Measurements of hadron resonance production with ALICE

ENRICO FRAGIACOMO
INFN – TRIESTE
ON BEHALF OF THE ALICE COLLABORATION

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Istituto Nazionale di Fisica Nucleare

RESONANCES IN HEAVY-ION COLLISIONS

time

Quark-Gluon Plasma (QGP) is created in ultra-relativistic heavy-ion collisions [J. D. Bjorken, Phys. Rev. D 27 (1983) 140]

After the collision, the QGP fireball expands and cools down

Phase transition to hadron gas at a temperature $T_{critical}$

Chemical composition frozen at T_{chem} (and strangeness enhancement)

Final-state interactions in the late hadron gas phase

Kinetic freeze-out at T_{kin} once elastic collisions stop

Temperature

Precise measurements of resonances allow one to study several aspects of the medium formed in the collisions.

In this presentation, focus on:

- Strangeness enhancement in QGP — *see also talk by D. Colella*
- Late hadron gas phase

HADRONIC RESONANCES IN ALICE

Several hadronic resonances studied with ALICE:

$\rho(770)$	$K^*(892)^0$	$K^*(892)^+$	$\phi(1020)$	$\Sigma(1385)^\pm$	$\Lambda(1520)$	$\Xi(1530)$
$\frac{u\bar{u}+d\bar{d}}{\sqrt{2}}$	$d\bar{s}$	$u\bar{s}$	$s\bar{s}$	uus dds	uds	uss

Run I results (2010-2013):

- pp at $\sqrt{s}$ = 7 TeV (MB and vs multiplicity)
- pp at $\sqrt{s}$ = 0.9, 2.76, 5.02, 8 TeV
- p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
- Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

Run II results (2015-):

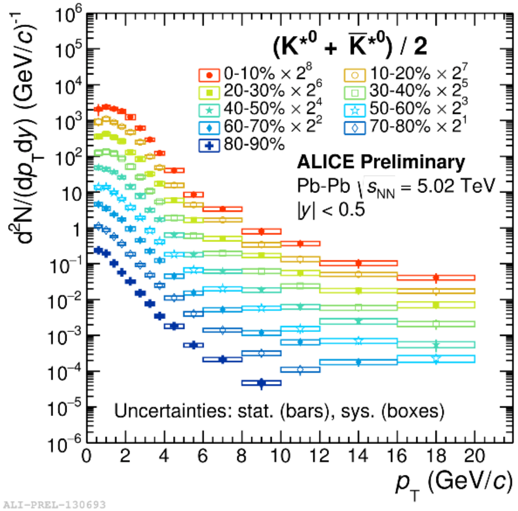
- pp at $\sqrt{s}$ = 5 (MB)
- pp at $\sqrt{s}$ = 13 TeV (MB and vs multiplicity)
- Pb-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

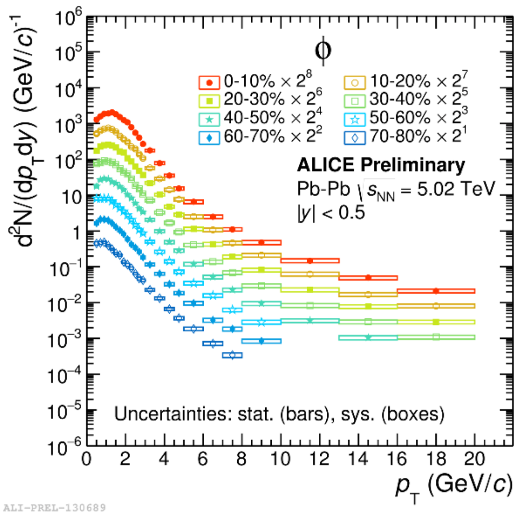
Lifetime (fm/c)

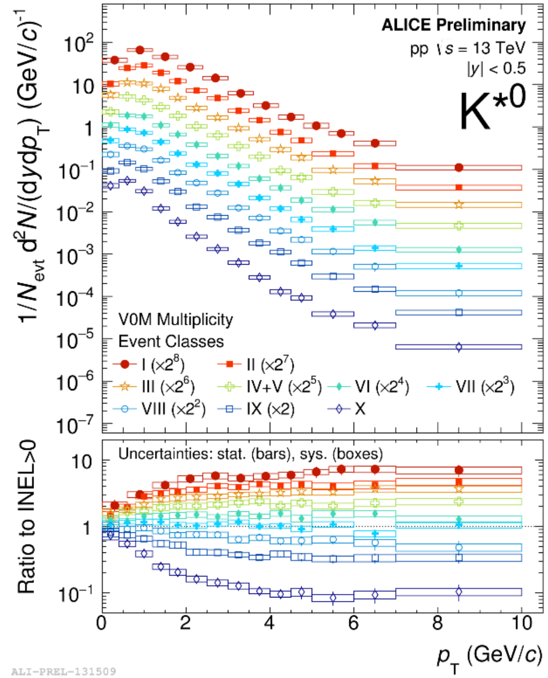
ρ^0	<	K^{*0}	<	$\Sigma^{*\pm}$	<	Λ^*	<	Ξ^{*0}	<	ϕ
1.3	**<**	**4.2**	**<**	**5.5**	**<**	**12.6**	**<**	**21.7**	**<**	**46.2**

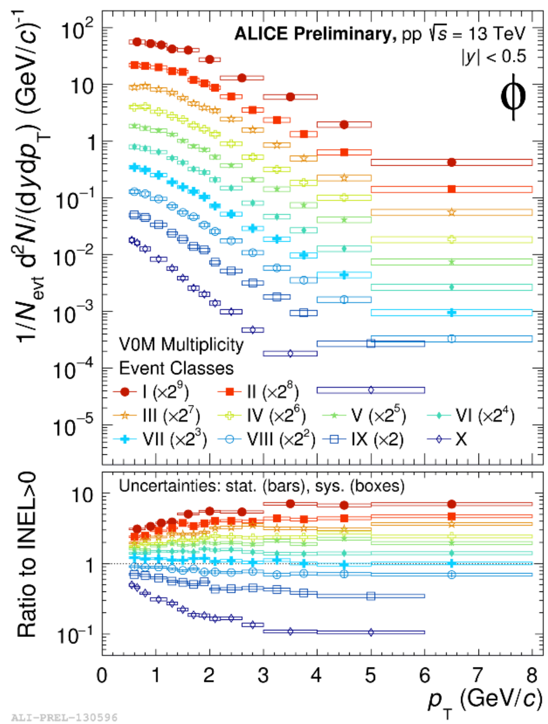
Phys. Rev. C 95 (2017) 064606
Eur. Phys. J. C 77 (2017) 389
Eur. Phys. J. C 76 (2016) 245
Phys. Rev. C 91 (2015) 024609
Eur. Phys. J. C 75 (2015) 1
Eur. Phys. J. C 72 (2012) 2183
Eur. Phys. J. C 71 (2011) 1594

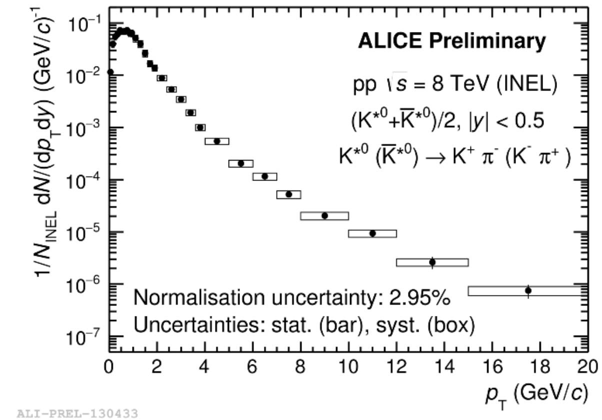
New preliminary results

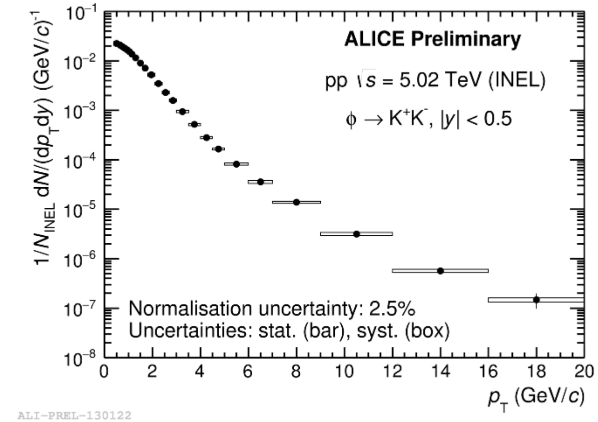


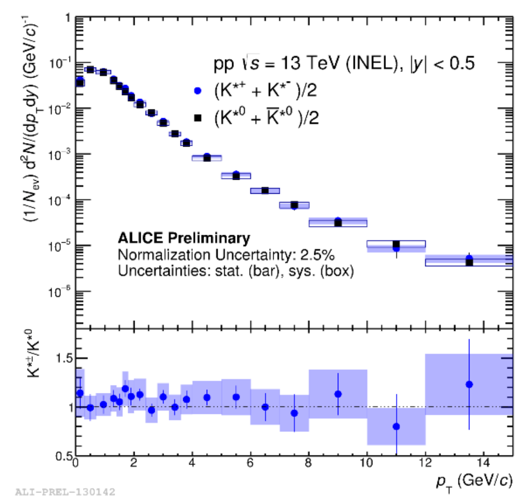








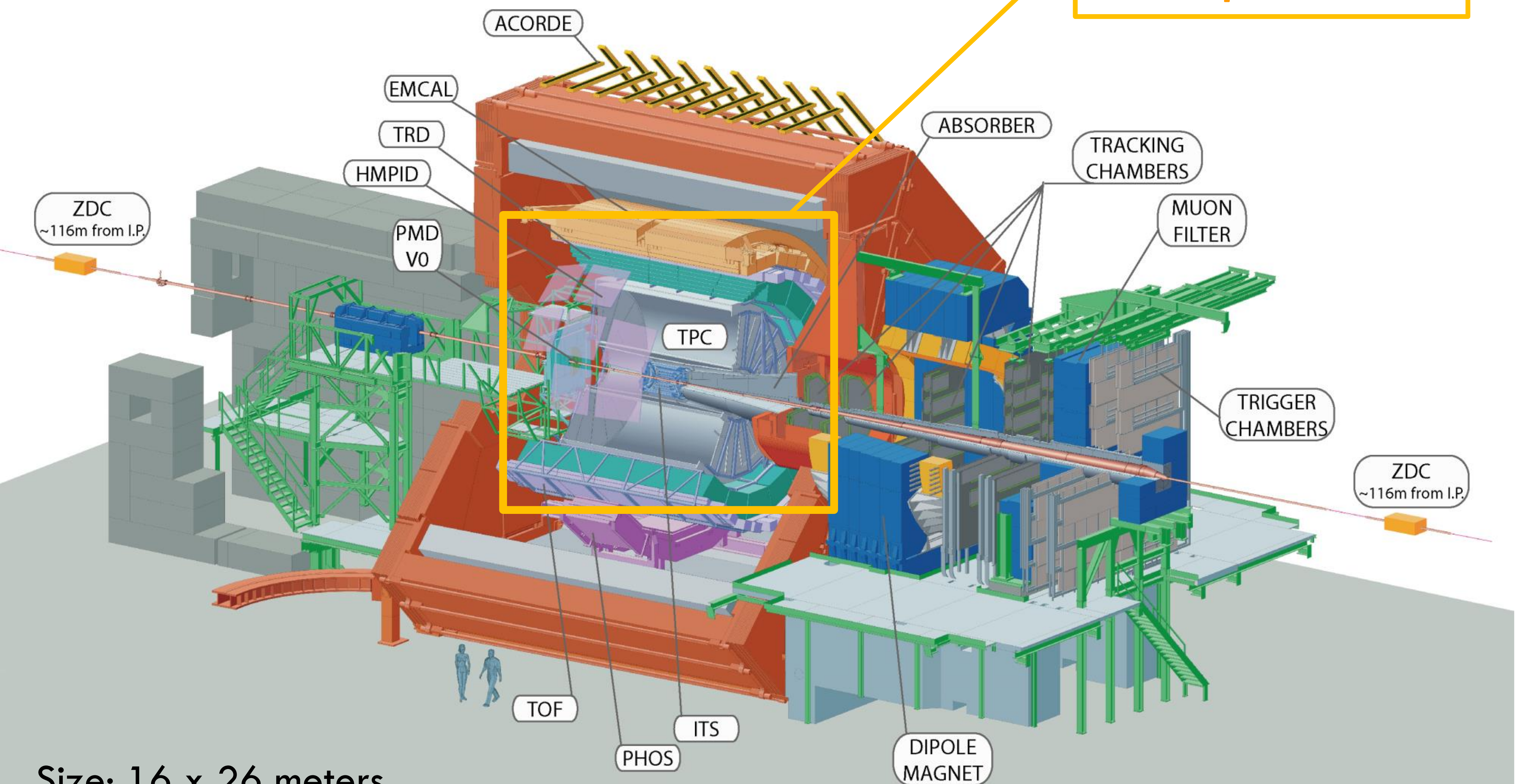




THE ALICE EXPERIMENT

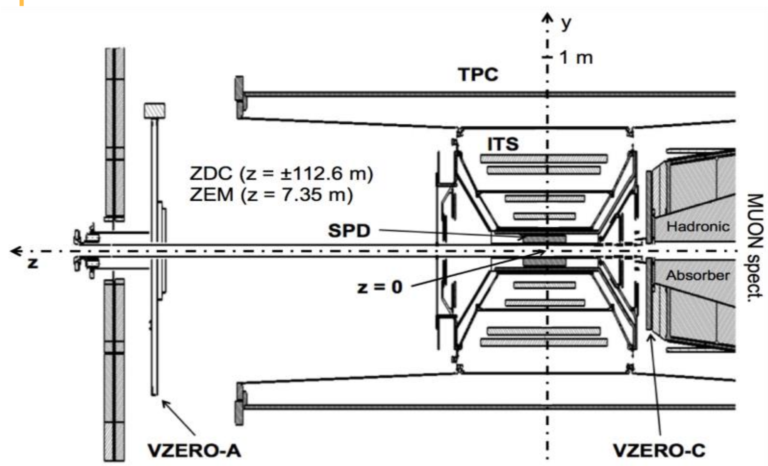
- Unique **particle identification** capabilities
- High granularity for high multiplicity
- **Tracking** down to $p_T \sim 0.1$ GeV/c

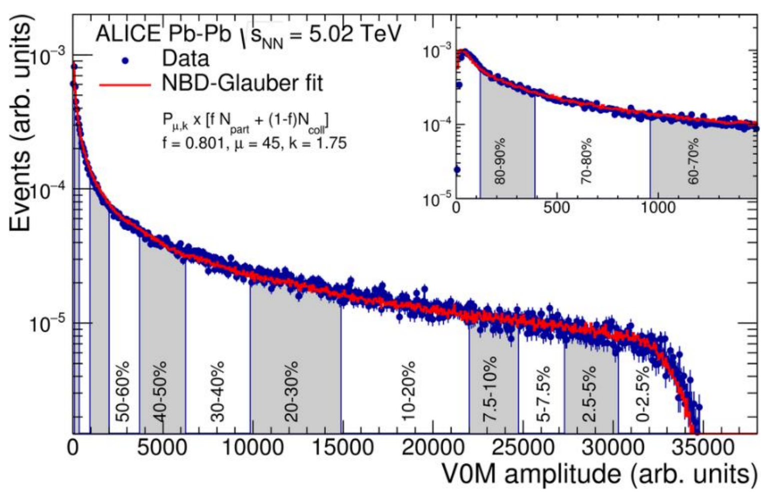
Central barrel
$|\eta|<0.9$



Size: 16 x 26 meters
Weight: 10,000 tons

MULTIPLICITY AND CENTRALITY





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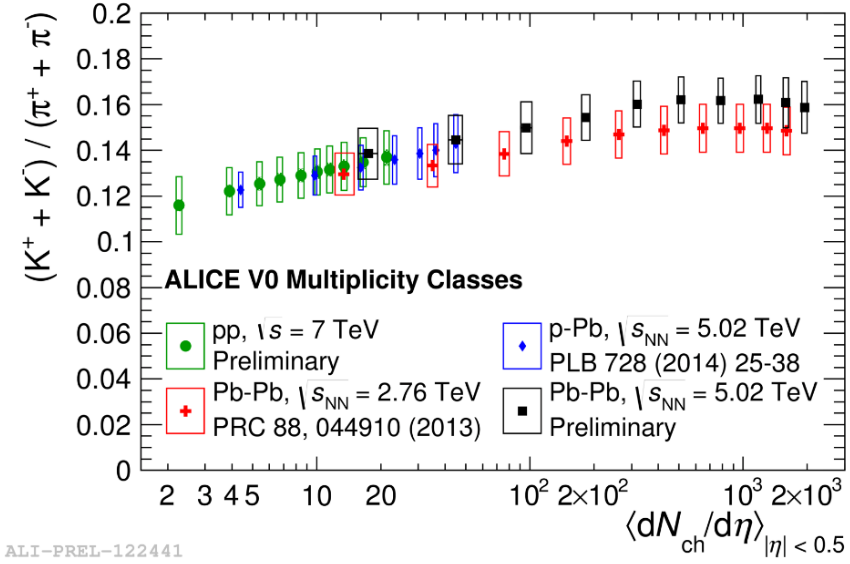
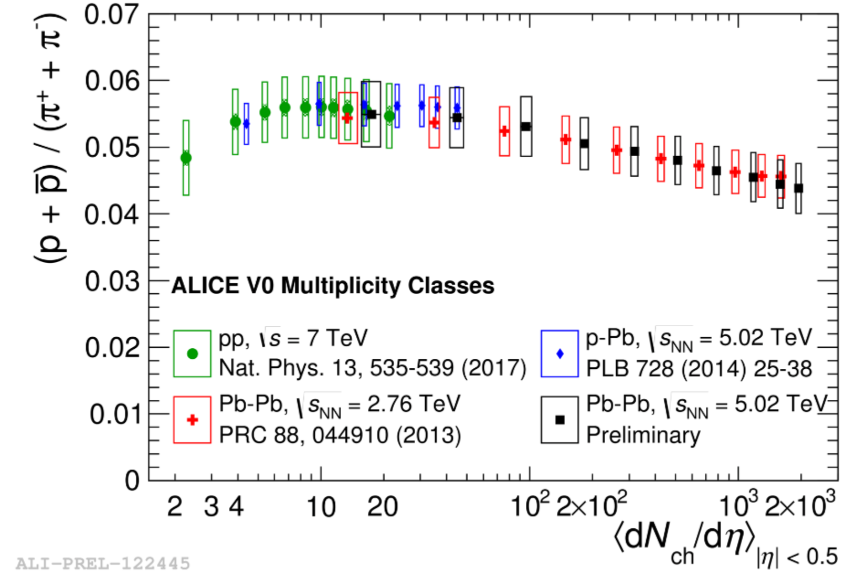
- **V0 scintillators** at $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C). V0M is defined as V0A&V0C
- **Event activity** is measured at forward rapidity with the V0 detector
- **Centrality** classes (Pb-Pb) defined as *percentiles* of the V0M signal distribution and related to observables via *Glauber model*
- **Multiplicity** ($\langle dN_{ch}/d\eta \rangle$) is defined as the number of primary charged particles per event (measured in $|\eta|<0.5$)

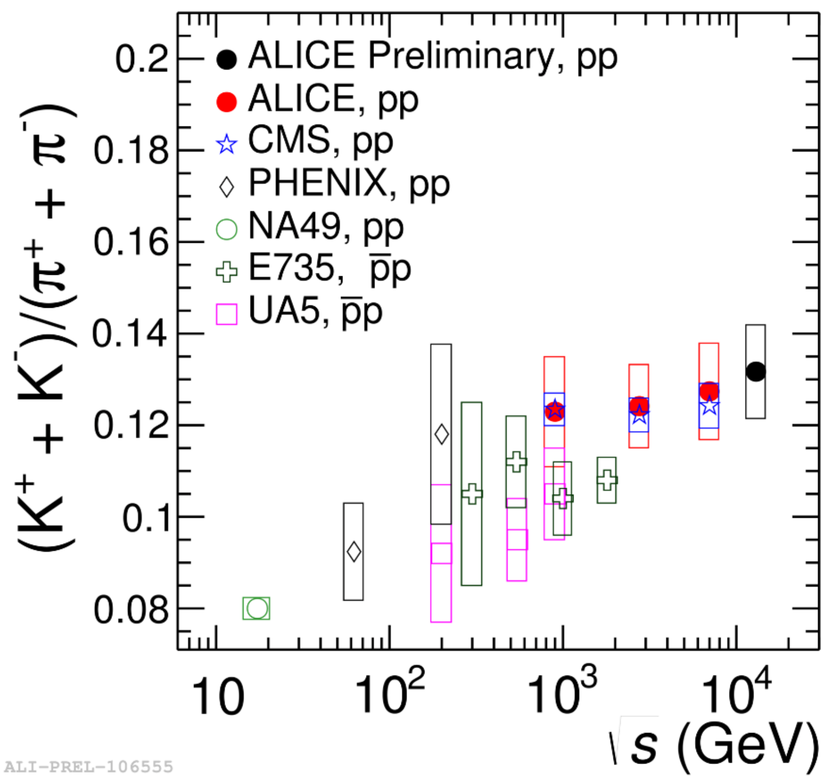
MULTIPLICITY DEPENDENCE OF PARTICLE RATIOS

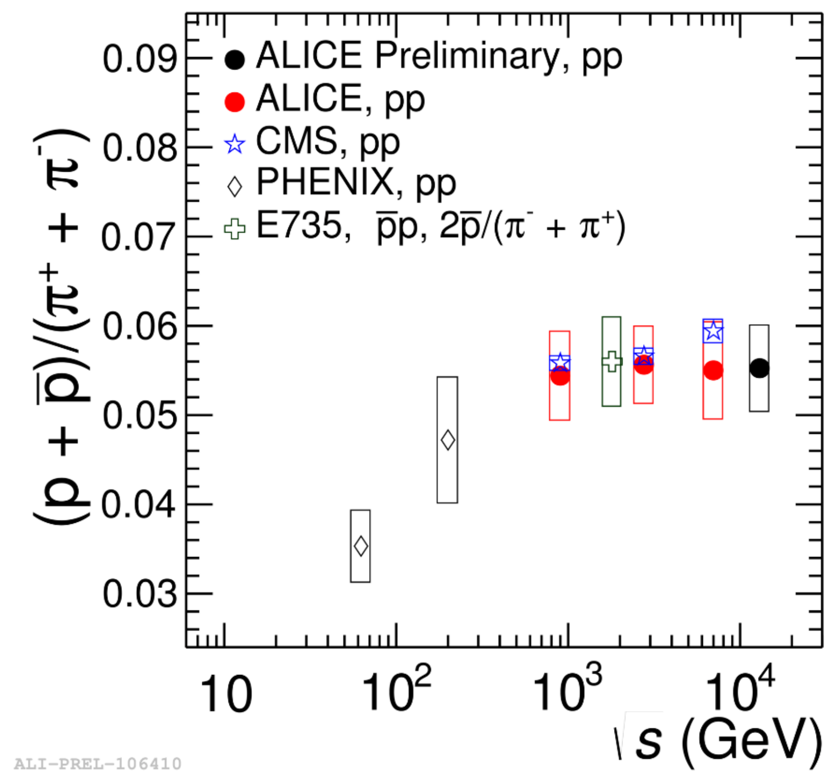




- Smooth evolution of K/π and p/π ratios across different systems
- High multiplicity pp at 7 TeV and peripheral Pb-Pb at 2.76 and 5.02 TeV are consistent

ENERGY DEPENDENCE OF PARTICLE RATIOS





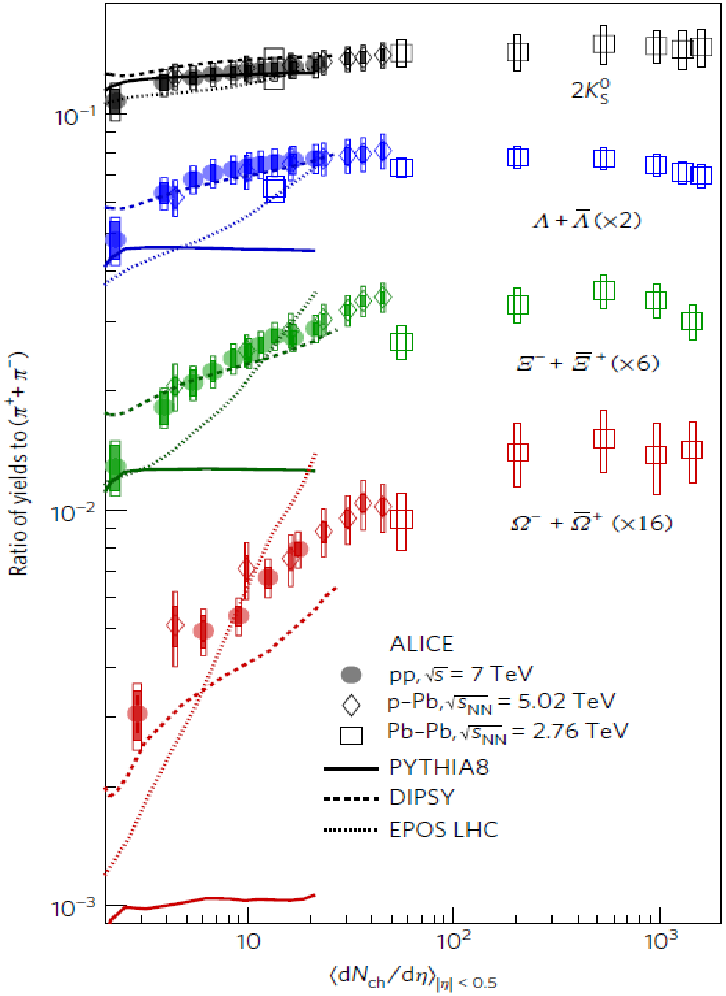
Saturation trend for $\sqrt{s} \gtrsim 1$ TeV

STRANGENESS ENHANCEMENT

see talk by D. Colella

ENHANCED STRANGENESS PRODUCTION

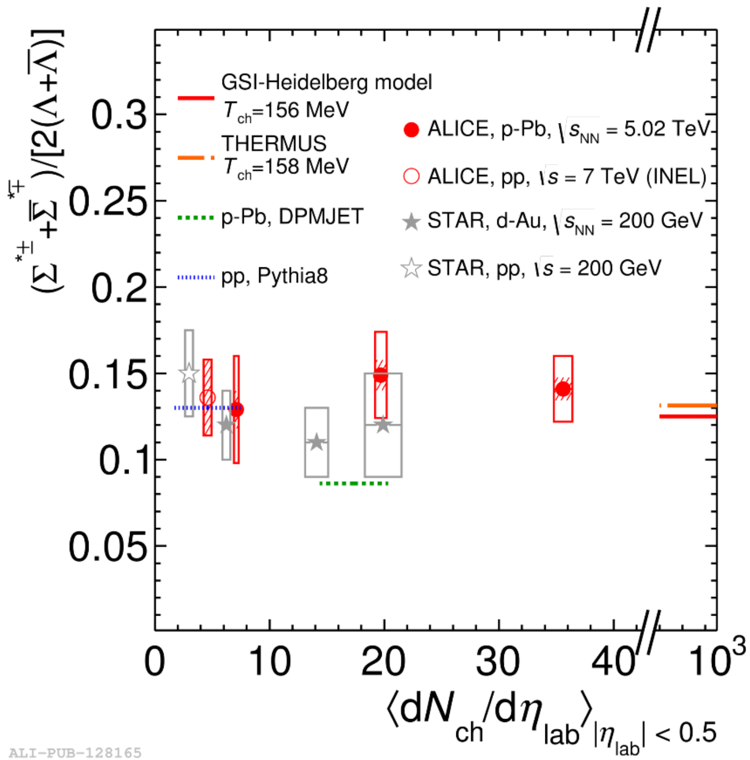
Nature Phys. 13 (2017) 535

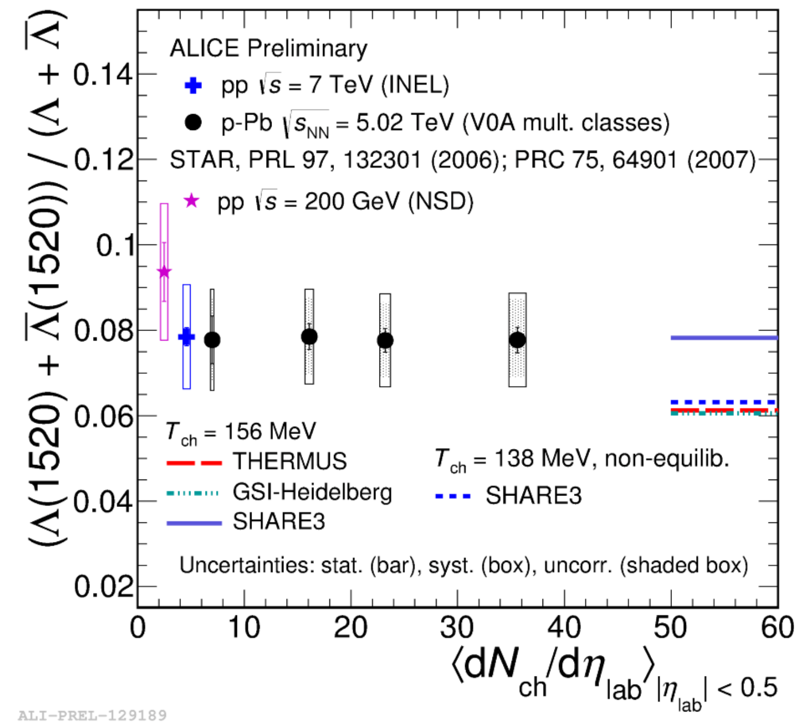


- **Clear increase of strangeness** production from pp to Pb-Pb
- Strangeness enhancement was one of the first **signatures** proposed **for QGP** formation
  [J. Rafelski and B. Müller, Phys. Rev. Lett. 48, 16 (1982) 1066 [Erratum: Phys. Rev. Lett. 56 (1986) 2334]]
- First observation of **enhanced production** of strange particles **in high-multiplicity pp collisions**
- Increase is not mass-related but **strangeness-related**

S = 1

STRANGE RESONANCE PRODUCTION

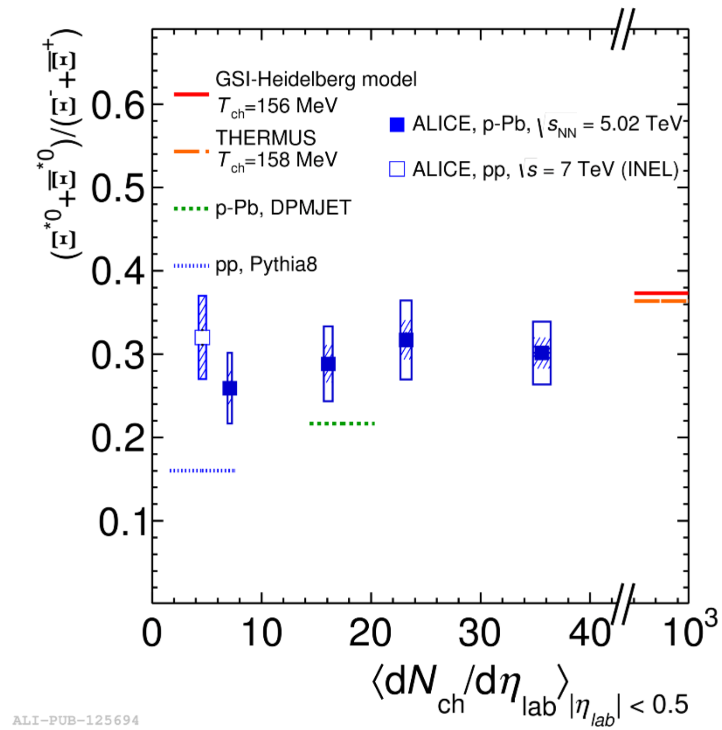




Ratio of resonance to stable particle with same strangeness content is flat irrespective of mass

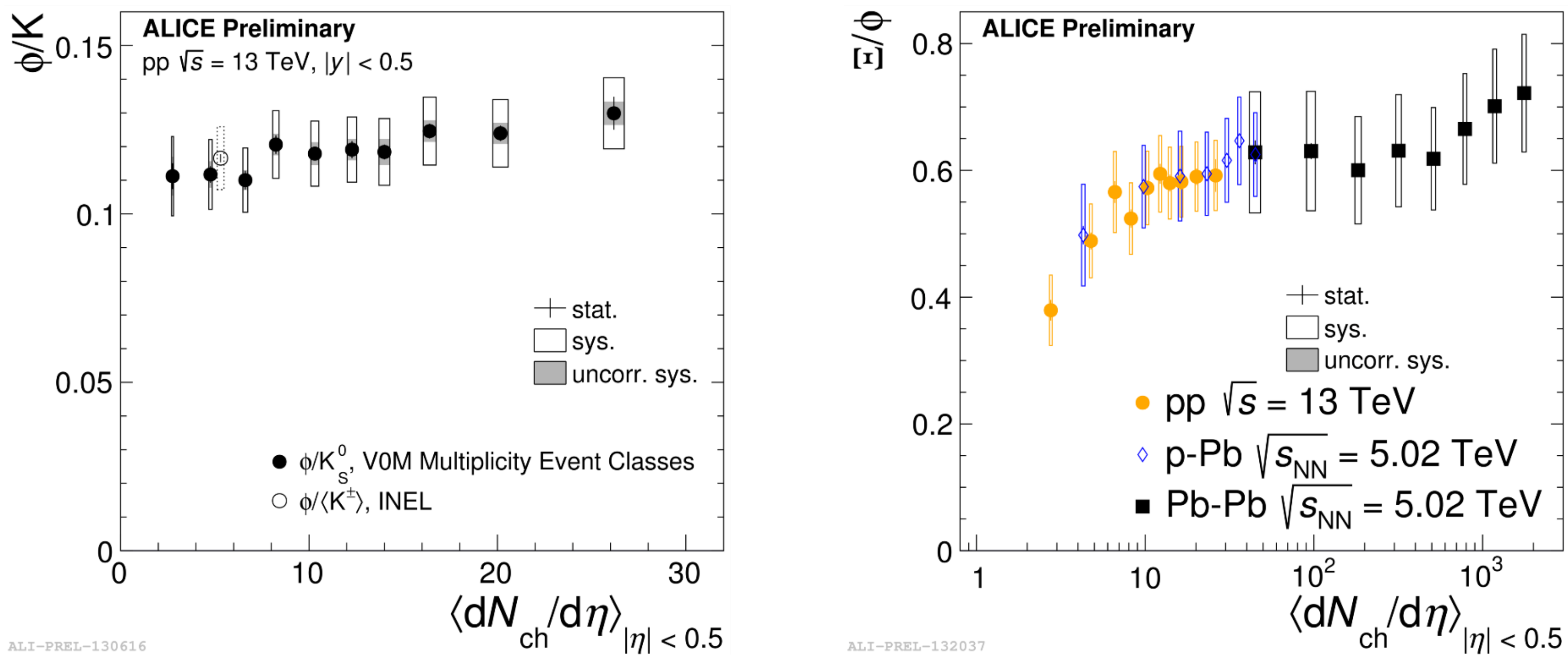
S = 2

STRANGE RESONANCE PRODUCTION



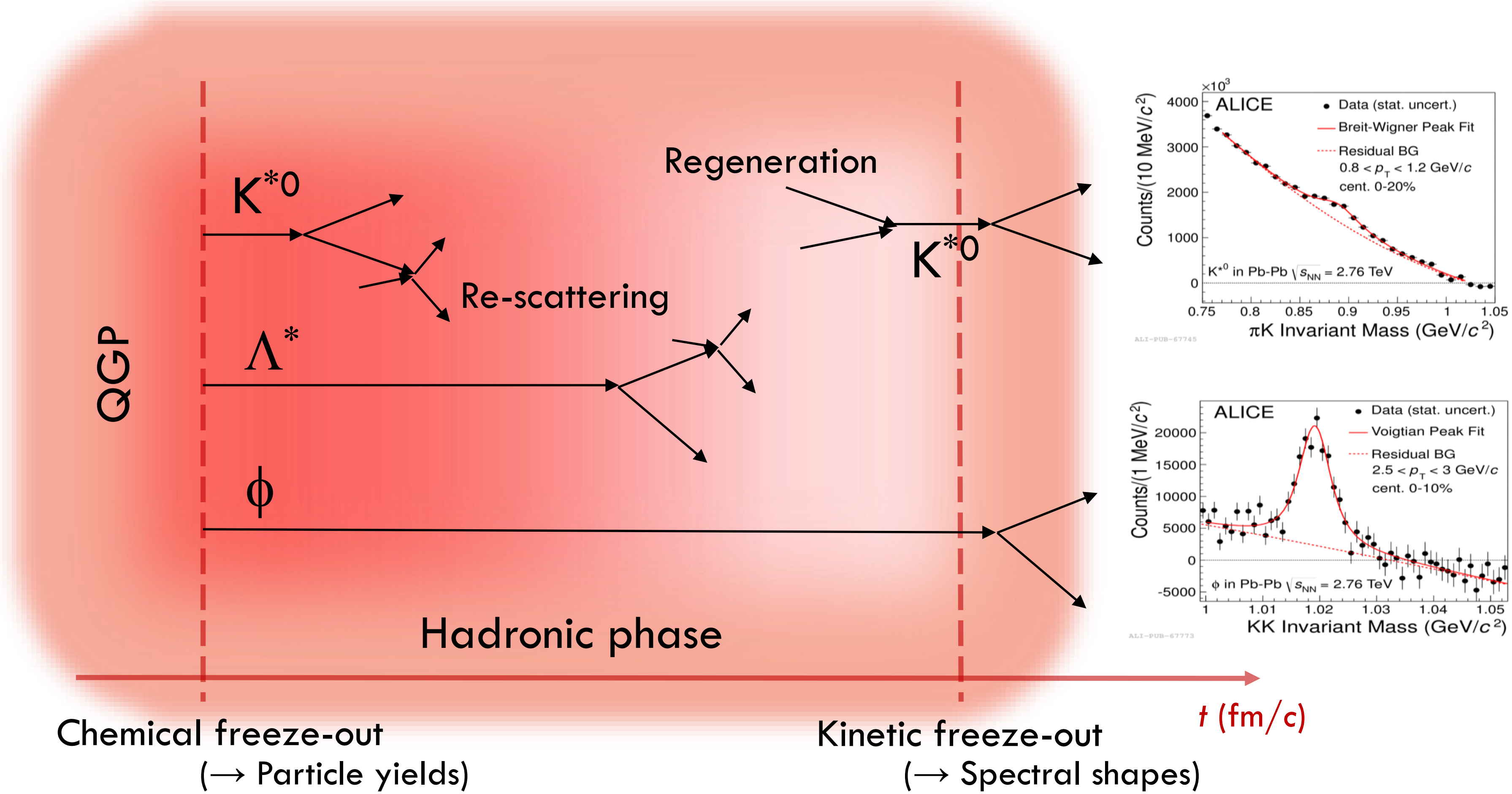
Ratio of resonance to stable particle with same strangeness content is flat irrespective of mass

STRANGE RESONANCE PRODUCTION



ϕ has strangeness S=0 but a behaviour between K and Ξ

LATE HADRONIC PHASE

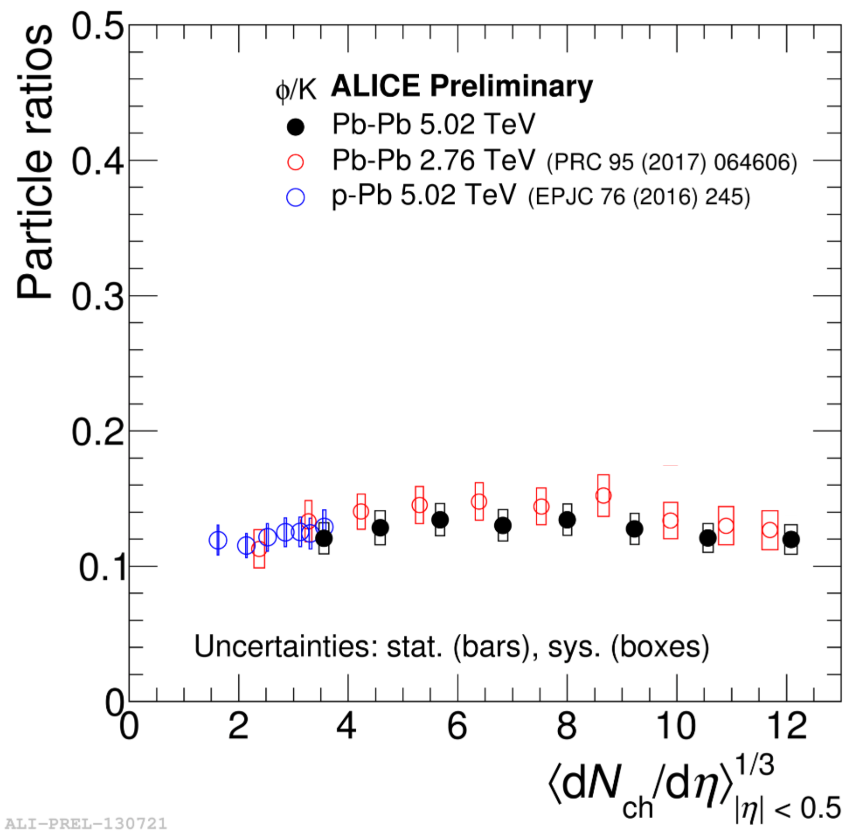


Phys. Rev. C 91 (2015) 024609

Re-scattering (elastic or pseudo-elastic scattering of the decay products) and regeneration modify the yields of reconstructible resonances

G. Torrieri and J. Rafelski, Phys. Lett. B509 (2001) 239-245
S. Vogel and M. Bleicher, Proc. of the XLIII Nucl. Phys. Winter Meeting in Bormio (2005)

RESONANCE-TO-STABLE-PARTICLE RATIO

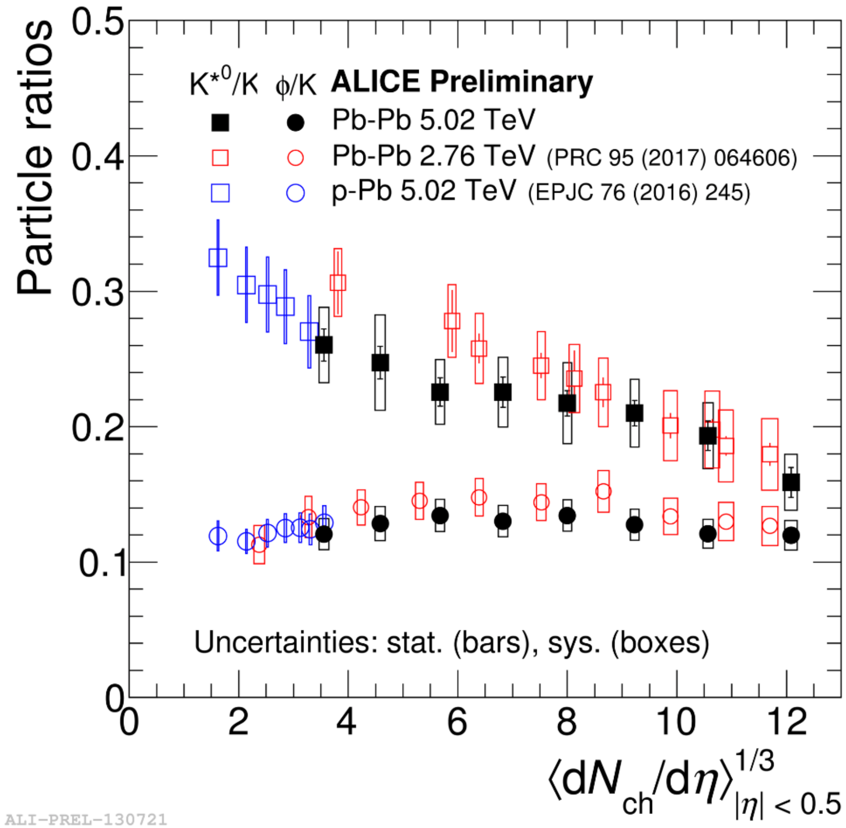


Lifetime (fm/c)										
ρ^0	<	K^{*0}	<	$\Sigma^{*\pm}$	<	Λ^*	<	Ξ^{*0}	<	ϕ
1.3	<	4.2	<	5.5	<	12.6	<	21.7	<	46.2

ϕ/K shows no suppression

- almost constant behaviour
- re-scattering is **not significant for ϕ**

RESONANCE-TO-STABLE-PARTICLE RATIO



Lifetime (fm/c)

$\rho^0 < K^{*0} < \Sigma^{*\pm} < \Lambda^* < \Xi^{*0} < \phi$

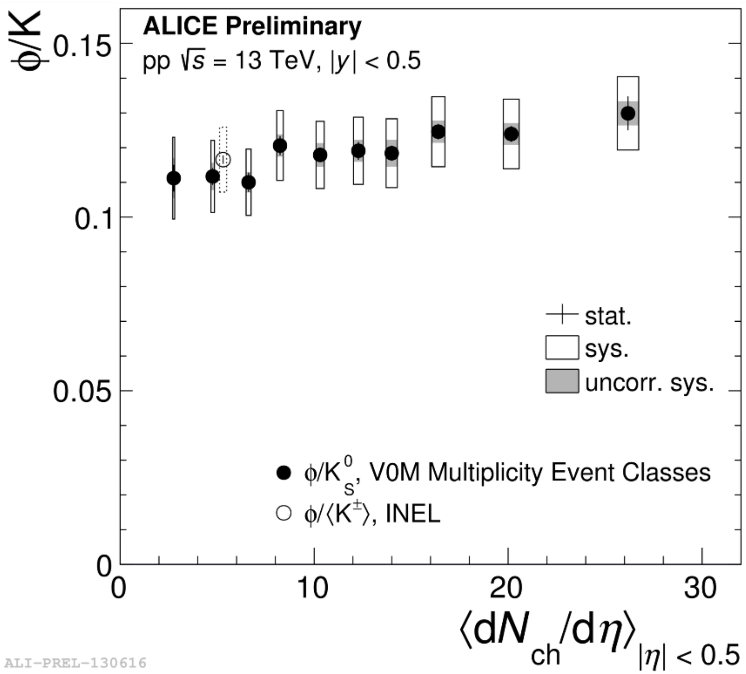
1.3 < 4.2 < 5.5 < 12.6 < 21.7 < 46.2

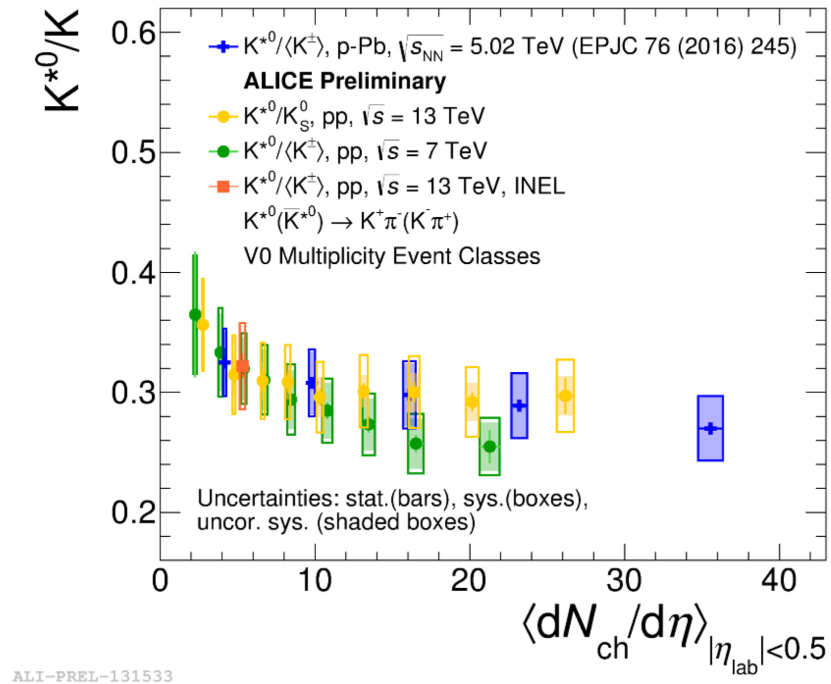
K*/K shows clear suppression

- going from pp, p-Pb and peripheral Pb-Pb collisions to central Pb-Pb
- New results in Pb-Pb at 5 TeV confirmed the trend observed in Pb-Pb at 2.76 TeV

Most favoured explanation of K* suppression is dominance of **rescattering over regeneration**

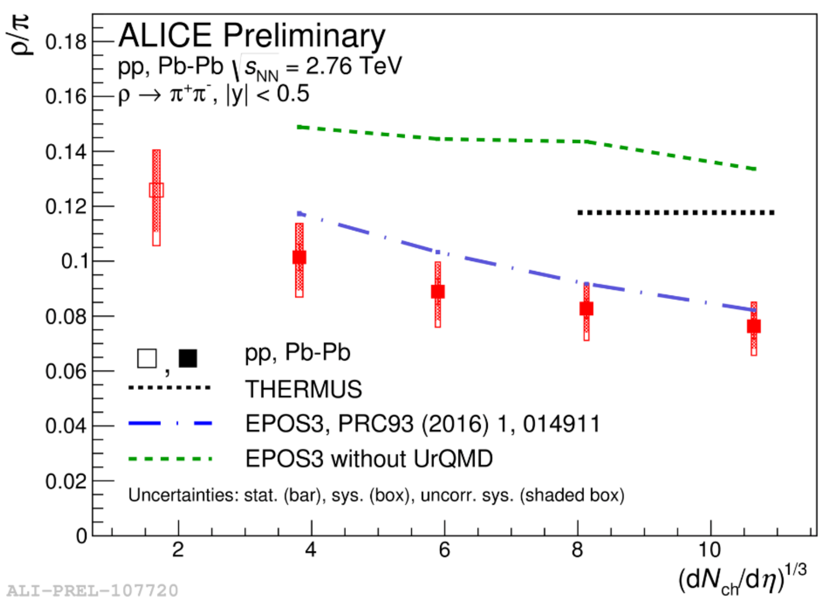
RE-SCATTERING IN SMALL SYSTEMS?





Hints of a similar behavior (flat for ϕ/K and decreasing for K*/K) as in Pb-Pb collision (but uncertainties are large!)

SHORTER-LIVED RESONANCES



Lifetime (fm/c)

$\rho^0 < K^{*0} < \Sigma^{*\pm} < \Lambda^* < \Xi^{*0} < \phi$

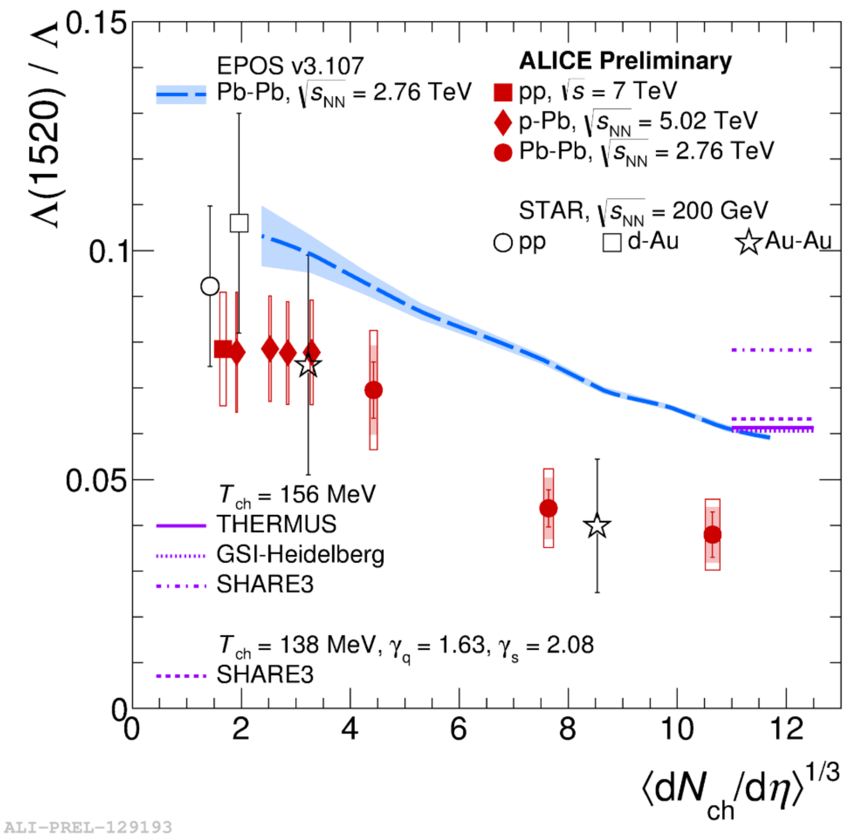
1.3 < 4.2 < 5.5 < 12.6 < 21.7 < 46.2

ρ/π shows clear suppression going from pp and peripheral Pb-Pb collisions to central Pb-Pb

EPOS3 with UrQMD qualitatively reproduces the trend of the suppression

- UrQMD added as afterburner to model re-scattering effects
- fails to reproduce the trend without UrQMD

RESONANCE-TO-STABLE-PARTICLE RATIO



Lifetime (fm/c)

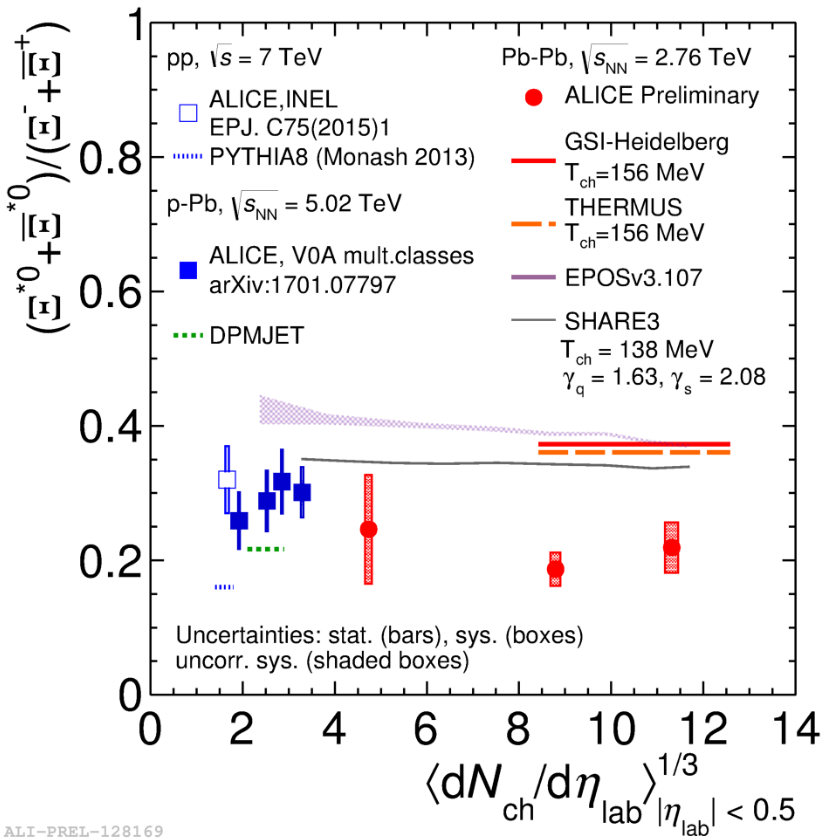
ρ^0	<	K^{*0}	<	$\Sigma^{*\pm}$	<	Λ^*	<	Ξ^{*0}	<	ϕ
1.3	**<**	**4.2**	**<**	**5.5**	**<**	**12.6**	**<**	**21.7**	**<**	**46.2**

Suppression of Λ(1520) in most central Pb-Pb (0-20%) wrt. pp, p-Pb, peripheral Au-Au, Pb-Pb and thermal models

- follows STAR trend with higher multiplicity and better accuracy

EPOS3 with UrQMD qualitatively reproduces the trend of the suppression

LONGER-LIVED RESONANCES



Lifetime (fm/c)

$\rho^0 < K^{*0} < \Sigma^{*\pm} < \Lambda^* < \Xi^{*0} < \phi$

$1.3 < 4.2 < 5.5 < 12.6 < 21.7 < 46.2$

Almost constant behaviour

- no significant multiplicity dependence in pp and p-Pb collisions
- hint of suppression in central Pb-Pb w.r.t pp and p-Pb, but systematics to be improved in peripheral Pb-Pb

EPOS3 with UrQMD

- no strong suppression expected from the model

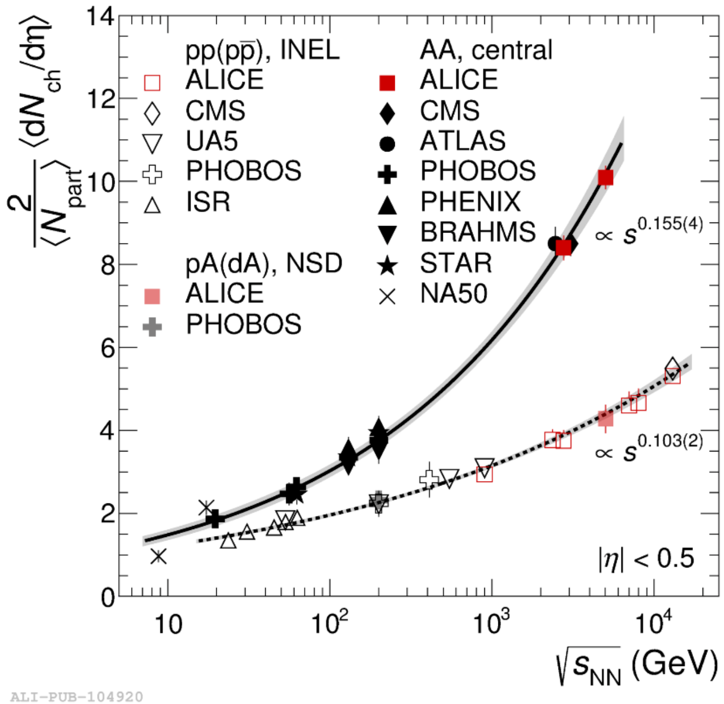
CONCLUSIONS

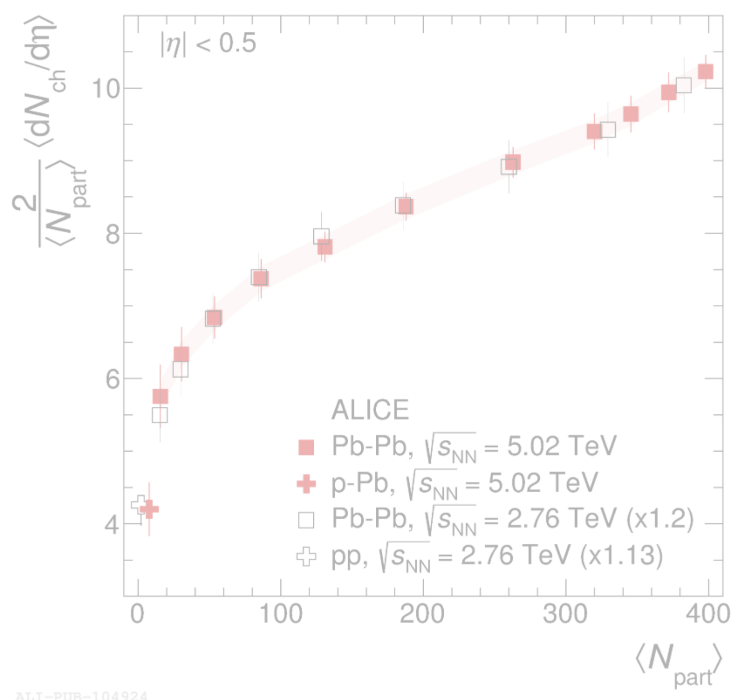
- Thanks to a campaign of precise measurements, hadronic resonances have become suitable tools in the study of bulk production in ultra-relativistic heavy-ion collisions and in the investigation of new effects in small systems
- Strangeness enhancement as signature of the QGP has been studied with resonances of different mass and strangeness content. In small systems strangeness enhancement as a function of multiplicity is found to be driven by strangeness content and not by mass
- Hadronic resonances are valuable probes of the hadronic medium in the late stage of ultra-relativistic heavy-ion collisions. Further results will give us a better understanding on final-state effects and will allow to quantify the duration of the late phase

Thank you for your attention!

BACKUP SLIDES

ENERGY DEPENDENCE OF MULTIPLICITY





- Much **stronger s dependence for A-A** than for pp collisions
- ALICE p-Pb and PHOBOS d-Au on the curve for pp collisions

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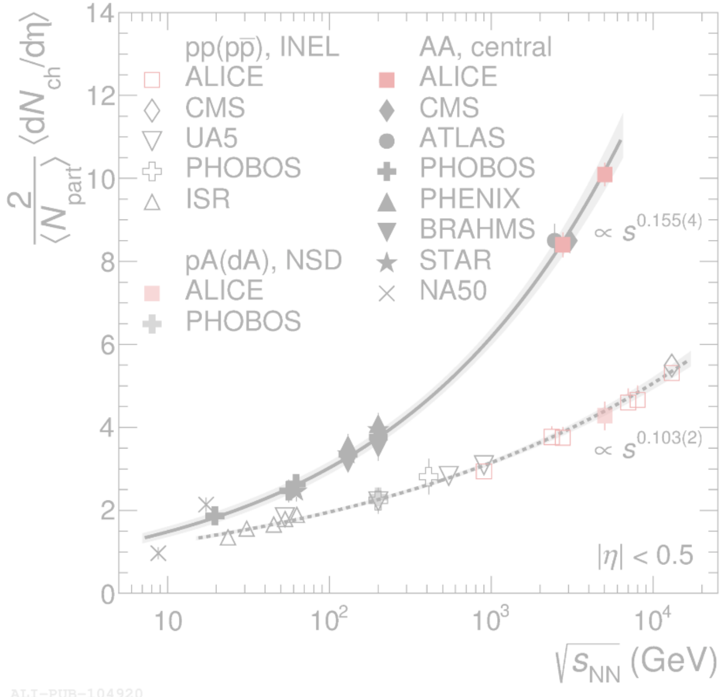
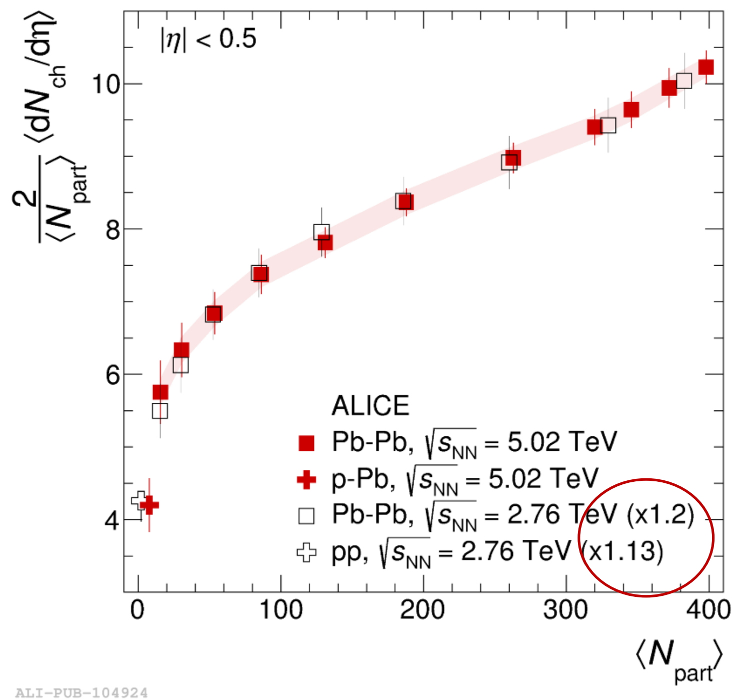
ENERGY DEPENDENCE OF MULTIPLICITY





- Data for 2.76 TeV scaled according to *s* dependence
- **Strong dependence** observed as a function of N_{part}

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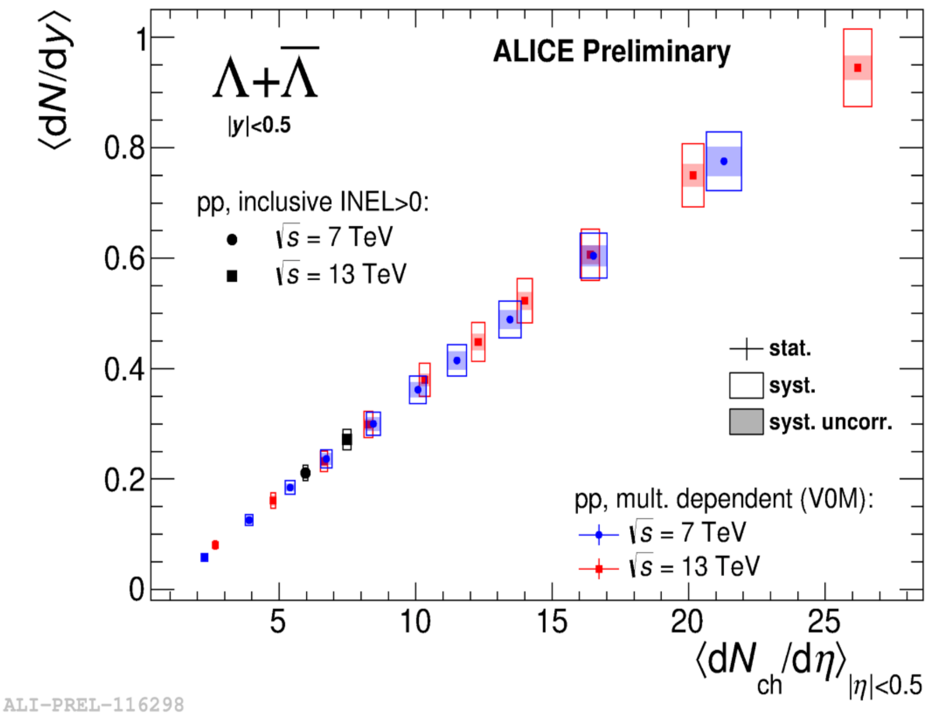
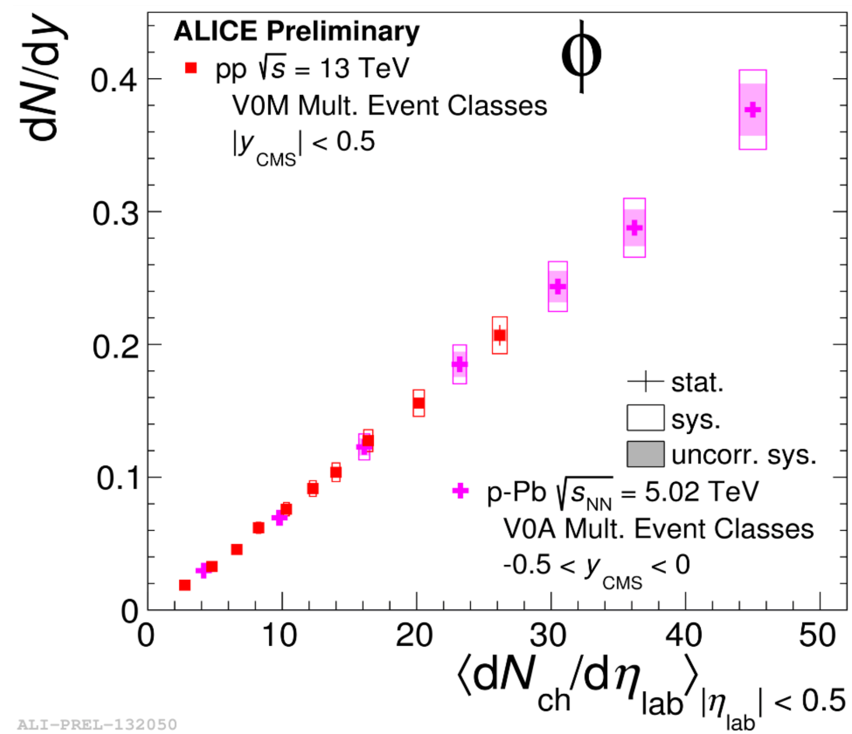
MULTIPLICITY DEPENDENCE OF PARTICLE YIELDS





In small systems the event multiplicity drives particle production