

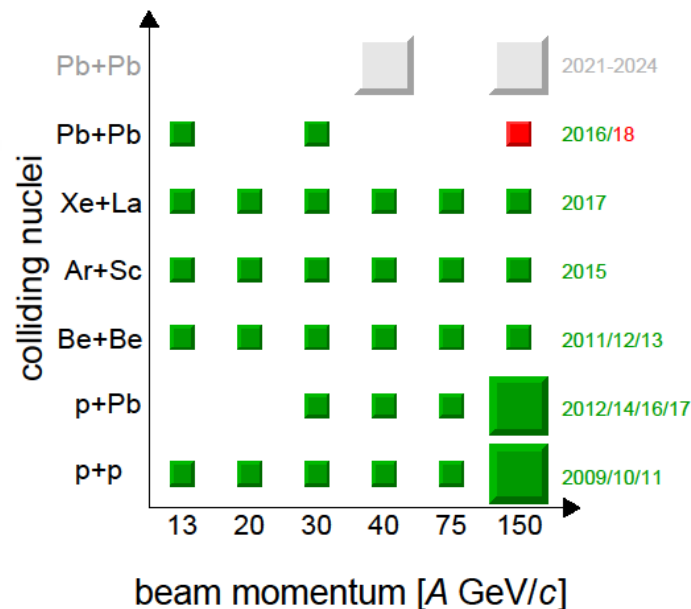
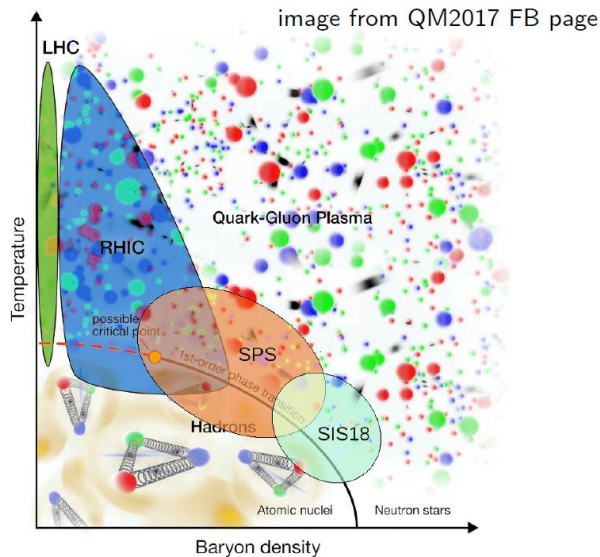
The background of the slide is decorated with several 3D models of atoms. These models consist of a central nucleus made of red and grey spheres, surrounded by one or more elliptical orbits with blue spheres representing electrons. The models are scattered across the slide, with some in sharp focus and others blurred in the background.

Recent results of the NA61/SHINE experiment - spectra and study of the onset of deconfinement

Szymon Pulawski
on behalf of NA61/SHINE collaboration

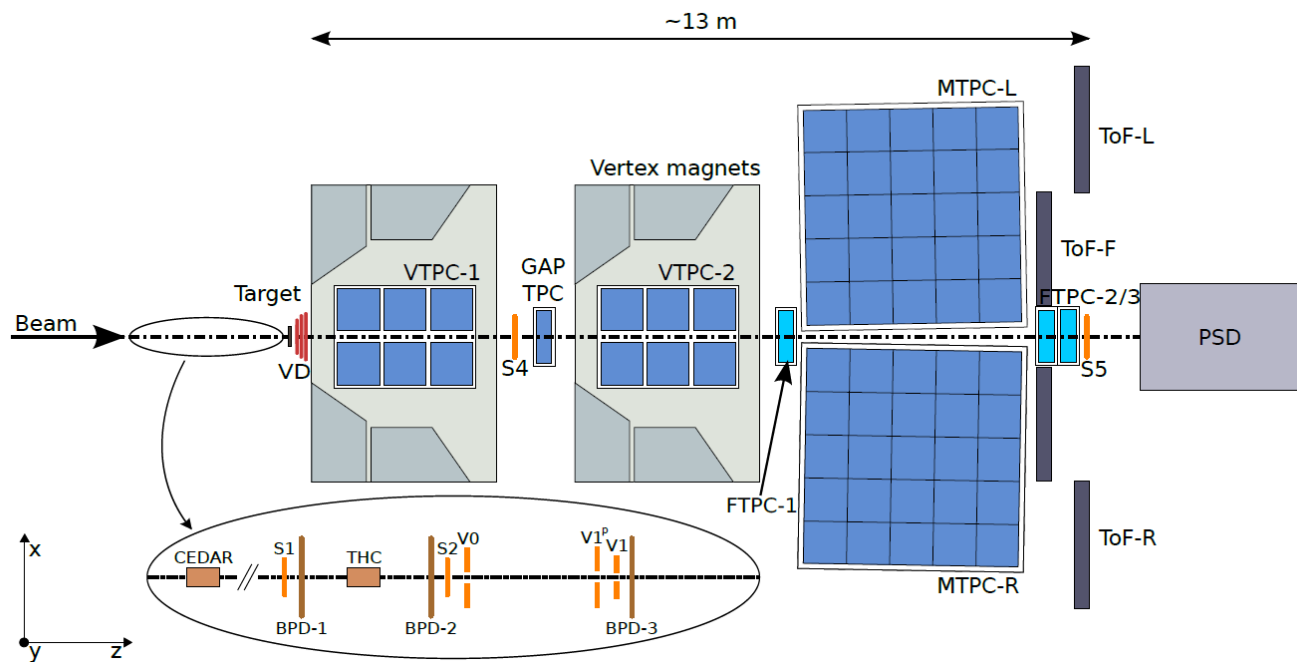
NA61/SHINE 2-dimensional scan

NA61/SHINE experiment performs 2D scan in **collision energy and system size** to study the phase diagram of strongly interacting matter in **baryon density and temperature**



NA61/SHINE spectrometer

Fixed target experiment located at the SPS accelerator



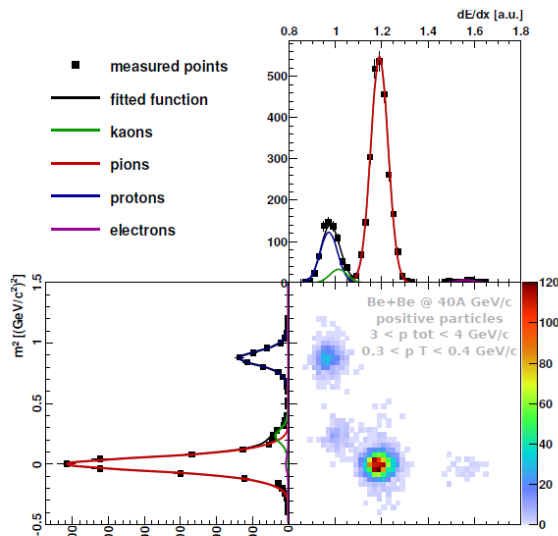
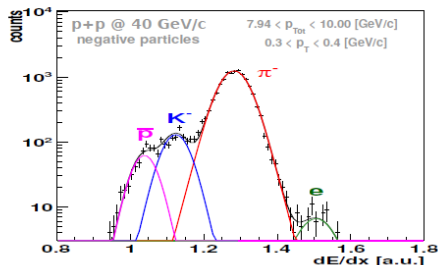
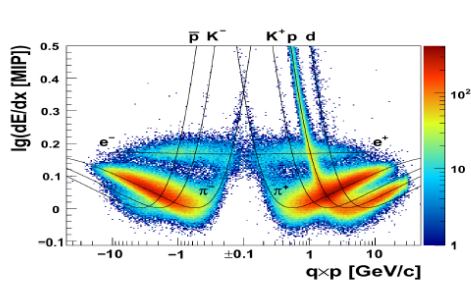
Beams:

- ions (Be, Ar, Xe, Pb)
 $p_{\text{beam}} = 13A - 150A \text{ GeV}/c$
- hadrons (π , K, p)
 $p_{\text{beam}} = 13 - 400 \text{ GeV}/c$
- $\sqrt{s_{NN}} = 5.1 - 16.8 (27.4) \text{ GeV}$

Large acceptance hadron spectrometer – coverage of the full forward hemisphere, down to $p_T = 0$

Charged particle identification

Final results stand for primary particles produced in strong and electromagnetic processes, they are corrected for detector geometrical acceptance and reconstruction efficiency as well as weak decays and secondary interactions.

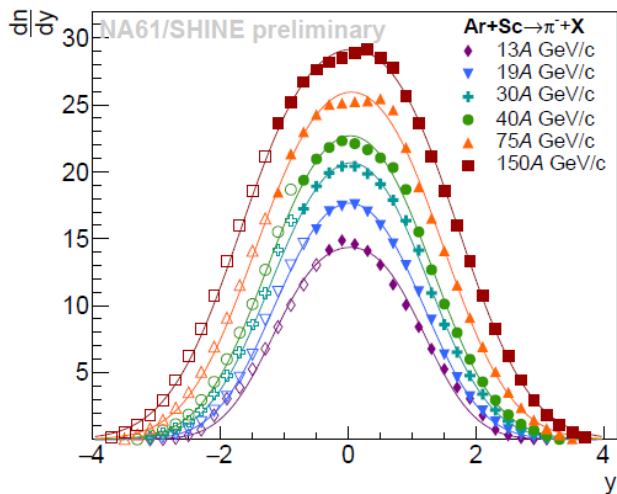


- **h^- analysis** based on the fact that the majority of negatively charged particles are π^- mesons. Contribution of the other particles is subtracted using EPOS Monte-Carlo
- **dE/dx analysis** uses TPC energy loss information to identify particles
- **tof- dE/dx** method estimates number of π , K , p using an energy loss and a particle time of flight measurements

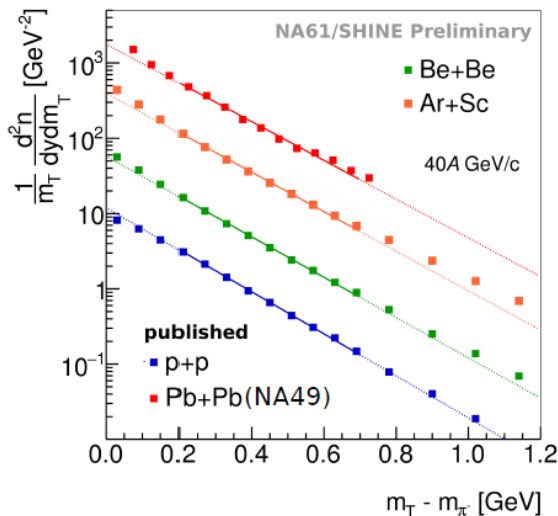
π^- spectra from 2D-scan

π^- spectra measured in large acceptance: p_T down to 0, in full forward hemisphere

Collision energy dependence



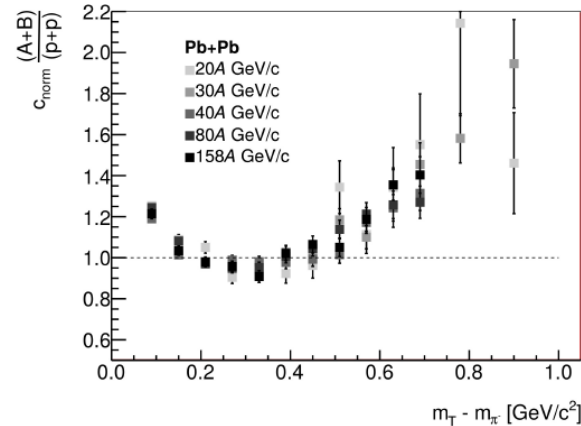
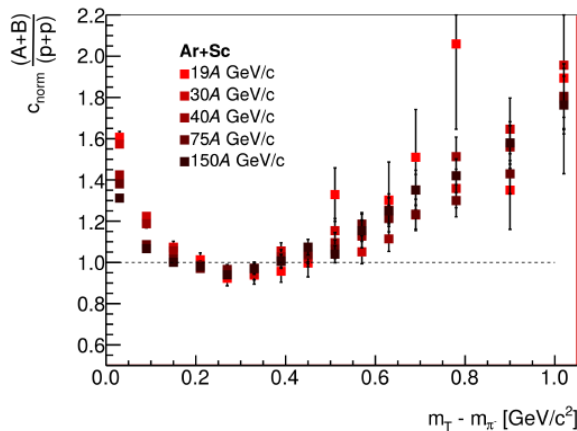
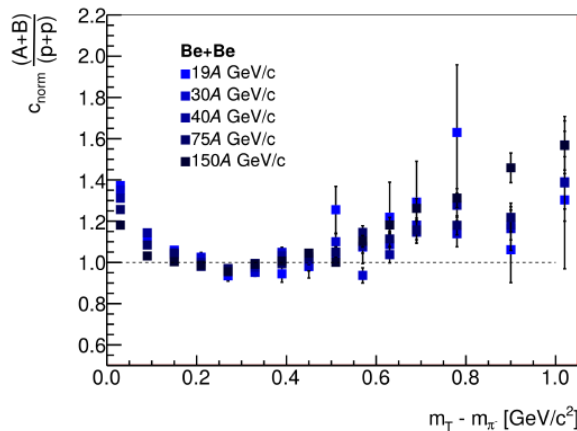
System size dependence



- Rapidity spectra \approx gaussian, independently of collision energy and system size
- Large acceptance allows to obtain 4π multiplicity (sum of data and extrapolation, for details see arXiv:1612.01334)
- m_T spectra in p+p are exponential, in larger systems (central collisions) deviate from the exponential shape

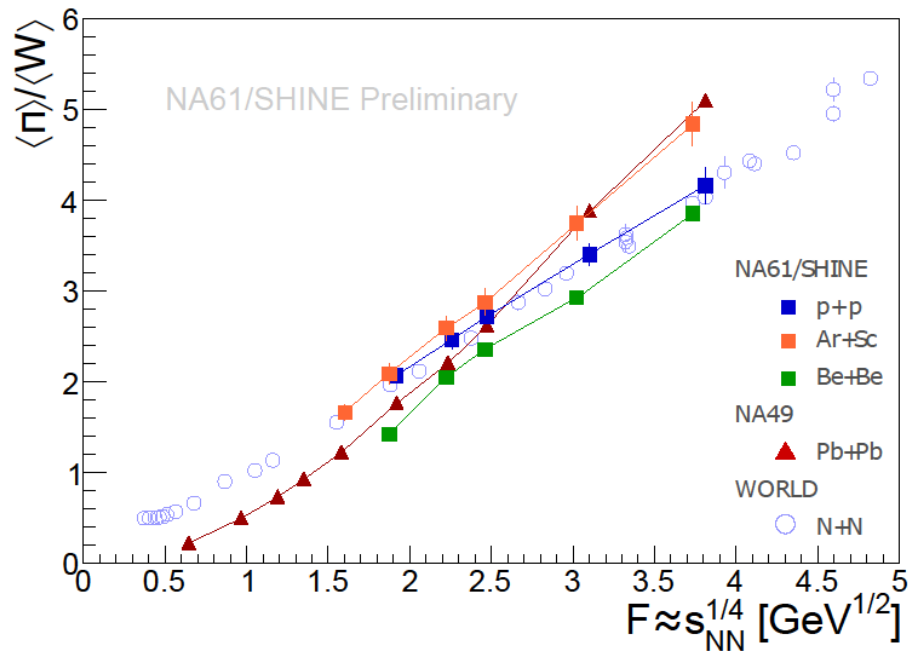
π^- spectra: m_T

Shape of m_T spectra differs significantly between p+p and A+A



- clear system size dependence
- small energy dependence
- the effect possibly associated to transverse collective flow

Onset of deconfinement: kink



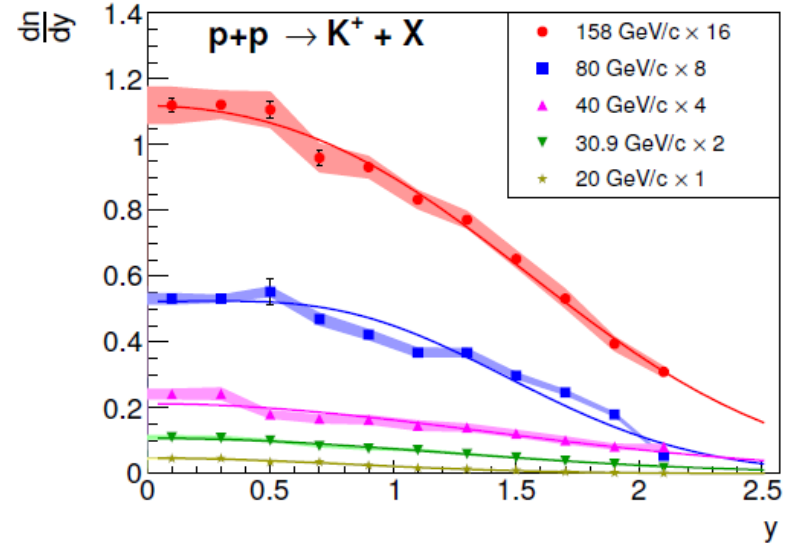
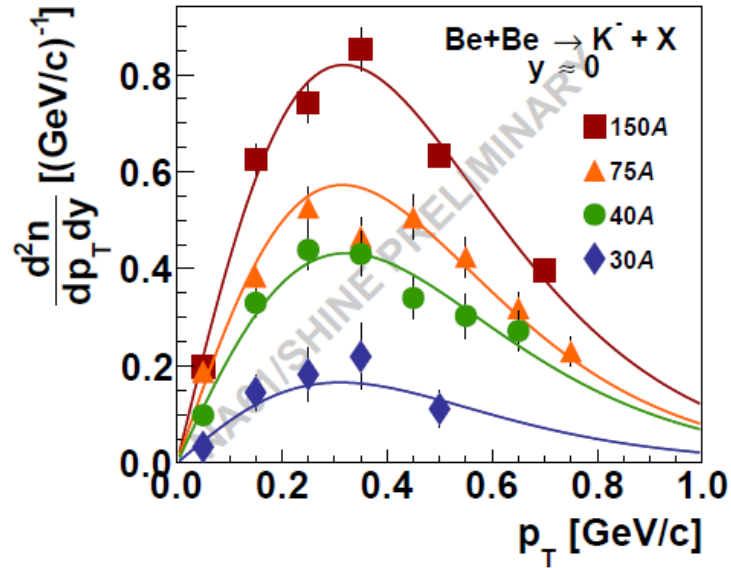
The slope of energy dependence for heavier systems is larger than for lighter systems at high SPS energies.

Statistical model with phase transition (SMES - Acta Phys. Pol. B30 (1999) 2705) predicts increase of the slope – **KINK** – of $\langle \pi \rangle / \langle W \rangle$ in QGP due to the larger number of degrees of freedom in comparison to HRG.

$\langle \pi \rangle$ – mean multiplicity in full acceptance

$\langle W \rangle$ – mean number of wounded nucleons

Onset of deconfinement: step and horn

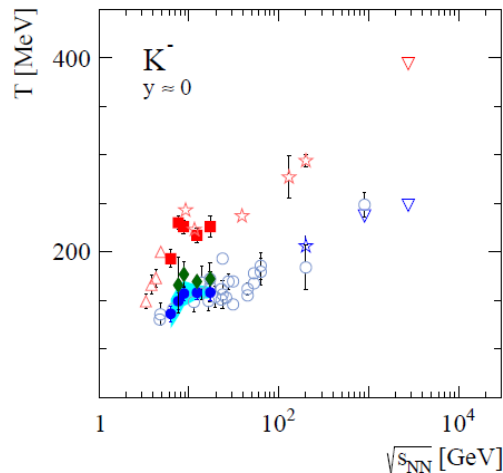
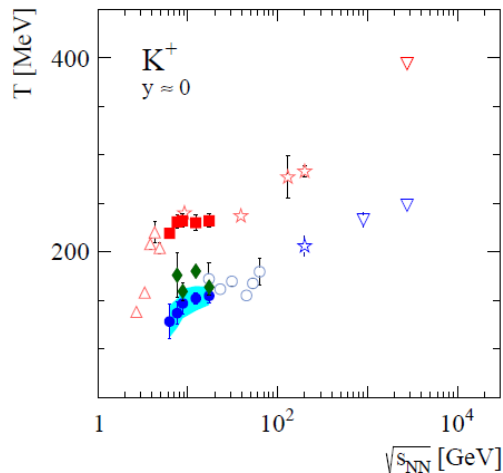


K^\pm spectra in p_T are fitted with exponential function

$$\frac{d^2n}{dp_T dy} = \frac{S}{T^2 + T} \frac{p_T}{m_K} \exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$

Onset of deconfinement: step

Plateau – **STEP** – in the inverse slope parameter of m_T spectra in Pb+Pb collisions observed. It is expected for the onset of deconfinement due to mixed phase of HRG and QGP (SMES).



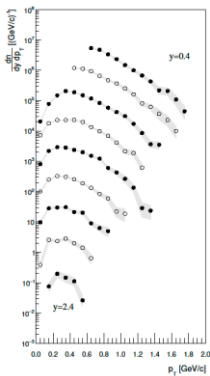
- p+p NA61 (prelim.)
- ◆ Be+Be NA61 (prelim.)
- ☆ p+p RHIC
- ▽ p+p LHC
- p+p world (4π)
- △ Au+Au AGS
- ☆ Au+Au RHIC
- Pb+Pb SPS
- ▽ Pb+Pb LHC

Qualitatively similar structure is visible in p+p and it seems to emerge in Be+Be

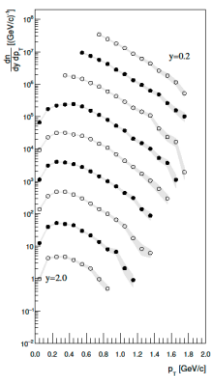
Be+Be slightly above p+p

K⁺ and K⁻ from Ar+Sc

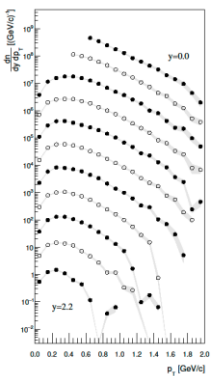
Ar+Sc → K⁺+X at 30A GeV/c



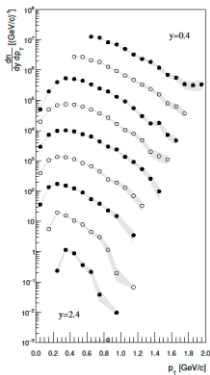
Ar+Sc → K⁺+X at 40A GeV/c



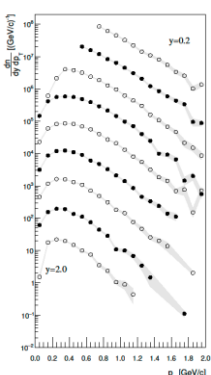
Ar+Sc → K⁺+X at 75A GeV/c



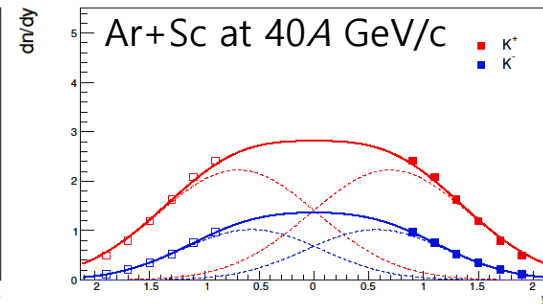
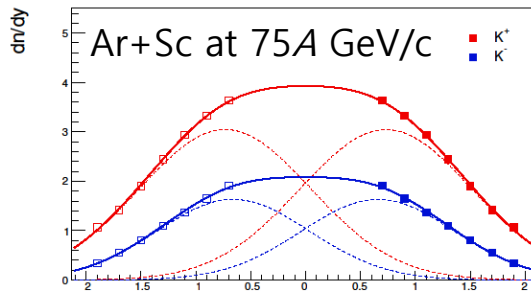
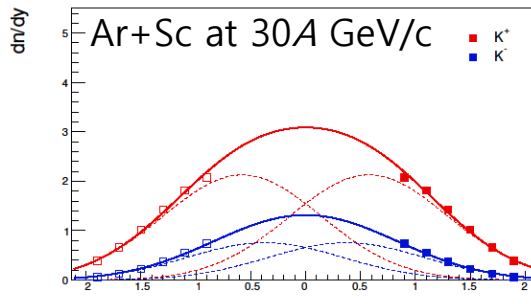
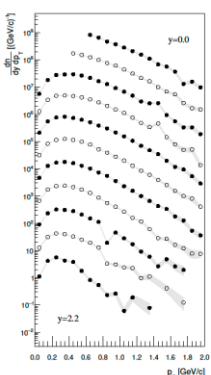
Ar+Sc → K⁺+X at 30A GeV/c



Ar+Sc → K⁺+X at 40A GeV/c



Ar+Sc → K⁺+X at 75A GeV/c

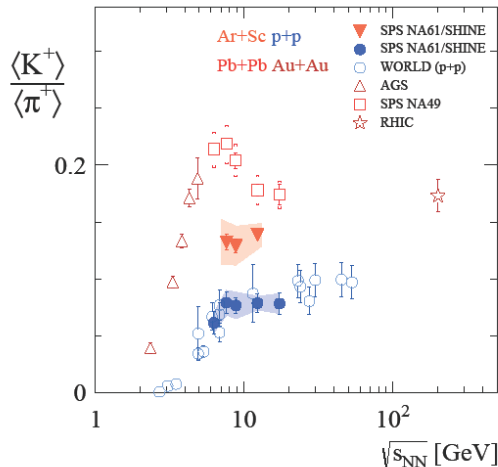
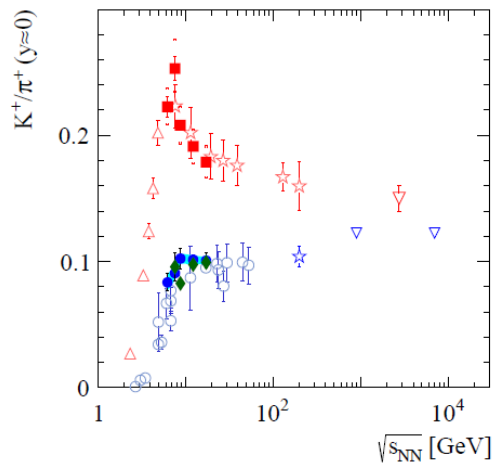


Results fitted by double gaussian with Pb+Pb parameters

$$\frac{dn}{dy} = \frac{\langle \pi^- \rangle (y_0, \sigma_0)}{2\sigma_0 \sqrt{2\pi}} \cdot \left[\exp\left(-\frac{(y-y_0)^2}{2\sigma_0^2}\right) + \exp\left(-\frac{(y+y_0)^2}{2\sigma_0^2}\right) \right]$$

Onset of deconfinement: horn

Rapid changes in K^+/π^+ – **HORN** – were observed in Pb+Pb collisions. It was predicted (SMES) as a signature of onset of deconfinement.



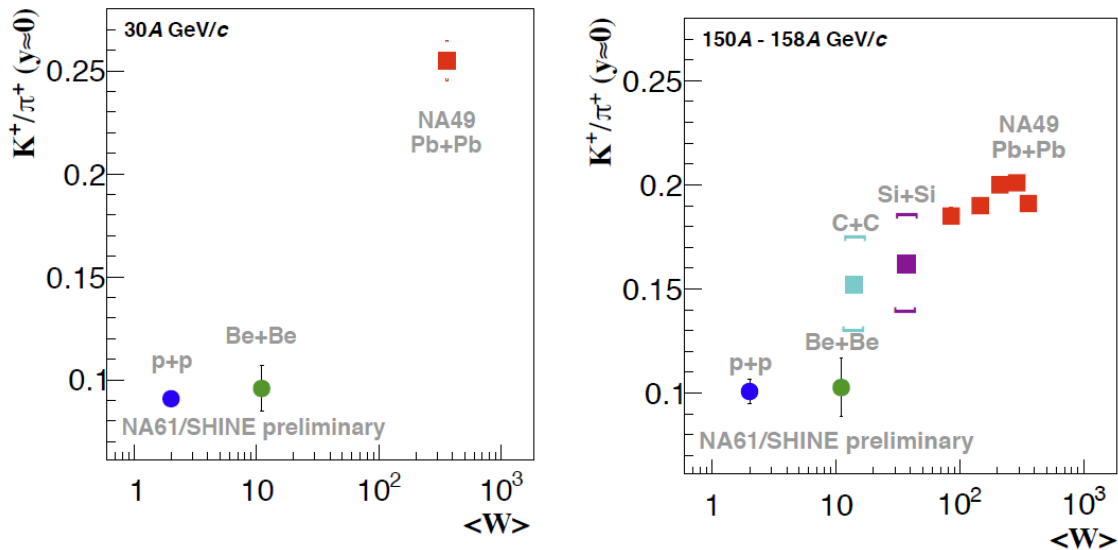
Plateau like structure visible in p+p

Be+Be close to p+p

$\langle K^+ \rangle / \langle \pi^+ \rangle$ in Ar+Sc show collision energy dependence similar to p+p

p+p NA61 (prelim.)
Be+Be NA61 (prelim.)
p+p RHIC
p+p LHC
p+p world (4 π)
Au+Au AGS
Au+Au RHIC
Pb+Pb SPS
Pb+Pb LHC

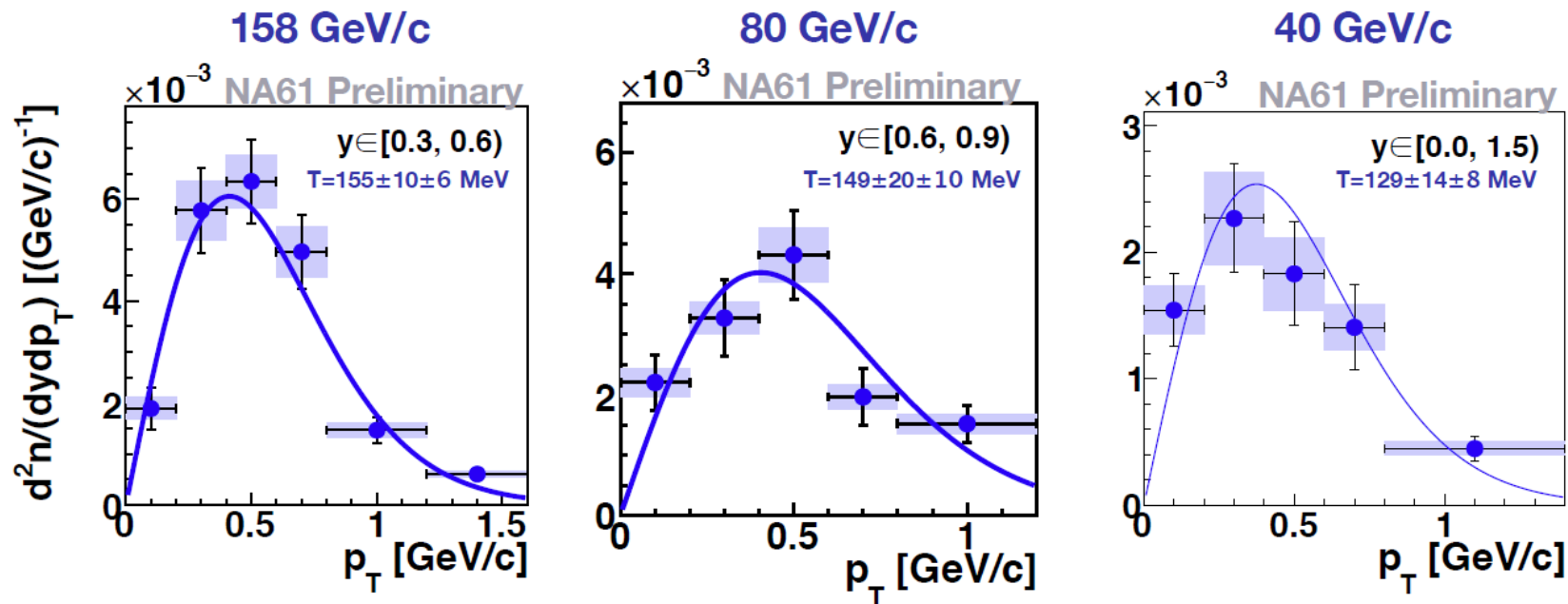
System size dependence of K^+/π^+



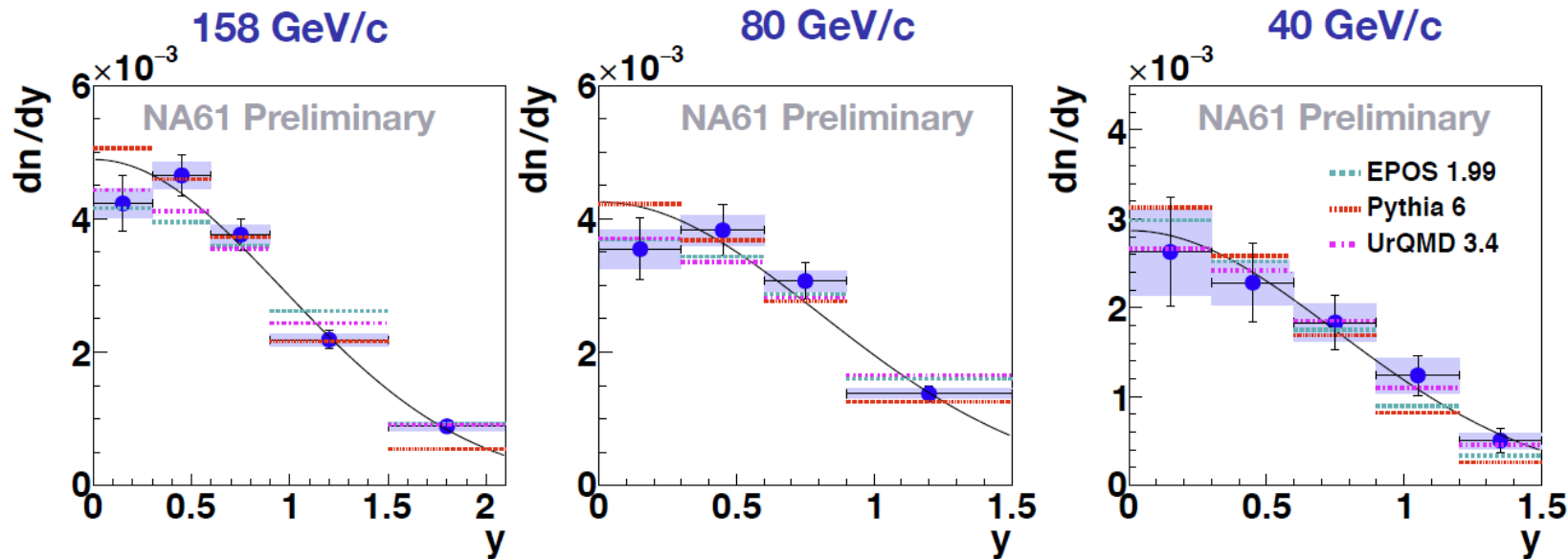
Surprisingly $Be+Be$ results are very close to $p+p$ independent of collision energy

$\Phi(1020)$ in p+p

First measurement of Φ production in p+p interactions at 40 and 80 GeV/c, more detailed and precise measurement at 158 GeV/c



$\Phi(1020)$ in p+p: rapidity spectra



Large coverage in rapidity, shape approximately described by Gaussian (black curve). Models approximately describe spectra shape (models normalised to the integral of data)

Summary



NA61/SHINE performs the unique system size vs energy scan for **systematic study of the phase diagram of strongly interacting matter**

- p+p, Be+Be, Ar+Sc and Xe+La data collected and being analysed
- Recent results of NA61/SHINE and LHC show some similarities between p+p and Pb+Pb hadron production
- Unexpected system size dependence of K^+/π^+ ratio observed in p+p and Be+Be