NICA

Nuclotron-based
Ion Collider fAcility

Status and plans of the MPD experiment

V. Riabov for the MPD Collaborations (MEPhI, JINR)



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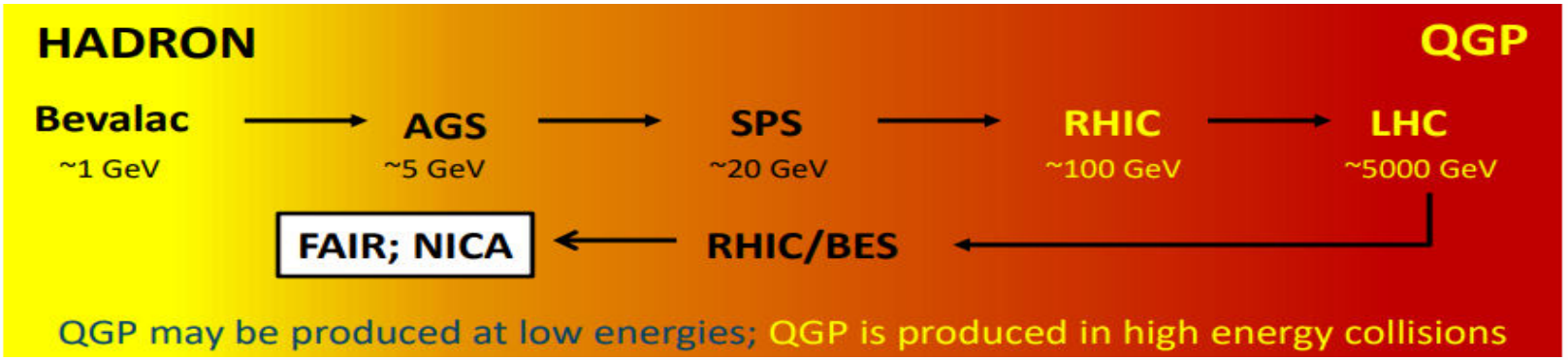
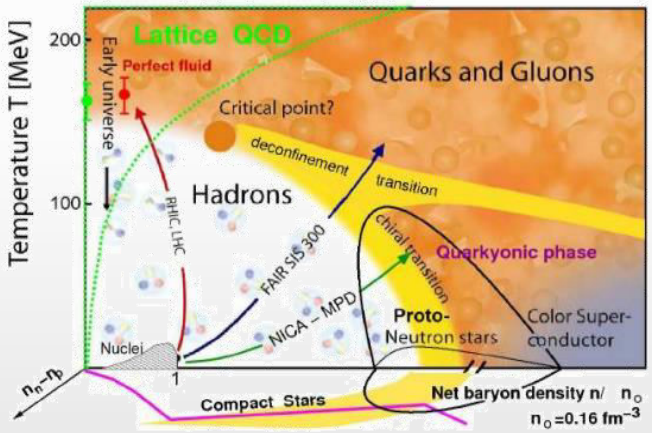
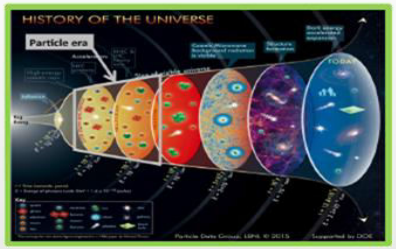
Heavy-ion collisions





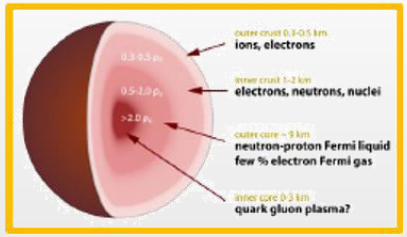
High beam energies ($\sqrt{s_{NN}}$ > 100 GeV)

High temperature:
Early Universe evolution



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

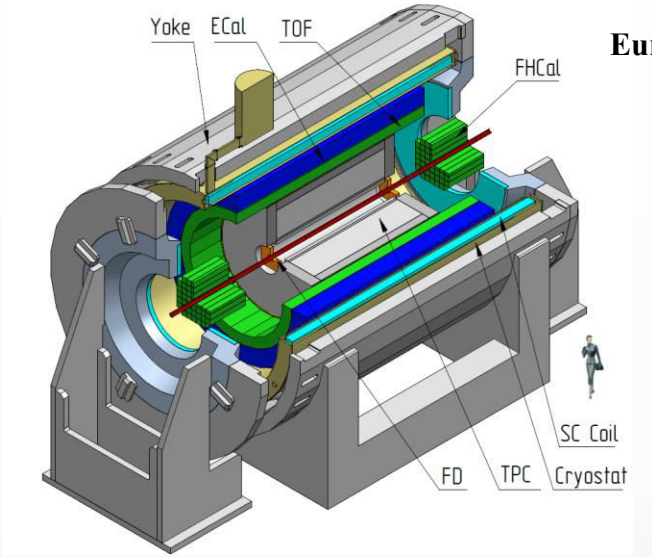
high baryon densities
→ inner structure of
compact stars



- RHIC/LHC: smooth crossover (lattice QCD calculations + data) at $\mu_B\,(n_B) \sim 0$
- NICA/FAIR: 1st order phase transition and QCD critical point at large $\mu_B\,(n_B)$
- MPD @ NICA → study QCD medium at extreme net baryon densities
- Critical end point: $(\mu_c, T_c) = (495 - 654, 100 - 119)$ MeV ➡ $3.5 < \sqrt{s_{NN}} < 4.9$ GeV

Multi-Purpose Detector

Stage-I → start of operation in 2026



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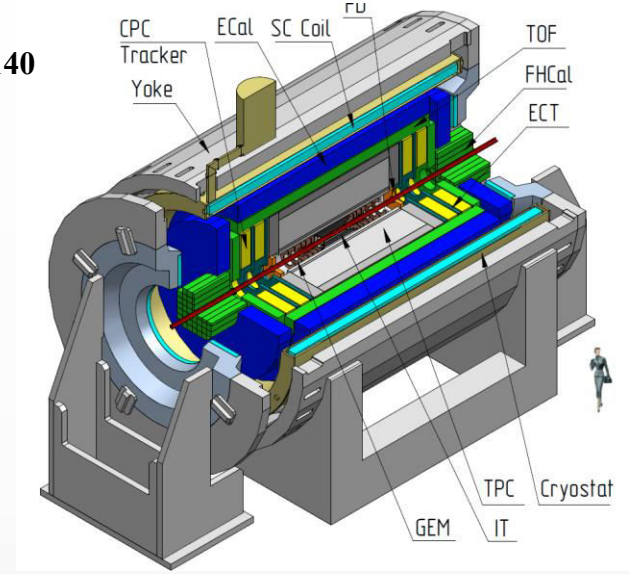
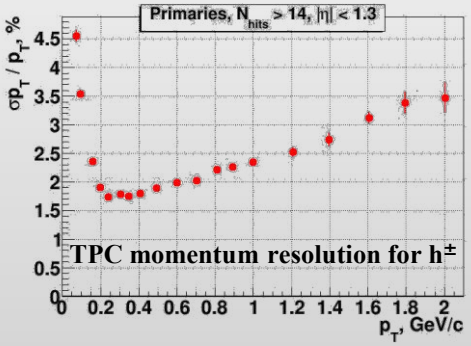
Stage-II → 2030+

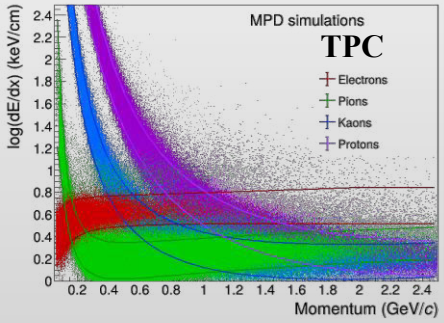


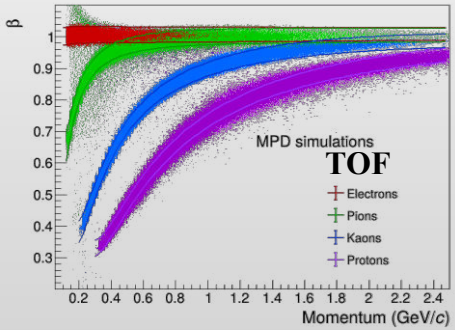
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$; **TOF, EMC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$; **FHCAL**: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

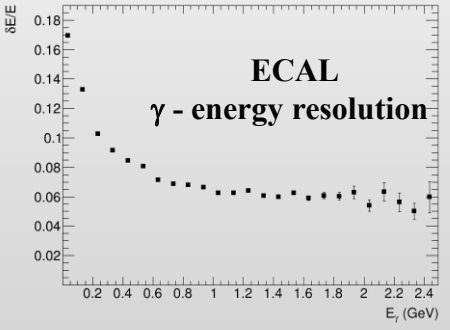
+ **ITS** : $|\Delta\varphi| < 2\pi$, $|\eta| \leq 3$
+ **Forward Spectrometers**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 2.2$

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



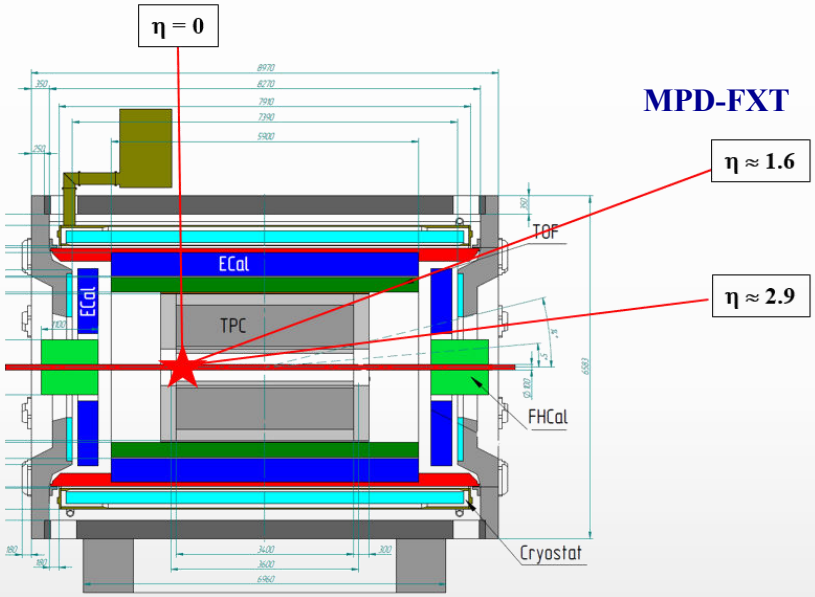


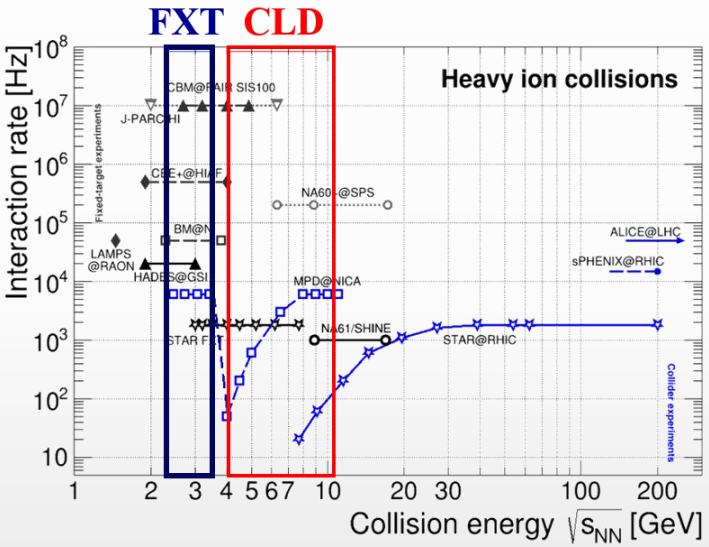




MPD strategy

- 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:





competitors:

Present:

RHIC/STAR (USA)
3-200 GeV
SIS18/HADES (Germany)
2.4-2.55 GeV

Future:

HIAF/CEE (China)
2.1-4.5 GeV (2026-?)
FAIR/CBM (Germany)
2.4-4.9 GeV (2029-?)
JPARC-HI (Japan)
2-5 GeV (2030-?)

- ✓ 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

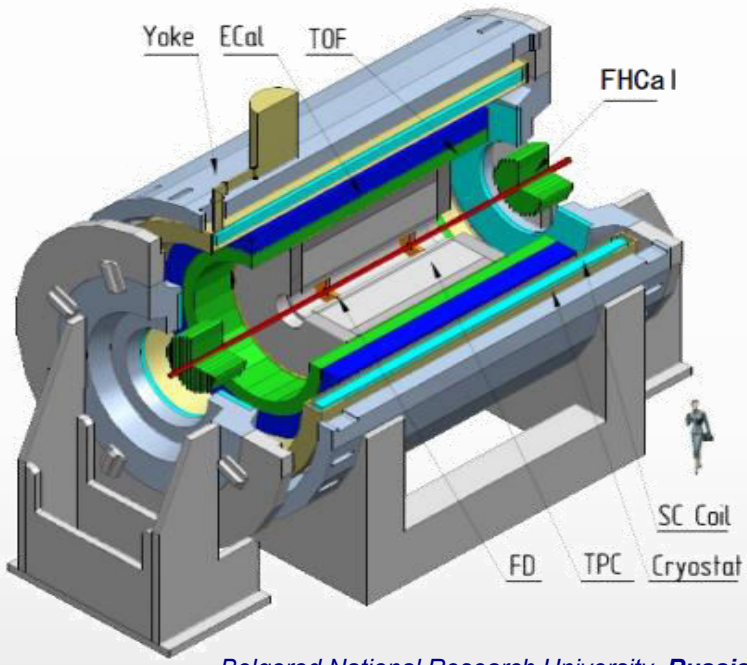
Multi-Purpose Detector (MPD) Collaboration

***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**;*
*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, 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***

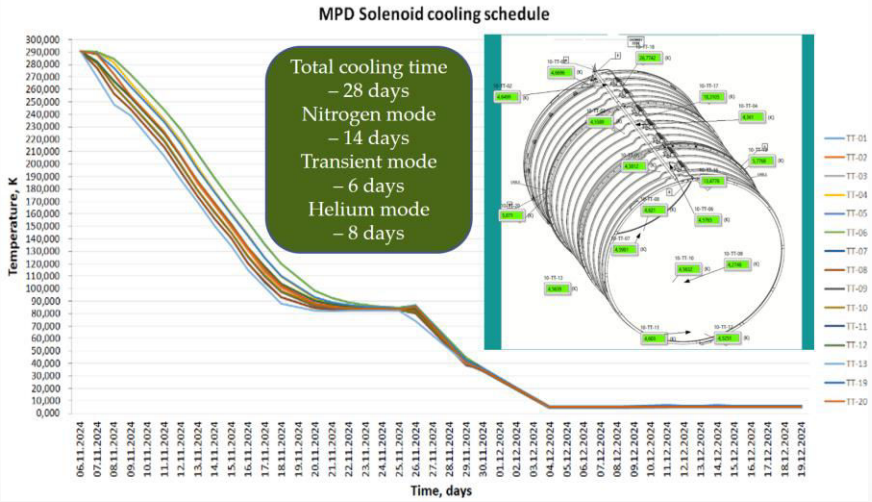
MPD superconducting magnet

- Cooling of the magnet to LN2 and LHe temperatures → SC coil training up to 0.3 T

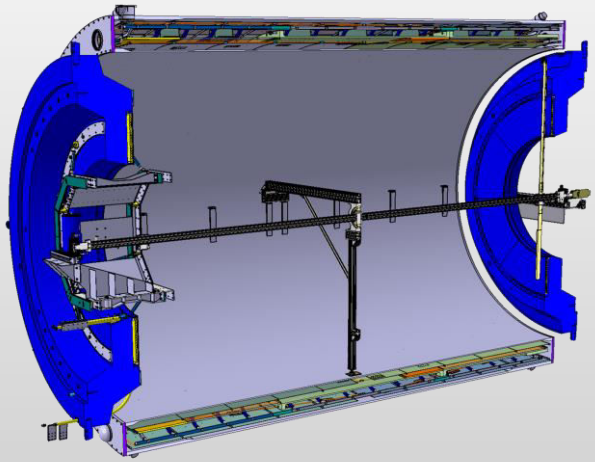
Magnet yoke and cryogenic platform

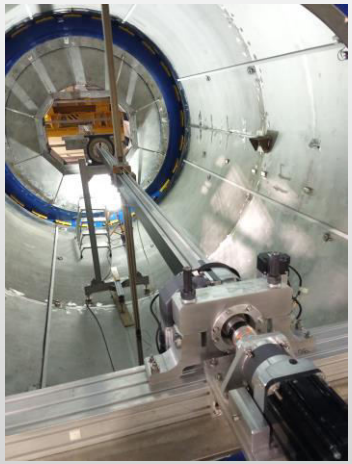


Cooling procedure and rate



- Magnetic field measurements: starting …





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

Central barrel subsystems

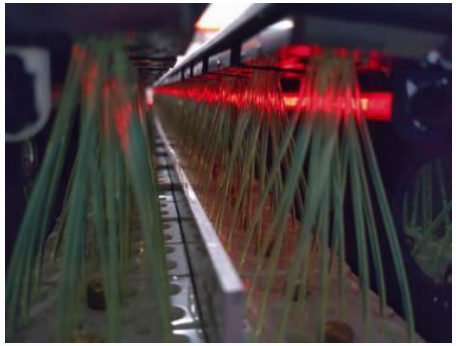
Frame - ready



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)

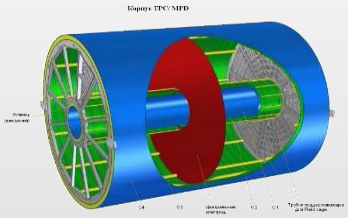
45 (50 in total) half-sectors to be ready by December (April)

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

Ongoing TPC gas volume assembly and HV/leakage tests

TPC + ECAL cooling systems under commissioning

Forward subsystems

FHCAL - ready

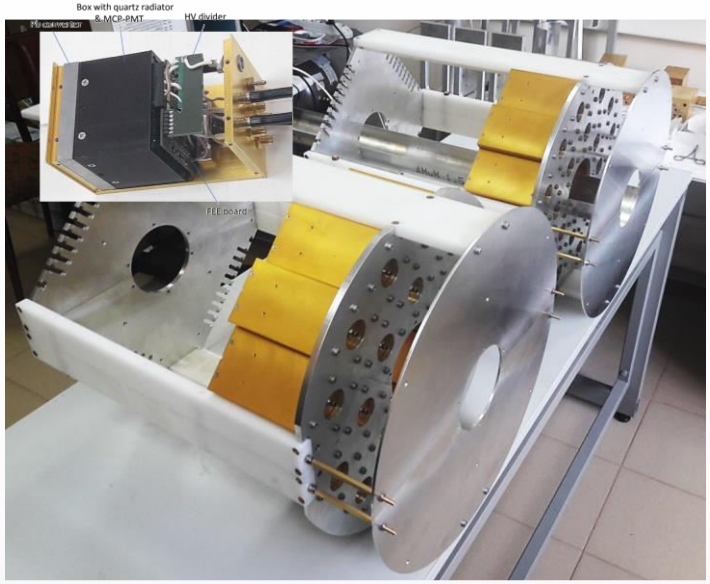




FHCal assembled on the platform,
(modules are equipped with FEE)

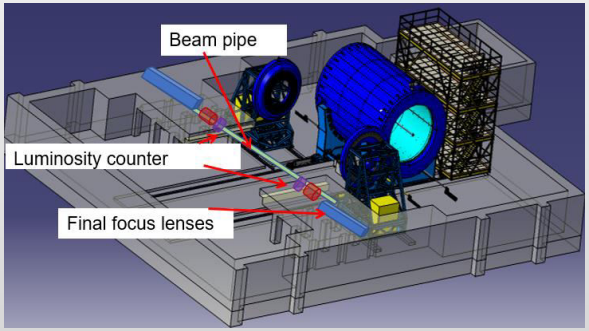
Test installation of FHCAL → autumn 2024
Final installation → Autumn 2025

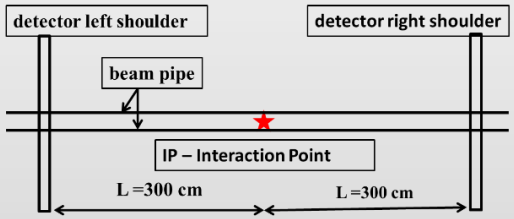
FFD - ready



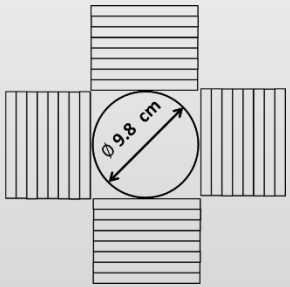
Cherenkov modules of FFDE and FFDW, mechanics for installation in container with beam pipe are available,
Long term tests with cosmic rays & laser ongoing

Beam and luminosity monitoring



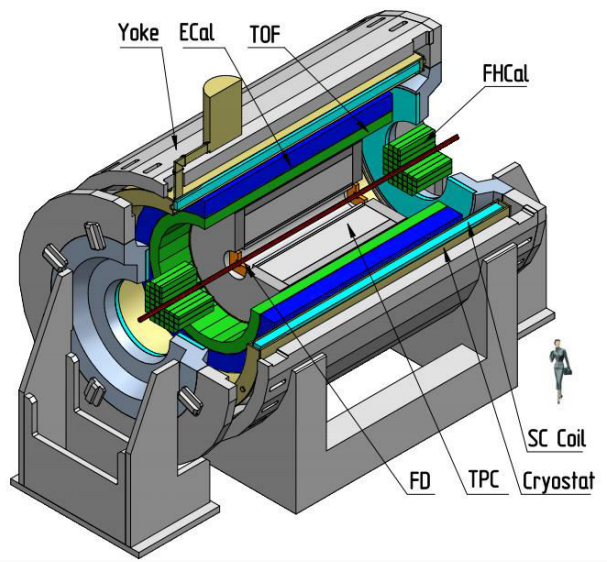


Measurement of transverse sizes of the bunches
Transvers and longitudinal convergence of bunches
Vertices distribution along the beam

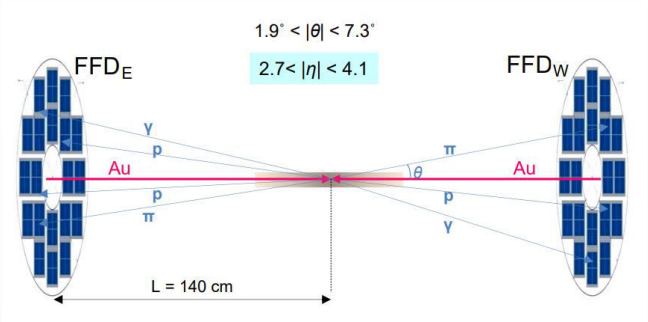


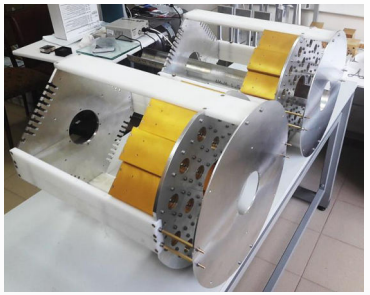
Assembly of the main components of the detector for the Run on the collider beam – end of 2025

Trigger system

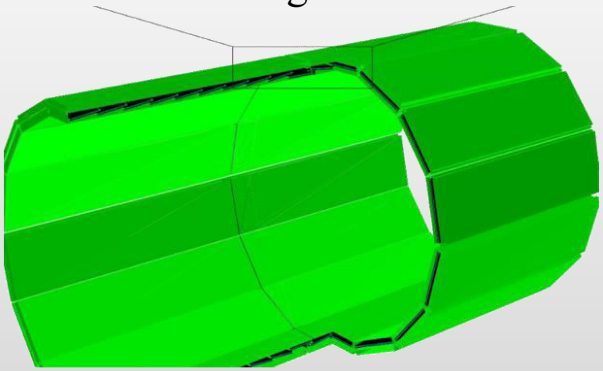


- FFD (Fast Forward Cherenkov Detector):
  - ✓ fast (~ 50 ps) event triggering → photons from π^0's
  - ✓ T_0 for time-of-flight measurements (TOF and ECAL)





- TOF (|η| < 1.5):
  - ✓ 280 fast signals for each MRPC chamber
  - ✓ no online timing information



- FHCAL (Forward Hadron Calorimeter):
  - ✓ Fast signals for event triggering
  - ✓ poor T_0 (~ 1 ns) and event z-vertex resolution

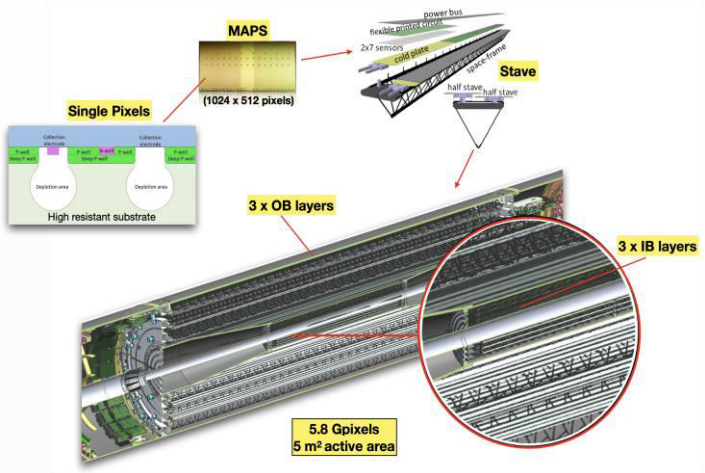


two FHCAL detectors
at $2 < |\eta| < 5$,
~ 1x1 m^2 each

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)

Future upgrade: Inner Tracking System (ITS)

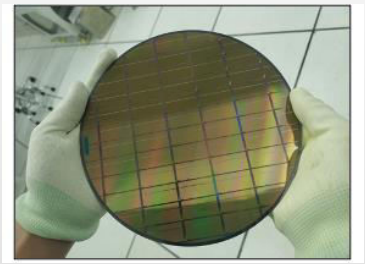
The ITS is the key to measuring the production of heavy-flavor hadrons



The complete structure of the 6-layer MPD-ITS detector, from a single pixel to the inner and outer cylindrical layers

1) The TDR was finalized to build an ITS consisting of six cylindrical layers of MAPS (Monolithic Active Pixel Sensors) around the interaction region: 3 layers of inner barrel (IB) surrounded by 3 layers of outer barrel (OB)

2) An agreement was reached with Chinese partners to jointly research, develop and manufacture in China the missing components needed to build the tracker and its readout system.



- first prototype of ALPIDE-like MAPS (MICA) sensor developed at CCNU and produced in China

- FPGA-based Readout System and the Power Unit developed at USTC for reading out the "staves" comprising of MICA sensors of IB and OB → tests at LHEP in 2025

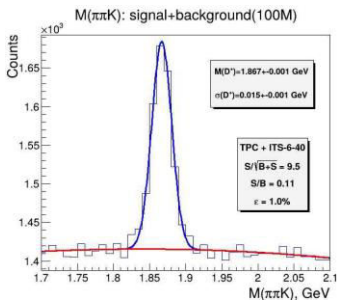
- first porotypes of the GBT ASICs for the fast aggregation of data and transfer via optical lines designed and manufactured → lab tests ongoing in CCNU.

6 layers in 2 barrels final conceptional design and its optimization - by 2024

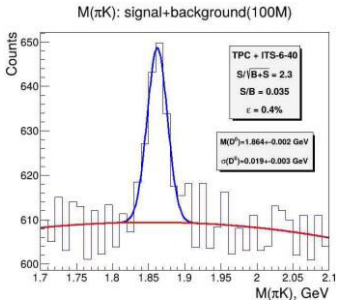
MPD - ITS

D^+ and D^0 reconstruction using KF with TPC-TOF PID

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



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



N_D = 19 000 mesons/month for D^+
N_D = 3 200 mesons/month for D^0

Using the optimal BDT cut allows to reconstruct D^+ and D^0 with an efficiency of **1.0%** and **0.4%** respectively.

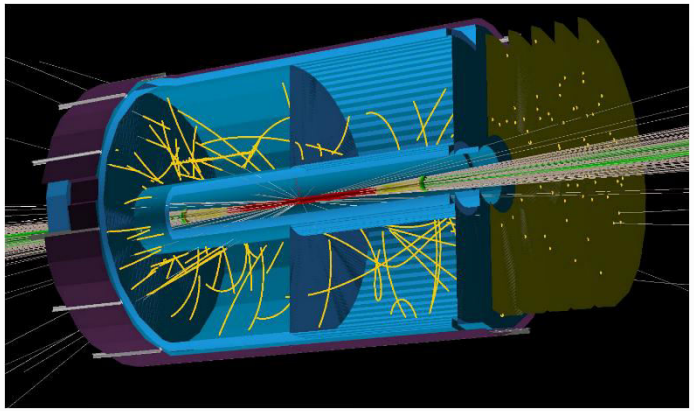
Particle	D^+	D^0
Efficiency, %	1.0	0.4
Significance	9.5	2.3
S/B(2σ) ratio	0.11	0.035

Courtesy of Prof. V.Kondratiev (SPbSU)

D^0 and D^+ reconstruction using information from ITS+TPC+TOF subsystems

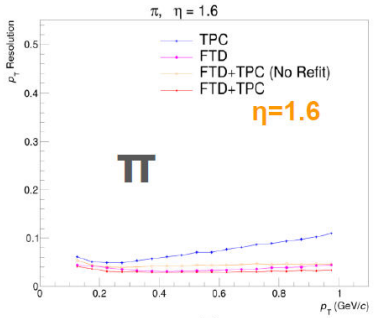
Future upgrade: Forward Spectrometers

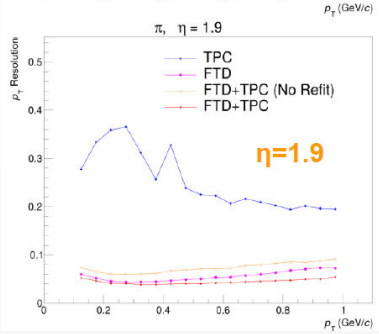
Conception of the Forward Tracker (FTD)



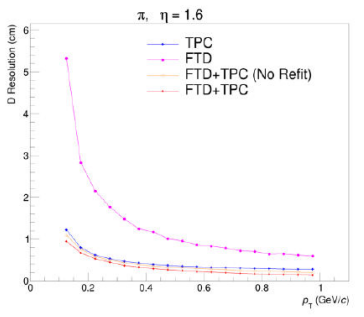
- ✓ five tracking layers within z = 210–300 cm,
- ✓ 1% X_0, ~ 80 μm spatial resolution

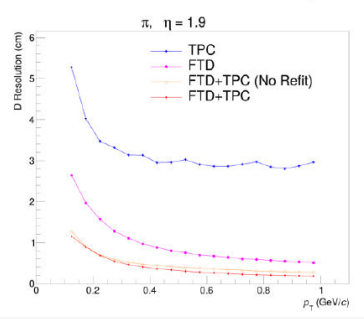
Momentum resolution



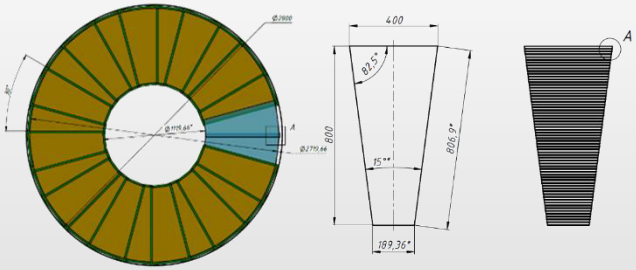


DCA resolution



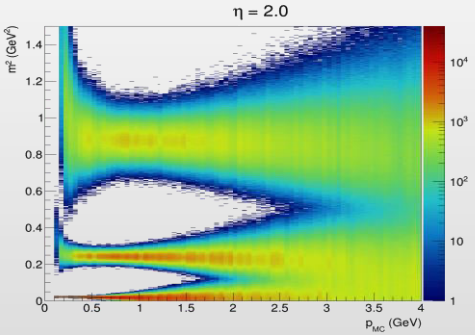


Conception of the end-cup TOF detector



- ✓ 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

π/K/p separation vs. particle momentum



(FTD+TPC) makes possible track reconstruction and identification up to |η| ~ 2 with momentum resolution < 10%

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, 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

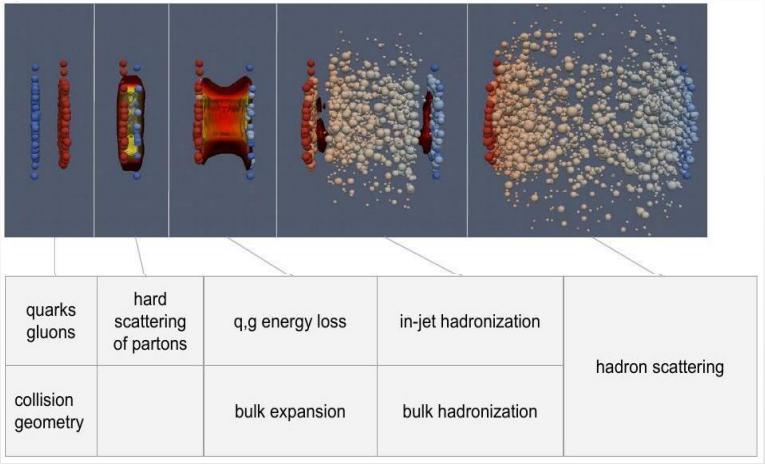
Discuss physics feasibility studies at regular cross-PWG meetings

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

- Mescheryakov Laboratory of Information Technologies takes active participation in MPD collaboration works. We are grateful for provided computing resources, development and support of IT services.

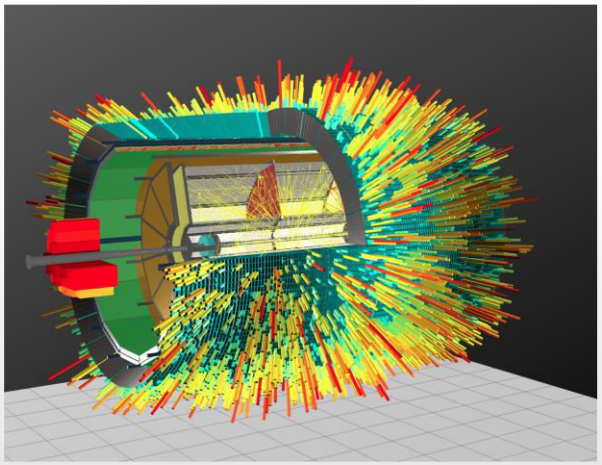
Event generator(s)



MpdRoot

JINR MLIT

Particle propagation & detector response



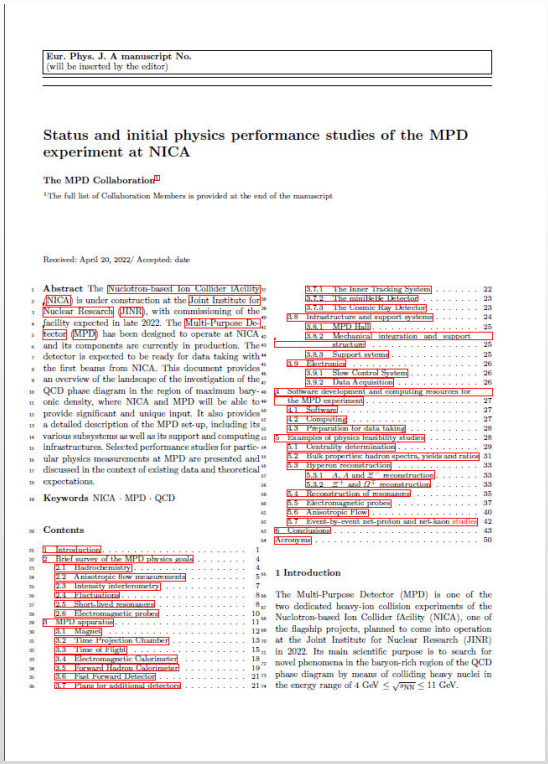
- Develop physics program, software and analysis infrastructure for real data analysis
- MPD-CLD and MPD-FXT studies with simulations:
  - ✓ collider mode: Bi+Bi @ 9.2 GeV
  - ✓ fixed-target mode: Xe + W @ T = 2.5 AGeV

Conference & publication activity

- ~ 50 reports at international conferences per year
- Overall 250+ publications indexed by SPIRES
- 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**
Rev.Mex.Fis. 71 (2025) 4, 041201, e-Print: 2503.21117 (~ 40 pages)



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[a]

[a]The full list of Collaboration Members is provided at the end of the manuscript

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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.



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MPD physics performance studies in Bi+Bi collisions at $\sqrt{s_{NN}} = 9.2$ GeV

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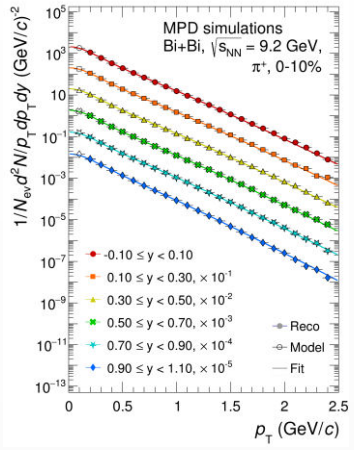
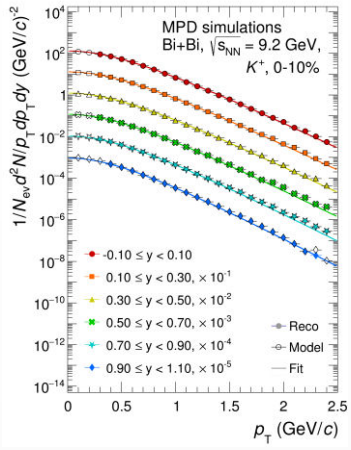
Light identified hadrons

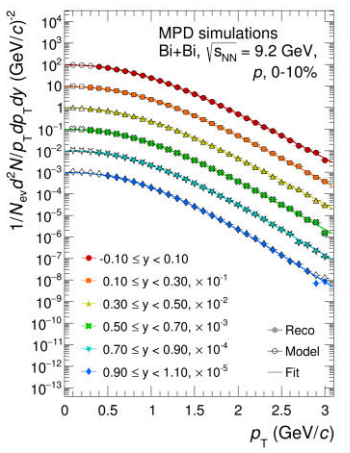
- ✓ probe freeze-out conditions
- ✓ radial flow and collective expansion
- ✓ hadronization mechanisms, thermal models vs. coalescence
- ✓ strangeness production, “horn” for K/π, hidden strangeness with $\phi(1020)$
- ✓ lifetime and properties of the late hadronic phase
- ✓ fluctuation of net-baryon (proton) and net-strangeness (kaon) numbers
- ✓ parton energy loss
- ✓ …

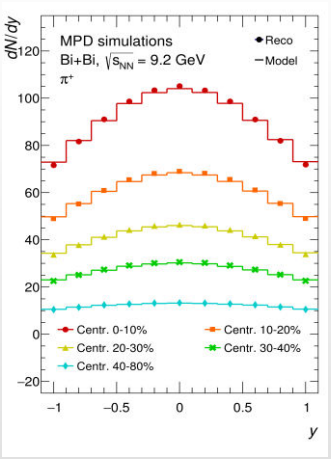
Charged identified hadrons, Bi + Bi @ 9.2 GeV

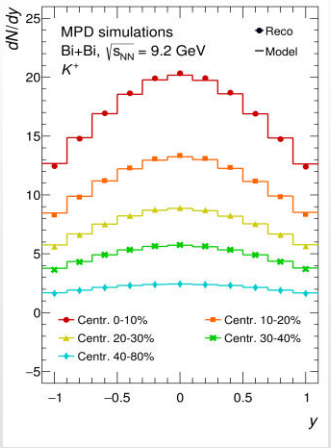
- Charged hadrons: large and uniform acceptance + excellent PID capabilities of TPC and TOF

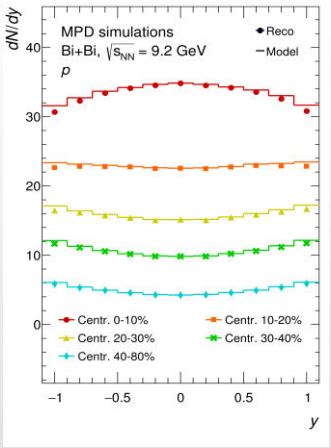












Cover (p_T - rapidity) phase space corresponding to ~ 70% of π/K/p total production

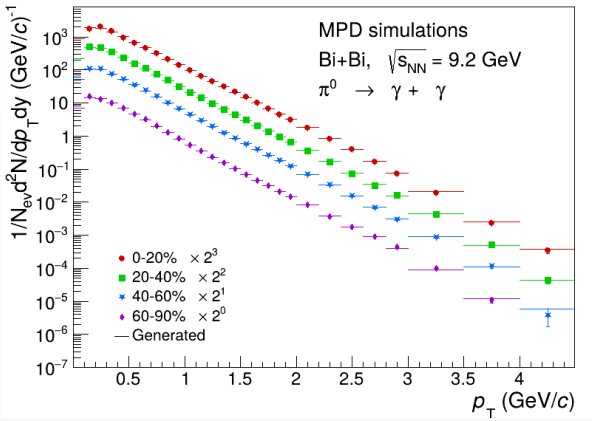
Cover p_T range that corresponds to > 90% of π/K/p total production at midrapidity → small unc. for dN/dy

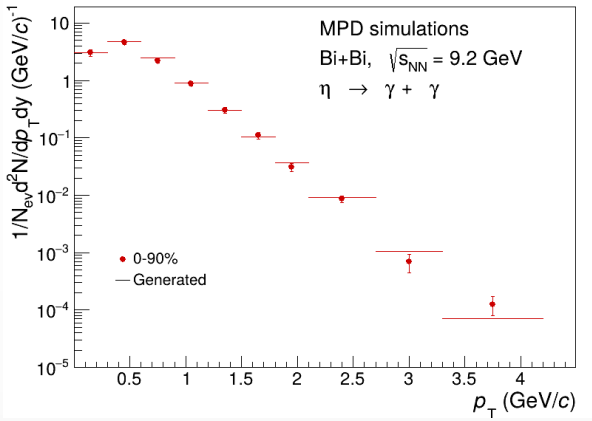
Wide p_T coverage for combined Blast-Wave fits → β, T_{kin}

Net-proton (kaon) fluctuation measurements

Neutral identified hadrons, Bi + Bi @ 9.2 GeV

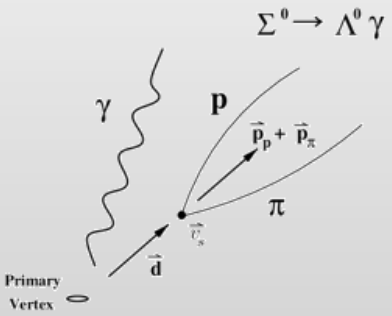
- Neutral mesons:
  - ✓ $\pi^0/\eta \to \gamma\gamma$, $\pi^0/\eta \to \gamma(e^+e^-)$, $\pi^0/\eta \to (e^+e^-)(e^+e^-)$; $K_s \to \pi^0\pi^0$; $\omega \to \pi^0\gamma$, $\omega/\eta \to \pi^0\pi^+\pi^-$; $\eta' \to \eta\pi^+\pi^-$
- Photons: ECAL reconstruction + photon conversion method (PCM)

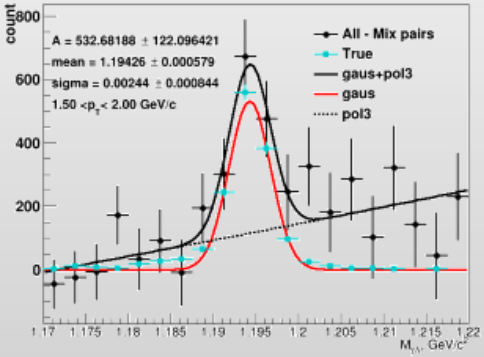


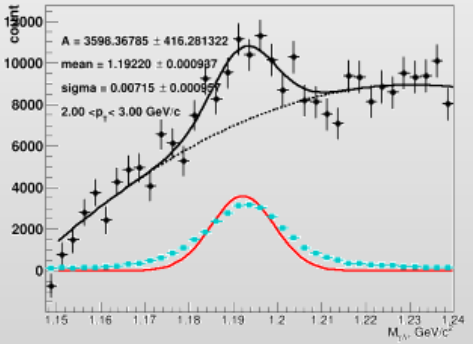


Extended p_T ranges compared to charged particle measurements
Wider hadron variety (masses, quark contents)
Different systematics and species (masses, quark contents)

- … and event baryons: $\Sigma^0 \to \Lambda\gamma$, $\Sigma^0 \to \Lambda(e^+e^-)$, $\Sigma^+ \to p\pi^0$

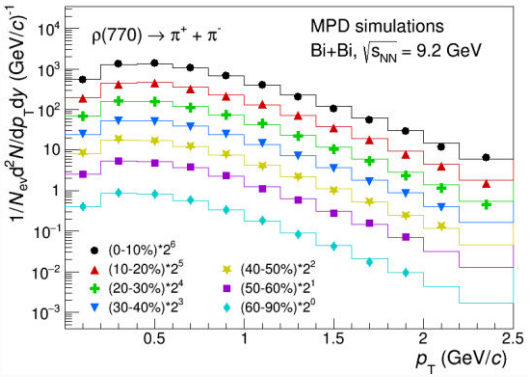


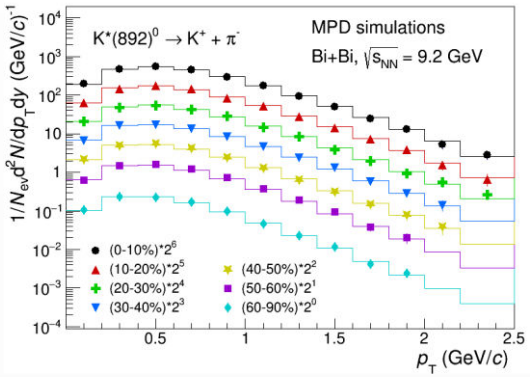


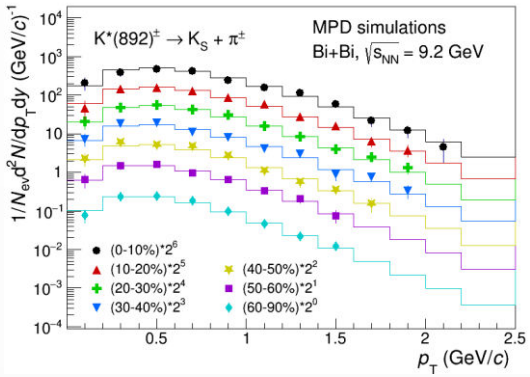


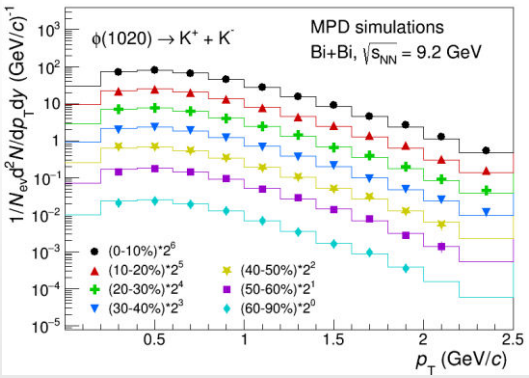
Hadronic resonances, Bi + Bi @ 9.2 GeV

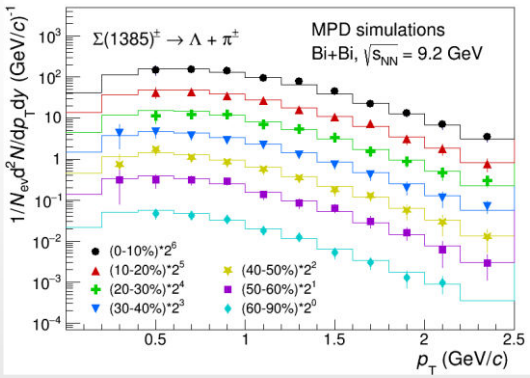
❖ PID capabilities of TPC and TOF + topology selections for weak decays of daughters (K_s, Λ)

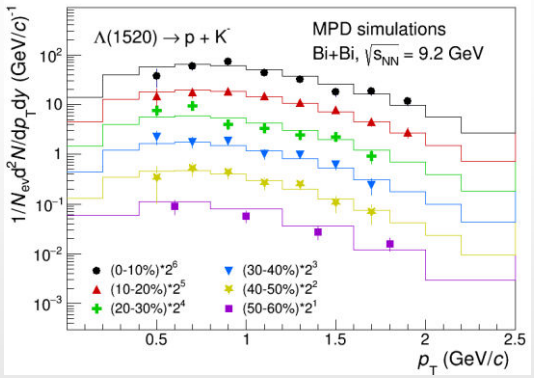












A wide variety of resonances is constructible, ρ(770), K*(892), ϕ(1020), Σ(1385), Λ(1520)

Measurements are possible starting from ~ zero momentum → sample most of the yields

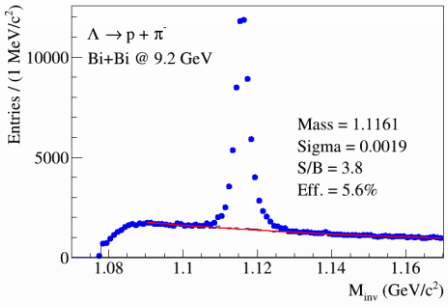
Angular dependent measurements with larger statistics → spin alignment, collective flow

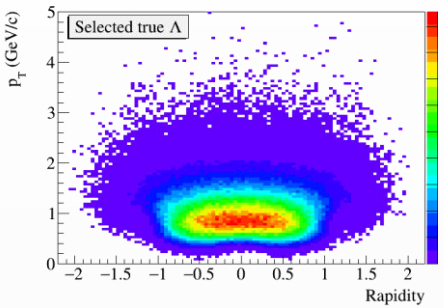
(Multi)strange baryons

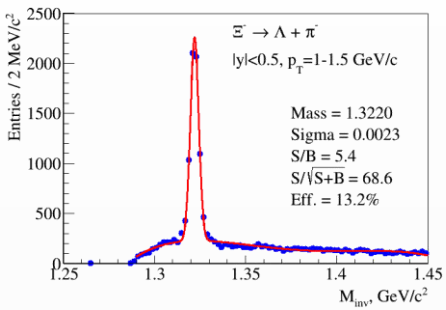
- Small hadronic cross-sections
  → sensitivity to early stages of medium dynamics
- Low p_T: yields of strange hadrons
  → strangeness enhancement, proposed as a signature of QGP since 80's, now described by statistical/thermal models
  → information about chemical freeze-out parameters
  → near or sub-threshold production
- Intermediate p_T: hyperon-to-meson ratios vs. p_T
  → hadronization with parton coalescence, freeze-out conditions

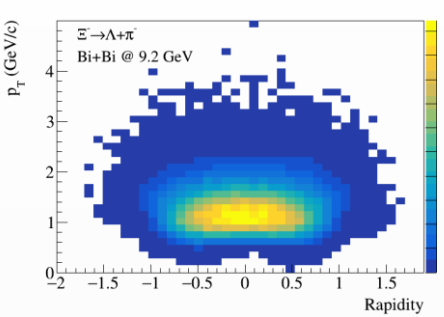
Hyperons, Bi + Bi @ 9.2 GeV

❖ PID capabilities of TPC and TOF + topology selections

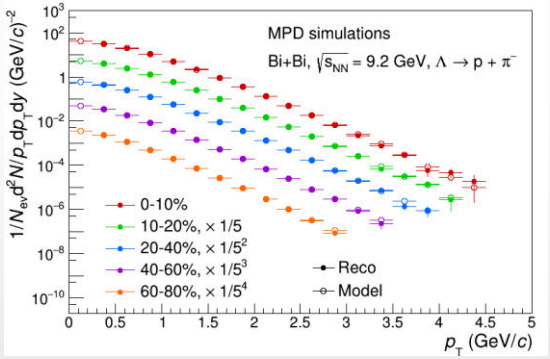


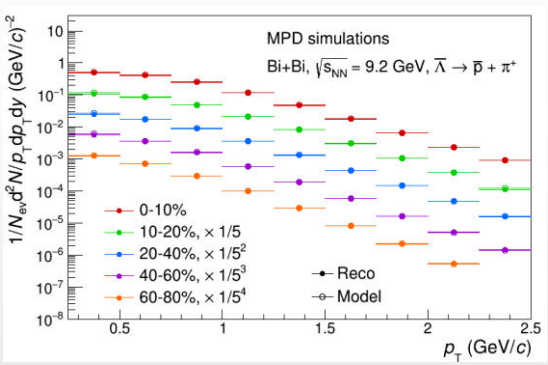


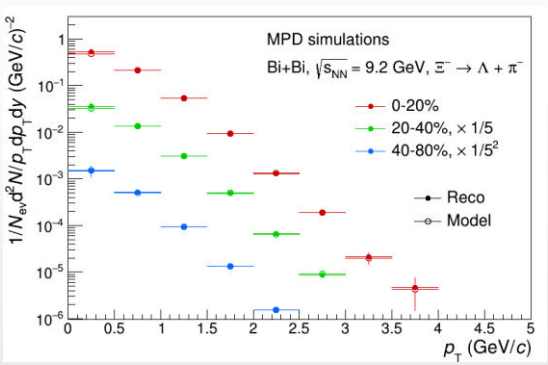


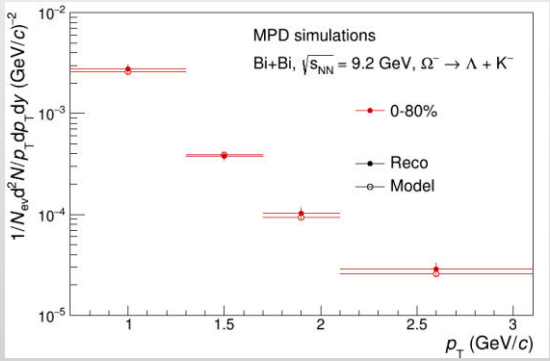


- different background estimates (fit function vs mixed-event), testing alternative Machine Learning techniques





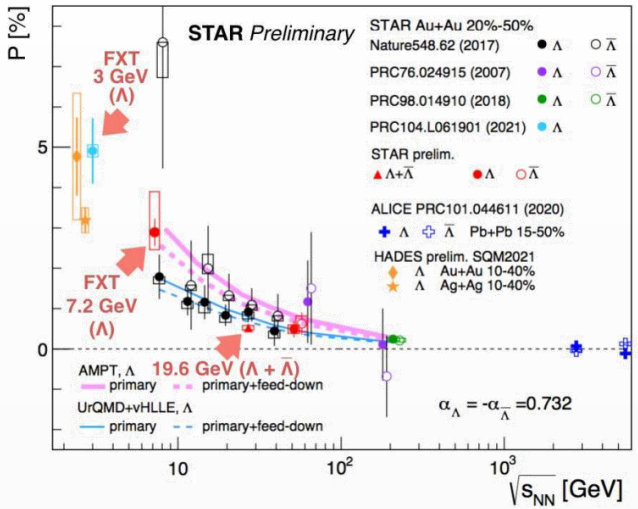




MPD has capabilities to measure production of strange charged/neutral kaons, (multi)strange baryons and resonances in pp, p-A and A-A collisions using h-ID in the TPC&TOF and different decay topology selections

Hyperon global polarization

❖ Global polarization of hyperons experimentally observed, decreases with $\sqrt{s_{NN}}$



✓ reproduced by AMPT, 3FD, UrQMD+vHLLE

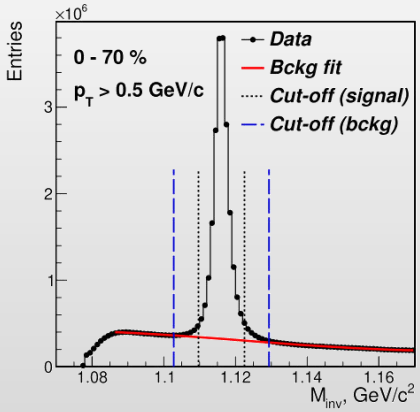
✓ hint for a Λ-$\bar{\Lambda}$ difference, magnetic field: ,

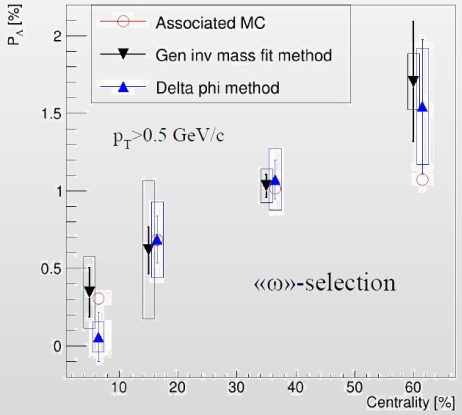
$$P_\Lambda \simeq \frac{1}{2}\frac{\omega}{T} + \frac{\mu_\Lambda B}{T} \qquad P_{\bar\Lambda} \simeq \frac{1}{2}\frac{\omega}{T} - \frac{\mu_\Lambda B}{T}$$

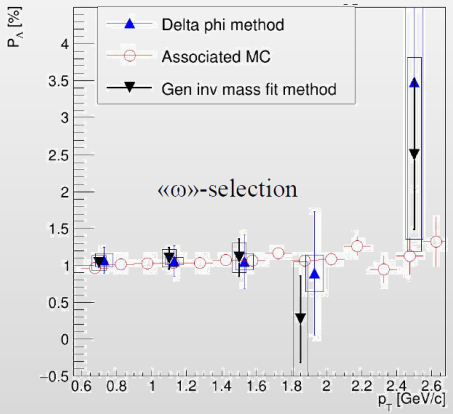
NICA: <u>extra points in the energy range 2-11 GeV</u> centrality, p_T and rapidity dependence of polarization, not only for Λ, but other (anti)hyperons (Λ, Σ, Ξ)

❖ MPD performance: BiBi@9.2 GeV (PHSD, 15 M events) → full reconstruction → Λ global polarization

Performance study of the hyperon global polarization measurements with MPD at NICA, Eur.Phys.J.A 60 (2024) 4, 85







MPD: first global polarization measurements for Λ/$\bar{\Lambda}$ will be possible with ~ 20M data sampled events

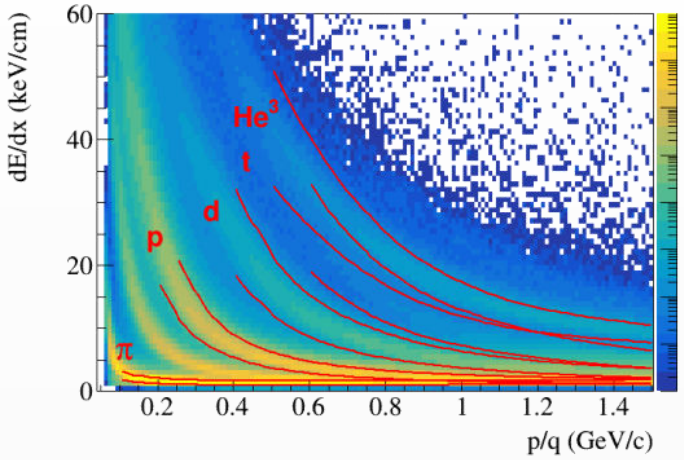
Light (hyper)nuclei

- Production mechanism usually described with two classes of phenomenological models :
  - ✓ statistical hadronization (SHM) → production during phase transition, $dN/dy \propto \exp(-m/T_{chem})$
  - ✓ coalescence → (anti)nucleons close in phase space ($\Delta p < p_0$) and matching the spin state form a nucleus
- Hyper nuclei measurement studies are crucial:
  - ✓ microscopic production mechanism, Y-N potential, strange sector of nuclear EoS
  - ✓ strong implications for astronuclear physics → hyperons expected to exist in the inner core of neutron stars
  - ✓ models predict enhanced hypernuclear production at NICA energies → great opportunity for hypernuclei measurements in MPD, double hypernuclei may be reachable
- Observables of interest: binding energies, lifetimes, branching ratios, $\langle p_T \rangle$, dN/dy, flow

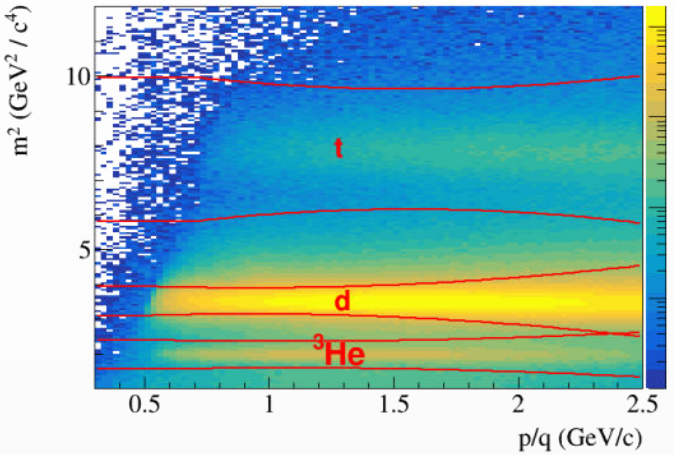
Light nuclei in the MPD

- MPD has excellent light fragment identification capabilities in a wide rapidity range

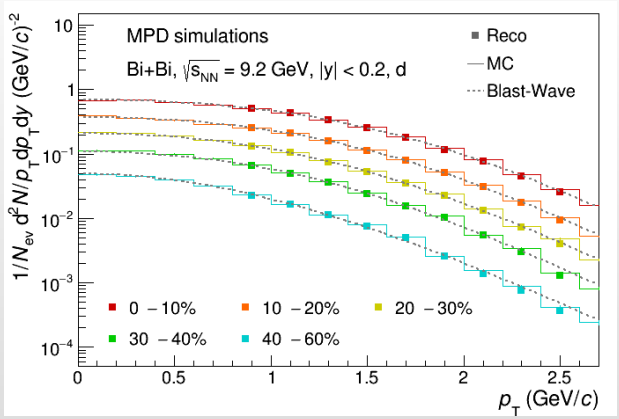
dE/dx vs momentum in TPC

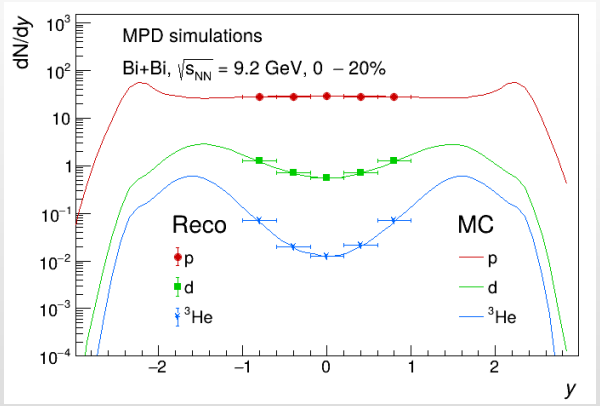


m^2 vs. momentum in TOF



- Light nuclei reconstruction, Bi + Bi @ 9.2 GeV (PHQMD)

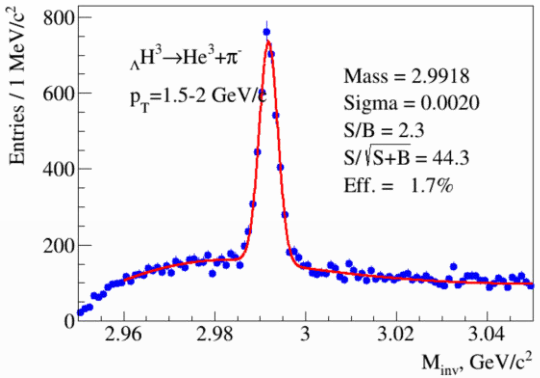


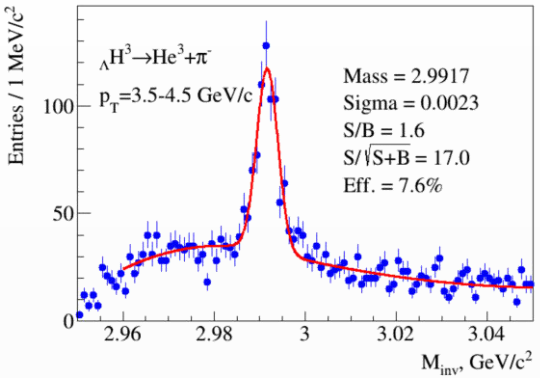


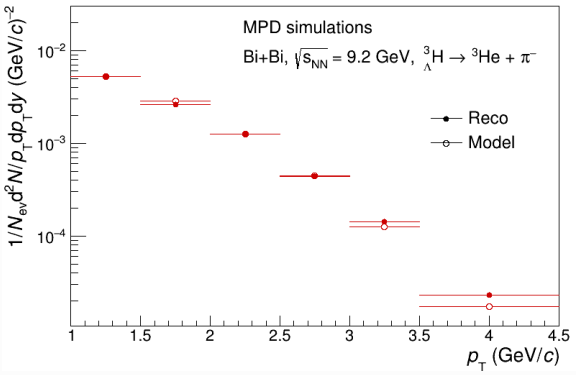
- NICA accelerator can deliver different ion beam species and energies → input to the heavy-ion data base for applied and space research to simulate damage from cosmic rays to astronauts, electronics, and spacecraft

MPD performance for hypenuclei

- Mass production 29 (PHQMD, BiBi@9.2 GeV, 40M events)



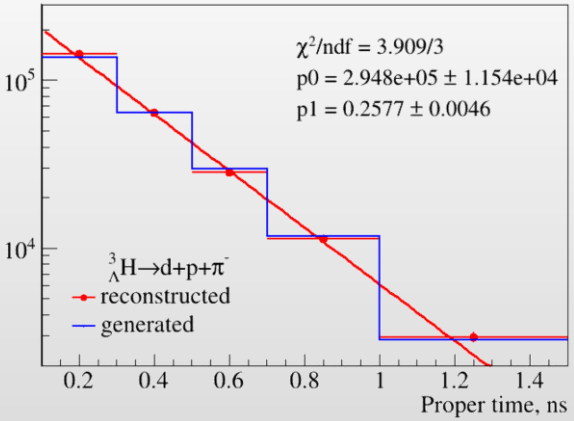


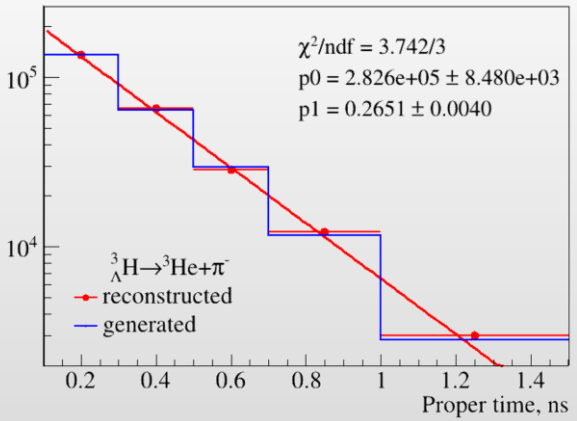


2- and 3-prong decay modes were studied separately to estimate systematics

$$N(\tau) = N(0)\exp\left(-\frac{\tau}{\tau_0}\right) = N(0)\exp\left(-\frac{ML}{cp\tau_0}\right),$$

Decay channel	Branching ratio	Decay channel	Branching ratio
$\pi^- + {}^3He$	24.7%	$\pi^- + p + p + n$	1.5%
$\pi^0 + {}^3H$	12.4%	$\pi^0 + n + n + p$	0.8%
$\pi^- + p + d$	36.7%	$d + n$	0.2%
$\pi^0 + n + d$	18.4%	$p + n + n$	1.5%





$_{\Lambda}H^3$ reconstruction with ~ 50M samples events

$_{\Lambda}H^4$, $_{\Lambda}He^4$ reconstruction with ~ 150M samples events

Conclusions

Collaboration meeting in Dubna, Autumn 2025



- Heavy-ion program at NICA → 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 11 GeV)
- NICA approaches its full commissioning → flagship project in the world on the study of heavy-ion collisions at intermediate energies
- MPD welcomes new members in the collaboration to participate in the comprehensive research programs

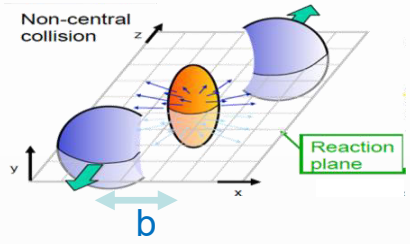
For more information please refer to http://mpd.jinr.ru

BACKUP

Anisotropic flow at RHIC/LHC

- Initial eccentricity and its fluctuations drive momentum anisotropy v_n with specific viscous modulation

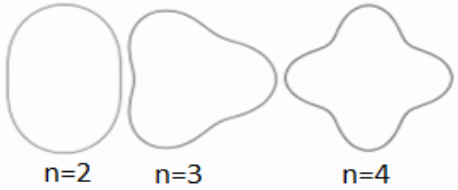
Spatial anisotropy of the nuclear overlap region



$$\epsilon_n = \sqrt{\frac{\langle r^n \cos n\phi \rangle + \langle r^n \sin n\phi \rangle}{\langle r^n \rangle}}$$

$\epsilon_n \propto v_n$

Azimuthal distribution of produced particles wrt to reaction plane (Ψ_n)

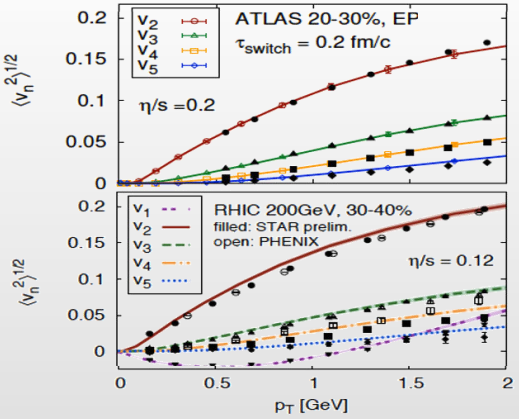


$$\frac{dN}{d\phi} \propto \left(1 + 2\sum_{n=1} v_n \cos\left[n\left(\phi - \Psi_n\right)\right]\right)$$

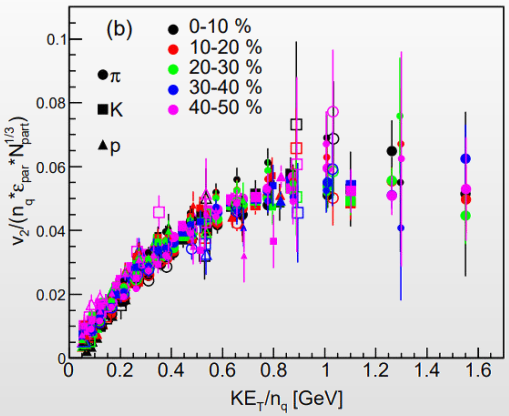
Anisotropic flow: $v_n = \langle \cos[n(\varphi - \Psi_n)] \rangle$

- Evidence for a dense perfect liquid found at RHIC/LHC (M. Roirdan et al., Scientific American, 2006)

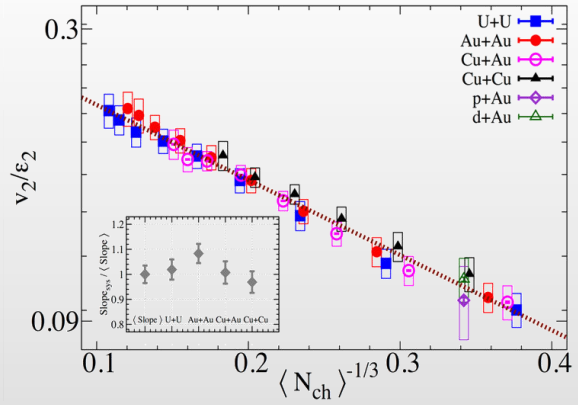
Gale, Jeon et al., Phys. Rev. Lett. 110, 012302



Phys.Rev.C 92 (2015) 3, 034913



Phys. Rev. Lett. 122 (2019) 172301

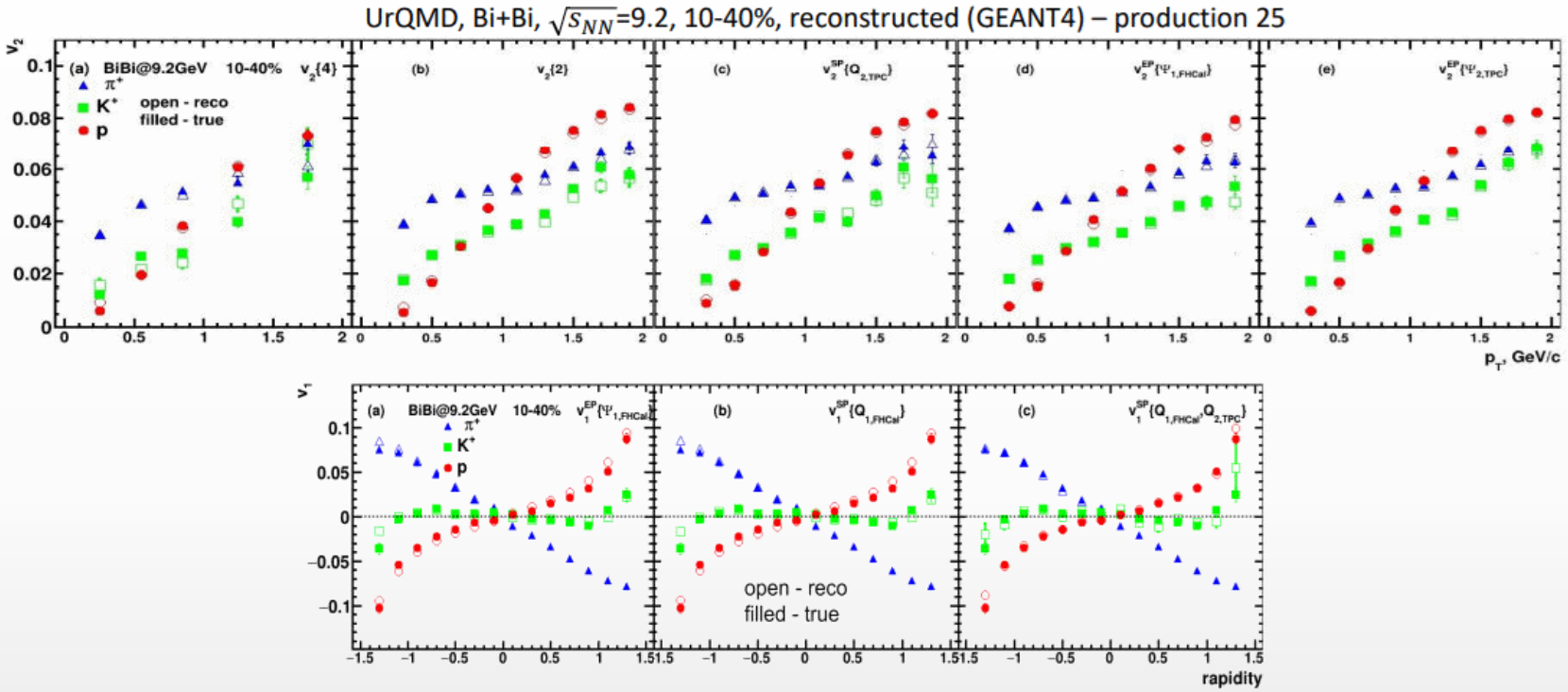


System size scan (p-A, A-A) is an important ingredient:

initial geometry → flow harmonics → $\frac{\eta}{s}(T,\mu), \frac{\zeta}{s}(T,\mu), c_s(T), \alpha_s(T)$, **etc.**

MPD performance for v_1, v_2 of π/K/p

- BiBi@9.2 GeV (UrQMD, 50M), full event reconstruction



- Reconstructed and generated v_1 and v_2 for identified hadrons are in good agreement for all methods

MPD has capabilities to measure different flow harmonics for a wide variety of identified hadrons

System size scan for flow measurements is vital for understanding of the medium transport properties and onset of the phase transition

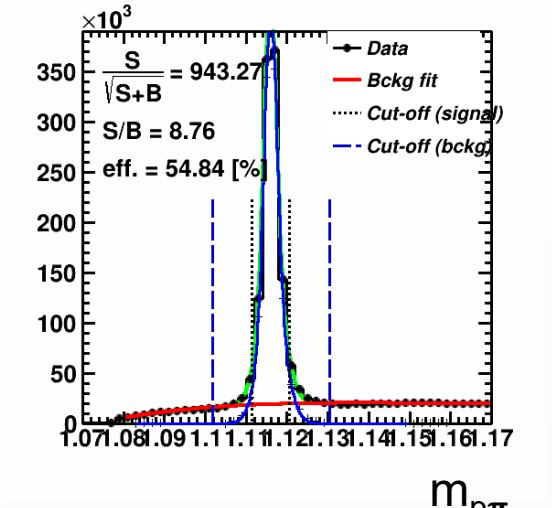
MPD performance for v_1, v_2 of V0 particles

- BiBi@9.2 GeV (PHSD, 15M), full event reconstruction

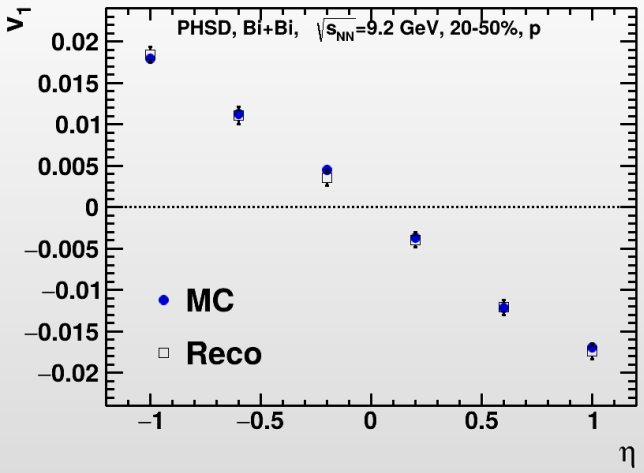
Differential flow can be defined using the following fit:

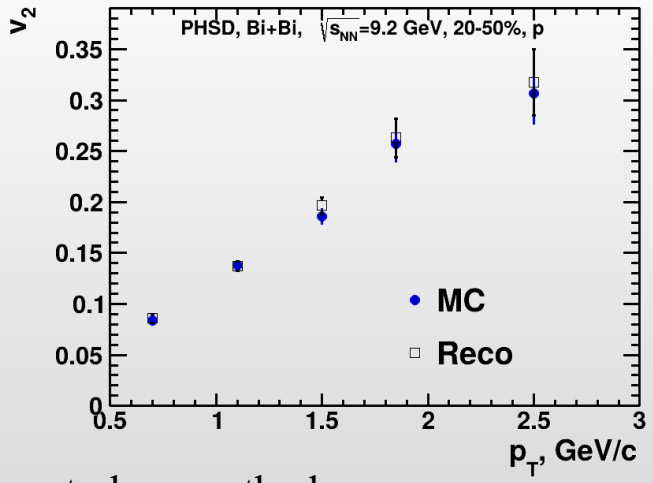
$$v_n^{SB}(m_{inv}) = v_n^S \frac{N^S(m_{inv})}{N^{SB}(m_{inv})} + v_n^B(m_{inv}) \frac{N^B(m_{inv})}{N^{SB}(m_{inv})}$$

- v_n^S - signal anisotropic flow (set as a parameter in the fit)
- $v_n^B(m_{inv})$ - background flow (set as polynomial function)



- Performance of v_1 and v_2 of Λ hyperons:





- Good performance for v_1, v_2 using invariant mass fit and event plane methods
- Similar measurements for Ks, other hyperons and short-lived resonances

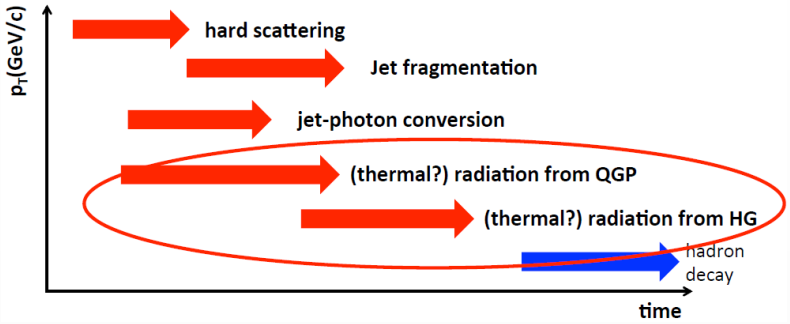
Direct photons and system temperature

- All photons not from the hadron decays:
  - ✓ produced during all stages of the collision → penetrating probe
- Thermal low-E photons → effective temperature of the system:

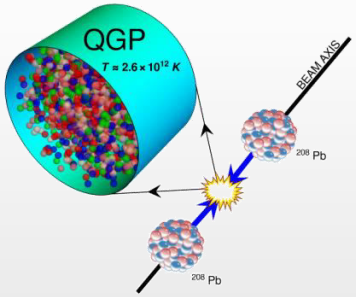
$$E_\gamma \frac{d^3 N_\gamma}{d^3 p_\gamma} \propto e^{-E_\gamma / T_{\text{eff}}}$$

- Prompt higher-p_T photons:

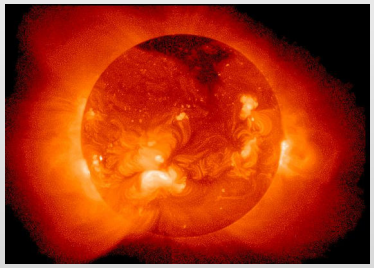
$$E\frac{d^3\sigma}{dp^3} = \sum_{i,j,k} f_i(x_i, Q^2) \otimes f_j(x_j, Q^2) \otimes D_k(z_k, Q^2) \quad \propto 1/p_T^n$$



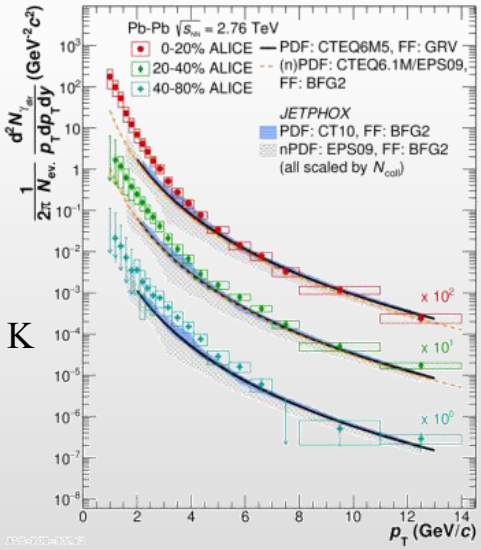
- Relativistic A+A collisions → the highest temperature created in laboratory ~ 10^{12} K

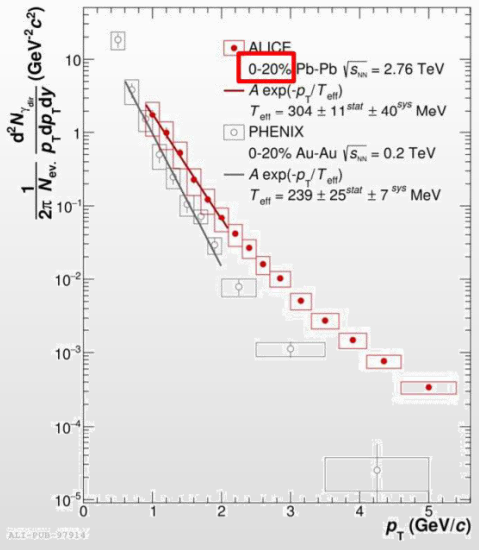


Temperature at the center of the Sun ~ 15 000 000 K



A medium of ~ 200 MeV is 100 000 times hotter !!!





T_{eff} ~ 240 MeV at RHIC; T_{eff} ~ 300 MeV at the LHC

$T_{eff} >> T_c$ ~ 160 MeV predicted by LQCD

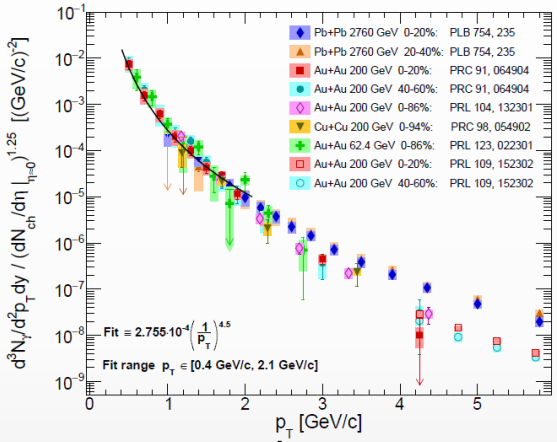
Direct photon yields at NICA

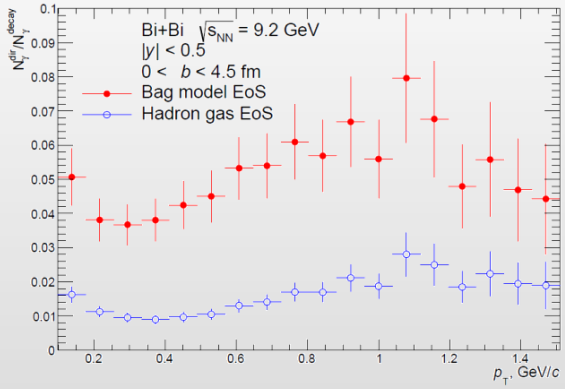
Estimation of the direct photon yields @NICA

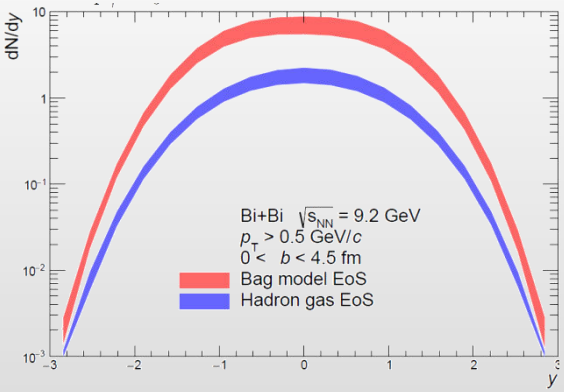
model calculations

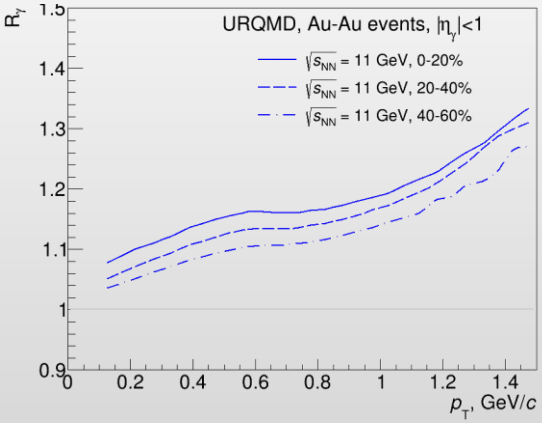
empirical scaling by PHENIX

- ✓ UrQMD v3.4 with hybrid model (3+1D hydro, bag model EoS, hadronic rescattering and resonances within UrQMD)
- ✓ each cell have Ti, Ei, μbi:
  - T is high – QGP phase (Peter Arnold, Guy D. Moore, Laurence G. Yaffe, JHEP 0112:009 2001)
  - T is low – HG phase (Simon Turbide, Ralf Rapp, Charles Gale, Phys.Rev.C69:014903,2004)
  - T is intermediate – mixed phase
- ✓ integrate over all cells and all time steps
- ✓ calculations reproduce hydro calculations for the SPS









$$R_\gamma = \frac{\gamma_{inc}}{\gamma_{decay}} = \frac{\gamma_{inc}/\pi^0}{\gamma_{decay}/\pi^0_{param}}$$

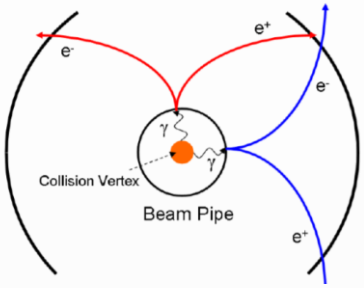
$$\gamma_{direct} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{inc}$$

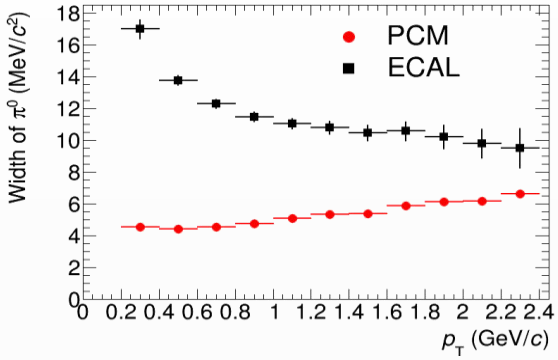
❖ Non-zero direct photon yields are predicted with Rγ ~ 1.05 – 1.15 and v2 ~ 0.5% at top NICA energy

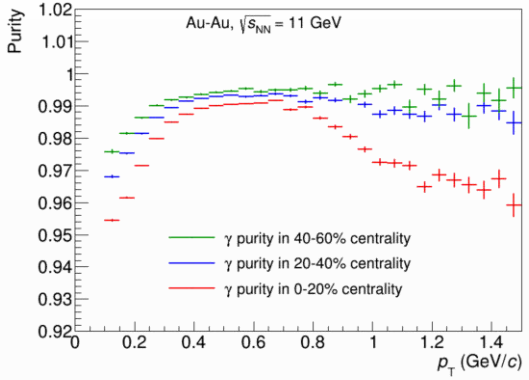
Prospects for the MPD

- Photons can be measured in the ECAL or in the tracking system as e^+e^- conversion pairs (PCM)

beam pipe (0.3% X_0) + inner TPC vessels (2.4% X_0)

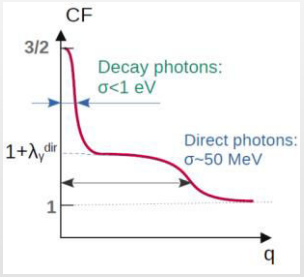






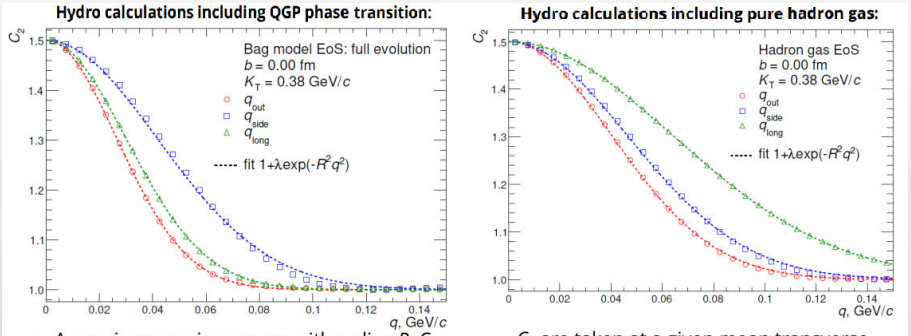
- Main sources of systematic uncertainties for direct photons → **potential yield measurements**:
  - ✓ detector material budget → conversion probability; p_T-shapes and reconstruction efficiencies of π^0 and η
  - ✓ with $R\gamma \sim 1.1$ and $\delta R\gamma/R\gamma \sim 3\%$ → uncertainty of $T_{eff} \sim 10\%$

- **Measurement of Bose-Einstein correlations** for direct photons:



$$C_2(\boldsymbol{q},\boldsymbol{K}) \approx 1 + \left| \frac{\int d^4x S(x,K)\, e^{iq\cdot x}}{\int d^4x S(x,K)} \right|^2$$

Kinematics variables:
- Relative momentum of the pair: $\boldsymbol{q} = \boldsymbol{p}_1 - \boldsymbol{p}_2$
- Mean pair momentum: $\boldsymbol{K} = \frac{1}{2}(\boldsymbol{p}_1 + \boldsymbol{p}_2)$



- Assuming gaussian source with radius R, C_2 might be described as

$$C_2(q) = \lambda \exp(-q^2R^2)$$

- C_2 are taken at a given mean transverse momentum of a pair

$$K_T = \frac{1}{2}(p_{1_T} + p_{2_T})$$

- ✓ Correlation function are different for QGP and HG scenario, the presence of the mixed phase causes increasing of the lifetime
- ✓ Possibility to extract yields of direct photons at low p_T:

$$\lambda = \frac{1}{2}\left(\frac{N_\gamma^{\mathrm{dir}}}{N_\gamma^{\mathrm{inc}}}\right)^2 \rightarrow R_\gamma = \frac{N_\gamma^{\mathrm{inc}}}{N_\gamma^{\mathrm{decay}}} = \frac{1}{1-\sqrt{2\lambda}}$$

MPD can potentially provide measurements for direct photon production in the NICA energy range