Exploring the hadronic phase of Pb-Pb collisions with resonances

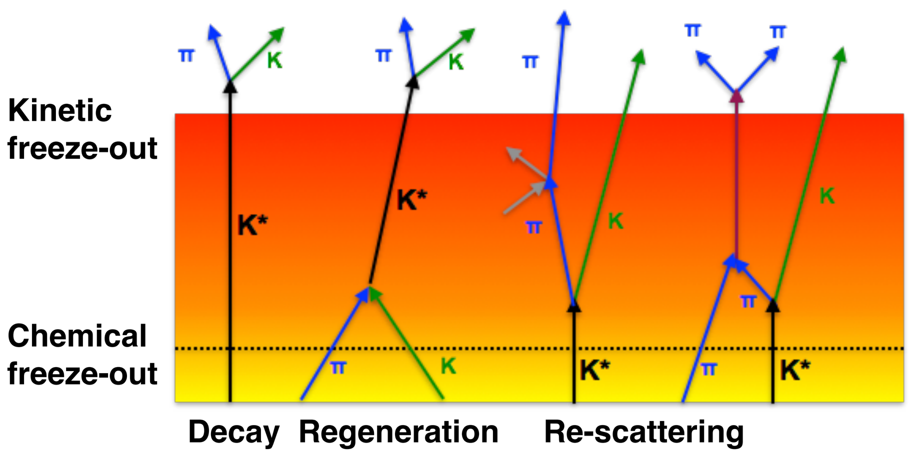
F. Bellini for the ALICE Collaboration
University and INFN, Bologna (Italy) – Email: fbellini@cern.ch

The role of resonances in the hadronic phase

In nucleus-nucleus collisions, the hadronic phase is the stage of the medium expansion that follows the hadronization process.
In central collisions at the LHC energies it is expected to last O(10 fm/c).

Hadronic resonances decay under the strong interaction with **lifetimes (~10^{-23}s) of the same order of magnitude as that of the fireball**.

Relative particle abundances are determined at chemical freeze-out, but processes involving hadronic resonances and occurring in the late hadronic phase can **affect the measured particle yields.**



After chemical freeze-out resonances **decay** and can undergo **re-scattering** and **regeneration** depending on

- lifetime of the hadronic phase
- lifetime of resonances
- scattering cross-section of the decay products

Key measurements:

✓ Resonance yields and ratios to long-lived particles vs. centrality
  i. Re-scattering effects expected to be stronger in central collisions, as the medium is denser and lasts longer

✓ Spectra down to low transverse momentum (p_T)
  i. Improve precision on the yields by minimising the extrapolated fraction
  ii. UrQMD predicts the largest effects of re-scattering and regeneration for $p_T < 2$ GeV/c [1]

✓ Resonances with different lifetimes

lifetime →

$\rho(770)^0$	$K(892)^0$	$\Sigma(1385)^{\pm}$	$\Lambda(1520)$	$\Xi(1530)^0$	$\phi(1020)$
$c\tau$ ~ 1.3 fm	$c\tau$ ~ 4 fm	$c\tau$ ~ 5.5 fm	$c\tau$ ~ 12.5 fm	$c\tau$ ~ 22 fm	$c\tau$ ~ 46 fm
$\rho^0 \longrightarrow \pi^+\pi^-$ (100%)	$K^{*0} \longrightarrow K^{\pm}\pi^{\mp}$(66.6%)	$\Sigma^{*\pm} \longrightarrow \Lambda\pi^{\pm}$(87%)	$\Lambda^* \longrightarrow pK$ (87%)	$\Xi^{*0} \longrightarrow \Xi^{\pm}\pi^{\mp}$ (66.7%)	$\phi \longrightarrow K^+K^-$(48.9%)

Resonance measurements with ALICE

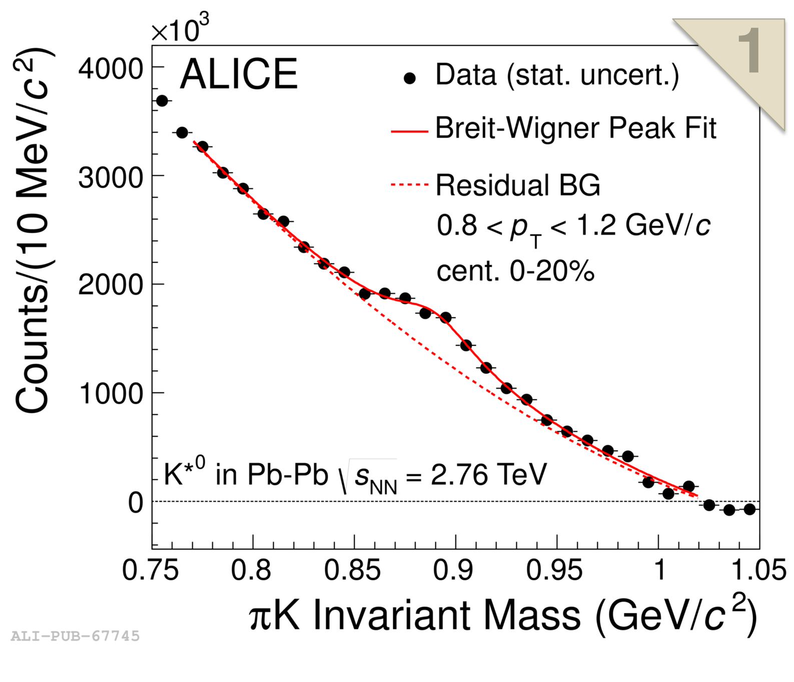
A Large **I**on **C**ollider **E**xperiment at the LHC can exploit its excellent tracking and particle identification capabilities to **identify resonance decay products** even at high charged-particle densities produced in central Pb-Pb collisions.

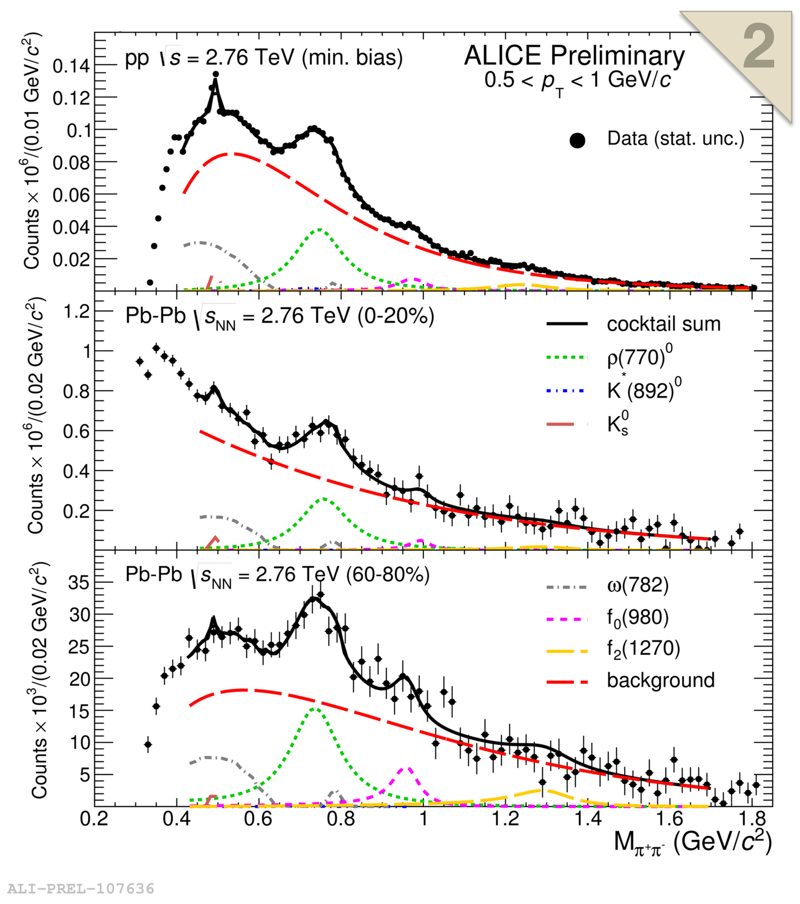
ALICE has measured the production of **$K^*(892)^0$ and $\phi(1020)$** [2,3], **$\rho(770)^0$** [4], **$\Lambda(1520)$, and $\Xi(1530)^0$** in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

Signal extraction

Resonance signals are reconstructed in the main hadronic decay channels (Fig. 1: $K^{*0} \longrightarrow K^{\pm}\pi^{\mp}$ [2]) via **invariant mass analysis**

✓ subtraction of like-sign or mixed-event background
✓ fit of the signal with Voigtian or Relativistic Breit-Wigner function plus a polynomial residual background
✓ no line shape modifications have been observed so far by ALICE





A closer look at $\rho(770)^0$

ρ^0 measurement via the hadronic decay channel $\rho^0 \longrightarrow \pi^+\pi^-$ (Fig. 2) is particularly challenging in Pb-Pb because of

- a large combinatorial background
  ✓ a cocktail is used to account for contributions to the residual background from K^0_S, ω, K^{*0}, f_0, f_2,
- the lack of detailed predictions for the line shape
  ✓ a vacuum peak model is used: rel. Breit-Wigner × phase space factor × mass-dependent efficiency correction × Söding interference term [5].

References

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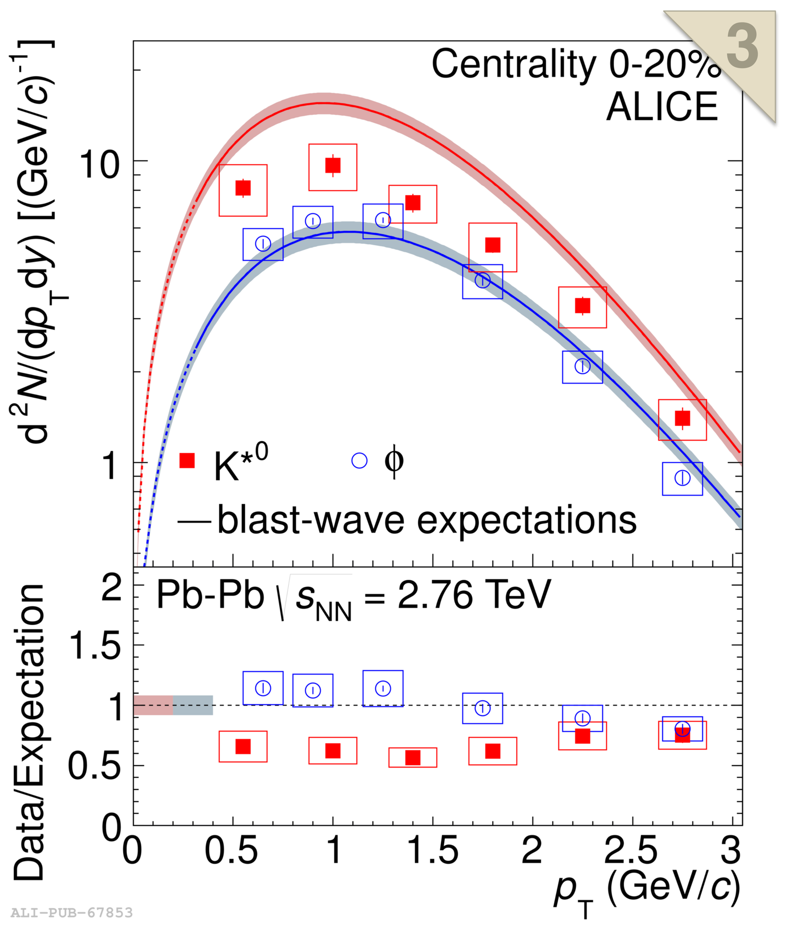
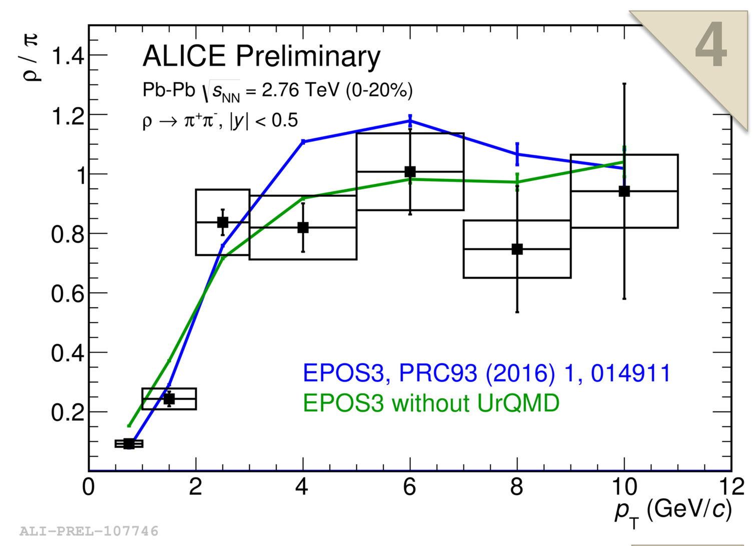
Resonance spectra in central Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

Yields have been measured as a function of p_T and centrality [2-4]. Spectra become harder from peripheral to central collisions under the effect of radial flow.

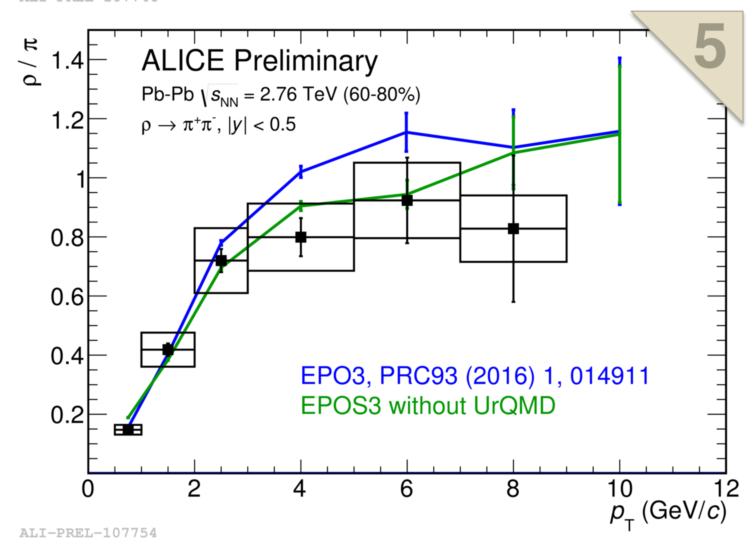
ϕ and K^{*0} spectra have been compared with a **Blast-Wave model** [6] that in 0-20% describes satisfactorily the ϕ spectrum but **overshoots K^{*0} at low p_T** (Fig. 3 [2]).





Blast-Wave model:

- parameters from a global Blast-Wave fit to π,K,p [7],
- normalisation to the resonance-to-K ratio from the thermal model [8] times the measured K yield [7].



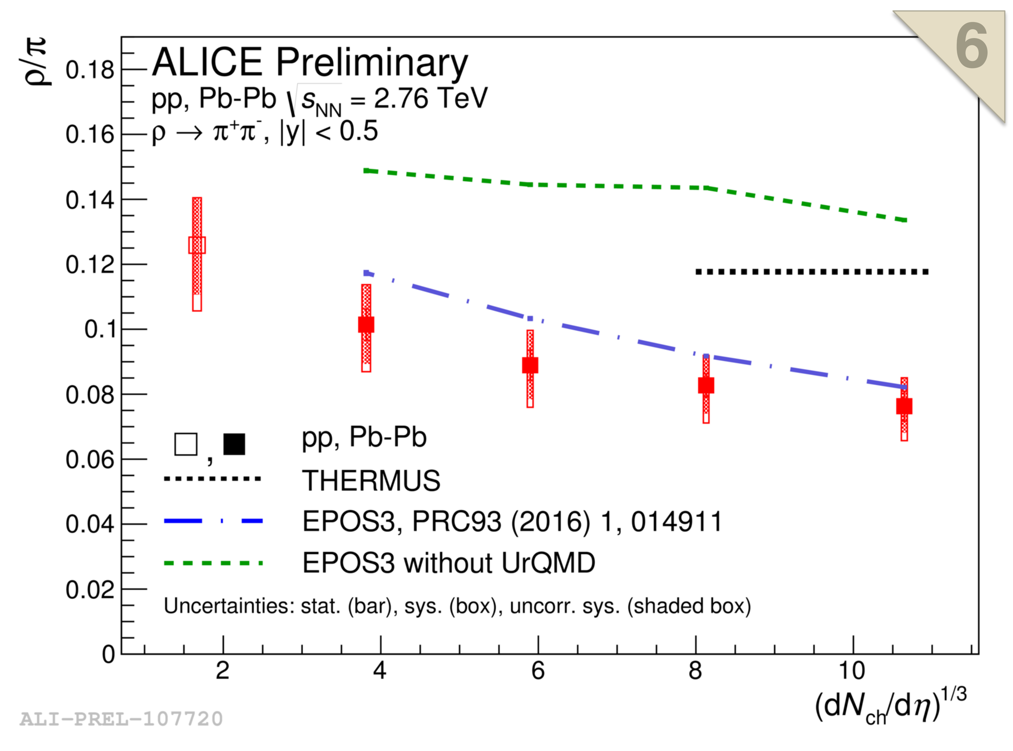
The **ρ^0/π ratio** in central Pb-Pb collisions (Fig. 4) is found to be significantly **suppressed for $p_T < 2$ GeV/c** with respect to the ratio in peripheral collisions (Fig. 5).

The suppression at low p_T is **reproduced by the EPOS3** [9] event generator when the core-corona development of the fireball is followed by a hadronic afterburner phase modeled **with UrQMD**.

System size dependence of resonance to long-lived hadron production

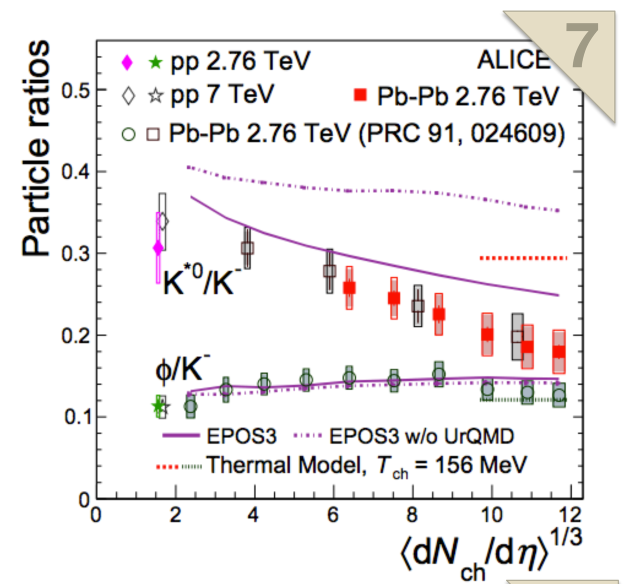
The p_T-integrated yield ratios of **ρ^0/π** (Fig. 6), **K^{*0}/K** (Fig.7, [3]), **Λ^*/Λ** (Fig. 8) **decrease from peripheral to central Pb-Pb collisions**, where they are suppressed with respect to the Grand-Canonical thermal model predictions [7].

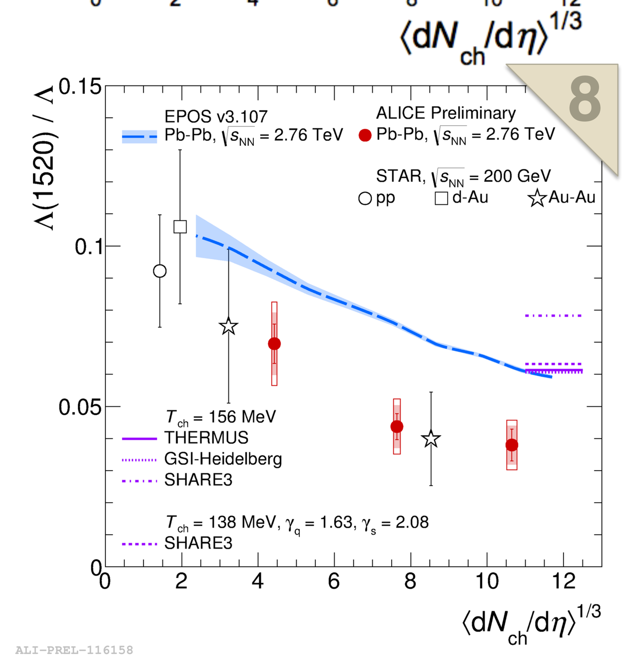
The ratio of the longer lived ϕ to K (Fig.7, [3]) and Ξ^*/Ξ (Fig. 9) show no significant trend with centrality. Whereas ϕ/K is consistent with the thermal model predictions, the model over-predicts Ξ^*/Ξ in central collisions.

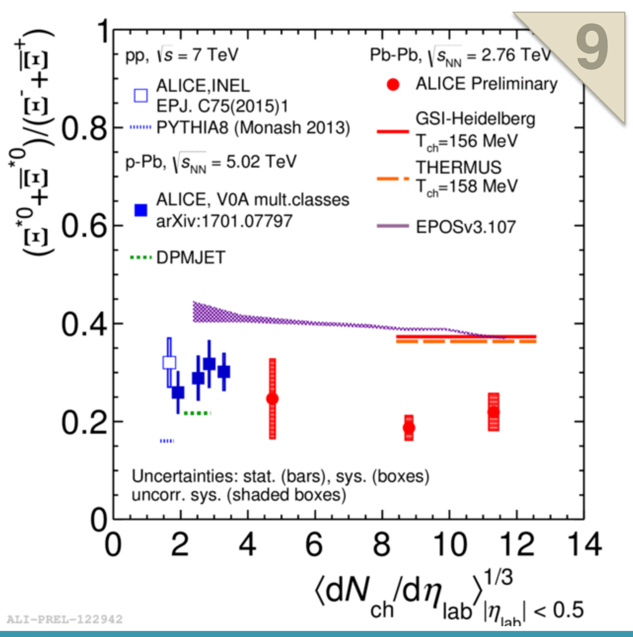


The trend of ρ^0/π, K^{*0}/K, Λ^*/Λ, ϕ/K is qualitatively reproduced by EPOS3 with UrQMD [9].

These results are suggestive of a **reduction of the yield of short-lived ρ^0, K^{*0}, Λ^*** due to **re-scattering** in the hadronic phase, important mainly at low-p_T.
The ϕ mainly decays outside the fireball due its longer lifetime.







Summary and outlook

✓ A set of ALICE measurements of ratios of resonance to long-lived hadrons suggest that short-lived resonance production is affected by **re-scattering in the hadronic phase**, important mainly at low-p_T.

✓ The Ξ^*/Ξ results indicate a strong suppression with respect to the thermal model predictions. If the Ξ^*/Ξ-ratio follows a suppression pattern similar to the short lived resonances cannot be concluded with the present uncertainties.

✓ A **lower limit for the lifetime of the hadronic phase, τ ≥ 2 fm/c**, is obtained combining the measured K^{*0}/K ratio with a model based on a thermal-model framework and including re-scattering effects after chemical freeze-out [10].

✓ Measurements of K^{*0}/K and other resonance ratios in p-Pb and pp as a function of multiplicity can be used to explore the possibility of the existence of a hadronic phase in small systems.

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