Approaching first physics in NICA-MPD at JINR

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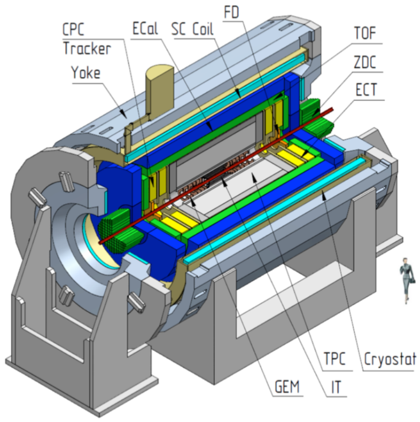
for the MPD Collaboration

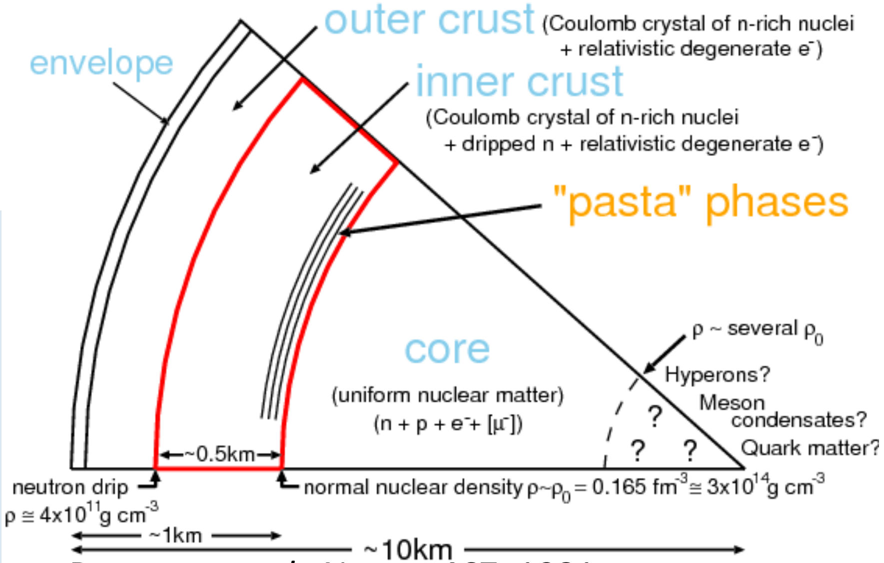


Access neutron star matter in laboratory

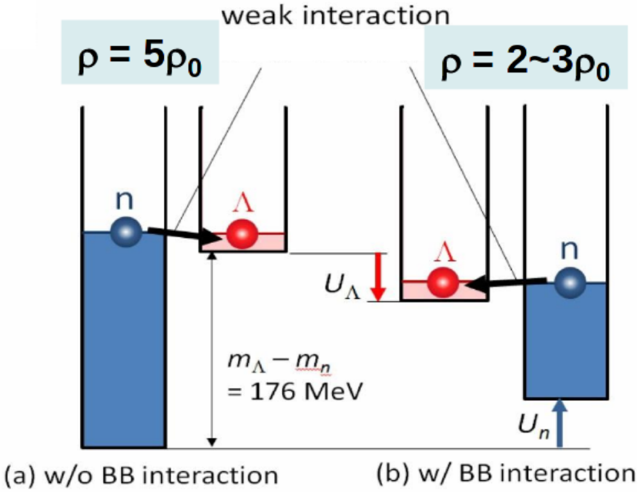
core of neutron stars reaches density several times nuclear density

appearance of strangeness changes Equation-of-State, depends on strangeness-nucleon interaction

Credit: LIGO Collaboration

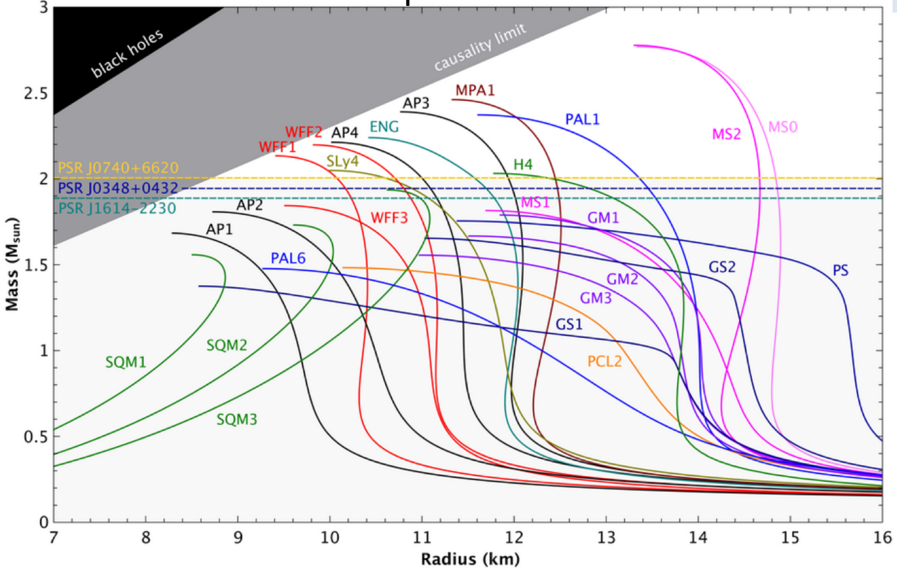


Demorest et al., Nature 467, 1081

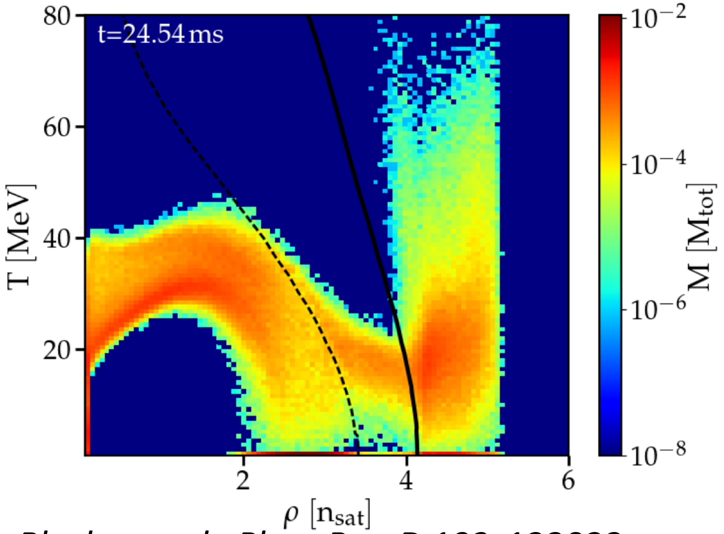


H. Tamura, Hadron 2017

Neutron Star EOS compilation

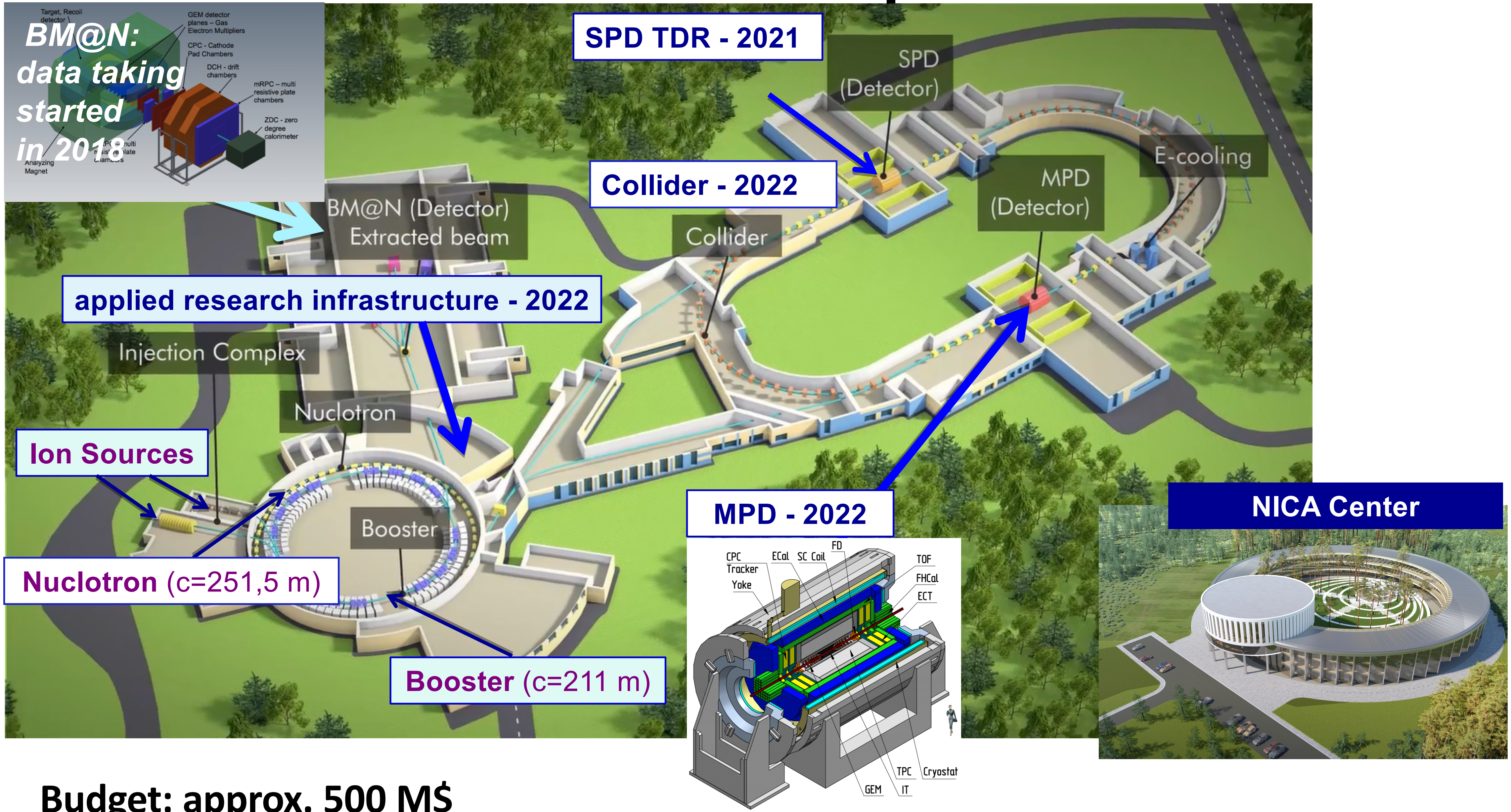


mergers populate NICA phase space



Blacker et al., Phys. Rev. D 102, 123023

NICA Accelerator Complex in Dubna



Budget: approx. 500 M$

Collider building

Civil Construction on Schedule

Main parameters of accelerator complex

Nuclotron

Parameter	**SC synchrotron**
particles	↑p, ↑d, nuclei (Au, Bi, ...)
max. kinetic energy, GeV/u	10.71 (↑p); 5.35 (↑d) **3.8** (Au)
max. mag. rigidity, Tm	38.5
circumference, m	251.52
vacuum, Torr	10^{-9}
*intensity, **Au** /pulse*	$1\ 10^{9}$

Booster

	value
ion species	A/Z $\leq$ 3
max. energy, MeV/u	**600**
magnetic rigidity, T m	1.6 – 25.0
circumference, m	210.96
vacuum, Torr	10^{-11}
*intensity, **Au** /pulse*	$1.5\ 10^{9}$

The Collider

Design parameters, Stage II

45 T*m, 11 GeV/u for Au^{79+}

Ring circumference, m	**503,04**
Number of bunches	**22**
r.m.s. bunch length, m	**0,6**
β, m	**0,35**
Energy in c.m., GeV/u	**4-11**
r.m.s. $\Delta p/p$, 10^{-3}	**1,6**
IBS growth time, s	**1800**

Stage I:

- ***without ECS in Collider, with stochastic cooling***
- ***reduced number of RF***
- ***reduced luminosity (10^{25} is the goal for 2023)***

Collision system limited by source. *Now Available: C(A=12), N(A=14), Ne(A=20), Ar(A=40), Fe(A=56), Kr(A=78-86), Xe(A=124-134), Bi(A=209)*

NICA: Unique and complementary

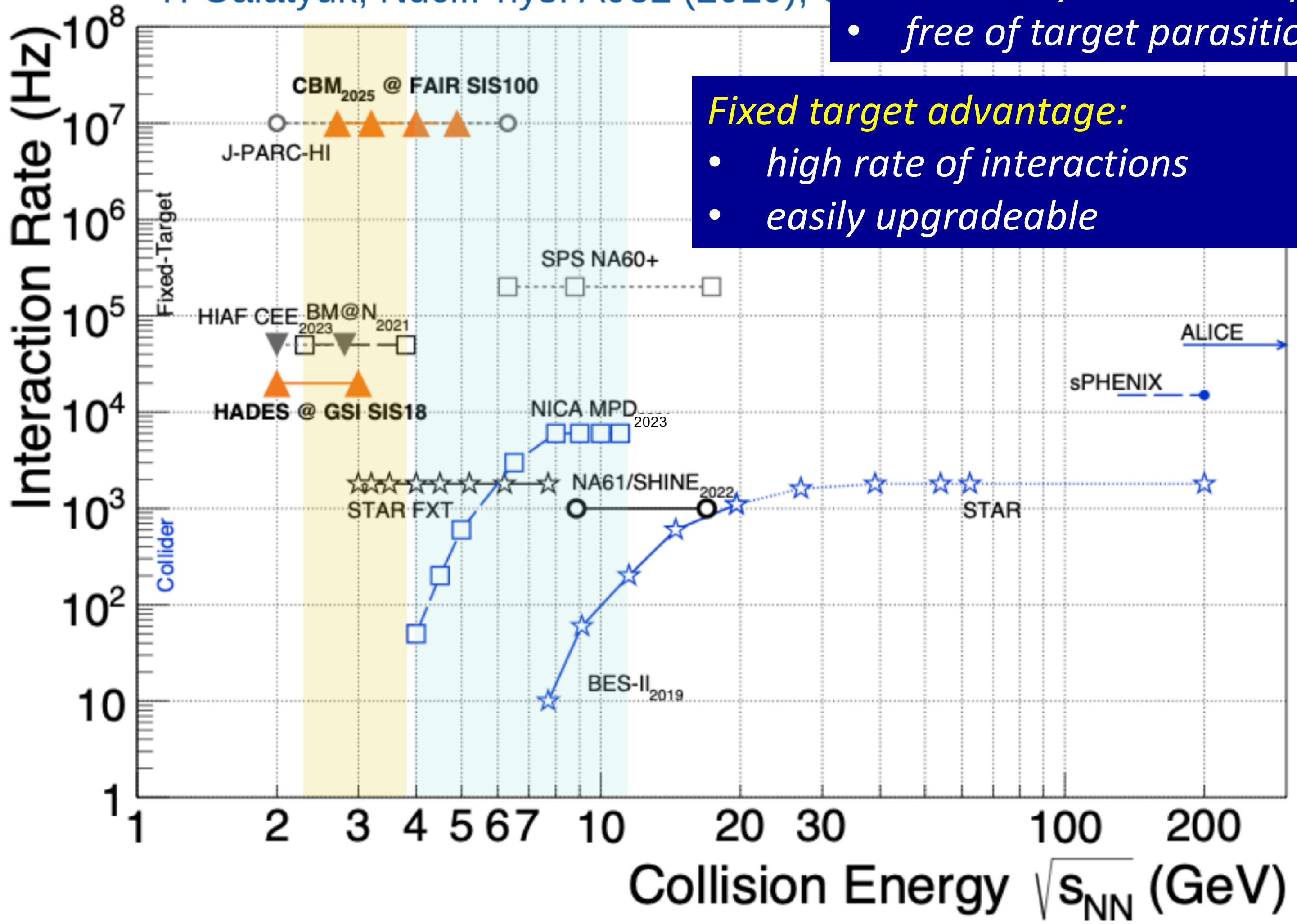
ESFRI Roadmap Landscape Analysis 2021

Collider advantage:
- *coverage of max. phase space*
- *minimally biased acceptance*
- *free of target parasitic effects*

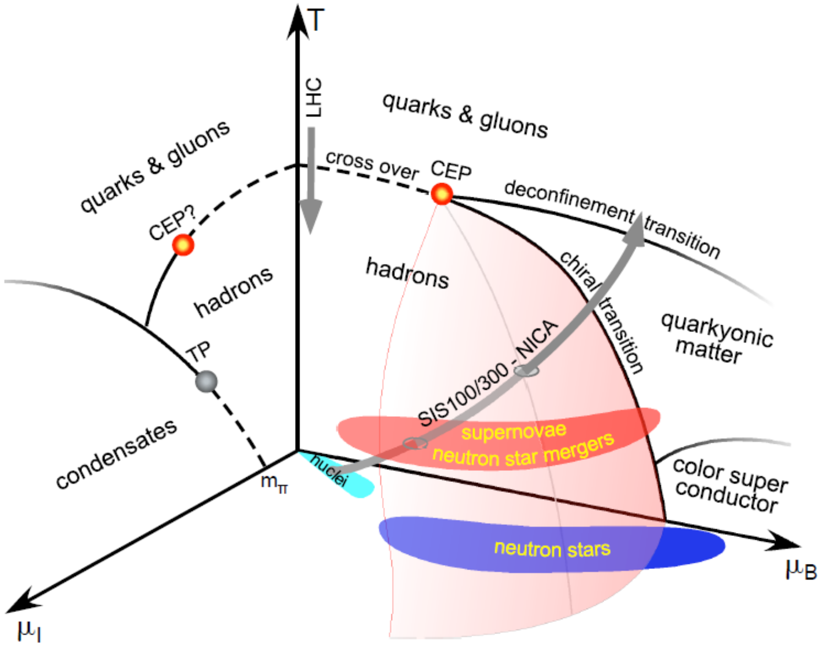
In NICA energy range maximum possible net-baryon density is reached

Fixed target advantage:
- *high rate of interactions*
- *easily upgradeable*

T. Galatyuk, Nucl.Phys. A982 (2019); C



NUPECC Long Range Plan 2017



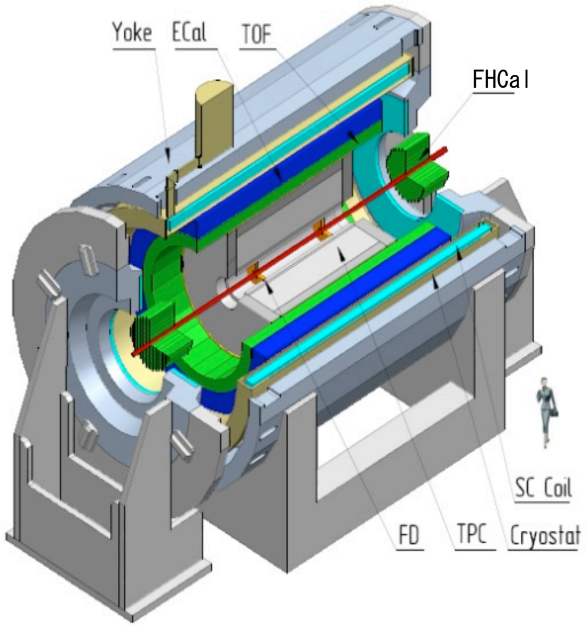
MPD at NICA – the "complete package”

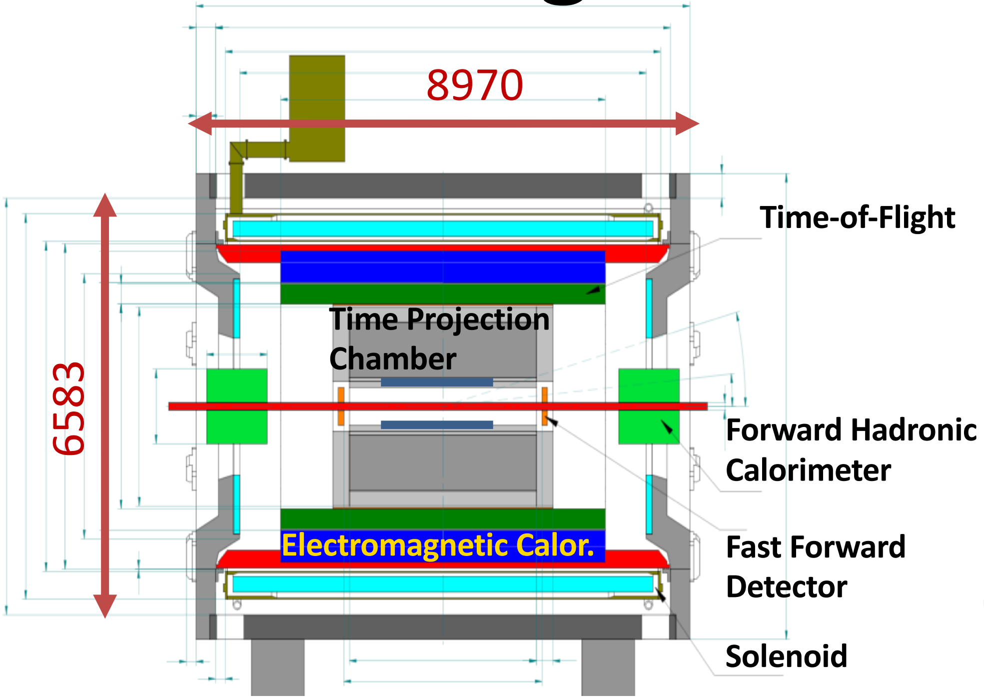
- **Operational environment at NICA**
  - Detailed energy scan available
  - Maximum luminosity at 7-11 AGeV
  - Practically all beam species (p to Bi) possible
- (limited only by ion source availability)
  - At least several months of beam time available each year
  - In the near future, no competition for NICA beams, sharing with SPD afterwards
  - Funding secured for foreseeable future
- **The MPD capabilities**
  - Collider geometry detector with large acceptance consistent with energy
  - Full centrality range available
  - Stage II upgrades possible for extension of detection capabilities (silicon inner tracker,

Status as of end of February 2022

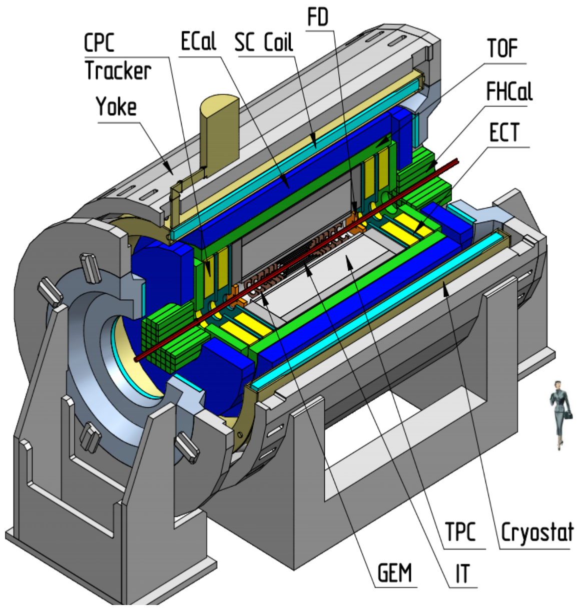
- Recent events related to war in Ukraine have significantly impacted the MPD collaboration and JINR:
- Suspension of collaboration with JINR from Germany (affects mostly BM@N, but also NICA and FAIR).
- Suspension of collaboration by decision of Polish institutions (impacts MPD directly).
- Sanctions affect supplies of many components for MPD (impact is still being assessed internally in MPD) and also bring up uncertainties for JINR-CERN collaboration (CERN Council in June).
- All this is still being assesed and will be discussed, also with the JINR management, at the MPD Collaboration meeting in April.
- The following is a status report as of the end of February, before all the changes mentioned above.

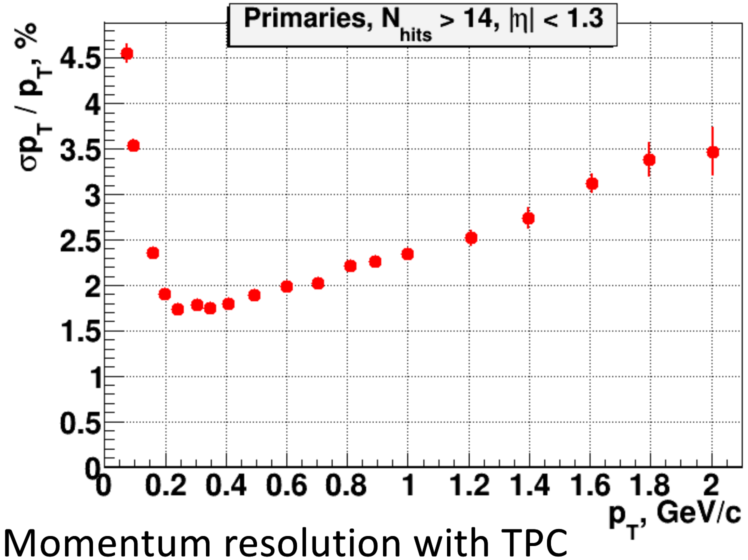
MPD - stage I and II



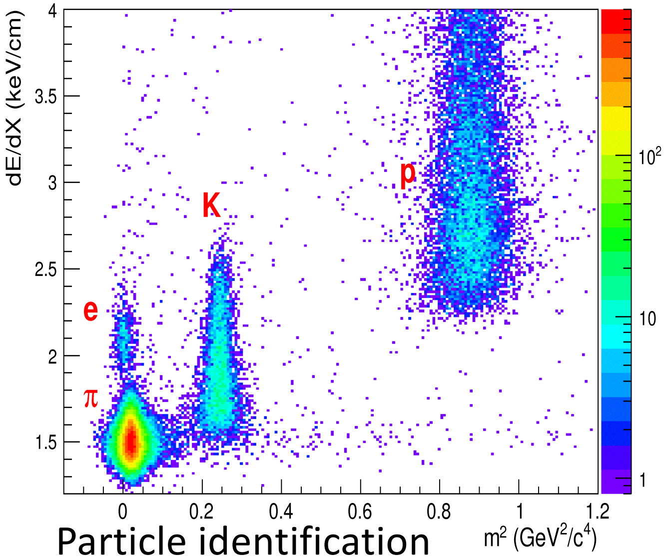


MPD - Stage II

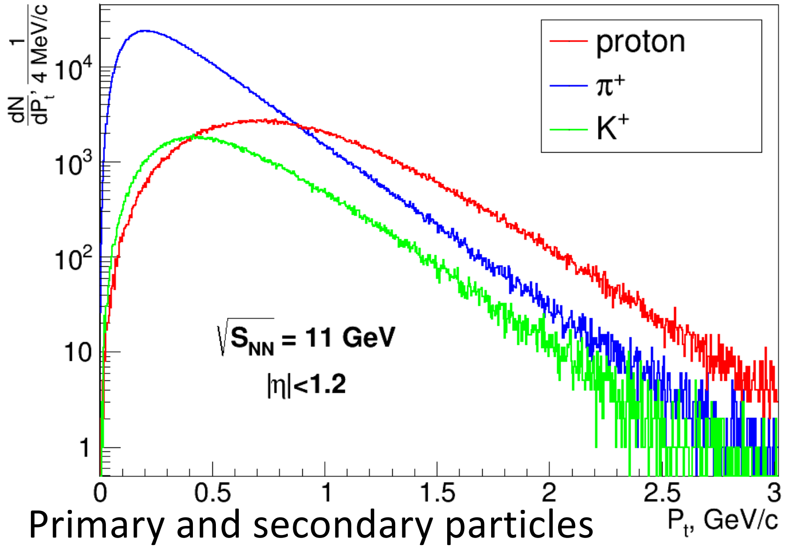




Momentum resolution with TPC



Particle identification



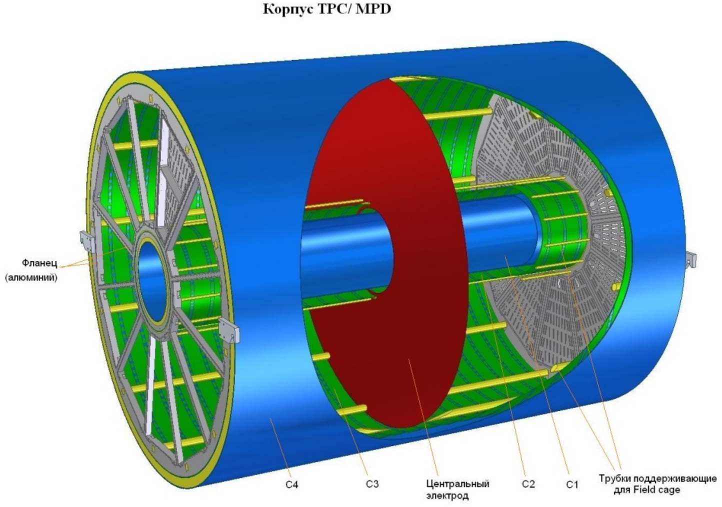
Primary and secondary particles

NICA

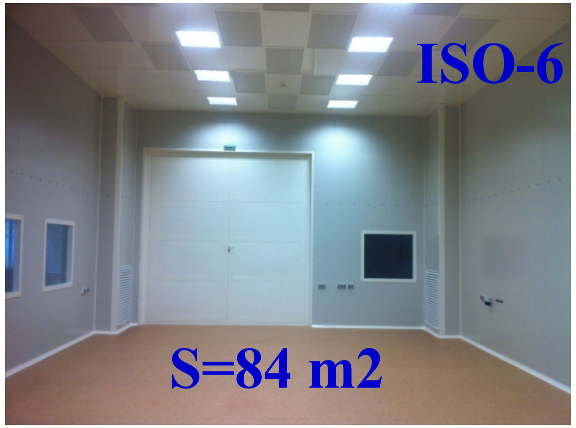
Solenoid in MPD Hall

- On 6-th of November 2020 the MPD Solenoid delivered to MPD Hall

Time Projection Chamber (TPC): main tracker



length	*340 см*
outer Radii	*140 см*
inner Radii	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kHz (L= 10^{27})*

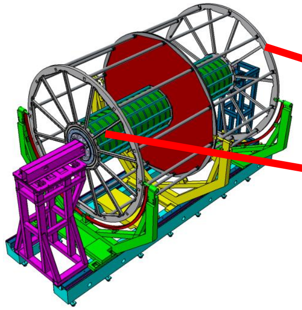


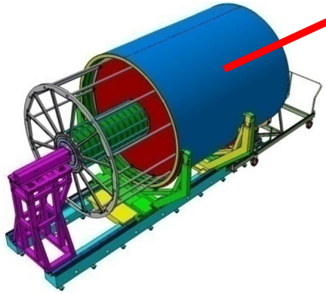
HV membrane – tested (NO corona)

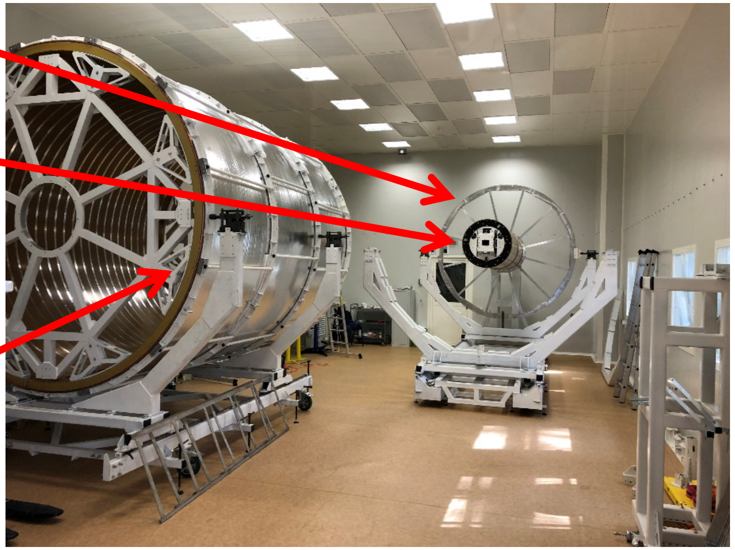
Field cage roads – in assembly

24 pc tested ROCs in stock

+ 2 pc spare – tests in progress







TPC assembly – in progress

MPD Time-of-Flight

Mass production staff: 4 physicists, 4 technicians, 2 electronics engineers

Productivity: ~ 1 detector per day (1 module/2 weeks)

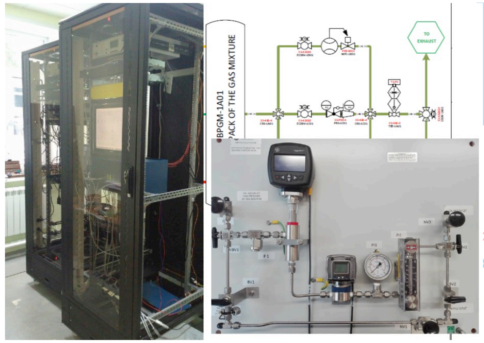
All procedures of detector assembling and optical control are performed in a clean rooms ISO class 6-7.

Glass cleaning with ultrasonic wave & deionized water

Automatic painting of the conductive layer on the glass

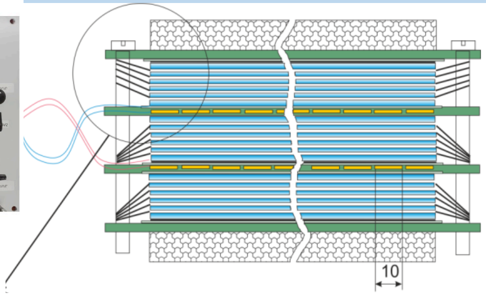
MRPC assembling

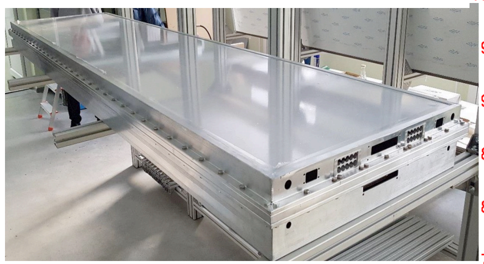
Soldering HV connector and readout pins

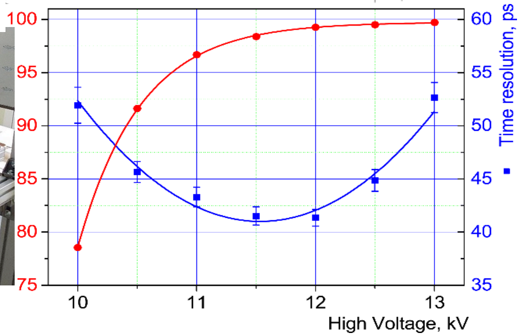


TOF gas system

Dimensions of sensitive area 600 x300 mm^2







Single detector time resolution: 50ps

	Number of detectors	Number of readout strips	Sensitive area, m^2	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)

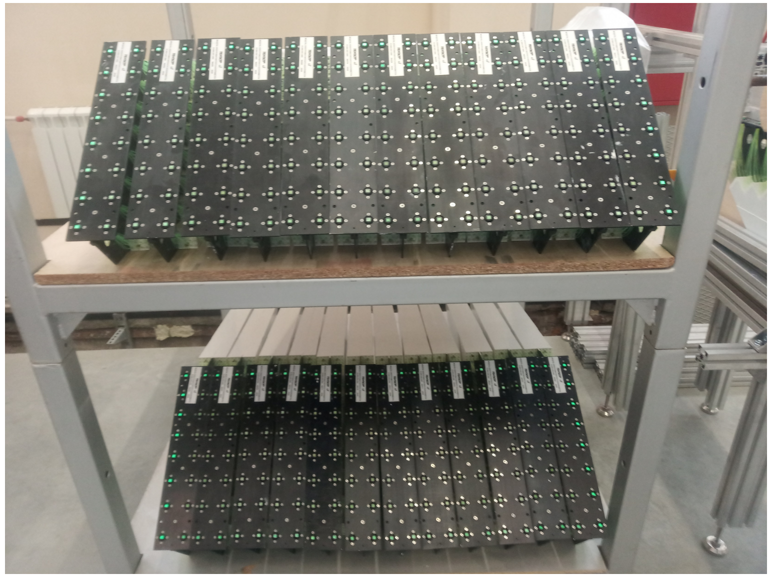
Purchasing of all detector materials completed

Assembled half sectors of TOF are under Cosmics tests

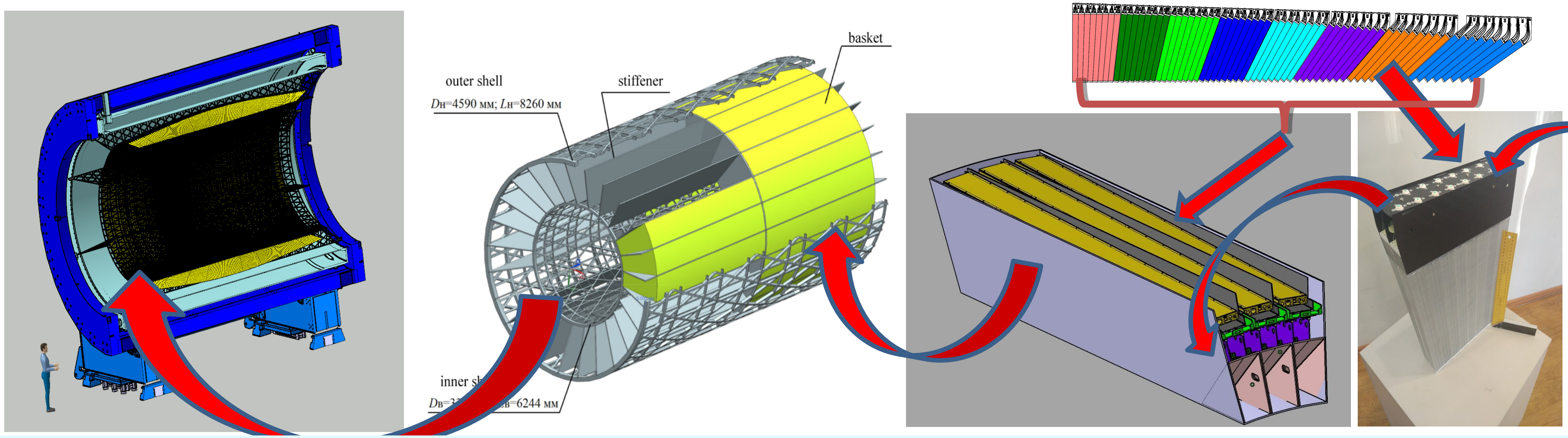
All crates, HV & LV PS, FE & R-O electronics - in stock.

Electromagnetic Calorimeter (ECAL)

Barrel ECAL = <u>38400</u> ECAL towers (2x25 half-sectors x 6x8 modules/half-sector x 16 towers/module)



Sectors in dedicated Containers



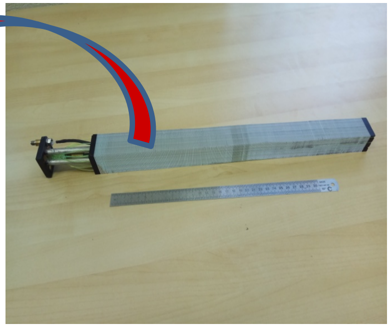
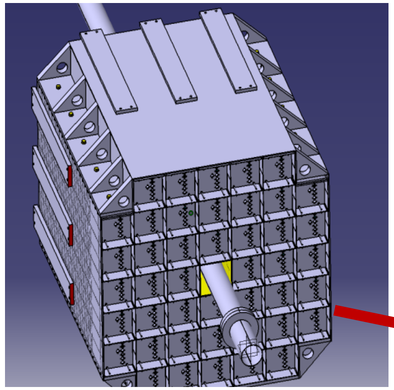
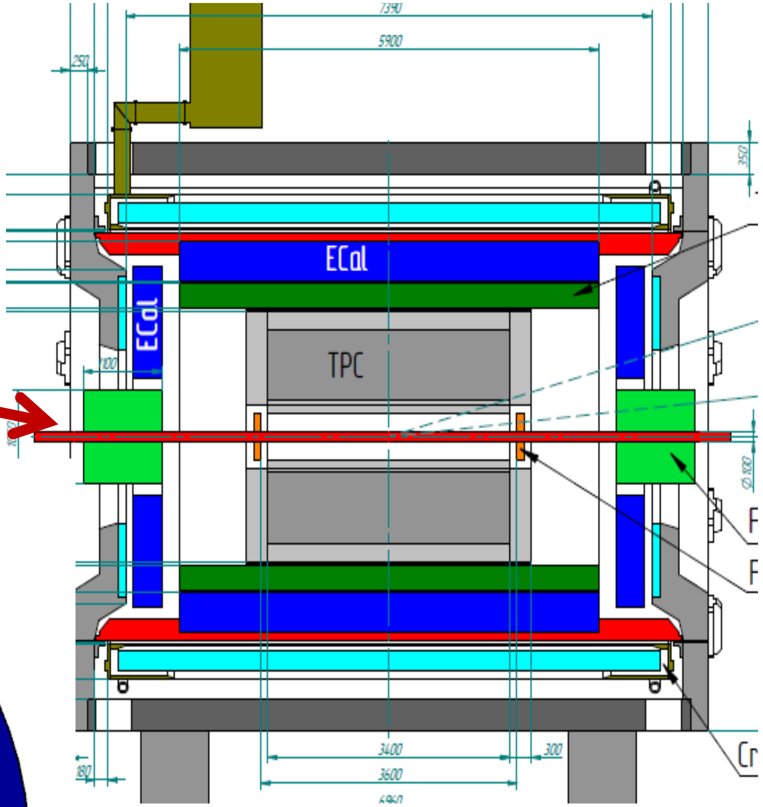


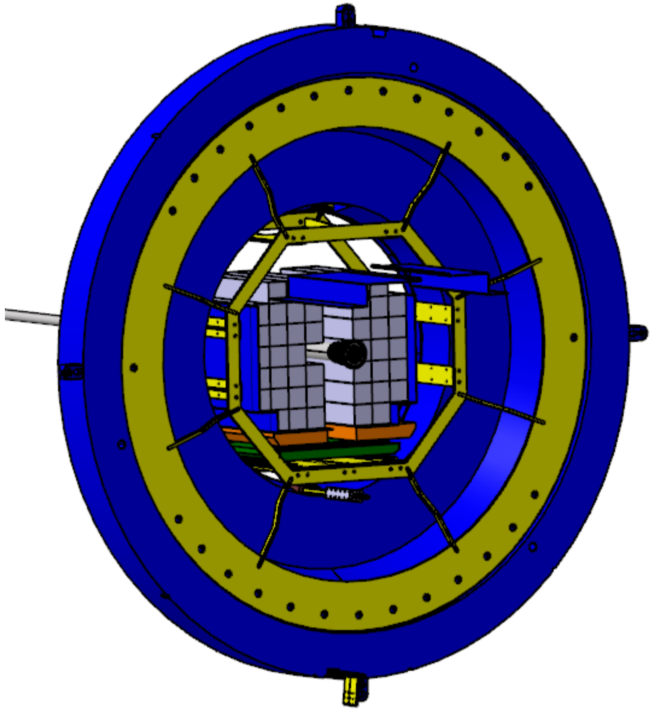
Photo of one element

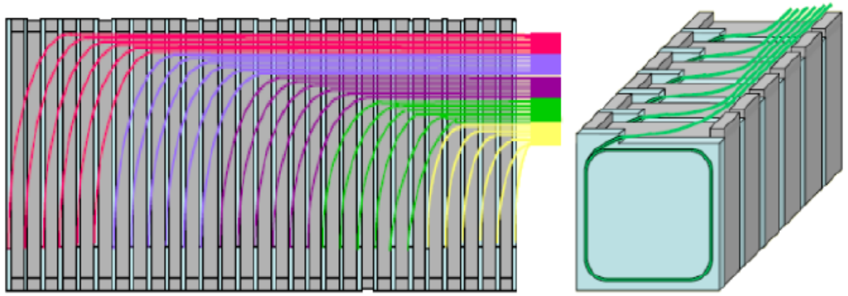
- *Pb+Sc "Shashlyk" ; read-out: WLS fibers + MAPD; L ~35 cm (~ 14 X_0); Segm. (4x4 cm^2); σ(E) ~ 5% @ 1 GeV; time res. ~500 ps*

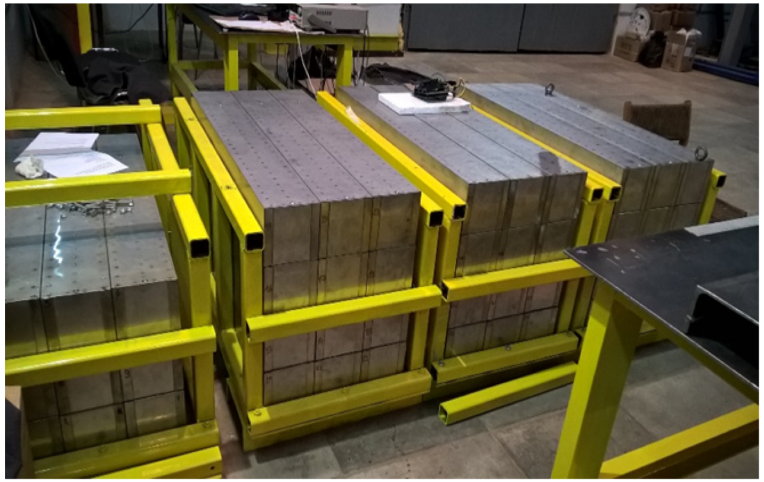
Forward Hadron Calorimeter (FHCal)







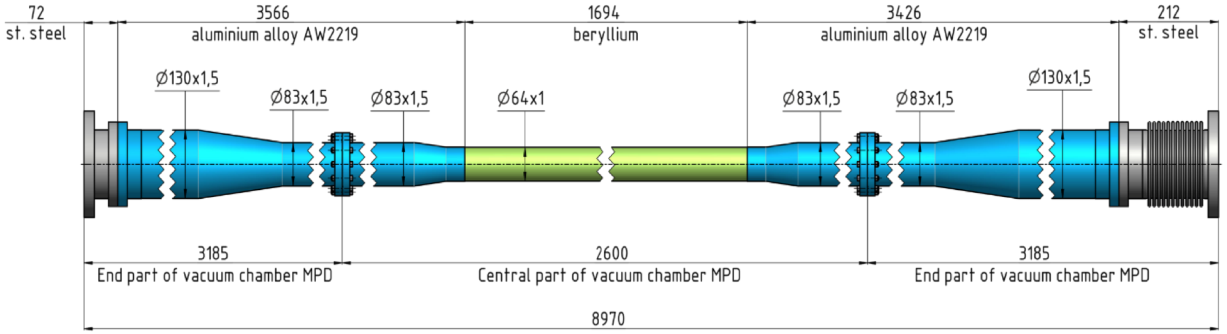


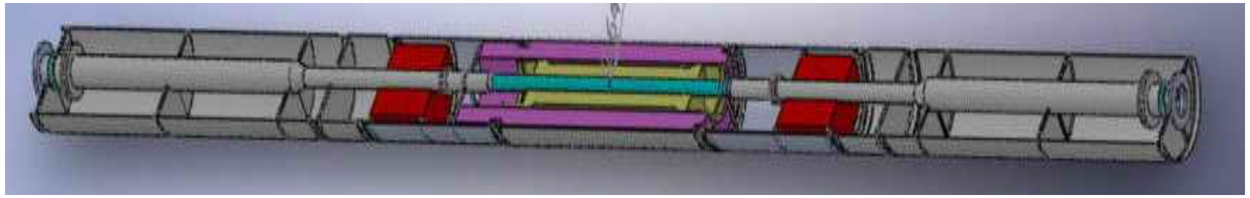


- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm³ (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

Beam pipe – stage I

Working version of pipe will consists of three parts – central made of Beryllium and two end parts made of Aluminum alloy.
Contract with Institute of Beryllium in Moscow for production two Be beam pipes with inner diameter 62 mm.
For Aluminum beam pipes (2 pc) we have prepared Contract with two Companies in Moscow

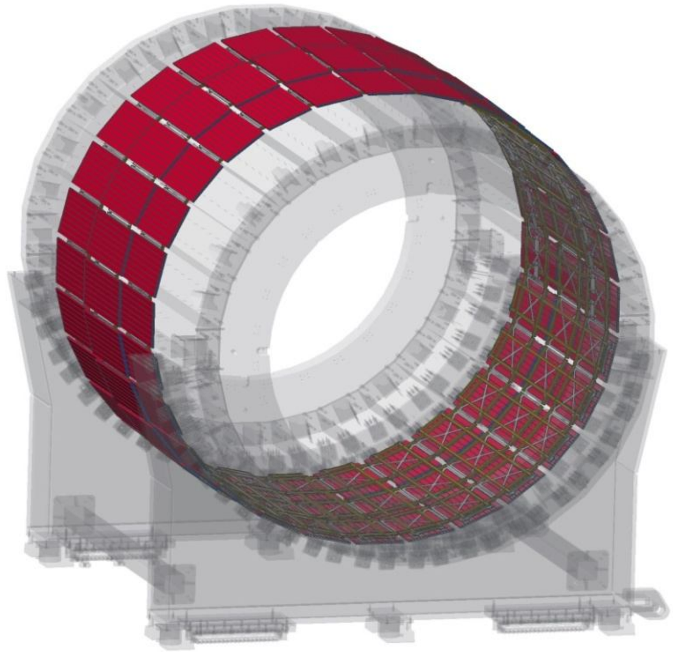




We plan to start work of MPD with Aluminum beam pipe in order to get experience with installation. In order to avoid electron clouds treatment of the inner surface of the beam pipe is required. Laser treatment or gettering are used for this purpose.

Two Beryllium beam pipes arrived to JINR in March this year.
They are prepared for vacuum test.

MPD Cosmic Ray Detector (MCORD)



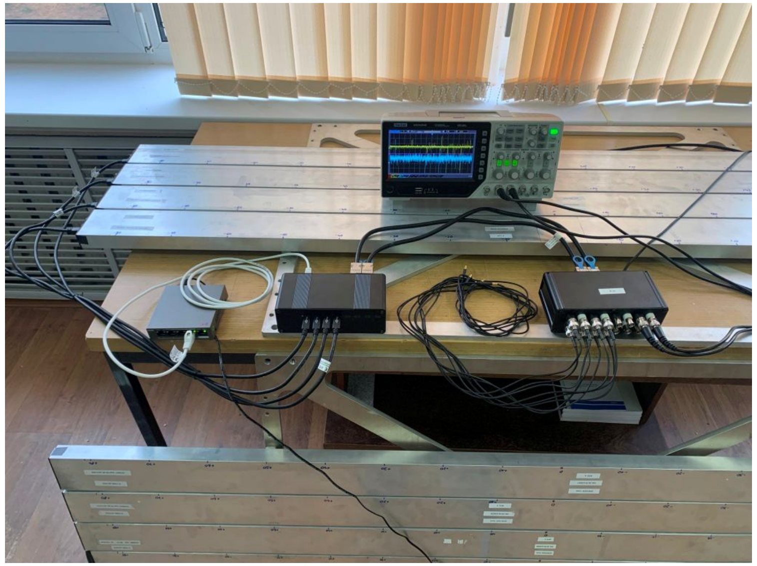
NCBJ, Świerk - WUT, Warsaw – UJK, Kielce (Poland)
18 scientists+12 engineers

CDR for MCORD approved by the MPD DAC

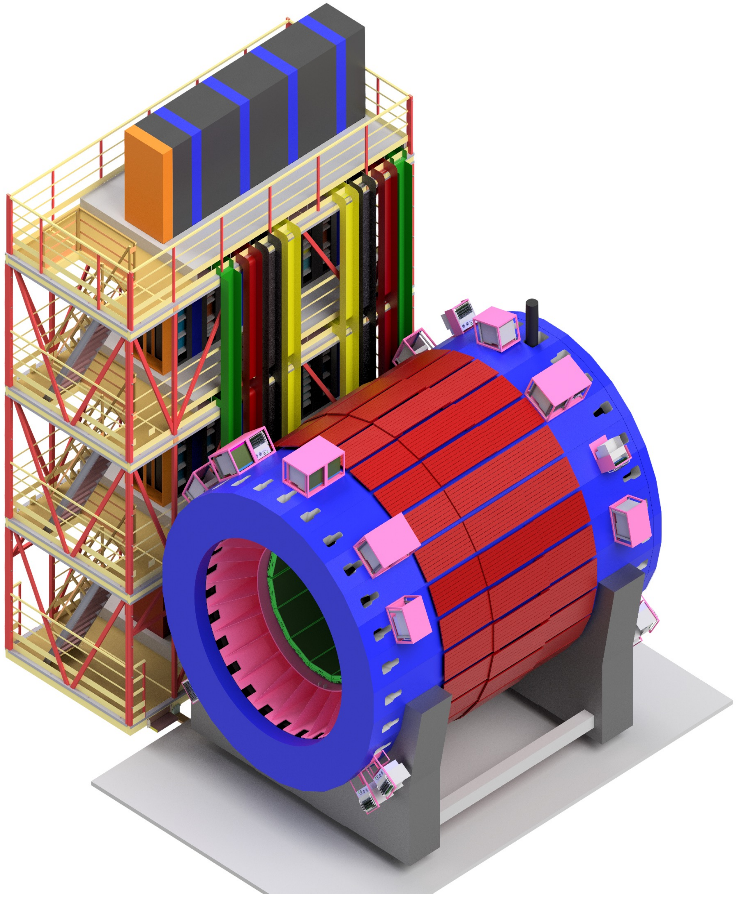
MCORD consists of plastic scintillators with SiPM (Phototubes) light converters, allowing for detection of muons on the outside of MPD Magnet Yoke

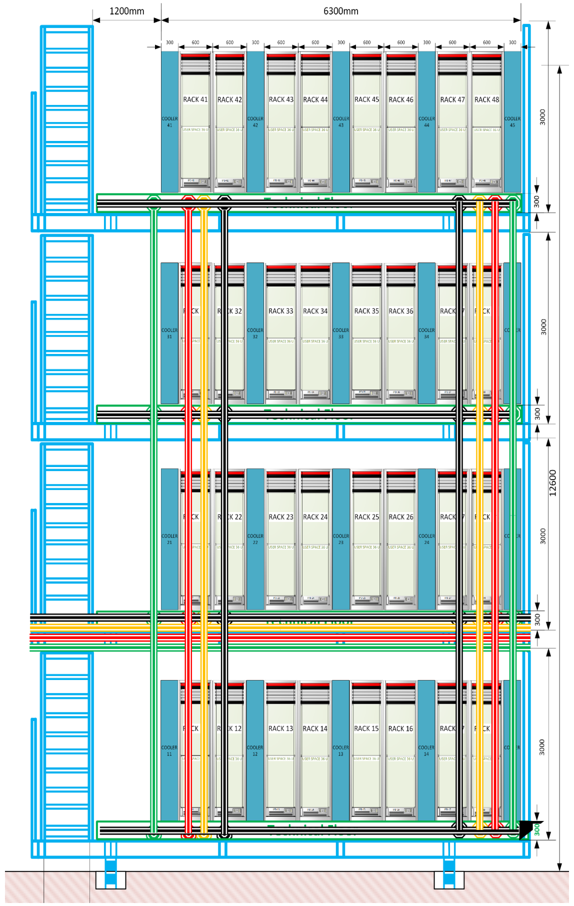
Major role of MCORD before Collider operation in Commissioning and tests of the MPD. MCORD will be a trigger in TPC and TOF tests after their installation.

First MCORD modules delivered to JINR on October 8 2021



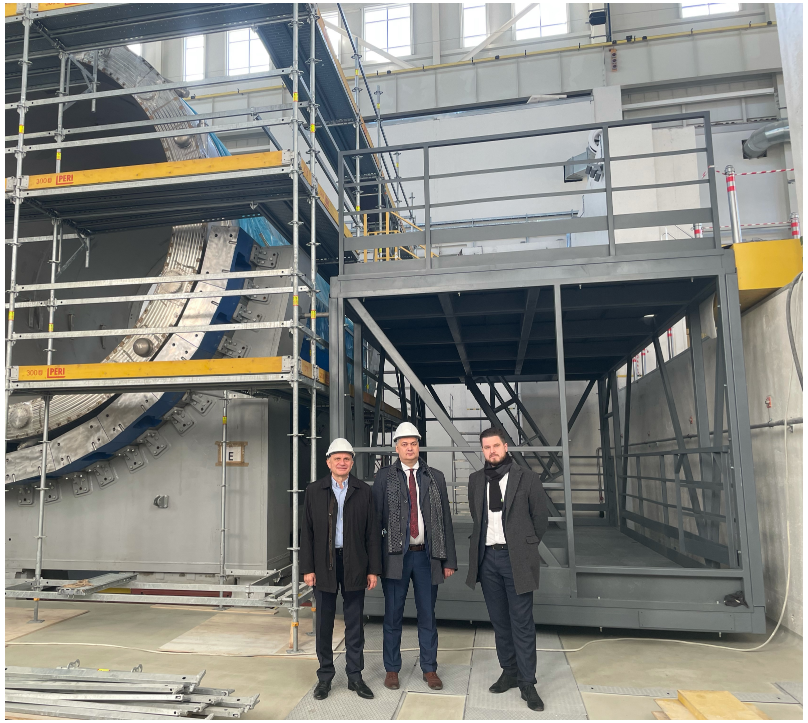
NICA-MPD-Platform for Electronics





NICA-MPD-Platform is a contribution of the Polish groups to MPD

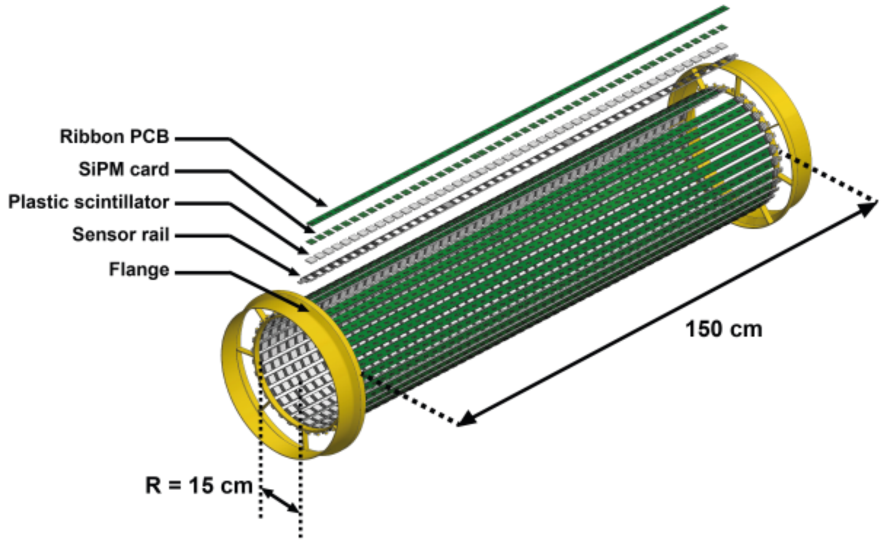
M. Peryt (WUT)   K. Rosłon (WUT)



- Engineering Support Sector no 3 in the structure of the Laboratory of High Energy Physics lead by Polish employees
- Electronics platform has 4 levels with 8 racks on each level, each Rack provides cooling, fire safety and radiation monitor
- Recent progress: the full design documentation of the NICA-MPD-Platform has been delivered to JINR
- The mechanical part of the Platform is delivered to MPD Hall, first two levels of the Platform installed in place
- The Engineering Support sector leads other important projects for MPD (MFS, gas system for MPD TOF, etc.)

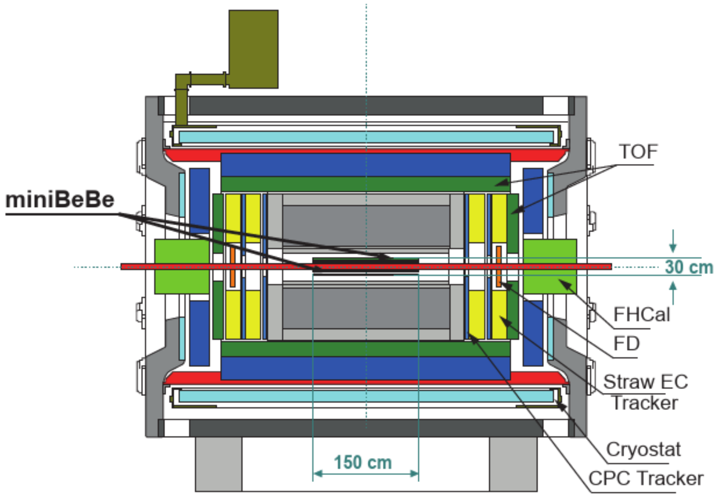
MiniBeBe (Mini Beam-Beam Counter)

MexNICA Collaboration



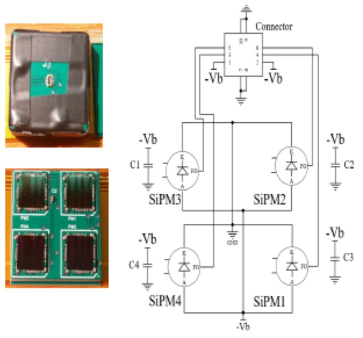
Main requirement:

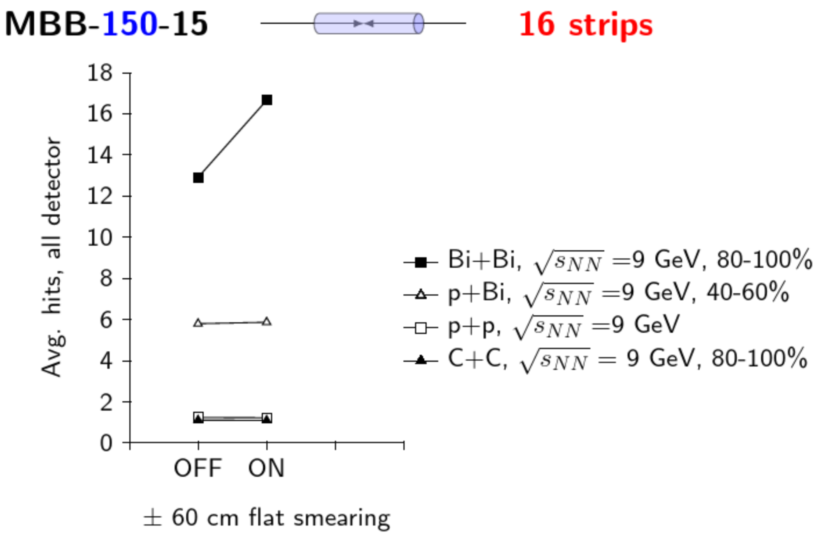
- Provide fast wake-up signal for TOF and reference time for TOF measurement with time resolution of ~30 ps
- Improve trigger efficiency for p+p, p-A and low multiplicity A-A
- Provide possibility to perform luminosity measurements at Phase 0 of NICA operation
- Presentation of MiniBeBe progress expected at MPD DAC in January 2022



Basic cell with four SiPMs & electronics

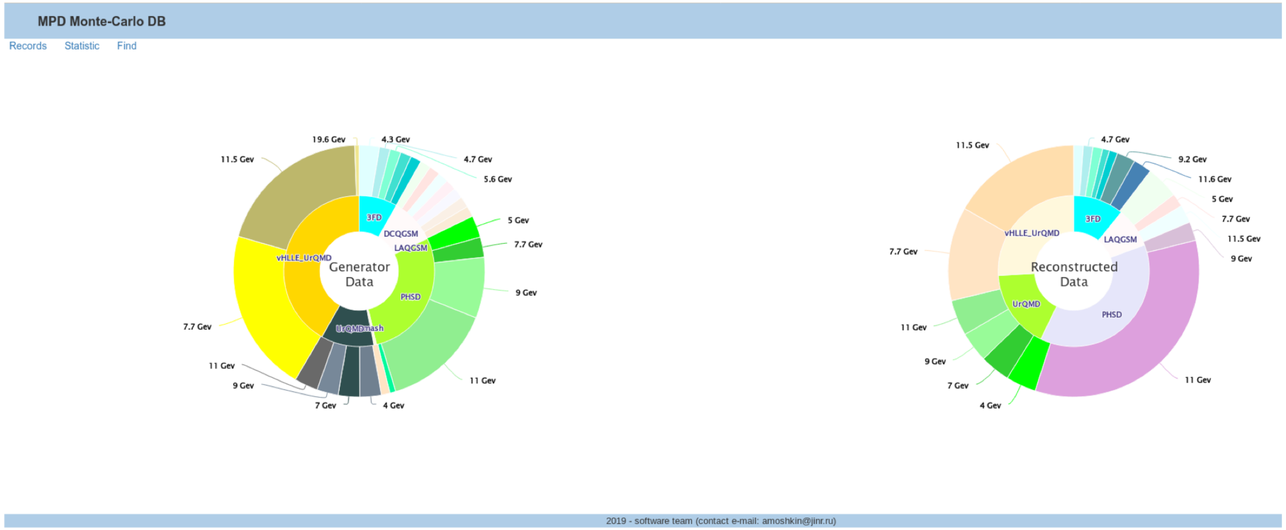
- 20x20 mm²
- 4 SiPMs card attached to BC404 plastic scintillator
- Fast outputs to “connector” (micro mezzannine)
- DC decoupling capacitors





Computing for the NICA Megaproject on the GOVORUN

- HybriLIT computing resources available for MPD Collaborators
- Full MPD software suite available
- Used for massive Monte-Carlo productions
- Dirac framework used to connect other computing centers
- Establishing communications with LIT team



DIRAC
THE INTERWARE

- DIRAC infrastructure enables integration of heterogenous computing resources at multiple sites
- Provide single access point for end users for MPD Computing
- First tutorials given by LIT staff to selected MPD users
- Will be provided to all MPD Collaborators

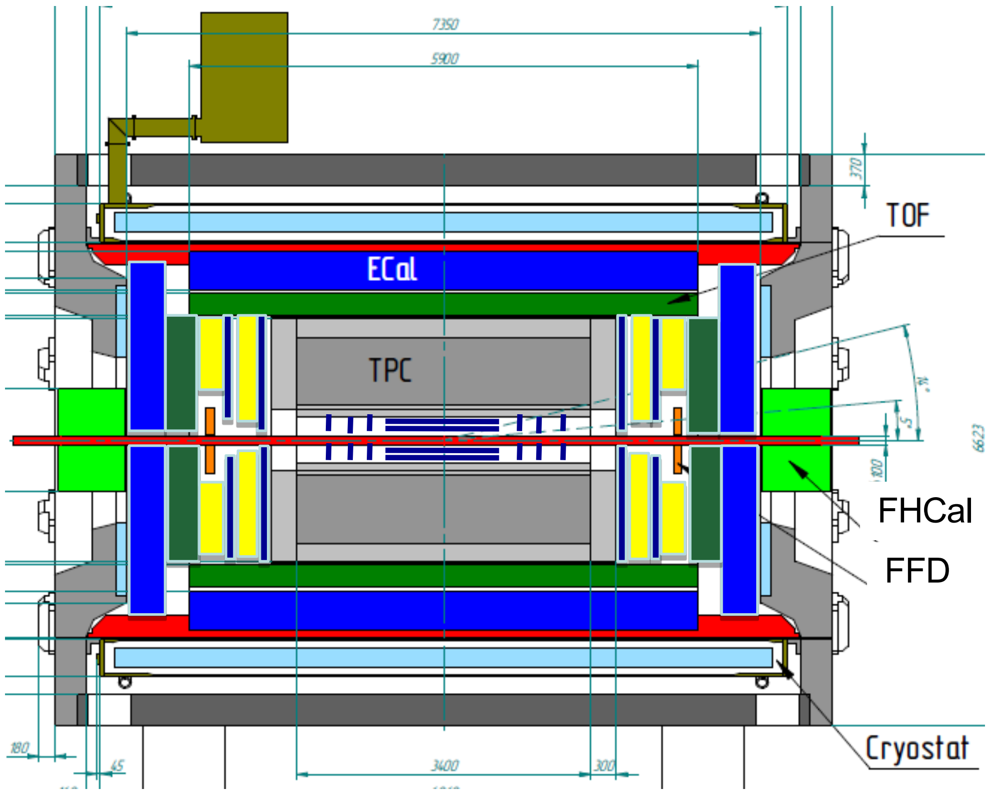
MPD Stage 2 and ITS

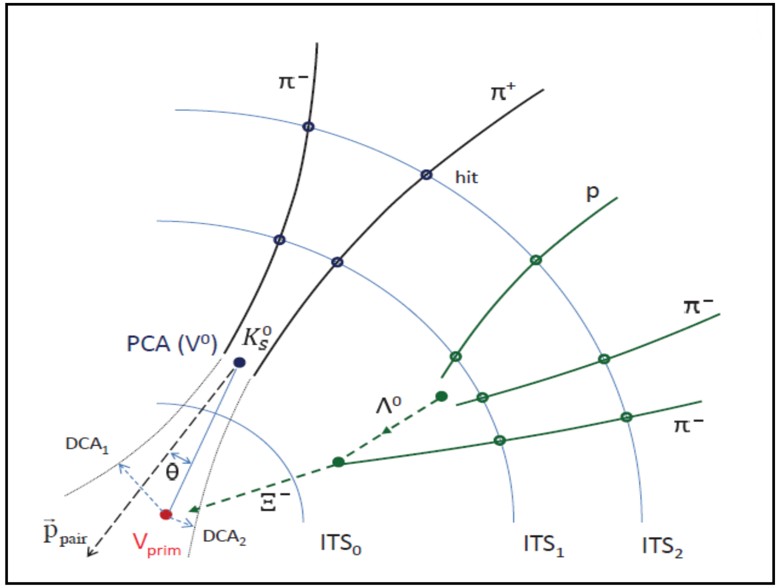
Stage I: TPC, TOF, ECAL, ZDC, FFD + ITS(OB)

Stage II : ITS(IB) + EndCap (CPC, Straw, TOF, ECAL)

Transfer of High Tech Instrumentation Know-How from CERN to NICA-MPD

Design of MPD ITS fully based on expertise from ALICE





$$\Xi^- \rightarrow \Lambda + \pi^-$$
$$\quad \llcorner\!\!\rightarrow p + \pi^-$$

$$\Omega^- \rightarrow \Lambda + K^-$$
$$\quad \llcorner\!\!\rightarrow p + \pi^-$$

$$D^+ \rightarrow K^- + \pi^+ + \pi^+$$

$$D^0 \rightarrow K^- + \pi^+$$

$$\Lambda_c \rightarrow p + K^- + \pi^+$$

STAR has shown that MFT (based on pixel detectors) allows for specific DCA selections improving S/B ratio for di-leptons

MPD Physics Programme

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

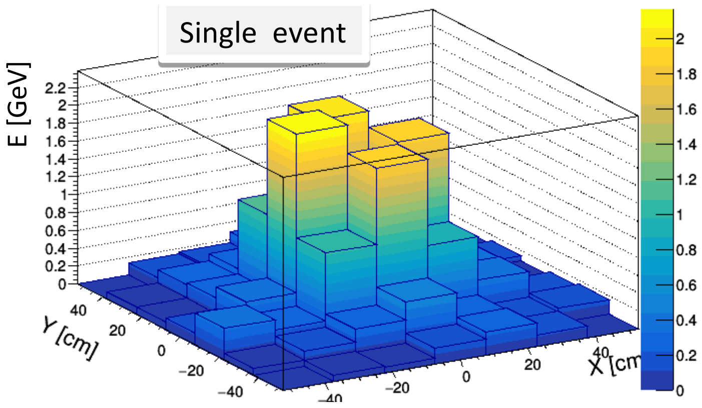
Wangmei Zha, A. Zinchenko

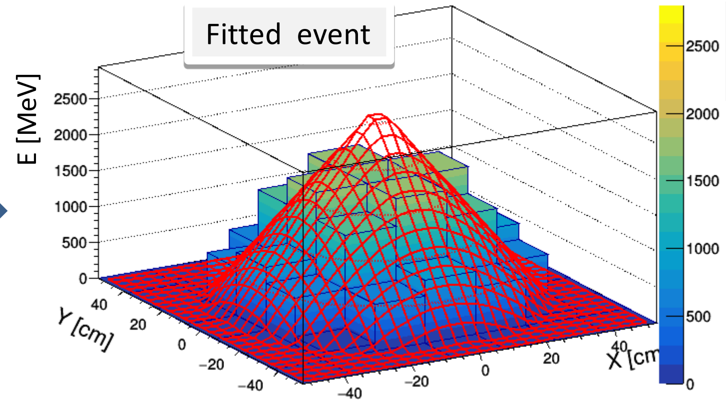
Heavy flavor

- 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

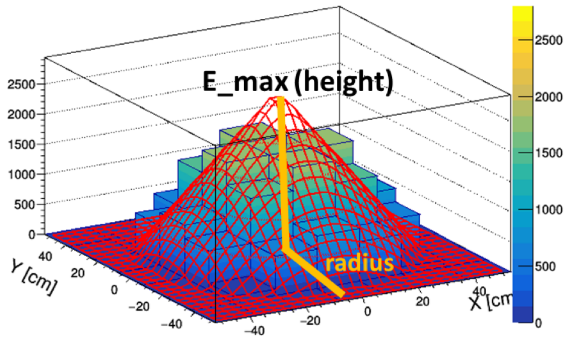
Centrality and reaction plane in FHCal

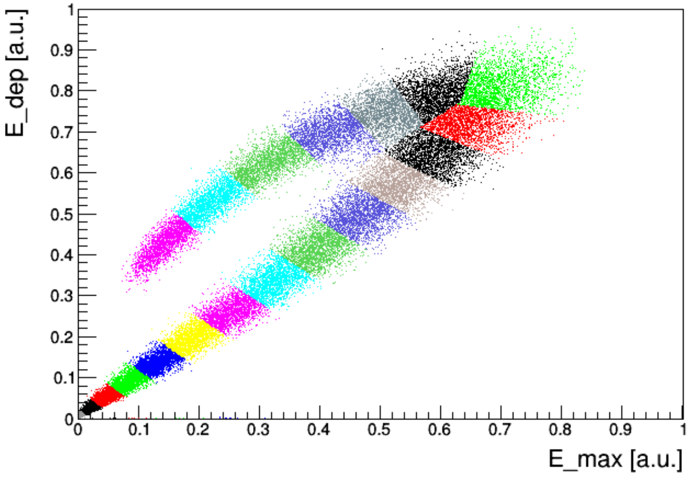
Energy distribution in FHCal modules



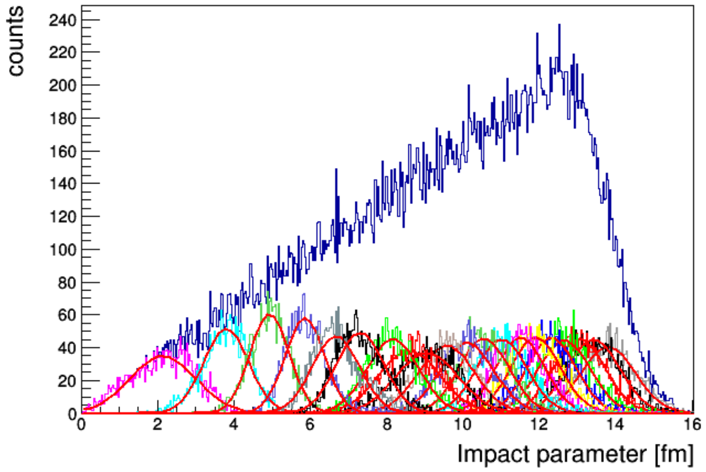


Initially we have experimental energy deposition E_{dep} in FHCal.

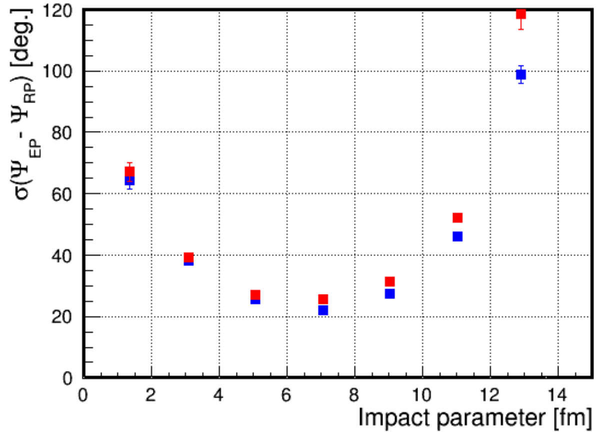




Each color bin is 5% fractions of the total number of events.



Centrality resolution

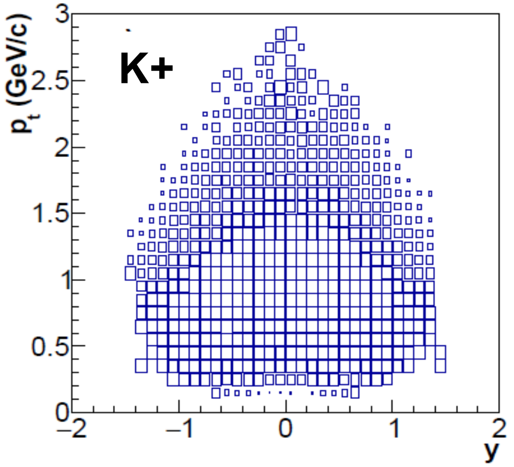


Reaction plane resolution

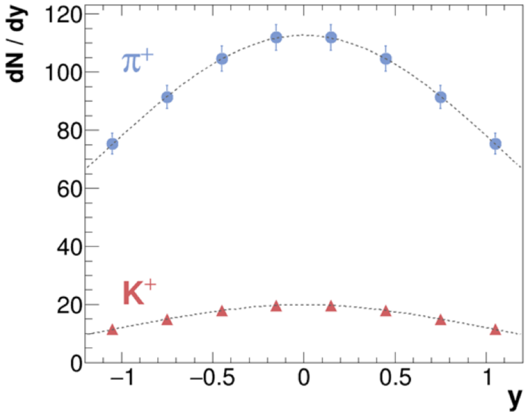
Hadroproduction with MPD

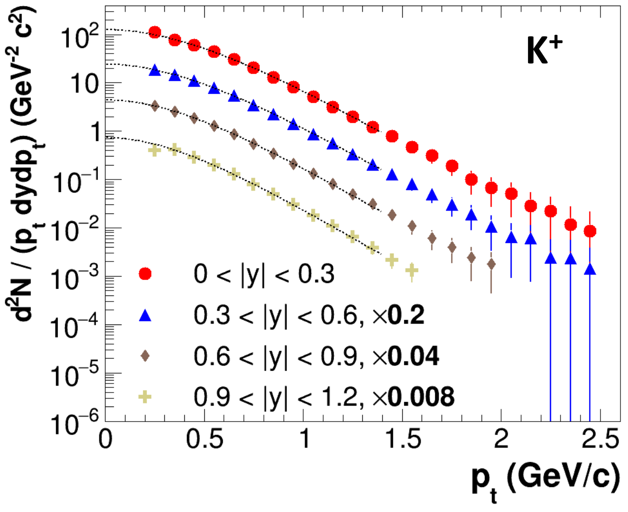
- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

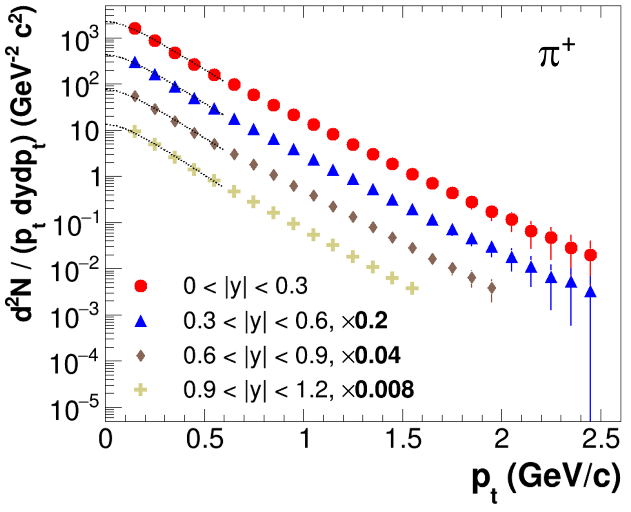
✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*



- MPD provides large phase-space coverage for identified pions and kaons (> 70% of the full phasespace at 9 GeV)
- Hadron spectra can be measured from p_T=0.2 to 2.5 GeV/c
- Extrapolation to full p_T-range and to the full phase space can be performed exploiting the spectra shapes (see BW fits for p_T-spectra and Gaussian for rapidity distributions)







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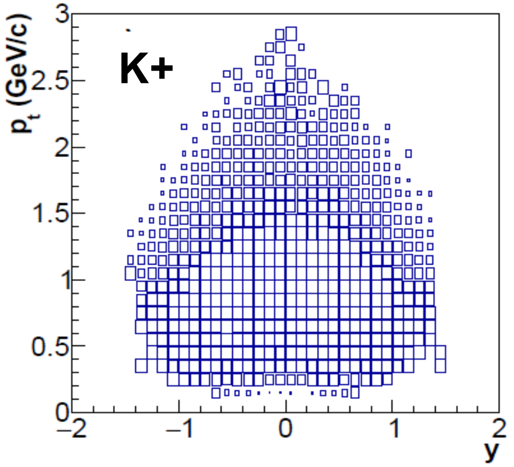

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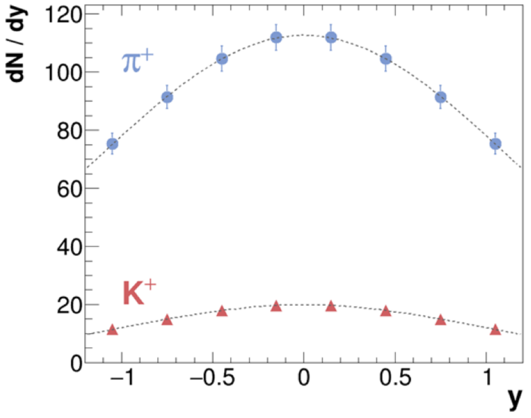
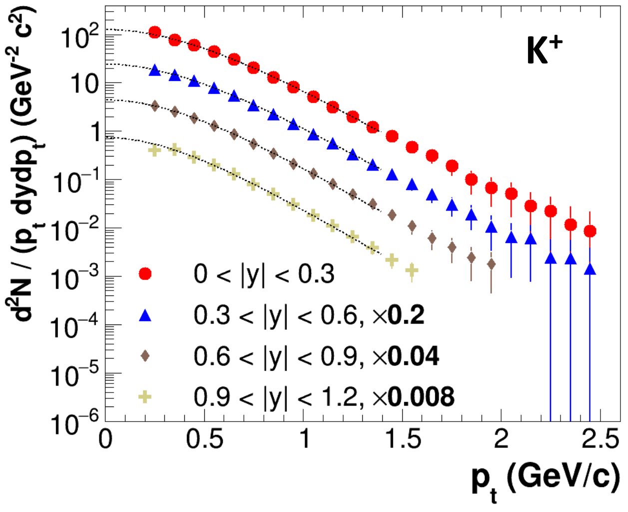
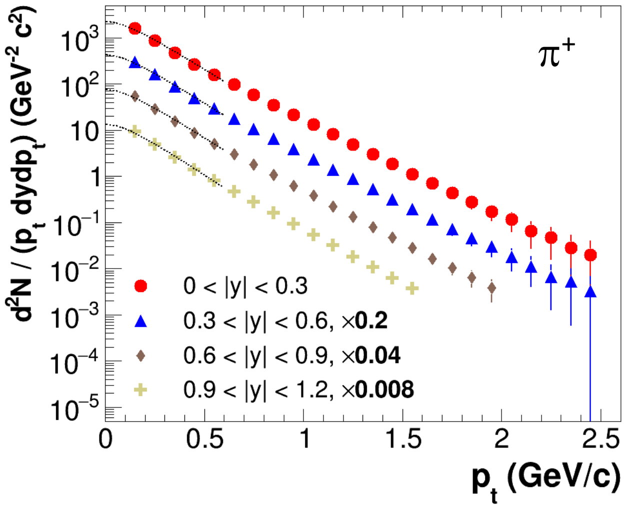
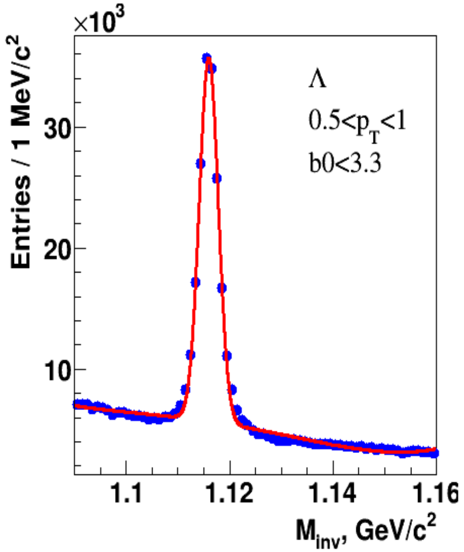


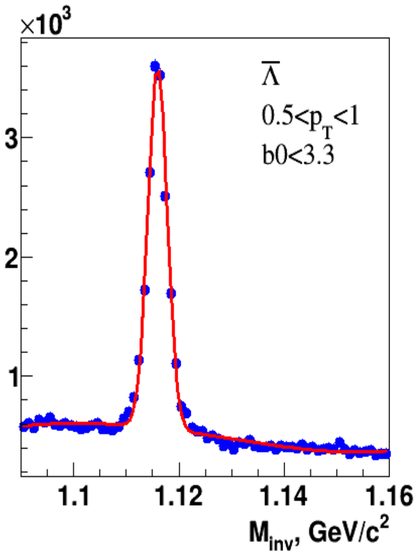


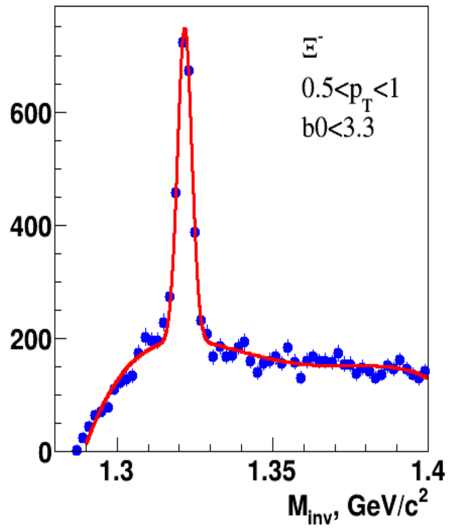


Strange and multi-strange baryons

Stage’1 (TPC+TOF): Au+Au @ 11 GeV, PHSD + MPDRoot reco.





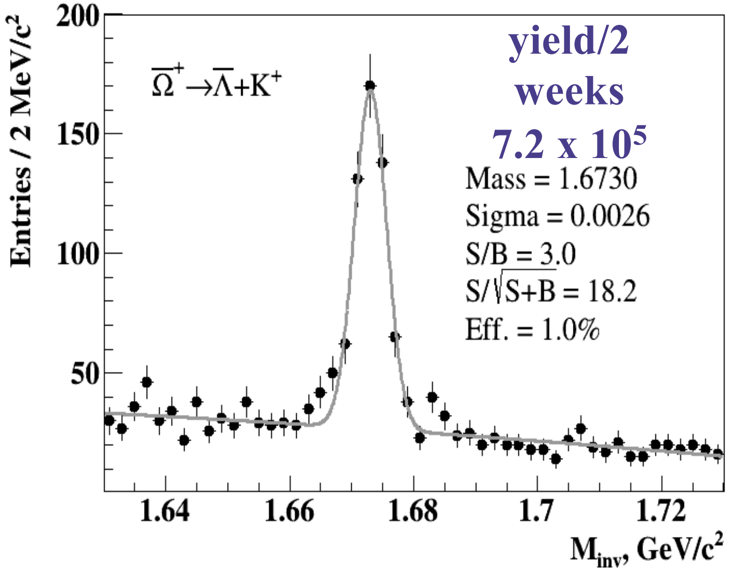


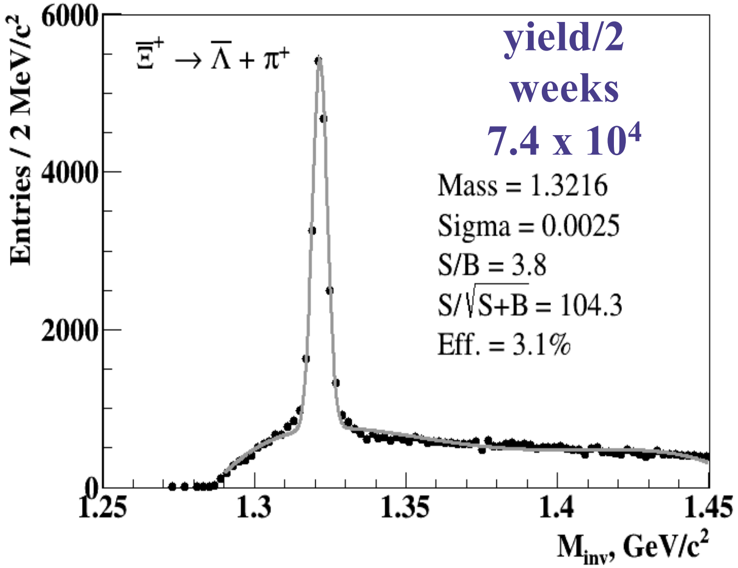
Detailed p_T spectra for hyperons in multiple centrality intervals

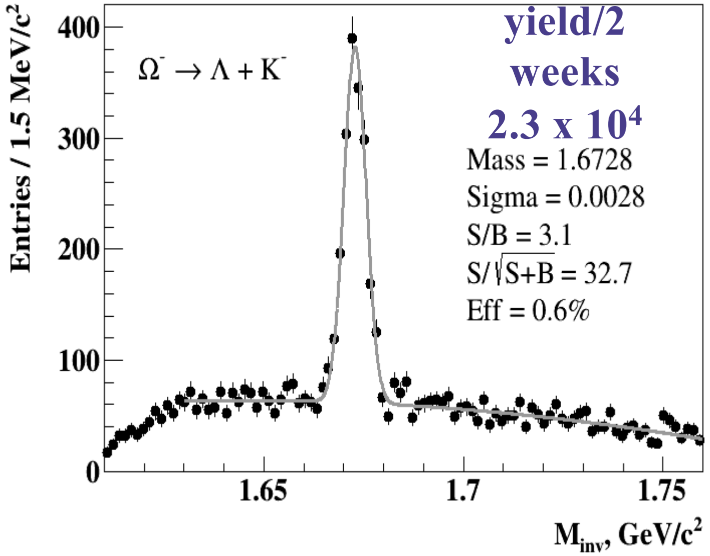
Large and consistent acceptance

Clean signal enhanced by good PID

Significant yield of rare hyperons



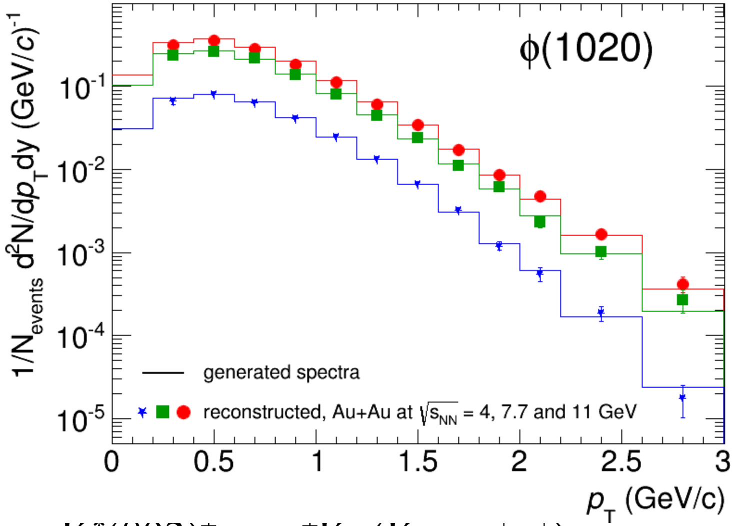




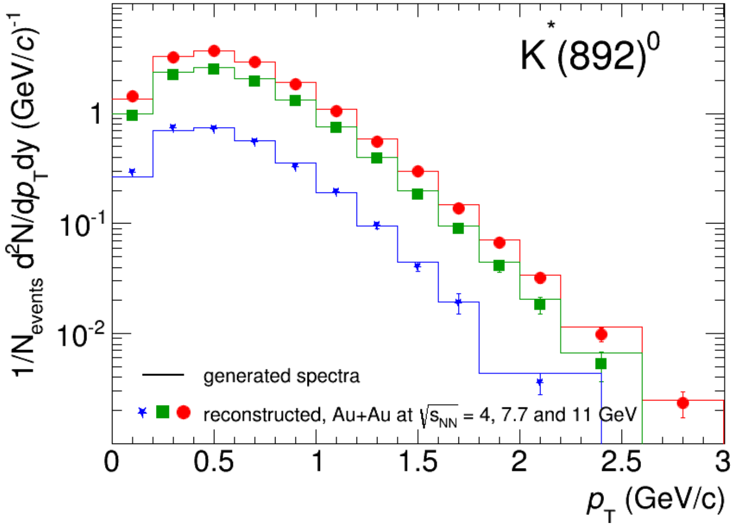
Resonances at MPD

· Minbias Au+Au@11 (UrQMD) · Full reconstruction and realistic PID · Topology cuts and secondary vertex · Event mixing for background

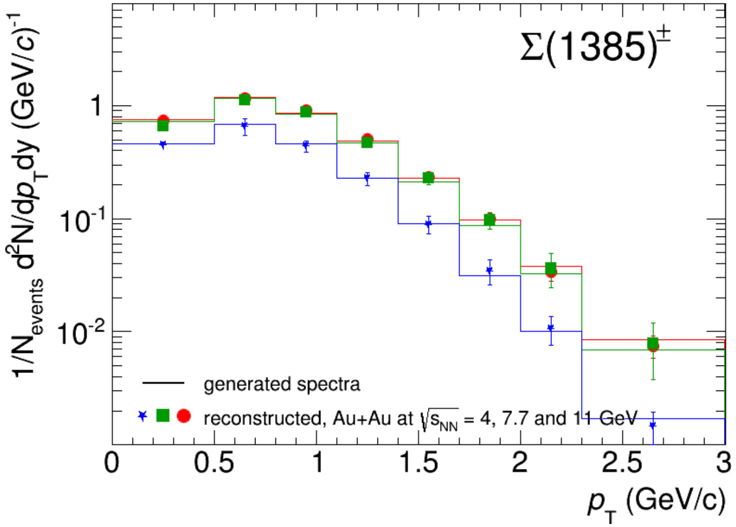
$\phi(1020) \to K^+K^-$



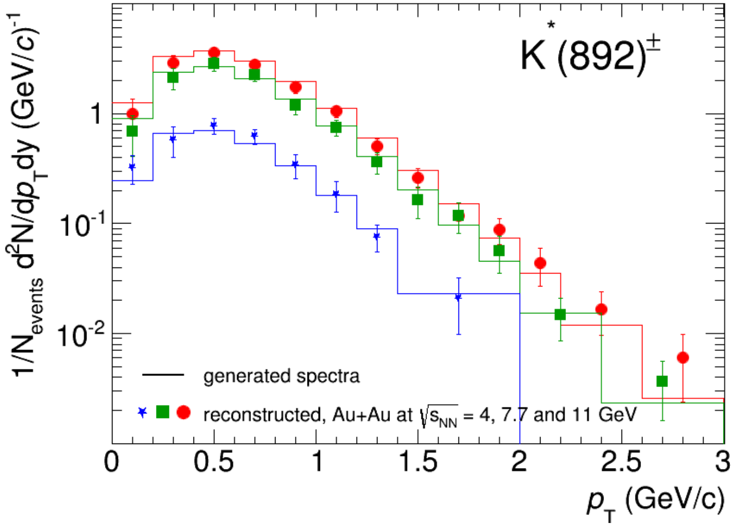
$K^*(892)^0 \to K^\pm\pi^\pm$



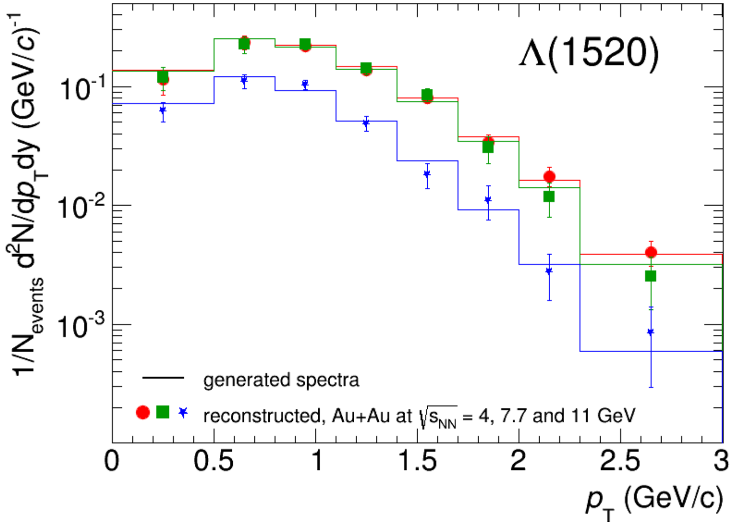
$\Sigma(1385)^\pm \to \pi^\pm\Lambda\ (\Lambda \to p\pi)$



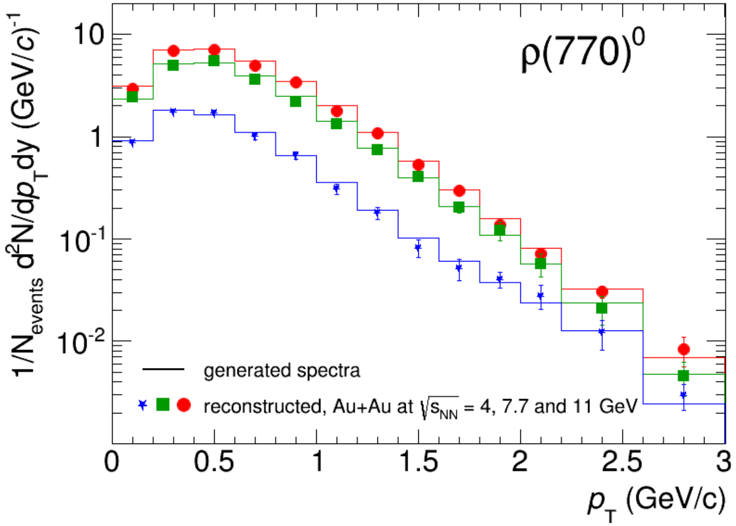
$K^*(892)^\pm \to \pi^\pm K_s\ (K_s \to \pi^+\pi^+)$



$\Lambda(1520) \to pK^-$

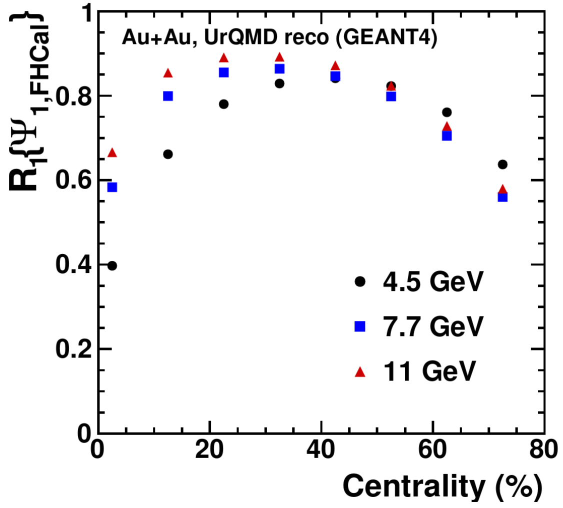


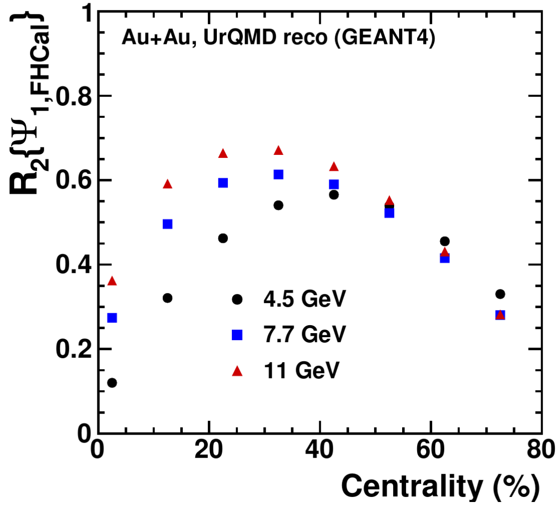
$\rho(770)^0 \to \pi^\pm\pi^\pm$

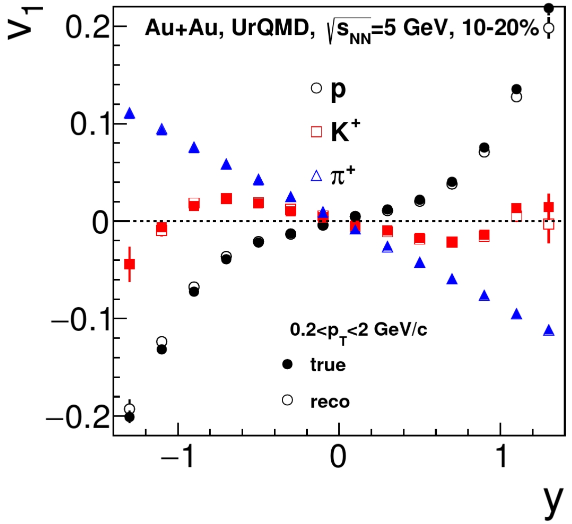


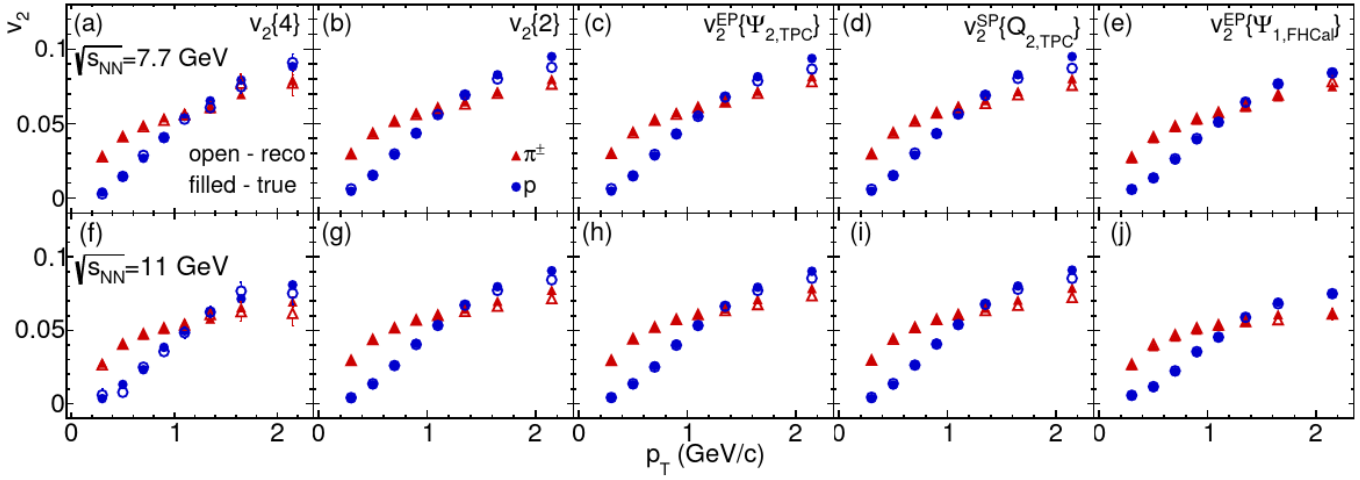
NICA Performance of collective flow studies

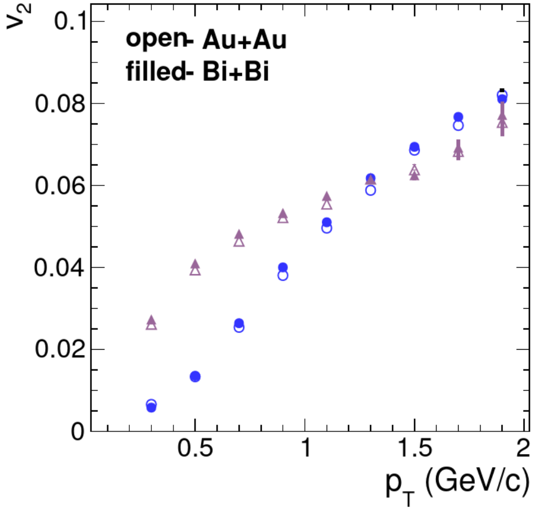
Au+Au, $\sqrt{s_{NN}}$ = 4.5, 7.7, 11 GeV, UrQMD, GEANT4 + MPDRoot reco.







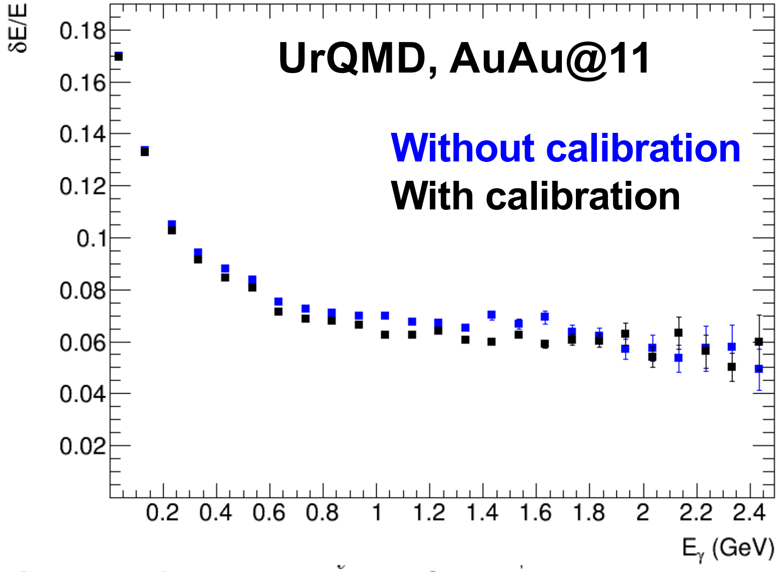


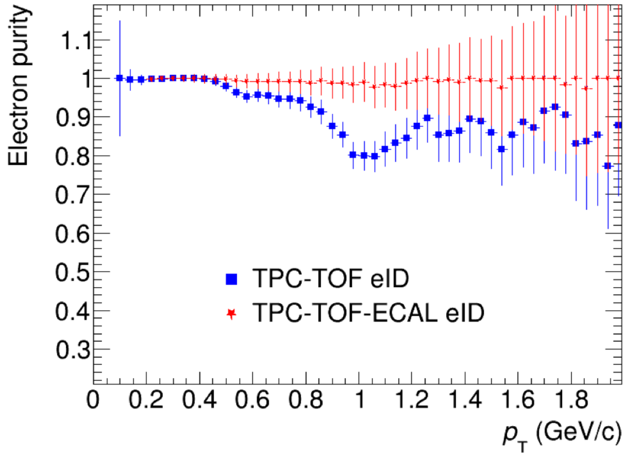


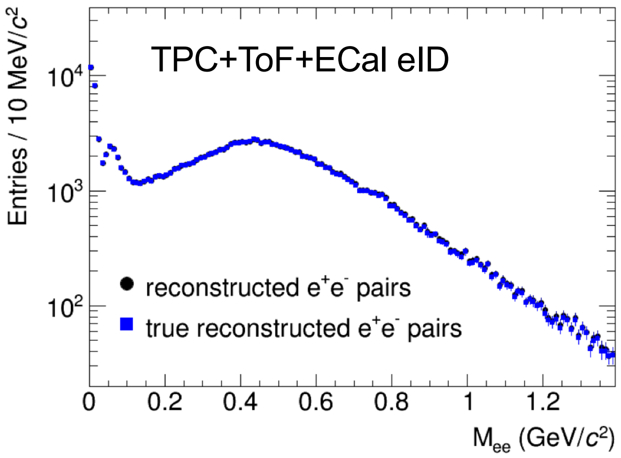
Collective flows a unique and direct way to probe EOS of QCD matter. Excellent flow measurement capabilities in MPD

Electromagnetic probes in ECAL

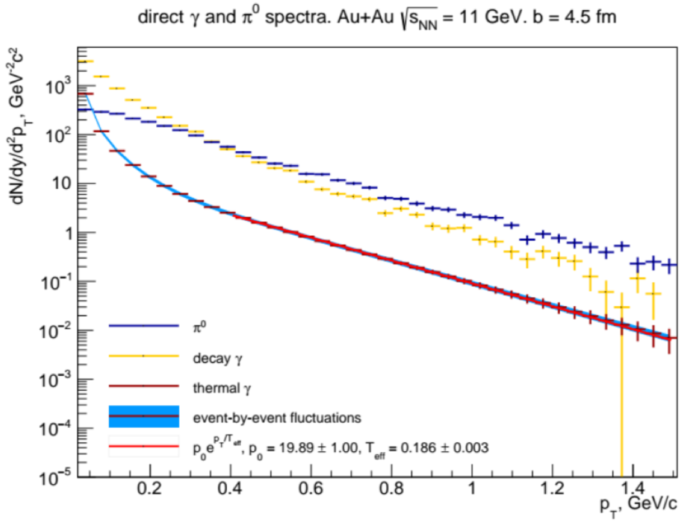
- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range

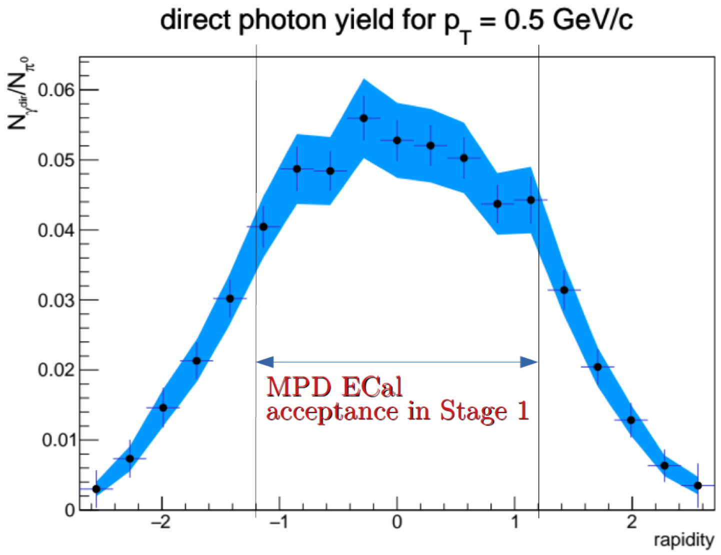






Statistical uncertainty in π^0: 1000 events



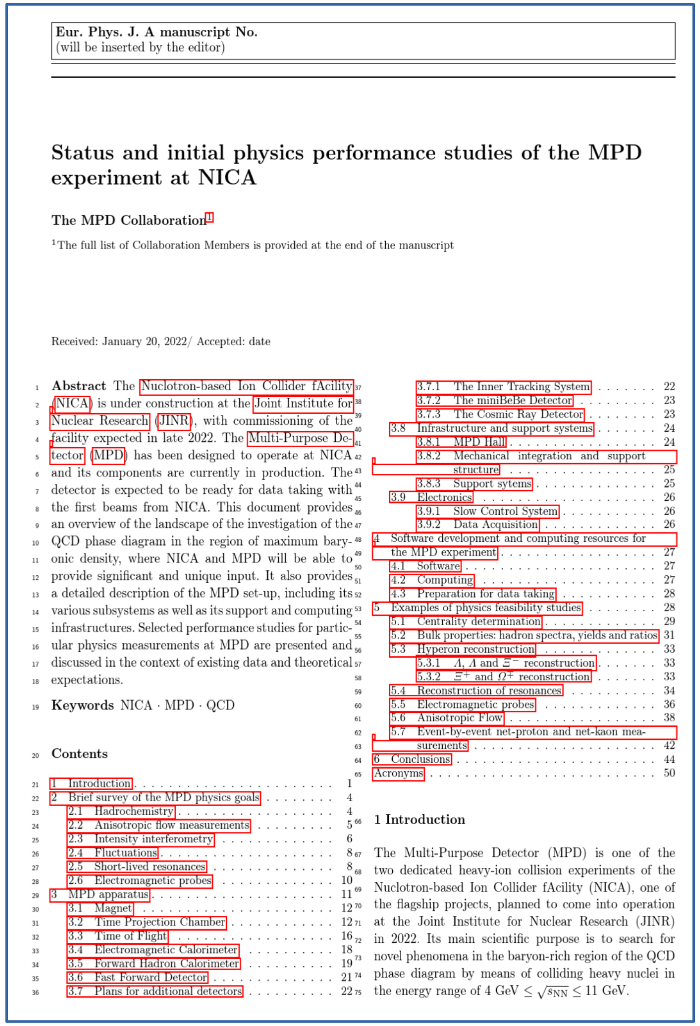


- Important feasibility cross-checks for di-leptons

- Promising feasibility studies for prompt photon measurements in MPD

MPD Status and Performance

e-Print: 2202.08970 [physics.ins-det]



Eur. Phys. J. A manuscript No.
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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: January 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 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.

- Large work of Editorial Committee to provide manuscript:
- Main physics goals of MPD in the landscape of current heavy-ion physics and astrophysics
- Status of the readiness of the MPD detector subsystems
- Report on example expected physics results on the first run of MPD, with relation to expected detector performance
- Submission as invited review to EPJA; reply to referees' comments in progress.
- Work already ongoing on the "First Physics with MPD" publication, focused on discovery potential with initial NICA beams

MPD assembling milestones 2020-2021

Year 2020

1.	Jul. 15th	- MPD Hall and pit ready to store and unpack Yoke parts
2.	Aug.	- The first 13 plates of Magnet Yoke are assembled for alignment checks
3.	Sep. 15th-Oct. 1st	- Solenoid is ready for transportation from ASG (Italy)
4.	Nov. 10th	- Solenoid arrived at MPD Hall
5.	Nov.-Dec.	- Assembling of Magnet Yoke

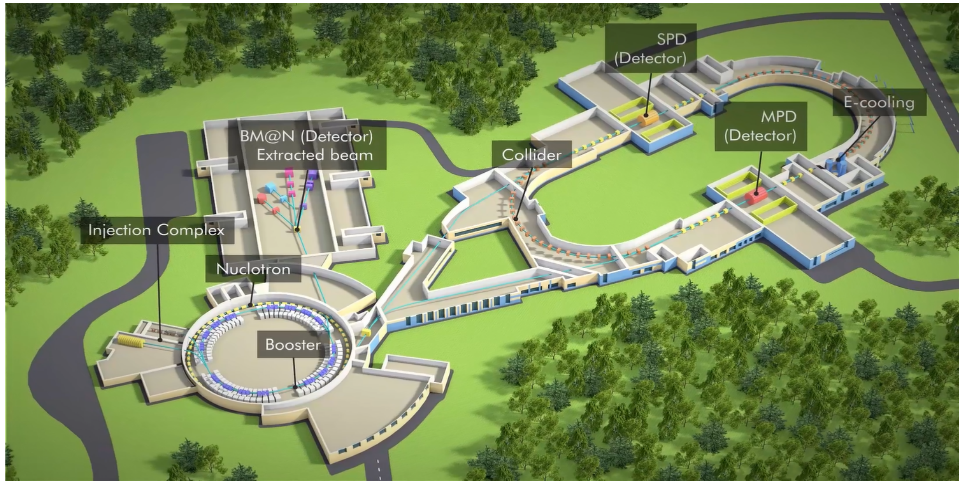
Year 2021

6.	Jul.-Aug.	- Solenoid installation into Iron Yoke and alignment
7.	Aug.-Dec.	- Electrical test, pressure tests and vacuum test
8.	Nov.-Dec.	- Assembling Iron Yoke, Cryogenic platform and Cryostat. Vacuum test

Plans for the years 2022 – 2025 are being revised and will be discussed during the coming Collaboration meeting (end of April 2022)

NICA running plan

- **Year 2021:**
  - Extensive commissioning of Booster accelerator
  - Heavy-ion (Fe/Kr/Xe) run with full Booster+Nuclotron setup
- **Year 2022:**
  - Completion of Collider and transfer lines



- **The schedule for the delivery of first beams as well as the plans for the first runs is currently being assesed at the level of the NICA managment. Plans to deliver the first beams by the end of 2023 seem to still be feasible.**

Summary

- The NICA Complex advanced in construction with important milestones achieved and clear plans for 2021 and 2022
- Broad MPD Physics program with initial NICA beams
- As of February 2022, all components of MPD 1st stage were under production.
- Contingency plans to cope with current situation will be discussed at the coming collaboration meeting (end of April)
- Ambitious physics goals aiming to map the QCD phase diagram