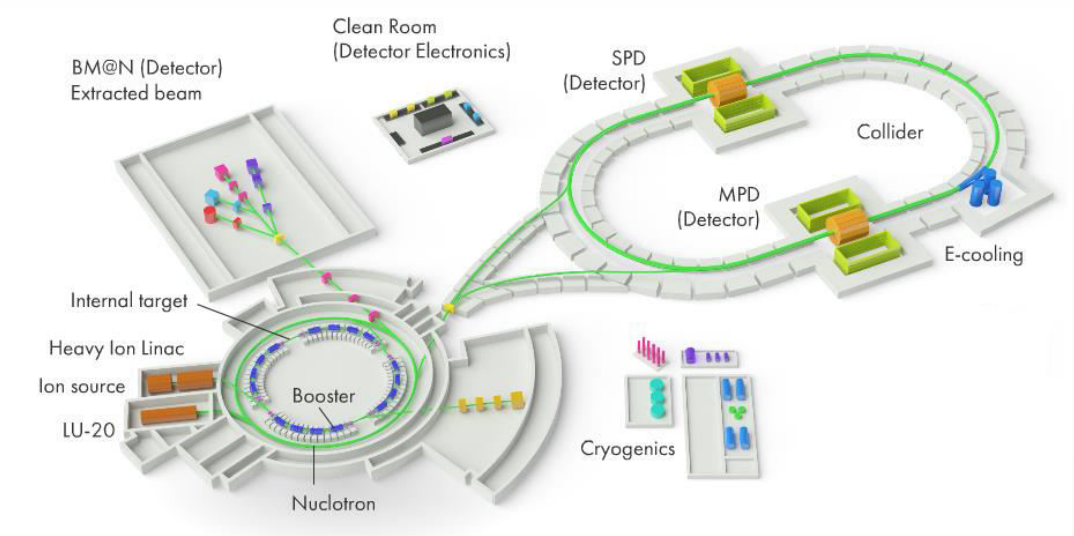
Эксперименты на ускорительном комплексе NICA

В.Г. Рябов

Nuclotron-based Ion Collider fAcility (NICA)



- Heavy-ion beams, fixed-target and collider (up to Au, $\mathcal{L} = 10^{27}$ cm^{-2}s^{-1}, $\sqrt{s_{NN}}$= 2.4-11 GeV) → strongly-interacting matter at extreme conditions of maximum baryonic density

Ion sourse (KRION-6T)
Heavy Ion Linac (HILac)
Booster

BM@N (Detector)
MPD (Detector)

- Polarized beams of protons and deuterons in the collider (up to $\mathcal{L} = 10^{32}$ cm^{-2}s^{-1}, $\sqrt{s_{NN}}$= 12.6 (d) 27 (p) GeV)
  → nucleon spin structure research and clarification of the spin origin

LU-20
Nuclotron

SPD (Detector)

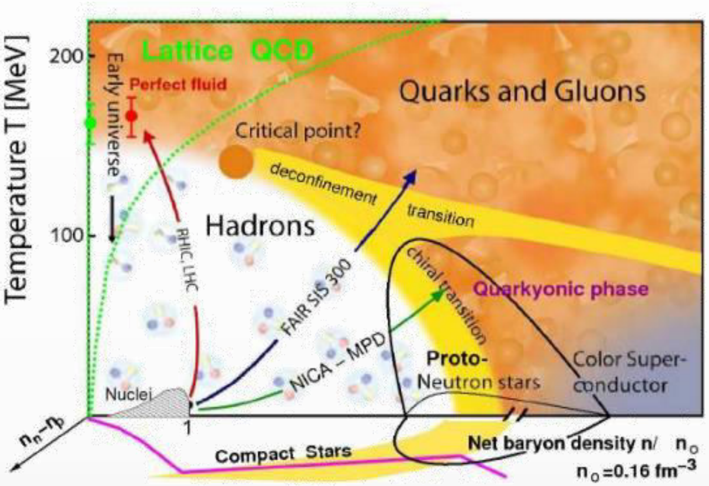
- Applied Research Infrastructure for Advanced Developments at NICA fAcility (ARIADNA)
  → beam channels and irradiation stations for applied research with heavy-ion beams

- NICA project is approaching its full commissioning:
  - ✓ already running in the fixed-target mode – BM@N, ARIADNA
  - ✓ start of operation in collider mode in 2025 – MPD and later SPD

Heavy-ion program

NICA is a bridge to neutron stars

- Heavy-ion collisions are used to:
  - ✓ study QCD under extreme conditions of high temperatures and densities
  - ✓ explore the QCD phase diagram, search for the QGP and study its properties



Why Quark-gluon plasma is of interest?

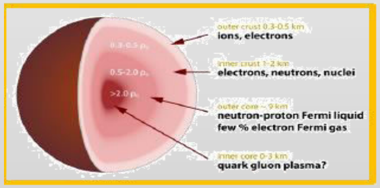
- ✓ primordial form of QCD matter at high temperatures and/or (net)baryon densities
- ✓ present during the first microseconds after Big Bang and in cores of the compact neutron stars / mergers
- ✓ provides important insights on the origin of mass for matter, and how quarks are confined into hadrons

- Heavy-ion collisions at NICA create extremely dense matter at moderate temperatures:
  - ✓ net baryon density (*n*) up to 10 times that in normal nuclear matter (n_0)
  - ✓ baryonic chemical potential μ_B = (300 - 600) MeV, T_{ch} ~ (120-150) MeV

- Comparable baryon density may exist in cores of compact neutron stars and in neutron star mergers

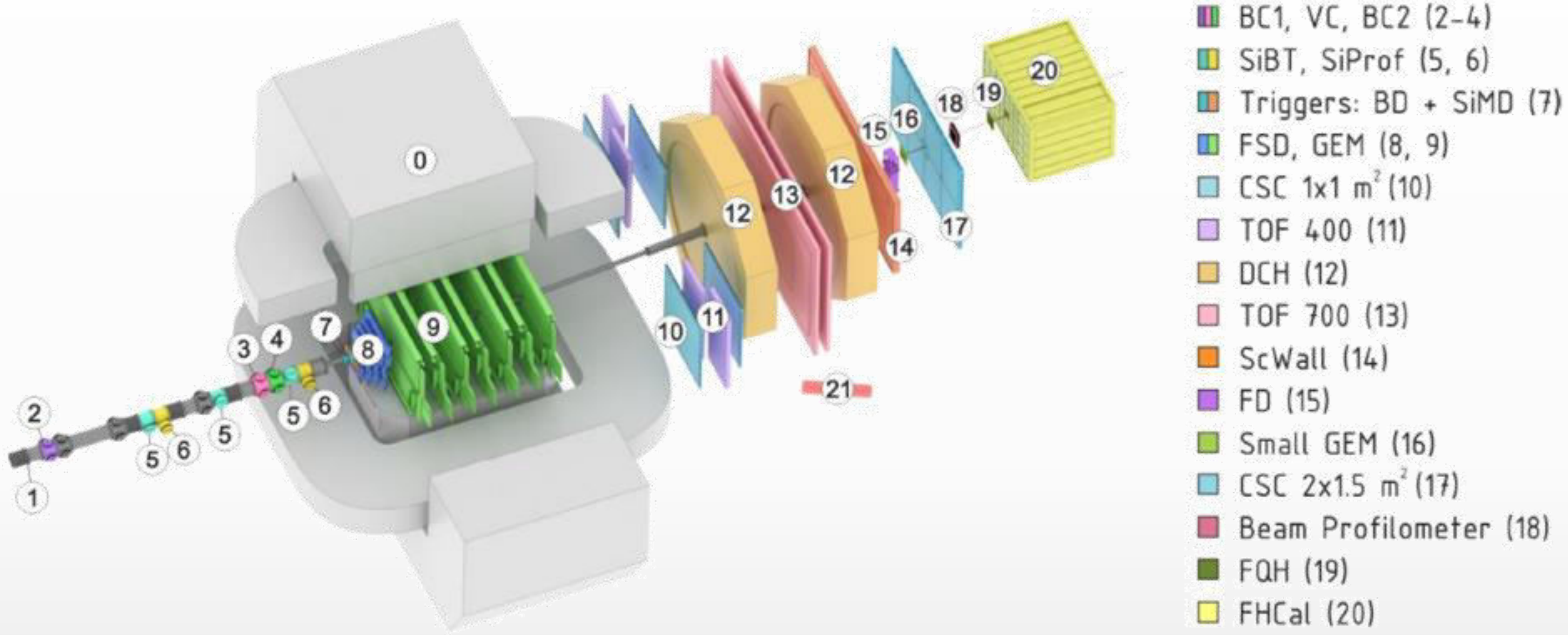
- Two experiments at NICA:
  - ✓ fixed-target - BM@N
  - ✓ fixed-target and collider - MPD

High baryon density:
Inner structure of
compact stars



Baryonic **M**atter @ **N**uclotron

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



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 3.8 AGeV, > $5.5 \cdot 10^8$ events

Н. Карпушкин, Высокогранулярный нейтронный детектор и система передних детекторов эксперимента BM@N, 18 февраля, 14:45-15:00
D. Idrisov, Comparison of different methods for centrality determination in Xe+CsI collisions at 3.8 A GeV in the BM@N experiment, 21 февраля, 14:00-14:15
A. Demanov, Определение центральности столкновений тяжелых ионов в эксперименте BM@N, 21 февраля, 14:15-14:30

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

❖ Technical run with Ar beam at 3.2 AGeV and C/Al/Cu/Sn/Pb targets

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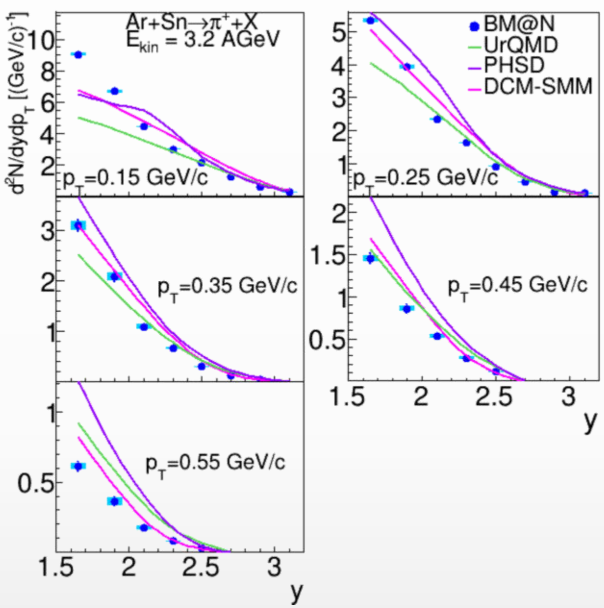
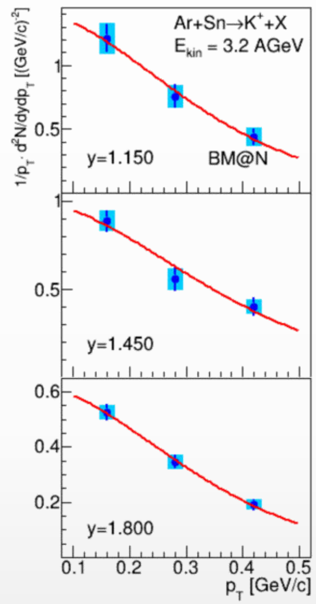
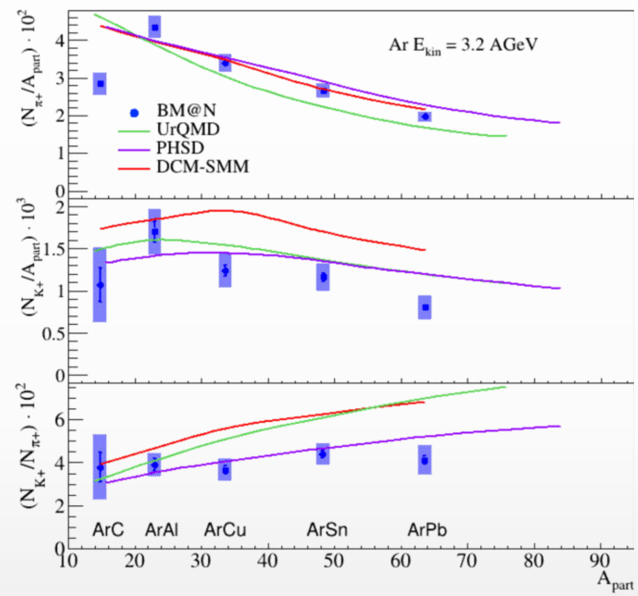
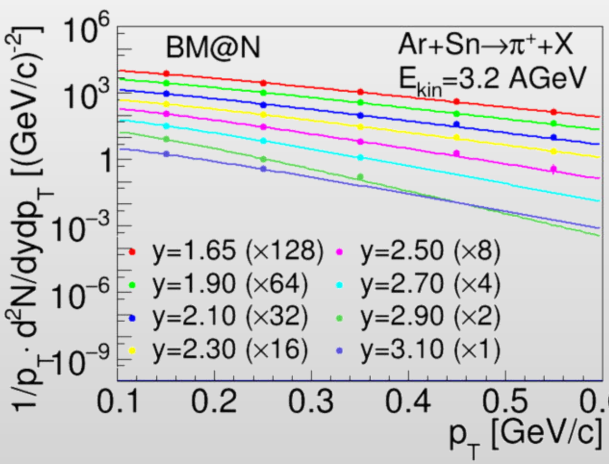
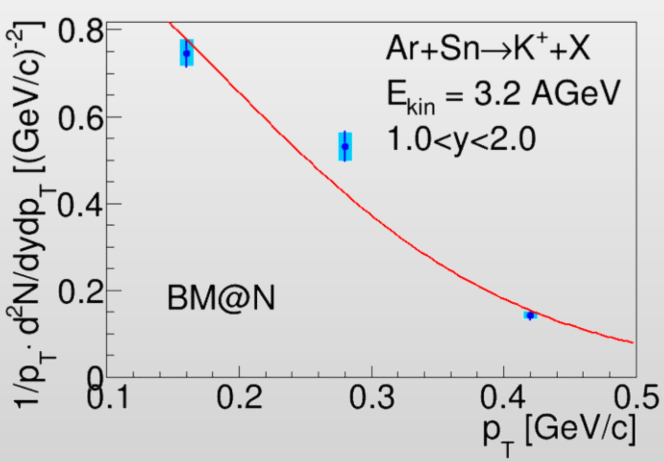






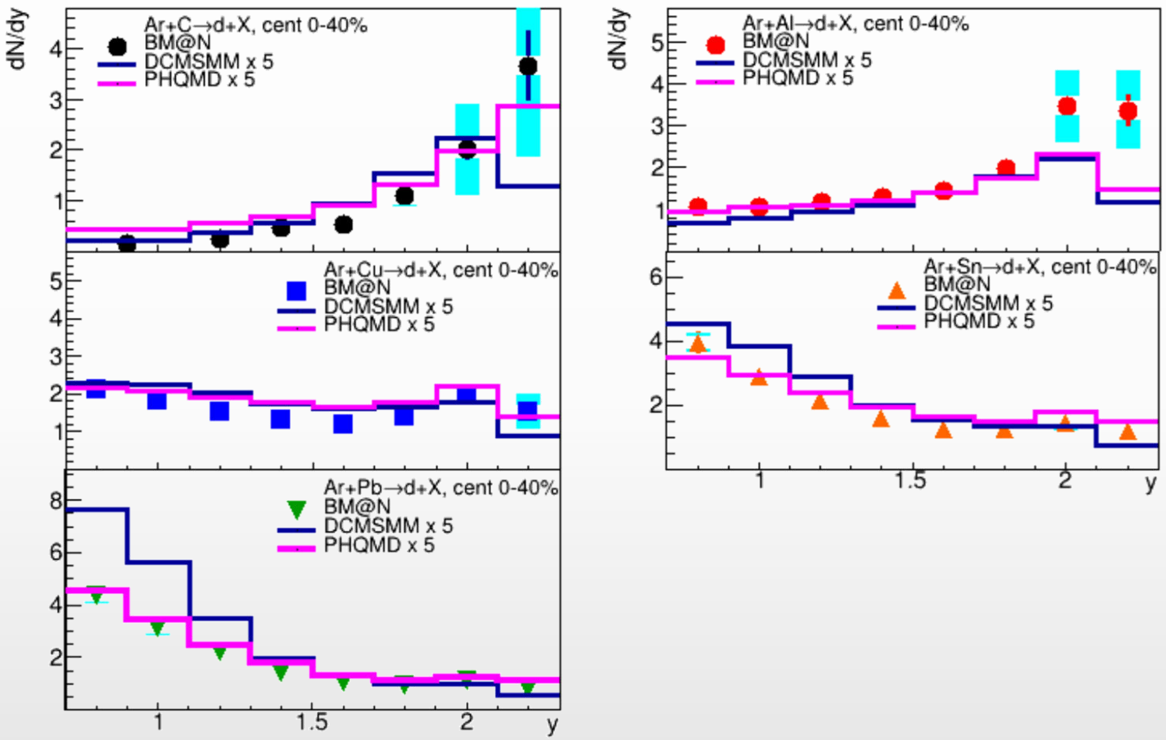




Production of protons and deuterons in argon-nucleus interactions at 3.2 AGeV

❖ Technical run with Ar beam at 3.2 AGeV and C/Al/Cu/Sn/Pb targets

Preliminary results



❖ dN/dy spectra are softer in interactions with heavier targets

❖ Models describe the shape of rapidity dependences, but underestimate yields by a factor of ~5

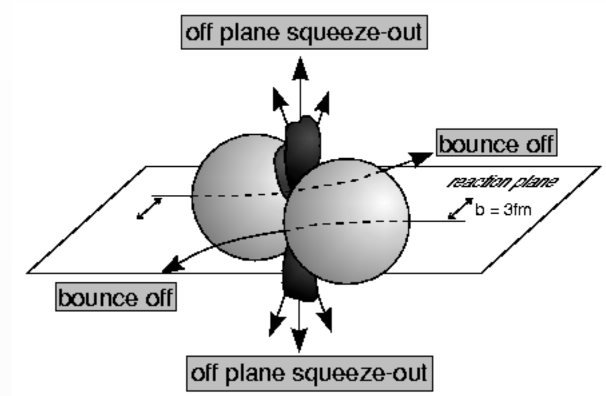
В. Колесников, Изучение рождения протонов, дейтронов и тритонов в столкновениях аргон-ядро в эксперименте BM@N на ускорительном комплексе NICA, 17 февраля, 16:30 - 16:45

Collective flow of protons and deutrons in Xe + CsI collision energy

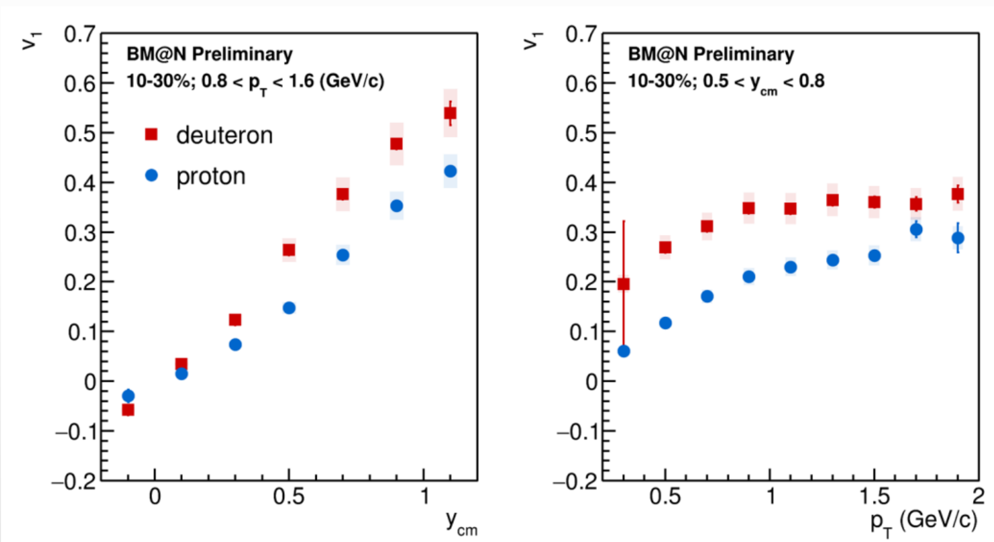
❖ Physics run with Xe beam at 3.8 AGeV and CsI target

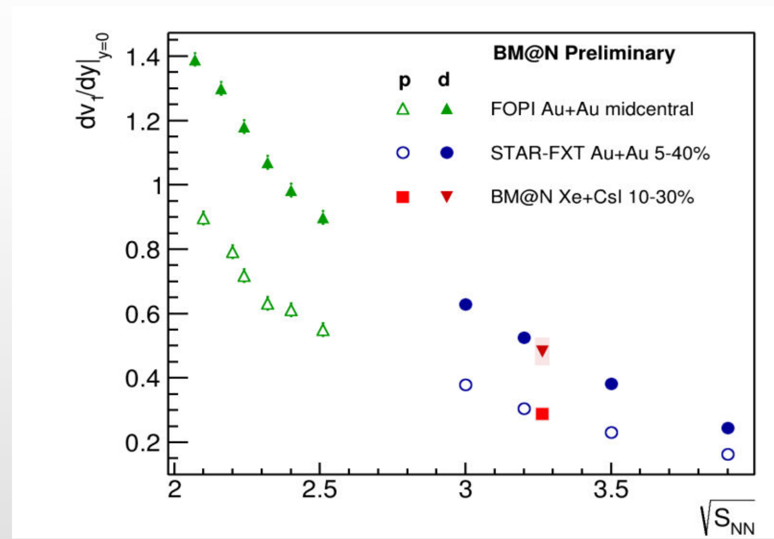
Azimuthal angle distribution of particles w/r to event plane:

$$dN/d\varphi \sim (1 + 2v_1 \cos\varphi + 2v_2 \cos 2\varphi)$$



Preliminary results





❖ Direct flow v_1 vs. rapidity and transverse momentum

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

❖ Analysis of charged pions and Λ hyperon flow is in progress

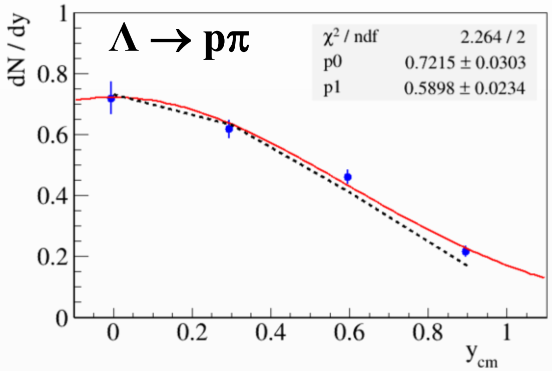
V. Troshin, Измерение анизотропных потоков лямбда-гиперонов в экспериментах MPD и BM@N, 17 февраля, 16:00-16:15
M. Mamaev, Направленный поток протонов в столкновениях Xe+CsI при энергии 3.8А ГэВ на установке BM@N, 17 февраля, 16:15-16:30
И. Жаворонкова, Первые результаты по измерению v_1 для *d* в столкновениях Xe+Cs(I) при энергии 3.8А ГэВ на BM@N, 17 февраля, 16:45-17:00

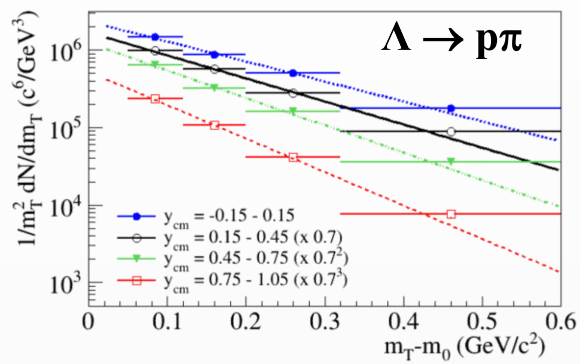
Near future

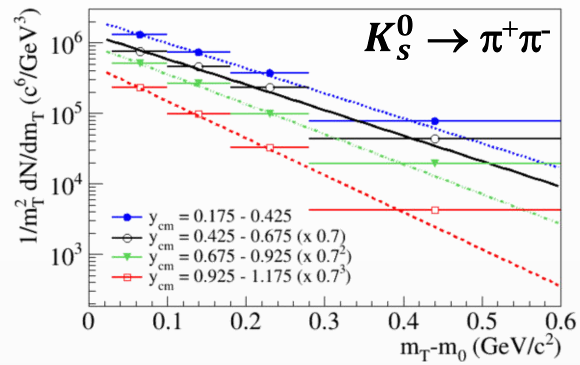
- Many ongoing analyses for identified hadrons and light nuclei

Work in progress

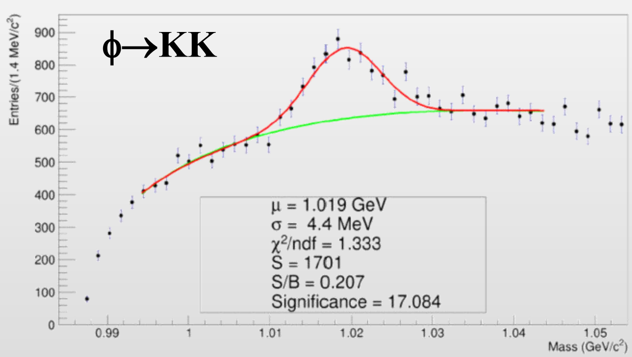
- Rapidity and transverse mass spectra of Λ and K_s^0

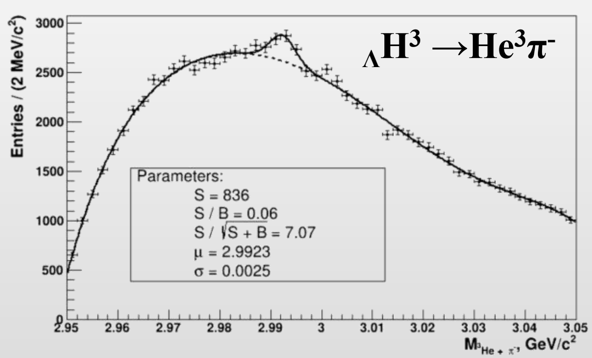


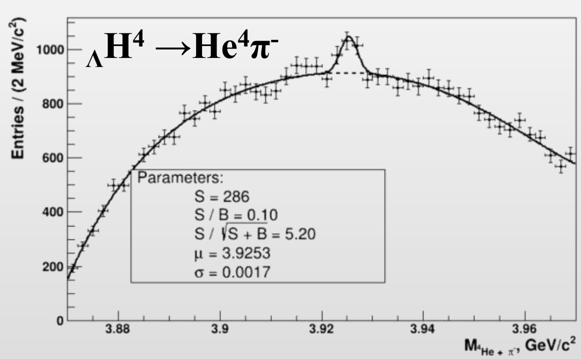




- Observation of signals from vector mesons and (hyper)nuclei $_{\Lambda}H^3$, $_{\Lambda}H^4$



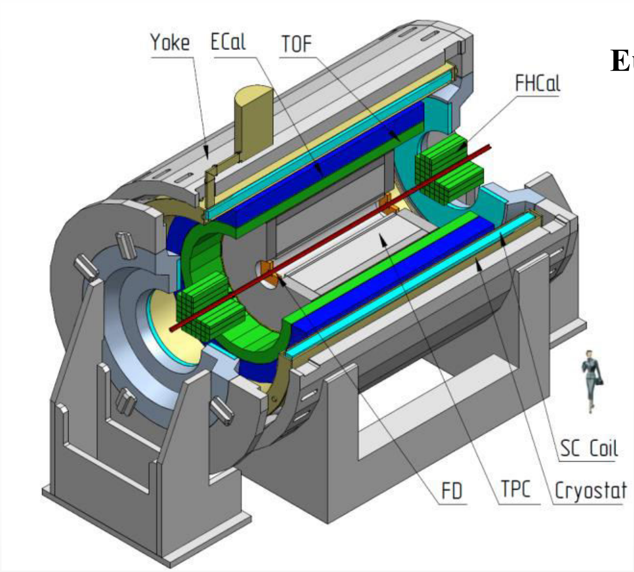




- Physics run in 2025 with new silicon micro-strip detectors and extended ToF-400 acceptance

Multi-Purpose Detector

Stage-I → start of commissioning in 2025



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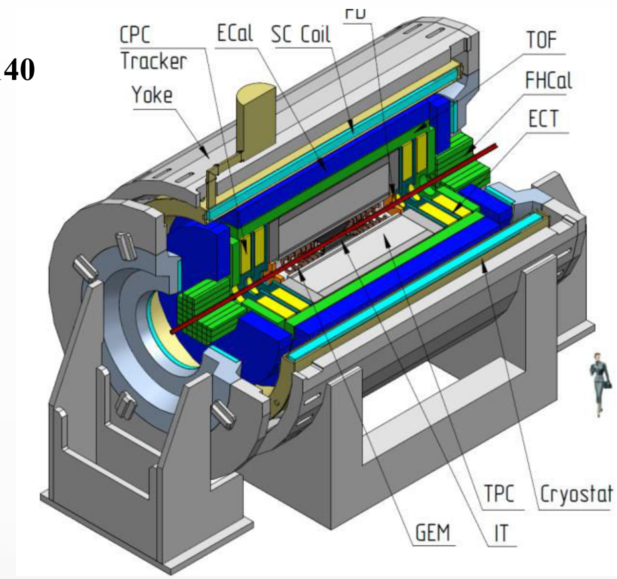
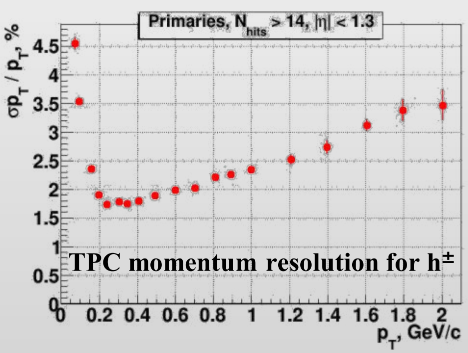
Stage-II → 2030+

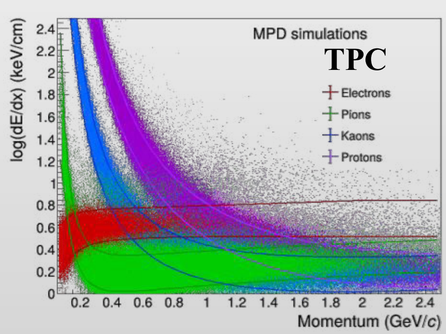


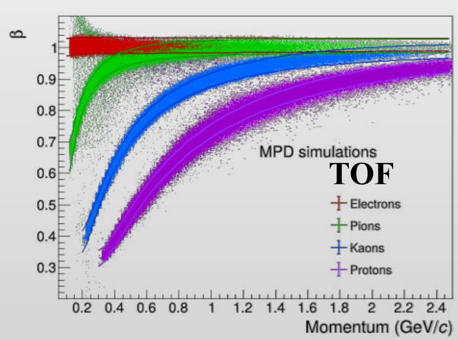
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$; **TOF, EMC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$; **FHCAL**: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

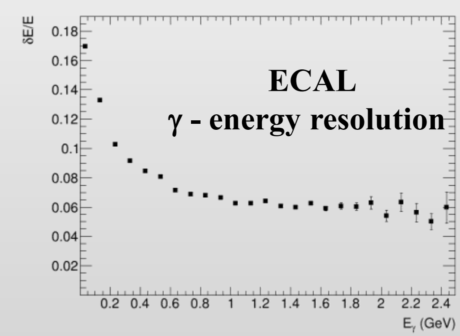
\+ **ITS** : $|\Delta\varphi| < 2\pi$, $|\eta| \leq 3$
\+ **Forward Spectrometers**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 2.2$

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



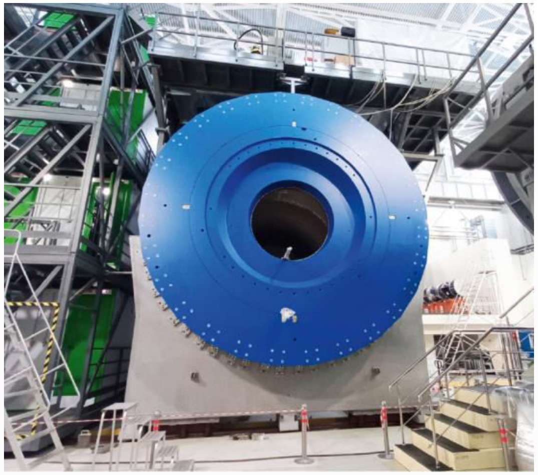






MPD magnet

Magnet yoke

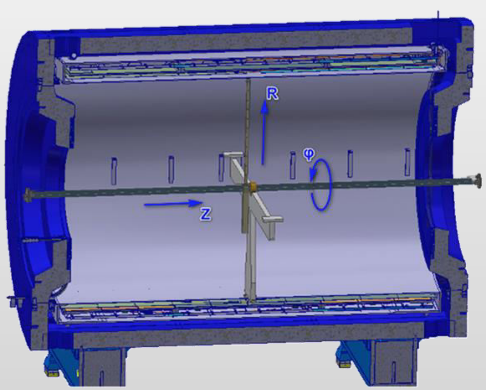


Cryogenic platform

Strings for cryogenic pipes and cables hold

- First cooling if the magnet to below LN2 temperature of ~ 70^0 K in February-March 2024
- Start of cooling to LHe temperature in October → cooled to 4.5^0 K in December 2024

Magnetic field 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	360º (1380 см at max. R)	700
Number of measurements	44	64	70

Single 3D Hall probe moves in 3 directions: z , R, ϕ
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

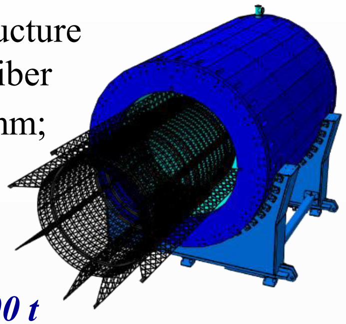
MPD subsystems

Support frame - READY

support structure of carbon fiber

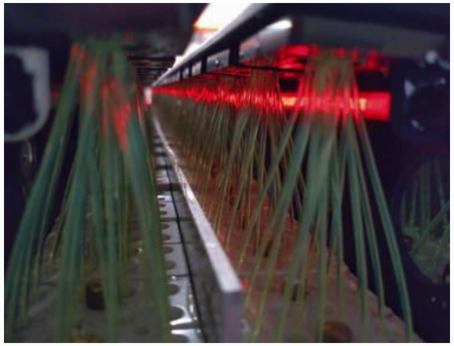
sagite ~ **5** mm;

0,13 X_0



ECAL ~ 100 t

ECAL – 83% READY



ECAL ~ 38400 towers (2400 modules)
produced by Chinese Universities (SDU, THU, FDU, SCUT, HZU) and JINR (IHEP (Protvino) and Tenzor (Dubna))

83% of calorimeter modules (~2000) is ready, remaining baskets to be ready by April 2025

TOF - READY

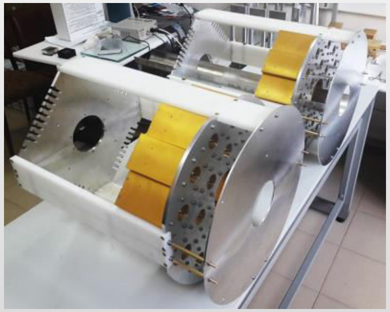
All 28 (100%) TOF modules are assembled, tested, stored and ready for installation. Spare modules in production

TPC - ASSEMBLY

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

Forward subsystems - READY

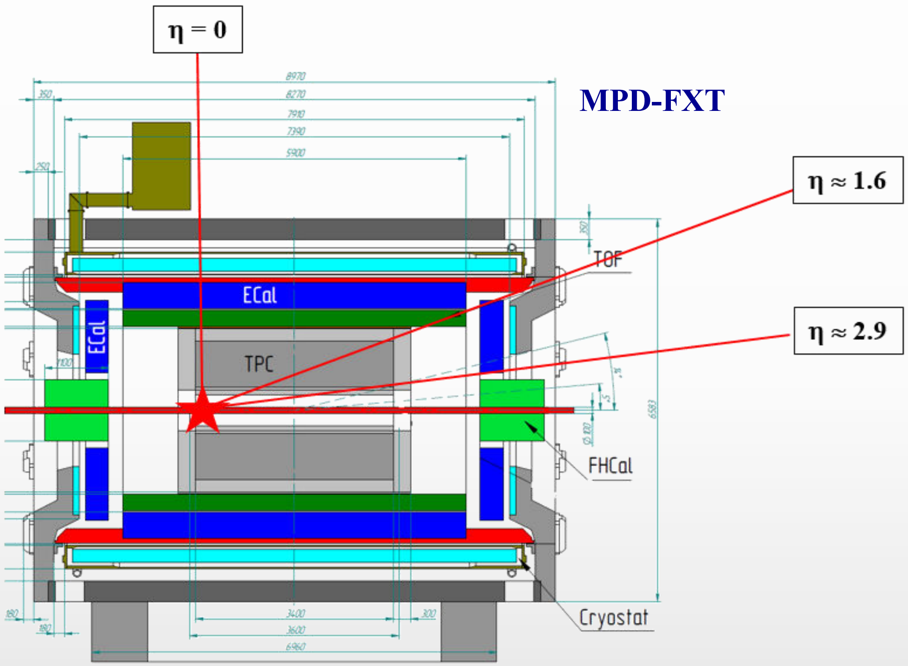
FHCAL in the Pole
(modules are equipped with FEE)

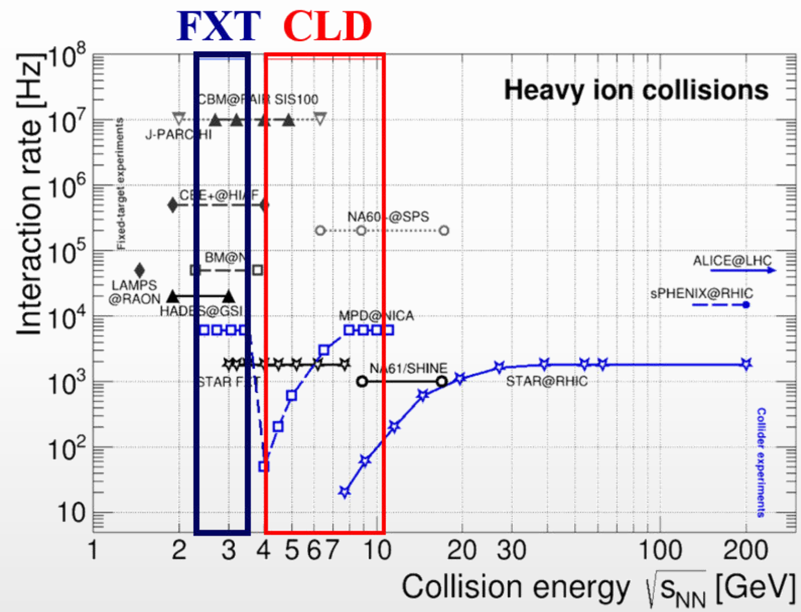


Cherenkov counters (FFD)
(tests with cosmics and lasers)

MPD strategy

- High-luminosity scans in **energy** and **system size** to measure a wide variety of signals
- Scans to be carried out using the **same apparatus** with all the advantages of collider experiments
- MPD-CLD and MPD-FXT operation modes approved from start-up:





- ✓ Collider mode: two heavy-ion beams, $\sqrt{s_{NN}}$ = 4-11 GeV
- ✓ Fixed-target mode: one beam + thin wire as a target (~ 50-100 μm) :
  - extends energy range to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, BM@N, CBM)
  - high event rate at lower collision energies

MPD physics program

❖ A comprehensive physics program: ions from **p** to **Au** and collision energies $\sqrt{s_{NN}}$= 2.4-11 GeV

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

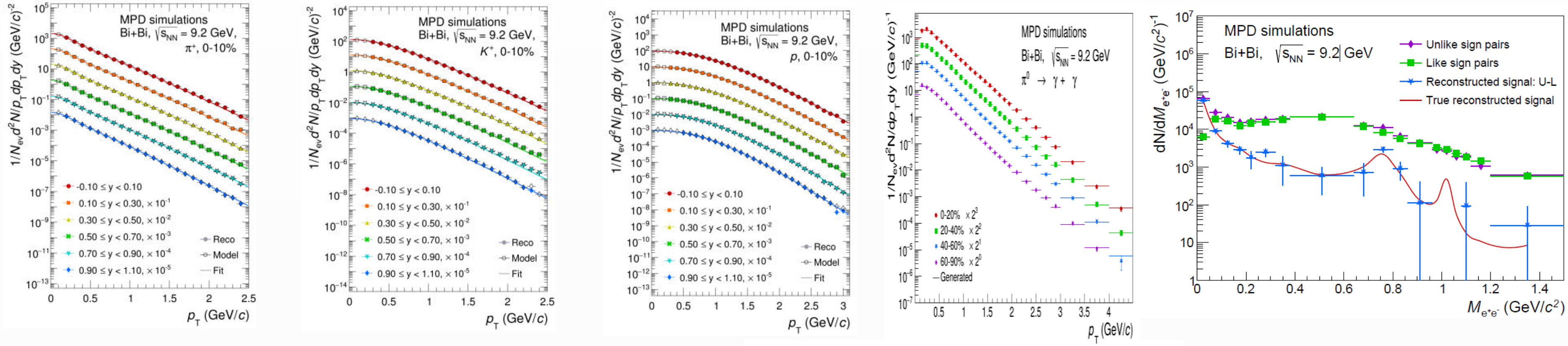
Heavy flavor

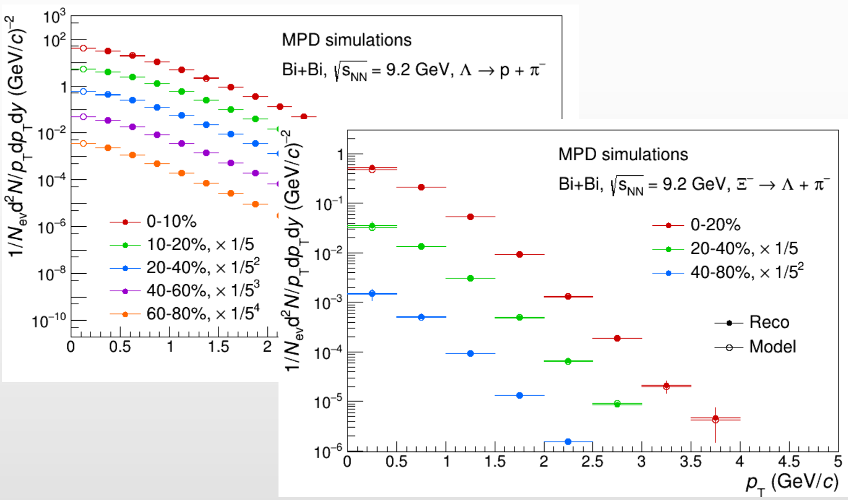
- Study of open charm production
- Charmonium with ECAL and central barrel
- Charmed meson through secondary vertices in ITS and HF electrons
- Explore production at charm threshold

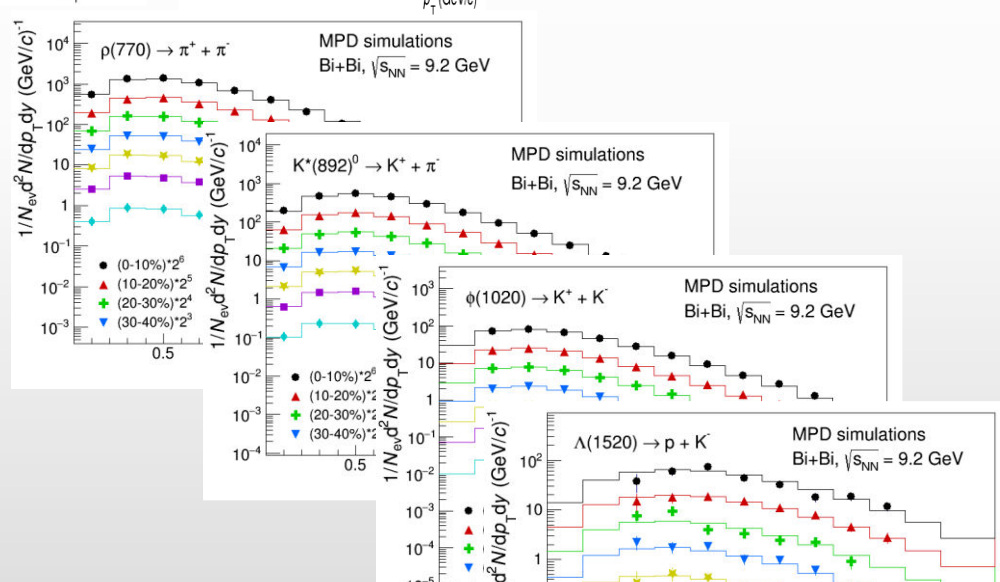
G. Feofilov, First physics studies planned with the MPD experiment at NICA in Bi+Bi collisions at 9.2 GeV, 17 февраля, 14:45 - 15:00
P. Gordeev, Измерение анизотропного потока и спектра нейтральных пионов в столкновениях Bi+Bi при энергии 9.2 ГэВ в MPD, 17 февраля, 15:00 - 15:15
А. Тараненко, Исследование зависимости коллективных потоков в A-A столкновениях от энергии с помощью скейлинговые соотношений, 20 февраля, 14:30-14:45
P. Parfenov, Измерение анизотропных потоков адронов в эксперименте MPD в NICA, 21 февраля, 13:45-14:00
D. Ivanishchev, Study of production of ϕ(1020) and charged K*(892) and Sigma(1385) in Bi+Bi collision at 9.2 GeV in the MPD at NICA, 21 февраля, 14:30-14:45

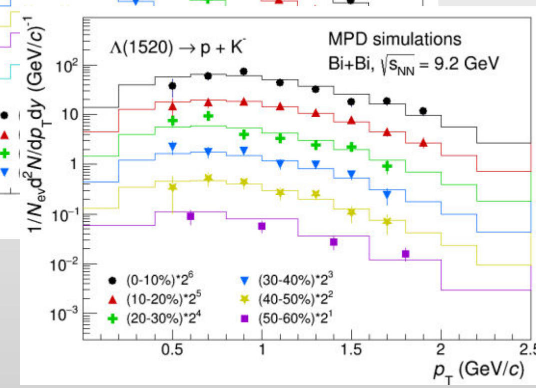
MPD feasibility studies

❖ Physics feasibility studies using large-scale Monte Carlo productions









❖ Develop physics program, analysis methods and algorithms:

- ✓ 250+ MPD publications indexed in SPIRES, ~ 30 papers per year
- ✓ 60+ reports at international conferences per year

BM@N and MPD Collaborations

❖ BM@N: ~210 members from 13 institutions from 5 countries

- **JINR**
- Bulgaria
- China
- Kazakhstan
- Russia
- Uzbekistan

❖ MPD: ~500 members from 39 institutions from 12 countries

- **JINR**
- Armenia
- Belarus
- Bulgaria
- China
- Georgia
- Kazakhstan
- Mexico
- Moldova
- Mongolia
- Russia
- Serbia
- Slovakia

Summary

- Heavy-ion program at NICA → study of the QCD phase diagram in the region of maximum net-baryon density

- A comprehensive physics program to be studied for different ions (from p to Au) and collision energies ($\sqrt{s_{NN}}$ from 2.4 to 11A GeV):
  - ✓ event-by-event fluctuation of multiplicity, momentum and conserved quantities
  - ✓ femtoscopic correlation
  - ✓ multiparticle correlations
  - ✓ differential collective flow (v_n) for various hadrons
  - ✓ strange meson (including resonances) and (multi)strange hyperon production
  - ✓ light nuclei production including hypernuclei
  - ✓ (direct)photon and (di)electron probes
  - ✓ charge asymmetry
  - ✓ heavy flavor production

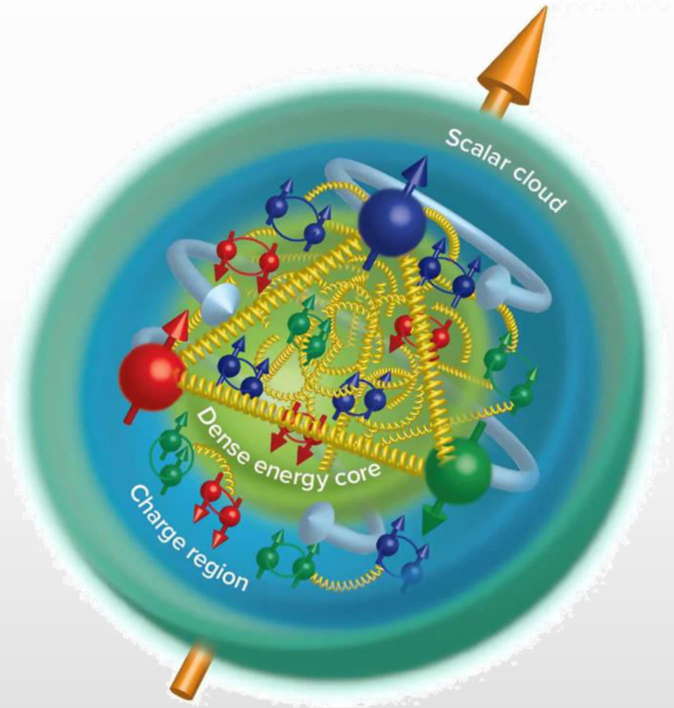
- Flagship project in the world on the study of heavy-ion collisions at intermediate energies

- More information can be found at http://bmn.jinr.ru and http://mpd.jinr.ru

Program with polarized p↑ and d↑ beams

Spin Physics Detector

❖ The Spin Physics Detector (**SPD**) at the NICA collider is a universal facility for comprehensive study of polarized and unpolarized gluon content of proton and deuteron in polarized high-luminosity p-p and d-d collisions



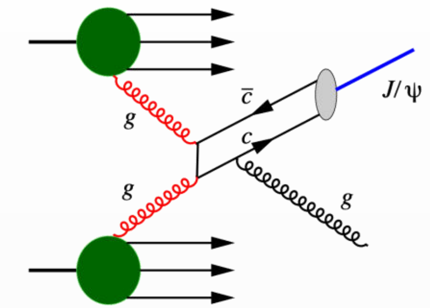
Study the contribution of partons to the nucleon and deuteron spins

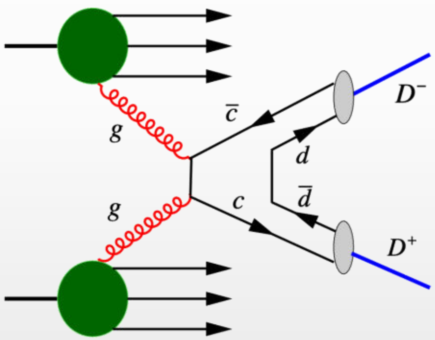
especially their gluon component!

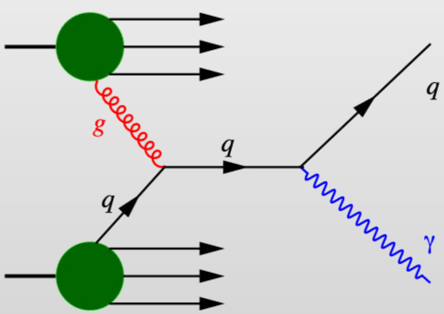
Gluon TMD PDFs via asymmetries and angular modulations in the cross sections

SPD and gluon structure of nucleon

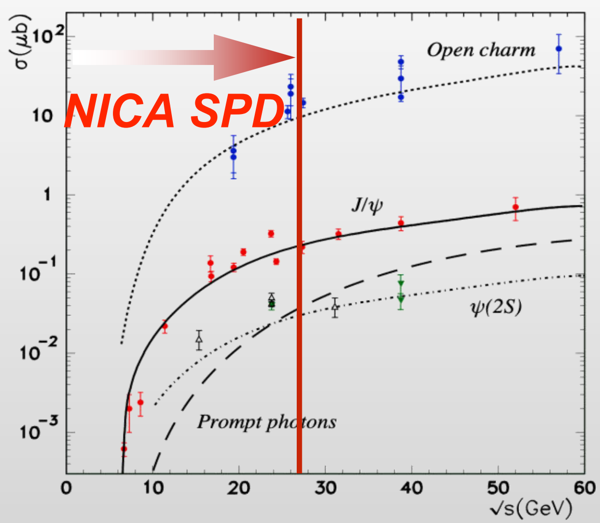
Not only J/ψ!

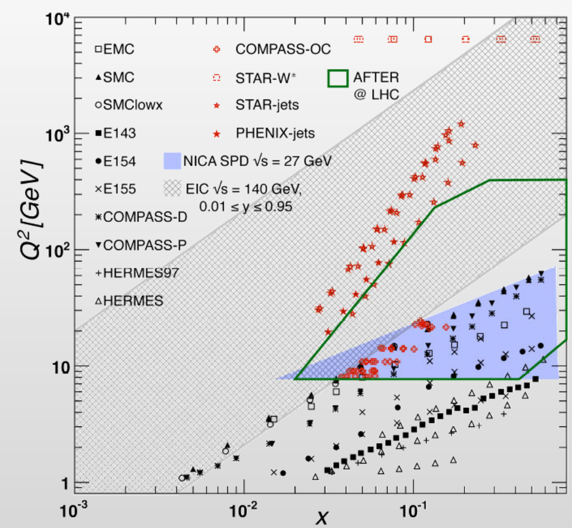




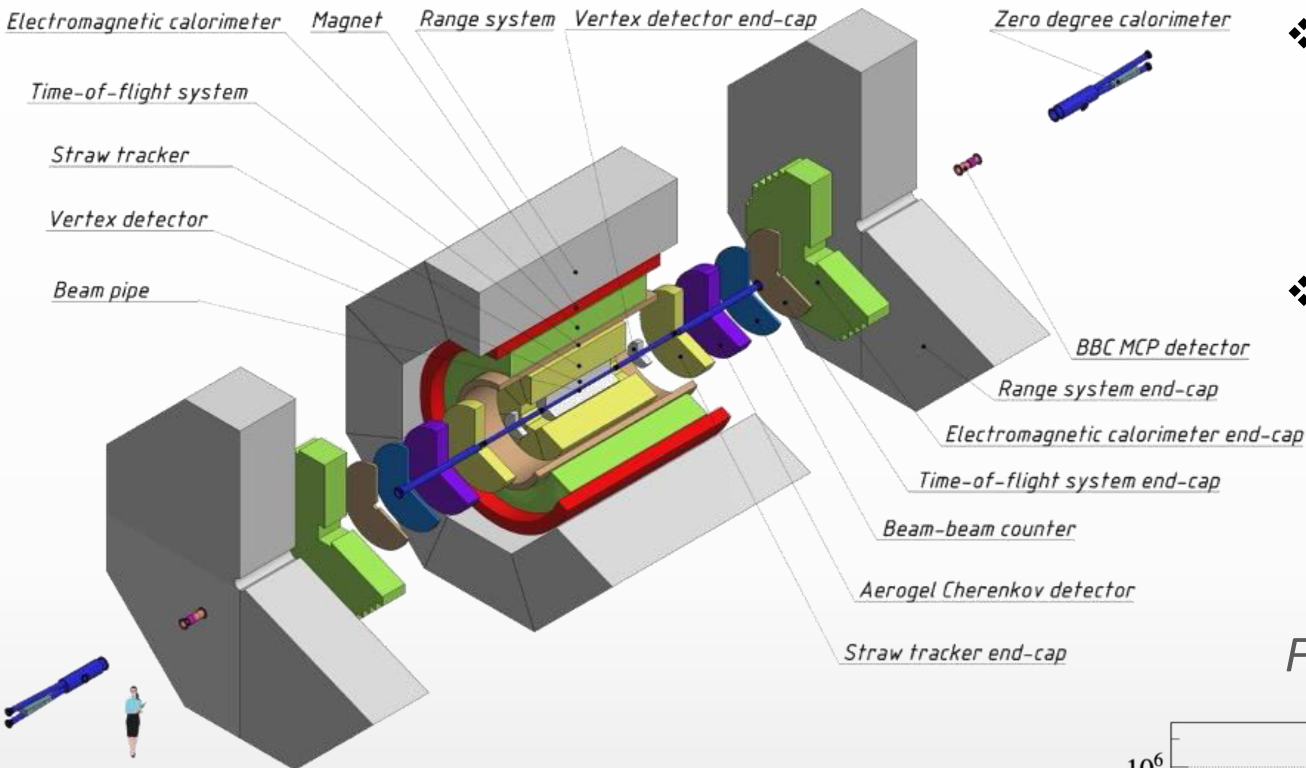


Physics goal	Observable	Experimental conditions
Gluon helicity $\Delta g(x)$	A_{LL} asymmetries	p_L-p_L, $\sqrt{s}=27$ GeV
Gluon Sivers PDF $f_{1T}^{\perp g}(x,k_T^2)$, Gluon Boer-Mulders PDF $h_1^{\perp g}(x,k_T^2)$ TMD-factorization test	A_N asymmetries, Azimuthal asymmetries Diff. cross-sections, A_N asymmetries	p_T-p, $\sqrt{s}=27$ GeV p-p, $\sqrt{s}=27$ GeV p_T-p, energy scan
Unpolarized gluon density $g(x)$ in deuteron Unpolarized gluon density $g(x)$ in proton	Differential cross-sections	d-d, p-p, p-d $\sqrt{s_{NN}}=13.5$ GeV p-p, $\sqrt{s}\leq 27$ GeV
Gluon transversity $h_1^g(x)$ "Tensor porlarized" PDF $C_G^T(x)$	Double vector/tensor asymmetries Single vector/tensor asymmetries	d_{tensor}-d_{tensor}, $\sqrt{s_{NN}}=13.5$ GeV d_{tensor}-d, p-d_{tensor}



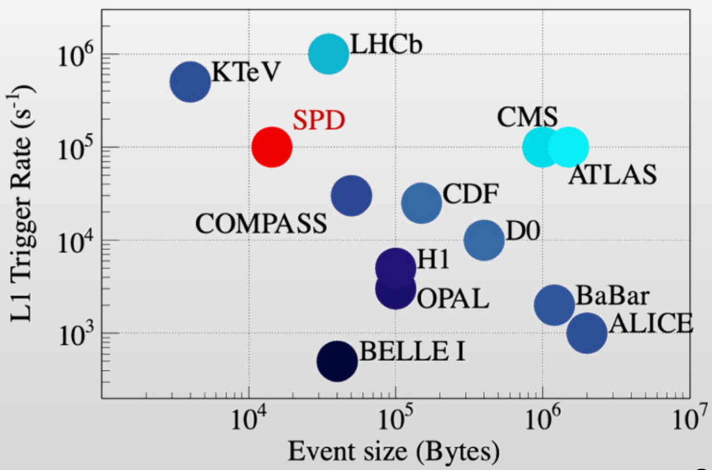


SPD setup



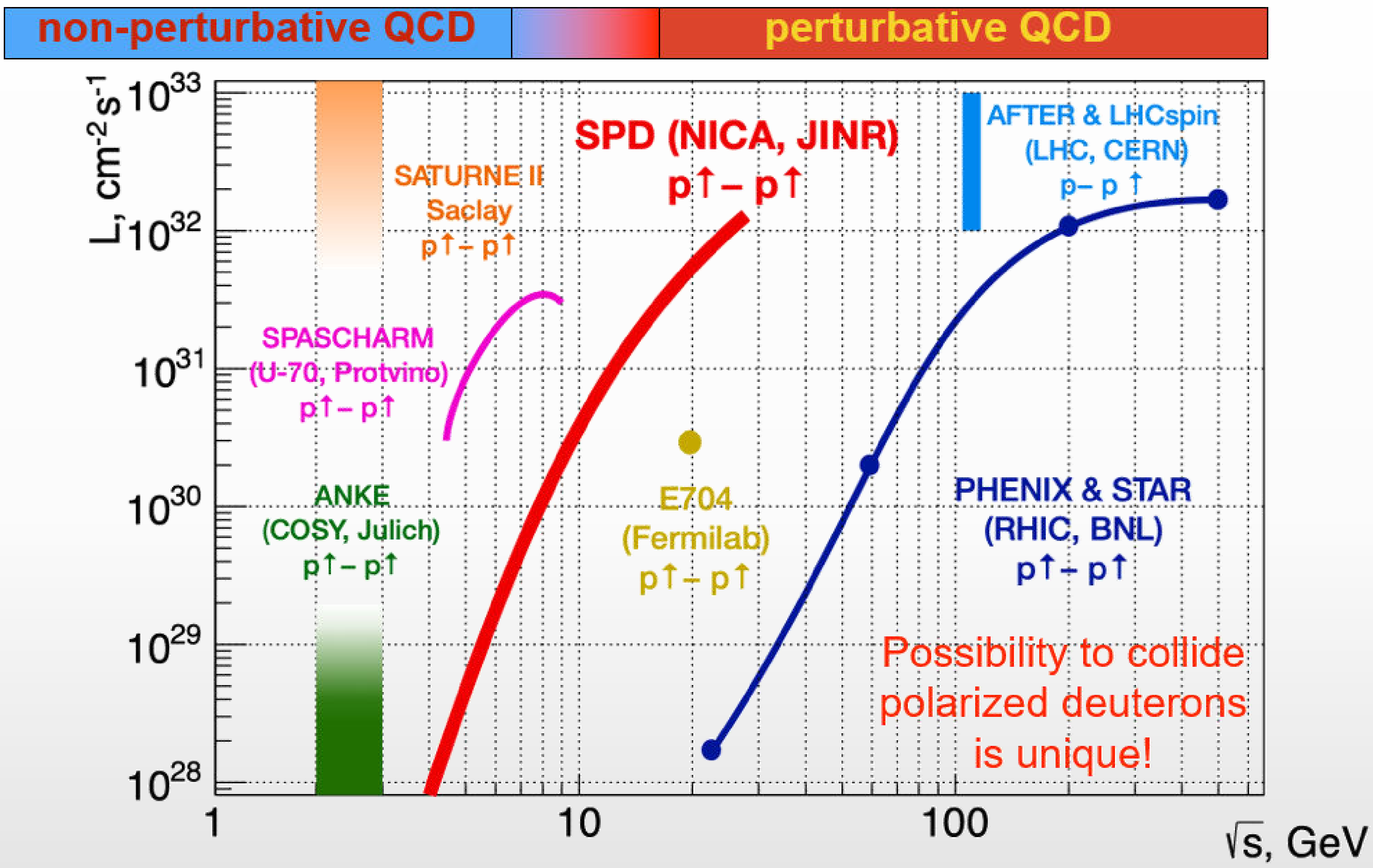
- Beams of protons and deuterons in the collider (up to $\mathcal{L} = 10^{32}$ cm^{-2}s^{-1}, $\sqrt{s_{NN}}$= 13 (dd), 19 (pd), 27 (pp) GeV)
- Beam polarization up to 70%

Free-running DAQ



A. Boikov, Система сбора данных эксперимента SPD на коллайдере NICA, 18 февраля, 17:30-17:45

SPD and others



❖ The SPD gluon physics program is complementary to the other intentions to study the gluon content of nuclei (RHIC, AFTER, LHC-Spin, EIC, JLab experiments, EICc, …)

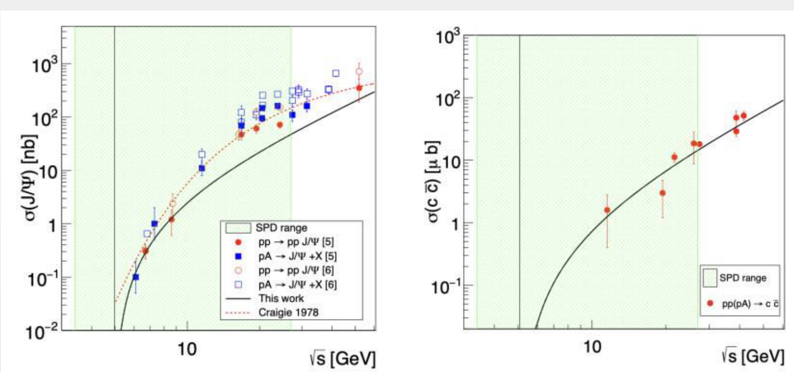
Physics of the first stage

Transition scan

Non-perturbative QCD ***Perturbative QCD***

$\sqrt{s}$

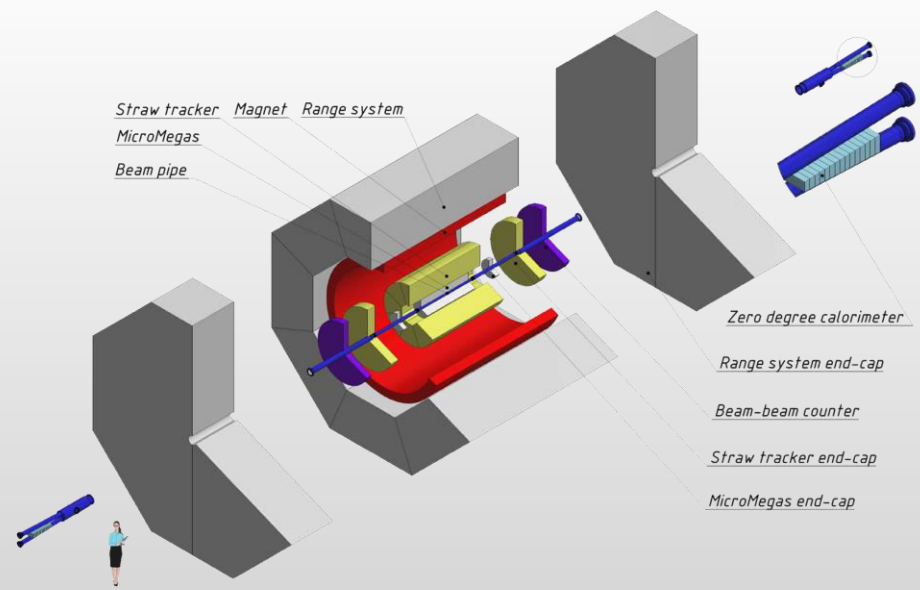
- Spin effects in p-p, p-d and d-d elastic scattering
- Spin effects in hyperons production
- Multiquark correlations
- Dibaryon resonances
- Physics of light and intermediate nuclei collision
- Exclusive reactions
- Hypernucei
- Open charm and charmonia near threshold
- Auxiliary measurements for astrophysics
- …



Creating of polarized infrastructure **Upgrade of polarized infrastructure**

0	+2	+4	+6	+8	years

SPD construction — **1st stage of operation** — **SPD construction** — **2nd stage of operation**

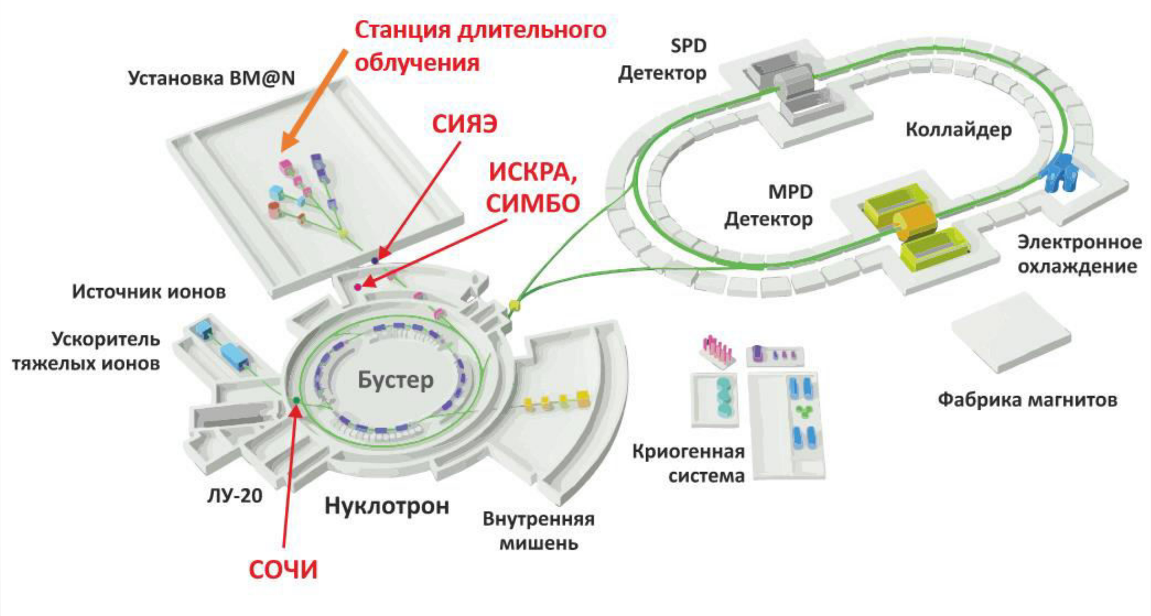


Status summary

- SPD **physics program** is available at:
  - ✓ https://arxiv.org/abs/2011.15005
  - ✓ https://arxiv.org/abs/2102.08477
- SPD **Technical Design Report** was presented firstly in Jan 2023, then was updated in 2024 and passed international expertise this year: https://arxiv.org/abs/2404.08317
- The **first phase** of the SPD project is included into the JINR's 7-year plan (2024-2030)
- The **SPD international collaboration** established in 2021
  Currently it consists of 35 institutes from 15 countries and more than 400 participants
- More information can be found at http://spd.jinr.ru

Applied research with heavy-ion beams

The Applied Research Infrastructure for Advanced Developments at NICA fAcility



Ионные пучки низких энергий (инжектор HILAC), 3.2 МэВ/нуклон	Ионные пучки промежуточных энергий (Нуклотрон), 150-1000 МэВ/нуклон	Ионные пучки высоких энергий (Нуклотрон), 4.5 ГэВ/нуклон
Радиационное материаловедение, науки о жизни и медицинские приложения; радиационные повреждения в микроэлектронике, новые технологии для задач ADS		

Моделирование воздействия галактических космических лучей: протоны и ионы с *Z* от 2 до 92

Облучение микросхем с предварительно удаленным корпусом ионами низкой энергии
~ 3,2 МэВ/нуклон

Ионы $^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$, $^{131}Xe^{54+}$, $^{197}Au^{79}$

Облучение инкапсулированных микросхем ионами с энергиями 150-350 МэВ/нуклон. Ионы вплоть до $^{197}Au^{79+}$ замедляются в корпусе микросхемы до энергий 5-10 МэВ/нуклон.

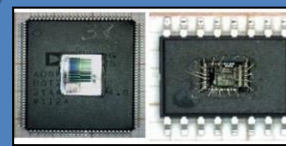
Ионы с энергией 500-1000 МэВ/нуклон будут доступны для облучения биологических объектов.

Ионы $^{1}H^{1+}$, $^{2}D^{1+}$, $^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{7}Li^{3+}$

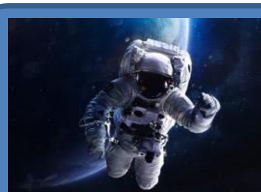
Станция будет оборудована мишенями из материалов от C до Pb, системами диагностики пучка, позиционирования мишени, теромометрии, синхронизации, радиационного контроля, сбора и распределения данных.

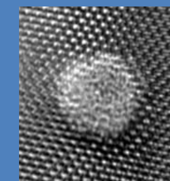
Направления прикладных исследований с использованием пучков тяжелых ионов на NICA

Радиационные эффекты
в микроэлектронике

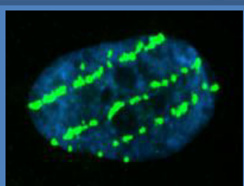


Задачи радиационной безопасности в космосе

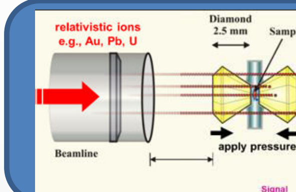




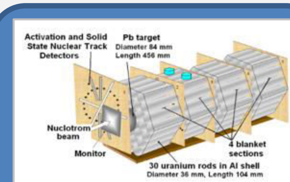
Радиационное материаловедение



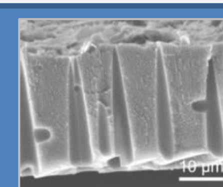
Общая радиобиология



Смежные задачи радиационной терапии



Новые технологии систем ADS

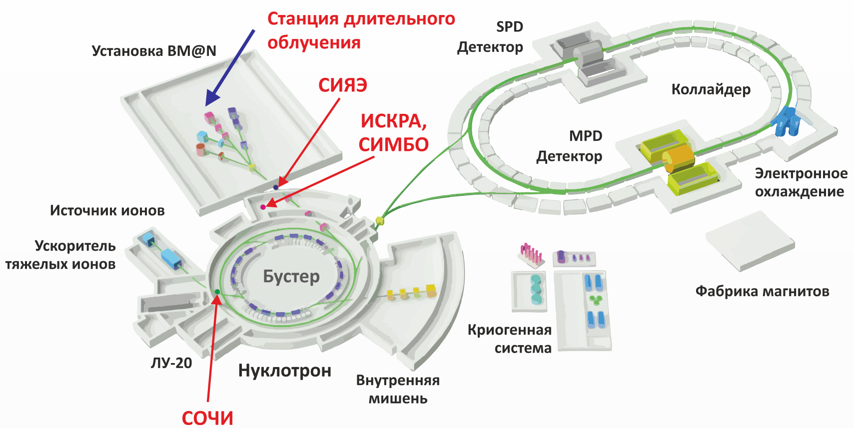


Исследование материалов в экстремальных условиях

Создание каналов и облучательных станций

В декабре 2021 года завершены работы по созданию **С**танции для **о**блучения **чи**пов (**СОЧИ**). Станция предназначена для облучения микросхем с предварительно удалённым корпусом пучками протонов и ускоренных ионов с *Z* от 2 до 92 низких энергий (3,2 МэВ/нуклон).

В декабре 2022 года на выходе из установки BM@N, был собран прототип **станции для длительного облучения образцов** ионами высоких энергий (~3,8 ГэВ/нуклон). Созданная станция позволяет использовать пучки ионов для прикладных исследований в режиме параллельной работы с установкой BM@N.



Научная коллаборация ARIADNA

В рамках проекта прикладные исследования на пучках комплекса NICA выполняются в соответствии с программами работ коллаборации ARIADNA, **закрепленной в соглашениях о сотрудничестве (MoU) с заинтересованными организациями.**

Организации, сотрудничающие в рамках коллаборации ARIADNA

1. Объединенный институт ядерных исследований (Дубна, Межд.)
2. Институт медико-биологических проблем РАН (Москва, Россия)
3. Федеральный медицинский биофизический центр им. А.И. Бурназяна (Москва, Россия)
4. НИИ ядерной физики им. Д.В. Скобельцына Московского государственного университета им. М.В. Ломоносова (Дубна, Россия)
5. Санкт-Петербургский государственный университет (Санкт-Петербург, Россия)
6. Медицинский радиологический научный центр имени А.Ф. Цыба (Обнинск, Россия)
7. Федеральный исследовательский центр химической физики им. Н.Н. Семенова РАН (Москва, Россия)
8. Институт теоретической и экспериментальной биофизики РАН (Москва, Россия)
9. Московский физико-технический институт (Долгопрудный, Россия)
10. Российский университет дружбы народов (Москва, Россия)
11. Институт общей и неорганической химии им. Н.С. Курнакова РАН (Москва, Россия)
12. Национальный исследовательский ядерный университет «МИФИ» (Москва, Россия)
13. Объединенный институт высоких температур РАН (Москва, Россия)
14. Северо-Осетинский государственный университет (Владикавказ, Россия)
15. Институт ядерных проблем Белорусского государственного университета (Минск, Белоруссия)
16. Объединенный институт энергетических и ядерных исследований – Сосны НАН Беларуси (Сосны, Белоруссия)
17. Институт ядерной физики АН РУз (Ташкент, Узбекистан)
18. Ереванский государственный университет (Ереван, Армения)
19. ИСИ CANDLE (Ереван, Армения)
20. ННЛА ЕрФИ (Ереван, Армения)
21. ООО «Научно-производственная компания «Квант-Р» (Москва, Россия)
22. ООО «С-Инновации» (Москва, Россия)
23. ООО «SOL-Instruments» (Минск, Беларусь)

182 участника

Conclusions

- **NICA** is a mega-science project, which approaches its full commissioning
- **BM@N** and **MPD**: heavy-ion program has been started in the fixed-target mode, collider collisions are expected in late 2025
- **SPD**: spin physics program with polarized beams is advancing to start in late 20-th
- **ARIADNA**: applied research program is already running with new opportunities to come
- Experiments at NICA are driven by **international collaborations** → new members are needed and welcome to fulfill the comprehensive research programs

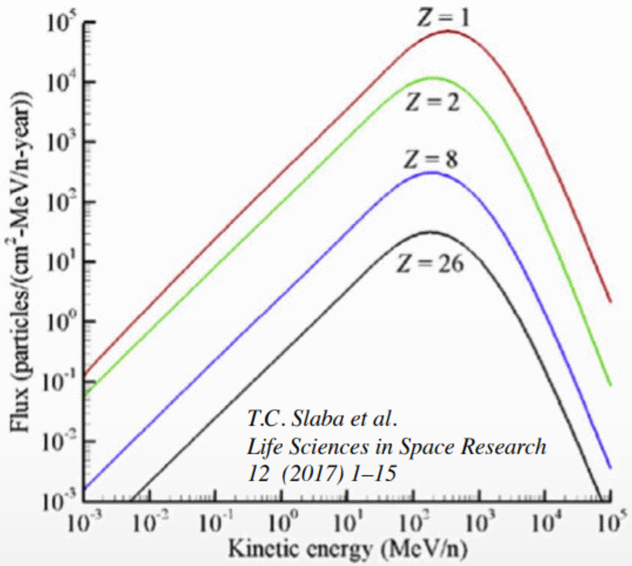
NICA на конференции (экспериментальные доклады)

- Установки проекта NICA - Андрей Бутенко
- Эксперименты на Ускорительном Комплексе NICA – Виктор Рябов
- Спектры и корреляции прямых фотонов в тяжелоионных столкновениях при энергии NICA - Vladislav Kuskov
- First physics studies planned with the MPD experiment at NICA in Bi+Bi collisions at 9.2 GeV - Grigory Feofilov
- Измерение анизотропного потока и спектра нейтральных пионов в Bi+Bi @ 9.2 ГэВ в эксперименте MPD - Pavel Gordeev
- Измерение анизотропных потоков лямбда-гиперонов в экспериментах MPD и BM@N - Valerii Troshin
- Направленный поток протонов в столкновениях Xe+CsI при энергии 3.8A ГэВ на установке BM@N - Mikhail Mamaev
- Изучение рождения протонов, d, t в столкновениях аргон-ядро в эксперименте BM@N на NICA - Vadim Kolesnikov
- Первые результаты по измерению направленного потока дейтронов в столкновениях Xe+Cs(I) при энергии 3.8A ГэВ на эксперименте BM@N - Ирина Жаворонкова
- Высокогранулярный нейтронный детектор и система передних детекторов эксперимента BM@N - Николай Карпушкин
- Система сбора данных эксперимента SPD на коллайдере NICA - Aleksandr Boikov
- Исследование зависимости коллективных потоков в ядро-ядерных столкновений от энергии столкновения с помощью скейлинговые соотношений - Аркадий Тараненко
- Измерение анизотропных потоков адронов в эксперименте MPD в NICA - Petr Parfenov
- Comparison of different methods for centrality determination in Xe+CsI collisions at 3.8 A GeV in the BM@N experiment - Dim Idrisov
- Определение центральности столкновений тяжелых ионов в эксперименте BM@N - Alexander Demanov
- Study of production of phi(1020)- and charged K*(892)-mesons and charged Sigma(1385)-baryons In collision of bismuth nuclei at 9.2 GeV in the MPD experiment at NICA - Dmitry Ivanishchev

BACKUP

High-energy heavy-ion reaction data

- Galactic Cosmic Rays composed of nuclei (protons, … up to Fe) and E/A up to 50 GeV
- These high-energy particles create cascades of hundreds of secondary, etc. particles

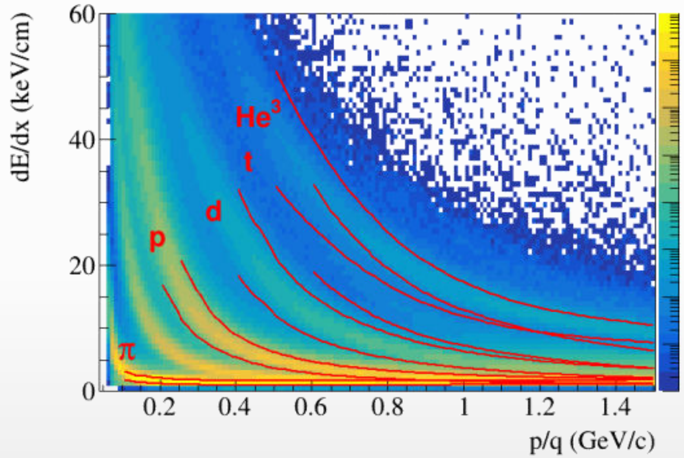


- Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.
- The damage is proportional to Z^2, contribution of secondaries p, d, t, ^{3}He, and ^{4}He is also significant
- Need input information for transport codes for shielding applications (Geant-4, Fluka, PHITS, etc.):
  - ✓ total, elastic/reaction cross section
  - ✓ particle multiplicities and coellecense parameters
  - ✓ outgoing particle distributions: $d^2N/dEd\Omega$

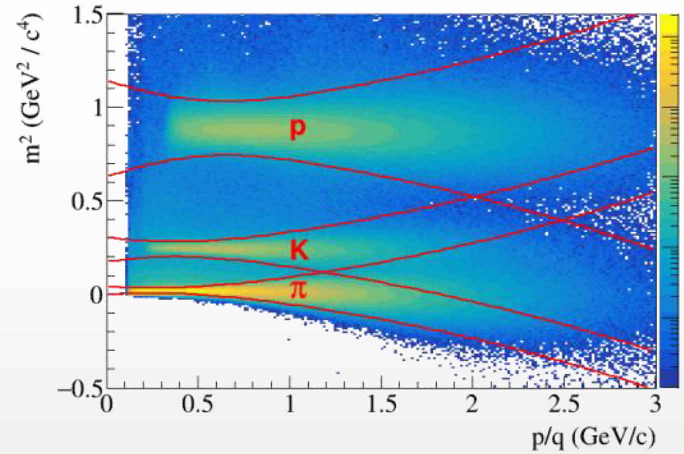
High energy heavy ion reaction data

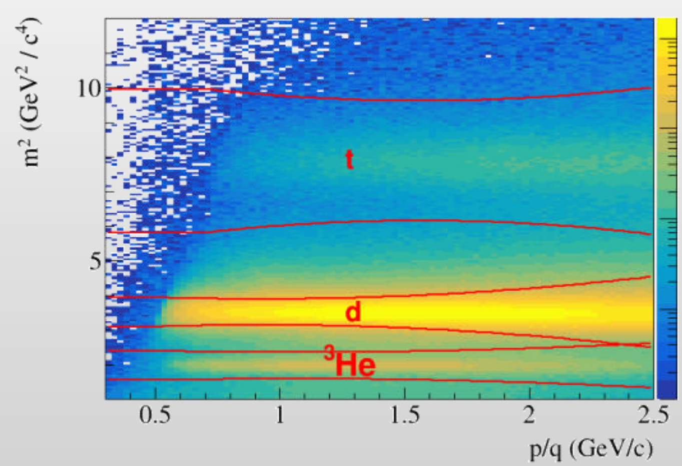
- NICA can deliver different ion beam species and energies:
  - ✓ Targets of interest (C = astronaut, Si = electronics, Al = spacecraft) + He, C, O, Si, Fe, etc.
- No data exist for projectile energies > 3 GeV/n

dE/dx vs momentum in TPC



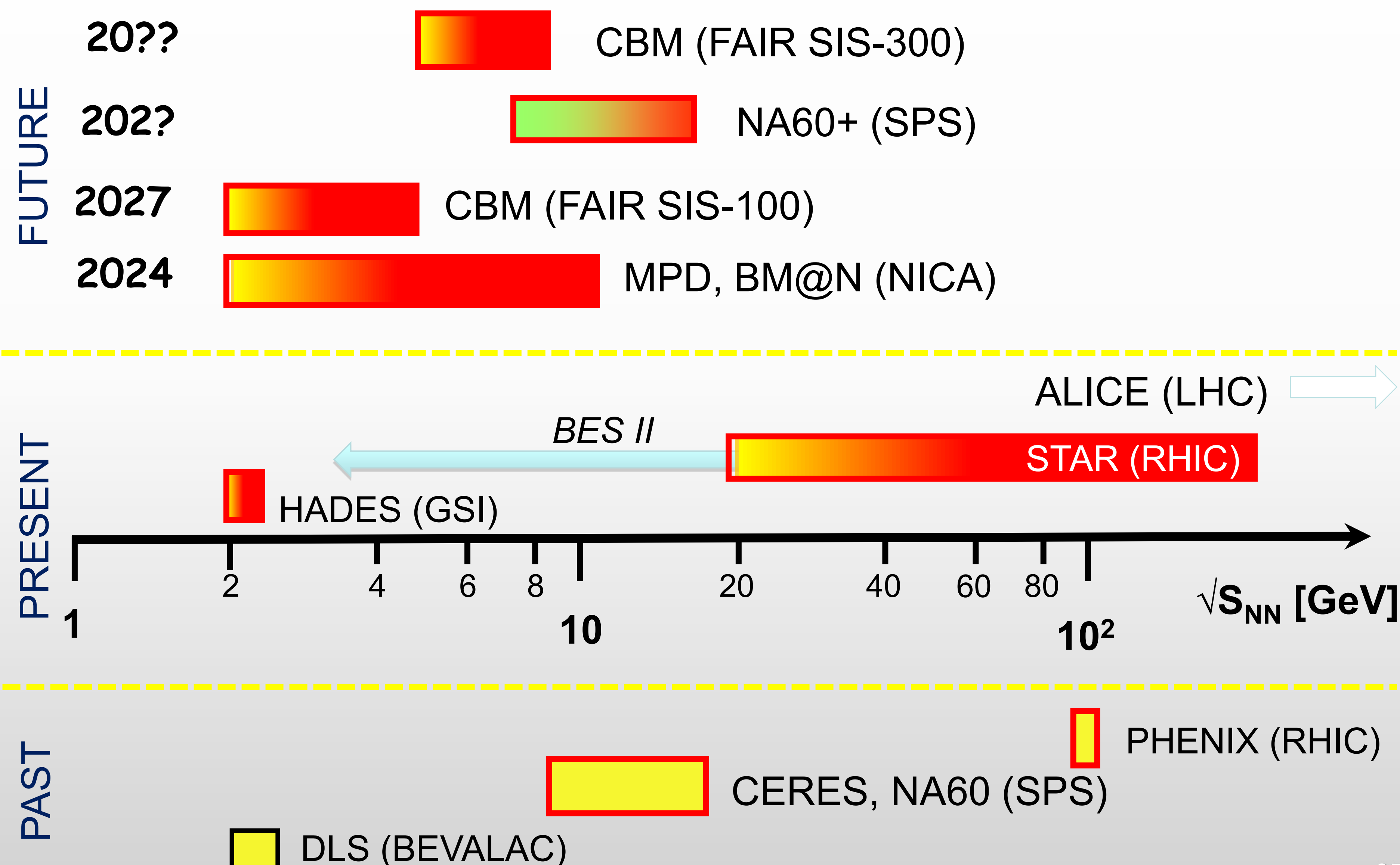
m² vs. momentum in TOF



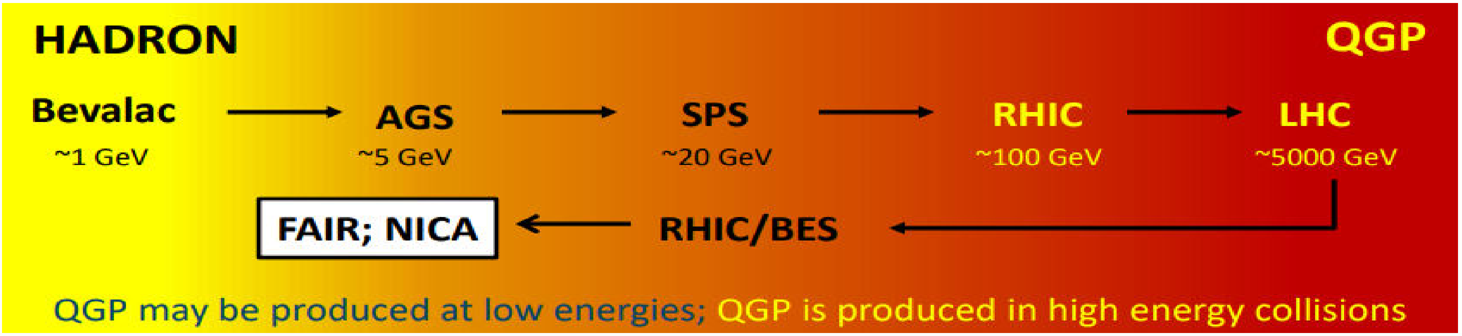


MPD has excellent light fragment identification capabilities in a wide rapidity range → <u>unique capability of the MPD</u> in the NICA energy range

Dilepton experiments



Heavy-ion collisions with accelerators



Short heavy-ion physics history

Fixed target

- **BEVALAC – LBNL** 1972-1984 max. $\sqrt{s_{NN}}$ = 2.2 GeV
- **SPS – CERN** 1986-2000 $\sqrt{s_{NN}}$ = 17.3 GeV — NA35/49, NA44, NA38/50/51, NA45, NA52, NA57, NA60, WA80/98, WA97 …
- **AGS – BNL** 1988-1996 $\sqrt{s_{NN}}$ = 4.8 GeV — E864/941, E802/859/866/917, E814/877, E858/878, E810/891, E896, E910 …
- **SIS18 – GSI** 1990 → $\sqrt{s_{NN}}$ = 2.4 GeV

Collider

- **RHIC – BNL** 2000-2025 $\sqrt{s_{NN}}$ = 200 GeV — BRAHMS, PHENIX, PHOBOS, STAR
- **LHC – CERN** 2010 → $\sqrt{s_{NN}}$ = 5.02 TeV — ALICE, ATLAS, CMS, LHCb

Near future

- NICA – JINR 2024 $\sqrt{s_{NN}}$ = 11 GeV — MPD, BM@N — Collider & Fixed target
- SIS100 – FAIR 2028? $\sqrt{s_{NN}}$ = 5 GeV — CBM, HADES — Fixed target

BM@N Collaboration

5 Countries, 13 Institutions, 214 participants

- *University of Plovdiv, Bulgaria*
- *St.Petersburg University*
- *Shanghai Institute of Nuclear and Applied Physics, CFS, China;*
- *Joint Institute for Nuclear Research;*
- *Institute of Nuclear Research RAS, Moscow*
- *NRC Kurchatov Institute, Moscow combined with Institute of Theoretical & Experimental Physics, NRC KI, Moscow*
- *Moscow Engineer and Physics Institute*
- *Skobeltsyn Institute of Nuclear Physics, MSU, Russia*
- *Moscow Institute of Physics and Technics*
- *Lebedev Physics Institute of RAS, Moscow*
- *Institute of Physics and Technology, Almaty*
- Physical-Technical Institute Uzbekistan Academy of Sciences, Tashkent
- High School of Economics, National Research University, Moscow

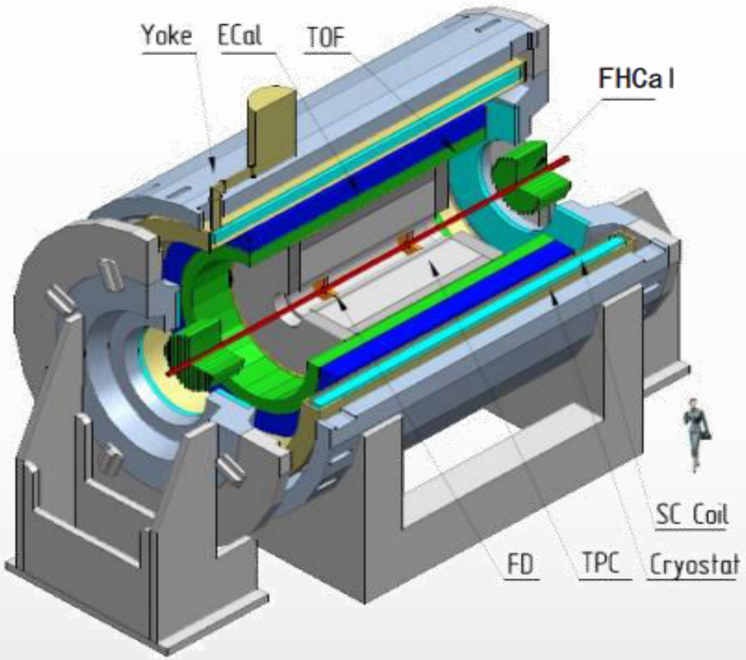
Multi-**P**urpose **D**etector (MPD) Collaboration

***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***