Energy and multiplicity dependence of the strangeness enhancement in pp collisions

F. Bellini (CERN) for the ALICE Collaboration

MPI workshop – Shimla, 12.12.2017

Outline

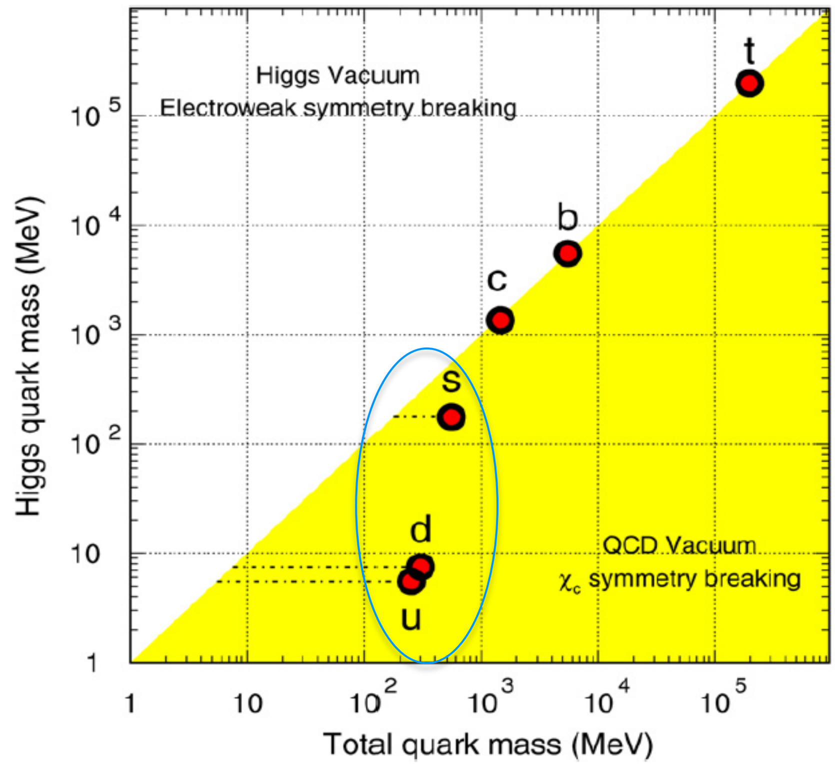
- Strangeness enhancement from the “historical” perspective of heavy ion collisions to pp
- Focus on the production of strangeness in pp collisions
- Comparison with models
- Perspectives for more measurements and outlook

→ *Input for discussion*

Strangeness from the HI perspective

- ~300 MeV are enough to create an $s\bar{s}$ pair[1] (even less if $m_s^{QCD} \rightarrow m_s^{Higgs}$ by restoration of chiral symmetry in the QGP phase)
- Strange quarks are dominantly produced by (thermalised[2]) gluon fusion in QGP
- Strangeness enhacement wrt pp collisions historically proposed as signature for a deconfined QGP[3]
- pp collisions as reference

arXiv:nucl-ex/0610043



$m_u \approx 2.3$ MeV
$m_d \approx 4.8$ MeV
$m_s \approx 96$ MeV

$< \Lambda_{QCD}$
$<< m_c \approx 1.3$ GeV

[1] PDG group, Chin. Phys. C38 (2014) 090001
[2] E. Shuryak, Phys. Rev. Lett. 68 (1992) 3270
[3] J. Rafelski and B. Muller, PRL 48 (1982) 1066

Strangeness from the pp perspective 

- Producing strangeness is "expensive" → threshold problem

  E.g. in the Lund String model

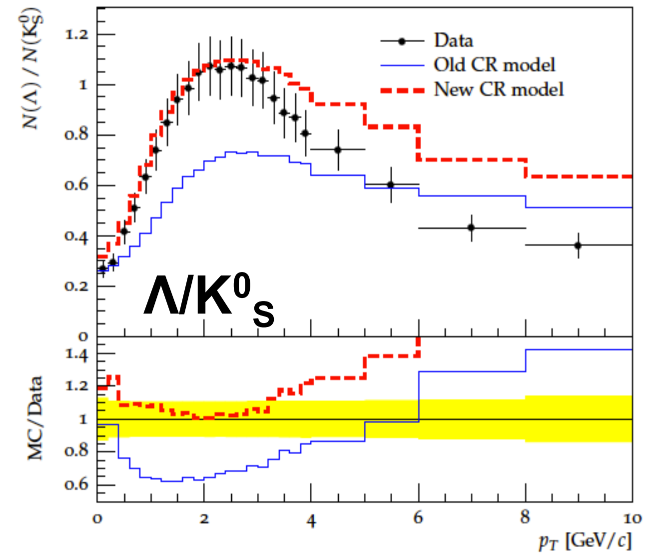
$$\mathrm{Prob}(m_q^2, p_{\perp q}^2) \propto \exp\left(\frac{-\pi m_q^2}{\kappa}\right) \exp\left(\frac{-\pi p_{\perp q}^2}{\kappa}\right)$$

  E.g. in a hadron gas
  π + π → π + π + Λ + Λ-bar, E_{th} ~ 2200 MeV

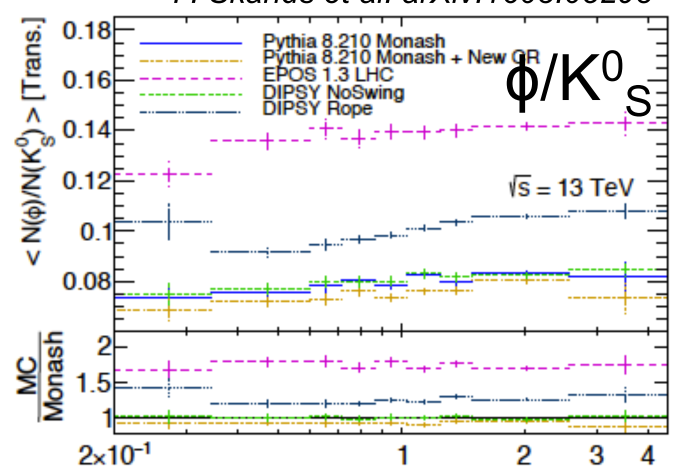
- Measurements of strange hadron production used as input for tuning Monte Carlo generators

- Contribute to the understanding of the rich structure of the underlying event arising from MPI in pp, p-Pb collisions

J.R. Christiansen, P. Skands, JHEP 08 (2015) 003

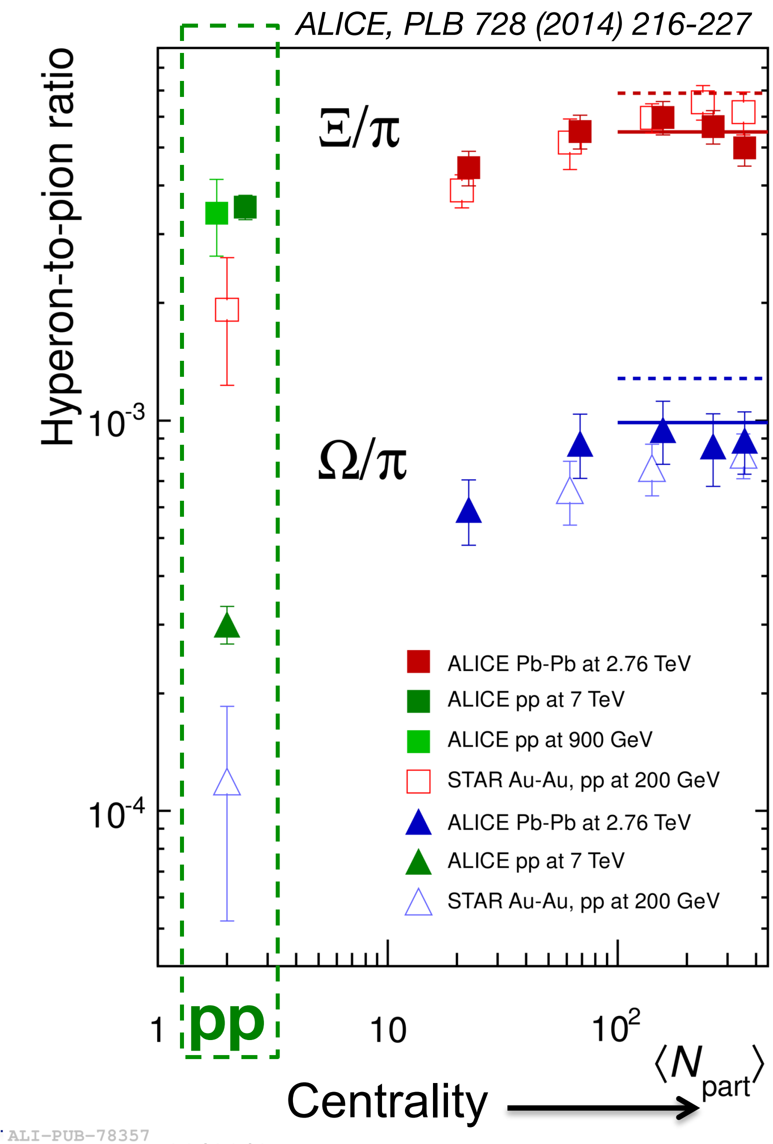


P. Skands et al. arXiv:1603.05298



Relative transverse activity, R_T

Strangeness enhancement



From pp to Pb-Pb strangeness production increases

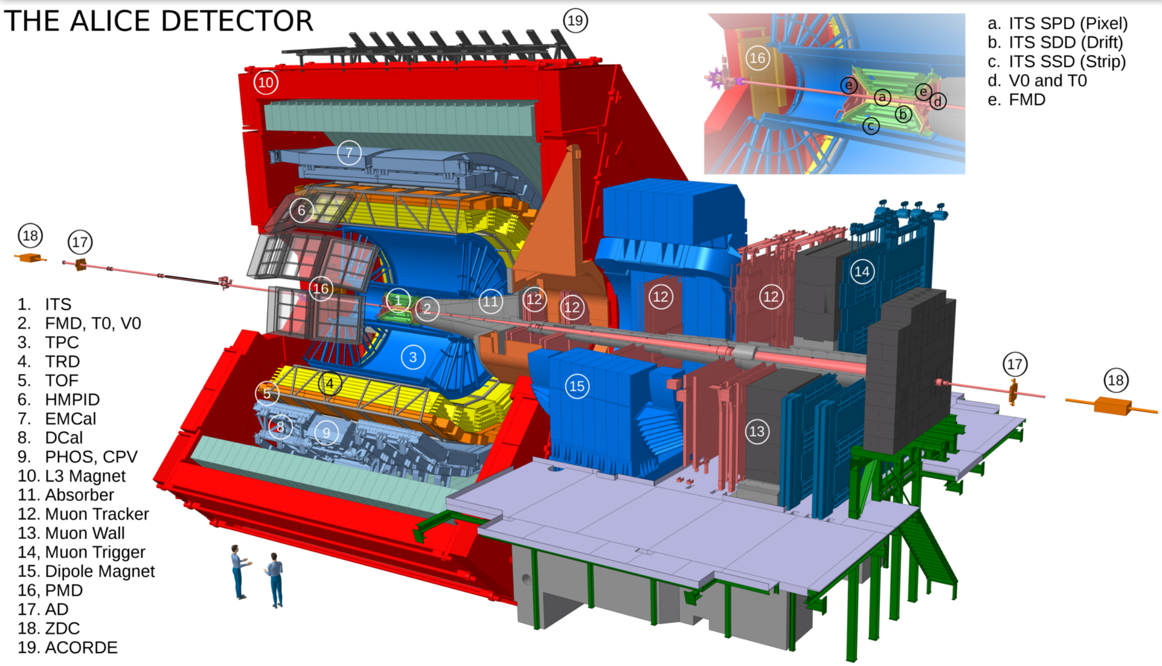
At RHIC and LHC, for similar multiplicities in A-A, similar relative strangeness production
(see also backup)

In pp collisions the production of strangeness relative to π at LHC is larger than at RHIC
→ understand the small system "reference"

Empty markers: RHIC $\sqrt{s_{NN}}$ = 200 GeV
Full markers: LHC $\sqrt{s_{NN}}$ = 2.76 TeV

FOCUS ON THE PRODUCTION OF STRANGENESS IN PP COLLISIONS

A Large Ion Collider Experiment

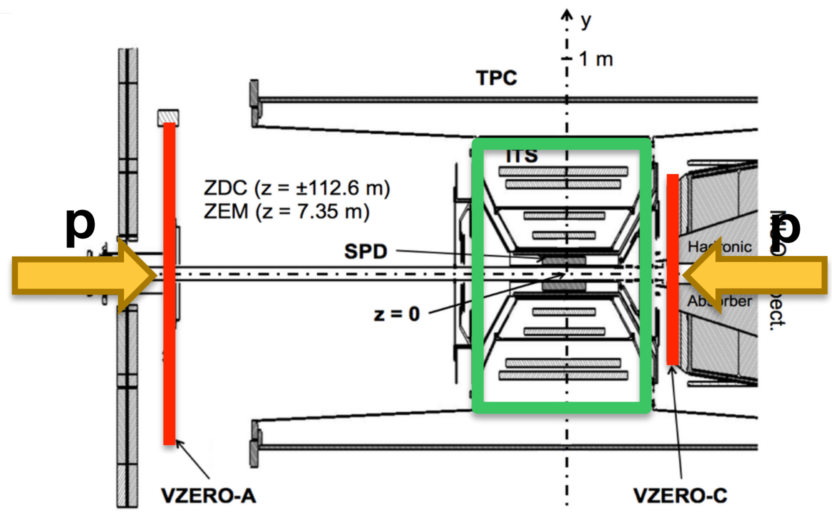


ITS, TPC: tracking, vertexing, PID via dE/dx, $|\eta| < 0.9$, reconstruction of the decay topology of weakly-decaying (multi-)strange hadrons

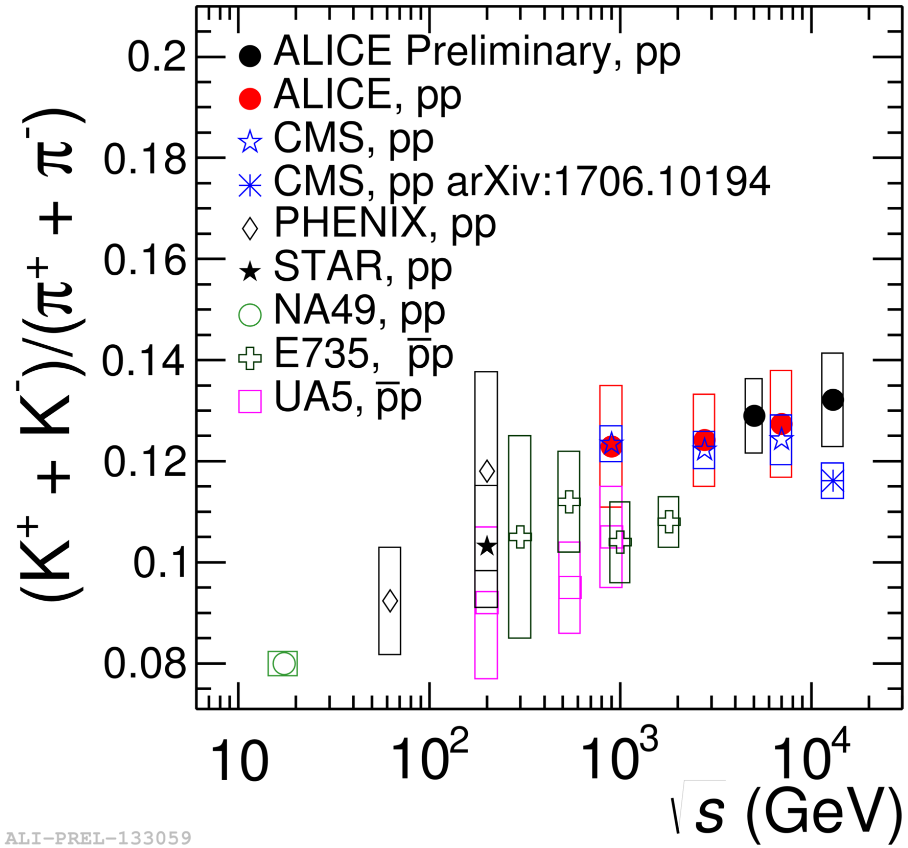
TOF: PID via Time-Of-Flight, $|\eta| < 0.9$, $\sigma_{TOF} \sim 80$ ps

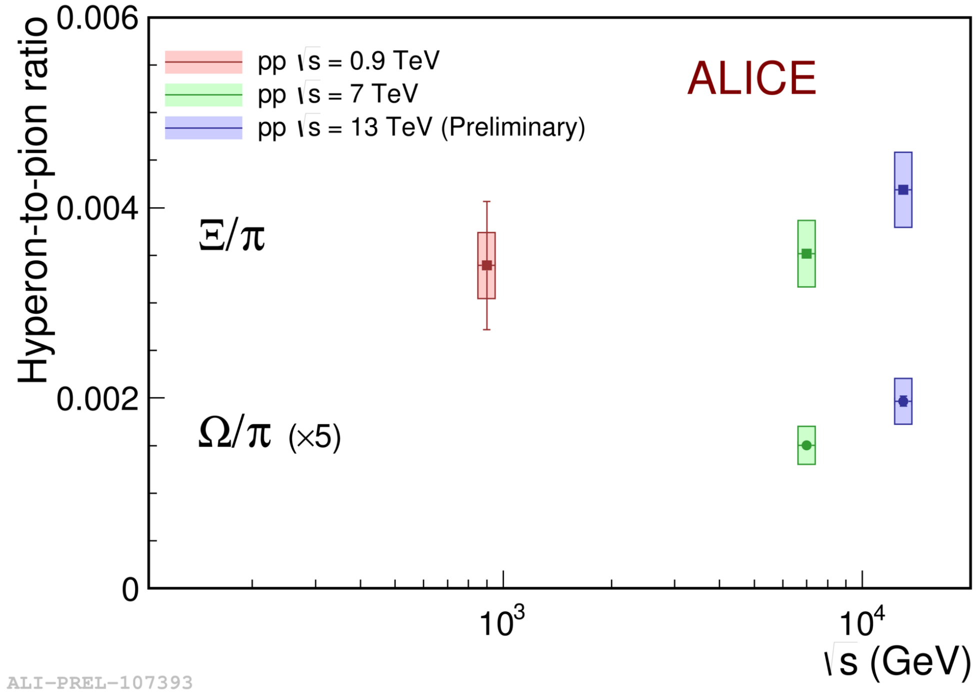
Event **multiplicity/centrality** classes are defined based on the amplitude measured in the **V0 scintillators**, placed at forward rapidity: $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C)

$\langle dN_{ch}/d\eta \rangle$ is measured in **SPD** in $|\eta| < 0.5$
→ avoid "auto-correlation biases"



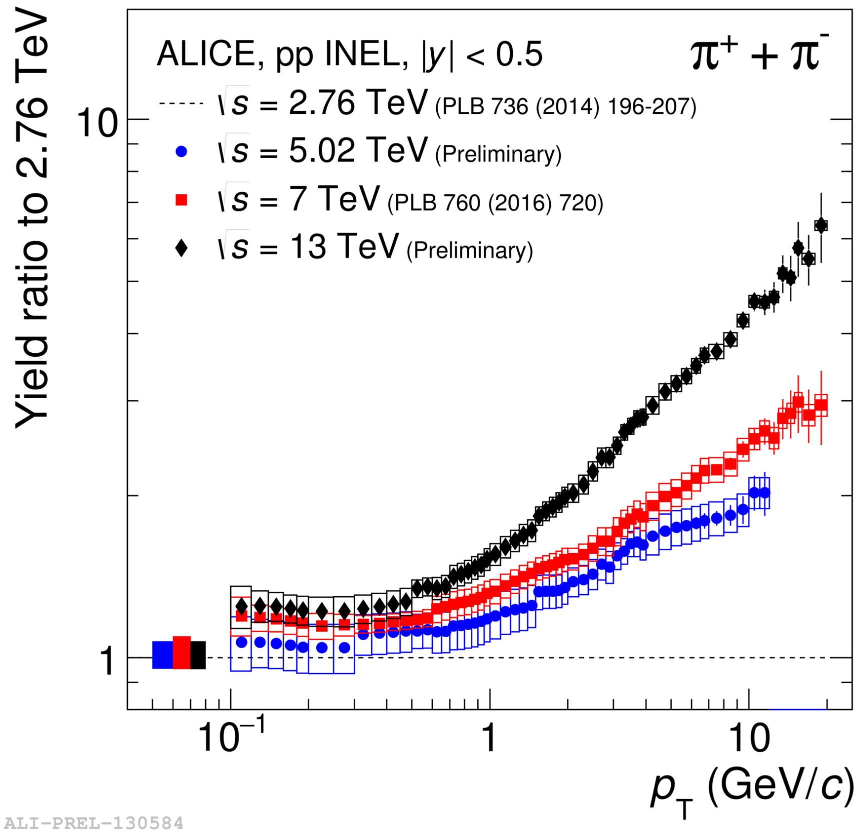
$\sqrt{s}$ dependence – relative yields

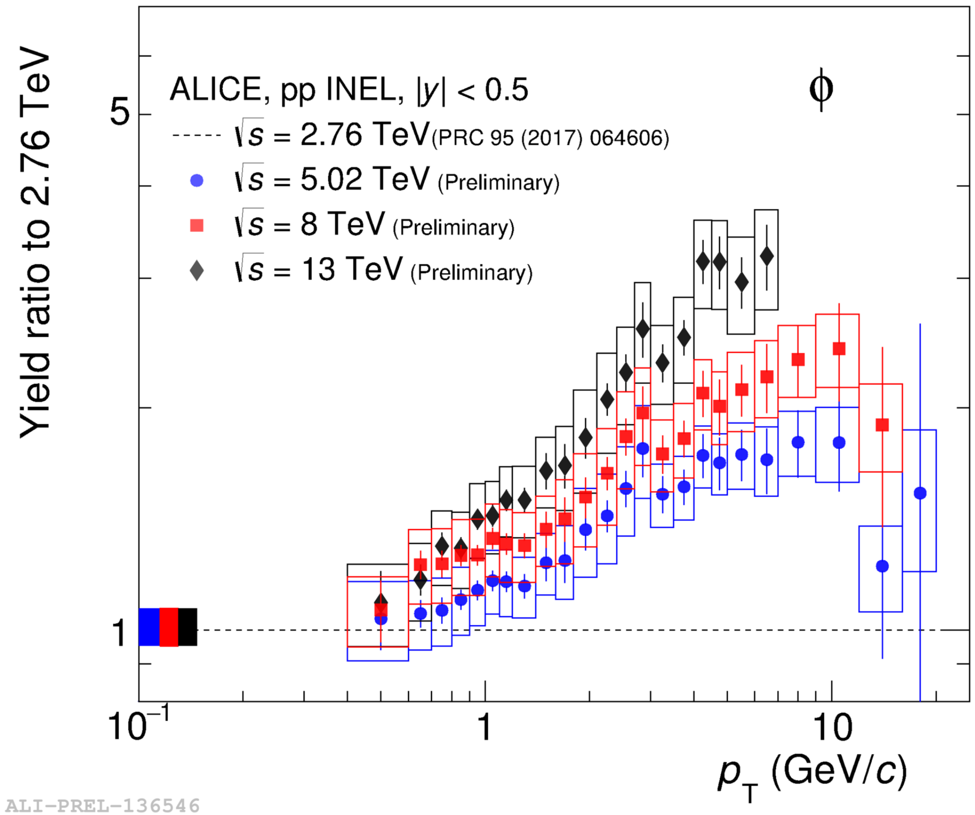




Hint for an increase in the production of (multi-)strange hadrons relative to π in **minimum bias pp** collisions as a function of √s at LHC energies

$\sqrt{s}$ dependence – p_T spectra



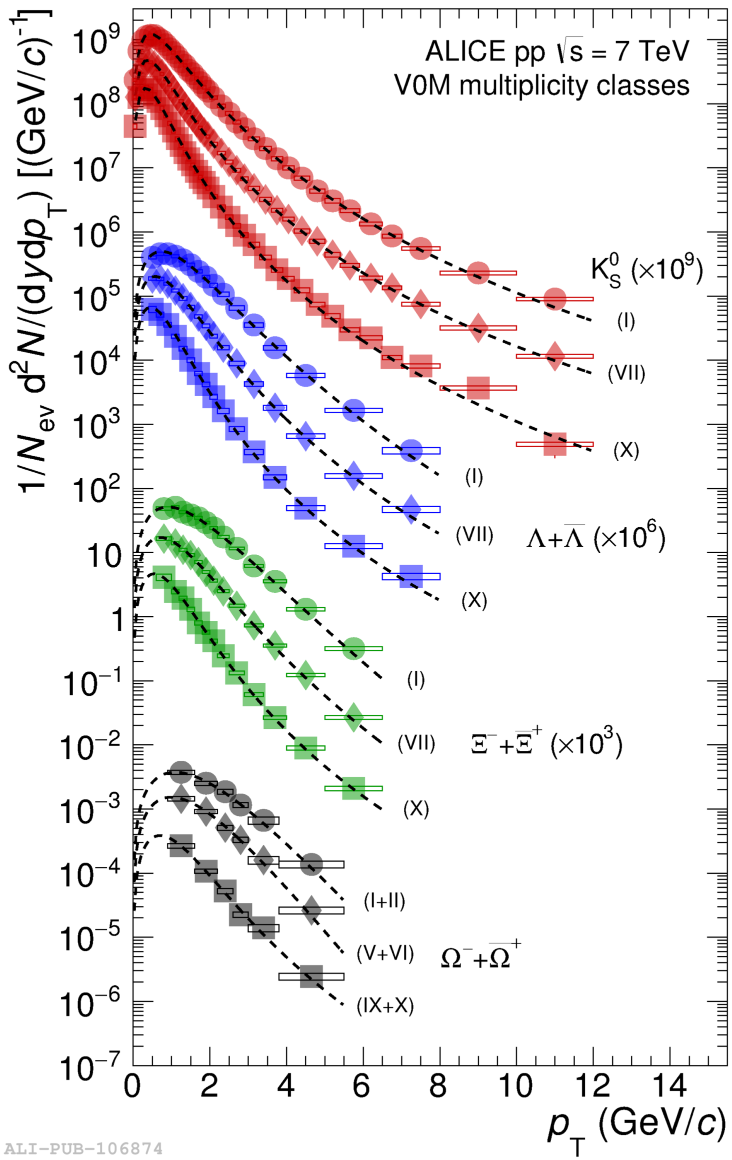


Strong energy dependence of spectra at high-p_T → hard regime

→ How does this reflect into $\langle p_T \rangle$?

→ Is $\langle p_T \rangle$ a suitable observable for model comparisons?

Multiplicity dependence – p_T spectra



ALICE, Nature Physics 13 (2017) 535-539

p_T differential yields of strange and multi-strange measured in 10 multiplicity bins

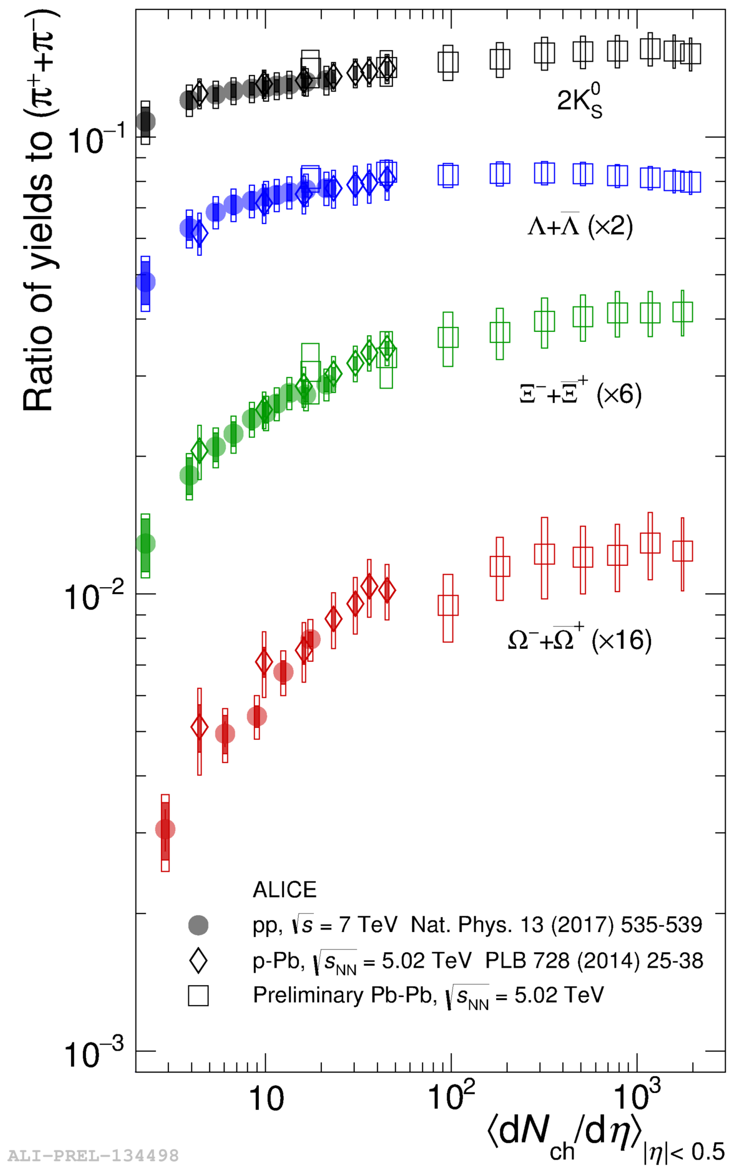
$$\begin{cases} I \rightarrow \langle dN_{ch}/d\eta \rangle \approx 3.5 \times \langle dN_{ch}/d\eta \rangle^{INEL>0} \\ \vdots \\ X \rightarrow \langle dN_{ch}/d\eta \rangle \approx 0.4 \times \langle dN_{ch}/d\eta \rangle^{INEL>0} \end{cases}$$

$$\left(\langle dN_{ch}/d\eta \rangle^{INEL>0} \approx 6.0 \right)$$

Spectra harden towards higher multiplicity (as observed in p-Pb and Pb-Pb)

p_T integrated yields extracted from measured points and extrapolation function at low p_T (Lévy-Tsallis, dashed line)

Multiplicity dependence – relative yields



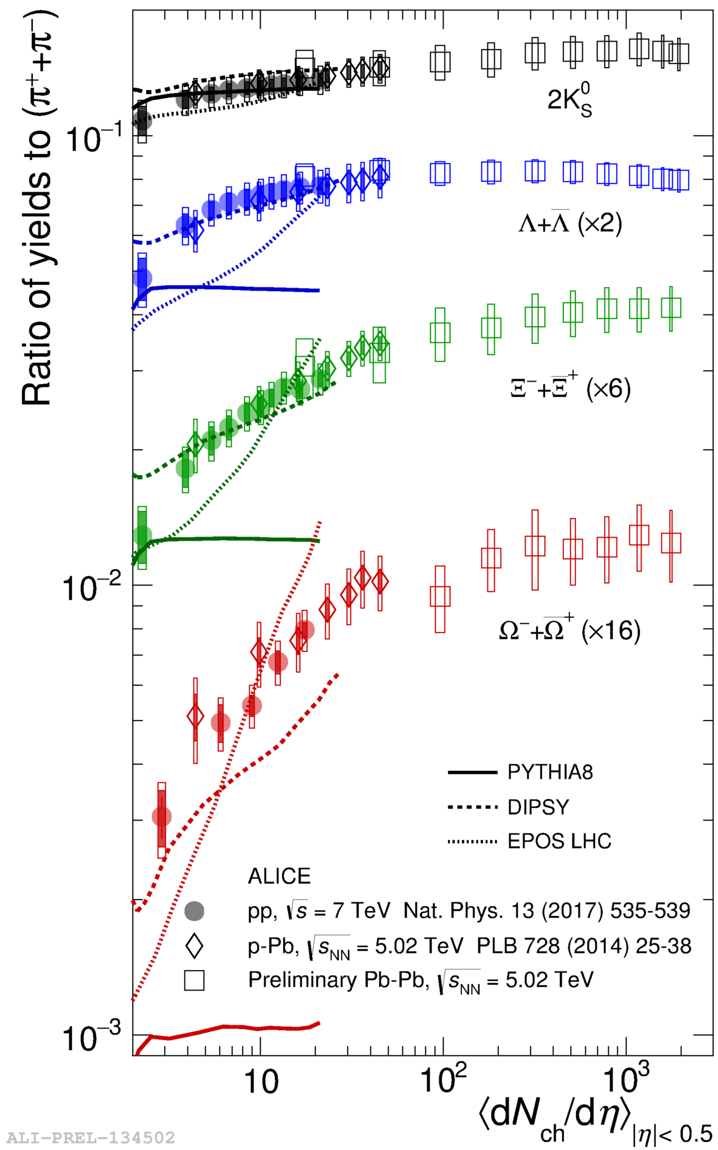
(Multi)strange to non-strange yield ratios increase significantly and smoothly with multiplicity in pp and p-Pb collisions

Smooth evolution of ratios and similarities across systems also for other light flavour hadrons and observables
→ A.K. Dash, N. Sharma

pp and p-Pb trends are remarkably consistent at similar multiplicities

→ What is driving the increase in small systems?
Mass, baryon/meson, strangeness content?

Model comparison – Relative yields



Models as

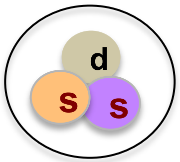
- PYTHIA8 (color reconnection)
- DIPSY (color ropes)
- EPOS LHC (core+corona)

exhibit a trend with multiplicity but may still **need tuning to reproduce all ratios simultaneously**

→ PYTHIA8 + ropes recently available
[C. Bierlich, HL-LHC workshop, CERN 31/10/2017]

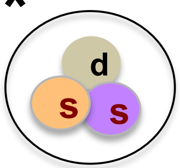
Multiplicity dependence – relative yields

Ξ

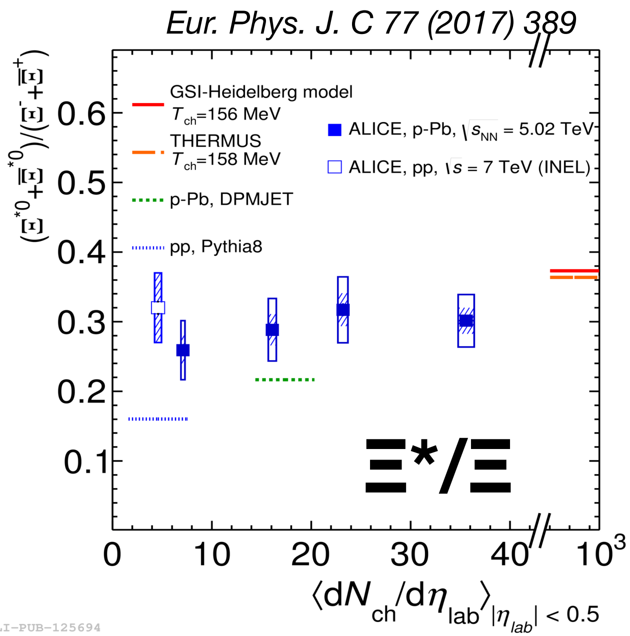


M ~ 1320 MeV

Ξ*



M ~ 1530 MeV

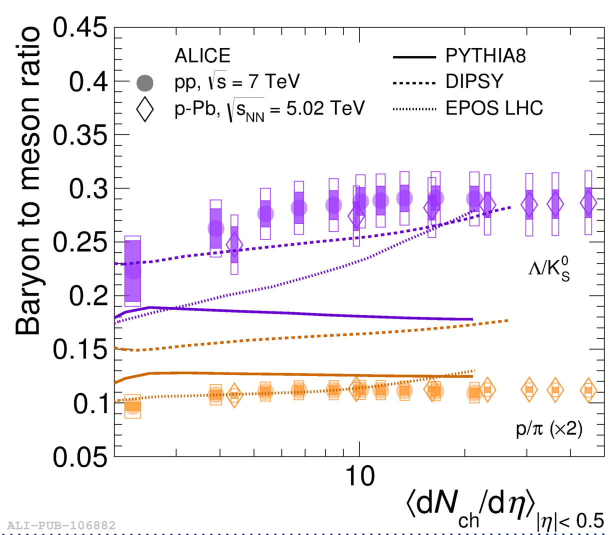


Ξ(1530)⁰ relative to π exhibits same increase with multiplicity in p-Pb as Ξ/π (Ξ*/Ξ flat)

→ Strangeness content more relevant than mass

Λ/K^0_S

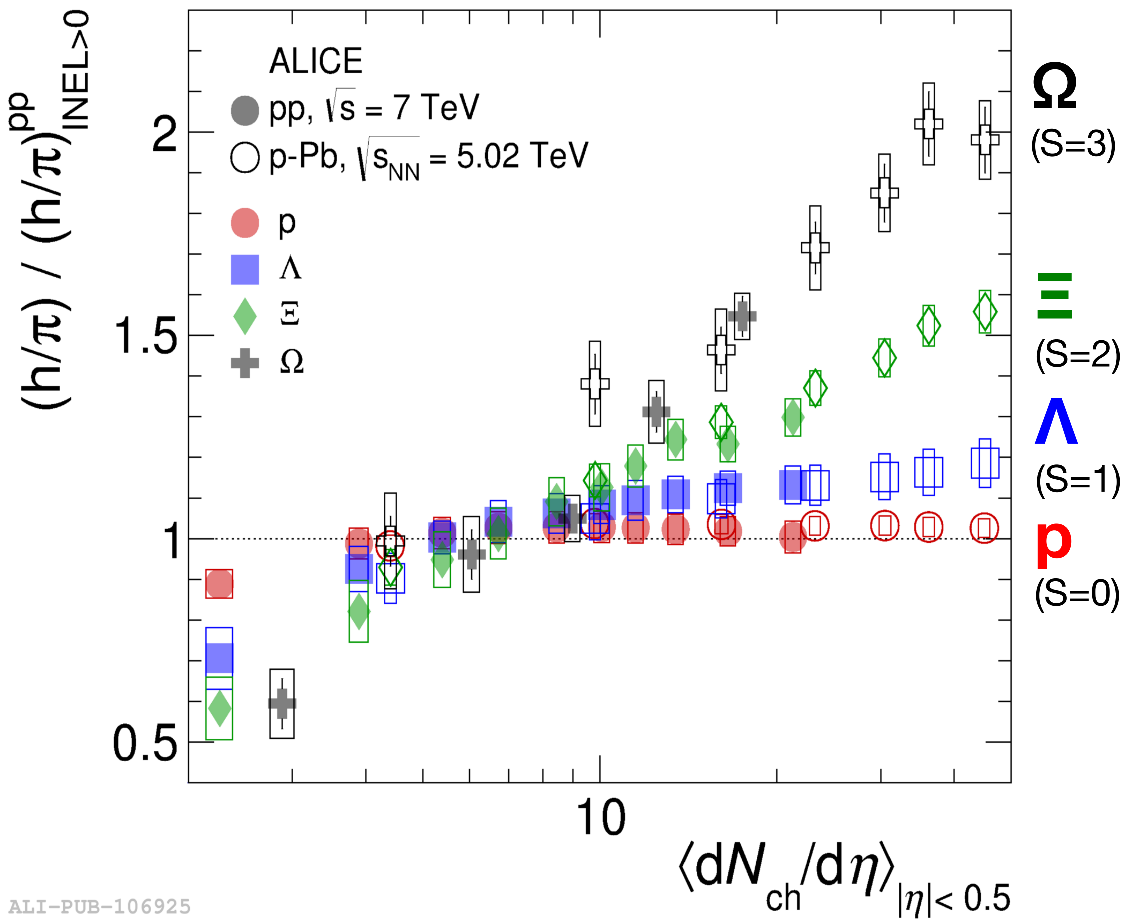
p/π



Baryon-to-meson ratios where the net strangeness content is zero, as p/π and Λ/K^0_S, are flat with multiplicity

→ Not a baryon/meson effect

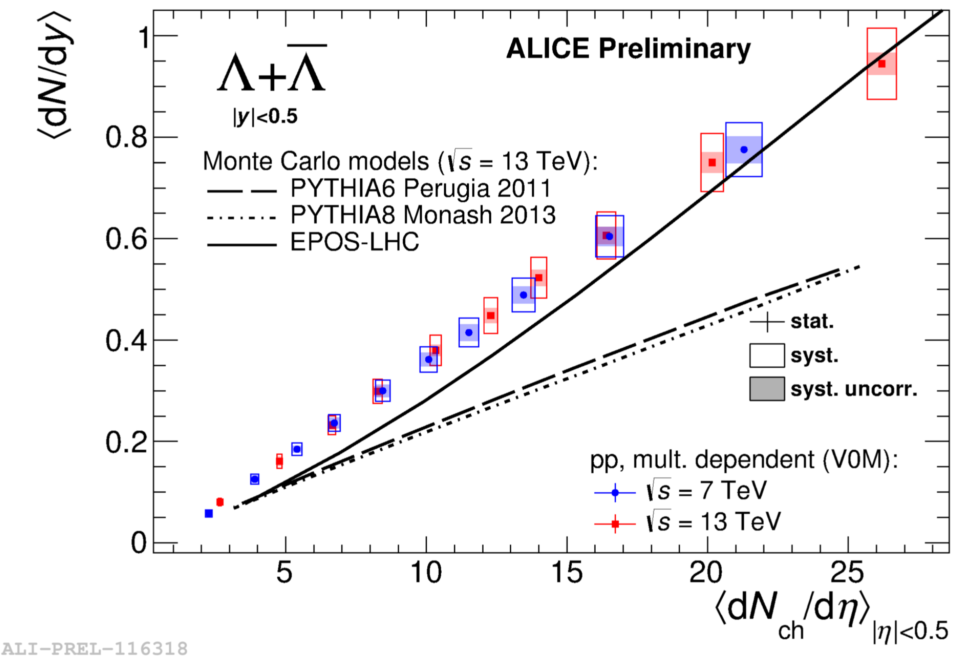
Strangeness enhancement in pp

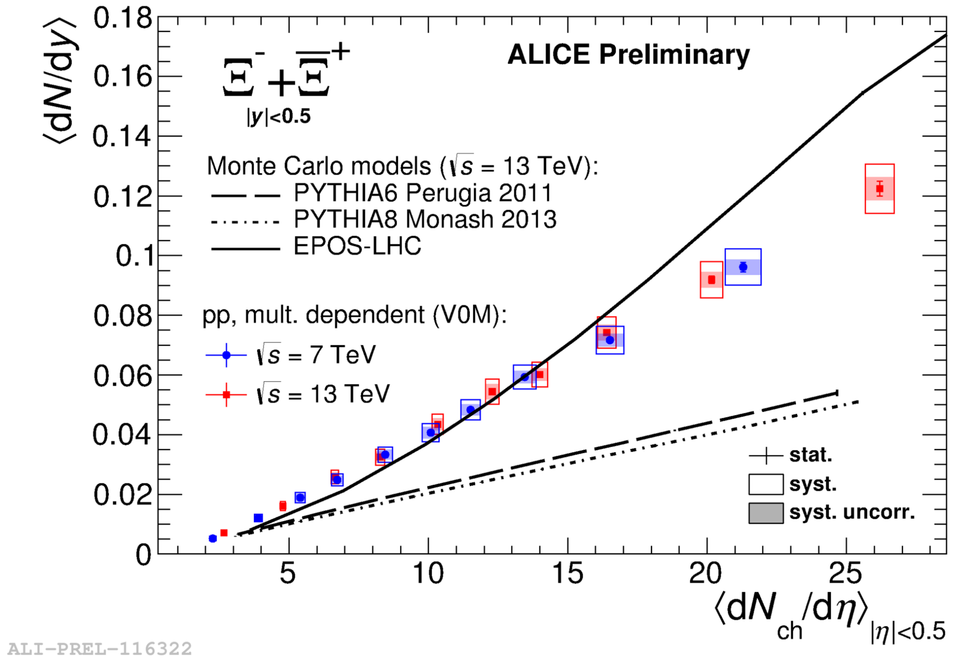


No increase for p/π is observed

Hierarchy of the increase associated **with the strangeness content**

$\sqrt{s}$ and multiplicity dependence - yields





Yields in pp 13 lie on the same trend with multiplicity as the 7 TeV data

The **event activity** drives particle production, **irrespective of the collision energy**

PYTHIA has troubles with (multi-)strange baryons
EPOS-LHC gives qualitative agreement for most particle species

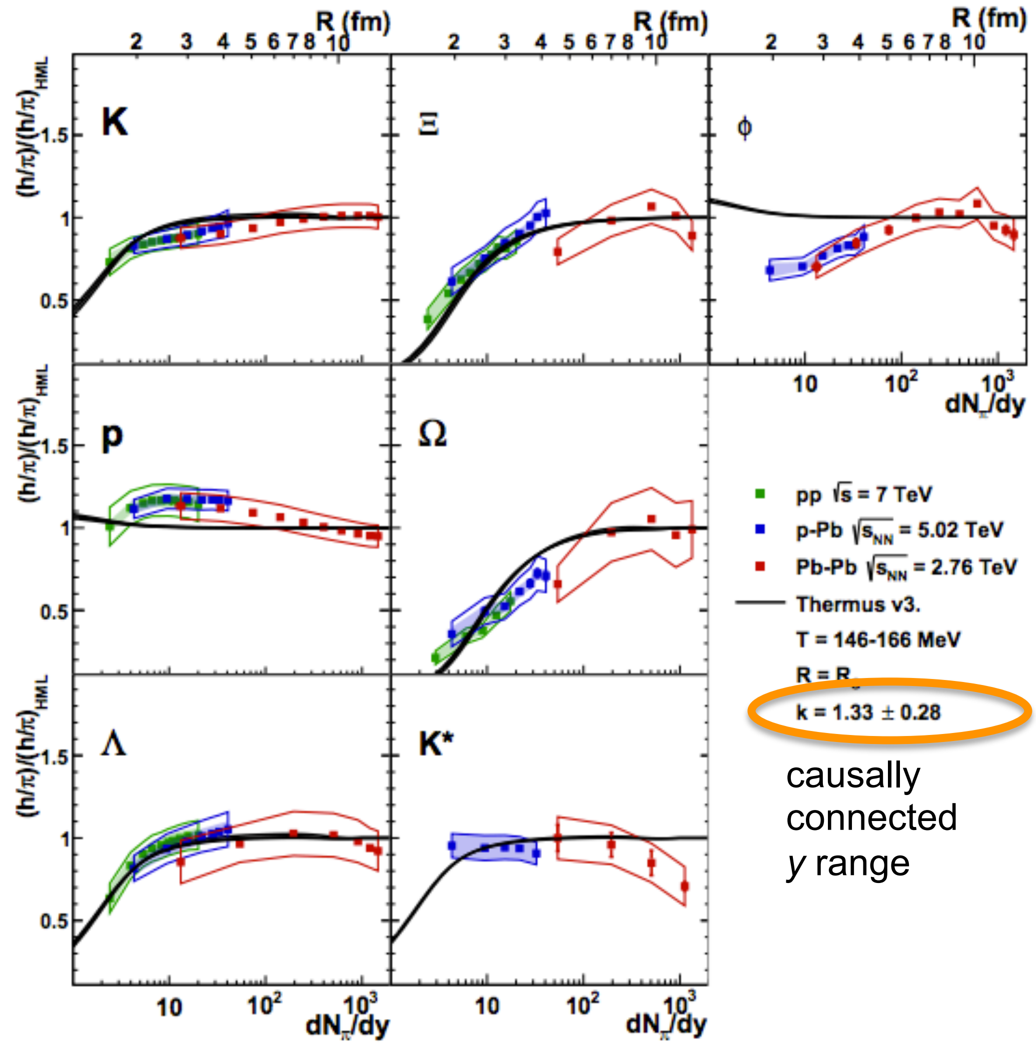
Statistical Hadronisation Model

In equilibrium SHM models strangeness enhancement is a result of the **canonical suppression** of strangeness production **in small systems** due to the explicit **conservation** of the **strangeness** quantum number in a finite system

First comparisons to model calculations based on THERMUS code

→ agreement with data within uncertainties, except for ϕ meson (also "immune" to canonical suppression)

V. Vislavicius, A. Kalweit, arXiv:1610.03001



The special role of ϕ meson

As a s-sbar pair (S=0) with the same mass as the proton, the ϕ meson is "special"

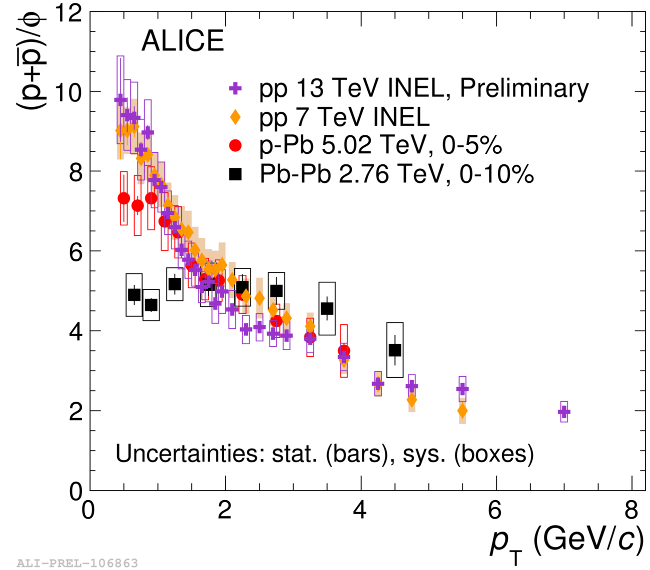
In pp the ϕ spectrum is harder than p, but no significant $\sqrt{s}$ dependence is observed

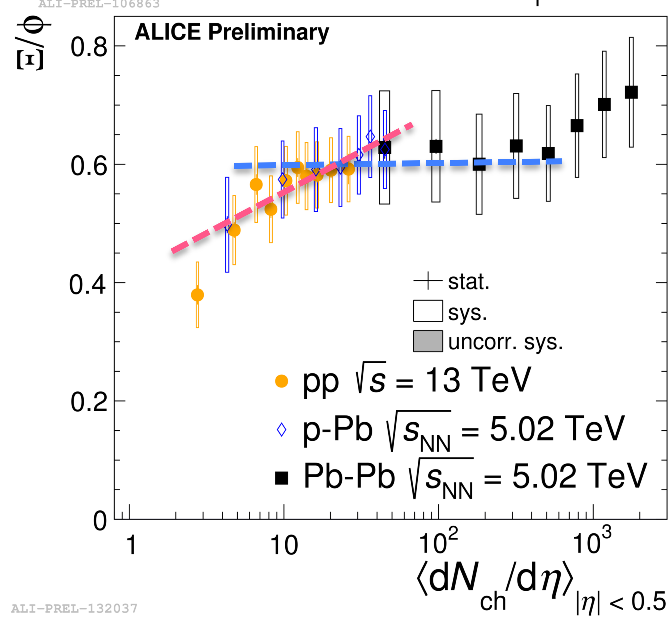
In central Pb-Pb collisions, where radial flow is strong, p/ϕ is flat vs p_T.

→ Does ϕ behave like a S=0 or S=2 particle?

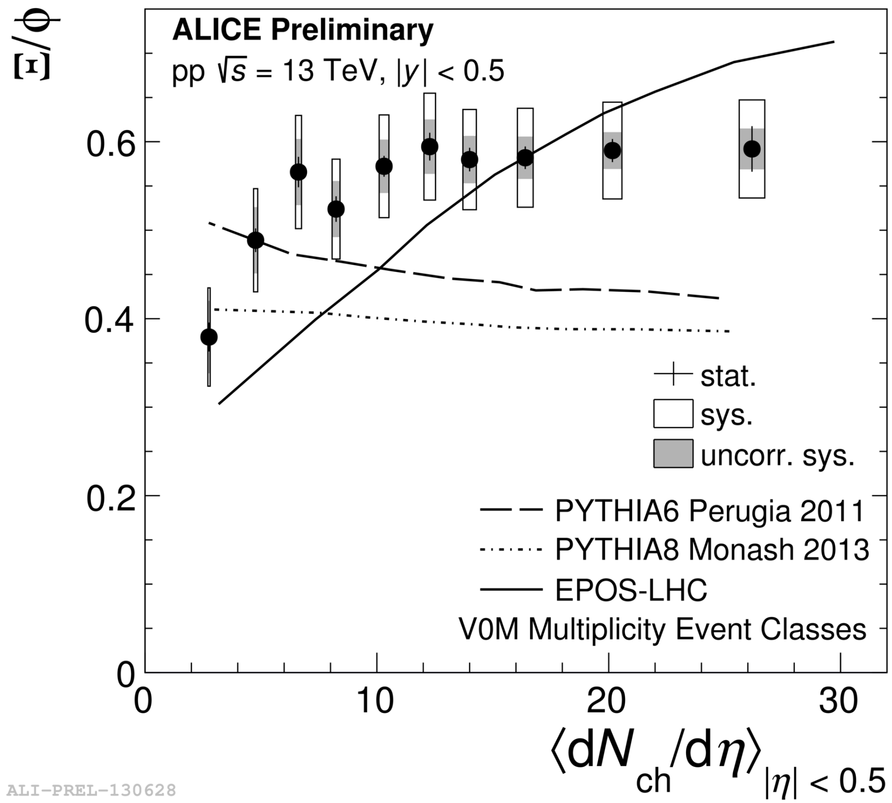
Flat Ξ/ϕ for multiplicities between ~6 and ~700? Or slightly increasing in pp, p-Pb vs multiplicity?

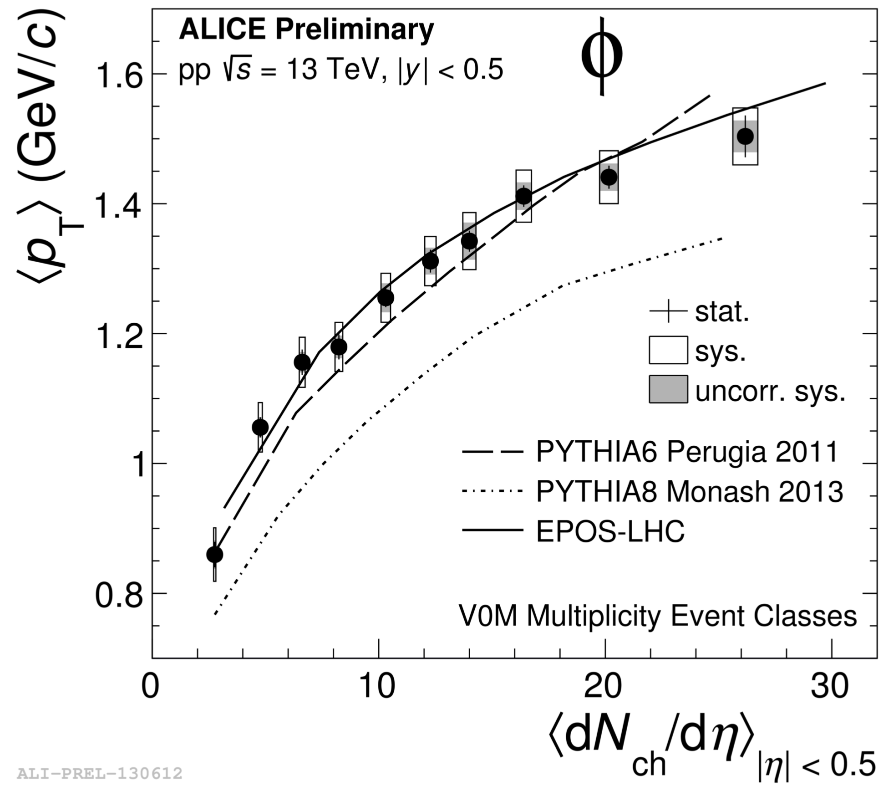
→ Need more precision from experiment!





ϕ meson and models





Ratio Ξ/ϕ is not well described by models.

PYTHIA6 and EPOS-LHC describe well the multiplicity dependence of <p_T>, whereas PYTHIA8 underestimates it.

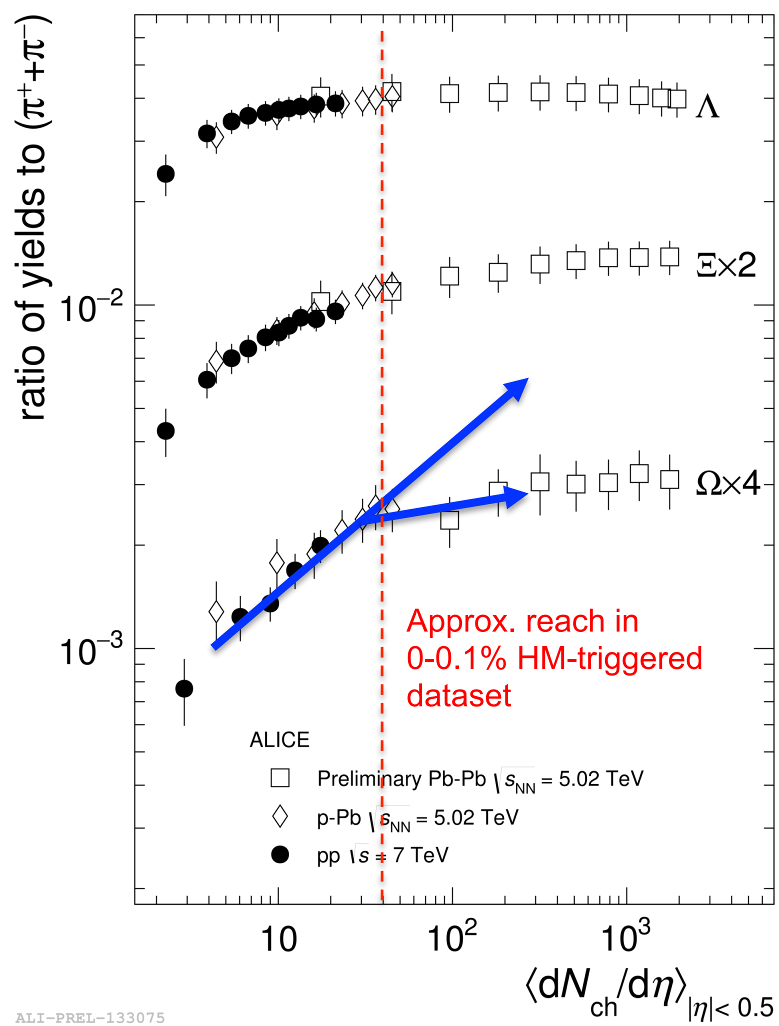
PERSPECTIVES FOR MORE MEASUREMENTS AND OUTLOOK

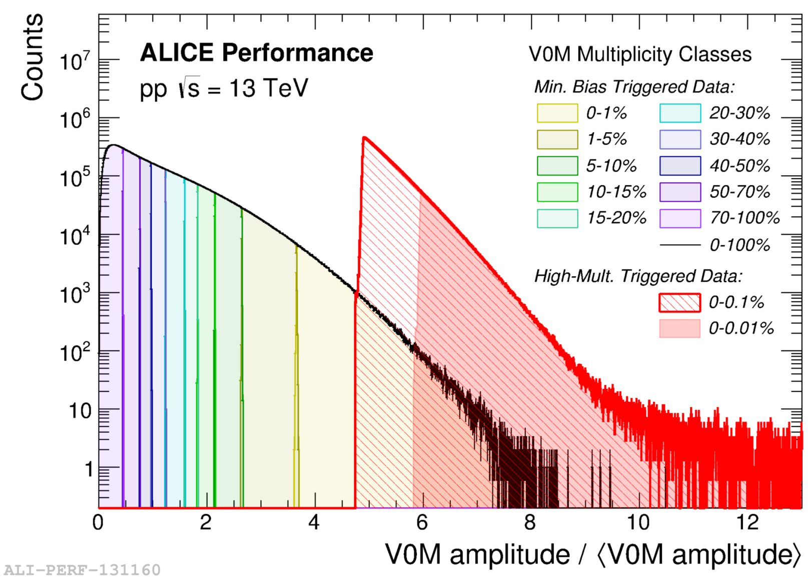
What's next?

① Does strangeness keep increasing with multiplicity or saturate?

High multiplicity-triggered data sample in pp 13 TeV (2016, 2017) being analysed

Measure in p-Pb at 8.16 TeV, Xe-Xe at 5.44 TeV, more differential in peripheral Pb-Pb collisions (2018)

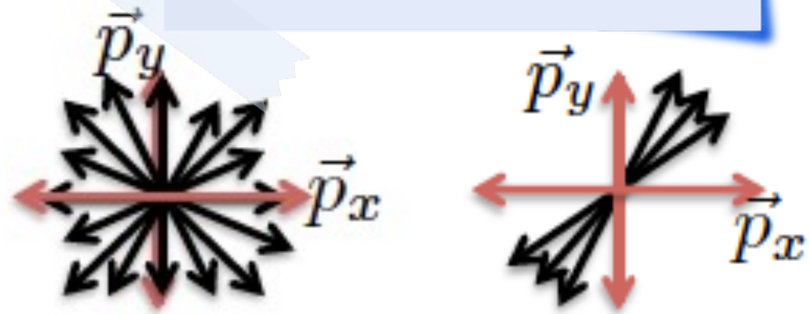




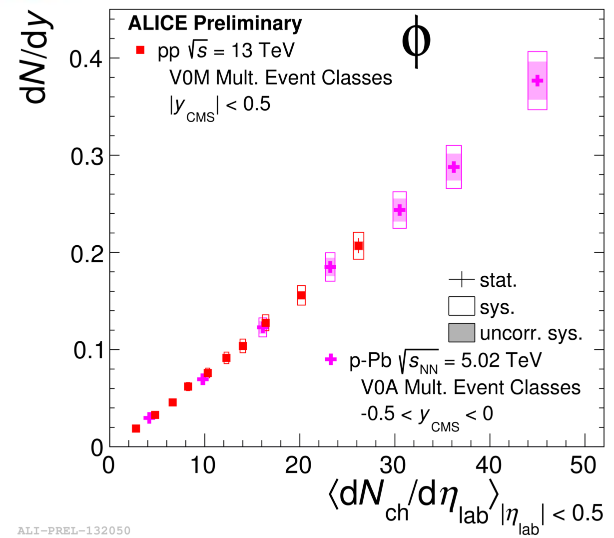
What's next?

② *Can we relate high multiplicity with soft- or hard-QCD dominated processes?*
Use event shapes as tools to select jetty/isotropic events in high multiplicity pp

Ongoing studies on inclusive charged and identified particle production vs transverse spherocity and multiplicity
*→ **S. Tripathy***

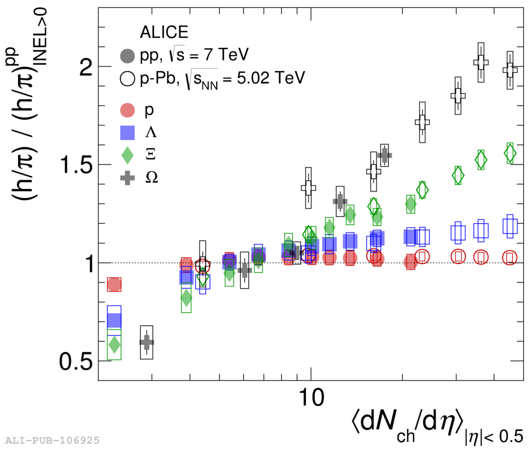


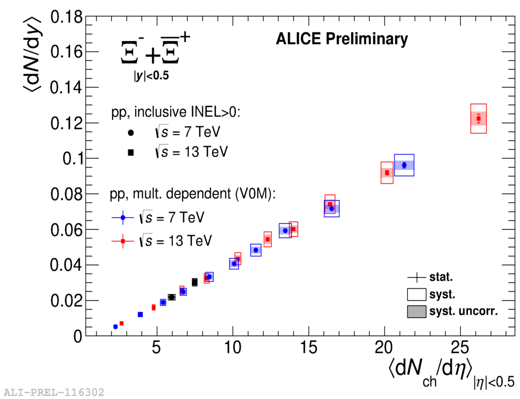
③ *Can the ϕ meson provide further insights on strangeness production vs multiplicity?*
Measure more differential (event shapes?), extract ϕ/π, improve precision

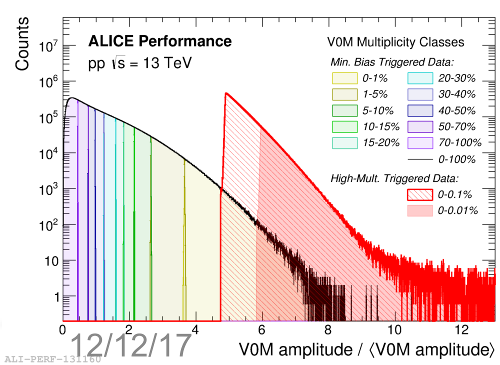


④ *New observables…*

Summary







ALICE has observed an enhancement of (multi)strange hadron production from low to high multiplicity pp (and p-Pb) collisions

Measurements at different energies as a function of multiplicity seem to indicate that the hadrochemistry is driven by event activity regardless of the collision energy

The full set of observations is poorly described by commonly used MC generators

Effort needed from the model/theory side

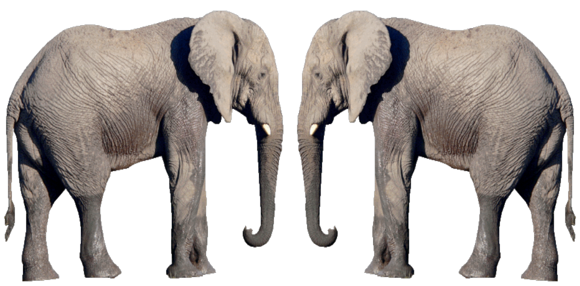
A long to do list for experiments

A personal outlook…

The intriguing similarities among different systems extend to the dynamics: we have indications for collectivity in small systems, whose origin and phenomenology is under investigation
→ See A. K. Dash, N. Sharma

→ *Can the same mechanisms that explain the dynamics also explain chemistry?*

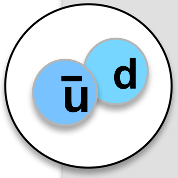
→ *Can we describe pp, p-Pb and Pb-Pb in a common "framework"?*



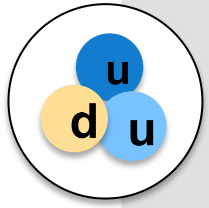
thank you!

Identified and strange hadrons in ALICE

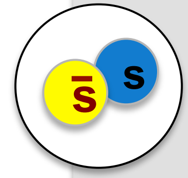
|S| = 0



π⁻
M = 140 MeV
Primary*

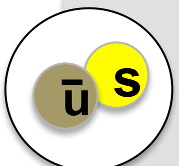


p
M = 938 MeV
Primary*

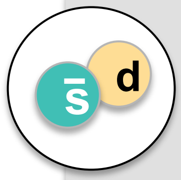


Φ
M = 1020 MeV
$\Phi \rightarrow K^+K^-$ (48.9%)
$c\tau$ = 45 fm

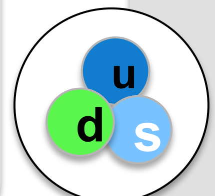
|S| = 1



K⁻
M = 494 MeV
Primary*

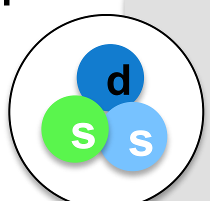


K^0_S
M = 497 MeV
$K^0_S \rightarrow \pi^+\pi^-$ (69.2%)
$c\tau$ = 2.68 cm



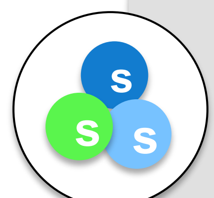
Λ
M = 1115 MeV
$\Lambda \rightarrow p\pi^-$ (63.9%)
$c\tau$ = 7.98 cm

|S| = 2



Ξ⁻
M = 1322 MeV
$\Xi^- \rightarrow \Lambda\pi^-$ (99.9%)
$c\tau$ = 4.91 cm

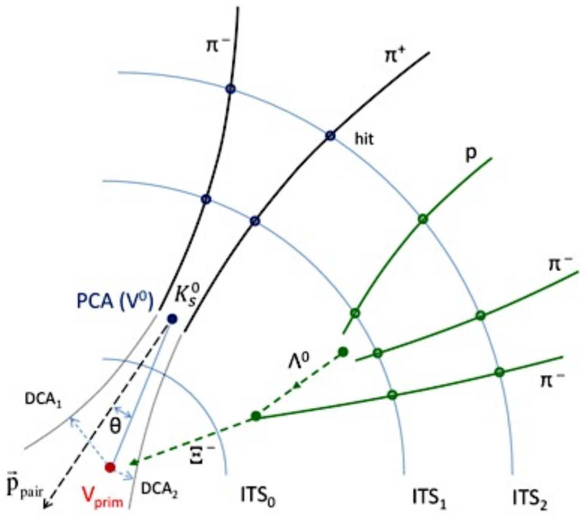
|S| = 3



Ω⁻
M = 1672 MeV
$\Omega^- \rightarrow \Lambda K^-$ (67.8%)
$c\tau$ = 2.46 cm

+ antiparticles
+ resonances

(Multi)Strange hadron reconstruction

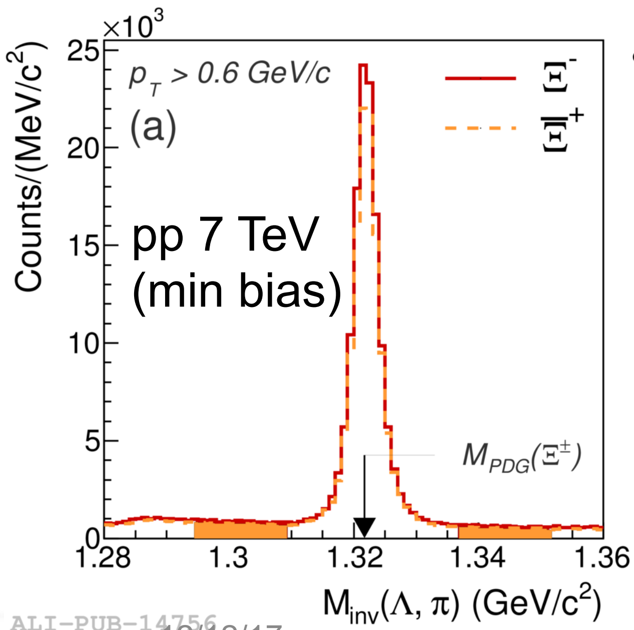


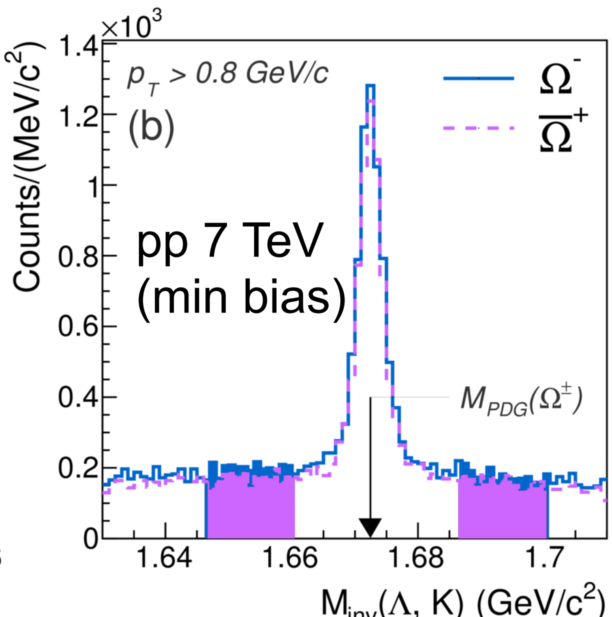
Reconstruction of the weak decay topology

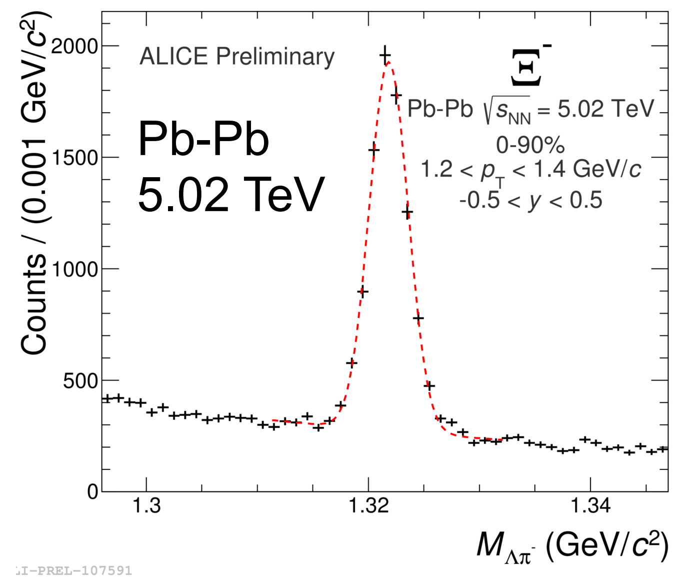
Yield extraction in each p_T bin:

- Fit polynomial + gaussian to get signal mean, σ
- Bin counting in the signal region (3σ)
- Fit background on side-bands
- Integral of background fit
- function in the signal region

→ Signal = Bin counting - Integral



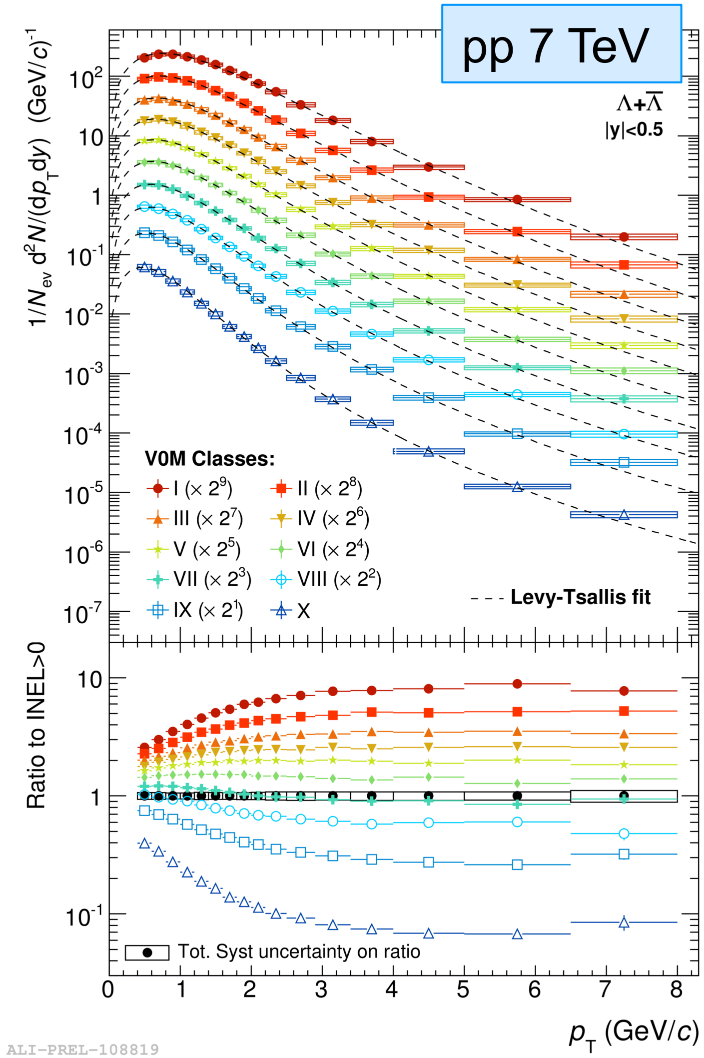


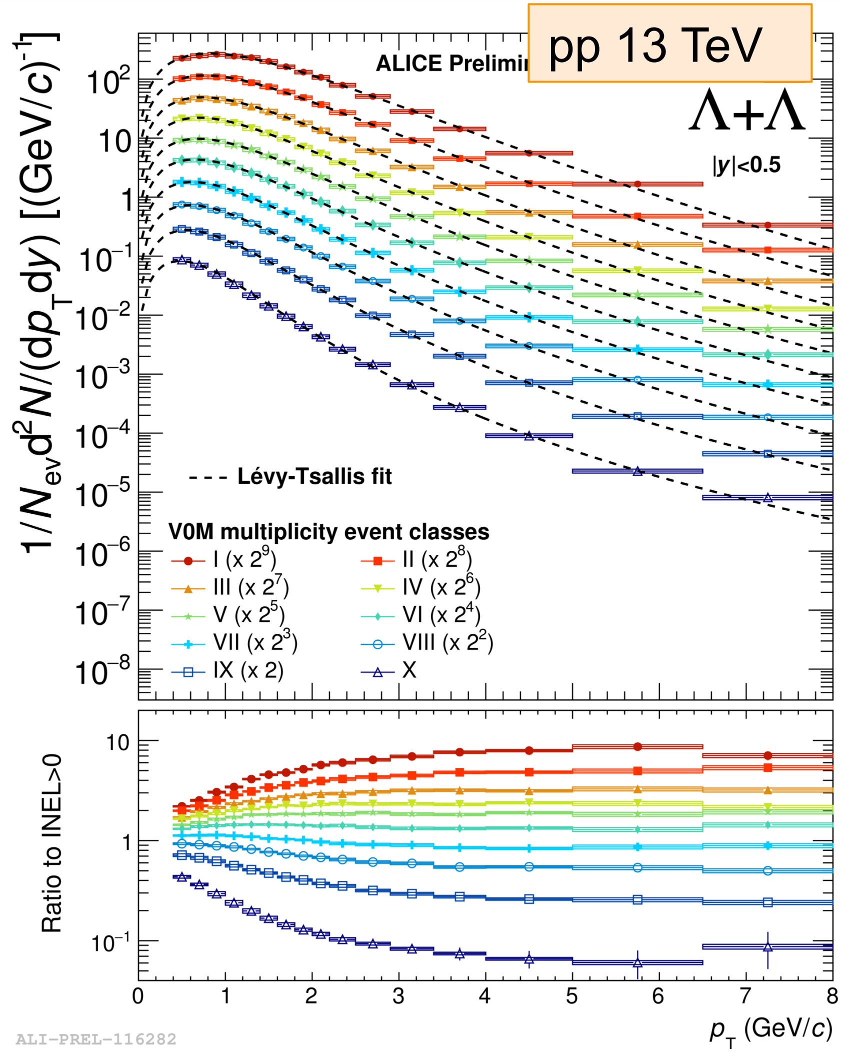


Charged particle multiplicity in pp 7 TeV

Class name	I	II	III	IV	V
$\sigma/\sigma_{\mathrm{INEL}>0}$ $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$	$0-0.95\%$ 21.3 ± 0.6	$0.95-4.7\%$ 16.5 ± 0.5	$4.7-9.5\%$ $13.5 \pm 0.4\%$	$9.5-14\%$ 11.5 ± 0.3	$14-19\%$ 10.1 ± 0.3
Class name	VI	VII	VIII	IX	X
$\sigma/\sigma_{\mathrm{INEL}>0}$ $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$	$19-28\%$ 8.45 ± 0.25	$28-38\%$ 6.72 ± 0.21	$38-48\%$ $5.40 \pm 0.17\%$	$48-68\%$ 3.90 ± 0.14	$68-100\%$ 2.26 ± 0.12

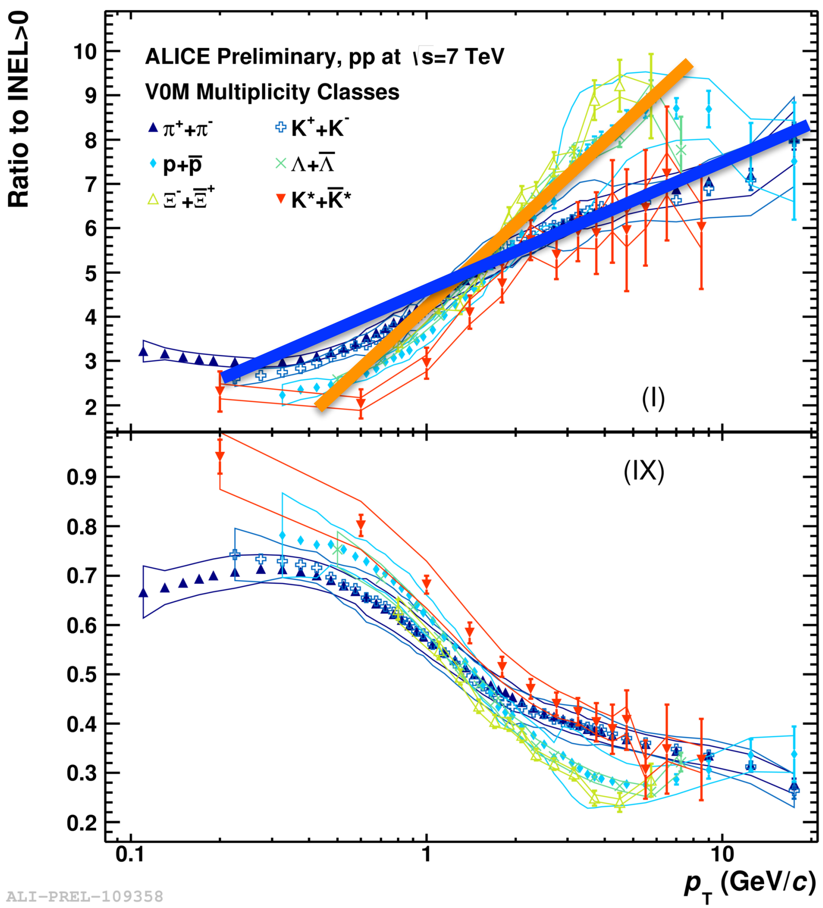
$\sqrt{s}$ and multiplicity dependence - spectra

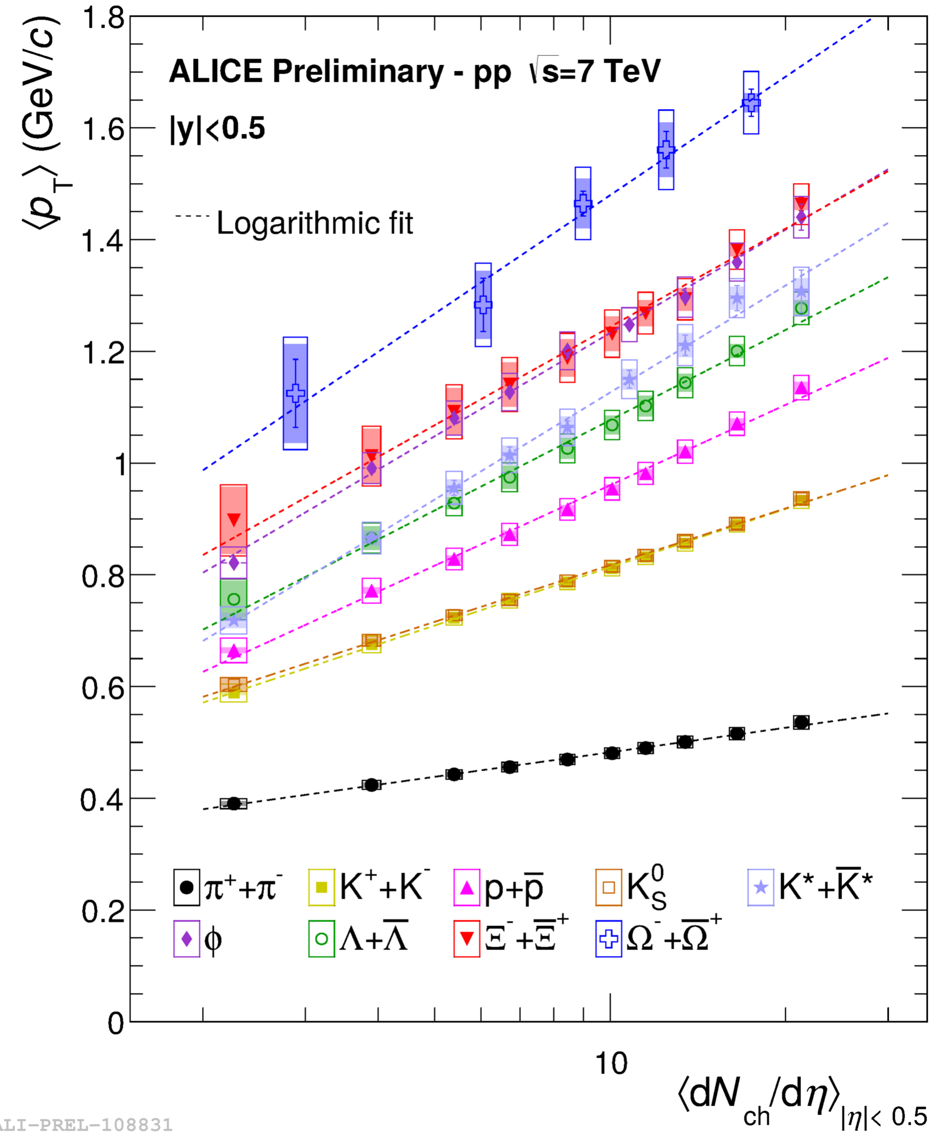




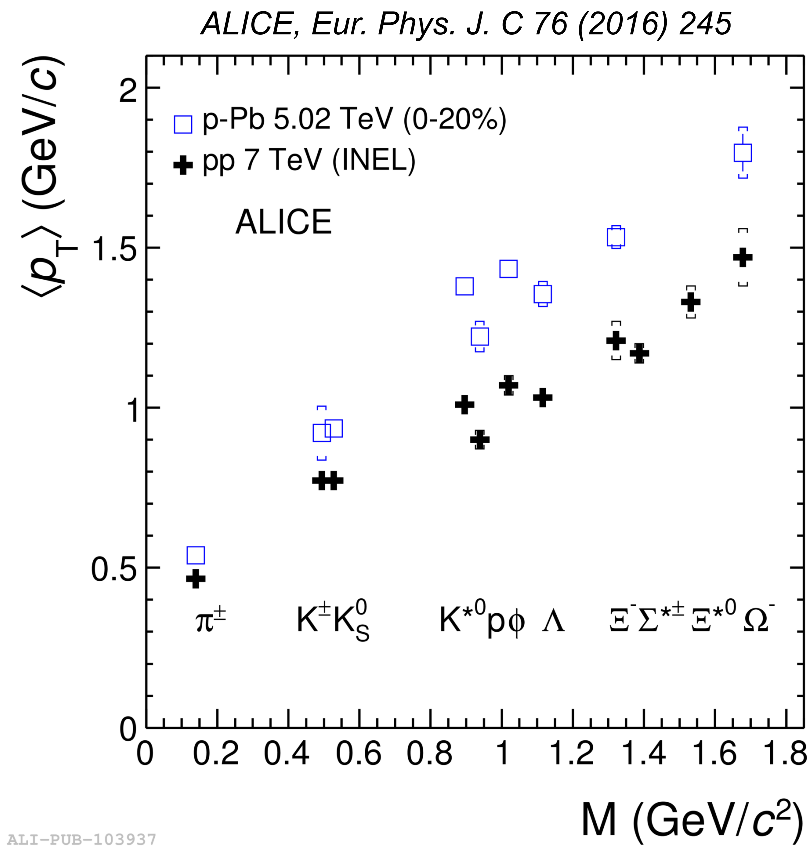
Hardening of spectra in high-multiplicity pp

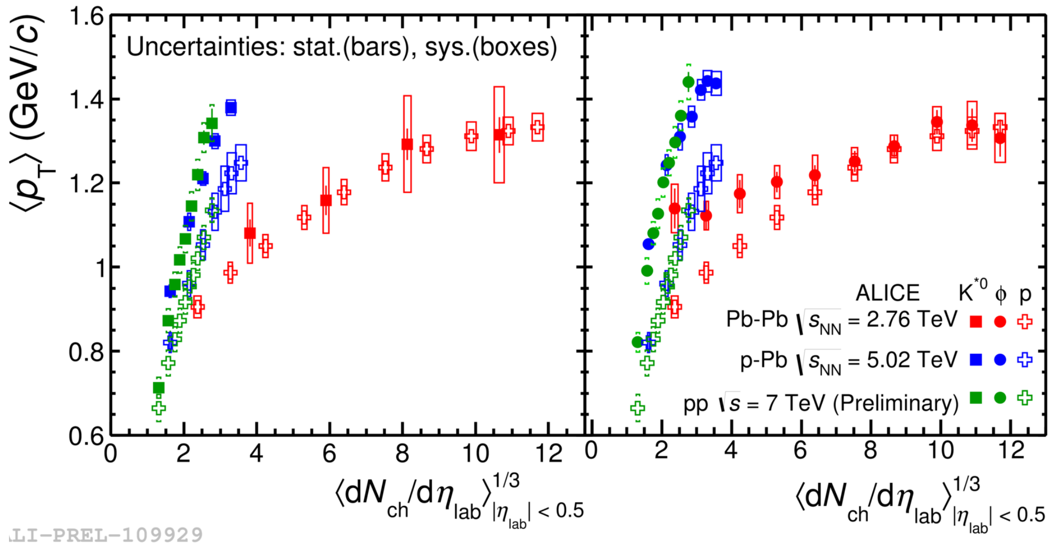
The hardening with multiplicity is more pronounced for baryons than for mesons





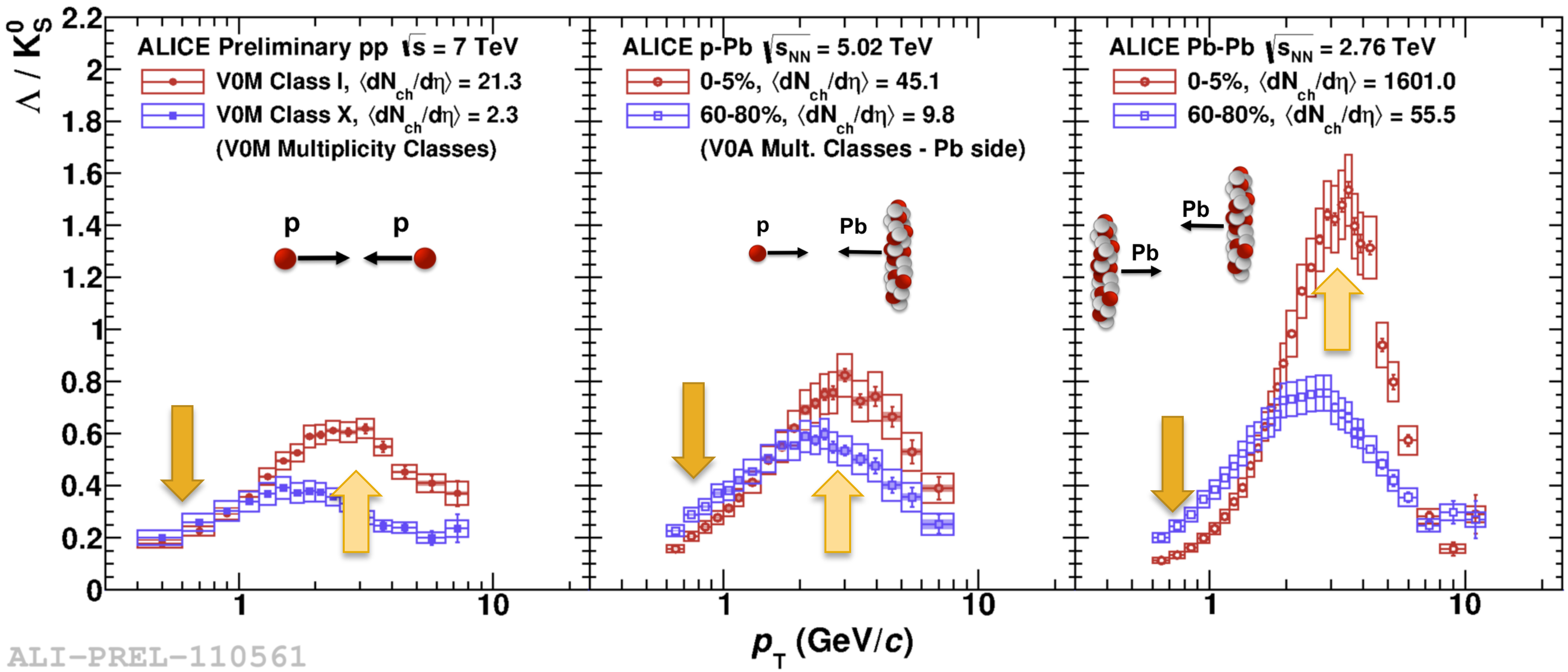
Mean p_T vs mass





Three systems compared: Λ/K^0_S

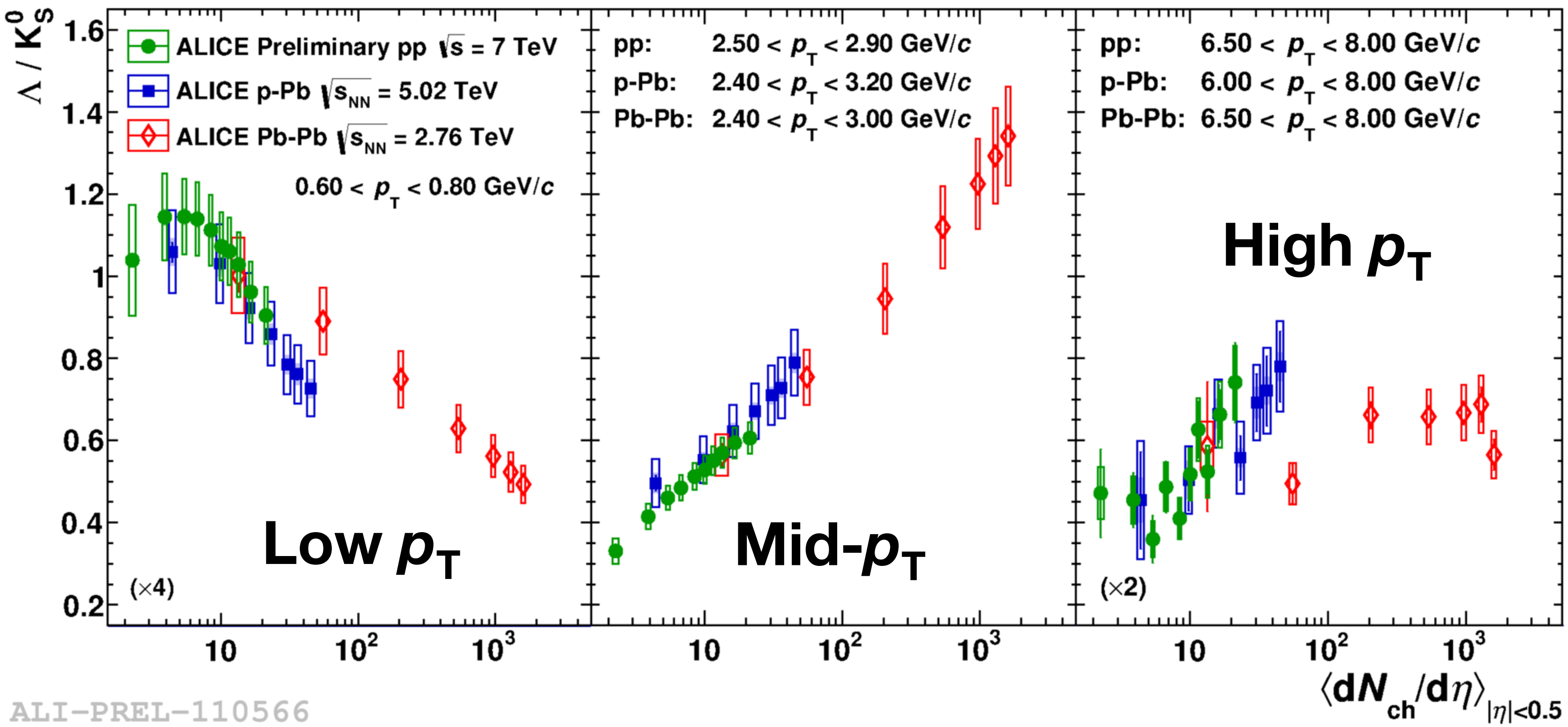
Phys. Rev. Lett. 111 (2013) 22301
Phys. Rev. C 93 (2016) 034913
Phys. Lett. B 728 (2014) 25-38
arXIv:1606.07424



Across the three systems the baryon-to-meson ratios **evolve with multiplicity**

– in a qualitatively similar way: depletion at low p_T, enhancement at intermediate p_T

Three systems compared: p_T slices

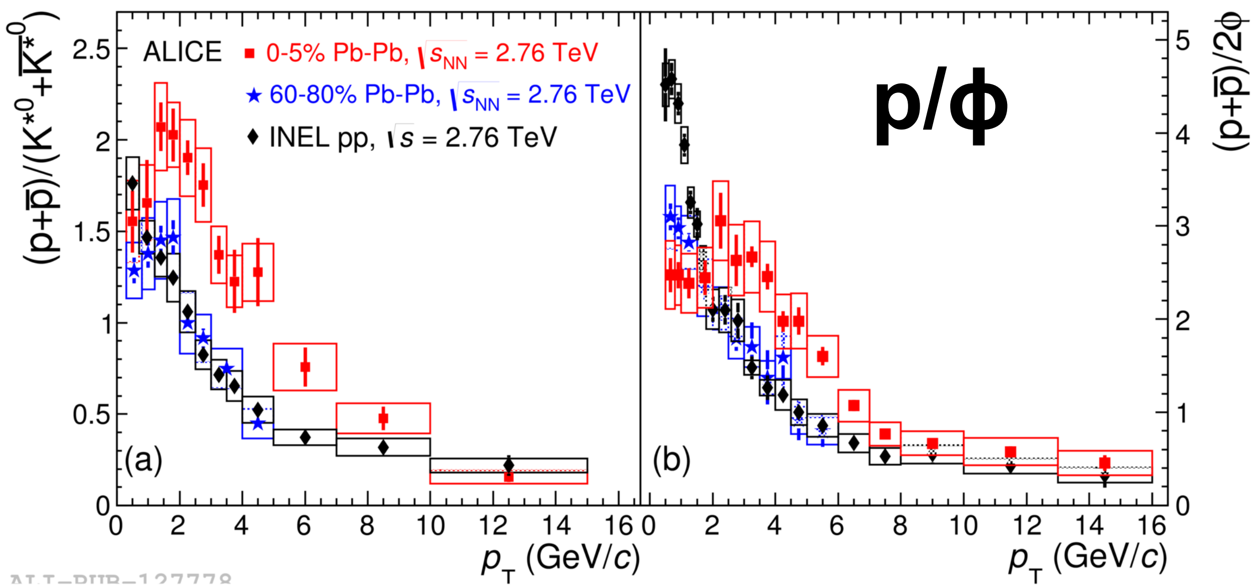


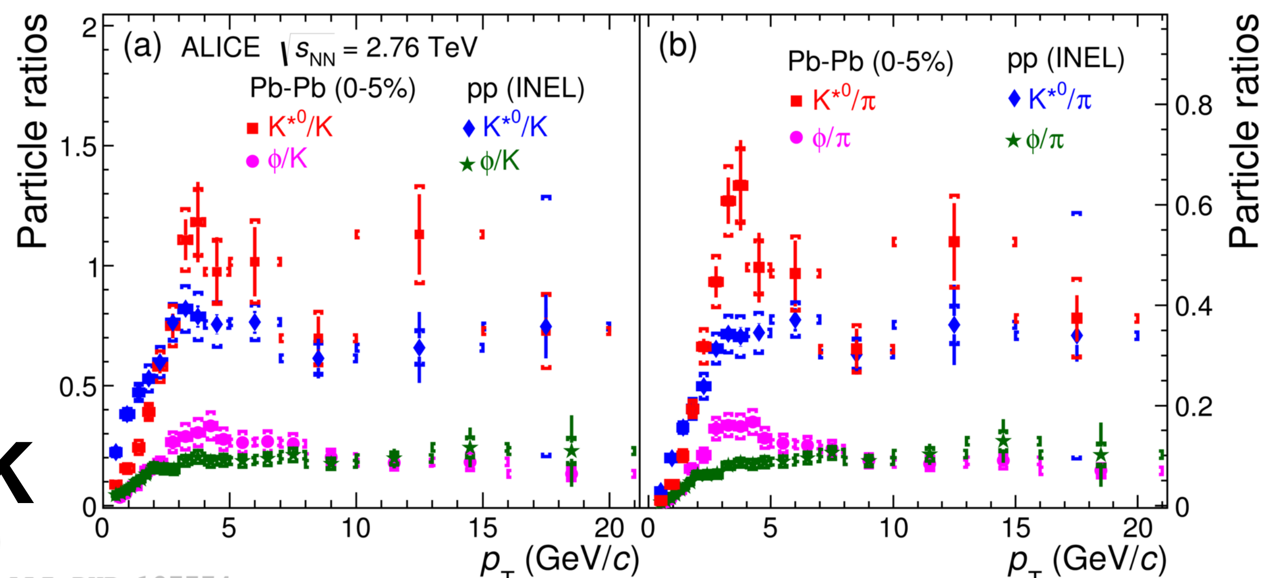
Across the three systems the baryon-to-meson ratios **evolve with multiplicity**

- in qualitatively similar way: depletion at low p_T, enhancement at intermediate p_T
- rather **smoothly for given p_T** intervals

p/ϕ, ϕ/K, ϕ/π ratios

ALICE, Phys. Rev. C 95, 064606





ϕ/K

ϕ/π

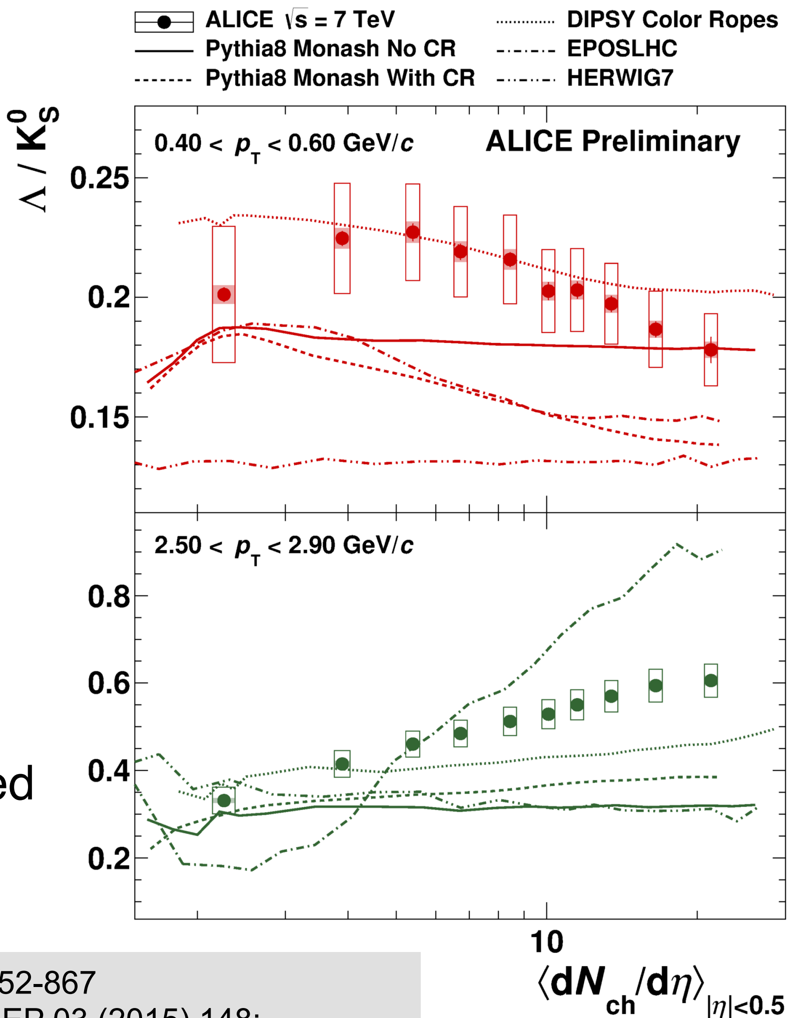
More model comparisons – pp

Comparison with MC predictions in pp:

Color Reconnection:
- Implemented in PYTHIA8 Monash
- Qualitative agreement with the data

Color Ropes:
- Similar mechanism in DIPSY
- also reproduces qualitatively the data

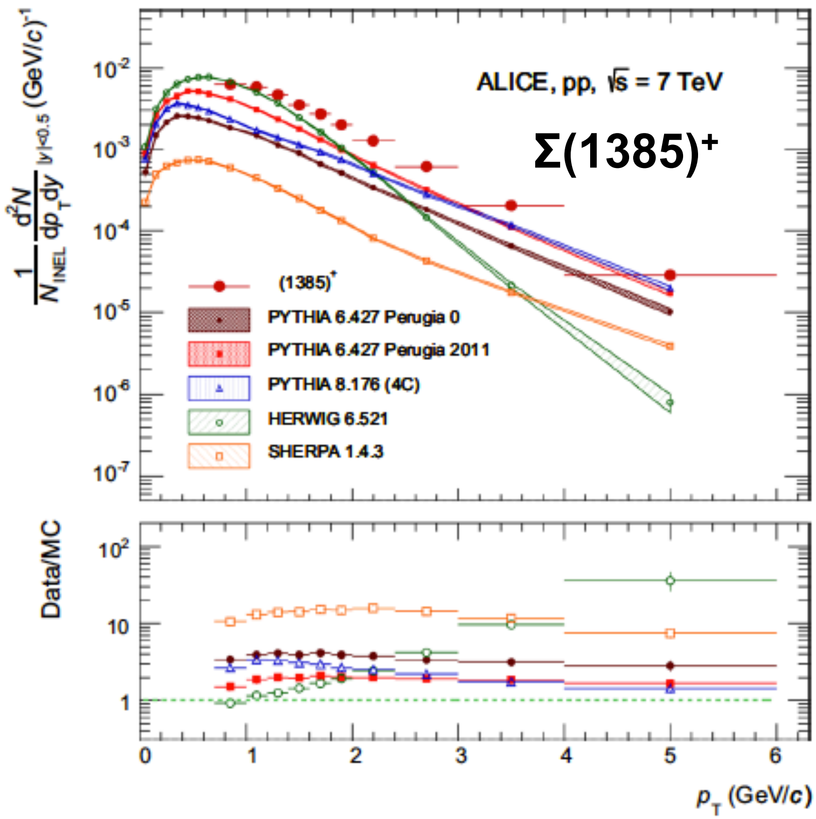
Collective Radial Expansion:
- Present in EPOS LHC
- viable explanation but effect is overestimated



PYTHIA8 – T. Sjöstrand et al., Comput. Phys. Commun. 178 (2008) 852-867
DIPSY – C. Flensburg et al., JHEP 08 (2011) 103; C. Bierlich et al., JHEP 03 (2015) 148; C. Bierlich et al., PRD 92 (2015) 094010
EPOS LHC – T. Pierog et al., arXiv:1306.0121
HERWIG7 – M. Bahr et al., EPJC 58 (2008) 639-707; J. Bellm et al., EPJC 76 no.4 (2016) 196

$\Sigma(1385)^{\pm}$, $\Xi(1530)^0$ vs models in pp 7 TeV

ALICE, Eur. Phys. J. C (2015) 75:1



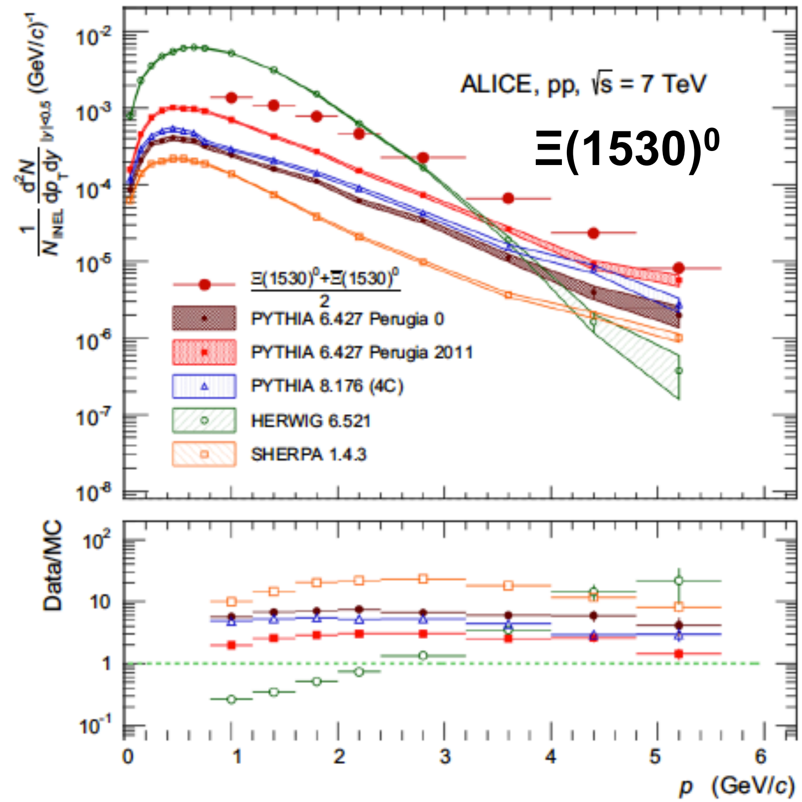


Fig. 6 The transverse momentum spectrum of $\Sigma(1385)^{+}$ is compared to standard tunes of PYTHIA 6 [34] and PYTHIA 8 [35], the latest release of HERWIG (6.521) [36], and SHERPA release 1.4.6 [37]. The MC data are binned according to the data. Spectra points are represented at the centre of the p_{T} interval. The *lower panel* shows the ratio data/MC. p_{T}-independent uncertainties are not shown

Strangeness at RHIC and at LHC