MPD PWG2 status report

Vadim Kolesnikov

(VBLHEP, JINR)

on behalf of the group

MPD Collaboration meeting
JINR, Dubna, April 23, 2020

Outline

- ❑ **Intro / reminder (PWG2 tasks)**
- ❑ **Feasibility study results for MPD physics cases :**

<u>Related to PWG2</u>

- Model development
- Hadroproduction with the MPD detector (hadron spectra and yields)
- Multistrange hyperons
- Hypernuclei

<u>Partially related to PWG2</u>

- Hyperon flow
- Ev-by-Ev fluctuations of net-protons

- ❑ **Summary**

PWG2 co-conveners:

Xianglei Zhu (Tsinghua Univ., China) *zhux@tsinghua.edu.cn*

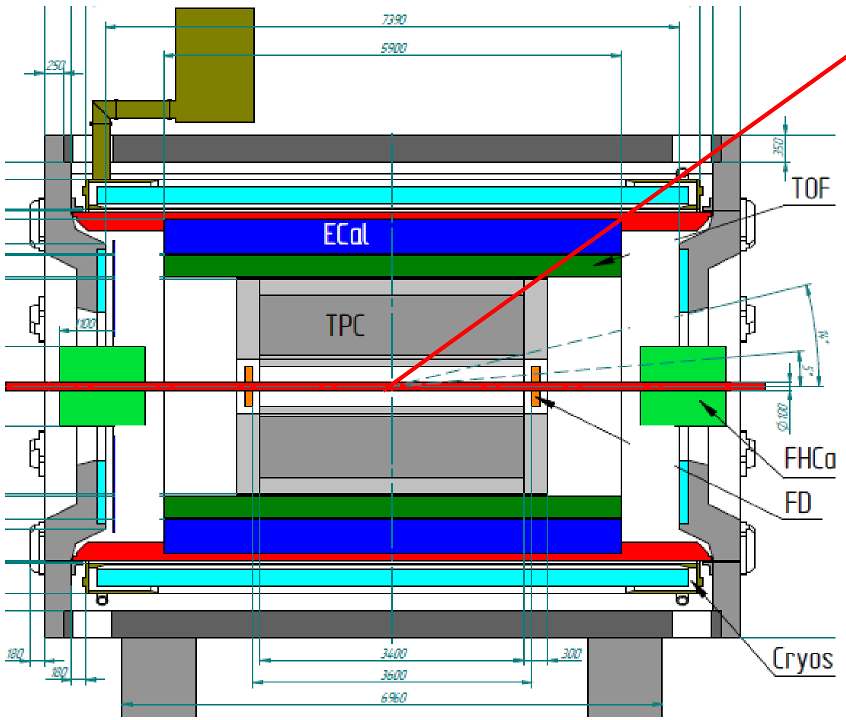
Vadim Kolesnikov (JINR, Dubna, Russia) *Vadim.Kolesnikov@cern.ch*

PWG2 members : currently 13 persons from Russia, Poland, China + several are interesting

PWG2 physics cases

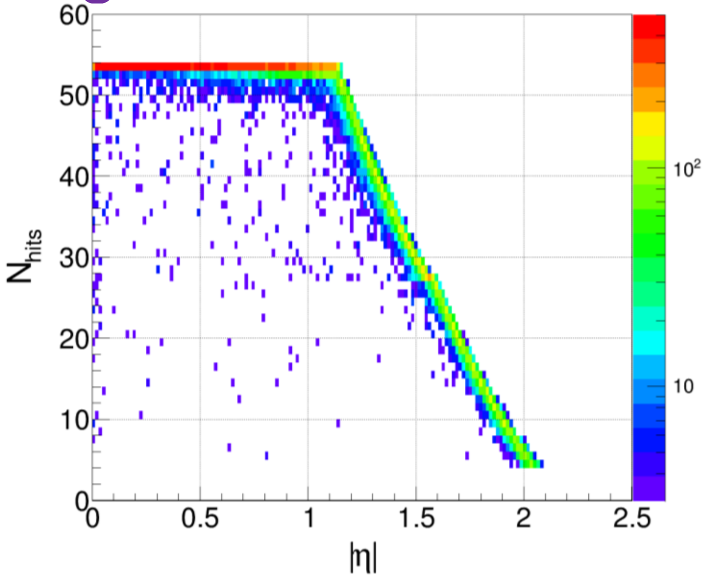
- **Light flavor hadron spectra, yields, and ratios**
  - Energy, system size and centrality dependence of the production of charged hadrons (pions, kaons, (anti)protons).
  - Extraction of transverse momentum spectra, rapidity distributions, mean multiplicities, and particle ratios.
  - Nuclear modification factor, antiparticle/particle ratio, radial flow, phase diagram mapping.
- **Strangeness (hyperons and hypernuclei)**
  - Analysis of strange hyperons (Lambda, Ksi, Omega) and their antiparticles: spectra, yields, antiparticle/particle ratio, nuclear modification factor, azimuthal anisotropy (together with PWG3).
  - (Anti)Lambda polarization.
  - Reconstruction of single and double hypernuclei: spectra, rapidity density, and lifetime.
- **Resonances**
  - Production of \rho, \phi, Kstar, Lambda(1520) etc.
- **Light nuclei**
  - Production of nucleon clusters (d, t, He3, He4) in various reactions (from p+p to Au+Au): spectra, yields, coalescence coefficients.

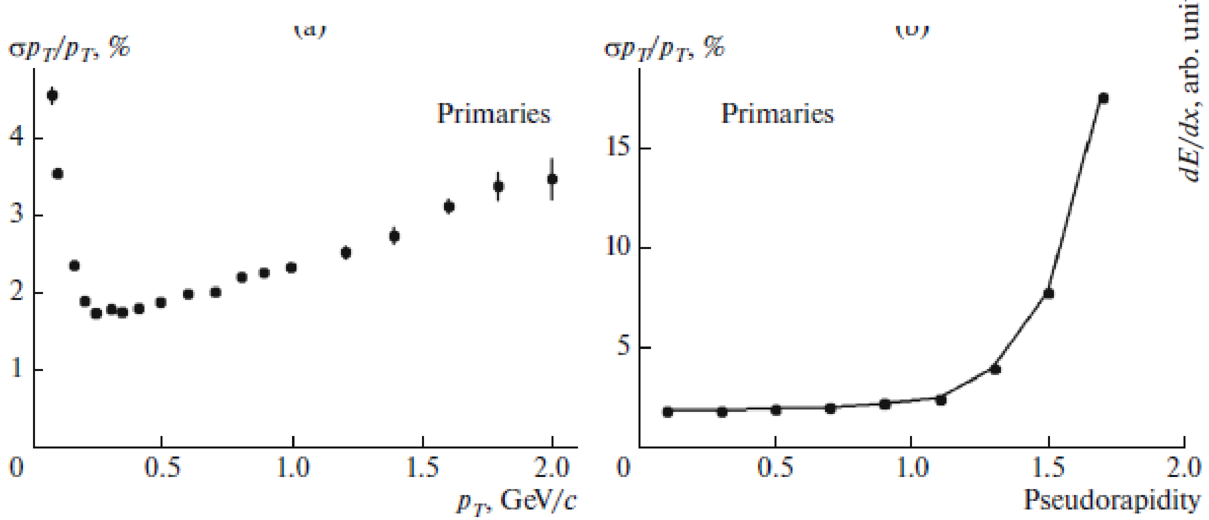
MPD setup abd overall performance for Stage1

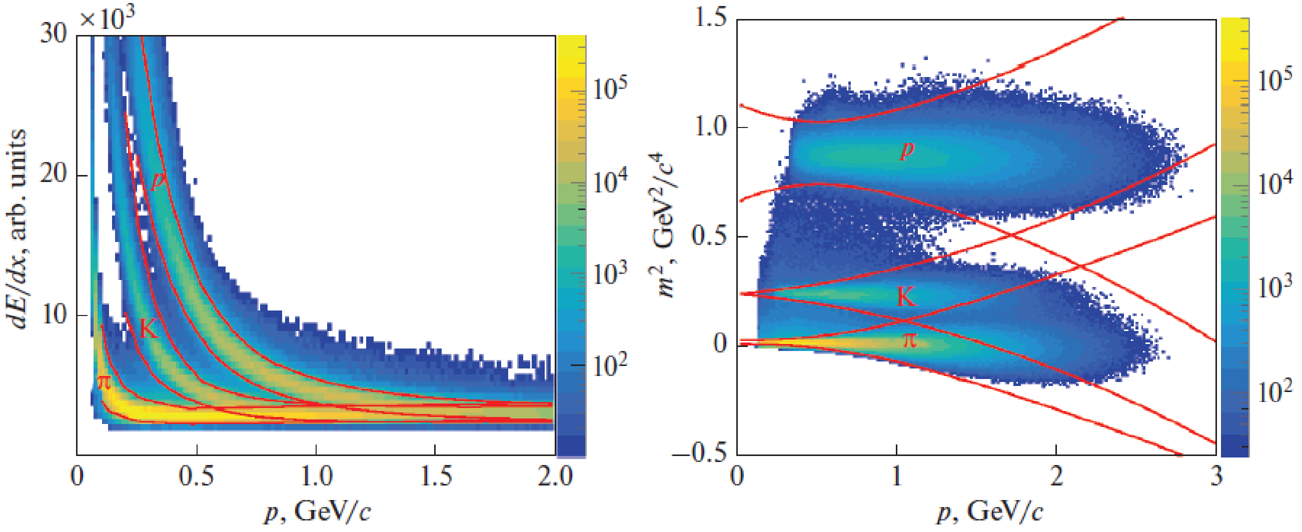


MPD at Stage'1:

- ***TPC*** *tracking: |η|<1.6 (Npoints>15)*
- ***TOF & ECAL*** *coverage: |η|<1.3*
- ***PID****: combined |η|<1.3, pT<3 GeV/c, limited PID 1.3</η|<1.6 (dE/dx)*

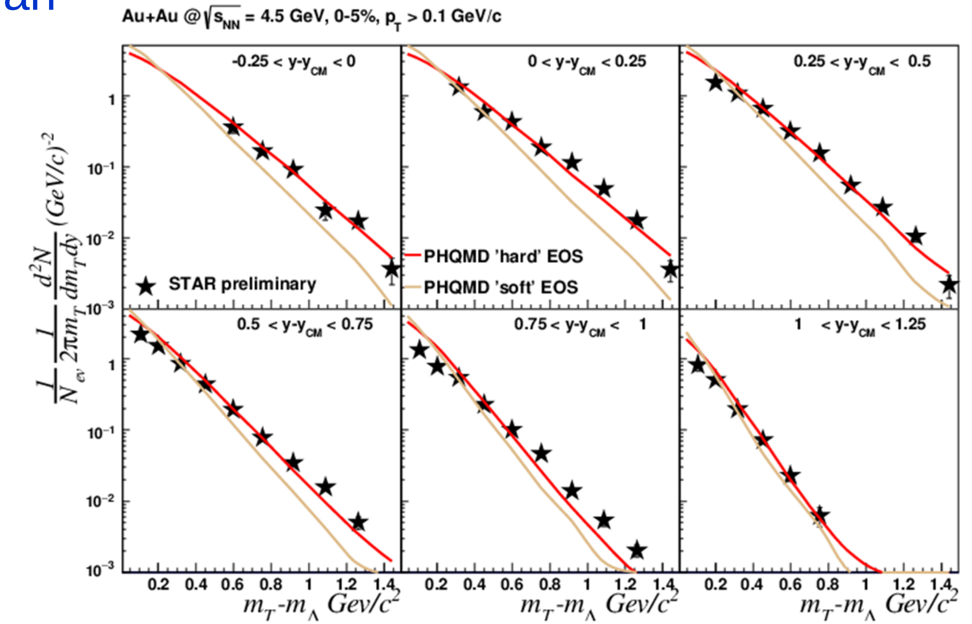






Development & tests of models

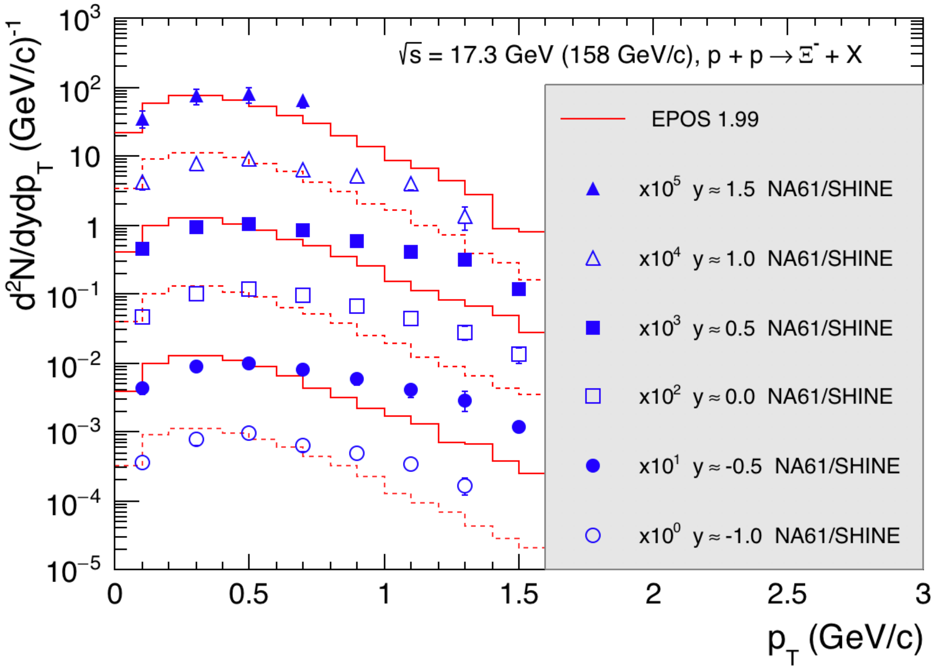
V.Kireyeu, V.Vasendina, K.Shtejer, D.Drnoyan

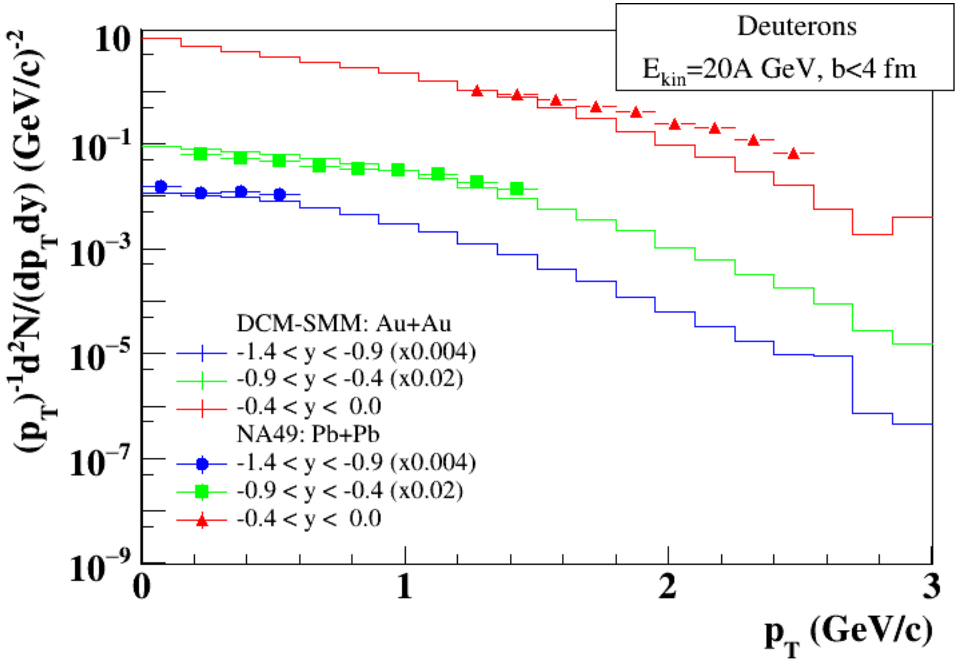


Goals of the activity:

- Reliable simulation input for particular energies/systems (for example, p+p)
- Testing dedicated event generators for specific probes (for instance for (hyper)nuclei)

Models under study/development: ***EPOS, PHSD/PHQMD, DSM-SMM***





Hadroproduction in *p+p* collisions at NICA energies

- To collect the most complete set of experimental data of hadron yields from p+p collisions in the NICA energy range including results of mean multiplicities, rapidity distributions, and transverse spectra.
- To undertake a systematic study of the collected experimental results as a function of the collision energy and obtain proper parameterizations for the energy dependence of inclusive production cross-sections, as well as investigate the evolution of the parameters of the hadron phase-space distributions.
- Since most bulk observables relate to the non-perturbative sector of QCD, it is one of the main goals of this work to obtain the basis for a model independent framework for predicting of hadron yields in p+p collisions at NICA energies.

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PHYSICS OF ELEMENTARY PARTICLES AND ATOMIC NUCLEI. EXPERIMENT

A New Review of Excitation Functions of Hadron Production in *pp* Collisions in the NICA Energy Range

V. Kolesnikov[a, *], V. Kireyeu[a], V. Lenivenko[a], A. Mudrokh[a], K. Shtejer[a], D. Zinchenko[a], and E. Bratkovskaya[b]

Abstract—Data on hadron multiplicities from inelastic proton-proton interactions in the energy range of the NICA collider have been compiled. The compilation includes recent results from the NA61/SHINE and NA49 experiments at the CERN SPS accelerator. New parameterizations for excitation functions of mean multiplicities $\langle\pi^{\pm}\rangle$, $\langle K^{\pm}\rangle$, $\langle K_S^0\rangle$, $\langle\Lambda\rangle$, $\langle p\rangle$, $\langle\bar{p}\rangle$ are obtained in the region of collision energies $3 < \sqrt{s_{NN}} < 31$ GeV. The energy dependence of the particle yields, as well as variation of rapidity and transverse momentum distributions are discussed. A standalone algorithm for hadron phase space generation in *pp* collisions is suggested and compared to model predictions using an example of the PHQMD generator. The investigation has been performed at the Laboratory of High Energy Physics, JINR.

Hadroproduction in *p+p* collisions at NICA energies : data compilation (II)

Table 1. The compiled results on the mean multiplicity of charged pions from inelastic proton-proton interactions at different collision energies

Reference	$\sqrt{s_{NN}}$, GeV	$\langle \pi^- \rangle$	Error, %
[6, 17]	2.99	0.2	10
[6, 17]	3.50	0.29	10
[6, 17]	4.93	0.63	10
[6, 17]	5.03	0.75	10
[17]	5.10	0.72	10
[17]	5.97	0.98	10
[6, 17]	6.12	1.01	10
[12]	6.27	1.05	5
[13]	6.27	1.08	19
[17]	6.38	1.08	10
[6, 17]	6.84	1.11	10
[17]	6.86	1.11	10
[17]	7.43	1.21	10
[12]	7.74	1.31	5
[13]	7.75	1.47	13
[12]	8.76	1.48	3
[13]	8.76	1.71	10
[12]	12.32	1.94	4
[13]	12.32	2.03	9
[6, 17]	13.90	2.19	10
[12]	17.30	2.44	5
[13]	17.30	2.40	8
[10]	17.30	2.36	2
[17]	19.75	2.82	10
[17]	22.02	2.98	10
[10, 17]	30.98	3.44	10
Reference	**$\sqrt{s_{NN}}$, GeV**	**$\langle \pi^+ \rangle$**	**Error, %**
[6, 17]	2.99	0.48	10
[6, 17]	3.50	0.67	10
[6, 17]	4.93	1.22	10
[6, 17]	5.03	1.37	10
[6, 17]	6.12	1.6	10
[13]	6.27	1.88	11
[6, 17]	6.84	1.88	10
[13]	7.75	2.08	10
[13]	8.76	2.39	7
[13]	12.32	2.67	5
[13]	17.30	3.11	13
[10]	17.30	3.02	2

Table 2. The compiled results on the mean multiplicity of charged kaons from inelastic proton-proton interactions at different collision energies

Reference	$\sqrt{s_{NN}}$, GeV	$\langle K^- \rangle$	Error, %
[6, 17]	5.03	0.0095	35
[6, 17]	6.15	0.036	14
[13]	6.27	0.024	26
[6, 17]	6.84	0.031	14
[13]	7.75	0.045	11
[6]	7.86	0.05	30
[6, 17]	8.21	0.07	29
[13]	8.76	0.084	8
[6, 17]	9.08	0.08	25
[6, 17]	9.97	0.11	27
[6, 17]	11.54	0.13	23
[13]	12.32	0.095	7
[13]	17.30	0.132	11
[10]	17.30	0.13	10
[17]	22.02	0.24	10
[10]	23.00	0.171	15
[6]	23.68	0.209	15
[6]	30.59	0.244	15
[10, 17]	30.98	0.245	10
Reference	**$\sqrt{s_{NN}}$, GeV**	**$\langle K^+ \rangle$**	**Error, %**
[6]	2.98	0.0046	15
[6, 17]	2.99	0.0035	16
[6]	2.99	0.0044	18
[6]	3.12	0.0057	18
[6]	3.35	0.0069	15
[6, 17]	3.50	0.008	21
[6]	4.11	0.02	20
[6, 17]	5.03	0.07	43
[6]	5.35	0.054	10
[6, 17]	6.15	0.107	2
[13]	6.27	0.097	14
[6, 17]	6.84	0.1188	1 3
[13]	7.75	0.157	12
[13]	8.76	0.17	15
[6, 17]	11.54	0.21	28
[13]	12.32	0.201	7
[13]	17.30	0.234	9
[10]	17.30	0.227	5
[17]	22.02	0.35	10
[10]	23.00	0.273	15
[6]	23.68	0.337	15

Table 3. The compiled results on the mean multiplicity of $\langle K_S^0 \rangle$ and $\langle \Lambda \rangle$ from inelastic proton-proton interactions at different collision energies

Reference	$\sqrt{s_{NN}}$, GeV	$\langle K_S^0 \rangle$	Error, %
[6]	2.98	0.00083	22
[6]	3.35	0.0019	16
[6, 17]	3.50	0.00364	3
[6]	3.63	0.0034	9
[6]	3.85	0.0064	8
[6]	4.08	0.0072	8
[6, 17]	4.93	0.0202	2
[6, 17]	5.01	0.023	2
[6, 17]	6.12	0.0415	3
[6, 17]	6.84	0.0495	2
[6]	6.91	0.045	9
[6]	11.45	0.109	6
[6]	13.76	0.122	8
[6, 17]	13.90	0.141	10
[6]	16.66	0.158	4
[6]	19.42	0.16	13
[6]	19.66	0.181	8
[10]	23.00	0.222	10
[6]	23.76	0.224	8
[6]	26.02	0.26	4
[6]	27.43	0.2	10
[6]	27.60	0.232	5
[10, 17]	30.98	0.274	10
Reference	**$\sqrt{s_{NN}}$, GeV**	**$\langle \Lambda \rangle$**	**Error, %**
[6]	2.98	0.0033	18
[18]	3.17	0.0073	4
[6]	3.35	0.0073	4
[6, 17]	3.50	0.0127	9
[6]	3.63	0.0109	6
[6]	3.85	0.0172	6
[6]	4.08	0.0201	5
[6, 17]	4.93	0.0388	2
[6, 17]	5.01	0.035	11
[6, 17]	6.12	0.061	3

Table 4. The compiled results on the mean multiplicity of $\langle p \rangle$ and $\langle \bar{p} \rangle$ from inelastic proton-proton interactions at different collision energies

Reference	$\sqrt{s_{NN}}$, GeV	$\langle p \rangle$	Error, %
[6, 17]	3.50	1.56	10
[6, 17]	4.93	1.68	10
[6, 17]	5.01	1.55	10
[6, 17]	6.12	1.41	10
[6, 17]	6.15	1.69	10
[13]	6.27	1.154	4
[6, 17]	6.84	1.615	10
[13]	7.75	1.093	6
[13]	8.76	1.095	8
[13]	12.32	0.977	14
[13]	17.30	1.069	12
[10]	17.30	1.162	15
[17]	22.02	1.28	10
[10, 17]	30.98	1.34	10
Reference	**$\sqrt{s_{NN}}$, GeV**	**$\langle \bar{p} \rangle$**	**Error, %**
[6, 17]	6.15	0.0023	10
[13]	6.27	0.0047	15
[6, 17]	6.84	0.004	10
[13]	7.75	0.0047	16
[6, 17]	8.21	0.005	10
[13]	8.76	0.0059	12
[6, 17]	9.08	0.008	10
[6, 17]	9.97	0.011	10
[6, 17]	11.54	0.015	10
[13]	12.32	0.0183	10
[13]	17.30	0.0402	9
[10]	17.30	0.039	15
[17]	22.02	0.061	10
[10, 17]	30.98	0.11	10

Hadroproduction in *p+p* collisions at NICA energies : data analysis (III)

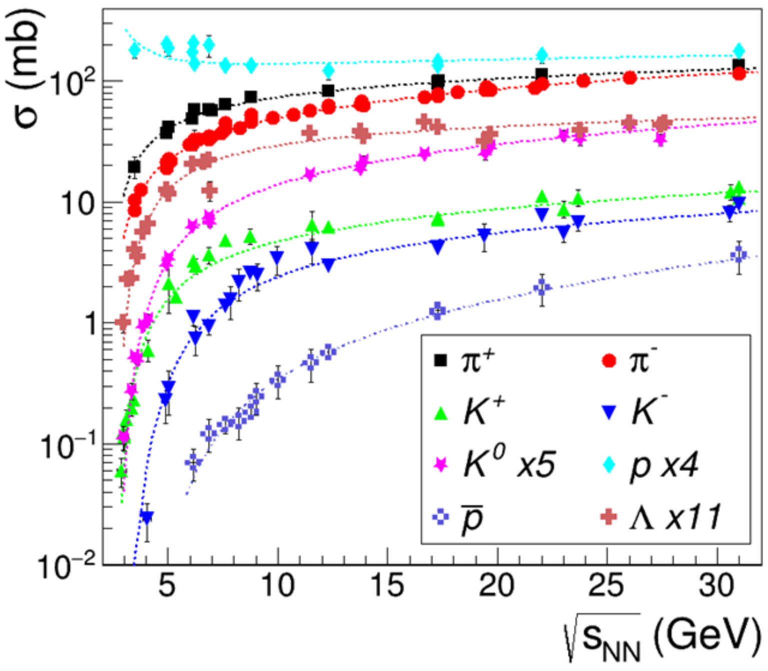
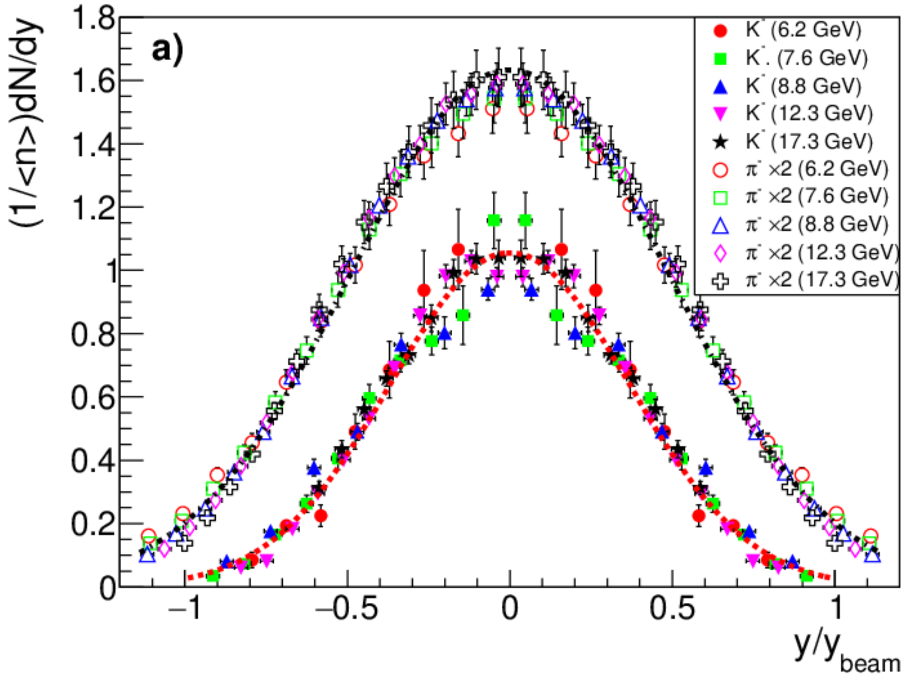
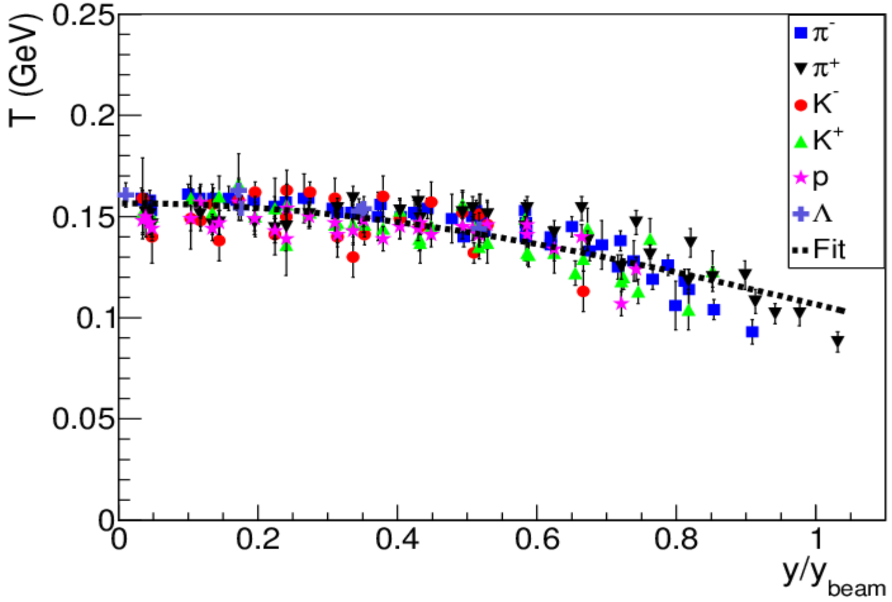


Fig. 4. Inclusive hadron production cross-sections from *pp* interactions as a function of the center-of-mass energy. Dashed lines are parameterizations to Eq. (2).



Scaled yields of K- and pi- as a function of normalized rapidity from p+p at 6-17 GeV

Similar shapes!



The slope parameter ***T*** in bins of y/y_{beam}

Unique parameterization!

Strangeness-to-entropy in Au+Au: MPD performance study

- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

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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

V. Kolesnikov[a, *], V. Kireyeu[a], A. Mudrokh[a], A. Zinchenko[a], and V. Vasendina[a]

[a]*Joint Institute for Nuclear Research, Dubna, Russia*

**e-mail: Vadim.Kolesnikov@cern.ch*

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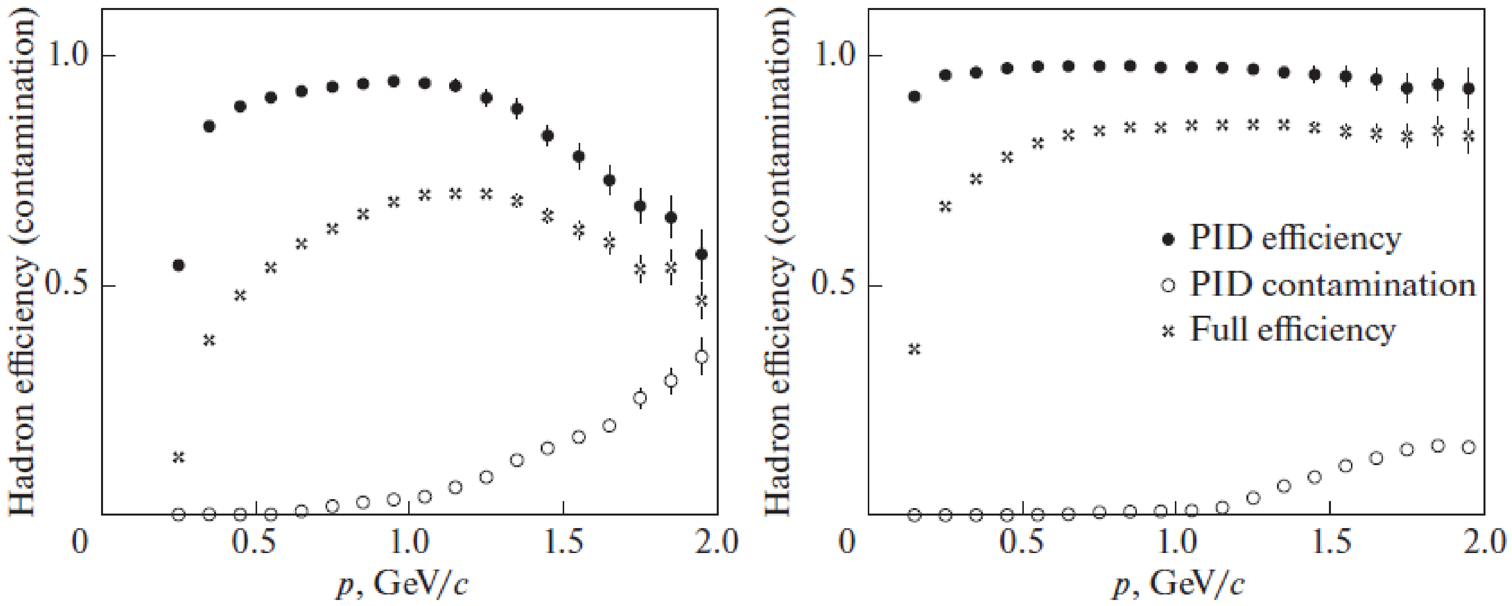
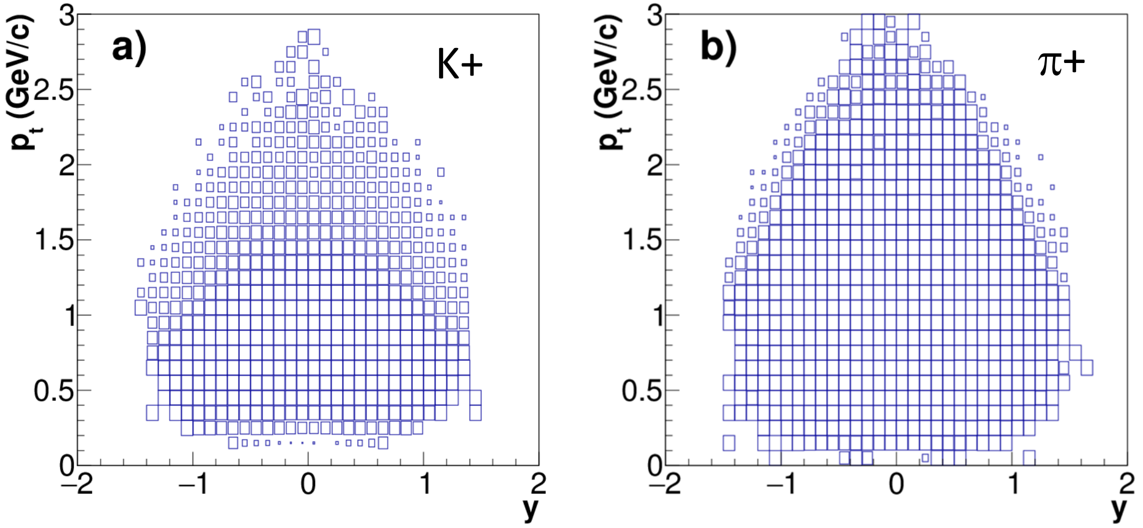
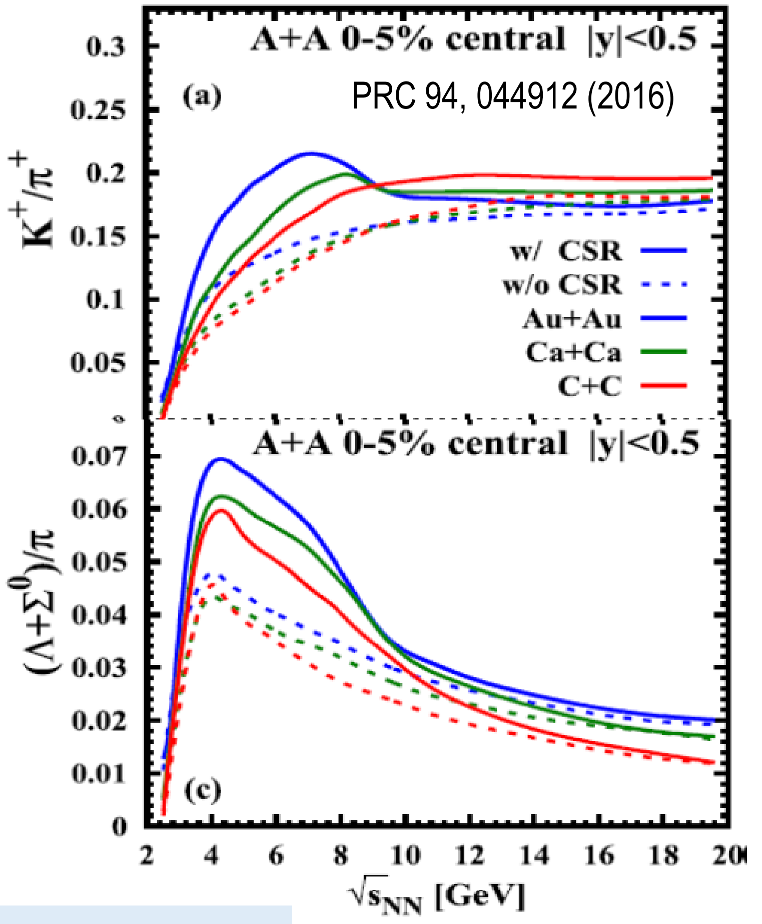
Abstract—Strangeness production in heavy-ion collisions is one of the main goals of the scientific program at the NICA accelerator complex. The MPD detector is designed to study the properties of strongly interacting matter at extreme baryon densities. In this article, the MPD performance to measure the excitation function of the strangeness to entropy ratio in central Au + Au collisions is reported. The investigation has been performed at the Laboratory of High Energy Physics, JINR.

Study of the K/π-ratio in MPD: analysis details

- ✓ *0-5% central Au+Au at 5 energies from the PHSD event generator, which implements partonic phase and CSR effects*
- ✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*

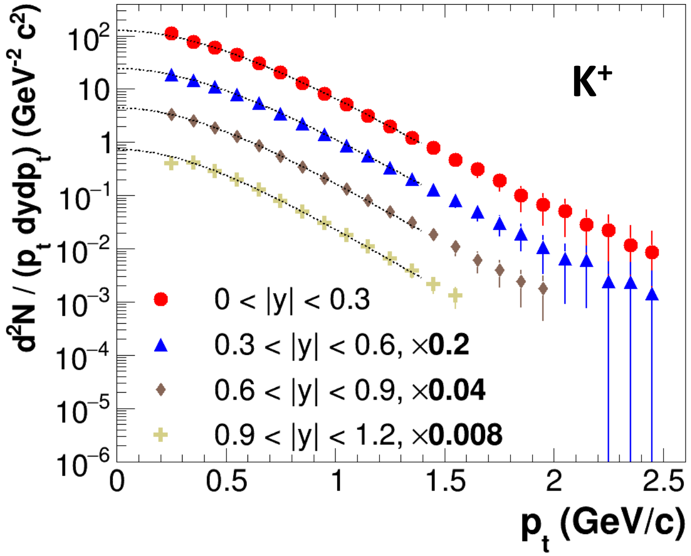


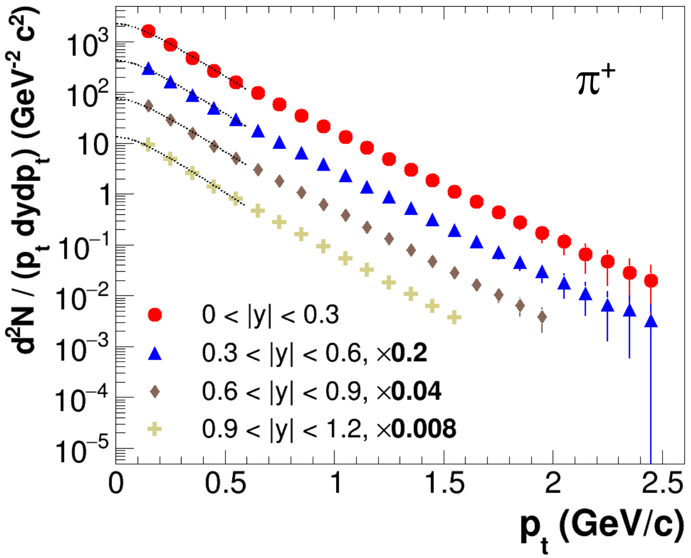




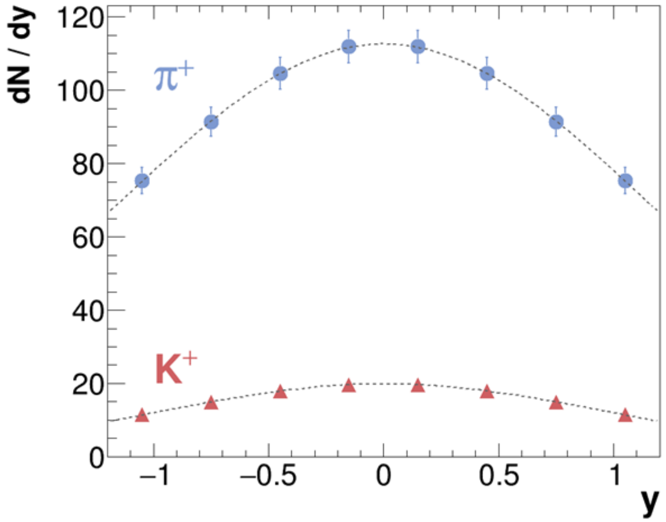
- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)

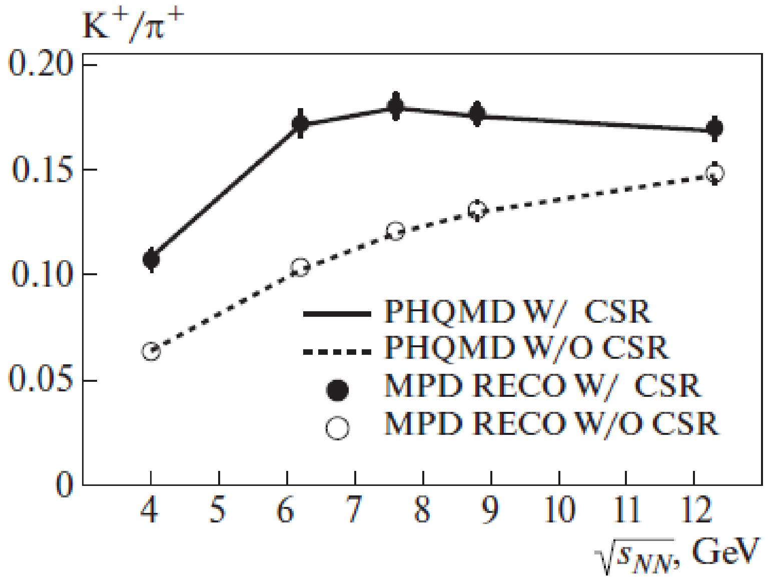
Study of the K/π-ratio in MPD: results

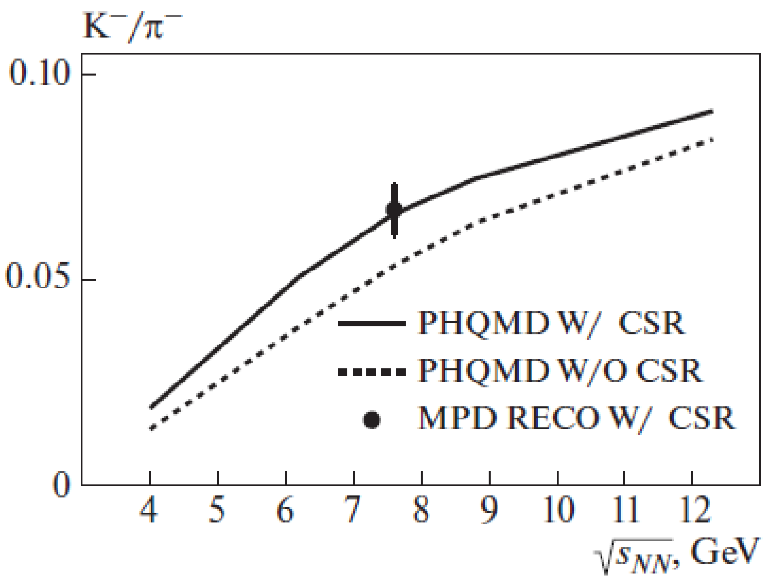




- Hadron spectra can be measured from pT=0.2 to 2.5 GeV/c
- Extrapolation to full pT-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for pT-spectra and Gaussian for rapidity distributions)
- A few percent error for the ratios







Study of hadroproduction with MPD: first results

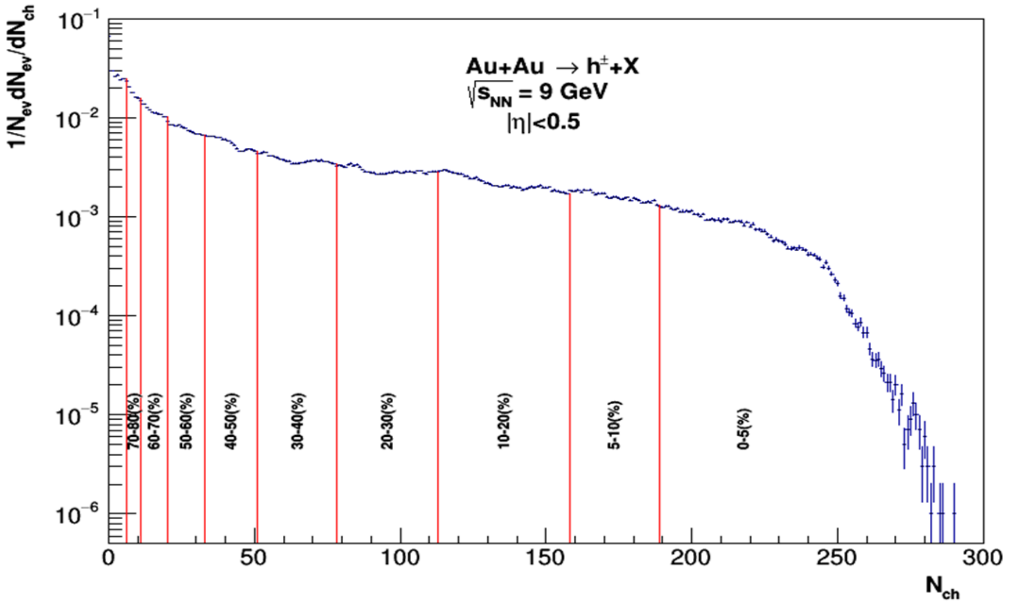
A. Aparin[1], E. Pervyshina[1,2], A. Tutebayeva[1,3]

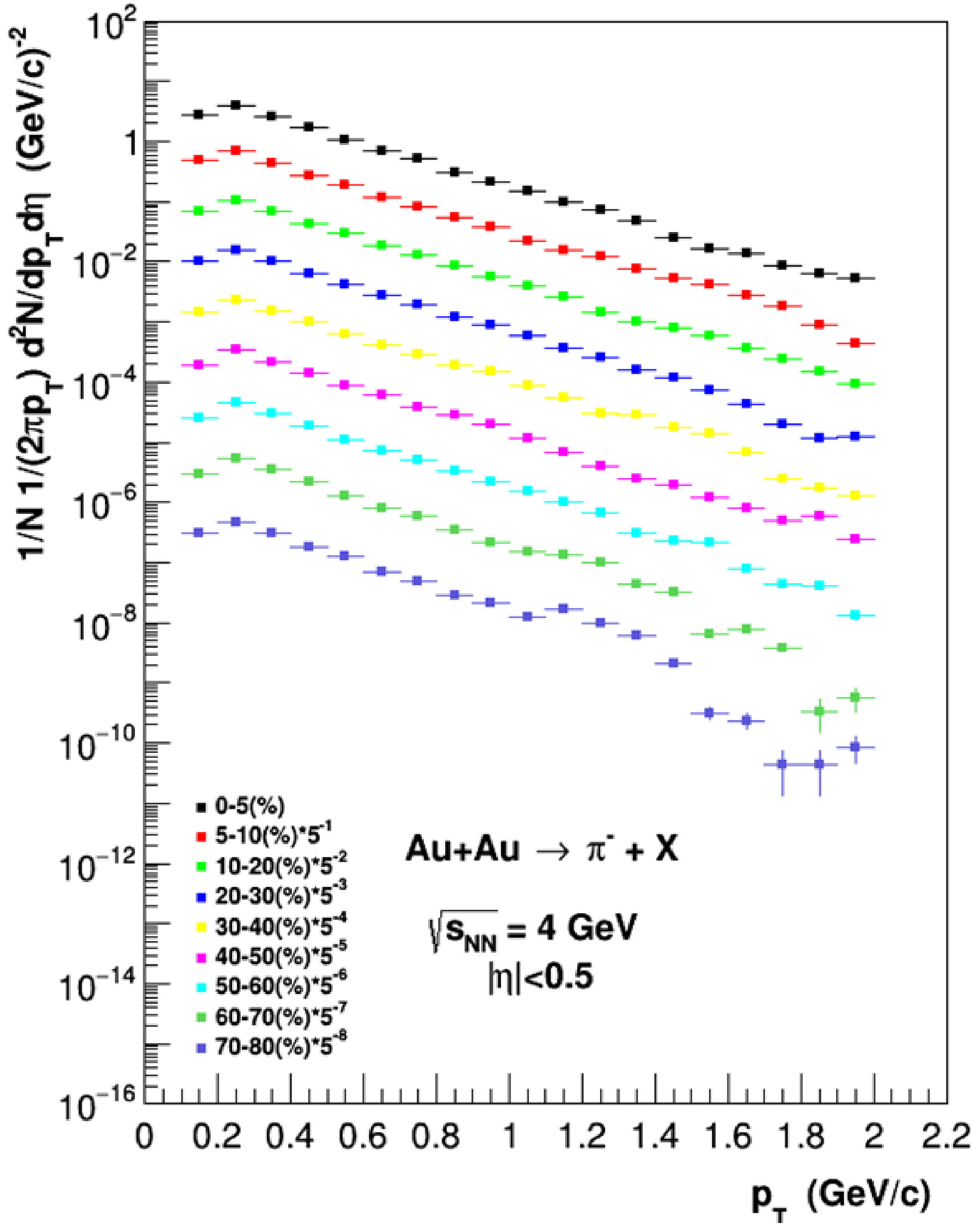
1. *Joint Institute for Nuclear Research*
2. *Lomonosov Moscow State University*
3. *Al-Farabi Kazakh National University*

- Min. bias Au+Au collisions (UrQMD)
- Centrality selection by charged multiplicity in TPC
- Primary, Nhits > 20, pT > 0.1 GeV/c

No final corrections yet - Analysis is ongoing

Different centrality classes for 9 GeV collisions





Study of hyperon production with the MPD: analysis details

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

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**METHODS
OF PHYSICAL EXPERIMENT**

Perspectives of Multistrange Hyperon Study at NICA/MPD from Realistic Monte Carlo Simulation[1]

J. Drnoyan[a], E. Levterova[a], V. Vasendina[a], A. Zinchenko[a, *], and D. Zinchenko[a]
[a]*Veksler and Baldin Laboratory of high energy physics, Joint Institute for Nuclear Research, Dubna, 141980 Russia*
**e-mail: Alexander.Zinchenko@jinr.ru*
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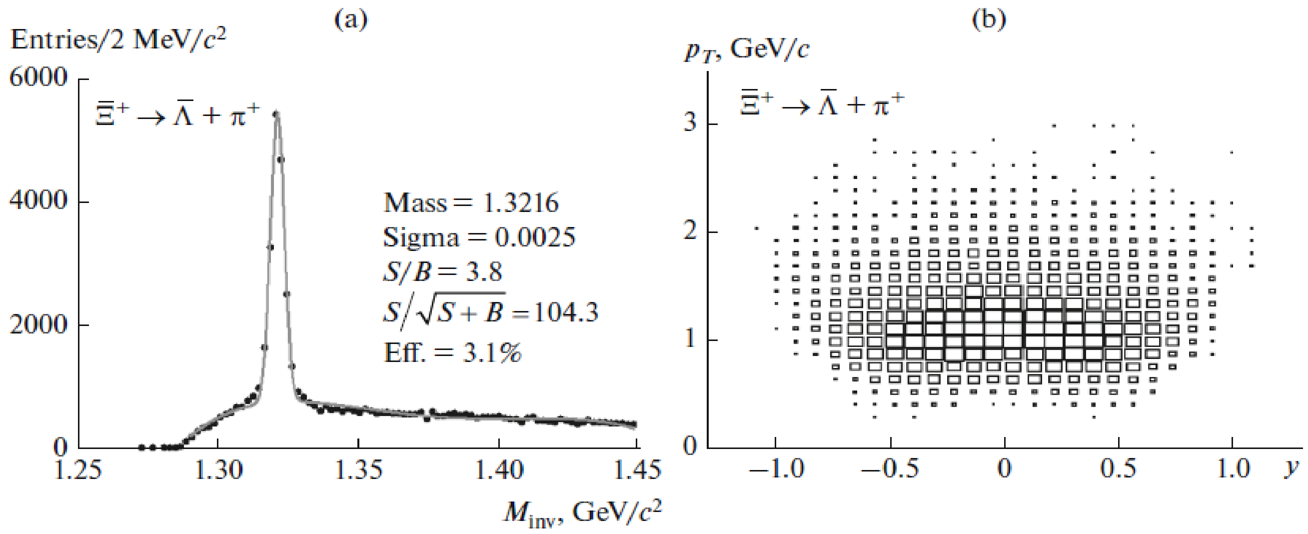
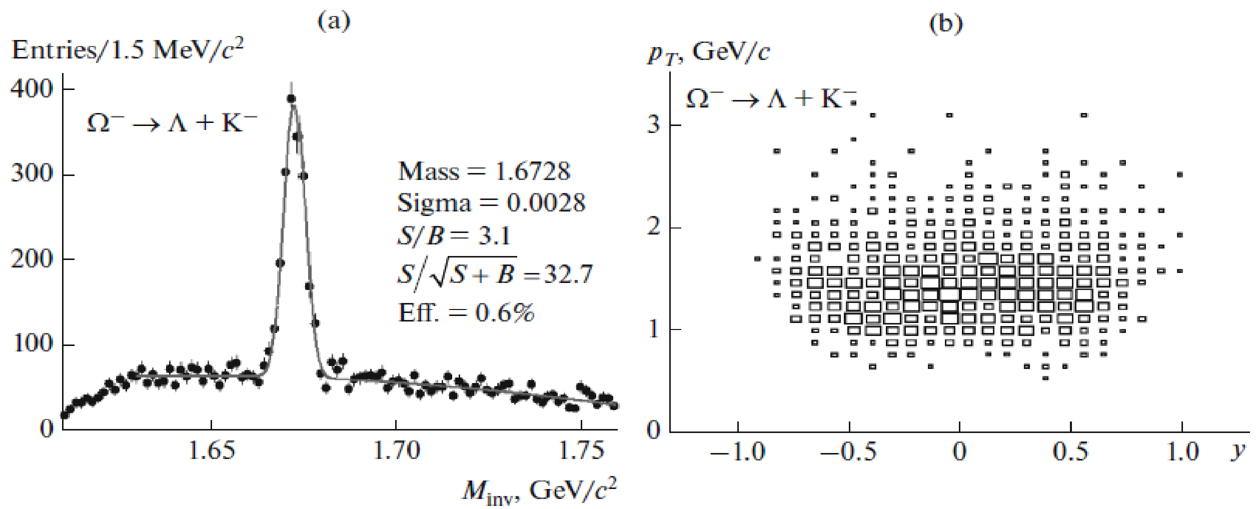
Abstract—One of the main tasks of the NICA/MPD physics program is a study of strangeness production in nuclear collisions. In this paper the MPD detector performance for measurements of multistrange hyperons in Au + Au collisions at NICA energies is presented based on the analysis of realistically simulated data samples. Perspectives of the studies on the strangeness production at the experiment start-up are evaluated.

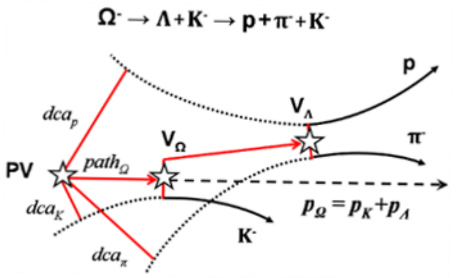
Study of hyperon production with the MPD: results



Reconstructed invariant mass of $\bar{\Xi}^+$ (a) and $y - p_T$ phase spase (b).



Reconstructed invariant mass of Ω^- (a) and $y - p_T$ phase spase (b).



Data set: 8M minbias Au+Au @ 11 GeV (PHSD)

MPD setup: TPC & TOF, ideal centrality binning (no FHCAL)

Selection criteria: $|\eta| < 1.3$, $N_{hits} \geq 10$ + quality/analysis cuts

Realistic track reconstruction: clustering in TPC

Realistic PID: combined dE/dx+TOF

Analysis: secondary vertex finding technique

Encouraging results for multi-strangeness!

Particle	Λ	anti-Λ	Ξ^-	anti-Ξ^+	Ω^-	anti–Ω^+
Yield*	$2 \cdot 10^7$	$3.5 \cdot 10^5$	$1.5 \cdot 10^5$	$8.0 \cdot 10^3$	$7 \cdot 10^3$	$1.5 \cdot 10^3$

Study of hypernuclei production in MPD: analysis details

- Precise information on Y-N interaction: strange sector of nuclear EOS, astrophysics
- Hypernuclei ground, excited states and life times: critical assessments or QCD calculations and model predictions
- Production mechanism of (hyper)nuclei: freezeout vs dynamical transport models

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Russian Text © The Author(s), 2020, published in Izvestiya Rossiiskoi Akademii Nauk, Seriya Fizicheskaya, 2020, Vol. 84, No. 4, pp. 575–579.

Prospects for Studying Hyperons and Hypernuclei on the NICA Collider

V. I. Kolesnikov[a, *], A. I. Zinchenko[a], and V. A. Vasendina[a]
[a] *Joint Institute for Nuclear Research, Dubna, 141980 Russia*
**e-mail: Vadim.Kolesnikov@cern.ch*

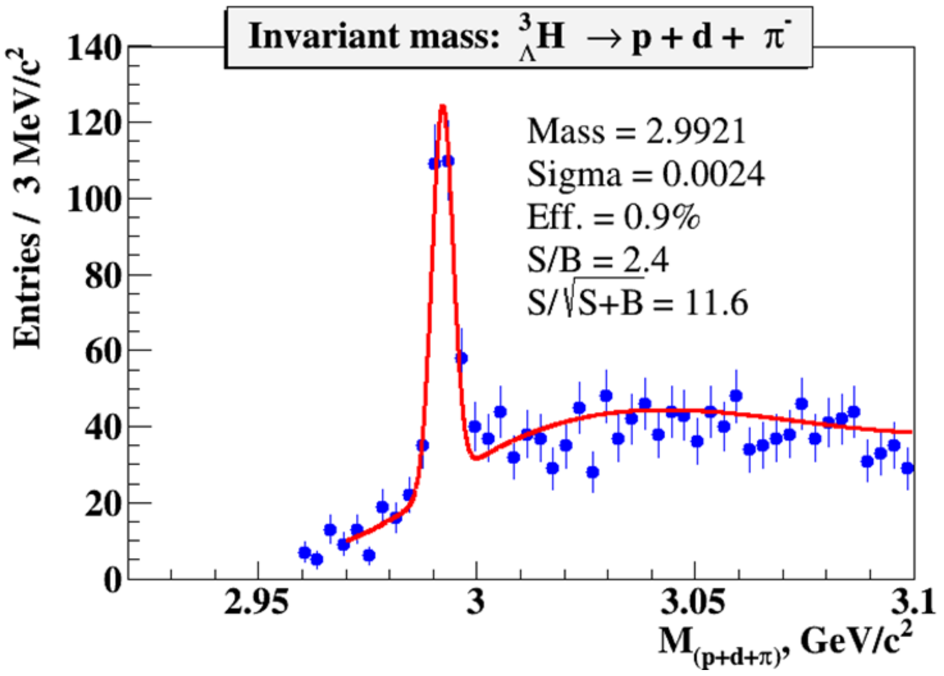
Received October 30, 2019; revised November 25, 2019; accepted December 27, 2019

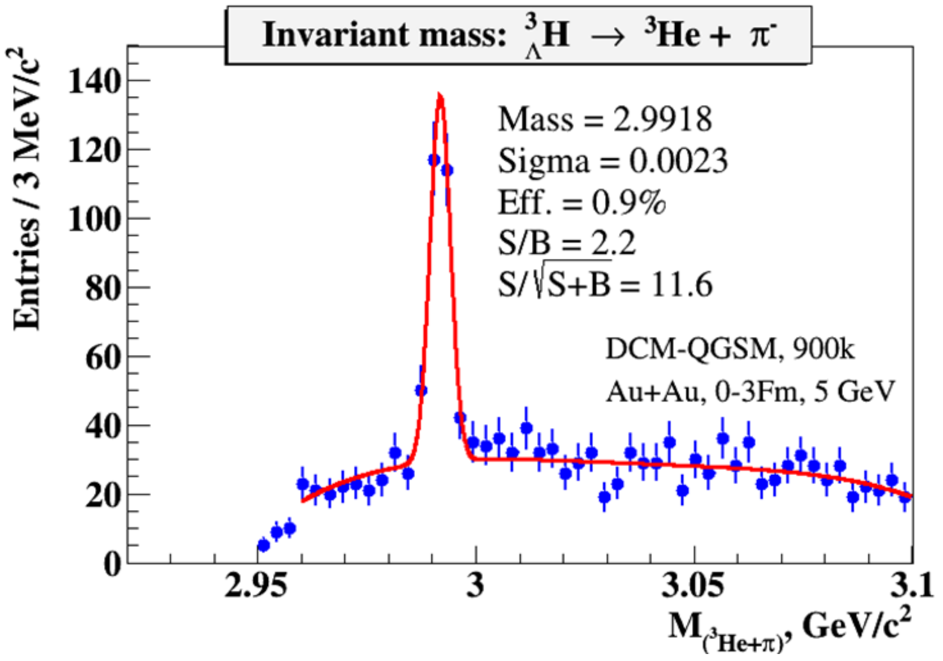
Abstract—NICA is a new flagship project in Dubna aimed at constructing a new accelerator complex for heavy ions. The main goal of the project is experimental exploration of the still poorly known region of the nuclear matter phase diagram of the highest net-baryon density. The MPD detector is a multi-purpose large acceptance spectrometer for studying heavy-ion collisions. An overview is presented of the NICA physics program for studying strangeness production and present MPD performance for reconstructing hyperons and hypernuclei.

Study of hypernuclei production with the MPD: results

- **Generator: 900k** central Au+Au @ 5 GeV (DCM-QGSM[1])
- **Detectors:** MPD Satge'1 configuration (barrel)
- **Track acceptance criterion:** $|\eta| < 1.3$, $N_{hits} \geq 10$
- Realistic track reconstruction and PID (TPC + TOF)

[1] J. Steinheimer, K. Gudima, et al, Phys. Lett. B 714 (2012) pp 85-91





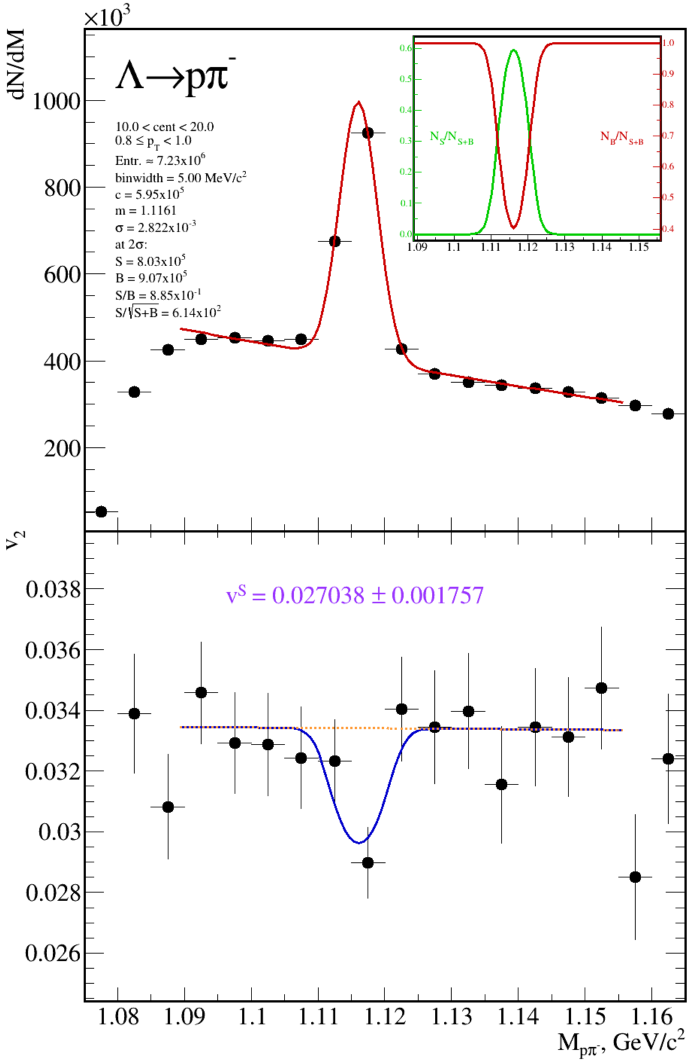
A signal of 400 $_{\Lambda}^{3}H$ is seen (~2 days of data taking)

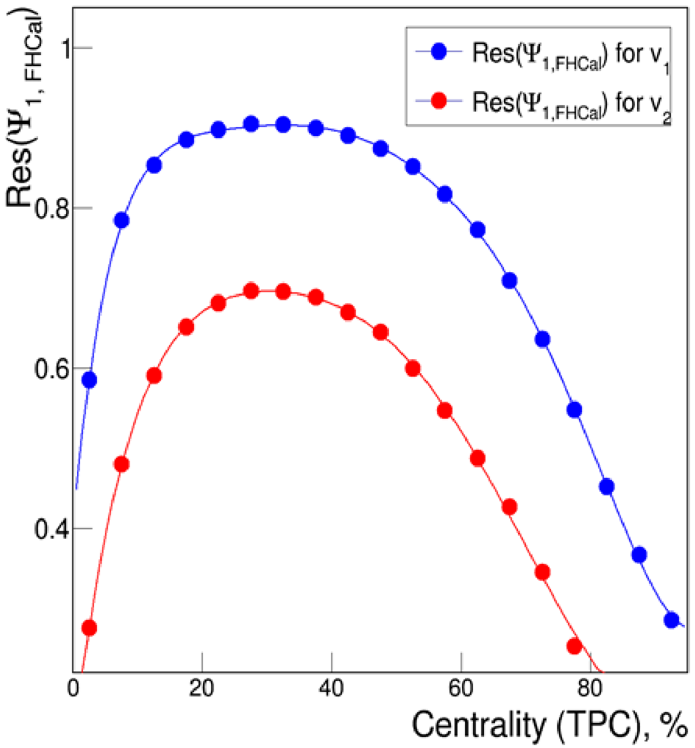
Hyperon Flow : results

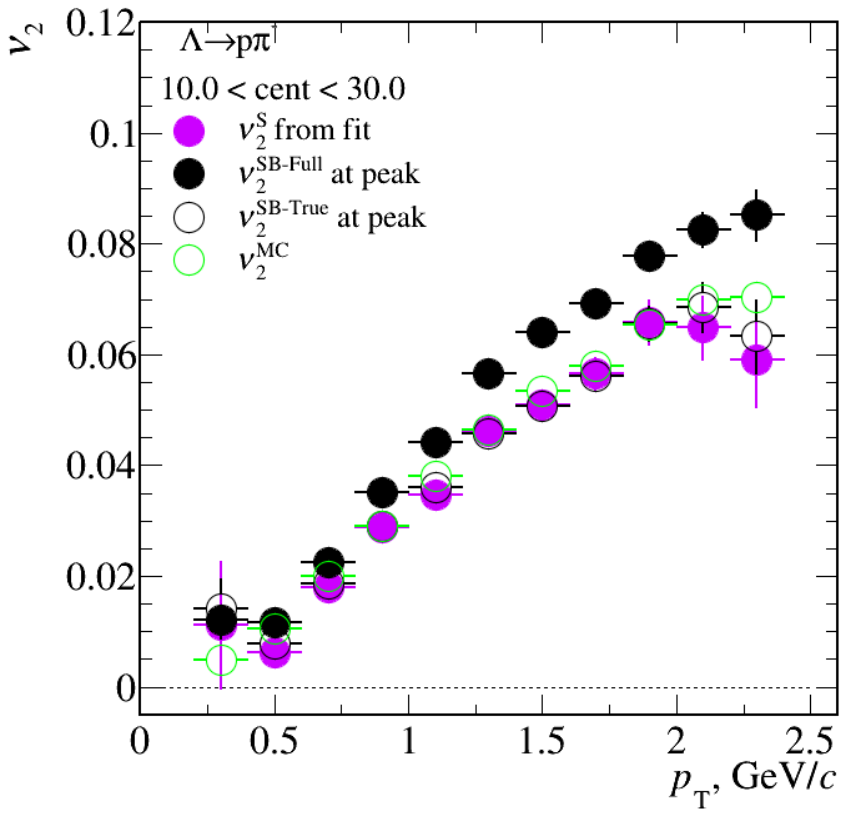
N.Geraksiev (JINR, Plovdiv Univ.)

- 15M Au+Au at 11 GeV (UrQMD)
- Recent tracking & V0 reco, MC PID
- Event plane - FHCAL

$$v_2^{SB}(m_{inv},p_T) = v_2^S(p_T)\frac{N^S(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)} + v_2^B(m_{inv},p_T)\frac{N^B(m_{inv},p_T)}{N^{SB}(m_{inv},p_T)}$$







Extracted flow signal after fit

Measured flow (s+bg) at peak region

Measured flow only for True

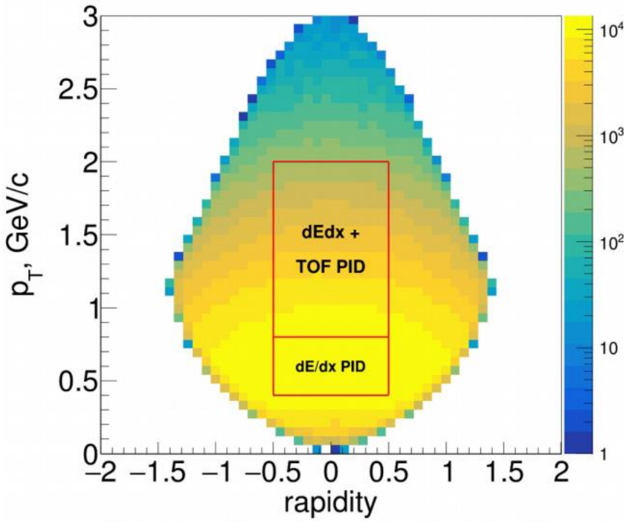
Measured flow from MC/model

MPD prospects for the QCD critical end point search: net-proton cumulants

A. Mudrokh (JINR)

Cumulant ratios of net-proton multiplicity distribution are directly compared to susceptibilities, which diverge in the proximity of CEP in central A+A collisions

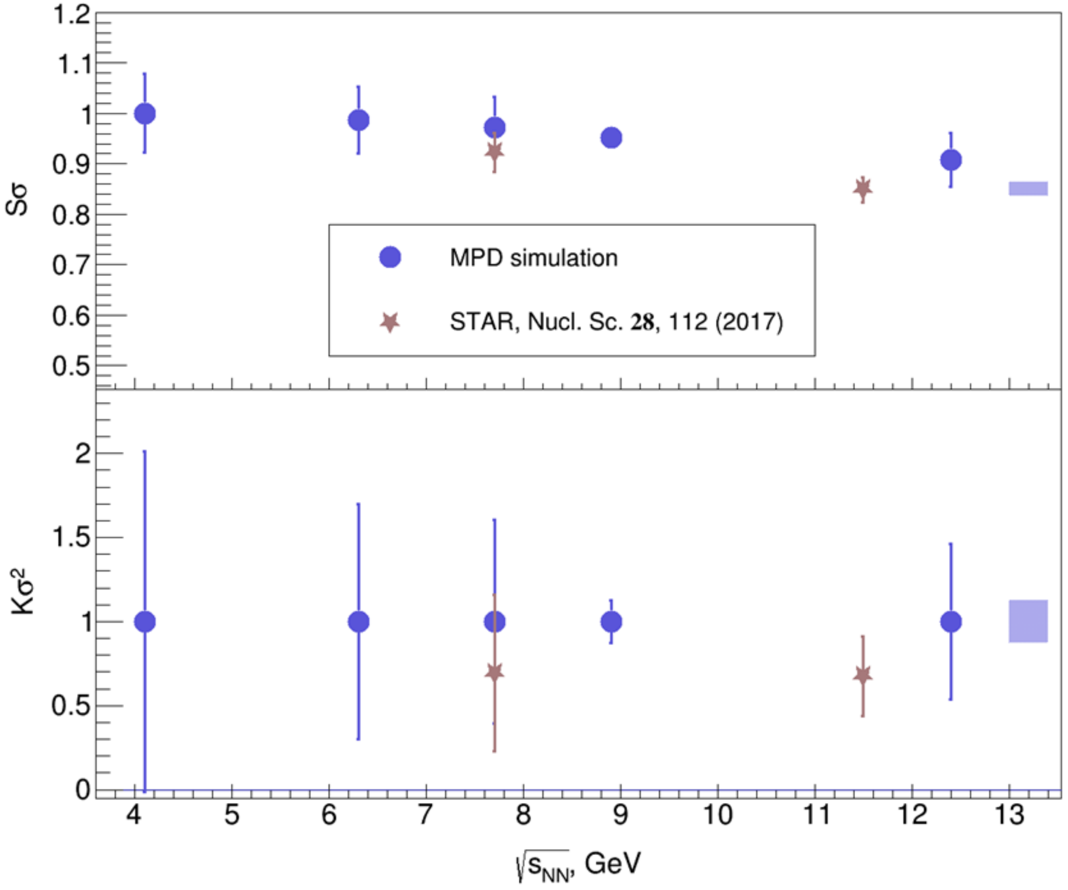
$$\frac{k_3}{k_2} = S\sigma \qquad \frac{k_4}{k_2} = K\sigma^2$$

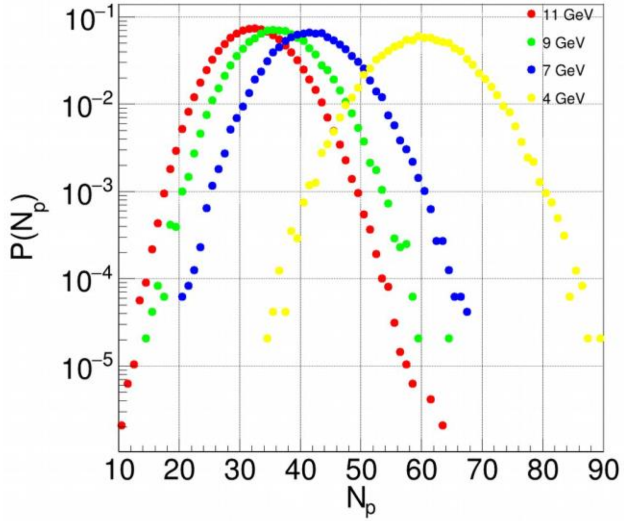


- Au+Au 5% central (PHSD model)
- Full MPD reconstruction
- Combined dE/dx+TOF particle ID

Corrections for the MPD inefficiency:
A..Bzdak and V. Koch,
Phys. Rev. C 86, 044904 (2012)

Cumulant ratio at MPD within
|y| < 0.5 and 0.2 < pT < 2.0 GeV/c





- **MPD detector provides a large midrapidity phase-space**
- **From 35 to 65 identified p-pbar (Au+Au, |y|<0.5, pT<1.8 GeV/c)**
- **Event statistics above 1Mevents provides sufficient precision of measurements**

Visibility of MPD PWG2 results in 2019-20

"A new review of excitation functions of hadron production in pp collisions in the NICA energy range",
V. Kolesnikov, V. Kireyeu, V. Lenivenko, A. Mudrokh, K. Shtejer, D. Zinchenko, E. Bratkovskaya,
Physics of Particles and Nuclei Letters, 2020, Vol. 17, No. 2, pp. 142–153.

"Prospects for Studying Hyperons and Hypernuclei on the NICA Collider",
V. I. Kolesnikov, A. I. Zinchenko, V. A. Vasendina,
Bulletin of the Russian Academy of Sciences: Physics, 2020, Vol. 84, No. 4, pp. 451–454.

"Performance of the MPD detector in the study of the strangeness to entropy ratio in heavy-ion collisions at the NICA accelerator complex",
V. Kolesnikov, V. Kireyeu, A. Mudrokh, A. Zinchenko, and V. Vasendina,
Physics of Particles and Nuclei Letters, Vol. 17, No 3 (2020), pp. 358–369.

"Prospects for the study of event-by-event fluctuations and strangeness production with the MPD detector at NICA",
A. Mudrokh, V. Kolesnikov, V. Vasendina and A. Zinchenko,
Accepted in the Physics of Elementary Particles and Atomic Nuclei Letters, Vol. 20, No 3 (2020).

Several oral talks at Conferences: **ICNFP19** (2 talks), **WPCF2019**, **Nucleus-2019** (2 talks), **19th Lomonosov**, **SQM'19** (poster), **QM'19** (poster)

Supported by RFBR grants 18-02-40037, 18-02-40060

Summary

- **MPD physics simulation within PWG2 is ongoing**

  Steady progressing : Hadron spectra, *Multistrangeness, Hypernuclei, Ev-by-Event fluctuations*

- **5 papers over the last half a year and >8 talks at Conferences in 2019**

- **In plans : extend analysis activities to a large data set for official DSTs (Bi+Bi?)**

Thank you for your attention!