Strangeness in Quark Matter 2017

Utrecht - 9 - 15 July 2017

Strangeness production at low μ_B

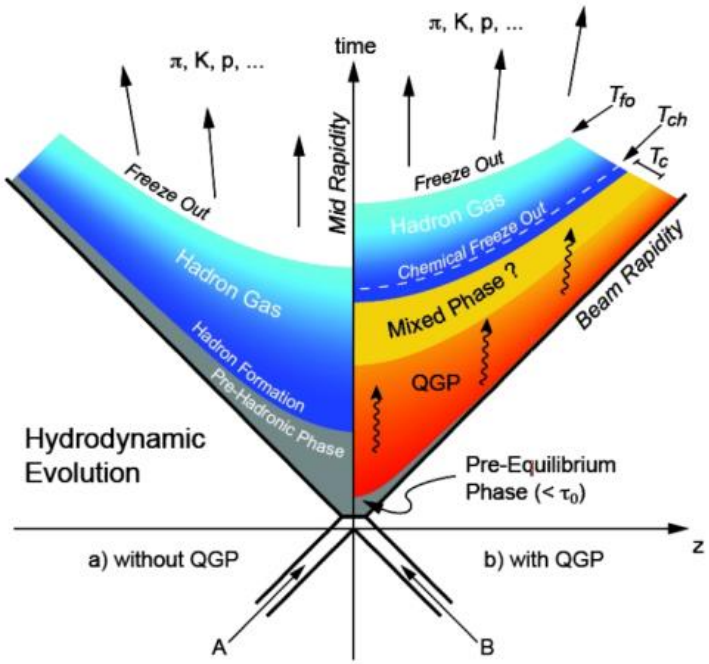
Livio Bianchi

University of Houston

Introduction

Motivation

Livio Bianchi
SQM 2017
Utrecht 10 Jul 17



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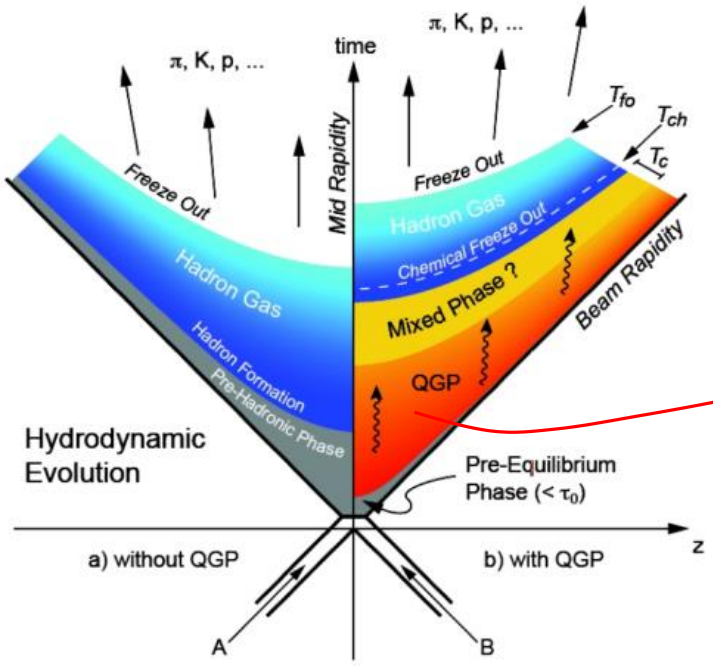

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- Lower Q-value for $s\bar{s}$ relative to $H_s H_{\bar{s}}$ formation
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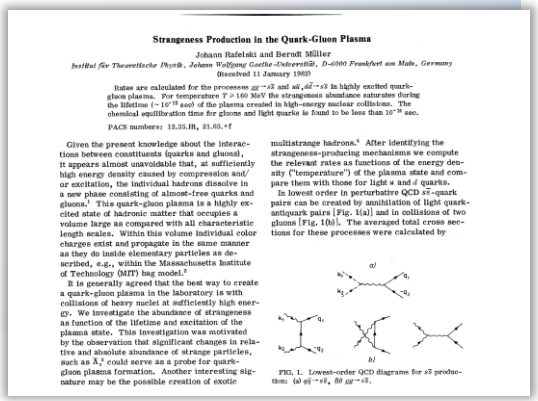

Strangeness Production in the Quark-Gluon Plasma

Johann Rafelski and Berndt Müller

Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, D-6000 Frankfurt am Main, Germany

(Received 11 January 1982)

Rates are calculated for the processes $gg \to s\bar{s}$ and $u\bar{u}, d\bar{d} \to s\bar{s}$ in highly excited quark-gluon plasma. For temperature $T \geq 160$ MeV the strangeness abundance saturates during the lifetime ($\sim 10^{-23}$ sec) of the plasma created in high-energy nuclear collisions. The chemical equilibration time for gluons and light quarks is found to be less than 10^{-23} sec.

PACS numbers: 12.35.Ht, 21.65.+f

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It is generally agreed that the best way to create a quark-gluon plasma in the laboratory is with collisions of heavy nuclei at sufficiently high energy. We investigate the abundance of strangeness as function of the lifetime and excitation of the plasma state. This investigation was motivated by the observation that significant changes in relative and absolute abundance of strange particles, such as $\bar{\Lambda}, \bar{\Lambda}^+$ could serve as a probe for quark-gluon plasma formation. Another interesting signature may be the possible creation of exotic multistrange hadrons.[3] After identifying the strangeness-producing mechanisms we compute the relevant rates as functions of the energy density ("temperature") of the plasma state and compare them with those for light u and d quarks.

In lowest order in perturbative QCD $s\bar{s}$-quark pairs can be created by annihilation of light quark-antiquark pairs [Fig. 1(a)] and in collisions of two gluons [Fig. 1(b)]. The averaged total cross sections for these processes were calculated by

FIG. 1. Lowest-order QCD diagrams for $s\bar{s}$ production: (a) $q\bar{q} \to s\bar{s}$, (b) $gg \to s\bar{s}$.

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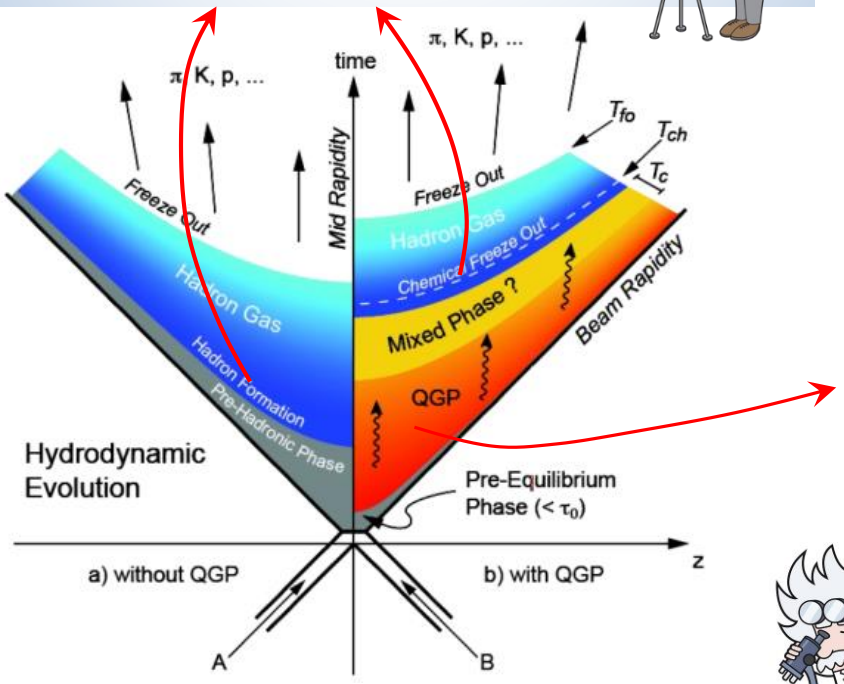
Statistical Hadronization Model (SHM): all hadrons are formed from an excited state following pure statistical laws. **Strangeness enhancement** could come from:

- **Canonical suppression** in pp
- **Incomplete equilibration** of strangeness
- ??



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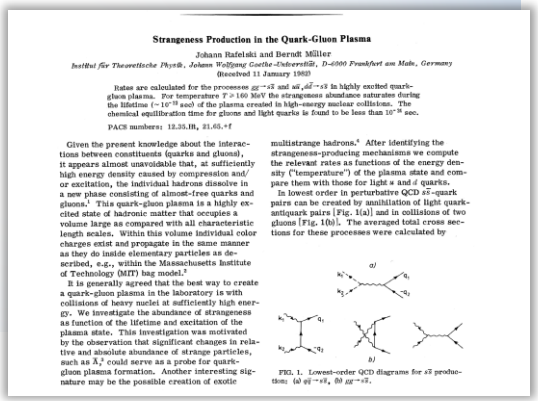

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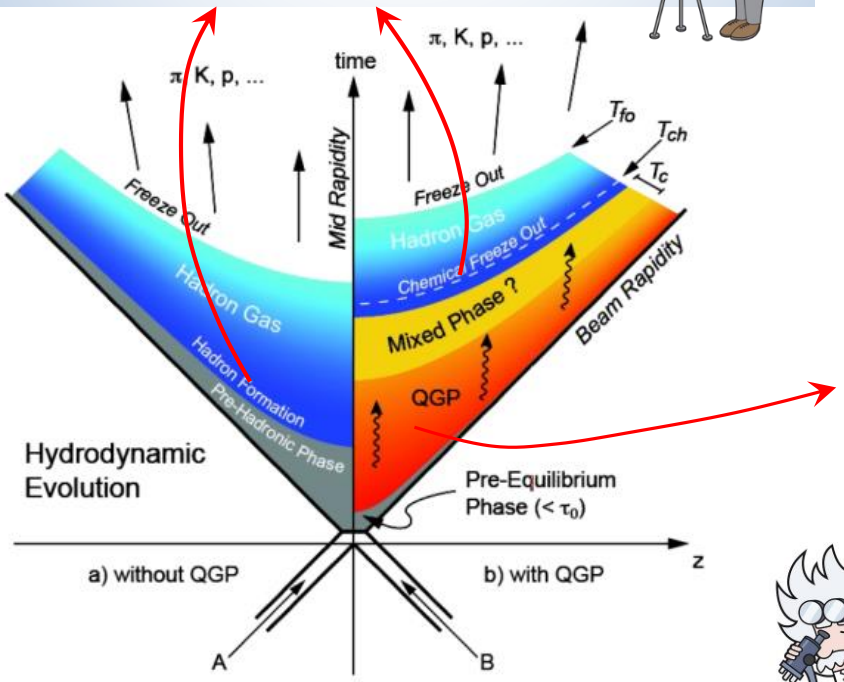
The success of SHM in describing hadron formation for very different colliding systems and energies does not eliminate two relevant questions:

What is the microscopical underlying mechanism which brings the system to enhance strangeness?

Can we anyway infer something about the QGP?



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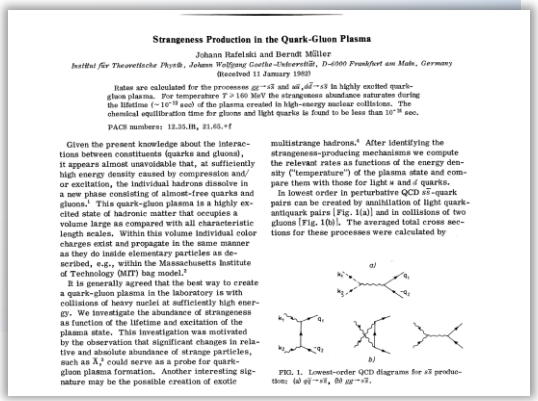

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…and much more…

Strangeness Production in HI

Strangeness undersaturation in the thermal model

Hadronic afterburner to take into account hadronic re-scattering

EPOS generator: interplay between hydro and jets

Sequential hadronization: Event-by-event fluctuations

Core + corona picture to model HI collisions

…

Rope mechanism and inclusion in MC generators

Vorticity and Λ polarization

Resonances and the study of the hadronic phase

DISCLAIMER:
for a more comprehensive list follow this conference!

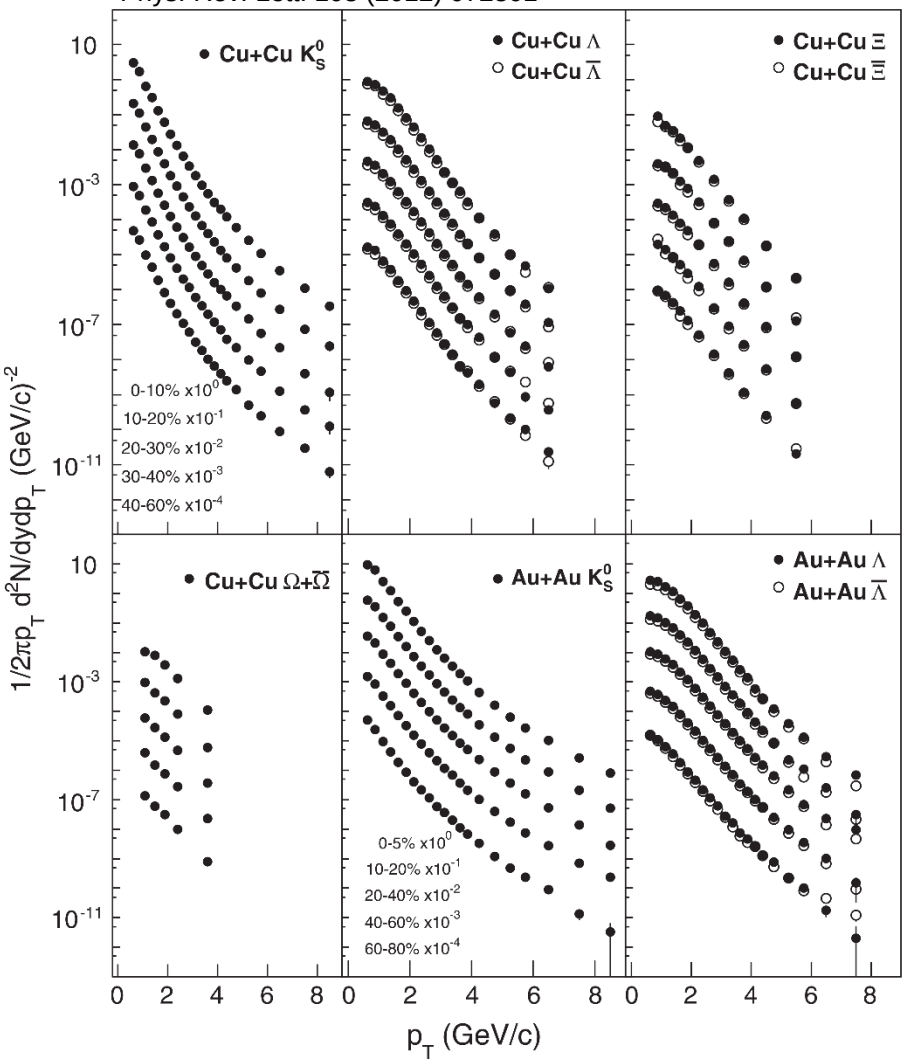
Aim to show in this talk:

low-μ_B experiments are providing key results which will boost our understanding of strangeness production in A-A and elementary collisions

Results

RHIC: Au-Au, Cu-Cu @ $\sqrt{s_{NN}}$ = 200 GeV

Phys. Rev. Lett. 108 (2012) 072301



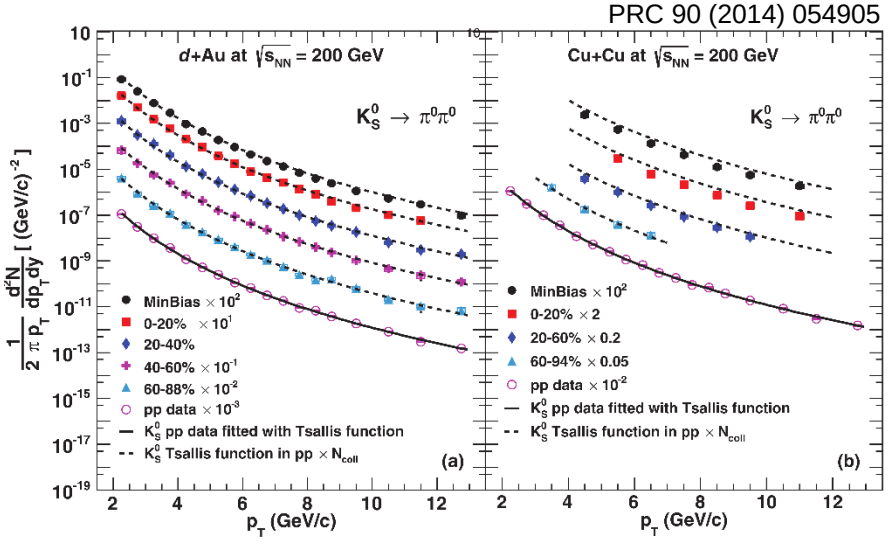
Top RHIC energy: $\sqrt{s_{NN}}$ = 200 GeV

Large set of results in Au-Au and Cu-Cu collisions from STAR, PHENIX and BRAHMS collaborations

Different detection techniques exploited

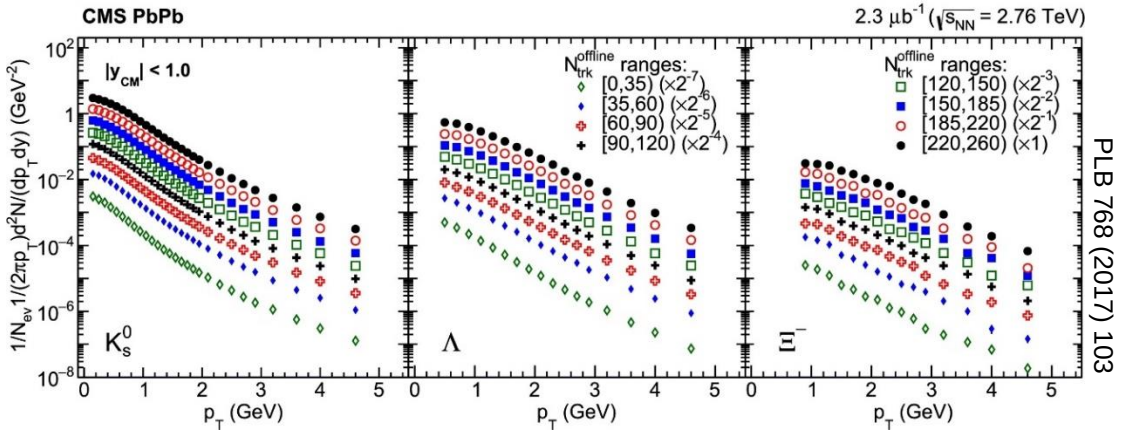
Hardening of spectra in central collisions consistent with hydro picture

PRC 90 (2014) 054905



LHC: Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 & 5.02 TeV

Livio Bianchi
SQM 2017
Utrecht 10 Jul 17



Strangeness production results at $\sqrt{s_{NN}}$ = 2.76 and 5.02 TeV

Together with:

pp at $\sqrt{s}$ = 0.9 , 7 , 13 TeV

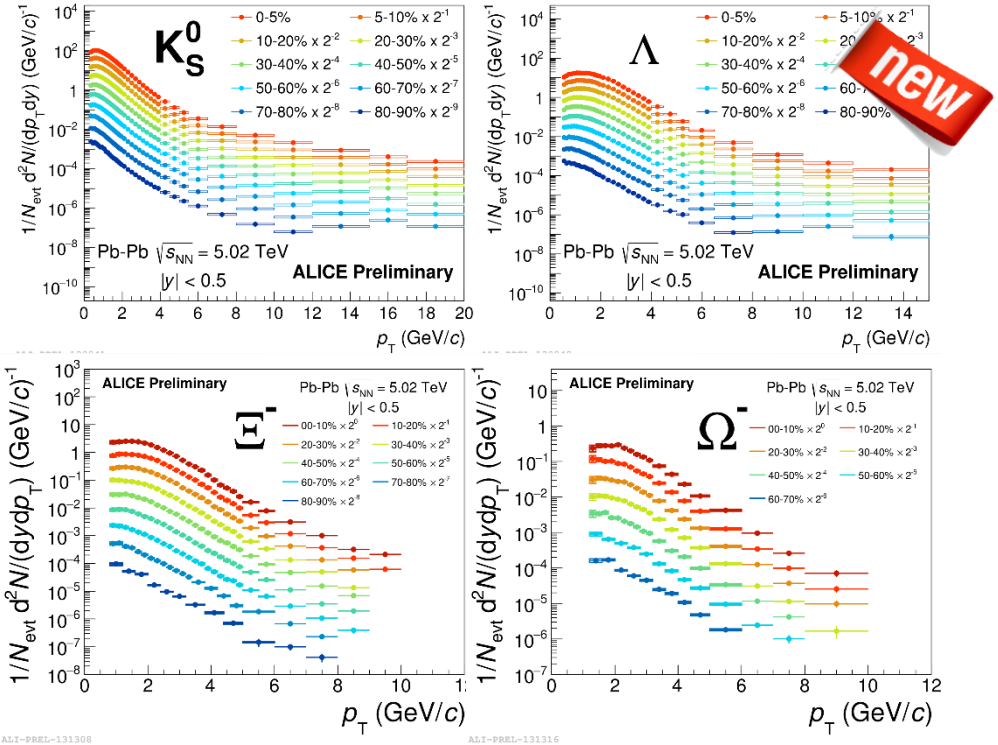
p-Pb at $\sqrt{s}$ = 5.02 TeV

ALICE and CMS main contributors.
ATLAS and LHCb have good potential: waiting for their results

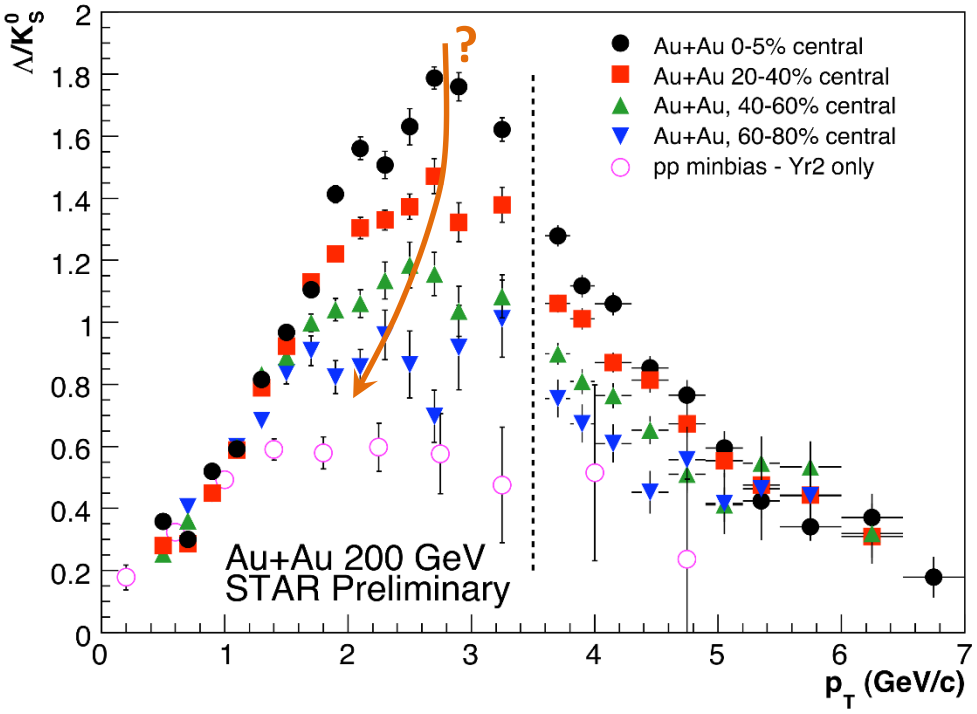
New at SQM2017:

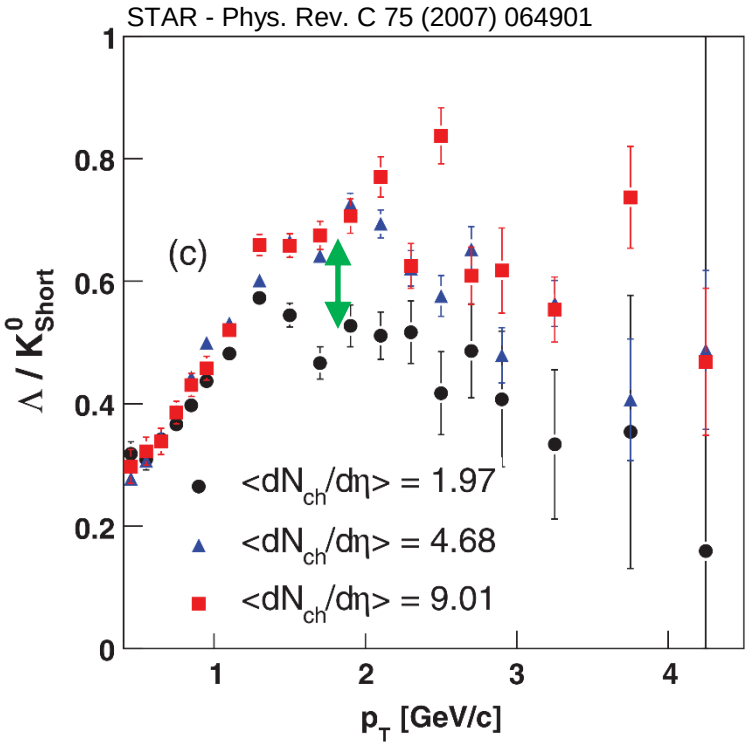
first results from ALICE for weak decay particles in PbPb at 5.02 TeV

Check M. Sefcik's talk
Thu 13/07 h.11:50



Λ/K^0_S - STAR





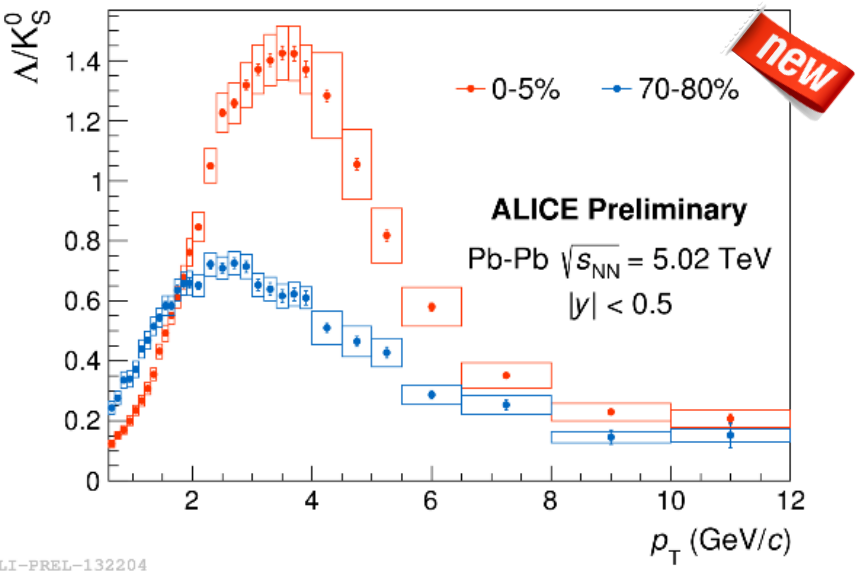
Increase at intermediate p_T in all centrality classes in Au-Au collisions:

different positions of the peak at different centralities?

Effect also observed in pp collisions:

hint for evolution when selecting collisions with different multiplicity

Λ/K^0_S LHC



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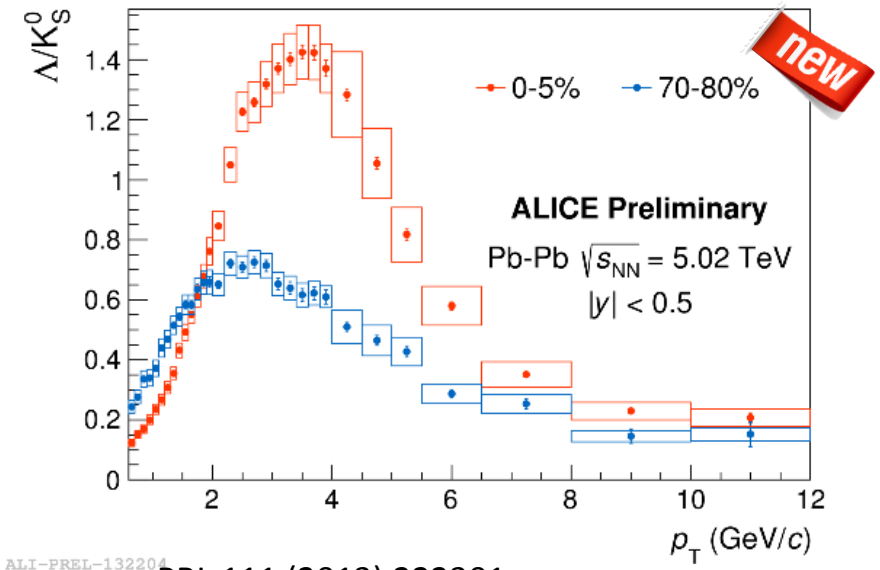
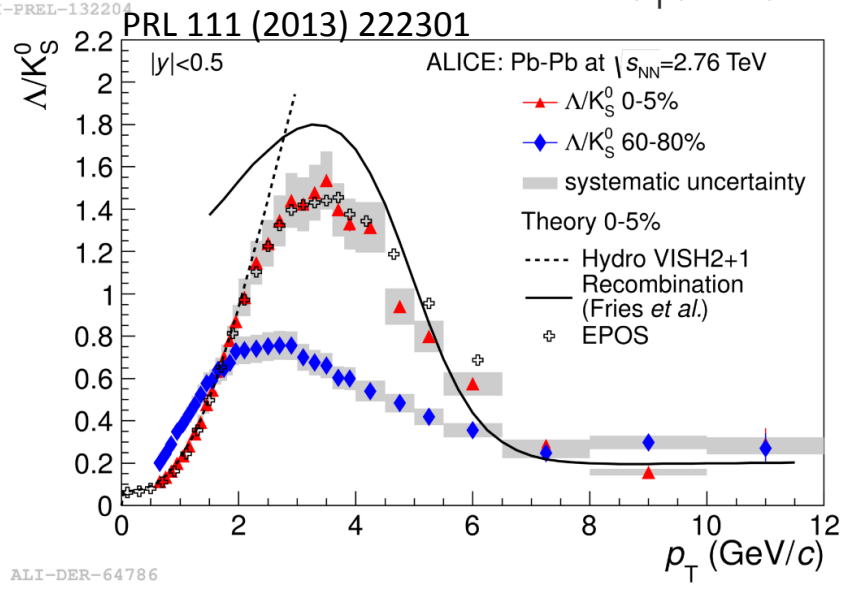


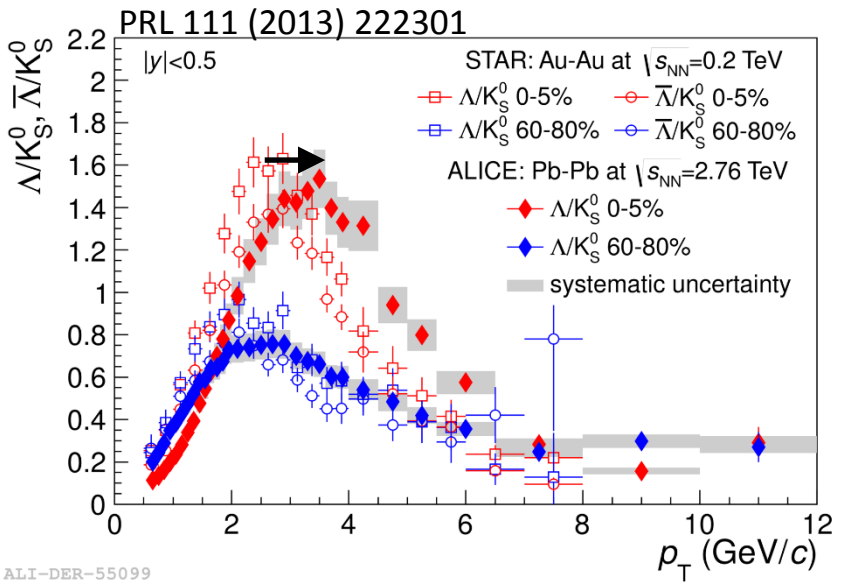
Hydro expansion can describe rising trend.

Coalescence and recombination give qualitative explanation of the falling at higher p_T.

EPOS (hydro+jets) can describe the baryon anomaly in a satisfactory way, when tuning its free parameters on other observables

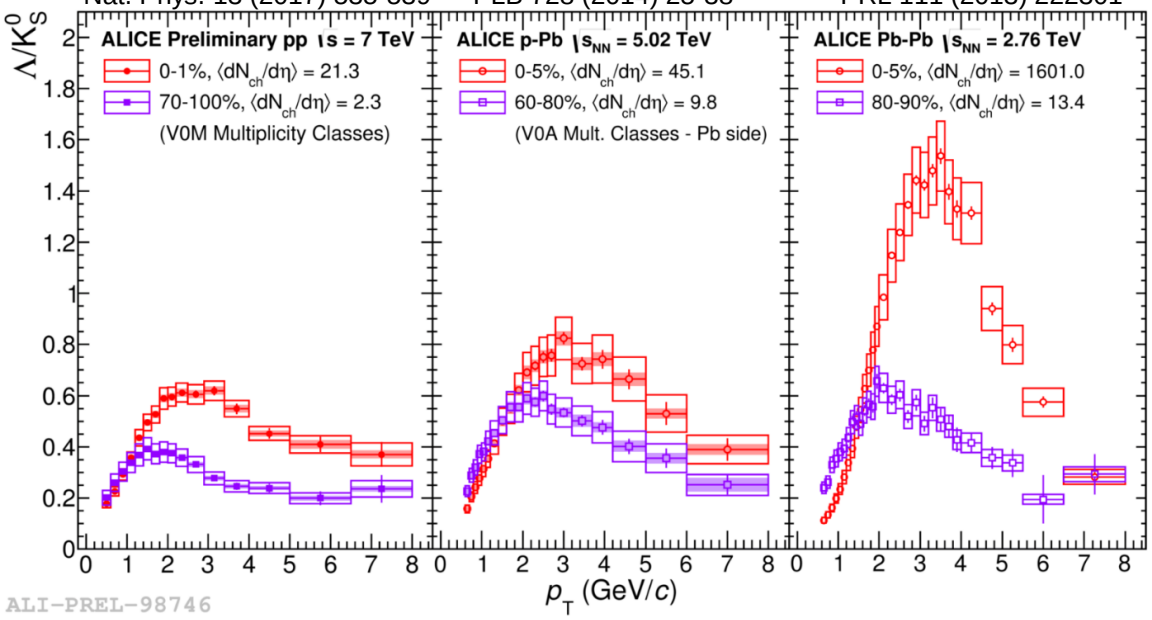
Higher radial boost at LHC → peak at higher p_T





Λ/K^0_S: small systems (I)

Nat. Phys. 13 (2017) 535-539 PLB 728 (2014) 25-38 PRL 111 (2013) 222301



Ratio depends on multiplicity in a **qualitatively similar** way **in pp, p-Pb and Pb-Pb**

Magnitude smaller in smaller systems

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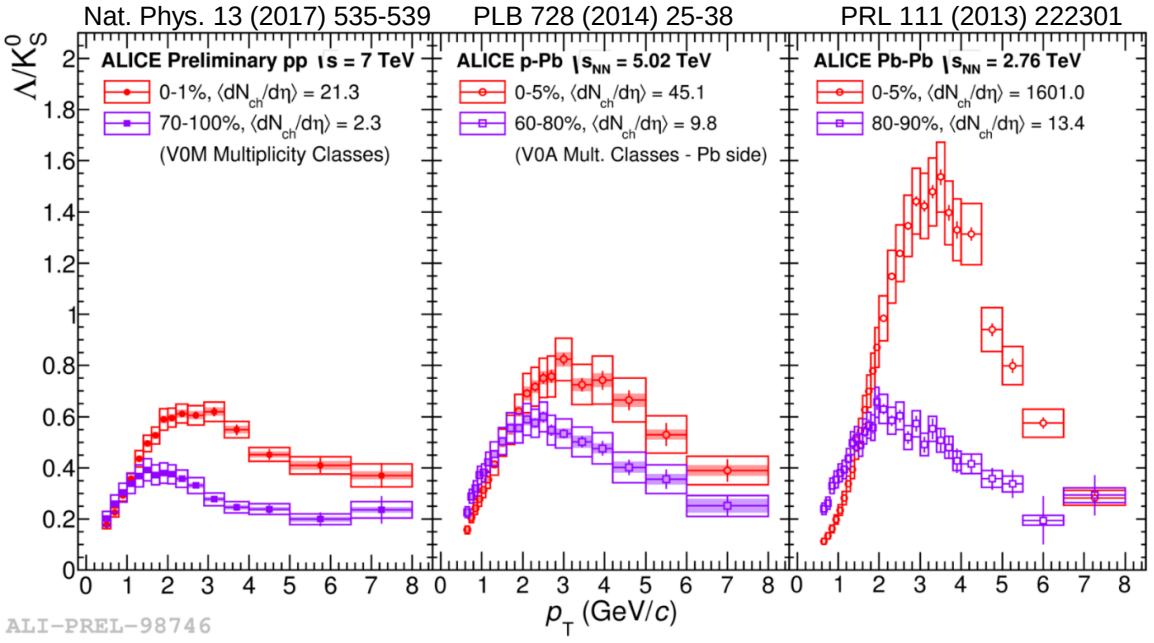

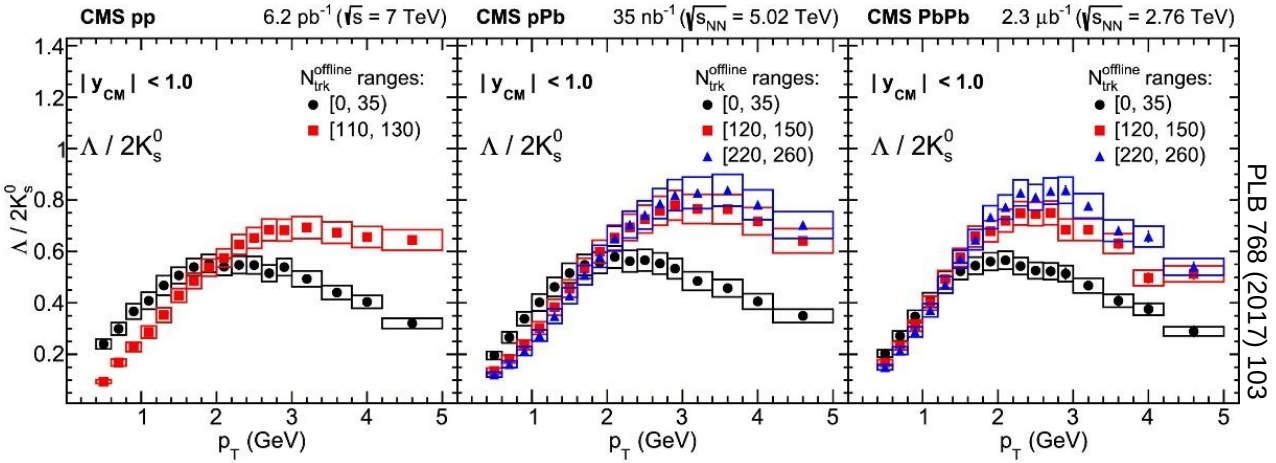

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Magnitude smaller in smaller systems

CMS:
similar multiplicity classes in the three systems:
similar magnitude!

Check H. Ni's talk
Thu 13/07 h.12:10

Can we quantify even more?
↓

Λ/K^0_S: small systems (II)

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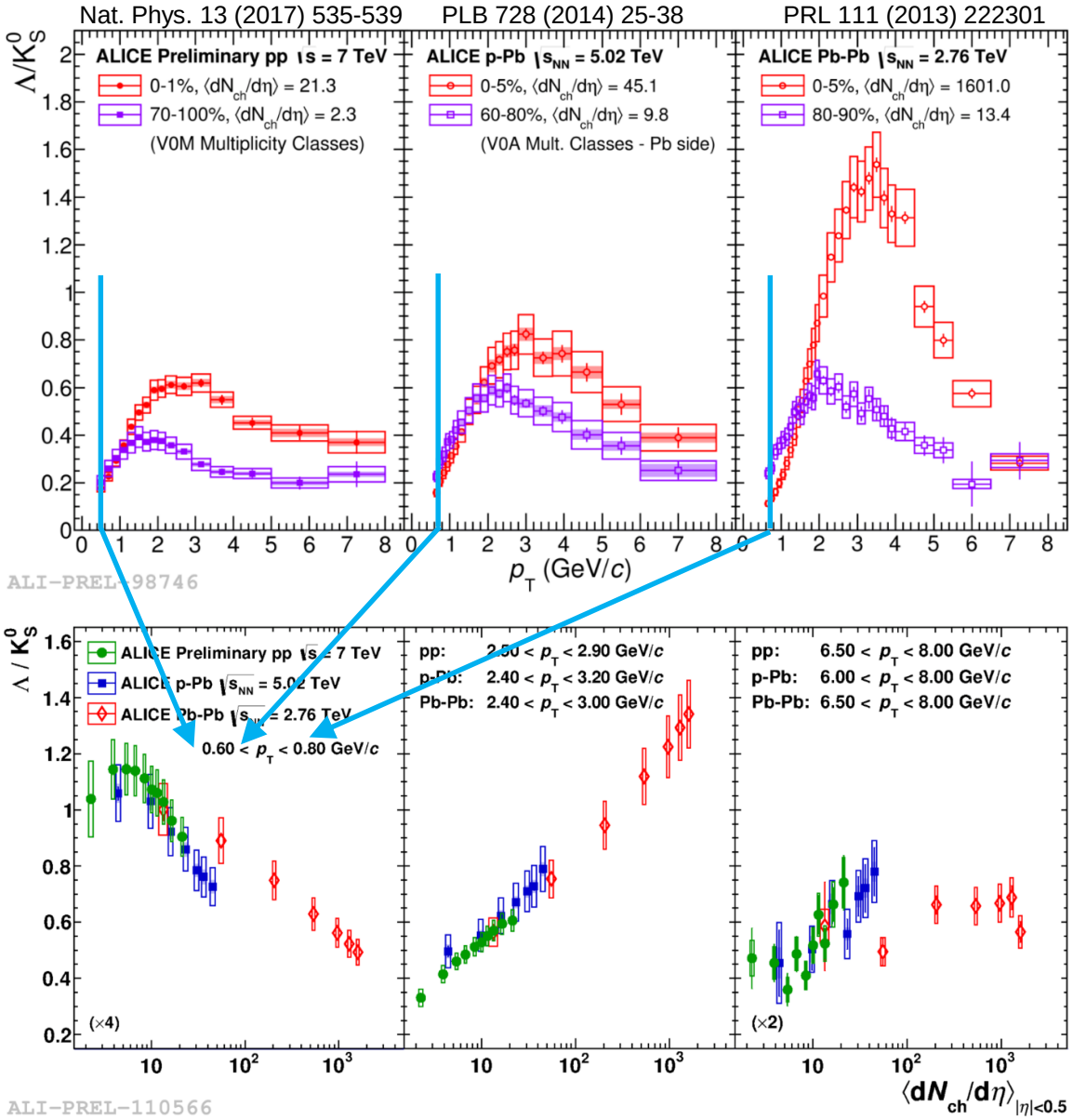

Chose three p_T bins (low, mid and high) and plot the $\langle dN_{ch}/d\eta \rangle$ dependence of the ratio

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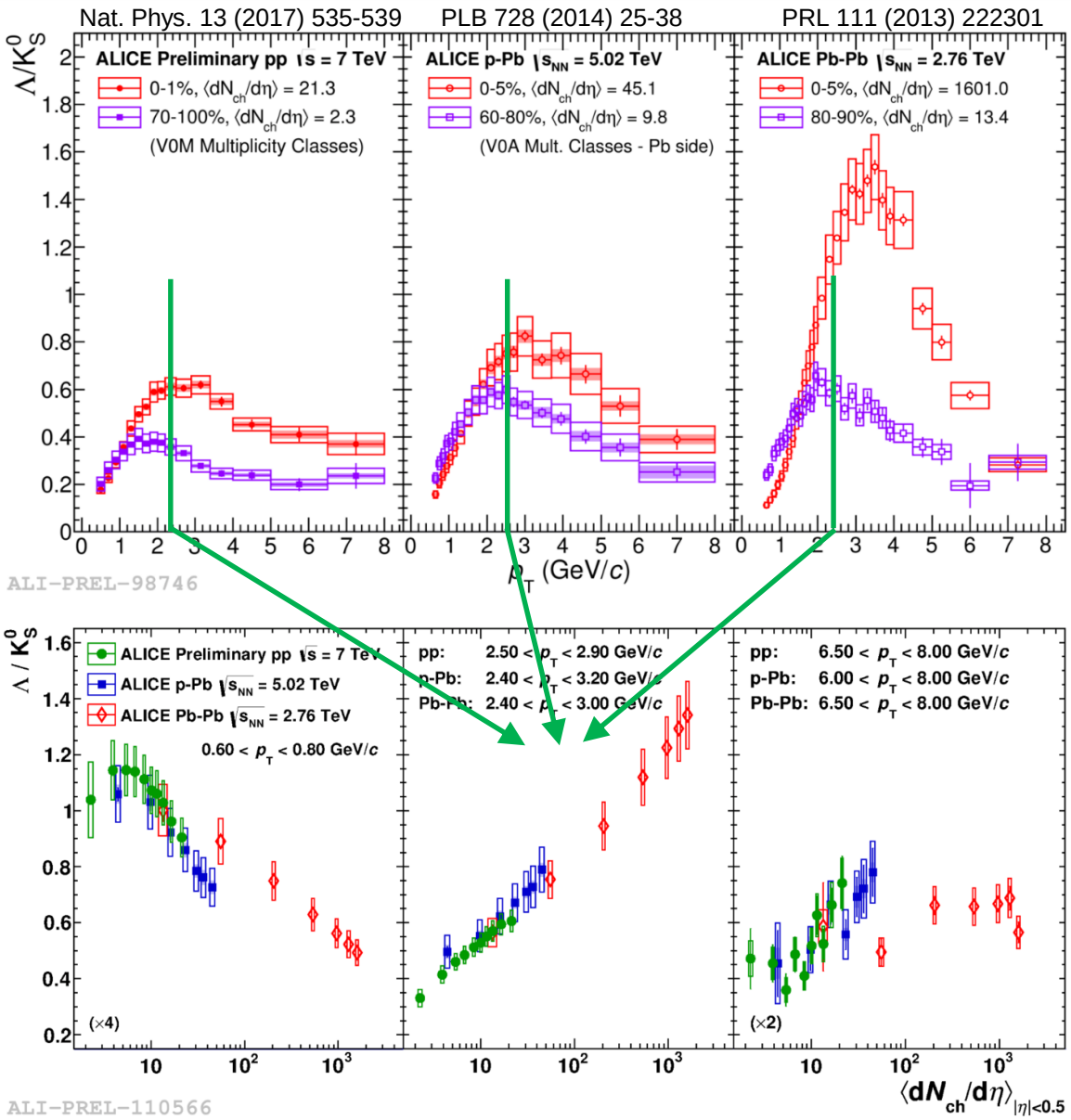

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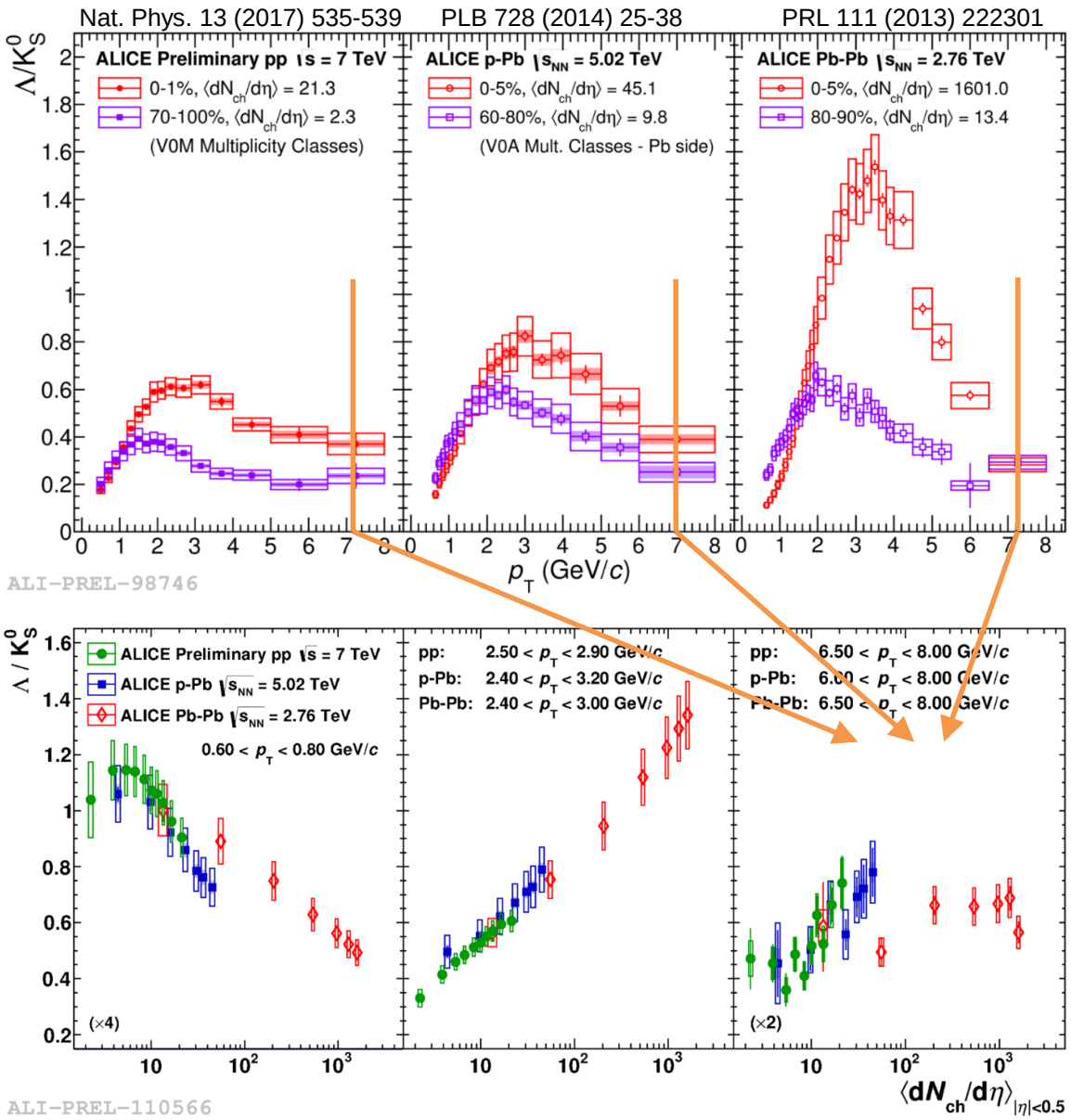

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Common trend in the three systems

TAKE HOME

Λ/K^0_S in A-A: hydro + coal. Also present in pp and p-A. Hydro in small systems?

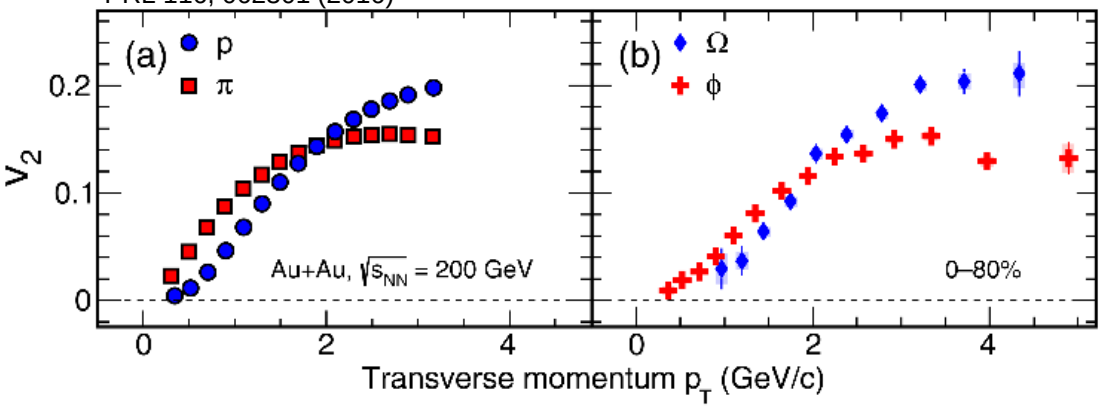
Possible to compare with pp MC generators!

Check F. Fionda's talk
Thu 13/07 h.11:10

Check R. Preghenella's talk
Sat 15/07 h.09:30

v_2 from STAR

PRL 116, 062301 (2016)



Mass ordering & baryon/meson splitting
equal for strange and non-strange hadrons

Hadronic cross-section: Ω and ϕ << p

⇓

observed v_2 driven by initial spatial anisotropy

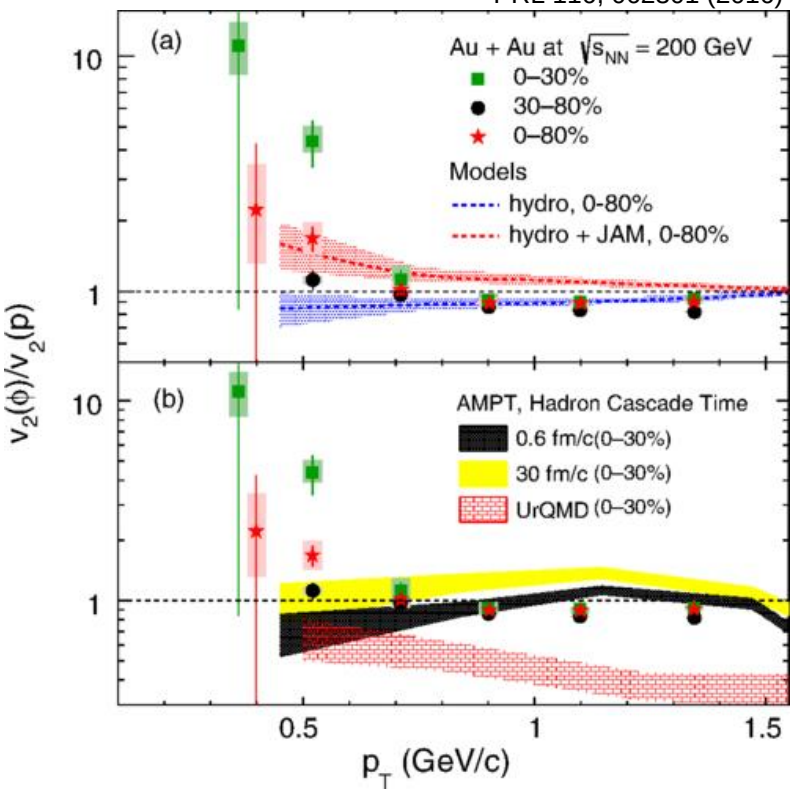
TAKE HOME

Strange & non-strange particles: similar v_2 features, favouring hydro at low-p_T and coalescence at mid-p_T

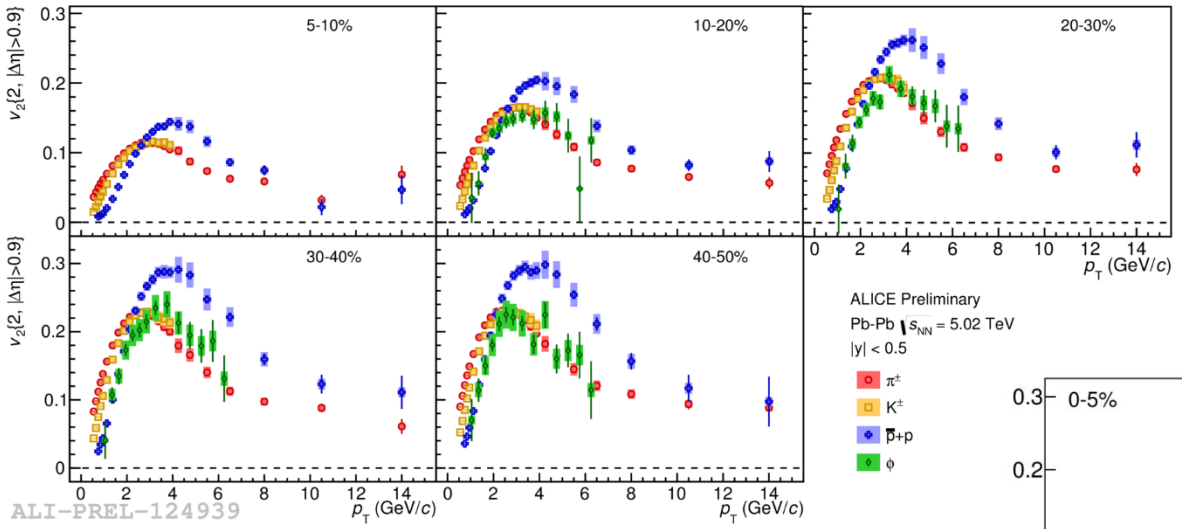
Mass ordering violated for ϕ-p: influence of hadronic re-scattering for p?

↓

PRL 116, 062301 (2016)



v_2 from ALICE

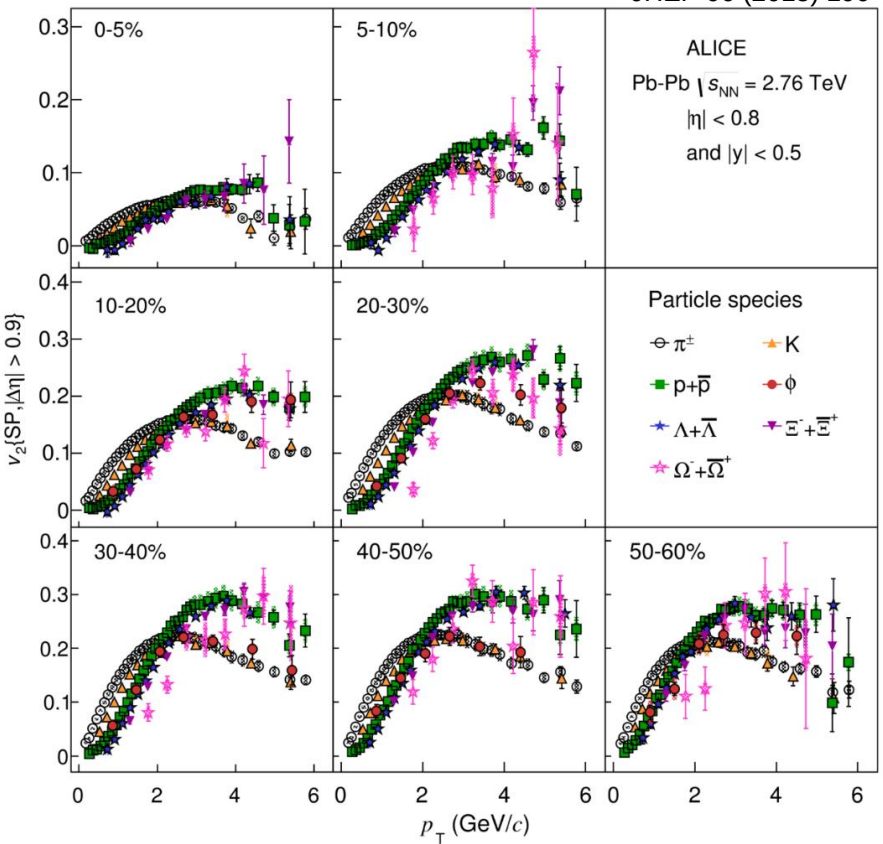


← **Run-2**

Same conclusions @LHC

Run-1 ↓

JHEP 06 (2015) 190



Hint for ϕ not behaving as a meson at intermediate p_T in central collisions?
Not confirmed by data from Run-2

Waiting for multi-strange baryon results from Run-2!

TAKE HOME

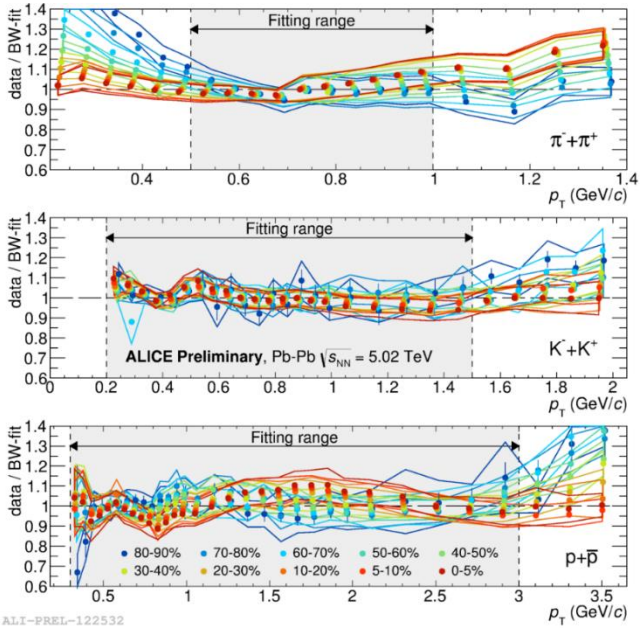
Strange & non-strange particles: similar v_2 features, favouring hydro at low-p_T and coalescence at mid-p_T

Blast-Wave: what's in and what's out

Strange particles seem to participate to the hydro expansion

Blast-Wave model: all particles follow hydro expansion and undergo instantaneous hadronization.

Combined fit to π,K,p - Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV:



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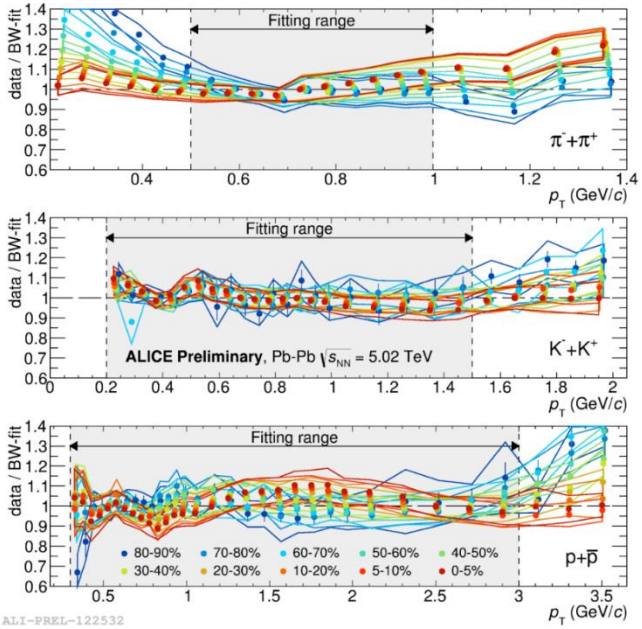
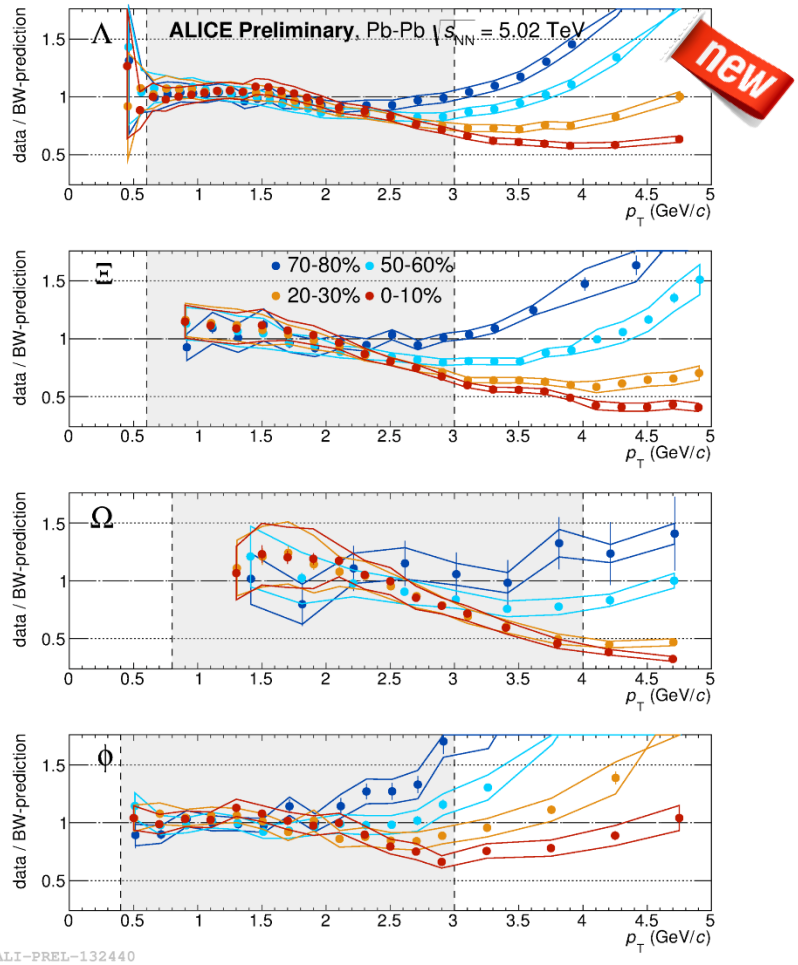
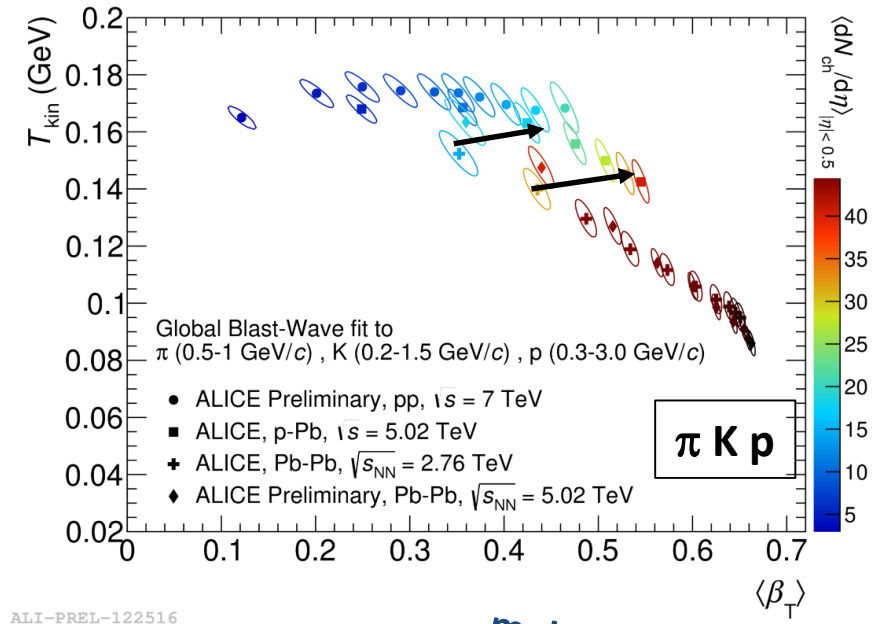


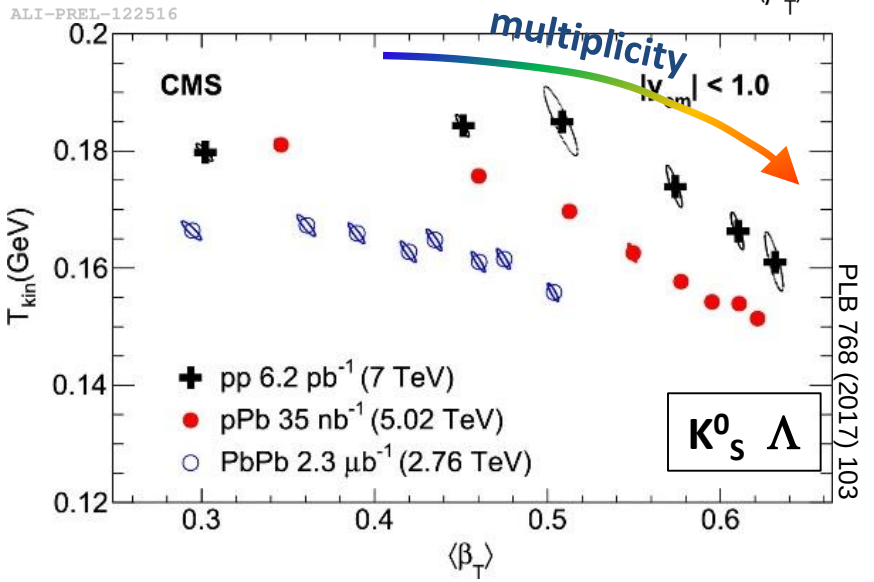


TAKE HOME

Strange baryons do not fit into the BW picture with π,K,p

Blast-Wave: $\langle\beta_T\rangle$-T_{kin} progression





ALICE:

- Similar result in Pb-Pb at two energies
- Similar result in pp and p-Pb
- Larger $\langle\beta_T\rangle$ in pp and p-Pb than in Pb-Pb for similar multiplicities.
  More violent expansion in small systems?

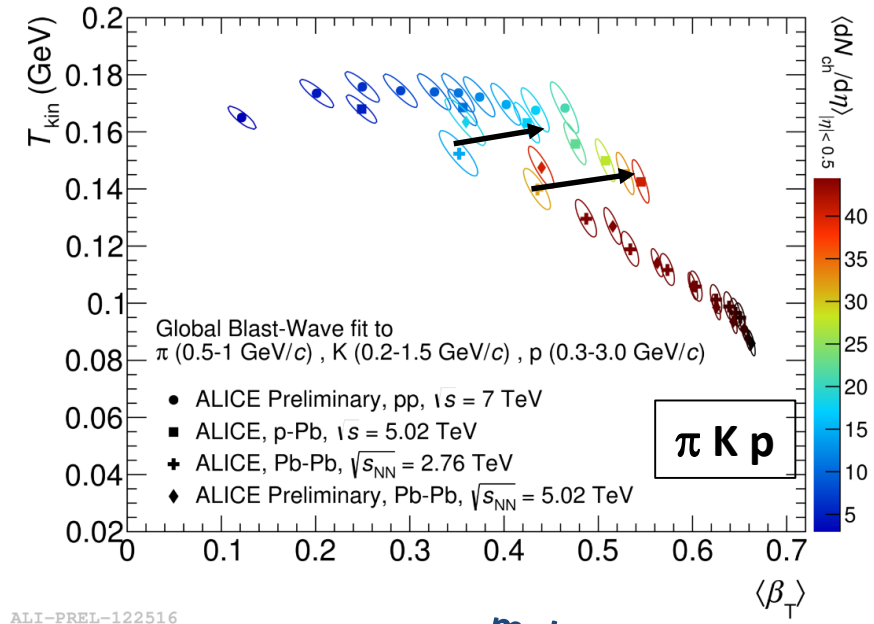
CMS:

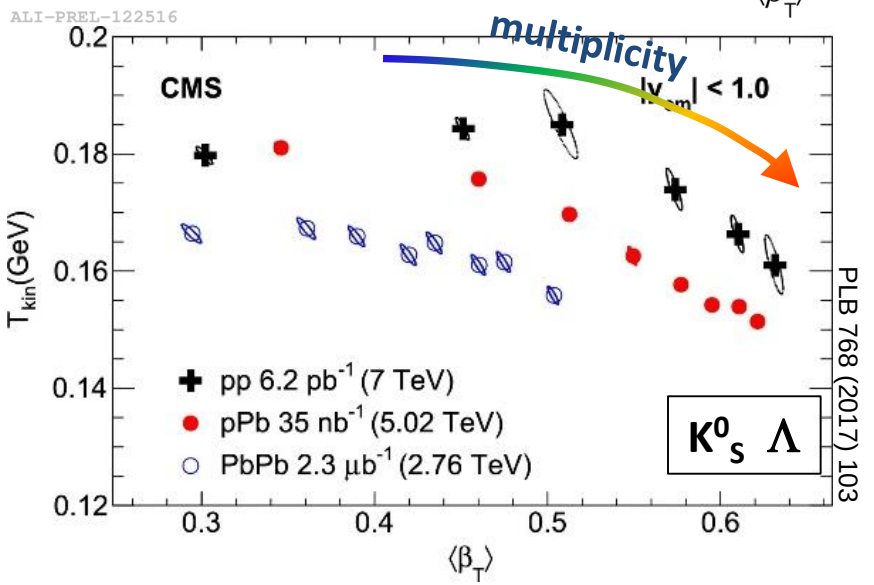
- Only strange particles in the fit
- Three systems give different results, with the tendency to join at low multiplicity

Differences in the fitting strategy make direct comparison difficult

Hint: fitting strangeness only
T_{kin} tends to increase.
Sometimes $T_{kin} > T_{ch}$ (!??)
[tentatively]
Maybe $T_{ch}^{s} > T_{ch}^{non-s}$?

Blast-Wave: $\langle\beta_T\rangle$-T_{kin} progression





ALICE:

- Similar result in Pb-Pb at two energies
- Similar result in pp and p-Pb
- Larger $\langle\beta_T\rangle$ in pp and p-Pb than in Pb-Pb for similar multiplicities.
  More violent expansion in small systems?

CMS:

- Only strange particles in the fit
- Three systems give different results, with the tendency to join at low multiplicity

Differences in the fitting strategy make direct comparison difficult

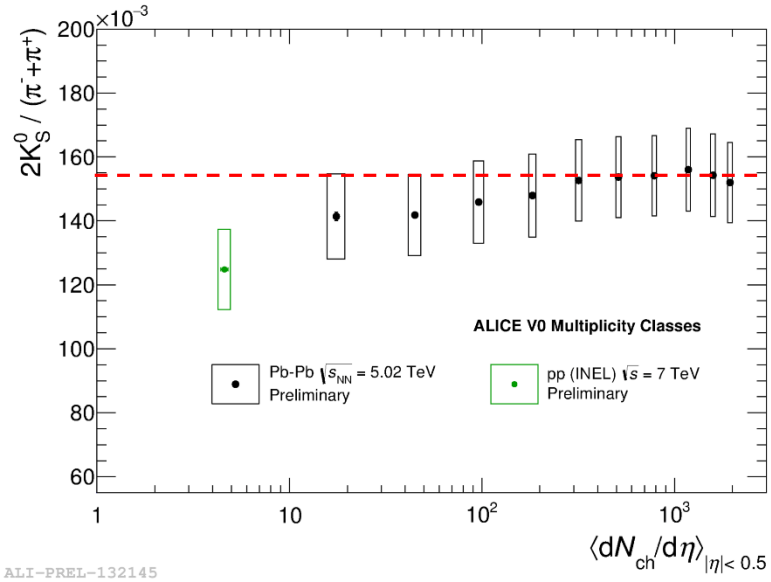
Hint: fitting strangeness only
T_{kin} tends to increase.
Sometimes $T_{kin} > T_{ch}$ (!??)
[tentatively]
Maybe $T_{ch}^{s} > T_{ch}^{non-s}$?

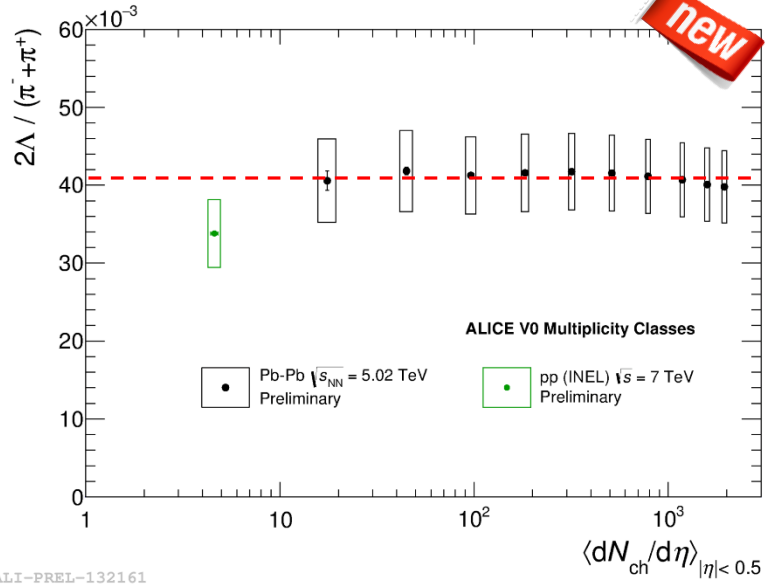
TO BE ADDRESSED IN THE COMING FUTURE

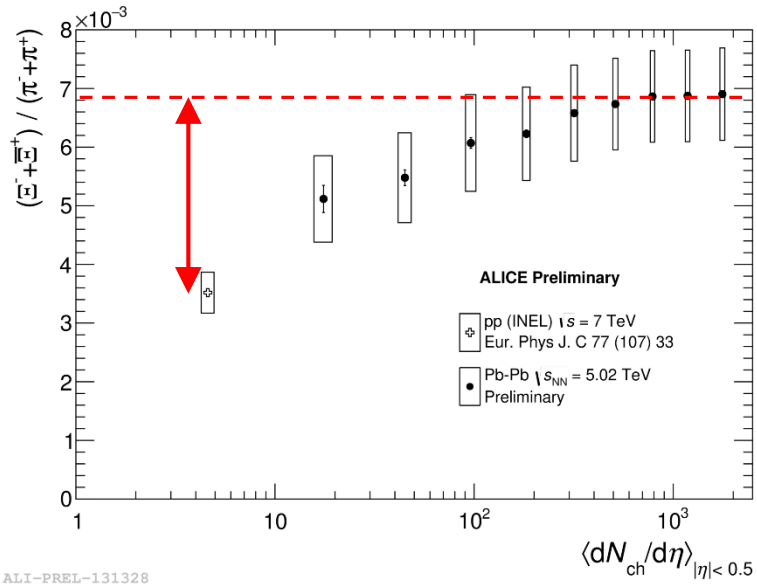
Enhancement: heavy ions against pp

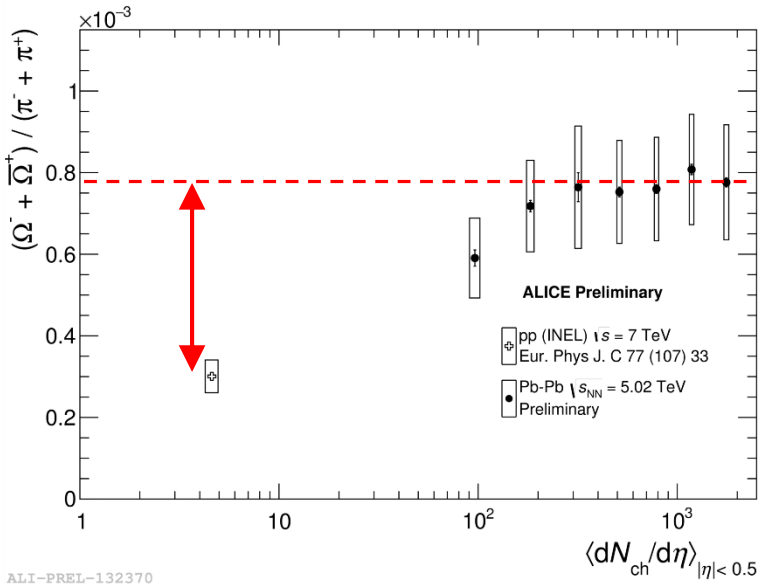
Strangeness enhanced in Pb-Pb with respect to pp(INEL):

$E_\Omega > E_\Xi > E_\Lambda \sim E_{K0S}$







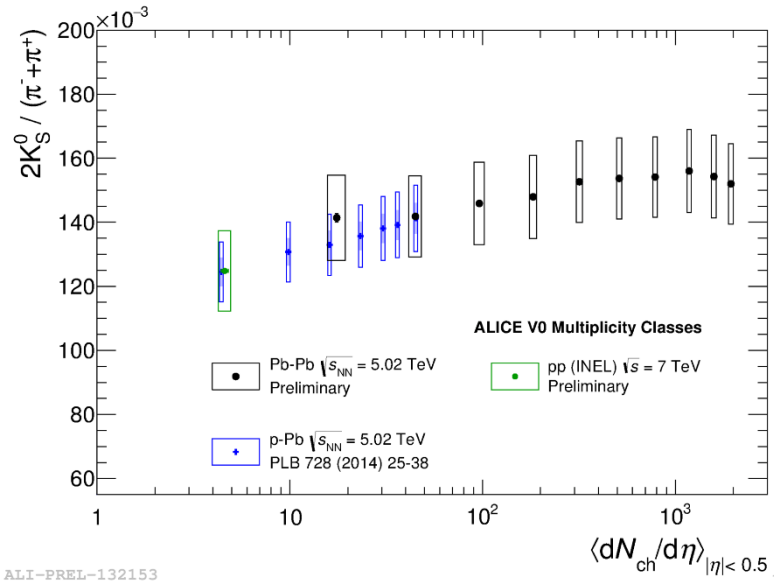


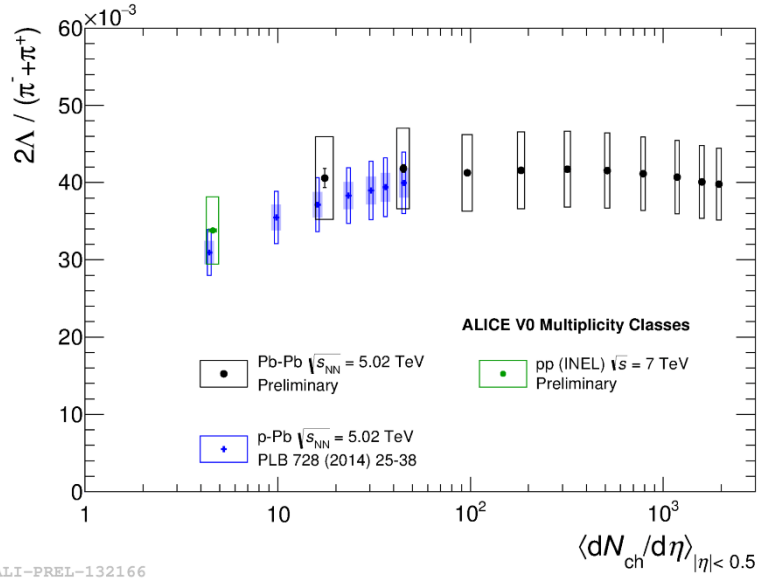
Enhancement: adding p-Pb VS multiplicity

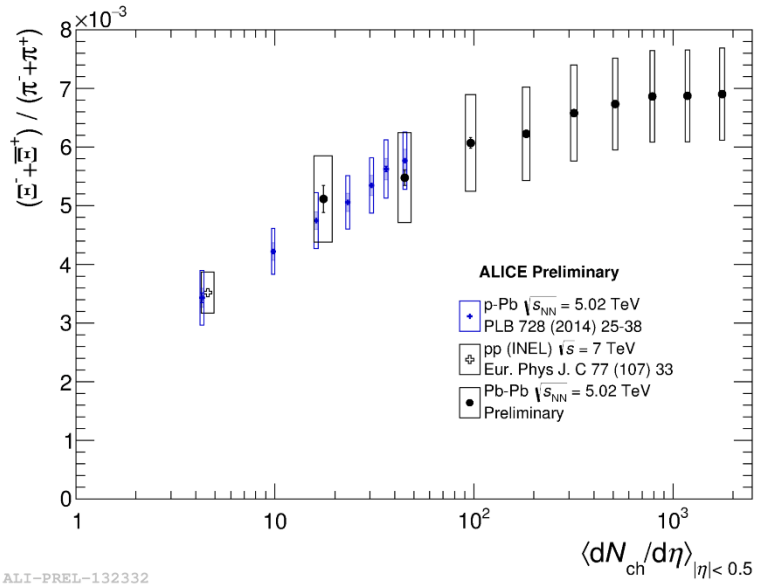
Strangeness enhanced in Pb-Pb with respect to pp(INEL):

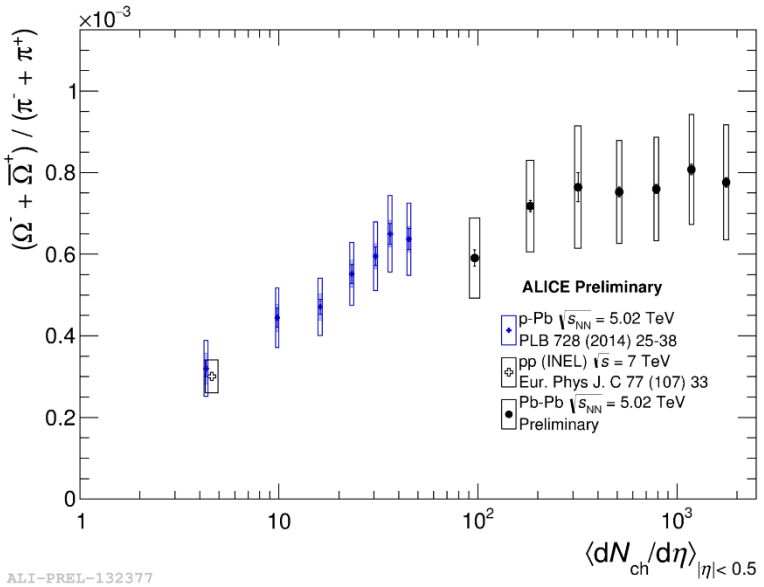
$E_\Omega > E_\Xi > E_\Lambda \sim E_{K0S}$

p-Pb results smoothly join pp to PbPb









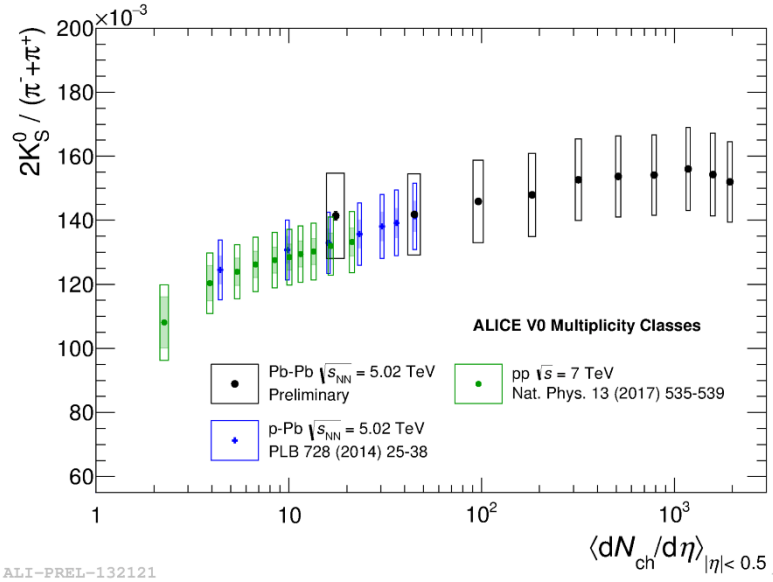
Enhancement: … and pp VS multiplicity

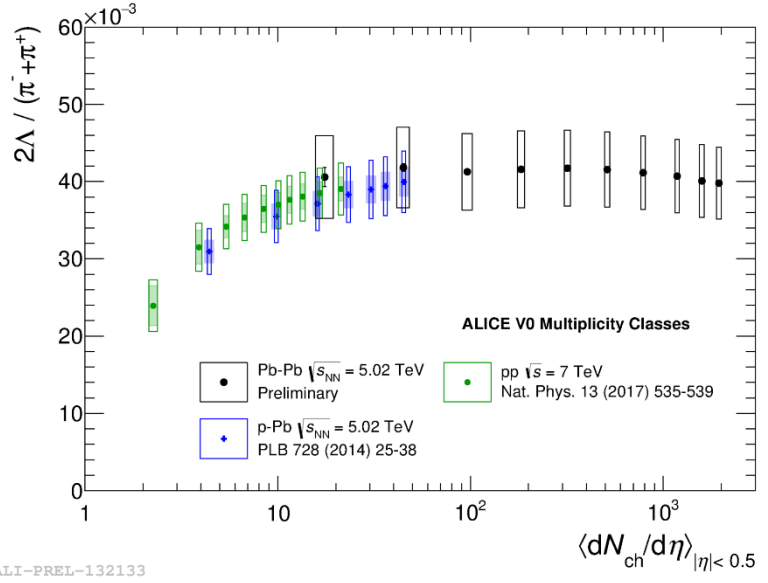
Strangeness enhanced in Pb-Pb with respect to pp(INEL):

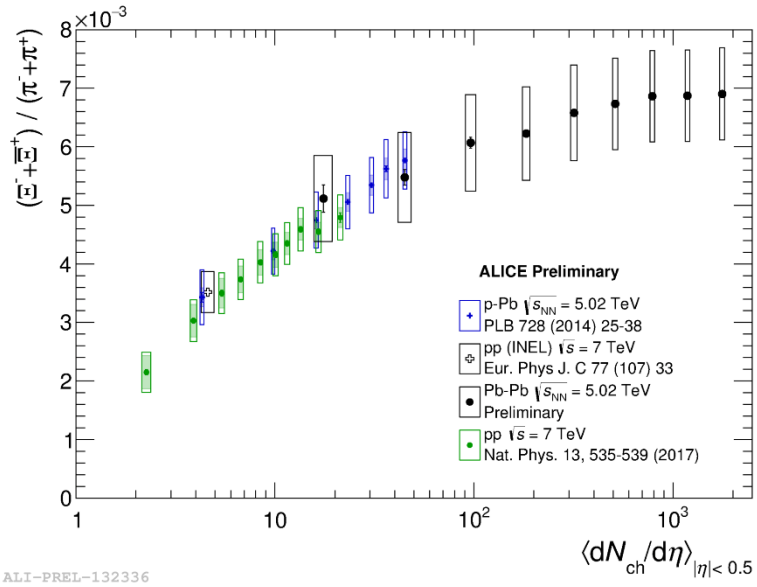
$E_{\Omega} > E_{\Xi} > E_{\Lambda} \sim E_{K0S}$

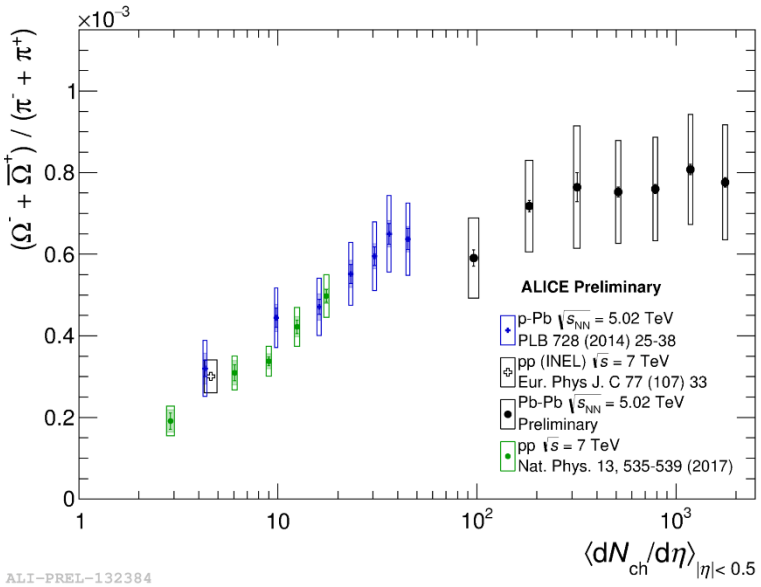
p-Pb results smoothly join pp to PbPb

And pp VS mult. points extend the same trend down to 2 particles at mid-rapidity!









Enhancement: comparison to Pb-Pb 2.76 TeV

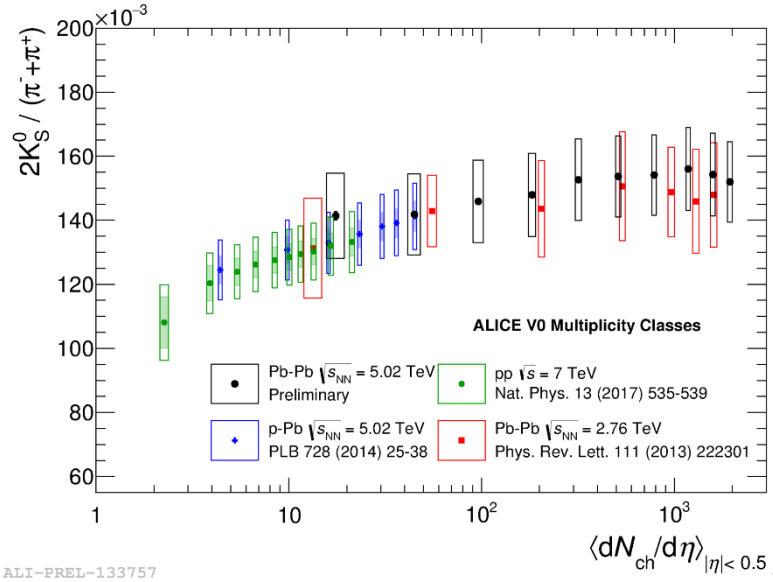
Strangeness enhanced in Pb-Pb with respect to pp(INEL):

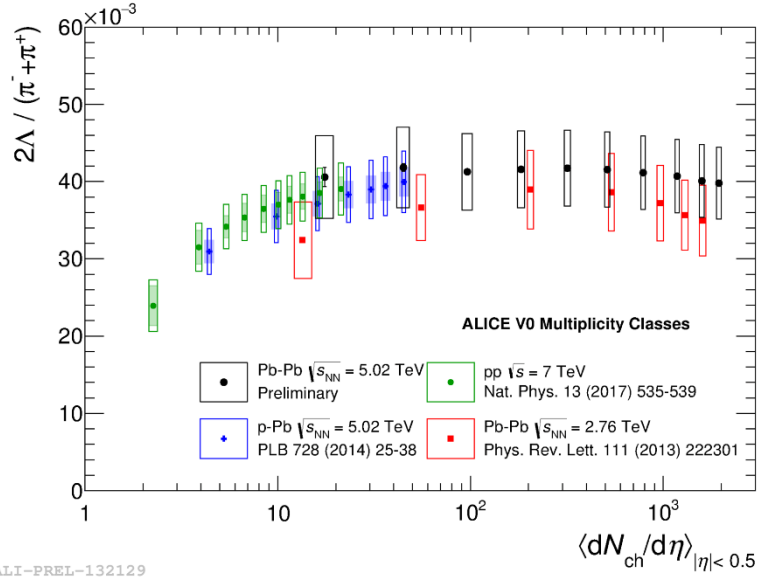
$E_{\Omega} > E_{\Xi} > E_{\Lambda} \sim E_{K0S}$

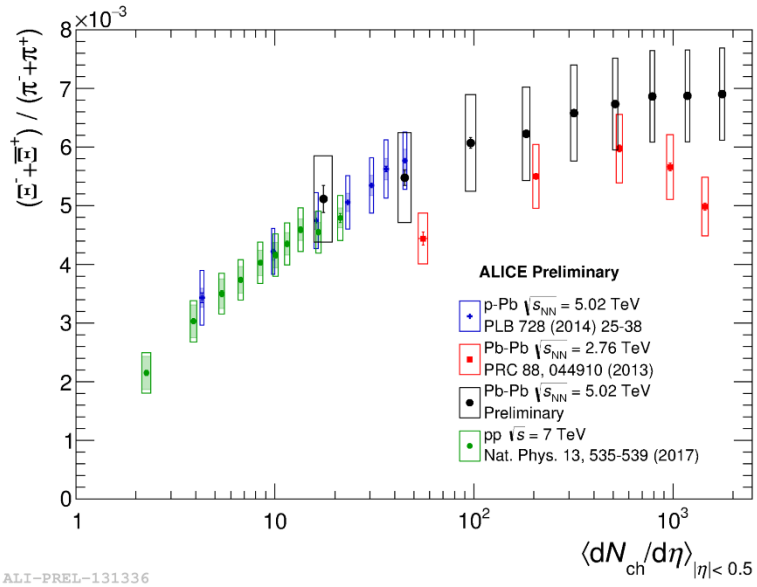
p-Pb results smoothly join pp to PbPb

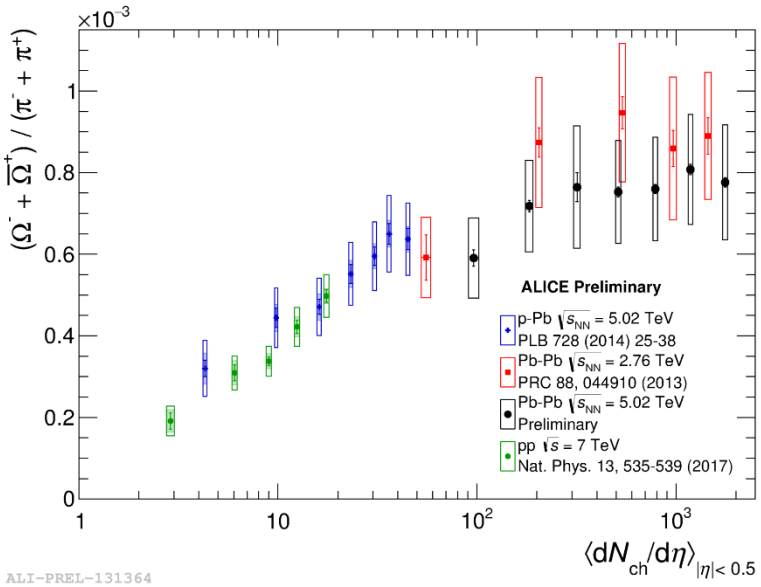
And pp VS mult. points extend the same trend down to 2 particles at mid-rapidity!

PbPb: agreement between 2.76 and 5.02 TeV data. Daviation for Ξ being investigated.



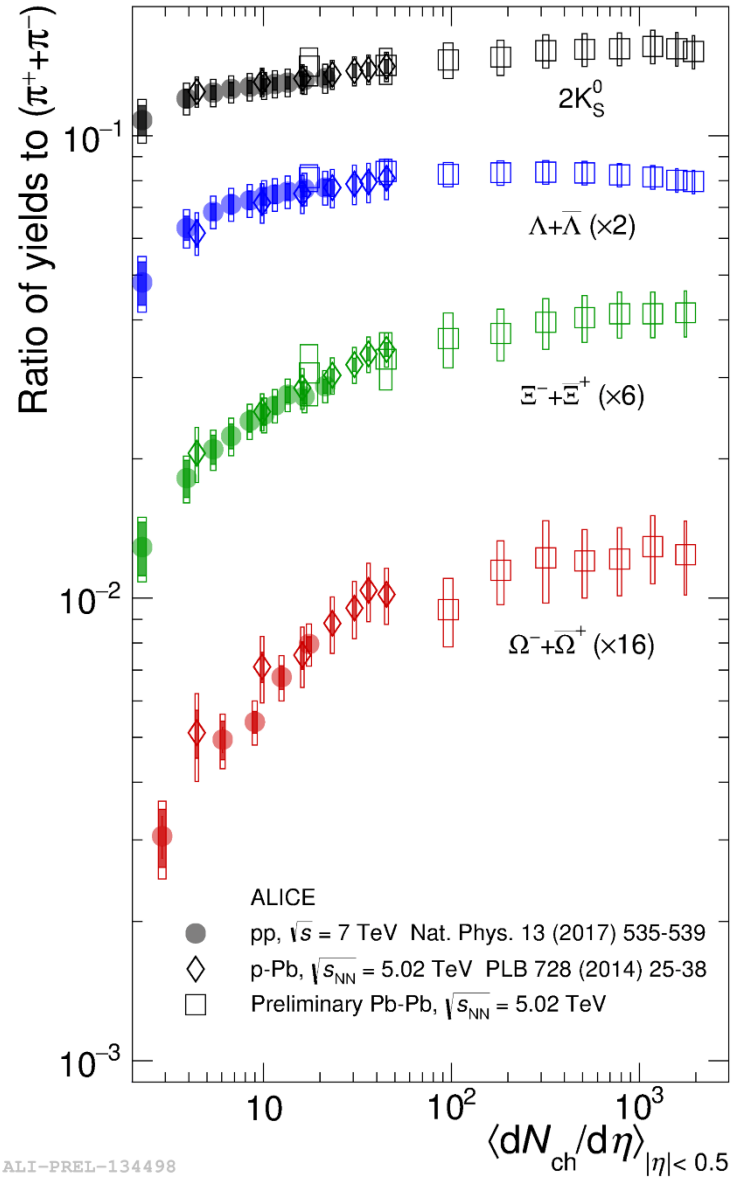


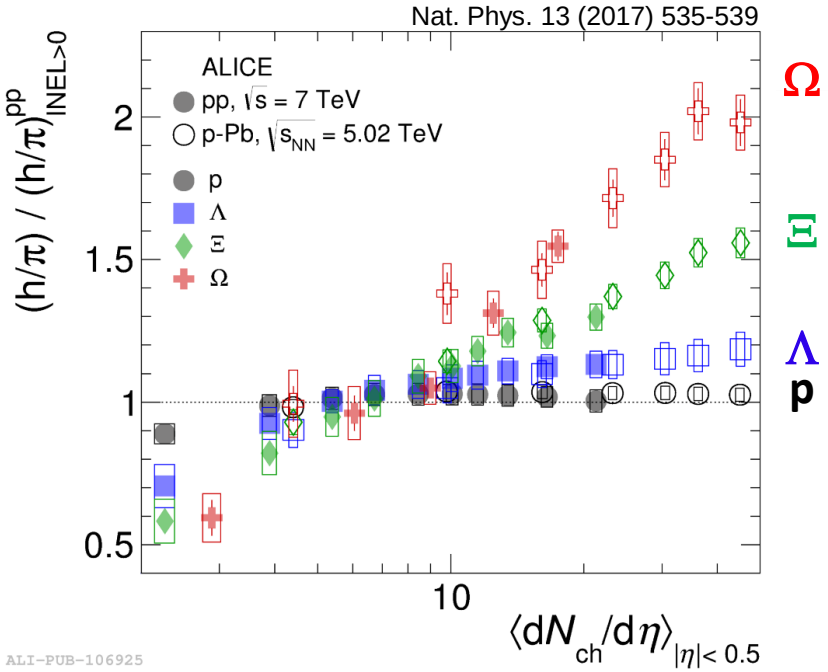




Strangeness enhancement at the LHC: wrap-up

Livio Bianchi
SQM 2017
Utrecht 10 Jul 17



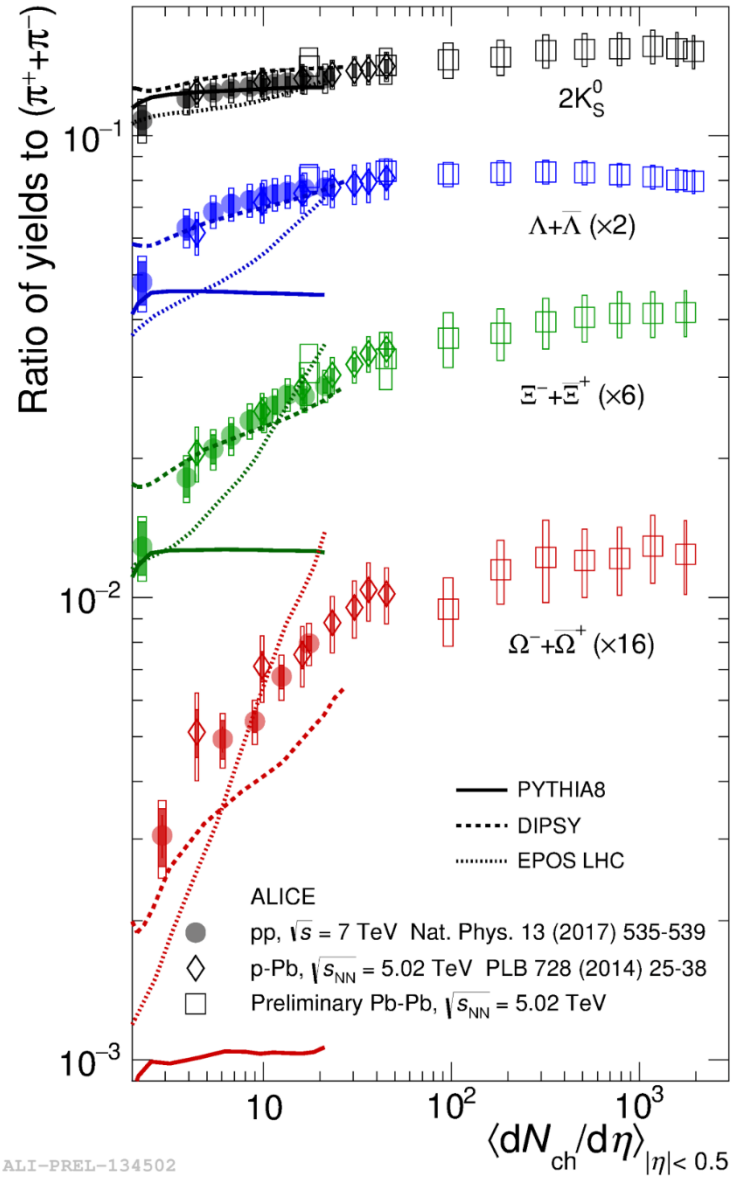


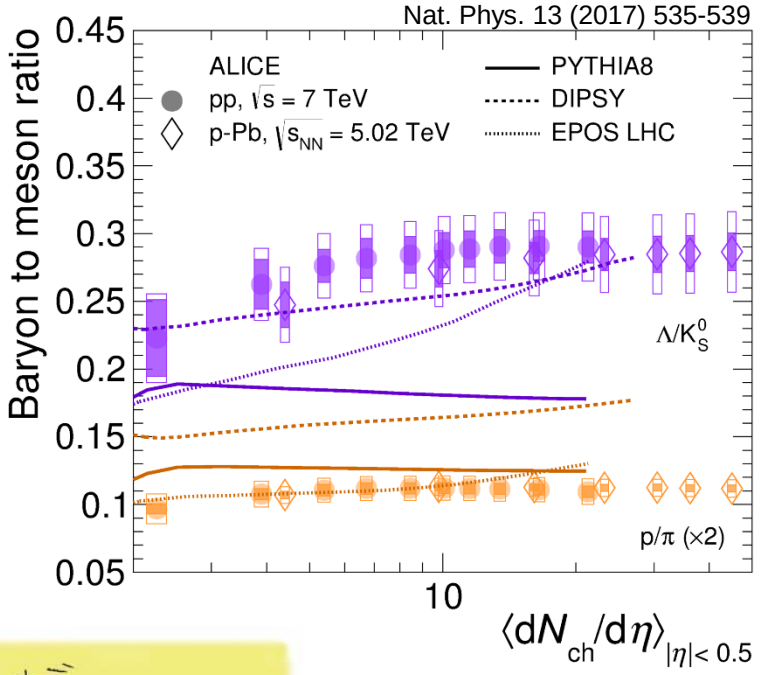
Ω Ξ Λ p

TAKE HOME

Strangeness enhancement
@LHC $\propto S_h$
no energy nor system dep.
Only multiplicity counts!!

Strangeness enhancement at the LHC: wrap-up

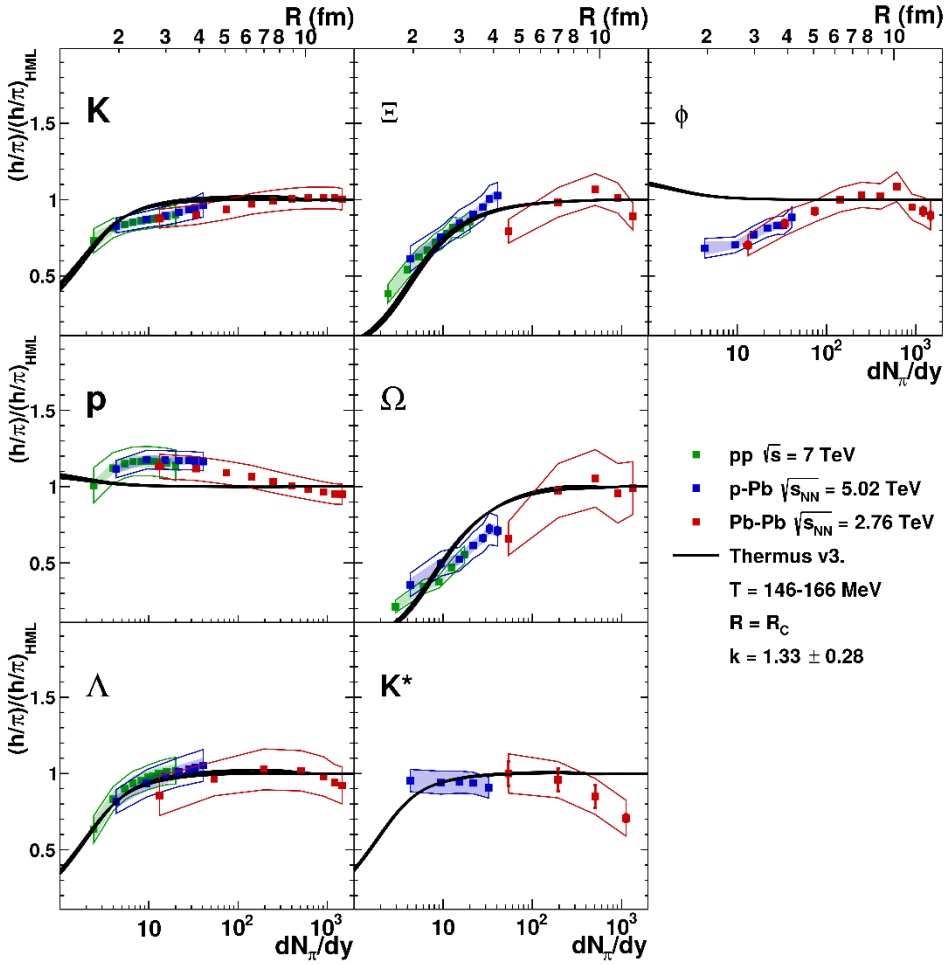




Opportunity to compare to microscopic models!!

Check F. Fionda's talk
Thu 13/07 h.11:10

Could it be canonical suppression?

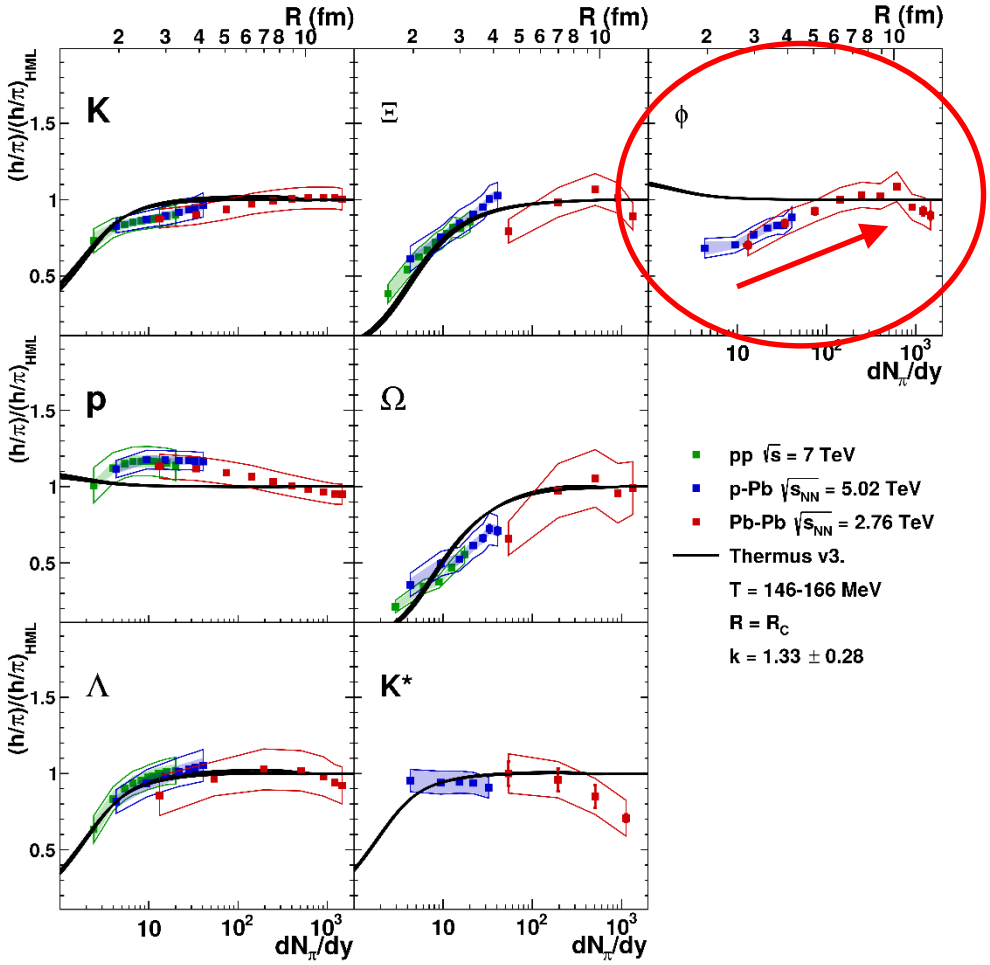


V. Vislavicius, A. Kalweit aXiv:1610.03001 [nucl-ex]

Fix yield's ratio to saturation limit.
Check the evolution when decreasing the volume (multiplicity)

Qualitatively the thermal fit describes K,Λ,Ξ,Ω

Could it be canonical suppression?



V. Vislavicius, A. Kalweit aXiv:1610.03001 [nucl-ex]

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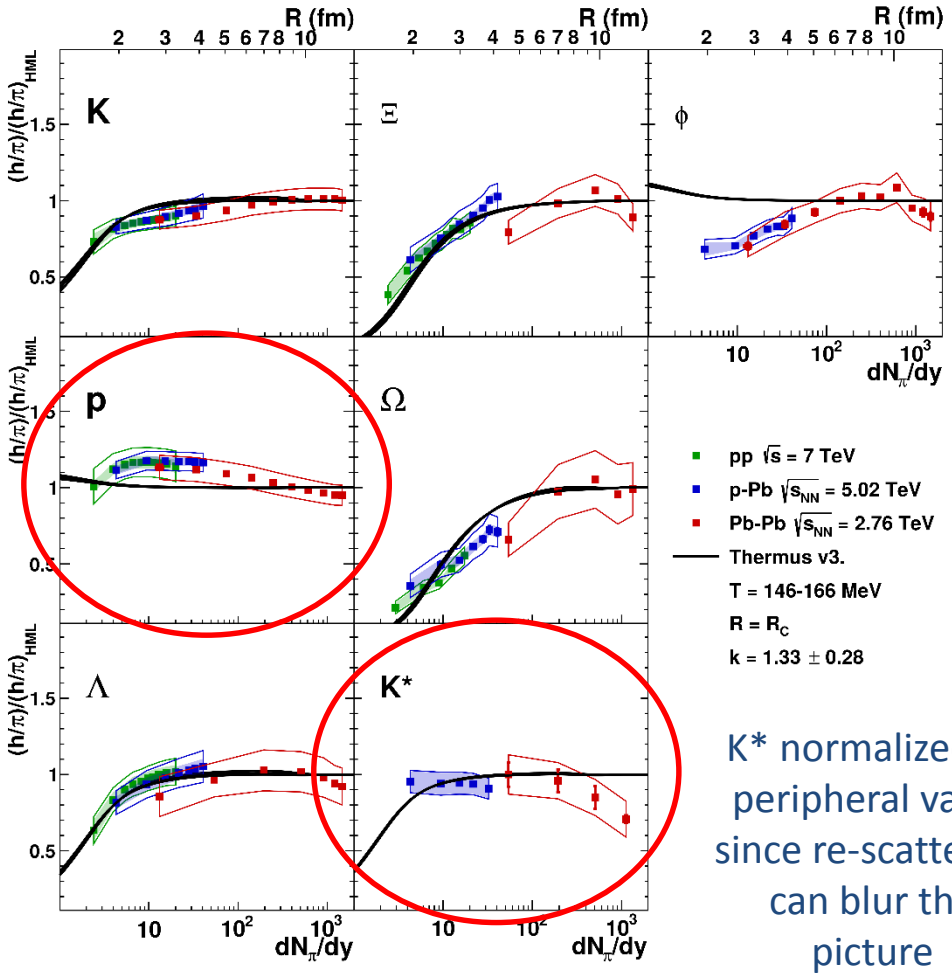
Notable exception is the ϕ!

Could it be canonical suppression?

V. Vislavicius, A. Kalweit aXiv:1610.03001 [nucl-ex]



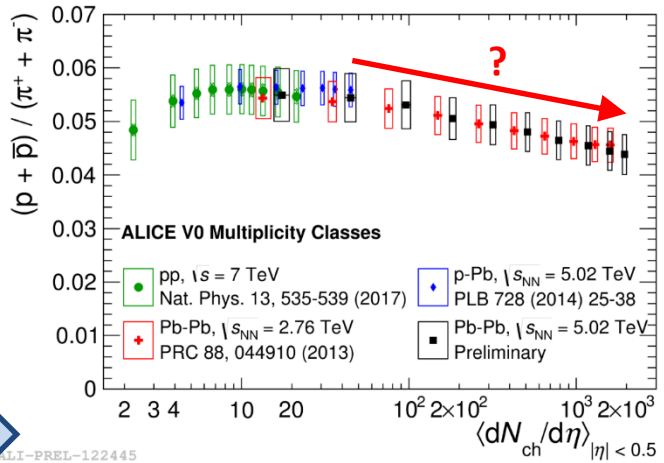
K* normalized to peripheral value since re-scattering can blur the picture

Fix yield's ratio to saturation limit.
Check the evolution when decreasing the volume (multiplicity)

Qualitatively the thermal fit describes K,Λ,Ξ,Ω

Notable exception is the ϕ!

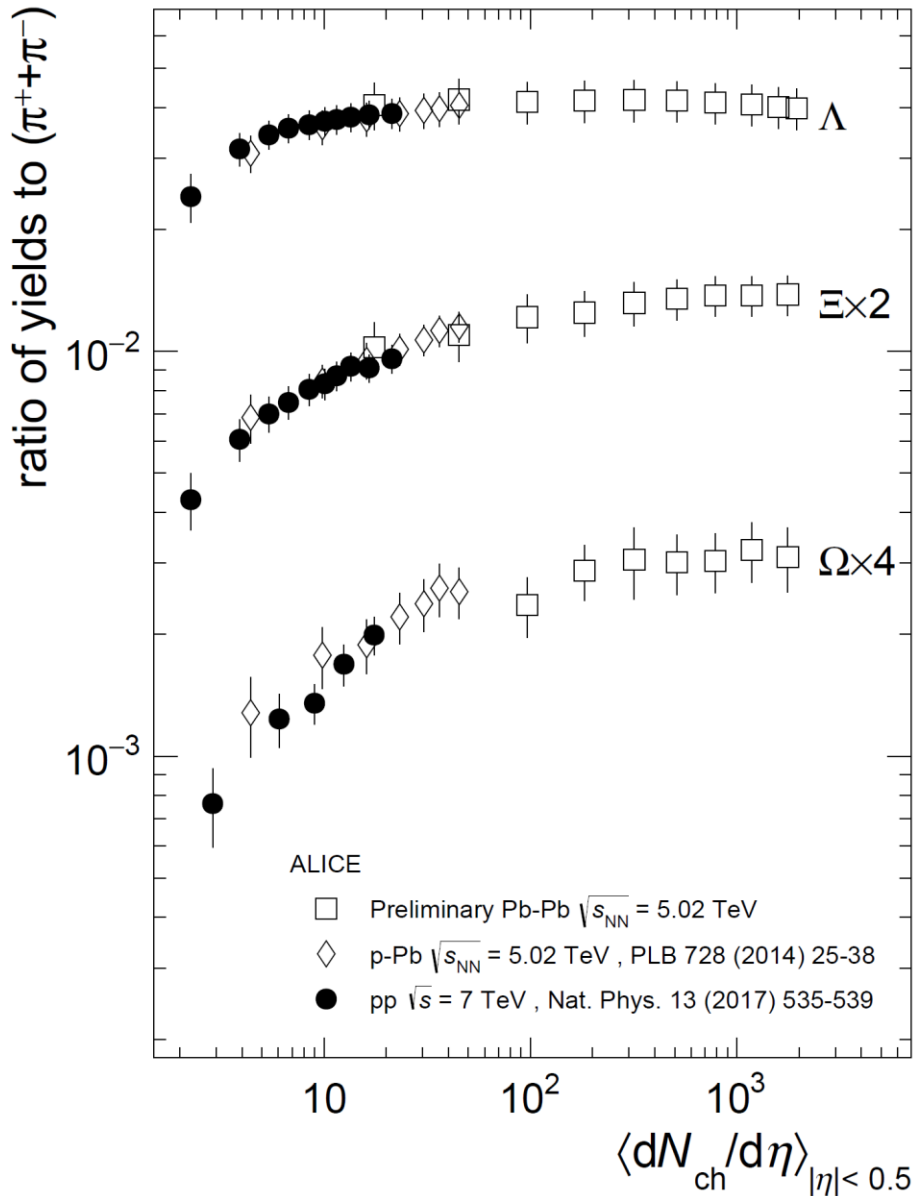
Slightly decreasing protons
Hint for hadronic re-scattering?
Not significant with current systematics
Need to evaluate degree of correlation across multiplicity!



Check N. Agrawal's talk
Fri 14/07 h.16:45

Check Anders Knospe's talk
Fri 14/07 h.09:00

Strangeness Enhancement: comparison to RHIC

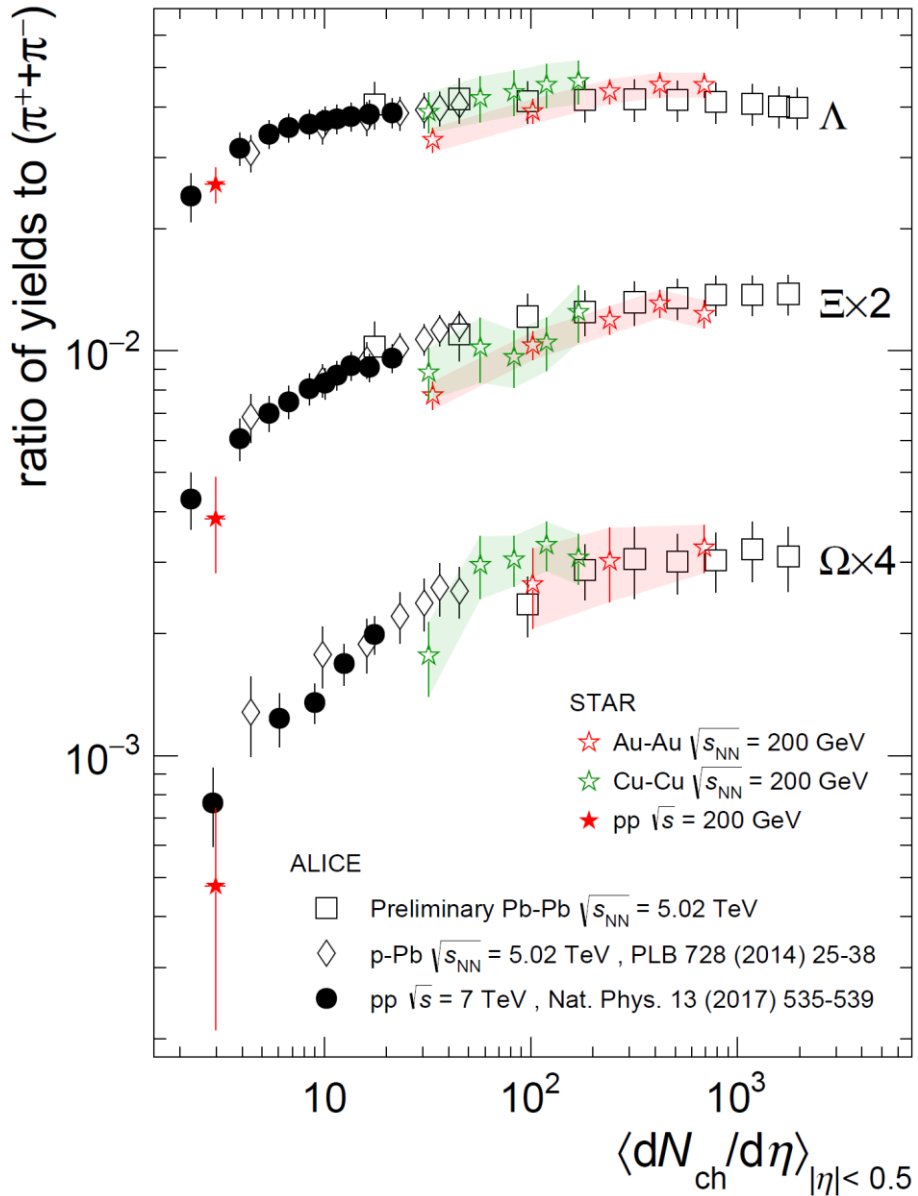


High precision data from the LHC suggest that the production of strangeness is driven by the final-state multiplicity of the collision

Independence on the collision energy

Can we extend this observation to lower energies?

Strangeness Enhancement: comparison to RHIC



High precision data from the LHC suggest that the production of strangeness is driven by the final-state multiplicity of the collision

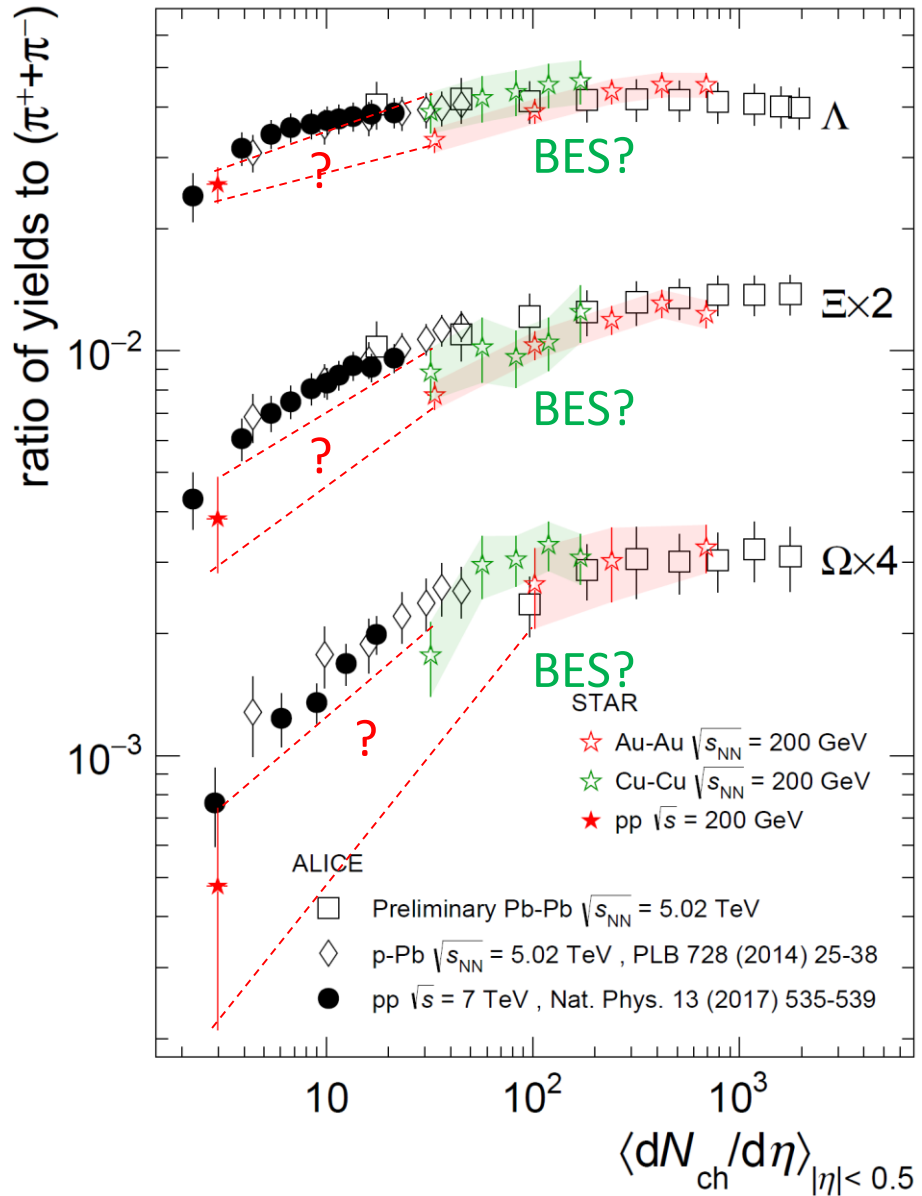
Independence on the collision energy

Can we extend this observation to lower energies?

High multiplicity STAR results superimpose to ALICE's points

Can we infer something looking at the trend at lower multiplicity?

Strangeness Enhancement: comparison to RHIC



High precision data from the LHC suggest that the production of strangeness is driven by the final-state multiplicity of the collision

Independence on the collision energy

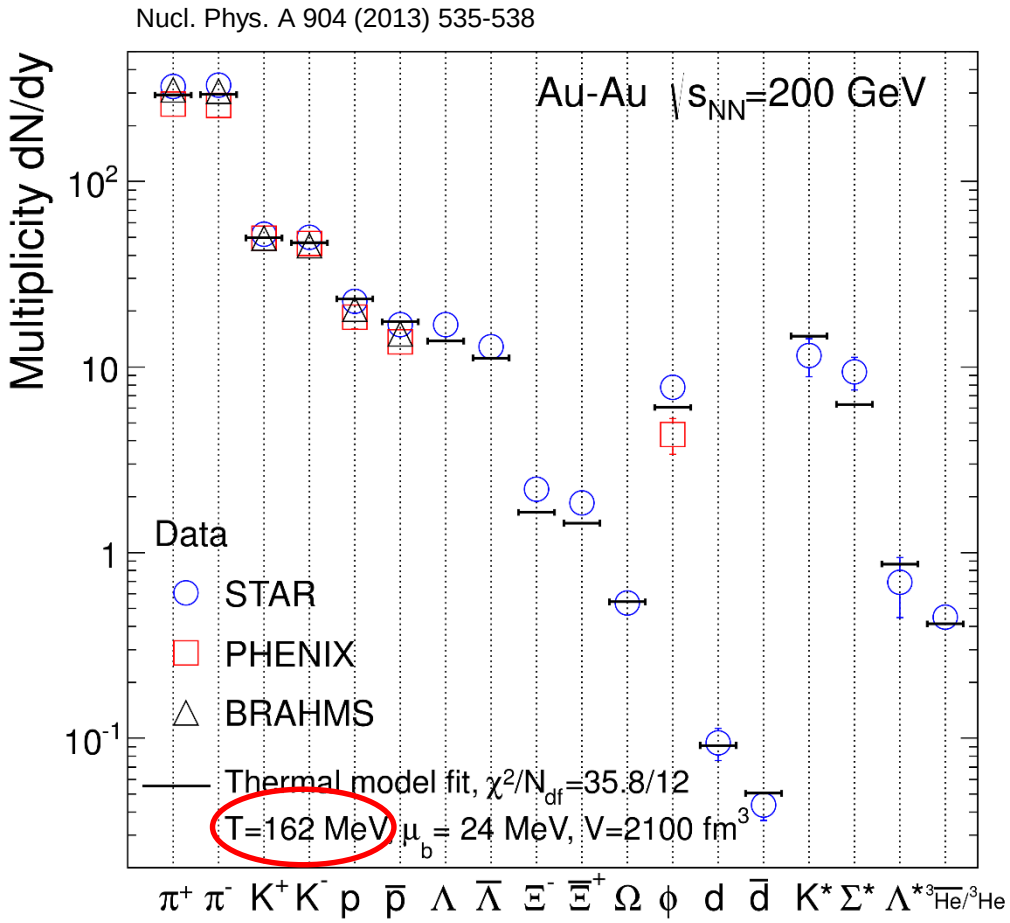
Can we extend this observation to lower energies?

High multiplicity STAR results superimpose to ALICE's points

Can we infer something looking at the trend at lower multiplicity?

Hint for different evolution with multiplicity? γ_S at play?
Would be interesting to complement with smaller systems results @RHIC!!

Thermal model RHIC



Thermal model fit performed on STAR, PHENIX and BRAHMS data.

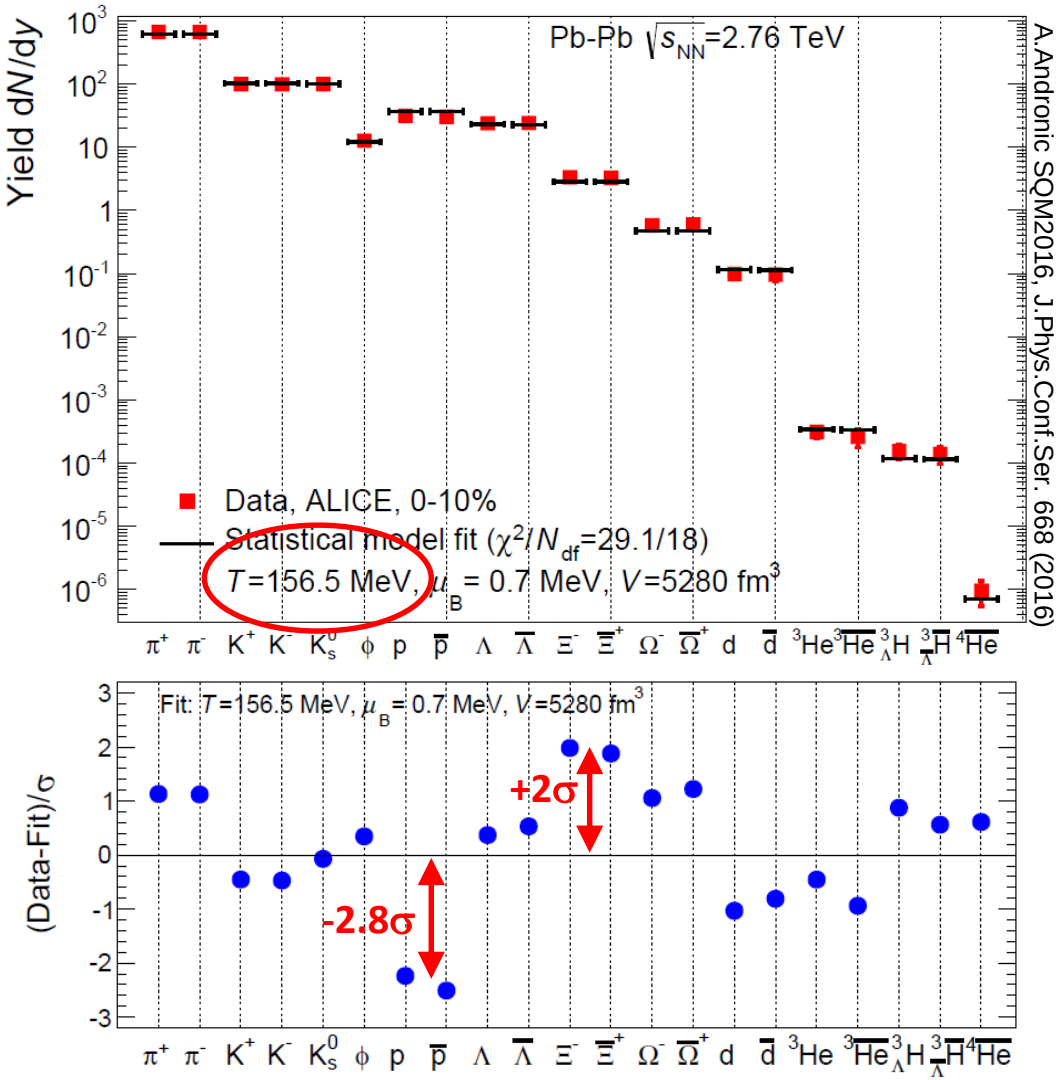
Protons in STAR corrected a-posteriori for feed-down. New heavy flavour tracker will allow to disentangle.

RHIC fit allows prediction for LHC

↓

Thermal model LHC

Simplest application of Thermal Model:



Tension for:

- **protons** (would favour lower T_{ch})
- Ξ (would favour higher T_{ch})

Run2 data will NOT cure this discrepancy!!

Possible solutions:

- re-scattering in the hadronic phase
  - Enforced hint from Run2 data for protons
  - …but no more hint for Ξ !
- Sequential freeze-out
  - Needs dedicated studies (fluctuations)
  - Requires high statistics
- …

Check R. Bellwied's talk
Mon 10/07 h.17:50

Summary

Conclusions and Outlook

After ~15 years from the RHIC start-up, low-μ_B experiments have produced an impressive amount of results on strangeness production in heavy ions and hadronic collisions

Results show:

Smooth **strangeness enhancement** pattern pp→p-A→A-A
Driven by multiplicity – No energy dependence at LHC (→RHIC?)
Canonical suppression describes data, but fails for ϕ!

v_2 and spectra ratios: **strangeness participates to hydro** expansion
Blast-Wave fit hints to $\neq T_{kin}$ wrt non-strange particles
Multiplicity smoothly **drives Λ/K^0_S** from pp to Pb-Pb

Coalescence seems to be the dominant process at intermediate p_T

Thermal model describes particle yields in A-A at LHC over 9 orders of magnitude. **Tensions** could **hint** to hadronic **re-scattering** and/or **sequential freeze-out**

Outlook:

BES data and pp(pA) VS mult @ RHIC

Solve ALICE-CMS tension on BW. Perform strangeness-dedicated fit

v_2 for multi-strange from LHC Run-2 data

Fit to LHC Run-2 data

Suggested talks and posters

Michal Sefcik
Strangeness production in Pb-Pb collisions at LHC energies with ALICE
Thursday 13/07 h.11:30 [Strangeness]

Hong Ni
Strange and Multi-strange Particle Production in pPb and PbPb with CMS
Thursday 13/07 h.12:10 [Strangeness]

Fiorella Fionda
Energy and multiplicity dependence of (non-)strange particle production in pp coll. at the LHC with ALICE Thursday 13/07 h.11:10 [Small Systems]

Rafael Derradi De Souza
Measurement of (multi-)strange hadron production in high-multiplicity pp collisions at 13 TeV with ALICE
Tuesday 11/07 [Poster]

Neelima Agrawal
Probing the hadronic phase with resonances of different lifetimes in ALICE at the LHC
Friday 14/07 h.16:45 [Resonances]

Rene Bellwied - *Sequential strangeness freeze-out* - Monday 10/07 h.17:50 [Plenary]

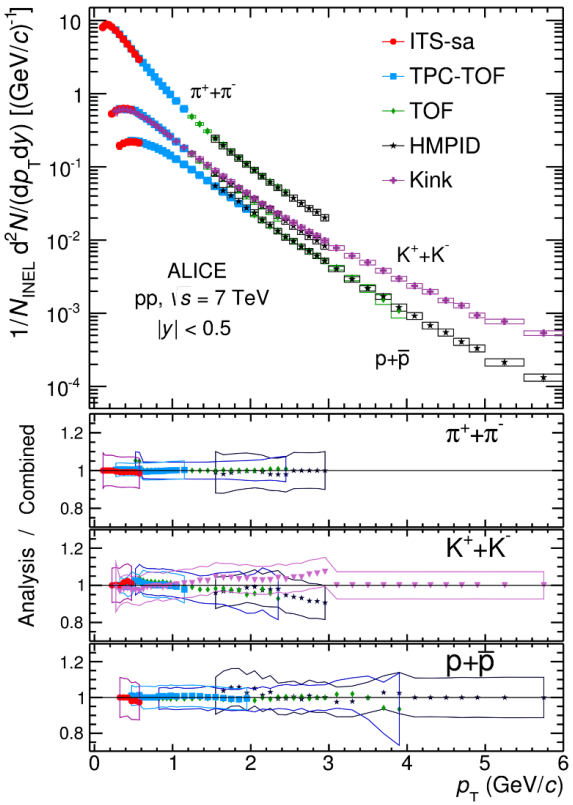
Anders Knospe - *Resonance production in heavy-ion collisions* - Friday 14/07 h.09:00 [Plenary]

Roberto Preghenella - *Small collision systems at the LHC* - Saturday 15/07 h.09:30 [Plenary]

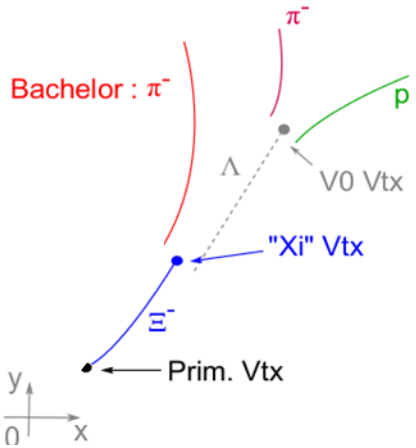
Backup

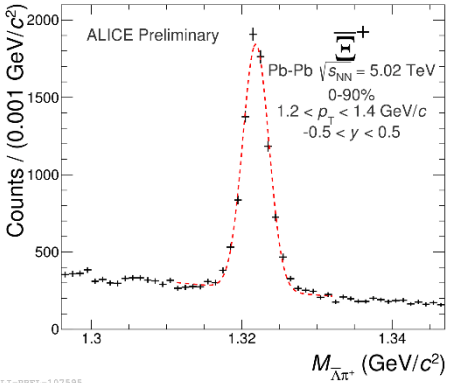
Good Results = good PID + good tracking

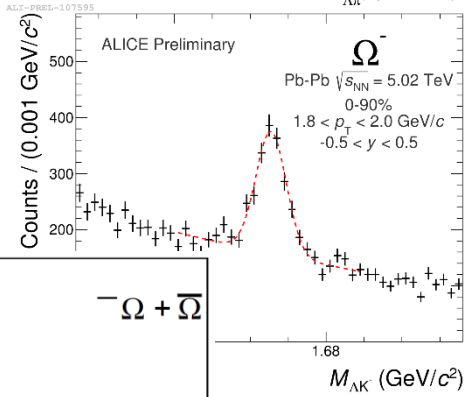
π, K and p spectra reconstructed using several techniques to cover different p_T ranges

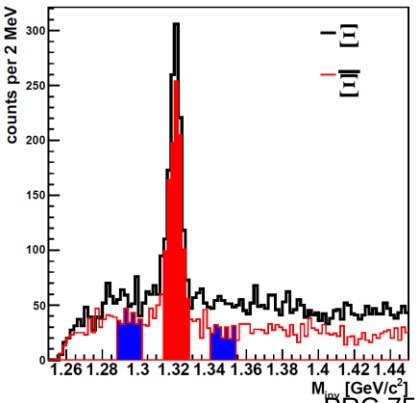


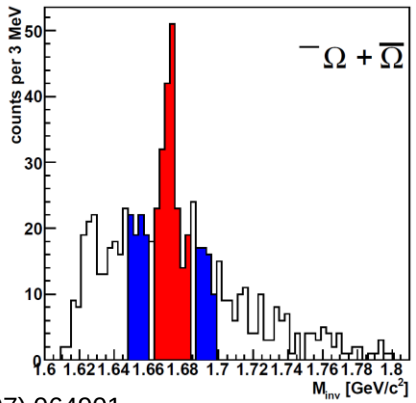
Weak decays reconstructed topologically and applying PID to identify daughters







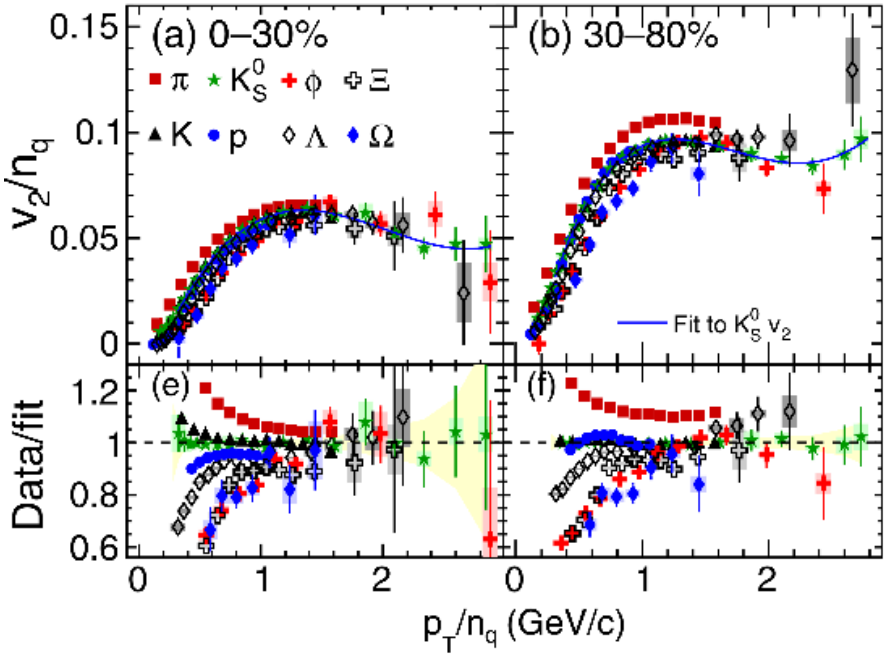




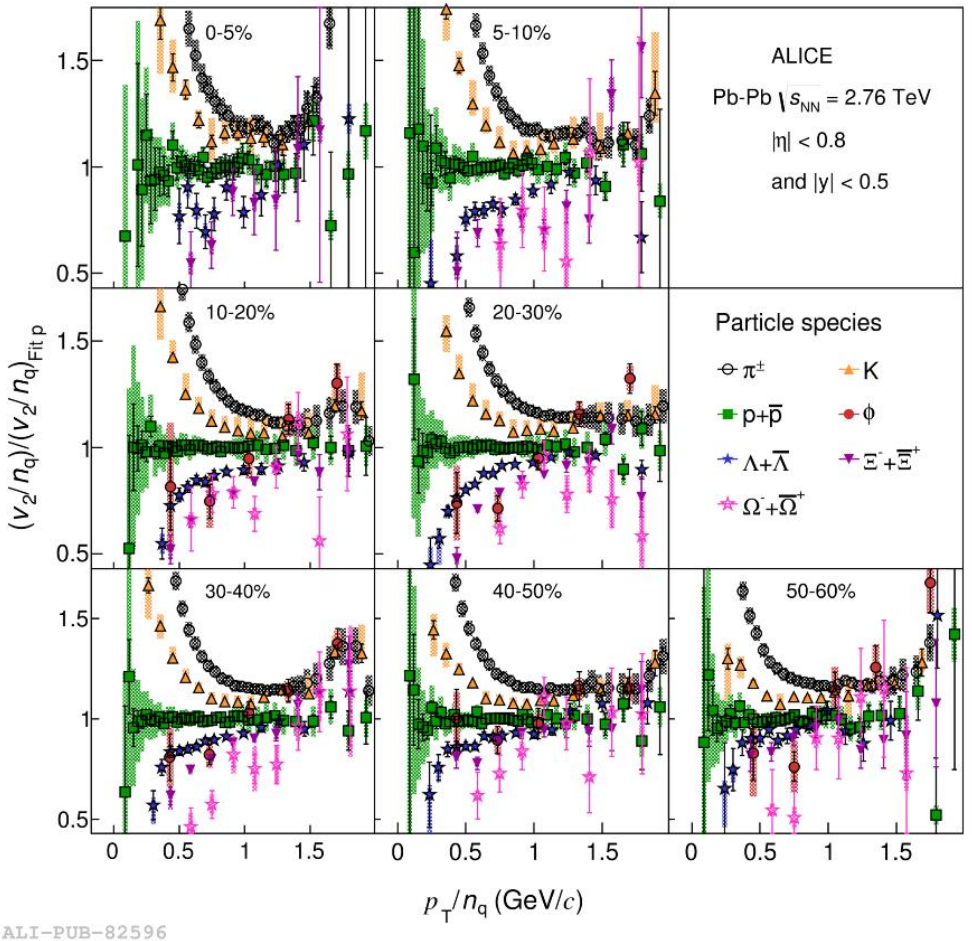
PRC 75 (2007) 064901

v_2: n_q scaling (?)

STAR

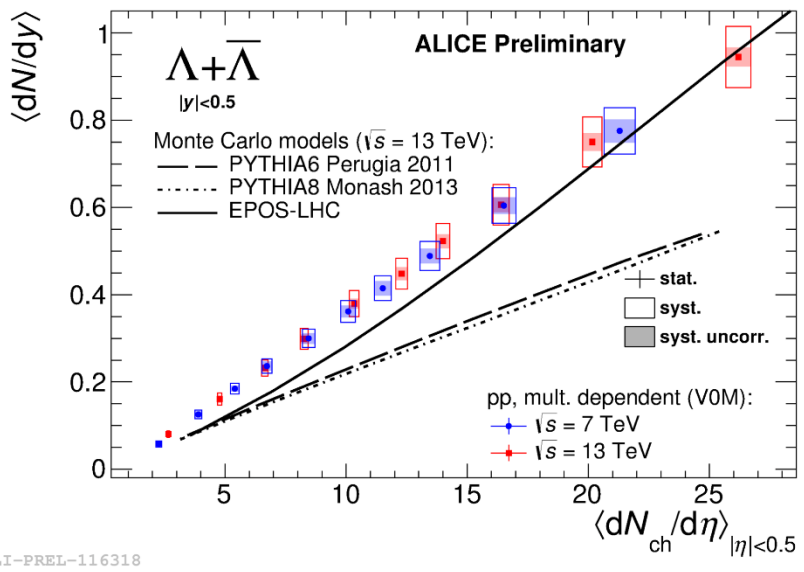


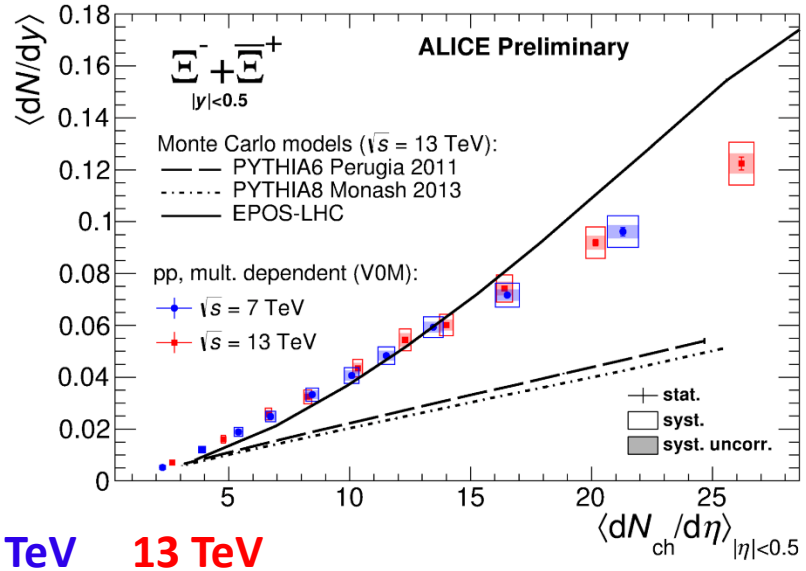
ALICE



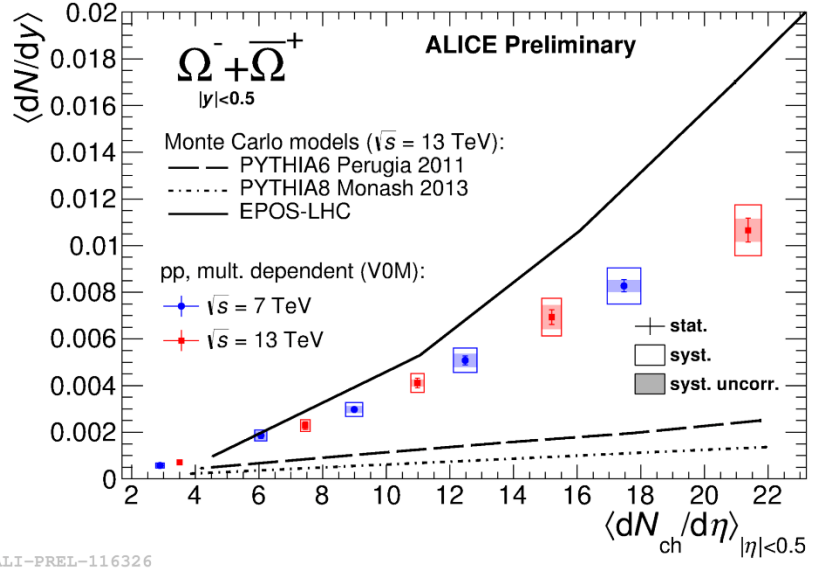
n_q scaling holds only up to the 10% at RHIC and 20% at the LHC

Strangeness enhancement: energy dependence?





7 TeV **13 TeV**



Strangeness enhancement does not depend on √s

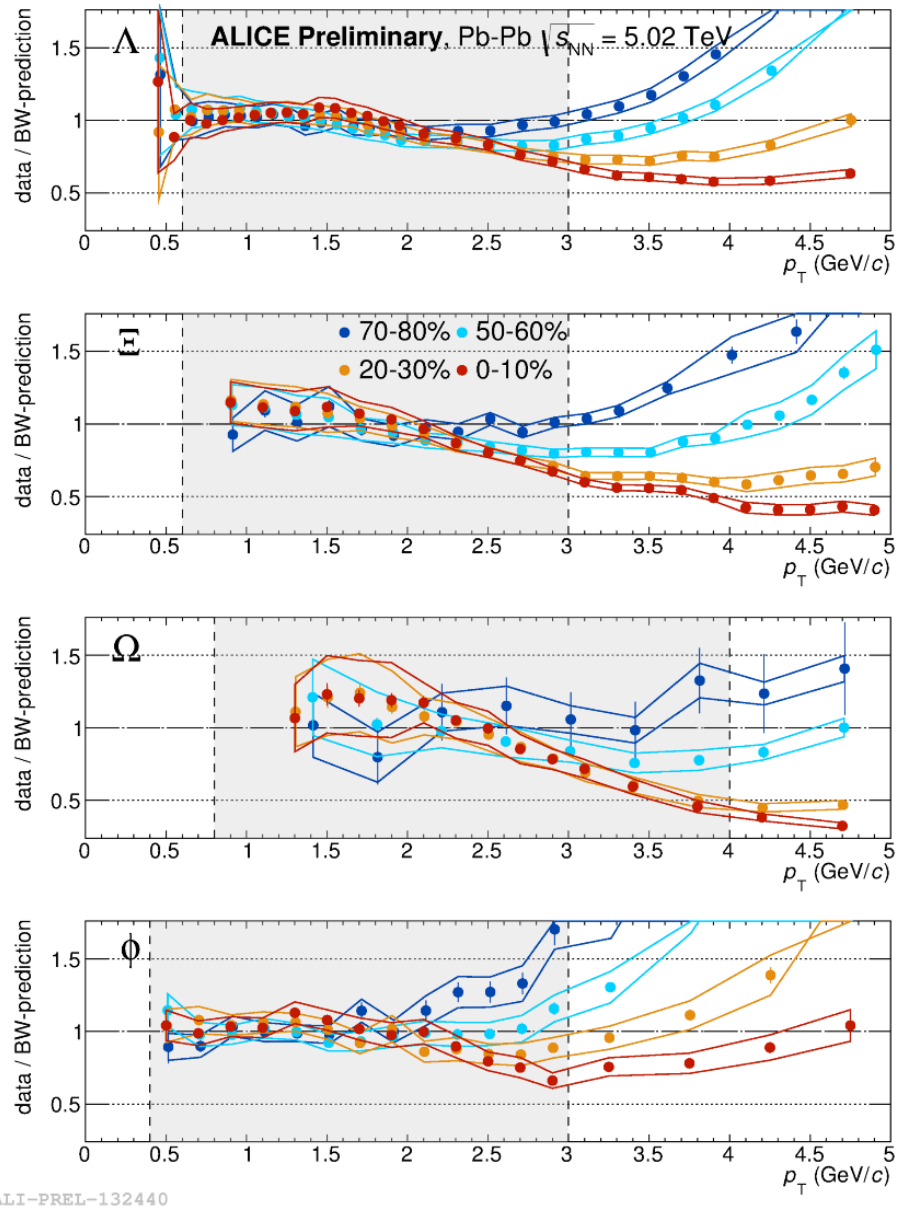
Will complement this with high multiplicity triggers at 13 TeV (should reach ~ $dN_{ch}/d\eta = 50$)

Blast Wave details

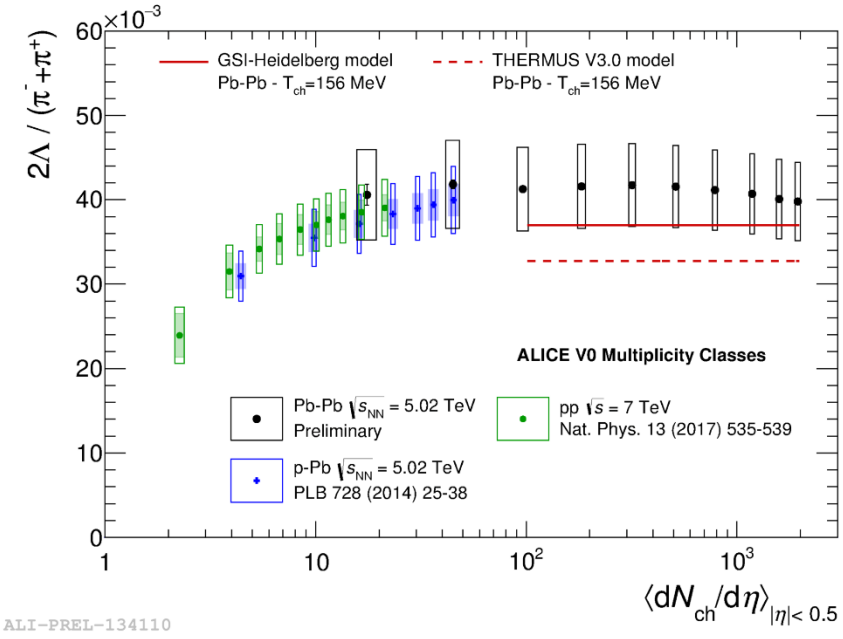
$$E\frac{d^3N}{dp^3} \propto \int_0^R m_T I_0\left(\frac{p_T \sinh(\rho)}{T_{Kin}}\right) K_1\left(\frac{m_T \cosh(\rho)}{T_{Kin}}\right) r\, dr$$

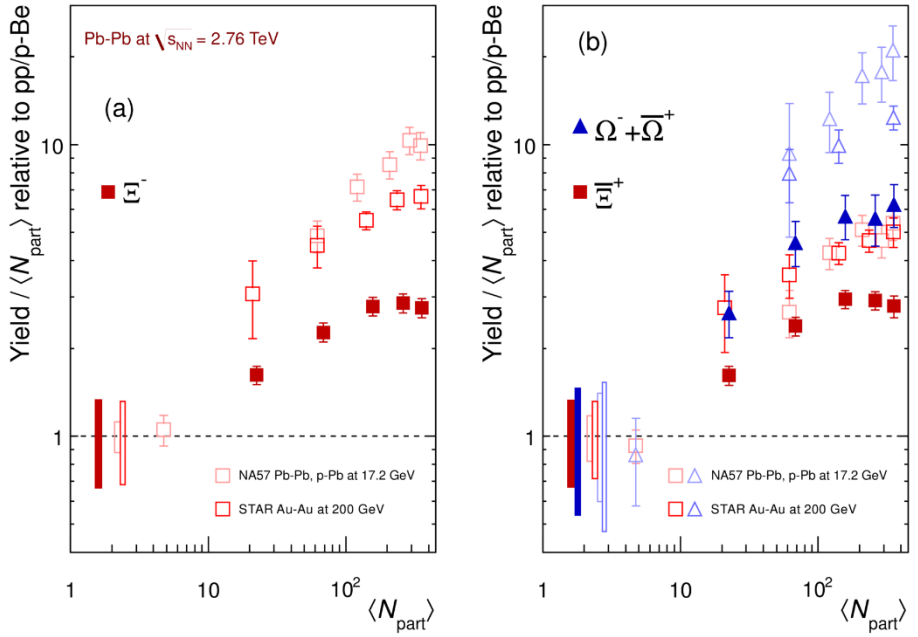
$$m_T = \sqrt{m^2 + p_T^2} \qquad \rho = \tanh^{-1}(\beta_T) \qquad \beta_T = \beta_s \left(\frac{r}{R}\right)^n$$

Schnedermann, Sollfrank and Heinz Phys. Rev. C 48, 2462



Other plots





Thermal model results from Run-1 data fit!!