MPD prospects for the study of the strangeness production and strangeness-to-entropy ratio at NICA energies

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(VBLHEP, JINR)

**Support from RFBR grant № 18-02-40037*

The scope of the RFBR grant studies is testing MPD performance to the probes sensitive to phase transformations and critical phenomena in dense nuclear matter:

- Strangeness production and strangeness-to-entropy ratio (this talk)
- Event-by-event fluctuations of conserved charges (talk of A.Mudrokh today at 17:00)

OUTLINE

- ❑ Motivation of the study: why to measure strangeness at NICA
- ❑ MPD detector setup and analysis details
- ❑ Results
  - pT-spectra of pions and kaons
  - rapidity distributions of hadrons
  - excitation function of the strangeness-to-entropy ratio
- ❑ Summary

“NAUKA” NATIONAL PROJECT

Decree of the President of RF № 204 on 7 May, 2018

TIMELINE: 01.10.2018 – 31.12.2024

GOALS AND TARGETS:

1. Ensuring the presence of the Russia among the 5 leading countries engaged in R&D in priority areas of science and technology development.
2. Ensuring the attractiveness of employment in Russia for Russian and foreign leading scientists and distinguished young researchers.
3. Advanced increase of internal R&D expenditures using all possible sources in comparison with the growth of the gross domestic product of the country.

FEDERAL PROJECTS INCLUDED IN THE “NAUKA” PROJECT:

- Development of the scientific and industrial cooperation.
- Development of the advanced infrastructure for R&D in Russia.
- Development of the human resources for R&D.

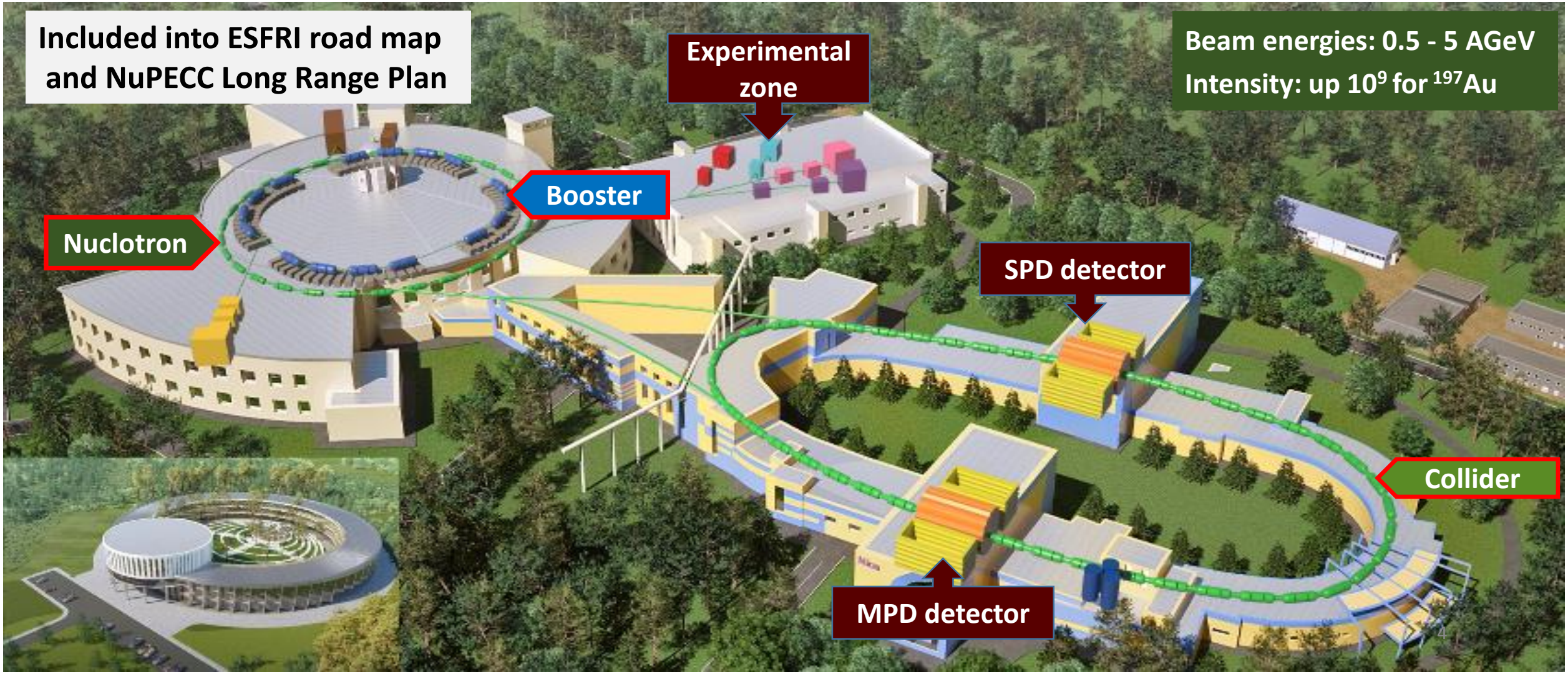
2020	Establishing 4 world-class international mathematical centers. Establishing 3 world-class genomic research centers. Beginning of international research at the megascience facility of the International Center for Neutron Research (based on the PIK high-flux reactor).
2021	Establishing 3 world-class research centers for R&D in priority fields of scientific and technological development.
	Holding of 29th World Mathematical Congress (St. Petersburg)
2022	**Beginning of international research at the megascience facility “The complex of superconducting rings on colliding heavy ion beams – NICA”.**

Start of the NICA complex operation – 2022

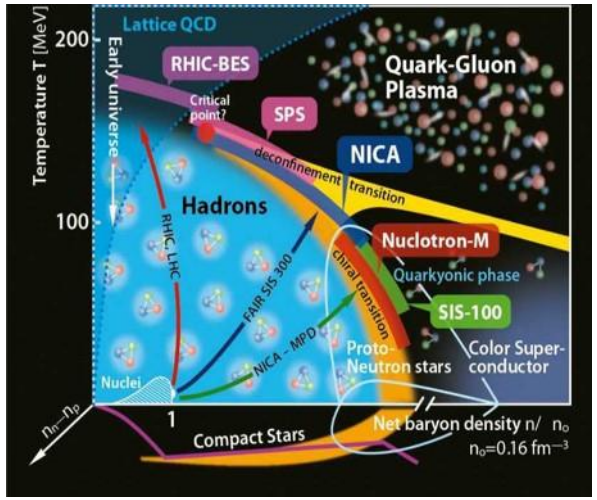
Unique RFBR program to support preparation of the NICA scientific program prior to the start of operation

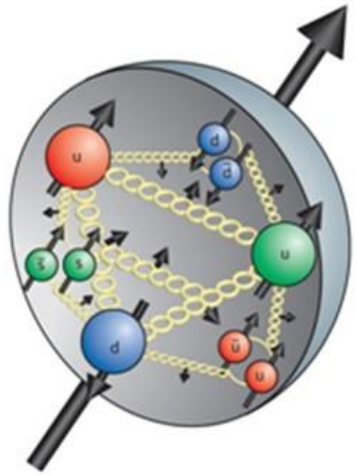
NICA – Nuclotron-based Ion Collider fAcility

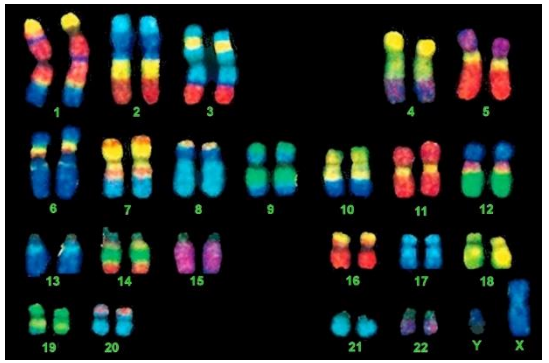
- Chain of accelerators providing ion beams (from *p* to Au) for fundamental physics studies & applied research
- Modern detectors for study dense nuclear matter and spin phenomena (MPD, SPD, BM@N)
- Experimental zone with beam lines for fundamental and applied research
- Factory with cryogenic infrastructure for production, testing and supply superconducting elements



Scientific pillars of the NICA program







Heavy-ion program

Probing of fundamental laws of physics with heavy-ion collisions:

- Formation of new state of matter (QGP)
- Properties of physical vacuum
- Origin of particle mass
- Properties of massive stellar objects (neutron stars)

Spin physics program

New comprehensive studies with polarized beams to:

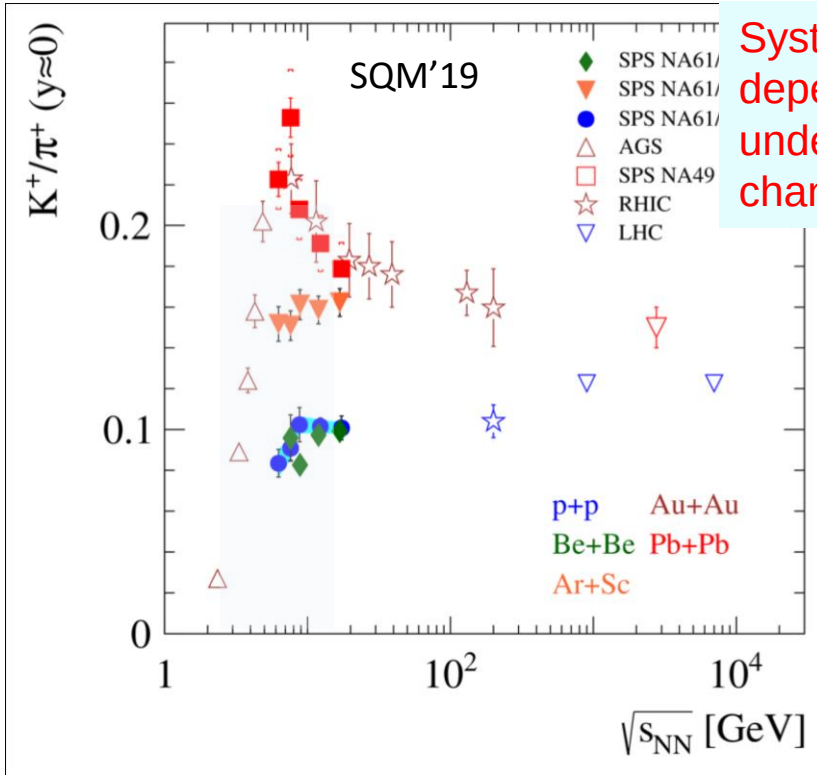
- Resolve nucleon spin crisis
- New precise measurements of the nucleon Parton Distribution Functions

Program of applied research

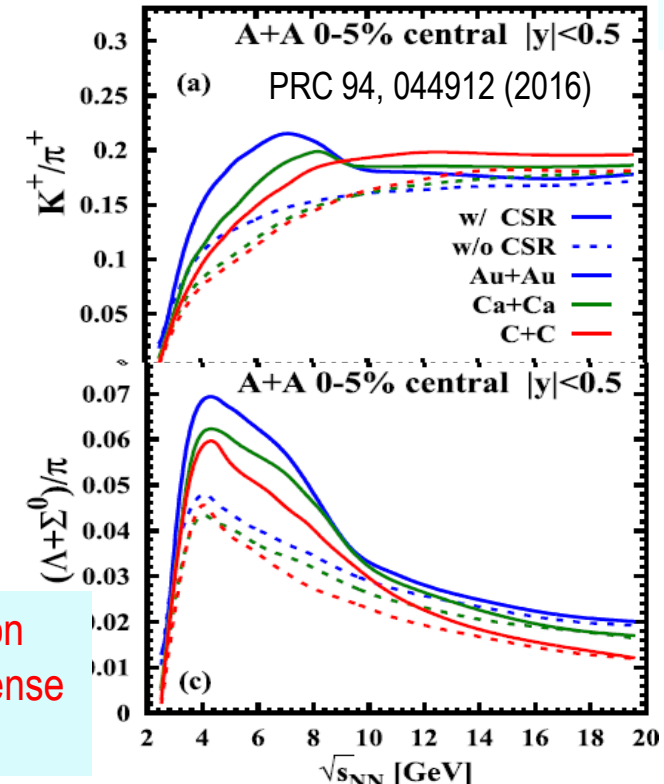
- Development of universal charged particle accelerators
- Universality of operating modes & increasing limiting parameters of superconducting magnets
- Radiation hardness and modification of materials
- Radiobiology research with heavy-ion beams

NICA/MPD physics cases: strangeness production

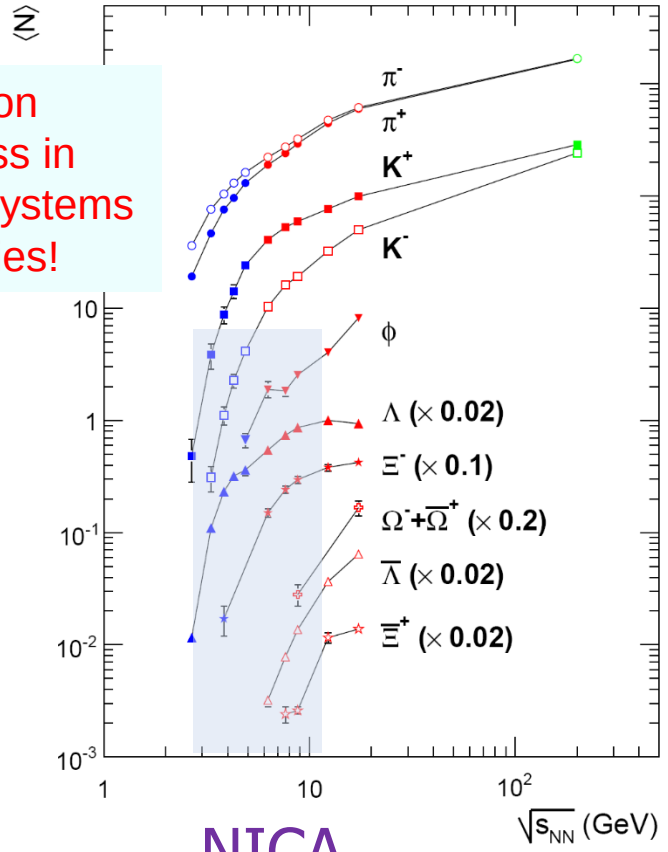
- Excitation function of hadrons, including strangeness (yields, spectra, and ratios)
- Nuclear matter EOS, in-medium effects, and chemical equilibration can be probed
- Non-monotonic strangeness-to-entropy ratio seen in heaviest systems (phase transformation?)



System size of the energy dependence is not fully understood. The largest changes at NICA!



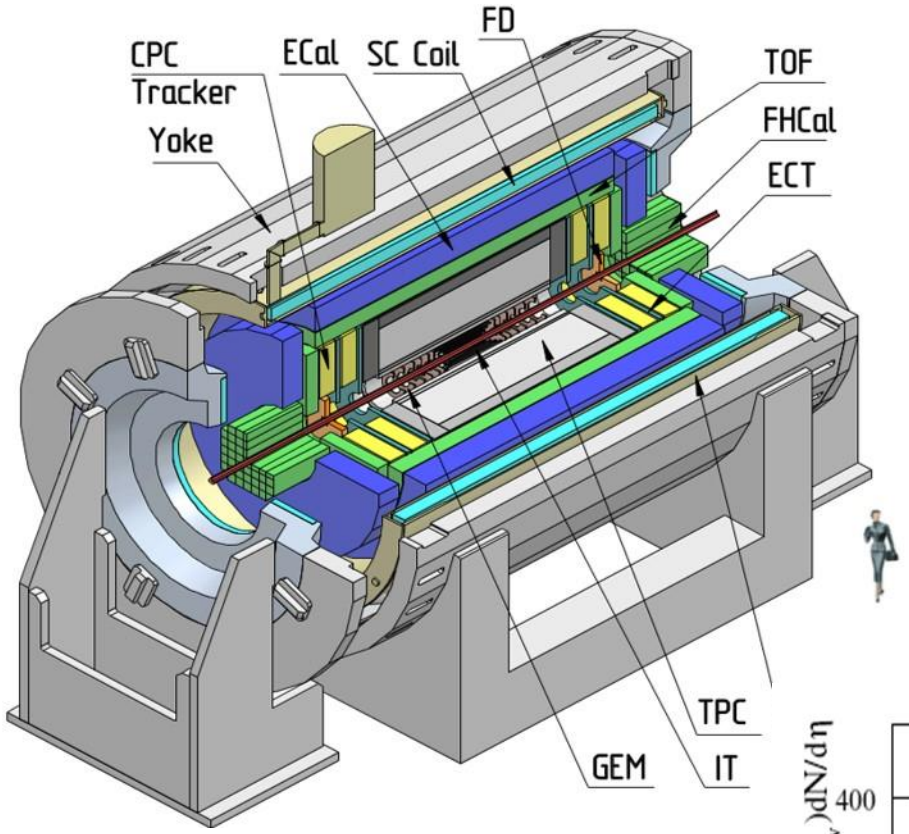
Lack of data on multistrangeness in different collision systems at NICA energies!



NICA

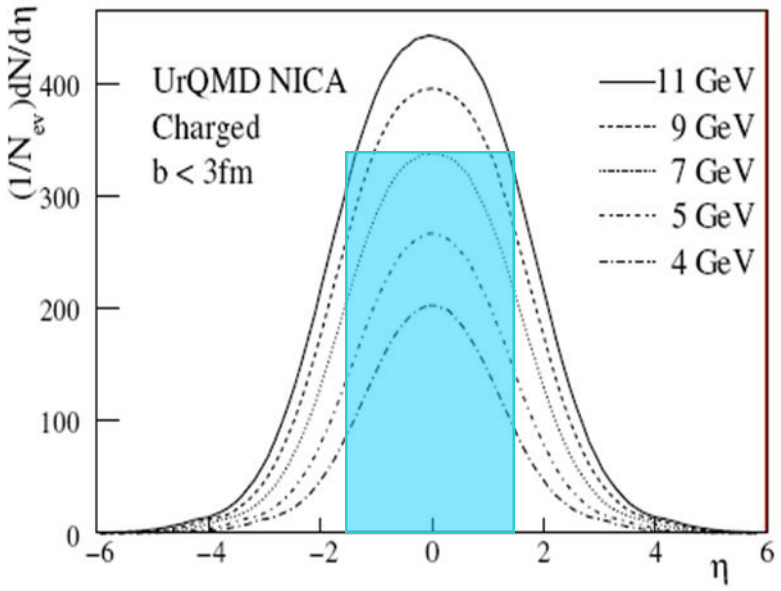
Theory predicts the largest effect for the hadron ratios due to chiral symmetry restoration in dense matter at NICA energies!

MultiPurpose Detector for A+A collisions @ NICA

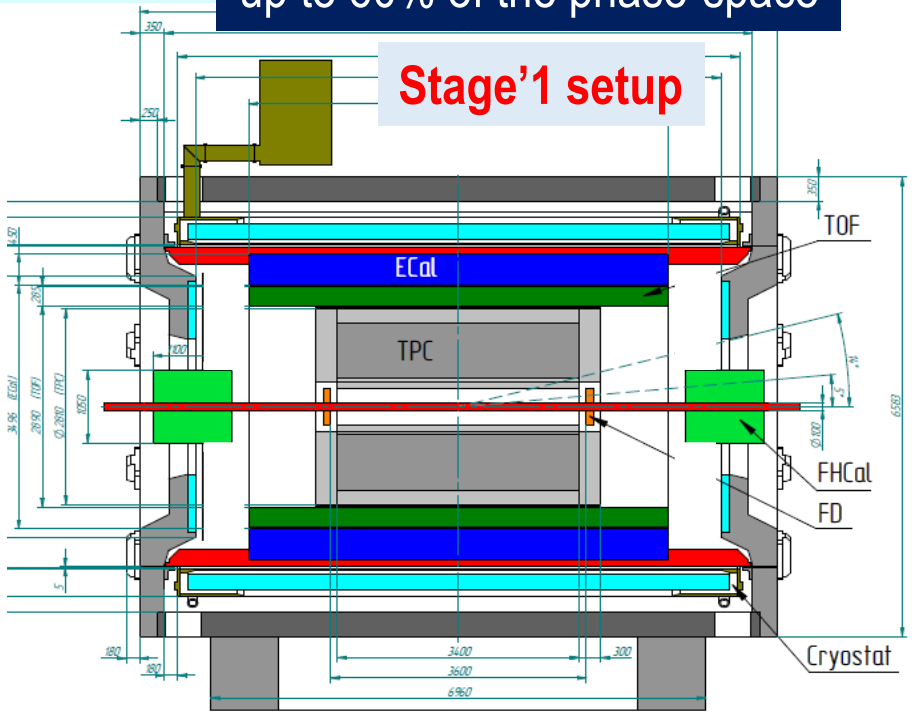


- 3D tracking, uniform acceptance, 2π in azimuth
- High resolution vertexing
- Powerful PID (TPC, TOF, ECAL)
  - π/K up to 1.7 GeV/c, K/p up to 3 GeV/c
  - γ, e : 0.1<p<3 GeV/c
- Precise event characterization (FHCAL)
- Fast timing and triggering (FFD)
- Low material budget
- High event rate (up to ~ 7 kHz)

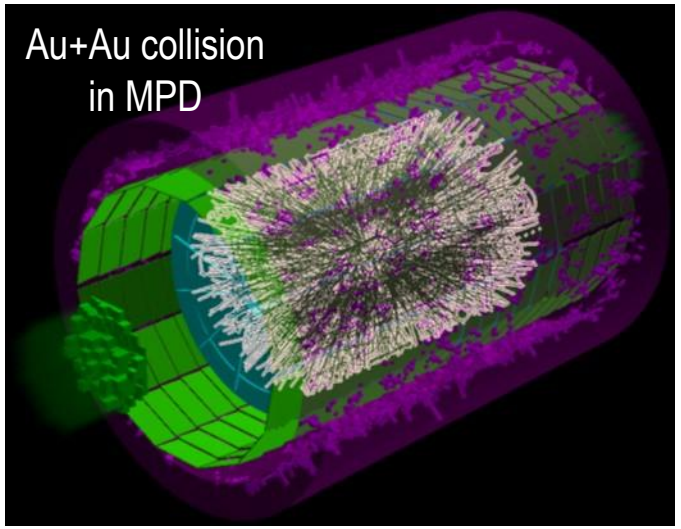
Stage'1 setup – extended midrapidity region (|η|<1.4)
up to 60% of the phase-space



I Stage (barrel part)
II Stage (full configuration)

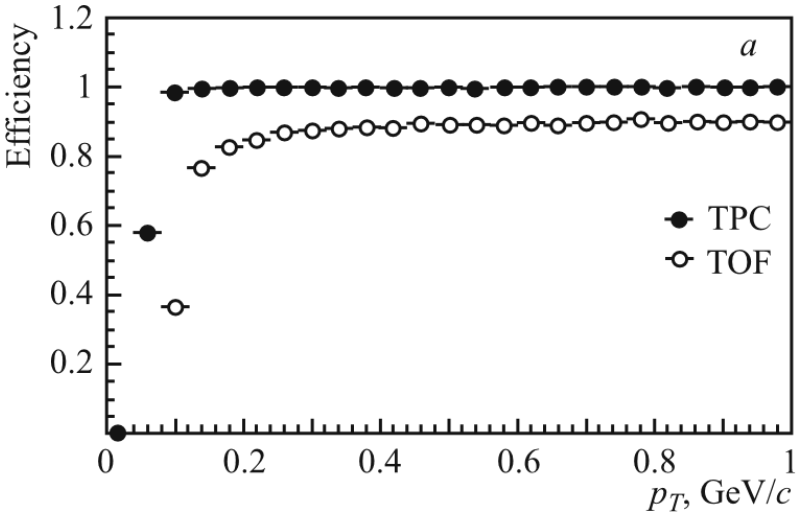


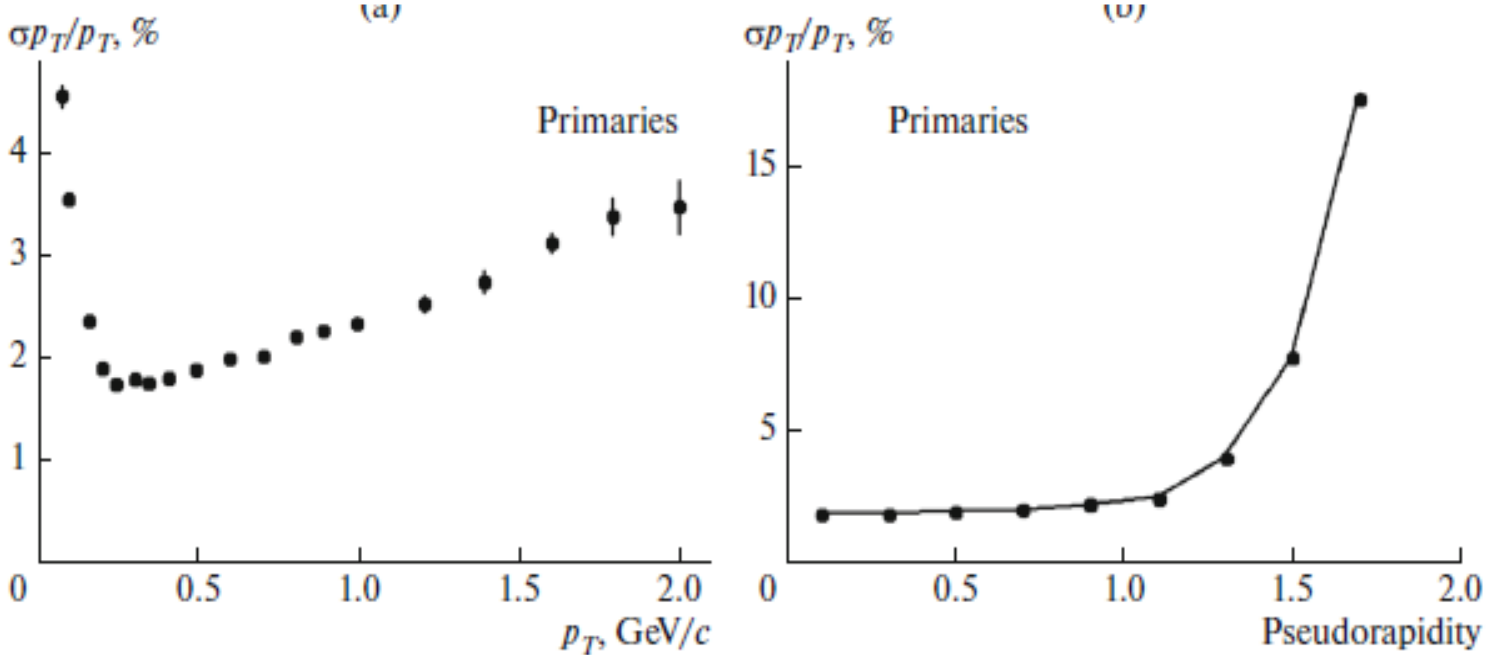
MPD performance for Stage'1

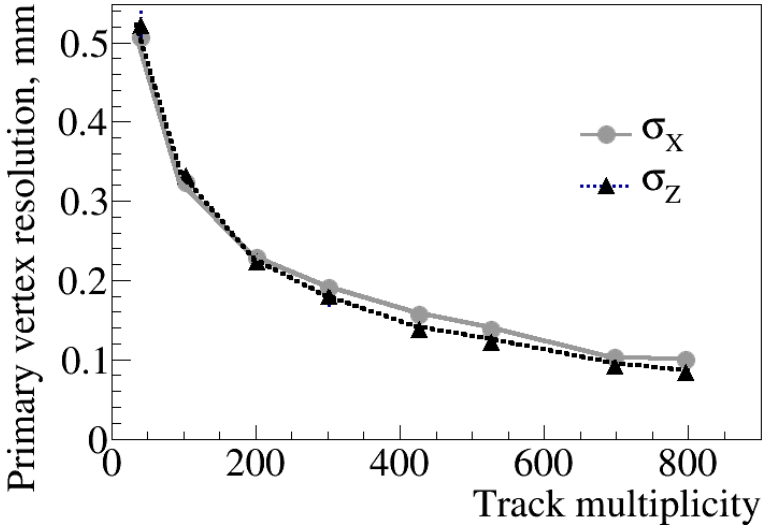


Based on realistic event simulation within the MPDRoot framework

- **High tracking efficiency over the reaction phase-space**
- **Efficient vertexing**

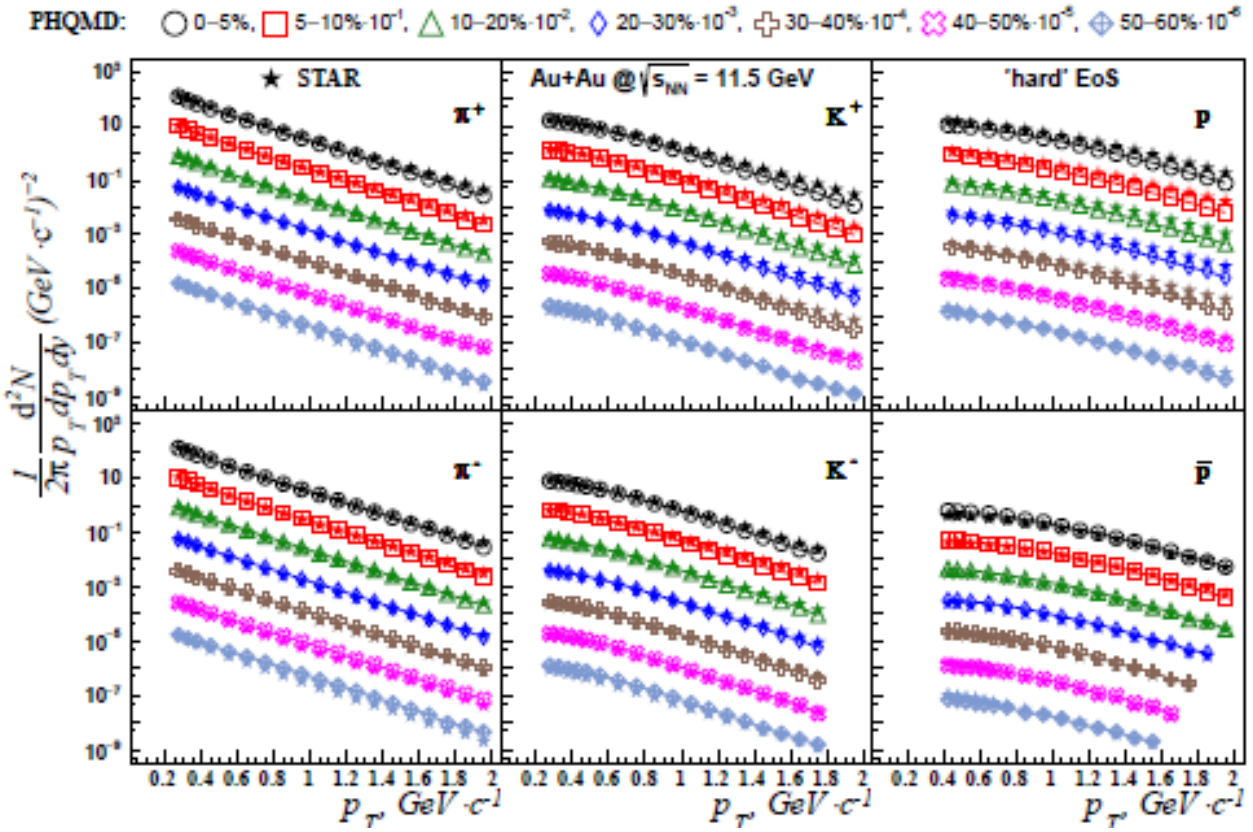






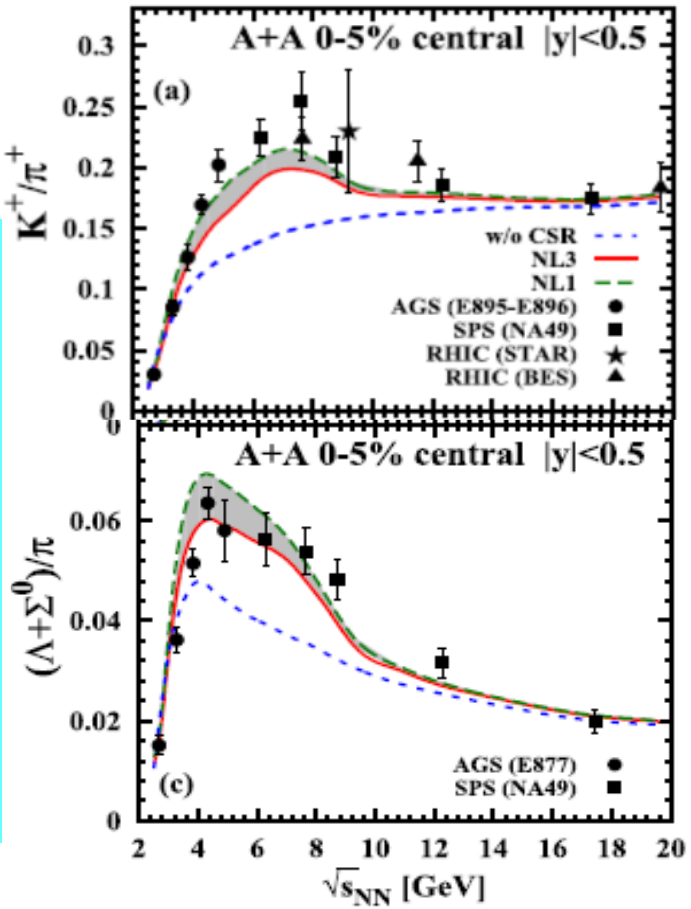
Analysis details : PHSD/PHQMD model for A+A collisions

- PHSD/PHQMD event generator simulates heavy-ion collisions from the initial touch until freezeout
- Partonic and hadronic degrees of freedom, tunable parameters for the EoS
- Implements chiral symmetry restoration (CSR) effects
- Reproduces experimental data for the bulk observables

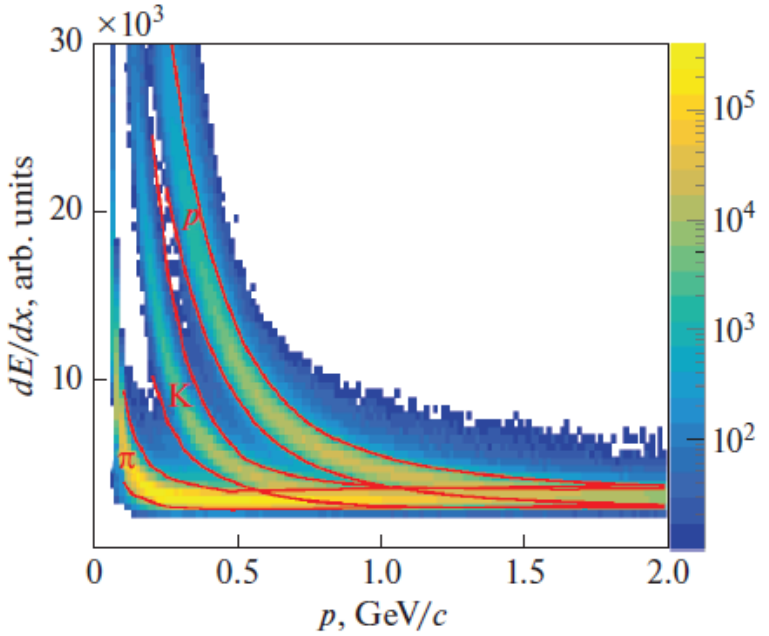


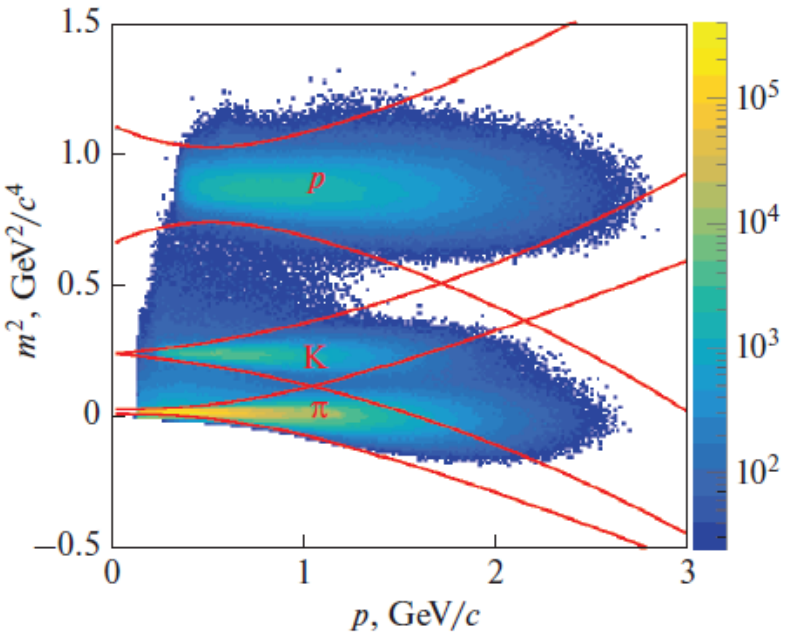
PHSD model with parton degrees of freedom implementing *Chiral Symmetry Restoration (CSR)* via density dependent string fragmentation mechanism. CSR is responsible for the Horn in the kaon-to-pion ratio, while the constant ratio is for the QGP phase.

Phys. Rev C 94, 044912 (2016)

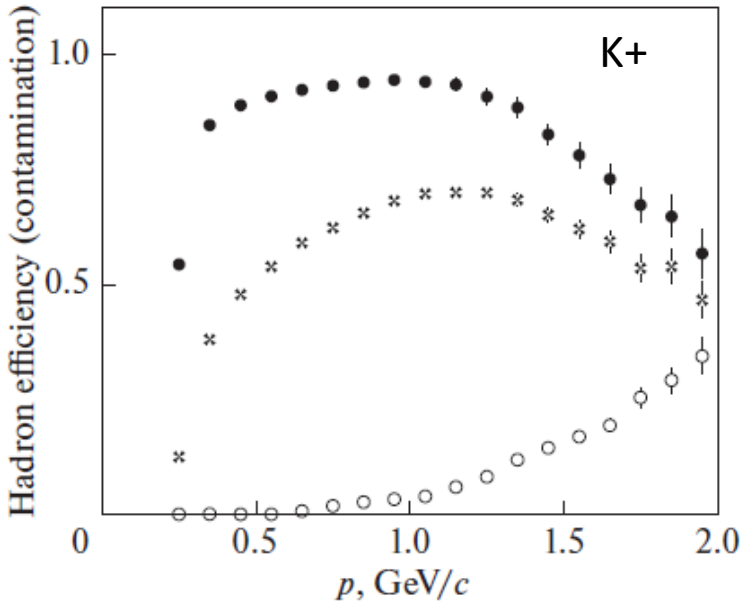


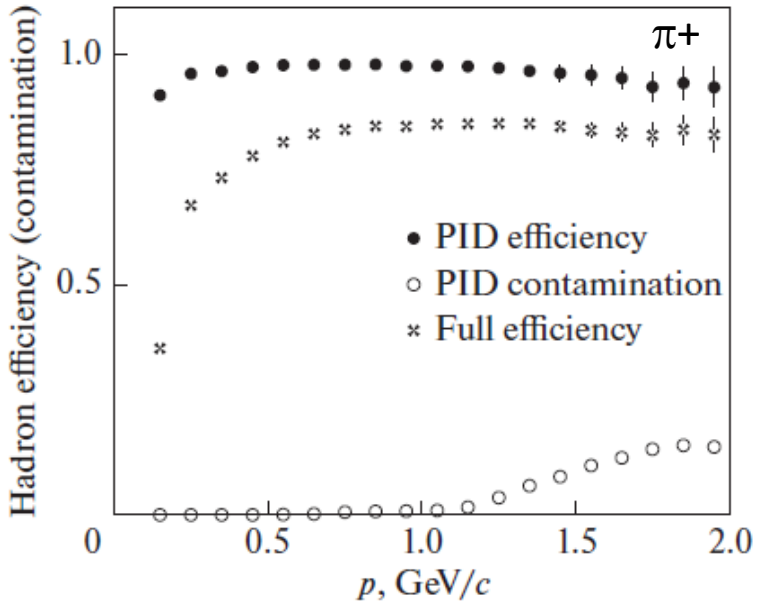
Analysis details : particle ID for hadrons





- ✓ *Combined dE/dx+TOF particle ID*
- ✓ *High efficiency for charged hadrons*





Principal results of the study

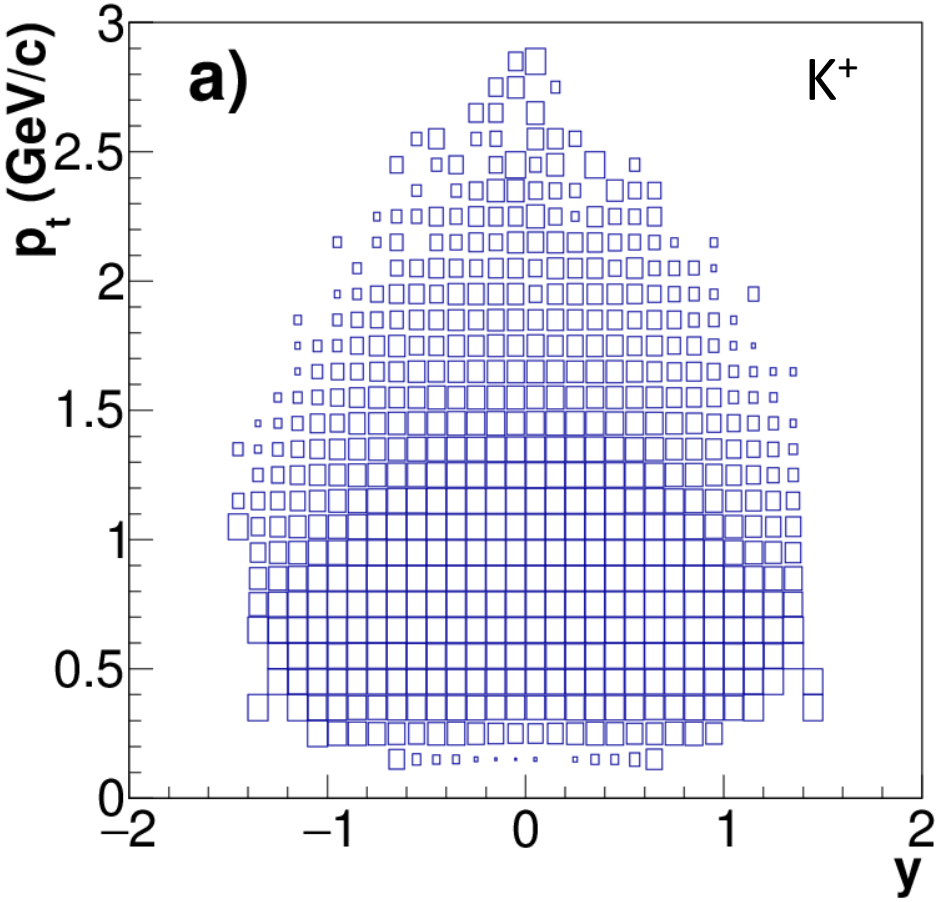
In the study we used central (0-5%) Au+Au collisions

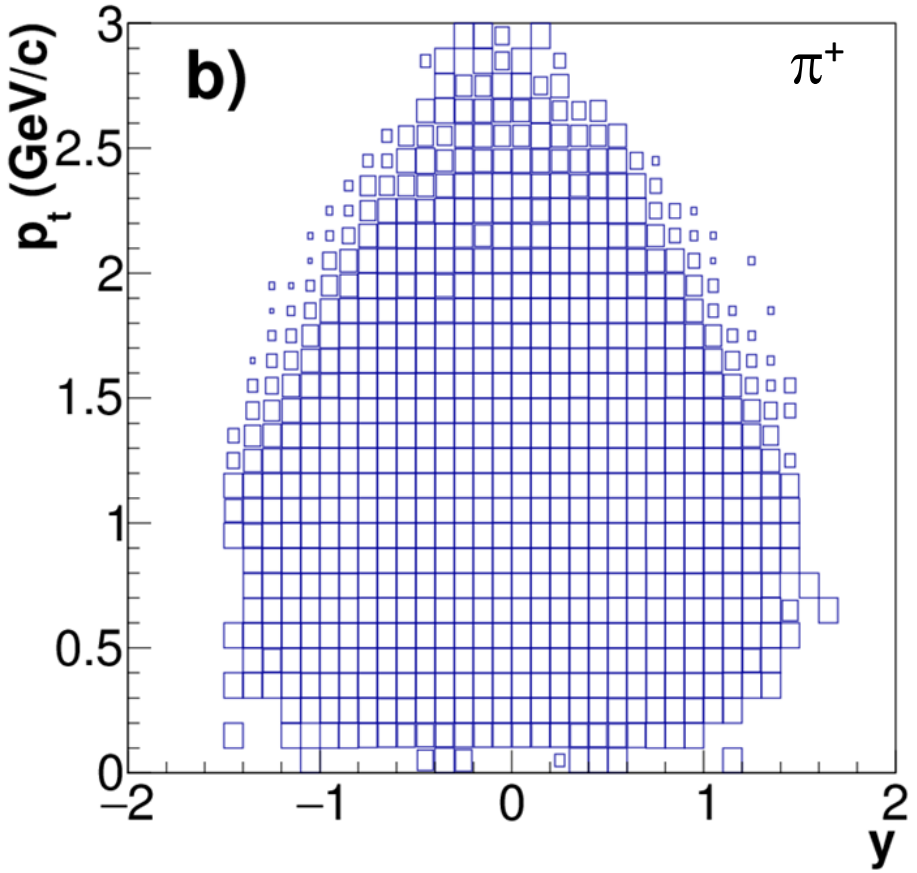
at center-of-mass energies 4, 6.3, 7.6, 8.8 and 12 GeV.

Moreover, two CSR settings in the model were used (CSR On/Off)

Results: phase-space for hadrons

0-5% central Au+Au at 8.8 GeV

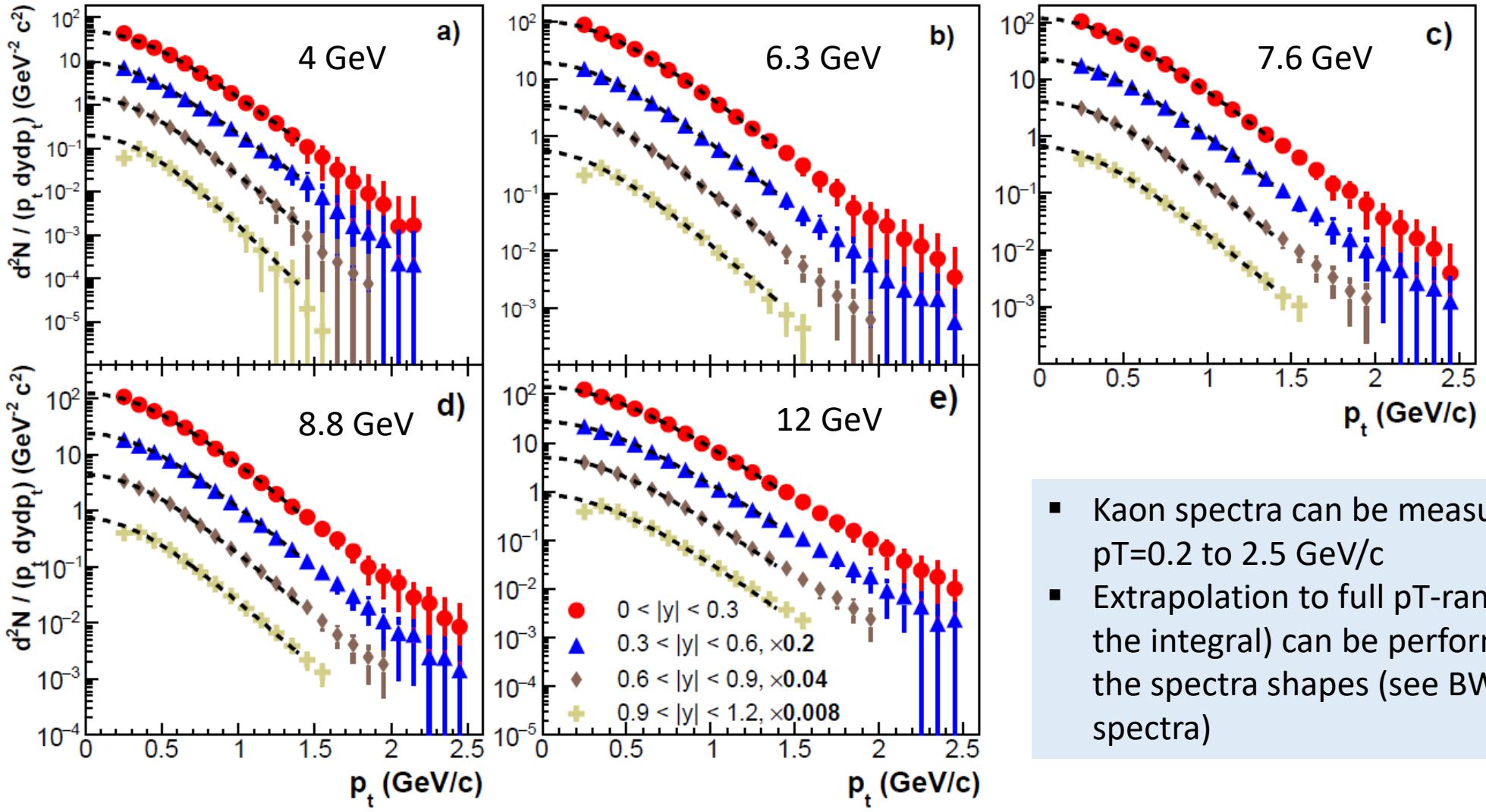




- MPD provides large coverage for identified pions and kaons (> 70% of the full phase space at 8.8 GeV)

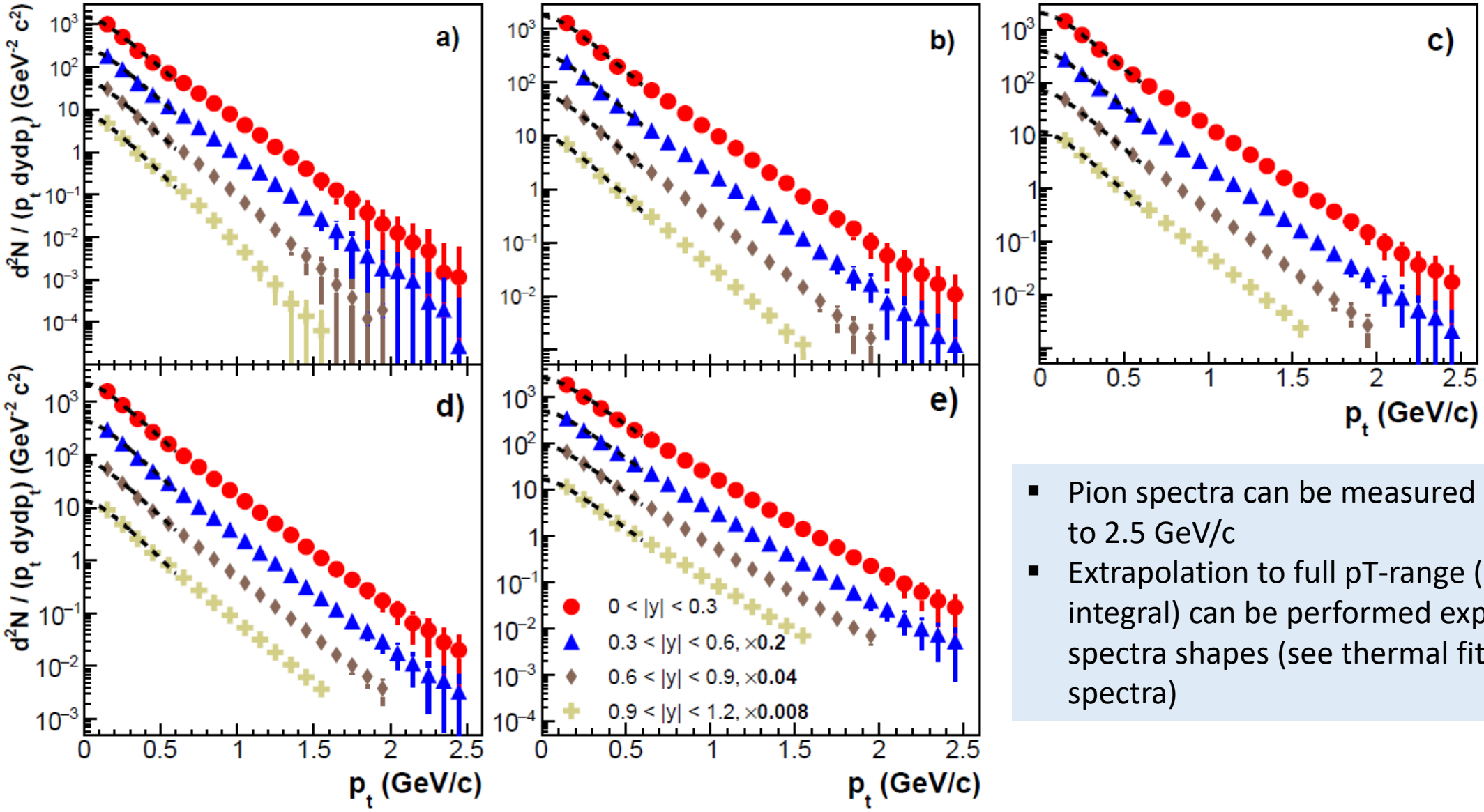
Results: invariant pT-spectra of K^+

Blast-Wave (BW) fits: $\frac{d^2N}{p_t dp_t dy} = C\int_0^1 p_t f(\xi) K_1\left(\frac{m_t \cosh(\rho)}{T}\right) I_0\left(\frac{p_t \sinh(\rho)}{T}\right)\xi d\xi$ $\quad m_t = \sqrt{p_t^2 + m^2}, \quad \rho = \mathrm{atan}(\beta_t(\xi)), \quad \xi = \frac{r}{R}$



- Kaon spectra can be measured from pT=0.2 to 2.5 GeV/c
- Extrapolation to full pT-range (25-30% of the integral) can be performed exploiting the spectra shapes (see BW fits for pT-spectra)

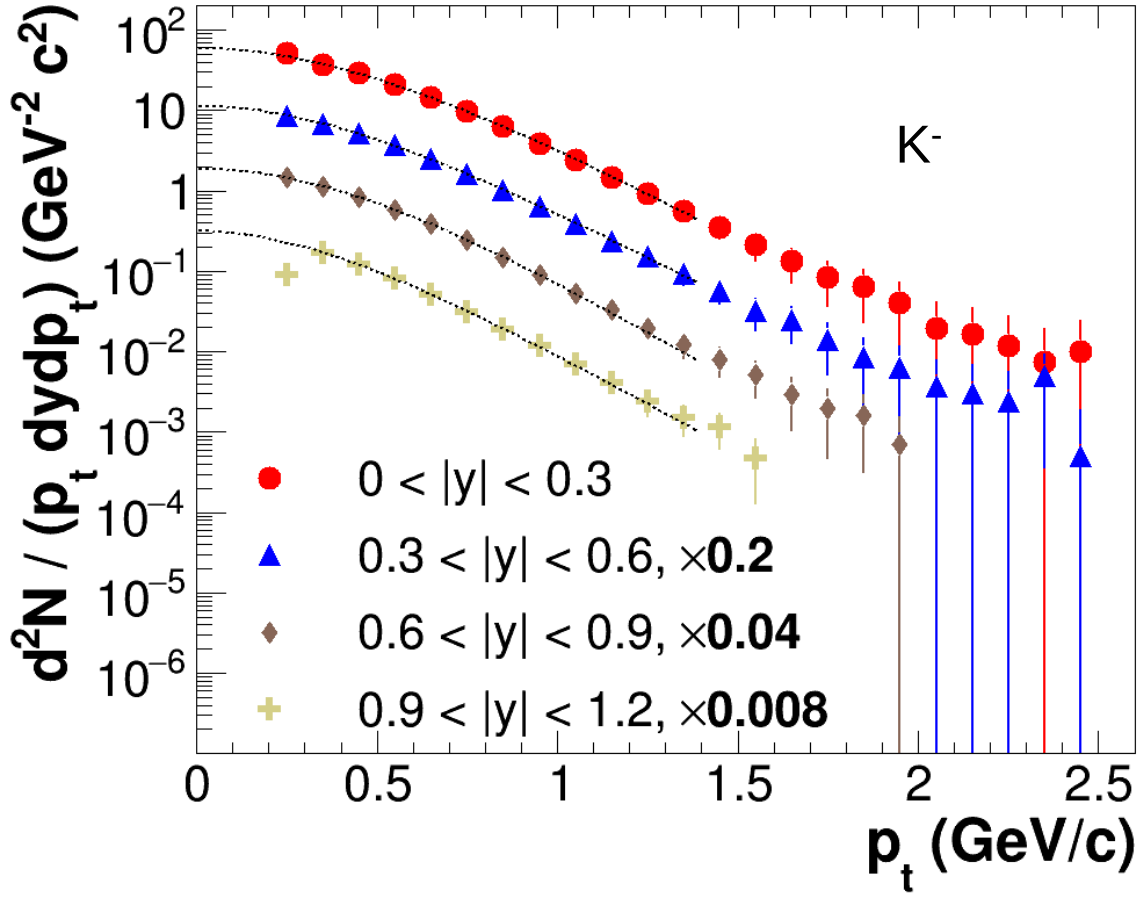
Results: invariant pT-spectra of π^+

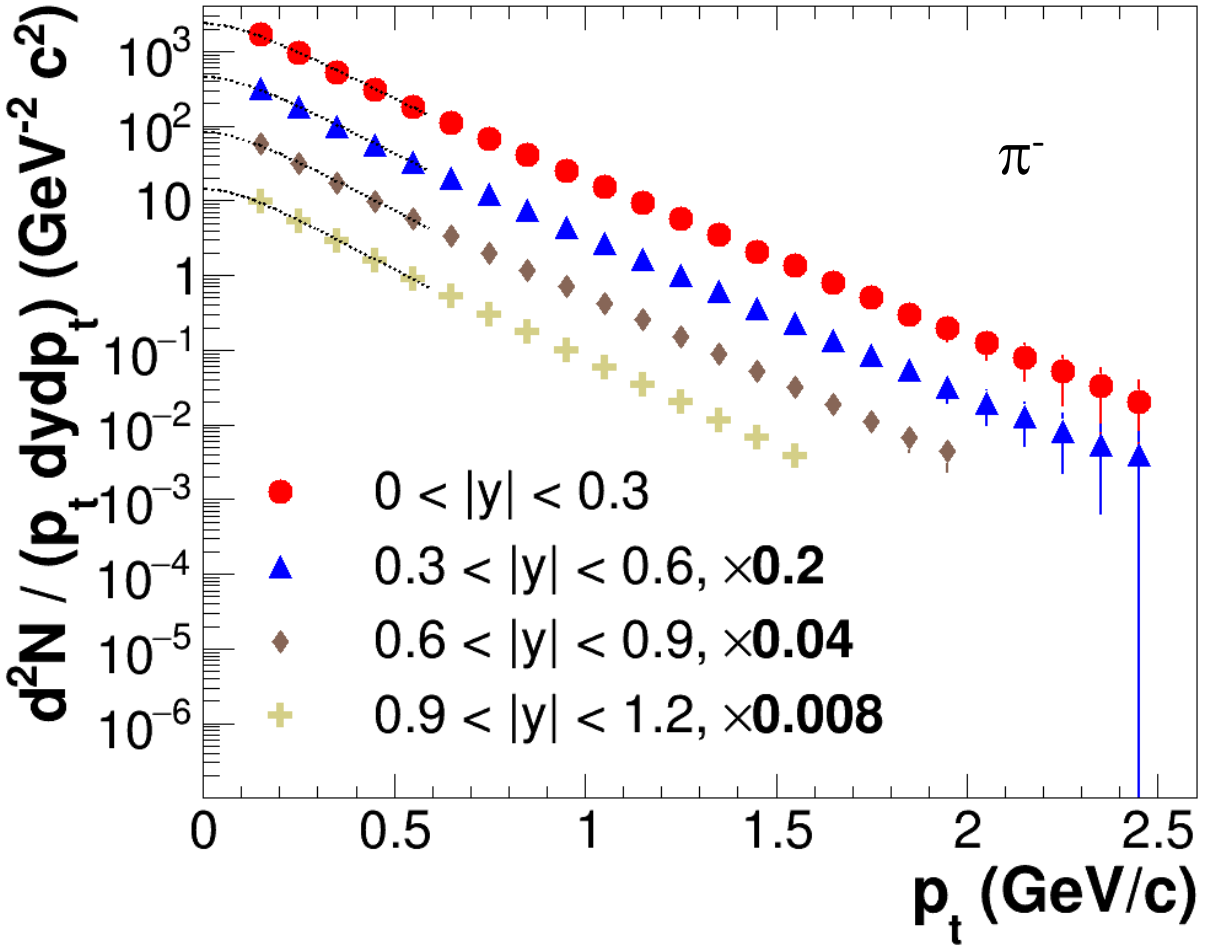


- Pion spectra can be measured from pT=0.2 to 2.5 GeV/c
- Extrapolation to full pT-range (~10% of the integral) can be performed exploiting the spectra shapes (see thermal fits for pT-spectra)

Results : Invariant spectra of K^- and π^-

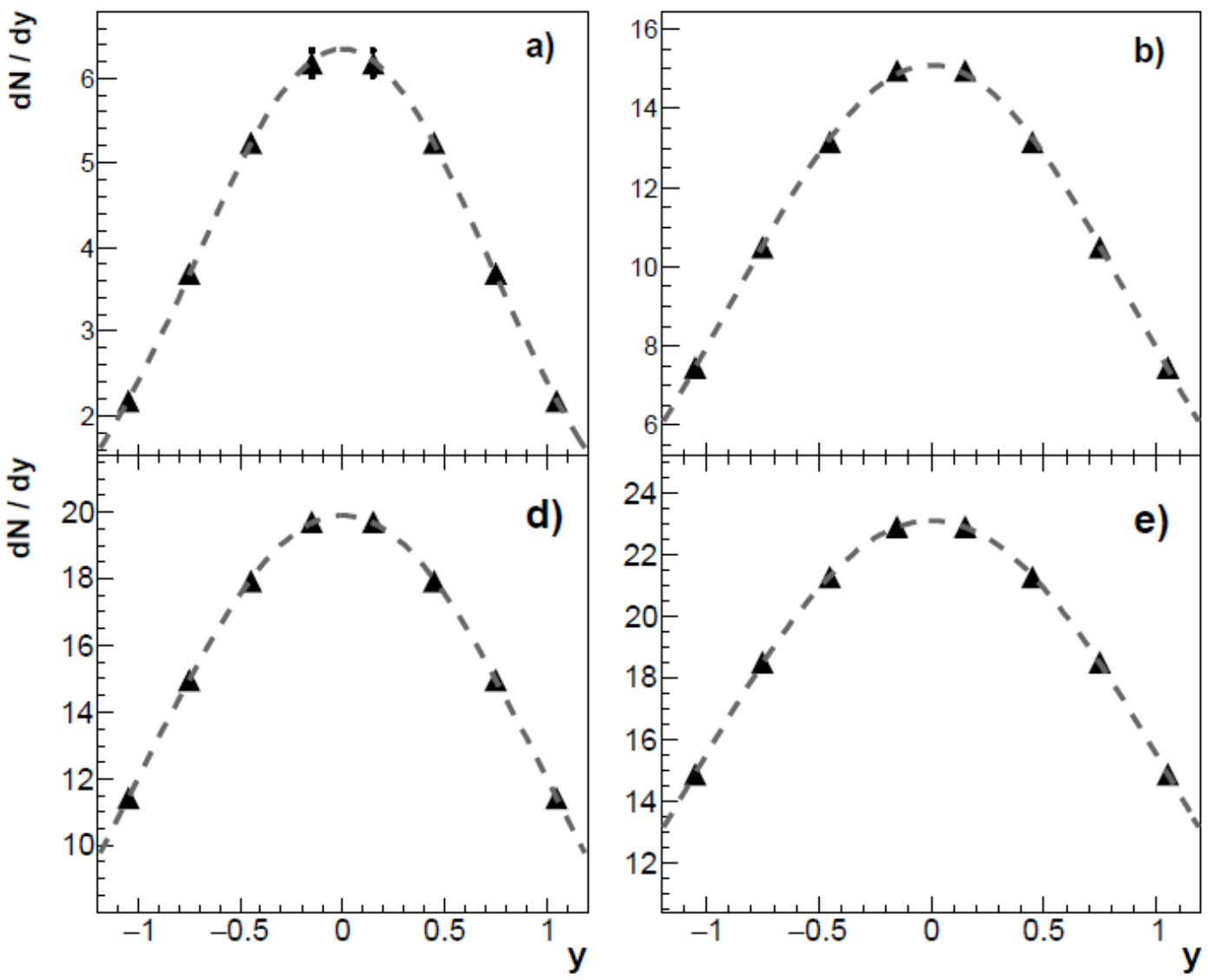
0-5% central Au+Au at 7.6 GeV





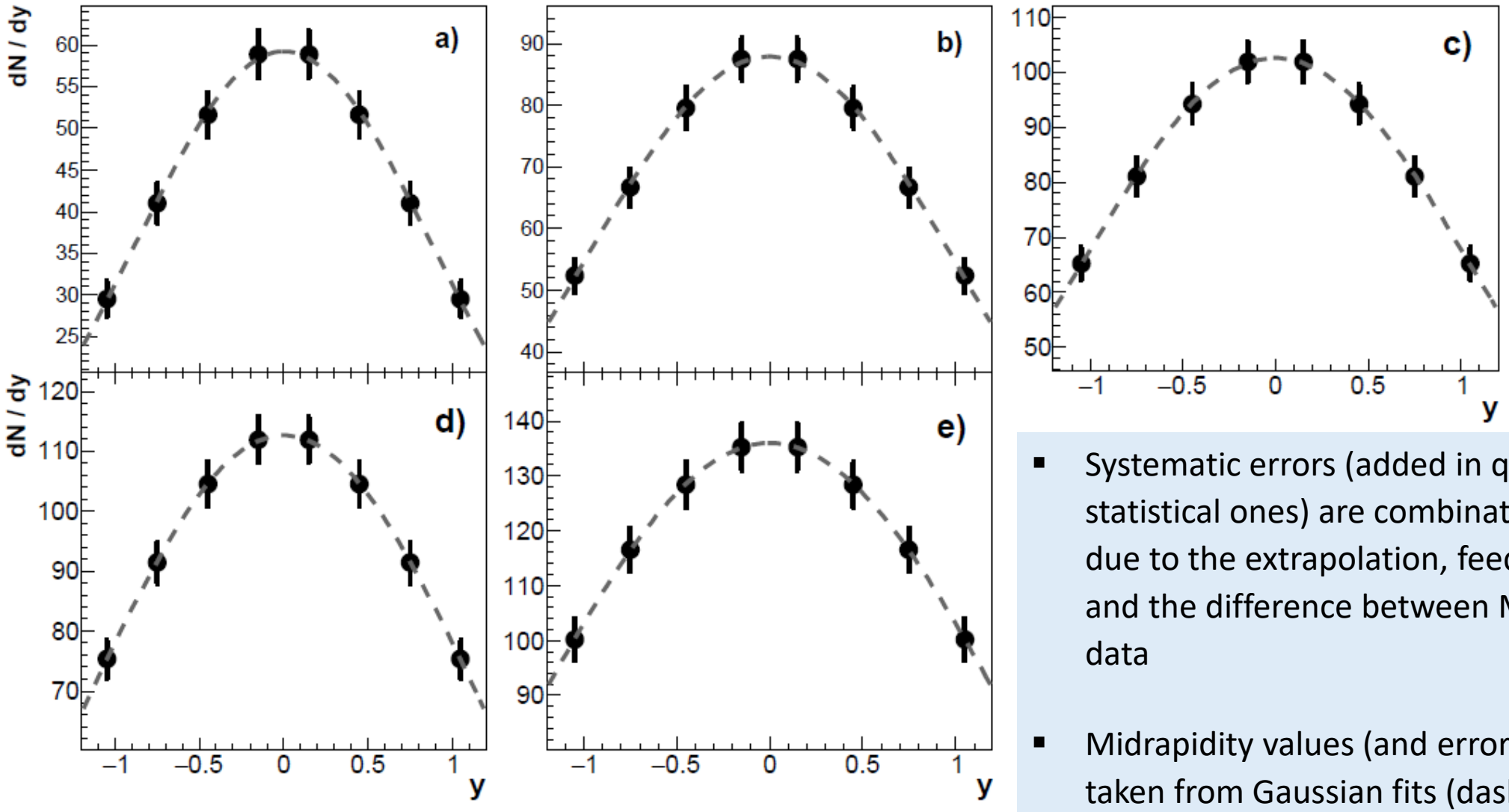
- Integrals of invariant spectra (dN/dy) are obtained by summing the reconstructed points and adding the extrapolations from fits

Results : rapidity distributions of K^+



- Extrapolation to full phase space can be performed exploiting the spectra shapes (Gaussian for rapidity distributions)
- An error of the order of 4-5% can be achieved for the total multiplicity (comparing to MC data)

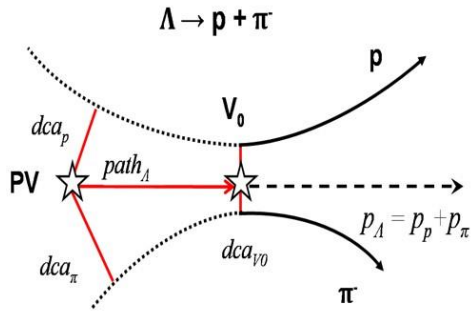
Results : rapidity distributions of π+



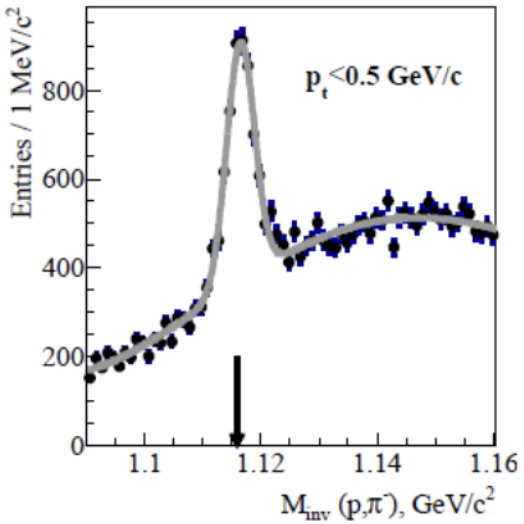
- Systematic errors (added in quadrature to the statistical ones) are combinations of the uncertainties due to the extrapolation, feeddown corrections to π's and the difference between MC and reconstructed data
- Midrapidity values (and errors) used in ratios are taken from Gaussian fits (dashed lines)

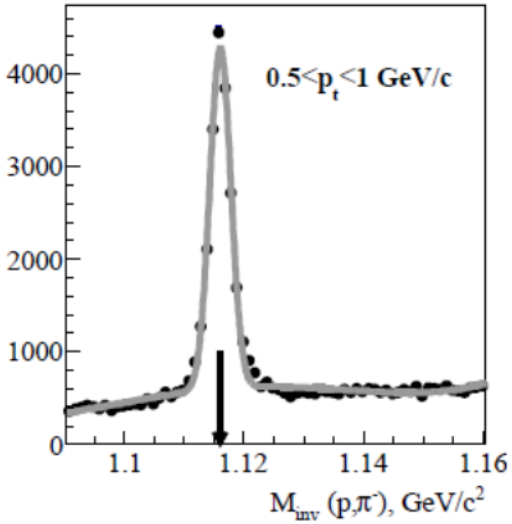
Analysis of Λ-hyperons

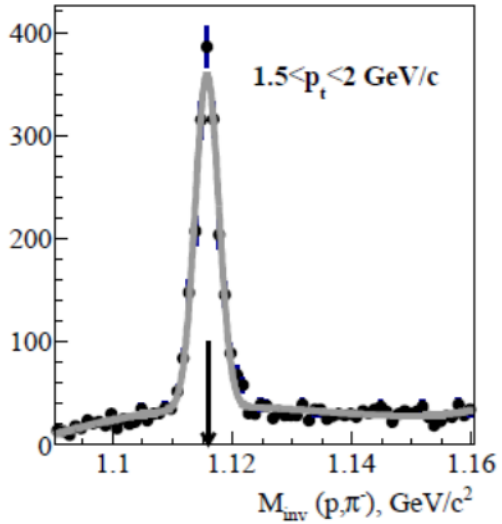
- *TPC & TOF, $|\eta|< 1.3$*
- *track reconstruction and PID (dE/dx+TOF)*
- *secondary vertex finding technique with a set of topological cuts*

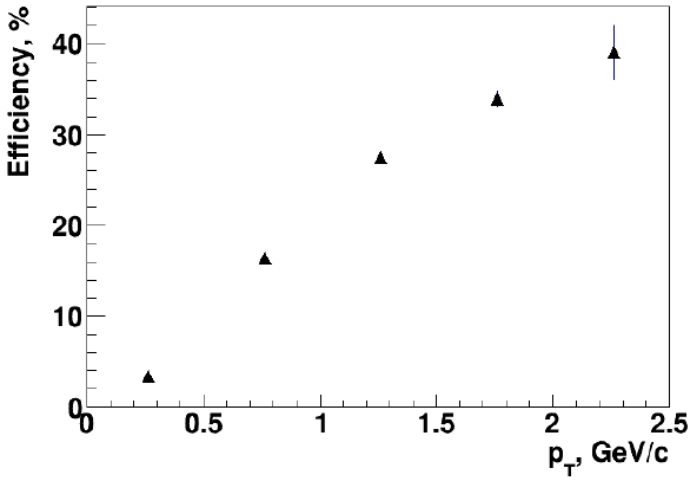


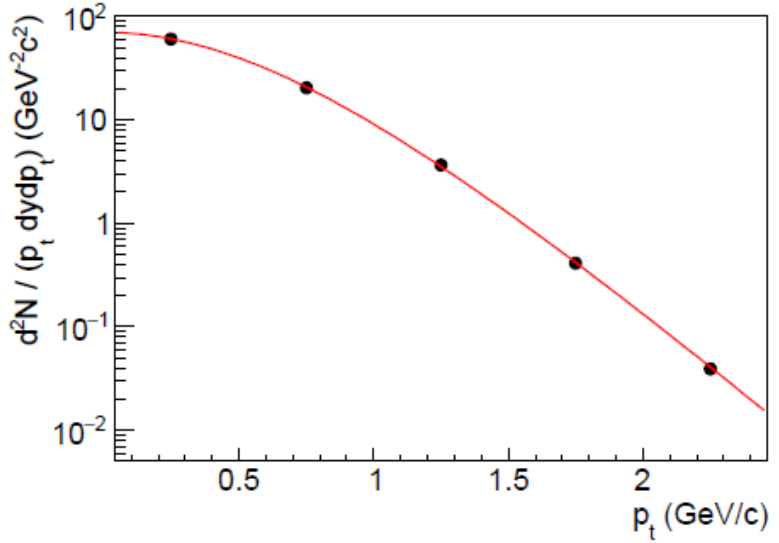
PV *- primary vertex*
V0 ***-*** *vertex of decay*
dca- *distance of closest approach*
path *– decay length*





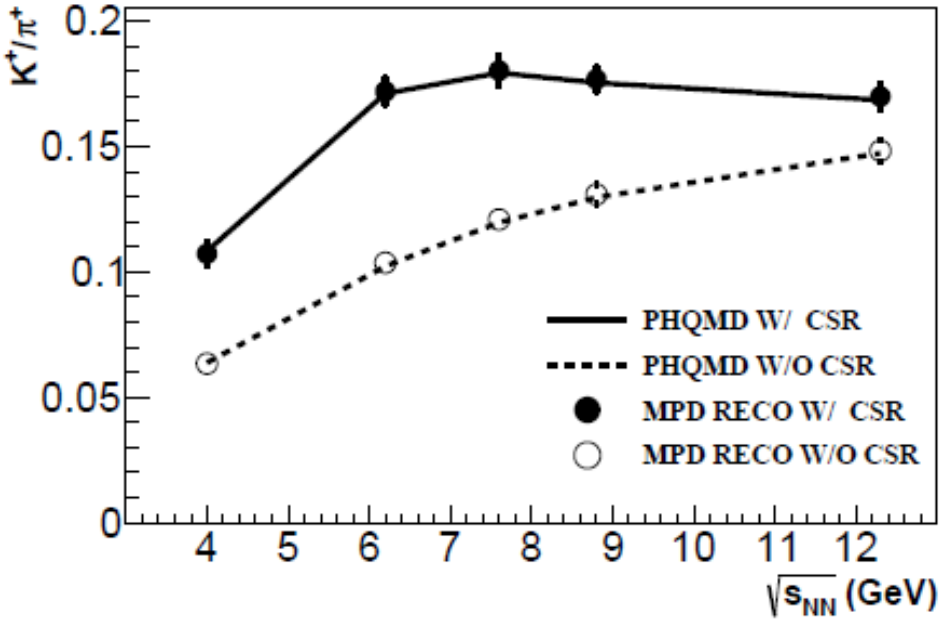


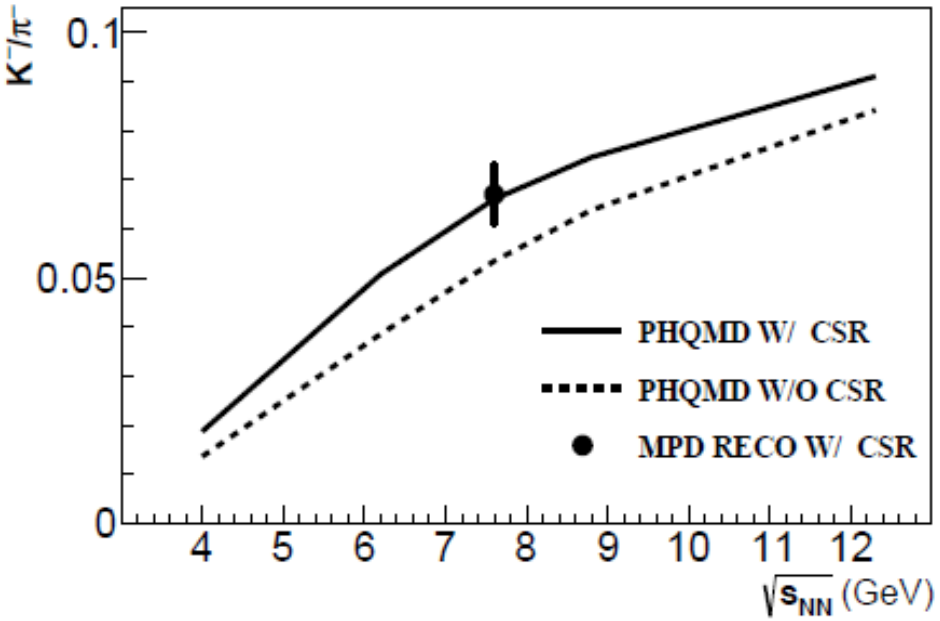


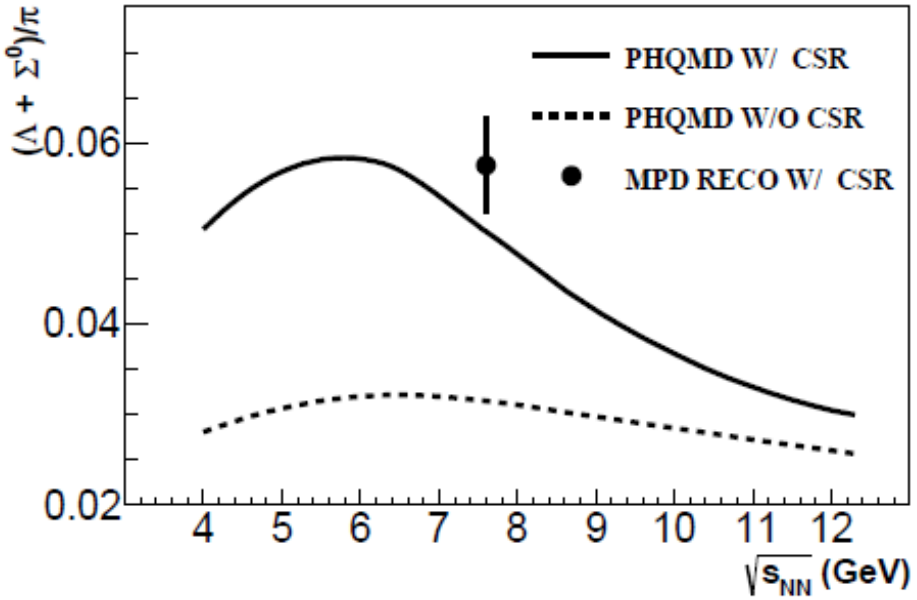


- Invariant pT-spectra for Λ is reconstructed and dN/dy is obtained
- No corrections for the feeddown from cascades and secondaries yet

Results : Excitation function of the strangeness-to-entropy ratio at NICA







- Midrapidity ratios are obtained from several data sets
- Excellent agreement with model for kaons and pions (less than 3% for the K/pi-ratio at all energies)
- Hyperons require extra corrections for the feeddown from weak decays of cascades

Grant RFBR 18-02-40037

The achieved results were presented at 5 Conferences (very recent are Cherenkov-2020 and Nucleus-2020) and published in 3 papers (3 more submitted and are in the queue)

A.A. Mudrokh et al, Physics of Particles and Nuclei, 2020, Vol. 51, No. 3, pp. 327–330

V. Kolesnikov et al, Physics of Particles and Nuclei Letters, 2020, Vol. 17, No. 3, pp. 358–369

V. I. Kolesnikov and A. A. Mudrokh, Physics of Atomic Nuclei, 2020, Vol. 83, No. 9, pp. 1–6

ISSN 1547-4771, Physics of Particles and Nuclei Letters, 2020, Vol. 17, No. 3, pp. 358–369. © Pleiades Publishing, Ltd., 2020.

METHODS OF PHYSICAL EXPERIMENT

Performance of the MPD Detector in the Study of the Strangeness to Entropy Ratio in Heavy-Ion Collisions at the NICA Accelerator Complex

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Summary

- Strangeness production is among the key topics in the NICA program
- A realistic MPD simulation and reconstruction of the yields of $K^{+/-}$, $\pi^{+/-}$ and Λ is conducted at several collision energies
- MPD potential for the study of the excitation function of the strangeness-to-entropy ratio is estimated

Thank you for attention