# Hadronic resonance production with ALICE at the LHC

Sergey Kiselev (NRC KI - ITEP Moscow) for the ALICE collaboration

- Motivation
- ALICE detector
- Signal extraction
- $p_T$ spectra
- Mean transverse momentum
- Yields
- Ratios to stable hadrons
- Nuclear modification factors
- Summary

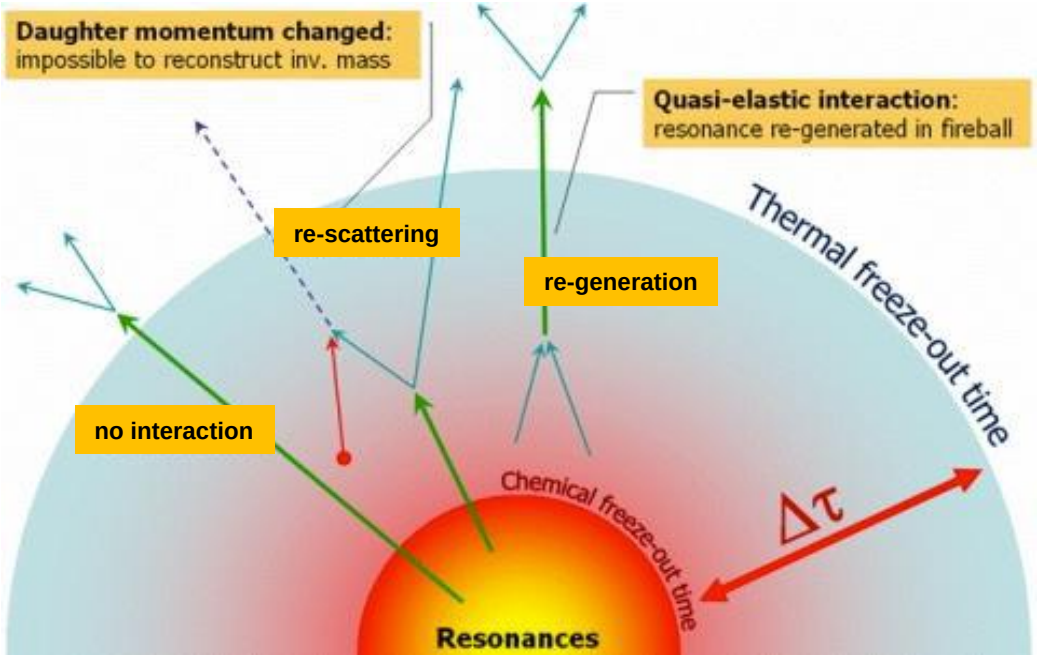
# Motivation

- **pp and p-Pb collisions:**
  - ✓ the baseline for heavy-ion collisions
  - ✓ system size dependence
  - ✓ role of cold nuclear matter
  - ✓ study of collectivity in small systems

- **AA collisions**:
  - ✓ in-medium energy loss
    - → nuclear modification factor for resonances
  - ✓ restoration of chiral symmetry
    - → modification of width, mass and branching ratio
  - ✓ re-generation and rescattering effects
    - → modification of yield and ratios to stable hadrons
    - → timescale between chemical and kinetic freeze-out

## recent results for resonances

| Resonance | cτ (fm) | Decay | System @energy (TeV) |
|---|---|---|---|
| **$\rho(770)^0$** | 1.3 | **$\pi\ \pi$** | pp/Pb-Pb@2.76 |
| **$K^*(892)^0$** | 4.2 | **$K\ \pi$** | pp@7/13 p-Pb/Pb-Pb@5.02 Xe-Xe@5.44 |
| **$\Sigma(1385)^{\pm}$** | 5-5.5 | **$\Lambda\ \pi$** | pp@7 p-Pb /Pb-Pb@5.02 |
| **$\Lambda(1520)$** | 12.6 | **p K** | pp@7 p-Pb@5.02 Pb-Pb@2.76 |
| **$\Xi(1530)^0$** | 21.7 | **$\Xi^-\ \pi$** | pp@7 p-Pb@5.02 Pb-Pb@2.76 |
| **$\phi(1020)$** | 46.4 | **K K** | pp@7/13 p-Pb/Pb-Pb@5.02 Xe-Xe@5.44 |

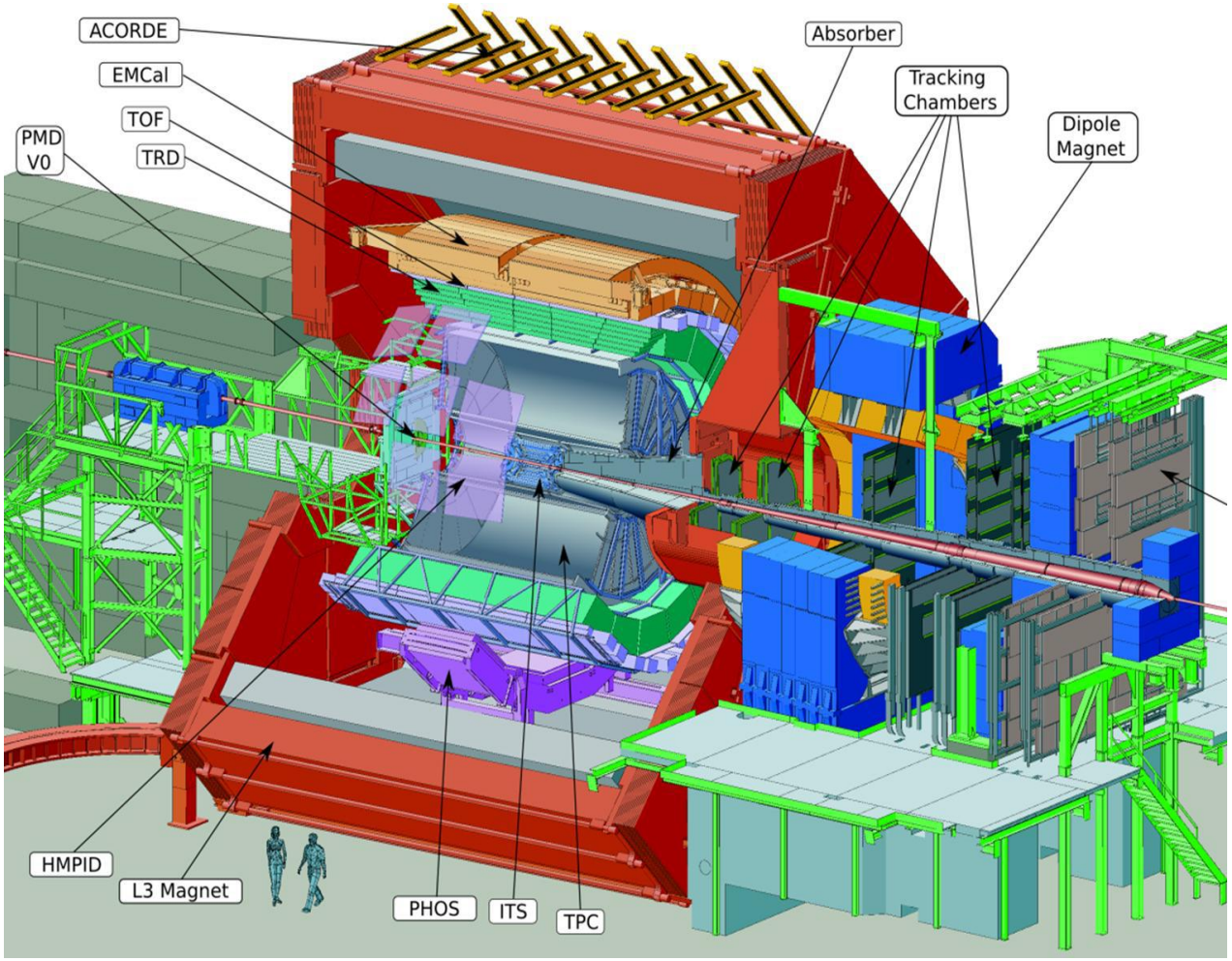


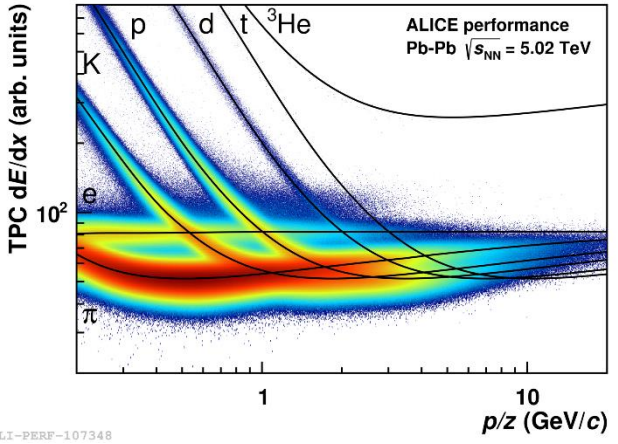
# ALICE detector

**V0** (scintillators):
→ triggering minimum bias collisions
→ centrality/multiplicity estimator

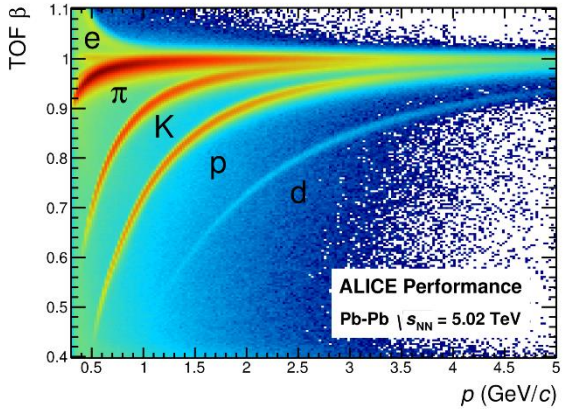
**ITS**: tracking and vertexing

**TPC**: tracking and PID through d*E*/d*x*




**TOF**: PID through particle time of flight



# Signal extraction

**Λ(1520)**

**pp@7 TeV**

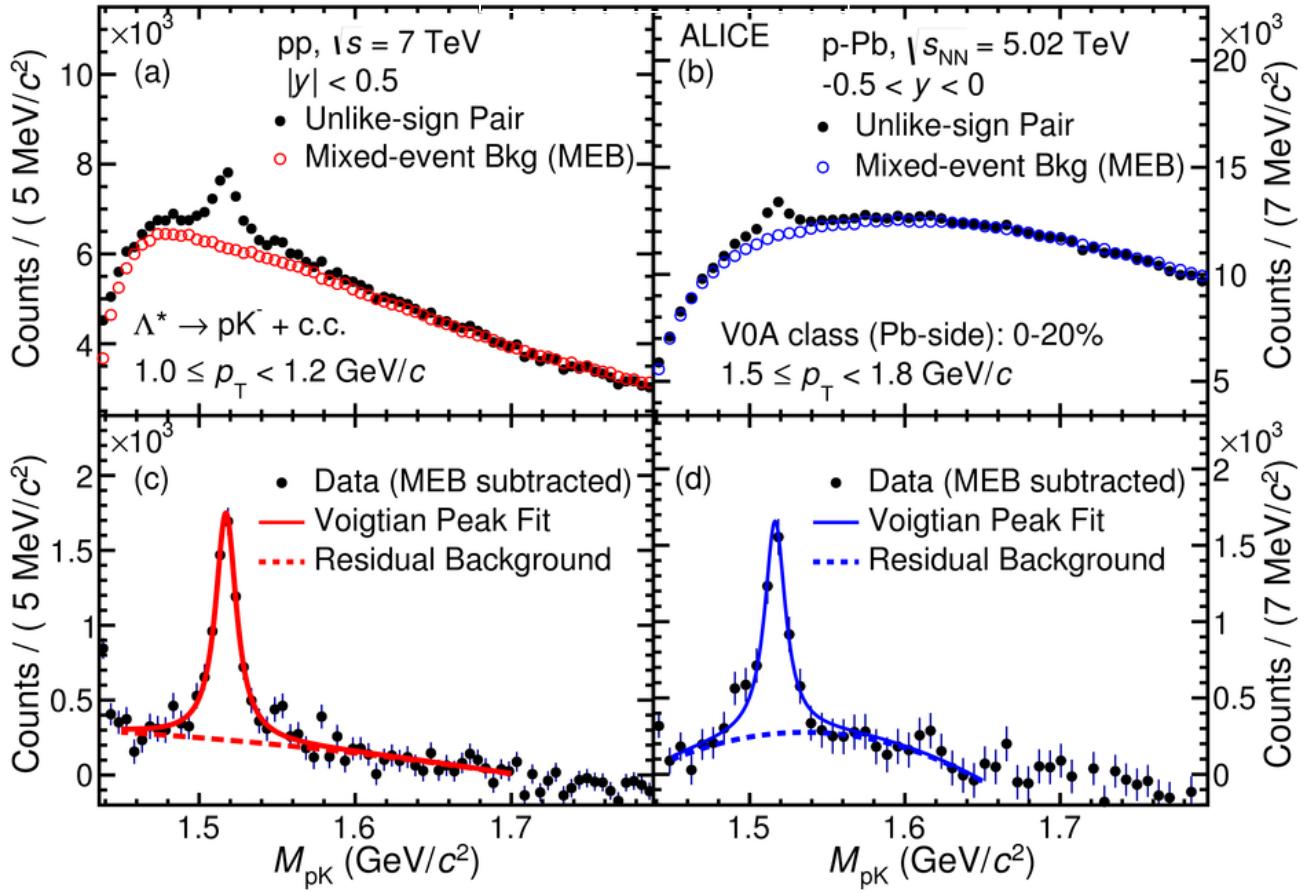
**p-Pb@5.02 TeV**

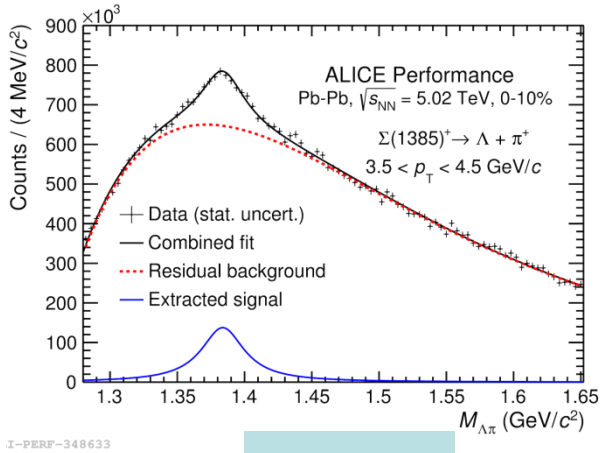
arXiv:1909.00486

**NEW**

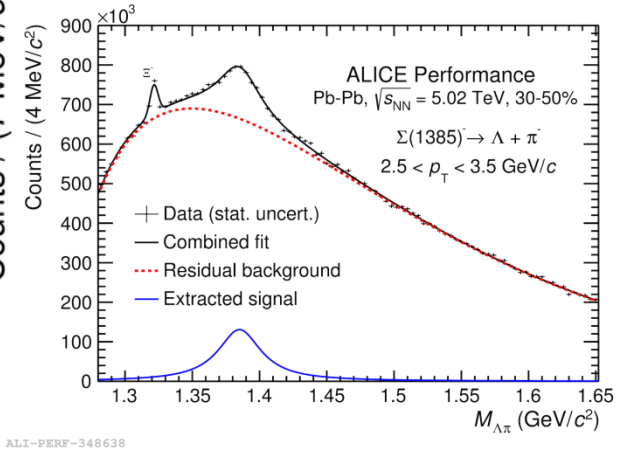
**Pb-Pb@5.02 TeV**

**Σ(1385)⁺**



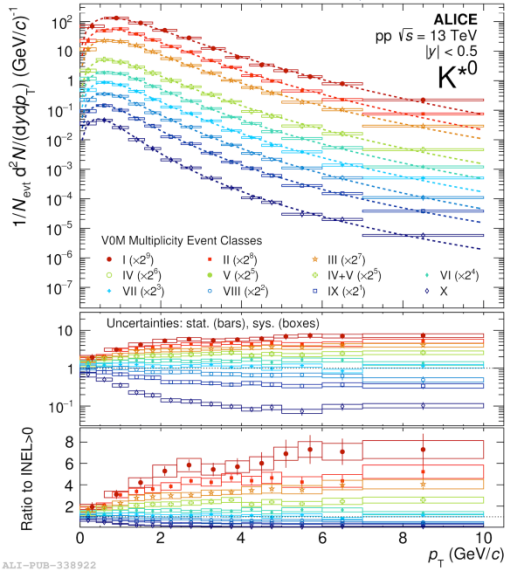

**Σ(1385)⁻**

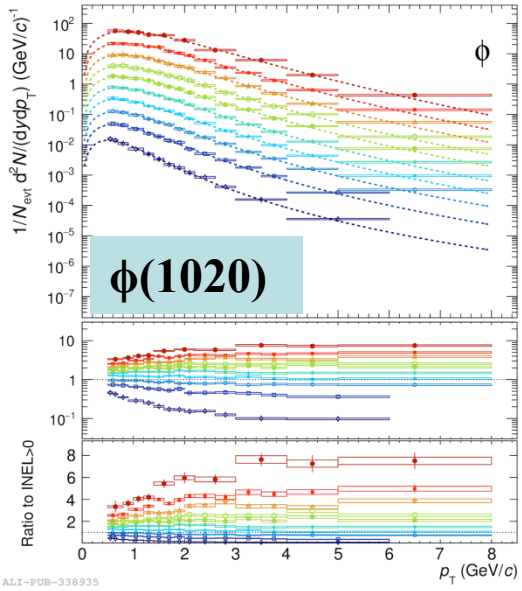


# $p_T$ spectra

**pp@13 TeV**

PL **B802** (2020) 135225



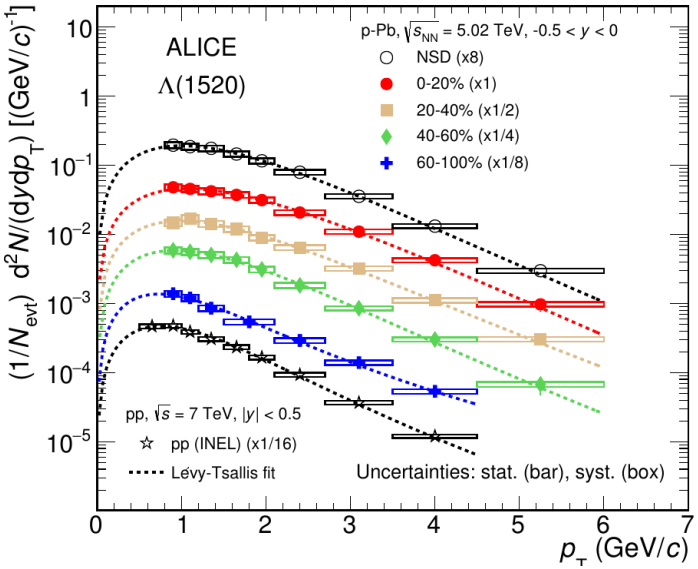

**ϕ(1020)**

**NEW**

**p-Pb@5.02 TeV**

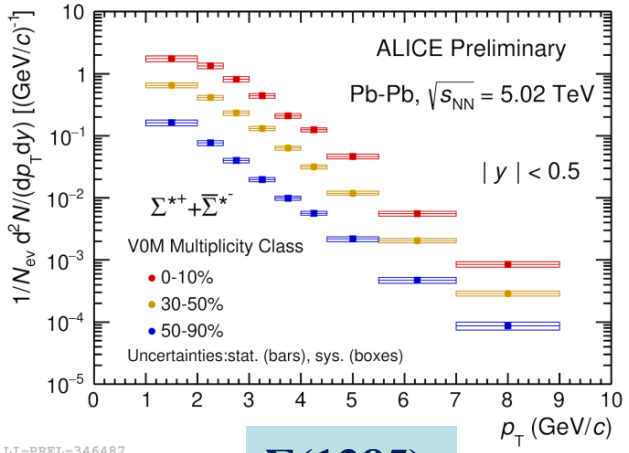
**Λ(1520)**

arXiv:1909.00486

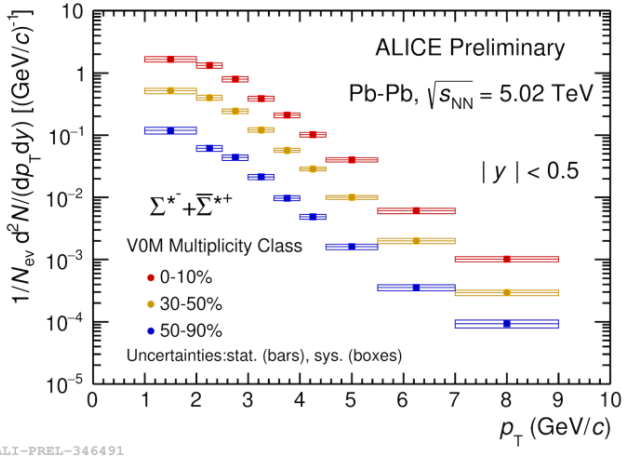



**Pb-Pb@5.02 TeV**

**Σ(1385)$^+$**




**Σ(1385)$^-$**



# ‹ $p_T$ › vs. $dN_{ch}/d\eta$

**Pb-Pb@2.76 ATeV**

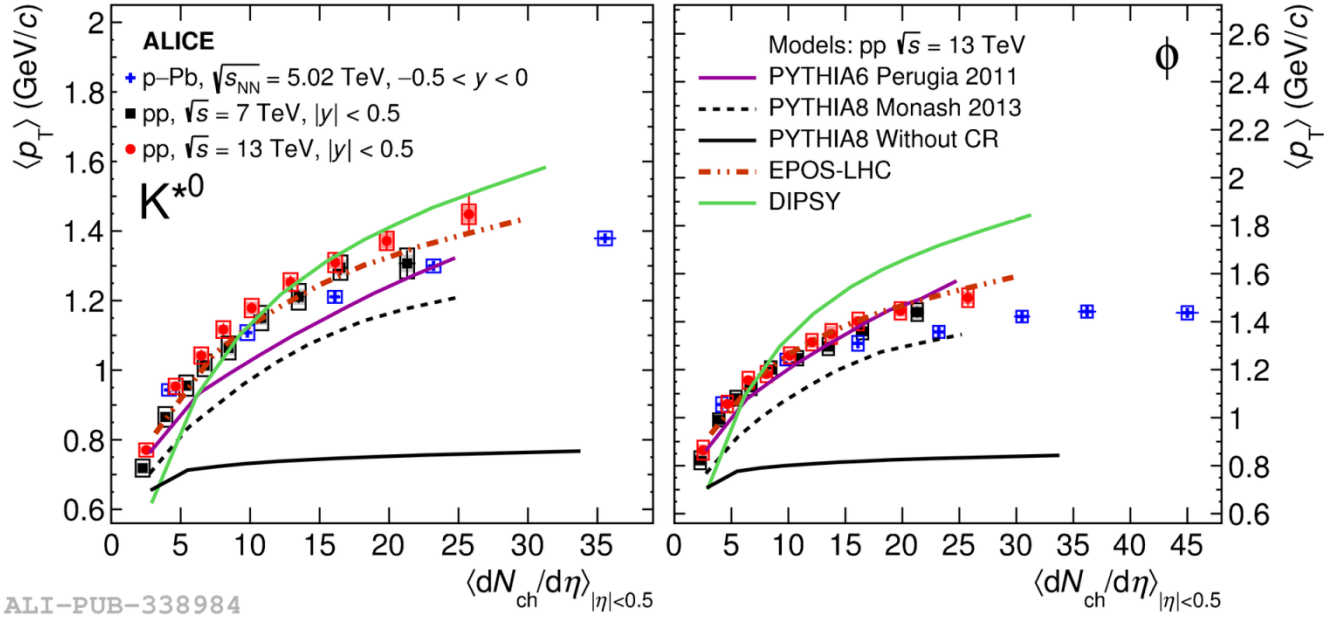
**NEW**

**pp@13 TeV**

**K*(892)$^0$**

**ϕ(1020)**

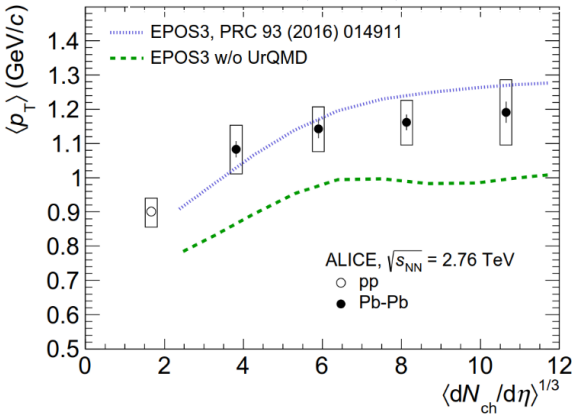
PL **B802** (2020) 135225




agree with EPOS with UrQMD

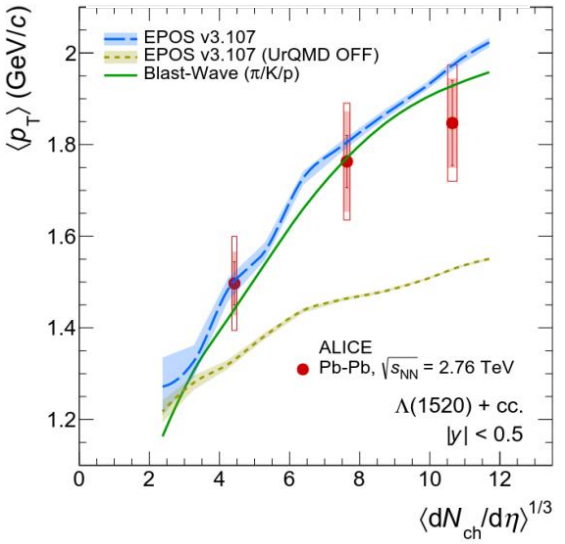
**ρ(770)$^0$**

PR **C99** (2019) 064901



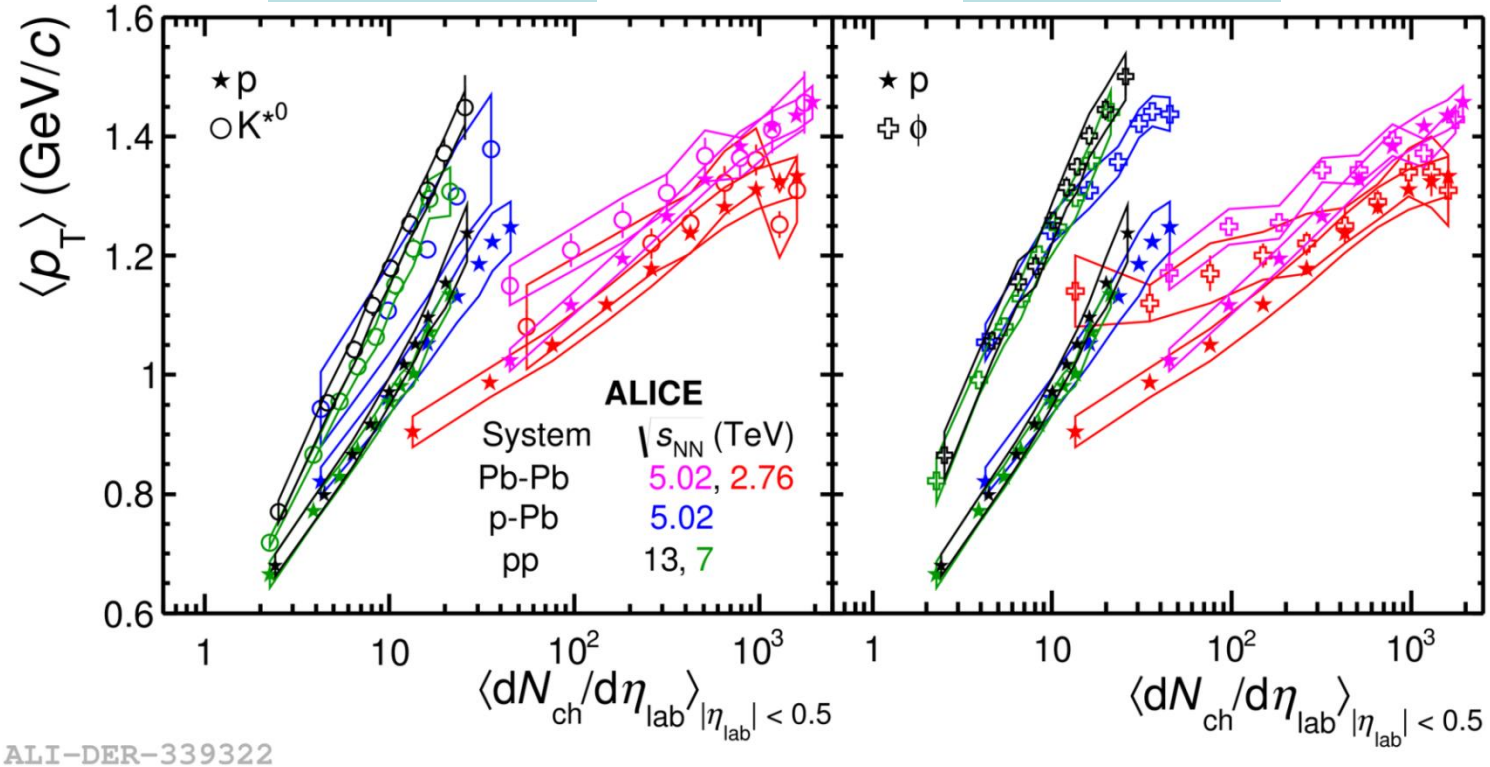

**Λ(1520)**

PR **C99** (2019) 024905



# ‹ $p_T$ › - system dependence

**K*(892)$^0$ vs. p** **NEW** **ϕ(1020) vs. p**




- pp: the increase with multiplicity at 13 TeV is similar to 7 TeV
- central Pb-Pb: mass ordering , ‹ $p_T$ ›$_{K^*}$ ≈ ‹ $p_T$ ›$_p$, ‹ $p_T$ ›$_\phi$ ≈ ‹ $p_T$ ›$_p$
  as expected from hydrodynamics
- pp, p-Pb: mass ordering breaks down , ‹ $p_T$ ›$_{K^*}$ > ‹ $p_T$ ›$_p$, ‹ $p_T$ ›$_\phi$ > ‹ $p_T$ ›$_p$,
- pp, p-Pb: steeper increase with multiplicity (can be understood as the effect of color reconnection between strings produced in multi-parton interactions)

# yields vs. $dN_{ch}/d\eta$

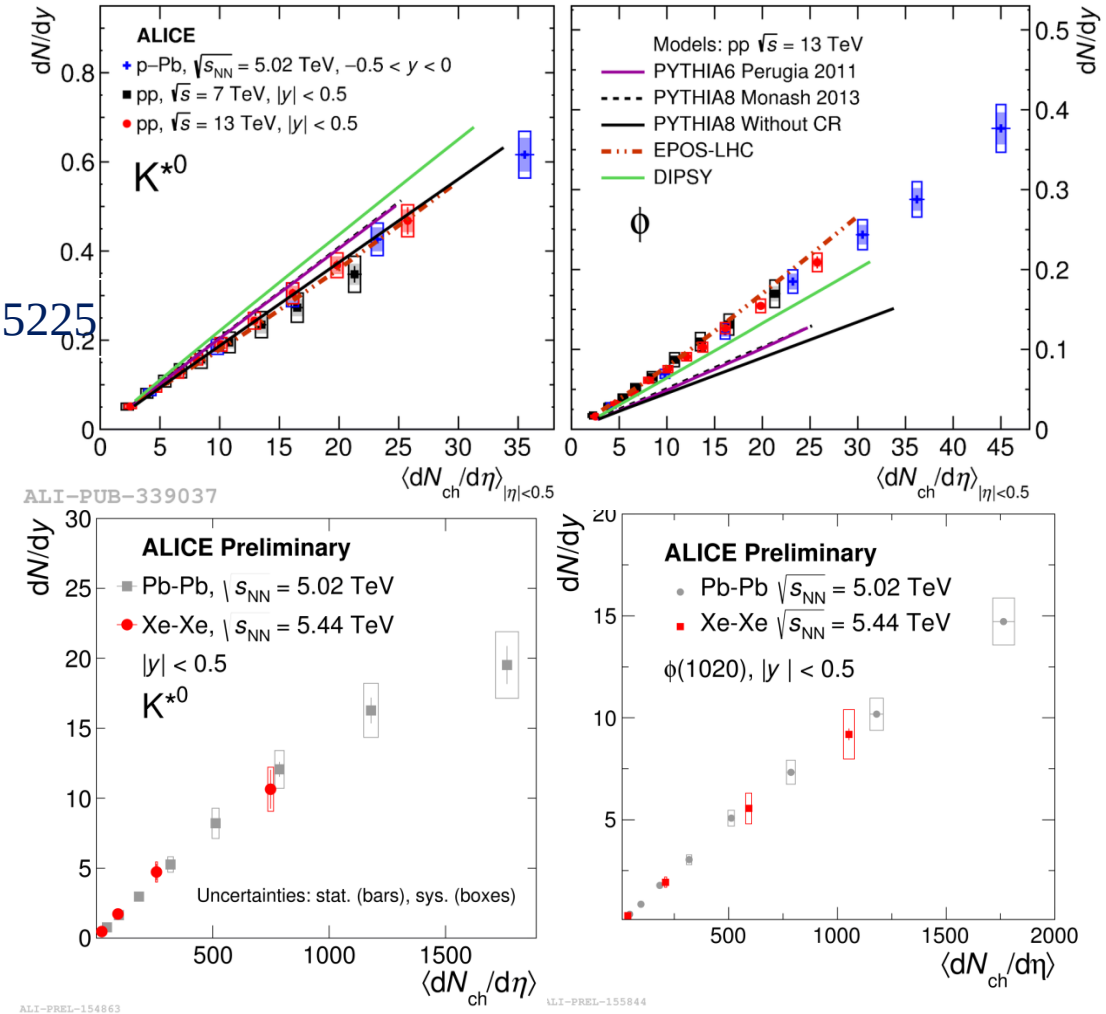
**NEW**

**pp, p-Pb**

PL **B802** (2020) 135225

**Xe-Xe, Pb-Pb**

**K*(892)$^0$** **$\phi$(1020)**




yields independent of collision system and energy

yields appear to be driven by event multiplicity

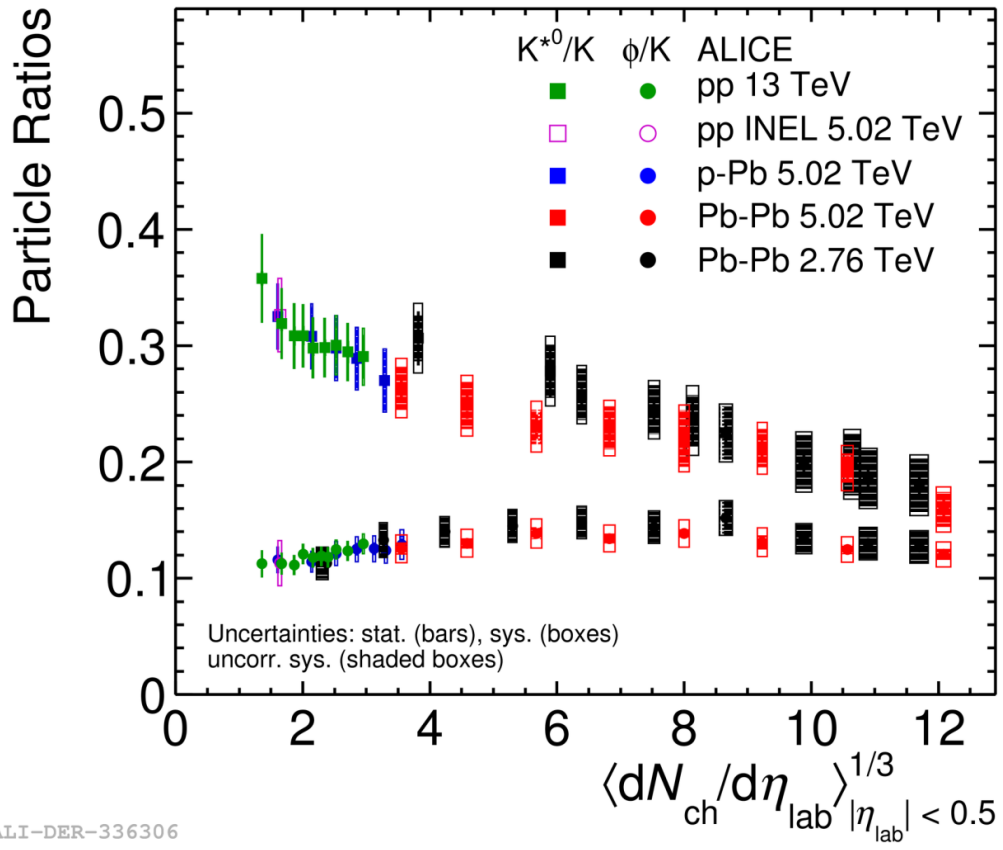
# $K^{*0}/K$, $\phi/K$ vs. $dN_{ch}/d\eta$

**NEW**

- **$K^{*0}/K$** shows a significant suppression
  - going from pp, p-Pb and peripheral Pb-Pb collisions to most central Pb-Pb
  → consistent with the re-scattering of daughters as the dominant effect
  - pp, p-Pb: hint of decrease

- **$\phi/K$** shows no suppression
  - almost constant behavior
  - re-scattering is not significant for $\phi$:

**$\tau(\phi)$ = 46.2 fm/c** >> **$\tau(K^{*0})$ = 4.2 fm/c**



# $\rho^0/\pi$ vs. $dN_{ch}/d\eta$

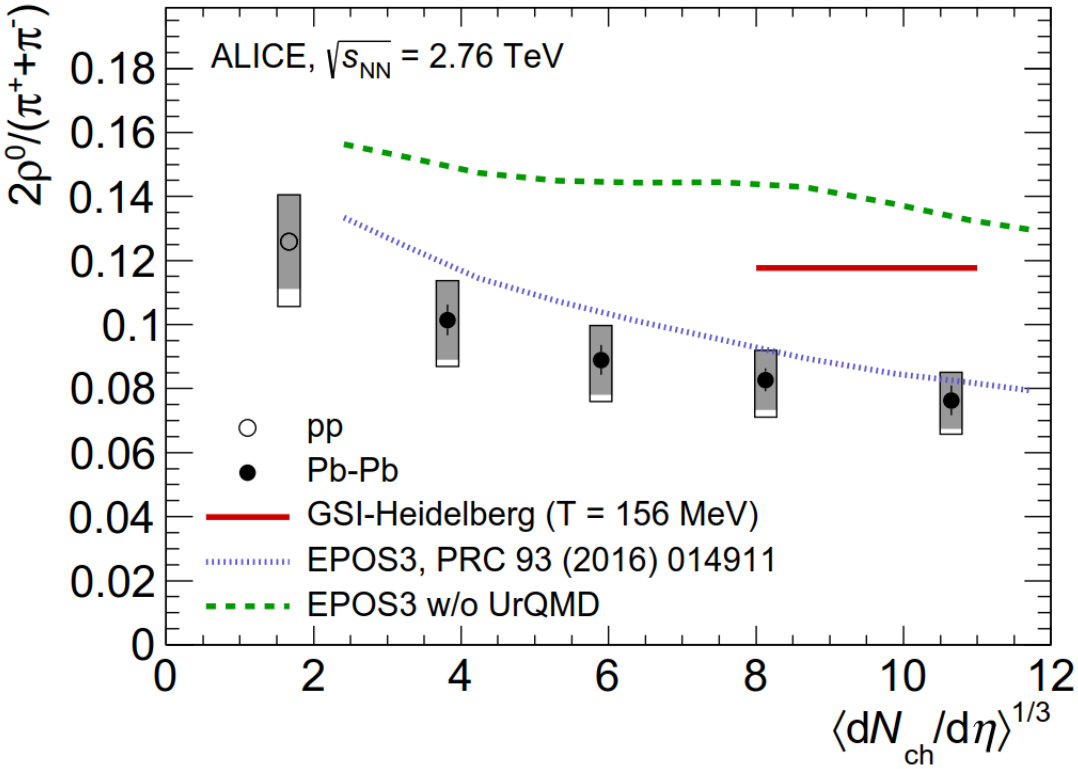
$\tau(\rho^0)$ = 1.3 fm/c

- $\rho^0/\pi$ shows a significant suppression
  - going from pp and peripheral Pb-Pb collisions to most central Pb-Pb
  → consistent with the re-scattering of daughters as the dominant effect

- EPOS3 with UrQMD:
  - overestimates the data
  - qualitatively reproduces the trend of the suppression
  - fails to reproduce the trend without UrQMD

- thermal model
  - overestimates the data

**PR C99 (2019) 064901**

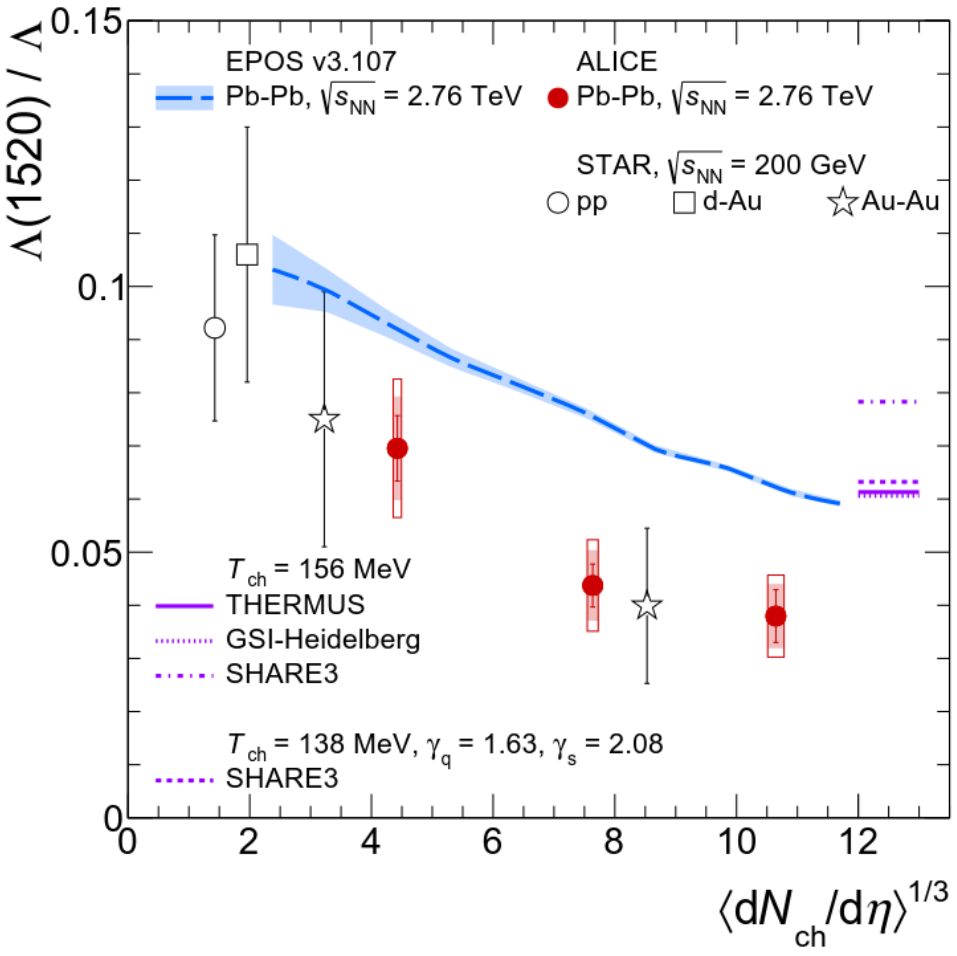


# $\Lambda^*/\Lambda$ vs. $dN_{ch}/d\eta$

**$\tau(\Lambda^*)$ = 12.6 fm/c**

- **$\Lambda^*/\Lambda$** shows a significant suppression
  - going from peripheral Pb-Pb collisions to most central Pb-Pb
  → consistent with the re-scattering of daughters as the dominant effect
- confirms trend seen by STAR at 200 GeV
- EPOS3 with UrQMD:
  - overestimates the data
  - qualitatively reproduces the trend of the suppression
- thermal models
  - all overestimate the ratio in central Pb-Pb collisions

PR **C99** (2019) 024905

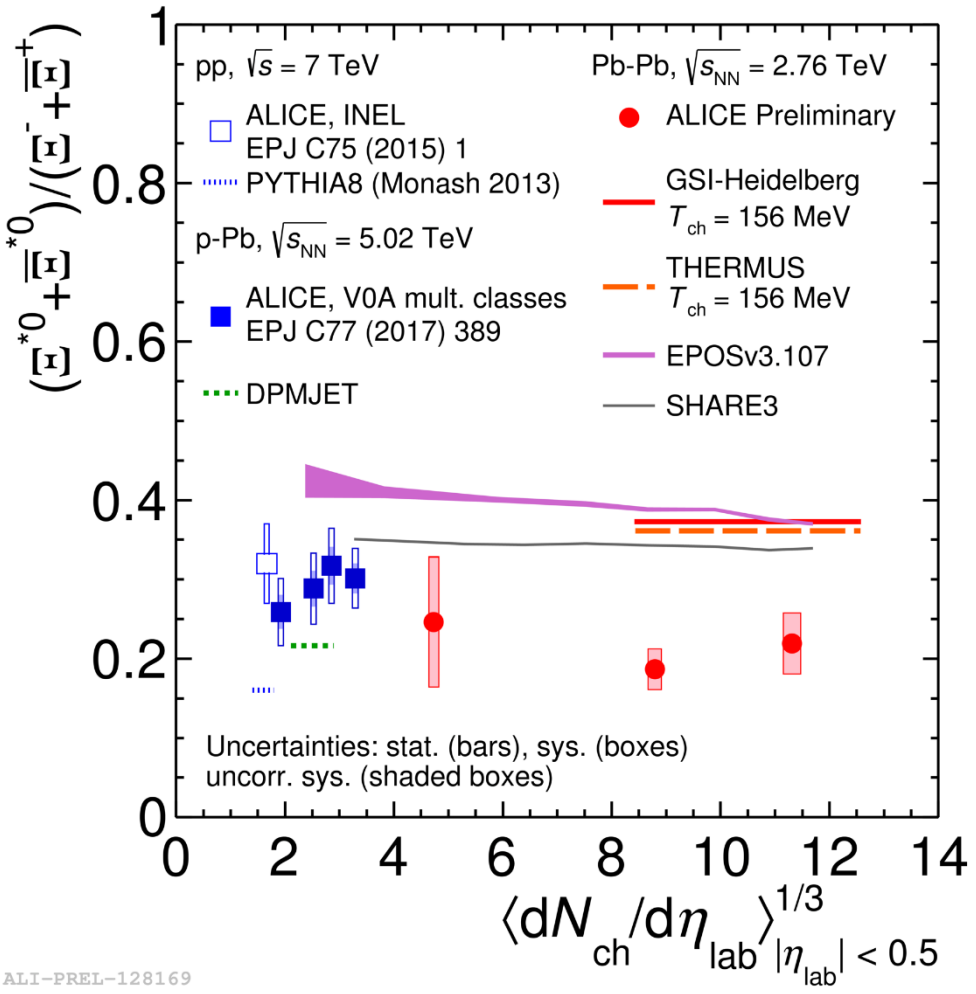



EPOS: PR **C93** (2016) 014911
THERMUS: Comput. Phys. Commun. **180** (2009) 84
GSI-Heidelberg: PL **B673** (2009) 142
SHARE3: Comput. Phys. Commun. **185** (20014) 2056
STAR data: PR **C78** (2008) 044906

# $\Xi^*/\Xi$ vs. $dN_{ch}/d\eta$

**$\tau(\Xi^{*0}) = 21.7$ fm/c**

- **$\Xi^*/\Xi$**
  - 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 suppression
  - overestimates the data
- thermal models
  - all overestimate the ratio in central Pb-Pb collisions



# $\Sigma^*/\Lambda$ vs. $dN_{ch}/d\eta$

**NEW**

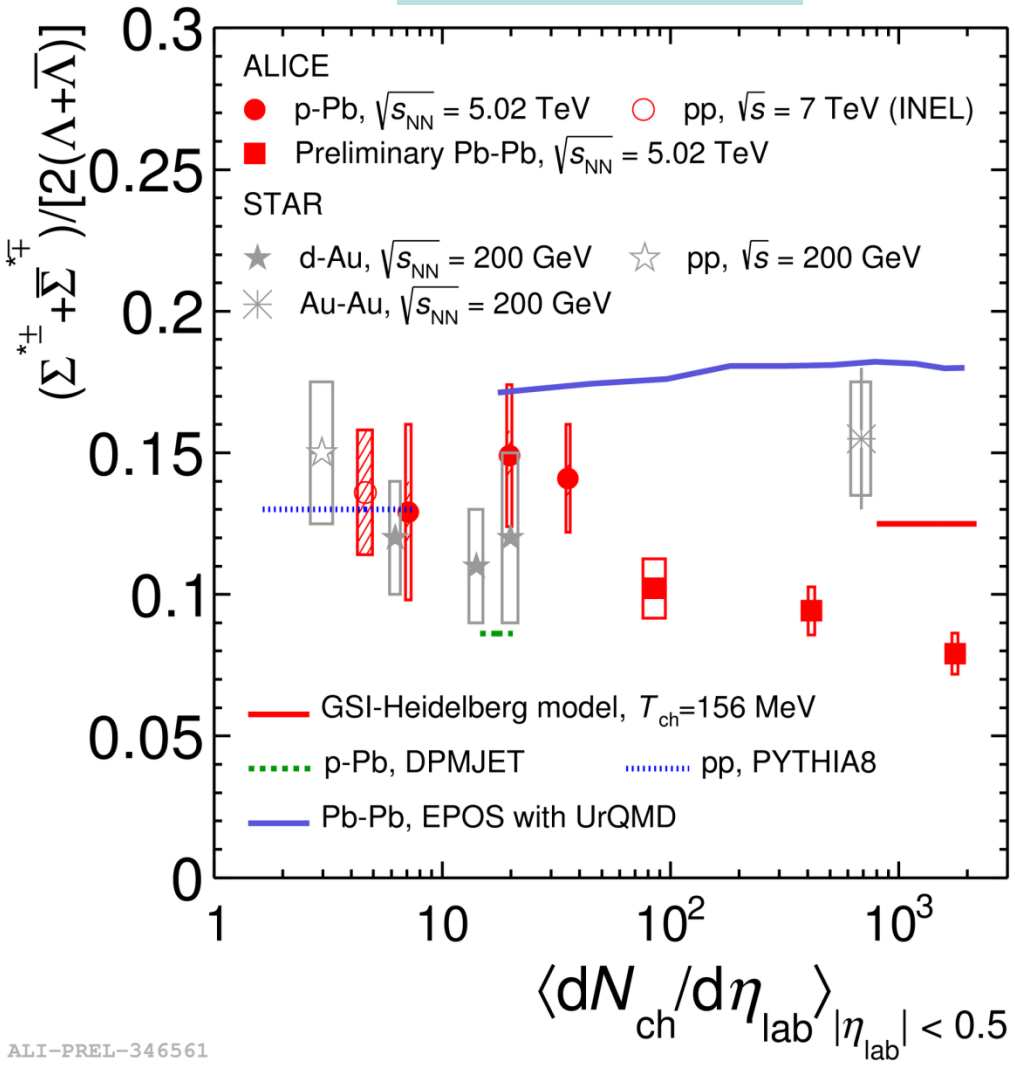
**$\tau(\Sigma^*)$ = 5-5.5 fm/c**

- **$\Sigma^*/\Lambda$:** a suppression is observed for the first time in Pb-Pb
  → consistent with the re-scattering of daughters as the dominant effect

- pp/p-Pb: close to the STAR pp/d-Au data
  Pb-Pb: lower than the STAR Au-Au value

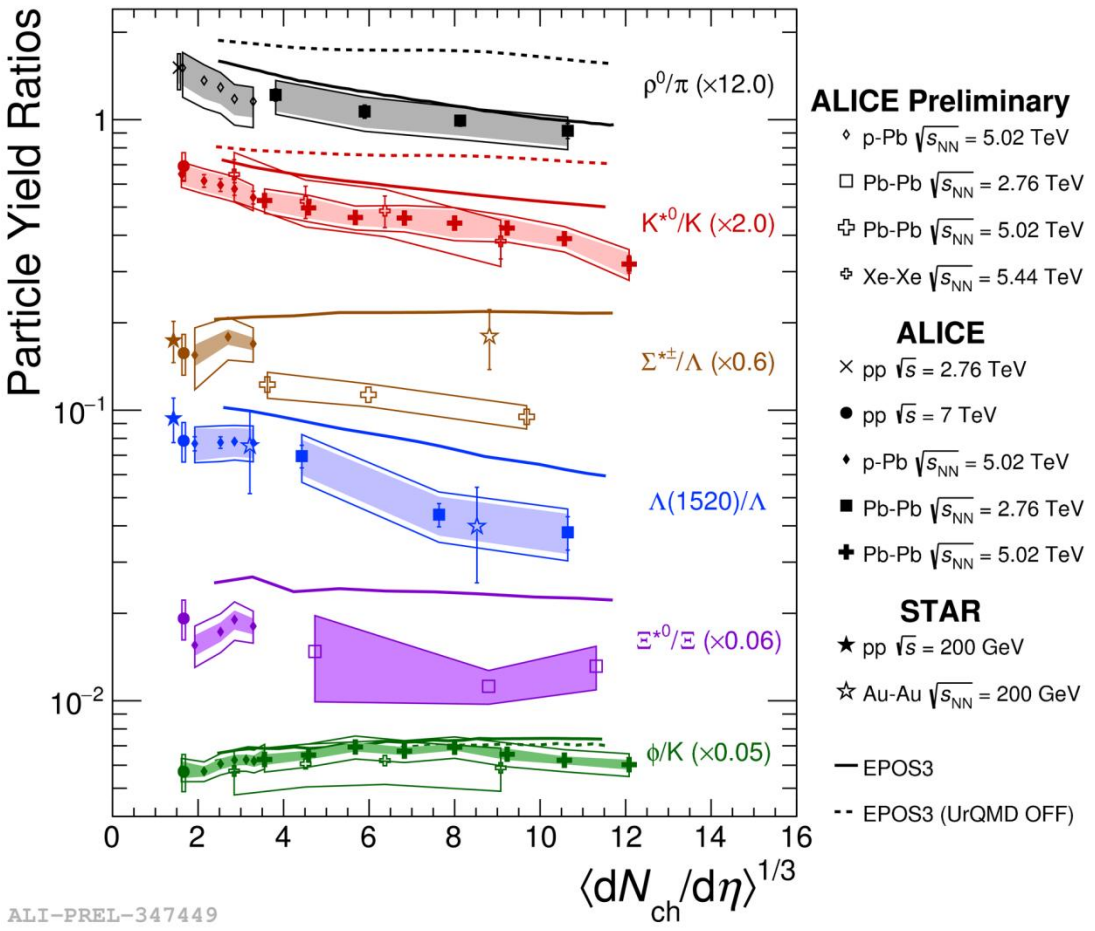
•EPOS with UrQMD:
  - no suppression
  - overestimates the data

•thermal model
  - overestimates the ratio in central Pb-Pb collisions




ALI-PREL-346561

# Resonance suppression



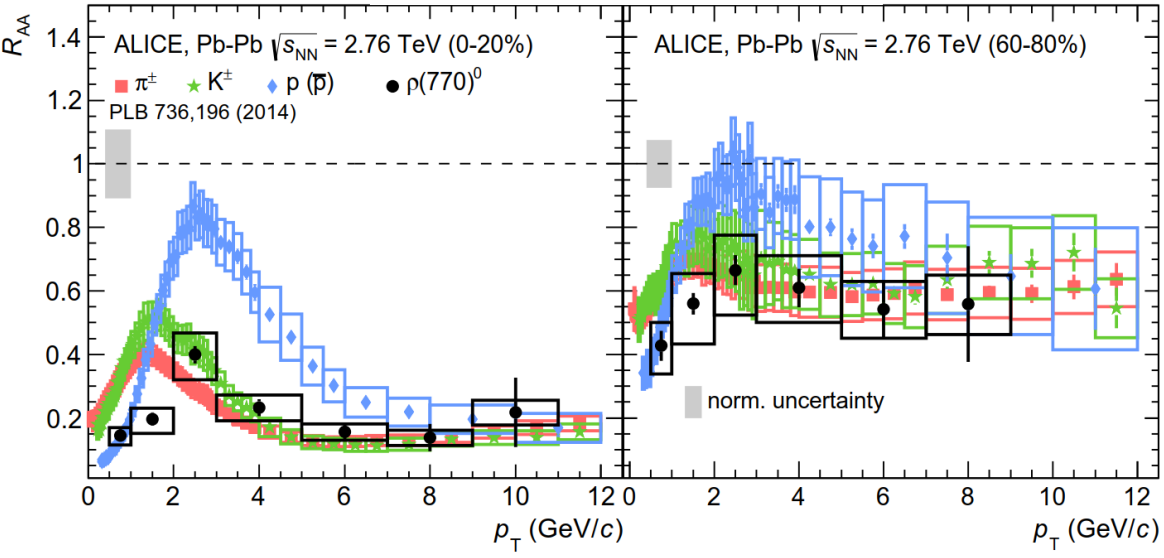

| resonance | $\rho^0$ | $K^{*0}$ | $\Sigma^{*\pm}$ | $\Lambda^*$ | $\Xi^{*0}$ | $\phi$ |
|---|---|---|---|---|---|---|
| lifetime (fm/c) | 1.3 | 4.2 | 5-5.5 | 12.6 | 21.7 | 46.4 |
| suppression | yes | yes | yes | yes | ? weak | no |

# Nuclear modification factor $R_{AA}$

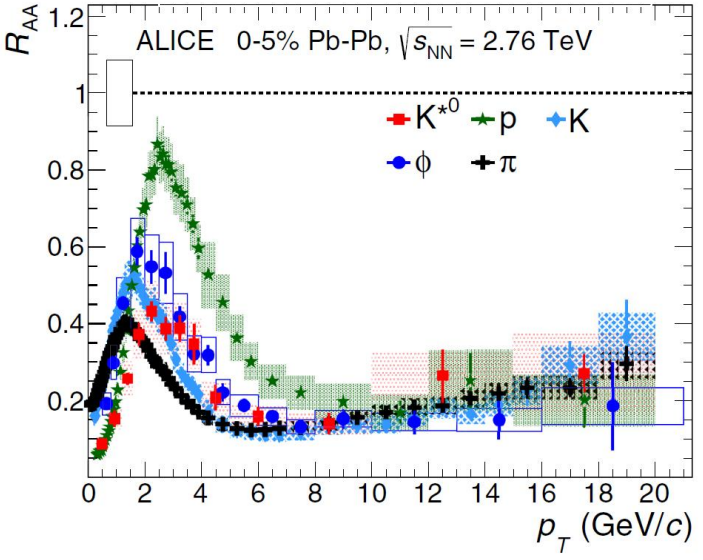
**Pb-Pb@2.76 ATeV**

**ρ(770)$^0$** **K*(892)$^0$** **ϕ(1020)**

PR **C99** (2019) 064901



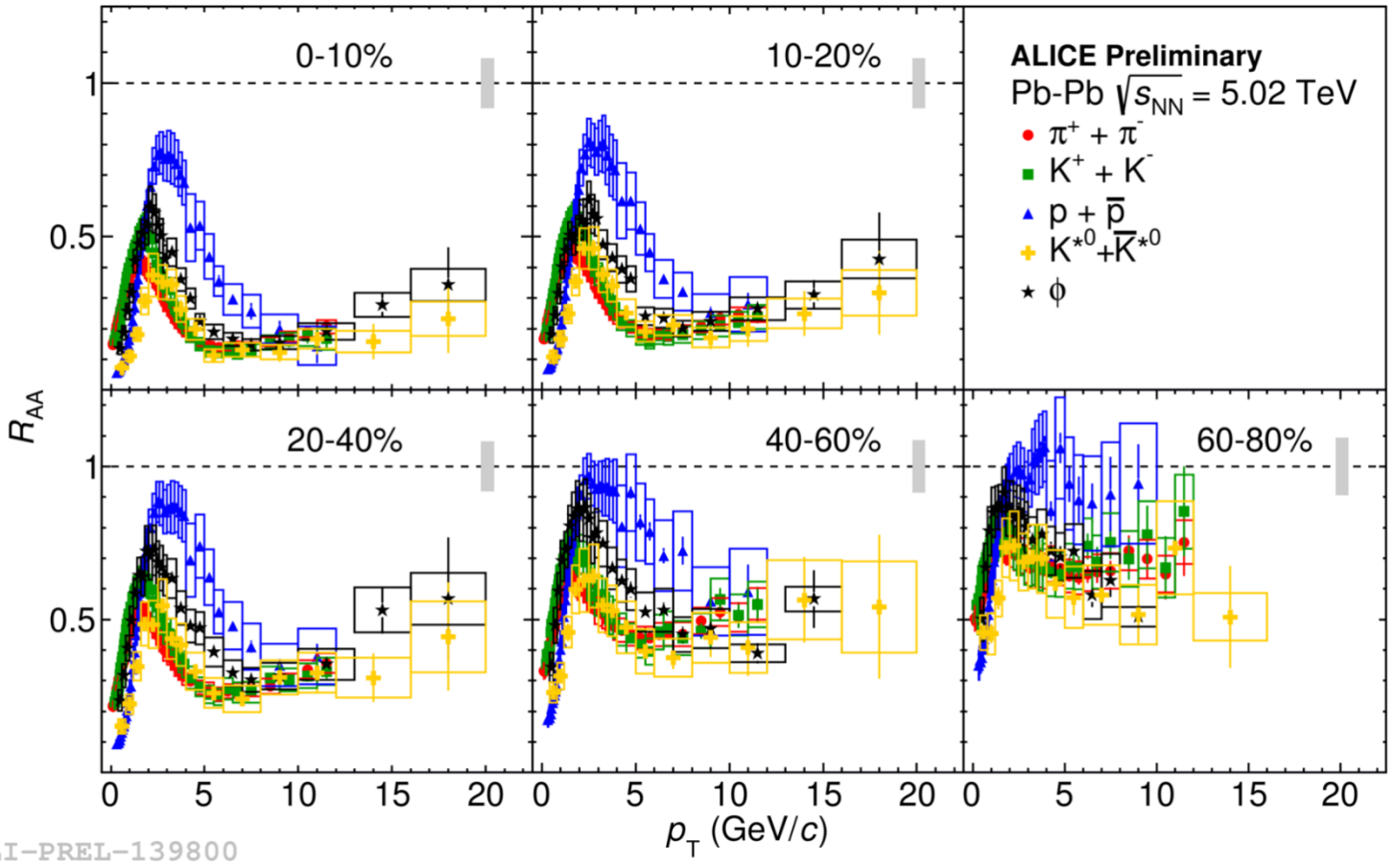

PR **C95** (2017) 064606




- consistent with other light-flavoured hadrons at $p_T > 8$ GeV/$c$
  → suppression at high $p_T$ is not dependent on hadron properties
- $\rho^0$ and $K^{*0}$ affected by radial flow and suppression at lower $p_T$

# $R_{AA}$ – centrality dependence

**Pb-Pb@5.02 ATeV** | **$K^*(892)^0$** | **$\phi(1020)$**

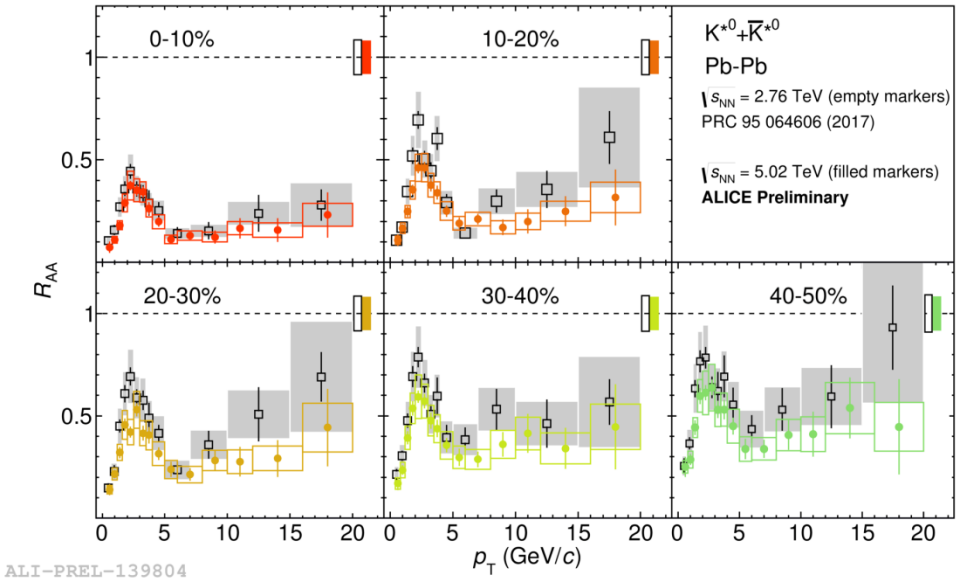



strong suppression for the most central collisions

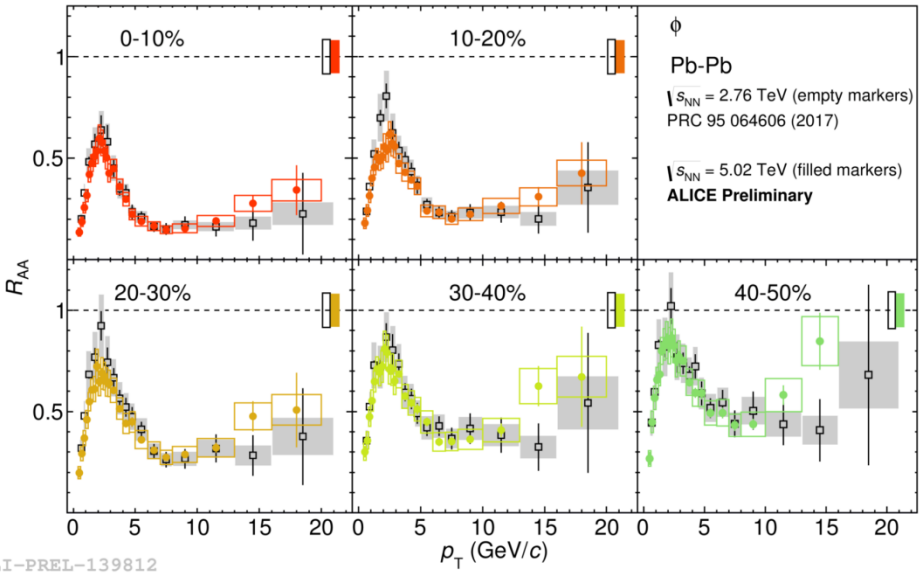
# $R_{AA}$ – energy dependence

**Pb-Pb**
**2.76 TeV** (empty markers)
**5.02 TeV** (filled markers)

**K*(892)$^0$**




**ϕ(1020)**

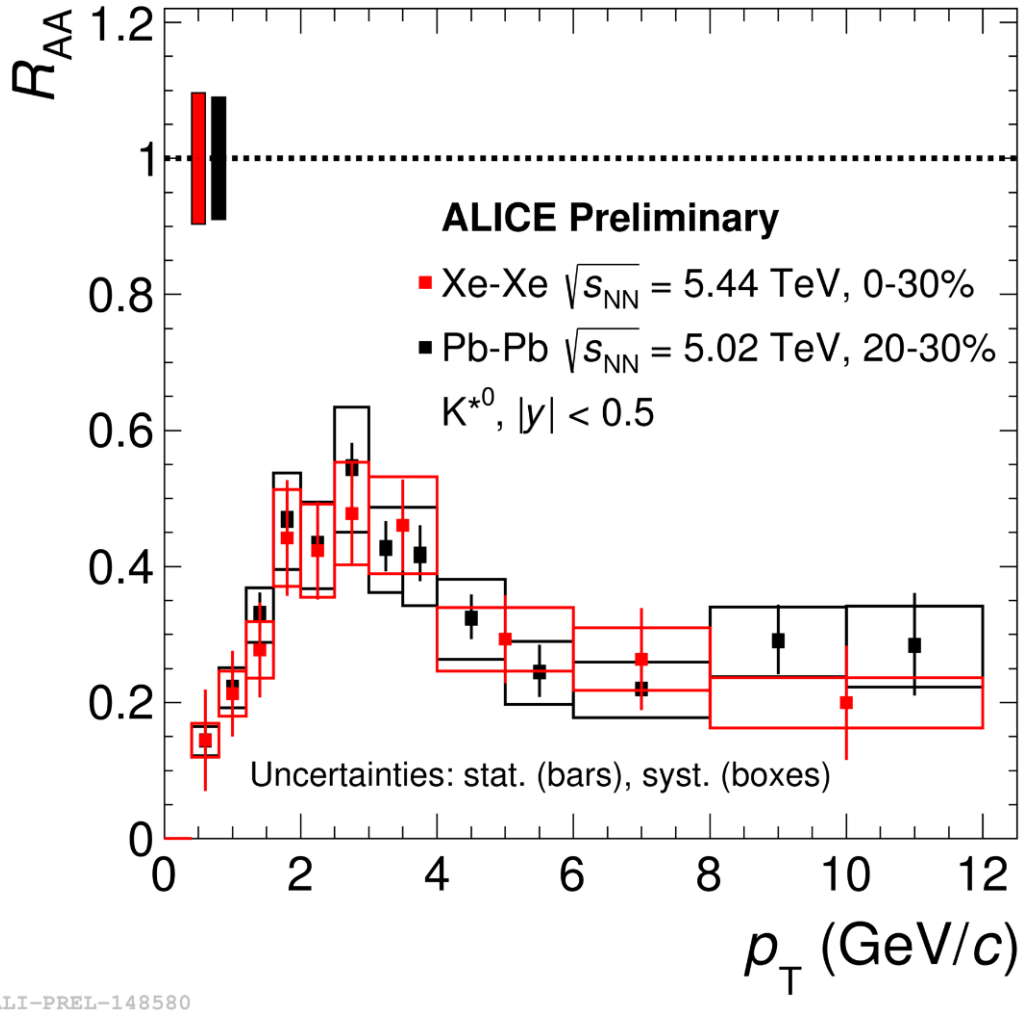



no significant energy dependence

# $R_{AA}$ – system size dependence

**K*(892)$^0$**

$R_{AA}$ in Xe-Xe and Pb-Pb are consistent within uncertainties once compared at the same multiplicity (and not just centrality percentile)



# Summary

**Mean $p_T$:**

- central **Pb-Pb**: mass ordering as expected from hydrodynamics
- **pp**, **p-Pb**: mass ordering violated
  steeper increase with multiplicity

**Yields:**

- **pp**, **p-Pb, Xe-Xe, Pb-Pb**: independent of collision system and energy
  appear to be driven by event multiplicity

**Particle yield ratios:**

- **Pb-Pb:**
  resonance
  suppression

| **resonance** | **$\rho^0$** | **$K^{*0}$** | **$\Sigma^{*\pm}$** | **$\Lambda^*$** | **$\Xi^{*0}$** | **$\phi$** |
|---|---|---|---|---|---|---|
| lifetime (fm/c) | 1.3 | 4.2 | 5-5.5 | 12.6 | 21.7 | 46.4 |
| suppression | **yes** | **yes** | **yes** | **yes** | **? weak** | **no** |

qualitatively described by EPOS with UrQMD (except for **$\Sigma^{*\pm}$**)

**$R_{AA}$:**

- **Pb-Pb:** consistent with light-flavoured hadrons at $p_T > 8$ GeV/$c$
  $\rho^0$ and $K^{*0}$ affected by radial flow and re-scattering at lower $p_T$
  no significant energy dependence
- **Xe-Xe:** consistent with **Pb-Pb** once compared at the same multiplicity

# Perspective

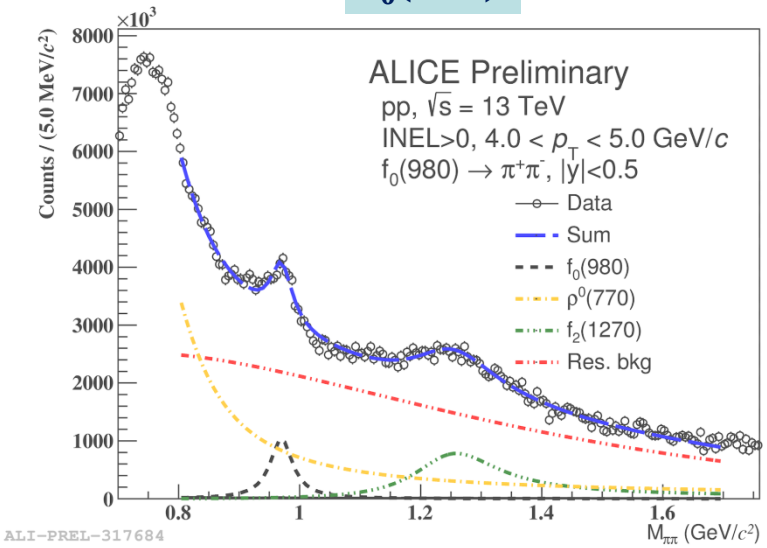
**more resonances are being explored:**

- $\Sigma^0$ in pp@7 TeV
- K*$^{\pm}$ in p-Pb@5.02/8.6 TeV
- $f_0(980)$ and $f_2(1270)$ in pp@5.02/13 TeV
- $\Xi(1820)^-$ in pp@13 TeV

…

**NEW**

**$f_0(980)$**




**$\Xi(1820)^{\pm}$**