Hadronic resonances as probes of the fireball evolution in heavy-ion collisions at the LHC

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Introduction

- Hadronic decay of short-lived mesons (K*, ϕ, ρ) and baryons (Δ++, Σ*, Λ*, Ξ*)
- Lifetimes of the order of a few fm/*c*

	ρ	Δ^{++}	K^{*0}	$\Sigma^{*\pm}$	Λ*	Ξ^{*0}	ϕ
Decay channel	$\pi^+\pi^-$	$p\pi^+$	$K^\pm\pi^\mp$	$\Lambda\pi^\pm$	pK^-	$\Xi^-\pi^+$	K^+K^-
***cτ* (fm)**	1.3	1.6	4	5	12	22	50

Why do we measure hadronic resonances?

In pp (√s=900 GeV, 2.76 TeV, 7 TeV ALICE@LHC) and p-Pb collisions ($\sqrt{s_{NN}}$=5.02 TeV @LHC):

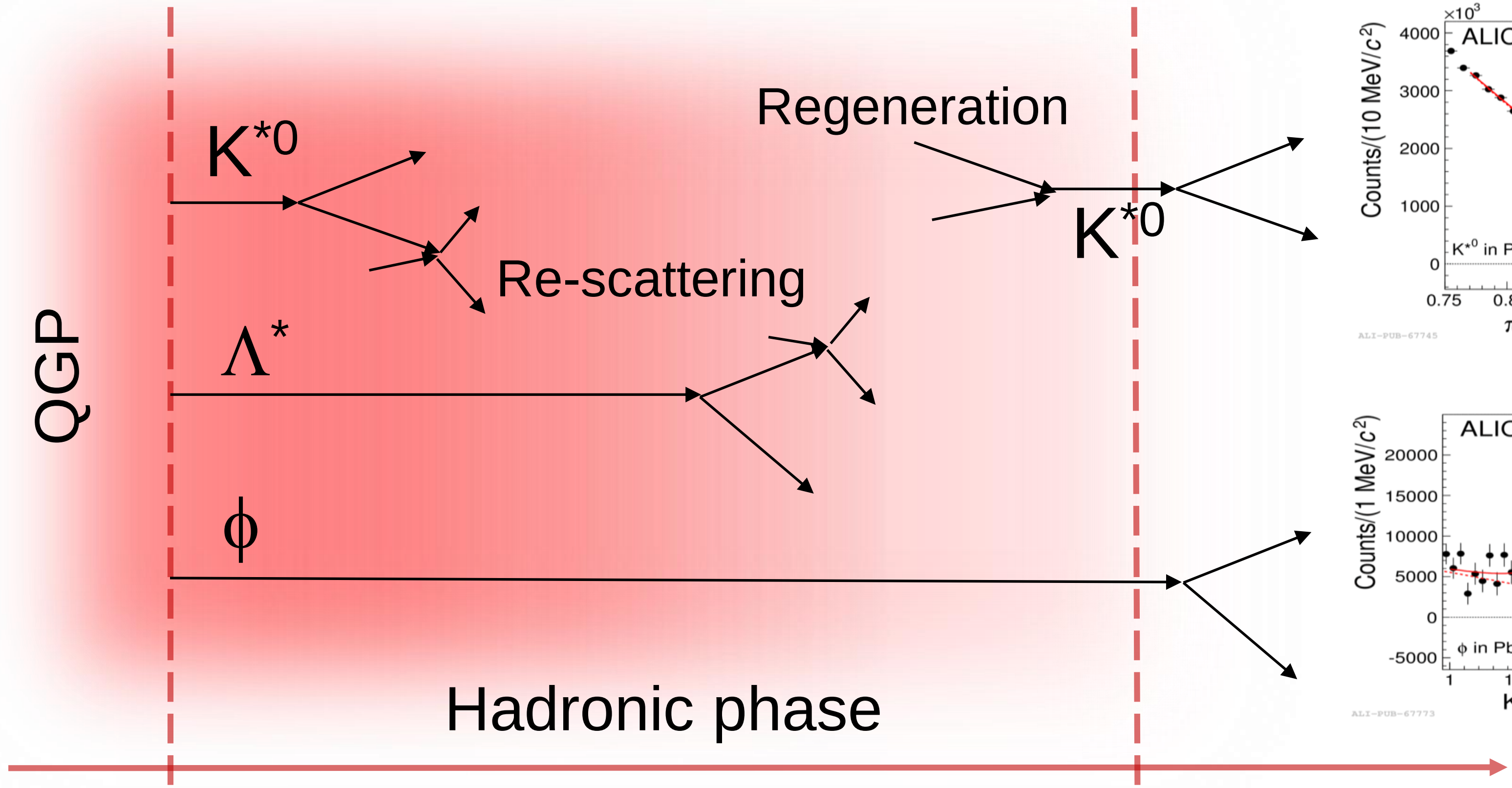
- particle production mechanisms
- baseline measurements for heavy-ion collisions

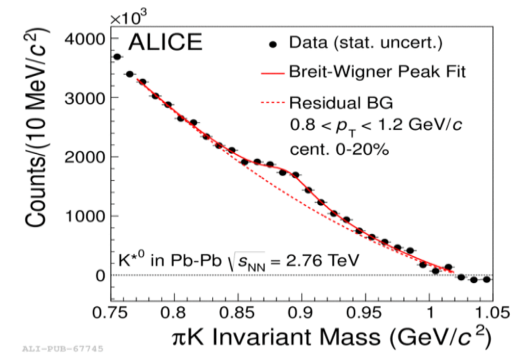
In Pb-Pb collisions ($\sqrt{s_{NN}}$=2.76 TeV @LHC):

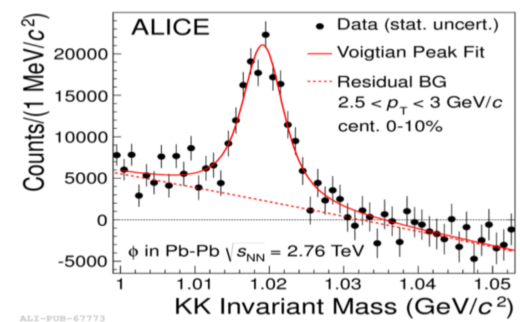
- hydrodynamics: masses determine shapes of p_T spectra
- thermodynamic properties of the fireball

★ Hadronic phase of the fireball after chemical freeze-out

ALICE Collaboration:
Eur. Phys. J. C 71 (2011) 1594
Eur. Phys. J. C 72 (2012) 2183
Eur. Phys. J. C 75 (2015) 1
Phys. Rev. C 91 (2015) 024609







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t (fm/*c*)

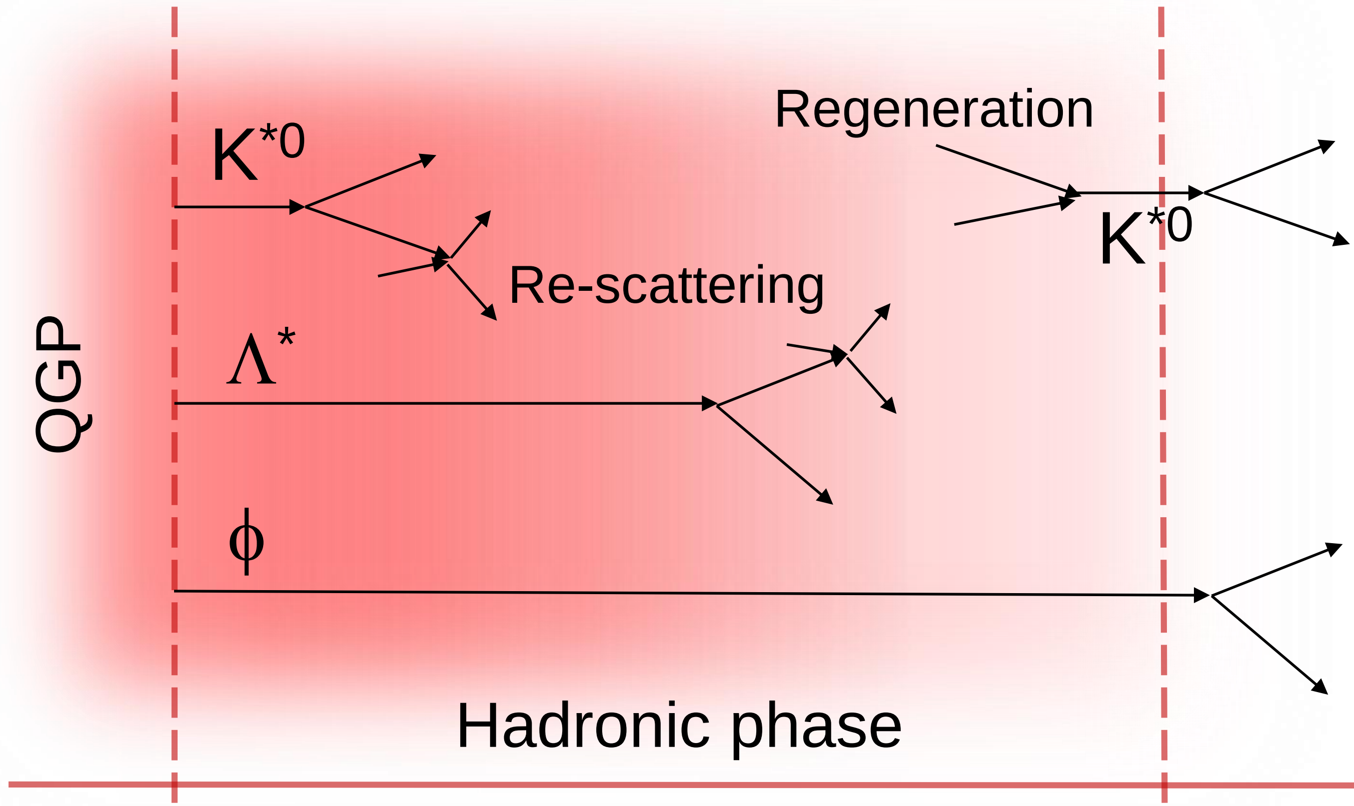
Chemical freeze-out
(→ Particle yields)

Kinetic freeze-out
(→ Spectral shapes)

- Statistical hadronization models (T, V, μ_q, μ_s, γ_q, γ_s) predict particle abundances (and particle yield ratios) at the chemical freeze-out;

M. Petráň *et al*., Phys. Rev. C 88 (2013) 034907
A. Andronic *et al*, Phys. Lett. B 673 (2009) 142

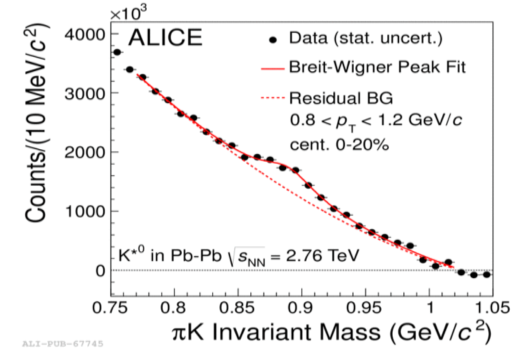
Hadronic phase

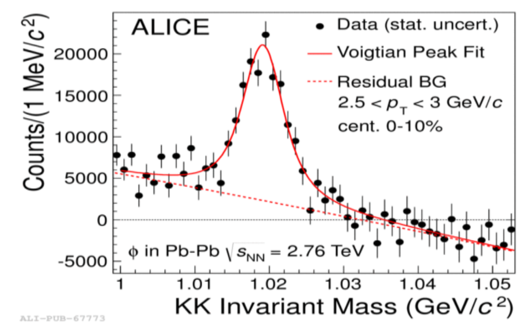


Chemical freeze-out (→ Particle yields)

Kinetic freeze-out (→ Spectral shapes)

t (fm/*c*)





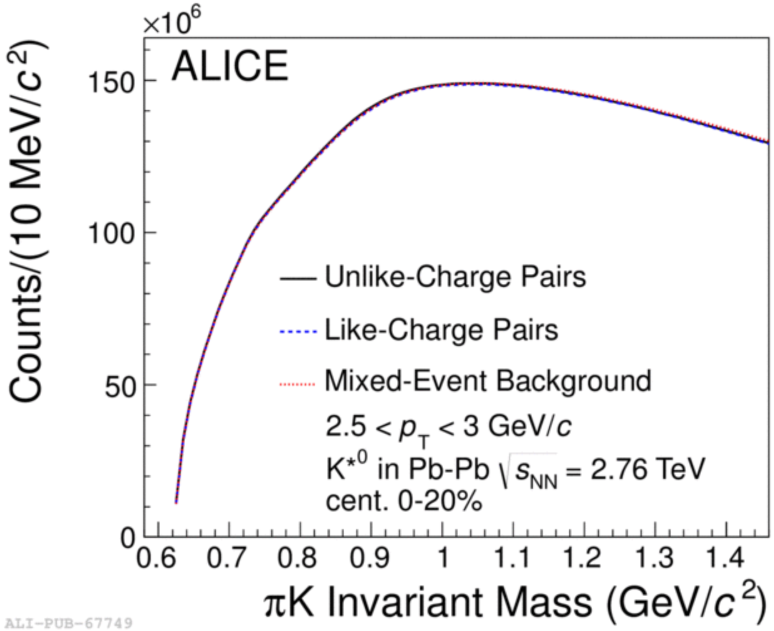
Phys. Rev. C 91 (2015) 024609

- Re-scattering (elastic or pseudo-elastic scattering of the decay products) and regeneration modify the yield 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)

Measuring resonances

Phys. Rev. C 91 (2015) 024609



- Combinatorial background from uncorrelated kaons and pions dominates the πK invariant mass distribution;
- No topological selection is possible;

Measuring resonances

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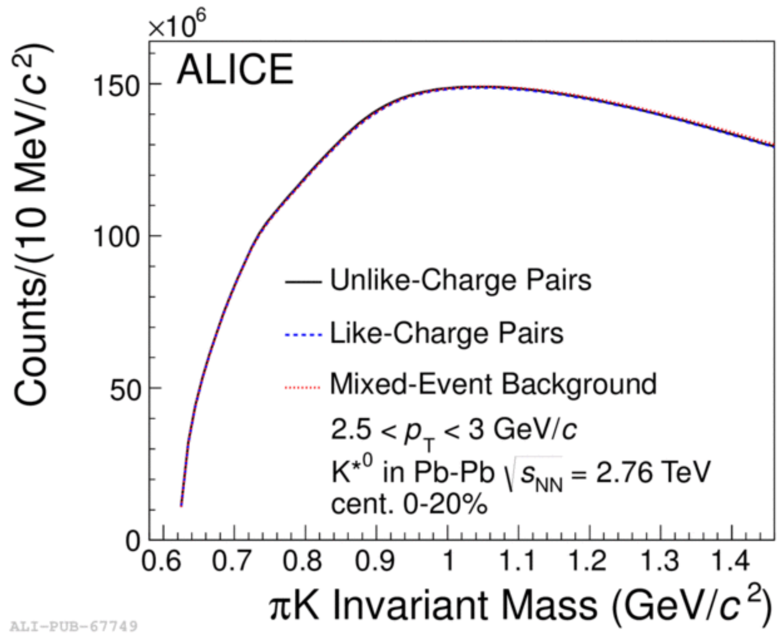
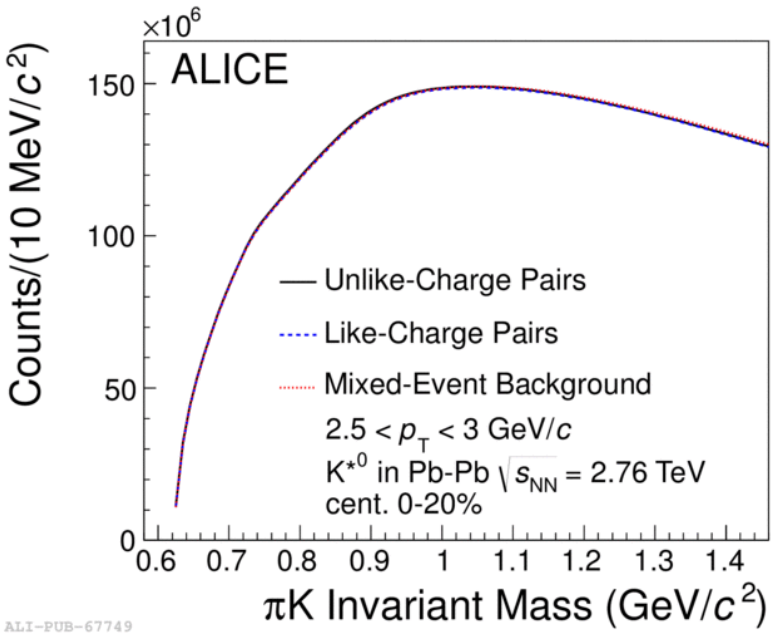
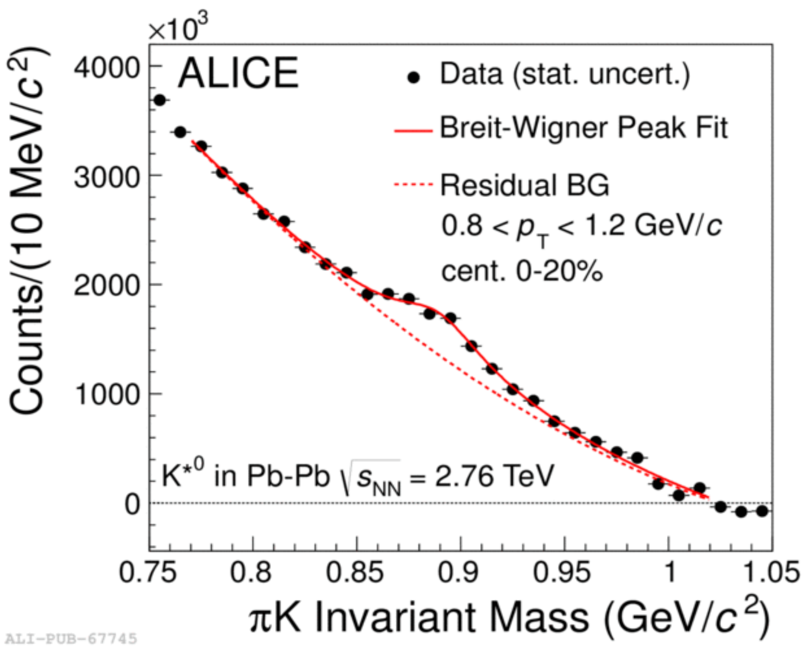


- Combinatorial background from uncorrelated kaons and pions dominates the πK invariant mass distribution;
- No topological selection is possible;
- Mixed-event distribution is filled with the invariant mass of πK pairs from different events;
- Correlations are removed and the background distribution is reproduced;

Measuring resonances





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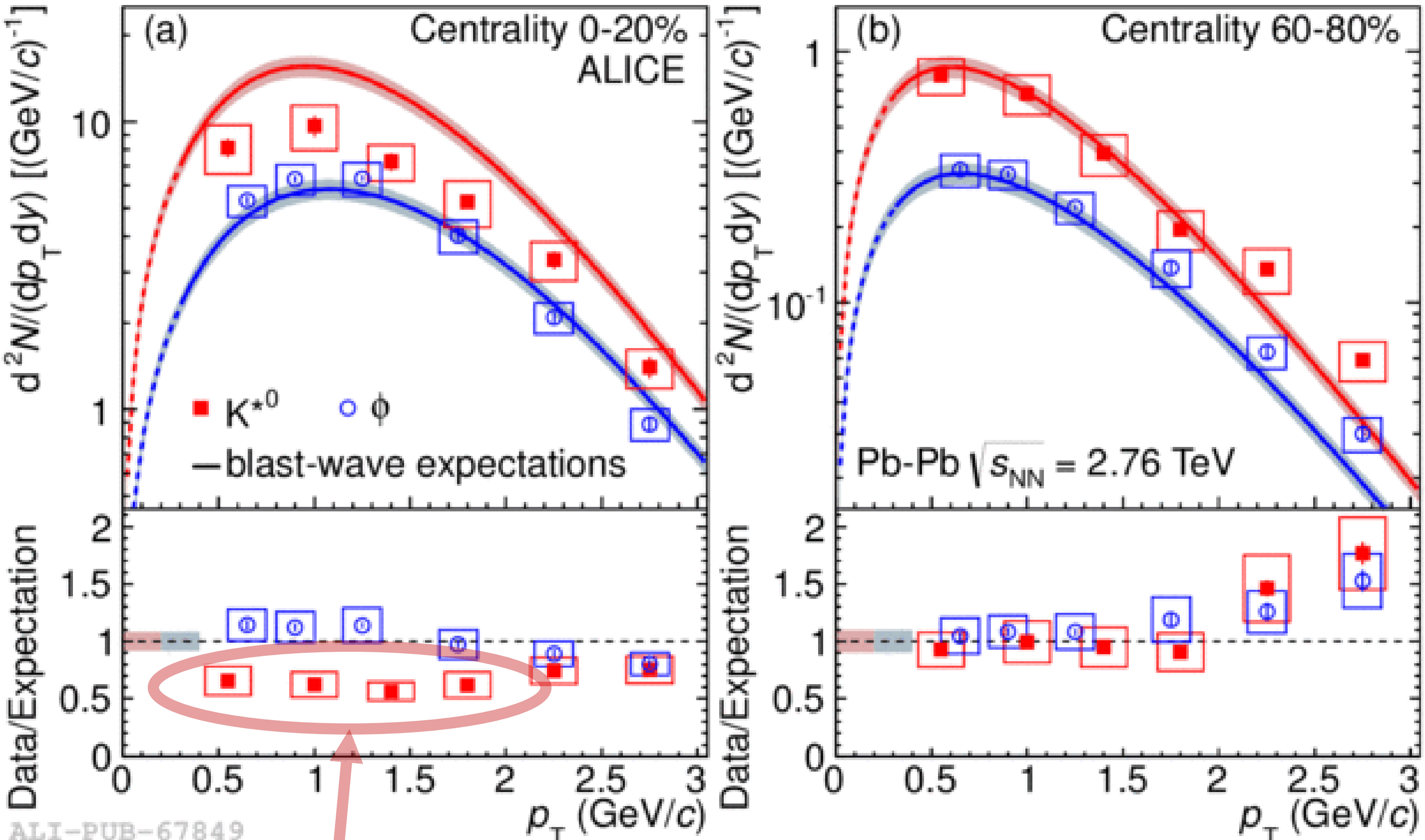
- **Combinatorial background** from uncorrelated kaons and pions **dominates** the πK invariant mass distribution;
- No topological selection is possible;
- **Mixed-event distribution** is filled with the invariant mass of πK pairs from different events;
- Correlations are removed and the background distribution is reproduced;
- **Residual background** is usually fit with a polynomial function;
- **Masses and widths consistent with the PDG values**

p_T-spectra with predictions

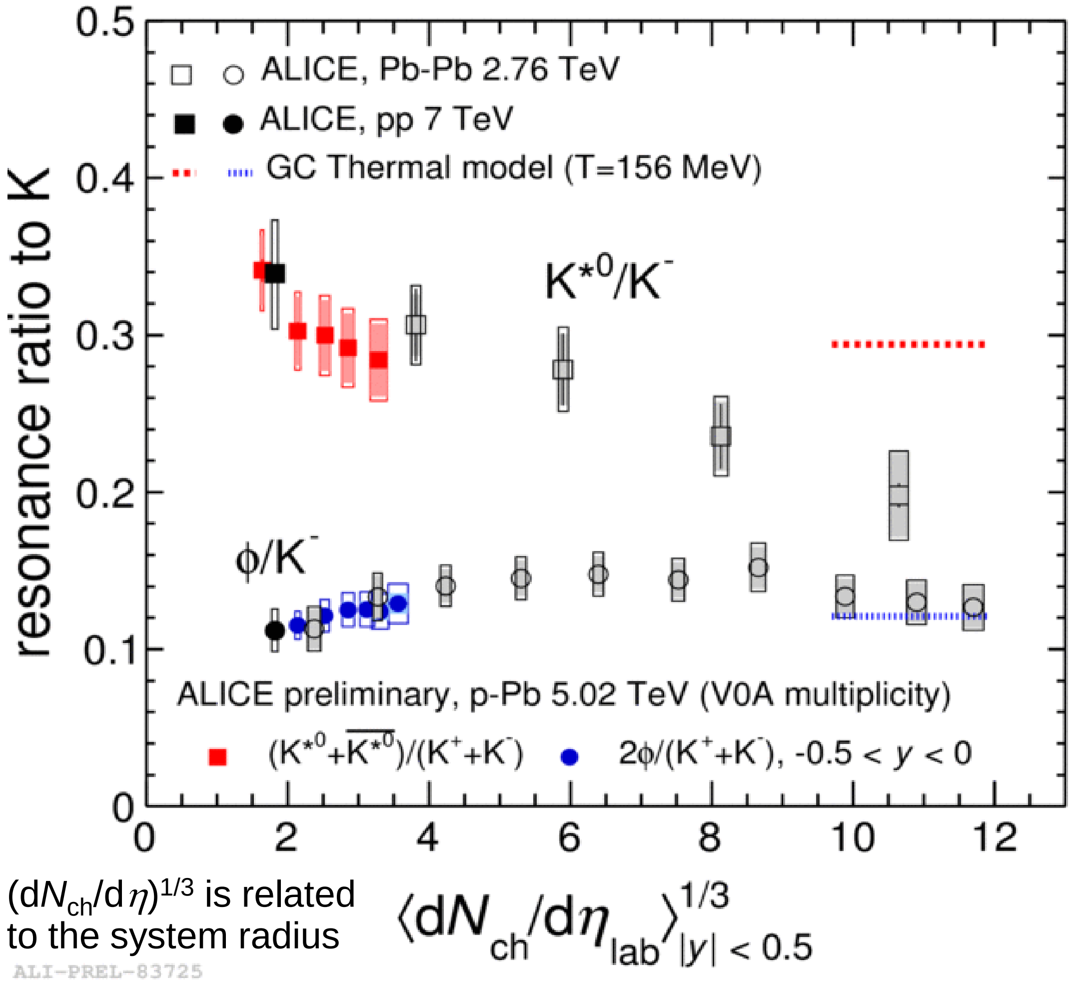
- Curves are obtained with a simultaneous fit to π/K/p distributions [1];
- Curves are normalized to the measured K^- yield times the K^{*0}/K^- (Φ/K^-) ratio from the thermal model (T = 156 MeV) [2].



Discrepancies → hints of re-scattering effects

[1] ALICE Coll., Phys. Rev. C 88 (2013) 044910
[2] J. Stachel *et al*., J. Phys.: Conf. Ser. 509 (2014) 012019

Resonance-to-stable-particle ratios



$(dN_{ch}/d\eta)^{1/3}$ is related to the system radius

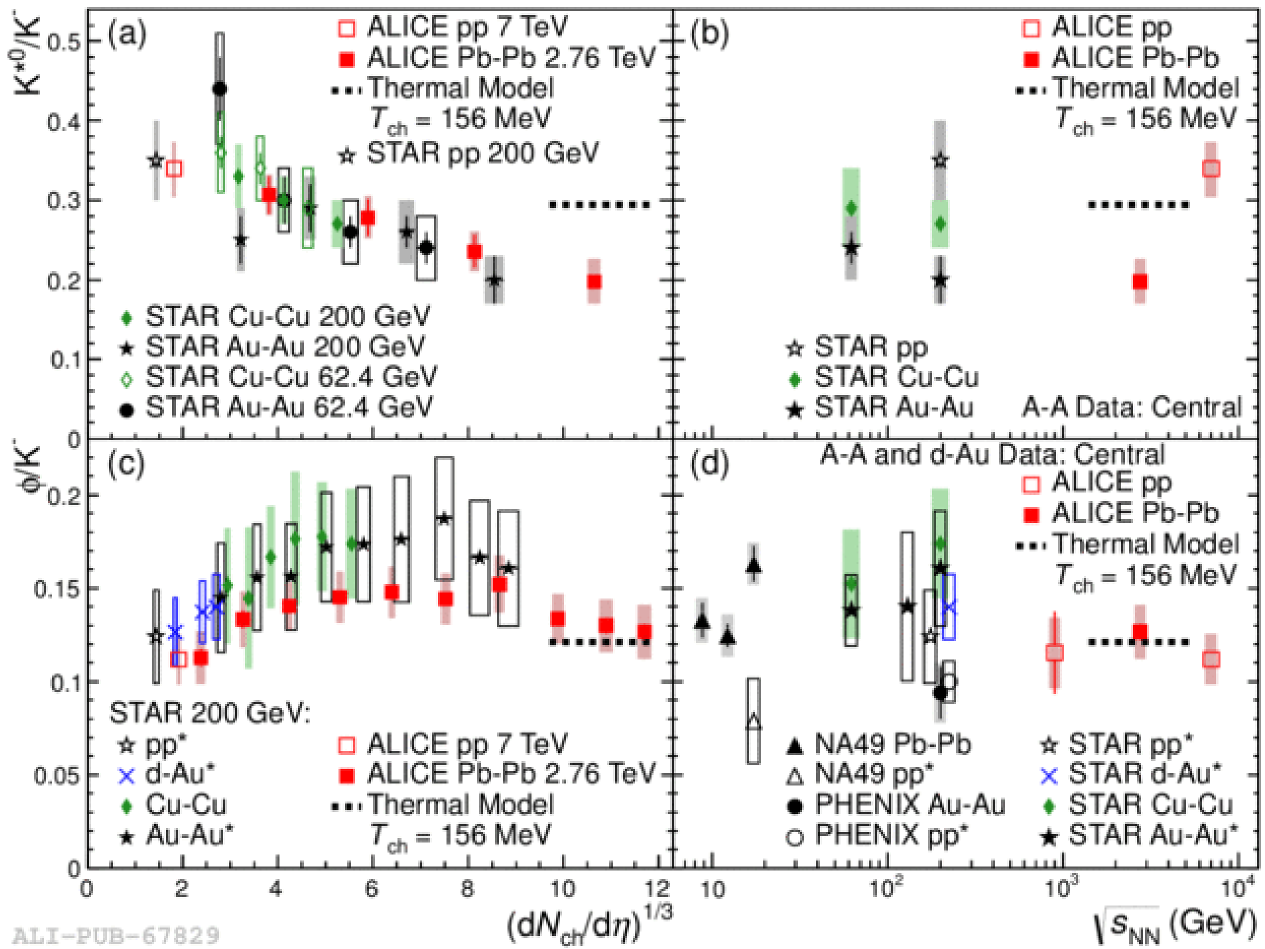
ALICE, pp 7 TeV: Eur. Phys. J. C 72 (2012) 2183
ALICE, Pb-Pb 2.76 TeV: Phys. Rev. C 91 (2015) 024609
Model: J. Stachel *et al*., J. Phys.: Conf. Ser. 509 (2014) 012019

- **K^{*0}/K^-** ratio is suppressed in central Pb-Pb collisions with respect to the thermal model prediction.
  - ✓ A decreasing trend is observed from pp to central Pb-Pb collisions.
  - ✓ Consistent with re-scattering of the decay products and no regeneration
- **ϕ/K^-** ratio almost flat from pp to Pb-Pb, with p-Pb in line with Pb-Pb measurements and consistent with a flat trend.
  - ✓ Pb-Pb measurements compatible with a hadronic phase shorter than the ϕ lifetime;
  - ✓ Compatible with no re-scattering and no regeneration.

Resonance-to-stable-particle ratios

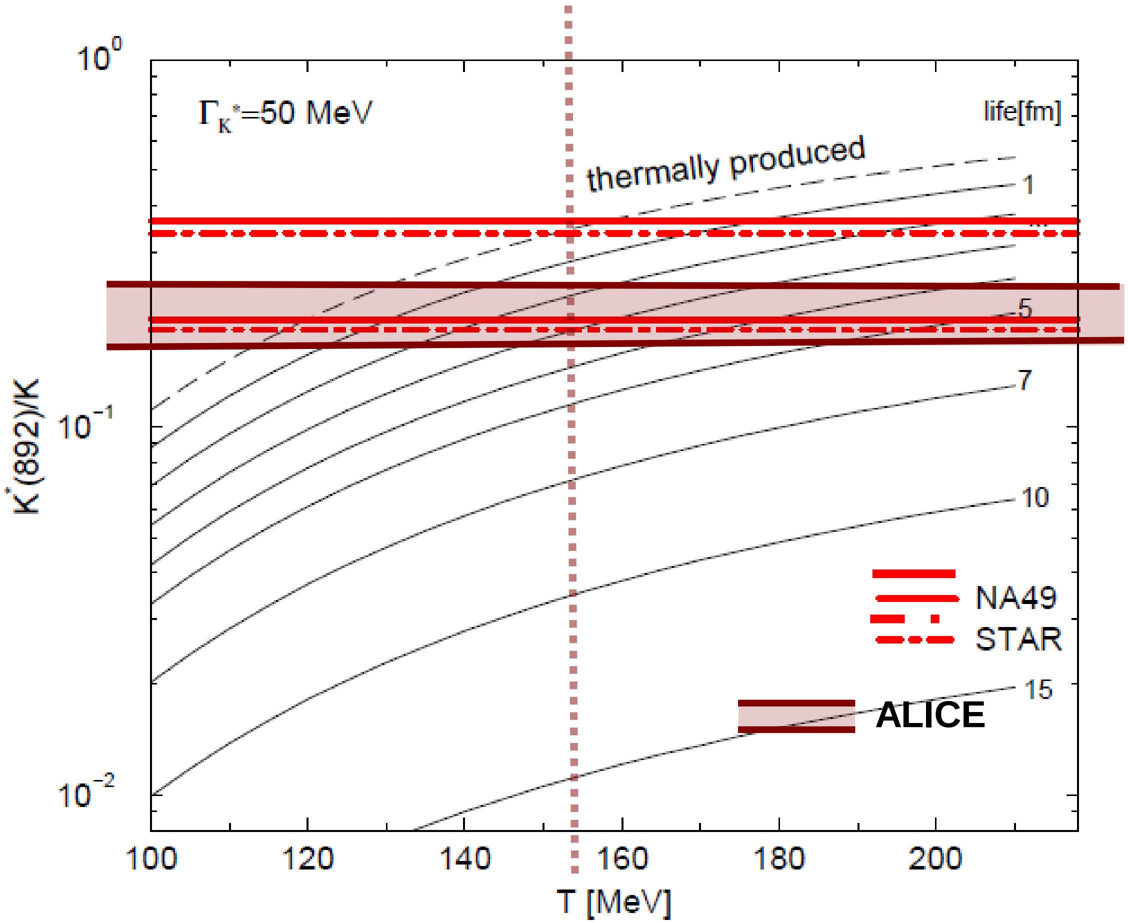
- K^{*0}/K^{-} ratio seems to have the same trend for both RHIC and LHC, with comparable **suppression of signal between pp and central A–A**;

- ϕ/K^{-} ratio has similar shapes in RHIC Au–Au and LHC Pb–Pb. Values for Au–Au tend to be larger than Pb–Pb, but consistent within uncertainties.



ALICE Collaboration, Phys. Rev. C 91 (2015) 024609

Lifetime of the hadronic phase



- In order to estimate the hadronic phase lifetime the chemical freeze-out temperature T_{chem} is needed;
- With a chemical freeze-out temperature T_{chem} = 156 MeV a lower limit of ~2 fm/c for the lifetime is obtained.

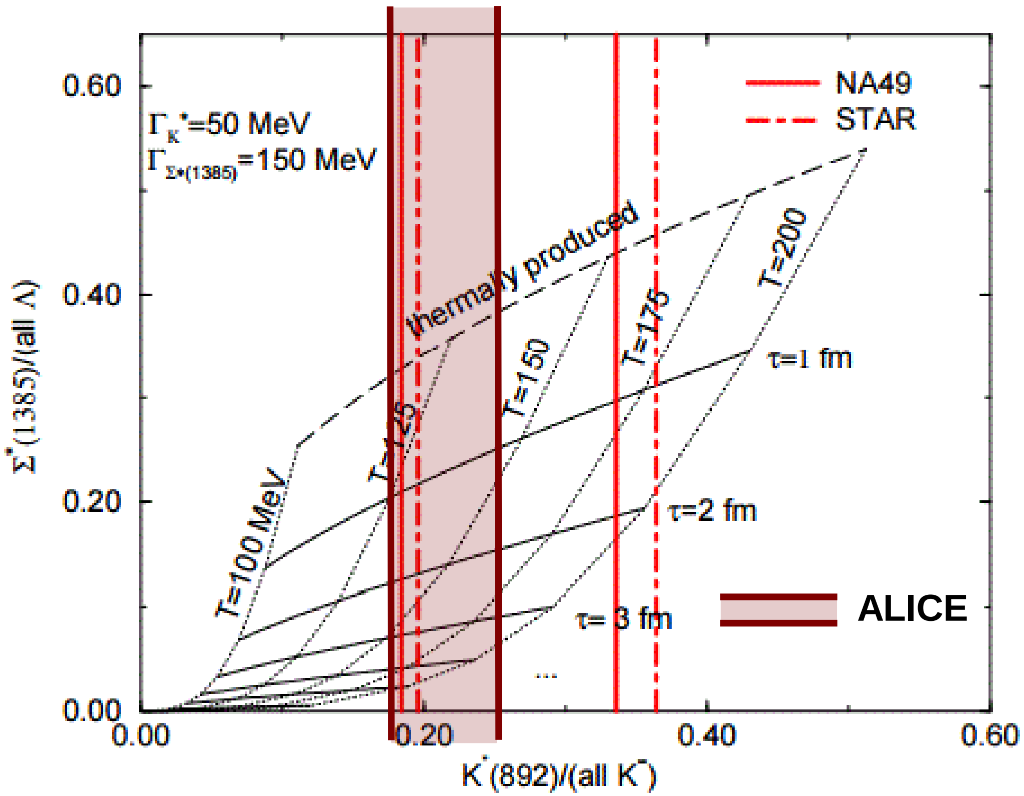
Thermal model + re-scattering effect in the hadronic phase

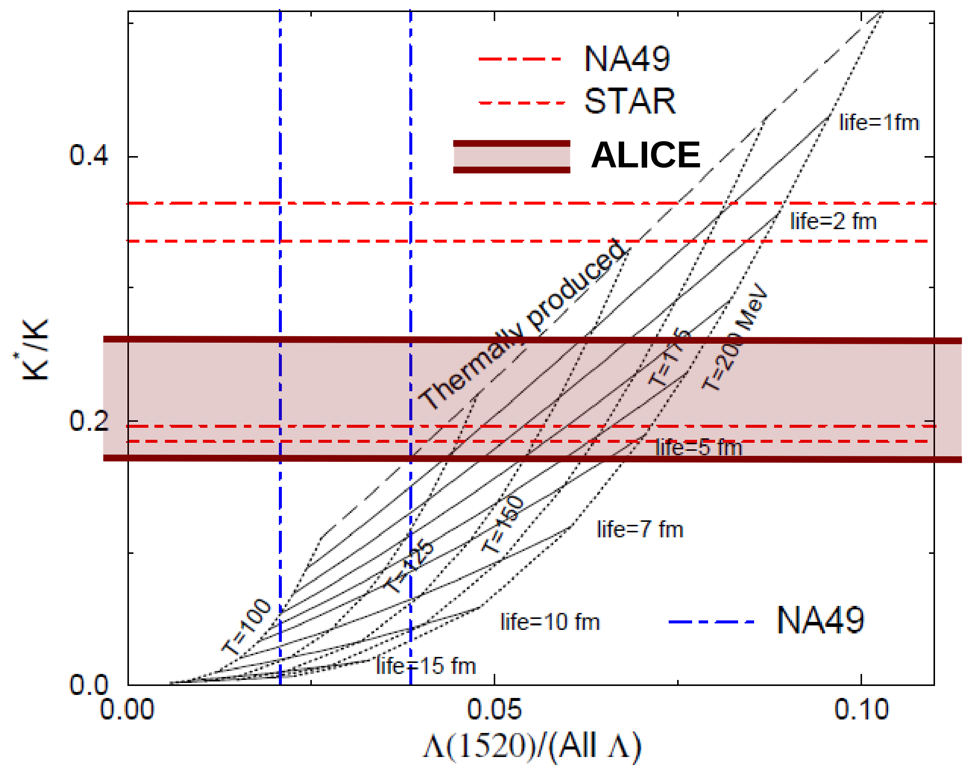
G. Torrieri and J. Rafelski, Phys. Lett. B 509 (2001) 239-245
J. Rafelski *et al*., Phys.Rev. C 65 (2002) 069902
C. Markert *et al.*, AIP Conf. Proc. 631 (2002) 533

ALICE: Phys. Rev. C 91 (2015) 024609

Future prospects

- Two ratios involving resonances with considerably different lifetimes (e.g. K^{*0}/K^- and $\Sigma(1385)^*/\Lambda$ or K^{*0}/K^- and $\Lambda(1520)^*/\Lambda$) can be used to constrain both the chemical freeze-out temperature T_{chem} and the lifetime of the hadronic phase





$\Sigma(1385)^*/\Lambda$ measurement to be performed

ALICE: Phys. Rev. C 91 (2015) 024609

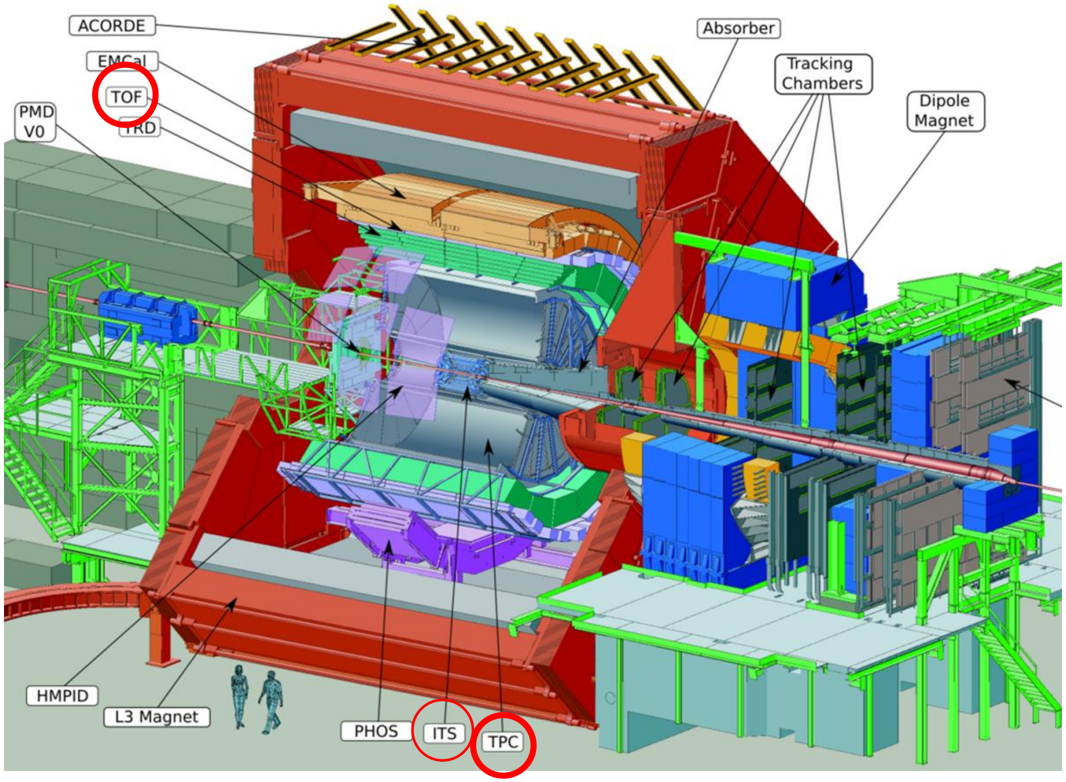
J. Rafelski *et al.*, Phys.Rev. C 65 (2002) 069902
C. Markert *et al.*, arXiv:hep-ph/0206260v2

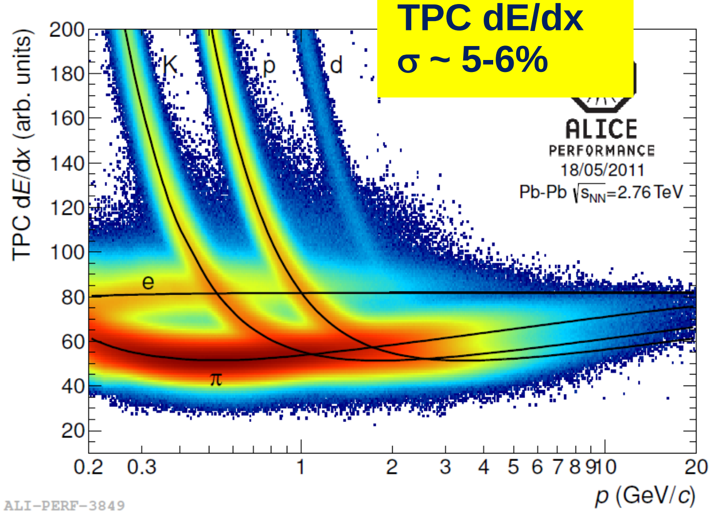
Conclusions

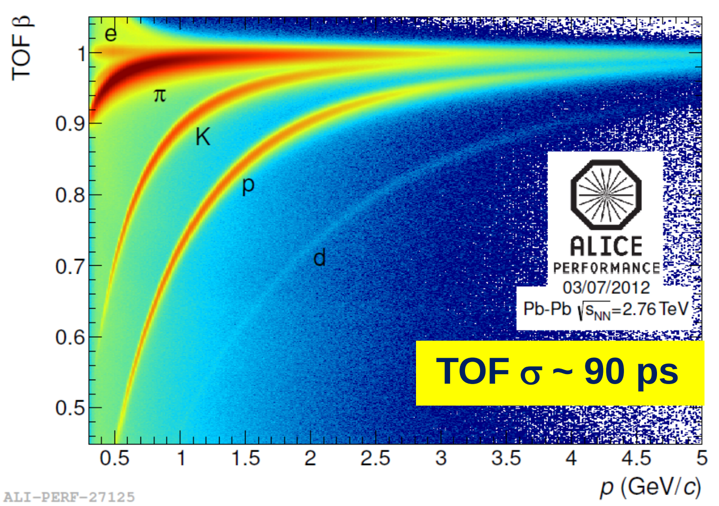
- ☺ In central Pb-Pb collisions, K^{*0} yields seem to be affected by re-scattering in the hadronic phase, while the ϕ, being a longer-lived particles, is unaffected;
- ☺ This scenario is supported by the predictions of the K^{*0} yields from the combined blast-wave fits and the resonance-to-stable-particle ratio;
- ☺ Models which assume thermal production at chemical freeze-out followed by re-scattering in the hadronic phase give a rough estimate of ~2 fm/*c* for the lifetime of the hadronic phase, if a chemical freeze-out temperature T_{chem} = 156 MeV is considered;
- ☺ Forthcoming results on baryon resonances ($\Sigma(1385)^*$, $\Lambda(1520)^*$, $\Xi(1530)^{*0}$) will help to clarify this picture.

Backup slides

ALICE detector



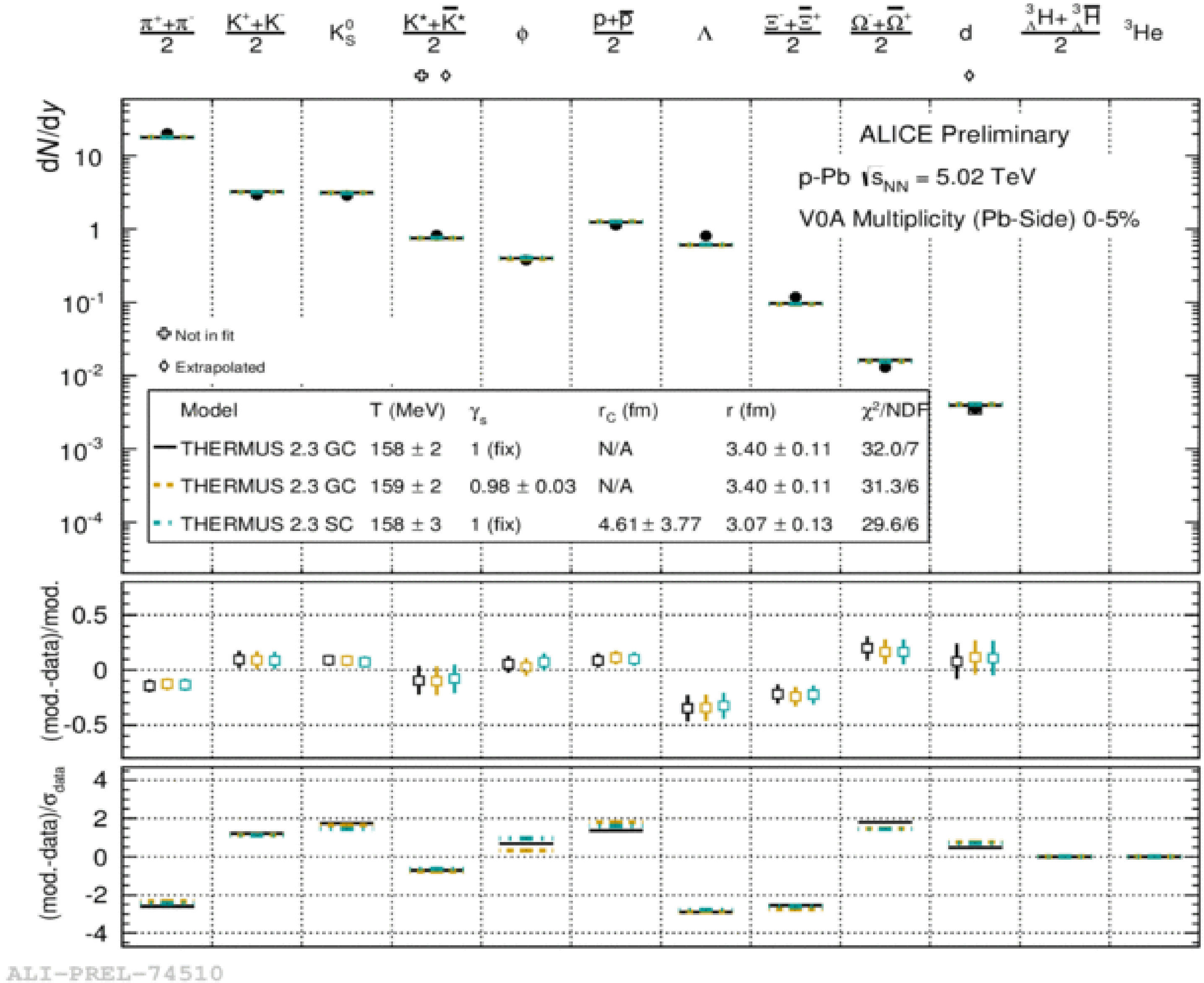




	TPC	TOF
π	0.2 ÷ 0.7	0.5 ÷ 2.0
K	0.3 ÷ 0.6	0.5 ÷ 2.0
p	0.5 ÷ 1.0	0.5 ÷ 2.5

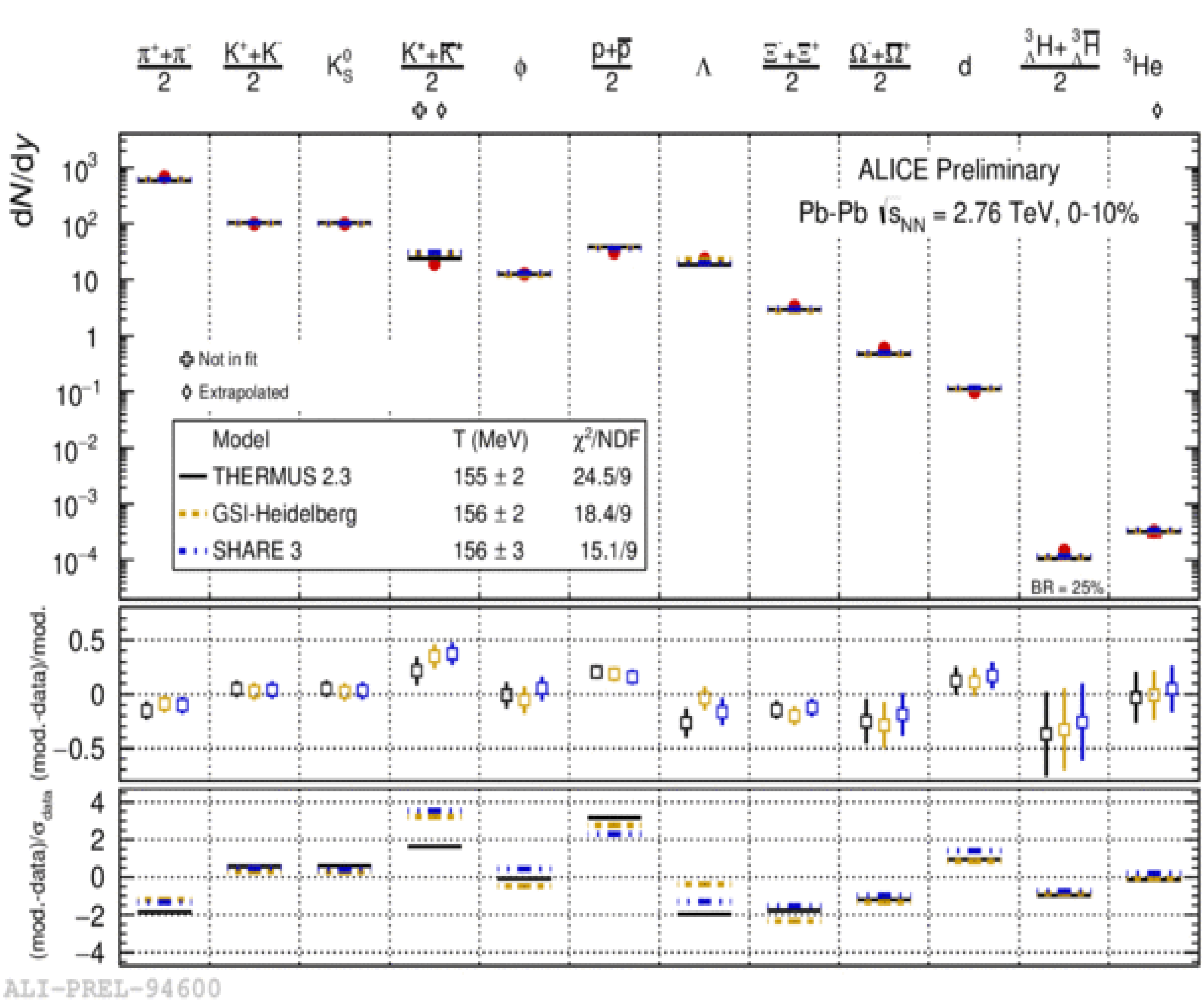
p_T-range in GeV/c with a 3σ separation

p-Pb



ALICE Preliminary
p-Pb √s_NN = 5.02 TeV
V0A Multiplicity (Pb-Side) 0-5%
Not in fit
Extrapolated
Model | T (MeV) | γ_s | r_C (fm) | r (fm) | χ²/NDF
THERMUS 2.3 GC | 158 ± 2 | 1 (fix) | N/A | 3.40 ± 0.11 | 32.0/7
THERMUS 2.3 GC | 159 ± 2 | 0.98 ± 0.03 | N/A | 3.40 ± 0.11 | 31.3/6
THERMUS 2.3 SC | 158 ± 3 | 1 (fix) | 4.61 ± 3.77 | 3.07 ± 0.13 | 29.6/6
dN/dy
(mod.-data)/mod.
(mod.-data)/σ_data
ALI-PREL-74510

Pb-Pb



Petran et al, arXiv:1310.5108
Wheaton et al, Comput.Phys.Commun, 180 84
Andronic et al, PLB 673 142