Energy dependence of negatively charged pion production in proton-proton interactions at the CERN SPS

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NA61/SHINE programme

SHINE ≡ **S**PS **H**eavy **I**on and **N**eutrino **E**xperiment

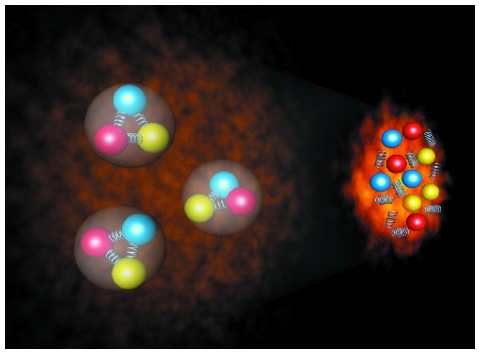
Physics of strongly interacting matter

Discovery potential:

- Search for the critical point of strongly interacting matter

Precision measurements:

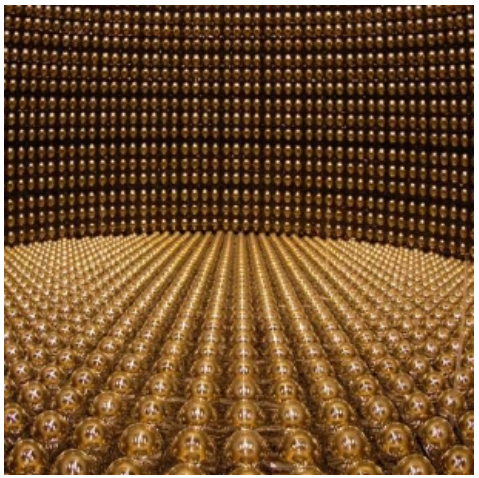
- Study the properties of the **onset of deconfinement** in nucleus-nucleus collisions
- Measure hadron production at high transverse momenta in p+p and p+Pb collisions as reference for Pb+Pb results



Data for neutrino and cosmic ray experiments

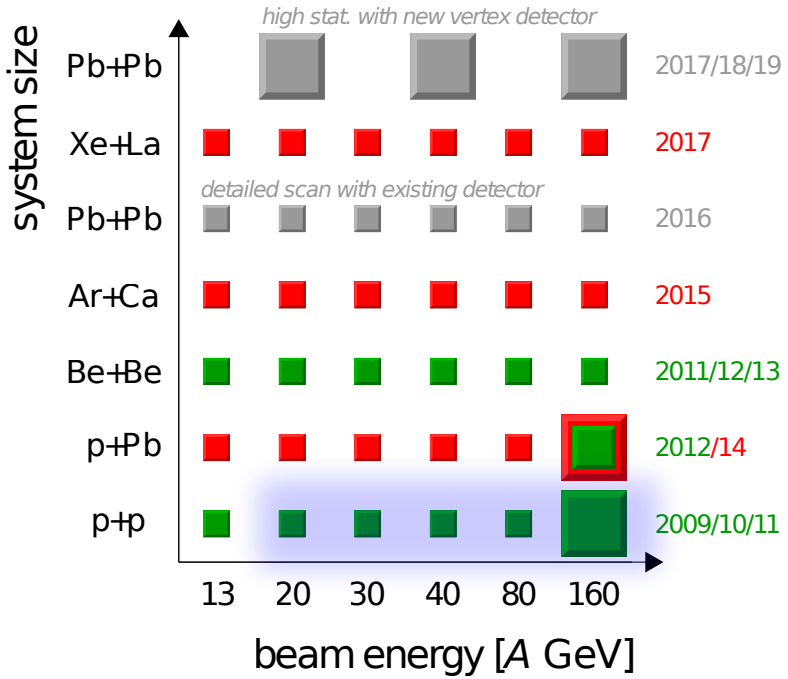
Precision measurements:

- Measure hadron production in the T2K target needed for the neutrino physics
- Measure hadron production in p+C and π+C interactions needed for T2K and cosmic-ray (Pierre Auger Observatory) experiments

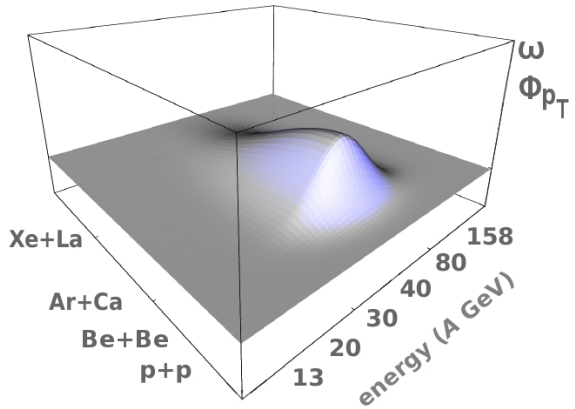


NA61/SHINE ion programme

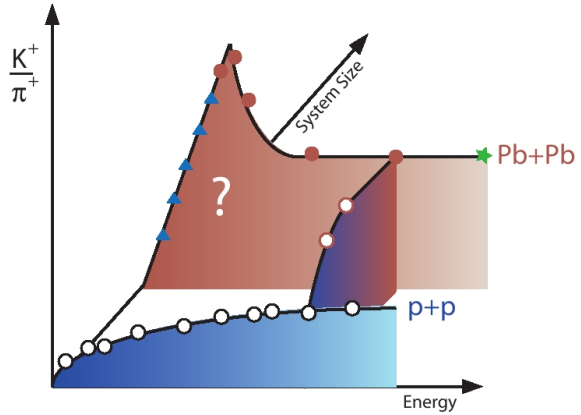
Two-dimensional scan in collision energy and the system size:



Search for the critical point of strongly interacting matter by analysis of fluctuations:

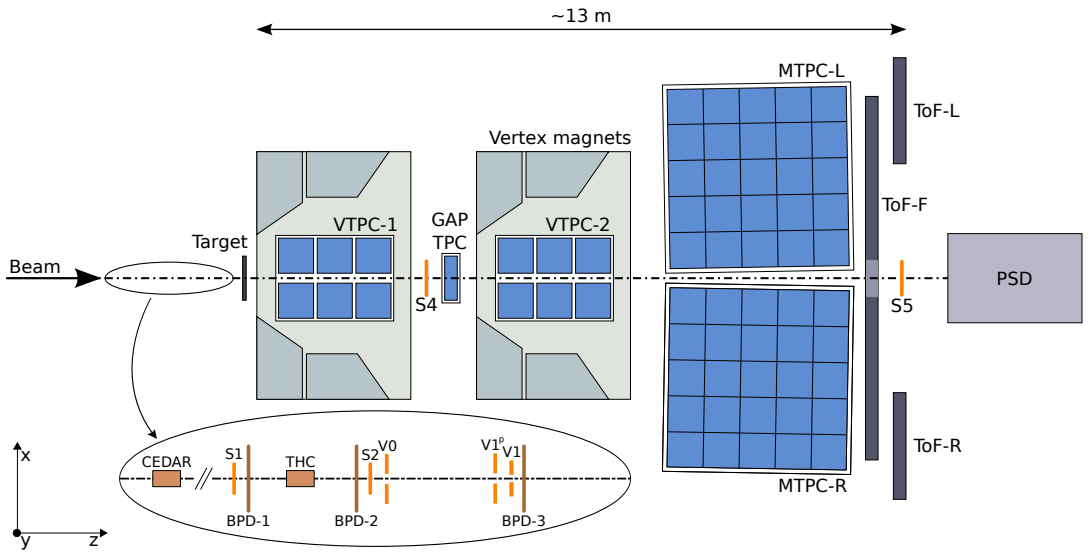


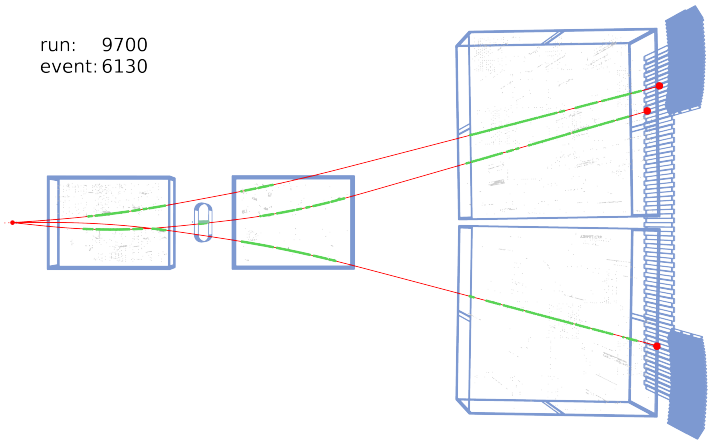
Study of the **onset of deconfinement** by measurement of the hadron spectra



- This presentation: π^- spectra at $p_{\mathrm{lab}} = 20, 31, 40, 80$ and 158 GeV/c

NA61/SHINE detector





(p+p interaction at 40 GeV/c measured in the NA61/SHINE detector)

- A large acceptance hadron spectrometer
- Beam particles measured in set of counters and detectors
- Charged tracks measured in set of 5 **TPC**s $\rightarrow$ measurement of $\boldsymbol{q}$, $\boldsymbol{p}$ and identification via $\mathrm{d}E/\mathrm{d}x$
- 3 ToF walls: identification via time of flight measurement
- Projectile spectator detector counts the non-interacting nucleons of the beam particle

Analysis strategy

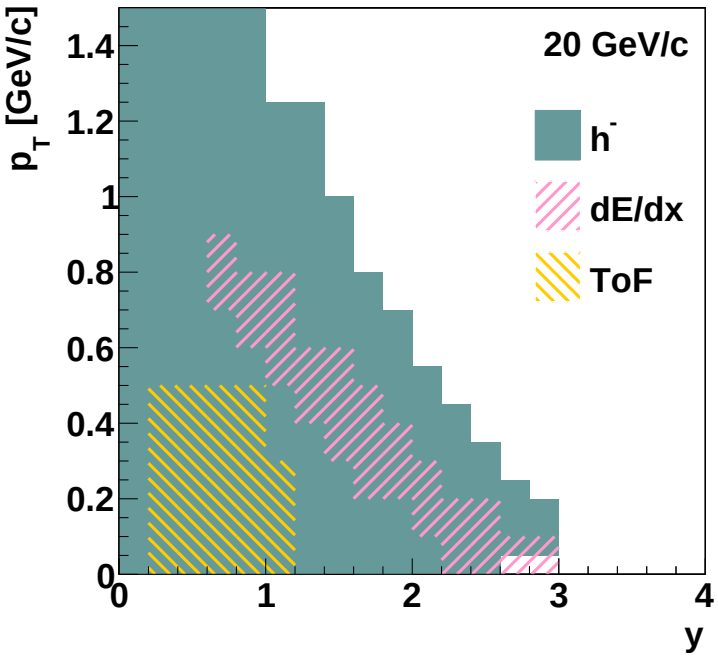
Presented analysis aims to derive spectra of the π^- mesons produced in strong and electromagnetic processes in the p+p interactions.
The data is corrected for the following effects:

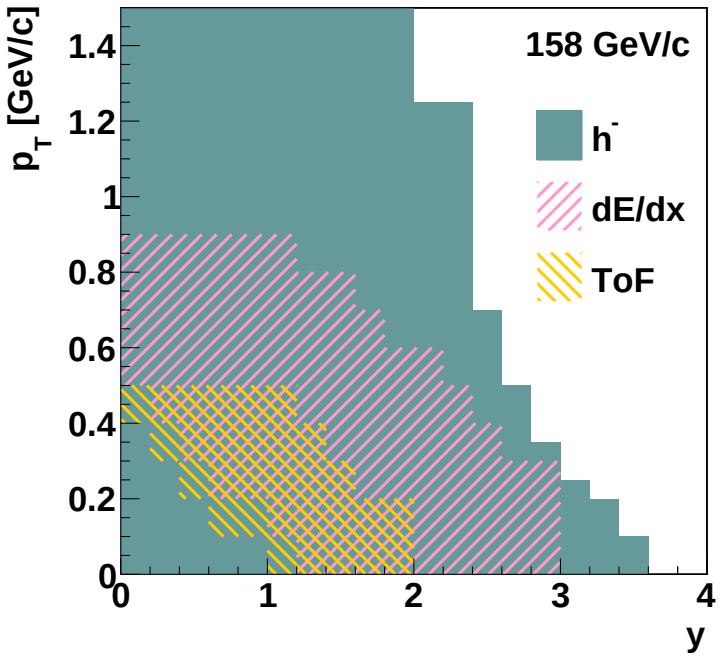
- The effect of the beam divergence is corrected using measurements from the Beam Position Detectors
- The off-target interactions are subtracted using data taken with target removed
- Electron contribution (2–5%) is removed from the analysis using the $\mathrm{d}E/\mathrm{d}x$ measurement
- Contribution of the non-primary-pions is removed with the h^- method
- Monte Carlo simulation is used to correct for effects related to the detection, analysis and reconstruction:
  - Geometrical acceptance
  - Migration of tracks between the (y, p_T) bins due to the limited reconstruction resolution
  - Reconstruction efficiency
  - Correction for event losses due to the on-line and off-line event selection

The result are π^- spectra derived in (y, p_T) and (y, m_T) bins, and parameters characterising the spectra.

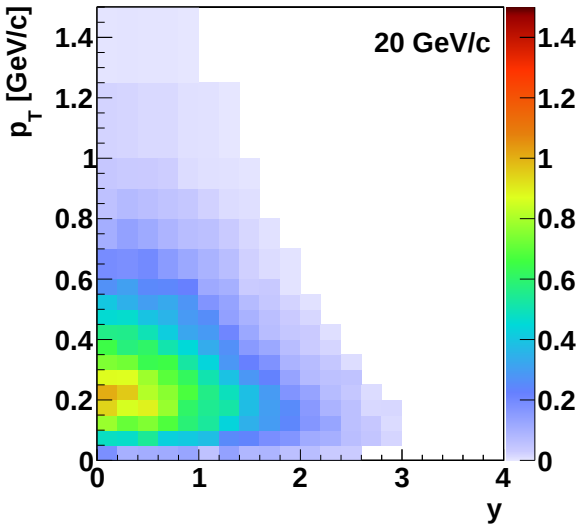
h^- analysis method

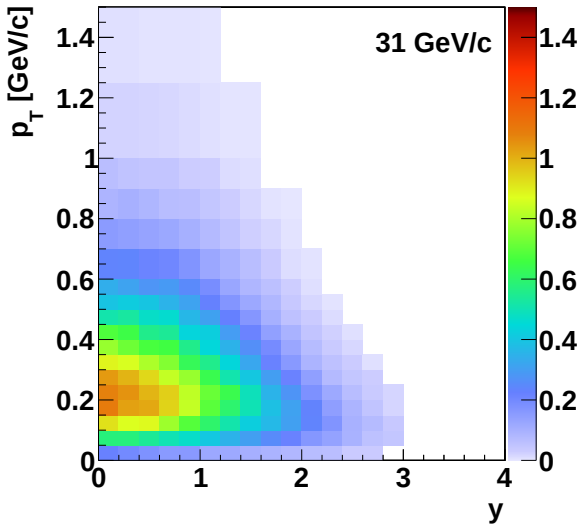
- >90% of the negatively charged hadrons produced in p+p interactions are π^-
- In the so-called h^- method small contribution of other particles (K^-, $\bar{p}$, and decays from Λ and K^0_S) is subtracted basing on the EPOS model predictions
- In comparison to the current results of the dE/dx and ToF identification methods, the h^- method covers much broader region of the phase-space

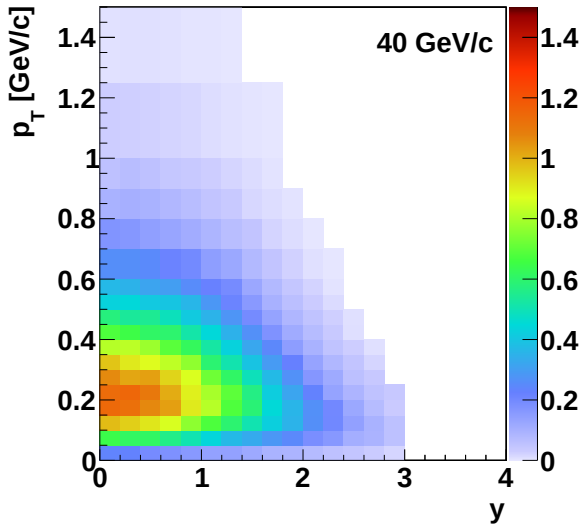


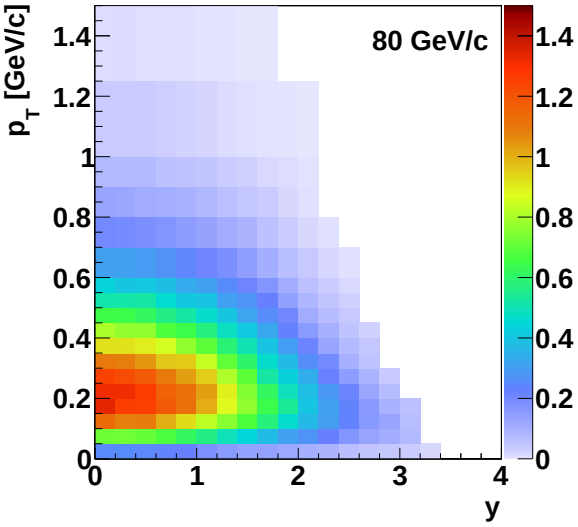


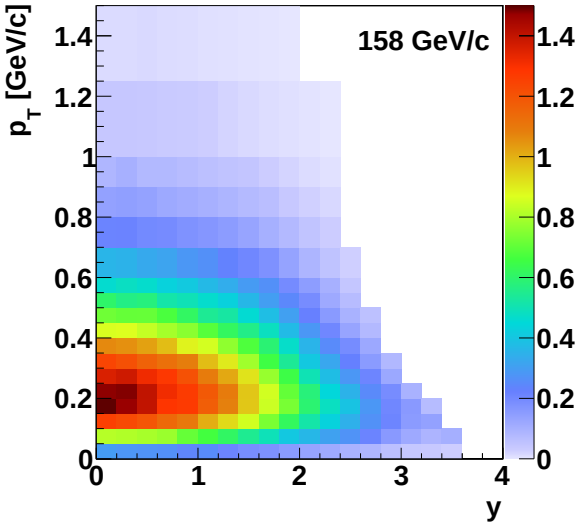
Double differential π^- spectra in p+p inelastic interactions at NA61/SHINE



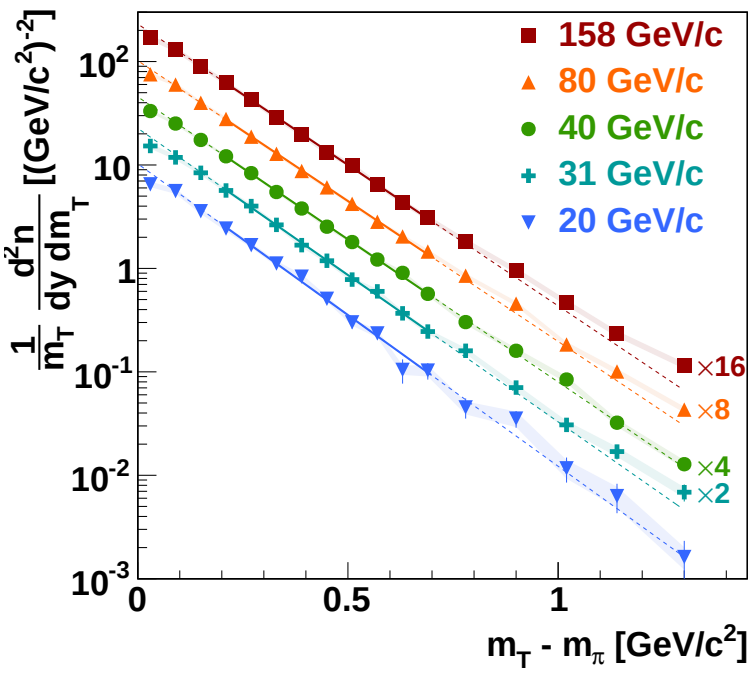


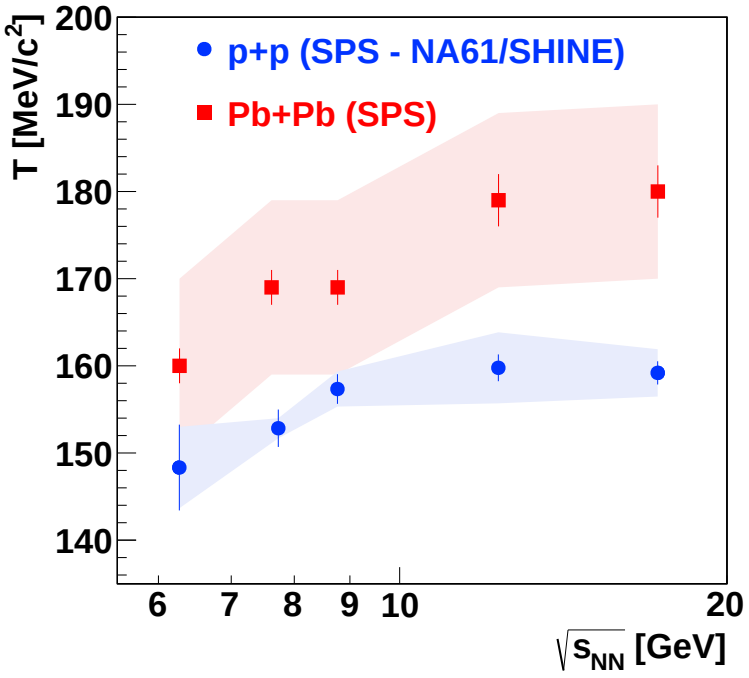






Transverse mass spectra





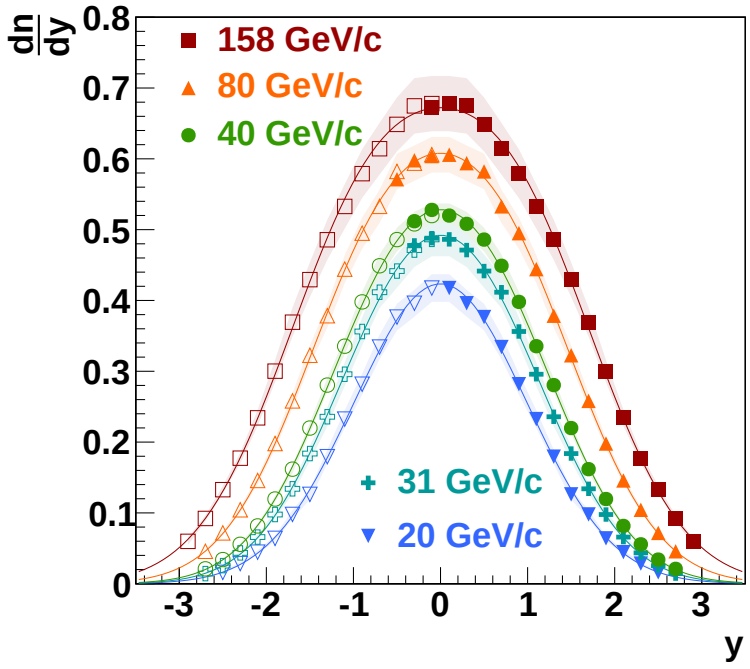
- Transverse mass ($m_T = \sqrt{p_T^2 + m^2}$) spectra at mid-rapidity ($0 < y < 0.2$) are fitted with an exponential function

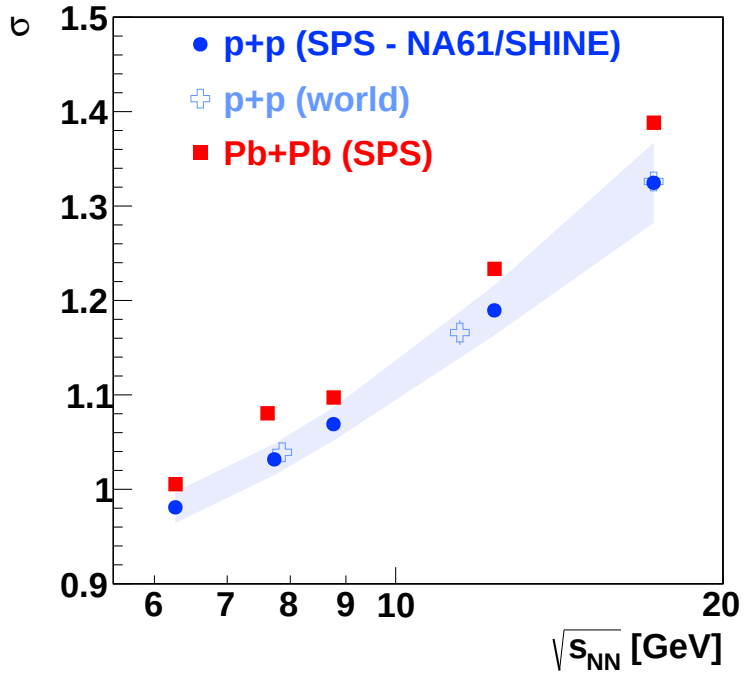
$$\frac{dn}{dm_T} = A \cdot m_T \cdot \exp\left(-\frac{m_T}{T}\right) \tag{1}$$

in range $0.2 < m_T - m < 0.7$ GeV/c^2

- The inverse slope parameter T increases slowly with the collision energy. It is smaller by about 10% than in the Pb+Pb collisions

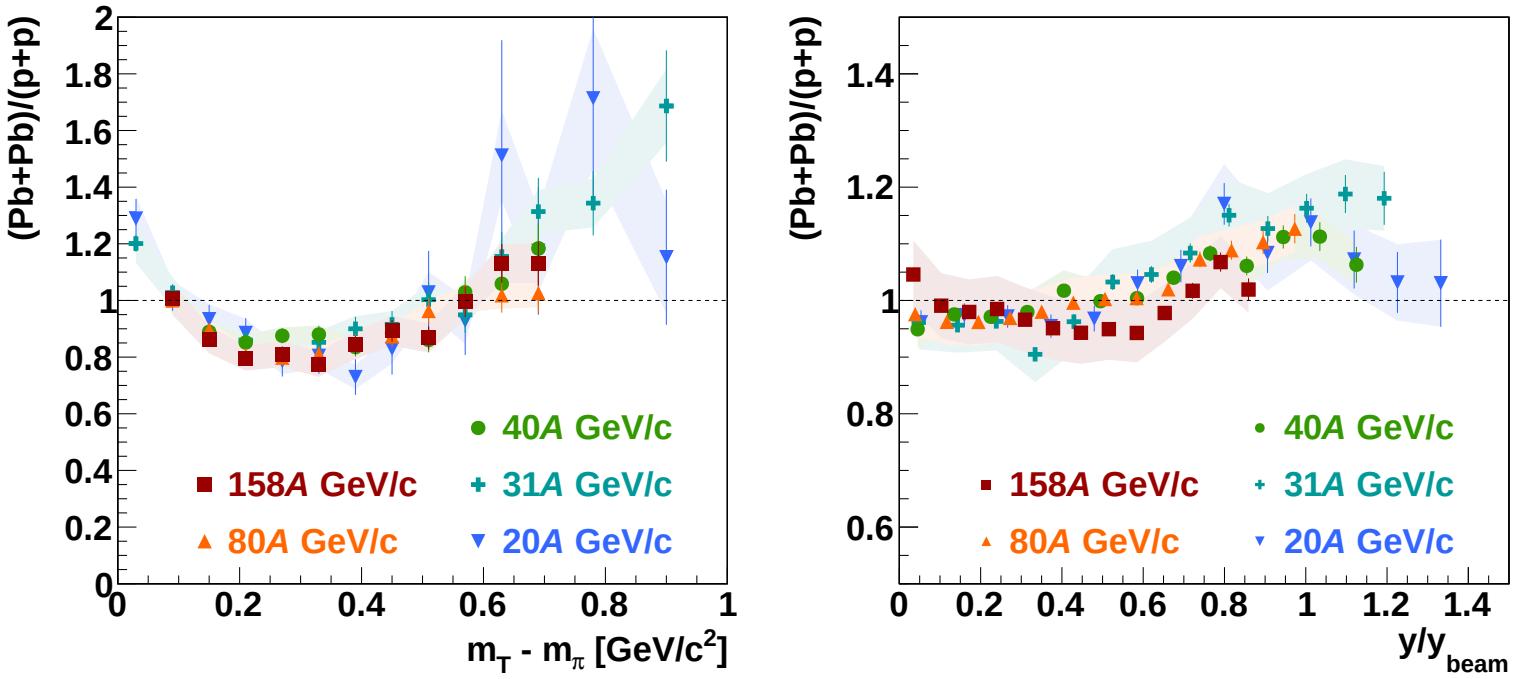
Integrated rapidity spectra





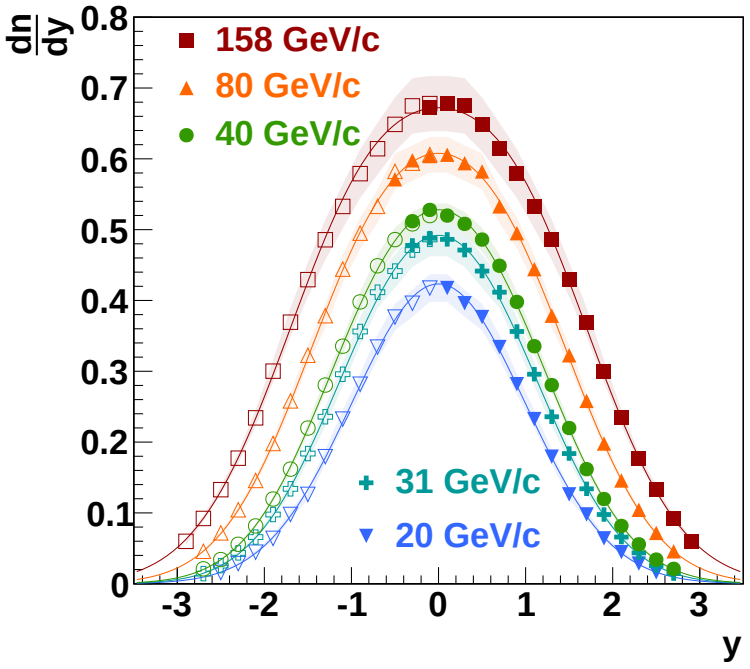
- π^- rapidity spectrum integrated in the full measured m_T range, extrapolated using exponential function
- The distribution is approximately Gaussian, best fit obtained by sum of two symmetrically displaced Gaussians
- Width of the rapidity distribution is smaller by 2.5–4.5% than in the Pb+Pb collisions

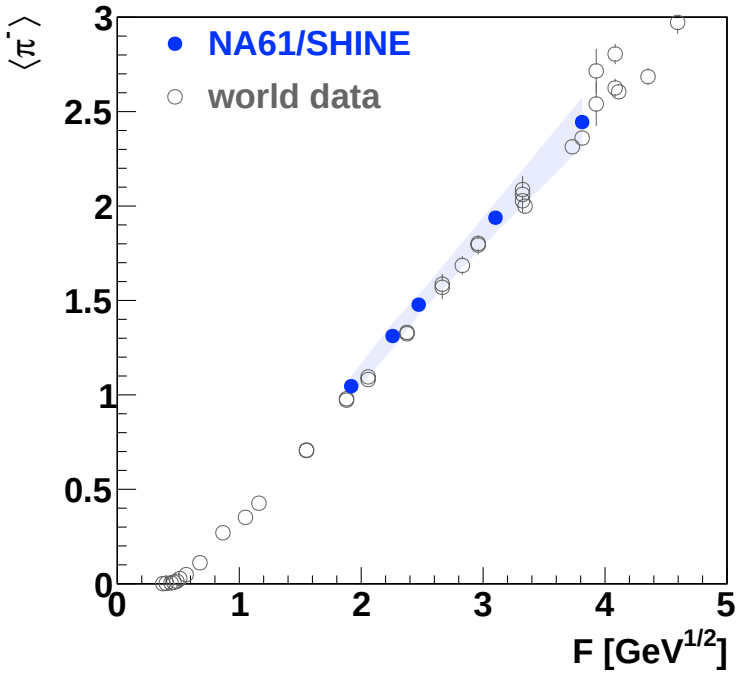
Comparison with Pb+Pb spectra



- The π^- spectra in Pb+Pb collisions divided by p+p results, normalised to unity before dividing
- The transverse mass spectra at mid-rapidity in Pb+Pb are higher at very low and very high m_T
- The rapidity spectra do not differ much between Pb+Pb and p+p
- Ratio of the spectra does not change with the collision energy

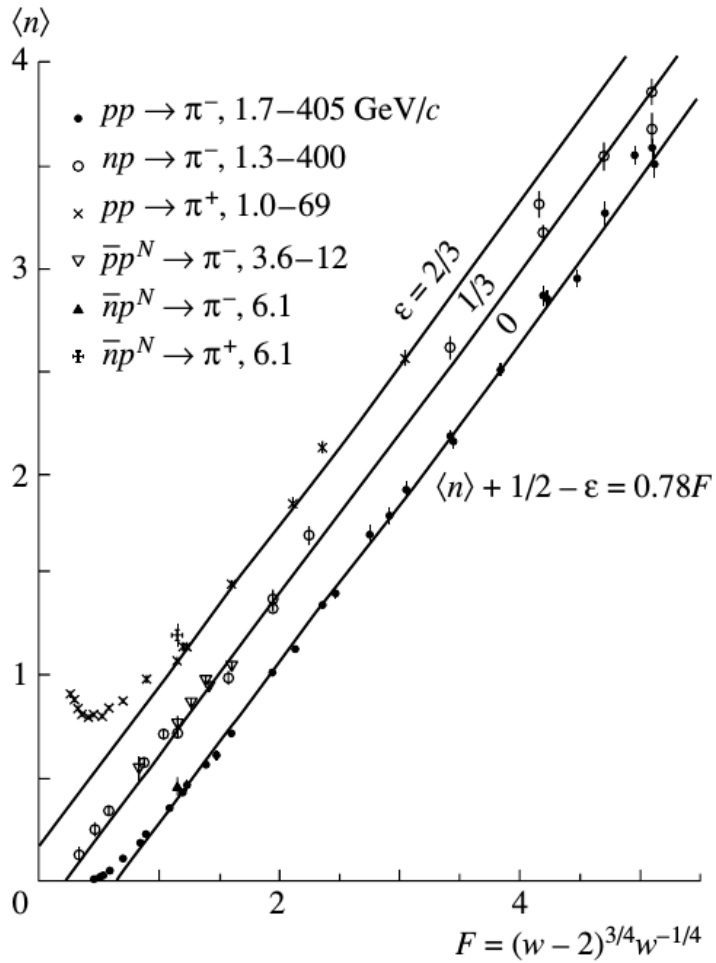
Total π^- multiplicity





- Total π^- multiplicity is calculated as a sum of the measured rapidity spectrum and integral over the fitted double Gaussian function
- NA61/SHINE results agree with the previous measurements

Multiplicity of pions of all charges



- Comparison of the p+p and A+A data requires taking into account effects of isospin
- Pions of all charges should be included in the analysis
- The total π yield is calculated as [1]:

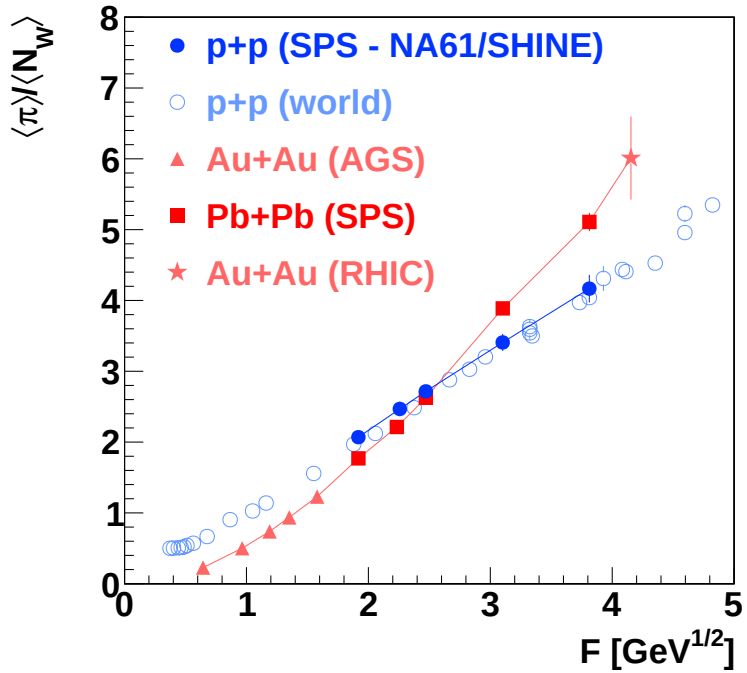
$$\langle \pi \rangle = \frac{3}{2} \left(\langle \pi^+ \rangle + \langle \pi^- \rangle \right) \ . \quad (2)$$

- In NA61/SHINE the non available (yet!) π^+ yield is calculated from the phenomenological formula [1]:

$$\langle \pi^+ \rangle = \langle \pi^- \rangle + 2/3. \quad (3)$$

[1] A. I. Golokhvastov, Phys. Atom. Nucl. **64**, 1841 (2001) [Yad. Fiz. **64**, 1924 (2001)]

Total π multiplicity



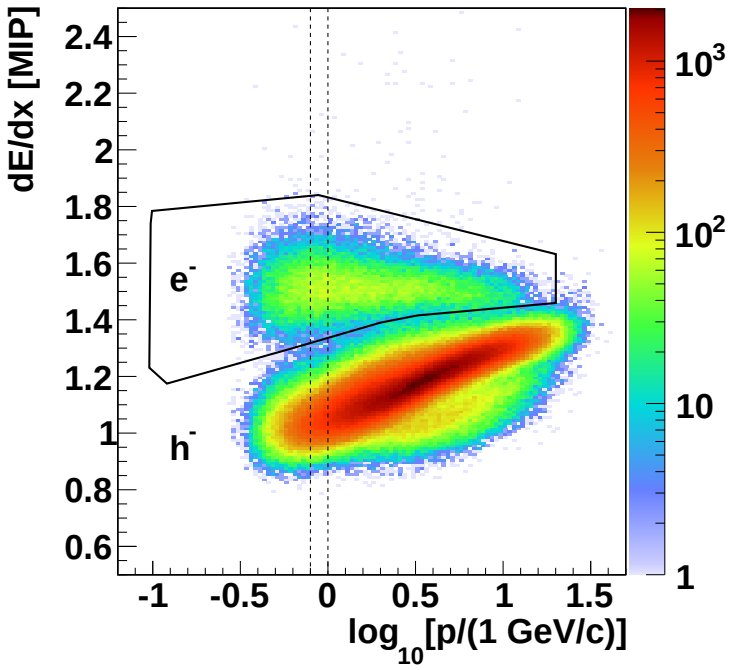
- π multiplicity about 200 times higher in Pb+Pb than in p+p ($\langle N_{\mathrm{W}}^{\mathrm{Pb+Pb}} \rangle \approx 350$, $N_{\mathrm{W}}^{\mathrm{p+p}} = 2$)
- π multiplicity at the SPS energies increases faster in central Pb+Pb than in p+p ("kink")
- The two dependences cross each other at about 40A GeV/c
- NA61/SHINE precision sufficient to study properties of the onset of deconfinement

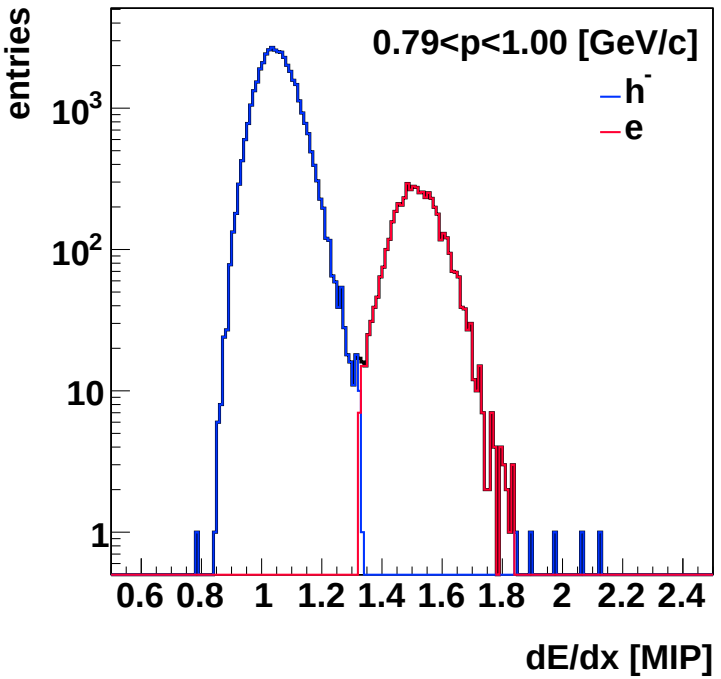
Summary

- π^- meson spectra produced in p+p interactions at 20, 31, 40, 80 and 158 GeV/c are presented
- Spectra are obtained using the h^- method in large phase-space region
- The rapidity spectra in p+p interactions are narrower with respect to the Pb+Pb collisions. The transverse mass spectra also different. This might be attributed to the longitudinal and transverse flow in Pb+Pb, however π^+ results are needed to clarify role of the isospin effects.
- Publication submitted to EPJC, arXiv:1310.2417 [hep-ex]
- Ph.D. in preparation

Additional slides

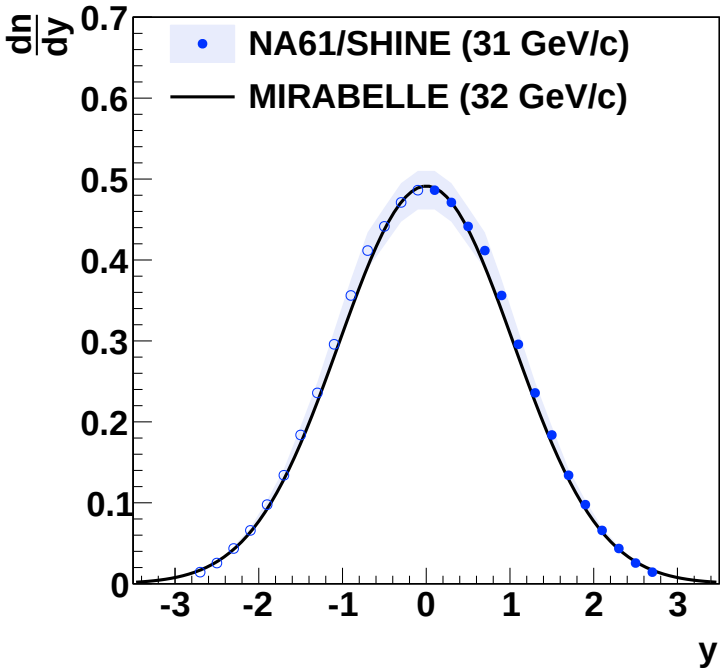
dE/dx performance

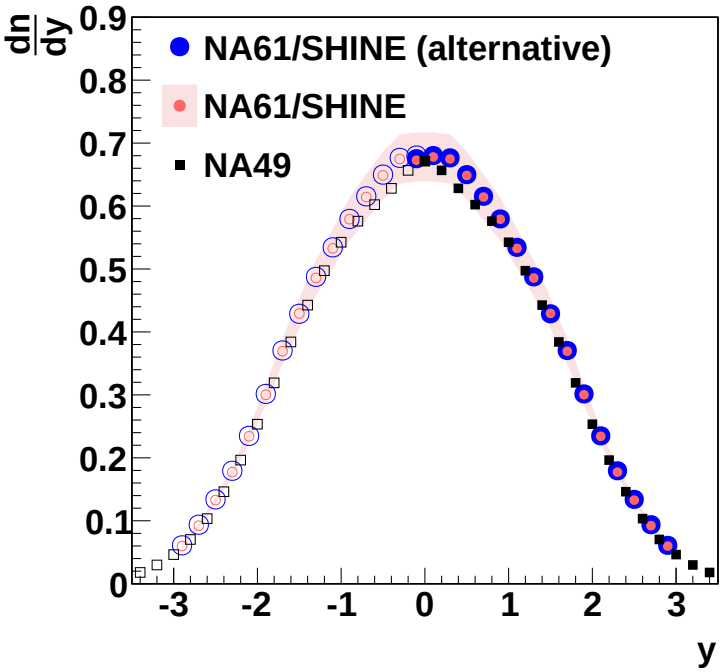




- Electrons are easily separated from hadrons
- Pions overlap with anti-protons at $p < 5$ GeV/c

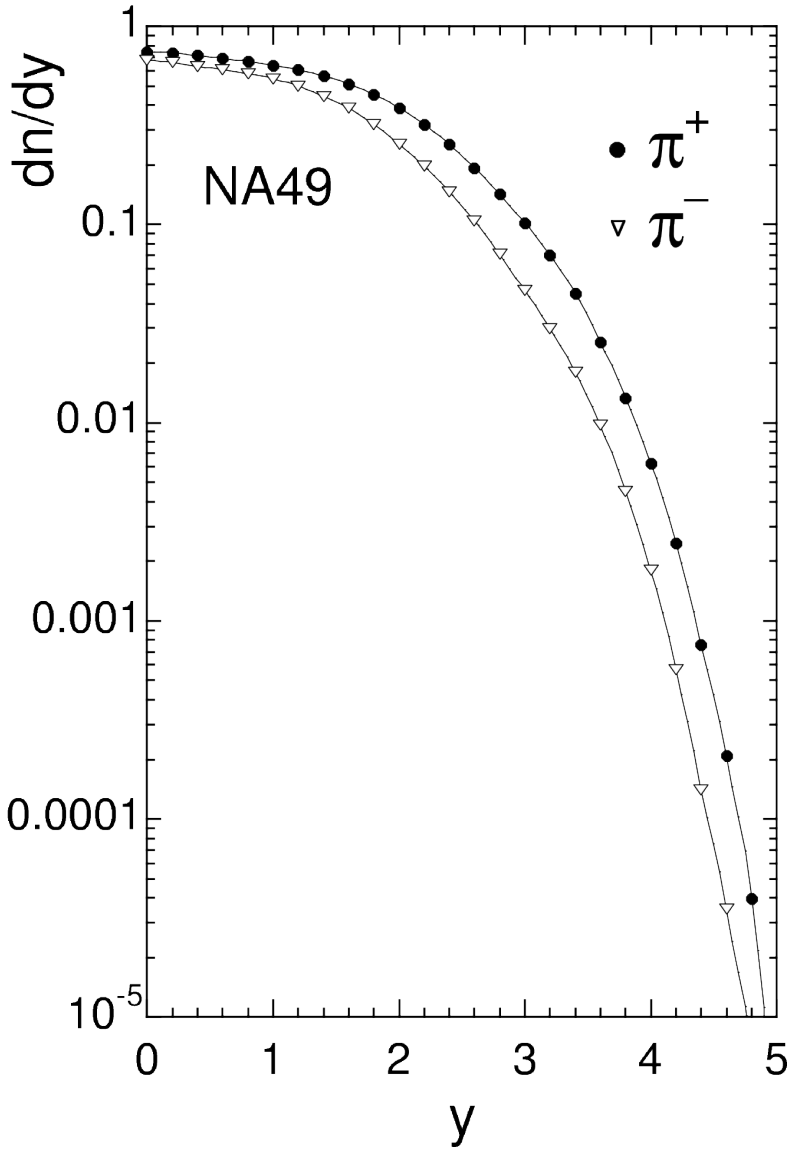
Comparisons with other experiments





- π^- spectra measured by NA61/SHINE agree with sparse other existing data

NA49 results



- NA49 measurement of the $\pi^{\pm}$ production in p+p interactions at 158 GeV/c
- Comparison of pions of all charges in p+p and A+A is necessary to take into account the isospin effects

$\rightarrow$ NA61/SHINE π^+ analysis ongoing (S. Puławski)