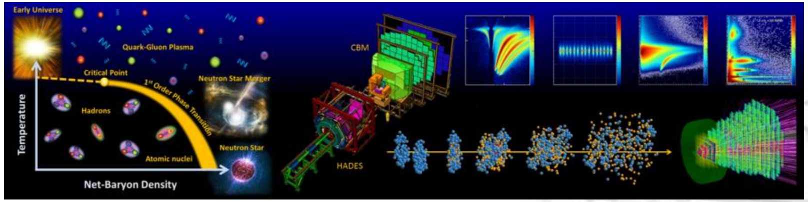
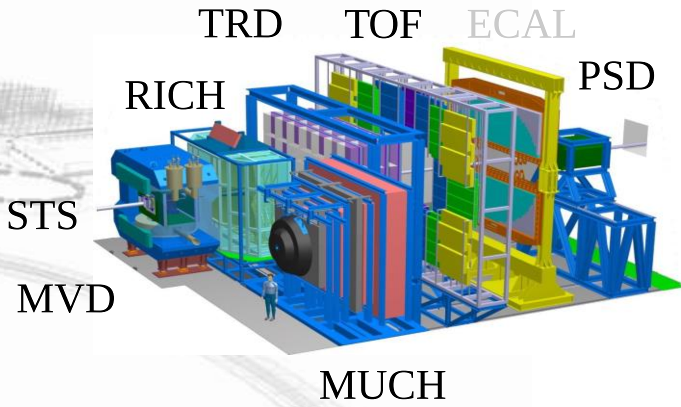
Perspectives on hypernuclei physics with the CBM experiment at FAIR (recent results from CBM)

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





- Motivation
- Tools
- FAIR Phase 0 research program
- Single-Λ & Double-Λ hypernuclei
- Outlook

Civil construction of all North Site buildings will be finished by October this year!

Motivation

One of the physics cases of the CBM experiment is study of hypernuclei:

- Single and **double** hypernuclei.
- Precise measurements of hypernuclei lifetime (YN & **YY** interaction).
- Measurement of branching ratios of hypernuclei decays.
- Direct access to the hyperon-nucleon YN interaction

through measurements of B_Λ in the hypernuclei.

- "Hyperon puzzle" in the astrophysics: understanding of YN interaction is crucial for neutron star physics.
- Search for strange matter in the form of heavy multi-strange objects.

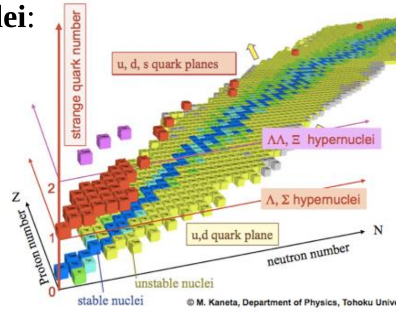
Advantages of CBM:

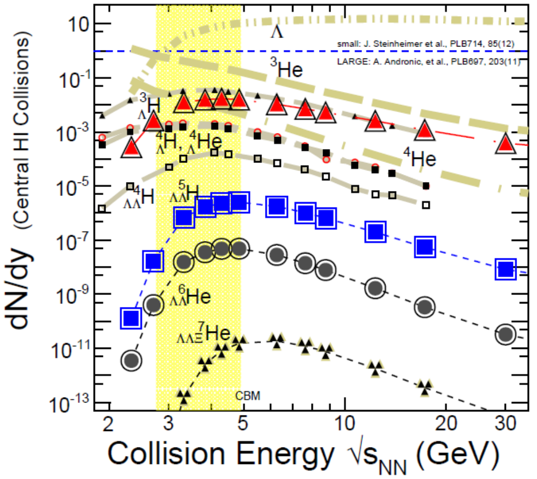
- According to theoretical predictions energy region of CBM is preferable for production of hypernuclei **(confirmed by STAR BES-II & HADES data!)**
- **Complex topology of decays** can be identified in CBM

with a low background (KFParticle Finder).

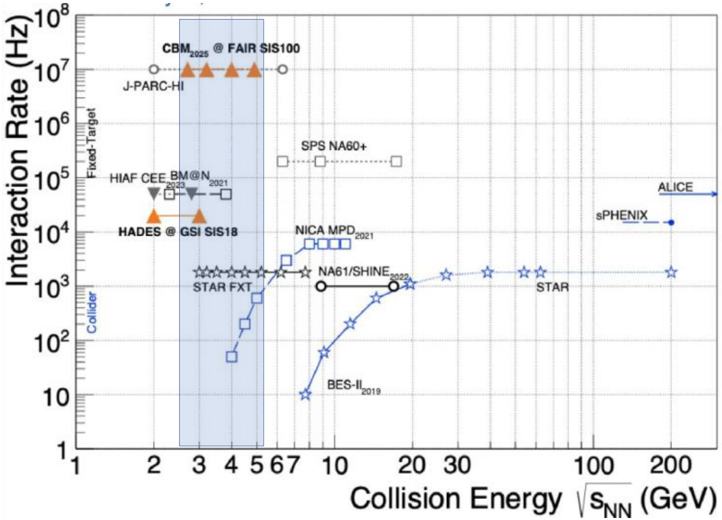
- The detector design is well suited for identification of produced hypersystems.
- **High interaction rates**, optimal collision energies and clean

identification will allow to search for ΛΛ-hypernuclei.

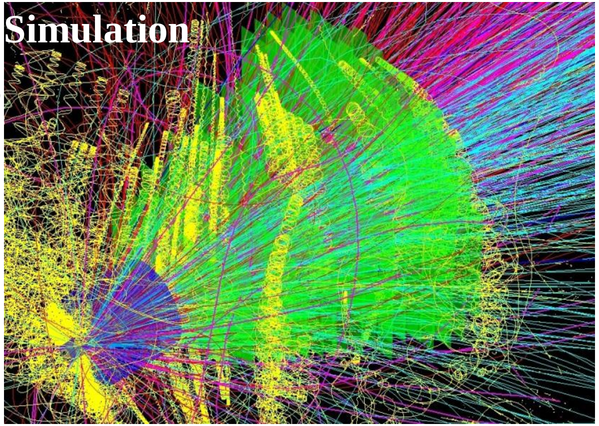


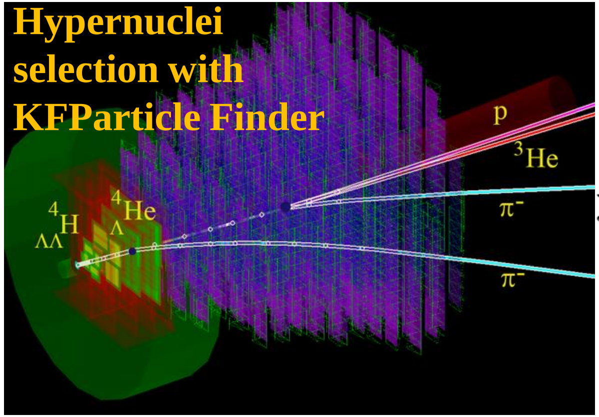


Nu Xu et al., arXiv:2209.05009



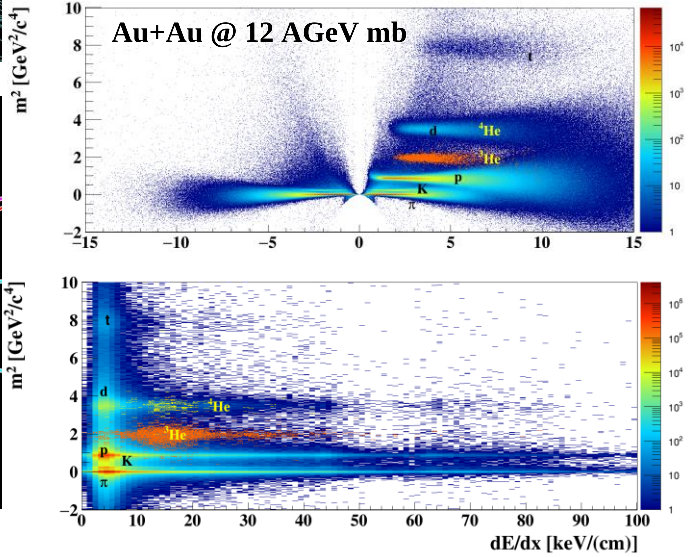
Tools: the CBM track finder & PID detectors





- For studies several theoretical models like UrQMD and PHSD 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.

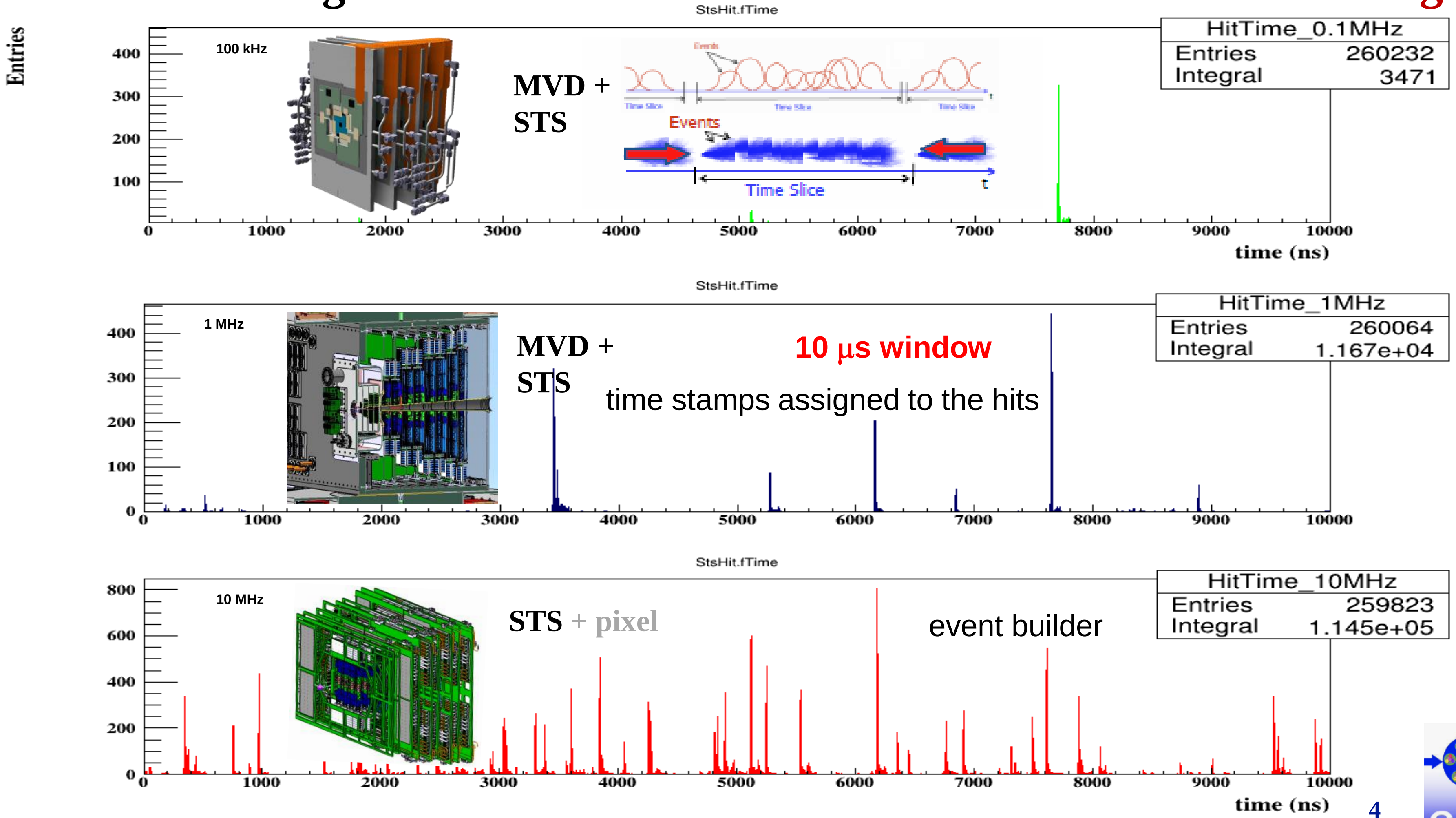
@10 AGeV Au+Au mbias : 8ms/core 1 ms/core KFParticle Finder



PID detectors:

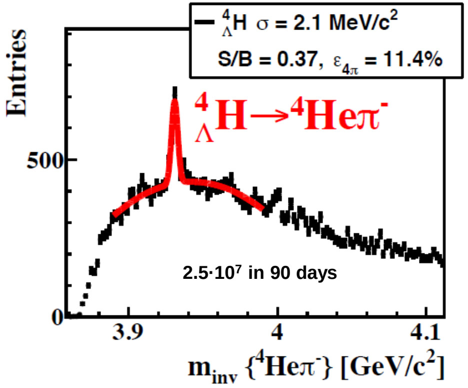
- ToF (Time of Filght) — hadron identification;
- TRD (Transition Radiation detector) — electron and heavy fragments identification

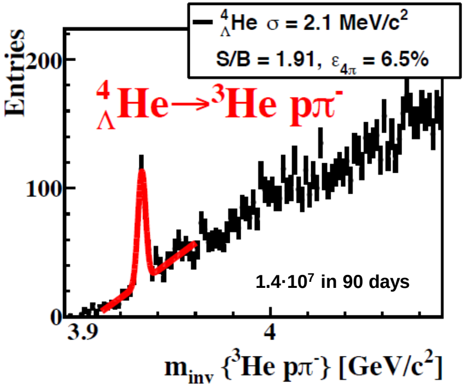
Tools for high rate scenario: event reconstruction with 4D tracking

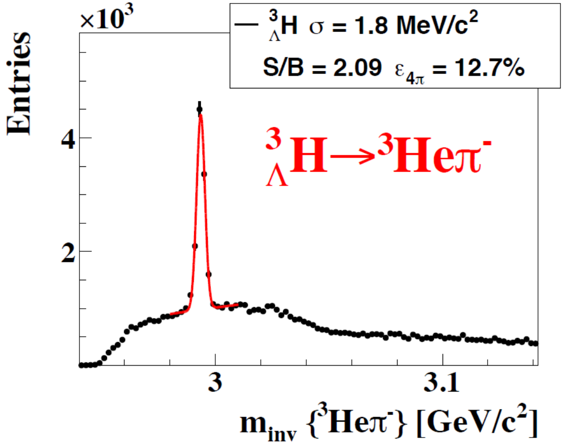


Single-Λ hypernuclei Au+Au @ 10 AGeV

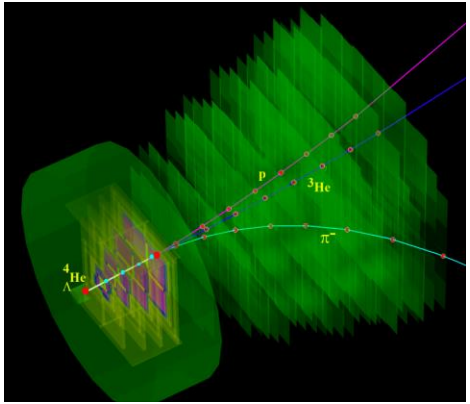
5M mbias events Au+Au at 10AGeV/c
50 sec (!) at 0.1MHz IR (1.8 k/sec)

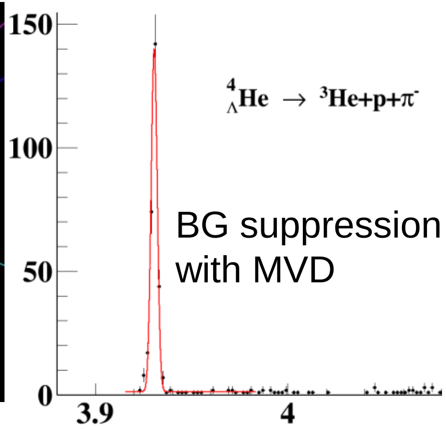






UrQMD





- AuAu, 10 AGeV, 5M central UrQMD events + thermal isotropic signal, TOF PID.
- Background can be further reduced with additional dE/dx PID.
- For $^{4}_{\Lambda}$He background can be reduced selecting only primary hypernuclei.

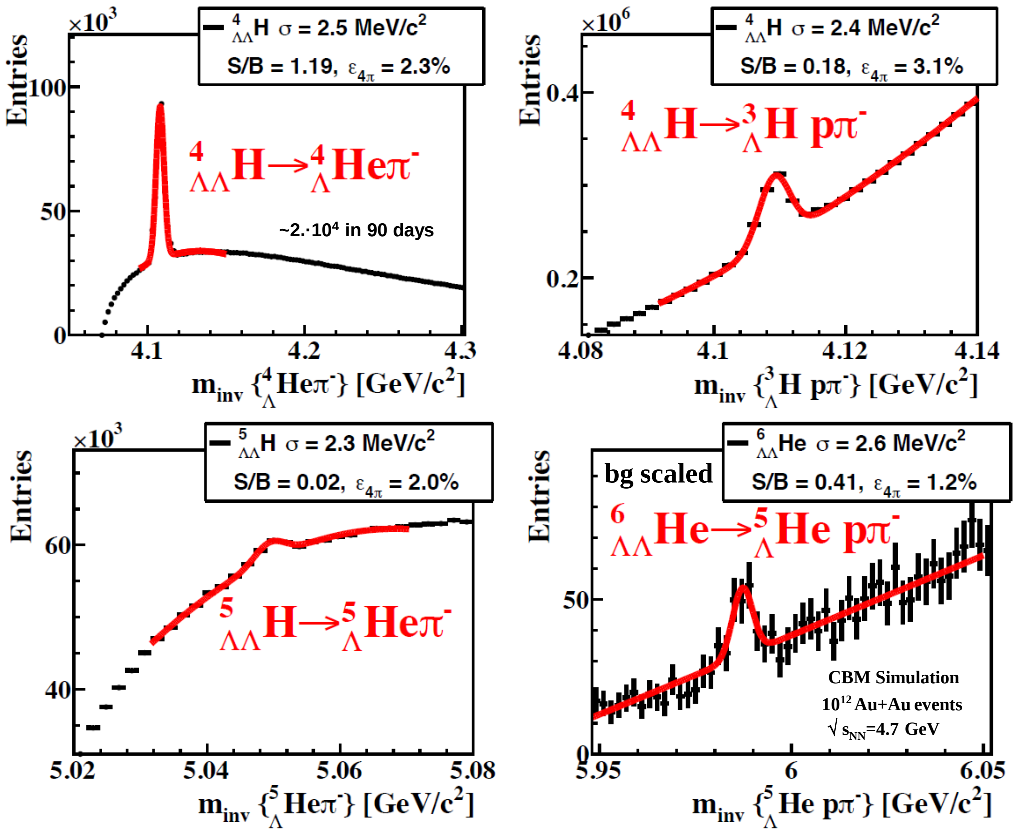
CBM is sensitive to light hypernuclei containing a single-Λ within current predictions of their multiplicities and STAR BES-II measurements.

Multiplicities:

- A.Andronic, et. al, “Production of light nuclei, hypernuclei and their antiparticles in relativistic nuclear collisions,” Phys. Lett. B, 697 (2011) 203
- J. Steinheimer et al., “Hypernuclei, dibaryon and antinuclei production in high energy heavy ion collisions: Thermal production versus Coalescence,” Phys. Lett. B 714 (2012) 85

CBM

Double-Λ hypernuclei Au+Au @ 10 AGeV

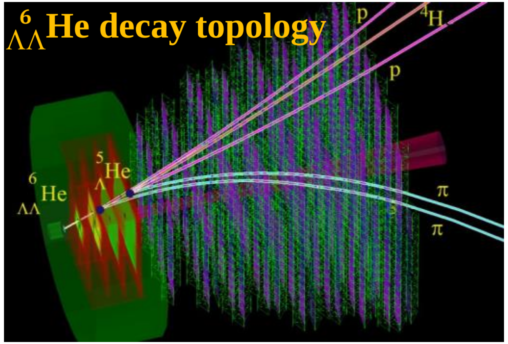


AuAu, 10 AGeV, 10¹² central UrQMD events equivalent thermal isotropic signal, TOF PID.

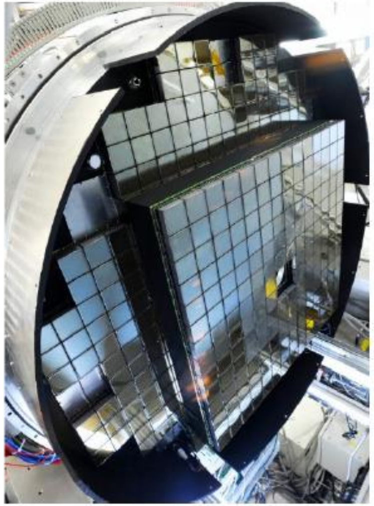
Intermediate Conclusions

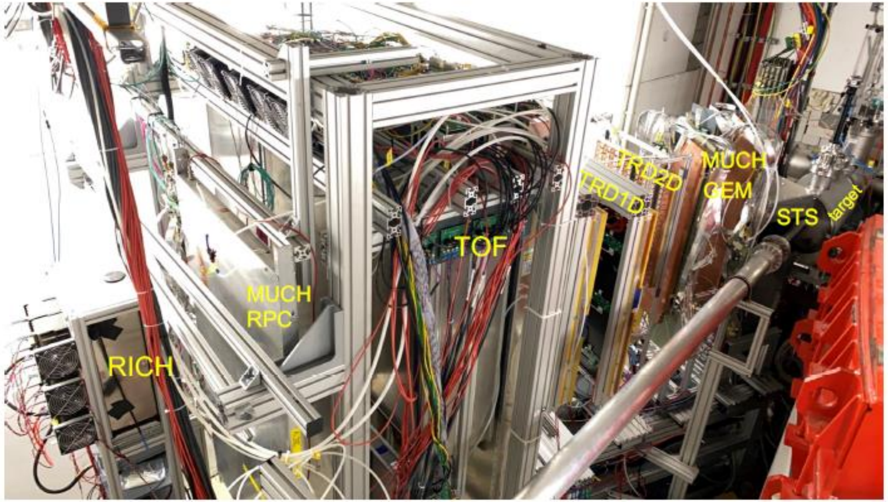
- The CBM experiment will provide multidifferential high precision measurements of single- and double-Λ hypernuclei.
- The discovery of double-Λ hypernuclei and the determination of their lifetimes will provide information on the hyperon-nucleon and hyperon-hyperon interactions, which are essential ingredients 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 1 week at **10MHz IR** (not day-1)



FAIR Phase-0 research program

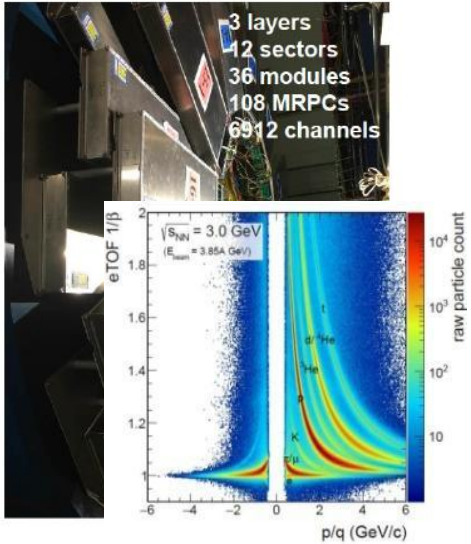


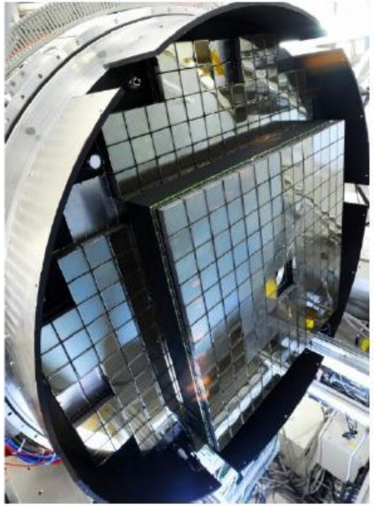


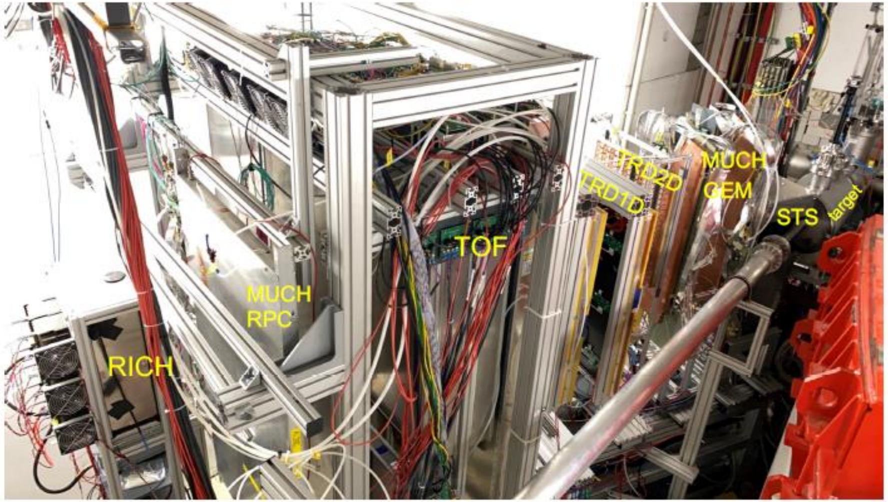
- eTOF @ STAR is installed, commissioned and running
- Use 430 out of 1100 CBM RICH multi-anode photo-multipliers in HADES
- mCBM @ SIS18: high-rate detector tests, CBM DAQ development, Λ excitation function measurement
- CBM FLES algorithms at STAR HLT farm running since 2019

FAIR Phase 0 Research Program

FAIR Phase-0 research program







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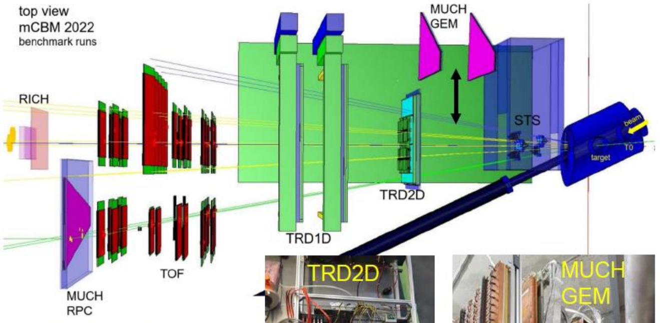
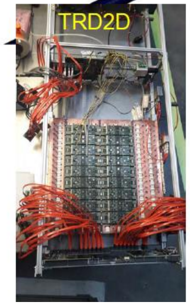
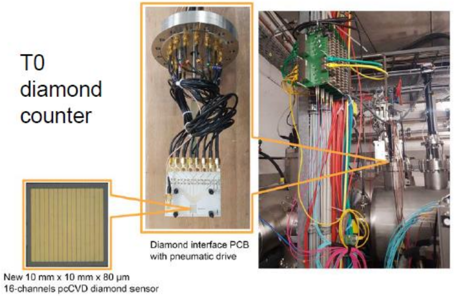
mCBM 2022



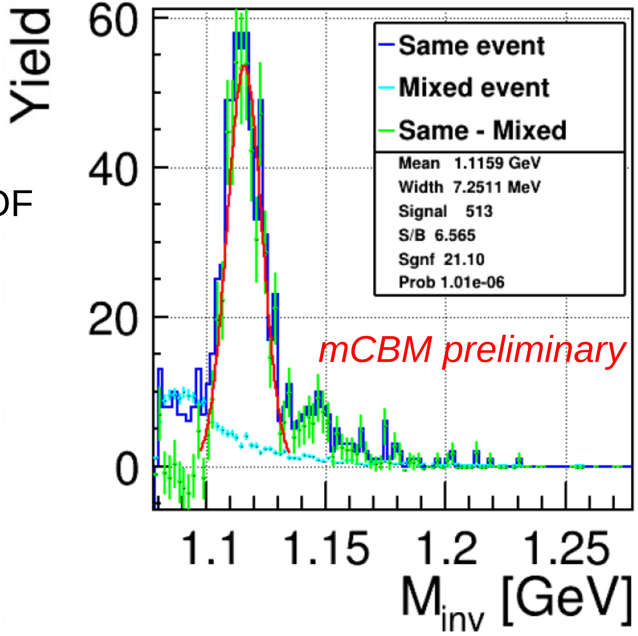


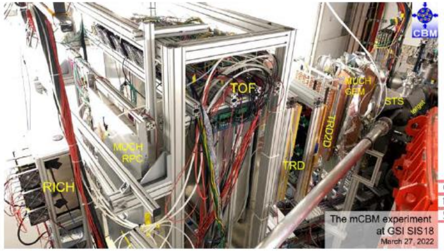
T0
diamond
counter

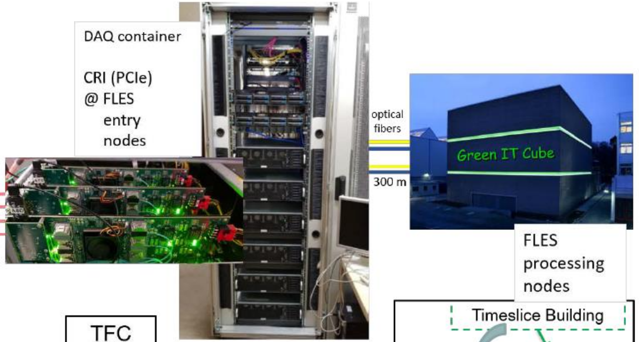


Tracking: 2STS+3TRD+TOF

Run 2391 Ni+Ni, T = 1.93 AGeV
Data taken May 26, 2022
Duration: ~2h







triggerless-streaming FEE **assigning time stamps to hits** → 1 m Copper → GBTx → 50 m optical → CRI FPGA **µSlice building** FLES entry nodes → 300 m optical InfiniBand → Green IT Cube

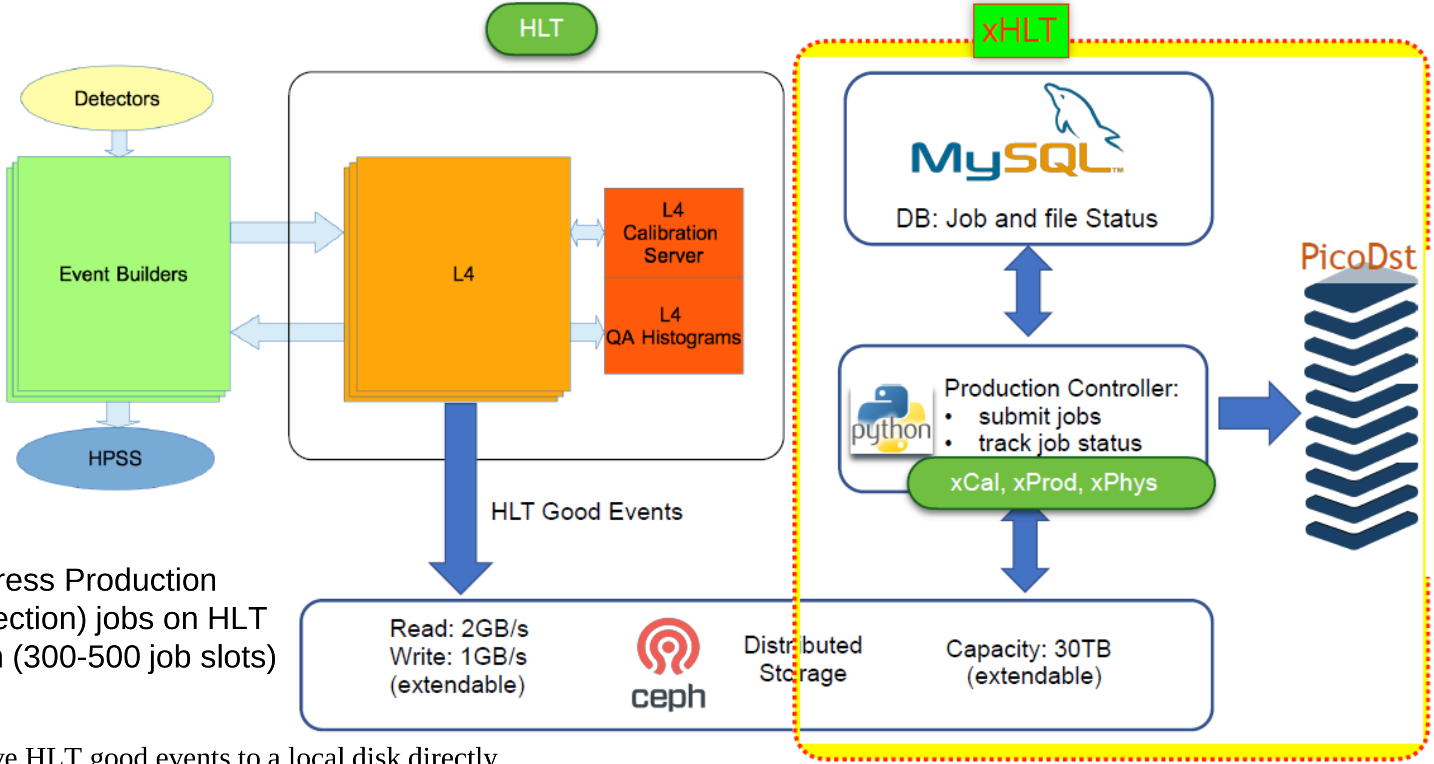
TFC (CRI based) → CRI FPGA

Green IT Cube: Timeslice Building → Event Reconstruction → Event Selection → Archiving

N.Herrmann, Theme Meeting on CBM: Science and Technology, Jatni, India

BES-II: HLT+xHLT

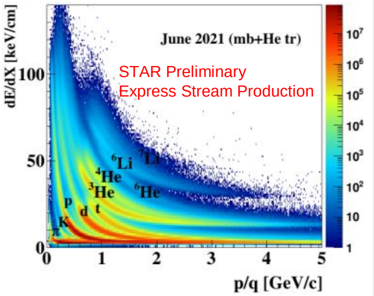
Extend the functionalities of STAR HLT farm with CBM FLES algorithms for express production (xHLT).



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

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

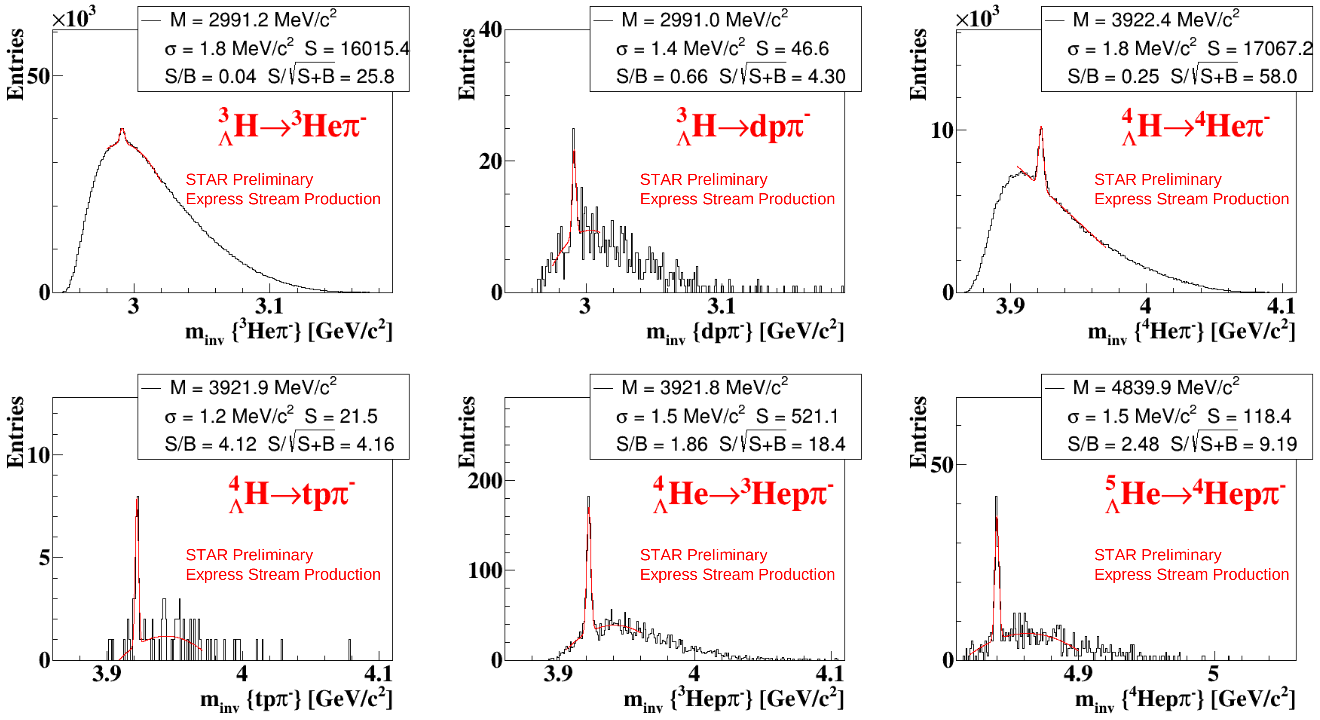
437M AuAu HLT triggered events at $\sqrt{s}$ = 3.0 GeV



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

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

Signal utilizing 437M AuAu HLT triggered events at $\sqrt{s}$ = 3.0 GeV Fixed Target, 2021 BES-II (x)production

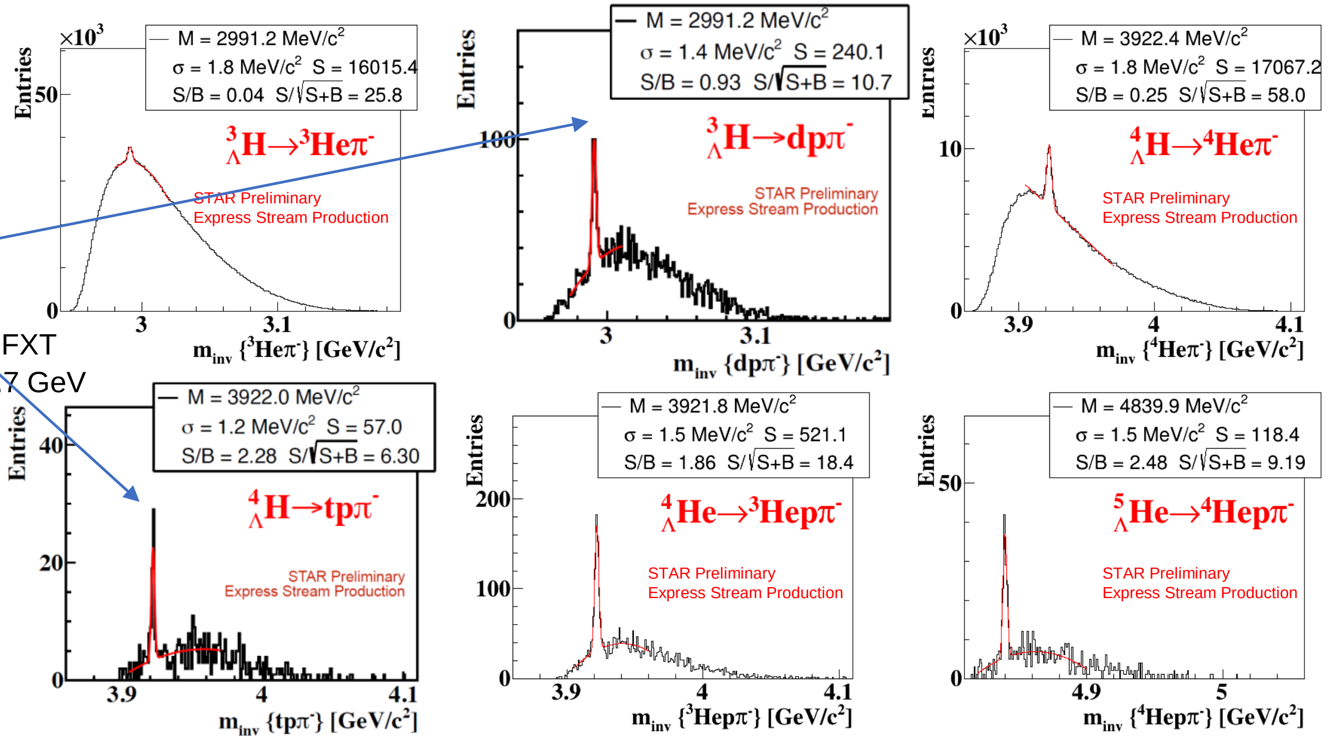


- With increased beam collision intensity in the Fixed Target mode HLT farm had not enough capacities to process all collected data online.
- Therefore a trigger on He has been introduced to enhance hypernuclei.

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

Signal utilizing 437M AuAu HLT triggered events at $\sqrt{s}$ = 3.0 GeV Fixed Target, 2021 BES-II (x)production

dpπ & tpπ
2018-2020, 2021x FXT
2021x collider at 7.7 GeV



- With increased beam collision intensity in the Fixed Target mode HLT farm had not enough capacities to process all collected data online.
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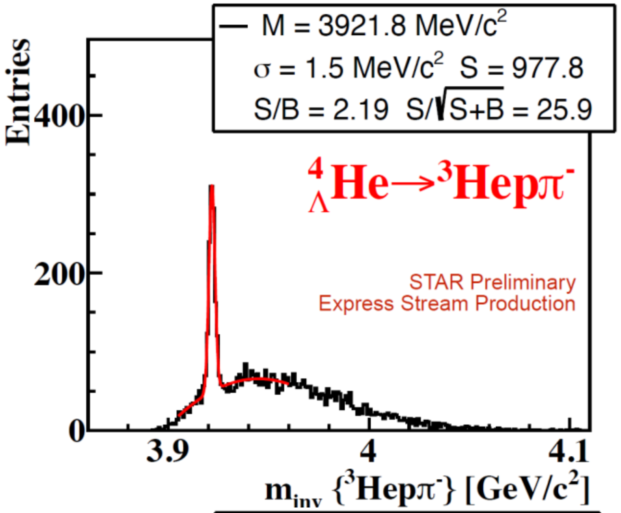
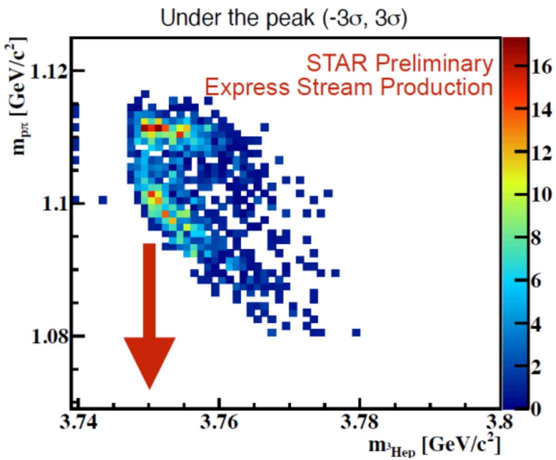
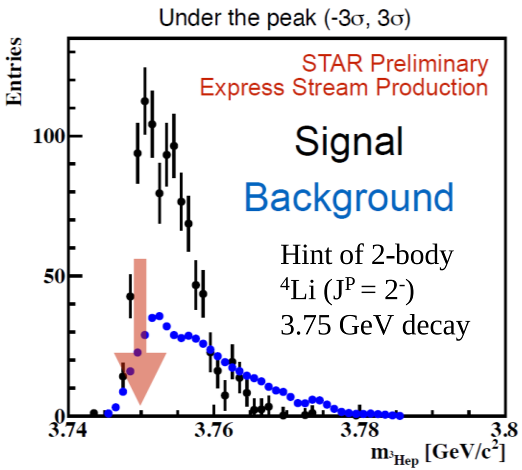
Signal (978)

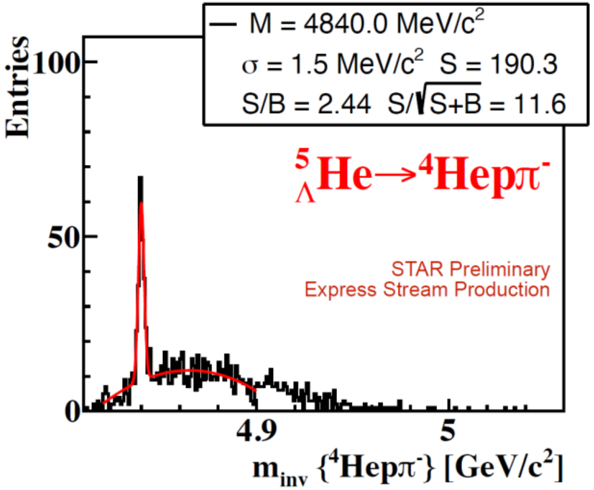
2018-2020, 2021x FXT and 2021x collider at 7.7 GeV

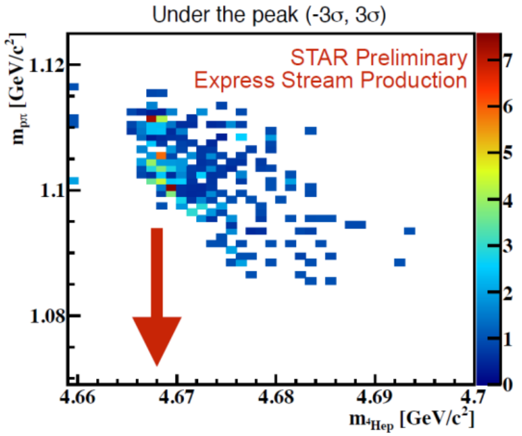


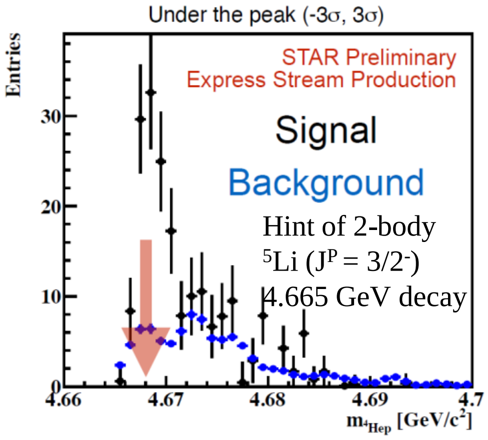




Signal (190)







New tools: PHQMD$_{\text{soft EoS}}$ Fragments & Hypernuclei at $\sqrt{(s)}$ = 3 GeV

PHQMD:

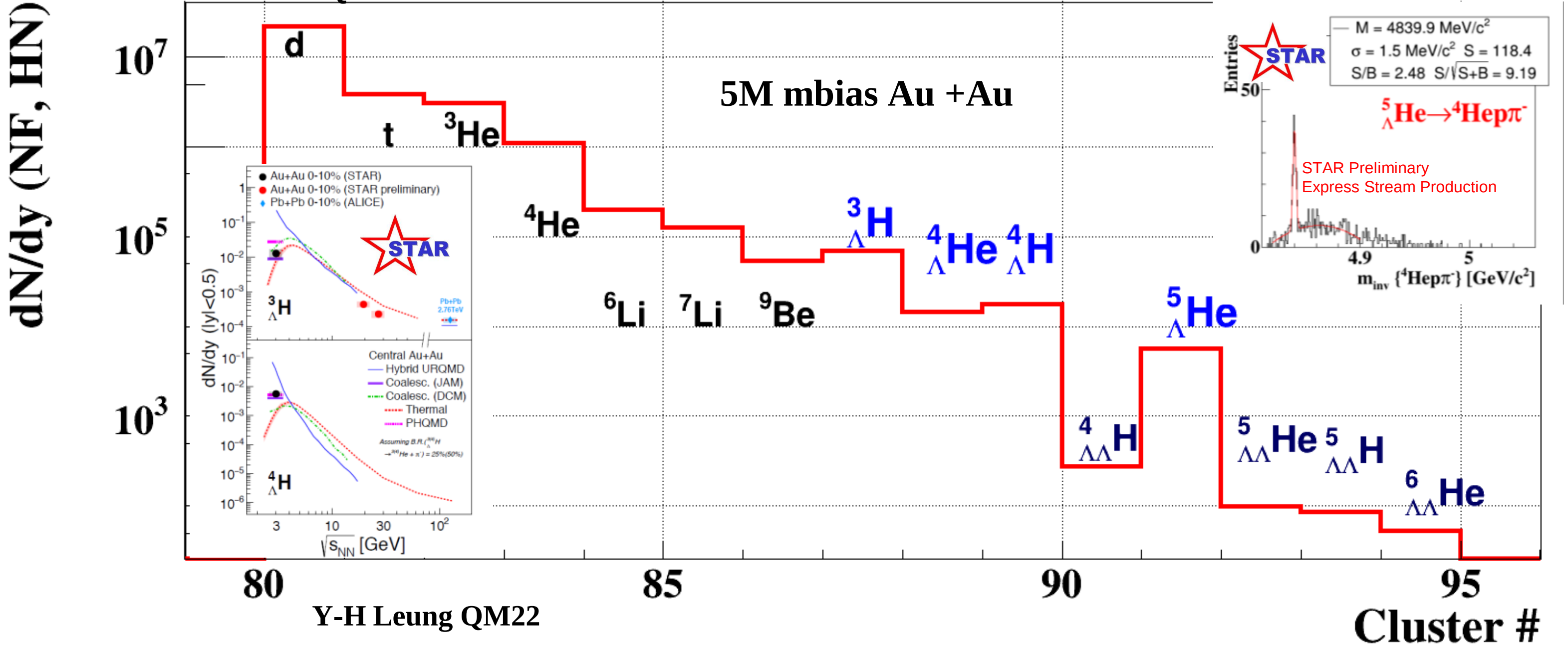
Parton-Hadron-Quantum-Molecular Dynamics - A Novel Microscopic N-Body Transport Approach for Heavy-Ion Collisions, Dynamical Cluster Formation and Hypernuclei Production

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

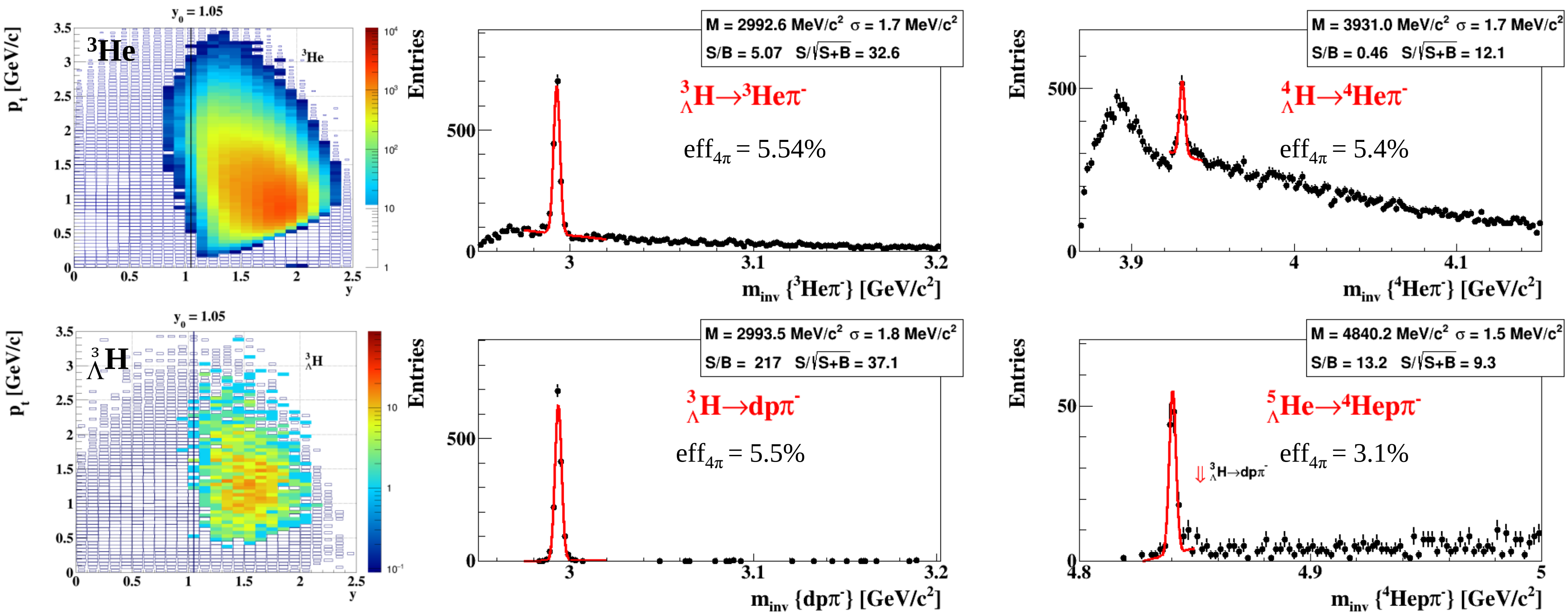
Phys.Rev.C 101 (2020) 4, 044905

Susanne Gläßel : **PHQMD.dat to UniGen convertor**

PHSD + Clusters + Hyper Clusters



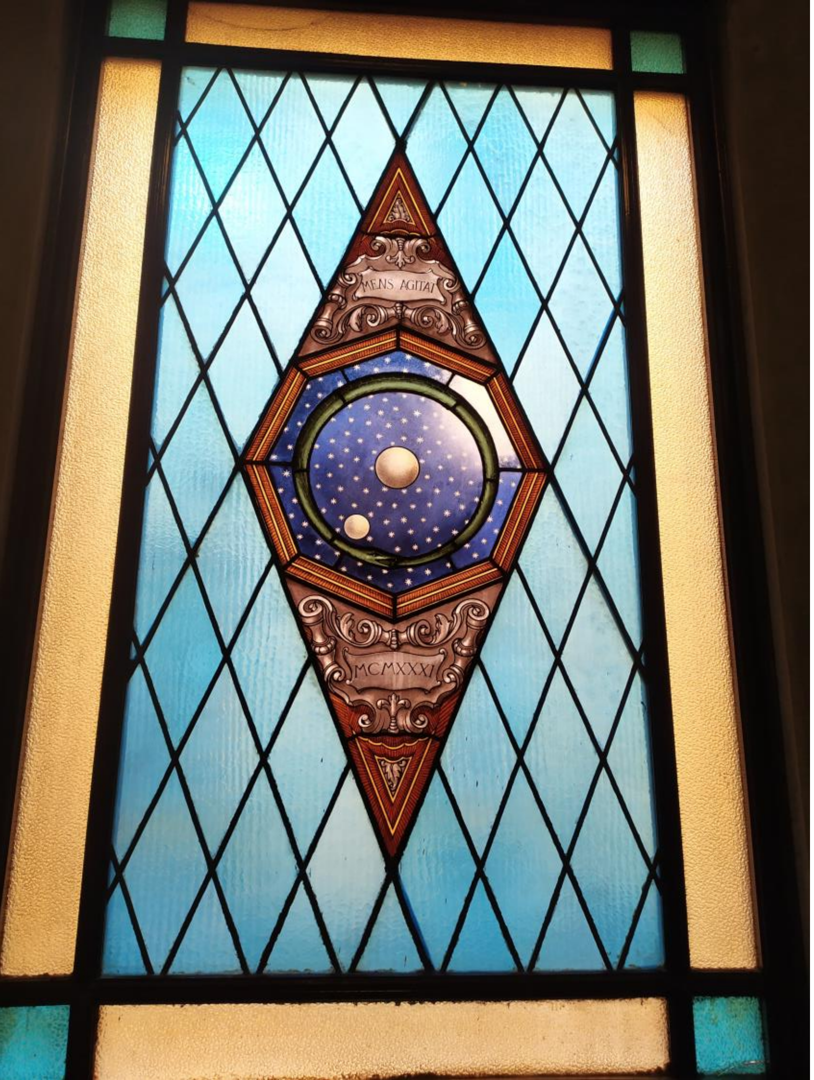
Hypernuclei: PHQMD$_{\text{soft EoS}}$ 5M mbias Au +Au @ $\sqrt{(s)}$ 3 = GeV



- **efficiency and cuts optimization is ongoing**
- **more statistic for double-Λ hypernuclei**

Outlook: Year 1 – 3 scenario as of May 2022

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)	$2\cdot10^{10}$ each	EB mBias
1	ELEHAD	C+C	2,4,6,8,10, max	18 (3 each)	$4\cdot10^{10}$ each	mBias
1	ELEHAD	p+Be	3,4,8,29	12 (3 each)	$2\cdot10^{11}$ each	mBias
2	MUON	Au+Au	2,4,6,8,10, max	30 (5 each)	$2\cdot10^{11}$ each	mBias
2	MUON	C+C	2,4,6,8,10, max	18 (3 each)	$4\cdot10^{11}$ each	mBias
2	MUON	p+Be	3,4,8,29	12 (3 each)	$2\cdot10^{12}$ each	mBias
3	HADR	Au+Au	2,4,6,8,10, max	12 (2 each)	$4\cdot10^{11}$ each	EB+ Selectors
3	HADR	C+C	2,4,6,8,10, max	6 (1 each)	$8\cdot10^{11}$ each	
3	HADES	Ag+Ag	2,4	28 (14 each)	10^{10} each	
3	ELEHAD	Ag+Ag	2,4	8 (4 each)	$2\cdot10^{10}$ each	mBias



Thank you for your attention!