

# Measurement of charged and neutral kaons in Ar+Sc collisions at NA61/SHINE experiment

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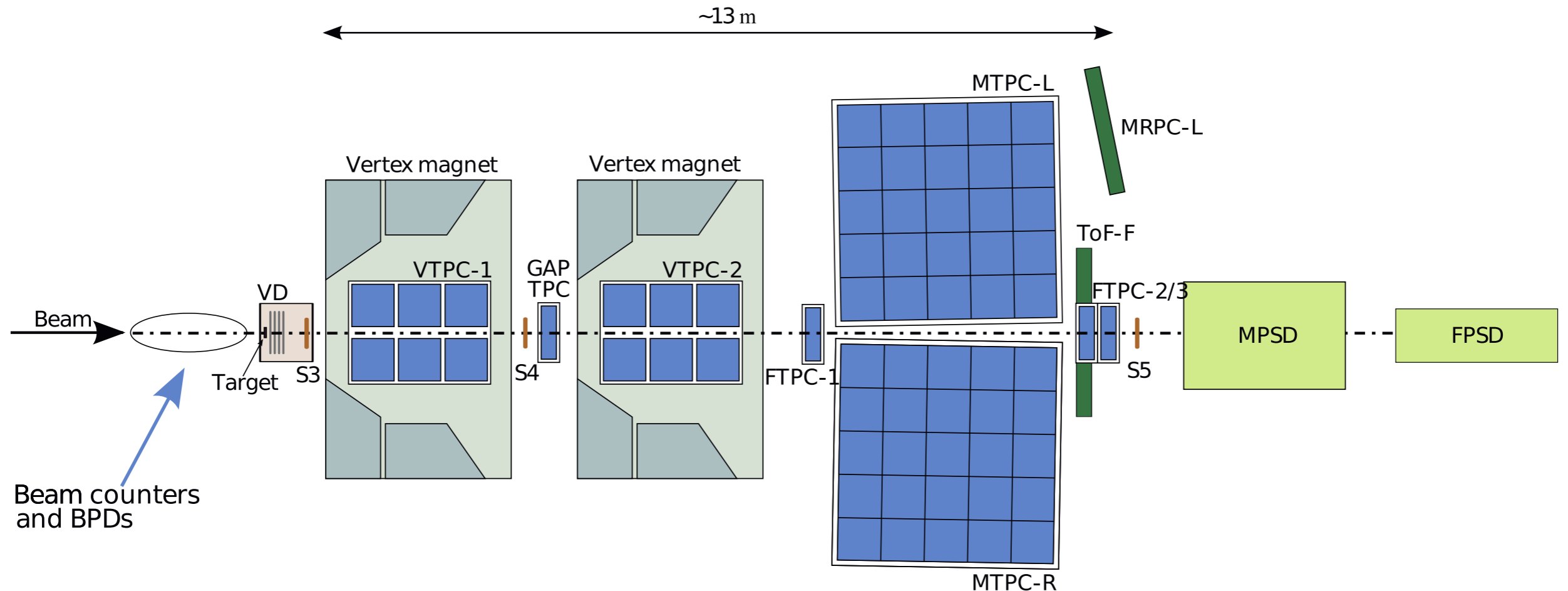


# NA61/SHINE - UNIQUE MULTIPURPOSE EXPERIMENT AT SPS:

Hadron production in hadron-hadron, hadron-nucleus, and nucleus-nucleus collisions at high energies



# NA61/SHINE Spectrometer



- ▶ Large acceptance hadron spectrometer
  - ▶ Coverage of the full forward hemisphere down to  $p_T = 0$
- ▶ Tracking by Time Projection Chambers (VTPC-1 and VTPC-2 inside magnets)
- ▶ PID by  $dE/dx$ , ToF measurement, decay topology, invariant mass
- ▶ Centrality selection by forward energy measured by PSD

## Beams:

- ▶ Ions (Be, Ar, Xe, Pb)
  - ▶  $p_{\text{beam}} = 13A - 150A \text{ GeV}/c$

$$\sqrt{s_{NN}} = 5.1 - 16.8 \text{ GeV}$$

- ▶ Hadrons ( $\pi$ , K, p)
  - ▶  $p_{\text{beam}} = 13 - 400 \text{ GeV}/c$

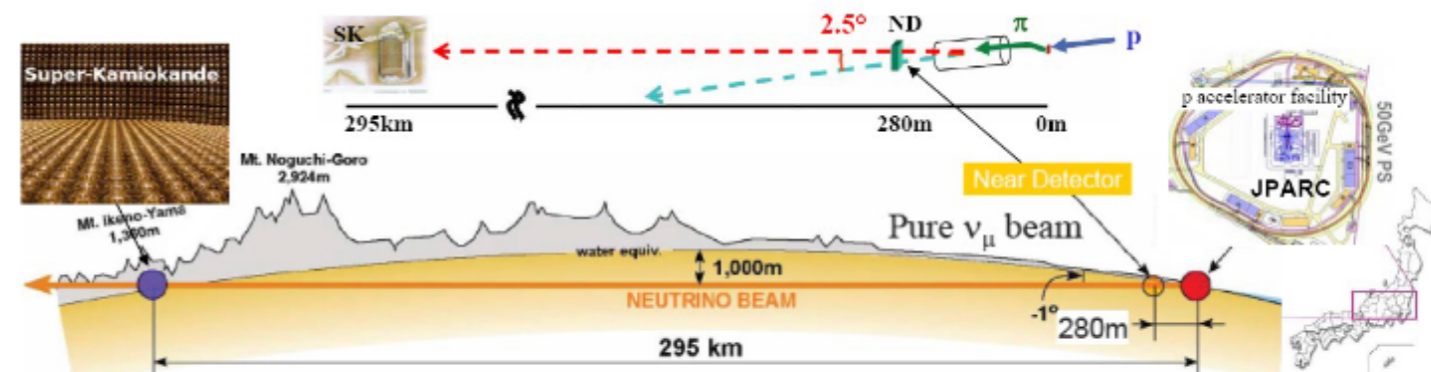
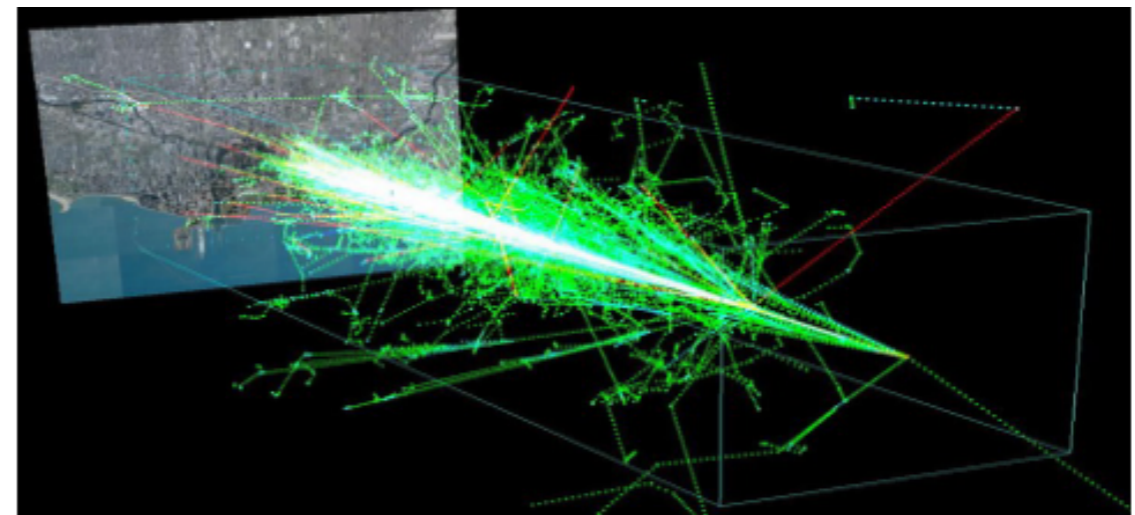
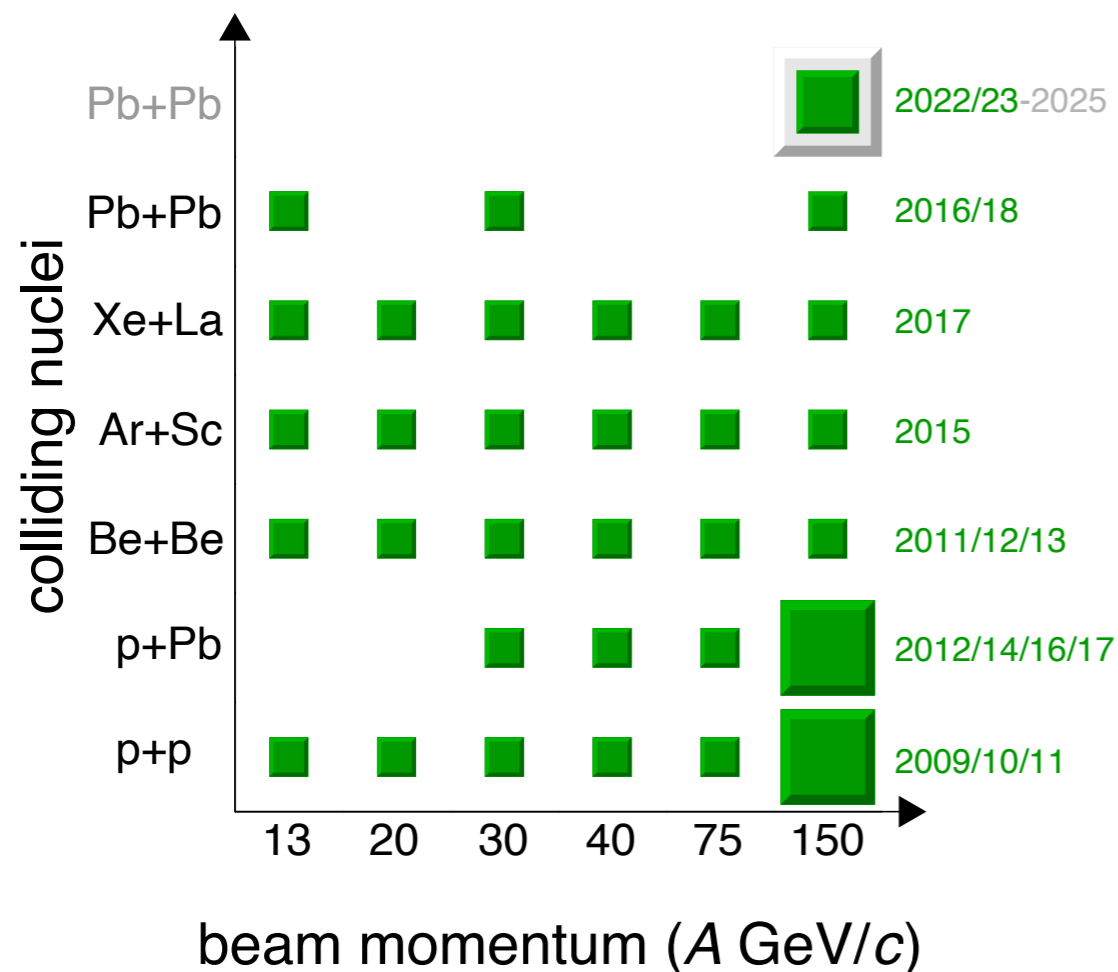
# NA61/SHINE Physics Program

## ▶ Strong interaction physics:

- ▶ Study of the properties of the onsets of deconfinement and fireball
- ▶ Search for the critical point of strongly interacting matter
- ▶ Direct measurement of open charm

## ▶ Neutrino and cosmic-ray physics:

- ▶ Measurements for neutrino programs at J-PARC and Fermilab
- ▶ Measurements of nuclear fragmentation cross section for cosmic-ray physics

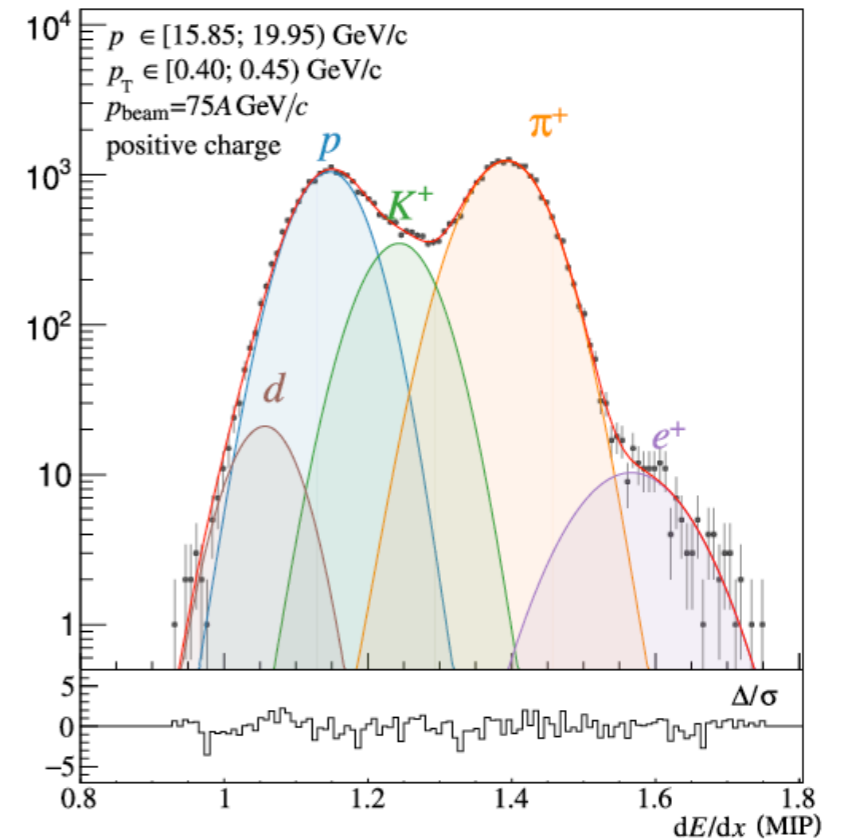
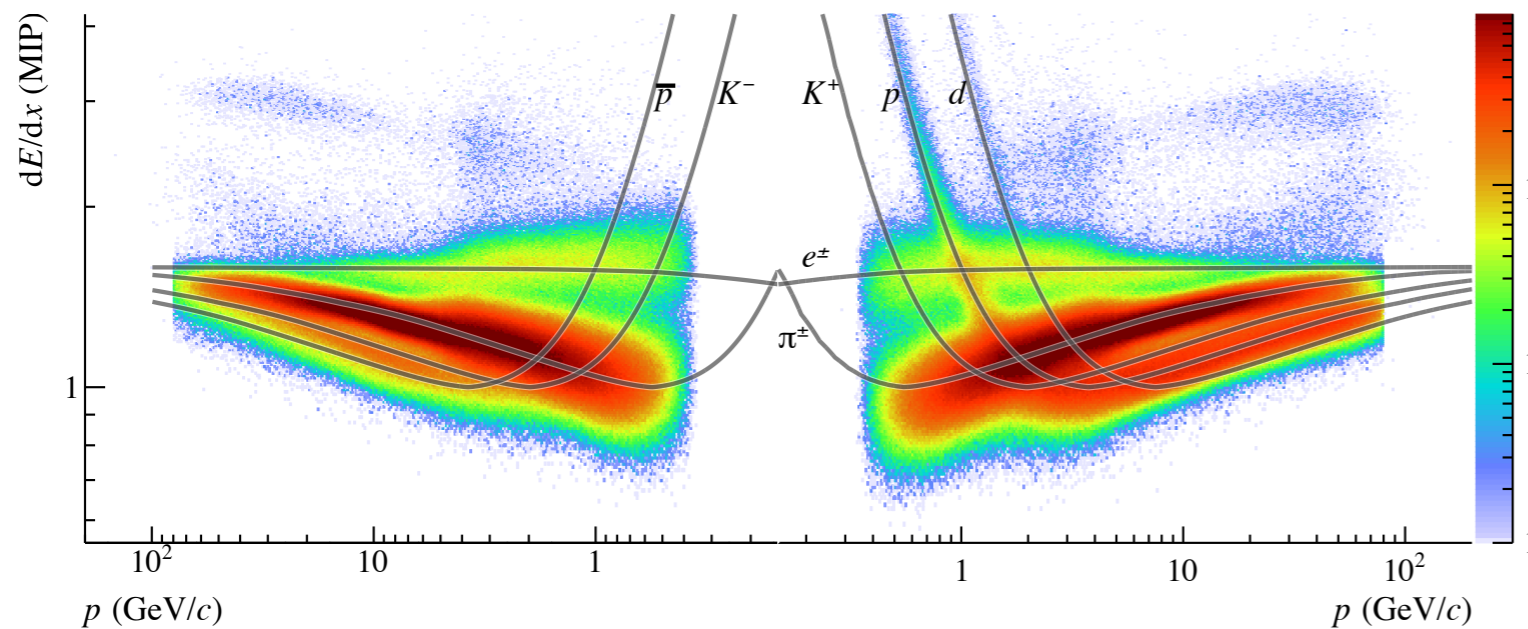




**Kaon Production in  
0 - 10% Central  
Ar+Sc Collisions**

# Charged Kaon Identification

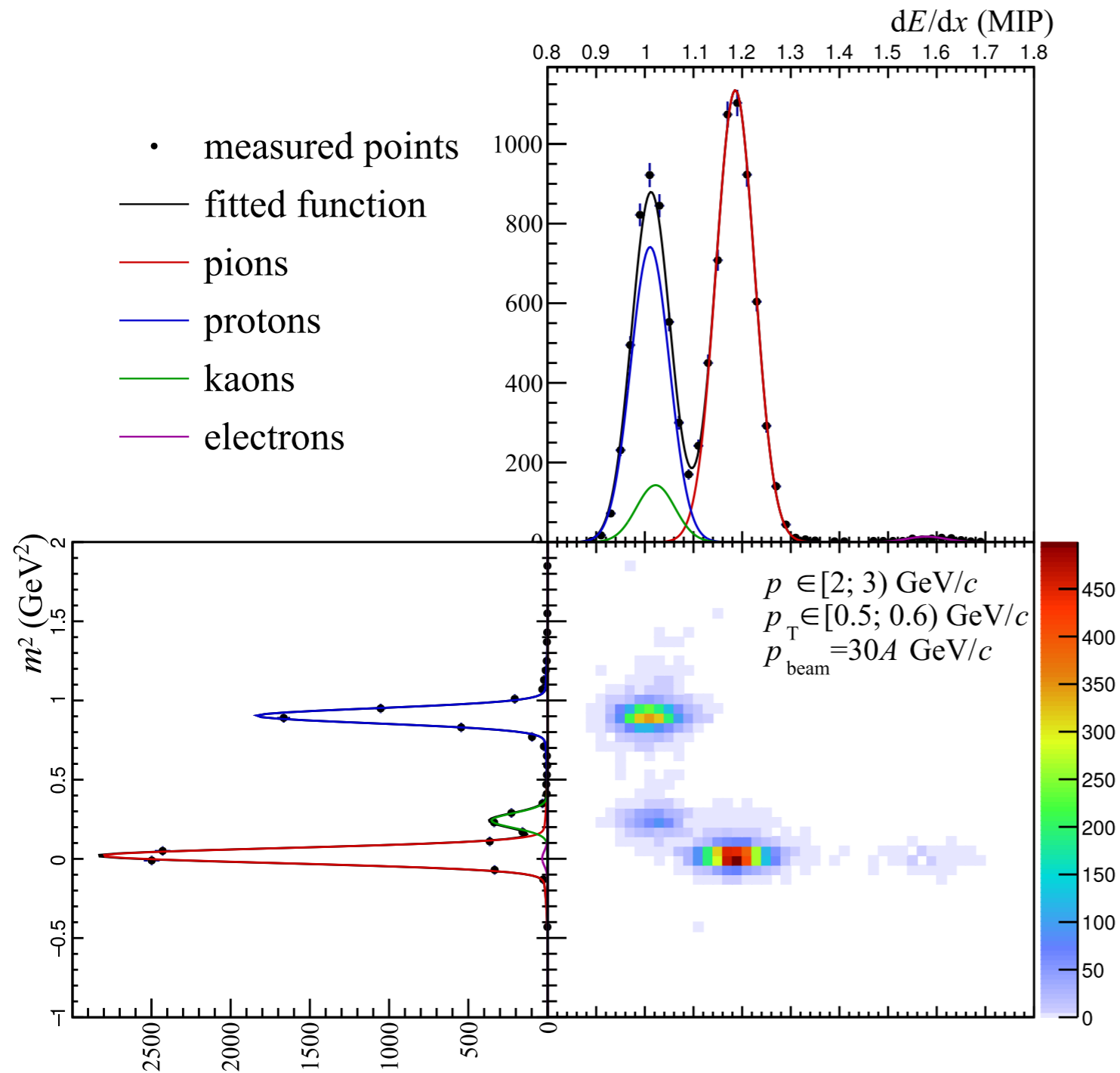
## dE/dx identification



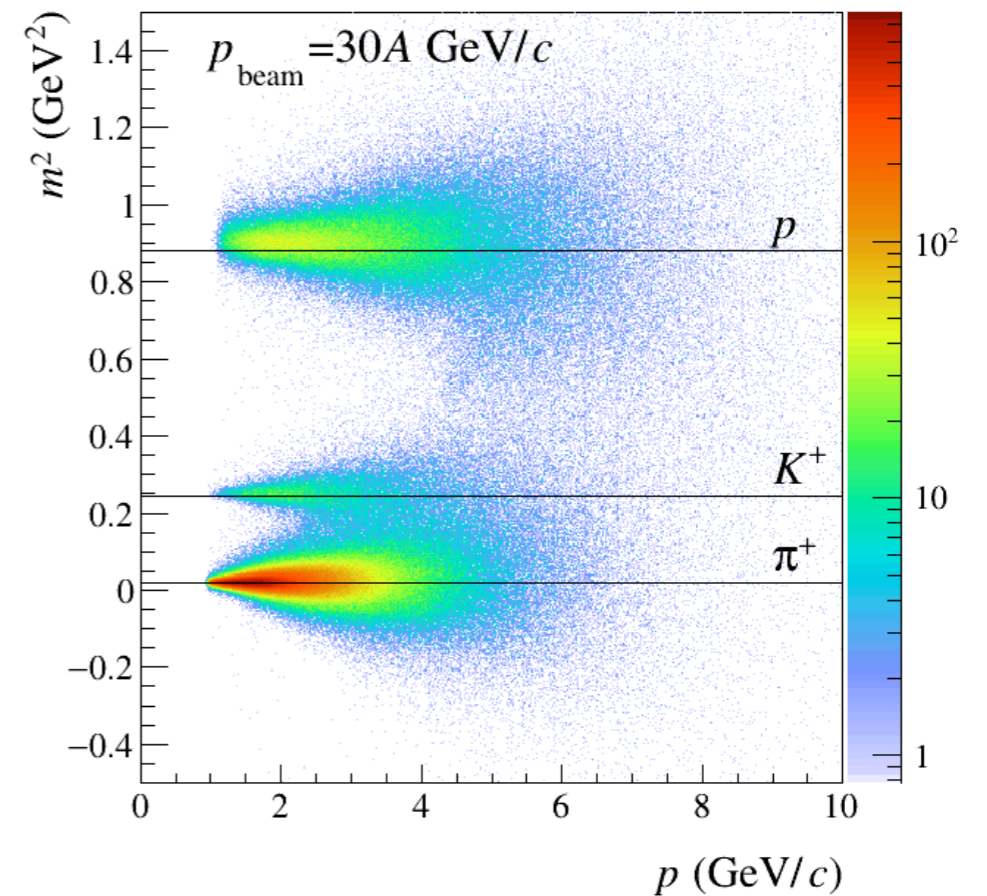
- ▶ dE/dx identification - based on the measurement of energy loss of charged particles along the particle trajectory in Time Projection Chambers
  - ▶ Performed in the relativistic rise region

# Charged Kaon Identification

## tof - dE/dx identification

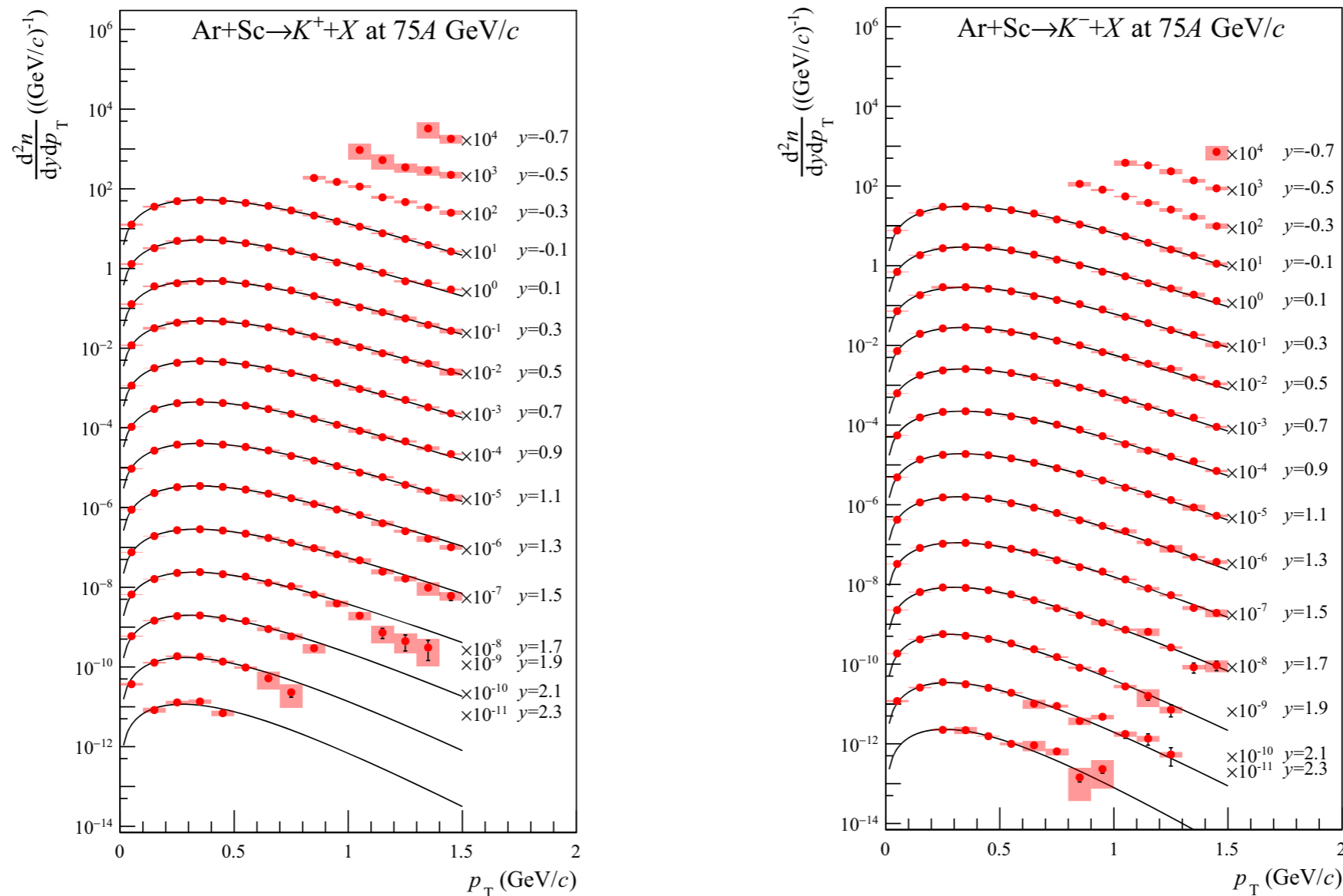


- ▶ Based on the measurement of energy loss of charged particles combined with the measurement of Time-of-Flight (tof)
- ▶ Momentum range  $< 10 \text{ GeV}/c$



# Charged Kaon Production

Example of transverse momentum spectra - ArSc at 75A GeV/c

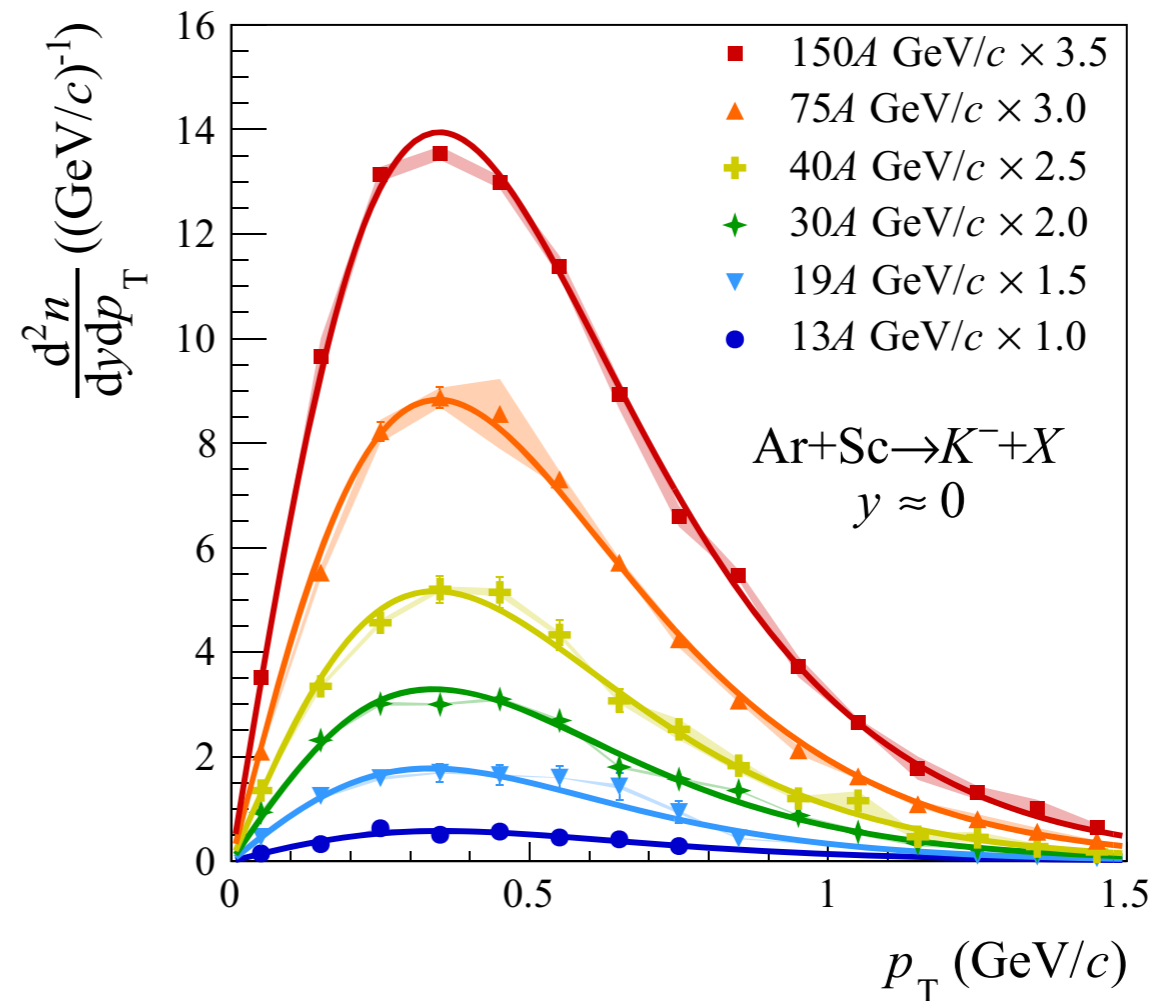
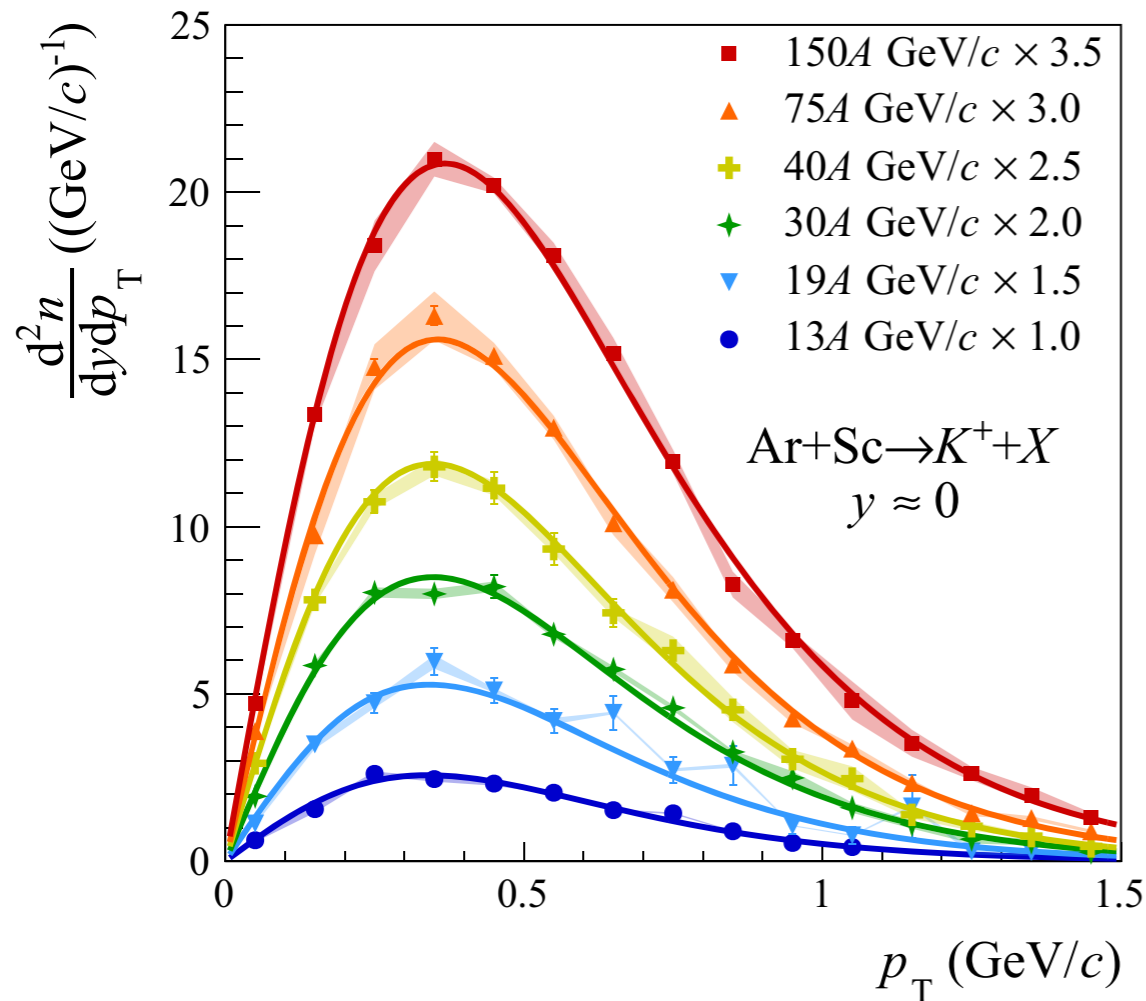


- ▶ Charged kaon production was measured at 13A, 19A, 30A, 40A, 75A, and 150A GeV/c
- ▶ Transverse momentum spectra are measured in a large rapidity range
- ▶ The systematic uncertainties are shown by the red shaded boxes
- ▶  $d^2n/dp_T dy$  spectra were fitted with the exponential functions



# Charged Kaon Production

Transverse momentum spectra at mid-rapidity

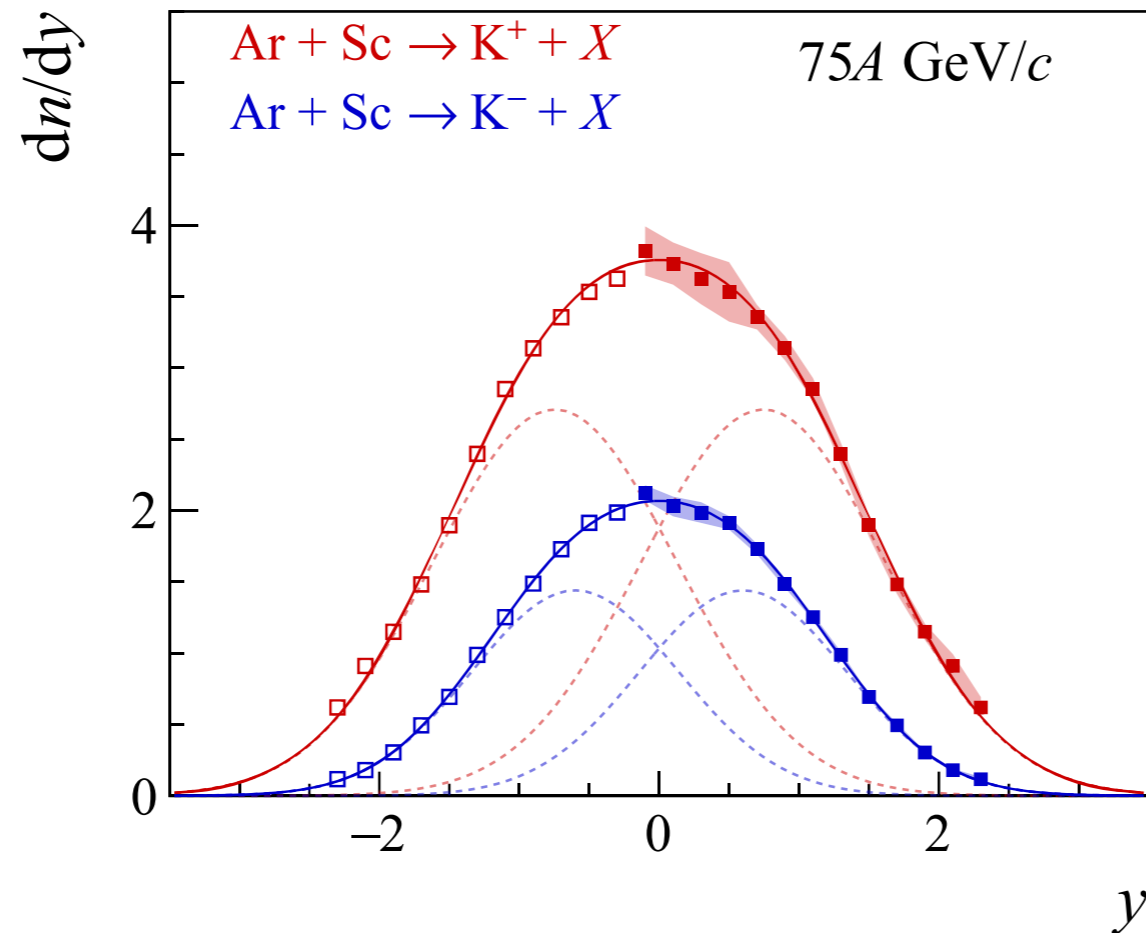


- The  $dn/dy$  yields of charged kaons at mid-rapidity were obtained from the measured  $d^2n/dp_T dy$  spectra and extrapolations using fitted functions

$p_{\text{beam}}$ (GeV/c)	$(dn/dy)_{y \approx 0}$ ( $K^+$ )	$(dn/dy)_{y \approx 0}$ ( $K^-$ )
75A	$3.732 \pm 0.016 \pm 0.148$	$2.029 \pm 0.012 \pm 0.069$

# Charged Kaon Production

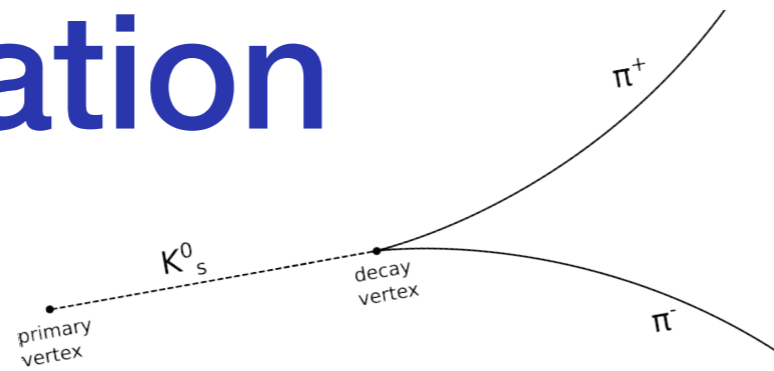
## Rapidity spectra



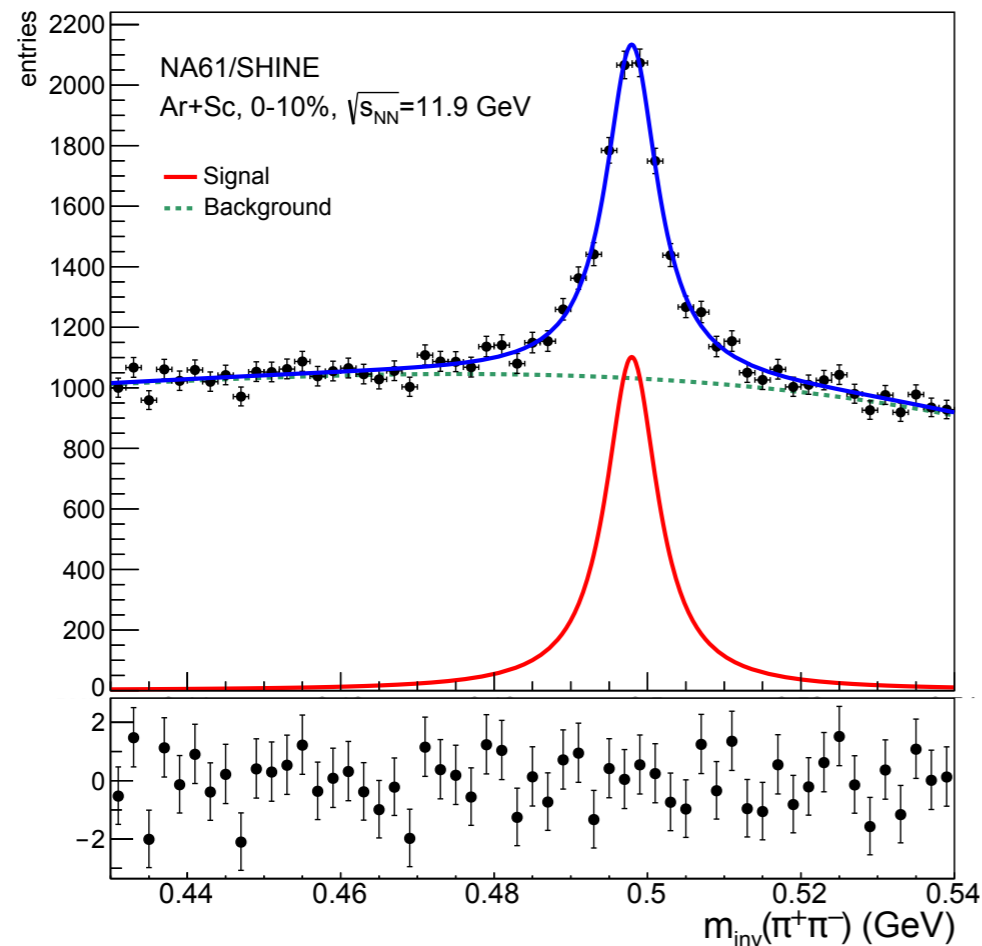
- ▶  $dn/dy$  points were obtained by integration of the  $d^2n/dp_T dy$  spectra and extrapolation using fitted exponential functions
- ▶ Obtained rapidity spectra were fitted with double-Gaussians
- ▶ Mean multiplicities were determined from  $dn/dy$  spectra supplemented with the extrapolated yields using fitted double-Gaussian functions

$p_{\text{beam}}$ (GeV/c)	$\langle K^+ \rangle$	$\langle K^- \rangle$
75A	$11.84 \pm 0.08 \pm 0.39$	$5.33 \pm 0.01 \pm 0.14$

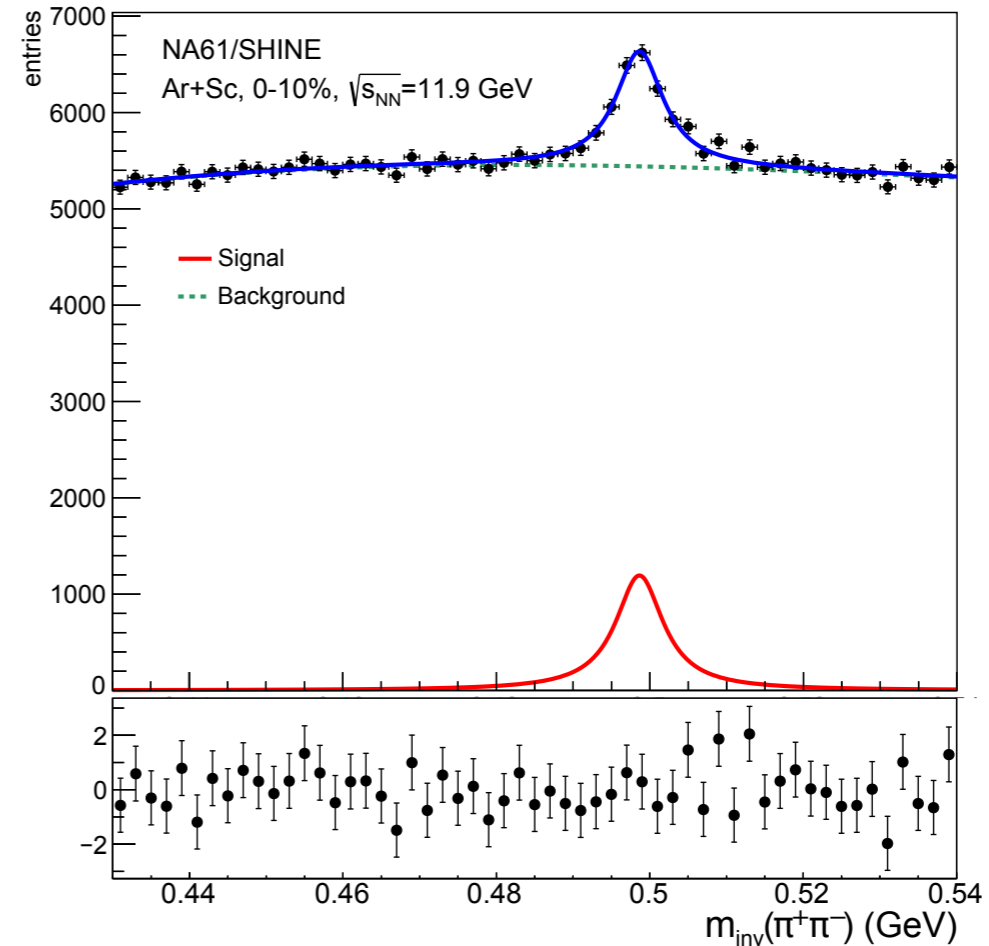
# $K^0_s$ Identification



$y \in (-1.0, -0.5)$ ,  $p_T \in (1.2, 1.5)$  GeV/c



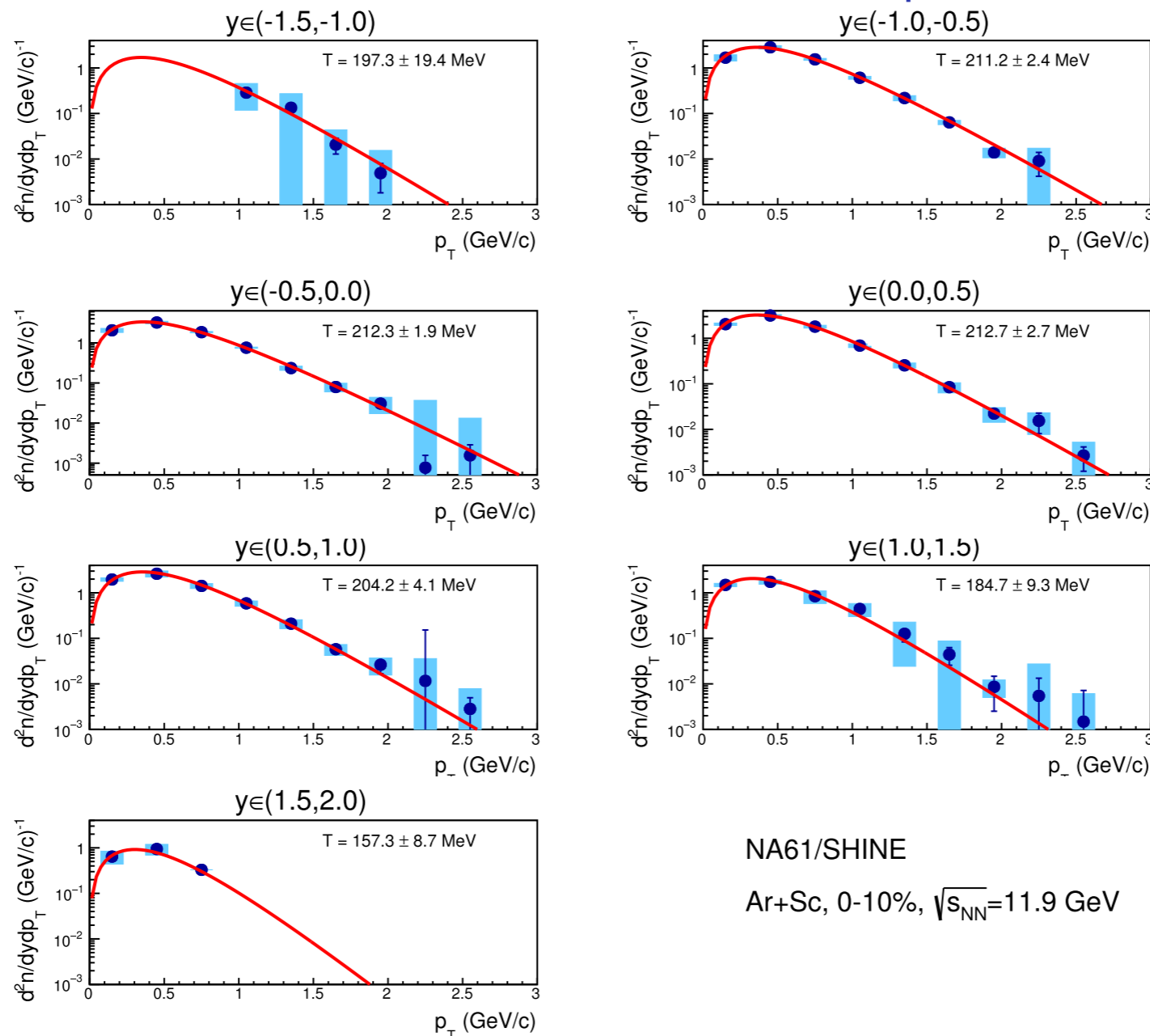
$y \in (0.5, 1.5)$ ,  $p_T \in (1.2, 1.5)$  GeV/c



- ▶ Reconstruction based on decay topology and invariant mass spectra
- ▶ Branching ratio  $BR \approx 69.2\%$  for  $K^0_s$  decays into charged pions
- ▶ Breit-Wigner function is used to describe the signal, a third order Chebychev polynomial to describe the background

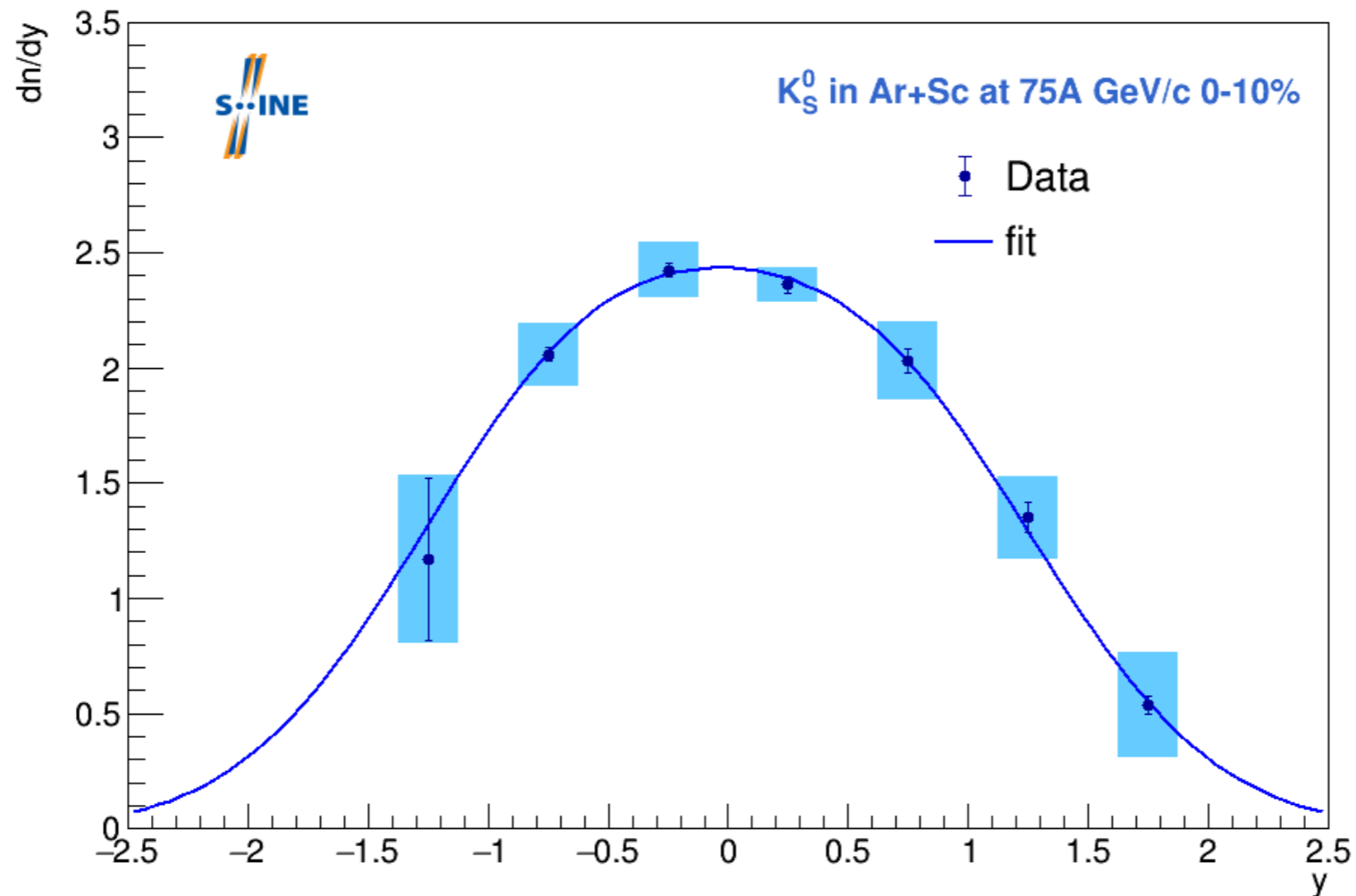
# $K^0_s$ Production in Ar+Sc at 75A GeV/c

## Transverse momentum spectra



- ▶  $p_T$  distributions of the  $K^0_s$  mesons are measured in seven rapidity bins in the rapidity range  $[-1.5, 2]$
- ▶ The systematic uncertainties are shown by the blue shaded boxes
- ▶  $d^2n/dp_T dy$  spectra were fitted with the exponential functions

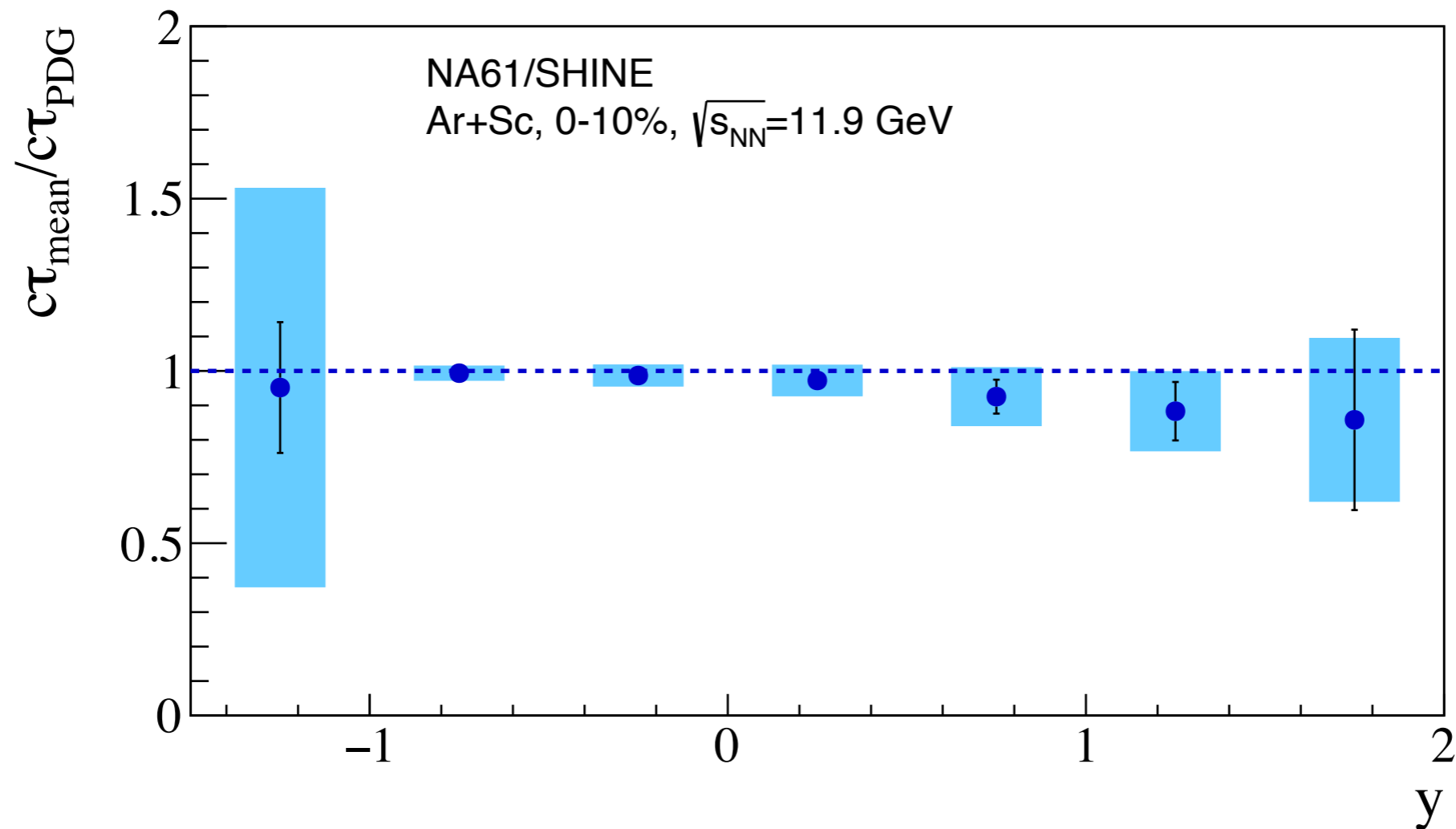
# $K^0_s$ Production in Ar+Sc at 75A GeV/c



- ▶  $dn/dy$  points of the  $K^0_s$  mesons were obtained as the integrals of the curves fitted to the corresponding transverse momentum spectra
- ▶ The systematic uncertainties are shown by the blue shaded boxes
- ▶ The rapidity spectrum was fitted with a double-Gaussian
- ▶ Mean multiplicity was determined as the integral of the fitted double-Gaussian function

$$\langle K^0_s \rangle = 6.49 \pm 0.10 \pm 0.74$$

# $K^0_s$ Production in Ar+Sc at 75A GeV/c



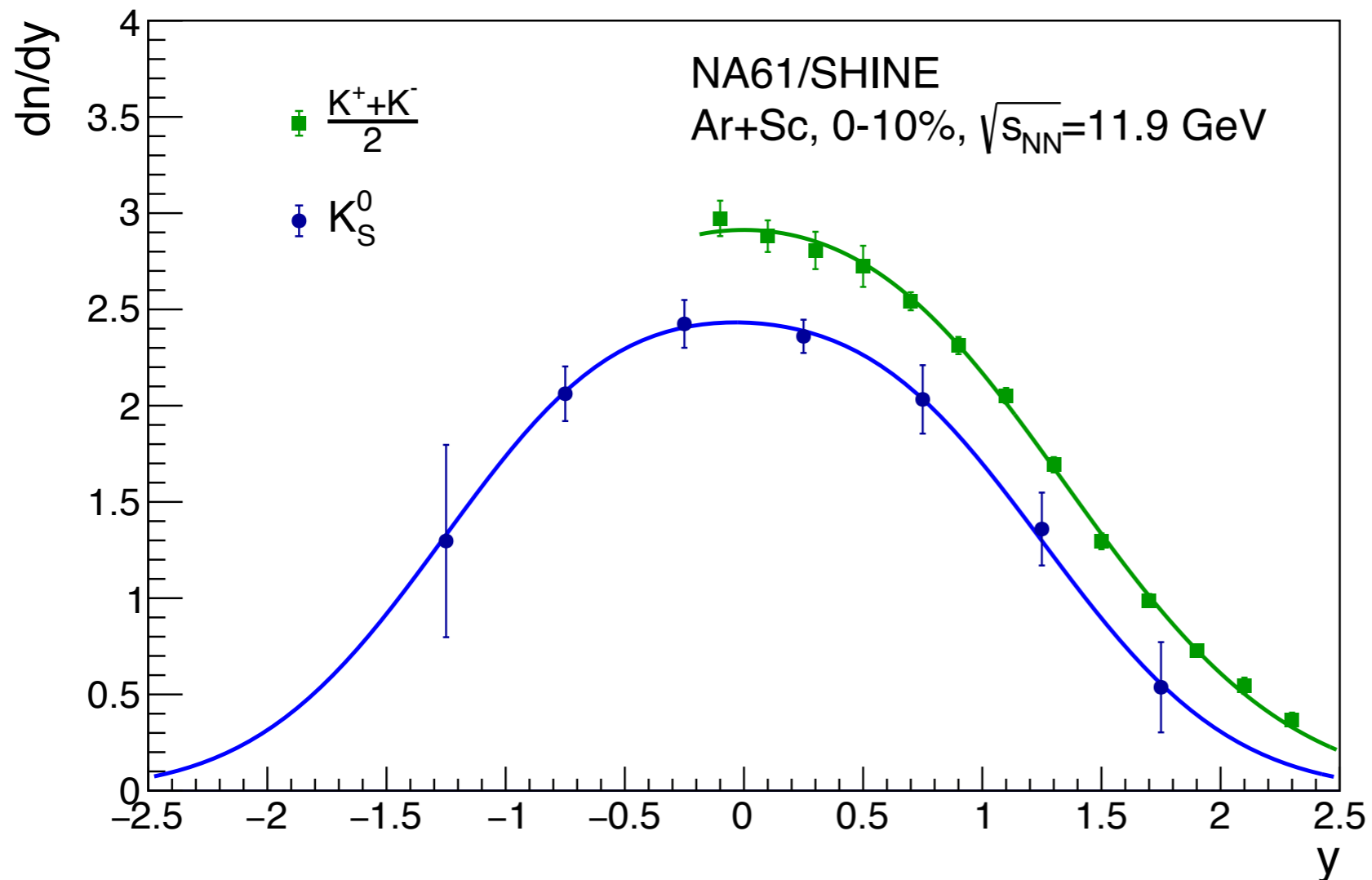
- ▶ The reliability of the  $K^0_s$  extraction is checked by studying the  $K^0_s$  lifetime
- ▶ Good agreement with the PDG value



## Comparison of Charged and Neutral Kaons

# Comparison of Charged and Neutral Kaons

## Ar+Sc at 75A GeV/c



Expected yields:

$$K^+ \approx K^0$$

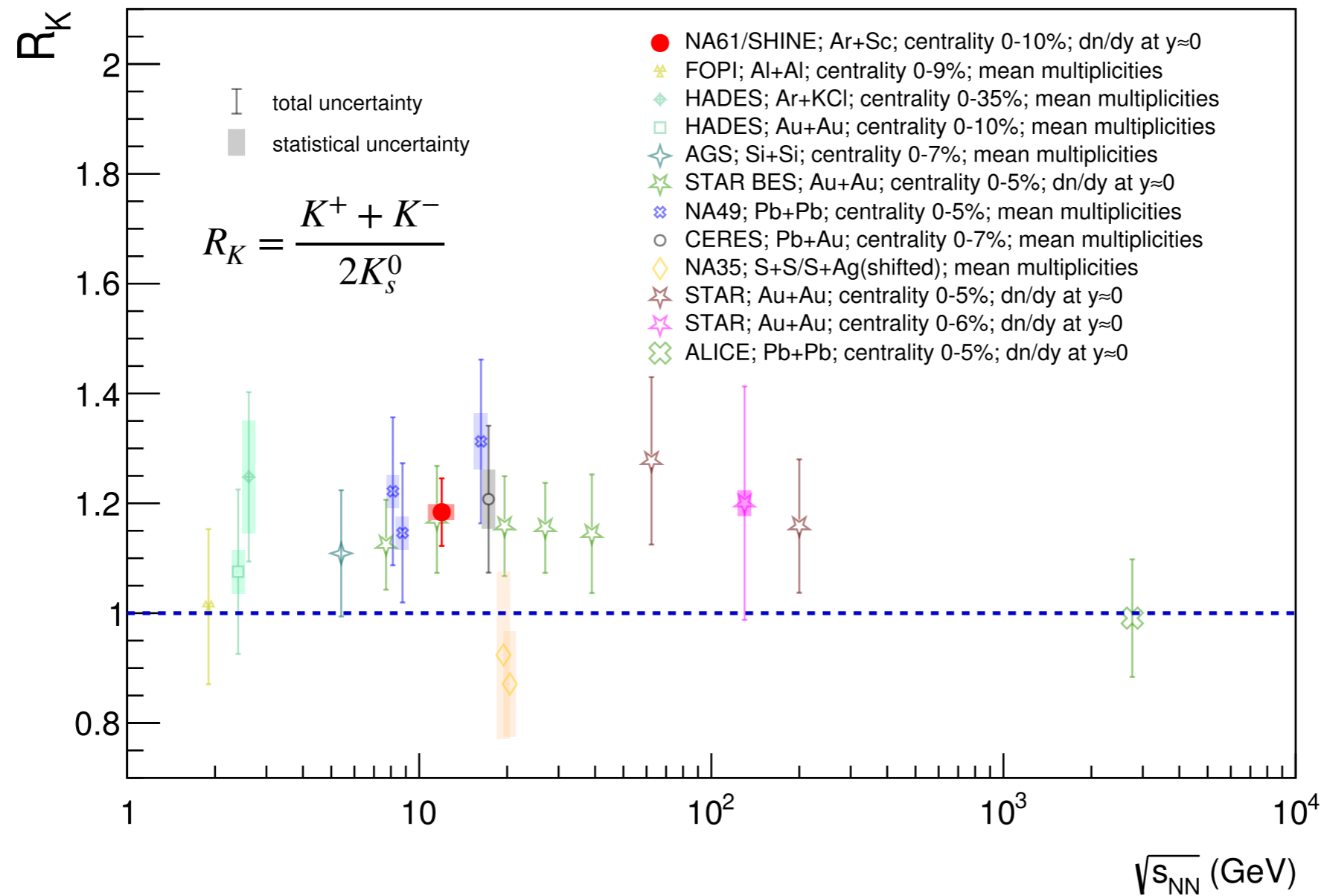
$$K^- \approx \bar{K}^0$$

$$\frac{K^+ + K^-}{2} \approx \frac{K^0 + \bar{K}^0}{2} = K_S^0$$

- ▶ Total uncertainties shown:  $\sqrt{stat^2 + sys^2}$
- ▶ Approximately equal abundance of charged and neutral kaons expected, as Ar and Sc nuclei are nearly isospin symmetric (valence  $u = d$  within 6%)
- ▶ **Excess of charged to neutral kaons** observed in the whole rapidity range



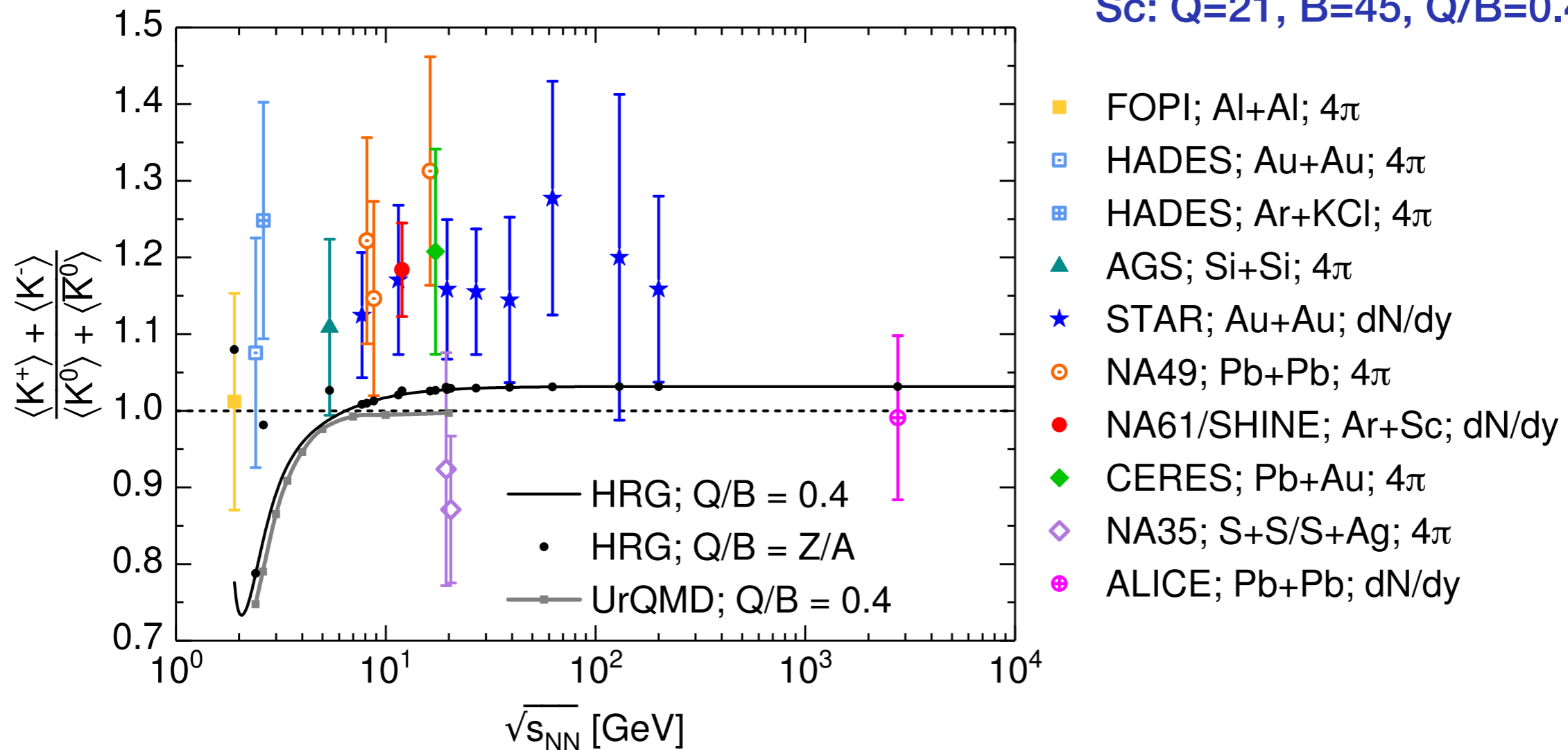
# Charged to Neutral Kaon Ratio - World Data



- ▶  $R_K$  measured by NA61/SHINE is significantly higher than 1:  $R_K = 1.184 \pm 0.061$  (tot.)
- ▶ Similar effect visible in the results from other experiments

# Charged to Neutral Kaon Ratio - Models

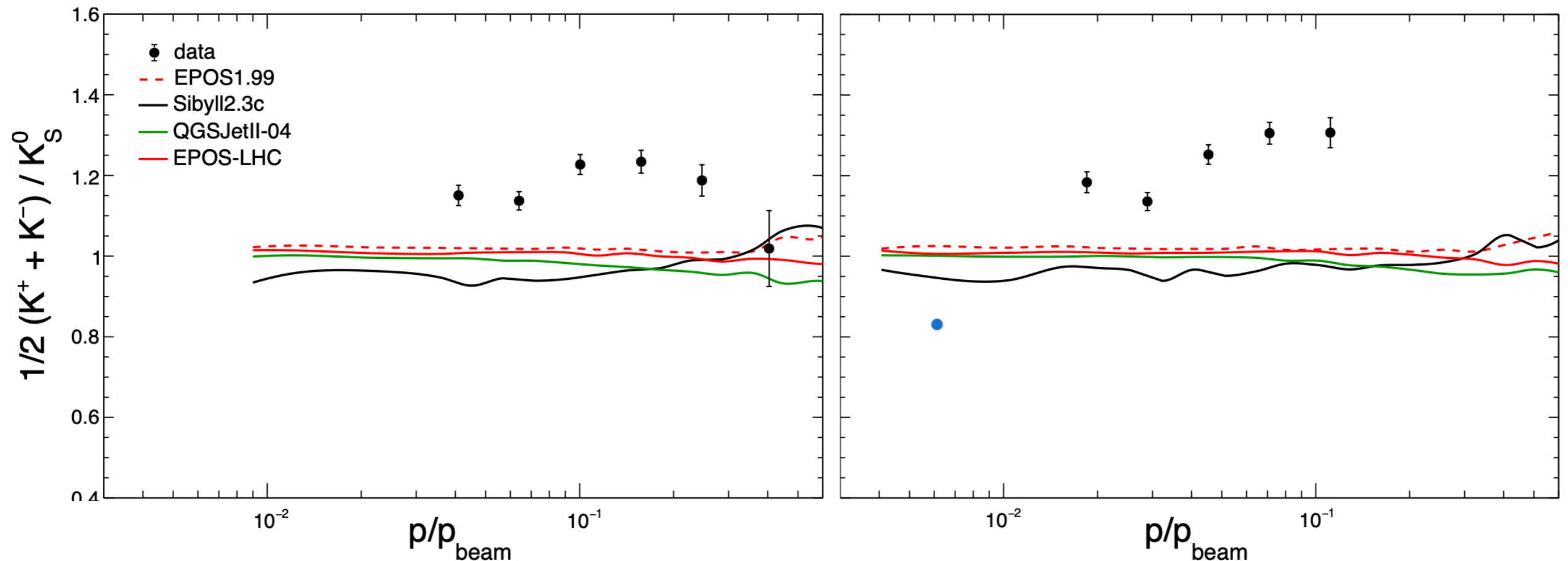
Ar:  $Q=18$ ,  $B=40$ ,  $Q/B=0.45$   
 Sc:  $Q=21$ ,  $B=45$ ,  $Q/B=0.47$



- ▶ Predictions from UrQMD and HRG models presented by F. Giacosa (Tuesday, 8:50 AM)
- ▶ Black and grey lines show the HRG and UrQMD predictions for electric to baryon charge  $Q/B = 0.4$
- ▶ Black dots represent the HRG baseline for  $Q/B$  values specified according to the given types of colliding nuclei
- ▶ HRG and UrQMD models do not reproduce the experimental result on charged to neutral kaon ratio

# Charged to Neutral Kaon Ratio in Asymmetric System

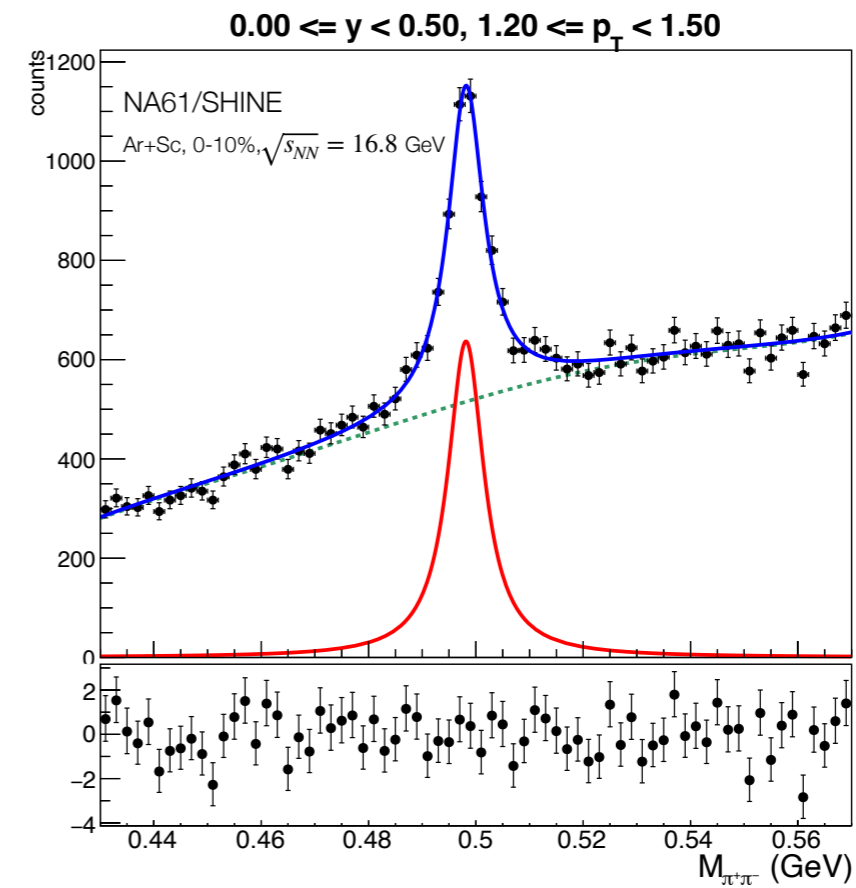
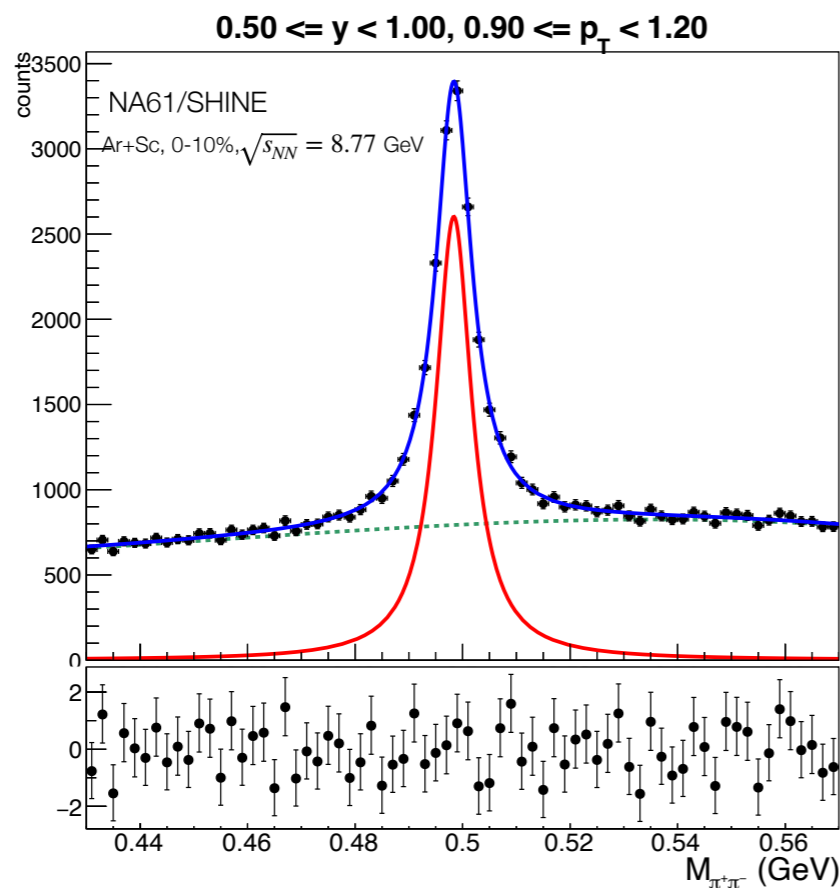
$\pi^- + C$  at 158 and 350 GeV/c:



- ▶ Experimental  $R_K > 1$
- ▶ Models fail to describe charged to neutral kaon ratio even for small asymmetric system

# Summary

- ▶ NA61/SHINE has measured charged kaon production in 0 - 10% central Ar+Sc collisions at 13A, 19A, 30A, 40A, 75A, and 150 AGeV
- ▶  $K^0_s$  production has been measured in 0 - 10% central Ar+Sc collisions at 75A GeV/c
- ▶ Ratio  $R_K = (K^+ + K^-)/(2K^0_s)$  for Ar+Sc at 75A GeV/c is on the level of 1.2
- ▶  $R_K > 1$  has been measured also in  $\pi^-+C$  collisions at 150 and 350 GeV/c
- ▶ HRG and UrQMD models do not reproduce the experimental result on charged to neutral kaon ratio in A+A collisions
- ▶ Models fail to describe charged to neutral kaon ratio also for small asymmetric  $\pi^-+C$  system
- ▶ Analysis of the production of  $K^0_s$  mesons in central Ar+Sc collisions at 40A and 150A GeV/c is ongoing → stay tuned



Thanks for you attention!