MPD Experiment at NICA

Adam Kisiel, WUT/JINR

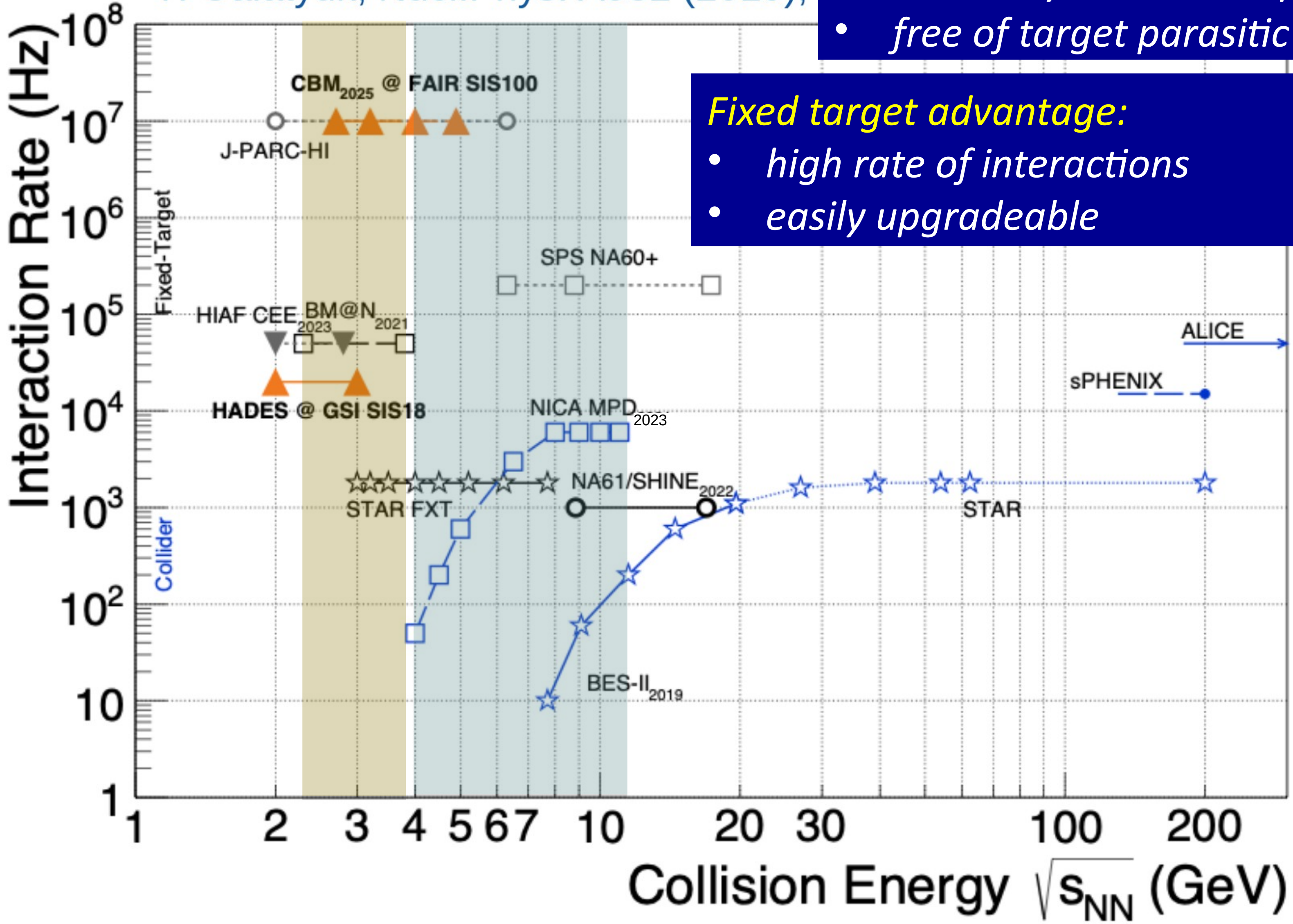
NICA: Unique and complementary

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

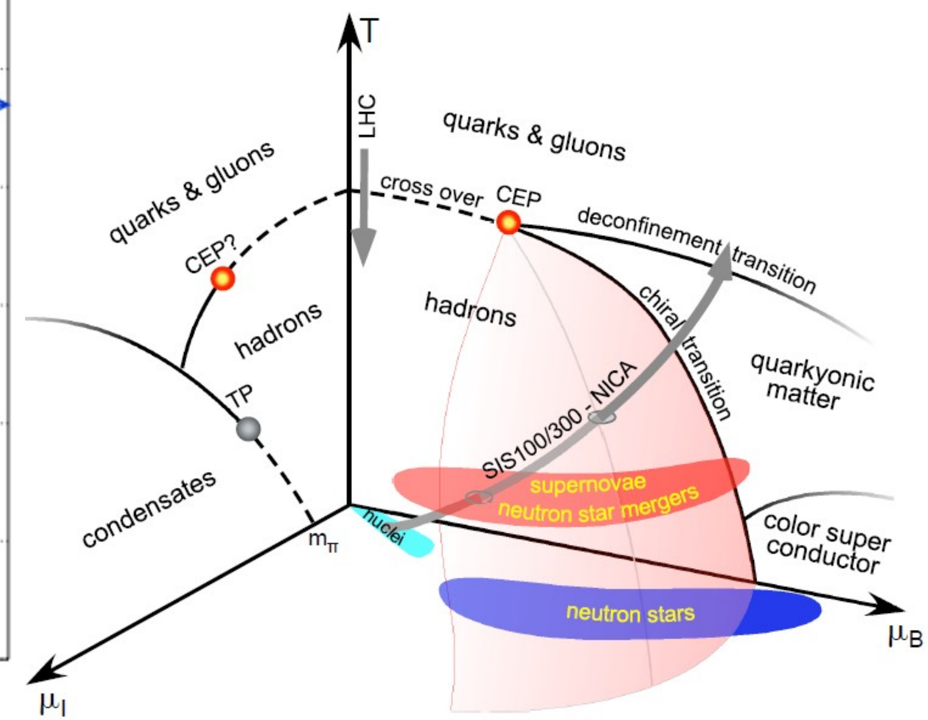
In NICA energy range maximum possible net-baryon density is reached

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

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



NUPECC Long Range Plan 2017

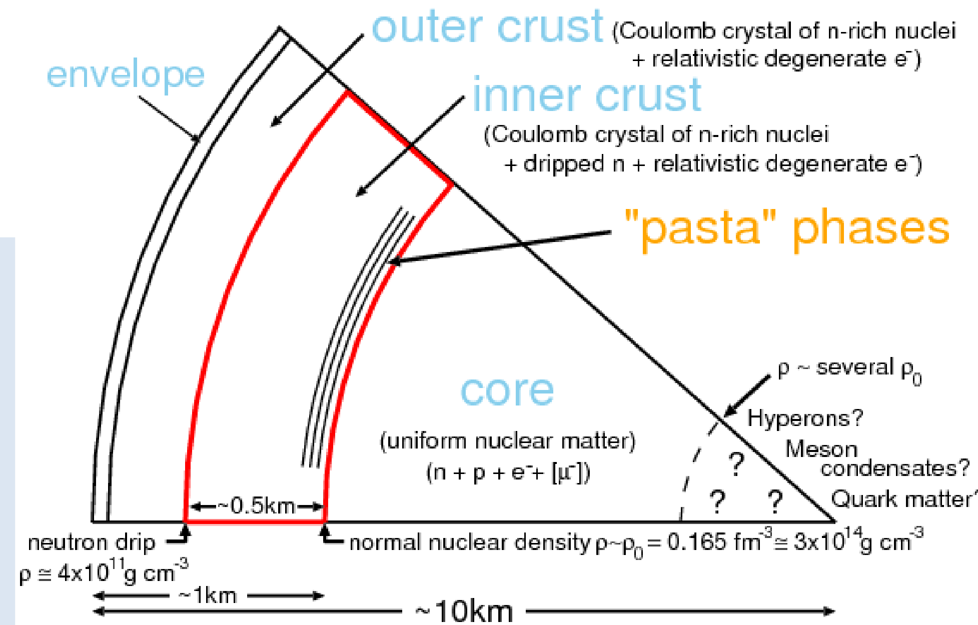


Access neutron star matter in laboratory

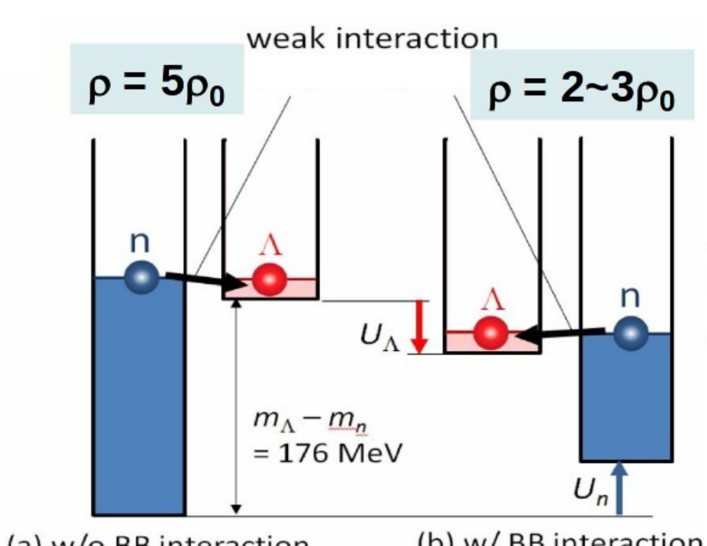
core of neutron stars reaches density several times nuclear density

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

Credit: LIGO Collaboration

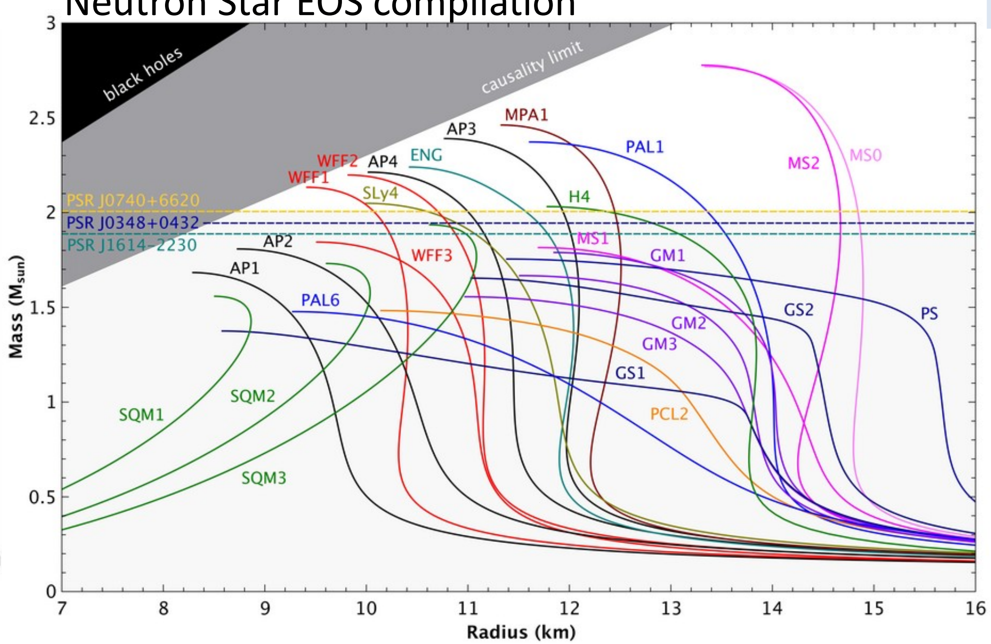


Demorest et al., Nature 467, 1081

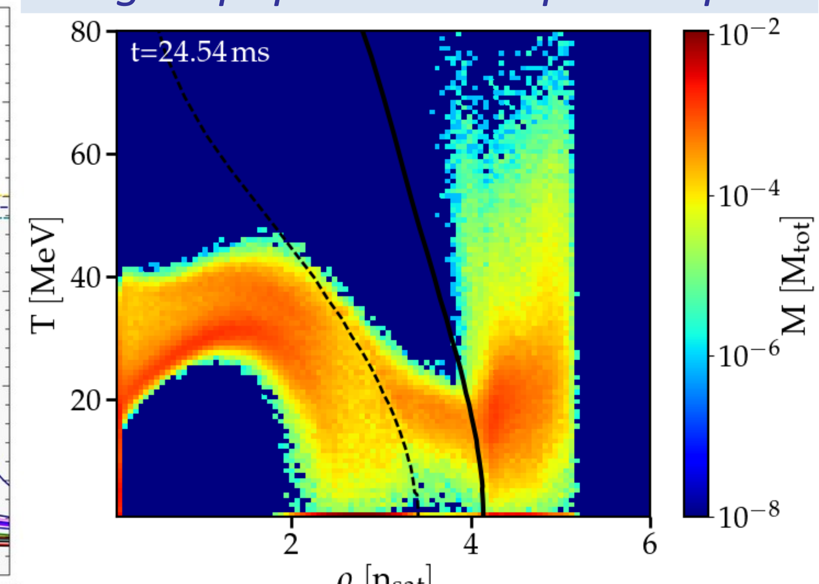


H. Tamura, Hadron 2017

Neutron Star EOS compilation

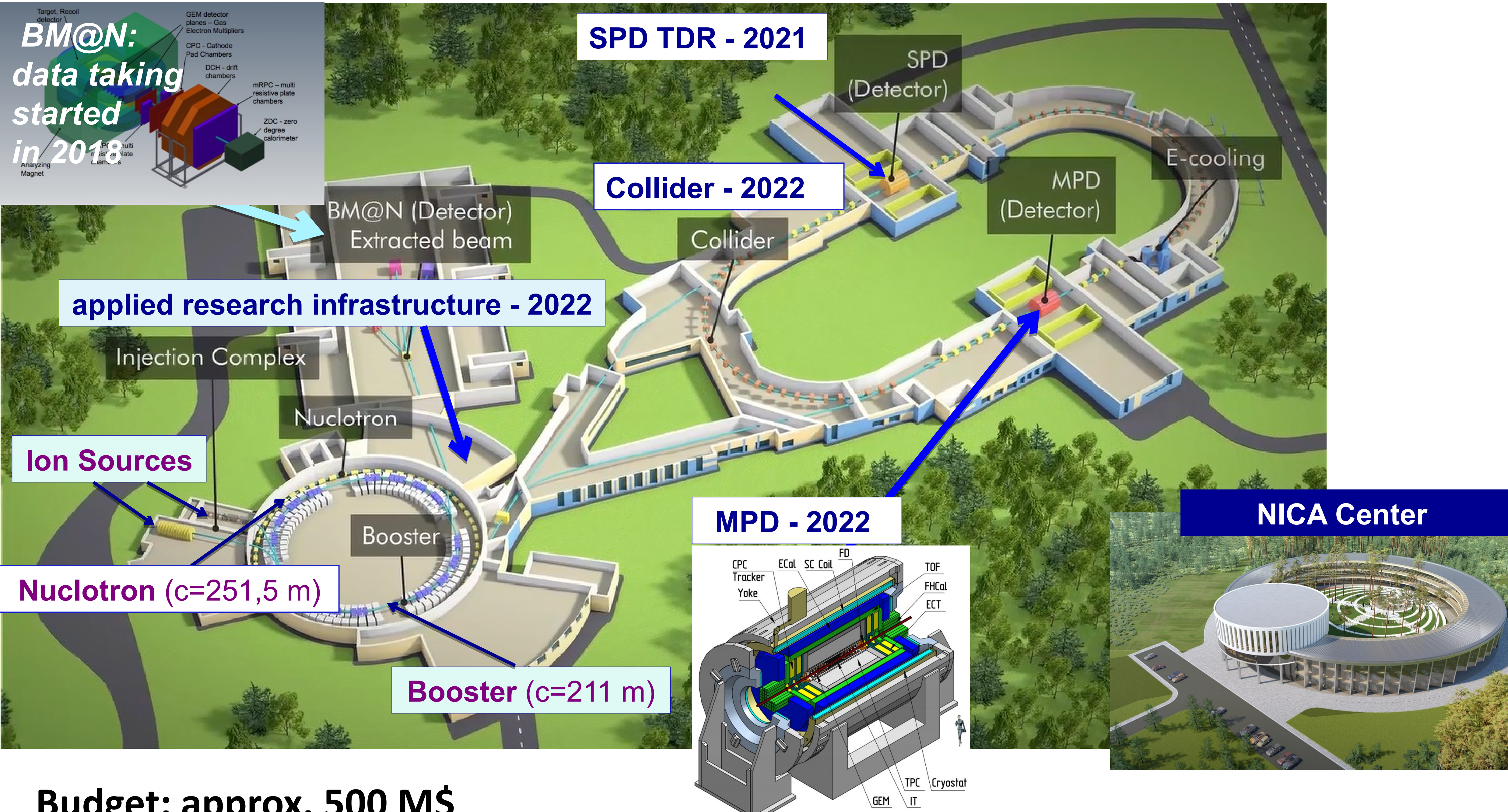


mergers populate NICA phase space



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

NICA Accelerator Complex in Dubna



Budget: approx. 500 M$

NICA construction live

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 ≤ 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. Δp/p, 10^{-3}	**1,6**
IBS growth time, s	**1800**
Luminosity, cm^{-2} s^{-1}	**1x10^{27}**

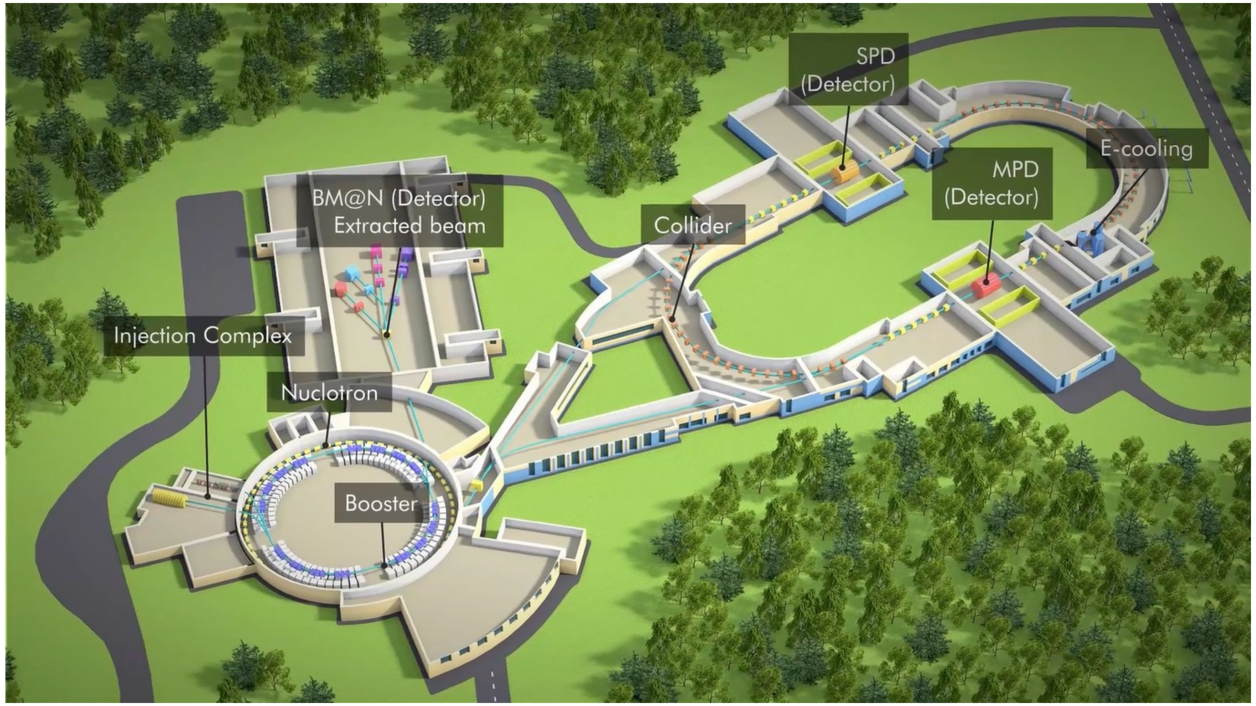
Stage I:

- ***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)*

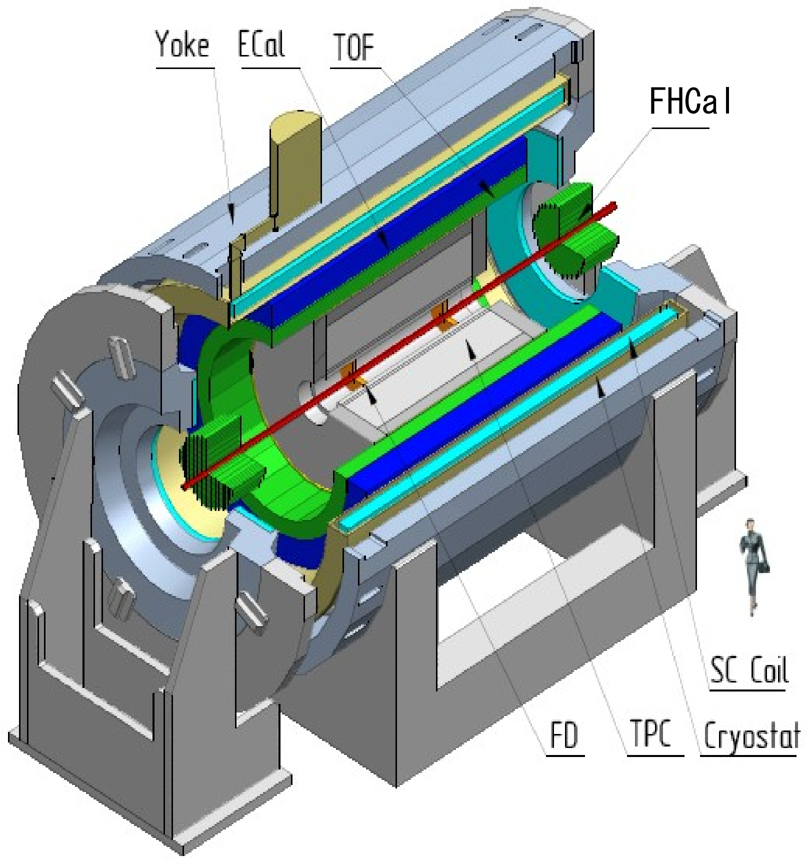
NICA running plan

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



- **Year 2023:**
  - Initial run of NICA with Bi+Bi @ 9.2 AGeV (other energies a second priority)
  - Goal to reach luminosity of 10^{25} cm^{-2}s^{-1}, collect 10^{8} good minimum-bias events
- **Year 2024:**
  - Goal to have Au+Au collisions and acceleration in Collider (up to 11 AGeV)
- **Beyond 2024:**
  - Maximizing luminosity, possibility of collision energy and system size scan

Multi-Purpose Detector (MPD) Collaboration



NICA

***13** Countries, **>500** participants,*
43** Institutes and **JINR

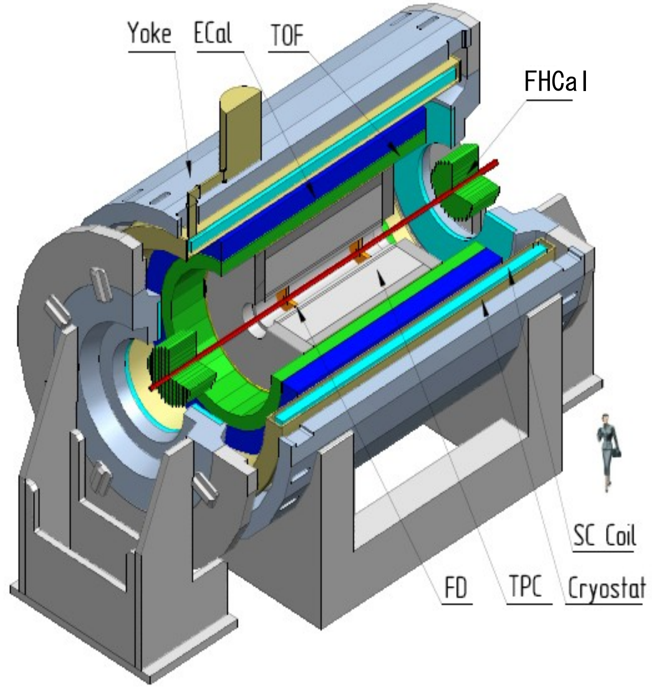
*Spokesperson: **Adam Kisiel***
*Inst. Board Chair: **Alejandro Ayala***
*Project Manager: **Slava Golovatyuk***

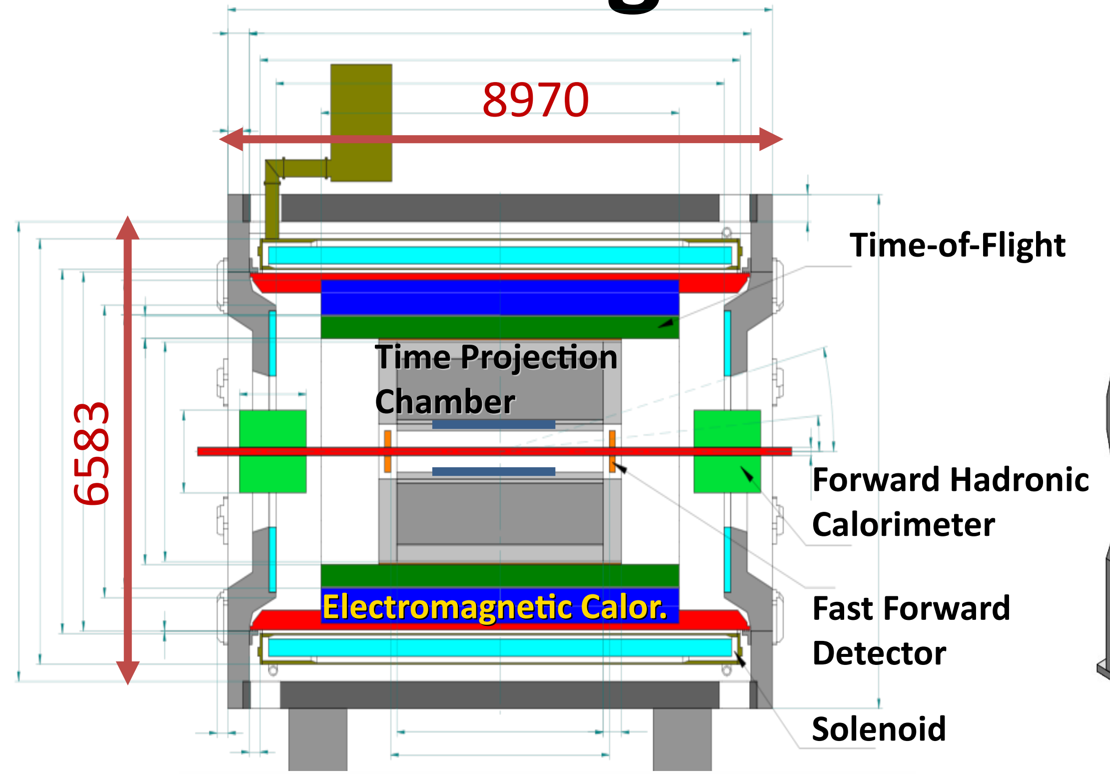
Deputy Spokespersons:
Victor Riabov, Zebo Tang

*International Collaboration established in **2018***
Still growing, open for new member institutions

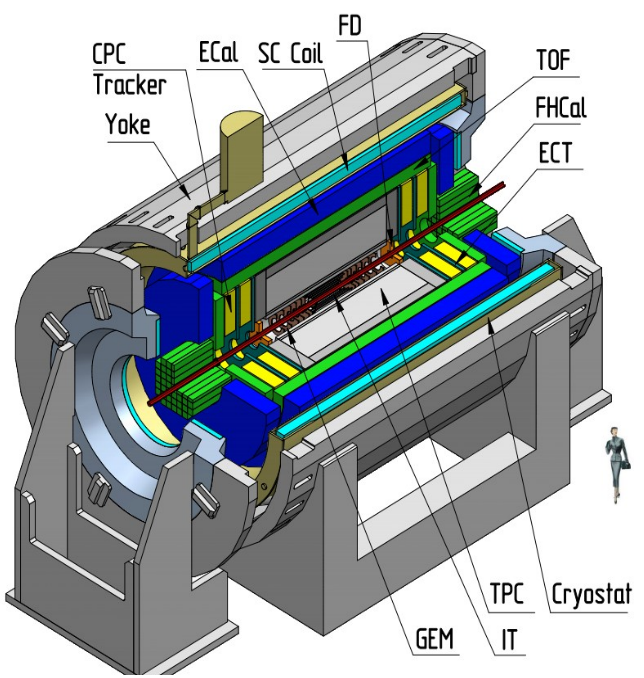
*AANL, Yerevan, **Armenia;***
*Baku State University, NNRC, **Azerbaijan**;*
*Plovdiv University Paisii Hilendarski, **Bulgaria;***
*University Tecnica Federico Santa Maria, Valparaiso, **Chile**;*
*Tsinghua University, Beijing, **China**;*
*USTC, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Central China Normal University, **China**;*
*Fudan University, Shanghai, **China**;*
*Shandong University, Qingdao, **China**;*
*SNST, UCAS, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics, CAS, Lanzhou, **China**;*
*Palacky University, Olomouc, **Czech Republic**;*
*NPI CAS, Rez, **Czech Republic**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
***Joint Institute for Nuclear Research**;*
*FCFM-BUAP Puebla, **Mexico**;*
*FC-University of Colima, Colima, **Mexico**;*
*FCFM-UAS, Culiacán, **Mexico**;*
*ICN-UNAM, Mexico City, **Mexico**;*
*CINVESTAV, Mexico City, **Mexico**;*
*Universidad Autónoma Metropolitana, Iztapalpa, **Mexico**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*WUT, Warsaw, **Poland**;*
*NCBJ, Otwock – Świerk, **Poland**;*
*University of Wrocław, **Poland**;*
*University of Silesia, Katowice, **Poland;***
*University of Warsaw, **Poland**;*
*Jan Kochanowski University, Kielce, **Poland**;*
*Institute of Nuclear Physics, PAS, Cracow, **Poland**;*
*Belgorod National Research University, **Russia**;*
*INR RAS, Moscow, **Russia**;*
*NRNU MEPhI, Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*NRC Kurchatov Institute, ITEP, **Russia**;*
*Kurchatov Institute, Moscow, **Russia**;*
*St. Petersburg State University, **Russia;***
*SINP, Moscow, **Russia**;*
*PNPI, Gatchina, **Russia**;*
*Vinča Institute of Nuclear Sciences, Belgrade, **Serbia**;*
*Pavol Jozef Šafárik University, **Slovakia;***

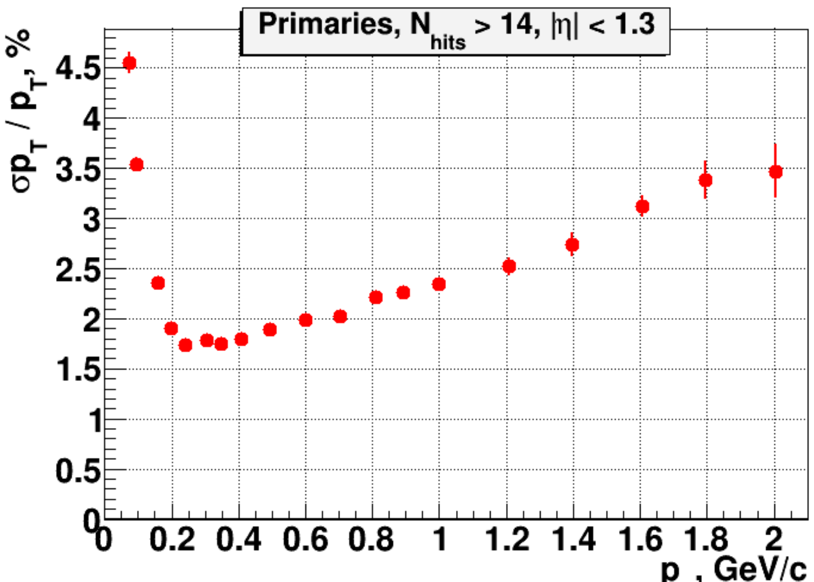
MPD - stage I and II



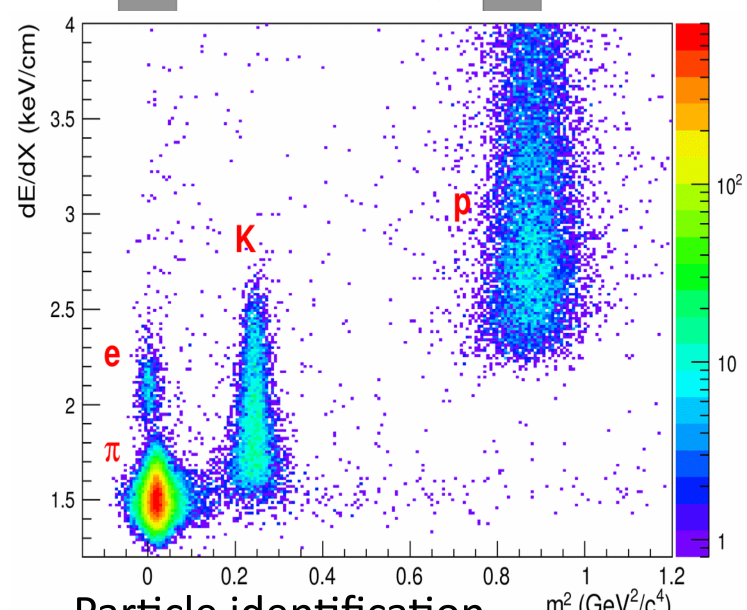


MPD - Stage II

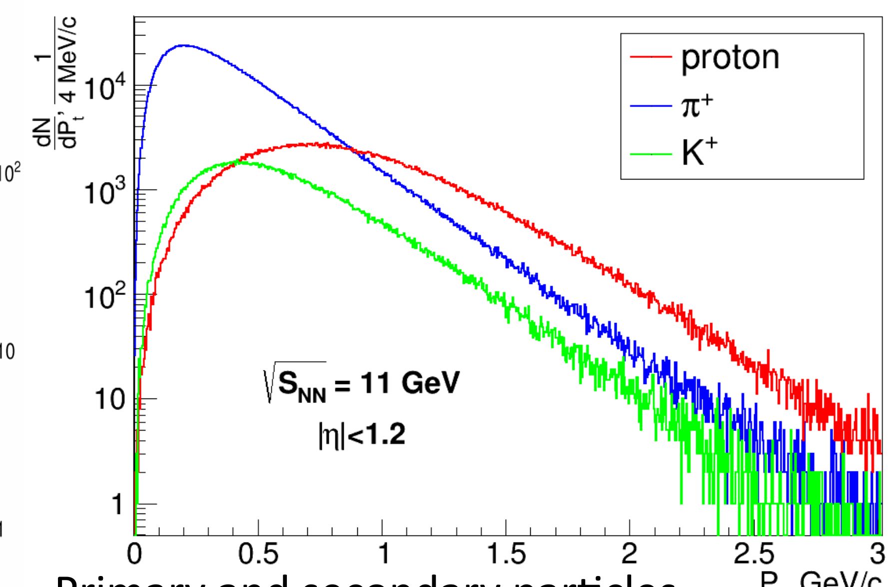




Momentum resolution with TPC



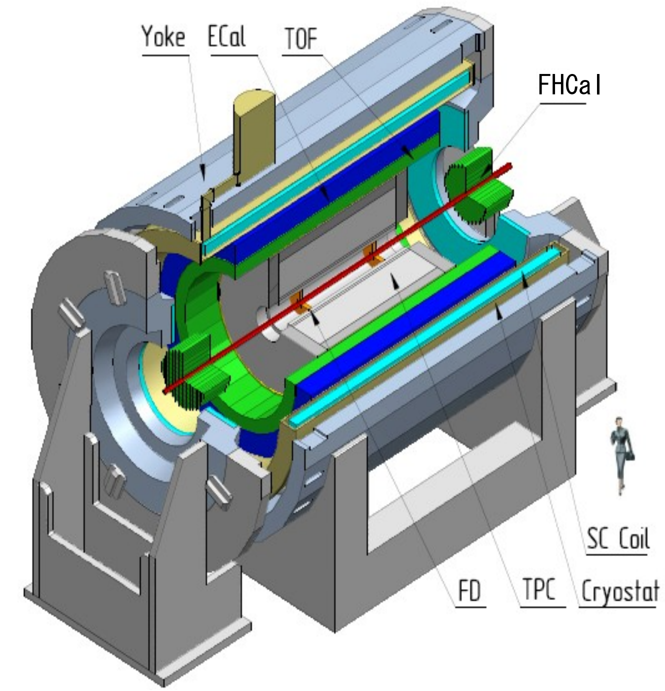
Particle identification



Primary and secondary particles

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
  - At least until 2025 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, forward region tracking with end-caps, muon detector, and more)

Solenoid in MPD Hall

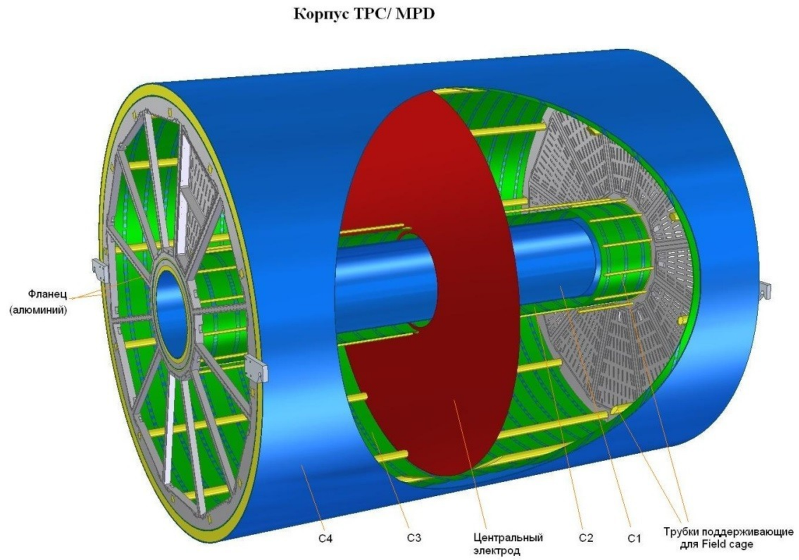
- On 6-th of November 2020 the MPD Solenoid delivered to MPD Hall

NICA

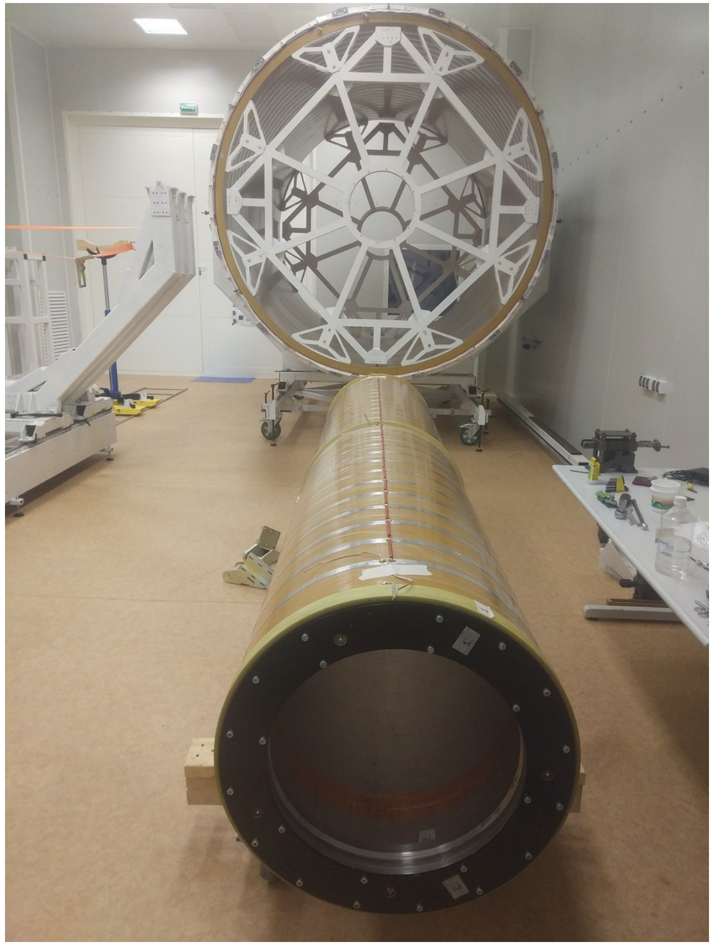
Interior of MPD Hall

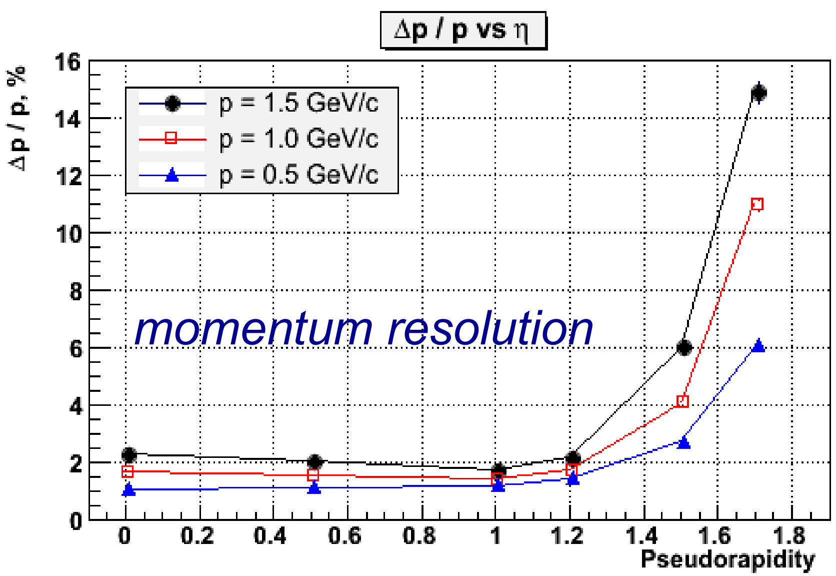
Installation of the MPD Supercoducting coil inside the iron Magnet Yoke in MPD Pit 29 July 2021

Time Projection Chamber (TPC): main tracker

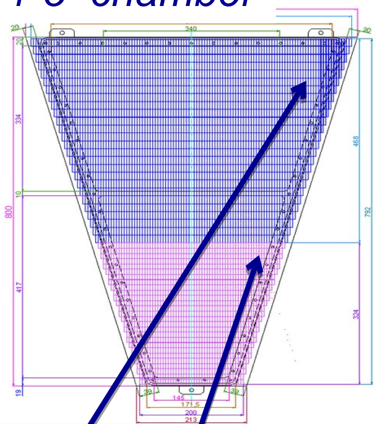


length	*340 см*
outer radius	*140 см*
inner radius	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kHz (L=10^{27})*





r-o chamber



FE electronics: **FEC64SAM** –
*dual **SAMPA** card (**ALICE** technology)*

pad structure:
- *rows – 53*
- *large pads 5×18 mm^2*
- *small pads 5×12 mm^2*

Read-Out Chambers (ROCs) are ready and tested (production at JINR)
Electronics sets in production
Two sites (Moscow, Minsk) tested for electronics production
C1-C2 and C3-C4 cylinders assembled
TPC flange under finalization

MPD Time-of-Flight

Mass production staff: 4 physicists, 4 technicians, 2 electronics engineers
Productivity: ~ 1 detector per day (1 module/2 weeks)

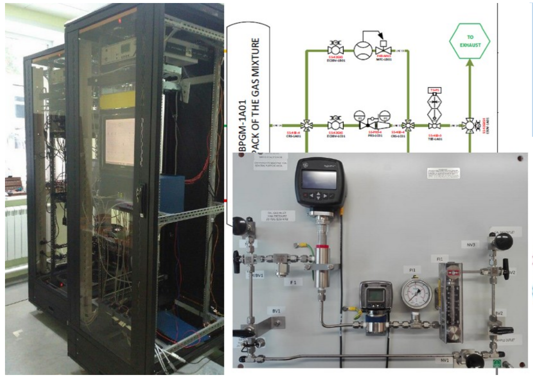

Glass cleaning with ultrasonic wave & deionized water


Automatic painting of the conductive layer on the glass

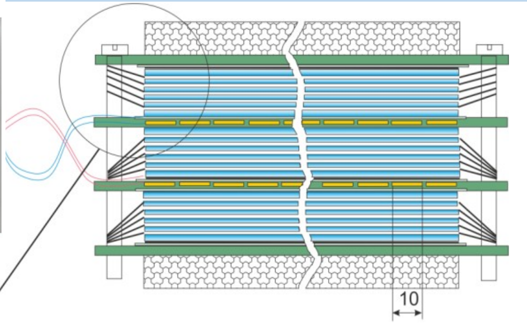

MRPC assembling

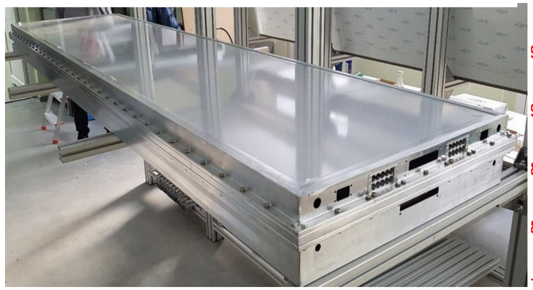

Soldering HV connector and readout pins

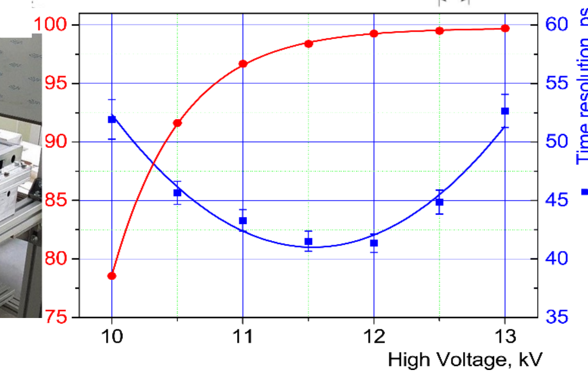
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.


TOF gas system

Dimensions of sensitive area
600 x300 mm^2







	No. of detectors	No. 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)

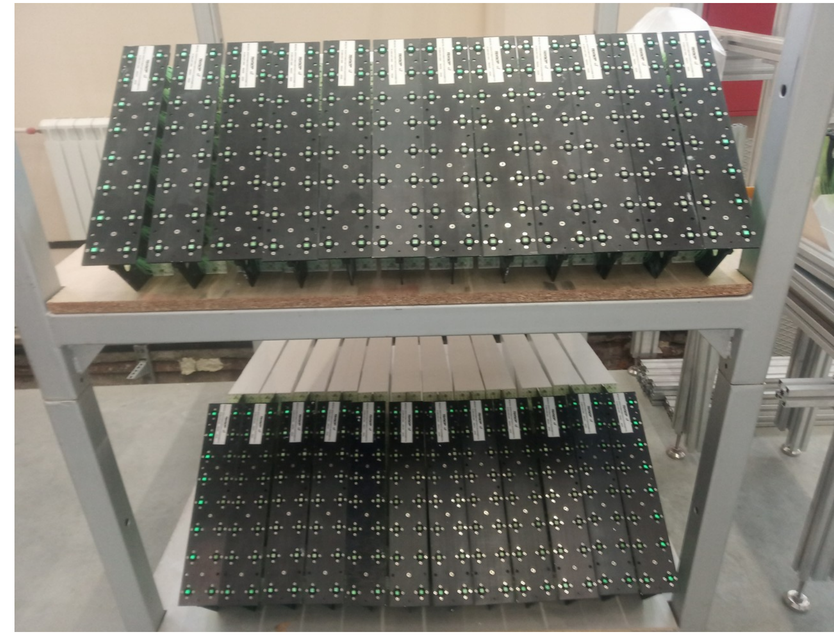
Single detector time resolution: 50ps

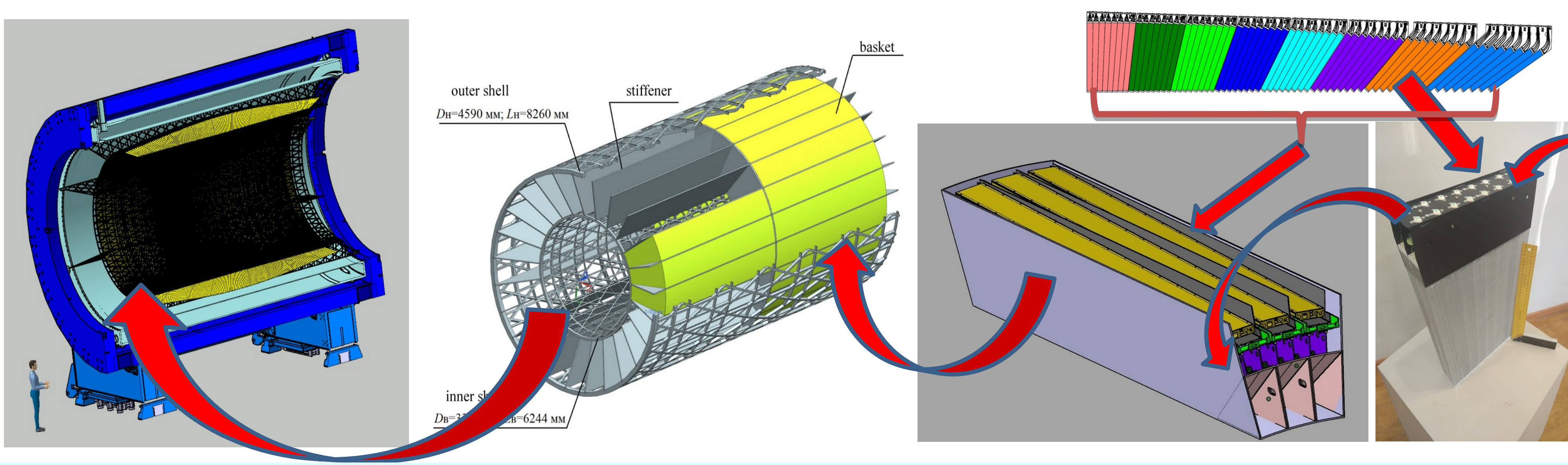
Purchasing of all detector materials completed
So far 40% of all MRPCs are assembled
Assembled half sectors of TOF are under Cosmics tests
Investigation of solutions for detector integration and technical installations

Electromagnetic Calorimeter (ECAL)

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

~**450** modules (16 towers each) = 4 sectors produced
400 modules – production started, finish by the end of Mar 2022
Sectors assembling procedure under development.
Mass assembling of ECal sectors start - October 2021
Up to 16 sectors could be ready in 2022





Sectors in dedicated Containers

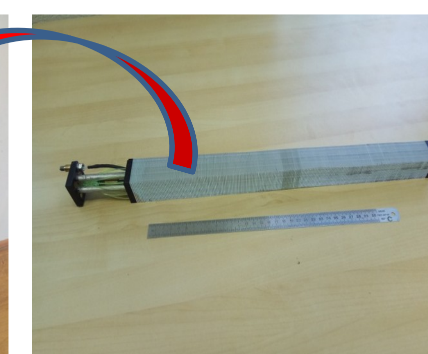
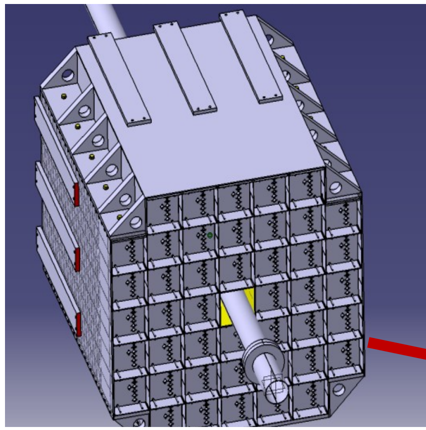
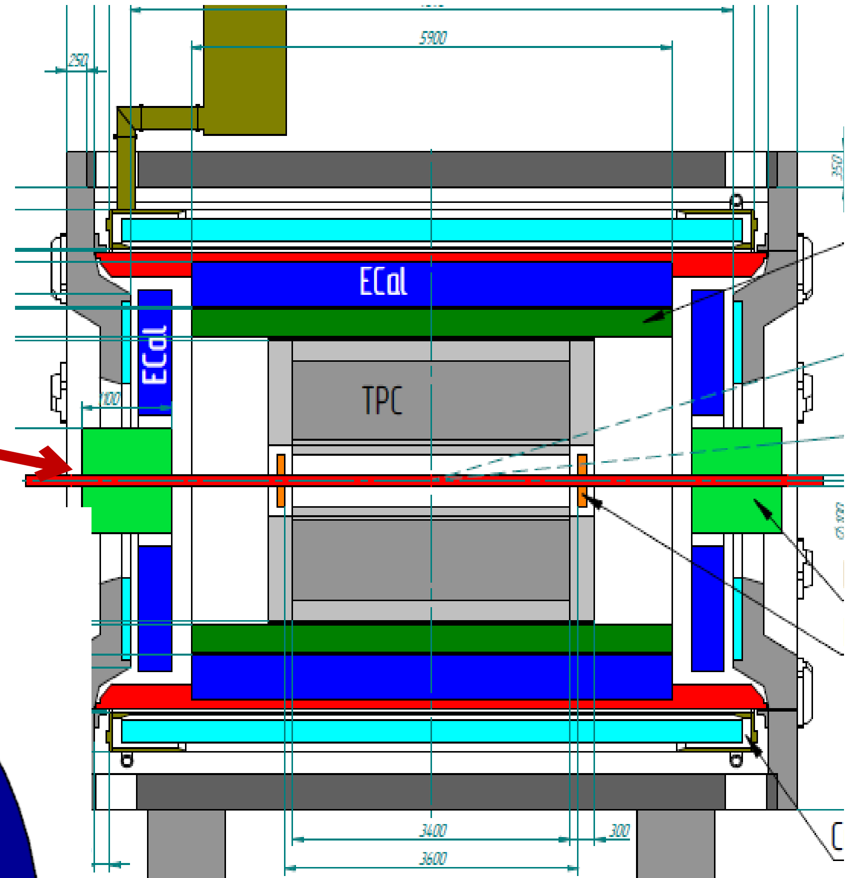


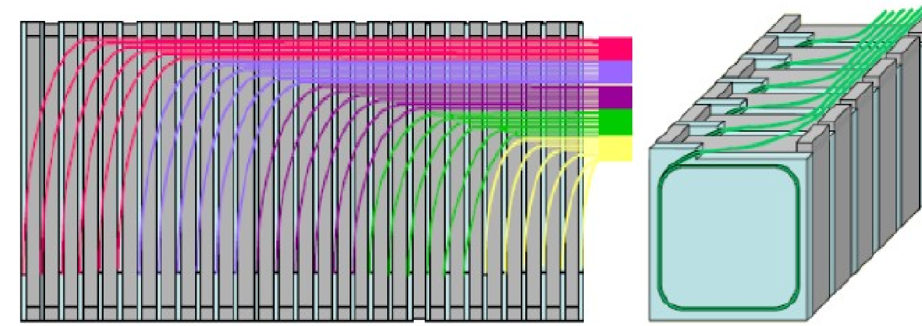
Photo of one element

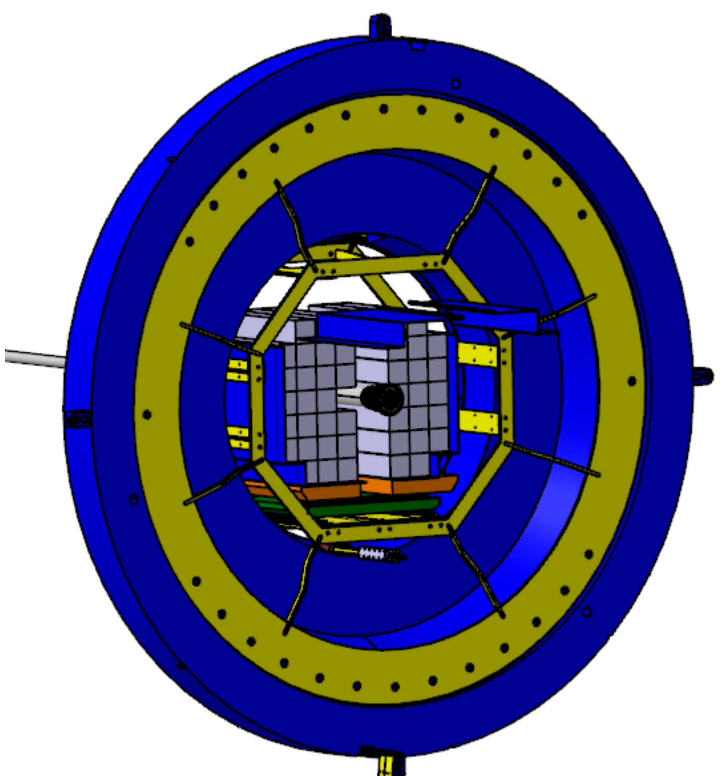
Pb+Sc "Shashlyk" ; read-out: WLS fibers + MAPD; L ~35 cm (~ 14 X_0); Segm. (4x4 cm^2); σ(E) ~ 5% @ 1 GeV; time res. ~500 ps

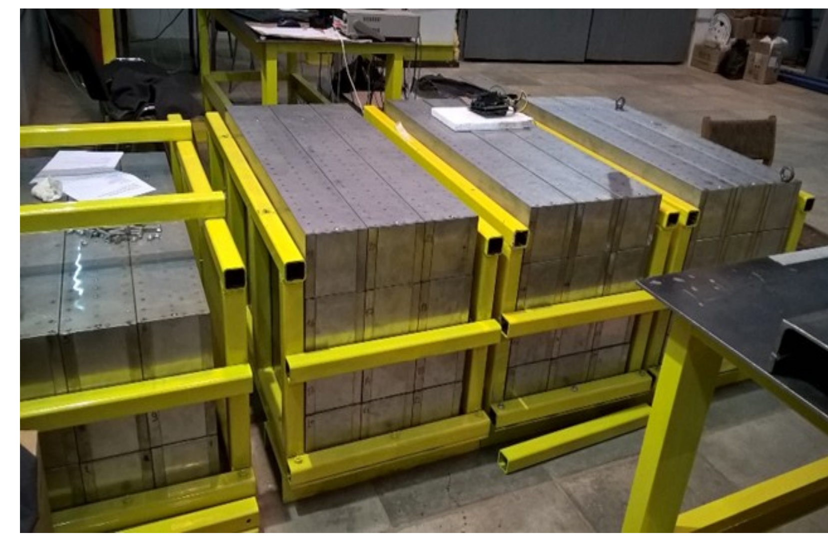
Forward Hadron Calorimeter (FHCal)





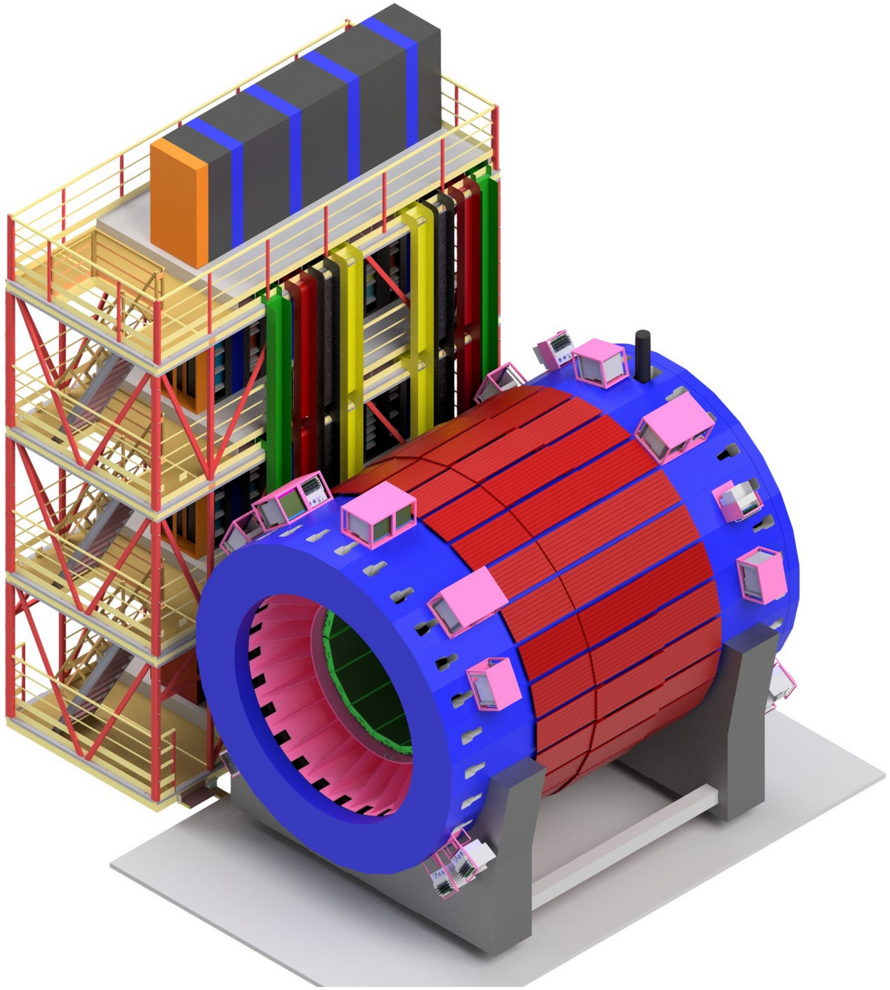


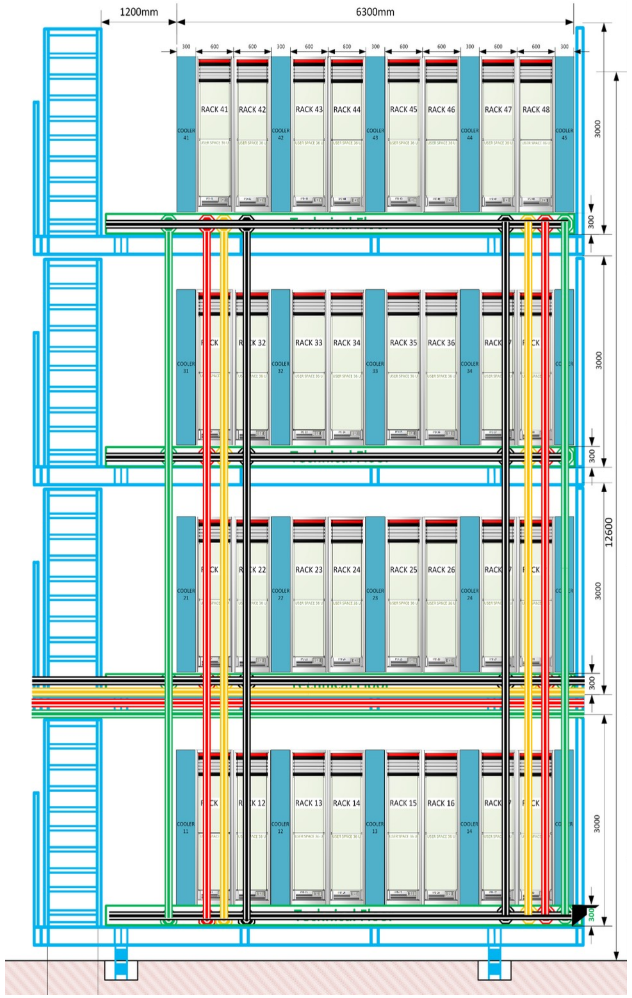




- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

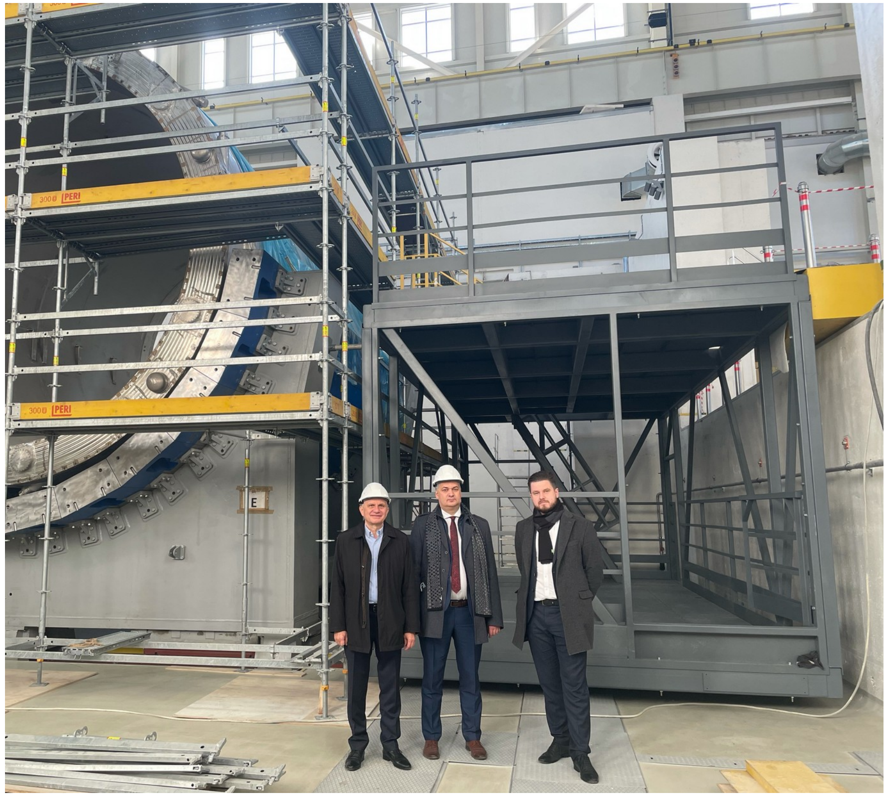
NICA-MPD-Platform for Electronics





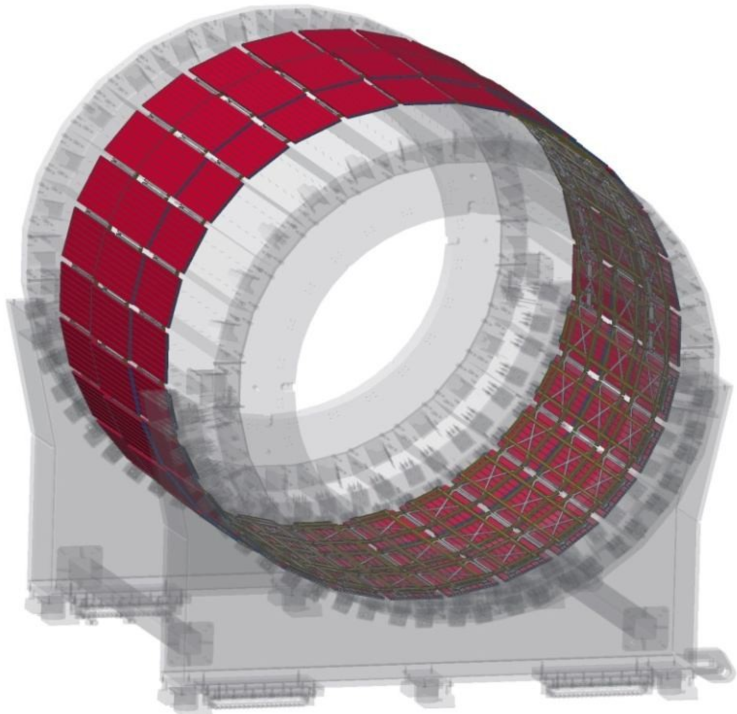
NICA-MPD-Platform is a contribution of the Polish groups to MPD

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.)

MPD Cosmic Ray Detector (MCORD)



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

CDR for MCORD approved by the MPD DAC

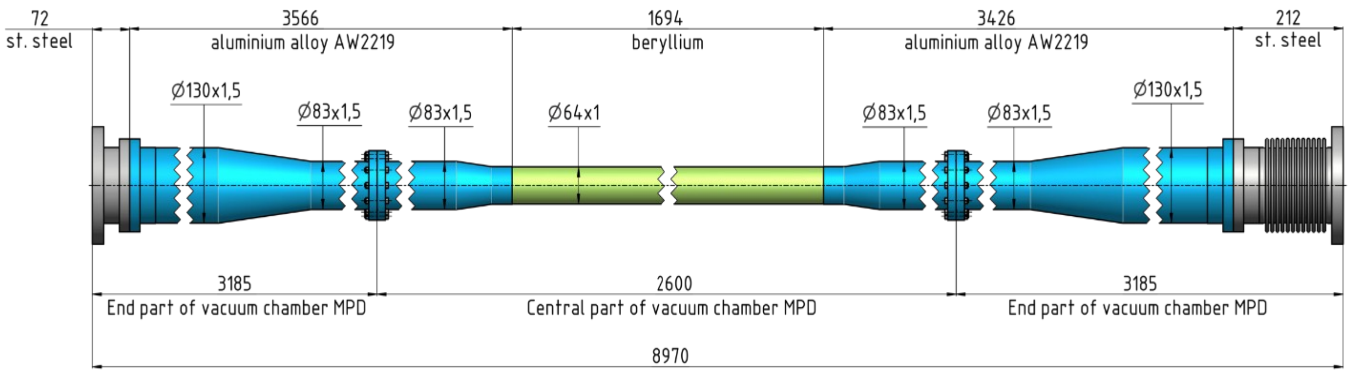
MCORD consists of plastic scintillators with SiPM (Phototubes) light converters, allowing for detection of muons on the outside of MPD Magnet Yoke

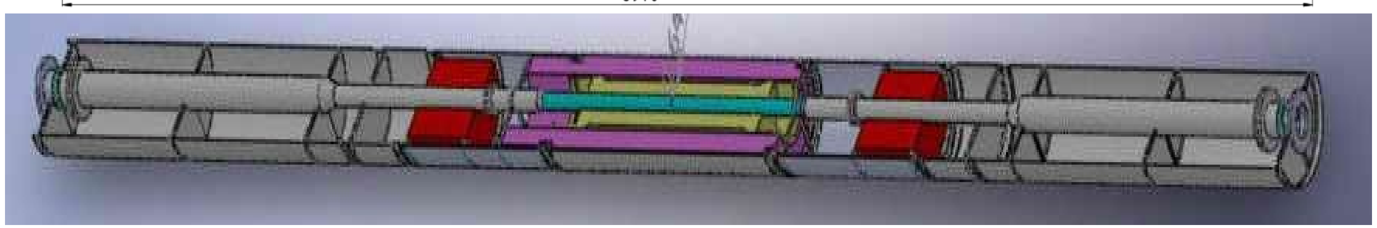
Major role of MCORD before Collider operation in Commissioning and tests of the MPD. MCORD will be a trigger in TPC and TOF tests after their installation.

First MCORD modules delivered to JINR on October 8th 2021

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.

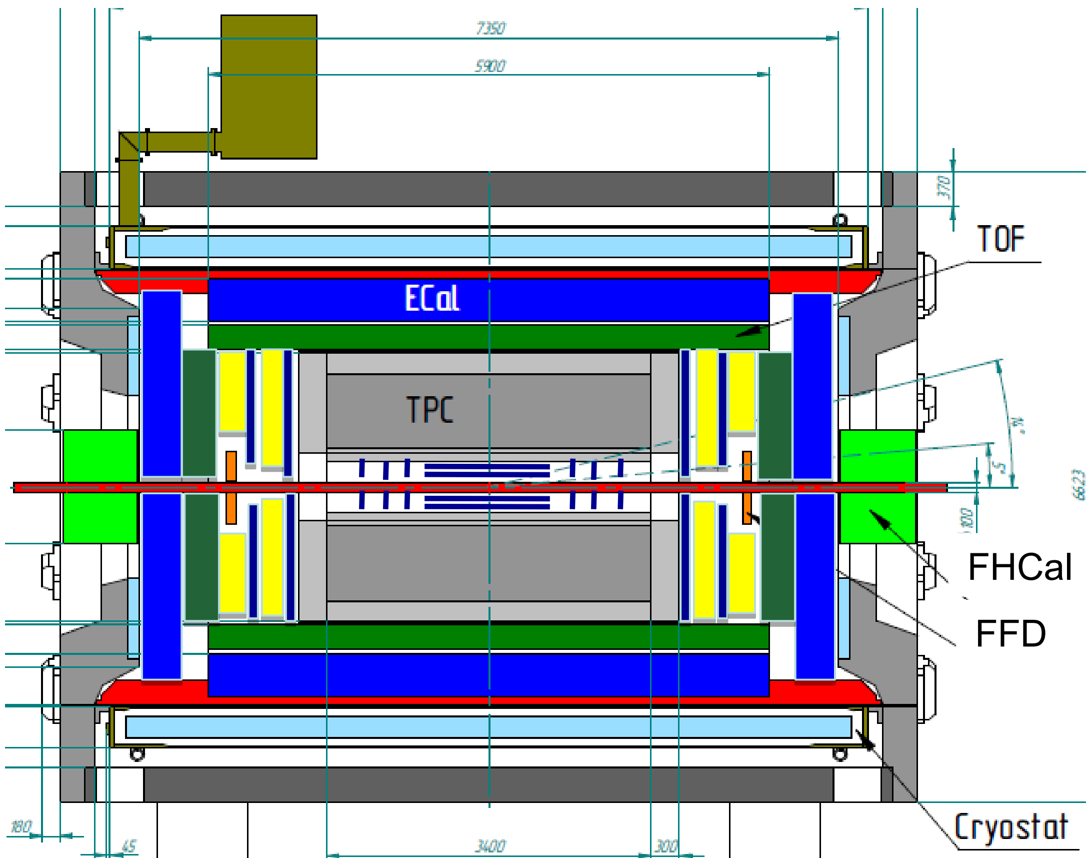
MPD Stage 2 and ITS

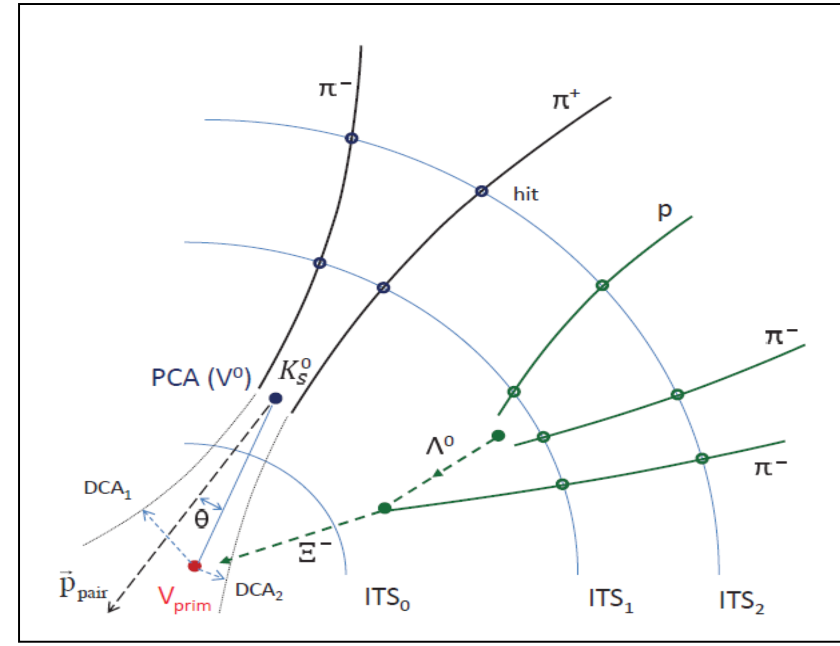
Stage I: TPC, TOF, ECAL, ZDC, FFD + ITS(OB)

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





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

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

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

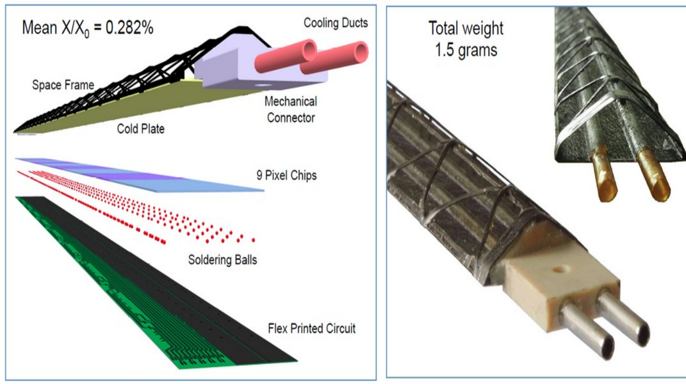
$D^0 \rightarrow K^- + \pi^+$

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

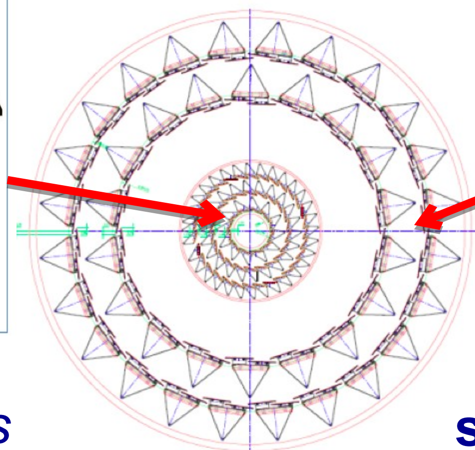
STAR has shown that MFT (based on pixel detectors) allows for specific DCA selections improving S/B ratio for di-leptons

ITS: new possibilities in Stage 2 (2025)

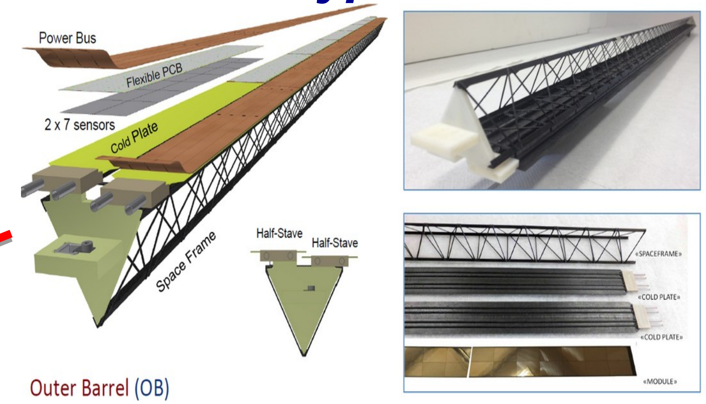
***Inner Barrel (IB)** – **3** layers*
modified staves



stave: 2 *modules x* **9** *chips*

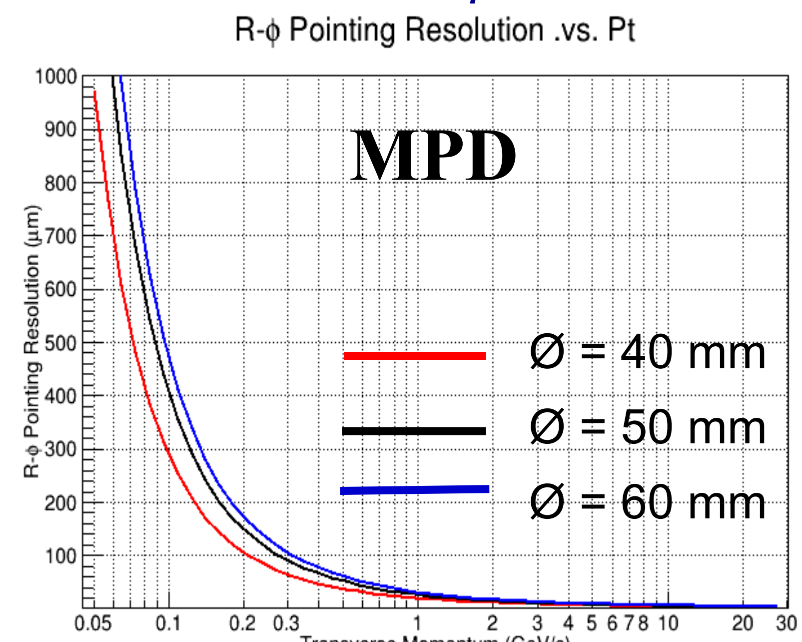


***Outer Barrel (OB)** – **2** layers*
ALICE type staves



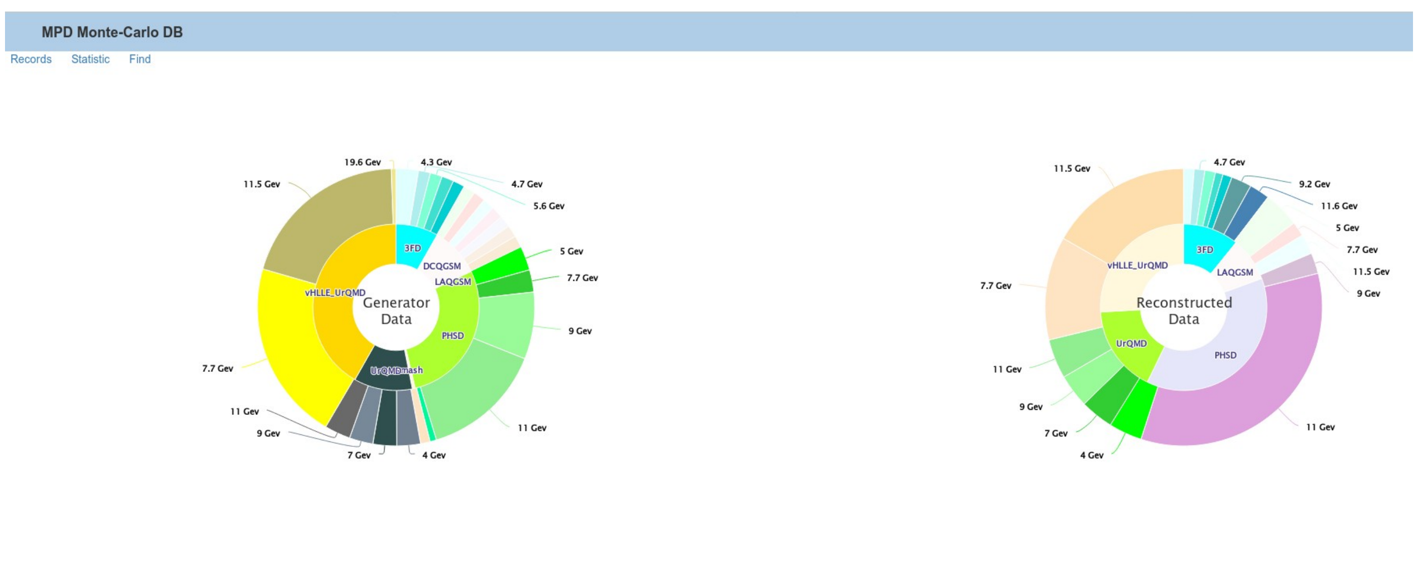
stave: ***14** modules x **14** chips*

layer #	type	staves/ layer	Rmin, mm	Rmax, mm	length, mm	chips/ layer	X0, %
1	IB	12	22,4	26,7	540	216	0,3
2	IB	22	40,7	45,9	540	396	0,3
3	IB	32	59,8	65,1	540	576	0,3
4	OB	18	144,1	147,9	1470	3528	1,0
5	OB	24	194,1	197,6	1470	4704	1,0
total		**108**				**9420**	**2,9**



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 assembling milestones 2022-2023

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 arrives 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 tests
8.	Nov.-Dec.	- Assembling Iron Yoke, Cryogenic platform and Cryostat. Vacuum test

Year 2022

9.	Jan. 17th-Apr. 30th	- Solenoid cooling down to Liquid Nitrogen temperature
10.	Jun. 30th	- Cryogenic infrastructure ready
11.	Jul.-Aug.	- Cooling down to Liquid Helium temperature
12.	Sep.-Oct.	- Magnetic Field measurement
13.	Nov.	- Support Frame Installation, Mounting of the Moving Platforms
14.	Dec.	- Installation of ECal half-sectors

Year 2023

15.	Jan.	- Installation of TOF modules
16.	Feb.	- TPC installation
17.	Mar.	- Mounting of the Electronics Platform
18.	Apr.	- Cabling
19.	May	- Installation of beam pipe, FHCal, Cosmic Ray test system
20.	Jun.-Jul.	- Switch-on of the MPD, Commissioning

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

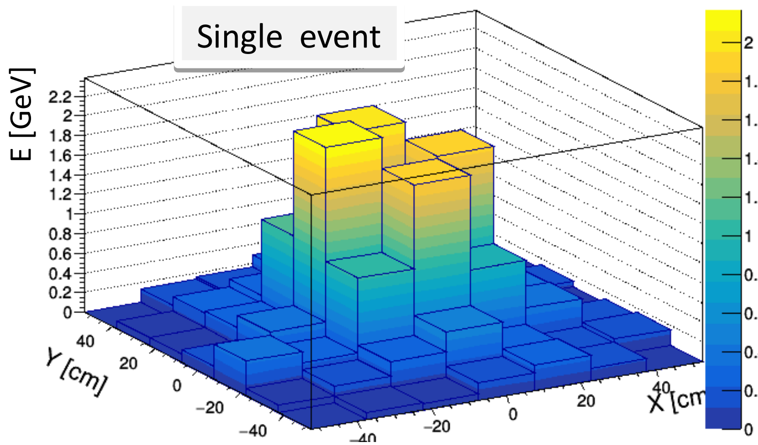
Wangmei Zha, A. Zinchenko

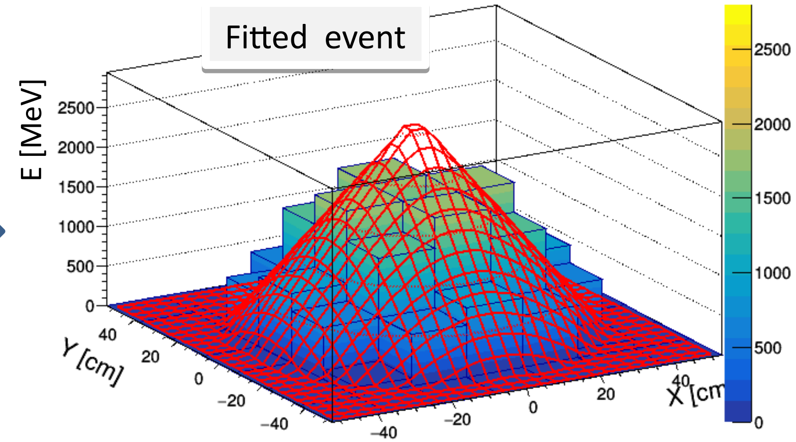
Heavy flavor

- 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

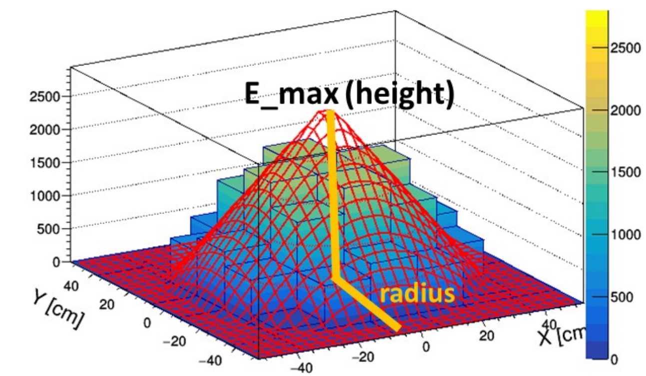
Centrality and reaction plane in FHCal

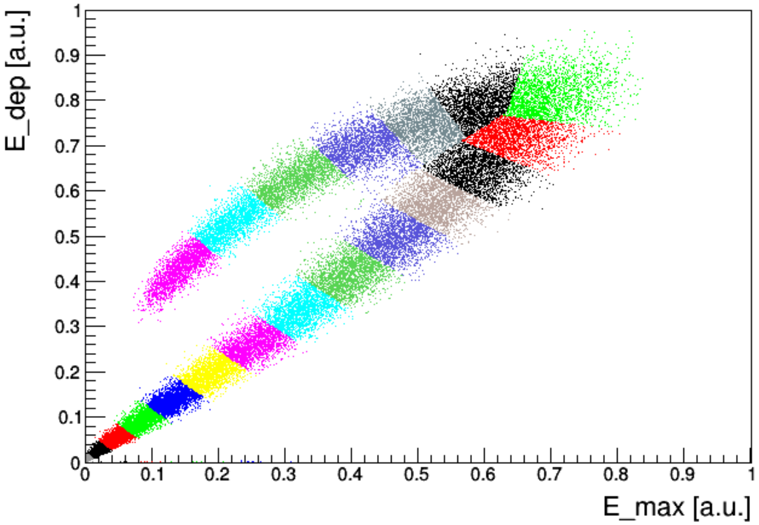
Energy distribution in FHCal modules



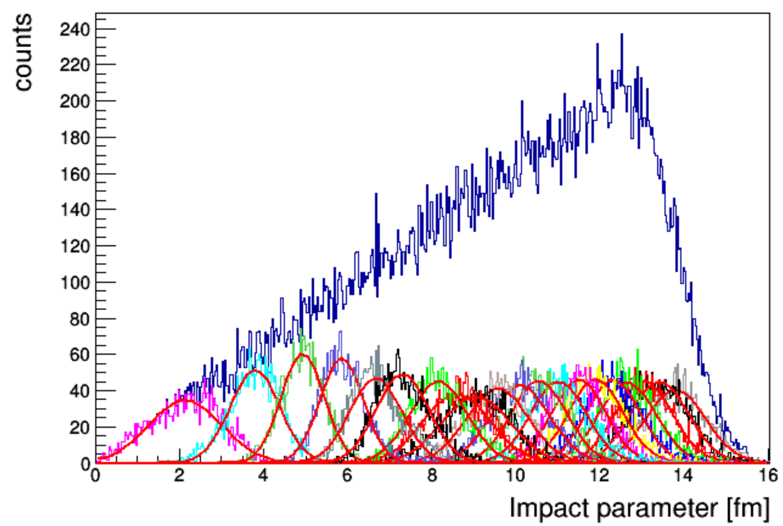


Initially we have experimental energy deposition E_{dep} in FHCal.

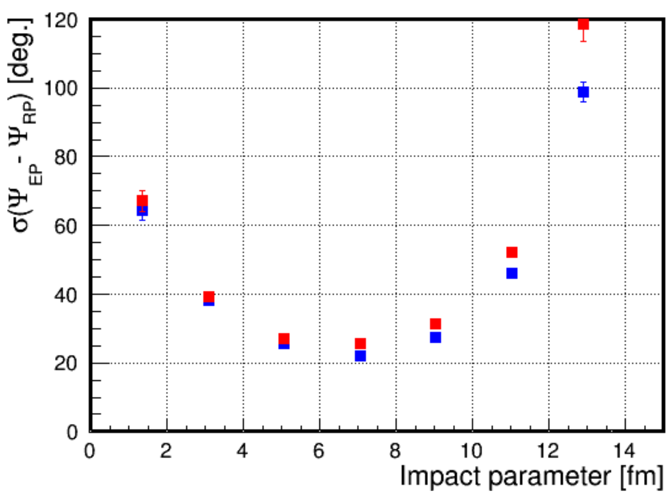




Each color bin is 5% fractions of the total number of events.



Centrality resolution

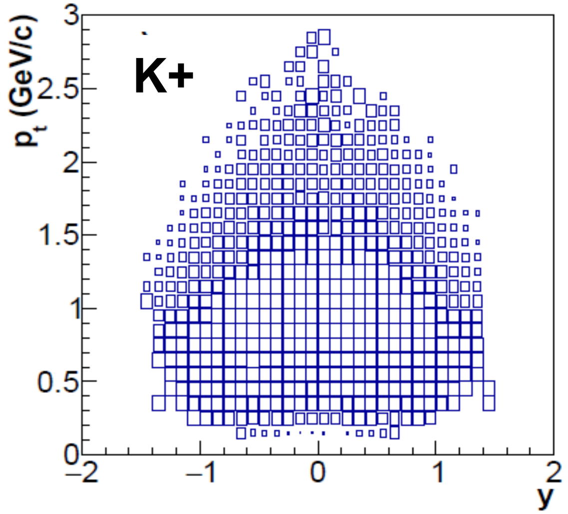


Reaction plane resolution

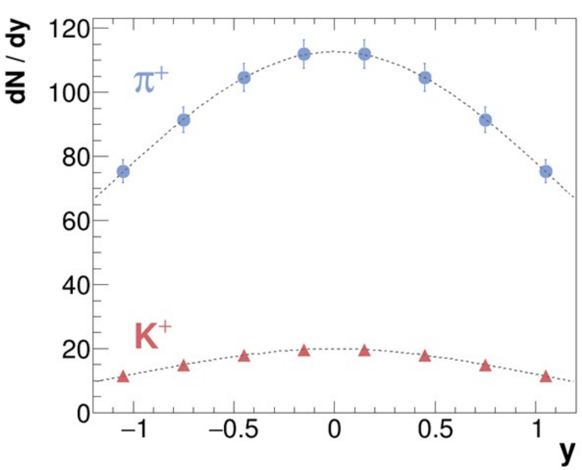
Hadroproduction with MPD

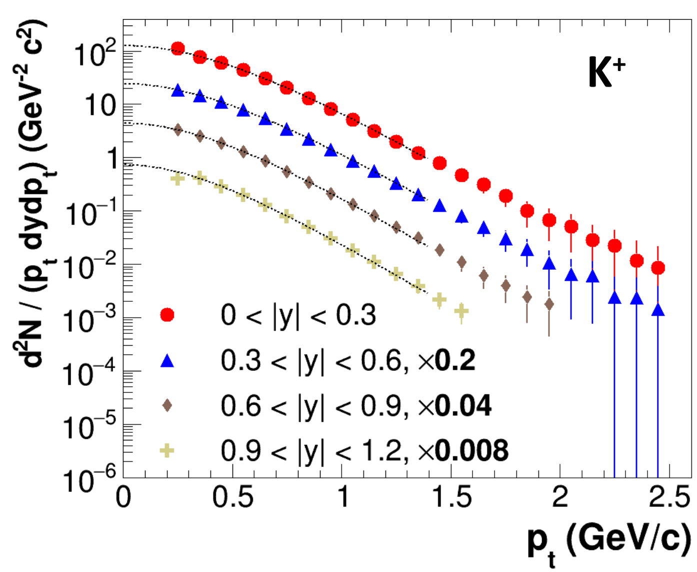
- **Particle spectra, yields & ratios are sensitive to bulk fireball properties and phase transformations in the medium**
- **Uniform acceptance and large phase coverage are crucial for precise mapping of the QCD phase diagram**

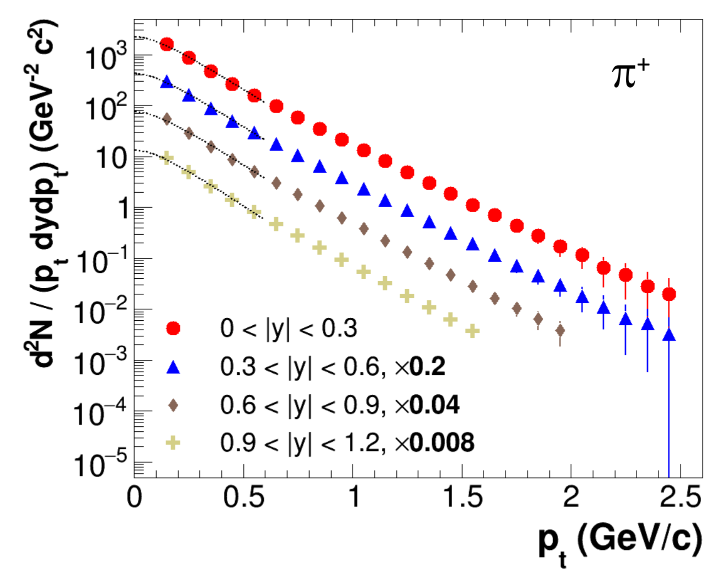
✓ *0-5% central Au+Au at 9 GeV from the PHSD event generator, which implements partonic phase and CSR effects*
✓ *Recent reconstruction chain, combined dE/dx+TOF particle ID, spectra analysis*



- 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)

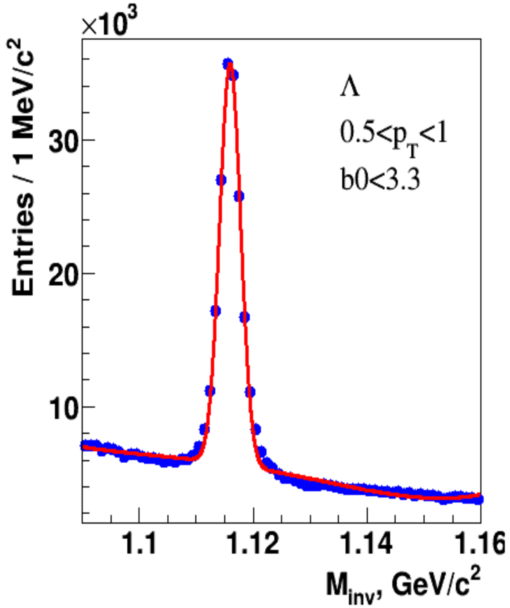


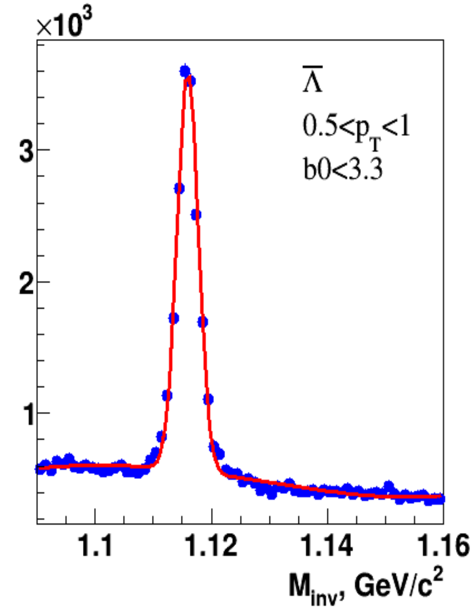


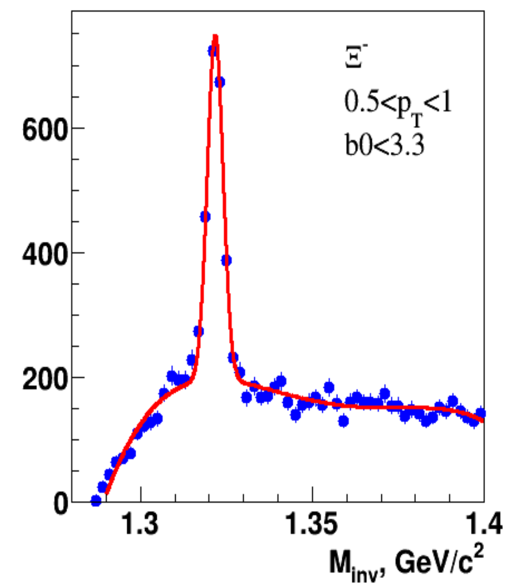


Strange and multi-strange baryons

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





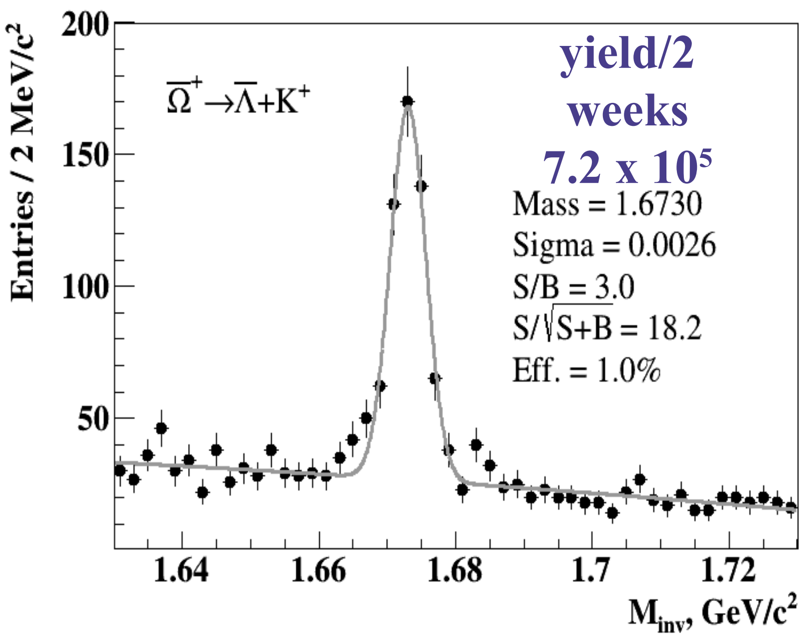


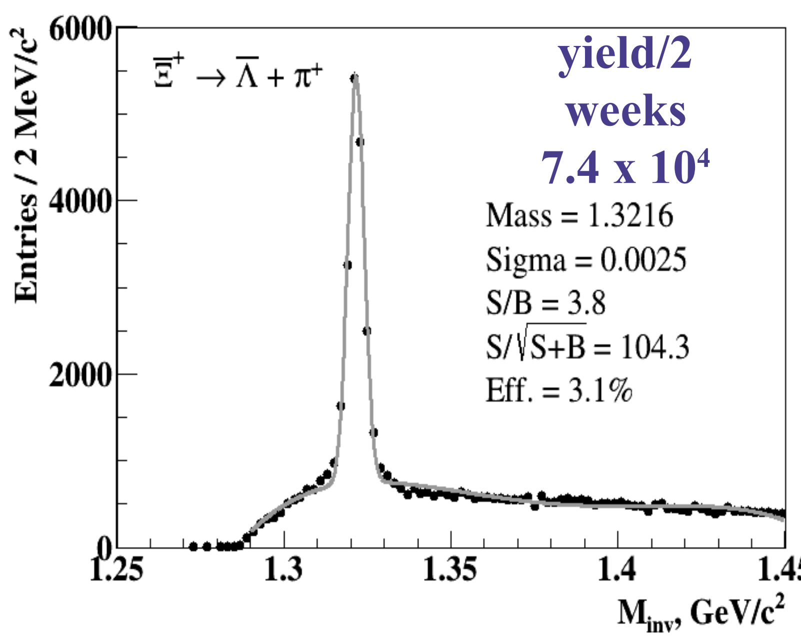
Detailed p_T spectra for hyperons in multiple centrality intervals

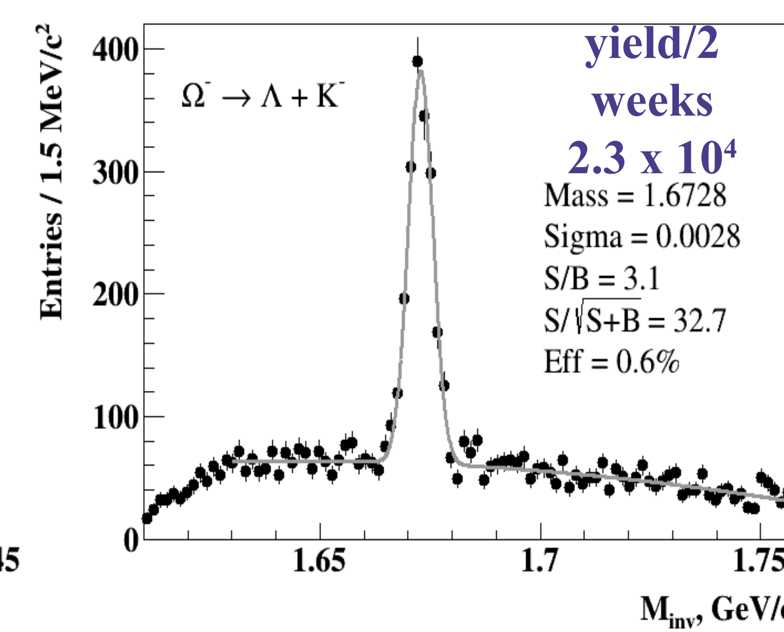
Large and consistent acceptance

Clean signal enhanced by good PID

Significant yield of rare hyperons



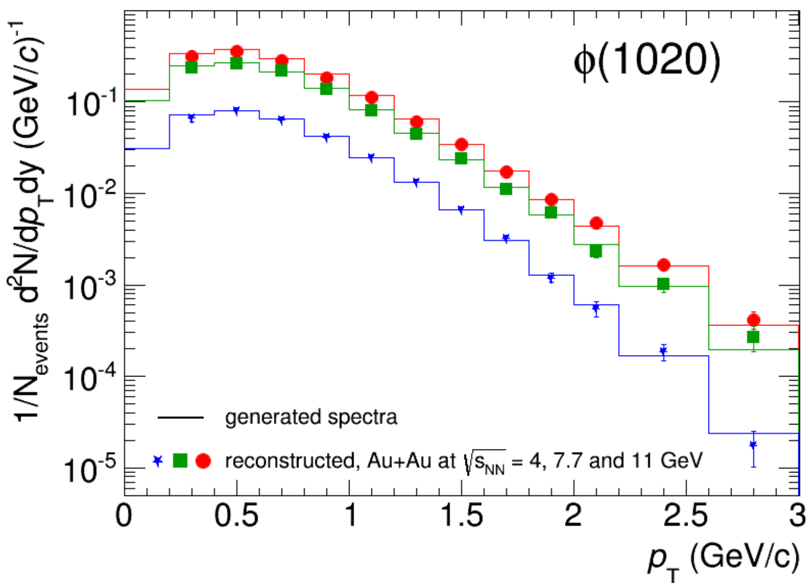




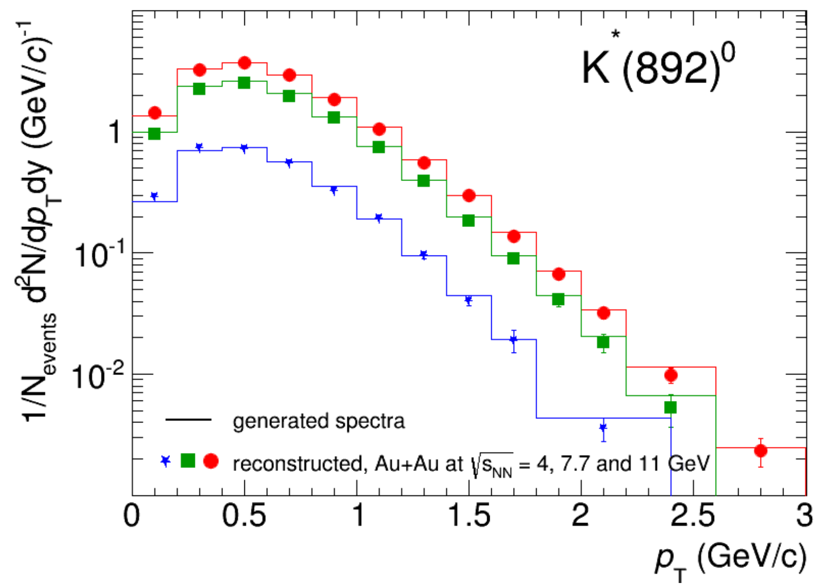
Resonances at MPD

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

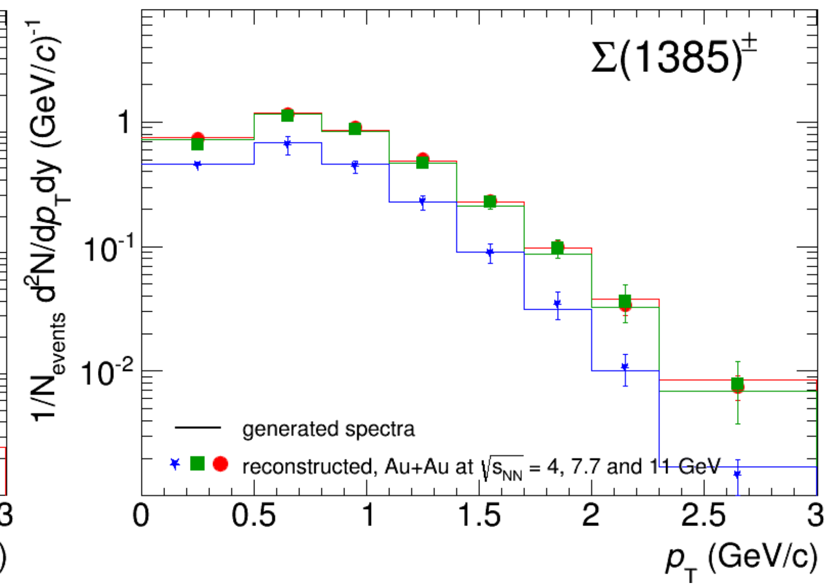
$\phi(1020) \rightarrow K^+K^-$



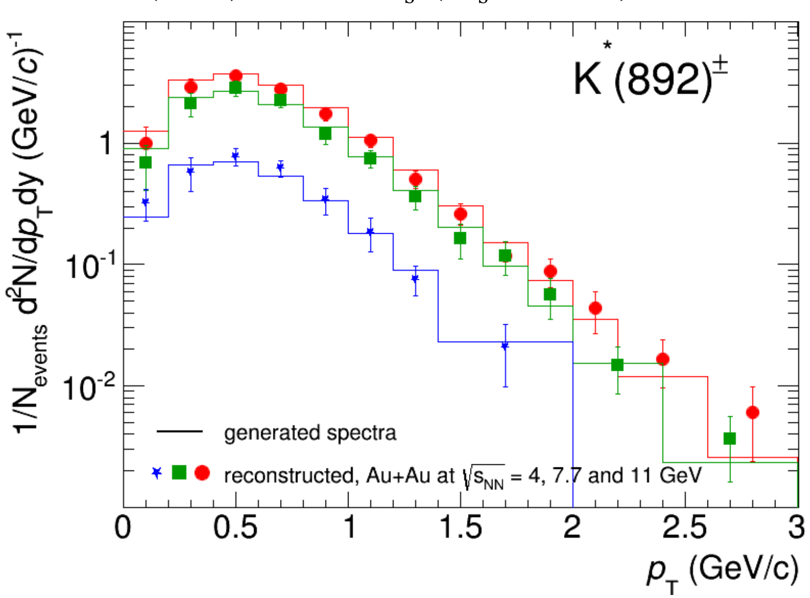
$K^*(892)^0 \rightarrow K^{\pm}\pi^{\pm}$



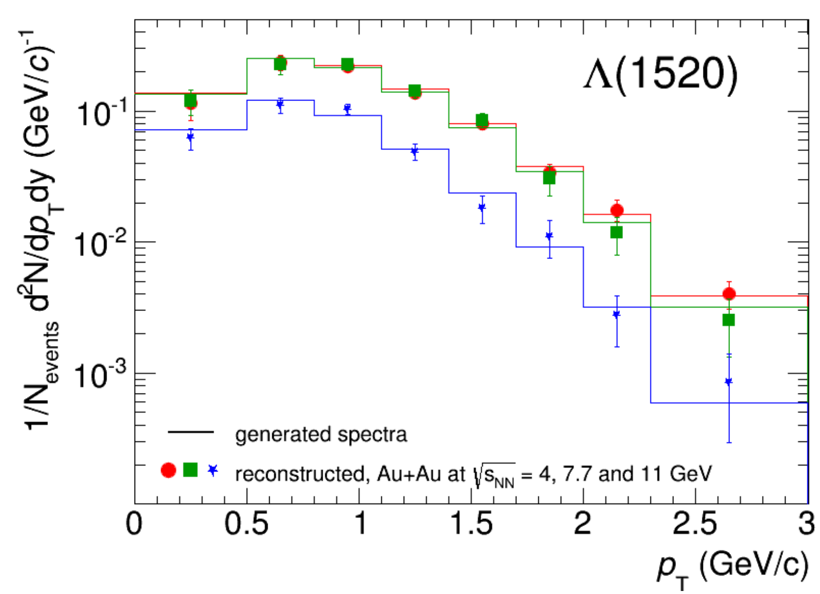
$\Sigma(1385)^{\pm} \rightarrow \pi^{\pm}\Lambda$ ($\Lambda \rightarrow p\pi$)



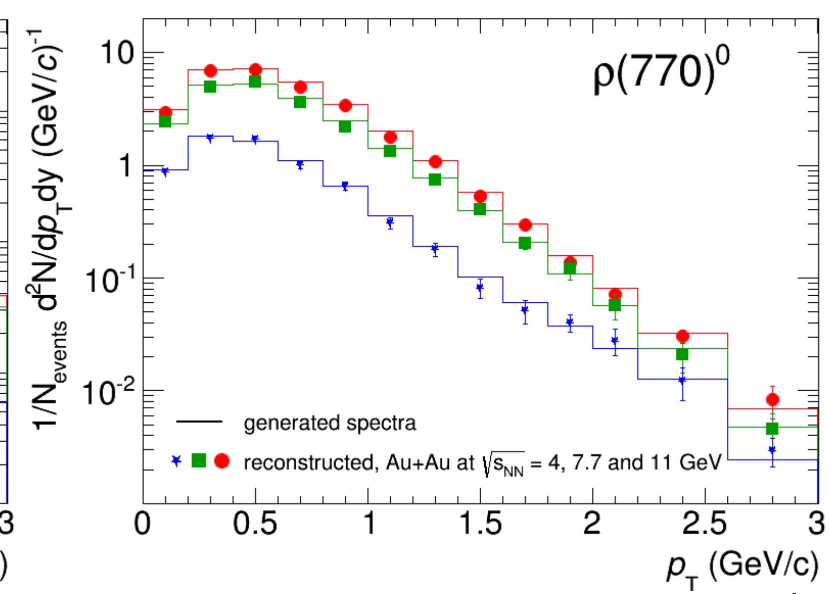
$K^*(892)^{\pm} \rightarrow \pi^{\pm}K_s$ ($K_s \rightarrow \pi^+\pi^+$)



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

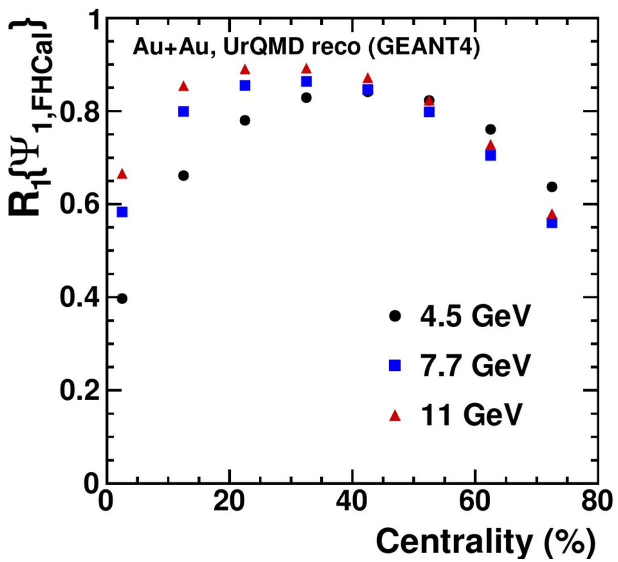


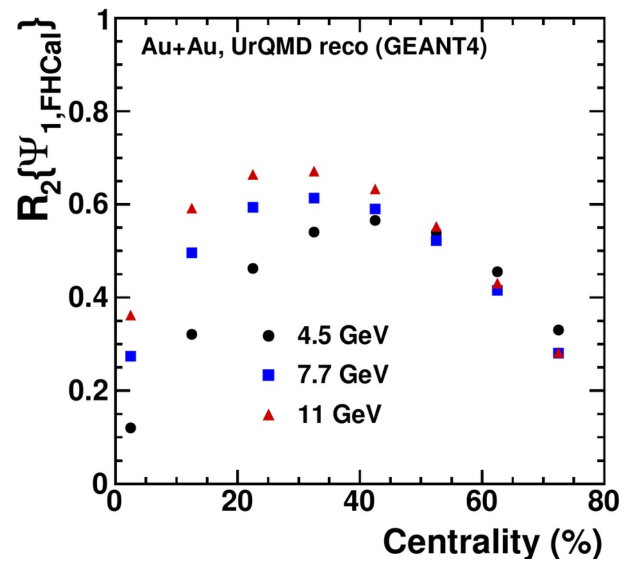
$\rho(770)^0 \rightarrow \pi^{\pm}\pi^{\pm}$

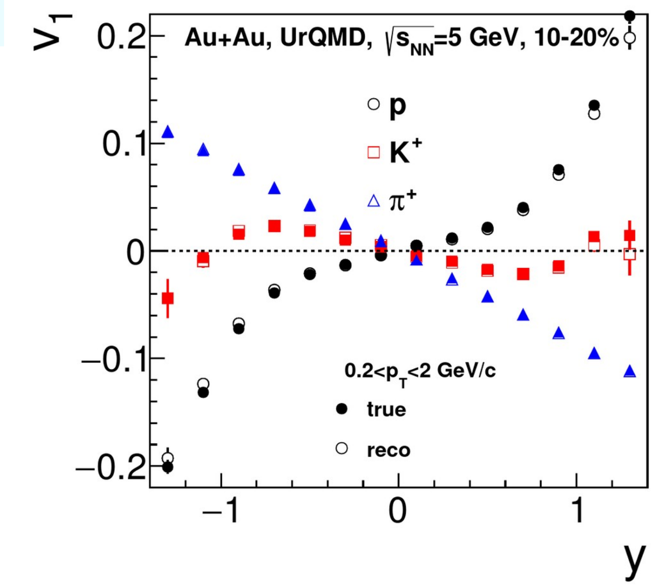


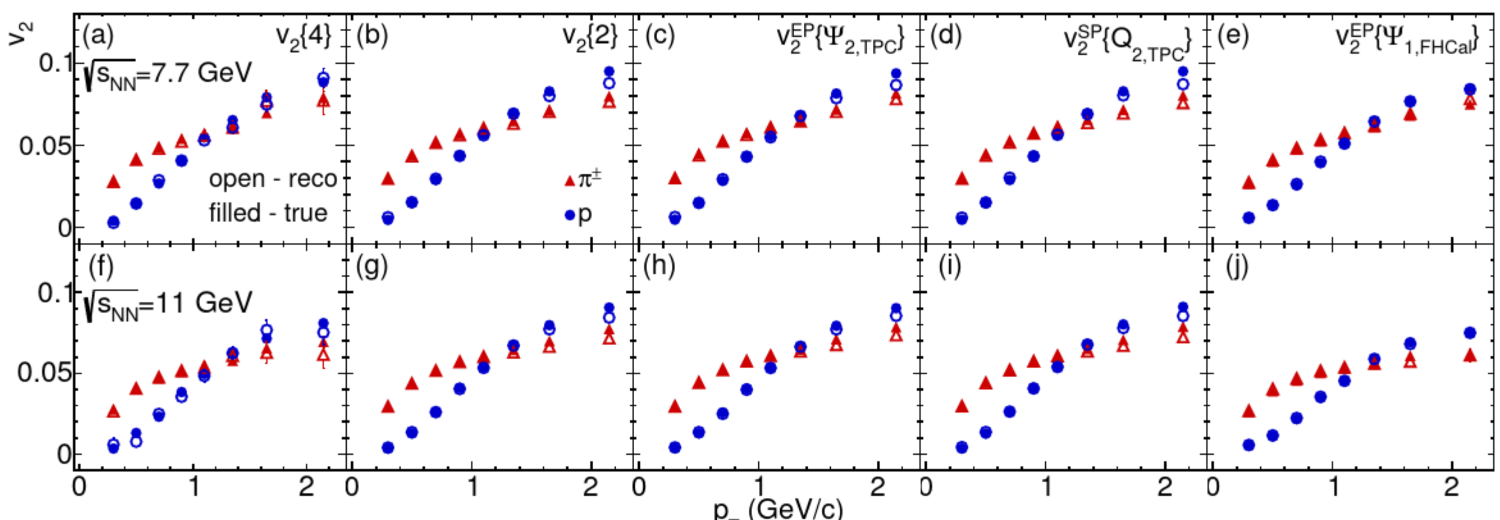
Performance of collective flow studies

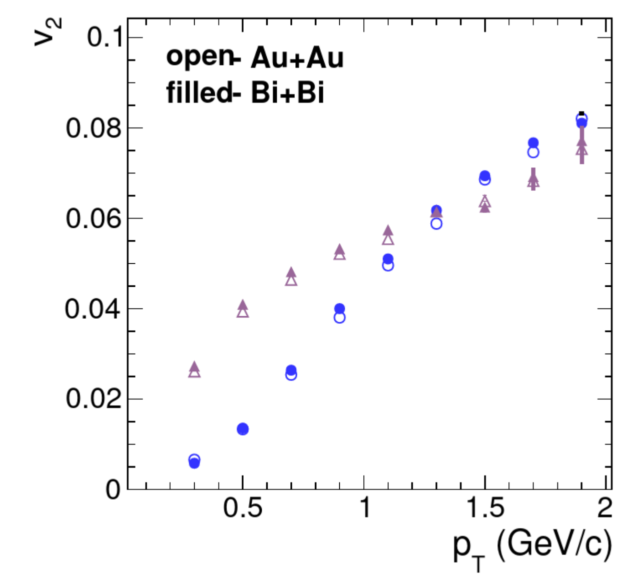
Au+Au, $\sqrt{s_{NN}}$ = 4.5, 7.7, 11 GeV, UrQMD, GEANT4 + MPDRoot reco.







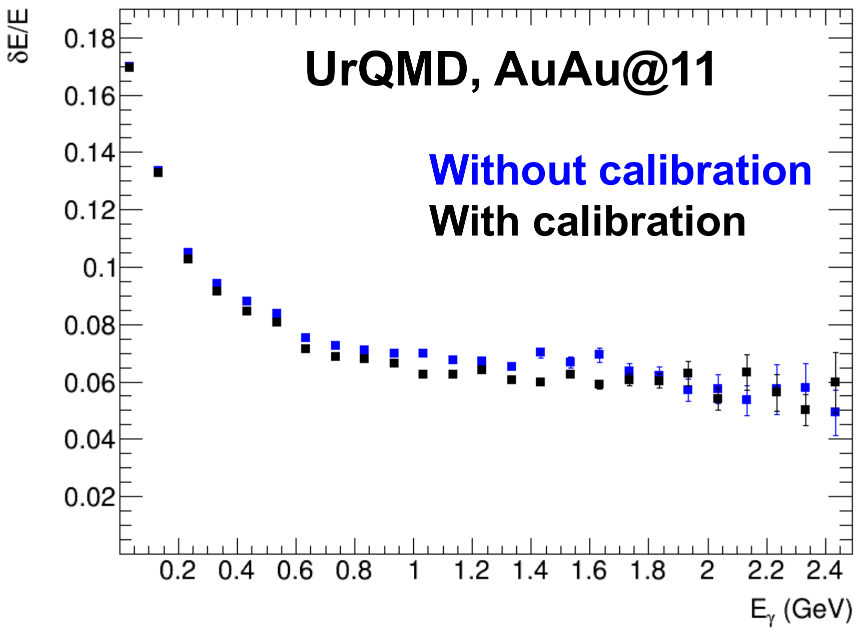


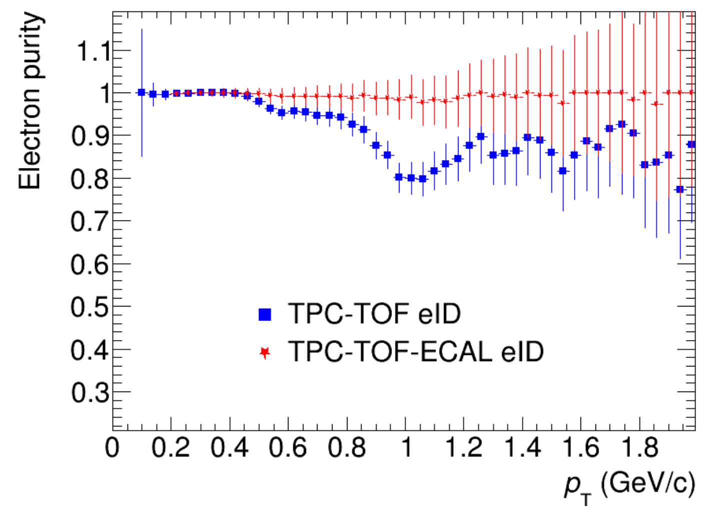


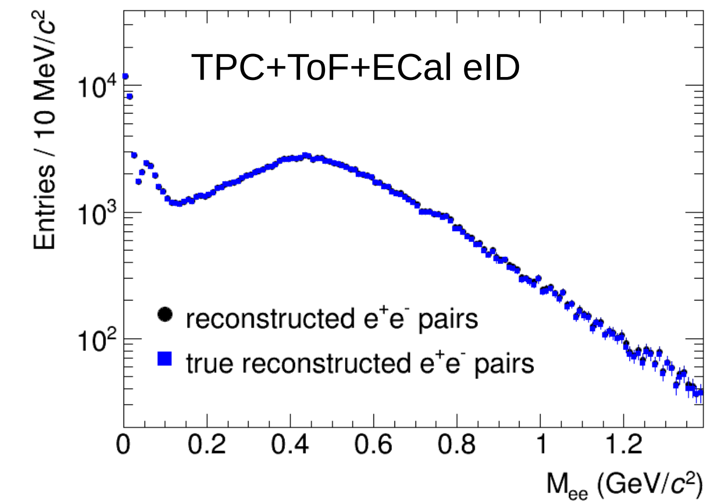
Collective flows a unique and direct way to probe EOS of QCD matter. Excellent flow measurement capabilities in MPD

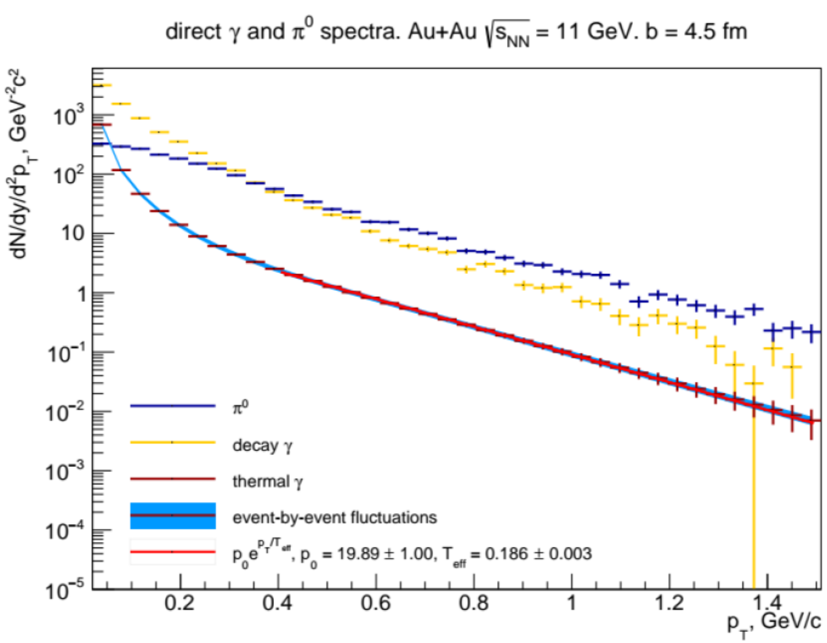
Electromagnetic probes in ECAL

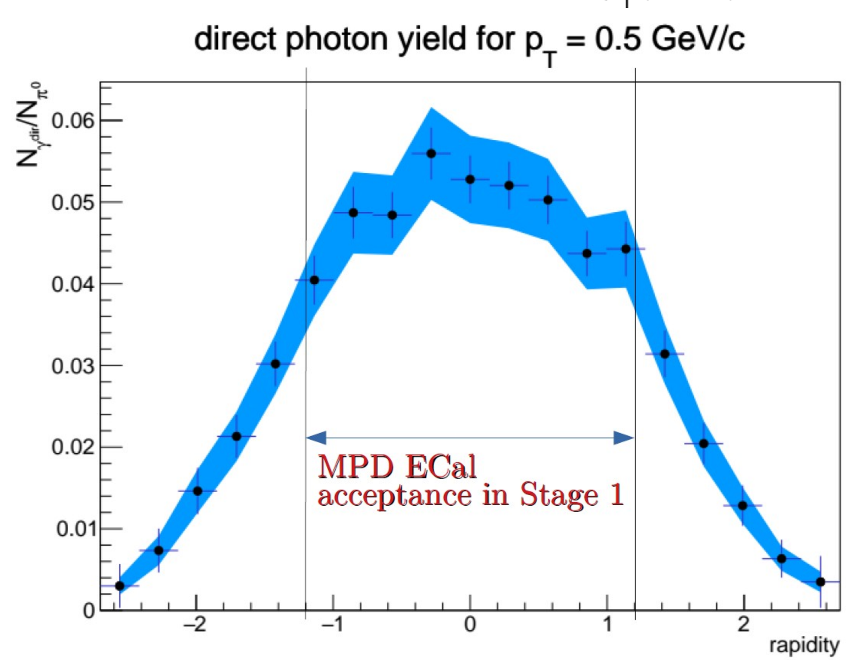
- Realistic ECAL reconstruction & analysis – large acceptance ECAL with good energy resolution: ideal tool for measurement of neutral mesons in a wide momentum range









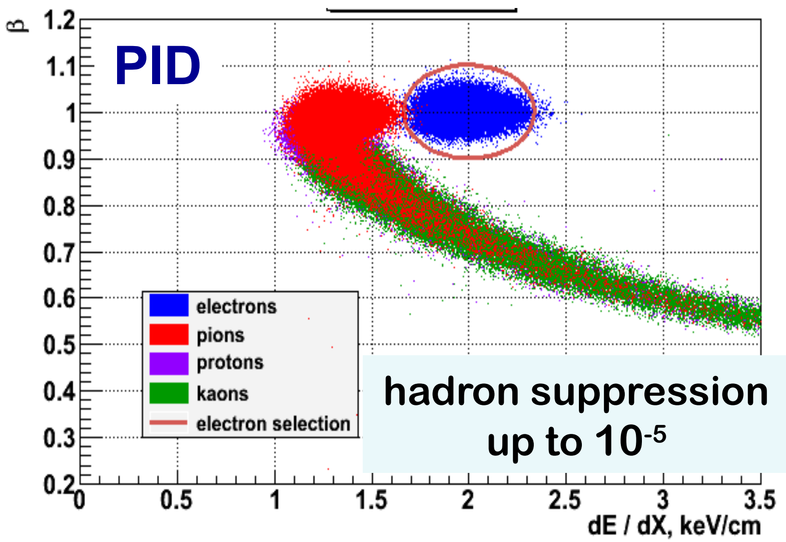


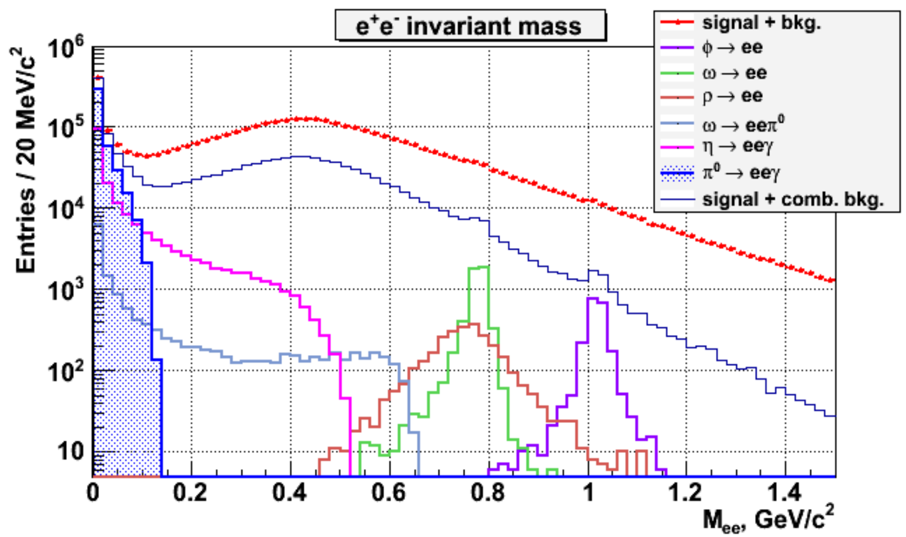
- Important feasibility cross-checks for di-leptons

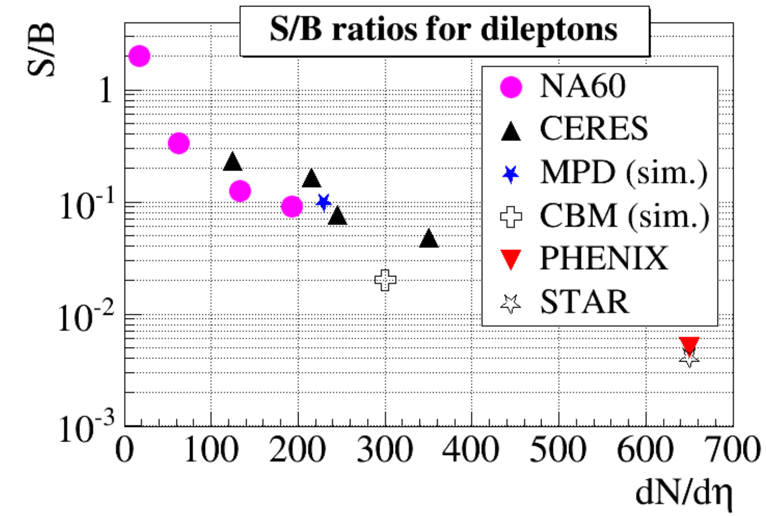
- Promising feasibility studies for prompt photon measurements in MPD

Prospects of dilepton studies

- **Event generator:** *UrQMD+Pluto (for the cocktail) central Au+Au @ 8 GeV*
- **PID**: *dE/dx (from TPC) + TOF (σ ~100 ps) + ECAL*

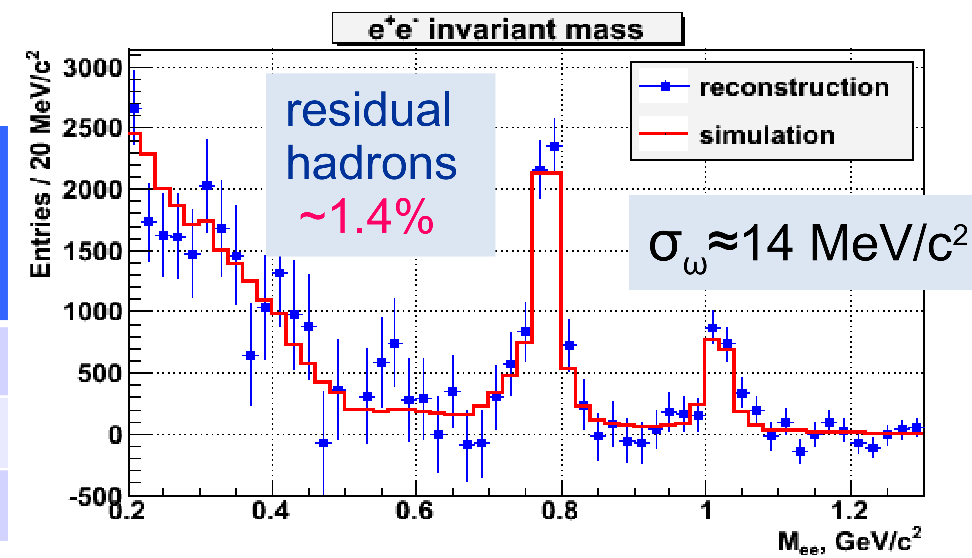






Yields, central Au+Au at $\sqrt{s_{NN}}$ = 8.8 GeV

Particle	Yields 4π	Yields y=0	Decay mode	BR	Effic. %	Yield /1 w
ρ	31	17	e+e-	$4.7 \cdot 10^{-5}$	35	$7.3 \cdot 10^4$
ω	20	11	e+e-	$7.1 \cdot 10^{-5}$	35	$7.2 \cdot 10^4$
φ	2.6	1.2	e+e-	$3 \cdot 10^{-4}$	35	$1.7 \cdot 10^4$



Summary

- The NICA Complex advanced in construction with important milestones achieved and clear plans for 2021 and 2022
- All components of MPD 1st stage in production
- Broad MPD Physics program with initial NICA beams
- International collaboration to carry out complete QCD phase diagram investigation for at least another decade