$K^*(892)^0$ production in p+p interactions at 158 GeV/c from NA61/SHINE

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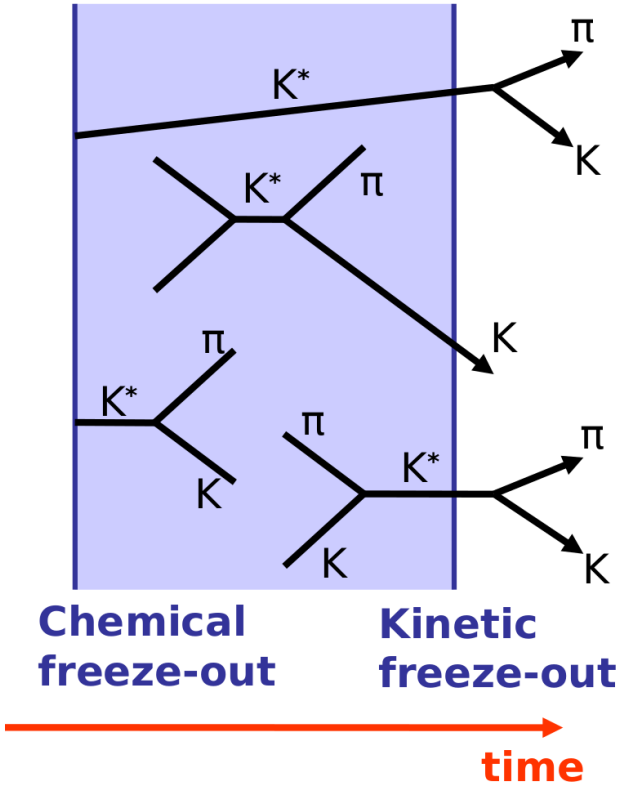
Critical Point and Onset of Deconfinement 2018

Motivation



- The resonance yield is affected by **regeneration** and **rescattering** process
- Momenta of K^* decay products can be modified due to elastic scatterings during the rescattering process $\rightarrow$ **Suppression of observed K^* yield**
- K^*/K^- **or** K^*/K^+ $\rightarrow$ **time between chemical and kinetic freeze-outs**, properties of hadron gas phase (C.Blume, APP B43, 577-586, 2012)

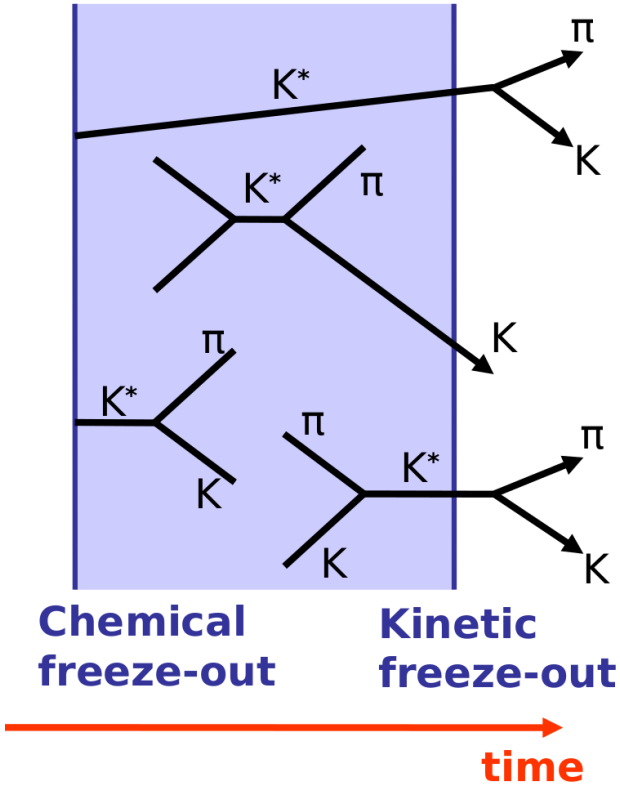
$$\left.\frac{K^*}{K}\right|_{kinetic} = \left.\frac{K^*}{K}\right|_{chemical} e^{-\frac{\Delta t}{\tau}} \quad (1)$$

Assumption: no regeneration process
Ratio for kinetic freeze-out from Pb+Pb interaction
Ratio for chemical freeze-out from p+p interaction

$K^*(892) = d\bar{s}$ meson according to PDG 2018

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

Motivation



- 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 interaction are useful as reference for system size dependence study

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- Mass $m = 895.55 \pm 0.20$ MeV
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Event selection

- inelastic p+p
- good quality of fitted vertex
- interaction in the target

Kinematical cuts

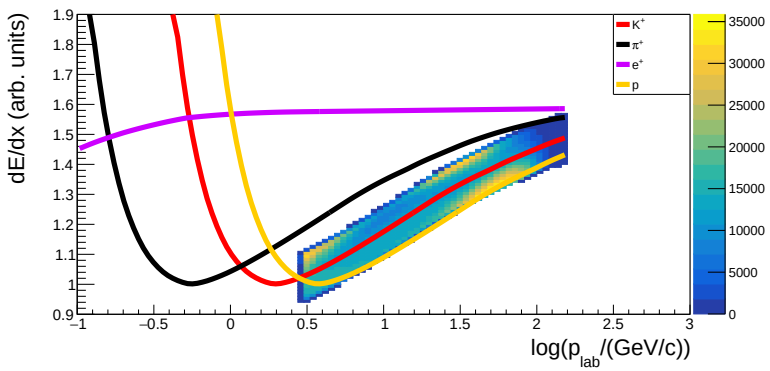
- p >3 GeV/c
- p_T <1.5 GeV/c

Track selection

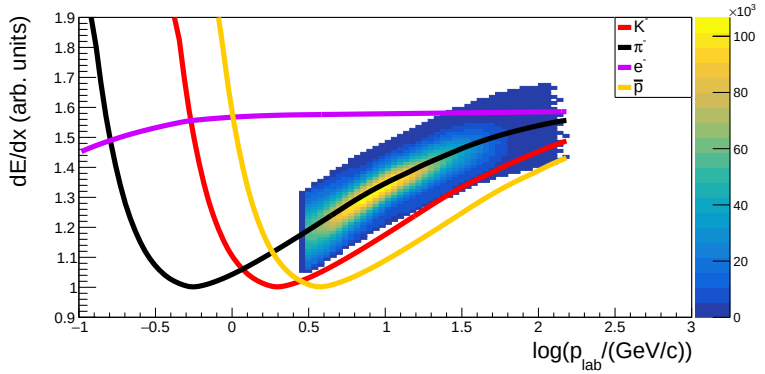
- from main vertex
- good momentum reconstruction
- number of points in TPCs
- PID cut: $\rightarrow dE/dx \sim K^+$ and π^-

Statistics - p+p @ 158 GeV/c

- $\mathbf{N_{events} = 27.9 \cdot 10^6}$
- $\mathbf{N_{tracks} = 106.1 \cdot 10^6}$ in accepted events

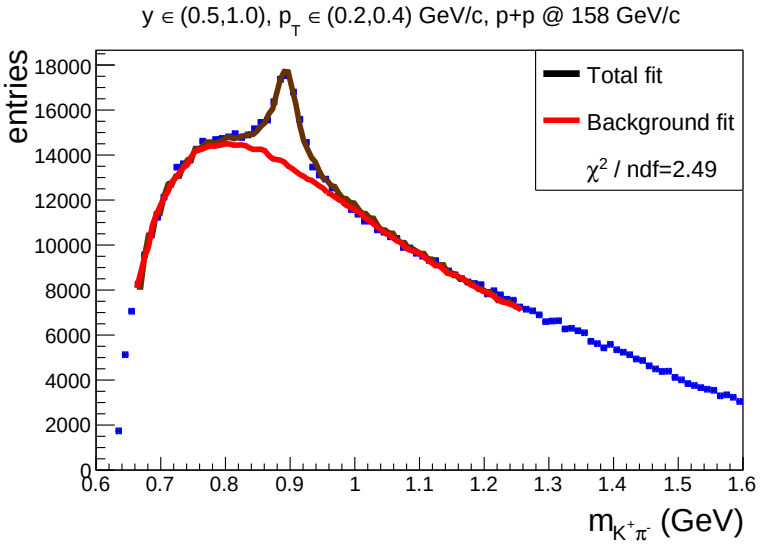


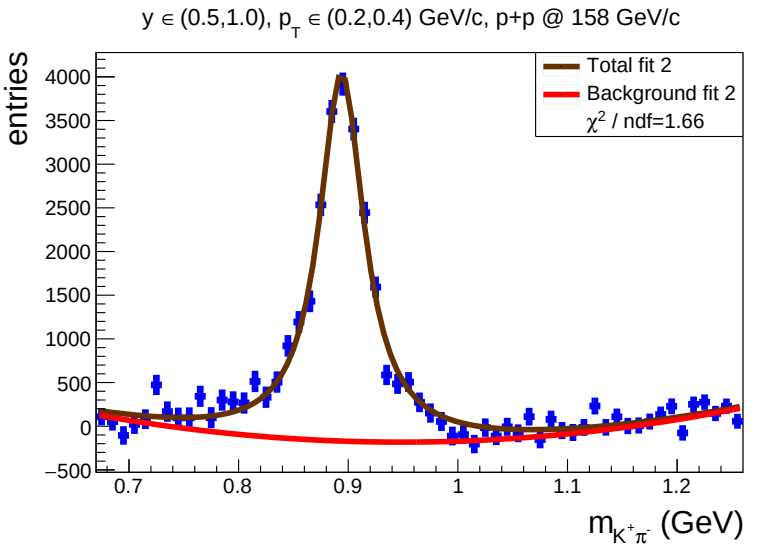
(A) K^+ ($1.5 \cdot \sigma_{K^+}$)



(B) π^- ($3.0 \cdot \sigma_{\pi^-}$)

Signal extraction





Signal extraction was done in two steps:

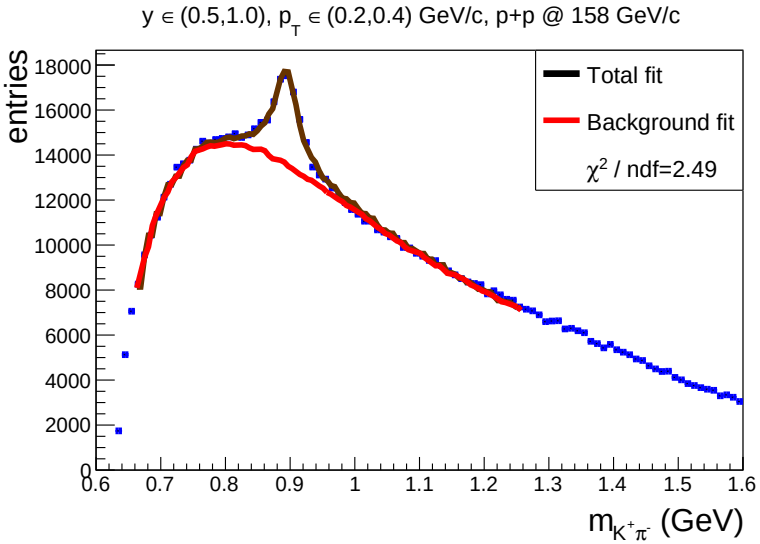
1. Extracting the resonances and correlated background:

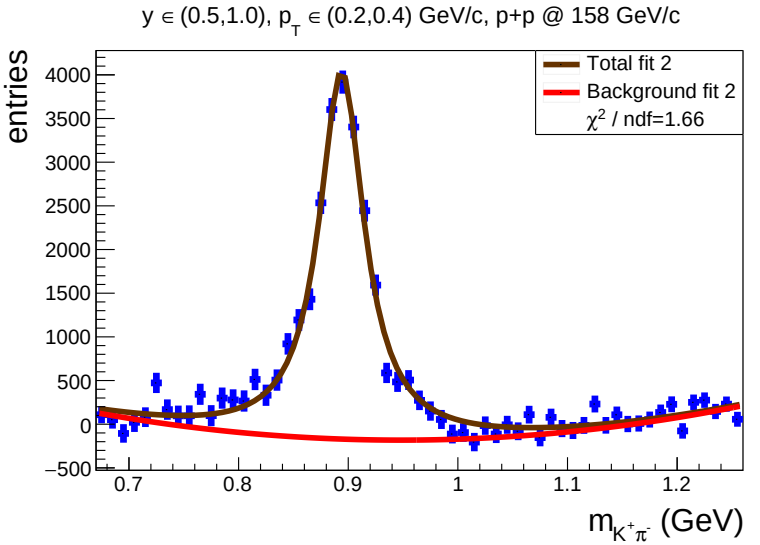
$$f(m_{inv}) = a \cdot T_{res}^{MC}(m_{inv}) + b \cdot T_{mix}^{DATA}(m_{inv}) + c \cdot BW(m_{inv}) \quad (2)$$

where:

- T_{res}^{MC} - resonance background template from reconstructed Monte Carlo data ($K^+\pi^-$ pairs, which come from resonance decay with exception of $K^*(892)^0$)
- T_{mix}^{DATA} - uncorrelated background from mixed events

Signal extraction





1.
   - $BW(m_{inv})$ - Breit-Wigner distribution:

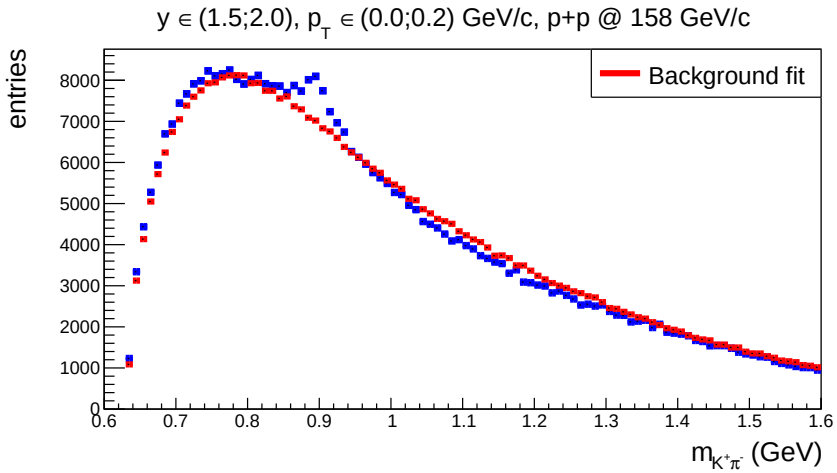
$$BW(m_{inv}) = A \cdot \frac{\frac{1}{4} \cdot \Gamma^2}{(m_{inv} - m_o)^2 + \frac{1}{4}\Gamma^2} \quad (3)$$

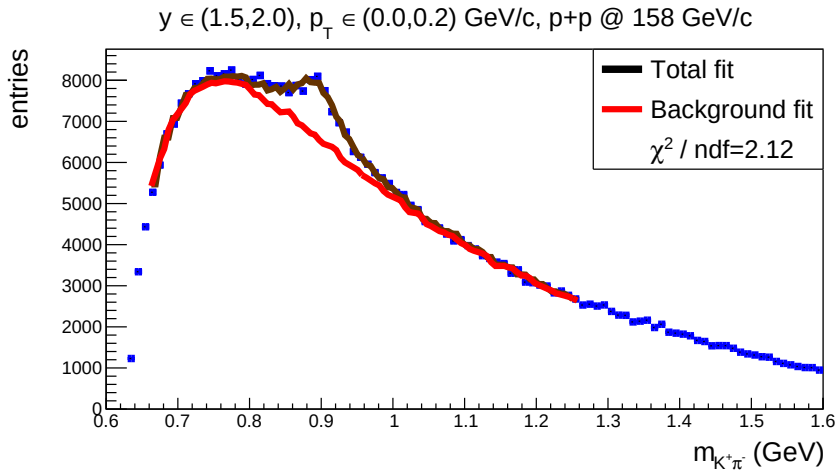
   - a, b, c - normalisation const (a+b+c=1)

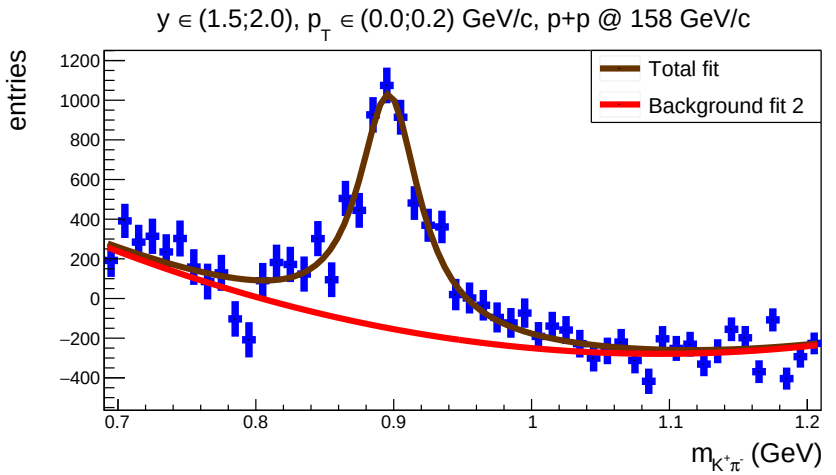
2. Extracting the residual background by using the 2nd order polynomial

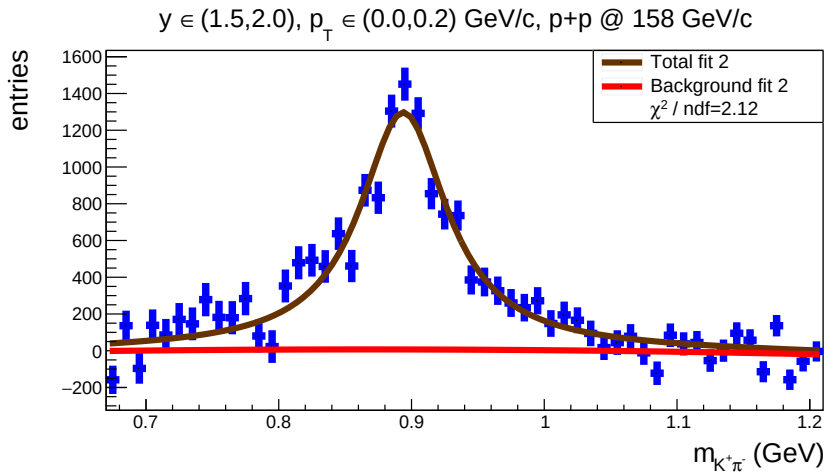
Standard Method vs. Template Method

- Standard method: background described by mixed events only
- Template method: described on previous slides



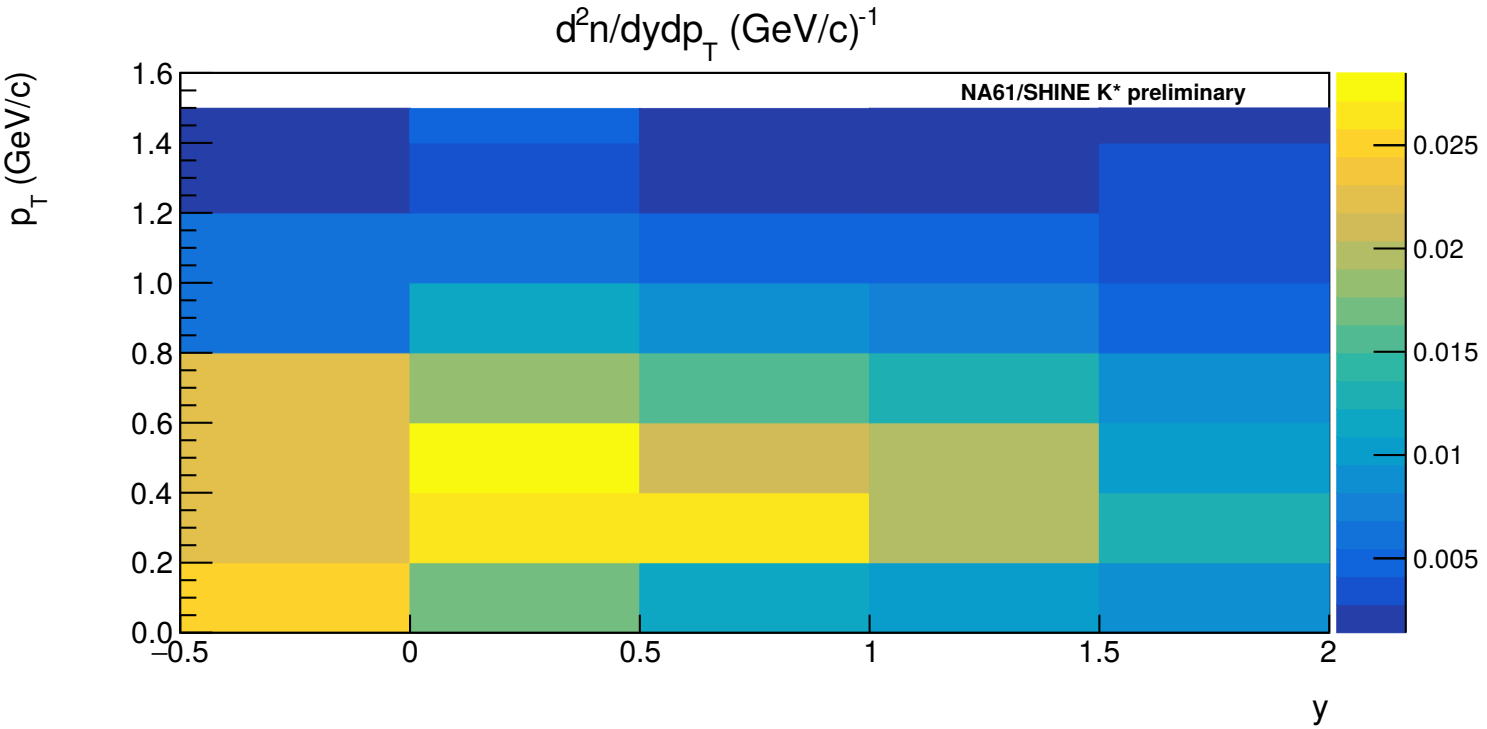






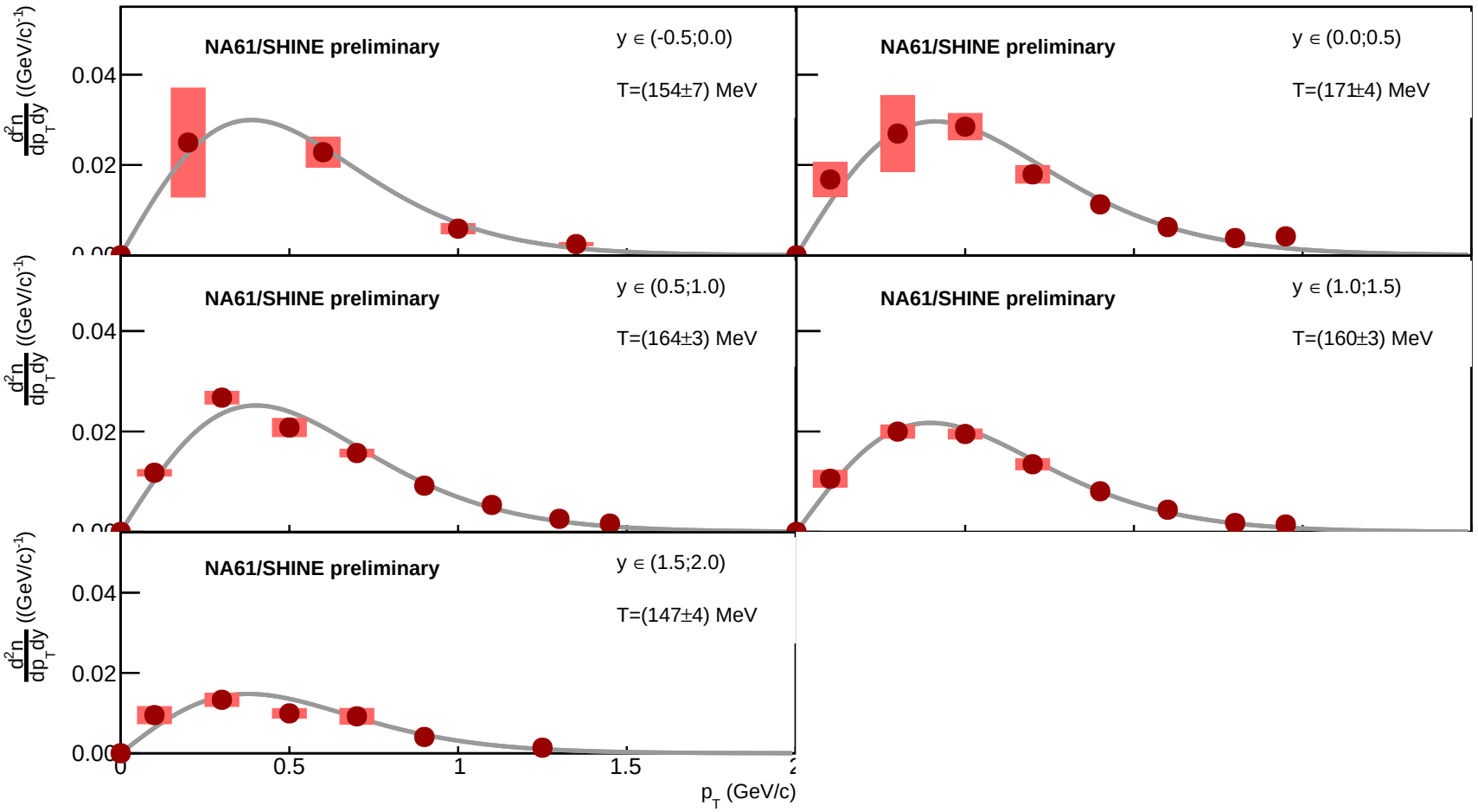
Double differential spectra

- Results refer to inelastic p+p interactions. They are corrected for detector acceptance and experimental biases
- First 2D (y vs p_T) spectra for p+p @ 158 GeV/c

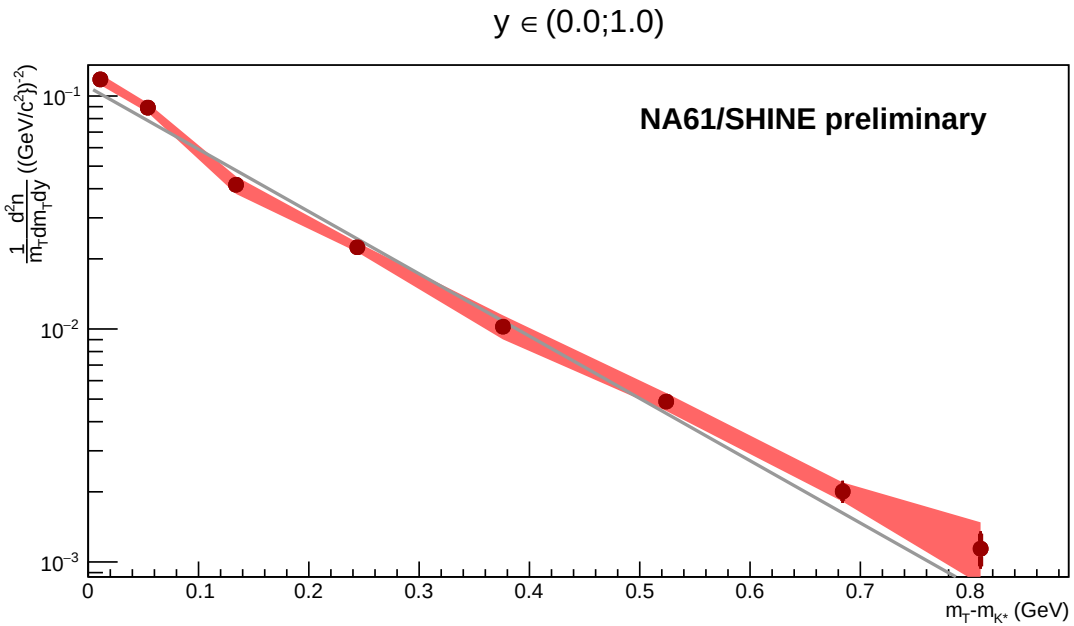


Double differential spectra

- Fit: $f(p_T) = A \cdot p_T e^{\frac{-\sqrt{p_T^2+m_{PDG}^2}}{T}}$ $\rightarrow$ extrapolation to $p_T = +\infty \rightarrow$ tail $\sim 1\%$



Transverse mass spectrum at mid-rapidity

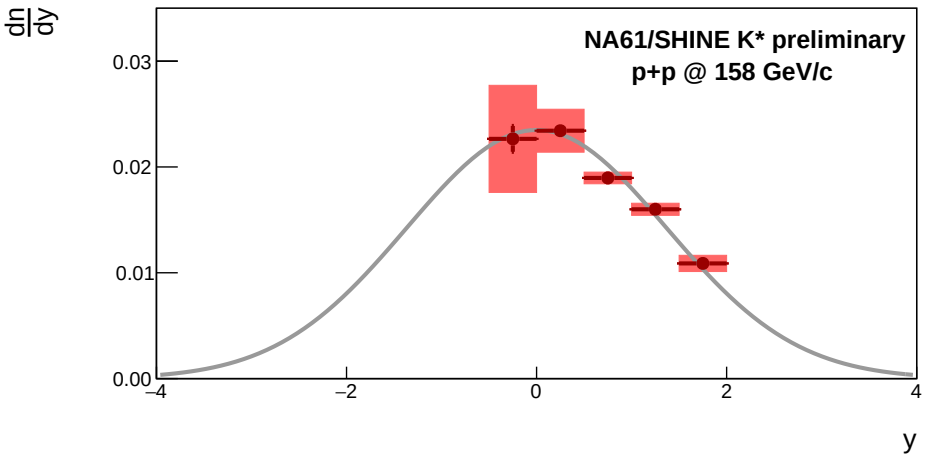


- The fit: $f(m_T) = A \cdot e^{-\frac{m_T}{T}}$

Fit results

	NA61/SHINE	NA49 (PR C84, 064909, 2011)
T_{K*} [GeV]	0.1624±0.0029±0.0059	0.166±0.011±0.010

Rapidity Spectrum



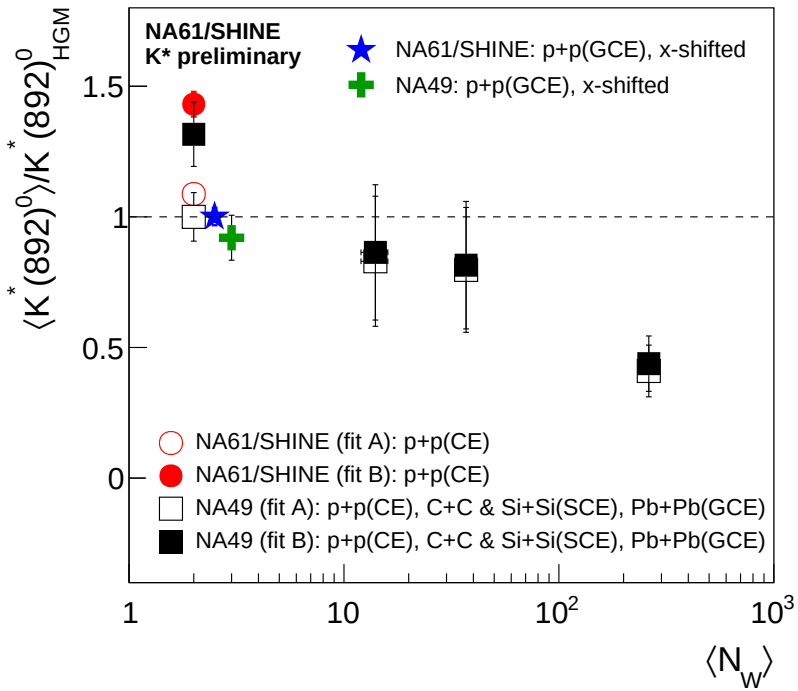
- First p_T-integrated $\frac{dn}{dy}$ spectra for p+p @ 158 GeV/c
- Gaussian fit: $f(y) = a \cdot e^{-\frac{y^2}{2\sigma_y^2}}$
- The $\langle K^* \rangle$ is calculated by summing points (only for y>0) and adding integral values in non-measured area

Mean multiplicity of $K^*(892)^0$

	NA61	NA49
$\langle K^*(892)^o \rangle$	$0.08058 \pm 0.00059 \pm 0.00260$	$0.0741 \pm 0.0015 \pm 0.0067$

NA49 results from PR C84, 064909, 2011

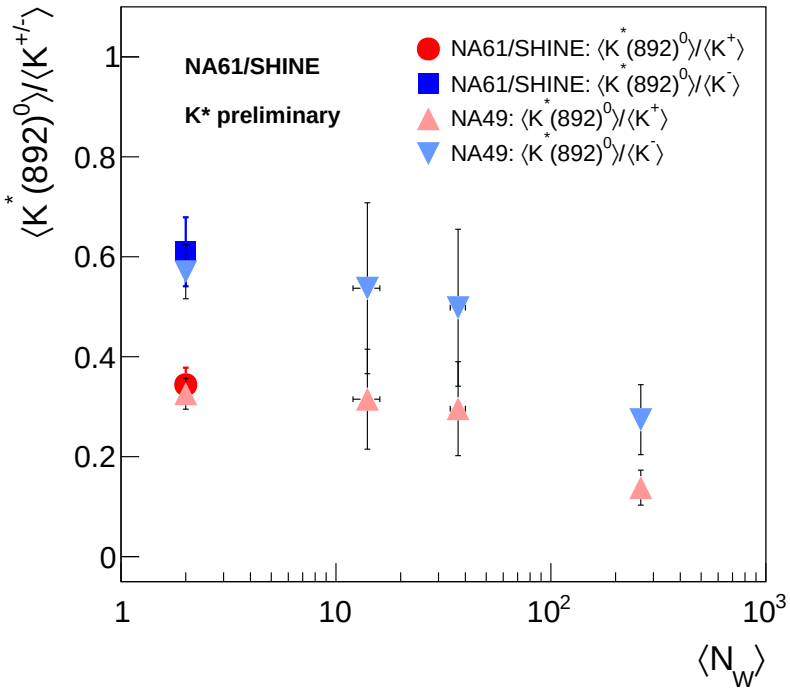
Comparison of $K^*(892)^0$ production with Hadron-Resonance Gas Model



- HRG by F.Becattini et al. (PR C73, 044905, 2006)
  - Fit B; uses "standard" γ_s; for p+p Ξ and Ω baryons excluded from fit
  - Fit A: γ_s replaced by $\langle s\bar{s}\rangle$; for p+p ϕ meson excluded from fit
- HRG by V.Begun et al. (arXiv:1805.01901)
  - p+p: GCE with ϕ meson included

- Deviation from HGM model increases with increasing system size
- **Small p+p collision can be described by GCE**
- **p+p data can be described by CE only for fit A (ϕ meson excluded from fit)**

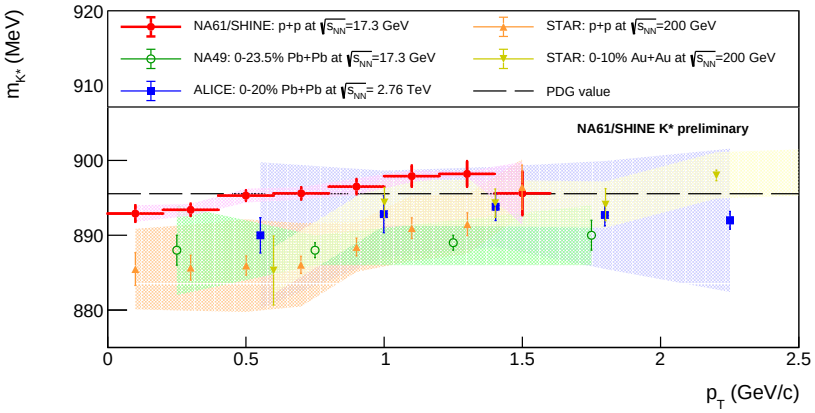
System size dependence of $K^*(892)^0$ to charged kaon ratio

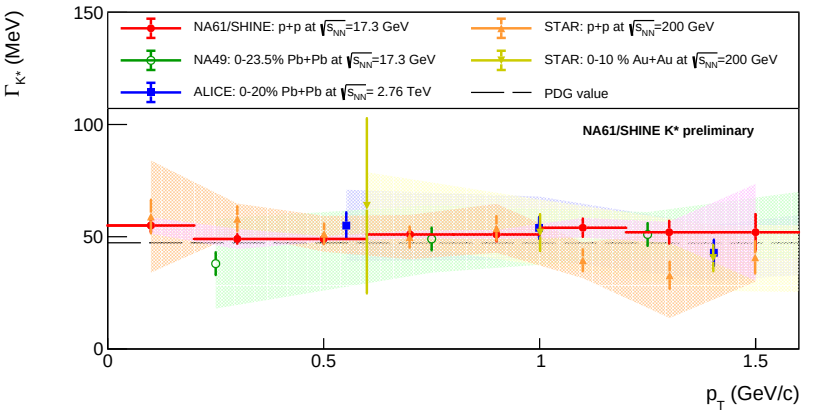


- Results from:
  - NA49 K^*: PR C84, 064909, 2011
  - NA49 $K^{+/-}$: EPJC 68, 1, 2010; PRL 94, 052301, 2005; PR C66, 054902, 2002
  - NA61/SHINE $K^{+/-}$: EPJC 77, 671, 2017
- **Time between chemical and kinetic freeze-outs** (assuming no regeneration processes):
  - 3.8 ± 1.1 fm/c for $K^*(892)^0/K^+$
  - 3.3 ± 1.2 fm/c for $K^*(892)^0/K^-$

- Δt at SPS $>$ Δt at RHIC (2 ± 1 fm/c, STAR, PR C71, 064902, 2005) suggesting that regeneration effects may start to play significant role for higher energies
- Regeneration may happen also at SPS $\rightarrow$ obtained Δt is lower limit of time between freeze-outs

K^{*0} mass and width





- Results from:
  - NA49: PR C84, 064909, 2011
  - ALICE: PR C91, 024609, 2015
  - STAR: PR C71, 064902, 2005
- The mass and width were calculated as average value in range $y\epsilon(0.0; 1.5)$ from three bins
- NA61: The K^{*0} mass and width agree with PDG values
- NA61: For K^{*0} no mass shift or width broadening

Summary

- The first 2D (y and p_T) and p_T-integrated rapidity spectra of K^* meson are obtained for p+p @ 158 GeV/c
- 4π acceptance NA61 results consistent with the NA49 ($0 < p_T < 1.5$ GeV/c) results but with better accuracy
- The $\langle K^*(892)^o \rangle$ can be described by HGM CE fit A (ϕ meson excluded) and by HGM GCE model with ϕ
- Time between chemical and kinetic freeze-outs at SPS is higher than at RHIC $\rightarrow$ regeneration effects may start to play significant role for higher energies
- The mass and Γ agree with the PDG values. No observed mass shift or width broadening
- Plans: $\bar{K}^*$ for p+p at 158 GeV/c, K^* and $\bar{K}^*$ for p+p at lower SPS energies

Acknowledgements

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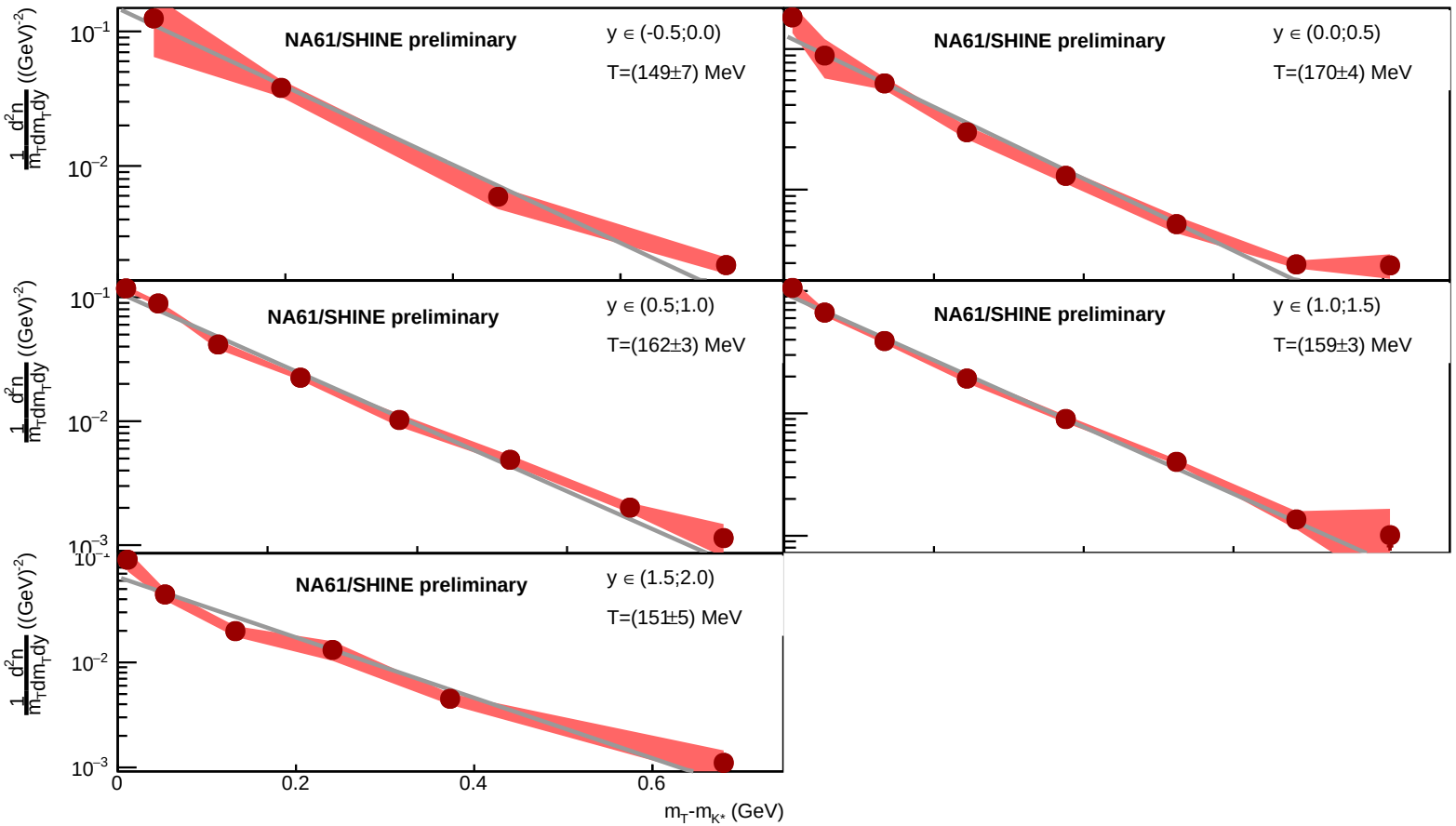
Back-up

Transverse mass spectra



- The fit: $f(m_T) = A \cdot e^{-\frac{m_T}{T}}$