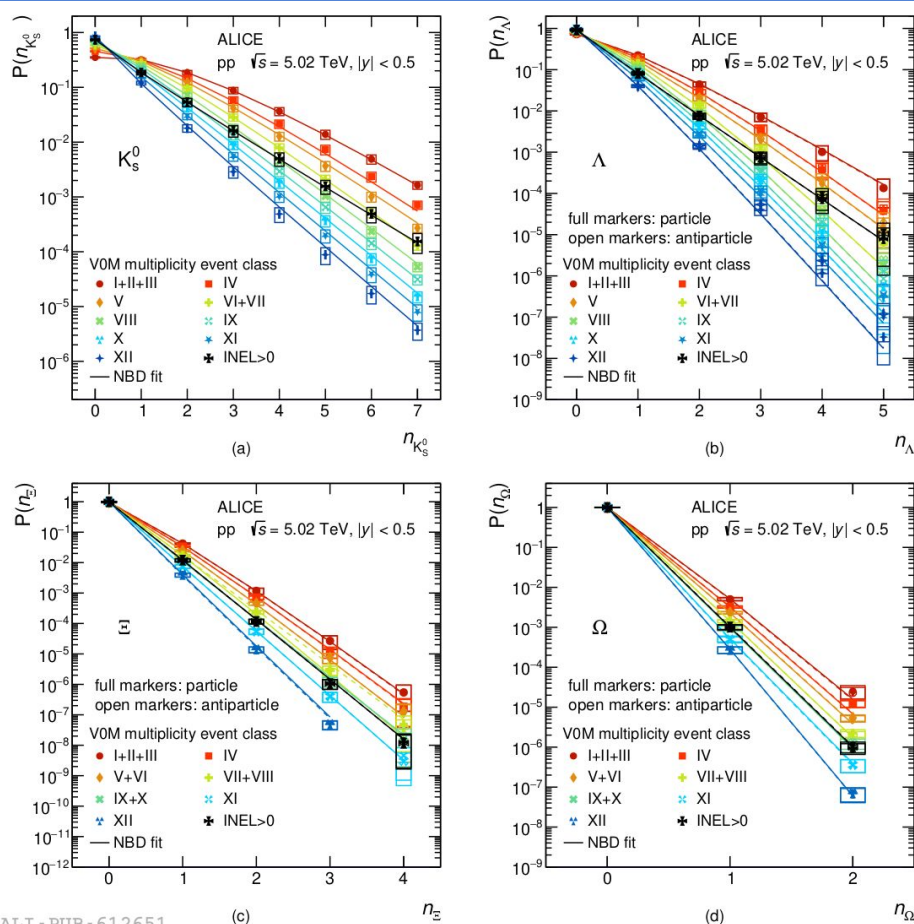




New paper !

First measurement of the probability to produce n particles of a given species per event $P(n_s)$

- dataset allows measurement of $P(n_s)$ up to 7 K_s^0 , 5 Λ , 4 Ξ and 2 Ω particles per event
- good agreement between particle and antiparticle
- Negative Binomial Distribution [10, 11] is able to accommodate all the data (V^0 s: $\chi^2 < 1$, cascades: $\chi^2 < 3$)
- same physics message discussed for K_s^0





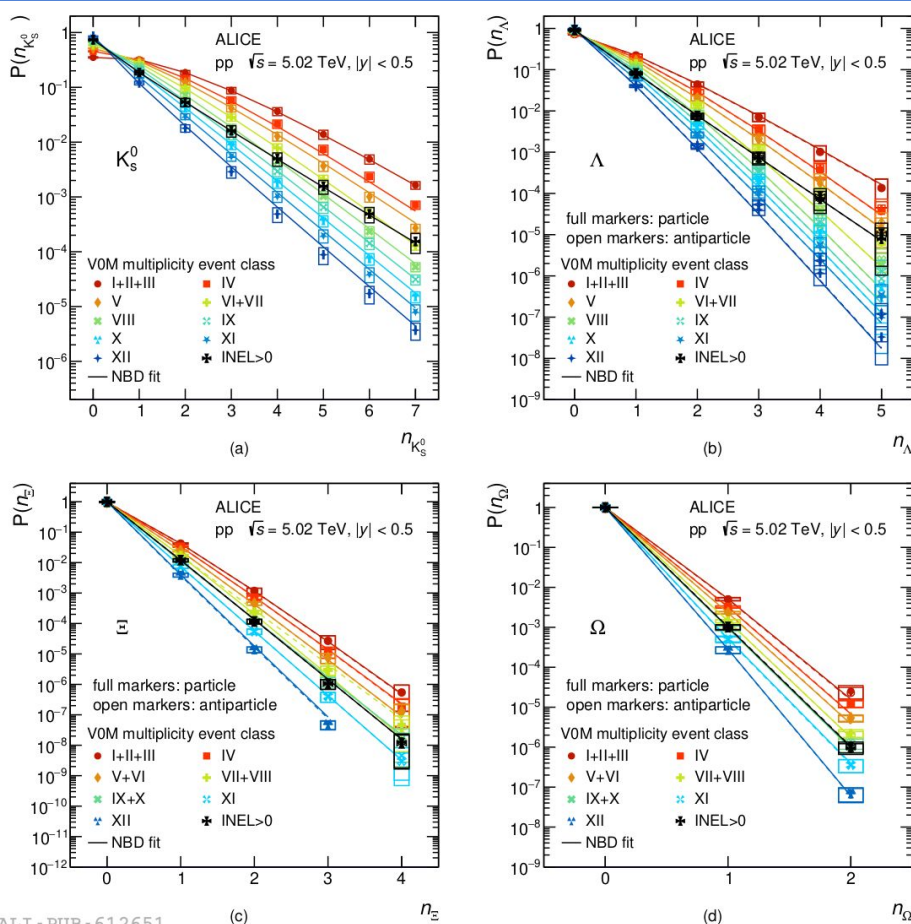
New paper !

First measurement of the probability to produce n particles of a given species per event $P(n_s)$

- dataset allows measurement of $P(n_s)$ up to 7 K_s^0 , 5 Λ , 4 Ξ and 2 Ω particles per event
- good agreement between particle and antiparticle
- Negative Binomial Distribution [10, 11] is able to accommodate all the data (V^0 s: $\chi^2 < 1$, cascades: $\chi^2 < 3$)
- same physics message discussed for K_s^0

TAKE HOME MESSAGE

The measurement of $P(n_s)$ represents a unique opportunity to test the connection between charged- and strange- particle production



ALI-PUB-612651

ALICE Coll., [arXiv:2511.10413](https://arxiv.org/abs/2511.10413)

NBI seminar - 28/05/2026





$P(n_S)$ allows to calculate the **average production yield of n particles/event**:

$$\langle Y_{nS} \rangle = \sum_{i=n}^{n_S^{\max}} \frac{i!}{n!(i-n)!} \cdot P(i_S)$$

- $\langle Y_{1S} \rangle$: **mean** of the multiplicity distribution (dN/dy in previous studies)
- $\langle Y_{n>1S} \rangle$: **average production yield of multiplets** ($n = 1$ singlet, $n = 2$ doublets, and so on) of the particle
 - e.g. doublets $\rightarrow$ equivalent to the extraction of double signal through 2D invariant mass fit



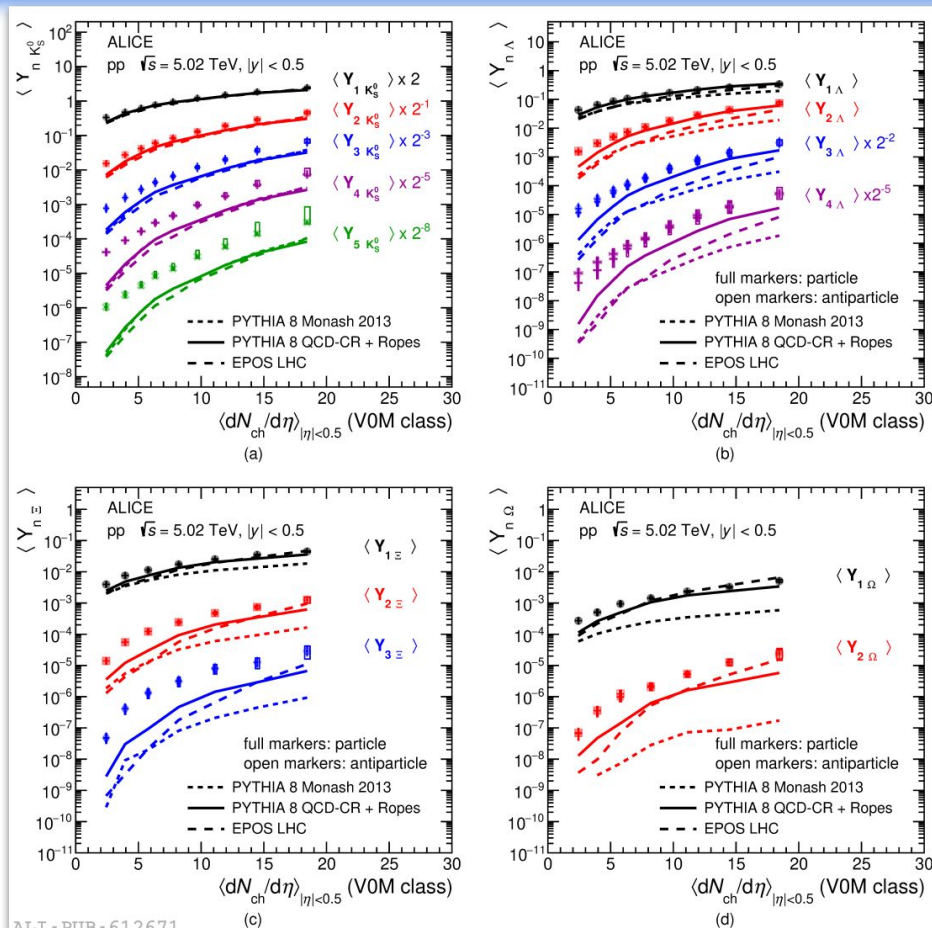


New paper !

Average production yield of n particles/event:

$$\langle Y_{nS} \rangle = \sum_{i=n}^{n_S^{\max}} \frac{i!}{n!(i-n)!} \cdot P(i_S)$$

- More than linear increase with multiplicity of the probability for $nhS > 1$
- Model comparison:
 - the agreement worsens with increasing n
 - K_S^0 : no differences between [Pythia 8 Monash](#) and [Pythia 8 QCD-CR Ropes](#)
 - for baryons: [Pythia 8 QCD-CR Ropes](#) approaches the data at high multiplicity; [EPOS LHC](#) does a rather good job at high multiplicity, but shows larger discrepancy at low multiplicity



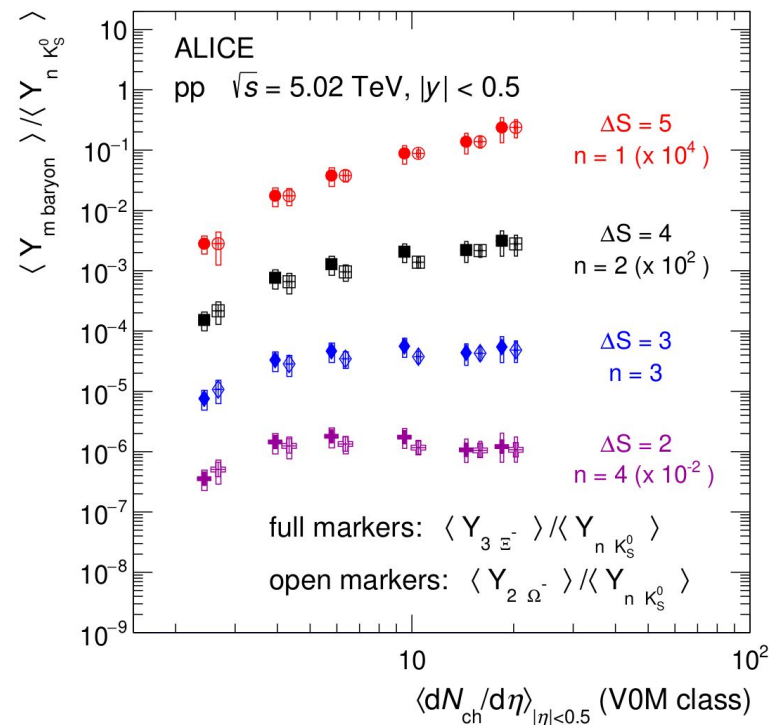


New paper !

 ΔS moves from 2 to 5

First-time investigation of strangeness enhancement with ΔS up to 5

- $\Delta S = 5$: unprecedented enhancement of 2 orders of magnitude between lowest and highest multiplicity classes
- consistency between trends for $\langle Y_{3\Xi} \rangle$ and $\langle Y_{2\Omega} \rangle$



Compatible with:

$$\frac{\Omega}{\pi}$$

$$\frac{\Xi/\pi}{\Omega/K_S^0}$$





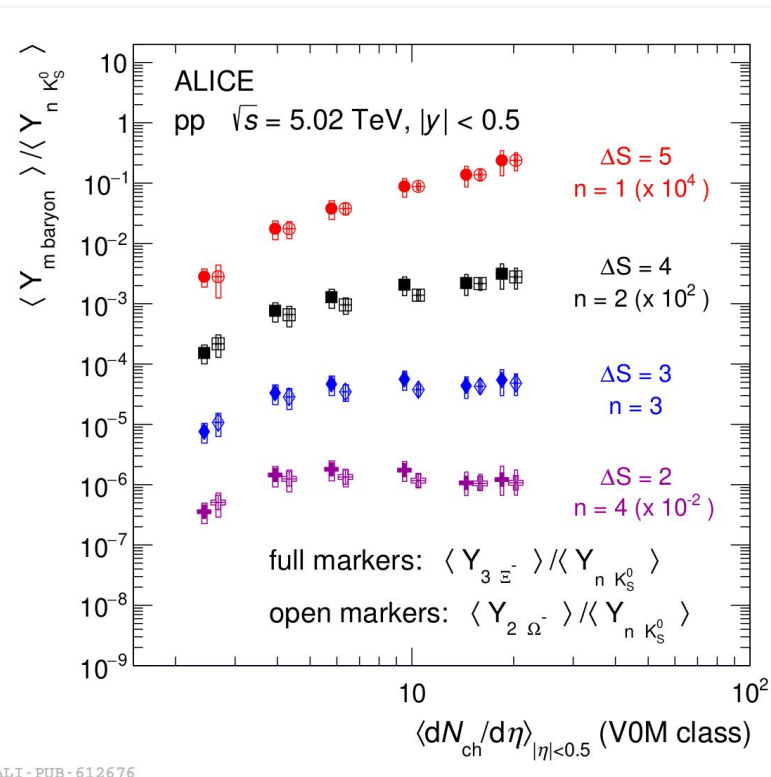
New paper !

 ΔS moves from 2 to 5First-time investigation of strangeness enhancement with ΔS up to 5

- $\Delta S = 5$: unprecedented enhancement of 2 orders of magnitude between lowest and highest multiplicity classes
- consistency between trends for $\langle Y_{3\Xi} \rangle$ and $\langle Y_{2\Omega} \rangle$

TAKE HOME MESSAGE

Enhancement proportional to S even when exceeding the maximum number of strange quarks in a single hadron (using multiplets)



Compatible with:

$$\frac{\Omega}{\pi}$$

$$\frac{\Xi/\pi}{\Omega/K_S^0}$$

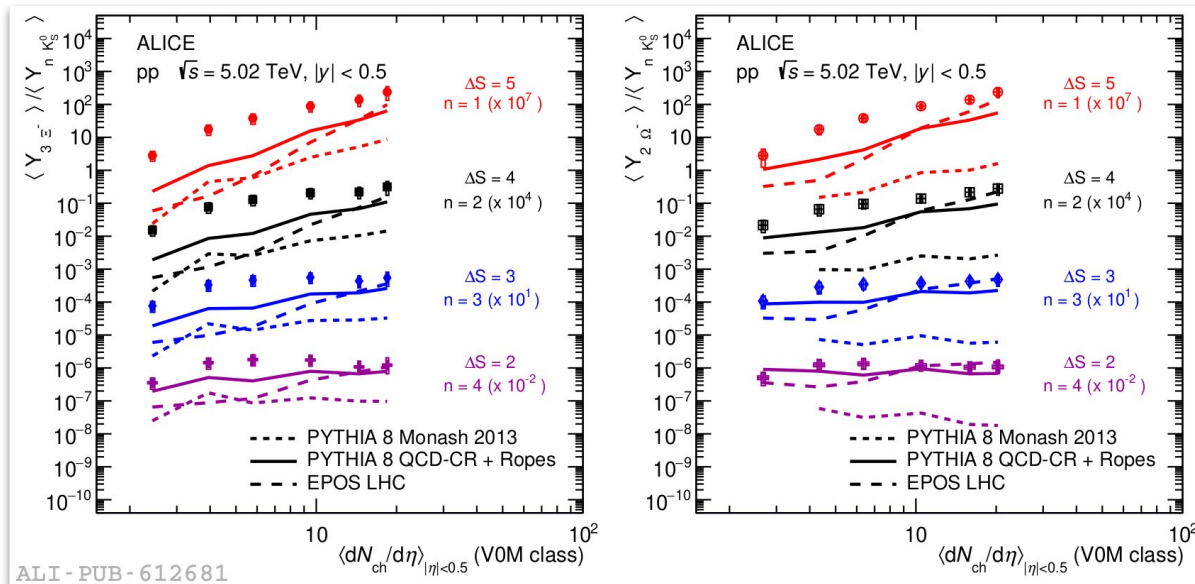




First-time investigation of strangeness enhancement with ΔS up to 5 - model comparison

New paper !

Ξ -triplets
/
 K_S^0 -multiplets



Ω -doublets
/
 K_S^0 -multiplets

- MC generators exhibit different multiplicity dependencies for $\langle Y_{3\Xi} \rangle$ and $\langle Y_{2\Omega} \rangle$
 - the increase with multiplicity in models is affected by the number of baryons in the numerator
- [EPOS LHC](#): agreement at high multiplicity, but incorrect multiplicity trend
- [Pythia 8 QCD-CR Ropes](#): closer to the data but still underestimating the observed behavior

ALICE Coll., [arXiv:2511.10413](#)

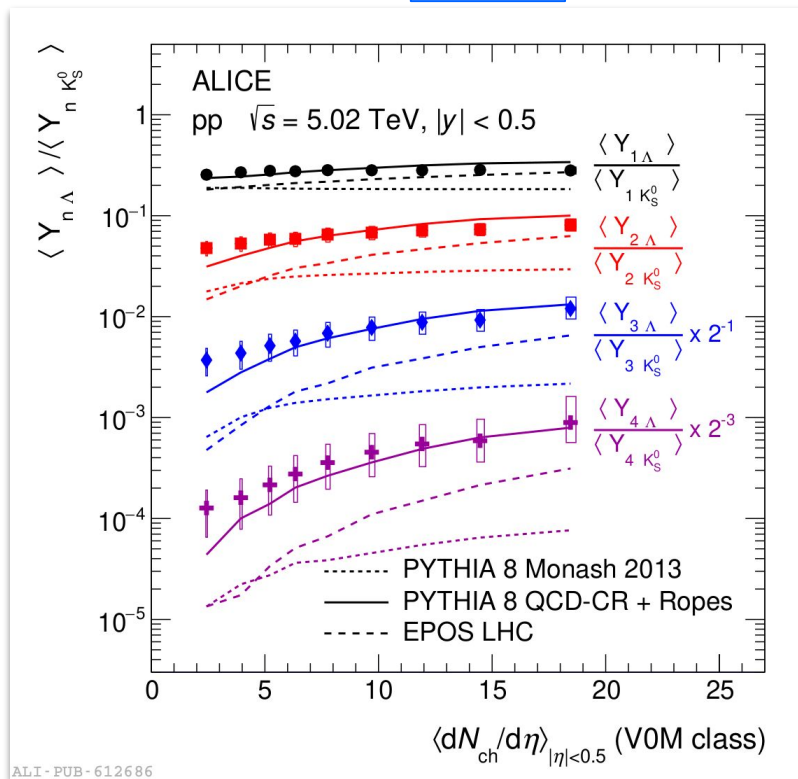


 $\Delta S = 0$

New paper !

Yield ratios with $\Delta S = 0$: important to factor-out non strangeness-related effects

- Λ -multiplets/ K_S^0 -multiplets VS multiplicity: extension beyond the mean ratio
- increase of Λ/K_S^0 VS multiplicity when looking at multiple production!
 - the evolution with multiplicity is **not** solely due to the strangeness imbalance between the numerator and denominator
 - Is it baryon enhancement?
- Model comparison:
 - possible baryon-related effect well reproduced by [Pythia 8 QCD-CR Ropes](#), especially at high multiplicity

 Λ/K_S^0 



New paper !

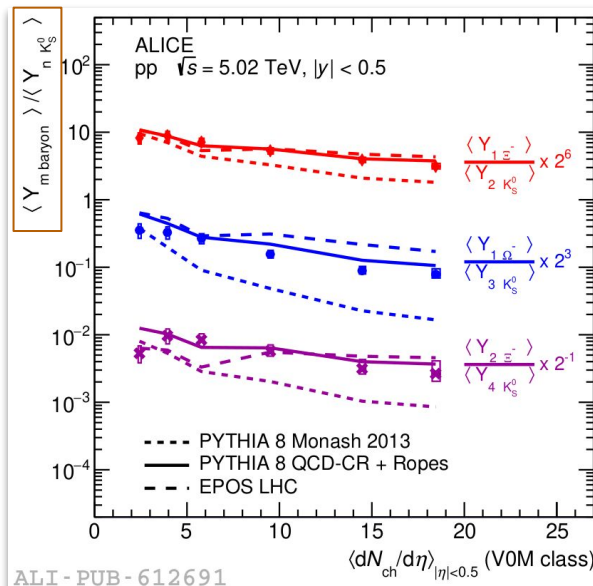
$m \text{ baryon}/nK_s^0$ and $m \text{ baryon}/n\Lambda$ – testing hadron production at fixed S and with different light quark content (ΔL)

 $\Delta S = 0$

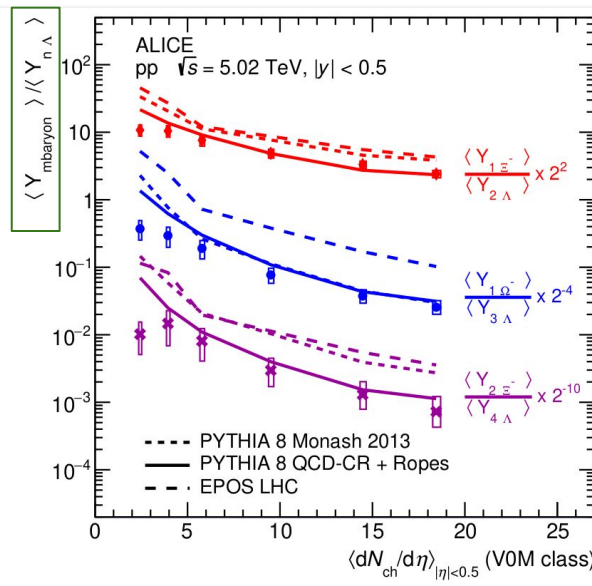
fixed S = 2
 $\Delta L = 2$

fixed S = 3
 $\Delta L = 3$

fixed S = 4
 $\Delta L = 4$



ALI-PUB-612691



fixed S = 2
 $\Delta L = 4$

fixed S = 3
 $\Delta L = 6$

fixed S = 4
 $\Delta L = 8$

ALICE Coll., [arXiv:2511.10413](https://arxiv.org/abs/2511.10413)

Decreasing trend with increasing multiplicity due to the larger number of light quarks involved in the denominator
→ trend VS multiplicity is not determined by the presence of a baryon!

- high multiplicity: it is simpler to pair s-quarks with light quarks (very abundant)
- low multiplicity: the shortage of light quarks enhances the probability of multi-strange baryon formation





New paper !

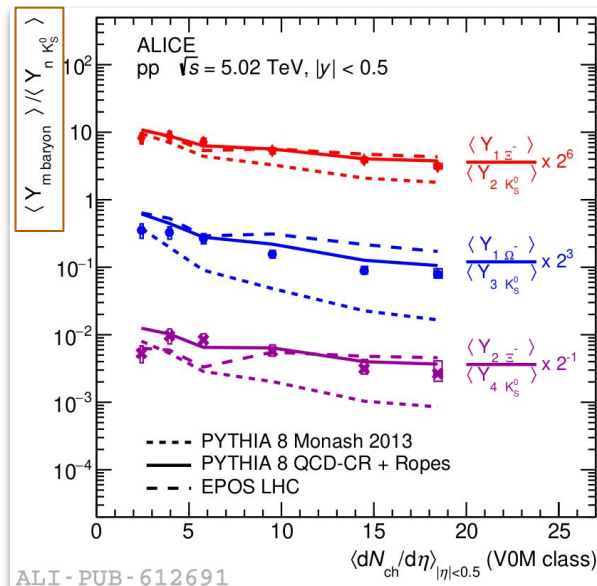
$m \text{ baryon}/nK^0_s$ and $m \text{ baryon}/n\Lambda$ – testing hadron production at fixed S and with different light quark content (ΔL)

 $\Delta S = 0$

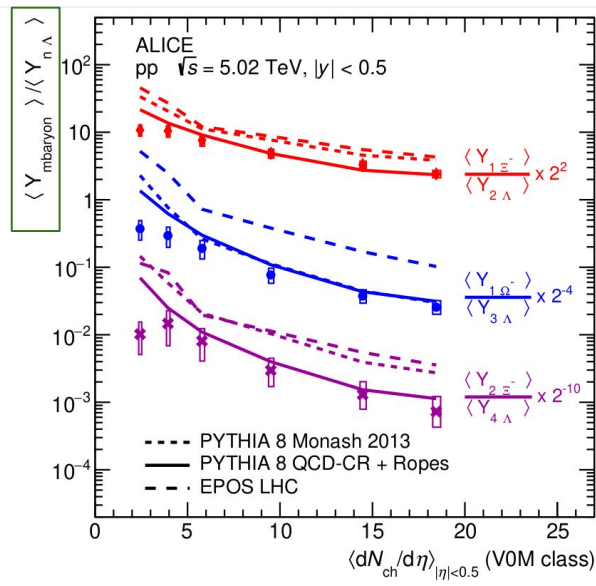
fixed $S = 2$
 $\Delta L = 2$

fixed $S = 3$
 $\Delta L = 3$

fixed $S = 4$
 $\Delta L = 4$



ALI - PUB - 612691



fixed $S = 2$
 $\Delta L = 4$

fixed $S = 3$
 $\Delta L = 6$

fixed $S = 4$
 $\Delta L = 8$

ALICE Coll., [arXiv:2511.10413](https://arxiv.org/abs/2511.10413)

Model comparison:

- [Pythia 8 QCD-CR Ropes](#): excellent description of all trends $\rightarrow$ QCD-CR mechanism implemented in the model effectively captures the reconnection of strange and light quarks as a function of multiplicity
- [Pythia 8 Monash](#) underestimates all particle ratios for K^0_s , while overestimating ratios relative to Λ (except for 1Ω)
- [EPOS LHC](#) qualitatively captures the trend for all ratios relative to K^0_s , while overestimates the trends relative to Λ





New paper !

$m \text{ baryon}/nK_s^0$ and $m \text{ baryon}/n\Lambda$ - testing hadron production at fixed S and with different light quark content (ΔL)

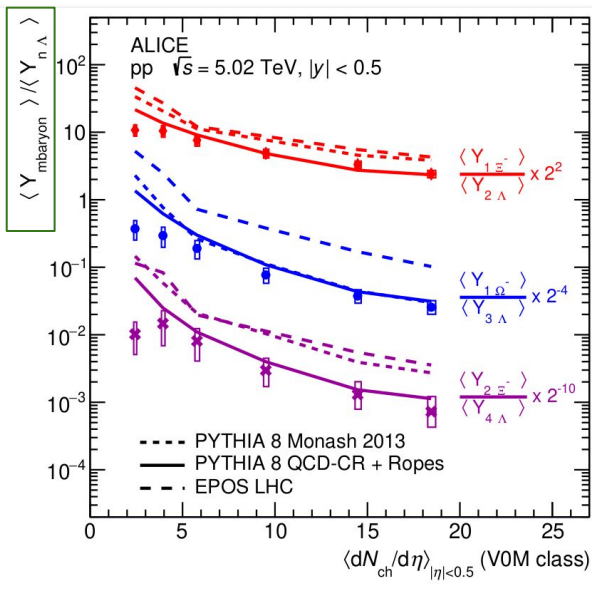
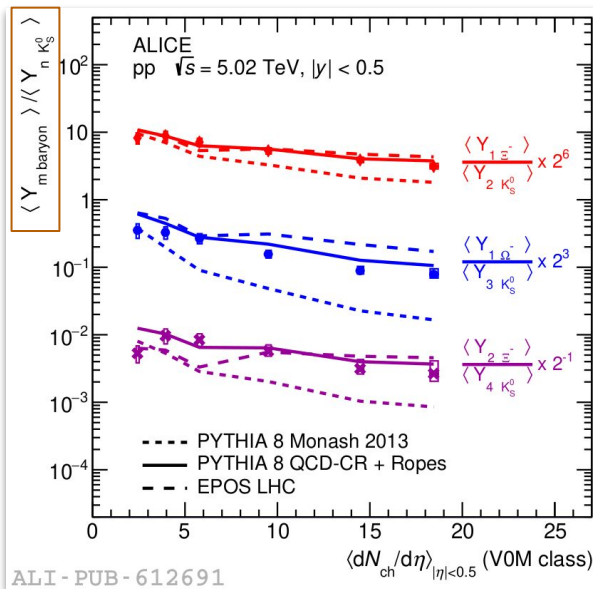


$\Delta S = 0$

fixed $S = 2$
 $\Delta L = 2$

fixed $S = 3$
 $\Delta L = 3$

fixed $S = 4$
 $\Delta L = 4$



fixed $S = 2$
 $\Delta L = 4$

fixed $S = 3$
 $\Delta L = 6$

fixed $S = 4$
 $\Delta L = 8$

ALICE Coll., [arXiv:2511.10413](https://arxiv.org/abs/2511.10413)

Model comparison:

- Pythia 8 QCD-CR Ropes captures the reconnection
- Pythia 8 Monash underestimates the trend for all ratios relative to K_s^0 , while overestimates the trends relative to Λ (except for 1Ω)
- EPOS LHC qualitatively captures the trend for all ratios relative to K_s^0 , while overestimates the trends relative to Λ

TAKE HOME MESSAGE

Multiplicity trends are driven by light quark availability, not by baryon content

tested in the model effectively

to Λ (except for 1Ω)





Strangeness production is a sensitive probe of QCD hadronization. ALICE investigates it through complementary measurements:





Strangeness production is a sensitive probe of QCD hadronization. ALICE investigates it through complementary measurements:

- High precision measurements of the **ratio of strange to non-strange hadron yields (h/π) across colliding systems**
 - **multiplicity-driven evolution** from pp to Pb–Pb, with OO bridging small and large systems





Strangeness production is a sensitive probe of QCD hadronization. ALICE investigates it through complementary measurements:

- High precision measurements of the **ratio of strange to non-strange hadron yields (h/π) across colliding systems**
 - **multiplicity-driven evolution** from pp to Pb–Pb, with OO bridging small and large systems
- **Additional experimental activity in small systems** under investigation trying connections between strange-particle production and local or global characteristics of the events under study
 - **first measurement of the strangeness production in- and out- of jets vs multiplicity**
 - strangeness **evolution with multiplicity** is primarily driven by the UE
 - the jet component gives the dominant contribution to the absolute strange-hadron production





Strangeness production is a sensitive probe of QCD hadronization. ALICE investigates it through complementary measurements:

- High precision measurements of the **ratio of strange to non-strange hadron yields (h/π) across colliding systems**
 - **multiplicity-driven evolution** from pp to Pb–Pb, with OO bridging small and large systems
- **Additional experimental activity in small systems** under investigation trying connections between strange-particle production and local or global characteristics of the events under study
 - **first measurement of the strangeness production in- and out- of jets vs multiplicity**
 - strangeness **evolution with multiplicity** is primarily driven by the UE
 - the jet component gives the dominant contribution to the absolute strange-hadron production
- **First measurement of (multi-)strange particle multiplicity distribution $P(n_s)$**
 - **relevant extension of the traditional yield determination**, as it tests at a higher order the strange hadron production mechanisms
 - **perfect benchmark to MC models to test the interplay between charged and strange particle multiplicity**
 - multiple strange hadron production yields
 - ratios with ΔS moves from 2 to 5: **strangeness enhancement at its extremes** → enhancement pattern is strongly driven by the strangeness content of the hadron
 - ratios with $\Delta S = 0$: **perfect strangeness balance** → exhibit a secondary role of u and d quarks





Model comparison:

- Ratio of strange to non-strange hadron yields (h/π) across collision systems
 - different kind of models have been considered → **recent model developments** improve the **qualitative description** of strangeness-enhancement patterns, but **quantitative tensions** with the data persist
 - **none of the available models simultaneously describes the trend and magnitude over the full multiplicity range**
- First measurement of (multi-)strange particle multiplicity distribution $P(n_s)$
 - multiple strange hadron production yields vs multiplicity: the agreement worsens with increasing n → **strange quark production rate remains an open issue**
 - yield ratios vs multiplicity: the majority are rather well reproduced by [Pythia 8 QCD-CR Ropes](#) → **once S is created the model of re-connection with light quarks catches the trends observed in the data**





- **Extension of presented study to other colliding systems**

- strangeness production as a function of multiplicity to p-O and Ne-Ne collisions
- *NOTE:* strangeness production in- and out- of jets is currently ongoing in OO collisions
- $P(n_s)$ to Pb-Pb
 - test the collision system invariance with multiplets of particles
 - test the trends up to extreme multiplicities and verify the relative importance of baryon/strangeness in a light-quark rich environment





- **Extension of presented study to other colliding systems**
 - strangeness production as a function of multiplicity to p-O and Ne-Ne collisions
 - *NOTE*: strangeness production in- and out- of jets is currently ongoing in OO collisions
 - $P(n_s)$ to Pb-Pb
 - test the collision system invariance with multiplets of particles
 - test the trends up to extreme multiplicities and verify the relative importance of baryon/strangeness in a light-quark rich environment
- **Extension of presented study to other particles**
 - strangeness production in- and out- of jets will be extended to multi-strange baryons (ongoing)
 - more generally: investigate resonance production (preliminary approved results in light-ion for K^* and ϕ , ongoing studies for Ξ^* and Λ^*)





- **Extension of presented study to other colliding systems**
 - strangeness production as a function of multiplicity to p-O and Ne-Ne collisions
 - *NOTE:* strangeness production in- and out- of jets is currently ongoing in OO collisions
 - $P(n_s)$ to Pb-Pb
 - test the collision system invariance with multiplets of particles
 - test the trends up to extreme multiplicities and verify the relative importance of baryon/strangeness in a light-quark rich environment
- **Extension of presented study to other particles**
 - strangeness production in- and out- of jets will be extended to multi-strange baryons (ongoing)
 - more generally: investigate resonance production (preliminary approved results in light-ion for K^* and ϕ , ongoing studies for Ξ^* and Λ^*)
- **Extension of $P(n_s)$ to Run 3 (and Run 4) data: larger statistics (3/4 orders of magnitude higher)**
 - several software filters have been developed for the selection of **events with strange hadron candidates** (e.g. events with at least 1 Ω , 2 or more Ξ , two or more Ω , at least 1 Ω and 1 Ξ)
 - useful for cascade analyses
 - enable investigations of the simultaneous production of multiple strange hadron species





- **Extension of presented study to other colliding systems**
 - strangeness production as a function of multiplicity to p-O and Ne-Ne collisions
 - *NOTE:* strangeness production in- and out- of jets is currently ongoing in OO collisions
 - $P(n_s)$ to Pb-Pb
 - test the collision system invariance with multiplets of particles
 - test the trends up to extreme multiplicities and verify the relative importance of baryon/strangeness in a light-quark rich environment
- **Extension of presented study to other particles**
 - strangeness production in- and out- of jets will be extended to multi-strange baryons (ongoing)
 - more generally: investigate resonance production (preliminary approved results in light-ion for K^* and ϕ , ongoing studies for Ξ^* and Λ^*)
- **Extension of $P(n_s)$ to Run 3 (and Run 4) data: larger statistics (3/4 orders of magnitude higher)**
 - several software filters have been developed for the selection of **events with strange hadron candidates** (e.g. events with at least 1 Ω , 2 or more Ξ , two or more Ω , at least 1 Ω and 1 Ξ)
 - useful for cascade analyses
 - enable investigations of the simultaneous production of multiple strange hadron species



Back up

Sara Pucillo^{1,2}

Niels Bohr Institute
University of Copenhagen
Invited seminar, 28/05/2026



1. Università degli Studi di Salerno



2. INFN Napoli



Istituto Nazionale di Fisica Nucleare
SEZIONE DI NAPOLI
Gruppo Collegato di Salerno



ITS: Inner Tracking System

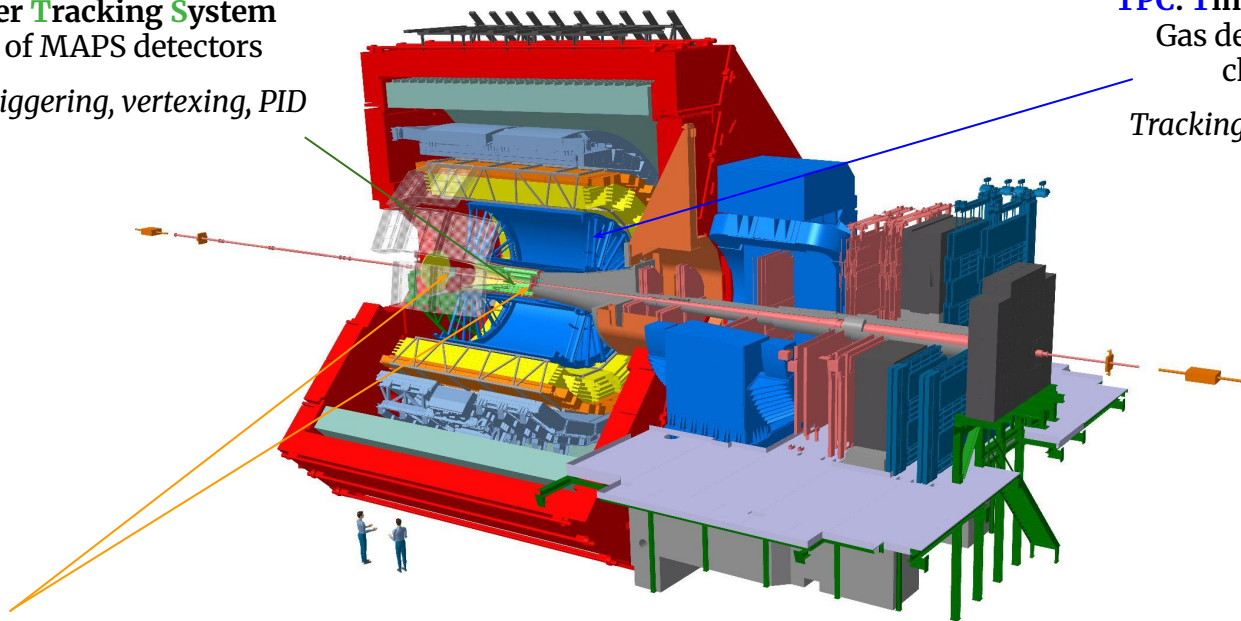
7 layers of MAPS detectors

Tracking, triggering, vertexing, PID

TPC: Time Projection Chamber

Gas detector (new readout chambers: GEM)

Tracking, vertexing, PID (dE/dx)



new FIT: Fast Interaction Trigger

two arrays, FT0A and FT0C, of Cherenkov radiators

Interaction trigger, online luminometer, forward multiplicity counter

In general:

- readout upgraded for most detectors to allow continuous readout
- excellent tracking & PID capabilities over broad p range
- low material budget





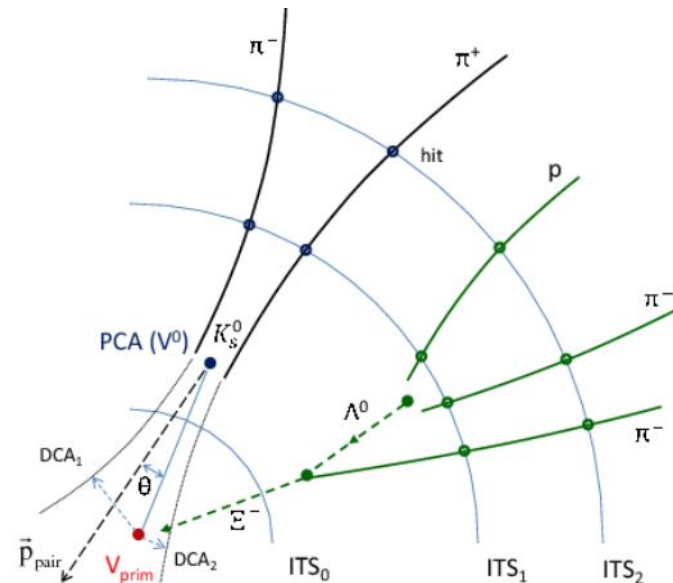
Particles reconstructed through their **weak decays**

Single strange particles: V^0 s

Multi-strange particles: Cascades

Particle	Quarks	S	I(J^P)	Mass (MeV/ c^2)	Decay channel	B.R.(Γ_i/Γ)	$c\tau$ (cm)
K_S^0	$\frac{d\bar{s}-s\bar{d}}{\sqrt{2}}$	—	$\frac{1}{2}(0^-)$	497.611 ± 0.013	$\pi^0\pi^0$ $\pi^+\pi^-$	$(30.69 \pm 0.5)\%$ $(69.20 \pm 0.5)\%$	2.68
Λ	uds	—1	$0(\frac{1}{2}^+)$	1115.683 ± 0.006	$p\pi^-$ $n\pi^0$	$(63.9 \pm 0.5)\%$ $(35.8 \pm 0.5)\%$	7.89
$\bar{\Lambda}$	$\bar{u}\bar{d}\bar{s}$	+1	$0(\frac{1}{2}^+)$	1115.683 ± 0.006	$\bar{p}\pi^+$ $n\pi^0$	$(63.9 \pm 0.5)\%$ $(35.8 \pm 0.5)\%$	7.89
Ξ^-	dss	—2	$\frac{1}{2}(\frac{1}{2}^+)$	1321.71 ± 0.07	$\Lambda\pi^-$	$(99.887 \pm 0.035)\%$	4.91
Ξ^+	$\bar{d}\bar{s}\bar{s}$	+2	$\frac{1}{2}(\frac{1}{2}^+)$	1321.71 ± 0.07	$\bar{\Lambda}\pi^+$	$(99.887 \pm 0.035)\%$	4.91
Ω^-	sss	—3	$0(\frac{3}{2}^+)$	1672.45 ± 0.29	ΛK^- $\Xi^0\pi^-$	$(67.7 \pm 0.7)\%$ $(24.3 \pm 0.7)\%$	2.461
$\bar{\Omega}^+$	$\bar{s}\bar{s}\bar{s}$	+3	$0(\frac{3}{2}^+)$	1672.45 ± 0.29	$\bar{\Lambda}K^+$ $\Xi^0\pi^+$	$(67.7 \pm 0.7)\%$ $(24.3 \pm 0.7)\%$	2.461

- Statistical identification using an invariant mass analysis



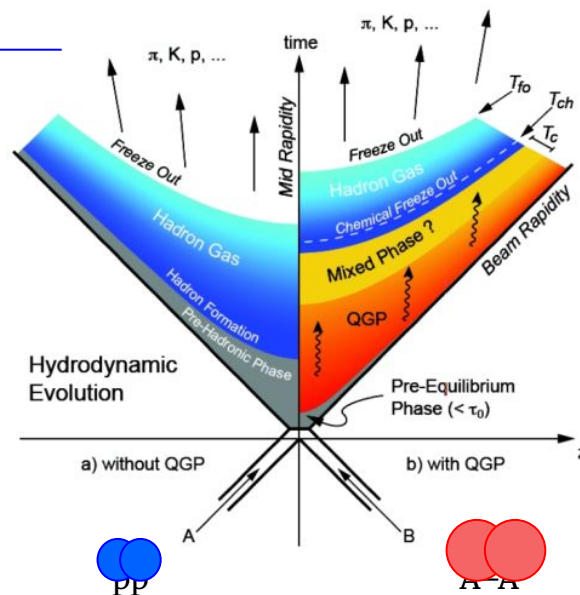


Strangeness enhancement: relative abundance of particles containing strange quarks is expected to be higher in AA collisions than in pp interactions

- proposed signature for QGP formation
([Rafelski J., Müller B., Phys.Rev.Lett. 48, 1066 \(1982\)](#))

Hadron gas → hadronic degrees of freedom

- energy threshold problem: cheaper production of $s\bar{s}$ compared to $K\bar{K}$ in vacuum ($Q_{\text{value}}^{\text{HG}} \sim 1 \text{ GeV}$)
- production mechanisms: multi-step hadronic interactions
 - penalized processes



QGP → partonic degrees of freedom

- strange quarks are thermally produced in the medium
- production mechanisms: gluon fusion $gg \rightarrow s\bar{s}$ ($Q_{\text{value}}^{\text{QGP}} \sim 200 \text{ MeV}$)
 - efficient way to produce strangeness
 - abundance of strange quarks

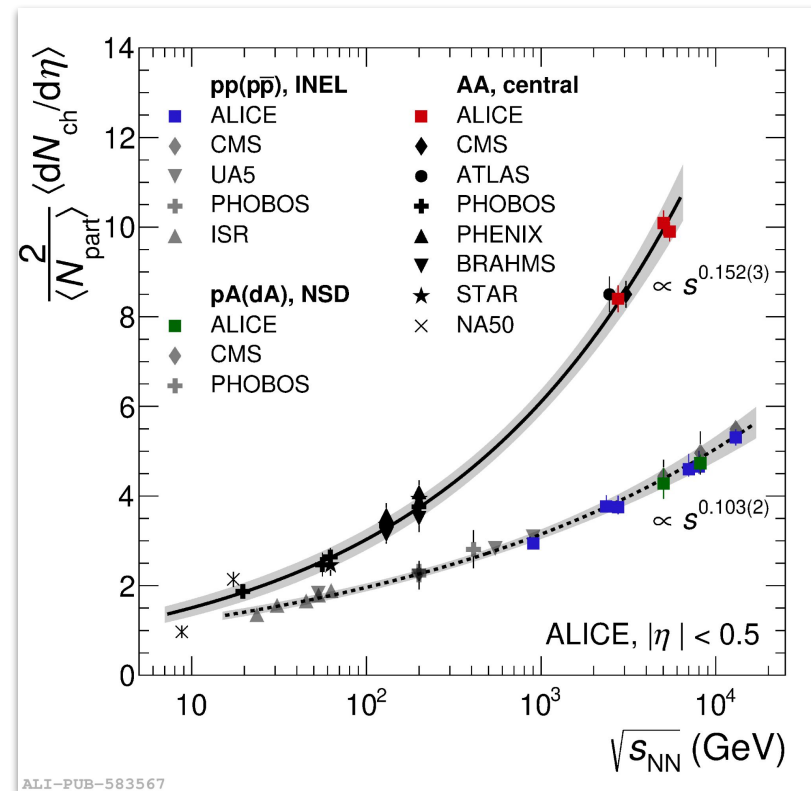




Explanation of the energy hierarchy: for all systems the number of charged-particles produced at central rapidity enhances as $\sqrt{s}$ increases

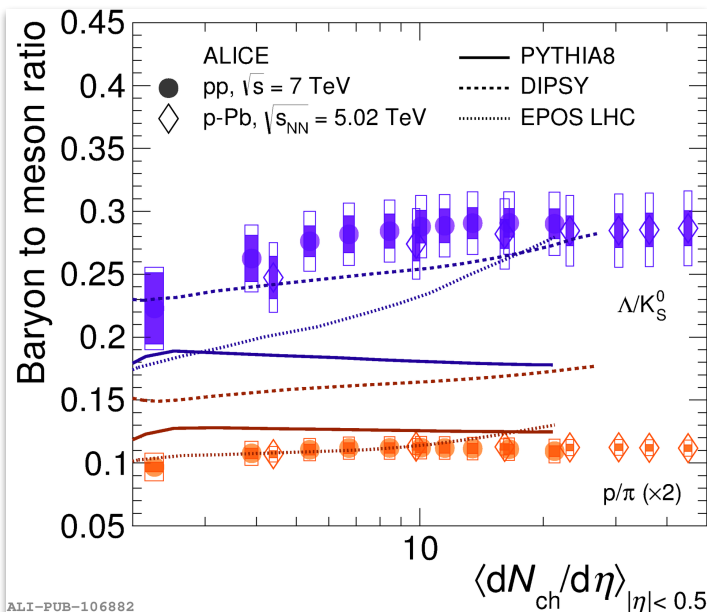
- the higher the energy in the pp reference, the higher the average charged-particle multiplicity and, hence, the lower the ratio between yields in AA and pp
- elementary collisions cannot be used as a baseline for comparisons between different energies

Further investigations into strange particle production rates in elementary interactions → improved observable: ratio of strange yields to pions at the same $\sqrt{s}$





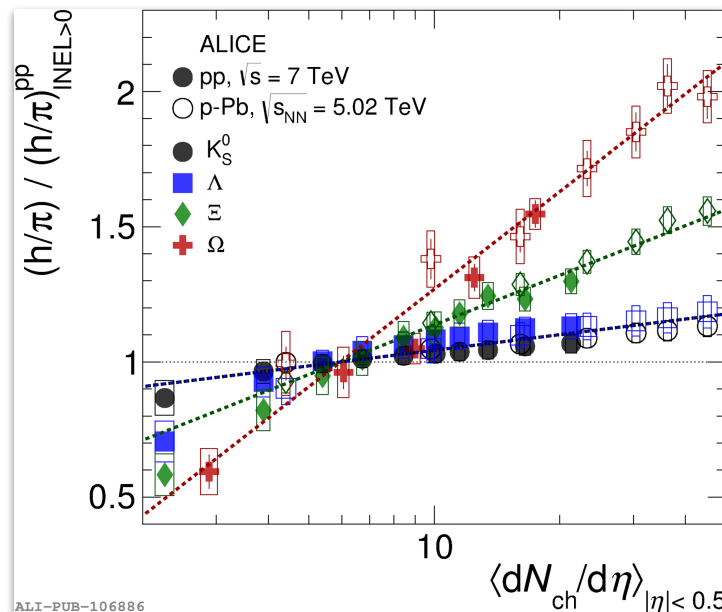
ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)



Baryon/Meson VS charged-particle multiplicity

→ Observed **flat trend** can be understood considering that the strangeness enhancement is proportional to the number of strange quarks in the hadron

ALICE Coll., [Nature Physics 13 \(2017\) 535–539](#)



Particle yield ratios to pions normalised to the values measured in the inclusive INEL> 0 pp sample

- low charged-particle multiplicity: **the increase vs multiplicity is more rapid as their content of strangeness grows**, being the highest for the triple-strange Ω

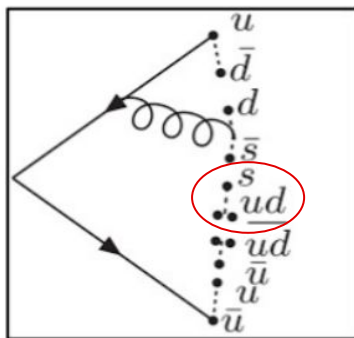




Pythia 8: linear parametrization of the QCD interaction potential at large distances (Lund string model)

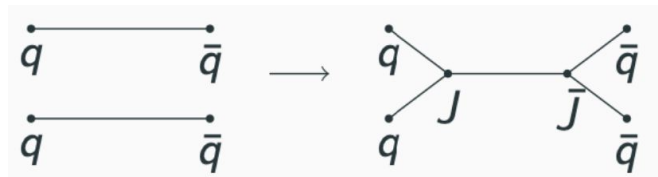
- confined color fields $\rightarrow$ “string”

Pythia 8 Monash



- hadron formation: string breaking (tension ~ 1 GeV/fm);
- multiplicity dependence of particle production: **Multi-Parton Interactions (MPI) + Color Reconnection (CR)**.

Pythia 8 QCD-CR Ropes

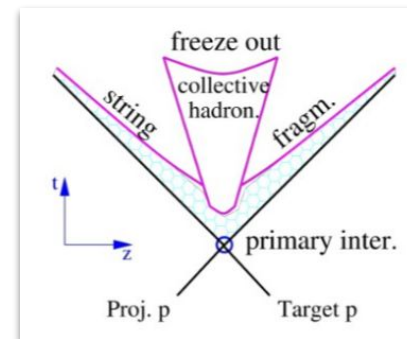


- hadron formation: overlapping strings (effective string tension from the lattice);
- multiplicity dependence of particle production: **MPI + sophisticated CR allowing 3-leg junctions.**

EPOS LHC

Double regime scenario

- core: high energy density (statistical hadronization)
- corona: vacuum hadronization



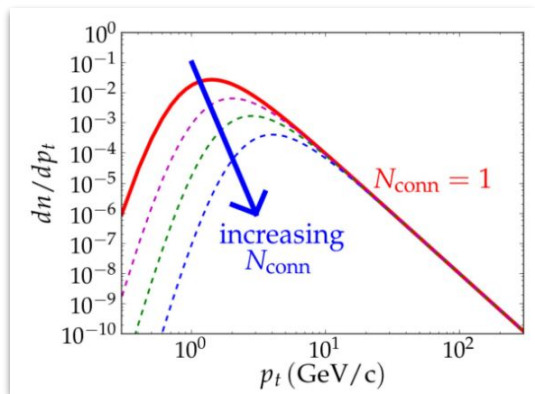
- multiplicity dependence of particle production: **different relative importance of core and corona across multiplicity.**





EPOS 4 : newest version of EPOS model

- **double-regime scenario with dynamic core–corona**
 - *core* → statistical hadronization + hydrodynamic expansion
 - *corona* → string fragmentation



- multiplicity dependence of particle production:
low- p_T suppression and collective expansion driven by saturation (via the number of partonic connections, N_{conn})

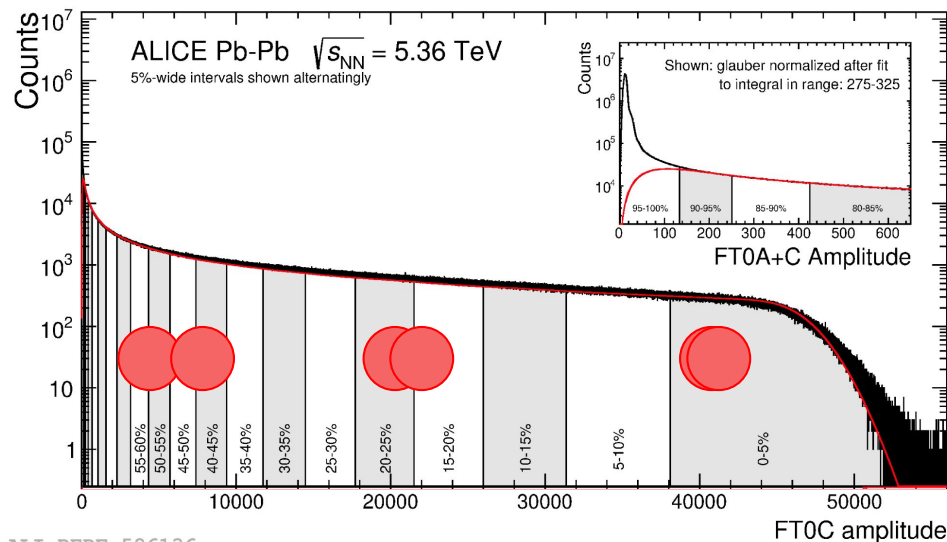
DCCI (Dynamical Core–Corona Initialization)

- state of the art core–corona approach
- **dynamical initialization of QGP**: partons deposit energy and momentum proportionally to the local density, leading to the dynamical formation of a fluid (core), while other partons remain non-equilibrated (corona)
- multiplicity dependence of particle production:
continuous transition from string fragmentation (low multiplicity) **to statistical hadronization** (high multiplicity) **via dynamical core–corona separation** (core fraction increases with multiplicity)
- hadronization: in vacuum (using PYTHIA) or using the Cooper-Frye formula from core droplets





- Event multiplicity is estimated from the FT0 detector signal amplitudes at forward rapidity
- Centrality is determined by fitting the FT0 amplitude distribution with a Glauber-inspired model coupled to a Negative Binomial Distribution (NBD)
 - **Glauber MC:** collision geometry is generated using the nuclear density profile parameters
 - **N-ancestor + NBD model:** particle production is described by assuming independent particle-emitting sources and fitting the measured distribution

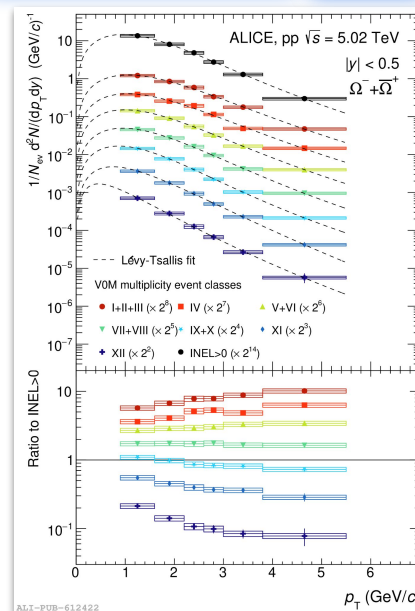
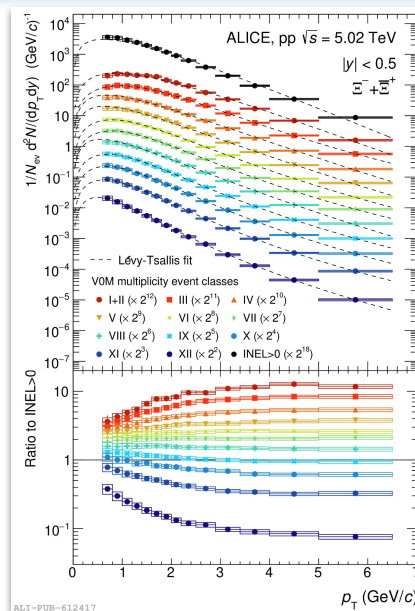
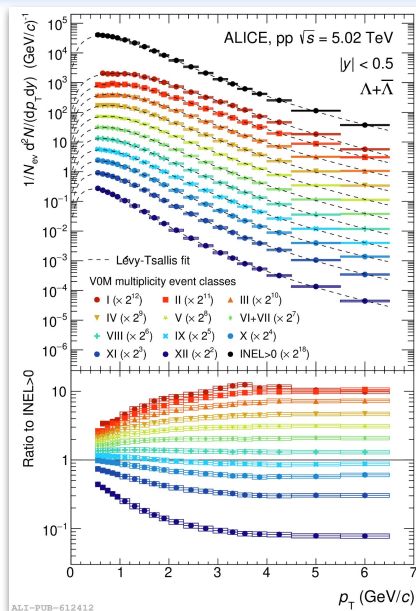
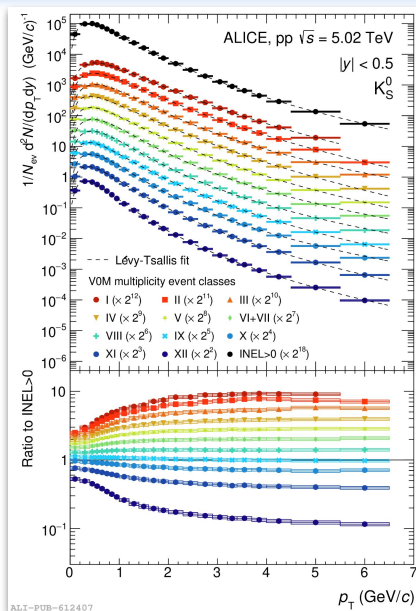


ALI-PERF-586136

$$N_{\text{ancestors}} = f N_{\text{part}} + (1-f) N_{\text{coll}}$$

Each ancestor emits particles according to an NBD with parameters (μ, k)





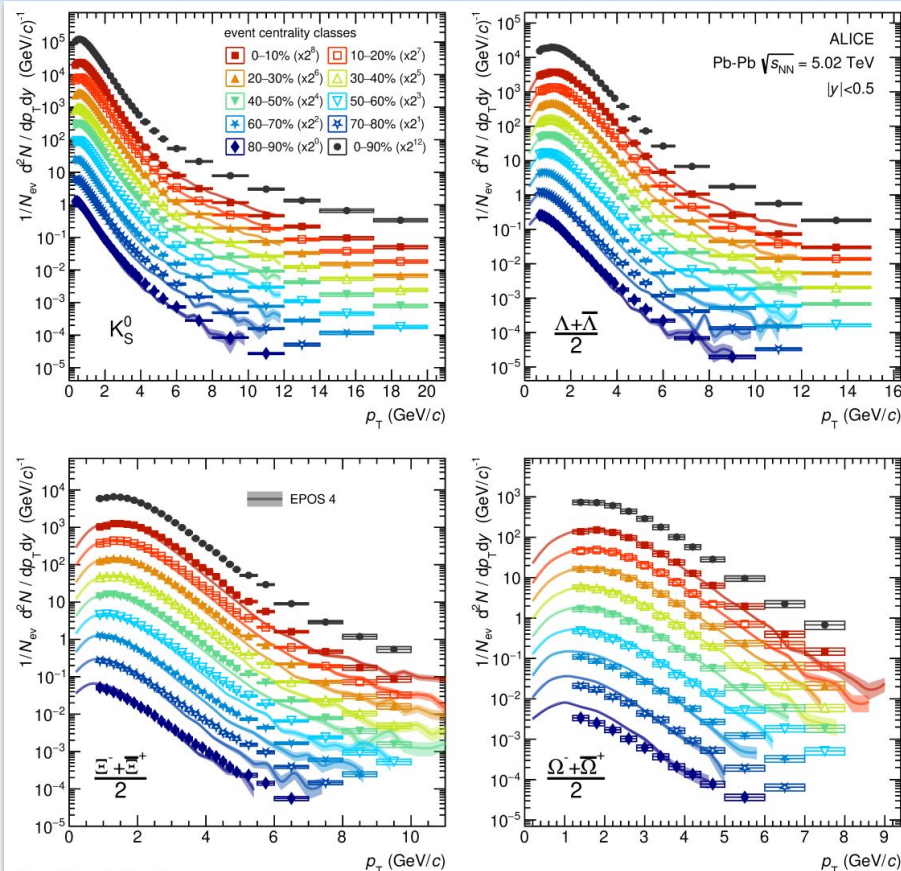
- extension of similar studies performed at 7 and 13 TeV to a lower energy regime
- improvement in the statistical precision
- p_T spectra show a maximum shifting to higher values with increasing multiplicity (as observed in large systems and attributed to radial collective flow)
 - lower panel: ratios evolve significantly at low p_T , approaching a plateau at around 4 GeV/c

New paper !





New paper !



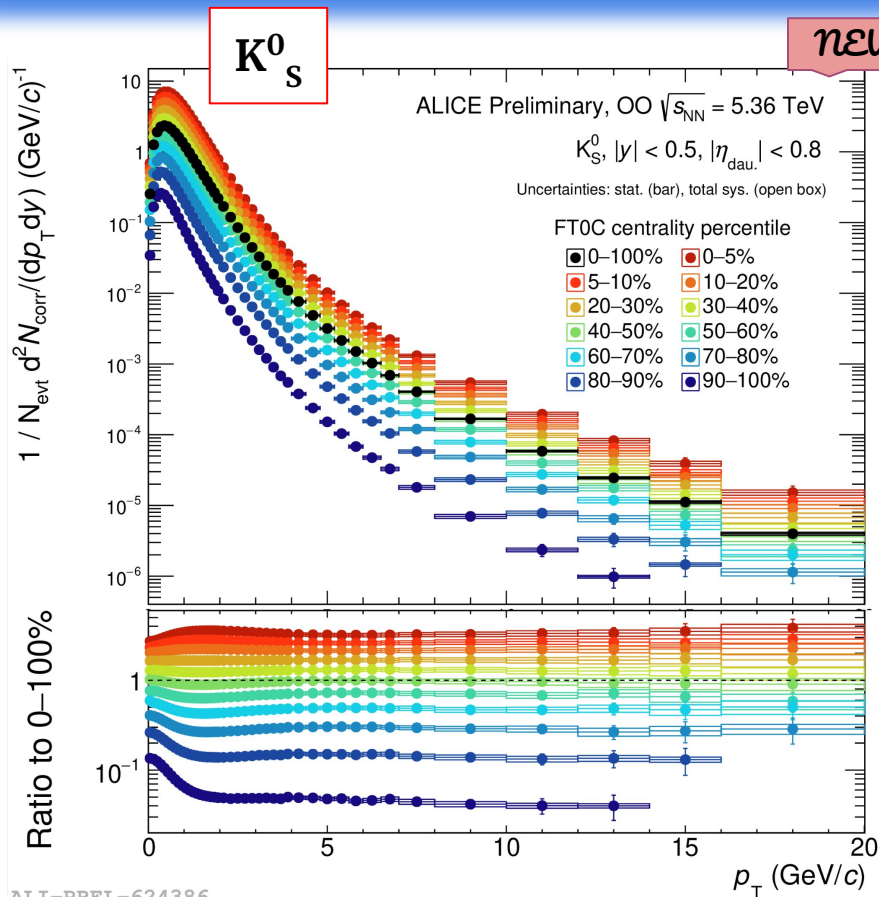
ALI-PUB-612593

ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360)

Strangeness production (K_S^0 , Λ , Ξ and Ω) as a function of charged-particle multiplicity in Pb–Pb collisions at $\sqrt{s} = 5.02$ TeV:

- **largest and highest energy heavy-ion data set analyzed to date at the LHC**
- **unprecedented statistical precision** (higher p_T granularity and extension to higher p_T)
- **model comparison:**
 - [EPOS 4](#) describes the K_S^0 and Λ spectra within uncertainties, underestimates Ξ at $p_T > 2$ GeV/c and overestimates the Ω in peripheral collisions
 - **hardening of the spectra from peripheral to central collisions reflects partonic radial flow**





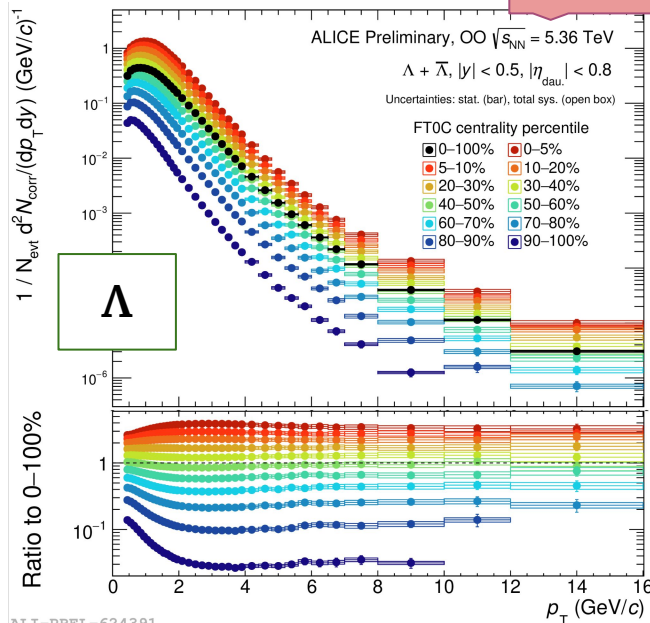
First measurement of the K_S^0 corrected p_T spectra in OO collisions for different centrality classes

- large amount of data allow to extend the strangeness production measurement up to 20 GeV/c
- **hardening** of the spectra from **peripheral** to **central** collisions
- maximum moves towards larger values as the multiplicity increases $\rightarrow$ interpreted as the result of a **collective boost** in the radial direction
- bottom panel: ratio to integrated 0-100%
 - large yield variations among different classes
 - evolve significantly at low p_T
 - reach a plateau ~ 3 GeV/c

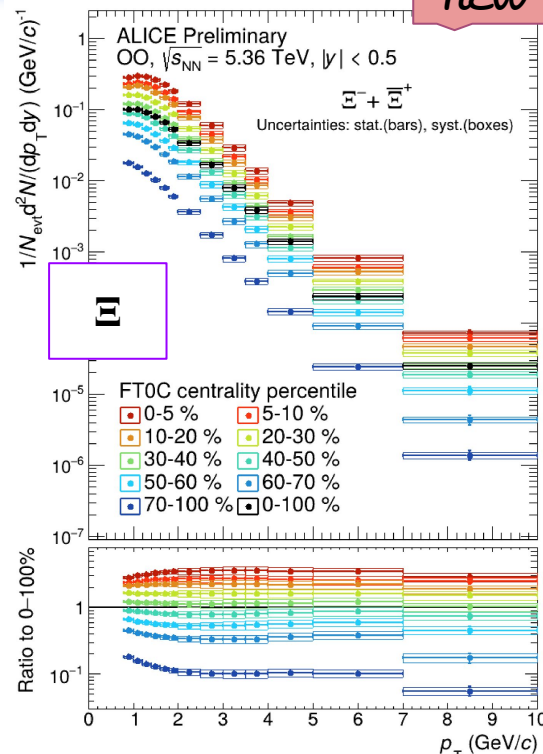




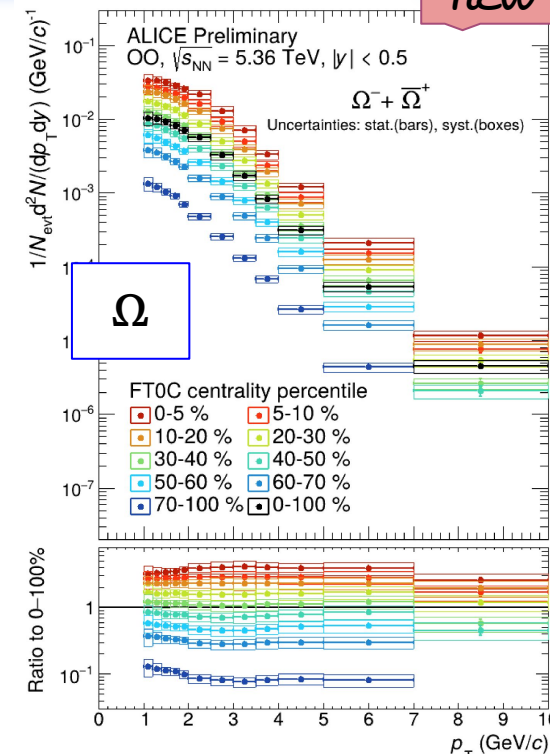
First measurement of the Λ , Ξ and Ω corrected p_T spectra in OO collisions for different centrality classes



ALI-PREL-624391



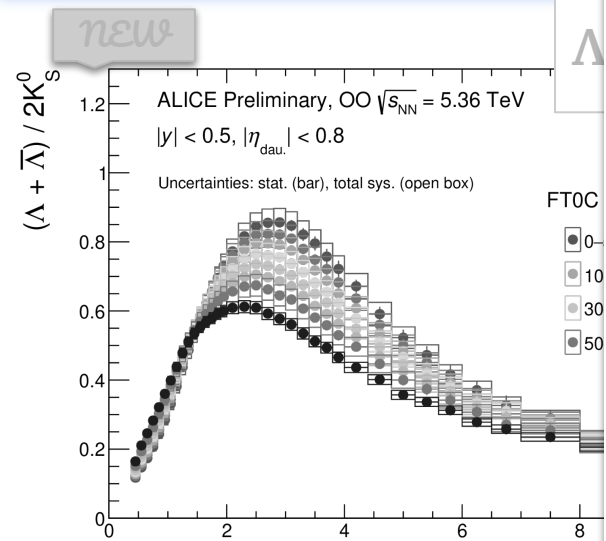
ALI-PREL-624078



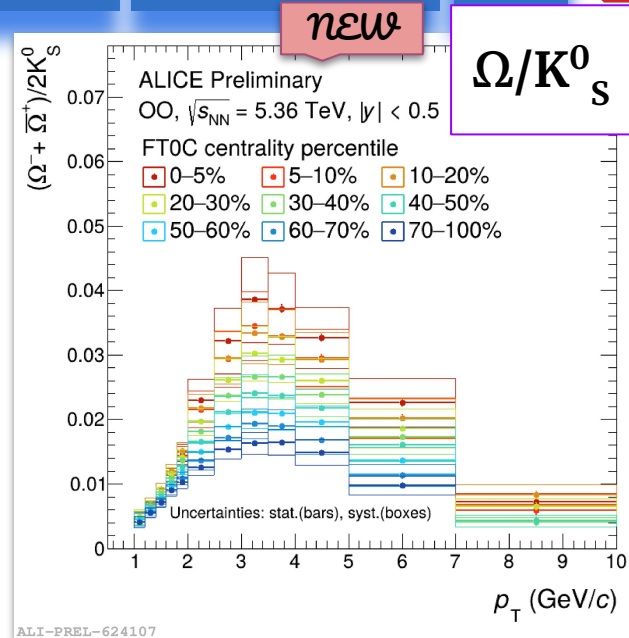
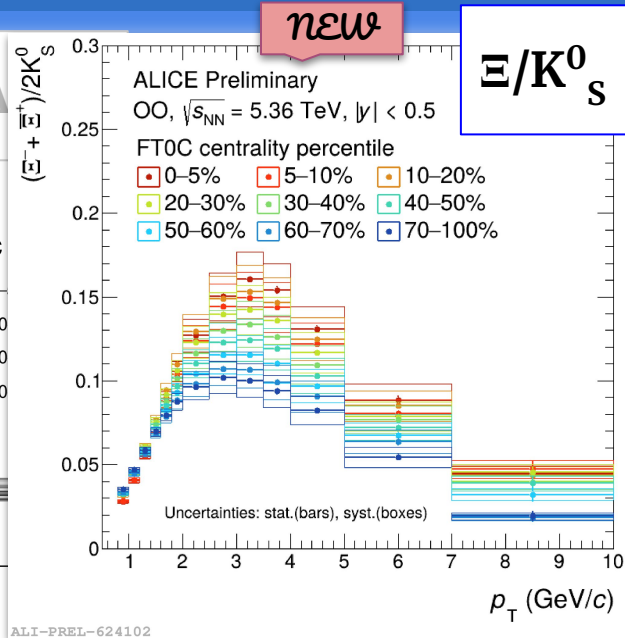
ALI-PREL-624083

- Same conclusions discussed previously for K_S^0
- Λ yields $\sim 10 \times \Xi$ yields $\sim 10 \times \Omega$ yields in OO collisions





ALI-PREL-624396

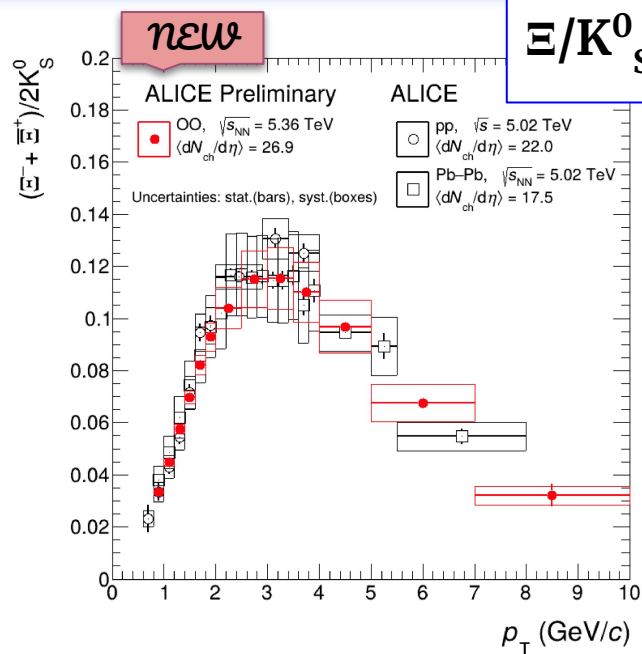


To study the particle production dynamics: **baryon-to-meson p_T spectra ratios in OO for each centrality class**

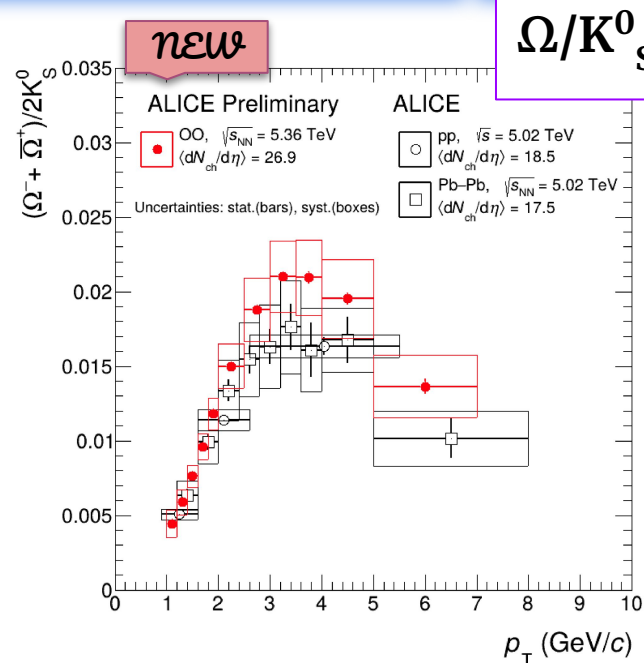
- increase at intermediate p_T across all centrality classes
 - peak shifts to higher p_T with increasing multiplicity
- convergence at high p_T across all centrality classes

OO baryon-to-meson pattern suggests an interplay of hydrodynamic expansion and coalescence, leading to enhanced baryon production at intermediate p_T





ALI-PREL-624122



ALI-PREL-624127

Baryon-to-meson p_T spectra ratios across collision systems

- comparable Ξ/K^0_S and Ω/K^0_S values in OO, Pb-Pb, and pp at similar charged-particle multiplicity

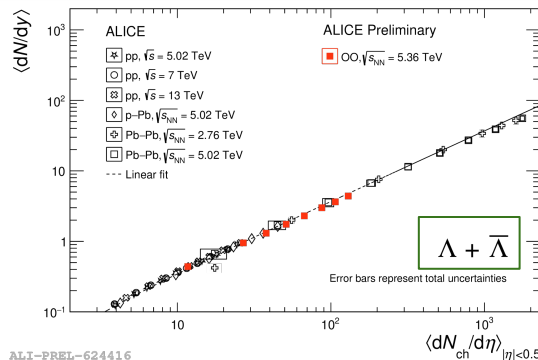
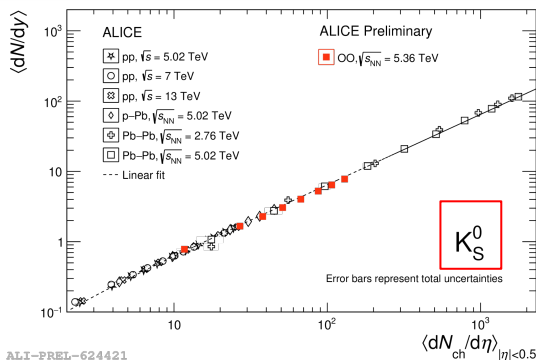
ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306) (NEW!)

ALICE Coll., [Phys.Lett.B 758 \(2016\) 389-401, 2016](https://arxiv.org/abs/2511.10360)

ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360) (NEW!)

Similar particle production dynamics in OO, peripheral Pb-Pb and central pp suggests common underlying hadron-production mechanisms

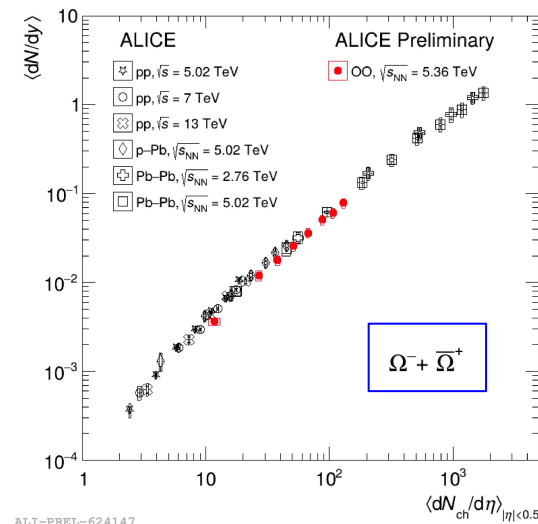
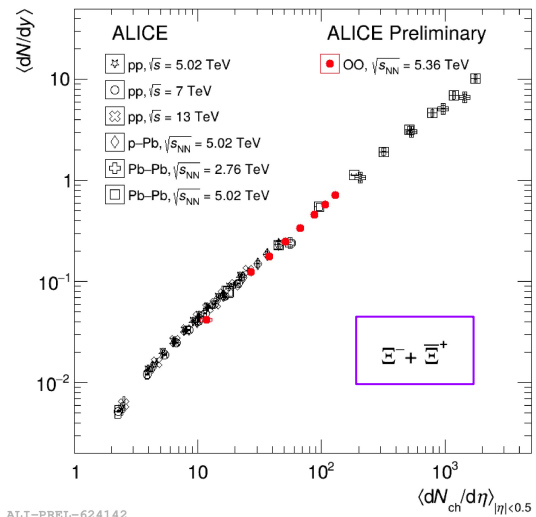




new

Fully corrected integrated yields for strange hadrons as a function of the charged-particle multiplicity

- OO yields have been obtained by extrapolating down to $p_T=0$ using a Blast-Wave function for V^0 s and a Lèvy-Tsallis function for cascades
- **OO results** are consistent with the smooth, multiplicity-driven evolution of strange-hadron production observed across colliding systems



ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306) (NEW!)

ALICE Coll., [arXiv:1807.11321](https://arxiv.org/abs/1807.11321)

ALICE Coll., [arXiv:1908.01861](https://arxiv.org/abs/1908.01861)

ALICE Coll., [Phys.Lett.B 728 \(2014\) 25-38, 2014](https://arxiv.org/abs/1404.2538)

ALICE Coll., [Phys.Lett.B 758 \(2016\) 389-401, 2016](https://arxiv.org/abs/1603.38940)

ALICE Coll., [arXiv:1012.1657](https://arxiv.org/abs/1012.1657)

ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360) (NEW!)

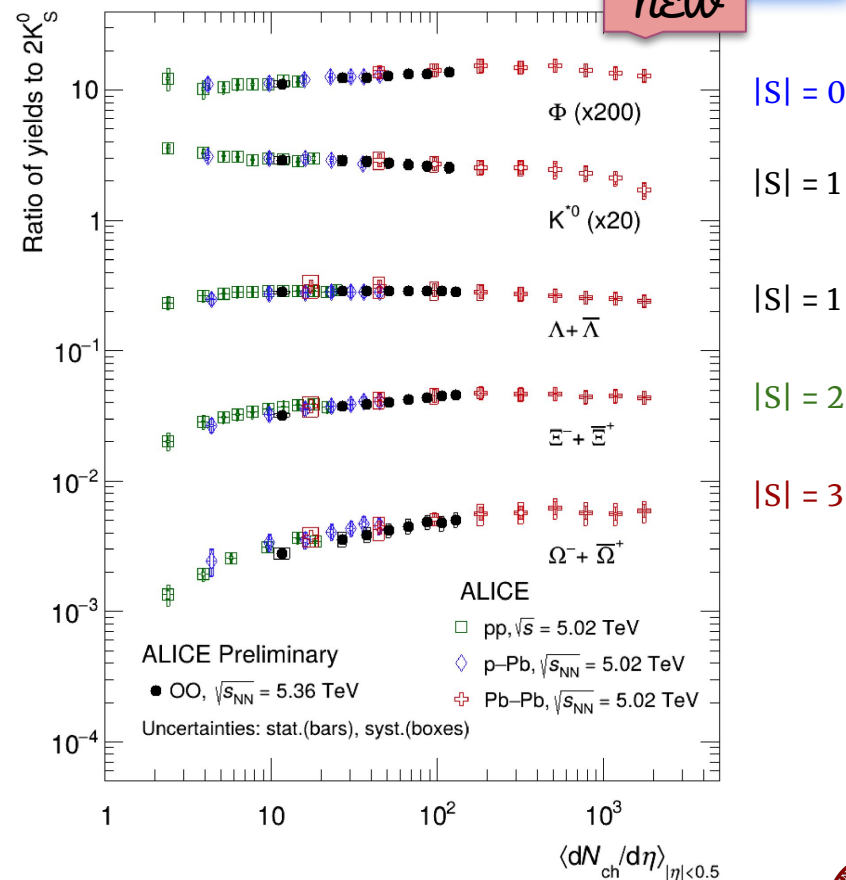




Strange and resonances yield ratios to $2K_s^0$ as a function of the charged-particle multiplicity in different colliding systems

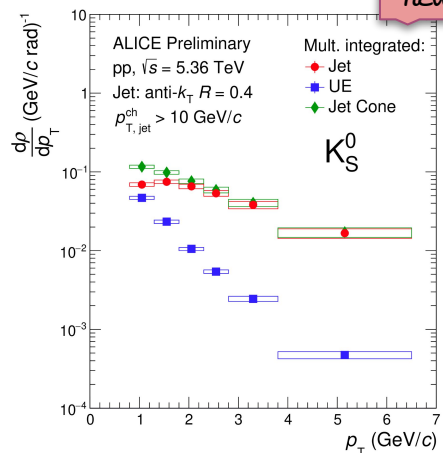
- **OO resonance production is consistent with hadronic-phase effects:** K^{*0}/K_s^0 decreases, while ϕK_s^0 remains largely unchanged
- **Strange-hadron production follows a common multiplicity scaling, with stronger enhancement for increasing strangeness content**

ALICE Coll., [arXiv:2511.10306](https://arxiv.org/abs/2511.10306) (NEW!)
 ALICE Coll., [Phys.Lett.B 728 \(2014\) 25-38, 2014](https://arxiv.org/abs/1402.2578)
 ALICE Coll., [Phys.Lett.B 758 \(2016\) 389-401, 2016](https://arxiv.org/abs/1602.03894)
 ALICE Coll., [arXiv:2511.10360](https://arxiv.org/abs/2511.10360) (NEW!)
 ALICE Coll., [arXiv:2204.10263](https://arxiv.org/abs/2204.10263)
 ALICE Coll., [arXiv:2106.13113](https://arxiv.org/abs/2106.13113) } resonances



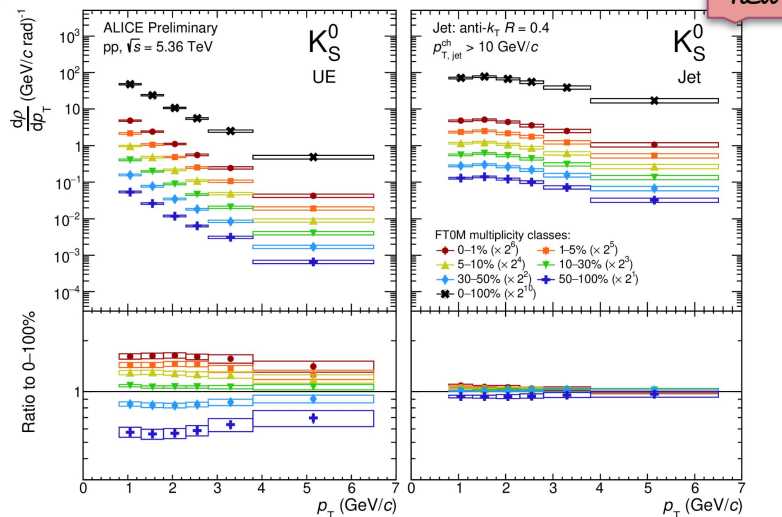
ALI-PREL-624137





ALI-PREL-626743

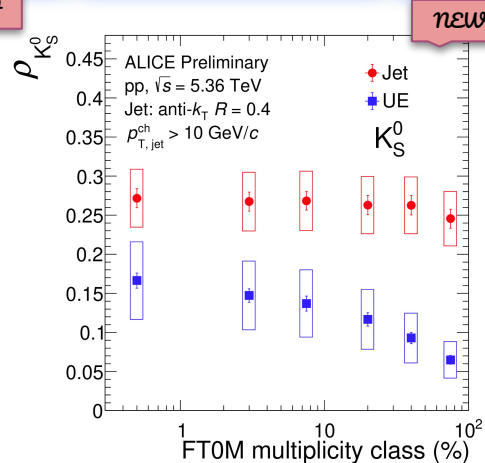
p_T differential density: the spectra in **jets** are harder than in the **UE**



ALI-PREL-626746

First measurement of the p_T differential density vs multiplicity

- UE: hardening of the p_T spectra with event multiplicity $\rightarrow$ similar to inclusive measurement
- In Jet: the effect is **suppressed** $\rightarrow$ spectral shapes and yields are consistent across multiplicity classes



ALI-PREL-626752

First measurement of the p_T integrated yields vs multiplicity

- Strangeness evolution with multiplicity is primarily driven by the UE
- The total production becomes dominated by the jet component in events with a jet $p_T > 10$ GeV/c



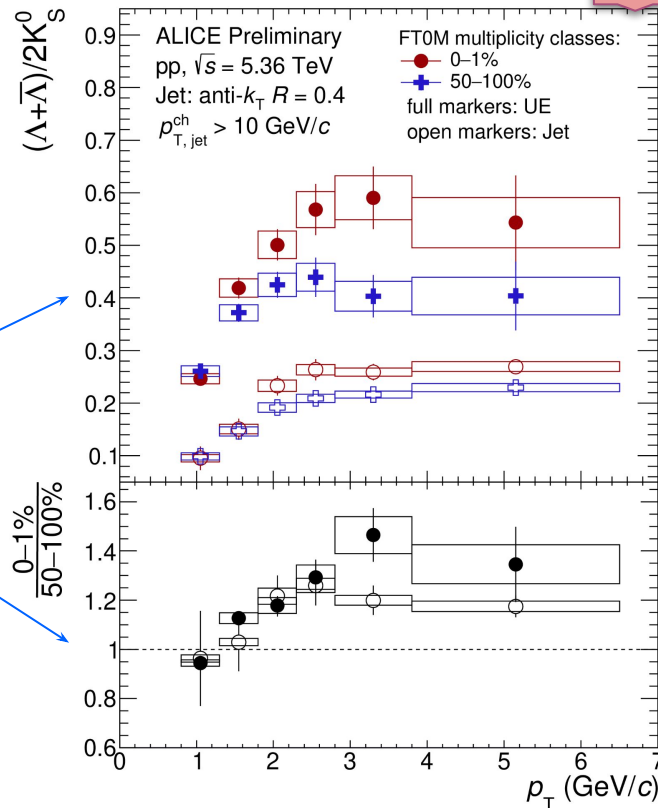


new

In pp @ 5.36 TeV ALICE observed that Λ/K_S^0 ratio shows an enhancement in the intermediate p_T region (~ 3 GeV/c) + evolution with multiplicity (flow-like effect + quark recombination)

Is this true in- and out-of-jets?

- UE ratios show a hint of **enhancement** in the intermediate- p_T region (~ 3 GeV/c), the effect is **suppressed in the Jet**
- A **multiplicity evolution** is observed in the UE, milder but significant sensitivity to the event activity also within the Jet



ALI-PREL-626748



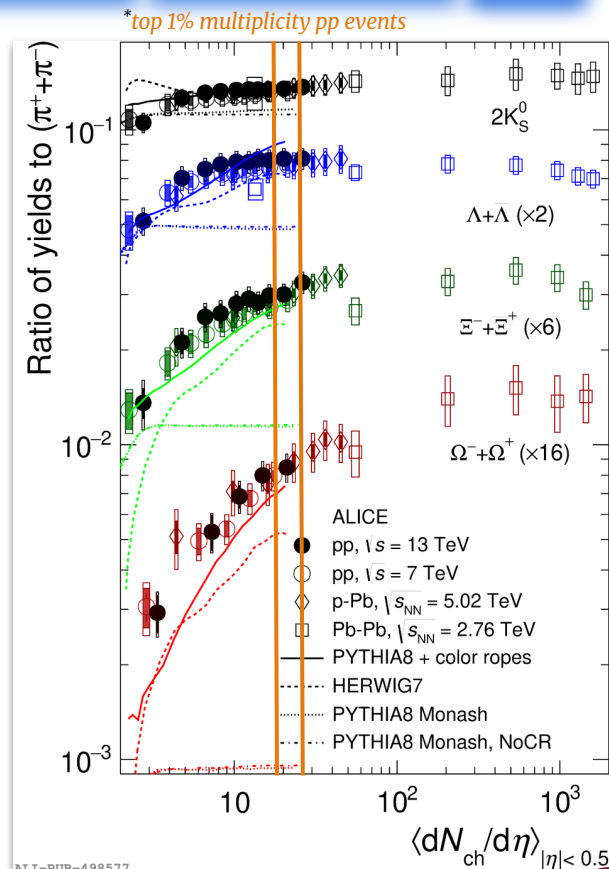


- Can the h/π independence across collision systems be characterized by properties other than differences in $\langle dN_{ch}/d\eta \rangle$?
 - classify HM events* based on event topology

TRANSVERSE SPHEROCITY estimation

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \sum_i \left(\frac{|\hat{p}_{T,i} \times \hat{n}|}{N_{\text{trk}}} \right)$$

→ categorize events by their azimuthal topology





**top 1% multiplicity pp events*

- Can the h/π independence across collision systems be characterized by properties other than differences in $\langle dN_{ch}/d\eta \rangle$?
 - **classify HM events*** based on event topology

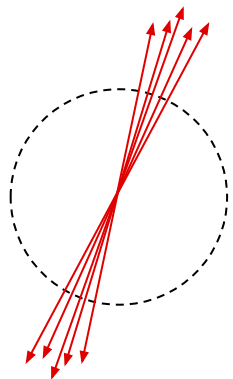
TRANSVERSE SPHEROCITY estimation

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \sum_i \left(\frac{|\hat{p}_{T,i} \times \hat{n}|}{N_{\text{trk}}} \right)$$

→ categorize events by their azimuthal topology

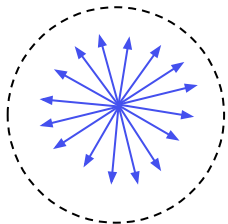
Jet-like events

- topology similar to a pair of back-to-back jets
- all tracks are parallel in the azimuthal plane
- particle production mainly driven by **hard processes** (in-vacuum hadronization)



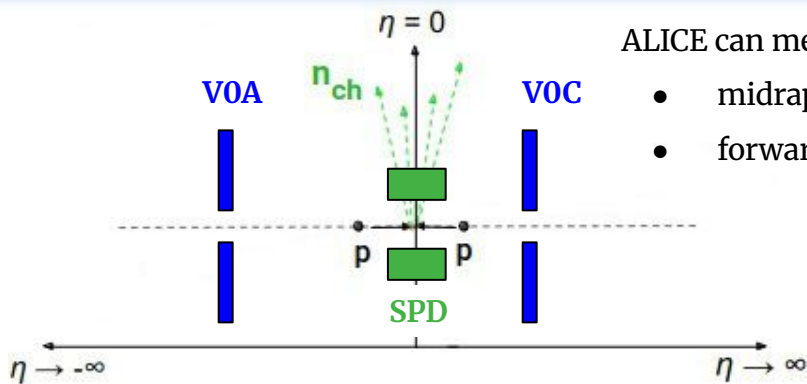
Isotropic events

- symmetric azimuthal topology
- all tracks are uniformly distributed in the azimuthal plane
- particle production mainly driven by **multiple softer collisions** (hadronization in a medium – QGP)



0 ← S_0 → 1



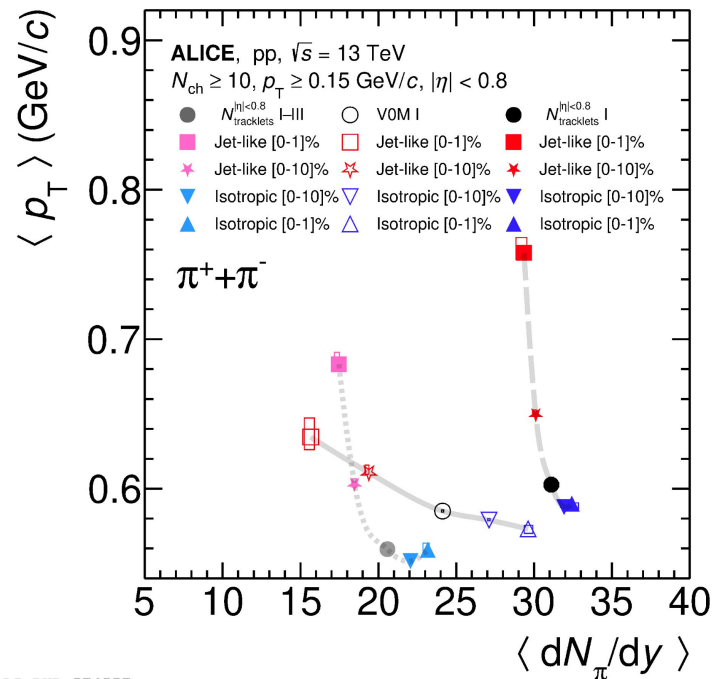


ALICE can measure:

- midrapidity multiplicity (**SPD**)
- forward multiplicity (**VO detectors**)

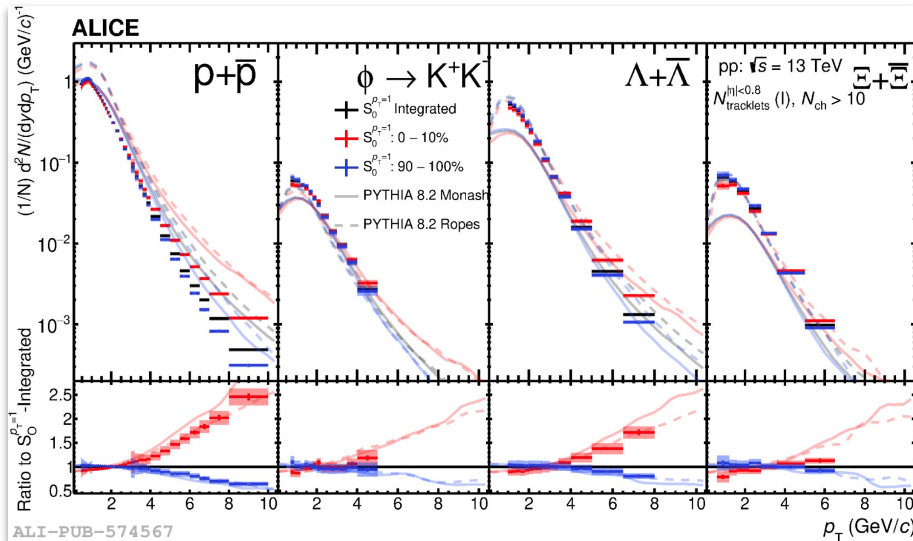
ALICE Coll., [JHEP 05 \(2024\) 184](#)

- Selecting the high **multiplicity at midrapidity** in conjunction with sphericity selection:
 - large differences in $\langle p_T \rangle$ among the event classes
 - small shift in yields
- **best at separating events based on their hardness**
- Selecting the high **multiplicity at forward** in conjunction with sphericity selection:
 - similar $\langle p_T \rangle$ among the event classes
 - large variations in yields



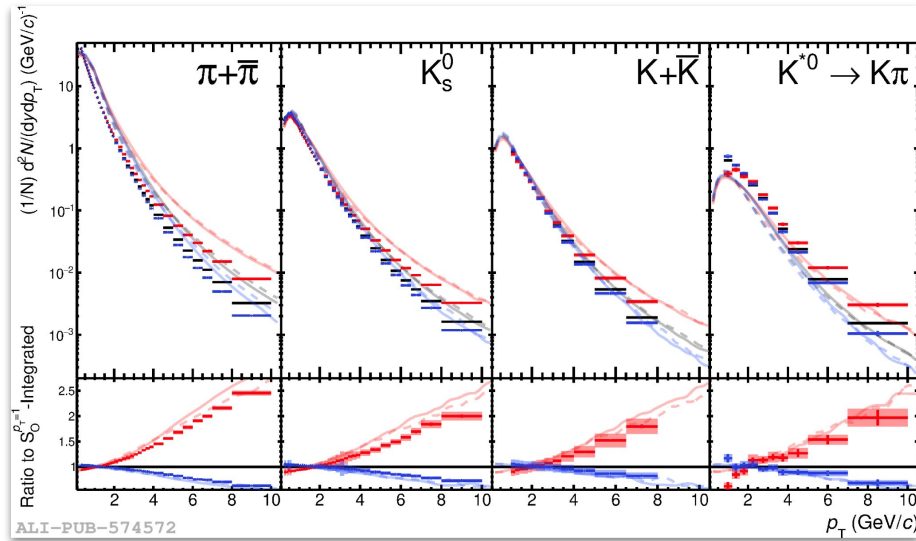


Baryons



Mesons

ALICE Coll., [JHEP 05 \(2024\) 184](#)

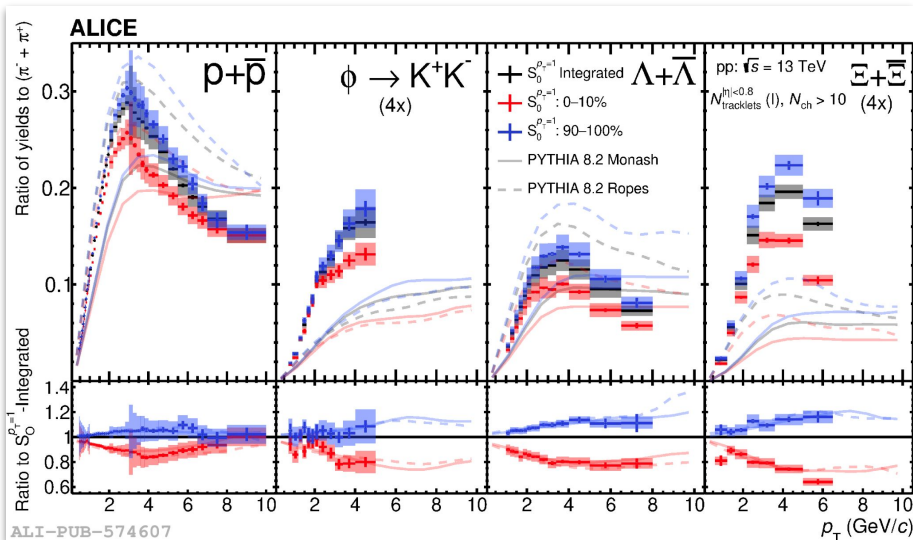


- Trends are consistent between all observed particle species:
 - for **jet-like events**: suppression at low- p_T , but enhancement at high- p_T (viceversa for **isotropic events**)
- Model comparison:
 - none of the available models is able to reproduce the absolute trends



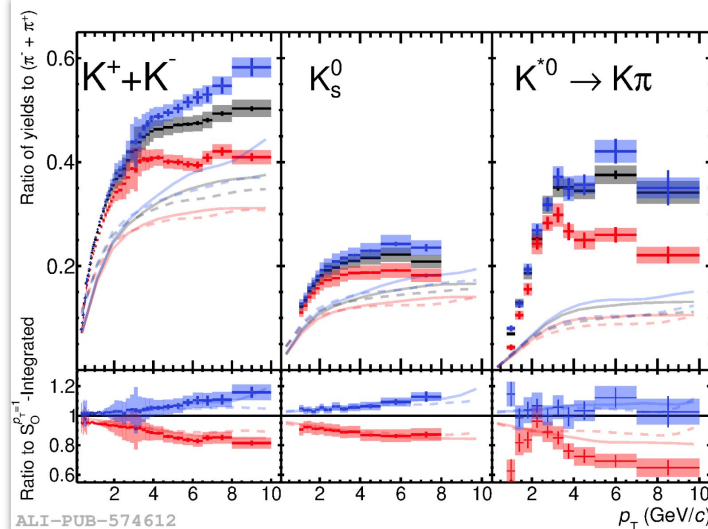


Baryons



Mesons

ALICE Coll., JHEP 05 (2024) 184

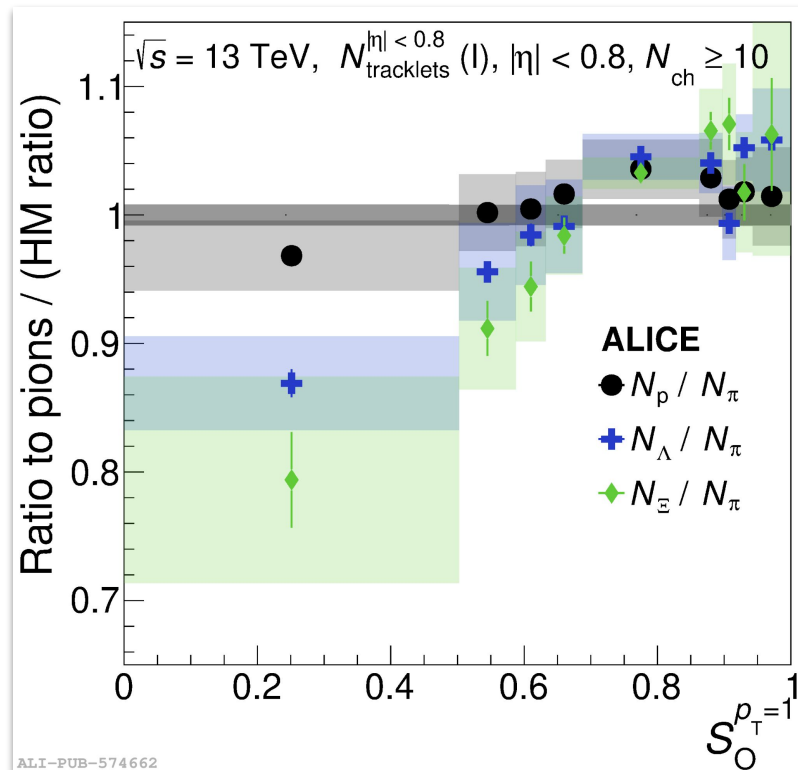


- Enhancement of strangeness yield in **isotropic events**, suppression in **jet-like events** → strange particle production is driven by isotropic topologies
- selecting top 1% of $N_{\text{tracklets}}^{|\eta| < 0.8}$, 1% $S_0^{pT=1}$ classes: more pronounced suppression in jet-like events
- Model comparison:
 - none of the available models is able to reproduce the absolute trends





- Strangeness production is suppressed in **jet-like events** ($S_0^{pT=1} \rightarrow 0$), slightly enhanced in softer, **isotropic events** ($S_0^{pT=1} \rightarrow 1$)
- **increase** as a function of $S_0^{pT=1}$ with indications of an ordering with strangeness content
 - Proton is mostly unmodified

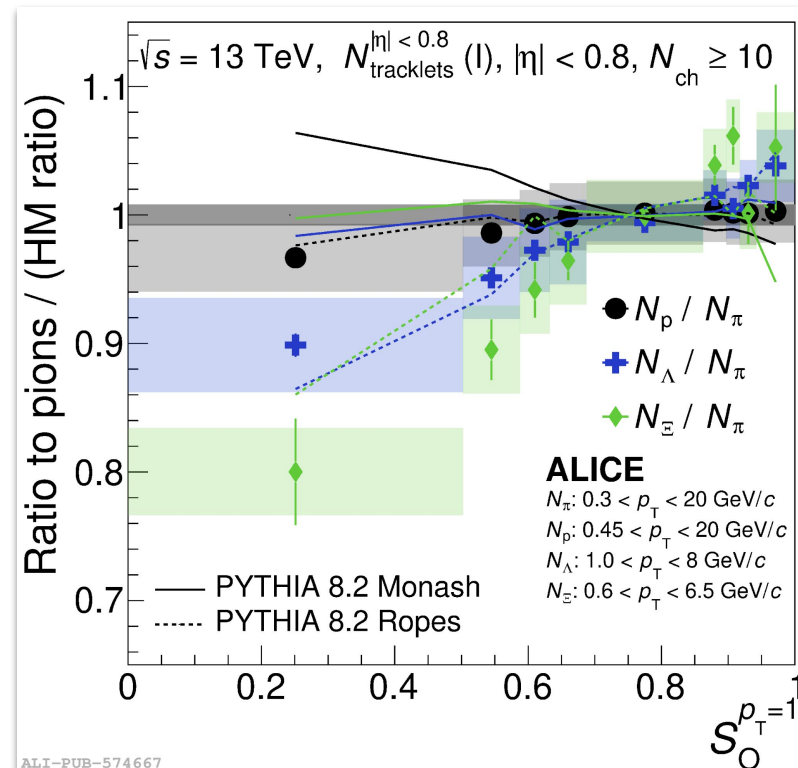


ALI-PUB-574662



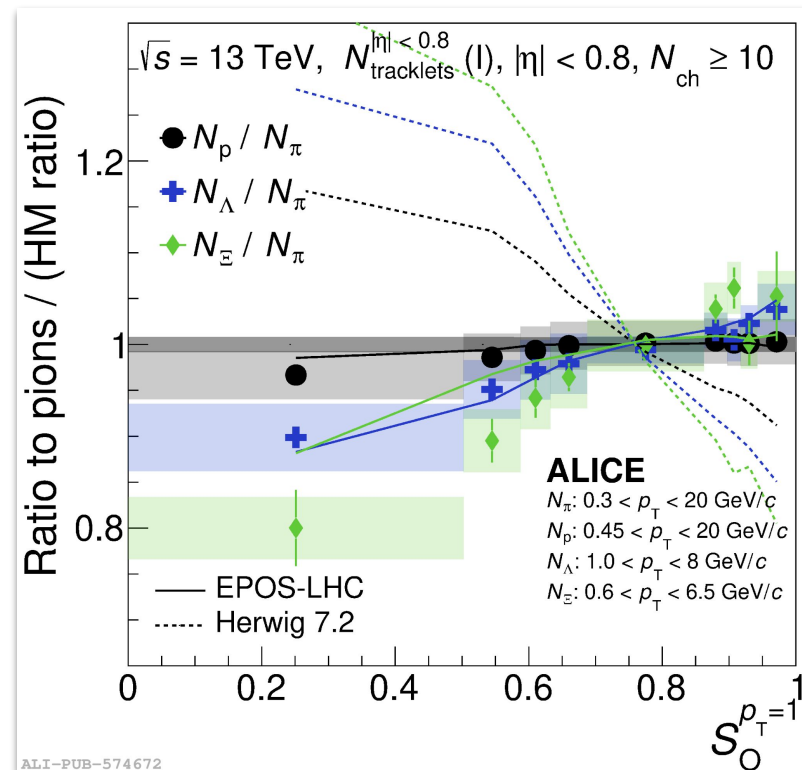


- Strangeness production is suppressed in **jet-like events** ($S_0^{pT=1} \rightarrow 0$), slightly enhanced in softer, **isotropic events** ($S_0^{pT=1} \rightarrow 1$)
- **increase** as a function of $S_0^{pT=1}$ with indications of an ordering with strangeness content
 - Proton is mostly unmodified
- Model comparison:
 - [PYTHIA 8.2 Ropes](#) qualitative predicts the trends, but not catching strangeness ordering, while [PYTHIA 8.2 Monash](#) is unable to capture the trends





- Strangeness production is suppressed in **jet-like events** ($S_0^{pT=1} \rightarrow 0$), slightly enhanced in softer, **isotropic events** ($S_0^{pT=1} \rightarrow 1$)
- **increase** as a function of $S_0^{pT=1}$ with indications of an ordering with strangeness content
 - Proton is mostly unmodified
- Model comparison:
 - [PYTHIA 8.2 Ropes](#) qualitative predicts the trends, but not catching strangeness ordering, while [PYTHIA 8.2 Monash](#) is unable to capture the trends
 - Also [EPOS LHC](#) qualitative predicts the trends, but not catching strangeness ordering, while [Herwig 7.2](#) predicts opposite trends



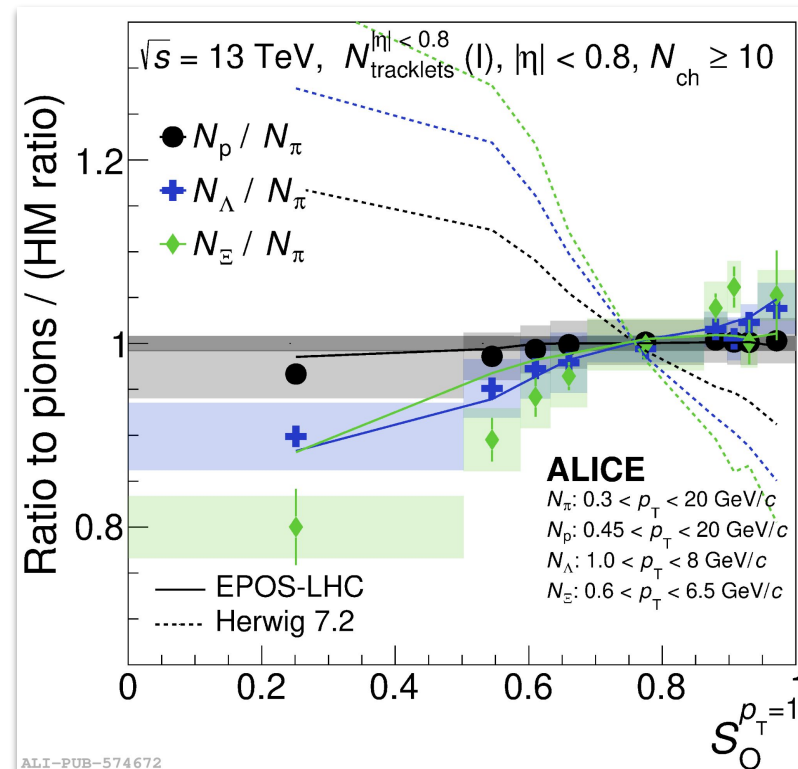
ALI-PUB-574672





- Strangeness production is suppressed in **jet-like events** ($S_0^{pT=1} \rightarrow 0$), slightly enhanced in softer, **isotropic events** ($S_0^{pT=1} \rightarrow 1$)
- **increase** as a function of $S_0^{pT=1}$ with indications of an ordering with strangeness content
 - Proton is mostly unmodified
- Model comparison:
 - [PYTHIA 8.2 Ropes](#) qualitative predicts the trends, but not catching strangeness ordering, while [PYTHIA 8.2 Monash](#) is unable to capture the trends
 - Also [EPOS LHC](#) qualitative predicts the trends, but not catching strangeness ordering, while [Herwig 7.2](#) predicts opposite trends

One is able to control the degree of QGP-like effects in small systems by categorizing events based on the azimuthal topology. $S_0^{pT=1}$ integrated HM events are dominated by isotropic processes



ALI-PUB-574672





- Can the h/π independence independence across collision systems be characterized by properties other than differences in $\langle dN_{ch}/d\eta \rangle$?
 - **decouple global properties and local effects**

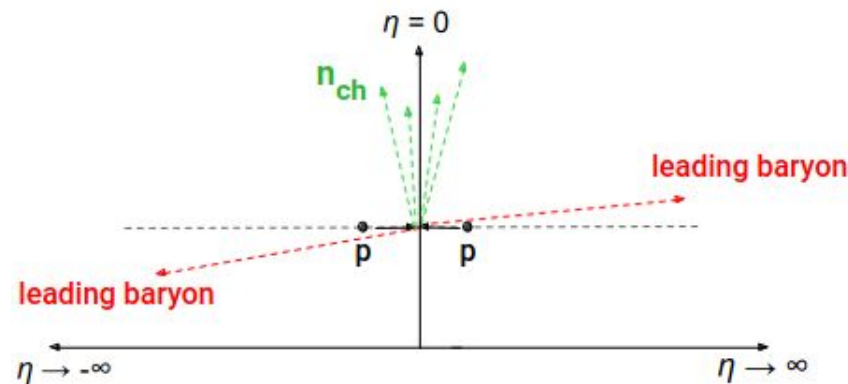
[Eur.Phys.J.C 50, 341-352 \(2007\)](#)

The charged-particle multiplicity produced in pp collisions is:

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

EFFECTIVE ENERGY: energy available for particle production in the initial stages of the collision

$E_{\text{eff}} < \sqrt{s}$ due to the **emission of leading baryons** at very forward rapidity





- Can the h/π independence across collision systems be characterized by properties other than differences in $\langle dN_{ch}/d\eta \rangle$?
 - decouple global properties and local effects

[Eur.Phys.JC 50, 341-352 \(2007\)](#)

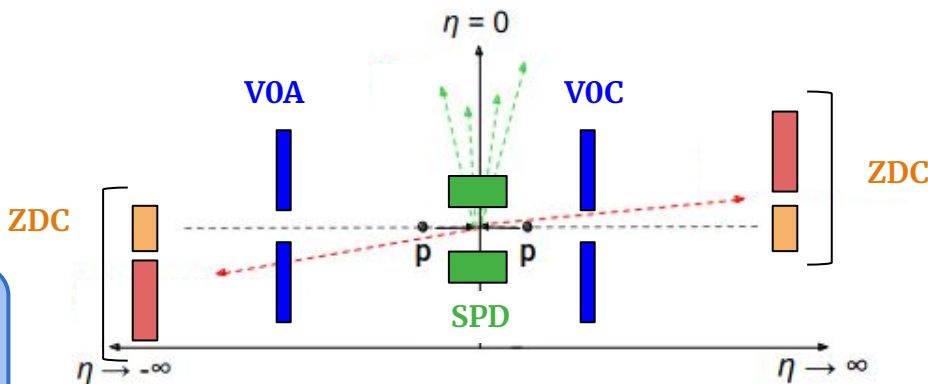
The charged-particle multiplicity produced in pp collisions is:

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

EFFECTIVE ENERGY: energy available for particle production in the initial stages of the collision

$E_{\text{eff}} < \sqrt{s}$ due to the **emission of leading baryons** at very forward rapidity

Is strangeness production correlated with E_{eff} , which is connected with the initial stage of the collision?



ALICE can measure:

- midrapidity multiplicity (**SPD**)
- forward multiplicity (**VO detectors**)
- leading energy (**ZDC**)

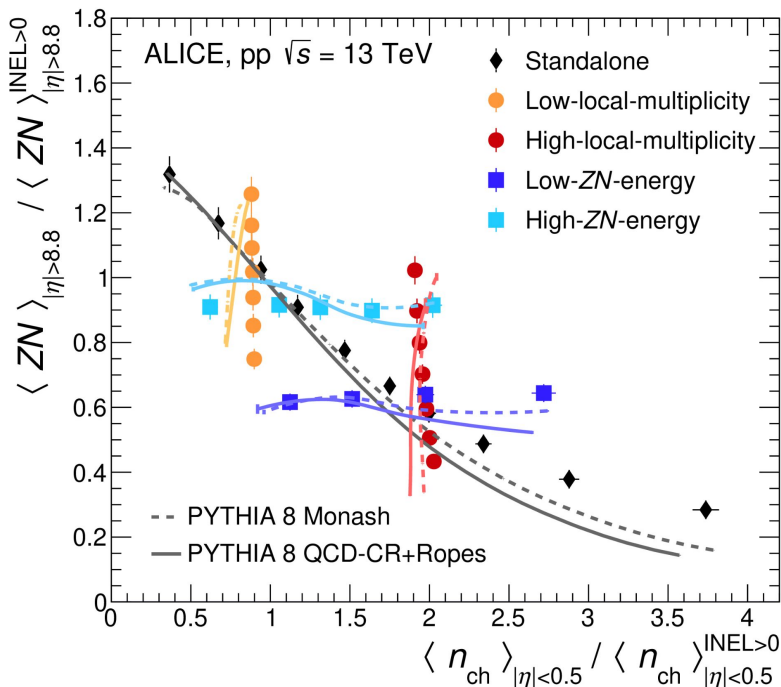
$$E_{\text{eff}} = \sqrt{s} - E_{\text{leading}} \sim \sqrt{s} - E_{\text{ZDC}}$$





ALICE measured that the **forward energy** (y-axis) **decreases with increasing particle multiplicity** produced at **midrapidity** (x-axis)

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



Standalone:

- V0M percentile classes
- increasing $\langle n_{\text{ch}} \rangle$ for decreasing $\langle ZN \rangle$

High/Low-local-multiplicity:

- V0M + SPD clusters percentile classes
- fixed $\langle n_{\text{ch}} \rangle$ and decreasing $\langle ZN \rangle$

High/Low-ZN-multiplicity:

- V0M + SPD clusters percentile classes
- fixed $\langle ZN \rangle$ and increasing $\langle n_{\text{ch}} \rangle$

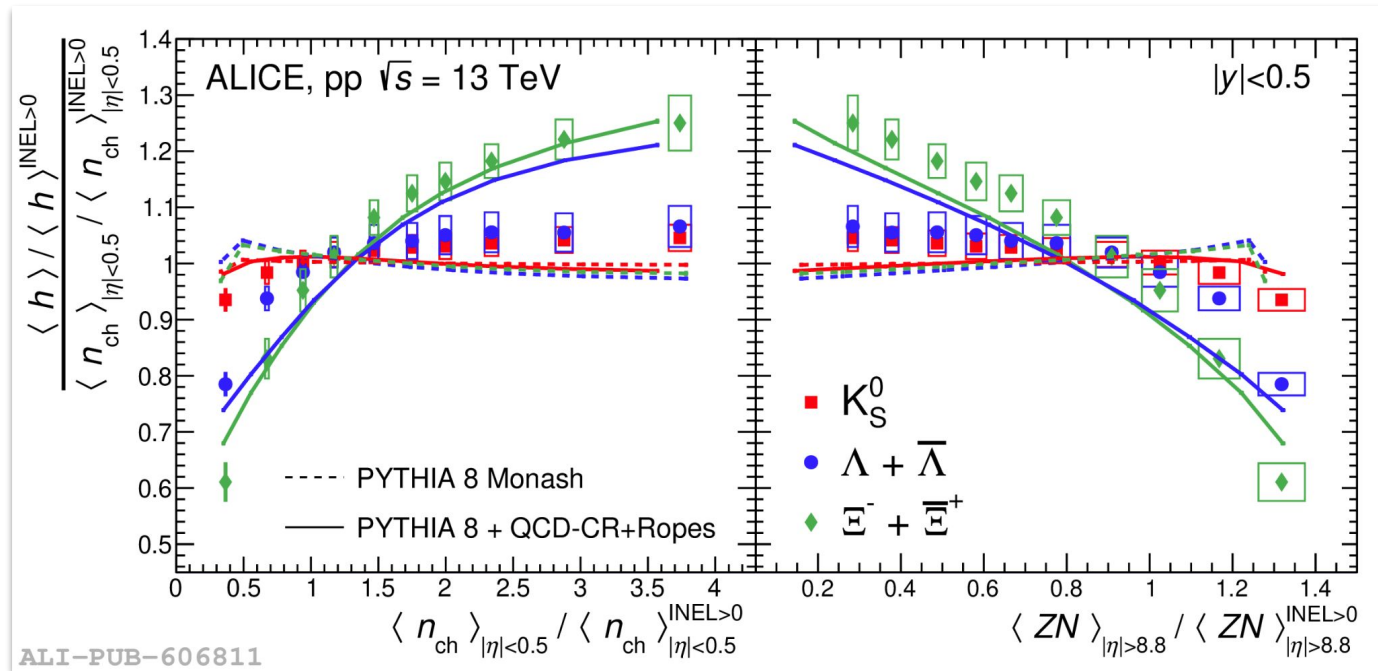
NOTE: SPD classes based on the number of clusters in the SPD





Yields of strange hadrons normalised to the charged particle multiplicity (proxy for pions):

- **increase** with the **multiplicity at midrapidity** (the well known strangeness enhancement!) – left
- are **anticorrelated** with the **ZDC energy** – right



There is a **hierarchy**:
increase/decrease with
strangeness content

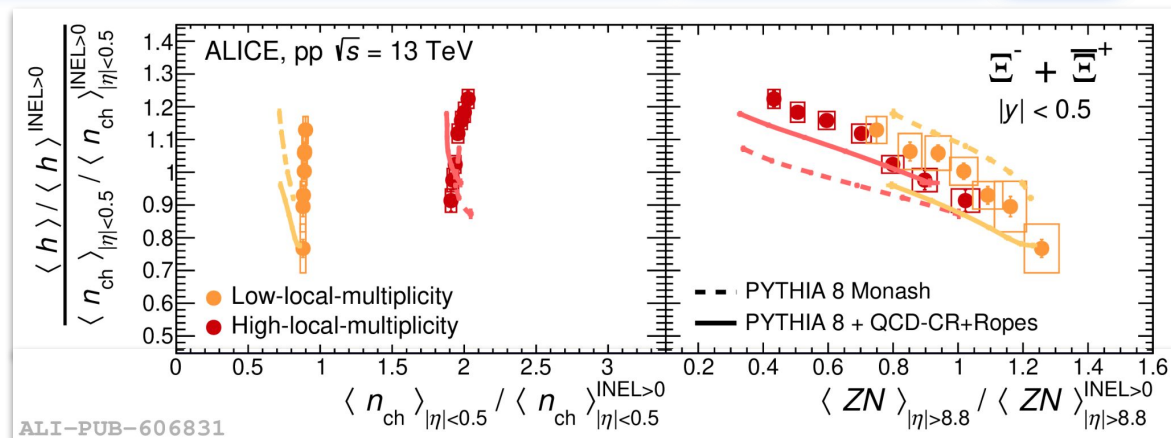
ALI-PUB-606811





Ξ yields normalised to the charged particle multiplicity, **fixing the multiplicity at midrapidity**:

- increase at fixed multiplicity (left) with decreasing forward energy (increasing E_{eff} , right)



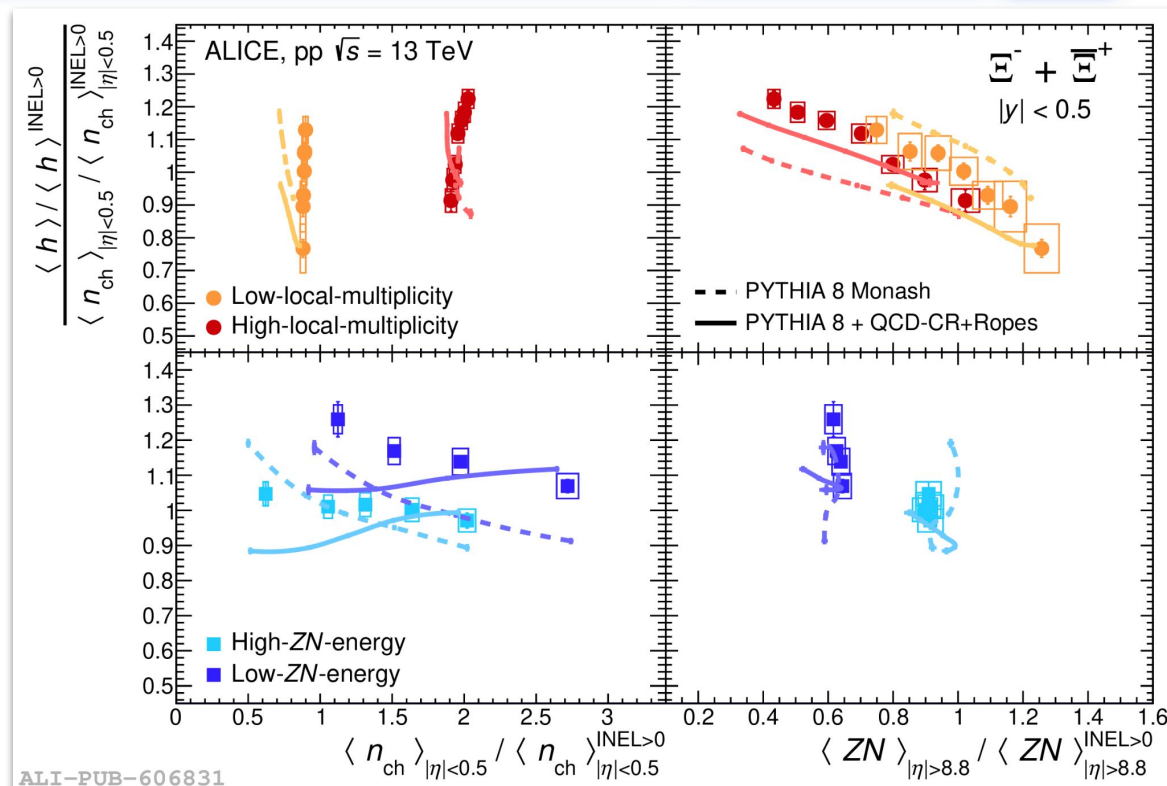


Ξ yields normalised to the charged particle multiplicity, **fixing the multiplicity at midrapidity**:

- increase at fixed multiplicity (left) with decreasing forward energy (increasing E_{eff} , right)

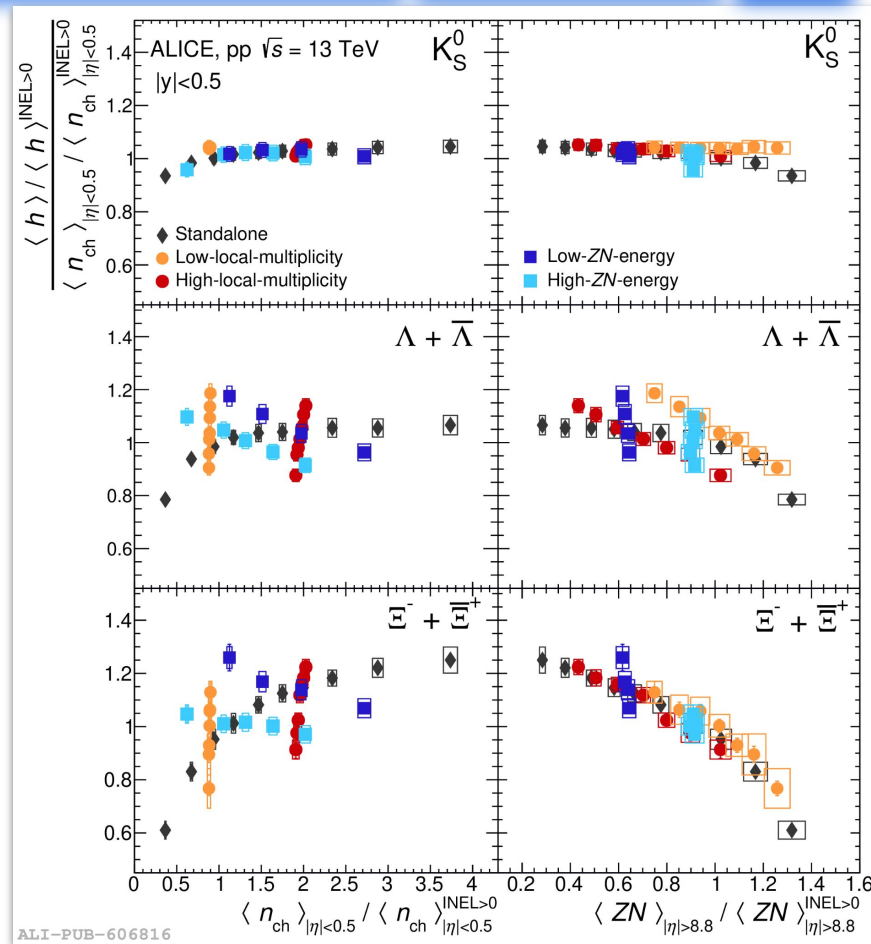
Ξ yields normalised to the charged particle multiplicity, **fixing the ZN energy**:

- no enhancement with multiplicity
- anticorrelation at fixed ZN energy





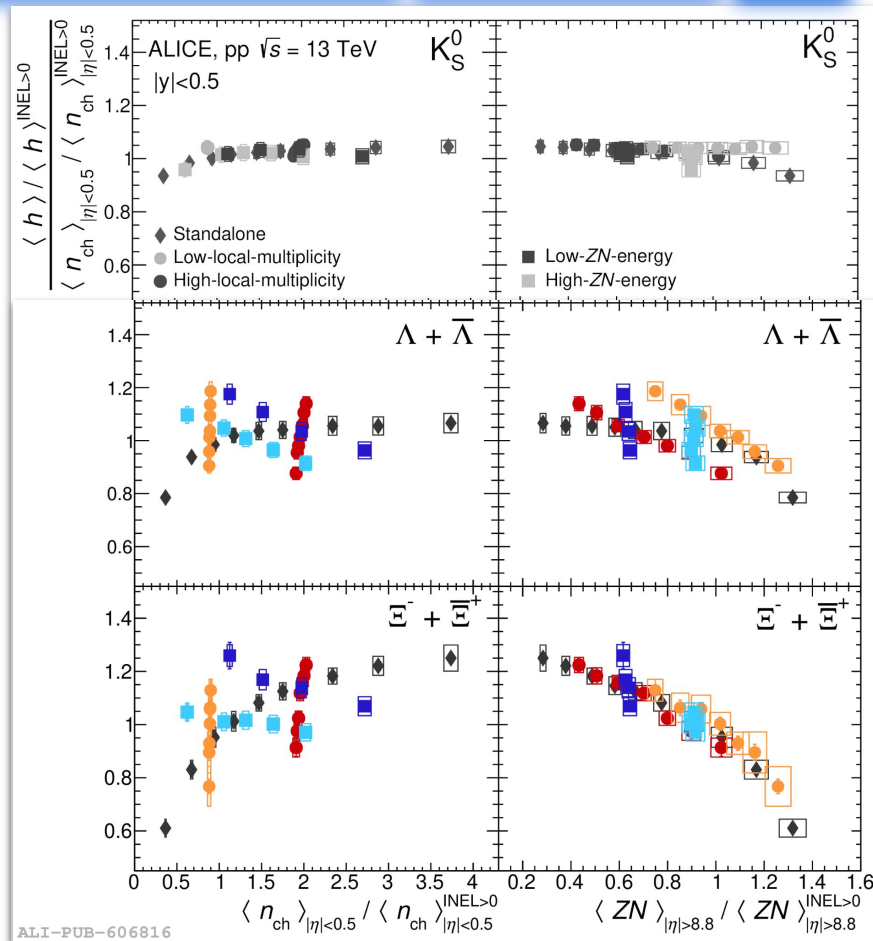
- *top:* K_S^0/n_{ch} follows standalone trend with moderate variations
- *middle:* Λ/n_{ch} higher increase achieved in double-differential analysis
- *bottom:* Ξ/n_{ch} displays ~universal dependence on forward energy within uncertainties





- *top*: K_S^0/n_{ch} follows standalone trend with moderate variations
- *middle*: Λ/n_{ch} higher increase achieved in double-differential analysis
- *bottom*: Ξ/n_{ch} displays ~universal dependence on forward energy within uncertainties
- Λ and Ξ ratios at **fixed multiplicity**
 - compatible relative increase
 - different dependence on the forward energy

Hadron strangeness content plays a role in the observed behaviour



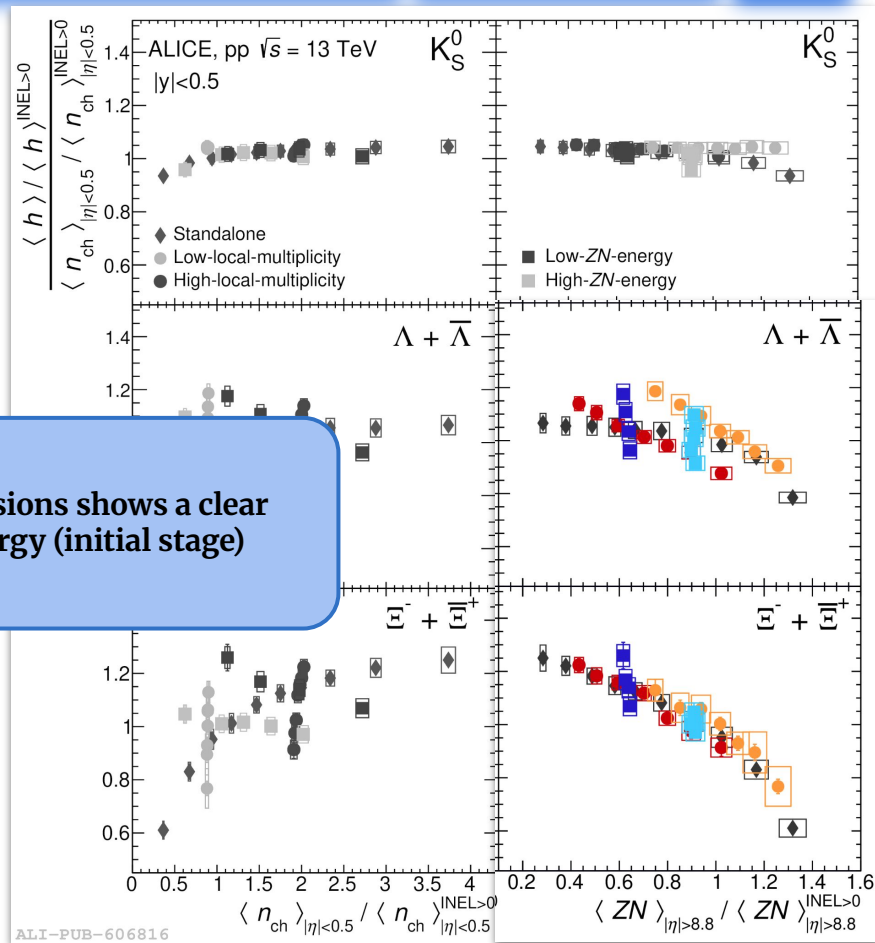


- *top:* K_S^0/n_{ch} follows standalone trend with moderate variations
- *middle:* Λ/n_{ch} higher increase achieved in double-differential analysis
- *bottom:* Ξ/n_{ch} displays ~universal dependence on forward energy within uncertainties

- Λ and Ξ ratios at fixed energy
 - compatible
 - different dependence

Strangeness production in pp collisions shows a clear correlation with the effective energy (initial stage)

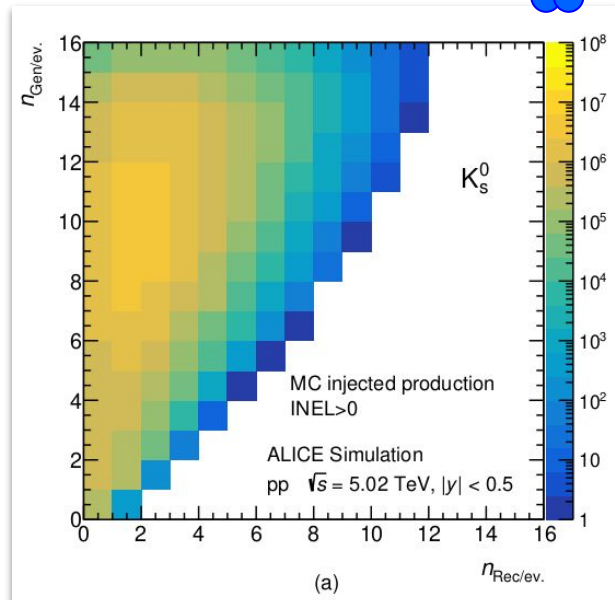
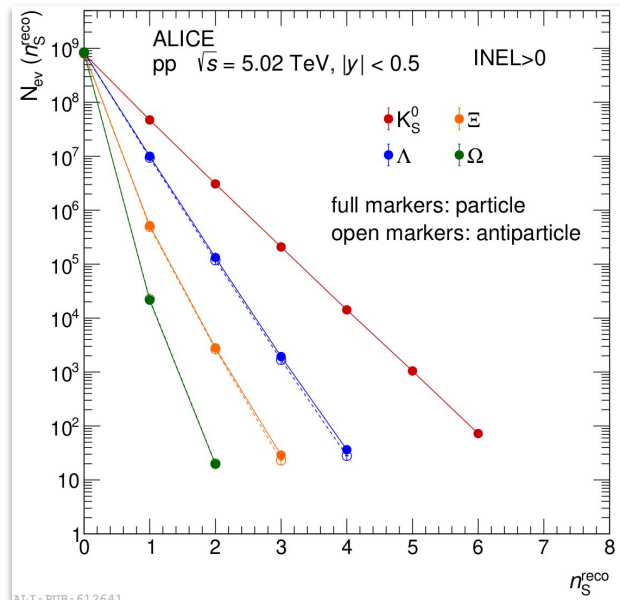
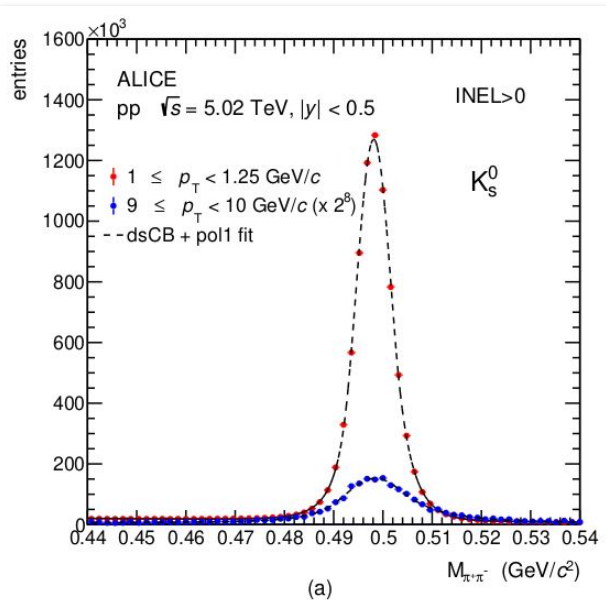
Hadron strangeness content plays a role in the observed behaviour





Counting the number of strange particles (K^0 , Λ , Ξ , Ω) event-by-event in pp collisions at $\sqrt{s} = 5.02$ TeV

New paper !



Each candidate **weighted** by **P(sig)** or **P(bkg)** estimated by **1D invariant mass fit** in p_T /multiplicity bins

Weights associated to each of the N candidates **combined** to obtain:
 $P(\text{all-sig}), \dots, P(\text{all-bkg})$

For each event: full probability spectrum spanning from 0 to N

Correction for detector response (MC production featuring correct p_T distribution)

Bayesian unfolding procedure applied



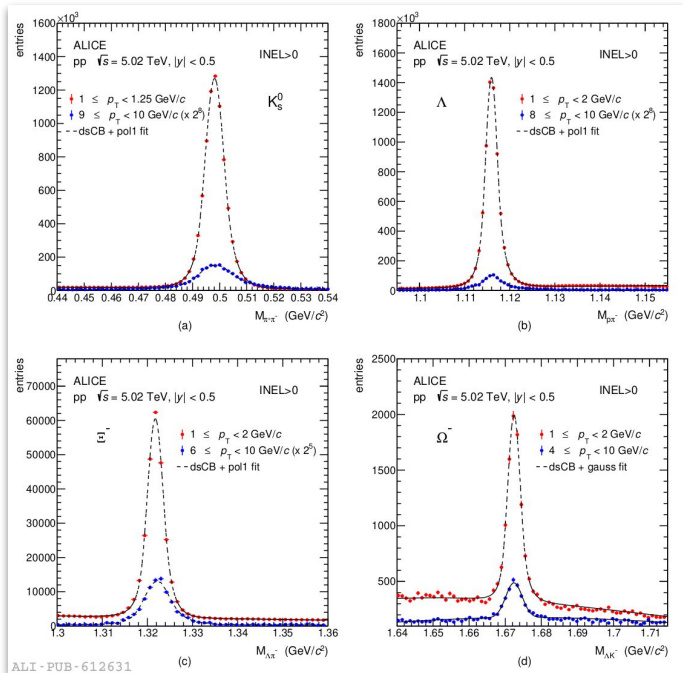


New paper !

- **1D fit to real data: sum = signal + bkg**
 → signal: double-sided Crystal-Ball (dsCB); bkg: linear (gaussian for Ω)
 → for each invariant mass value → probability that candidate is signal or background
- Procedure applied for several p_T /multiplicity bins

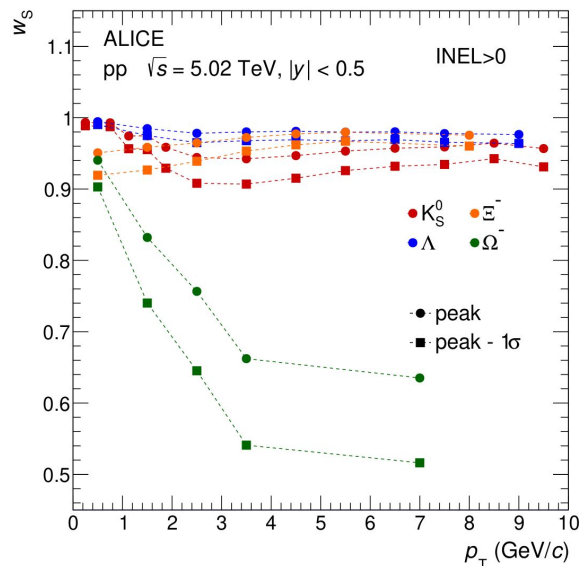
$$w_S(p_T, m_{inv}; VOM) = \frac{dsCB(p_T, m_{inv}; VOM)}{\text{Total}(p_T, m_{inv}; VOM)}$$

$$w_B(p_T, m_{inv}; VOM) = 1 - w_S(p_T, m_{inv}; VOM)$$



Signal weights as a function of p_T at the peak and at a distance of $1\sigma_{dsCB}$

- $w_S > 0.9$ for all particles, except for Ω^- (lower signal/bkg → smaller w_S)
- w_S evolves smoothly with p_T

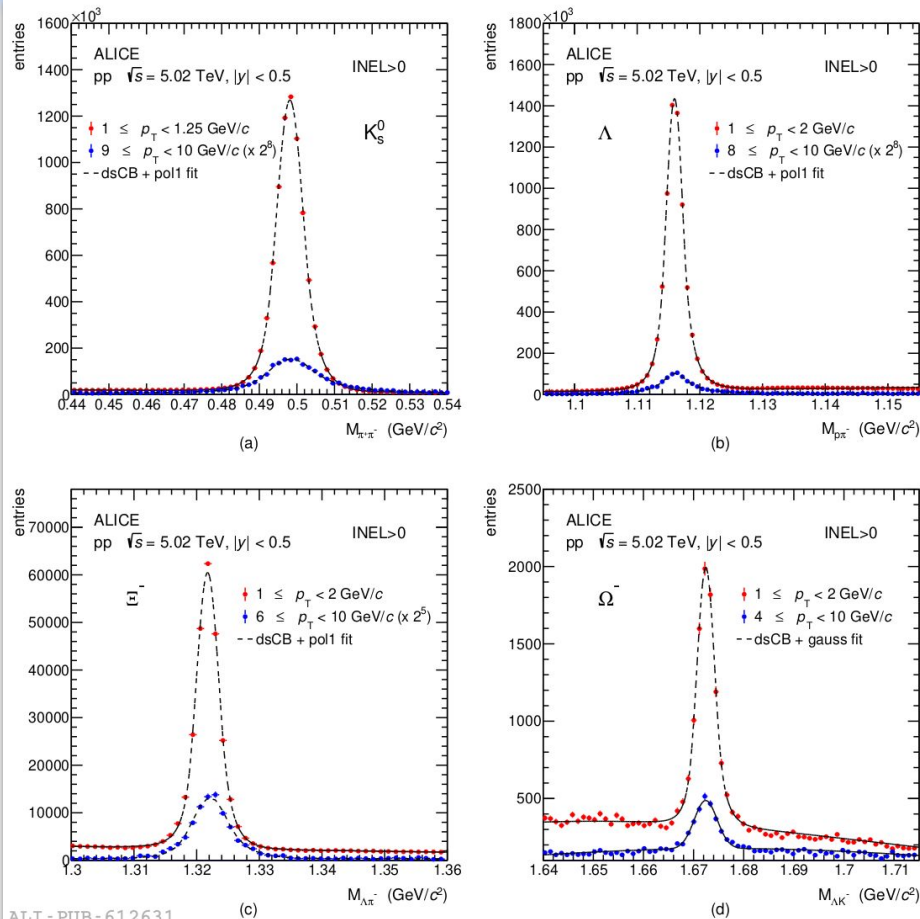


ALICE Coll., [arXiv:2511.10413](https://arxiv.org/abs/2511.10413)





New paper !



- 1D invariant mass distributions for K_s^0 (top, left), Λ (top, right), Ξ^- (bottom, left) and Ω^- (bottom, right), at low (~ 1 GeV/c, red circles) and high transverse momentum (blue circles) for the INEL > 0 event class

- dashed lines: signal + bkg fits.

- NOTE**
Signal: dsCB

$$f(x; \bar{x}, \sigma, \alpha_L, n_L, \alpha_H, n_H) = \begin{cases} \left(\frac{n_L}{|\alpha_L|} \right)^{n_L} \cdot e^{-\frac{|\alpha_L|^2}{2}} \cdot \left(\frac{n_L}{|\alpha_L|} - |\alpha_L| - \frac{x-\bar{x}}{\sigma} \right)^{-n_L} & \left(\frac{x-\bar{x}}{\sigma} \right) < -\alpha_L, \\ e^{-\frac{1}{2} \left(\frac{x-\bar{x}}{\sigma} \right)^2} & -\alpha_L \leq \left(\frac{x-\bar{x}}{\sigma} \right) < \alpha_H, \\ \left(\frac{n_H}{|\alpha_H|} \right)^{n_H} \cdot e^{-\frac{|\alpha_H|^2}{2}} \cdot \left(\frac{n_H}{|\alpha_H|} - |\alpha_H| - \frac{x-\bar{x}}{\sigma} \right)^{-n_H} & \left(\frac{x-\bar{x}}{\sigma} \right) \geq \alpha_H. \end{cases}$$

- Bkg: linear/gaussian

$$f(x; a, b) = a \cdot x + b \quad f(x; \bar{x}, \sigma) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{(x-\bar{x})^2}{2\sigma^2}}$$

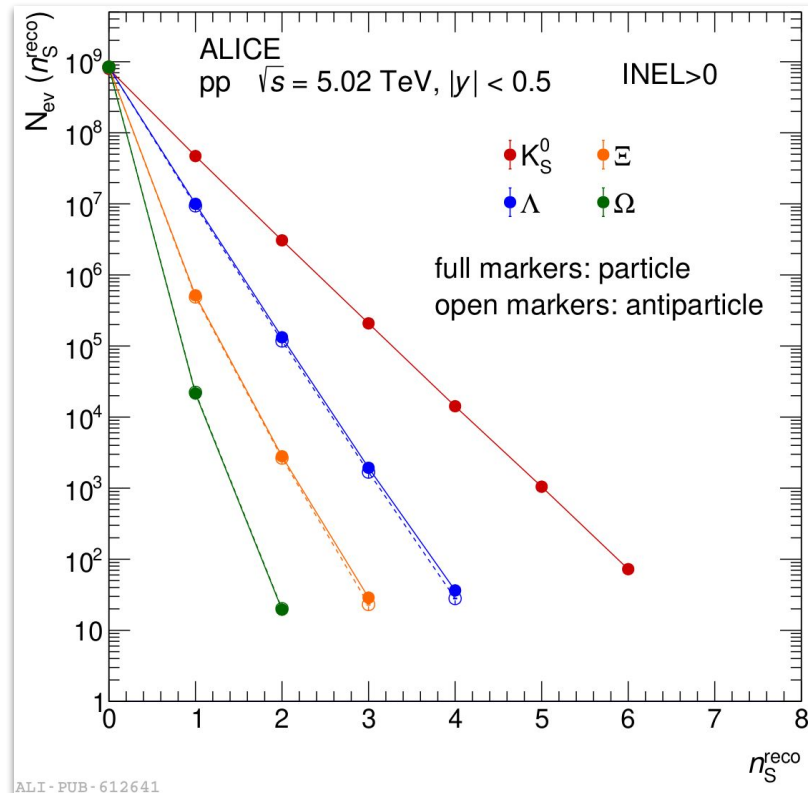




- **Weights** associated to each of the N candidates **combined** to obtain: $P(\text{all-sig}), \dots, P(\text{all-bkg})$
- for each event:
full probability spectrum spanning from 0 to N
- sum over all events:
un-corrected multiplicity spectrum

NOTE: for Λ ($\bar{\Lambda}$) feed-down (FD) contribution from the decays of Ξ^- (Ξ^+) and Ξ^0 has been considered

Un-corrected multiplicity spectrum

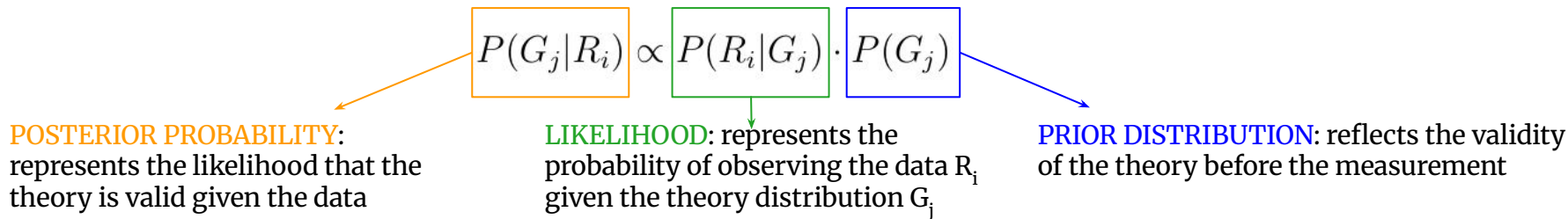




Correction for the detector response:

- typically: $A \times \epsilon$ method (ratio between the number of reconstructed particles and the number of generated particles) → suitable for correcting the yield
- this work: **Bayesian unfolding technique** [12] (considering Monte Carlo simulation featuring realistic p_T distribution [13]) → suitable for correcting the number of events containing a specific number of particles of a given species

Bayesian unfolding [12] → **iterative process** based on Bayes' theorem



- choice of the prior distribution in order to apply the Bayes' theorem → posterior probability matrix obtained
- application to reconstructed spectra → 1st estimation of the corrected spectra
- corrected spectra obtained in the previous step becomes the prior distribution and the correction proceeds as before
- procedure is reiterated until stability is achieved (**regularization parameter: n_{iter}**)

[12] G. D'Agostini, "[A multidimensional unfolding method based on Bayes' theorem](#)"

[13] ALICE Coll., [arXiv:2511.10306](#)





probability of reconstructing i particles given
that j particles were generated

$$\begin{bmatrix} R0 \\ R1 \\ R2 \\ \dots \\ Rn \end{bmatrix} = \begin{bmatrix} P(R0|G0) & P(R0|G1) & P(R0|G2) & \dots & P(R0|Gn) \\ P(R1|G0) & P(R1|G1) & P(R1|G2) & \dots & \dots \\ P(R2|G0) & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ P(Rn|G0) & \dots & \dots & \dots & P(Rn|Gn) \end{bmatrix} \cdot \begin{bmatrix} G0 \\ G1 \\ G2 \\ \dots \\ Gn \end{bmatrix}$$

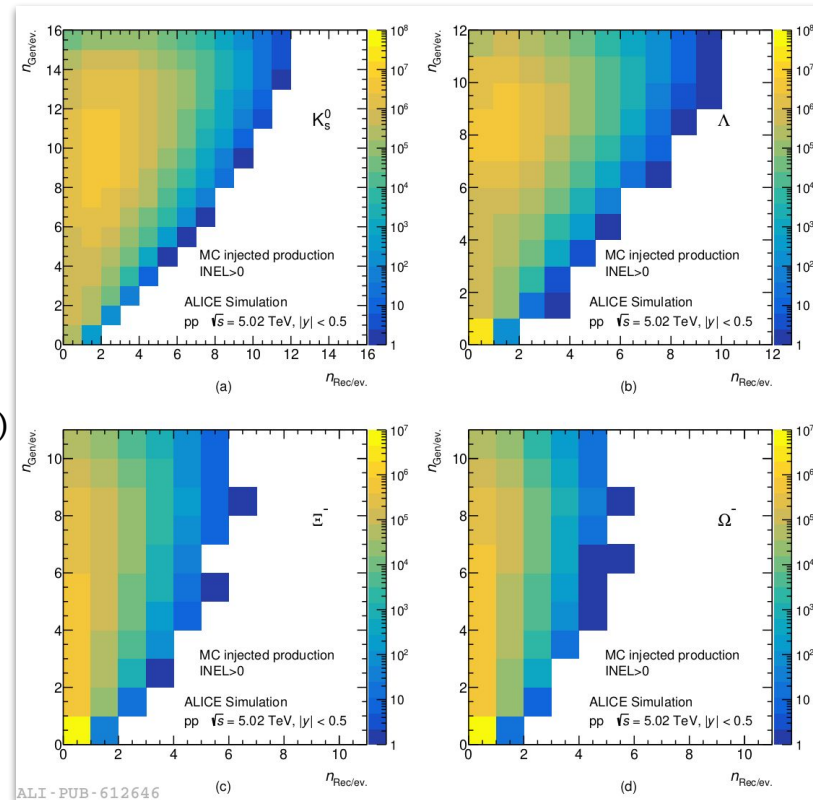
Reco. yields (R)

Response matrix (M)

Corr. distr. (G)

- Response matrices obtained considering a dedicated MC simulation including the measured p_T distributions of K_s^0 (top, left), Λ (top, right), Ξ^- (bottom, left) and Ω^- (bottom, right) for INEL > 0 event class
- **NOTE:** strange particles were injected following a sub-sample scheme designed to ensure similar statistics in events with varying strange particle multiplicities

Reweighted response matrices for INEL>0



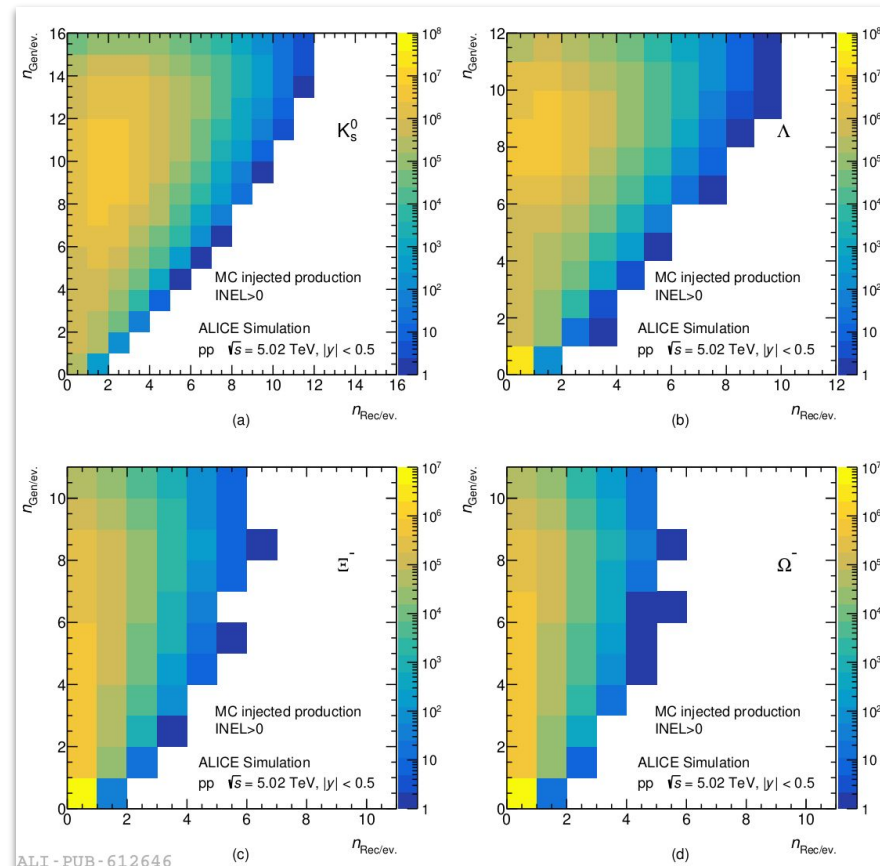


- After the initial ~ 10 iterations: the unfolded spectrum undergoes substantial changes
 - injected MC yields response matrix with flat generated distributions
 - unfolding converges to a steeply declining spectrum
- Beyond 10 iterations: fluctuations in the corrected spectrum <1%

To have a more realistic generated distribution:

- unfolded spectrum obtained after 10 iterations is fitted with a Negative Binomial Distribution (NBD)
- **reweight the response matrix to match the extracted preliminary NBD**
- new unfolding procedure is performed
 - smaller n_{iter} to achieve convergence

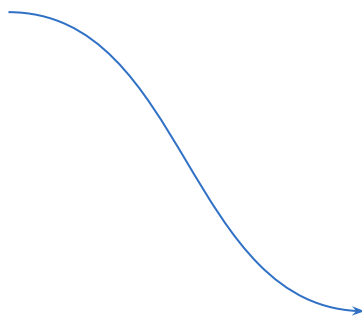
Reweighted response matrices for INEL>0





To perform the analysis for several multiplicity classes:

- signal extraction was performed for each class $\rightarrow$ reconstructed spectra
- Ax_ε trend VS p_T doesn't change with multiplicity, but when the response matrix is evaluated, the candidate's p_T is taken into account



Response matrix for each class were created correcting the response matrix obtained for INEL>0 by a **weight**:

$$\frac{p_T \text{ distrib. for class}_i}{p_T \text{ distrib. for INEL>0}}$$

$\rightarrow$ for each event, the weight was equal to the product of the weights obtained for each candidate looking at its p_T



Relative systematic uncertainties for $INEL > 0$

Hadron n_S	Systematic uncertainty (%)											
	K_S^0			Λ			Ξ			Ω		
	0	3	7	0	2	5	0	2	4	0	1	2
Cut variation	0.3	5.6	21	0.07	5.7	38	0	6.3	38	0	4.4	10
Signal extraction	0.09	0.4	0.6	0	0.17	0.9	0	0.19	0.23	0.01	0.04	0.07
Unfolding procedure	1.6	17.8	22.5	0.4	16.8	65	0.2	15.1	65	0	10.7	24
ϵ_{part}	0.9	6.3	15.8	0.2	3.7	9.5	0.04	7.3	14	0	2.95	5.9
p_T distribution	0.4	11.9	12.5	3.5	4.9	45	3	3.3	5.6	0	5.4	13
OOB pile-up cut	0.09	8.5	16.5	0.4	9.8	26	0.01	2.6	5	0	0.43	0.85
Feed-down correction	-	-	-	0.15	3.01	7.8	-	-	-	-	-	-
material budget	0.6	1.6	3.7	1.1	2.2	5.4	1.2	2.3	4.7	1	1.1	2
Strangeness from material	0.15	0.38	0.9	0.4	0.7	1.7	0.48	0.9	1.8	0.25	0.31	0.44
Hadronic interaction	-	-	-	(0.17)	(0.31)	(0.8)	(0.2)	(0.36)	(0.72)	(0.2)	(0.28)	(0.36)
Total	2	23.5	37	3.7	21.5	90	3.3	17.6	66	1.1	14.4	30

- Systematic sources increase significantly with n_S





$P(n_s)$ allows to calculate the **average production yield of n particles/event**:

$$\langle Y_{nS} \rangle = \sum_{i=n}^{n_s^{\max}} \frac{i!}{n!(i-n)!} \cdot P(i_s)$$

- $\langle Y_{1S} \rangle$: **mean** of the multiplicity distribution (dN/dy in previous studies)
- $\langle Y_{n>1S} \rangle$: **average production yield of multiplets** (doublets, triplets ...) of the particle
- **NOTE**: in principle the summation is defined over an infinite range
 - n -tuplets computed up to $n = n_s^{\max}-1$ for all particles, except for Ω ($n = n_s^{\max}$)
 - **systematic uncertainty due to the truncation**:
 - extrapolate the tail of the multiplicity distribution using an exponential fit to the last three bins
 - extend summation to $n = 100$ using extrapolated probabilities $P(n_s > n_s^{\max})$ for additional terms
 - difference between extended calculation and the default approach = systematic uncertainty
 - due to this systematic, $\langle Y_{6K0S} \rangle$ is omitted

Relative systematic uncertainty related to the sum truncation for INEL>0

hadron	Sum truncation systematic uncertainty (%)				
	$\langle Y_{1S} \rangle$	$\langle Y_{2S} \rangle$	$\langle Y_{3S} \rangle$	$\langle Y_{4S} \rangle$	$\langle Y_{5S} \rangle$
K_S^0	<1	1.3	6.6	23.7	79.0
Λ	<1	<1	1.5	6.1	-
Ξ	<1	<1	<1	-	-
Ω	<1	<1	-	-	-





New paper !

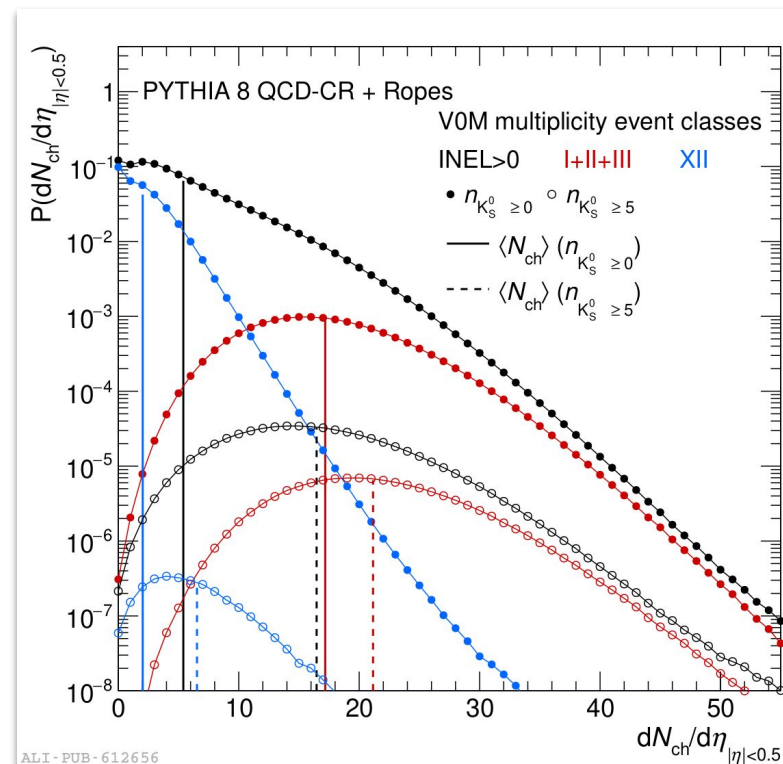
Charged-particle multiplicity distribution at mid-rapidity covers a wide range [14]

- events with high n_s : mid-rapidity multiplicity distribution that is shifted towards higher values compared to the unbiased distribution $\rightarrow$ higher $\langle dN_{ch}/d\eta \rangle$
- events with low n_s : charged-particle multiplicity distribution skewed towards lower values

$P(n_s)$ for INEL>0 align more closely with those of low-multiplicity classes at low n_s , while tending towards high-multiplicity classes at high n_s

To quantify the “multiplicity bias”: MC study comparison using [Pythia 8 QCD-CR Ropes](#) between un-biased $dN_{ch}/d\eta$ distributions and corresponding distributions when $n_{K^0_S} \geq 5$

- similar shape, but the average is systematically shifted



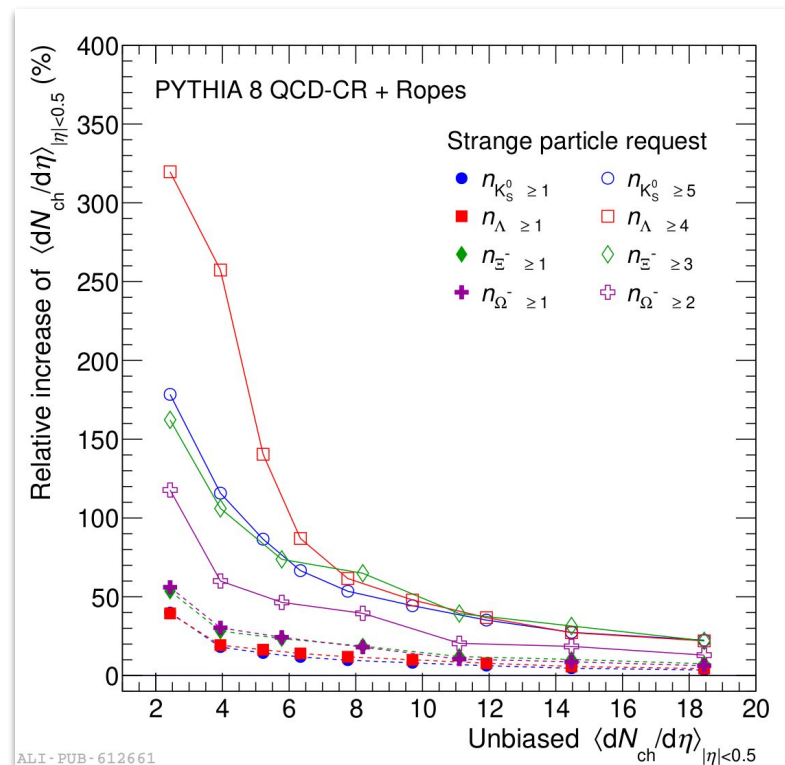


New paper !

Relative shift in the $\langle dN_{ch}/d\eta \rangle$ for all VOM event classes, requiring at least one or more strange particle per event

- depends on the specific requirement for the number of strange particles: **the bias is stronger under more stringent requirements for n_s**
- depends on the type of strange particle being analyzed: **stronger effect observed for multi-strange hadrons**
- **is more pronounced in low-multiplicity classes**, decreases to below 50% in the highest-multiplicity class for all particles and n_s
- **is model-dependent**: differences in how models implement microscopic mechanisms governing strange particle production and their correlations with non-strange hadrons

NOTE: this feature introduce complications when analyzing particle ratios VS multiplicity $\rightarrow$ in this work: particle ratios VS un-biased $\langle dN_{ch}/d\eta \rangle$ [$\langle dN_{ch}/d\eta \rangle$ (VOM class)]



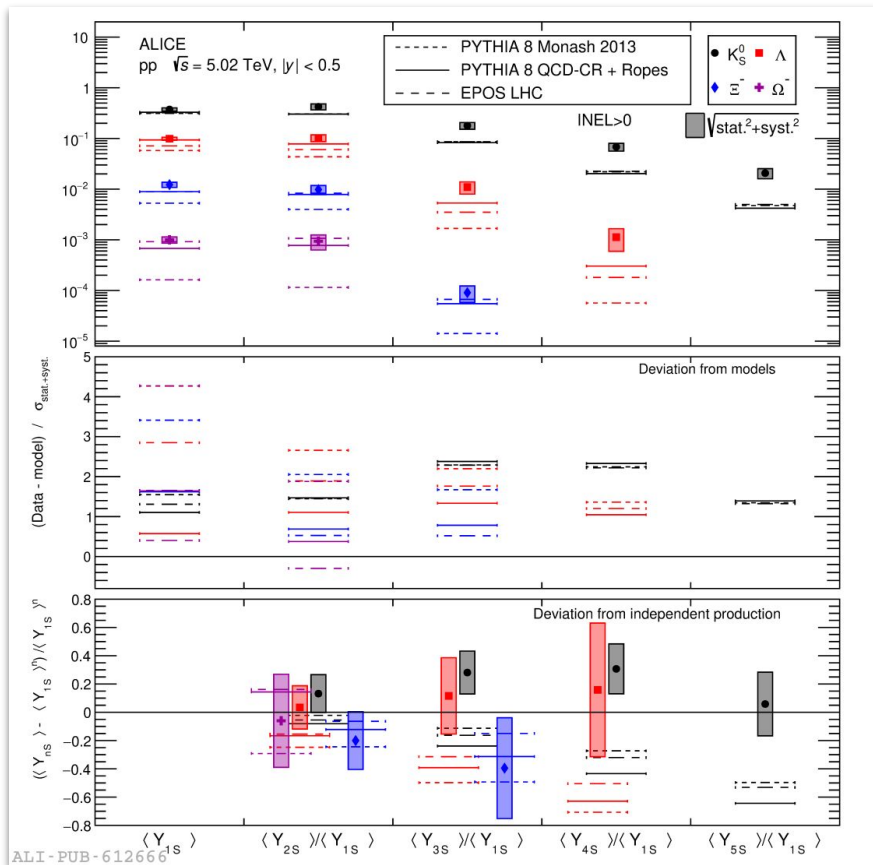
ALICE-PUB-612661





$\langle Y_{nhS} \rangle / \langle Y_{1hS} \rangle$: tool to assess the performance of MC generators in reproducing average production yield for $nhS > 1$ particles/event under the assumption that $\langle Y_{1hS} \rangle$ is correct

New paper !



- $\langle Y_{1hS} \rangle$: for all particles the deviation between data and [Pythia 8 QCD-CR Ropes](#) or [Epos LHC](#) is within $2-3\sigma$
 - improvements in Pythia generator are particularly evident for baryons
- $\langle Y_{n>1S} \rangle / \langle Y_{1hS} \rangle$: for all particles the comparison with model predictions indicates discrepancies not exceeding 2.5σ
 - for all baryons the discrepancy between [Pythia 8 Monash](#) and [Pythia 8 QCD-CR Ropes](#) tends to decrease, while for mesons there is no difference

