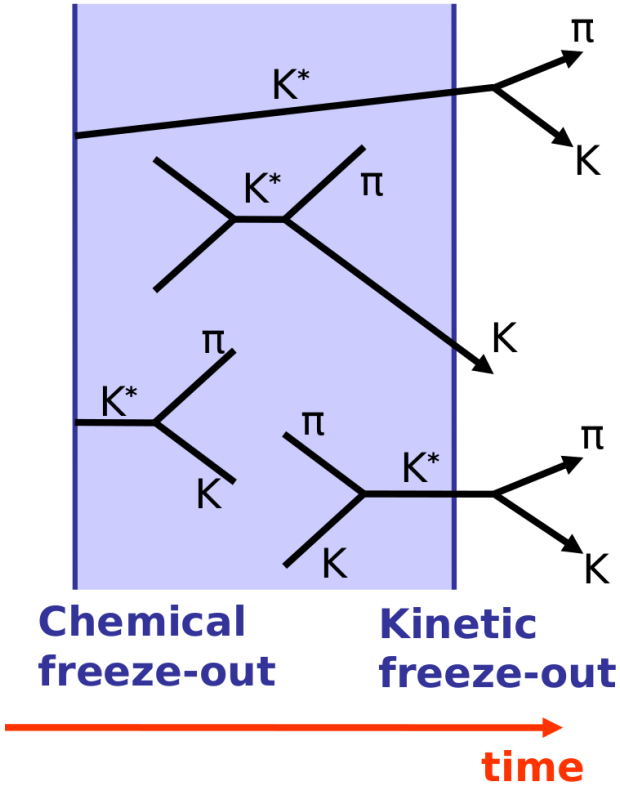
$K^*(892)^0$ production in p+p interactions from NA61/SHINE

Angelika Tefelska [1]
for the NA61/SHINE Collaboration

[1]Warsaw University of Technology

The 18^{th} International Conference on Strangeness in Quark Matter

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 $\rightarrow$ **Suppression of observed K^* yield**
- 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)

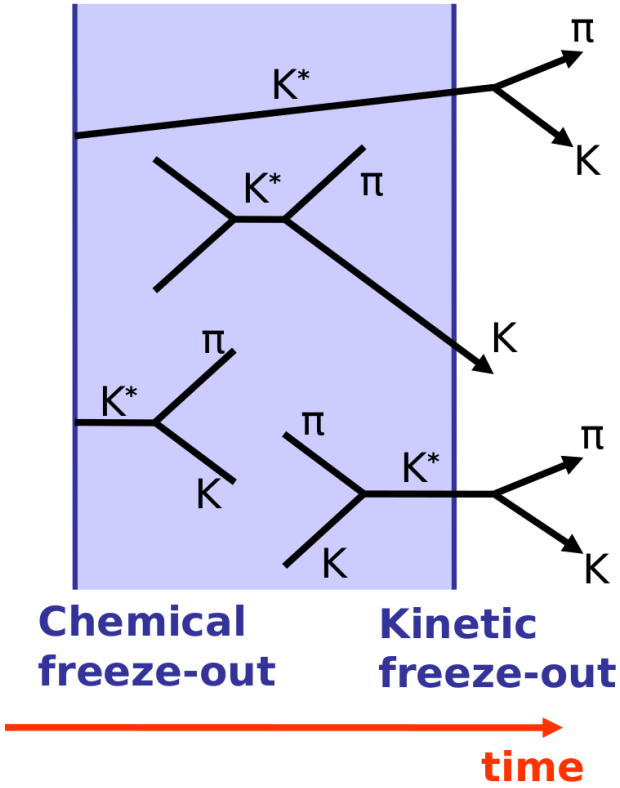
$$\left.\frac{K^*}{K}\right|_{kinetic} = \left.\frac{K^*}{K}\right|_{chemical} e^{-\frac{\Delta t}{\tau}} \quad (1)$$

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

$K^*(892) = d\bar{s}$ 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 interactions are useful as reference for system size dependence study

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

- Mass $m = 895.55 \pm 0.20$ MeV
- Width $\Gamma = 47.3 \pm 0.5$ MeV
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Event and Track selection criteria

Event selection

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

Kinematical cuts

- p >3 GeV/c for p+p @ 158 GeV/c
- $p \geq$0 GeV/c for p+p @ 40 and 80 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

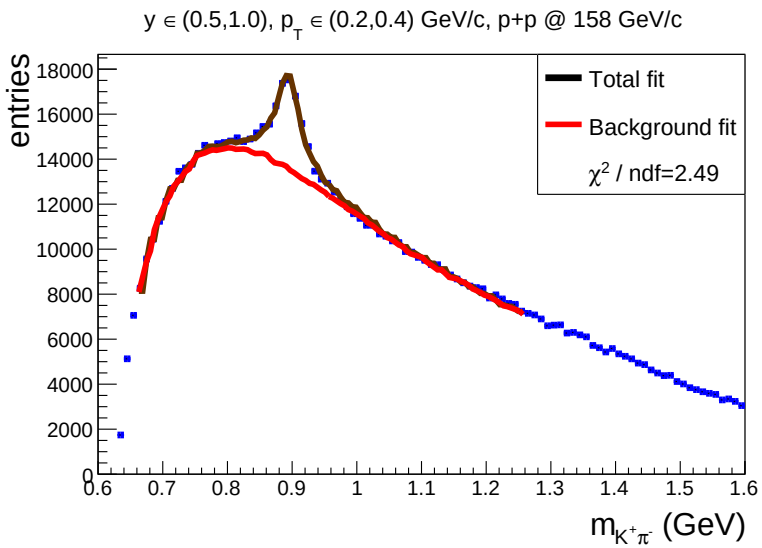
Statistics - p+p @ 80 GeV/c

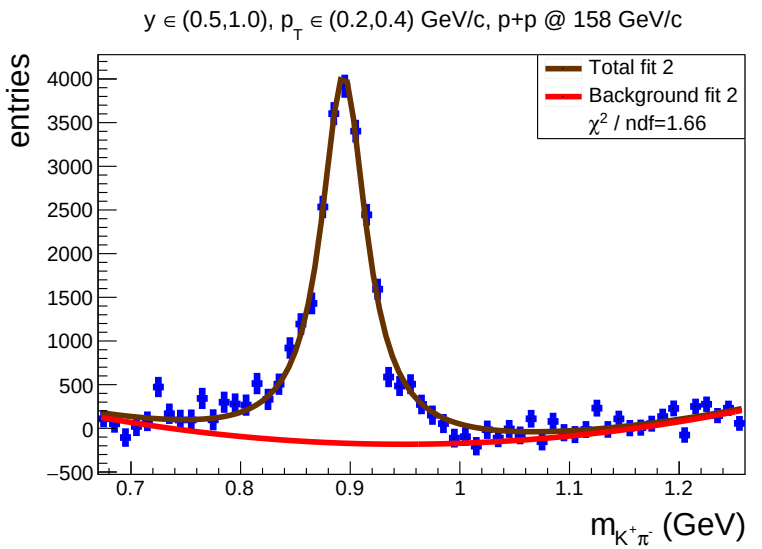
- $\mathbf{N_{events} = 1.26 \cdot 10^6}$
- $\mathbf{N_{tracks} = 4.68 \cdot 10^6}$ in accepted events

Statistics - p+p @ 40 GeV/c

- $\mathbf{N_{events} = 1.34 \cdot 10^6}$
- $\mathbf{N_{tracks} = 3.65 \cdot 10^6}$ in accepted events

Signal extraction - Template Method





Signal extraction was done by 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:

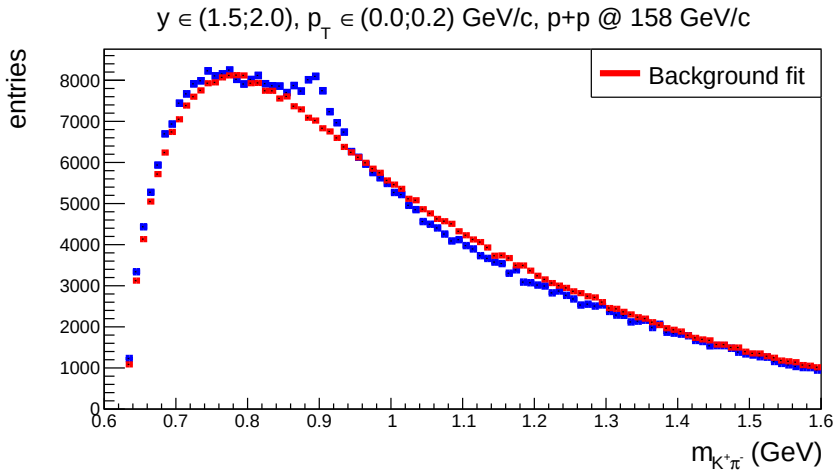
- T_{res}^{MC} - resonance background template from reconstructed Monte Carlo data ($K^+\pi^-$ pairs, which come from resonance decay with exception of $K^*(892)^0$)
- T_{mix}^{DATA} - uncorrelated background from mixed events
- $BW(m_{inv})$ - Breit-Wigner distribution:

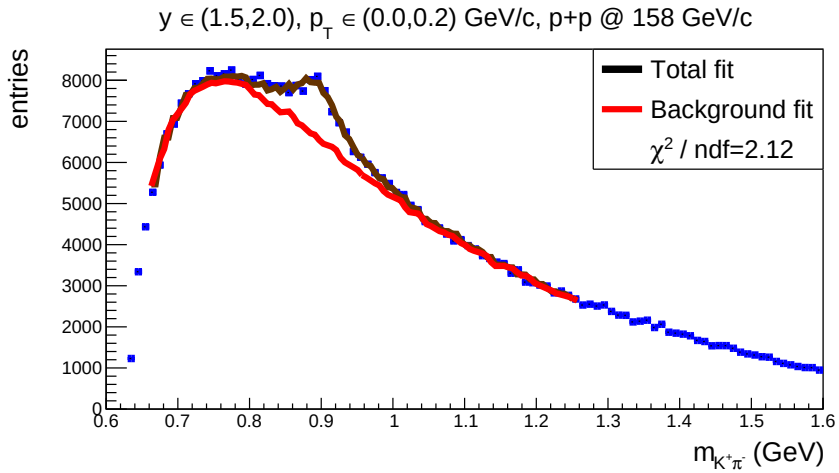
$$BW(m_{inv}) = A \cdot \frac{\frac{1}{4} \cdot \Gamma^2}{(m_{inv} - m_o)^2 + \frac{1}{4}\Gamma^2} \quad (3)$$

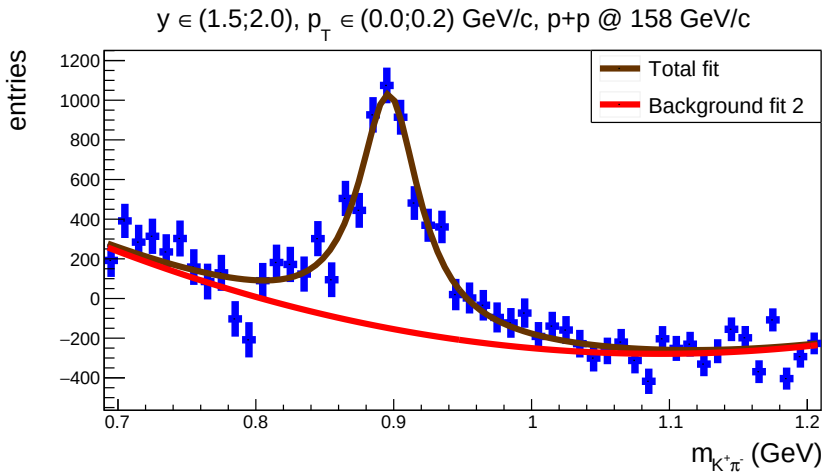
- a, b, c - normalisation const (a+b+c=1)

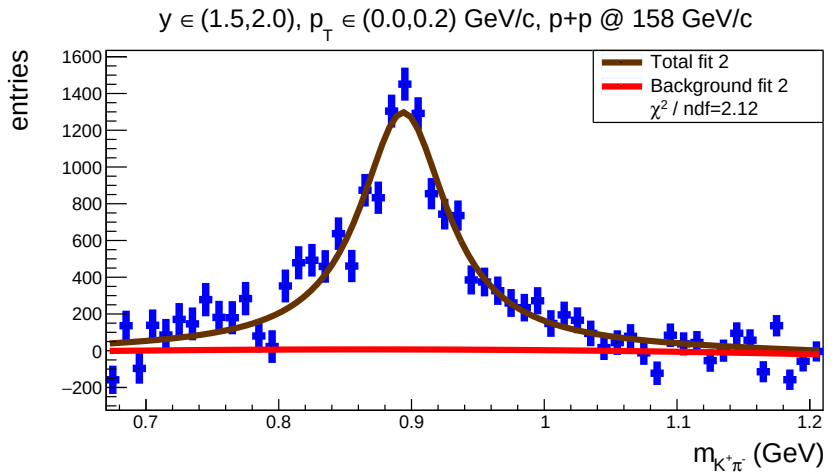
Standard Method vs. Template Method

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



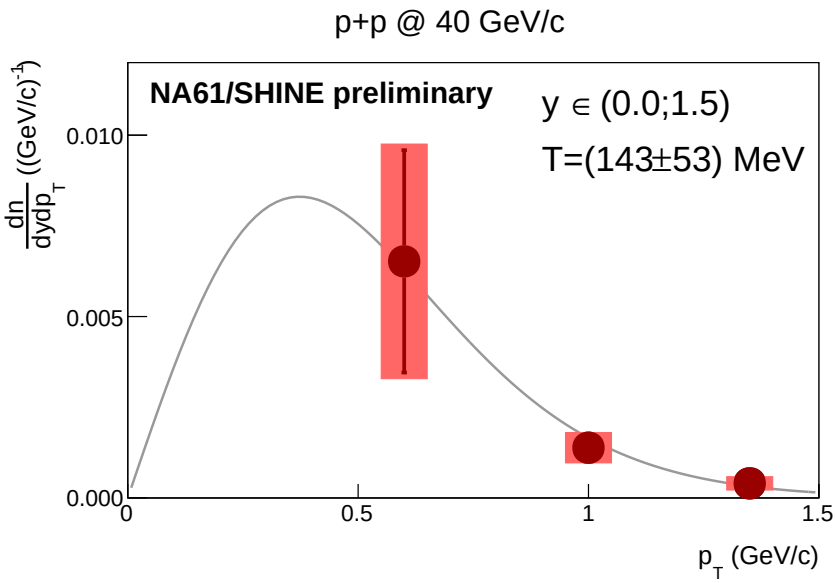


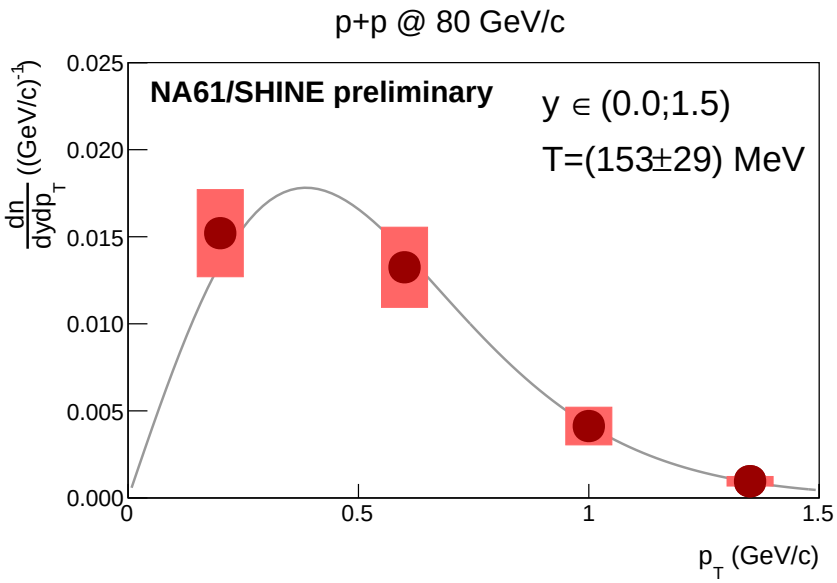




Mid-rapidity spectra for p+p @ 40 and 80 GeV/c

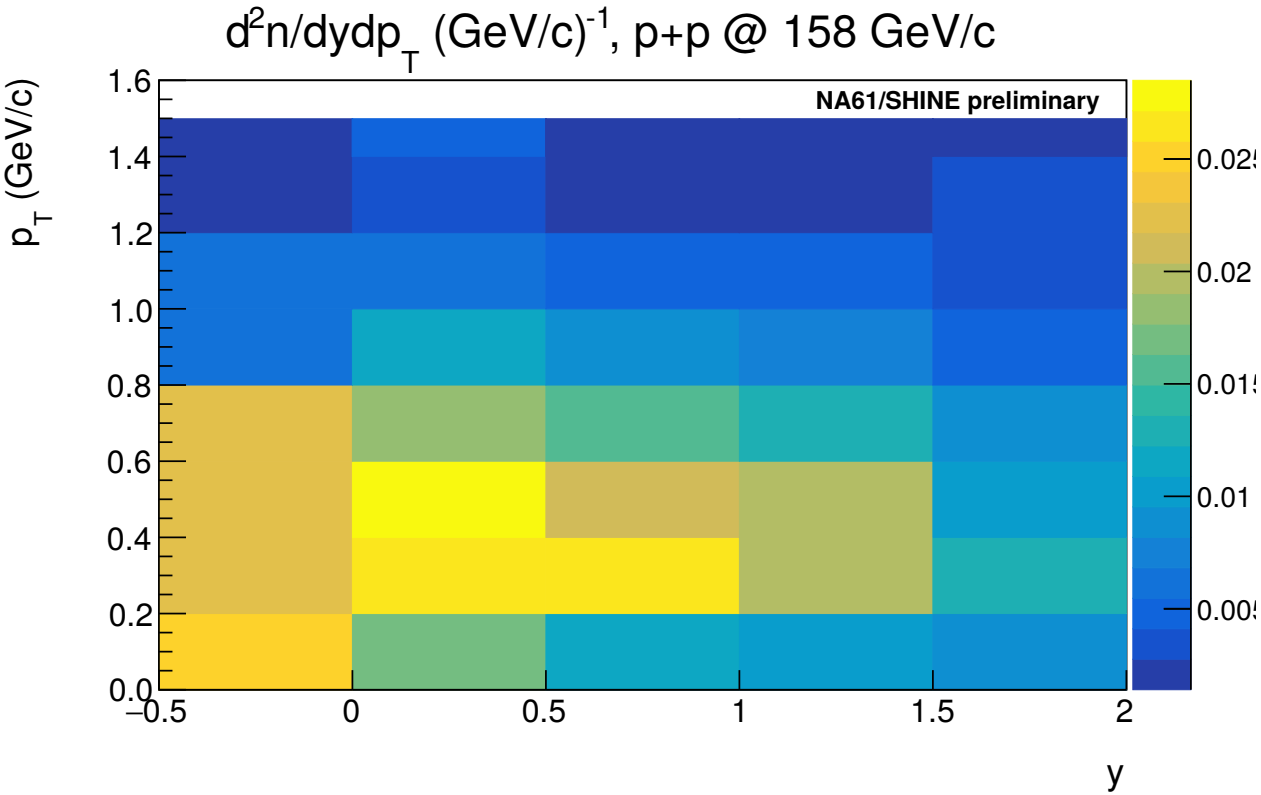
- Results refer to inelastic p+p interactions. They are corrected for detector acceptance and experimental biases
- Fit: $f(p_T) = A \cdot p_T e^{\frac{-\sqrt{p_T^2+m_{PDG}^2}}{T}}$





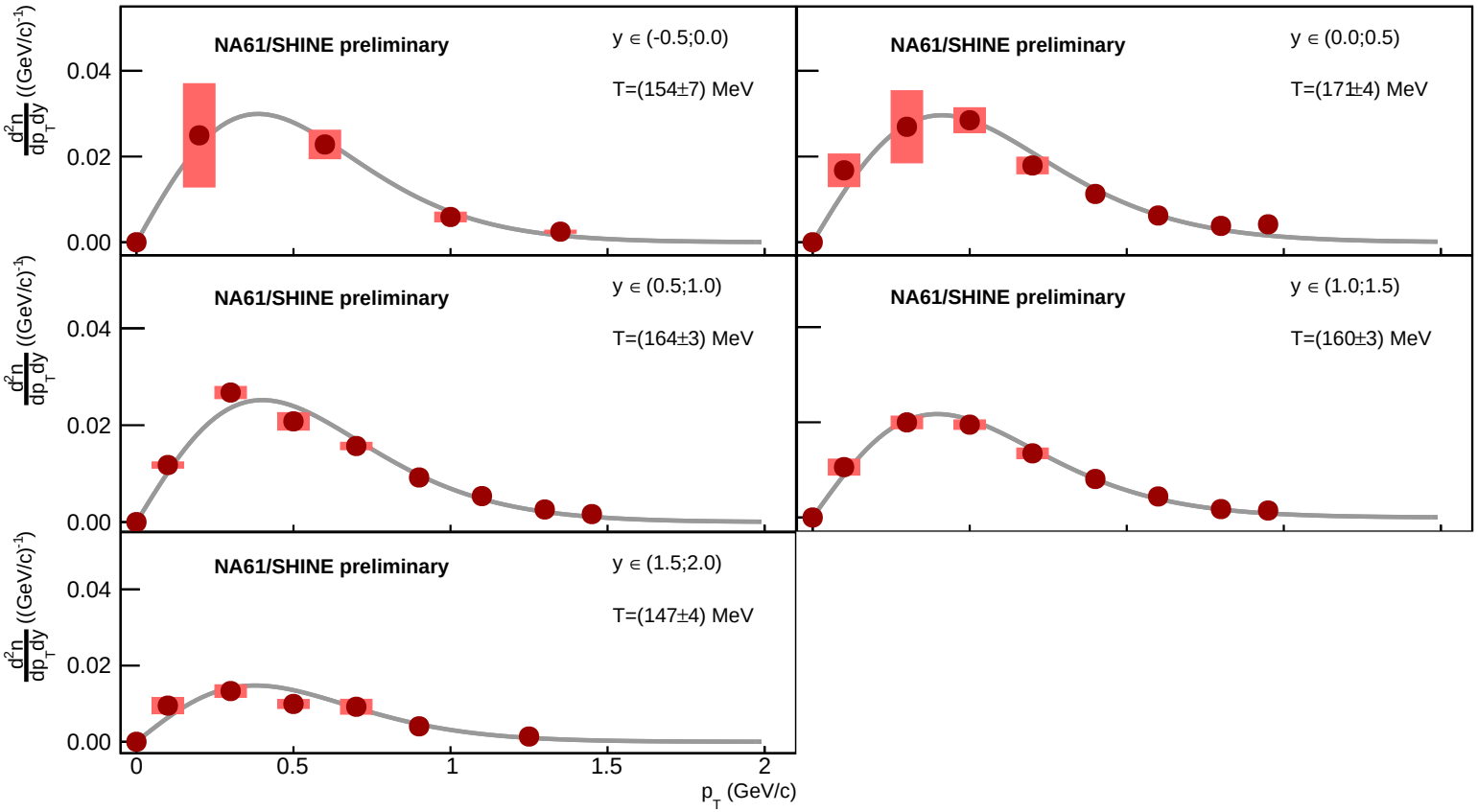
2D spectra in y, p_T

- Results refer to inelastic p+p interactions. They are corrected for detector acceptance and experimental biases

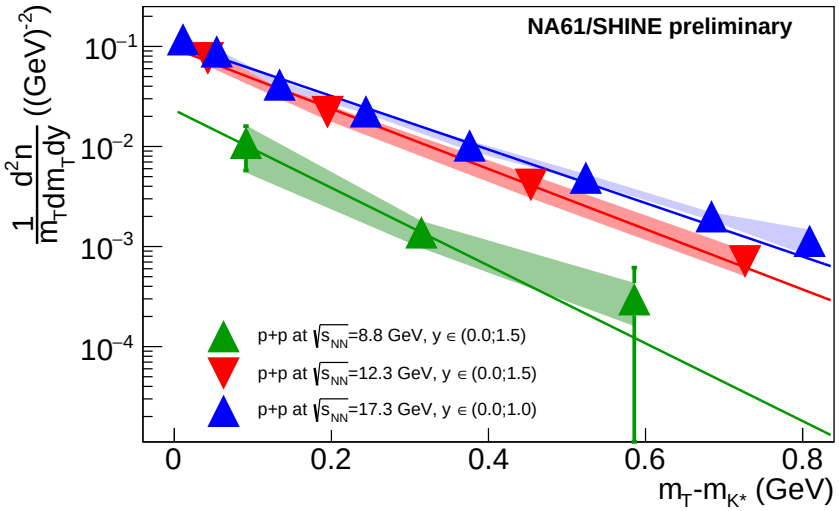


Double differential spectra for p+p @ 158 GeV/c

- Results refer to inelastic p+p interactions. They are corrected for detector acceptance and experimental biases
- 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 $\sim 1\%$ (to obtain p_T extrapolated and integrated dn/dy)



Transverse mass spectra at mid-rapidity

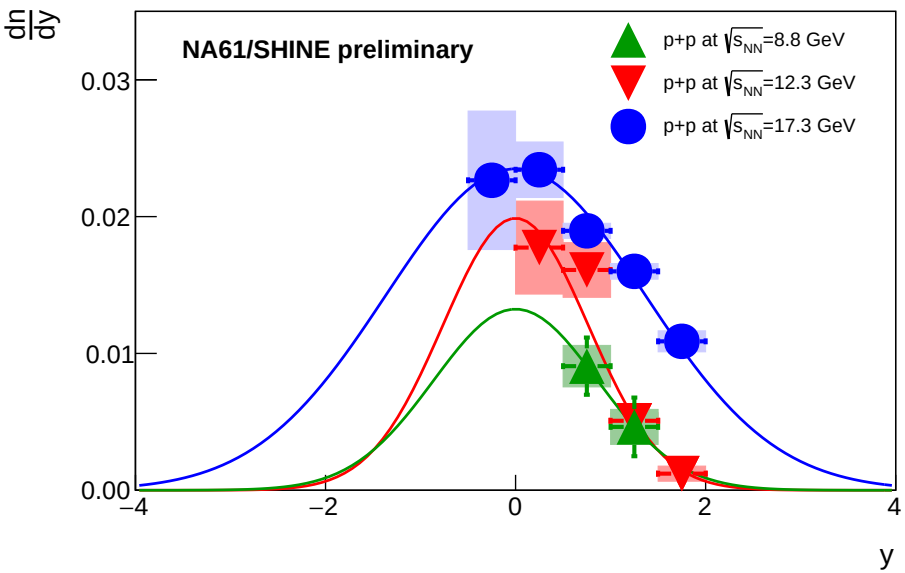


- Fit: $f(m_T) = A \cdot e^{-\frac{m_T}{T}}$

Fit results - T_{K*} (GeV)

$\sqrt{s_{NN}}$	NA61/SHINE	NA49 (PR C84, 064909, 2011)
8.8	0.136±0.074±0.017	-
12.3	0.1443±0.0005±0.0068	-
17.3	0.1624±0.0029±0.0059	0.166±0.011±0.010

Rapidity Spectrum



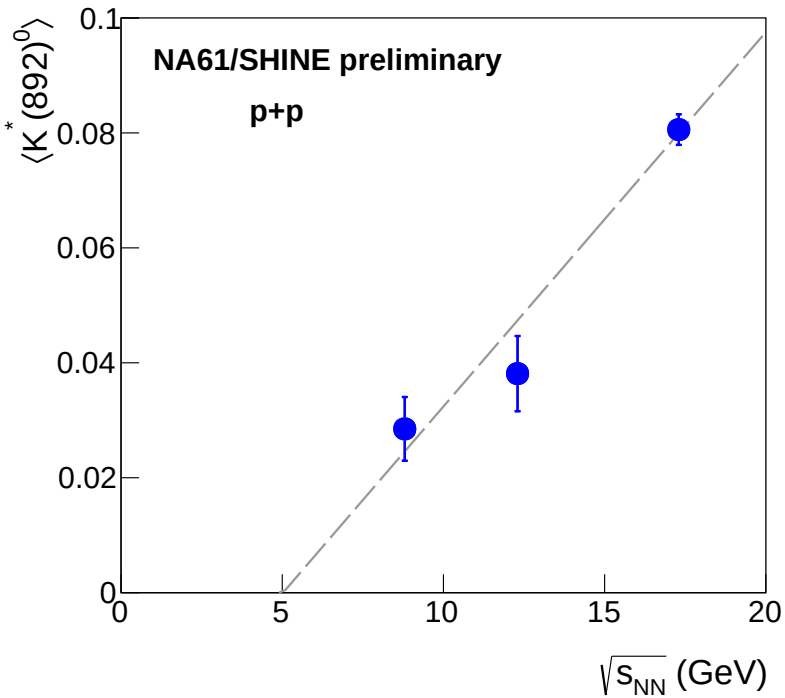
- First p_T-extrapolated and integrated $\frac{dn}{dy}$ spectra for p+p @ 158 GeV/c
- First $\frac{dn}{dy}$ spectra for p+p @ 40 and 80 GeV/c ($p_T \epsilon (0.0;1.5)$ GeV/c)
- Gaussian fit: $f(y) = a \cdot e^{-\frac{y^2}{2\sigma_y^2}}$
- $\langle K^* \rangle$ is calculated by summing points (only for y>0) and adding integral values in non-measured area

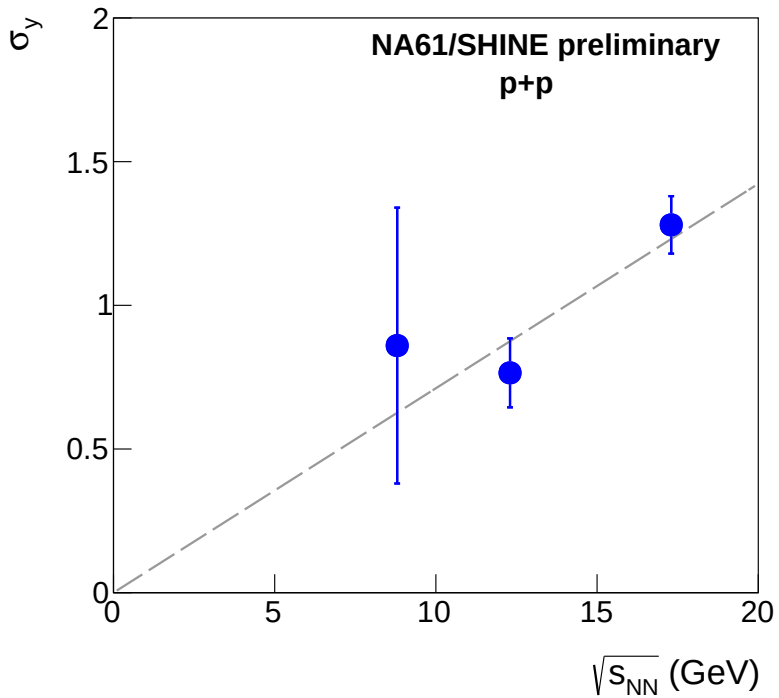
Mean multiplicity of $K^*(892)^0$

$\sqrt{s_{NN}}$	NA61	NA49
8.8	0.0285 ± 0.0031 ± 0.0046	-
12.3	0.0381 ± 0.0054 ± 0.0037	-
17.3	0.08058 ± 0.00059 ± 0.0026	0.0741 ± 0.0015 ± 0.0067

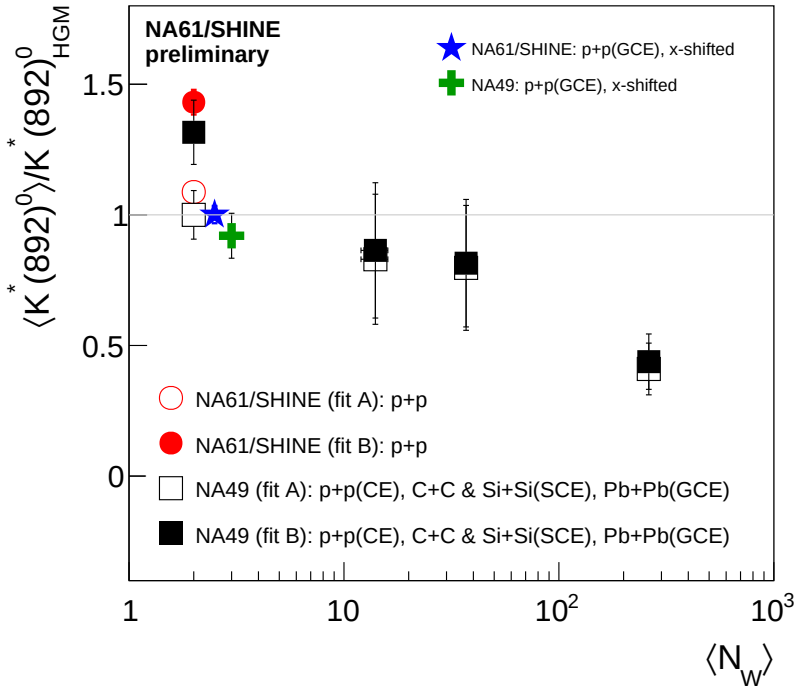
NA49 results from PR C84, 064909, 2011

Energy dependence of $\langle K^*(892)^0 \rangle$





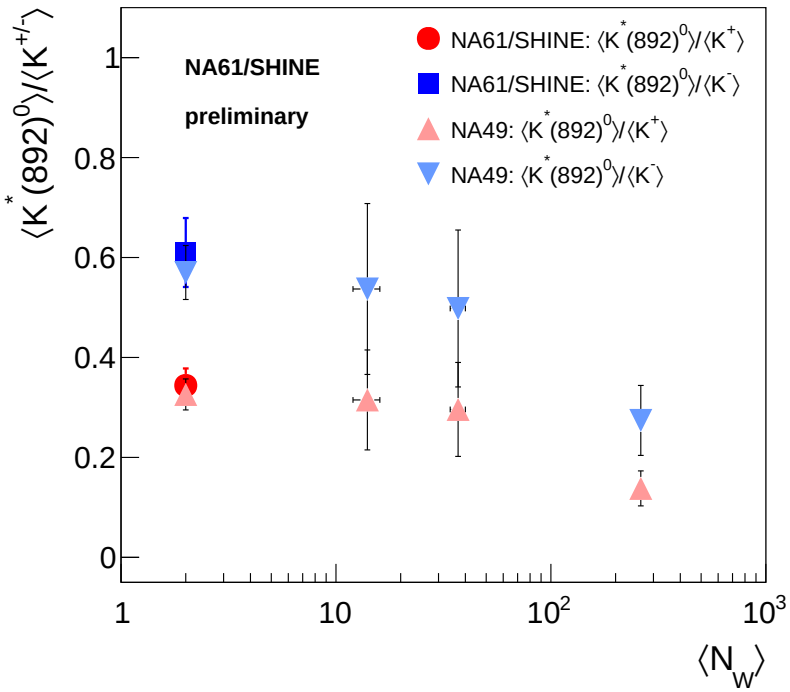
Comparison of $K^*(892)^0$ production with Hadron-Resonance Gas Model at 158 GeV/c



- 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. (PR C98, 054909, 2018)
  - 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)**

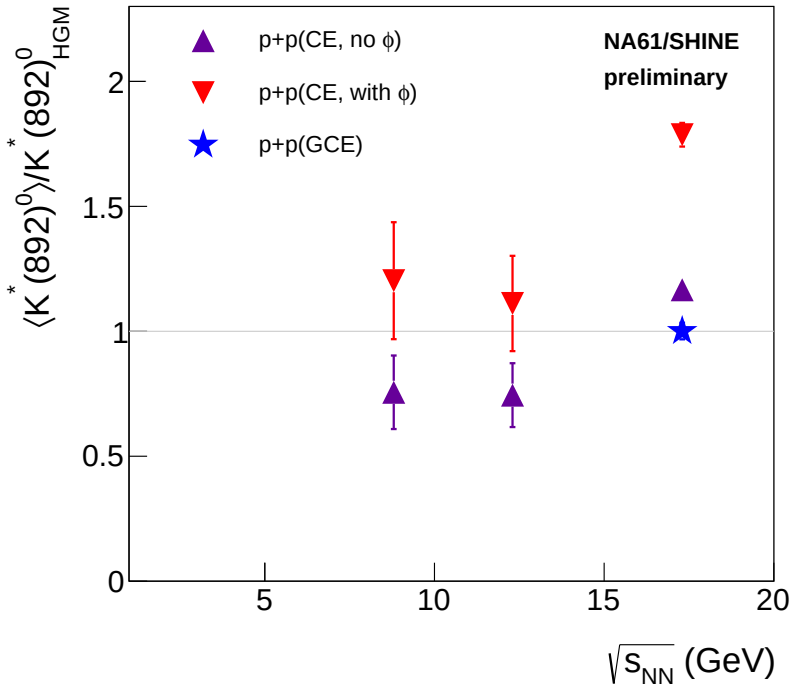
System size dependence of $K^*(892)^0$ to charged kaon ratio at 158 GeV/c

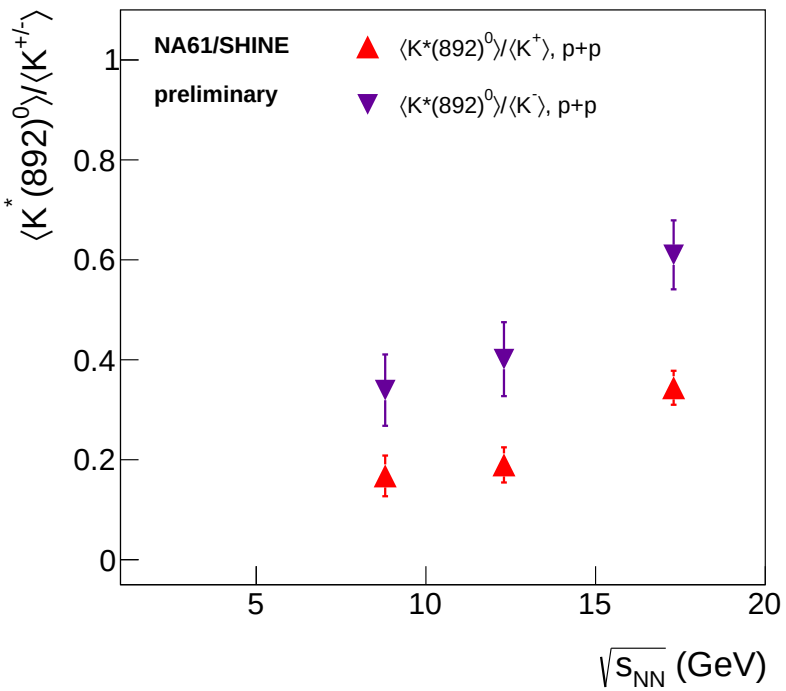


- Results from:
  - NA49 K^*: PR C84, 064909, 2011
  - NA49 $K^{+/-}$: EPJC 68, 1, 2010; PRL 94, 052301, 2005; PR C66, 054902, 2002
  - NA61/SHINE $K^{+/-}$: EPJC 77, 671, 2017
- **Time between chemical and kinetic freeze-outs** (assuming no regeneration processes $\left.\frac{K^*}{K}\right|_{Pb+Pb} = \left.\frac{K^*}{K}\right|_{p+p} e^{-\frac{\Delta t}{\tau}}$):
  - 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**

Energy dependence of $K^*(892)^0$



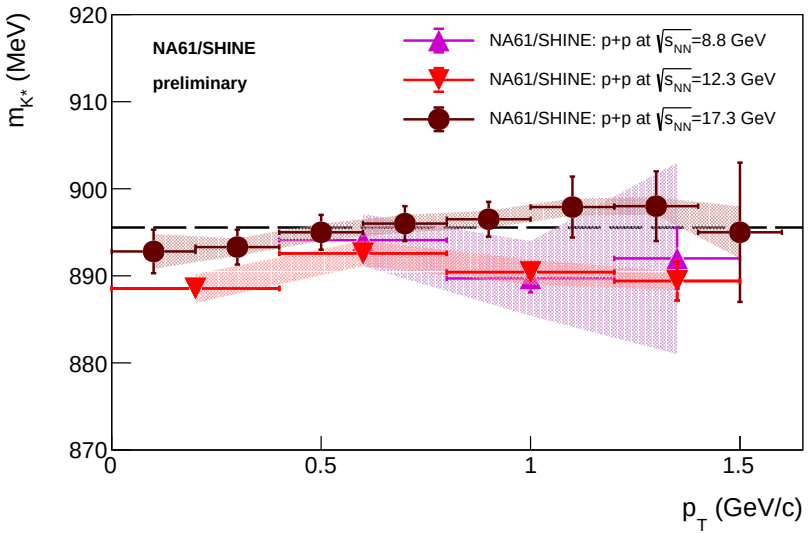


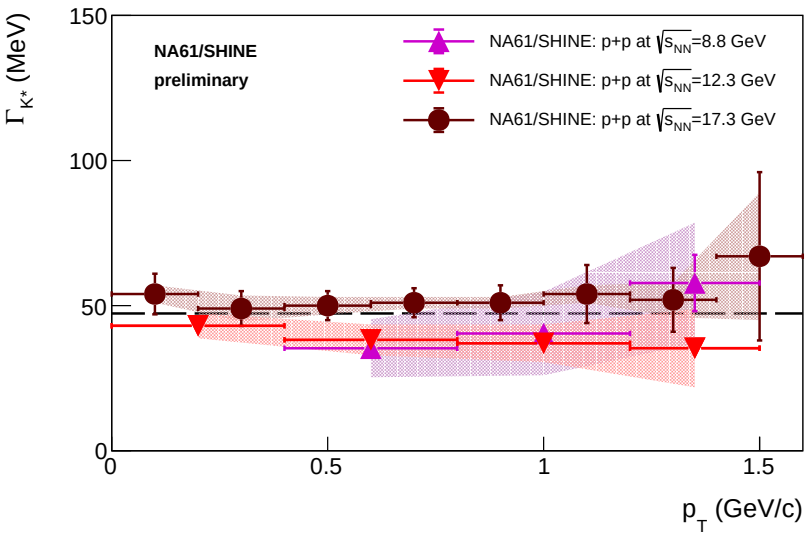
NA61/SHINE $K^{+/-}$: EPJC 77, 671, 2017
HRG by V. Begun et al. (PR C98, 054909, 2018)

- **Small p+p (158 GeV/c) collisions can be described by GCE**
- **p+p data for 158 GeV/c can be described by CE only for fit without ϕ**

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

K^{*0} mass and width





- Mass and width were calculated as average value in range $y\epsilon(0.0; 1.5)$ from three bins for p+p @ 158 GeV/c
- Mass and width were taken from bin $y\epsilon(0.0; 1.5)$ for p+p @ 40 and 80 GeV/c
- Within expected uncertainties mass and width of K^* in agrement with PDG

Summary

- Rapidity and p_T spectra of **K^* mesons** are obtained for **p+p @ 40, 80 and 158 GeV/c**
- 4π acceptance **NA61** results (for p+p @ 158 GeV/c) **consistent with NA49** ($0 < p_T < 1.5$ GeV/c) results but with better accuracy
- **Time between chemical and kinetic freeze-outs at SPS** (at 158 GeV/c) is **higher than at RHIC** $\rightarrow$ regeneration effects may start to play significant role for higher energies. Future analysis of heavy systems (Ar+Sc, Xe+La, Pb+Pb) in NA61 will allow to estimate time between freeze-outs at lower SPS energies
- **K^* production in p+p at 158 GeV/c** can be **described by GCE** model; **CE** can also reproduce data provided the **ϕ meson is rejected** from fit
- Within expected uncertainties **mass and width of K^* in agrement with PDG**
- Plans: $\overline{K^*}$ for p+p at 158, 80 and 40 GeV/c

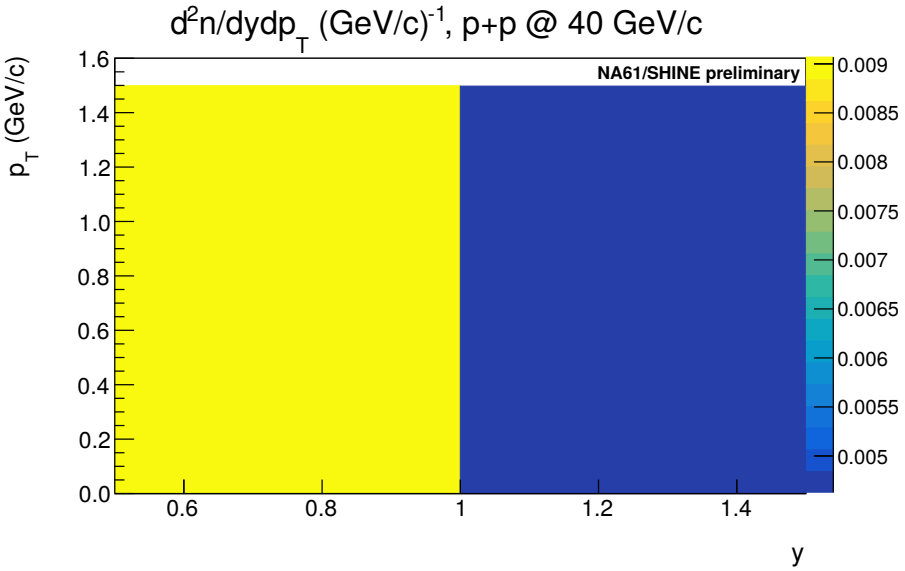
Acknowledgements

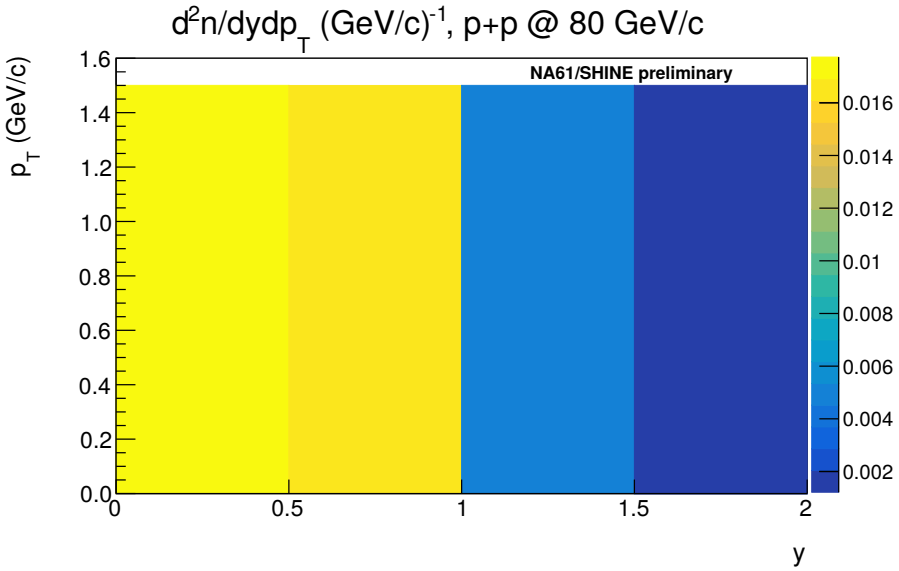
This work was supported by the National Science Centre, Poland under grant no: 2017/25/N/ST2/02575

Back-up

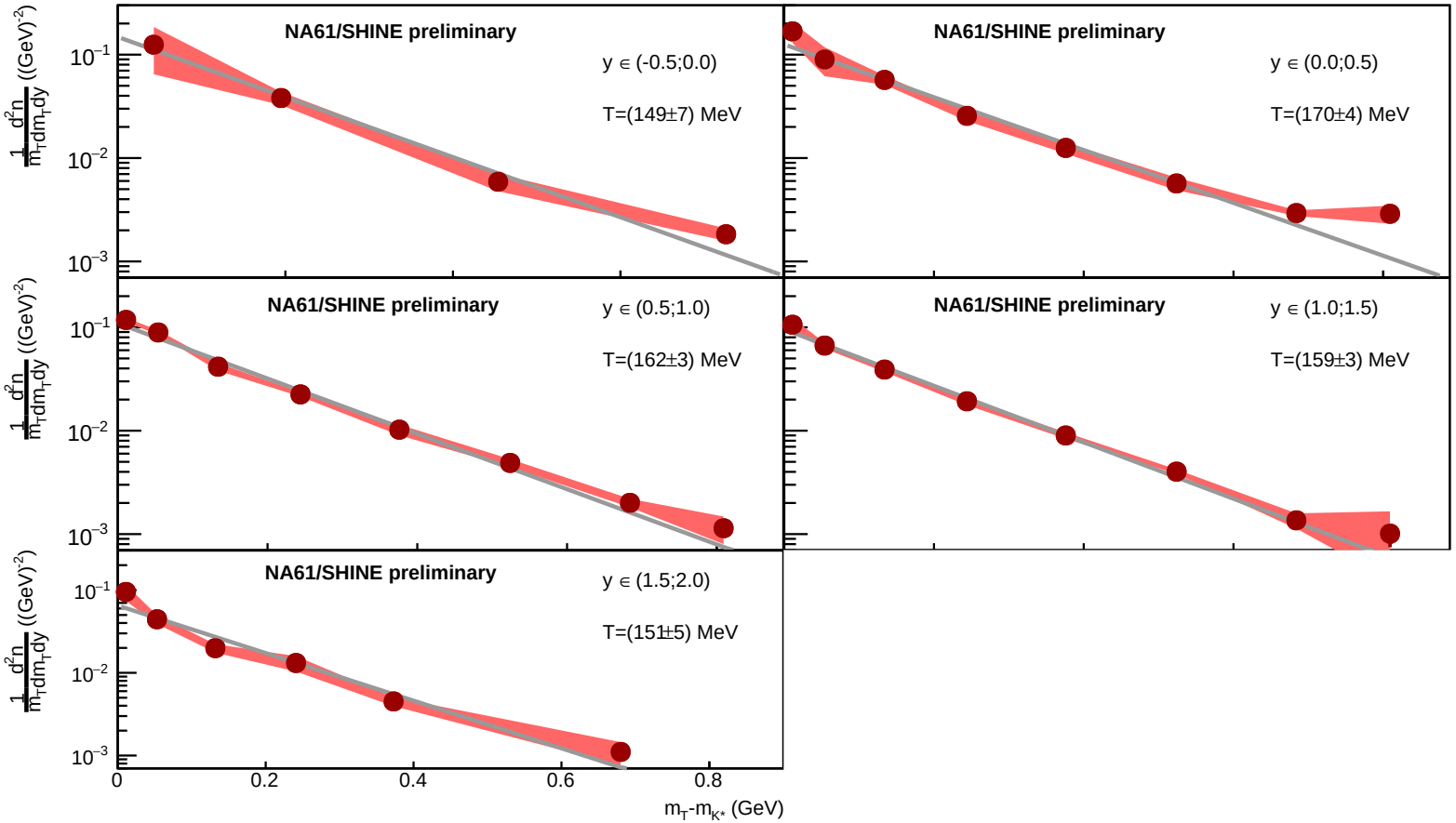
1D spectra in y, p_T

- Results refer to inelastic p+p interactions. They are corrected for detector acceptance and experimental biases



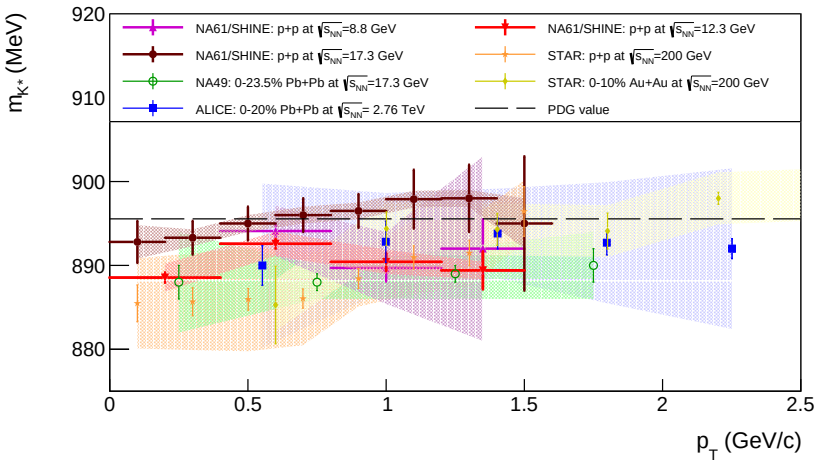


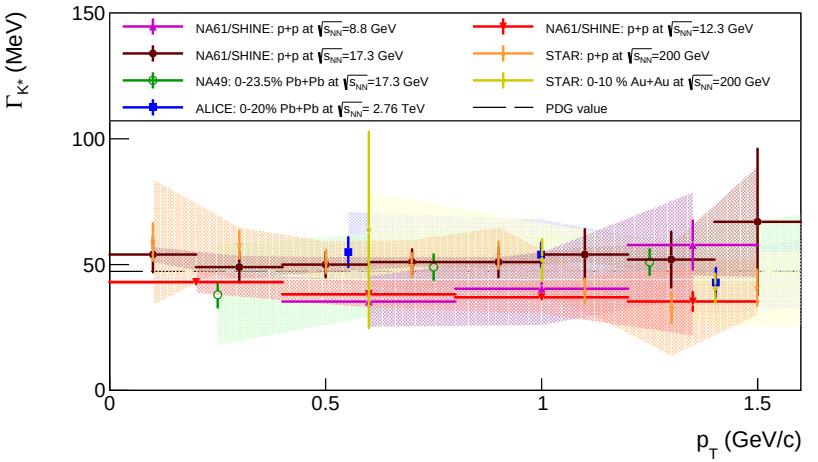
Transverse mass spectra



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

K^{*0} mass and width





- Results from:
  - NA61/SHINE: this analysis
  - NA49: PR C84, 064909, 2011
  - ALICE: PR C91, 024609, 2015
  - STAR: PR C71, 064902, 2005
- Mass and width were calculated as average value in range $y\epsilon(0.0; 1.5)$ from three bins for p+p @ 158 GeV/c
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