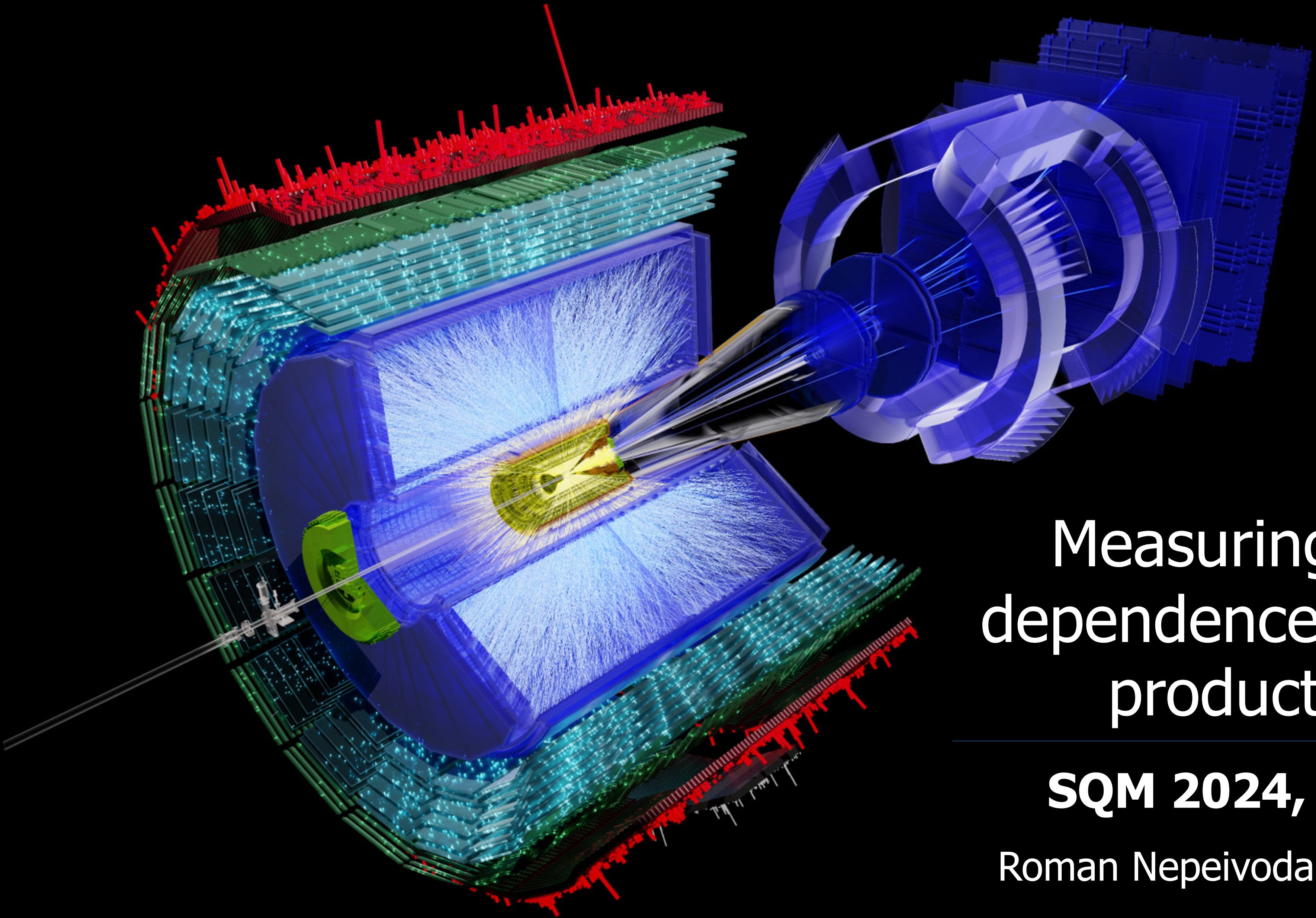


Measuring the system size dependence of the strangeness production with ALICE

SQM 2024, Strasbourg, France

Roman Nepeivoda* for the ALICE Collaboration

*roman.nepeivoda@cern.ch

Strangeness enhancement phenomenon

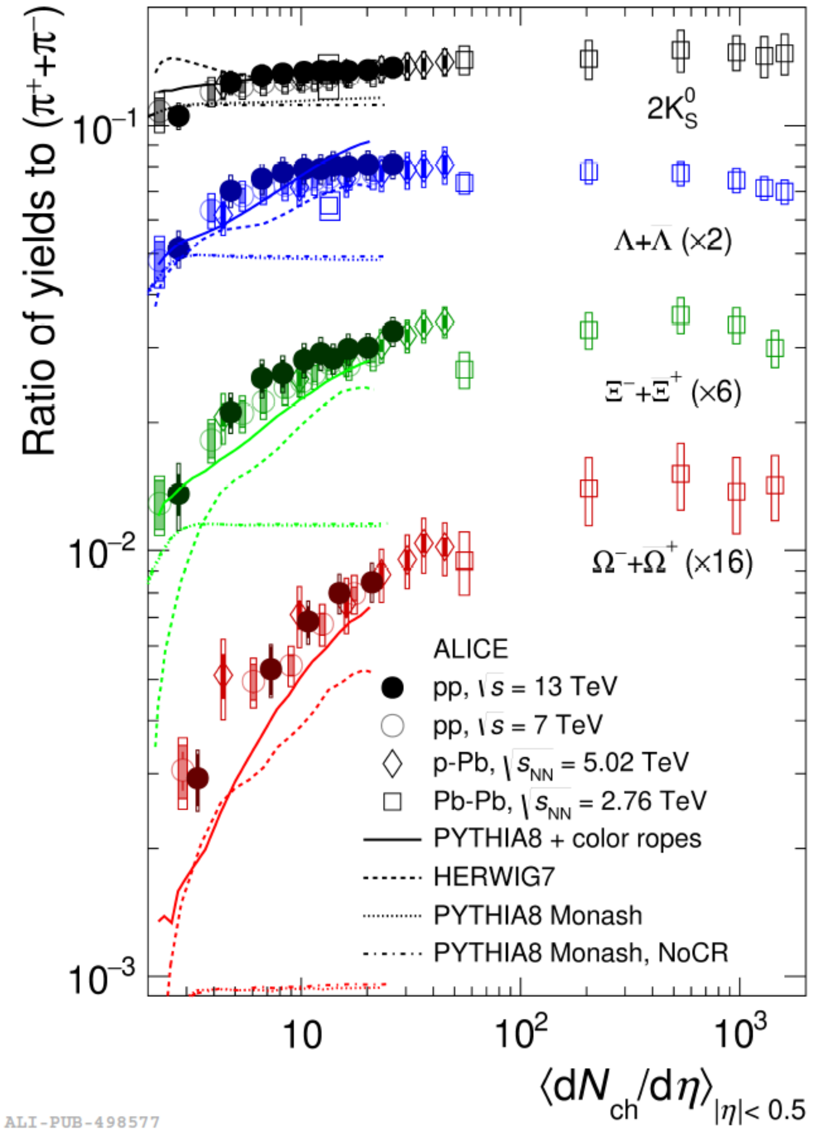
Strangeness originally proposed as a signature of QGP

QGP → deconfinement → lower effective s quark mass → thermal $s\bar{s}$ production → more (multi)strange hadrons

Strangeness enhancement with particle multiplicity is **independent** of collision system and energy

interaction between **MPI** systems?

core-corona approach down to **pp** systems?



Eur. Phys. J. C 80, 693 (2020)

Strangeness enhancement phenomenon

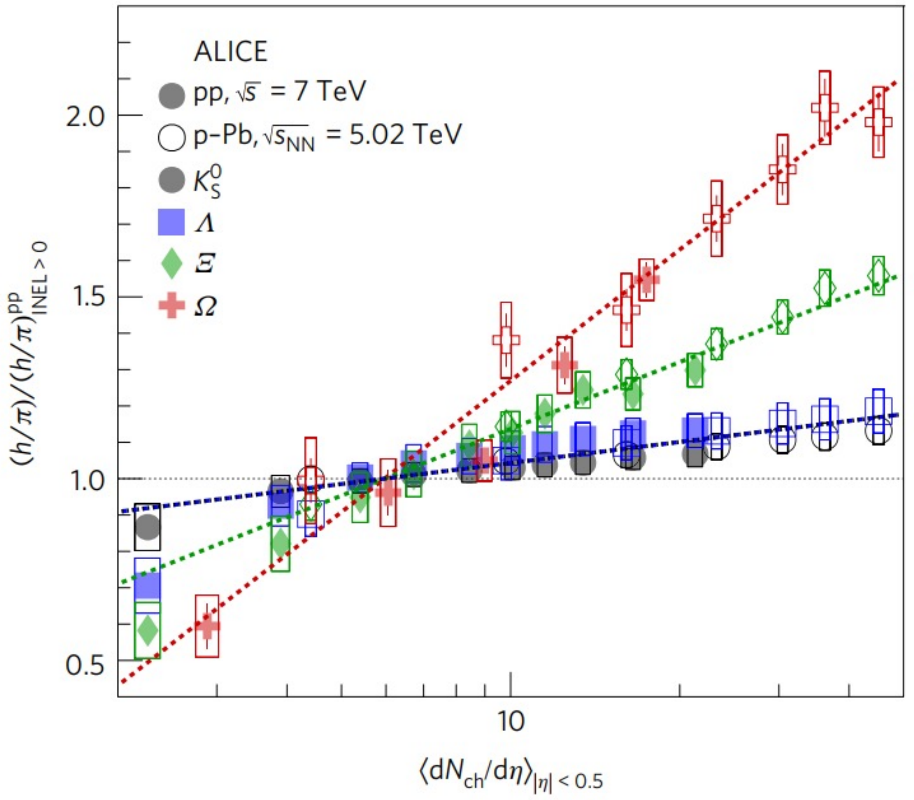
Strange content hierarchy: SE(Ω) > SE(Ξ) > SE(Λ, K^0_S)

$$\frac{(h/\pi)}{(h/\pi)^{\mathrm{pp}}_{\mathrm{INEL>0}}} = 1 + a\,S^b \log\left[\frac{\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle}{\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta\rangle^{\mathrm{pp}}_{\mathrm{INEL>0}}}\right]$$

$$a = 0.083 \pm 0.006,\ b = 1.67 \pm 0.09,\ \frac{\chi^2}{ndf} = 0.66$$

Recent ALICE results focus on:

- **connecting** results in **small systems at high multiplicity** to compatible **semi-peripheral AA** collisions
- **exploring** particle production with different **event classifiers** and **event triggers**



Particle yield ratios to pions normalized to the values measured in the inclusive inelastic pp sample

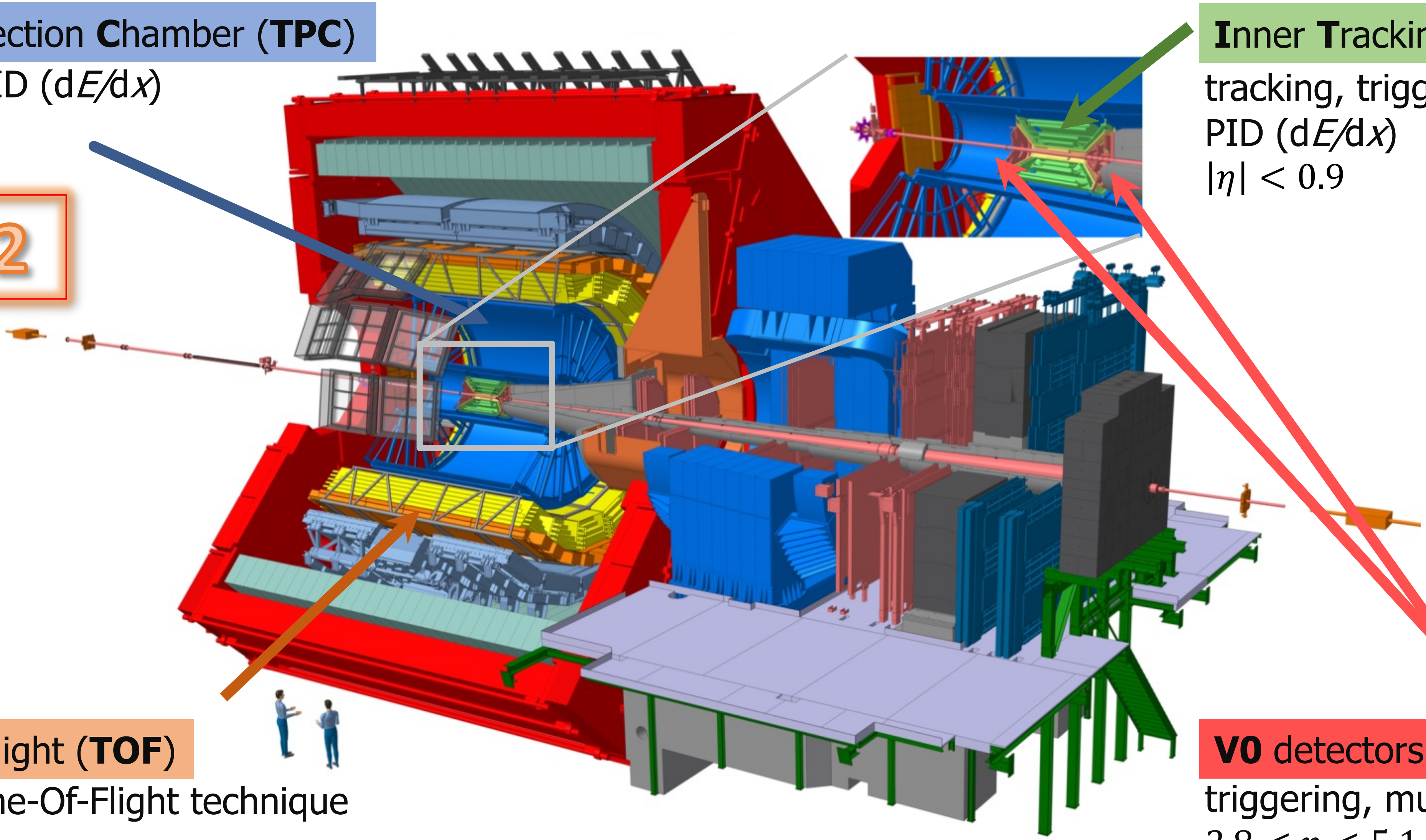
Nature Physics **13**, 535-539 (2017)

The ALICE detector: a window into high-energy collisions

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

tracking, PID (dE/dx)
$|\eta| < 0.9$

Run 2



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

tracking, triggering, vertexing, PID (dE/dx)
$|\eta| < 0.9$

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

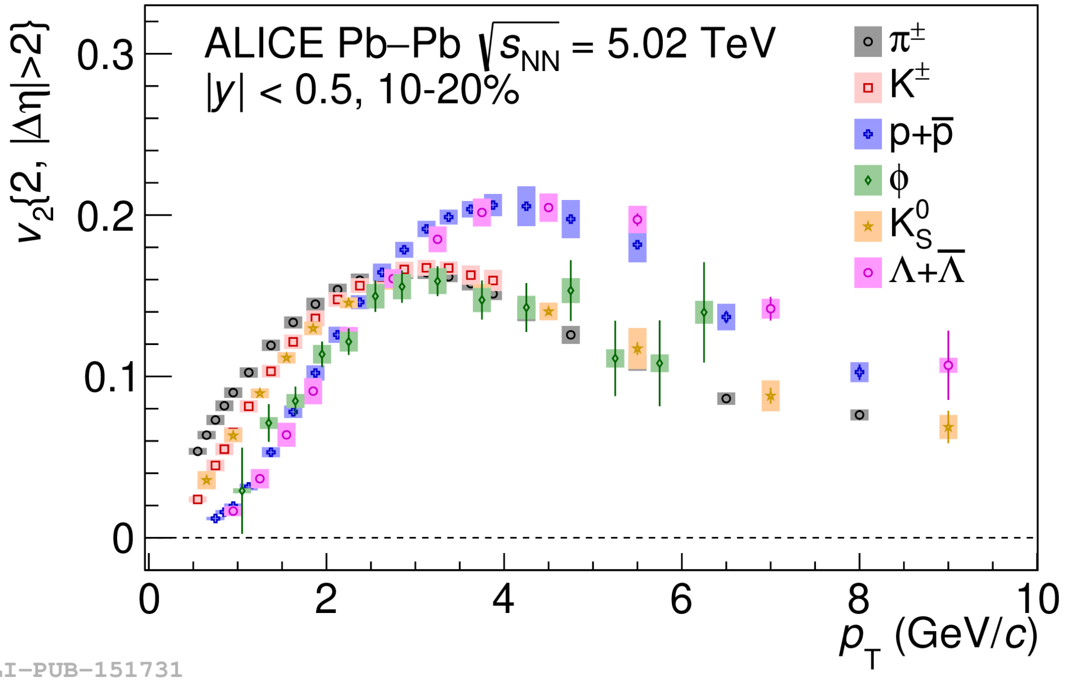
PID via Time-Of-Flight technique
$|\eta| < 0.9$

V0 detectors (**V0A** & **V0C**)

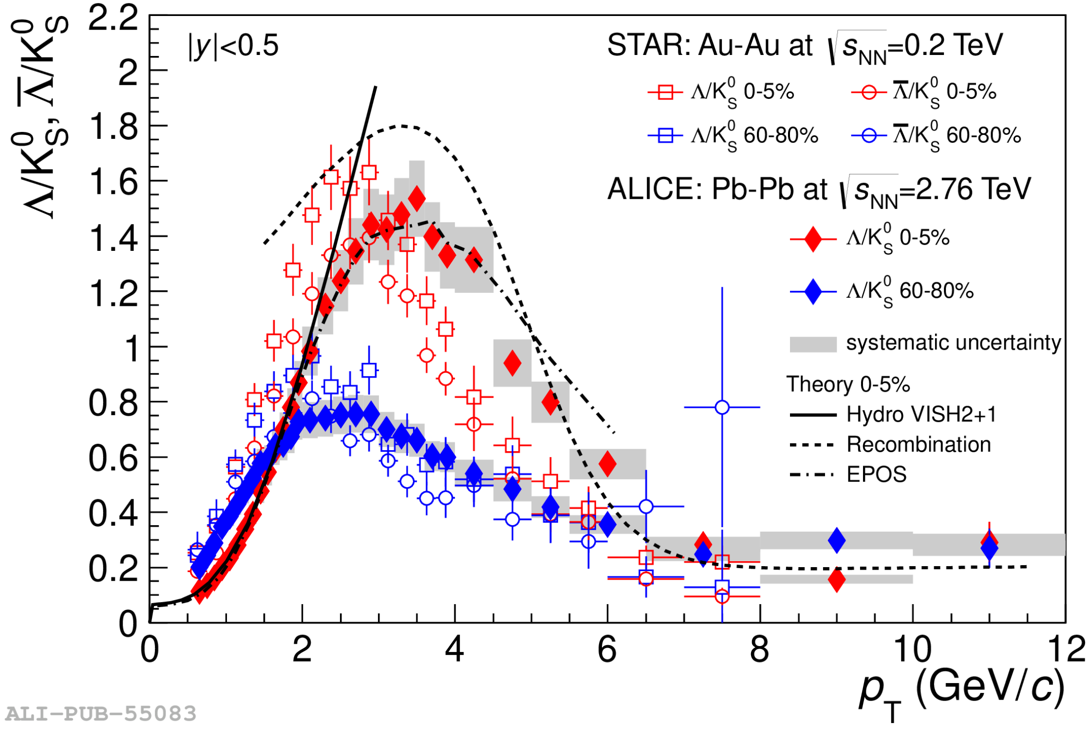
triggering, multiplicity estimator
$2.8 < \eta < 5.1$ (V0A)
$-3.7 < \eta < -1.7$ (V0C)

Strange hadron dynamics in large systems

JHEP09, 006 (2018)



Phys. Rev. Lett. 111, 222301 (2013)



Elliptic flow of strange particles follows **mass ordering** at low p_T and **meson-baryon splitting** at intermediate p_T

→ Centrality dependent **spectra hardening & baryon/meson ratio** can be explained considering **common expansion velocity of partons**

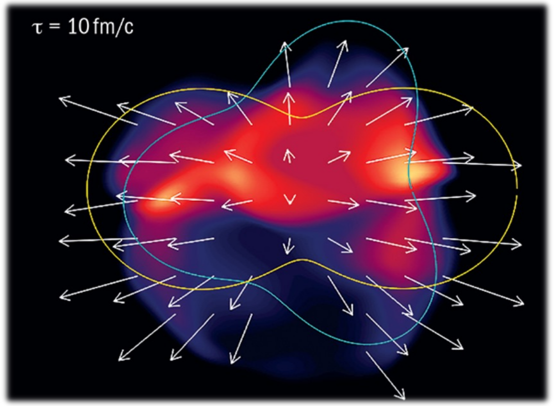
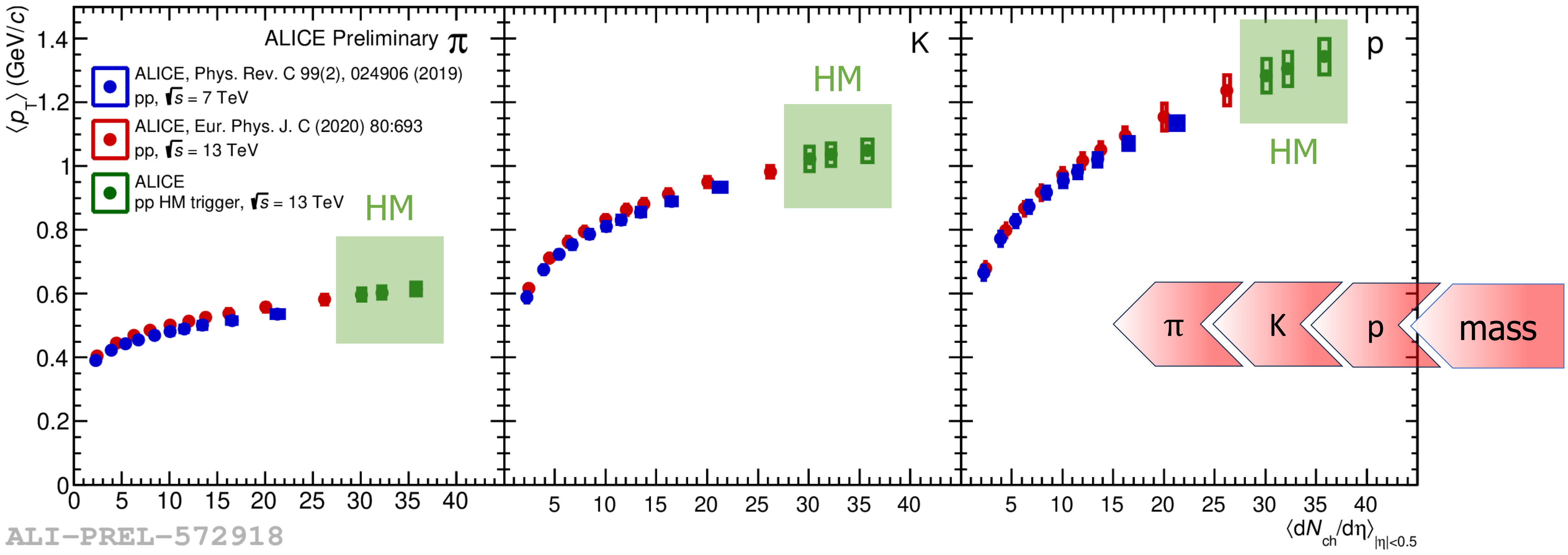


IMAGE: MUSIC

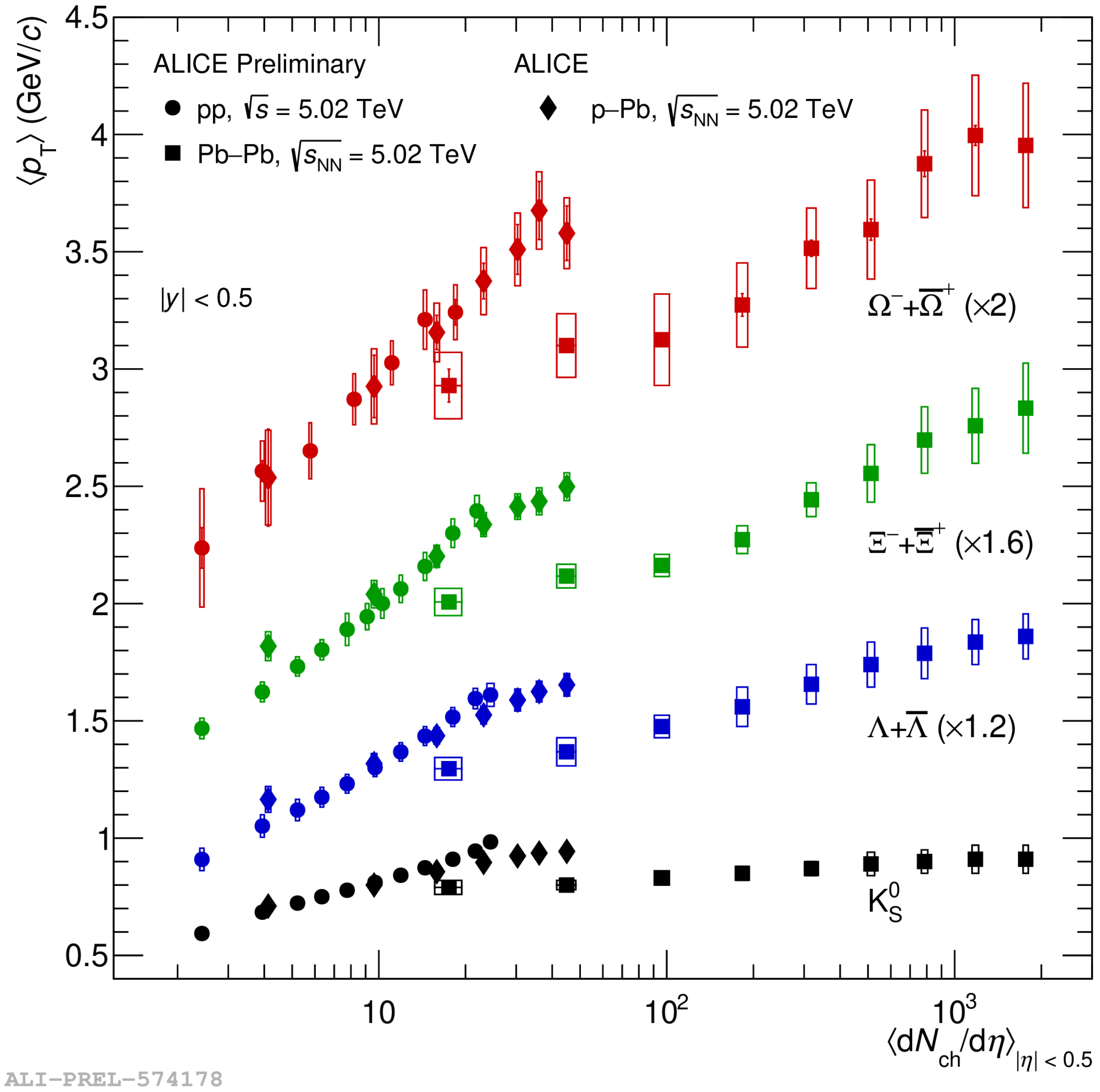
Collective evolution in small systems



Multiplicity dependent $< p_T >$ increases in pp systems with a **steeper** trend for **higher hadron masses** supporting the picture of a **collective evolution in small systems** (similar to radial flow)

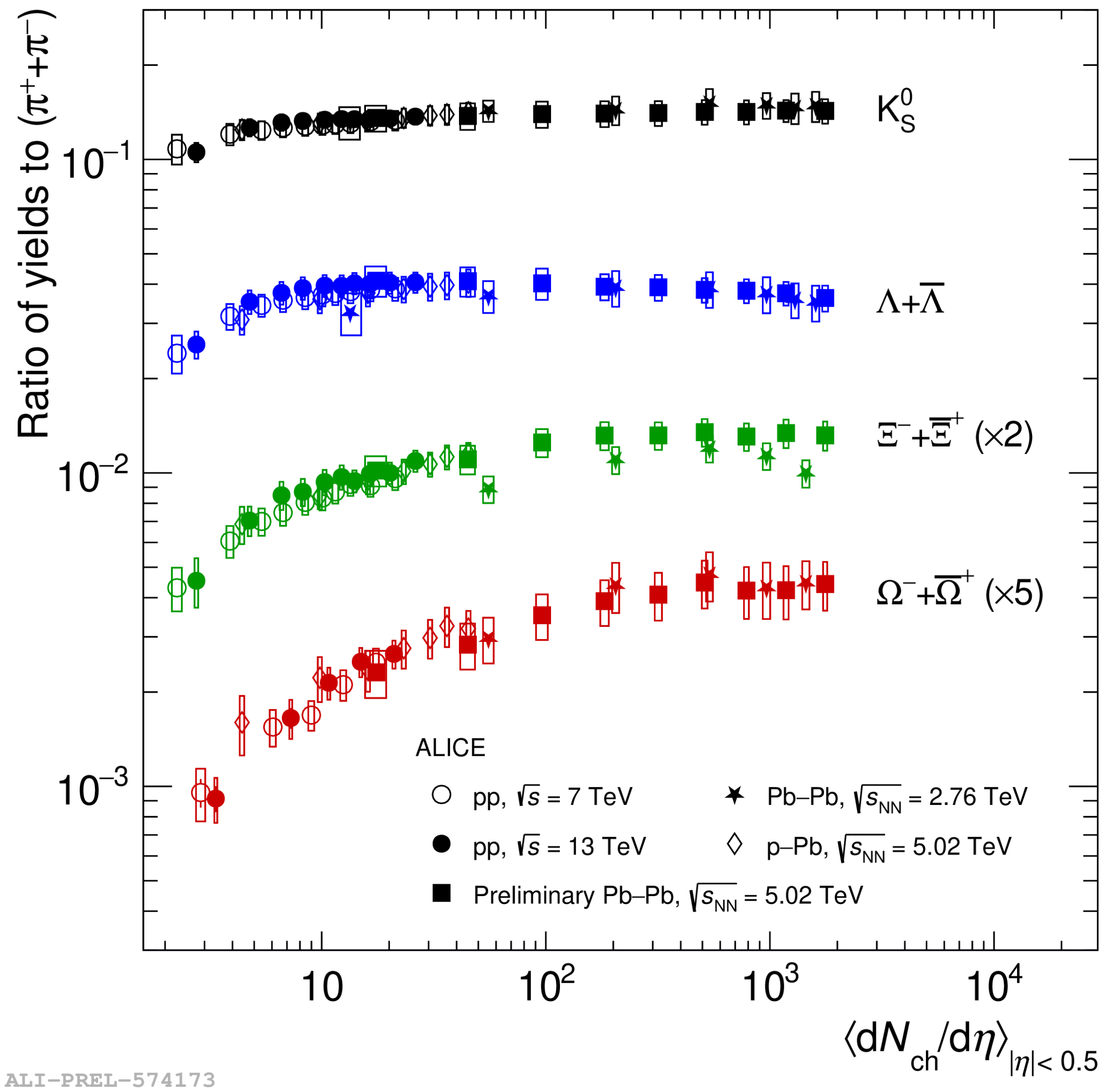
➡ s-quark is **sufficiently light** to participate in the **collective motion**

Multiplicity dependent $< p_T >$ of strange particles



- $< p_T >$ **doesn't connect** between different collision systems
- **Same mid-rapidity activity** in pp and Pb-Pb corresponds to harder spectra in pp
- Influence of **jets** in pp?

Strangeness production across different systems

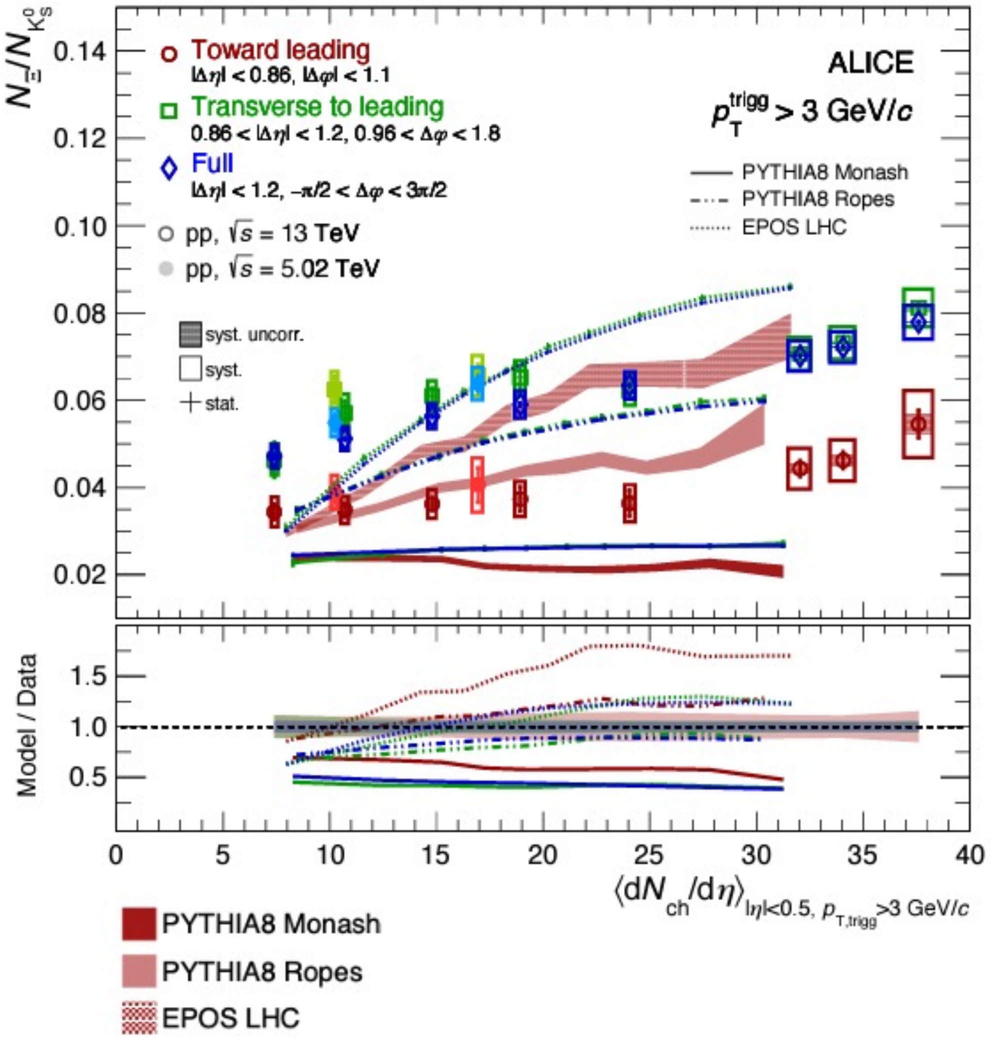


- $<p_T>$ **doesn't connect** between different collision systems
- **Same mid-rapidity activity** in pp and Pb-Pb corresponds to harder spectra in pp
- Influence of **jets** in pp?
- **However,** the ratios of strange particle yields to pions in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV follow the **same continuous trend** observed before **starting from low-multiplicity pp** at $\sqrt{s} = 7$ TeV **up to central Pb-Pb collisions** at $\sqrt{s_{NN}} = 2.76$ TeV

➡ Hadron yields depend only on the **multiplicity**, while the p_T distribution of the formed hadrons is affected by the **hadronizing environment**

In- and out-of-jet strangeness production

NEW! arXiv:2405.14511

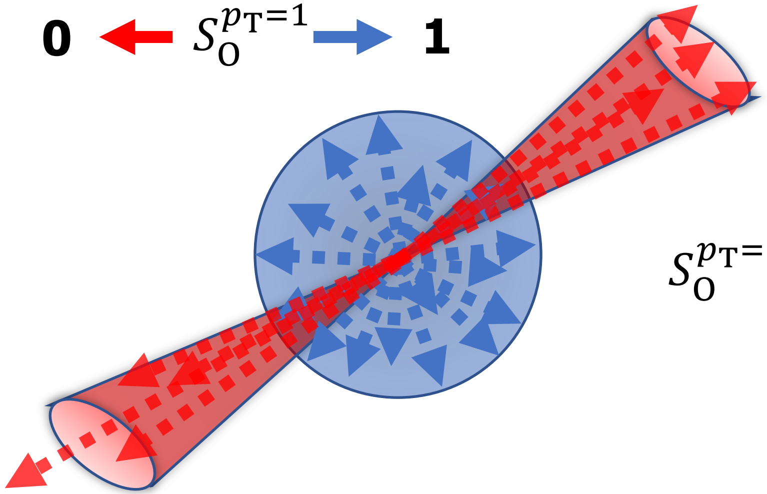


- **Strangeness production** can be differentiated into the one **inside and outside of the jets** represented by a **leading particle** $(p_{\mathrm{T}}^{\mathrm{trigg}} > 3\ \mathrm{GeV}/c)$
- Both transverse-to-leading and toward-leading **increase with multiplicity** in a compatible way
- The transverse-to-leading part of Ξ/K^0_S is a **good proxy** of the ratio of full yields
- **No dependence** on collision energy

More in Talk by Chiara De Martin

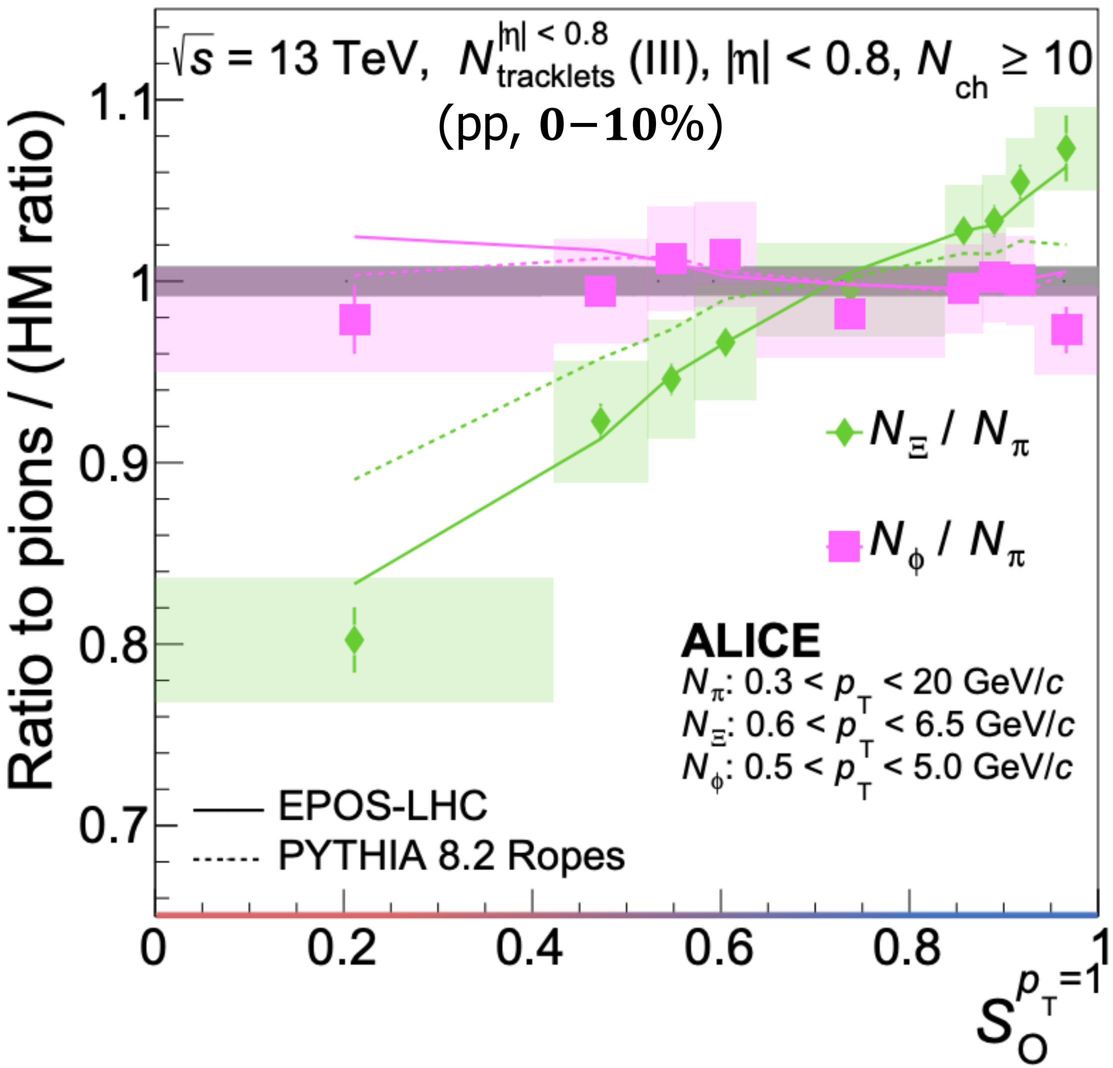
Jun 4, 12:00 PM, Room Madrid

Strangeness enhancement as a function of transverse spherocity



$$S_{\mathrm{O}}^{p_{\mathrm{T}}=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\frac{\Sigma_i |\widehat{p_{\mathrm{T,i}}} \times \hat{n}|}{N_{\mathrm{tracks}}} \right)^2$$

NEW! JHEP05, 184 (2024)



ϕ **production is not enhanced** in **isotropic** events compared to the **jet-like** ones **opposite to** Ξ

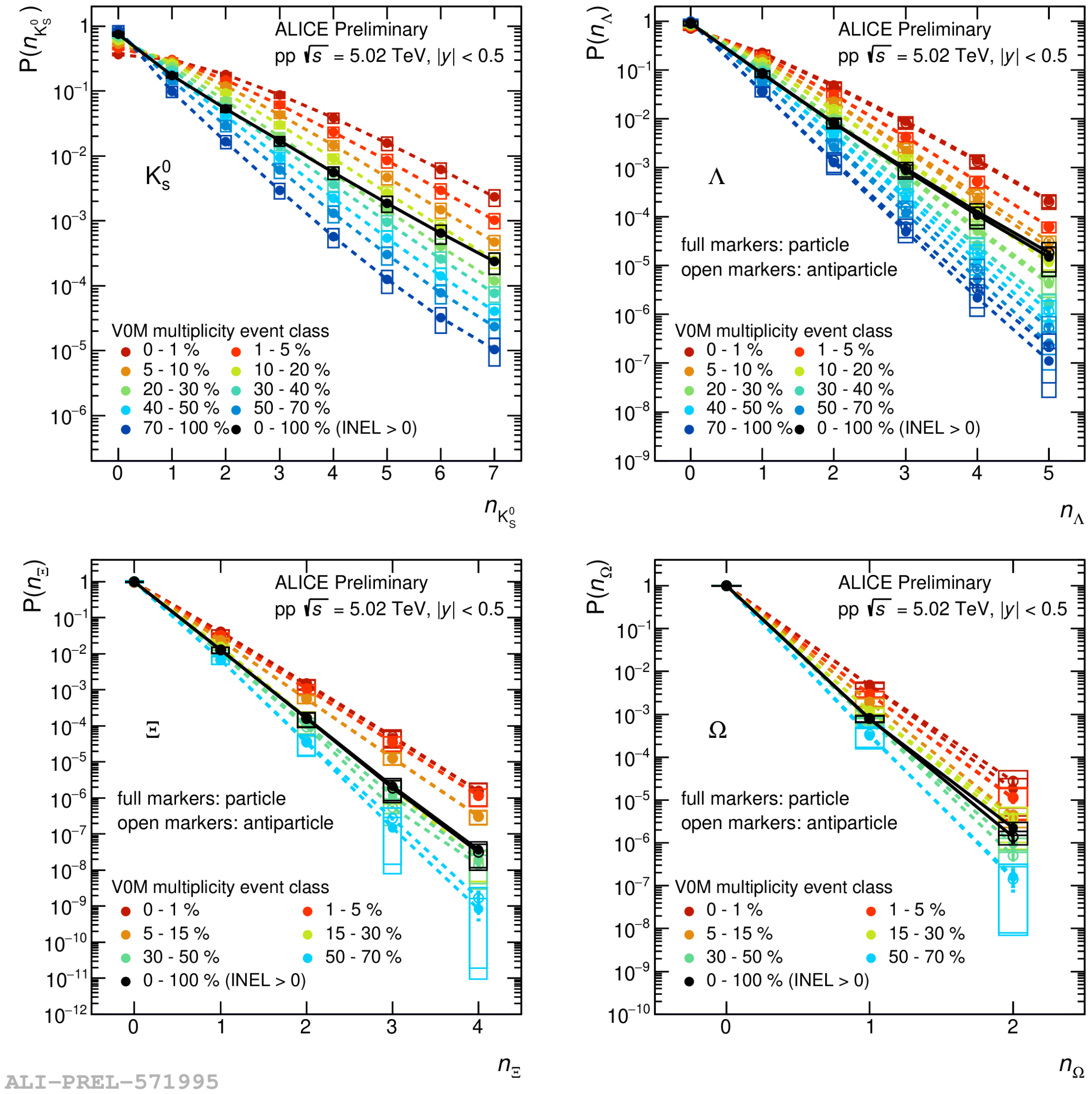
Increase might be associated to the **baryon-related effect** or to the different mechanism of **hidden strangeness** production ($|S| = 0$)

More in Talk by Adrian Nassirpour

Jun 4, 17:50, Room Madrid

Multiplicity distribution of strange particles

NEW!



- **Probability to produce n particles of a given species** per event ($P(n_s)$) in pp collisions at $\sqrt{s} = 5.02$ TeV in different V0M multiplicity classes
- **The probability** of producing more than one strange particle per event **increases** as a function of the charged particle **multiplicity**
- **Unique opportunity** to test the **connection between charged and strange particle multiplicity** production all the way to "extreme" situations: large and small numbers of particles in low and high multiplicity event classes accordingly

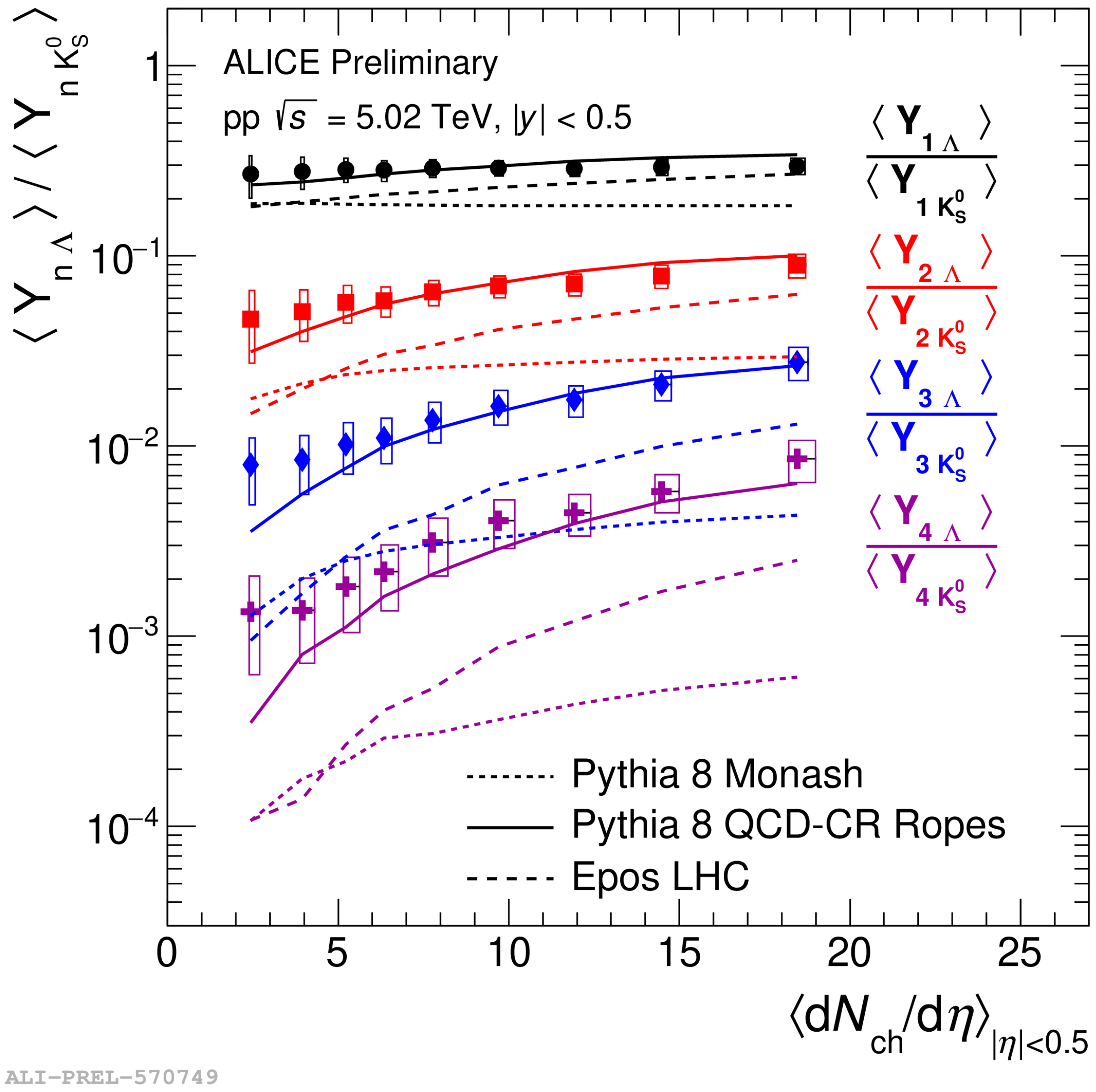
NOTE: in each V0M bin the charged-particle multiplicity can fluctuate and $\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ can significantly change for events with small/large n_S

Baryon/strangeness enhancement

NEW!

$$< Y_{\mathrm{k-part}} > = \sum_{n=k}^{\infty} \frac{n!}{k!\,(n-k)!} P(n)$$

- Important to **decouple strangeness-related** from **baryon-related** effects
- **Increase of** $\Lambda/_{K^0_S}$ with multiplicity when looking at **multiple production**
- Possibly in all strange-hadron/π vs multiplicity plots we have a **strangeness-related** and a **contribution to the enhancement**
- **Baryon-related** effect **well-reproduced** by Pythia 8 QCD-CR Ropes

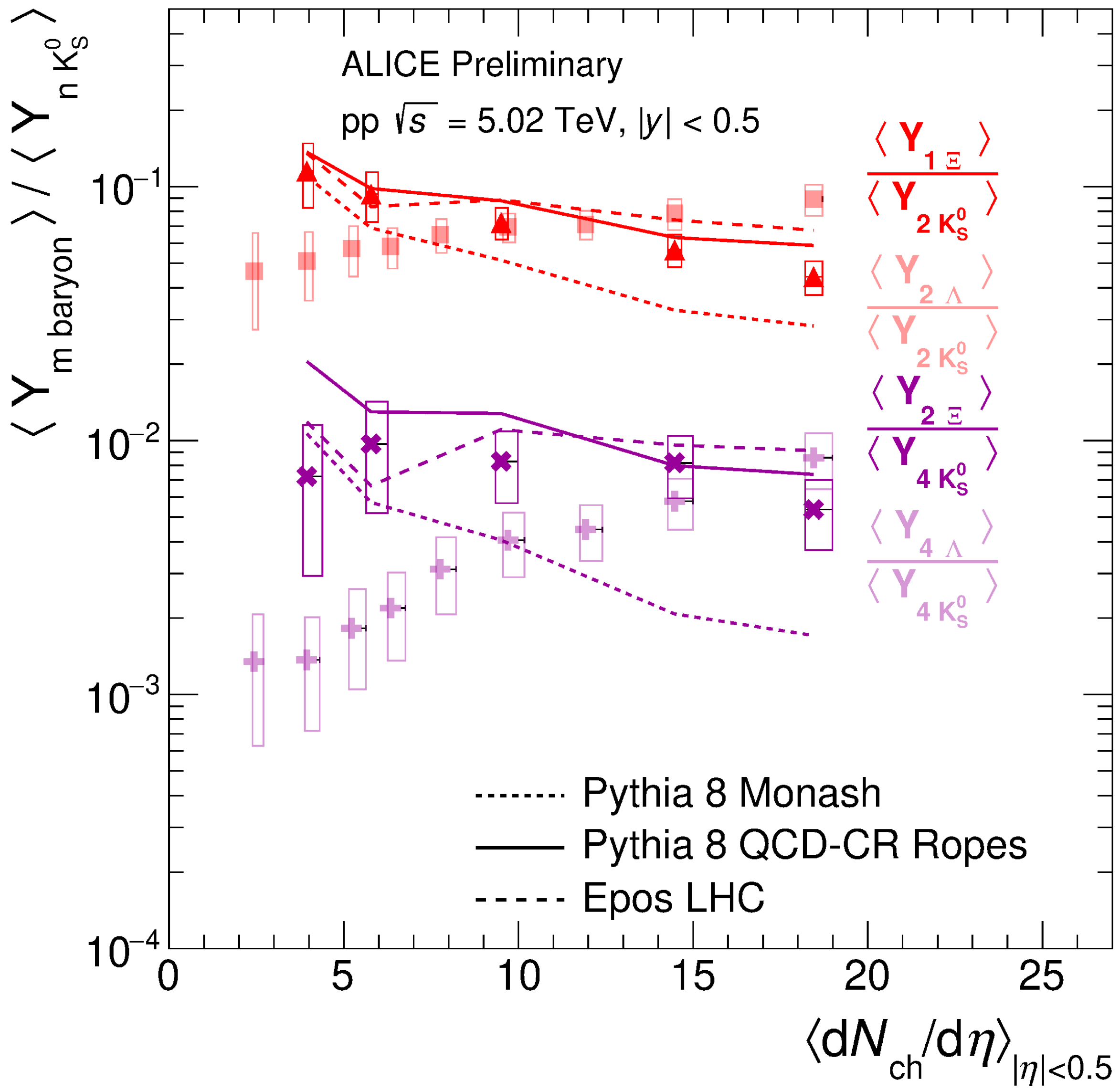


Baryon/strangeness enhancement

NEW!

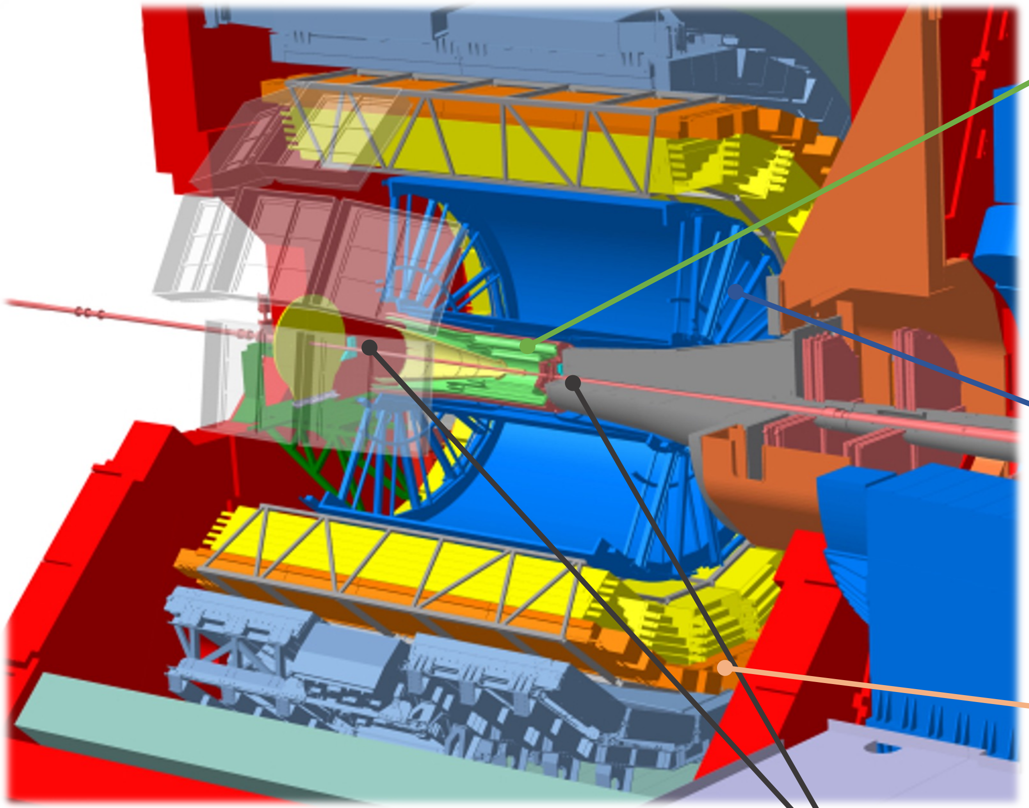
- One can study **strangeness hadronization** in detail examining the likelihood ratio of that the final state contains a **multi-strange baryon to** the **number of mesons** which **compensates the strange content**
  - **Low multiplicity**: the surplus of s-quarks increases the probability of Ξ formation
  - **High multiplicity**: it is simpler to pair s-quarks with a light quark, which are plentiful in the event

See More in Poster by Sara Pucillo



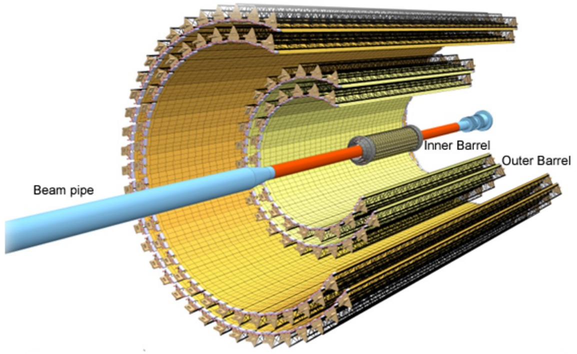
ALI-PREL-570764

The ALICE detector in Run 3



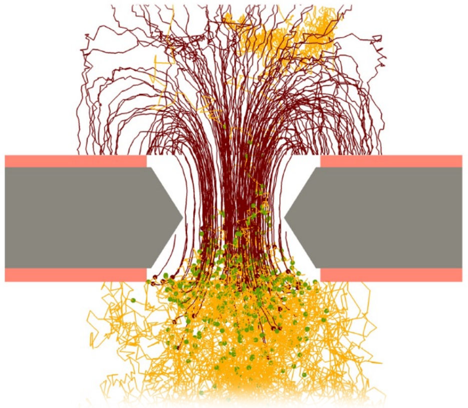
ITS upgrade
NIM 1032, 166632 (2022)

- 7 layers of silicon pixel detectors with reduced material budget
- First detection layer closer to IP + new beam pipe (ITS L0 at 22 mm)



Time Projection Chamber (TPC)
JINST 16, P03022 (2021)

- Tracking, PID (*dE/dX*)
- MWPCs replaced with GEMs
- Continuous readout up to 50 kHz Pb-Pb interaction rate (x50 w.r.t. Run 2)



Time Of Flight (TOF)

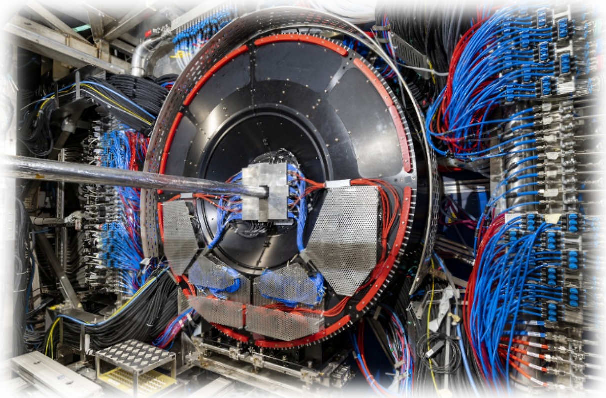
- PID via Time-Of-Flight technique

New O^2 framework
CERN-LHCC-2015-006, ALICE-TDR-019

- One common Online Offline (O^2) computing system
- Faster online and offline processing
- Increased data volume x100 w.r.t. Run 2

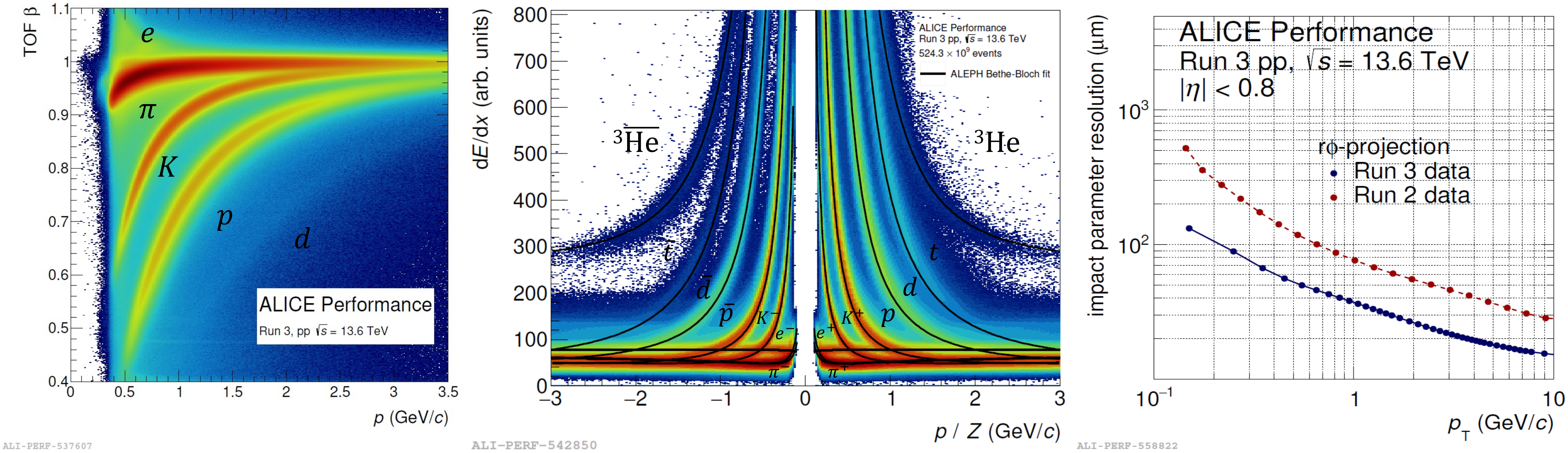
New Fast Interaction Trigger (FIT)
NIM 1039, 167021 (2022)

- 4 arrays of Cherenkov detectors and scintillators
- Triggering, collision time, centrality estimation



Performance of the ALICE detector in Run 3

The LHC Run 3 started in 2022, ALICE already collected more than **x800** events w.r.t. Run 2 in pp data taking at **~500 kHz** and more than **x30** Pb-Pb min. bias collisions in continuous readout

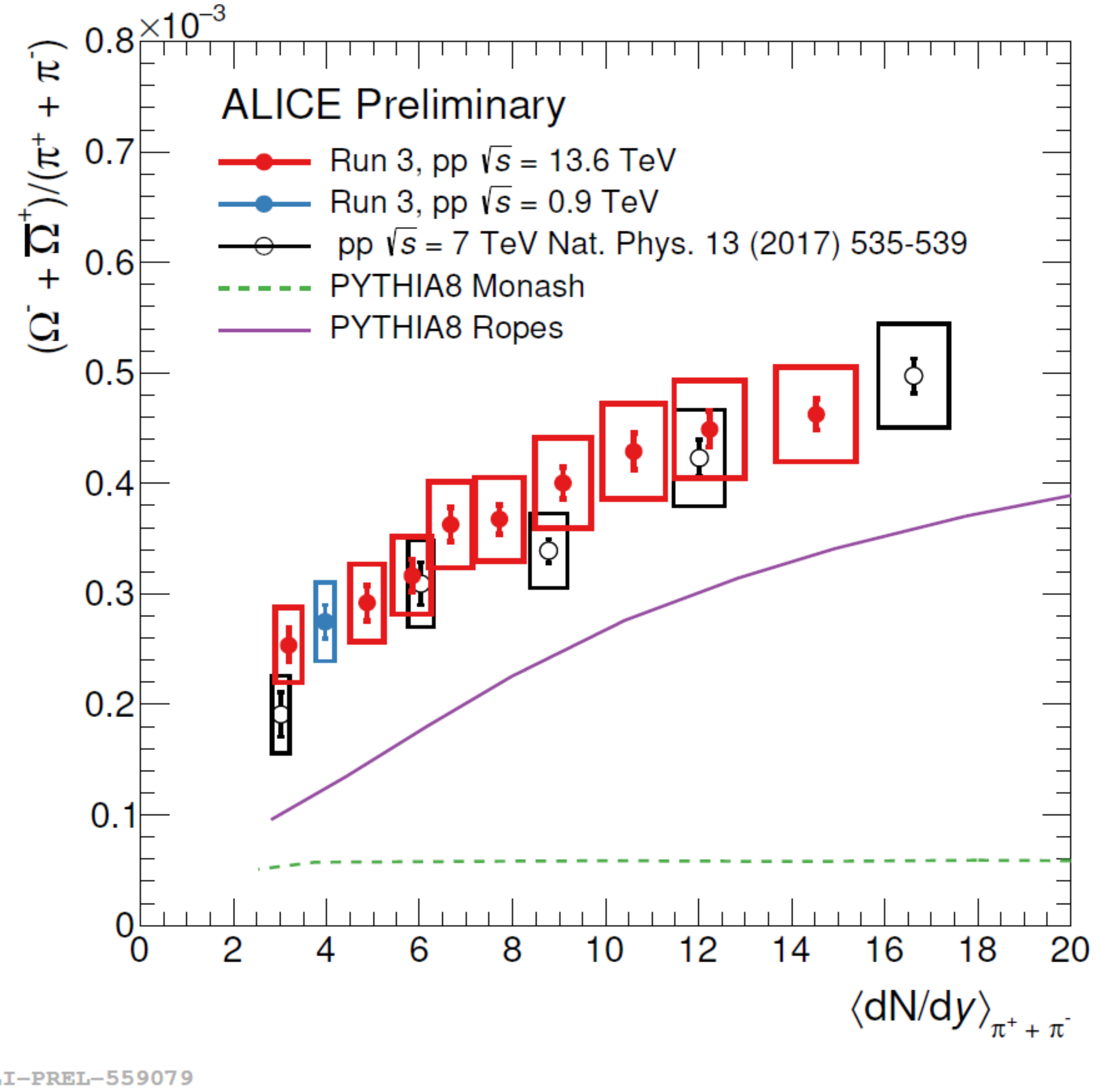


- **Extend** our studies further to higher multiplicities
- **Increase** our precision on existing studies
- **Measure** rarer species

Ω/π ratio vs multiplicity

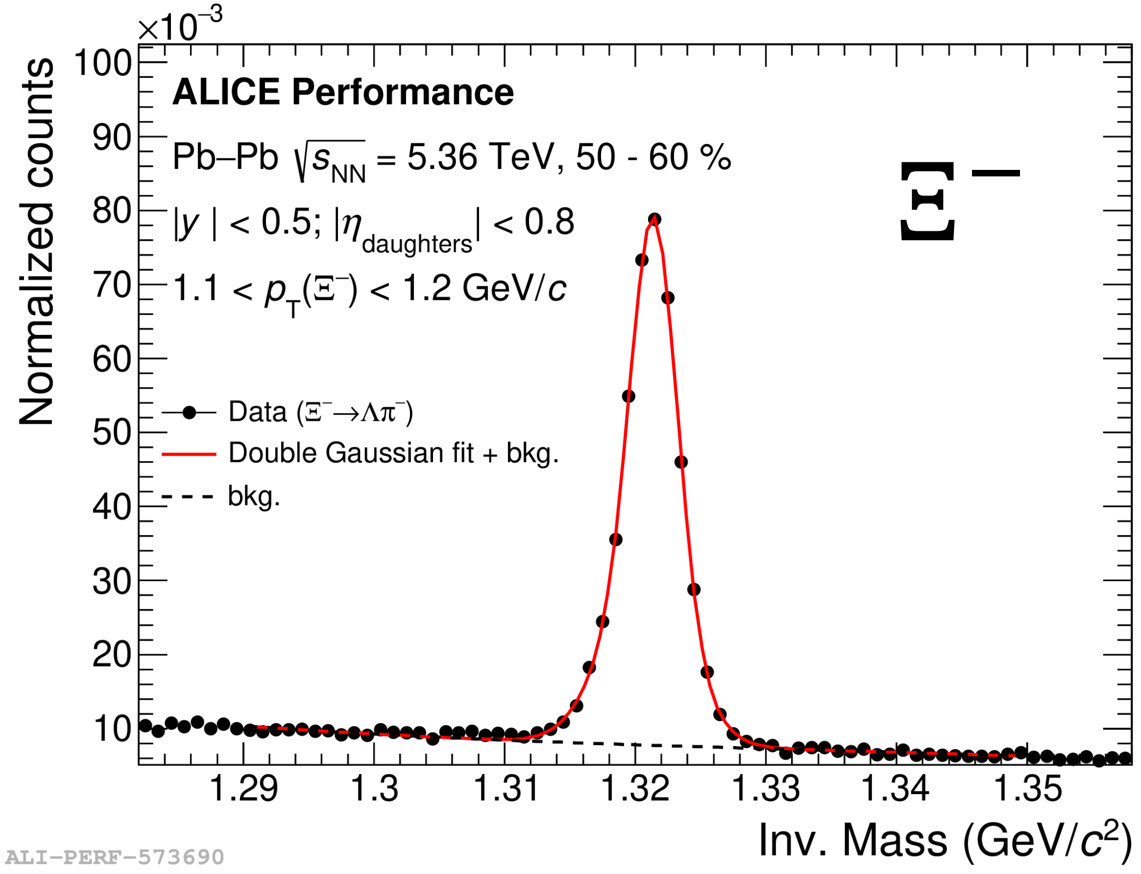
See Poster by Upasana Sharma

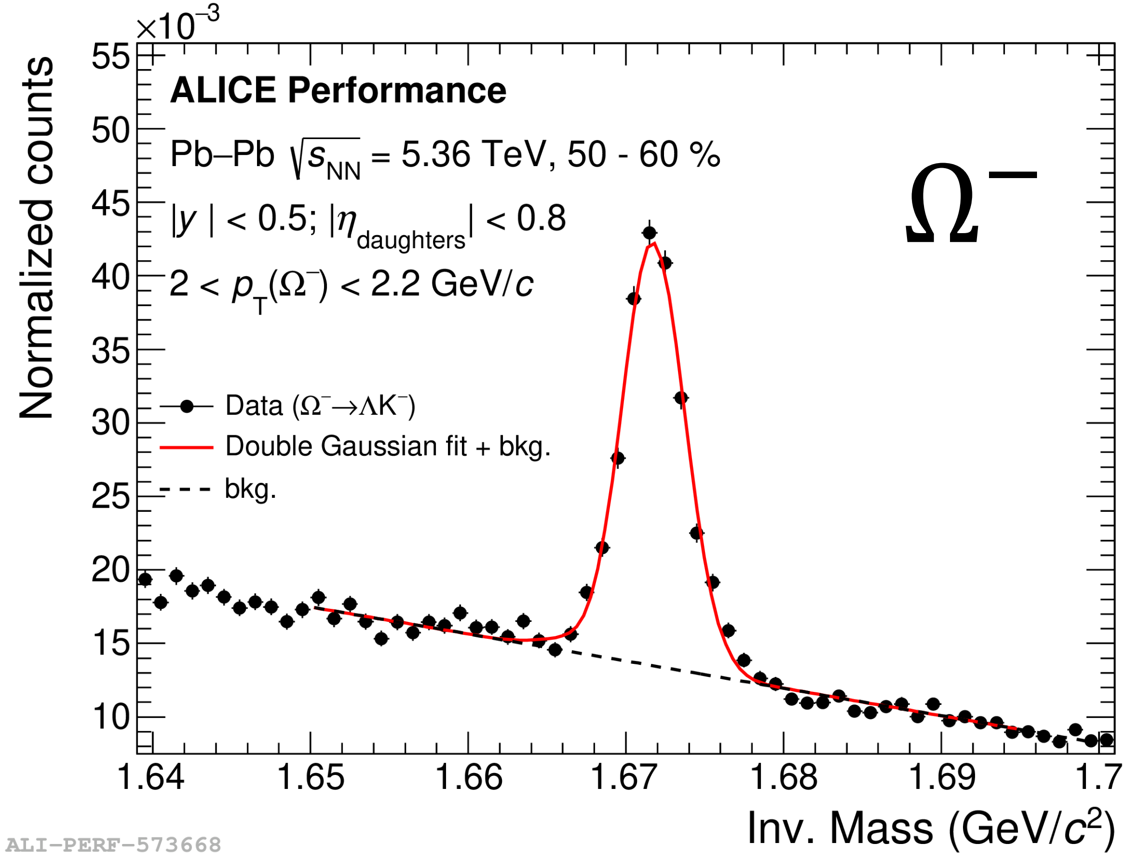
- **Unprecedented** multiplicity differential study of Ω/π production in pp collisions at $\sqrt{s}$ = **13.6 TeV**
- **First** Ω yield measured in INEL>0 pp collisions at $\sqrt{s}$ = **900 GeV** at the LHC
- Run 3 statistics will allow to extend this study to higher multiplicities!
- MB pp sample (this analysis) + **software triggers** to select events containing multi-strange hadrons



Cascade reconstruction performance in Pb-Pb

NEW!



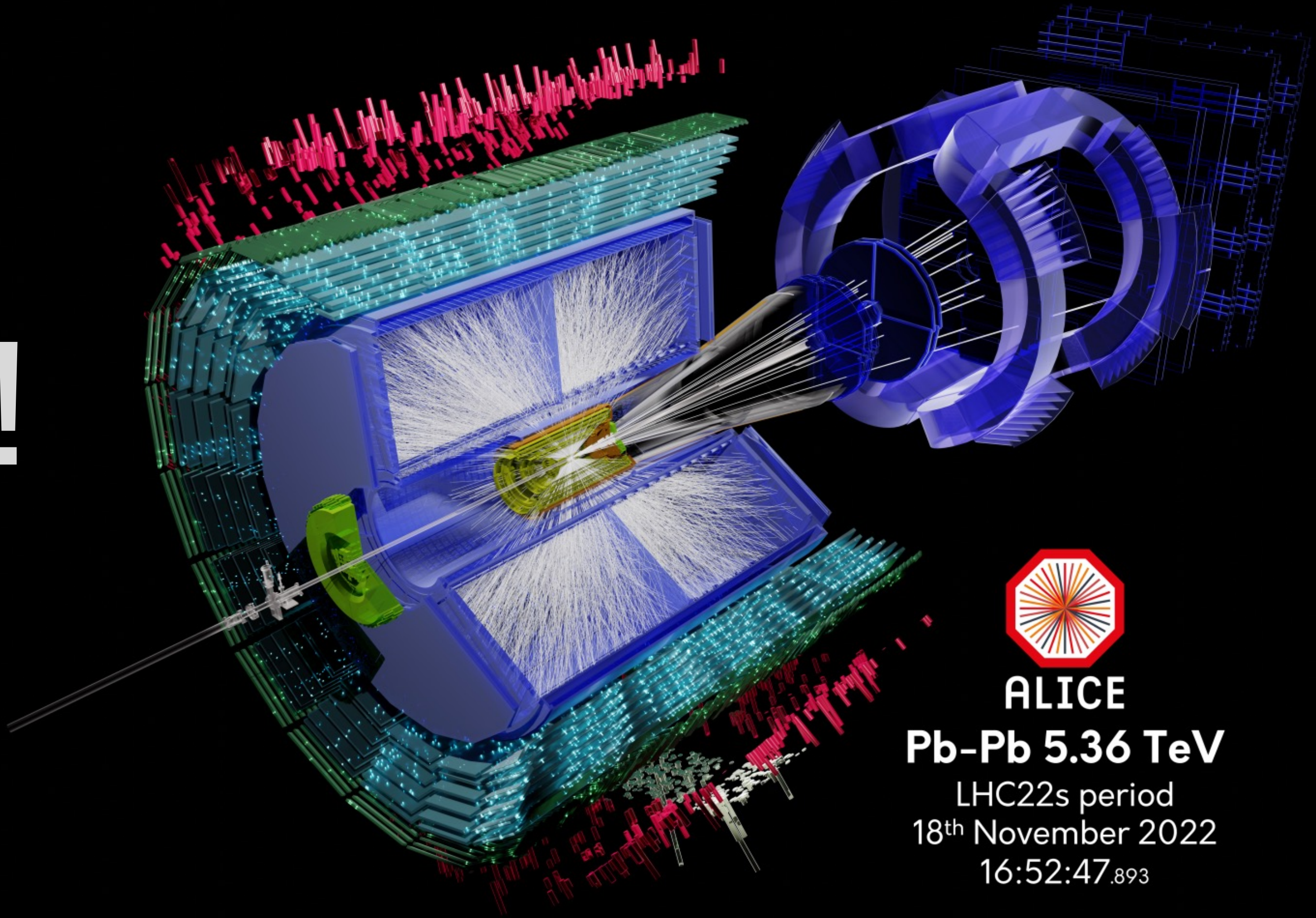


- **Excellent performance** for strange hadron reconstruction with ALICE in Run 3!
- **Wealth of statistics** allows performing fine p_T- and centrality-differential studies in Pb-Pb collisions

Summary

- **High-multiplicity trigger data** and **elliptic flow studies** support the collective evolution in small systems
- Hadron yields depend only on the **multiplicity**, while the p_{T} distribution of the formed hadrons is affected by the **hadronizing environment**
- **In- and out-of-jet** and **spherocity** analyses provide deeper insights on the **origin of strangeness enhancement**
- **Increase of** Λ/K_S^0 with multiplicity in multiple strangeness production **highlights the importance** of **decoupling strangeness-related** from **baryon-related** effects
- **First** measurement of $\Omega - \mathrm{to} - \pi$ ratio in pp at $\sqrt{s} = 13.6$ TeV in an **unprecedented multiplicity binning with an extension to the lowest collision energy** (900 GeV) available at the LHC
- **Excellent performance** of the cascade reconstruction in Pb-Pb collisions **in Run 3**

Thank you!



ALICE

Pb-Pb 5.36 TeV

LHC22s period

18th November 2022

16:52:47.893

Strangeness reconstruction with ALICE

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

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

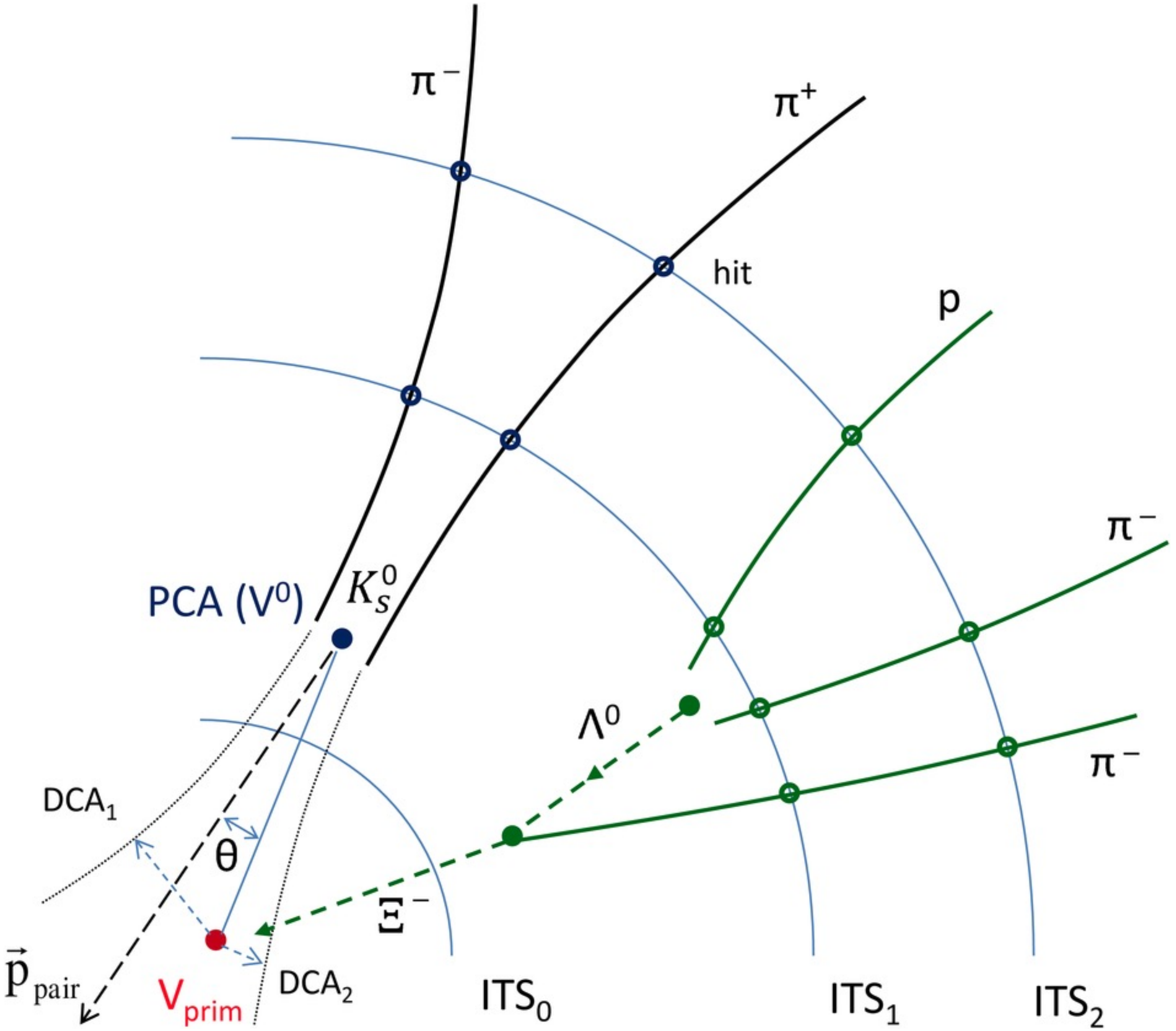
$$\mathrm{K}^0_S \rightarrow \pi^+ + \pi^- \quad (d\bar{s})$$

$$\Lambda\,(\bar{\Lambda}) \rightarrow \mathrm{p}\,(\bar{\mathrm{p}}) + \pi^-\,(\pi^+) \quad (uds)$$

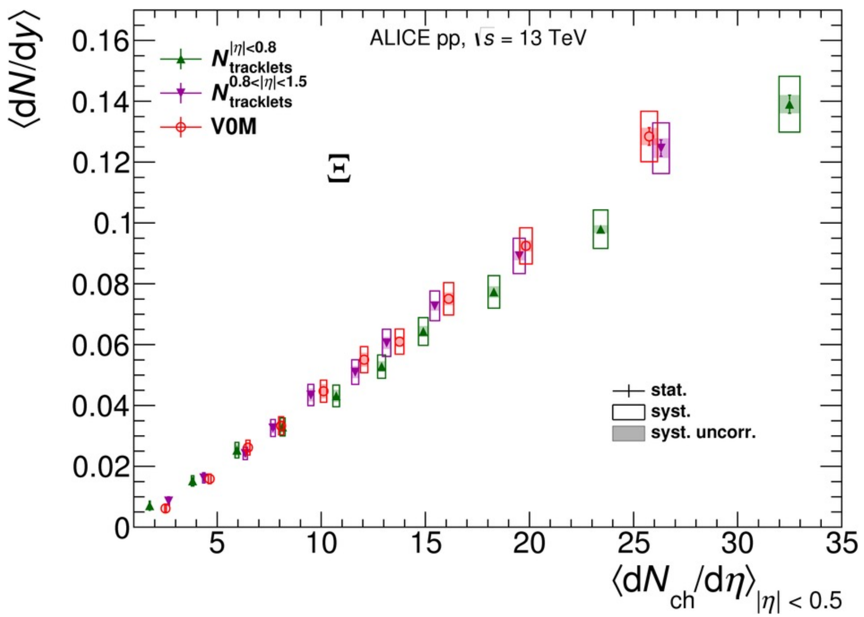
Cascade: charged particle decaying weakly into a V^0 + charged particle

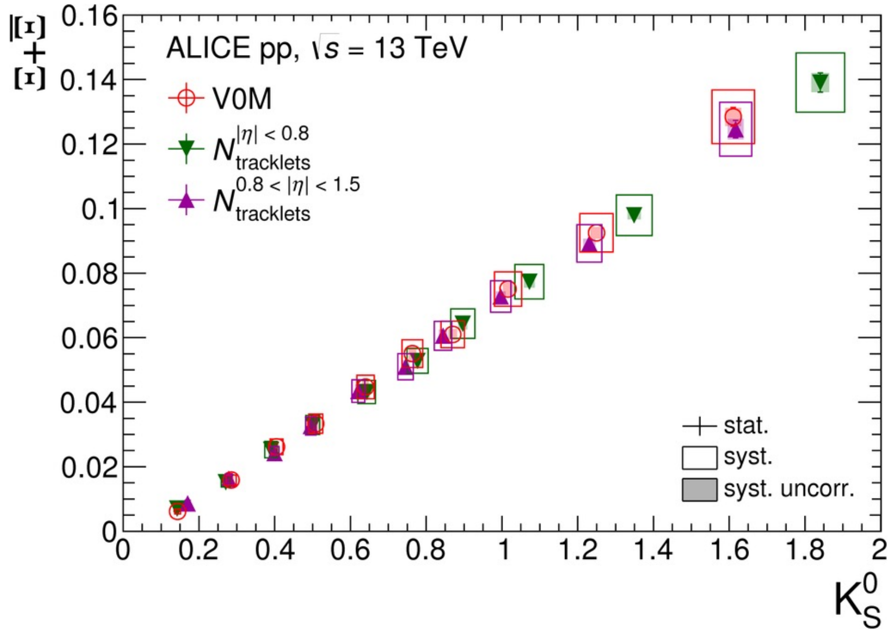
$$\Xi^-\,(\bar{\Xi}^+) \rightarrow \Lambda\,(\bar{\Lambda}) + \pi^-\,(\pi^+) \quad (dss)$$

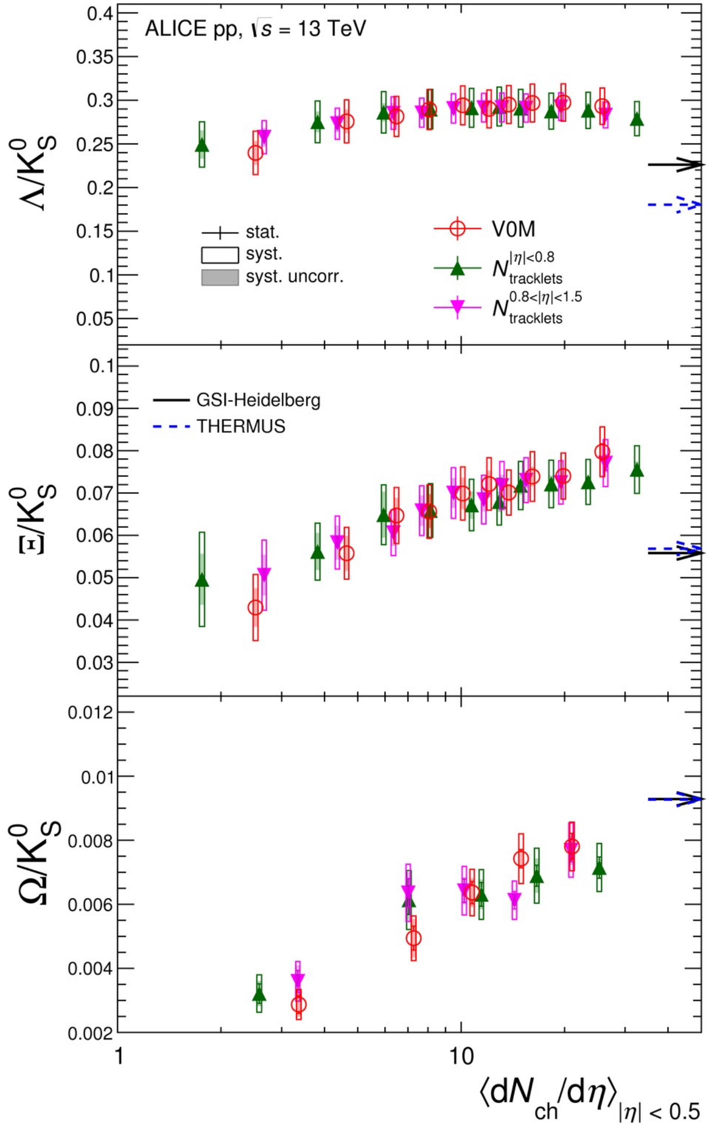
$$\Omega^-\,(\bar{\Omega}^+) \rightarrow \Lambda\,(\bar{\Lambda}) + \mathrm{K}^-\,(\mathrm{K}^+) \quad (sss)$$



Choice of an Event Classifier







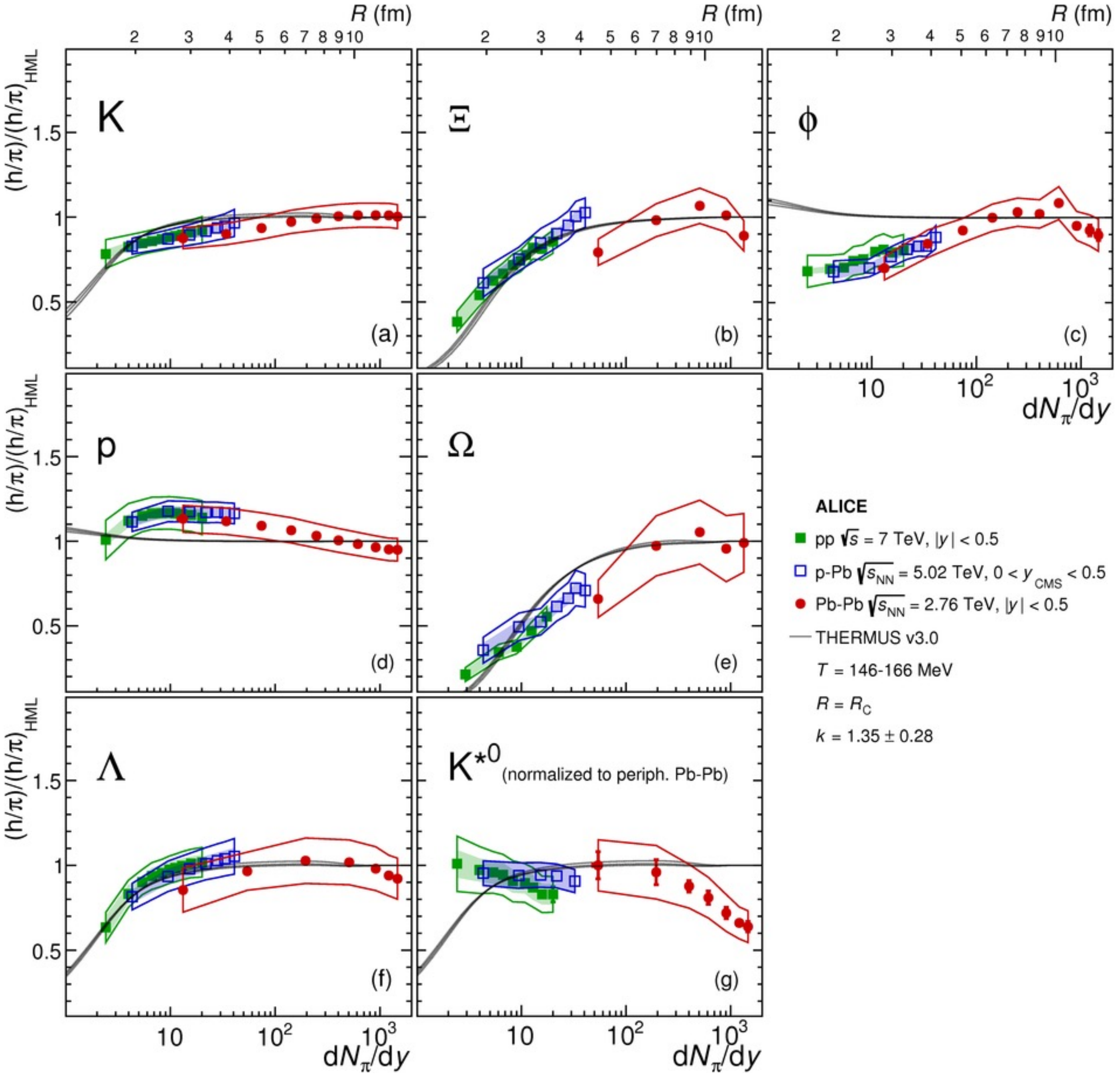
- Mid-rapidity estimator ($N^{|\eta|<0.8}_{\mathrm{tracklets}}$) **enhances charged-particles** yield with respect to strange hadrons leading to a saturation
- Results for **V0M** and $N^{0.8<|\eta|<1.5}_{\mathrm{tracklets}}$ estimators **follow a similar trend** without saturation

Selection bias on primary charged-particles is stronger than that on strange hadrons

➡ One can study $^{\mathrm{hadrons}}/_{K^0_S}$ independently of the choice of event classifier

Eur. Phys. J. C 80, 167 (2020)

Strangeness Canonical Approach to Rule Them All



- The **conservation of strangeness is guaranteed locally** and not only globally (THERMUS 3.0 code)
- **The bulk** of the particles **is still described** in the grand-canonical ensemble
- **Ratios are normalized** to the mean ratio in the 0–60% most central Pb-Pb collisions for the data to
  - **cancel** the influence of the freeze-out temperature
  - **isolate** the volume dependence
- **Volume of strangeness production** is defined such that $\frac{dN_\pi}{dy}$ is described at $y \in [-k \cdot 0.5; k \cdot 0.5]$, where k is obtained in a one-parameter fit for all the particles and multiplicities
- **Strangeness as a conserved quantity** in QCD was found to be **effectively equilibrated** over the $y = \pm 0.67$