**NA61/SHINE facility**

The NA61/SHINE experiment uses a large acceptance hadron spectrometer located in the CERN North Area at the SPS accelerator. NA61/SHINE performs 2D scan with energy and system size ($p+p$, $p+Pb$, $Be+Be$, $Ar+Sc$, $Xe+La$, $Pb+Pb$ at beam momenta 13.4-190(84) GeV/c). The experimental setup consists of:

- 8 Time Projection Chambers
- 3 Time of Flight walls
- Projectile Spectator Detector
- Beam monitoring system

**Method**

The raw numbers of $K^*$ are obtained by using the template method, in which the invariant mass spectra of data (blue points) are fitted with a function:

$$f(m_{K^*}) = a \cdot T_{MC}(m_{K^*}) + b \cdot T_{est}(m_{K^*}) + c \cdot BW(m_{K^*})$$

$T_{MC}$ - resonance background template from reconstructed Monte Carlo data ($K^\pi$ pairs, which come from resonance decays with exception of $K^{*(892)^0}$)

$T_{est}$ - the background estimated based on the mixing method

$BW$ - Breit-Wigner distribution

$a, b, c$ - normalisation constant ($a+b+c=1$)

In left figure, the fitted invariant mass spectra, using Eq. 1, is presented by brown curves (total fit 1). The red lines (fitted background) show the same fitted functions but without the signal description elements ($BW$). The spectra after background subtraction is shown in right figure. The red line here (polynomial background) is an additional background descriptions based on the second order polynomial curve.

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**Motivation**

- the resonance yield is affected by regeneration and rescattering processes
- momenta of $K^*$ decay products can be modified due to elastic scatterings during the rescattering process → Suppression of observed $K^*$ yield
- $K^+/K^-$ or $K^*/K^+$ → time between chemical and kinetic freeze-outs, properties of hadron gas phase (STAR, PR C71, 064902, 2005, C. Blume, APP B43, 357, 2012)
- mass and/or width changes for A+A interactions → chiral symmetry restoration (G.E. Brown, M. Rho, PRL 66, 2720, 1991)
- the reference data to Blast-Wave models and statistical Hadron Resonance Gas models
- resonance measurements in p+p interactions are useful as reference for larger systems

**Results**

First results on $K^{*(892)^0}$ resonance production via its $K^*\to\pi^+\pi^-$ decay mode in inelastic p+p collisions at beam momenta 40-158 GeV/c ($\sqrt{s_{NN}}=8.8-17.3$ GeV). They are corrected for the losses of the $K^{*(892)^0}$ due to the $dE/dx$ requirement, geometrical acceptance, reconstruction efficiency, losses due to the trigger bias, detector acceptance as well as the quality cuts applied in the analysis. The mean multiplicities of $K^{*(892)^0}$ are calculated by summing points (only for $y>0$) and adding integral of gaussian fit in non-measured area.

The NA61/SHINE ($K^{*(892)^0}$/$K^*$) and ($K^{*(892)^0}$/$K^*$) yield ratios for p+p collisions can be used to estimate the time between chemical and kinetic freeze-outs in Pb+Pb. Assuming no regeneration processes and following PR C71, 064902, 2005:

$$\frac{K^*}{K}^{\text{chemical}} = \frac{K^*}{K}^{\text{kinetic}} e^{-\frac{\Delta t}{\tau}}$$

- ($K^{*(892)^0}$/K$^+$) ratio in inelastic p+p interactions can be treated as the one at chemical freeze-out,
- ($K^{*(892)^0}$/K$^+$) ratio for central Pb+Pb (NA49) interactions can be used as the one at kinetic freeze-out,
- $\tau$ is the $K^{*(892)^0}$ lifetime of 4.17 fm/c (PDG, CPC, 40, 100001, 2016),
- $\Delta t$ is the time between chemical and kinetic freeze-outs.


Left figure: For Pb+Pb at 158 GeV/c, the calculated times between chemical and kinetic freeze-outs assuming no regeneration processes are equal:

- $3.8 \pm 1.1$ fm/c for $K^{*(892)^0}$/$K^*$
- $3.3 \pm 1.2$ fm/c for $K^{*(892)^0}$/$K^*$

Right figure: Reference heavy ion data needed to estimate time between freeze-outs at lower energies (40 and 80 GeV/c).

The statistical Hadron Resonance Gas Models (HRG) are commonly used to predict particle multiplicities in elementary and nucleus-nucleus collisions, using as adjustable parameters the chemical freeze-out temperature $T_{chem}$, the baryochemical potential $\mu_B$, strangeness saturation parameter $\gamma_S$, etc.

The ($K^{*(892)^0}$) values are compared with predictions of two HGM models described in: F. Becattini et al., PR C73, 044905, 2006 (left plot) and V. Vescan et al., PR C98, 054909, 2018 (right and left plots). The two versions of fits (PR C73) where used to create left plot:

- Fit B: uses "standard" $\gamma_S$; for p+p $C$ and $\Omega$ baryons excluded from fit
- Fit A: $\gamma_S$ replaced by $(sQ)$; for p+p $\phi$ meson excluded from fit

**References**


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