Status of MPD Experiment at NICA

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for the MPD collaboration

Joint Institute for Nuclear Research (JINR), Dubna

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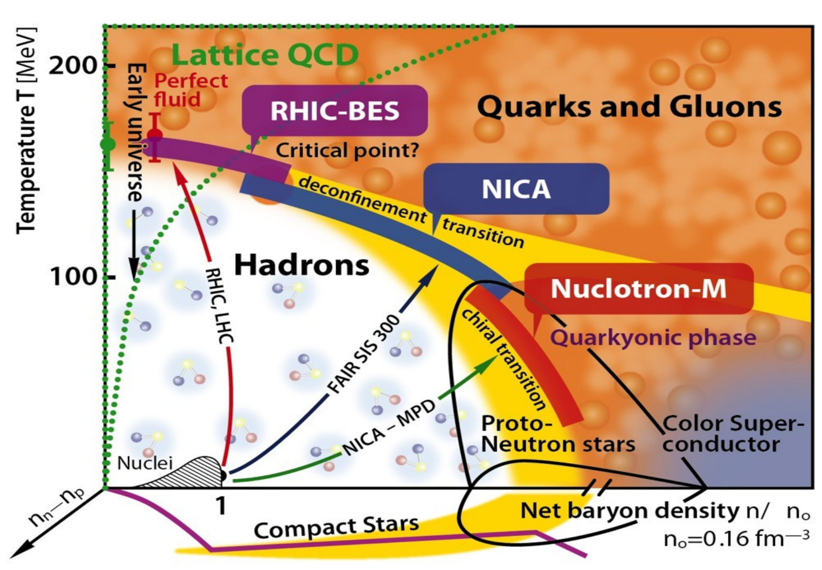
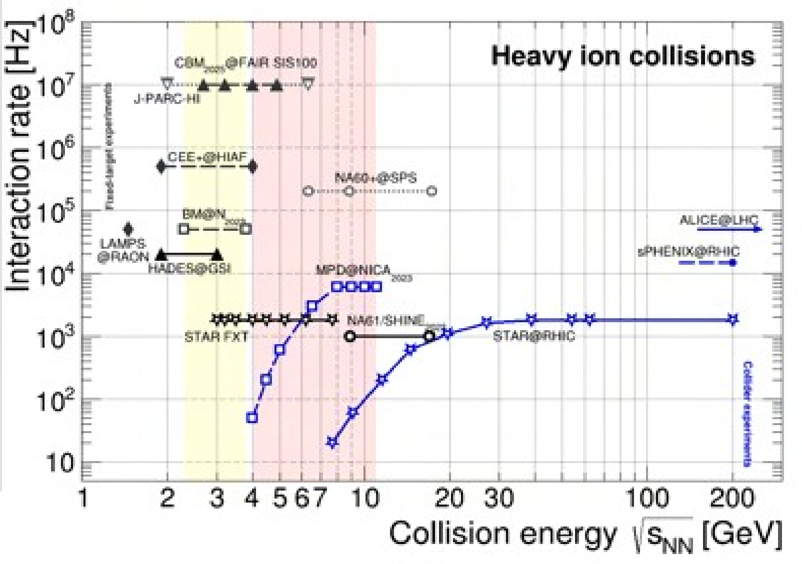
Physics at NICA





T. Galatyuk, Nucl. Phys. A982(2019);
https://github.com/tgalatyuk/interaction_rate_facilities

- Smooth crossover at $\mu_B \sim 0$.
- NICA energies suitable to explore high μ_B matter → Critical end point and 1st order phase transition.
- Similar net baryon density expected as in neutron stars.
- MPD and BM@N → QCD matter study at these densities.
- Ongoing (NA61/Shine, STAR-BES) and future (CBM) experiments in similar beam energy range.

NICA project

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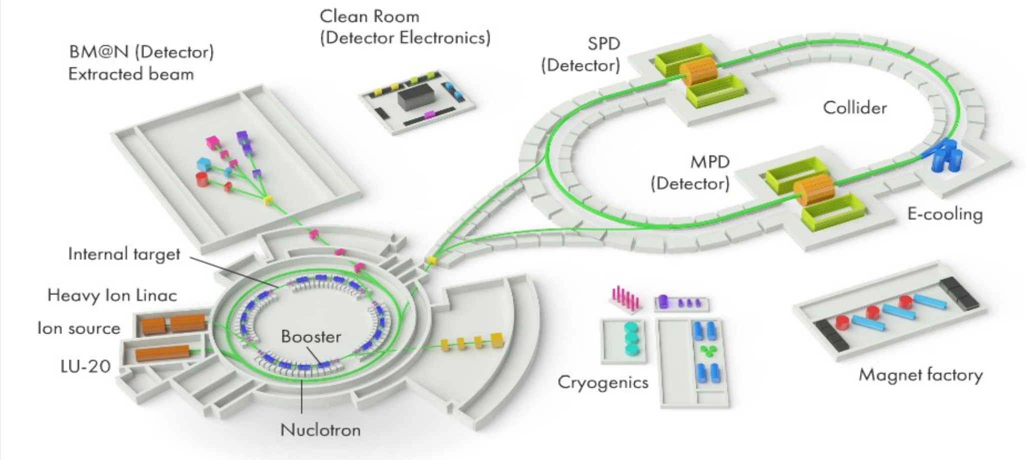
- The first megascience project in Russia → approaching its full commissioning:
  - already running in the fixed-target mode – BM@N
  - start of operation in collider mode in 2025 – MPD



Collider parameters for 45 T·m, 11 GeV/u for Au^{79+}			
Ring circumference (m)	503.4	Luminosity (cm^{-2} s^{-1})	10^{27}
Number of bunches	22	RMS bunch length (m)	0.6
β (m)	0.35	Energy in CM (GeV)	4 - 11
RMS Δρ/ρ (10^{-3})	1.6	IBS growth time (s)	1800

Progress of civil construction

Collider construction

- Last year, all the collider dipole magnets were installed and mechanically adjusted in the collider tunnel.
- Until completion of the engineering infrastructure mounting, expected during this year, assembly of the collider is postponed.

MPD@NICA

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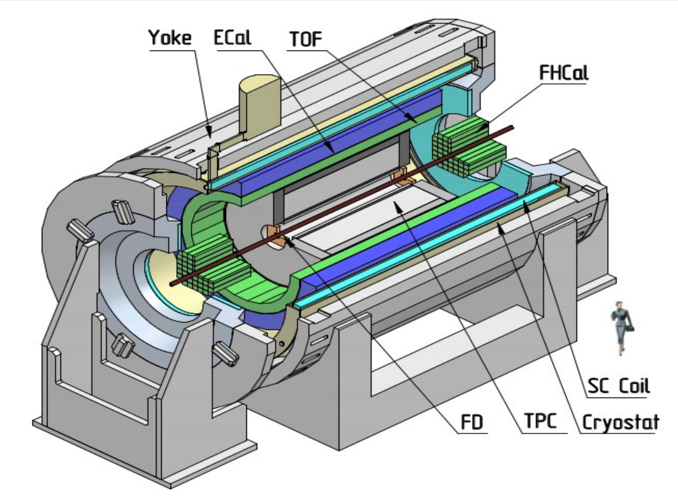
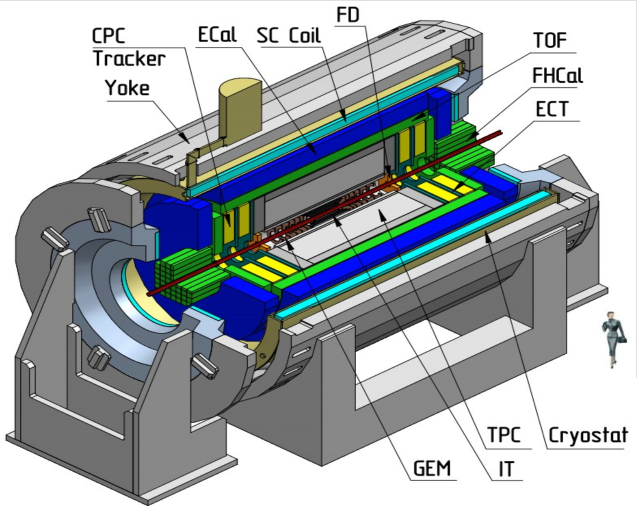


Stage I: TPC, TOF, ECAL, FHCal, FFD

Acceptance:

	$\|\Delta\phi\|$	$\|\eta\|$
TPC:	$< 2\pi$	≤ 1.6
TOF, EMC:	$< 2\pi$	≤ 1.4
FFD:	$< 2\pi$	$2.9 - 3.3$
FHCal:	$< 2\pi$	$2 - 5$

Upgrade

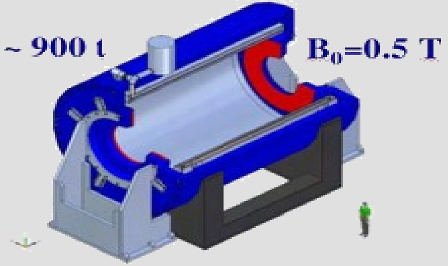


Stage II: ITS and Forward spectrometers

- Expected beam configuration in Stage-I:
  - not-optimal beam optics with wide z-vertex distribution, σ_z ~ 50 cm
  - reduced luminosity (~10^{25}) → collision rate ~ 50 Hz
  - collision system available with the current sources: C (A=12), N (A=14), Ar (A=40), Fe (A=56), Kr (A=78-86), Xe (A=124-134), Bi (A=209) → start with Bi+Bi @ 9.2 GeV in 2025

MPD Subsystems

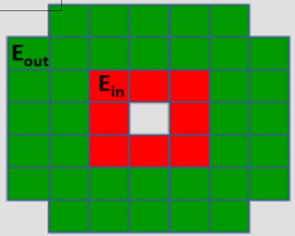
SC Solenoid + Iron Yoke



TOF

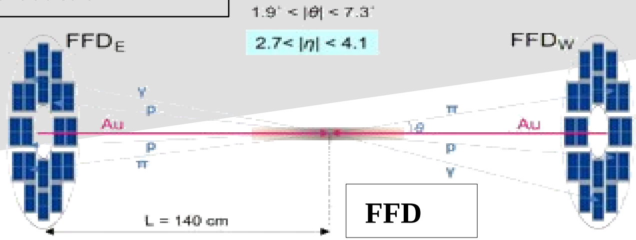
100% of MRPCs (modules) are ready, cosmic tests ongoing.

FHCal



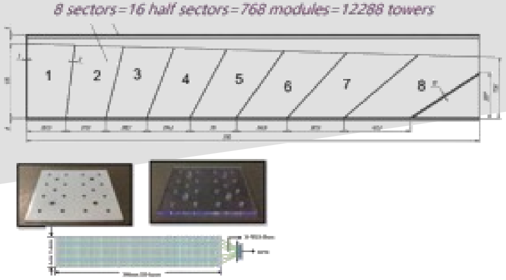
In advance stage of production

Support structure

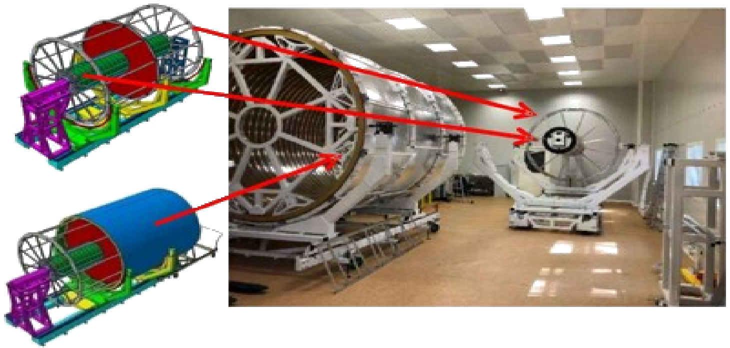


FFD

ECal (geometry)



66-83% of of the detector would be produced for stage - I



TPC

MPD status and plan

- **<u>2023</u>**: Vacuum test of Solenoid with cryostat, Solenoid cooling down.
- **<u>2024</u>**: Supplying the current to the solenoid and Correction coils. MF measurements. Support frame and detectors installation. Cabling and Installation of beam pipe.
- **<u>2025 and beyond</u>**:
  - Move the MPD on Collider beam line.
  - MPD commissioning first run with Bi+Bi @ 9.2 GeV, ∼ 50-100 M events for alignment calibration and physics. Au+Au @ 11 GeV, design luminosity system size and collision energy scans.
- Preparation of the MPD detector as well as experimental program is ongoing.
- All components of the MPD 1-st stage detector are in advanced stage of production: subsystems, support frame, electronics platforms, LV/HV, control systems, cryogenics, cabling, etc.

Multi-Purpose Detector (MPD) Collaboration

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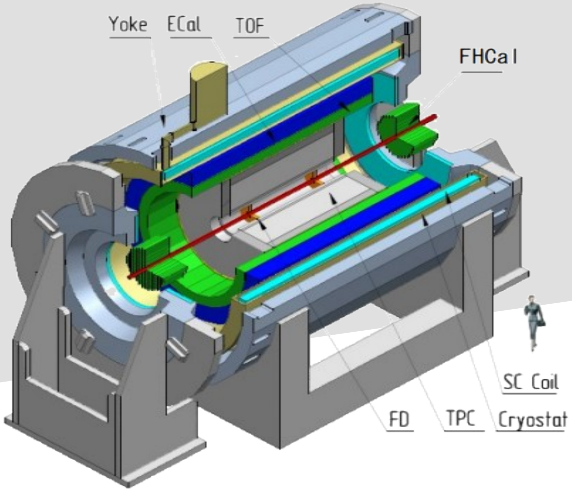
NICA MPD

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

11** Countries, **>500** participants, **35** 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**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*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**;*
*Institute of Applied Physics, Chisinev, **Moldova**;*
*Institute of Physics and Technology, **Mongolia**;*

NICA

*Belgorod National Research University, **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 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***

MPD physics program

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G. Feofilov, A. Aparin

Global Observables

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

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 correlations
- Jet-like correlations

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 Diagram

D. Peresunko, C. Yang

Electromagnetic probes

- Electromagnetic calorimeter measurement
- Photons in ECAL and central barrel
- Low mass dilepton spectra, in-medium modification of resonances and intermediate mass region

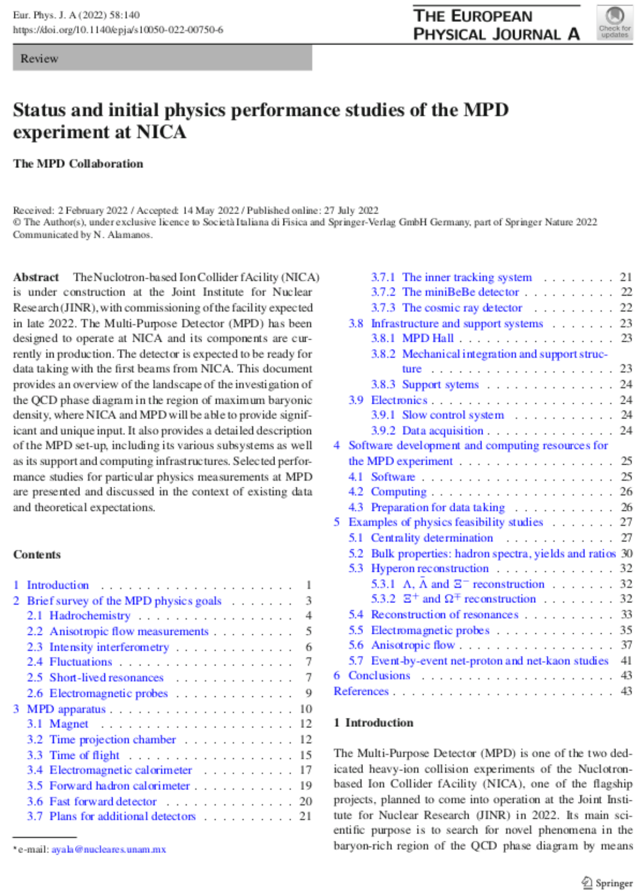
Wangmei Zha, A. Zinchenko

Heavy flavour

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

First MPD Paper

- Recently, First collaboration paper was published in EPJA: Eur. Phys. J. A 58 (2022) 7, 140



Eur. Phys. J. A (2022) 58:140
https://doi.org/10.1140/epja/s10050-022-00750-6
THE EUROPEAN PHYSICAL JOURNAL A

Review

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

The MPD Collaboration

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Communicated by N. Alamanos.

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.

Contents

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

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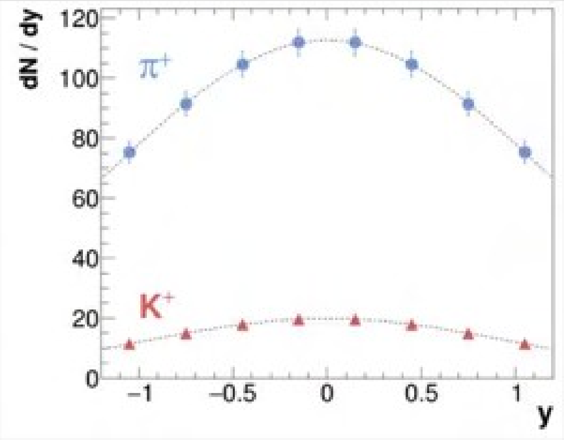
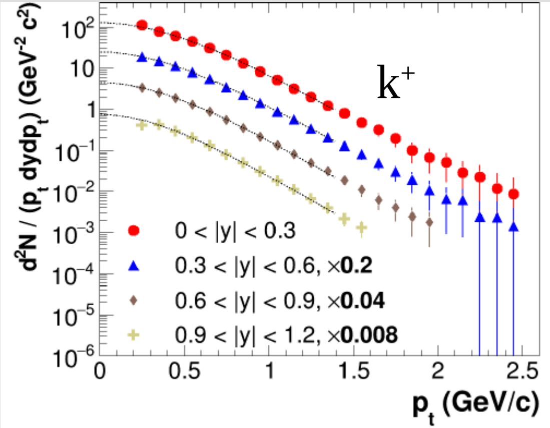
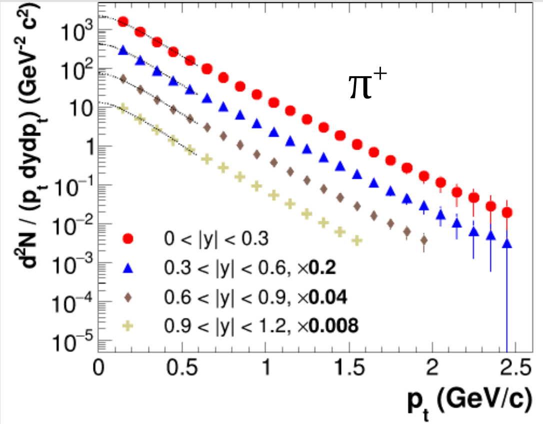
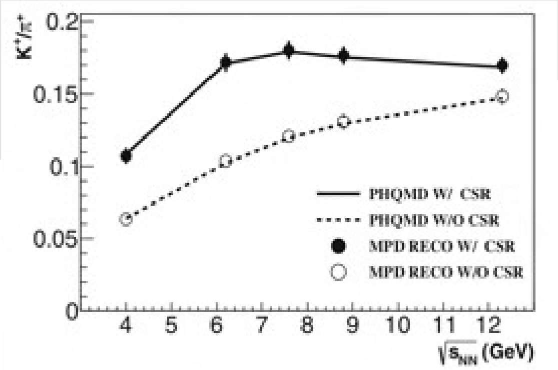
Identified hadrons









Phys.Part.Nucl. 53 (2022) 2, 203-206

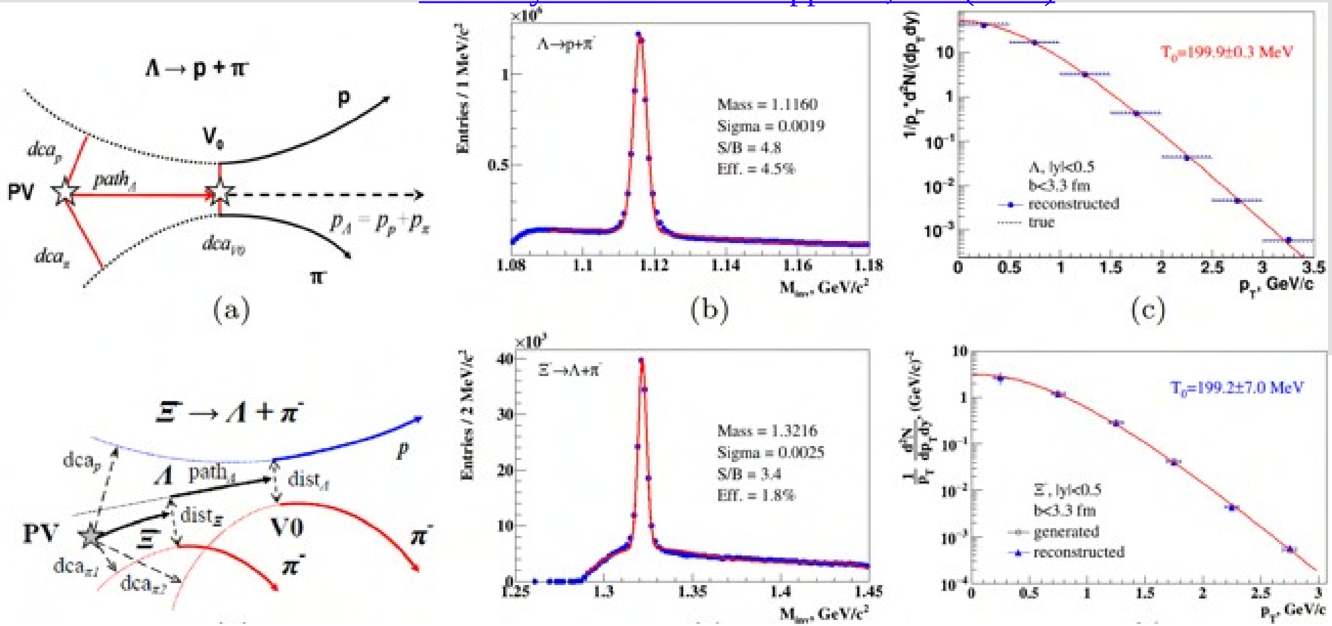
- Useful to probe fireball properties, hadronization, strangeness production.
- MPD offers good PID capabilities with TPC and TOF → uniform and large acceptance.
- Full phase space → 70% of the π/K/p production.
- Hadron spectra are measured from p_T ~ 0.1 GeV/c

Hyperon Reconstruction

Acta Phys. Pol. B Proc. Suppl. 14, 529 (2021)

- Strangeness enhancement is considered as a signature of the QGP formation - Rafelski, Phys. Rep. 88(1982)331, Rafelski, Múller, P.R.Lett. 48(1982)1066

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

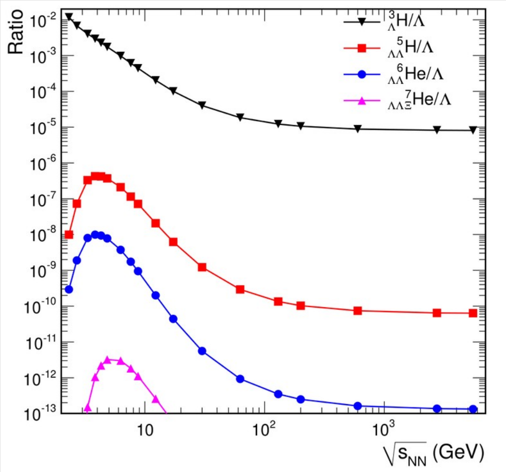


AuAu@11 GeV (PHSD), 10 M events → full event/detector simulation and reconstruction

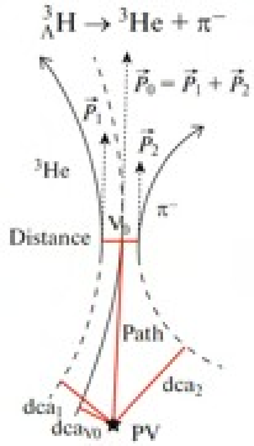
- Reconstructed and generated spectra agree with each other.

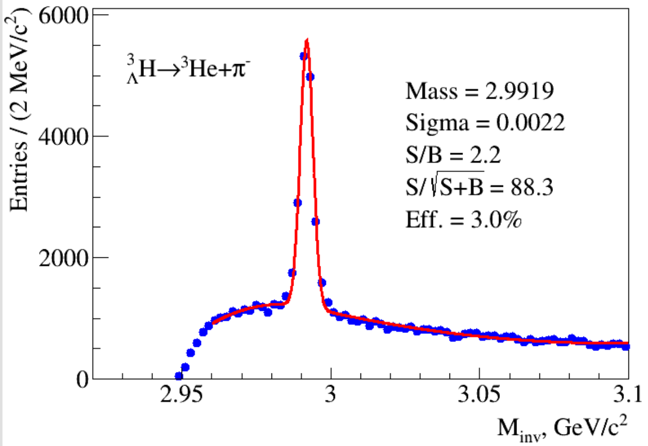
- MPD has capabilities to measure production of charged p/K/p and (multi)strange baryons in pp, p-A and A-A collisions using charged hadron identification in TPC & TOF and different decay topology selections.

Hypertritons



Phys.Lett.B697:203-207,2011



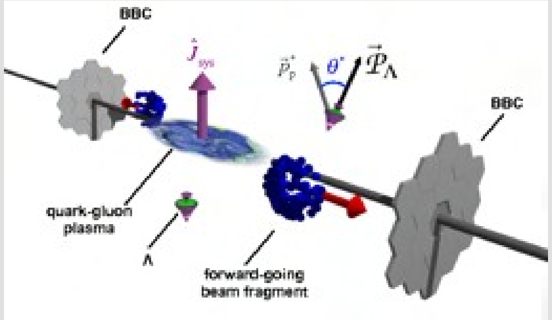


First measurements for hypertriton would be possible with 50M Bi+Bi @ 9.2 events

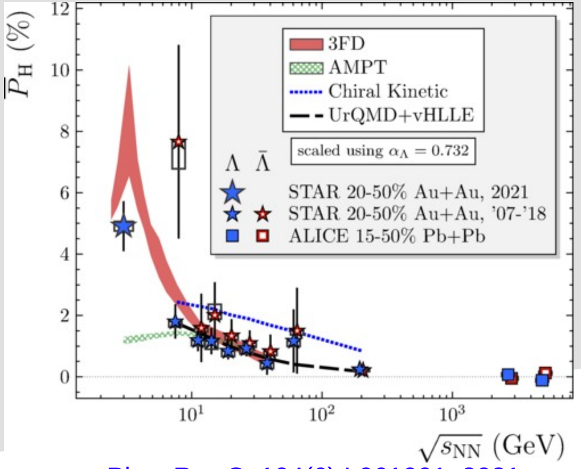
Phys.Part.Nucl.Lett. 19 (2022) 1, 46-53, https://doi.org/10.3390/physics5020028

- Measurement of hyper nuclei informs about production mechanism, Y-N potential, strange sector of nuclear EoS.
- It has strong implications for astronuclear physics, since are expected in the inner core of neutron stars.
- Their production mechanism can be described by phenomenological models: statistical hadronization (SHM) and coalescence.
- Statistical models predict enhanced hypernuclear production at NICA energies → even double hypernuclei are reachable.

Global Polarization

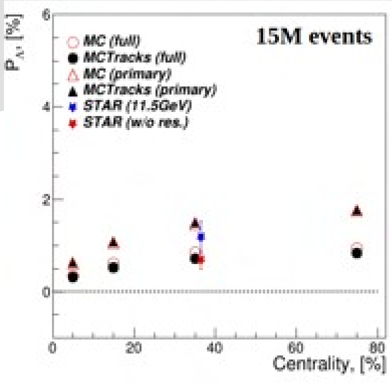


- Global polarization decrease with $\sqrt{s_{NN}}$.
- Transport models used to reproduce global polarization are: AMPT, 3FD, UrQMD+vHLLE



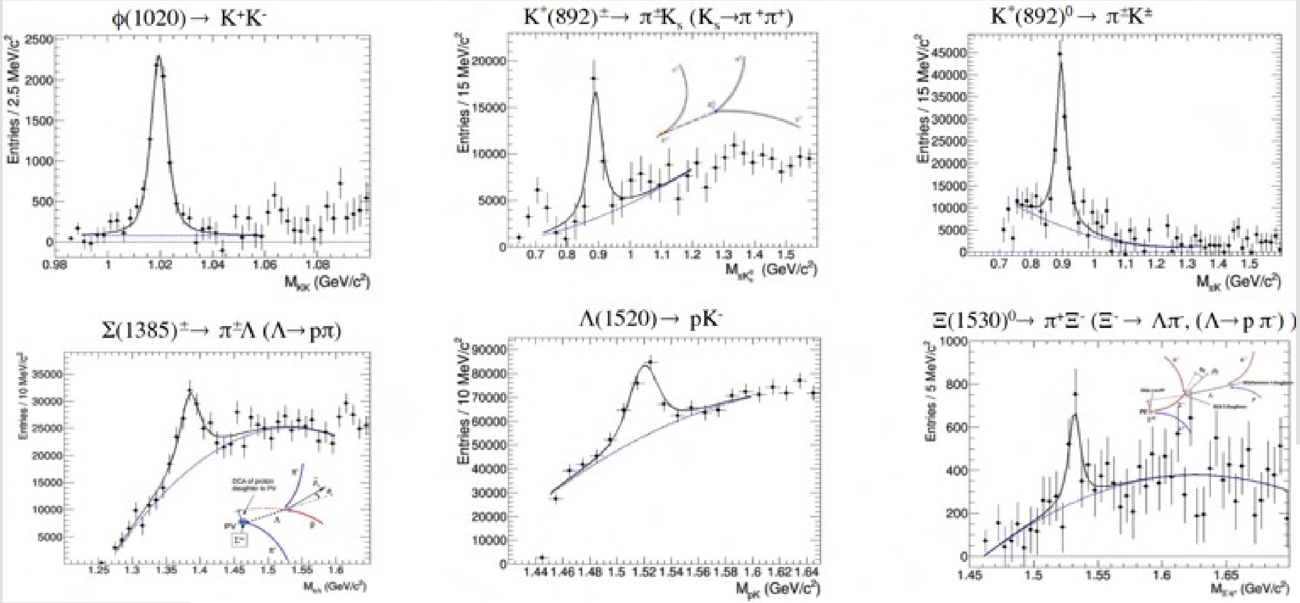
Phys.Rev.C, 104(6):L061901, 2021

- In mid-central collisions, large angular momentum as well as strong magnetic field is formed → Vorticity to the QGP and polarization of particles in the final state.
- Λ and $\bar{\Lambda}$ polarization can be measured by its self analyzing charged decay → preferential emission of p is along spin direction.



- MPD will cover $\sqrt{s_{NN}}$ = 4-11 GeV as a function of centrality, p_T and y not only for Λ but other hyperons($\bar{\Lambda}$, Ξ, $\bar{\Xi}$, Σ, $\bar{\Sigma}$).
- PHSD simulation of 15M events for Bi+Bi at $\sqrt{s_{NN}}$ = 9.2 GeV
- Full event/detector simulation and reconstruction First global measurements for Λ/$\bar{\Lambda}$ will be possible with ∼ 10M data sampled events

Resonances

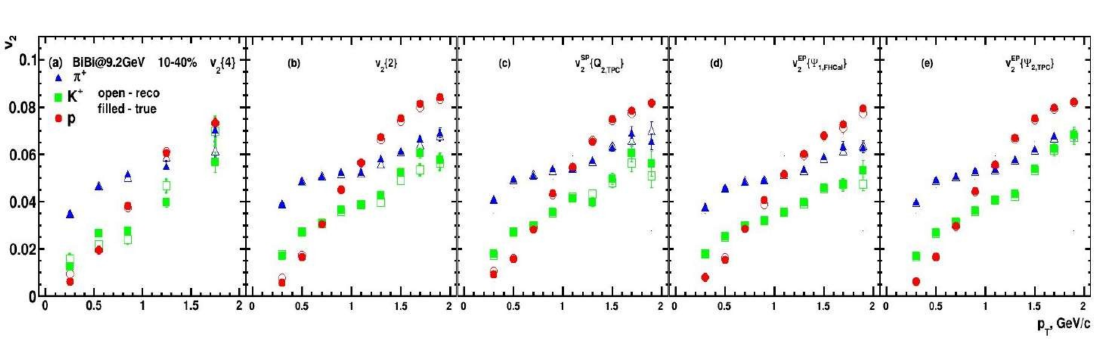


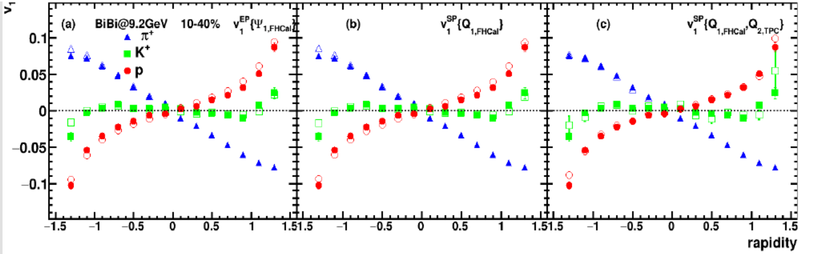
Phys.Scripta 96 (2021) 6, 064002

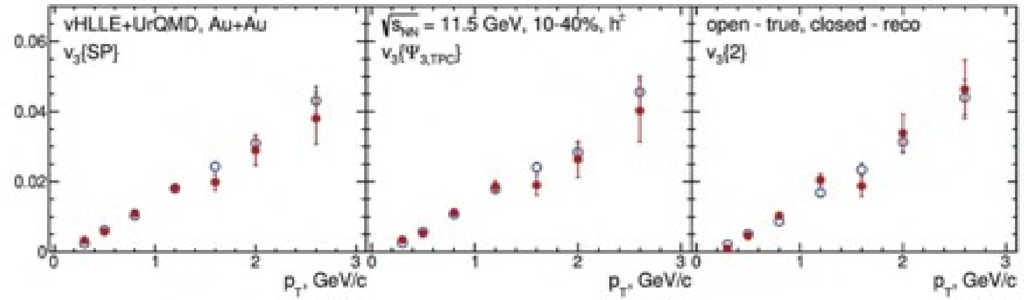
- Best suited to probe density and lifetime of the late hadronic phase of HI collisions.
- This phase affects most of observables measured in the final state (flow, yields etc)
- Measurements are important to test the hadronic phase models

- MPD has capabilities to reconstruct resonances using invariant mass spectra with PID using TPC and TOF.
- For reconstruction, additional secondary and topological selections are required due to weak decaying daughters.
- First measurements for resonances would be possible with the sample of ∼ 10 M of Bi+Bi events.

Anisotropic Flow



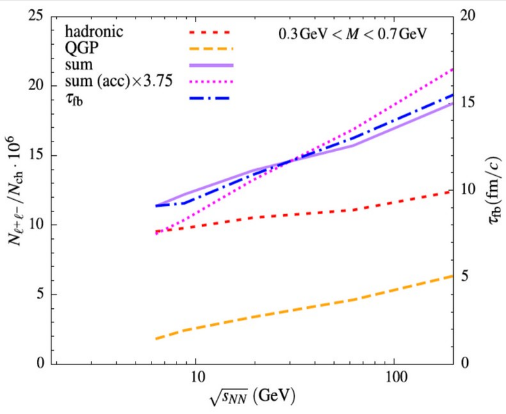


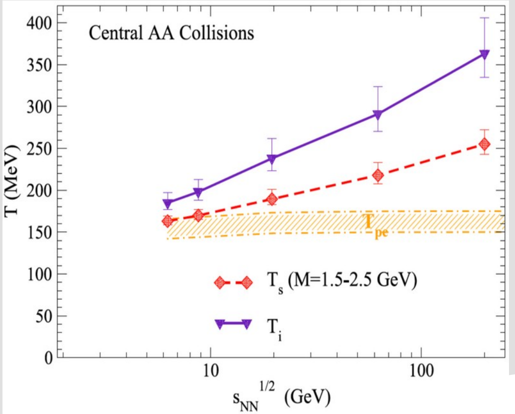


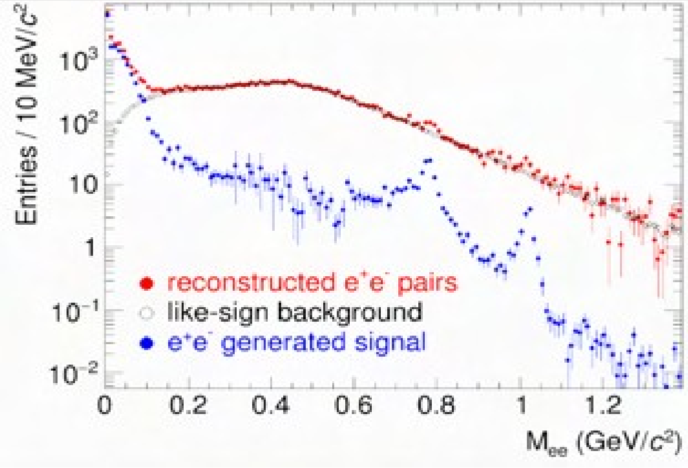
- Flow has high sensitivity to the transport properties of the QCD matter: EoS, speed of sound (c s), specific viscosity (η/s), etc.
- MPD detector is able to provide detailed differential measurements of directed and elliptic flows with high accuracy.
- UrQMD events for Bi+Bi @ 9.2 GeV measured at mid-centrality 10-40%
  - AuAu@11.5 GeV (vHLLE + UrQMD), 15 M events → full event/detector simulation.
  - Reconstructed and generated v_2 of pions and protons and v_3 of charged hadrons are in good agreement

Dielectrons

- Electromagnetic probes:
  - probe deconfinement and chiral symmetry restoration.
  - *Chronometer*: QGP and hadronic contributions in low mass region proportional to fireball lifetime.
  - *Thermometer*: Inverse slope parameter in intermediate mass region is closely related to the initial temperature T_i of the fire ball.



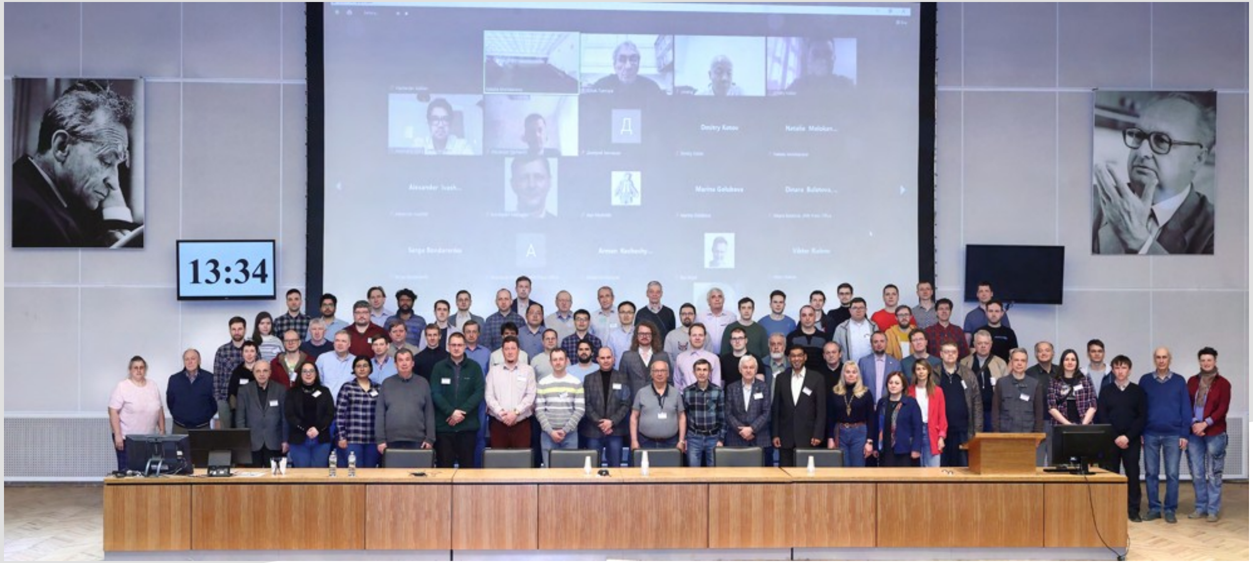




BiBi@9.2 GeV (UrQMD+PHSD), 10 M events → full event/detector simulation and reconstruction

- S/B (integrated in 0.2 -1.5 GeV/c) ~ 5-10%.
- Methods to improve S/B ratio with a minimal compromise on pair reconstruction are being developed.
- Meaningful measurements for e^+e^- continuum and LVMs would require $\sim 10^8$ events, first observations would be possible with $\sim$ 50 M events

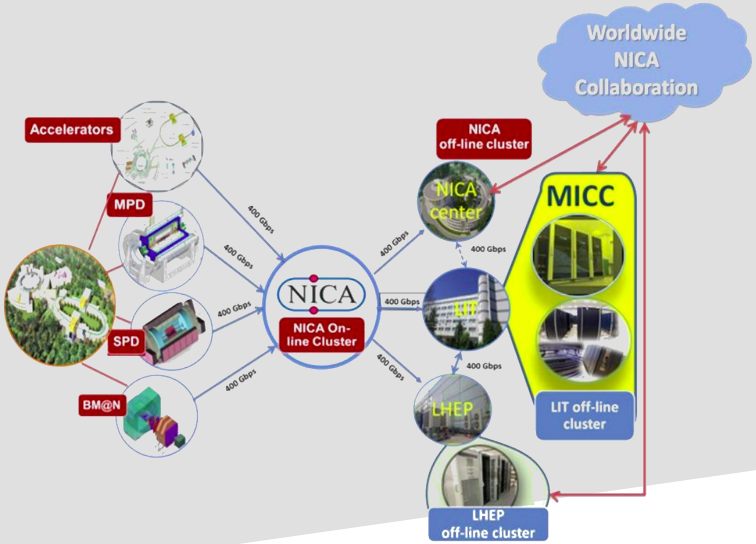
Summary



- ✓ MPD collaboration is coming along steadily towards the integration of MPD apparatus as well as first beam from NICA.
- ✓ MPD physics program has been formulated and recently, first physics paper was published.
- ✓ Detector commissioning and data taking with Bi beam at $\sqrt{s_{NN}}$ = 9.2 GeV at the NICA complex is foreseen in year, 2025.

BACK-UP

Computing



- MPDROOT Software framework - to simulate, transport and reconstruct MC
- events within MPD experiment

- Main technological elements at VBLHEP and LIT
  - LIT NICA part of MICC → connection with computing complexes of other organizations involved in NICA Complex
  - DIRAC → infrastructure enables integration of heterogeneous computing resources at multiple sites

Centrality determination

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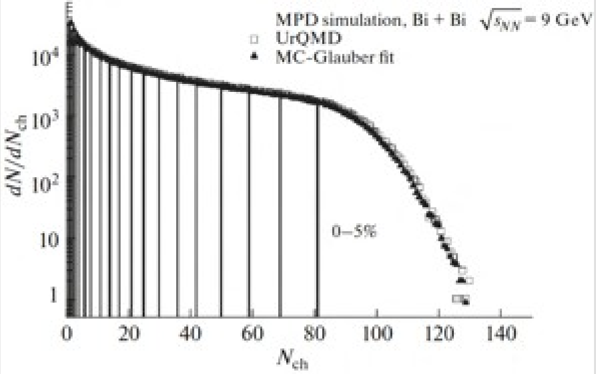
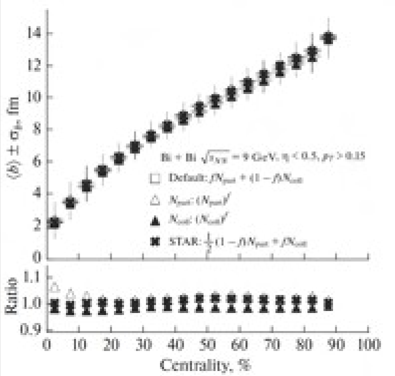
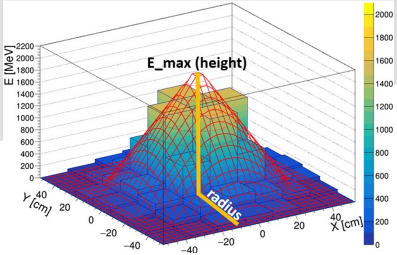
TPC multiplicity:

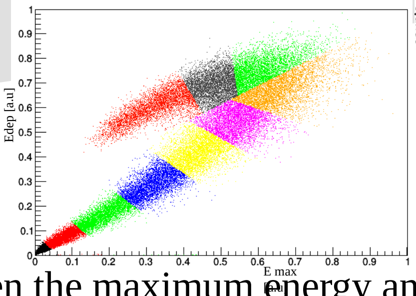


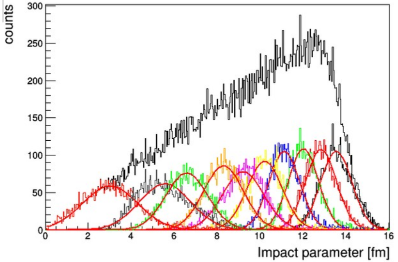


- Impact parameter, *b*, from Monte Carlo Glauber model.
- Compatible with Bayesian inversion method as well as different event generator at various energies.

FHCal:

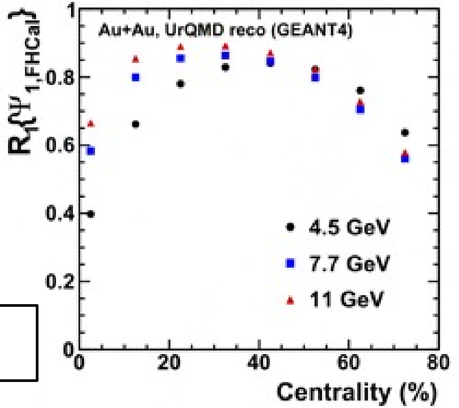






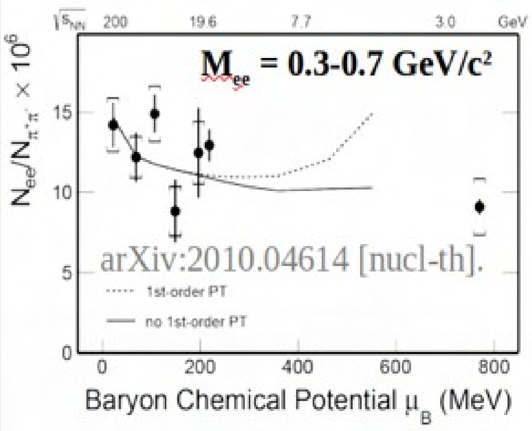
The correlation between the maximum energy and the deposited energy in 10% centrality classes using 2D linear fit energy deposition in FHCal

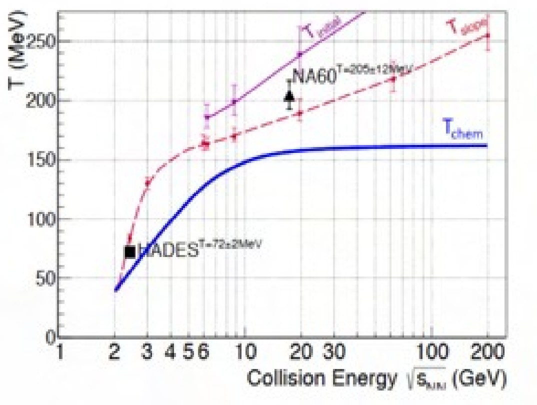
$$\Psi_{EP} = \tan^{-1}(E_i \sin\phi_i / \cos\phi_i)$$



Dielectrons

- Electromagnetic probes:
  - probe deconfinement and chiral symmetry restoration
  - effective temperature





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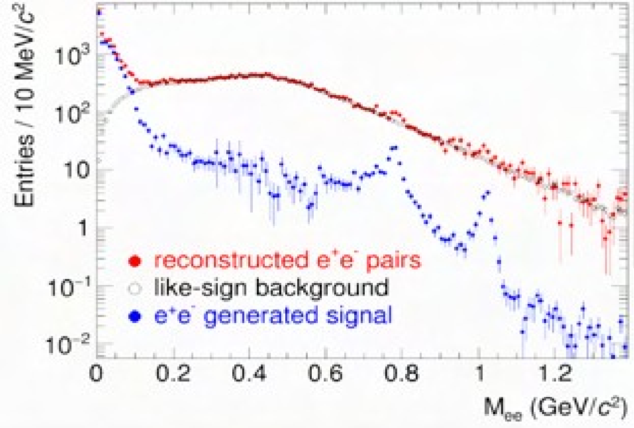
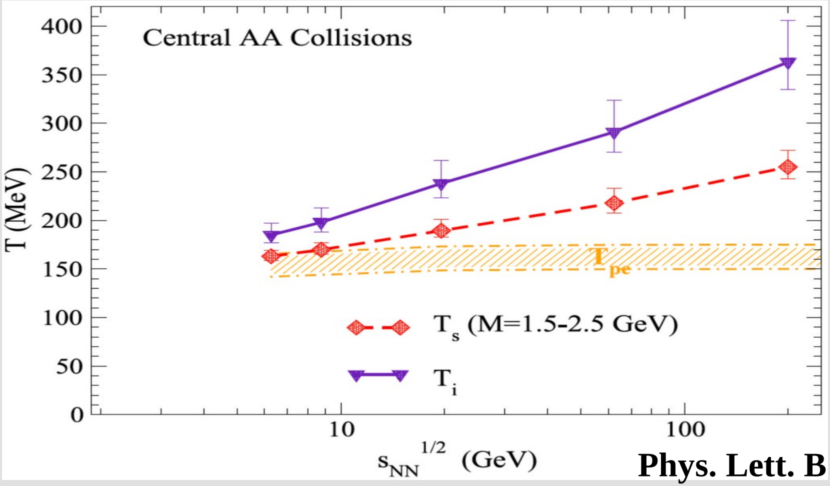
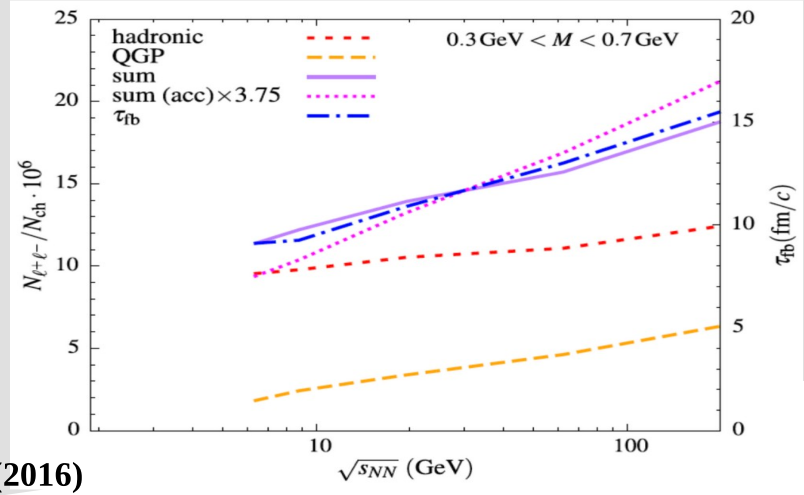


BiBi@9.2 GeV (UrQMD+PHSD), 10 M events → full event/detector simulation and reconstruction

- S/B (integrated in 0.2 -1.5 GeV/c) ~ 5-10%.
- Methods to improve S/B ratio with a minimal compromise on pair reconstruction are being developed
- Meaningful measurements for e^+e^- continuum and LVMs would require $\sim 10^8$ events, first observations would be possible with $\sim$ 50 M events

Why Dileptons?





Phys. Lett. B 753, 586 (2016)

- Intermediate Mass Region: Excitation function of the inverse-slope parameter, T_s (M = 1.5 − 2.5 GeV).
- Closely related to the initial temperature T_i of the fire ball: “thermometer” for the heavy-ion collisions.

- Low Mass Region: At SPS and RHIC, the excess in dilepton yields: broadening of the ρ meson spectral function -> restoration of chiral symmetry.
- Sum of QGP and hadronic contributions proportional to fireball lifetime: “chronometer” for heavy-ion collisions