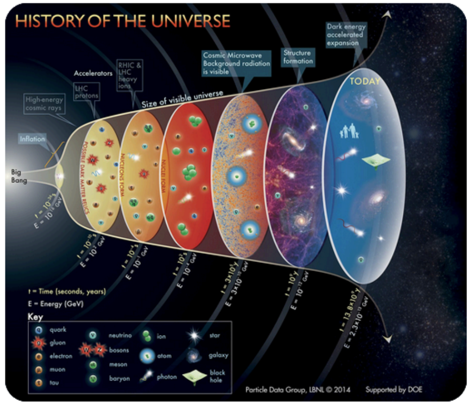
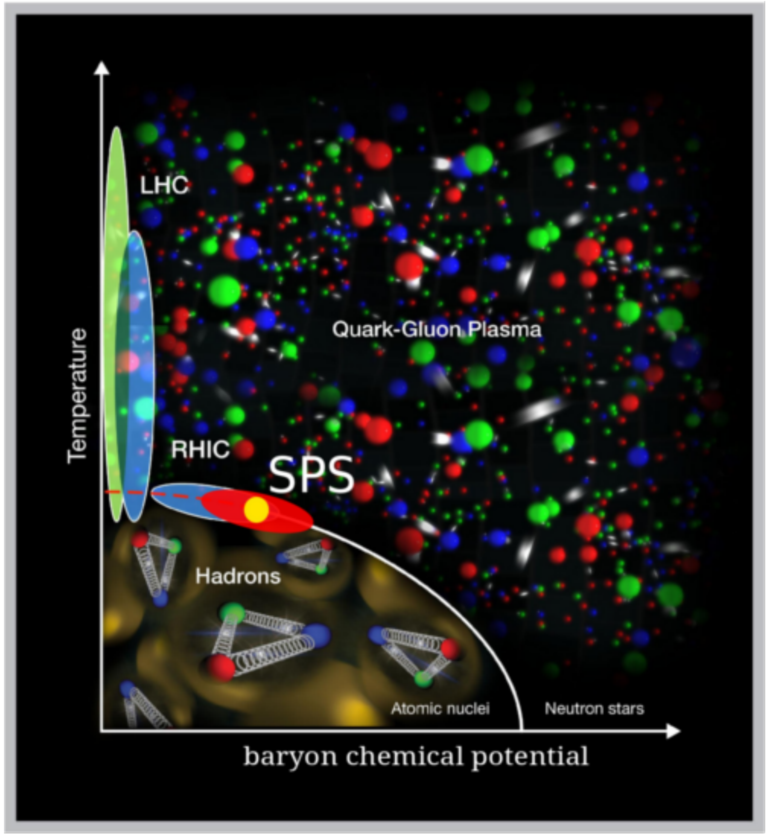
Study of hyperon production and dynamics in heavy ion collisions

Stefania Bufalino
Istituto Nazionale di Fisica Nucleare
and Politecnico di Torino

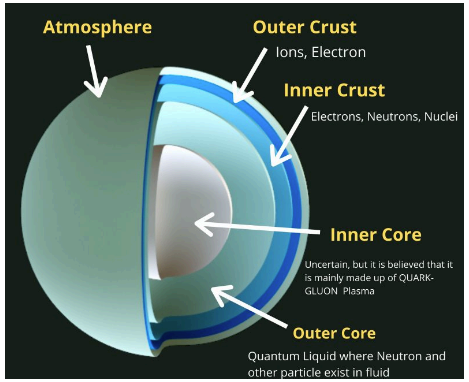
QCD phase diagram



High temperature:
Early Universe evolution



High baryon density:
Inner structure of compact stars

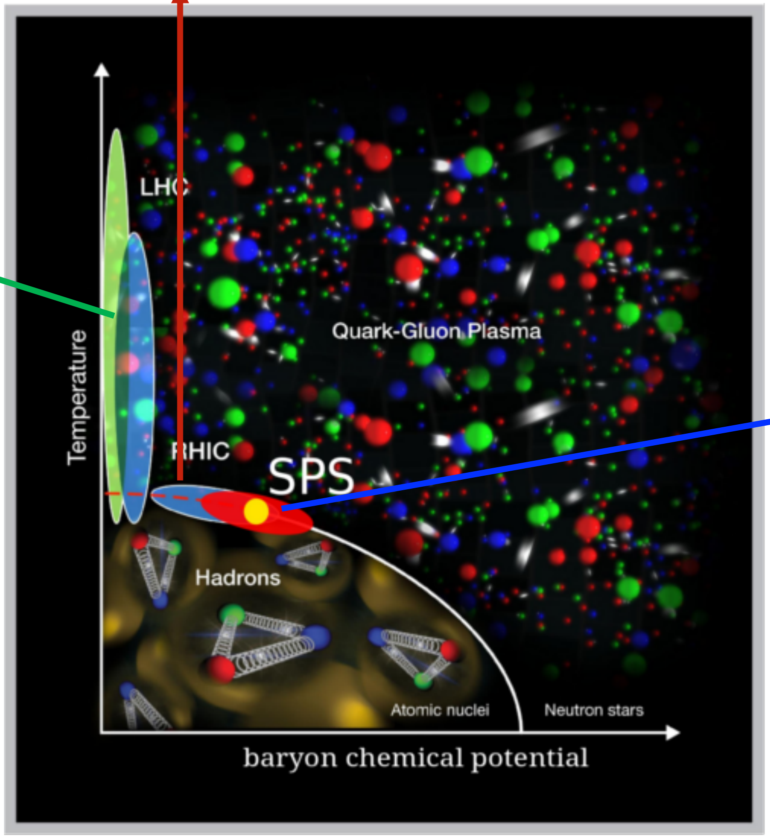


- At $\mu_B = 0$, smooth crossover
- Large μ_B, 1st order phase transition → QCD critical point

QCD phase diagram

RHIC Beam Energy Scan
- Search for Critical Point
- Locate the first-order phase boundary

RHIC 200 GeV and LHC
- Small viscosity, high temperature
- Evidence of Quark-Gluon Plasma



RHIC BESII & SPS
- EoS of matter
- Strange production not fully understood
- Neutron stars

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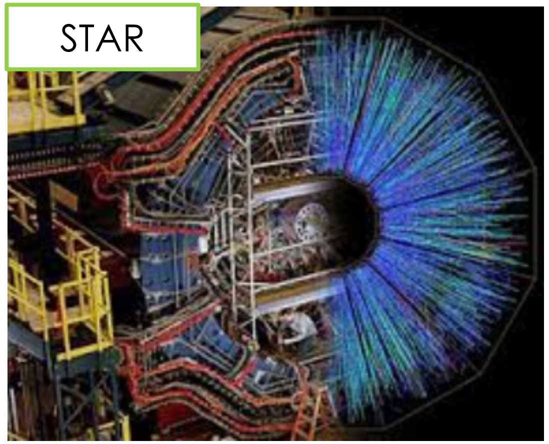
STAR



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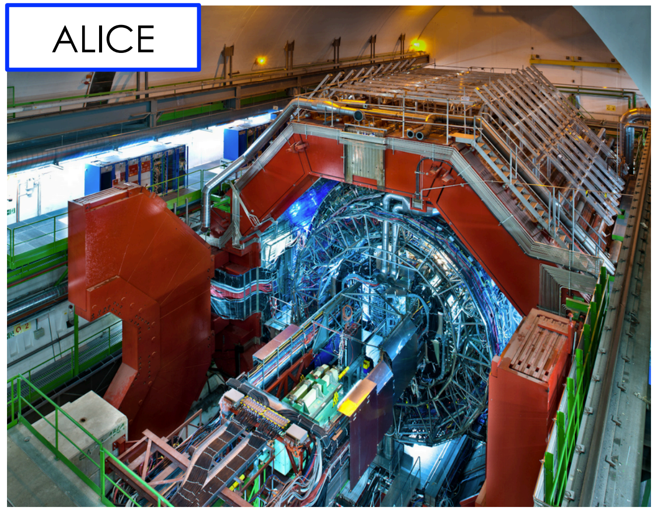
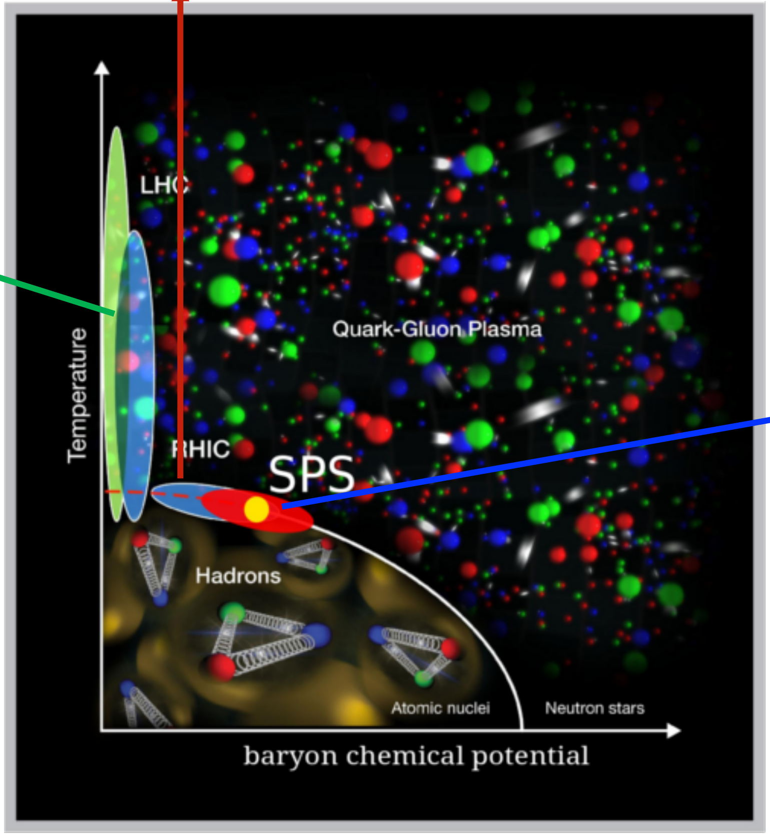
ALICE





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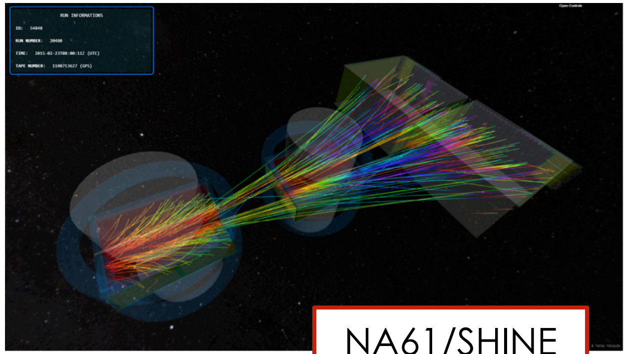

NA61/SHINE

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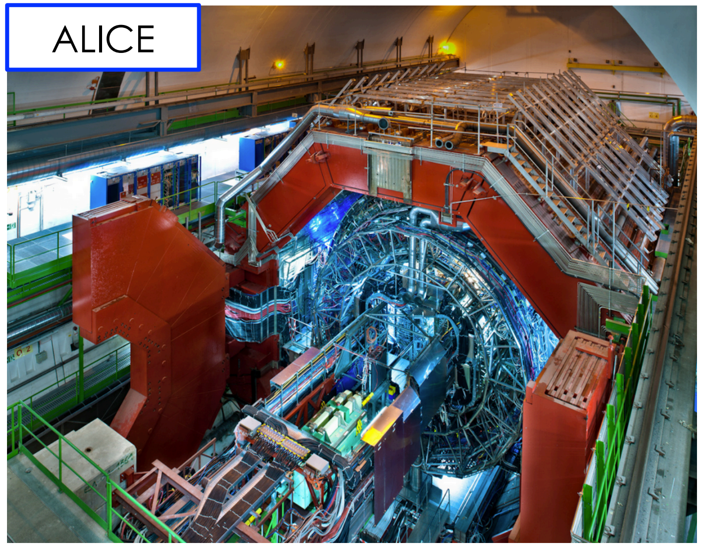
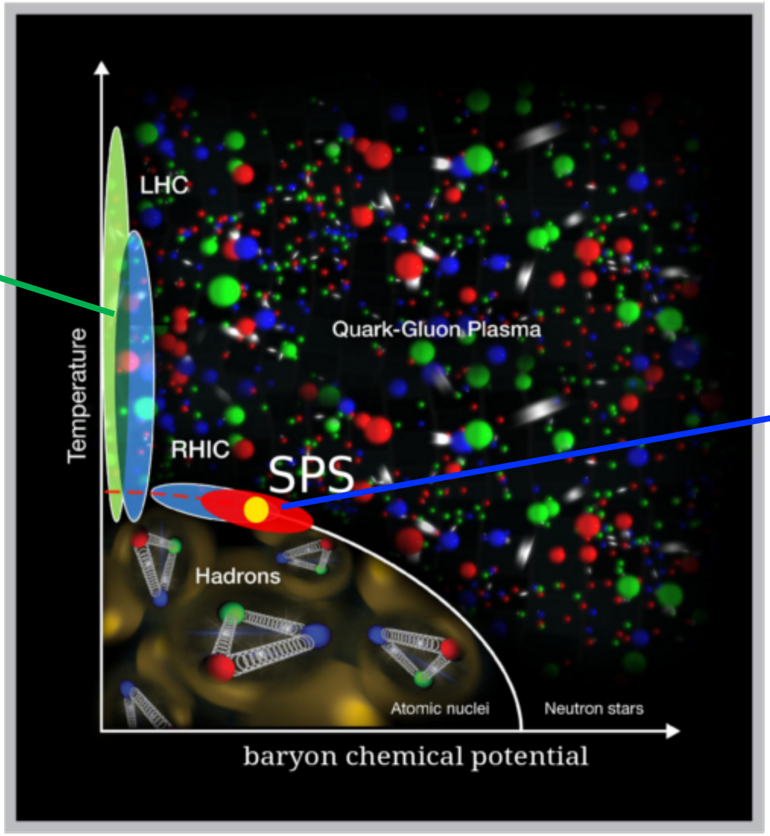
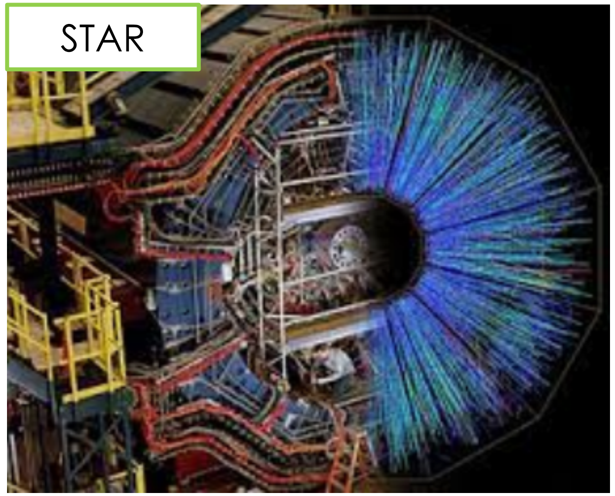
QCD phase diagram

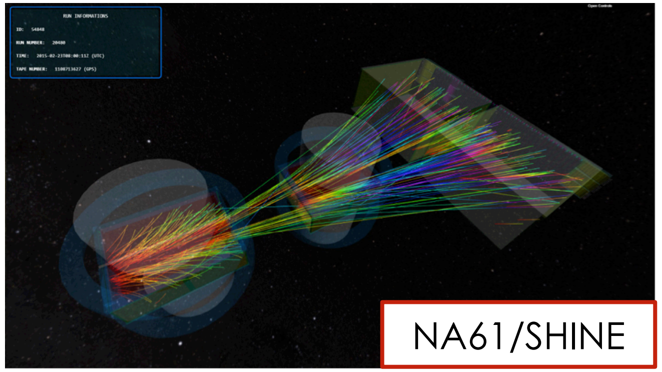
- **Strangeness enhancement** from small to large systems
- New developments with **multi-differential analyses**







- **Collectivity** in the **high μ_B** region
- **Strangeness production**: particle yields vs rapidity
- **Strangeness enhancement at SPS energies**



QCD phase diagram

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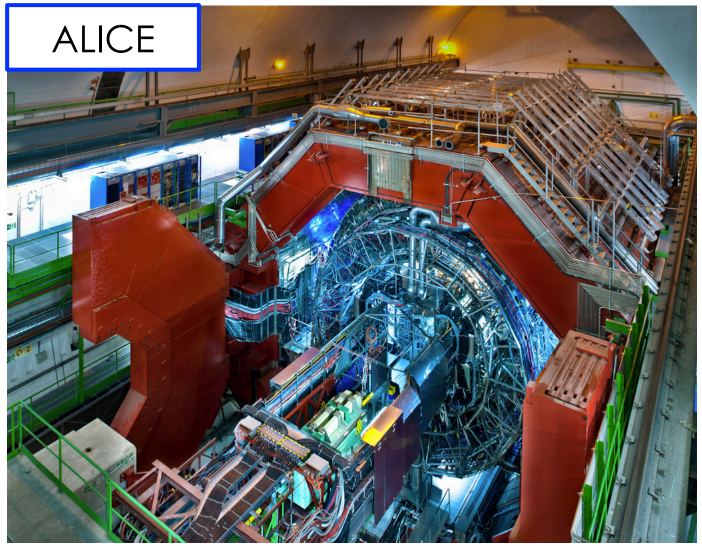
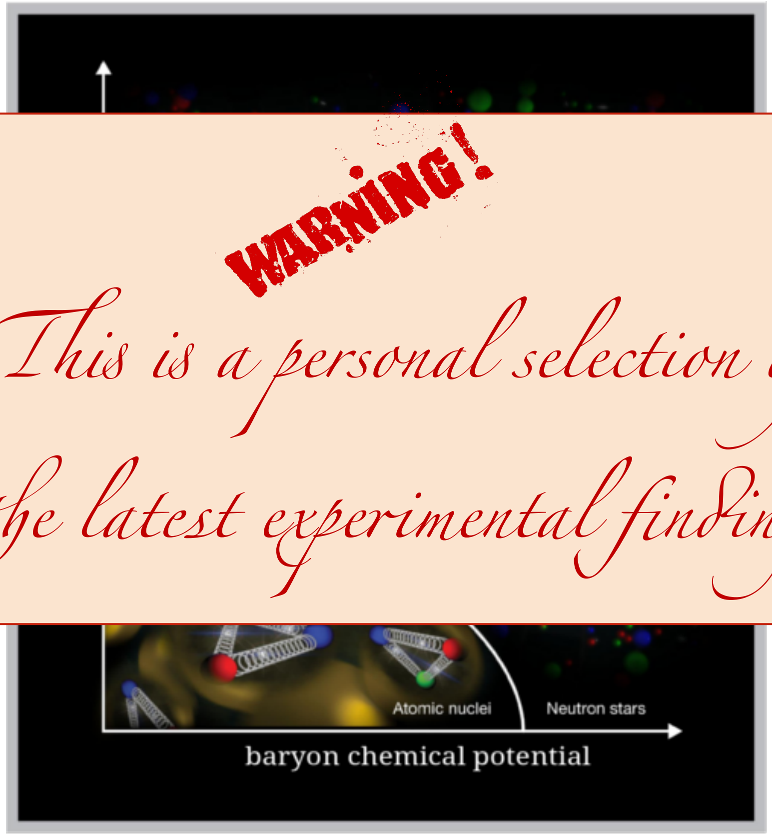
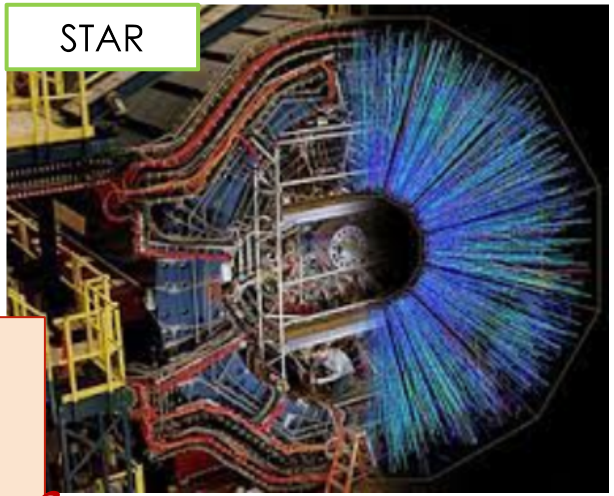
- New developments with **multi-differential analyses**





WARNING!

This is a personal selection of the latest experimental findings



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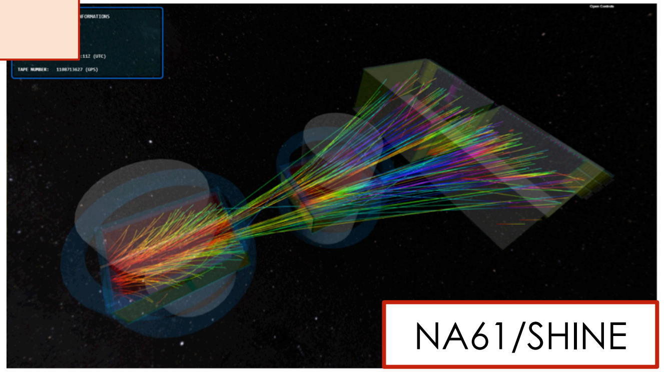
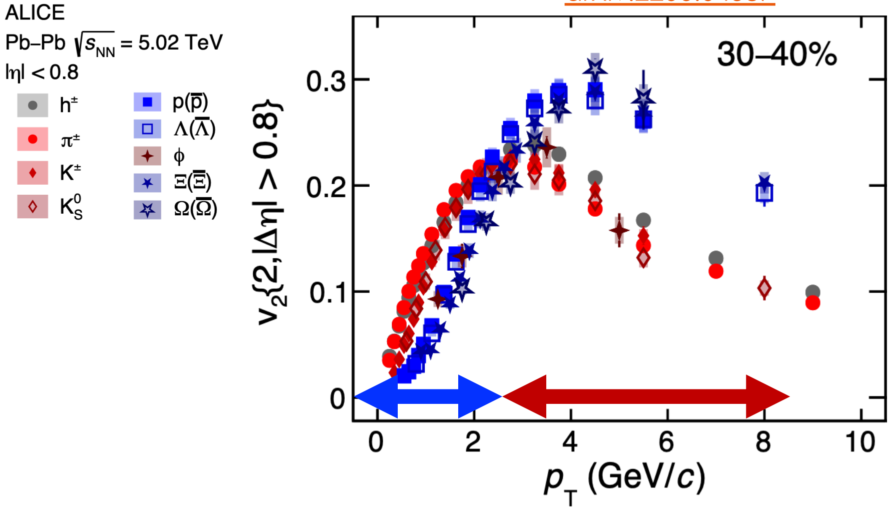
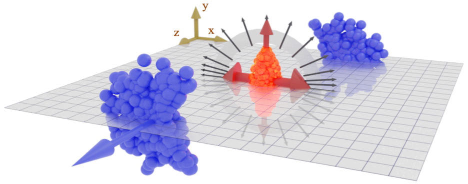


Strangeness enhancement from small to large systems at the LHC

Strange hadron dynamic across collision systems

arXiv:2206.04587



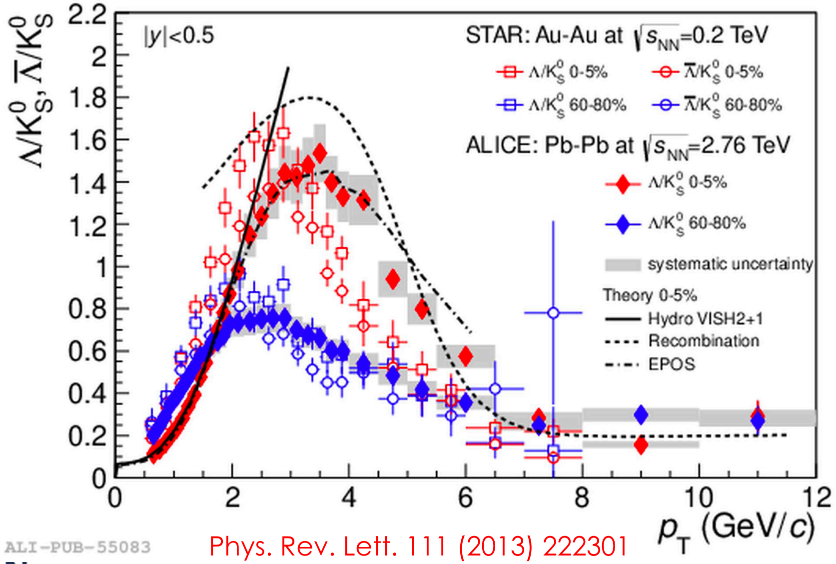


Mass ordering at **low p_T**

- described by hydrodynamics.

Baryon vs mesons grouping at **higher p_T**

- quark-level flow + recombinations.



Phys. Rev. Lett. 111 (2013) 222301

baryon/meson ratio
explained considering common
expansion velocity of partons

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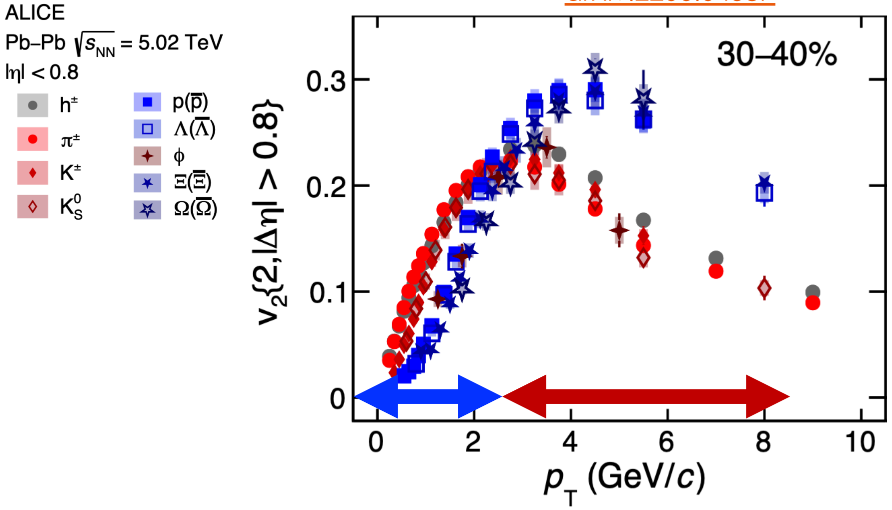

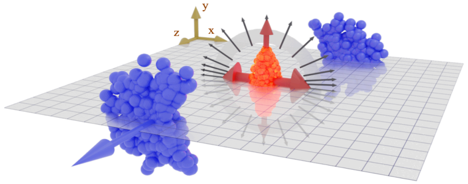

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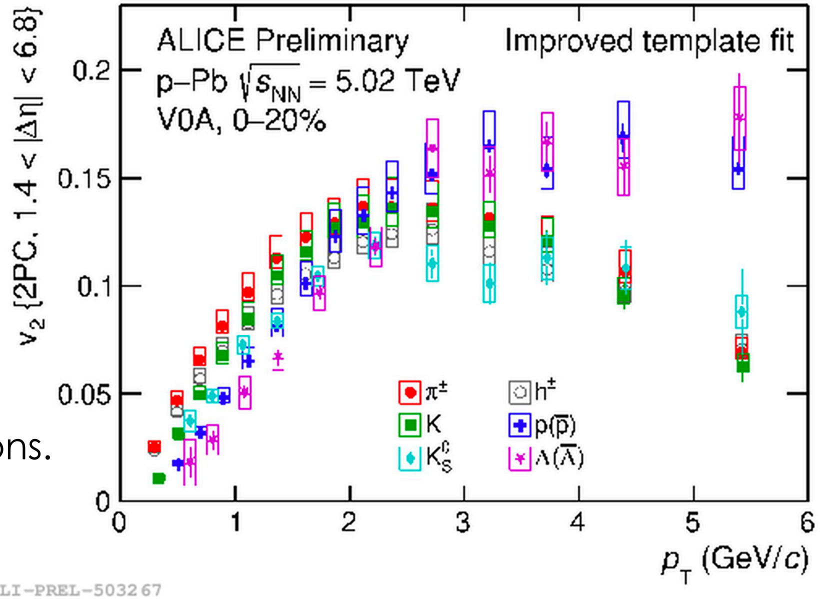

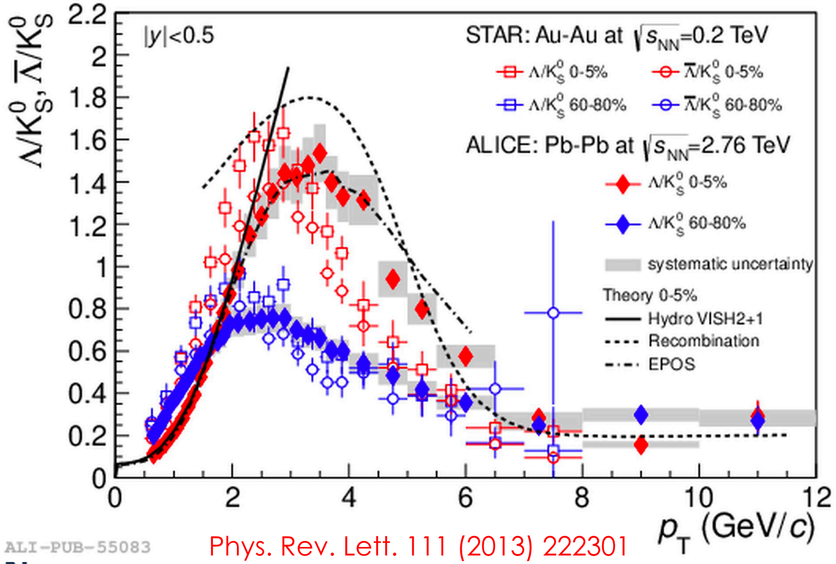

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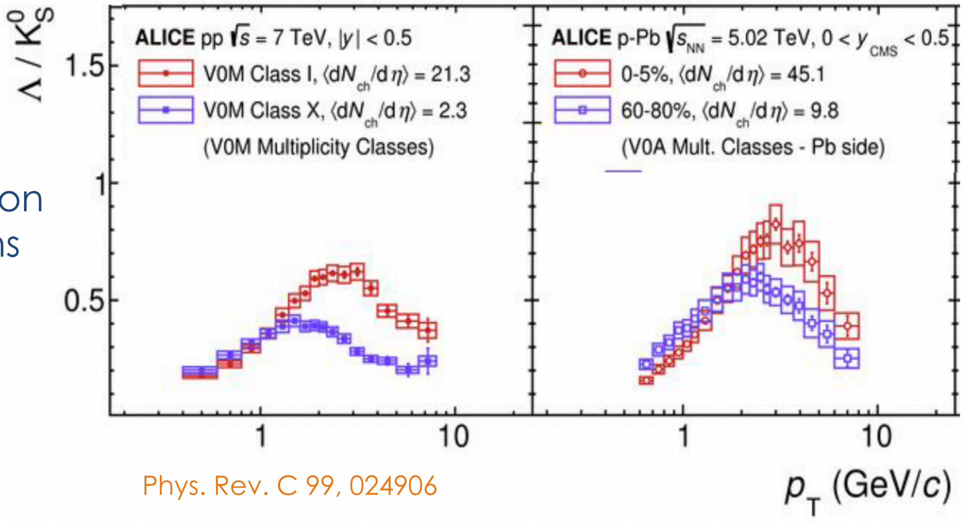
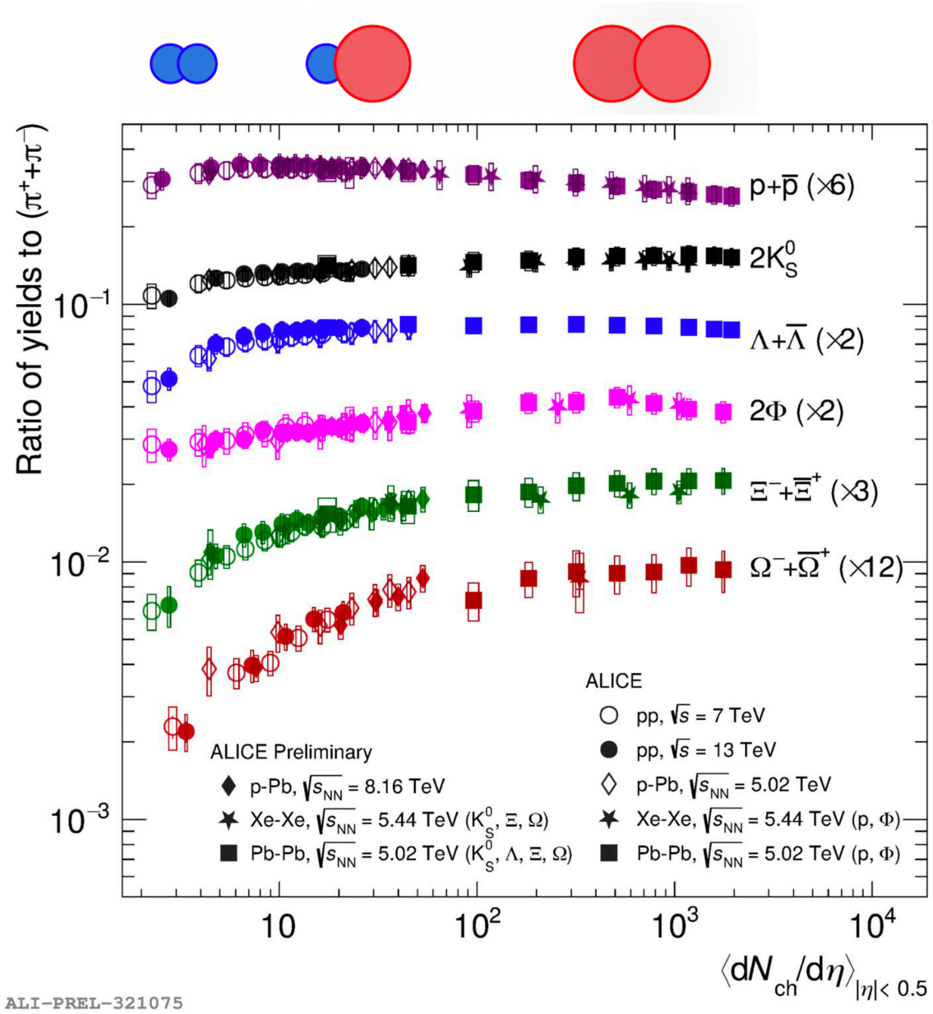


Phys. Rev. C 99, 024906

INFN

Strangeness production across collision systems



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

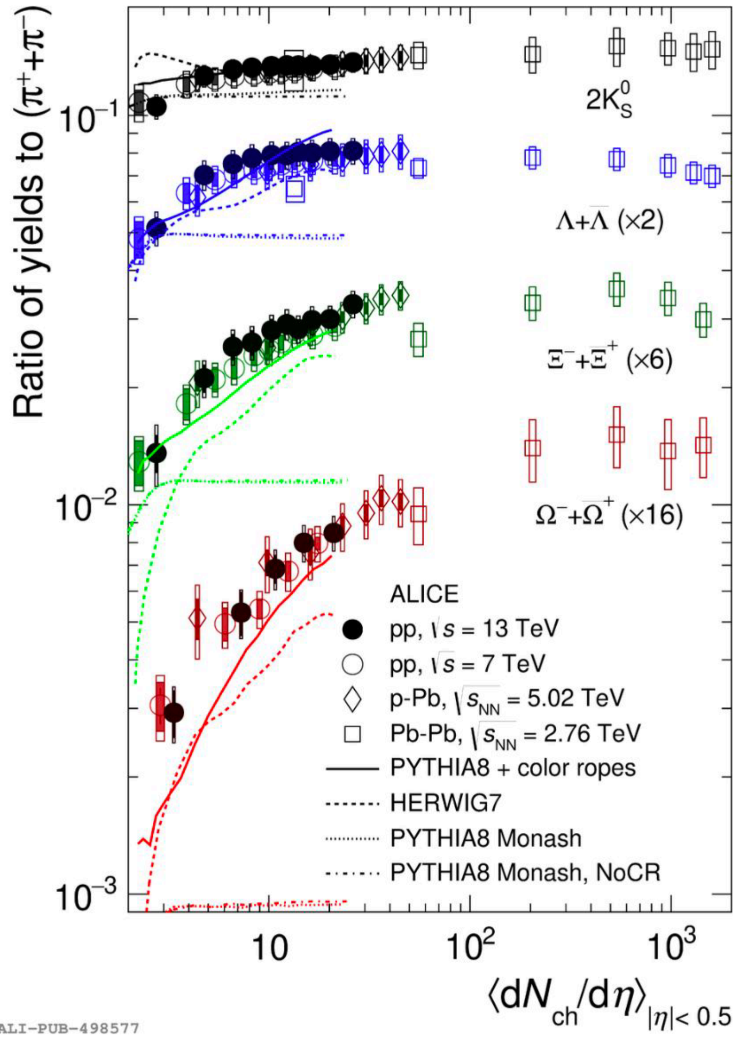
Strangeness enhancement was one of the first proposed signatures of **QGP formation** in heavy-ion collisions

What can we learn from this iconic figure?

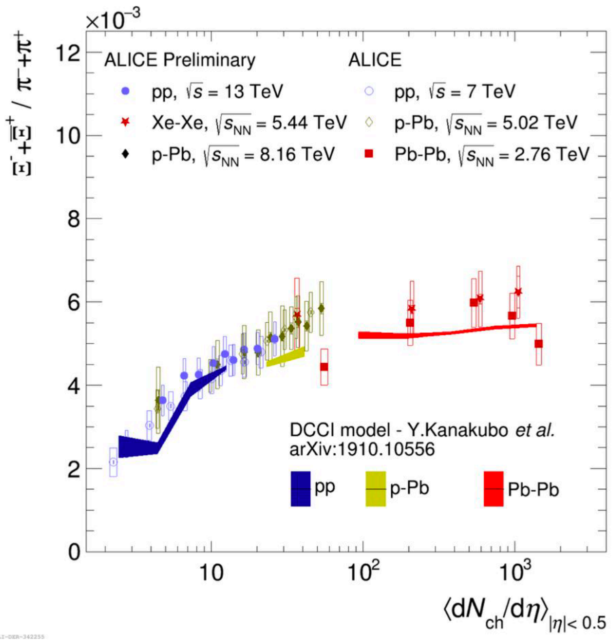
- smooth strangeness enhancement (SE) vs final state multiplicity
- strange content hierarchy: SE(Ω) > SE(Ξ) > SE(Λ,K^0_S)
- strangeness- and not baryon-related

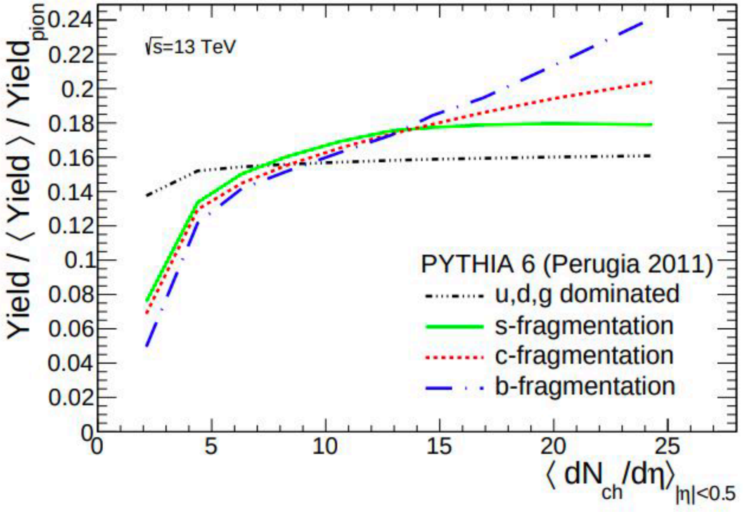
The interpretation..so far

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



Y. Kanakubo at al., Phys. Rev. C 101, 024912 (2020)





A. Morsch, C. Loizides, arxiv.org/abs/2109.05181

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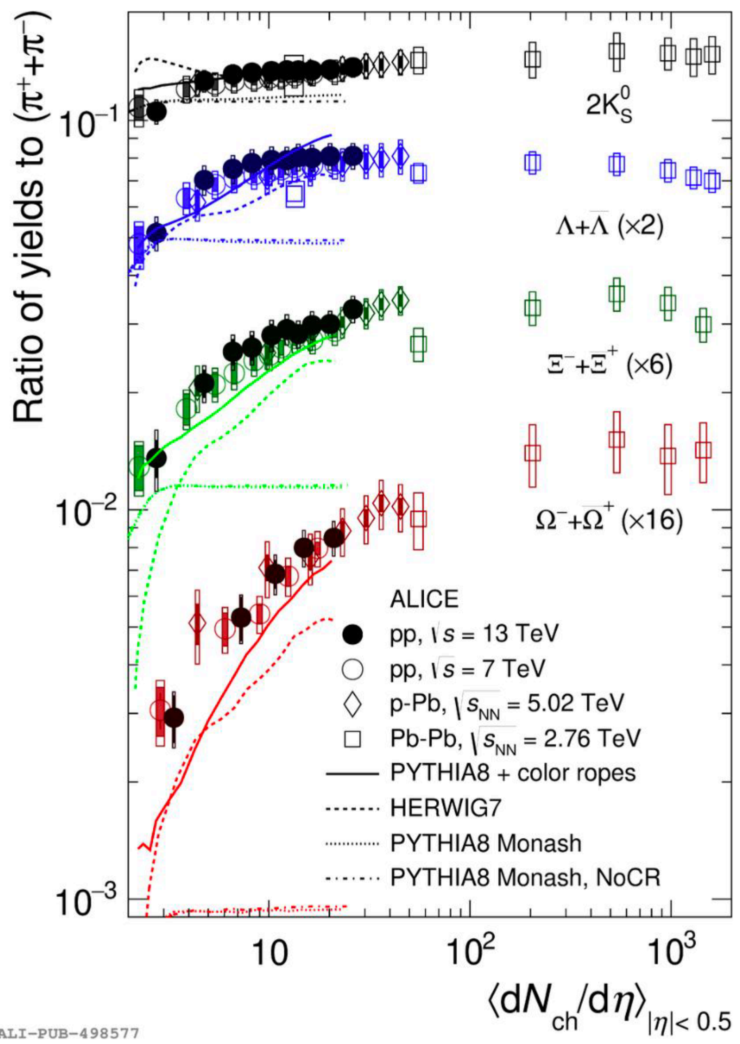

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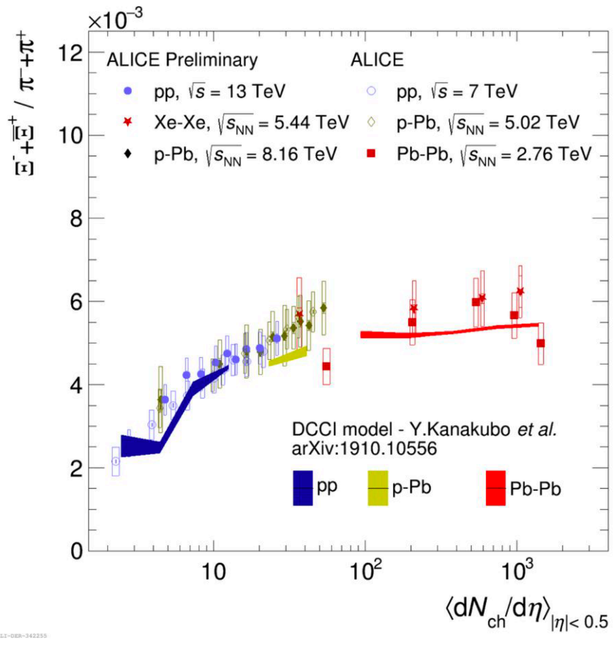
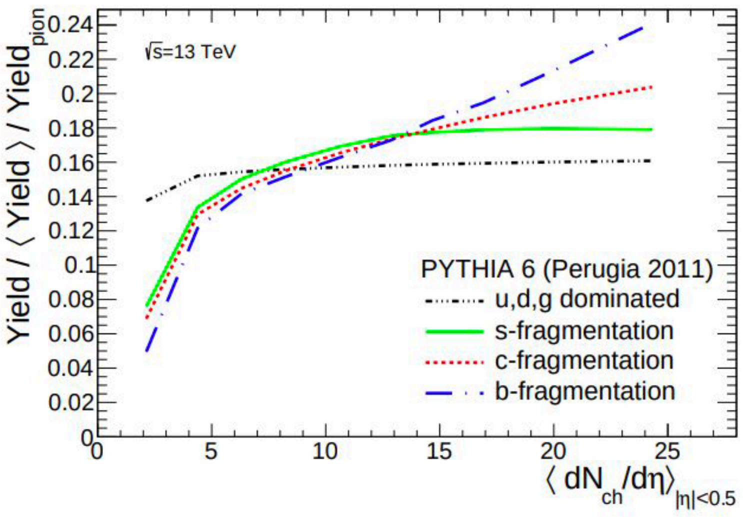


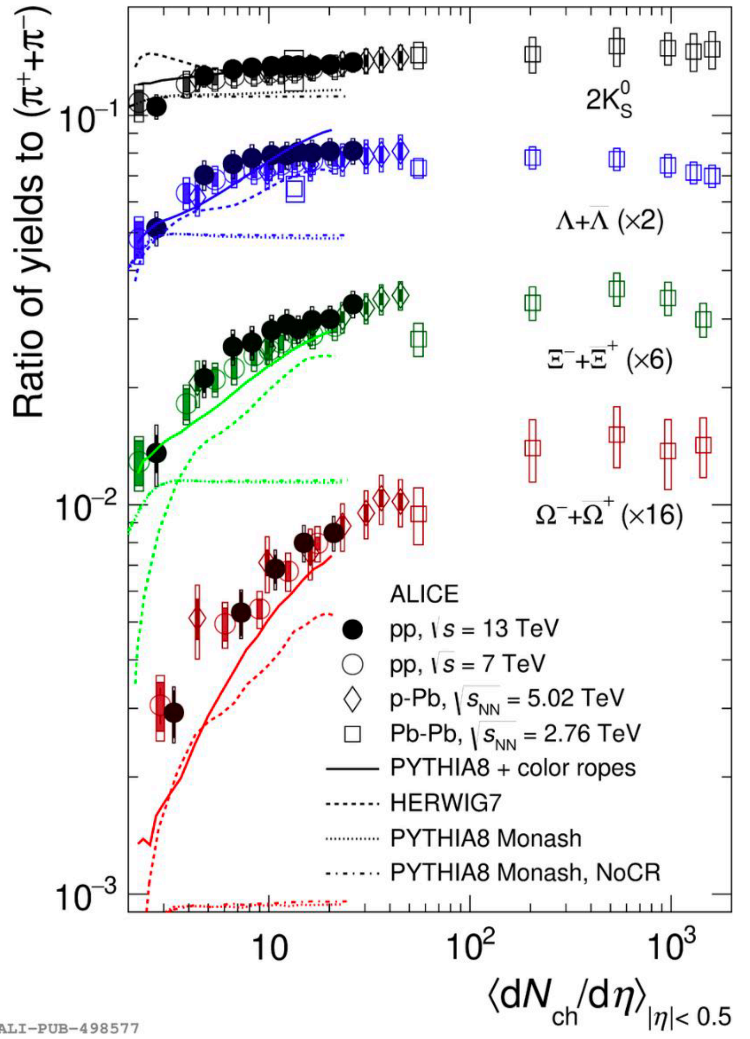


A. Morsch, C. Loizides, arxiv.org/abs/2109.05181

- Microscopic models are improving hadrochemistry description (color ropes)
- Two component models ok for hadrochemistry (interplay between core and corona) and basic features of hydro-like phenomena (e.g. radial flow)

Recent developments to address some questions

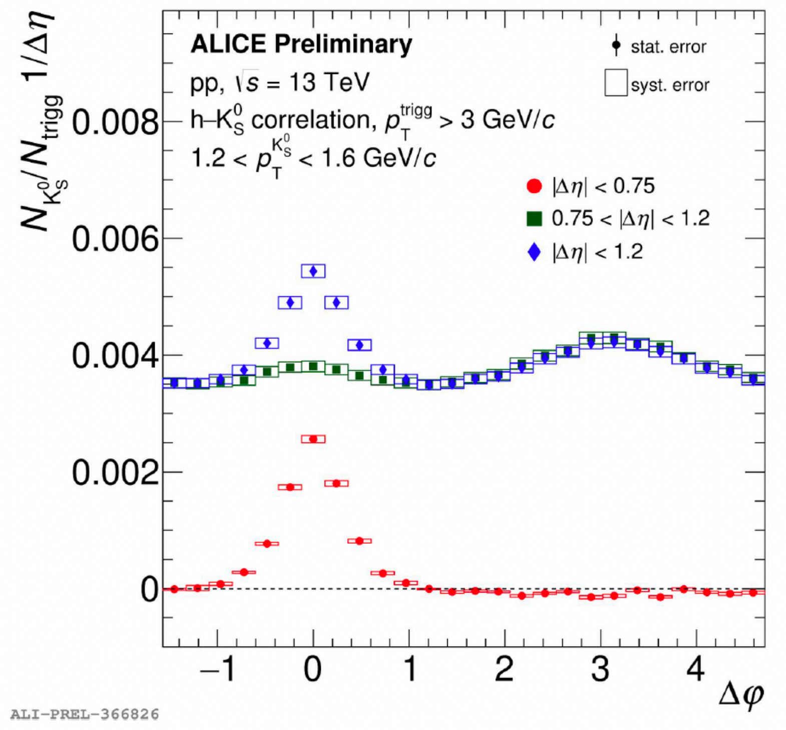
ALICE Collaboration, Eur. Phys. J. C 80 (2020) 693



Does strangeness production depend only on final state particle multiplicity, or is it also correlated to the initial stage of the collision?

Is strangeness mainly produced in hard processes, such as jets, or out-of-jet processes?

Strangeness production in- and out-of- jets



Toward leading = Full − Transverse to leading

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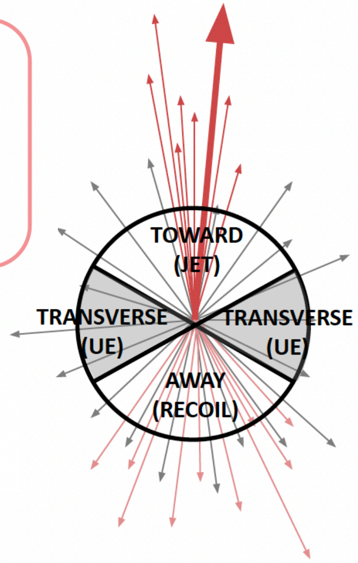
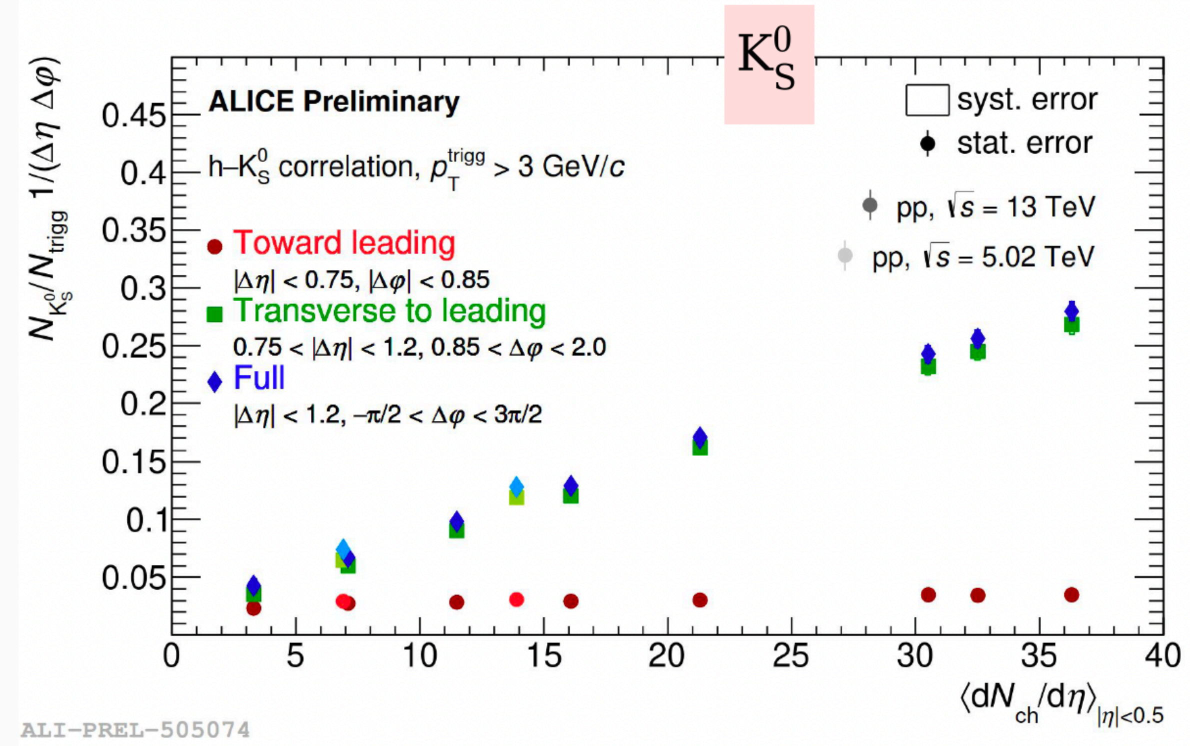
ANGULAR CORRELATION METHOD

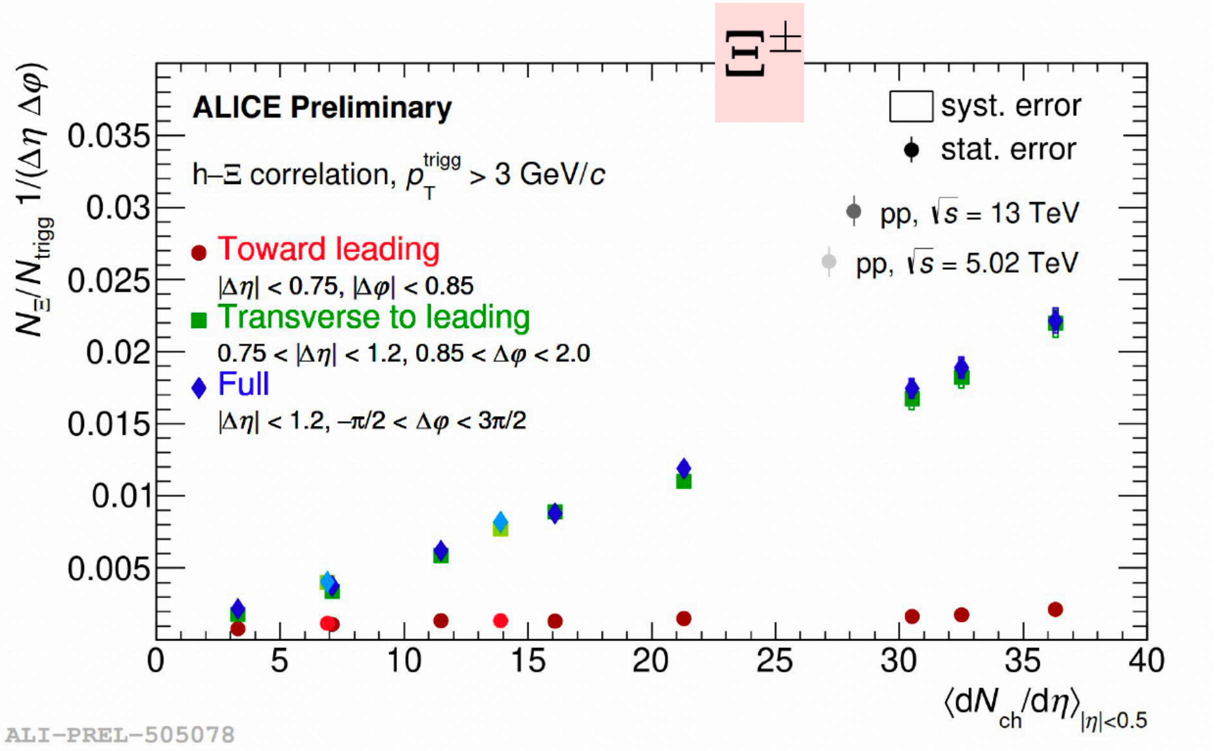
1) **Trigger particle** as a proxy for the **jet axis** (p_T > 3 GeV/c)
2) Identification of **associated particles** (strange hadrons)
3) **Angular correlation** between trigger and associated particles



The jet direction is the direction of the highest-p_T hadron ($p_T^{leading}$ > X GeV/c)

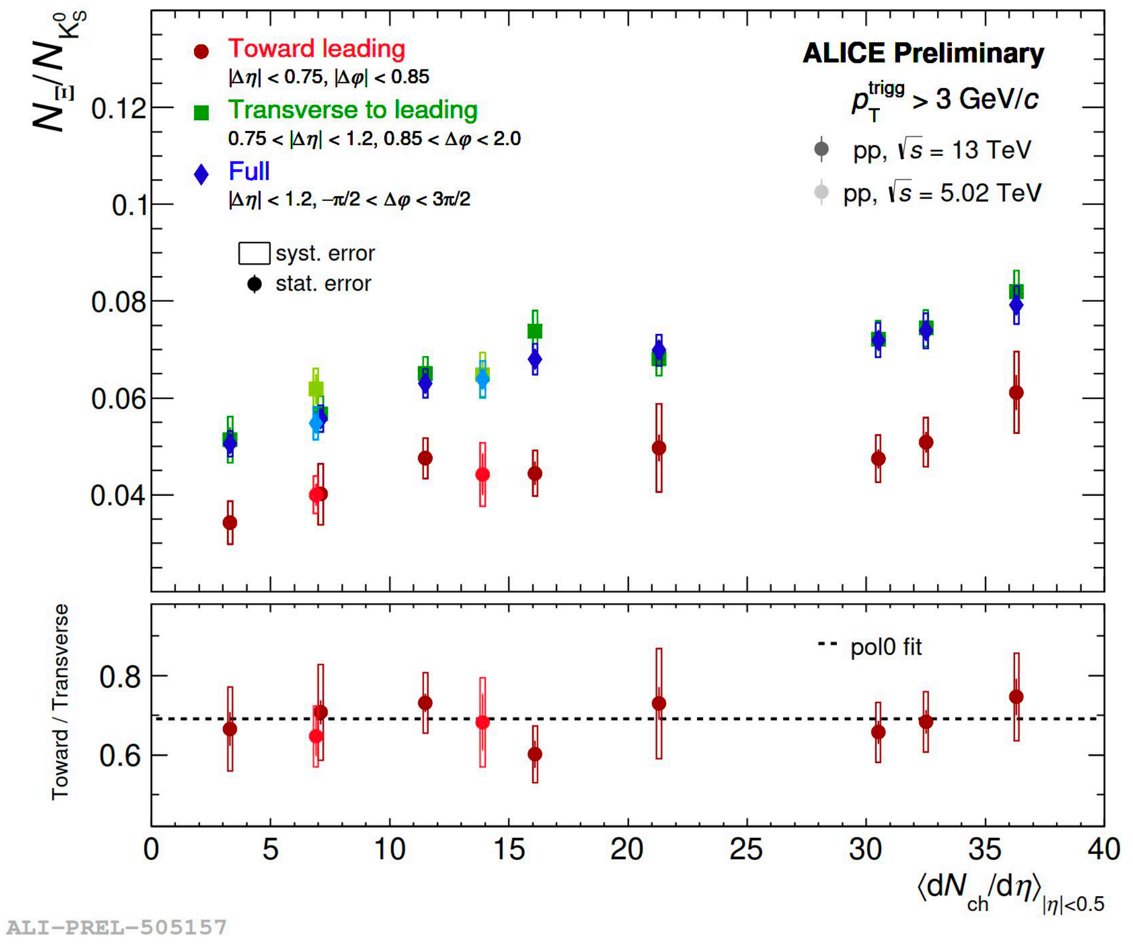
Yields in- and out-of- jets





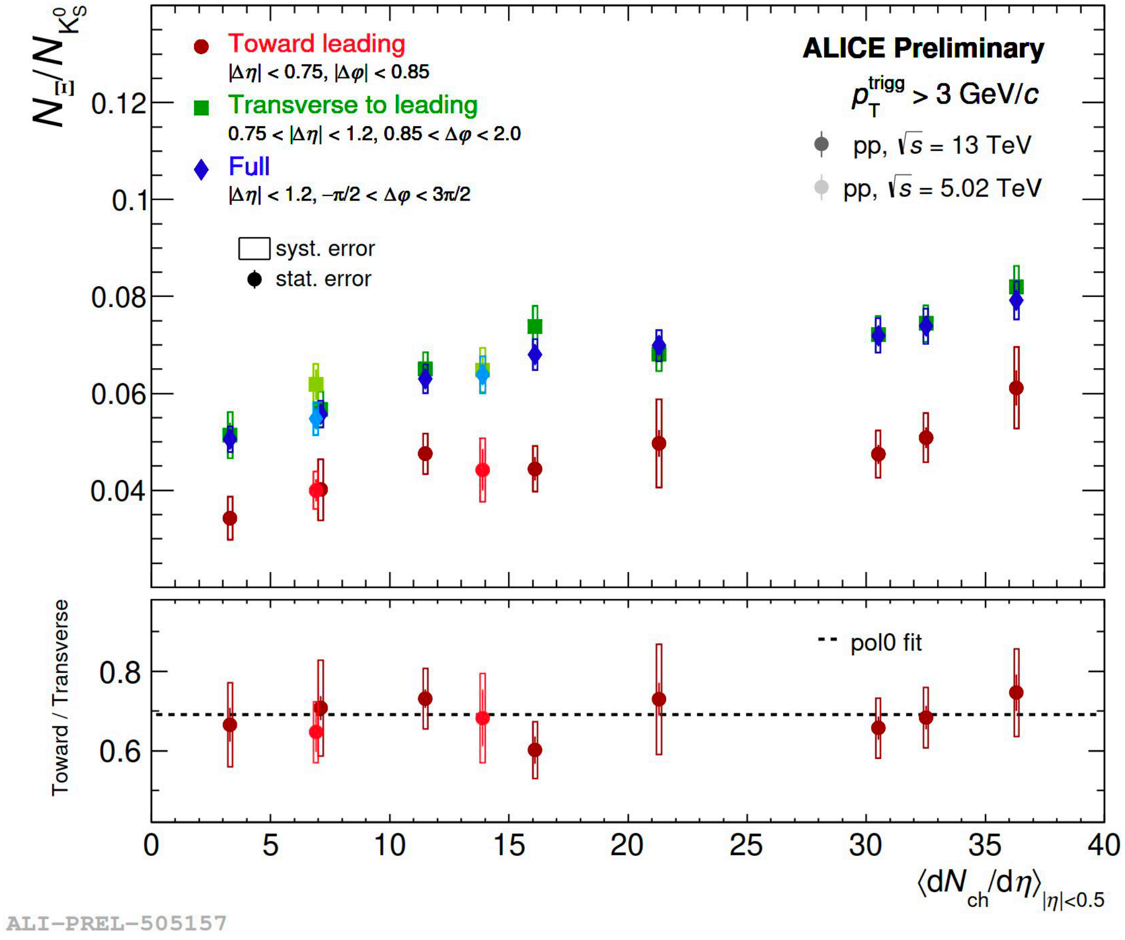
- transverse to leading production w.r.t. toward leading production increases with multiplicity
- The full yield and the transverse to leading yield increase with multiplicity
- (multi-)strange hadrons are mostly produced outside the jet

Strangeness enhancement in- and out-of- jets



(multi-)strange hadrons are mostly produced outside the jet but in- and out-of jet strangeness enhancement looks very similar

Let's look to the effective energy



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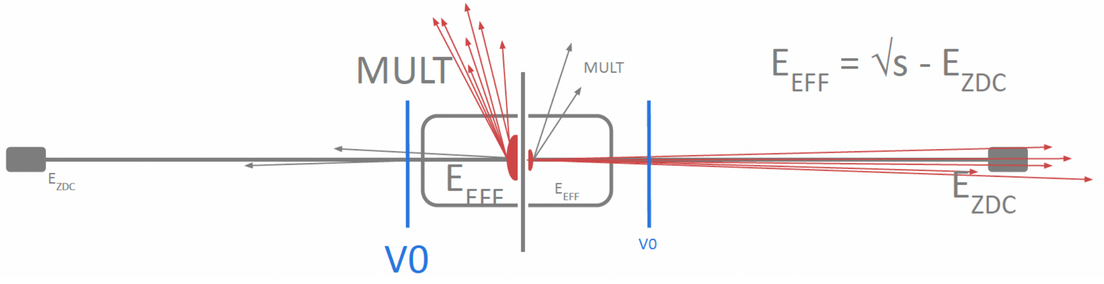
Charged-particle multiplicity produced in a pp collision:

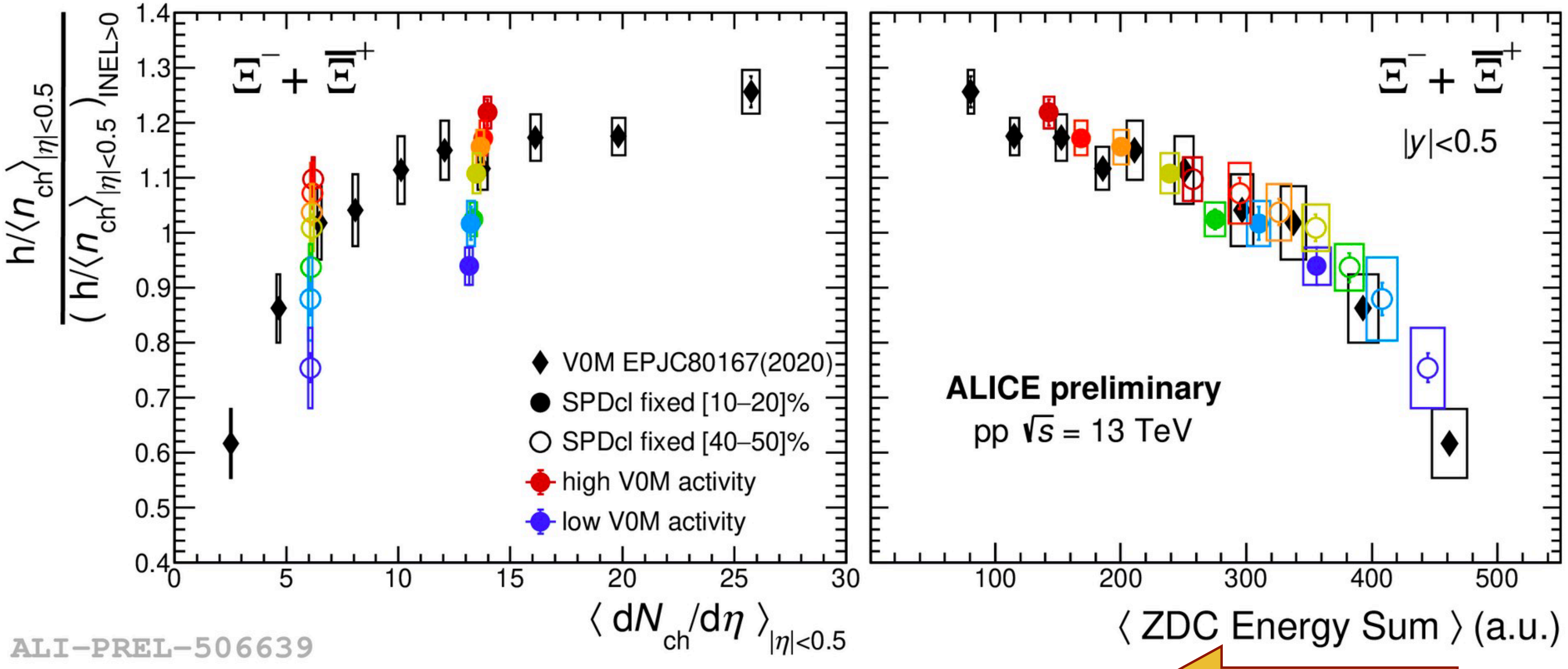
- characteristic of the hadronic final state
- strongly correlated to the **initial effective energy**



EFFECTIVE ENERGY

energy available for particle production in the **initial stages** of the pp collision

Ξ production at fixed multiplicity

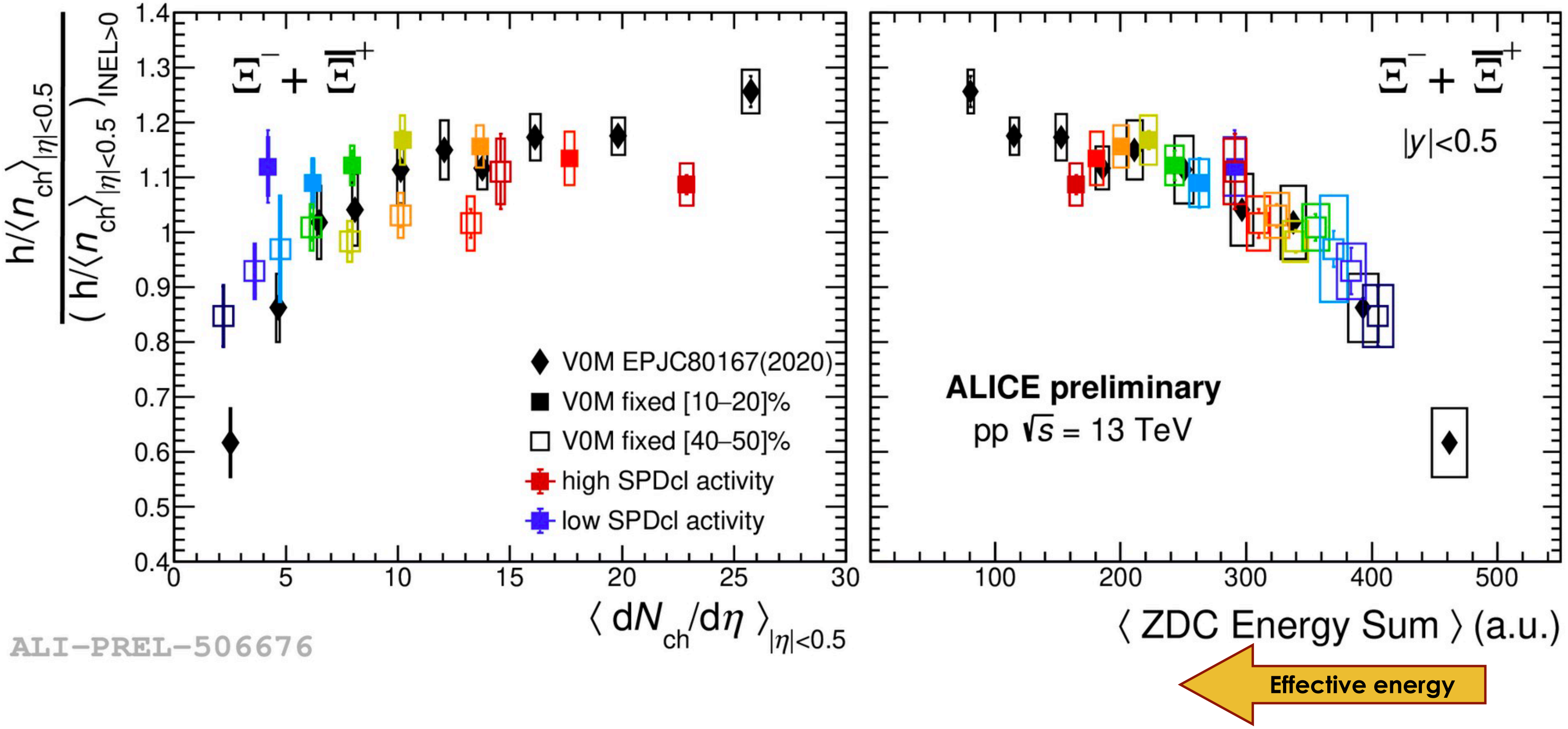


Effective energy

There is SE with the effective energy when the multiplicity at mid-rapidity is fixed

➡ Effective energy plays an important role in the strangeness enhancement

Ξ production with reduced effective energy



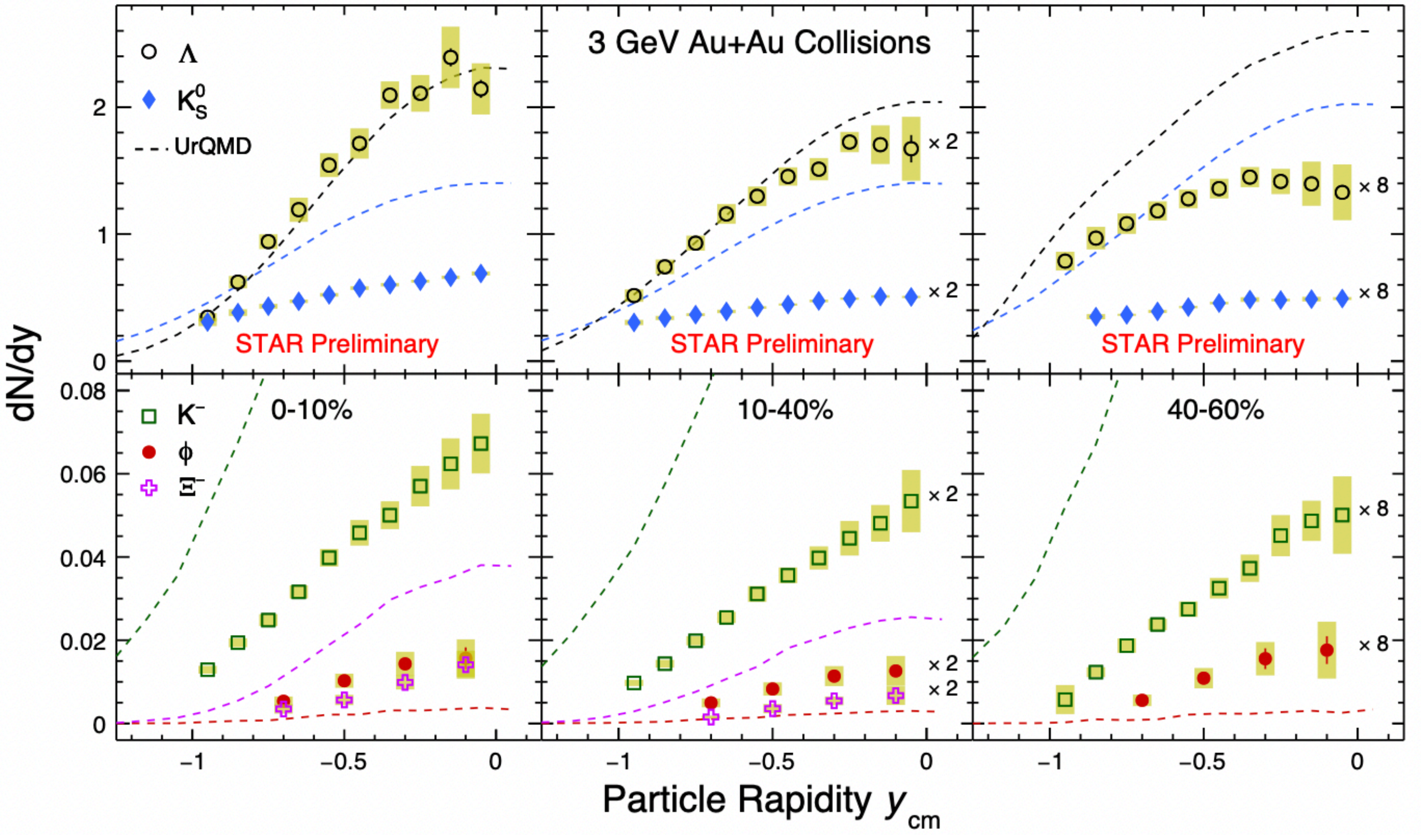
The evolution of SE strongly affected from constrained effective energy

➡ **physics mechanism behind SE strongly connected to the initial state of the collision**

Strange particle production and collectivity in the high μ_B region

Strange hadron production at 3 GeV

Phys. Lett. B 831 (2022),137152



- Measurements from mid-rapidity to target rapidity
- UrQMD reproduces Λ yield in central collisions, but over-estimates K^0_s, K^-, Ξ^- and under-estimates ϕ production

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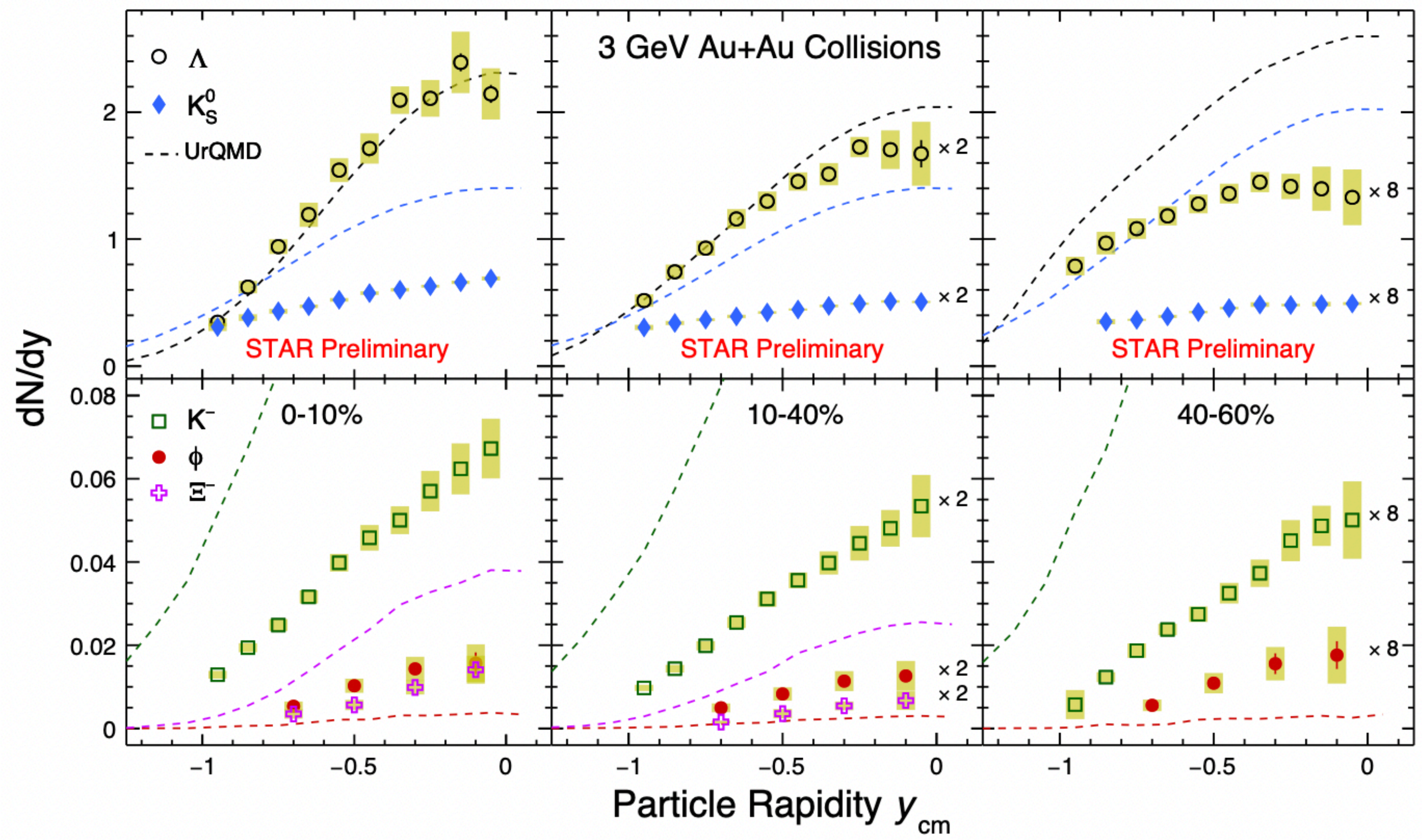

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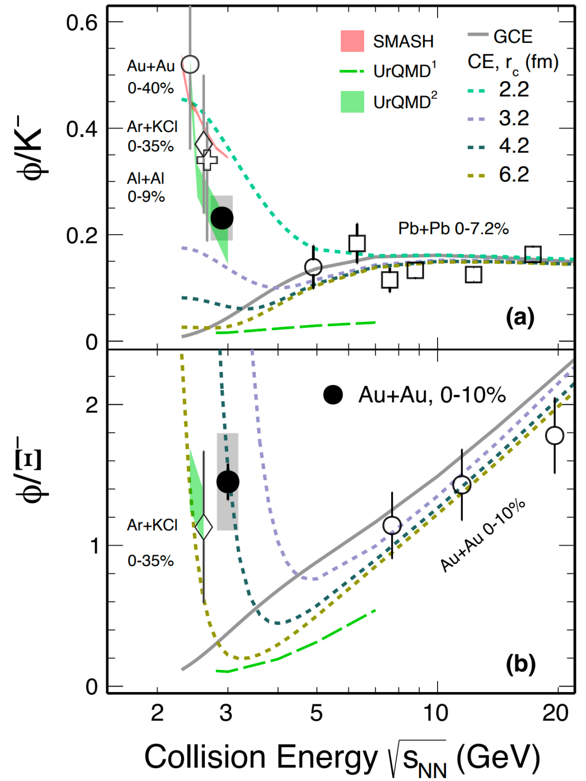
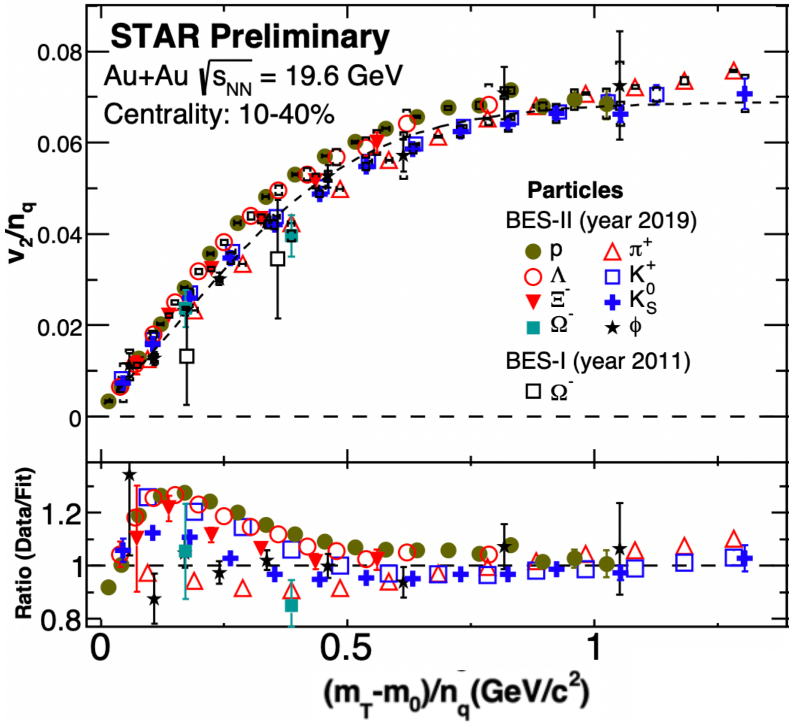


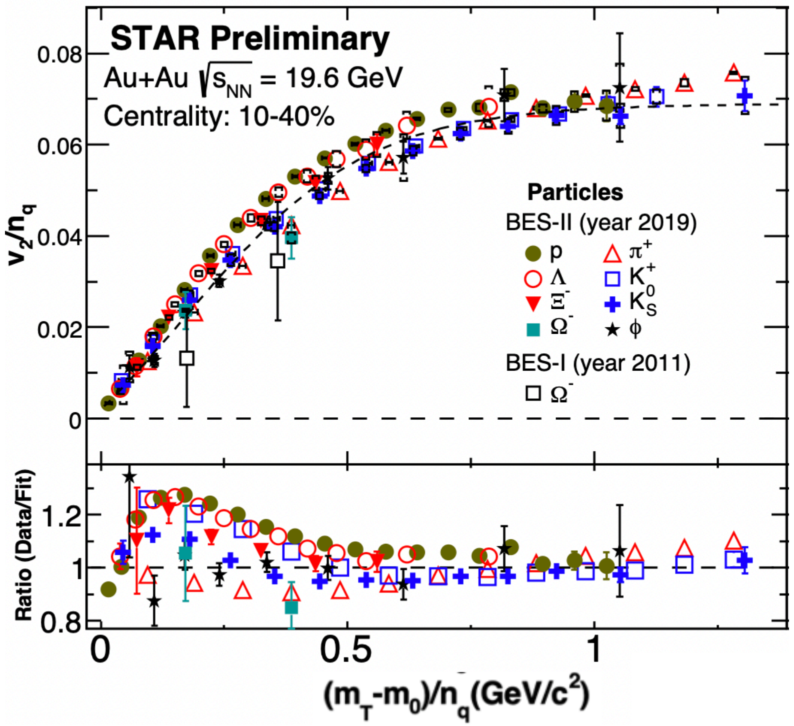
- Yield ratios show canonical suppression of strangeness at 3 GeV
- Can help constrain strangeness correlation length in the medium
- Default UrQMD fails to describe the data

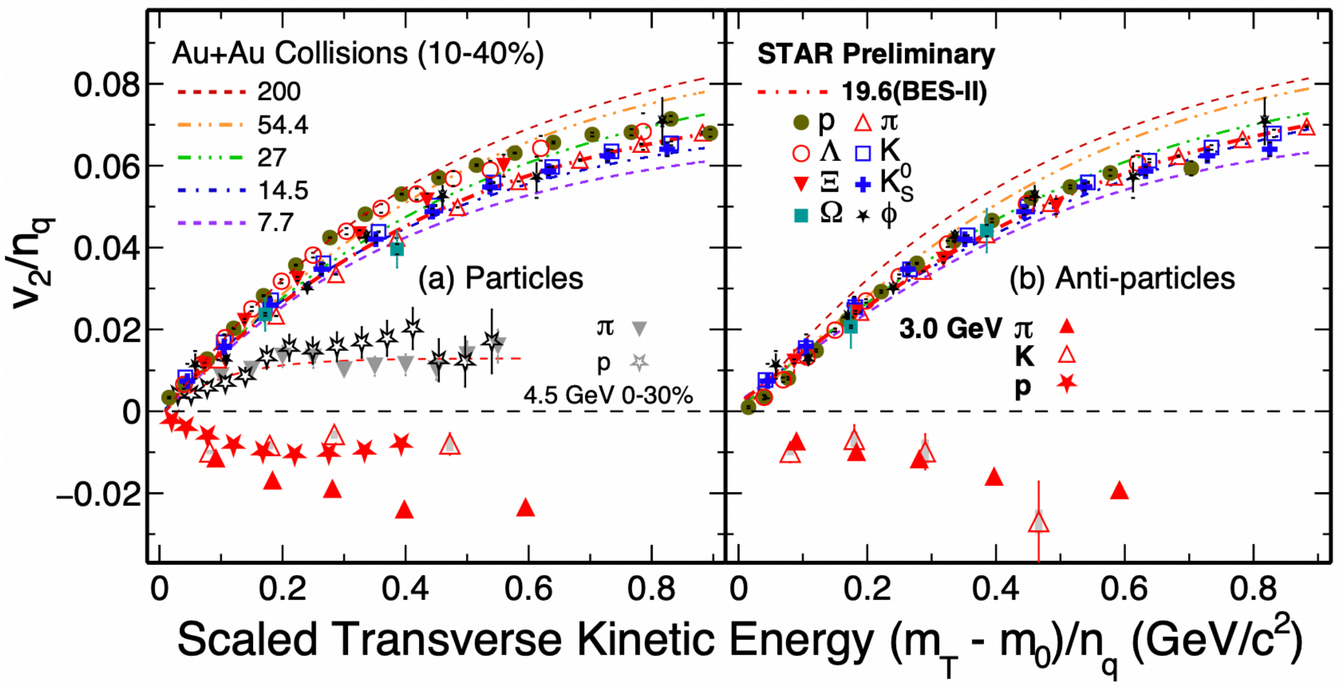
Collectivity: test of NCQ scaling



- improvement of precision of v_2 measurements with BES-II data
- NCQ scaling observed to hold within 10% for anti-particles and within 20% for particles
- dominance of partonic interactions in the generation of collective flow

Collectivity: test of NCQ scaling

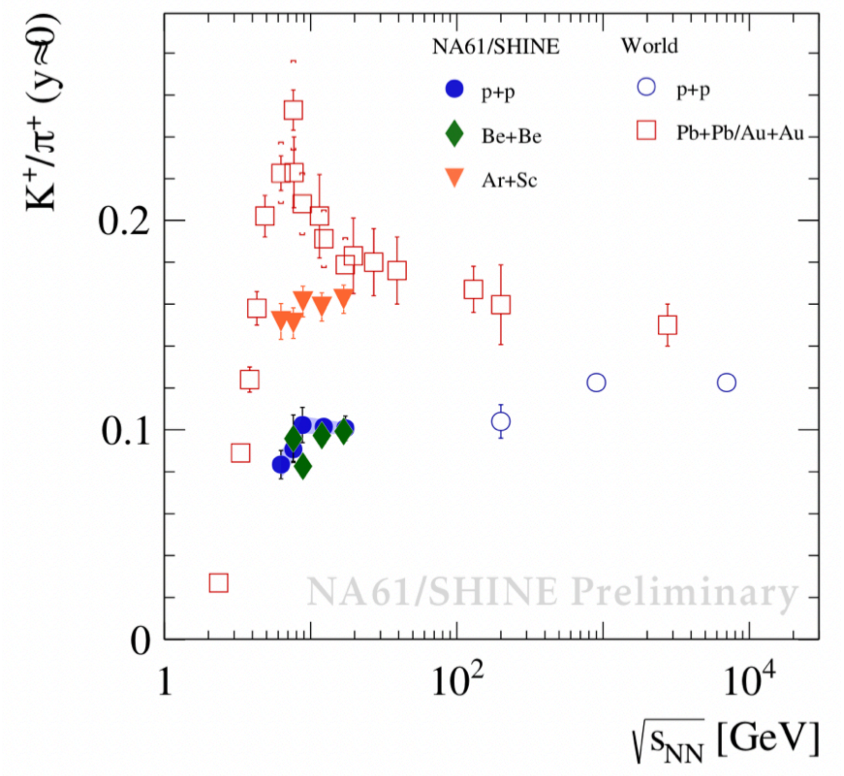


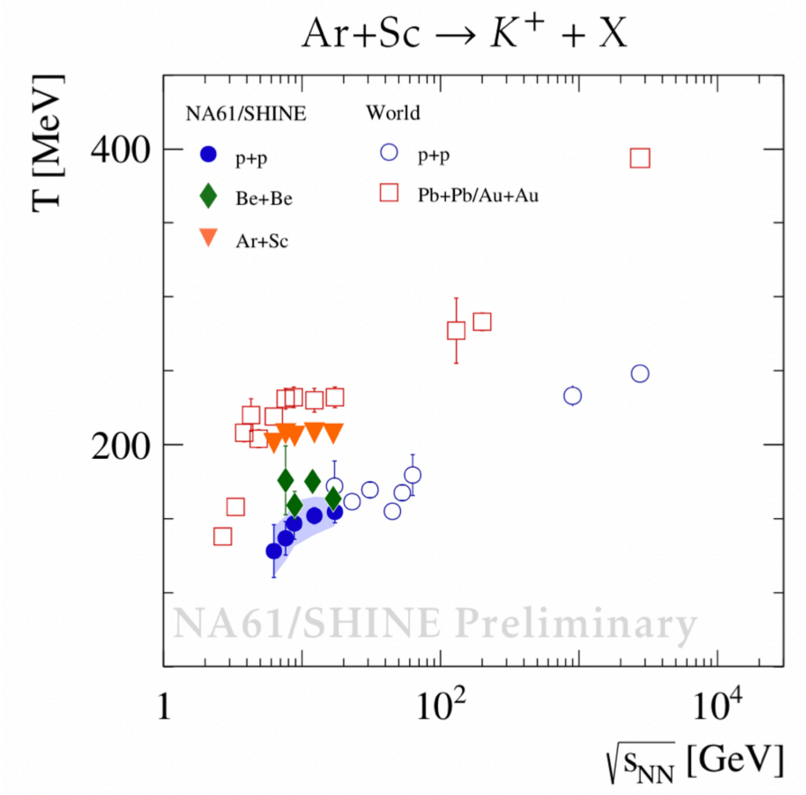


STAR, Phys. Lett. B 827, 137003 (2022)

NCQ scaling holds within uncertainties till = 4.5 GeV
The scaling breaks for 3 GeV collisions: medium not dominated by partonic interactions

Strangeness enhancement at SPS energies





- Yield ratio: rapid increase collision energy in Pb-Pb/Au-Au and then plateaus. Argued to be from deconfinement and enhancement of strangeness
- Ratio in **Be-Be and p+p show similar behavior**. Trend for Ar-Sc clearly separated from small systems but its **energy dependence does not resemble the sharp peak seen in heavy-ion reaction**
- Strong system size dependence for both the yield ratio and T

Summary

Solid observations on strangeness production from small to large systems at the LHC energies:

- Enhancement VS multiplicity ∝ s-content. Saturation at high multiplicity
- Intense theoretical activity trying to reproduce these data
- New developments with multi-differential analyses in small systems show hints of a significant correlation of SE with initial state conditions

Indication of change in EoS of matter produced in collisions at 3 GeV

- Disappearance of partonic collectivity at 3 GeV
  - Flow dominated by baryonic interactions

Strangeness production and collectivity at high μ_B

- Canonical suppression of strangeness in 3 GeV collisions and below
- At SPS energies no indication of «horn» in Ar+Sc collisions
- Unexpected system size dependence (p+p ≈ Be+Be) ≠ (Ar+Sc ⩽ Pb+Pb)