K^*/K ratio and the time between freeze-outs for intermediate-mass Ar+Sc system at the SPS energy range

Bartosz Kozłowski for the NA61/SHINE Collaboration

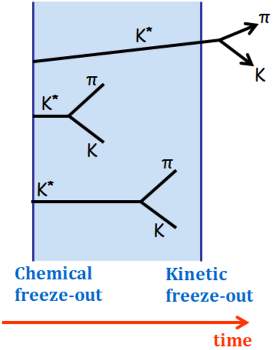
Warsaw University of Technology

Motivation

- $K^*(892)^0$ resonance
  - $\Gamma = 47.3$ MeV $\rightarrow \tau = 4.17$ fm$/c$
  - $K^*(892)^0 \rightarrow K^+\pi^-$ (BR $= 2/3$)

- K^* spectra and yields can be used as input data to Blast-Wave and Hadron Resonance Gas models

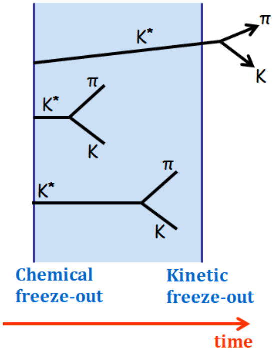
- K^* lifetime is comparable with time between freeze-outs $\rightarrow$ some resonances may decay inside the fireball
- Momenta of their decay products can be modified due to elastic scatterings $\rightarrow$ problems with experimental reconstruction of resonance via invariant mass $\rightarrow$ suppression of the observed K^* yield



Motivation – time between frezee-outs

- Assuming no regeneration processes (Fig.) time between freeze-outs can be determined from (STAR, Phys.Rev.C 71, 064902, 2005; C. Markert, G. Torrieri, J. Rafelski, AIP Conf.Proc. 631, 533, 2002):

$$\frac{K^*}{K}\Big|_{kinetic} = \frac{K^*}{K}\Big|_{chemical} \cdot e^{-\frac{\Delta t}{\tau}} \qquad (1)$$

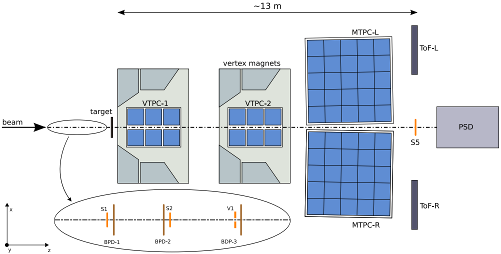


- $\frac{K^*}{K}\Big|_{chemical}$ – K^*/K ratio in inelastic p+p collisions
- $\frac{K^*}{K}\Big|_{kinetic}$ – K^*/K ratio in central Ar+Sc collisions
- τ – $K^*(892)^0$ lifetime = 4.17 fm/c
- Δt – time between chemical and kinetic freeze-outs (in K^* rest frame)

The picture assumes that conditions at chemical freeze-out of p+p and Ar+Sc are the same

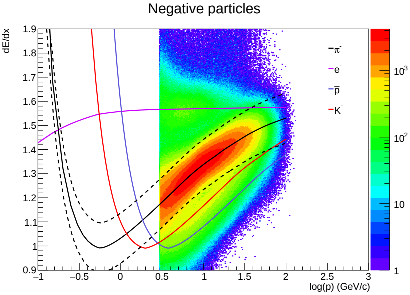
NA61/SHINE research program:

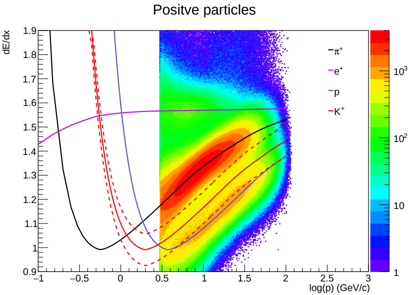
- Strong interaction physics
  - Study the properties of the onset of deconfinement
  - Search for the critical point of strongly interacting matter
  - Direct measurement of open charm
- Neutrino and cosmic-ray physics
  - Measurements for neutrino programs (J-PARC, Fermilab)
  - Measurements for cosmic-ray physics (Pierre-Auger, KASCADE, satellite experiments)



Detector layout during Ar+Sc data taking
NA61/SHINE, Eur.Phys.J.C 84, 416, 2024

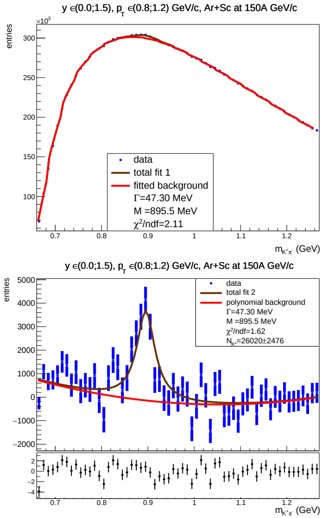
- Fixed-target, multipurpose spectrometer
- 4 TPCs – tracking and PID (by dE/dx)
- PSD – centrality selection





- Analyzed data: 0-10% central Ar+Sc collisions at 40A, 75A, 150A GeV/c ($\sqrt{s_{NN}} = 8.8, 11.9, 16.8$ GeV)
- Candidates for K^+ and π^- were selected based of their energy loss (dE/dx) in TPCs
- Particles were accepted if they were located $2\sigma_\pi$ (for π^-) and $1.5\sigma_K$ (for K^+) around their empirical parametrizations of Bethe-Bloch curves
- $\sigma_\pi = 0.052$ and $\sigma_K = 0.044$
  NA61/SHINE, Eur.Phys.J.C 82, 322, 2022

$K^*(892)^0$ signal extraction

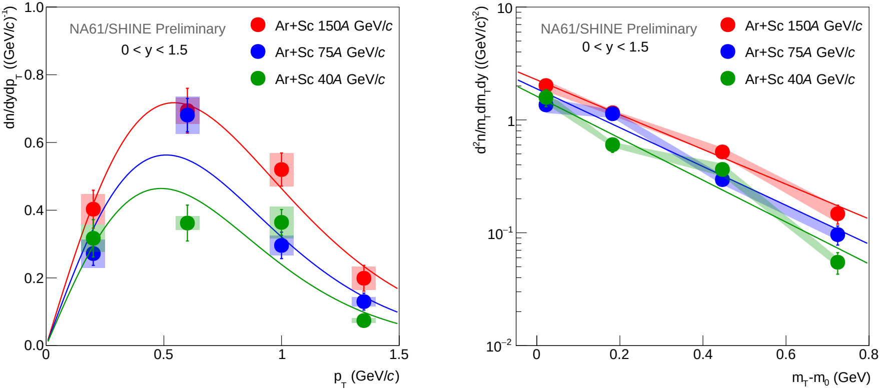


Template method (NA61/SHINE, Eur.Phys.J.C 80, 460, 2020)

$$f(m_{K^+\pi^-}) = a \cdot T^{MC}_{res}(m_{K^+\pi^-}) + b \cdot T^{DATA}_{mix}(m_{K^+\pi^-}) + c \cdot BW(m_{K^+\pi^-})$$

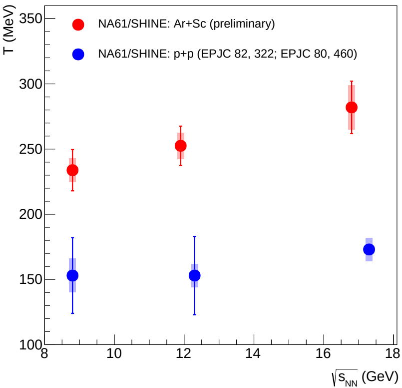
- $T^{DATA}_{mix}(m_{K^+\pi^-})$ – background estimated using mixing method
- $T^{MC}_{res}(m_{K^+\pi^-})$ – resonance background estimated using reconstructed Monte Carlo data (combination of tracks that come from decays of resonances different than $K^*(892)^0$ and combination of tracks where one comes from the decay of resonance and one comes from direct production in primary interaction)
- $BW(m_{K^+\pi^-})$ – Breit-Wigner distribution
- a, b, c - normalisation factors

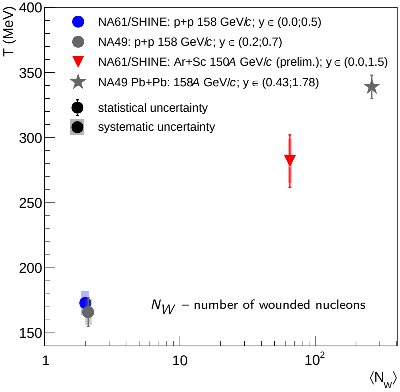
$K^*(892)^0$ p_T and m_T distributions



Transverse momentum and transverse mass spectra of $K^*(892)^0$ measured in 0-10% central Ar+Sc collisions at $0 < y < 1.5$

$K^*(892)^0$ inverse slope parameters



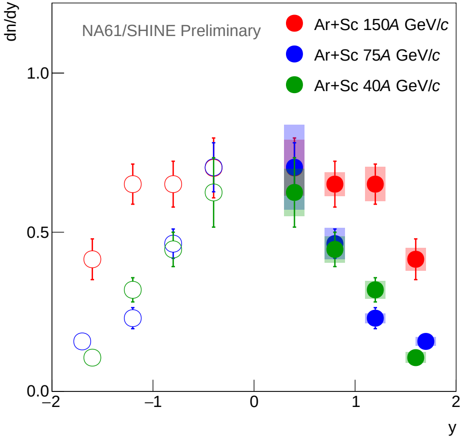


Values of T are larger in A+A due to radial flow

Inverse slope parameters were calculated in rapidity ranges specified below
NA61/SHINE: Ar+Sc: $0 < y < 1.5$, p+p 40 and 80 GeV/c: $0 < y < 1.5$, p+p 158 GeV/c: $0 < y < 0.5$;
NA49: p+p: $0.2 < y < 0.7$, Pb+Pb: $0.43 < y < 1.78$

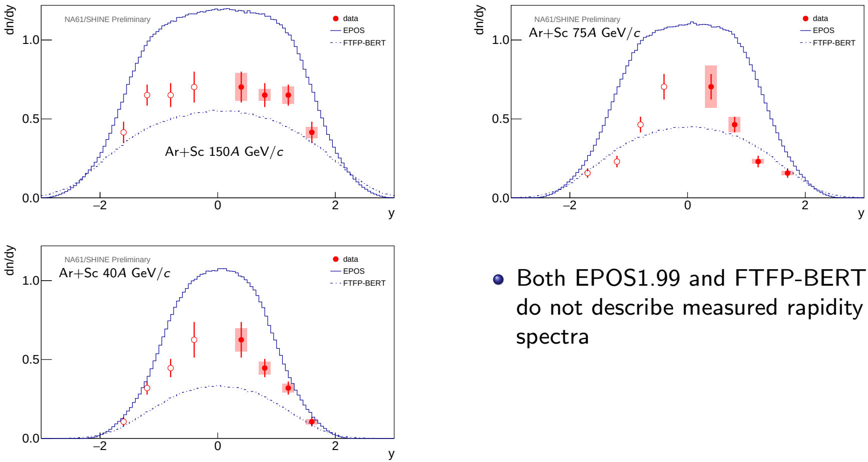
NA49: Phys.Rev.C 84, 064909, 2011;
NA61/SHINE: Eur.Phys.J.C 80, 460, 2020, Eur.Phys.J.C 82, 322, 2022

$K^*(892)^0$ rapidity distributions at $0 < p_T < 1.5$ GeV/c



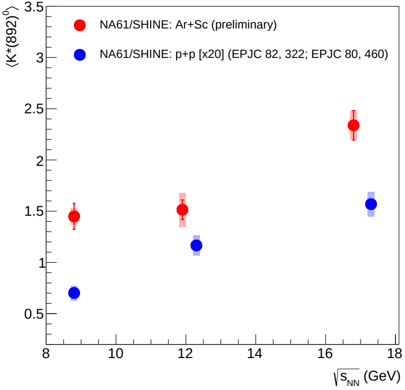
- Rapidity spectra of $K^*(892)^0$ were measured in 0-10% central Ar+Sc collisions at $0 < p_T < 1.5$ GeV/c
- Full symbols represent the measurements, open symbols were obtained by reflection around mid-rapidity

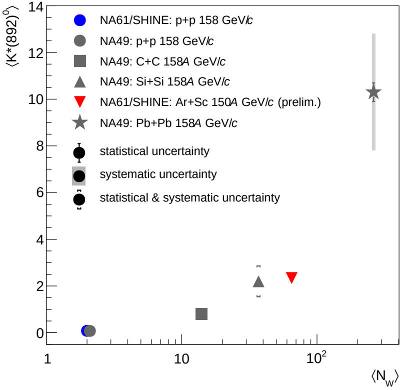
$K^*(892)^0$ rapidity distributions – comparison with models



- Both EPOS1.99 and FTFP-BERT do not describe measured rapidity spectra

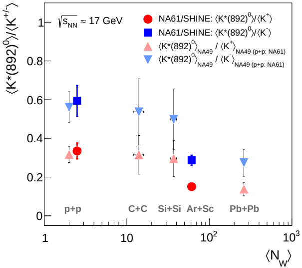
$K^*(892)^0$ mean multiplicities

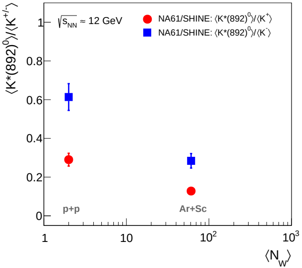


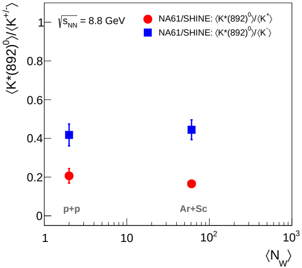


NA49: Phys.Rev.C 84, 064909, 2011;
NA61/SHINE: Eur.Phys.J.C 80, 460, 2020, Eur.Phys.J.C 82, 322, 2022

$\langle K^* \rangle / \langle K^\pm \rangle$ ratios



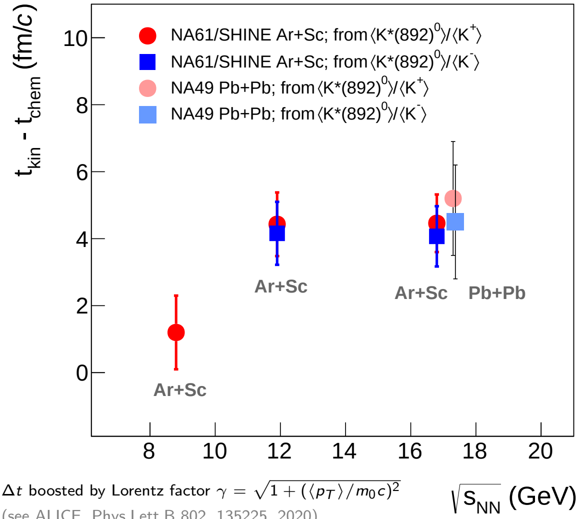




- Suppression of K^* in Ar+Sc at $\sqrt{s_{NN}} \approx 17$ GeV similar to Pb+Pb
- No suppression of K^* observed in Ar+Sc at $\sqrt{s_{NN}} = 8$ GeV

NA49:
Phys.Rev.C 84, 064909, 2011, Phys.Rev.C 66, 054902, 2002, Phys.Rev.Lett. 94, 052301, 2005;
NA61/SHINE p+p:
Eur.Phys.J.C 80, 460, 2020, Eur.Phys.J.C 82, 322, 2022, Eur.Phys.J.C 77, 671, 2017;
NA61/SHINE Ar+Sc:
Eur.Phys.J.C 84, 416, 2024

Time between freeze-outs



Δt boosted by Lorentz factor $\gamma = \sqrt{1 + (\langle p_T \rangle / m_0 c)^2}$

(see ALICE, Phys.Lett.B 802, 135225, 2020)

Summary

- First results on $K^*(892)^0$ production in 0-10% central Ar+Sc collisions at 40A, 75A, and 150A GeV/c are presented
- Values of dn/dy for all measured energies are between values obtained from EPOS1.99 and FTFP-BERT models
- $\langle K^* \rangle / \langle K^\pm \rangle$ ratios show expected suppression of $K^*(892)^0$ production in Ar+Sc collisions at 150A and 75A GeV/c. There is no observed suppression in Ar+Sc collisions at 40A GeV/c
- Estimated times between freeze-outs for Ar+Sc collisions at 150A and 75A GeV/c are similar

Thank you for your attention!

This work was supported by the Polish Ministry of Science and Higher Education (WUT ID-UB) and the Polish Minister of Education and Science (contract No. 2021/WK/10)