HELLENIC REPUBLIC
National and Kapodistrian University of Athens
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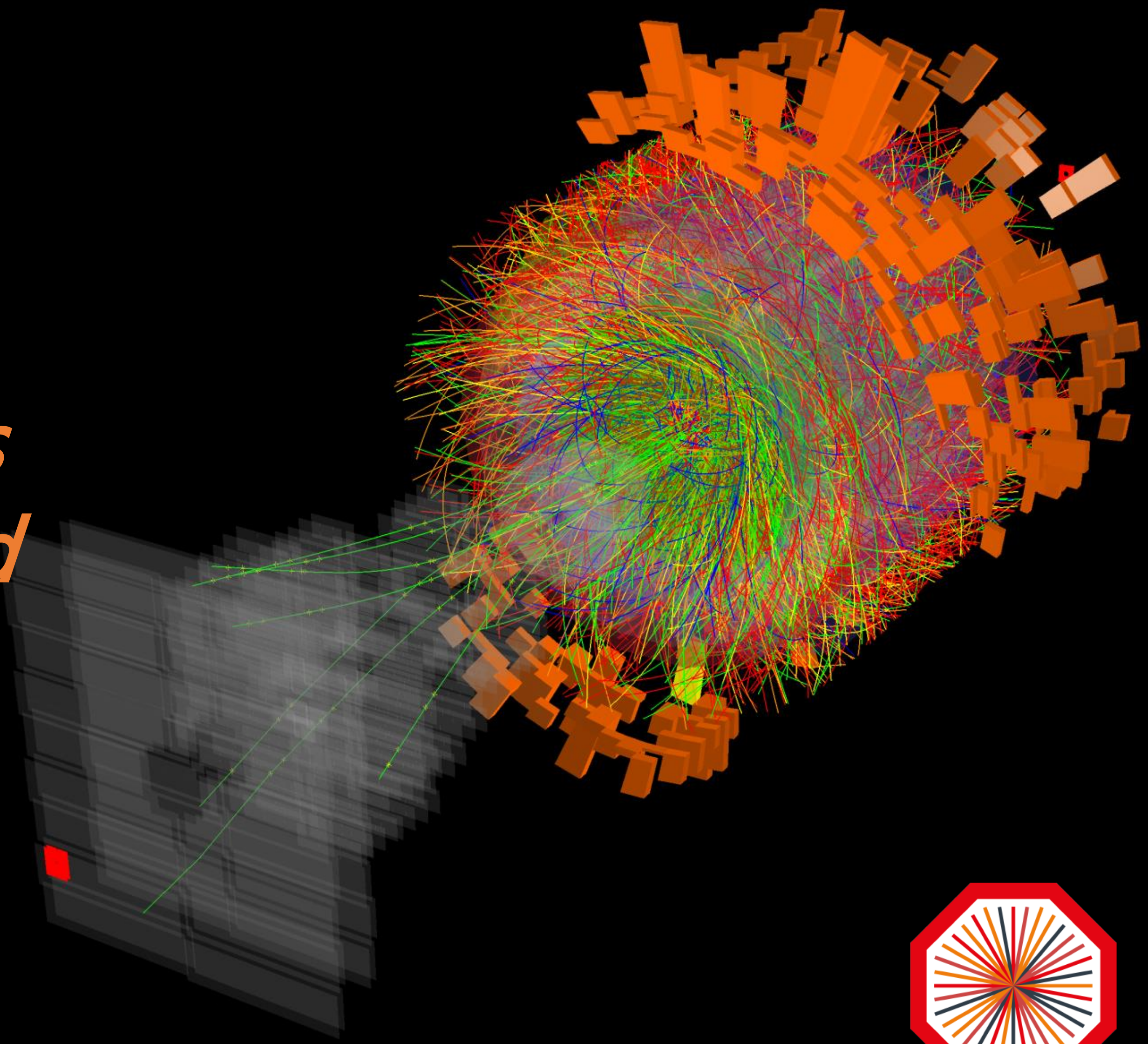
Exploring hadronization at the LHC: Investigating strange particles in various collision systems and energies with ALICE



Maria Barlou on behalf of the ALICE Collaboration
National and Kapodistrian University of Athens, Greece

ICNFP - Crete 10-23 July 2023

ALICE

Outline

Introduction

QGP and strangeness

Strangeness enhancement results from Runs 1,2

Comparison between different systems

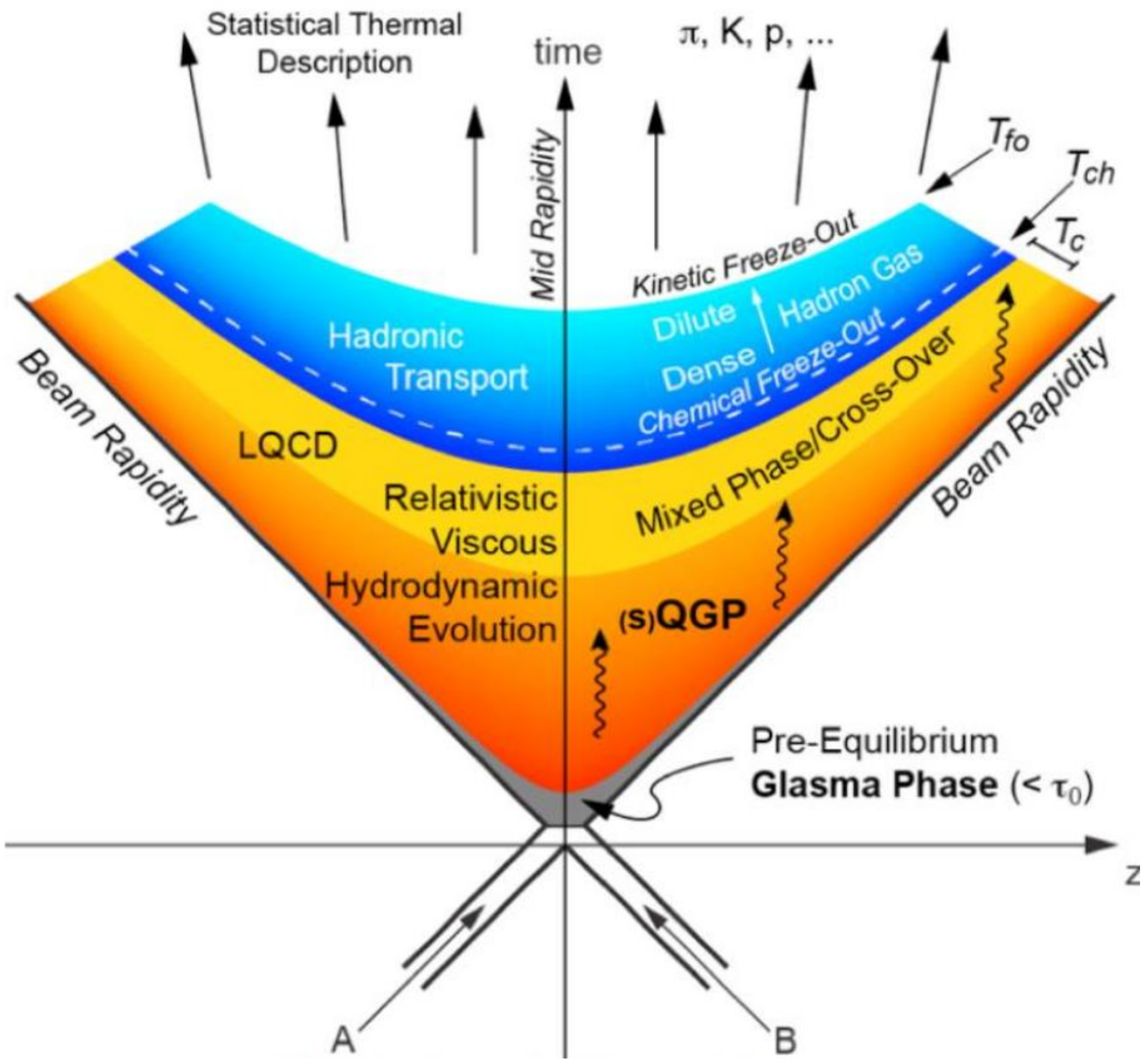
Upgrade & Run 3

Results and expectations

Nuclear matter evolution

- At sufficiently **high temperature** and **energy density**, nuclear matter undergoes a transition to a phase in which quarks and gluons are **not** confined: the **quark–gluon plasma (QGP).**

- Such an exotic state of strongly interacting quantum chromodynamics matter is produced in the laboratory in heavy nuclei high-energy collisions, where an enhanced production of **strange** hadrons is observed.

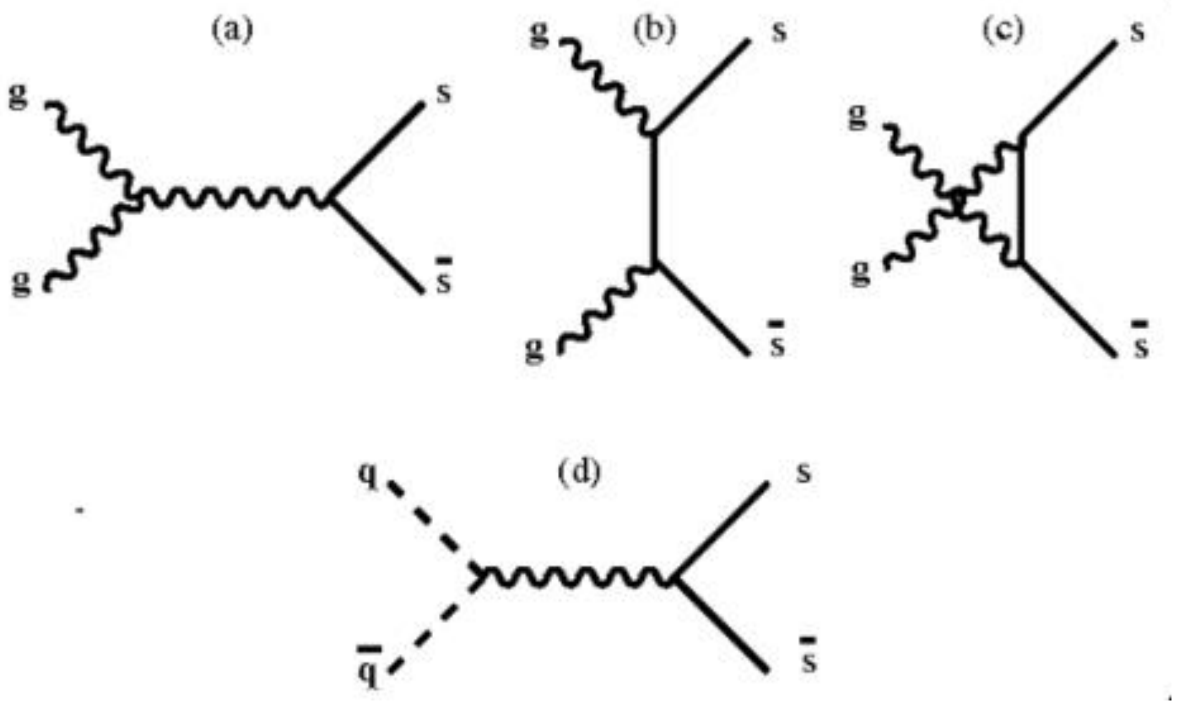


Nuclei A and B before the collision

Strangeness in QGP

Strangeness production is considered as a signal of QGP formation in nuclear collisions, as:

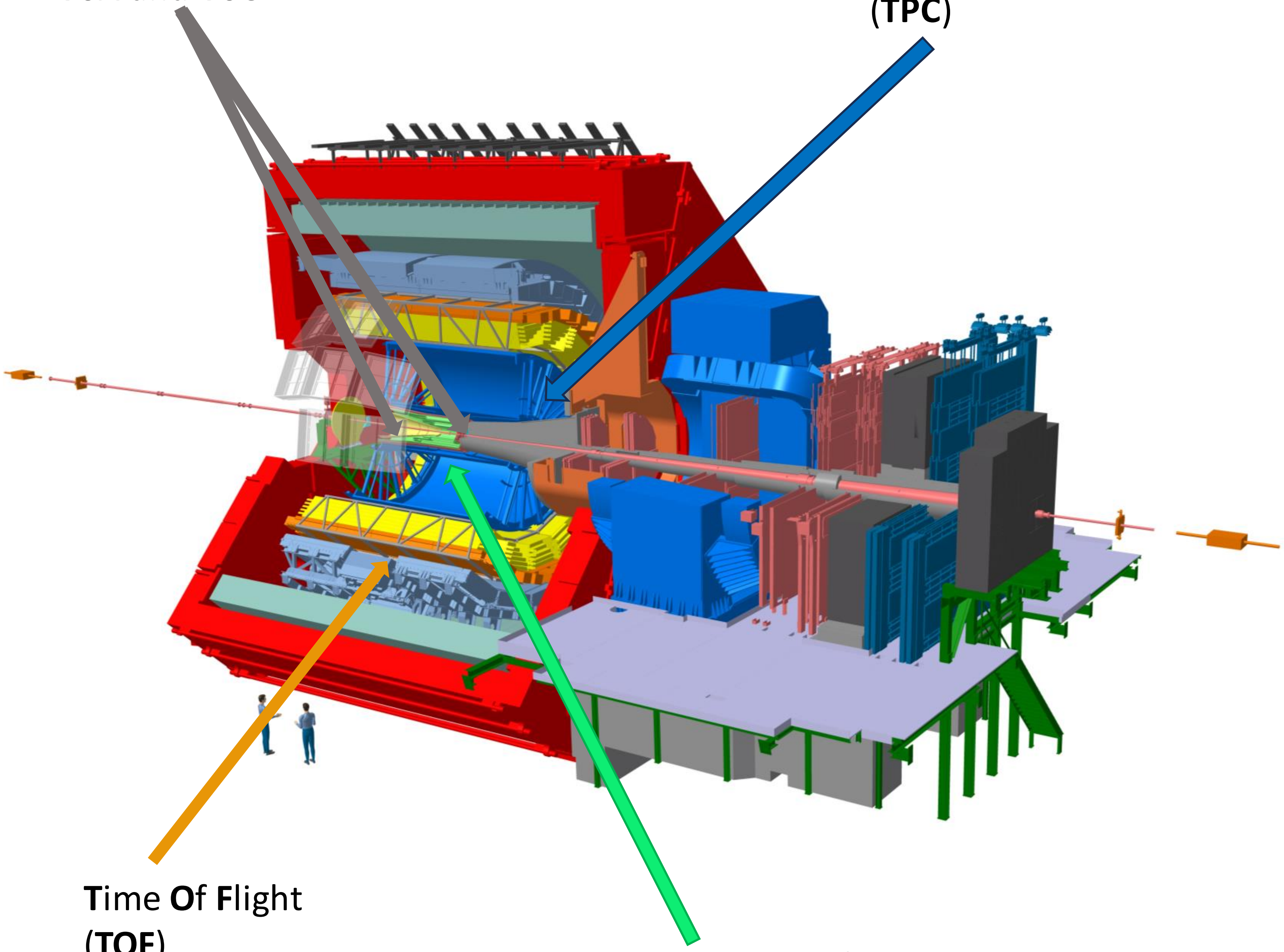
- NO strange valence quarks in the initial state of the collision.
- Strange quark is sufficiently light to be created during the course of the collision and participate in collective motion.



Strangeness production via:
i) gluonic fusion (fig. a, b, c)
Ii) quark – antiquark annihilation (fig.d)

THE ALICE EXPERIMENT

ALICE (A Large Ion Collider Experiment) is dedicated to heavy-ion physics at the LHC. It is designed to study the physics of the **QGP** thanks to its **state-of-the-art** PID technology and **high-precision** tracking and vertexing.



Extending to different collision systems and energies

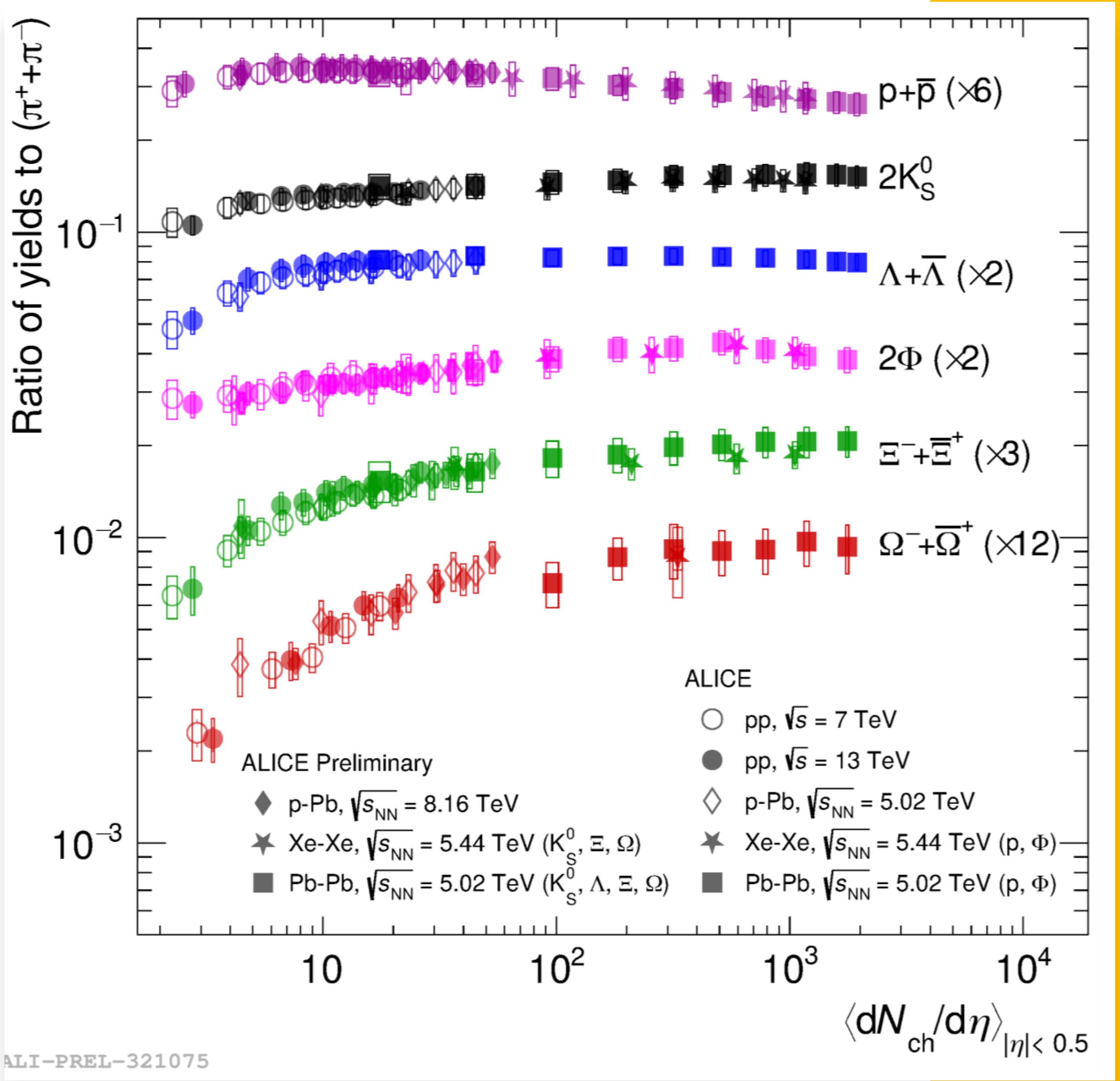
- Ratio of strange to non-strange hadron yields increases with charged-particle multiplicity

-> **smooth evolution across different collision systems and energies.**

- In high-multiplicity pp events strangeness production rates are in remarkable agreement with those observed in Pb-Pb and Xe-Xe collisions.

- Steeper increase for hadrons with a higher strangeness content: SE(Ω) > SE(Ξ) > SE(Λ,K0S)

-> **Strange content hierarchy.**



Extending to different collision systems and energies

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  -> **smooth …**
  collision s…

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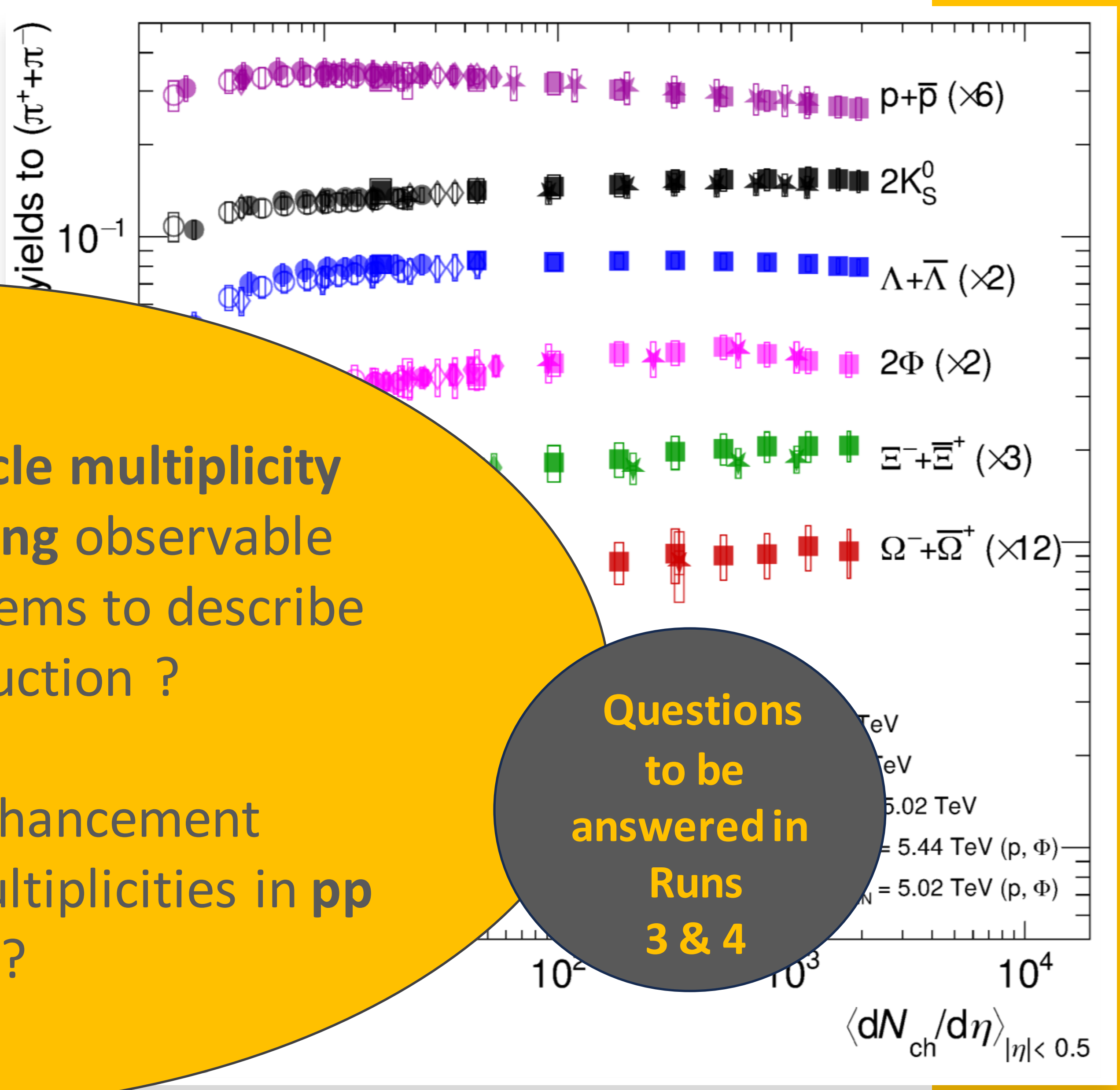
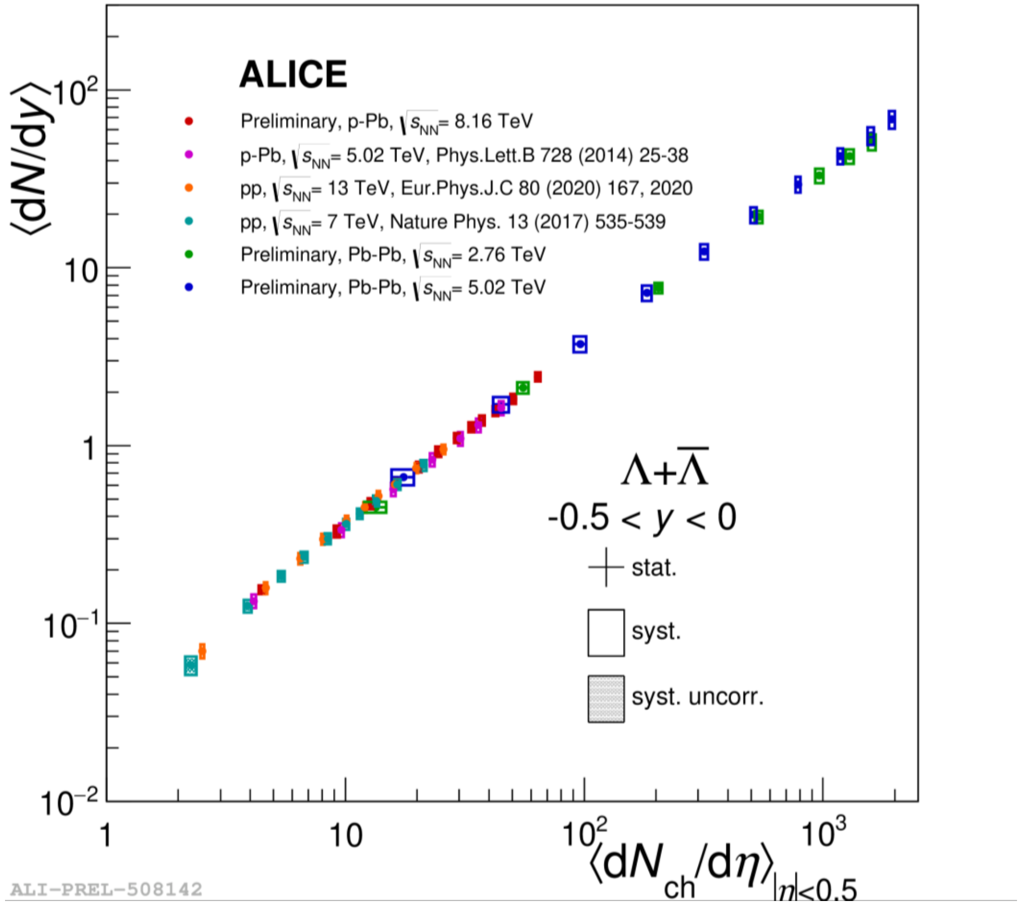


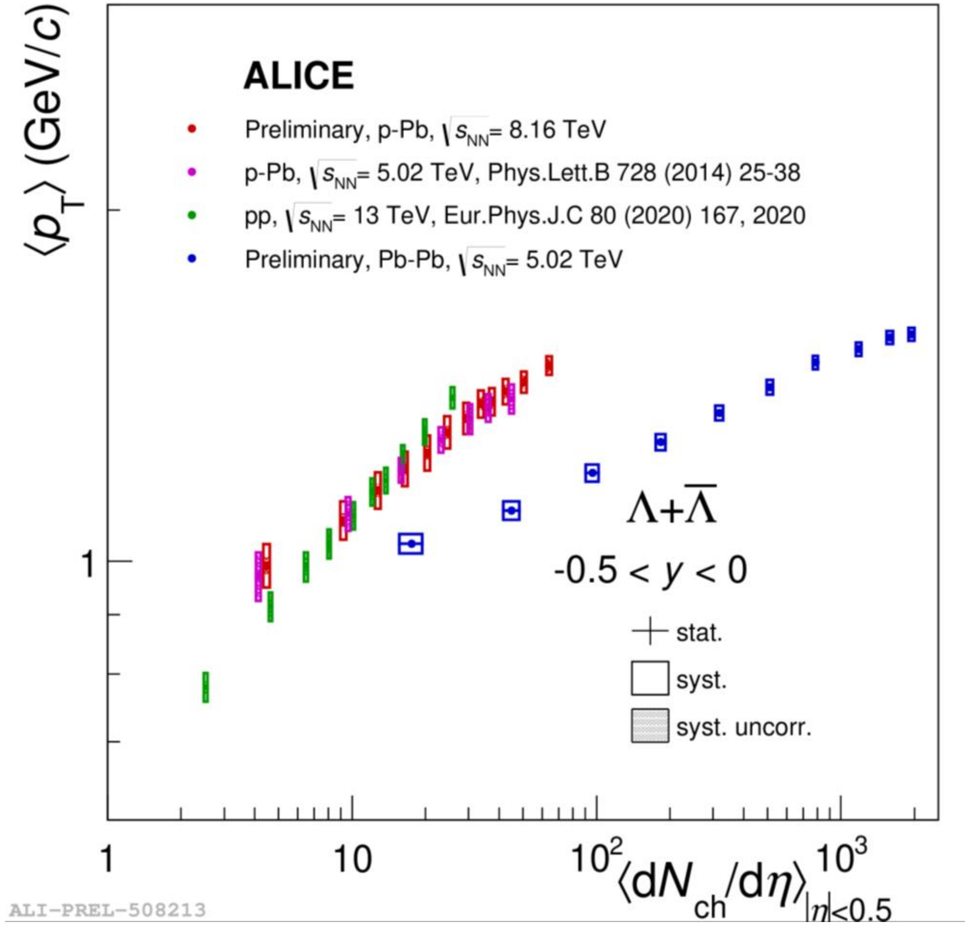
- Is the **charged particle multiplicity density** a good **scaling** observable among **different** systems to describe particle production ?

- Is strangeness enhancement persisting at **higher** multiplicities in **pp** collisions?

Questions to be answered in Runs 3 & 4

Mean <p_T> & Total Yields: Small -> Large System



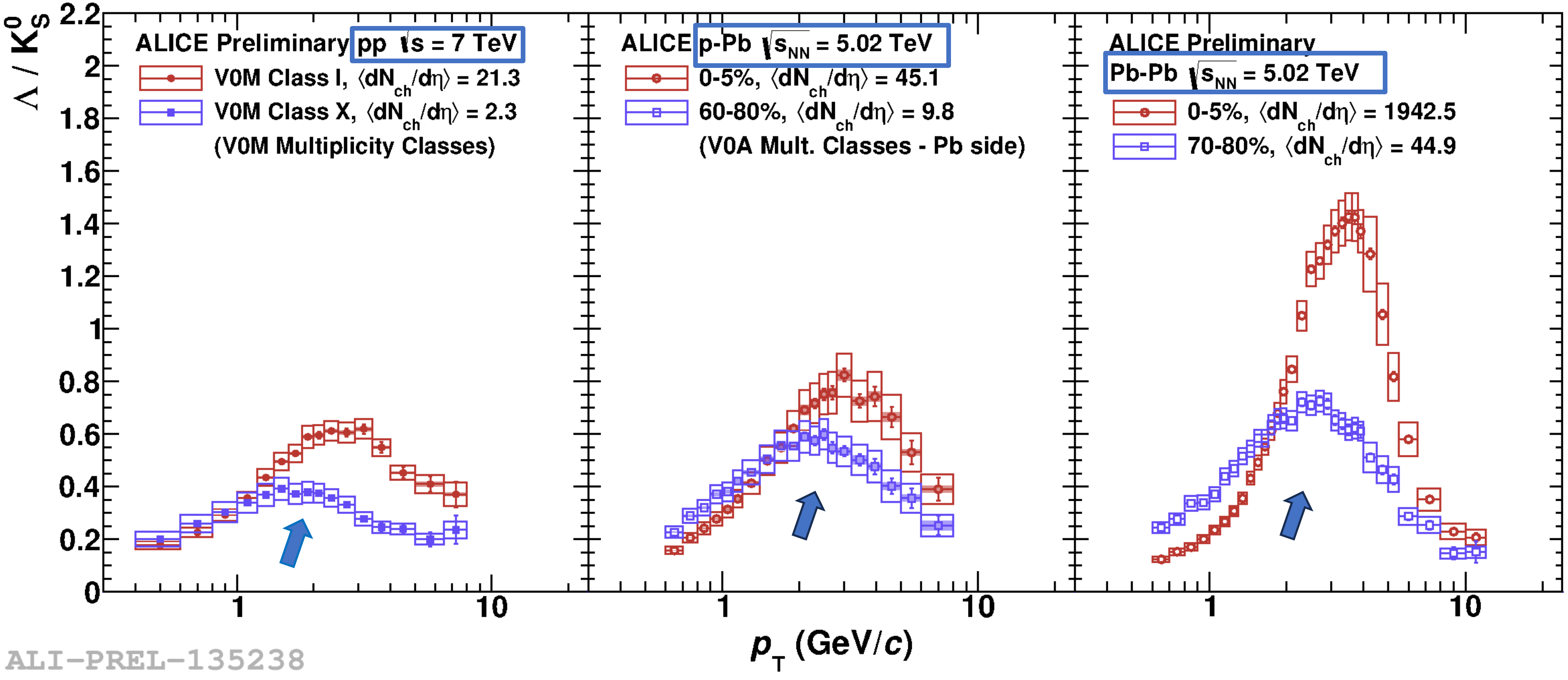


Continuity across multiplicity is verified for yields.

Yet, p_T spectra are affected by collective motion in **large** systems.

-> The trend is **not** universal.

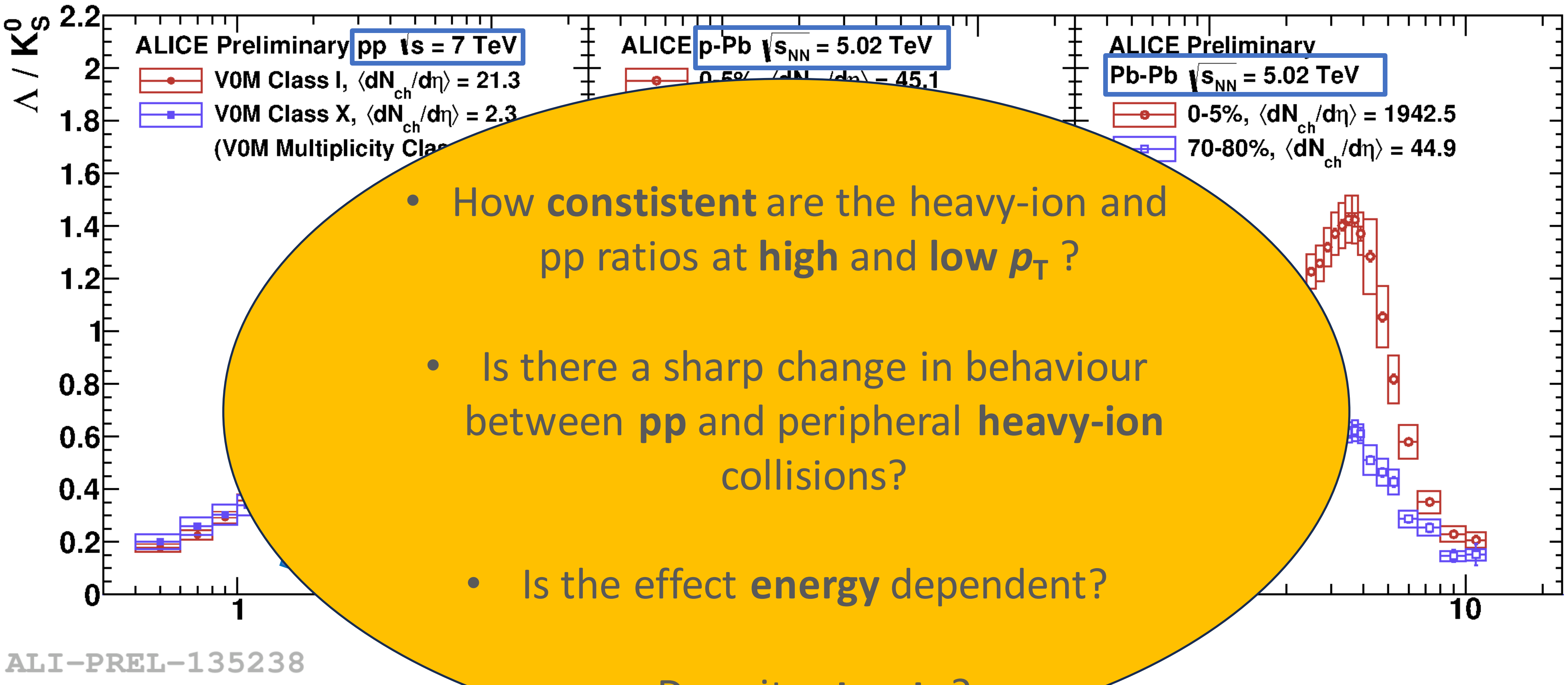
Baryon to meson ratio: Small -> Large System



- **Enhancement** of baryon over meson ratio at intermediate p_T across **different** collision systems.
- Intermediate p_T: Bump whose peak **drifts** from peripheral to central -> Expected in *Radial Flow*

& described by recombination models. High p_T-> consistency between the 3 systems.

Baryon to meson ratio: Small -> Large System



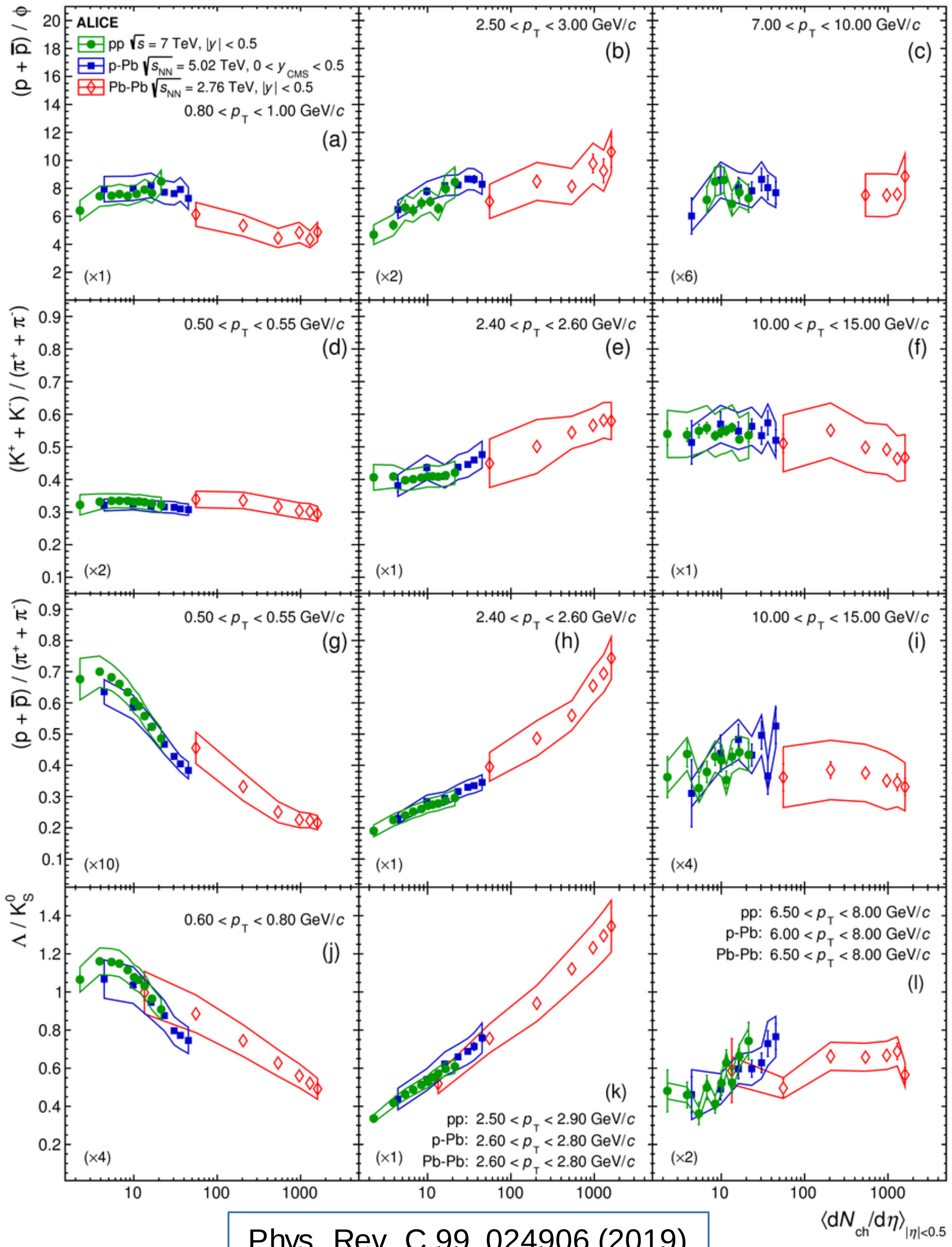
- How **constistent** are the heavy-ion and pp ratios at **high** and **low** p_T ?
- Is there a sharp change in behaviour between **pp** and peripheral **heavy-ion** collisions?
- Is the effect **energy** dependent?
- Does it **saturate**?

- **Enhancement** of baryon over meson ratio ... p_T across **different** collision systems.
- Intermediate p_T: Bump whose peak **drifts** from peripheral to central -> Expected in *Radial Flow & described by recombination models.* High p_T-> consistency between the 3 systems.

Baryon to meson ratio:
Small -> Large System

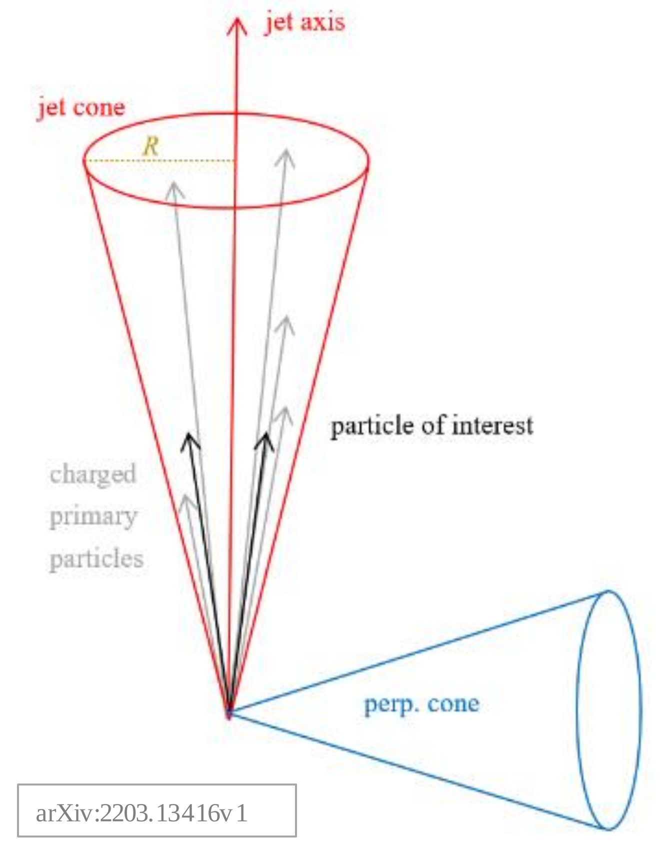
- Ratios depend on multiplicity in a remarkably **similar** manner for **all** collision systems, despite differences in energy and collision geometry.

- Is this behavior connected to hard or soft processes such as **in jet** or **out-of-jet** processes?

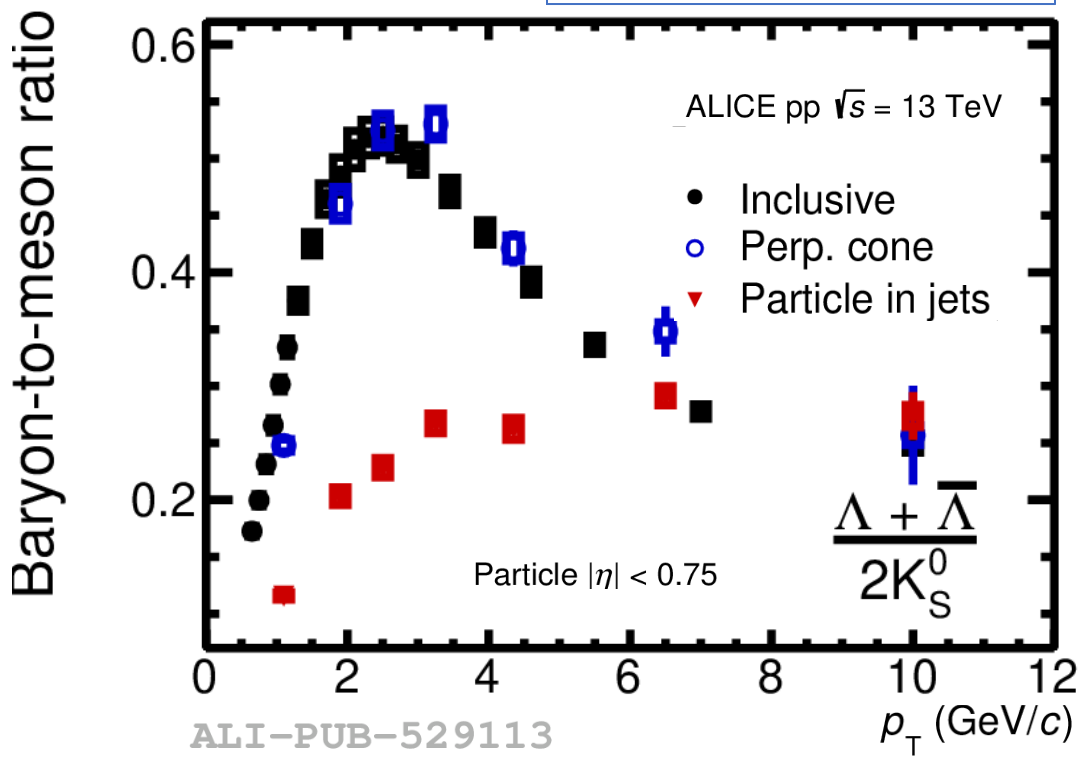


Phys. Rev. C 99, 024906 (2019)

Baryon to meson ratio in and out of jets



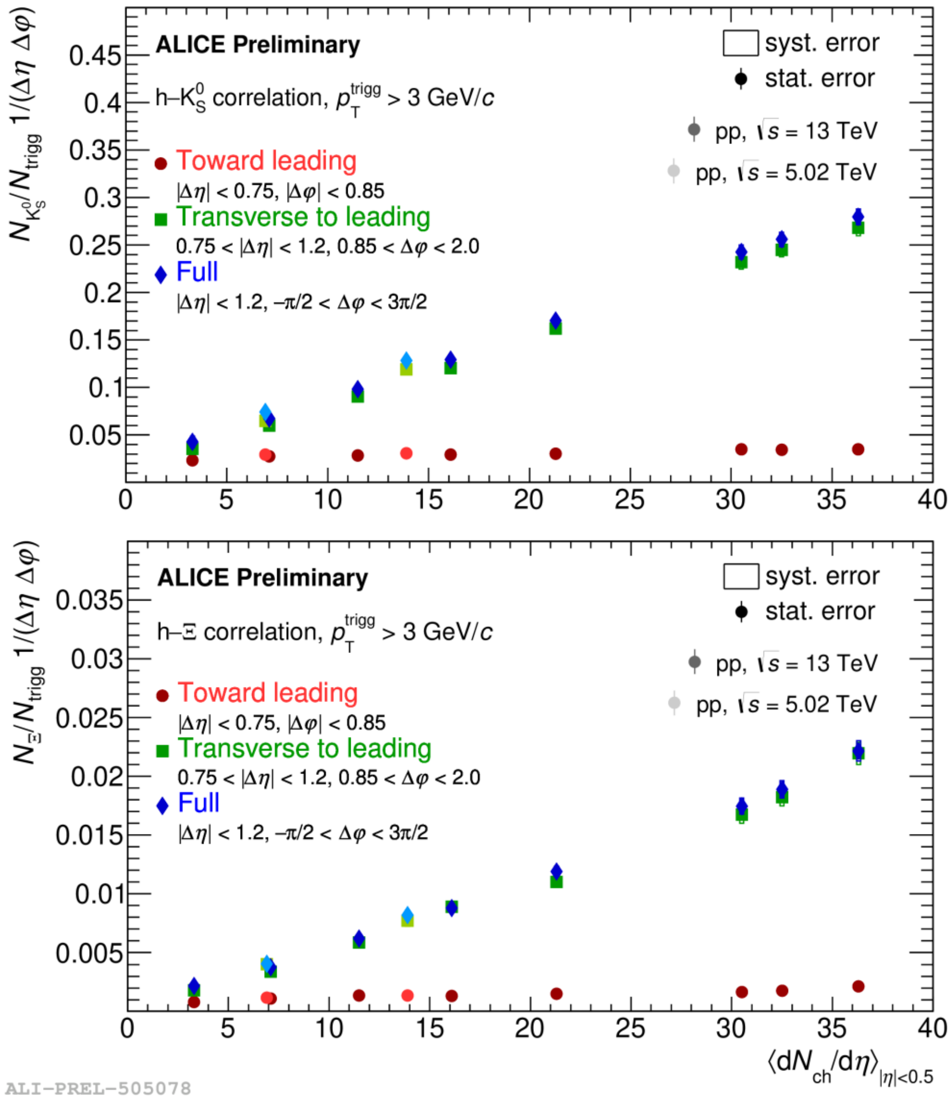
Phys. Lett. B 827, 136984 (2022)
arXiv:2211.08936 (2022)

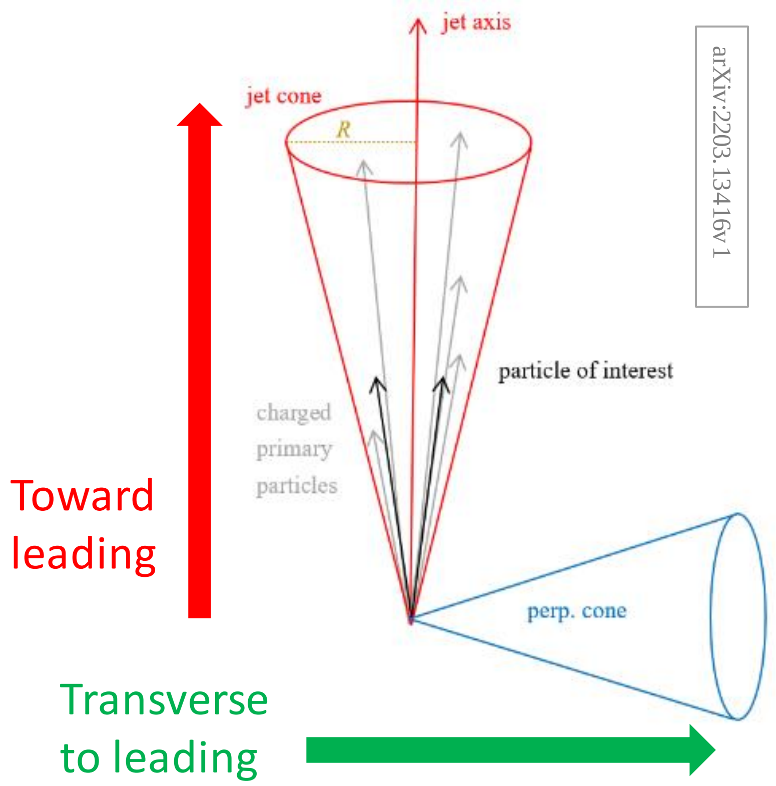


- The **enhancement** is observed in **UE**, but is very much reduced in jets.
- **Similar** situation in p-Pb collisions at 5.02 TeV.

-> The baryon-over-meson enhancement emerges from **transverse-to-leading** processes.

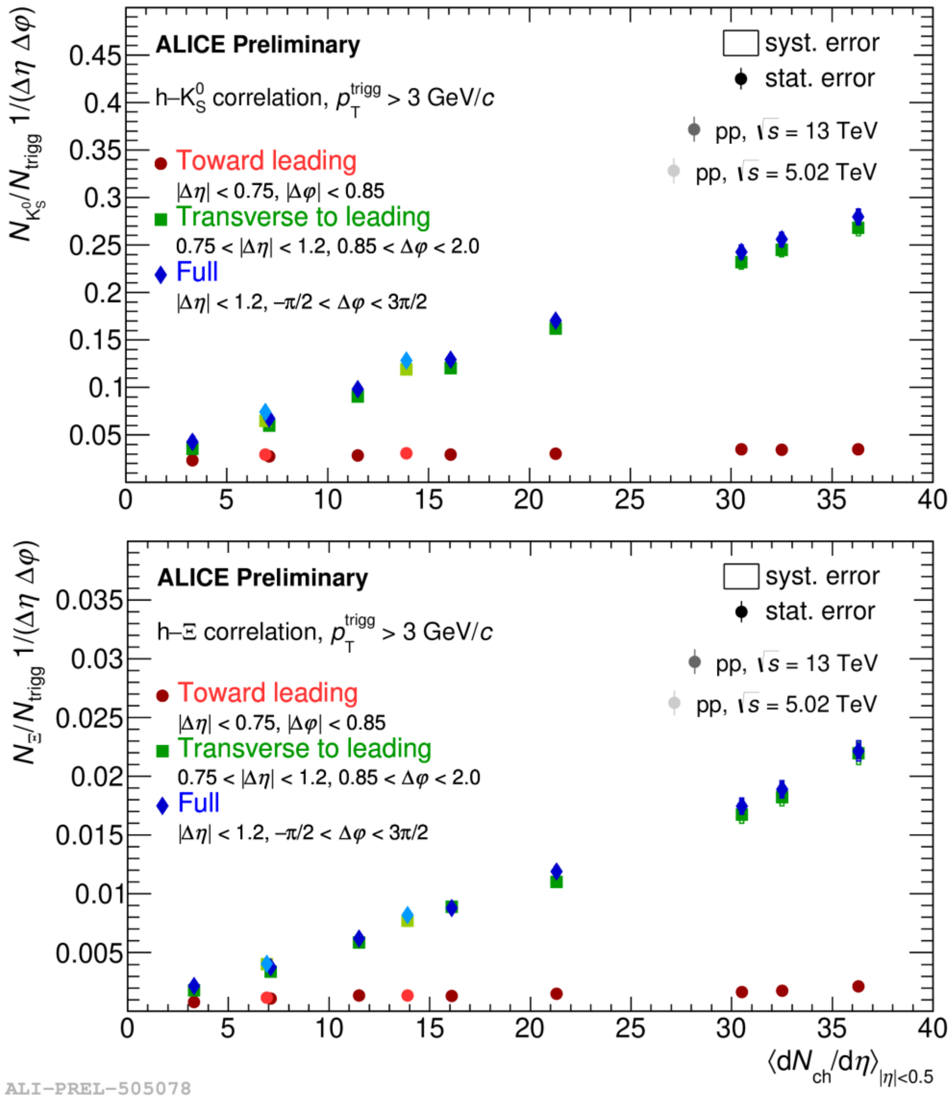
Strangeness in and out of jets

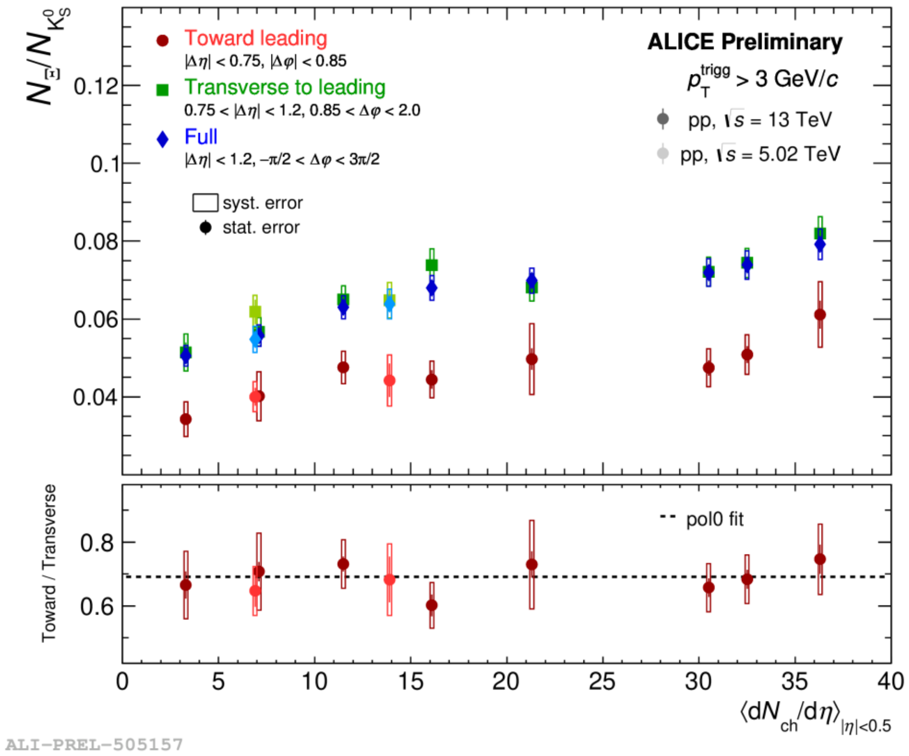




- Larger contribution of **out-of-jet** processes on strange and multi-strange hadron production.
- No centre-of-mass energy dependence.

Strangeness in and out of jets





- Larger contribution of **out-of-jet** processes on strange and multi-strange hadron production.
- No centre-of-mass energy dependence.
- Toward leading and transverse to leading processes are **consistent** in **strangeness enhancement**.

THE UPGRADED ALICE

In order to answer the questions discussed above ALICE has now achieved:

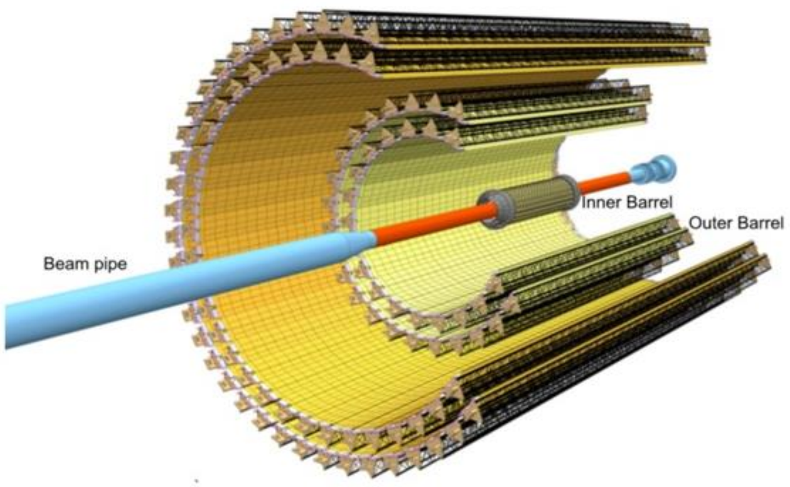
- Higher luminosity (multiplicity in pp events reaches the multiplicity of central Pb-Pb events)
- Higher Interaction rates (~50kHz in Pb-Pb collision)
- Excellent resolution to lower p_T
- Improved statistics

Multi-differential analysis is taking place in order to show that:

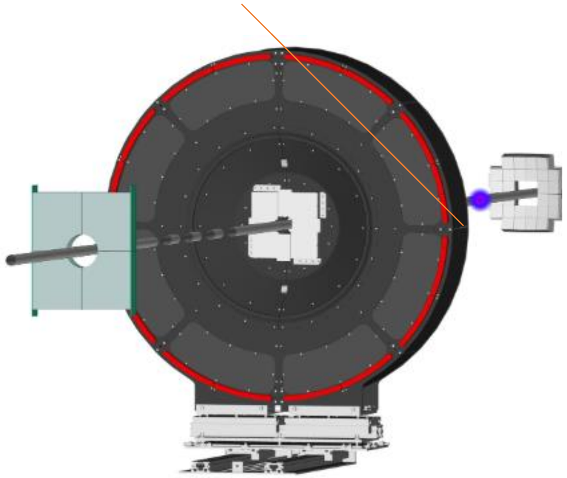
- there is a unified picture of particle production and QCD mechanisms from small (pp, p-Pb) to large (Pb-Pb) systems, or
- new mechanisms are important in heavy ion collision.

THE UPGRADED ALICE
Detectors

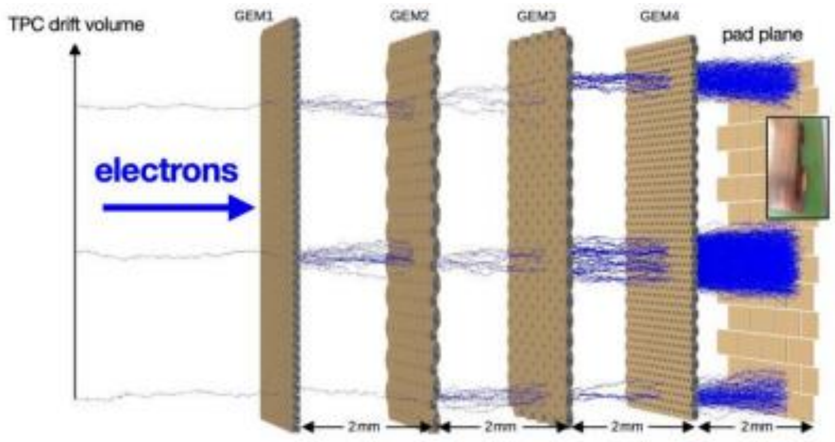
- Improved pointing resolution
- Increased readout rate
- Larger data collection
- Greater background supression



New Inner Tracking System (ITS)



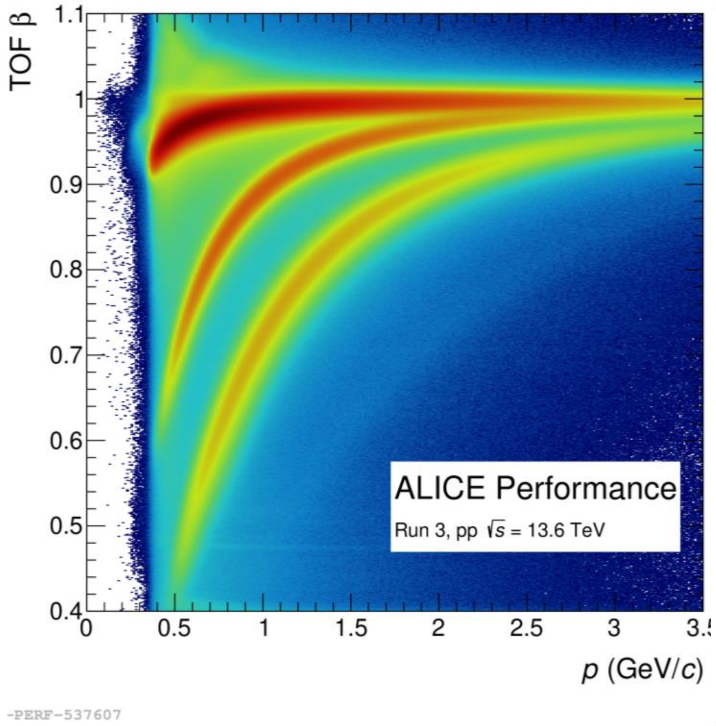
New Fast Interaction Trigger (FIT)



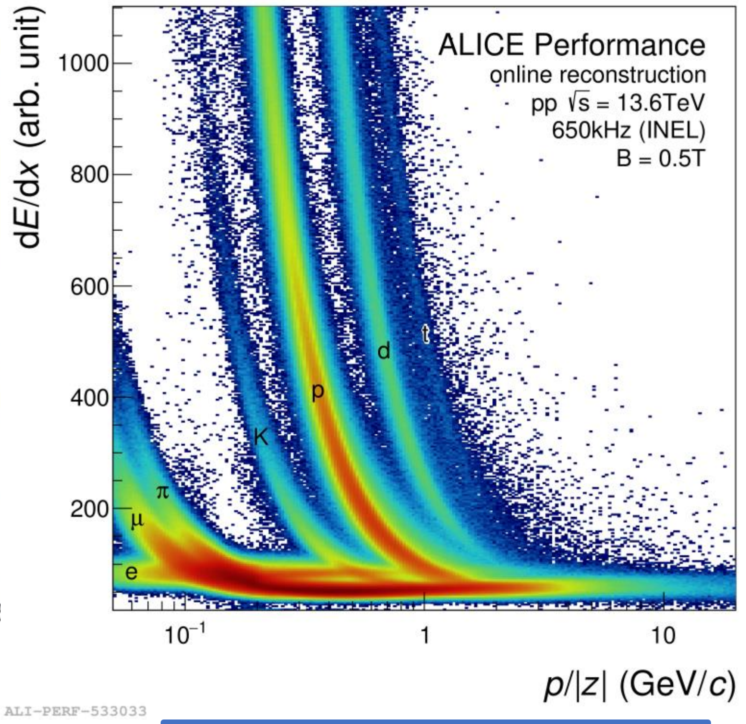
Upgraded Time Projection Chamber (TPC)

THE UPGRADED ALICE

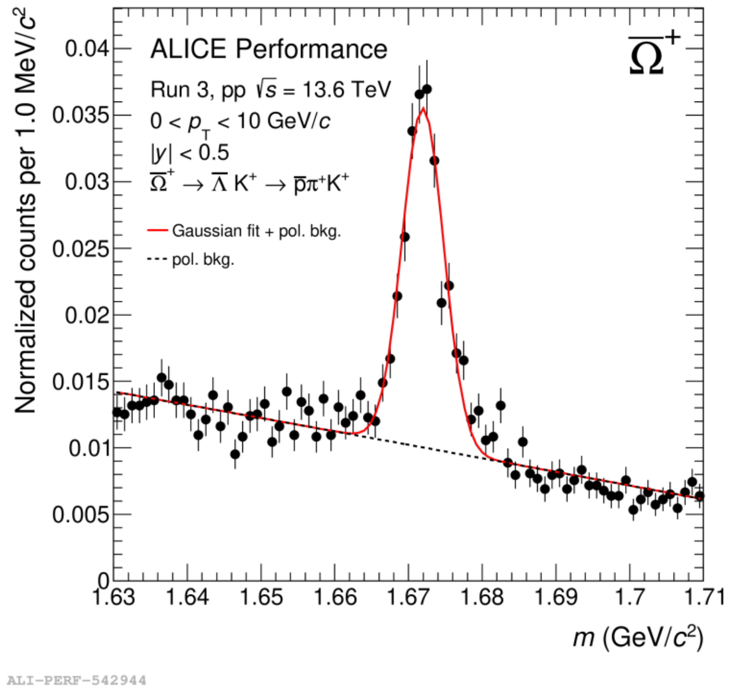
Performance



ALICE TOF Performance



ALICE TPC Performance



Invariant Mass

Summary & Expectations

•**Strange** hadron yields **increase** with charged-particle **multiplicity** density, **regardless** of the collision system or the center-of-mass energy.

•Several features observed in large collision systems and explained as due to the formation of the **QGP** or **collective phenomena** are also observed in the small systems.

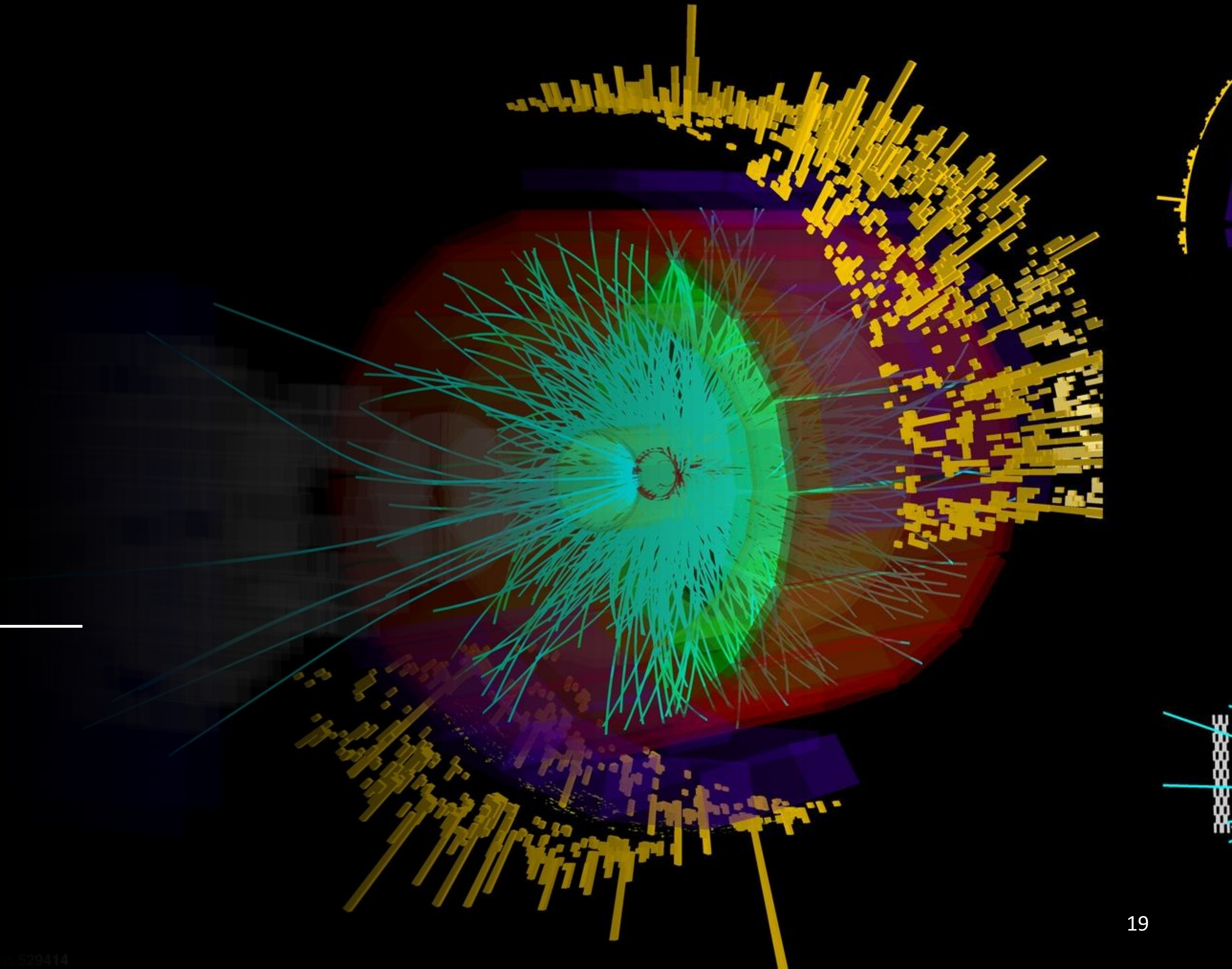
Studies in ALICE RUN 3 results expect to:

- demonstrate whether strangeness production in **huge multiplicity pp** collisions **saturates** at the

thermal equilibrium that is reached in Pb-Pb collisions or continues to **increase**.

- understand the mechanisms responsible for the behavior in **small systems**.

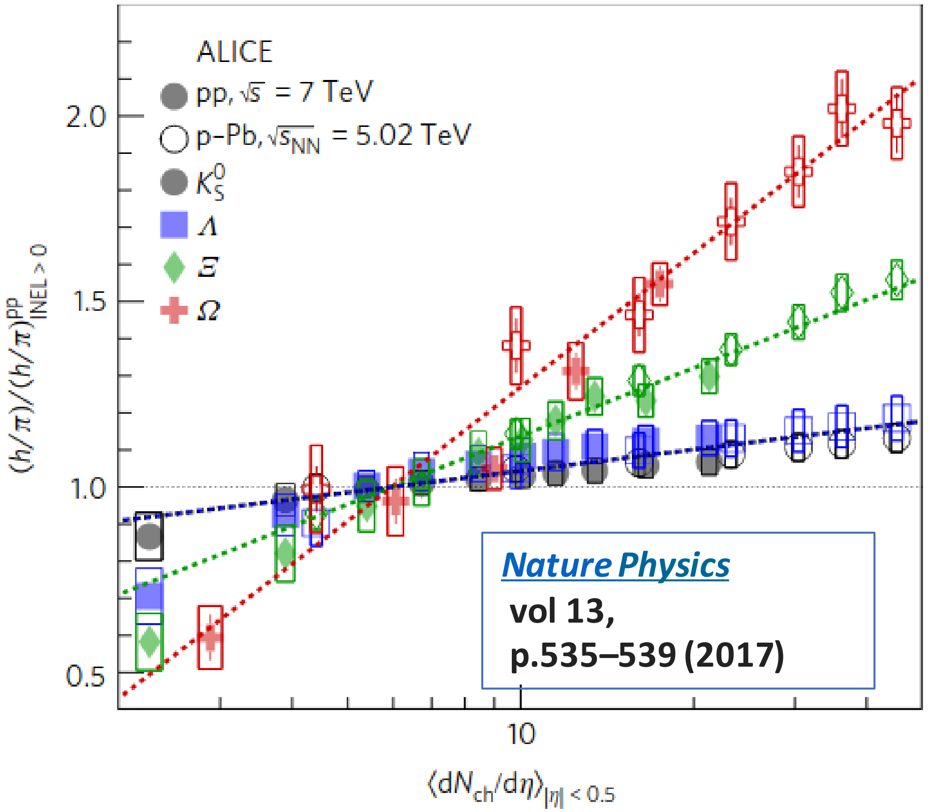
Thank you



BACKUP

Strangeness Enhancement:

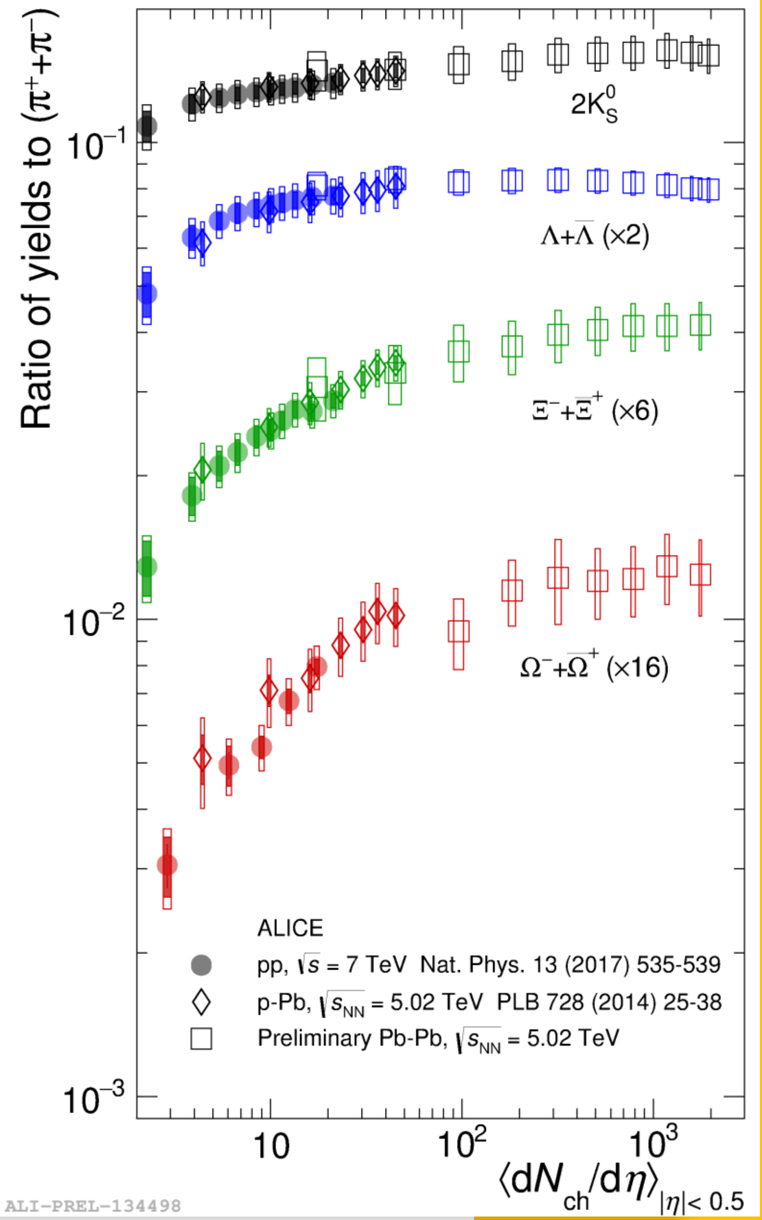
1rst observation in pp collisions



Strangeness hadron production:

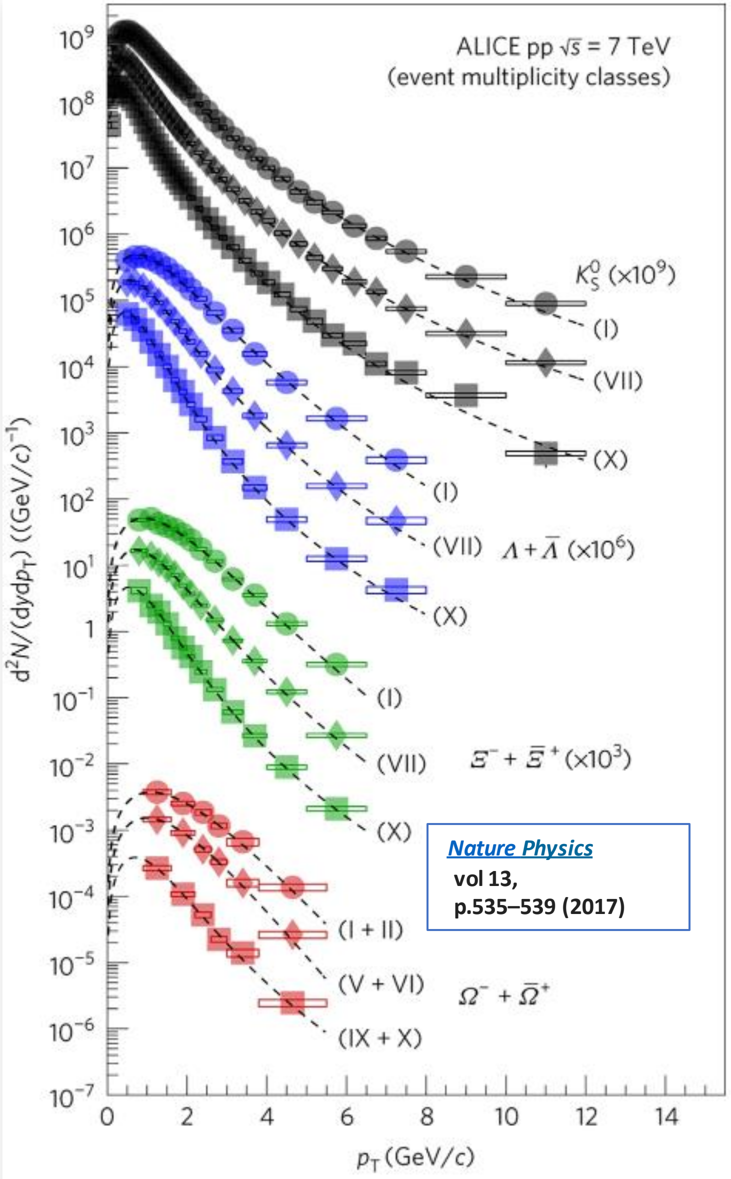
- depends on charged particle multiplicity rather than in the initial collision system or center-of-mass energy.
- Is proportional to the strangeness content in the hadron.

Strangeness enhancement has been observed at SPS, RHIC and LHC in **large** collision systems. The unprecedented observation of **enhanced production of multi strange hadrons in high-multiplicity pp collisions with the ALICE** experiment showed that strangeness enhancement is **not** an exclusive feature of heavy ion collisions.



Strangeness Enhancement:
1rst observation in pp collisions

- The pT spectra become harder as the multiplicity increases, with the hardening being more pronounced for higher-mass particles.
- A similar observation was reported for p–Pb collisions, where the results are consistent with the appearance of collective behaviour at high multiplicity.
- In heavy-ion collisions these observations are successfully described by models based on relativistic hydrody-namics.
- In this framework, the pT distributions are determined by particle emission from a collectively expanding thermal source.



Nature Physics
vol 13,
p.535–539 (2017)

Transverse momentum spectra in elementary interactions are affected by partonic collectivity even when only few particles are produced at midrapidity.

Current Analysis close to finalization: **Strangeness Production in Pb-Pb at 5.02 TeV**

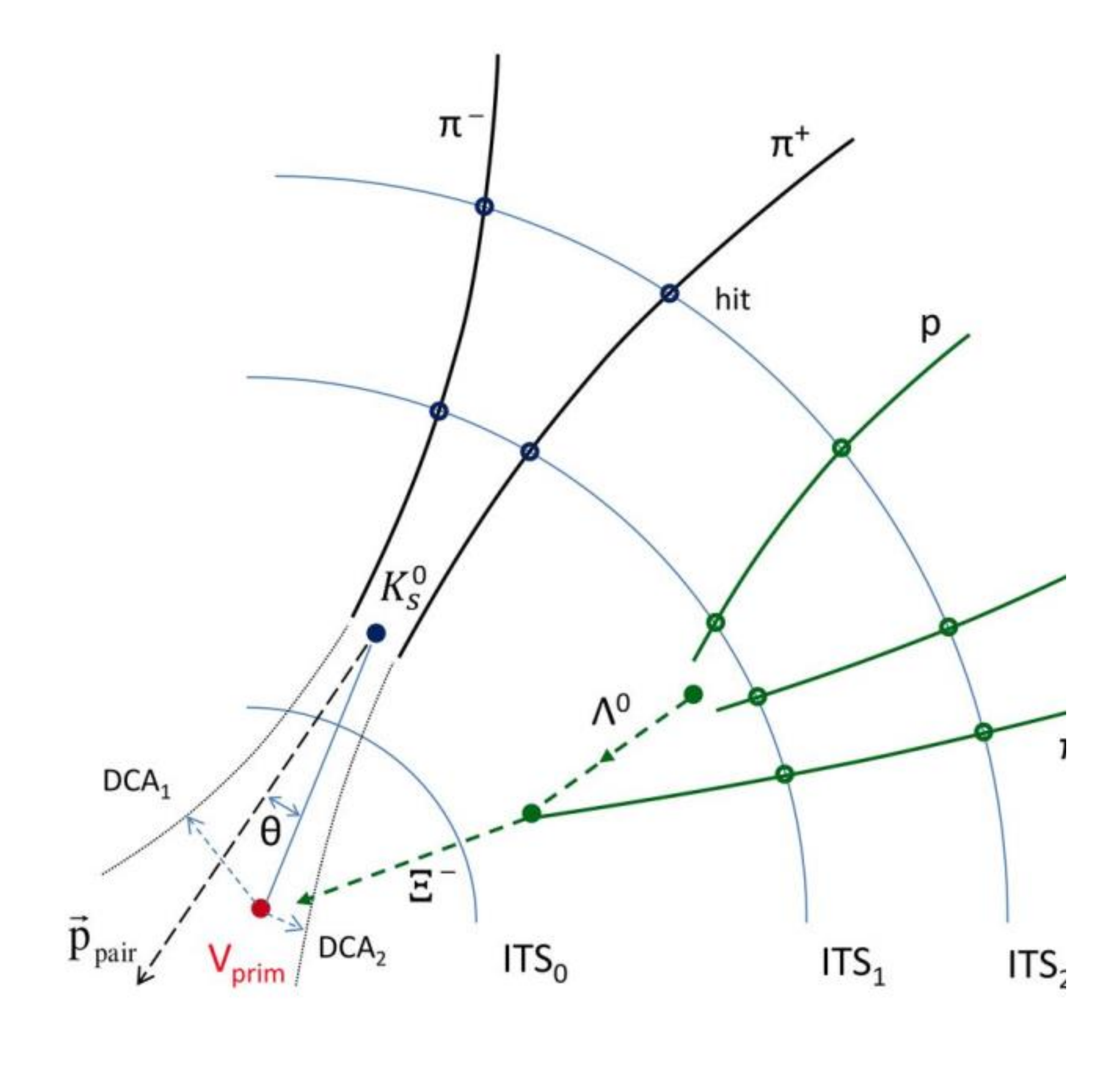
Λ and K0s:

- ✓ are the lightest baryon and meson respectively.
- ✓ they decay only through weak interaction. Thus,
- ✓ they have distinctive decay topologies,

separated from the primary vertex.

- ✓ are identified via the topology of V^0 : neutral particle decaying weakly into a pair of charged particles (V-shaped decay).

$$K^0_S \rightarrow \pi^+ + \pi^-$$
$$\Lambda\,(\overline{\Lambda}) \rightarrow p\,(\overline{p}) + \pi^-\,(\pi^+)$$



Preliminary:

Strangeness Production in Pb-Pb at 5.02 TeV