# Mesonic strange resonances in p+p collisions at SPS energies

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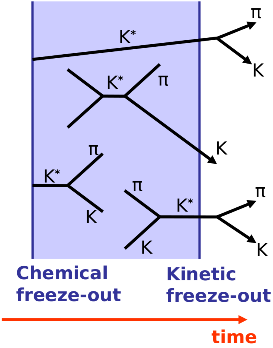
# $K^*(892)^0$ AND $\phi(1020)$ ANALYSIS MOTIVATION



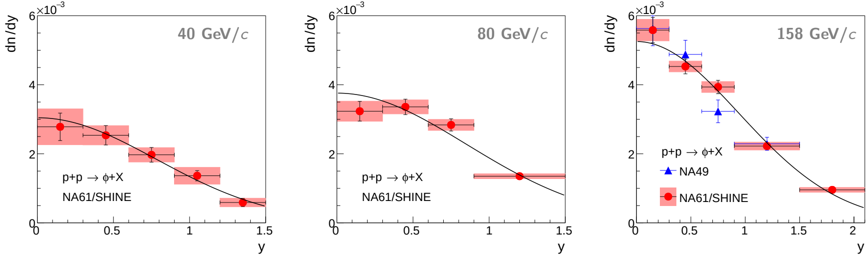

$K^*(892) = d\bar{s}$ meson

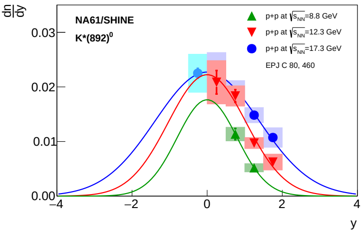
- Mass $m = 895.55 \pm 0.20$ MeV
- Width $\Gamma = 47.3 \pm 0.5$ MeV ($\tau \cong 4.17$ fm/c)

$\phi(1020) = s\bar{s}$ meson

- Mass $m = 1019.461 \pm 0.016$ MeV
- Width $\Gamma = 4.249 \pm 0.01$ MeV ($\tau \cong 46$ fm/c)

- 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 $\rightarrow$ **suppression of observed $K^*$ yield**
- $\phi$ yield should not be affected by rescattering and regeneration processes due to longer lifetime
- $\phi/K$ and $K^*/K$ $\rightarrow$ studying rescattering effects in heavy-ion collisions
- $K^*/K^-$ **or** $K^*/K^+$ $\rightarrow$ **time between chemical and kinetic freeze-outs**, properties of hadron gas phase (STAR, PR C71, 064902, 2005; C. Blume, APP B43, 577, 2012)
- $\phi$ interesting due to its hidden strangeness ($s\bar{s}$)
- $K^*$ and $\phi$ - reference data to Blast-Wave models and statistical Hadron Resonance Gas models

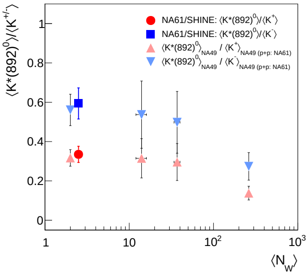


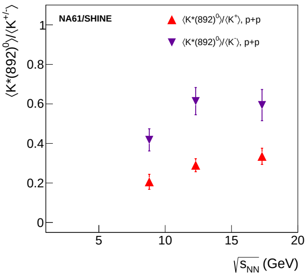




$K^*(892)^0$ results from: EPJ C80, 5, 460, 2020; EPJ C82, 4, 322, 2022
$\phi(1020)$ results from: EPJ C80, 3, 199, 2020

- Gaussian fit: $f(y) = a \cdot e^{-\frac{y^2}{2\sigma_y^2}}$
- $\langle K^* \rangle$ and $\langle \phi \rangle$ are calculated by summing points (only for y>0) and adding integral values in non-measured area

| $\sqrt{s_{NN}}$ | $\langle K^* \rangle$ $[\cdot 10^{-3}]$ | $\langle \phi \rangle$ $[\cdot 10^{-3}]$ |
|---|---|---|
| 8.8 | $35.1 \pm 1.3 \pm 3.6$ | $5.87 \pm 0.35 \pm 0.44$ |
| 12.3 | $58.3 \pm 1.9 \pm 4.9$ | $7.89 \pm 0.29 \pm 0.39$ |
| 17.3 | $78.44 \pm 0.38 \pm 6.0$ | $12.56 \pm 0.33 \pm 0.32$ |



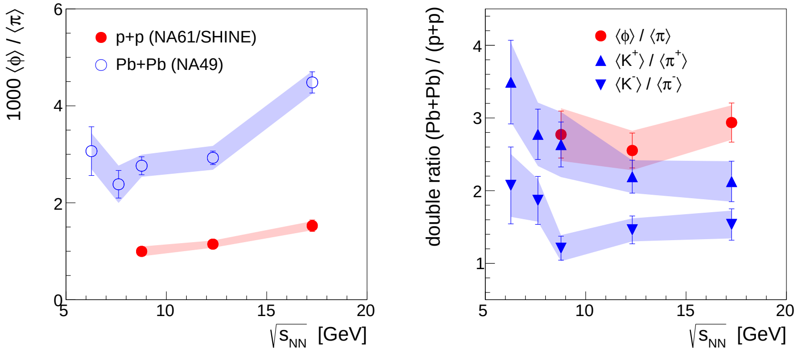

- $K^*/K^-$ **or** $K^*/K^+$ $\rightarrow$ **time between chemical and kinetic freeze-outs**, properties of hadron gas phase (STAR, PR C71, 064902, 2005; C. Blume, APP B43, 577, 2012)

$$\left.\frac{K^*}{K}\right|_{kinetic} = \left.\frac{K^*}{K}\right|_{chemical} e^{-\frac{\Delta t}{\tau}} \quad (1)$$

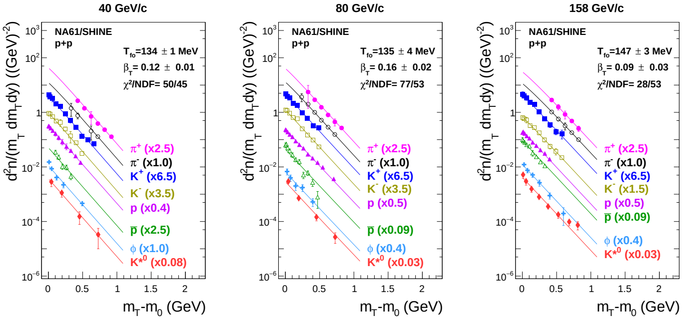
Assumption: no regeneration processes
Ratio for kinetic freeze-out from Pb+Pb interact.;
Ratio for chemical freeze-out from p+p interact.;

- **$\Delta t$ in the collision center-of-mass reference system** for p+p at 158 GeV/$c$:
  - 5.3 fm/c for $K^*(892)^0/K^+$
  - 4.6 fm/c for $K^*(892)^0/K^-$

- **$\Delta t$ at SPS $>$ $\Delta t$ at RHIC** (at corresponding centrality), NA61/SHINE, EPJ C80, 5, 460, 2020.
  $\rightarrow$ regeneration effects may be significant at higher energies
- Regeneration effects may exist also at SPS
  $\rightarrow$ obtained **$\Delta t$ is lower limit of time between freeze-outs**
- Reference ion data are needed to estimate $\Delta t$ at lower energies ($K^*/K^{\pm}$ for p+p data already exist – left plot)

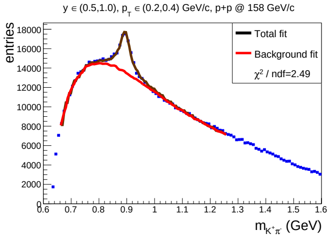


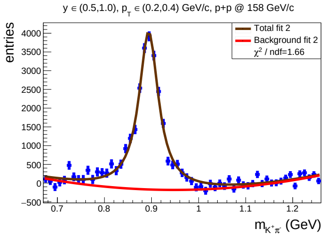

- $\langle\phi\rangle/\langle\pi\rangle$ ratio increases with collision energy
- $\phi$ production is enhanced roughly threefold for all 3 measured energies
- The strangeness enhancement of $\phi$ mesons can be compared to $\langle K^+\rangle/\langle\pi^+\rangle$ and $\langle K^-\rangle/\langle\pi^-\rangle$; it is systematically larger for $\phi$ mesons than for kaons, being however comparable to that for positive kaons




- The fitted formula follows: $\frac{d^2 n_i}{m_T dm_T dy} = A_i\, m_T\, K_1\left(\frac{m_T \cosh\rho}{T_{fo}}\right) I_0\left(\frac{p_T \sinh\rho}{T_{fo}}\right)$, where $I_0$ and $K_1$ are the modified Bessel functions, $A_i$ are the fitted normalization parameters, and index $i$ refers to different particle species. The fit parameter $\rho$ is related to the transverse flow velocity by $\rho = tanh^{-1}\beta_{\mathrm{T}}$
- The obtained thermal freeze-out temperatures ($T_{fo}$) vary between 134 and 147 MeV
- $\beta_T$ are close to 0.1–0.2 of the speed of light. The $\beta_T$ values for p+p collisions are significantly smaller than the ones determined by NA49 in central Pb+Pb interactions

# Back-up




NA61/SHINE, EPJ C80, 5, 460, 2020

- The p+p data was analysis for 40 GeV/$c$ ($1.34 \cdot 10^6$ events), 80 GeV/$c$ ($1.26 \cdot 10^6$ events) and 158 GeV/$c$ ($27.9 \cdot 10^6$ events)
- Signal extraction was done by extracting the resonances and correlated background:

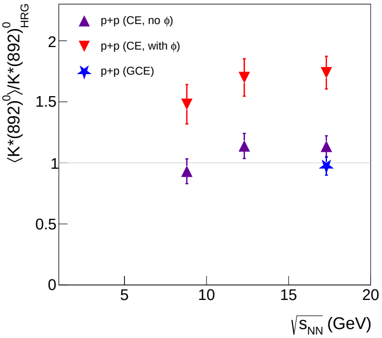
$$f(m_{inv}) = a \cdot T^{MC}_{res}(m_{inv}) + b \cdot T^{DATA}_{mix}(m_{inv}) + c \cdot BW(m_{inv}) \quad (2)$$

where:

- $T^{MC}_{res}$ - resonance background template from reconstructed Monte Carlo data ($K^+\pi^-$ pairs, which come from resonance decay with exception of $K^*(892)^0$)
- $T^{DATA}_{mix}$ - uncorrelated background from mixed events
- $BW(m_{inv})$ - Breit-Wigner distribution:

$$BW(m_{inv}) = A \cdot \frac{\frac{1}{4} \cdot \Gamma^2}{(m_{inv} - m_o)^2 + \frac{1}{4}\Gamma^2} \quad (3)$$

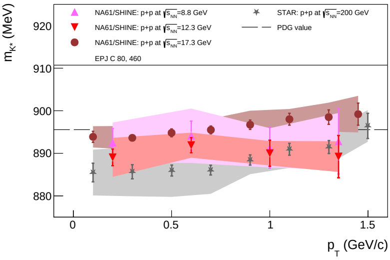
- $a, b, c$ - normalisation const (a+b+c=1)

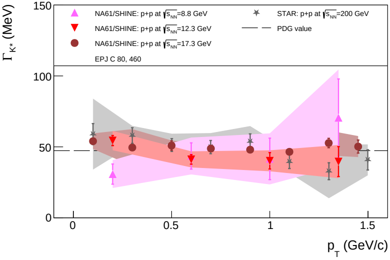



p+p at 158 GeV/$c$ results from EPJ C80, 5, 460, 2020;
p+p at 40 and 80 GeV/$c$ from EPJ C82, 4, 322, 2022

- HRG by V. Begun et al. (PR C98, 054909, 2018) in the Canonical Ensemble (CE):
  - Red triangles correspond to the HRG fits with the $\phi$ meson multiplicities included
  - Violet triangles represent the situation where the $\phi$ mesons were not included in the HRG model fits
  - Blue start correspond to the HRG fits in GCE with $\phi$ meson included

- **Small p+p collision can be described by GCE**
- **p+p data can be described by CE only for fit with $\phi$ meson excluded**




- Mass and width were calculated in the range $y\epsilon(0.0; 0.5)$ for p+p at 158 GeV/$c$
- Mass and width were calculated in the range $y\epsilon(0.0; 1.5)$ for p+p at 40 and 80 GeV/$c$
- The values of mass and width of $K^*$ are generally close to the PDG results