System size dependence of strangeness production from NA61/SHINE

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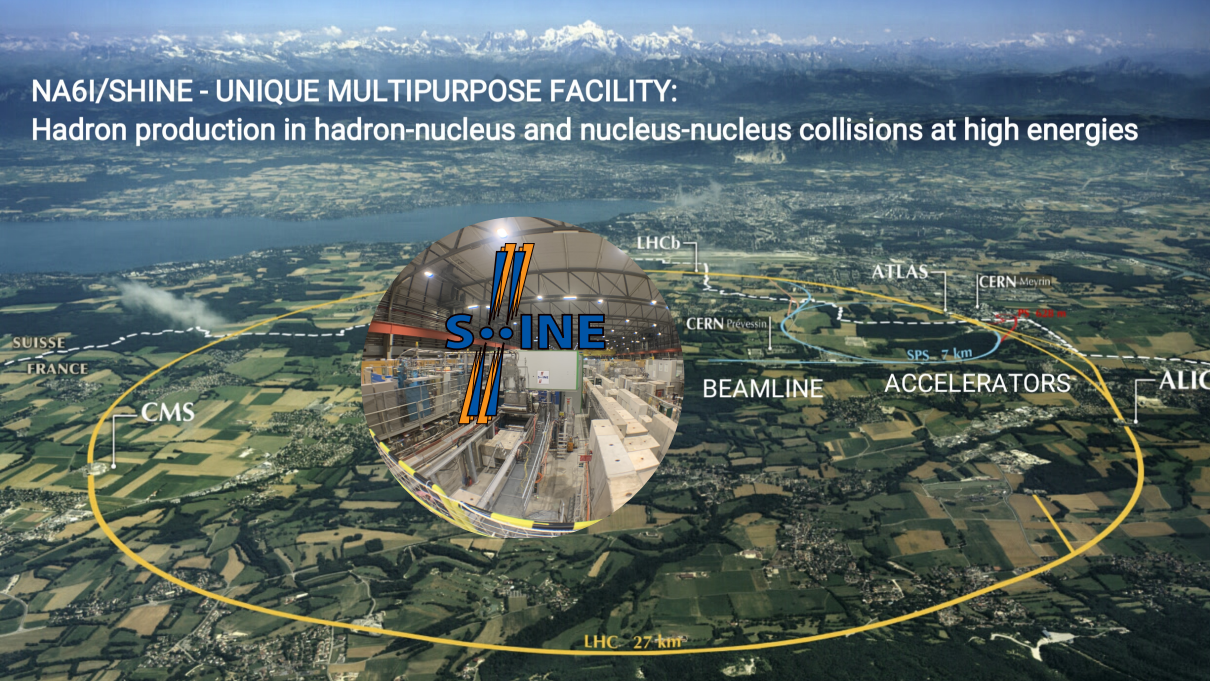
Workshop on Critical Point and Onset of Deconfinement
28.11-2.12.2022

FACULTY OF PHYSICS
UNIVERSITY OF WARSAW

SHINE

NA6I/SHINE - UNIQUE MULTIPURPOSE FACILITY:
Hadron production in hadron-nucleus and nucleus-nucleus collisions at high energies



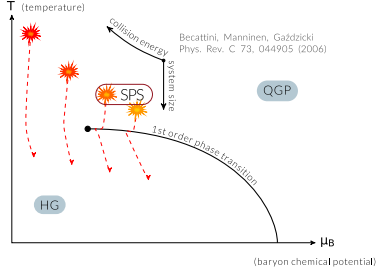
NA61/SHNE physics program

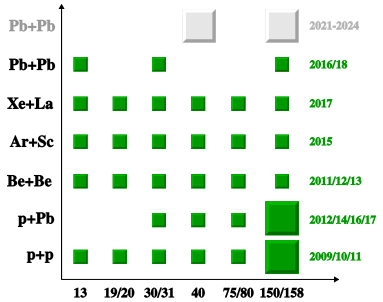
Strong interaction physics:

- study properties of the **onsets of deconfinement and fireball**
- search for the **critical point** of strongly interacting matter
- direct measurements of **open charm**

Neutrino and cosmic ray physics:

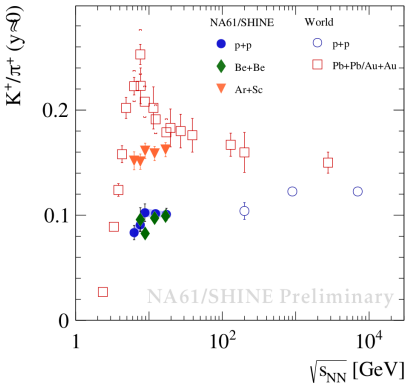
- measurements for neutrino programs at J-PARC and Fermilab
- measurements of nuclear fragmentation cross section for cosmic ray physics

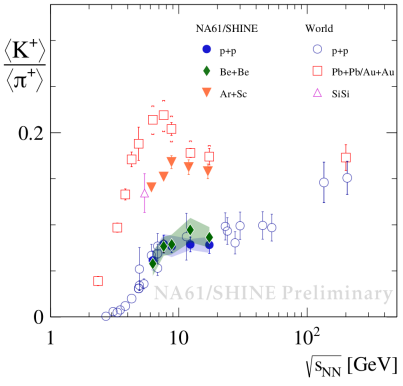




Study of the onset of deconfinement

Onset of deconfinement: horn

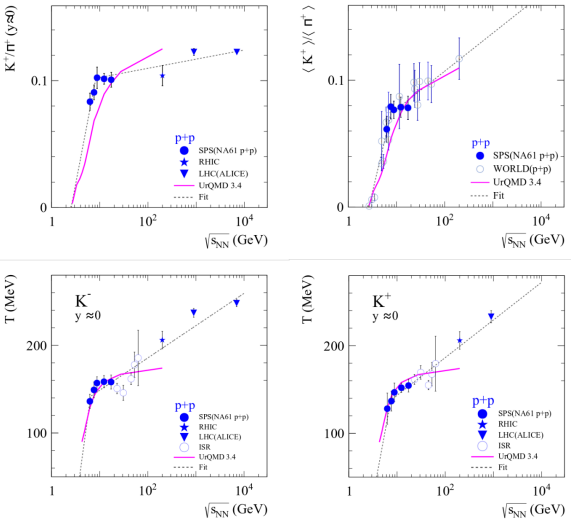




- Rapid change in the energy dependence of K^+/π^+ ratio in Pb+Pb collisions indicated the onset of deconfinement in the SPS energy range, as predicted within SMES
- Plateau like structure visible in light systems (p+p and Be+Be)
- Ar+Sc systematically higher, shows dependence on collision energy qualitatively similar to p+p and Be+Be (no horn structure)

Eur.Phys.J.C 81 (2021) 1, 73 (Be+Be), Eur.Phys.J.C 77 (2017) 10, 671 (p+p)

Onset of deconfinement: $p+p$ data

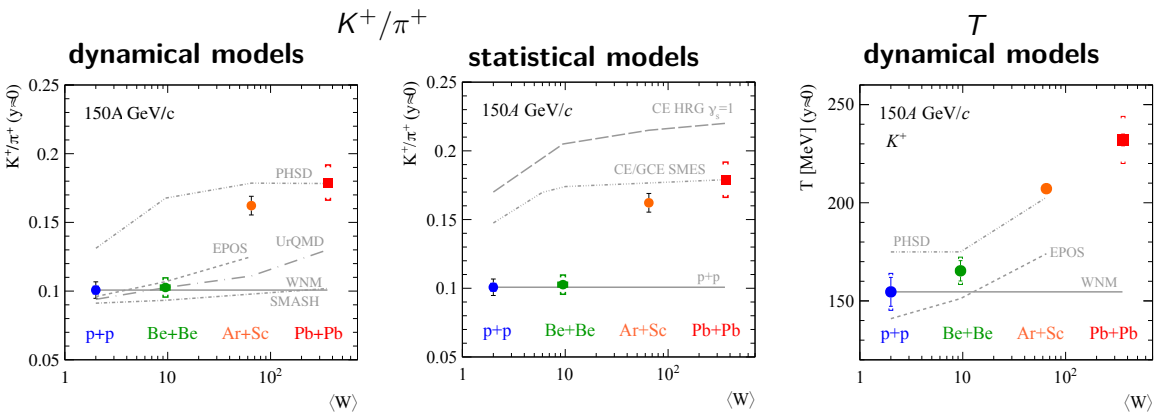


- Rates of increase of K^+/π^+ and T change sharply in $p+p$ collisions at SPS energies
- The fitted change energy is ≈7 GeV - close to the energy of the onset of deconfinement ≈8 GeV
- Models assuming change from resonances to string production mechanism show similar trend

Phys.Rev.C 102 (2020) 1, 011901

Study of the onset of fireball

System size dependence of K^+/π^+ and T at 150A GeV/c

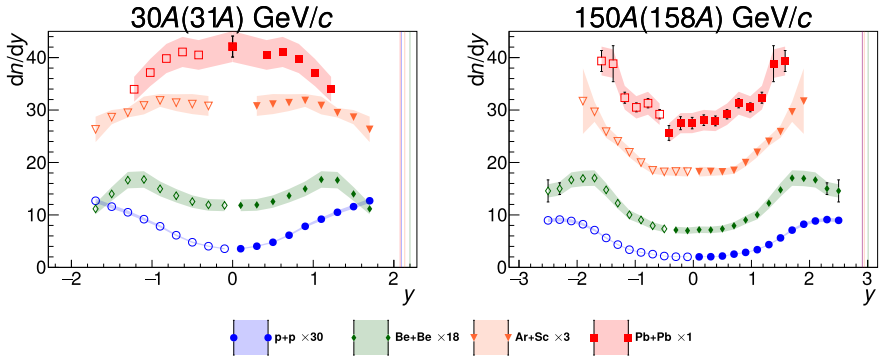


- None of the models reproduce K^+/π^+ ratio or T in the whole $\langle W \rangle$ range

PHSD: Eur.Phys.J.A 56 (2020) 9, 223, arXiv:1908.00451 and private communication;
SMASH: J.Phys.G 47 (2020) 6, 065101 and private communication;
UrQMD and HRG: Phys. Rev. C99 (2019) 3, 034909;
SMES: Acta Phys. Polon. B46 (2015) 10, 1991 - recalculated

p+p: Eur. Phys. J. C77 (2017) 10, 671
Be+Be: Eur. Phys. J. C81 (2021) 1, 73
Ar+Sc: NA61/SHINE preliminary
Pb+Pb: Phys. Rev. C66, 054902 (2002)

New results on rapidity spectra of protons

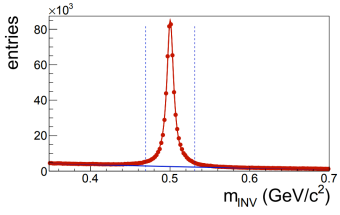


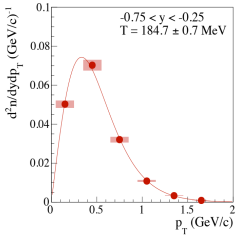
- "Peak-dip" transition is observed in medium and heavy systems: Ar+Sc and Pb+Pb within SPS energy range.
- No such transition for small systems: p+p and Be+Be

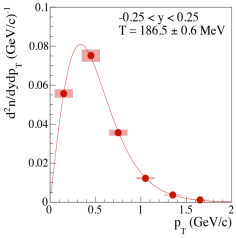
Eur.Phys.J.C 81 (2021) 1, 73 (Be+Be)
Eur.Phys.J.C 77 (2017) 10, 671 (p+p)
PRC83, 014901 (Pb+Pb at 158A GeV/c)
NA61 prelim. (Ar+Sc)
NA49 prelim. (Pb+Pb at 30A GeV/c)

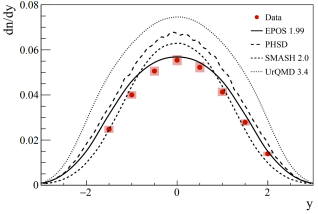
(Multi-)strange hadron production in p+p interactions at $\sqrt{s} = 17.3$ GeV

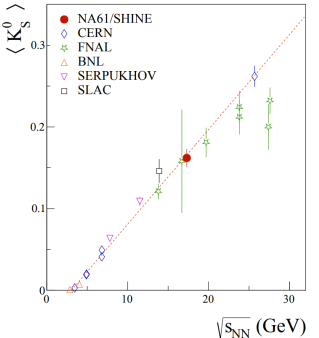
K^0_S meson production in $p+p$ interactions at 158 GeV/c





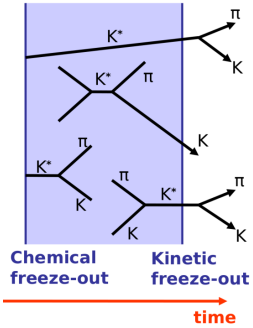


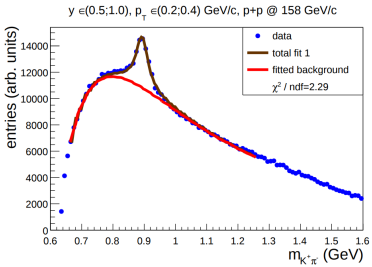


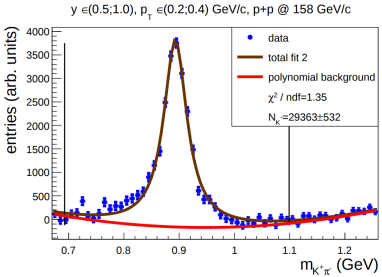


- Results on K^0_S production were recently published in Eur.Phys.J.C 82 (2022), 96
- Mean multiplicity: $\langle K^0_S \rangle = 0.162 \pm 0.001 \pm 0.011$
- Model predictions deviate by up to 20% from the measurements

$K^*(892)^0$ meson production in $p+p$ interactions



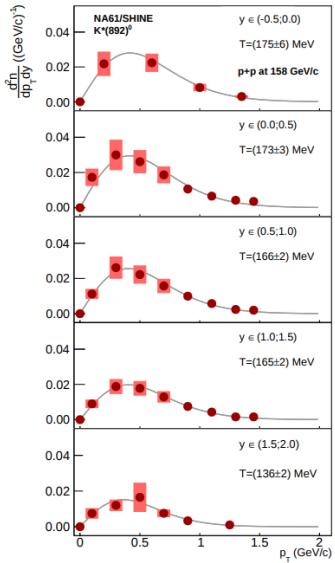




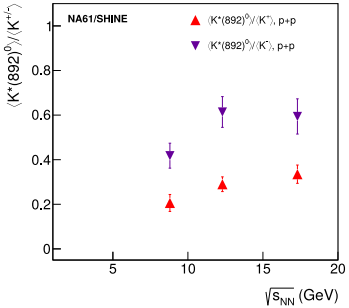
- $K^*(892)^0$ was reconstructed in $K^* \to K^+ + \pi^-$ channel
- The resonance yield is affected by regeneration and rescattering processes
- We have observable sensitive to time between chemical and kinetic freezouts Δt:

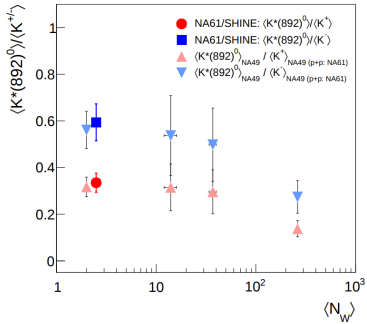
$$\left.\frac{K^*}{K^\pm}\right|_{kinetic} = \left.\frac{K^*}{K^\pm}\right|_{chemical} \cdot e^{-\Delta t/\tau}, \qquad \tau = 4.17 \text{ fm}/c$$

$K^*(892)^0$ meson production in $p+p$ interactions



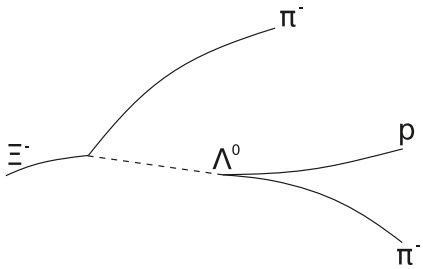
Eur.Phys.J.C 80 (2020) 5, 460
Eur.Phys.J.C 82 (2022) 4, 322



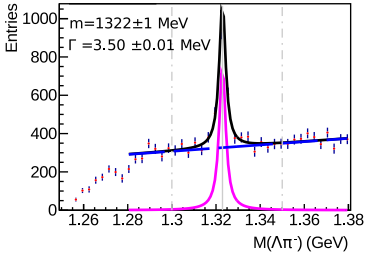


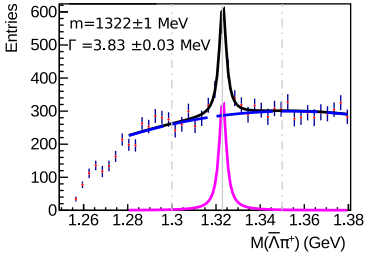
- **Results on $K^*(892)^0$ mass and width were included in PDG**
- time between freezeouts at 158 GeV/c estimated to be $\Delta t \approx 5.3 fm/c$
- $\Delta t_{\mathrm{SPS}} > \Delta t_{\mathrm{RHIC}} \rightarrow$ lifetime of hadronic phase longer at SPS and/or regeneration more important at RHIC energies

Ξ^- and $\bar{\Xi}^+$ production in p+p interactions at 158 GeV/c

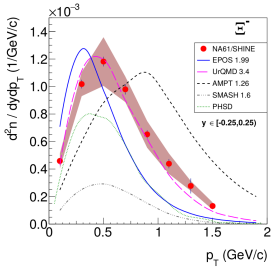


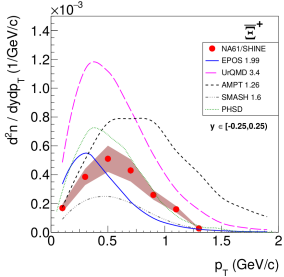
- Reconstruction based on decay topology
- $\Xi^{\pm}$ decays into $\pi^{\pm}$ and $\Lambda(\bar{\Lambda})$ with BR≈99.9%
- A set of quality cuts is imposed onto Ξ candidates to improve SNR
- Breit–Wigner function is used to describe signal

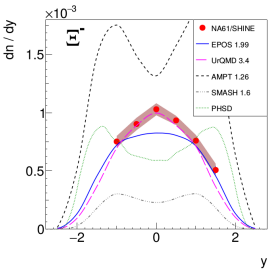


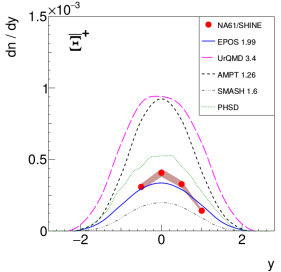


Ξ^- and $\bar{\Xi}^+$ production in p+p interactions at 158 GeV/c

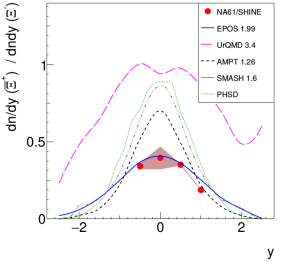






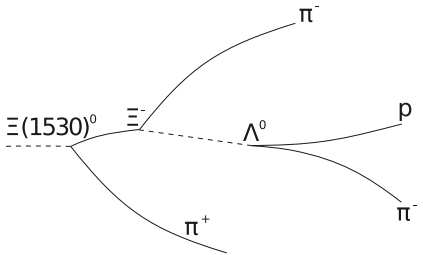


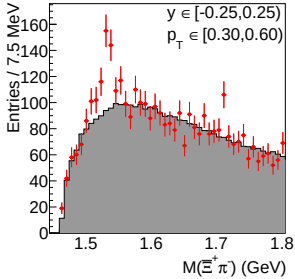
- The only existing results on Ξ^- and $\bar{\Xi}^+$ production in SPS energy range in p+p interactions
- Strong suppression of $\bar{\Xi}^+$: $\langle\bar{\Xi}^+\rangle/\langle\Xi^-\rangle = 0.24 \pm 0.01 \pm 0.05$
- Transport models fail to describe the results on Ξ production in p+p collisions

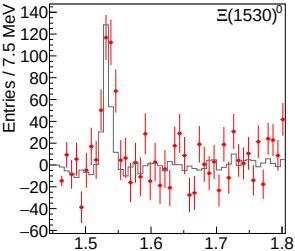


Eur.Phys.J.C 80 (2020) 9, 833, Erratum: Eur.Phys.J.C 82 (2022) 2, 174

$\Xi^0(1530)$ and $\bar{\Xi}^0(1530)$ production in $p+p$ interactions at 158 GeV/c



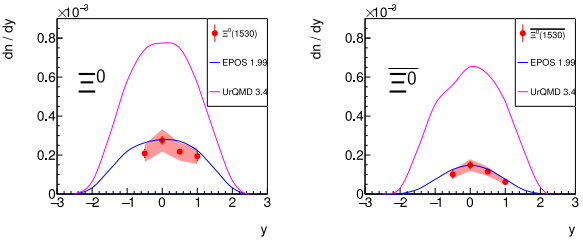


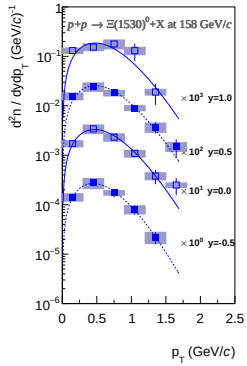


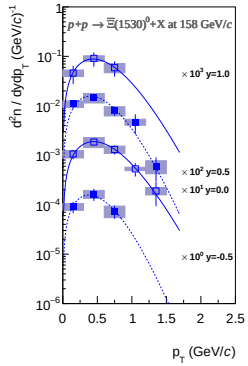
- Reconstruction based on decay topology
- $\Xi^0(1530)$ decays into Ξ and π exclusively
- A set of quality cuts is imposed onto Ξ candidates to improve SNR
- Breit–Wigner function is used to describe signal

$\Xi^0(1530)$ and $\bar{\Xi}^0(1530)$ production in p+p interactions at 158 GeV/c

Eur.Phys.J.C 81 (2021) 10, 911



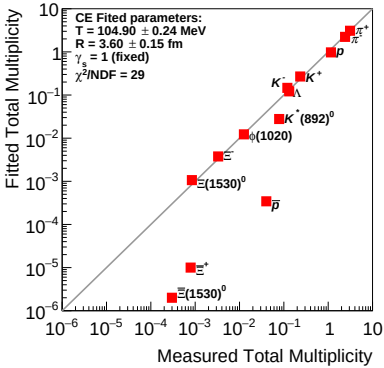


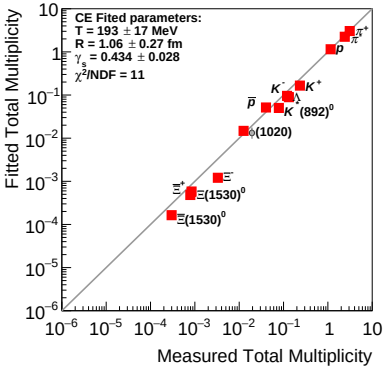


- The first results on $\Xi^0(1530)$ production in p+p in SPS energy range
- The second result results on $\Xi^0(1530)$ production in p+p (other measurement was provided by ALICE at 7 TeV Eur.Phys.J.C 75 (2015) 1)
- Suppression of $\bar{\Xi}^0(1530)$: $\langle\bar{\Xi}^0(1530)\rangle/\langle\Xi^0(1530)\rangle \approx 0.40 \pm 0.03 \pm 0.05$

HRG model and $p+p$ data

Eur.Phys.J.C 81 (2021) 10, 911





Fit done with different variants of HRG (THERMAL_FIST1.3):

- Canonical Ensemble with fixed $\gamma_s = 1$
- Canonical Ensemble with fitted γ_s

- Statistical model fails when strangeness saturation parameter γ_s is fixed
- The fit with free γ_s finds $\gamma_s = 0.434 \pm 0.028$
- Disagreement between model predictions and data is slightly reduced by allowing for out-of-equilibrium strangeness production

Summary

- No horn structure observed in Ar+Sc data
- Unexpected system-size dependence: (p+p $\approx$ Be+Be) $\neq$ (Ar+Sc $\leqslant$ Pb+Pb)
- New results on rapidity spectra of protons
- Unique results on multi-strange baryons production in p+p interactions in SPS energy range
- Present transport models do not describe well the NA61/SHINE results on strange particles production ($K^{\pm}$, K^0, Ξ and $\Xi(1530)$)

Thank you

Backup

$K^{\pm}$ spectra parametrisation

- In order to obtain the dn/dy yields, the data is extrapolated beyond the detector acceptance
- Exponential dependence in p_T is assumed:

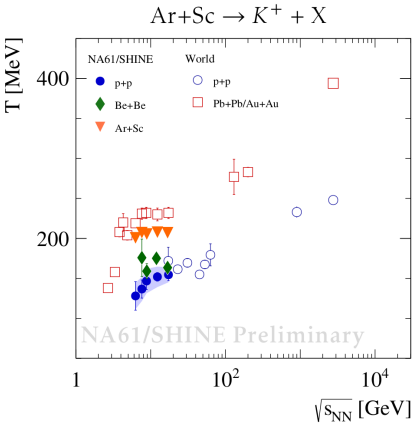
$$f(p_T) = S \cdot p_T \cdot \exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$

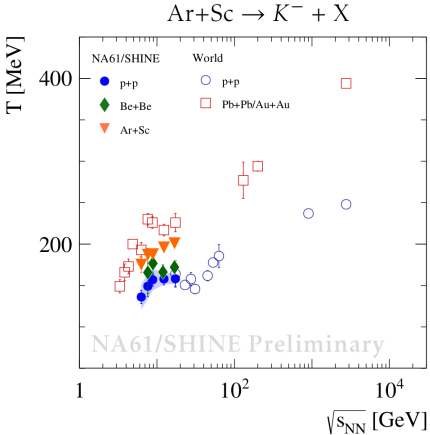
- To obtain mean multiplicity of produced particles rapidity distribution is fitted with following function:

$$f_{fit}(y) = \frac{A}{\sigma_0\sqrt{2\pi}} exp\left(-\frac{(y-y_0)^2}{2\sigma_0^2}\right) + \frac{A}{\sigma_0\sqrt{2\pi}} exp\left(-\frac{(y+y_0)^2}{2\sigma_0^2}\right)$$

- A, y_0 and σ_0 parameters are fitted

Onset of deconfinement: step





- Plateau in the inverse slope parameter T of m_T spectra of $K^{\pm}$ spectra in Pb+Pb was predicted within SMES due to mixed phase of hadron gas and QGP *Acta Phys. Polon.* **B30**, 2705 (1999)
- Similar structures are visible in recently measured reactions
- Magnitude of the T parameter increases with the colliding system size

Eur.Phys.J.C 81 (2021) 1, 73 (Be+Be)

Eur.Phys.J.C 77 (2017) 10, 671 (p+p)