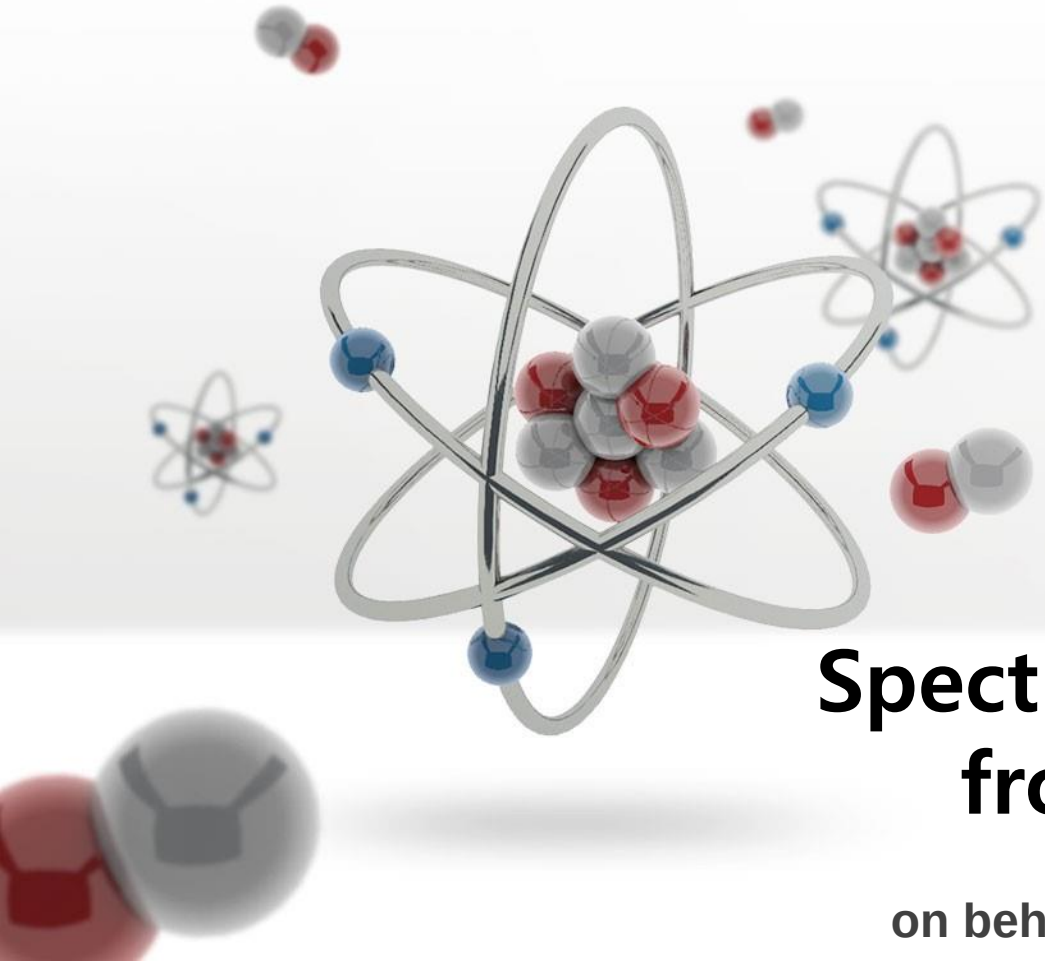


Spectra and multiplicities from NA61/SHINE

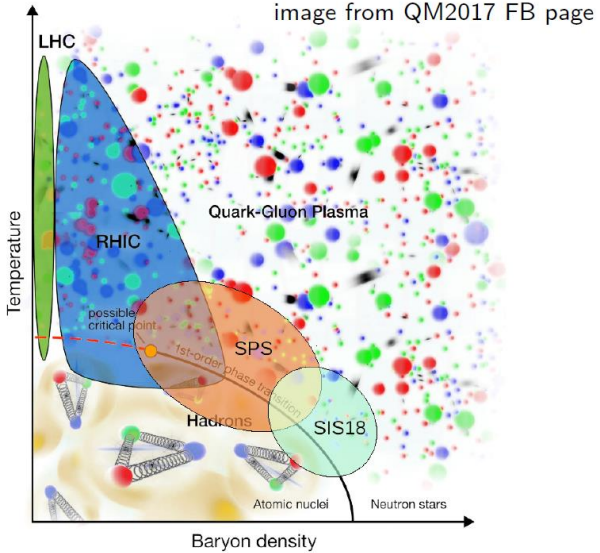
Szymon Pulawski
on behalf of NA61/SHINE collaboration

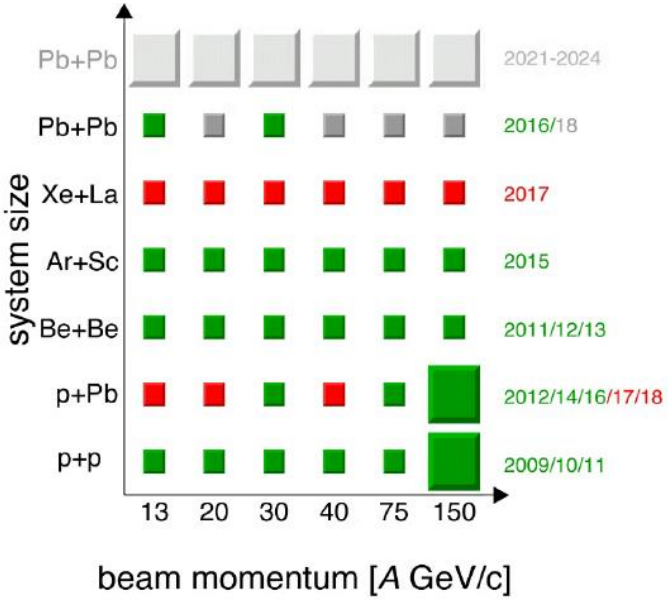
NA61/SHINE on CPOD 2017

- Monday 16:00 **Identified hadron production in Ar+Sc collisions at SPS energies** – Lewicki
- Tuesday 17:00 **Multiplicity, transverse momentum and forward energy fluctuations from the NA61/SHINE experiment CERN** – Seryakov
- Wednesday 15:00 **Two-particle correlations in azimuthal angle and pseudorapidity in Be+Be collisions at SPS energies** - Maksiak
- Thursday 10:00 **Fluctuations and correlation from NA61/SHINE** – Gazdzicki
- Thursday 16:00 **Search for the critical point of strongly interacting matter through power-law fluctuations of the proton density in NA61/SHINE** - Davis
- Thursday 17:00 **Mean pion multiplicities in Ar+Sc collisions** - Naskręt

NA61/SHINE 2-dimensional scan

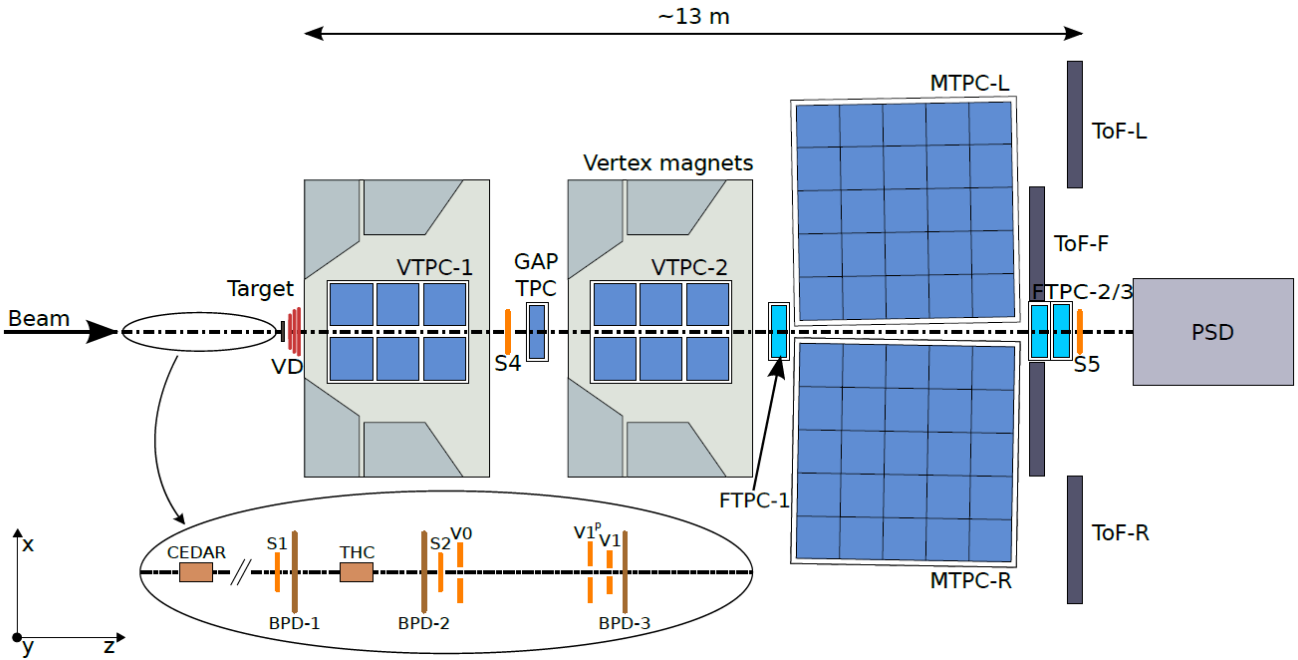
NA61/SHINE experiment performs 2D scan in **collision energy and system size** to study the phase diagram of strongly interacting matter in **baryon density and temperature**





NA61/SHINE spectrometer

Fixed target experiment located at the SPS accelerator



Beams:

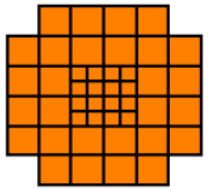
- ions (Be, Ar, Xe, Pb)
  p_{beam}=13A–150A GeV/c
- hadrons (π, K, p)
  p_{beam}=13–400 GeV/c
- $\sqrt{s_{NN}}$= 5.1–16.8 (27.4) GeV

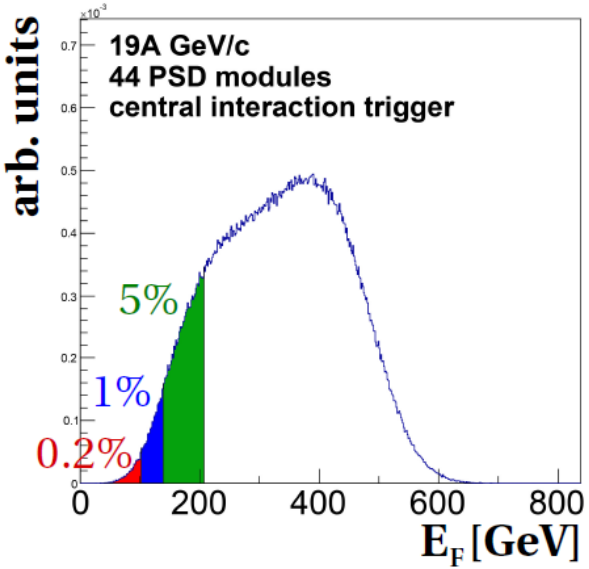
Large acceptance hadron spectrometer – coverage of the full forward hemisphere, down to p_T = 0

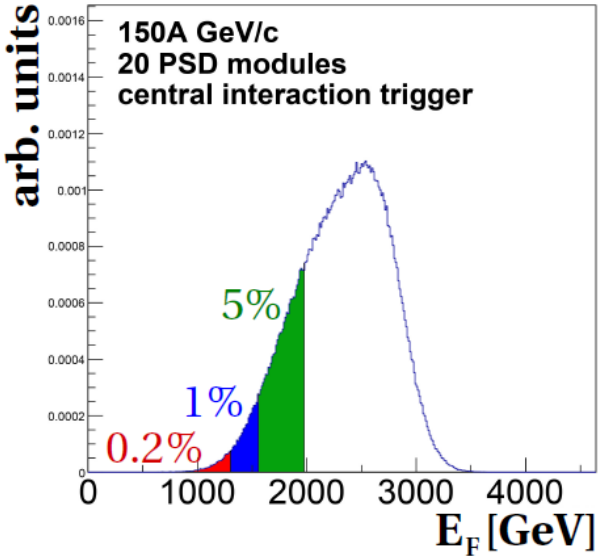
Event selection based on forward energy measurements

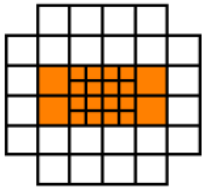
Event (violence) selection is done using **the forward energy** (E_F) dominated by energy of projectile spectators

Ar+Sc example



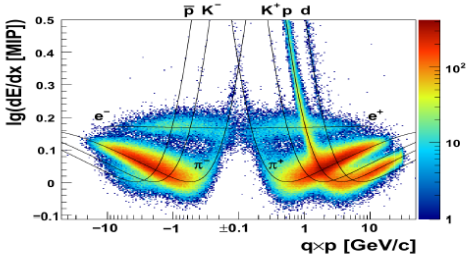


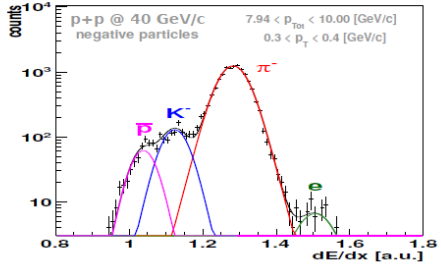


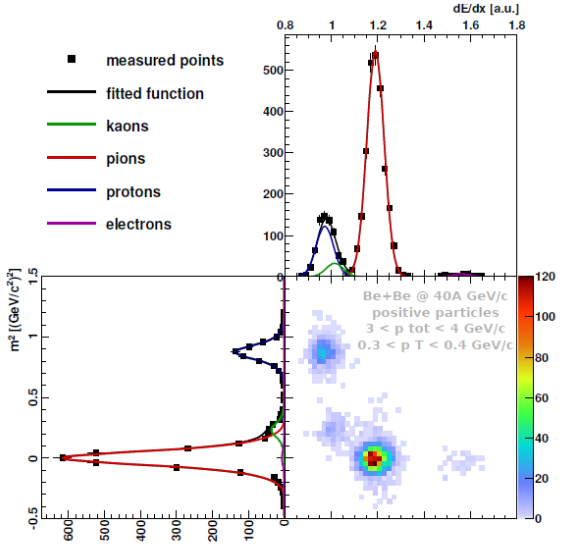


Charged particle identification

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.





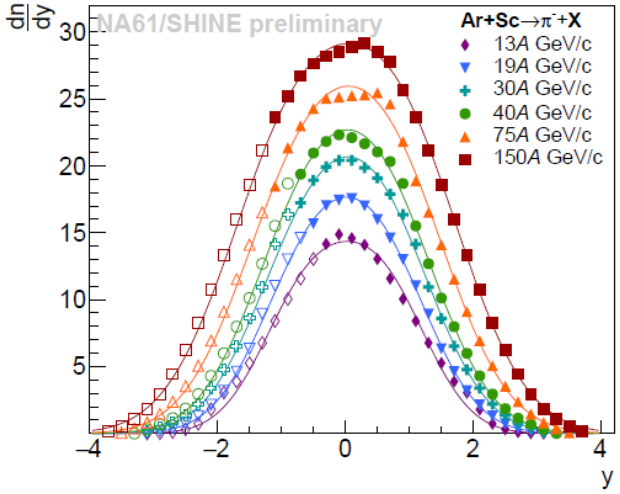


- **h⁻ analysis** based on the fact that the majority of negatively charged particles are π^- mesons. Contribution of the other particles is subtracted using EPOS Monte-Carlo
- **dE/dx** analysis uses TPC energy loss information to identify particles
- **tof-dE/dx** method estimates number of π, K, p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

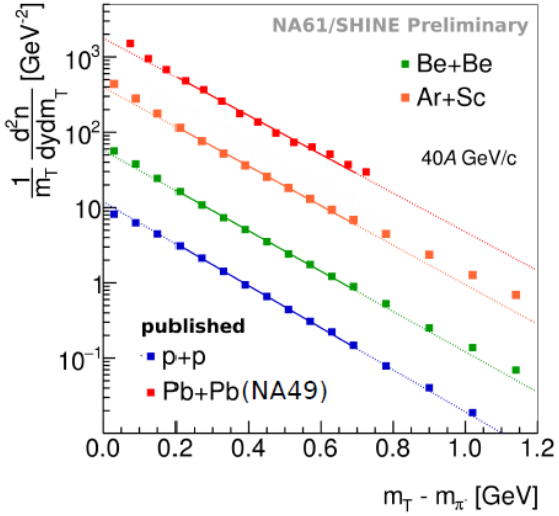
π^- spectra from 2D-scan

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

Collision energy dependence



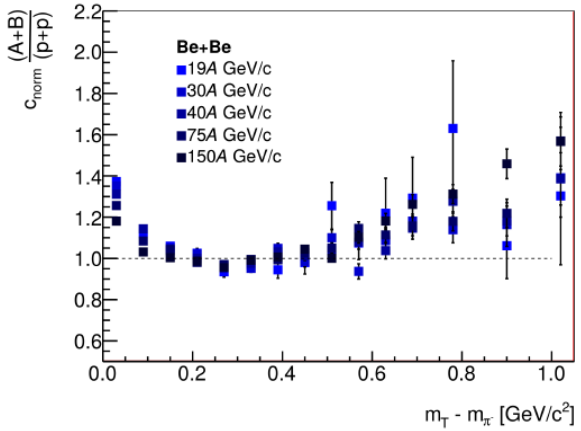
System size dependence

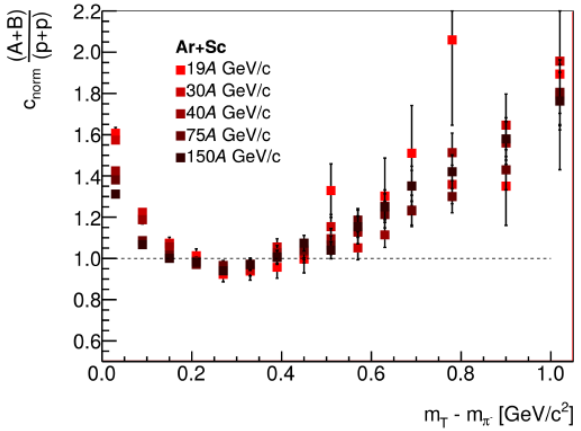


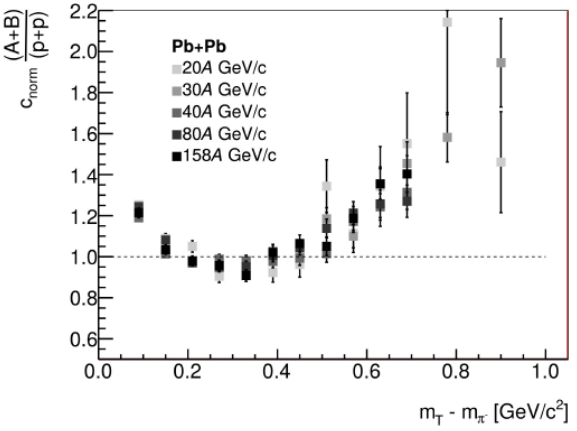
- Rapidity spectra ≈ gaussian, independently of collision energy and system size
- Large acceptance allows to obtain 4π multiplicity (sum of data and extrapolation, for details see arXiv:1612.01334)
- m_T spectra in p+p are exponential, in larger systems (central collisions) deviate from the exponential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

π^- spectra: m_T

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

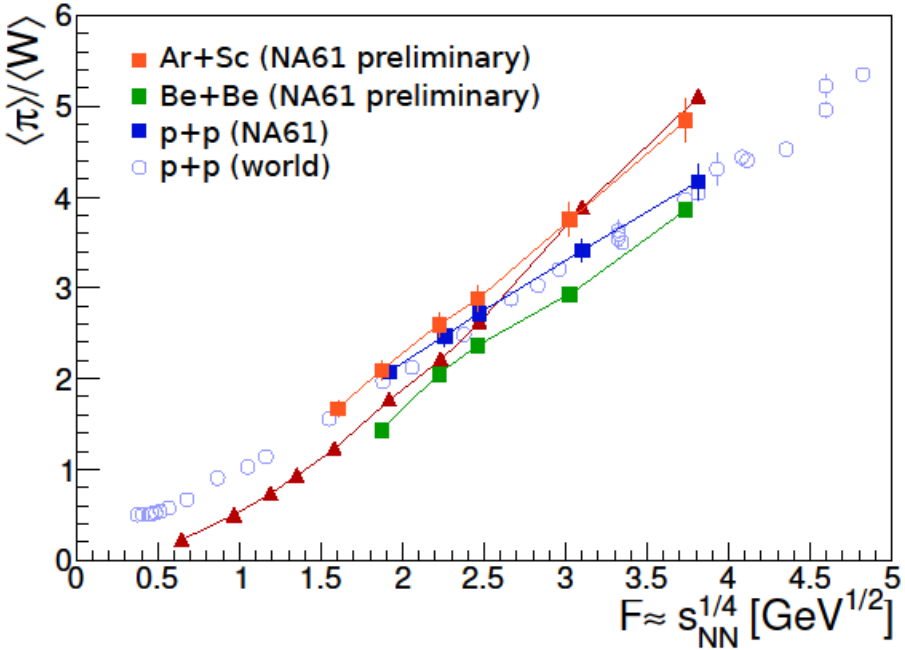






- clear system size dependence
- small energy dependence
- the effect possibly associated to transverse collective flow

Onset of deconfinement: kink

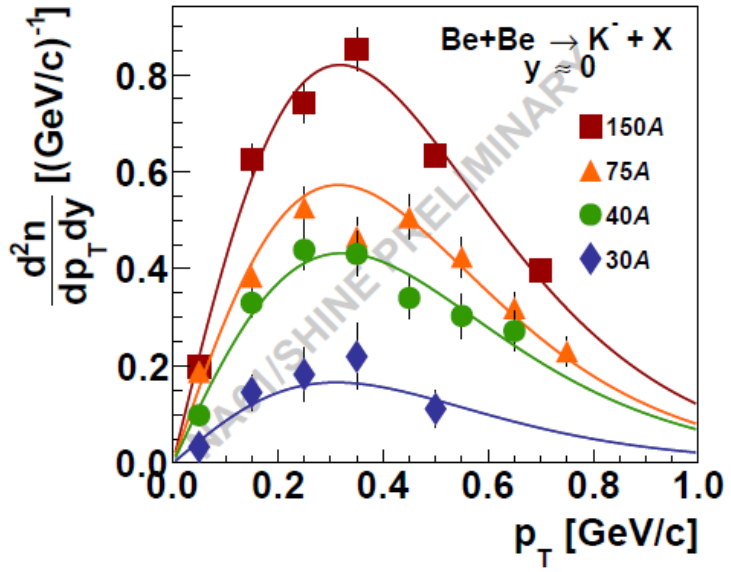


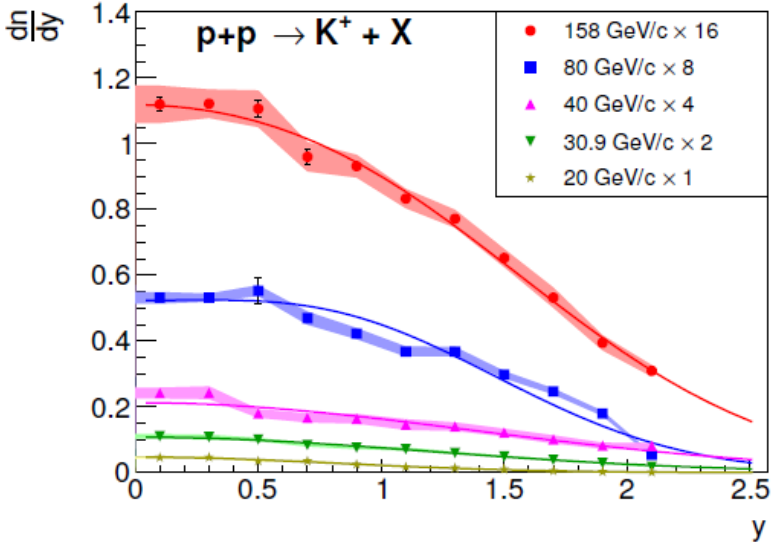
The slope of energy dependence for heavier systems is larger than for lighter systems at high SPS energies.

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

<π> – mean multiplicity in full acceptance
<W> – mean number of wounded nucleons (details Thursday 17:00 Naskręt)

Onset of deconfinement: step and horn



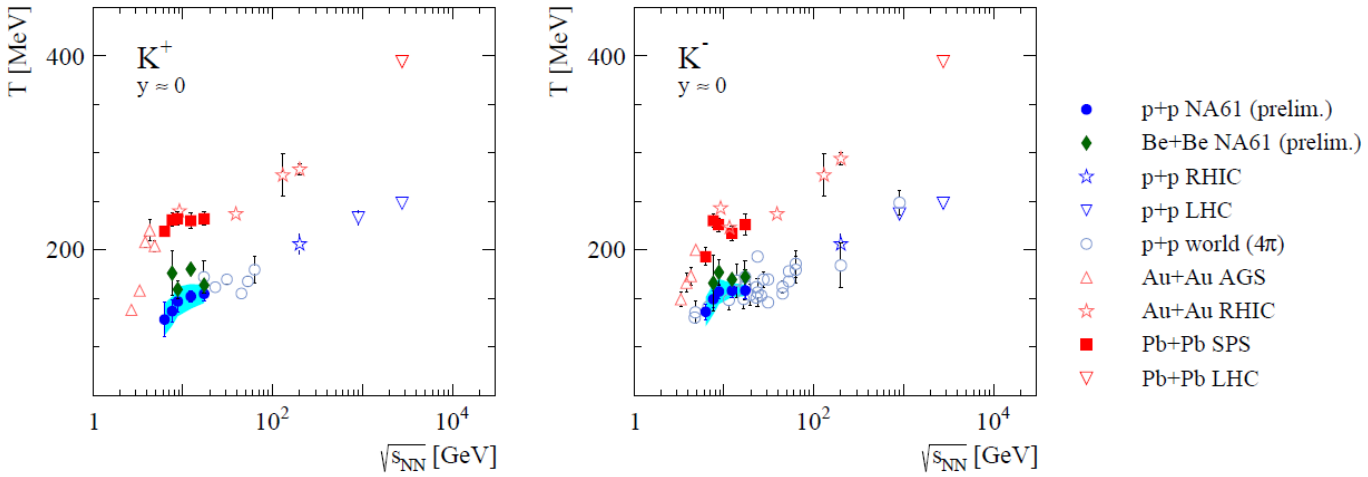


K± spectra in p_T are fitted with exponential function

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

Onset of deconfinement: step

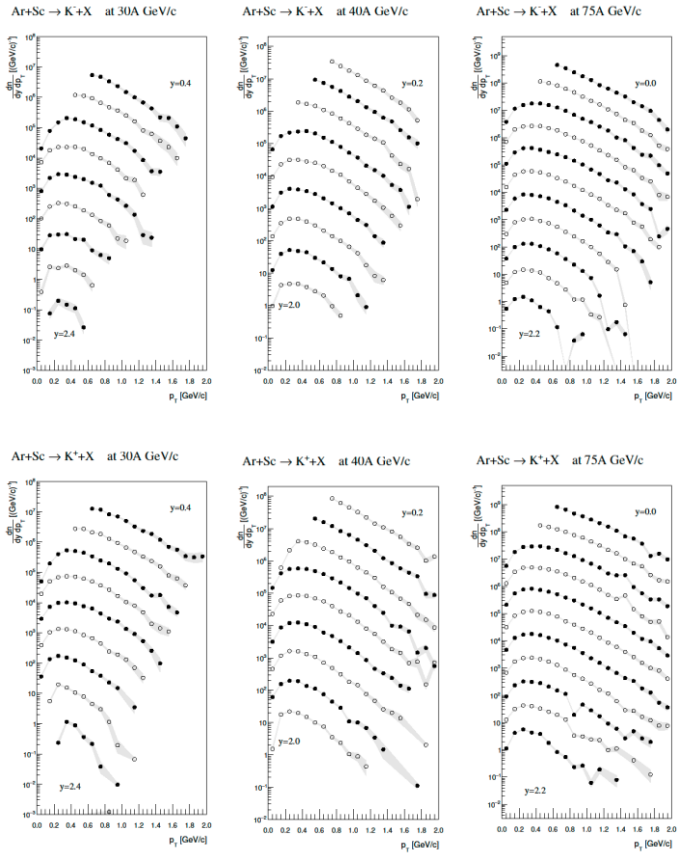
Plateau – **STEP** – in the inverse slope parameter of m_T spectra in Pb+Pb collisions observed. It is expected for the onset of deconfinement due to mixed phase of HRG and QGP (SMES).

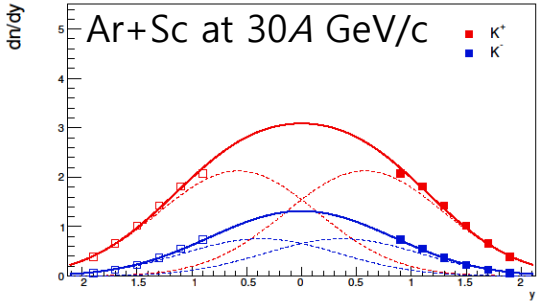


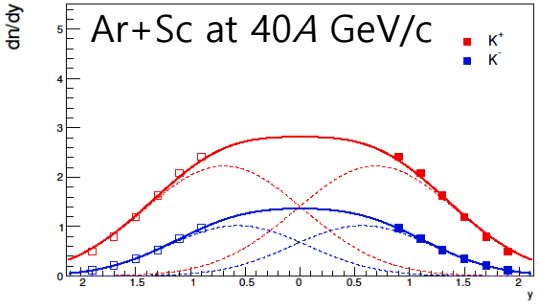
Qualitatively similar structure is visible in p+p and it seems to emerge in Be+Be

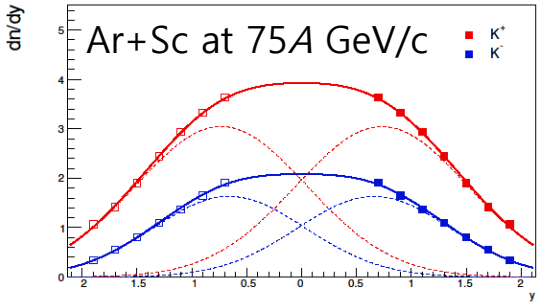
Be+Be slightly above p+p

K^+ and K^- from Ar+Sc









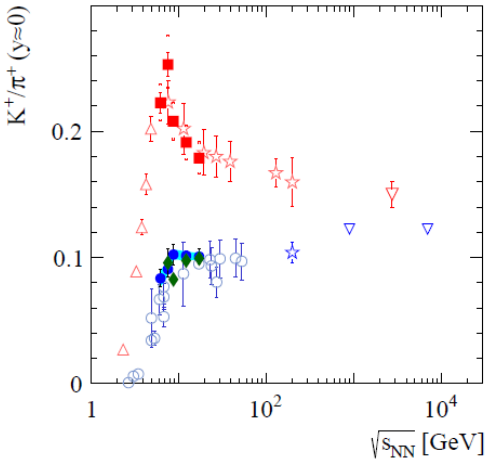
Results fitted by double gaussian with Pb+Pb parameters

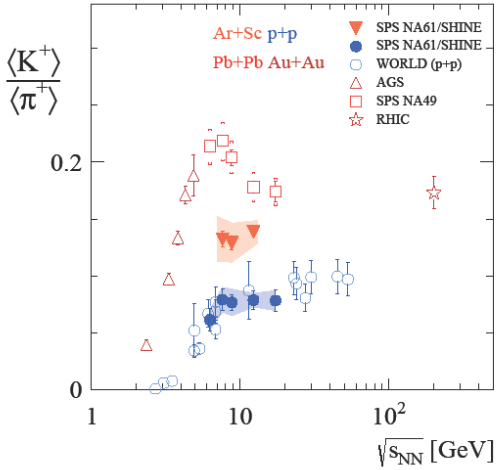
$$\frac{dn}{dy} = \frac{\langle \pi^- \rangle (y_0, \sigma_0)}{2\sigma_0\sqrt{2\pi}} \cdot \left[\exp\left(-\frac{(y-y_0)^2}{2\sigma_0^2} \right) + \exp\left(-\frac{(y+y_0)^2}{2\sigma_0^2} \right) \right]$$

Lewicki – Today 16:00

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.





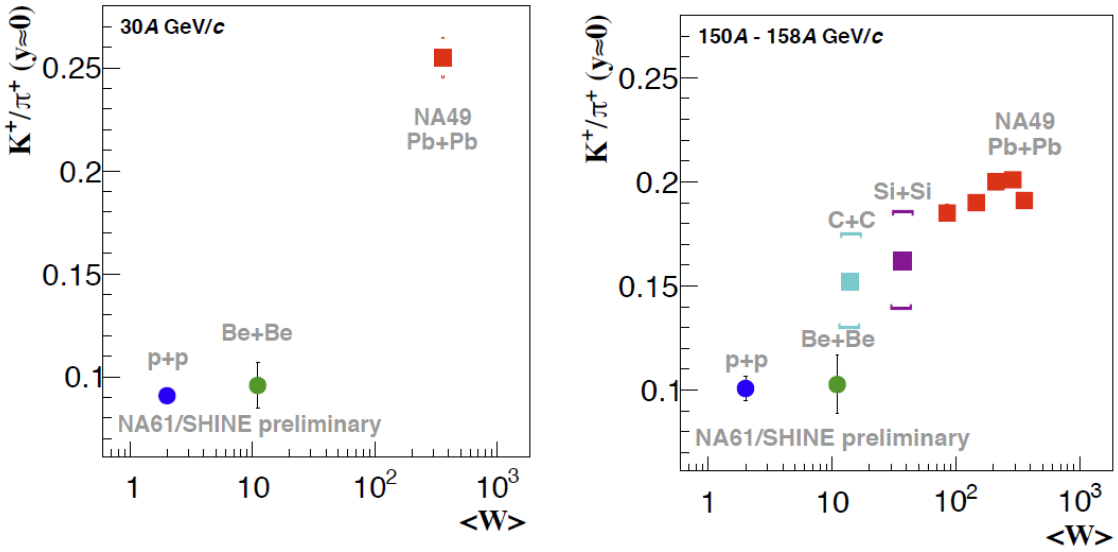
p+p NA61 (prelim.)
Be+Be NA61 (prelim.)
p+p RHIC
p+p LHC
p+p world (4π)
Au+Au AGS
Au+Au RHIC
Pb+Pb SPS
Pb+Pb LHC

Plateau like structure visible in p+p

Be+Be close to p+p

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

System size dependence of K^+/π^+

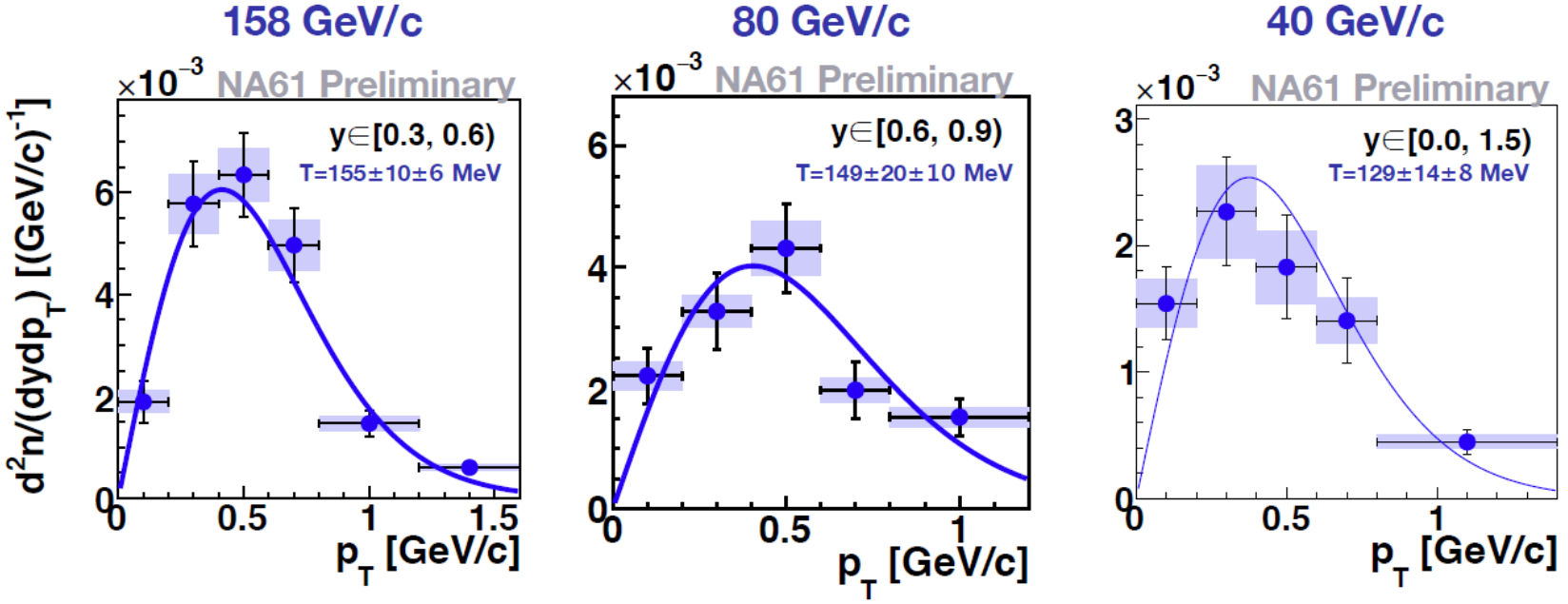


Surprisingly Be+Be results are very close to p+p independent of collision energy

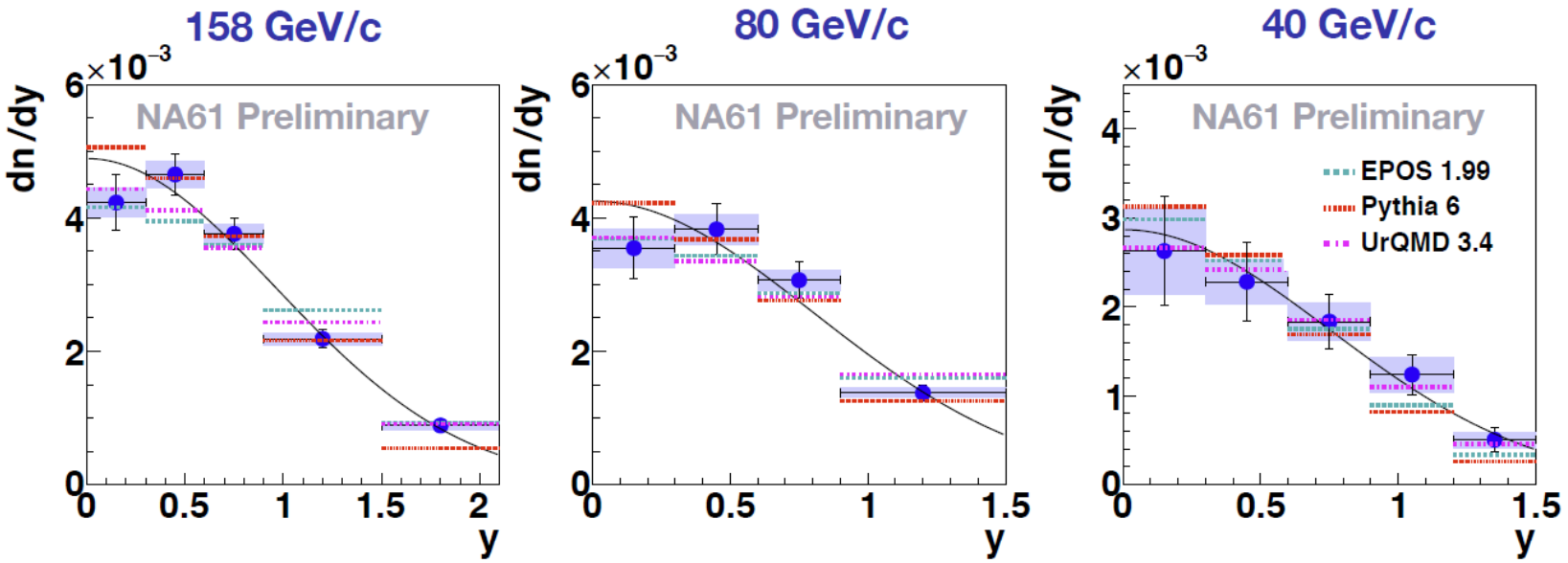
As in the case of multiplicity fluctuations data suggest a jump between light and heavy systems (see M. Gazdzicki on Thursday 10:00)

Φ(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



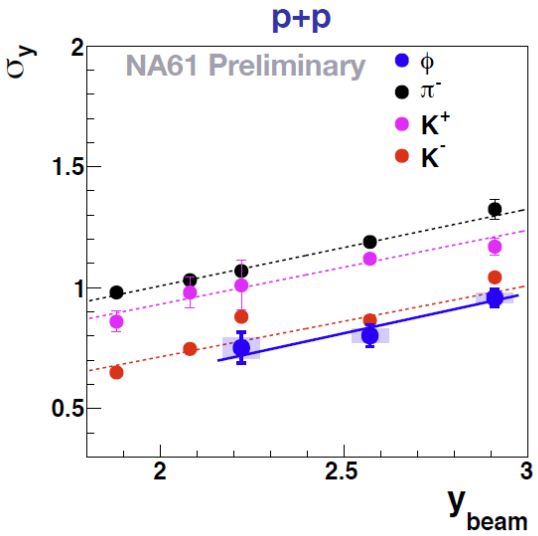
Φ(1020) in p+p: rapidity spectra

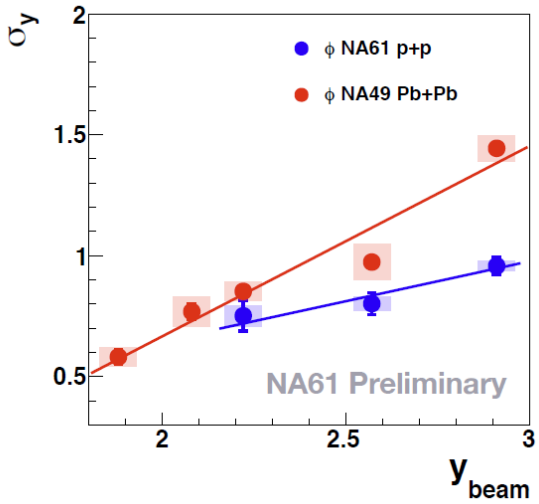


Large coverage in rapidity, shape approximately described by Gaussian (black curve).

Models approximately describe spectra shape (models normalised to the integral of data)

Φ(1020) in p+p: width of rapidity



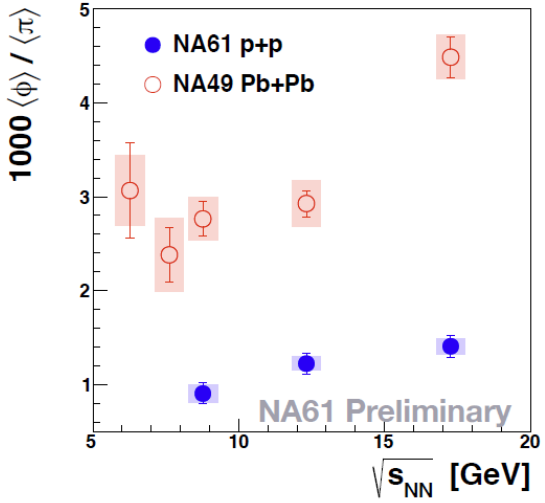


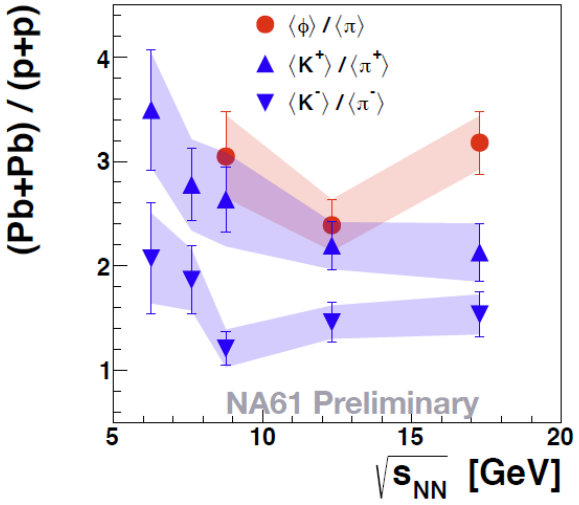
$$\frac{dn}{dy} = \frac{\langle \pi^- \rangle (y_0, \sigma_0)}{2\sigma_0\sqrt{2\pi}} \cdot \left[\exp\left(-\frac{(y-y_0)^2}{2\sigma_0^2} \right) + \exp\left(-\frac{(y+y_0)^2}{2\sigma_0^2} \right) \right]$$

σ_y in p+p follows the trend of other hadrons.

σ_y in p+p and Pb+Pb exhibit different y_{beam} dependence.

Φ(1020) in p+p: $\sqrt{s_{NN}}$ dependence



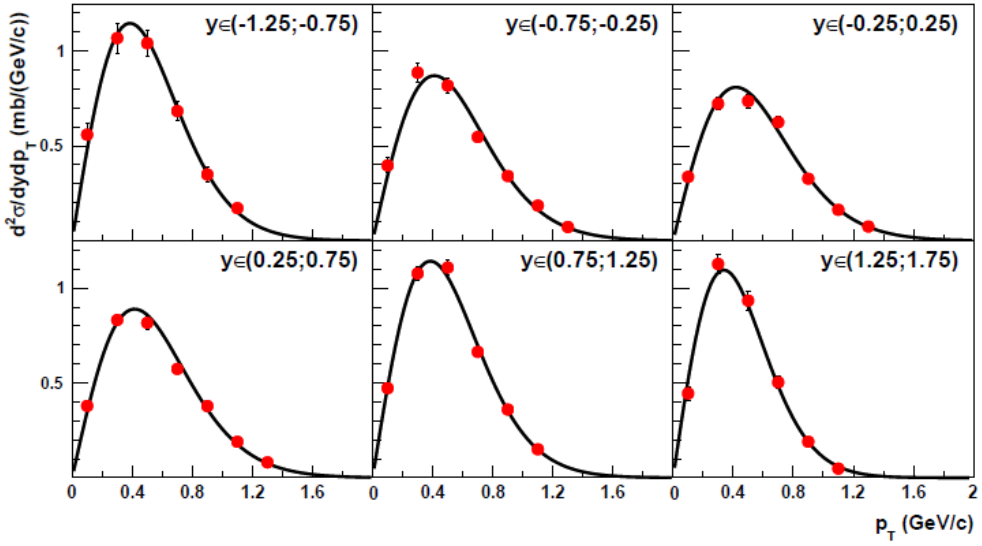


<Φ>/<π> in p+p increases with $\sqrt{s_{NN}}$

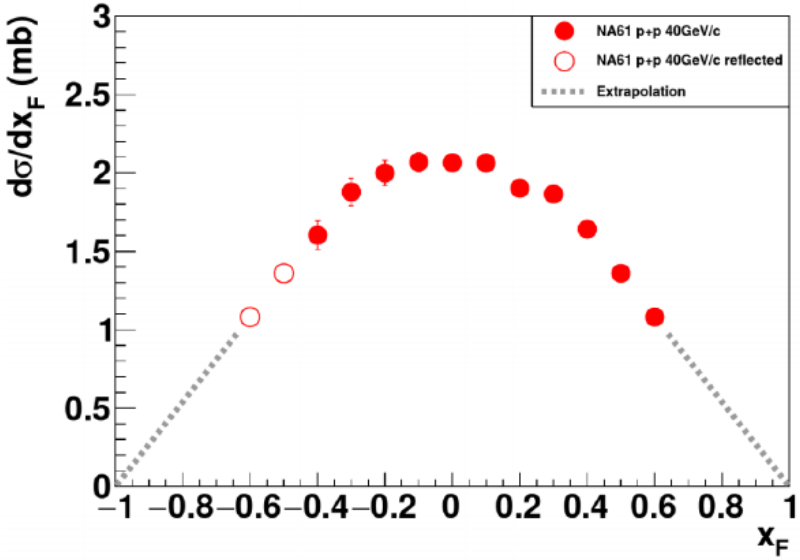
<Φ>/<π> ratio about 3x larger in Pb+Pb collisions independently of interaction energy

Enhancement of <Φ>/<π> ratio is close to $\langle K^+\rangle/\langle \pi^+\rangle$, larger than for $\langle K^-\rangle/\langle \pi^-\rangle$

Λ in p+p at 40 GeV/c

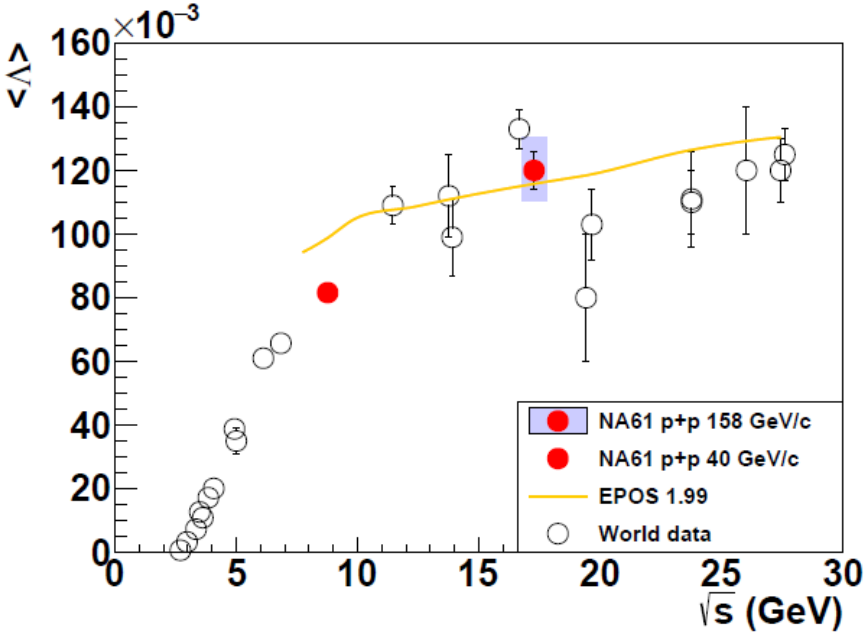


Solid lines: exponential fit.



Dotted lines: used to extrapolate to 4π

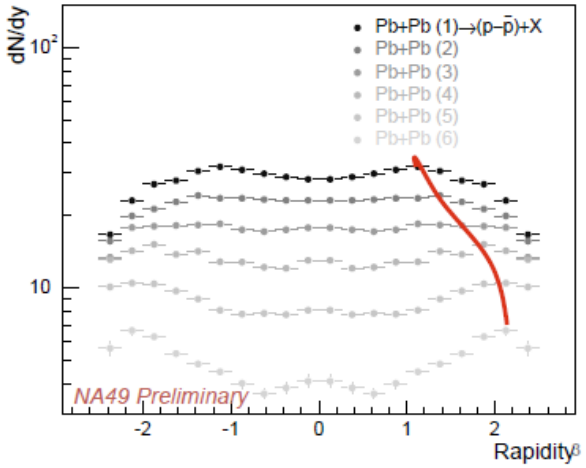
Λ in p+p: < Λ>

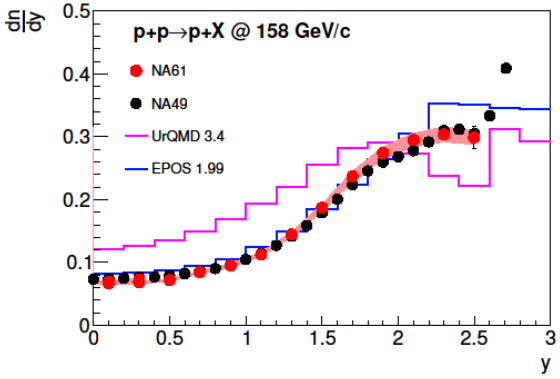


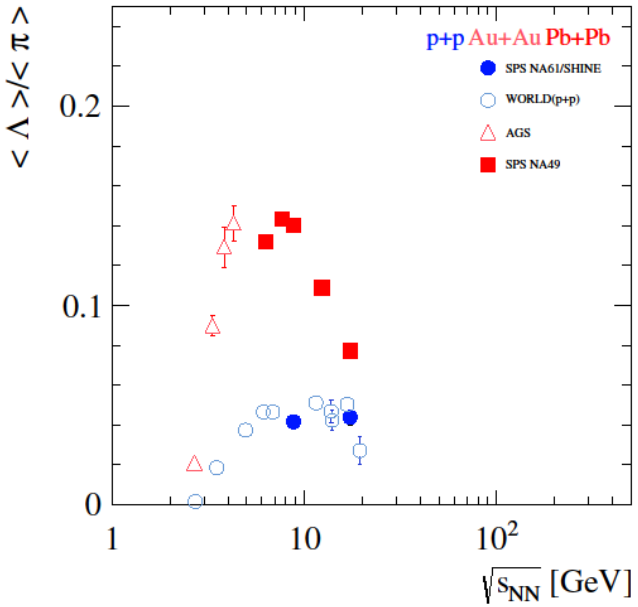
The NA61 data follow the trend set by the world data, at the same time reducing the uncertainty significantly.

EPOS overestimates <Λ> at 40 GeV/c.

<Λ> / <π>







The presented NA61/SHINE results agree with the world data.

Measurements in A+A collisions at the AGS and by NA49 show a different behaviour than that observed in p+p reactions due to baryon density.

NA61/SHINE plans

- Measurements of Xe+La collisions at 20*A* – 150*A* GeV/c in 2017
- Measurement of Pb+Pb collisions at 150*A* GeV/c in 2018
    - New Vertex detector ⟶ pilot open charm measurements and precise measurement of fluctuations and collective effects in Pb+Pb collisions

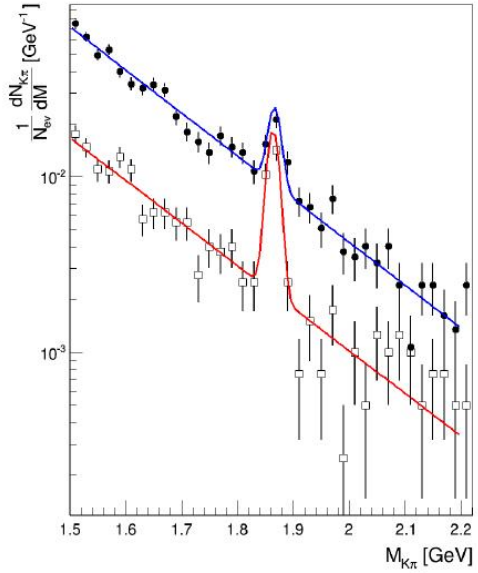
- Detector upgrade foreseen during long shutdown (2019-2020)

- NA61/SHINE in 2021-2024: High statistics beam momentum scan with Pb+Pb collisions for the precise measurements of open charm and multi-strange hyperon production

- NA61/SHINE performs precise particle production for **neutrino physics programs** which is planned to be continued after 2020

NA61/SHINE Vertex Detector

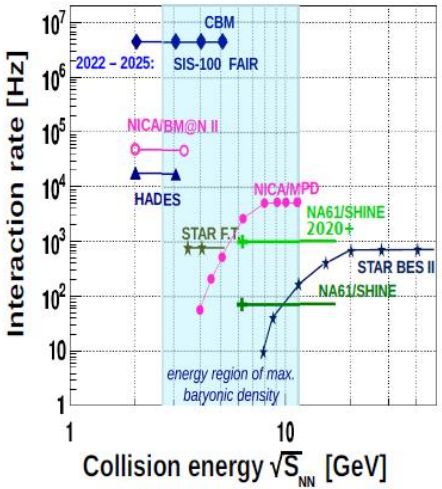
Small Acceptance **Vertex Detector** was commissioned in 2015. Pilot data was recorded in 2016. Vertex fit resolution on the level of 50 μm.



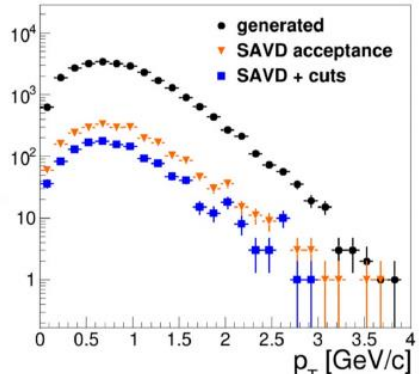
Invariant mass of pion-kaon pair candidates for D^0 signal. The results for realistic PID (open) and without PID (solid).

NA61/SHINE in 2021–2024

Detector upgrades during Long Shutdown in 2019–2020: **1 kHz readout by upgrading TPCs readout electronics**, **Large Acceptance Vertex Detector**, increase and improve beam intensity and quality, ToF, PSD

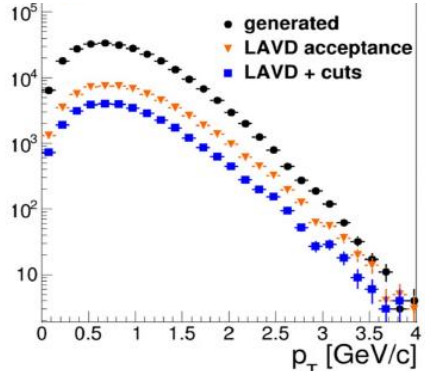


10 days in 2018



≈ 3000 D^0 in 4 M events

10 days in 2021
(1000Hz + LAVD)



≈ 40000 D^0 in 40 M events

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 and Ar+Sc 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
- Plans to extend NA61/SHINE program with measurements of open charm and multi-strange hyperon production in 2021-2024