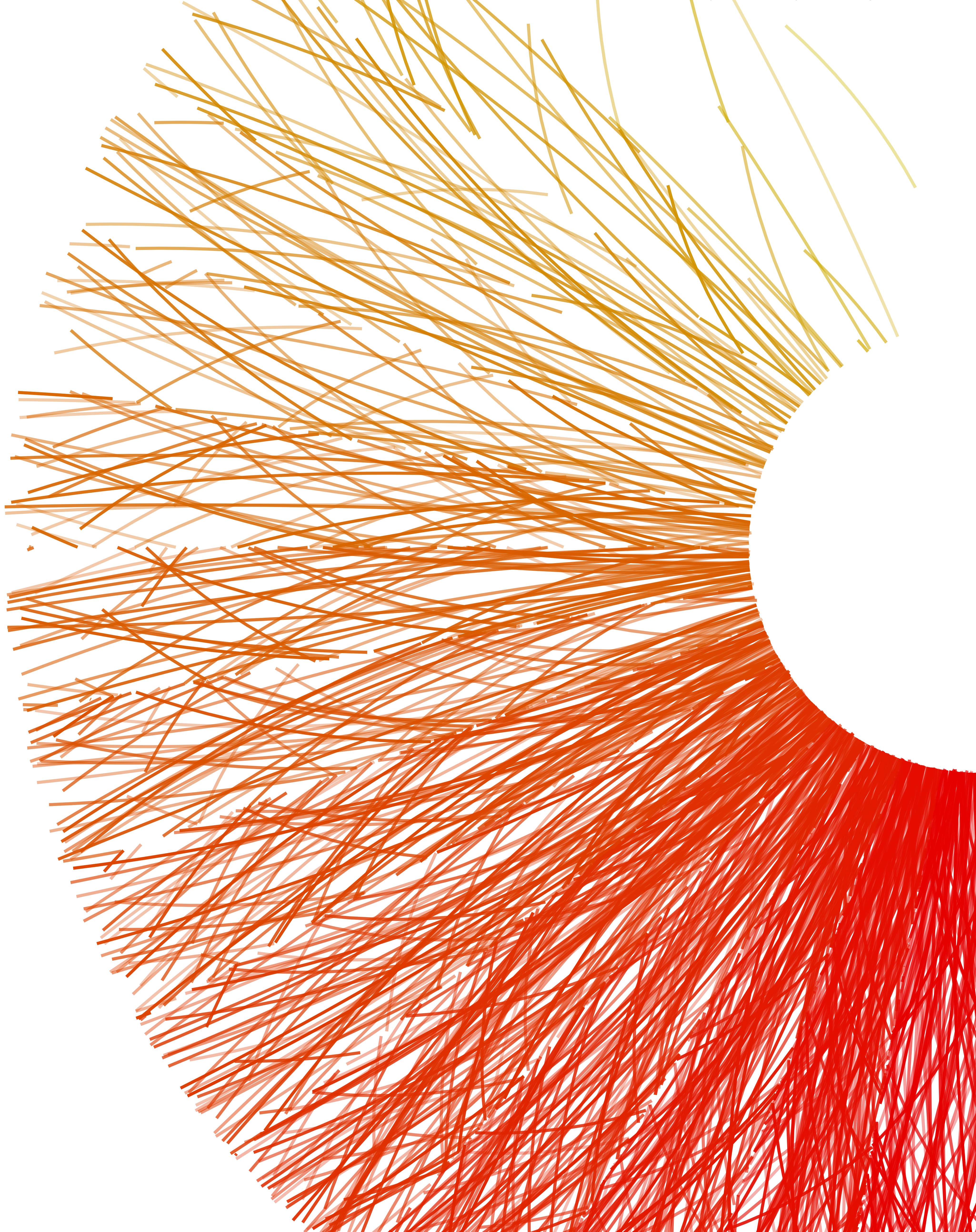
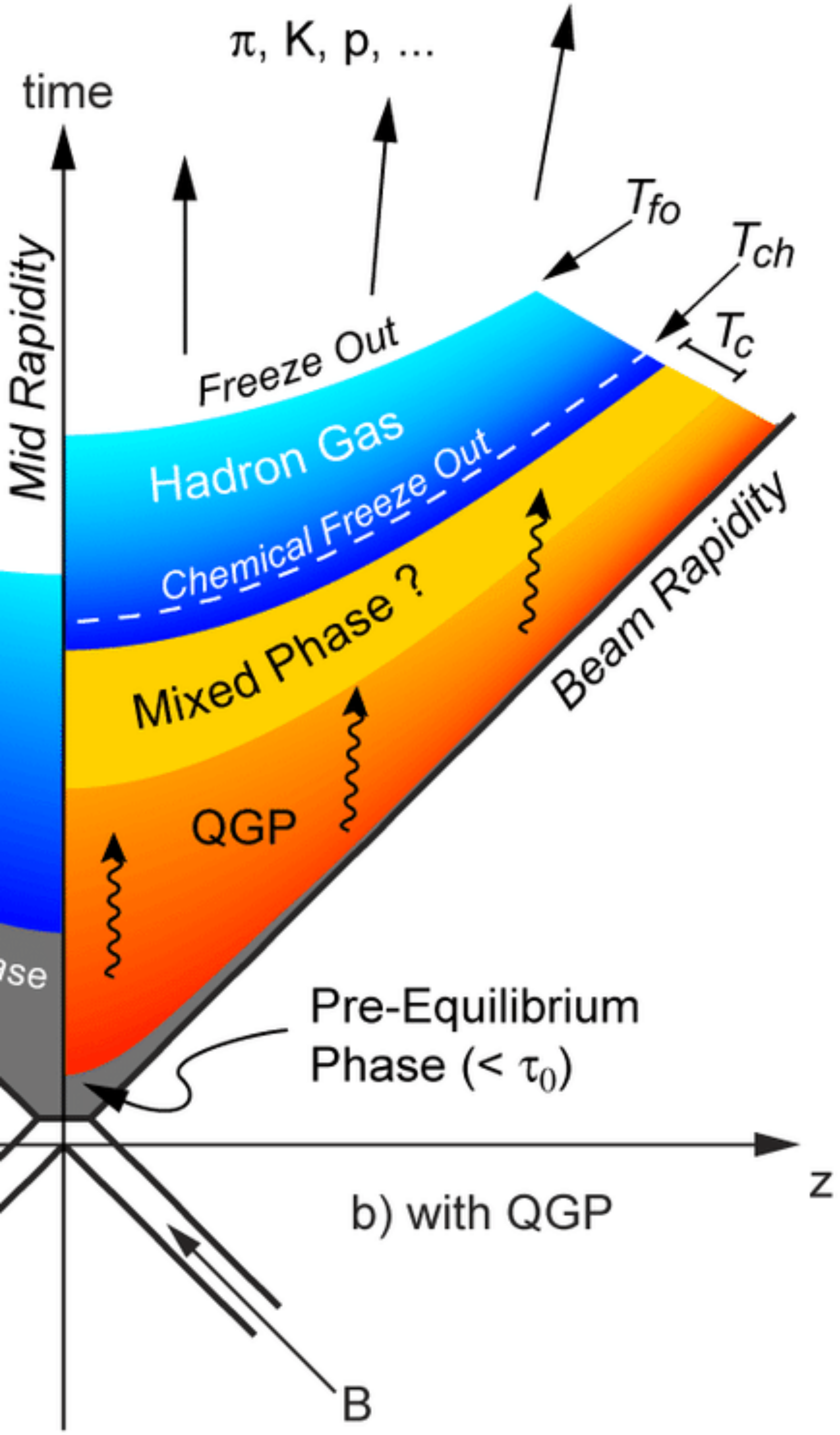
Hadronic Resonance Analysis with ALICE at the LHC

Bong-Hwi Lim (Pusan National University, KR)



Why Resonances?

In Light Flavour(Strangeness)



- **Short lifetimes**
  - Comparable to Hadronic Phase
- **Excited States**
  - Can compare results to other particles with similar quark content

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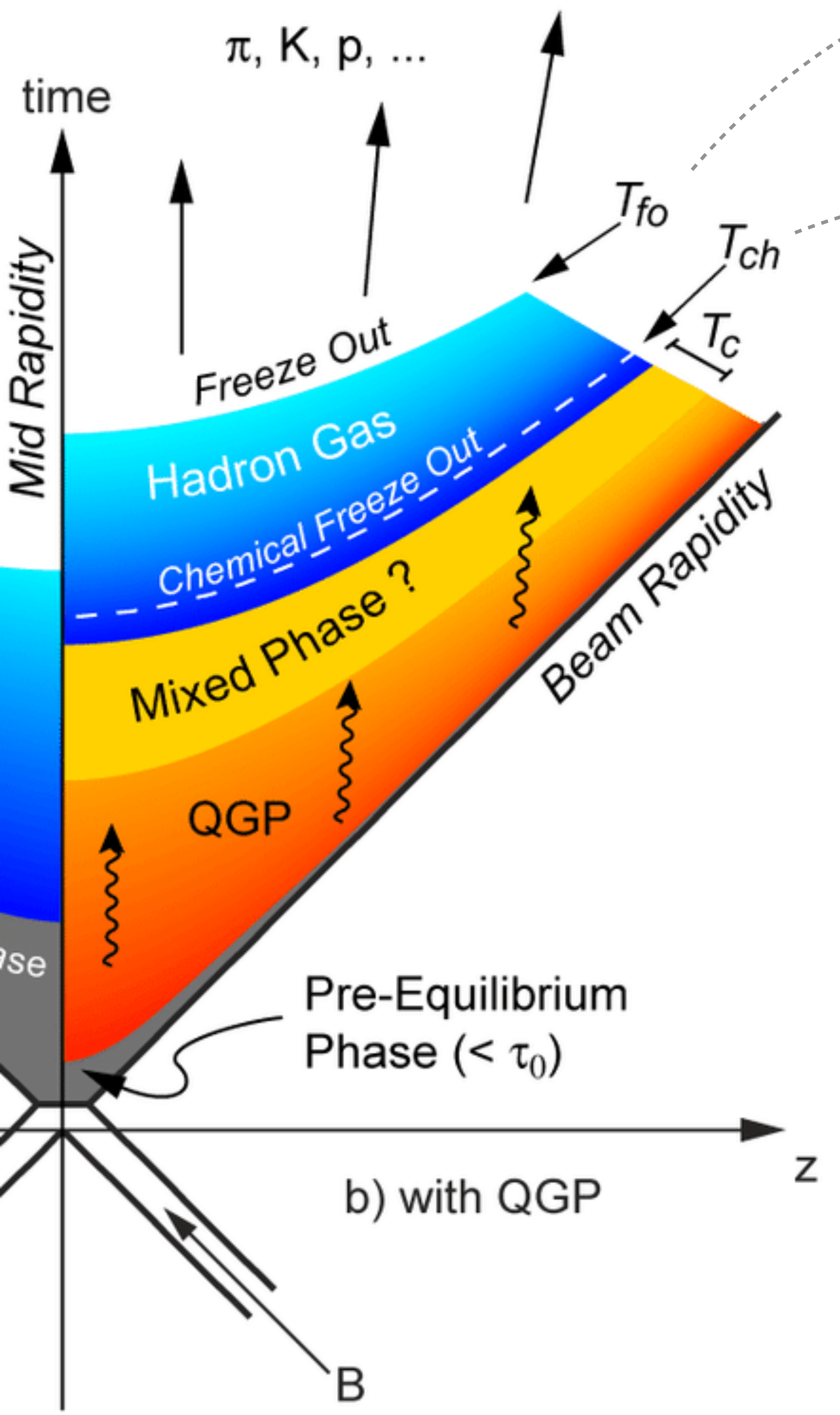

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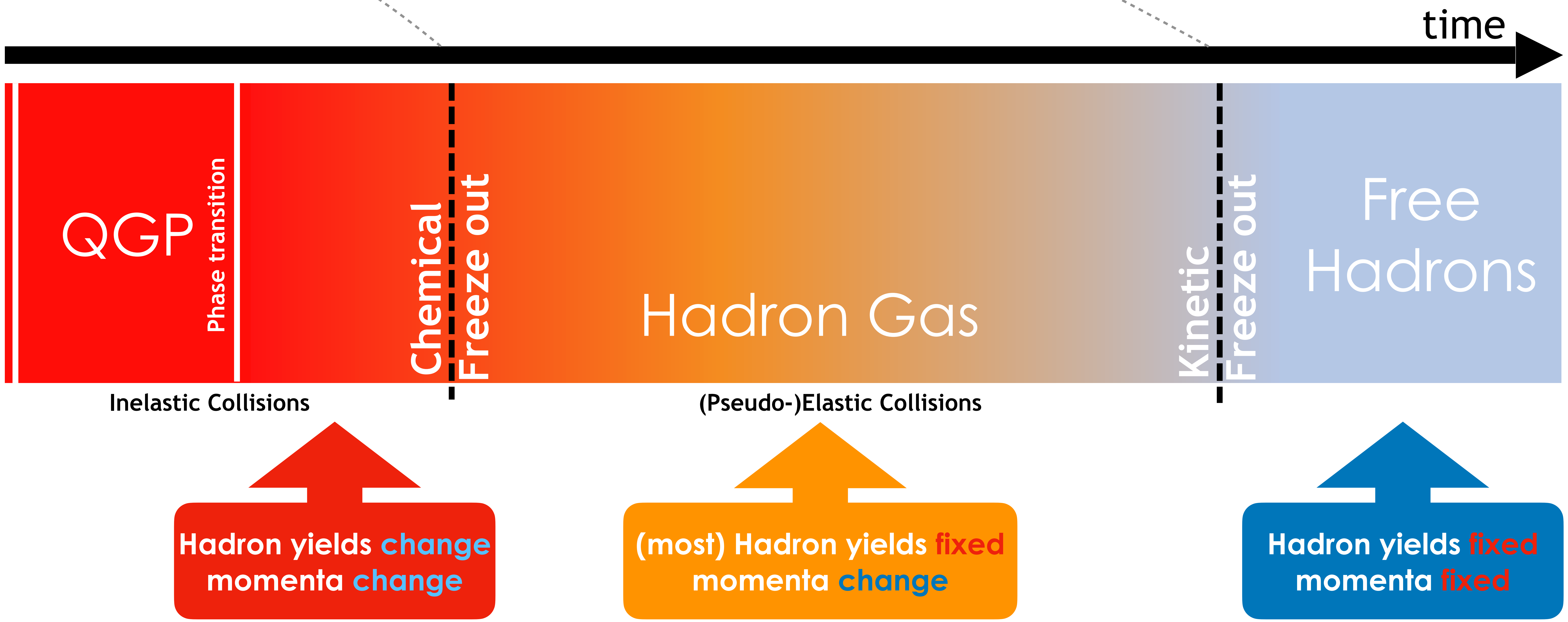

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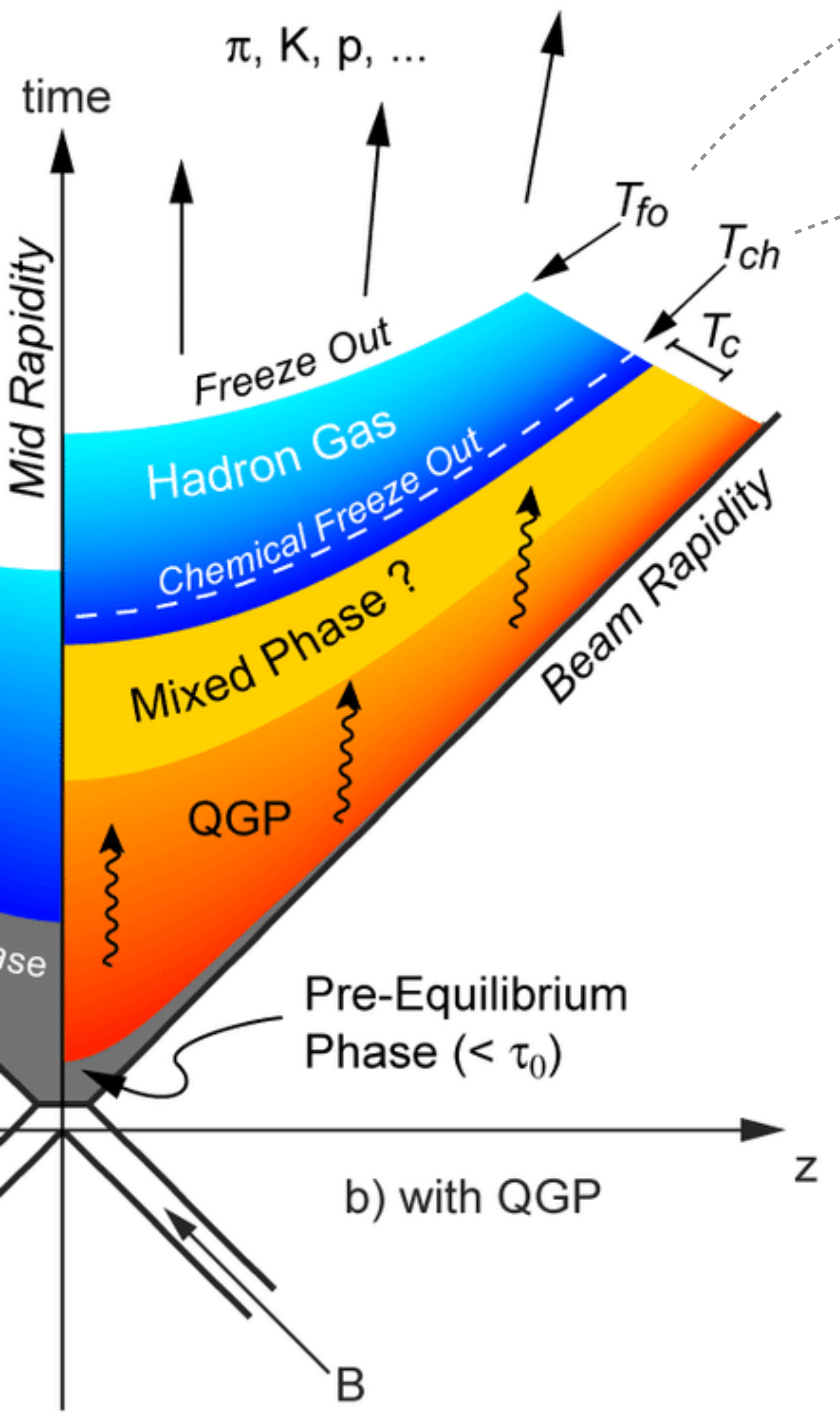

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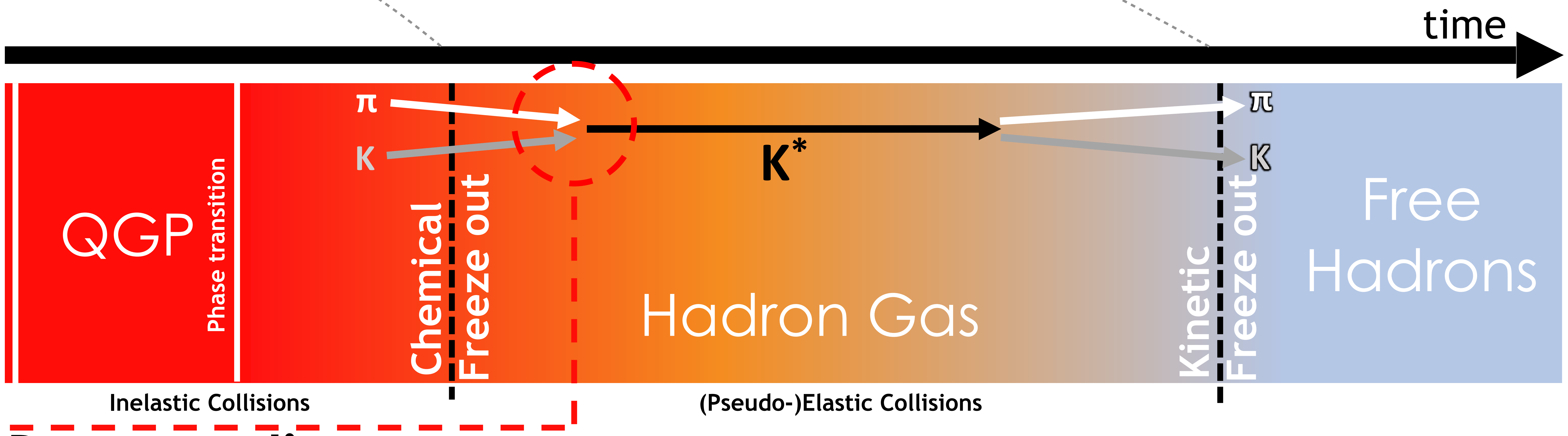

Regeneration

: pseudo-elastic scattering through resonance state

➡ **Enhanced yield**

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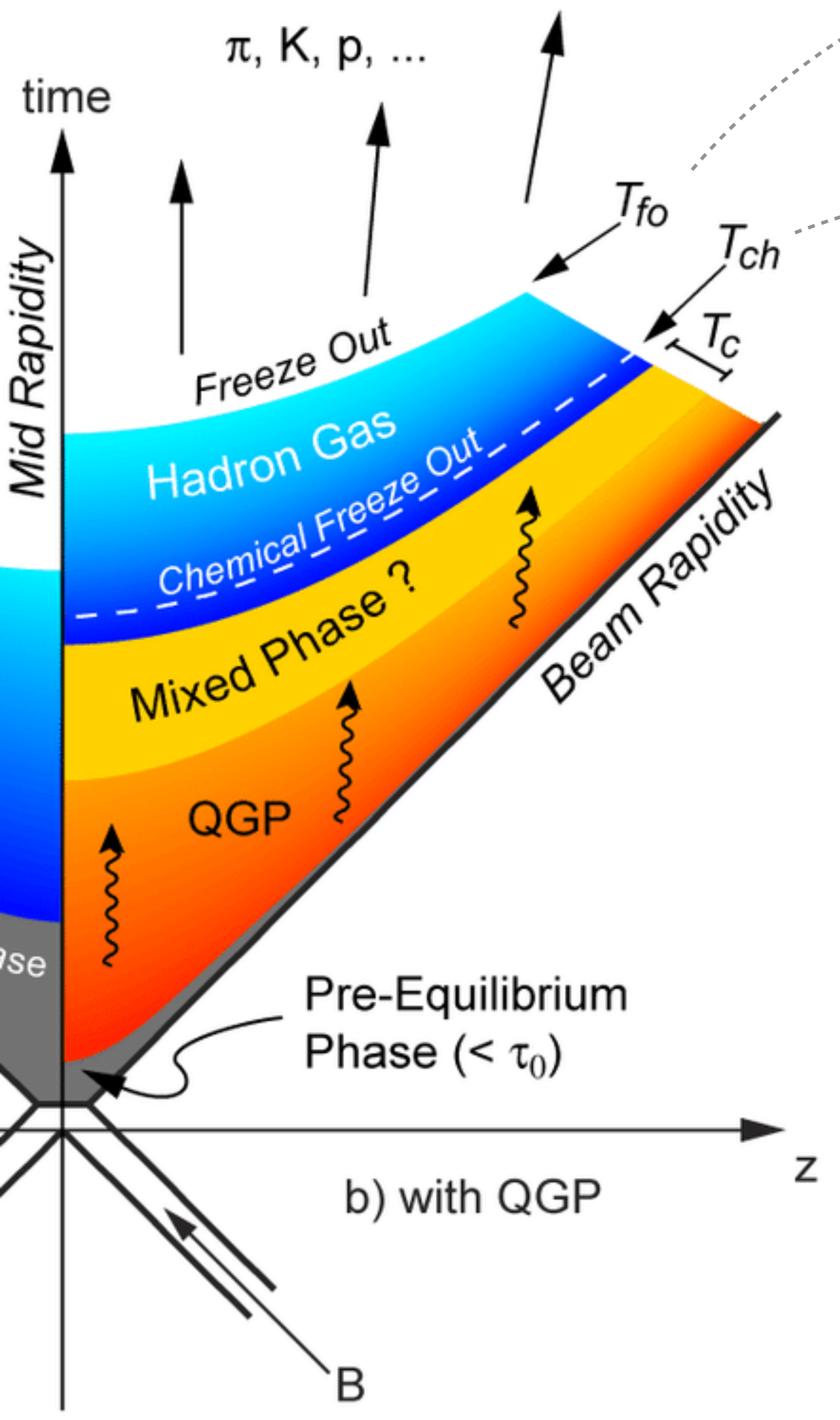

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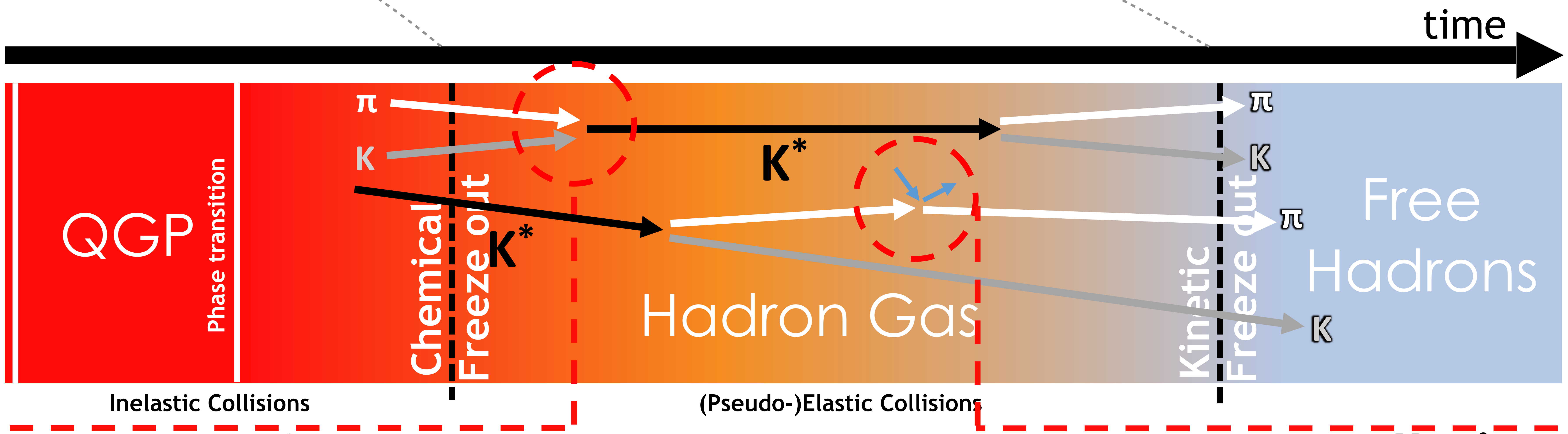

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Enhanced yield

Re-scattering

: elastic scattering smears out mass peak

Reduced yield

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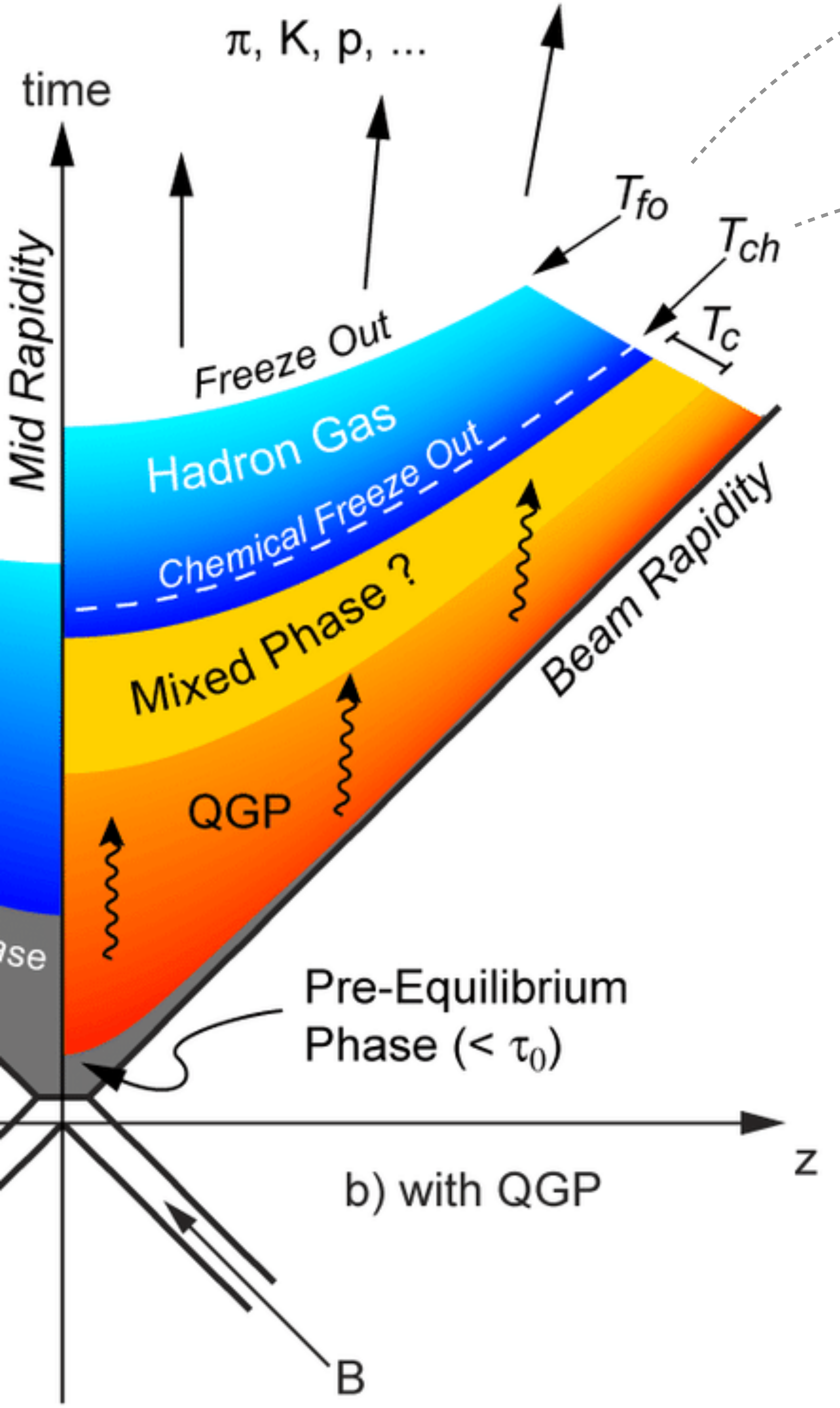

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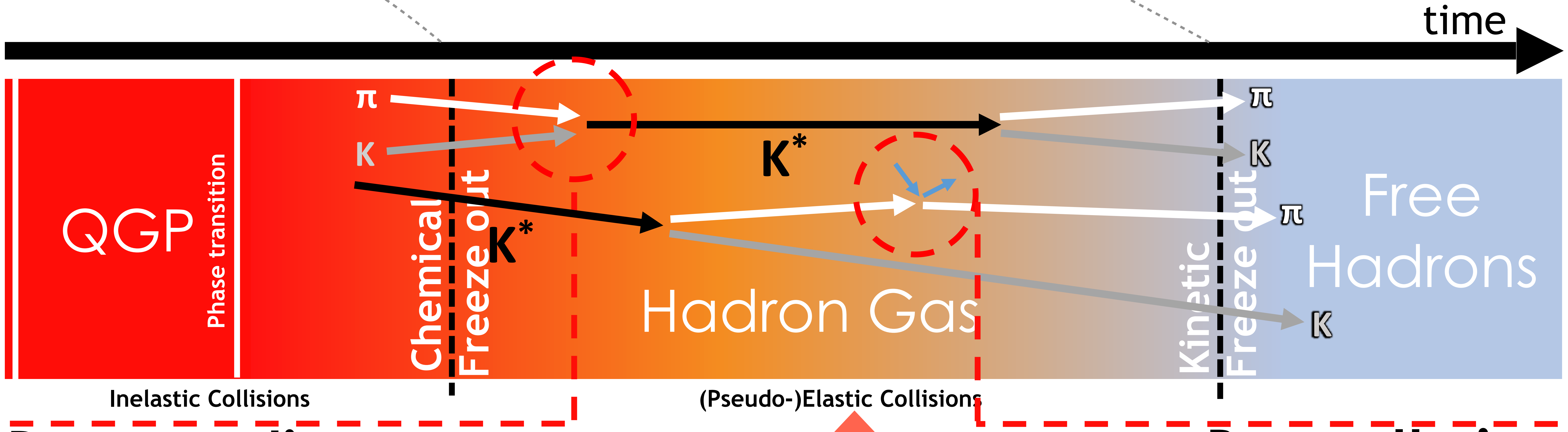

Regeneration

: pseudo-elastic scattering through resonance state

Enhanced yield

Re-scattering

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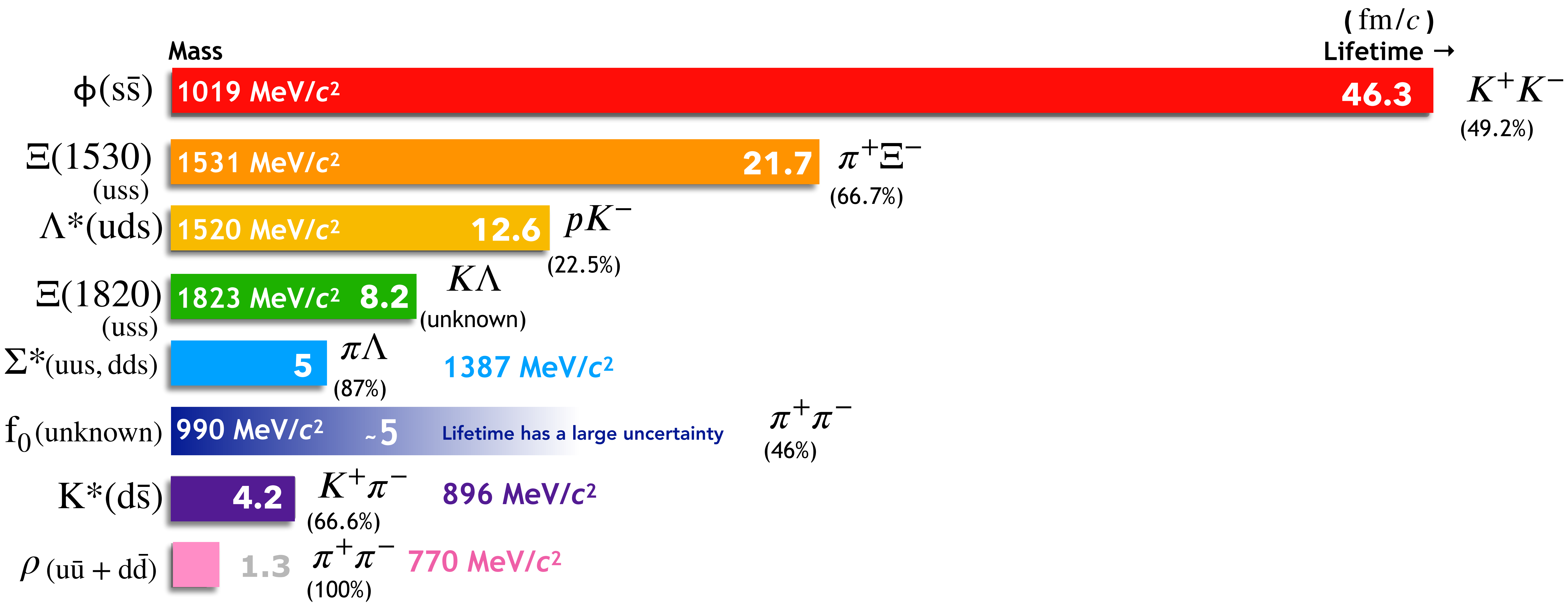
Reduced yield

- **Chemical freeze out temperature(T_{ch})**
- **Lifetime of Hadronic Phase**
- **Lifetime of resonance itself**
- **Scattering cross-sections of decay products**

Overview: Light Flavour Resonances

Characteristics // knobs



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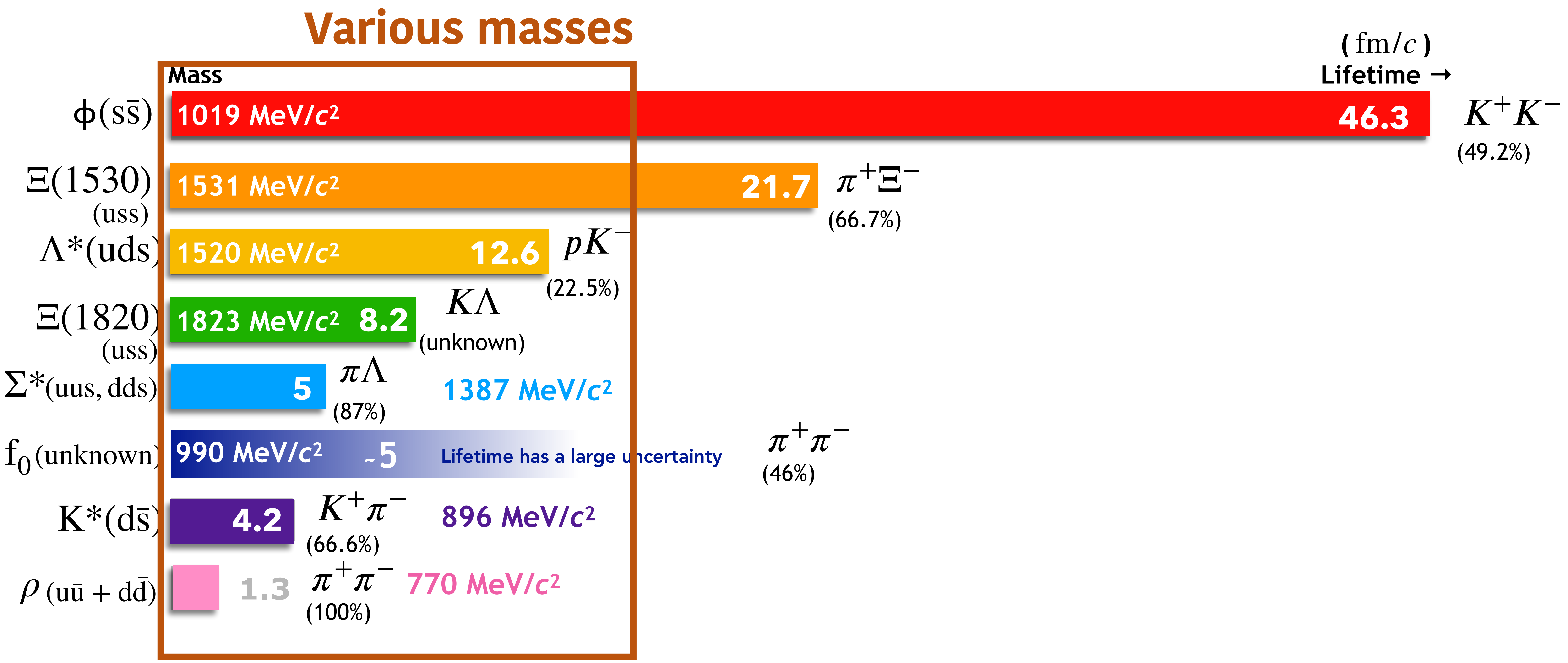

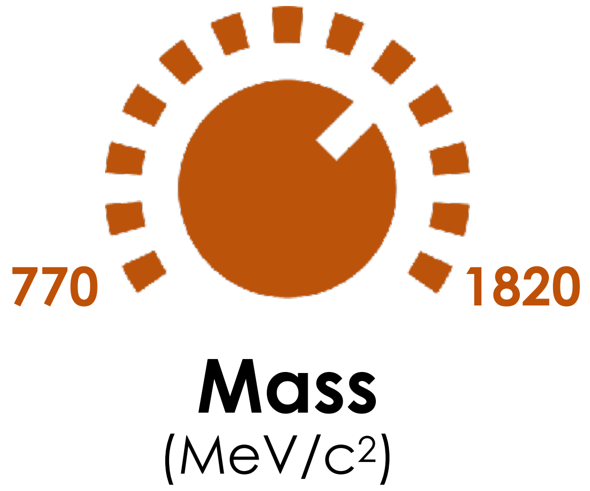

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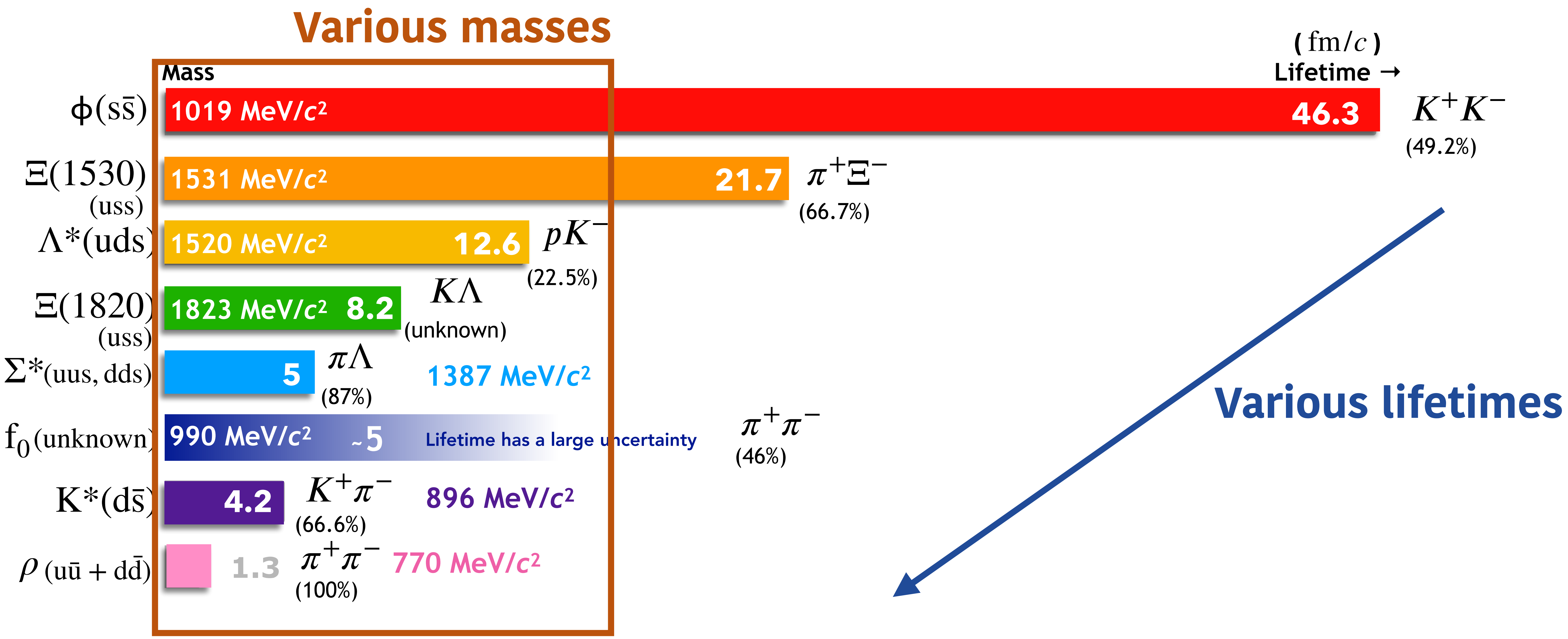

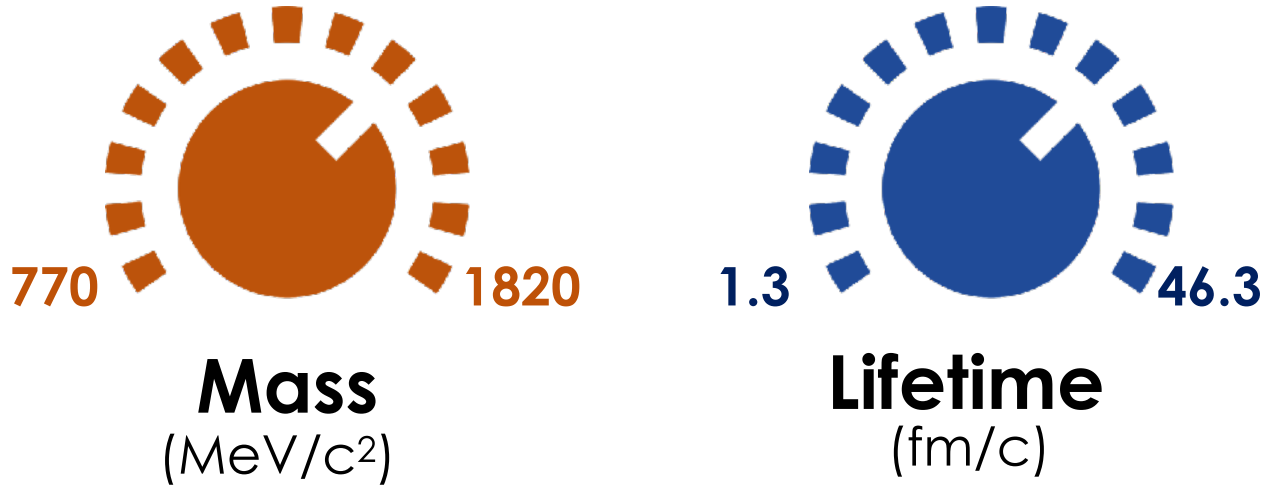

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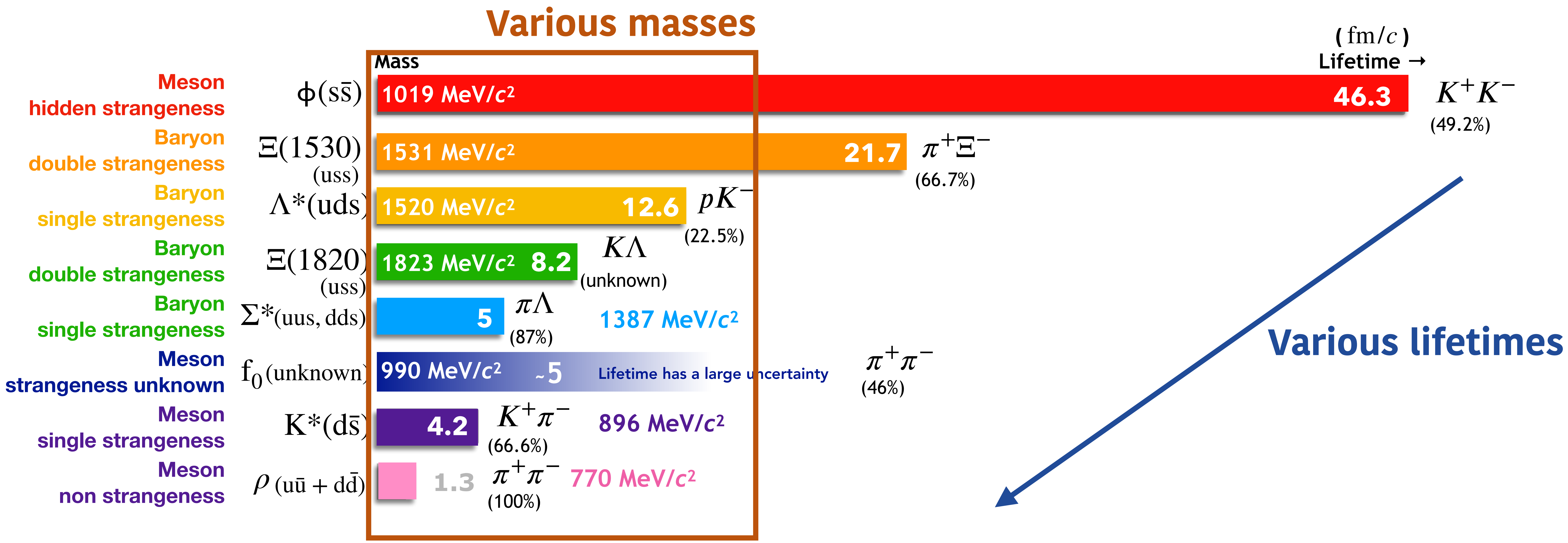
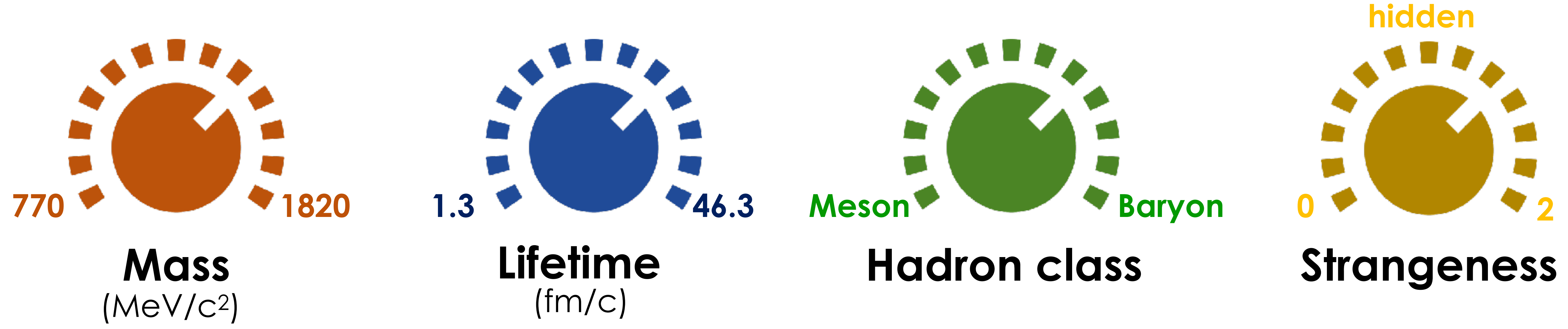


Different hadron class / Strangeness



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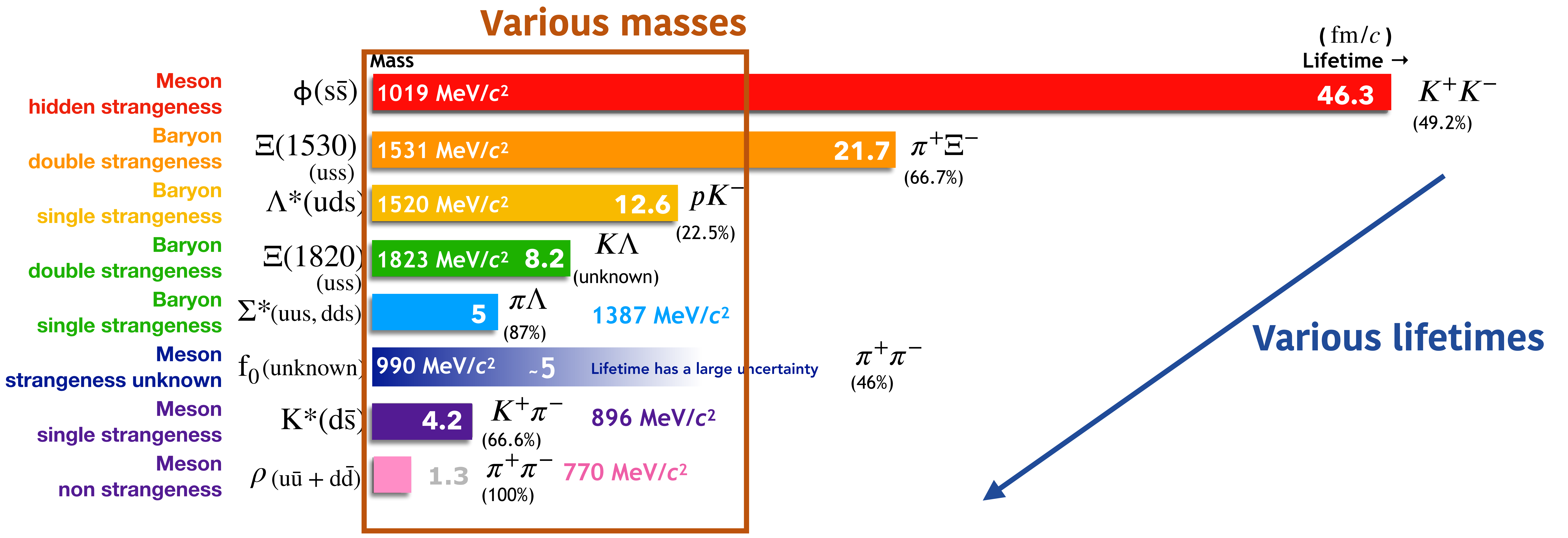

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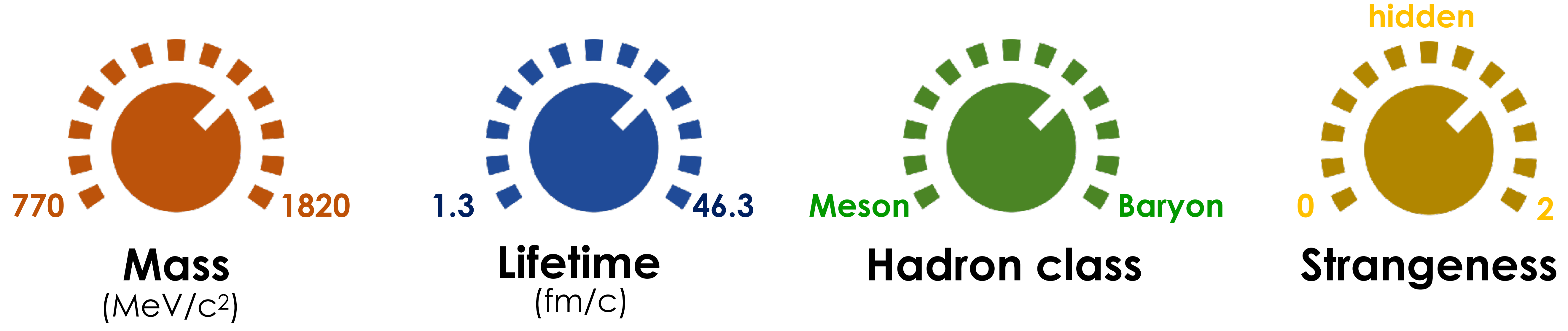
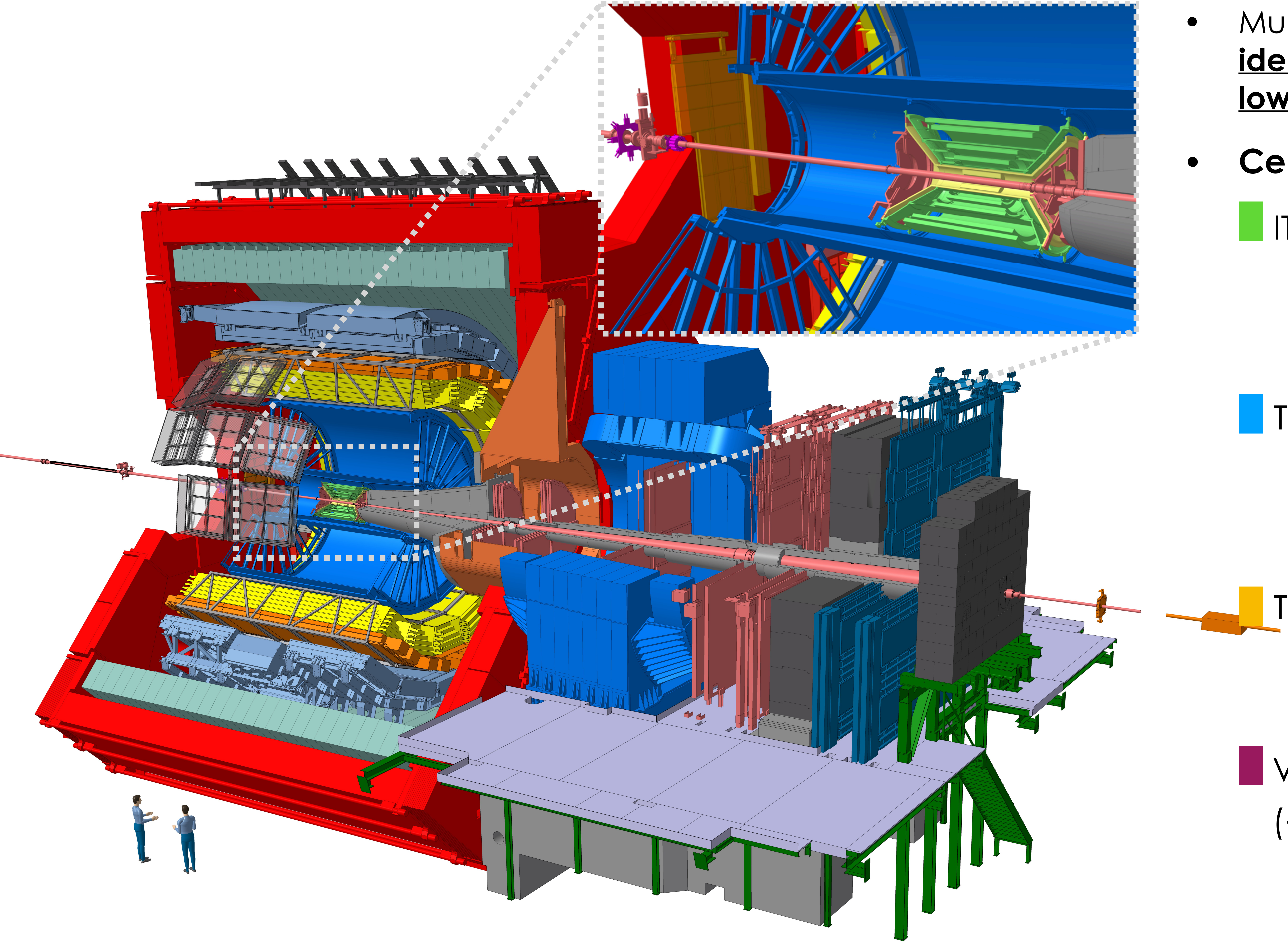


RESONANCES may have control knobs that can be used to study the hadronic phase.

The ALICE detector



- Multi-purpose detector at the LHC with unique **particle identification** capabilities and tracking down to **very low momenta**
- **Central Barrel Detectors ($|\eta| < 1$)**

ITS ($|\eta| < 0.9$)

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

TPC ($|\eta| < 0.9$)

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

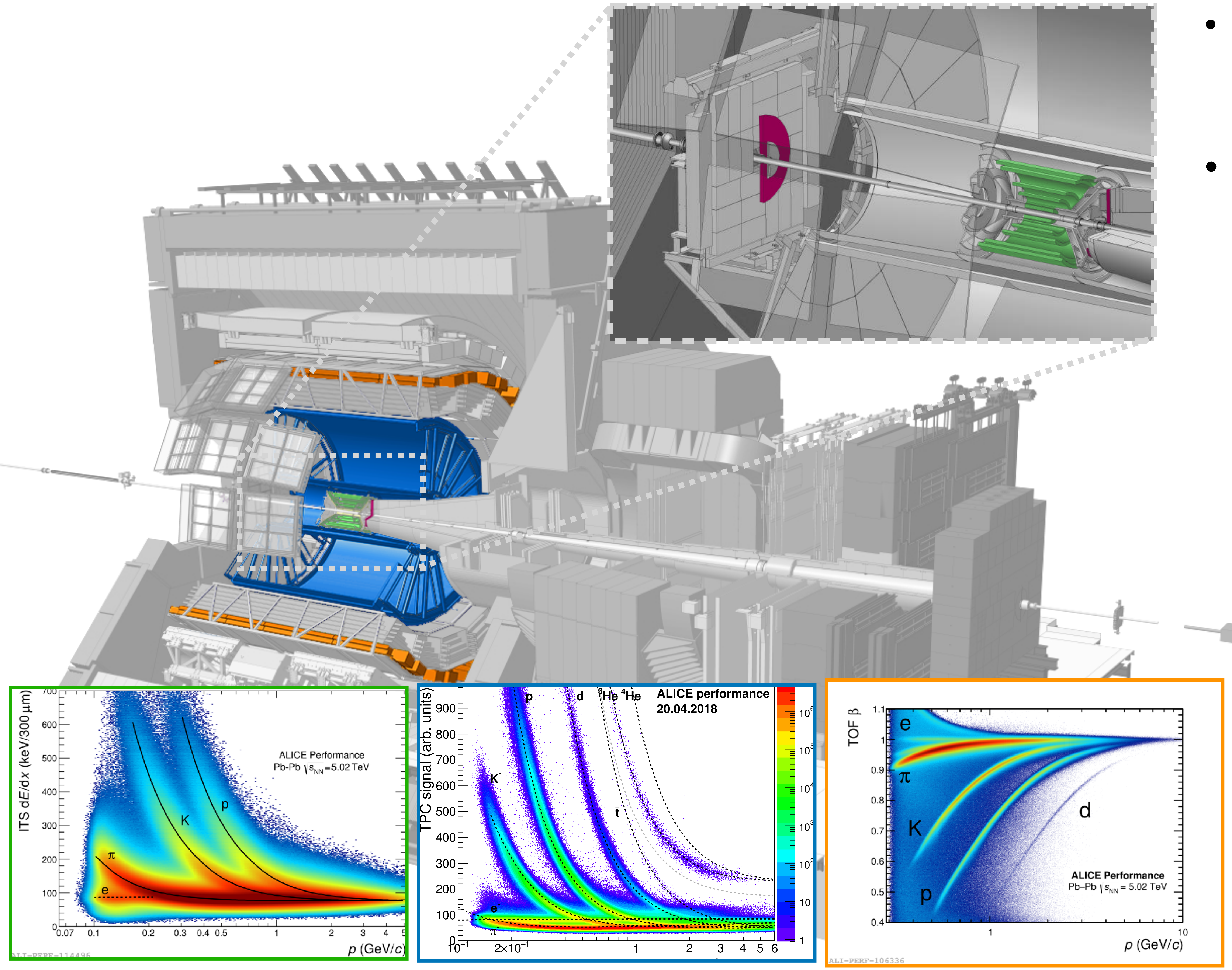
TOF ($|\eta| < 0.9$)

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

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

- Arrays of scintillators
- Trigger, beam gas rejection, **Multiplicity estimator**

The ALICE detector



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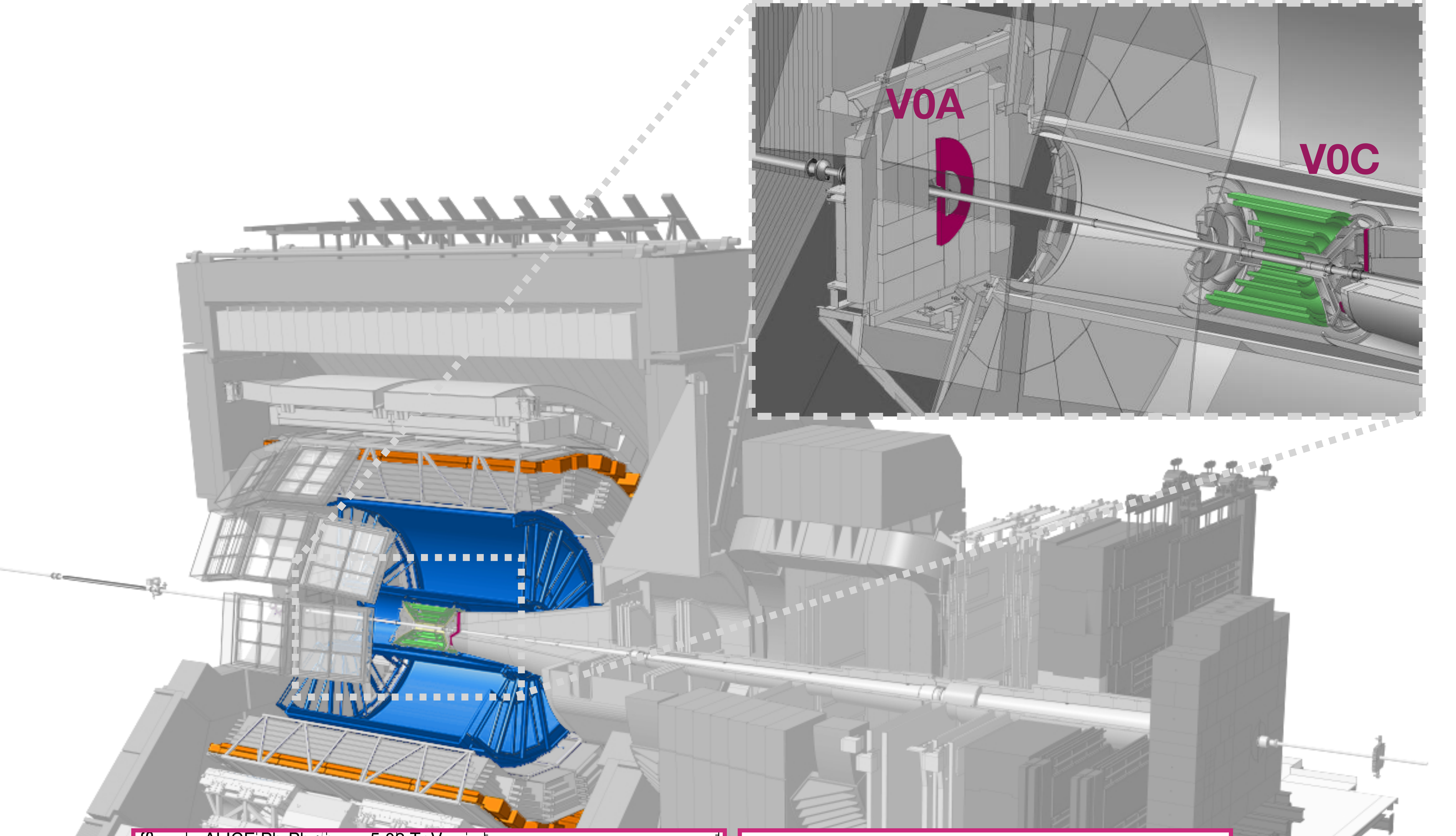

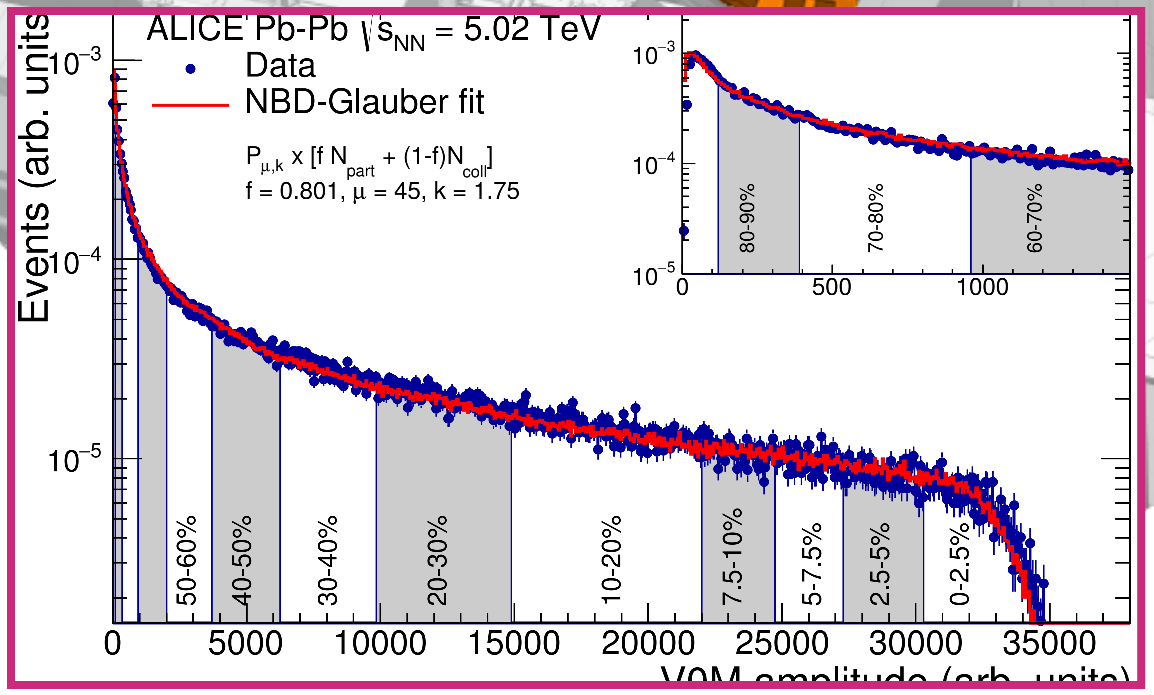

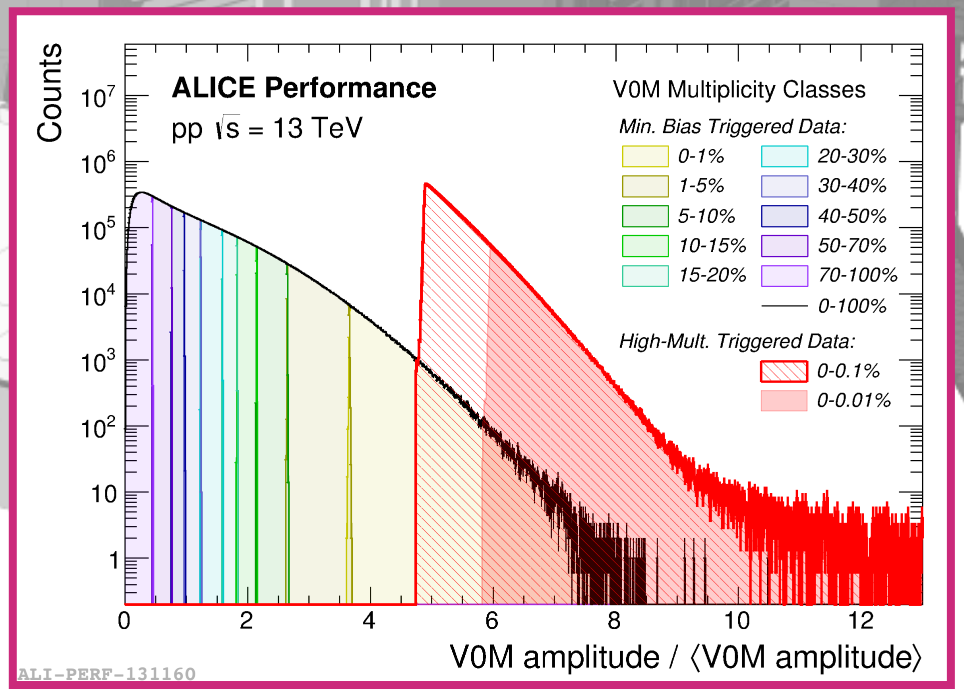

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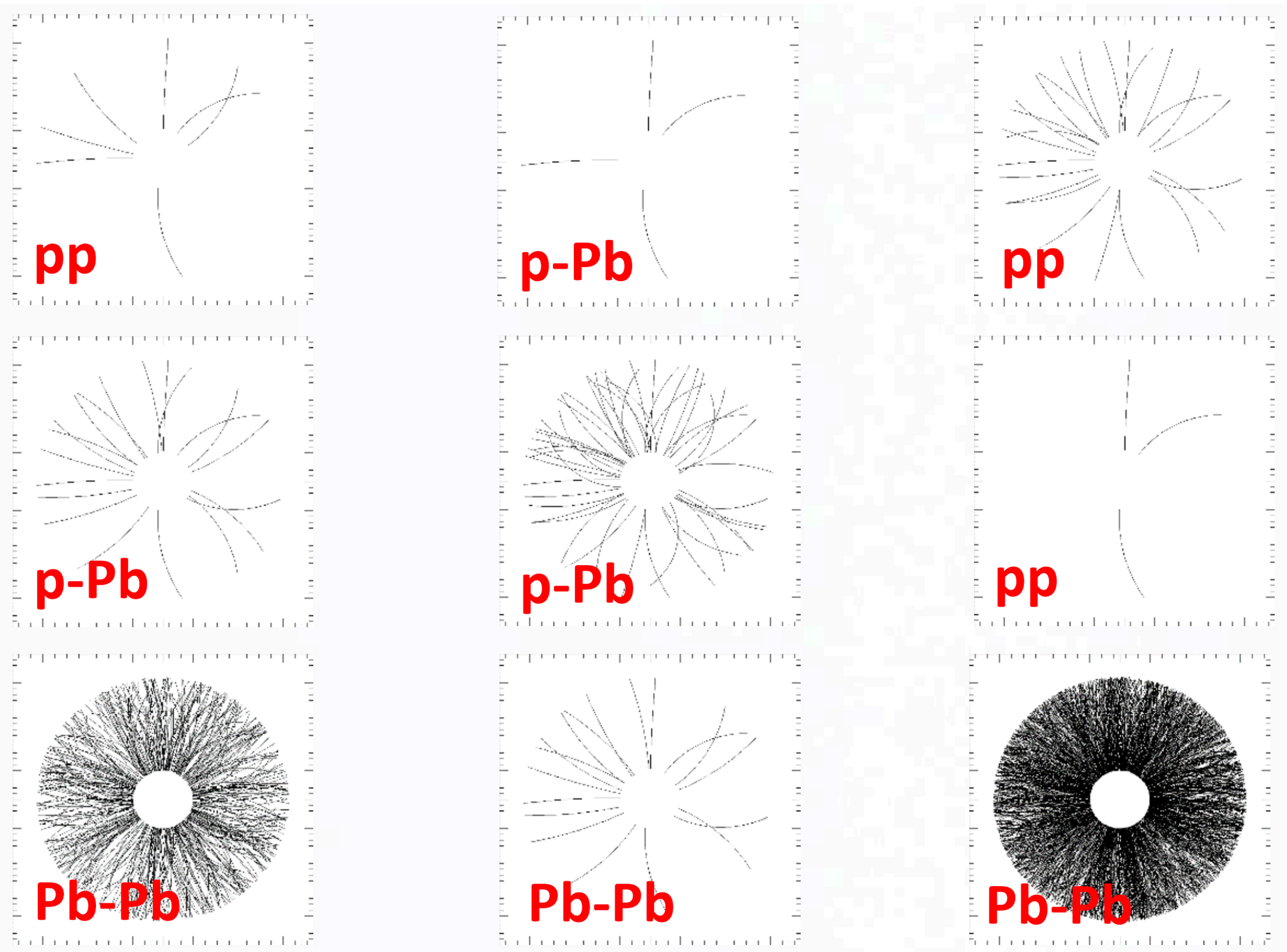
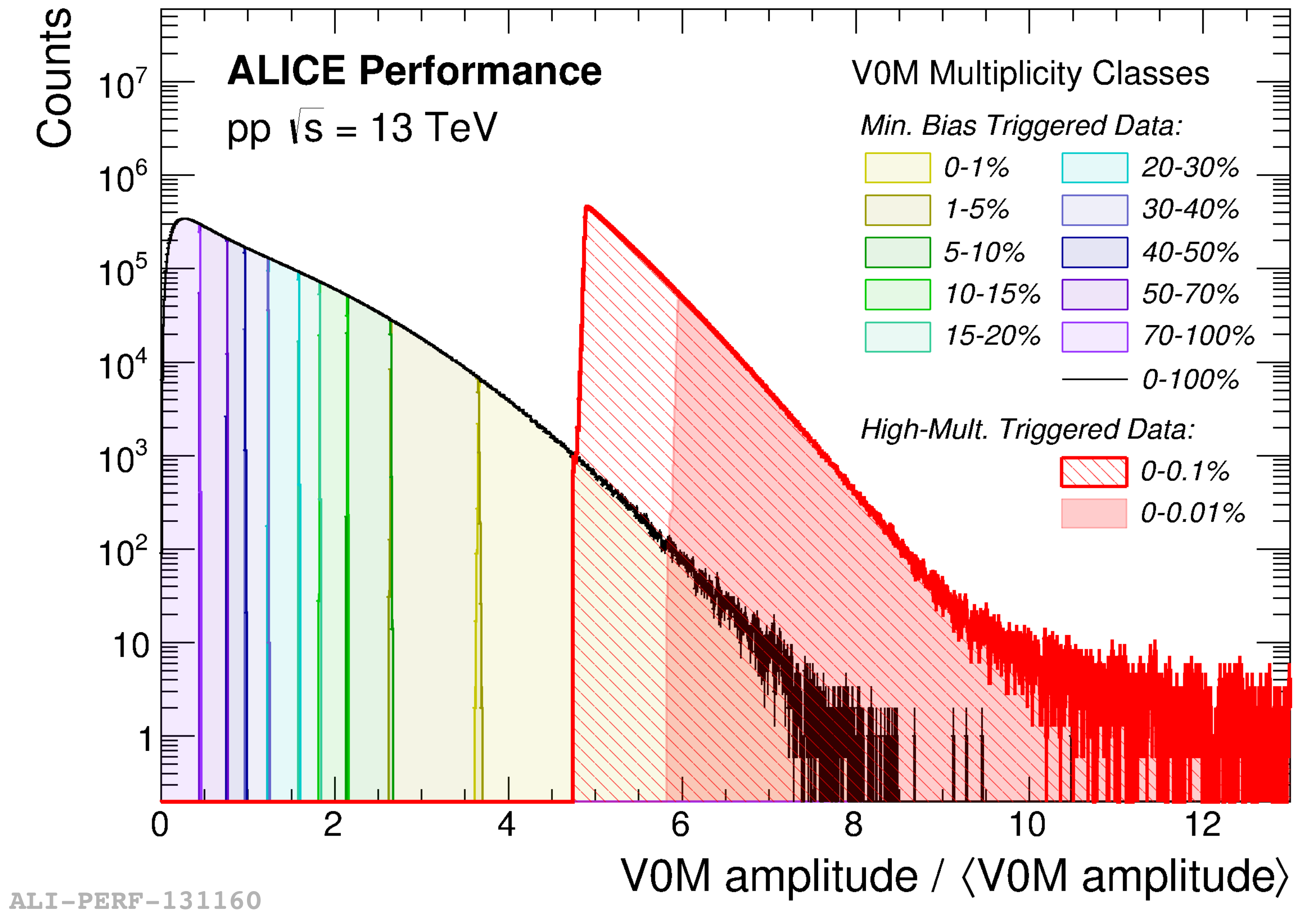
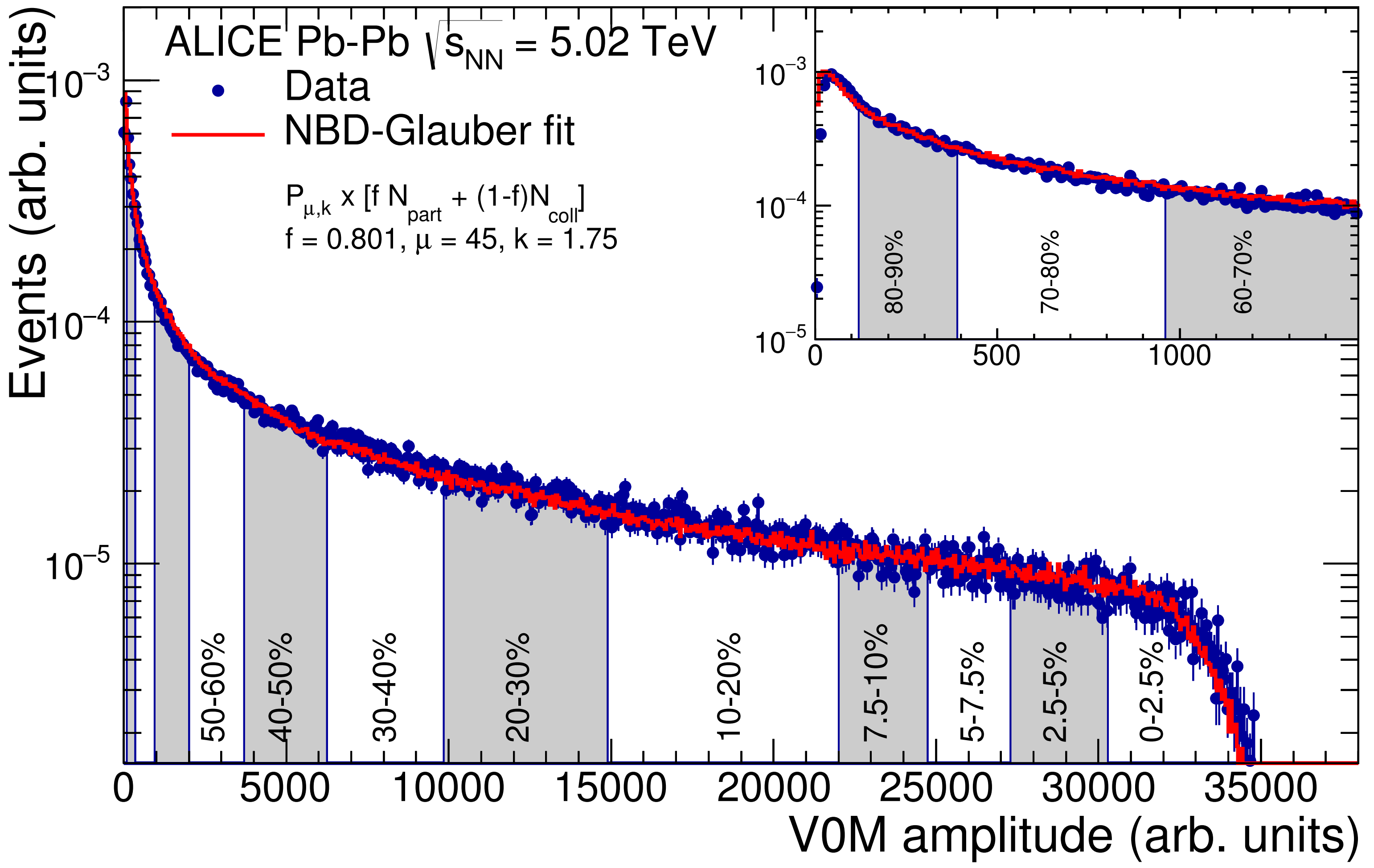
"Multiplicity"

Small system // Large system

- **System size** may refer…
  - *Size of the colliding objects*
    - Common way of thinking
    - (ee <) pp < pA < AA
  - *Size of the created medium*
    - Correspondence to the previous true only on average
    - N_{part}, N_{coll}, **Multiplicity**
- **Multiplicity**: Number of particles produced in a defined kinematic region.
  - Estimated by Multiplicity estimator
    - Categorize each event according to its multiplicity







Example of Analysis: Ξ(1530)⁰

Scheme-Procedure

- **Final Goal:** Get the number(N) of produced particle in specific condition.

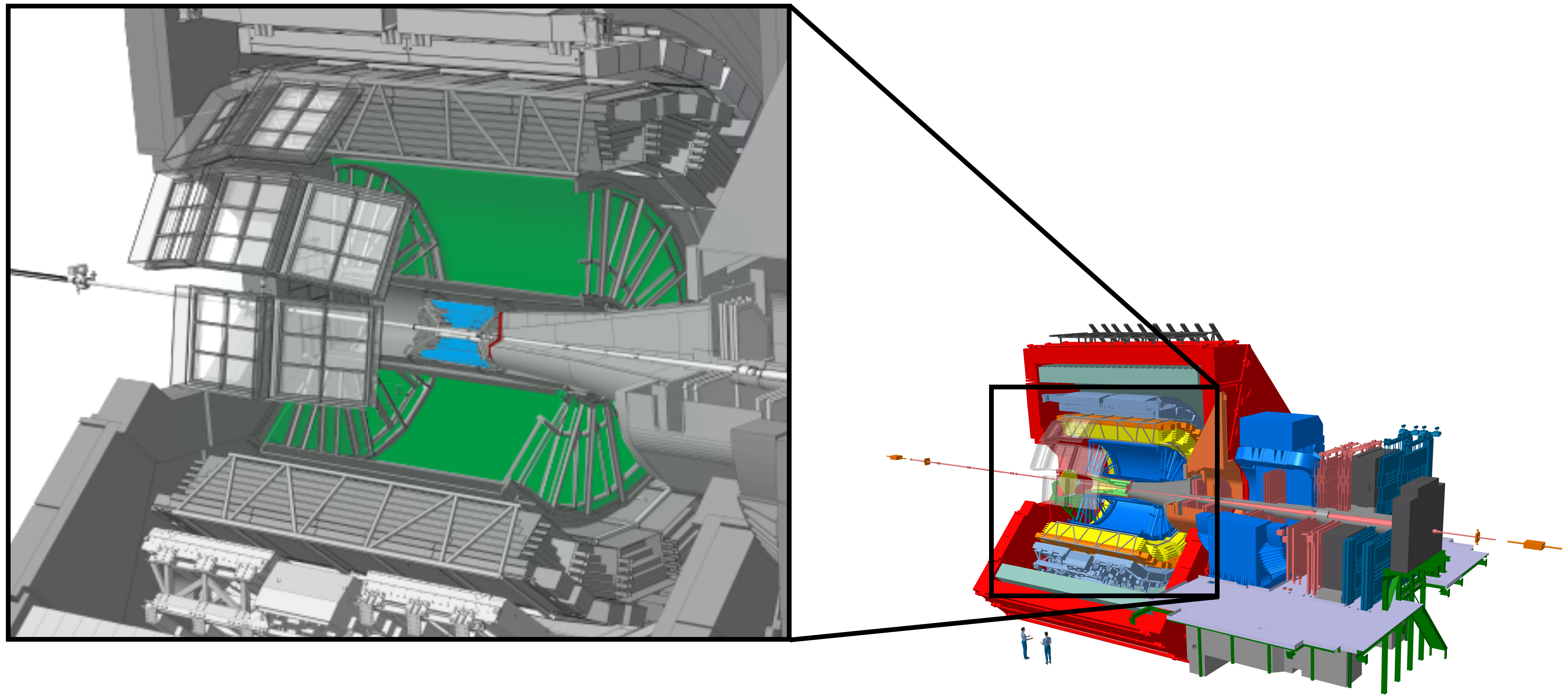
$$\frac{1}{N_{E}^{INEL>0}}\frac{d^2N}{dy dp_{\mathrm{T}}} = \frac{\epsilon^{trigg.\ INEL>0}}{N_{E,PhysSel}} \frac{N_{raw}}{\Delta p_{\mathrm{T}} \Delta y \Delta Multiplicity\ percentile} \frac{1}{\epsilon_{MC}} \frac{1}{(S.L.)}$$

What we want to get | Event Selection | Reconstruction | MC Correction

- **Analysis Flow:**

Event Selection ➜ Track Reconstruction ➜ MC Correction ➜ Final Result

- **Used Detectors:**
  - **ITS**: Trigger / Tracker / Vertexer
  - **V0**: Trigger / Multiplicity Estimator
  - **TPC**: Tracker / PID(dE/dX)



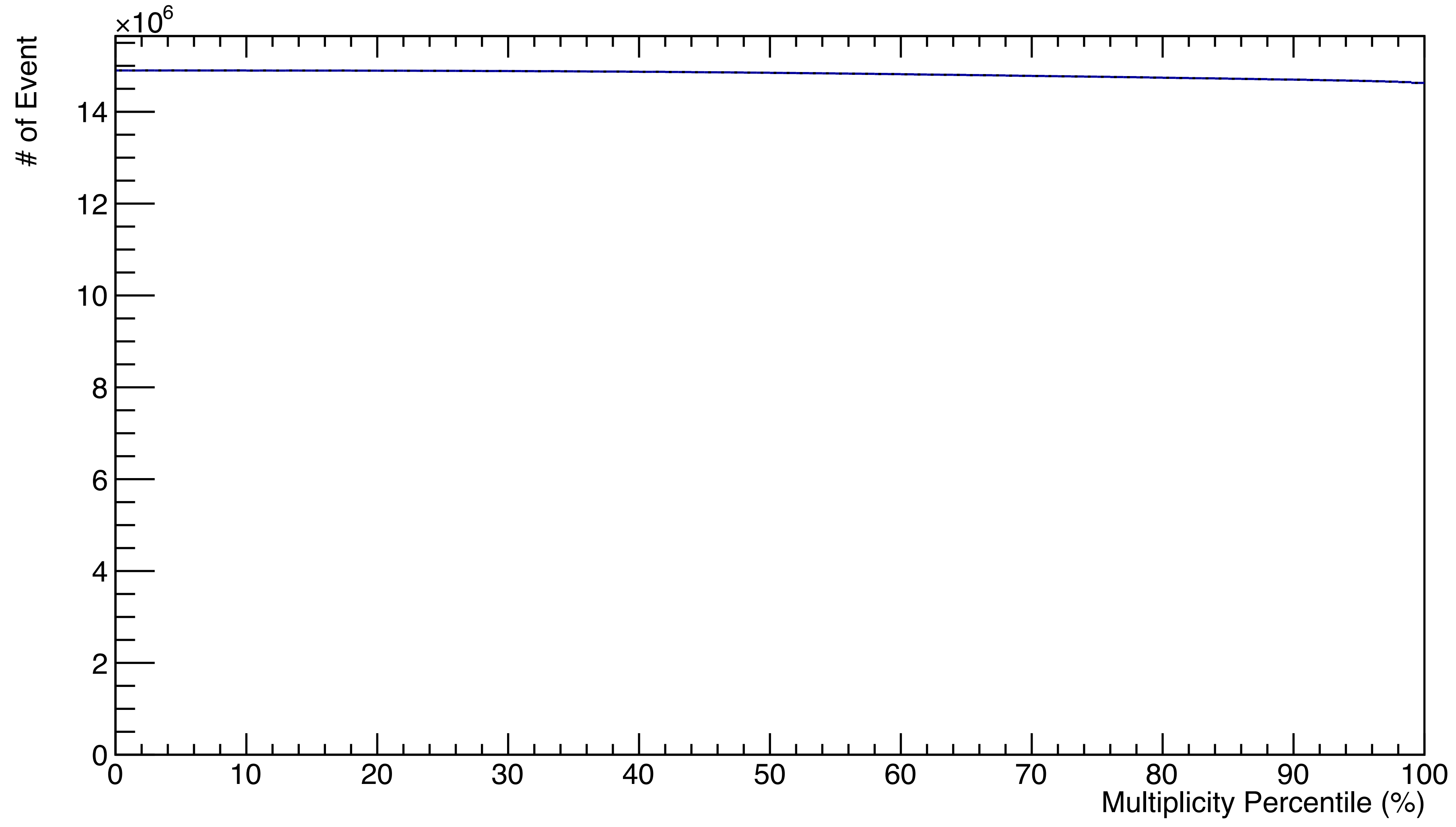
Analysis Details

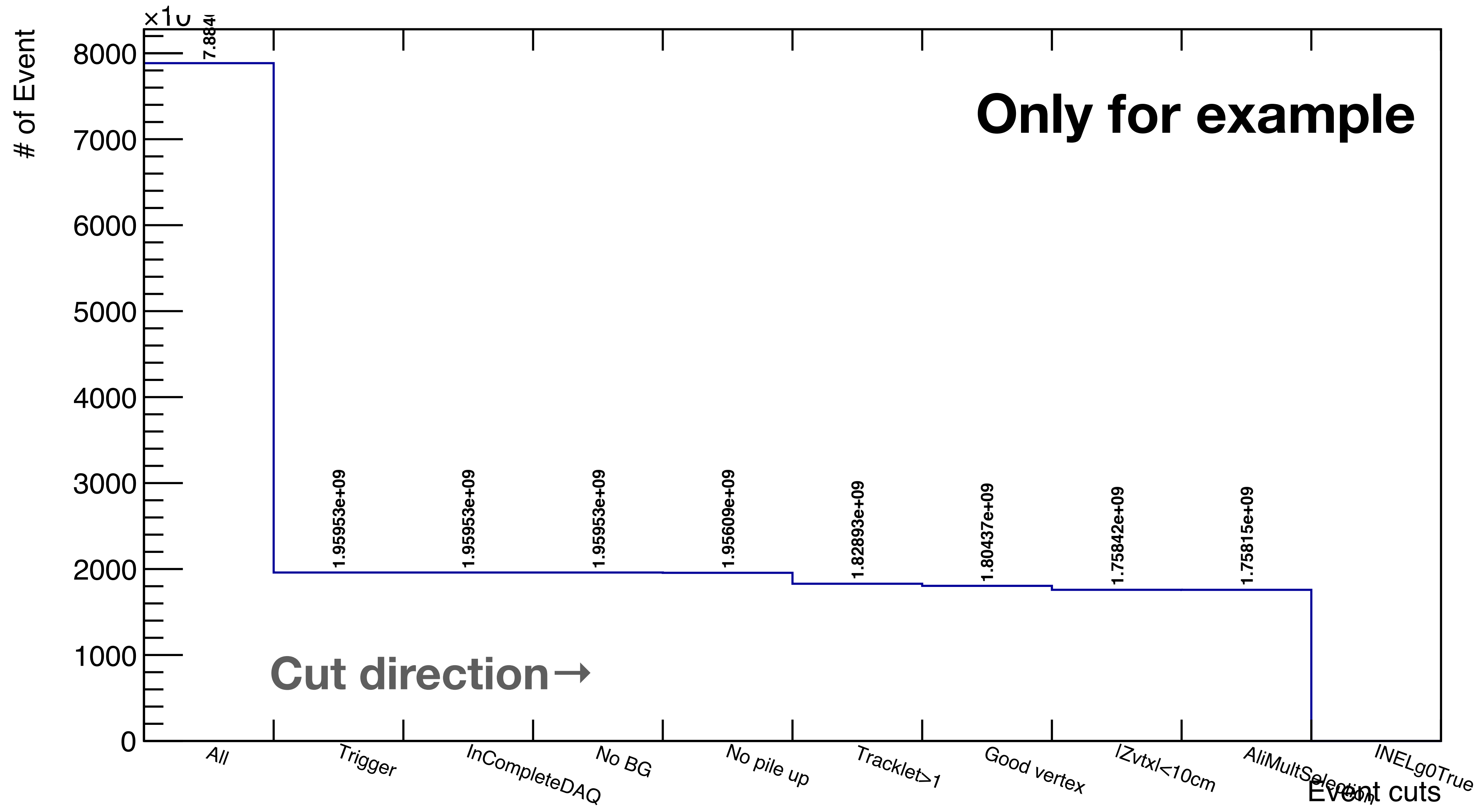
Event Selection ➜ Track Reconstruction ➜ MC Correction ➜ Final Result

- **Data set:** Recommended pp 13 TeV collision, **1.59B events**
  - LHC16deghijklop_17cefgijklmor_18bdefghikmnop

- **Trigger:** kINT7, Minimum bias trigger (V0A && V0C)

- **Event cuts:**
  - `IsIncompleteDAQ`
  - `IsSPDClusterVsTrackletBG`
  - `IsNotPileupSPDInMultBins`
  - Good Vertex Selection:
    - | zVertex | < 10 cm
    - SPDVertex dispersion < 0.04 cm
    - zVertex resolution < 0.25 cm
    - z-position difference < 0.5 cm
  - `IsSelected` in `AliMultSelection`



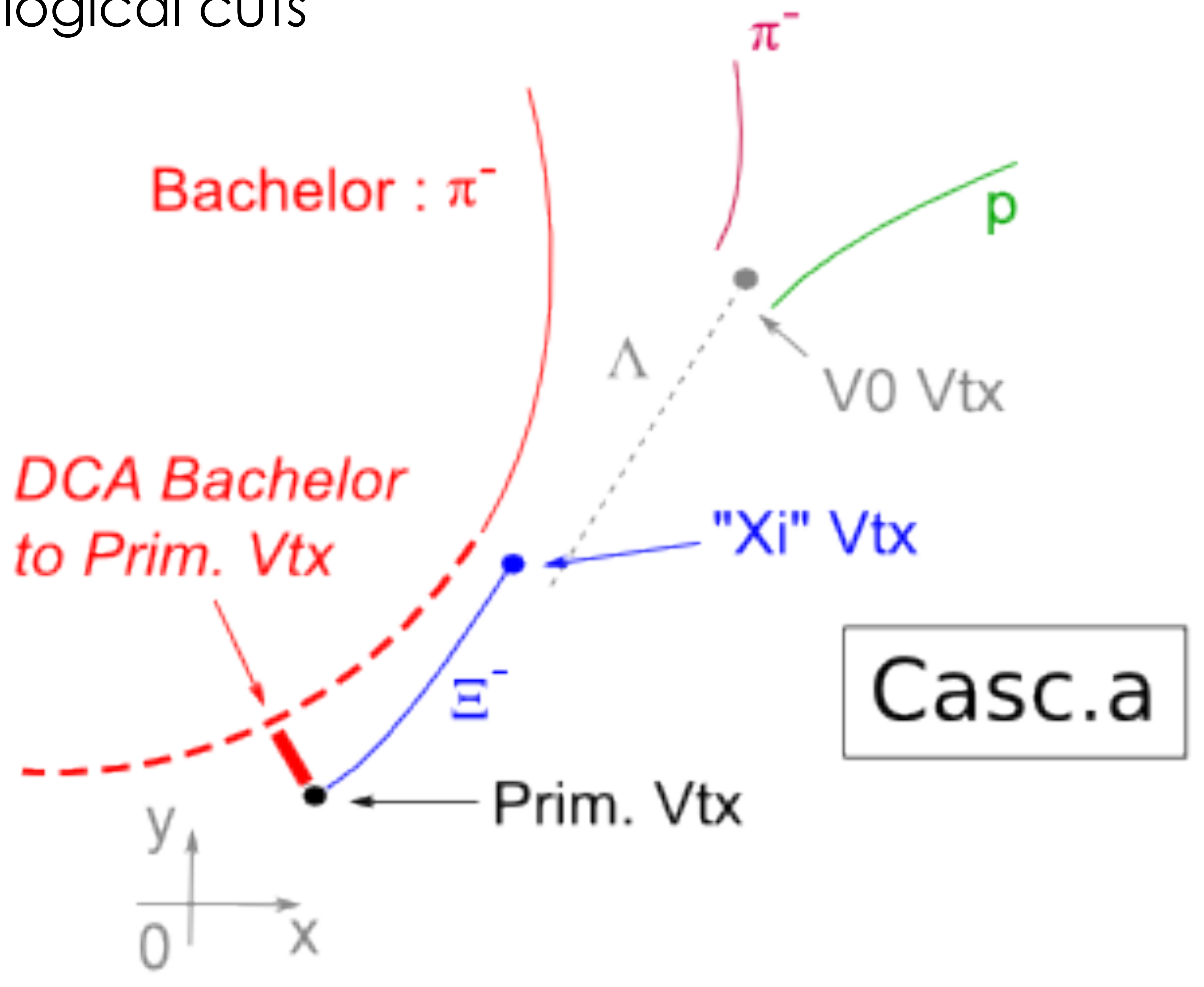


Analysis Details

Event Selection ➜ **Track Reconstruction** ➜ MC Correction ➜ Final Result

- **Decay channel:** $\Xi^{*0} \longrightarrow \Xi^{-} + \pi^{+}$

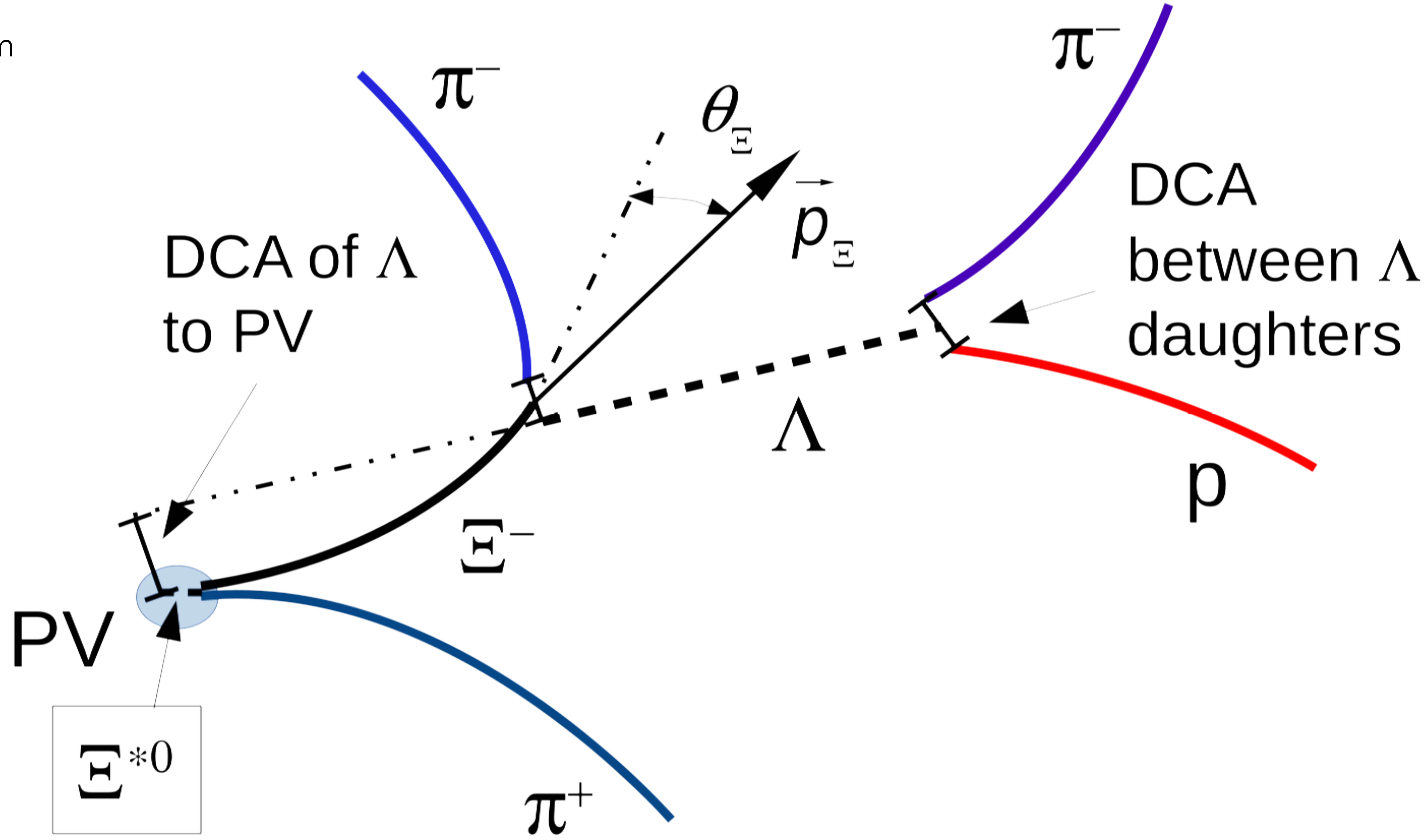
- **Basic concept:** Select π, and Select Ξ and apply topological cuts
  - Good π Selection(Track cut):
    - Standard 2011 ITS-TPC Track cut(link) with Primary cut option
    - $\eta < |0.8|$
    - $p_T > 0.15$ GeV/c
    - TPC PID(π) sigma < 3
    - zVertex dispersion < 2.0 cm
  - Good Ξ Selection(Track cut):
    - Reject AcceptKinkDaughters
    - Number of Clusters in TPC > 50
    - Require TPC Refit
    - Chi2 Per Cluster TPC < 4
    - $p_T > 0.15$ GeV/c
    - TPC PID(π, p) sigma < 3



Analysis Details

Event Selection ➜ **Track Reconstruction** ➜ MC Correction ➜ Final Result

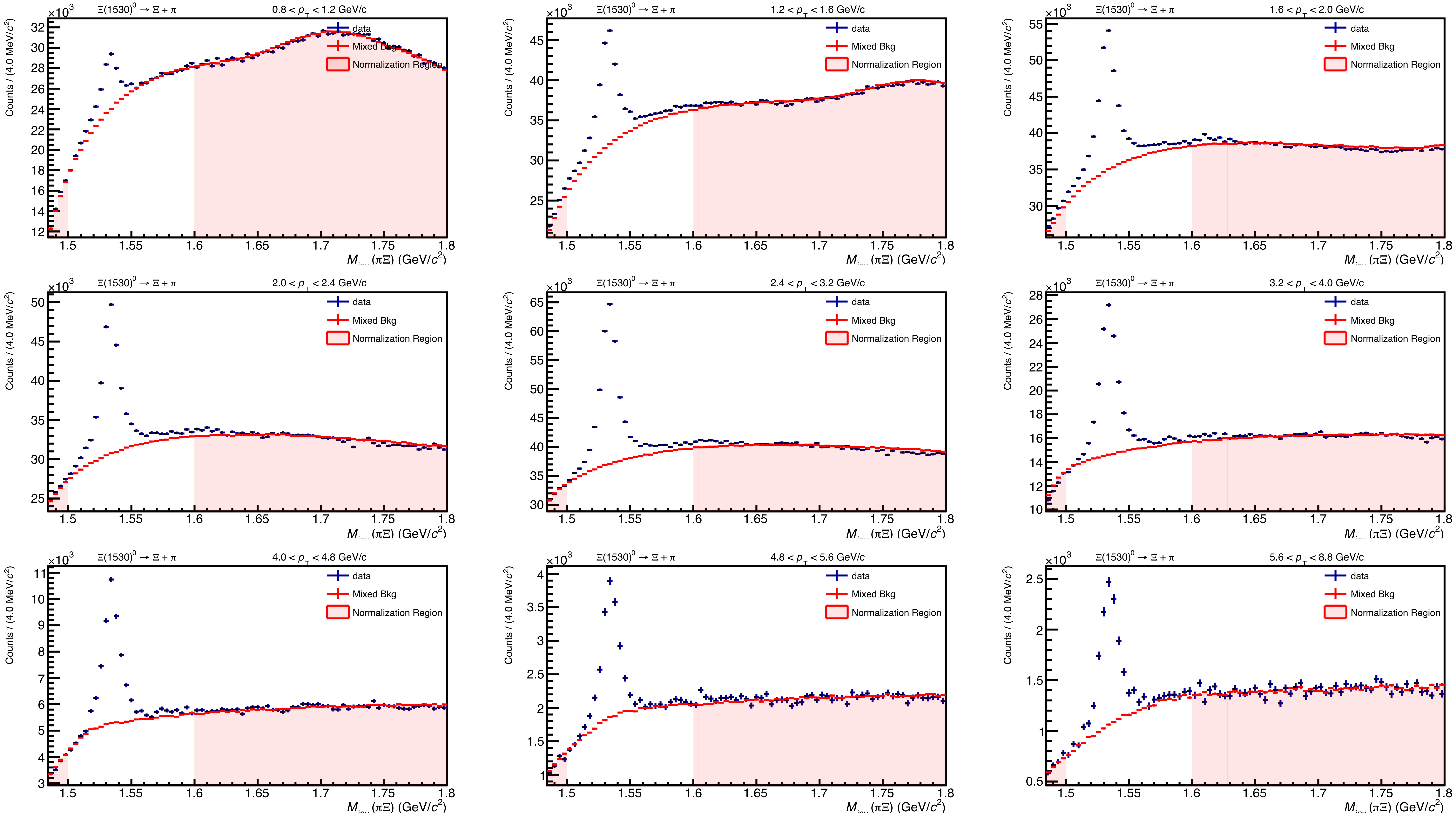
- **Topological Selection:**
  - DCA of Λ to PV > 0.07 cm
  - DCA between Λ daughters < 1.6 cm
  - DCA Λ and second emitted pion < 1.6 cm
  - Decay length xy of Λ >1.4 cm
  - Decay length xy of Ξ∓ > 0.8 cm
  - Fiducial limit of Λ and Ξ∓ = 100 cm
  - Cosine of pointing angle of Λ > 0.97
  - Cosine of pointing angle of Ξ∓ > 0.97
  - Mass Window of Λ and Ξ∓ = ± 6 MeV/c2
  - Ξ(1530)0 |y|< 0.5



Analysis Details

Event Selection ➜ **Track Reconstruction** ➜ MC Correction ➜ Final Result

- **Reconstructed Signal + Mixed-Event Background (0-100% Minimum Bias)**

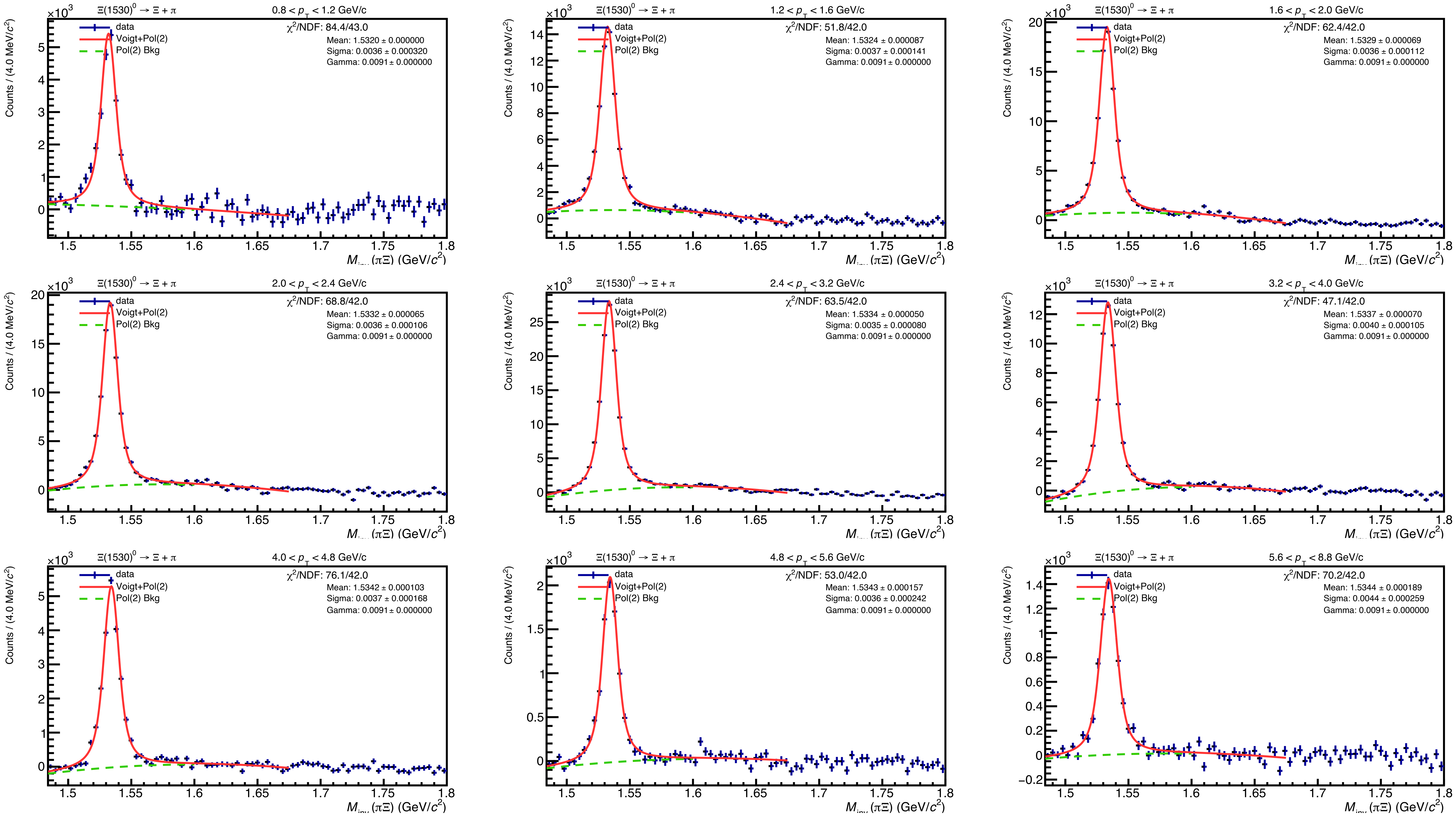


Analysis Example

Analysis Details

Event Selection ➜ **Track Reconstruction** ➜ MC Correction ➜ Final Result

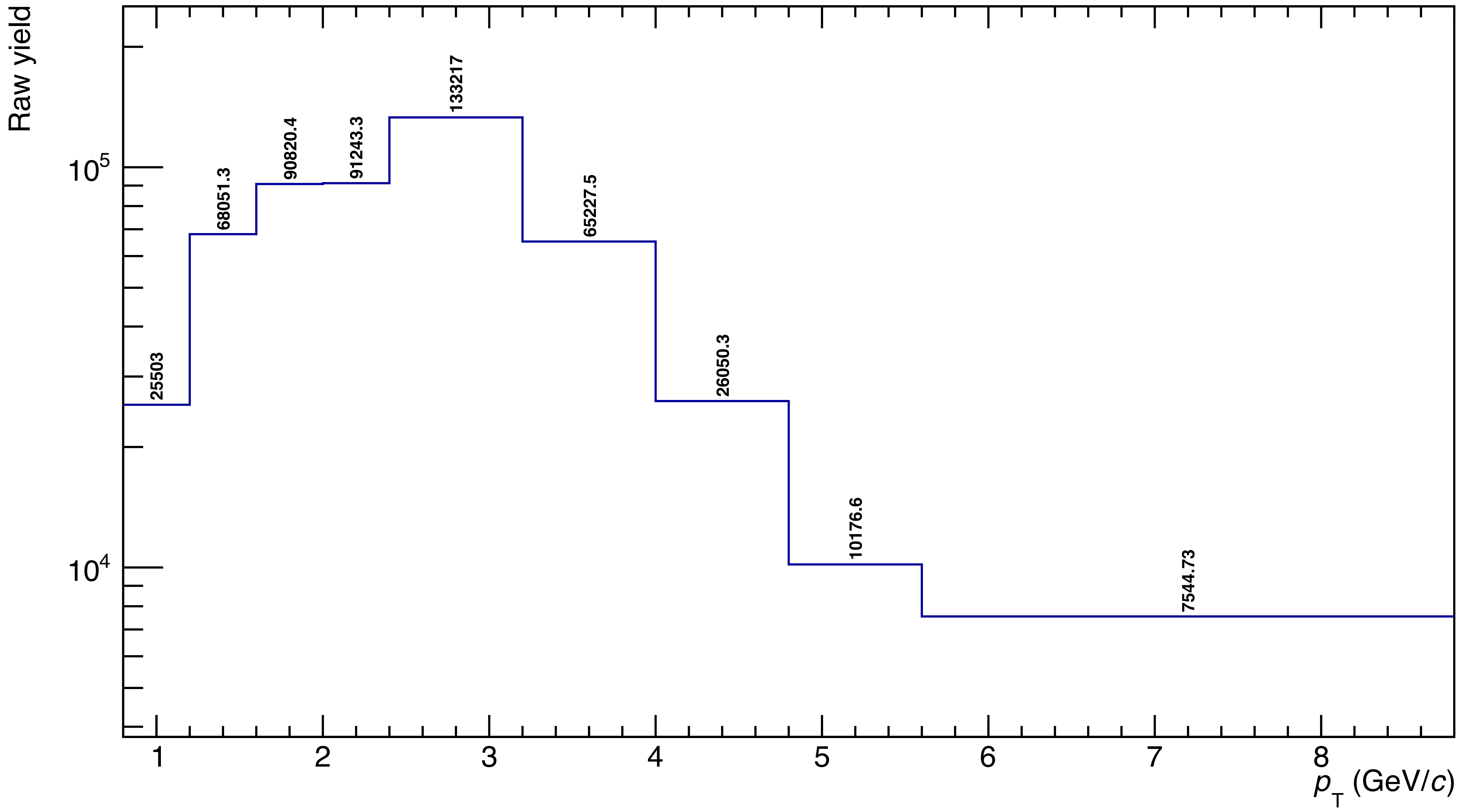
- **Reconstructed Signal - Background, fit (0-100% Minimum Bias)**



Analysis Details

Event Selection ➜ **Track Reconstruction** ➜ MC Correction ➜ Final Result

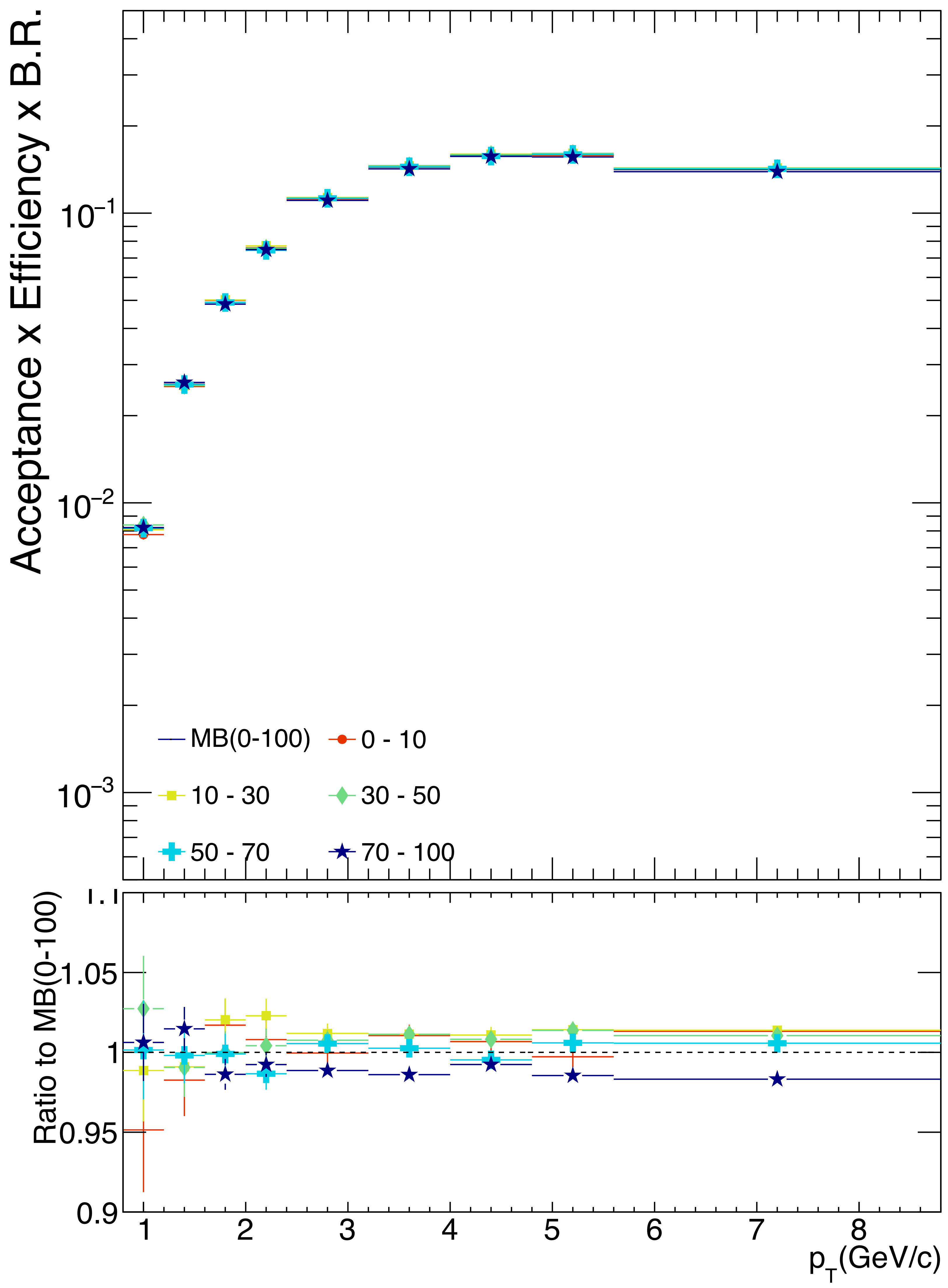
- **Raw yield distribution**



Analysis Detail:

Event Selection ➜ Track Reconstruction ➜ **MC Correction** ➜ Final Result

- **Corrections:**
  - **Reconstruction Efficiency**
  - Trigger Efficiency (skip)
  - Signal Loss (skip)



- **Reconstruction Efficiency:**
  \# of Reconstructed particle / # of MC True particle after Event Selection.
  - Acceptance and Branching Ratio are calculated together.
  - All Reconstruction Efficiency through several multiplicity bins looks consistent with in their stat.error.

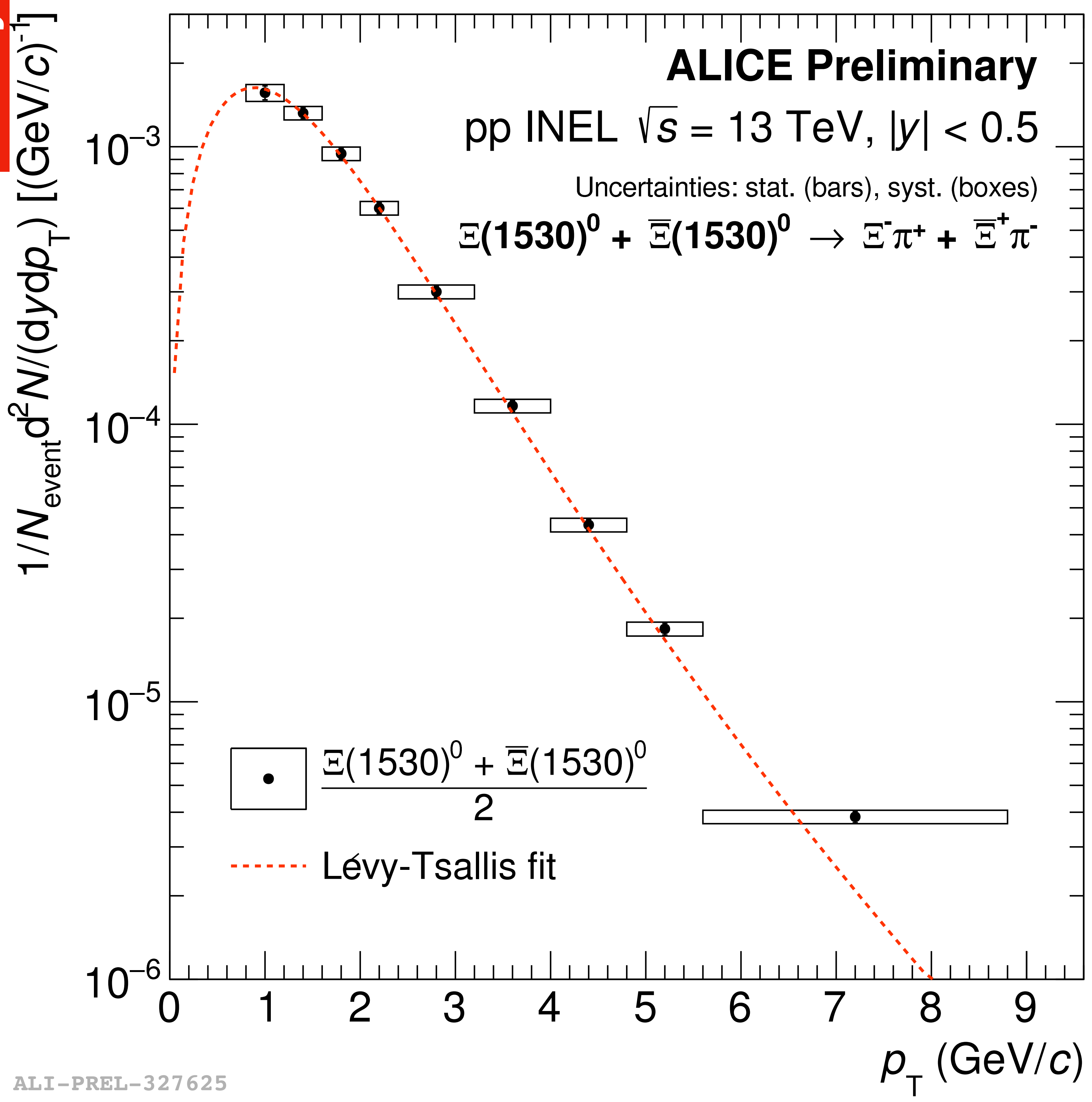
$$\frac{1}{N_E^{INEL>0}}\frac{d^2N}{dydp_{\mathrm{T}}} = \frac{\epsilon^{trigg.\ INEL>0}}{N_{E,PhysSel}} \frac{N_{raw}}{\Delta p_{\mathrm{T}}\Delta y\Delta Multiplicity\ percentile} \frac{1}{\epsilon_{MC}} \frac{1}{(S.L.)}$$

What we want to get | **Event Selection** | **Reconstruction** | **MC Correction**

Analysis Example

Analysis Detail:

Event Selection ➜ Track Reconstruction ➜ MC Correction ➜ **Final Result**



- **Corrected Spectra**
  - Assemble these values into final spectrum.
  - Using the fit functions, such as Levy-Tsallis, missing parts (low p_{T}, high p_{T}) can be supplemented.

- **Next step...**
  - Repeat the same step for each **event class**.
  - Repeat the same step for each **systematic variation**.

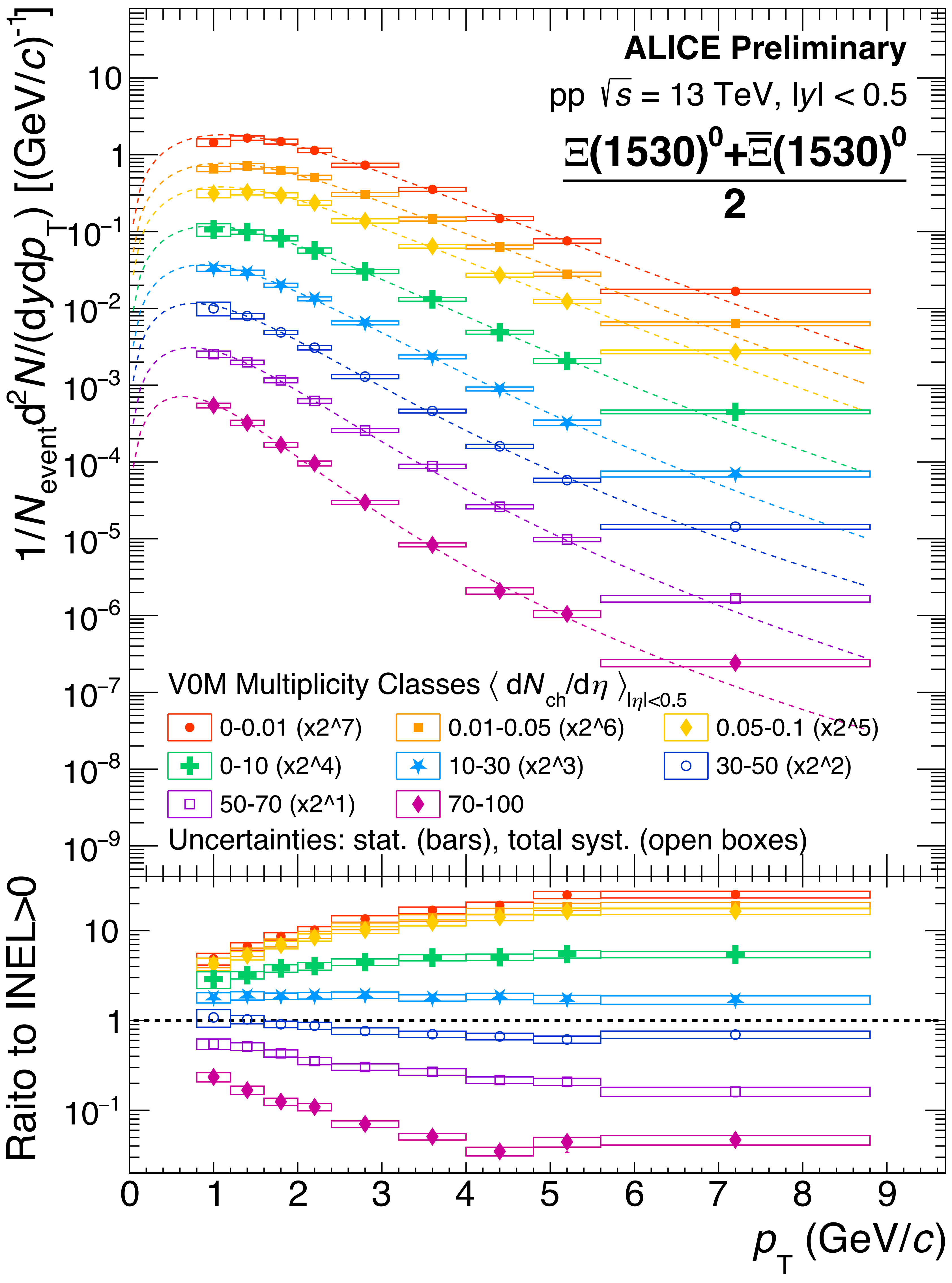
$$\frac{1}{N_E^{INEL>0}}\frac{d^2N}{dydp_{\mathrm{T}}} = \frac{\epsilon^{trigg.\ INEL>0}}{N_{E,PhysSel}} \frac{N_{raw}}{\Delta p_{\mathrm{T}}\Delta y \Delta Multiplicity\ percentile} \frac{1}{\epsilon_{MC}} \frac{1}{(S.L.)}$$

What we want to get | Event Selection | Reconstruction | MC Correction

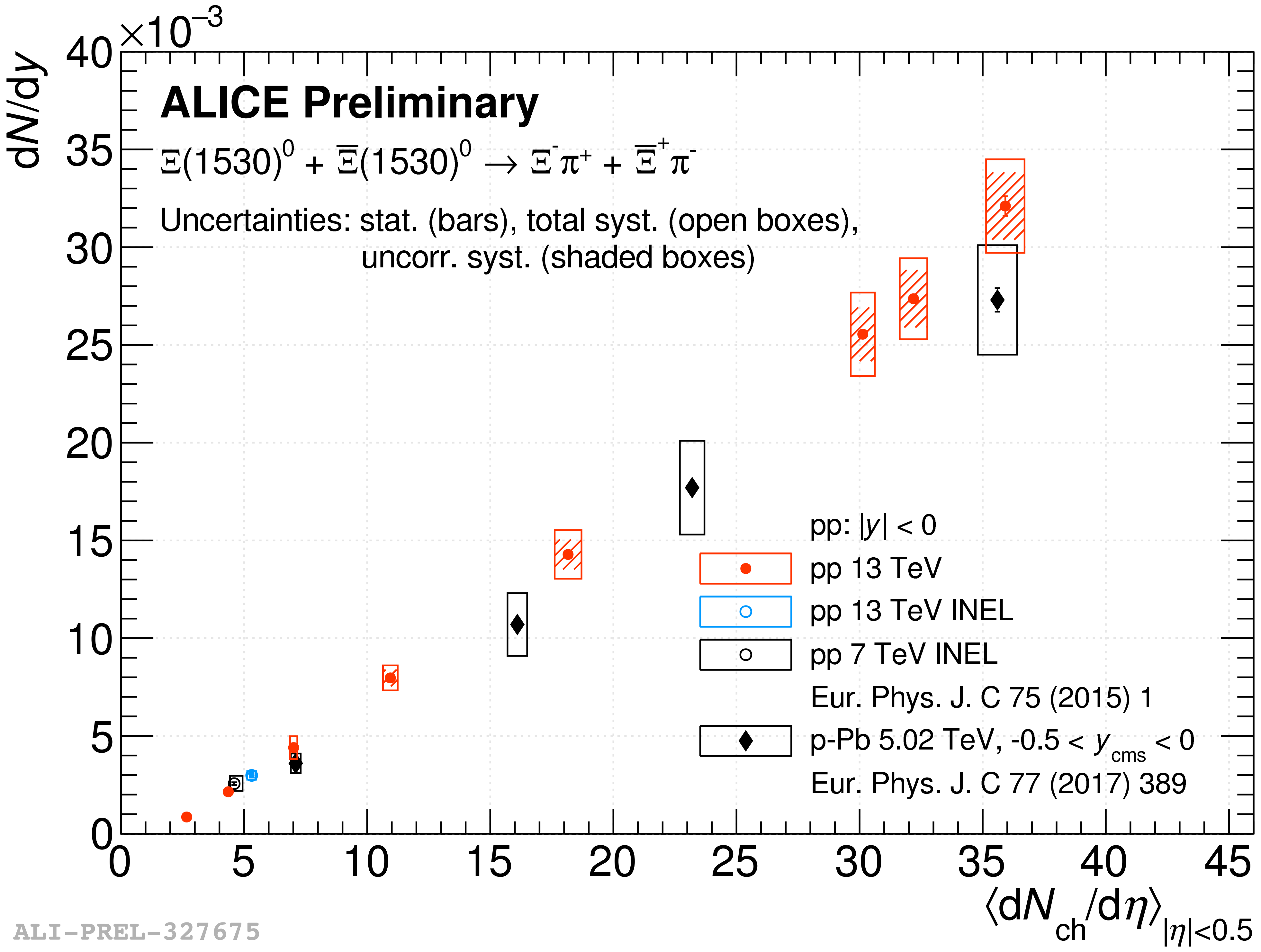
Analysis Example

Analysis Detail:

Event Selection ➜ Track Reconstruction ➜ MC Correction ➜ **Final Result**

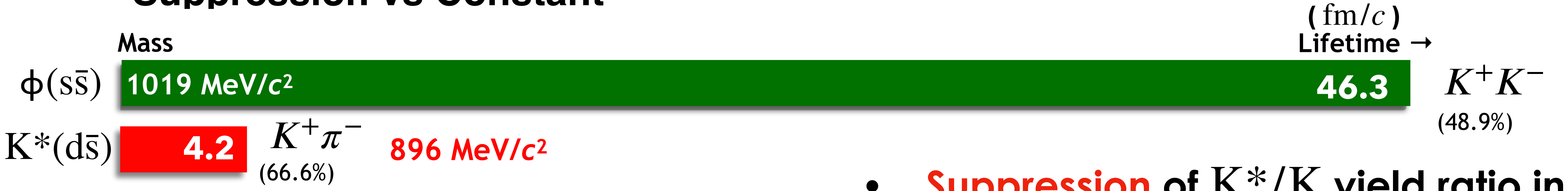


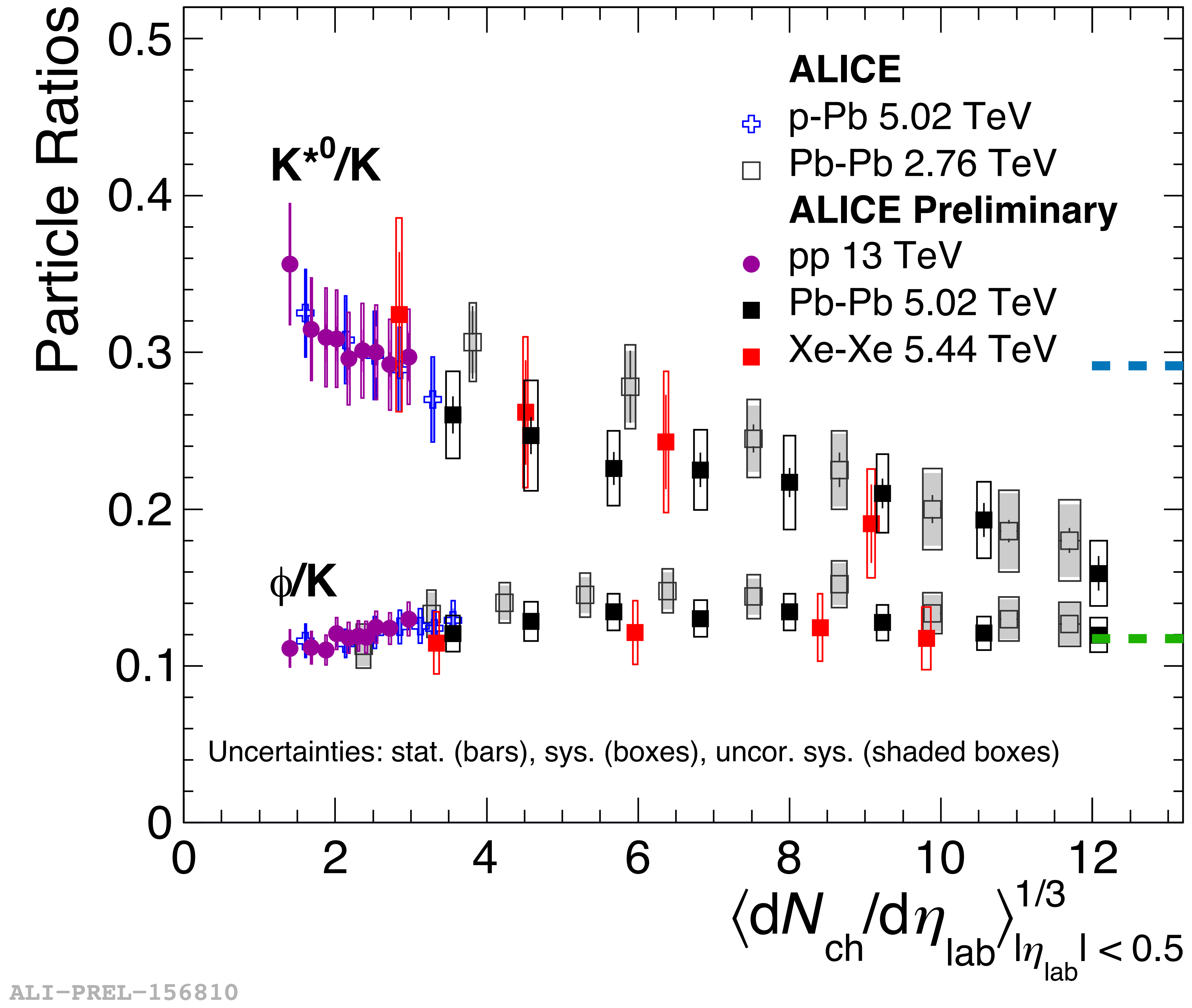
- **Final Results**
  - Adding Systematic uncertainties.
  - Extract Total yield, Mean p_T



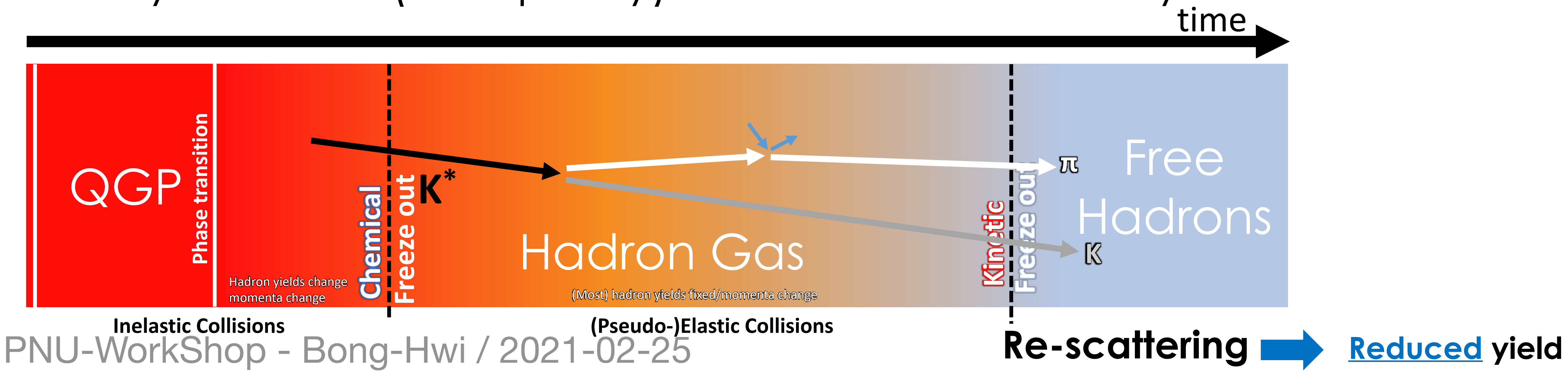
Focus on particle ratios: K* and ϕ

Suppression vs Constant



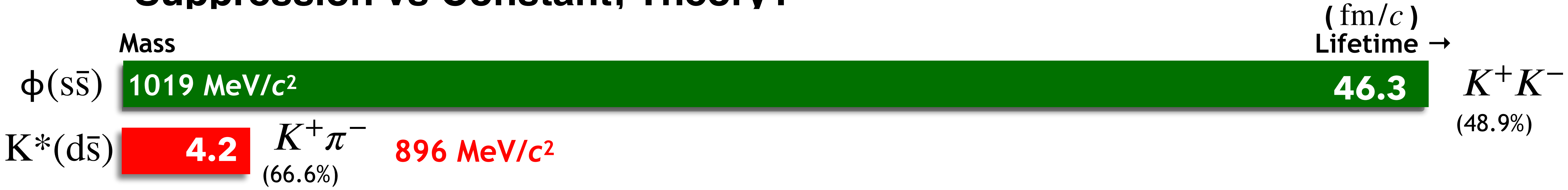


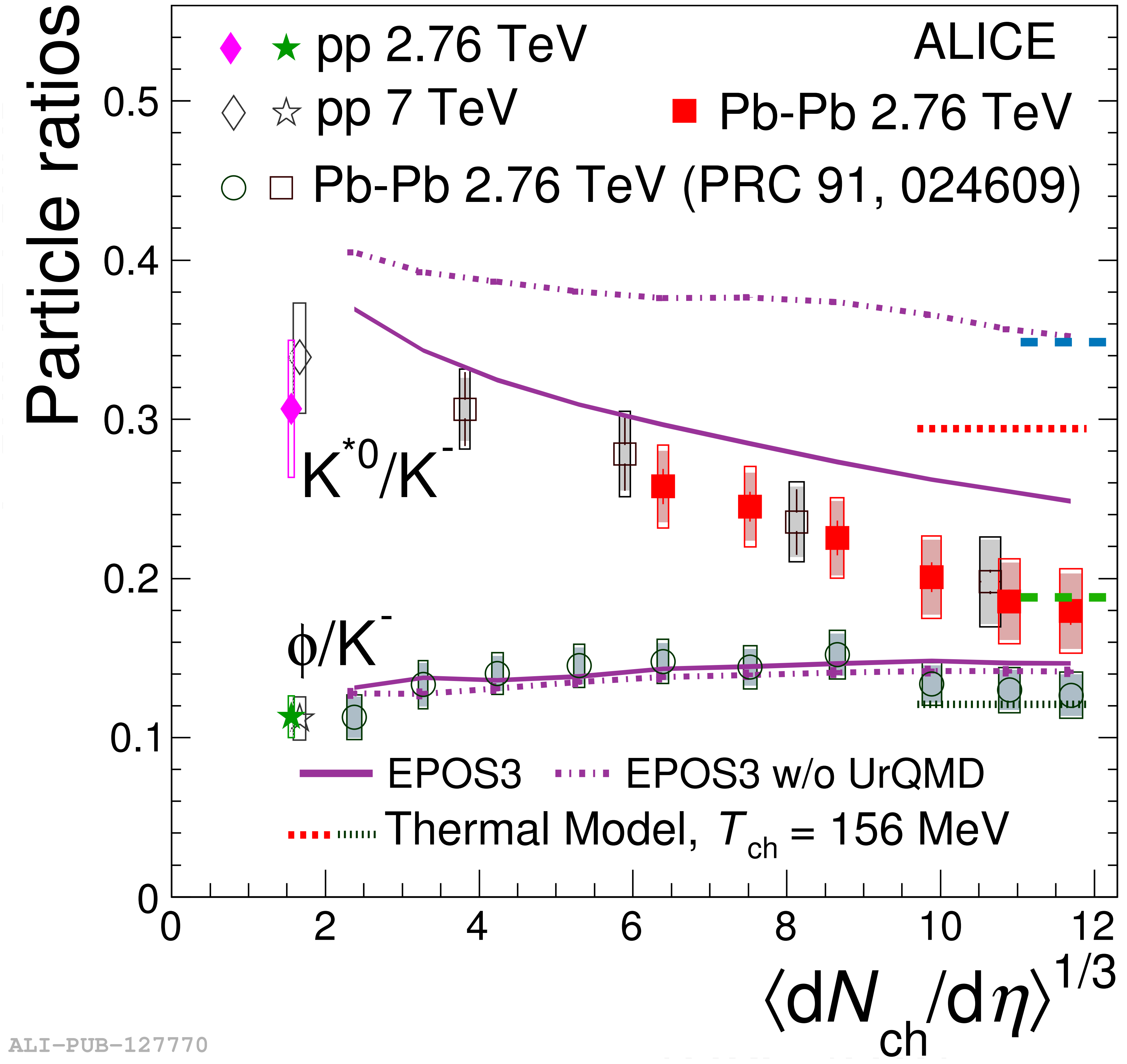
- **Suppression of K*/K yield ratio in high multiplicity events (AA Collisions)**
  - Shows reducing yield trend from low(pp) to high multiplicity
  - Yields in central AA collisions below Thermal model prediction.
- **Constant φ/K yield ratio**
  - Consistent with Thermal model prediction.
  - ϕ lifetime is ~ 10 times longer than K*
- **Suggests Re-scattering of K* decay products in hadronic phase.**
- **Small systems**
  - K*/K yield suppression in high-multiplicity pp, p-Pb?
  - Smooth transition from pp to AA:
    → System size (Multiplicity) controls Resonance yields



Focus on particle ratio: K* and ϕ

Suppression vs Constant; Theory?



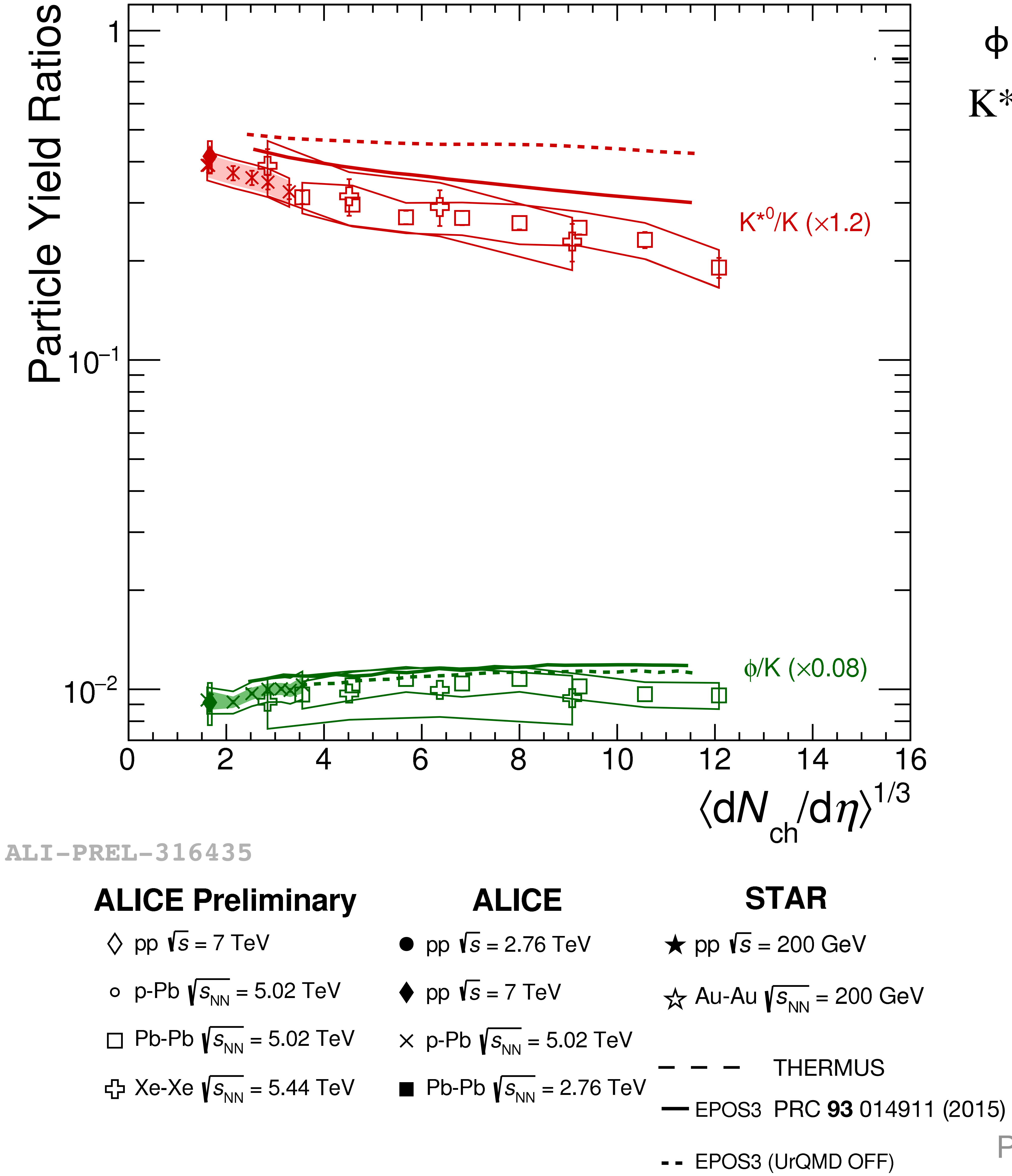


- **EPOS3 with UrQMD**
  - (Re-)Scattering effects modeled with UrQMD [1]
    - The effect is more pronounced in K* than ϕ
  - Qualitatively describes the trend from low to high multiplicity in K*

[1] PRC **93** 014911 (2015) arXiv:1509.07895

Full Story: Particle Ratio in Resonances

Suppression vs Constant



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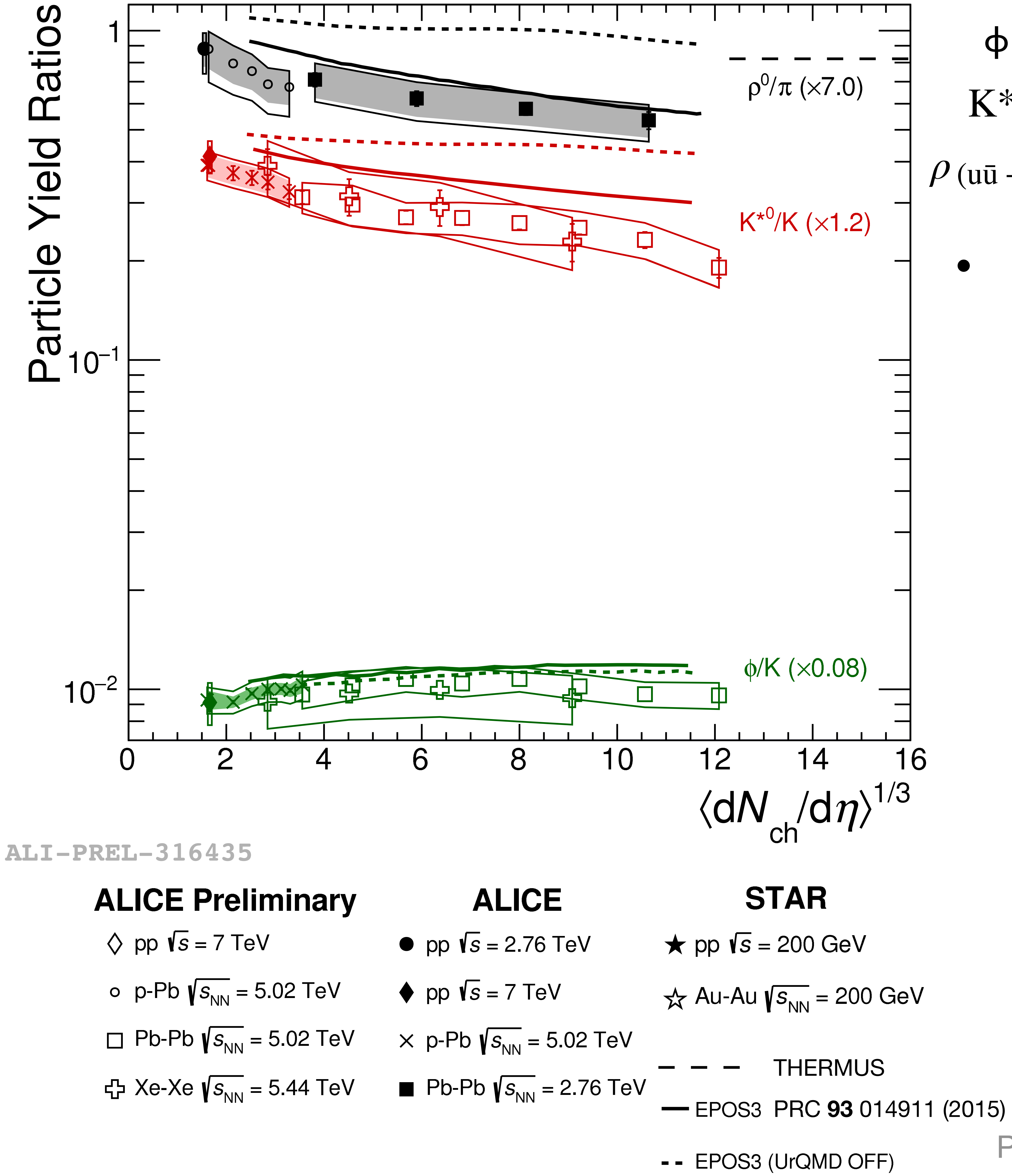
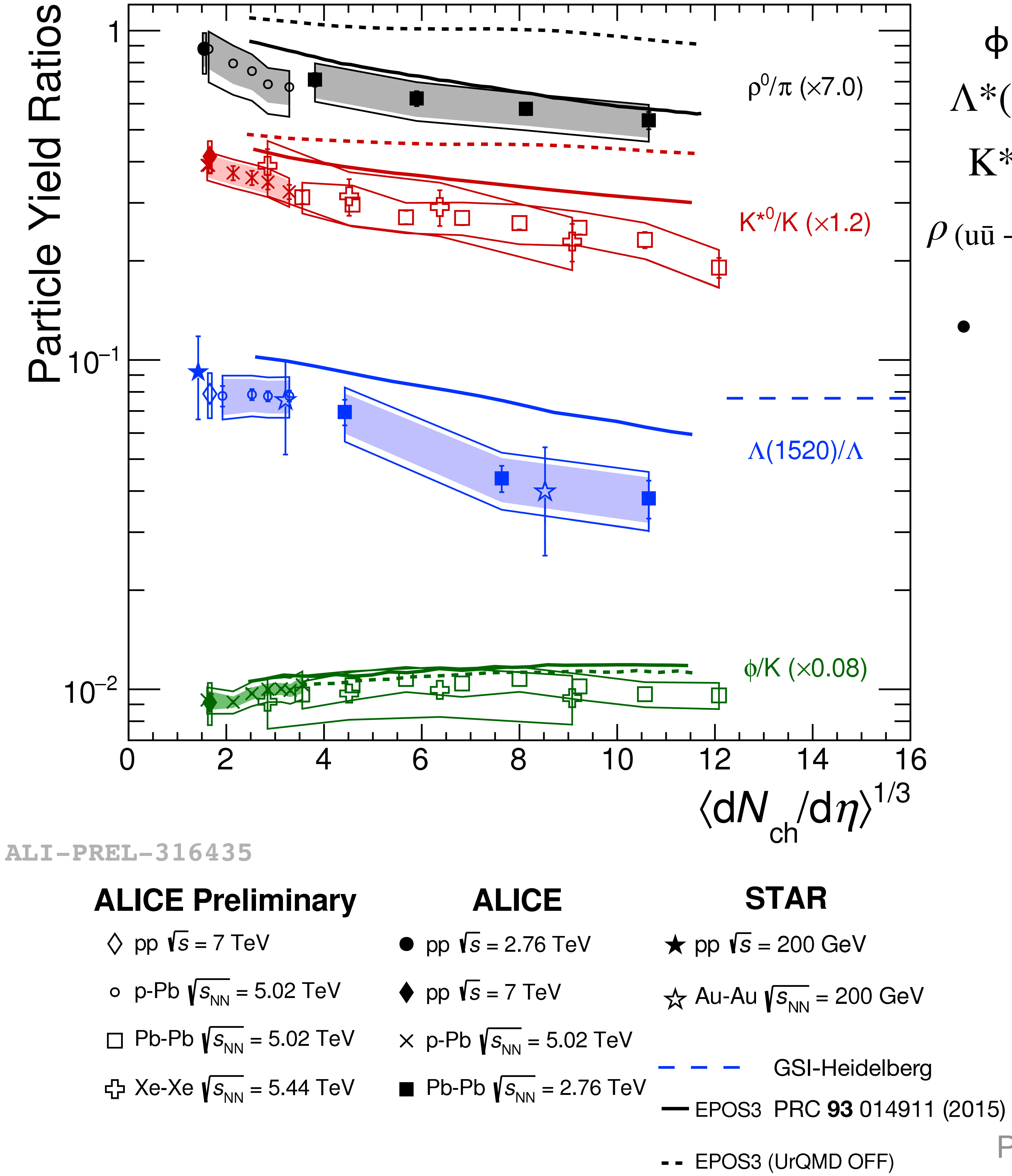


- **ρ - Short lifetime**
  - Suppression of ρ/π yield ratio in high multiplicity events (AA collisions)
  - Same story as K^*
    - Shows reducing yield trend from low(pp) to high multiplicity
    - Yields in central AA collisions below Thermal model prediction.
  - Hint of suppression in high-multiplicity p-Pb

Full Story: Particle Ratio in Resonances

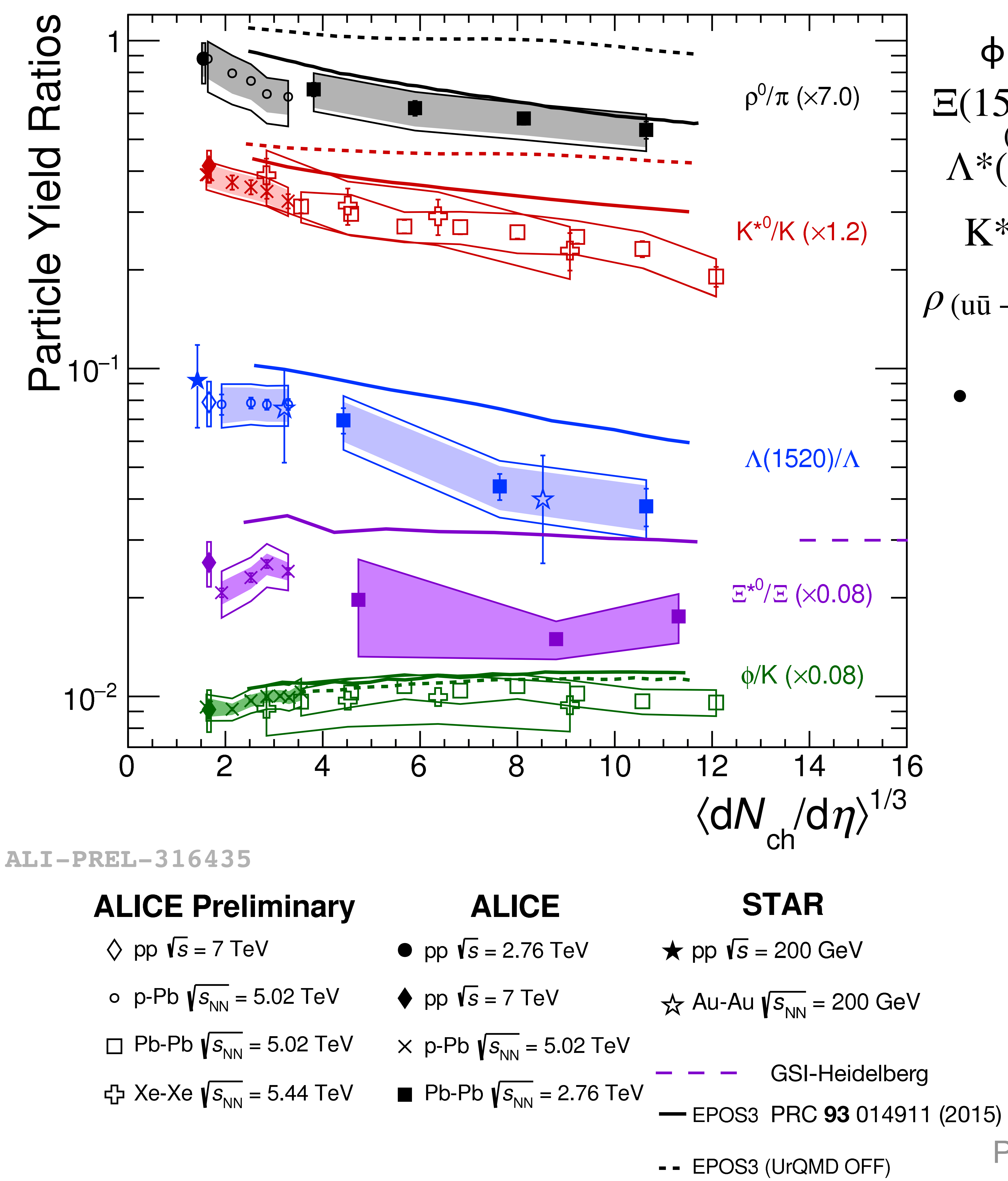
Suppression vs Constant

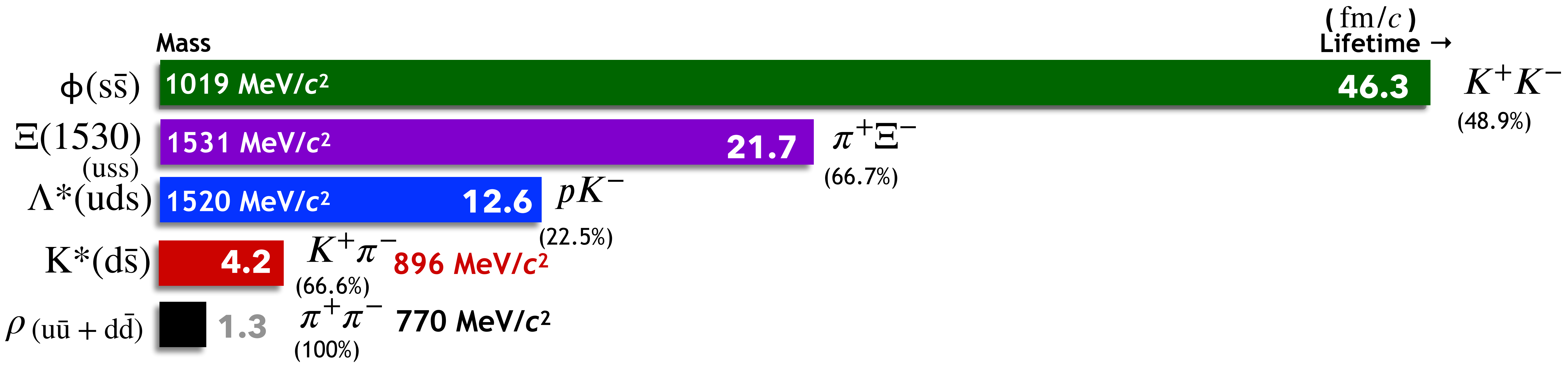


- $\Lambda(1520)$ - **Short lifetime**
  - Suppression of $\Lambda(1520)/\Lambda$ yield ratio in high multiplicity events (AA)
    - No suppression in p-Pb region.
  - Yields in central AA collisions below Thermal model prediction

Full Story: Particle Ratio in Resonances

Suppression vs Constant

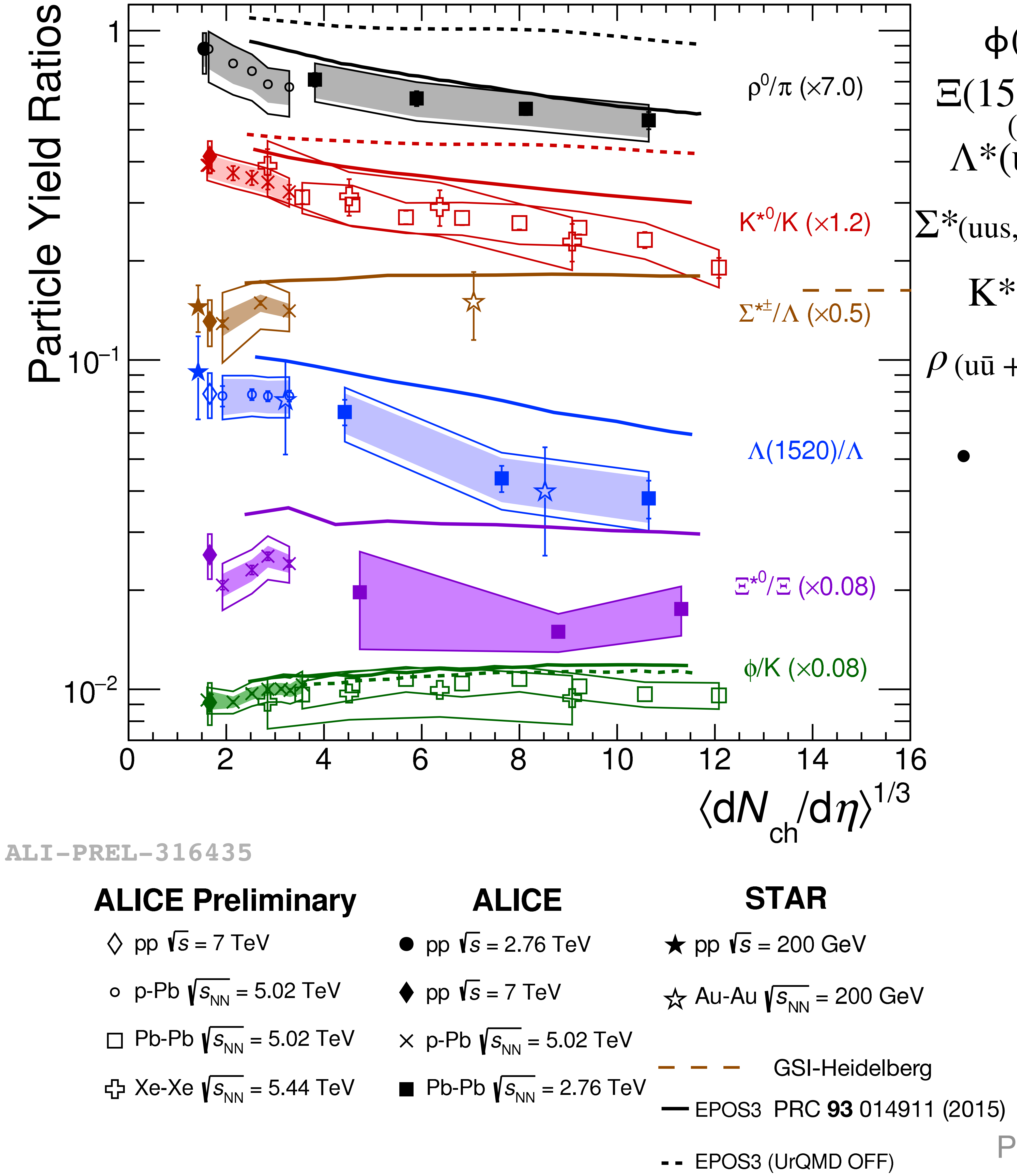


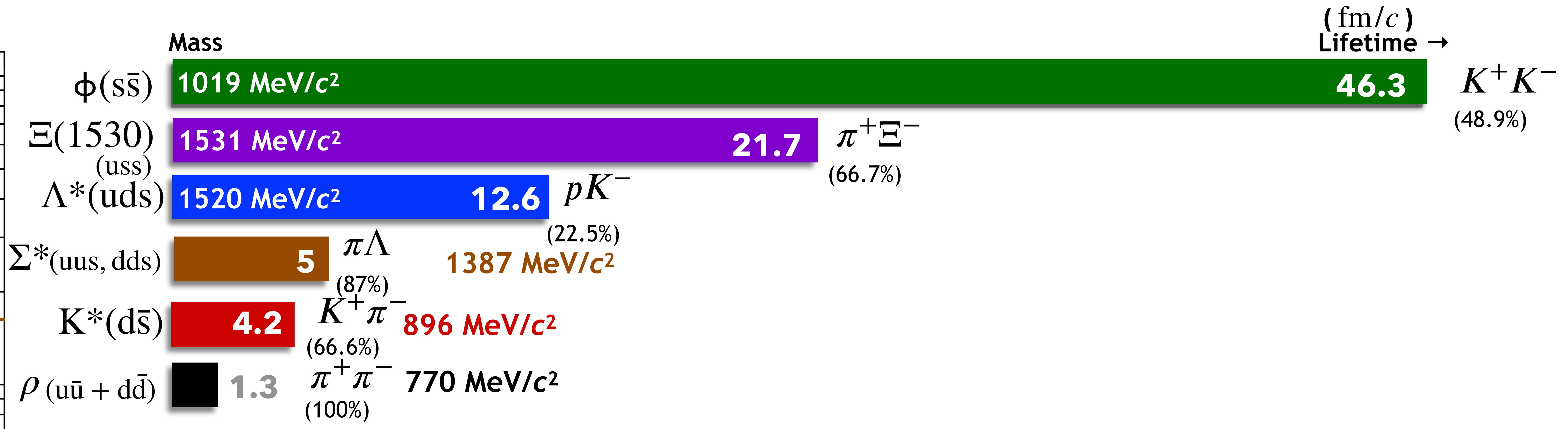


- $\Xi(1530)^0$ **- Intermediate lifetime**
  - No significant multiplicity dependent suppression.
  - Lower than Thermal model prediction
  - Systematically lower result in central Pb-Pb than pp, p-Pb
    - Hint of weak suppression?

Full Story: Particle Ratio in Resonances

Suppression vs Constant



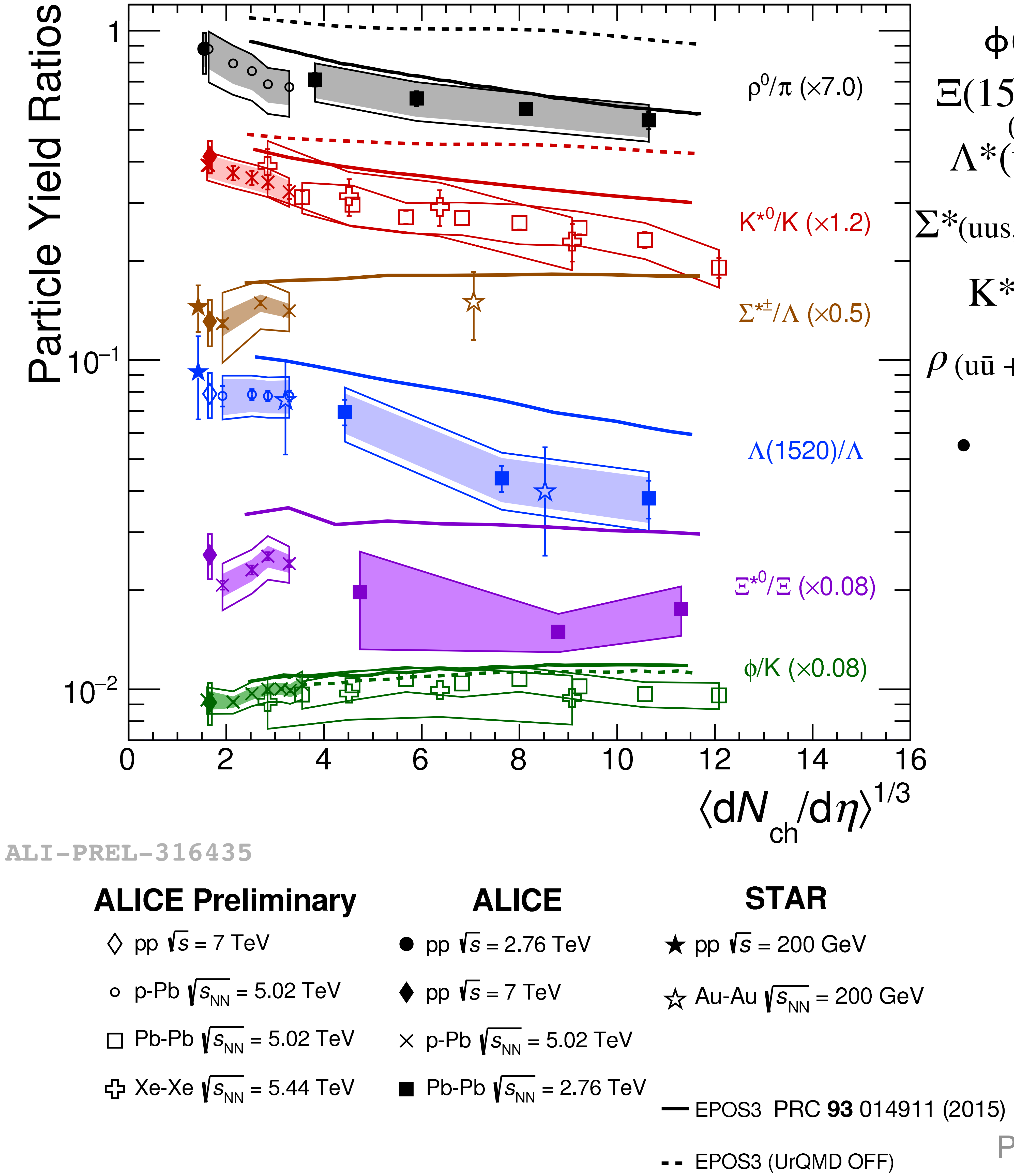


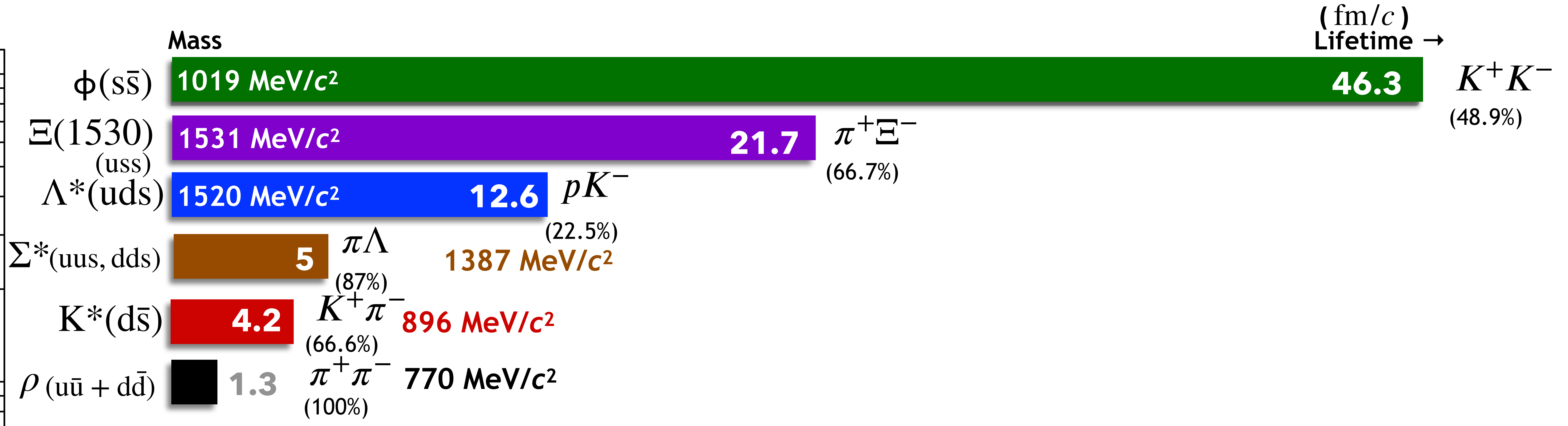
- $\Sigma(1385)^{\pm}$ **- Short lifetime**
  - Flat in pp, p-Pb
    - Consistent with Thermal model prediction
  - No measurement in Pb-Pb from ALICE
    - No suppression in result from STAR (Au+Au)
  - EPOS prediction: No suppression

- **Resonance yield is not only affected by lifetime**

Full Story: Particle Ratio in Resonances

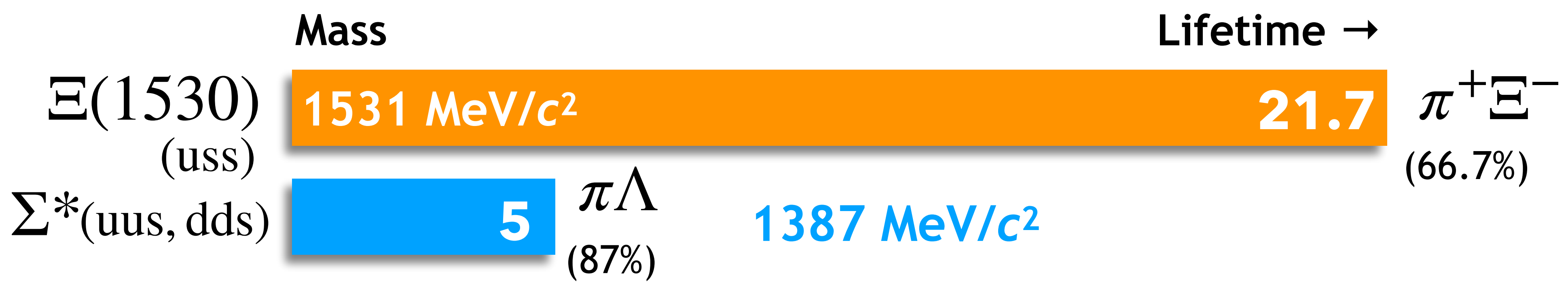
Suppression vs Constant

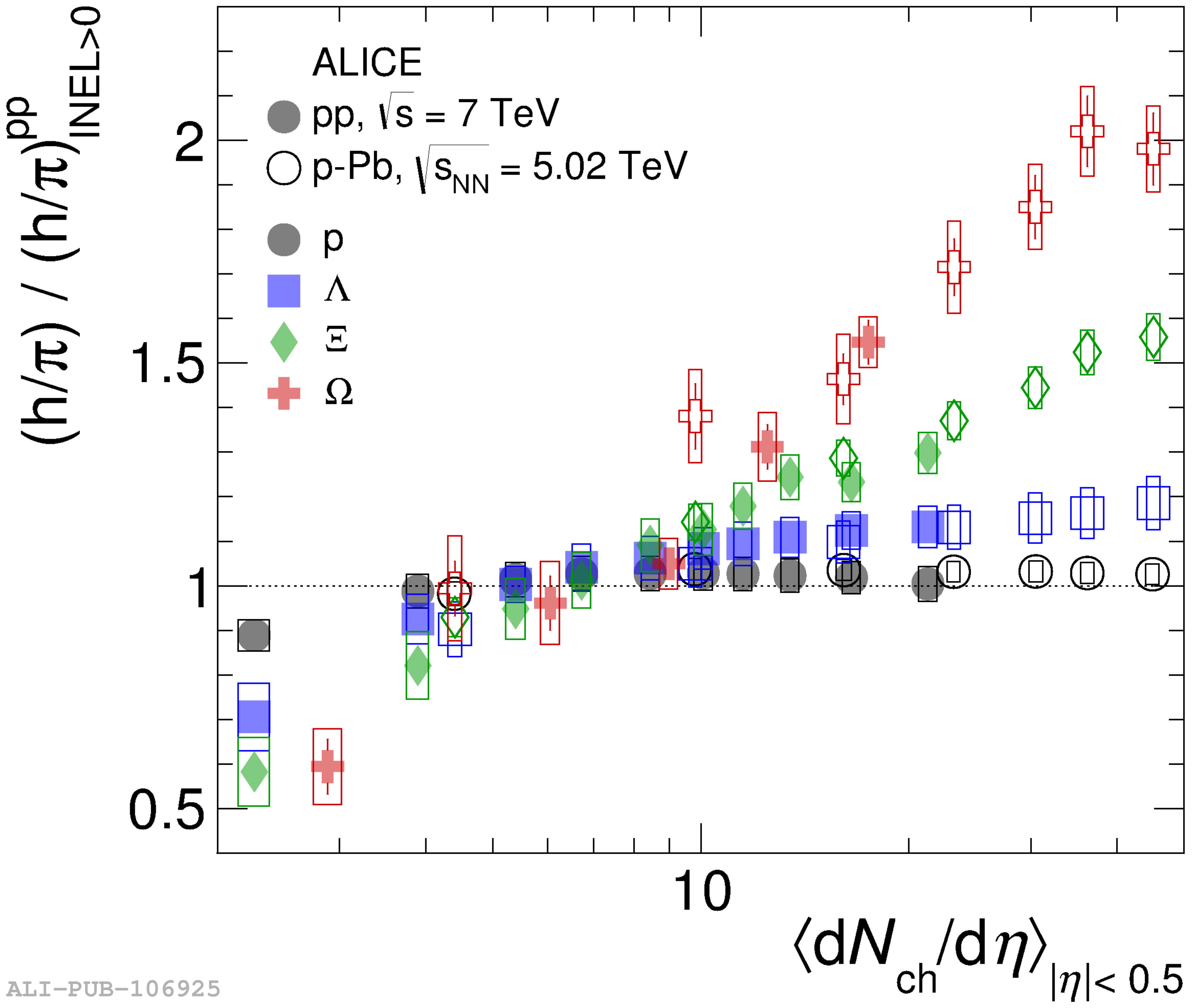




- **Overview**
  - No energy dependence for RHIC to LHC
  - EPOS3 with UrQMD describes the result qualitatively.
  - Lifetime is not the only consideration
    - Re-scattering vs Re-generation?
    - Different scattering cross-section

Strangeness Enhancement in Resonances

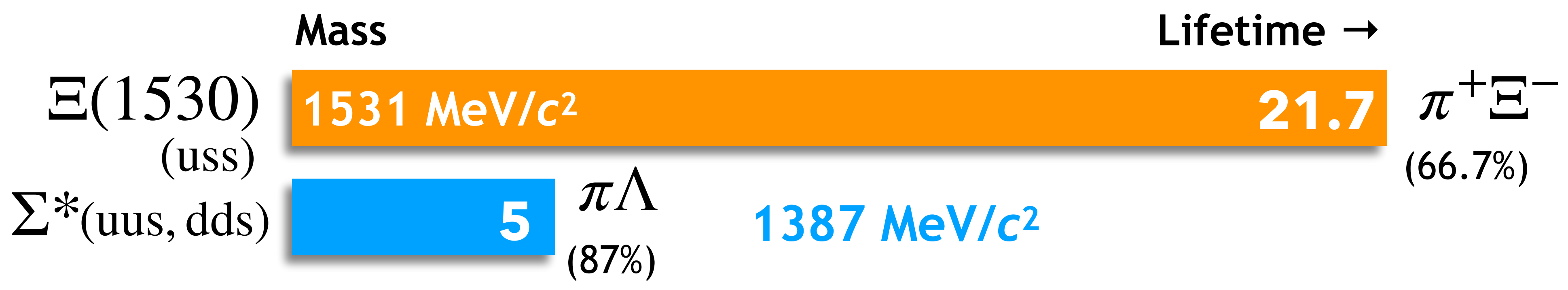


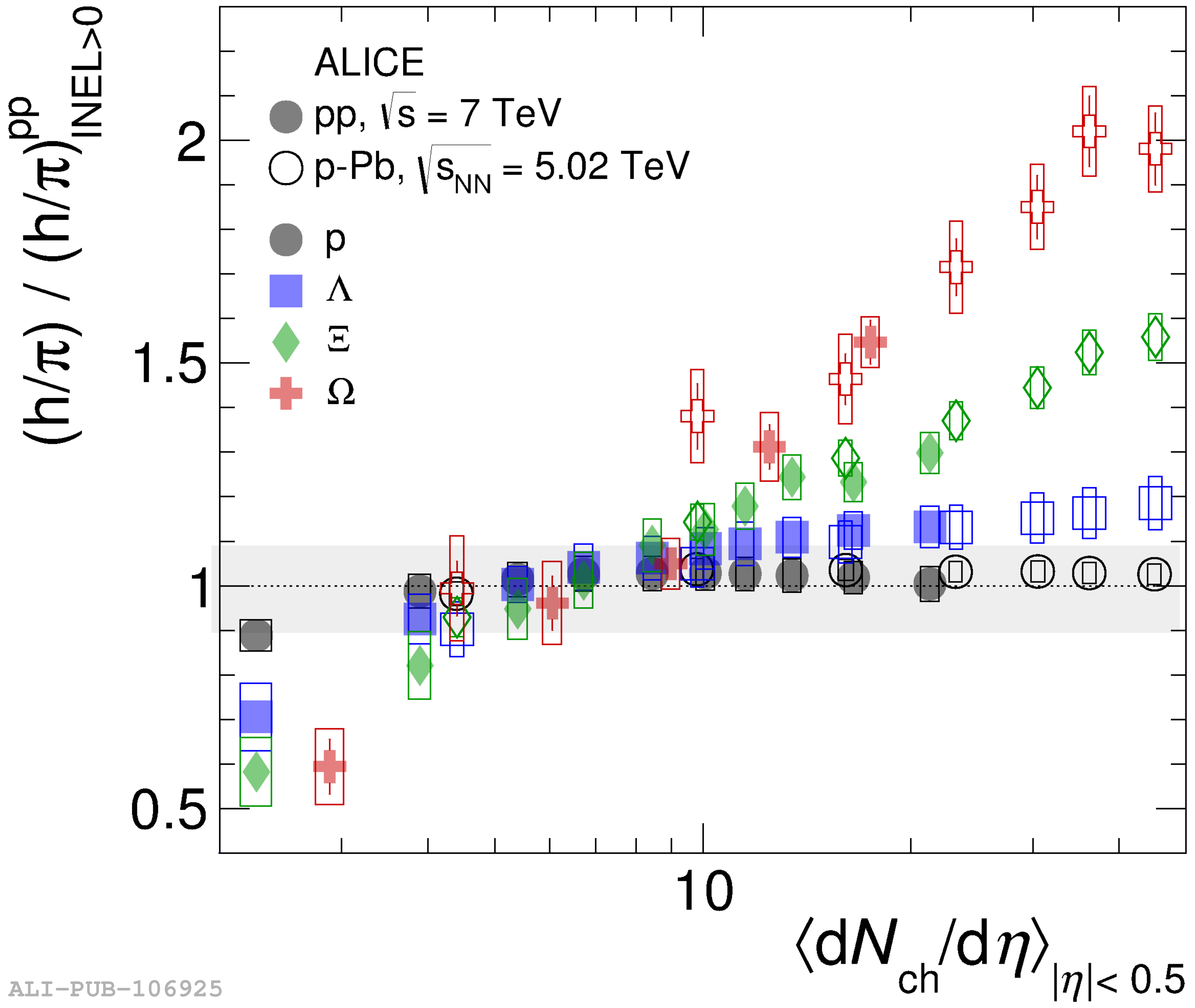


- **Strangeness enhancement in small systems**
  - Does it really come from the strangeness?
  - How about baryon number, mass?
    - <u>Baryon number?</u> -
    - <u>Mass?</u> -

Baryon	Mass (MeV/c²)	|S|
Ω	1672	3
Ξ	1530	2
Σ*	1385	1
Ξ	1322	2
Λ	1116	1
p	938	0

Strangeness Enhancement in Resonances





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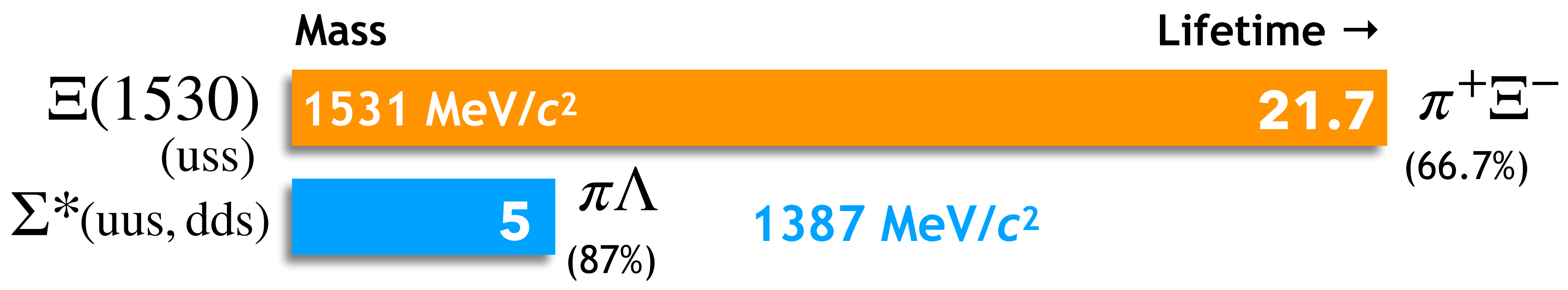

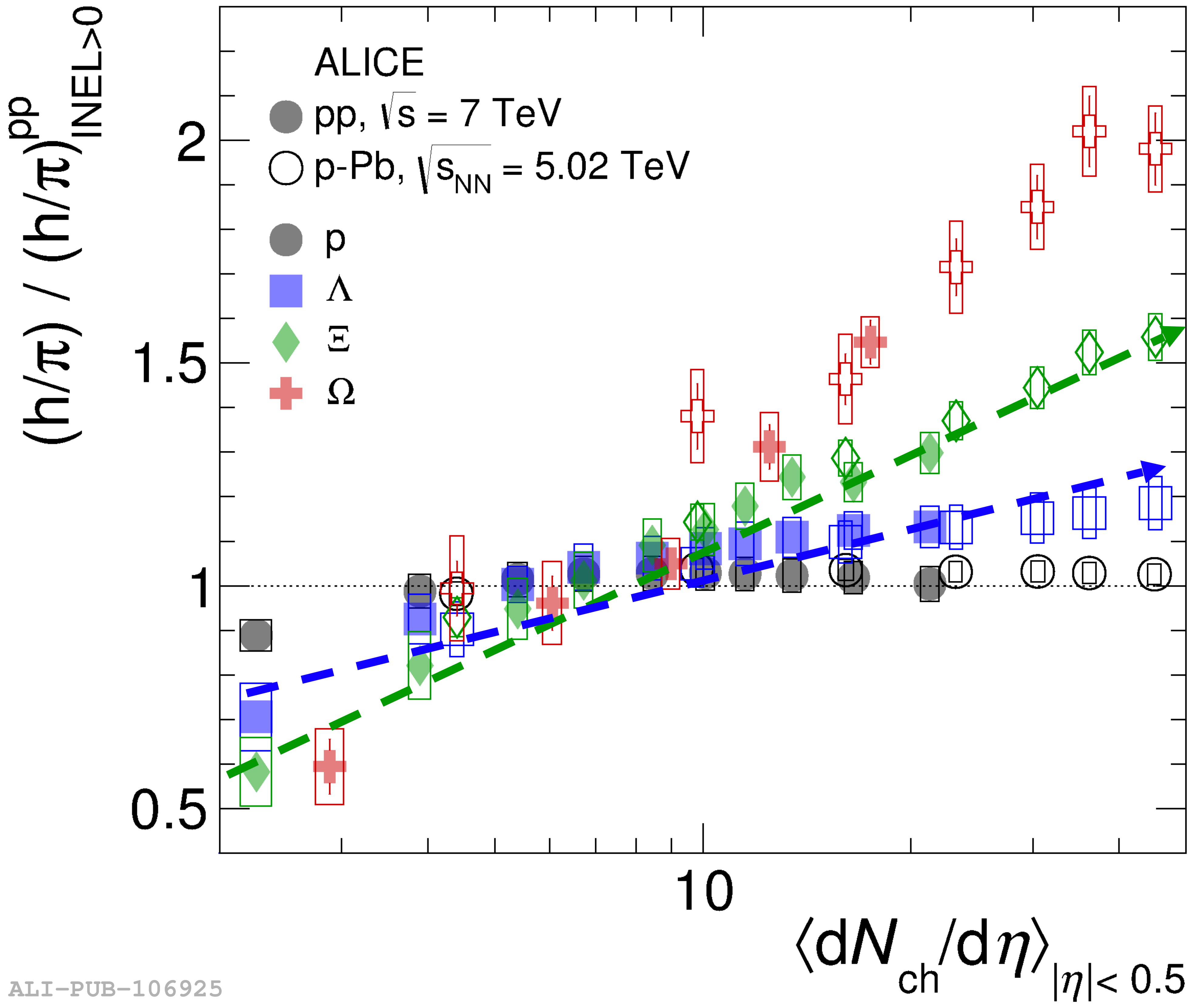

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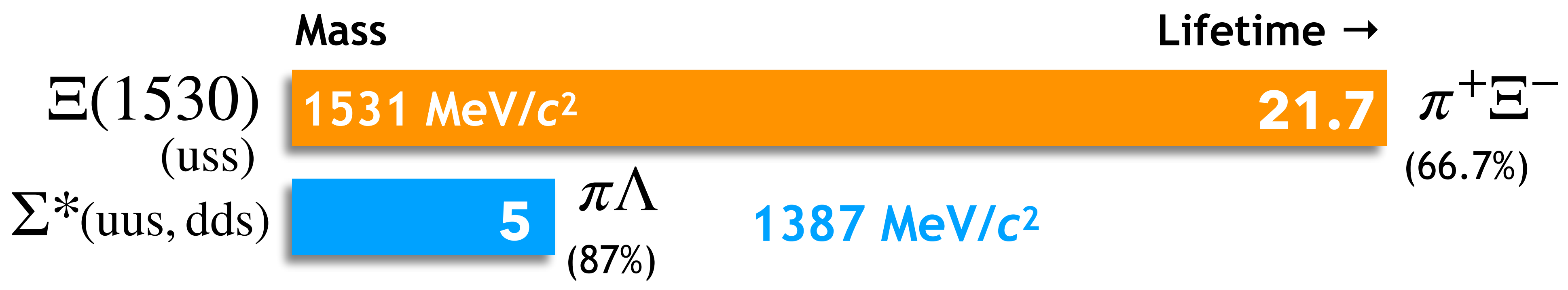

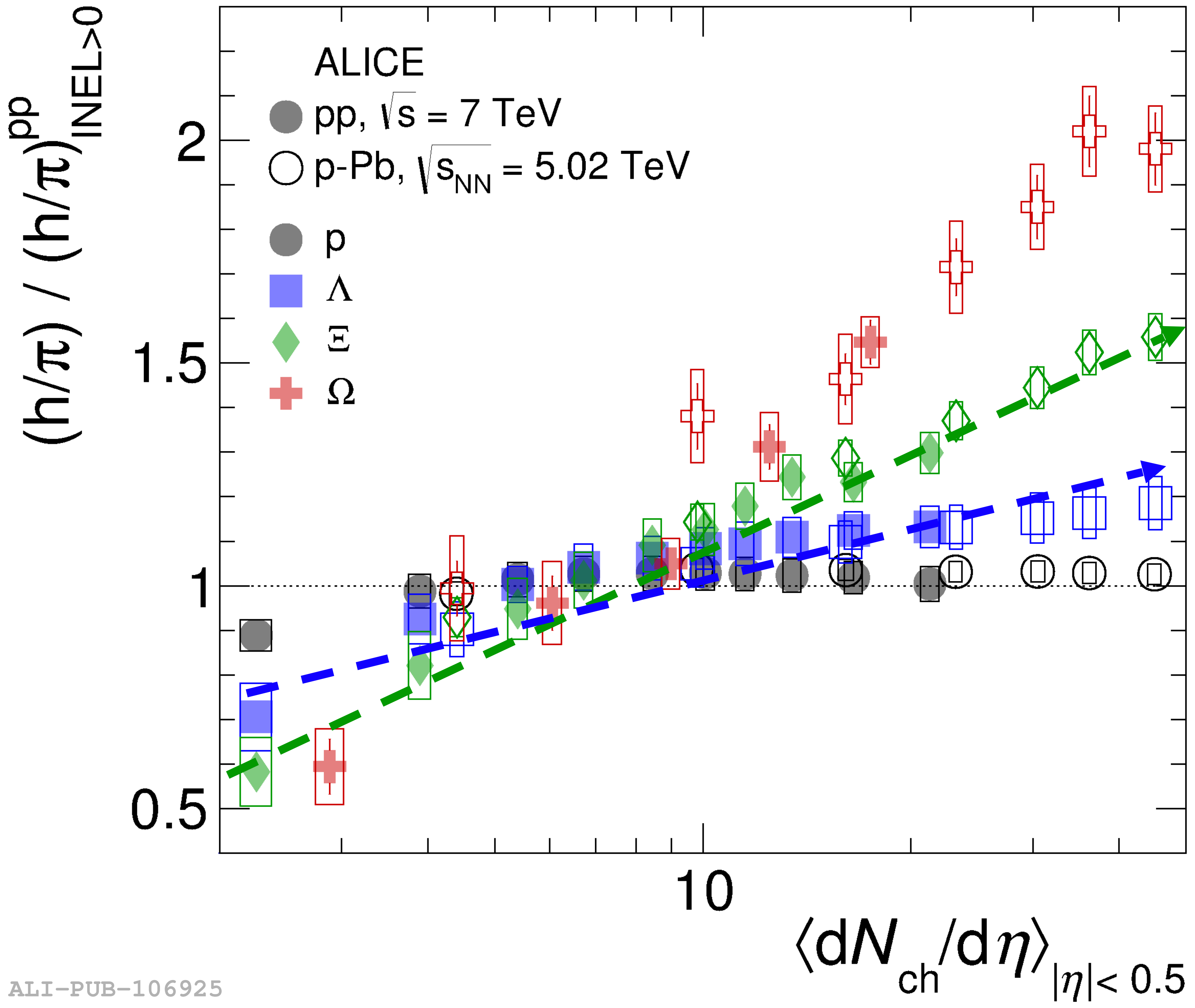

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- **Solid conclusion:**

  O Enhancement in small system comes from **Strangeness**

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Summary

- **Resonances are useful tools to probe the characteristics of the hadronic phase.**
  - Various masses, lifetimes, particle types, strangeness…
- **ALICE has measured a rich set of resonance particles in various systems.**
- **An Example of Resonance Analysis was shown.**
  - From the Event Selection to the Final spectra.
- **(Non-)Suppression of Resonances in large collision system**
  - Short-lived particles (ρ, K^*, Λ^*) - Suppressed
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  - Long-lived particles (ϕ) - not suppressed
  - **Lifetime is not the only consideration** ($\Sigma(1385)$)
- **Strangeness enhancement in p-Pb** was due to the strangeness, not mass, baryon number

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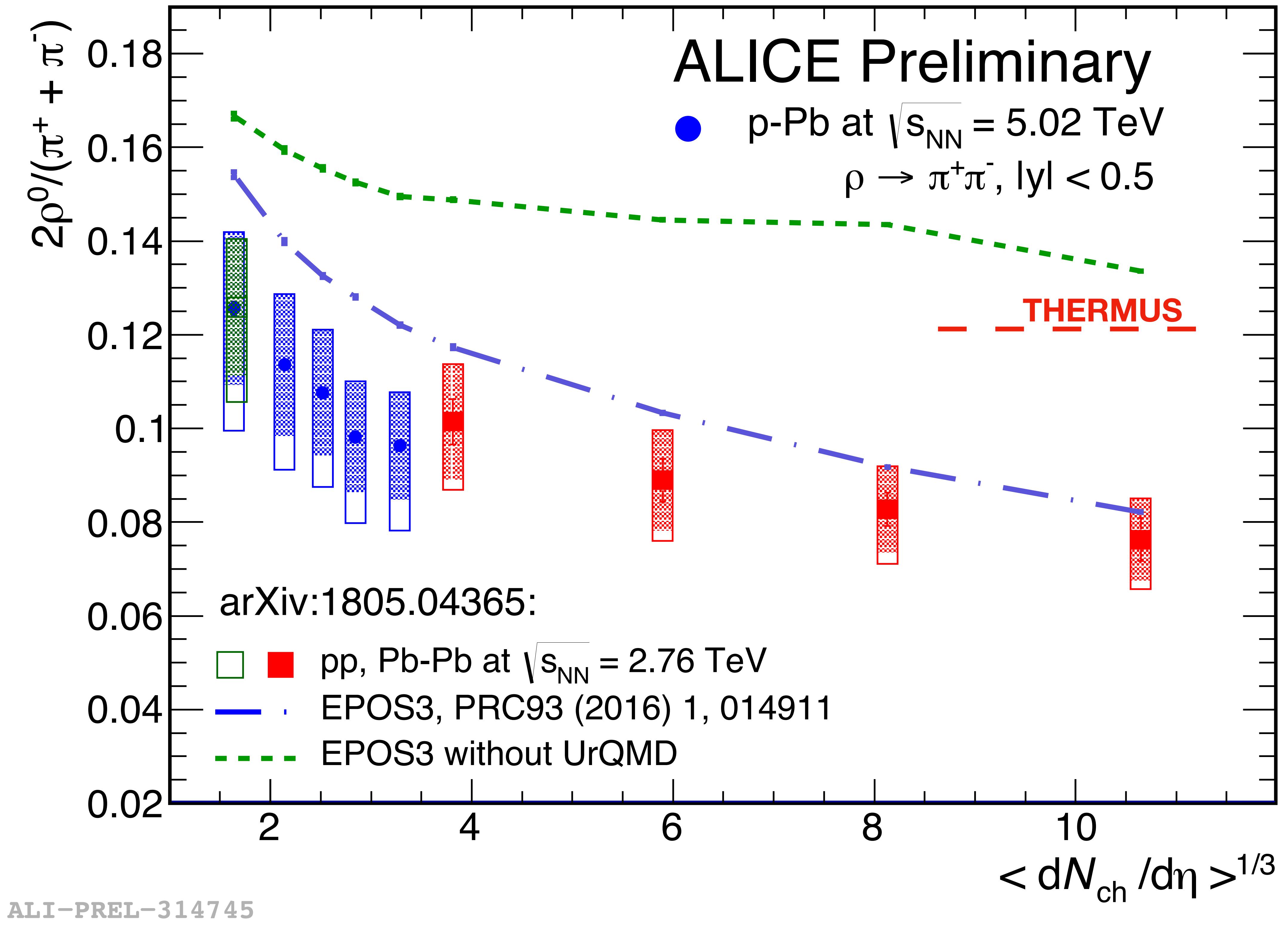
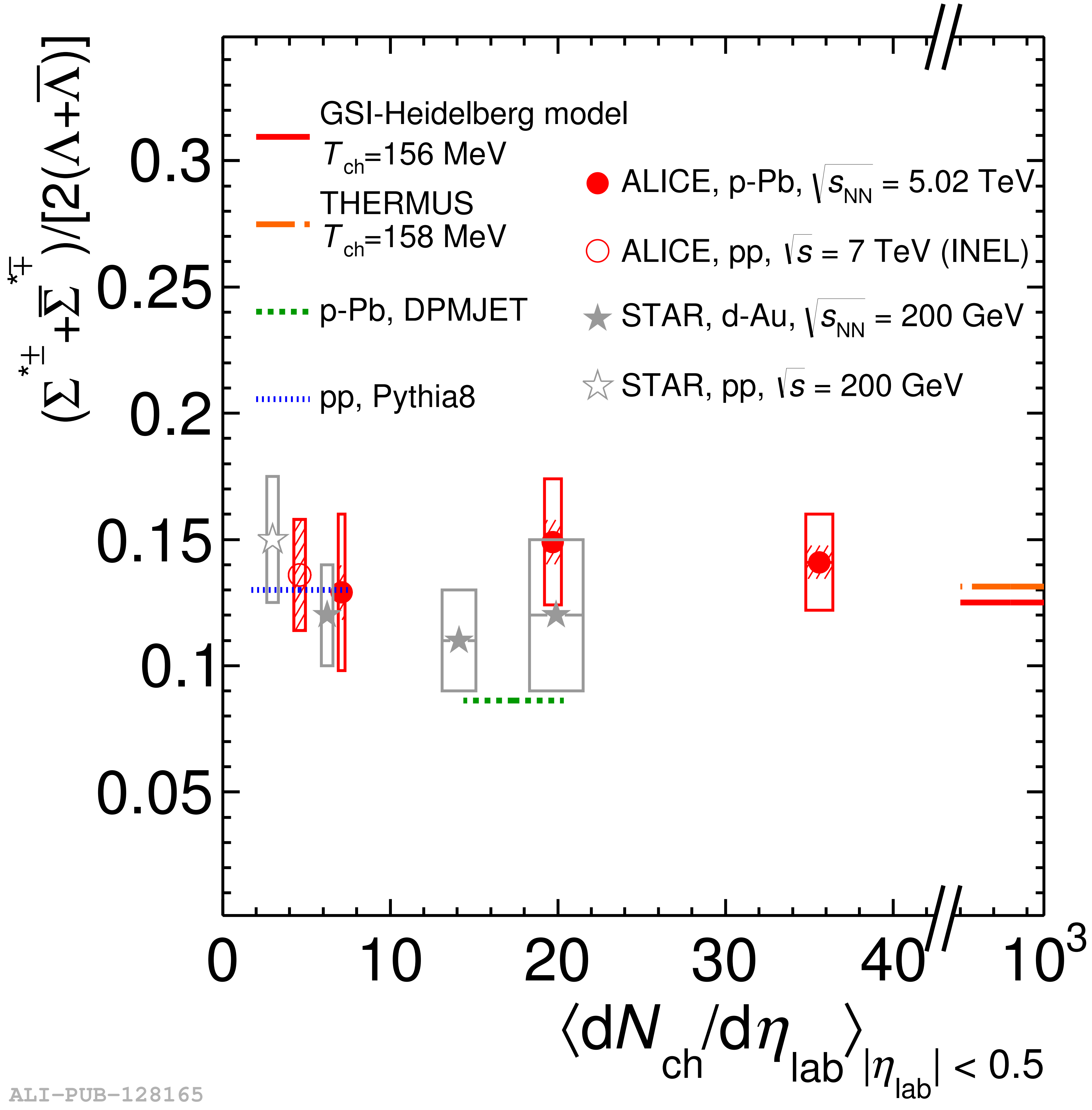
Thanks

Backup

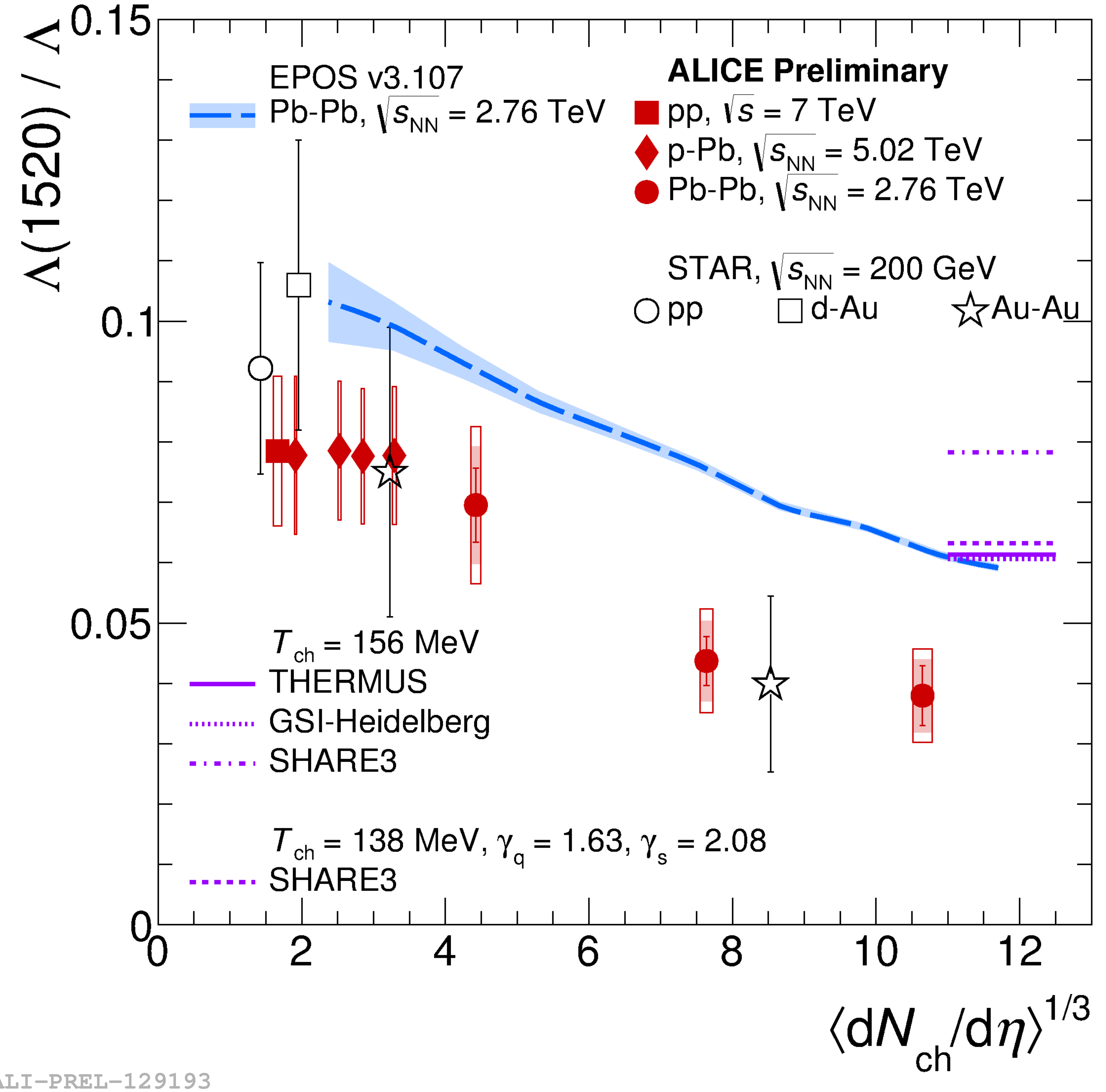
$\rho(770)$, $\Sigma(1385)^{\pm}$

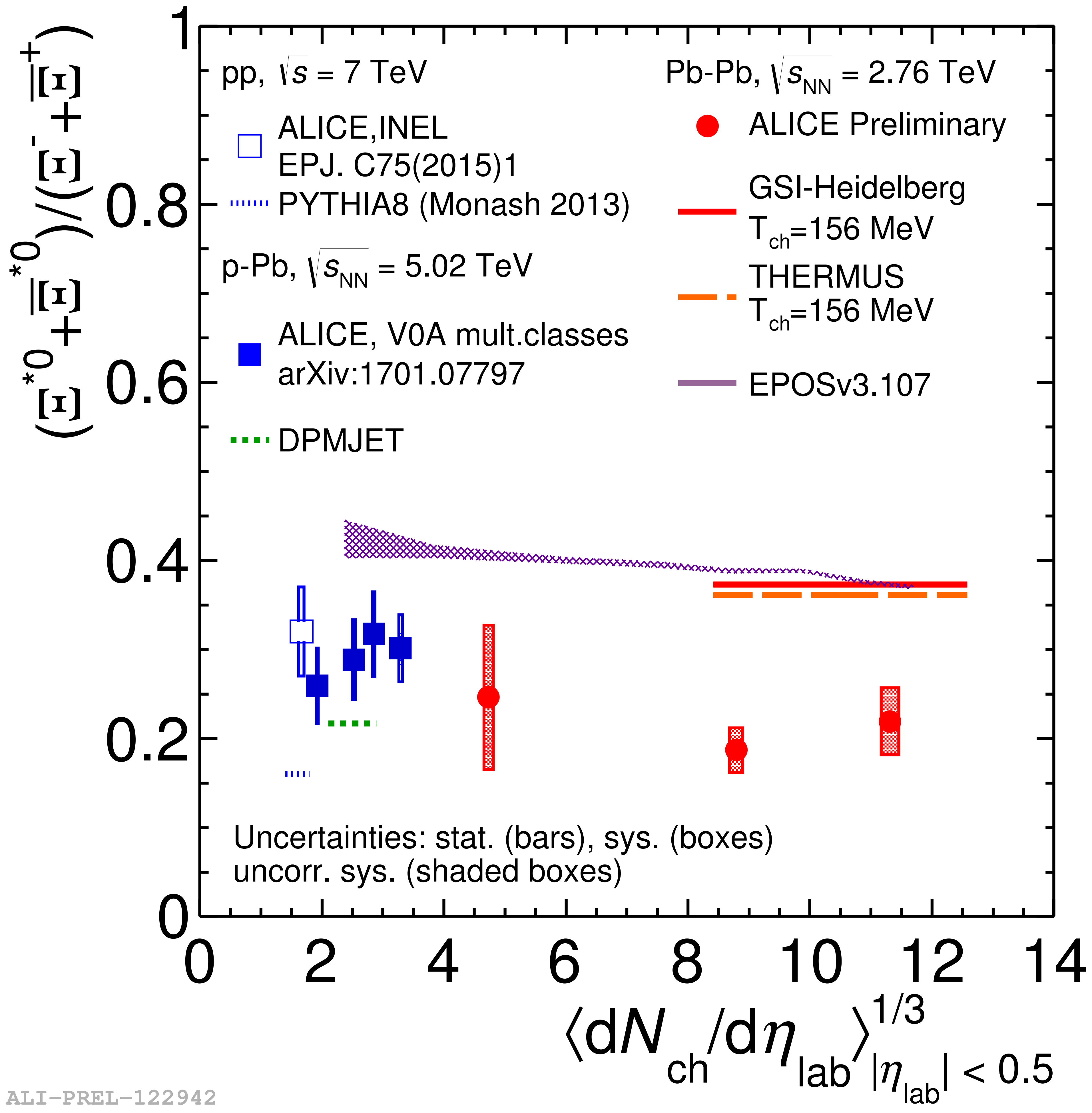




$\Lambda(1520)$, $\Xi(1530)^0$

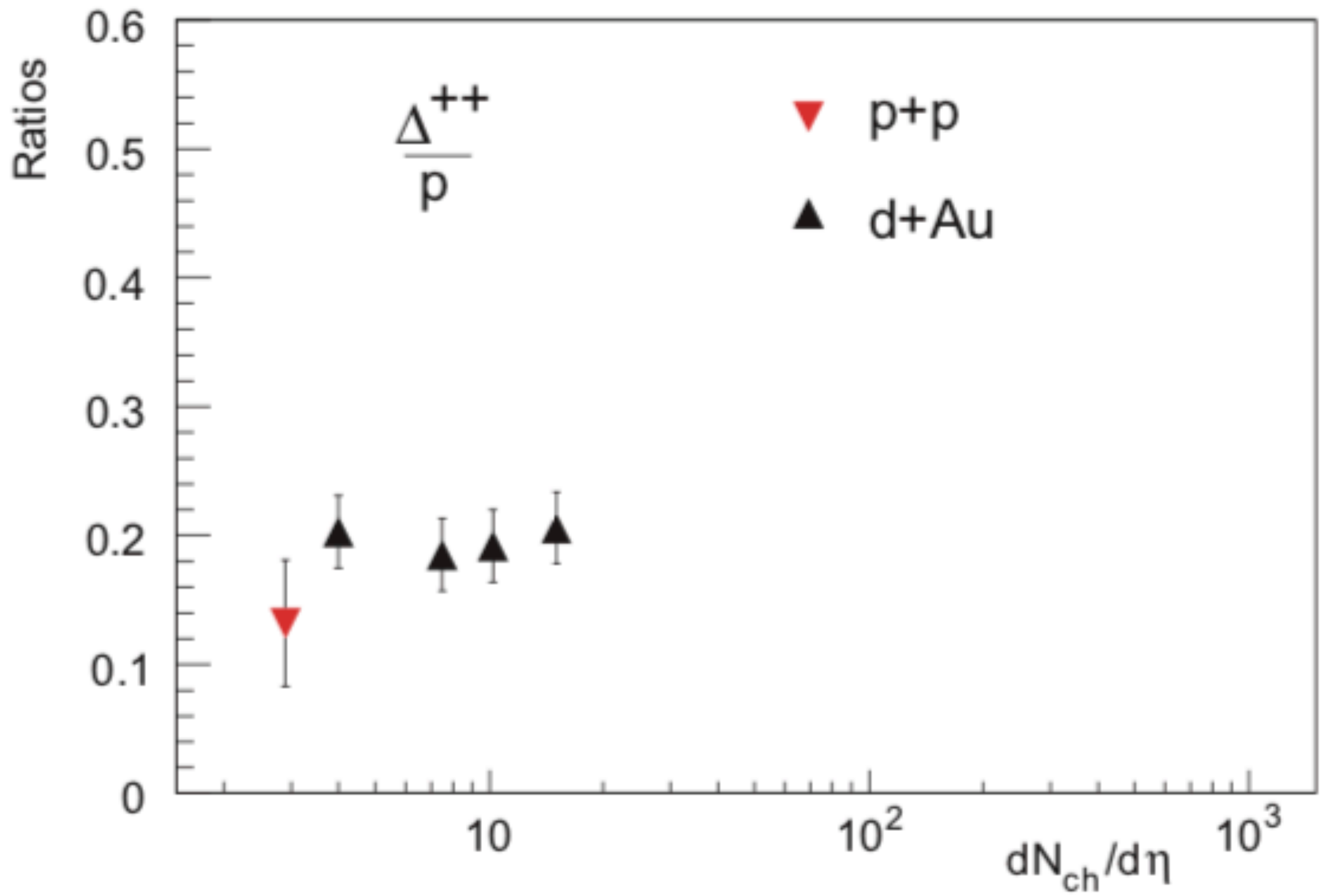
ALICE





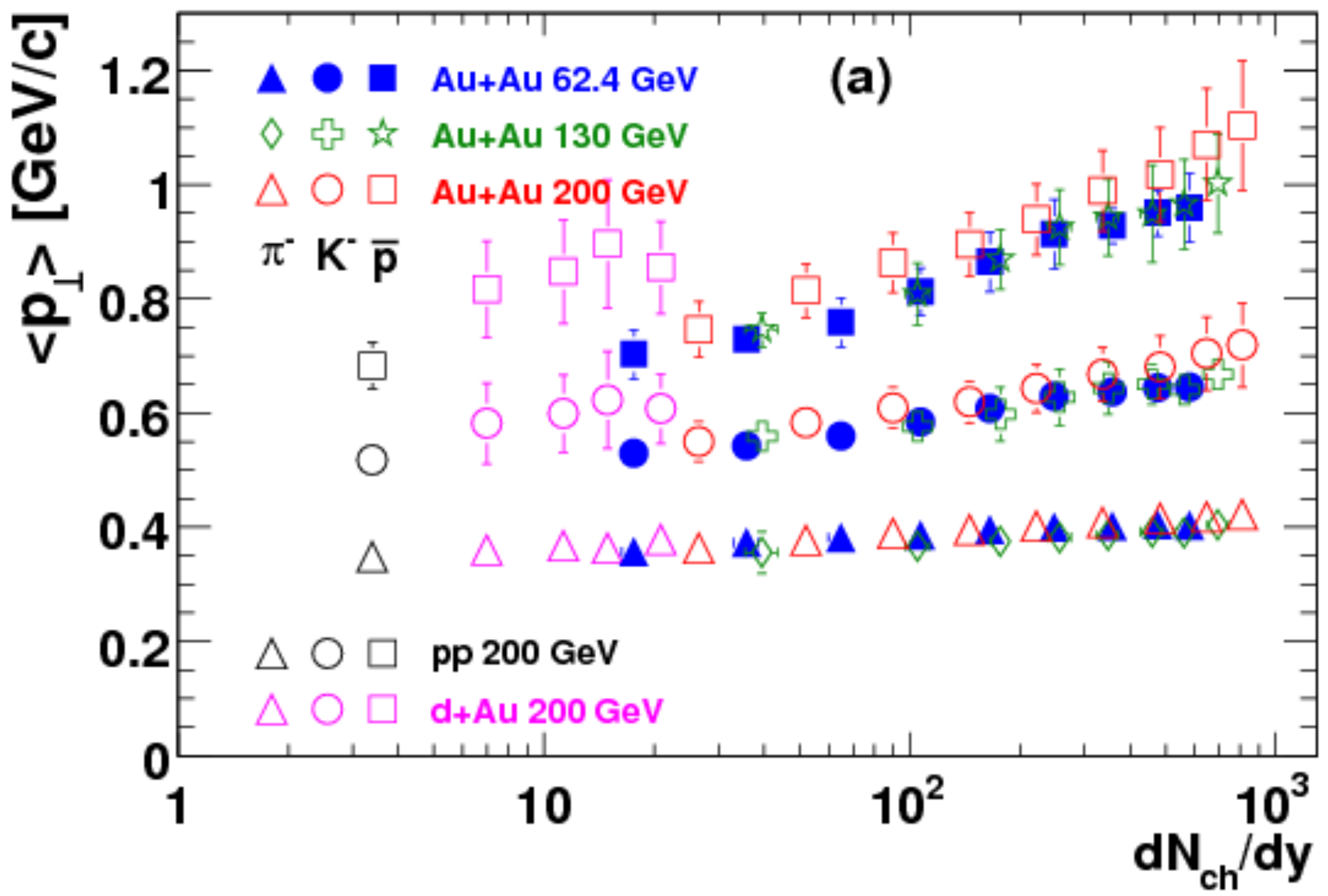
Δ^{++} in RHIC

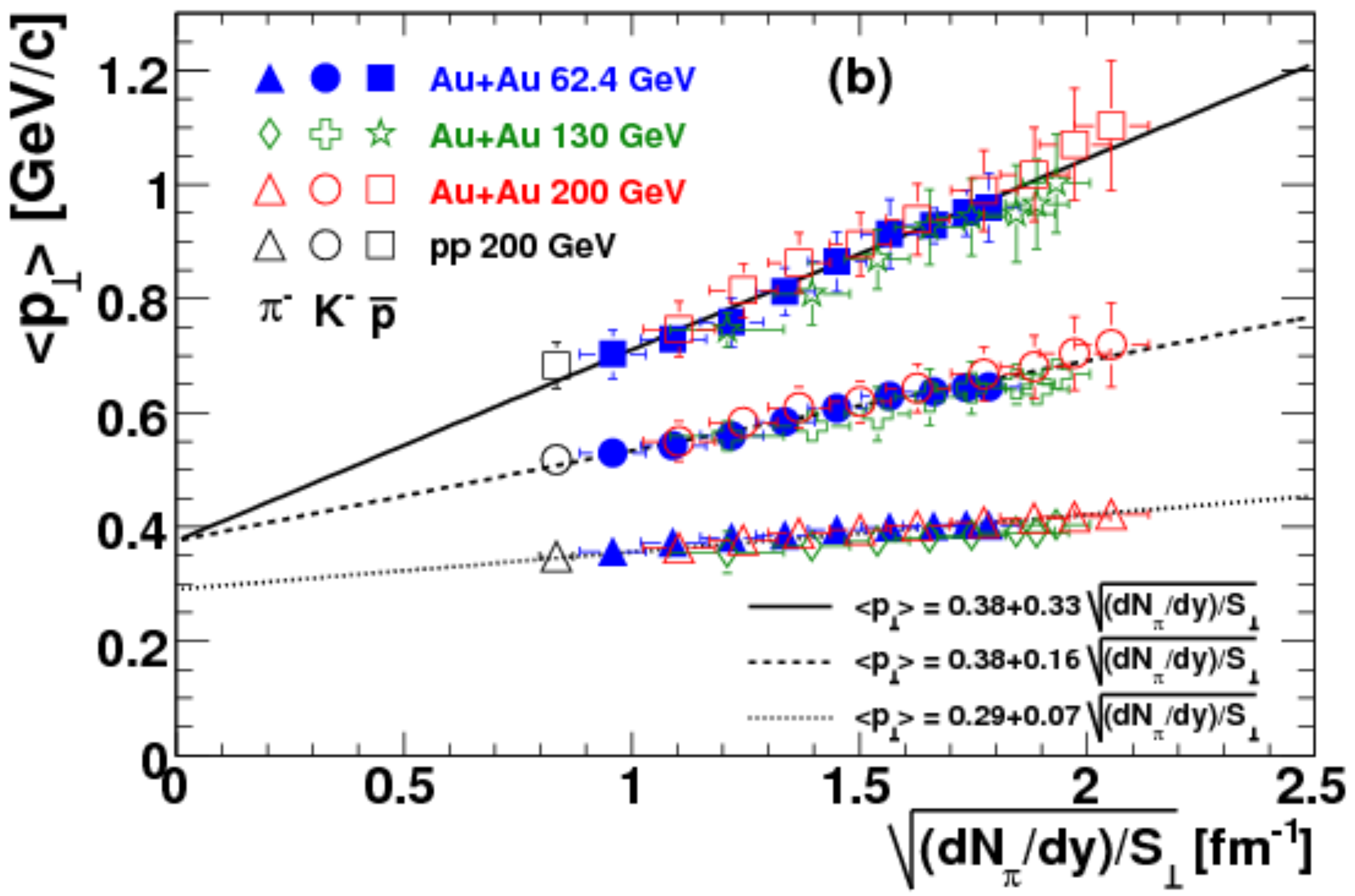
B. I. Abelev et al. (STAR Collaboration) Phys. Rev. C 78, 044906 , t = 1.6 fm



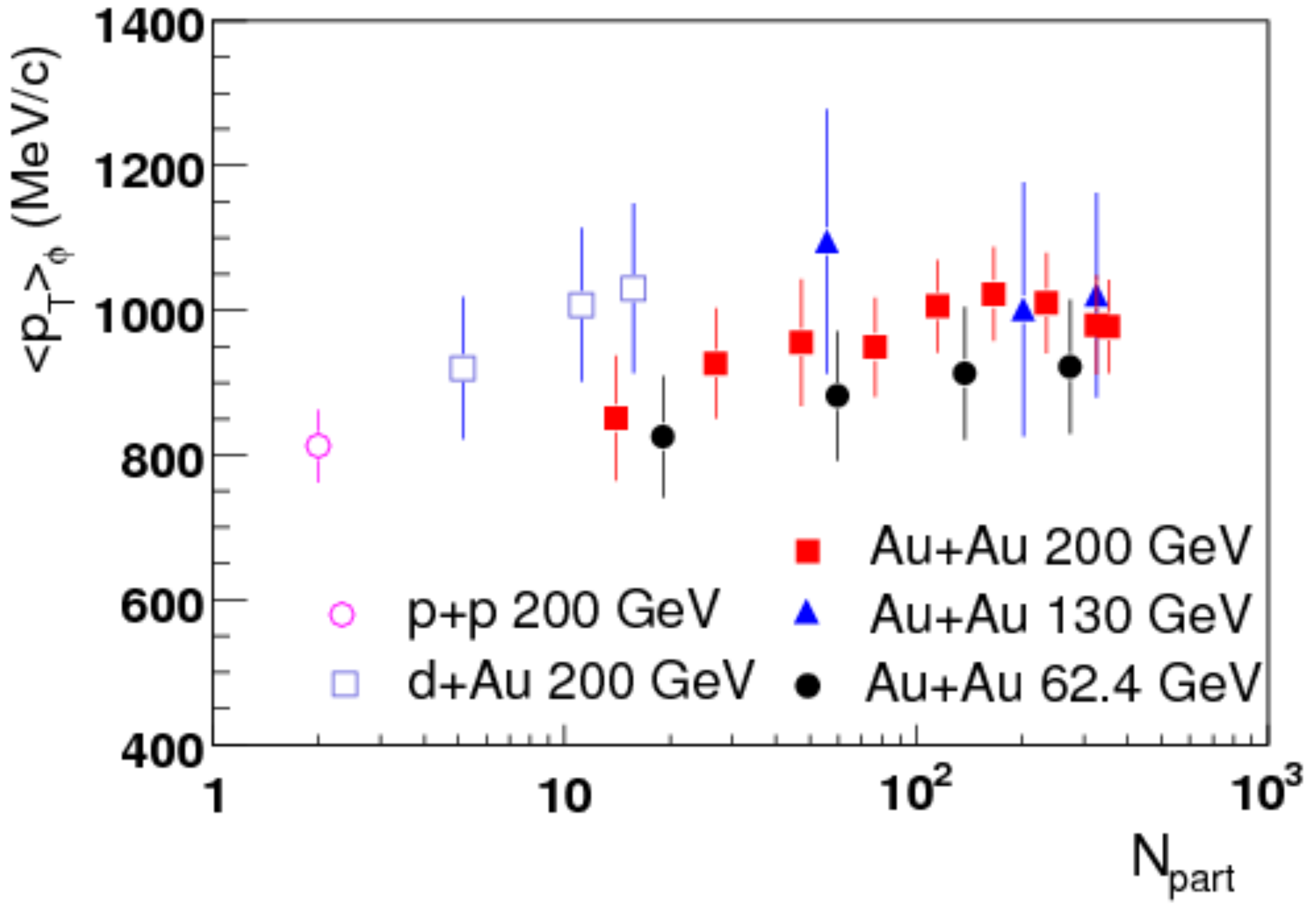
Φ, K* Mean pt in RHIC

B. I. Abelev et al. [STAR Collaboration], Phys. Rev. C 79, 034909 (2009). arXiv:0808.2041

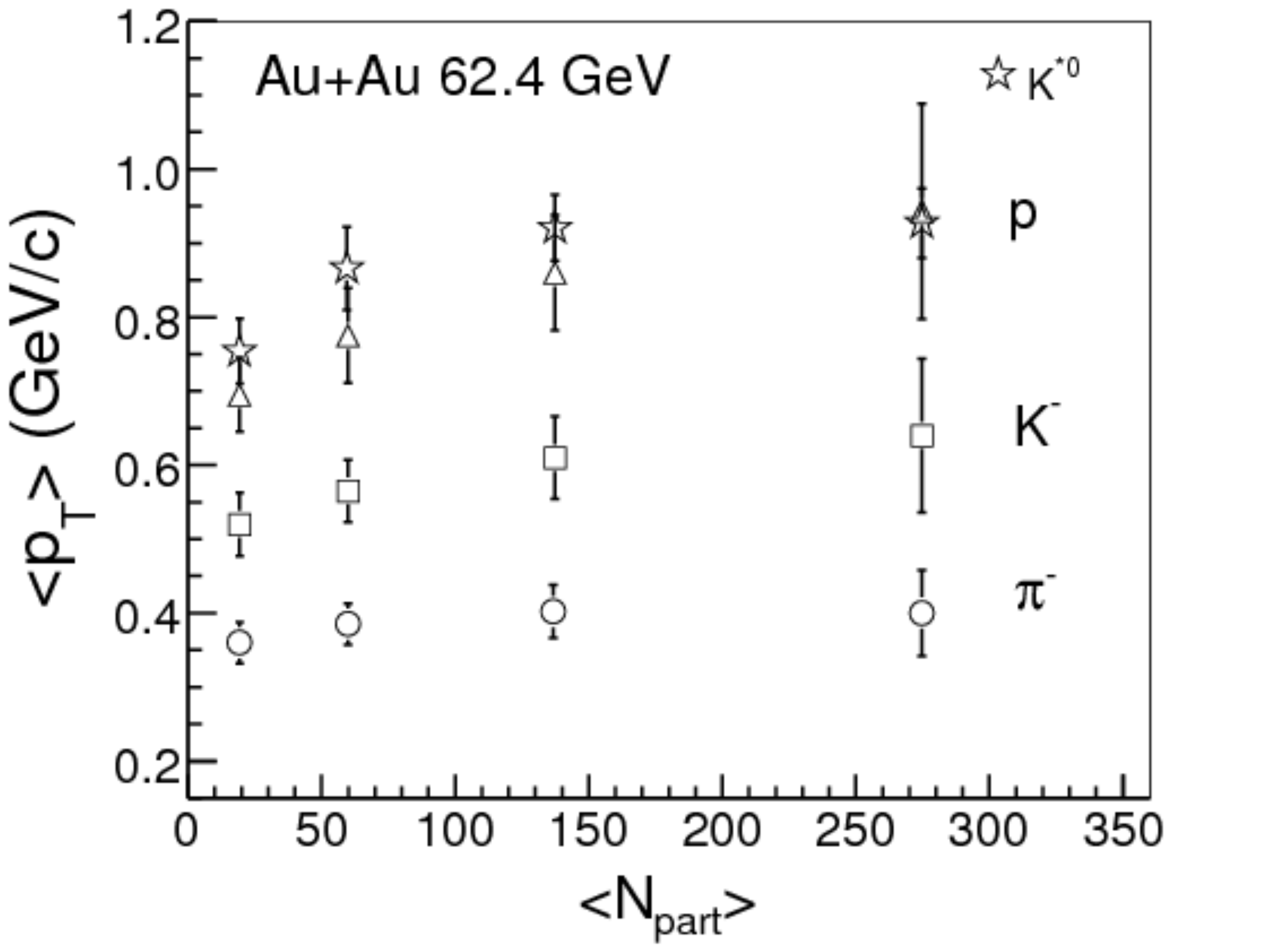




Phys.Rev. C79 (2009) 064903 arXiv:0809.4737 [nucl-ex]



Phys.Rev. C84 (2011) 034909 arXiv:1006.1961 [nucl-ex]



Particle ratio Φ/K

J. Adamczewski-Musch et al. (HADES), Phys. Lett. B 778, 403 (2018), arXiv:1703.08418.