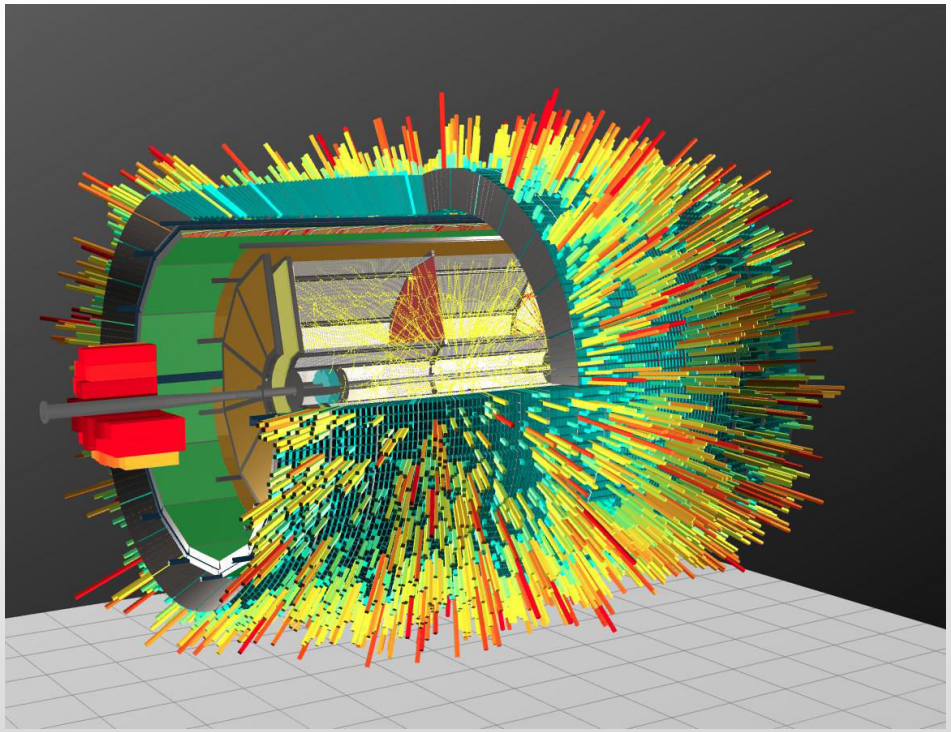
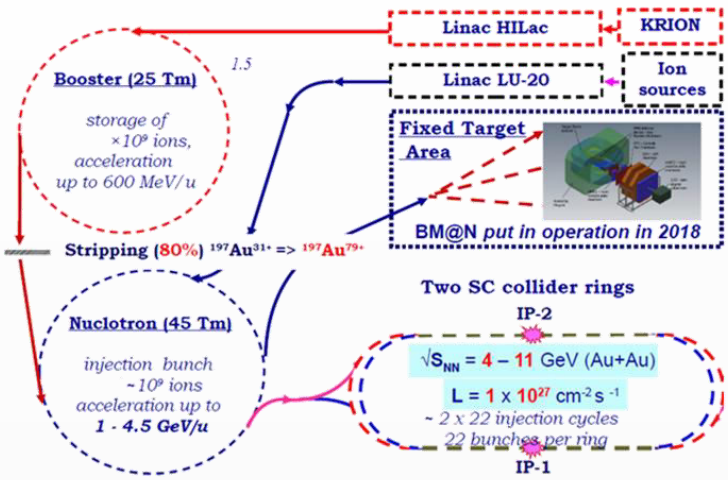
Статус эксперимента MPD-NICA

В. Рябов, ЛРЯФ ОФВЭ



NICA accelerator complex



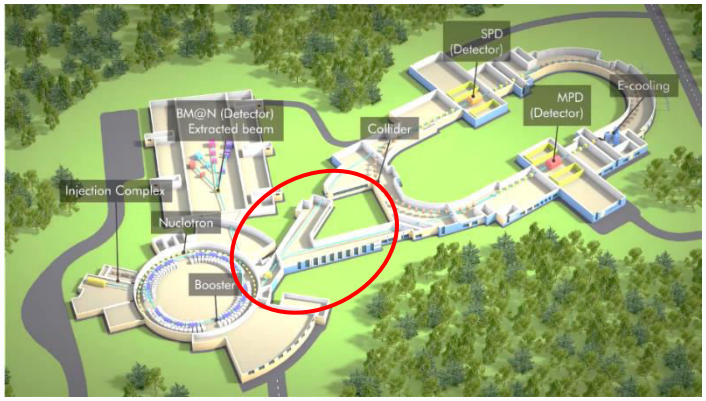
Booster

Nuclotron

- Stages of the accelerator complex commissioning:
  - ✓ HILAC + transfer line to Booster → commissioned in 2018 with He^{1+}, Fe^{14+}, C^{4+}, Ar^{14+} and Xe^{28+}
  - ✓ HILAC + Booster → first run in November-December, 2020 with He^{1+}
  - ✓ HILAC + Booster + transfer line to Nuclotron → second run in October, 2021 with He^{1+} and Fe^{16+}
  - ✓ HILAC + Booster + Nuclotron + transfer line to BM@N → third run in Jan. – Apr., 2022 with C^{6+}
  - ✓ HILAC + Booster + Nuclotron + transfer line to BM@N -> fourth run in September, 2022 – February, 2023 with Ar and Xe beams → 500+ M events at BM@N

NICA collider

Nuclotron-NICA transfer line

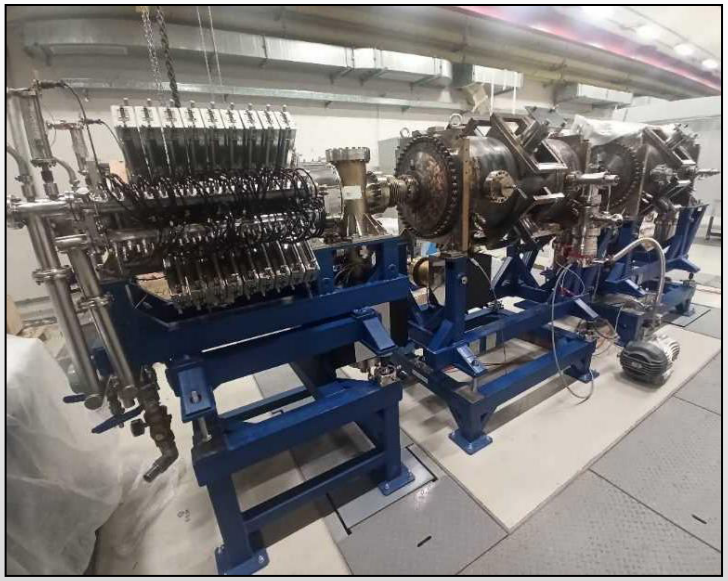


- Magnet and RF installation – nearly finalized
- Ongoing:
  - ✓ Fast extraction system from the Nuclotron
  - ✓ Nuclotron-to-Collider transfer line
- First run with beams – second half of 2025

NICA collider

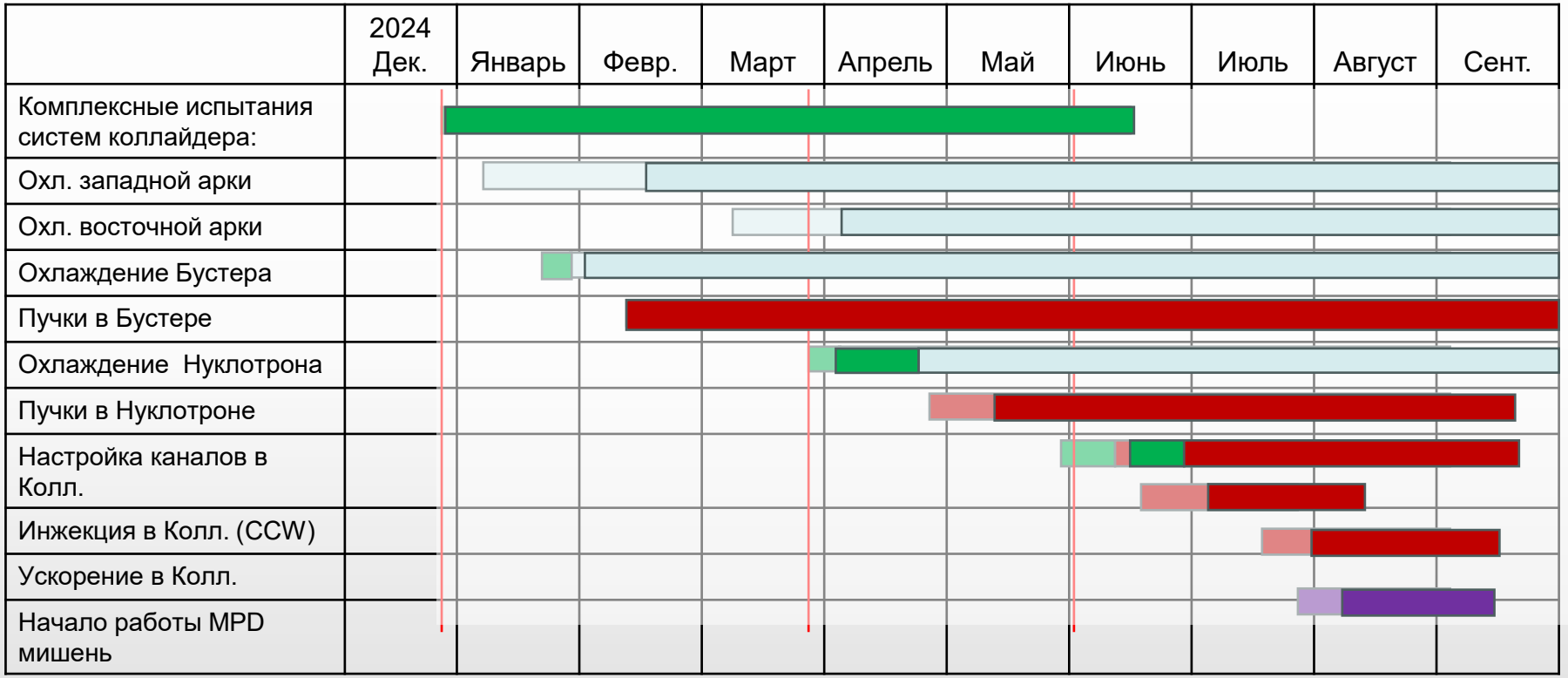
dipoles and quadrupoles have been installed in the tunnel

RF-1 и four RF-2 systems installed in the tunnel



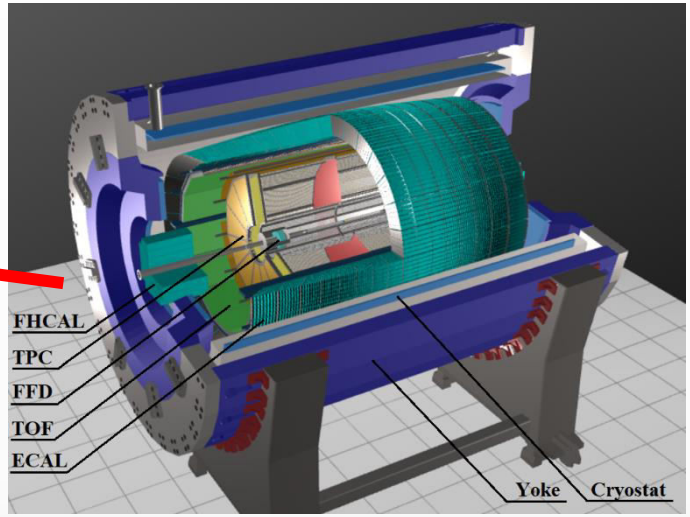
Пусконаладочные работы NICA

С 25.12.2024

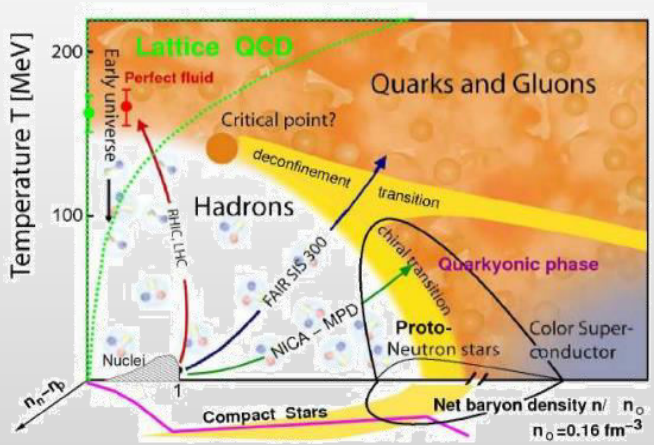


MPD @ NICA

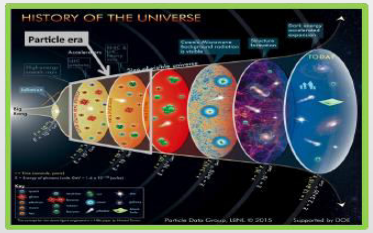
- One of two experiments at NICA collider to study heavy-ion collisions at $\sqrt{s_{NN}}$= 4(2.4)−11 GeV



TPC: |Δφ| < 2π, |η| ≤ 1.6; **TOF, EMC**: |Δφ| < 2π, |η| ≤ 1.4; **FFD**: |Δφ| < 2π, 2.9 < |η| < 3.3; **FHCAL**: |Δφ| < 2π, 2 < |η| < 5



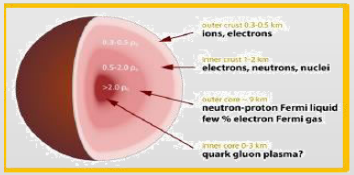
High beam energies ($\sqrt{s_{NN}}$ > 100 GeV)



High temperature:
Early Universe evolution

Low beam energies ($\sqrt{s_{NN}}$~ 10 GeV)

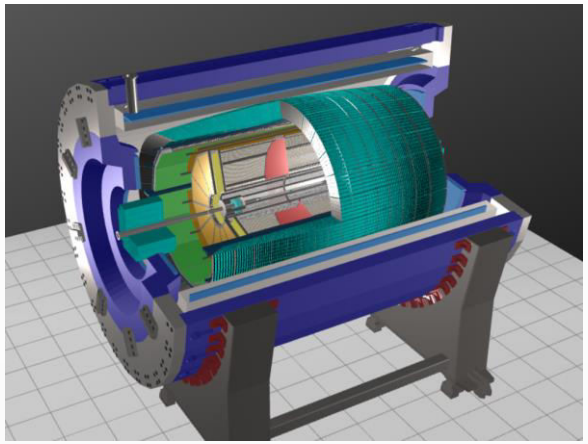
High baryon density:
Inner structure of
compact stars

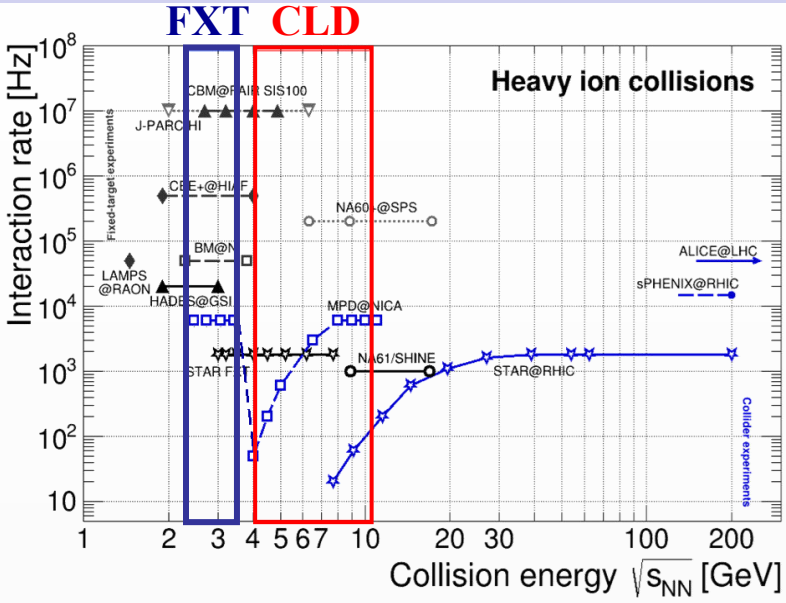


BM@N and MPD @ NICA study QCD medium at extreme net baryon densities

Fixed-target operation at NICA

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





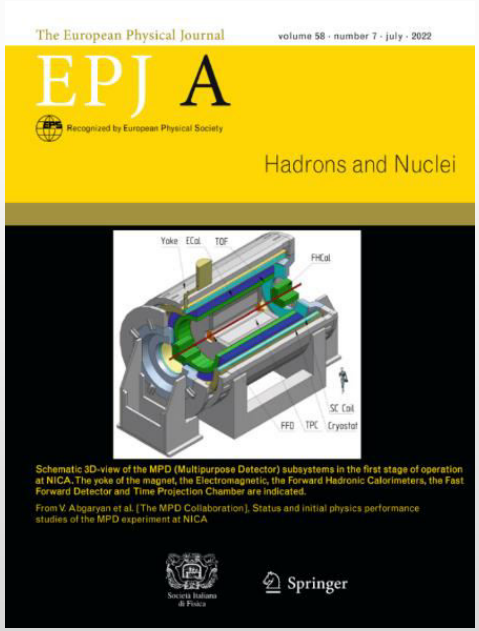
- MPD-CLD and MPD-FXT options approved by accelerator department (default option from start-up)
- Collider mode: two beams, $\sqrt{s_{NN}}$ = 4-11 GeV
- Fixed-target mode: one beam + thin wire (~ 50-100 μm) close to the edge of the MPD central barrel:
  - ✓ extends energy range of MPD to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N and CBM)
  - ✓ solves a problem of low event rate at lower collision energies (only ~ 50 Hz at $\sqrt{s_{NN}}$ = 4 GeV at design luminosity)
- Expected beam condition for the first year(s):
  - ✓ MPD-CLD: Xe+Xe/Bi+Bi at $\sqrt{s_{NN}}$ ~ 7 GeV, reduced luminosity → collision rate ~ 50 Hz
  - ✓ MPD-FXT: Xe/Bi+W at $\sqrt{s_{NN}}$ ~ 3 GeV

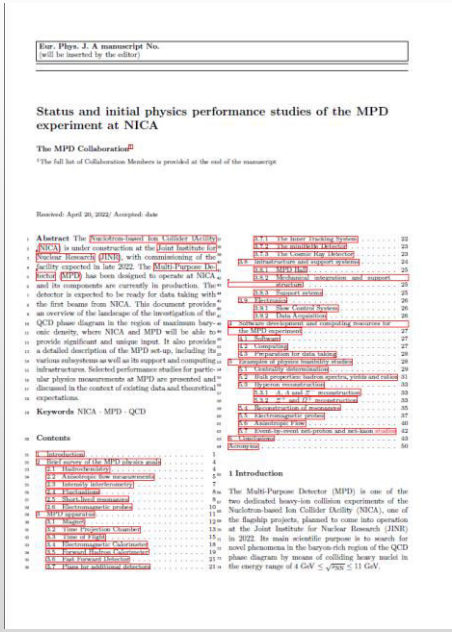
MPD strategy

- MPD strategy − high-luminosity scans in **energy** and **system size** to measure a wide variety of signals:
  - ✓ order of the phase transition and search for the QCD critical point → structure of the QCD phase diagram
  - ✓ hypernuclei and equation of state at high baryon densities → inner structure of compact stars, star mergers
- Scans to be carried out using the **same apparatus** with all the advantages of collider experiments:
  - ✓ maximum phase space, minimally biased acceptance, free of target parasitic effects
  - ✓ correlated systematic effects for different systems and energies → simplified extraction of physical signals

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

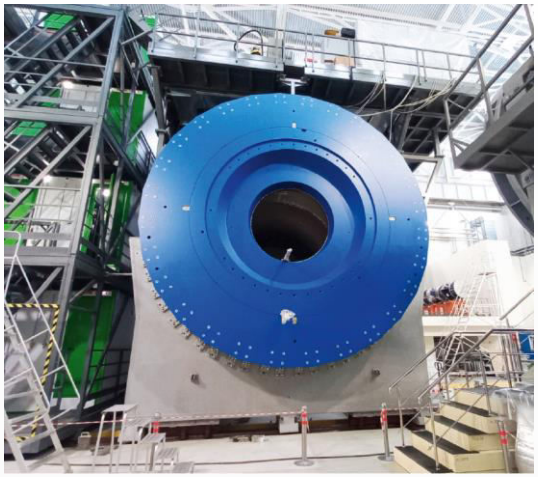
MPD Collaboration @ Eur.Phys.J.A 58 (2022) 7, 140 (~ 50 pages)





Activities in the MPD Hall

Magnet yoke



Cryogenic platform

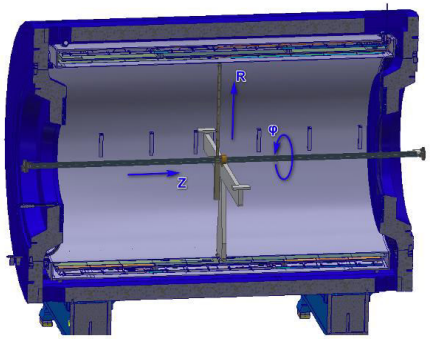
Strings for cryogenic pipes and cables hold

- First cooling if the magnet to below LN2 temperature of ~ 70^0 K in February-March 2024
- Cooling to LHe temperature in November → cooled to 4-5 K since December, 3

- Magnetic field measurements → beginning of 2025
- Installation of barrel detectors → middle of 2025
- Commissioning with beams → end of 2025

Detector construction

SC Solenoid + Iron Yoke + Mapper

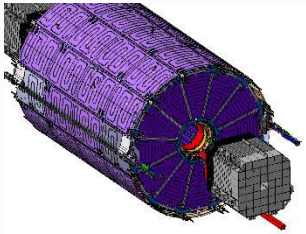


Novosibirsk BINP magnetic field mapper

	Along radius (R)	Along azimuth angle (ϕ)	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

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: ~ 4 months

TPC – central tracking detector



24+ ROC ready; FE ~ 90% manufactured; TPC gas volume assembly and HV/leakage tests – ongoing; TPC + ECAL cooling systems under commissioning; rails installation into support frame

Support structure

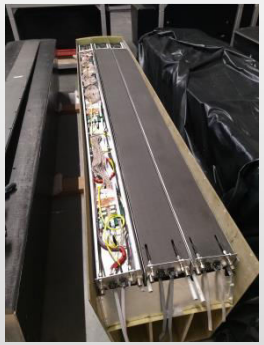
Carbon fiber support frame delivered and unpacked, sagita ~ 5 mm at full load, rails for the TPC and TOF are installed

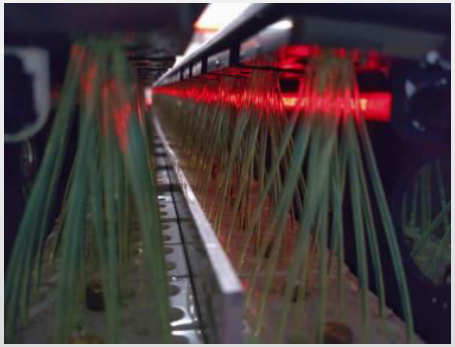
TOF - ready

28 modules are produced and ready for installation

ECAL

Assembly and tests of half-sectors





83% of calorimeter is ready in 2024. The rest of the baskets will be ready for mounting into MPD in April 2025

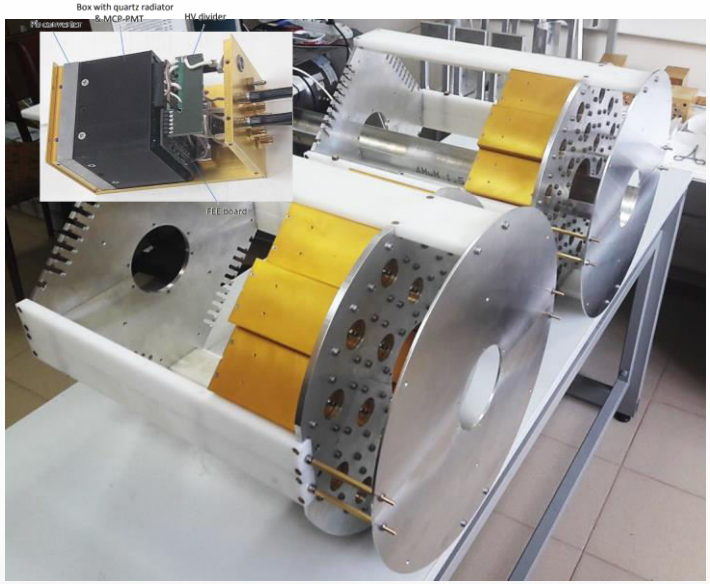
Forward subsystems in production

FHCAL

FHCal assembled on the platform, ready to be installed in the Poles (modules are equipped with FEE)

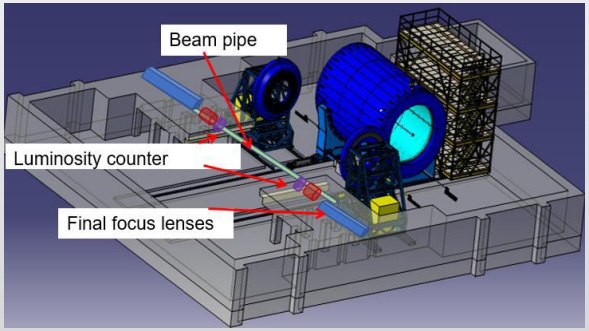
FHCAL modules have been produced and tested → installation in autumn 2024

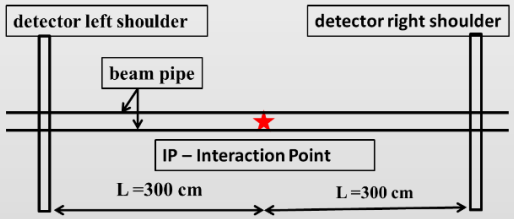
FFD



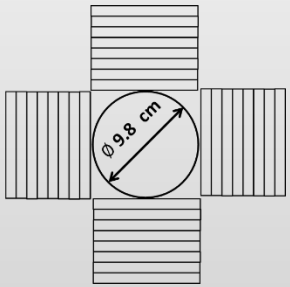
Cherenkov modules of FFDE and FFDW, mechanics for installation in container with beam pipe are available, Long term tests with cosmic rays & laser ongoing

Beam and luminosity monitoring





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



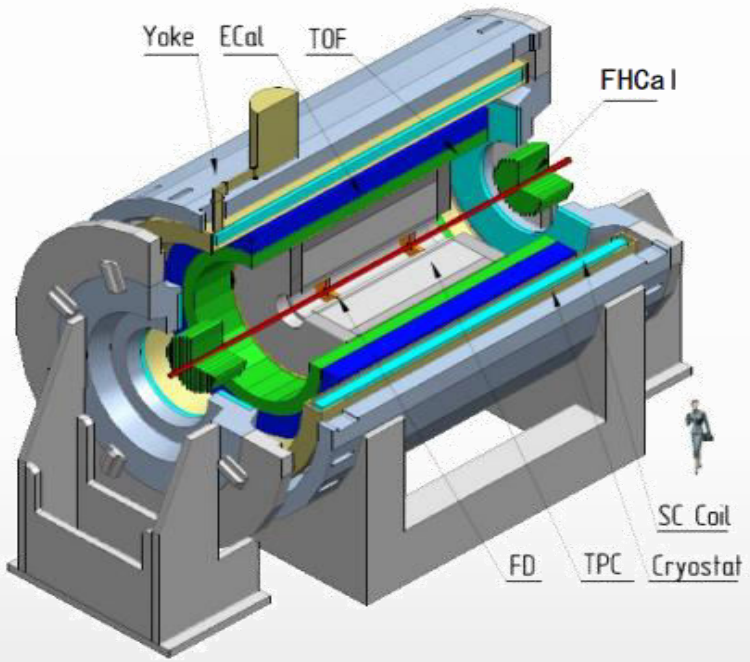
Multi-Purpose Detector (MPD) Collaboration

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

12** Countries, **>500** participants, **38** Institutes 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, Dubna**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*SSI "Joint Institute for Energy and Nuclear Research – Sosny" of the National Academy of Sciences of Belarus, Minsk, **Belarus***
*University of Plovdiv, **Bulgaria;***
*Tsinghua University, Beijing, **China**;*
*University of Science and Technology of China, Hefei, **China**;*
*Huzhou University, Huzhou, **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**;*
*Tbilisi State University, Tbilisi, **Georgia**;*
*Institute of Physics and Technology, Almaty, **Kazakhstan**;*
*Benemérita Universidad Autónoma de Puebla, **Mexico**;*
*Centro de Investigación y de Estudios Avanzados, **Mexico**;*
*Instituto de Ciencias Nucleares, UNAM, **Mexico**;*
*Universidad Autónoma de Sinaloa, **Mexico**;*
*Universidad de Colima, **Mexico**;*
*Universidad de Sonora, **Mexico**;*
*Universidad Michoacana de San Nicolás de Hidalgo, **Mexico***
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*

*Belgorod National Research University, **Russia**;*
*Institute for Nuclear Research of the RAS, Moscow, **Russia**;*
*High School of Economics University, Moscow, **Russia***
*National Research Nuclear University MEPhI , Moscow, **Russia**;*
*Moscow Institute of Science and Technology, **Russia**;*
*North Osetian State University, **Russia**;*
*National Research Center "Kurchatov Institute", **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***

2nd China-Russia Joint Workshop on NICA Facility

The 2nd China-Russia Joint Workshop on NICA Facility will be held in China from September 10th-13th. The workshop consists of a three-day scientific program held at Qingdao (Sep.10th -12th) and a discussion session held at Beijing (Sep.13th). The first-day operation of NICA facility will start in year 2025. The joint workshop aims to bring together the experimental experts and theorists on NICA hardware/physics from both China and Russia, discussing the most recent progresses, plans and opportunities on NICA facility.

The proposed topics will include but are not limited to:

Local organization:

Sessions at Qingdao: Shandong University, Fudan University, Central China Normal University, University of Science and Technology of China.

Sessions at Beijing: Tsinghua University, Institute of Modern Physics of Chinese Academy of Sciences, University of Chinese Academy of Sciences.

Local organization committee:

Deqing Fang (Fudan University)

Shuang LI (Three Gorges University)

Zebo Tang (University of Science and Technology of China, *co-chair*)

Jiansong Wang (Huzhou University)

Xiaodong Wang (University of South China)

Yaping Wang (Central China Normal University)

YI Wang (Tsinghua University, *co-chair*)

Guannan Xie (University of Chinese Academy of Sciences)

Chi Yang (Shandong University, *co-chair*)

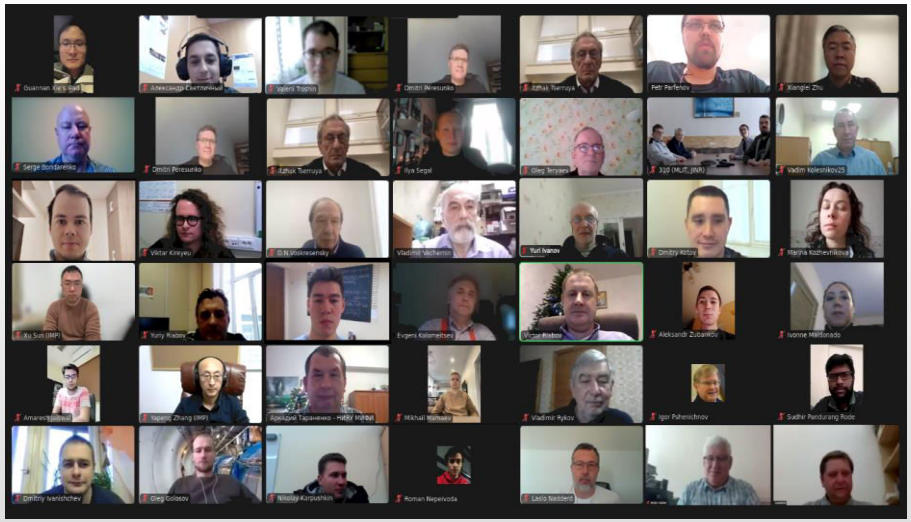
ChengXin Zhao (Institute of Modern Physics of the Chinese Academy of Science)

Indico.jinr.ru/event/4642

Conferences and workshops

- MPD presentations at conferences since last meeting (> 40 talks):
  - ✓ ICPPA - 2024, Moscow, Russia, Oct 22-25
  - ✓ Hard Probes - 2024, Nagasaki, Japan, Sep 22-27
  - ✓ HEP&FT - 2024, Protvino, Russia, July 23025
  - ✓ Nucleus - 2024, Dubna, Russia, July 1-5
  - ✓ HSFI - 2024, Gatchina, Russia, July 8-12
  - ✓ XIV LASNPA - 2024, Mexico, June 17-21
  - ✓ CPOD - 2024, Berkeley, USA, May 20-24

- JINR-MEPhI organized International Workshop NICA-2024
  - ✓ joint platform for discussion of NICA physics at BM@N and MPD



Co-chairs
Arkadiy Taranenko (MEPhI, JINR)
Evgeni Kolomeitsev (JINR, UMB, Banska Bystrica)
Victor Riabov (PNPI, MEPHI)

Organizing commitee
Zebo Tang (USTC, China)
Yi Wang (Tsinghua University, China)
Shusu Shi (CCNU, China)
Natalia Barbashina (MEPhI)
Ivan Astapov (MEPhI)
Dmitry Blau (NRC Kurchatov Institute)
Serge Bondarenko (BLTP JINR)
Fedor Guber (INR RAS)
Vadim Kolesnikov (JINR)

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. 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

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

MPD mass productions

- Physics feasibility studies using centralized large-scale MC productions → consistent picture of the MPD physical capabilities with the first data sets, preparation for real data analyses
- https://mpdforum.jinr.ru/c/mcprod/26:

  Request 25: General-purpose, 50M UrQMD BiBi@9.2 → **DONE**

  Request 26: General-purpose (trigger), 1M DCM-QGSM-SMM BiBi@9.2 → **DONE**

  Request 27: General-purpose (trigger), 1M PHQMD BiBi@9.2 → **DONE**

  Request 28: General-purpose with reduced magnetic field, 10M UrQMD BiBi@9.2 → **DONE**

  Request 29: General-purpose (hypernuclei), 20M PHQMD BiBi@9.2 → **DONE**

  Request 30: General-purpose (hyperon polarization), 15M PHSD BiBi@9.2 → **DONE**

  Request 31: General-purpose (femtoscopy), 50 M UrQMD BiBi@9.2 with freeze-out → **DONE**

  Request 32: General purpose (flow), 15M vHLLE+UrQMD with XPT → **DONE**

  Request 33: General purpose (FXT), (11 x 3)M UrQMD (mean field) → **DONE**

  Request 34: General-purpose, 15M UrQMD BiBi@9.2, electron enhanced → **DONE**

  Request 35: General-purpose, 15M UrQMD (mean-field) Xe+W@2.9 (FXT) → **DONE**

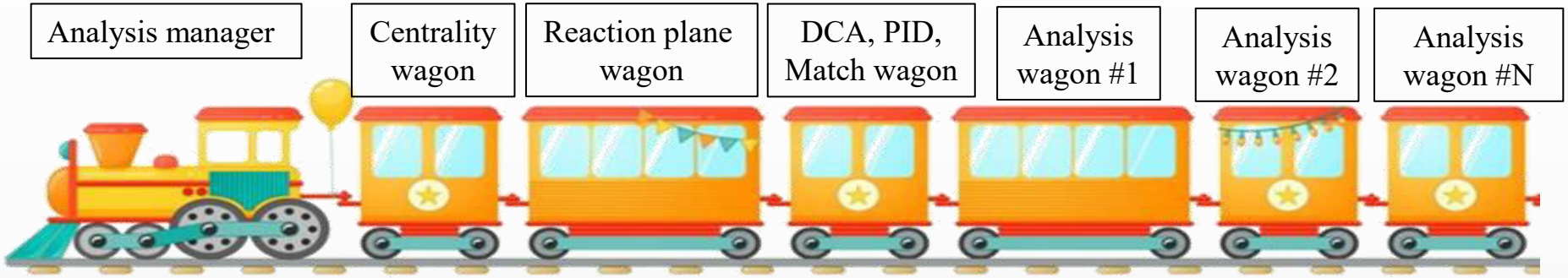
  Request 36: General-purpose, 15M UrQMD (mean-field) Xe+Xe@2.9 (FXT) → **DONE**

- Production comparable in size to the first expected real data samples test the existing computing and software infrastructure
- Develop realistic analysis methods and techniques, set priorities and find group leaders

Handling the big data sets

- Centralized Analysis Framework for access and analysis of data:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes

- Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:



- First Analysis Train runs started in September, 2023 → regular runs on request ever since
- Many new services and improvements (improved PID parameterizations, new wagons):
  - ✓ https://indico.jinr.ru/event/4401/: constrained tracks, track ID refits
  - ✓ https://indico.jinr.ru/event/4314/: track quality selections
- Train become a new standard for physics (feasibility) studies

Summary

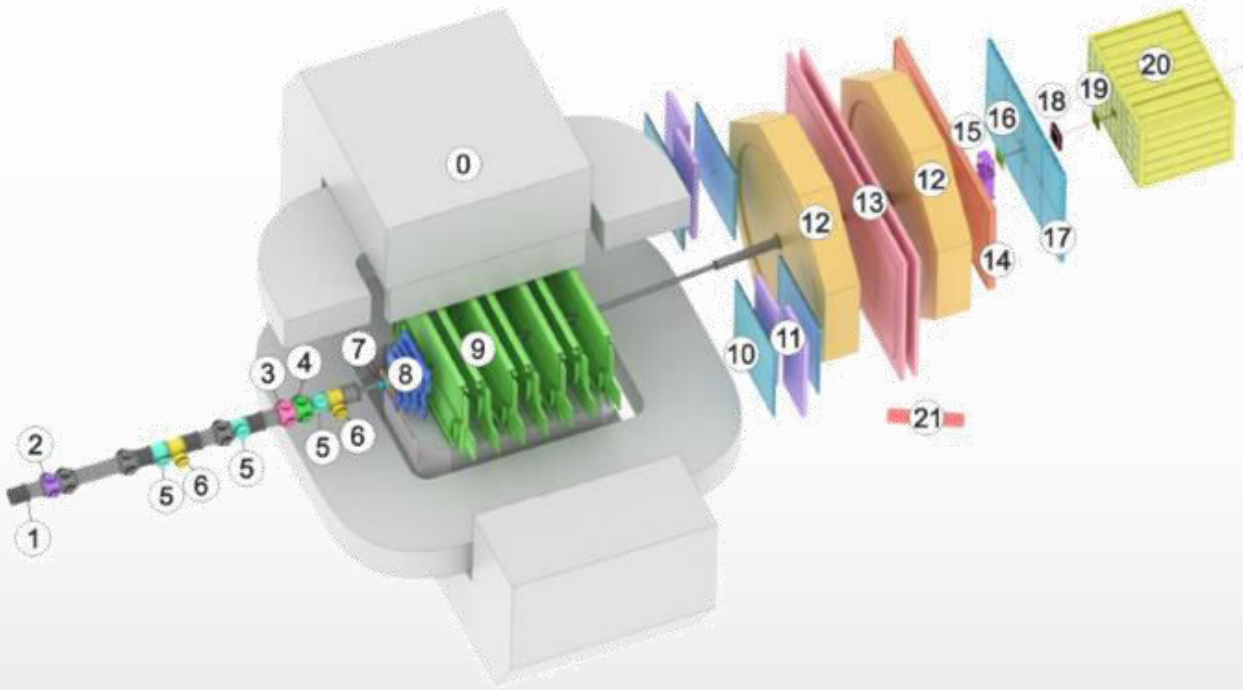
MPD Collaboration meeting in JINR (Dubna): October 14-16

- Heavy-ion collisions at $\sqrt{s_{NN}}$ = 2.4-11 GeV → QCD matter at maximum (net)baryon densities
- Preparation of the MPD detector and experimental program is continued
- Start of the MPD commissioning in 2025 is the main goal
- Develop physics program of the experiment, prepare tools and methods for data analysis


2025

Baryonic Matter @ Nuclotron

Nucl.Instrum.Meth.A 1965 (2024) 169352



- Magnet SP-41 (0)
- Vacuum Beam Pipe (1)
- BC1, VC, BC2 (2-4)
- SiBT, SiProf (5, 6)
- Triggers: BD + SiMD (7)
- FSD, GEM (8, 9)
- CSC 1x1 m^2 (10)
- TOF 400 (11)
- DCH (12)
- TOF 700 (13)
- ScWall (14)
- FD (15)
- Small GEM (16)
- CSC 2x1.5 m^2 (17)
- Beam Profilometer (18)
- FQH (19)
- FHCal (20)
- HGN (21)

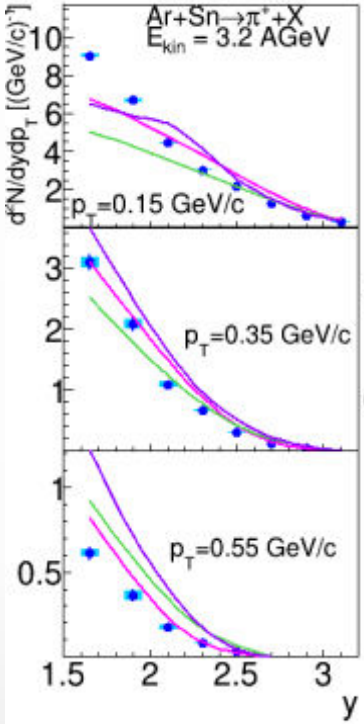
FSD, GEM, CSC, DCH: charged particle tracking + momentum measurements
TOF400, TOF700: charged particle identification by m^2/β
FQH, FHCAL: event geometry, event centrality

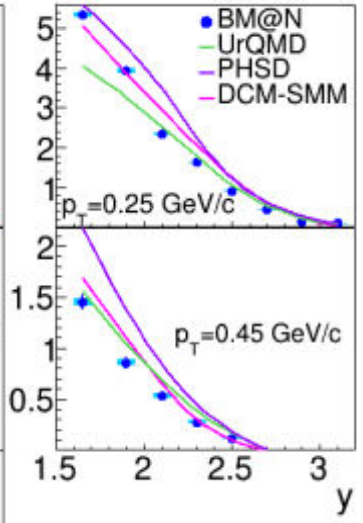
Several technical runs since 2015

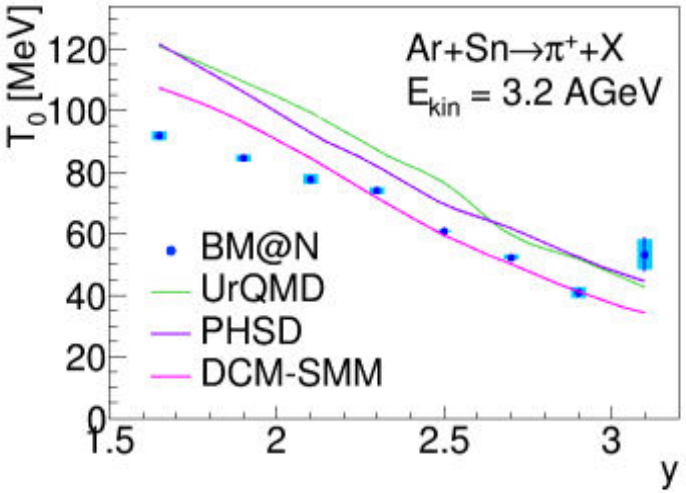
First physical run in 2022/2023: ^{124}Xe + CsI at 3 and 3.9 AGeV, > 5.5·10^8 events

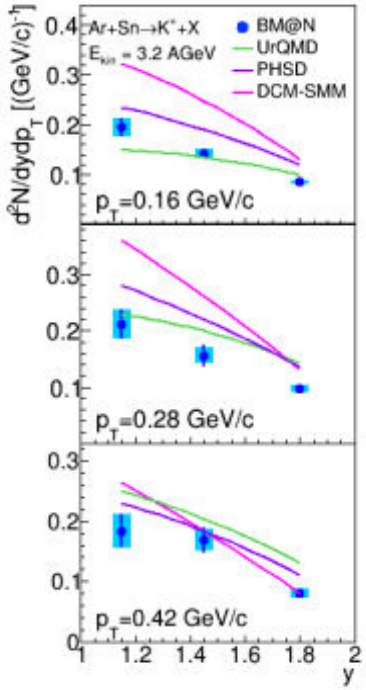
Production of π^+ and K^+ mesons in 3.2 AGeV argon-nucleus interactions at the Nuclotron

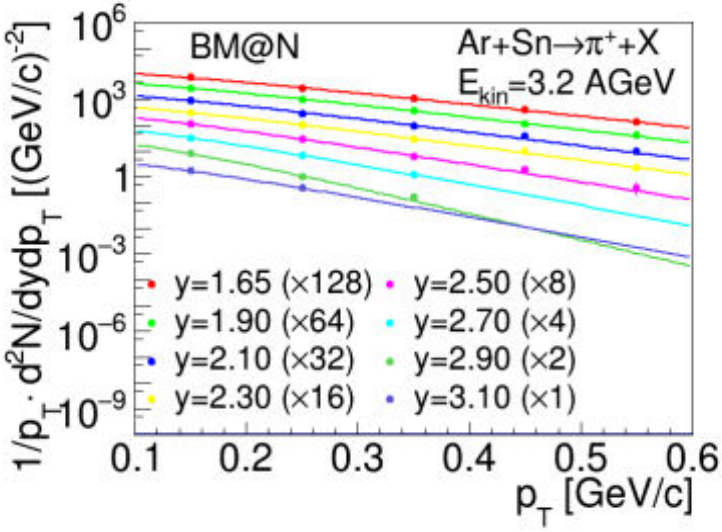
https://arxiv.org/abs/2303.16243v3
Published in JHEP 07 (2023) 174

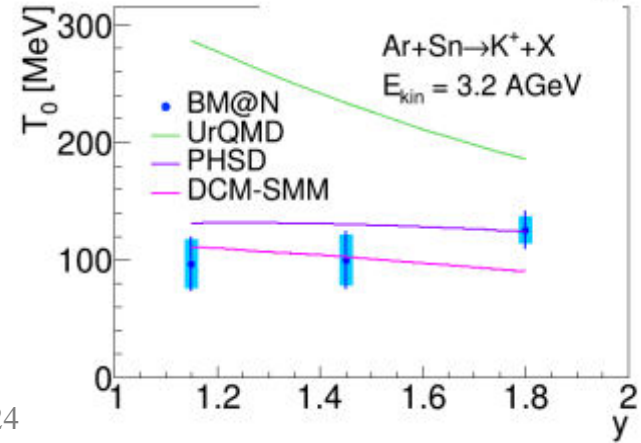




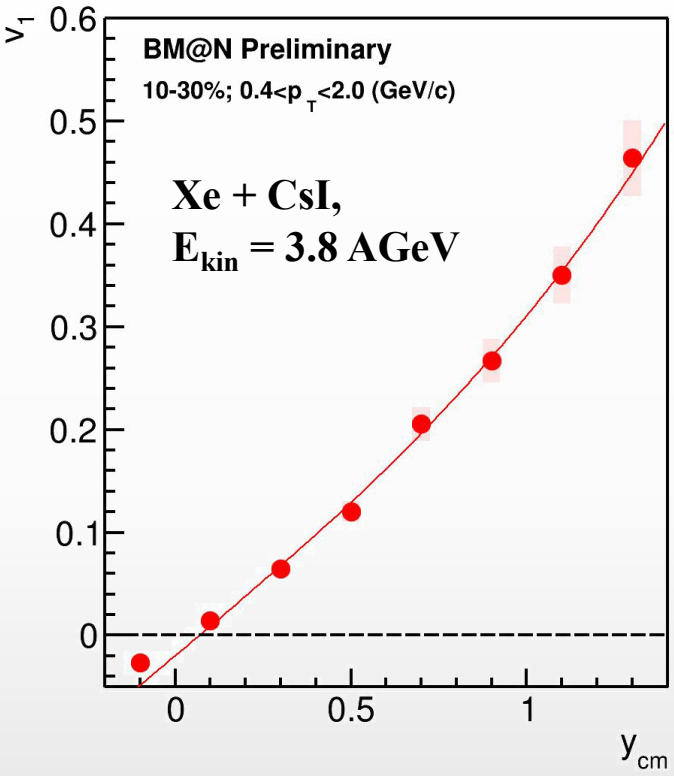


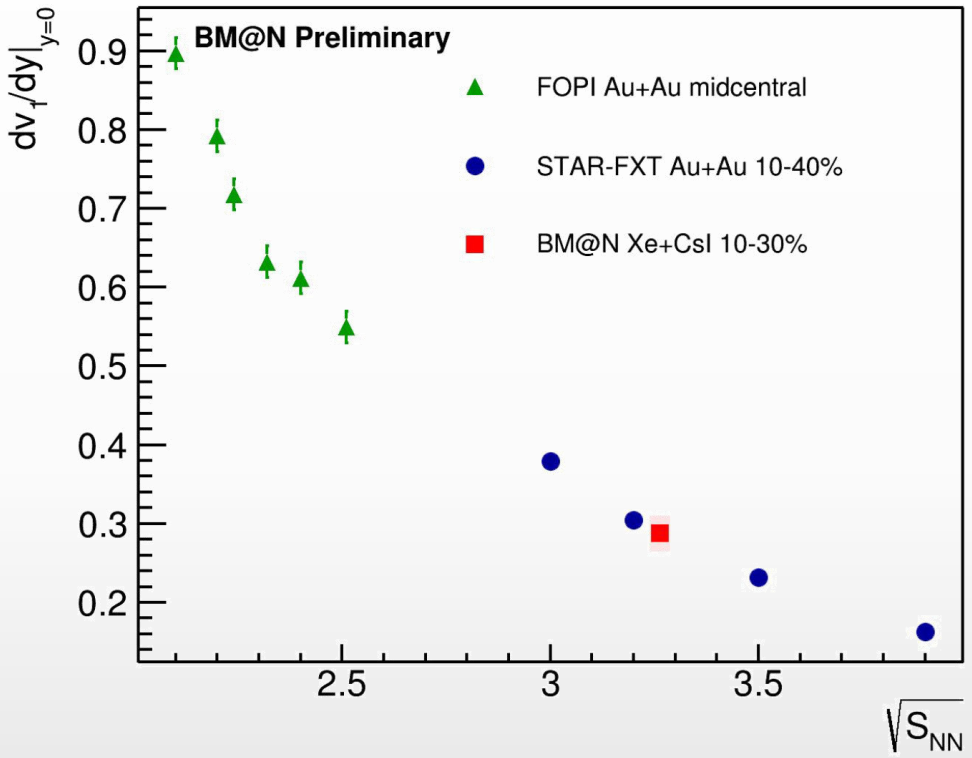






$dv_1/dy|_{y=0}$ for protons vs. collision energy





- Slope of v_1 is in good agreement with the world data