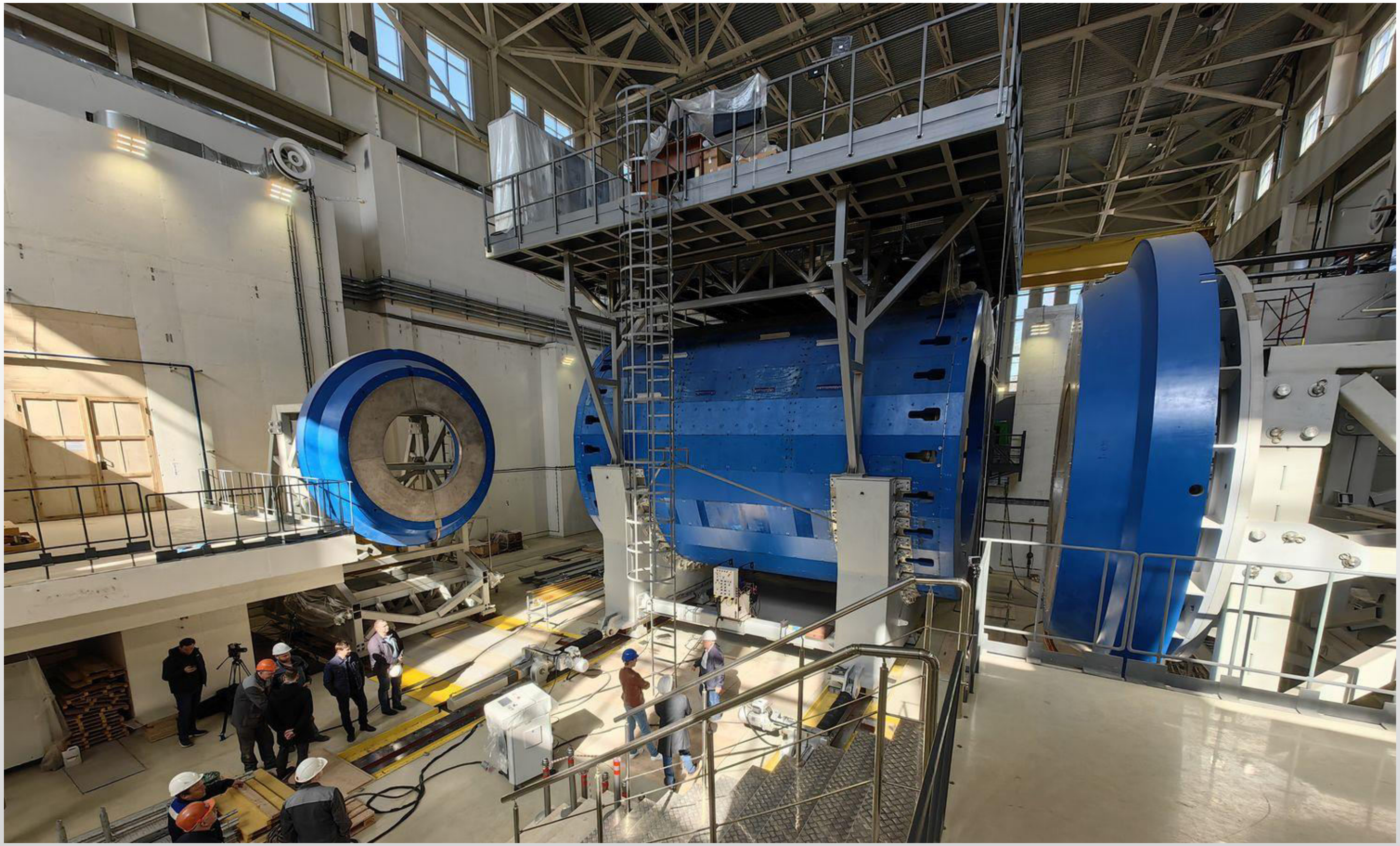
NICA Nuclotron based Ion Colider fAcility

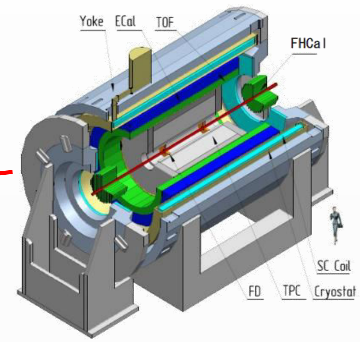
Implementation of the MPD project

V. Riabov for the MPD Collaboration



MPD at NICA

❖ One of two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4−11 GeV

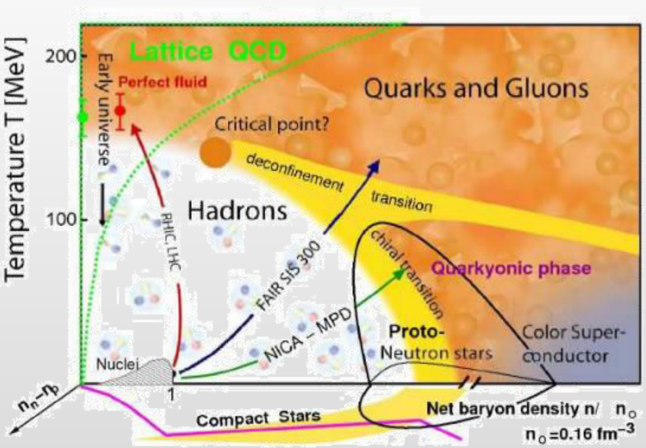


Stage- I

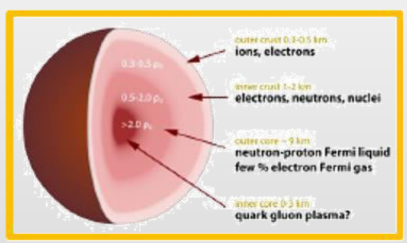
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

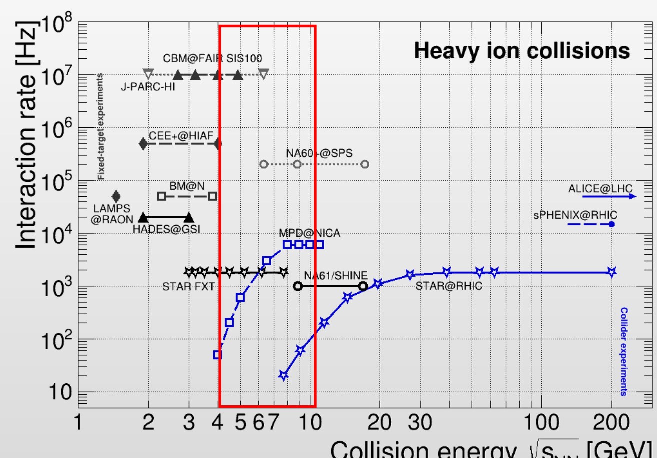
Expected configuration in first year(s) :

✓ not-optimal beam optics → wide z-vertex distribution, σ_z ~ 50 cm
✓ reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
✓ first collision system → Bi+Bi @ 9.2 GeV



high baryon densities
→ inner structure of
compact stars





❖ NICA will study QCD medium at extreme net baryon densities → 1st order phase transition + QCD CEP
❖ Many ongoing (NA61/Shine, STAR-BES) and future experiments (CBM) in ~ same energy range

MPD assembling milestones and plans

❖ Latest estimates provided by Project manager (V. Golovatyuk)

	Year 2023	
12	Jan 15 - April 15th	Preparation for Vacuum test of Solenoid with Cryostat
13	April 20 - May 20th	Vacuum tests
14	May 25 - June 15th	Solenoid cooling down to Liquid Nitrogen temperature (-80K)
15	April 20 June 15th	Electronic Platform construction
16	June 15 – September 15	Activities in the MPD Hall will be stopped
17	October – December	Cooling down to the He temperature
	Year 2024	
18	January. - February 15	Supplying the current to the solenoid and Correction coils
19	March - May 15	Magnetic Field measurements
20	June 1 - June 10	Support Frame installation
21	June 20 – August 30th	Installation ECal sectors, Insertion devices mounting
22	Sept 1 – September 20th	Installation TOF modules, FHCal into poles
23	Sept 15 - Nov 20	TPC installation
24	Sept 18 - Nov 20	Cabling
25	Oct 20 - Nov 25	Installation of beam pipe
26	Nov 30 - Dec 10th	Move the MPD on Collider beam line, Commissioning

Commissioning and start of data taking → 2025

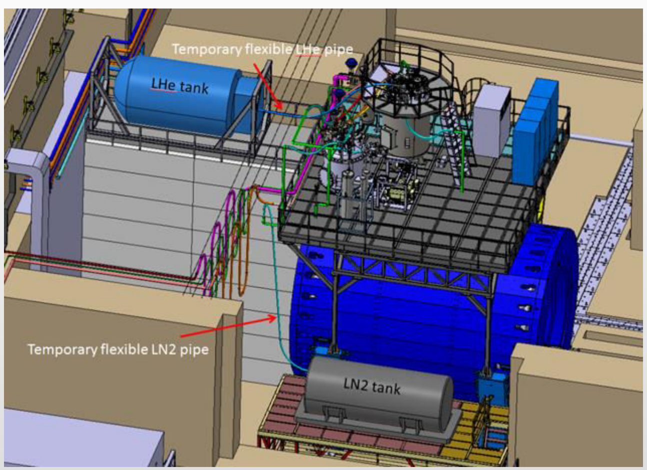
Activities in the MPD Hall

Top platform (cryogenics, power supplies, control system)

Chimney

Cryogenic platform

Temporary scheme of Solenoid cooling

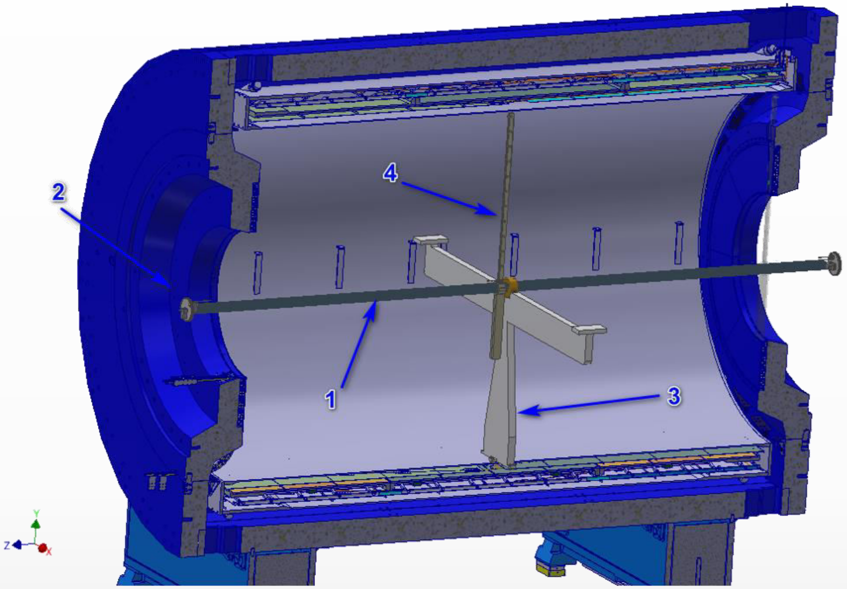


Thermostable rooms, LN tank

Cryogenic pipes

- Yoke, TRIM coils, top platform, chimney assembled, ongoing tests of the refrigerators and control Dewar
- Pipes, LN2 tanks, LHe pipe, heaters and other equipment re-ordered in Russia and delivered
- Cooling to LN temperature in June

Magnetic field measurements



1. Aluminum (carbon fiber plastic) guiding rod
2. End cap fixation
3. Intermediate support
4. Carbon fiber plastic carriage

Novosibirsk INP mapper: specifications

Parameter	Value
Length of movement for Z	2× 4,5 m
Length of movement for R	0.1 – 2.2 m
Rotation of measurement block	3600
Accuracy of movement for Z	50 microns
Accuracy of movement for R	50 microns
Accuracy of rotation	0.20
Hall 3D sensor	HE444, HE Hoeben Electronix,
Hall 3D sensor accuracy	0.1 Gs
Hall 3D sensor accuracy total (with accuracy of laser tracker and temperature correction)	0.3 Gs
Sag of guide line	5 mm
Weight of mapper	100 kg
Reading time per one measurement	1 sec

- ❖ Provides better precision compared to CERN mapper
- ❖ 3 months to produce magnetic field map(s) at different currents in the Solenoid and Correction coils

❖ Schedule:
- ✓ Nov, 2023 - production and delivery of the mapper to JINR
- ✓ May, 2024 - magnetic field measurements

Time Projection Chamber (TPC)

- ❖ TPC cylinders, central membrane and service wheels are ready – final vessel assembly in October, 2023
- ❖ Read-out chambers (ROCs) - 24 tested chambers in stock + 4 tested spare chambers

- ❖ Gas system ready – testing
- ❖ TPC FE electronics status:
  - ✓ 65% manufactured (967 pc)
  - ✓ no more problems with components → 100% available

- ❖ On critical path:
  - ✓ TPC rails prod./inst. – October-November, 2023
  - ✓ TPC cooling system – (INP BSU, Belarus) – FEE cooling ready by November, 2023; thermostabilization panels by September, 2024

- ❖ TPC schedule:
  - ✓ Final assembly and leak tests - December, 2023
  - ✓ TPC installation in the MPD: November, 2024

Time-of-Flight (TOF)

- ❖ The production of MRPC detectors was completed in September 2022, (107%) chambers
- ❖ TOF modules are assembled → long-term cosmic ray tests
- ❖ Electronics & cables, HV distribution modules, installation equipment - in stock
- ❖ Started assembly of the TOF gas system in the MPD hall in September 2022 → finished in summer, 2023

Storage of tested TOF modules

TOF installation bench in LHEP

- ❖ The equipment for installing the modules in the MPD is ready for use and stored in the laboratory

❖ TOF schedule:
- ✓ Production of all modules: June, 2023
- ✓ TOF installation in the MPD: September, 2024

Electromagnetic calorimeter (ECAL)

- Sampling calorimeter with projective geometry (70 tons):
  - ✓ 25 sectors (50 half-sectors); 2400 modules; 38,400 “shashlyk”-type Pb-Sc towers with segmentation of 4x4 cm^2
- 1600 modules (66%) have been produced (800 in Russia + 800 in China)
- Production of additional 400 modules in Russia is ongoing, use Russian-made WLS fibers → 83% in total
- 59 clusters produced, production rate ~ 10 clusters/month, to be completed by September, 2023
- Mass production of half-sectors in JINR by international team, 18 half-sectors assembled

Half-sectors at different stages of assembly

- ECAL schedule:
  - ✓ Half-sectors ready: January, 2024
  - ✓ ECAL installation in the MPD: August, 2024

Beam and luminosity monitoring

- To be used with MPD in service/working position:
  - ✓ assistance in controlling the transverse sizes of the bunches
  - ✓ assistance in setting up transvers and longitudinal convergence of bunches
  - ✓ control of the distribution of vertices in the longitudinal direction.

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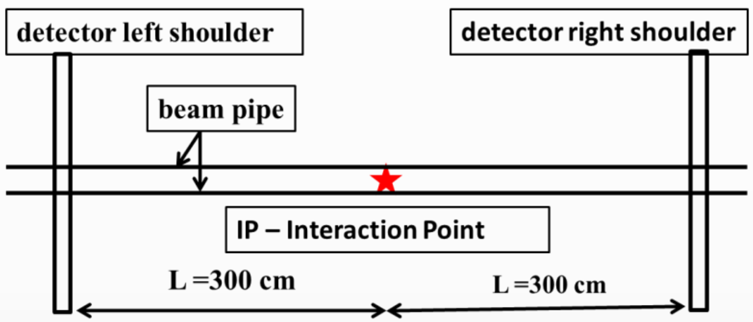
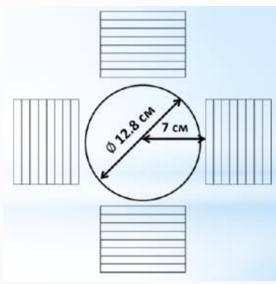
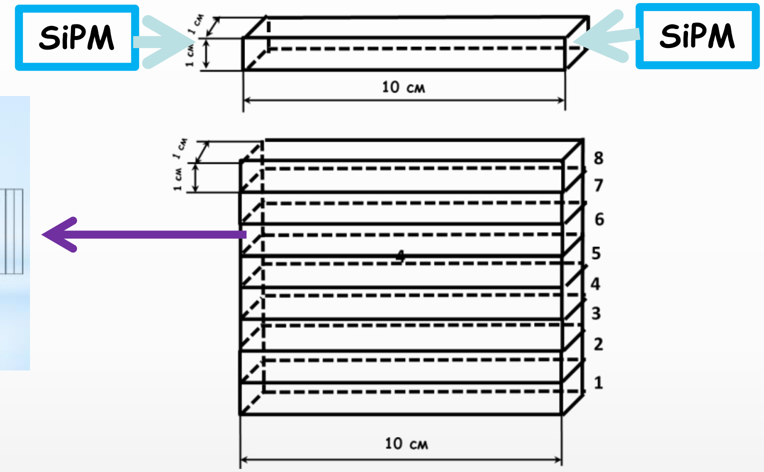






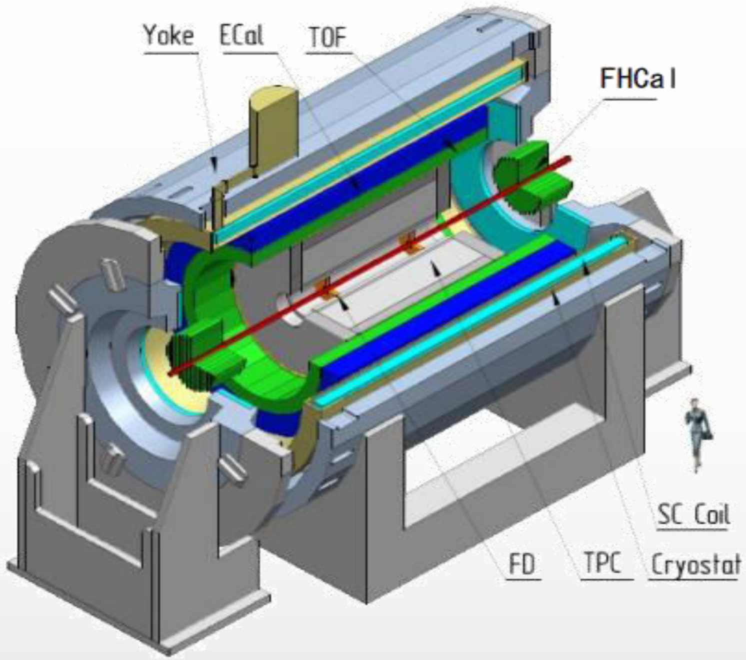
The detector consists of 100x10x10 mm^3 plastic scintillator strips (organic polystyrene scintillator with the addition of 1.5% p-terphenyl and 0.05% POPOP) viewed from both sides with SiPMs (HAMAMATSU S13360 6025 CS)

- Trigger: condition: $|T_L^{min} - T_R^{min}| < 10$ ns; efficiency – 77% in AuAu@11 GeV (DCM-SMM)
- Observables & methods:
  - ✓ counting rate and z-vertex distribution ($\sigma_{z\text{-vertex}}$ ~ 5 cm with $\delta\tau$ ~ 300 ps)
  - ✓ Van der Meer and ΔZ scans for optimization of beam optics
- Two planes have been assembled and tested with beams at CERN, analysis of results is in progress
- Mass production started

Multi-Purpose Detector (MPD) Collaboration

***MPD** International Collaboration was established in **2018** to construct, commission and operate the detector*

11** Countries, **>500** participants, **35** Institutes and **JINR

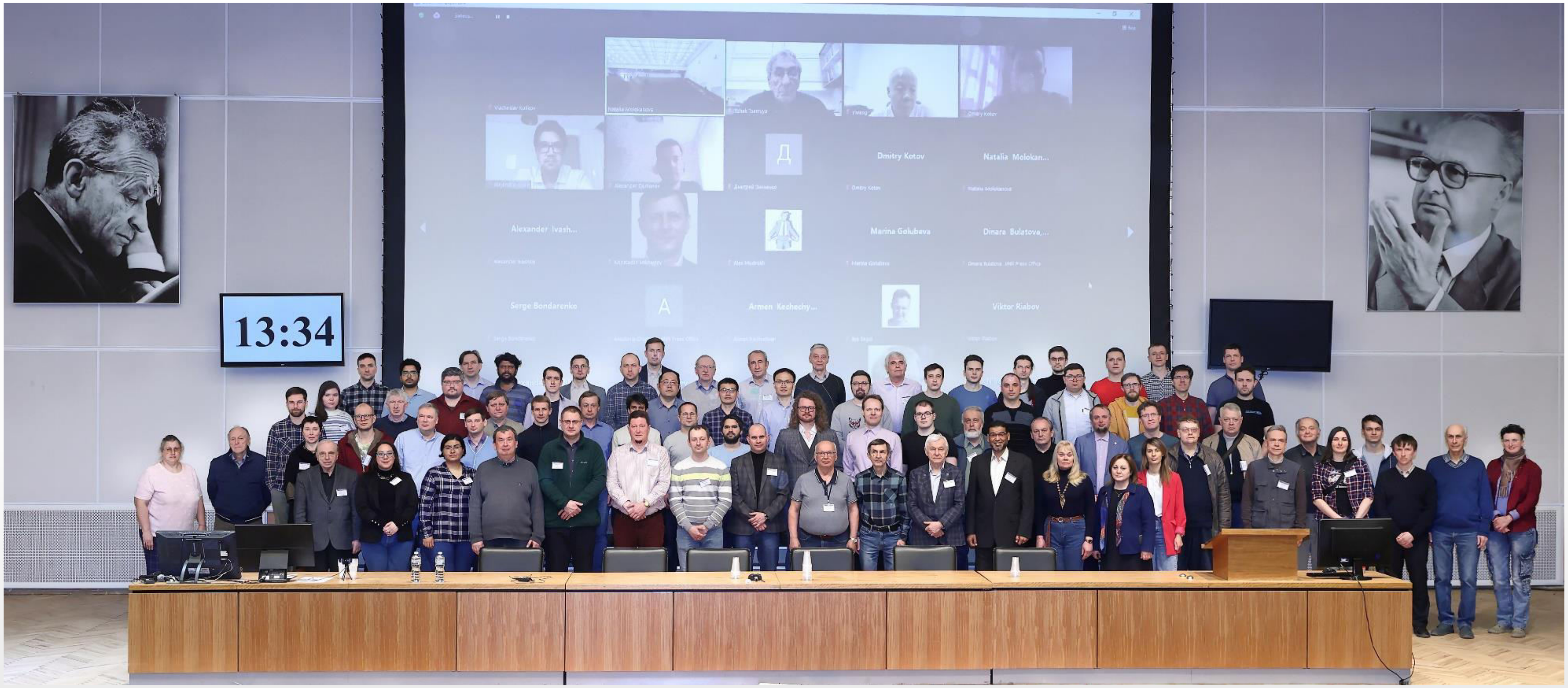


Organization

Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Zebo Tang, Arkadiy Taranenko***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***

***Joint Institute for Nuclear Research**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*University of Science and Technology of China, Hefei, **China**;*
*Huzhou University, Huzhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*University of Chinese Academy of Sciences, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Benemérita Universidad Autónoma de Puebla, **Mexico**;*
*Centro de Investigación y de Estudios Avanzados, **Mexico**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad de Sonora, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*
*Belgorod National Research University, **Russia**;*
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **Russia**;*
*Peter the Great St. Petersburg Polytechnic University Saint Petersburg, **Russia**;*
*Plekhanov Russian University of Economics, Moscow, **Russia**;*
*St.Petersburg State University, **Russia**;*
*Skobeltsyn Institute of Nuclear Physics, Moscow, **Russia**;*
*Petersburg Nuclear Physics Institute, Gatchina, **Russia**;*
*Vinča Institute of Nuclear Sciences, **Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

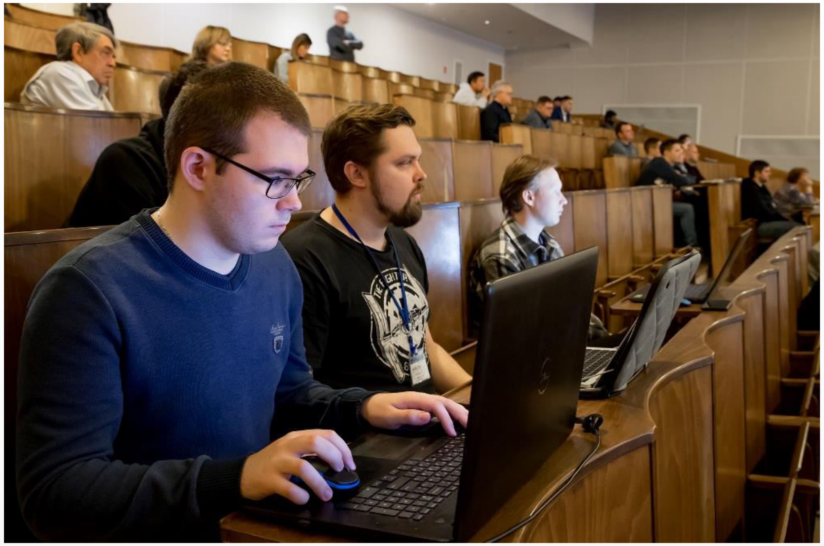
XI-th MPD Collaboration Meeting, 18-20 April, 2023



- ❖ Held in mixed mode at JINR with over 160 participants, > 80% present in-person
- ❖ Over 30 reports in three days for recent progress in MPD construction, development of computing and software infrastructure and preparations for physics analyses → preparation of the MPD detector and experimental program is continued
- ❖ Next Collaboration meeting proceeded by ‘NICA days’ workshop will be held in Belgrade, Serbia in October, 2-6 (https://indico.jinr.ru/event/3746/)

NICA university

MPD and **BM@N** are among the main heavy-ion experiments in the world for the next decades



PhD students are the main driving force for any major experimental project in modern physics

➡ Current programs at the universities do not take into account the specifics and complexity of heavy-ion physics

We propose to organize a scientific and educational program at JINR to prepare future PhD students for the NICA projects – the NICA University

BLTP, VBLHEP, FLNR, PNPI, MEPhI ⟶ **NICA University**

- ❖ Training for 20-25 bachelor/master students from Member States
- ❖ Four schools with an intensive program during two years – one two-week school per semester
- ❖ Courses in experimental, theoretical physics and information technologies are taught by the team of leading scientists from JINR and universities participating in the NICA project

Conferences

- MPD presentations at conferences since the last CM:
  - ✓ DAE-BRNS CETHENP-2022, India, November 15 – 17
  - ✓ XVIII Mexican Workshop on Particles and Fields (XVIII MWPF), Mexica, November 21 – 25
  - ✓ International Conference on Particle Physics and Astrophysics (ICPPA-2022), November 29 – December 2
  - ✓ Infinite and Finite Nuclear Matter (INFINUM-2023), February 27 – March 3
  - ✓ Nuclear Physics, China, May, 12-16, 2023
  - ✓ Hadrons-2023, Italy, June 5-9, 2023

- JINR-MEPhI organized International Workshop NICA-2022 (http://indico.oris.mephi.ru/event/298):
  - ✓ 25 lectures in three days on experimental and theoretical topics
  - ✓ joint platform for discussion of NICA physics at BM@N and MPD

  Published 14 papers in Particles 2023, 6(2), reviewed by 31 referee from 13 countries

  Special Issue "Selected Papers from "Physics Performance Studies at FAIR and NICA""

  Special Issue Editors:
  - ✓ Prof. Dr. Peter Senger,
  - ✓ Prof. Dr. Arkadiy Taranenko,
  - ✓ Prof. Dr. Ilya Selyuzhenkov

- NICA-2023 workshop in December, 2023

MPD physics program

G. Feofilov, A. Aparin

Global observables

- Total event multiplicity
- Total event energy
- Centrality determination
- Total cross-section measurement
- Event plane measurement at all rapidities
- Spectator measurement

V. Kolesnikov, Xianglei Zhu

Spectra of light flavor and hypernuclei

- Light flavor spectra
- Hyperons and hypernuclei
- Total particle yields and yield ratios
- Kinematic and chemical properties of the event
- Mapping QCD Phase Diag.

K. Mikhailov, A. Taranenko

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

Electromagnetic probes

- Electromagnetic calorimeter meas.
- Photons in ECAL and central barrel
- Low mass dilepton spectra in-medium modification of resonances and intermediate mass region

Wangmei Zha, A. Zinchenko

Heavy flavor

- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

❖ Cross-PWG format of meetings for discussion of results and analysis techniques

MPD mass productions

- Physics feasibility studies using centralized large-scale MC productions → consistent picture of the MPD physical capabilities with the first data sets, preparation for real data analyses

- https://mpdforum.jinr.ru/c/mcprod/26:

  Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**

  Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**

  Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**

  Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**

  Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **DONE**

  Request 30: General-purpose (hyperon polarization), 15M PHSD BiBi@9.2 → **DONE**

  Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **QA**

  Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **DONE**

- Production comparable in size to the first expected real data samples test the existing computing and software infrastructure

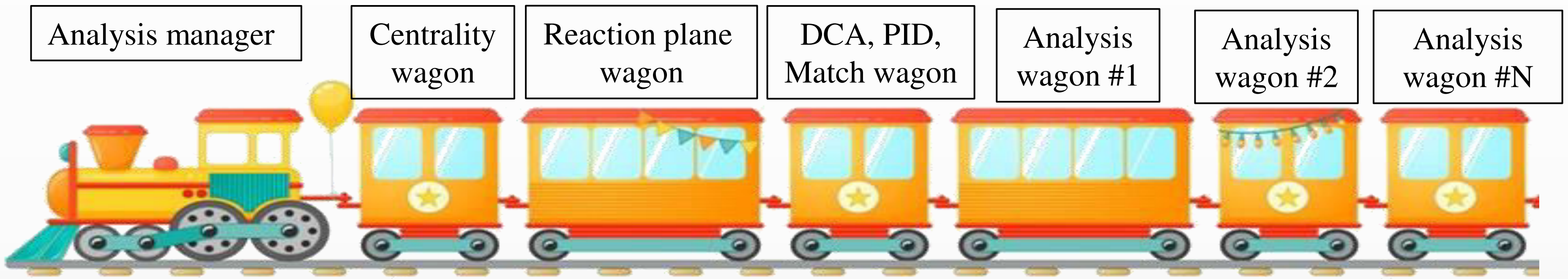
- Develop realistic analysis methods and techniques, set priorities and find group leaders

- Thanks to A. Moshkin (production manager), LIT specialists, computing/software team !!!

Handling the big data sets

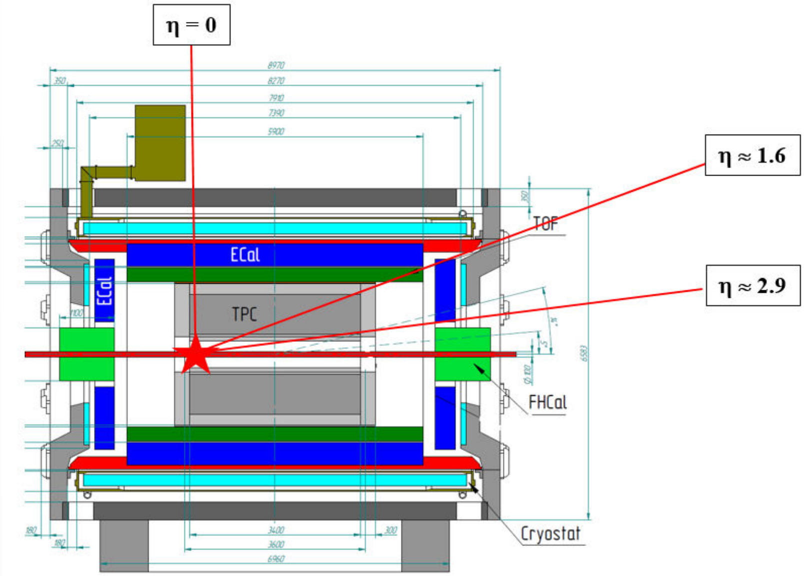
- ❖ Centralized Analysis Framework for access and analysis of data:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes

- ❖ Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:

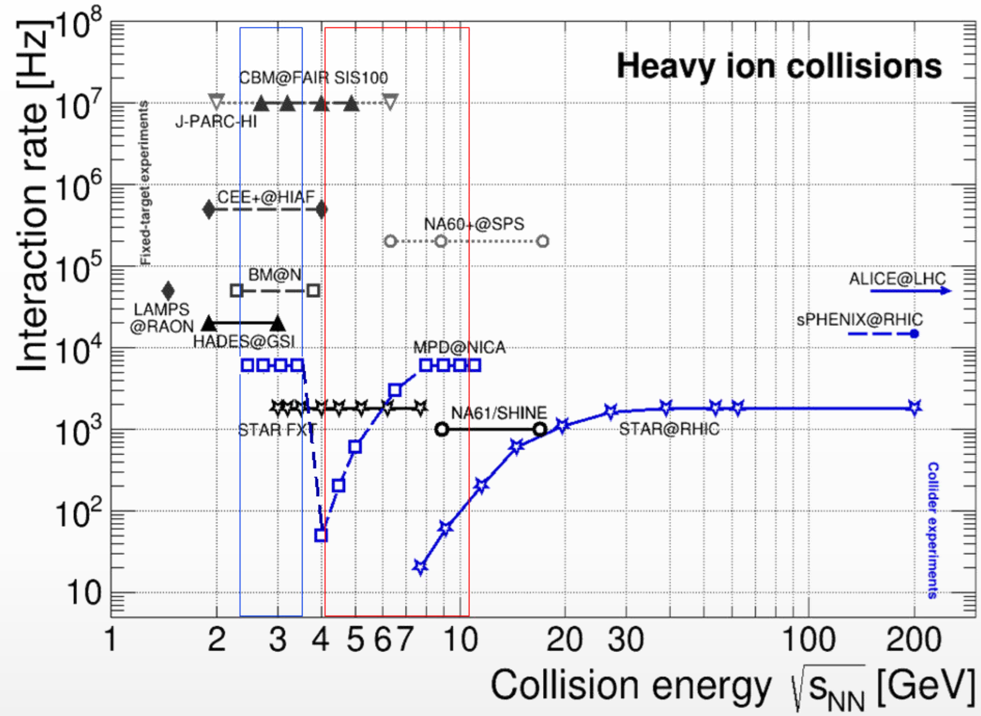


- ❖ The Analysis manager and the first Wagons have been created, in MpdRoot @ mpdroot/physics
- ❖ Eventually all analysis codes will be committed to MpdRoot as Wagons
- ❖ The Train will run on a group of DST files, ~ 100k events → 500 jobs for 50M production
- ❖ Results for all analyses/wagons run on a big production (~ 50 M events) in a day !!!
- ❖ First runs of the Analysis Train in July-August

Running in the fixed-target mode



E_{beam}	$\sqrt{s_{NN}}$ collider mode	$\sqrt{s_{NN}}$ FXT mode	η_{CM}	CMS coverage
2.0	4	2.4	0.7	-0.7; 0.9 (2.2)
5.5	11	3.5	1.23	-1.23; 0.37 (1.67)



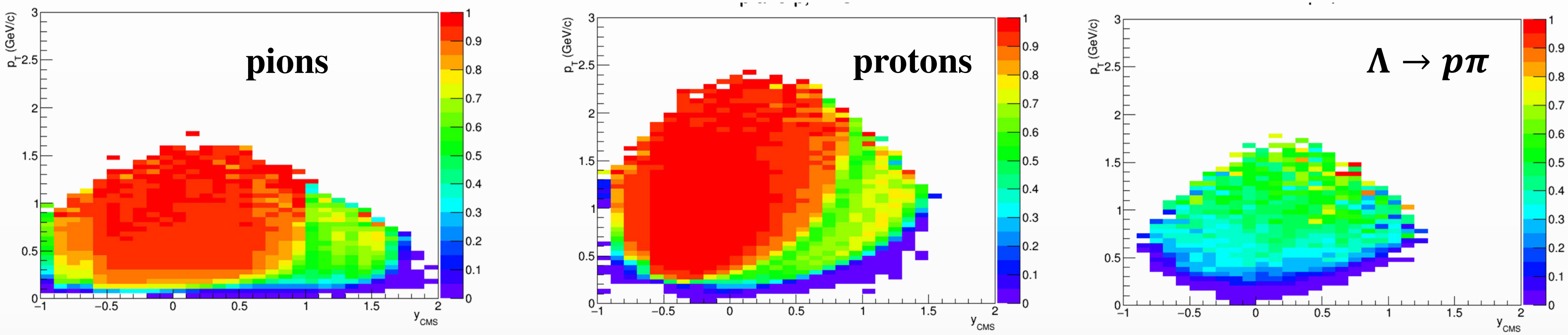
- ❖ Fixed-target mode: one beam + thin wire (~ 100 μm) close to the edge of the MPD central barrel:
  - ✓ extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
  - ✓ solves problem of low event rate at lower collision energies (only ~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
  - ✓ backup start-up solution (too low luminosity, only one beam, etc.)

Detector performance in FXT mode

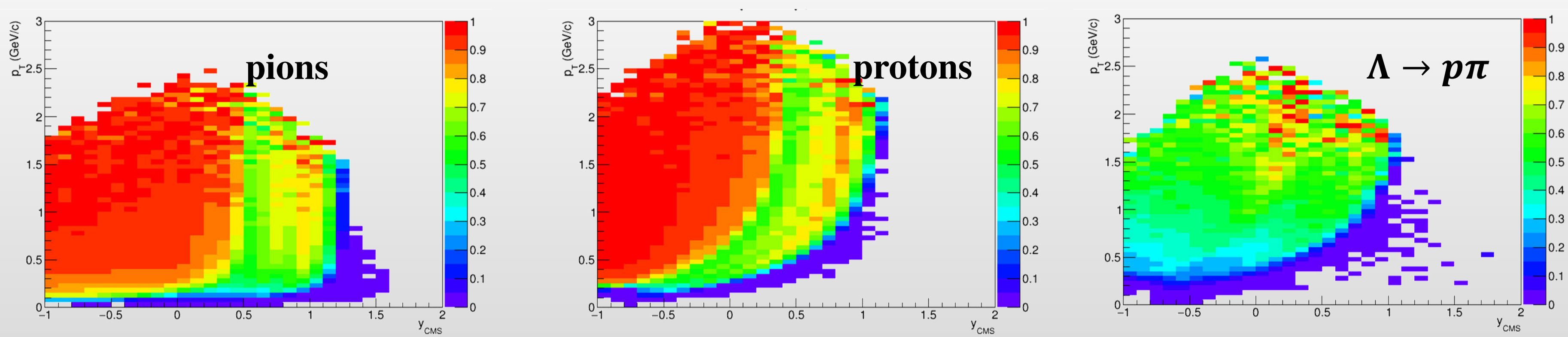
- Existing trigger system is even more efficient compared with the collider mode (FFD + FHCAL + TOF)
- MPD detector provides good enough acceptance for identified hadrons at midrapidity ($y_{CMS} \sim 0$):

✓ E = 2 A·GeV

Track selections: $N_{hits} > 10$; DCA < 2 cm; Primary particles ($R_{production} < 1$ cm)



✓ E = 5.5 A·GeV



MPD detector is able to run in the fixed-target mode in the default configuration

https://indico.jinr.ru/event/3783/; https://indico.jinr.ru/event/3762/

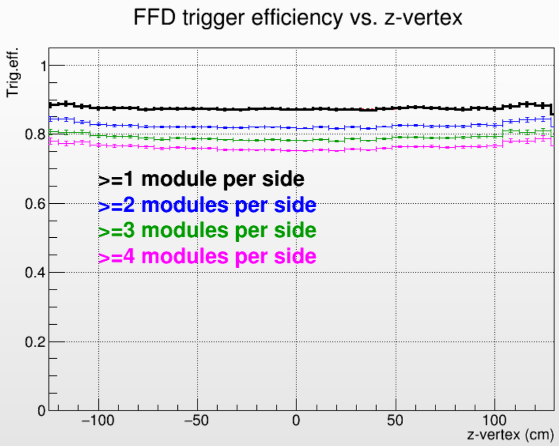
Trigger simulation, BiBi@9.2 GeV

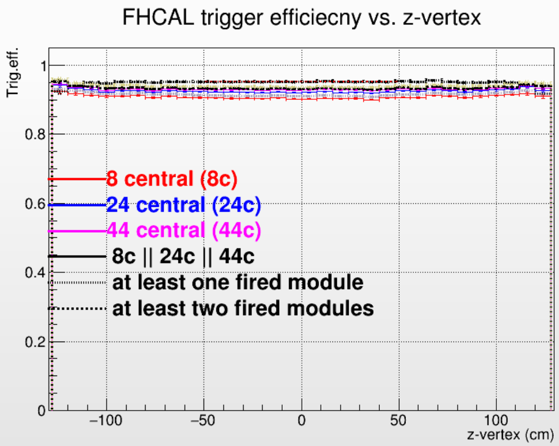
- ❖ Trigger system consists of FFD (2.7 < |η| < 4.1), FHCAL (2 < |η| < 5) and TOF (|η| < 1.5)
- ❖ MPD trigger system challenges at NICA energies:
  - ✓ low multiplicity of particles produced in heavy-ion collisions
  - ✓ particles are not ultra-relativistic (even the spectator protons)
- ❖ DCM-QGSM-SMM, BiBi@9.2: trigger efficiency is 87-98% for different trigger configuration

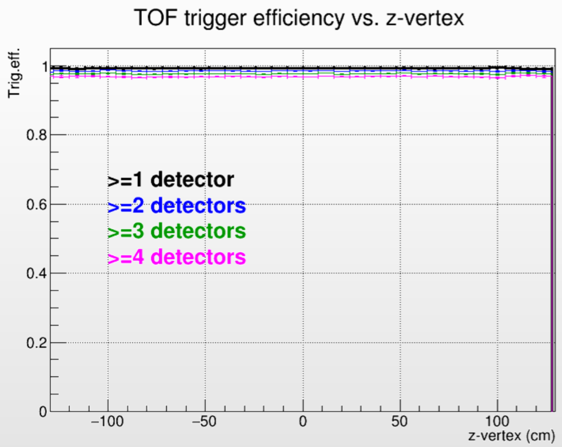
- FFD trigger definition:
  - ✓ at least one fired module per side
  - ✓ meaningful times, $0 < \text{time}_{E,W} < 50$ ns
  - ✓ reconstructed z-vertex, |z-vertex| < 140 cm

- FHCAL trigger definition:
  - ✓ at least one fired module per side
  - ✓ meaningful times, $0 < \text{time}_{E,W} < 50$ ns
  - ✓ reconstructed z-vertex, |z-vertex| < 150 cm

- TOF trigger definition:
  - ✓ at least one fired MRPC



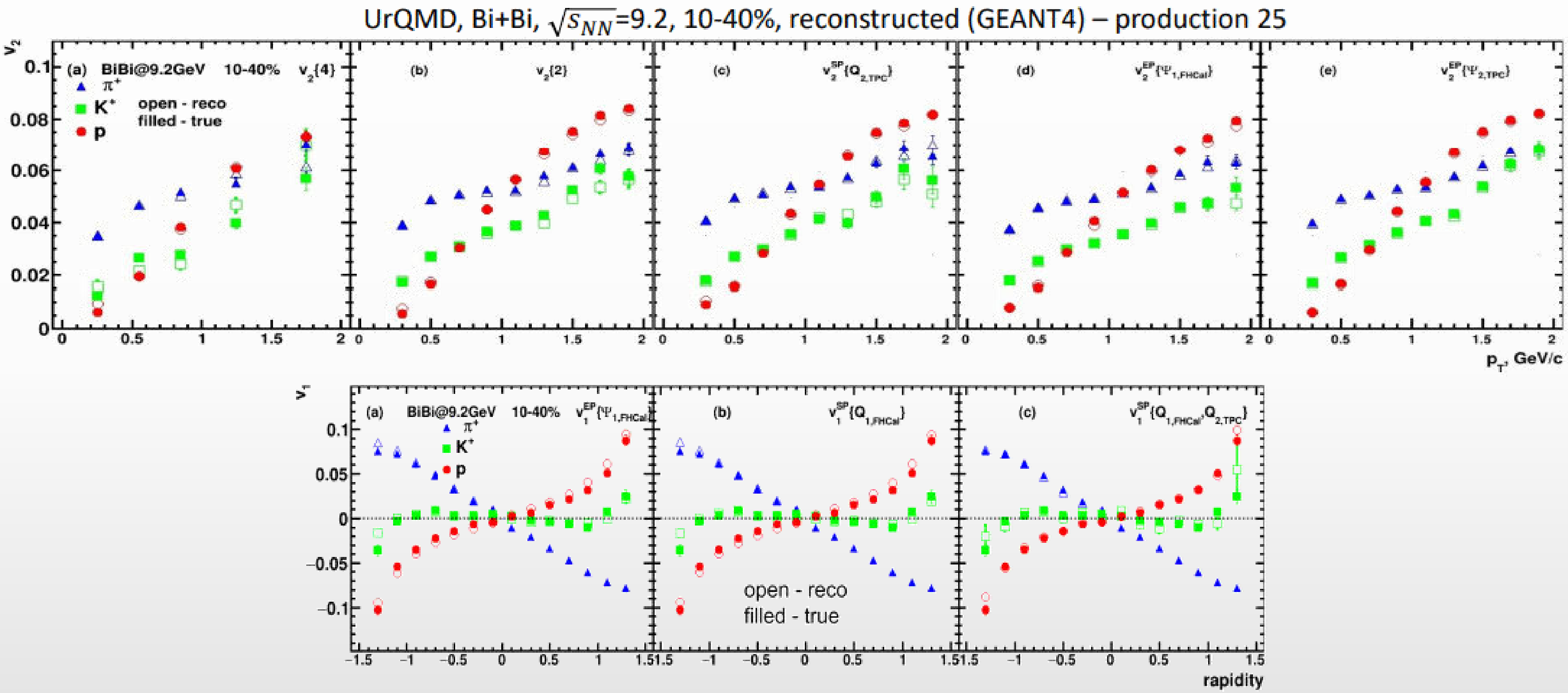




- ❖ Trigger system of the MPD based on FFD, FHCAL and TOF detectors provides high efficiency in HIC
- ❖ Simulation of the MPD trigger system is now included in the Analysis Train (centralized)
- ❖ 'evCentrality wagon' has been implemented in the Analysis Train to provide centrality for all analyses
- ❖ Light collision systems: ~ 50% for C+C, vanishingly small for d+d

Performance for v_1, v_2 of identified hadrons

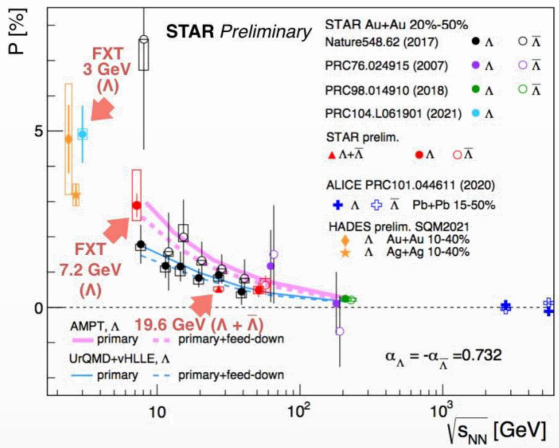
- ‘EvPlane wagon’ has been implemented in the Analysis Train to provide Event Plane for all analyses
- UrQMD, BiBi@9.2 GeV – Production 25

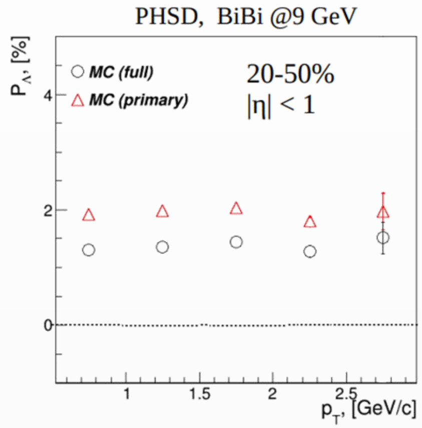


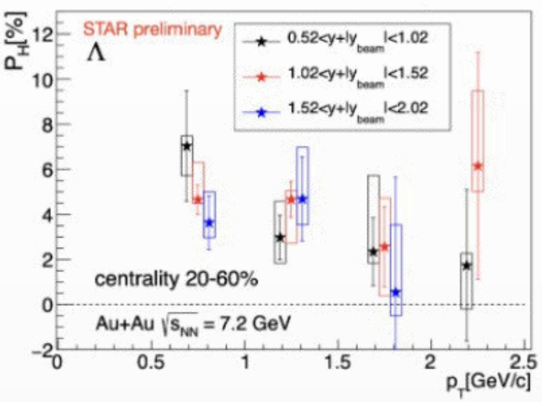
- Reconstructed and generated v_1 and v_2 for identified hadrons are in good agreement for all methods

Hyperon global polarization

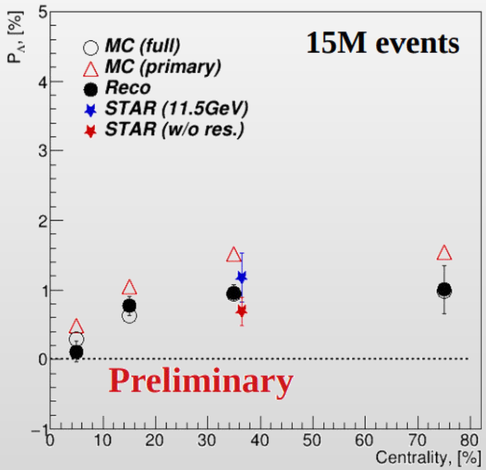
- BiBi@9.2 GeV (PHSD), 15 M events → full event/detector simulation and reconstruction
- Global hyperon polarization (thermodynamical Becattini approach [1]) by the event generator → reproduce at generator level basic features measured by STAR







- Reconstruction of Λ global polarization, work in progress, BiBi@9.2 GeV:



- Analysis performed using 'Polarization wagon' of the Analysis Train
- Measured polarization is consistent with the generated one
- First global polarization measurements for $\Lambda/\bar{\Lambda}$ will be possible with ~ 10M data sampled events

[1] F. Becattini, V. Chandra, L. Del Zanna, E. Grossi, Ann. Phys. 338 (2013) 32

Summary

- Preparation of the MPD detector and experimental program is continued
- Commissioning and start of data taking → 2025
- Further program will be driven by the physics demands and NICA capabilities

BACKUP

RHIC BES program

❖ Data taking by STAR at RHIC: 3 < $\sqrt{s_{NN}}$ < 200 GeV (750 < μ_B < 25 MeV)

Au+Au Collisions at RHIC

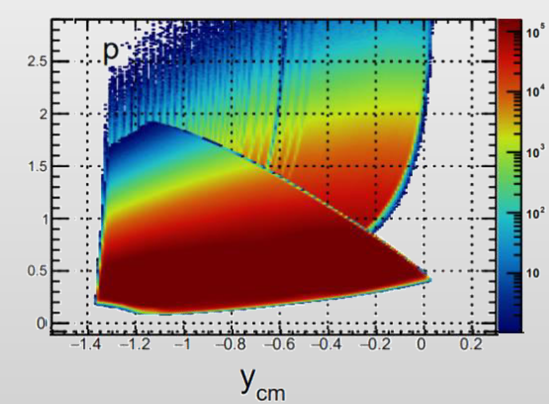
Collider Runs						Fixed-Target Runs					
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run
1	200	380 M	25 MeV	5.3	Run-10, 19	1	13.7 (100)	50 M	280 MeV	-2.69	Run-21
2	62.4	46 M	75 MeV		Run-10	2	11.5 (70)	50 M	320 MeV	-2.51	Run-21
3	54.4	1200 M	85 MeV		Run-17	3	9.2 (44.5)	50 M	370 MeV	-2.28	Run-21
4	39	86 M	112 MeV		Run-10	4	7.7 (31.2)	260 M	420 MeV	-2.1	Run-18, 19, 20
5	27	585 M	156 MeV	3.36	Run-11, 18	5	7.2 (26.5)	470 M	440 MeV	-2.02	Run-18, 20
6	19.6	595 M	206 MeV	3.1	Run-11, 19	6	6.2 (19.5)	120 M	490 MeV	1.87	Run-20
7	17.3	256 M	230 MeV		Run-21	7	5.2 (13.5)	100 M	540 MeV	-1.68	Run-20
8	14.6	340 M	262 MeV		Run-14, 19	8	4.5 (9.8)	110 M	590 MeV	-1.52	Run-20
9	11.5	157 M	316 MeV		Run-10, 20	9	3.9 (7.3)	120 M	633 MeV	-1.37	Run-20
10	9.2	160 M	372 MeV		Run-10, 20	10	3.5 (5.75)	120 M	670 MeV	-1.2	Run-20
11	7.7	104 M	420 MeV		Run-21	11	3.2 (4.59)	200 M	699 MeV	-1.13	Run-19
						12	3.0 (3.85)	2000 M	750 MeV	-1.05	Run-18, 21

❖ A very impressive and successful program with many collected datasets, already available and expected results

❖ Limitations:

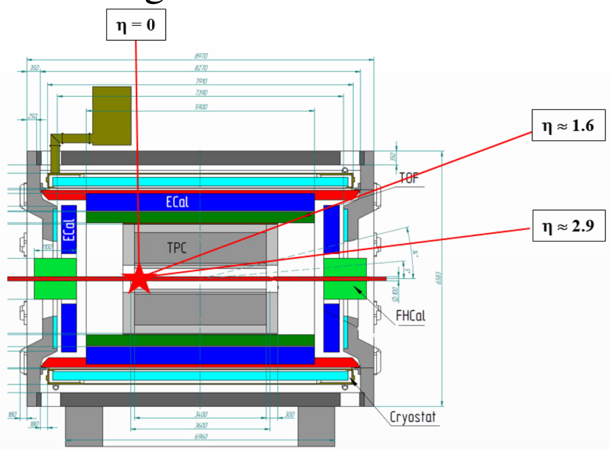
- ✓ Au+Au collisions only
- ✓ Among the fixed-target runs, only the 3 GeV data have full mid-rapidity coverage for protons (|y| < 0.5), which is crucial for physics observables

Au+Au @ 3.9 GeV



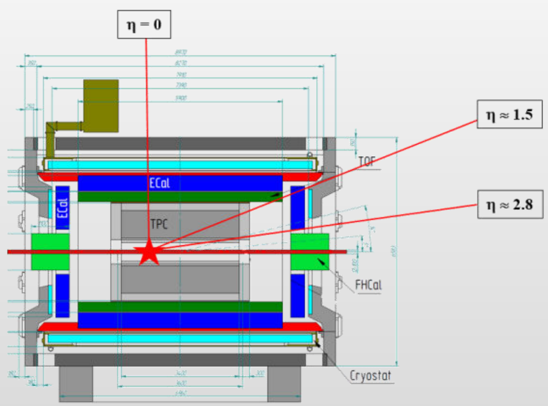
Fixed target configurations

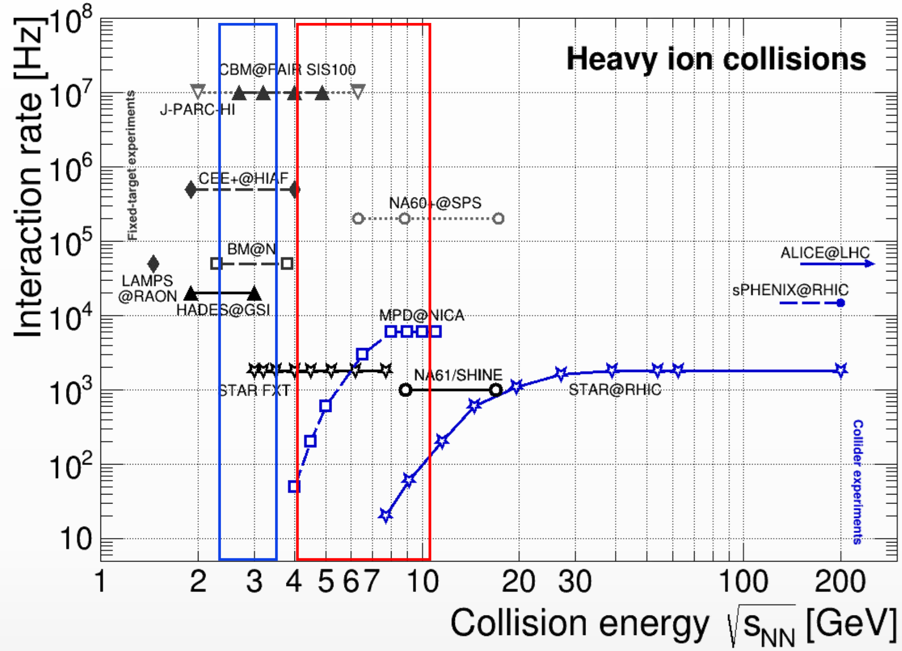
- With a target located at z = -150 cm



E_{beam}	$\sqrt{s_{NN}}$ collider mode	$\sqrt{s_{NN}}$ FXT mode	η_{CM}	CMS coverage
2.0	4	2.4	0.7	-0.7; 0.9 (2.2)
5.5	11	3.5	1.23	-1.23; 0.37 (1.67)

- With a target located at z = -115 cm

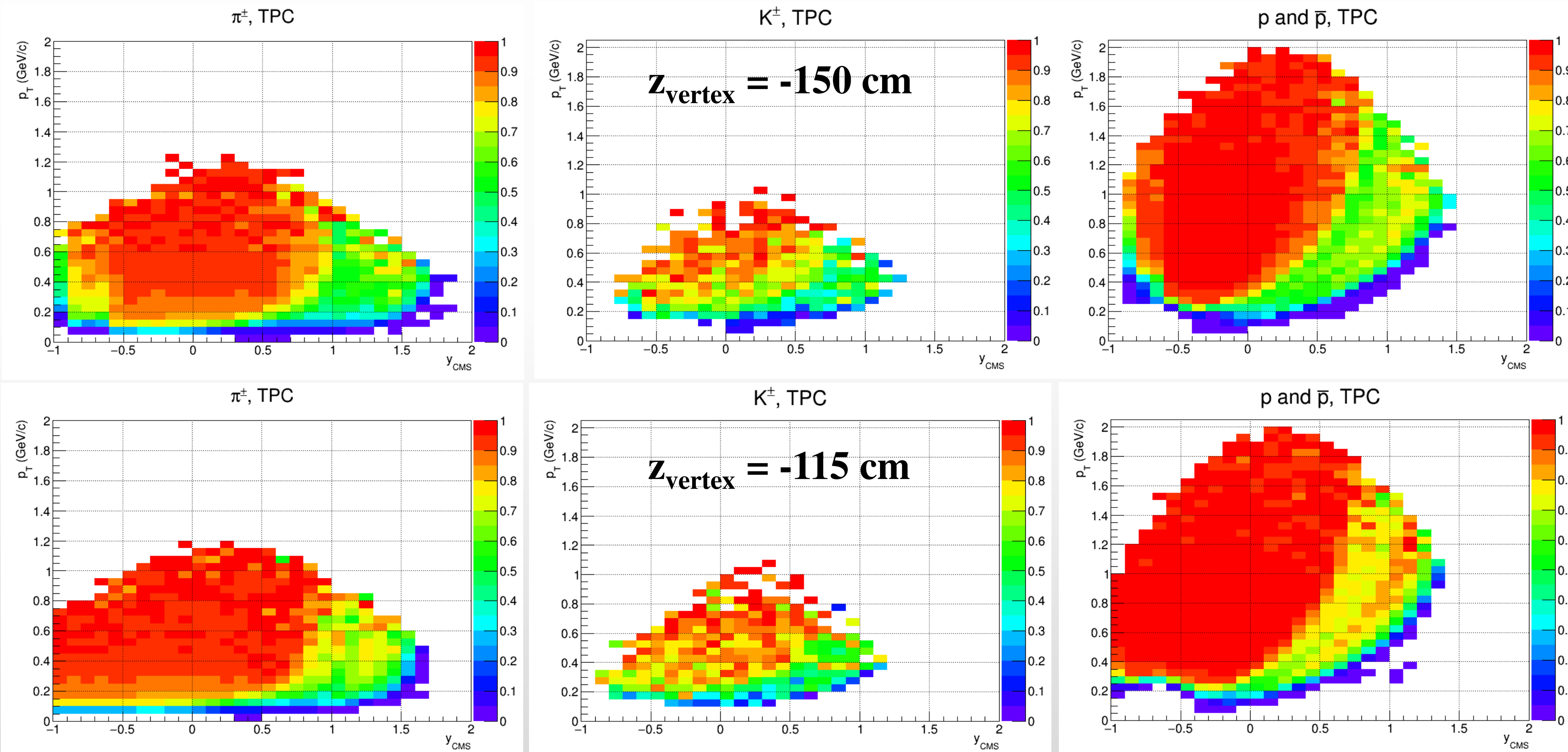




- In heavy-ion collisions:
  - ✓ MPD trigger system based on the FFD, FHCAL and TOF provides high efficiency in the FXT mode
  - ✓ potential problems with online T0 and vertex at lower beam energies

TPC phase space for π/K/p, E_{lab} = 2·A GeV z_{vertex} = -150 cm vs. z_{vertex} = -115 cm

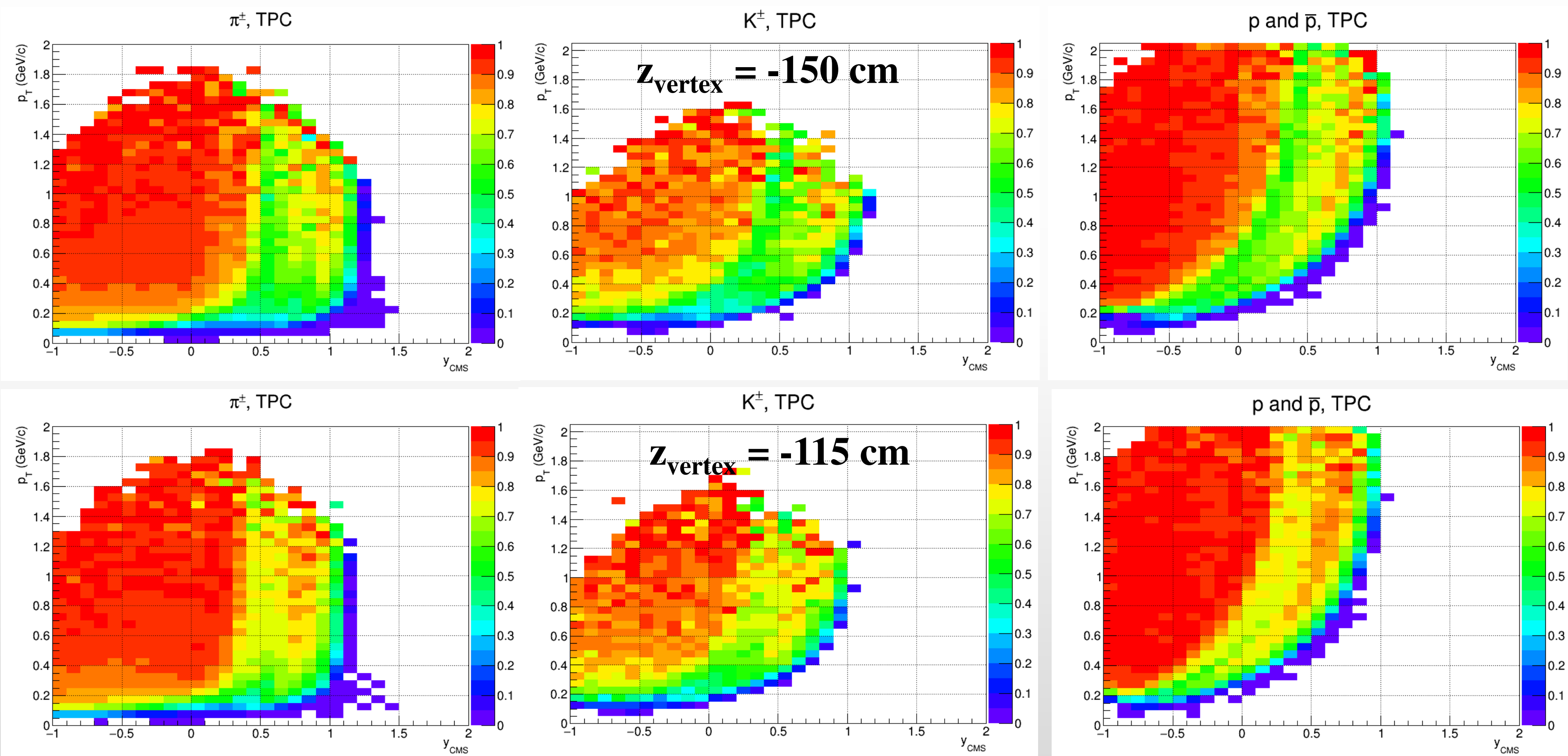
- N_{hits} > 10; DCA < 2 cm; Primary particles ($R_{production}$ < 1 cm)



- Results at z_{vertex} = -115 and -150 cm are similar
- Acceptance shifts by ~ 0.1 unit of rapidity towards negative values → consistent with slide 12

TPC phase space for π/K/p, E_{lab} = 5.5·A GeV z_{vertex} = -150 cm vs. z_{vertex} = -115 cm

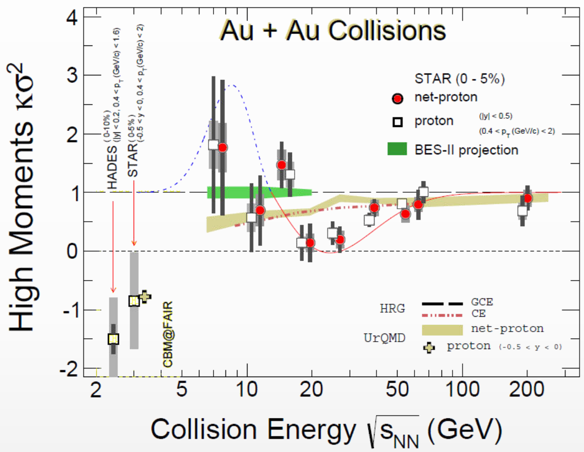
- $N_{hits} > 10$; DCA < 2 cm; Primary particles ($R_{production}$ < 1 cm)

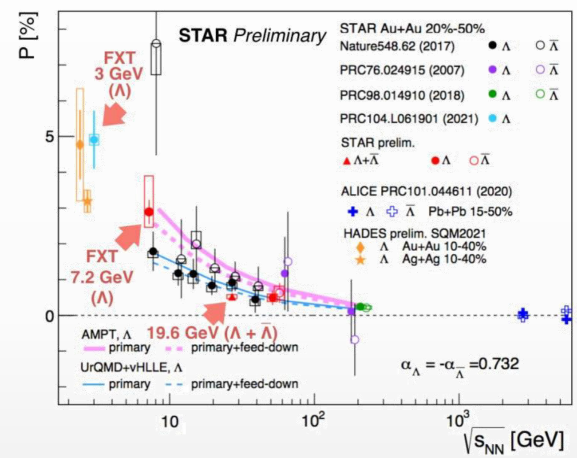


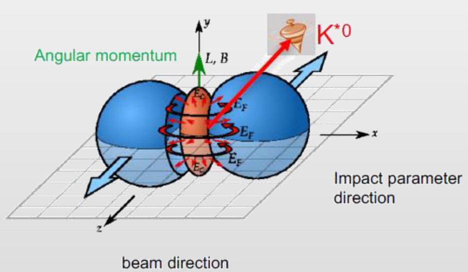
- Results at z_{vertex} = -115 and -150 cm are similar
- Acceptance shifts by ~ 0.1 unit of rapidity towards negative values → consistent with slide 12

Hot topics to fill the gaps

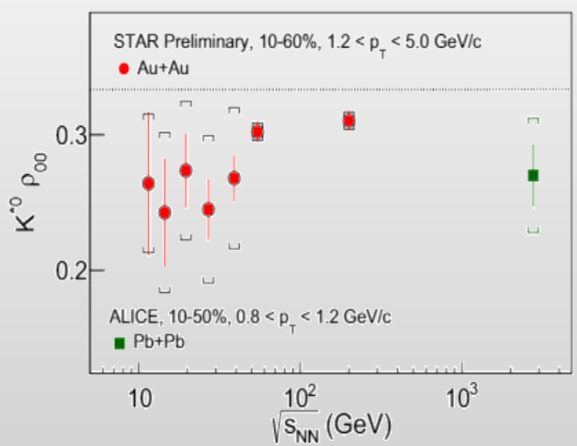
- Critical fluctuations for (net)proton/kaon multiplicity distributions
- Global hyperon polarization in mid-central A+A collisions (Λ, Ξ, Ω)
- Spin alignment of vector mesons ($K^*(892)$, ϕ(1020))
- Dielectron continuum and LVMs
- ….

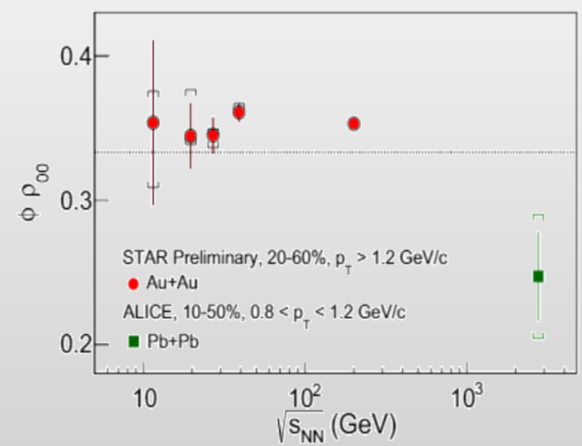






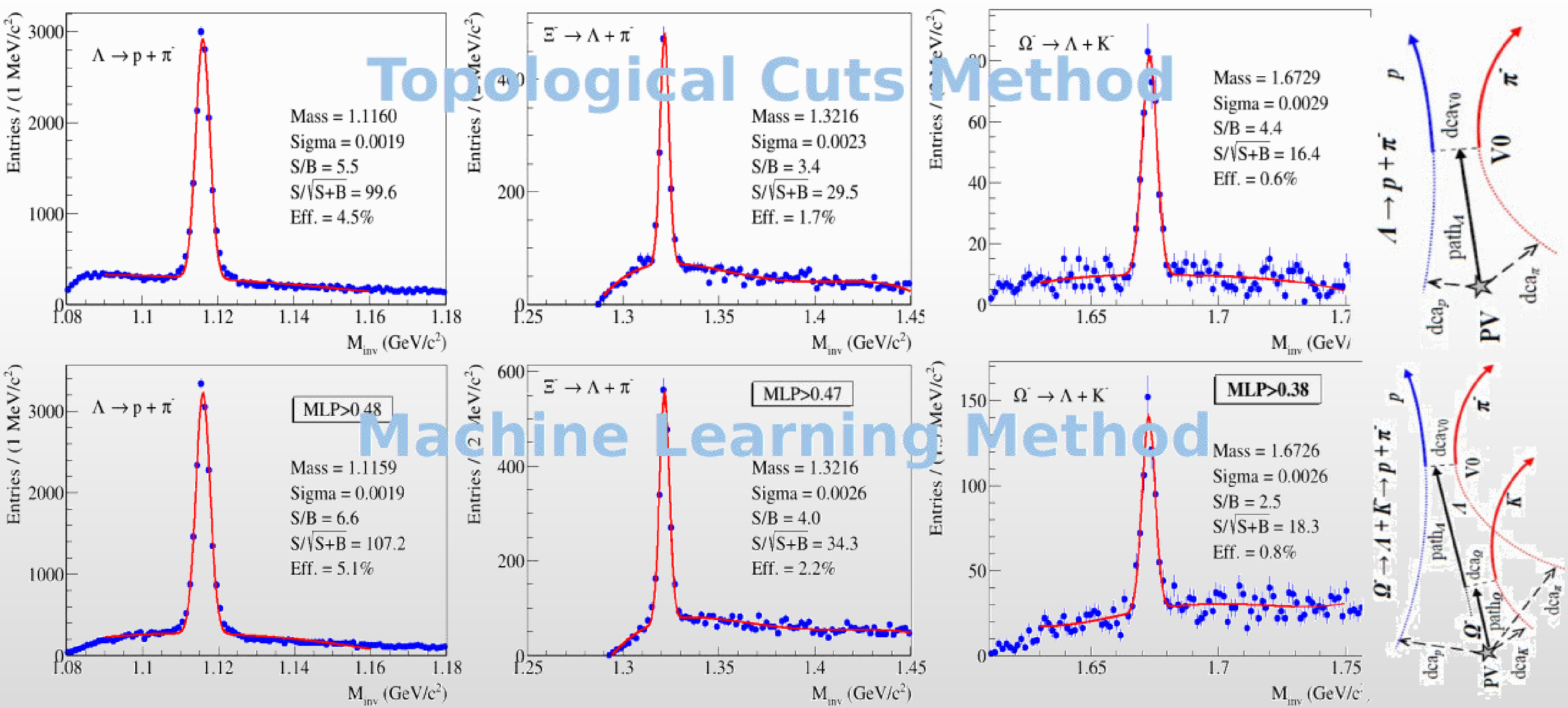
$$\frac{dN}{dcos\theta} = N_0[1 - \rho_{0,0} + cos^2\theta(3\rho_{0,0} - 1)]$$





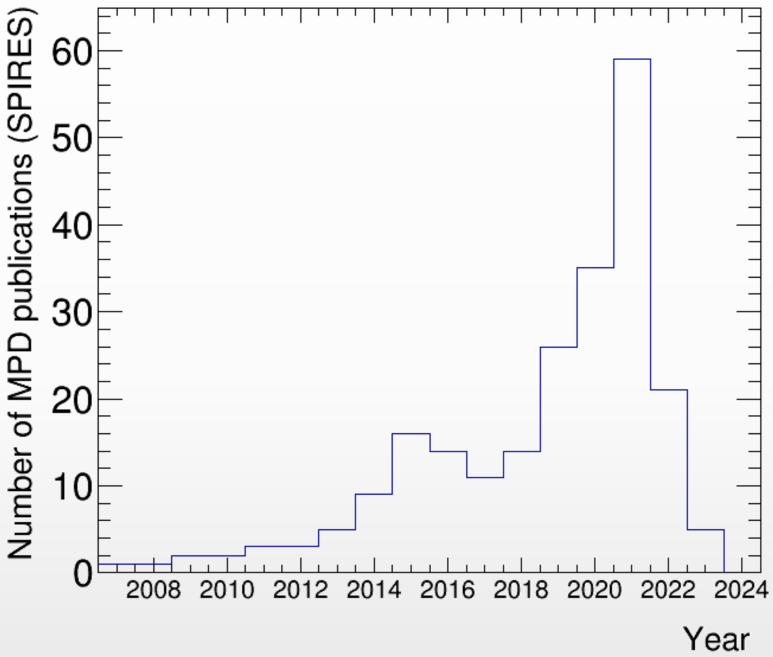
Machine learning techniques at MPD

- TPC fast digitizer
- PID for TOF matched TPC tracks
- Open charm reconstruction with ITS
- Hyperon reconstruction



Collaboration activity

- Many ongoing hardware, software and physics feasibility studies
- MPD publications: over 200 in total for hardware, software and physics studies:



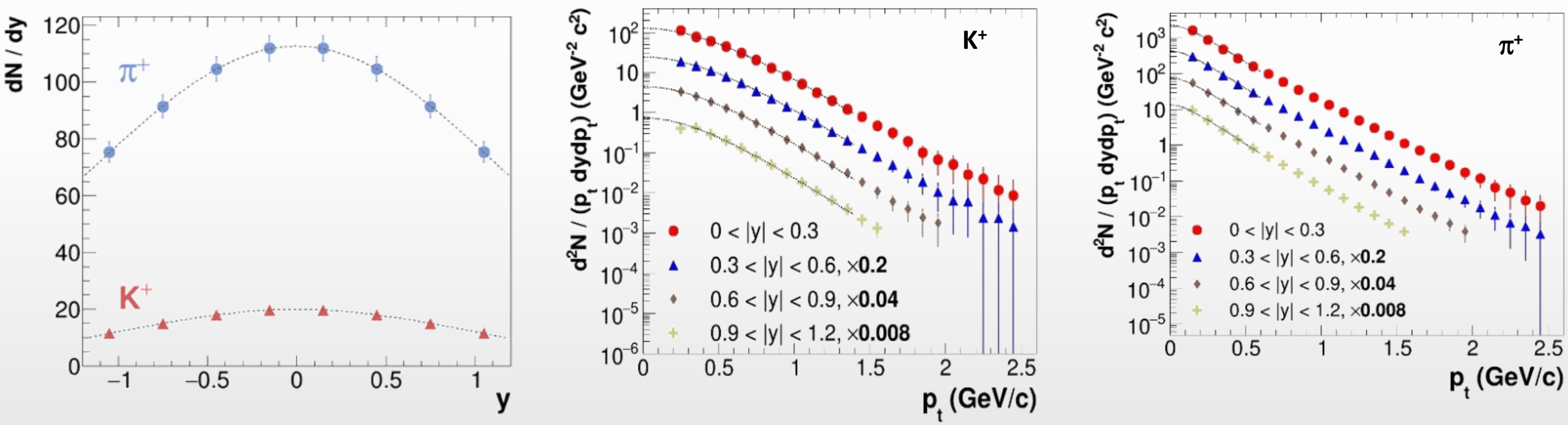
- Support of Russian institutions in the NICA project:
  - ✓ 2019-2021: RFBR grant program, 2019-2021
  - ✓ 2022: internal JINR grants for students/PhD, 2022
  - ✓ 2023: internal JINR grants for leaders/students/PhD, 2023
  - ✓ 2023 and beyond: expect support by Russian Ministry of Science

Identified light hadrons

- Probe freeze-out conditions, collective expansion, hadronization mechanisms, strangeness production (“horn” for K/π), parton energy loss, etc. with particles of different masses, quark contents/counts
- Charged hadrons: large and uniform acceptance + excellent PID capabilities of TPC and TOF

0-5% central AuAu@9 GeV (PHSD), 5 M events → full event/detector simulation and reconstruction

Phys.Part.Nucl. 53 (2022) 2, 203-206



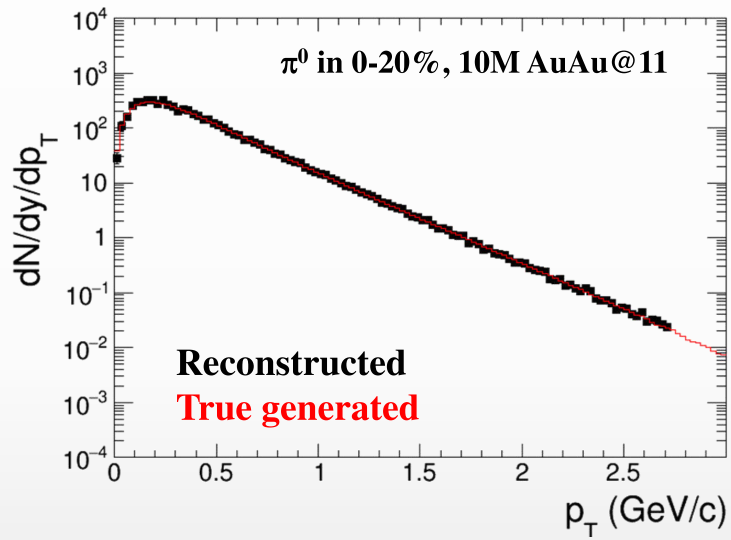
✓ sample ~ 70% of the π/K/p production in the full phase space

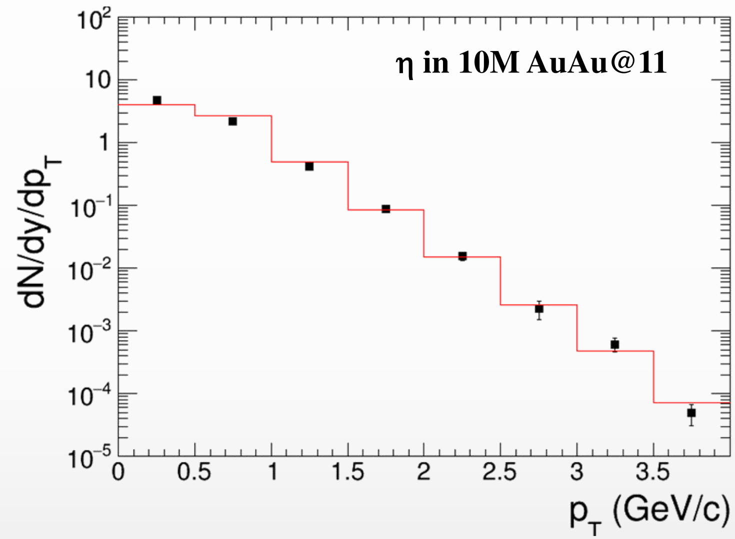
✓ hadron spectra are measured from p_T ~ 0.1 GeV/c

Identified light hadrons

❖ Neutral mesons (π^0, η, K_s, ω, η'): ECAL reconstruction + photon conversion method (PCM)

AuAu@11 GeV (UrQMD), 10M events → full event/detector simulation and reconstruction





✓ extend p_T ranges of charged particle measurements
✓ different systematics

MPD will be able to measure differential production spectra, integrated yields and $\langle p_T \rangle$, particle ratios for a wide variety of identified hadrons (π, K, η, ω, p, η')

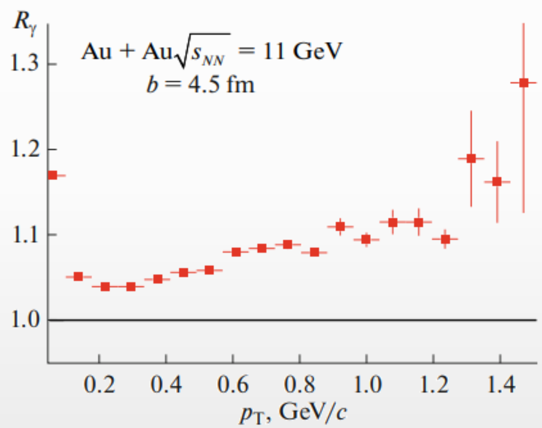
First measurements will be possible with a few million sampled heavy-ion events

Electromagnetic probes

- Photons and electrons do not participate in strong interactions → undistorted information about the system at the production time → promising signals of the phase transition and chiral symmetry restoration
- Interpretation of results requires theoretical models that describe the dynamics of heavy-ion collisions during the whole system evolution

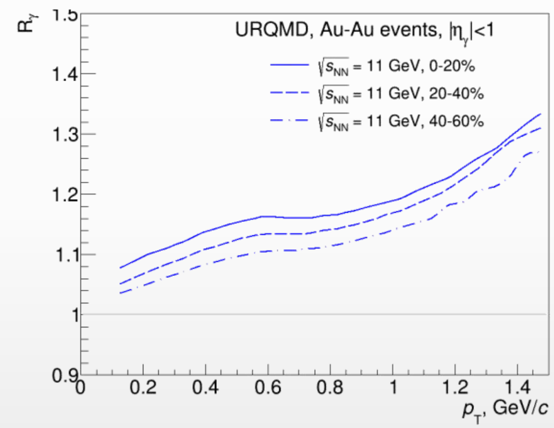
AuAu@11 GeV (UrQMD)

Physics of Particles and Nuclei, 2021, Vol. 52, No. 4, pp. 681–685



$$R_\gamma = \frac{\gamma_{inc}}{\gamma_{decay}} = \frac{\gamma_{inc}/\pi^0}{\gamma_{decay}/\pi^0_{param}}$$

$$\gamma_{direct} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{inc}$$



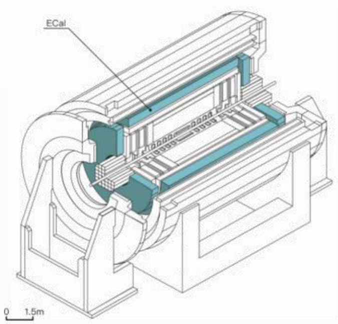
Non-zero direct photon yields are predicted with Rγ ~ 1.05 – 1.15 and v2 ~ 0.5% at top NICA energy

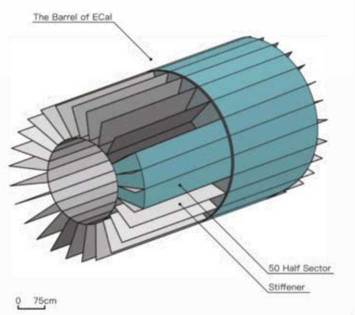
Development of reconstruction techniques and estimation of needed statistics are in progress

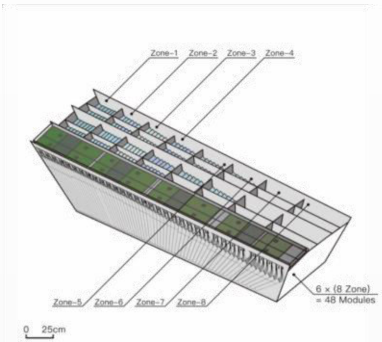
→ MPD can provide <u>unique measurements</u> for direct photon production @ NICA energies

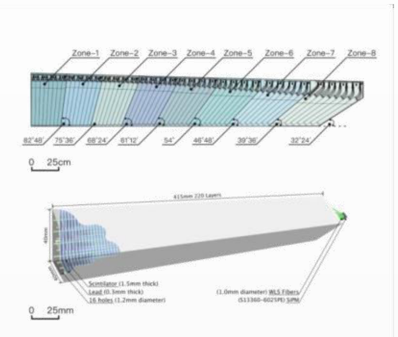
Electromagnetic calorimeter (ECAL)

- Sampling calorimeter with projective geometry (70 tons):
  - ✓ 25 sectors (50 half-sectors); 2400 modules; 38,400 “shashlyk”-type Pb-Sc towers with segmentation of 4x4 cm^2
  - ✓ read-out: WLS fibers + SiMP; L ~ 35 cm (~ 14 X_0); $\delta E/E$ ~ 5% @ 1 GeV; $\delta\tau$ ~ 500 ps







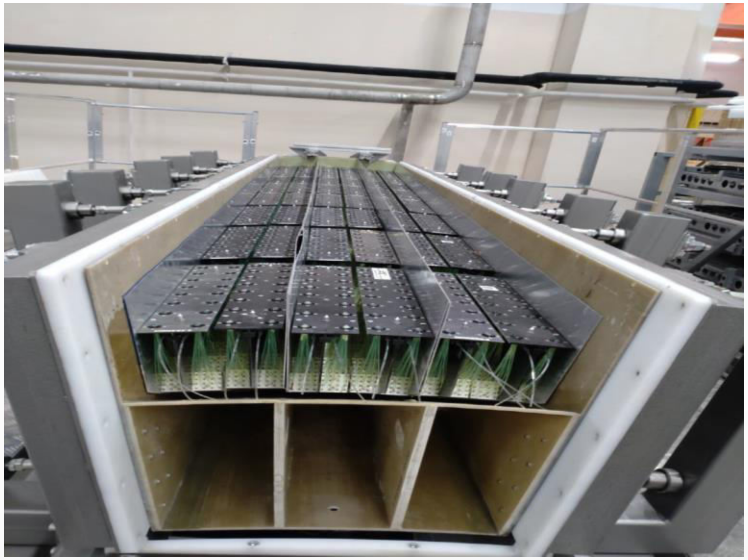


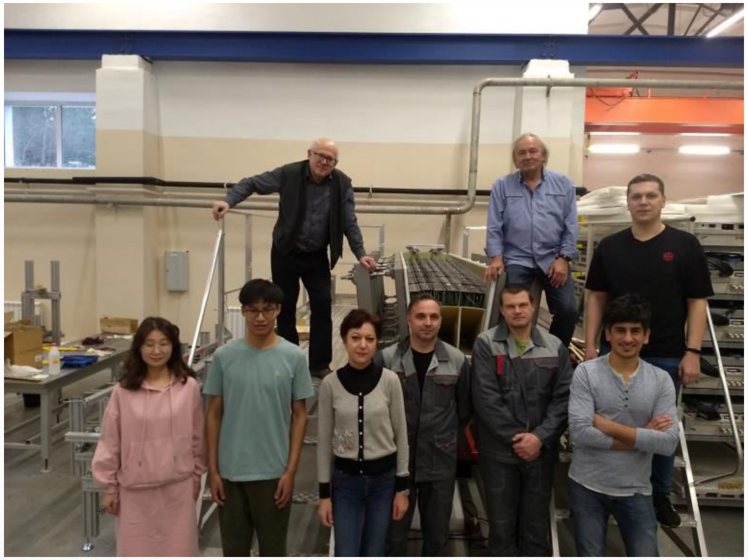
- 1600 modules (66%) have been produced (800 in Russia + 800 in China)
- Additional 400 modules can be produced in Russia by summer 2023, supply of WLS fibers is a bottleneck
- Mass production of half-sectors started

- Clusters production:
  - ✓ production rate ~ 1/day
  - ✓ 49 clusters are ready
- Half-sector frames:
  - ✓ production rate ~ 2/week
  - ✓ mass production in January - March

Electromagnetic calorimeter (ECAL)

- ❖ Assembly of half-sectors has started in JINR by international team (Russia, Bulgaria, China, India, Chili)





- ❖ Tests and preliminary calibration of modules with cosmic muons and electron beams, meet requirements
- ❖ Long-term stability test of ECAL is ongoing, preliminary results are in agreement with the expectations
- ❖ LED-based monitoring system is developed for calibration and control

- ❖ ECAL schedule:
  - ✓ towers/modules are produced (66%), production of extra 17% modules depends on supply of WLS fibers
  - ✓ clusters ready by summer, 2023
  - ✓ 32 half-sectors ready by November, 2023
  - ✓ ECAL cooling system (outside of barrel) is under development

China MOST MPD-ECal project

- Hardware:
  - Construction of 8 sectors ECal prototype. 768 modules in total.
  - Production of FEE PCB (1800 FEEs)
  - R&D on fast readout electronics, time resolution is less than 150ps
- Software and simulation
- Schedule: 2020.6-2024.5
- Institutes:
  - Tsinghua University 100%
  - Shandong University 100%
  - University of South China 100%
  - Fudan University 90%
  - Huzhou University