Nuclotron based Ion Colider fAcility

MPD Collaboration Status

V. Riabov for the MPD Collaboration

Force Majeure Situation

- Situation in Ukraine significantly impacted the MPD collaboration and JINR:
  - ✓ suspension of collaboration with JINR from Germany
  - ✓ suspension of collaboration by decision of Polish and Czech Republic institutions (impacts MPD directly)
  - ✓ suspension of JINR-CERN cooperation (shipment of equipment and materials from CERN to Russia and from Russia to CERN, participation of CERN scientists in all scientific committees, engagement in new projects, JINR Observer status are suspended)
- Sanctions affect supplies of many components for MPD, most of communications with western companies are frozen. However, many contractors are interested to continue cooperation with JINR. A new logistics has to be figured out to carry out the works according to contracts. Problems exist mainly with electronics and cryogenic systems for the solenoid preparation for cooling
- Suspension of participation by Polish/Czech institutions results in shortage of technical specialists. A major problem is with technical staff from WTU who participated in construction of the electronics platform. Nevertheless, a new group has been formed
- ASG broke the contract. MPD takes responsibility of the magnet
- Problems with delivery from CERN of tooling for magnetic field measurements
- Impact and consequences are being continuously assessed in JINR/MPD

Extraordinary IB Meeting MPD

- Took place on April, 4
- Members of the suspended member institutions are cut off of the mailing lists and computing infrastructure:
  1) Nuclear Physics Institute CAS, CZECH Republic
  2) Jan Kochanowski University, POLAND
  3) University of Warsaw
  4) University of Wroclaw, POLAND
  5) Warsaw University of Technology, Warsaw, POLAND
  6) Institute of Nuclear Physics PAS, Kraków, POLAND
  7) University of Silesia, Katowice, POLAND

MPD assembling milestones and plans

❖ Latest estimates provided by V. Golovatyuk (subject to change)

Year 2021

6. July-Aug - Solenoid installation into Iron Yoke and alignment
7. Aug - Dec - Electrical, pressure and vacuum tests

Year 2022

8. April 30 - Cables for Solenoid probes signals are installed. Ready for assembling of Iron Yoke
9. Apr 30 - June 15 - Assembling Iron yoke, Cryogenic platform and Cryostat. Vacuum test
10. June 16t - July 30 - Solenoid cooling down to Liquid Nitrogen temperature
11. September 30th - Cryogenic infrastructure ready
12. Oct 1st - Nov 20 - Cooling down to LHe temperature
13. Nov 20th – Dec 30. - Magnetic Field measurement

Year 2023

14. Jan 20 -Feb 15 - Support Frame installation. Moving Platforms mounting
15. Feb 15th – April 10th - Installation of ECal half sectors
16. March-July - Electronics Platform assembling.
17. April-July - Cabling
18. April 1 – June 5th - Installation TOF modules
19. May15st – August 1st - TPC installation
20. June-July - - FHCal. Cosmic Ray test system
21. August - Switch on the MPD. Commissioning

Multi-Purpose Detector (MPD) Collaboration

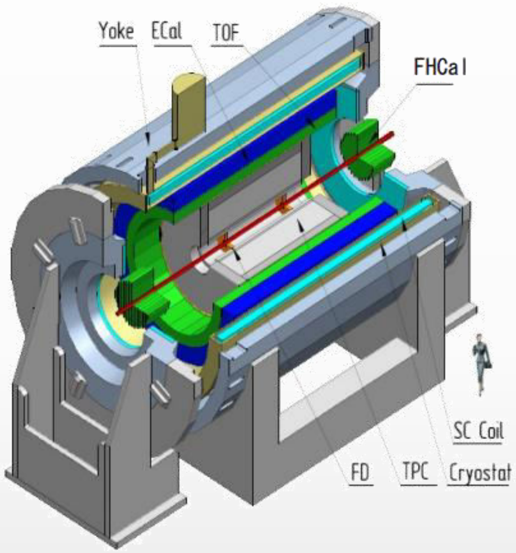
MPD *International Collaboration established in* ***2018*** *to construct, commission and operate the detector*

9 *Countries,* ***>450*** *participants,*
30 *Institutes and* ***JINR***

Acting Spokesperson: ***Victor Riabov***
Inst. Board Chair: ***Alejandro Ayala***
Project Manager: ***Slava Golovatyuk***

Deputy Spokespersons:
Zebo Tang

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****;*



Joint Institute for Nuclear Research*;*
AANL, Yerevan, ***Armenia;***
Baku State University, NNRC, ***Azerbaijan****;*
University of Plovdiv, ***Bulgaria;***
University Tecnica Federico Santa Maria, Valparaiso, ***Chile****;*
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****;*

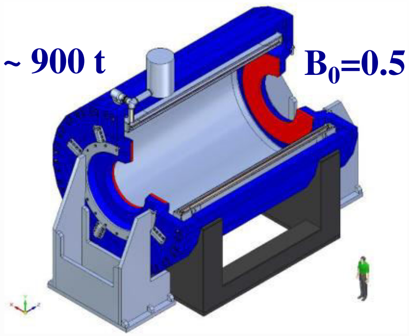
FCFM-BUAP (Heber Zepeda) Puebla, ***Mexico****;*
FC-UCOL (Maria Elena Tejeda), Colima, ***Mexico****;*
FCFM-UAS (Isabel Dominguez), Culiacán, ***Mexico****;*
ICN-UNAM (Alejandro Ayala), Mexico City, ***Mexico****;*
Institute of Applied Physics, Chisinev, ***Moldova****;*
Belgorod National Research University, ***Russia****;*
INR RAS, Moscow, ***Russia****;*
MEPhI, Moscow, ***Russia****;*
Moscow Institute of Science and Technology, ***Russia****;*
North Osetian State University, ***Russia****;*
NRC Kurchatov Institute, ITEP, ***Russia****;*
Kurchatov Institute, Moscow, ***Russia****;*
St. Petersburg State University, ***Russia;***
SINP, Moscow, ***Russia****;*
*PNPI, Gatchina****, Russia****;*

Access to computing infrastructure

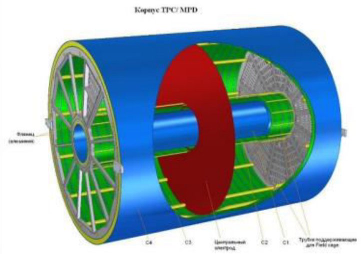
- Due to numerous hacker attacks, access to JINR computing resources (NICA cluster, LIT, etc.) was limited to internal network. Access to collaboration web sites (mpd.jinr.ru, mpdforum.jinr.ru, etc.) from outside was intermittent in the last weeks
- For full access to these resources from outside users are required to register and use VPN connection
- IB representatives were contacted and asked to provide a list of people from their institutions who would need to register and setup the VPN connection
- If for some reason this information was not relayed to you and you need the access please contact me and/or Natalia providing your name, username and e-mail address
- JINR computing infrastructure is running and is ready to provide services to MPD users
- Special thanks to NICA cluster administrators who made operation of this centralized computing resource stable and convenient in the last months

MPD subsystems in production

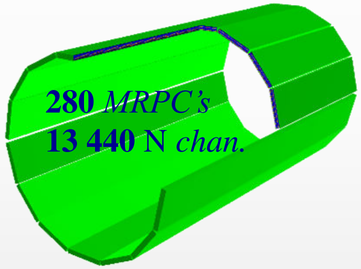
SC Solenoid + Iron Yoke



TPC – central tracking detector



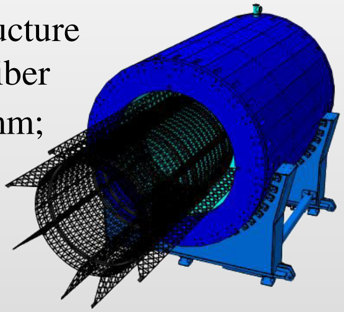
TOF



Support structure

support structure of carbon fiber

sagite ~ **5** mm;
0,13 X_0



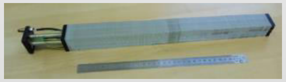
ECAL ~ 100 t

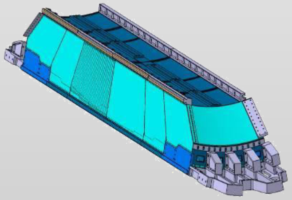
ECAL

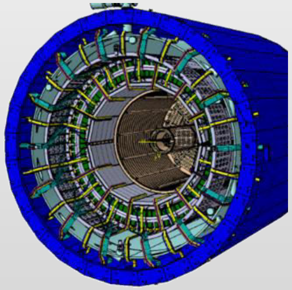
Pb+Sc "shashlyk"

38 400 towers

70% sectors in production for Stage I







*** Excursion to the MPD Hall on Tuesday morning**
**** See subsystem reports for details**

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

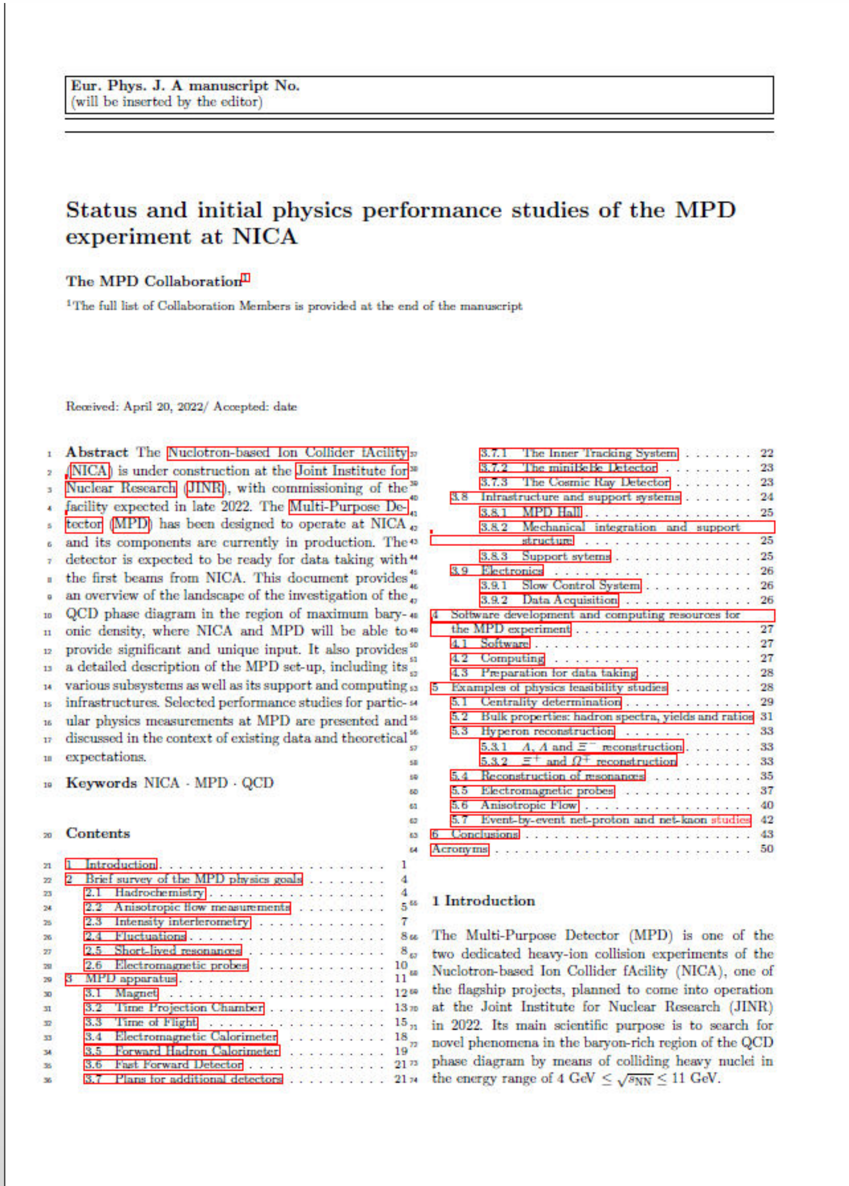
Wangmei Zha, A. Zinchenko

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

Move to cross-PWG format of meetings
See PWG1-PWG5 status reports on Wednesday

MPD Status and Performance Paper



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

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1 Introduction

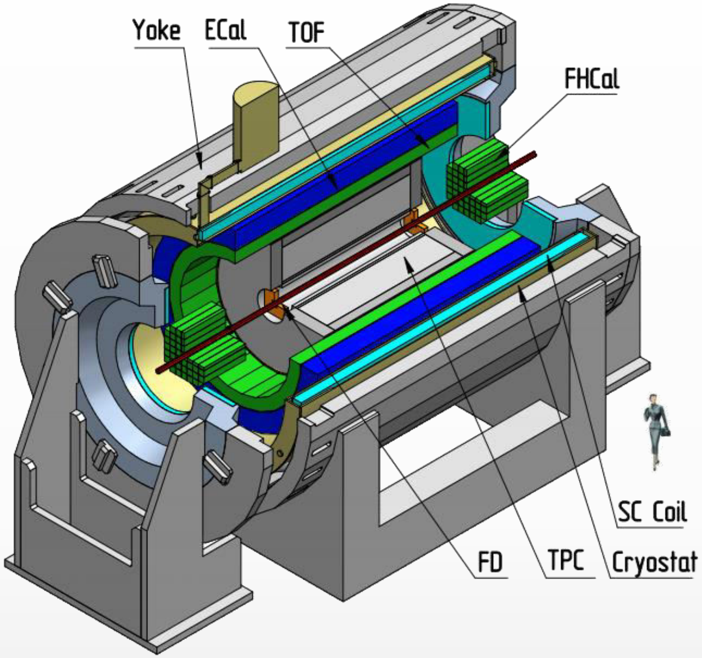
The Multi-Purpose Detector (MPD) is one of the two dedicated heavy-ion collision experiments of the Nuclotron-based Ion Collider fAcility (NICA), one of the flagship projects, planned to come into operation at the Joint Institute for Nuclear Research (JINR) in 2022. Its main scientific purpose is to 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.

- Editorial Committee: A. Ayala, D. Blaschke, S. Golovatyuk, A. Kisiel, V. Kolesnikov, V. Riabov, O. Rogachevsky, A. Taranenko
- IRC: I. Tserruya (chair), F. Wang, Z. Tang
- The paper reports status of the MPD detector and selected results of physics feasibility studies that demonstrate capabilities of the detector
- Received the referee reports from EPJA. Overall the reports are positive and only some small changes of the text and figures are requested
- EB has addressed the comments and IRC has approved the replies
- The paper draft is currently in collaboration review
- The deadline for resubmission is May, 8
- Alejandro Ayala is a contact person for communication with the journal
- No known cases of authorship withdrawal so far (paper was written before Feb, 24)

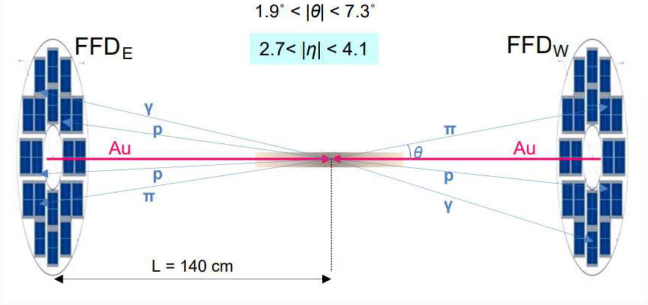
MPD Physics Performance Paper (№2)

- The first collaboration paper is nearly published
- Start preparations for a new paper - MPD physics performance on the first beams
- The idea is to publish a paper before the first data comes to provide expectations for the first beam results and to guide the experimental program:
  - ✓ up-to-date detector performance based on the beam test results and Monte Carlo simulations
  - ✓ feasibility studies with event generators, which account for recent theoretical developments
  - ✓ minimization of the number of event generators for different observables
- Need a solid guidance from Accelerator Department on the first beam configuration (species, energy, luminosity, vertex, etc.) to plan the observables for the first physics
- Coordination of topics, simulations and feasibility studies is on the Physics Council and PWG conveners

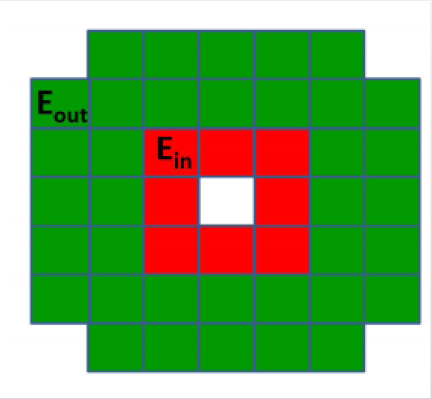
Trigger system



- FFD (Fast Forward Detector):
  - ✓ fast event triggering
  - ✓ T_0 for time measurements in the TOF and ECAL



- FHCAL (Forward Hadron Calorimeter) – detector for event centrality and reaction plane measurements with potential for event triggering



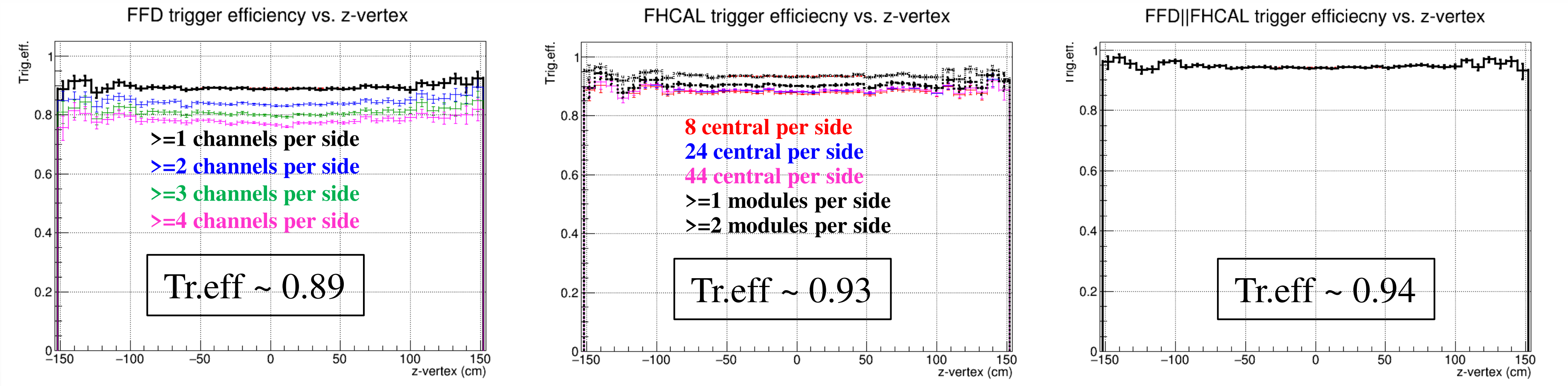
$2 < |\eta| < 5$

~ 1x1 m^2

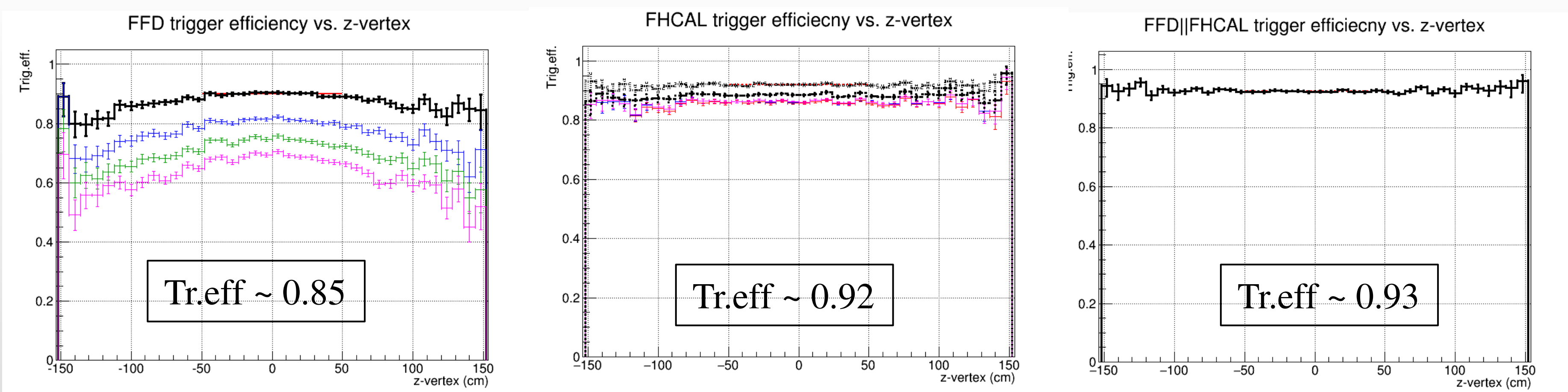
- MPD challenges at NICA energies:
  - ✓ low multiplicity of particles produced in heavy-ion collisions
  - ✓ particles are not ultra-relativistic (even the spectator protons)

Trigger efficiency vs. z-vertex

DCM-QGSM-SMM, BiBi@9.2



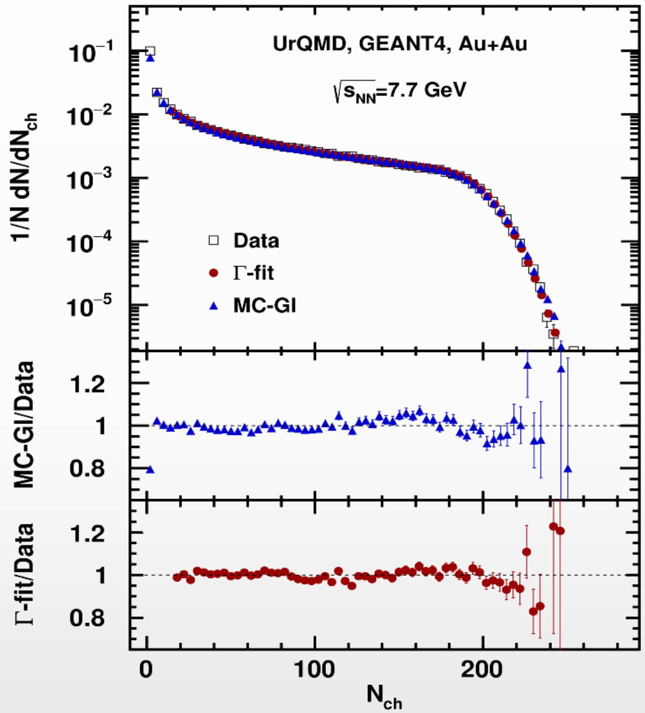
PHQMD, BiBi@9.2

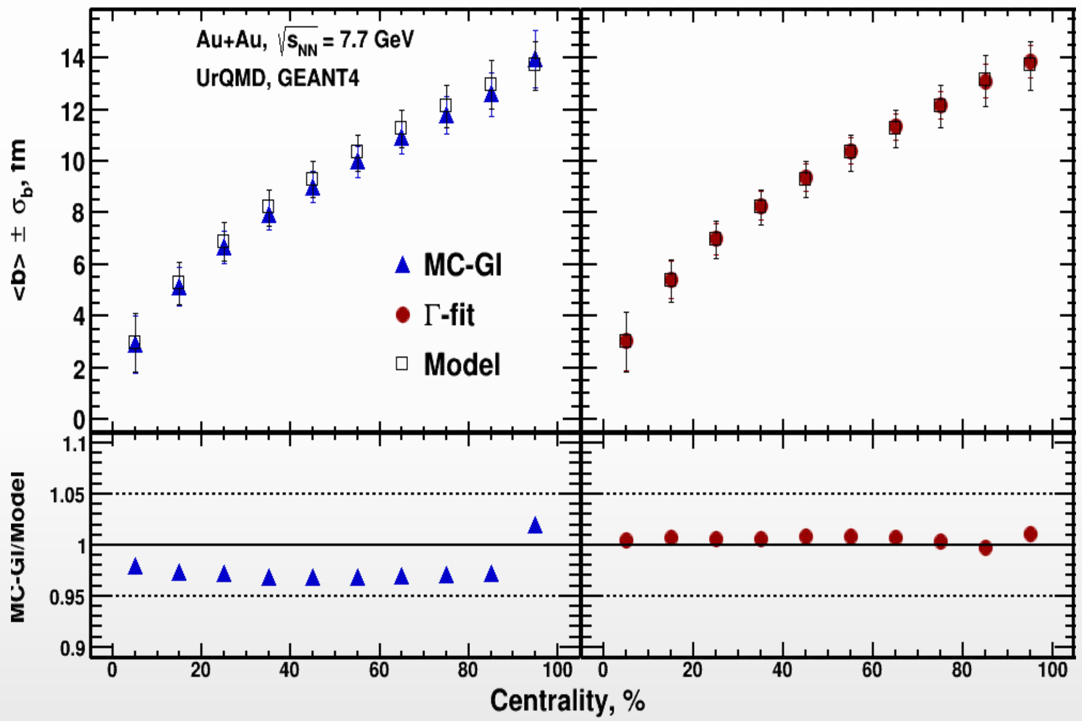


- Efficiency is 80-95% in different trigger configuration; approximately the same numbers for two generators
- FFD efficiency shows z-vertex dependence for PHQMD; FHCAL and FFD||FHCAL does not
- Need full understanding of the trigger system and trigger logic for physics studies !!!

Centrality studies by TPC

- AuAu@7.7 GeV (UrQMD), reconstructed data
- **MC Glauber (MC-Gl)** and **Bayesian inversion method (Γ-fit)** methods for extraction of b

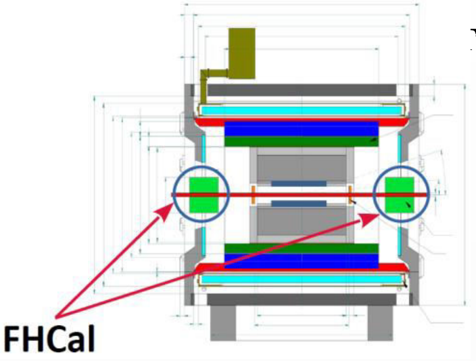




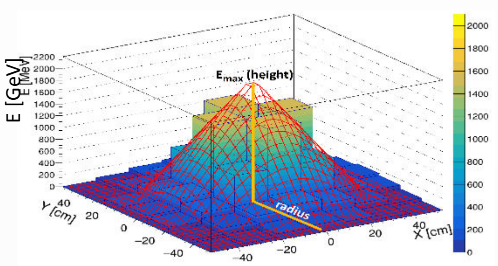
- Comparable results with PHSD and SMASH event generators at different energies → robust method
- Exact event/vertex and track selections, track efficiency corrections are subject of further studies
- Centrality estimation consistent with STAR → good for cross-checks between the experiments
- Centrality measurements are possible at |z-vertex| < 120 cm
- Centrality studies should be performed for the data sample accepted by the MPD trigger system !!!

Centrality by FHCAL

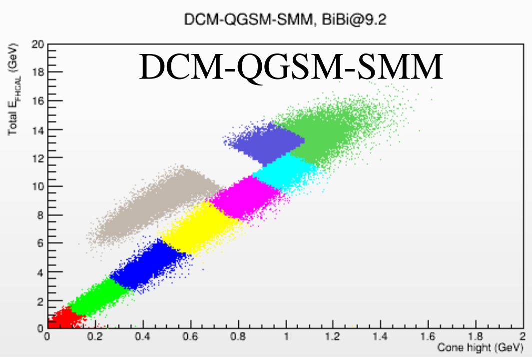
- FHCAL is a hadronic calorimeter, ~ 1 m^2, 44 towers by 15x15 cm^2, $2 < |\eta| < 5$

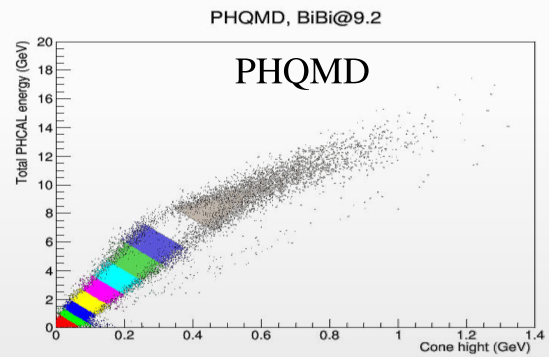


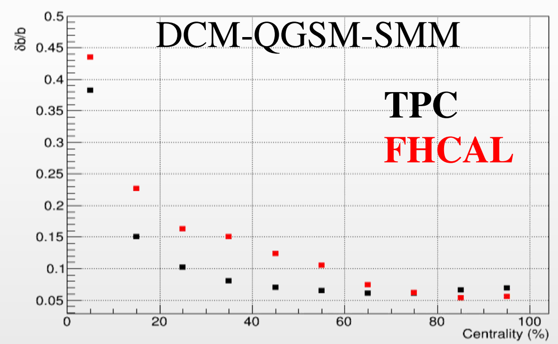
Two-dimensional fit of energy deposition

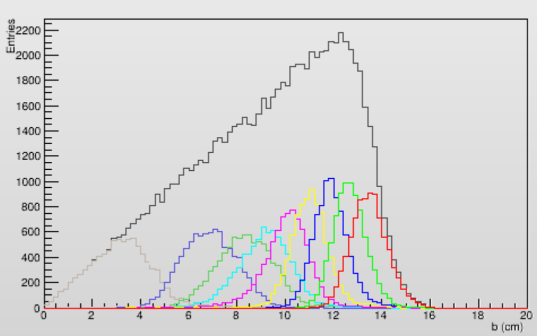


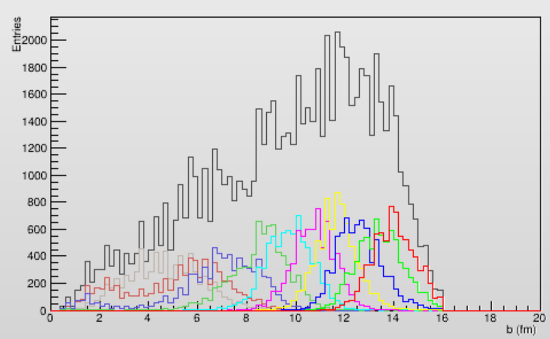
- Alternative centrality estimation at $|\eta| >> 1$
- Predictions are model dependent → model verification with experimental data (NA61 ???)
- Centrality is available for |z-vertex| < 100 cm
- Resolution is worse wrt to TPC in central collisions
- No framework to relate the initial Glauber parameters (b, N_{part}, N_{coll}) to the final state energy

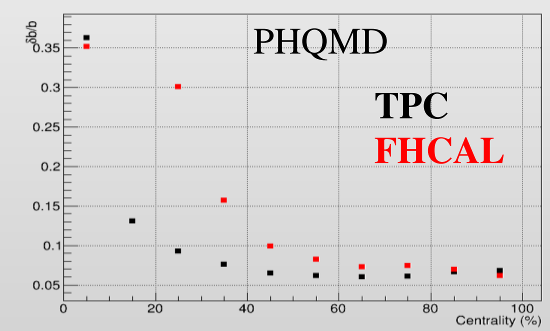






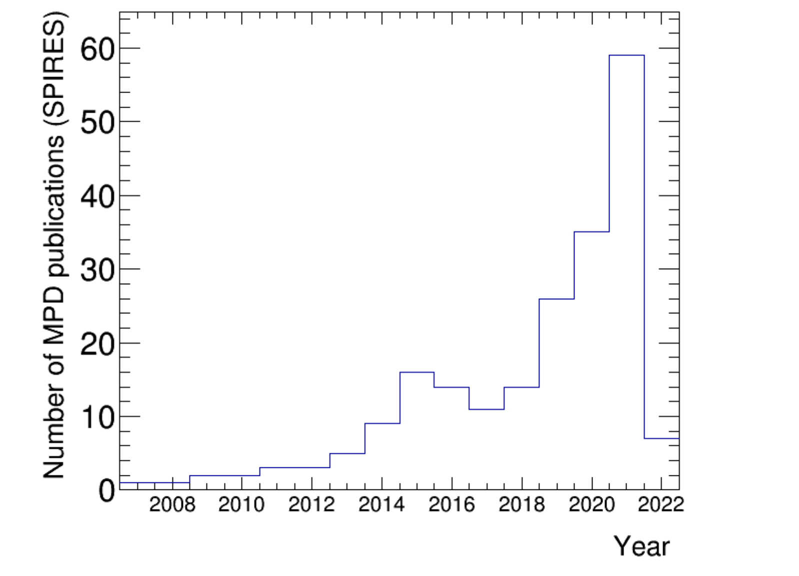






Collaboration activity

- ❖ Many new results and ongoing studies for different observables
- ❖ PWG summary and specific topic reports on Wednesday
- ❖ MPD publications (including proceedings): ~ 210 in total for hardware and physics studies



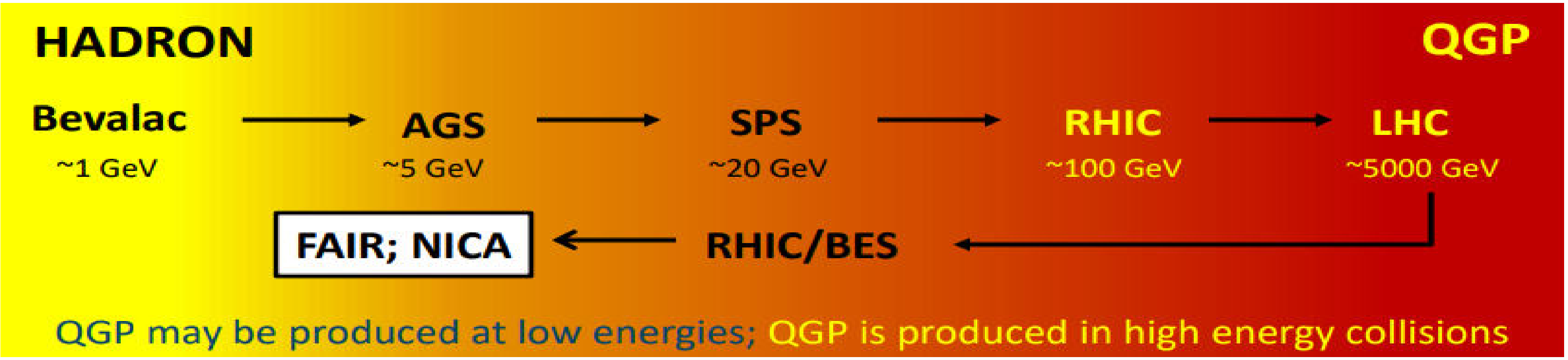
- ✓ In the last three years the number of collaboration talks at international conferences and the number of collaboration publications was sky-rocketing
- ✓ The exponential growth is due to a very successful RFBR grant program that supported participation of Russian scientists (including senior and young students) in the MPD-NICA
- ✓ Organization of the grant program might not be optimal, but its results are undeniable: many new researches were attracted to works on the MPD

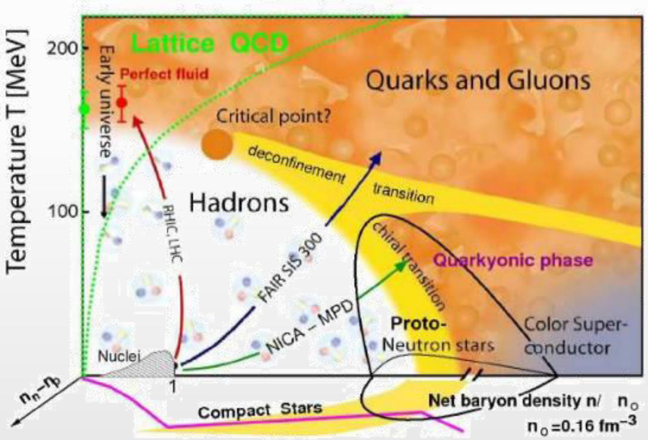
- ❖ The RFBR grant program is now over + suspension of collaboration members → expect a dramatic drop in collaboration activities, presence of collaboration at conferences, number of publications, number of active members
- ❖ The only possible solution is to find resources to support the working groups, to stimulate their participation in feasibility studies, shifts and data analysis → <u>topic of paramount importance for the collaboration</u>

Summary

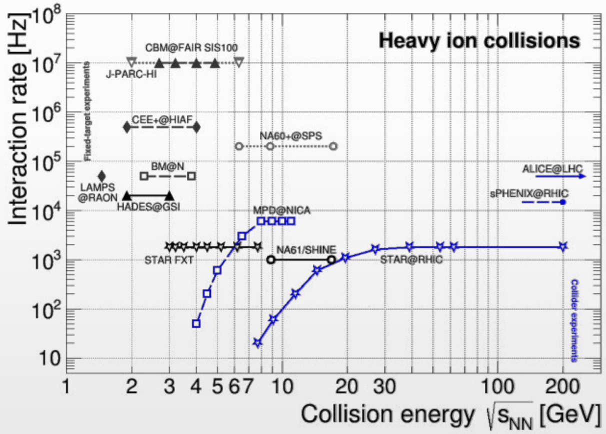
- We need a new collaboration photo in person. Hopefully it will become possible this year
- Preparation of the MPD detector and experimental program is ongoing, all activities are continued
- All components of the MPD 1-st stage detector are in advanced state of production
- Commissioning of the MPD Stage-I detector is expected in 2023
- Further program will be driven by the physics demands

Heavy-ion collisions





https://github.com/tgalatyuk/interaction_rate_facilities



- ❖ Study of the QCD medium at extreme net baryon densities, phase transition at $\rho_c \sim 5\rho_0$
- ❖ Studied in several ongoing and future experiments:
  - ✓ collider experiments: maximum phase space, minimally biased acceptance, free of target parasitic effects
  - ✓ fixed-target experiments: high rate of interactions, easily upgradeable, better vertex-finder for heavy flavor decays

Positioning of the NICA

- Many experiments to study a similar physics case in the same decade

	NA61/SHINE at SPS	CBM at FAIR	STAR BES+FXT at RHIC	MPD + BM@N at NICA
Coverage of region of transition from baryon to meson dominance („horn”)	only higher $\sqrt{s_{NN}}$	only lower $\sqrt{s_{NN}}$	Yes (mixing collider and fixed target)	Yes (consistent acceptance)
expected luminosity (w.r.t. MPD)	lower	higher	lower	reference
possibility for system size scan	yes	yes	yes (?)	yes
full centrality range	no	yes (?)	yes	yes
acceptance type	Fixed target	Fixed target	Collider + fixed target	Collider + fixed target
running plan (heavy-ions)	approved for 2021 (per-year decision)	beyond 2025	running concluded in 2021	2023 and beyond
status at the facility (possible running time)	in competition with many projects (LHC)	CBM one of four main experiments	end of datataking (heavy-ion) in 2021	flagship experiments several months/year

- The MPD strategy consists of performing a high-luminosity scan in energy and system size, looking for a wide variety of signals sensitive to the phase transition and presence of the critical point
- The scans are going to be performed using the same apparatus with all the advantages of collider experiments

Monte-Carlo productions

MPD

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

Monte-Carlo productions | Latest | Top | New Topic

Topic		Replies	Views	Activity
Request 24: PWG4 - dielectrons, 15M UrQMD BiBi@9.2 (new dEdx and v.4 ECAL geometry)	R	0	13	1d
Request 23: PWG2 - PHSD, polarization, 10M min. bias BiBi @ 9 GeV	E A	5	69	Mar 21
Request: 22: PWG3 UrQMD, fluctutations BiBi 9 GeV UrQMD	D K A	5	79	Feb 24
Request 21: PWG3 - DCM-QGSM-SMM, flow, 5M min. bias AgAg, AuAu, BiBi @ 4.0, 9.2 GeV	P A A	2	76	Feb 23
Request 19: PWG 3 - pp&9 GeV UrQMD	D K A	11	159	Jan 4
Request 18: PWG3 - JAM, flow, 10M min.bias AuAu @ 3.0, 3.3, 3.5, 3.8, 4.0, 4.2, 4.5, 5.0 GeV	P A A	3	94	Jan 4
Request 20: PWG3 - SMASH AuAu 11 GeV	V A	3	72	Dec '21
Location of simulation production	R A	2	63	Oct '21

- Regular Monte Carlo productions using MPD computing resources
- Any analyzer can request a new production via corresponding PWG convener(s)
- Most of recent requests are for BiBi@9.2, however vertex conditions are not defined yet
- Many new requests are expected in the near future for the Physics Performance paper

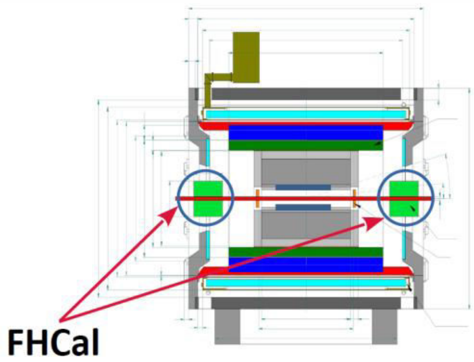
BACKUP

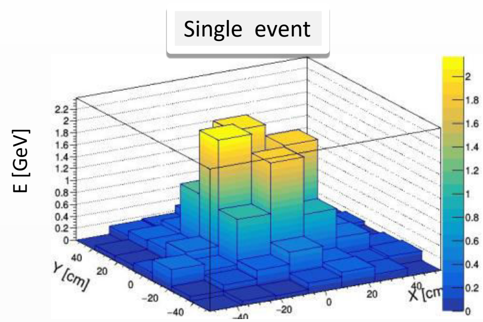
IT resources for the MPD members

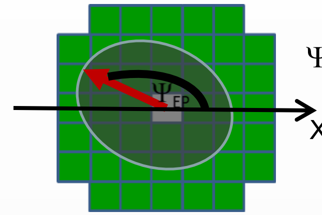
- Several IT resources are available to MPD members. To request access, a member **must** be on the MPD Collaboration List (members are added to the list on the request of the Group Leader)
  - Computing account at LIT (HybriLIT) – job submission, access to data, access to the DIRAC Infrastructure
  - Computing account at the NICA Cluster – job submission, access to data, including central Monte-Carlo productions
  - Account at the MPD Forum – place for internal MPD discussions
  - 50GB Private „cloud”: http://disk.jinr.ru (very useful for sharing large files)
- Other useful IT resources, available to all users
  - Account at the JINR INDICO (http://indico.jinr.ru)
  - Account in the Volna webconferencing system

Reaction plane measurements

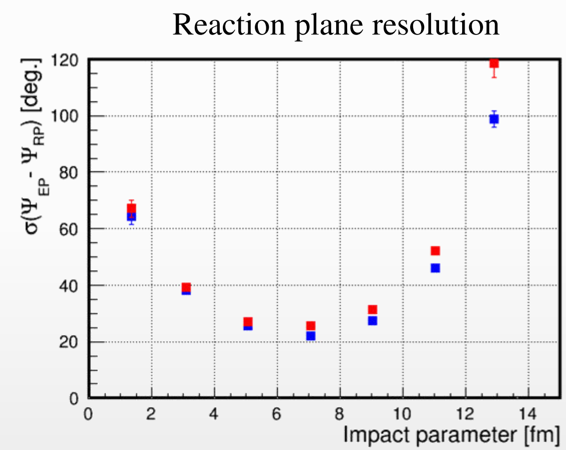
- FHCAL is a hadronic calorimeter, ~ 1 m^2, 44 towers by 15x15 cm^2, $2 < |\eta| < 5$



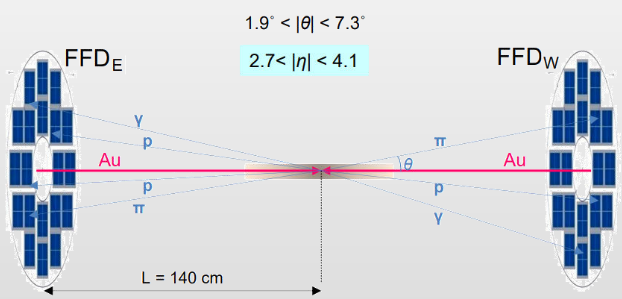




$$\Psi_{EP} = acrtg \frac{\sum E_i \sin(\varphi_i)}{\sum E_i \cos(\varphi_i)}$$



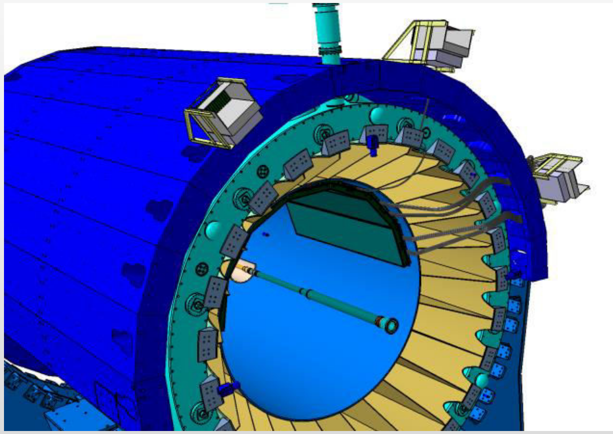
- FHCAL is considered as the main detector for event-plane measurements
- Need further studies for the FFD, which can also be used for reaction plane measurements



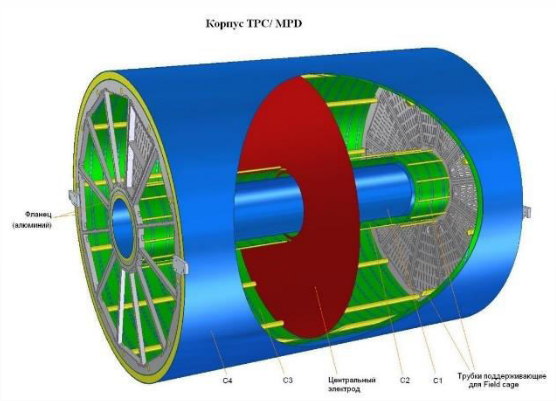
Support Frame for detectors inside of the Solenoid

The structure of Support Frame is made of carbon fiber which allows for deformation less than 3 mm under load with detectors (~80 T).
Producer - The Central Research Institute for Special Machinery, Khotkovo, Moscow region is a leading Russian enterprise in design and production of structures on the basis of advanced polymer composite materials for rocket & space engineering, transport, power, petrochemical machinery and other industries.

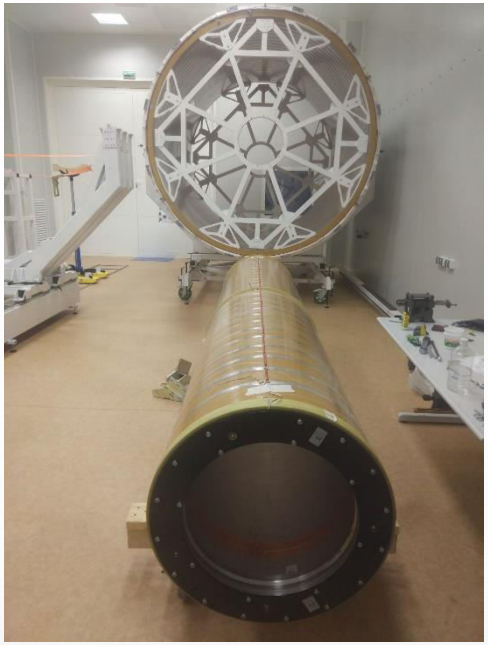
- the Frame will be transported to Dubna in November 2021
- December 2021 (as soon as Magnetic field measurements is finished)
- Representatives of the Company will participate in the process of installation of Support Frame into MPD and its alignment

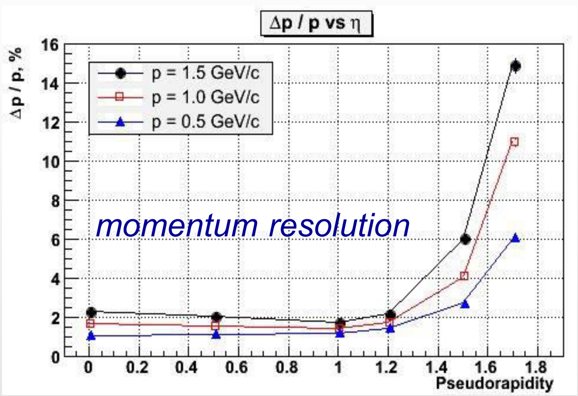


Time Projection Chamber (TPC): main tracker



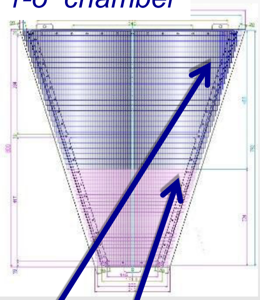
length	*340 см*
outer Radii	*140 см*
inner Radii	*27 см*
gas	*90%Ar+10%CH_4*
drift velocity	*5.45 см / μs;*
drift time	*< 30 μs;*
# R-O chamb.	*12 + 12*
# pads/ chan.	***95 232***
max rate	*< 7kGz (L= 10^{27})*





TPC/MPD Front-end card

r-o chamber



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

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

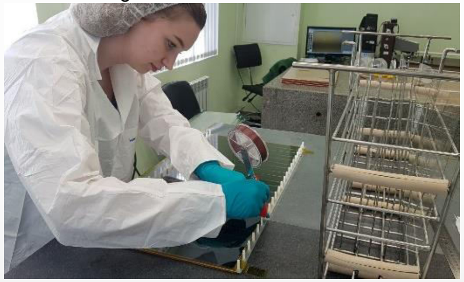
Read-Out Chambers (ROCs) are ready and tested (production at JINR)
113 Electronics sets (8%) produced
Two sites (Moscow, Minsk) tested for electronics production
C1-C2 and C3-C4 cylinders assembled
TPC flange under finalization

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

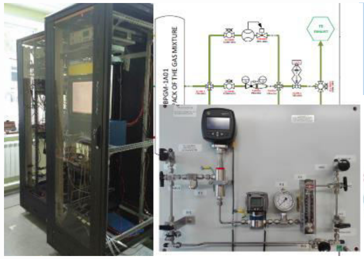

Automatic painting of the conductive layer on the glass


MRPC assembling


Soldering HV connector and readout pins

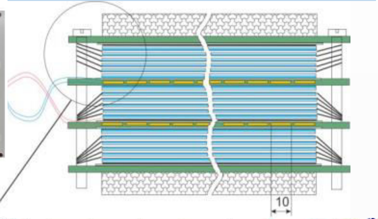
	Number of detectors	Number of readout strips	Sensitive area, m²	Number of FEE cards	Number of FEE channels
MRPC	1	24	0.192	2	48
Module	10	240	1.848	20	480
Barrel	280	6720	51.8	560	**13440** (1680 chips)

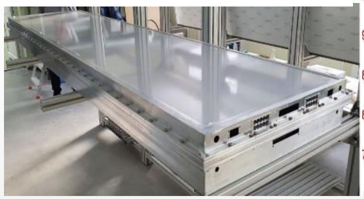
All procedure of detector assembling and optical control is performed in a clean rooms ISO class 6-7.

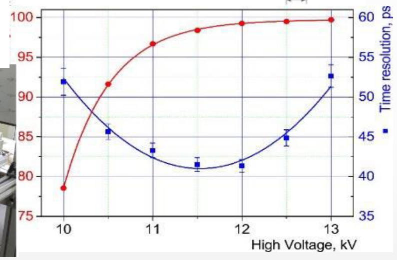


TOF gas system: Responsibility of the Polish group (WUT)

Dimensions of sensitive area 600 x300 mm^2







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

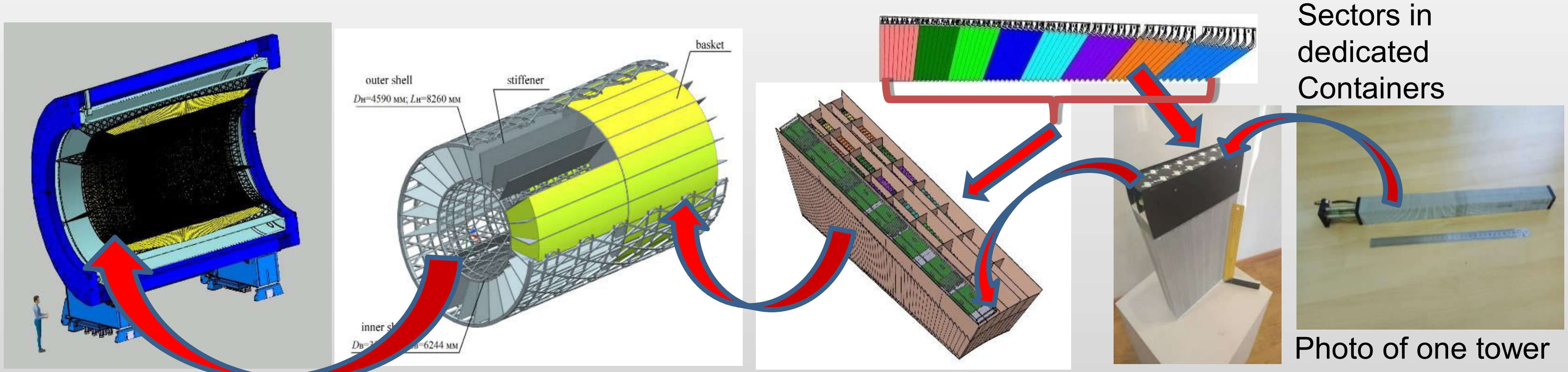
Electromagnetic Calorimeter (ECAL)

- *Pb+Sc "Shashlyk"* — *read-out: WLS fibers + MAPD* — *L ~35 cm (~ 14 X_0)*
- *Segmentation (4x4 cm^2)* — *σ(E) better than 5% @ 1 GeV* — *time resolution ~500 ps*

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

So far ~300 modules (16 towers each) = 3 sectors are produced
Another 3 sectors are planned to be completed by May 2021
Chinese collaborators will produce 8 sectors by the end of 2021
25% of all modules are produced by JINR (production area in Protvino) 75% produced in China, currently funding is secured for approx. 25%

Projective geometry



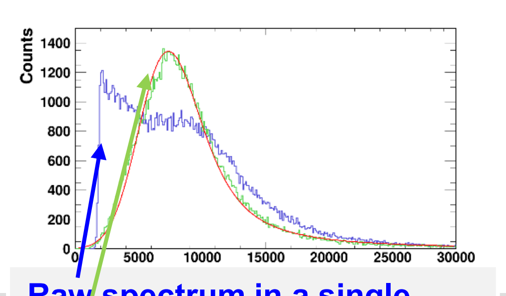
Forward Hadron Calorimeter (FHCal)

- All (90+spare) FHCal modules are assembled and are used for the tests.
- 100 Front-End-Electronics (FEE) boards are produced and tested.

The activities with modules:

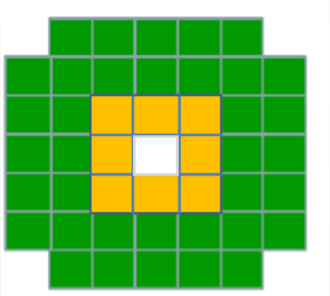
- **Tests with cosmic muons;**
- **Tests of Front-End-Electronics (FEE);**
- **Study of FEE electronic noises;**
- **Development of FHCal trigger;**
- **Development of Slow Control.**

FHCal energy calibration with cosmic

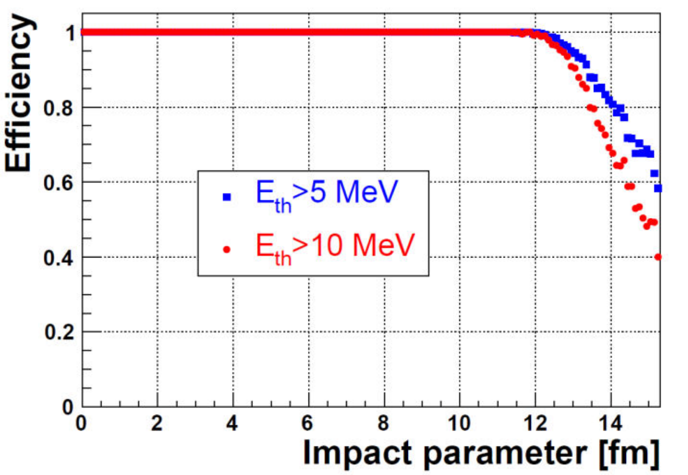


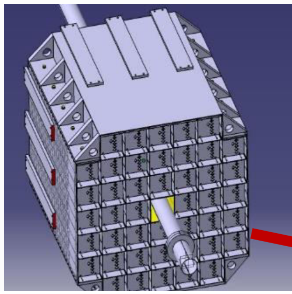
Raw spectrum in a single

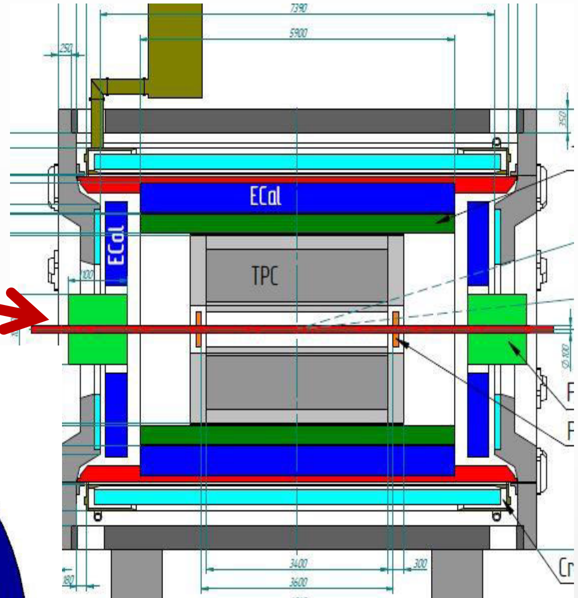
Corrected to the pass length in scintillators

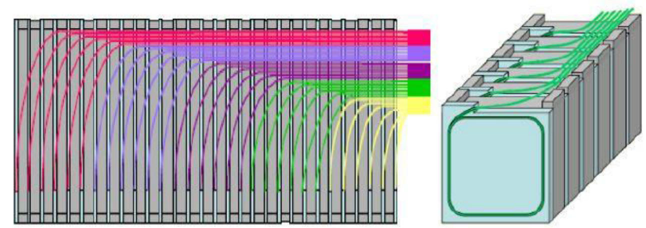


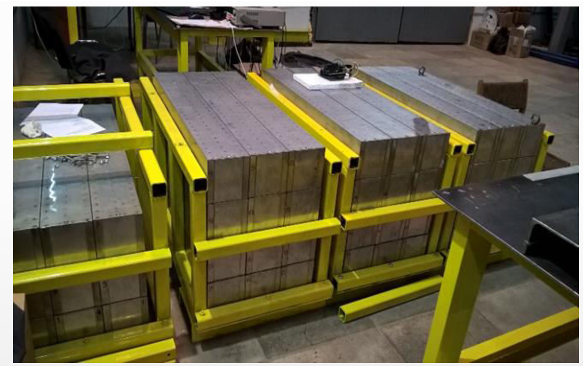
FHCal Trigger efficiency

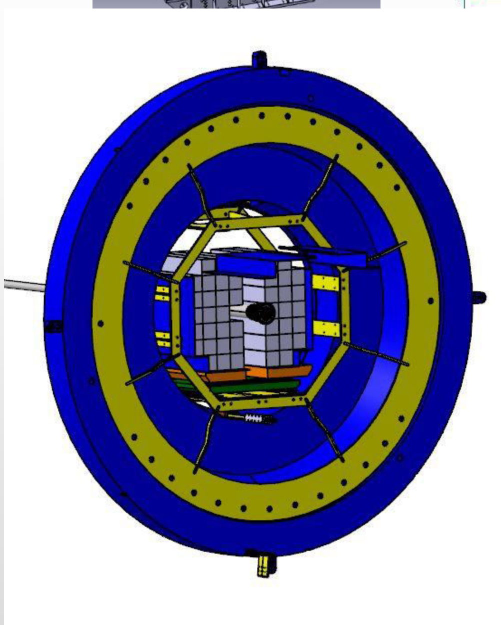






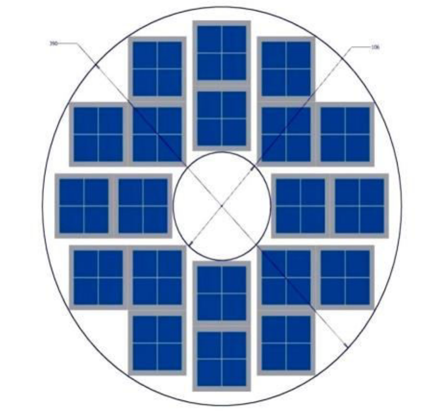


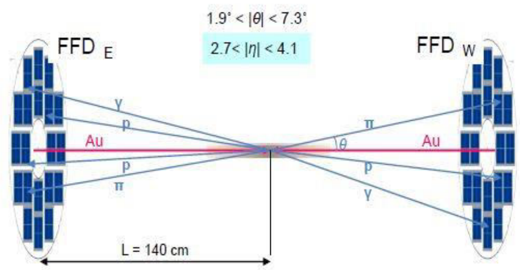




- Two-arms at ~3.2 m from the interaction point.
- Each arm consists of 44 individual modules.
- Module size 150x150x1100cm^3 (42 layers)
- Pb(16mm)+Scint.(4mm) sandwich
- 7 longitudinal sections
- 6 WLS-fiber/MAPD per section
- 7 MAPDs/module

FFD - Fast Trigger L_0 for MPD





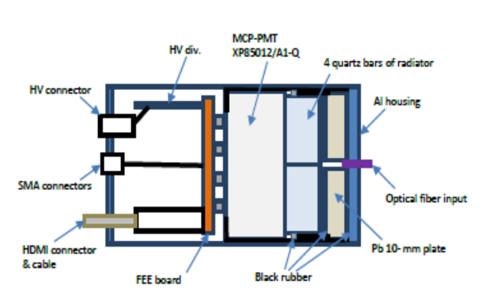


Fig. 4-1. A scheme of the FFD module.

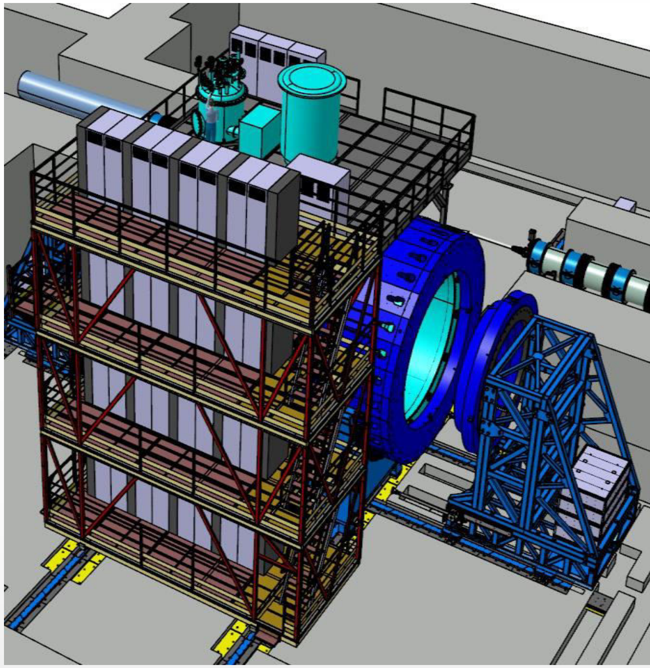
15 mm quartz radiator
10 mm Lead converter

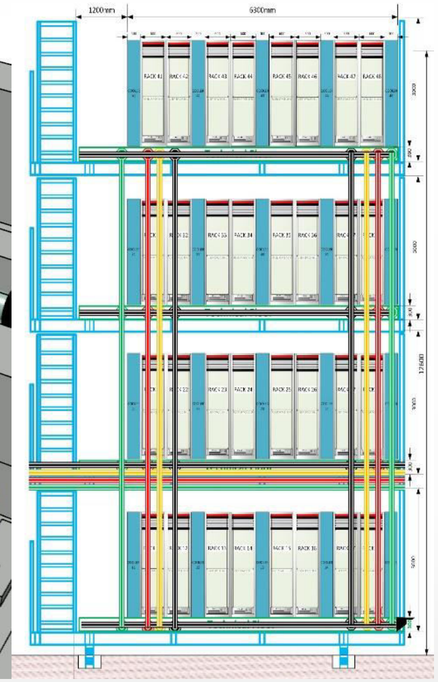
FFD provides information on
- interaction rate (luminosity adjustment)
- bunch crossing region position

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

MPD Electronics Platform



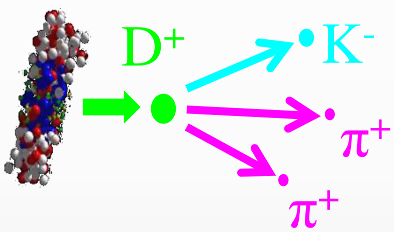


- Electronics platform has 4 levels with 8 racks on each level
- Each Rack provides cooling, fire safety and radiation control system
- Cable ducts connect detectors inside of MPD and Electronics Platform
- The mechanical part of the Platform is ready

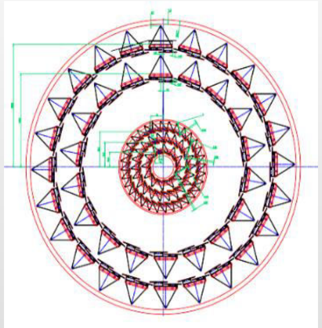
The design of the MPD Electronics Platform is a major contribution of the Polish groups to MPD
M. Peryt (WUT) – leader of the „Engineering Support" Sector of VBLHEP

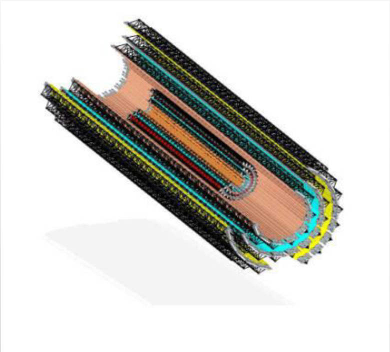
Inner Tracker System (ITS): precise tracking

Consortium includes JINR, NICA (BM@N & MPD) , **FAIR, Russian, Polish and Ukrainian Institutes + CCNU Central China Normal Univ., IMP- Institute of Modern Physics, USTC – Hefei**



Protocol # 134 between CERN and JINR states the legal terms for transaction of CERN developed novel technology and the know-how for building the MPD-ITS on the basis of Monolithic Active Pixel Sensors *(the **MAPS**)* ALPIDE, signed in 2018. This document laid a clear road towards the MPD ITS.





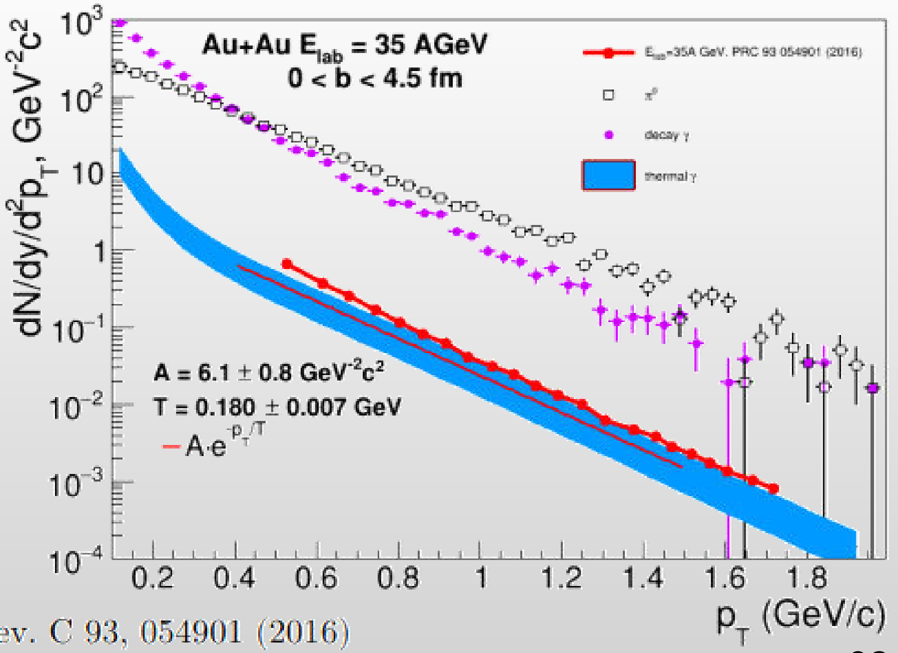
MPD ITS based on ALICE type staves

Simulation setup

- ✓ UrQMD v3.4 with hybrid model (3+1d hydro, **bag model** EoS, hadronic rescattering and resonances within UrQMD)
- ✓ π^0 and decay photon spectrum are calculated **within the same simulation**
- ✓ impact parameter range $0<b<9$ fm
- ✓ In hydrodynamical evolution, for each volume we calculate thermal gamma yield based on T, energy density (e), QGP fraction, baryonic chemical potential. We integrate these yields over time (until freeze-out time) and space.
- ✓ Two extreme cases: calculate thermal gamma emission from the volume above freeze-out criterion ($e > e_{freezeout}$), or calculate for all volumes. Reality somewhere in between (all volumes interact during hydro evolution). Comparing these options one can estimate theoretical uncertainties

$$\frac{d^3 N^{\gamma, therm}}{dy\, d^2 k_T} = \int_\Omega dV\, dt\, R_\gamma \left| k, T(x), \mu(x), u(x) \right|$$

Why simulations in PRC 93 054901 (2016) and PRC 81 044904 (2010) have almost the same yield despite ~5 times difference in energy (35 vs 158 AGeV)?

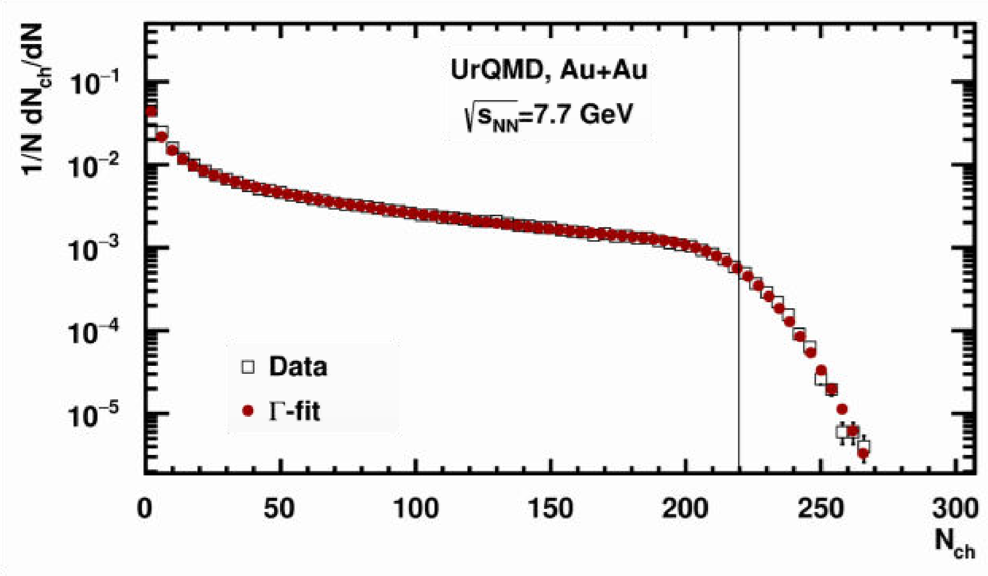


Comparison with S. Endres, H. van Hees, M. Bleicher, Phys. Rev. C 93, 054901 (2016)

The Bayesian inversion method (Γ-fit): main assumptions

- Relation between multiplicity N_{ch} and impact parameter b is defined by the fluctuation kernel:

$$P(N_{ch}|c_b) = \frac{1}{\Gamma(k(c_b))\theta^k} N_{ch}^{k(c_b)-1} \mathrm{e}^{-n/\theta}$$



c_b – impact parameter based centrality

$$c_b = \frac{1}{\sigma_{inel}} \int_0^b P_{inel}(b')2\pi b' db' \simeq \frac{\pi b^2}{\sigma_{inel}}$$

σ_{inel} – geometrical inelastic NN cross section

$P_{inel}(b)$ – probability of inelastic NN collision ($P_{inel}(b) \approx 1$)

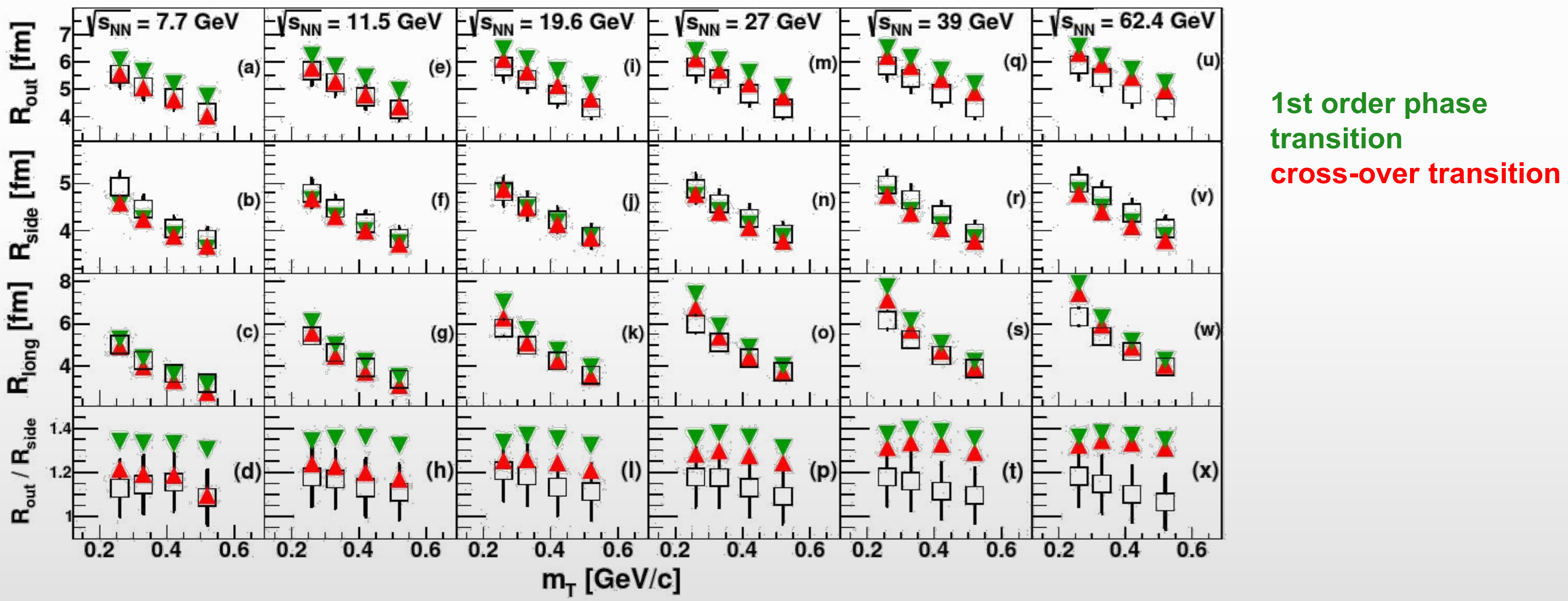
R. Rogly, G. Giacalone and J. Y. Ollitrault, Phys.Rev. C98 (2018) no.2, 024902

Implementation in MPD: https://github.com/Dim23/GammaFit

Two particle correlations

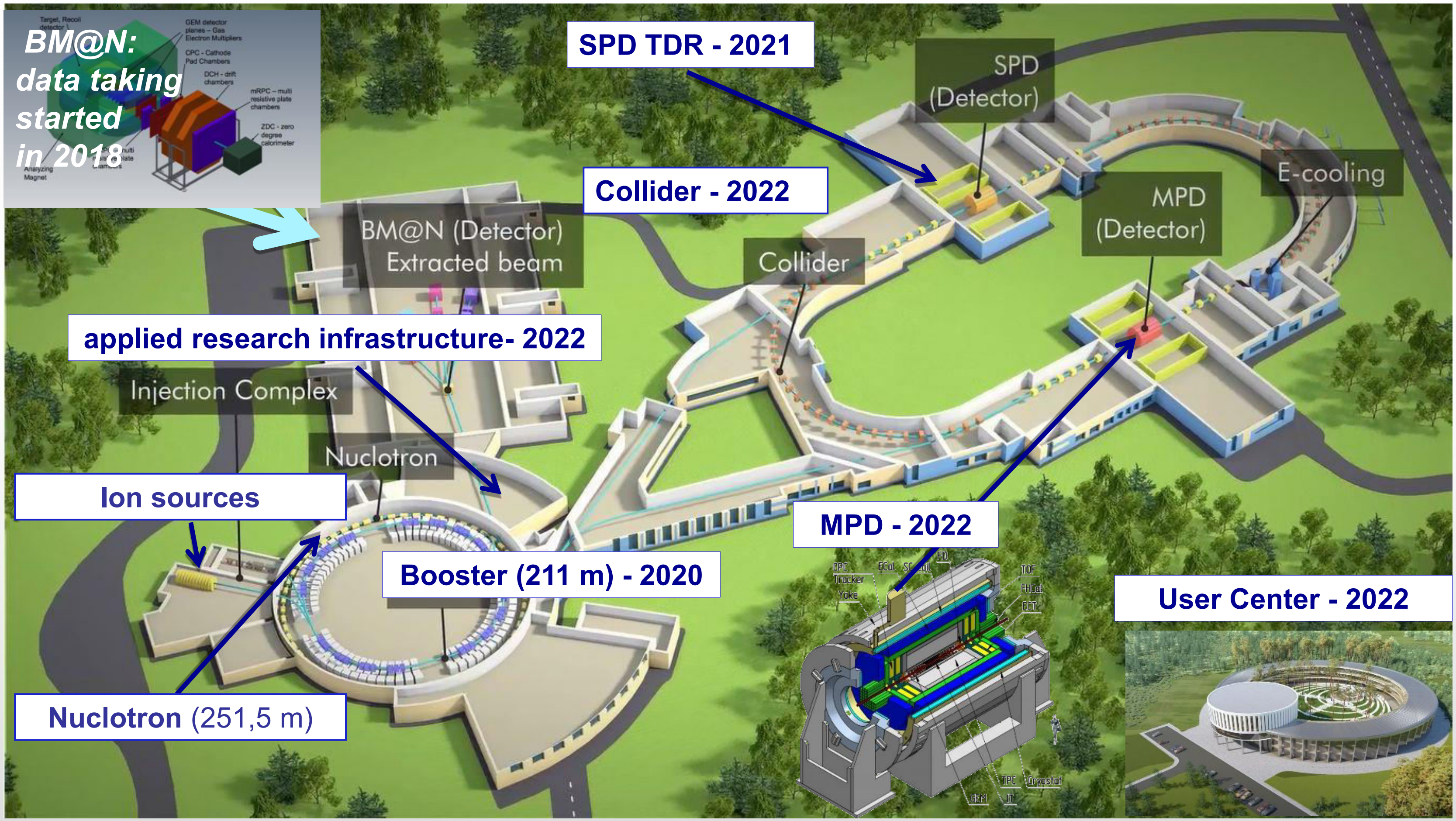
- ❖ Femtoscopy is used in heavy-ion collision to determine the size of the particle-emitting region and space-time evolution of the produced system.
- ❖ Measurement for pions are straightforward and robust, large discovery potential in correlations for kaons and protons, as well as correlations including hyperons

AuAu@7.7 GeV (vHLLE), extracted 3D pion radii versus m_T vs. STAR data (PRC 96, 024911(2017))



- ❖ Simulations predict sensitivity of pion source size to the nature of the phase transition

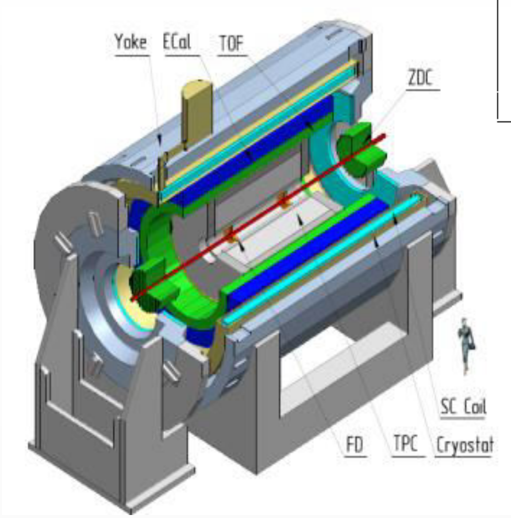
Accelerator Complex in Dubna



- ❖ Budget ~ 500 M$
- ❖ First collisions in MPD – end of 2023

Multi-Purpose Detector

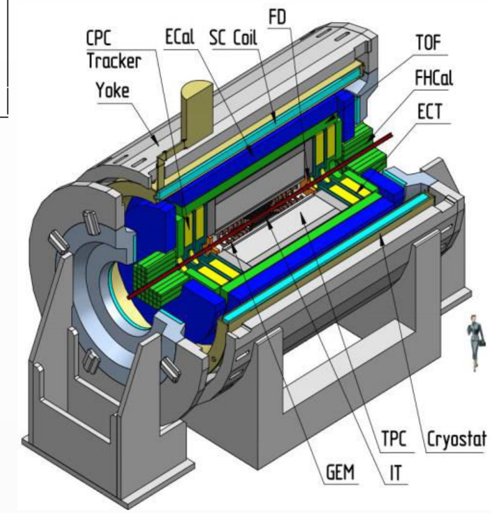
Stage- I



Length	340 cm
Vessel outer radius	140 cm
Vessel inner radius	27 cm
Default magnetic field	0.5 T
Drift gas mixture	90% Ar+10% CH_4
Maximum event rate	7 kHz ($L = 10^{27}$ $cm^{-2}s^{-1}$)

upgrade

Stage- II



TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$

TOF, EMC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$

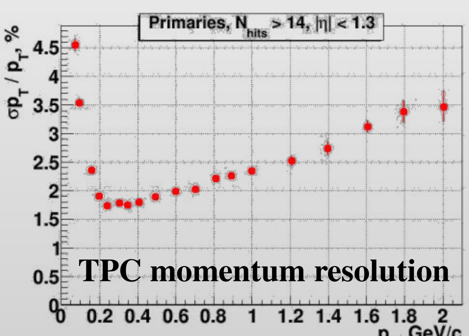
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$

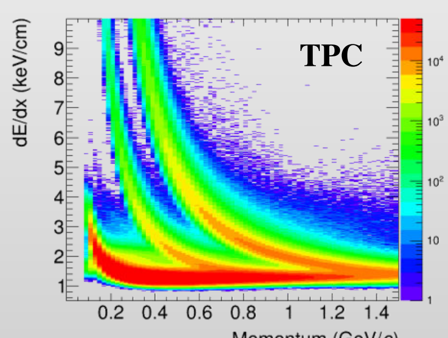
FHCAL: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

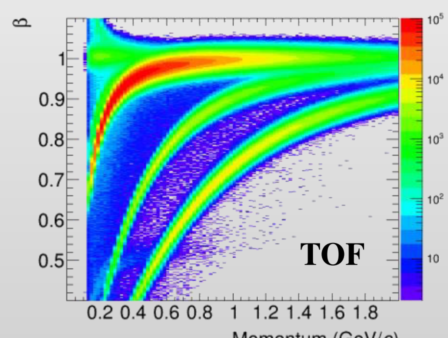
+ **ITS** (heavy-flavor measurements)

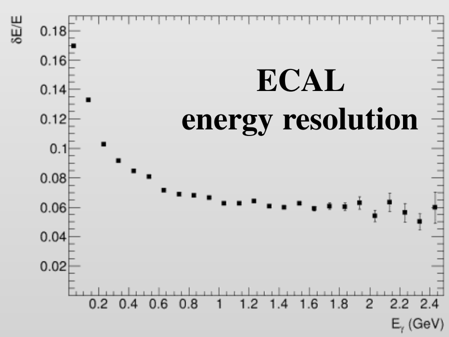
+ **forward spectrometers**

Au+Au @ 11 GeV (UrQMD + full chain reconstruction)





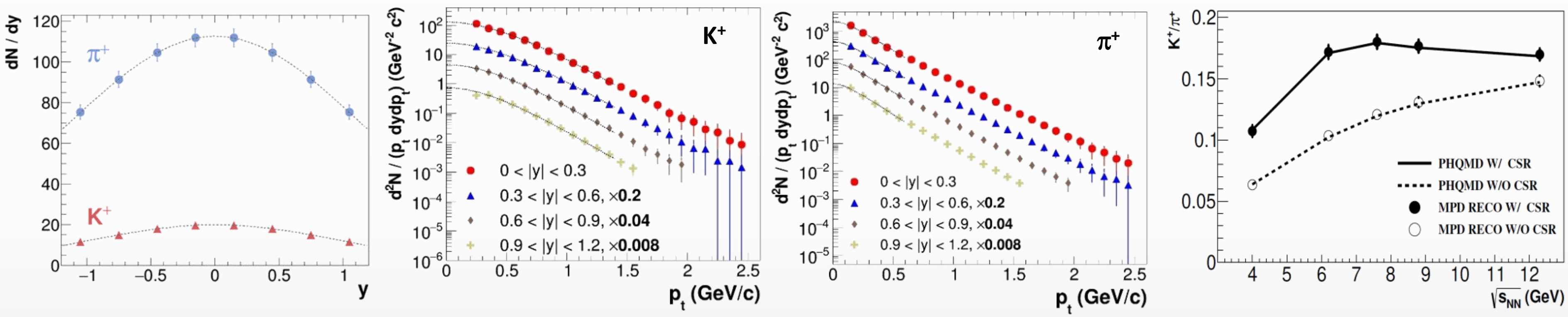




Identified hadron spectra

- Particle spectra, yields and ratios probe bulk properties of the fireball and flow
- Advantage of the MPD is in large and uniform acceptance, excellent PID capabilities using combined analysis of TPC (dE/dx) and TOF signals

- 0-5% central AuAu@9 GeV (PHSD, with partonic phase and chiral symmetry restoration effects):

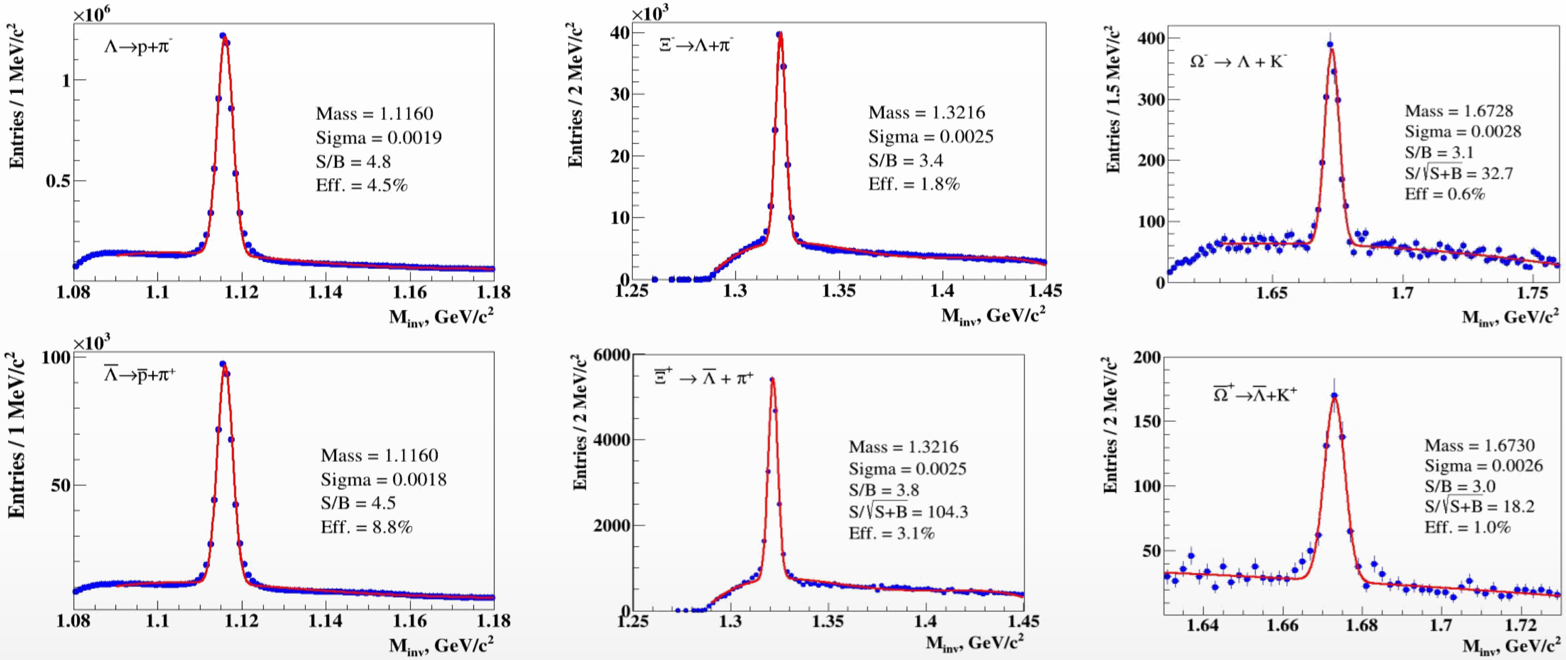


  - ✓ MPD samples ~ 70% of the π/K/p production in the full phase space
  - ✓ hadron spectra are measured from 0.2 MeV/c to 2.5 GeV/c in transverse momentum with the TPC&TOF
  - ✓ unmeasured hadron yields at low p_T and large values of rapidity can be extracted from extrapolation of the measured spectra (B-W for p_T spectra and Gaussian for rapidity spectra in exampled above)

- Ability to cover full energy range of the "horn" with consistent acceptance across different collision systems and collision energies

Weak decays of strange baryons

❖ AuAu@11 GeV (PHSD):

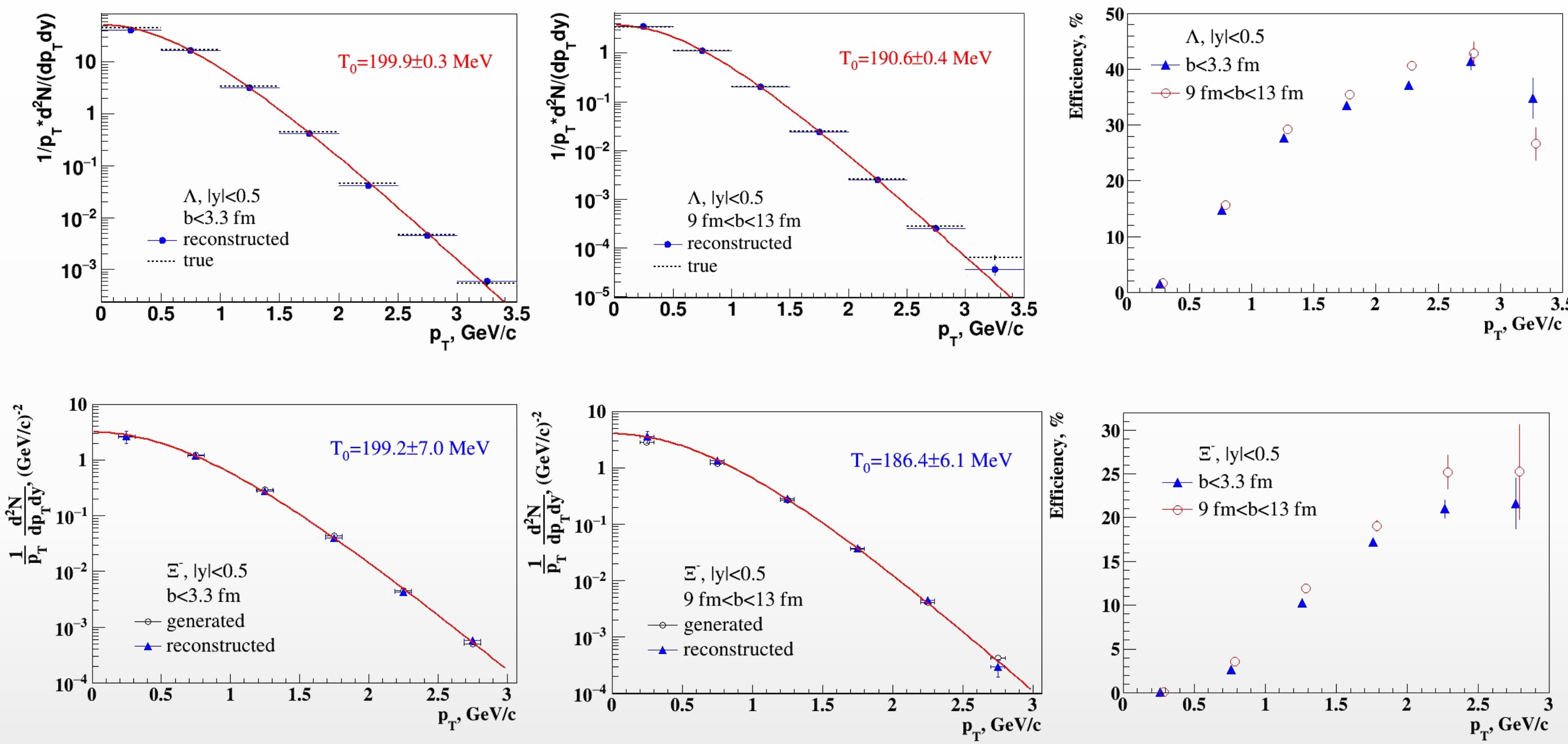


✓ Strange baryons can be reconstructed with good S/B ratios using charged hadron identification in the TPC&TOF and different decay topology selections

✓ Relative yields of the baryons for ~ 500 M sampled events:

Λ	anti-Λ	Ξ⁻	anti-Ξ⁺	Ω⁻	anti–Ω⁺
$3 \cdot 10^8$	$3.5 \cdot 10^6$	$1.5 \cdot 10^6$	$8.0 \cdot 10^4$	$7 \cdot 10^4$	$1.5 \cdot 10^4$

Efficiencies and p_T spectra



- ✓ Capability to reconstruct baryon yields down to low momenta with reasonable efficiencies
- ✓ High-p_T reach is limited by statistics
- ✓ Reconstructed spectra are consistent with the generated ones → MC closure test

Short-lived resonances

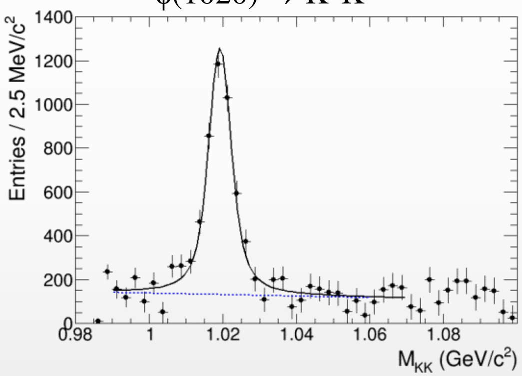
- Resonances probe reaction dynamics and particle production mechanisms vs. system size and $\sqrt{s_{NN}}$:
  ✓ hadron chemistry and strangeness production, lifetime and properties of the hadronic phase, spin alignment of vector mesons, flow etc.

increasing lifetime ⟶

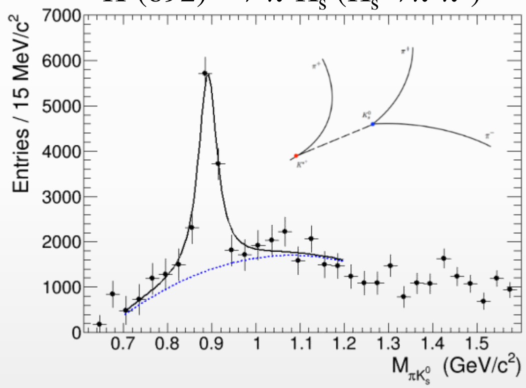
	ρ(770)	$K^*(892)$	Σ(1385)	Λ(1520)	Ξ(1530)	φ(1020)
cτ (fm/c)	1.3	4.2	5.5	12.7	21.7	46.2
$\sigma_{rescatt}$	$\sigma_\pi\sigma_\pi$	$\sigma_\pi\sigma_K$	$\sigma_\pi\sigma_\Lambda$	$\sigma_K\sigma_p$	$\sigma_\pi\sigma_\Xi$	$\sigma_K\sigma_K$

- AuAu@11 GeV (UrQMD) after mixed-event background subtraction:

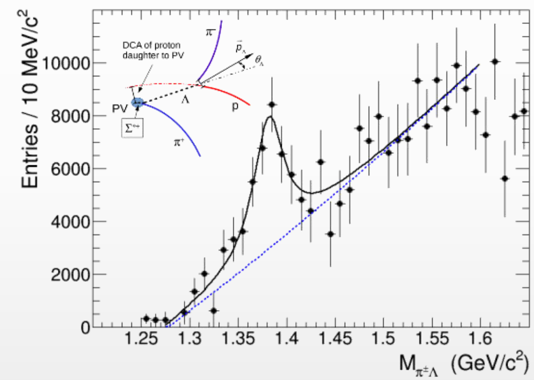
$\phi(1020) \rightarrow K^+K^-$



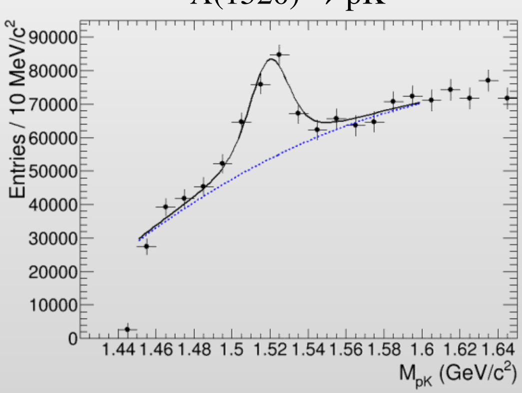
$K^*(892)^\pm \rightarrow \pi^\pm K_s$ ($K_s \rightarrow \pi^+\pi^+$)



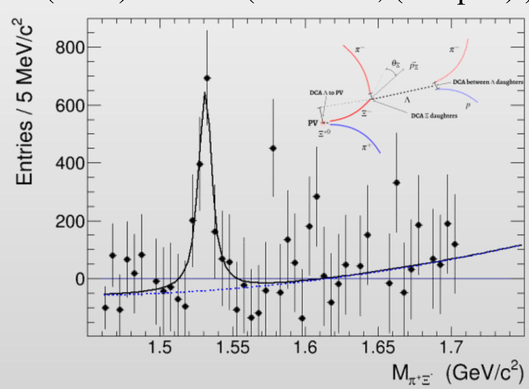
$\Sigma(1385)^\pm \rightarrow \pi^\pm\Lambda$ ($\Lambda \rightarrow p\pi$)



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



$\Xi(1530)^0 \rightarrow \pi^+\Xi^-$ ($\Xi^- \rightarrow \Lambda\pi^-$, ($\Lambda \rightarrow p\,\pi^-$))

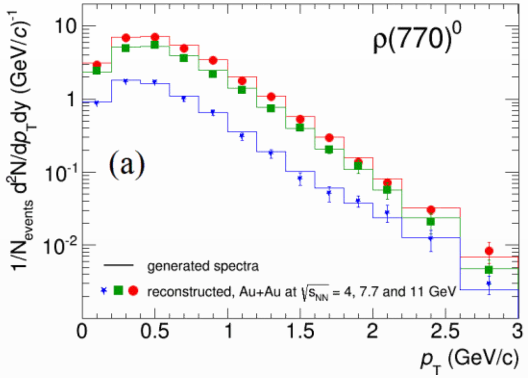


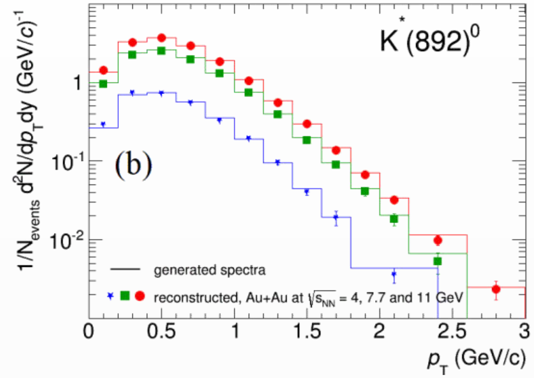
✓ MPD is capable of reconstruction the resonance peaks in the invariant mass distributions using combined charged hadron identification in the TPC and TOF

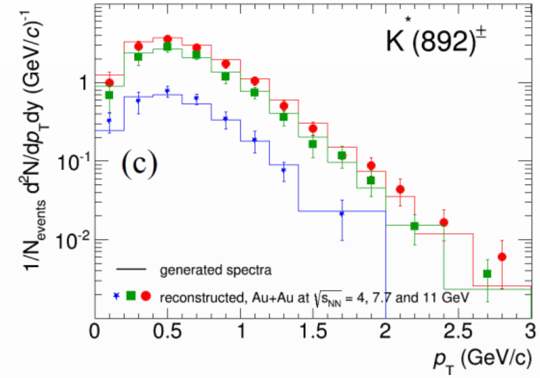
✓ decays with weakly decaying daughters require additional second vertex and topology cuts for reconstruction

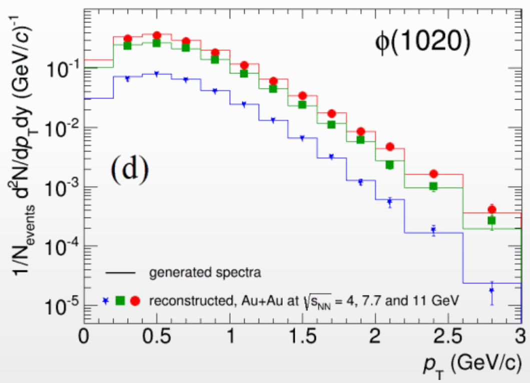
MC closure tests

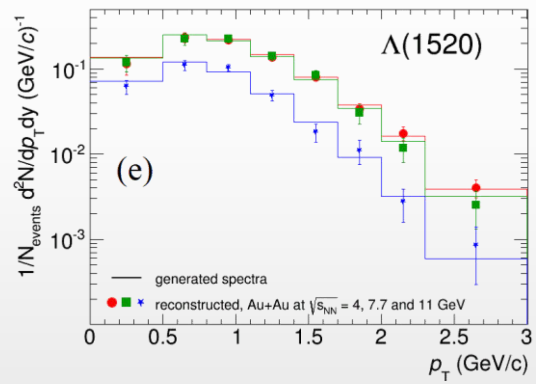
- Full chain simulation and reconstruction, p_T ranges are limited by the possibility to extract signals, $|y| < 1$

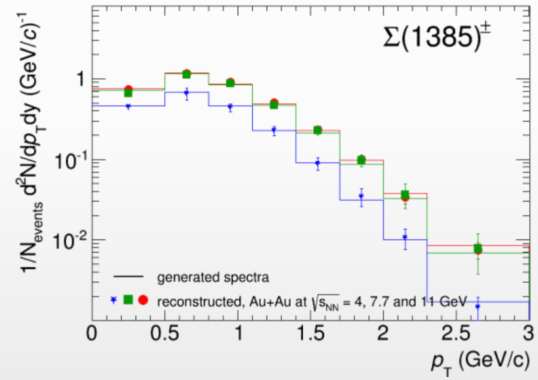


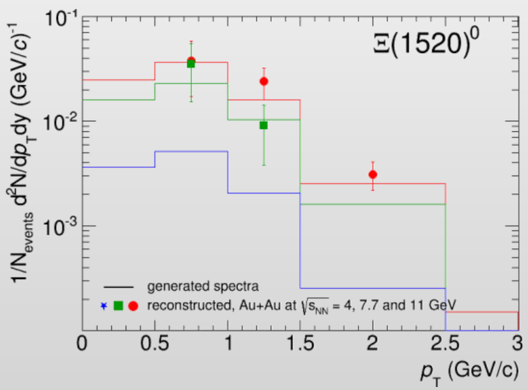








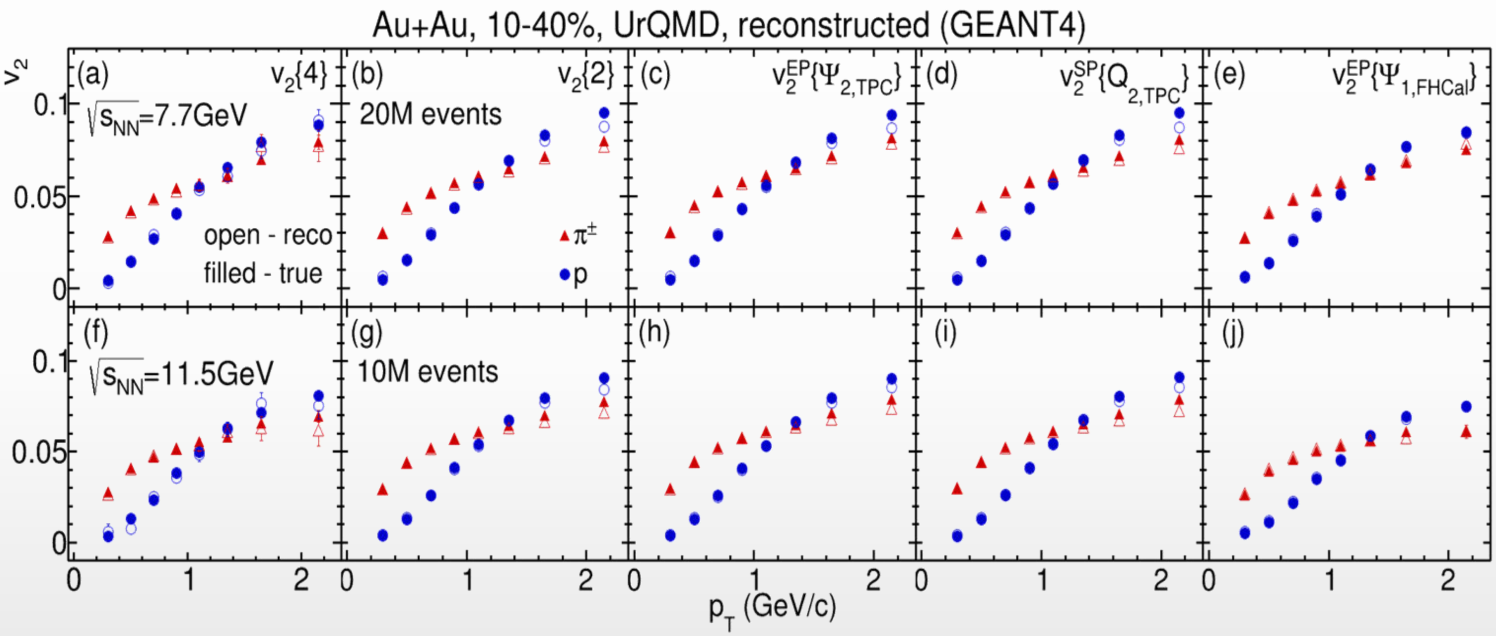




- Reconstructed spectra match the generated ones within uncertainties
- First measurements for resonances will be possible with accumulation of ~ 10^7 A+A events
- Measurements are possible starting from ~ zero momentum → sample most of the yield, sensitive to possible modifications
- Measurements of $\Xi(1530)^0$ are very statistics hungry

v_2 for pions and protons

- Flow has high sensitivity to the transport properties of the QCD matter: EoS, speed of sound (c_s), specific viscosity (η/s), etc.
- Lack of existing differential measurements of v_n vs. p_T, centrality, species, etc.)

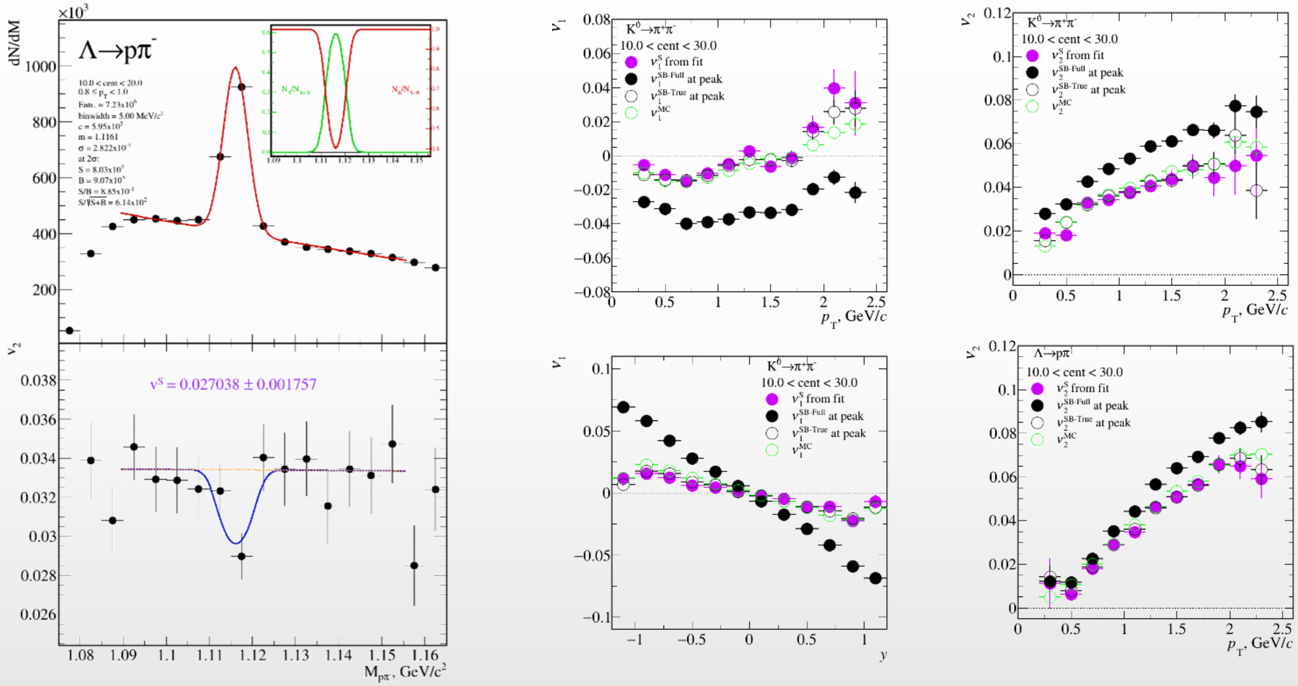


- Reconstructed and generated v_2 of pions and protons are in good agreement for all methods

Collective flow for V0 (K_s^0 and Λ)

- 25 M AuAu@11 GeV (UrQMD)
- Differential flow signal extraction using invariant mass fit method

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



v_1/v_2 flow after fit

Measured flow for (S+BG)

Measured flow for true pairs

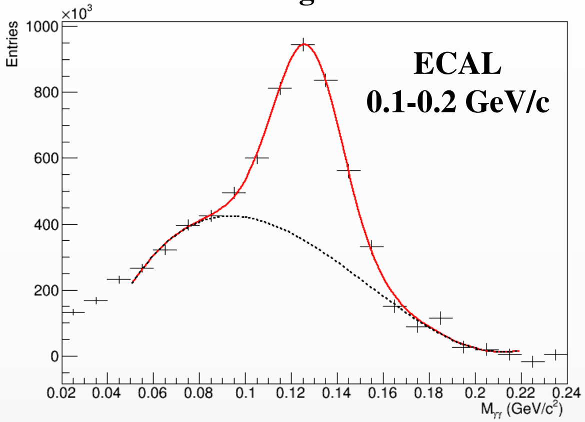
Flow from event generator

- Reasonable agreement between reconstructed and generated v_n signals for K_s^0 and Λ

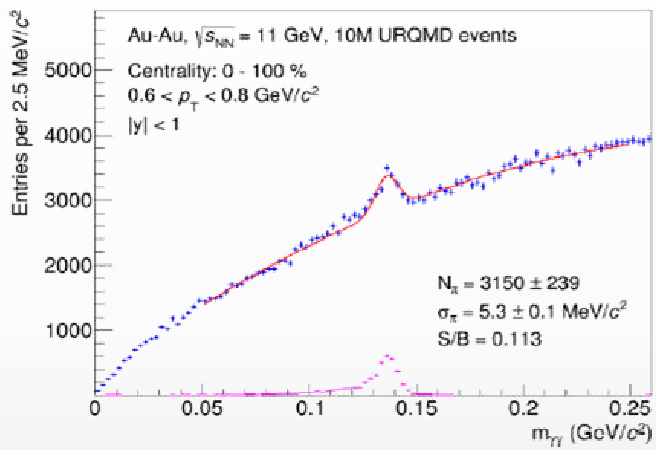
Neutral mesons

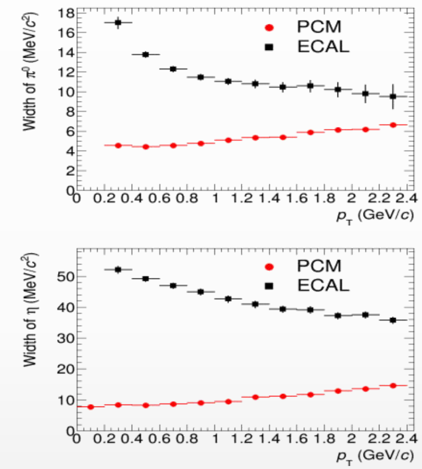
- Extend p_T range of charged particle measurements, various species (η, ω, η’, etc.)
- AuAu@11 GeV (UrQMD): realistic ECAL reconstruction and analysis in high multiplicity environment + photon conversion method

mixed-event background subtracted

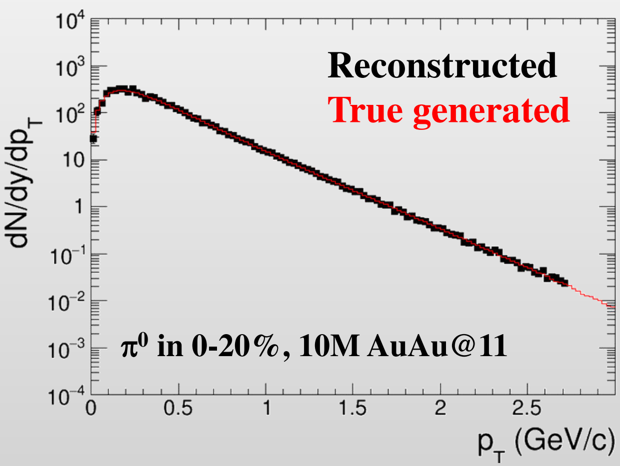


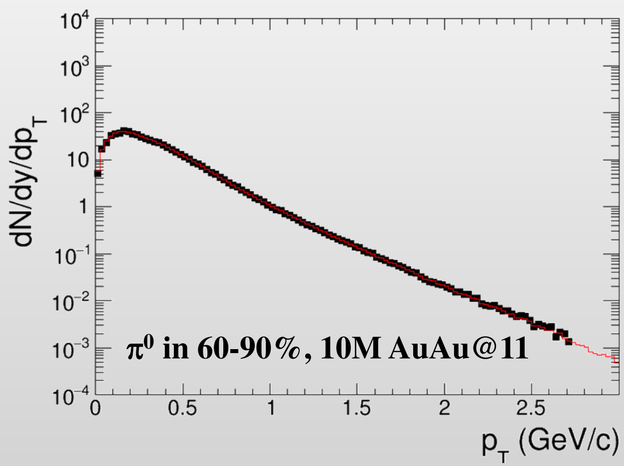
$\pi^0 \to \gamma\ (\gamma \to e^+e^-) + \gamma\ (\gamma \to e^+e^-)$

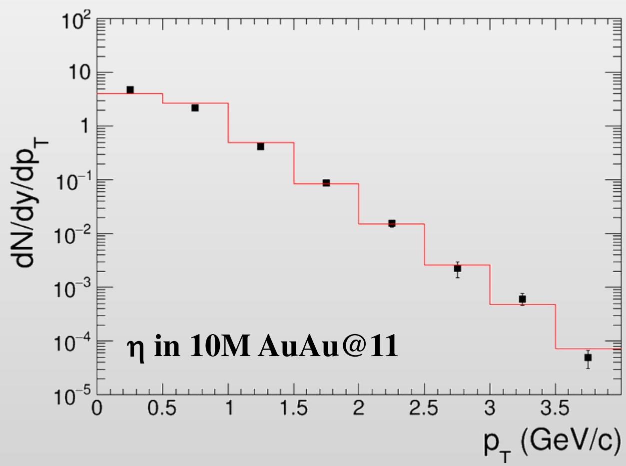




- π^0 and η MC closure tests: reconstructed spectra match the generated ones

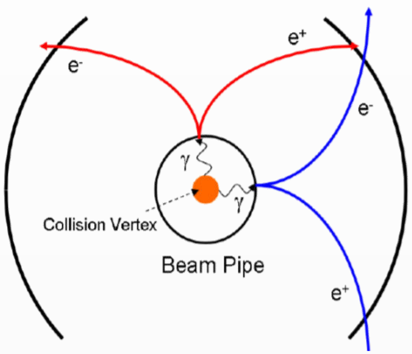


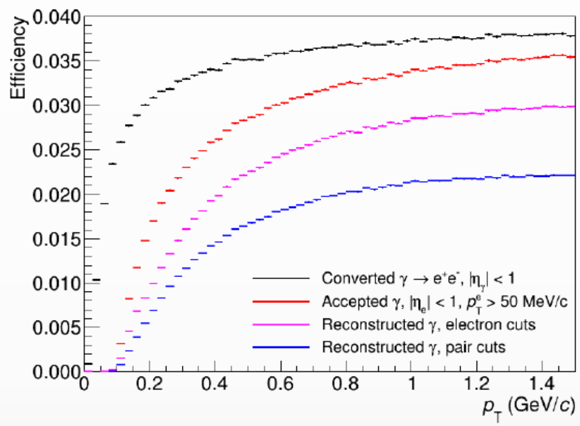


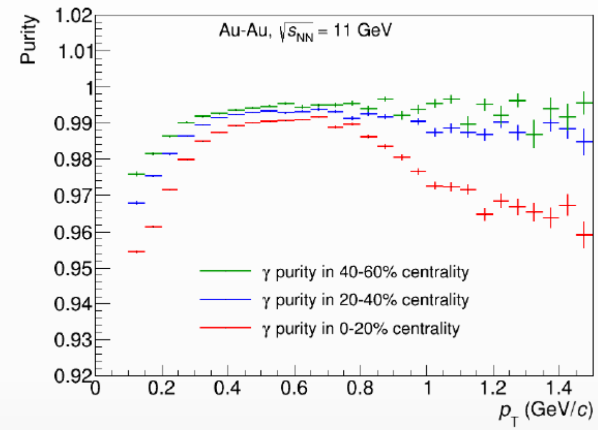


Photons

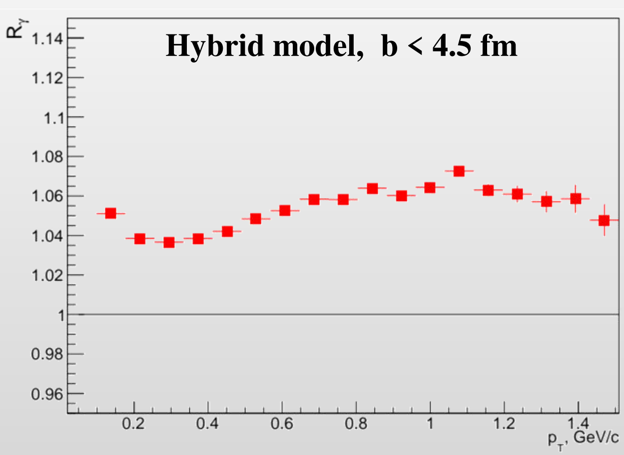
- AuAu@11 GeV (UrQMD)
  - ✓ EMCAL: large acceptance but modest resolution and small S/B at low momentum
  - ✓ Conversion method: low efficiency (~ 1.5%) but high purity (> 95%) and good energy resolution

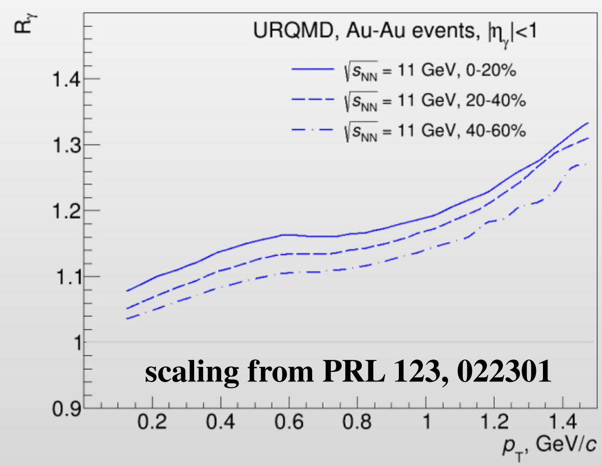






- $R_\gamma = \frac{\gamma^{incl}}{\gamma^{hadron}}$, Rγ estimations from 5% to 10% at p_T > 0.5 GeV/c at top NICA energies



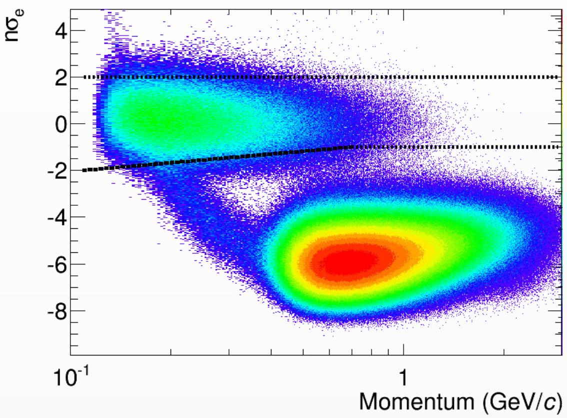


- Rγ values ~5% have been measured by PHENIX → potential for direct photon measurements @MPD

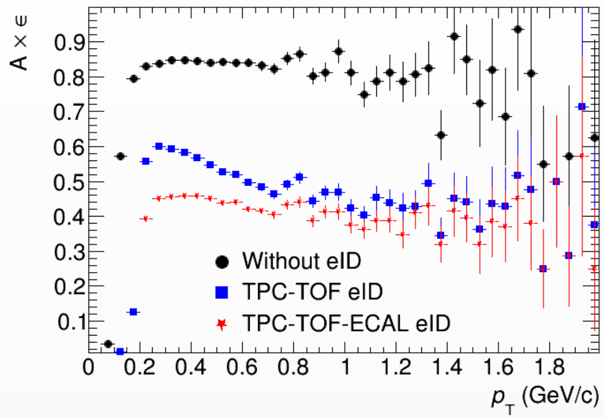
Dielectrons

- Dielectron spectra are sensitive probes of the deconfinement and the chiral symmetry restoration
- AuAu@11 GeV (UrQMD for background & PHQMD for signal)

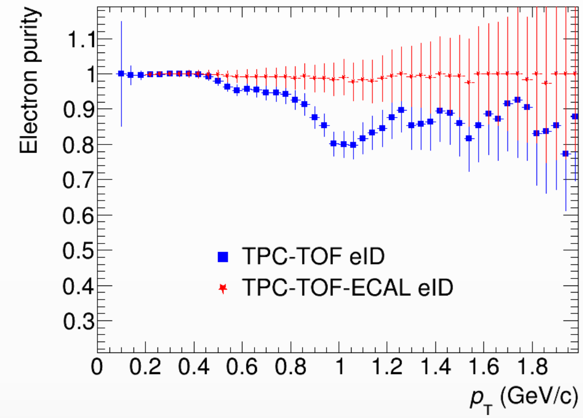
$n \cdot \sigma_e^{TPC}$ with $2\sigma_e$ PID in the TOF

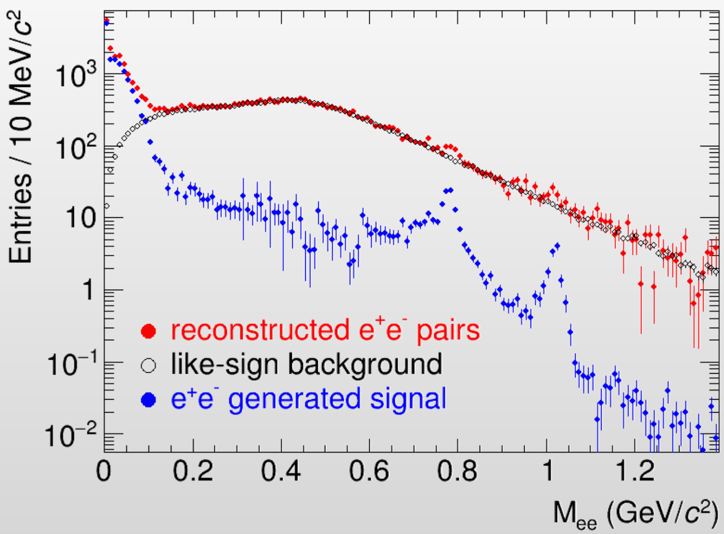


Efficiency of e-track reconstruction



Electron purity





- S/B (integrated in 0.2-1.5 GeV/c^2) ~ 5-10%
- Methods to improve S/B ratio while preserving reasonable efficiency for the pairs are being developed and matured

Milestones of MPD assembling in 2020-2023

Year 2020

1. July 15^{th} - MPD Hall and pit are ready to store and unpack Yoke parts
2. August - The first 13 plates of Magnet Yoke are assembled for alignment checks
3. Sept 15ht-Oct 1^{st} - Solenoid is ready for transportation from ASG (Italy)
4. November 10^{th} - Solenoid arrived
5. Nov-Dec - Assembling of Magnet Yoke

Year 2021

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

Year 2022

9. Jan 17^{th} -March - Liquid Nitrogen cooling
10. May - Cryogenic infrastructure ready
11. June-July - Cooling down to LHe temperature
12. July - Aug - Magnetic Field measurement
13. September - Installation of Support Frame.
14. Sept – Nov - Installation of TOF, TPC, Electronics Platform, Cabling
15. November - Installation of beam pipe, FHCal, Cosmic Ray test system
16. Nov - Dec. - Cosmic Ray tests
17. December - Commissioning

Year 2023

18. **January - Run on the beam**