Hadronic resonance production with ALICE at LHC

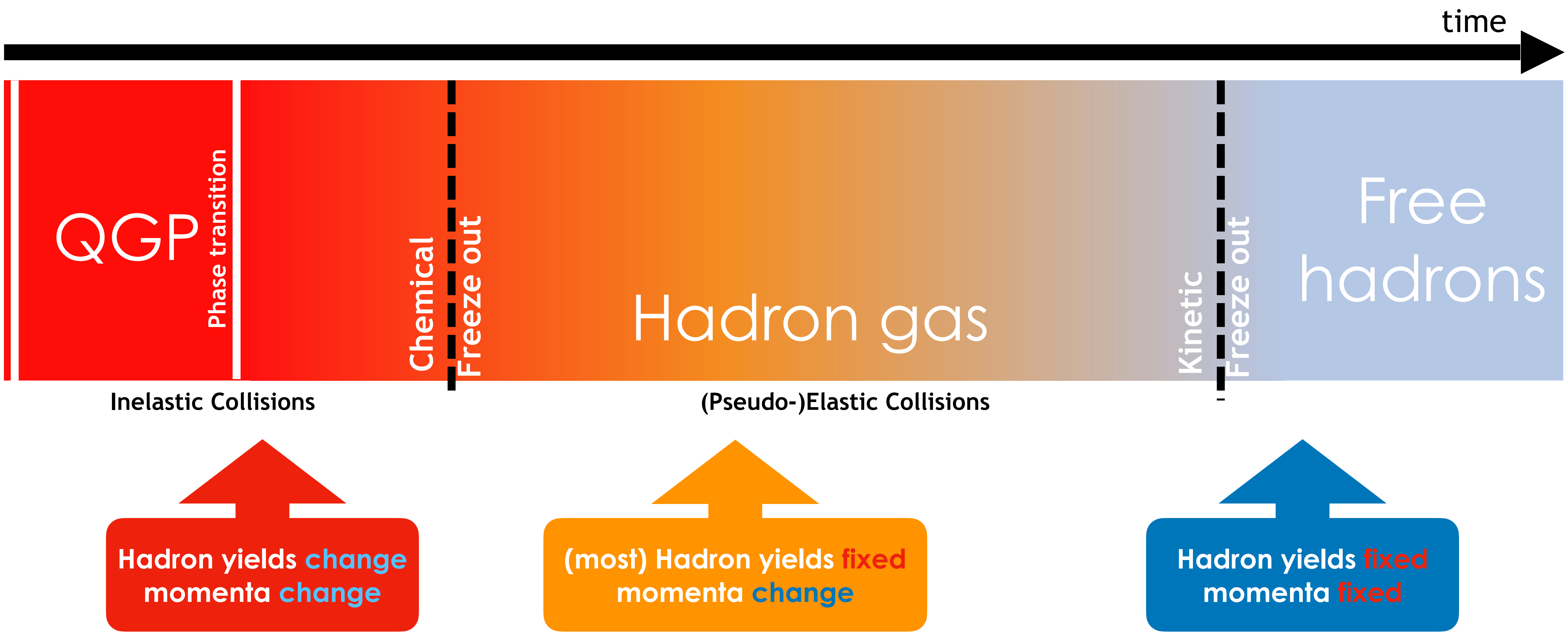
WPCF-Resonance Workshop 2023

Bong-Hwi Lim on behalf of the ALICE Collaboration | 06/11/2023
University and INFN Torino

Outline

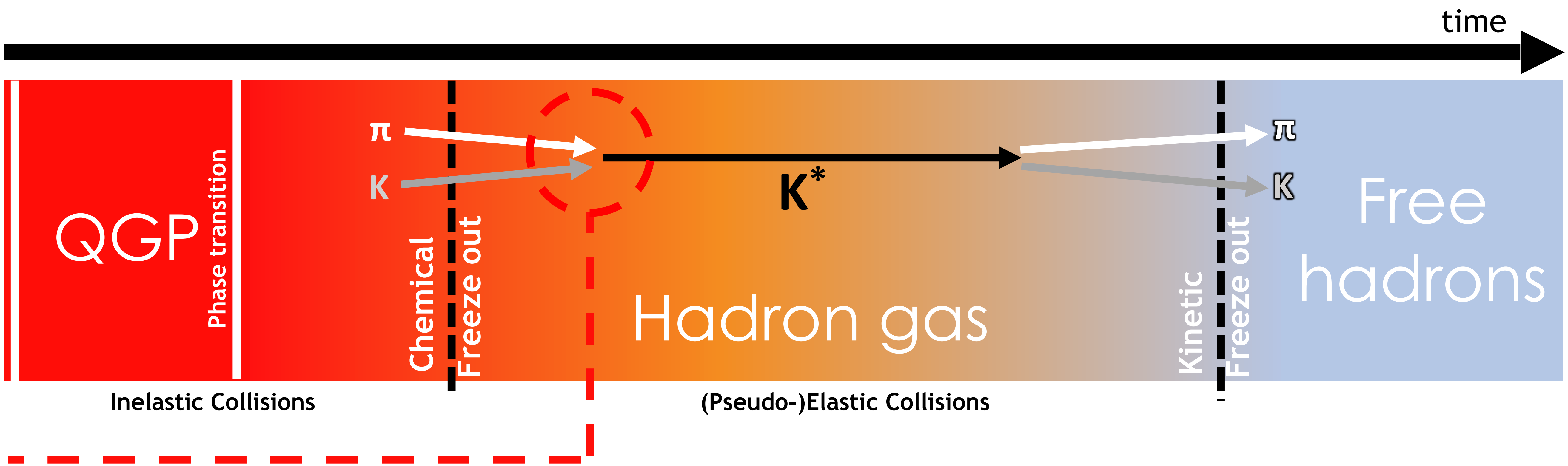
- Introduction - Resonances in hadronic phase
- Hadronic resonances in ALICE
- ALICE Detector
- Highlights from recent publications
  - The ALICE experiment - A journey through QCD arXiv:2211.04384
  - System Size Dependence of Hadronic Rescattering Effect at LHC Energies arXiv:2308.16115
  - $\mathrm{K}^{*\pm}$ Production in Pb-Pb Collisions at 5.02 TeV arXiv:2308.16119
  - Multiplicity Dependence of $\Sigma(1385)^{\pm}$and $\Xi(1530)^{0}$ Production in pp Collisions at $\sqrt{s}$=13TeV arXiv:2308.16116
- Future studies in LHC Run3
- Conclusion

Introduction: Resonances in hadronic phase



- **Resonance**
  - **Short life time (τ ~ few fm/c)**
  - ➡ Can decay within the hadronic medium
  - ✓ Suitable tool for studying hadronic medium effects.

Introduction: Resonances in hadronic phase



Regeneration

pseudo-elastic scattering through resonance state

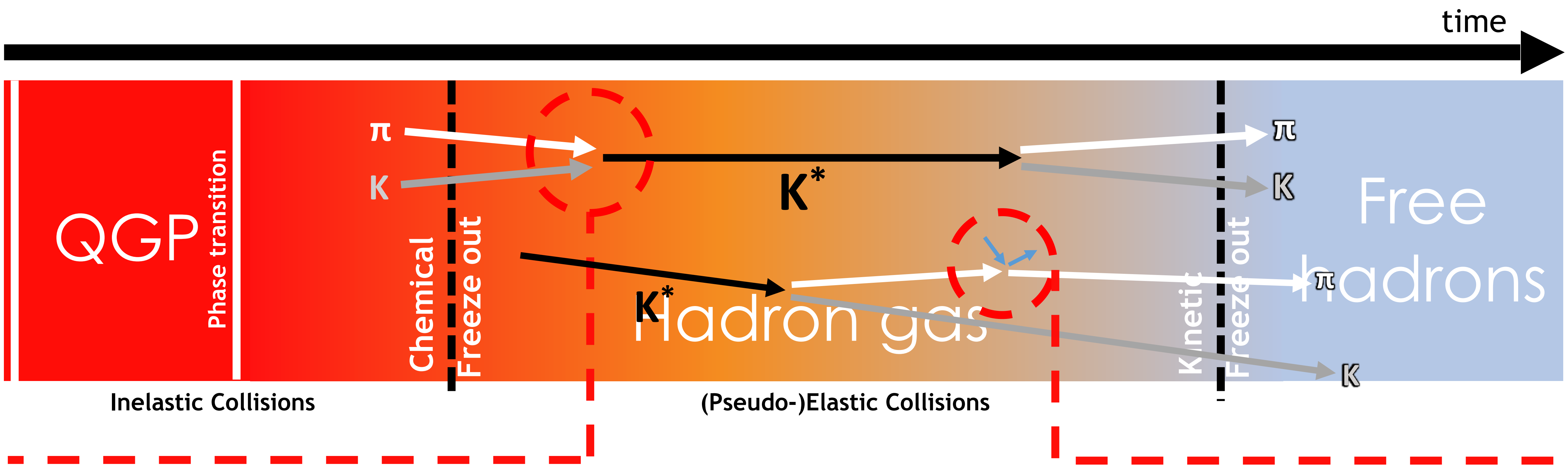
➡ **Enhanced yield**

- **Resonance**
  - **Short life time (τ ~ few fm/c)**

  ➡ Can decay within the hadronic medium

  ✓ Suitable tool for studying hadronic medium effects.

Introduction: Resonances in hadronic phase



Regeneration

pseudo-elastic scattering through resonance state

➡ **Enhanced yield**

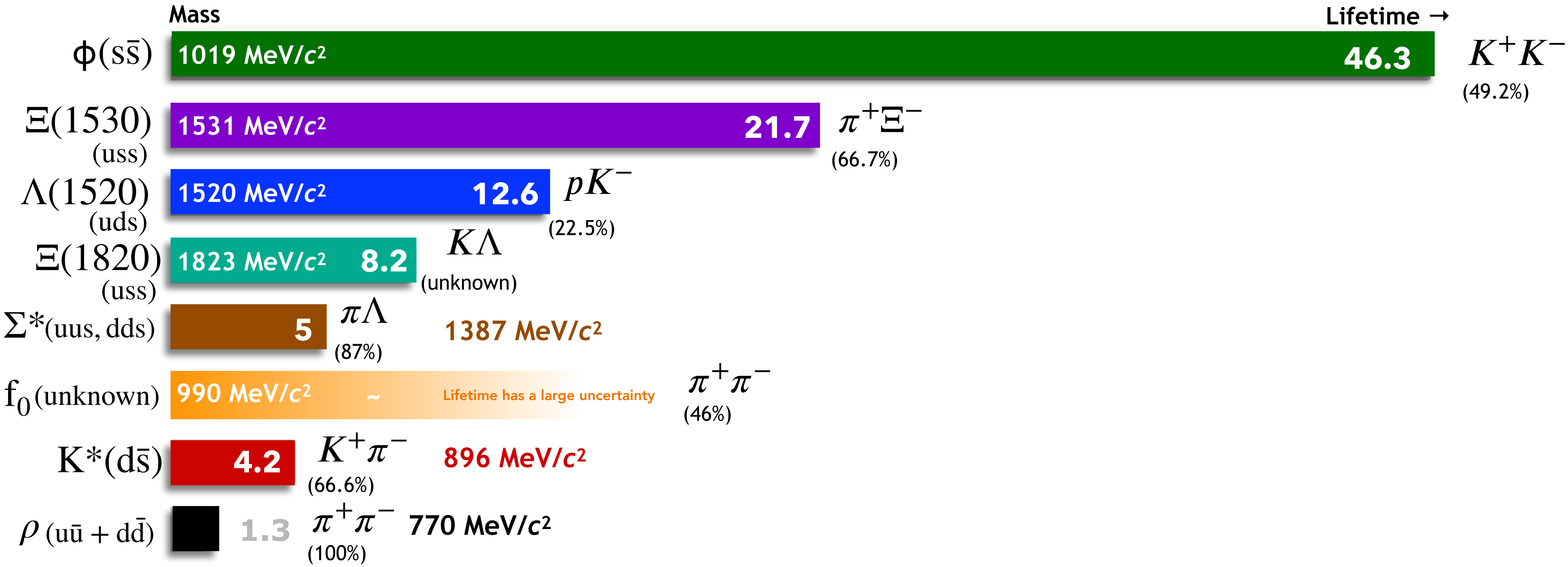
Rescattering

elastic scattering smears out mass peak

➡ **Reduced yield**

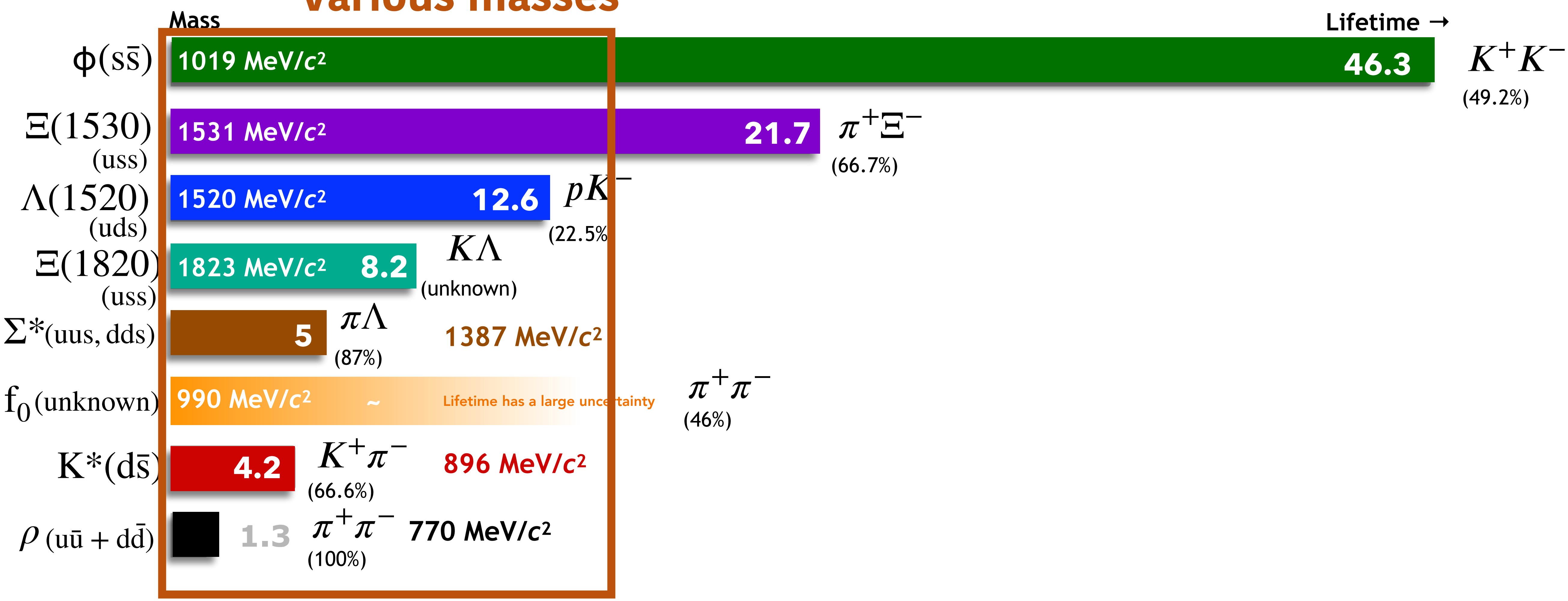
- **Resonance**
  - **Short life time (τ ~ few fm/c)**
  - ➡ Can decay within the hadronic medium
  - ✓ Suitable tool for studying hadronic medium effects.

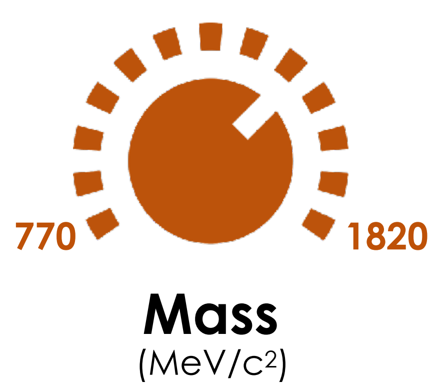
Hadronic resonances in ALICE



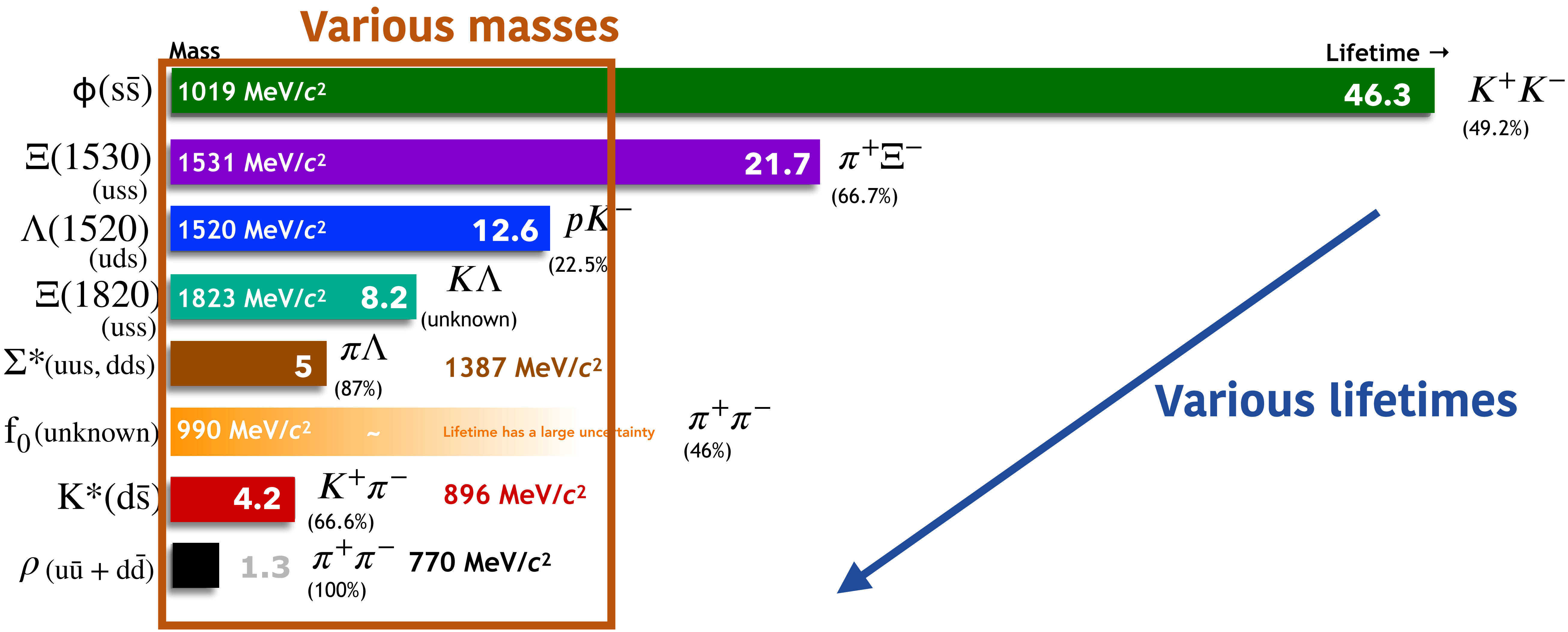
Hadronic resonances in ALICE

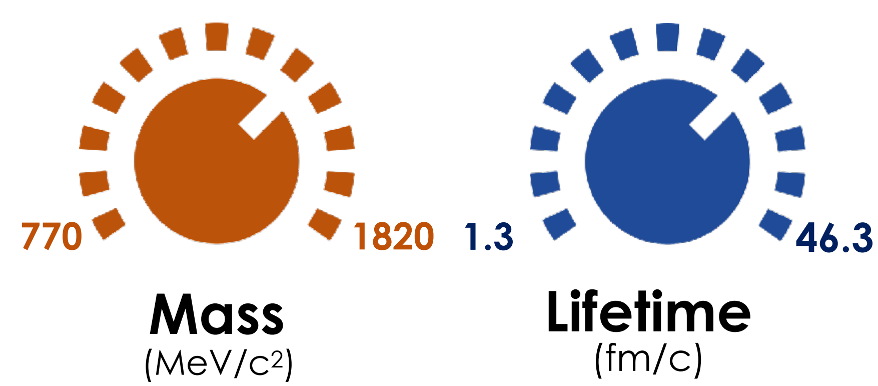
Various masses





Hadronic resonances in ALICE





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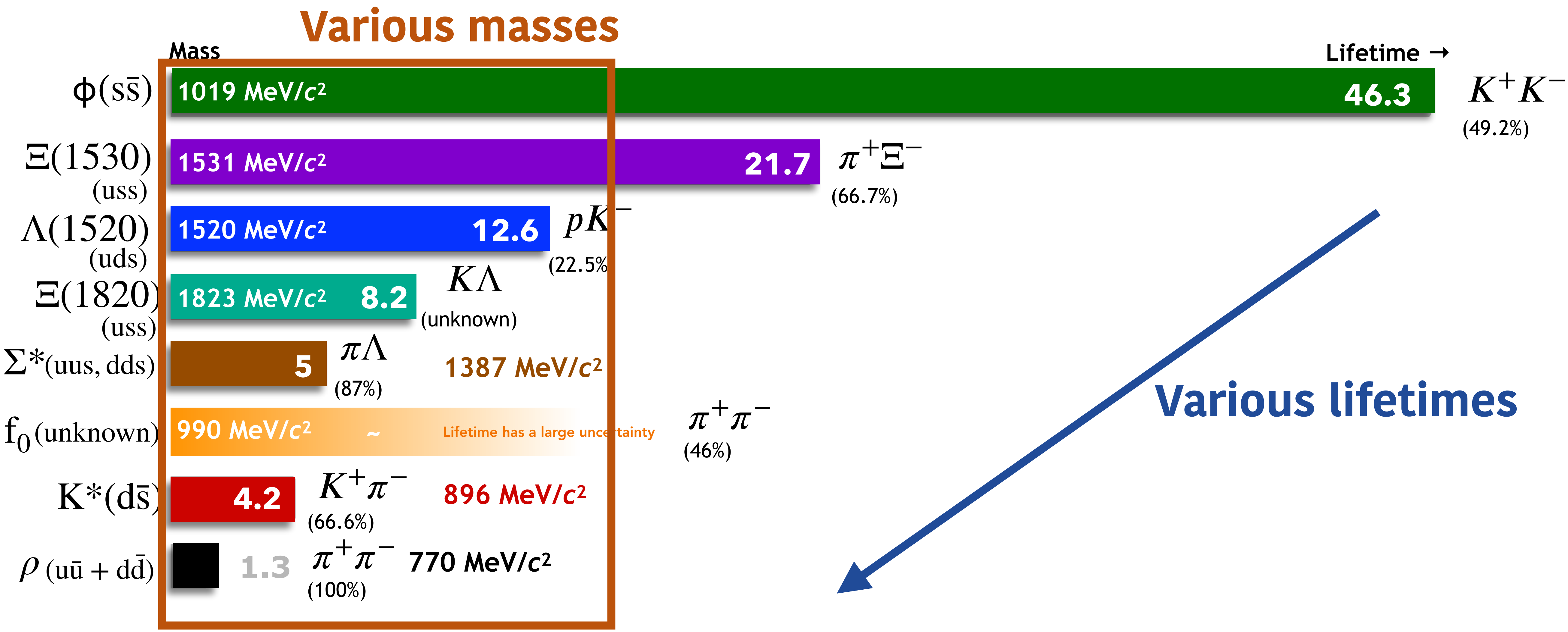
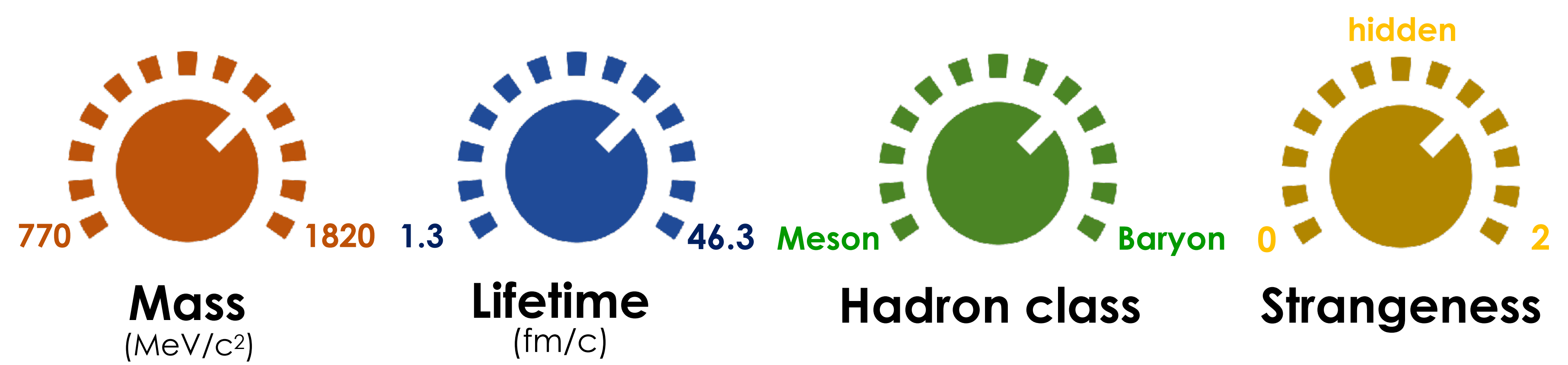
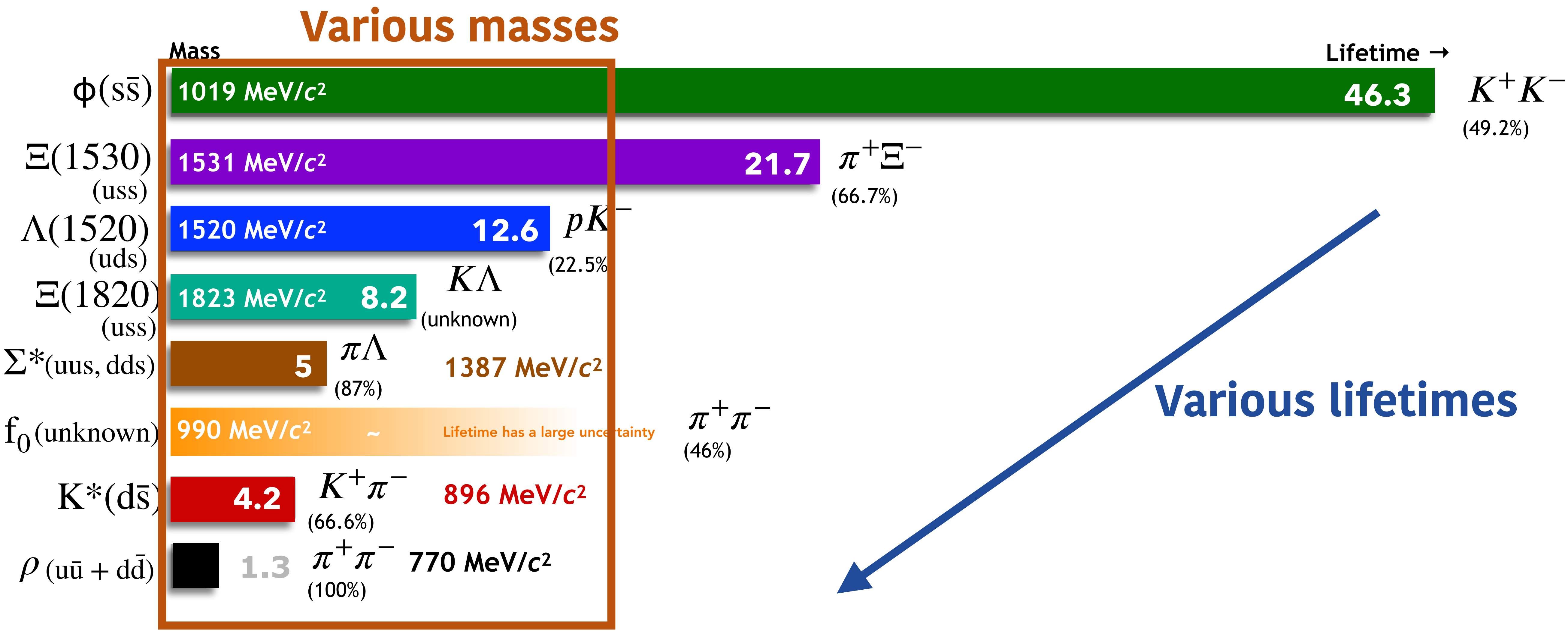


Different hadron class /

Strangeness



Hadronic resonances in ALICE



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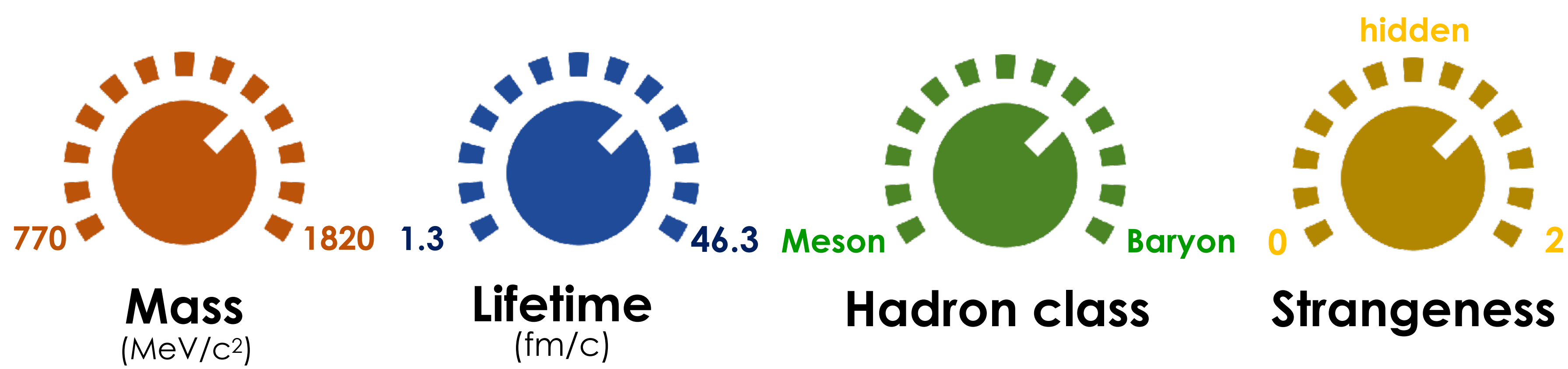
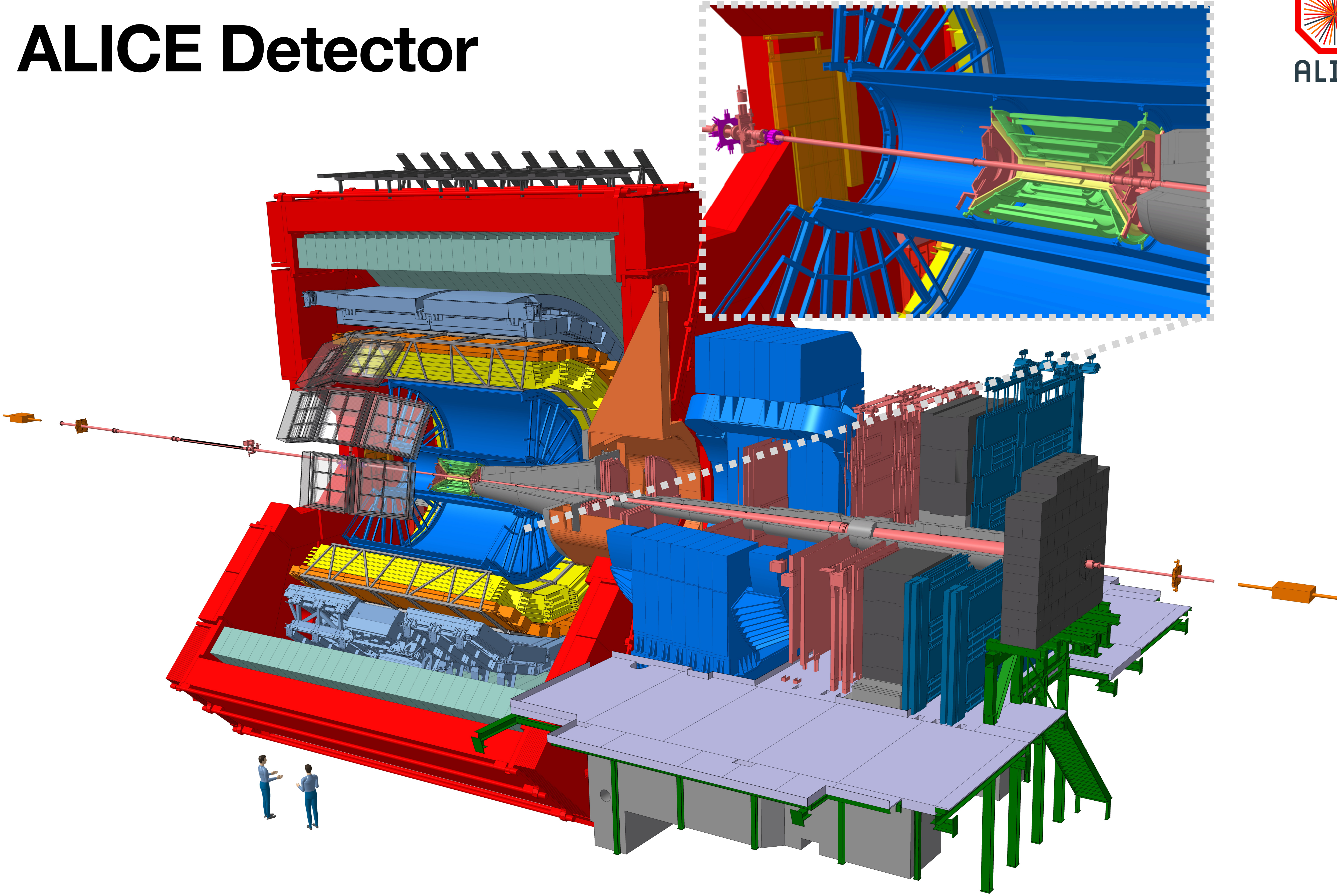


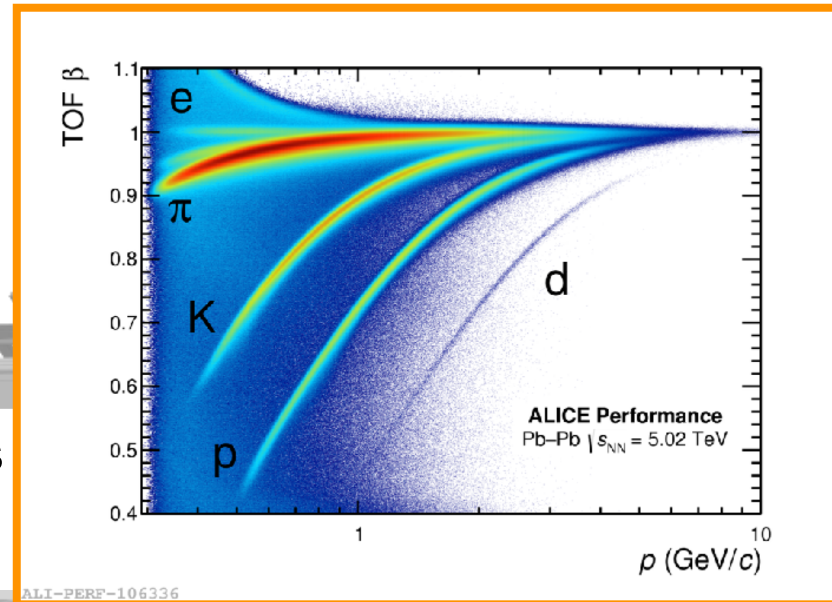
RESONANCES may have control knobs that can be used to study the hadronic phase.

ALICE Detector



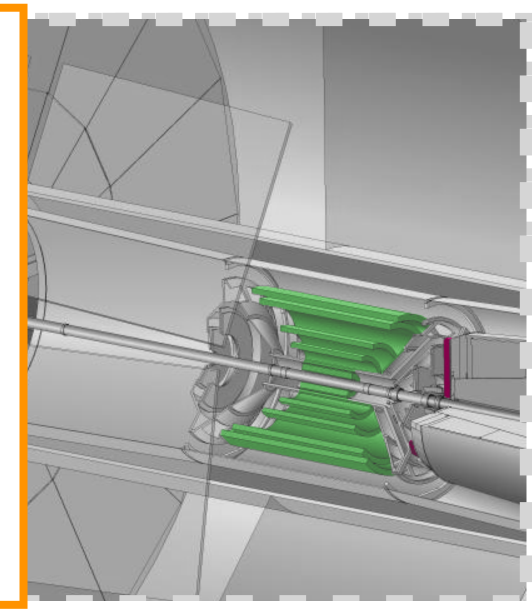
- Multi-purpose detector at the LHC with unique **particle identification** capabilities and tracking down to **very low momenta**

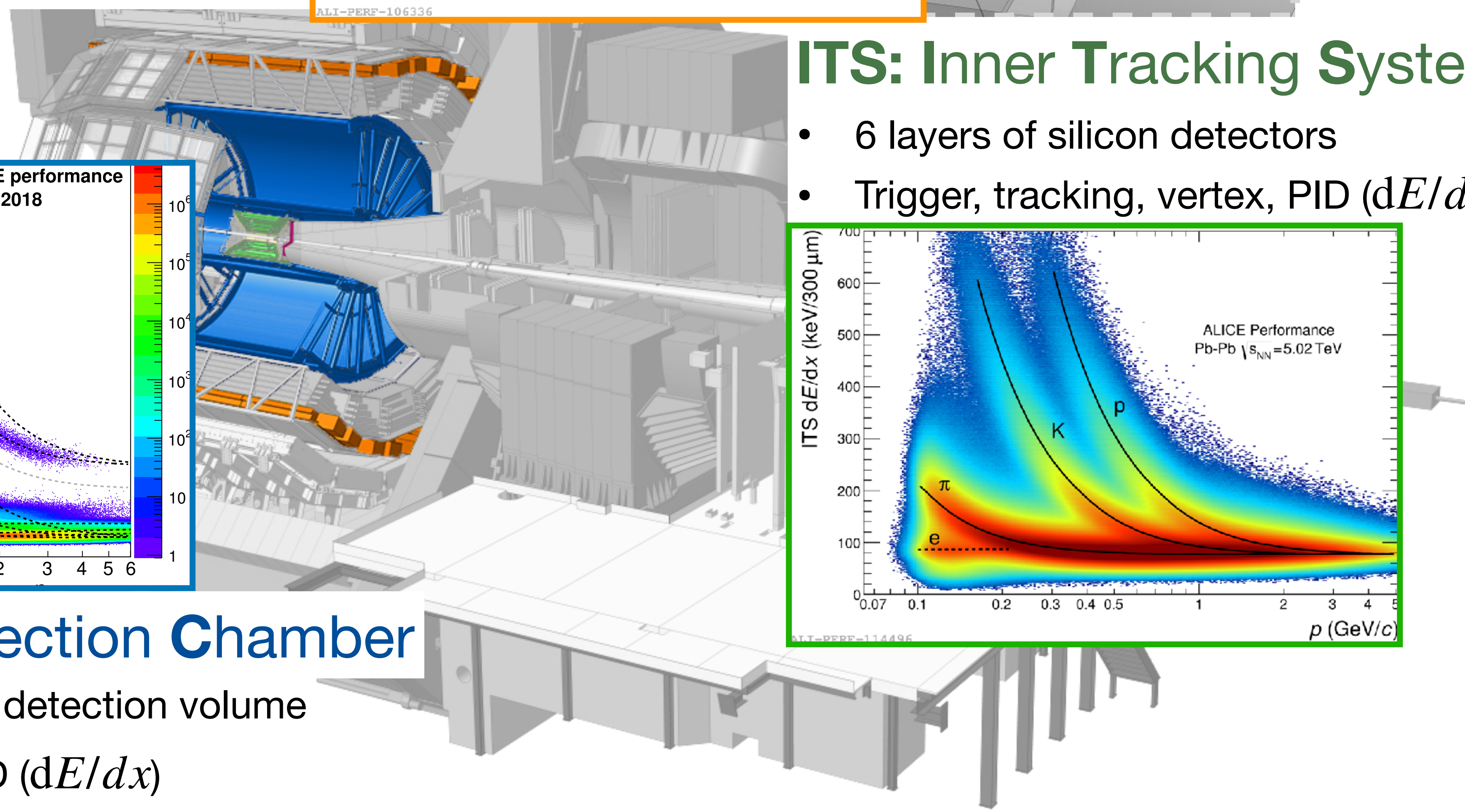
ALICE Detector



TOF: Time of Flight

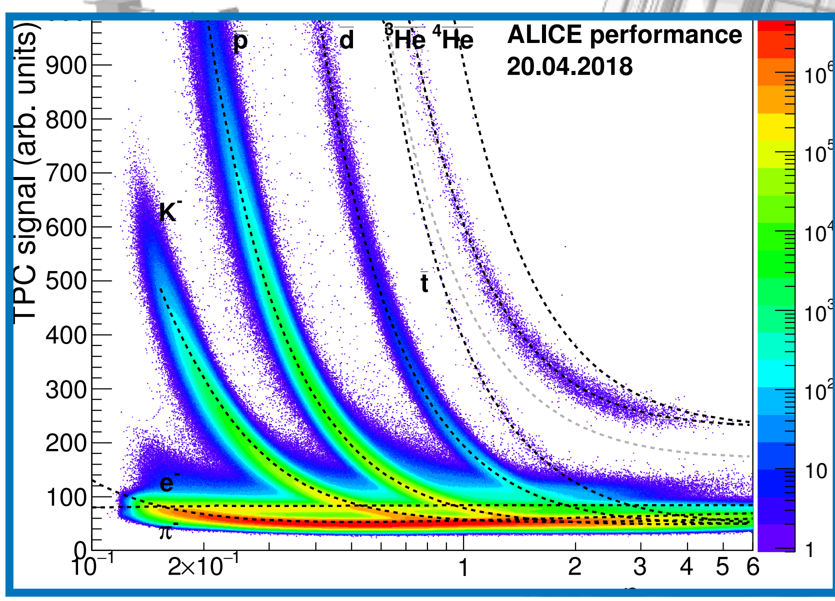
- Multi-gap resistive plate chambers
- PID (β, time-of-flight)





ITS: Inner Tracking System

- 6 layers of silicon detectors
- Trigger, tracking, vertex, PID ($\mathrm{d}E/dx$)



TPC: Time Projection Chamber

- Gas-filled ionization detection volume
- Tracking, vertex, PID ($\mathrm{d}E/dx$)

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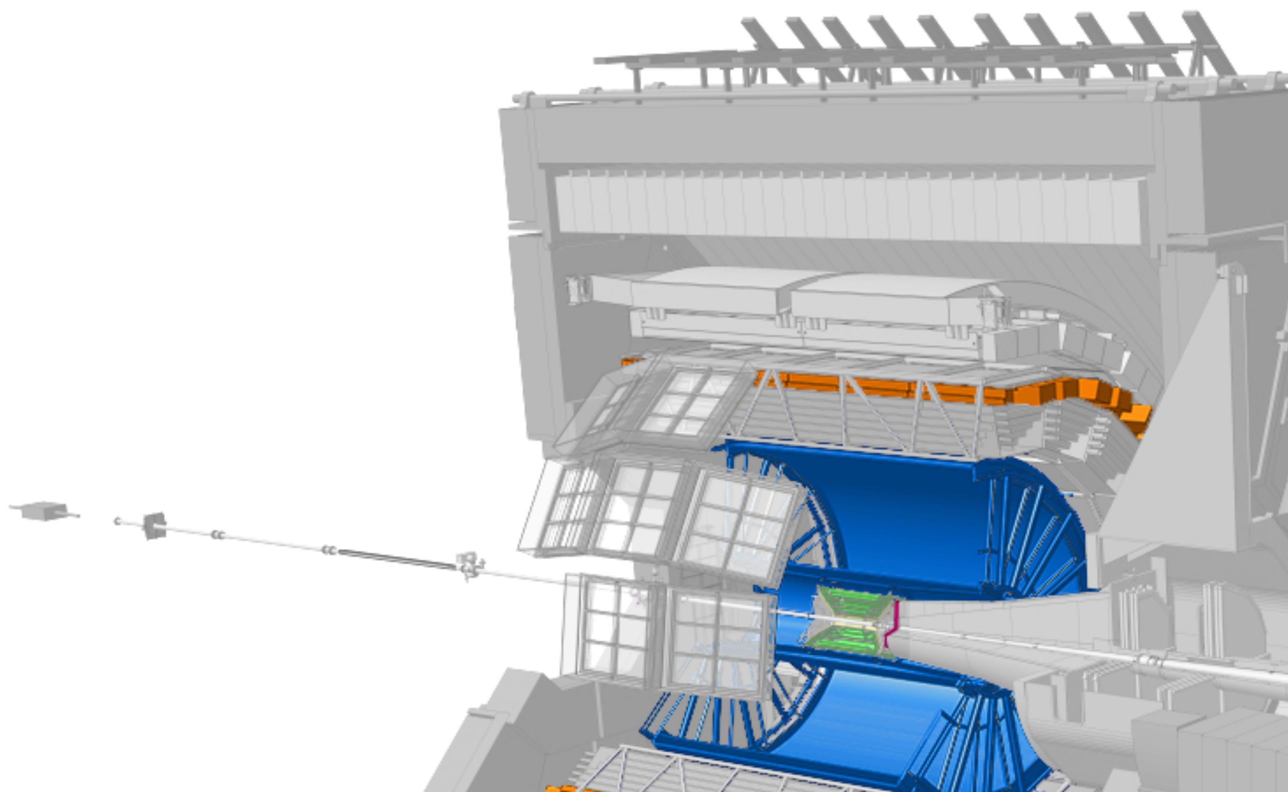
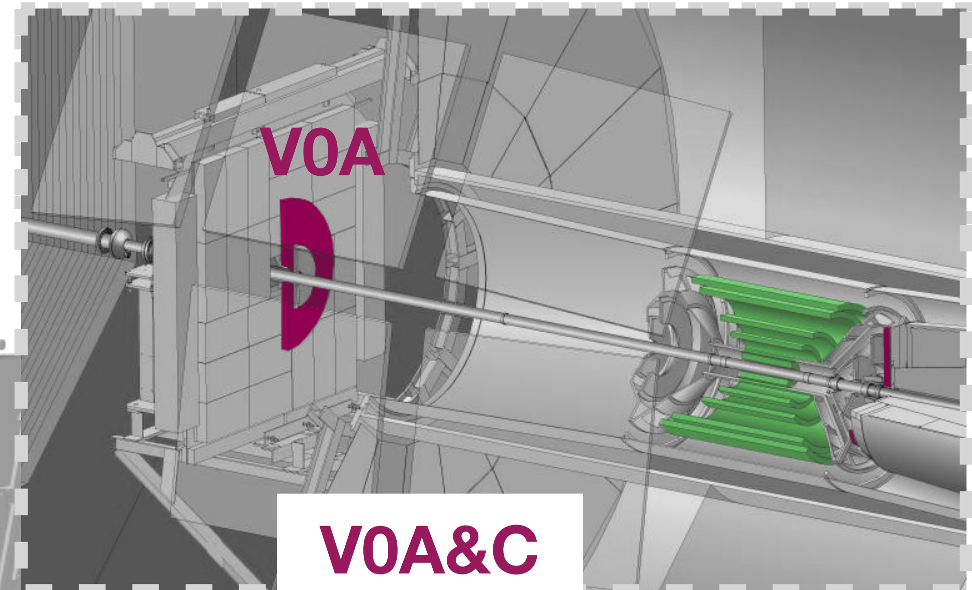
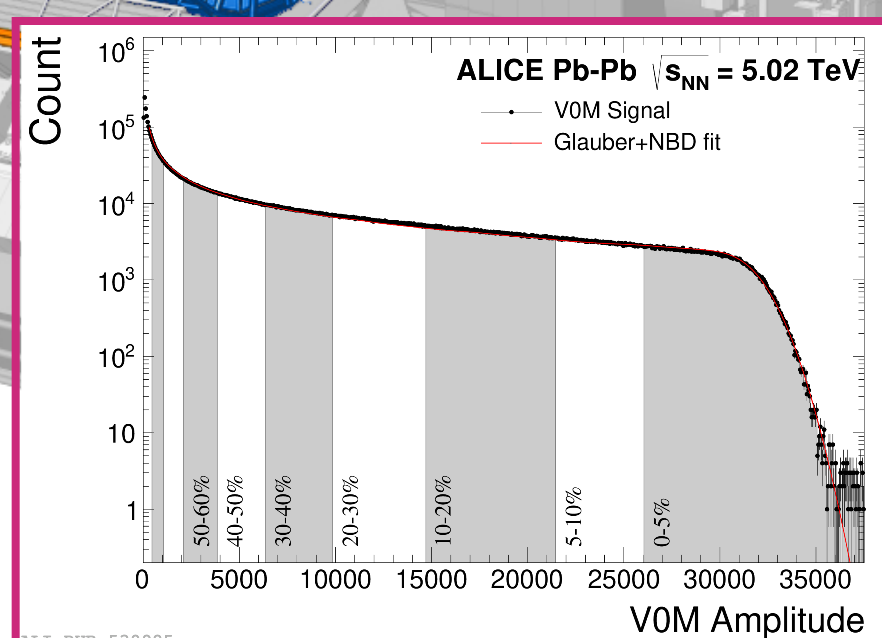
ALICE Detector

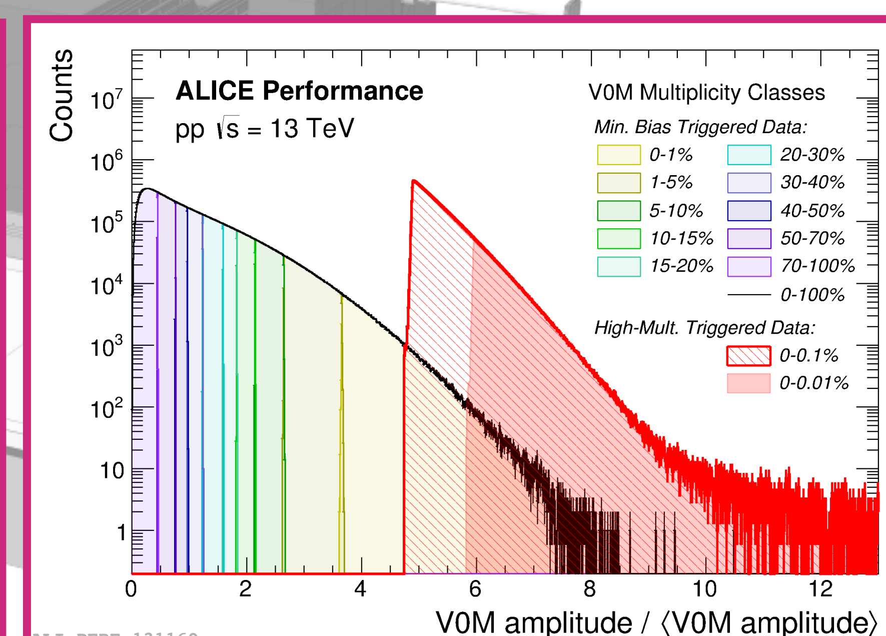




V0A&C

- Arrays of scintillators
- Trigger, beam gas rejection, multiplicity estimator





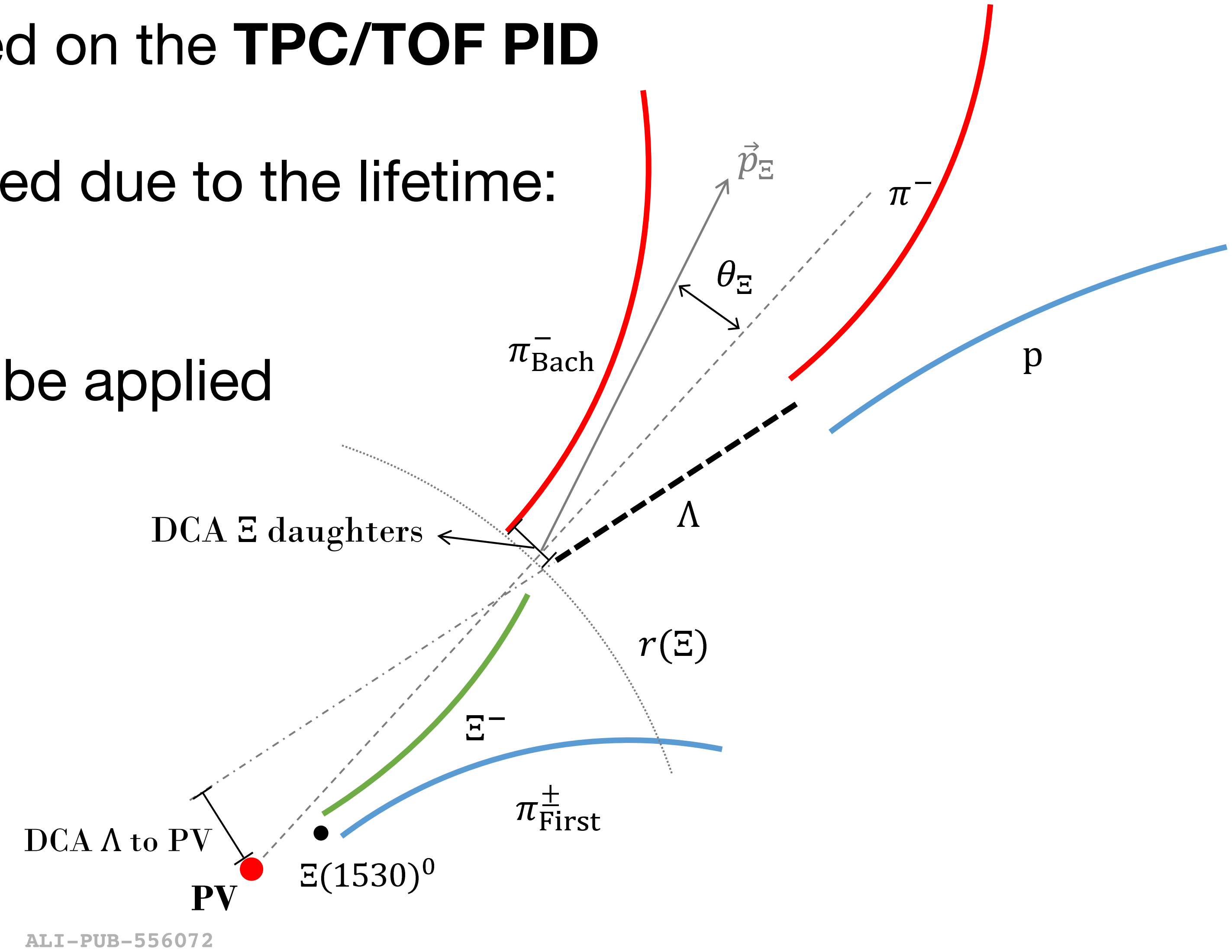
- Multi-purpose detector at the LHC with unique **particle identification** capabilities and tracking down to **very low momenta**

Resonance analysis: Invariant mass

- Resonances are reconstructed via their invariant masses

$$M_{\text{inv}} = \sqrt{(E_1 + E_2)^2 - |\vec{p}_1 + \vec{p}_2|^2}$$

- Daughter tracks are selected based on the **TPC/TOF PID**
- **<u>No secondary vertex</u>** reconstructed due to the lifetime: SV of resonance = Primary vertex
- Instead, topological selection can be applied to limit the PV tracks.

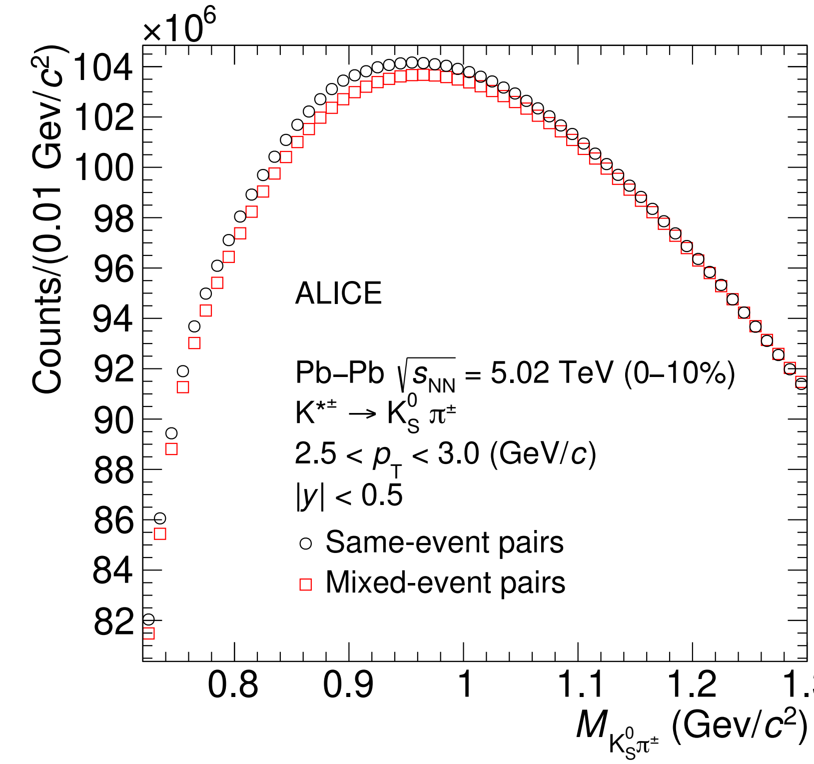


Resonance analysis: Invariant mass

- Resonances are reconstructed via their invariant masses

$$M_{\text{inv}} = \sqrt{(E_1 + E_2)^2 - |\vec{p}_1 + \vec{p}_2|^2}$$

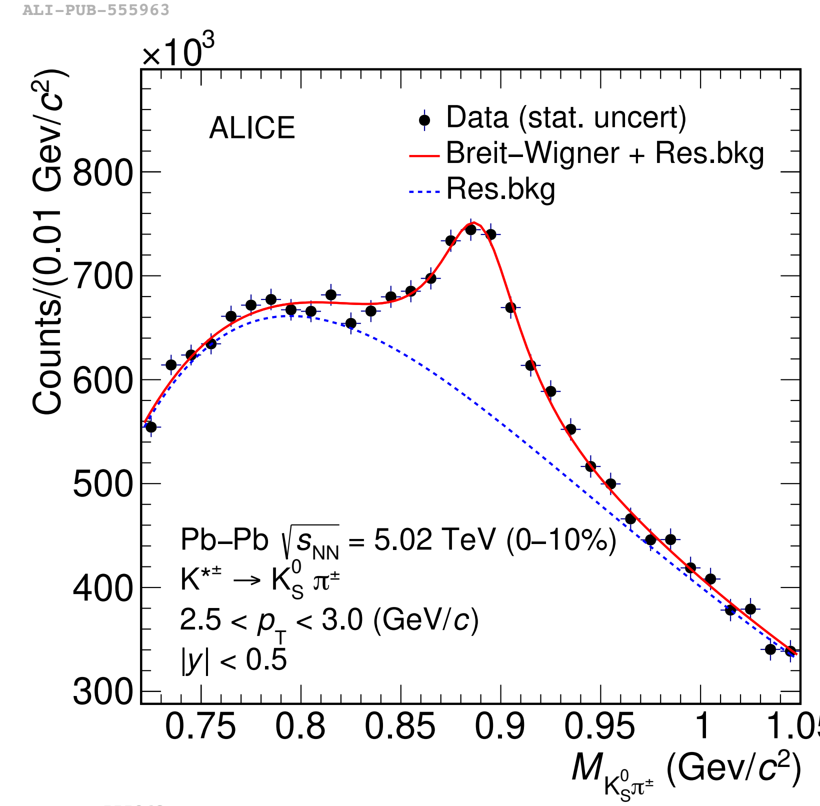
- **Uncorrelated background**: estimated via event-mixing or like-sign techniques



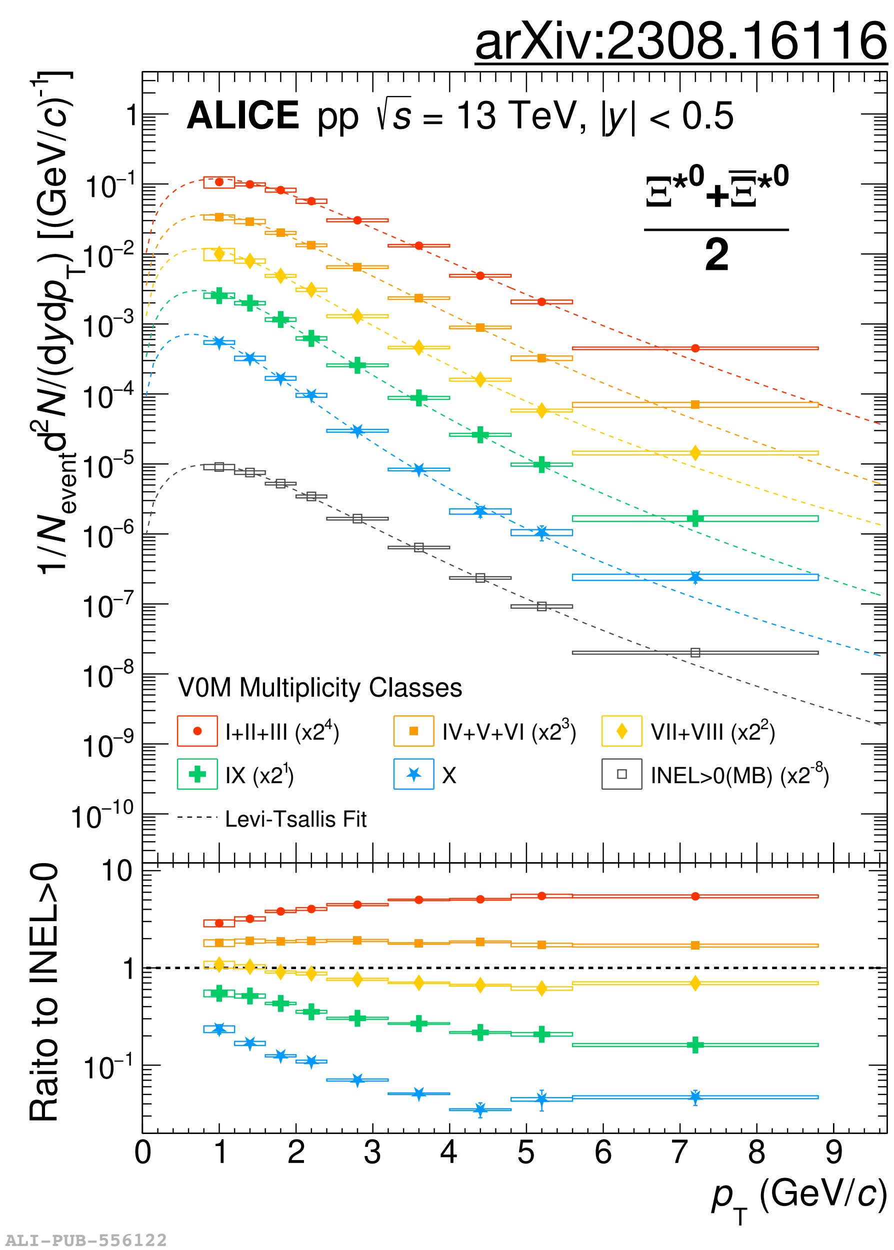
- **Residual background:** correlated pairs or misidentified decay products, modelled by custom functions (eg. polynomial function)

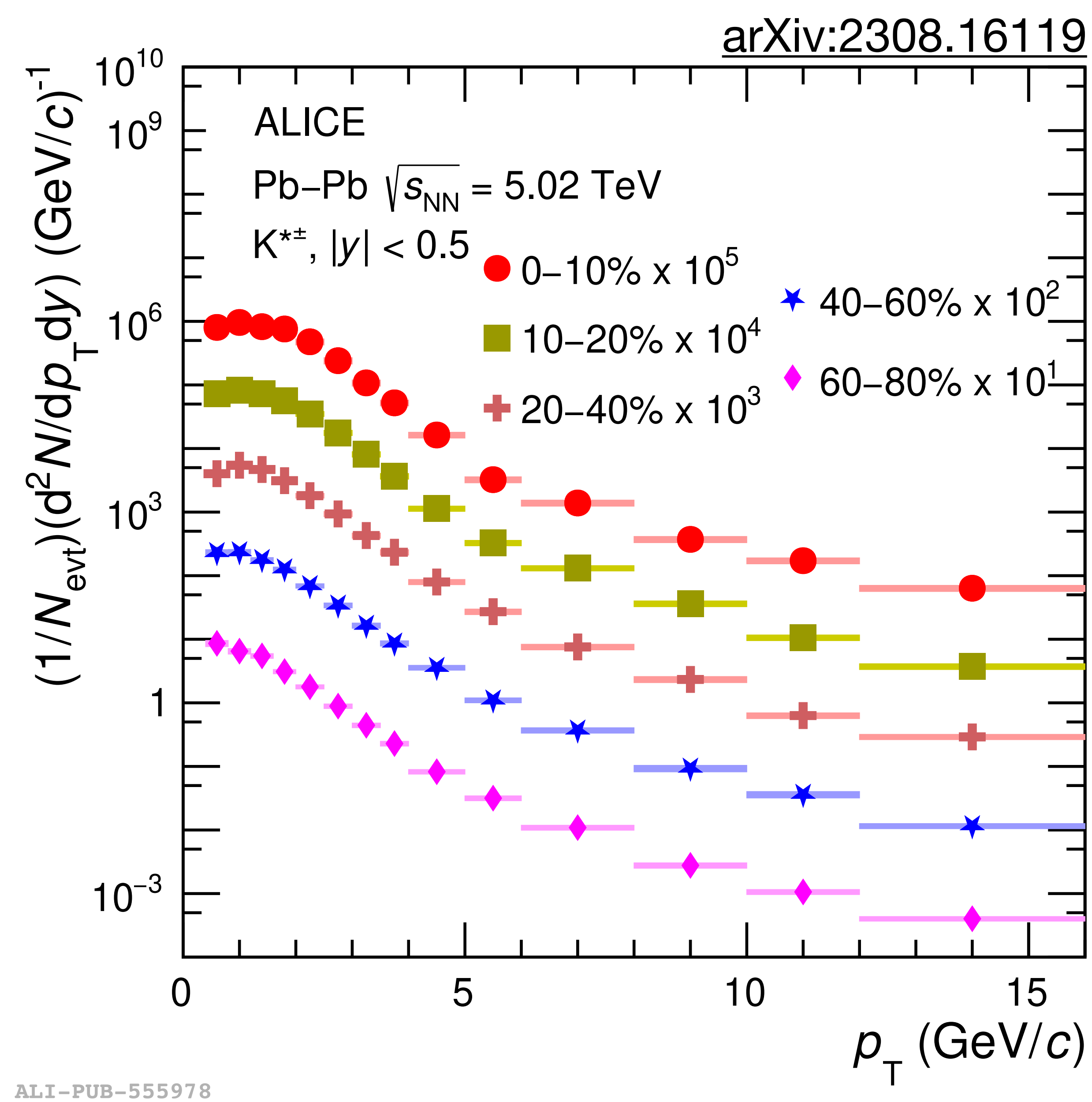
- **Signal**: Fit with a Breit-Wigner or Voigtian function and the residual background

- Yields are calculated by integrating the signal function



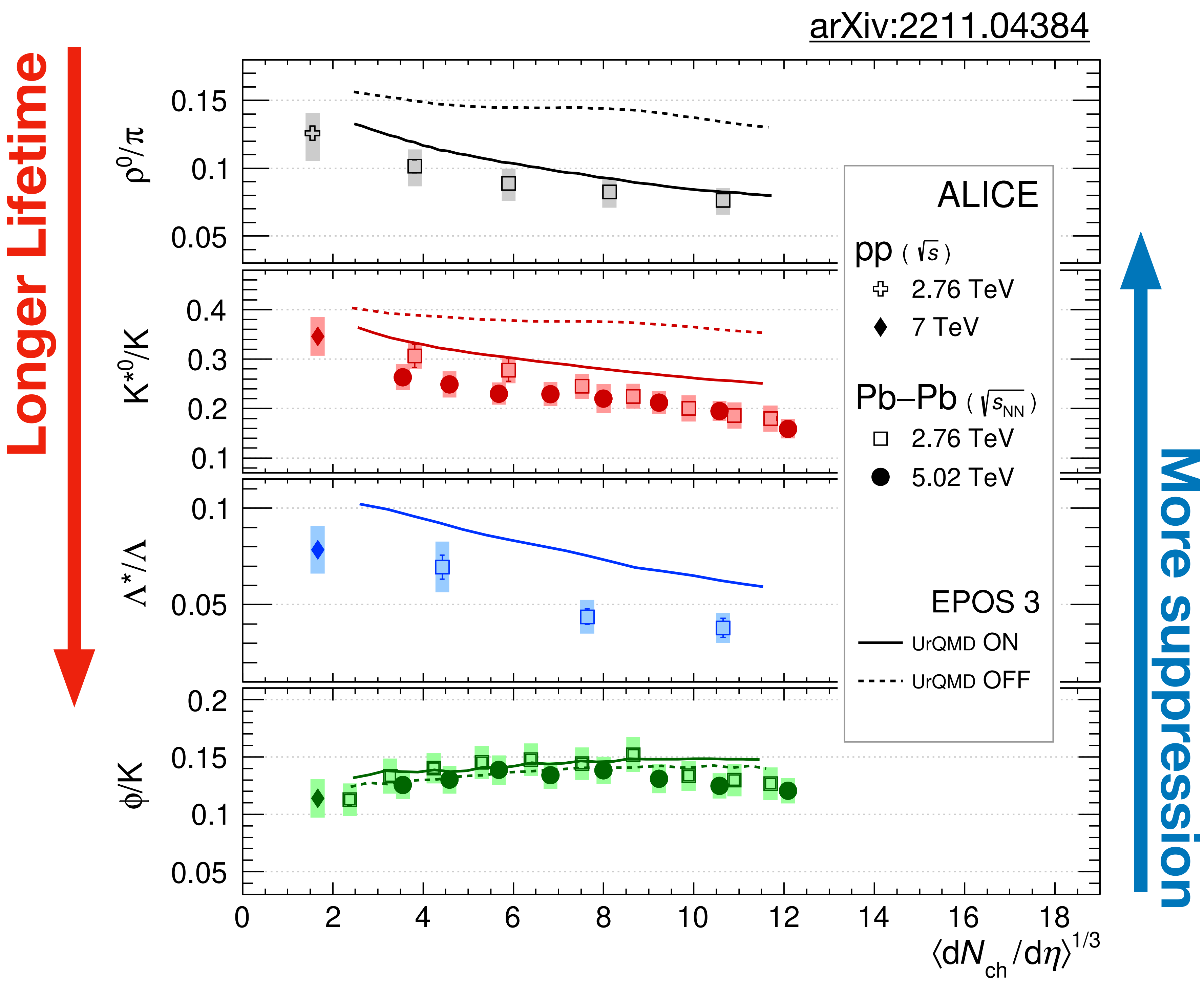
Resonance analysis: p_T spectra





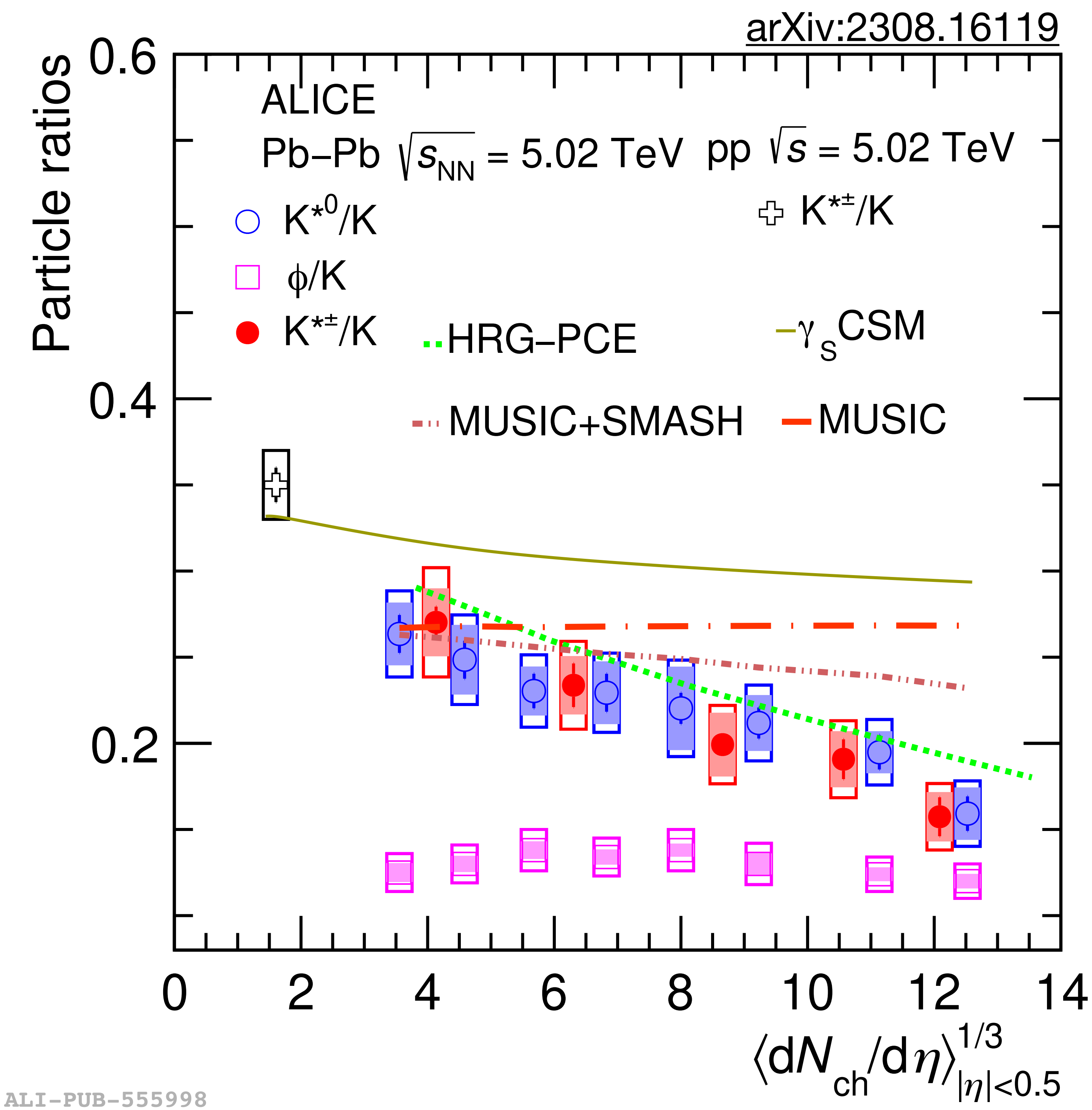
- ***p_T*-Spectra**: p_T differential corrected yields based on the raw yields
  - p_T-Integrated yields → Particle yields ratio
  - Average p_T → Estimate system condition

Resonance analysis: Particle ratio



- **Resonance yield ratio** to the long-lived particle with the same quark contents
  - **Suppression** of the ratios of the **short-lived resonances**
  - Huge role of a hadronic phase afterburner (UrQMD). arXiv:1509.07895 → Suggests rescattering of decay products in the hadronic phase.
- **Smooth** transition observed from pp to AA collisions → Resonance yields controlled by **system size (multiplicity)**

Particle ratio: $K^{*\pm}/K$

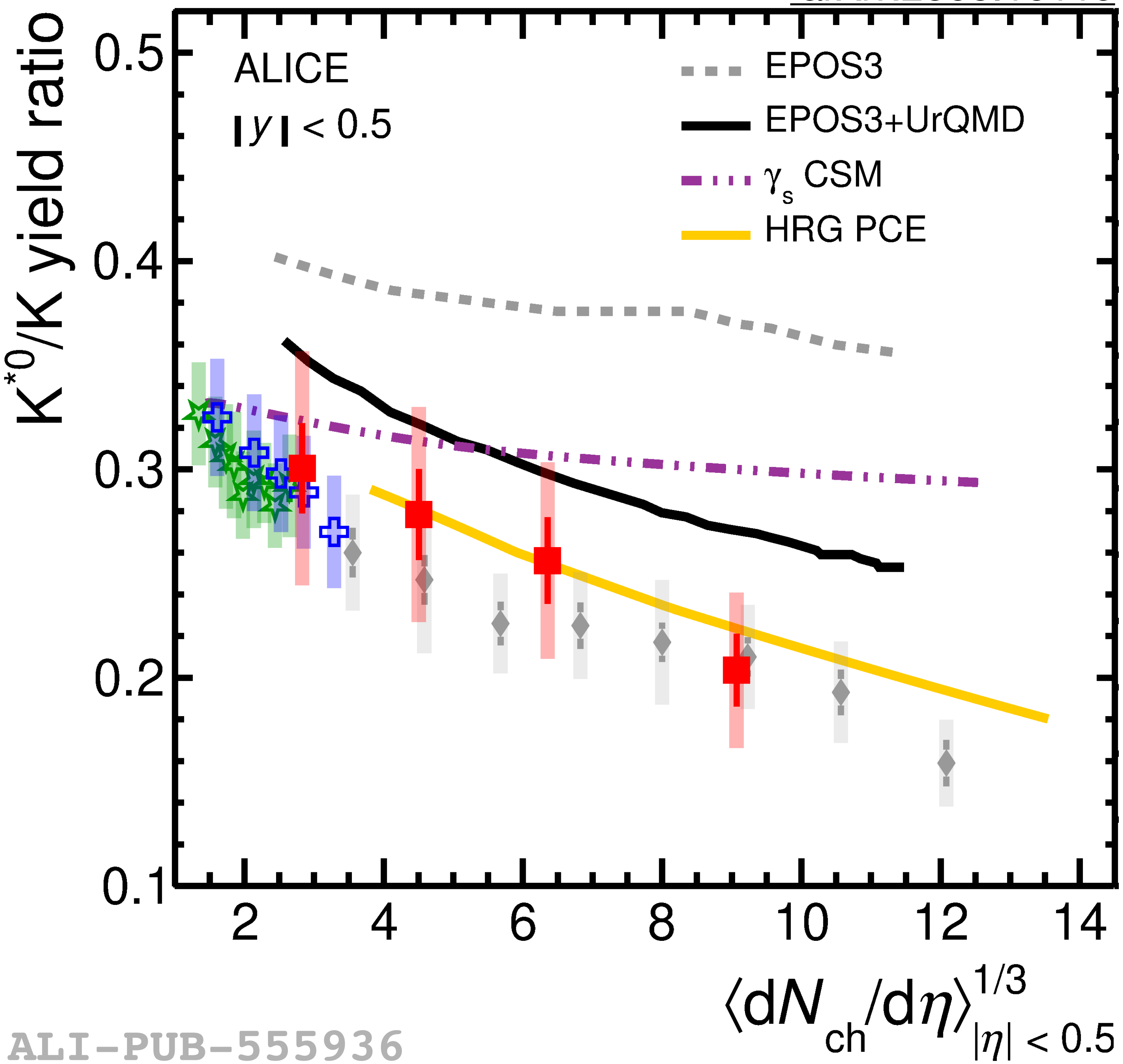


- **Resonance yield ratio** to the long-lived particle with the same quark contents
  - Similar decreasing trend to the one of K^{*0}/K
- **Model comparisons**
  - arXiv:1906.03145
    γ_s Canonical Statistical Model
  - arXiv:1908.11730
    Hadron Resonance Gas Partial Chemical Equilibrium model
  - arXiv:1908.11730
    Hydrodynamic MUSIC model w/wo hadronic afterburner

Recent publication

Particle ratio: K^{*0}/K

arXiv:2308.16115



System	Collision energy
pp	5.02 TeV
p–Pb	5.02 TeV
Xe–Xe	5.44 TeV
Pb–Pb	5.02 TeV

- **Resonance yield ratio** to the long-lived particle with the same quark contents
  - Comparison with the similar energy systems
  - Continuous decreasing trend from small to large system
- **Model comparisons**
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    γ_s Canonical Statistical Model
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    Hadron Resonance Gas Partial Chemical Equilibrium model
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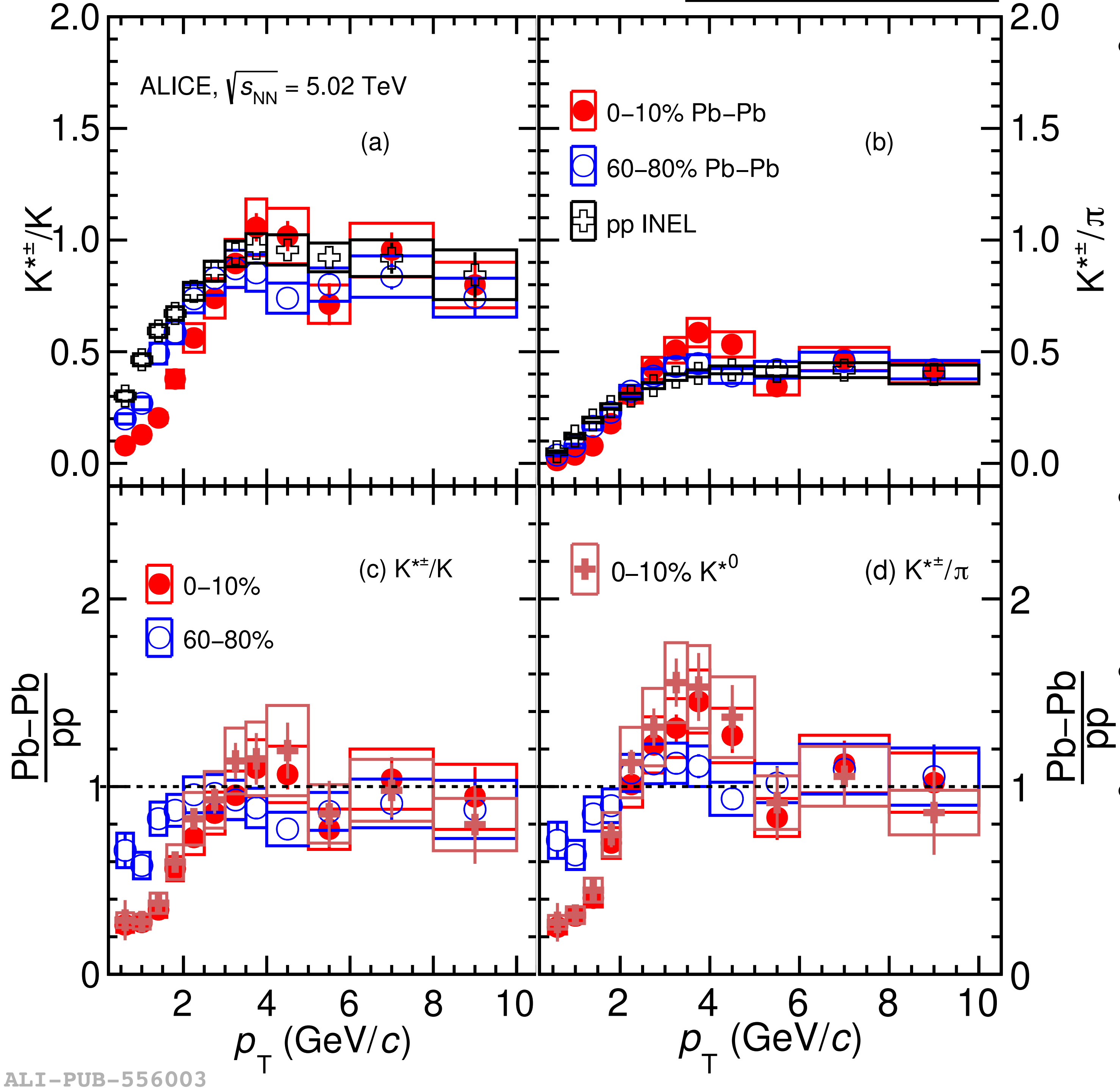
    EPOS3 w/wo UrQMD

Recent publication

p_T-differential particle ratio: K*±/K

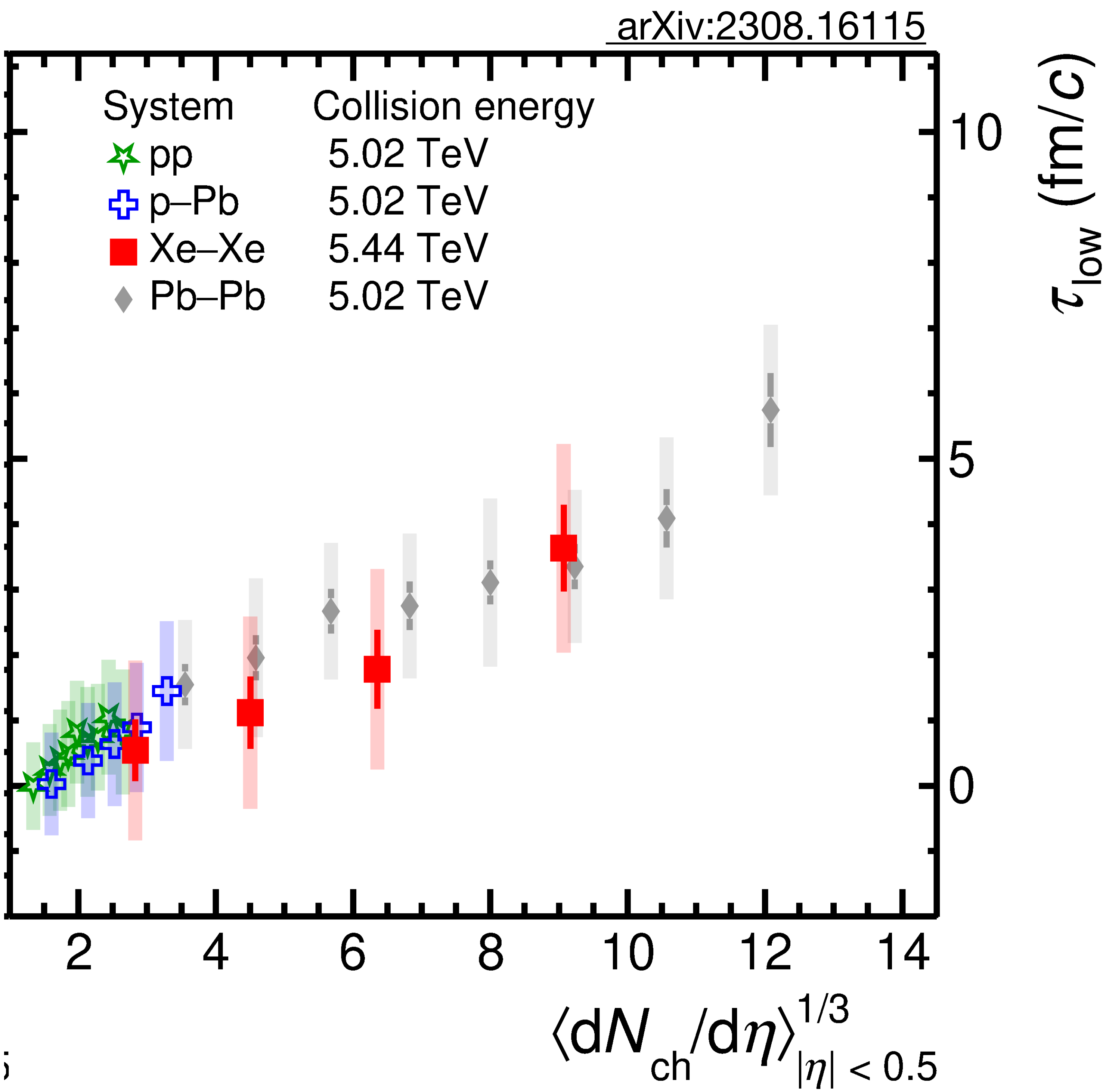
arXiv:2308.16119



- **p_T dependence** of the rescattering effect?
  - Left/Right: particle ratio K*±/K, K*±/π
  - Top: same system
  - Bottom: double ratios of Pb–Pb to pp results $(K^{*\pm}/K)_{PbPb}/(K^{*\pm}/K)_{pp}$, $(K^{*\pm}/\pi)_{PbPb}/(K^{*\pm}/\pi)_{pp}$
- Suppression in **low p_T region** → rescattering is low p_T phenomenon
- Consistent results with K*0
- Right bottom: the enhancement is more pronounced for K*±/π
  - Consistent picture of larger radial flow in the central Pb–Pb collisions

Recent publication

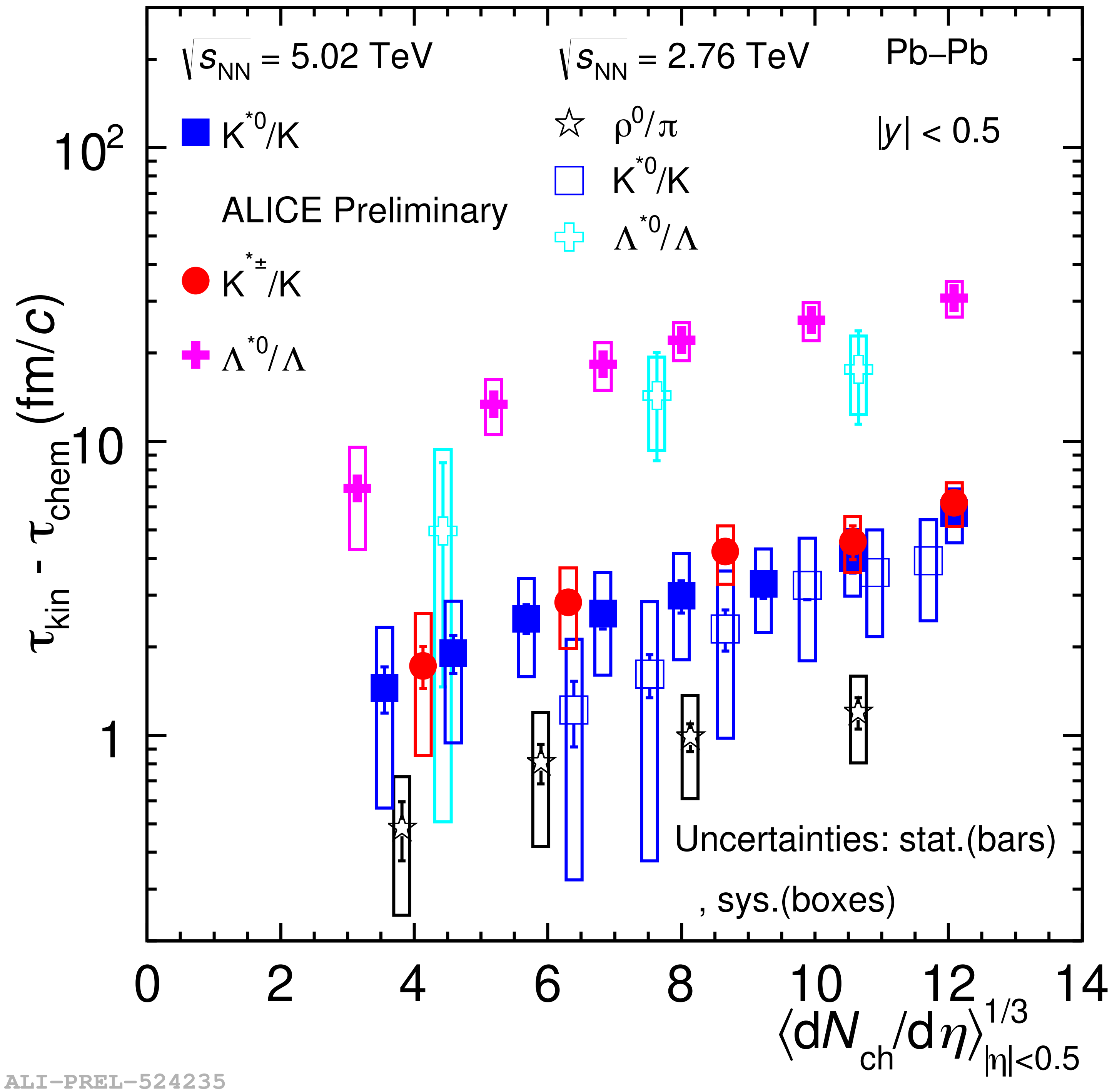
Estimating lifetime of the hadronic phase



$$r_{kin} = r_{chem} \times e^{-(\tau_{kin} - \tau_{chem})/\tau_{res}}$$

- **<u>Lower bound</u> on the hadronic phase lifetime**
  - r_{kin}: Particle ratio at kinetic freeze-out (Pb-Pb)
  - r_{chem}: Particle ratio at chemical freeze-out (pp)
  - τ_{res}: lifetime of resonance
  - **Assumptions:** Simultaneous freeze-out of all particles Negligible regeneration
  - Scaled with Lorentz factor $\sqrt{1 + (\frac{< p_T >}{\text{mass of } K^{*0}})^2}$
- **Smooth transition** from small to large system
  - Reach to 0 at the small system

Estimating lifetime of the hadronic phase



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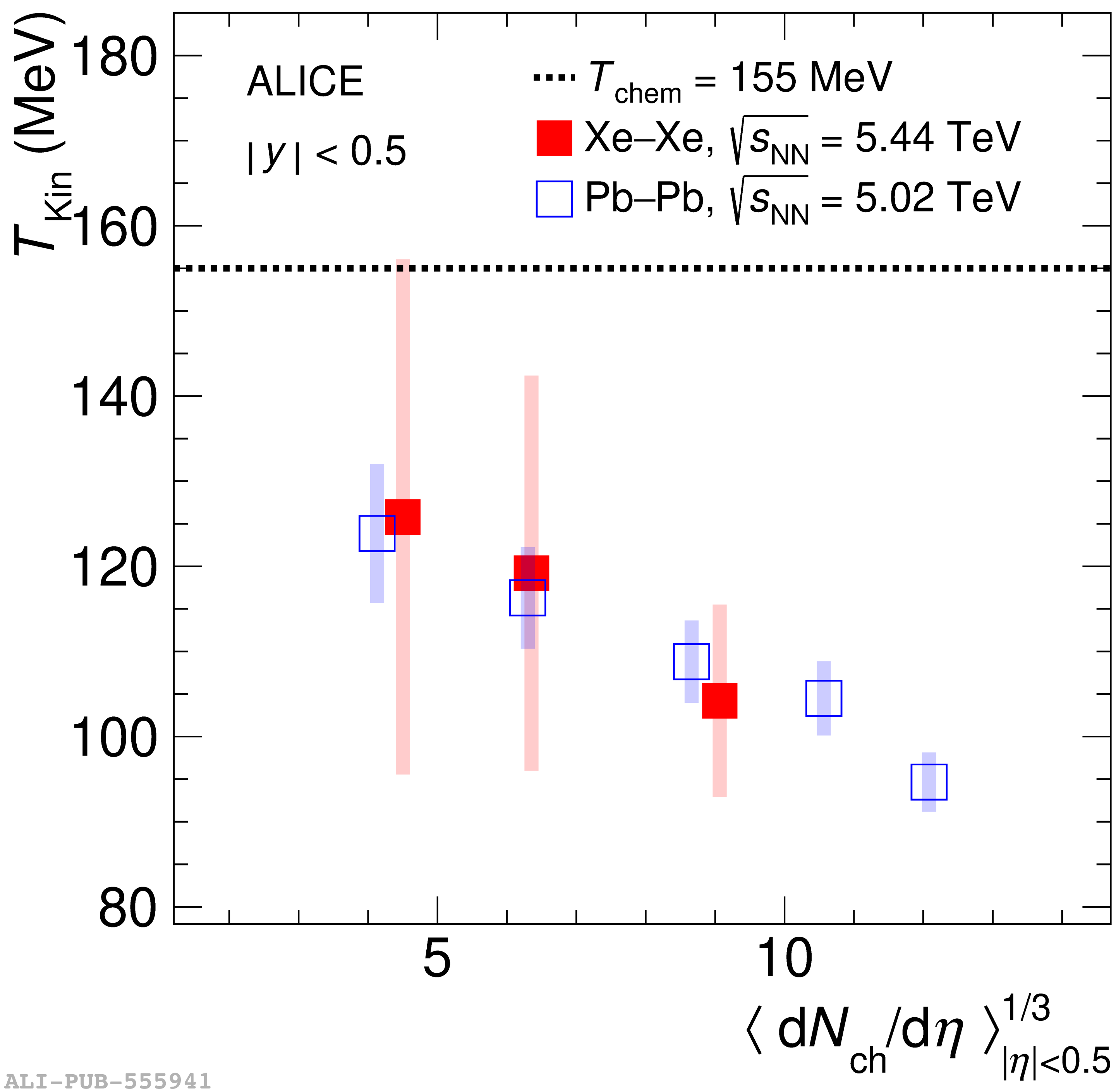
- **Lower bound on the hadronic phase lifetime**
  - r_{kin}: Particle ratio at kinetic freeze-out (Pb-Pb)
  - r_{chem}: Particle ratio at chemical freeze-out (pp)
  - τ_{res}: lifetime of resonance
  - **Assumptions:**
    Simultaneous freeze-out of all particles
    Negligible regeneration
- **Low mass** resonances
  → **Shorter lifetime** of lower bound **hadronic phase**

  → More **regeneration?**

Kinetic freeze-out temperature

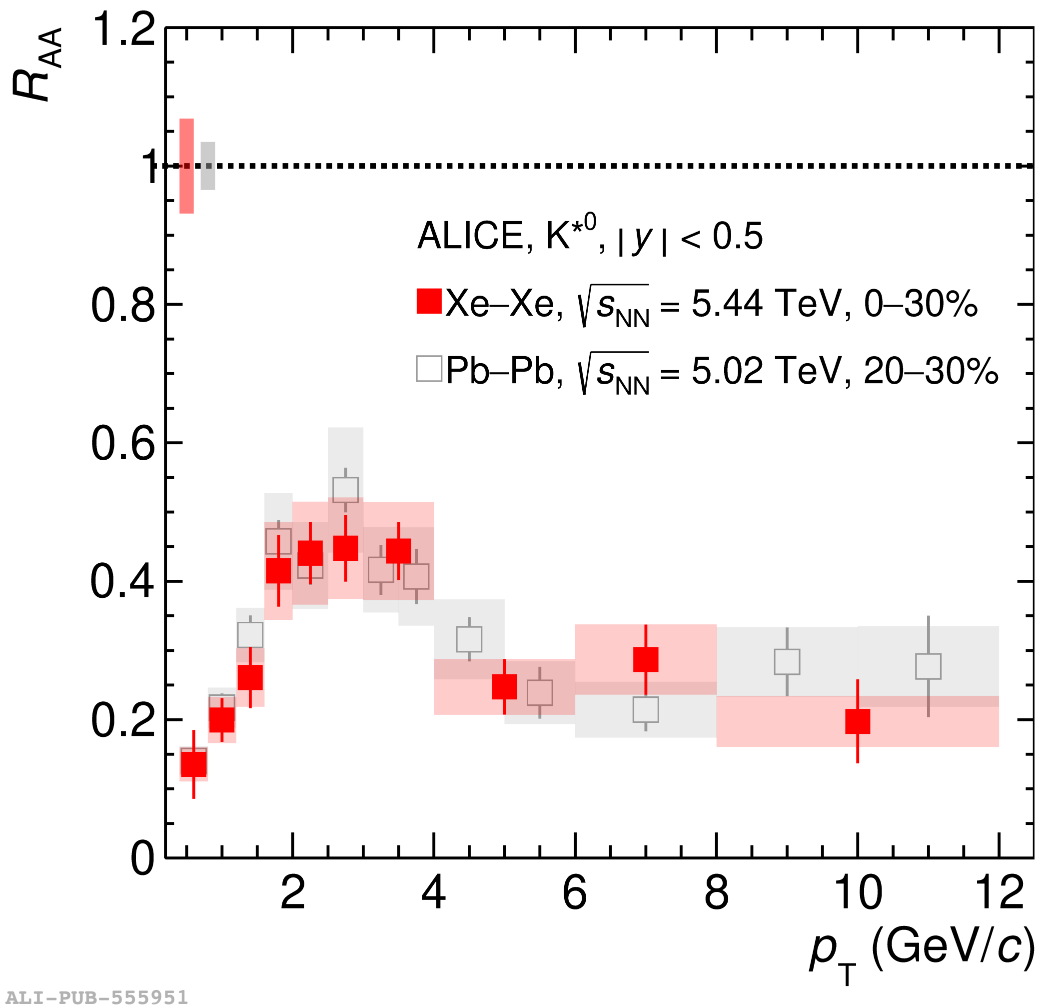
arXiv:2308.16115



- **The kinetic freeze-out temperature** estimated using the fit of HRG-PCE model to the measured yields of hadrons (π, K, p, ϕ, K*)
  - **Fit parameters:**
  - Baryon chemical potential: 0
  - chemical freeze-out temperature: 155 MeV
  - kinetic freeze-out temperature
  - freeze-out volume
- **Freeze-out temperature:** **Increase** systematically while moving from central to peripheral centrality
  - **Presence of the hadronic phase with a finite lifetime** regardless of the colliding particle.

Recent publication

Nuclear modification factor: R_{AA}



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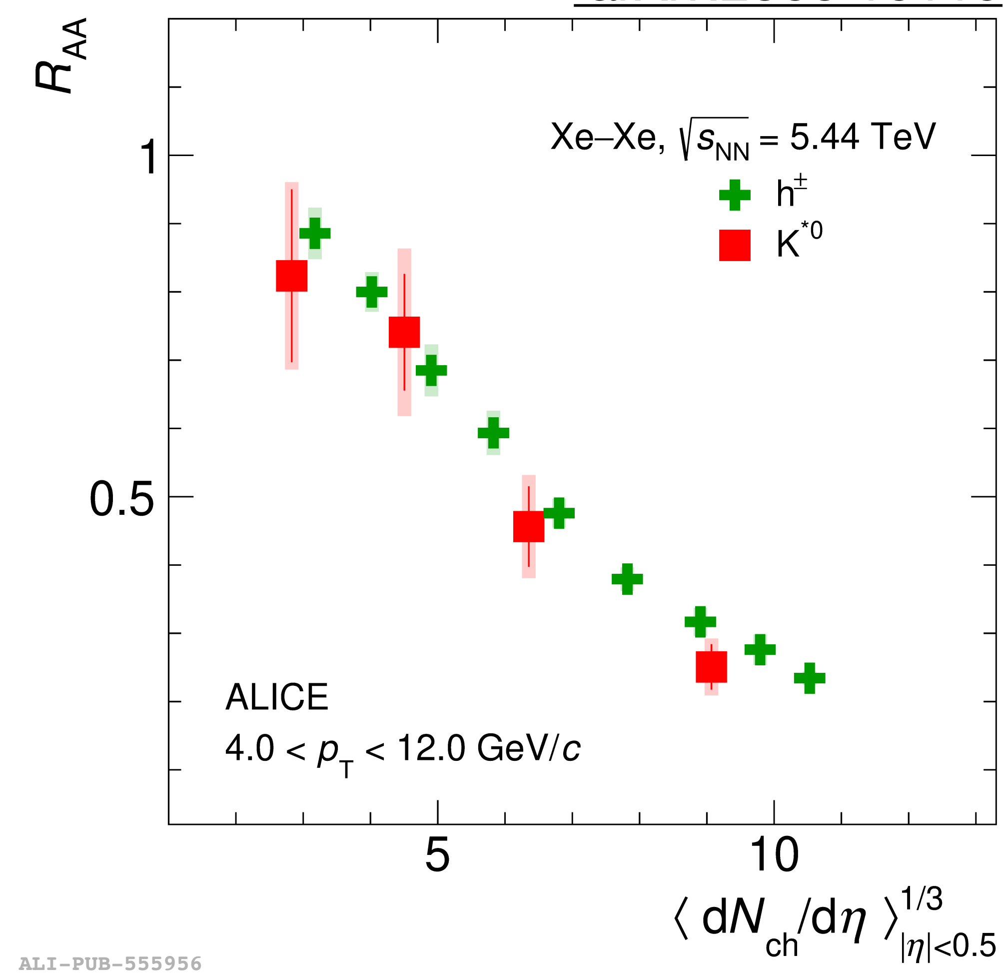
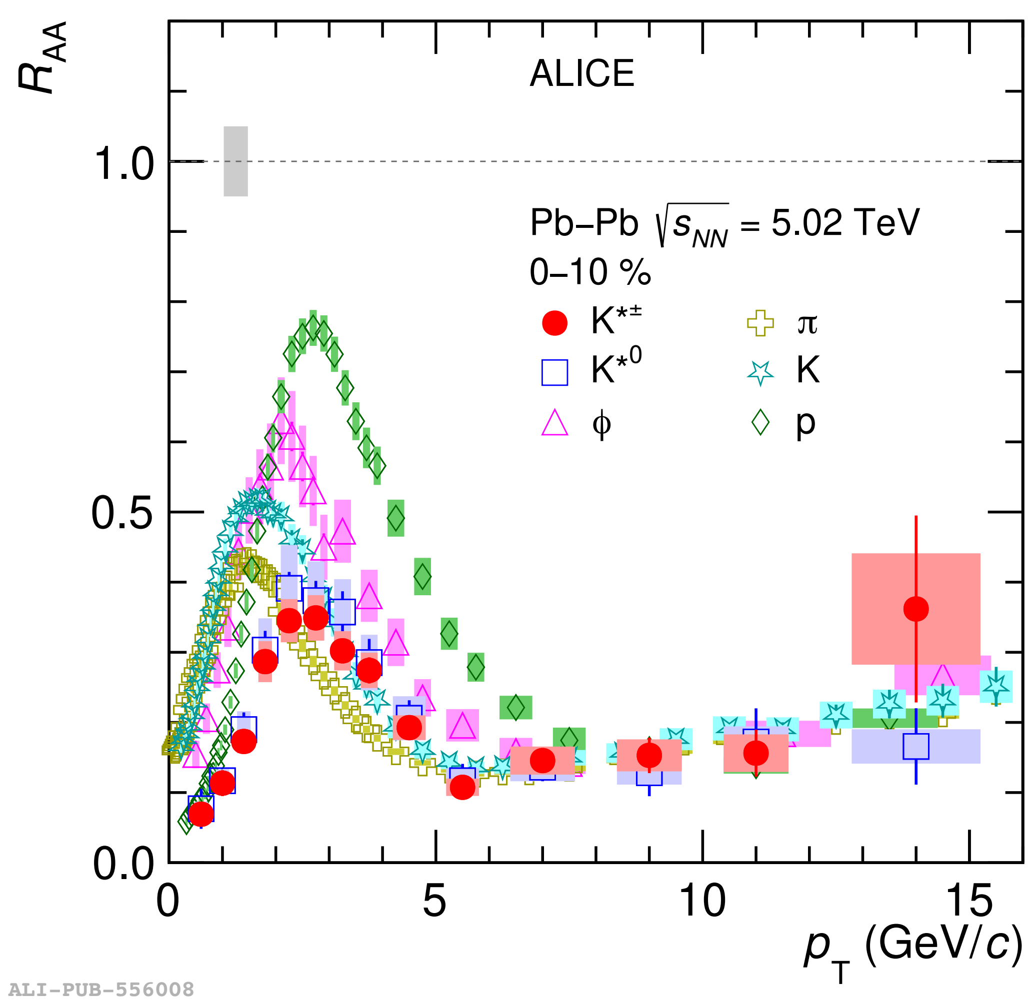


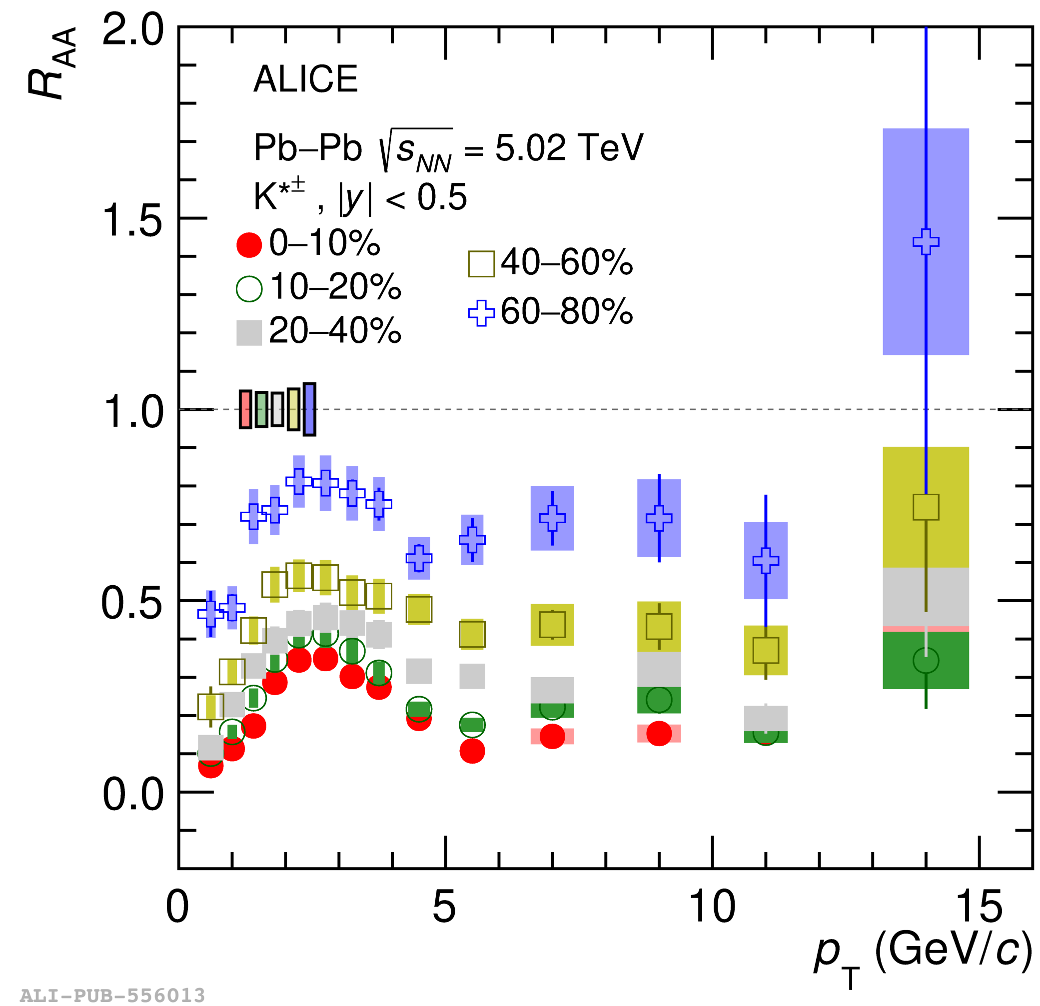
- ***R_{AA}***: Comparison of the yields with the corrected number of collisions between pp and AA collisions.
  - **Left:** R_{AA} is less than 1 in high p_T for both systems.
    → It shows Hydro-like expansion (low p_T) and Partonic energy loss (high p_T)
  - **Right:** Centrality-dependent p_T-integrated R_{AA} shows same trend with **charged hadrons(h±)**
    → No strong effect from jet-quenching to LF particle species composition for the leading particles

Recent publication

Nuclear modification factor: R_{AA}

arXiv:2308.16119



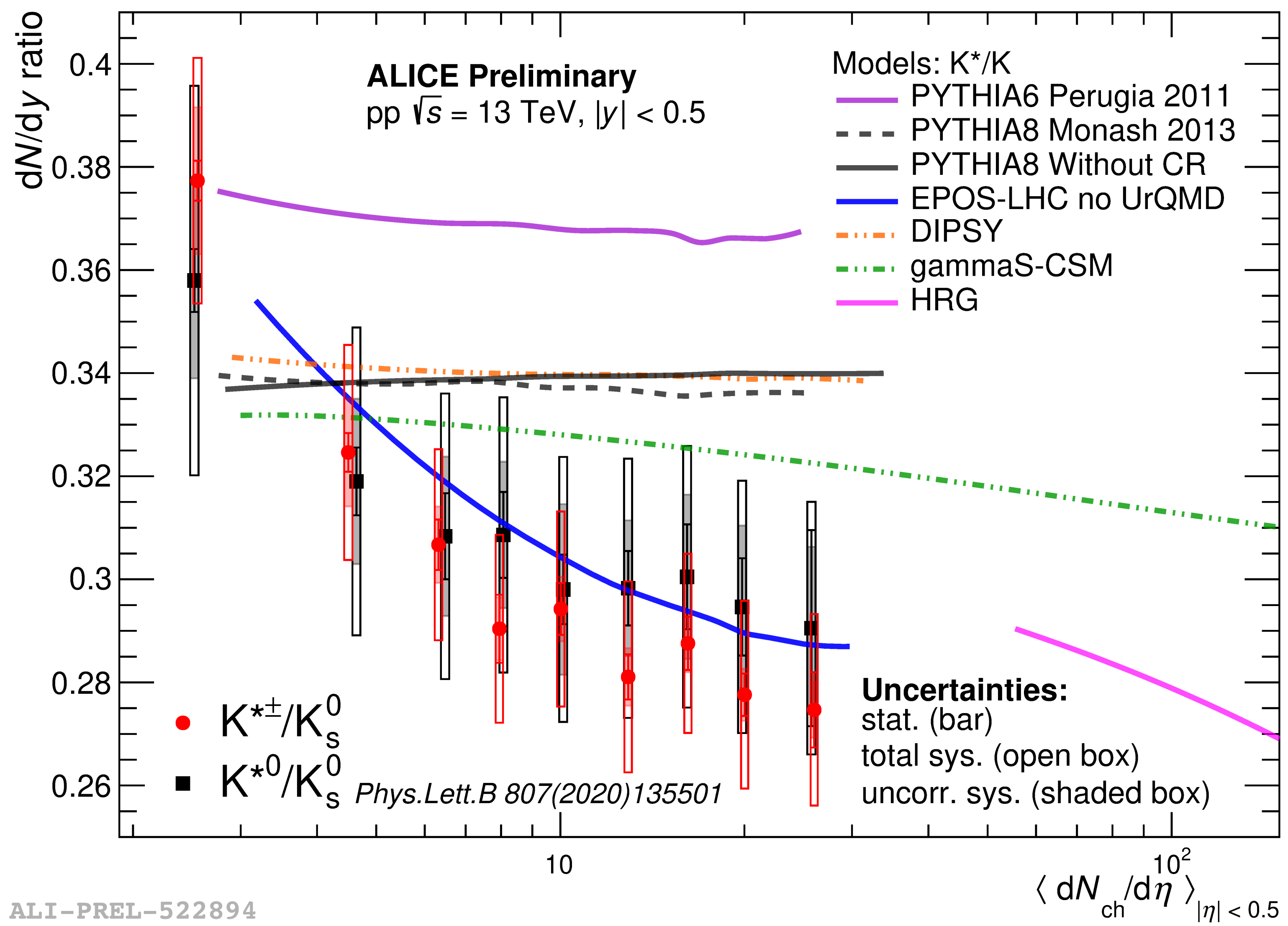


- ***R***

- **R_{AA}**: Comparison of the yields with the corrected number of collisions between pp and AA collisions.
  - **Left:** Species dependent R_{AA} (mass range: 0.139 to 1.020 GeV/c^2)
    → K^{*0}/K , $K^{*\pm}$/K show the smallest values due to the rescattering effect.
  - **Right:** Evolution of R_{AA} with centrality
    → Larger suppression in larger system.

Hadronic interactions in small system

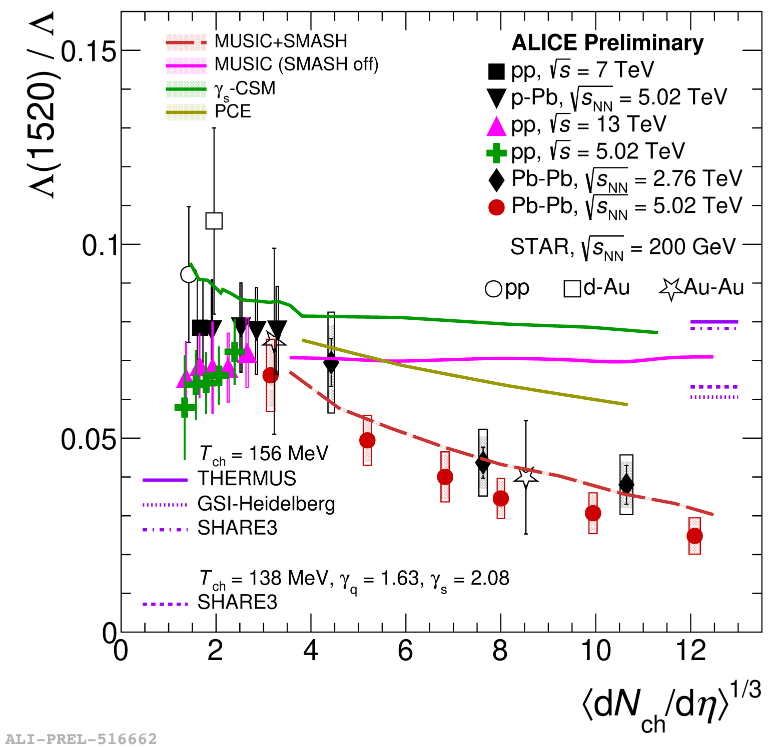
Paper under preparation!



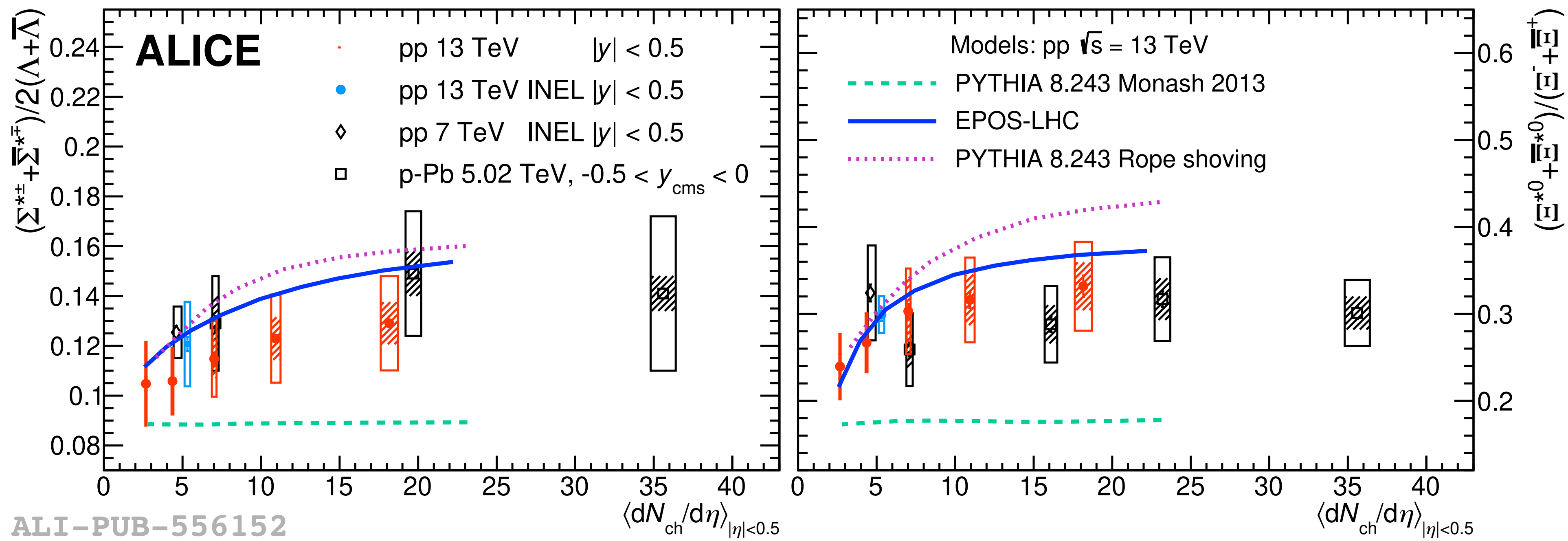
- Can we find the **rescattering/regeneration** effects even in **small systems**?
  - K*/K shows a **smooth decreasing trend** even at pp collisions

Recent publication

Hadronic interactions in small system

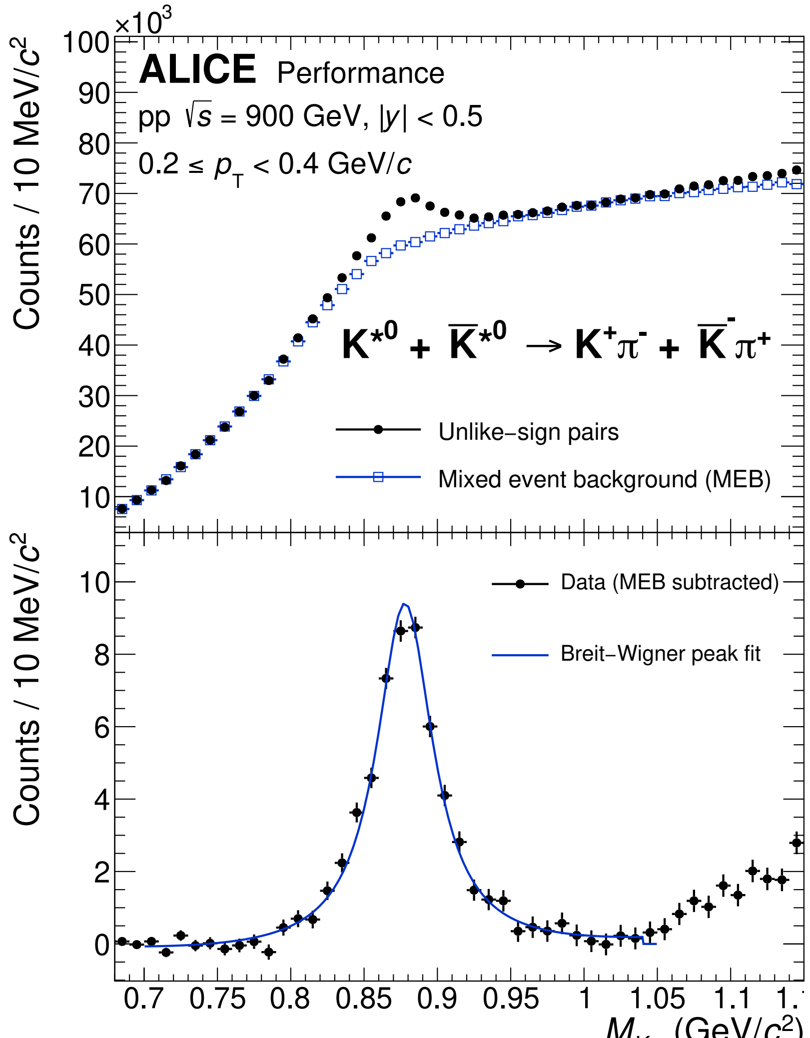


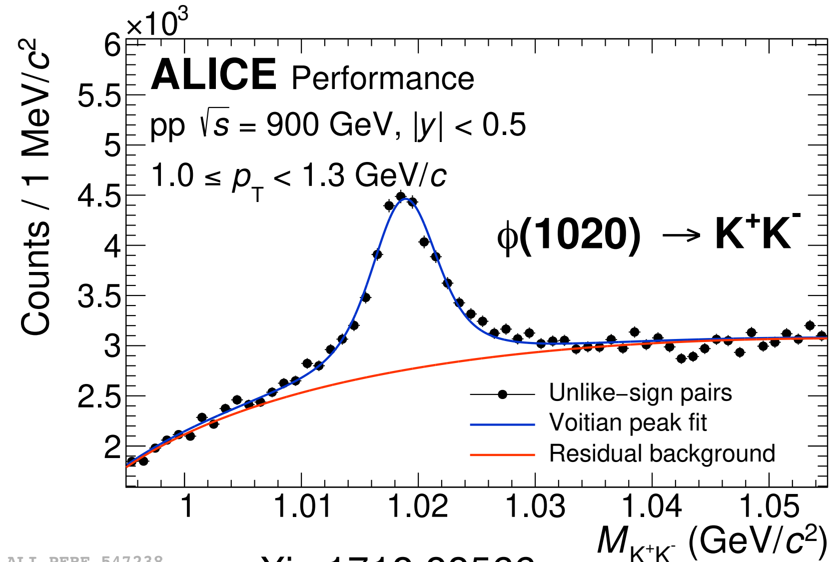
arXiv:2308.16116



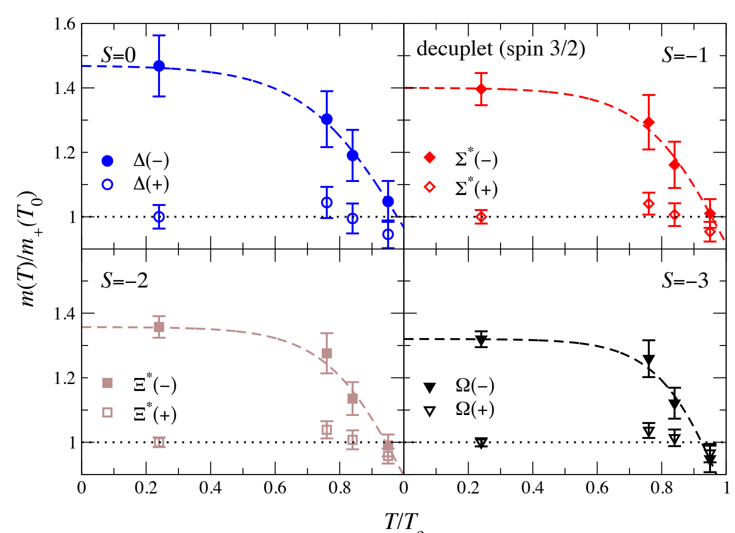
- Can we find the **rescattering/regeneration** effects even in **small systems**?
  - K*/K shows a **smooth decreasing trend** even at pp collisions
  - Λ(1520)/Λ, Σ*±/Λ, Ξ*0/Ξ show increasing(?) trends in small systems
- **No decreasing trend found from baryon resonance so far,**
  Σ*± has short life time, but it is not affected. might be due to the regeneration?

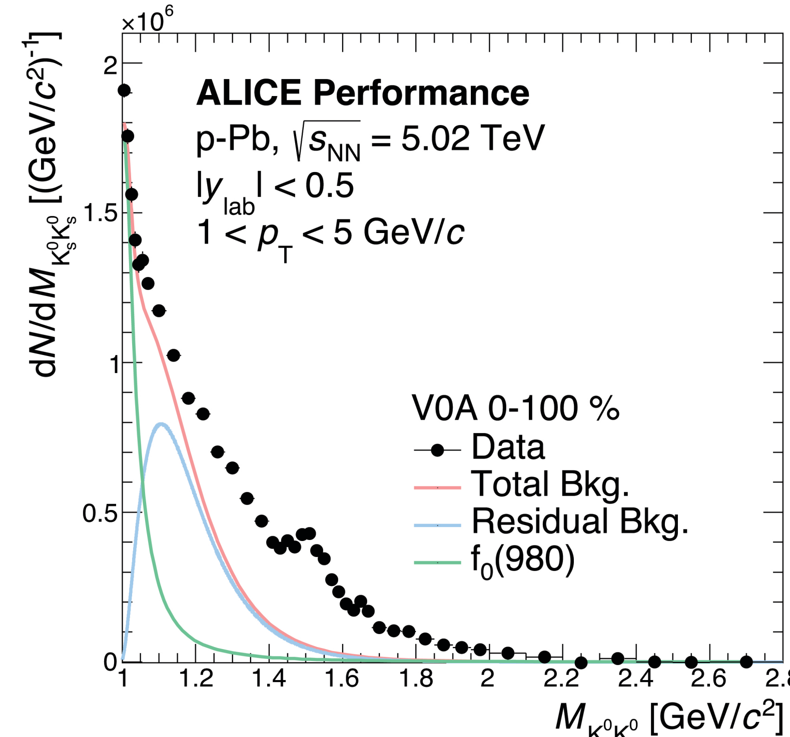
LHC-Run3: Resonance in flow and jets

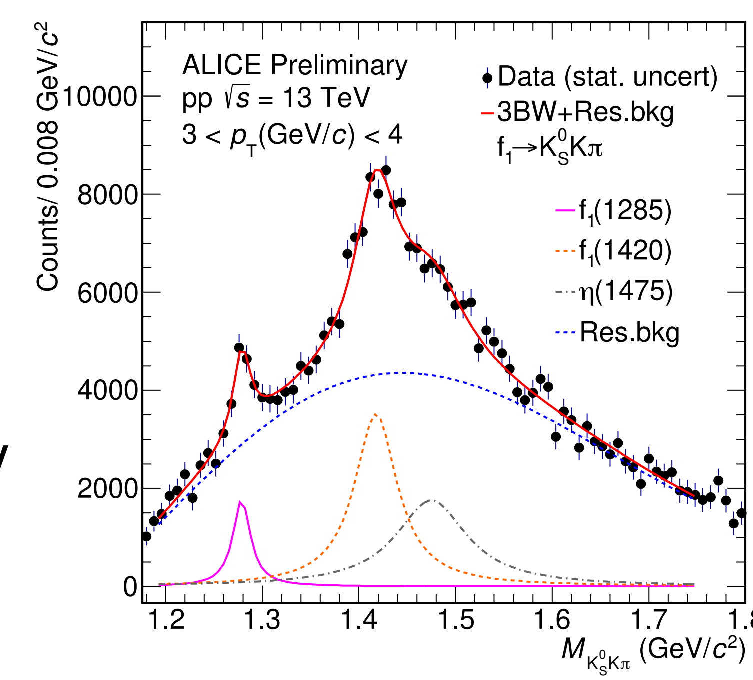




arXiv:1710.00566







- **ALICE Run3** data analyses are under preparation!
  - Performance plots of K^{*0}, ϕ, Λ(1520) from pp 900 GeV and 13.6 TeV
- **More statistics → More possibilities!**
  - **Chiral symmetry restoration** using resonances (f_1, K_1(1720), Ξ(1820))
  - Search for the **glueball candidate** F. Bellini Wed. afternoon
  - Resonance **flow** and **Jets** to constrain the hadronic phase effect

Conclusion

- **Resonance** is a useful tool for studying **Hadronic Phase**
- **ALICE** has published interesting studies:
  - **Rescattering** effect is **dominant** in large systems
  - **Kinetic freeze-out temperature**
  - **Lifetime** of the **hadronic phase**
    - **Regeneration** has to be considered as well!
    - **Continuous evolution** of the lifetime from small to large system
  - Hint of suppression in **Small System**
    - **No decreasing trend from baryonic resonance** in small system
- **Outlook:** Promising amount of data from **Run3!**

Back up