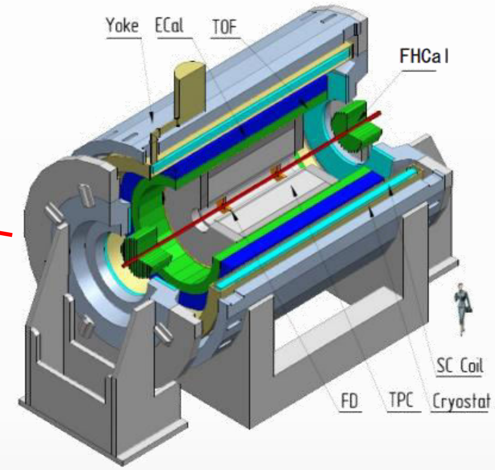
Implementation of the MPD project

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



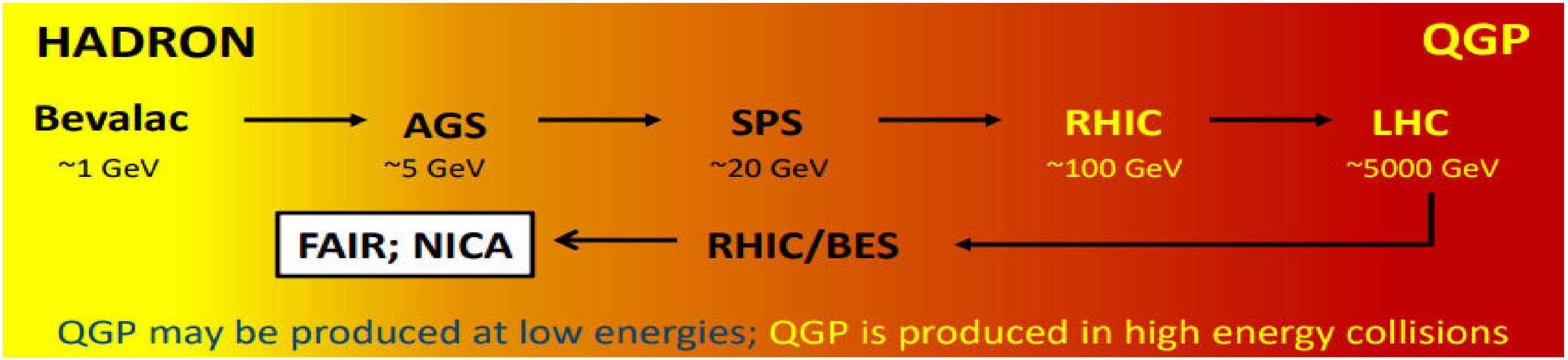
Stage- I

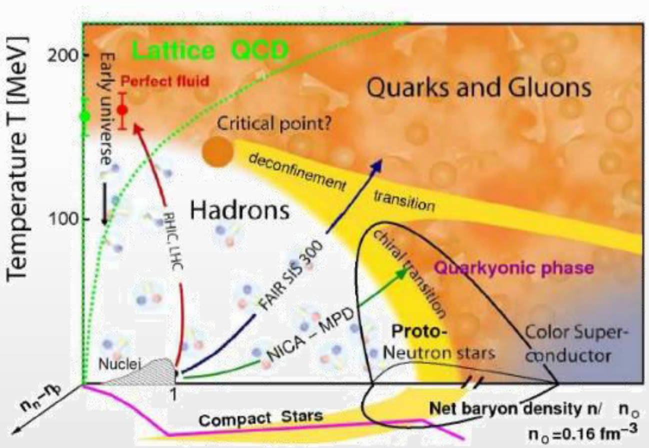
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$
TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

❖ Expected beam configuration in first year(s) of operation:

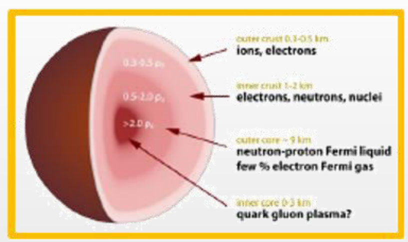
- ✓ not-optimal beam optics with wide z-vertex distribution, $\sigma_z \sim 50$ cm
- ✓ reduced luminosity (~10^{25} is the goal for 2023) → collision rate ~ 50 Hz
- ✓ collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209)
- ✓ Bi+Bi @ 9.2 GeV in 2024

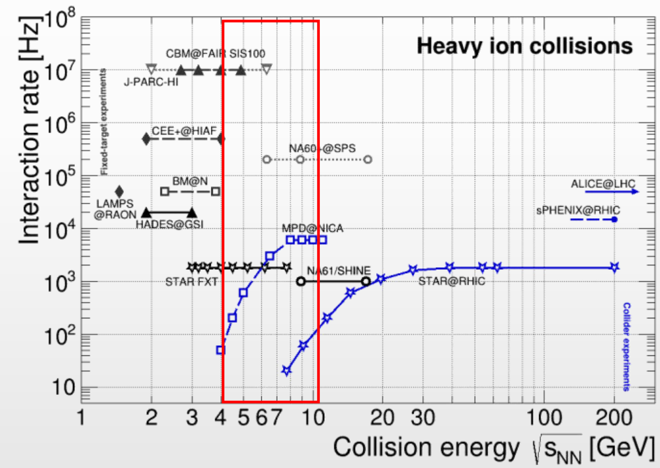
Relativistic heavy-ion collisions





high baryon densities
→ inner structure of
compact stars





- At μ_B ~ 0, smooth crossover (lattice QCD calculations + data)
- At large μ_B, 1st order phase transition is expected → QCD critical point
- BM@N and MPD will study QCD medium at extreme net baryon densities
- Many ongoing (NA61/Shine, STAR-BES) and future experiments (CBM) in ~ same energy range

MPD assembling milestones and plans

❖ Latest estimates provided by V. Golovatyuk

	Year 2022	
8	Jan 20 - April 30	Cables for Solenoid probes signals installation
9	May 16 - Dec 25th	Assembling Iron yoke, platforms and Cryostat. New LHe and LN pipes order
10	Sept - Dec 30	Cryogenic infrastructure for cooling down by temporary scheme, power Supply and Control system preparation
11	Oct - February 15th , 2023	Preparation power supply and Solenoid Control systems
	Year 2023	
12	Jan 15 - March 20th	Vacuum test of Solenoid with Cryostat
13	April 1 - June 30	Solenoid cooling down to Liquid Helium temperature (temporary scheme)
14	July1 - July20	Mounting FHCal into poles
14	August 1 – September 30	Magnetic Field measurements
15	October 1 - October 30	Installation ECal and TOF sectors
16	Nov 1 - Dec 30th	TPC installation, Luminosity detector
	Year 2024	
17	Jan 10 - Feb	Move the MPD on Collider beam line, Commissioning

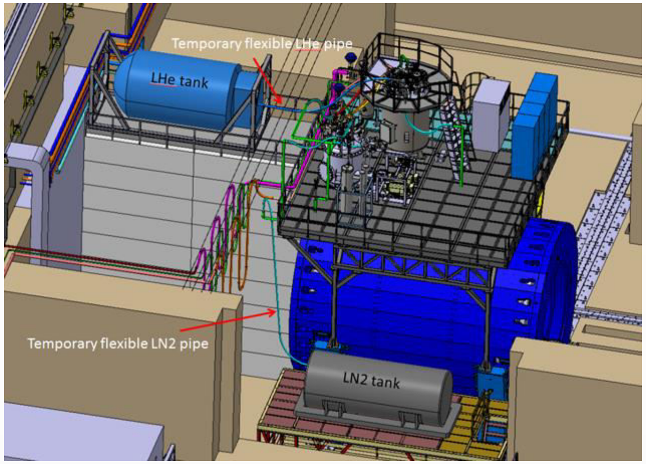
Schedule of the MPD-NICA is significantly affected by the current geopolitical situation (suspension of collaboration with CERN and Polish & Czech Republic member institutions, economic sanctions and problems with supplies of many components from western companies). The primary goal to have the MPD commissioned by the first beams at NICA collider is preserved:

2024 – first run with BiBi29.2 GeV, 50-100 M events for alignment, calibration and physics

Activities in the MPD Hall

Top platform (cryogenics, power supplies, control system)

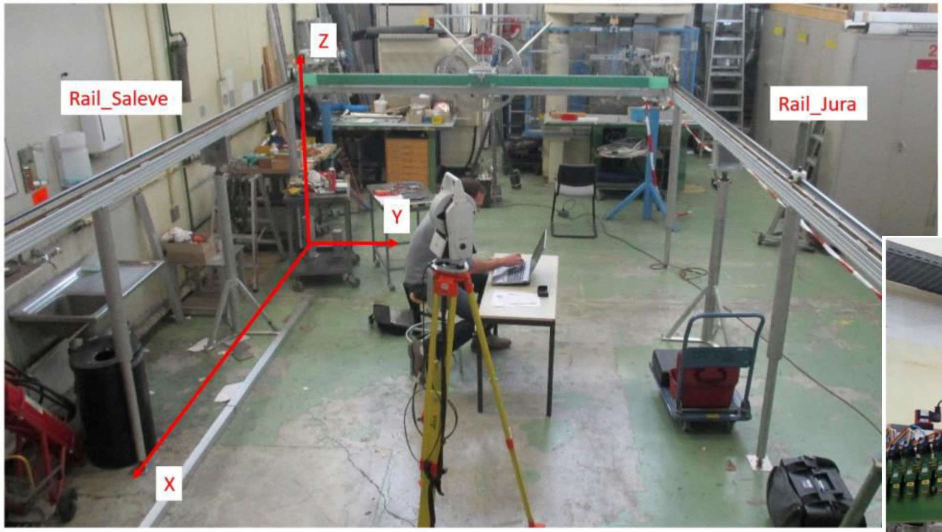
Temporary scheme of Solenoid cooling



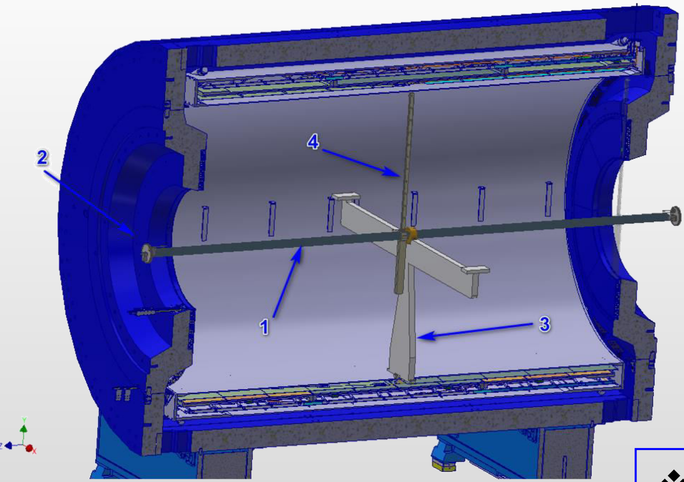
- Yoke, TRIM coils, top platform assembled
- Started assembling of the refrigerators and control Dewar
- Chimney area partly assembled, missing elements for SC cable connections ordered in Russia
- Pipes, LN2 tanks, LHe pipe, heaters and other equipment was re-ordered in Russia
- Power supplies and control system are being tested, works with cables are ongoing

- Start-up schedule:
  - ✓ Vacuum tests and cooling of the solenoid by temporary scheme to 4,5K: January - June, 2023
  - ✓ Power tests and slow current supply to solenoid and TRIM coils: August, 2023
  - ✓ Cryogenic system operation by stationary scheme: end of 2023

Magnetic field measurements



- CERN design of mapper :
  - ✓ 38 Hall probes move in z and ϕ directions
  - ✓ accuracy – 1.5-2.0 Gs
  - ✓ range of fields 0.57 -0.5 T



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

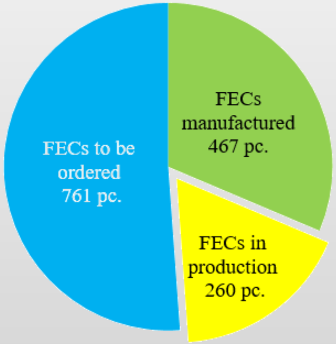
- Concept of Novosibirsk INP mapper:
  - ✓ 1 Hall 3D probe moves in 3 directions: z, R, ϕ
  - ✓ accuracy: 0.3 – 0.5 Gs
  - ✓ range of fields: 0.2-0.57 T

- Schedule:
  - ✓ Measurements, different SC and TRIM currents: August-September, 2023

Time Projection Chamber (TPC)

- TPC cylinders, central membrane and service wheels are ready – final vessel assembly in March, 2023
- Read-out chambers (ROCs) - 24 tested chambers in stock + 2 tested spare chambers

- Gas system ready – testing
- TPC FE production status:



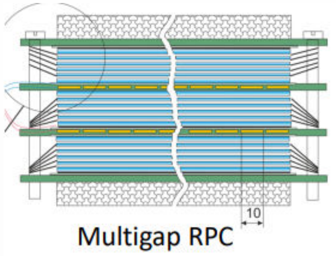
- ✓ produced 727 FECs out of 1500 → 11 ROCs equipped (48%)
- ✓ components in stock for 60%
- ✓ remaining FECs to be produced during 2023
- ✓ testing of the readout system for one ROC (62 FECs) is ongoing
- ✓ RCU controllers mass production and integration - 2023

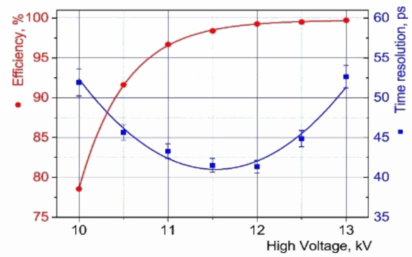
- TPC schedule:
  - ✓ TPC installation in the MPD: Nov, 2023
  - ✓ Cabling and piping: Sept-Dec, 2023
  - ✓ TPC commissioning: Jan-Feb, 2024

- On critical path:
  - ✓ TPC rails (design, manufacturing) – June, 2023
  - ✓ TPC cooling system – tender finished (INP BSU, Belarus) – FEE cooling ready by Nov., 2023; thermostabilization panels by summer, 2024
  - ✓ Slow control system, including integration

Time-of-Flight (TOF)

	Number of detectors	Number of readout strips	Sensitive area, m²	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)





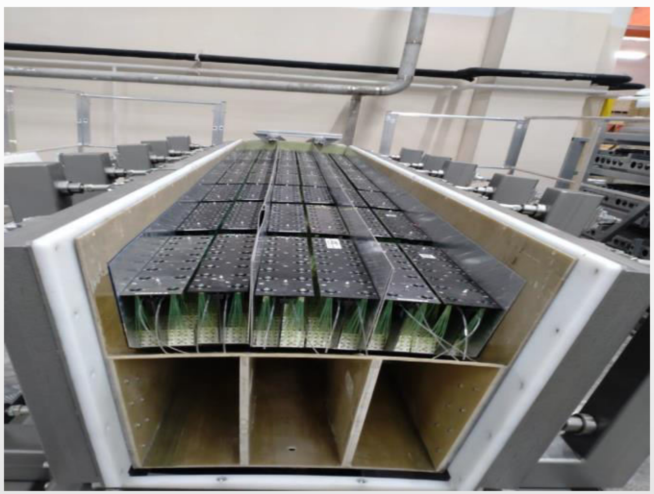
- ❖ The production of MRPC detectors is completed, produced and tested 300 (107%) chambers
- ❖ 24 of 28 (86%) TOF modules are already assembled, to be completed in March, 2023
- ❖ Produced modules are subject to long-tern cosmic ray tests
- ❖ Electronics & cables - in stock, gas system - in assembly, HV distribution modules - 25/28 in stock

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

- ❖ TOF schedule:
  - ✓ TOF modules ready for installation in the MPD: April-May 2023
  - ✓ TOF installation in the MPD: October, 2023
  - ✓ TOF in full configuration: end of 2023

Electromagnetic calorimeter (ECAL)

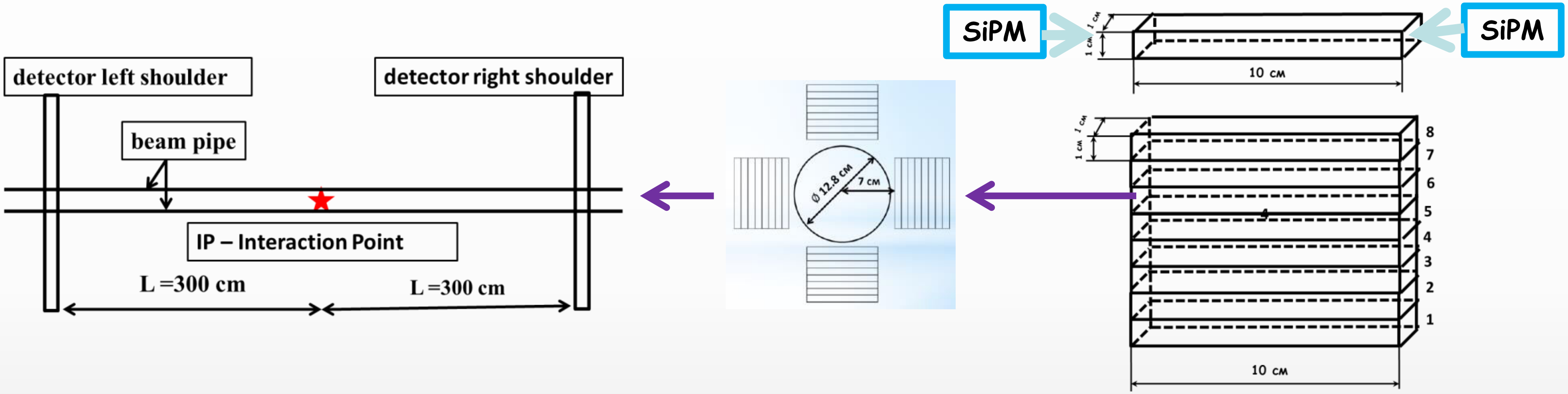
- Sampling calorimeter with projective geometry (70 tons):
  - ✓ 25 sectors (50 half-sectors); 2400 modules; 38,400 “shashlyk”-type Pb-Sc towers with segmentation of 4x4 cm^2
- 1600 modules (66%) have been produced (800 in Russia + 800 in China)
- Additional 400 modules can be produced in Russia by summer 2023, supply of WLS fibers is a bottleneck
- Clusters production rate ~ 1/day, 49 clusters ready
- Half-sector frames production rate ~ 2/week, mass production in January - March
- Assembly of half-sectors has started in JINR by international team (Russia, Bulgaria, China, India, Chili)



- ECAL schedule:
  - ✓ 32 half-sectors ready: by October, 2023
  - ✓ ECAL installation in the MPD: October, 2023
  - ✓ ECAL cooling system (outside of barrel) is under development

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.



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

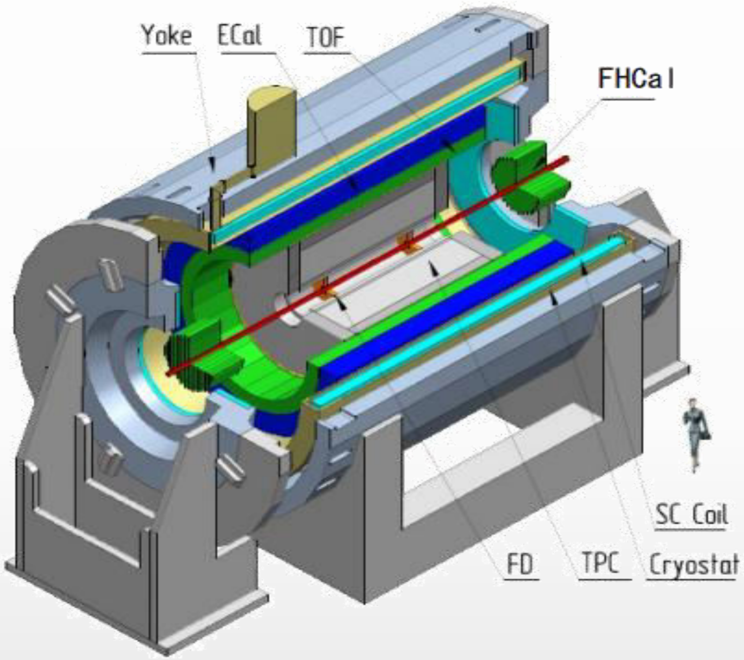
Multi-Purpose Detector (MPD) Collaboration

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

10** Countries, **>450** participants, **33** Institutes and **JINR

Organization

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



***Joint Institute for Nuclear Research**;*
*AANL, Yerevan, **Armenia;***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*IHEP, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*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**;*
*INR RAS, Moscow, **Russia**;*
*MEPhI, Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*NRC Kurchatov Institute, **Russia**;*
*Plekhanov Russian University of Economics, Moscow, **Russia**;*
*St. Petersburg State University, **Russia;***
*SINP, Moscow, **Russia**;*
*PNPI, Gatchina**, Russia**;*
*Vinča Institute of Nuclear Sciences**, Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

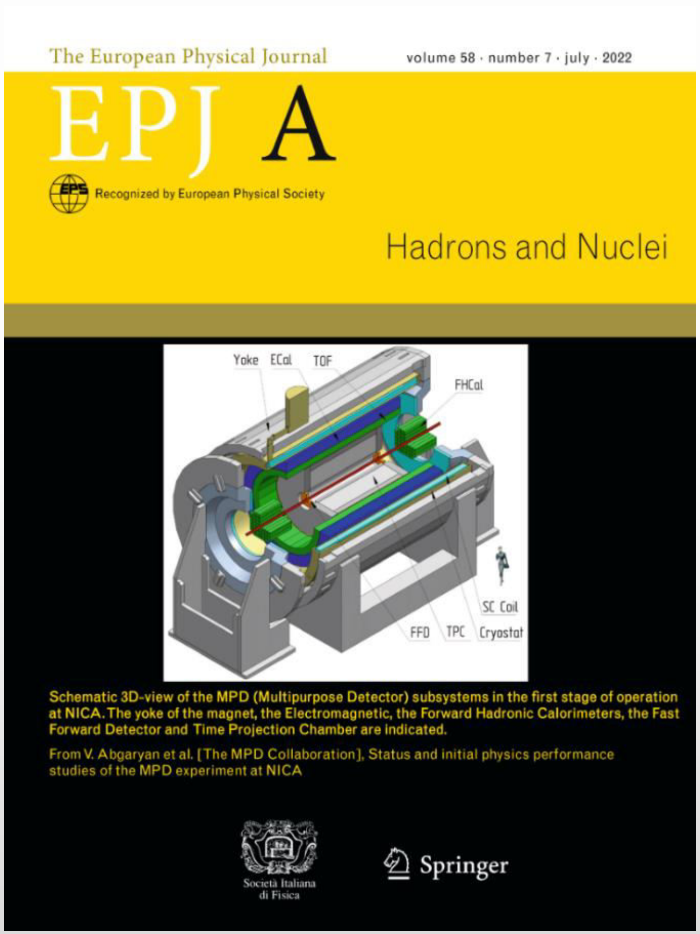
X-th MPD Collaboration Meeting, 8-10 November, 2022

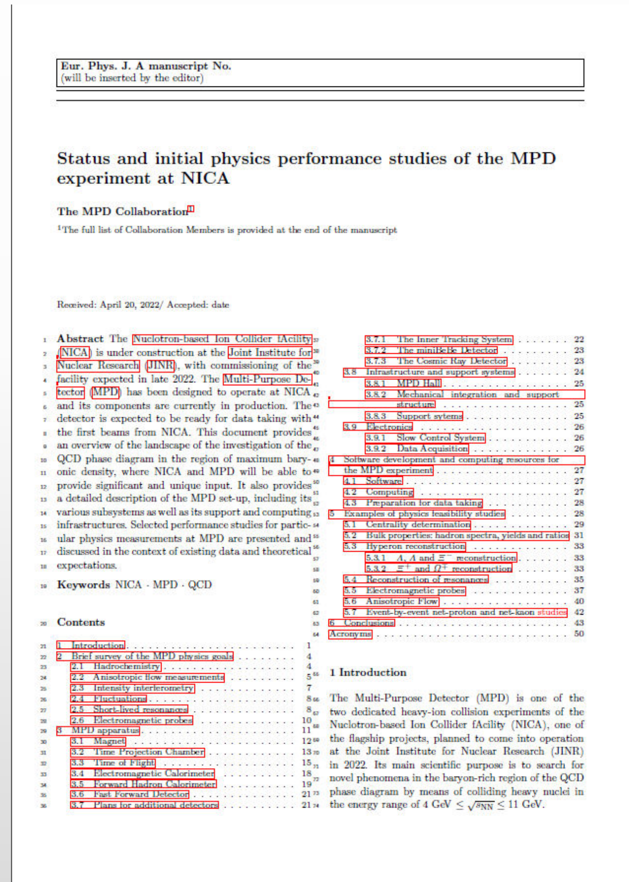
- Held in mixed mode at JINR with over 160 participants, half present in-person
- 35 reports in three days for recent progress in MPD construction, development of computing and software infrastructure and preparations for physics analyses
- Preparation of the MPD detector and experimental program is continued

First collaboration paper

❖ First collaboration paper recently published EPJA (~ 50 pages): Eur.Phys.J.A 58 (2022) 7, 140

<u>Status and initial physics performance studies of the MPD experiment at NICA</u>





Eur. Phys. J. A manuscript No.
(will be inserted by the editor)

Status and initial physics performance studies of the MPD experiment at NICA

The MPD Collaboration[1]

[1]The full list of Collaboration Members is provided at the end of the manuscript

Received: April 20, 2022/ Accepted: date

Abstract The Nuclotron-based Ion Collider fAcility (NICA) is under construction at the Joint Institute for Nuclear Research (JINR), with commissioning of the facility expected in late 2022. The Multi-Purpose Detector (MPD) has been designed to operate at NICA and its components are currently in production. The detector is expected to be ready for data taking with the first beams from NICA. This document provides an overview of the landscape of the investigation of the QCD phase diagram in the region of maximum baryonic density, where NICA and MPD will be able to provide significant and unique input. It also provides a detailed description of the MPD set-up, including its various subsystems as well as its support and computing infrastructures. Selected performance studies for particular physics measurements at MPD are presented and discussed in the context of existing data and theoretical expectations.

Keywords NICA · MPD · QCD

Contents

1 Introduction

The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to search for novel phenomena in the baryon-rich region of the QCD phase diagram by means of colliding heavy nuclei in the energy range of 4 GeV $\leq \sqrt{s_{NN}} \leq$ 11 GeV.

International conferences

- MPD was presented at all major conferences in the field:
  - ✓ Quark Matter (QM-2022), April 4-10
  - ✓ Nucleus-2022, July 11-16
  - ✓ International Conference on High Energy Physics (ICHEP-2022), July 6-13
  - ✓ International Scientific Forum “Nuclear Science and Technologies (NST-2022), September 26-30
  - ✓ European Nuclear Physics Conference (EuNPC-2022), October 24-28
  - ✓ International Symposium on Origin of Matter and Evolution of Galaxies, October 25-28
  - ✓ DAE-BRNS CETHENP-2022, November 15-17
  - ✓ XVIII Mexican Workshop on Particles and Fields (XVIII MWPF), November 21-25
  - ✓ International Conference on Particle Physics and Astrophysics (ICPPA-2022), November, 29 - December, 2

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

- Over twenty five plenary and parallel talks given in 2022

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

V. Riabov, 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
- ✓ increase the attendance
- ✓ improve communication and sharing of ideas between different analysis groups

Monte Carlo mass productions

- Physics feasibility studies using centralized large-scale MC productions to deliver a clear and consistent picture of the MPD physical capabilities with the first data sets and prepare for the real data analyses
- https://mpdforum.jinr.ru/c/mcprod/26:
  - General-purpose, **50M** UrQMD BiBi@9.2 → **Done**
  - General-purpose + trigger, **1M** DCM-QGSM-SMM BiBi@9.2 → **Done**
  - General-purpose + trigger, **1M** PHQMD BiBi@9.2 → **Done**
  - General-purpose with reduced magnetic field, **10M** UrQMD BiBi@9.2 → **Done**
  - General-purpose + hypernuclei, **20M** PHQMD BiBi@9.2 → **Done**
  - General-purpose + hyperon polarization, **15M** PHSD BiBi@9.2 → **Done**
  - General-purpose + femtoscopy, **50M** UrQMD BiBi@9.2 with freeze-out → **In progress**
  - General purpose + flow/femtoscopy, **15M** vHLLE+UrQMD with XPT → **in preparation**
  - General purpose + flow/femtoscopy, **15M** vHLLE+UrQMD with 1PT → **in preparation**
- Production and analysis of data sets, which are comparable in size to the first expected real data samples test the existing computing and software infrastructure
- Learn how to handle the big data sets, develop analysis methods and techniques, set priorities for different analyses, find group leaders, etc.

Computations are held on the basis of the HybriLIT heterogeneous computing platform (thanks!!!)

→ see a dedicated poster presentation later today !

Handling the big data sets

- ❖ Move to a centralized Analysis Framework for access and analysis of data: (used at RHIC/LHC)
  - ✓ analogous approaches are used at RHIC/LHC, proved to be very useful
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ analyses are grouped in trains and run simultaneously with a single access to data per train → 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:

Analysis manager	wagon #1	wagon #2	wagon #3	wagon #4	wagon #5	wagon #6

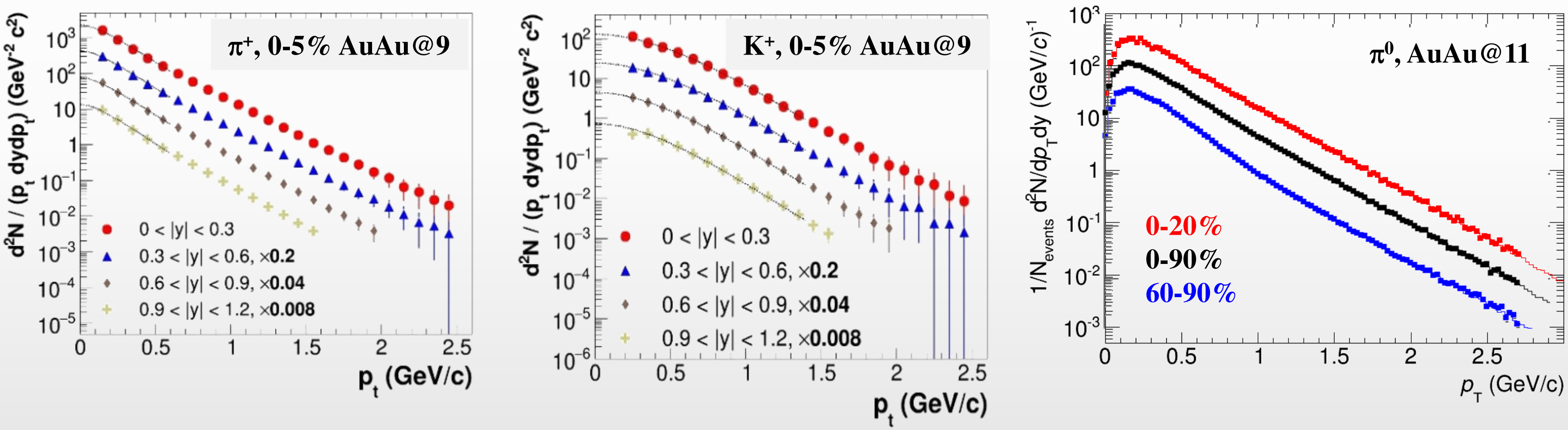
- ❖ Example:
  - ✓ Wagon #1 – event selector – selects events to be analyzed
  - ✓ Wagon #2 – centrality analyzer – returns values of centrality for all other wagons in the train
  - ✓ Wagon #3 – recalibrator – redefines some DST variables that need recalibration after production
  - ✓ ………………………..
  - ✓ Wagon #4, 5, … – physics analysis 1, 2, …

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

AuAu@9-11 GeV, 10 M events → full event/detector simulation and reconstruction

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



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’)

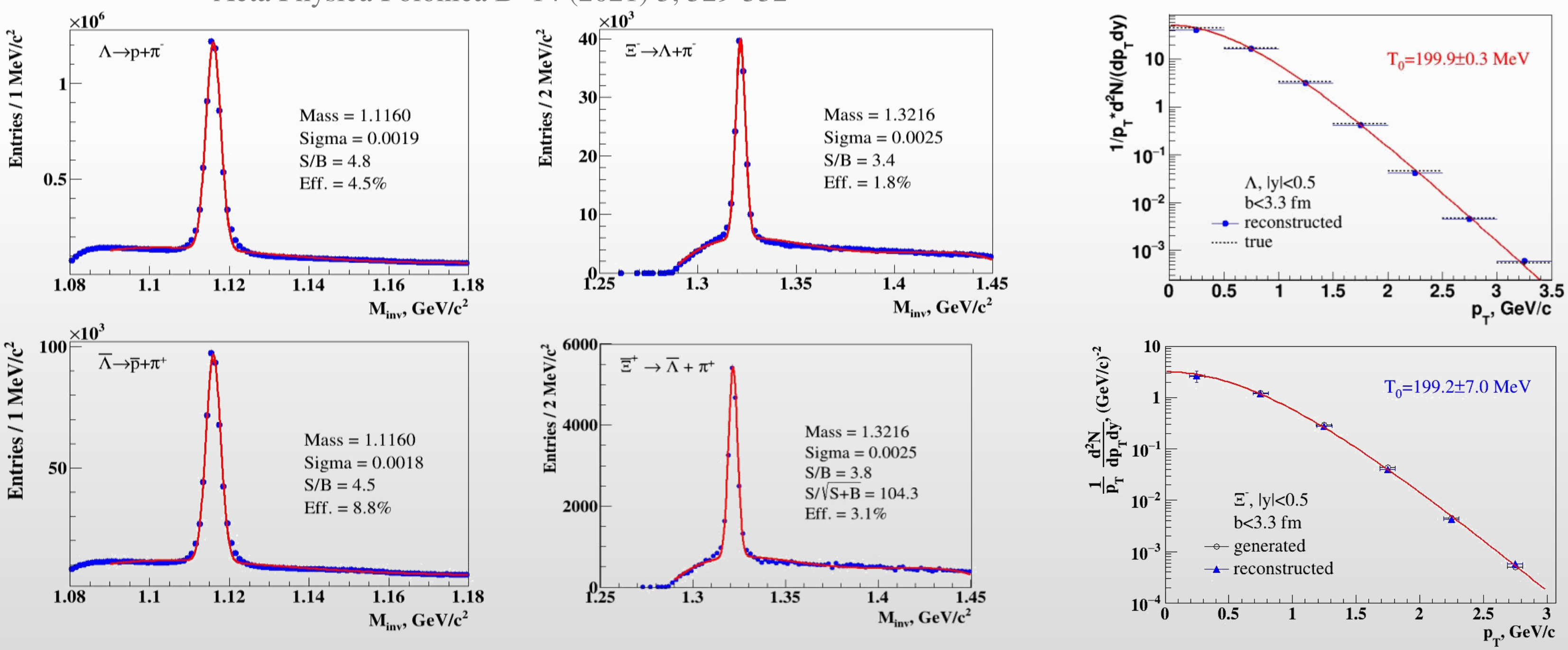
First measurements will be possible with a few million sampled heavy-ion events

Strange baryons

- Since the mid 80s, strangeness enhancement is considered as a signature of the QGP formation
- Experimentally observed in heavy-ion collisions at AGS, SPS, RHIC, and LHC energies.
- No consensus on the dominant strangeness enhancement mechanisms:
  - ✓ strangeness enhancement in QGP contradicts with the observed collision energy dependence
  - ✓ strangeness suppression in pp within canonical suppression models reproduces most of results except for ϕ(1020)

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

Acta Physica Polonica B 14 (2021) 3, 529-532



Measurements for strange baryons will be possible with accumulation of ~ 10 M BiBi@9.2 events

Short-lived resonances

❖ Resonances are best suited to probe density and lifetime of the late hadronic phase of HI collisions

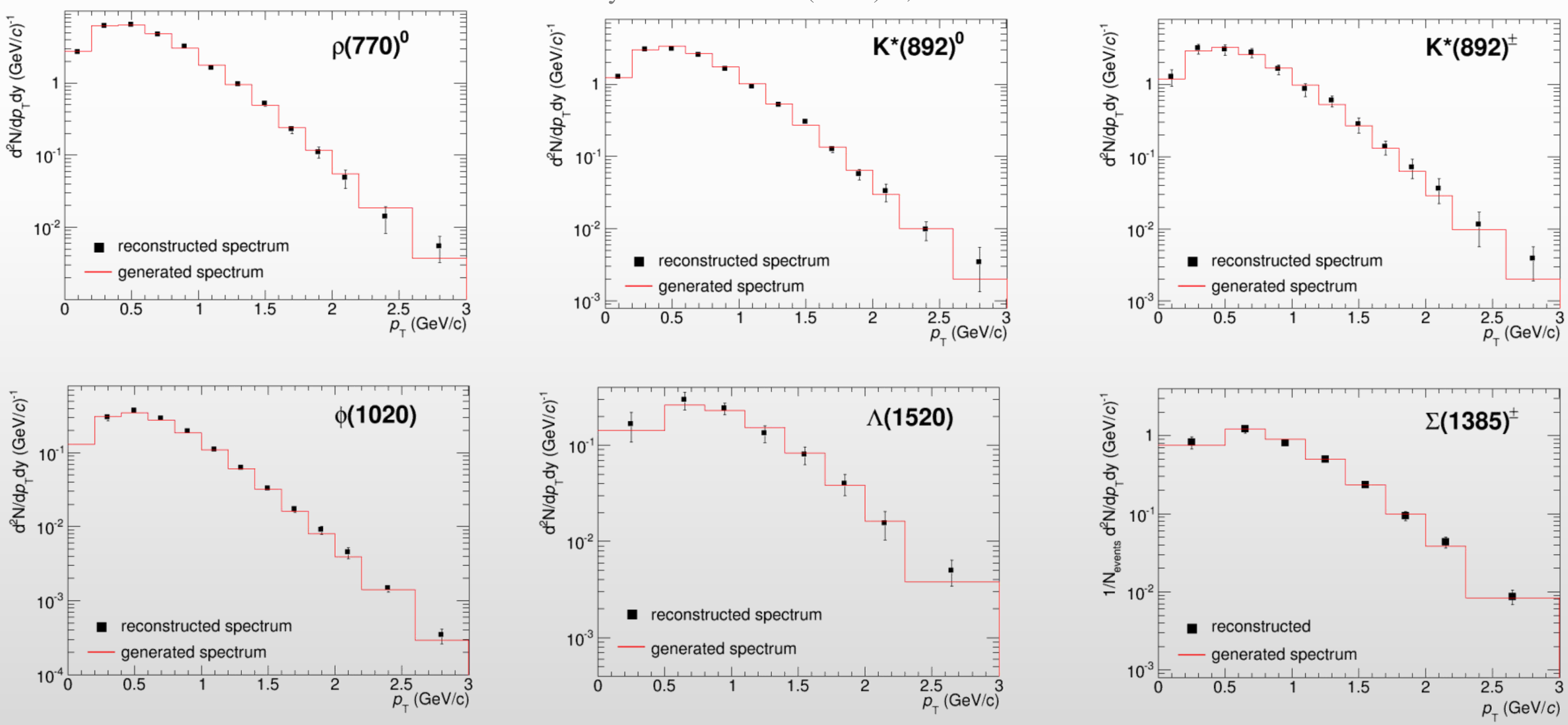
increasing lifetime →

	ρ(770)	K*(892)	Σ(1385)	Λ(1520)	Ξ(1530)	ϕ(1020)
cτ (fm/c)	1.3	4.2	5.5	12.7	21.7	46.2
$\sigma_{rescatt}$	$\sigma_\pi\sigma_\pi$	$\sigma_\pi\sigma_K$	$\sigma_\pi\sigma_\Lambda$	$\sigma_K\sigma_p$	$\sigma_\pi\sigma_\Xi$	$\sigma_K\sigma_K$

❖ Spin alignment of vector mesons in non-central A-A collisions - recombination in a polarized medium

BiBi@9.2 GeV (UrQMD), 10 M events→ full event/detector simulation and reconstruction

Phys.Part.Nucl. 53 (2022) 2, 347-353

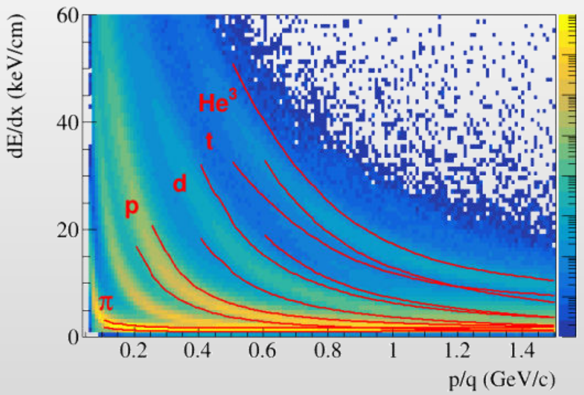


First measurements for resonances will be possible with accumulation of ~ 10 M Bi+Bi events

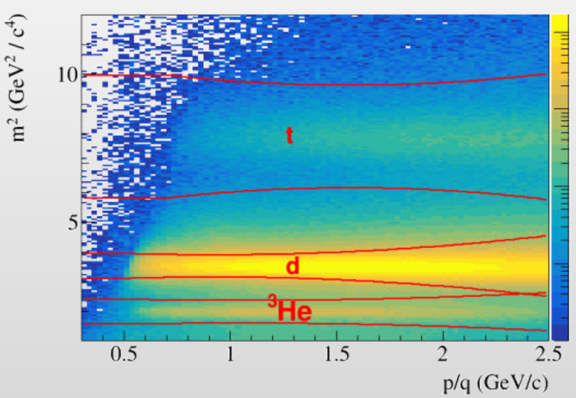
Light nuclei & cosmic radiation

- Production mechanism usually described with two classes of phenomenological models :
  - ✓ statistical hadronization (SHM) → production during phase transition, $dN/dy \propto \exp(-m/T_{chem})$
  - ✓ coalescence → (anti)nucleons close in phase space ($\Delta p < p_0$) and matching the spin state form a nucleus
- Space radiation studies:
  - ✓ Galactic Cosmic Rays composed of nuclei (protons, … up to Fe) and E/A up to 50 GeV
  - ✓ damage is proportional to Z2, damage from secondary production of p, d, t, 3He, and 4He is important
  - ✓ cosmic rays are a serious concern to astronauts, electronics, and spacecraft
- Need input information for transport codes for shielding applications (Geant-4, Fluka, PHITS, etc.):
  - ✓ total, elastic/reaction cross section
  - ✓ particle multiplicities and coellecense parameters, outgoing particle distributions: $d^2N/dEd\Omega$
- NICA can deliver different ion beam species and energies:
  - ✓ targets of interest (C = astronaut, Si = electronics, Al = spacecraft) + He, C, O, Si, Fe, etc.
- No data exist for projectile energies > 3 GeV/n

dE/dx vs. momentum in TPC



m^2 vs. momentum in TOF

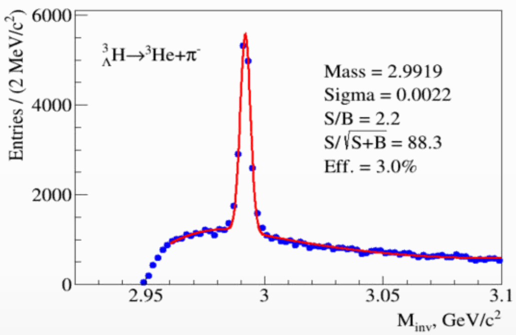


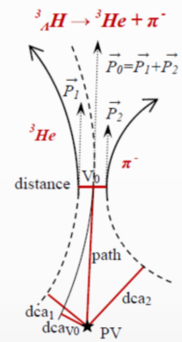
Light fragment identification in a wide y-range → unique capability of the MPD in the NICA range

Hypernuclei production

- Hyper nuclei measurement studies are crucial:
  - ✓ microscopic production mechanism, Y-N potential, strange sector of nuclear EoS
  - ✓ strong implications for astronuclear physics → hyperons expected to exist in the inner core of neutron stars
- Observables of interest: precise measurements of binding energies, lifetimes and branching ratios

BiBi@9.2 GeV (PHQMD), 40 M events → full event/detector simulation and reconstruction

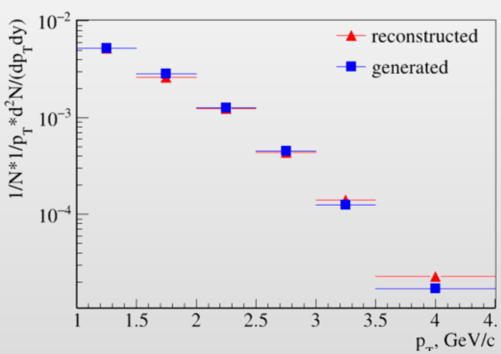




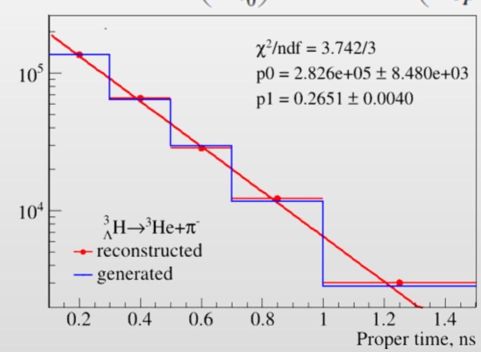
Phys.Part.Nucl.Lett. 19 (2022) 1, 46-53

Decay channel	Branching ratio	Decay channel	Branching ratio
$\pi^- + {}^3He$	24.7%	$\pi^- + p + p + n$	1.5%
$\pi^0 + {}^3H$	12.4%	$\pi^0 + n + n + p$	0.8%
$\pi^- + p + d$	36.7%	$d + n$	0.2%
$\pi^0 + n + d$	18.4%	$p + n + n$	1.5%

Spectrum is reconstructed up to p_T=4.5 GeV/c



$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right),$$



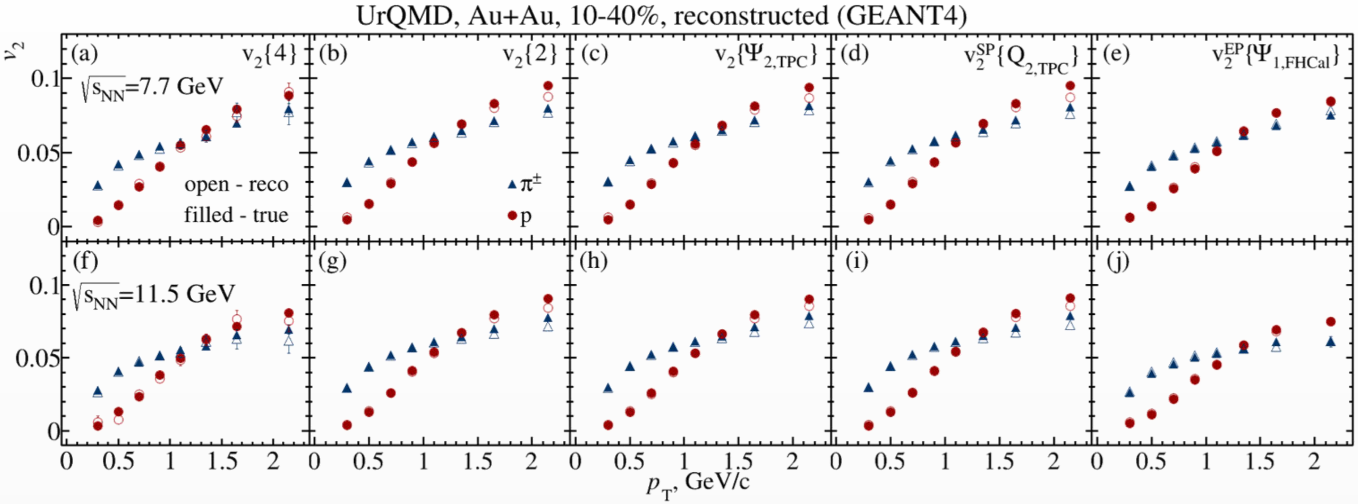
First measurements for hypertriton will be possible with accumulation of ~ 50 M BiBi@9.2 events

Reconstruction of heavier hypernuclei ($^{4}_{\Lambda}H$, $^{4}_{\Lambda}He$) requires equivalent statistics of ~150 M events

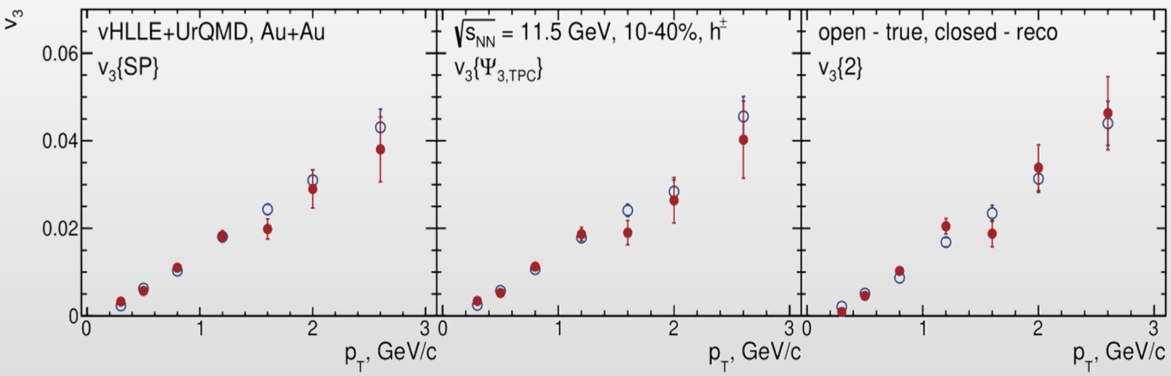
MPD performance: v_2 for π/p, v_3 for h$^{\pm}$

AuAu@7.7 GeV (UrQMD), 15 M events → full event/detector simulation and reconstruction

Particles 5 (2022) 4, 561-579; Particles 6 (2023) 1, 17-29;



AuAu@11.5 GeV (vHLLE + UrQMD), 15 M events → full event/detector simulation and



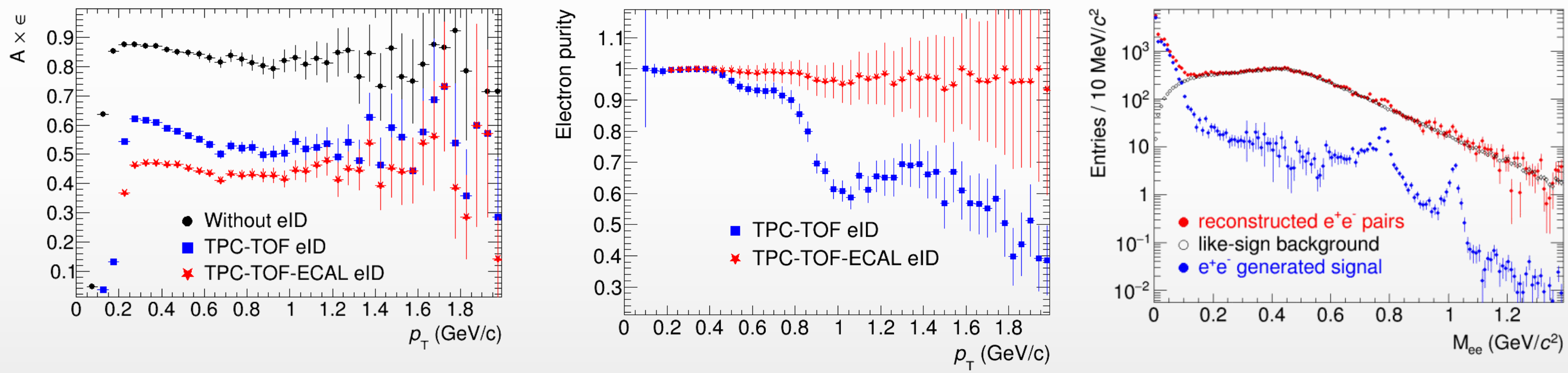
- ❖ Reconstructed and generated v_2 of pions and protons and v_3 of charged hadrons are in good agreement
- ❖ Models show that higher harmonic ripples are more sensitive to the existence of a QGP phase

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

BiBi@9.2 GeV (PHSD), 15 M events → full event/detector simulation and reconstruction

Phys.Part.Nucl. 52 (2021) 4, 783-787

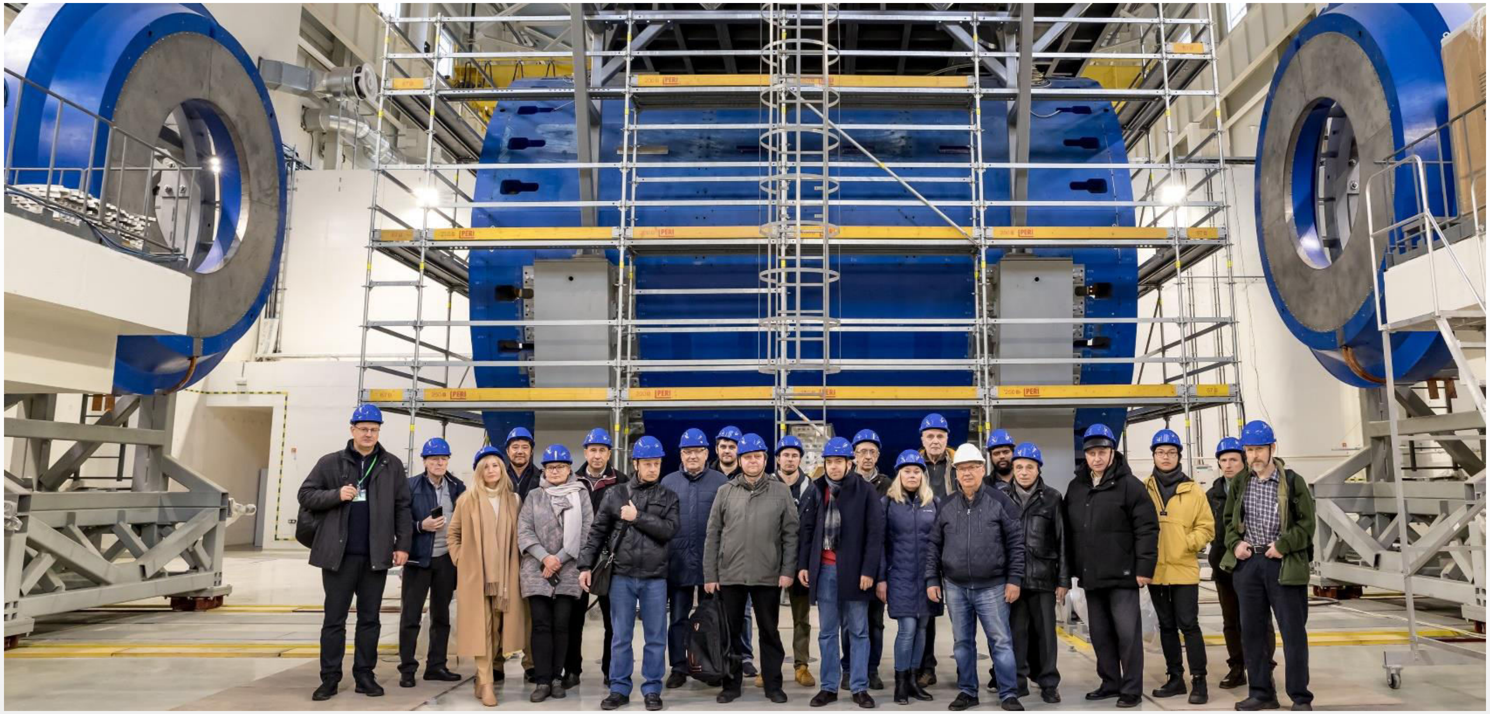


Excellent electron reconstruction and identification capabilities in the MPD with TPC, TOF and ECAL

Achieved S/B (0.2-1.5 GeV/c^2) ~ 5-10%, works on suppression of combinatorial background are continued

Need accumulation of ~ 100 M events for the first physics results

Summary

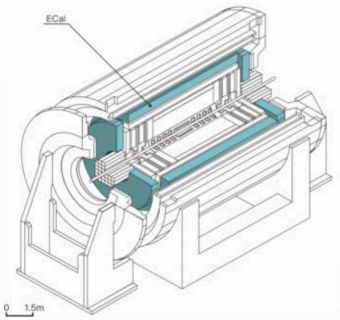


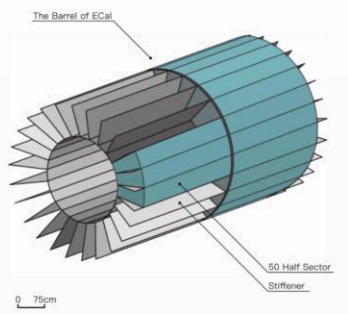
- Preparation of the MPD detector and experimental program is ongoing, all activities are continued
- Commissioning of the MPD Stage-I detector and start of data taking with BiBi@9.2 in 2024
- Further program will be driven by the physics demands and NICA capabilities

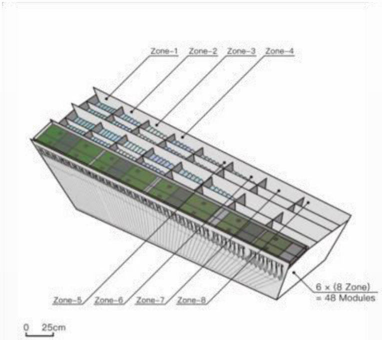
BACKUP

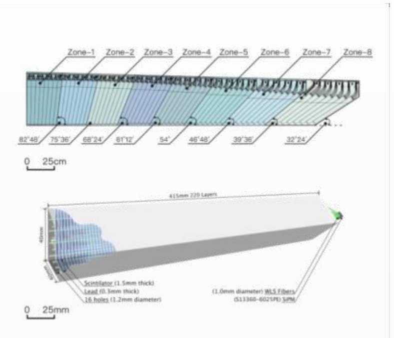
Electromagnetic calorimeter (ECAL)

- 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







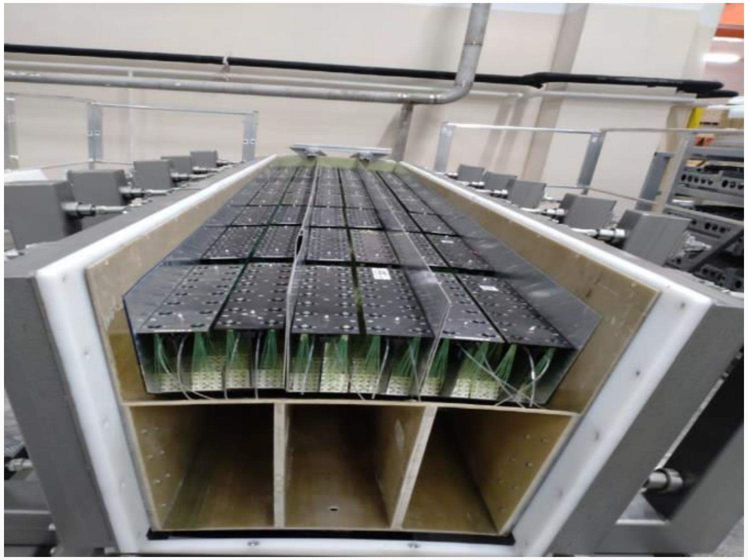


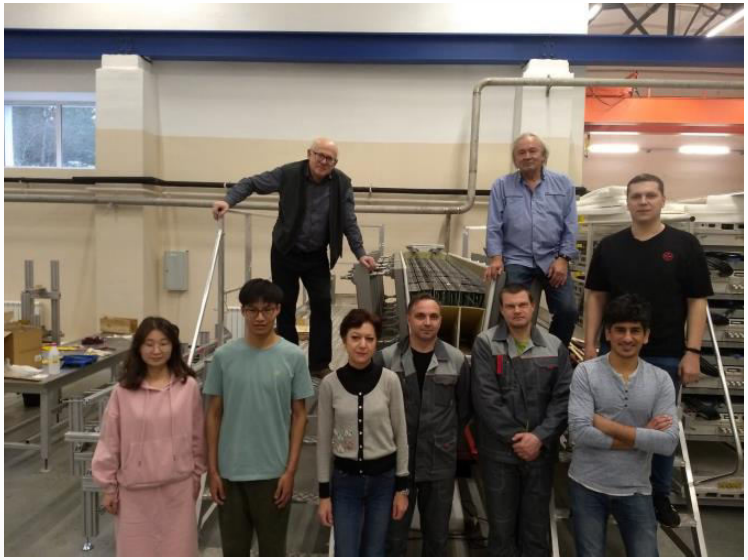
- 1600 modules (66%) have been produced (800 in Russia + 800 in China)
- Additional 400 modules can be produced in Russia by summer 2023, supply of WLS fibers is a bottleneck
- Mass production of half-sectors started

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

NICA 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

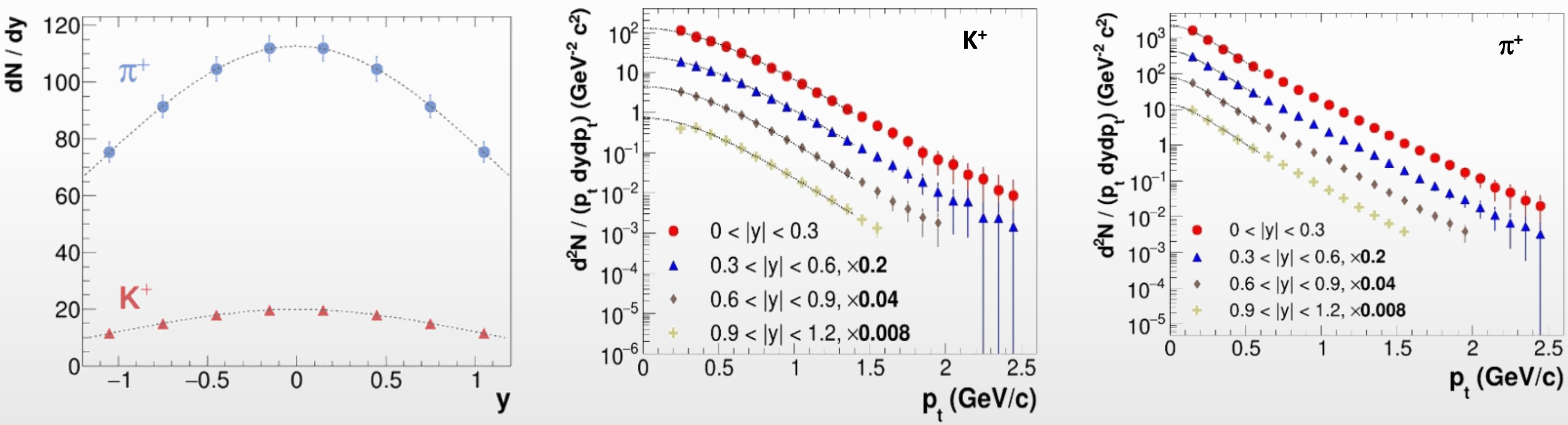
❖ ECAL schedule:
- ✓ towers/modules are produced (66%), production of extra 17% modules depends on supply of WLS fibers
- ✓ clusters ready by summer, 2023
- ✓ 32 half-sectors ready by November, 2023
- ✓ ECAL cooling system (outside of barrel) is under development

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

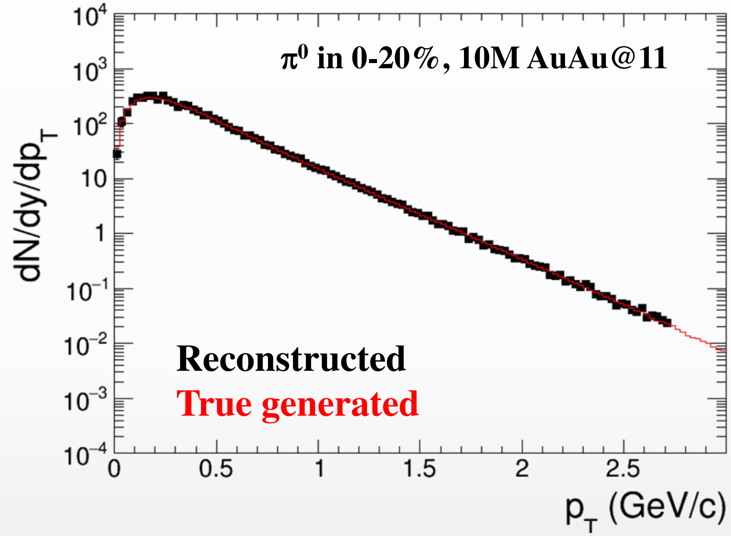


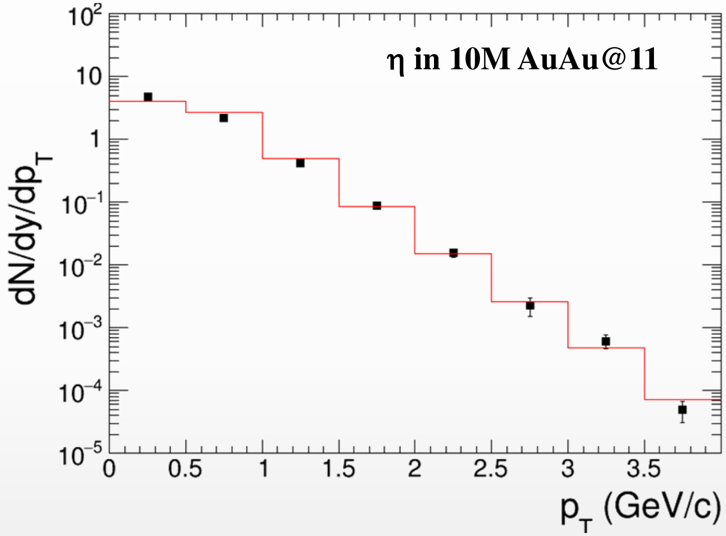
✓ sample ~ 70% of the π/K/p production in the full phase space
✓ hadron spectra are measured from p_T ~ 0.1 GeV/c

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’)

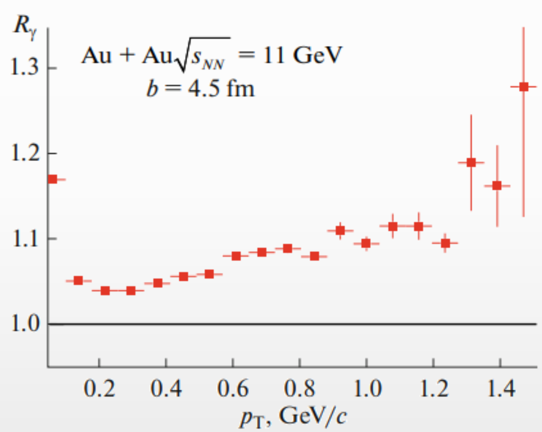
First measurements will be possible with a few million sampled heavy-ion events

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

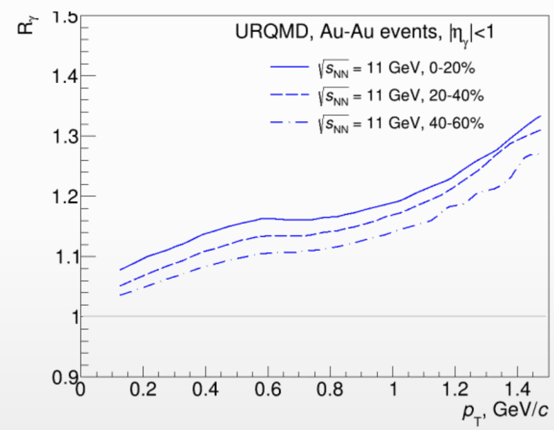
AuAu@11 GeV (UrQMD)

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



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

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



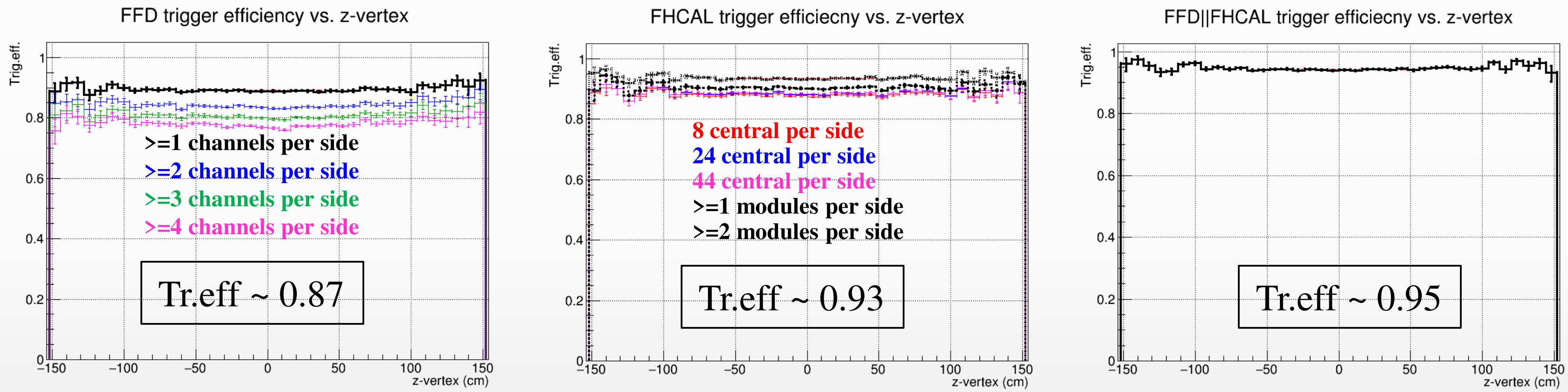
Non-zero direct photon yields are predicted with Rγ ~ 1.05 – 1.15 and v2 ~ 0.5% at top NICA energy

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

→ MPD can provide unique measurements for direct photon production @ NICA energies

Trigger system efficiency

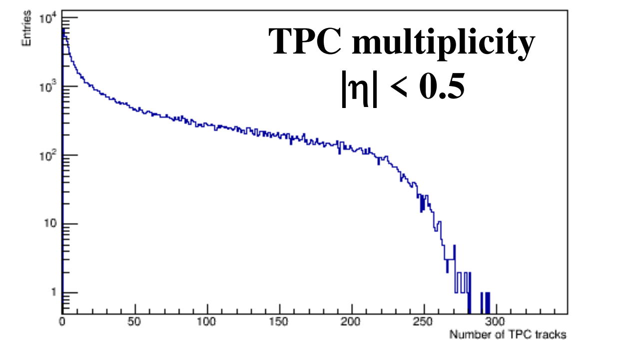
- Trigger system consists of FFD (2.7 < |η| < 4.1) and FHCAL (2 < |η| < 5); only FFD provides T_0
- MPD trigger system challenges at NICA energies:
  - ✓ low multiplicity of particles produced in heavy-ion collisions
  - ✓ particles are not ultra-relativistic (even the spectator protons)
- DCM-QGSM-SMM, BiBi@9.2: trigger efficiency is 87-95% for different trigger configuration

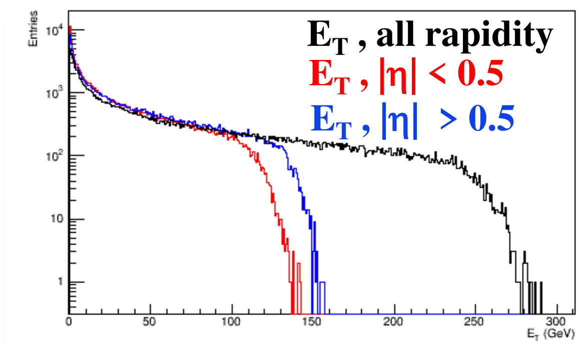


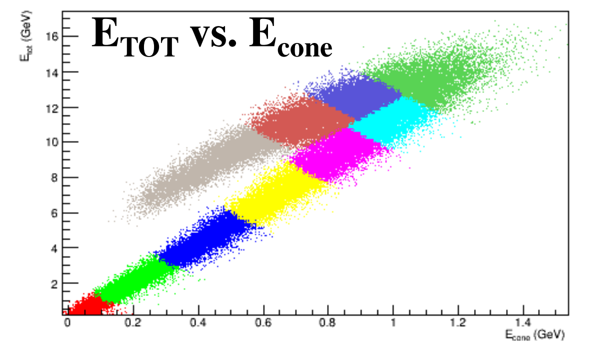
- DCM-QGSM-SMM, CC@9.2: trigger efficiency < 50%; pp@9.2: efficiency vanishingly small
- The existing trigger system does not provide high enough efficiency in light A-A and pp collisions
- Further updates are needed to realize competitive advantages of the MPD experiment – system size scan

Event centrality categorization

- Use TPC multiplicity, transverse energy E_T and FHCAL energy to determine event centrality

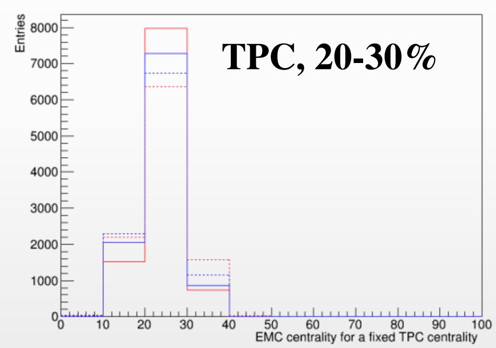


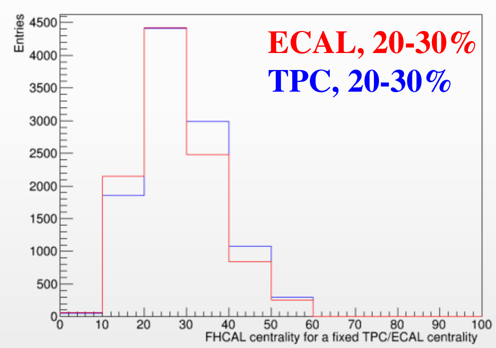


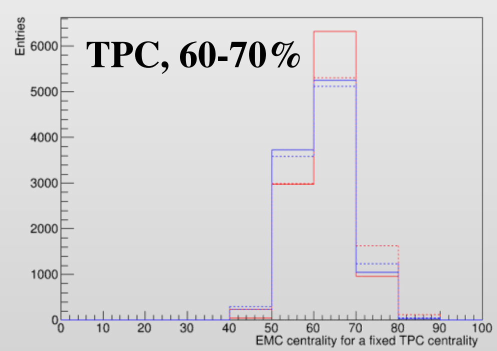


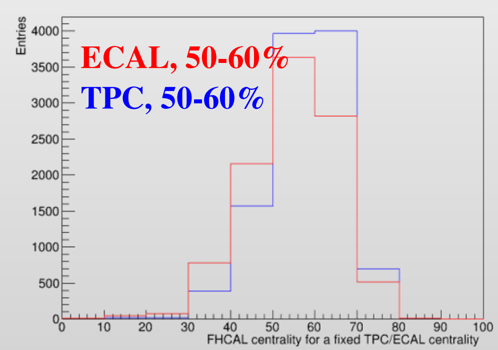
- TPC and ECAL produce similar results for centrality

- FHCAL centrality has a very wide correlation with the TPC/ECAL centrality; resolution by impact parameter is worse





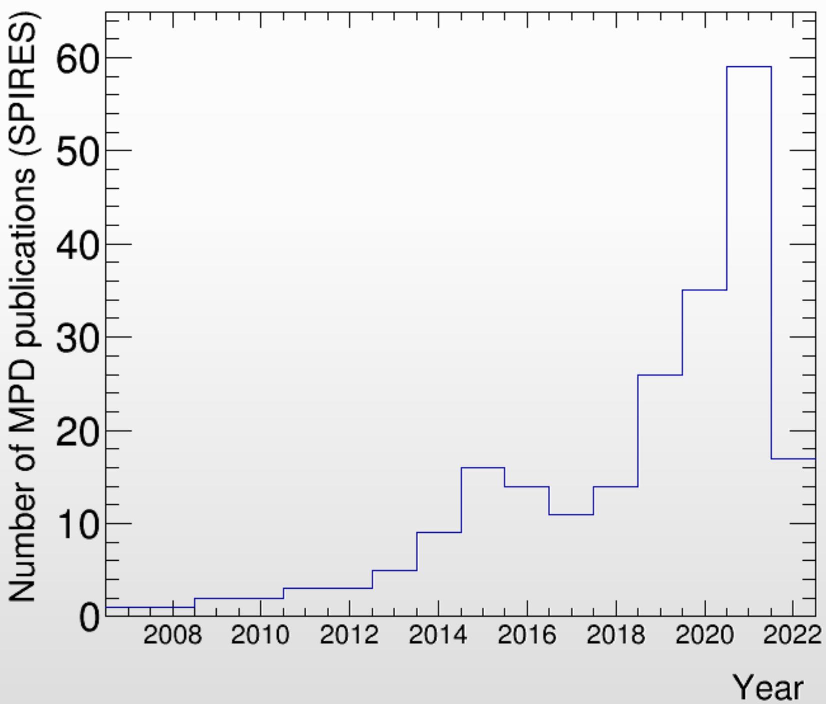




Collaboration activity

- Many ongoing construction works, theoretical and physics feasibility studies, see reports on hardware/software/physics topics at the collaboration meeting

- MPD publications: ~ 220 in total for hardware, software and physics studies:
  - ✓ RFBR grant program (now completed) attracted many new Russian institutions in the NICA activities
  - ✓ financial support for participation of Russian institutions in the MPD-NICA is needed for success of the project



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

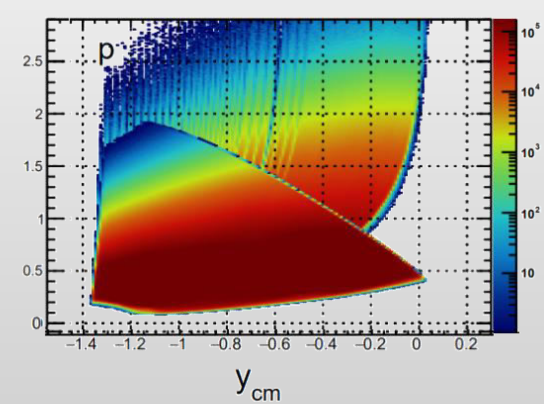
Collider Runs						Fixed-Target Runs					
	$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run		$\sqrt{s_{NN}}$ (GeV)	#Events	μ_B	y_{beam}	run
1	200	380 M	25 MeV	5.3	Run-10, 19	1	13.7 (100)	50 M	280 MeV	-2.69	Run-21
2	62.4	46 M	75 MeV		Run-10	2	11.5 (70)	50 M	320 MeV	-2.51	Run-21
3	54.4	1200 M	85 MeV		Run-17	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:

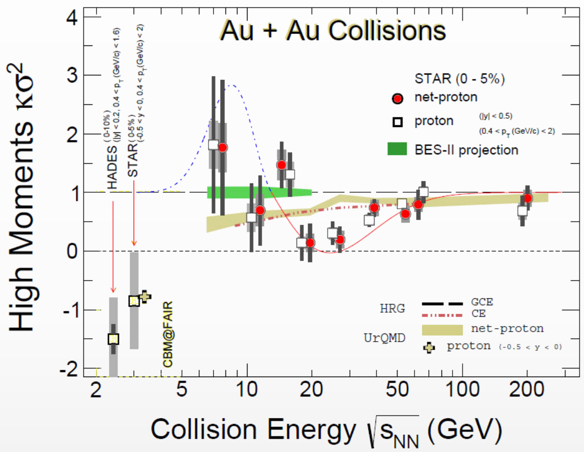
- ✓ Au+Au collisions only
- ✓ Among the fixed-target runs, only the 3 GeV data have full mid-rapidity coverage for protons (|y| < 0.5), which is crucial for physics observables

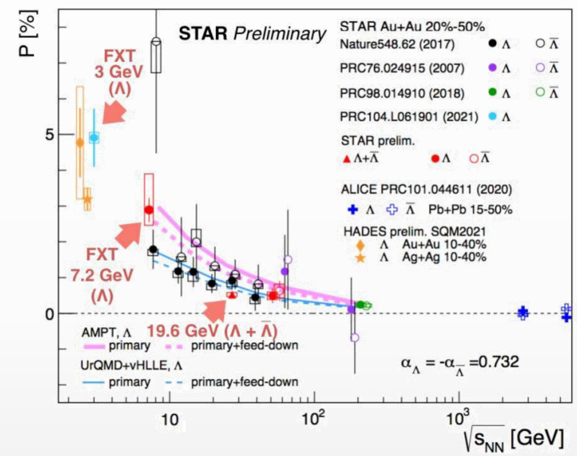
Au+Au @ 3.9 GeV

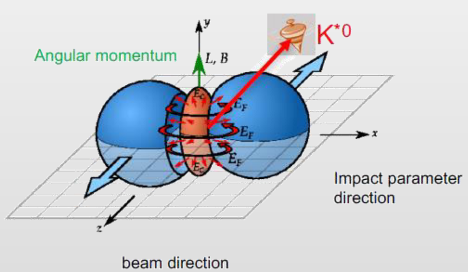


Hot topics to fill the gaps

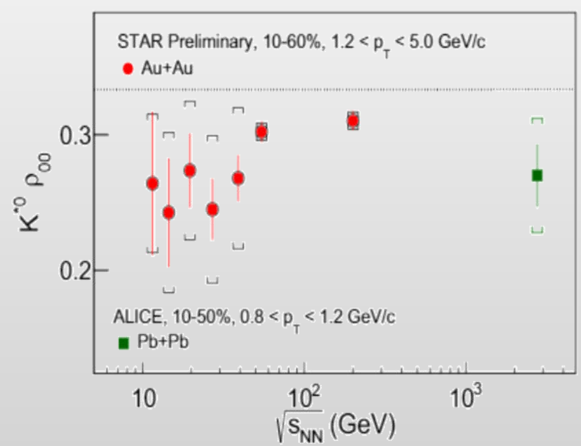
- Critical fluctuations for (net)proton/kaon multiplicity distributions
- Global hyperon polarization in mid-central A+A collisions (Λ, Ξ, Ω)
- Spin alignment of vector mesons ($K^*(892)$, $\phi(1020)$)
- Dielectron continuum and LVMs
- ….

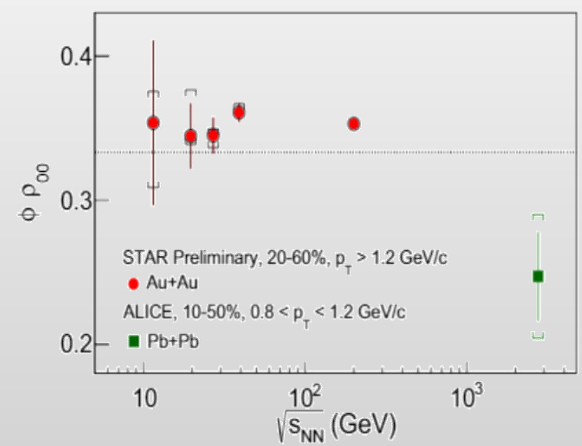




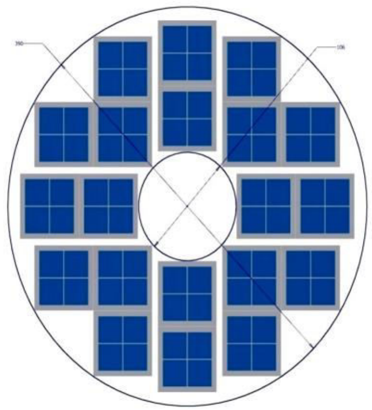


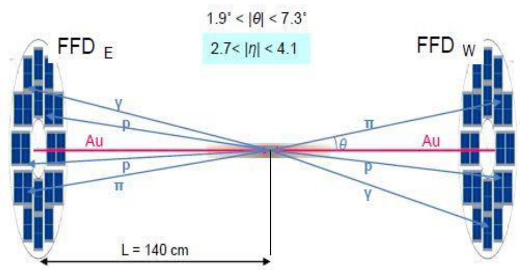
$$\frac{dN}{dcos\theta} = N_0[1 - \rho_{0,0} + cos^2\theta(3\rho_{0,0} - 1)]$$





FFD - Fast Trigger L_0 for MPD





FFD provides information on
- interaction rate (luminosity adjustment)
- bunch crossing region position

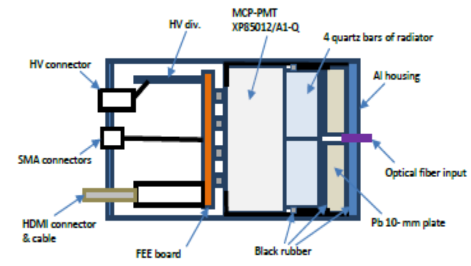


Fig. 4-1. A scheme of the FFD module.

15 mm quartz radiator
10 mm Lead converter

The FFD sub-detector consists of
20 modules based on
Planacon multianode MCP-PMTs
80 independent channels

MPD trigger group is created on the basis of FFD team
Beside FFD we consider the signals from FHCal to be implemented into trigger L0
The FHCal team have produced trigger electronics.
Monte Carlo studies will be used to optimize the properties of the L0 trigger

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

清華大学
TSINGHUA UNIVERSITY

Summary

- ✓ The China Group has established a complete QA& QC system. QA & QC of Material, Tower and Module have reached the requirements.
- ✓ The cosmic test results show that the light yield of different tower is very consistent. Time resolution is 270ps.
- ✓ The results of the covered optical simulations are consistent with the beam test.
- ✓ 575 modules produced in THU and SDU have been shipped to JINR, now is arrived. 2 more containers will be shipped to JINR as soon as possible.
- ✓ 100% module have been completed in China.
- ✓ The third container will be sent out by December 2022.