Hadronic resonances, strange and multi-strange particle production in Xe-Xe and Pb-Pb collisions with ALICE at the LHC

Danilo Albuquerque
Universidade Estadual de Campinas, Brazil
on behalf of the ALICE Collaboration

The 27th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions

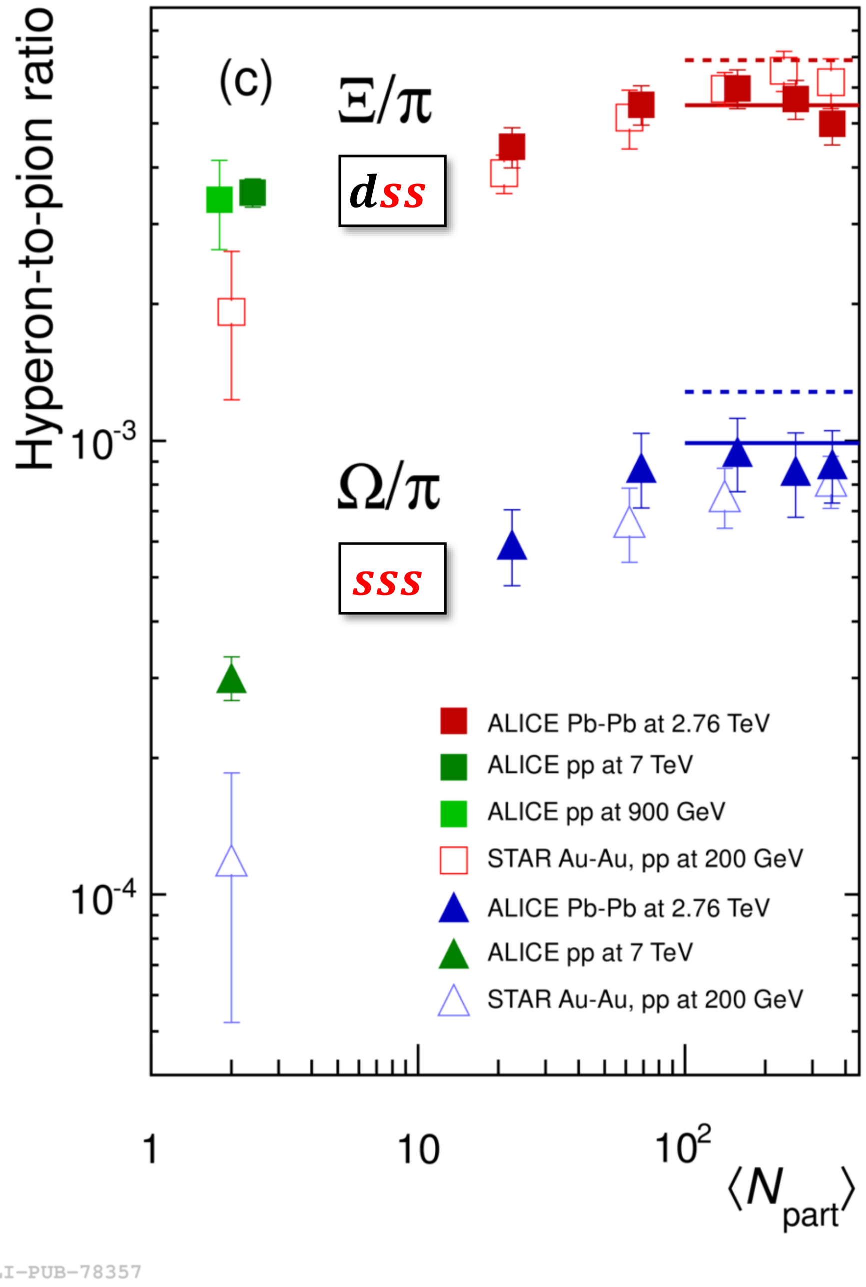
Venezia, Italy, May, 14-19, 2018

Work Supported by CNPq Grant 141186/2015-1

The Role of Strangeness

- Historically a signature of the QGP†
- **Enhancement** observed in AA
- Increases with **strangeness content**

ALICE Coll., *PLB* **734**, 409-410 (2014)



†J. Rafelski and B.Müller, *Phys. Rev. Lett.* **48**, 1066 (1982)

The Role of Strangeness

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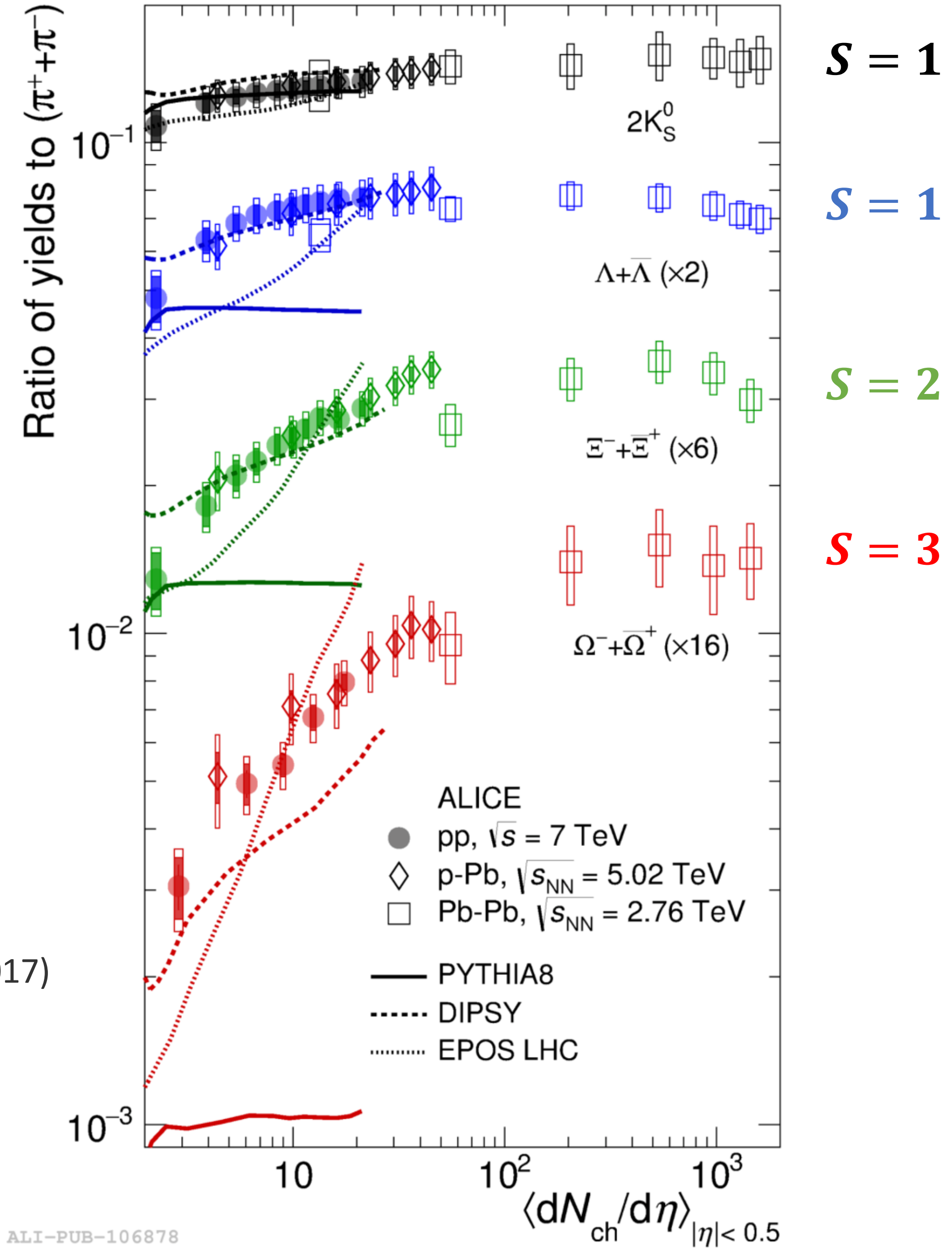
- **Enhancement** observed in AA
- Increases with **strangeness content**
- Recently observed in **smaller systems**



ALICE Coll., *Nature Physics* **13**, 535–539 (2017)

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The Role of Strangeness

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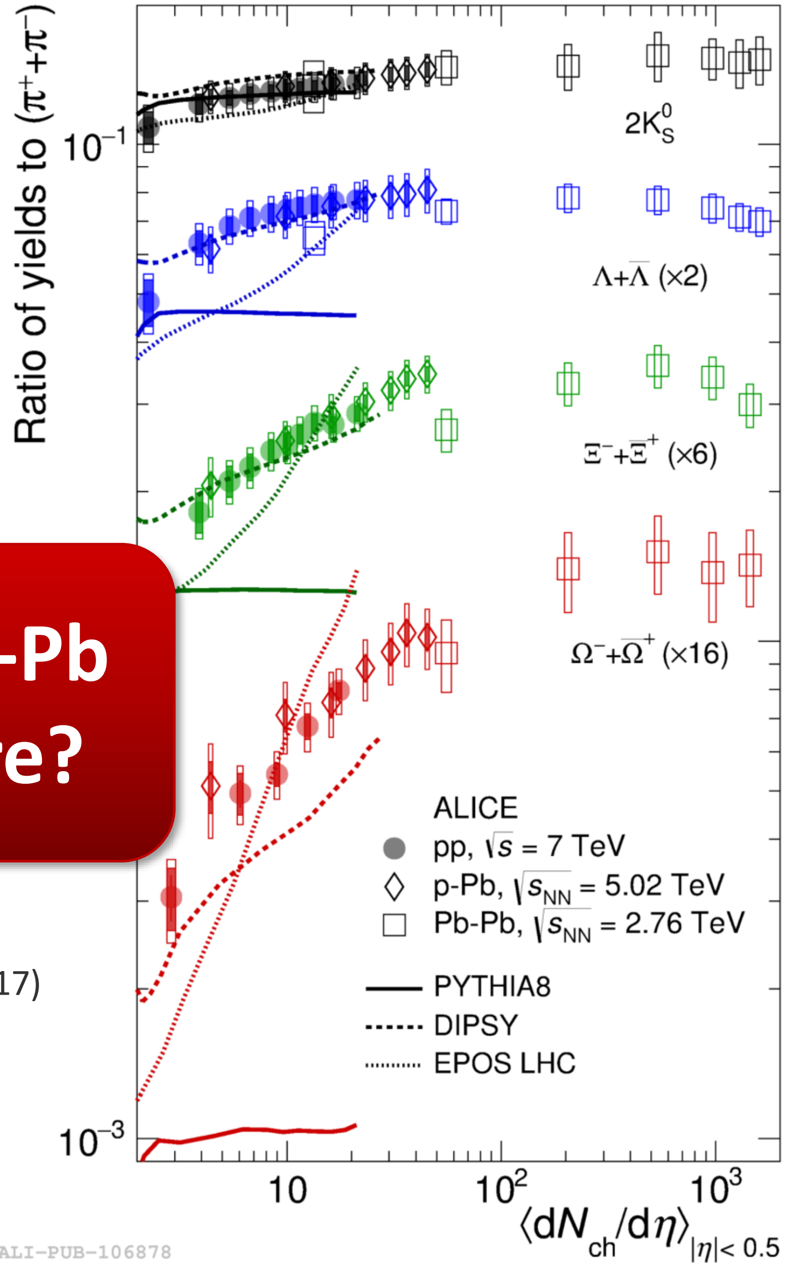
- Rec

How do new results from Pb-Pb and Xe-Xe fit into this picture?



$S = 1$

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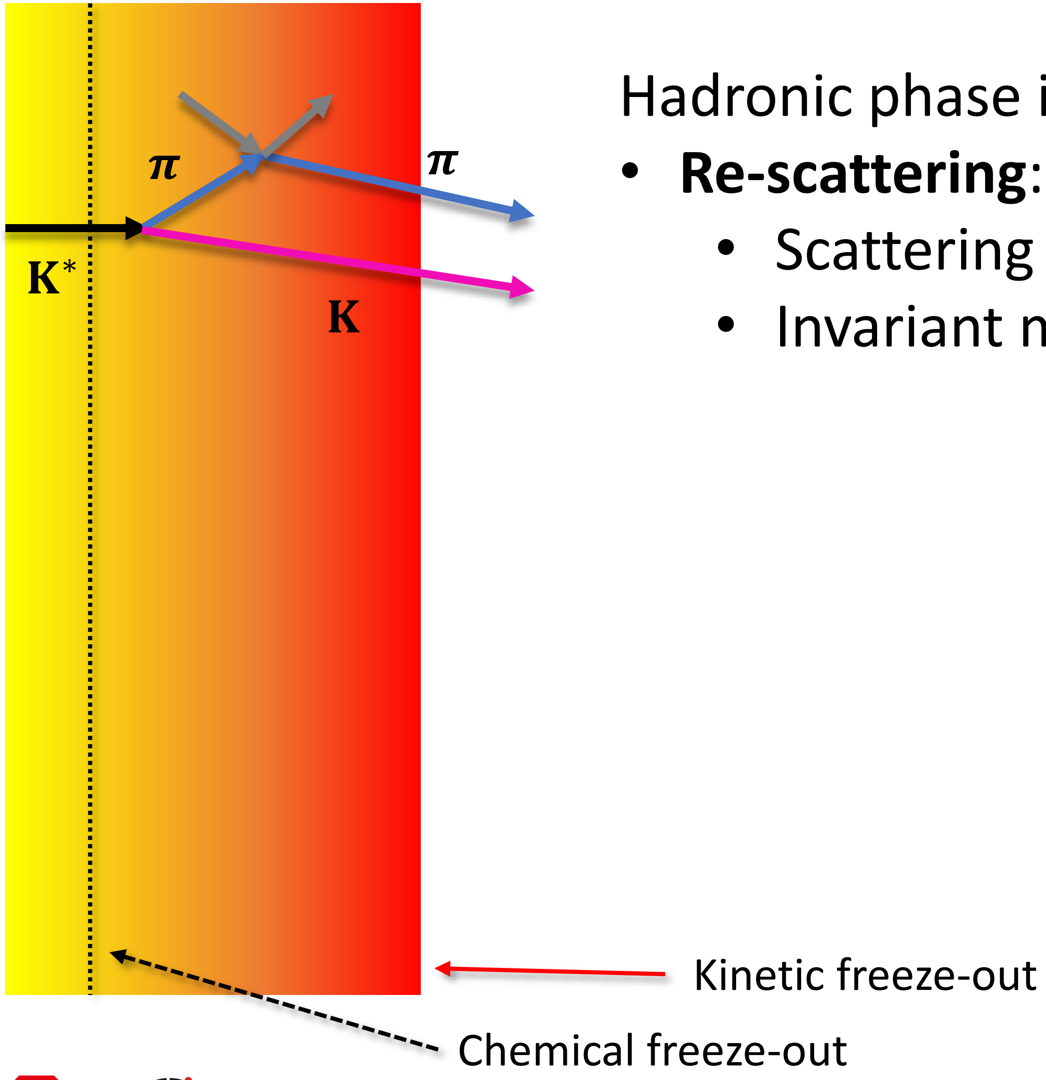
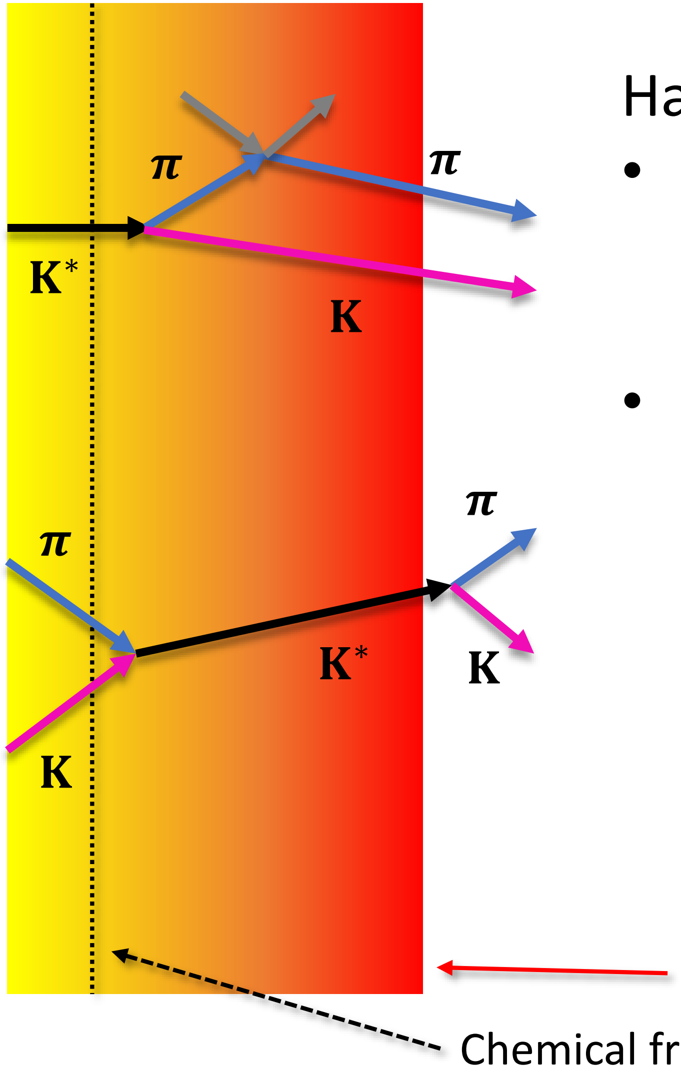
Re-Scattering and Regeneration



Hadronic phase influences measured resonances yields

- **Re-scattering**:
  - Scattering of decay products
  - Invariant mass correlation lost

Re-Scattering and Regeneration



Hadronic phase influences measured resonances yields

- **Re-scattering**:
  - Scattering of decay products
  - Invariant mass correlation lost
- **Regeneration**:
  - Pseudo-elastic scattering through resonant state
  - e.g.: $\pi K \rightarrow K^* \rightarrow \pi K$

Kinetic freeze-out

Chemical freeze-out

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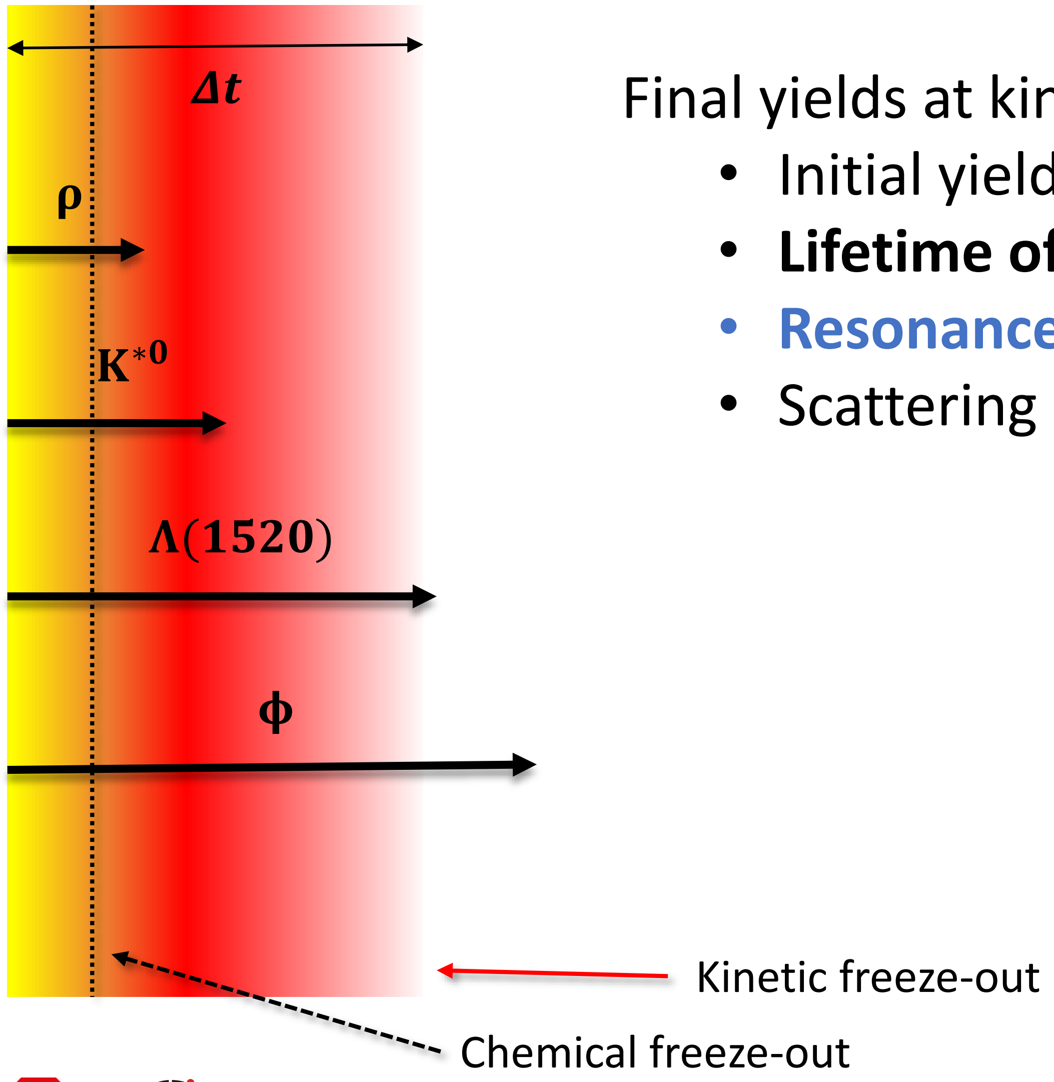
Re-Scattering and Regeneration

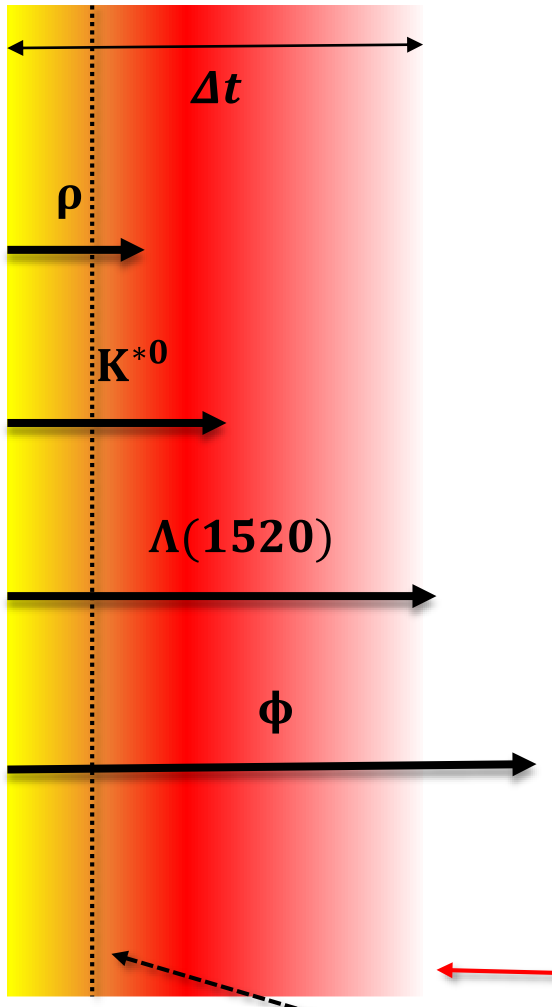


Final yields at kinetic freeze-out will depend on:

- Initial yield after chemical freezeout
- **Lifetime of hadronic phase**
- **Resonance lifetime**
- Scattering cross-section of decay products

Resonance	ρ^0	K^{*0}	$\Lambda(1520)$	ϕ
Lifetime (fm/c)	1.3	4.16	12.6	46.2

Re-Scattering and Regeneration



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New results for several resonances in heavy-ion collisions

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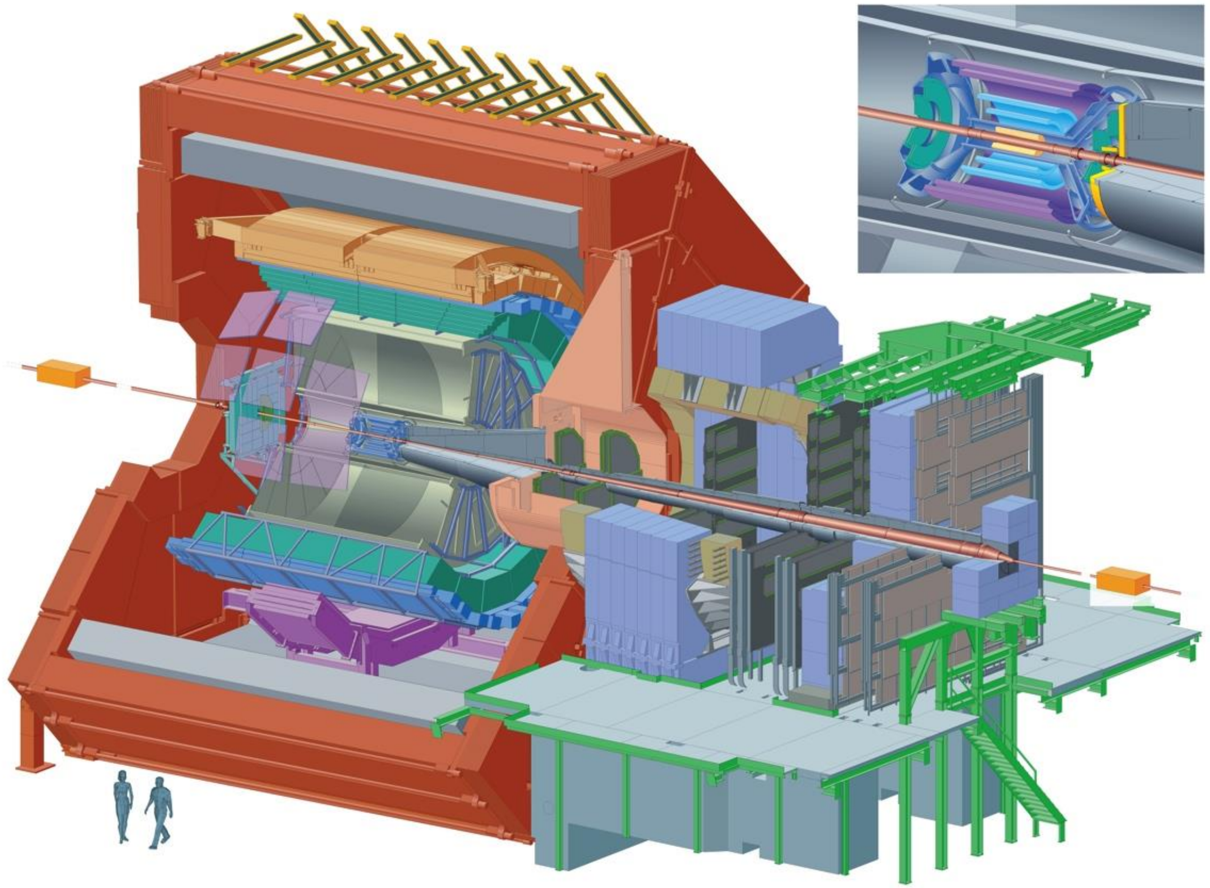
The ALICE Detector



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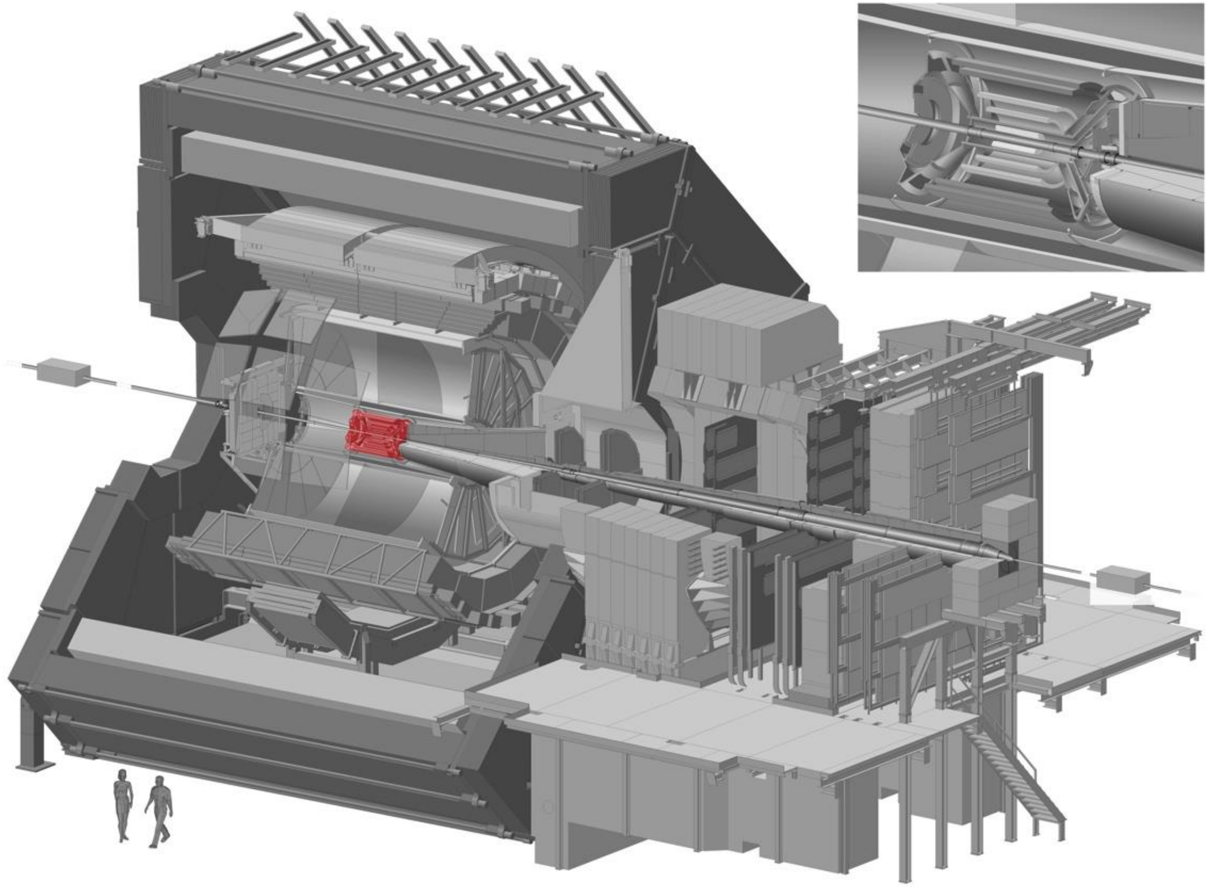

ITS (|η|<0.9)

Six layers of silicon detectors:

- Trigger, tracking, vertex, PID (dE/dx)

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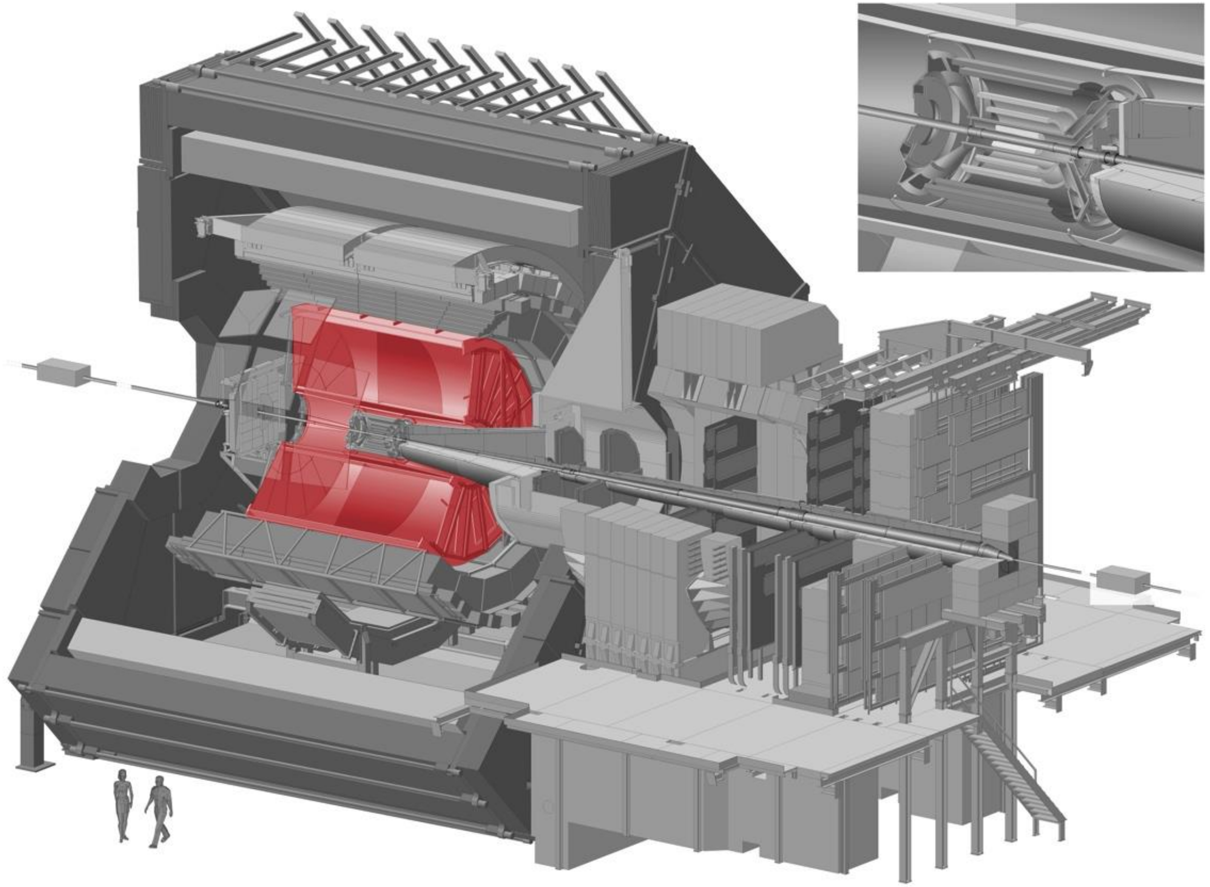

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Gas-filled ionization detection volume:

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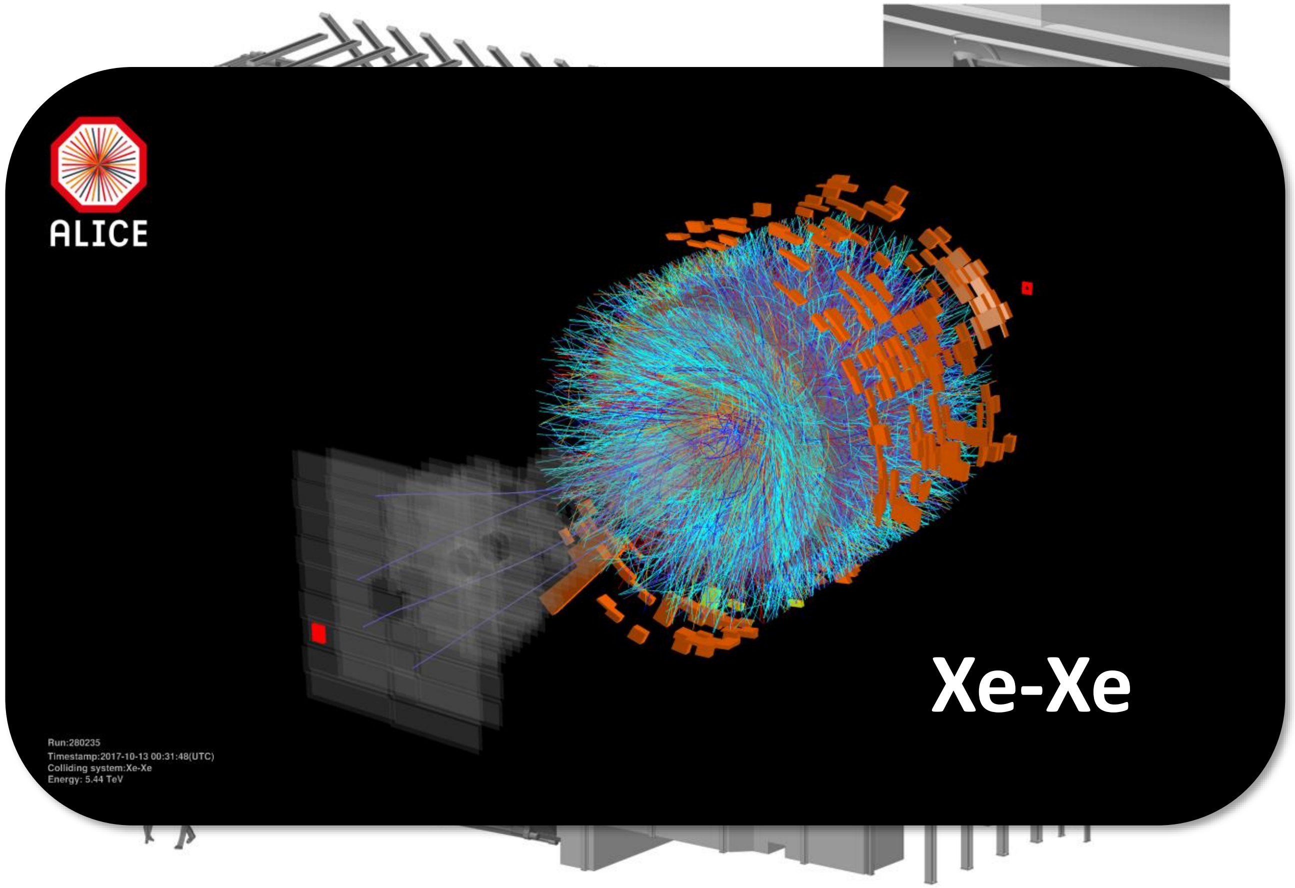

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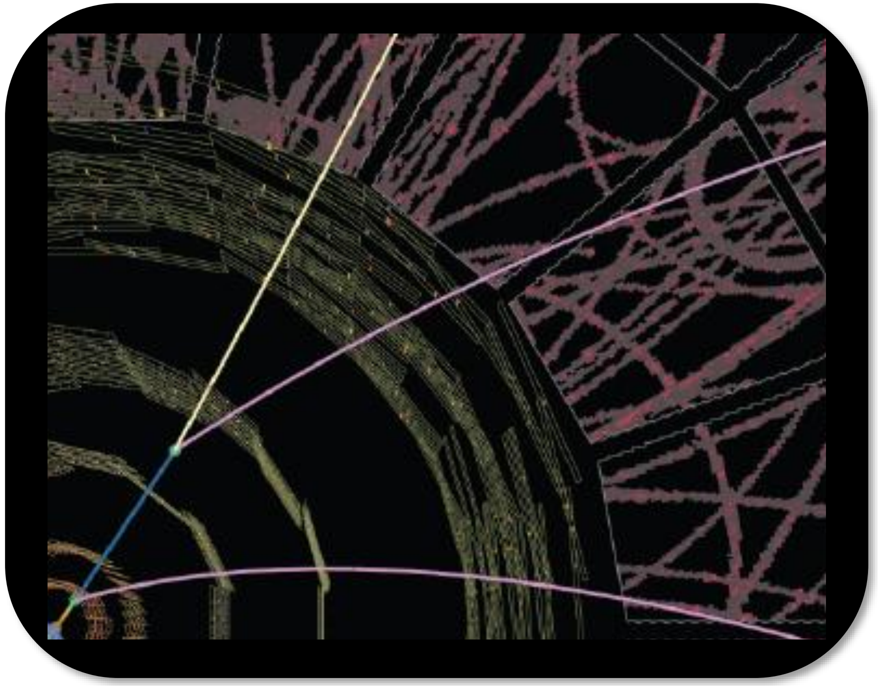

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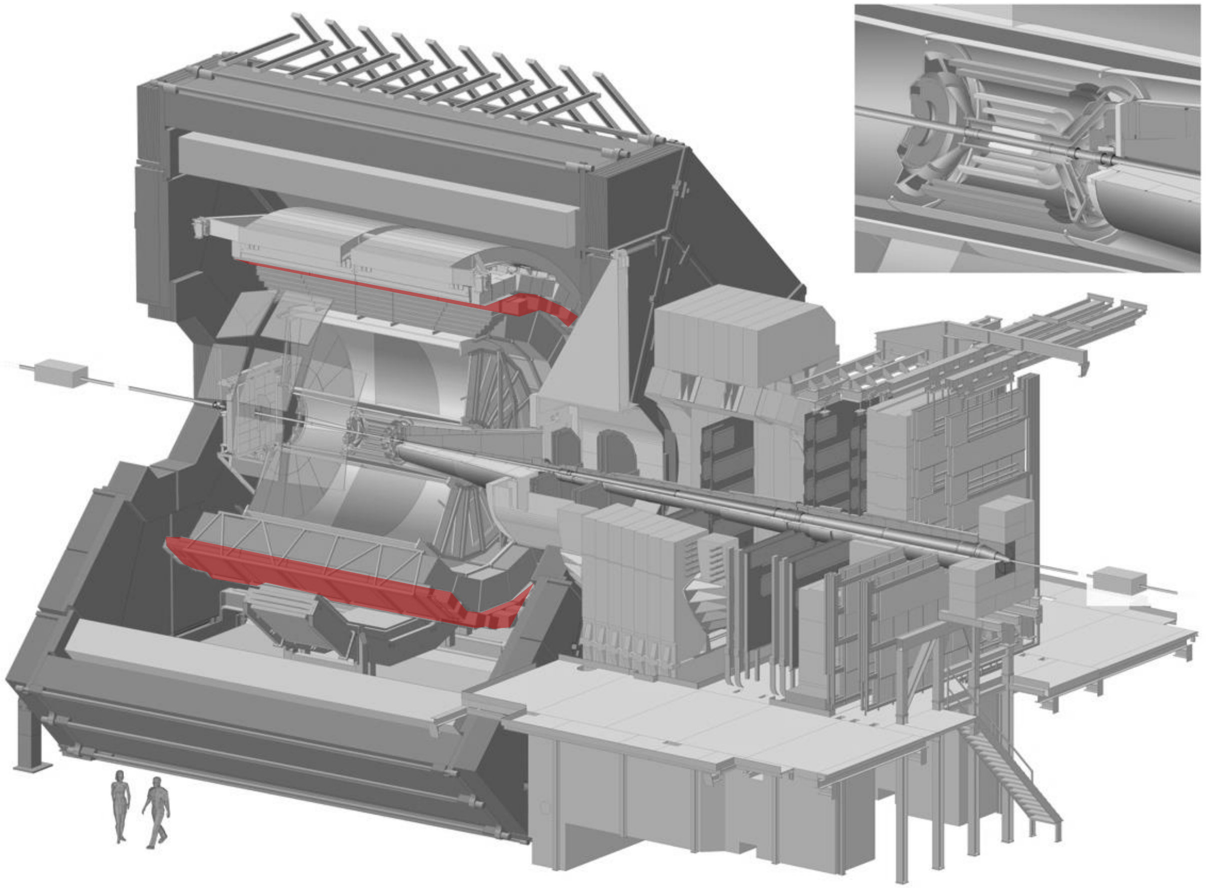

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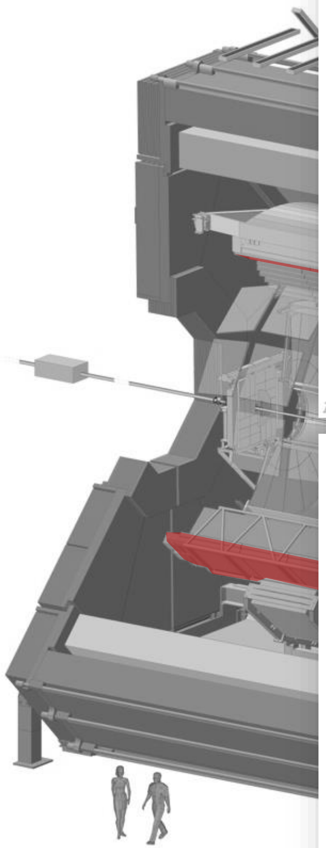
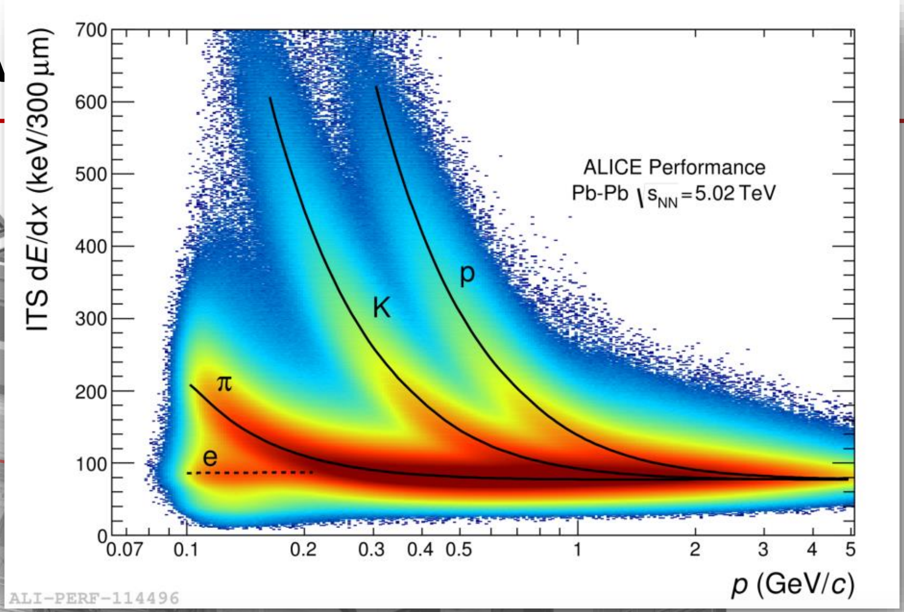
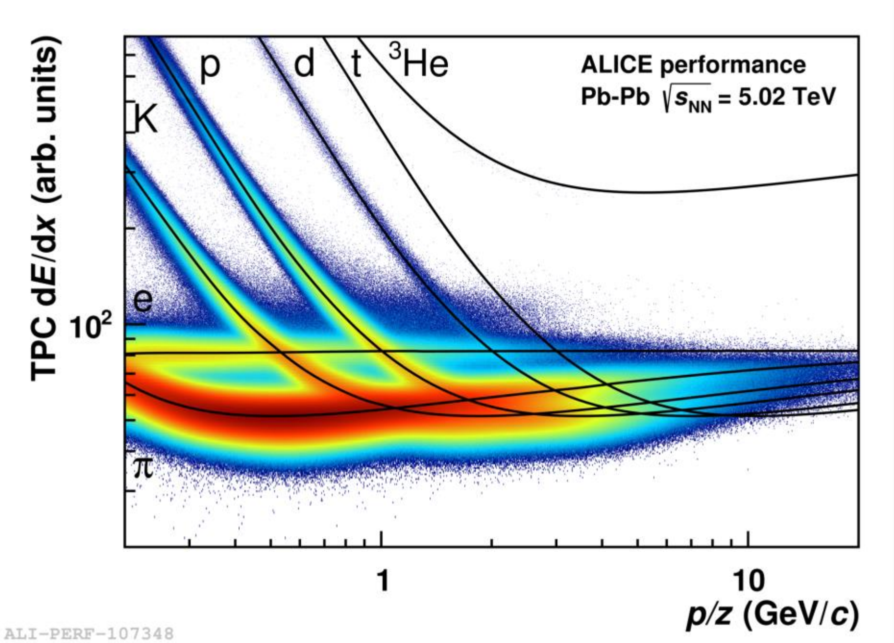
Chamber of resistive plates

- PID through particle time of flight

The A







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Six layers of silicon detectors:

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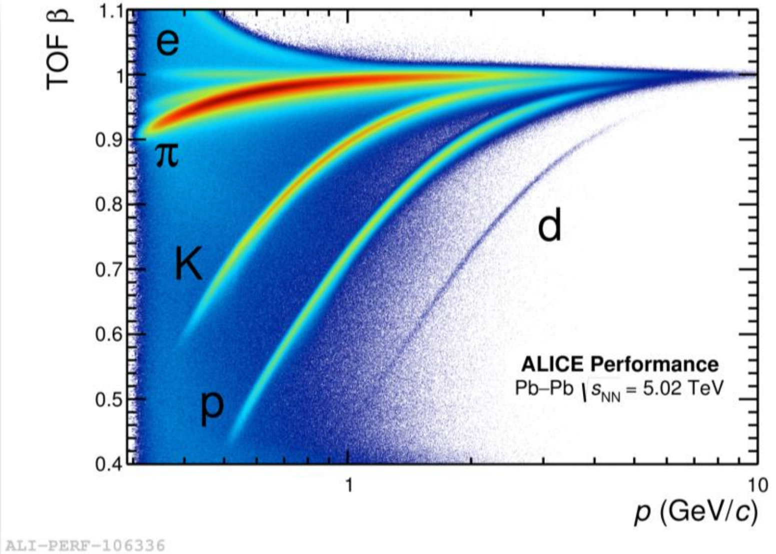

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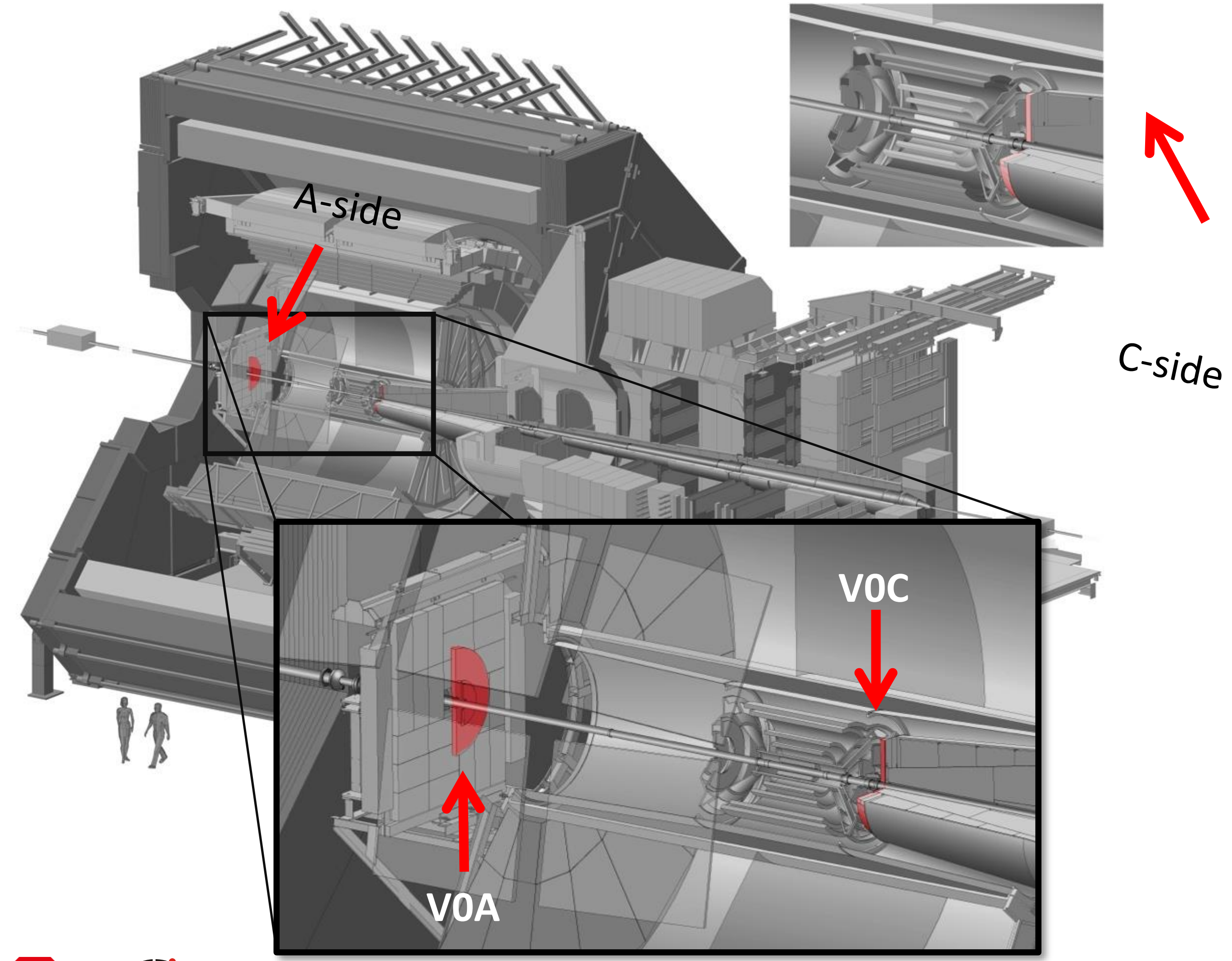

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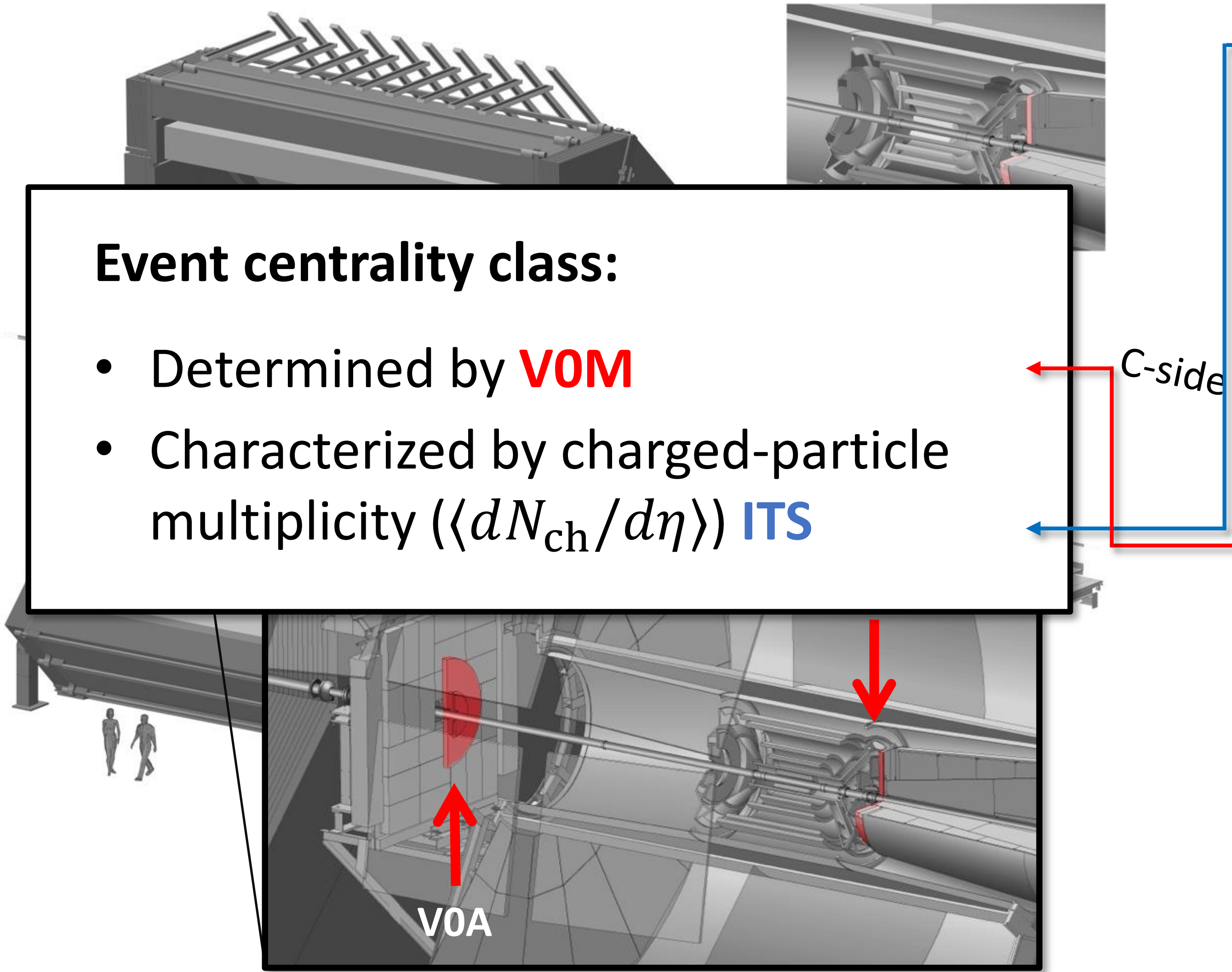
V0 [V0A($2.8<\eta<5.1$)&V0C($-3.7<\eta<-1.7$)]

Forward array of scintillators:

- Trigger, centrality estimator

The ALICE Detector



Event centrality class:

- Determined by **V0M**
- Characterized by charged-particle multiplicity ($\langle dN_{\mathrm{ch}}/d\eta \rangle$) **ITS**

ITS ($|\eta|<0.9$)

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Measuring strange particles and resonances

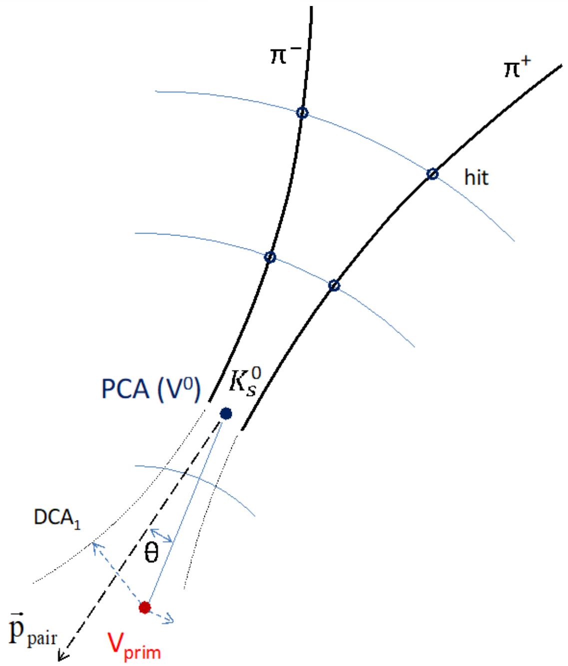
V^0 and cascade reconstruction via weak decay topology

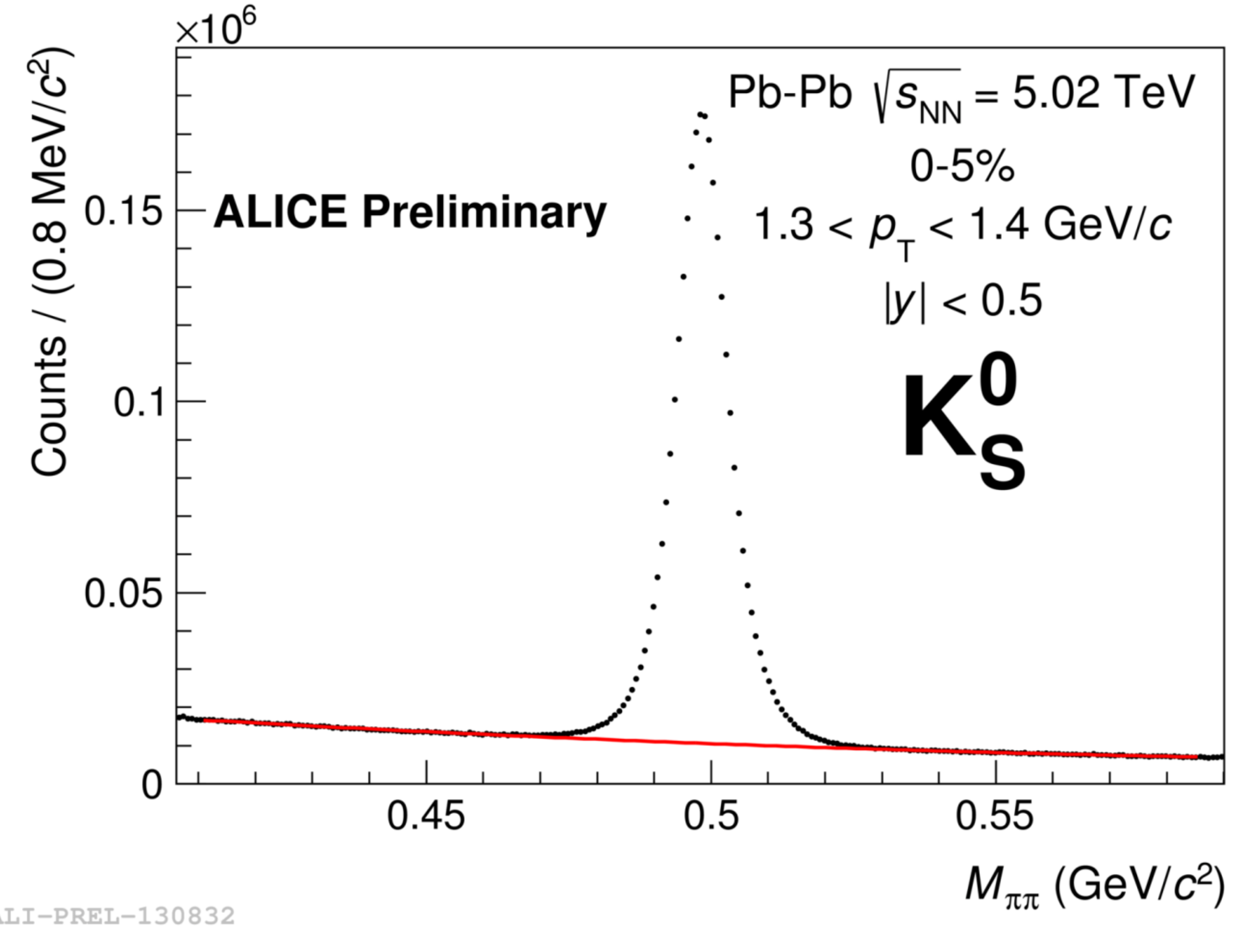
$K^0_S \to \pi^+ + \pi^-$

$\Lambda \to p + \pi^-$

$\Xi^- \to \Lambda + \pi^-$

$\Omega^- \to \Lambda + K^-$





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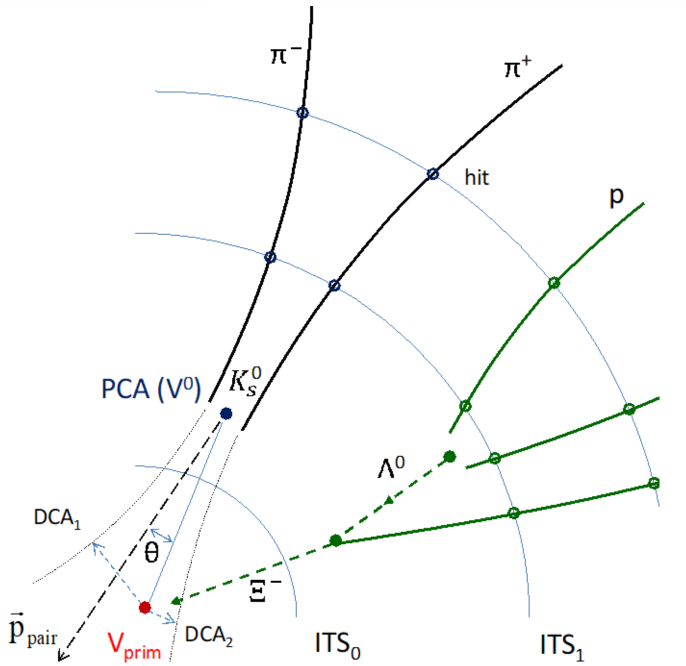

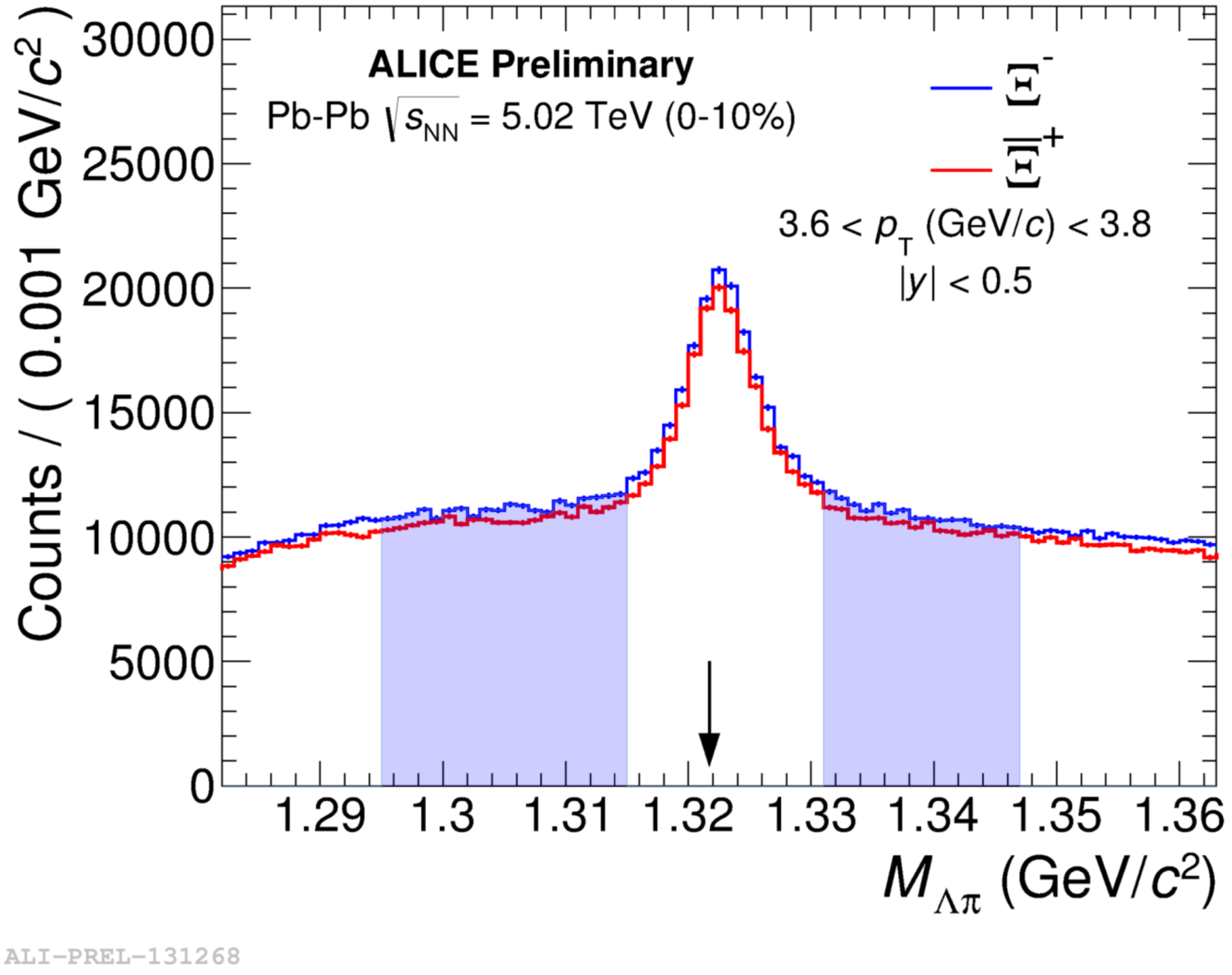

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Resonances reconstructed via strong decay

$\rho(770)^0 \rightarrow \pi^+ + \pi^-$

$K^{*0}(892) \rightarrow K^+ + K^-$

$\Lambda(1520) \rightarrow p + K^-$

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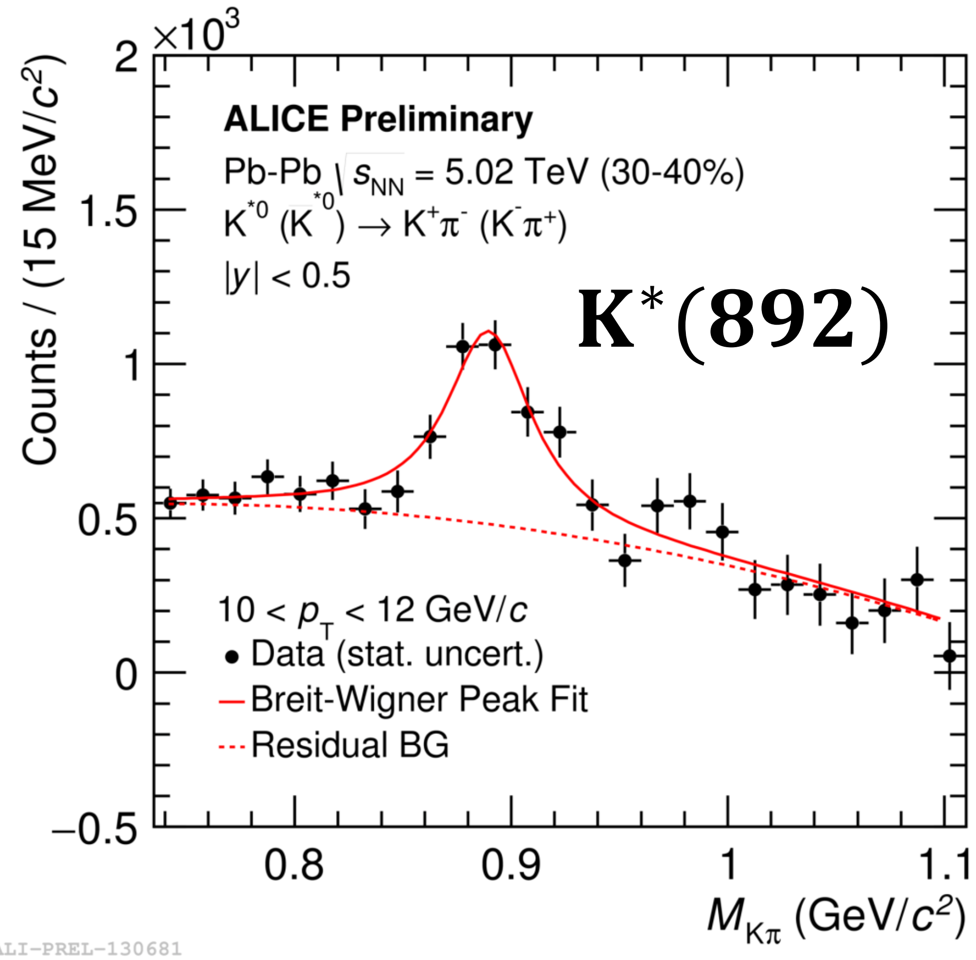

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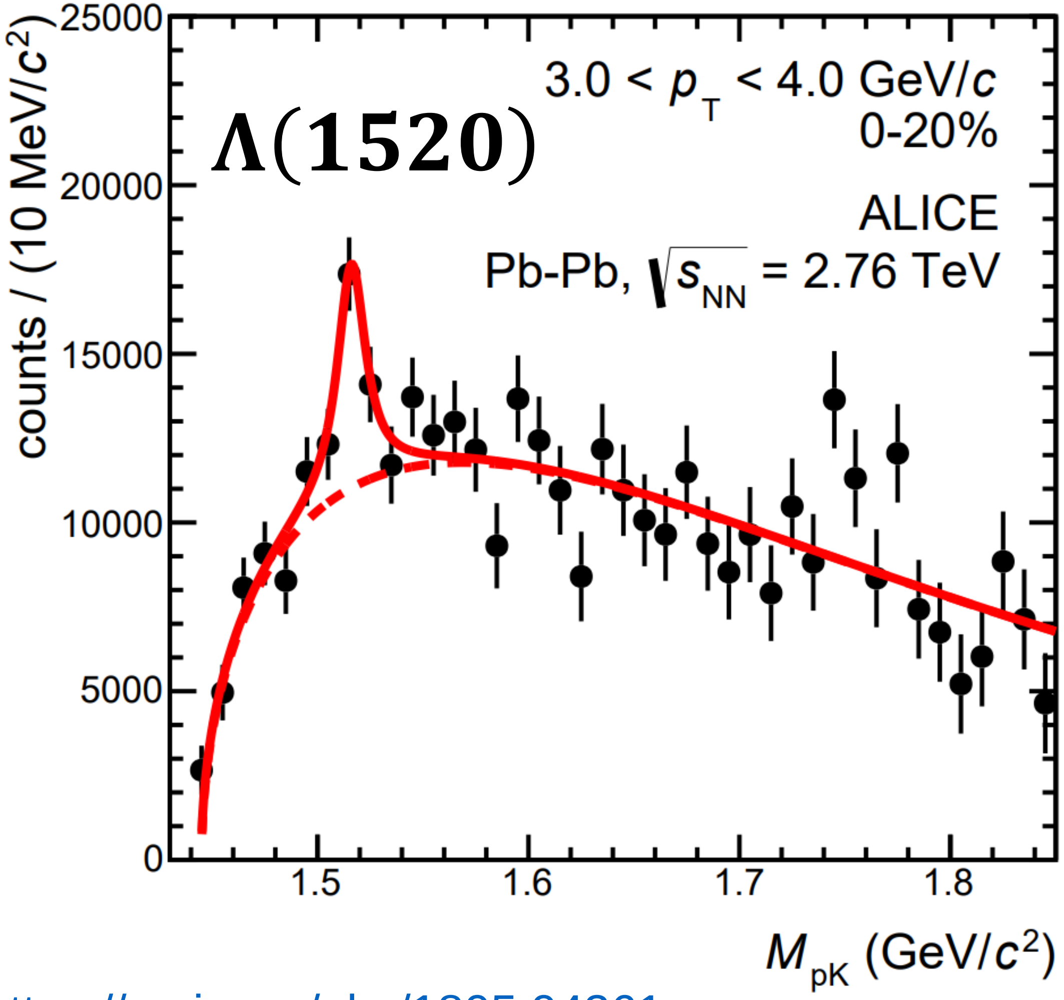
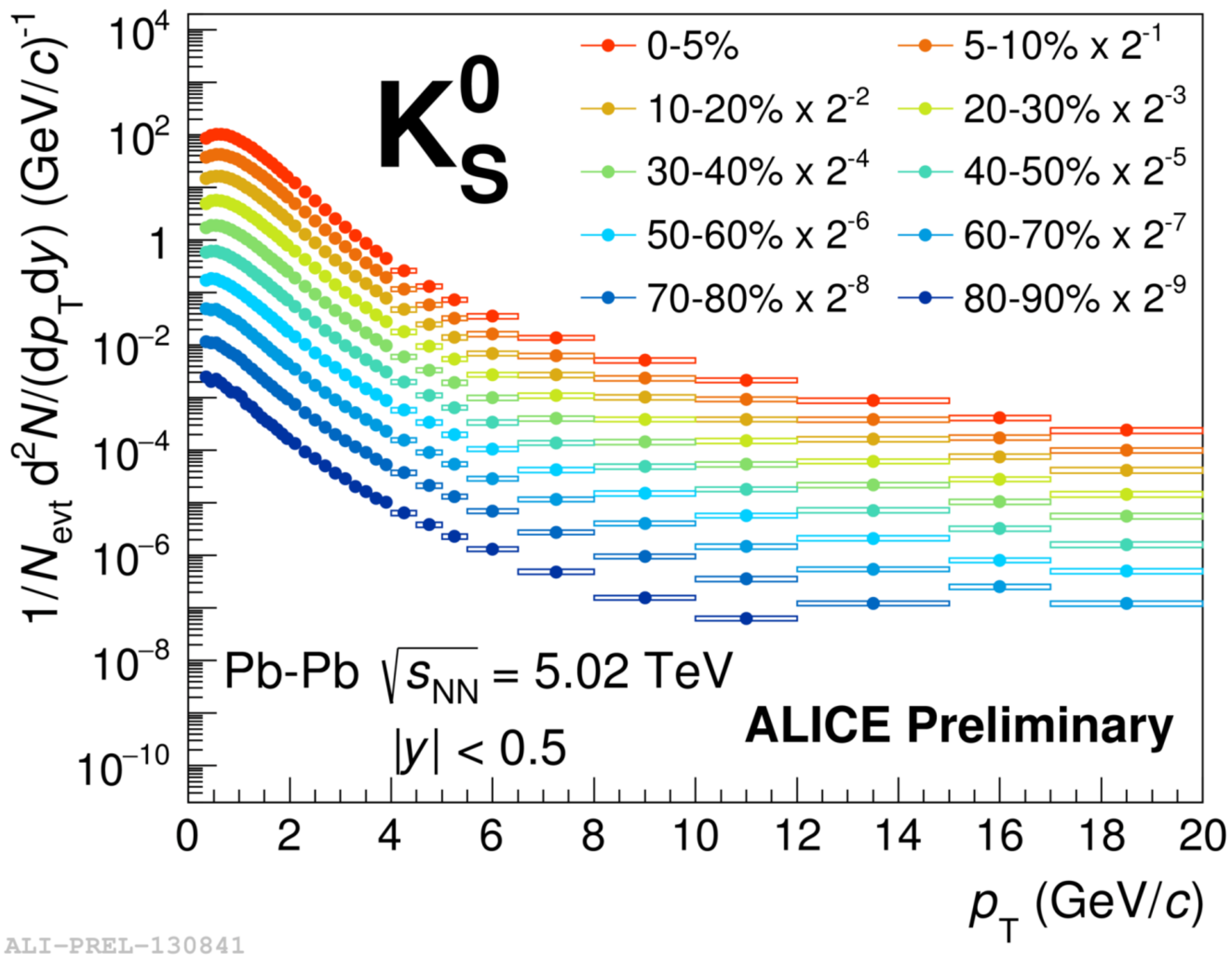


https://arxiv.org/abs/1805.04361

Strangeness particle spectra in Pb-Pb at $\sqrt{s_{NN}} = 5.02$ TeV



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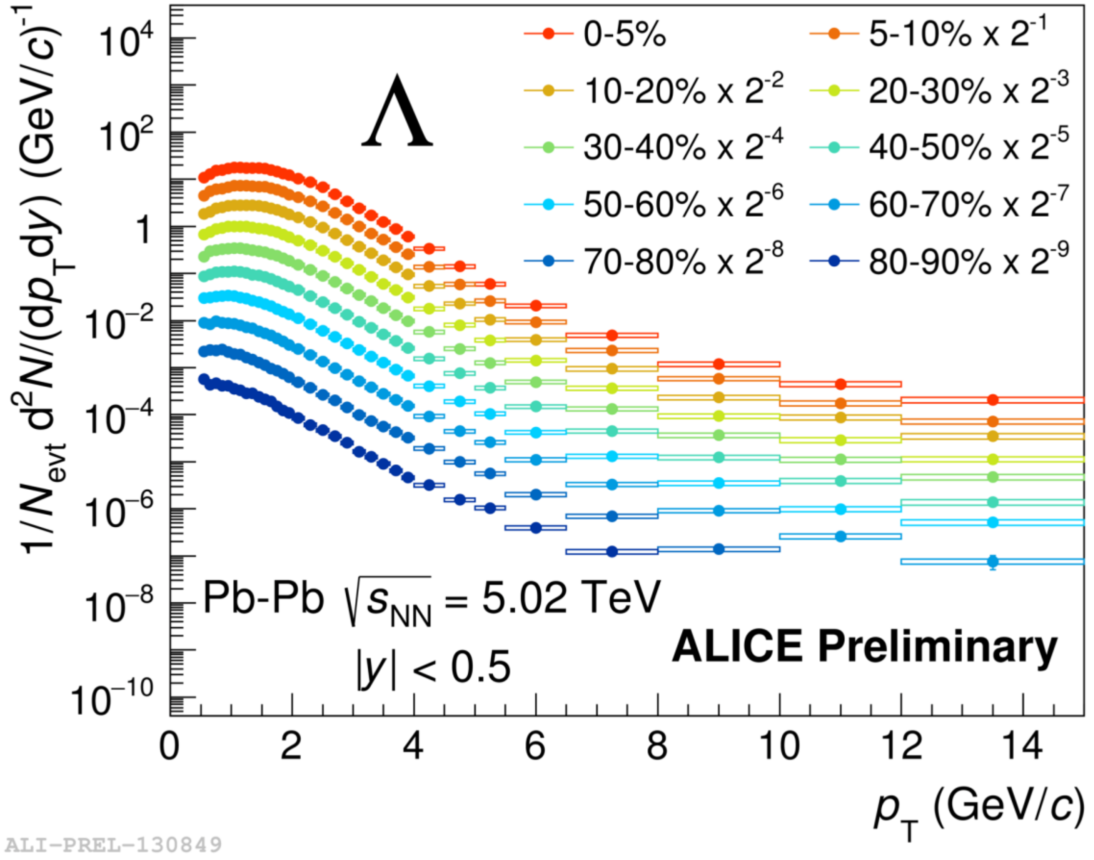

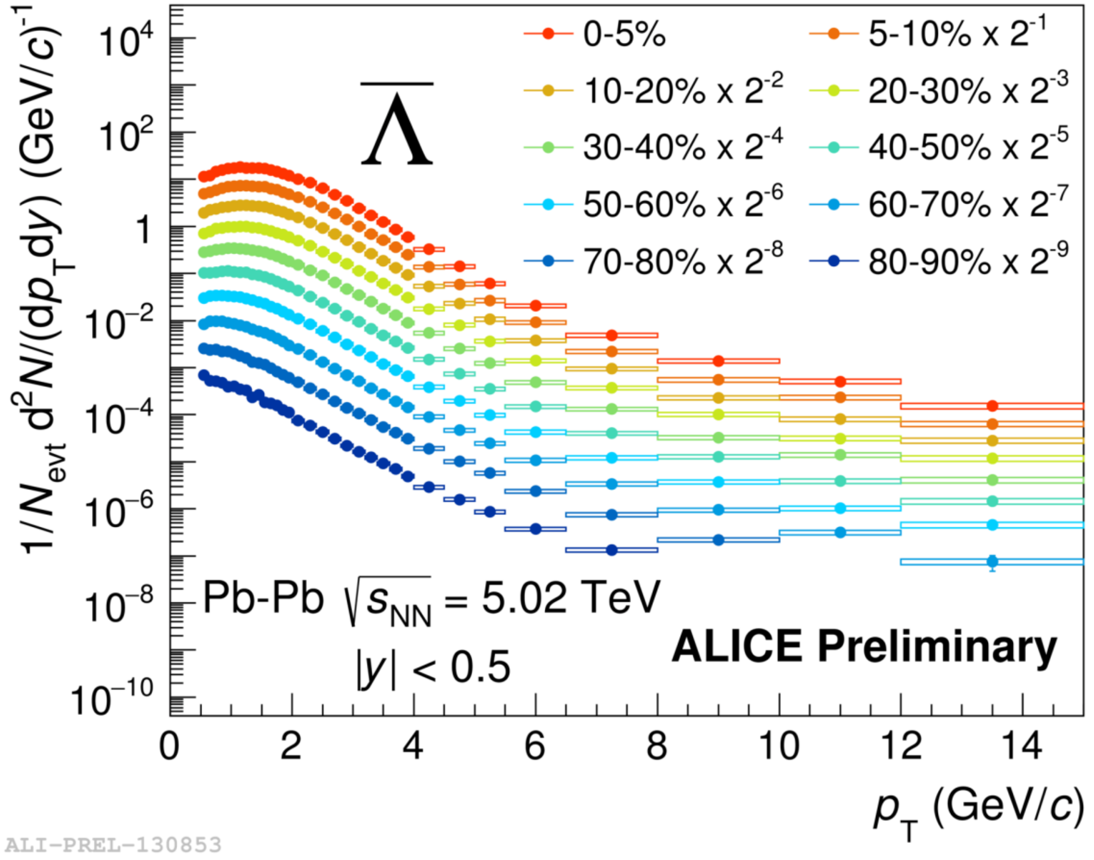

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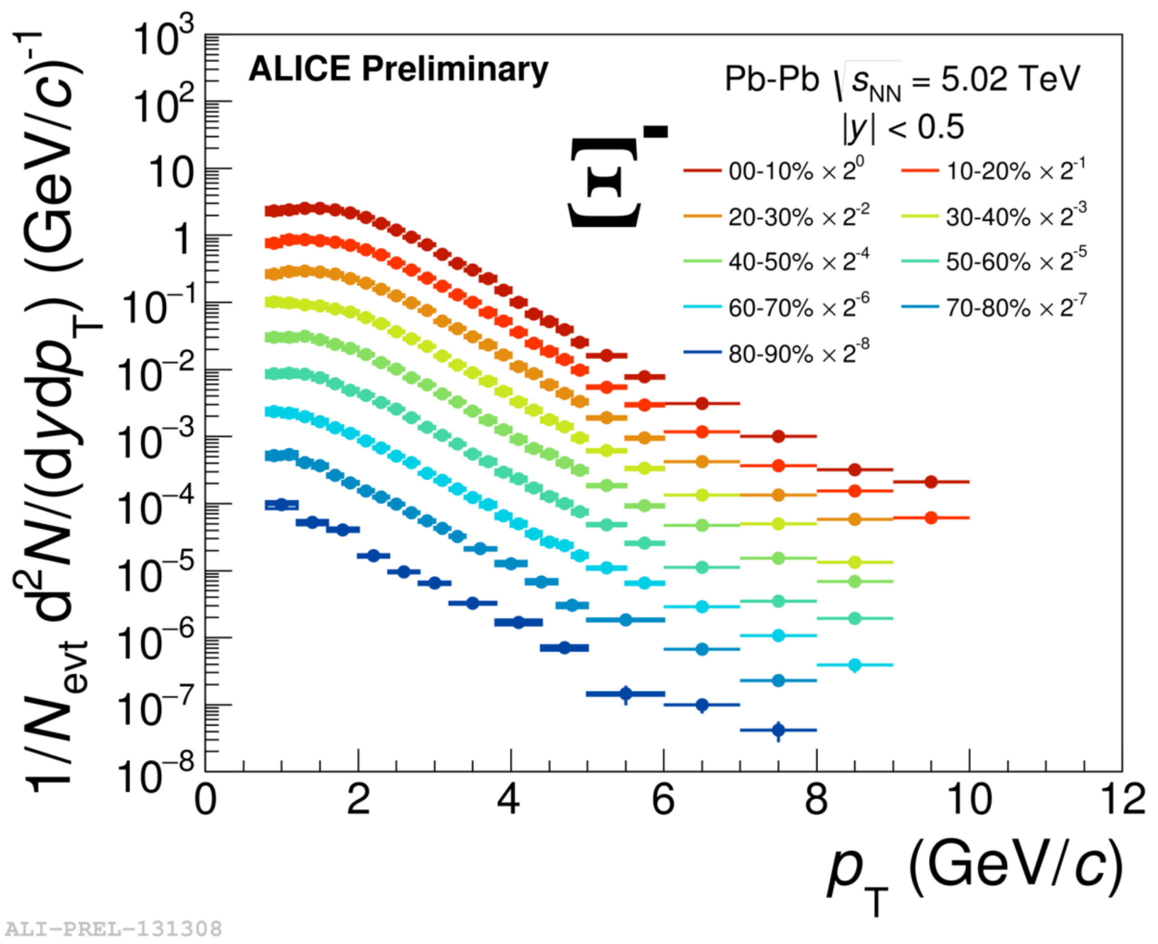

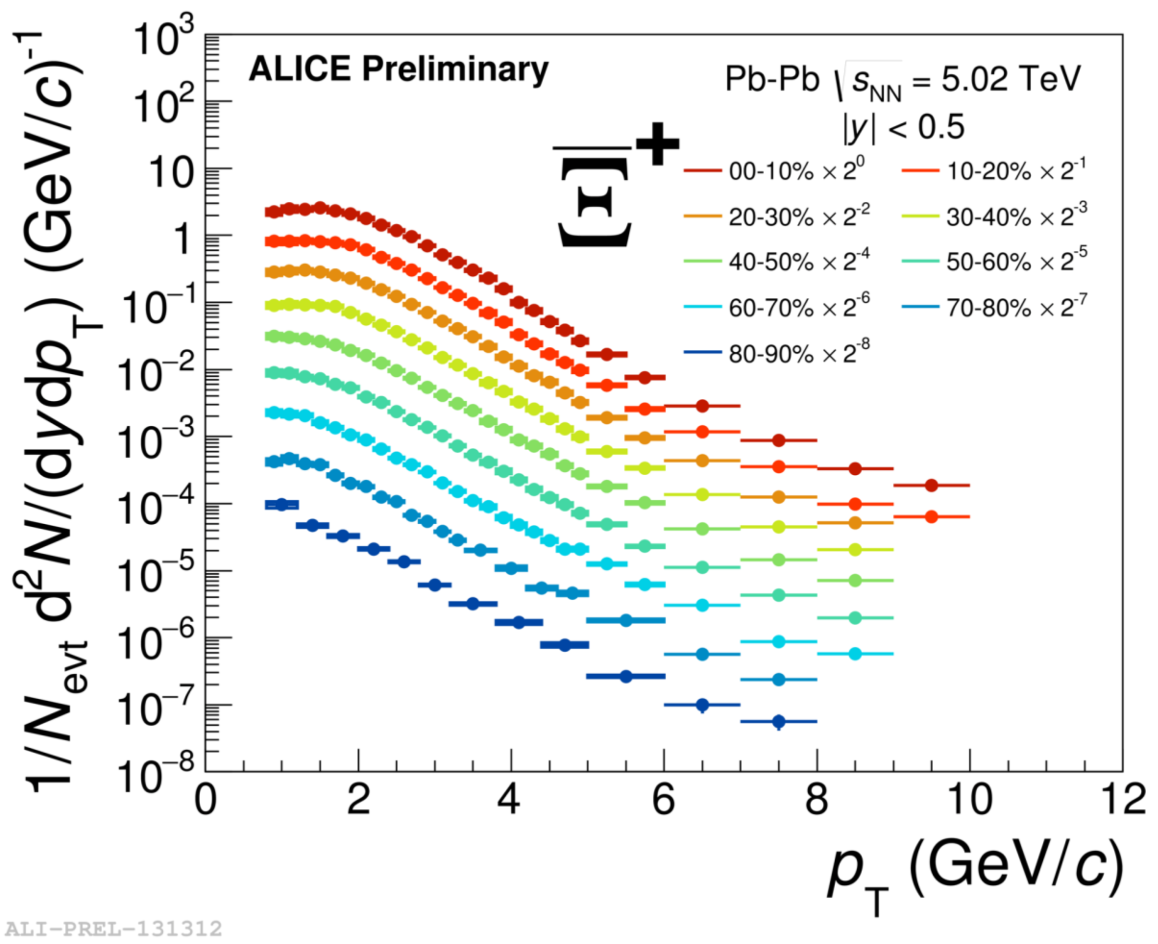

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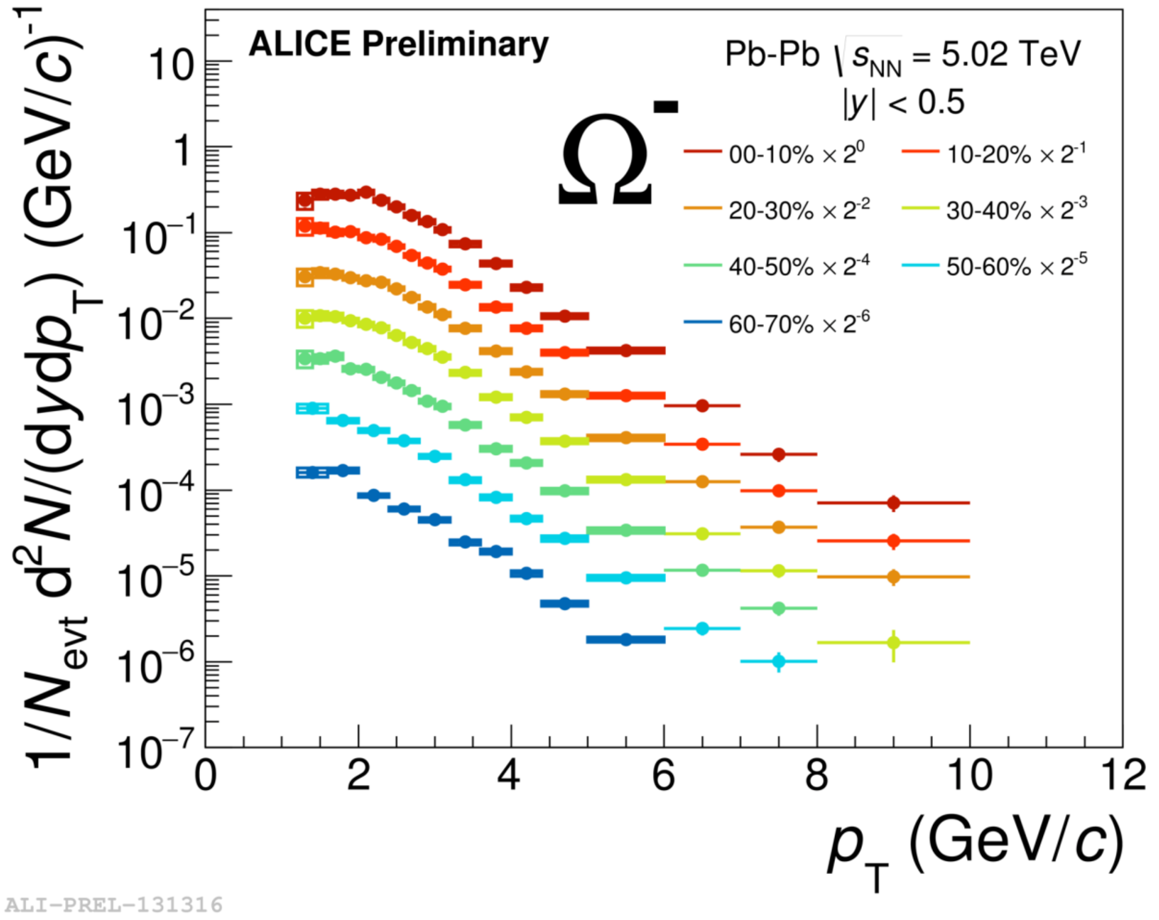

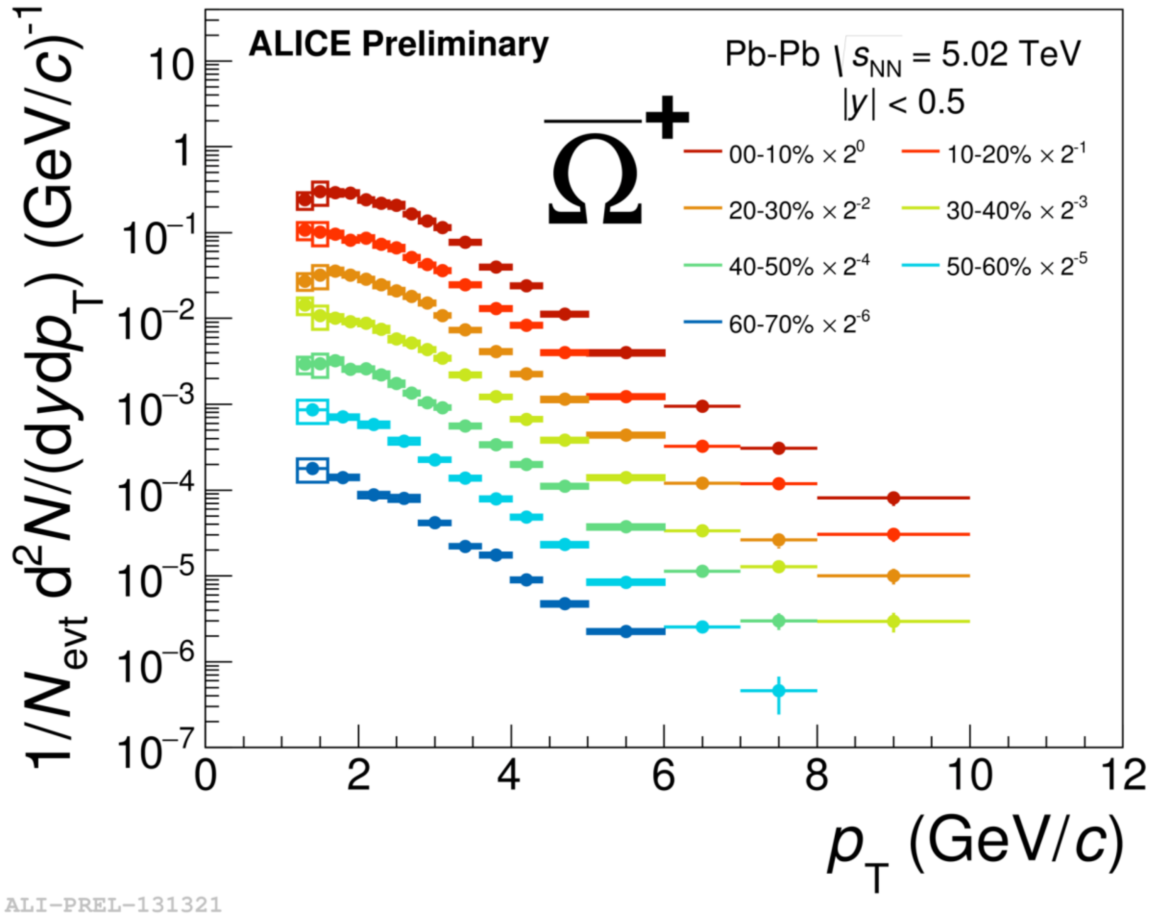

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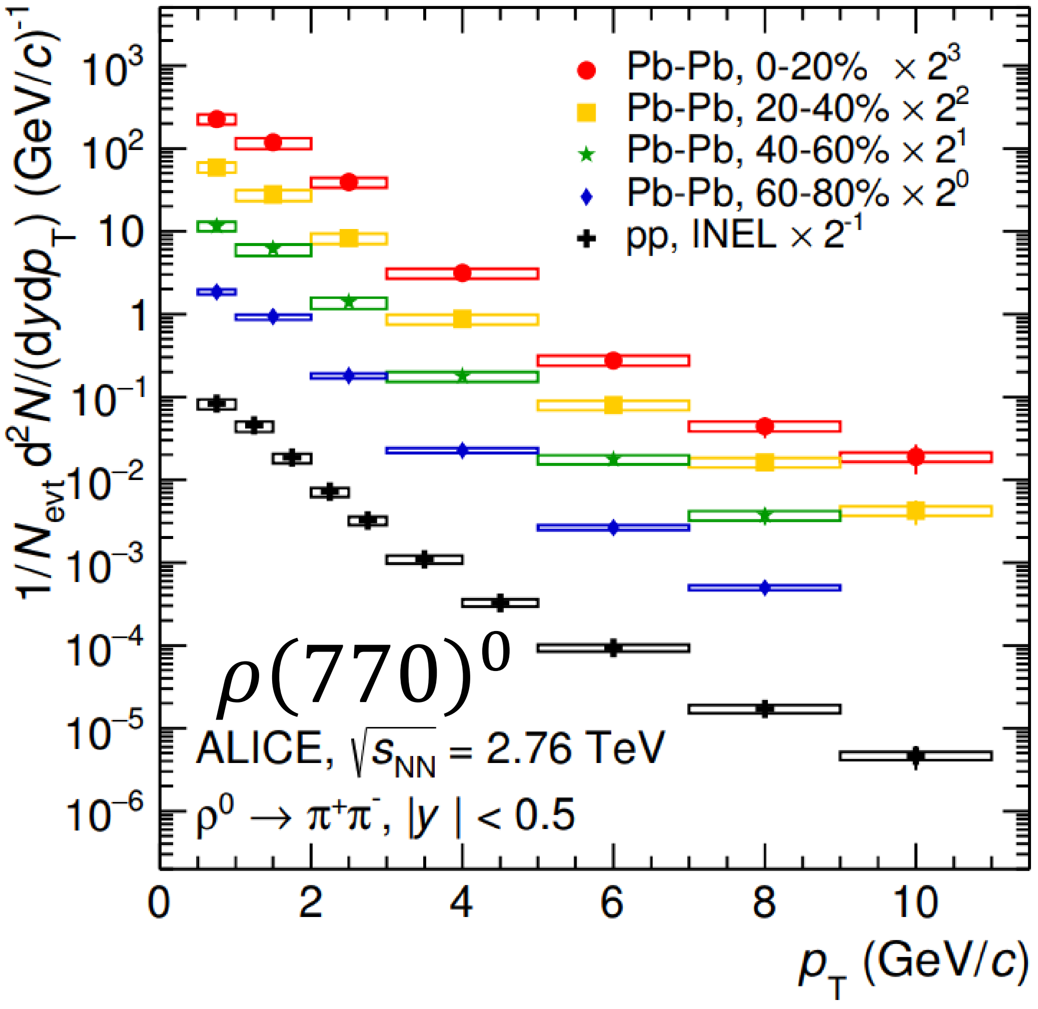
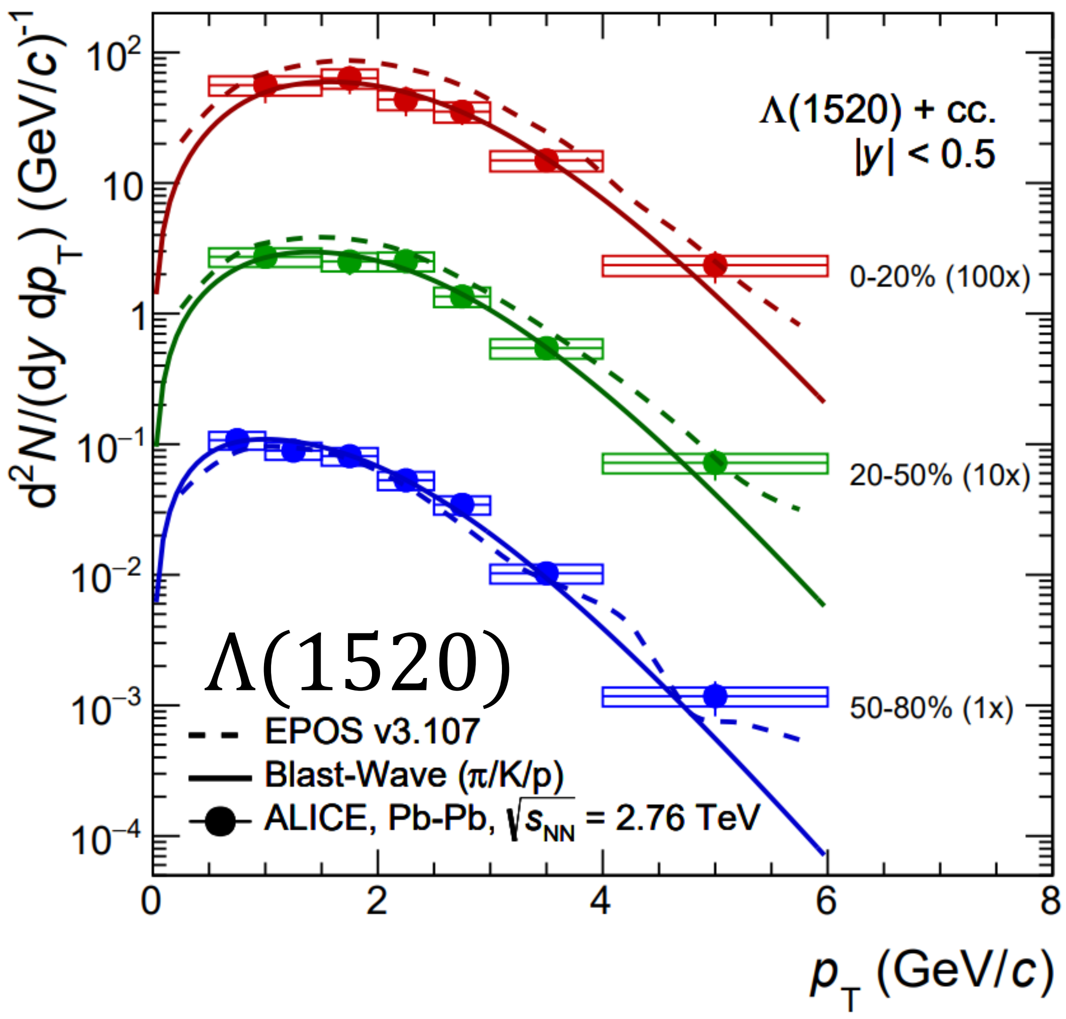
Resonances spectra in Pb-Pb at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV



https://arxiv.org/abs/1805.04365



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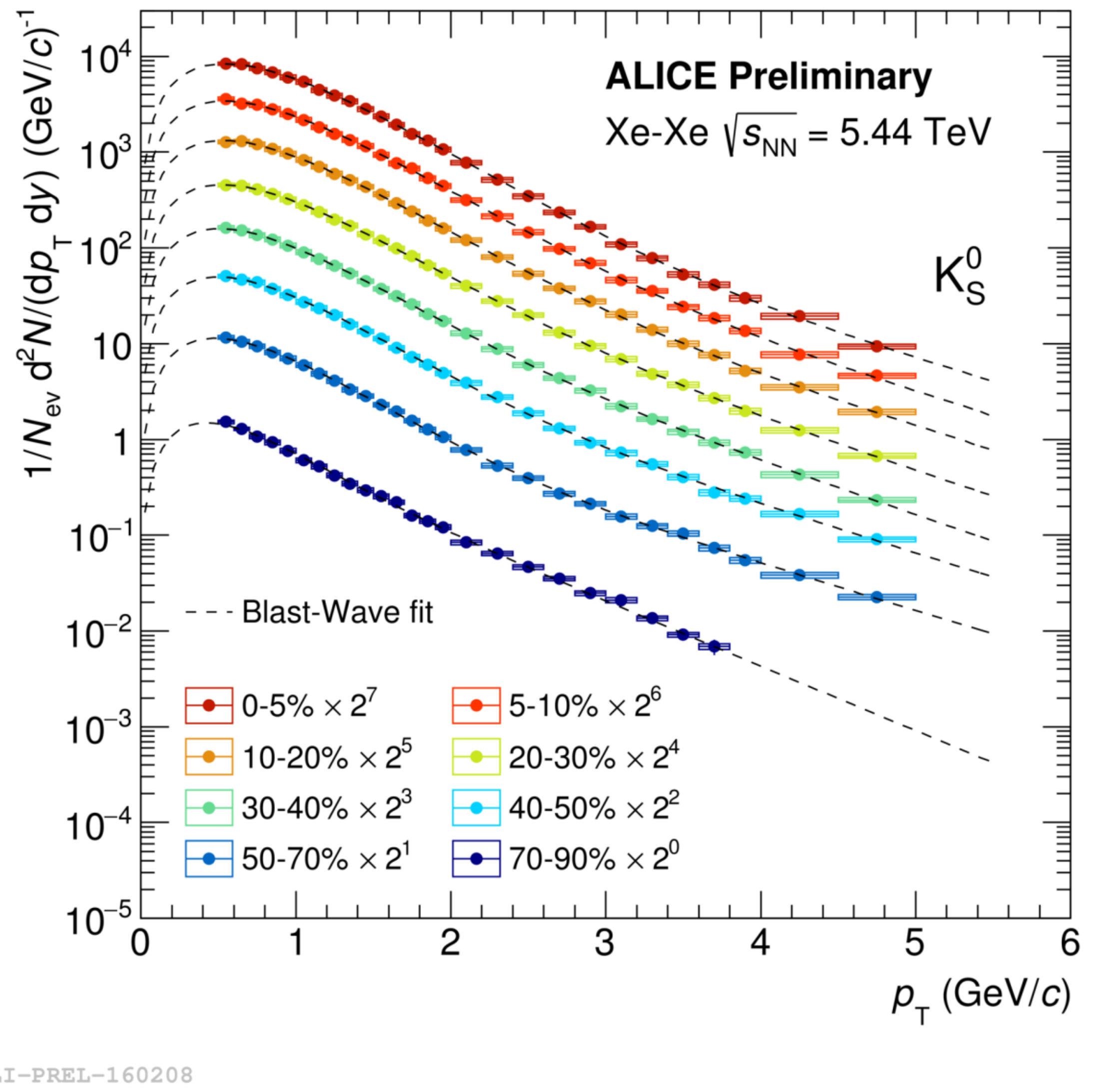
Strangeness in Xe-Xe at $\sqrt{s_{NN}} = 5.44$ TeV



- Unprecedented results at **new system**

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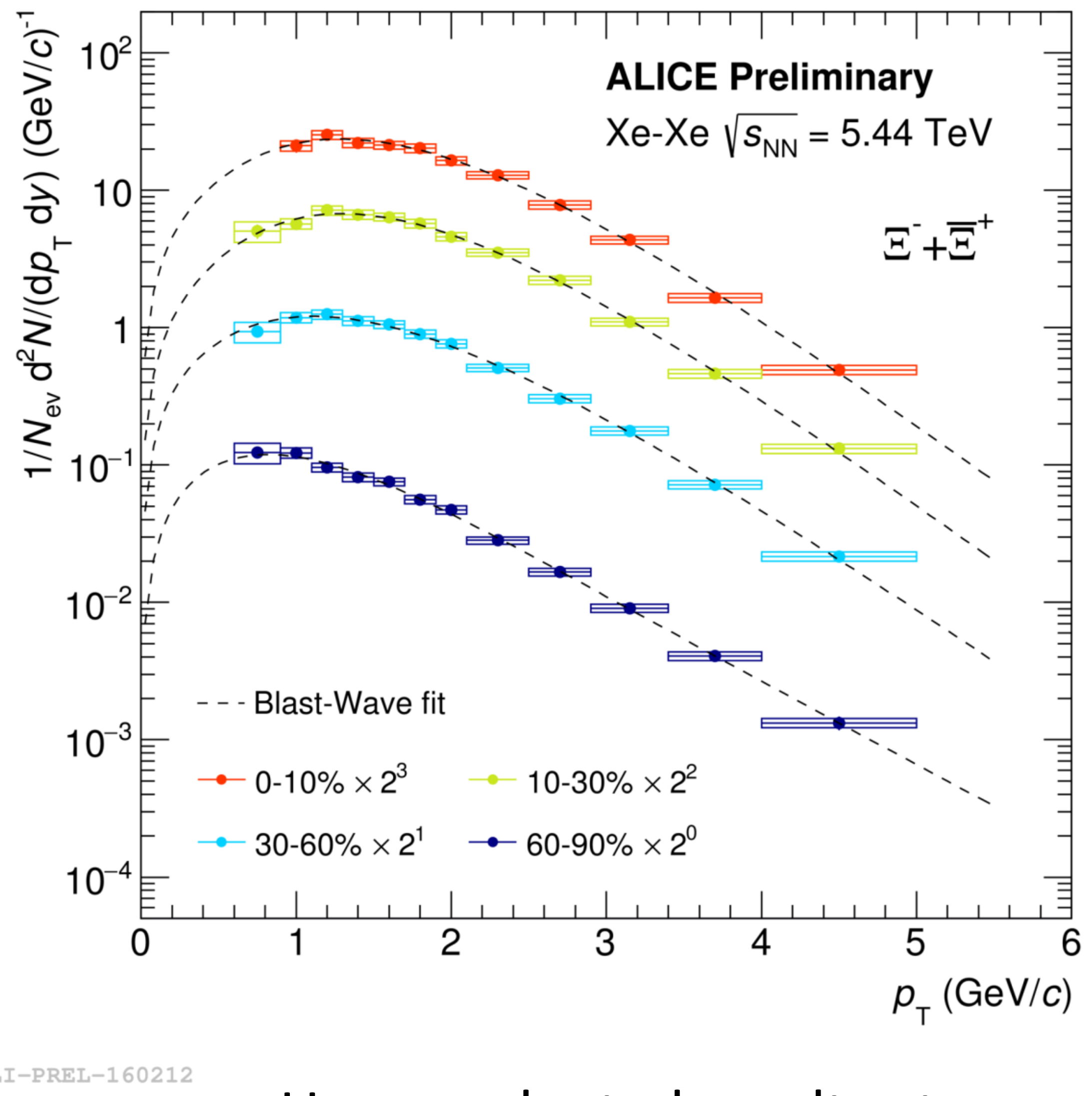

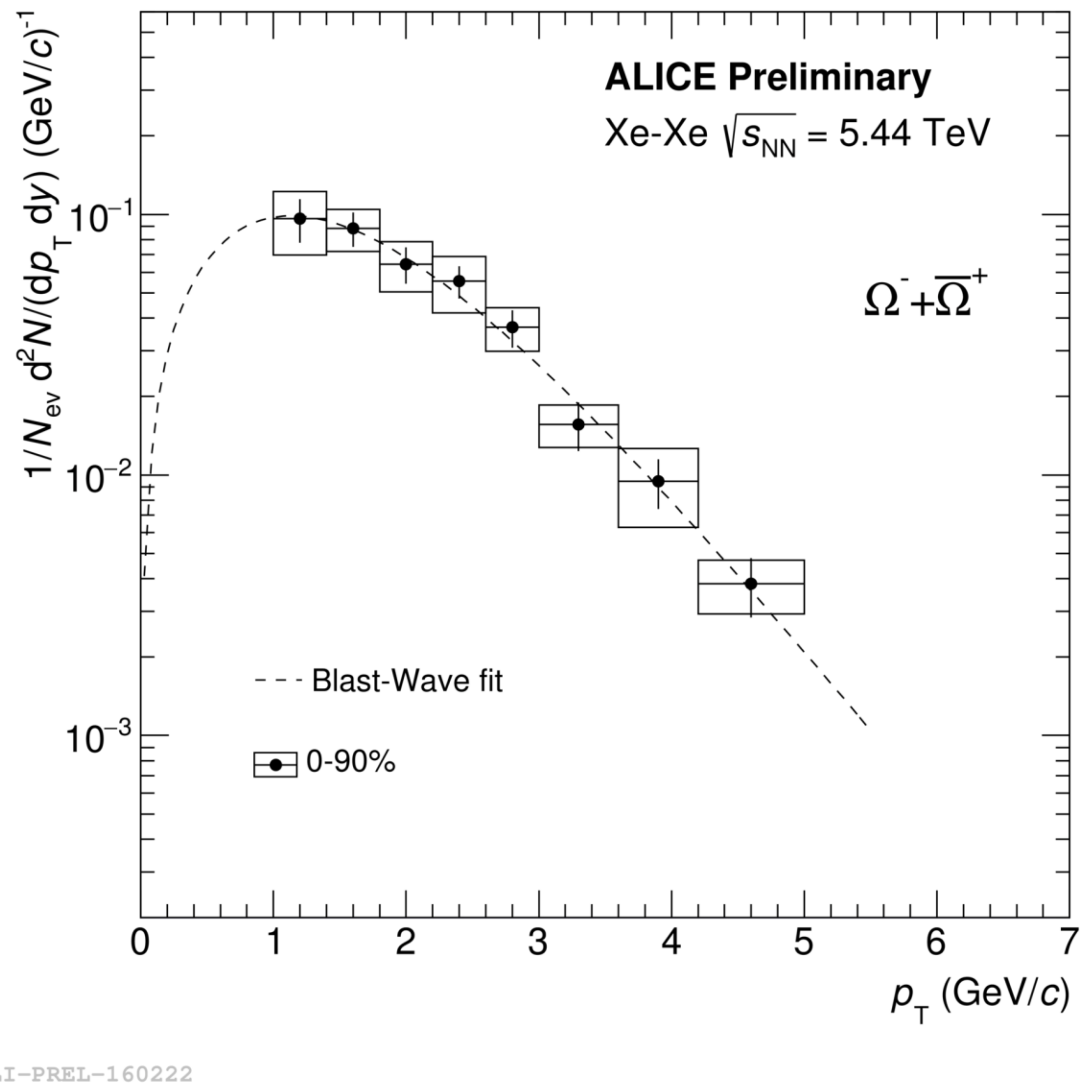

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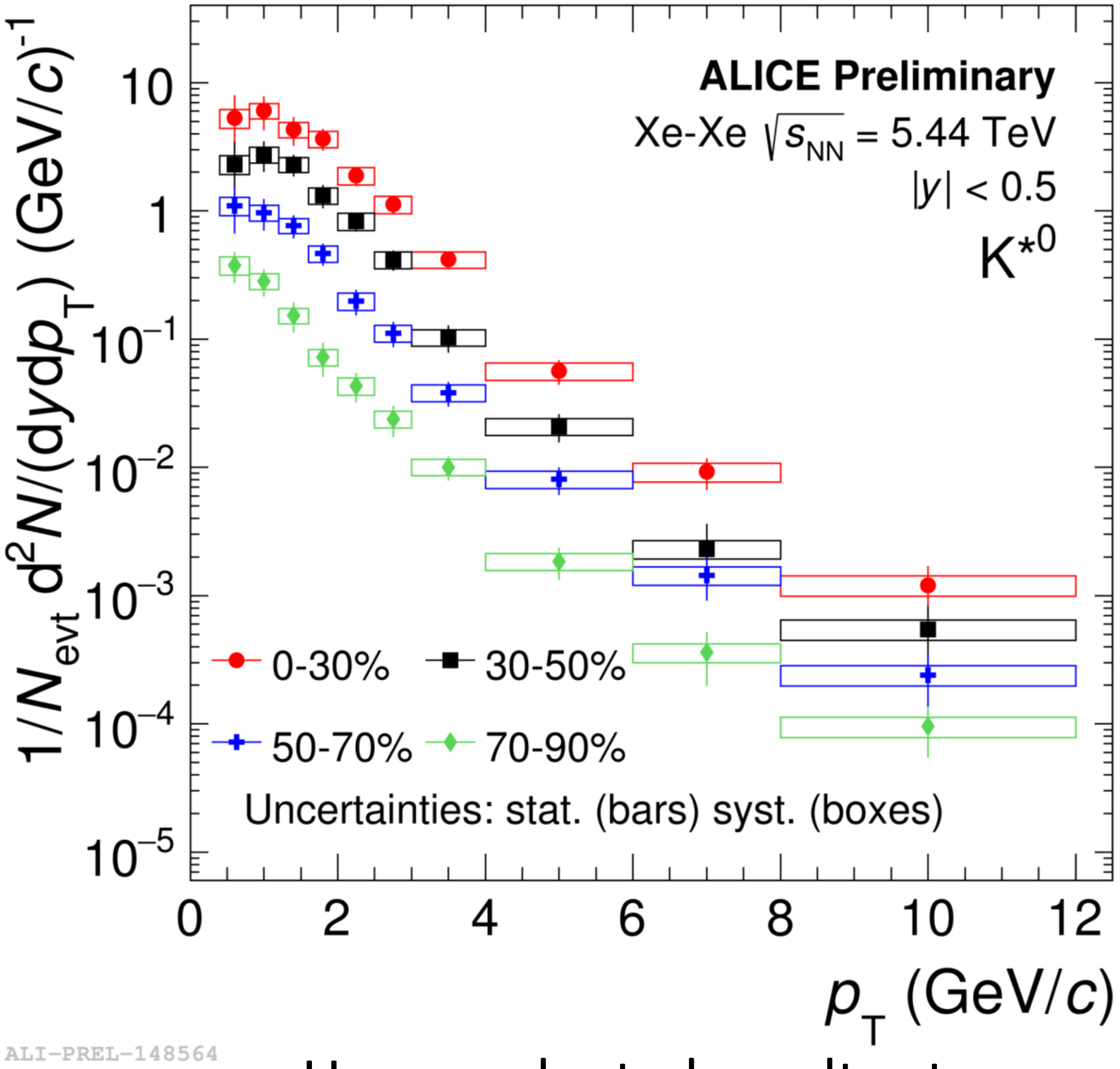

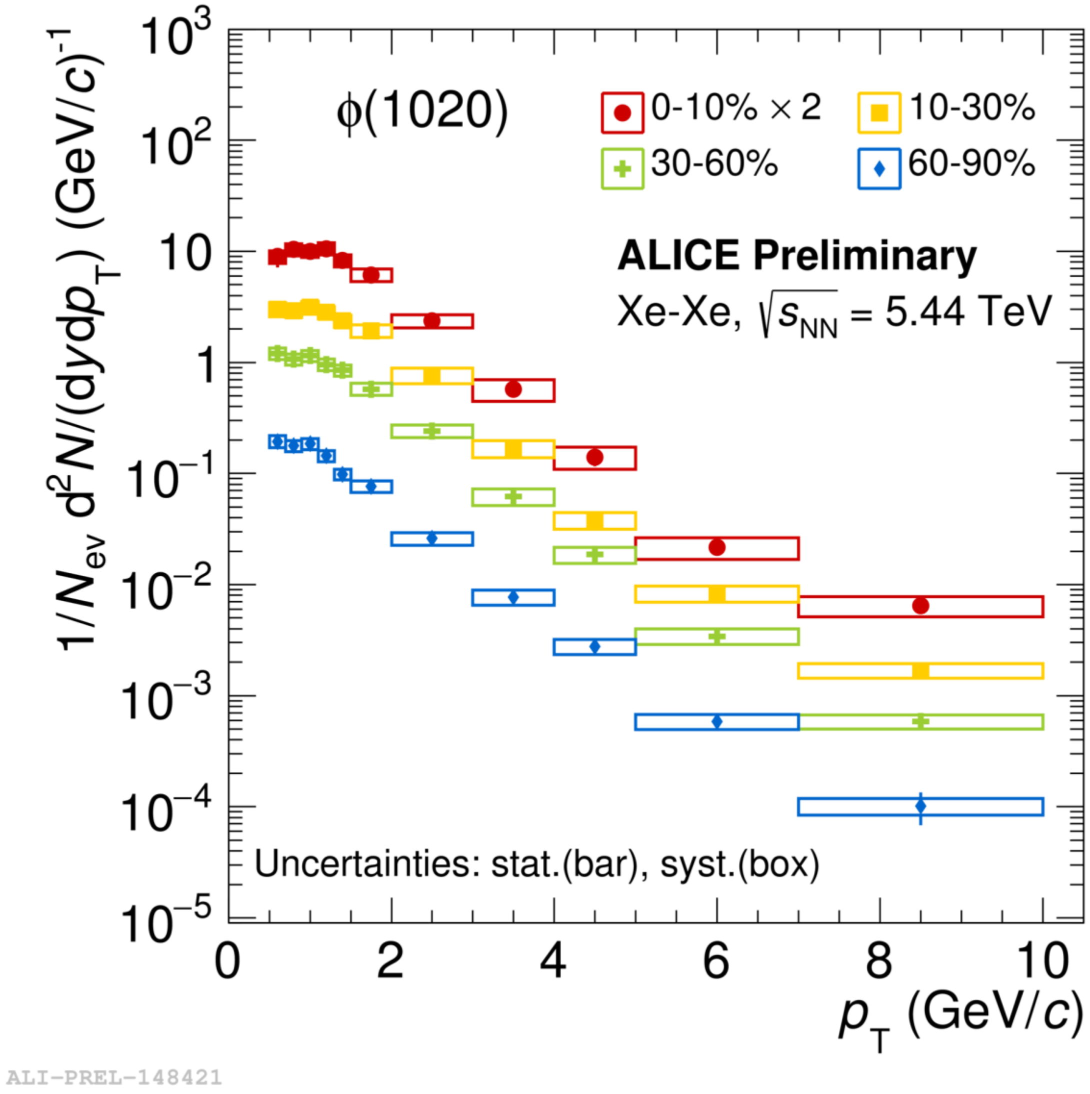

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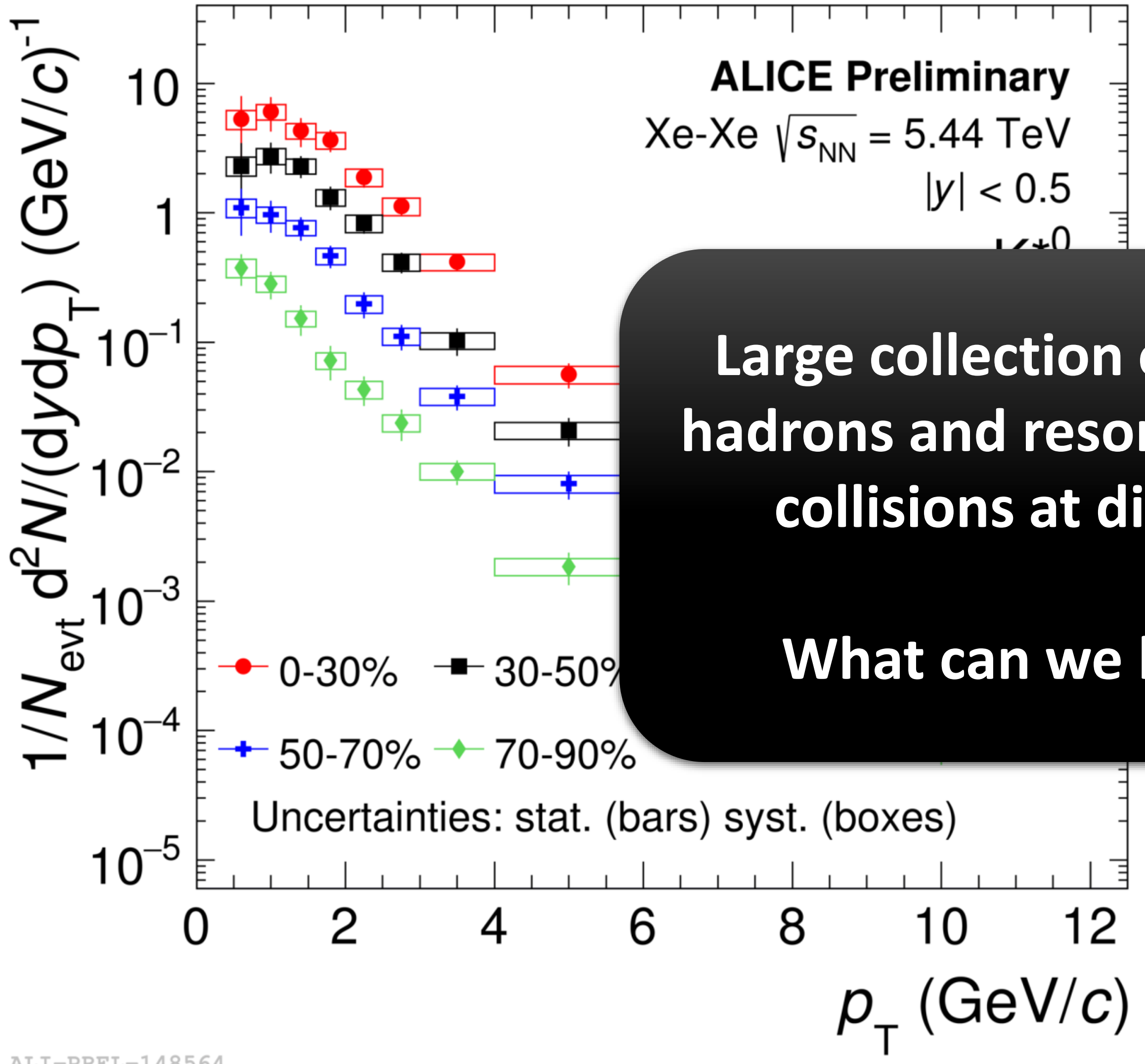
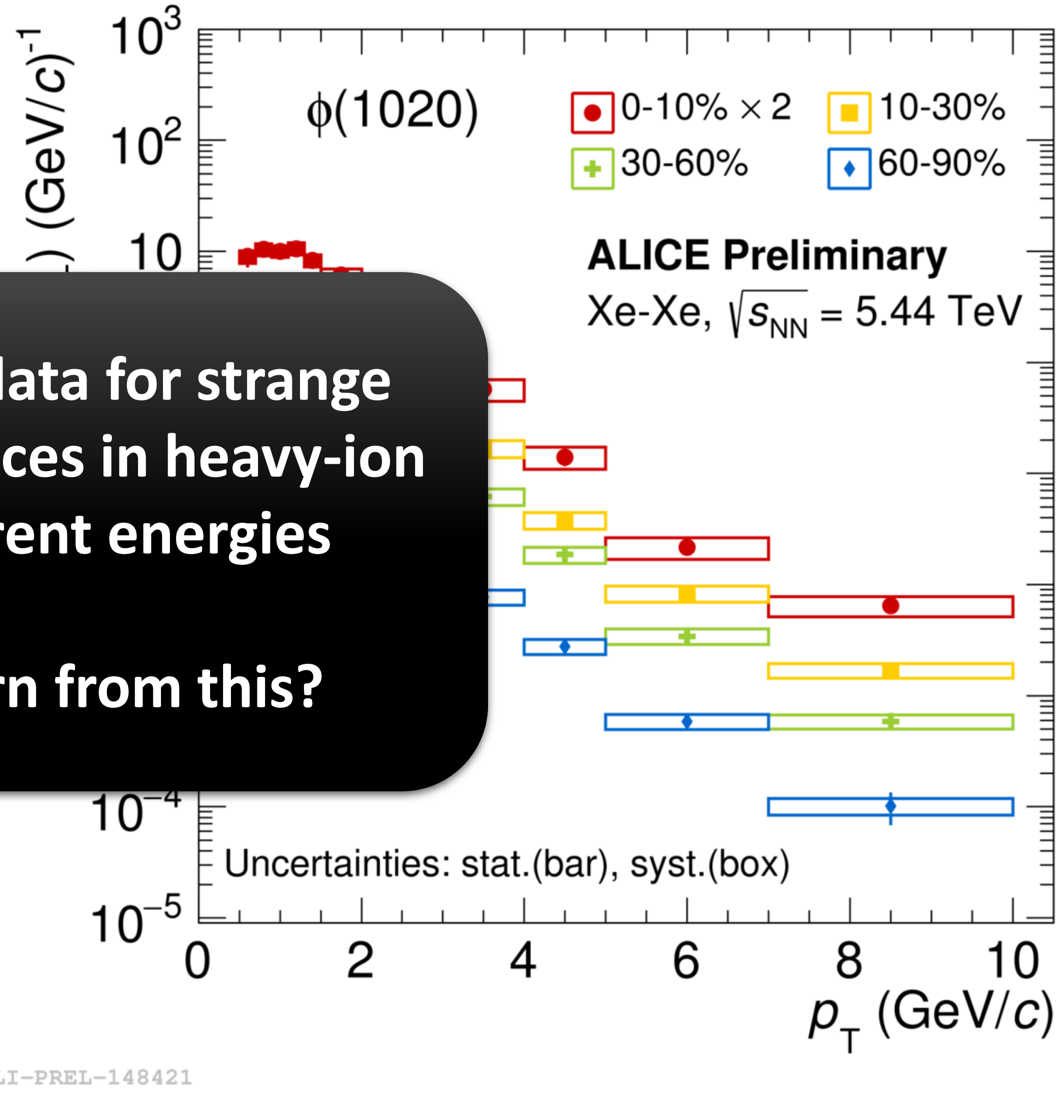




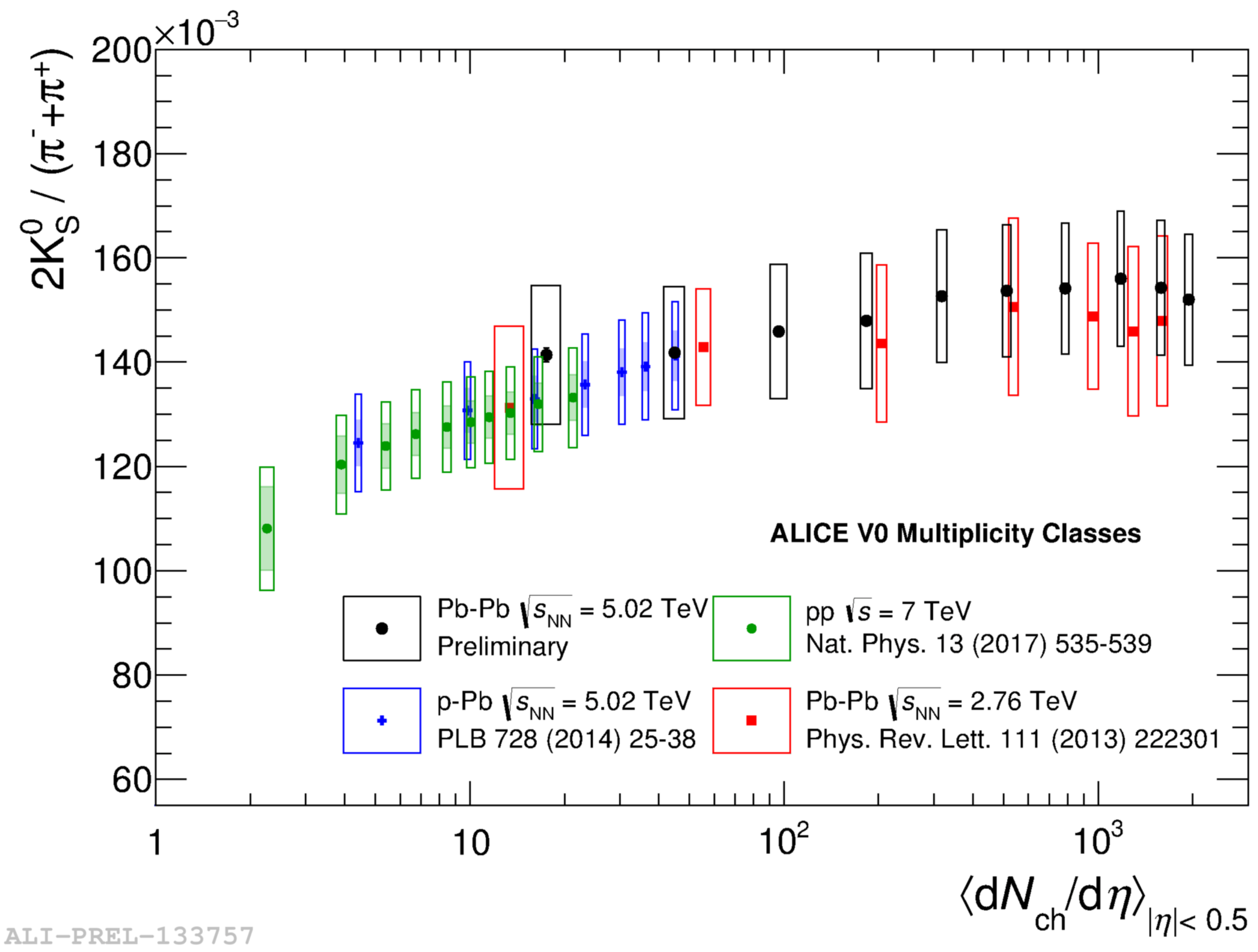
Large collection of data for strange hadrons and resonances in heavy-ion collisions at different energies

What can we learn from this?

- Unprecedented results at **new system**

K_s^0/π ratio as a function of multiplicity

- Smooth evolution from pp to Pb-Pb



Λ/π ratio as a function of multiplicity

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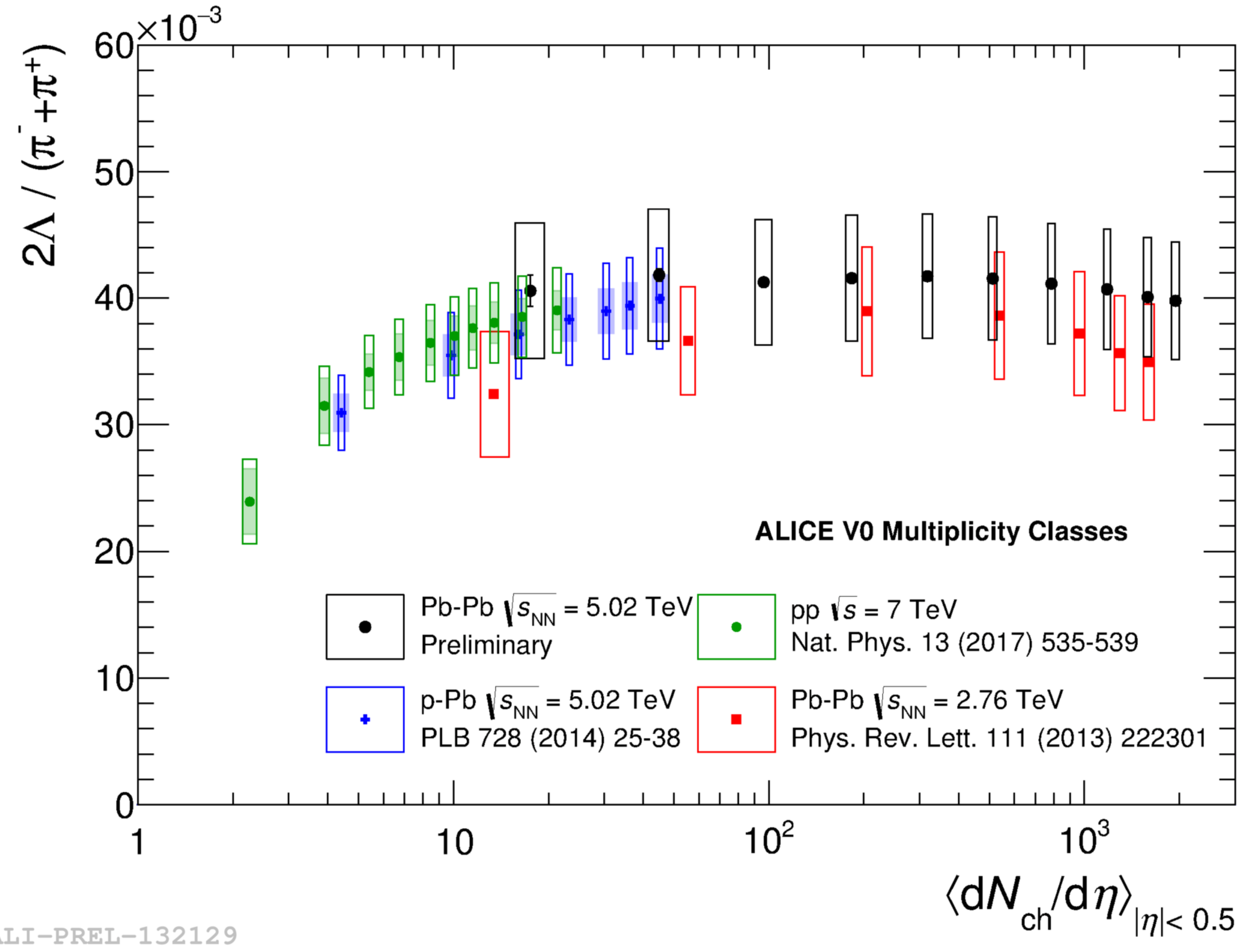

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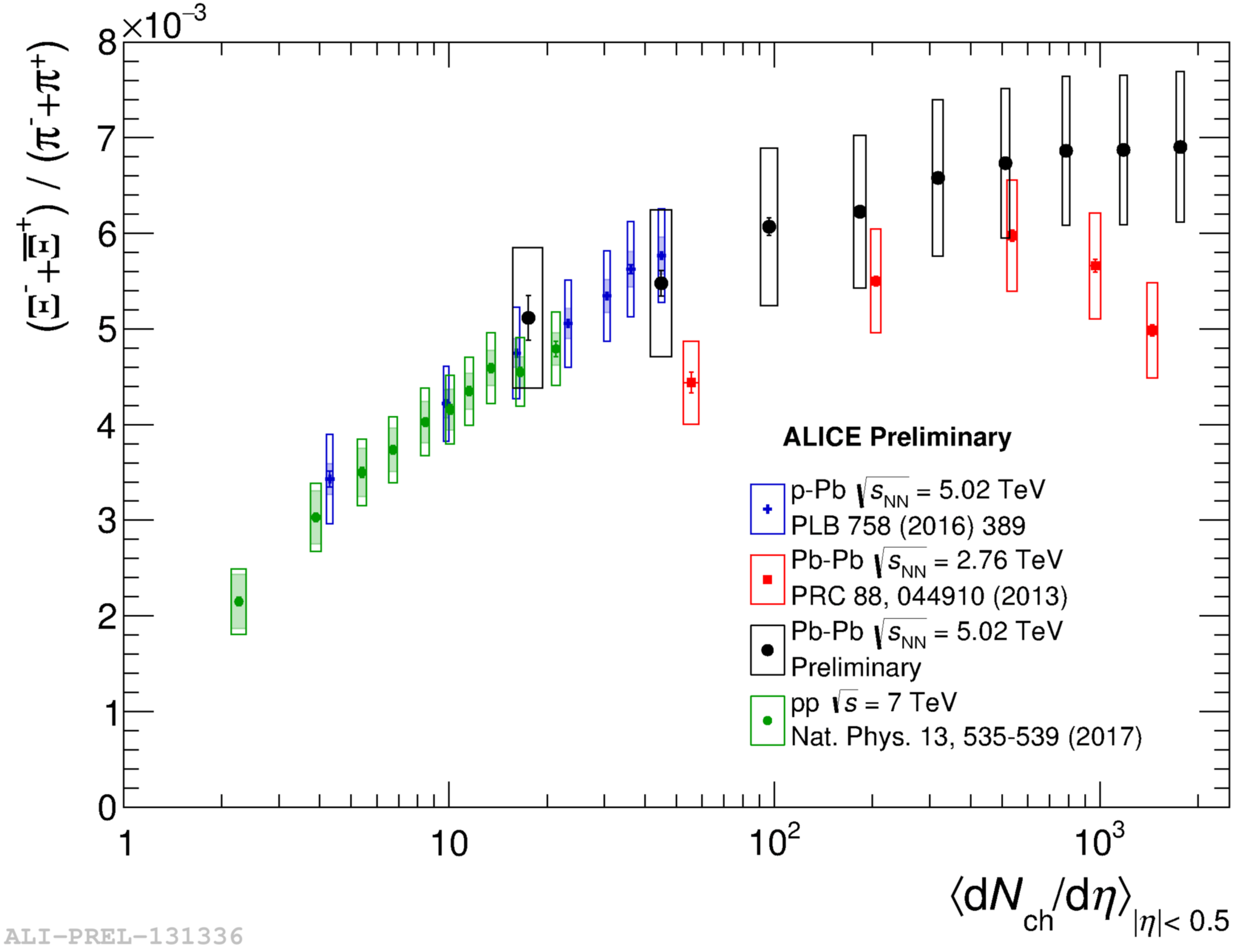

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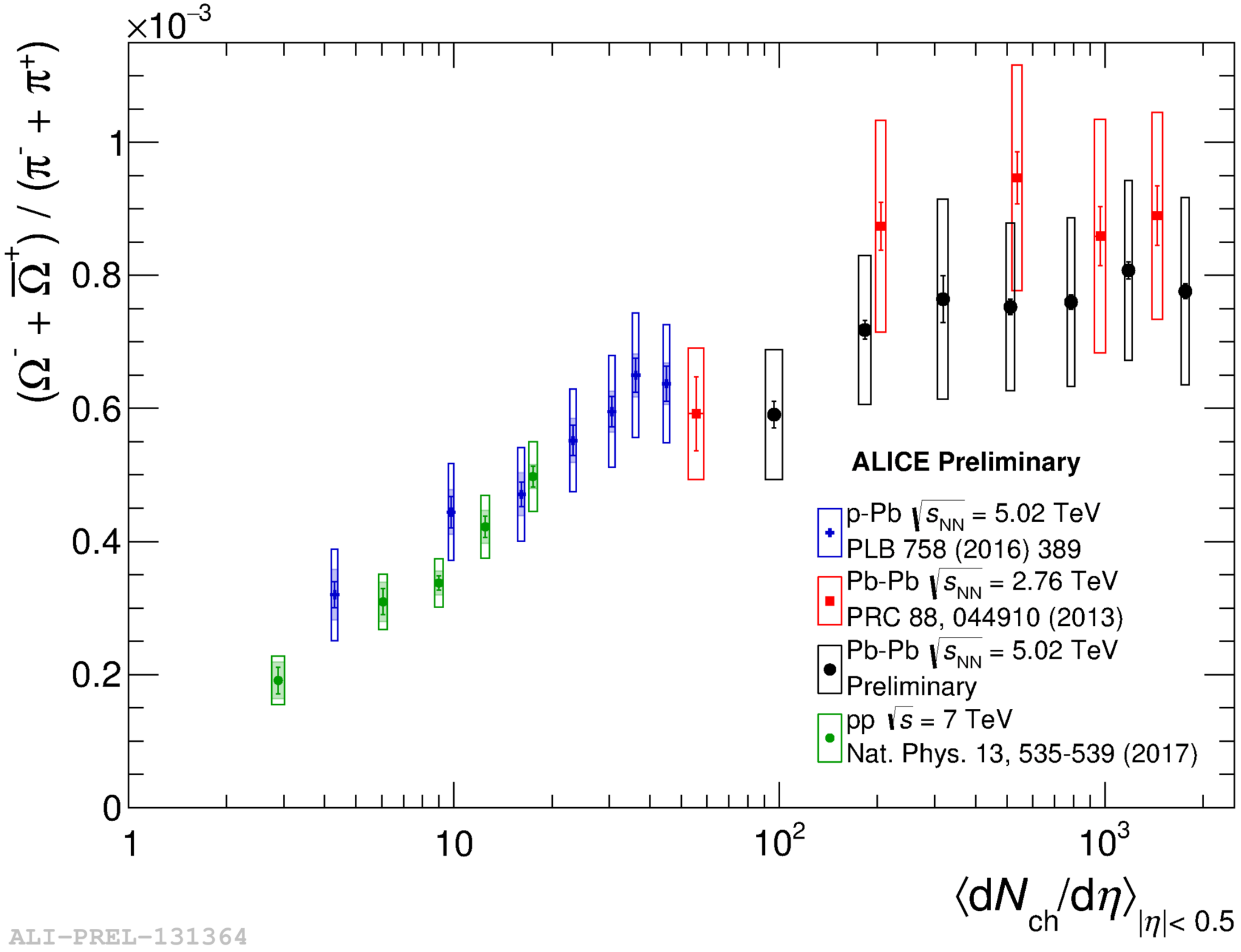

Relative Strangeness Production

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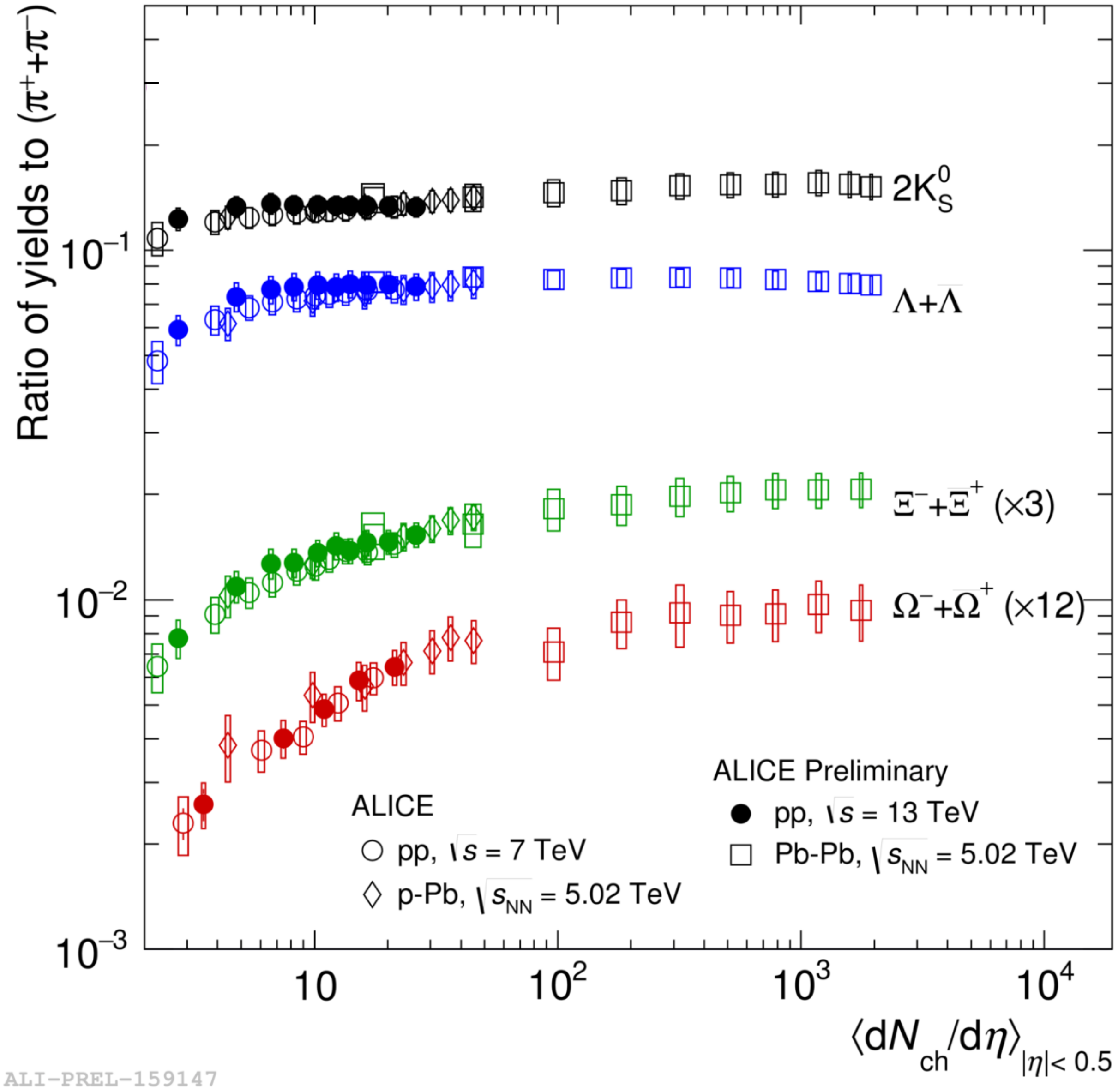
- At similar multiplicity, no dependence with system nor energy is observed



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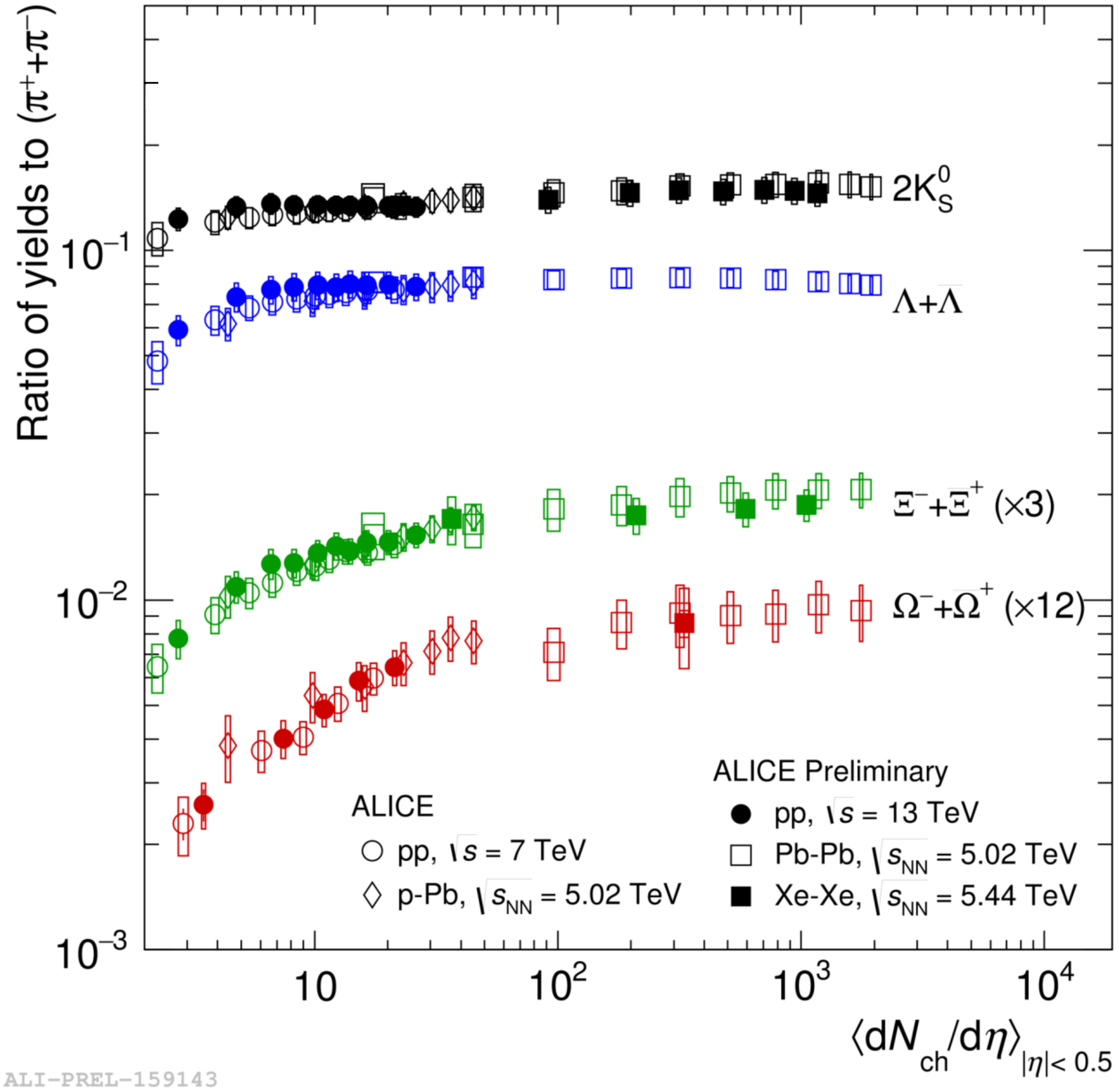
- **New results in Xe-Xe** in agreement with previous measurements



Suppression of Hadronic Resonances

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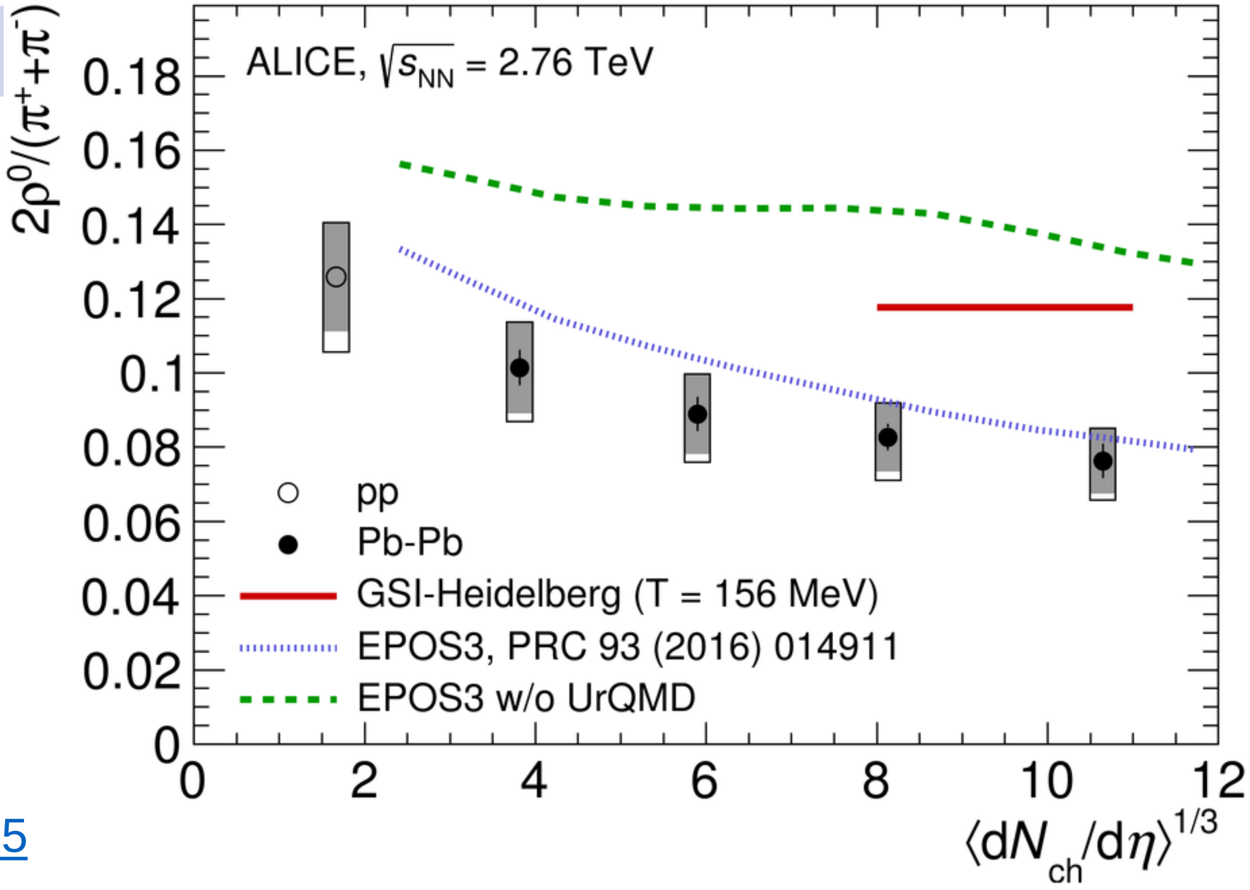
- $\rho^0(770)/\pi^\pm$



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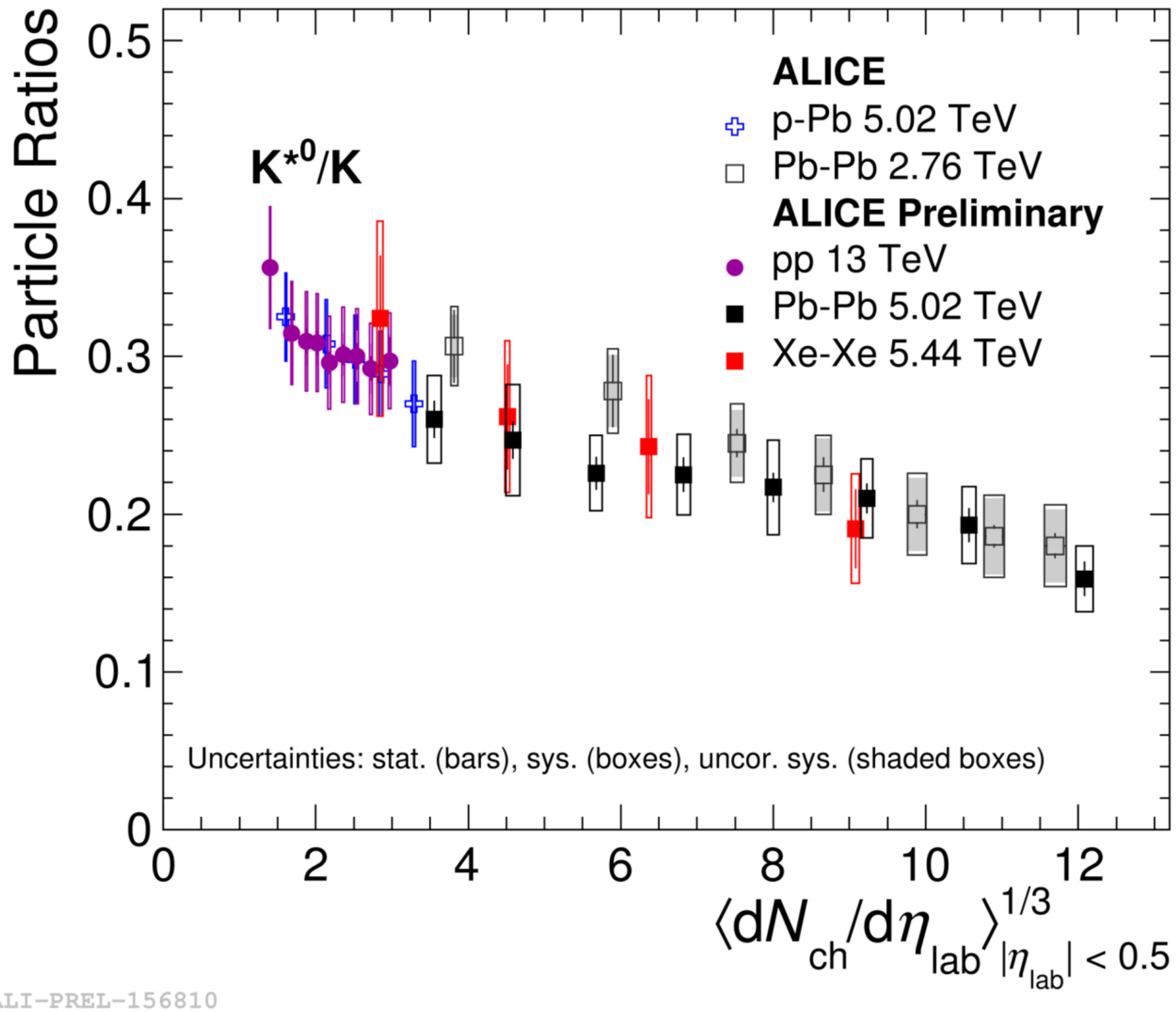

- ➢ Hadronic phase (UrQMD) important in EPOS to describe data
- ➢ Consistent results for Xe-Xe and Pb-Pb at similar multiplicity

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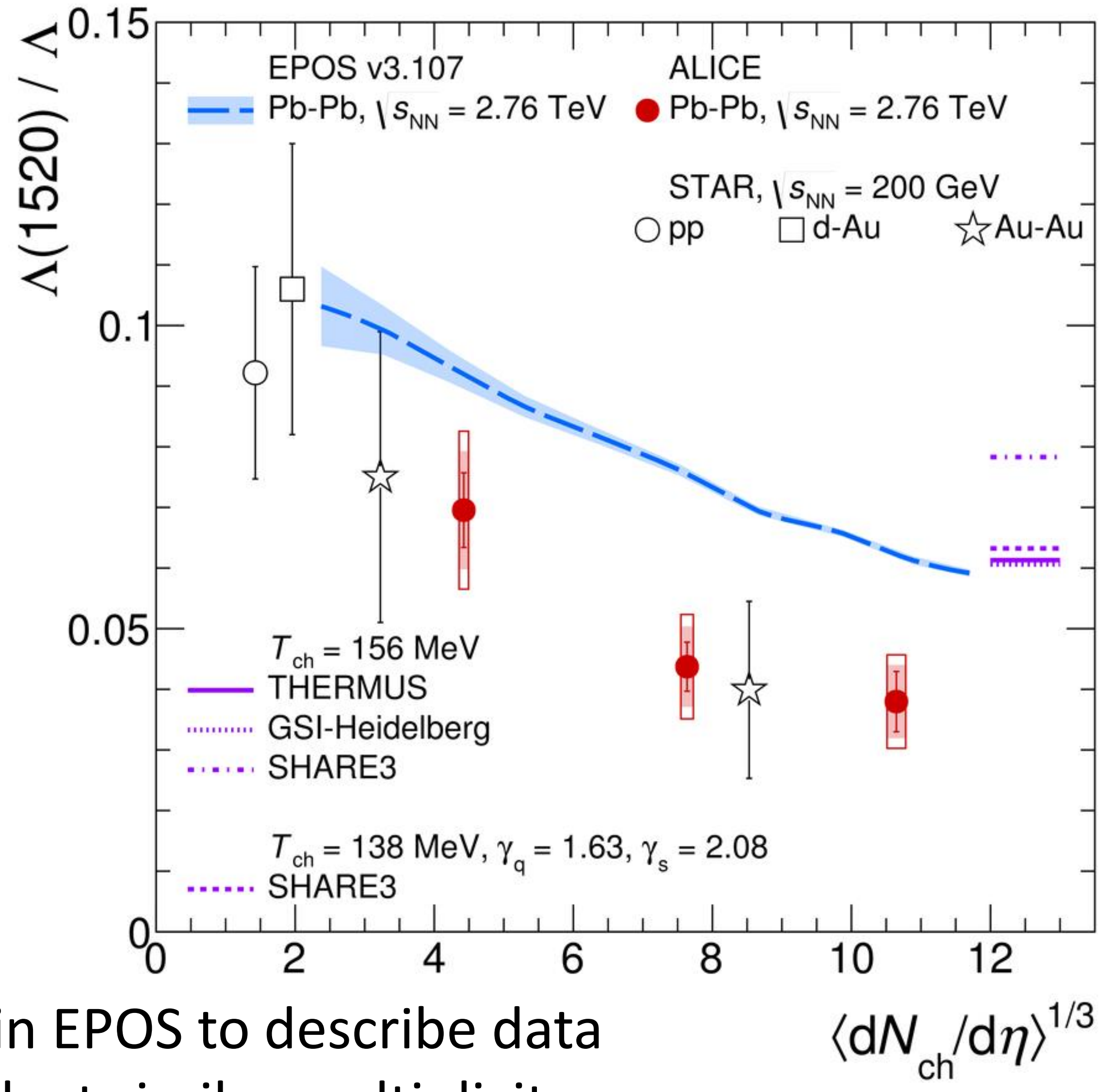
Lifetime (fm/c)	1.3	4.16	12.6	46.2

- $\rho^0(770)/\pi^{\pm}$
- $K^*(892)^0/K^{\pm}$
- $\mathbf{\Lambda(1520)/\Lambda}$

https://arxiv.org/abs/1805.04361

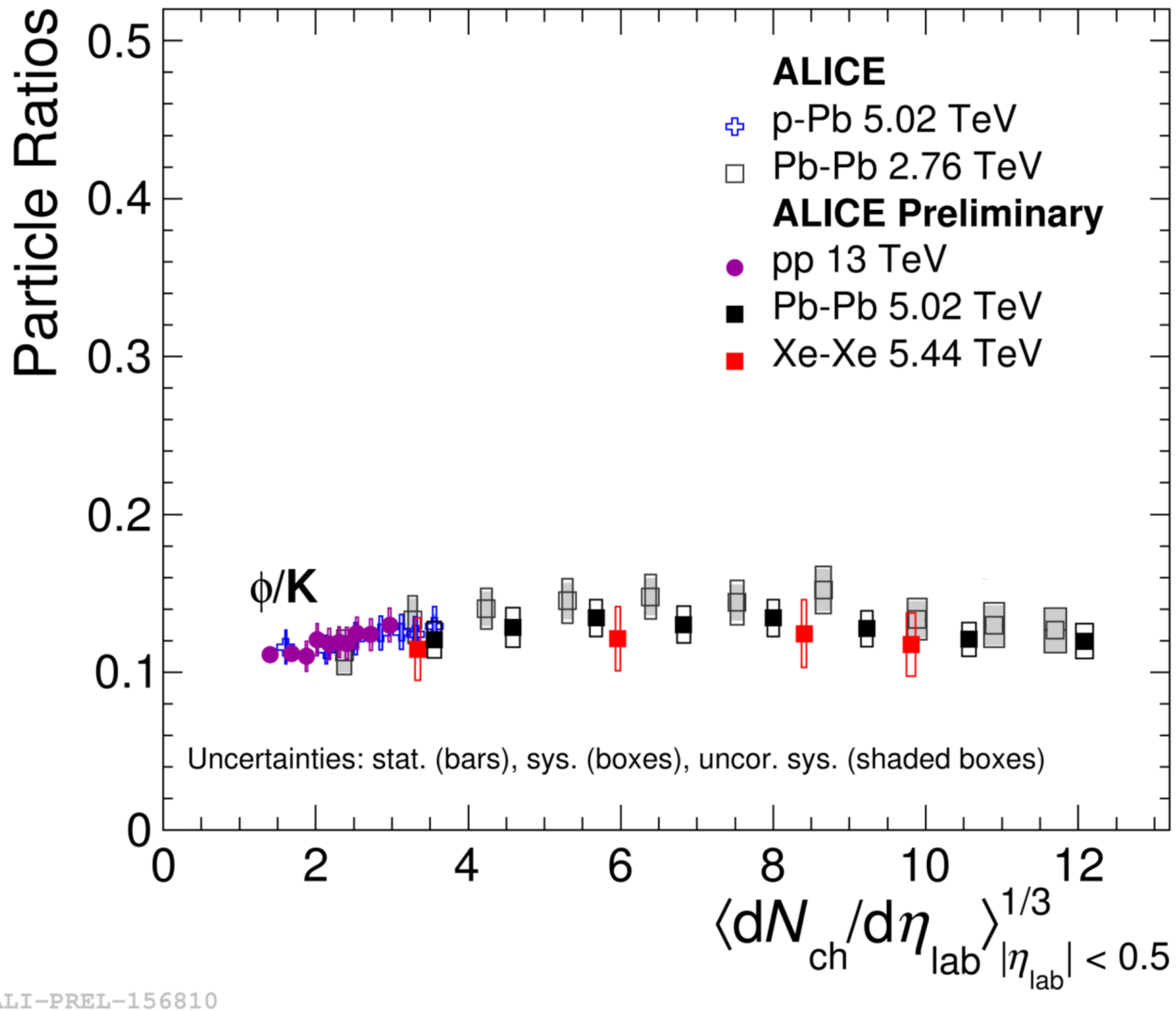


➢ Hadronic phase (UrQMD) important in EPOS to describe data
➢ Consistent results for Xe-Xe and Pb-Pb at similar multiplicity

Suppression of Hadronic Resonances

Resonance	ρ^0	K^{*0}	$\Lambda(1520)$	ϕ
Lifetime (fm/c)	1.3	4.16	12.6	46.2

- $\rho^0(770)/\pi^\pm$
- $K^*(892)^0/K^\pm$
- $\Lambda(1520)/\Lambda$
- $\boldsymbol{\phi(1020)/K^\pm}$
  - No re-scattering effects due to larger τ



- ➢ Hadronic phase (UrQMD) important in EPOS to describe data
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Summary

Large amount of new strangeness and resonances measurements

- Strange Hadrons
  - **Smooth enhancement with multiplicity** from pp to central AA
  - **New Xe-Xe data follows trend observed** in other systems
  - At similar multiplicity, **no dependence with system nor energy**

- Hadronic Resonances
  - **Suppression** of $\rho^0, K^{*0}, \Lambda(1520)$, while ϕ not suppressed
  - Qualitative description is obtained with **EPOS+UrQMD**

Summary

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Thank you!

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Extra Material

Weak Decay Measurements

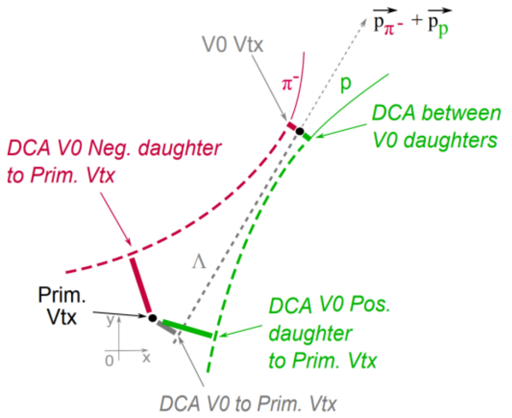
V⁰'s (single-strange hadrons)

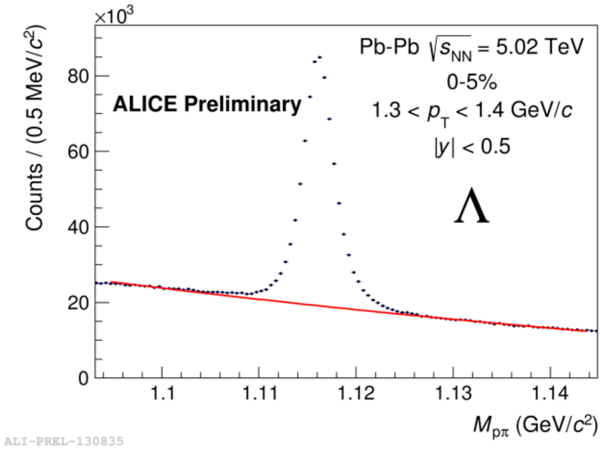
$K_s^0 \rightarrow \pi^+ + \pi^- \left(\frac{\boldsymbol{ds} + \boldsymbol{sd}}{\sqrt{2}}\right)$

- **B.R.** $= 69.2\%$
- $c\tau = 2.68$ cm
- $m = 497.61$ MeV/c

$\Lambda \rightarrow p + \pi^- \quad (\boldsymbol{uds})$

- **B.R.** $= 63.9\%$
- $c\tau = 7.89$ cm
- $m = 1115.68$ MeV/c





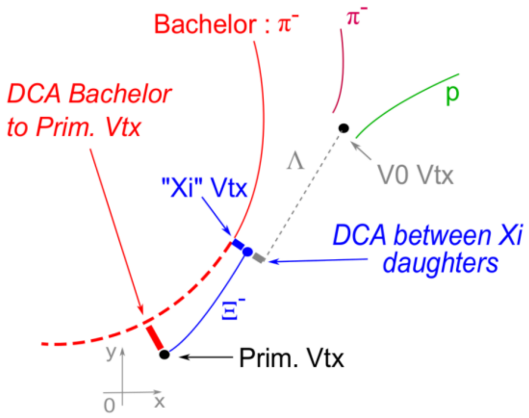
Cascades (multi-strange hadrons)

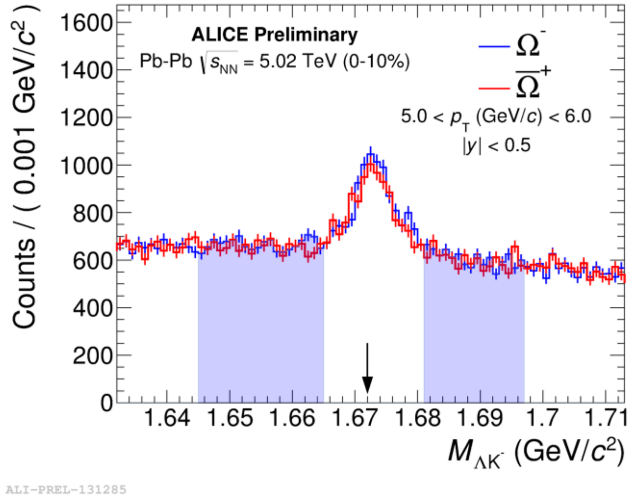
$\Xi^- \rightarrow \Lambda + \pi^- \ (\boldsymbol{dss})$

- **B.R.** $= 99.9\%$
- $c\tau = 4.91$ cm
- $m = 1321.71$ MeV/c

$\Omega^- \rightarrow \Lambda + K^- \ (\boldsymbol{sss})$

- **B.R.** $= 67.8\%$
- $c\tau = 2.46$ cm
- $m = 1672.45$ MeV/c





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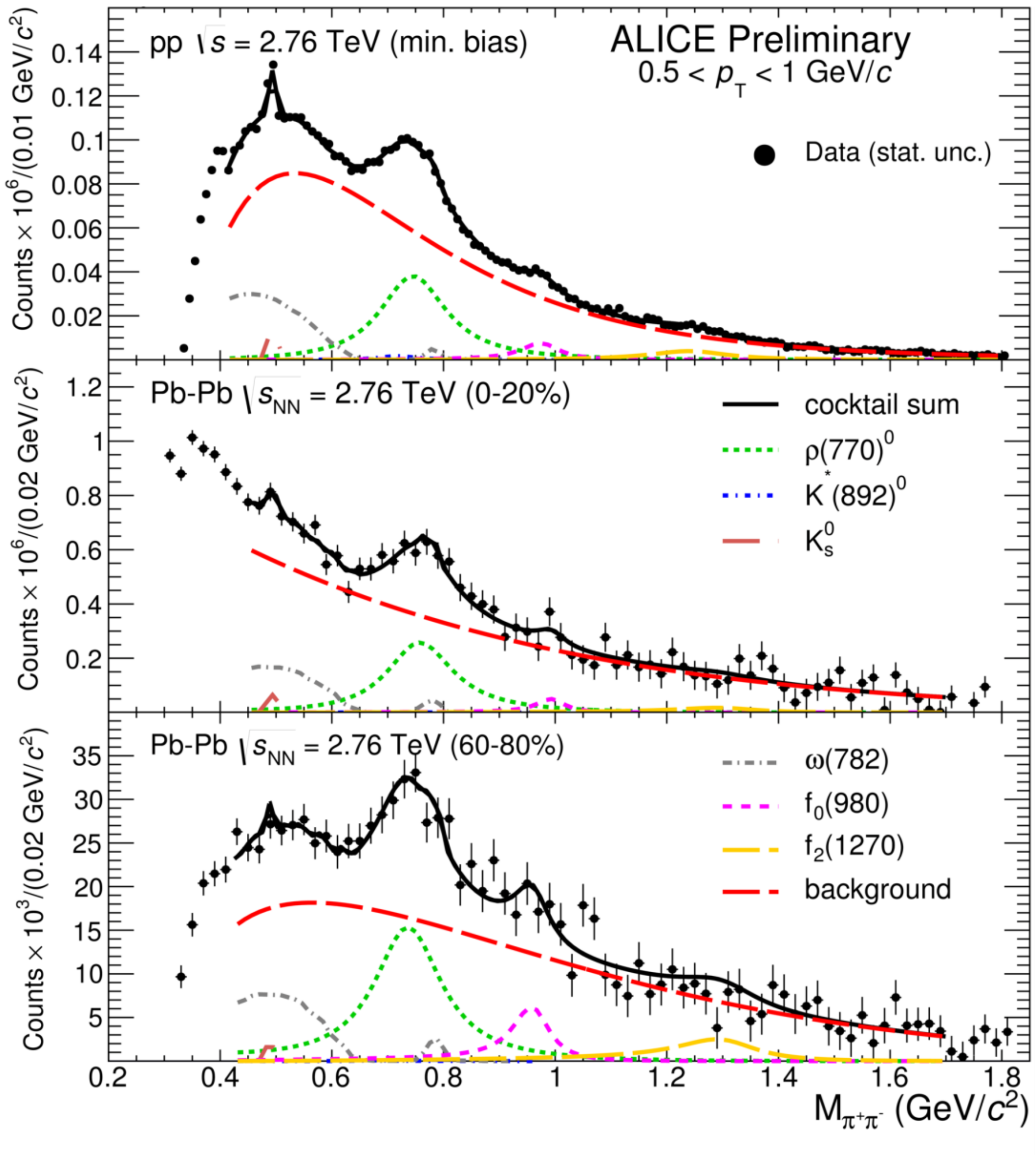
ρ^0 reconstruction

$\rho(770)^0 \rightarrow \pi^+ + \pi^- (\frac{u\bar{u}+d\bar{d}}{\sqrt{2}})$

- **B.R.** $= \sim 100\%$
- $c\tau = 1.3$ fm
- $m = 775.26$ MeV/c

- Background subtracted with like-sign method
- Fit with **residual background** + cocktail ($K_s^0, K^*, \omega, f_0, f_2$)
- Peak model:
  - Breit-Wigner
  - Phase space correction
  - Mass dependent efficiency
  - Söding parameterization

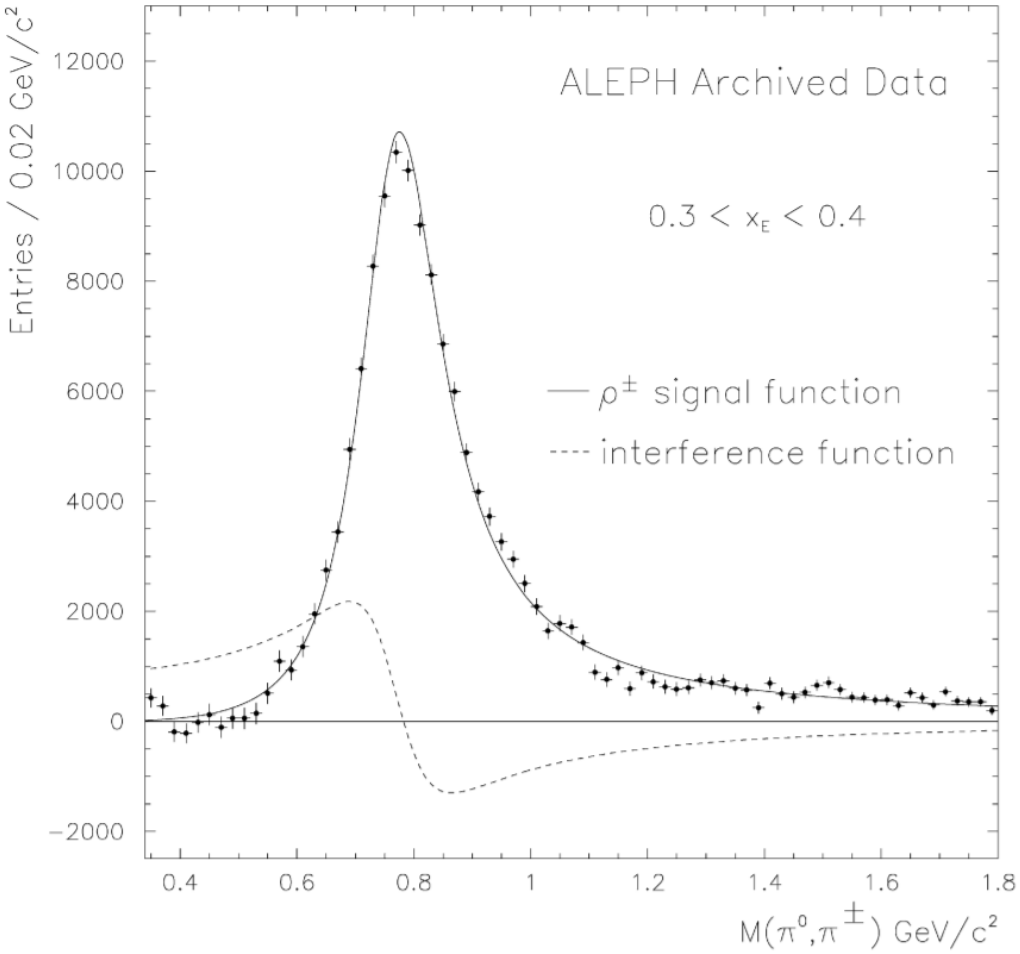


Söding interference term

- ρ^0 mesons mass peaks reconstructed in the $\pi^+\pi^-$ channel are distorted (shifted to lower values)
- Bose-Eistein correlations between identical pions at final states

$$f_i(M_{\pi\pi}) = C\left(\frac{M_0^2 - M_{\pi\pi}^2}{M_{\pi\pi}\Gamma(M_{\pi\pi})}\right) f_s(M_{\pi\pi})$$

P. Soding, *Phys. Lett.* **19** 702–704 (1966)



ALEPH [Archived Data]
Acta Phys. Polon. B **39** 173-180 (2008)

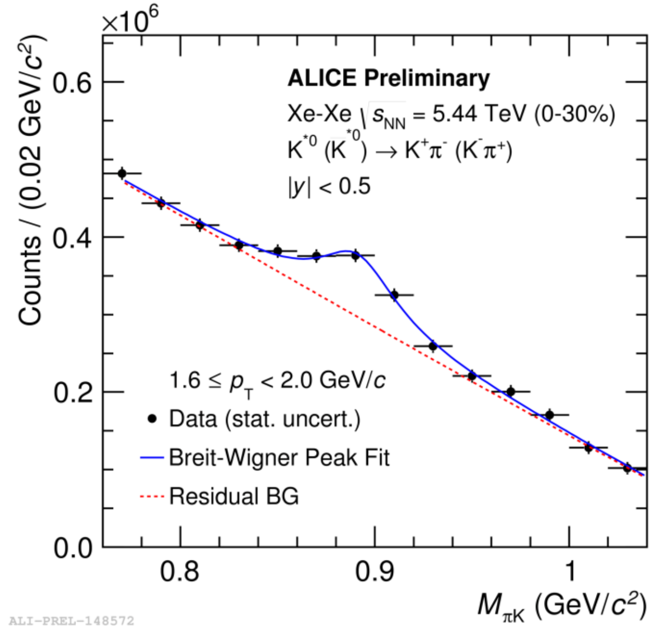
K^* and ϕ reconstruction

$K^{*0}(892) \rightarrow K^+ + K^-(\boldsymbol{d\bar{s}})$

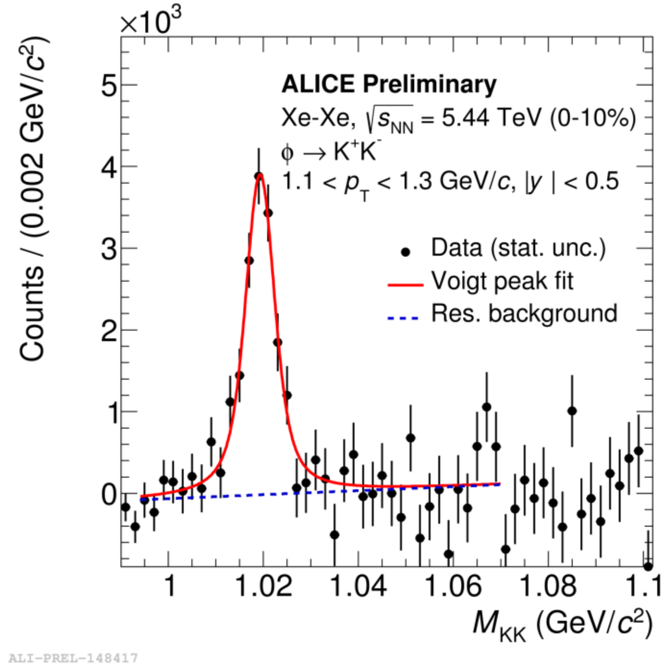
- **B.R.** $= 66.7\%$
- $c\tau = 4.17$ fm
- $m = 891.76$ MeV$/c$

$\phi(1020) \rightarrow K^+ + K^-(\boldsymbol{s\bar{s}})$

- **B.R.** $= 48.9\%$
- $c\tau = 46.2$ fm
- $m = 1019.46$ MeV$/c$



- Subtract mixed event or like-charge combinatorial background
- Polynomial residual background
- Peaks: Breit-Wigner (K^*) and Voigtian (ϕ)

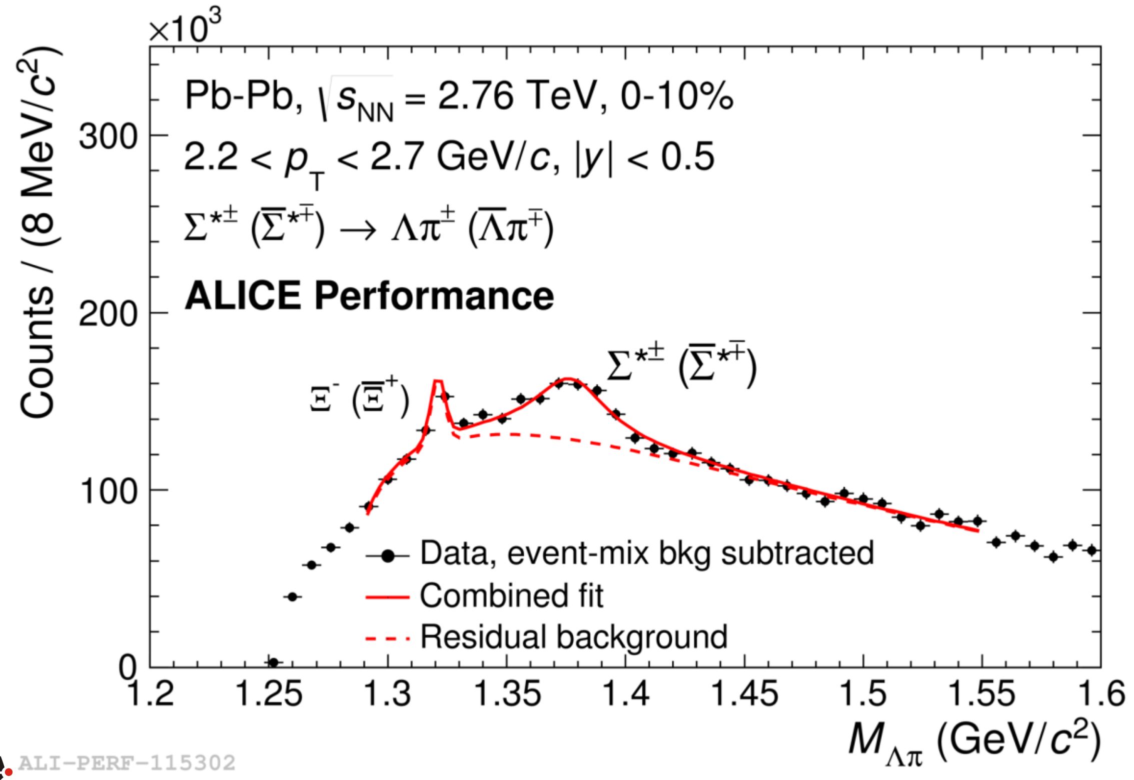


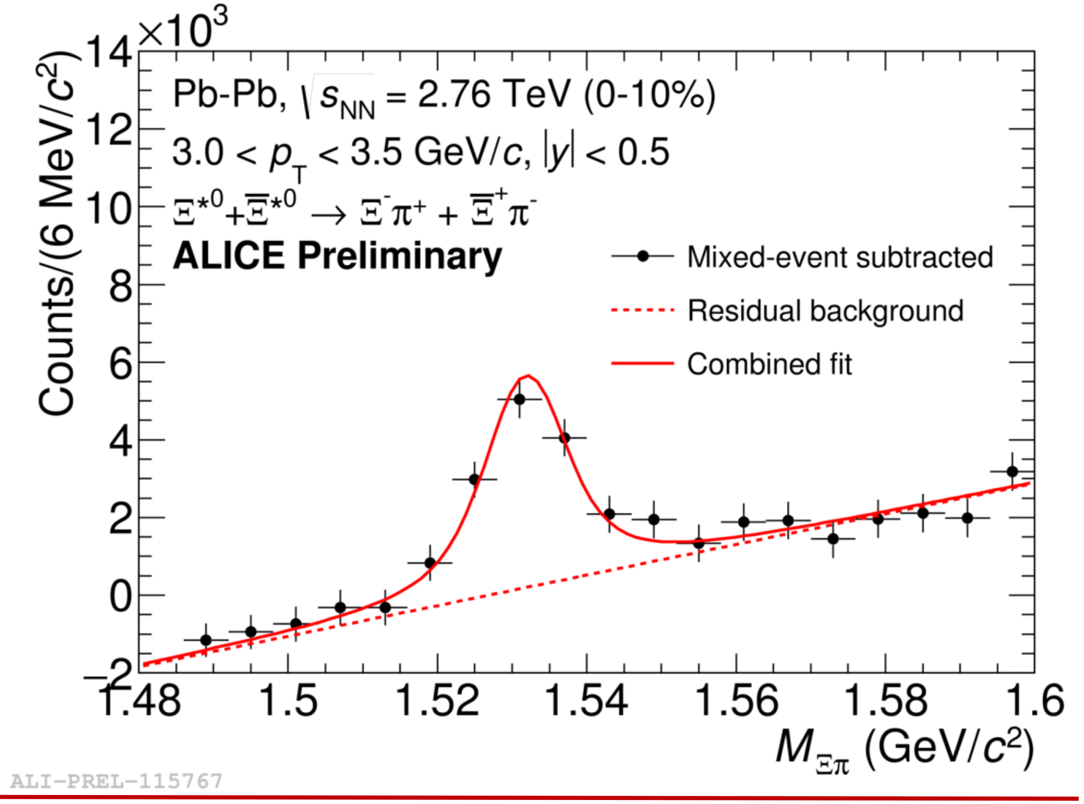
$\Sigma^{*\pm}$ and Ξ^{*0}

- Subtract mixed event combinatorial background
- Polynomial residual background
- Peaks: Breit-Wigner ($\Sigma^{*\pm}$) and Voigtian (Ξ^{*0})

$\Sigma^{*\pm}(1385) \rightarrow \Lambda + \pi^{\pm}$ $(\boldsymbol{uus/dds})$
- **B.R.** $= 87.0\%$
- $c\tau = 5.0$ fm
- $m = 1383$ MeV$/c$

$\Xi^{*0}(1530) \rightarrow \Xi^{-} + \pi^{+}(\boldsymbol{uss})$
- **B.R.** $= 66.7\%$
- $c\tau = 21.7$ fm
- $m = 1532$ MeV$/c$





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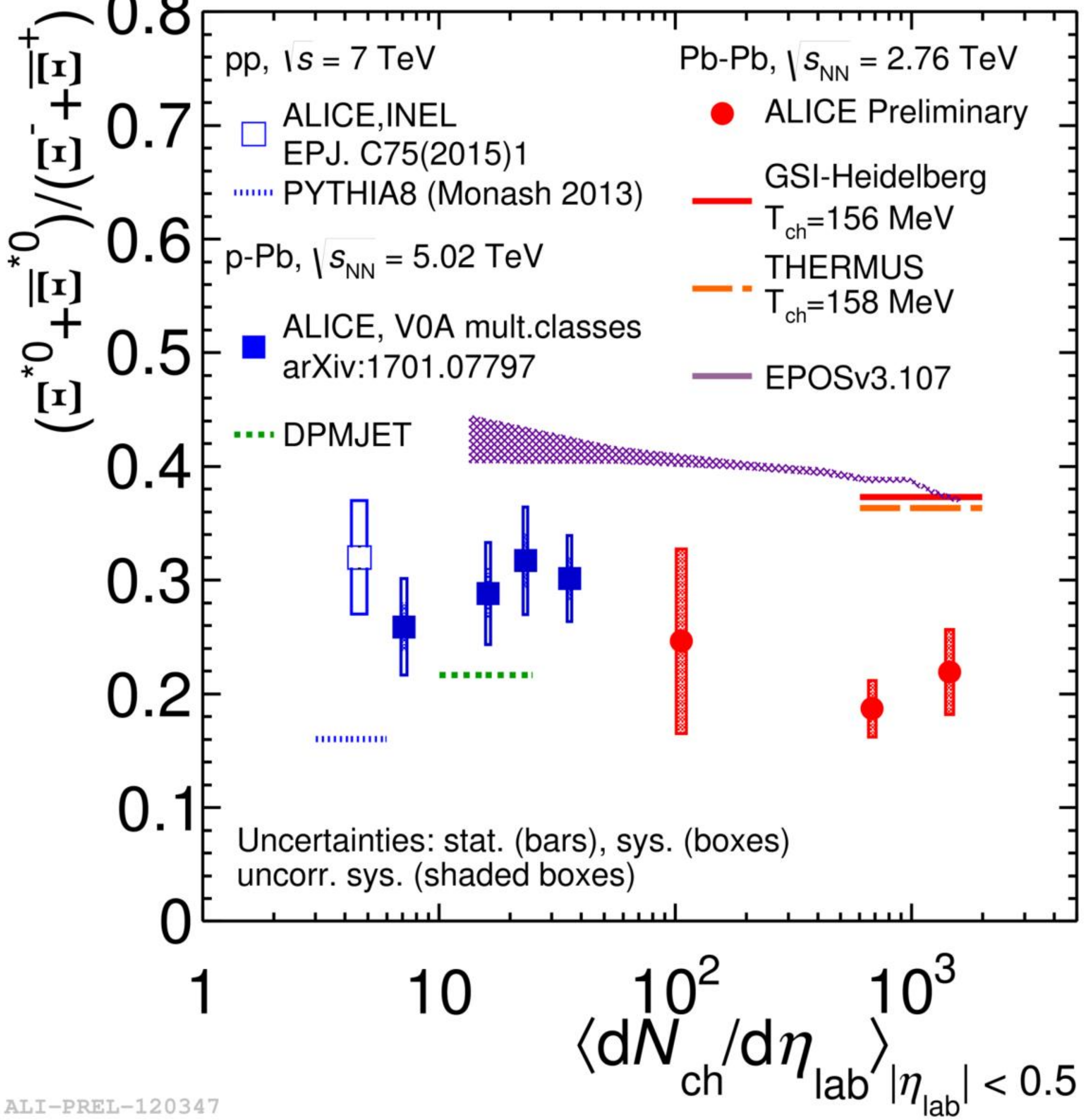
$\Sigma^{*\pm}$ and Ξ^{*0}

- Subtract mixed event combinatorial background
- Polynomial residual background
- Peaks: Breit-Wigner ($\Sigma^{*\pm}$) and Voigtian (Ξ^{*0})

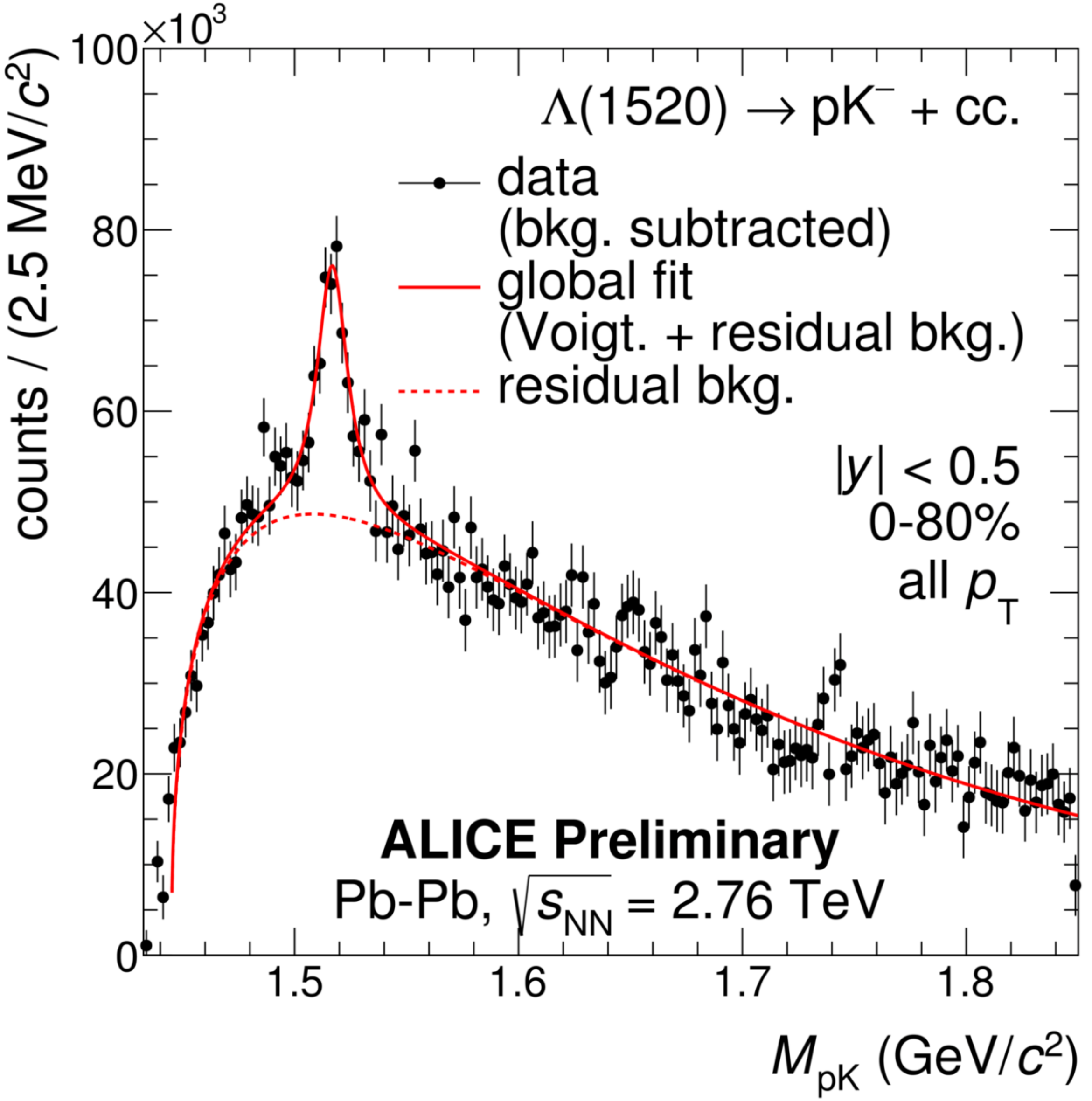


$\Lambda(1520)$ reconstruction

$\Lambda(1520) \rightarrow p + K^{-}(\boldsymbol{uds})$

- **B.R.** $= 22.5\%$
- $c\tau = 12.6$ fm
- $m = 1520$ MeV$/c$

- Subtract mixed event combinatorial background
- Polynomial residual background
- Voigtian peak



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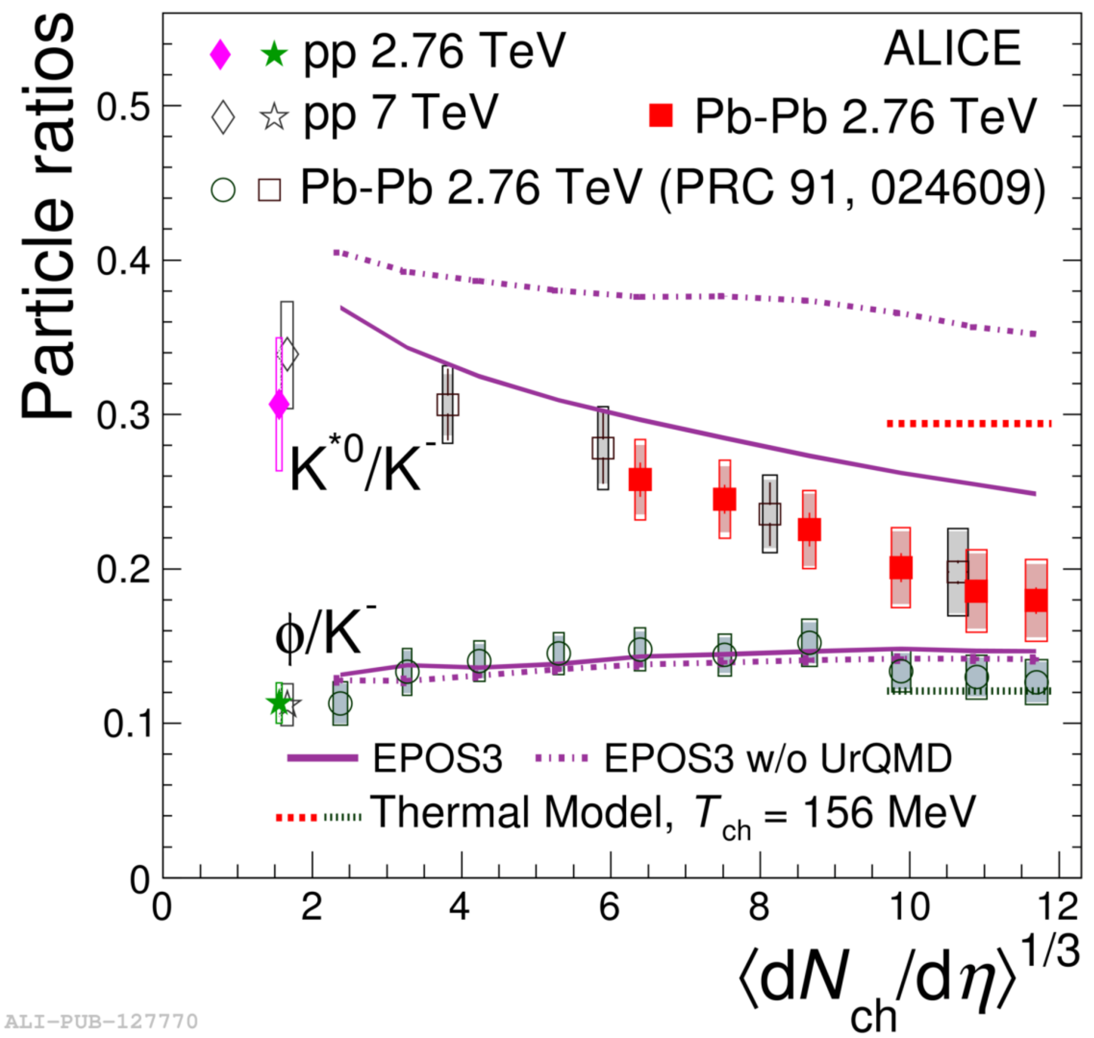
EPOS and UrQMD

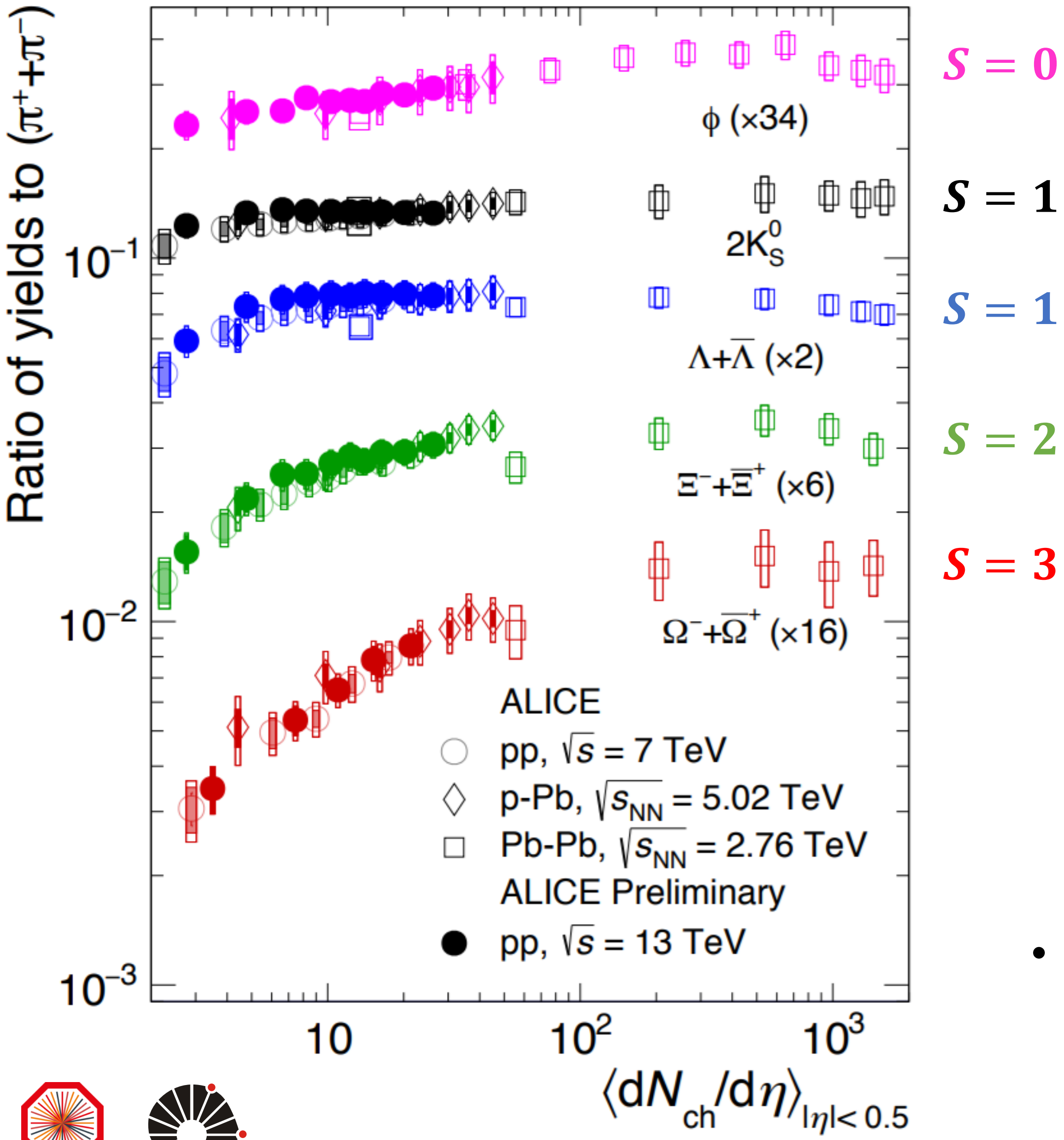
EPOS: pp, pA and AA with common framework

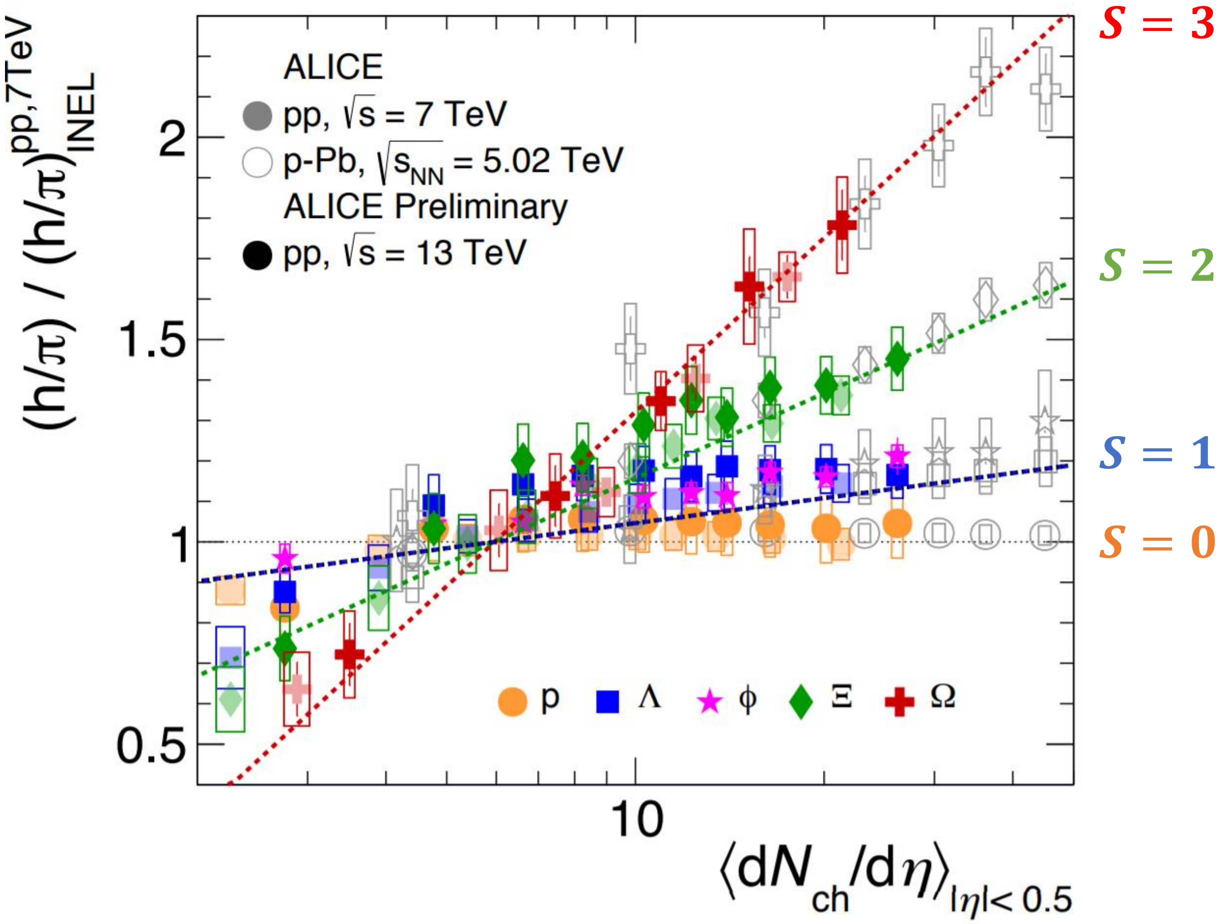
- **Core** (QGP) and a **corona** of jets
- Core evolves hydrodynamically
- Hadronic phase with re-scattering and regeneration (UrQMD)
- Turn off UrQMD: test importance of scattering processes



EPOS: *Phys. Rev. C.* **93**, 014911 (2016)
UrQMD: *Prog. Part Nucl. Phys.* **41**, 255 (1998)

Enhancement of ϕ





- ϕ yield enhanced as a $1 < S < 2$ particle

ALICE Coll., *Nature Physics* **13**, 535–539 (2017)