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Realistic simulation of Hypernuclei at MPD / NICA with new PID

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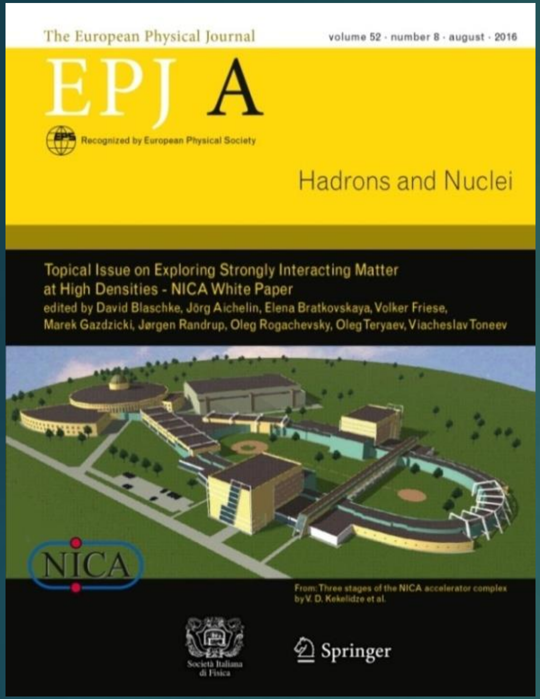
Outline

- NICA project and MPD detector geometry
- Hypernuclei in HIC
- Track reconstruction tuning
- New *dEdx* in TPC: from GEANT3 to Garfield++
- New PID performance in TPC & TOF (n-sigma method)
- Realistic reconstruction of hypernuclei
- Outlook

NICA complex and NICA physics



- New flagship project at JINR (Dubna)
- Based on the technological development of the Nuclotron facility
- Optimal usage of the existing infrastructure
- Modern facility incorporating new technological concepts

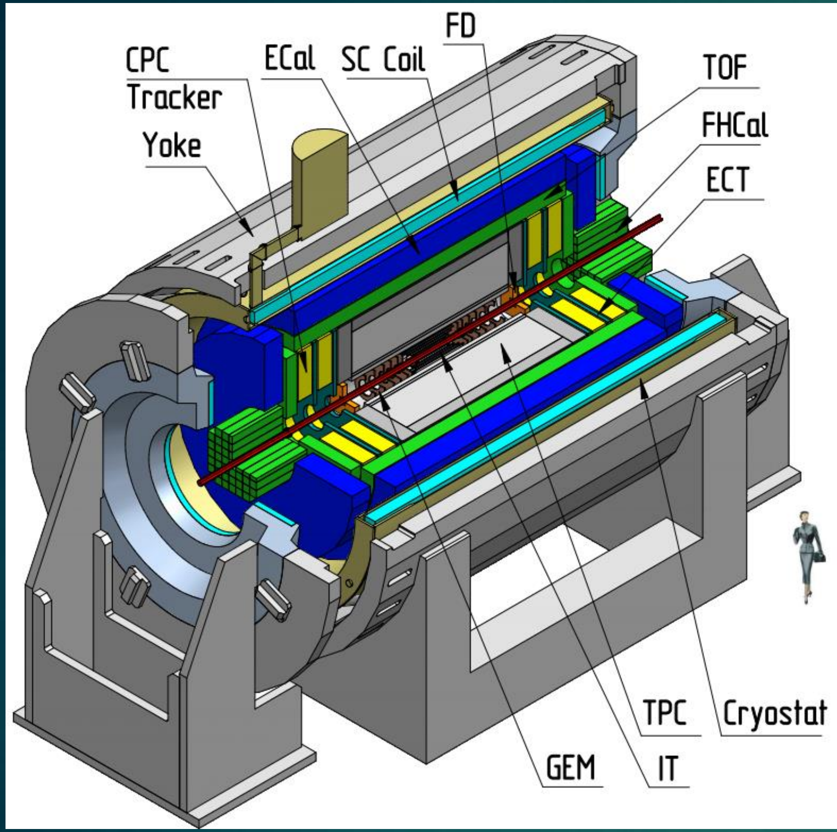
NICA parameters:

Beams: p, d(h)..$^{197}Au^{79+}$
Collision energy: 4-11 GeV (nuclei)
Luminosity: 10^{27} $cm^{-2}s^{-1}$ (Au), 10^{32} (p)
2 Interaction points: MPD and SPD
Fixed target: 1-6A GeV beams

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

- *Bulk properties, EOS:* particle yields & spectra, ratios, femtoscopy, flow
- *In-Medium modification of hadron properties:* dileptons and resonances
- *Deconfinement (chiral) phase transition at high* r_B: strangeness, Chiral Magnetic (Vortical) effect
- *QCD Critical Point:* event-by-event fluctuations and correlations
- *YN, YY interactions in nuclear matter:* hypernuclei

Multi-Purpose Detector @ NICA



Requirements to the apparatus:

- Hermeticity, homogenous acceptance : 2π in azimuthal angle
- Highly efficient 3-D track reconstruction ($|\eta|<2$), high resolution vertexing
- Powerful PID: π/K up to 1.5 GeV/c, K/p up to 3 GeV/c, ECAL for γ, e
- Careful event characterization: impact parameter & event plane reconstruction
- Minimal dead time, event rate capability up to ~ 6 kHz

Stage 1: TPC, TOF, ECAL, ZDC, FFD+ITS(OB)
Stage 2: ITS(IB)+EndCaps (CPC, Straw, TOF, ECAL)

To study hypernuclei, MPD detector must be able to detect and identify light nuclei in a wide rapidity range as well to have a good capability for precise secondary vertex reconstruction

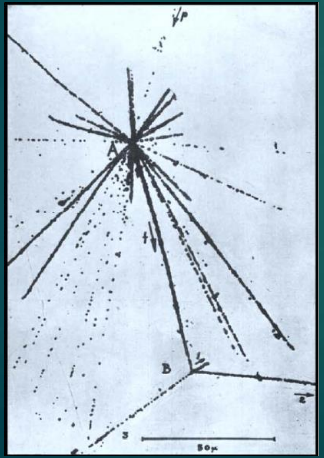
HIC: Hypermatter production

Hypernuclei – strange nuclear systems (S=-1, -2, …)

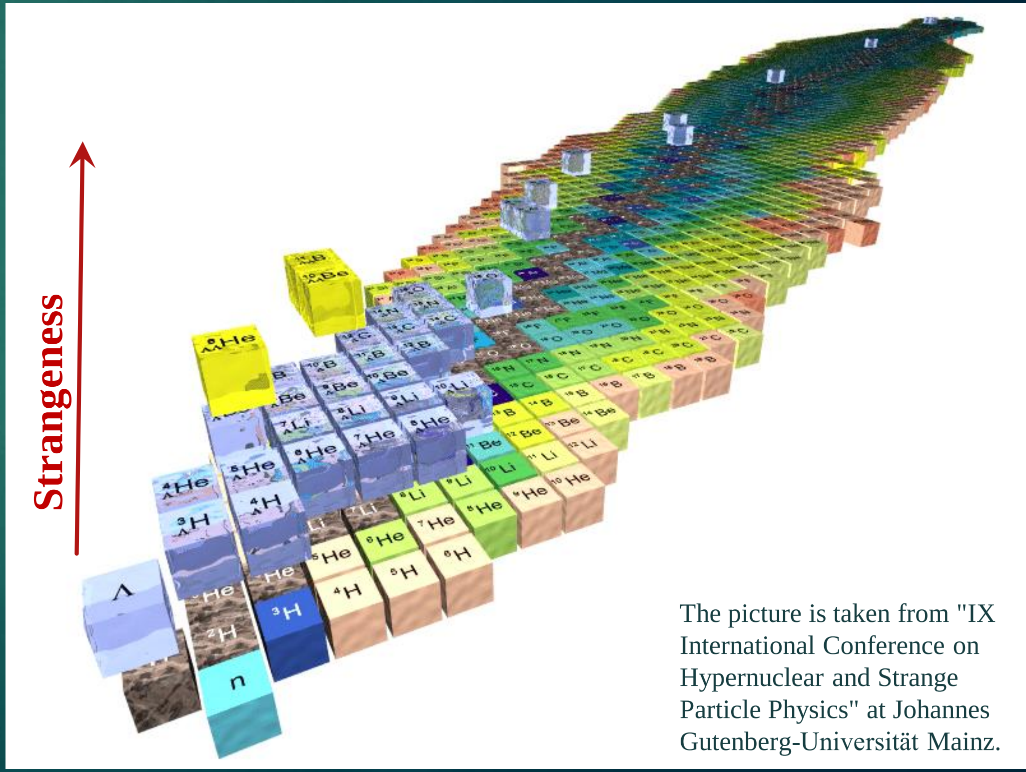
- Contain one (or more) hyperons (Λ, Σ or Ξ) instead of a nucleon
- Give access to the third dimension of the nuclear chart (strangeness)
- Lifetimes close to free Λ (weak decay)
- Precise information on *YN* interaction: nuclear EOS, astrophysics
- Hypernuclei ground, excited states and life times: critical assessments for QCD calculations and model predictions
- Production mechanism of bound states with hyperons: coalescence versus spectators-participants interactions, exotic states, dibaryons

No hyperon target available. No hyperon beam available. However, *YN* and *YY* interaction can be investigated: hypernuclei is micro-laboratory with protons, neutrons and hyperon

Duality: Nuclear ⟷ Particle Physics



The first hypernuclear measurement by Danysz and Pniewski in 1952 from a cosmic ray emulsion event.

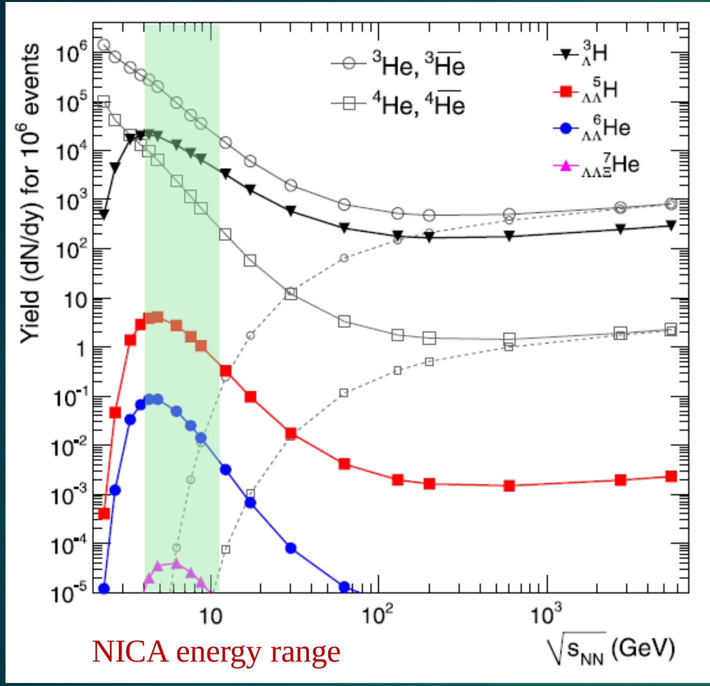


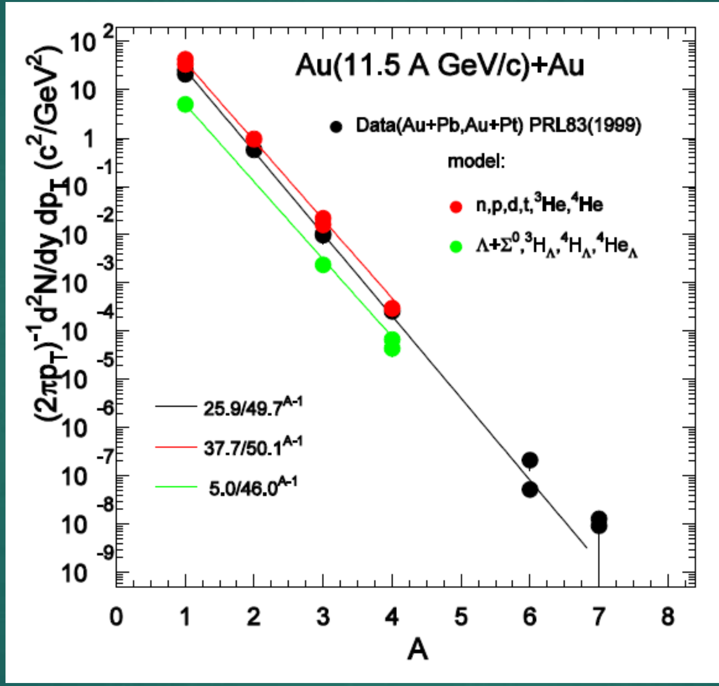
The picture is taken from "IX International Conference on Hypernuclear and Strange Particle Physics" at Johannes Gutenberg-Universität Mainz.

HIC: Multy-hypernuclear production

Statistical model:
A.Andronic, P.Braun-Munzinger, J.Stachel, H.Stocker
Physics Letters B 697 (2011)

DCM-QGSM model:
K.Gudima, V.Toneev Journal of Nuclear Physics, 42 (1985) 3





Expected yields (Stage'2)

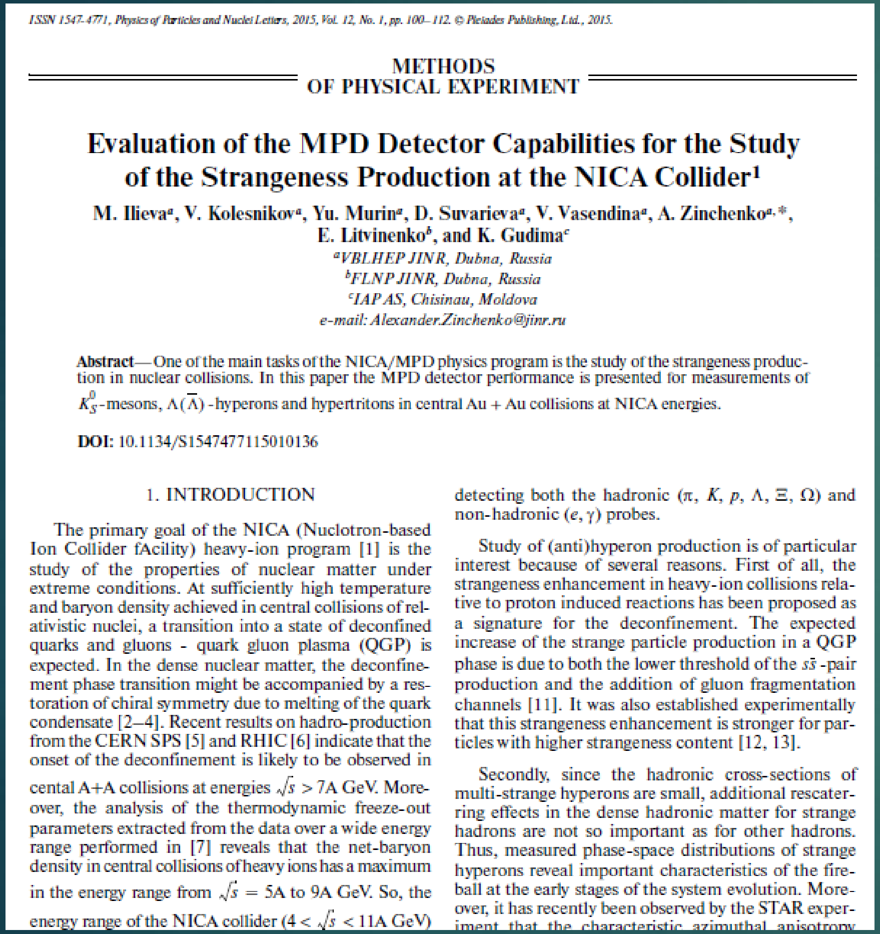
$^{3}_{\Lambda}H$ for MPD (10 weeks) @ 5 GeV: $\mathbf{9 \cdot 10^5}$
$^{4}_{\Lambda}He$ for MPD (10 weeks) @ 5 GeV: $\mathbf{1 \cdot 10^5}$

- ***In heavy-ion reactions:*** production of hypernuclei through coalescence of Λ with light frafments
- ***Maximal yield*** predicted for $\sqrt{s_{NN}}$ = 4-5 GeV (statistical model)

⟶ NICA energy range is ideally suited for the search of (duble) hypernuclei

Main goal:

– realistic hypernuclei reconstruction with realistic MPD performance



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METHODS
OF PHYSICAL EXPERIMENT

Evaluation of the MPD Detector Capabilities for the Study of the Strangeness Production at the NICA Collider[1]

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Abstract—One of the main tasks of the NICA/MPD physics program is the study of the strangeness production in nuclear collisions. In this paper the MPD detector performance is presented for measurements of K_S^0-mesons, $\Lambda(\bar{\Lambda})$-hyperons and hypertritons in central Au + Au collisions at NICA energies.

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1. INTRODUCTION

The primary goal of the NICA (Nuclotron-based Ion Collider fAcility) heavy-ion program [1] is the study of the properties of nuclear matter under extreme conditions. At sufficiently high temperature and baryon density achieved in central collisions of relativistic nuclei, a transition into a state of deconfined quarks and gluons - quark gluon plasma (QGP) is expected. In the dense nuclear matter, the deconfinement phase transition might be accompanied by a restoration of chiral symmetry due to melting of the quark condensate [2–4]. Recent results on hadro-production from the CERN SPS [5] and RHIC [6] indicate that the onset of the deconfinement is likely to be observed in cental A+A collisions at energies $\sqrt{s} > 7A$ GeV. Moreover, the analysis of the thermodynamic freeze-out parameters extracted from the data over a wide energy range performed in [7] reveals that the net-baryon density in central collisions of heavy ions has a maximum in the energy range from $\sqrt{s} = 5A$ to $9A$ GeV. So, the energy range of the NICA collider ($4 < \sqrt{s} < 11A$ GeV) detecting both the hadronic (π, K, p, Λ, Ξ, Ω) and non-hadronic (e, γ) probes.

Study of (anti)hyperon production is of particular interest because of several reasons. First of all, the strangeness enhancement in heavy-ion collisions relative to proton induced reactions has been proposed as a signature for the deconfinement. The expected increase of the strange particle production in a QGP phase is due to both the lower threshold of the $s\bar{s}$-pair production and the addition of gluon fragmentation channels [11]. It was also established experimentally that this strangeness enhancement is stronger for particles with higher strangeness content [12, 13].

Secondly, since the hadronic cross-sections of multi-strange hyperons are small, additional rescattering effects in the dense hadronic matter for strange hadrons are not so important as for other hadrons. Thus, measured phase-space distributions of strange hyperons reveal important characteristics of the fireball at the early stages of the system evolution. Moreover, it has recently been observed by the STAR experiment that the characteristic azimuthal anisotropy

First hypernuclei simulation with early version of MPD and simplified track reconstruction in TPC

Software development:

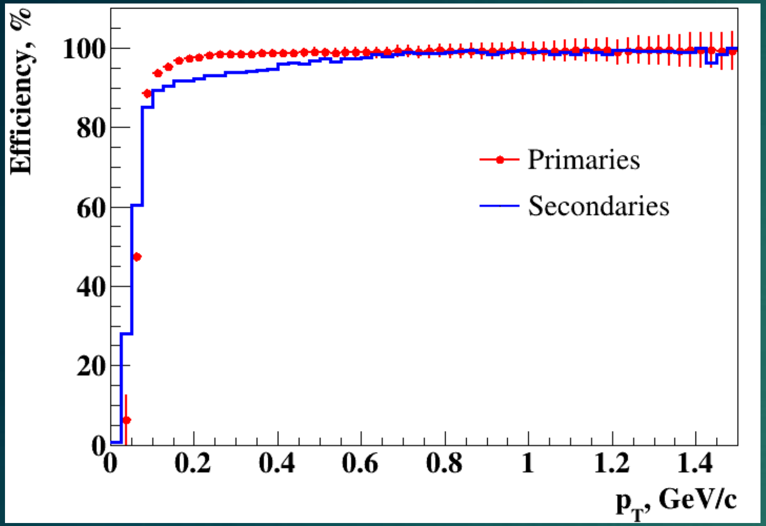
Towards a realistic simulation of the MPD / NICA

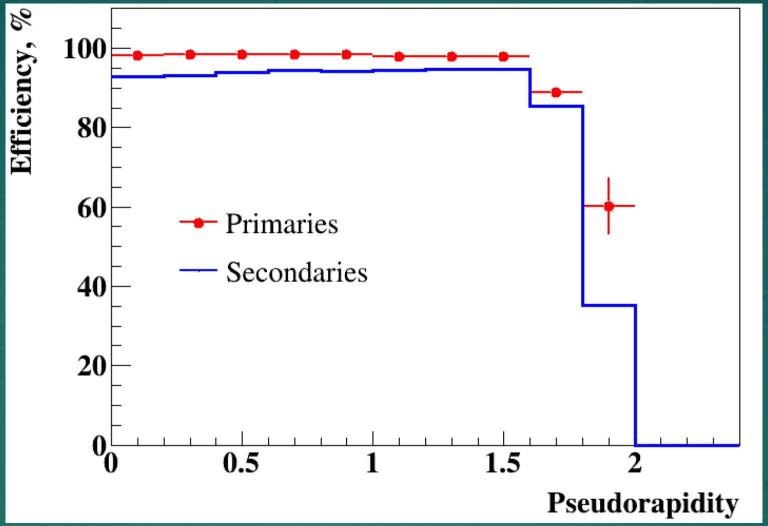
- реалистичное описание отклика детекторов , создание и настройка алгоритмов реконструкции сигналов в детекторах
- реалистичная процедура реконструкции треков в TPC
- описание ионизационных потерь в газе TPC на основе моделирования в Garfield++, которое согласуются с данными STAR
- новая реалистичная идентификация электронов, адронов и легких ядер в TPC и TOF

Software requirements for hypernuclei simulation:

- Качественная реконструкция треков адронов и легких ядер
- Хорошее восстановление первичной вершины и вершины распада
- Высокая эффективность идентификации как адронов, так и легких ядер

MPD tracking tuning

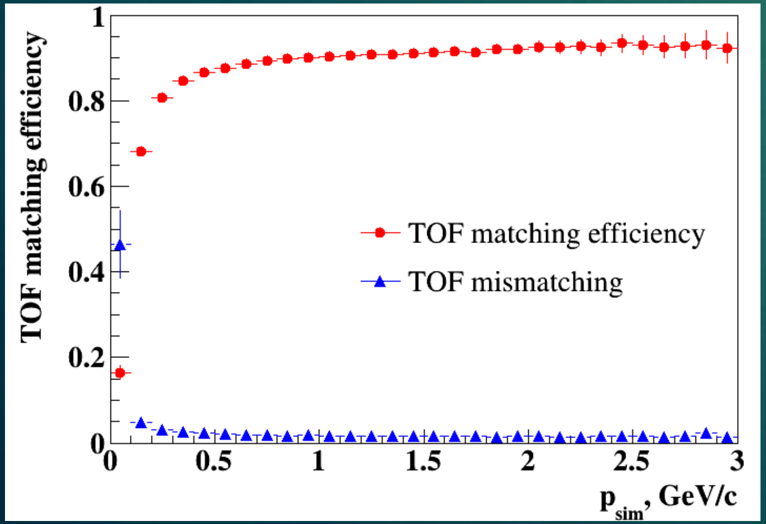


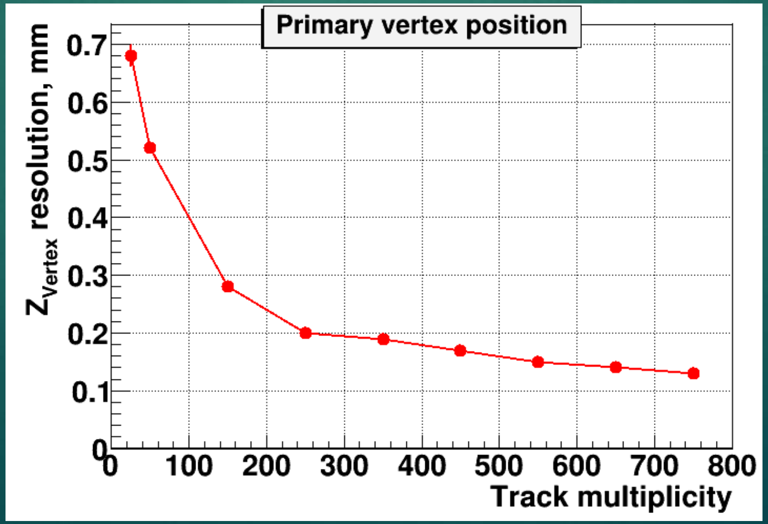


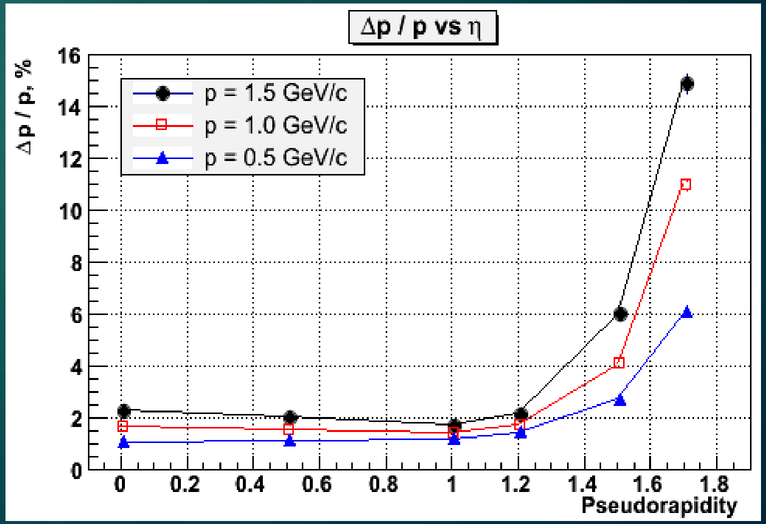
More details in A. ZInchanko`s talk

Based on realistic event simulation within the MPDRoot framework

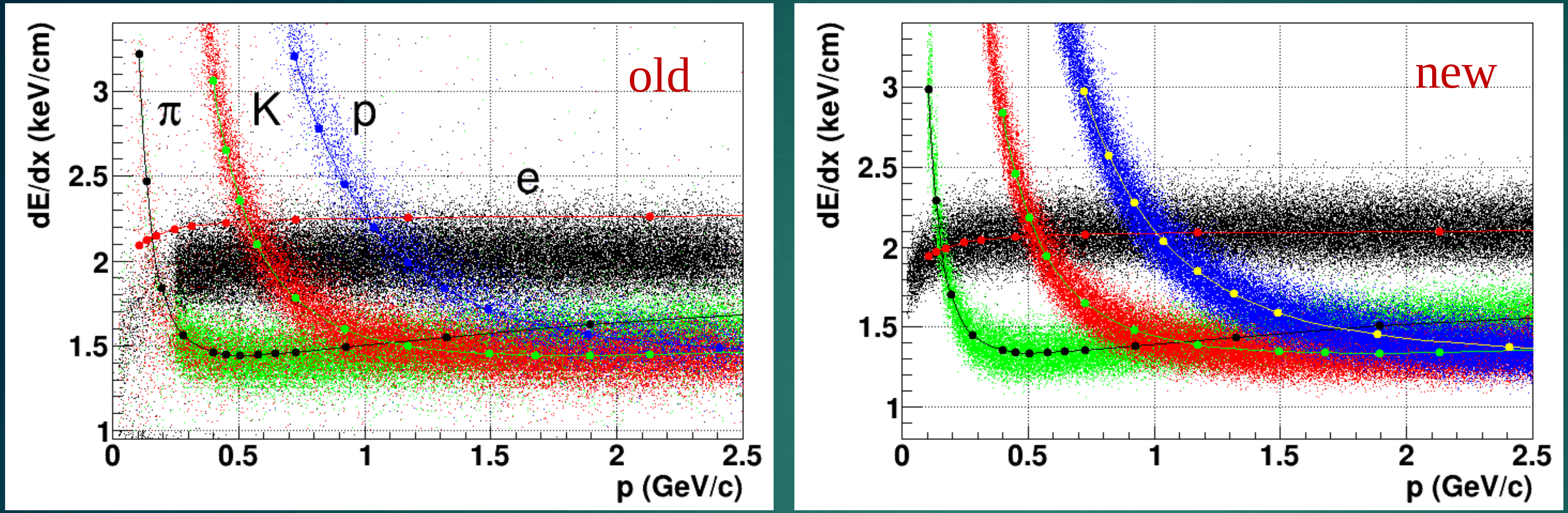
- High tracking efficiency over the reaction phase-space
- Good vertexing







New *dEdx* in TPC



More details in I.Rufatov`s talk

dEdx vs momentum for TPC/MPD
Box generator (*e*, *π*, *K*, *p*);
Curves – STAR standard function
(Bicshel`s functions)
[NIM A558 (2006) 419-429]

	ALICE	STAR	MPD
Gas	85% *Ne* mixtures	P10	P10
N rows x pitch (mm):			
Inner pads	64 x 7.5 mm	13 x 12 mm	26 x 12 mm
Outer pads	64 x 10 mm	32 x 20 mm	27 x 18 mm
Outer-2 pads	32 x 32 mm	–	–
P10 mixture – 90% *Ar*, 10% methane			

- From GEANT3 to Garfield++ parameterization of energy loss in P10 gas mixtures in TPC
- Good agreement with STAR data

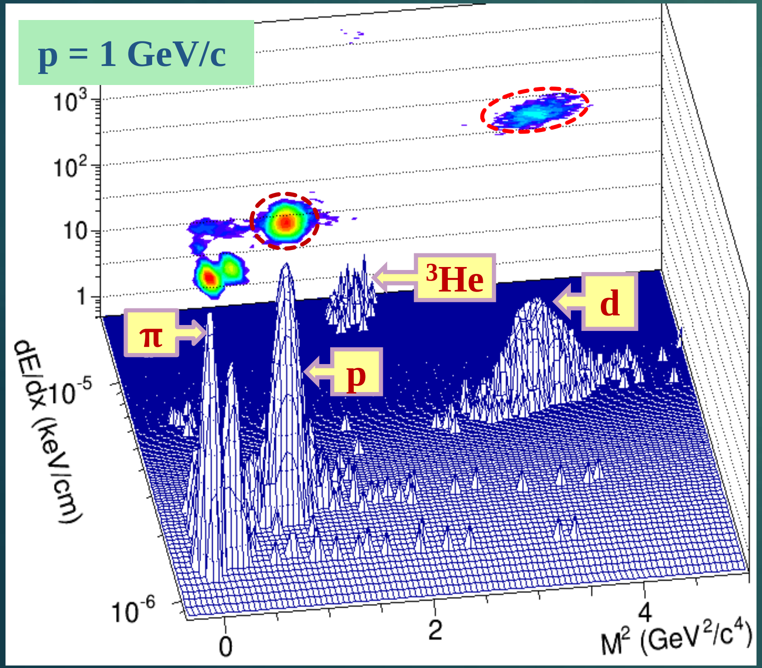
Comparison of TPC in ALICE, STAR, MPD

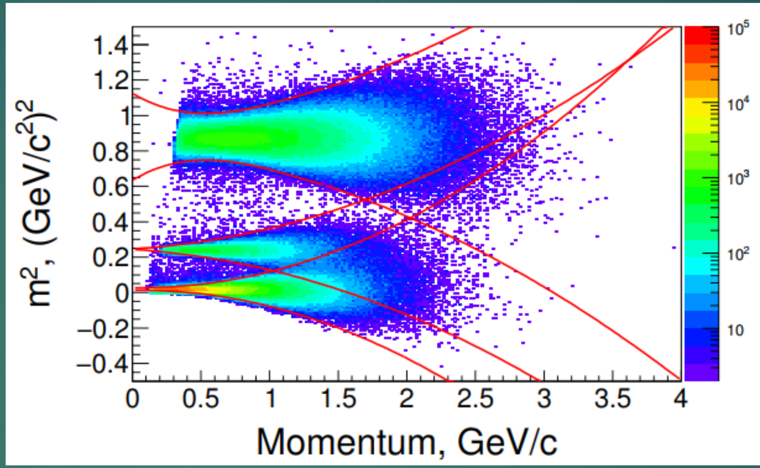
New PID performance

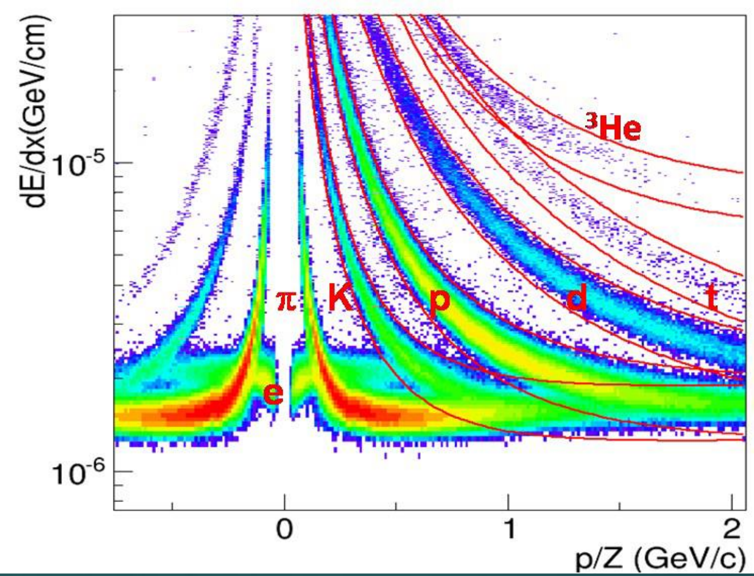
Combined (dE/dx+TOF) PID for hadrons provides π/K up to 2 GeV/c and K/p up 3 GeV/c

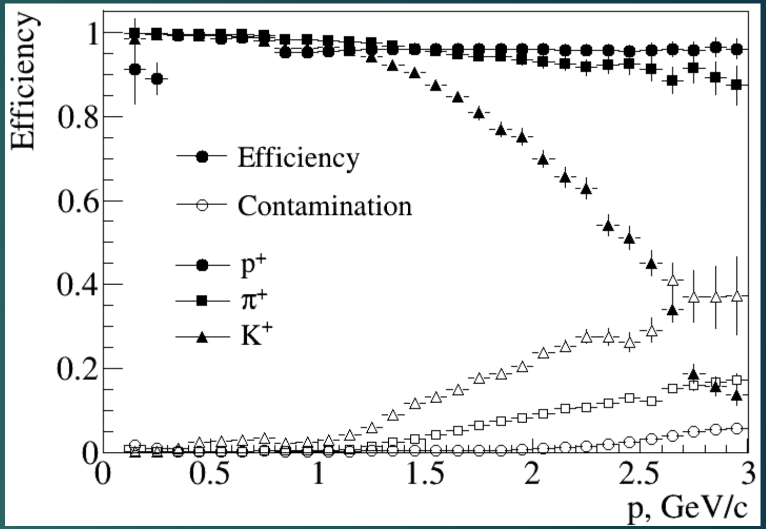
Mass square calculated using the measurements of momentum (p), time-of-flight (T) and trajectory length (L):

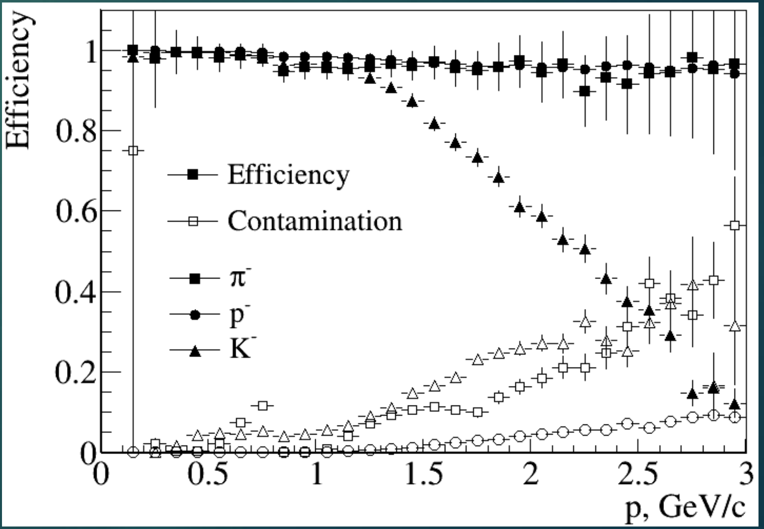
$$m^2 = p^2\left(\frac{c^2T^2}{L^2} - 1\right)$$







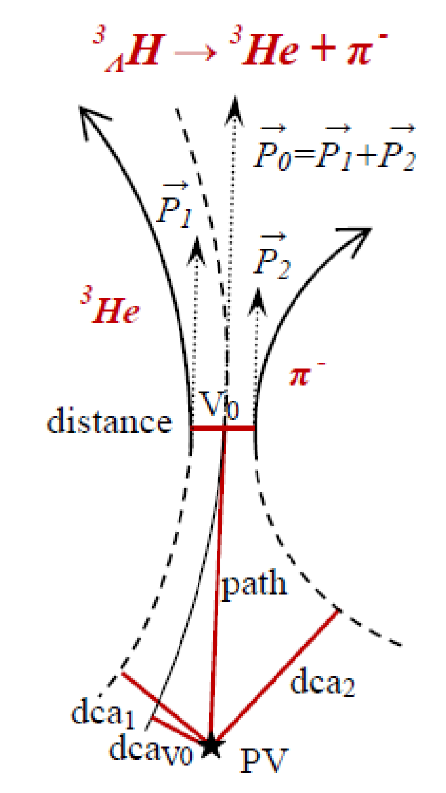


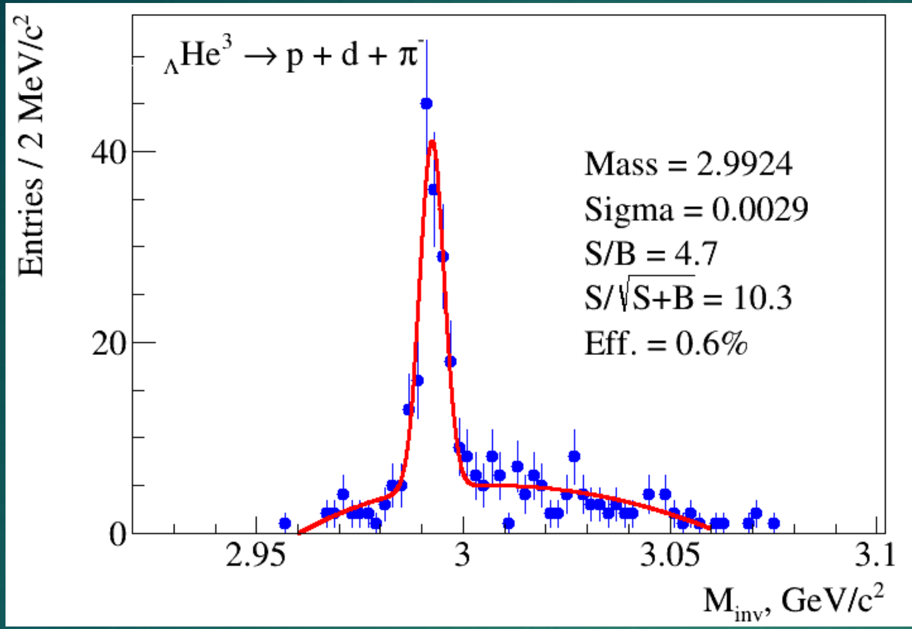


Data set

- **Generators:** DCM-QGSM, Au+Au @ 5 GeV, central, 0.9M events, signal mixing technique
- **Detectors:** start version of MPD with up-to-date TPC & TOF
- **Cluster / hit reconstruction:** precluster finder *(group of adjacent pixels in time bin – pad space*); hit finder *("peak-and-valley" algorithm either in time bin – pad space (for simple topologies) or in time-transverse coordinate pixel space after Bayesian unfolding (for more complicated topologies))*→ COG around local maxima
- **Track reconstruction:** two-pass Kalman filter with track seeding using outer hits (*1st pass*) or leftover inner hits (*2nd pass*)
- **Track acceptance criterion:** $|\eta| < 1.3$, $N_{hits} \geq 10$
- **NEW energy loss simulation in gas TPC:** with Garfield++
- **NEW PID:** *dE/dx* in TPC & m^2 in TOF (n-sigma method)
- **Vertex reconstruction:** Kalman filter based formalism working on MpdParticle objects

Hypertriton reconstruction





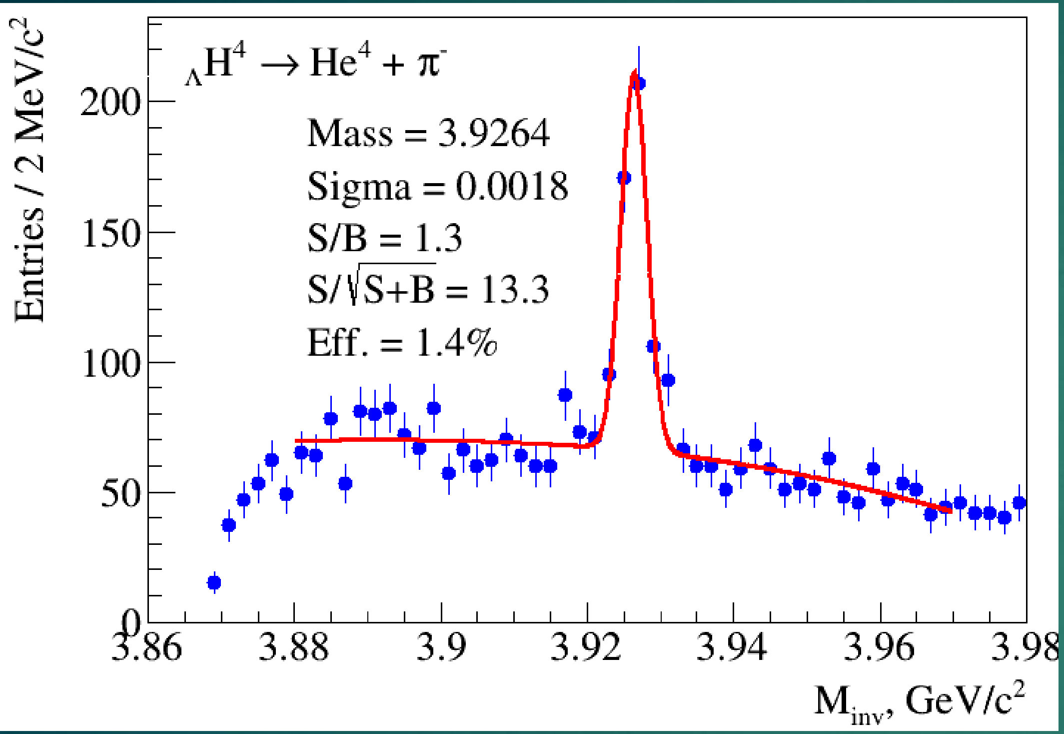
Mesonic decay of $^3_\Lambda H$: Event topology

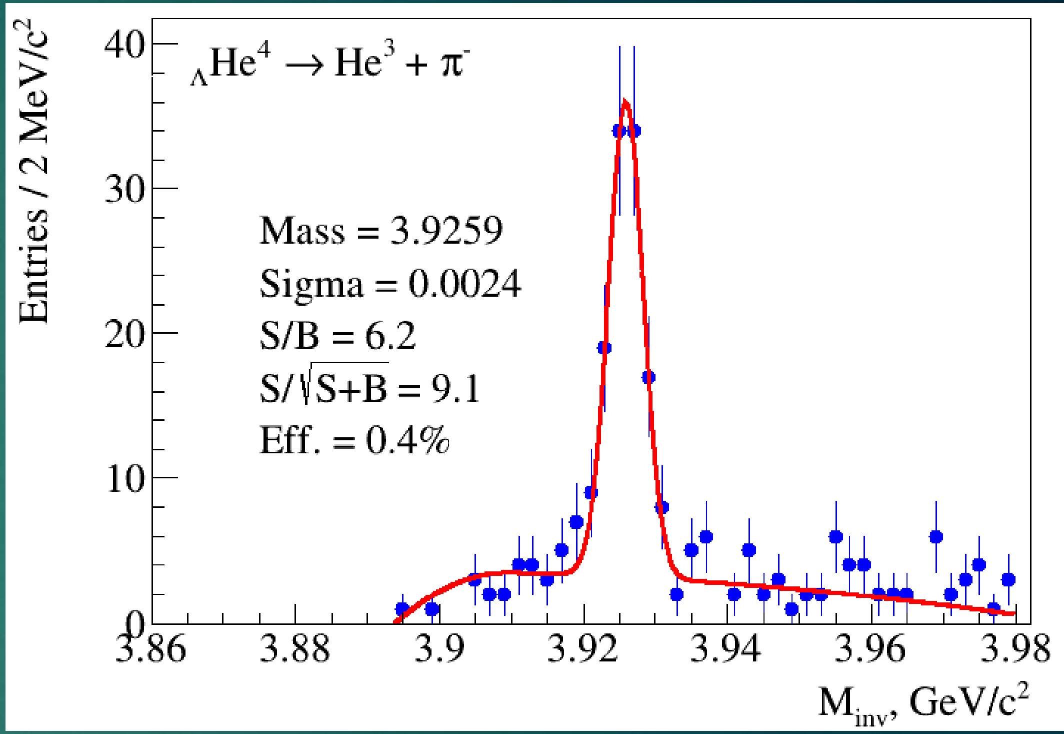
- PV – primary vertex
- V_0 – vertex of hyperon decay
- dca – distance of the closest approach
- path – decay length

Table: $^3_\Lambda H$ decays

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

$_{\Lambda}H^4$ and $_{\Lambda}He^4$ reconstruction





Mesonic decays of $_{\Lambda}H^4$ and $_{\Lambda}He^4$

Outlook and Acknowledgements

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Thank you for attention!