The Multipurpose Detector at NICA:

Status and Physics Capabilities

Yaping Wang

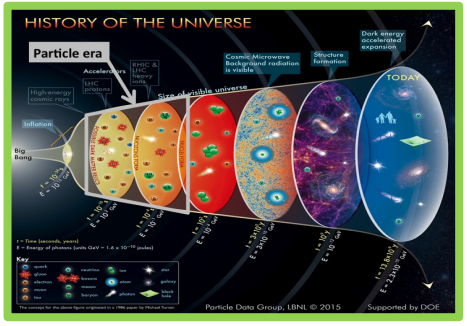
for the MPD Collaboration

Central China Normal University

Outline

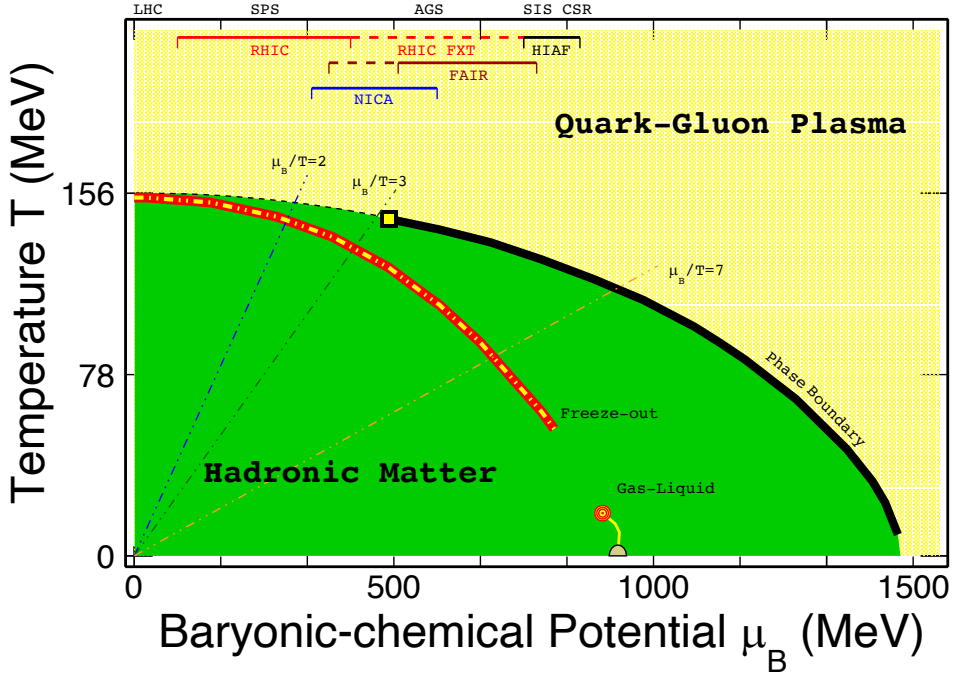
- Introduction
- MPD Status
- MPD Physics Capabilities
- Summary and Outlook

High-Energy Nuclear Collisions & QCD Phase Diagram



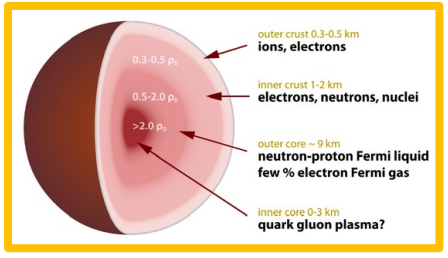
High temperature:
Early Universe evolution

LHC | RHIC BES | FAIR, NICA, …



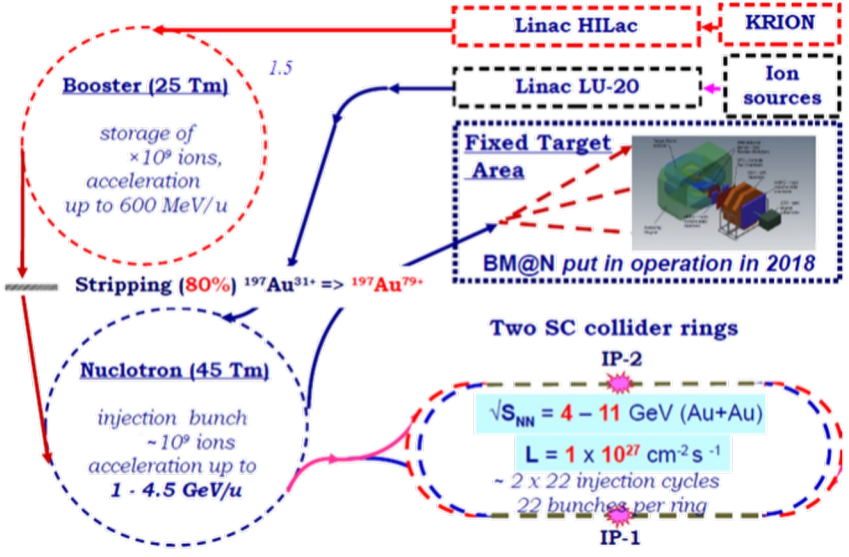
Ref.: N. Xu @sQM2022

High baryon density:
Inner structure of compact stars



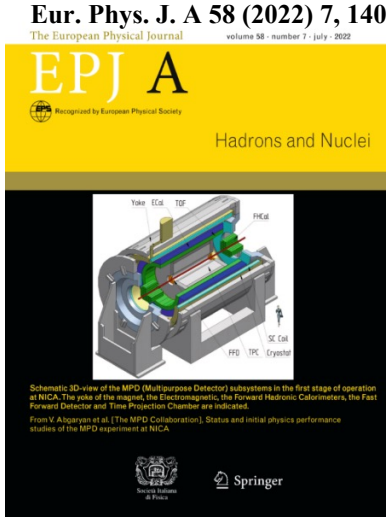
- At $\mu_B = 0$, smooth crossover (LGT + data)
- At large μ_B, 1st order phase transition → **QCD critical point**

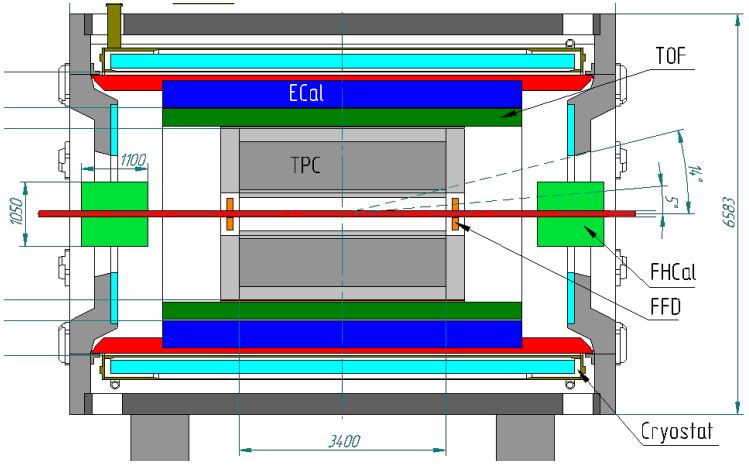
NICA Project

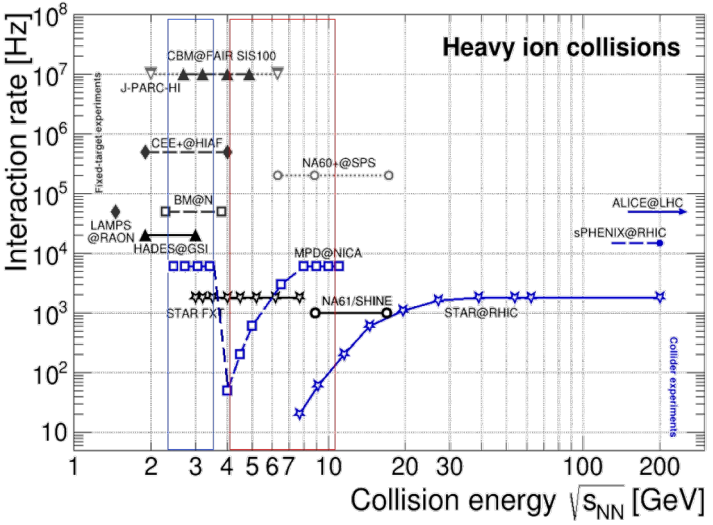


- The Nuclotron-based Ion Collider fAcility (NICA) is approaching its full commissioning:
  - ✓ Already running in the fixed-target mode – Baryonic Matter @ Nuclotron (**BM@N**)
  - ✓ Start of operation in collider mode in 2025 – Multipurpose Detector (**MPD**)
- Expected beam condition for the first year(s) :
  - ✓ First beams: Bi+Bi / Xe+Xe at $\sqrt{s_{NN}} \leq 7$ GeV@σ_z~50 cm (not-optimal beam optics)
  - ✓ Reduced luminosity (~10^{25} cm^{-2}s^{-1}) → collision rate ~ 50 Hz @ $\sqrt{s_{NN}} = 4$ GeV

MPD @ NICA





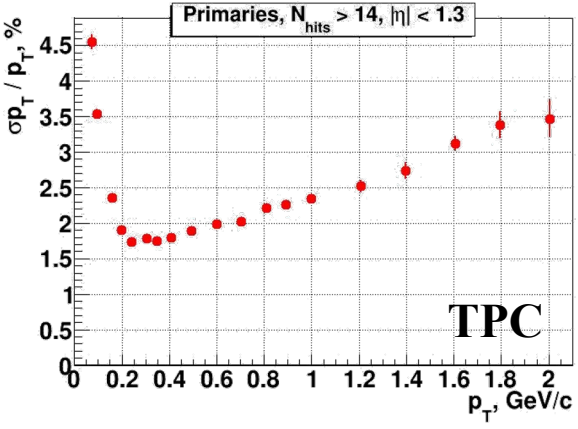


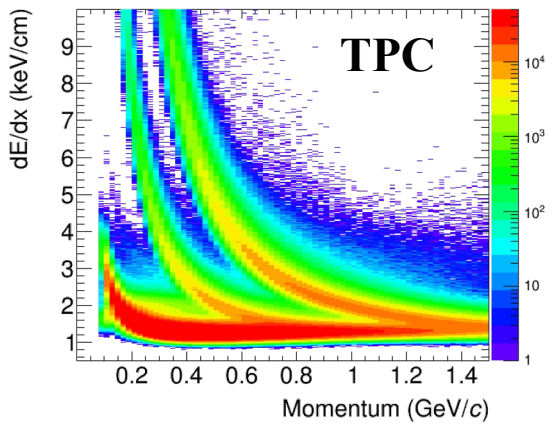
- Collider mode: Au+Au collisions at $\sqrt{s_{NN}}$ = 4–11 GeV
- Fixed-target mode: a beam + thin wire (~100 μm) close to edge of the MPD central barrel
  - ✓ extends energy range to $\sqrt{s_{NN}}$ = 2.4-3.5 GeV (overlap with HADES, RHIC BES and CBM)
  - ✓ backup start-up solution (too low luminosity, only one beam)
- Existing trigger system (FFD, FHCAL, TOF) provides high efficiency of event selection
- **Complementary of both target and collision energy to the CBM and STAR experiments**

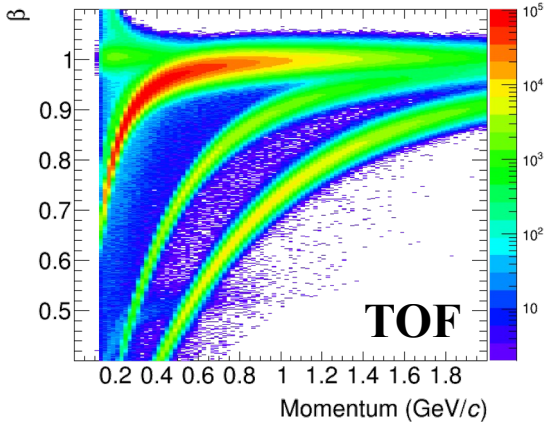
MPD Physics Goal

- The MPD enables a wide variety of physics measurements via high-luminosity scans in **energy** and **system size** with excellent PID and large acceptance
  - ✓ Order of phase transition and search for QCD critical point → **structure of QCD phase diagram**
  - ✓ Hypernuclei and equation of state at high baryon densities → **inner structure of compact stars**

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

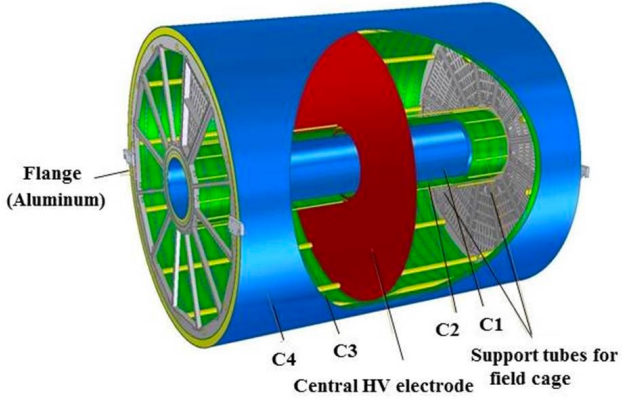


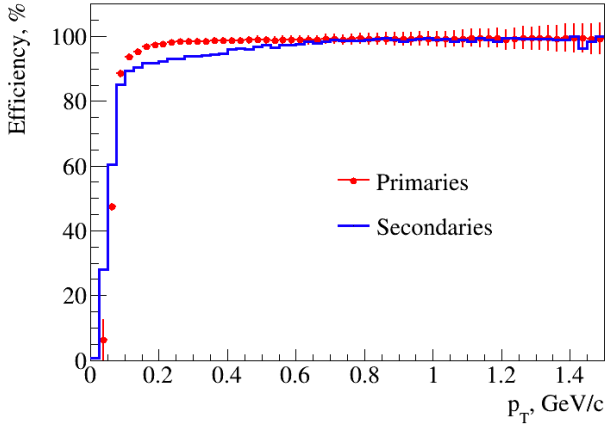


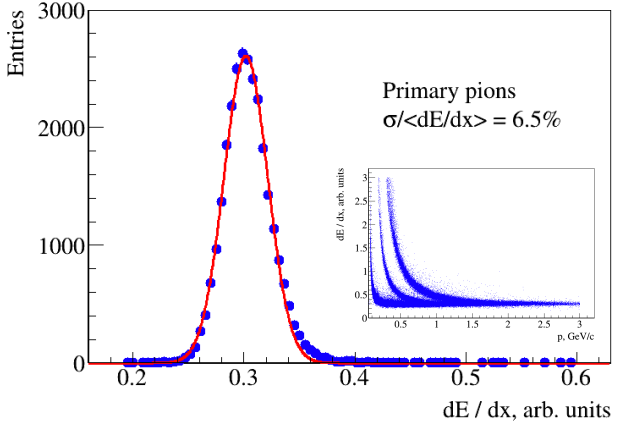


Au+Au @ 11 GeV (UrQMD + full chain reconstruction)

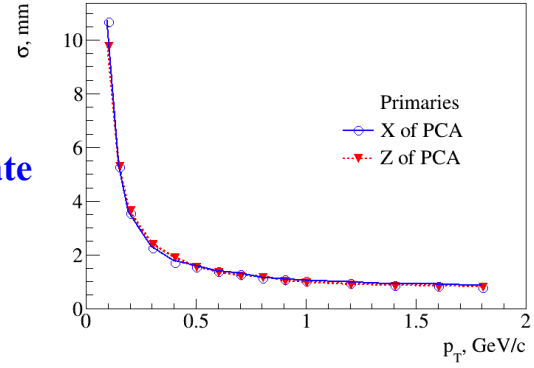
MPD Status – Time Projection Chamber (TPC)





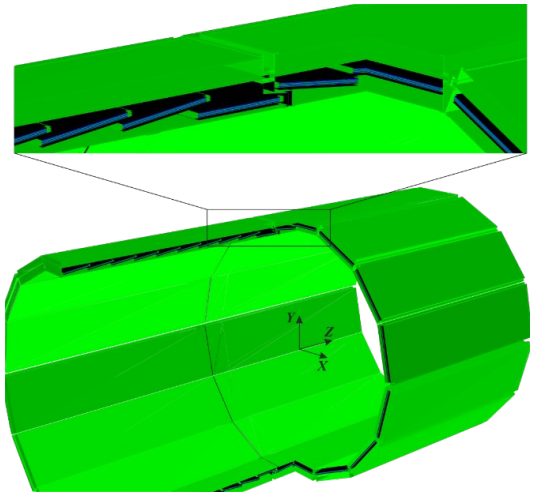


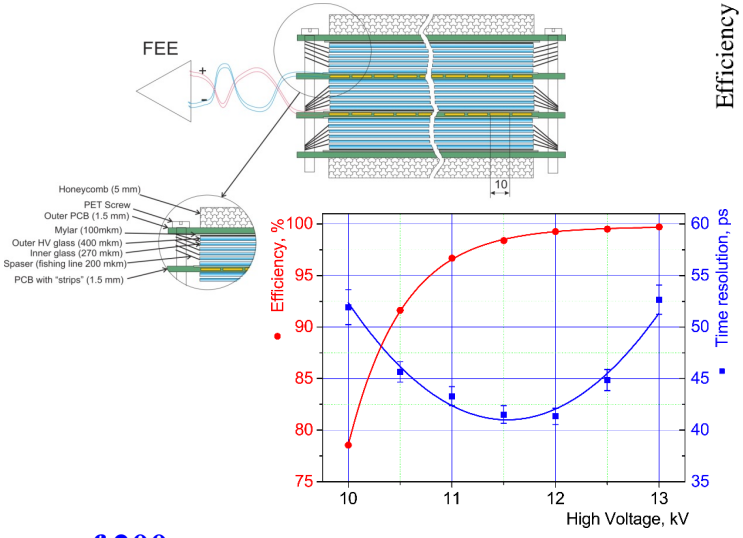
- **Volume: 27 < R < 140 cm, 340 cm length**
- **Gas: 90% Ar+10% CH_4 @ Atm + 2mbar**
- **Magnetic field: 0.5 Tesla**
- **Readout MWPC chambers: 12 per end-plate**
- **Readout pad size: 5×12 mm², 5×18 mm²**
- **Maximum event rate: 7 kHz**
- **Two track resolution: ~ 1 cm**

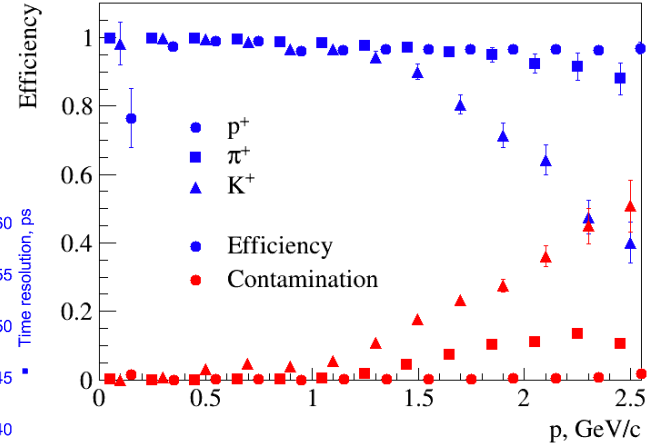


- ❖ TPC cylinders, central membrane and service wheels are ready
- ❖ Readout MWPC chambers (ROCs) – 28 out of 24 (12x2) needed are produced and tested
- ❖ Assembly of the vessel with field cage is ongoing – full TPC assembly by November, 2024

MPD Status – Time-Of-Flight (TOF)







A time resolution of 50 ps for a single module

- **Triple-stack MRPCs with 5 gaps of 200 μm**
- **Gas mixture is composed of 90% of $C_2H_2F_4$, 5% of SF_6 and 5% of i-C_4H_{10}**
- **Designed time (position) resolutions: ~80 ps (~0.5 cm)**

❖ MRPC production completed in Sept. 2022, (+7% spares)

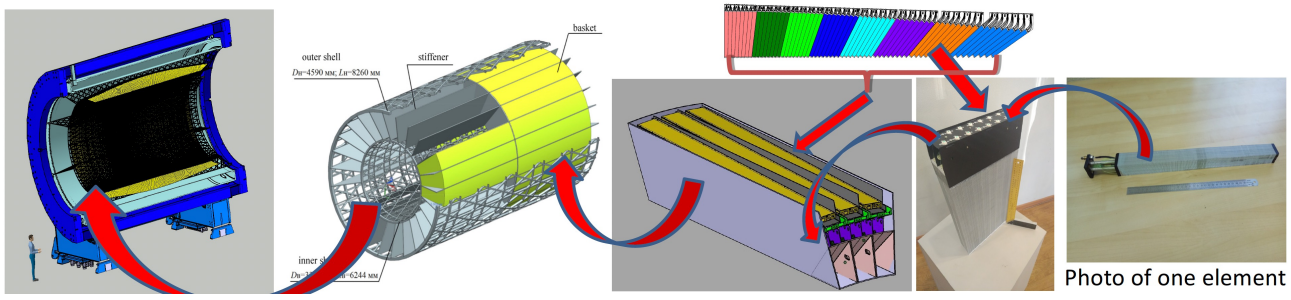
❖ All 28 TOF modules assembled → long-term cosmic tests

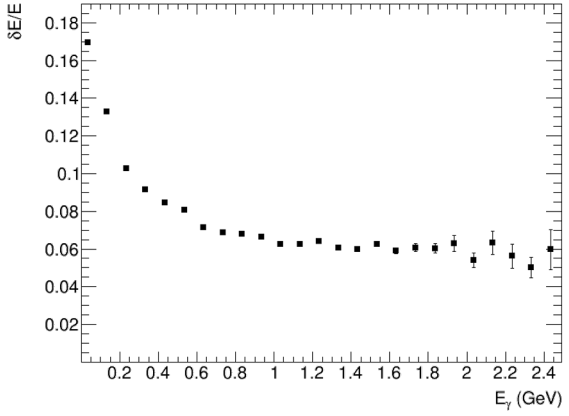
❖ Electronics & cables, HV distribution modules → in stock

❖ Assembled the TOF gas system in the MPD hall

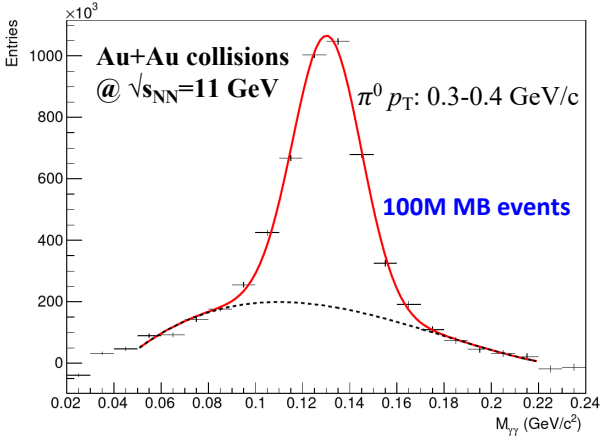
Storage of tested TOF modules

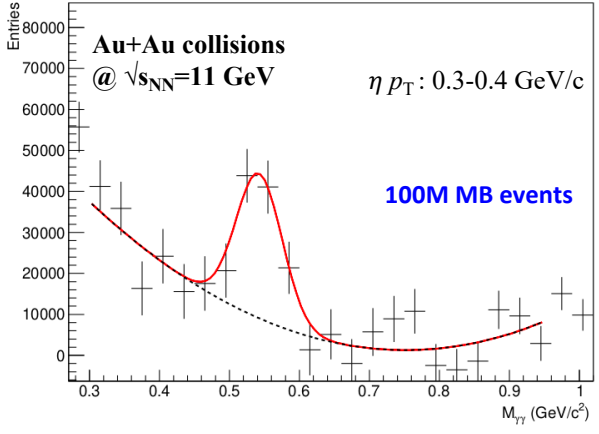
MPD Status – Electromagnetic Calorimeter (ECal)





- **Pb+Sc Shashlyk**
- **Readout via WLS fibers + MAPD**
- **Longitudinal length ~35 cm (~ 14 X_0)**
- **Lateral Segmentation 4×4 cm^2**
- **$\pi^0(\eta)$ differential yields of p_T > 0.1 GeV/c; Electron PID via E/p**

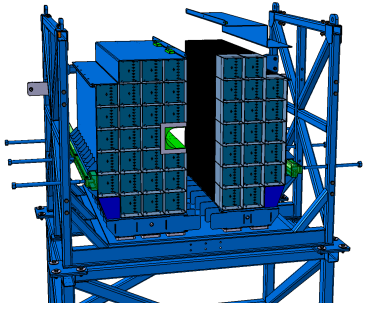


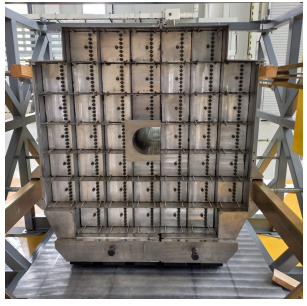


- ❖ 83% of calorimeter will be ready till November of 2024, remaining 400 modules will be produced
- ❖ Electronics installation procedure under development

MPD Status – Forward Subsystems (FHCal + FFD)

FHCal



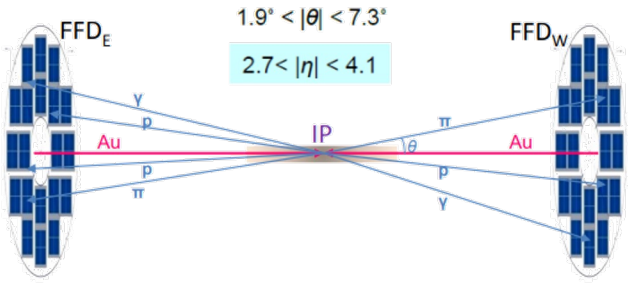


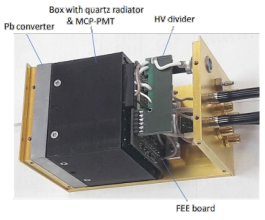
- **2 identical detectors, 44 modules each**
- **Each module consists of 42 lead-scintillator sandwiches (sampling ratio 4:1)**
- **Module transverse size 15×15 cm², 90 cm length**
- **WLS fibers + SiPM readout**
- **$\sigma_E/E \approx 55\%/\sqrt{E}$ (GeV)**

❖ 90 modules, 100 FEE boards and trigger boards are tested and complete installation

❖ FHCal assembled on the platform is ready to be installed in the Pole.

FFD





- **2 identical Cherenkov modular arrays, 20 modules each**
- **10 mm lead converter + 15 mm quartz radiator**
- **MCP-PMT readout**
- **Provides fast trigger and T_0 ($\sigma \sim 50$ ps)**

❖ Cherenkov modules of FFDE and FFDW are available

❖ Mechanics of FFD sub-detectors is available for installation in container with vacuum beam tube

MPD Physics Capabilities

Global observables

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

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

Correlations and Fluctuations

- Collective flow for hadrons
- Vorticity, Λ polarization
- E-by-E fluctuation of multiplicity, momentum and conserved quantities
- Femtoscopy
- Forward-Backward correlation
- Jet-like correlations

Electromagnetic probes

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

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

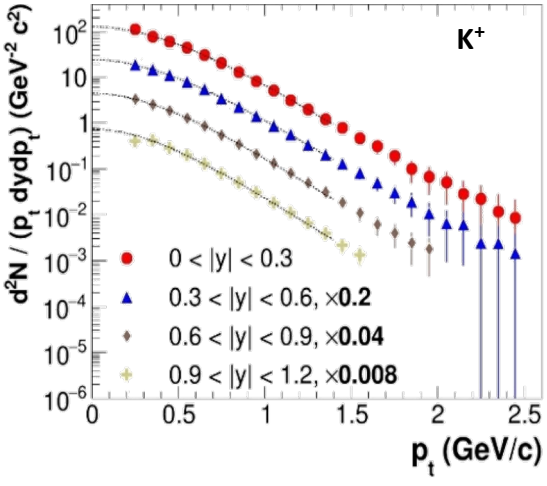
➢ **Physics feasibility studies using large-scale MC productions → consistent picture of MPD physics capabilities with the first data sets, preparation for real data analyses**

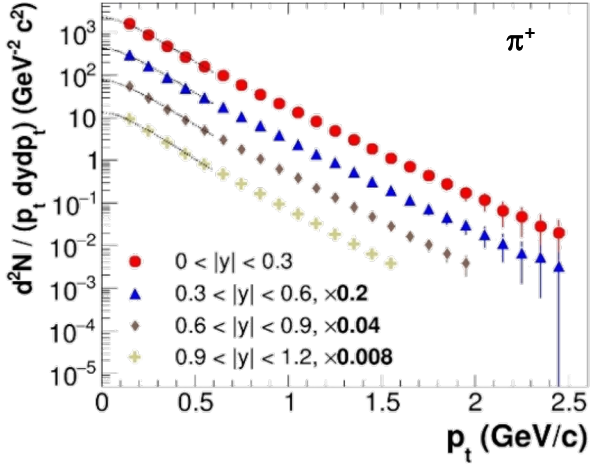
Identified Hadron Production

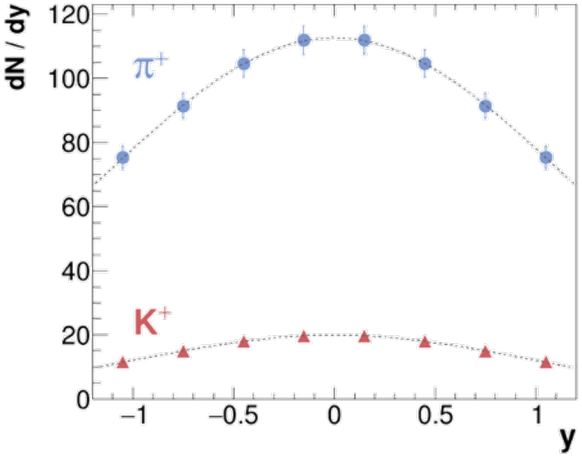
- MPD will be able to measure differential production spectra, integrated yields and $\langle p_T \rangle$, particle ratios, multiplicity distributions for a wide variety of identified hadrons
- Charged hadrons: large and uniform acceptance + excellent PID capabilities of TPC and TOF

0-5% central AuAu@9 GeV (PHSD), 5 M events → full event/detector simulation and reconstruction

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





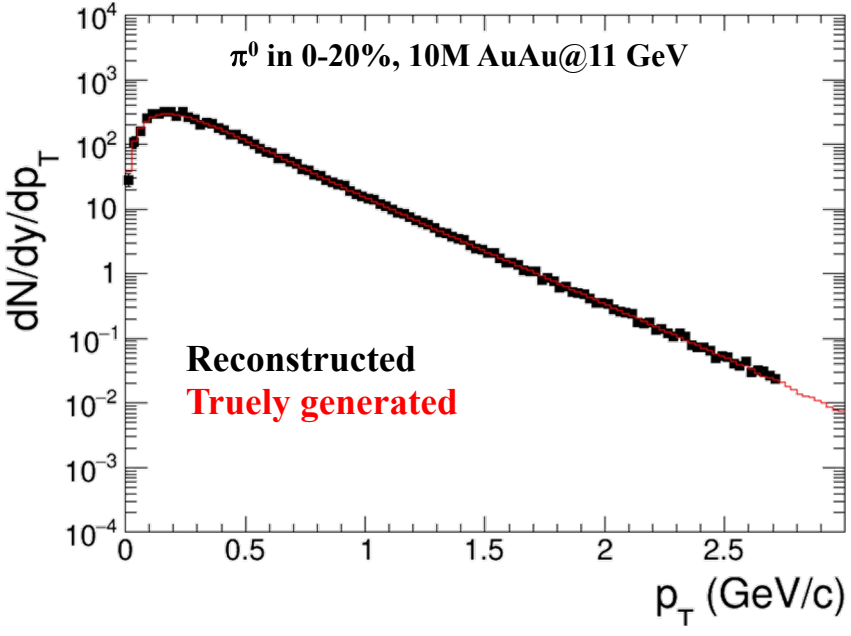


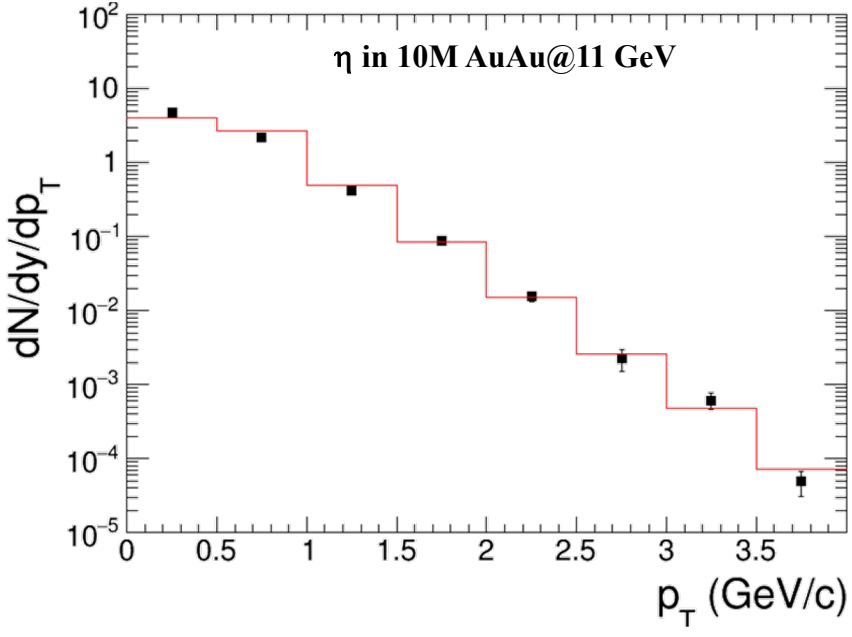
✓ sample ~ 70% of the π/K/p production in the full phase space
✓ hadron spectra are measured from p_T ~ 0.1 GeV/c

Neutral Hadron Production

- Neutral mesons (π^0, η): ECAL reconstruction + photon conversion method (PCM)

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

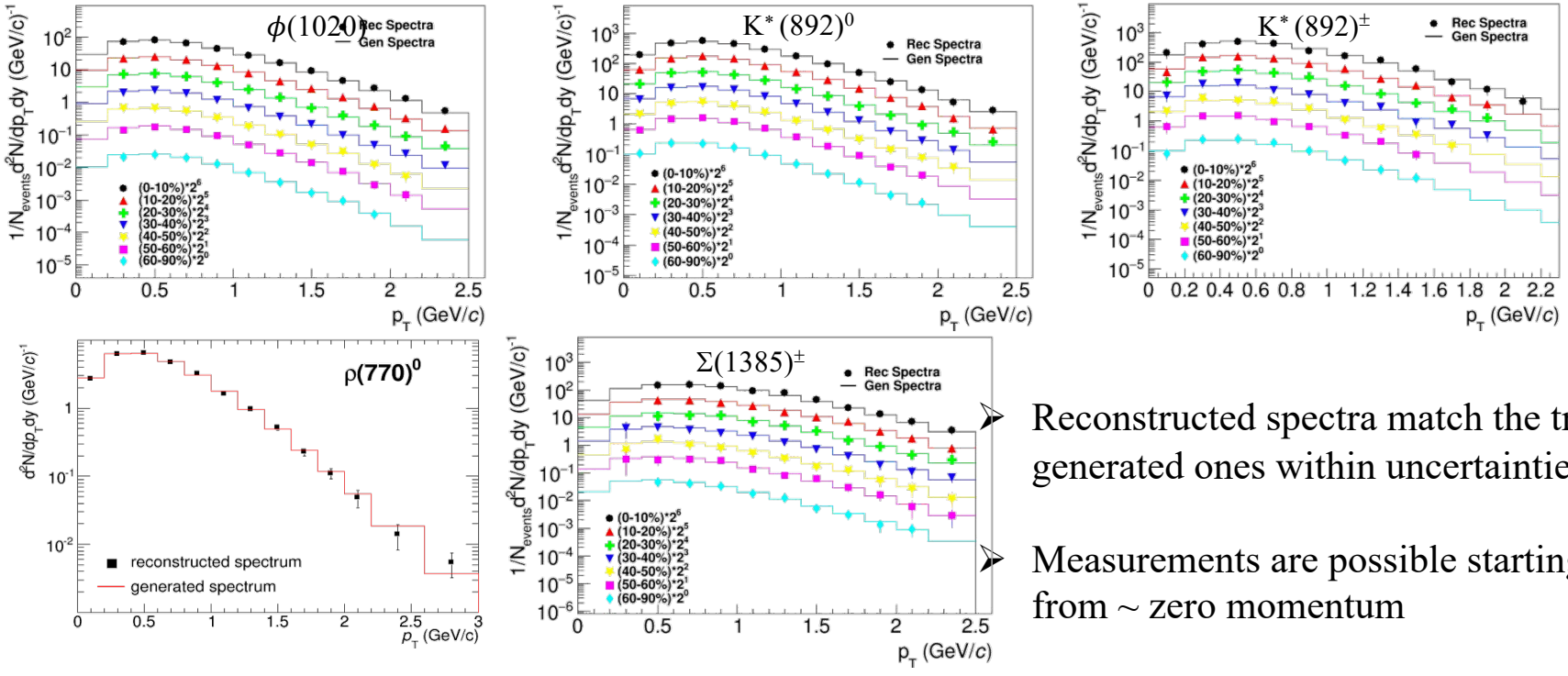




Resonance Production

- Short-lived resonances are sensitive to re-scattering and regeneration in the hadronic phase
- Precise measurements at NICA are needed to validate description of the hadronic phase in models
- Resonance reconstruction using PID in TPC and TOF + decay topology selections

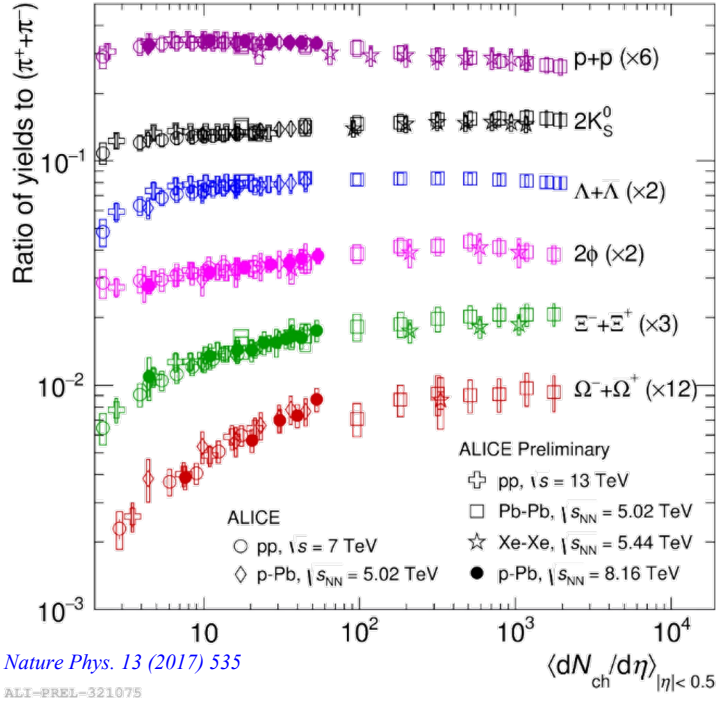
BiBi@9.2 GeV (UrQMD) after mixed-event background subtraction, 50M events



- Reconstructed spectra match the truly generated ones within uncertainties
- Measurements are possible starting from ~ zero momentum

Strangeness Production

- System size scan for (multi)strange baryon and meson production in p+p, p+A and A+A collisions is a key to understanding of strangeness production using PID in the TPC & TOF and different decay topology selections: **excitation function of hadrons**, **nuclear matter EOS**, **…**

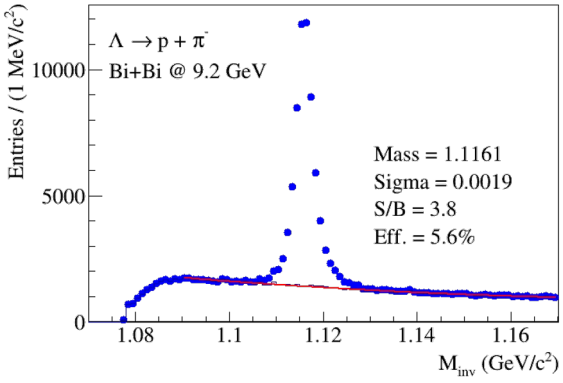


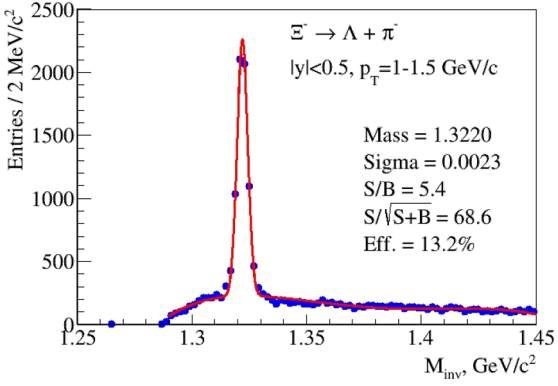
Nature Phys. 13 (2017) 535

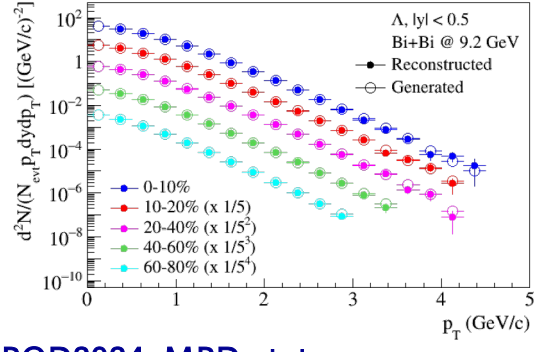
ALI-PREL-321075

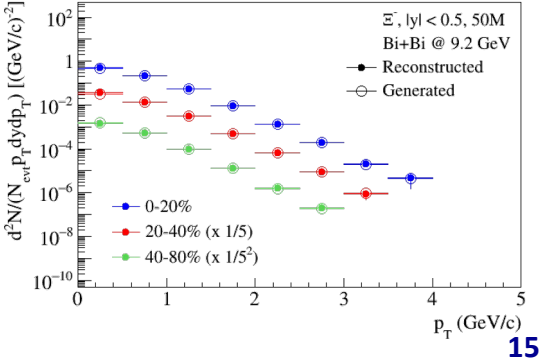
System size scan is unique capability of NICA in the energy range!

UrQMD, BiBi@9.2 GeV, 50M events



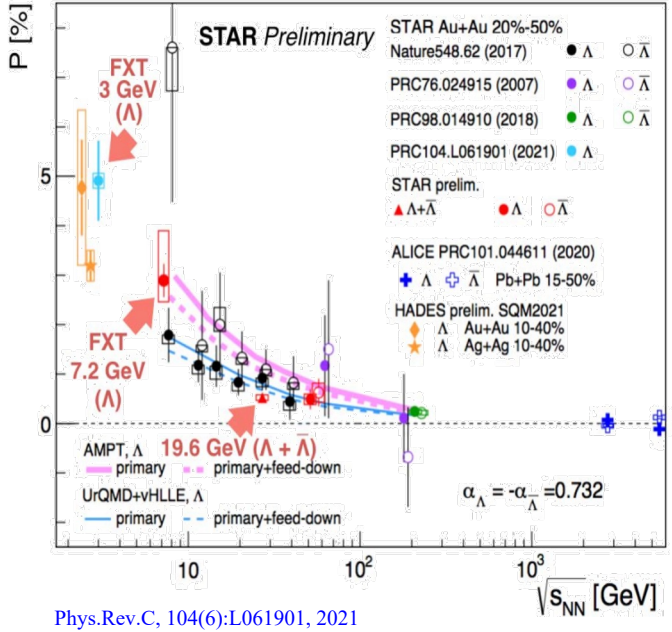






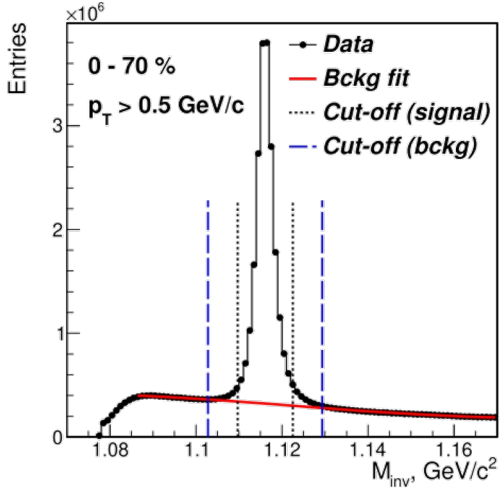
Hyperon Global Polarization

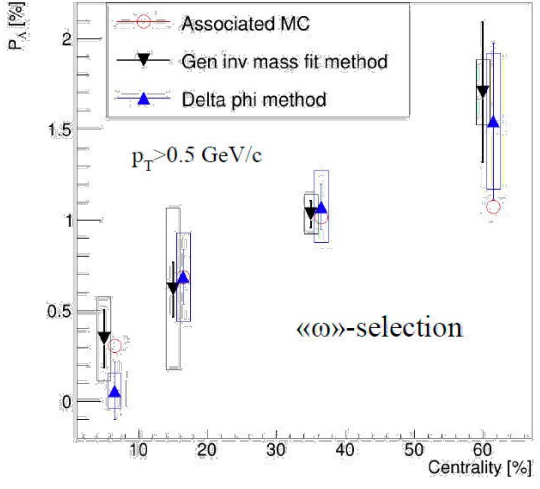
- NICA contributes extra points in the energy range 2-11 GeV with small uncertainties
- Centrality, p_T and rapidity dependence of polarization not only for Λ, but other (anti)hyperons (Λ, Σ, Ξ)
- Global hyperon polarization reproduces at generator level basic features measured by STAR



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

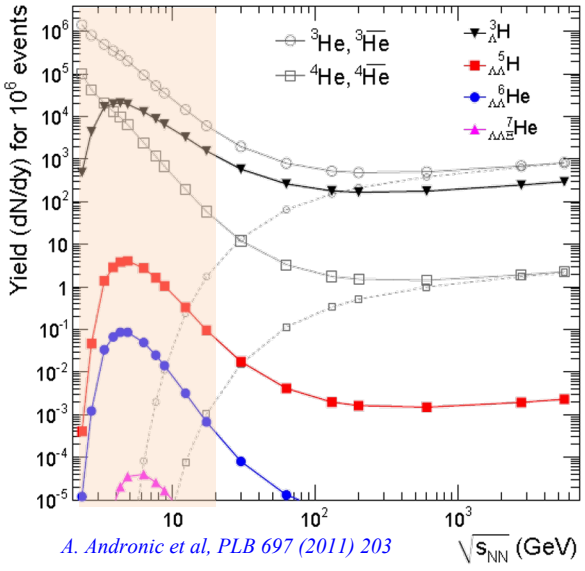
BiBi@9.2 GeV (PHSD), 15 M events → full event/detector simulation and reconstruction





First global polarization measurements for $\Lambda/\bar{\Lambda}$ will be possible with ~ 10M data sampled events

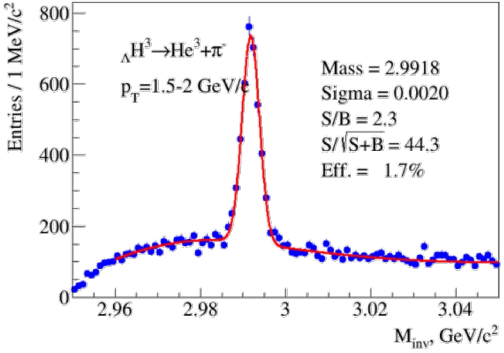
Hyper-nuclei Production

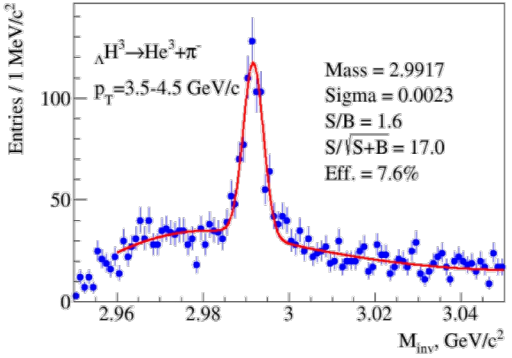


A. Andronic et al, PLB 697 (2011) 203

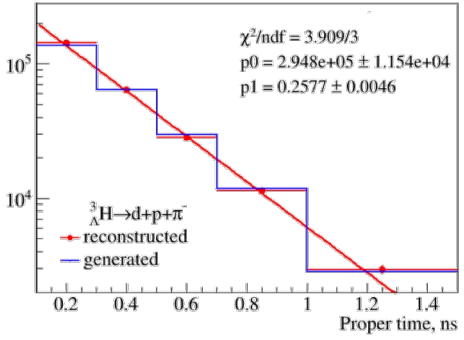
- Hyper-nuclei measurement studies are crucial:
  - ✓ models predict enhanced hyper-nuclei production at NICA energies
  - ✓ microscopic production mechanism via Y-N (Y-Y, Y-N-N) interactions
  - ✓ hyperons expected to exist in the inner core of neutron stars

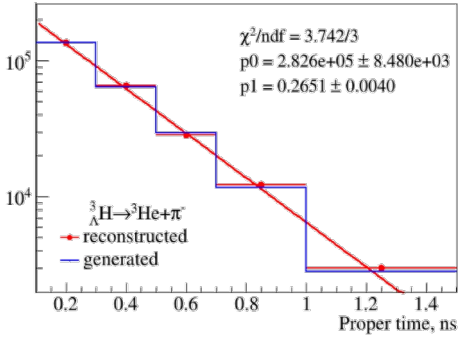
PHQMD, BiBi@9.2 GeV, 50M events





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





- ✓ $_\Lambda H^3$ reconstruction with ~50M sample events
- ✓ $_\Lambda H^4$, $_\Lambda He^4$ reconstruction with ~150M sample events
- ✓ double hyper-nuclei are reachable

Summary and outlook

- Preparation of the MPD detector and experimental program is continued
- MPD fixed-target mode was approved as a default option
- Develop realistic analysis methods and techniques to be ready for analysis of the first data
- First beam is scheduled to be delivered to the MPD in 2025

Thanks for your attention!