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

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on behalf of NA61/SHINE collaboration
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)
  \( \rho_{\text{beam}} = 13A-150A \text{ GeV/c} \)
- hadrons (n, K, p)
  \( \rho_{\text{beam}} = 13-400 \text{ GeV/c} \)
- \( \sqrt{s_{NN}} = 5.1-16.8 \ (27.4) \text{ GeV} \)

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 $\pi^-$ 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 $\pi$, $K$, $p$ using an energy loss and a particle time of flight measurements
$\pi^{-}$ spectra from 2D-scan

$\pi^{-}$ spectra measured in large acceptance: $p_T$ down to 0, in full forward hemisphere

- Rapidity spectra $\approx$ gaussian, independently of collision energy and system size
- Large acceptance allows to obtain $4\pi$ 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
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:

$$\frac{d^2n}{dp_T dy} = S \frac{p_T}{T^2 + T \cdot m_K} \exp\left(-\frac{\sqrt{p_T^2 + m_K^2} - m_K}{T}\right)$$
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 slightly above p+p.
K$^+$ and K$^-$ from Ar+Sc

Results fitted by double gaussian with Pb+Pb parameters

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

Rapid changes in $K^+ / \pi^+$ – **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

$<K^+>/<\pi^+>$ in Ar+Sc show collision energy dependence similar to p+p
Surprisingly Be+Be results are very close to p+p independent of collision energy
First measurement of $\Phi$ production in p+p interactions at 40 and 80 GeV/c, more detailed and precise measurement at 158 GeV/c
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 $K^+ / \pi^+$ ratio observed in $p+p$ and Be+Be