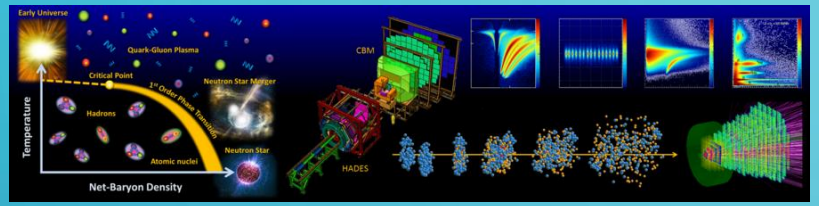
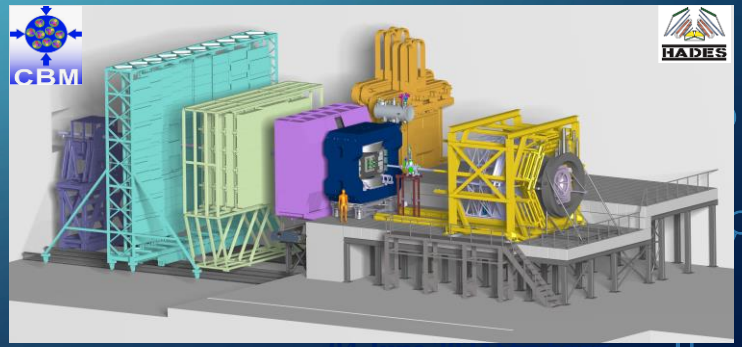
PERSPECTIVES ON (MULTI-STRANGE) HYPERNUCLEI PHYSICS WITH THE CBM EXPERIMENT AT FAIR

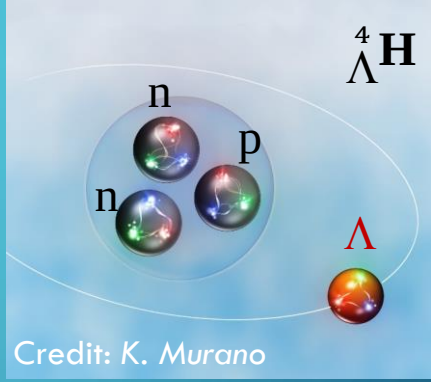
Iouri Vassiliev, i.vassiliev@gsi.de, *for the CBM Collaboration*



https://edms.cern.ch/ui/file/2893949/LATEST/FAIR*.mp4



Hypernuclei



- Precise measurements of hypernuclei lifetime (**YN** & **YY** interaction)
- Strangeness in high density nuclear matter, EoS for NS, Hadronic phase of HI collisions
- Measurement of branching ratios of hypernuclei decays, Dalitz plots for 3-body decays
  - hypernuclei internal structure
- Measurements of B_Λ in the hypernuclei
  - direct access to the hyperon-nucleon **YN** interaction
- Observation of double lambda hypernuclei can provide an access to the **YY** forces

Motivation

Advantages of CBM:

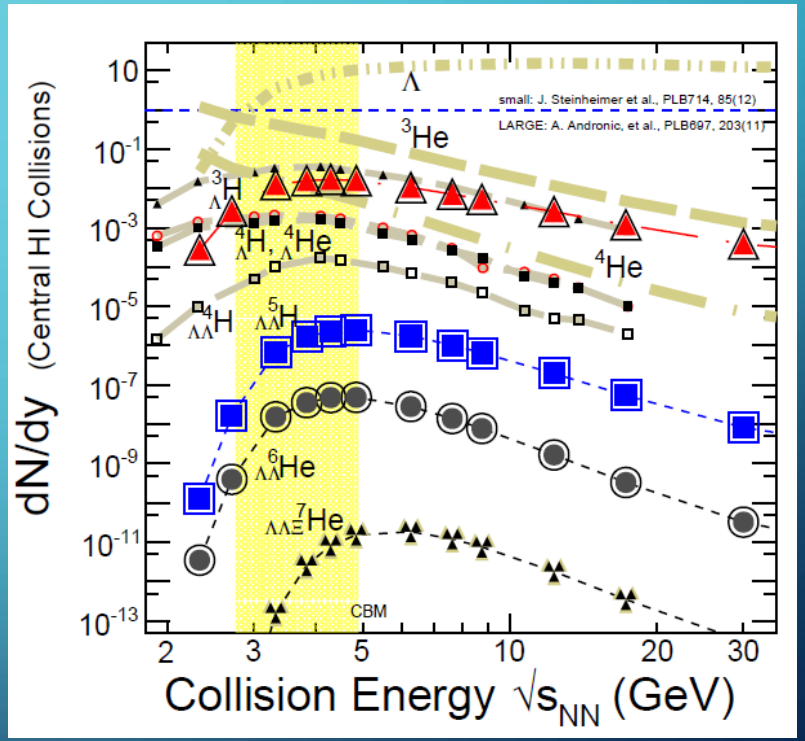
• According to the theoretical predictions energy region of CBM is preferable for production of hypernuclei

(confirmed by STAR BES-II & HADES data!)

• **Complex topology of decays** can be identified in CBM with a low background (KFParticle Finder).

• The detector design is well suited for identification of produced hypersystems.

• **High interaction rates**, optimal collision energies and clean identification will allow to search for ΛΛ-hypernuclei.



Motivation

Advantages of CBM:

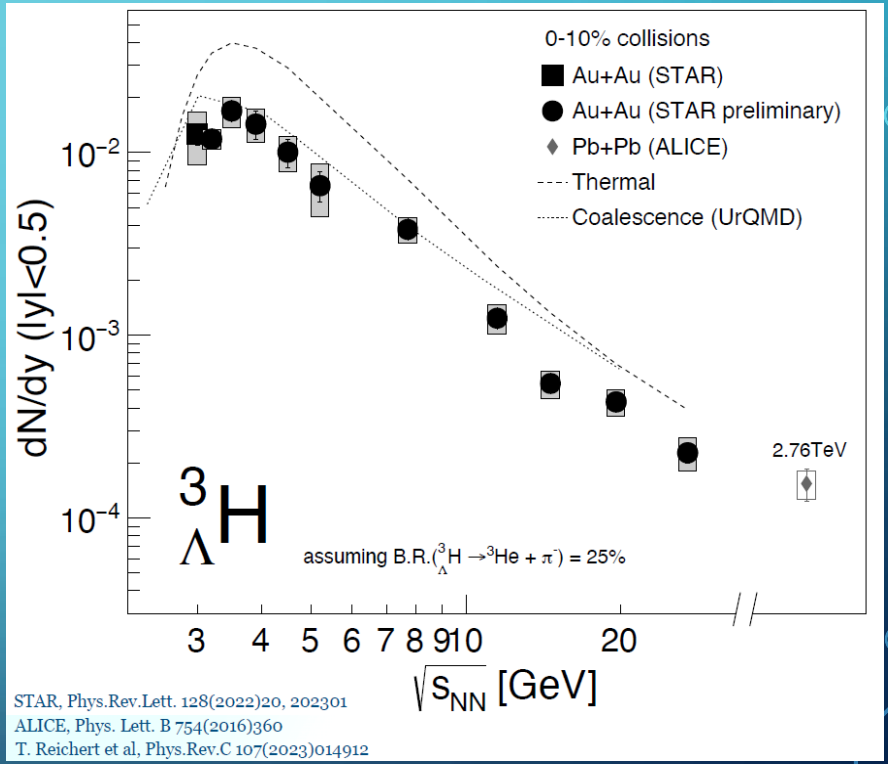
• According to the theoretical predictions energy region of CBM is preferable for production of hypernuclei

(confirmed by STAR BES-II & HADES data!)

• **Complex topology of decays** can be identified in CBM with a low background (KFParticle Finder).

• The detector design is well suited for identification of produced hypersystems.

• **High interaction rates**, optimal collision energies and clean identification will allow to search for ΛΛ-hypernuclei.



STAR, Phys.Rev.Lett. 128(2022)20, 202301
ALICE, Phys. Lett. B 754(2016)360
T. Reichert et al, Phys.Rev.C 107(2023)014912

Motivation

Advantages of CBM:

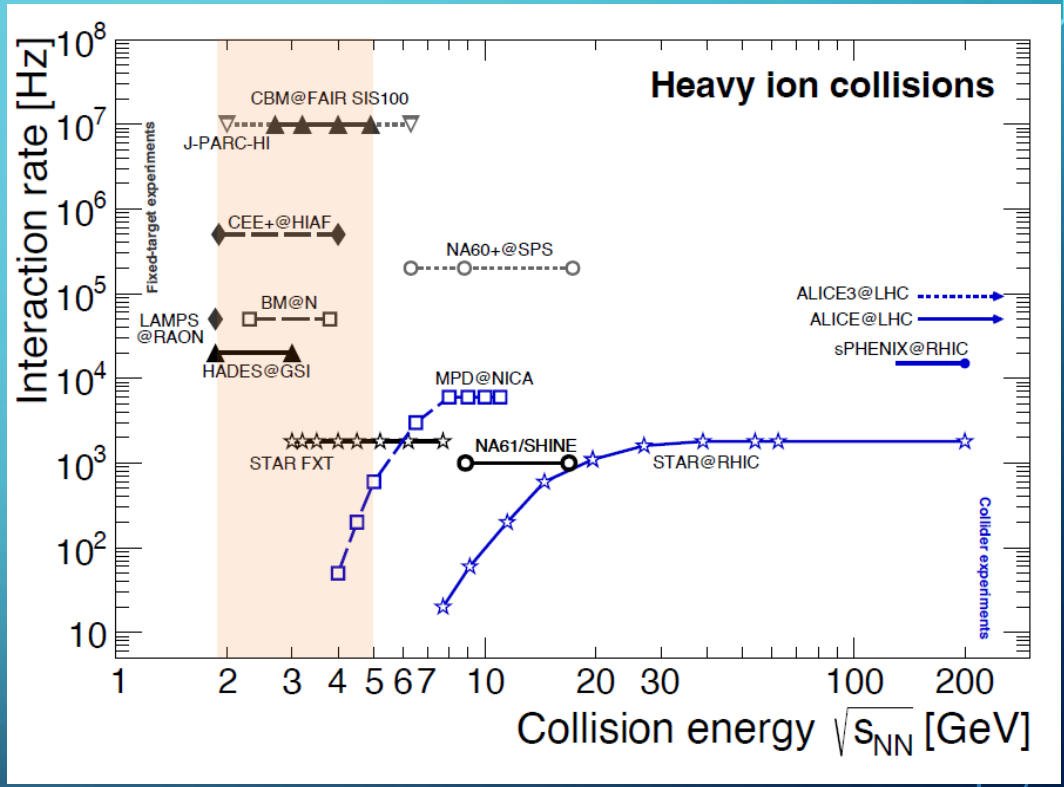
• According to the theoretical predictions energy region of CBM is preferable for production of hypernuclei

(confirmed by STAR BES-II & HADES data!)

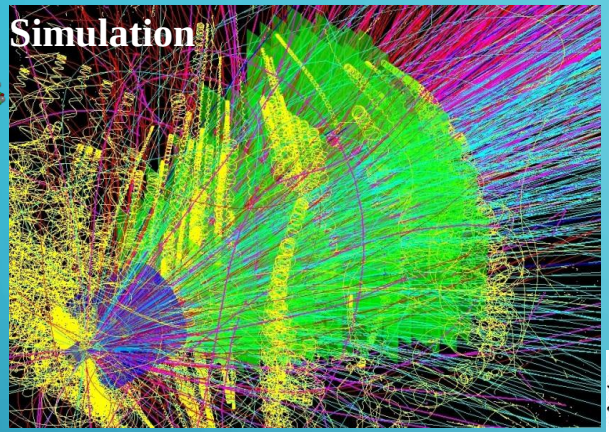
• **Complex topology of decays** can be identified in CBM with a low background (KFParticle Finder).

• The detector design is well suited for identification of produced hypersystems.

• **High interaction rates**, optimal collision energies and clean identification will allow to search for ΛΛ-hypernuclei.

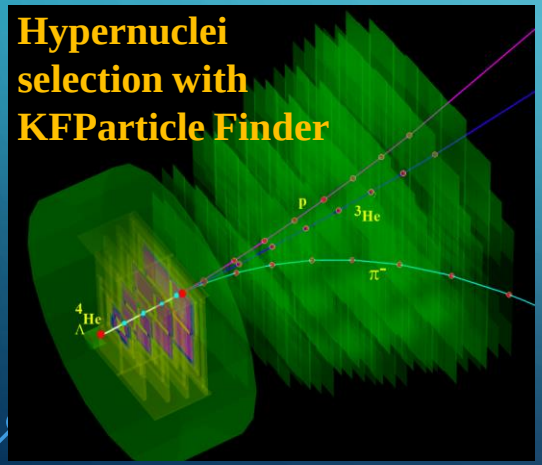


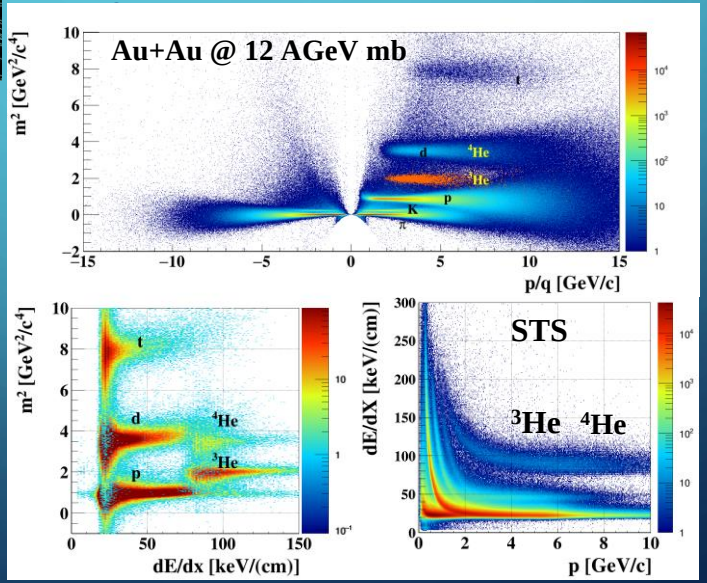
Tools: Models, Tracking & PID detectors and KFParticle Finder



- Several theoretical models like UrQMD and PHQMD are used.
- Track finder is based on the Cellular Automaton method.
- High efficiency for track reconstruction of more then **94%**, including fast (more then **90%**) and slow (more then **65%**) **secondary** tracks.
- **Time-based** track finder is developed, efficiency is stable with respect to the interaction rate.
- Low level of split and wrongly reconstructed (ghost) tracks.

@10 AGeV Au+Au mbias : 8ms/core 1 ms/core KFParticle Finder





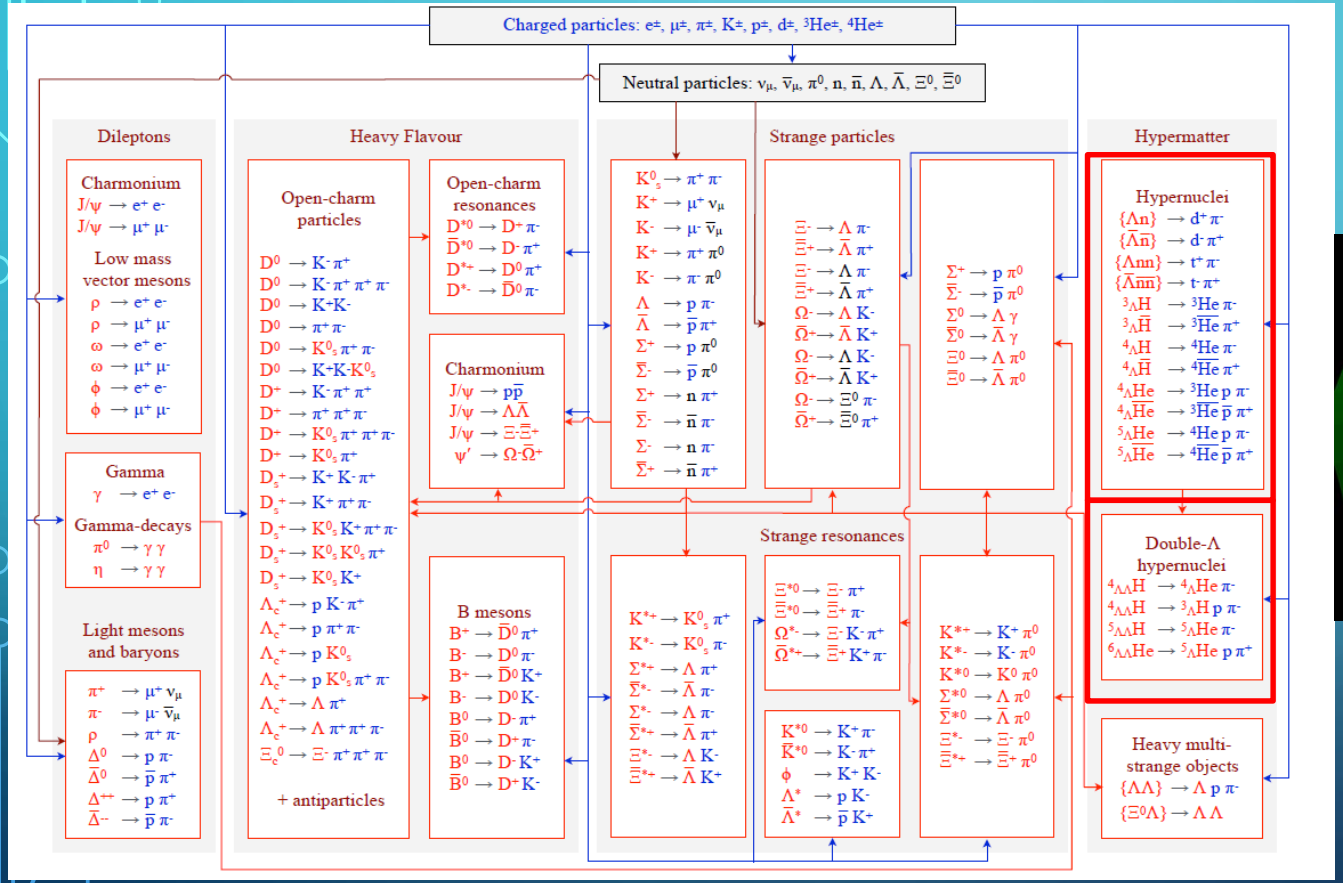
PID detectors:

ToF - hadron identification

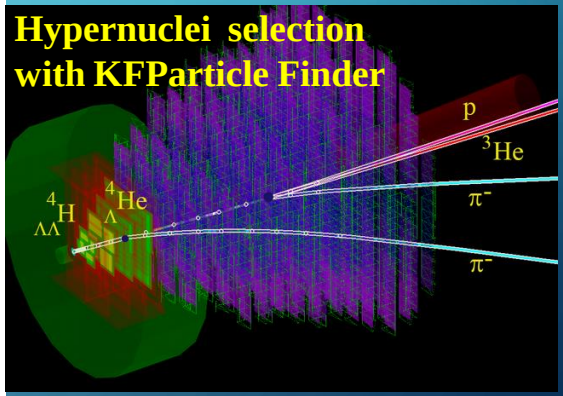
STS heavy fragments identification by dE/dX

TRD electron and heavy fragments identification

KFParticle Finder



- More than 250 decays. All decays are reconstructed in one go.
- Covariance matrix contains essential information about tracking and detector performance.



- **Complex topology of decays** can be identified in CBM with a low background

1. KF Particle Finder — **M. Zyzak**, "Online selection of short-lived particles on many-core computer architectures in the CBM experiment at FAIR," Dissertation thesis, Goethe University of Frankfurt, 2016, http://publikationen.ub.uni-frankfurt.de/frontdoor/index/index/docId/41428

PHQMD: Fragments & Hypernuclei at CBM energy range

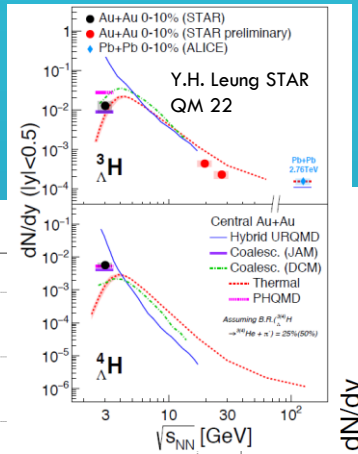
Parton-Hadron-Quantum-Molecular Dynamics - A Novel Microscopic N-Body Transport Approach for Heavy-Ion Collisions, Dynamical Cluster Formation and Hypernuclei Production

J. Aichelin, E. Bratkovskaya, A. Le Fevre, V. Kireyeu, V. Kolesnikov, Y. Leifels, V. Voronyuk, G. Coci, Susanne Gläßel

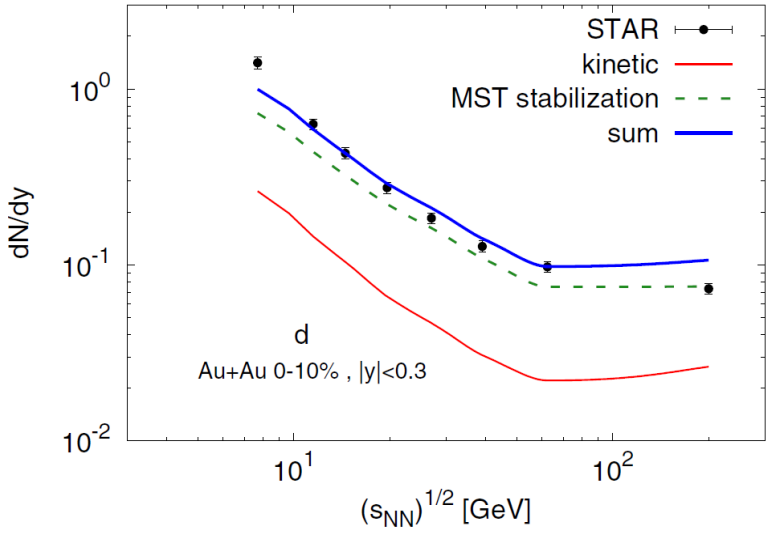
Phys.Rev.C 101 (2020) 4, 044905

J. Aichelin CPOD 2024

5M Au+Au events at $\sqrt{(s)}$ = 3 GeV



Excitation function dN/dy of deuterons at midrapidity



PHQMD: Fragments & Hypernuclei at CBM energy range

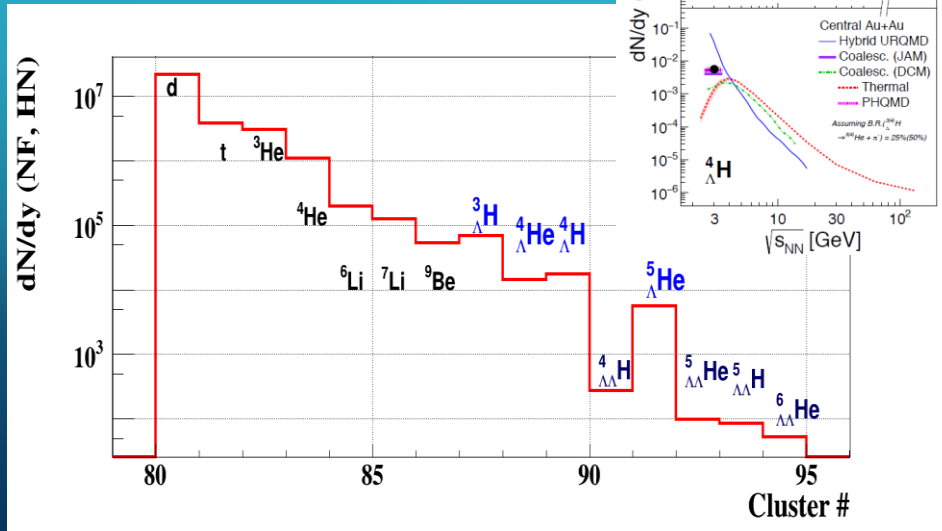
Parton-Hadron-Quantum-Molecular Dynamics - A Novel Microscopic N-Body Transport Approach for Heavy-Ion Collisions, Dynamical Cluster Formation and Hypernuclei Production

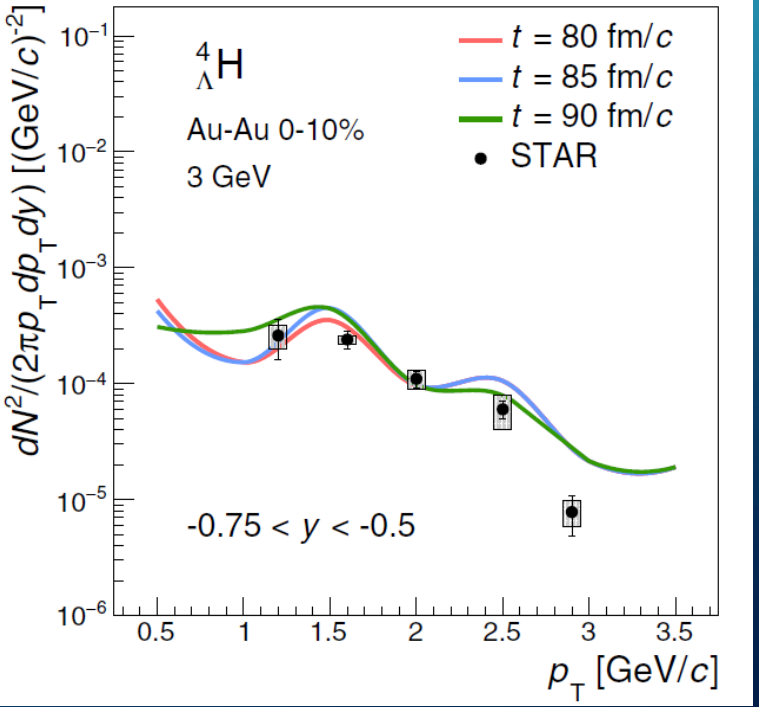
J. Aichelin, E. Bratkovskaya, A. Le Fevre, V. Kireyeu, V. Kolesnikov, Y. Leifels, V. Voronyuk, G. Coci, Susanne Gläßel

Phys.Rev.C 101 (2020) 4, 044905

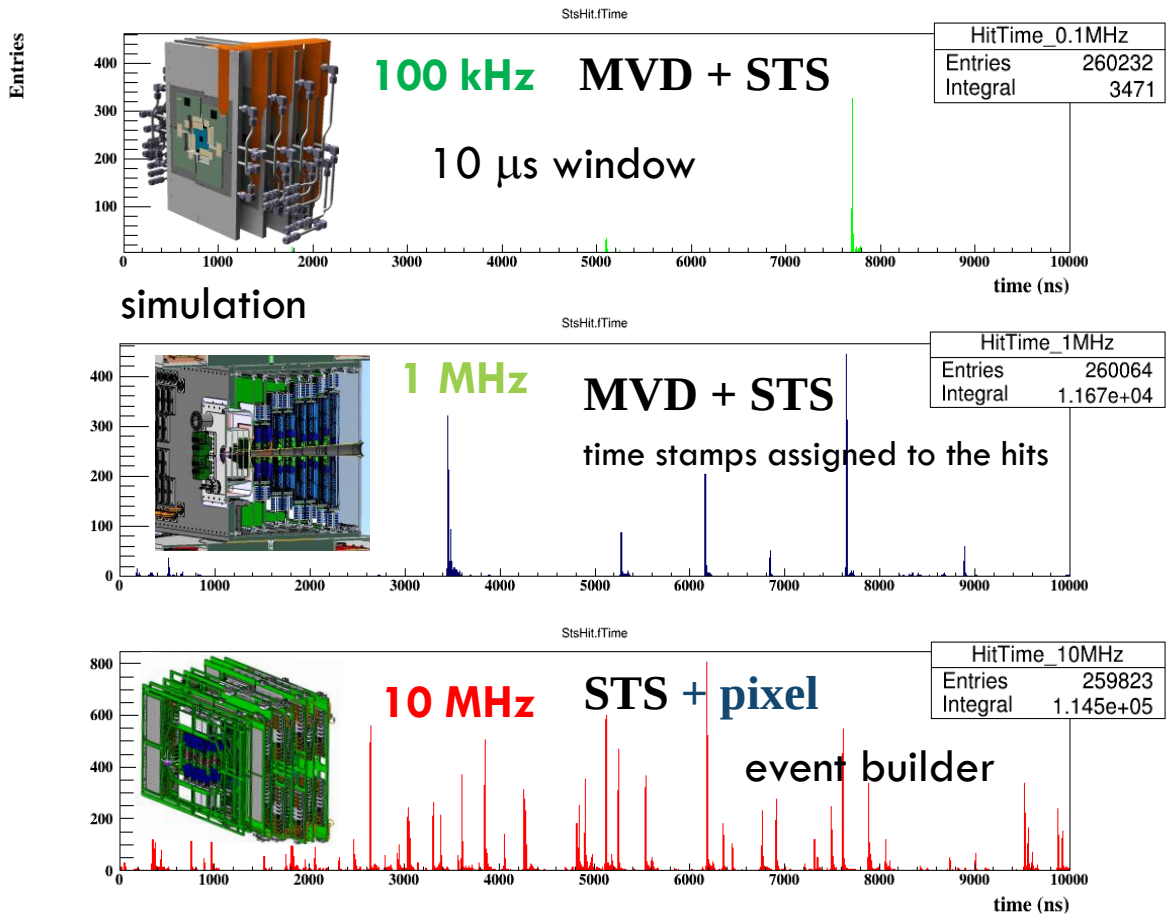
J. Aichelin CPOD 2024

5M Au+Au events at $\sqrt{(s)}$ = 3 GeV



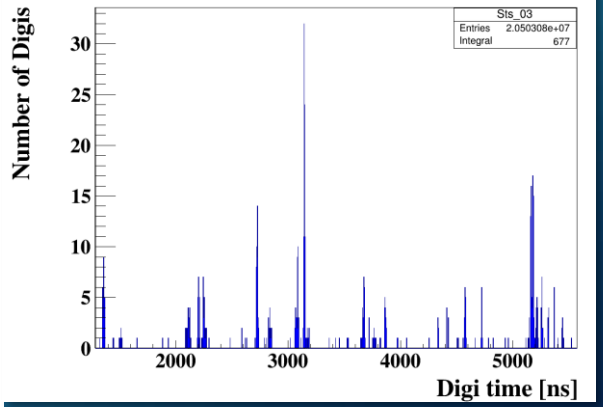


Tools for high rate scenario: event reconstruction with 4D tracking



Ni+Ni @ 1.93 AGeV mCBM 2022 run 2391

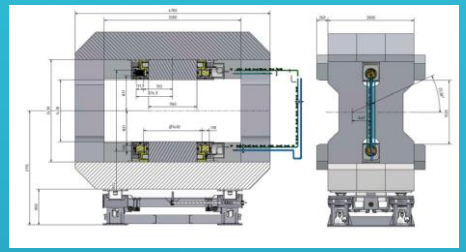
D. Ramirez



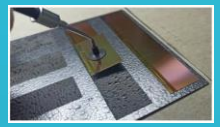
- mCBM experiment data allows us verify the time-based MC simulation

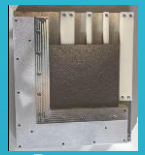
All CBM subsystems tested with mCBM and ready to series production

Superconducting dipole magnet
award of contract to Bilfinger Noell GmbH



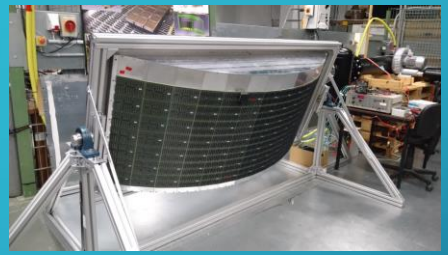
Micro Vertex Detector
sensor/module integration





Silicon Tracking System
> 100 modules need assembled

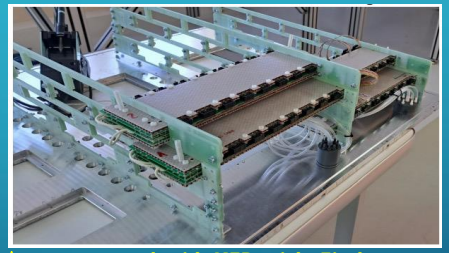
Ring Imaging Cherenkov detector
1 of 2 photo cameras ready
50% FEE produced



MUon CHamber system

Beam monitoring system

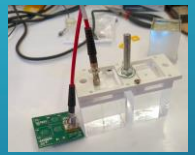
Transition Radiation Detector



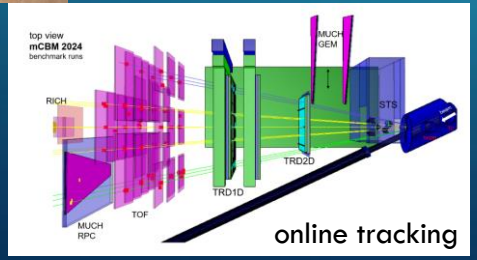
Λ reconstructed with KFParticle Finder

Time of flight detector

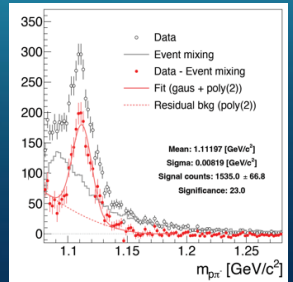
Forward Spectator Detector

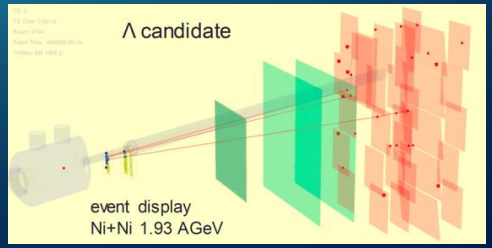


Prototype of CBM online data processing tests with mCBM



T. Galatyuk
CPOD 2024

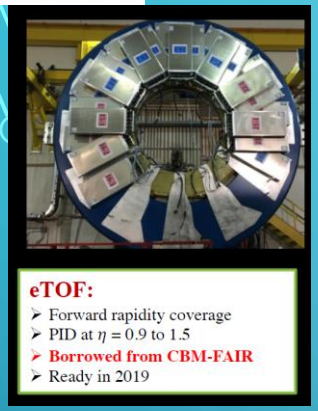




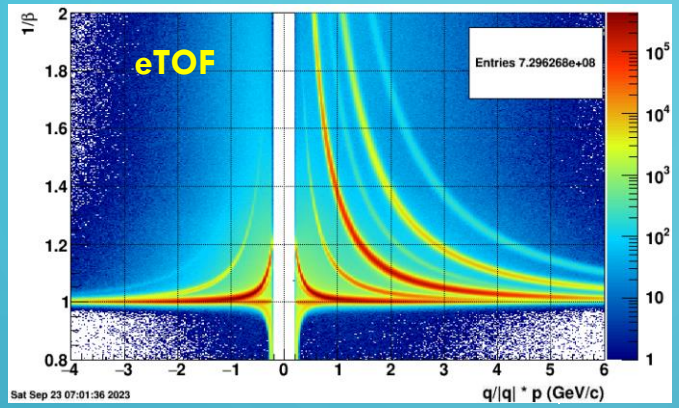
eTOF performance at STAR

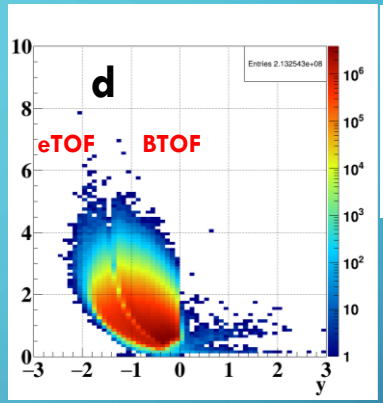
Yannick Söhngen

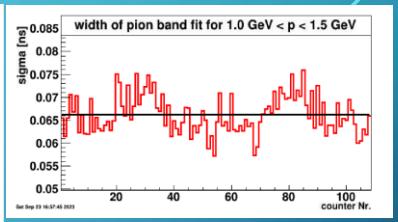
Run 2020 $\sqrt{s_{NN}}$ = 3.5 GeV

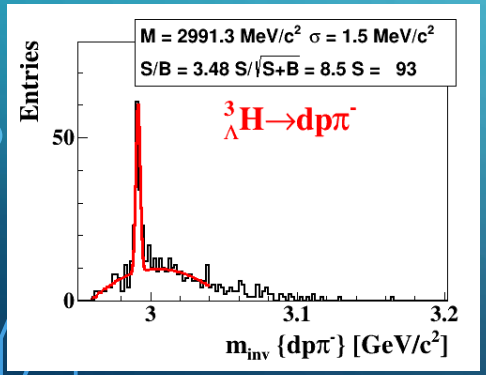


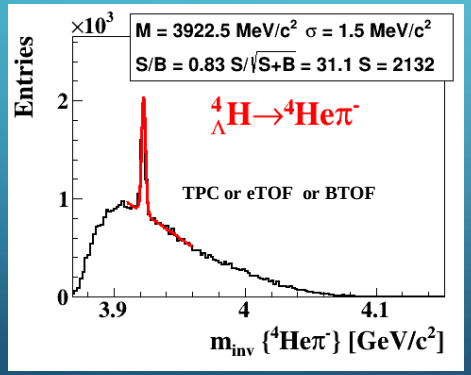
eTOF:
- Forward rapidity coverage
- PID at η = 0.9 to 1.5
- **Borrowed from CBM-FAIR**
- Ready in 2019

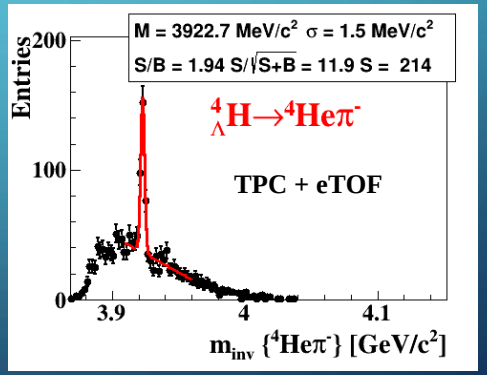






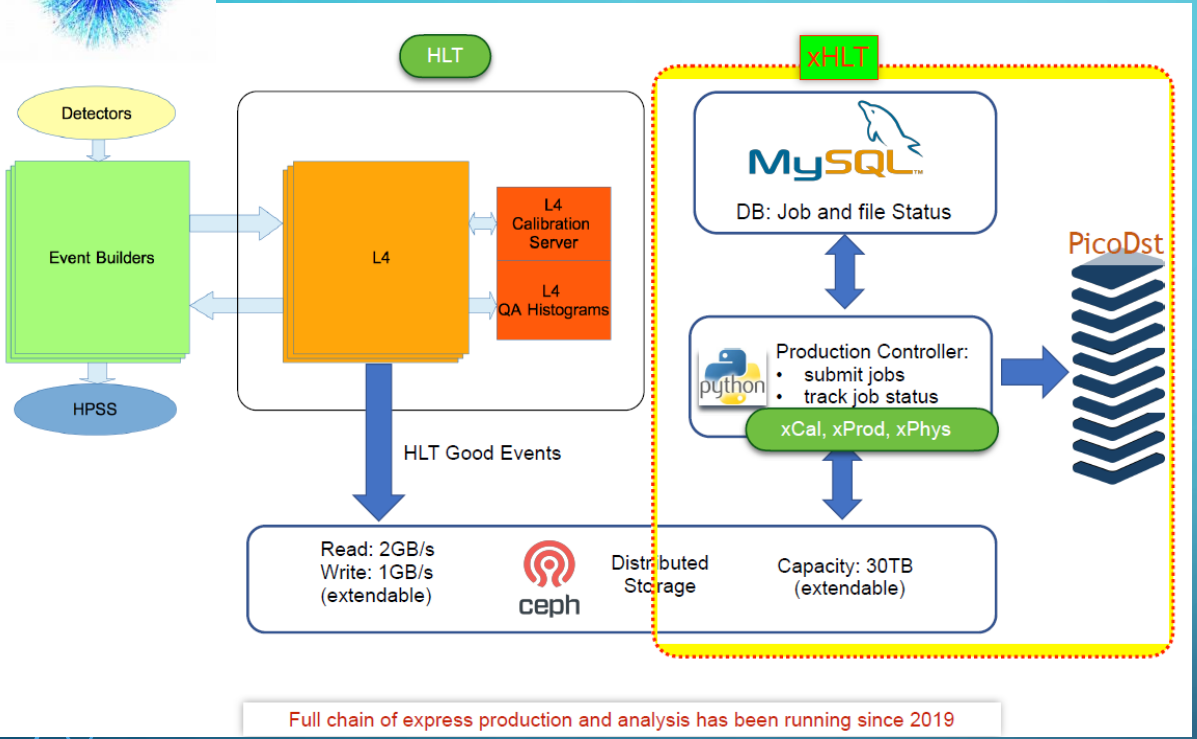






- About 30% more deuterons selected with eTOF
- low rapidity region covered by eTOF

Hypernuclei in STAR with Express Analysis

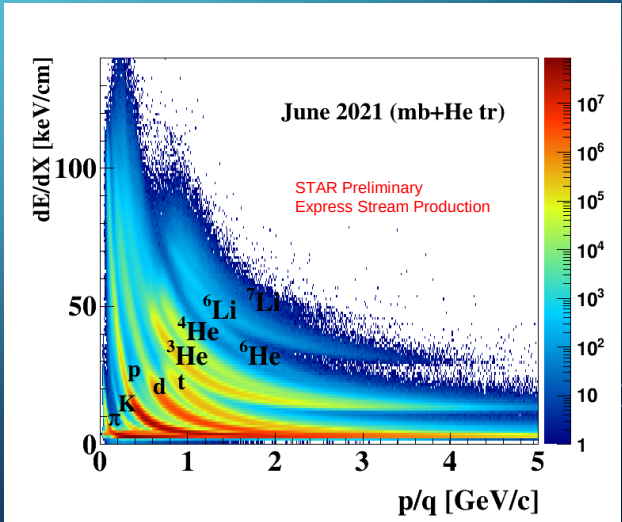


Full chain of express production and analysis has been running since 2019

Express Production (selection) jobs on HLT farm (300-500 job slots)

Trigger on He has been introduced to enhance **hypernuclei.**

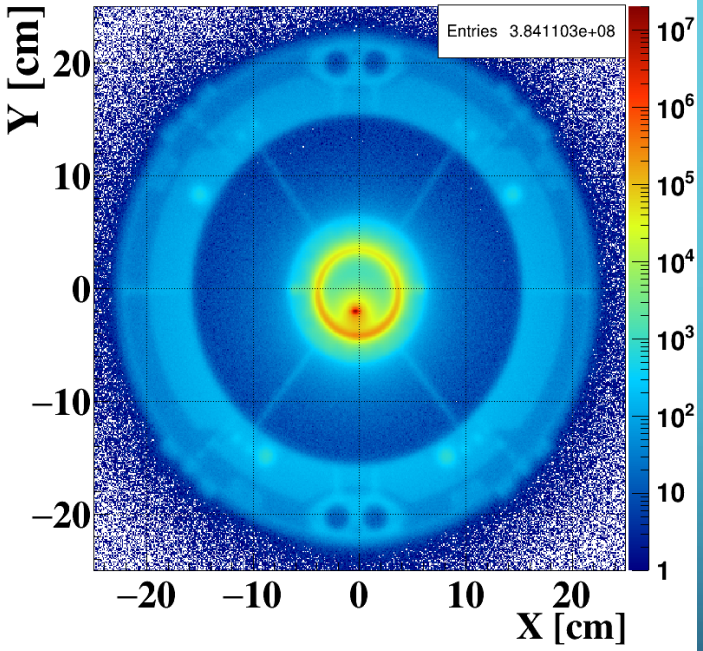
437M AuAu HLT triggered events at 3 GeV

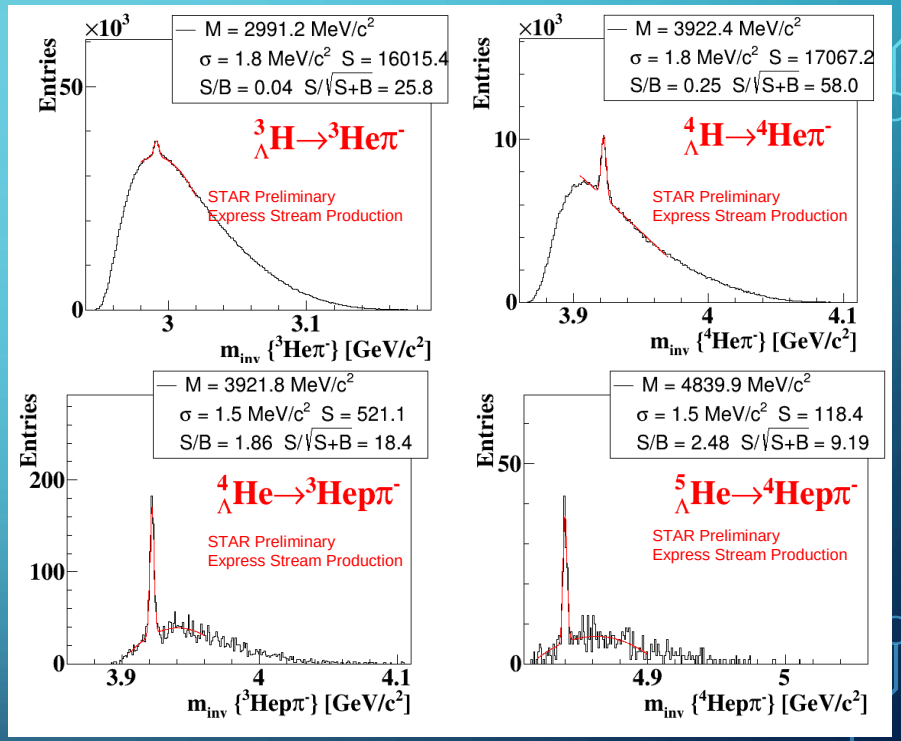


Save HLT good events to a local disk directly
PicoDst files produced in hours (collisions) or days (FXT) after data taking

Hypernuclei at 3 GeV online (express) reconstruction

437M AuAu HLT triggered events at 3 GeV



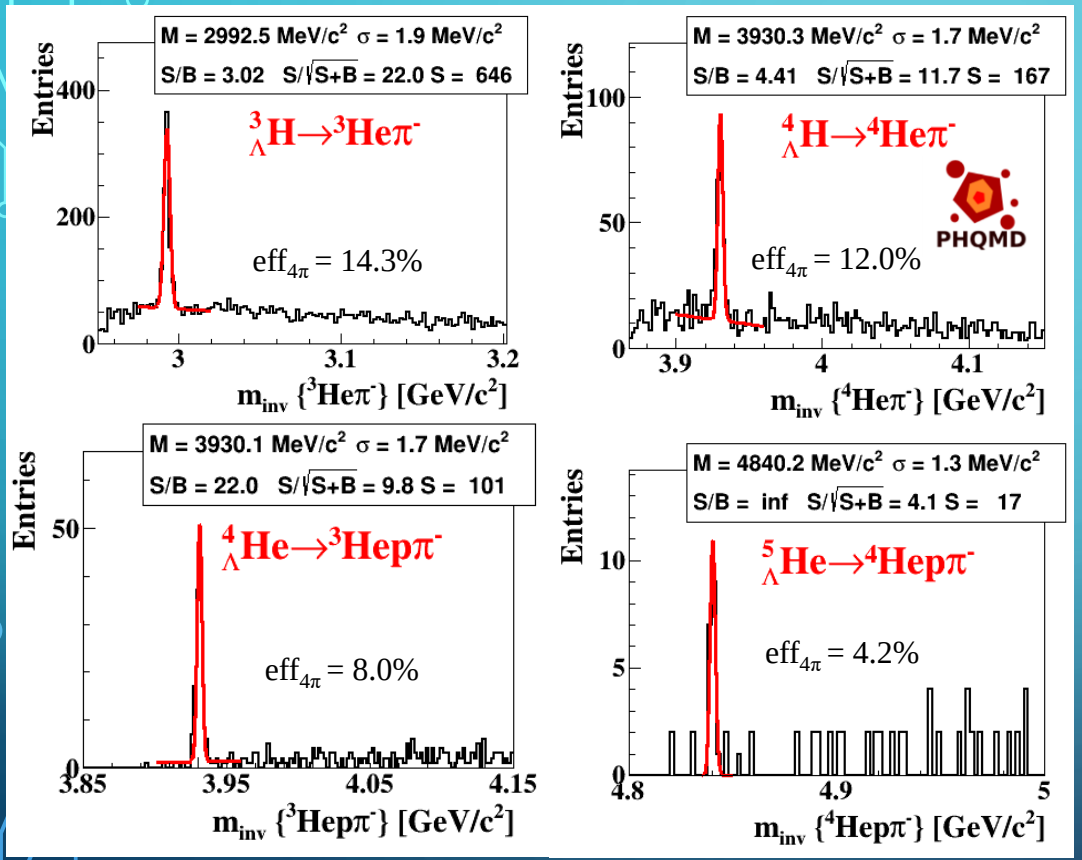


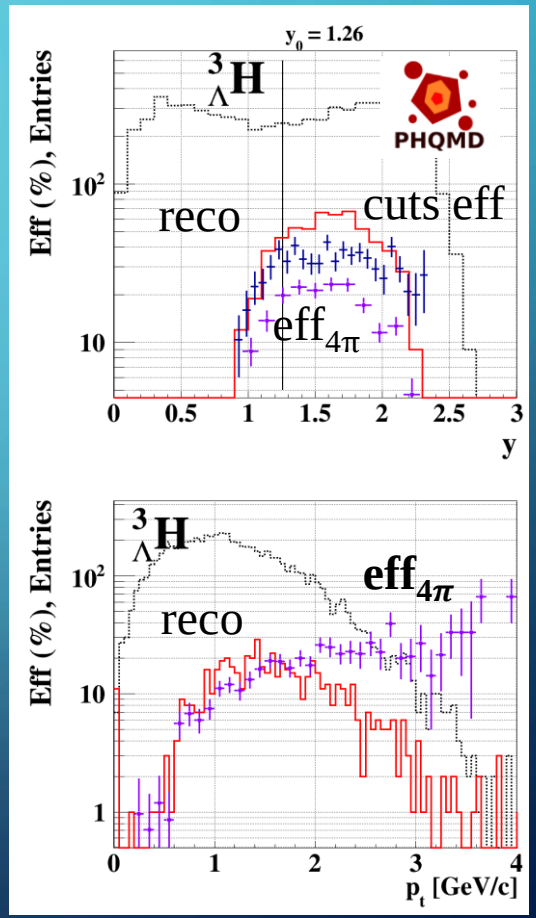
We reconstruct vertices from **pileup** and interaction with the pipe. Tracks from these vertices are **removed** from further consideration. The procedure allows to noticeably reduce the background in 3-body channels.

- The collected statistics is enough to measure yields, lifetimes and spectra of these hypernuclei

Single-Λ hypernuclei @ 3.5 GeV/c

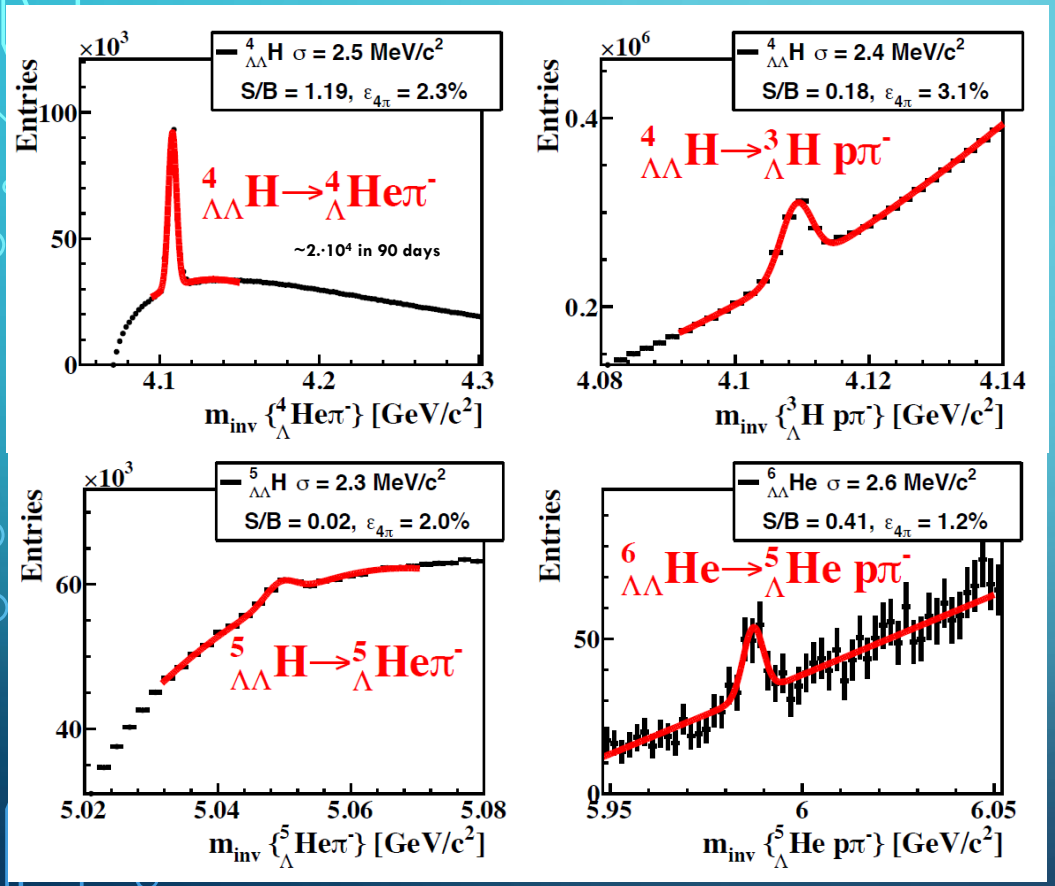
1M mbias events Au+Au at 3.5 GeV/c
10 sec (!) at 0.1MHz IR





CBM is sensitive to light hypernuclei containing a single-Λ within current predictions of their multiplicities and STAR BES-II measurements.

Double-Λ hypernuclei Au+Au @ 10 AGeV

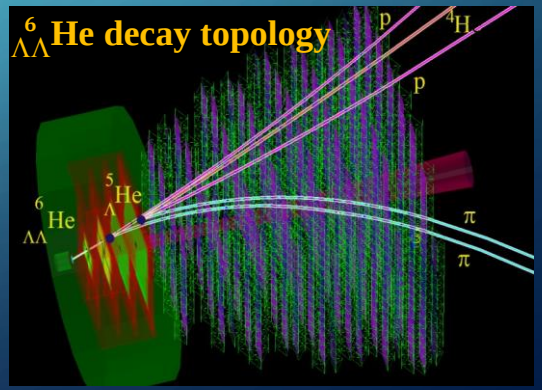


AuAu, 10 AGeV, 10^{12} central UrQMD events equivalent thermal isotropic signal, TOF PID.

Conclusions

- The CBM experiment will provide multidifferential high precision measurements of single- and double-Λ hypernuclei.
- The discovery of double-Λ hypernuclei and the determination of their lifetimes will provide information on the hyperon-nucleon and hyperon-hyperon interactions, which are essential ingredients for the understanding of the nuclear matter EoS at high densities, and, hence, of the structure of neutron stars.

Expected collection rate: ~60 $^{6}_{\Lambda\Lambda}$He in a week at **maximum IR**



Outlook: Year 1 – 3 scenario as of September 2023

Year	Setup	Reaction	T_{Lab} (AGeV)	Days on Target	Number of events	Remarks
0 (2028*)	ELEHAD	C+C, Ag+Ag, Au+Au	2,4,6,8,10, max	60		Commissioning
1	ELEHAD	Au+Au	2,4,6,8,10, max	30 (5 each)	$2 \cdot 10^{10}$ each	EB mBias
1	ELEHAD	C+C	2,4,6,8,10, max	18 (3 each)	$4 \cdot 10^{10}$ each	mBias
1	ELEHAD	p+Be	3,4,8,29	12 (3 each)	$2 \cdot 10^{11}$ each	mBias
2	MUON	Au+Au	2,4,6,8,10, max	30 (5 each)	$2 \cdot 10^{11}$ each	mBias
2	MUON	C+C	2,4,6,8,10, max	18 (3 each)	$4 \cdot 10^{11}$ each	mBias
2	MUON	p+Be	3,4,8,29	12 (3 each)	$2 \cdot 10^{12}$ each	mBias
3	HADR	Au+Au	2,4,6,8,10, max	12 (2 each)	$4 \cdot 10^{11}$ each	EB+ Selectors
3	HADR	C+C	2,4,6,8,10, max	6 (1 each)	$8 \cdot 10^{11}$ each	
3	HADES	Ag+Ag	2,4	28 (14 each)	10^{10} each	
3	ELEHAD	Ag+Ag	2,4	8 (4 each)	$2 \cdot 10^{10}$ each	mBias

Focus on beam energy scan:

- 60 days / year beam on target
- factor 100 more statistics w.r.t. STAR FXT

Summary

- How do nuclei and hyper-nuclei form in HI collisions?
- What are their properties – lifetime, binding energy, radius, decay modes?
- How do YN and YY interact?

Thank you for your attention!