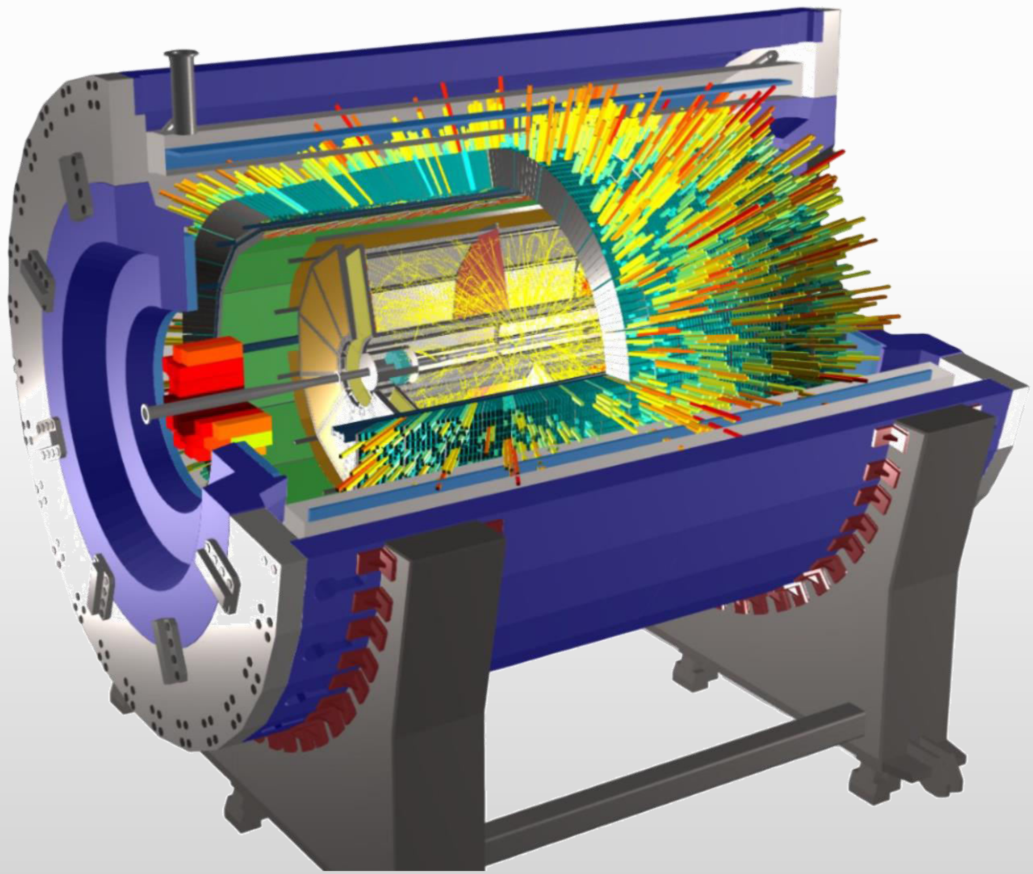
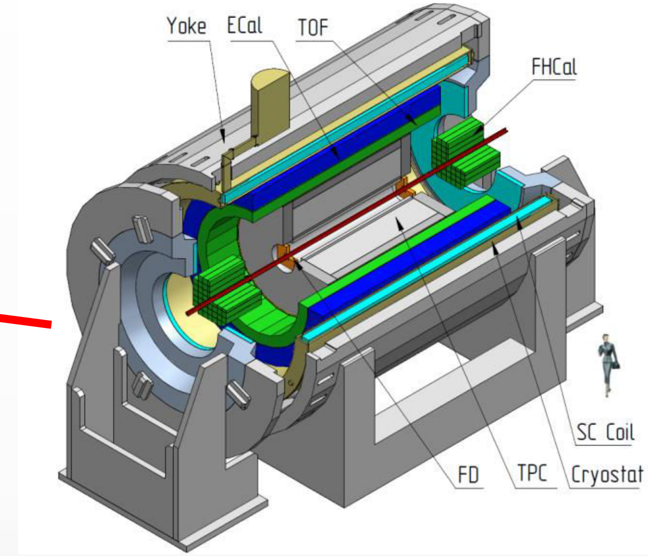
# Realization of the MPD project

V. Riabov for the MPD Collaboration



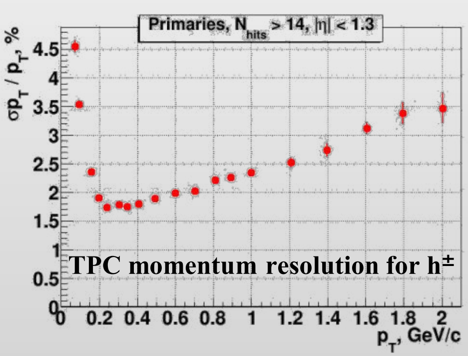
# Multi-Purpose Detector (MPD)

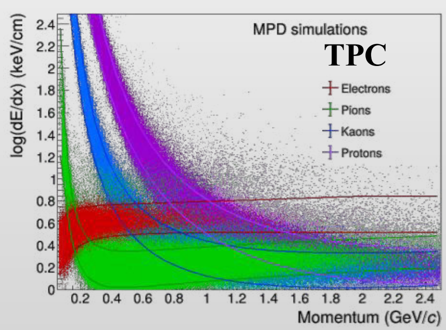
## Stage-I

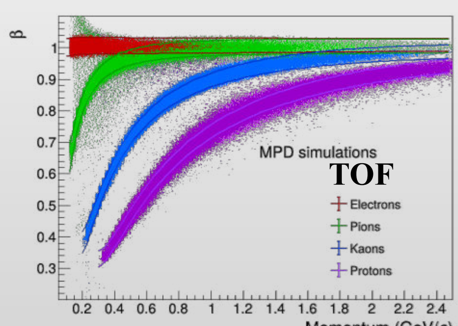



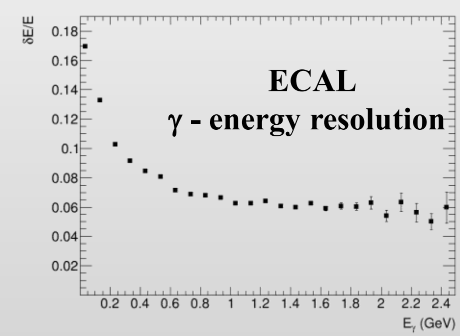

**TPC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$; **TOF, EMC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
**FFD**: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$; **FHCAL**: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

Au+Au @ 11 GeV (full event simulation and reconstruction)



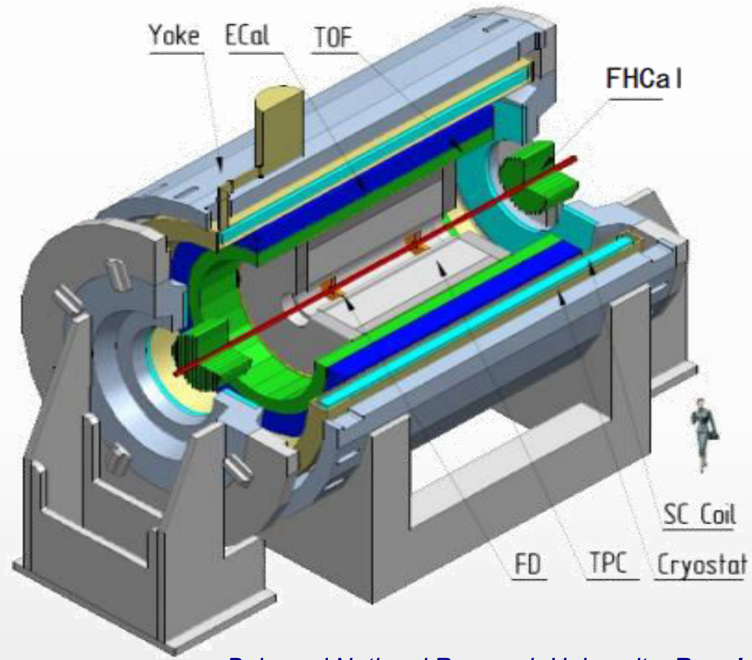
# Multi-Purpose Detector (MPD) Collaboration

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

***12** Countries, **>500** participants, **38** Institutions and **JINR***

## Organization

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

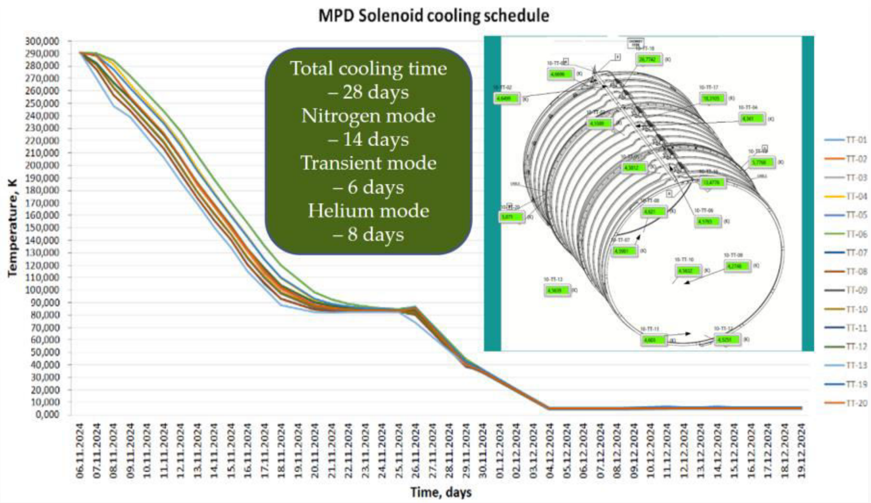



***Joint Institute for Nuclear Research**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*Institute for Nuclear Problems of Belarusian State University, **Belarus**;*
*Institute of Power Engineering of the National Academy of Sciences of Belarus, **Belarus**;*
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*University of Science and Technology of China, Hefei, **China**;*
*Huzhou University, Huizhou, **China**;*
*Institute of Nuclear and Applied Physics, CAS, Shanghai, **China**;*
*Central China Normal University, **China**;*
*Shandong University, Shandong, **China**;*
*University of Chinese Academy of Sciences, Beijing, **China**;*
*University of South China, **China**;*
*Three Gorges University, **China**;*
*Institute of Modern Physics of CAS, Lanzhou, **China**;*
*Egyptian Center for Theoretical Physics, **Egypt**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad Autónoma Metropolitana, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad Michoacana de San Nicolás de Hidalgo, **Mexico**;*
*Institute of Physics and Technology, **Mongolia**;*

*Belgorod National Research University, **Russia**;*
*High School of Economics University, Moscow, **Russia;***
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Ossetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **Russia**;*
*National Research Tomsk Polytechnic University, **Russia**;*
*Peter the Great St. Petersburg Polytechnic University Saint Petersburg, **Russia**;*
*Plekhanov Russian University of Economics, Moscow, **Russia**;*
*St.Petersburg State University, **Russia**;*
*Skobeltsyn Institute of Nuclear Physics, Moscow, **Russia**;*
*Petersburg Nuclear Physics Institute, Gatchina, **Russia**;*
*Vinča Institute of Nuclear Sciences, **Serbia**;*
*Pavol Jozef Šafárik University, Košice, **Slovakia***

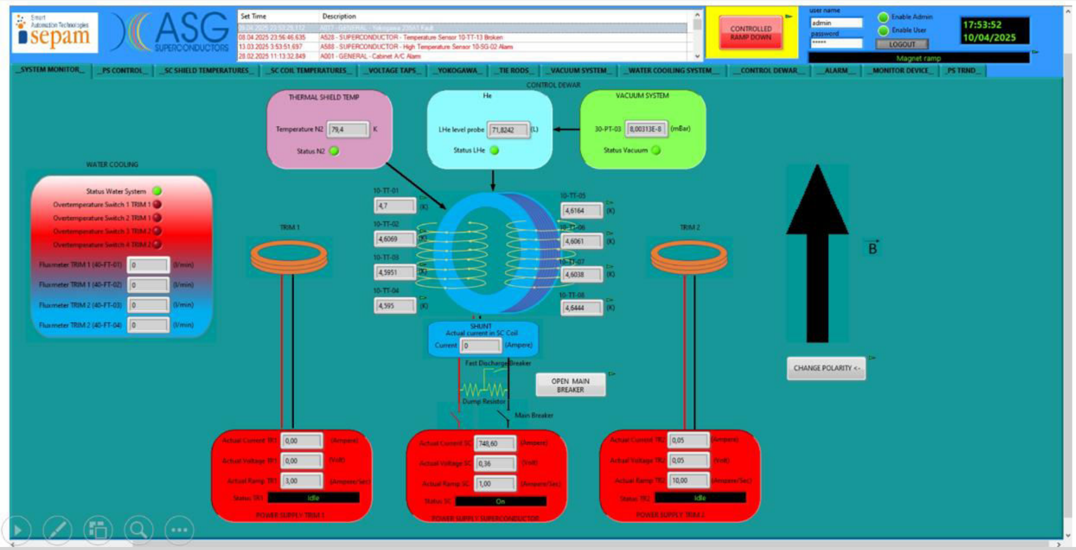
# MPD solenoid

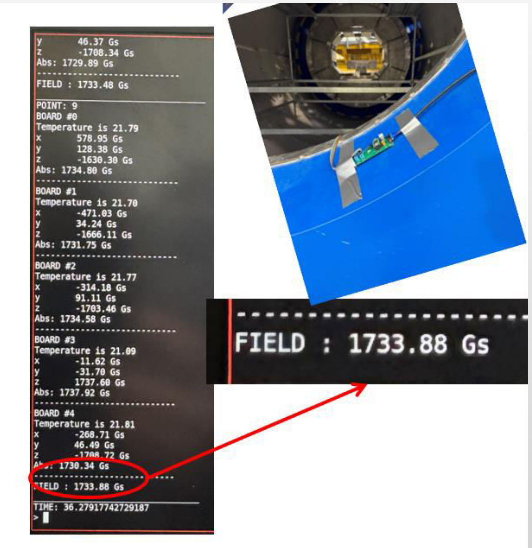
- ❖ February: solenoid power cable thermal isolation in the Chimney, LHe pipe installed in the MPD Hall
- ❖ April: solenoid cooled down to the working temperature of 4.5 K, test current supply at ~ 0.2 T



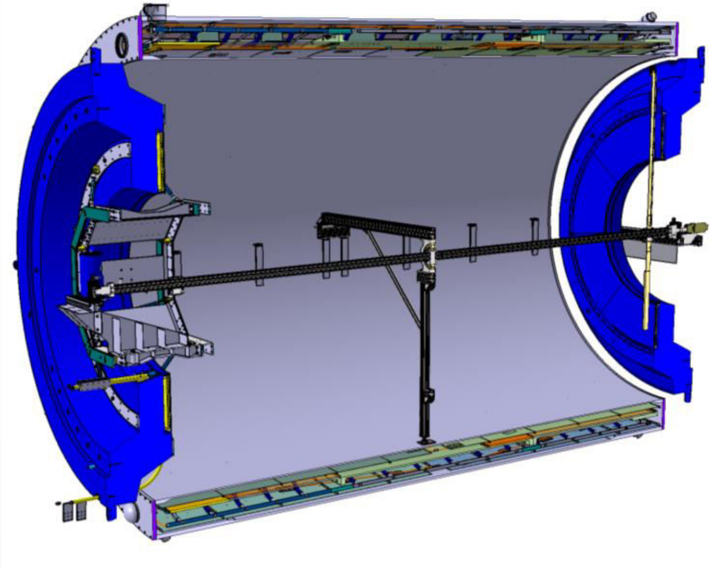

- ✓ successful cooling to 4.5 K, cooling rate ~ 1.5 K/h
- ✓ no leak in thermal shield and LHe chain
- ✓ heat load of ~ 100 W is consistent with design
- ✓ April: from room temperature to 80 K - 15 days, from 80 K to 4.5 K - 8 days

- ❖ SC coil training up to 0.15-0.2 T, water cooling required for higher currents and long-term operation



# Magnetic field measurements



Novosibirsk BINP magnetic field mapper

| | Along radius (R) | Along azimuth angle ($\phi$) | Along beam (z) |
|---|---|---|---|
| Step size, см | 5 | 21 | 10 |
| Total length, см | 220 | 360° (1380 см at max. R) | 700 |
| Number of measurements | 44 | 64 | 70 |

Single 3D Hall probe moves in 3 directions: z , R, $\phi$
Accuracy: 0.1 – 0.3 Gs
Number of points: ~ $2{\cdot}10^5$ (90 hours)
Fields to measure: 0.3 – 0.57 T (5-6 points)
Number of tunes per field: 5
Total time of measurements: ~ 3-4 months

Calculation and experimental current for optimal field configuration

| Current of nominal $I_{SC}$,A | Current in to TRIM 2, A $I_{trim2}$ | Current in to TRIM 1, A $I_{trim1}$ | Calc. field, Gs | Measured data $I_{SC}$, A | Measured data Gs |
|---|---|---|---|---|---|
| $0.2{\times}I_{SC}$=358 | 0 | 0 | 987 | 400 | 1067 |
| | 176 | 0 | 989 | 500 | 1350 |
| | 588 | 412 | 996 | 600 | 1600 |
| $0.4{\times}I_{SC}$=716 | 588 | 412 | 1986 | 644 | 1730 |
| | 940 | 412 | 1989 | 700 | 1880 |
| | 1176 | 824 | 1995 | 750 | 2210 |
| $0.6{\times}I_{SC}$=1074 | 1176 | 824 | 2982 | | |
| | 1352 | 824 | 2984 | | |
| | 1764 | 1236 | 2988 | | |
| $0.8{\times}I_{SC}$=1432 | 1764 | 1236 | 3971 | | |
| | 1940 | 1236 | 3972 | | |
| | 2352 | 1648 | 3983 | | |
| $1{\times}I_{SC}$=1790 | 2352 | 1648 | 4955 | | |
| | 2528 | 1648 | 4957 | | |
| | 2940 | 2060 | 4964 | | |

June: mapper delivery to JINR and installation of stationary Hall probes (40 – sensors evenly distributed over the inner surface of the solenoid)

July-September: MF measurements at 02-0.55 T

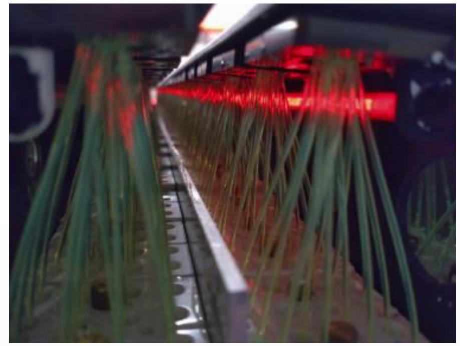
*Drawing of mapper by S. Gerasimov
*Computing calculation table data by E. Antokhin

# Central barrel subsystems

## Frame - ready

Successful test installation of the carbon fiber support frame in the magnet, sagita ~ 5 mm at full load, rails for the TPC and TOF are installed

## ECAL



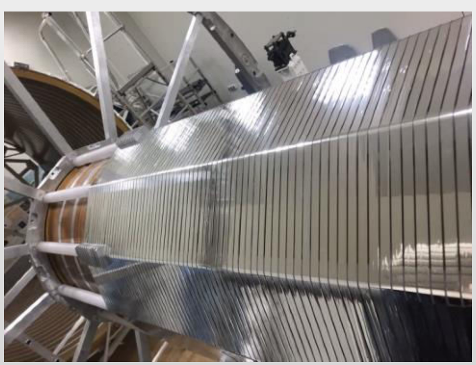
ECAL ~ 38400 towers (2400 modules)
produced by Tsinghua University, Shandong University, Fudan University, South China University, Huzhou University and JINR – production in IHEP (Protvino) and Tenzor (Dubna)

40(45) half-sectors to be ready by August (December), rest depends on WLS fiber supply from Tver (production rate 6 km/month, need 60 km)

## TOF - ready

All 28 (100%) TOF modules are assembled, tested, stored and ready for installation.
Spare modules in production

## TPC – central tracking detector



24+ ROC ready; 100+ % FE cards manufactured
TPC gas volume assembly and HV/leakage tests – ongoing
TPC + ECAL cooling systems under commissioning

| | |
|---|---|
| **TPC mechanical body assembly with ROCs, leak test and HV test** | **July 2025** |
| **TPC installation to MPD and test** | **Nov – Dec 2025** |

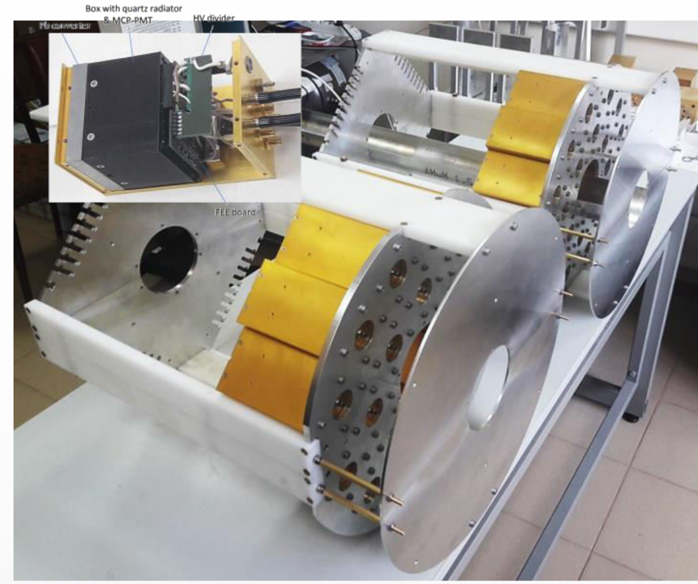
# Forward subsystems

## FHCAL - ready

FHCal assembled on the platform,
(modules are equipped with FEE)

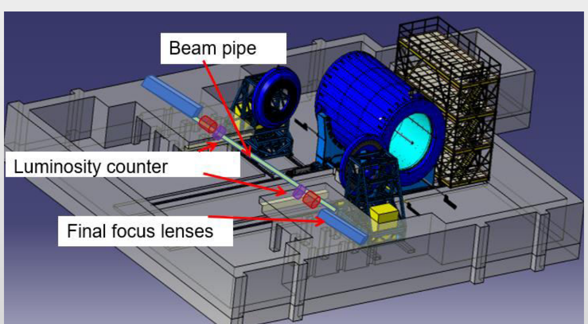
Test installation of FHCAL → autumn 2024
Final full installation → October 2025

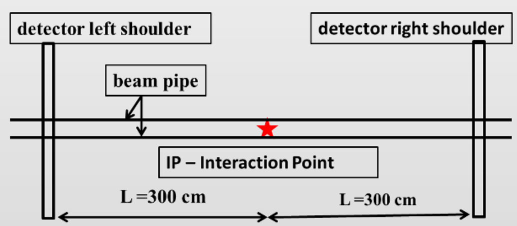
## FFD - ready



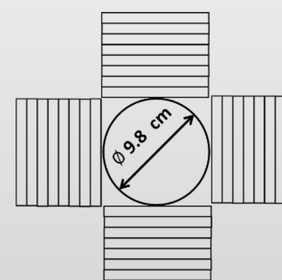
Cherenkov modules of FFDE and FFDW, mechanics for installation in container with beam pipe are available,
Long term tests with cosmic rays & laser ongoing

## Beam and luminosity monitoring




Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam




Assembly of the main components of the detector for the Run on the collider beam - summer 2025

NICA

# MPD schedule – 2025

| | | |
|---|---|---|
| 1 | January 13th- 30th | Solenoid and Correction Coils Power Supplies control system tests |
| 2 | January 25th – February 21st | Solenoid Safety regimes of emergent energy evacuation working out<br>Development of algorithms of cooling on base of experience with manual regime |
| 3 | February 1st – February 27th | Solenoid Power cable temperature isolation inside of the Chimney |
| 4 | March 3d – April 7th | Cooling down of the Solenoid to the working temperature 4K |
| 5 | April 7th -April 30th | Development procedure of current supplying to the Solenoid, training |
| 6 | June 2d – 25th | Installation stationary Hall probes |
| 7 | May 25th – June 20th | Final test of the Field Mapper at Novosibirsk |
| 8 | June 15th | Delivering Mapper to the JINR |
| 9 | June 25th - July 10th | Installation Magnetic Field Mapper, Calibration, preparation for measurements of Field |
| 10 | July 10th - September 30th | Magnetic field measurements on nominals: 0.2T, 0.3T, 0.4T, 0.45T, 0.5T, 0.55T |
| 11 | July 15th | TPC mechanical body is assembled, leak test and HV test are finished |
| 12 | October 1st – October 12th | Installation FHCal into poles |
| 13 | October 6th – November 10th | ECAL installation |
| 14 | October 13th – November 10th | Installation TOF modules (access from both sides ) |
| 15 | November 11th – December 20th | TPC installation and test |
| 16 | June 22d – November 30th | Cabling |
| 17 | December 4th – December 14th | Beam pipe installation |
| 18 | December 22d | Moving to the beam line |
| 19 | December 30th | Readiness for Data taking |

Starting detector commissioning in late 2025 remains the main priority

# Funding

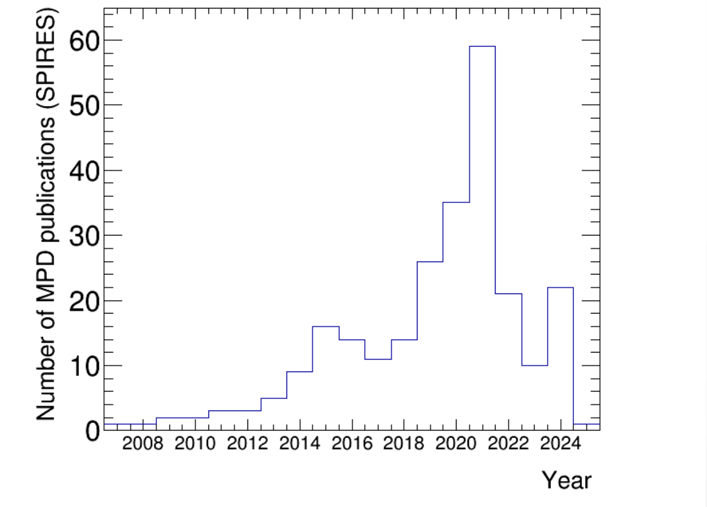
- Support program from Russian Ministry of Education and Science for NICA:
  - ✓ Russian groups from subordinated organizations participating in NICA with signed MOUs
  - ✓ 200 MRUB (~2.2 M$) in 2024 for all NICA activities: MPD, BM@N, SPD, ARIADNA collaborations, accelerator
  - ✓ program has been extended to 2025-2026
  - ✓ new participating institution are possible

- ~ 40 MRUB for MPD per year:
  - ✓ supported organizations: MEPhI, St. Petersburg Polytechnic University, INR RAS, Belgorod National Research University, North Ossetia State University

- Problems:
  - ✓ KI, MSU, SPbSU, HSE University are excluded from the program (not subordinated organizations)
  - ✓ no funds for travel (shifts, etc.)

# Scientific activity

- ~ 50 reports at international conferences per year
- Annual NICA Workshops organized by JINR-MEPhI, https://indico.jinr.ru/event/4973/overview
- Overall publication activity (200+ publications SPIRES indexed) :




- Collaboration papers:

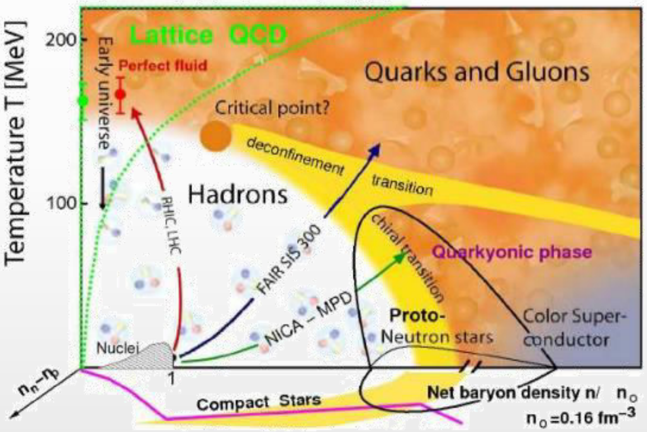
  I. **Status and initial physics performance studies of the MPD experiment at NICA**
  Eur.Phys.J.A 58 (2022) 7, 140 (~ 50 pages)

  II. **MPD physics performance studies in Bi+Bi collisions at $\sqrt{s_{NN}}$ = 9.2 GeV**
  consolidation and publication of physics feasibility studies for BiBi@9.2 GeV, 40+ pages

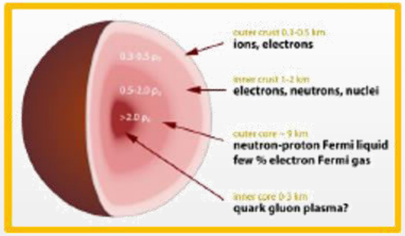
  arXiv:2503.21117 [nucl-ex], accepted by Revista Mexicana de Física

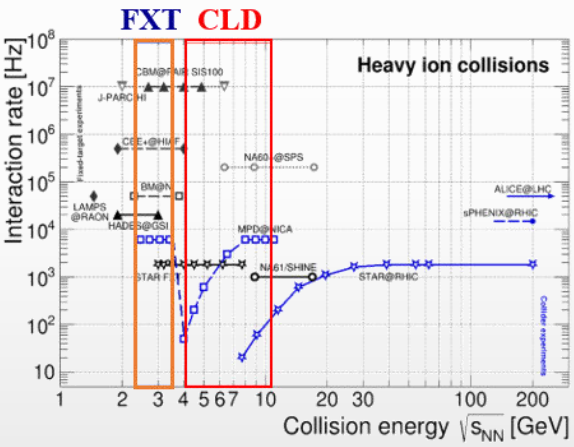
# Physics feasibility studies

- ❖ Physics feasibility studies using centralized large-scale MC productions
- ❖ Centralized Analysis Framework for access and analysis of data → Analysis Train:
  - ✓ consistent approaches and results across collaboration, easy storage and sharing of codes
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes
- ❖ Heavily rely on the LIT and VBLHEP computing resources, thanks to computing and software teams!
- ❖ Develop physics program, software and analysis infrastructure for real data analysis




high baryon densities
→ inner structure of
compact stars



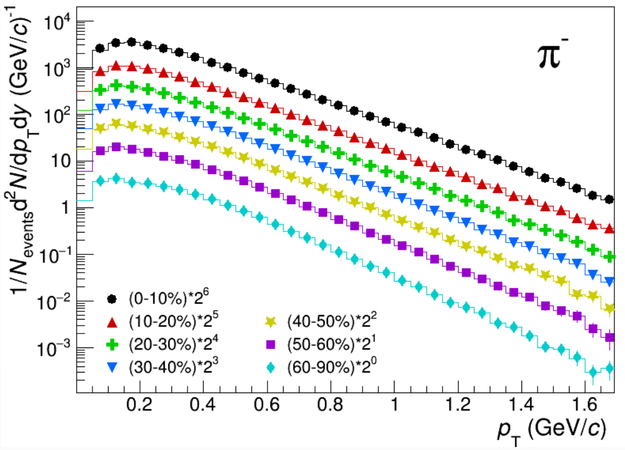



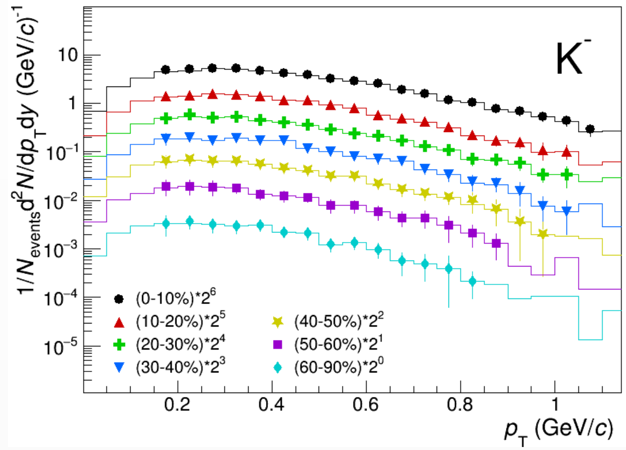

QCD medium at extreme net baryon densities → 1st order phase transition + CEP

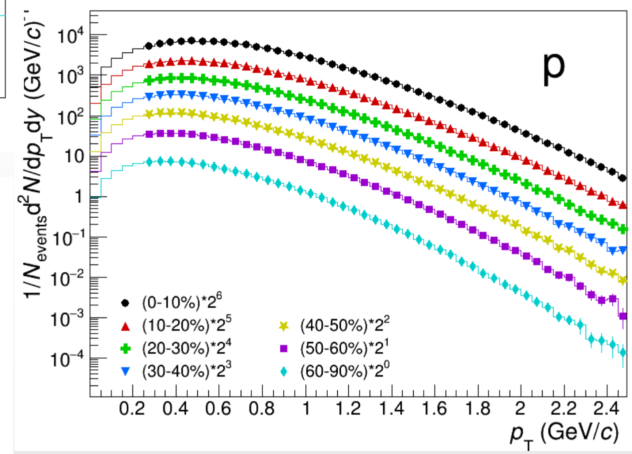
- ❖ MPD-CLD and MPD-FXT from start-up:
  - ✓ Collider mode: Xe+Xe (Bi+Bi) at $\sqrt{s_{NN}}$ ~ 7 GeV
  - ✓ Fixed-target mode: Xe (Bi) beam + W/Au target (~ 50-100 μm wire) at $\sqrt{s_{NN}}$ ~ 3 GeV :
    - extends energy range to those of (HADES, BM@N, CBM); high event rate even with low-intensity beam

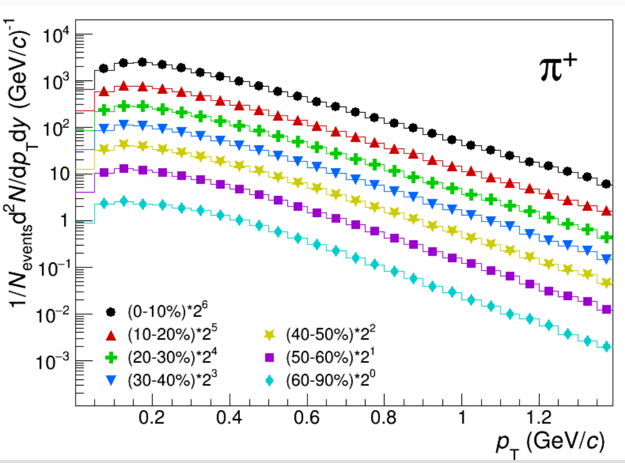
# MPD-FXT: Identified charged π/K/p - I

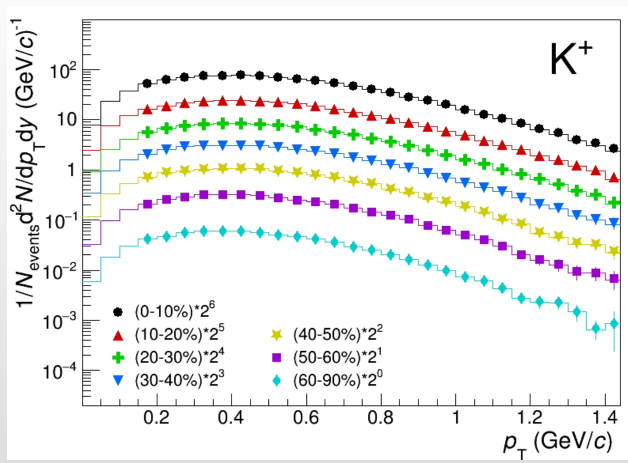
- XeW@ T=2.5 AGeV (UrQMD), 15 M events → full event/detector reconstruction
- π/K/p identification based on n-sigma selections in the TPC/TOF → good for the first-day measurements



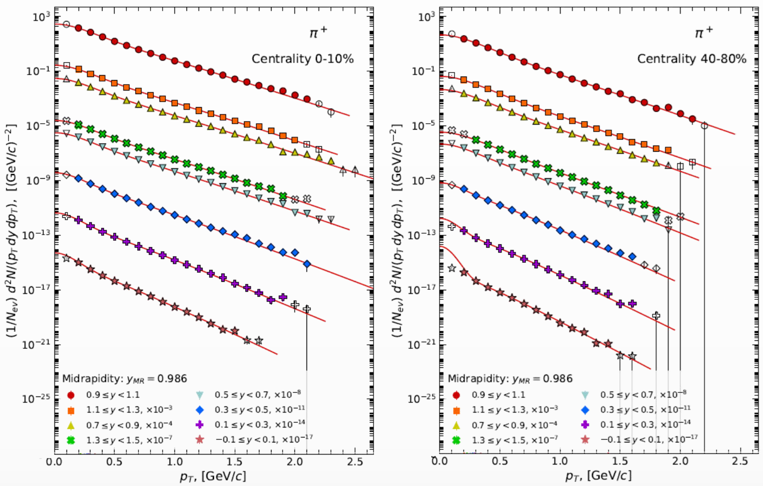



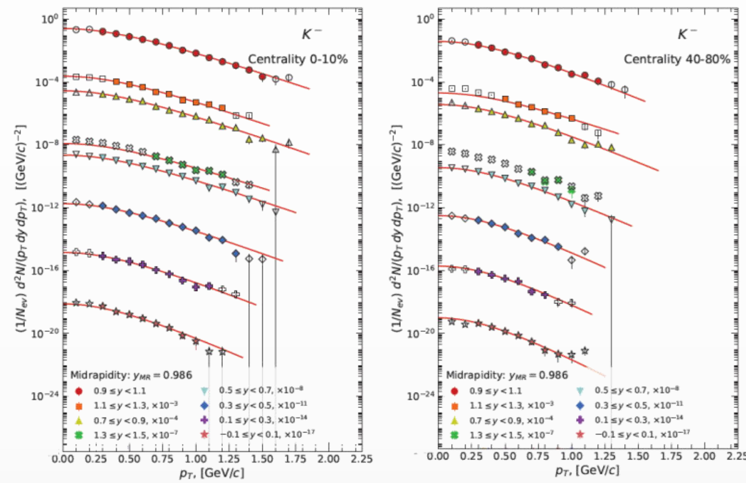

**Best possible coverage at low-$p_T$ → ideal for dN/dy and $\langle p_T \rangle$**

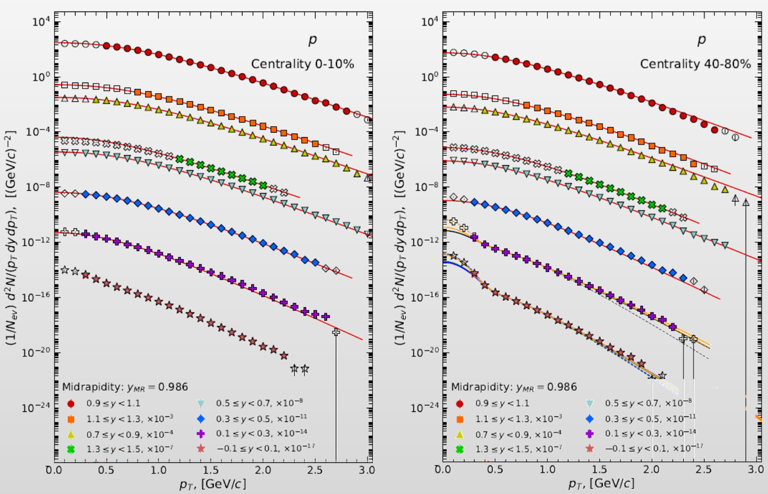
**Sampled $p_T$ range accounts for > 95% ($\pi^{\pm}$, $K^{+}$, p) and > 85% ($K^{-}$) of the total yield**

# MPD-FXT: Identified charged π/K/p - II

- XeW@ T=2.5 AGeV (UrQMD), 15 M events → full event/detector reconstruction
- π/K/p identification based on Bayesian probability in the TPC&TOF combined



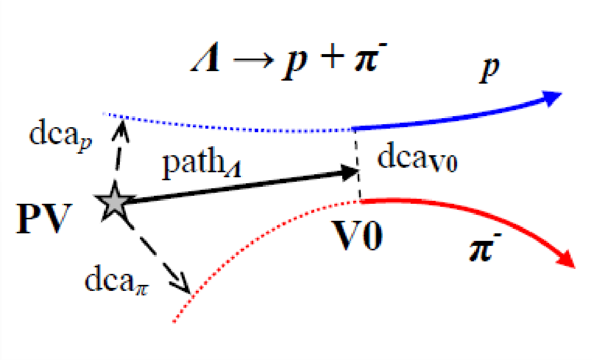



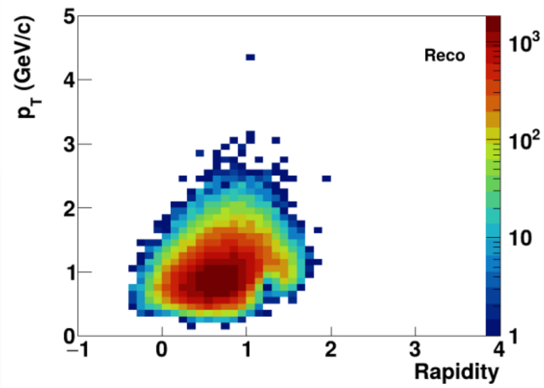

- **Better coverage at higher momenta, low-$p_T$ coverage is limited due to TOF-matching requirement**
- **Good for advanced study of spectra shapes, radial flow, differential particle ratios (B/M, etc.)**
- **Contamination corrections may be quite significant → require systematic study**

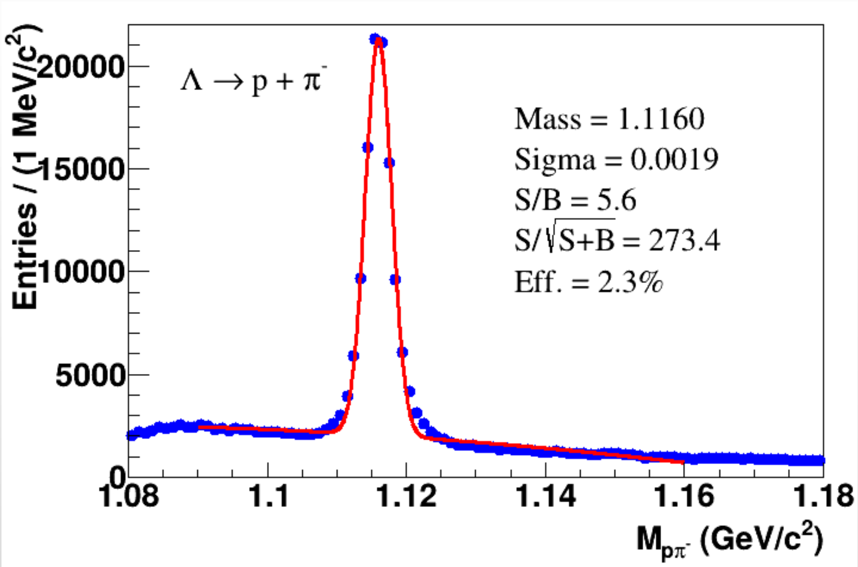
# MPD-FXT: Λ hyperon

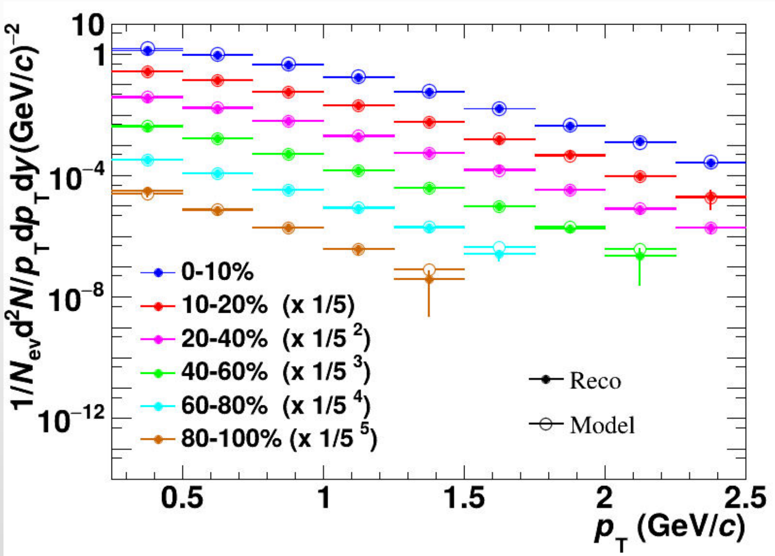
- XeW@ T=2.5 AGeV (UrQMD), 15 M events → full event/detector reconstruction
- Λ identification based on topological selections




MPD phase space for reconstructed Λ



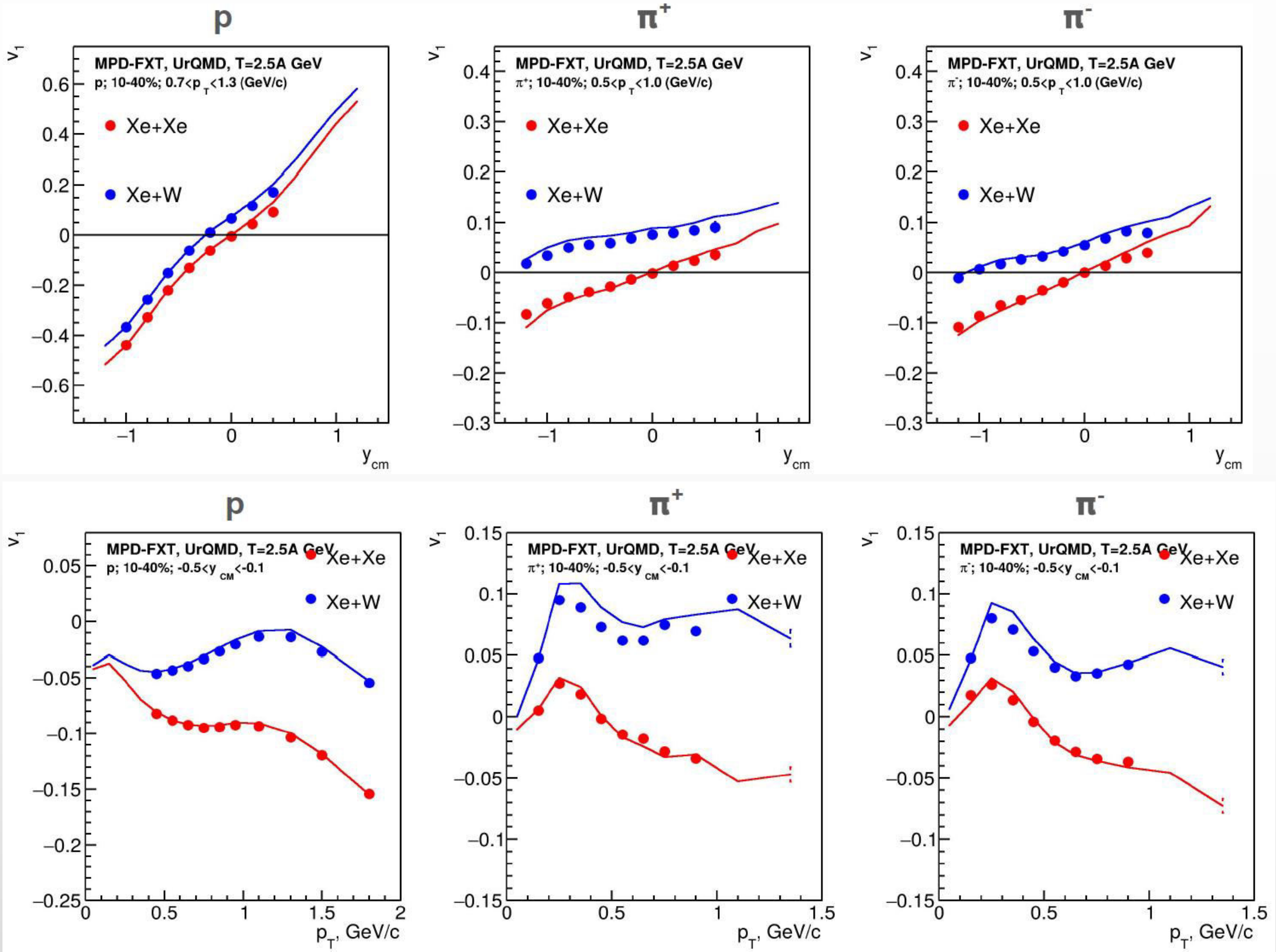

- **Good agreement between generated and reconstructed signals**

# MPD-FXT: $v_1$ for charged π and protons

- XeW@ T=2.5 AGeV (UrQMD), 15 M events → full event/detector reconstruction
- New: realistic PID (TPC+TOF); efficiency corrections; centrality by TPC multiplicity

***$v_1$* vs. rapidity**

***$v_1$* vs. $p_T$**



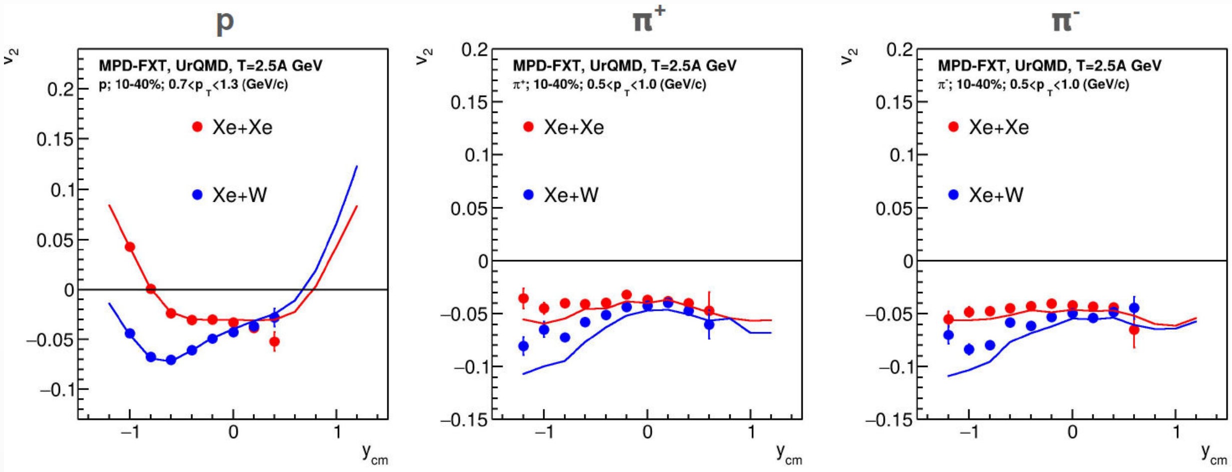

**Reconstructed and generated signals mostly agree**

**Some remaining discrepancies to be resolved**

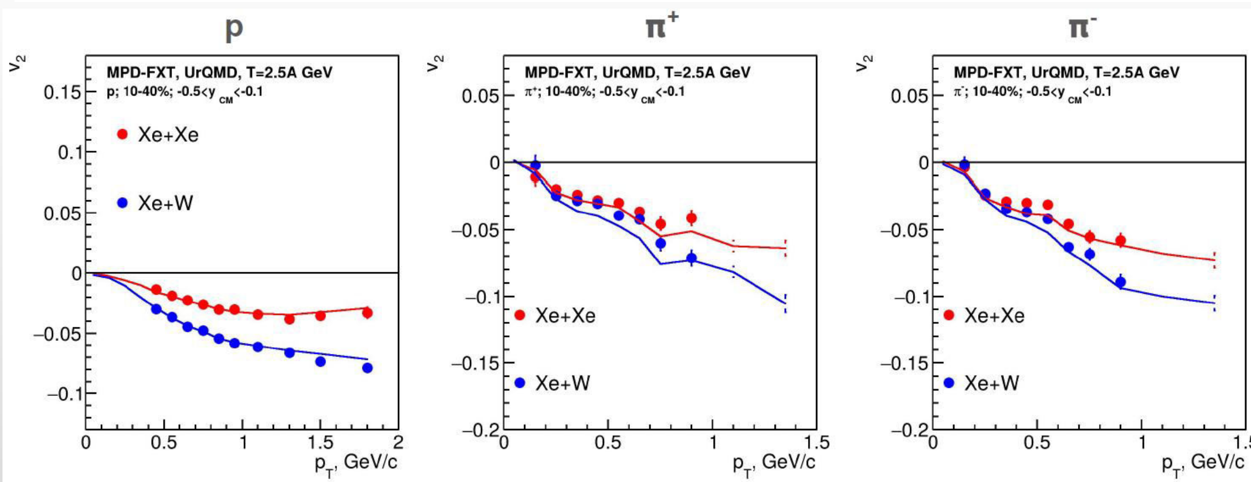
# MPD-FXT: $v_2$ for charged π and protons

- XeW@ T=2.5 AGeV (UrQMD), 15 M events → full event/detector reconstruction
- New: realistic PID (TPC+TOF); efficiency corrections; centrality by TPC multiplicity

**$v_2$ vs. rapidity**




**$v_2$ vs. $p_T$**

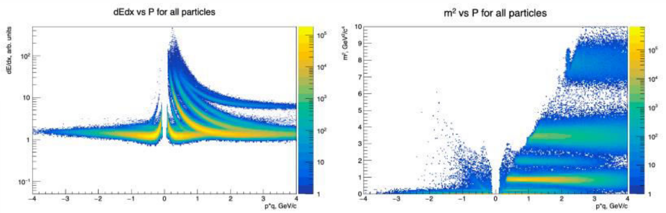


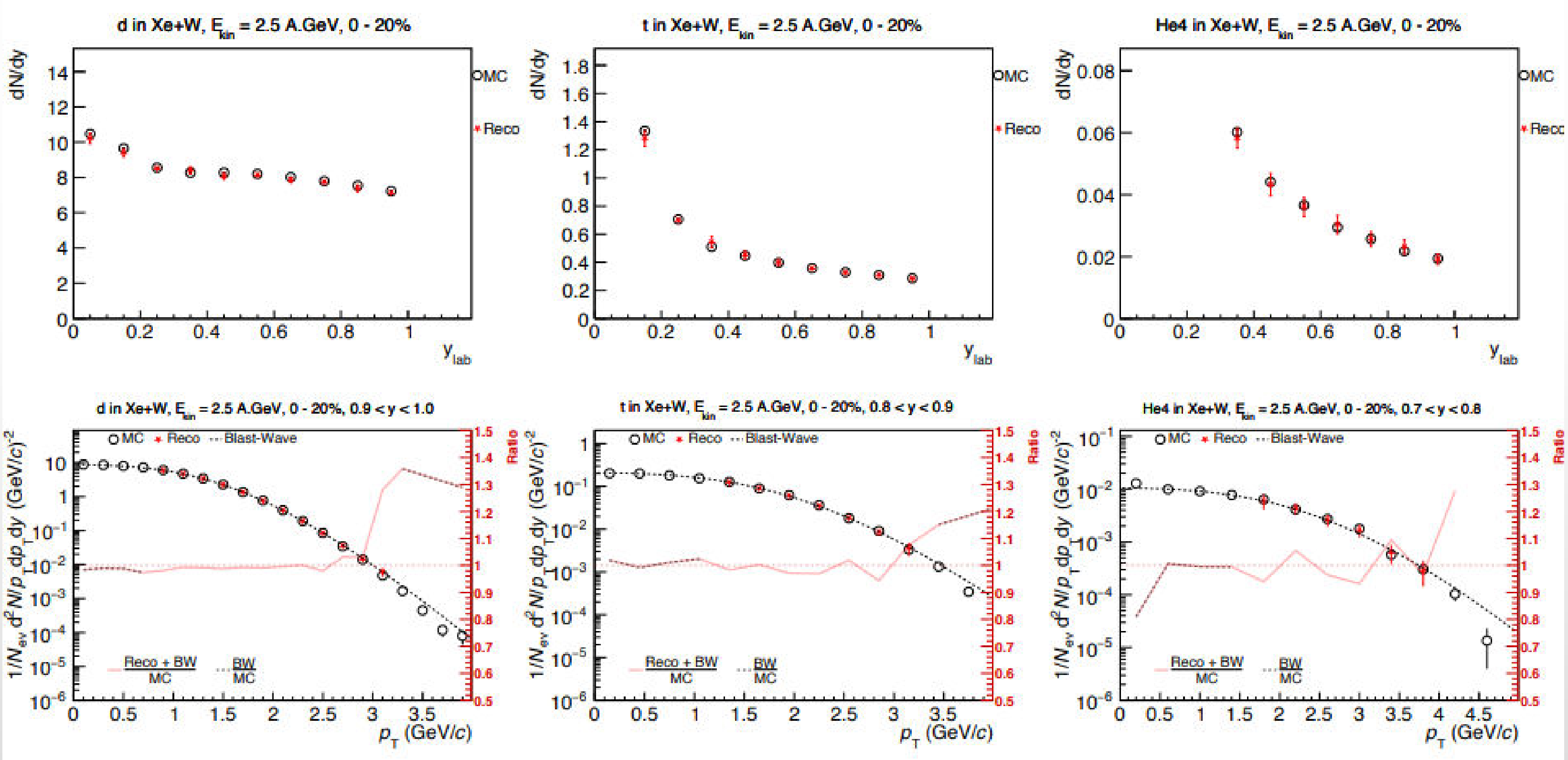

**Reconstructed and generated signals mostly agree**

**Some remaining discrepancies to be resolved**

# MPD-FXT: Light nuclei (d, t, $He^4$)

- XeW@ T=2.5 AGeV (PHQMD), 15 M events → full event/detector reconstruction
- Realistic PID (TPC+TOF); efficiency and contamination corrections

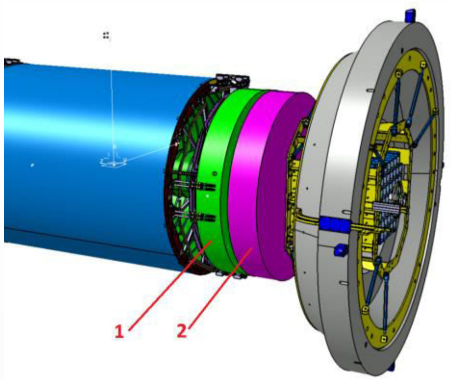


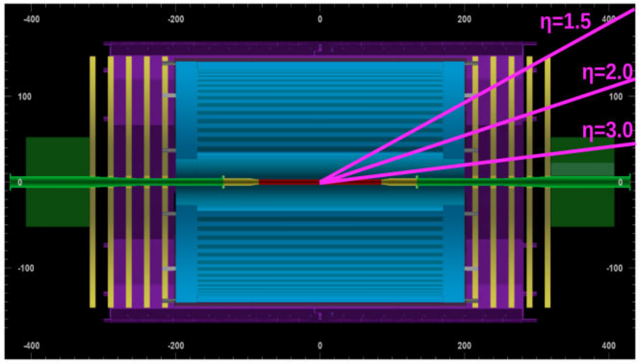

**Reconstructed and generated $p_T$ and rapidity distributions agree**

**Further developments to extend $p_T$ range of measurements**

# Development of the Forward Spectrometers

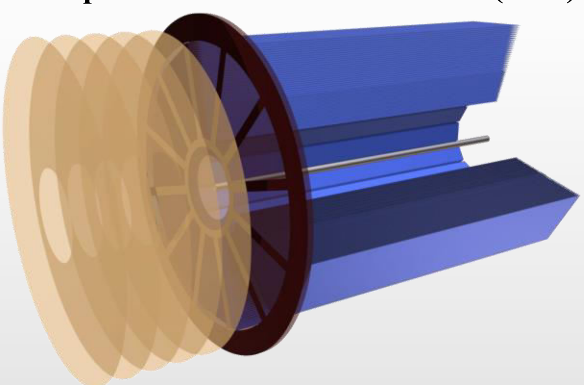



Two volumes (green and magenta) available for the installation of forward tracker stations

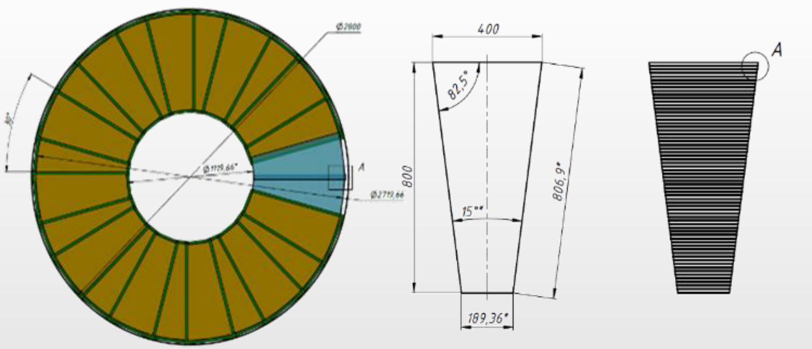



Pseudorapidity coverage of the forward spectrometer

**Conception of the Forward Tracker (FTD)**



**Conception of the end-cup TOF detector**



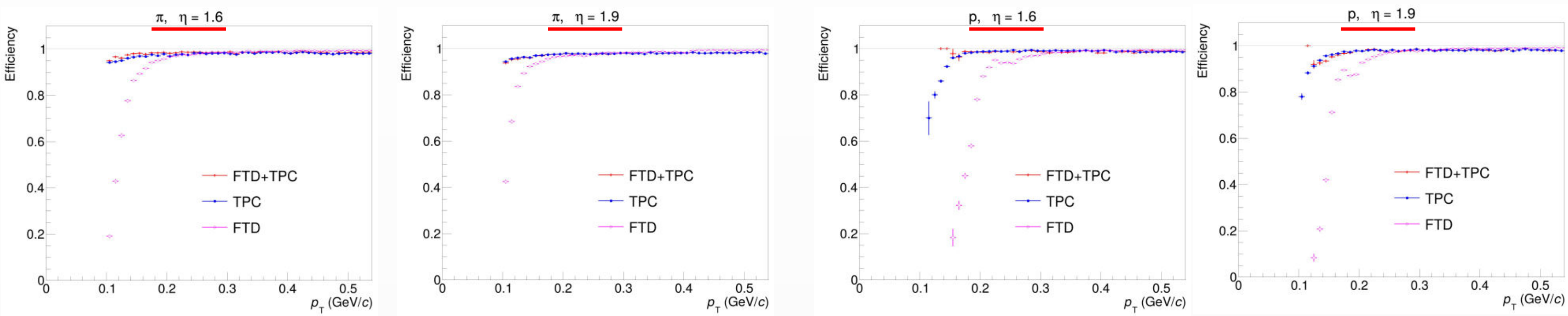

- ✓ five tracking layers within z = 210–300 cm,
- ✓ 1% $X_0$, ~ 80 μm spatial resolution
- ✓ a layer of MRPC-based TOF detectors, δτ ~ 50-70 ps

❖ Tracking: ACTS package for FTD alone and combined (FTD + TPC)

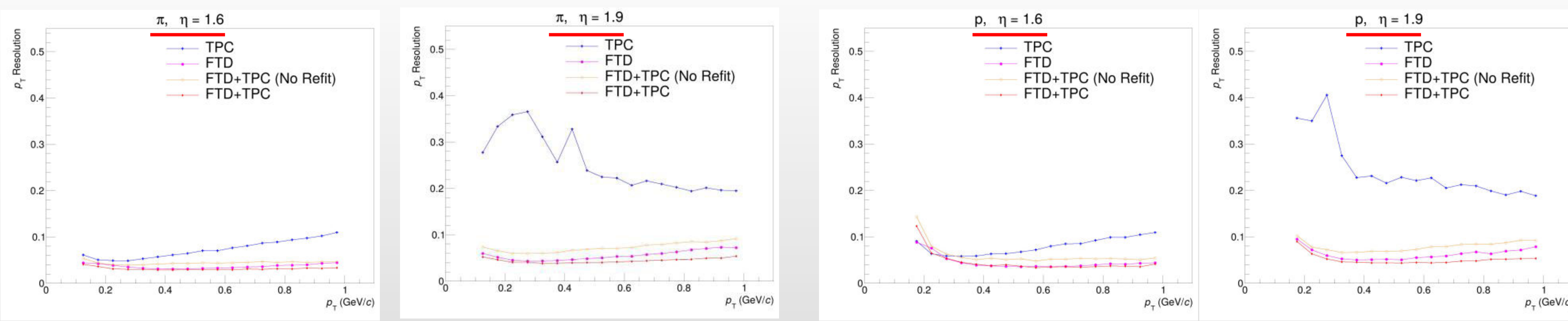
# Tracking efficiency and momentum resolution

- FTD performance for (FTD-alone) and (TPC+FTD) tracks for pions and protons at η = 1.6 and 1.9

**Reconstruction efficiency**



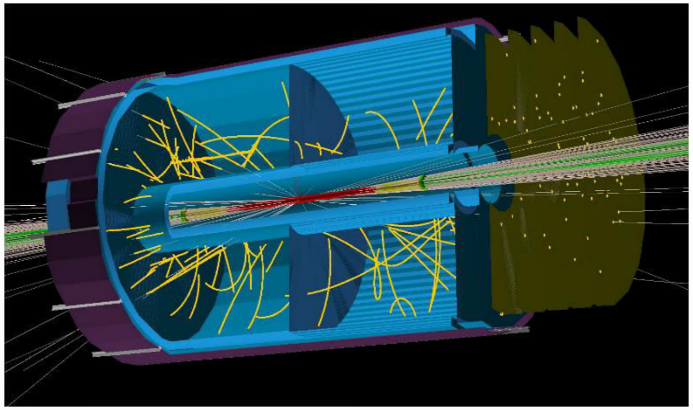

**Momentum resolution**



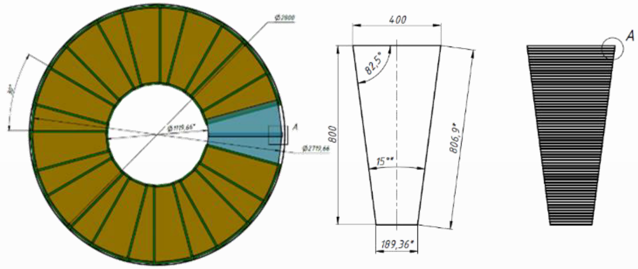

- ✓ FTD makes possible track reconstruction up to η ~ 2 with momentum resolution < 10%
- ✓ (FTD + TPC) tracks provide the best operation parameters

# Charged particle identification

❖ Last layer is a TOF detector built of MRPC chambers

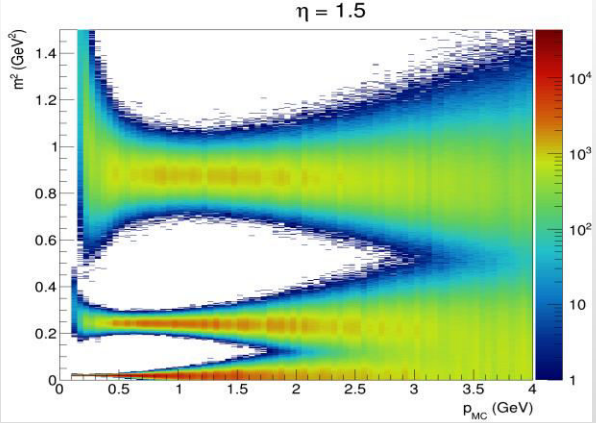


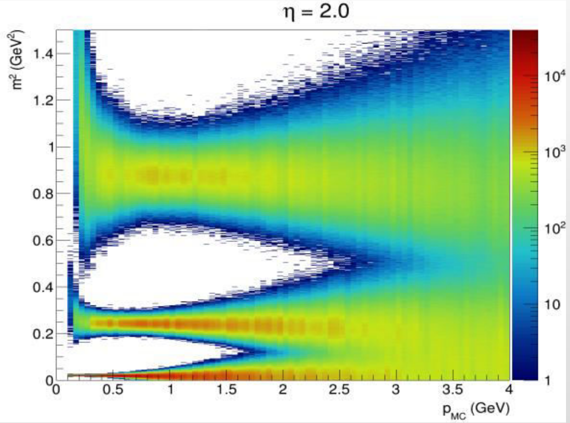
**End-cap TOF detector based on a trapezoidal MRPCs**




- ✓ each MRPC chamber contains 64 strips, which both-sides read-out
- ✓ each TOF ring contains 24 MRPCs → 6144 read-out channels in total
- ✓ same electronics based on NINO and HPTDC chips as in the basic TOF-MPD

❖ Reliable π/K/p separation vs. particle momentum for different rapidity ranges




Rather limited momentum resolution is compensated by a large path length (~3m) → reasonable PID for charged hadrons

# Summary


- MPD commissioning in the end of 2025 remains the main priority
- Extensive program of physics feasibility studies for MPD-CLD and MPD-FXT
- Prepare software and analysis infrastructure for real data analysis

# BACKUP

# MPD physics program

G. Feofilov, P. Parfenov

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

V. Kireev, 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, $\Lambda$ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward corr.
- Jet-like correlations

D. Peresunko, Chi Yang

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

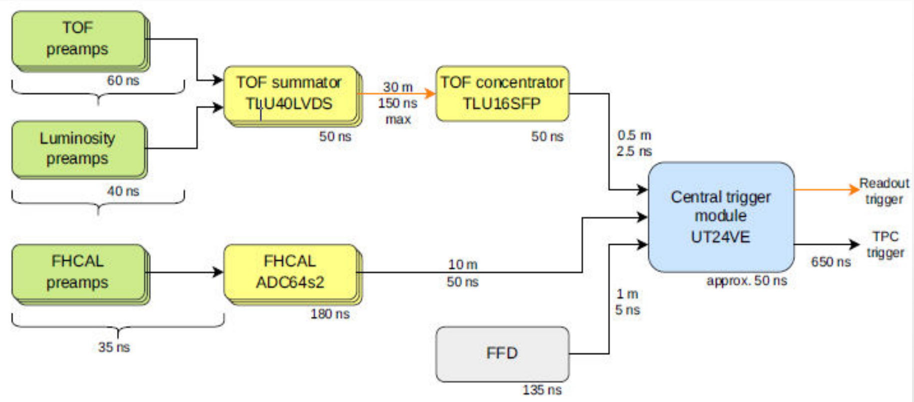
Wangmei Zha, A. Zinchenko

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

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

# Trigger detectors and performance

- FFD ($2.7 < |\eta| < 4.1$):
  - ✓ fast (~ 50 ps) event triggering → photons from $\pi^0$'s
  - ✓ $T_0$ for time-of-flight measurements (TOF and ECAL)
- TOF ($|\eta| < 1.5$):
  - ✓ 280 fast signals for each MRPC chamber
  - ✓ no online timing information
- FHCAL ($2 < |\eta| < 5$):
  - ✓ Fast signals for event triggering
  - ✓ poor $T_0$ (~ 1 ns) and event z-vertex resolution




| Trigger subsystems | | | Central trigger | TPC | Full delay |
|---|---|---|---|---|---|
| | Electronics delay | Cable delay | | | |
| TOF | 150 ns | 150 ns | 50 ns | 650 ns | ~1000 ns |
| Luminosity | 150 ns | 150 ns | | | |
| FHCAL | 200 ns | 50 ns | | | |
| FFD | 135 ns | 5 ns | | | |

**Trigger system of the MPD is effective for <u>different HI collision systems and energies</u> as well as for <u>different operation modes</u> (MPD-CLD vs. MPD-FXT)**