

# FEASIBILITY STUDY OF HYPERNUCLEI PRODUCTION AT NICA/MPD

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Joint Institute for Nuclear Research

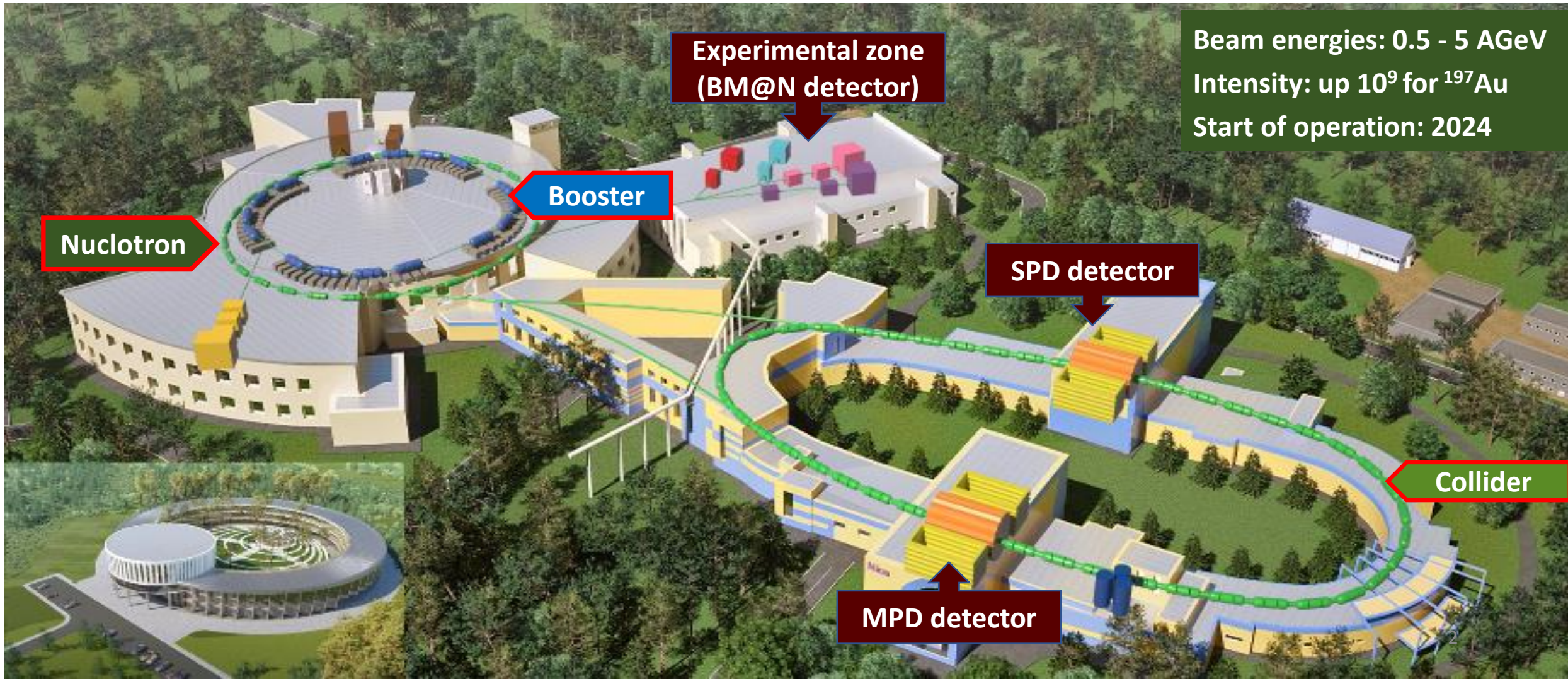


6<sup>th</sup> International Conference on Particle Physics and Astrophysics  
Moscow, Russia, November 29 – December 2, 2022



# NICA – Nuclotron-based Ion Collider fAcility

- Chain of accelerators providing ion beams (from  $p$  to Au) for fundamental physics studies & applied research
- Modern detectors for study dense nuclear matter and spin phenomena (MPD, SPD, BM@N)
- Experimental zone with beam lines for physics study and applied research
- Cryogenic infrastructure for production, testing and supply superconducting elements





# NICA/MPD physics. Tasks and Observables

**Experimental strategy:** energy and system size scan to measure a large variety of signals systematically changing collision parameters (energy, centrality, system size). Reference data (ip+p) will be taken in the same experimental conditions.

## Bulk properties, EOS

particle yields & spectra, ratios, femtoscopy, flow

**measure:**  $\gamma$ ,  $\pi$ ,  $K$ ,  $p$ ,  $\Lambda$ ,  $\Omega$ , (anti)particles, light nuclei

## In-Medium modification of hadron properties

onset of low-mass dilepton enhancement

**measure:**  $\rho$ ,  $\omega$ ,  $\phi \rightarrow e+e^-$

## Deconfinement (chiral) phase transition at high $\rho_B$

enhanced strangeness production

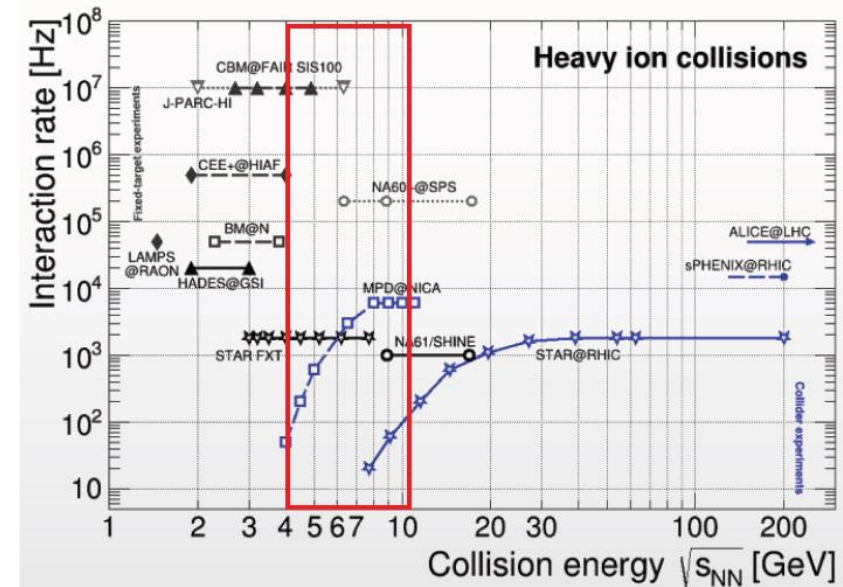
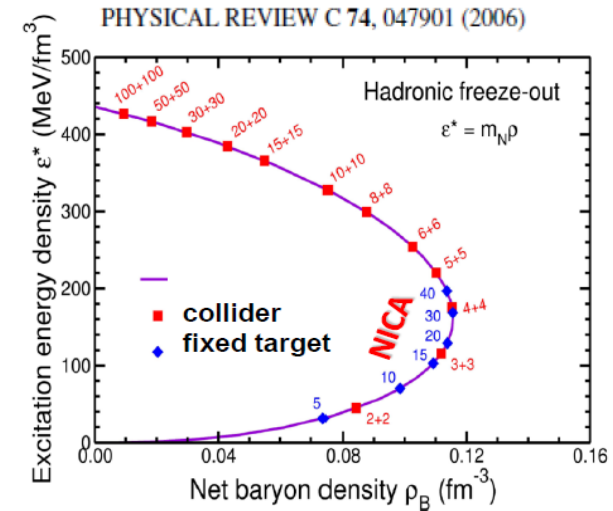
Chiral Magnetic (Vortical) effect

## QCD Critical Point

event-by-event fluctuations and correlations

This talk  $\rightarrow$

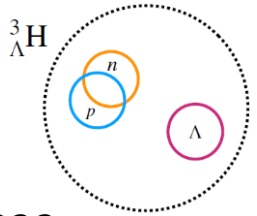
- In-medium  $\Lambda$ -N and  $\Lambda$ -N interactions
- Yields, spectra, lifetimes of hypernuclei



# Hypernuclei in HIC : expectations & data

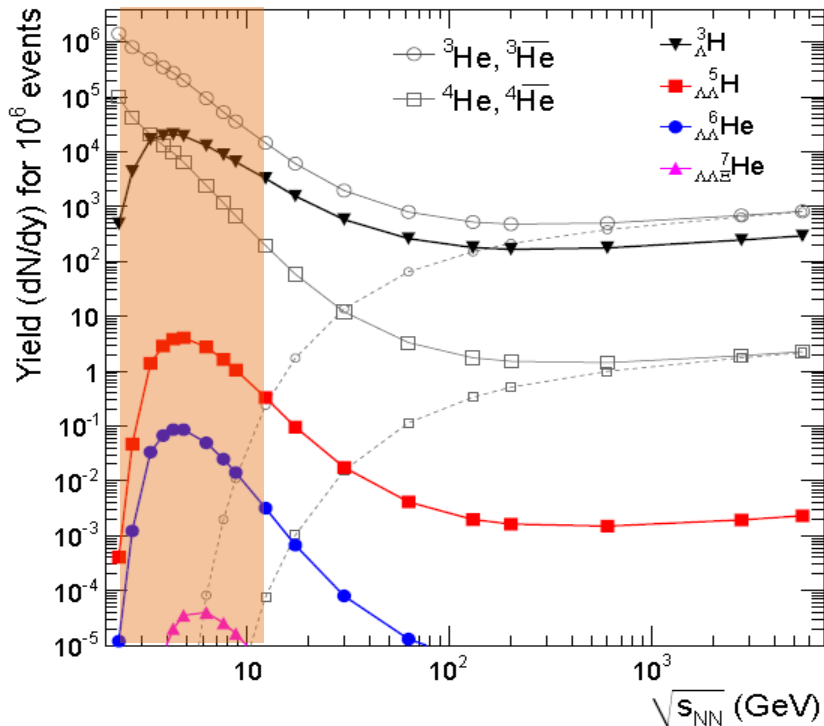
- Nuclear matter EOS is of importance for QCD, nuclear physics and astrophysics
- Only NN potential are very well determined from scattering experiments
- But YN or YY potentials are rather uncertain since such experiments difficult to perform
- High multiplicity heavy-ion collisions provide several methods to do the job: two-particle correlations and hypernuclei

*Hypernuclei are nuclei containing at least one hyperon*



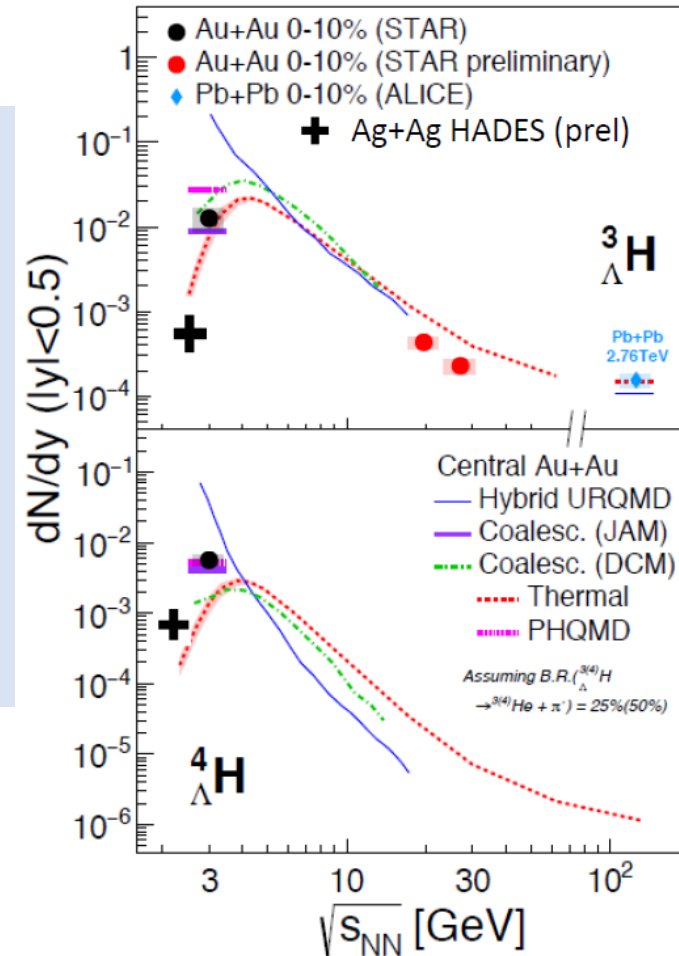
QM'2022

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



Thermal model predicts an enhanced production of (hyper)nuclei within the NICA energy range

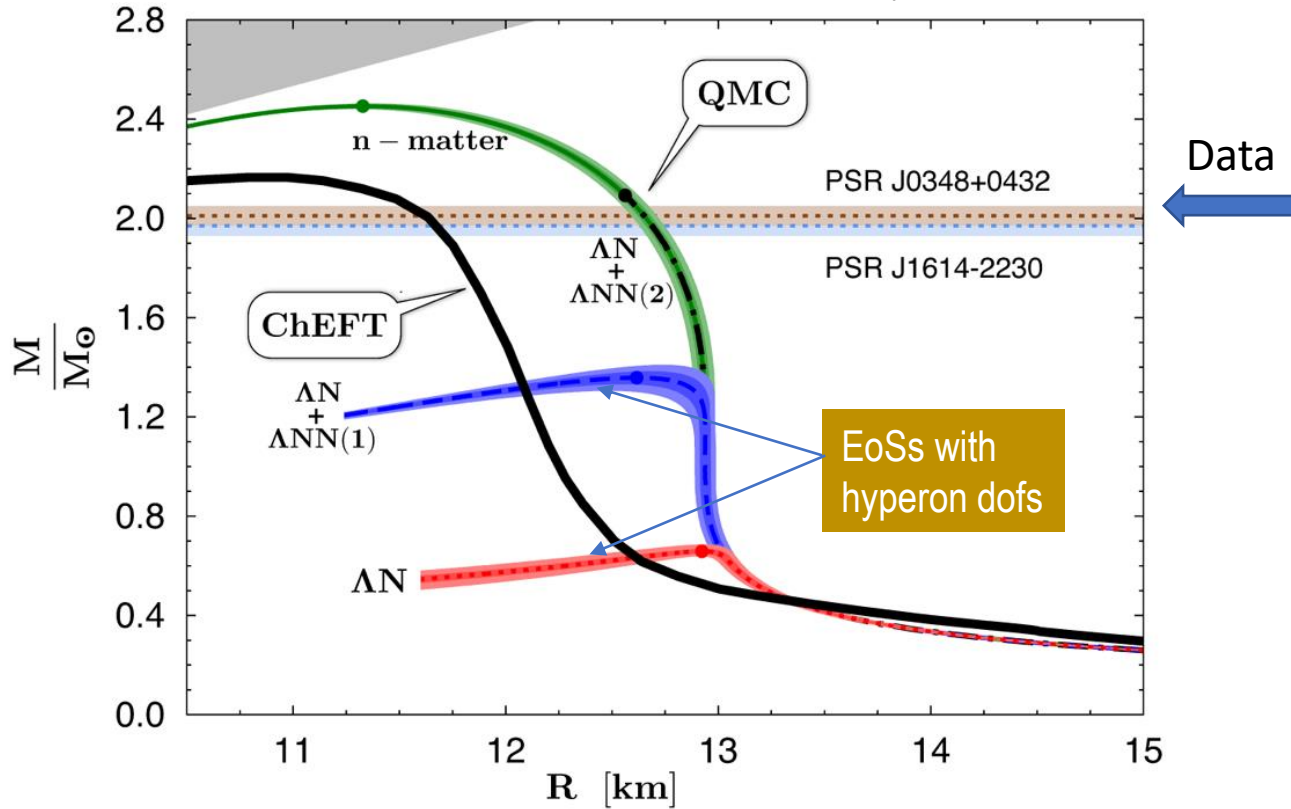
- Few data on the production of hypernuclei in HIC
- Available data leave space for various model predictions (thermal, coalesce, hybrid)
- Further and deeper investigations of the hypernuclear formation mechanisms require additional measurements at different energies and collision systems (**NICA**)



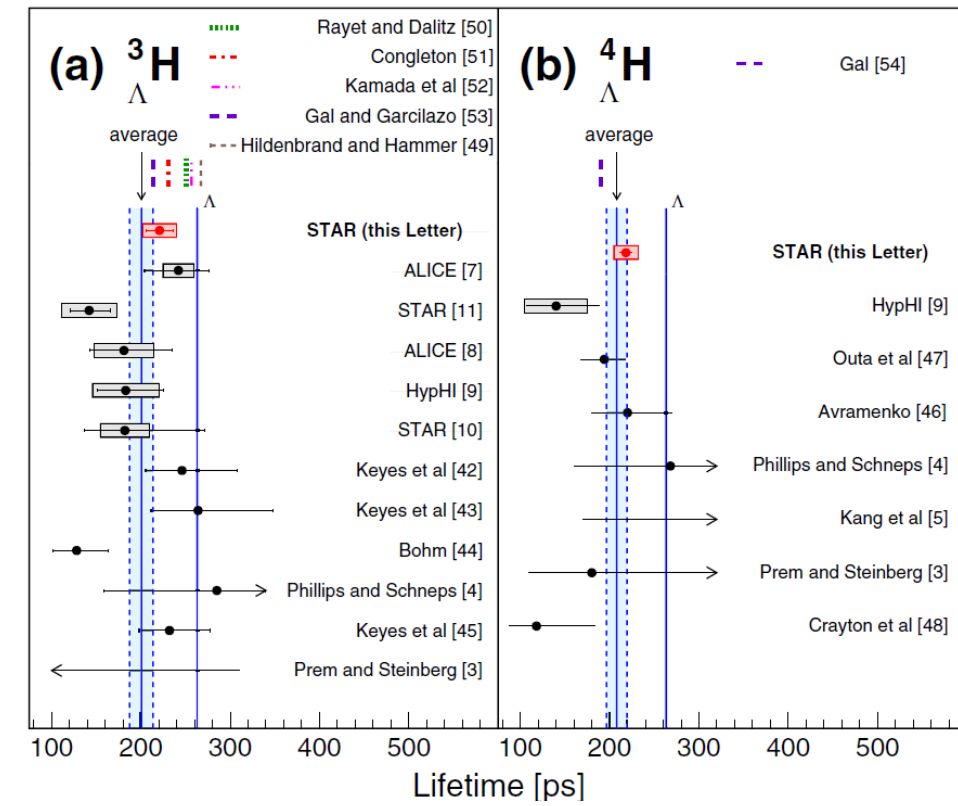
# Strangeness in dense nuclear matter : puzzling behavior

- Hyperons appear in the core of neutron stars (NS) at  $\sim (2-3)n_0$  leading to softening EoS and reducing the max. mass for NSs, but the latter is in contradiction with observations (**NS hyperon puzzle**)
- Averaged lifetimes of hypernuclei from A+A are shorter than expected from theory (**lifetime puzzle**)

REVIEWS OF MODERN PHYSICS 88 (2016)



PRL 128, 202301 (2022)

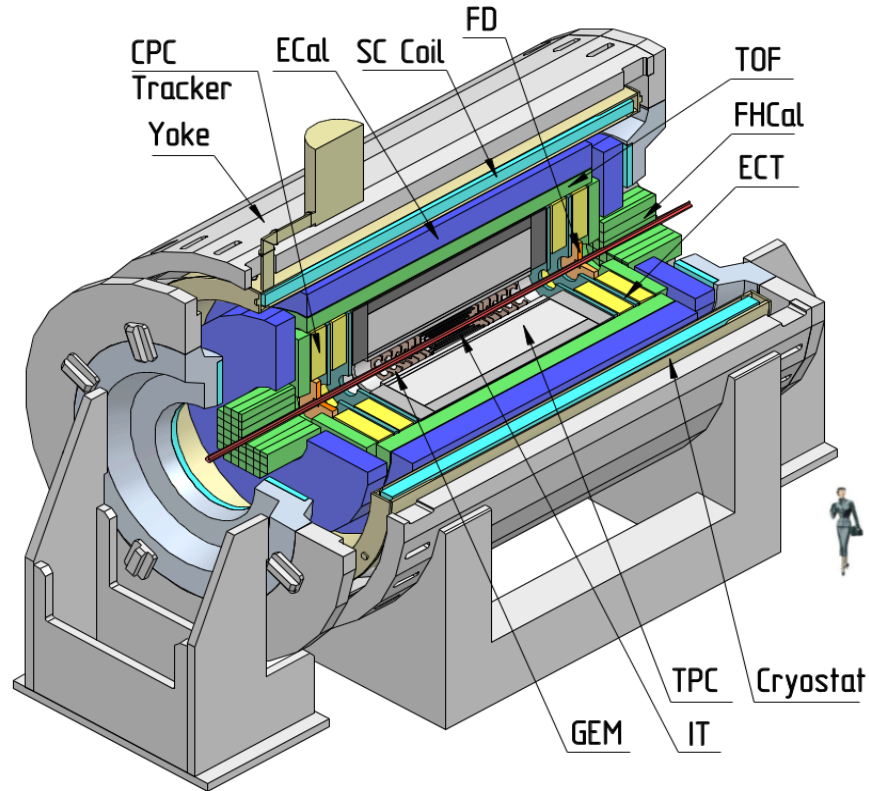


Many open questions on YN (YY, YNN) potentials in dense matter, new data on  $B_\Lambda$ , lifetimes, branching ratios are needed to provide tighter constraints

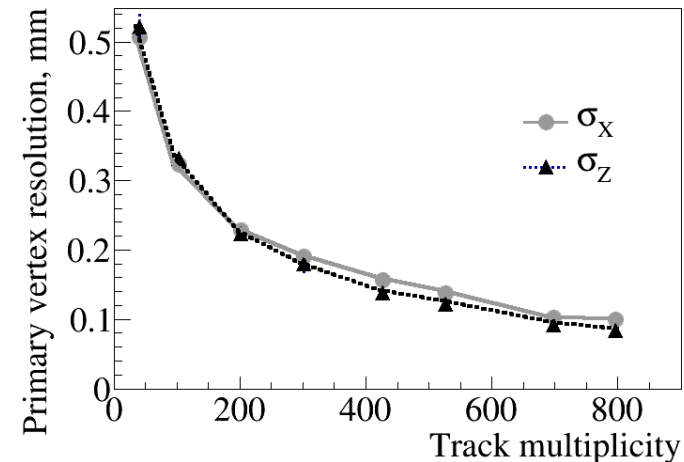
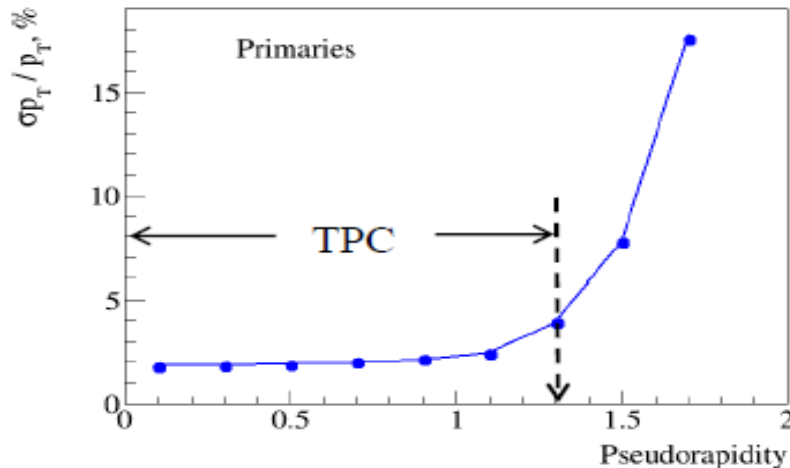
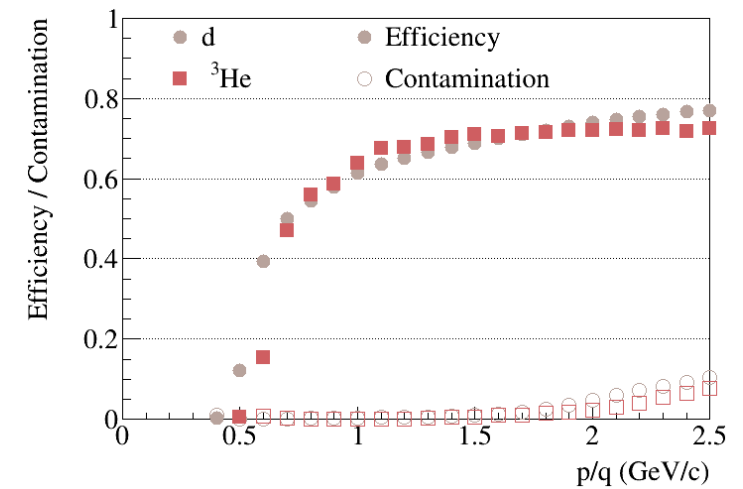
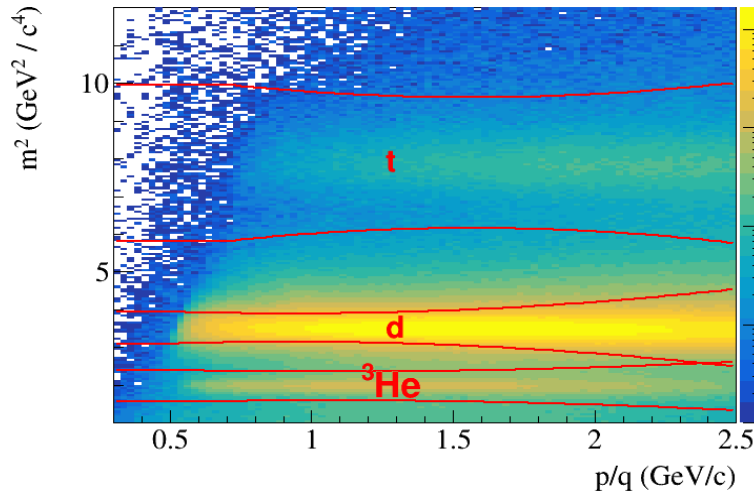
More data are required to reduce current uncertainty  
(**NICA/MPD**)

# MultiPurpose Detector for A+A collisions @ NICA

For more details see plenary talk by A.Taranenko at 15:30



- 3D tracking (TPC), uniform acceptance
- Powerful PID (TPC, TOF, ECAL)
- Precise event characterization (FHCAL)
- Fast timing and triggering (FFD)





# MPD simulation, reconstruction & analysis framework (MPDRoot)

<http://mpdroot.jinr.u>

- Branches for all the MPD subdetectors
- A variety of event generator options
- Detector response simulation + reconstruction tasks



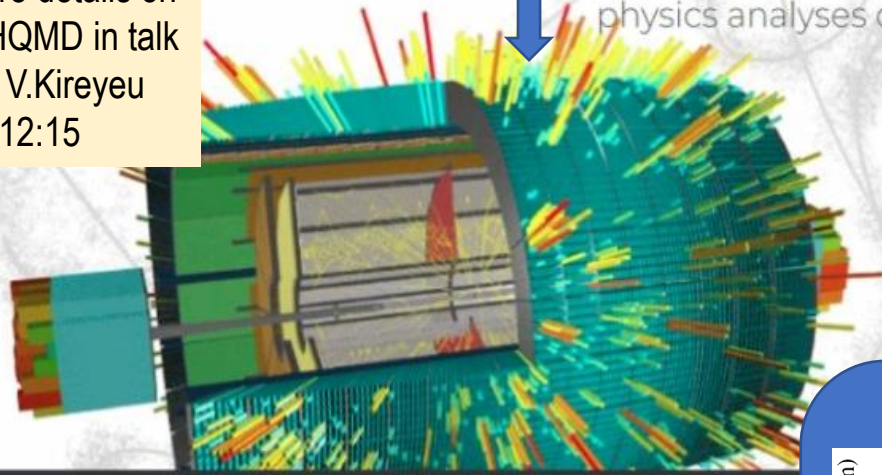
## THE MPDROOT

mpdroot is the off-line software framework for simulation, reconstruction and physics analyses of the simulated or experimental data for MPD experiment

Event generator  
(PHQMD model)

Transport  
GEANT3,4

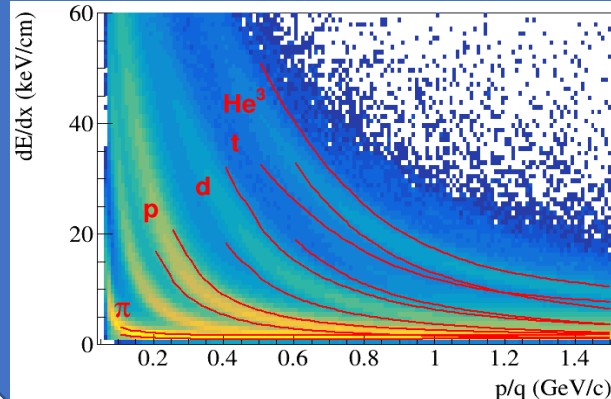
More details on  
PHQMD in talk  
by V.Kireyeu  
at 12:15



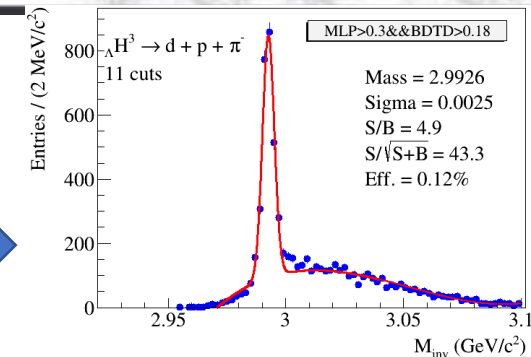
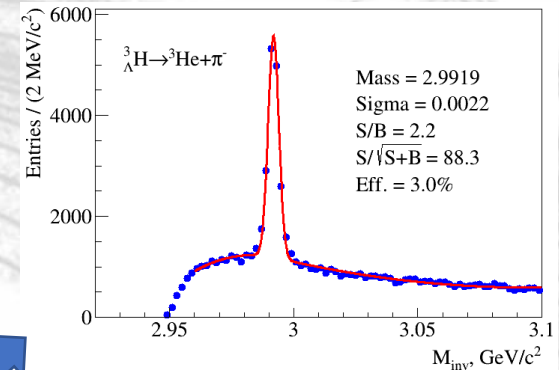
Detector  
response  
(TPC, TOF)

Event  
reconstruction  
(tracking,  
vertexing,  
PID)

PID

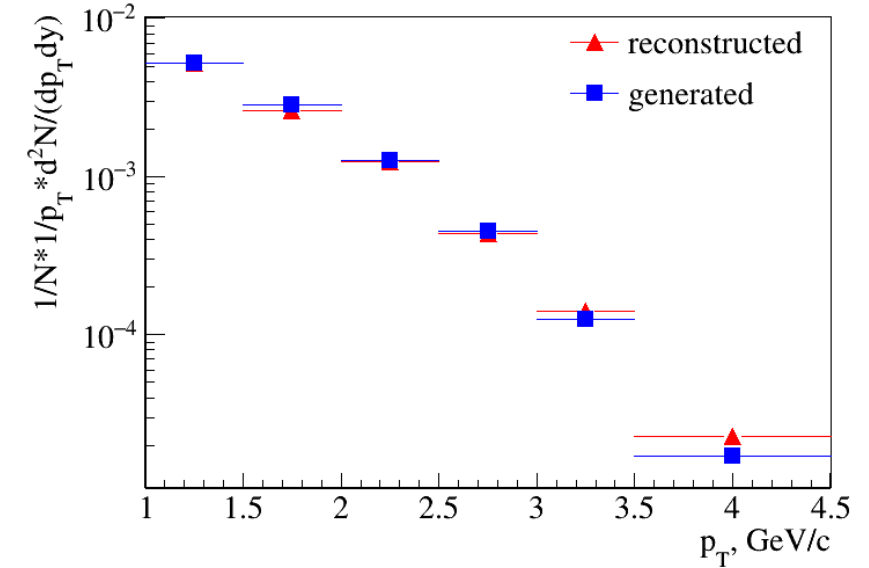
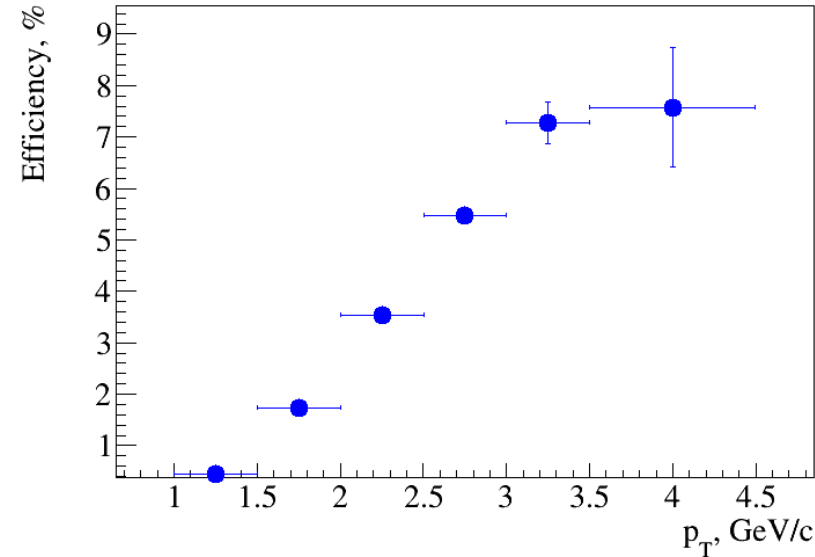
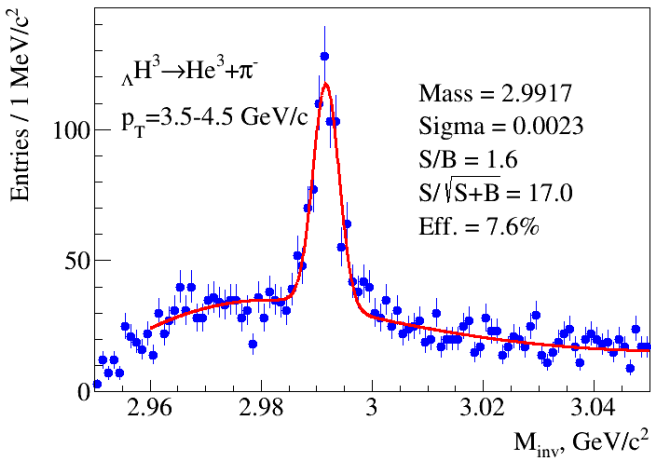
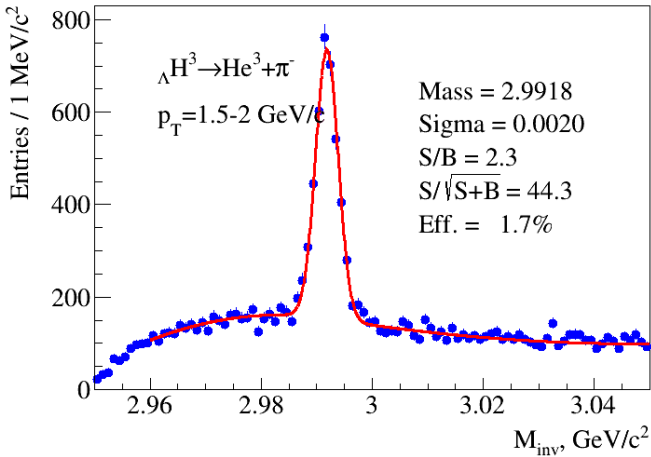
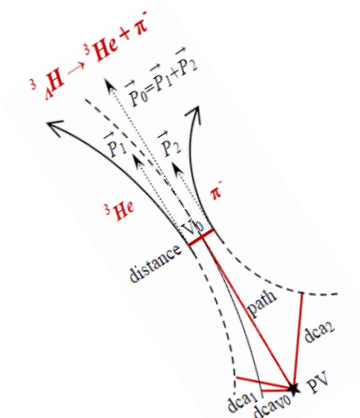


Secondary  
vertex  
technique:  
topology  
selection  
or  
ML-based  
TMVA



# Reconstruction of hypertritons in MPD

- 40M Events Bi+Bi at 9.2 GeV,  $|y| < 1$
- Full event simulation and reconstruction
- A set of topological cuts aimed at maximizing significance

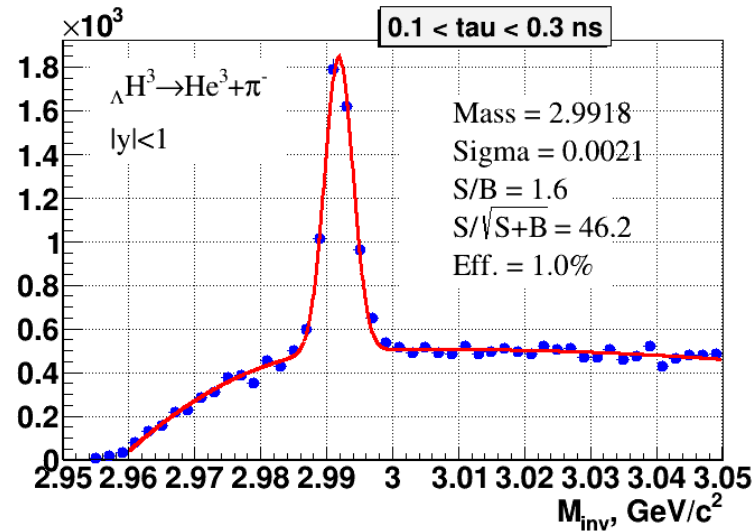
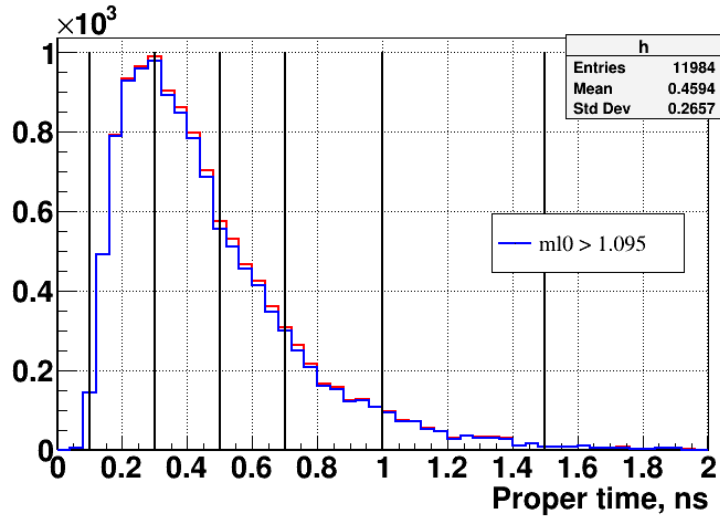


- Invariant spectrum of hypertritons is reconstructed up  $p_T = 4.5 \text{ GeV}/c$
- With a larger data sets,  $p_T$ -spectra and rapidity densities can be obtained in centrality selected Bi+Bi collisions over a large phase space shedding light to the formation details and collective behavior of hypernuclei

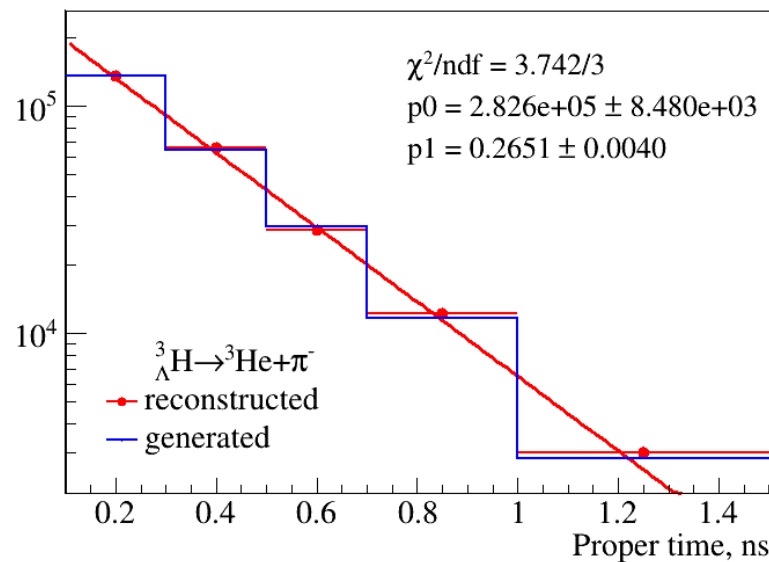
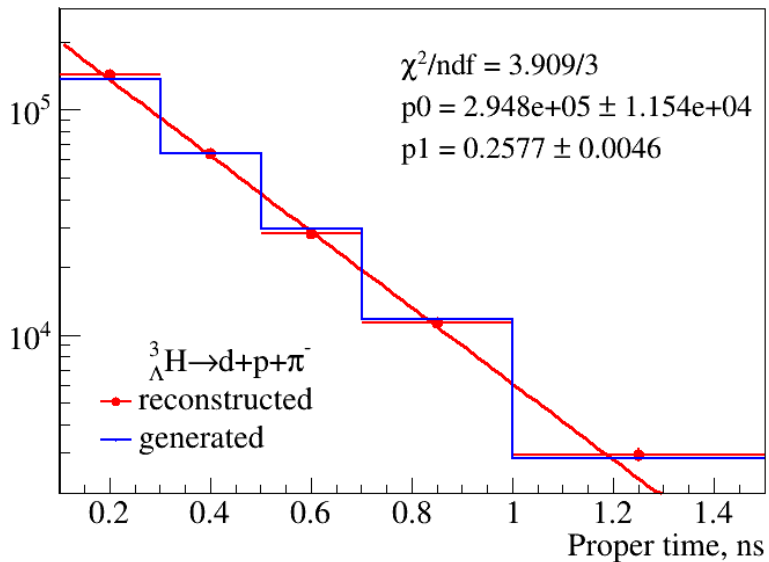


# Hypertriton lifetime study

- Hypertritons are reconstructed in several  $\tau$  bins
- 2- and 3-prong decay modes were studied separately to estimate systematics



$\tau = ML/p$  (p – momentum, M-hypertriton mass, L-track length)



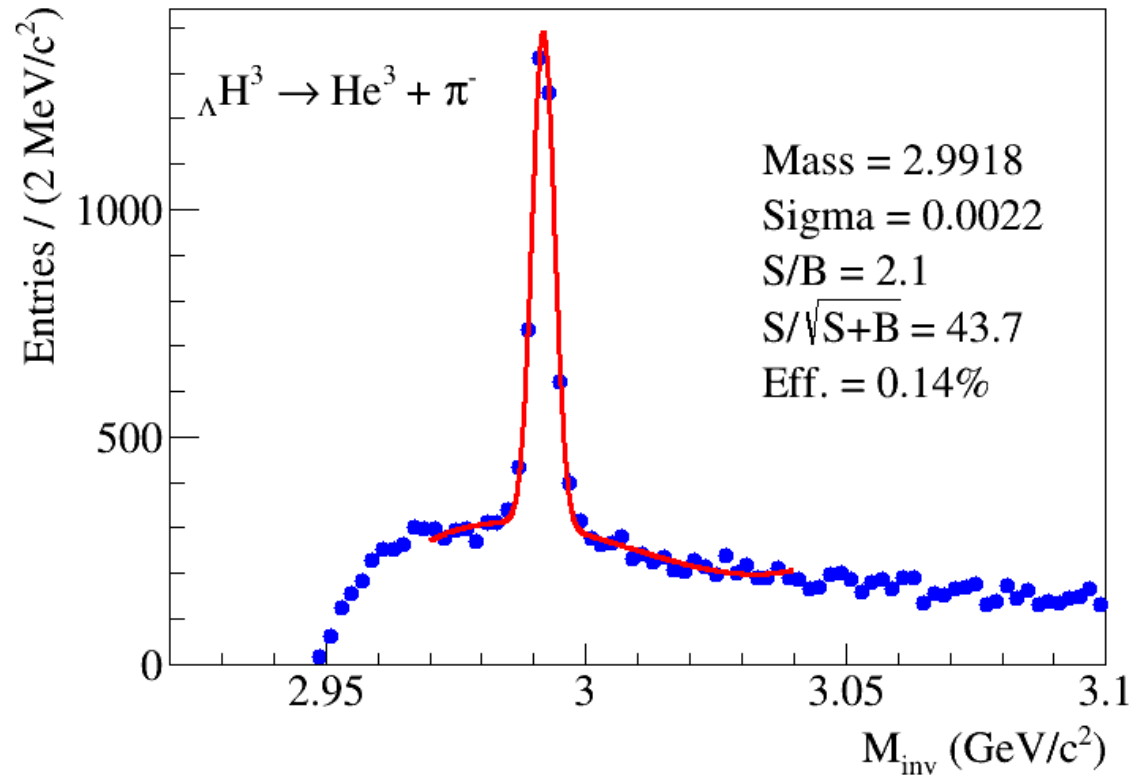
$$N(\tau) = N(0) \exp\left(-\frac{\tau}{\tau_0}\right) = N(0) \exp\left(-\frac{ML}{cp\tau_0}\right),$$

Results for different decay modes are consistent

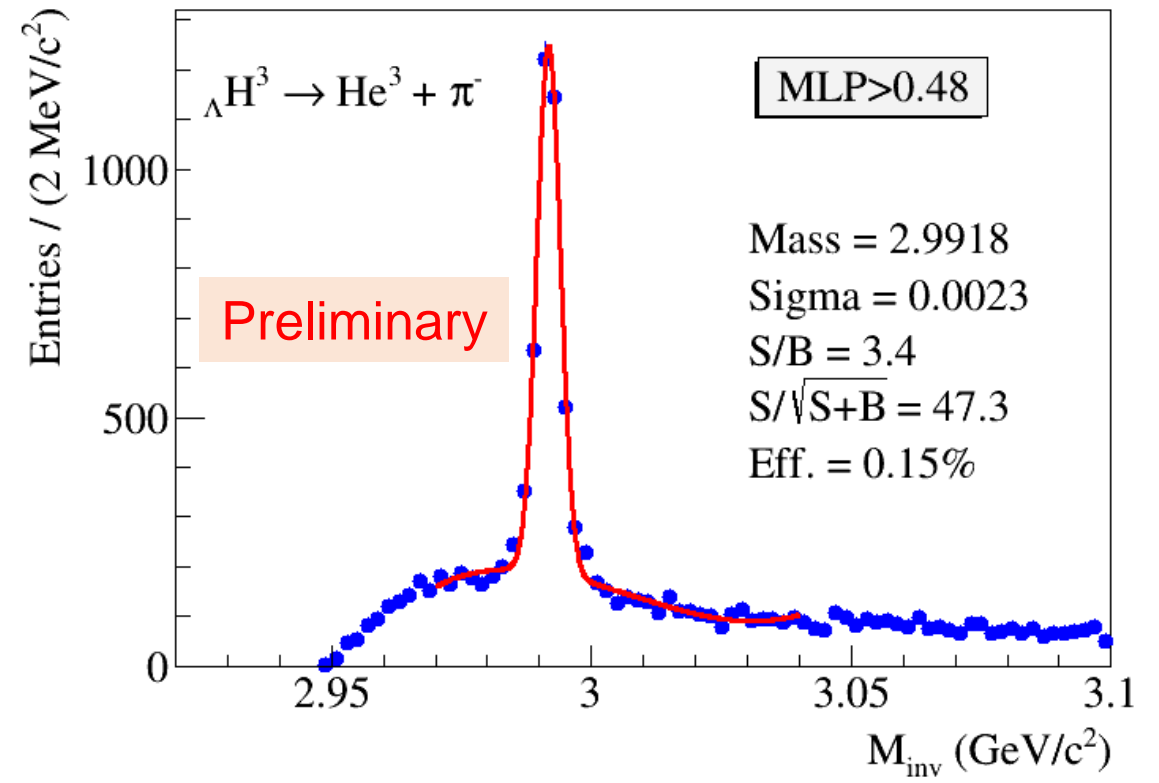
# ${}^3_{\Lambda}\text{H}$ reconstruction (2-prong): standard chain vs TMVA

- Standard chains – set of 7 cuts optimized in semi-automatic mode to maximize significance
- Machine learning approach – TMVA (Multivariate Data Analysis with ROOT)

Standard method of topological cuts



ML-based TMVA approach

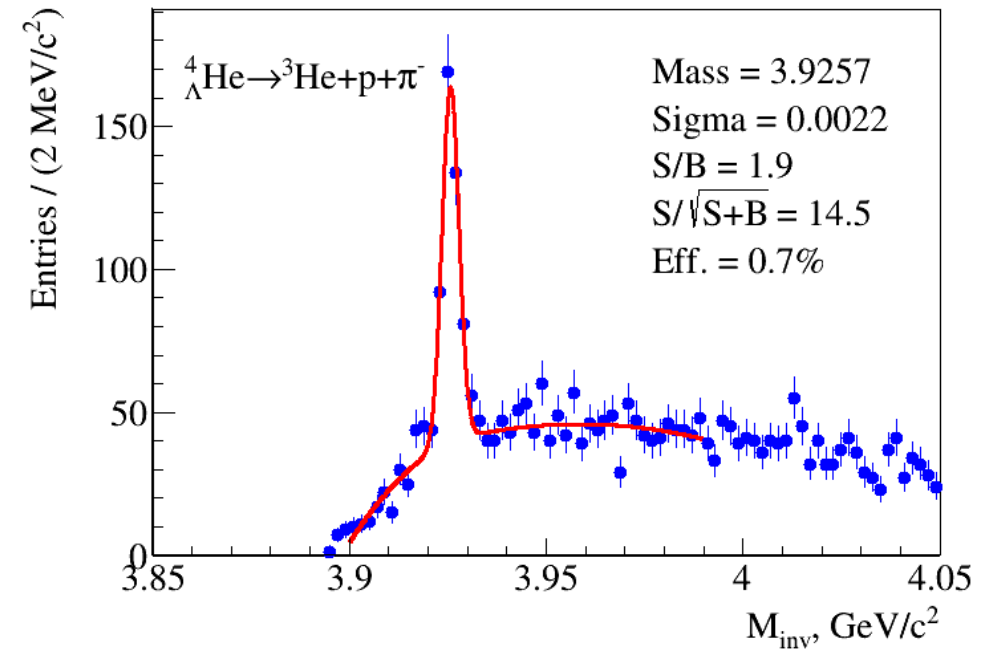
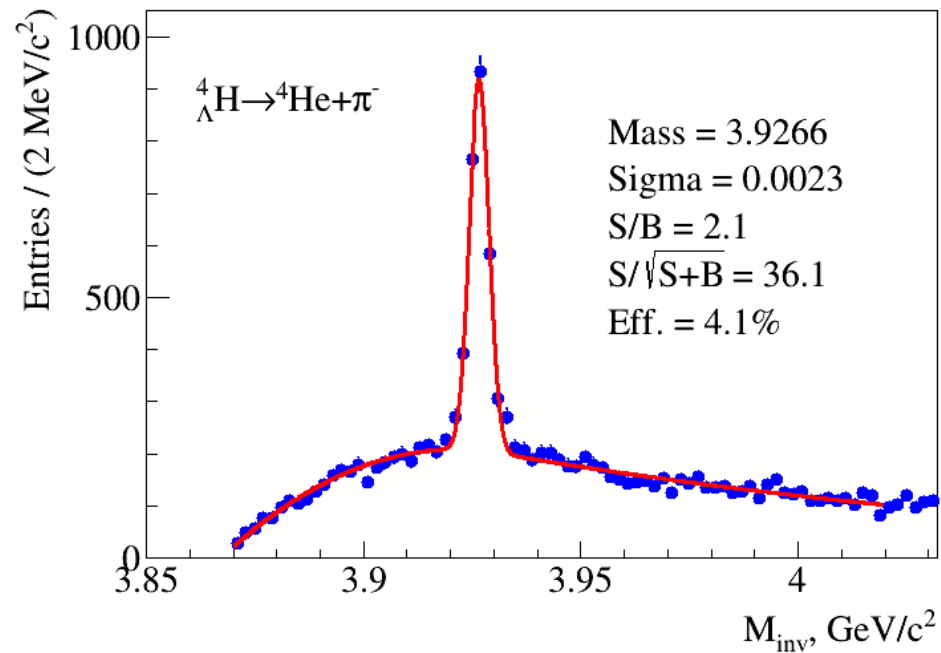


Better selectivity of hypertritons with the TMVA toolkit

# Results for heavier hypernuclei in MPD

- 40Mevents Bi+Bi at 9.2 GeV,  $b < 12$  fm (PHQMD) enriched by signal particles

Equivalent statistics:  $\sim 140$  M events for  ${}^4_{\Lambda}\text{H}$  and for  ${}^4_{\Lambda}\text{He}$



Good MPD performance for heavier hypernuclei in Bi+Bi at 9 GeV



# Summary

- Intensive preparations for the start of the MPD physics program at NICA is ongoing
- Production of hypernuclei is sensitive to the strange sector of the nuclear matter EOS and has implication for nuclear physics and astrophysics
- The results of MPD feasibility studies indicate good hypernuclei reconstruction performance of the detector
- Future high statistics data from NICA/MPD can provide better constraints for hypernuclei production models in the high baryon density regime

***Thank you for listening!***