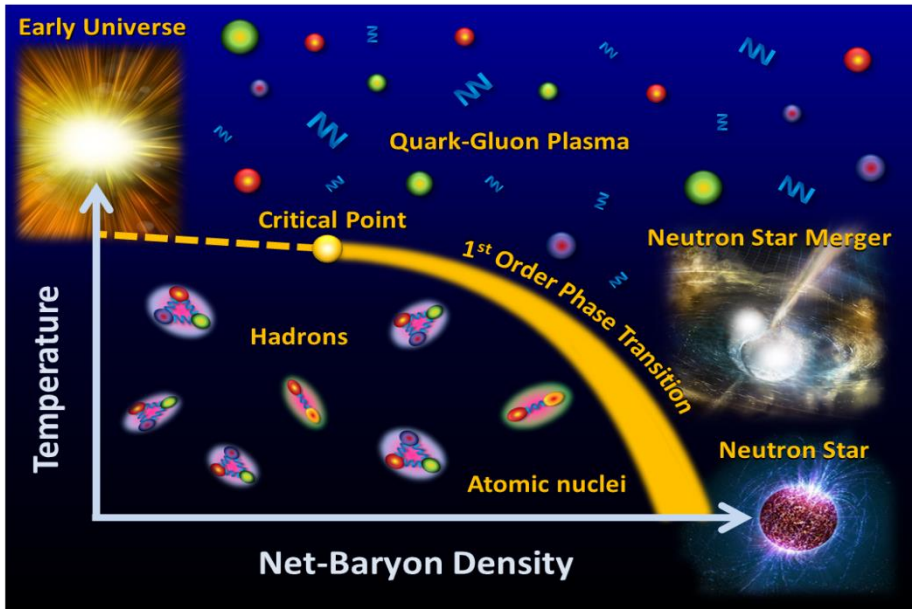
Status and perspectives of the MPD experiment at NICA

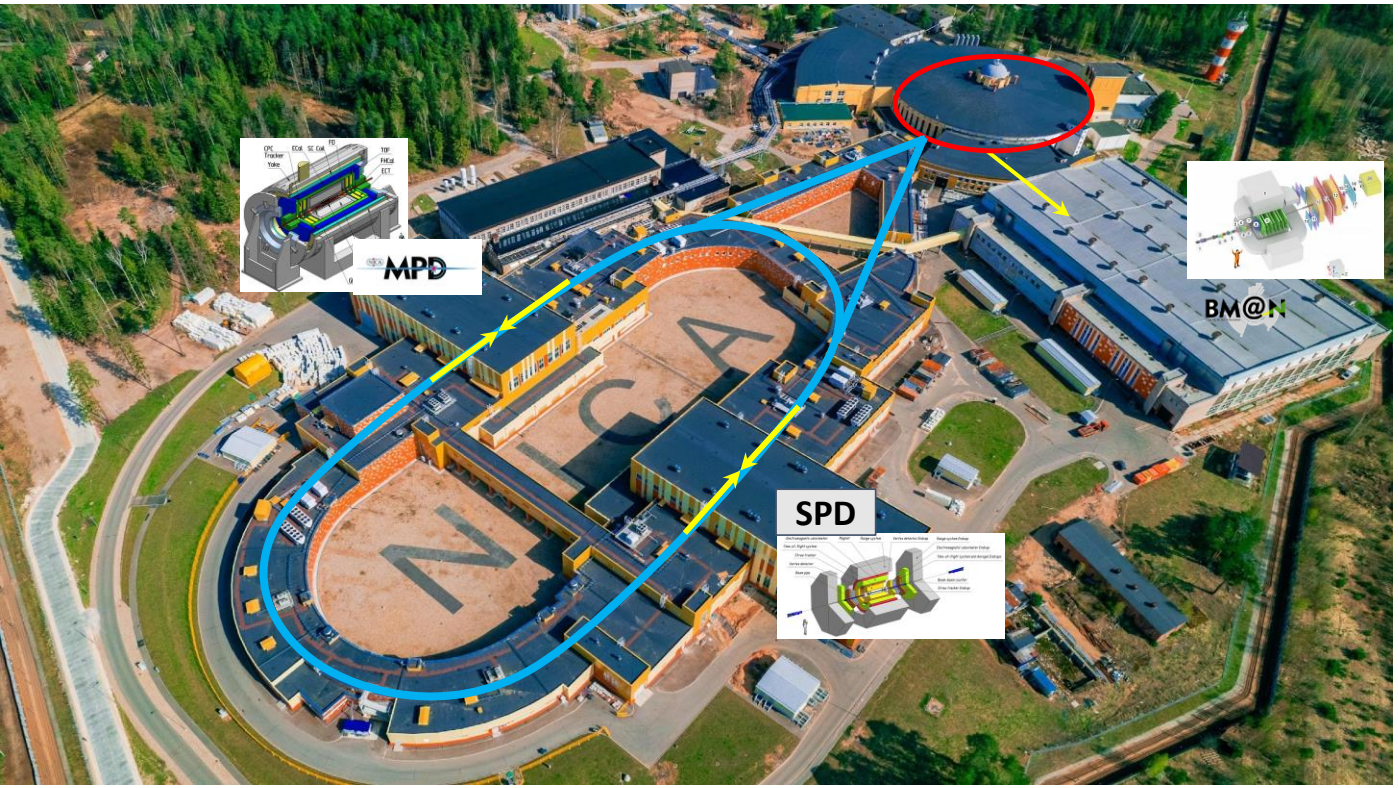


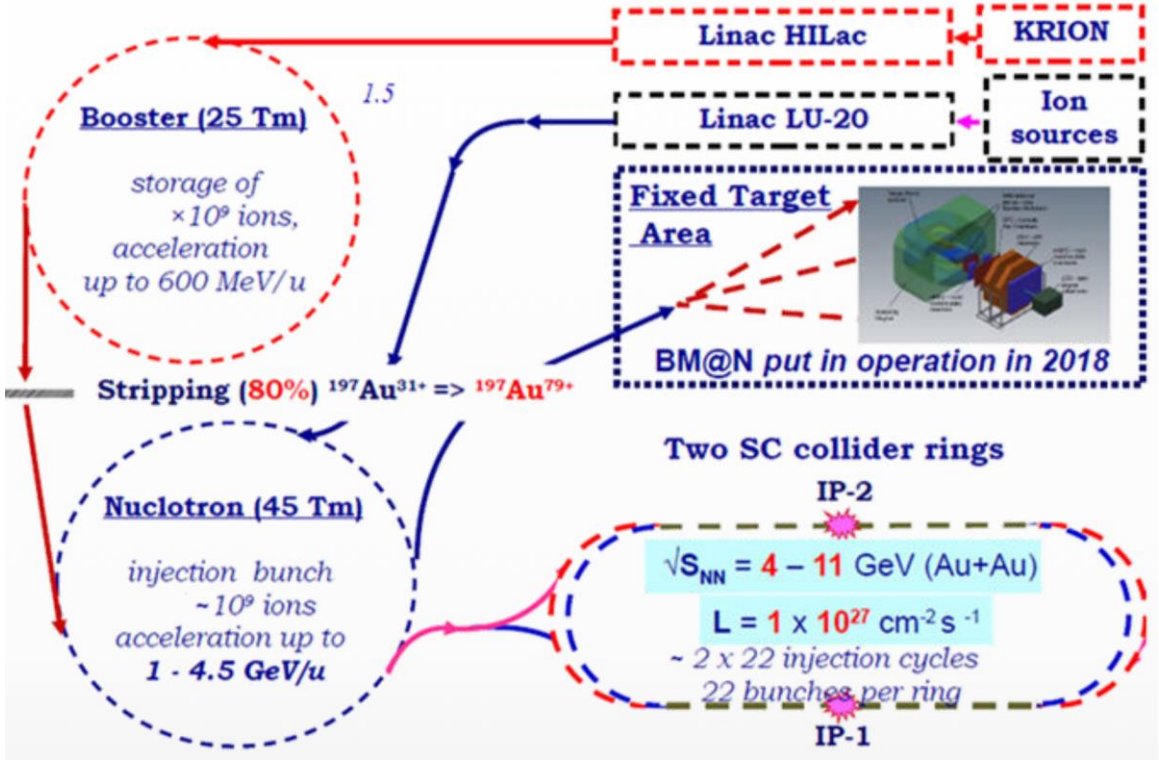


Arkadiy Taranenko (JINR, MEPhI) on behalf of the MPD Collaboration

XXth Workshop on High Energy Spin Physics - DSPIN-26 , JINR, Dubna, 7-11/09/2026

NICA Project





- **The first megascience project in Russia, which is approaching its full commissioning:**
  - **Baryonic Matter at Nuclotron (BM@N) –** fixed-target experiment, Xe+Cs(I), Sn: 3.8, 3.0, 2.2, 1.6 AGeV
  - **Multi-Purpose Detector (MPD) –** planned start of operation at the end of 2026 (MPD-FXT + MPD-COL)
  - **Spin Physics Detector (SPD) –** collider experiment (2030-?)

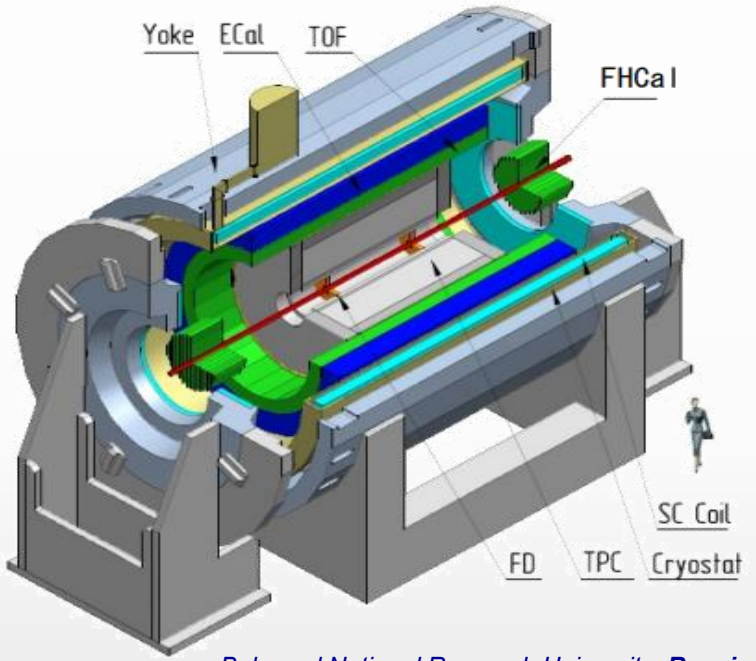
Multi-Purpose Detector (MPD) Collaboration

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

12** Countries, **>500** participants, **39** Institutions and **JINR

Organization

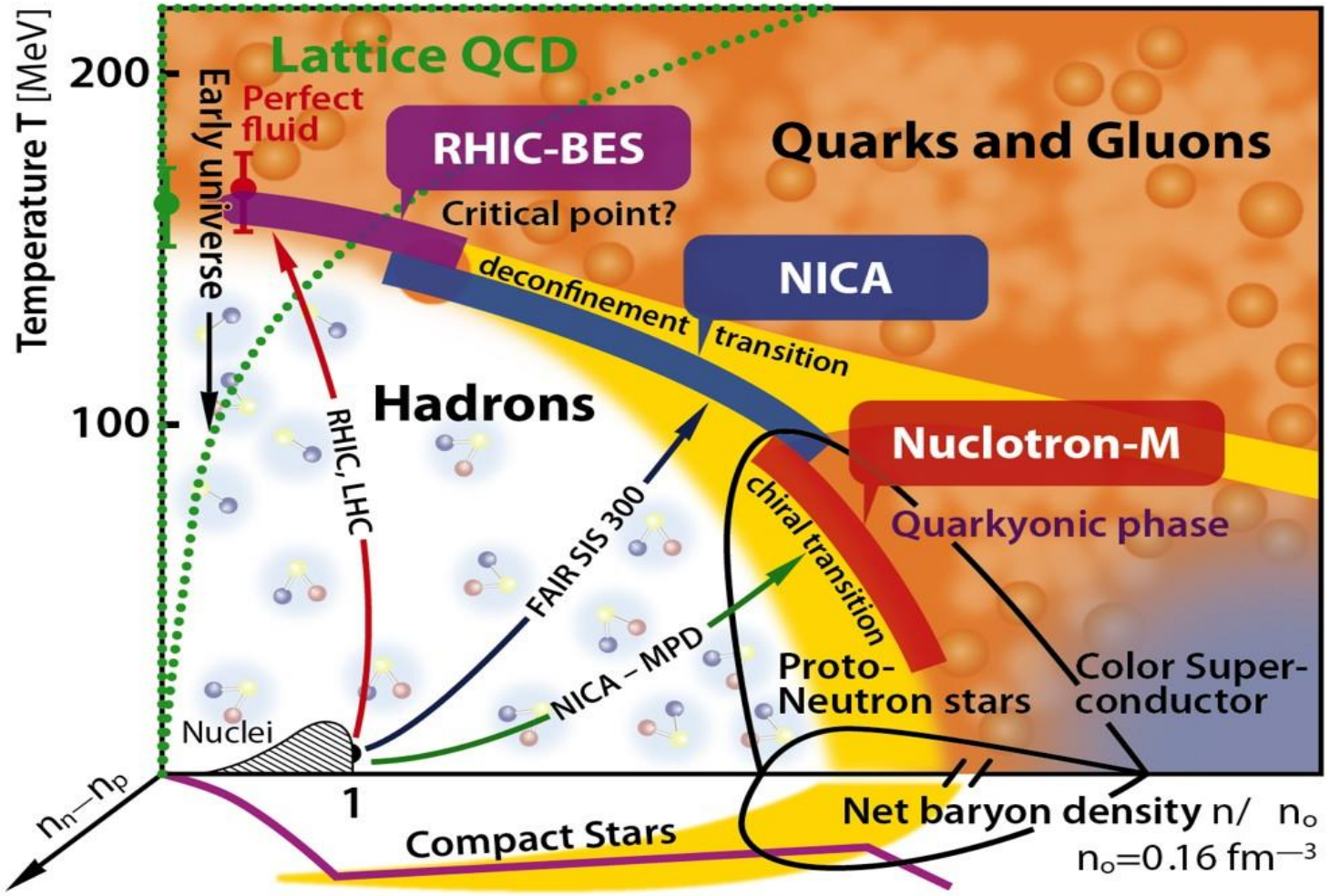
Acting Spokesperson:	***Victor Riabov***
Deputy Spokespersons:	***Arkadiy Taranenko, Chi Yang***
Institutional Board Chair:	***Alejandro Ayala***
Project Manager:	***Slava Golovatyuk***

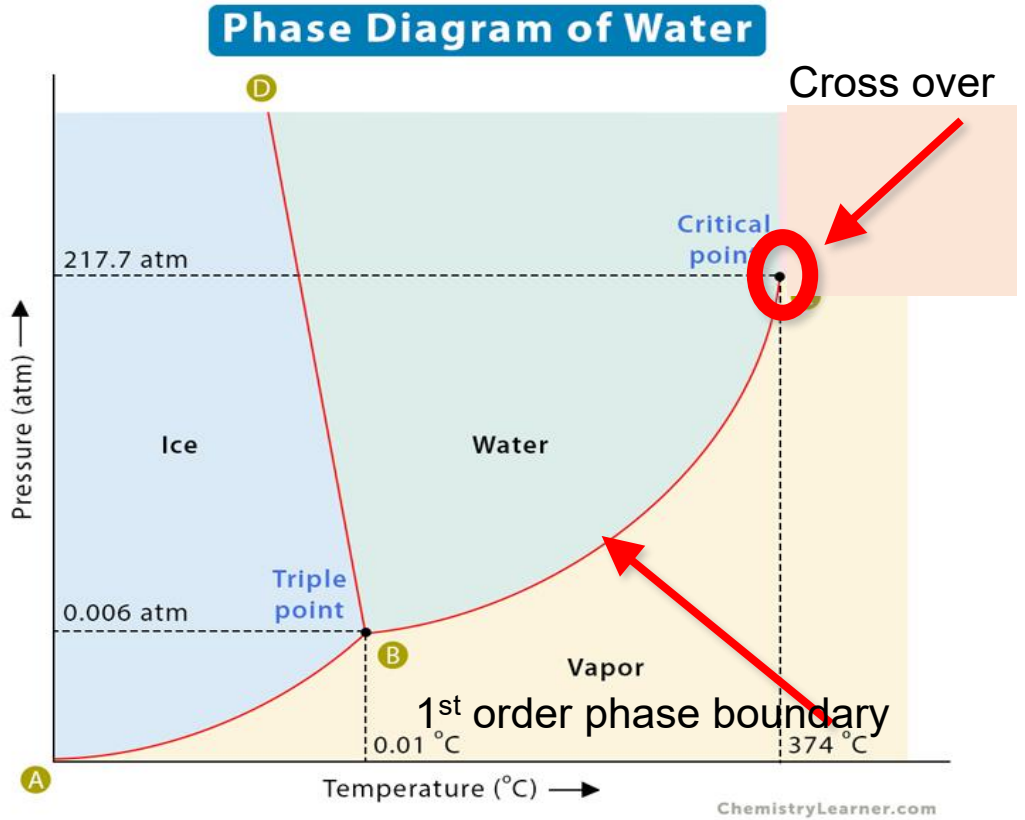


***Joint Institute for Nuclear Research**;*
*A.Alikhanyan National Lab of Armenia, Yerevan, **Armenia;***
*Institute for Nuclear Problems of Belarusian State University, **Belarus**;*
*Institute of Power Engineering of the National Academy of Sciences of Belarus, **Belarus**;*
*SSI "Joint Institute for 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***

Relativistic Heavy-Ion Collisions and QCD Phase Diagram





Method	μ_c (MeV)	T_c (MeV)
Holography + Bayesian	560 - 625	101 - 108
FRG/DSE	495 - 654	108 - 119
Lee-Yang edge singularities	500 - 600	100 - 105
Lattice QCD	$\mu_c/T_c > 3$	F. Karsch et al.
Summary	**495 - 654**	**100 - 119**

- ❖ What is the structure of the QCD phase diagram in the high baryon density region?
- ❖ How the dominant degrees of freedom in HIC change with the beam energy?
- ❖ Can the onset of the 1st order phase transition and QCD CEP be detected?

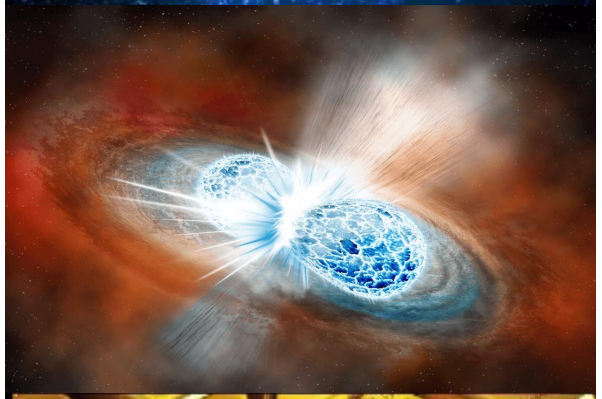
$(\mu_c, T_c) = (495 - 654, 100 - 119)$ MeV ➡ $3.5 < \sqrt{s_{NN}} < 4.9$ GeV

MPD and BM@N are both in the collision energy range of the predicted CEP location.

Neutron Stars and Big Questions



Nature of matter at extreme density?

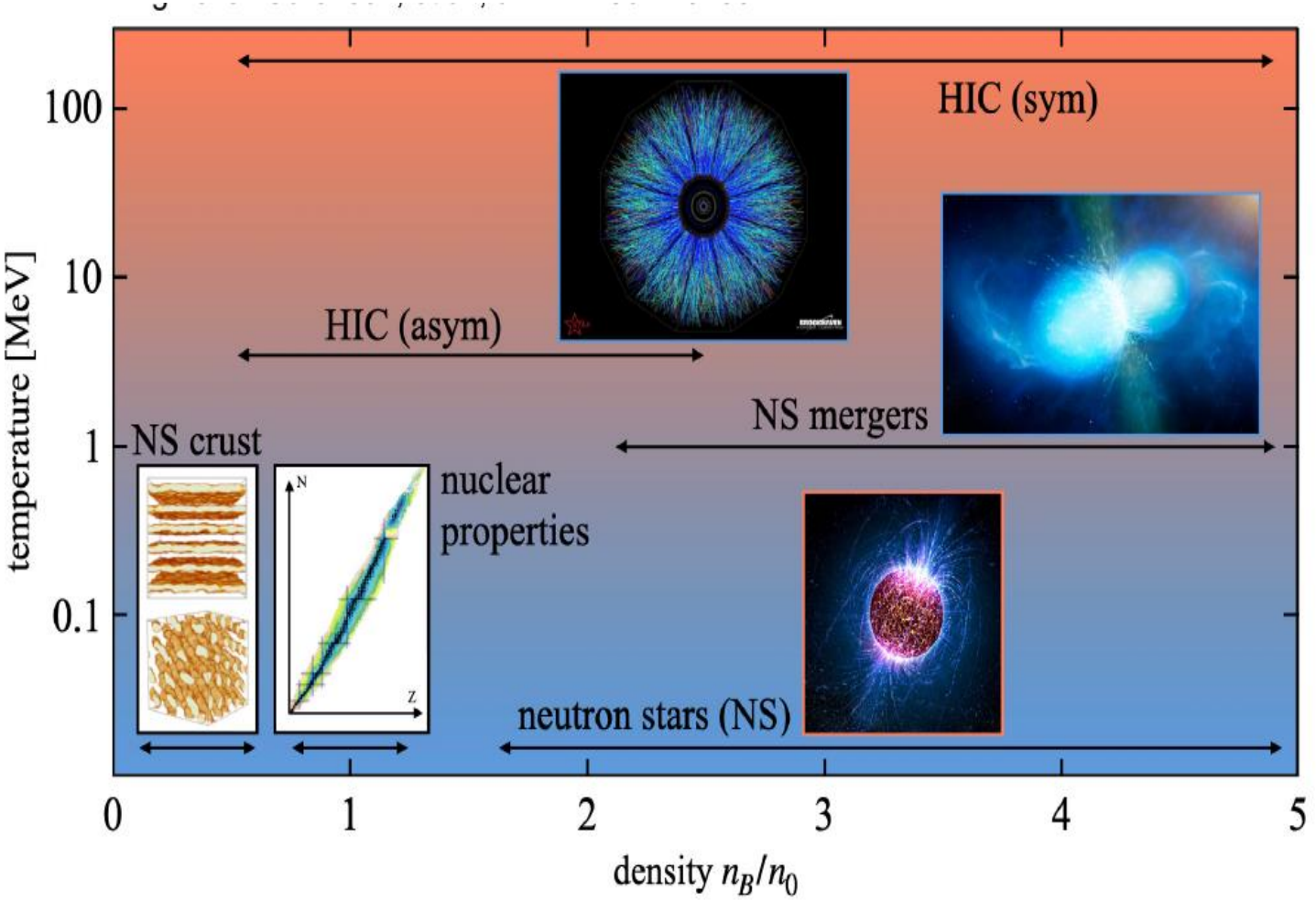


Origin of cosmic explosions?



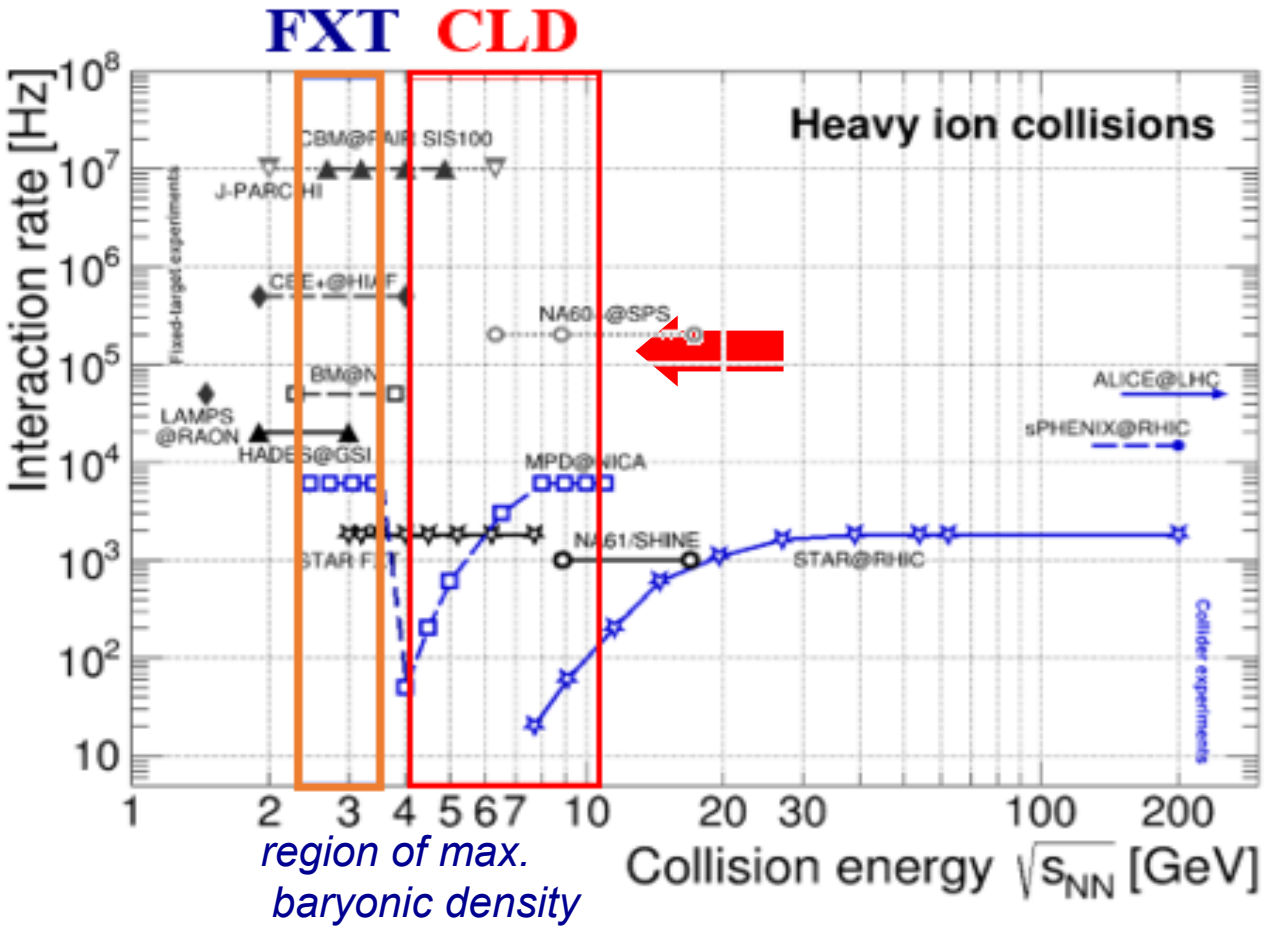
Synthesis of heavy elements?

Dense Nuclear Matter



Relativistic heavy-ion collisions provide a unique and controlled experimental way to study the properties of nuclear matter at high baryon density.

Relativistic Heavy Ion Collision Experiments



MPD competitors:

Present:

RHIC/STAR (USA) 3-200 GeV
NA61/SHINE (CERN) 5.1-17.3 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 (2034-?)
JPARC-HI (Japan) 2-5 GeV (2035-?)
FIXE (BNL,USA) 3-14 GeV (2036-?)

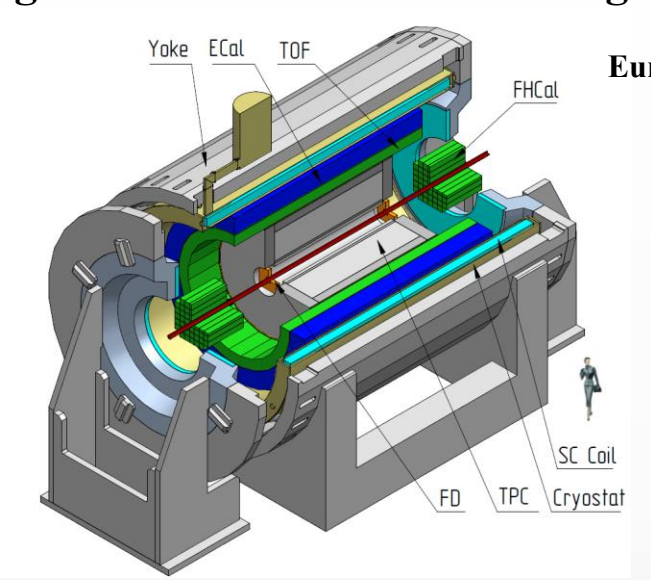
BM@N: $\sqrt{s_{NN}}$ = 2.3 - 3.3 GeV
MPD (CLD): $\sqrt{s_{NN}}$ = 4 - 11 GeV
MPD(FXT): $\sqrt{s_{NN}}$ = 2.3 - 3.3 GeV

❖ **MPD-CLD and MPD-FXT from start-up (2026-):**

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

Multi-Purpose Detector

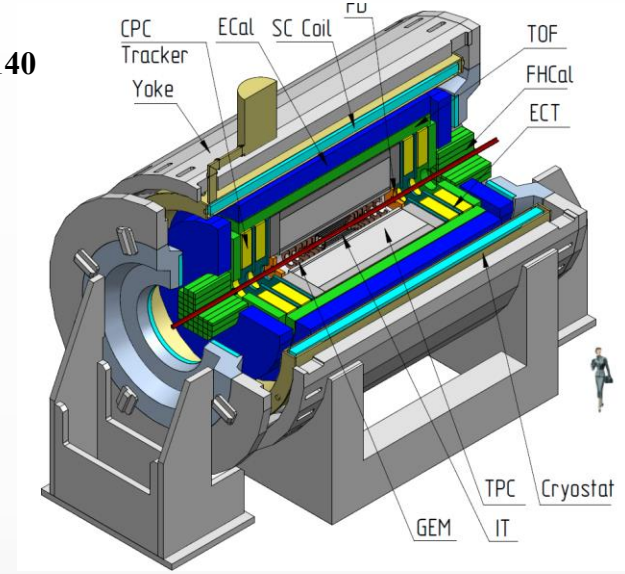
Stage-I → start of commissioning in 2026



Eur.Phys.J.A 58 (2022) 7, 140

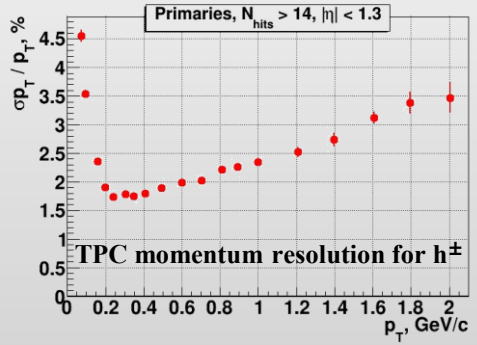
TPC: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.6$; **TOF, EMC**: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 1.4$
FFD: $|\Delta\varphi| < 2\pi$, $2.9 < |\eta| < 3.3$; **FHCAL**: $|\Delta\varphi| < 2\pi$, $2 < |\eta| < 5$

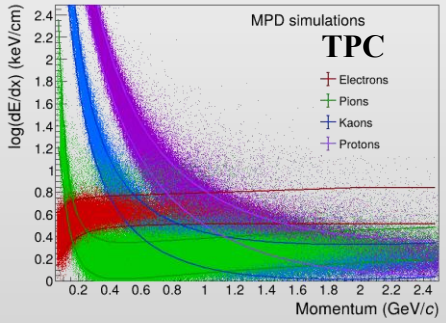
Stage-II → 2030+

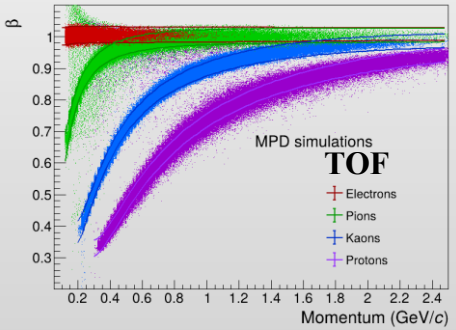


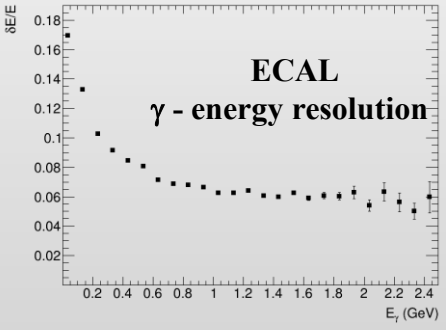
+ ITS : $|\Delta\varphi| < 2\pi$, $|\eta| \leq 3$
+ Forward Spectrometers: $|\Delta\varphi| < 2\pi$, $|\eta| \leq 2.2$

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









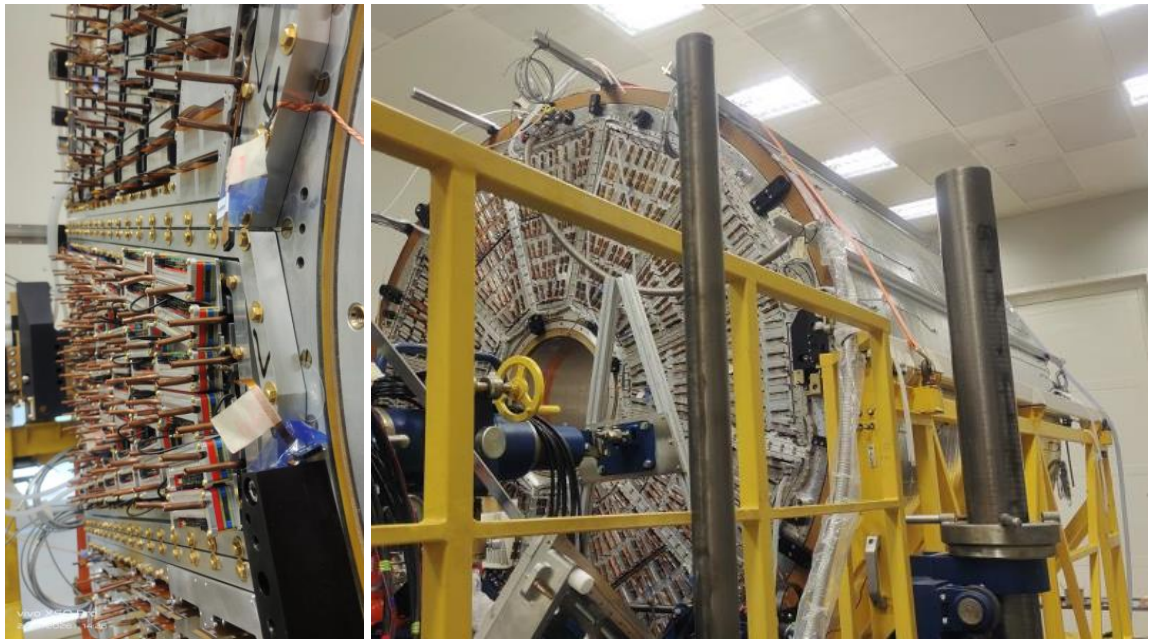
MPD subsystem status (I)

Magnet and cryogenics



- Cooled the magnet to LN2 and LHe temperatures: nominal MF of 0.57T had been reached
- Magnet is fully operational since Feb 15, 2026
- MF measurements are finished – Aug 1, 2026

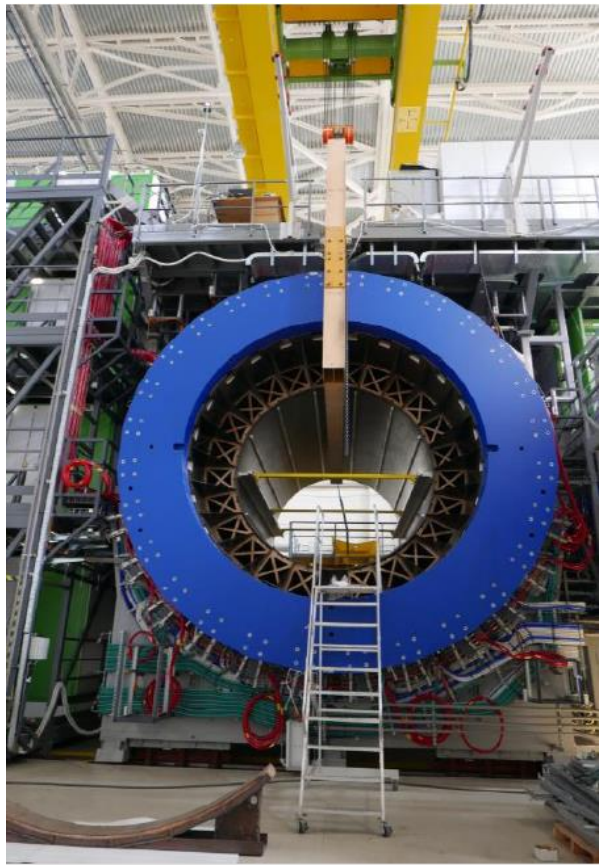
TPC – central tracker



- Gas volume assembled and tested for leaks and HV
- 24 Read-Out-Chambers (ROC) installed
  - Operational HV has been applied to the membrane and ROC (Cathode), cosmics detected

MPD subsystem status (II)

Support structure



Carbon fiber power frame is installed in the magnet

- sagita ~5 mm at full load
- rails for TPC and TOF are installed

TOF



All 28 modules are assembled, tested and installed

Beam luminosity detector



Operated at collider start-up

ECAL



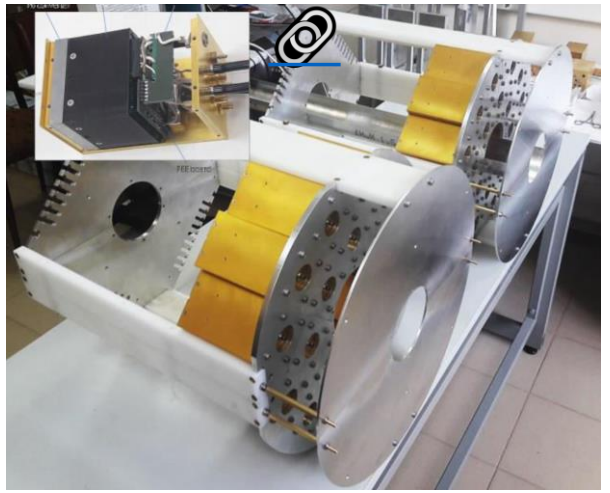
- Manufactured together with universities of China
- Installation of ECAL half-sectors is finished

FHCal



FHCal assembled on the platform

FFD



Cherenkov modules, mechanics for installation in container with the beam pipe are available

MPD schedule

		2026
1	January 12th – January 23d	Fixation the Current leads cooling problem
2	January 26th February 15th	Cooling the Solenoid to working temperature
3	February 25 – March 25th	Magnetic field measurements at nominals 0.5T - 0.4T -0.3T
4	March 30th - April 17th	Support Frame installation into Magnet
5	April 30th – May 30th	Ecal installation from the East side
6	May 27th	West platform mounted
7	May 28th – June 15th	Installation of the TOF modules (access from both sides)
8	June 10th	Ecal module installation finishing
9	June 15 – June 20	Installation the Mapper into Magnet
10	June 22th - July 12th	Magnetic field measurements at 0.5T
11	July 15th – August 10th	Ecal&TOF cooling pipes and cabling laying
12	July 20th - August 10th	FHCal mounting
13	August 10th – September 30th	TPC installation and test
14	October 1st – October 15th	Beam pipe installation
15	October 20 - October 25th	Closing MPD (Installation of Poles)
16	October 30th	Moving MPD on the Collider beam line

MPD in the beam position by the end of October to comply with the NICA Run-2 schedule

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

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

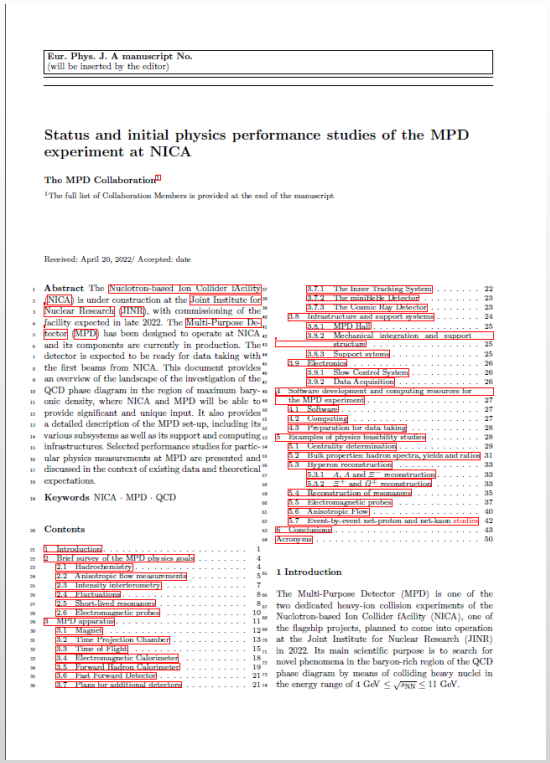
Physics performance studies and activity

- ~ 50 reports at international conferences per year
- Overall 200+ 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)

III. MPD physics performance in the fixed target Xe+W collisions at $\sqrt{s_{NN}}$ = **2.87 GeV (Particles 2027)**



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

Received: April 20, 2022/ Accepted: date

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

Contents

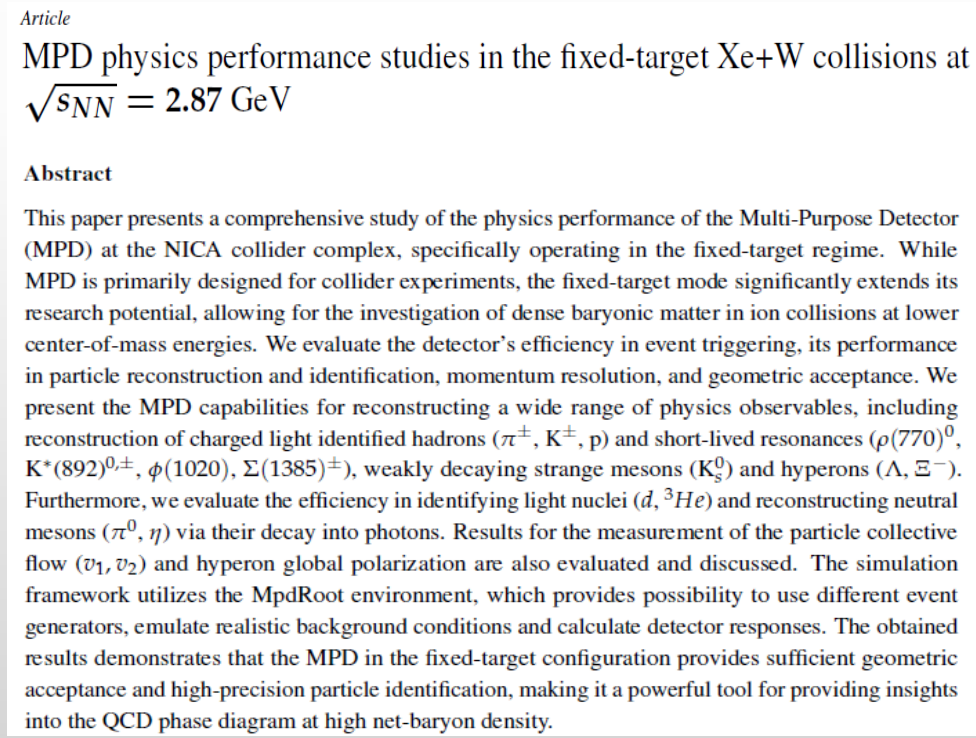
1 Introduction

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 of colliding heavy nuclei in the energy range of 4 GeV $\leq \sqrt{s_{NN}} \leq$ 11 GeV.



Nuclear Physics Revista Mexicana de Física *71 041201 1–45 JULY-AUGUST 2025

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

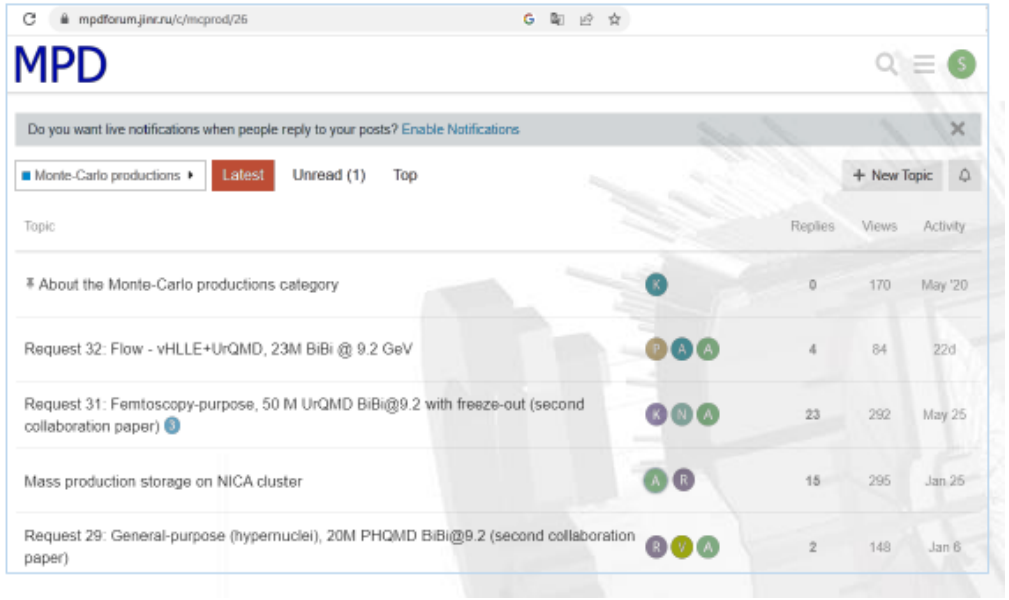


Article

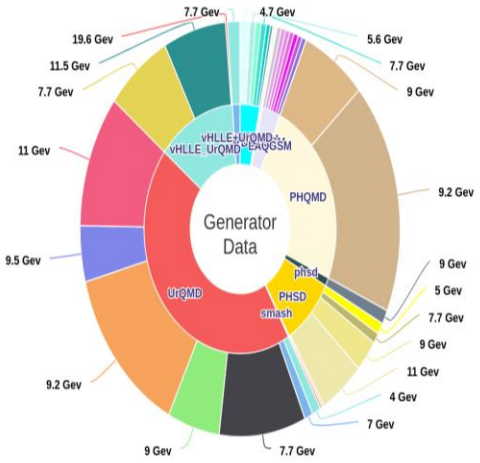
MPD physics performance studies in the fixed-target Xe+W collisions at $\sqrt{s_{NN}} = 2.87$ GeV

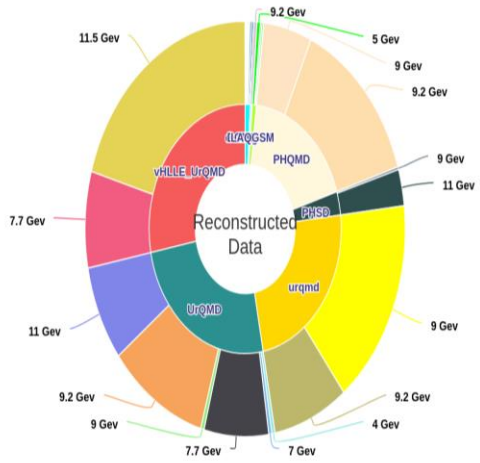
Abstract

This paper presents a comprehensive study of the physics performance of the Multi-Purpose Detector (MPD) at the NICA collider complex, specifically operating in the fixed-target regime. While MPD is primarily designed for collider experiments, the fixed-target mode significantly extends its research potential, allowing for the investigation of dense baryonic matter in ion collisions at lower center-of-mass energies. We evaluate the detector's efficiency in event triggering, its performance in particle reconstruction and identification, momentum resolution, and geometric acceptance. We present the MPD capabilities for reconstructing a wide range of physics observables, including reconstruction of charged light identified hadrons ($\pi^{\pm}$, $K^{\pm}$, p) and short-lived resonances ($\rho(770)^0$, $K^*(892)^{0,\pm}$, $\phi(1020)$, $\Sigma(1385)^{\pm}$), weakly decaying strange mesons (K^0_s) and hyperons (Λ, Ξ^-). Furthermore, we evaluate the efficiency in identifying light nuclei (d, ^3He) and reconstructing neutral mesons (π^0, η) via their decay into photons. Results for the measurement of the particle collective flow (v_1, v_2) and hyperon global polarization are also evaluated and discussed. The simulation framework utilizes the MpdRoot environment, which provides possibility to use different event generators, emulate realistic background conditions and calculate detector responses. The obtained results demonstrates that the MPD in the fixed-target configuration provides sufficient geometric acceptance and high-precision particle identification, making it a powerful tool for providing insights into the QCD phase diagram at high net-baryon density.



http://db-nica.jinr.ru/mpdmc/stat.php





Generator	PWG	Coll.	$\sqrt{s}$	# of events(10^6)	Reco
UrQMD	PWG4	AuAu	11	15	+
		BiBi	9	10	+
			9.46	10	+
			9.2	135	+
	PWG2	AuAu	11	10	+
	PWG3	AuAu	7.7	10	+
		BiBi	7.7	10	+
			9	15	+
		pp	9	10	+
		BiBi fix target	2.5	12	+
		BiBi fix target	3.0	12	+
		BiBi fix target	3.5	12	+
		XeW fix target	2.5	15	+
		XeXe fix target	2.5	15	+
	PWG1	BiBi	9.2	76	+
DCM-SMM	PWG1	BiBi	9.2	2	+
PHQMD	PWG2	BiBi	8.8	15	+
			9.2	61	+
			2.4/3.0/4.5	10/10/2	-
vHLLE-UrQMD	PWG3	BiBi	11.5	15	+
		AuAu	11.5	15	+
		AuAu	7.7	20	+
		BiBi	9.2	48	+
Smash	PWG1	BiBi	9.46	10	+
		ArAr	4/7/9/11	20/20/20/20	-
		AuAu	4/7/9/11	20/20/20/22	-
		XeXe	4/7/9/11	20/20/20/20	-
		CC	4/7/9/11	20/20/20/20	-
		pp	4/7/9/11	50/50/50/50	-
JAM	PWG3	AuAu	3/3.3/3.5/3.8/4.0/4.2/4.5/5	40/40/40/40/40/40/40/40	
DCM-QGSM-SMM	PWG3	AuAu	4/9.2	5/5	+
		AgAg	4/9.2	5/5	+
		BiBi	4/9.2	5/6	+
PHSD		BiBi	9/9.2	25	+
Total				1453	609

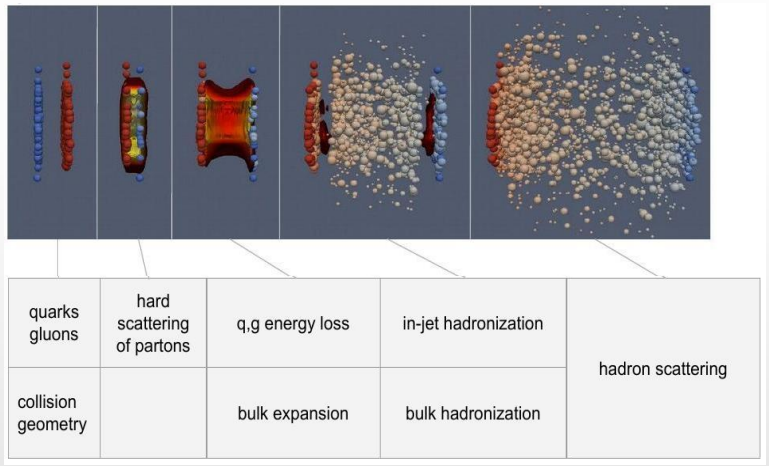
Total amount of generated data is around 1.97 PB, 40 mass productions have been done.

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.

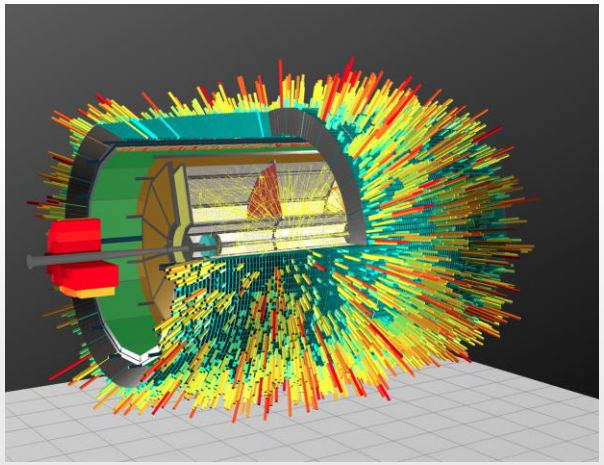
Event generator(s)



MpdRoot

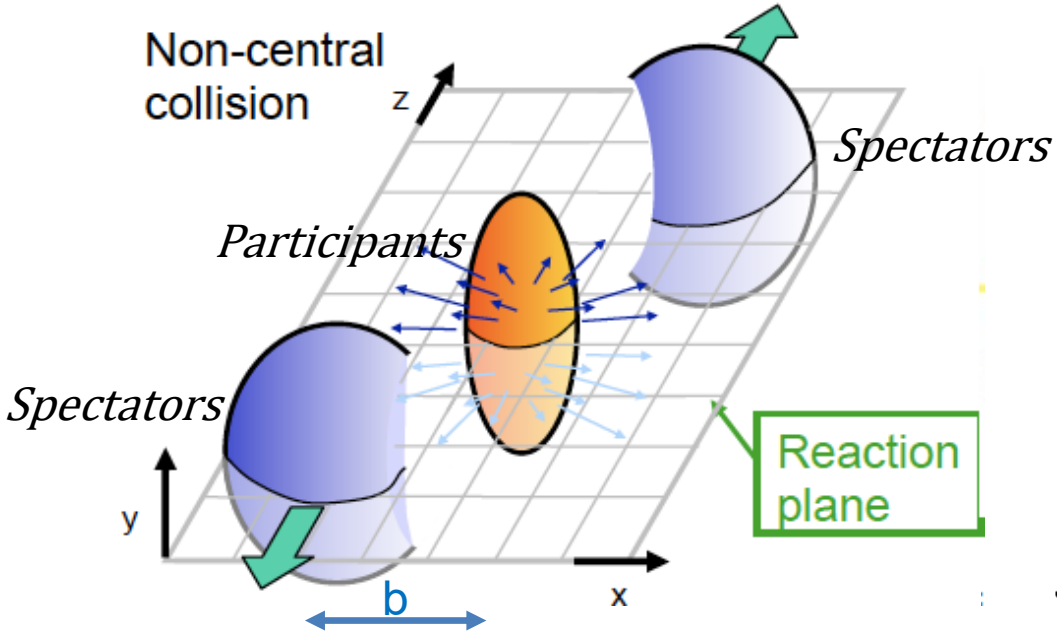
JINR MLIT

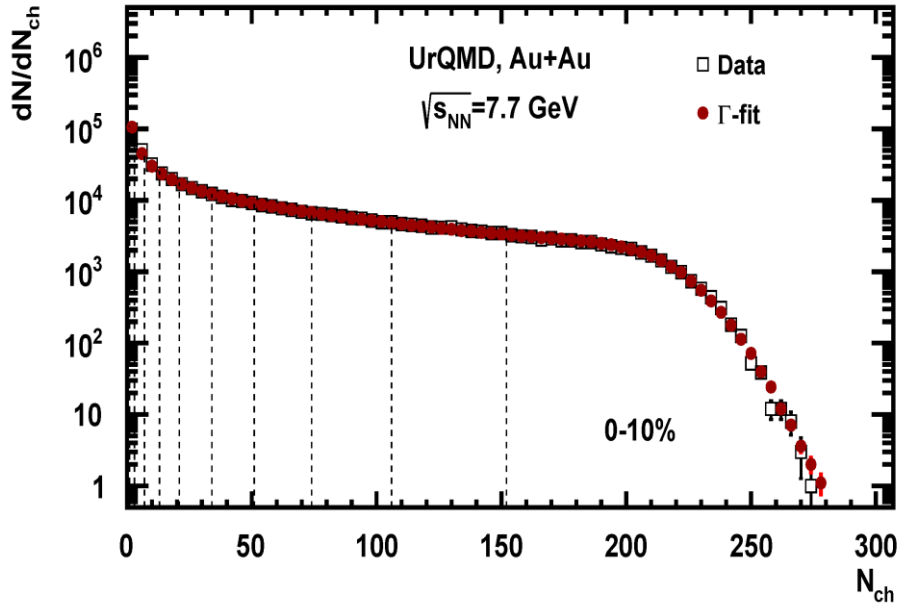
Particle propagation & detector response

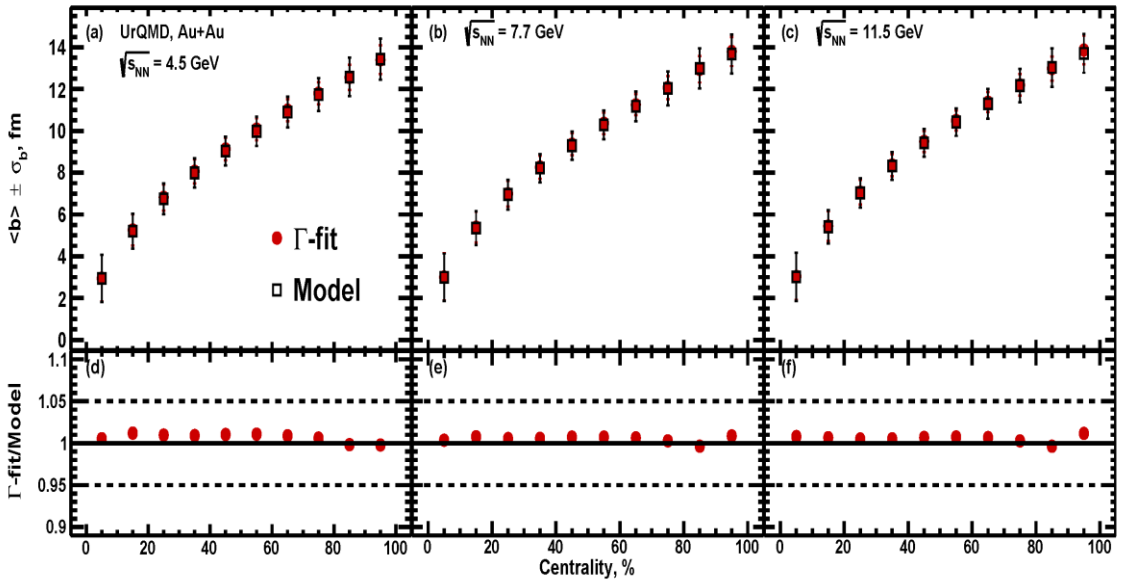


- Develop physics program, software and analysis infrastructure for real data analysis
- MPD-CLD and MPD-FXT studies with simulations:
  - ✓ collider mode: Bi+Bi @ 9.2 GeV
  - ✓ fixed-target mode: Xe + W @ T = 2.5 AGeV

Geometry of Heavy-Ion Collisions

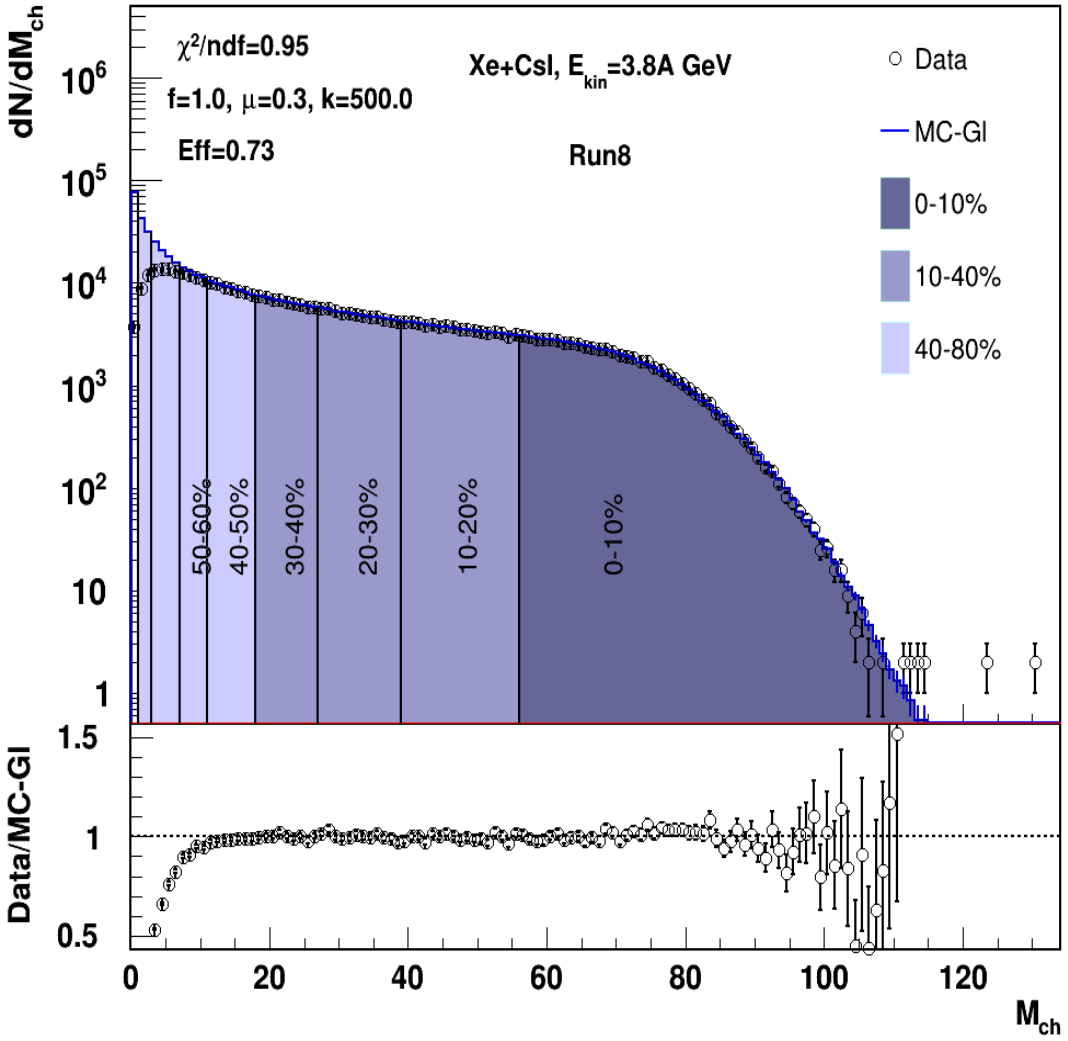


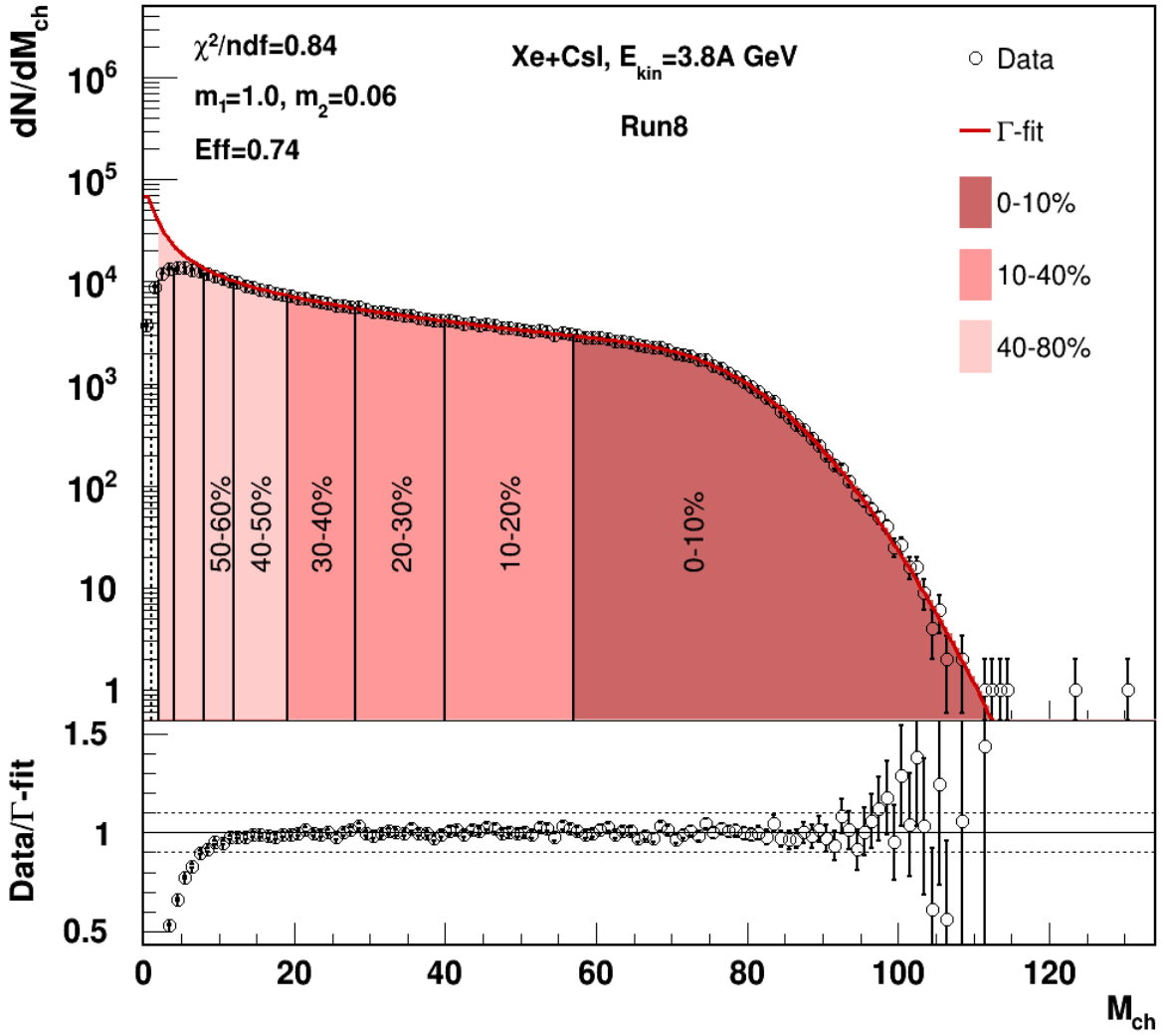




- $N_{participants}$: number of nucleons in the overlap region
- $N_{collisions}$: number of inelastic nucleon-nucleon collisions
- Reaction plane: defined by beam axis and impact parameter
- Centrality: percentile of the total cross section

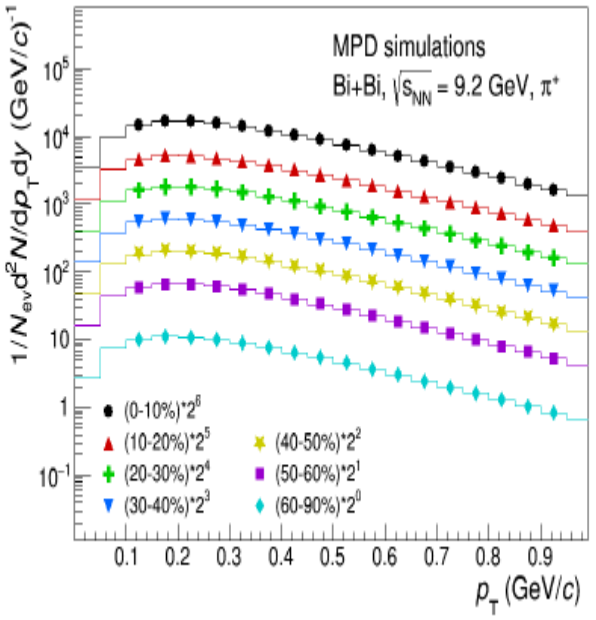
Geometry of Heavy-Ion Collisions

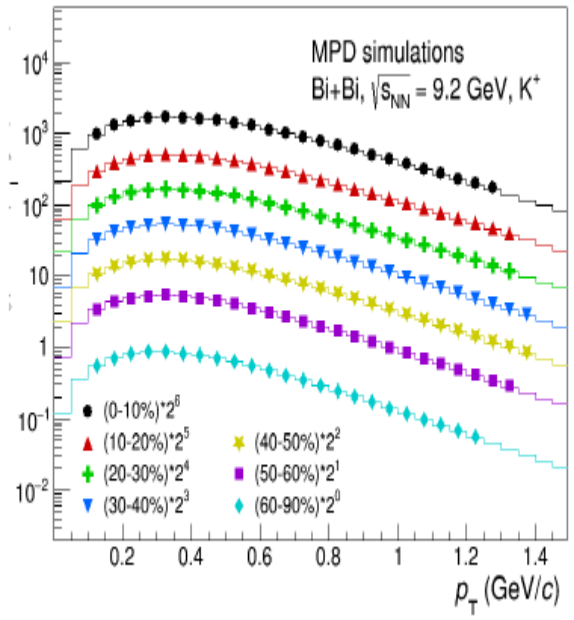


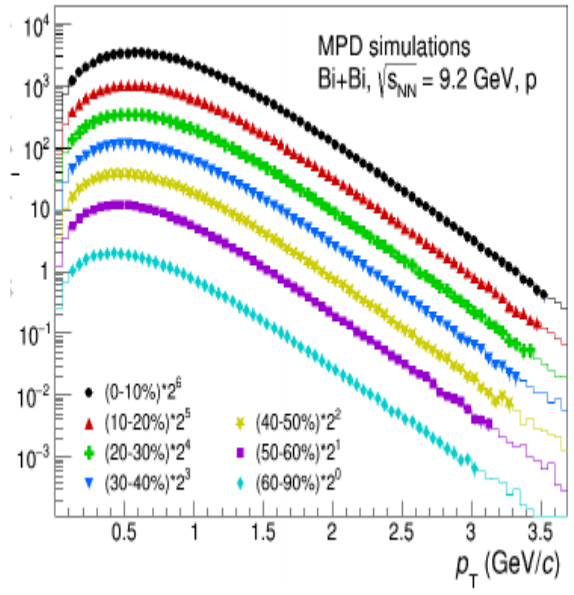


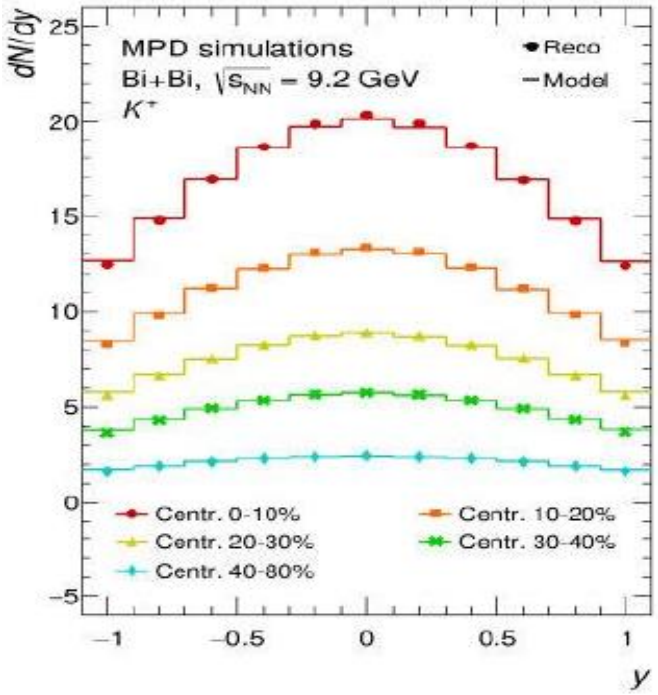
MPD feasibility study: light identified hadrons

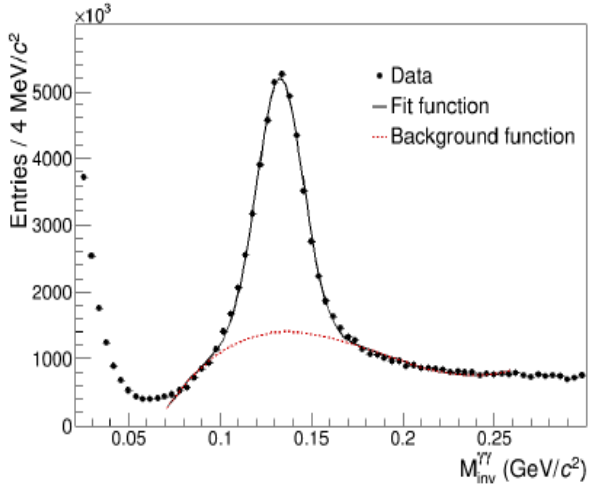
Rev. Mex. Fís., vol. 71, no. 4, pp.1–45,2025.

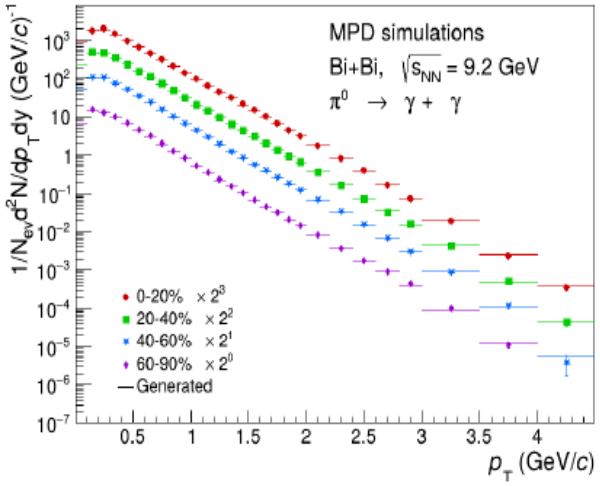








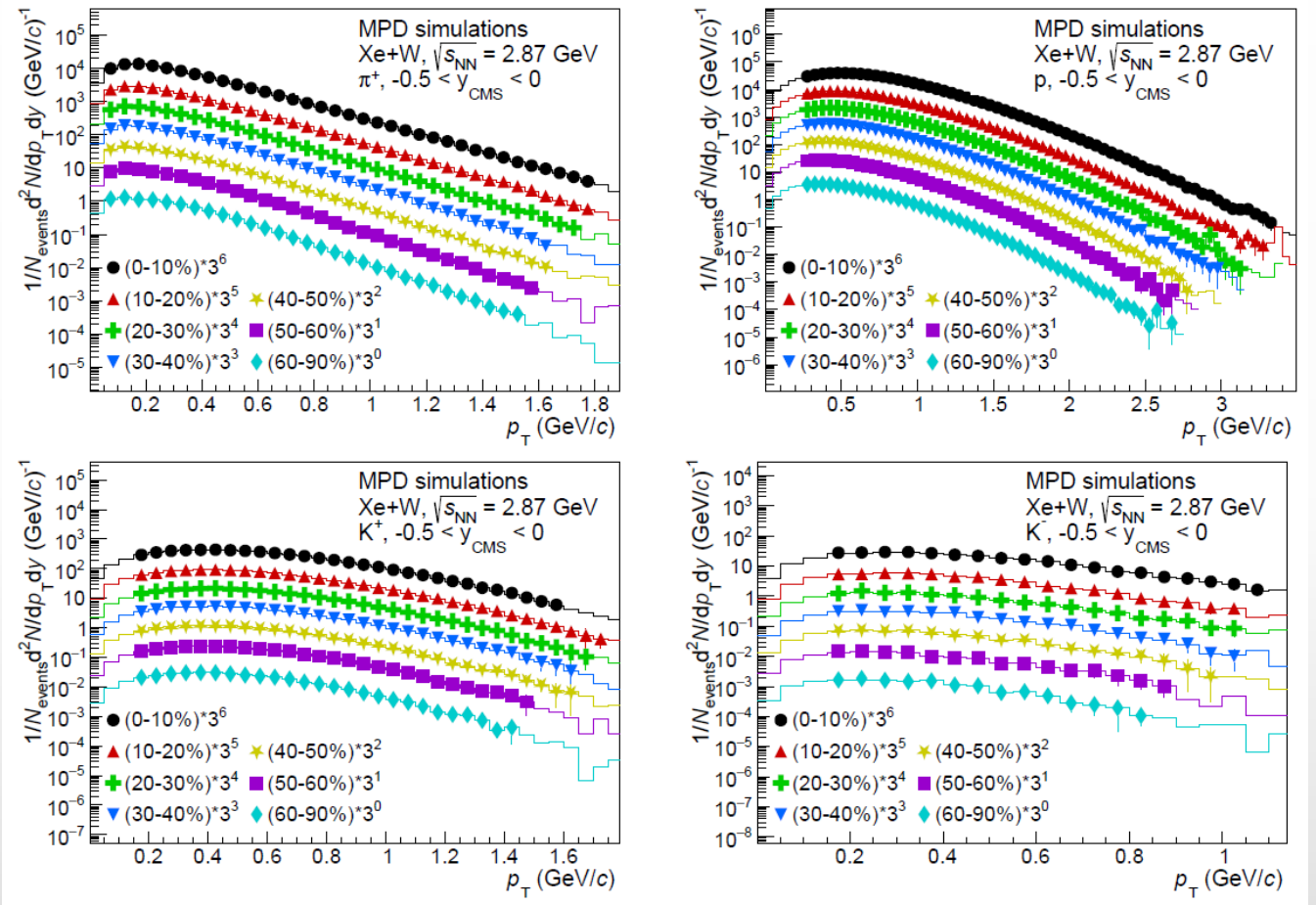




- Charged hadrons: excellent PID and good phase-space coverage (~ 70% of the π/K/p)
- Neutral mesons (π^0, η, K_s, ω, η'): ECAL reconstruction + photon conversion method (PCM) allow to extend p_T ranges of charged particle measurements and provide different systematics

MPD-FXT: π/K/p

❖ MPD-FXT: XeW@ T=2.5 AGeV (UrQMD), 100M events → full event reconstruction

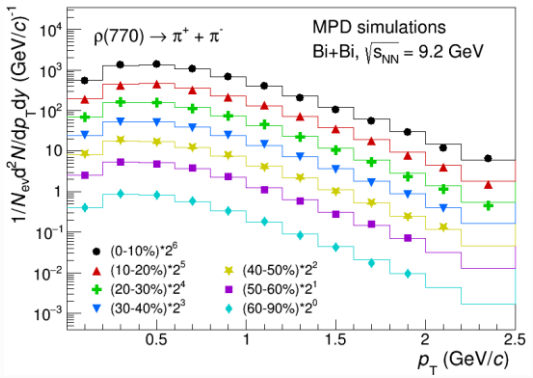


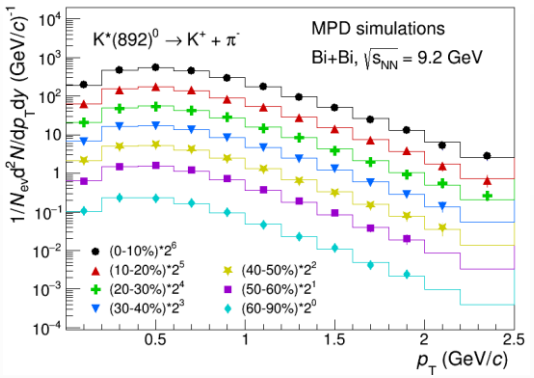
Rapidity coverage -1.3 < y_{CMS} < 0

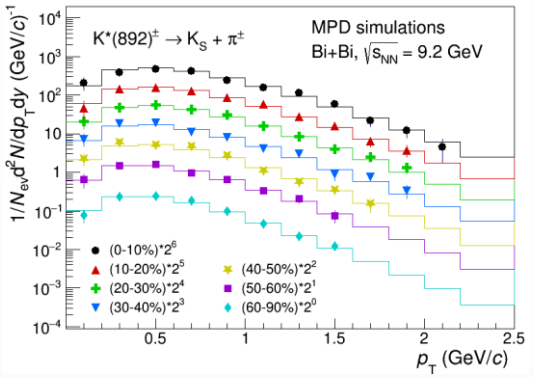
Spectra at mid-rapidity cover the p_T ranges that correspond to production of over 95% (85%) of the total $\pi^{\pm}$ (p) yields and 93% (85%) of K^+ (K^-) → robust basis for extracting the integrated yields

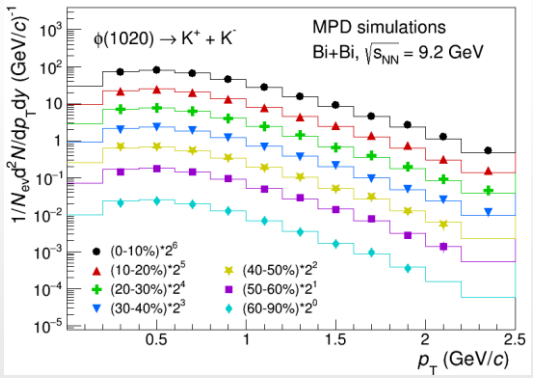
Hadronic resonances, Bi + Bi @ 9.2 GeV

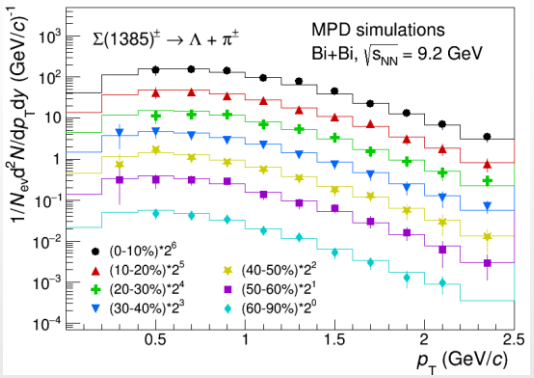
❖ PID capabilities of TPC and TOF + topology selections for weak decays of daughters (K_s, Λ)

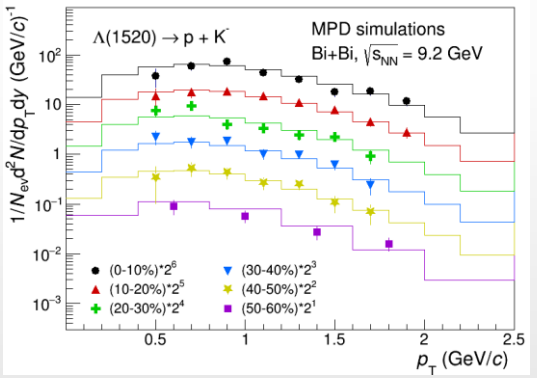












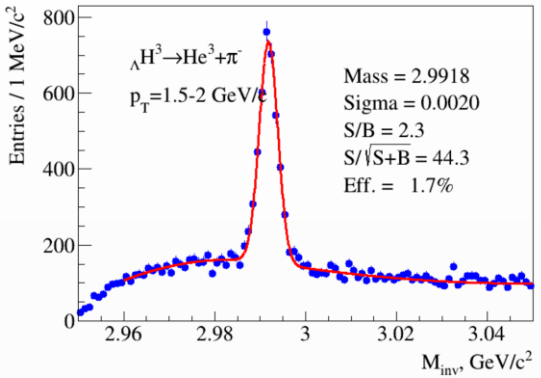
A wide variety of resonances is constructible, ρ(770), K*(892), ϕ(1020), Σ(1385), Λ(1520)

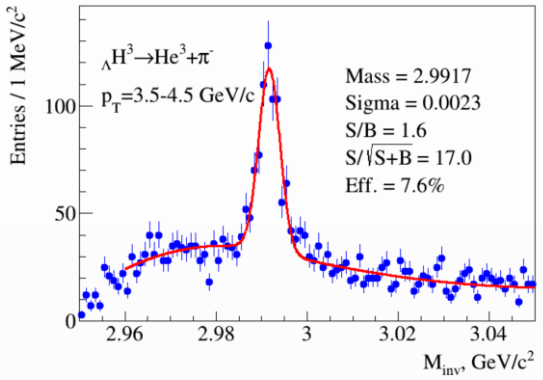
Measurements are possible starting from ~ zero momentum → sample most of the yields

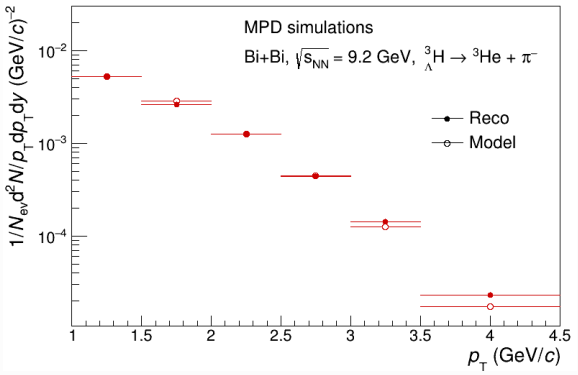
Angular dependent measurements with larger statistics → spin alignment, collective flow

MPD performance for hypenuclei

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



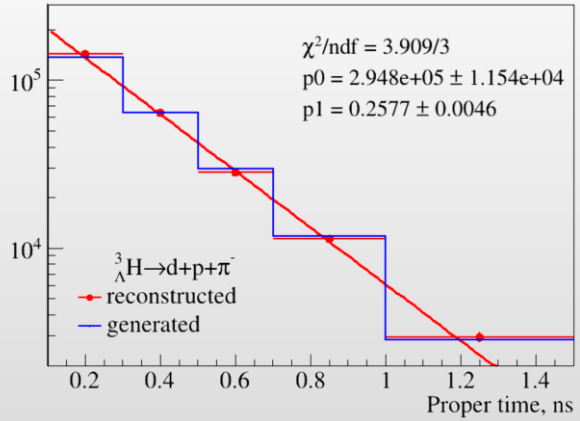


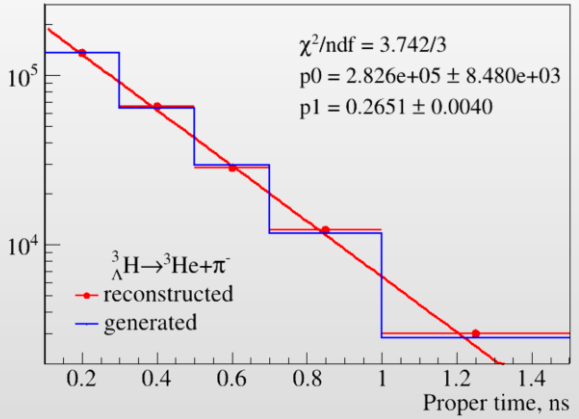


2- and 3-prong decay modes were studied separately to estimate systematics

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

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%

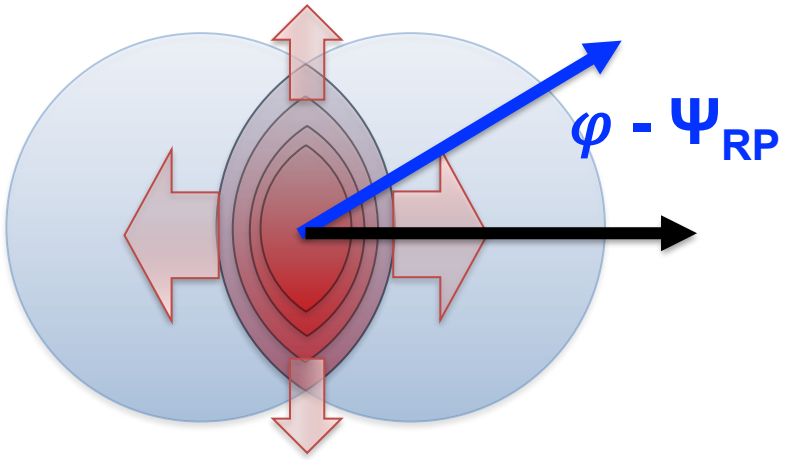




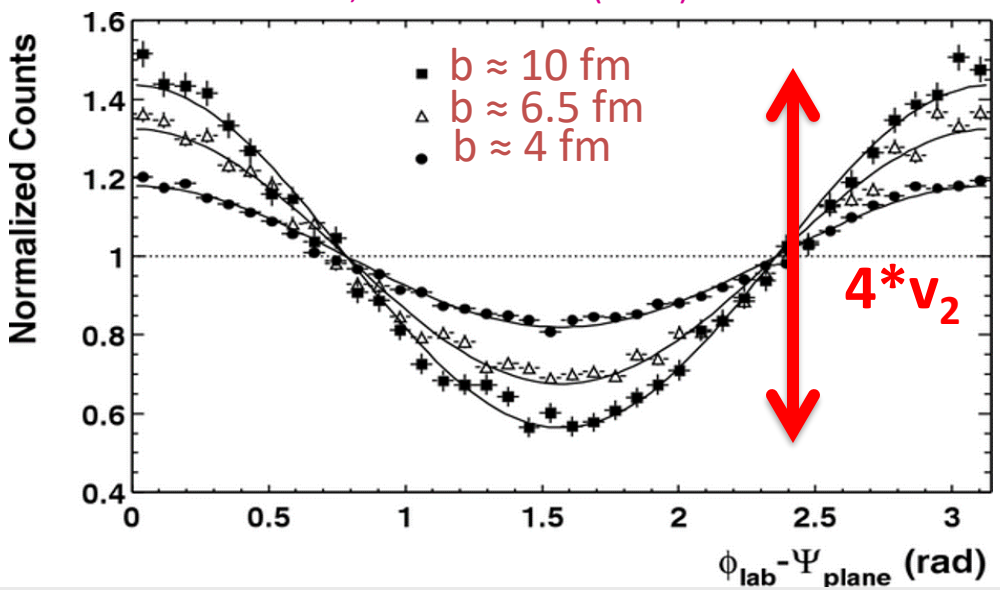
$_{\Lambda}H^3$ reconstruction with ~ 50M samples events

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

Azimuthal anisotropy of particles at HIC



STAR, PRL**90** 032301 (2003)



Sergei Voloshin, Y. Zhang, Z. Phys. C70,(1996), 665

$$\frac{dN}{d(\varphi-\Psi_{RP})}=\frac{N_0}{2\pi}\left(1+2v_1\cos(\varphi-\Psi_{RP})+2v_2\cos(2(\varphi-\Psi_{RP}))+\ldots.\right)$$

- The sinus terms are skipped by symmetry arguments
- From the properties of Fourier's series one has

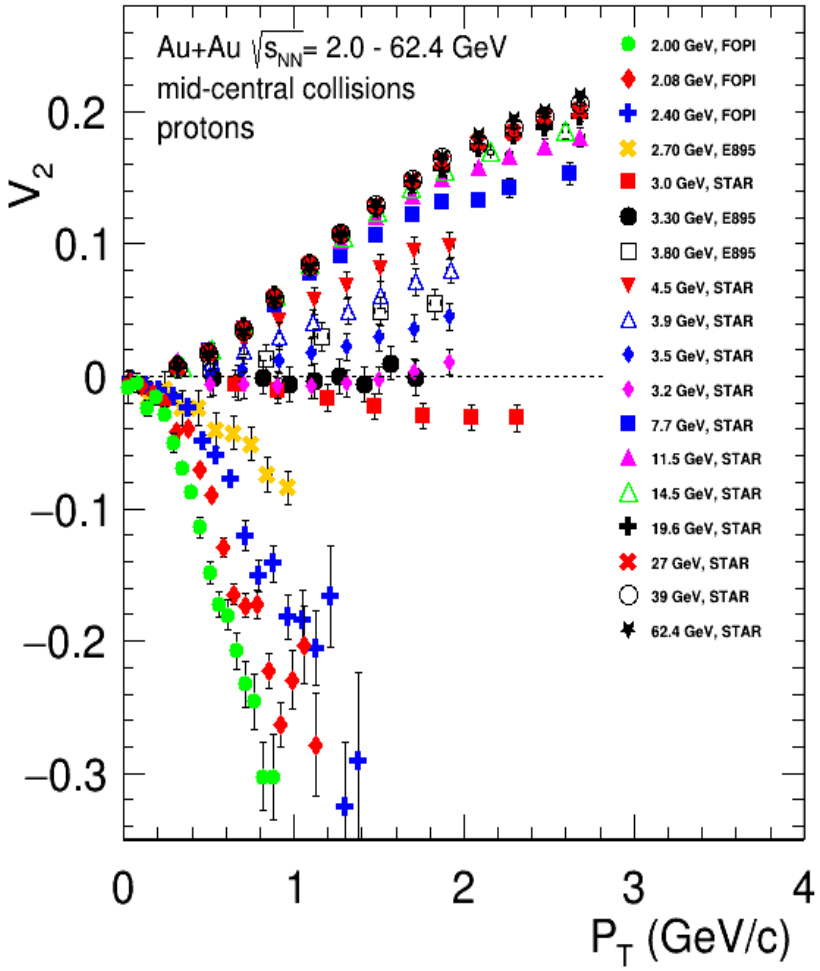
$$v_n=\langle\cos[n(\varphi-\Psi_{RP})]\rangle$$

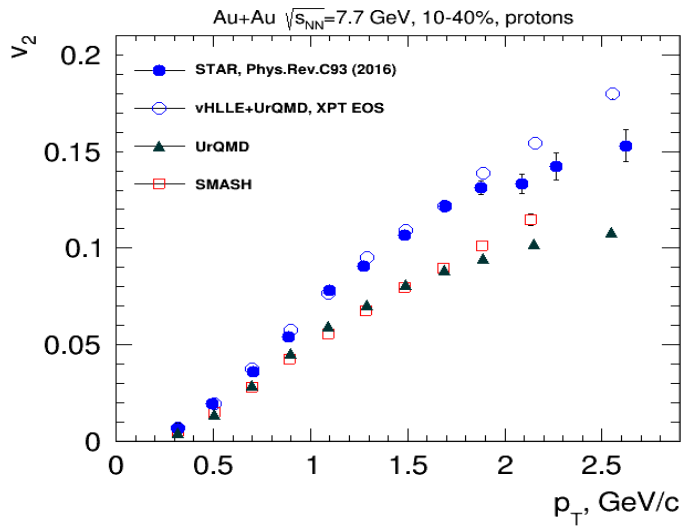
- Fourier coefficients $\mathbf{V_n}$ quantify anisotropic flow:

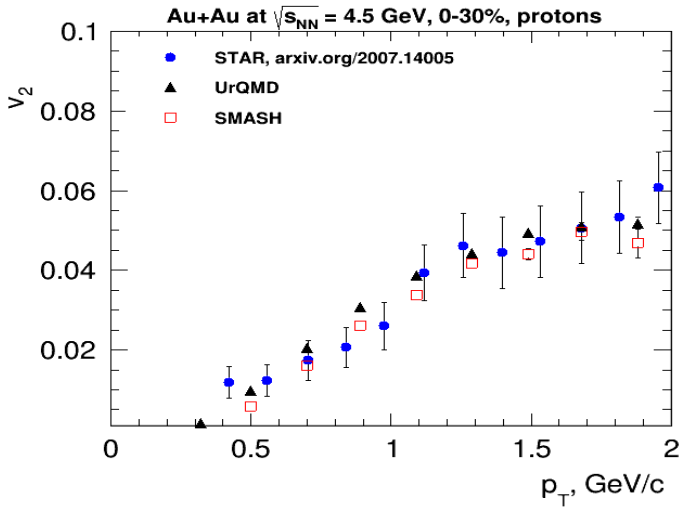
v_1 is directed flow, v_2 is elliptic flow, v_3 is triangular flow, etc.

Term "flow" does not mean necessarily "hydro" flow – used only to emphasize the collective behavior of particles in event or multiparticle azimuthal correlation

Beam Energy Dependence of Elliptic Flow (v_2)

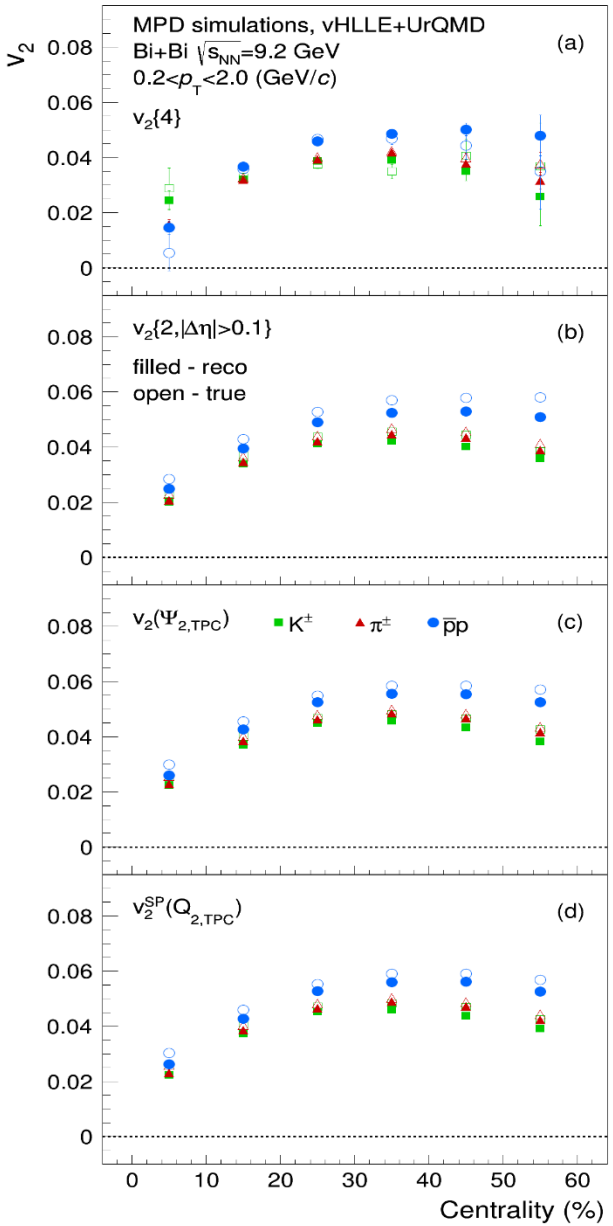


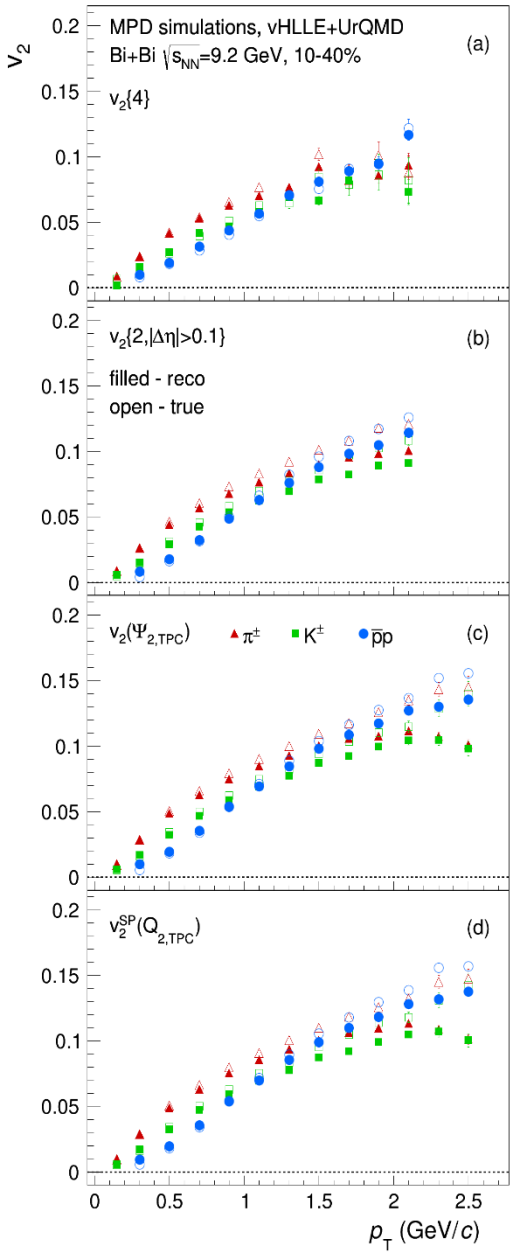


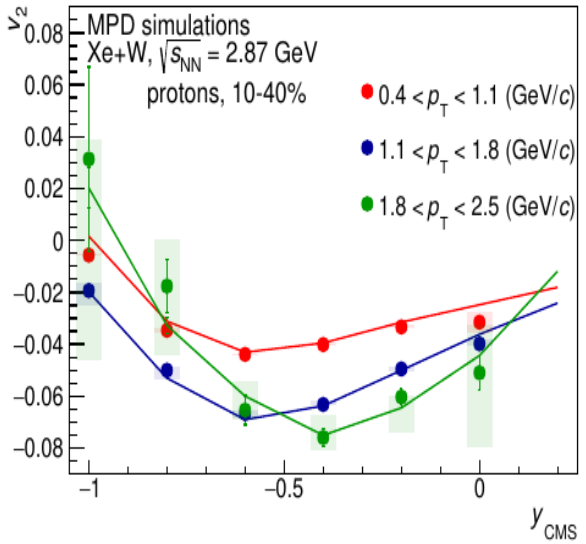


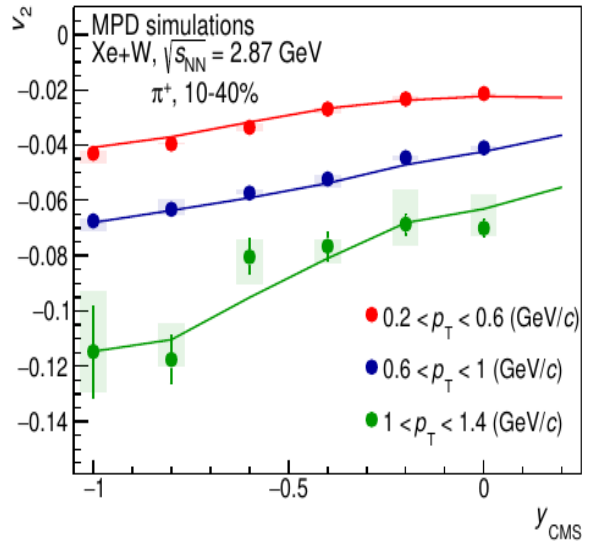
- **Strong energy dependence of v_2 at $\sqrt{s_{NN}}$ = 2.4-7 GeV**

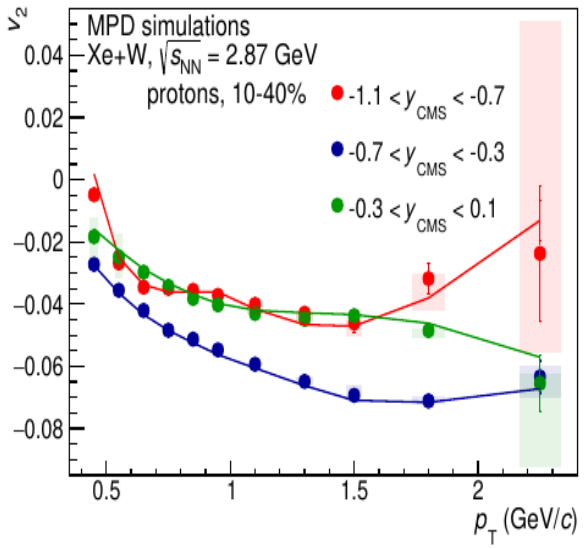
MPD performance: Elliptic Flow (v_2)

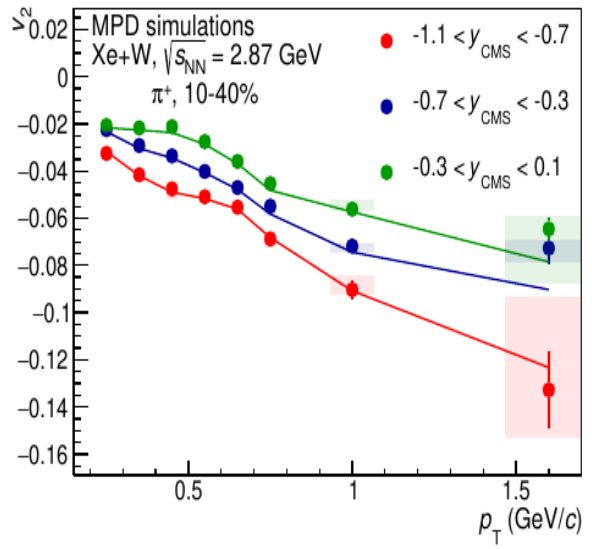




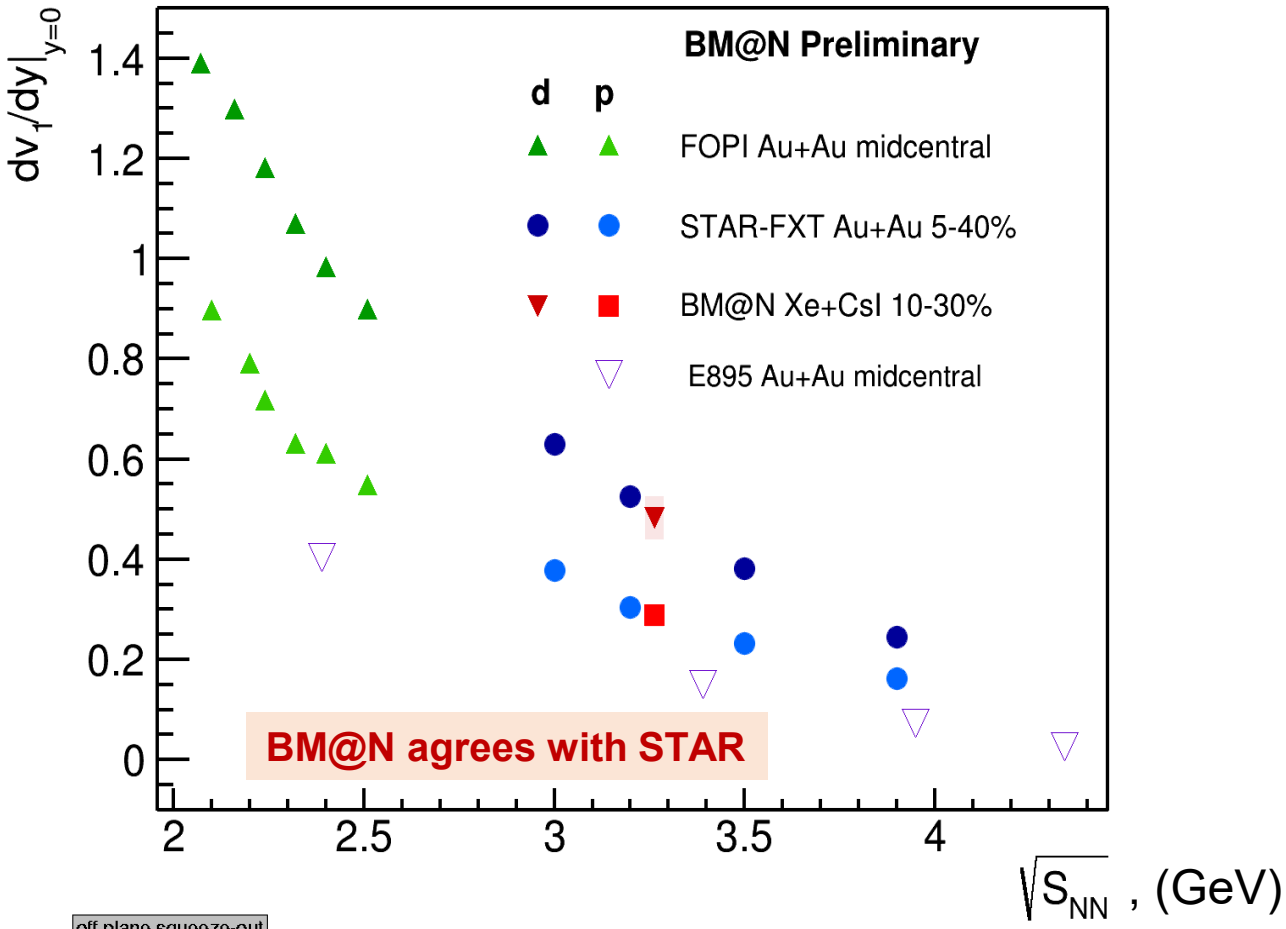


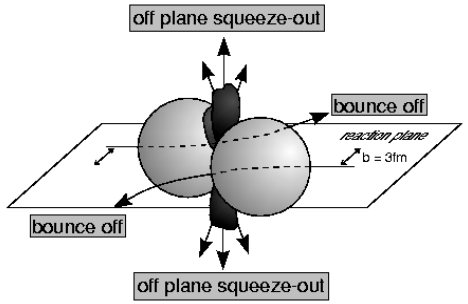






Directed flow of protons and deuterons (BM@N run8 data)





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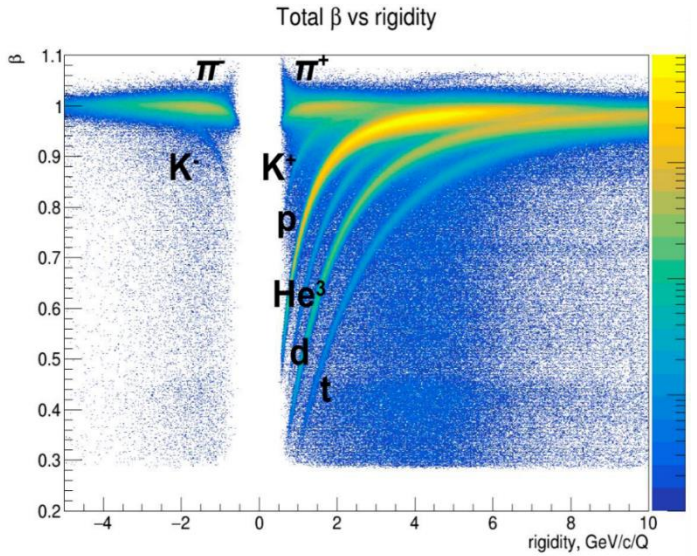
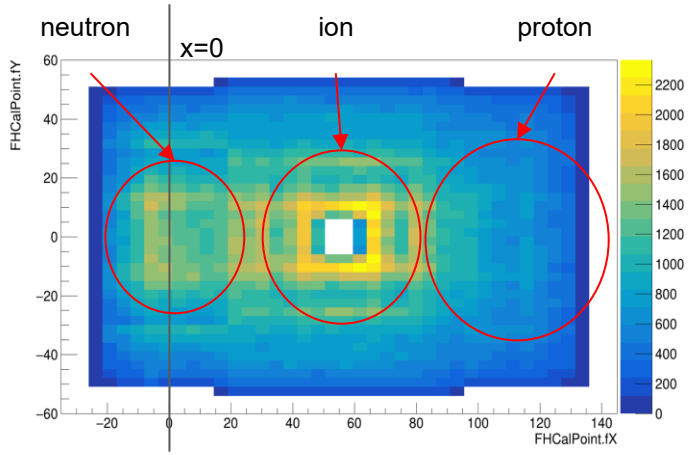
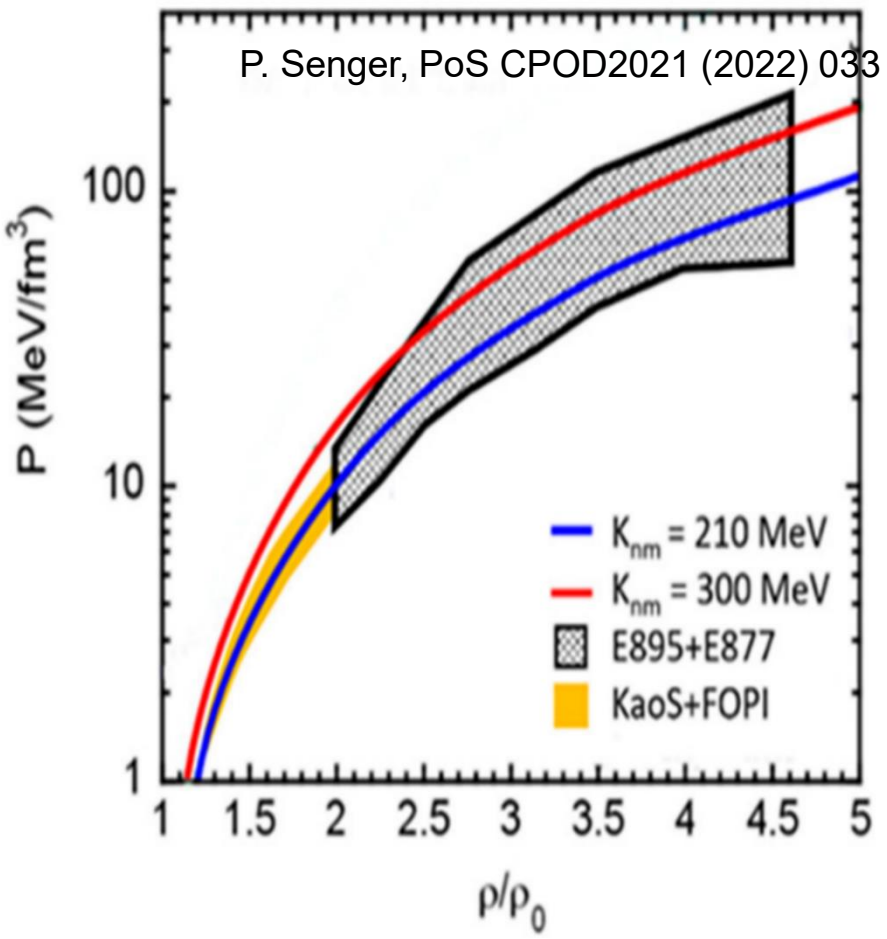


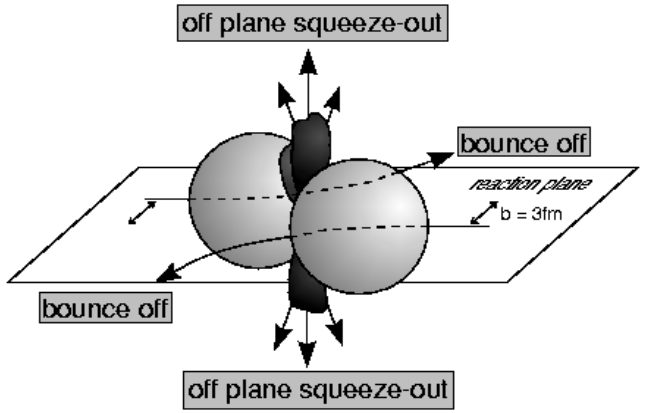
TOF

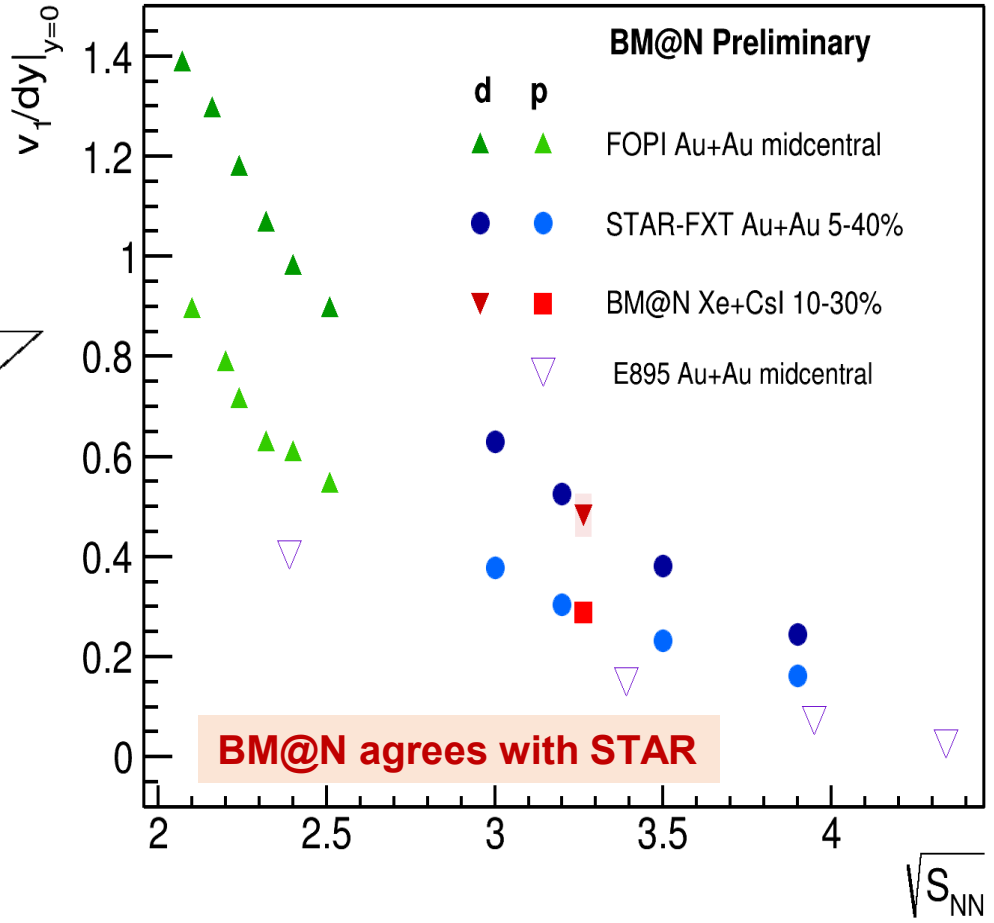


FHCaL

Directed flow of protons and EOS of symmetric matter







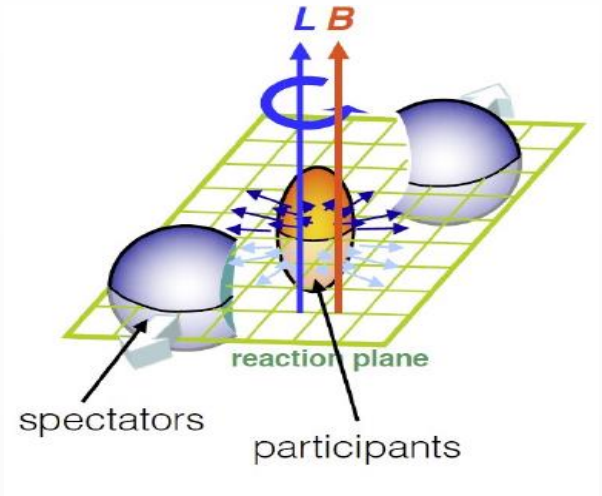
Nuclear incompressibility from collective proton flow

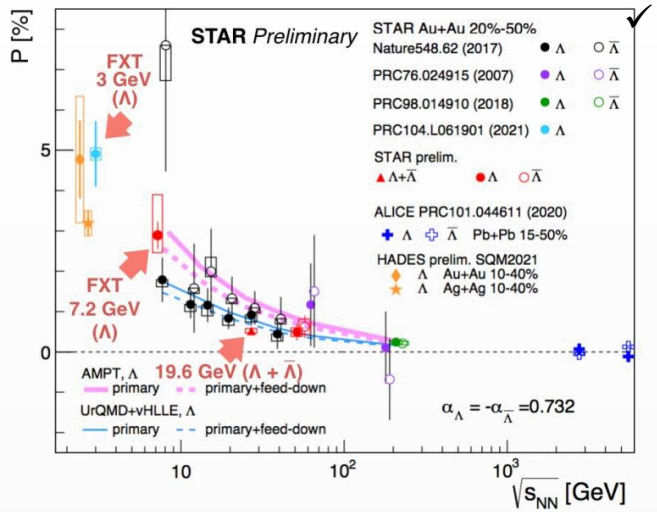
P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592

Both STAR and BM@N results for directed flow prefer stiff EOS

Hyperon global polarization

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





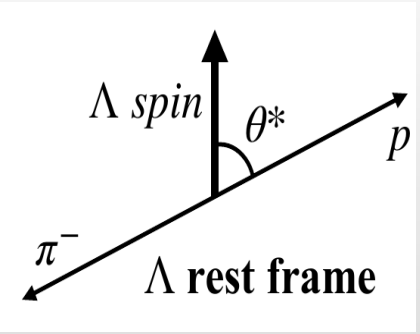
reproduced by AMPT, 3FD, UrQMD+vHLLE

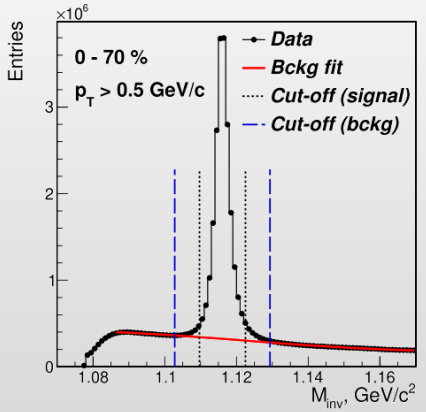
$$P_\Lambda = \frac{8}{\pi \alpha_\Lambda} \frac{\langle \sin(\Psi_1 - \phi_p^*) \rangle}{\mathrm{Res}(\Psi_1)}$$

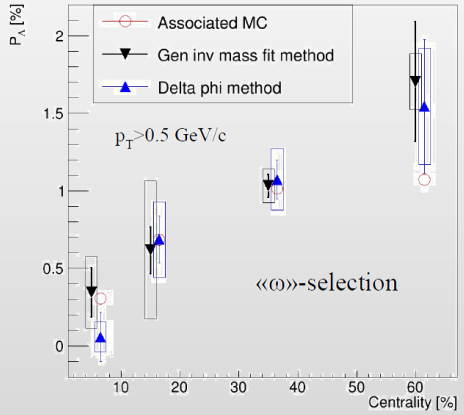
NICA: <u>extra points in the energy range 2-11 GeV</u> centrality, p_T and rapidity dependence of polarization, not only for Λ, but other (anti)hyperons (Λ, Σ, Ξ)

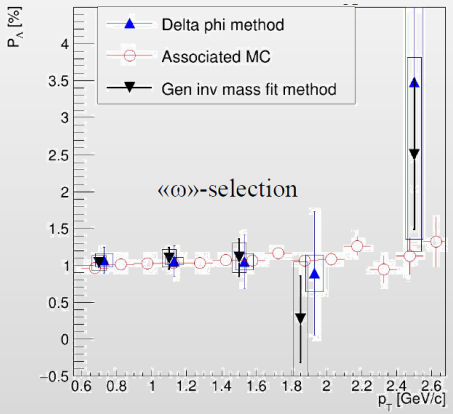
- MPD performance: BiBi@9.2 GeV (PHSD, 15 M events) → full reconstruction → Λ global polarization

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









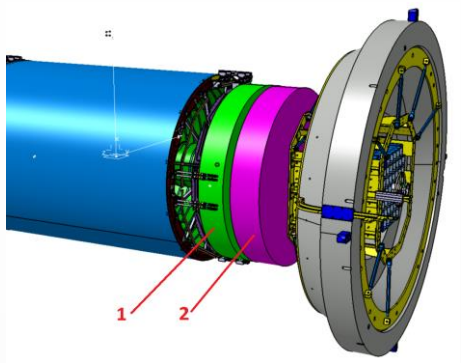
MPD: first global polarization measurements for Λ/$\bar{\Lambda}$ will be possible with ~ 20M data sampled events

Summary

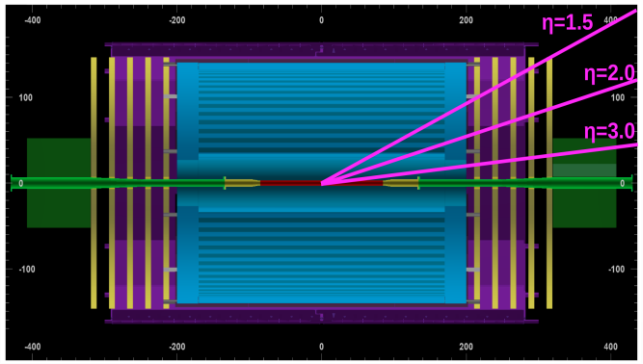


- MPD commissioning in the end of 2026 remains the main priority
- Extensive program of physics feasibility studies for MPD-CLD and MPD-FXT
- Prepare software and analysis infrastructure for real data analysis

Development of the Forward Spectrometers for MPD

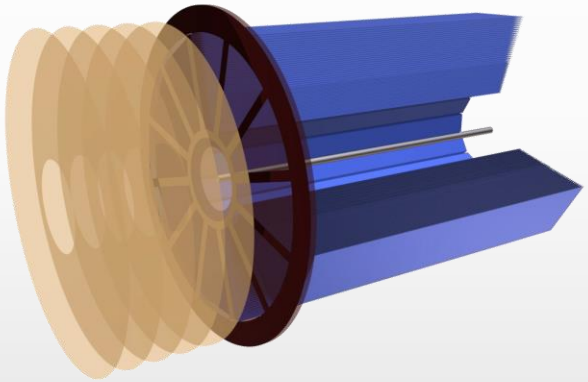


Two volumes available for the installation of forward tracker stations



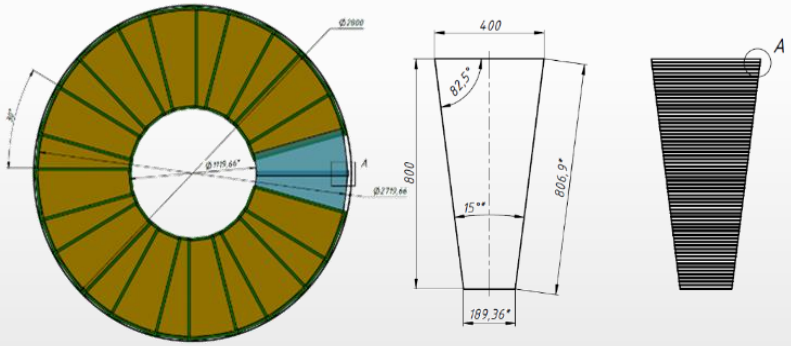
Pseudorapidity coverage of the forward spectrometer

Conception of the Forward Tracker (FTD)



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

Conception of the end-cup TOF detector



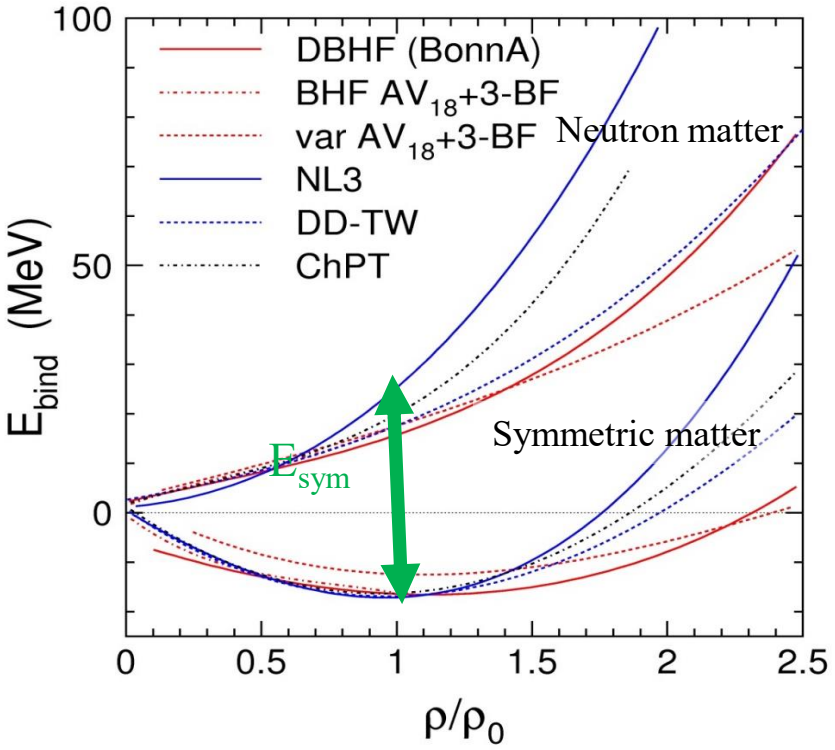
- ✓ a layer of MRPC-based TOF detectors, δτ ~ 50-70 ps

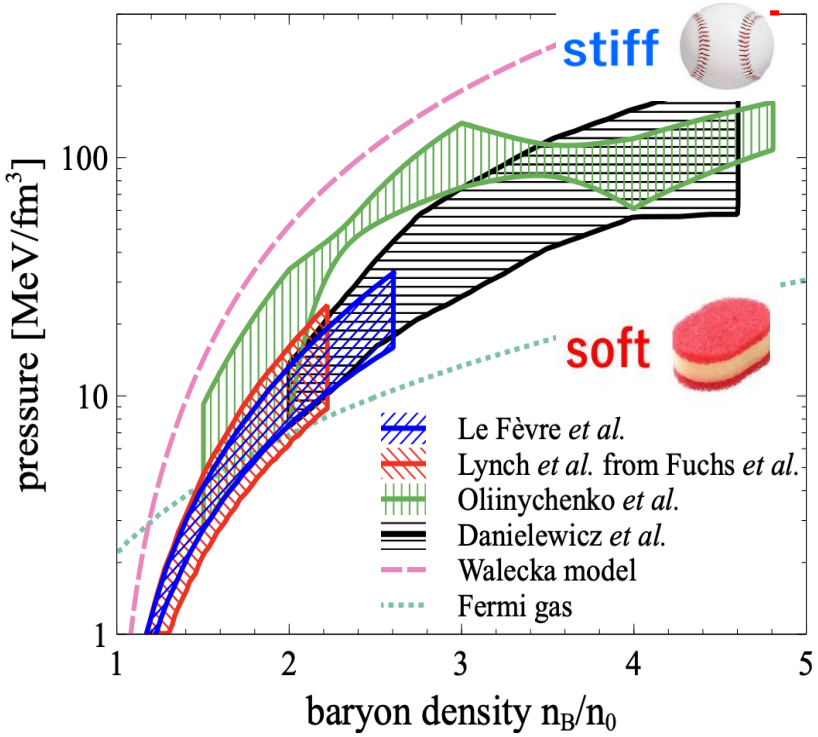
Equation of state (EoS) for high baryon density matter

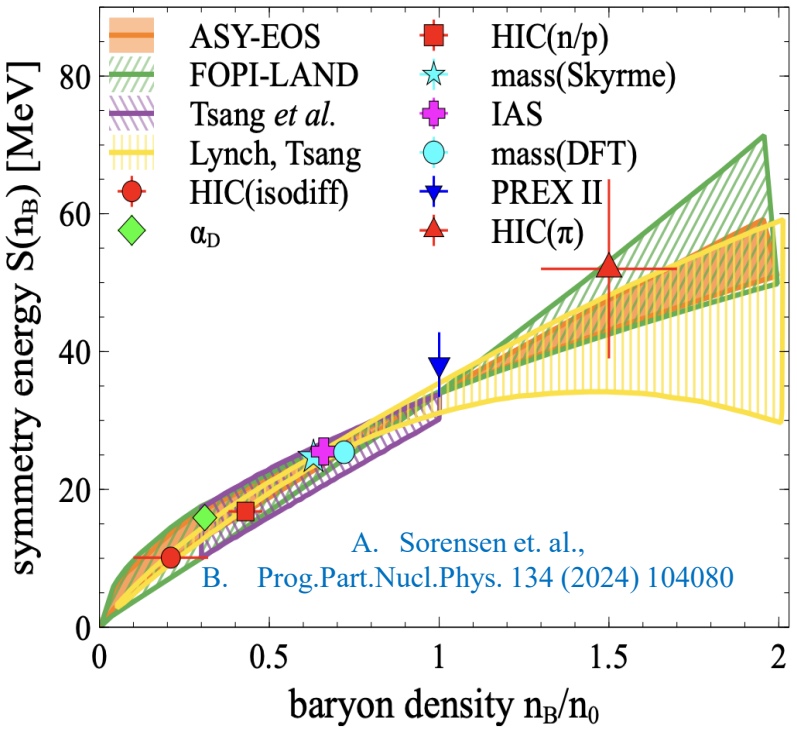
pressure $P = n^2 \frac{\mathrm{d}(E/A)}{\mathrm{d}n_b}$ *energy per nucleon* $\frac{E}{A} = m_N + E_A(n_\mathrm{B}) + E_\mathrm{sym}(n_\mathrm{B}) \frac{(n_p - n_n)^2}{n_\mathrm{B}^2}$ isospin asymmetry

$n_\mathrm{B} = n_p + n_n$

Symmetric matter **Symmetry energy**



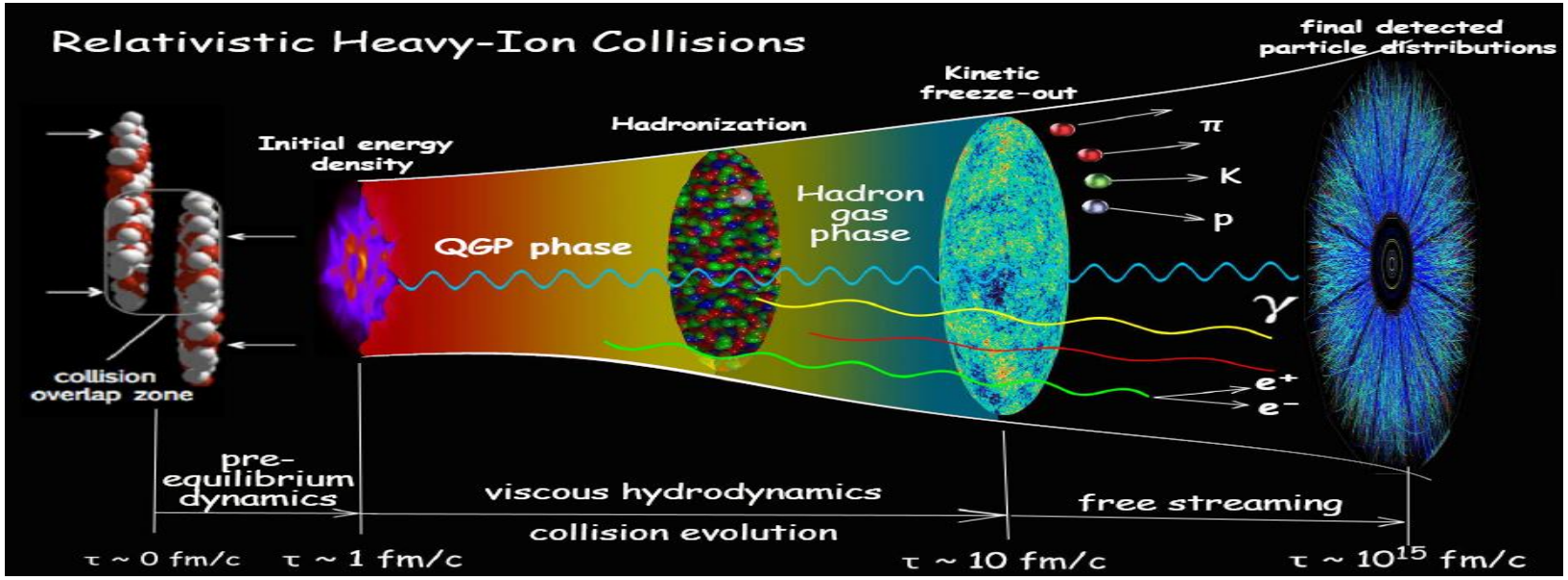


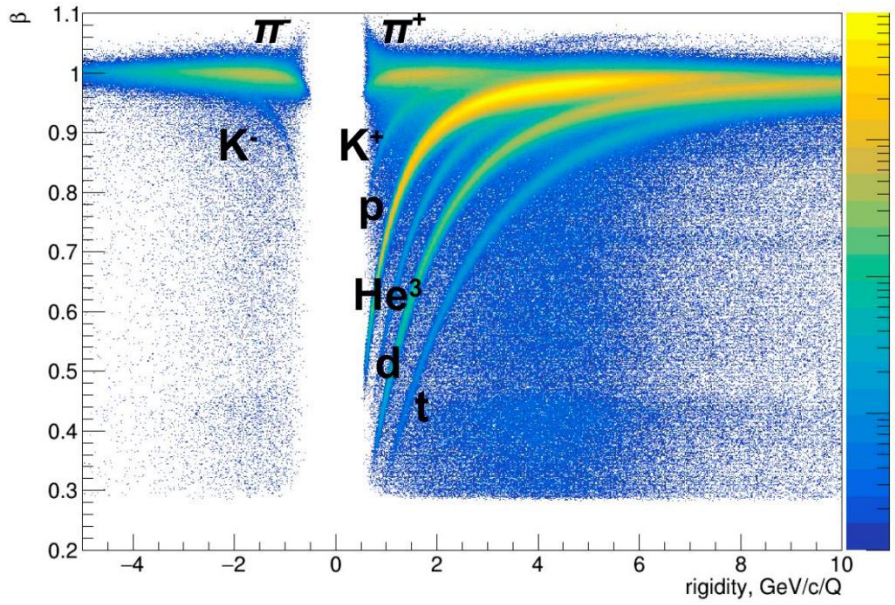


EOS describes the relation between density (n_B), pressure (P), temperature (T), energy (E), and isospin asymmetry (n_p-n_n)/n_B

HADRON → QGP

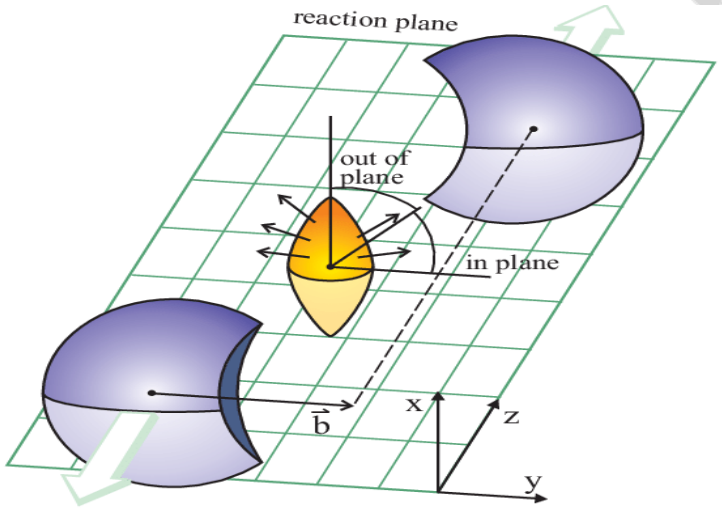
~1980	~1990	~2000	~2005	~2010
Bevalac	AGS	SPS	RHIC	LHC
~1 GeV	~5 GeV	~20 GeV	~100 GeV	~5000 GeV





~200+200 nucleons in 10^{-22} seconds = 1000-30000 hadrons

Relativistic heavy-ion collisions provide a unique and controlled experimental way to study the properties of nuclear matter at high temperature and/or baryon density.

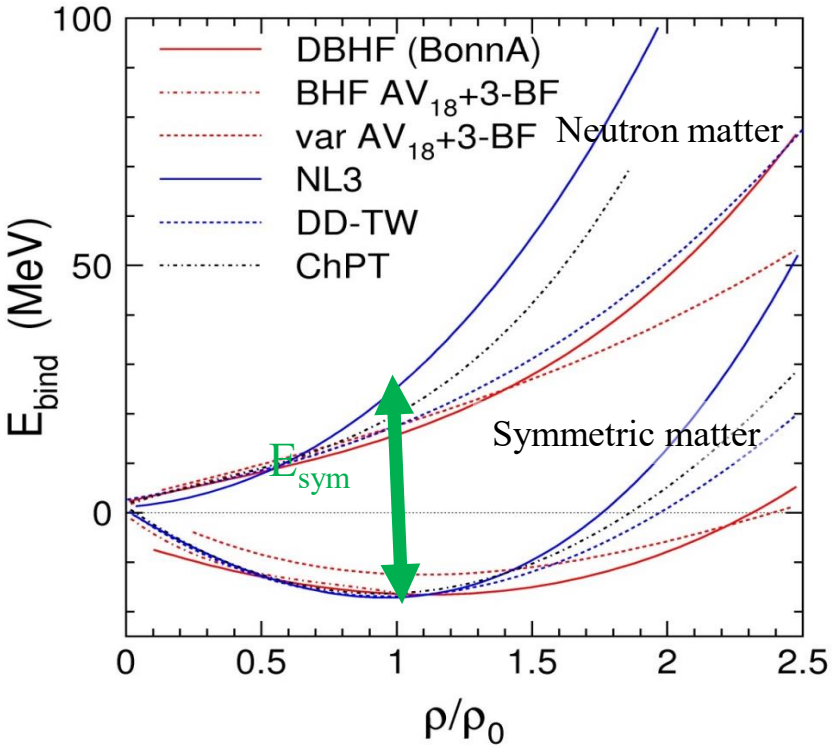


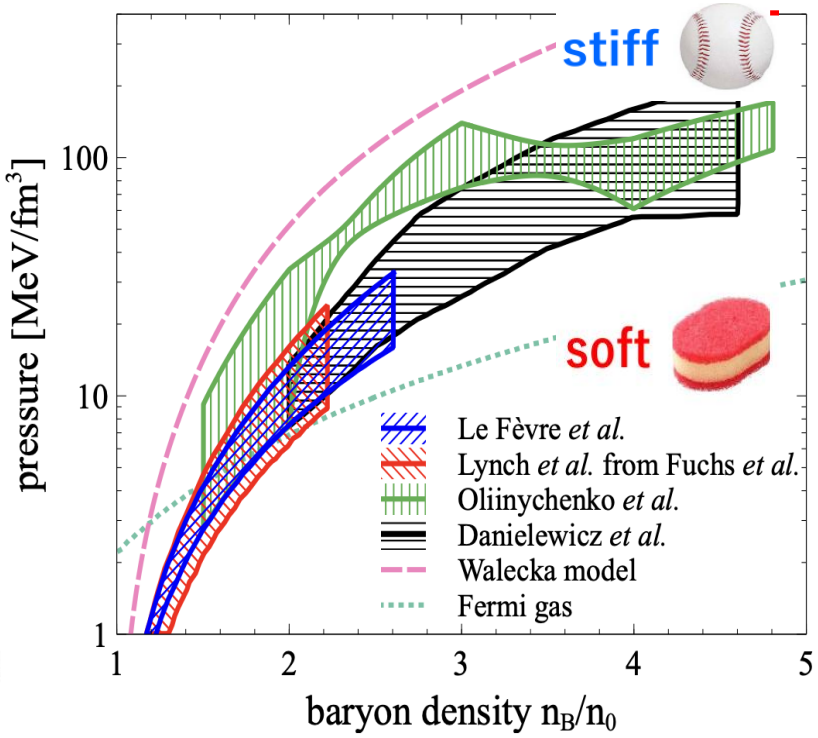
Equation of state (EoS) for high baryon density matter

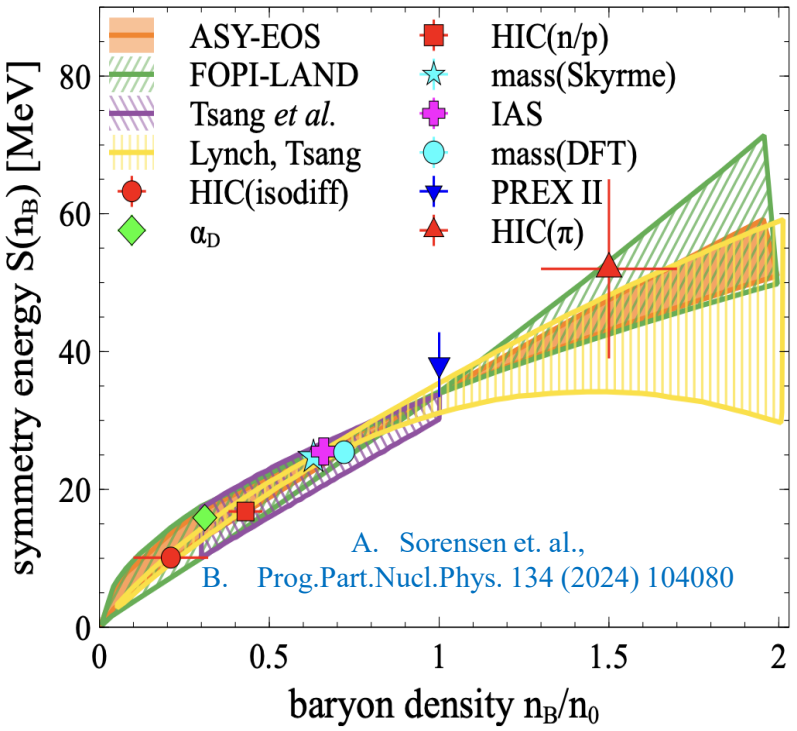
pressure ← $P = n^2 \frac{\mathrm{d}(E/A)}{\mathrm{d}n_b}$; *energy per nucleon* → $\frac{E}{A} = m_N + E_A(n_\mathrm{B}) + E_\mathrm{sym}(n_\mathrm{B}) \frac{(n_p - n_n)^2}{n_\mathrm{B}^2}$ ← isospin asymmetry

$n_\mathrm{B} = n_p + n_n$

Symmetric matter **Symmetry energy**

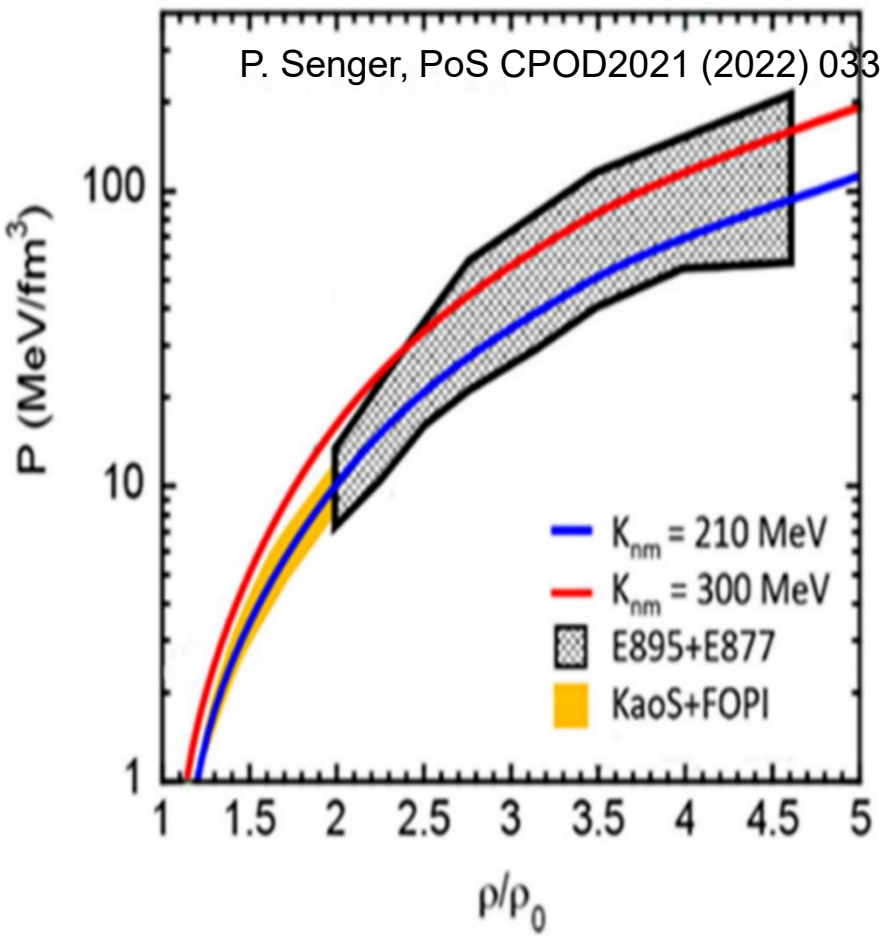


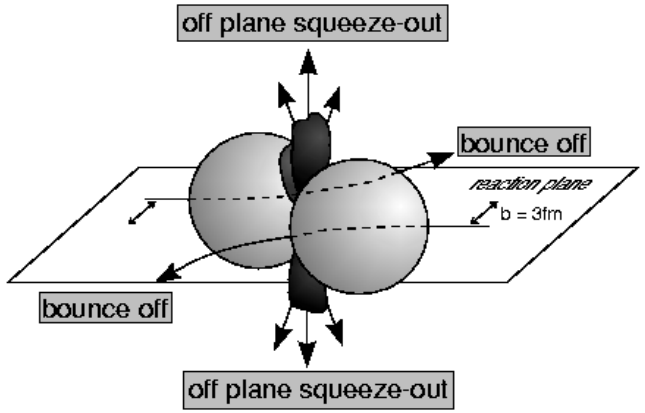


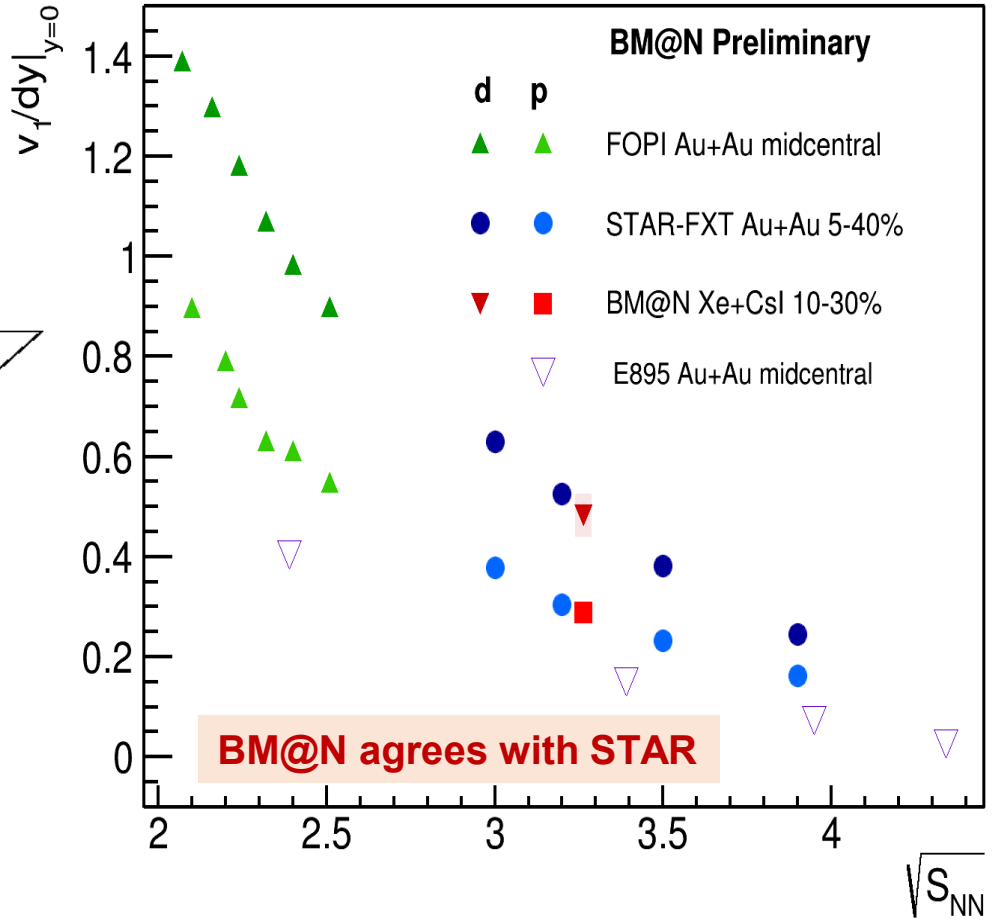


EOS describes the relation between density (n_B), pressure (P), temperature (T), energy (E), and isospin asymmetry (n_p-n_n)/n_B

Directed flow of protons and EOS of symmetric matter





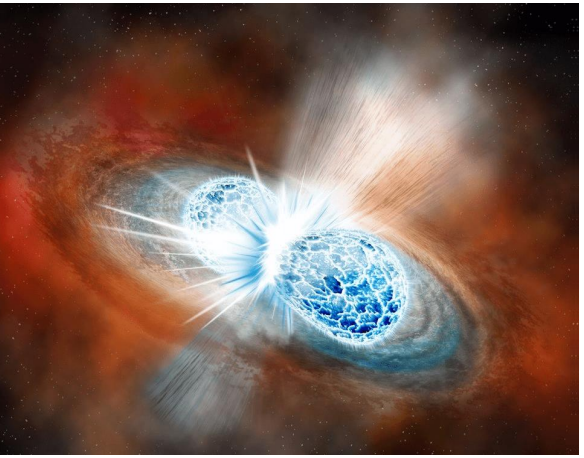


Nuclear incompressibility from collective proton flow

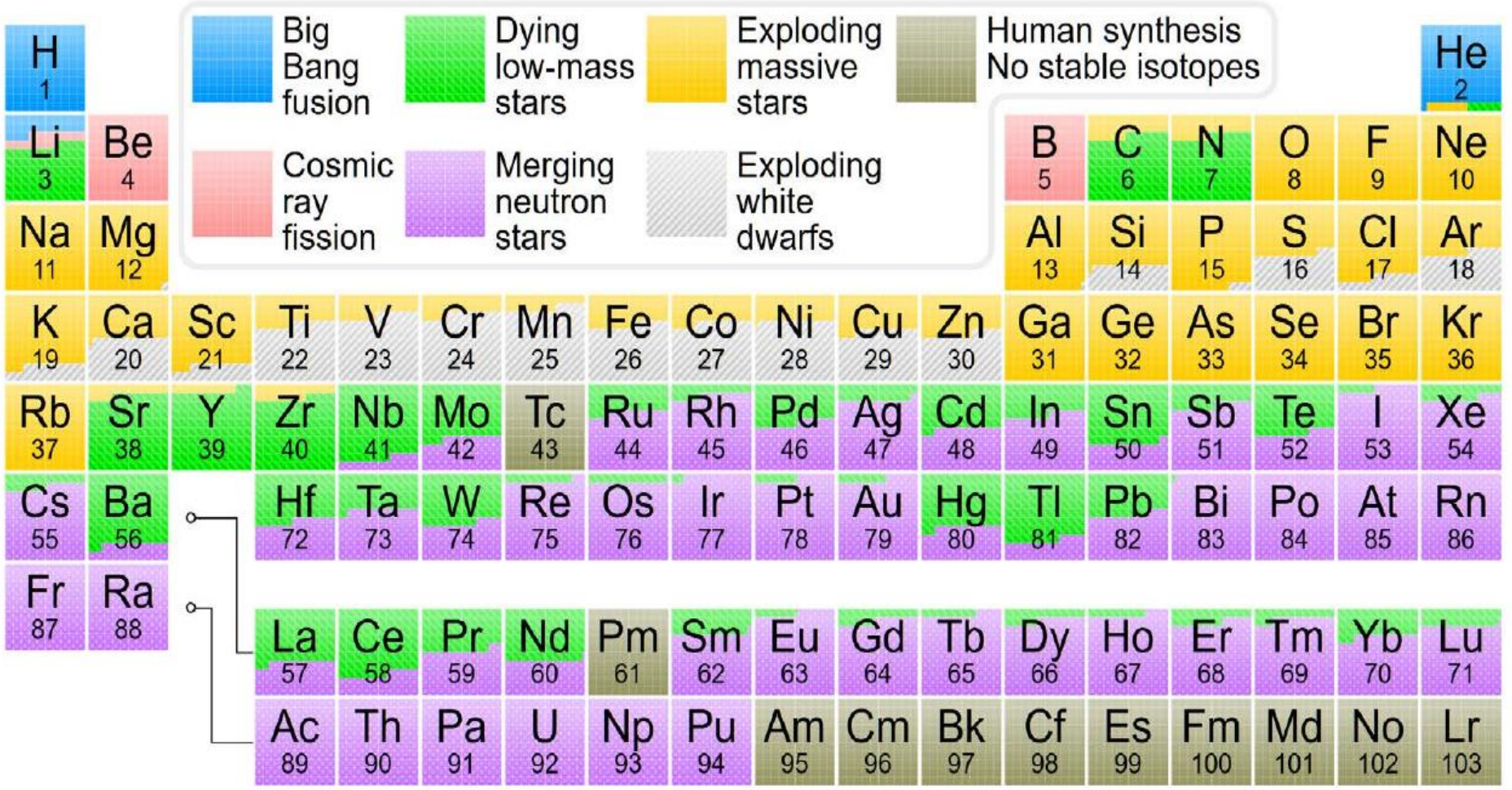
P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592

Both STAR and BM@N results for directed flow prefer stiff EOS

Nuclear EoS is important also for the r-process nuclear synthesis in neutron star merger



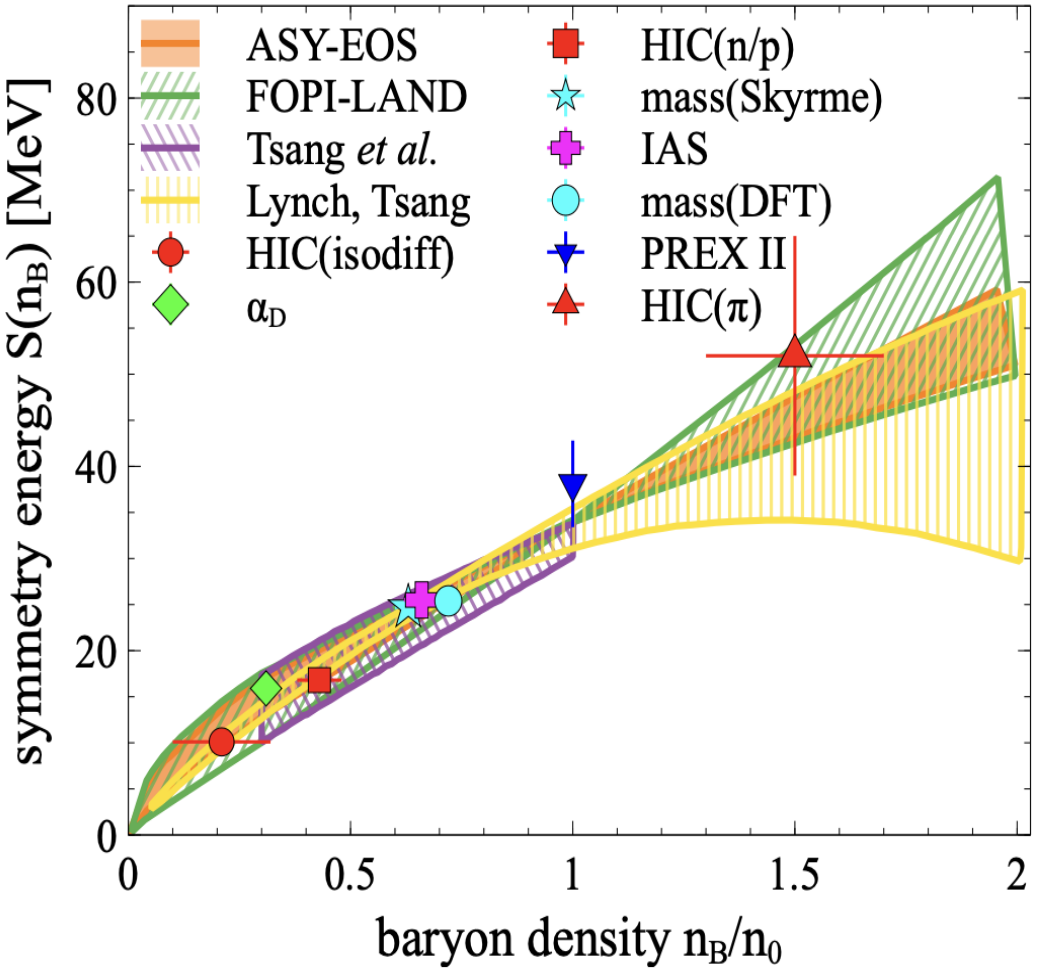




r-process - source of heavy elements including gold, platinum, and uranium.

Observables to study symmetry energy (EoS)

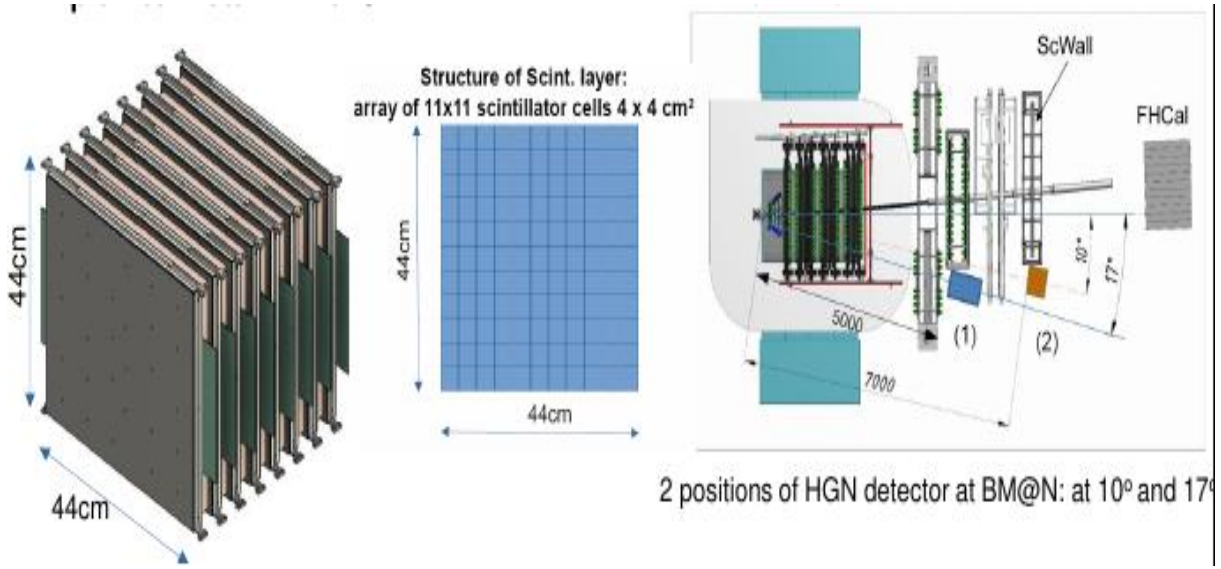
A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080



Nuclotron-NICA density region: $2 < n_B/n_0 < 8$

Symmetry energy E_{sym} has strong density dependence

BM@N Neutron Detector (2026-)

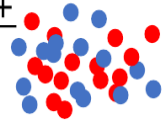


The Highly-Granular time-of-flight Neutron Detector for the BM@N experiment, Nucl. Instrum. Meth. A 1072 (2025) 170152

Stiff symmetry energy (large L)

→ lower ρ_n/ρ_p in higher dense region

→ lower n/p, lower π^-/π^+



Soft symmetry energy (small L)

→ larger ρ_n/ρ_p in higher dense region

→ larger n/p, higher π^-/π^+

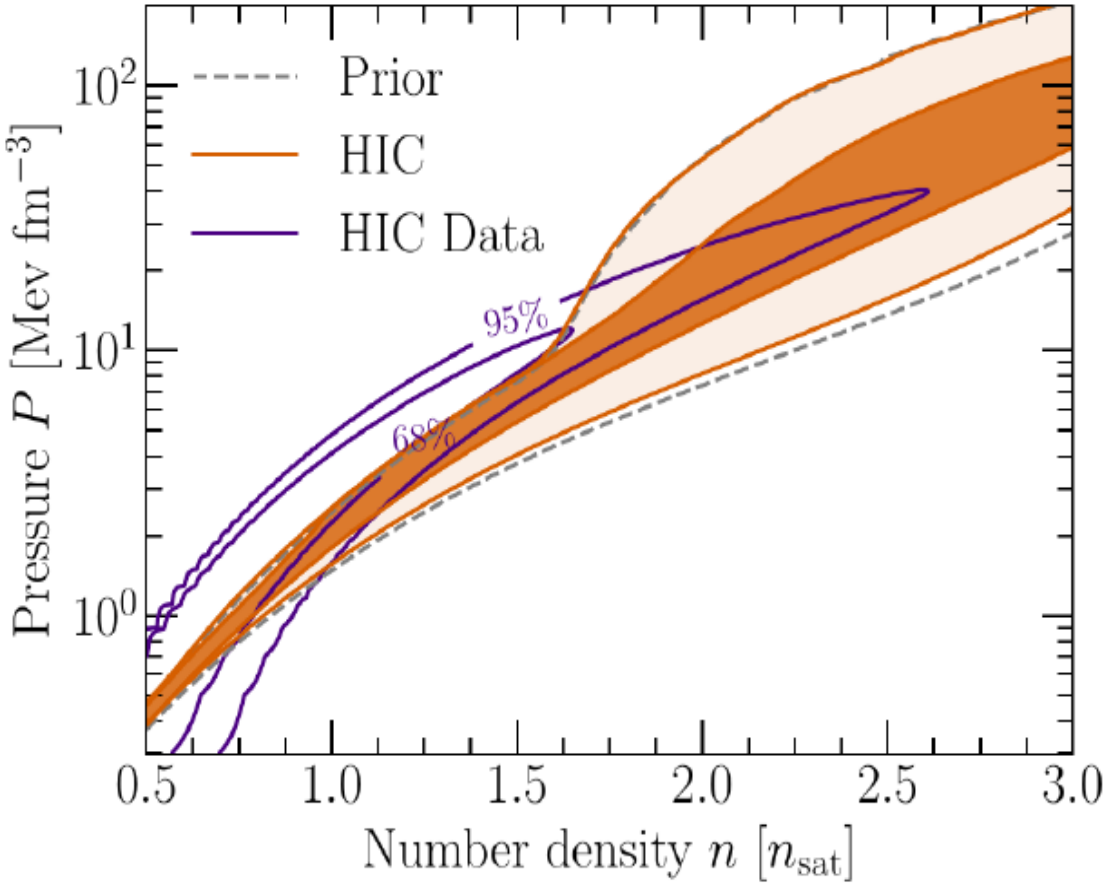


Constraining neutron-star matter with microscopic and macroscopic collisions

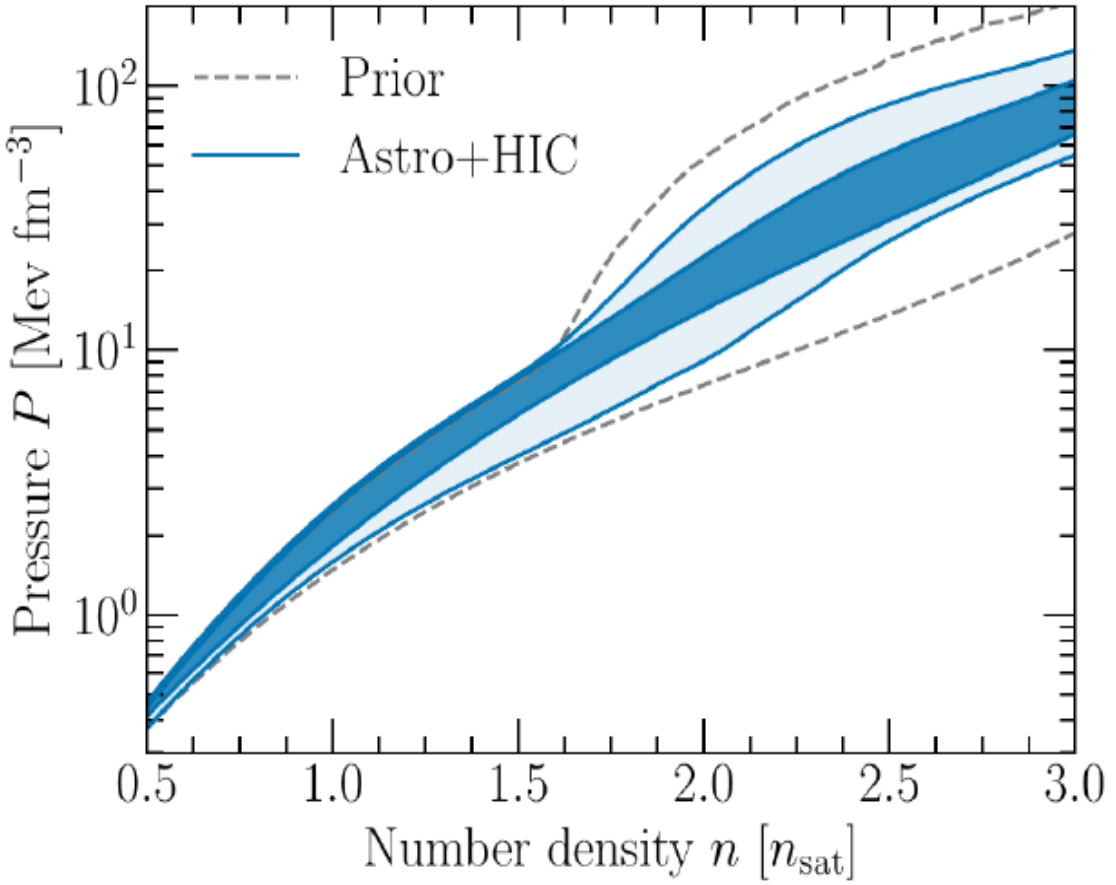
Huth, Pang et al. Nature 606(22)276

HIC experiments:

Bayesian combinations



HIC and Astro combined:



Astrophysical observations narrow constraints above 2 n_{sat}

Conclusion and outlook:

Relativistic Heavy-ion collisions at Nuclotron-NICA provide a unique and controlled experimental way to study the properties of nuclear matter at high baryon density.

Physics at High Baryon Density

- Critical point and phase boundary;
- Nuclear matter EOS at high baryon density;
- Y-N interactions, inner structure of compact stars.

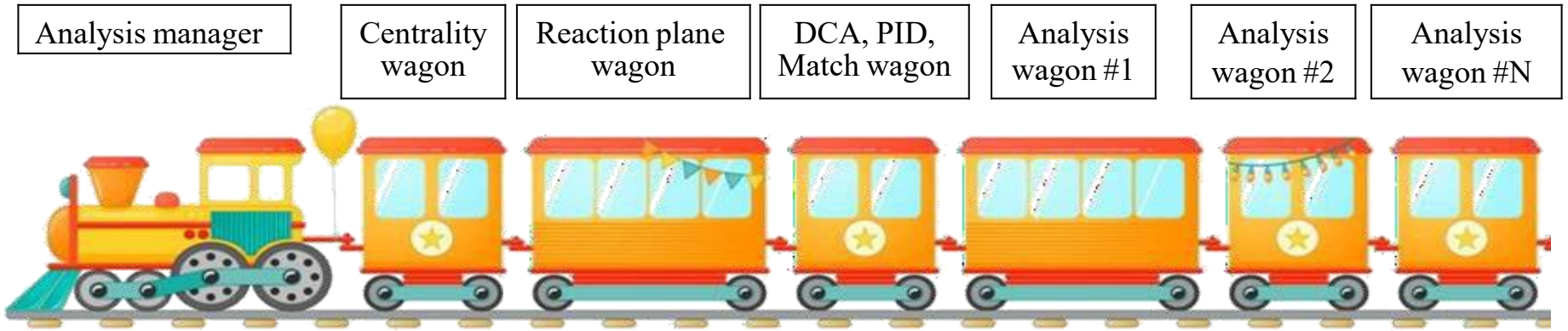


Twelve young scientists and Ph.D. students from JINR member states are doing physics analyses at BM@N preparing their theses.

Backup slides

Handling the big data sets

- Centralized Analysis Framework for access and analysis of data:
  - ✓ consistent approaches and results across collaboration, easier storage and sharing of codes and methods
  - ✓ reduced number of input/output operations for disks and databases, easier data storage on tapes
- Analysis manager reads event into memory and calls wagons one-by-one to modify and/or analyze data:



- 12 productions of physical analysis of simulated data already done.

- Example:
- Wagon #1 – event selector – selects events to be analyzed
- Wagon #2 – centrality analyzer – returns values of centrality for all other wagons in the train
- Wagon #3 – recalibrator – redefines some DST variables that need recalibration after production
- ……
- Wagon #4, 5, … – physics analysis 1, 2, …

Relativistic Heavy-Ion Collisions and Quark Gluon Plasma (QGP)

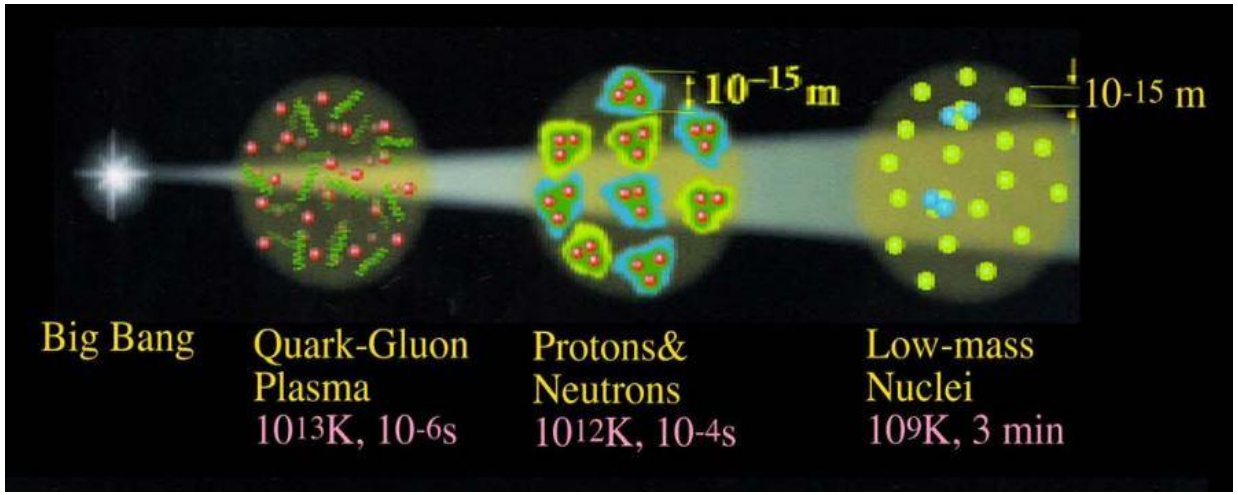


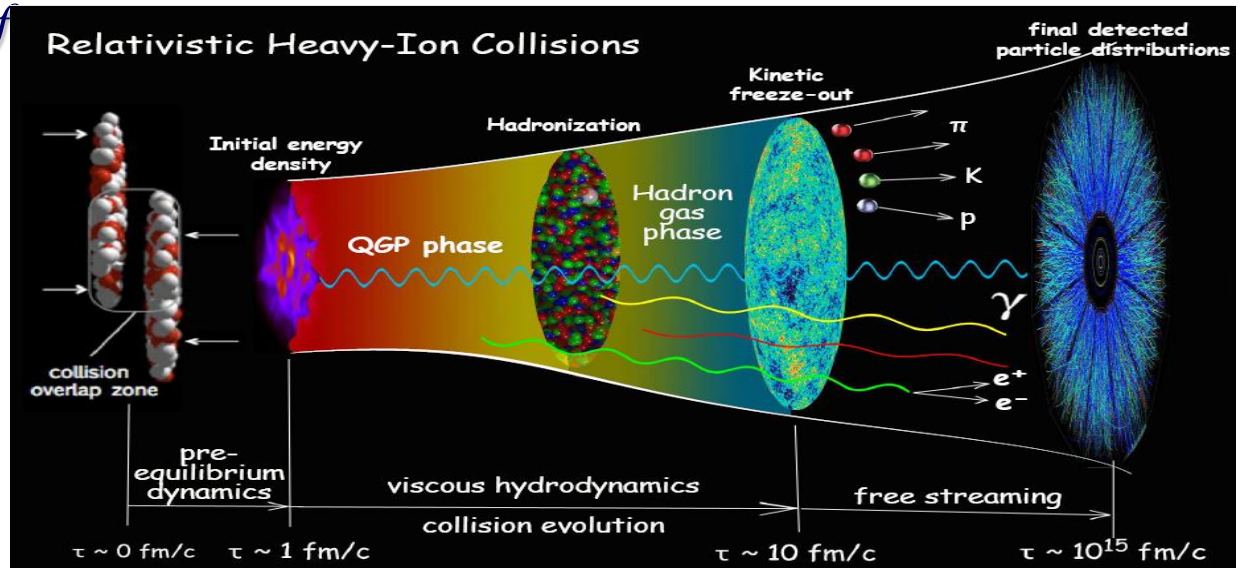
1

2. *It was present during the first few microseconds of the Big Bang.*

3. *It provides an example of phase transitions which may occur at a variety of higher temperature scales in the early universe.*

4. *It can provide important insights on the origin of mass for matter, and how quarks are confined into hadrons.*

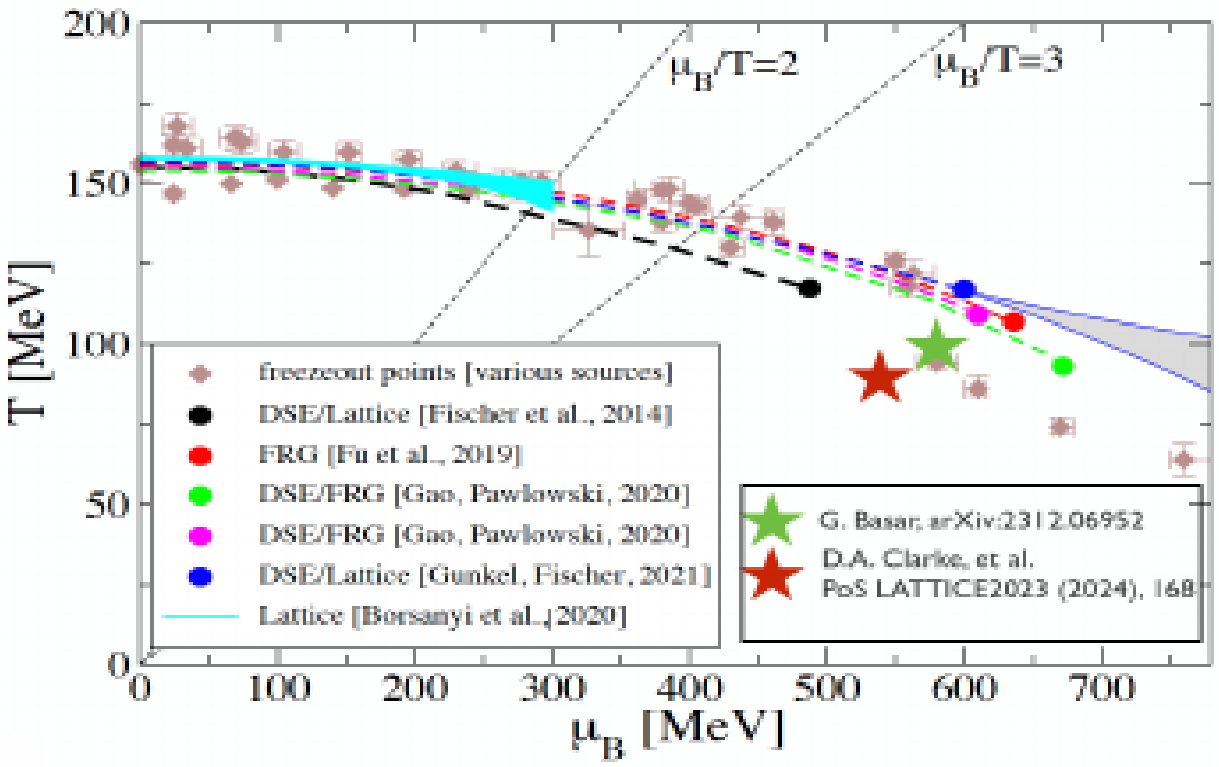




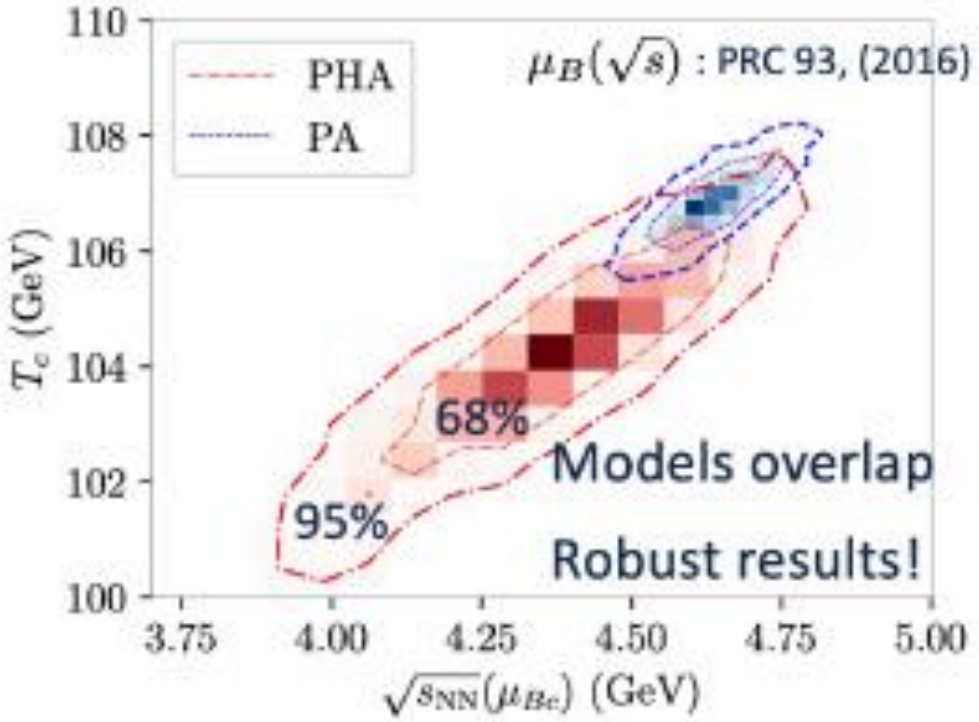
M. Gyulassy, Nucl. Phys. A750, 30-63, 2005

Temperature ~150-170 MeV ($2*10^{13}$ K)
and density ~1 GeV/fm^3 (10^{15} g/cm^3)

Location of the QCD Critical Point: Theoretical Estimation/Prediction



M. Hippert et al., Phys. Rev. D 110, 094006 (2024)



Method	μ_c (MeV)	T_c (MeV)
Holography + Bayesian	560 - 625	101 - 108
FRG/DSE	495 - 654	108 - 119
Lee-Yang edge singularities	500 - 600	100 - 105
Lattice QCD	$\mu_c/T_c > 3$	F. Karsch et al.
Summary	**495 - 654**	**100 - 119**

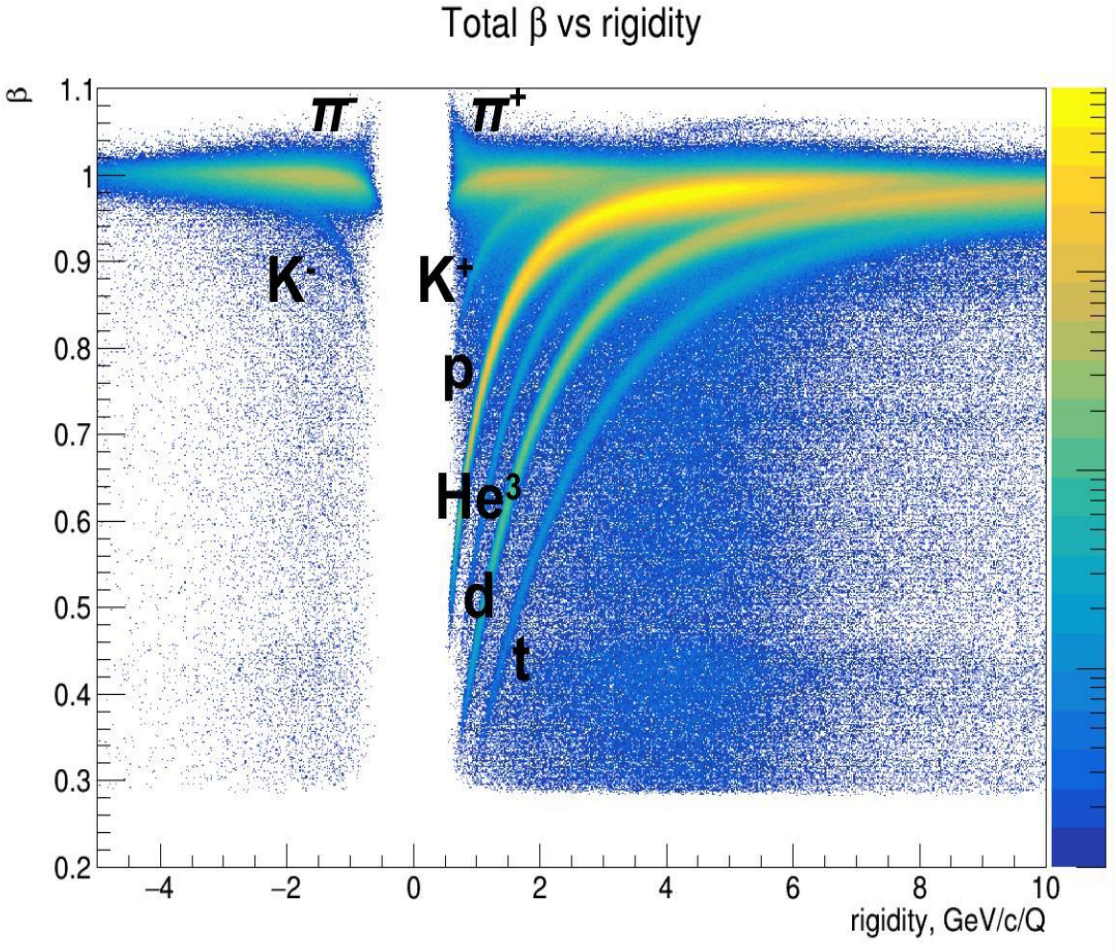
$(\mu_c, T_c) = (495 - 654, 100 - 119)$ MeV ➡ $3.5 < \sqrt{s_{NN}} < 4.9$ GeV

BM@N: $\sqrt{s_{NN}}$= 2.3 - 3.3 GeV

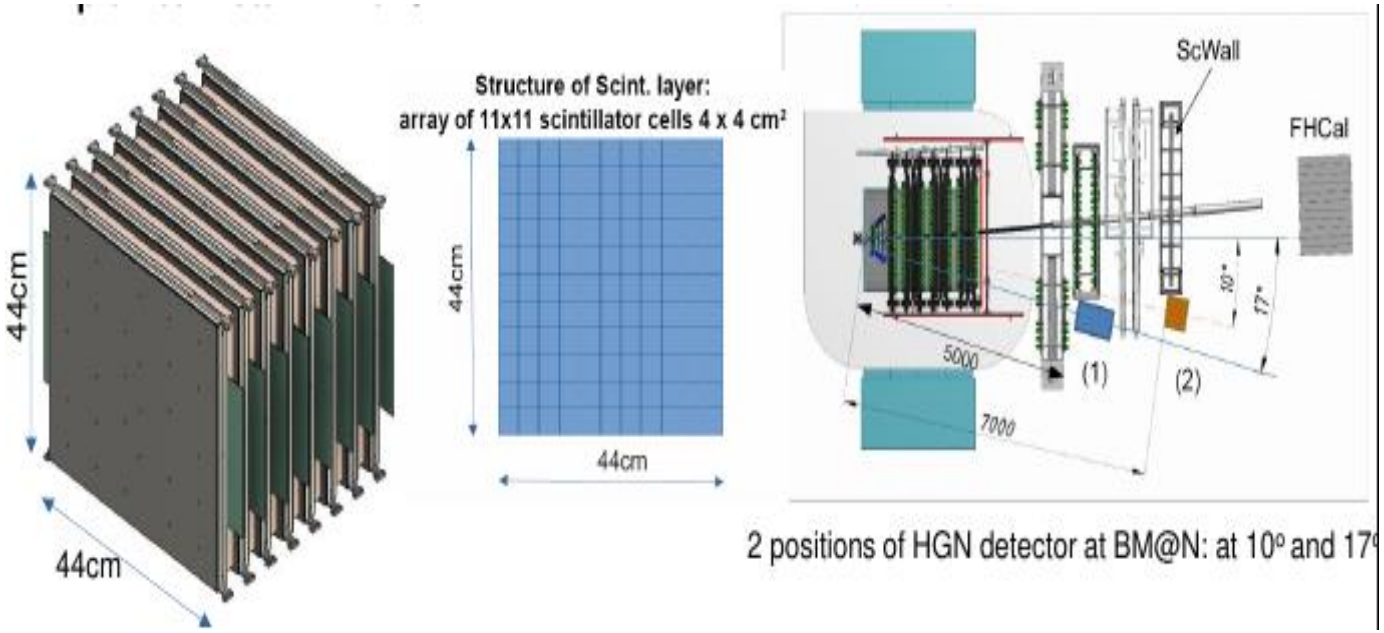
MPD: $\sqrt{s_{NN}}$= 4 - 11 GeV

BM@N and MPD are both in the collision energy range of the predicted CEP location.

BM@N: Observables to study symmetry energy



BM@N Neutron Detector



The Highly-Granular time-of-flight Neutron Detector for the BM@N experiment, Nucl. Instrum. Meth. A 1072 (2025) 170152

Nuclear Matter Equation of State

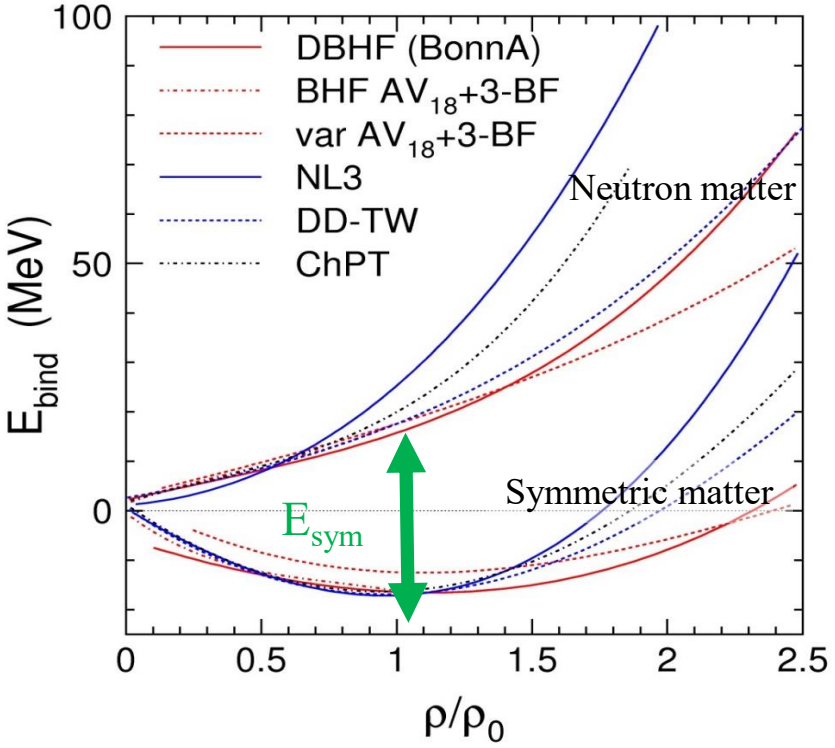
$E(N_p,N_n)$ Energy of the system of A nucleons (N_p, N_n=A-N_p) $\mathcal{E}$ - energy density

The binding energy per nucleon: $$E_{\rm bind}(n_p,n_n) = \frac{E}{A} - m_N = \frac{\mathcal{E}}{n} - m_N = E_A(n_b) + E_{\rm sym}(n_b)\frac{(n_p-n_n)^2}{n_b^2}$$

isospin asymmetry

symmetric matter

symmetry energy



Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5

- Being extensively studied nowadays using observables (flow, meson yields, etc.) to explore compressibility
- $$K_0 = 9n_0^2\frac{{\rm d}^2E_A}{{\rm d}n^2}\Big|_{n_0}$$
- One of the main sources of uncertainty: discrepancy between experimental data

- One of the main parameters to study is the E_{sym} slope

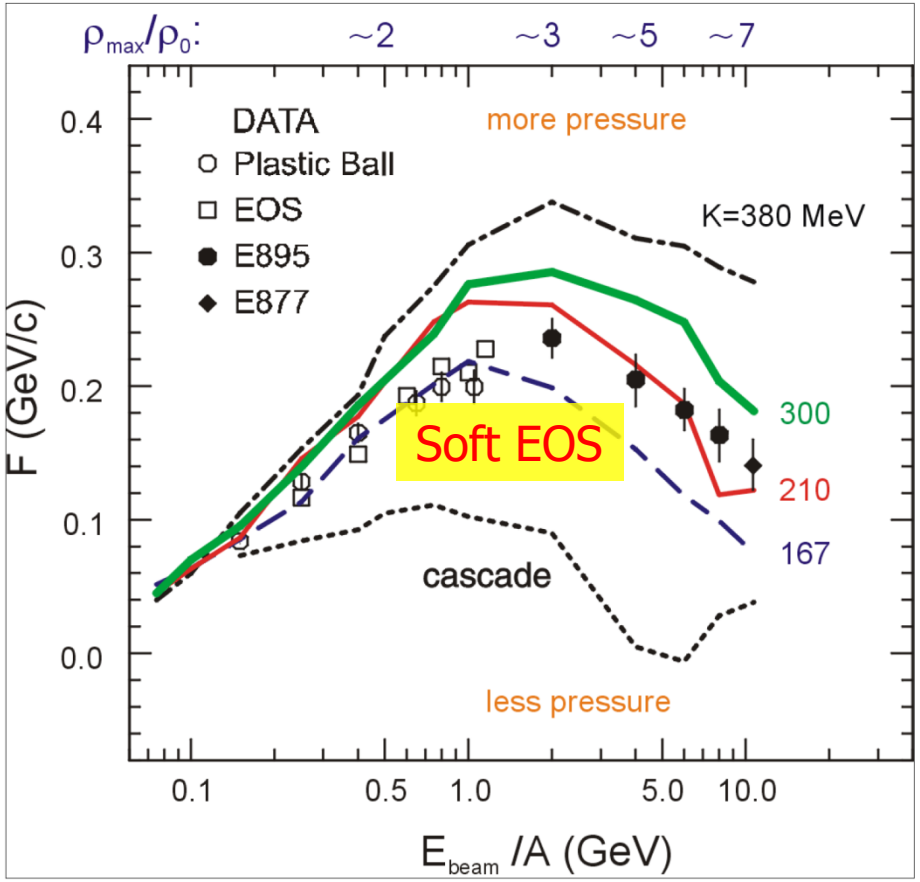
$$L = 3n_0\frac{{\rm d}E_{\rm sym}}{{\rm d}n}\Big|_{n_0}$$

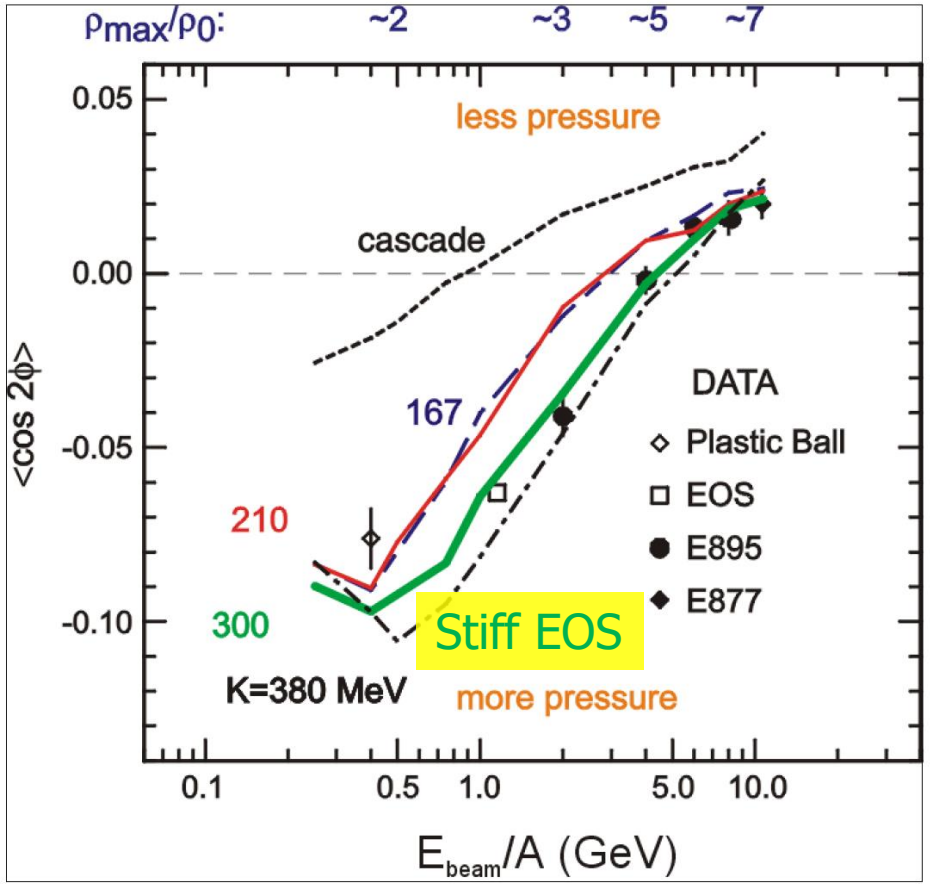
- No experimental data for beam energies $E_{kin} > 0.4$ GeV
- One needs to establish observables sensitive to ***L*** and obtain new experimental data

New data is needed to further constrain transport models with hadronic d.o.f.

Nuclear incompressibility from collective proton flow

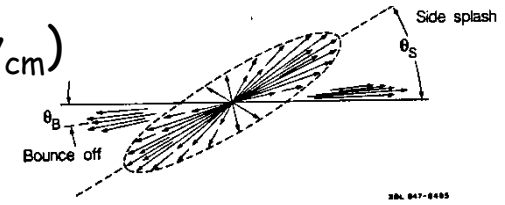
P. Danielewicz, R. Lacey, W.G. Lynch, Science 298 (2002) 1592



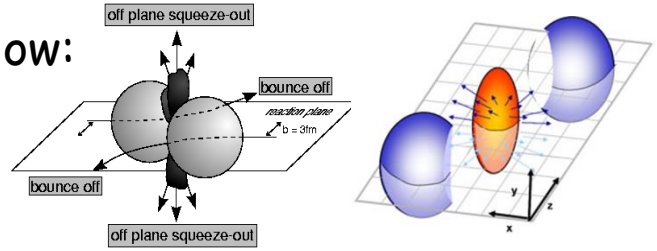


Transverse in-plane flow:

$F = d(p_x/A)/d(y/y_{cm})$



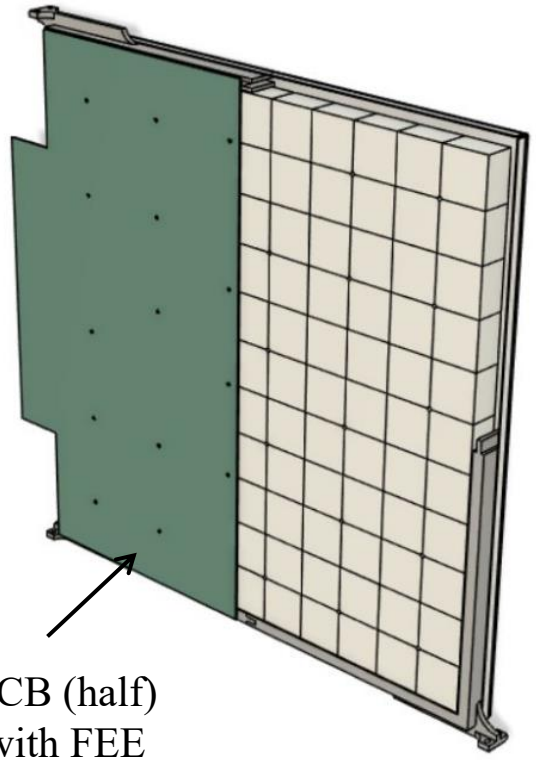
Elliptic flow:



$dN/d\Phi \propto (1 + 2v_1 \cos\Phi + 2v_2 \cos 2\Phi)$

Mechanical design

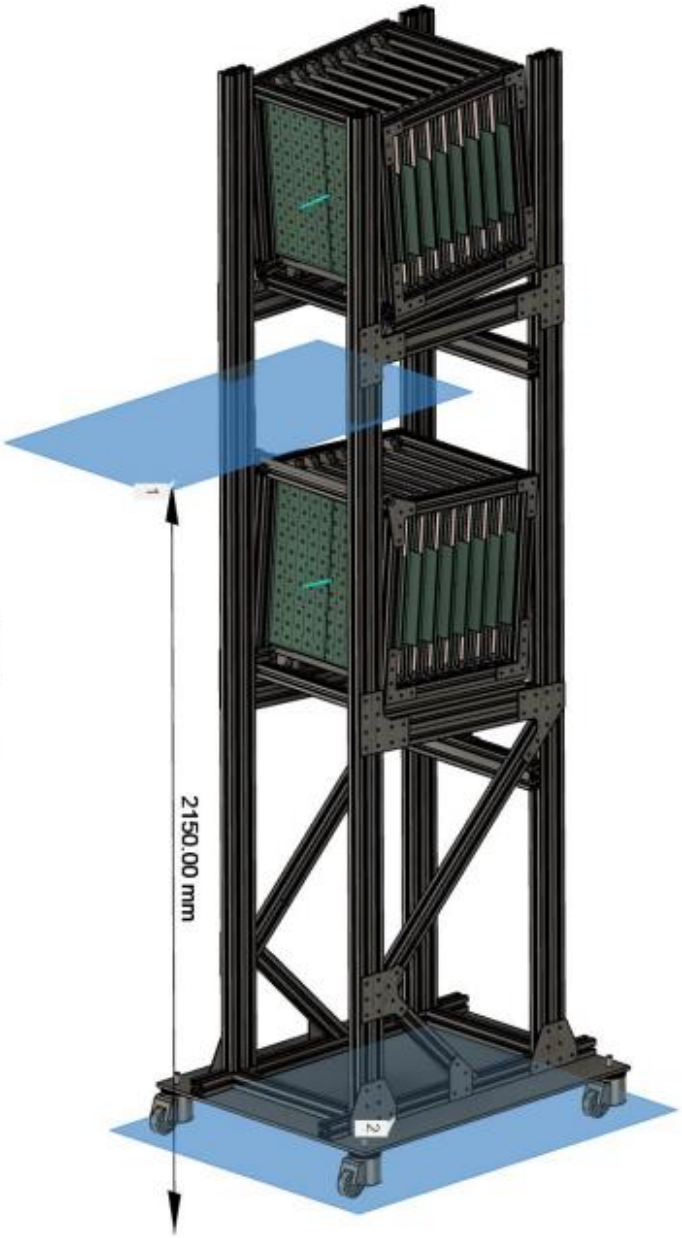
F. Guber, et al., Instrum. Exp. Tech. №3 (2024)



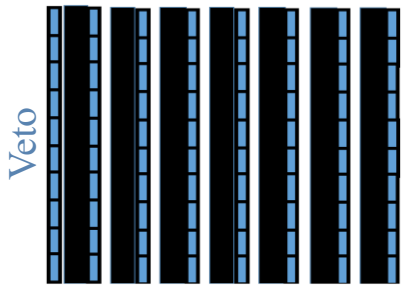
PCB (half)
with FEE

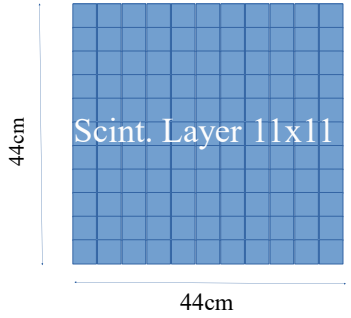
Light-tight and air-cooled assembly

- 1 veto-layer
- 7 Cu absorber layers (3 cm thick)
- 7 sensitive layers:
  - 11x11 matrix of scintillator detectors 4x4x2.5 cm^3
  - surrounded from both sides by PCBs
    - upstream board: LEDs for time calibration
    - downstream board: SiPMs and FEE

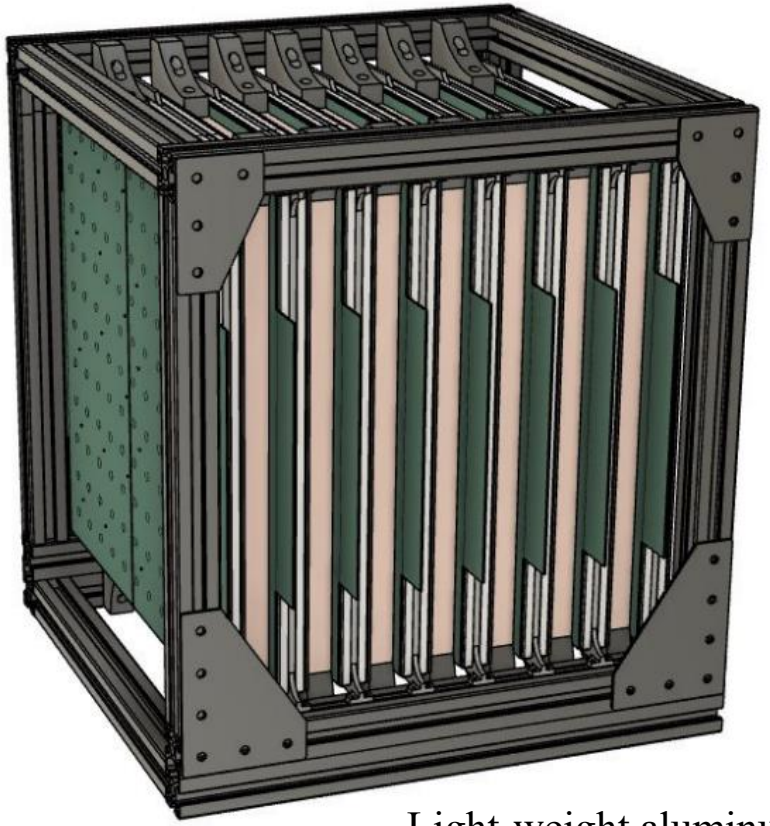


7 layers (Cu/Scint)





total length ~ 48cm (1.5 λ_{in})



Light-weight aluminum frame

EOS for high baryon density matter

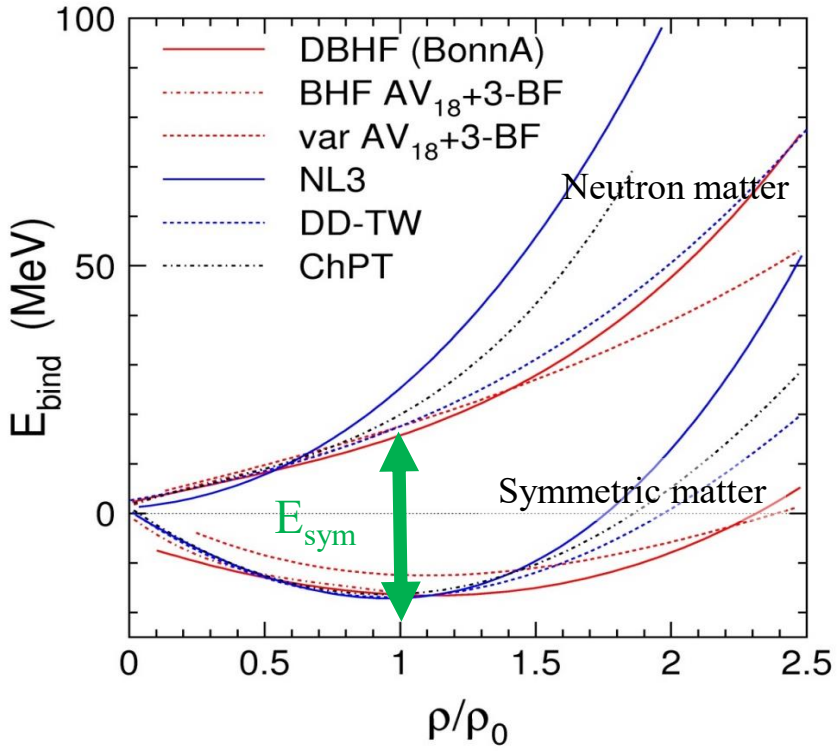
The binding energy per nucleon: $E_A(\rho,\delta) = E_A(\rho,0) + E_{sym}(\rho)\delta^2 + O(\delta^4)$

Isospin asymmetry:

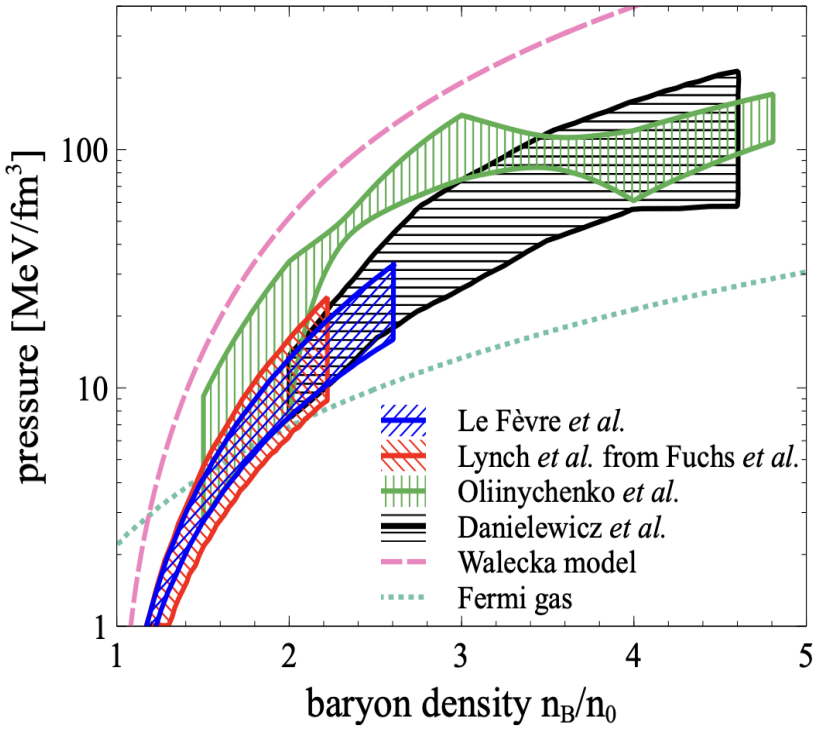
$\delta = (\rho_n - \rho_p)/\rho$

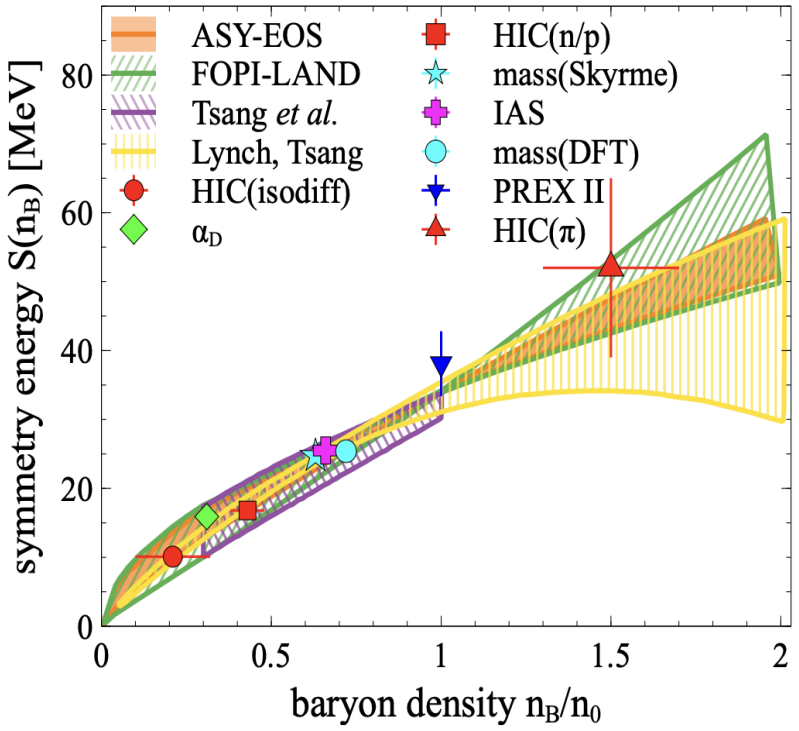
Symmetric matter

Symmetry energy



Ch. Fuchs and H.H. Wolter, EPJA 30 (2006) 5





A. Sorensen et. al., Prog.Part.Nucl.Phys. 134 (2024) 104080