Role Of CBM-FAIR In Multi-Messenger Pursuit Of Dense Matter EOS

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Eberhard-Karls-Universität Tübingen (DE)

- For the CBM Collaboration -

Workshop on "Dense Matter Equation of State from Theory and Experiments"

IRL-NPA FRIB, Oct 28 – Nov 01, 2024

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

MATHEMATISCH-NATURWISSENSCHAFTLICHE FAKULTÄT
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CBM

FAIR

Current Role Of Heavy-Ion Collisions In Supra-Saturation EOS

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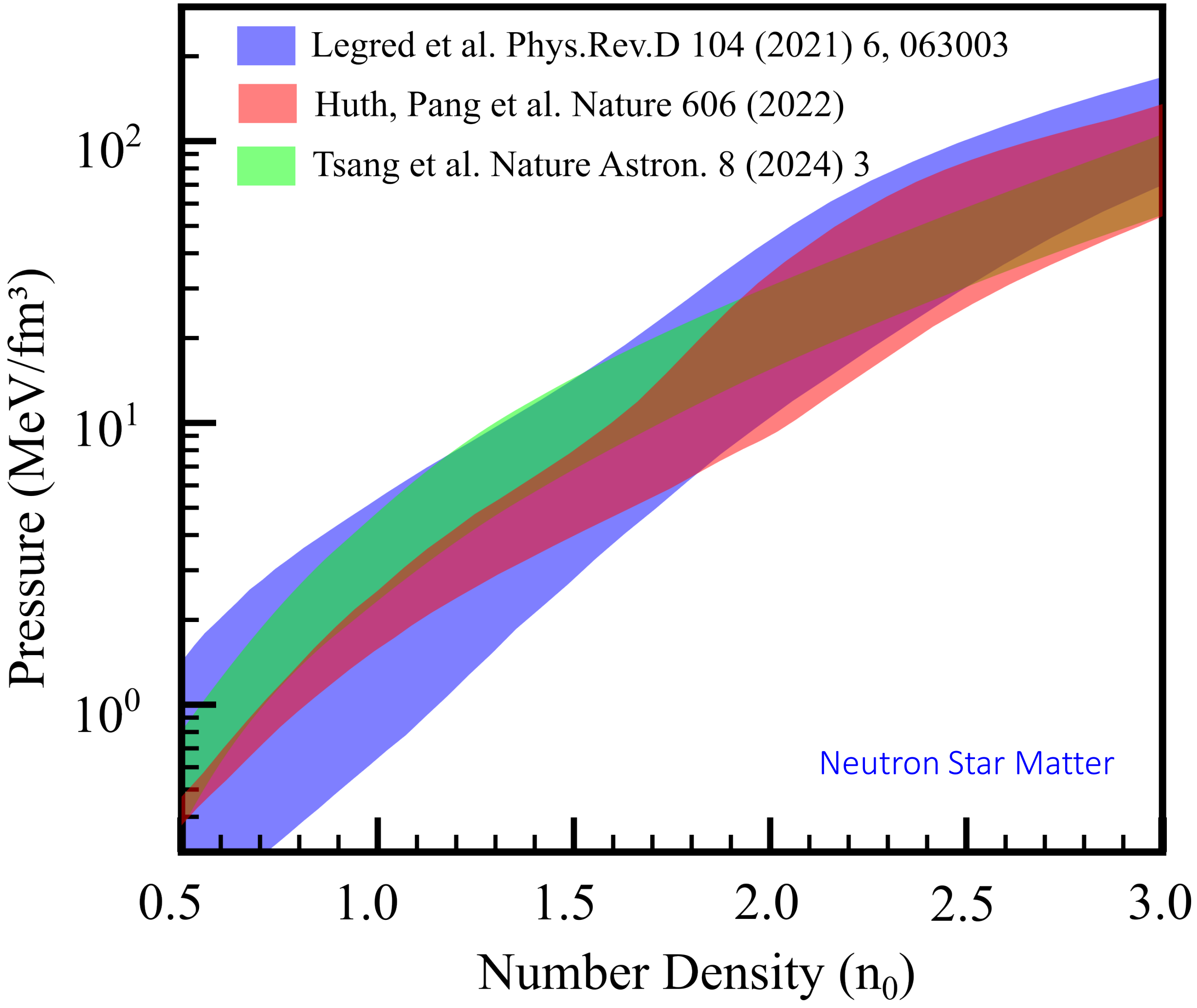

Adapted from: C.Y. Tsang et al., Nature Astron. 8 (2024) 3, 328-336

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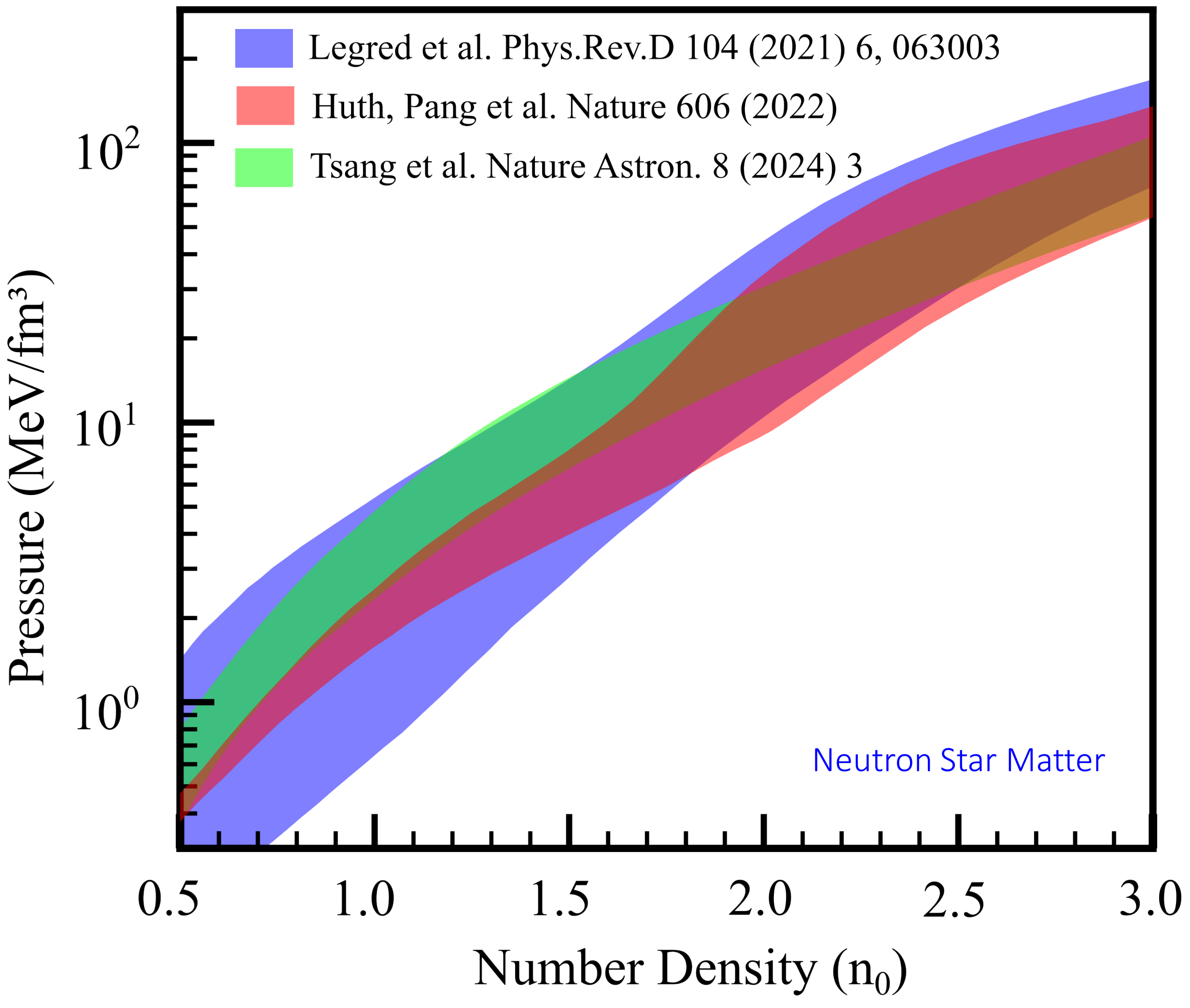

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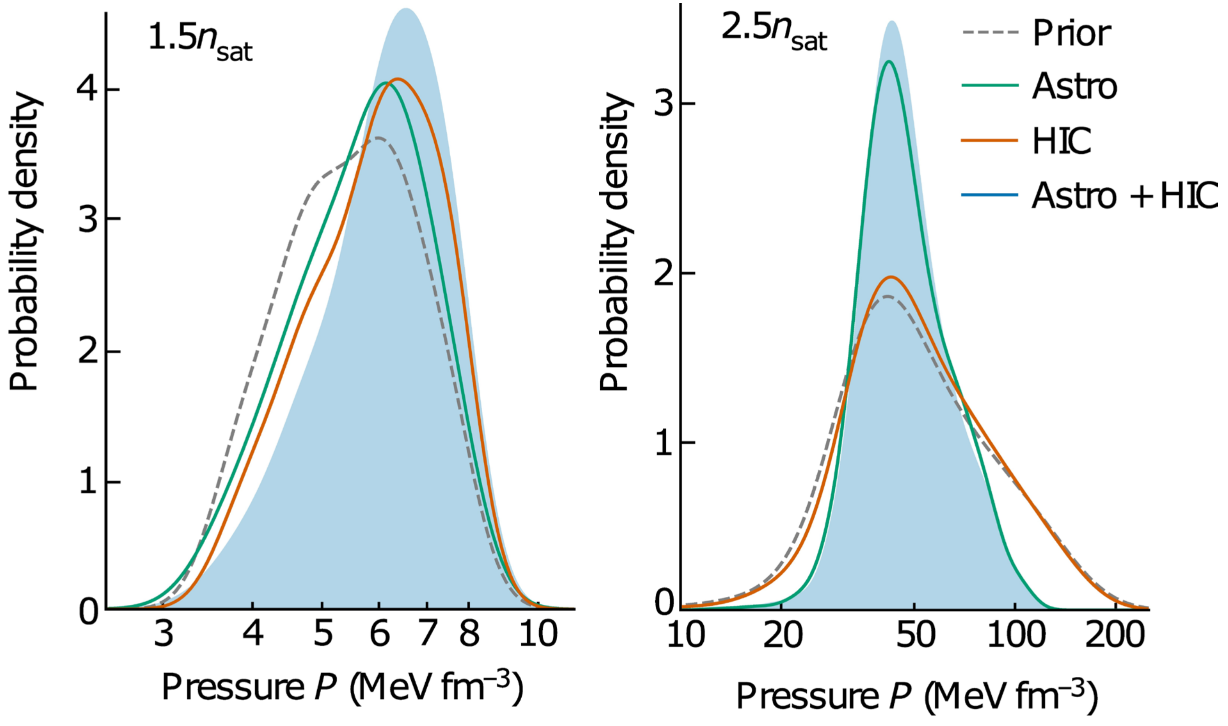
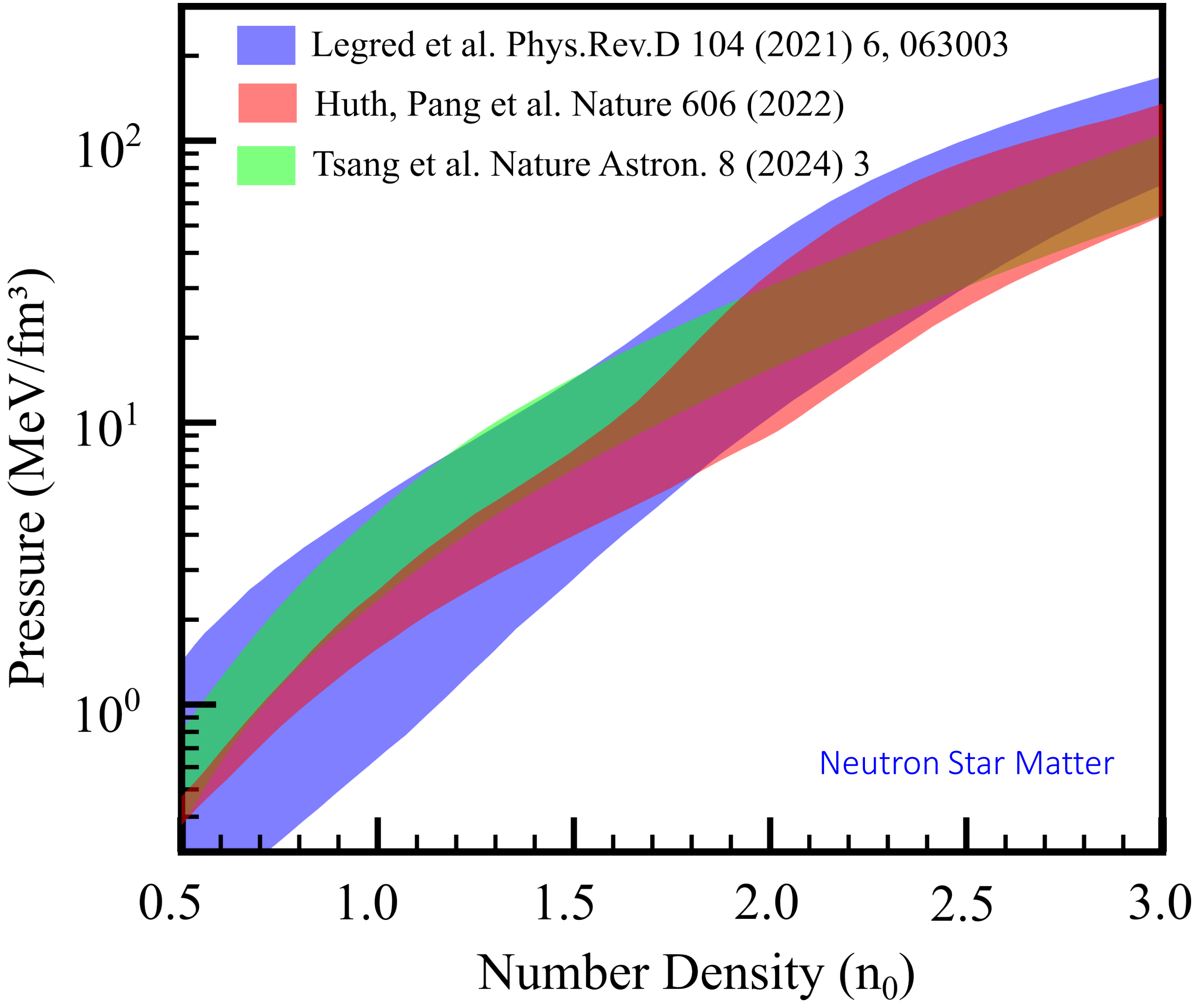
Bayesian Inference used to combine the information from nuclear theory (χEFT), astrophysical observations and heavy-ion collision experiments



S. Huth, P.T.H. Pang et al., Nature 606, 276-280 (2022)



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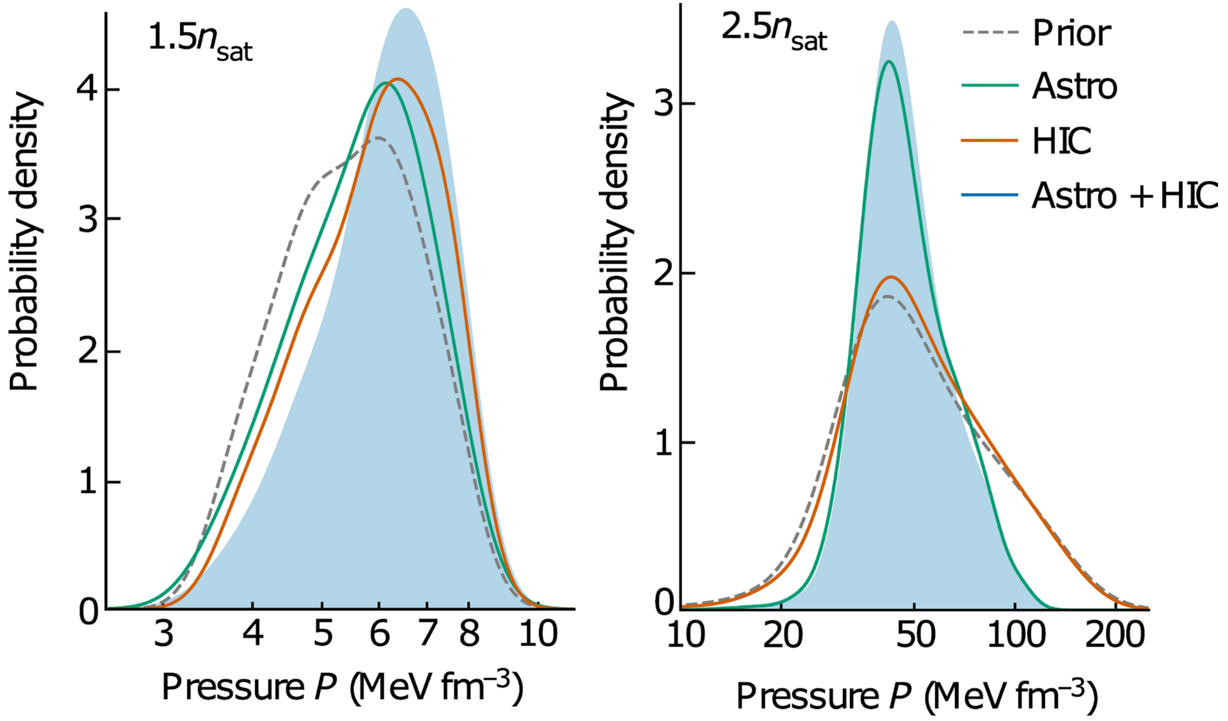

S. Huth, P.T.H. Pang et al., Nature 606, 276-280 (2022)

Although a remarkable compatibility has been established between heavy-ion collisions and astrophysical observations till $1.5\rho_0$, the dense matter EOS at neutron star core densities is driven by astrophysical sources, so the terra incognita for heavy-ion collisions lies beyond $\sim 2\rho_0$

Dense Matter EOS ($\gtrsim 2\rho_0$) Is Becoming Increasingly Interesting…

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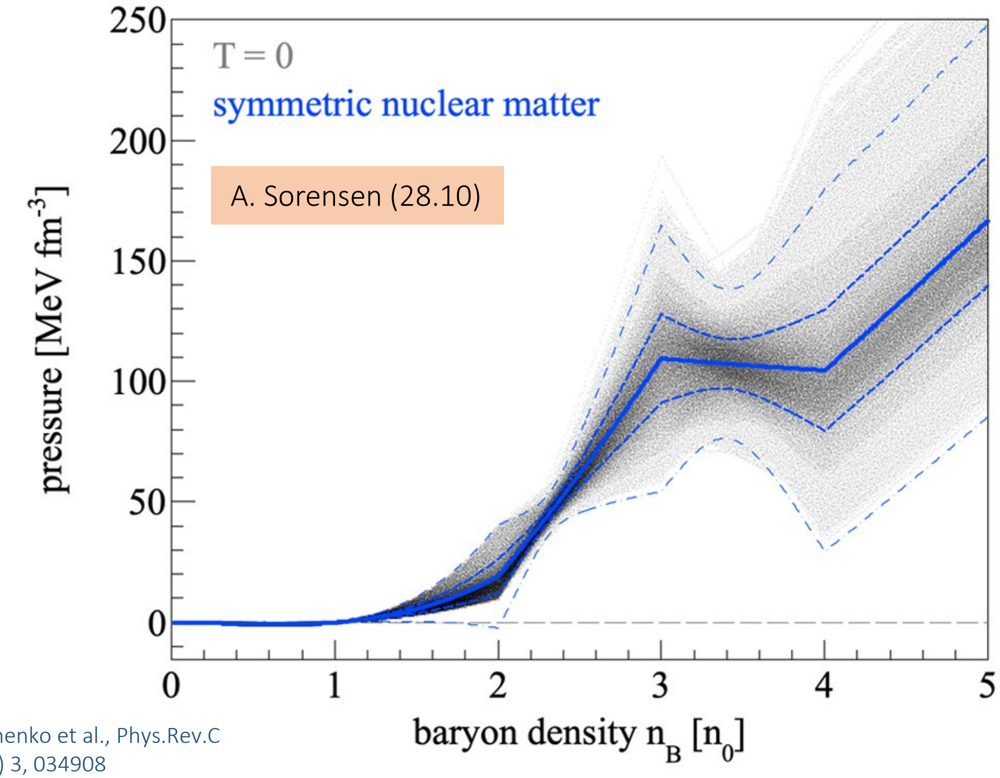
Current data and observations hint that the nuclear matter at neutron-star core densities, both symmetric and neutron-rich, exhibit some softening and potential transition from hadronic to partonic degrees-of-freedom

Symmetric Nuclear Matter

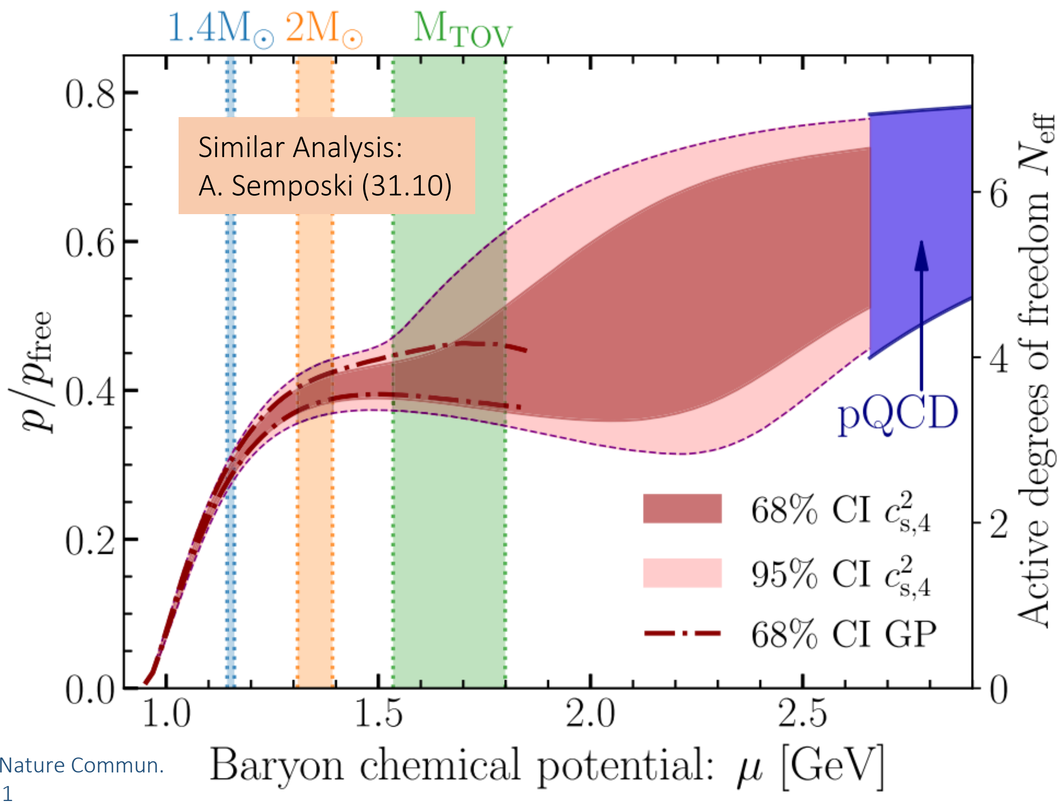
Heavy-Ion Collisions
STAR Flow Data (v_1 and v_2) at $\sqrt{s_{NN}}$ = 3 and 4.5 GeV (Au + Au)
SMASH Transport Code (w/o p-dependence)



D. Oliinychenko et al., Phys.Rev.C 108 (2023) 3, 034908

Neutron Star Matter

ChEFT constraints till 1.2 n_{sat} and pQCD constraints from 40 n_{sat}
Parametric (c_s^2, γ) and non-parametric (GP) interpolation at int. densities
Astrophysical observations (X-ray, GW)



E. Annala et al., Nature Commun. 14 (2023) 1, 8451

TOWARDS BUILDING A MULTI-PURPOSE HIC EXPERIMENT

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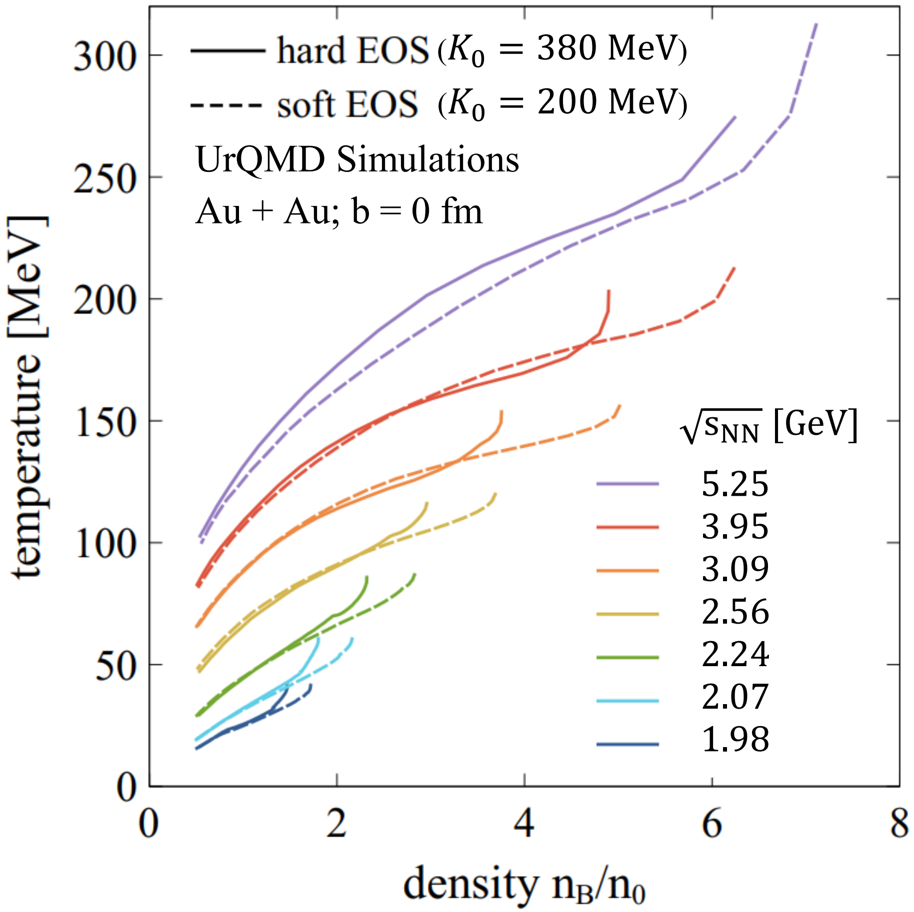
INGREDIENT #1: Heavy-ion high-intensity beams



A. Sorensen et al., Prog.Part.Nucl.Phys. 134 (2024) 104080

Towards Building A Multi-Purpose HIC Experiment

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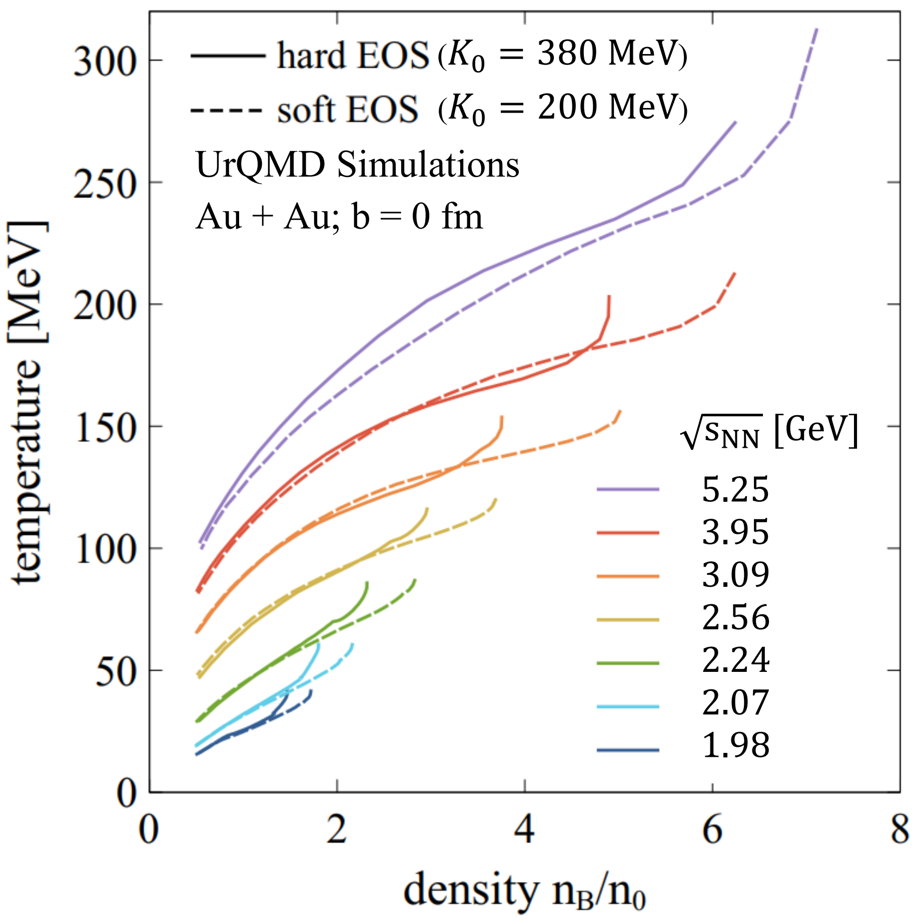
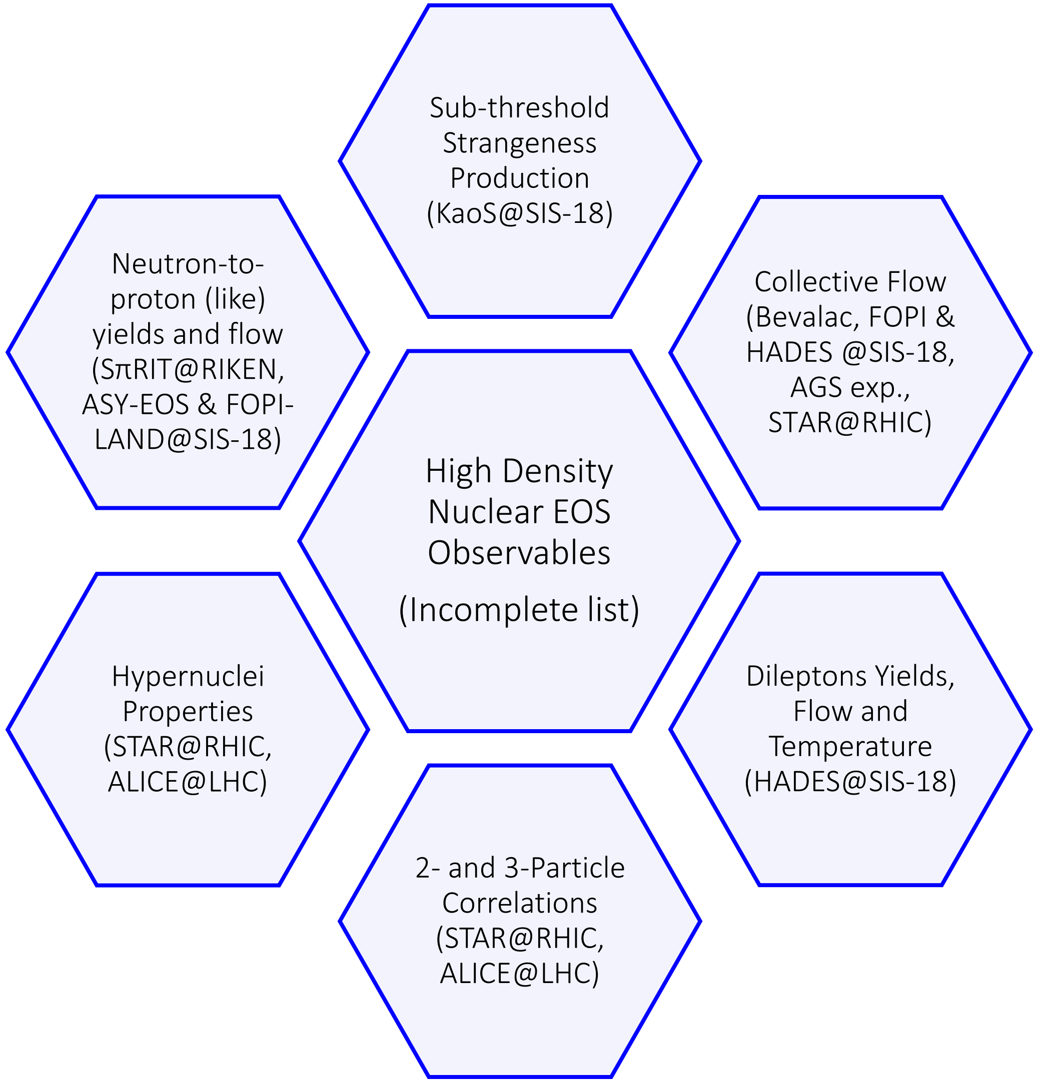
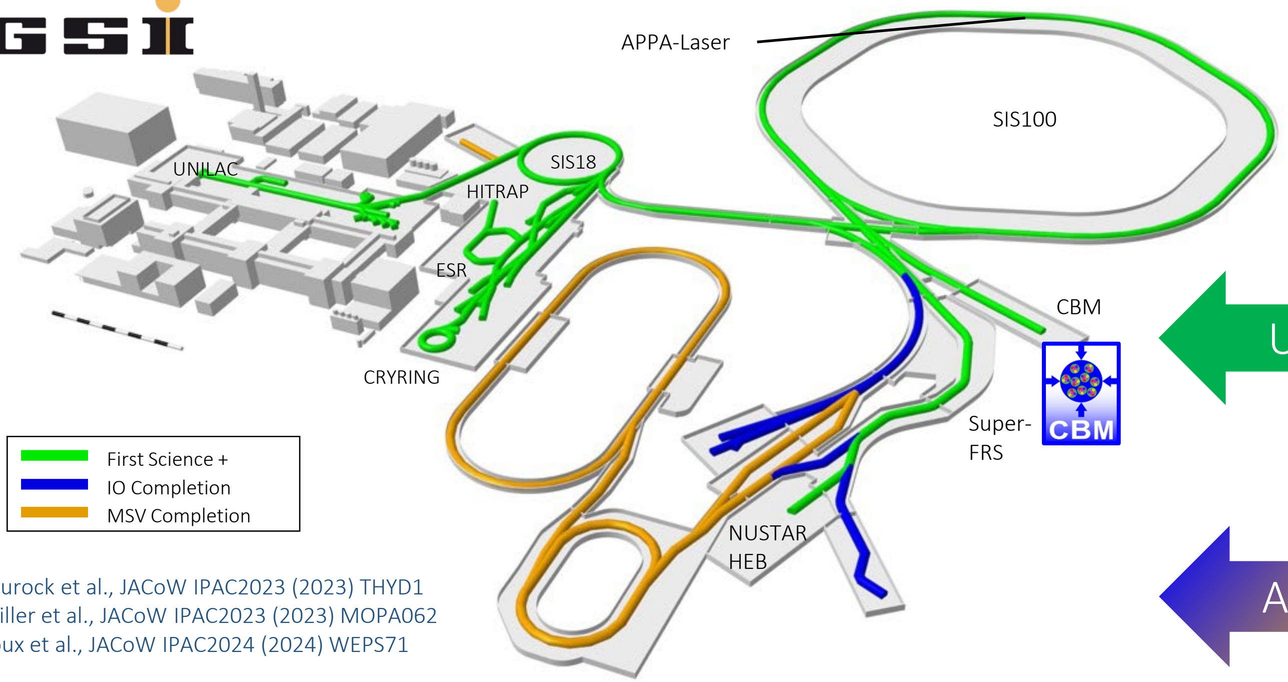


A. Sorensen et al., Prog.Part.Nucl.Phys. 134 (2024) 104080

INGREDIENT #2: Experiment capable of measuring candidate observables



Facility For Anti-Proton And Ion Research (FAIR)



J. Blaurock et al., JACoW IPAC2023 (2023) THYD1
P. Spiller et al., JACoW IPAC2023 (2023) MOPA062
C. Roux et al., JACoW IPAC2024 (2024) WEPS71

Until 2028

After 2028

- Intensity gain w.r.t. SIS-18@GSI: x 100 – 1000 (~10^9/s for Au)
- Energy gain w.r.t. SIS-18@GSI : x 10
- Ion beams up to 11 A GeV energy → $\sqrt{s_{NN}}$ = 2.9 – 4.9 GeV (Au + Au)
- Antiproton beams
- Precision: System of storage and cooler rings
- Current estimate: SIS-100 commissioning with beams starts in 2028

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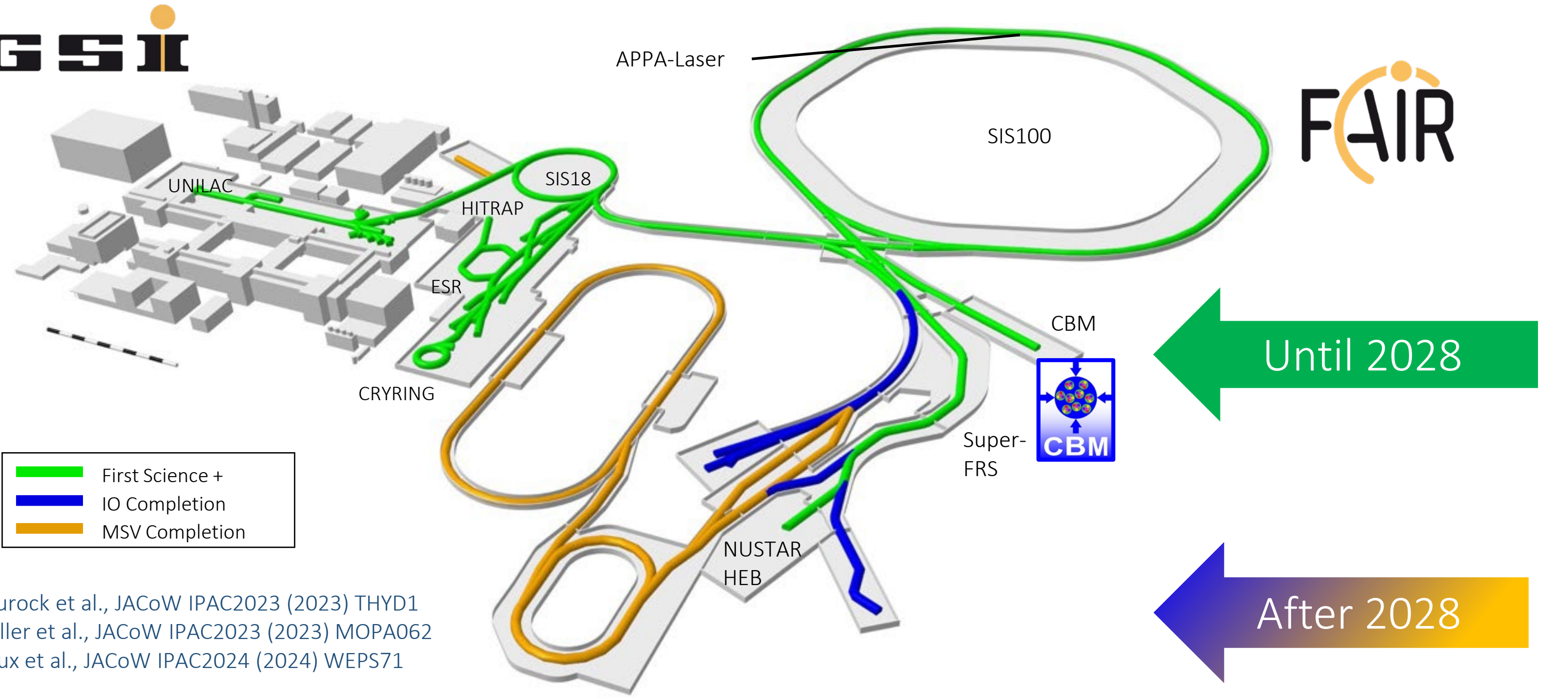

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P. Spiller et al., JACoW IPAC2023 (2023) MOPA062
C. Roux et al., JACoW IPAC2024 (2024) WEPS71

SIS-100 dipole magnets installation commenced at FAIR

Technical Building Infrastructure to support FAIR

YouTube | LinkedIn | Instagram | Facebook | Mastodon | X | GSI/FAIR News

- Intensity gain w.r.t. SIS-18@GSI: x 100 – 1000 (~10^9/s for Au)
- Energy gain w.r.t. SIS-18@GSI : x 10
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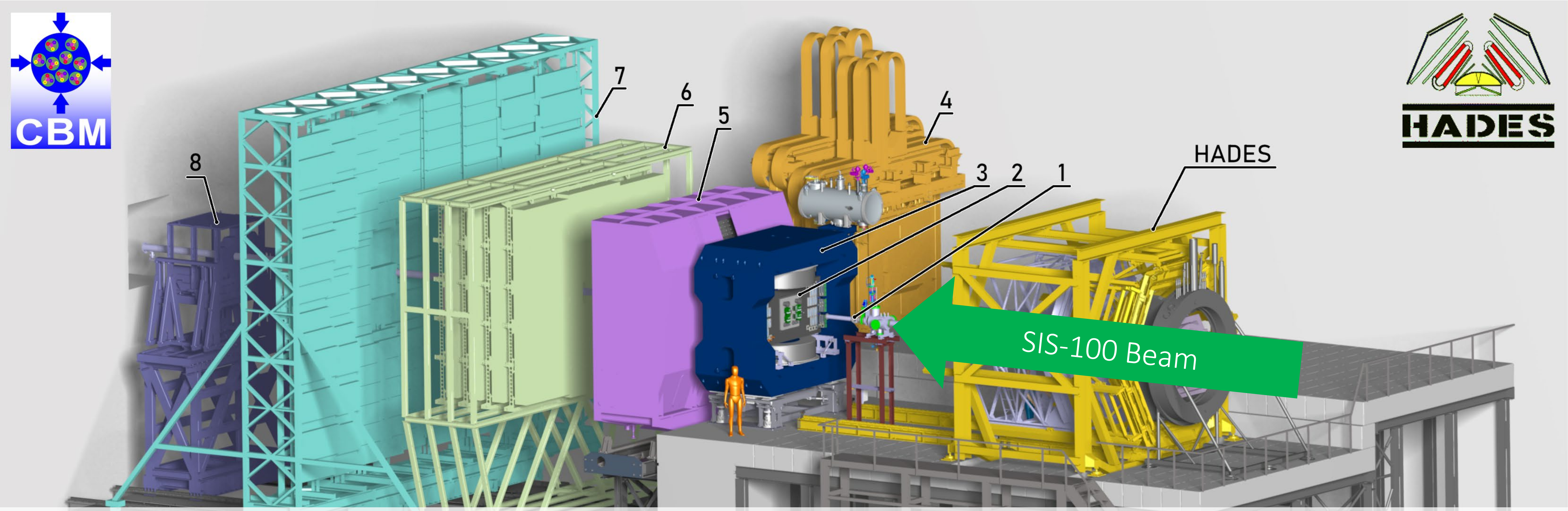
High-intensity heavy-ion beams from SIS-100 at FAIR, with its First Science + milestone from 2028, are optimal to extend the EOS reach of nuclear experiments to neutron star core densities

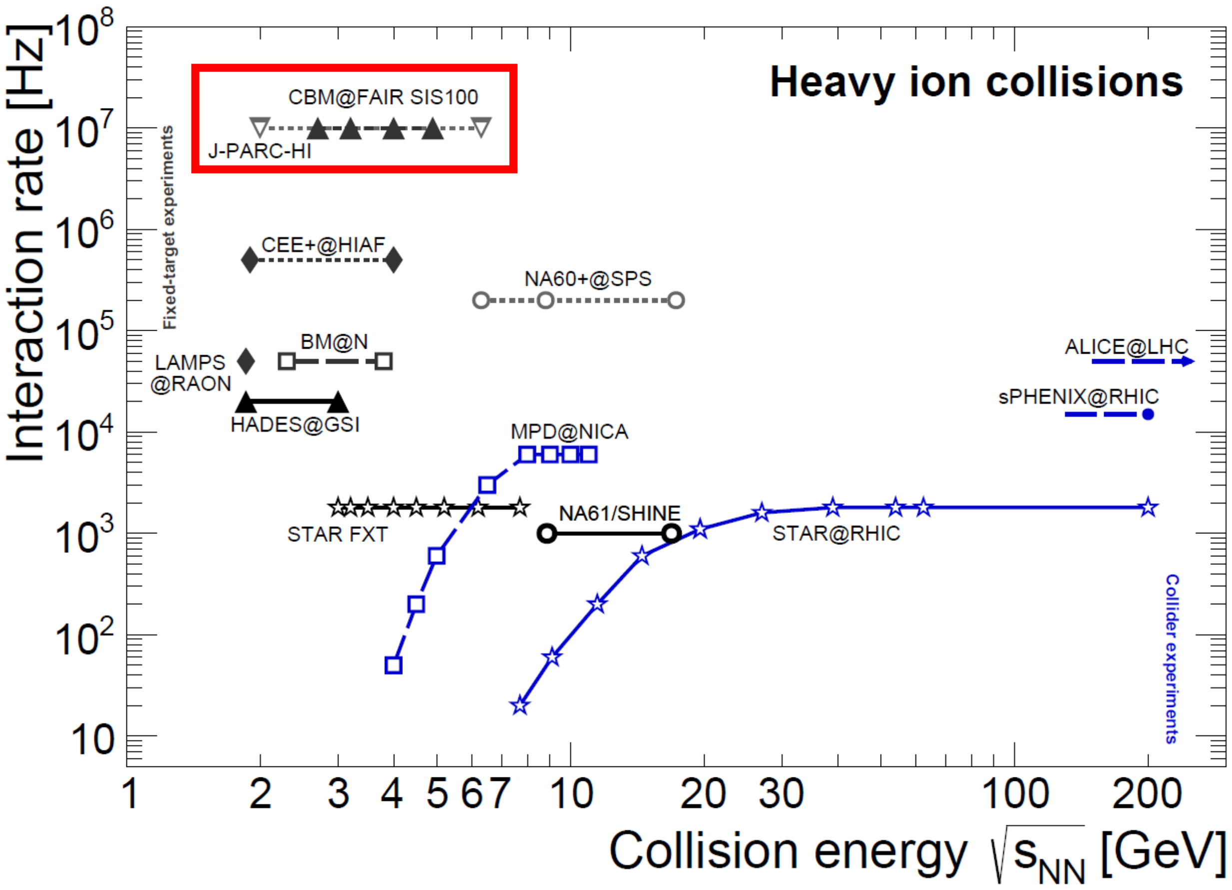
COMPRESSED BARYONIC MATTER (CBM) EXPERIMENT



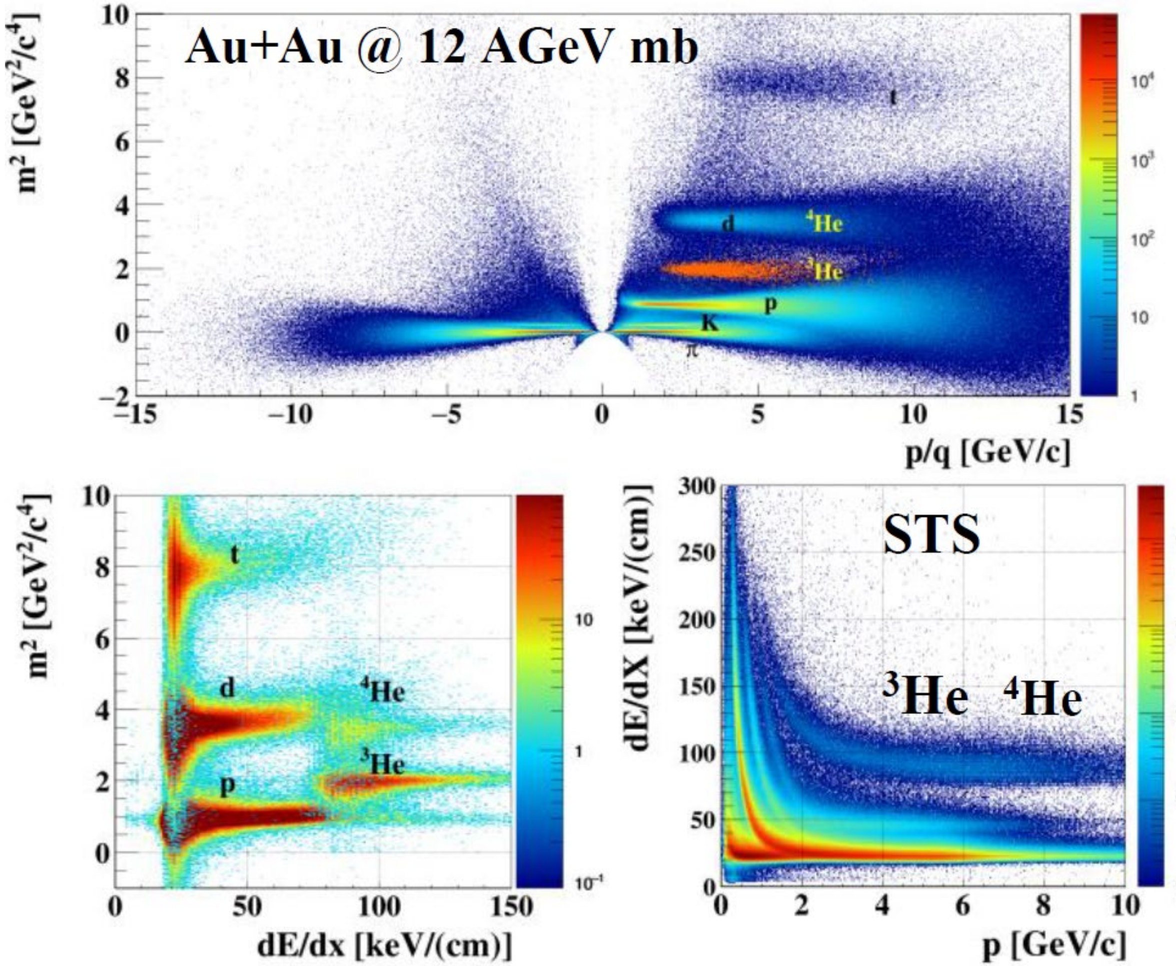
1. Time-Zero Detector and Beam Diagnostics
2. Silicon Tracking System and Micro Vertex Detector
3. Superconducting Dipole Magnet
4. Muon Chambers
5. Ring Imaging Cherenkov Detector
6. Transition Radiation Detector
7. Time of Flight Detector
8. Forward Spectator Detector

- Determination of vertices ($\sigma \approx 50$ µm)
- Identification of leptons and hadrons
- Di-electron and muon setup
- Fast and radiation hard detectors
- Trigger-less free-streaming readout
- Online event selection
- 4-D event reconstruction
- Operation with beam from 2028-29

Compressed Baryonic Matter (CBM) Experiment



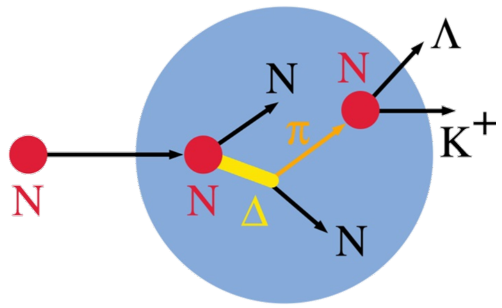
[CBM], Eur.Phys.J.A 53 (2017) 3, 60
T. Galatyuk, Nucl.Phys.A 982 (2019) 163-169, update (06/2022)

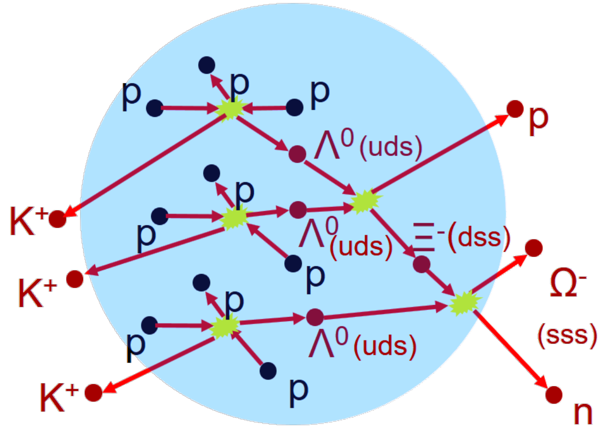


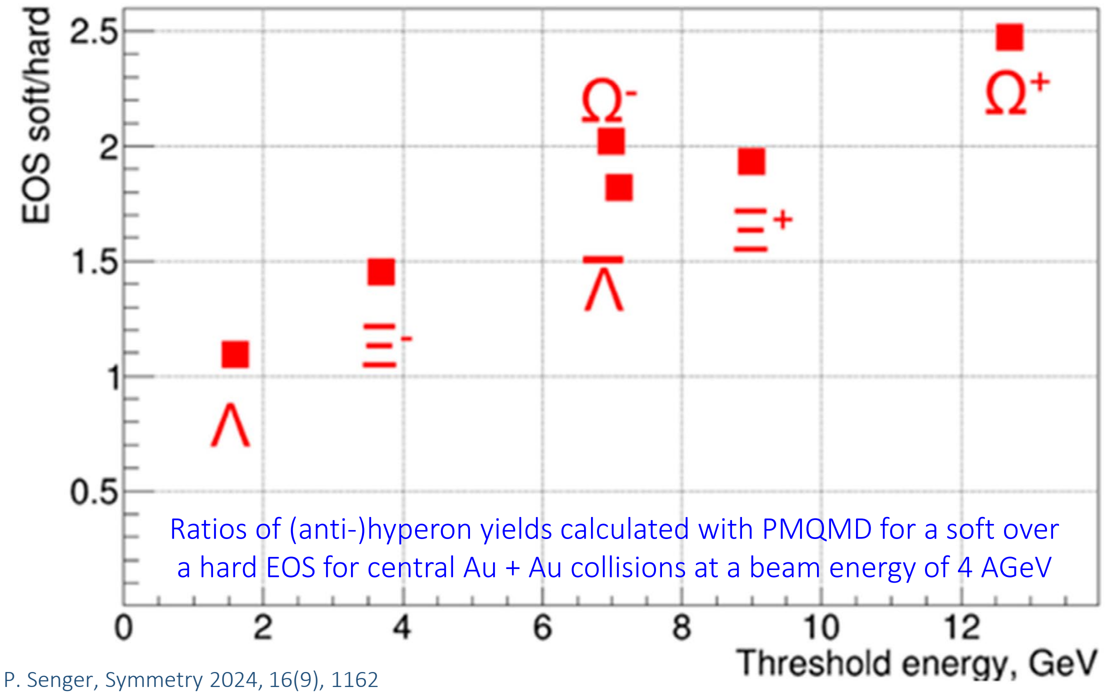
I. Vassiliev, Strangeness in Quark Matter 2024

CBM is designed to conduct its research program over the SIS-100 energy range at up to 10 MHz beam-target interaction rates giving an unprecedent access to the 'rare probes'

OBSERVABLE #1: SUB-THRESHOLD STRANGENESS PRODUCTION



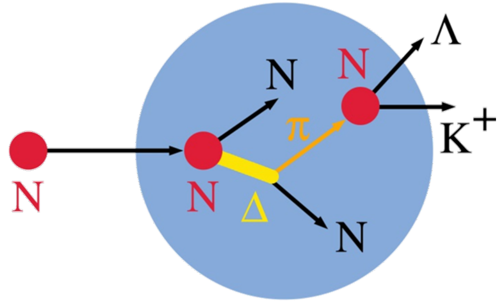


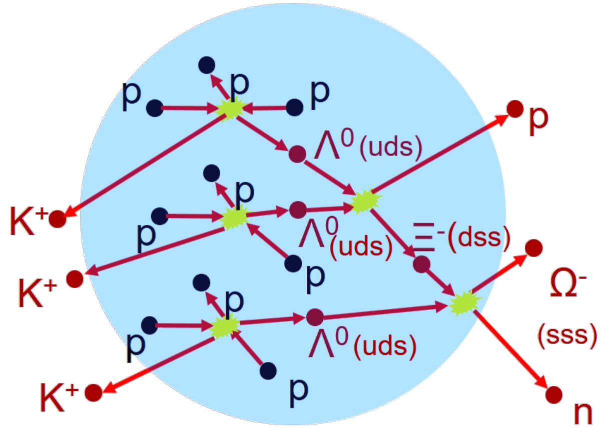


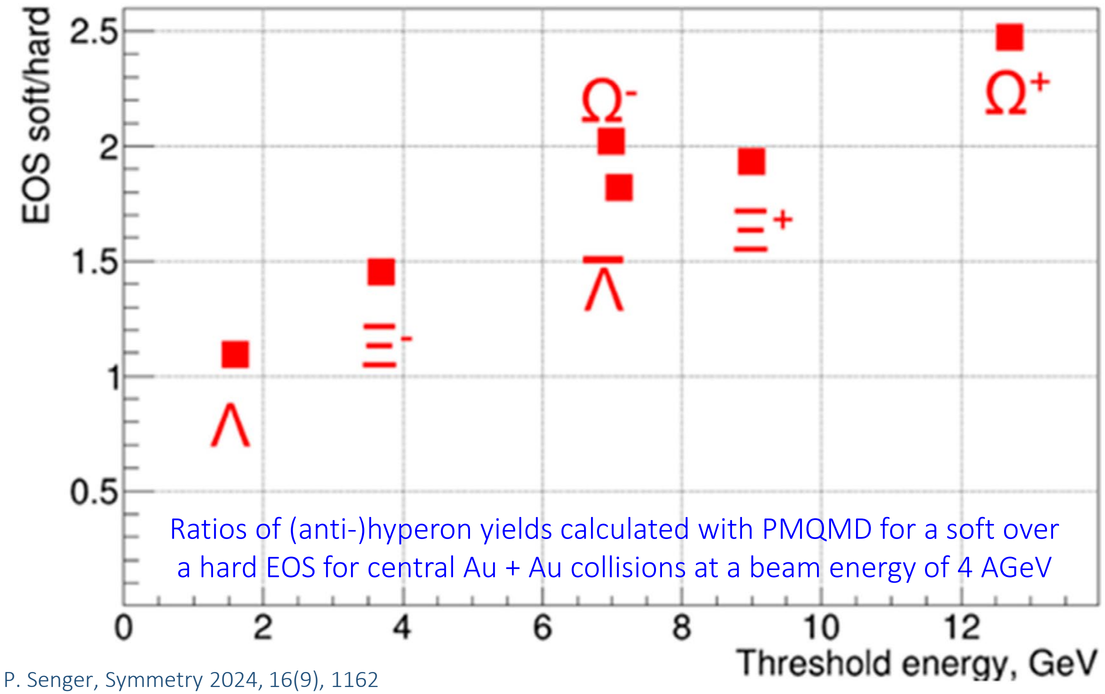
Ratios of (anti-)hyperon yields calculated with PMQMD for a soft over a hard EOS for central Au + Au collisions at a beam energy of 4 AGeV

P. Senger, Symmetry 2024, 16(9), 1162
J. Aichelin et al., Phys. Rev. C 101, 044905

Observable #1: Sub-Threshold Strangeness Production







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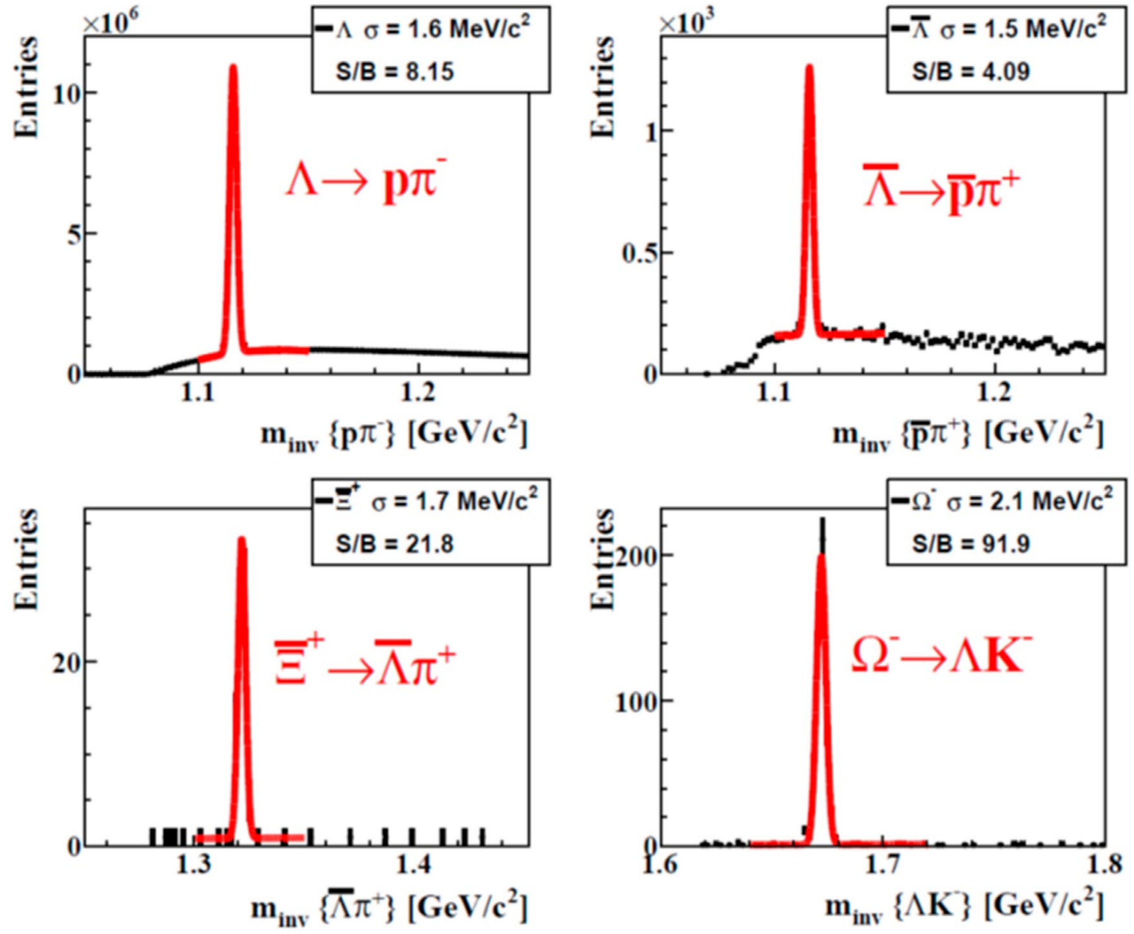
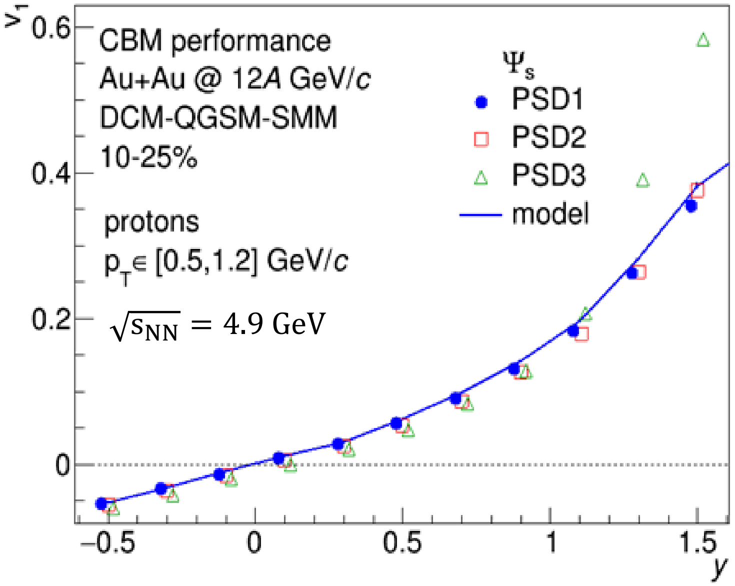
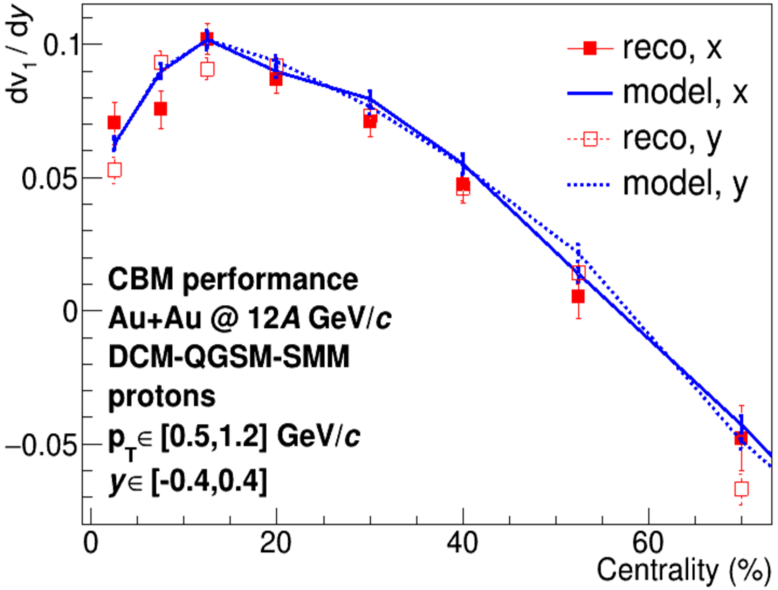


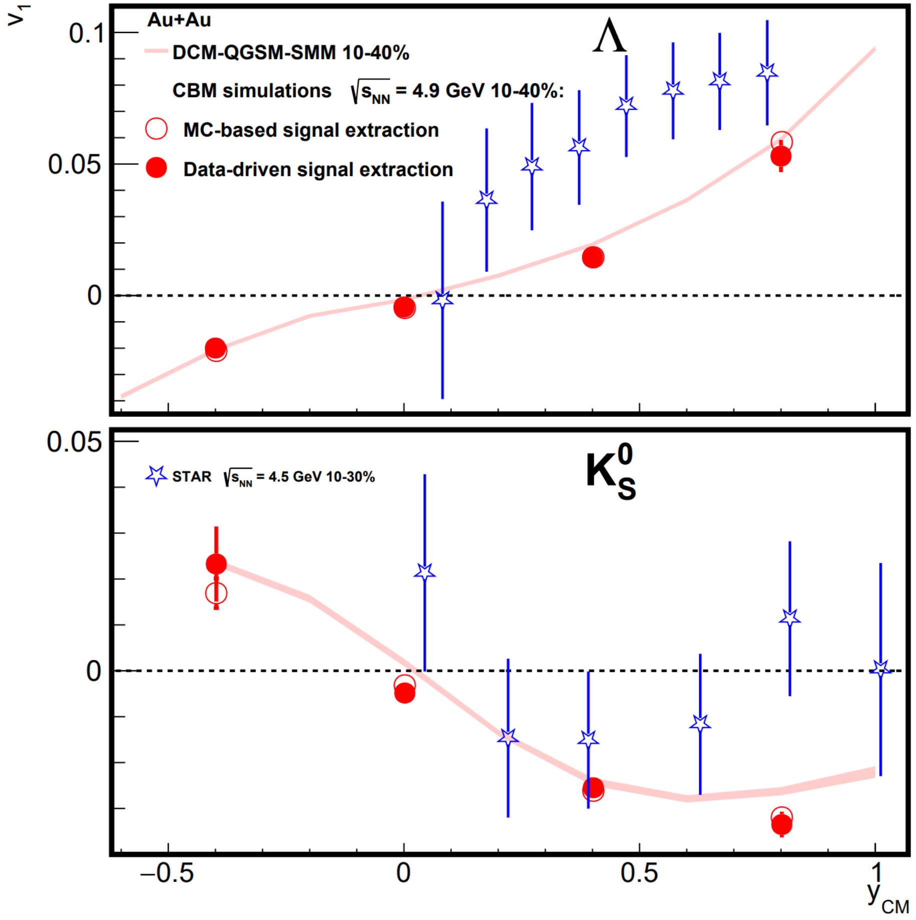
I. Vassiliev et al., CBM Progress Report 2019 (2020)

CBM performance simulations show precise reconstruction of multi-strange hyperons, enabling the setup's sensitivity to yield variations due to EOS





O. Golosov et al., CBM Progess Report 2020
O. Golosov et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012104



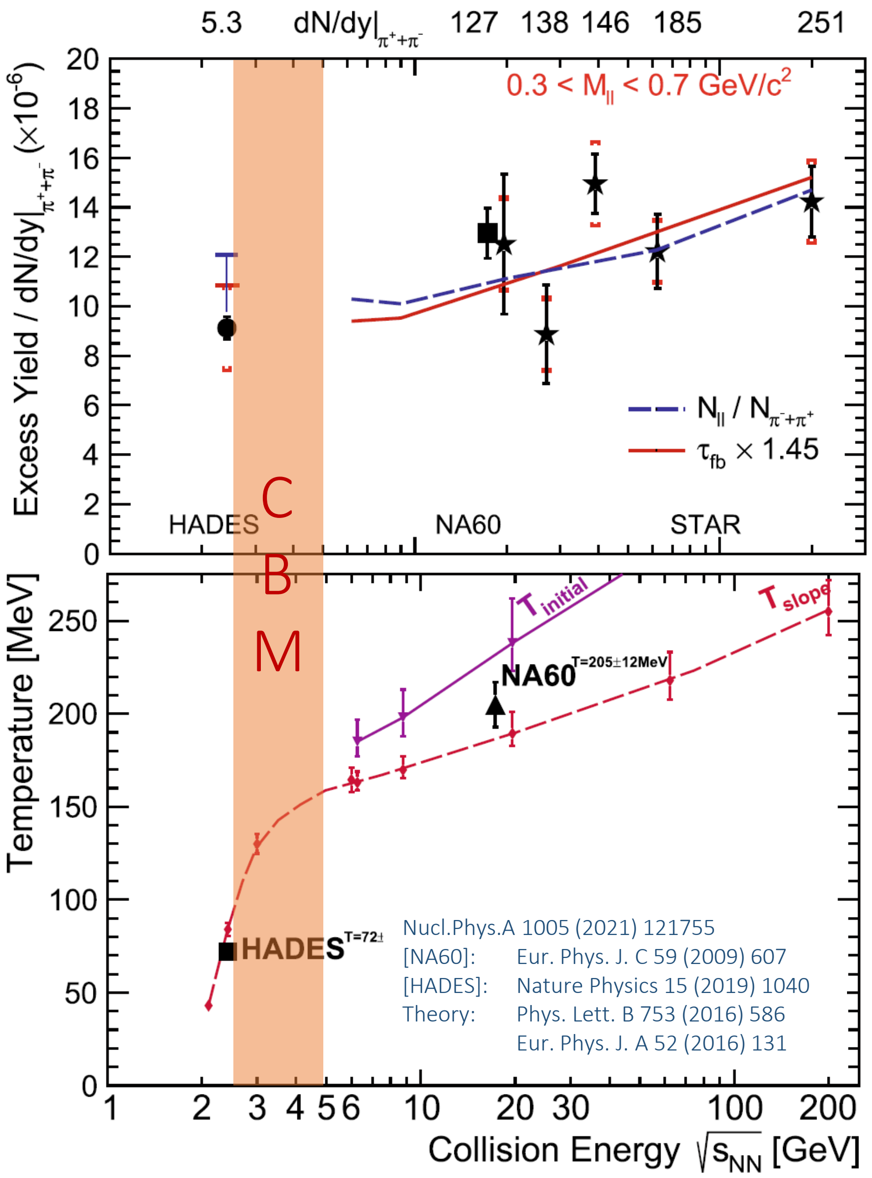
- Data-driven methods to perform extensive multi-differential v_1 flow analysis for protons and strange hadrons (Λ, K^0_S) have been developed
- Comparable v_1 predicted by DCM-QGSM-SMM for STAR-FXT at $\sqrt{s_{NN}}$ = 4.5 GeV
- Ongoing – Higher harmonics (v_2, …) and energy scan throughout SIS-100 range
- Ongoing – Feasibility study for asymmetric flow cumulants

O. Lubynets, FAIRNESS 2022
[STAR], Phys. Rev. C 103, 034908 (2021)

High-rate capability of CBM can enable a precise multi-differential flow analyses of not only protons, but of strange hadrons too. v_1 analyses tools have been developed and for high-harmonics are under development.

Observable #3: Fireball Caloric Curve & Dileptons Yields

F. Seck (30.10)



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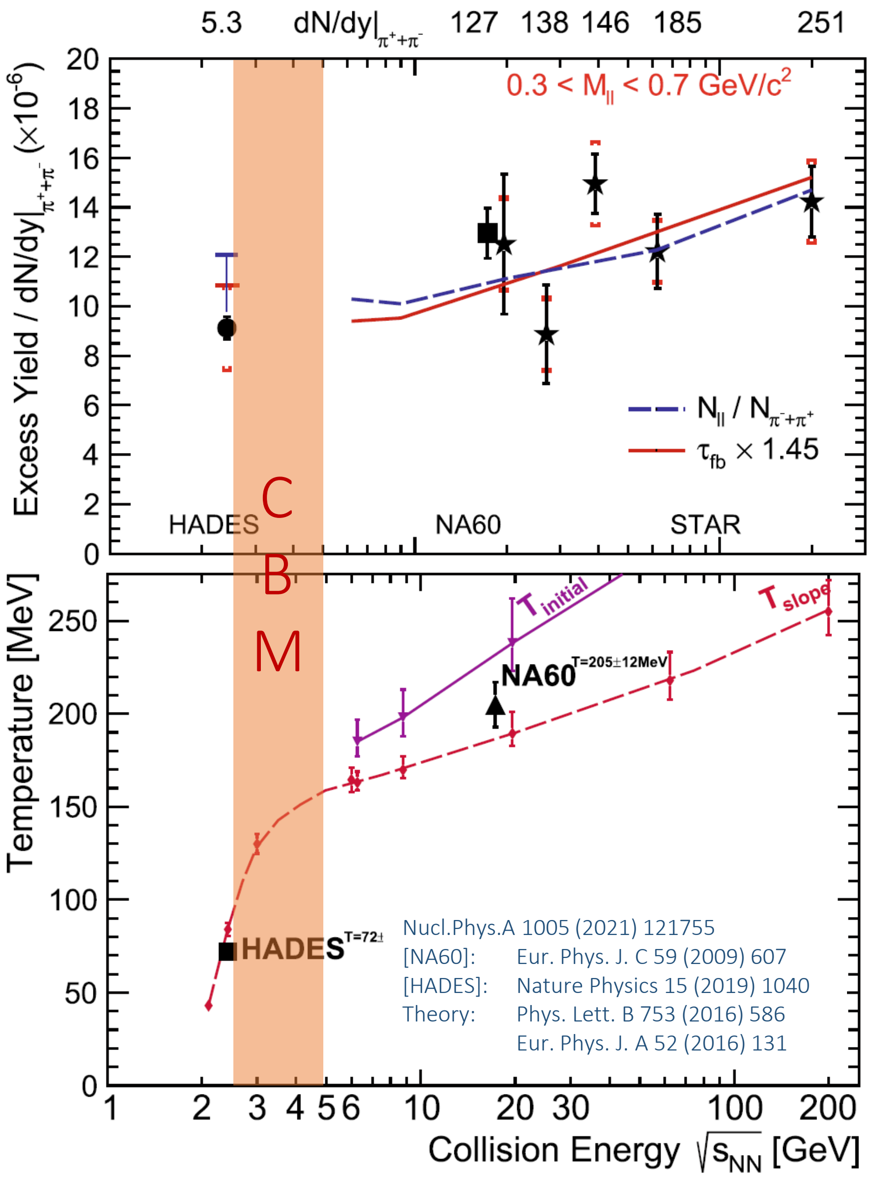
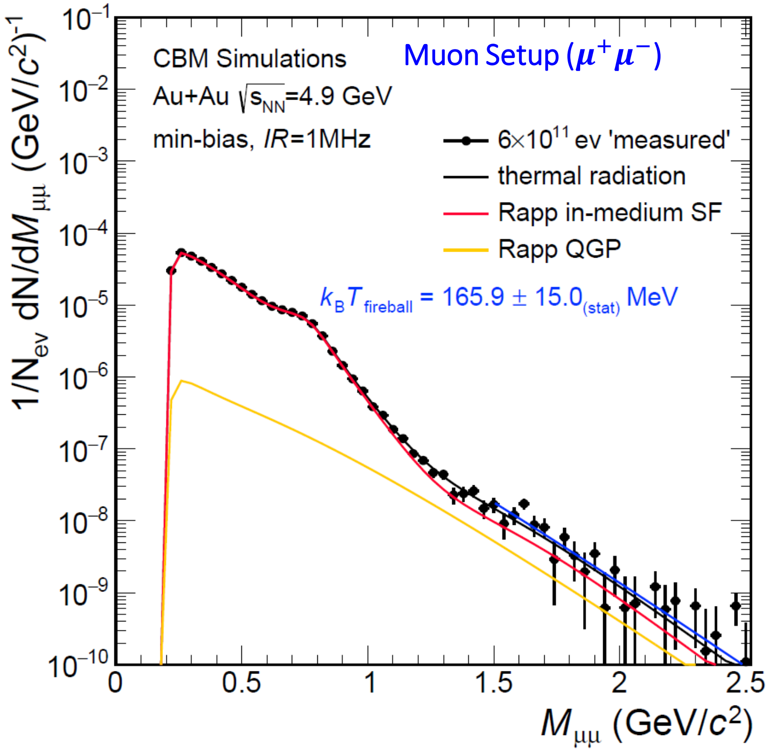
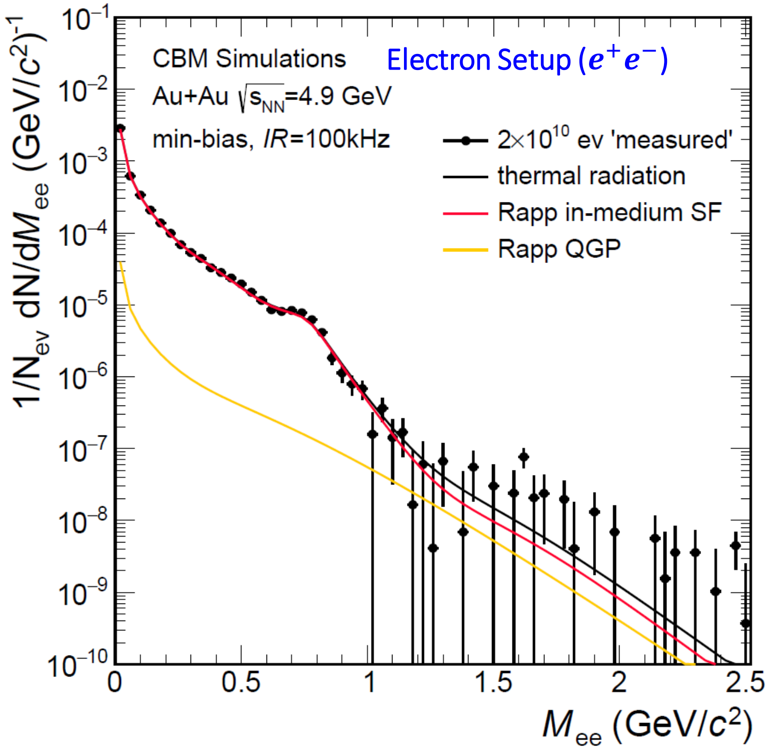


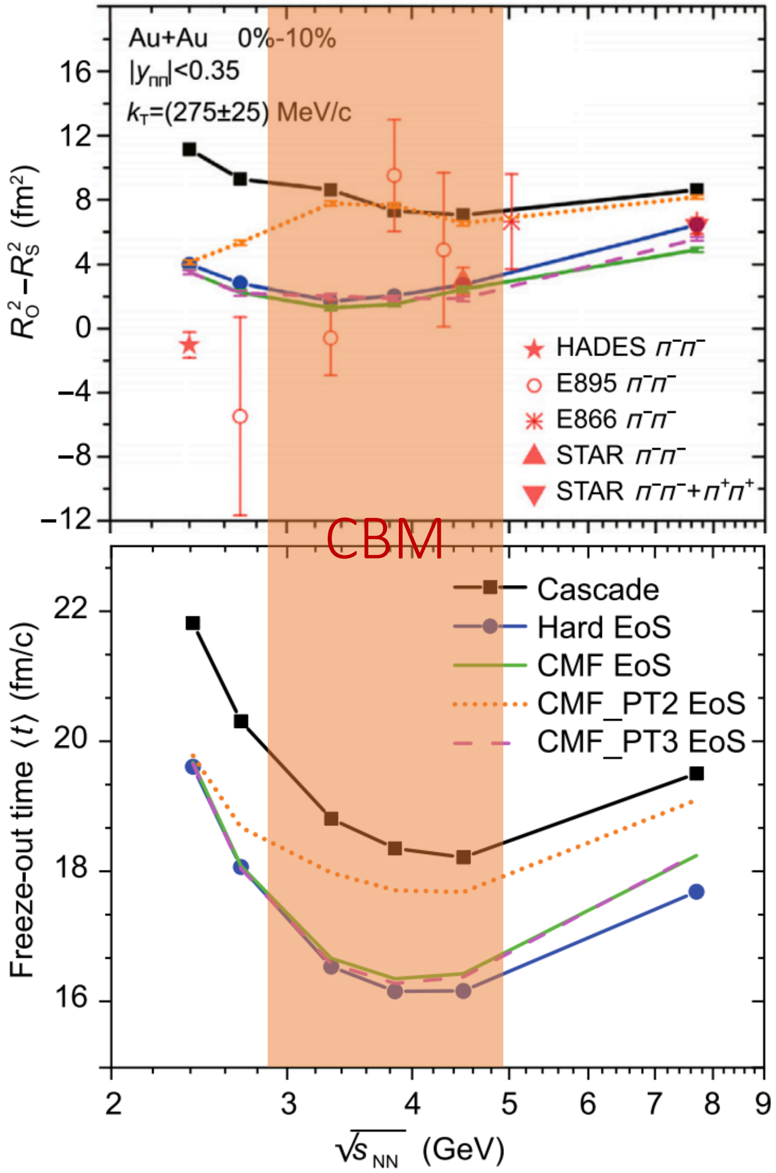




- Performance studies with realistic detector geometries, material budget, and response for both, muon ($\mu^+\mu^-$) and electron setup (e^+e^-)
- Access to thermal signal is feasible with good background description; Mass Resolution $\sigma_{M_{ll}}(\omega)$ = 14 MeV/c^2

CBM, operable in muon- and electron-setup, can efficiently detect dileptons to scan the energy dependence of fireball properties (lifetime, temperature, lifetime, …) to detect potential phase transition signatures

OBSERVABLE #4: FEMTPSCOPY & PARTICLE CORRELATIONS

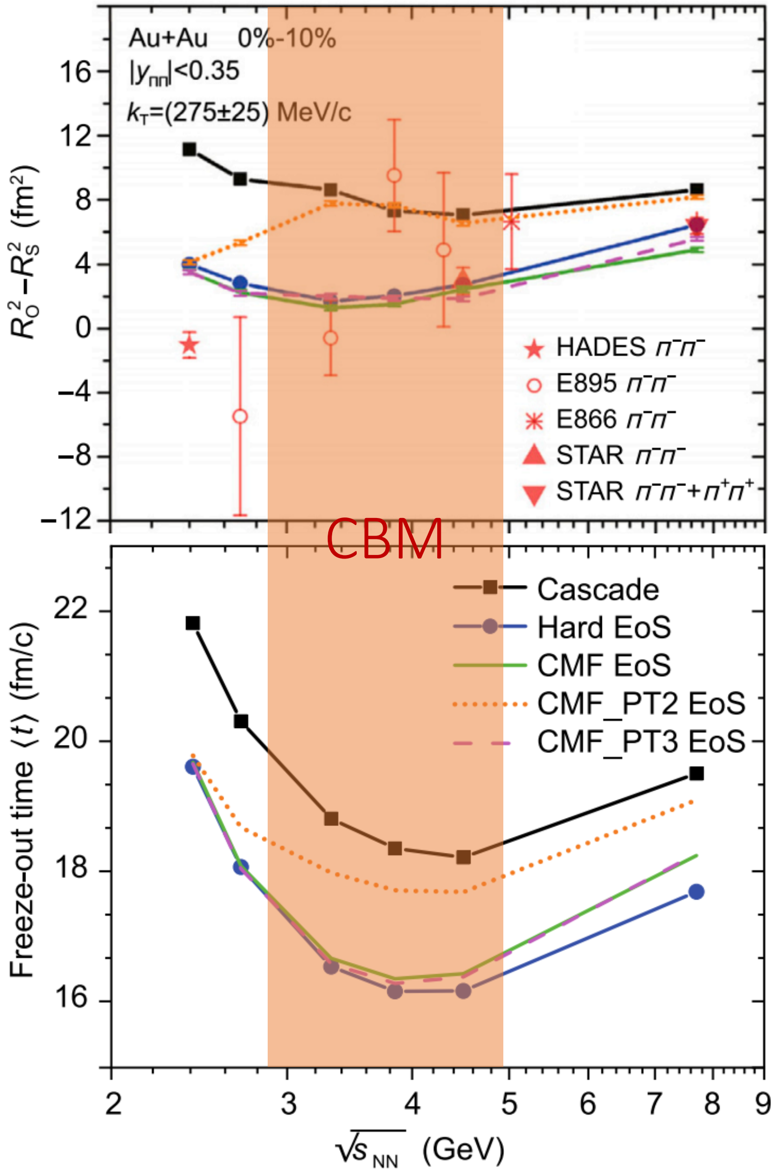


P. Li et al., Sci.China Phys.Mech.Astron. 66 (2023) 3, 232011

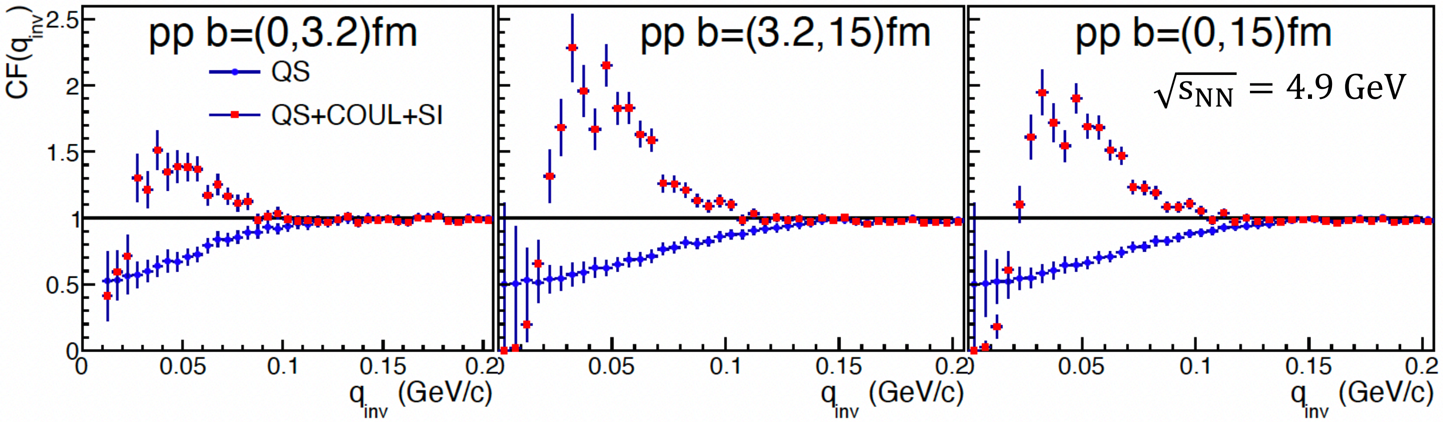
Observable #4: Femtpscopy & Particle Correlations

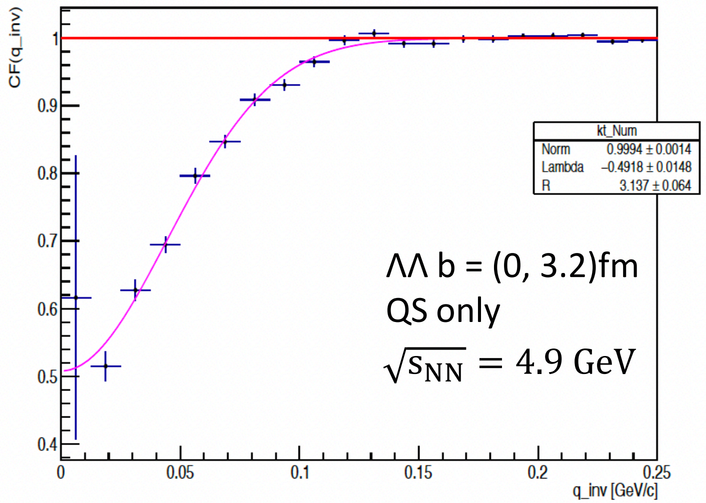
P. Nzabahimana (30.10)

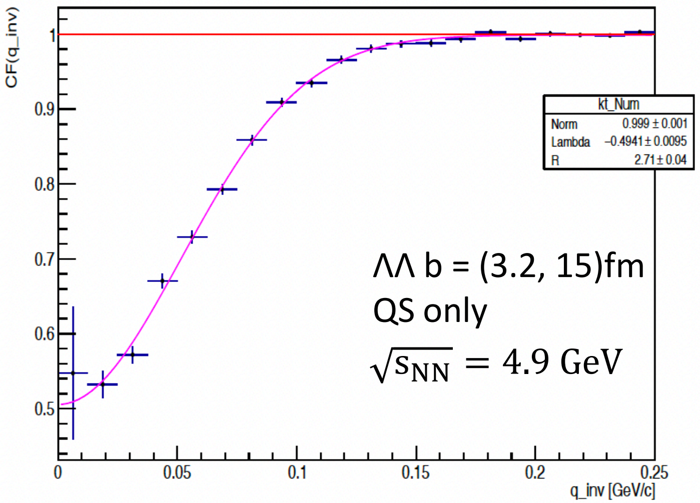
CBM



P. Li et al., Sci.China Phys.Mech.Astron. 66 (2023) 3, 232011



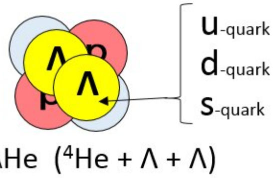


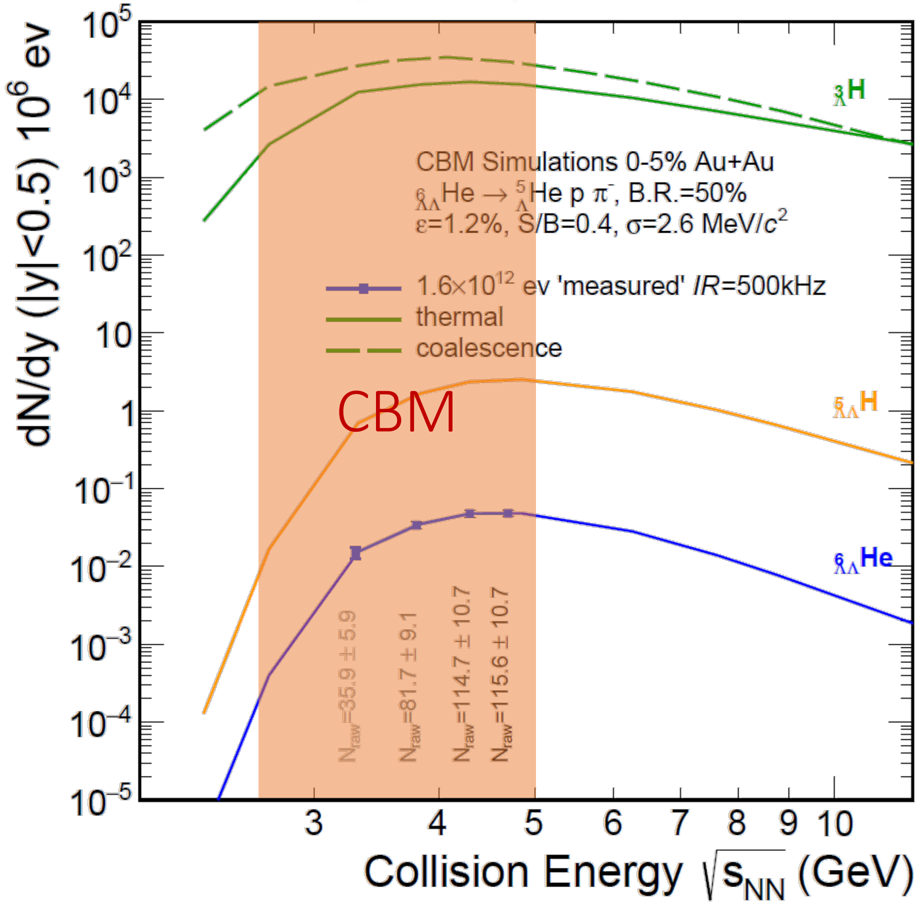


H. Zbroszczyk, WPCF 2024

The currently large experimental uncertainties represent an opportunity for CBM to explore femtoscopic and azimuthally dependent observables (potentially by using optical deblurring techniques to precisely infer the emission source)

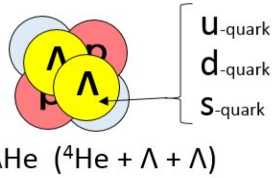
OBSERVABLE #5: HYPERNUCLEI PROPERTIES

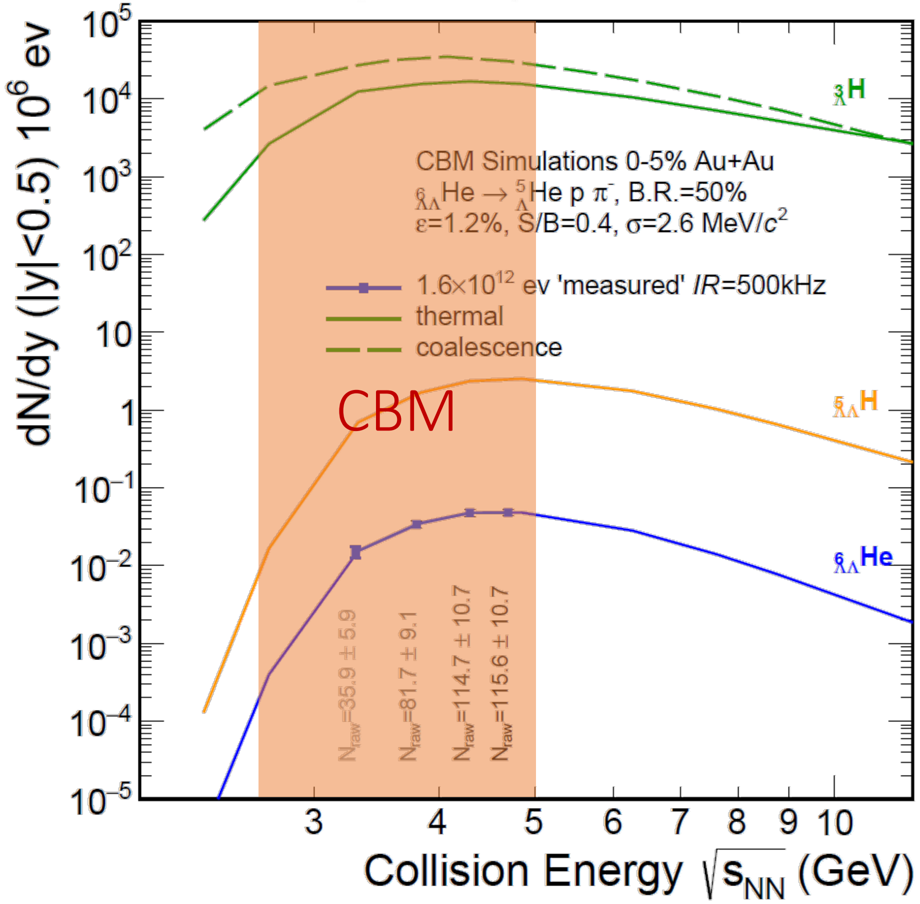


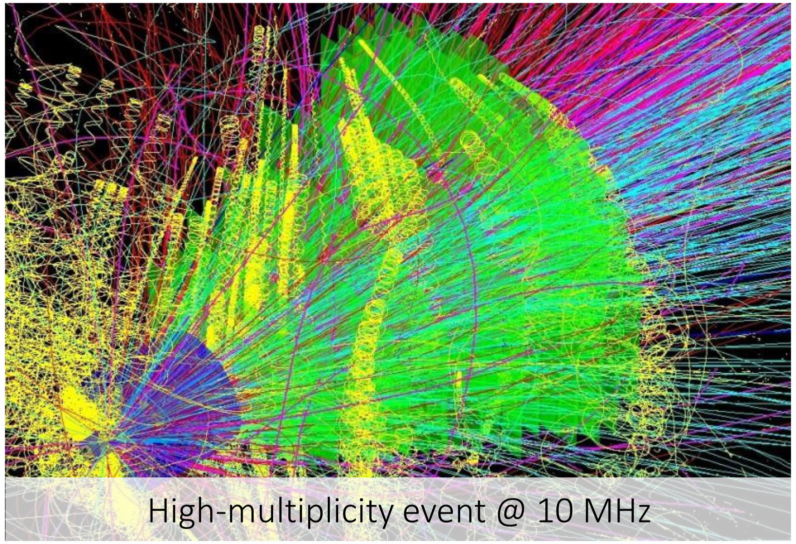


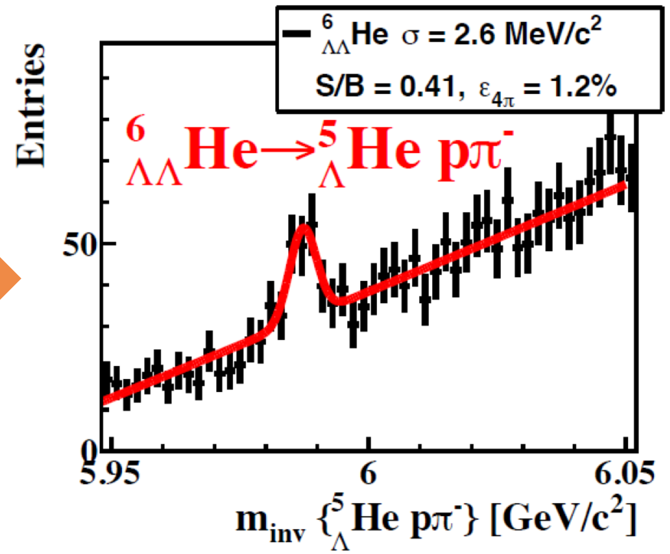
Thermal: A. Andronic et al., Phys.Lett.B 697 (2011) 203-207
Coalescence: J. Steinheimer et al., Phys.Lett.B 714 (2012) 85-91

Observable #5: Hypernuclei Properties









- Tools in place for the multi-differential physics analysis of strange hadrons and hypernuclei
- Reconstruction based on the dedicated KFParticleFinder package, with reconstruction routines tested with STAR FXT data (efficiency and cuts optimization are ongoing with ML approach)

S. Glässel [CBM], Quark Matter 2023 | Link
I. Vassiliev [CBM], Strangeness in Quark Matter 2024

- Production estimate for $_{\Lambda\Lambda}^{6}\mathrm{He}$ at 0.5 MHz interaction rate for 90 days:

$\Rightarrow \mathrm{IR} \times f_{av} \times \varepsilon_{duty} \times P_{prod} \times f_{mb/cen} \times \mathrm{BR} \times \varepsilon_{rec} \times \Delta t$

$\approx (0.5 \times 10^6) \times 0.5 \times 0.7 \times (0.5 \times 10^{-7}) \times 0.25 \times 0.5 \times 0.012 \times (7.6 \times 10^6)$

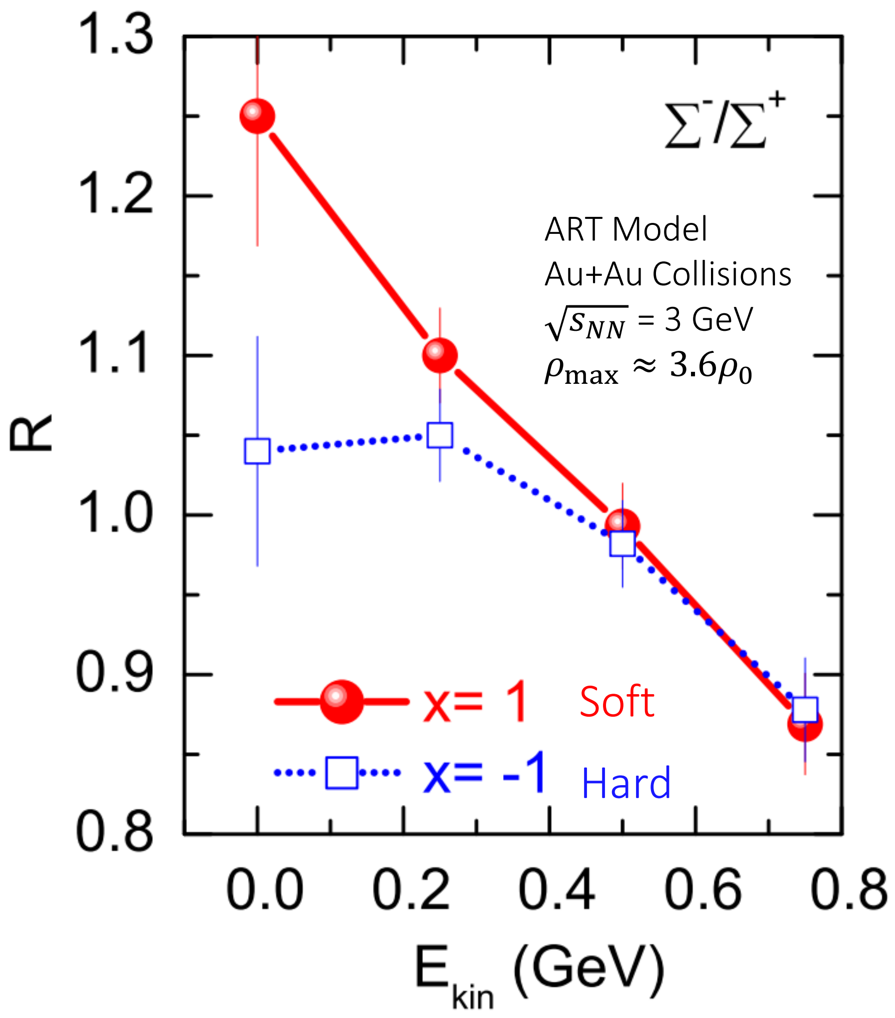
$= 100$ signal counts (currently, only 3 observations reported)

Thermal: A. Andronic et al., Phys.Lett.B 697 (2011) 203-207
Coalescence: J. Steinheimer et al., Phys.Lett.B 714 (2012) 85-91

The high-interaction rate at CBM will give a better handle on Y-Y interactions by studying elusive hypernuclei such as $_{\Lambda\Lambda}^{6}\mathrm{He}$

Observable #6: $(n/p)_{\text{like}}$ Particle Ratios

Motivation for pion ratios at FRIB: K. Brown (28.10)



G-C. Yong et al., Phys. Rev. C 106, 024902 (2022)

OBSERVABLE #6: $(n/p)_{\text{like}}$ PARTICLE RATIOS

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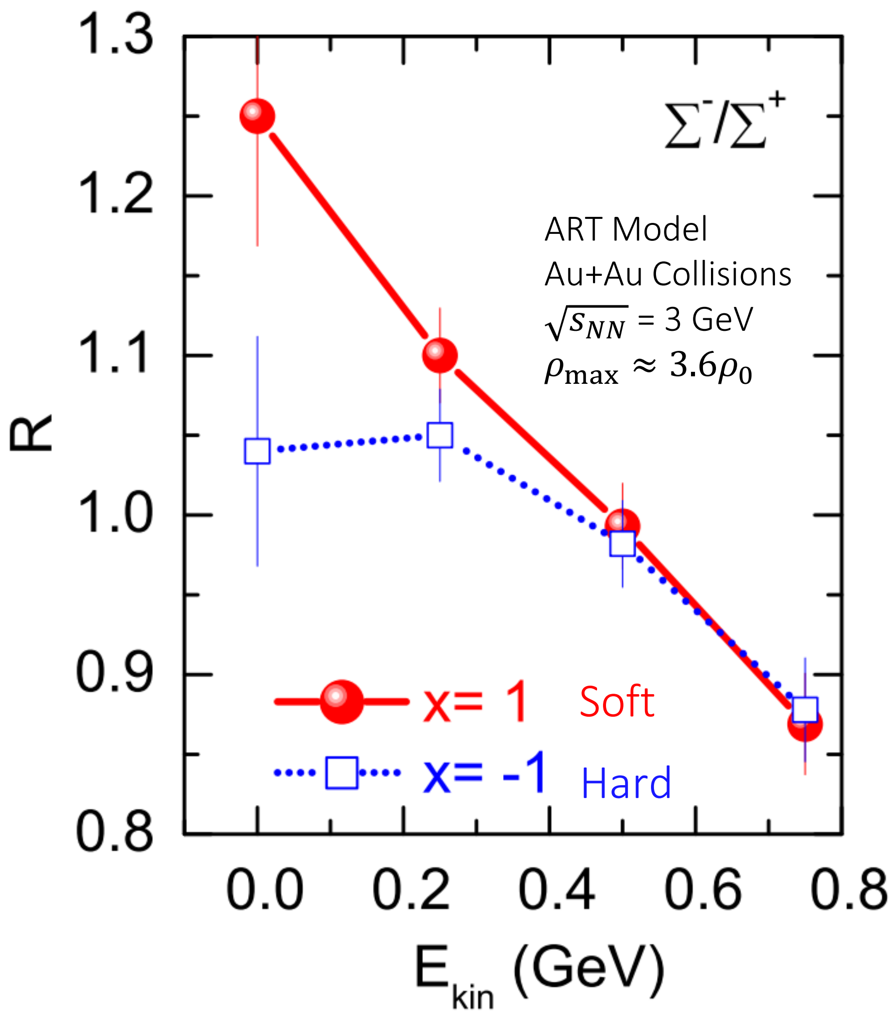
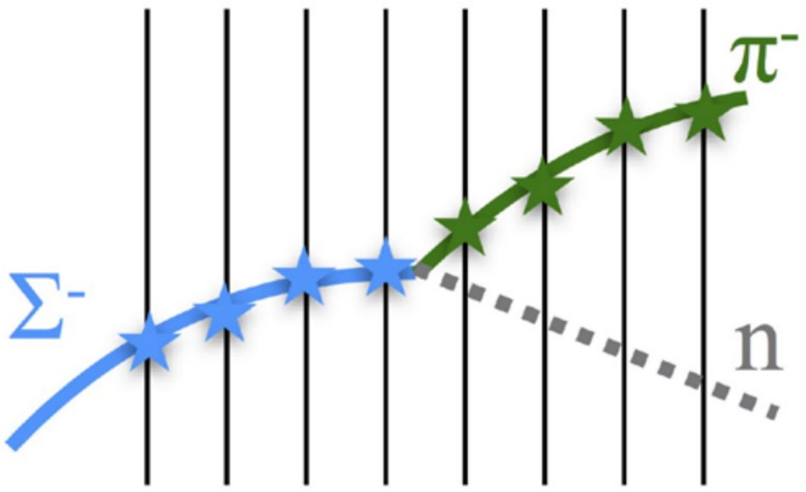
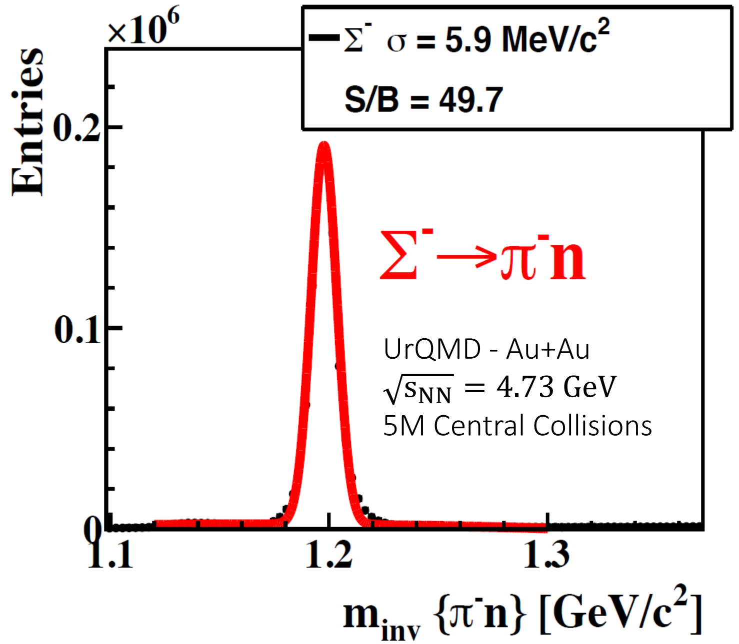


G-C. Yong et al., Phys. Rev. C 106, 024902 (2022)

- Experimentally, Σ baryons are difficult to identify
  → Short-lived ($c\tau_{\Sigma^+}$ = 2.4 cm and $c\tau_{\Sigma^-}$ = 4.4 cm)
  → Decay with at least one neutral daughter particle ($\Sigma^- \to n\pi^-, \Sigma^+ \to n\pi^+, \Sigma^+ \to p\pi^0$)
- Tracking-Vertexing detectors located close to the target, in combination with the Missing Mass Method of particle reconstruction allows to achieve clean identification of Σ

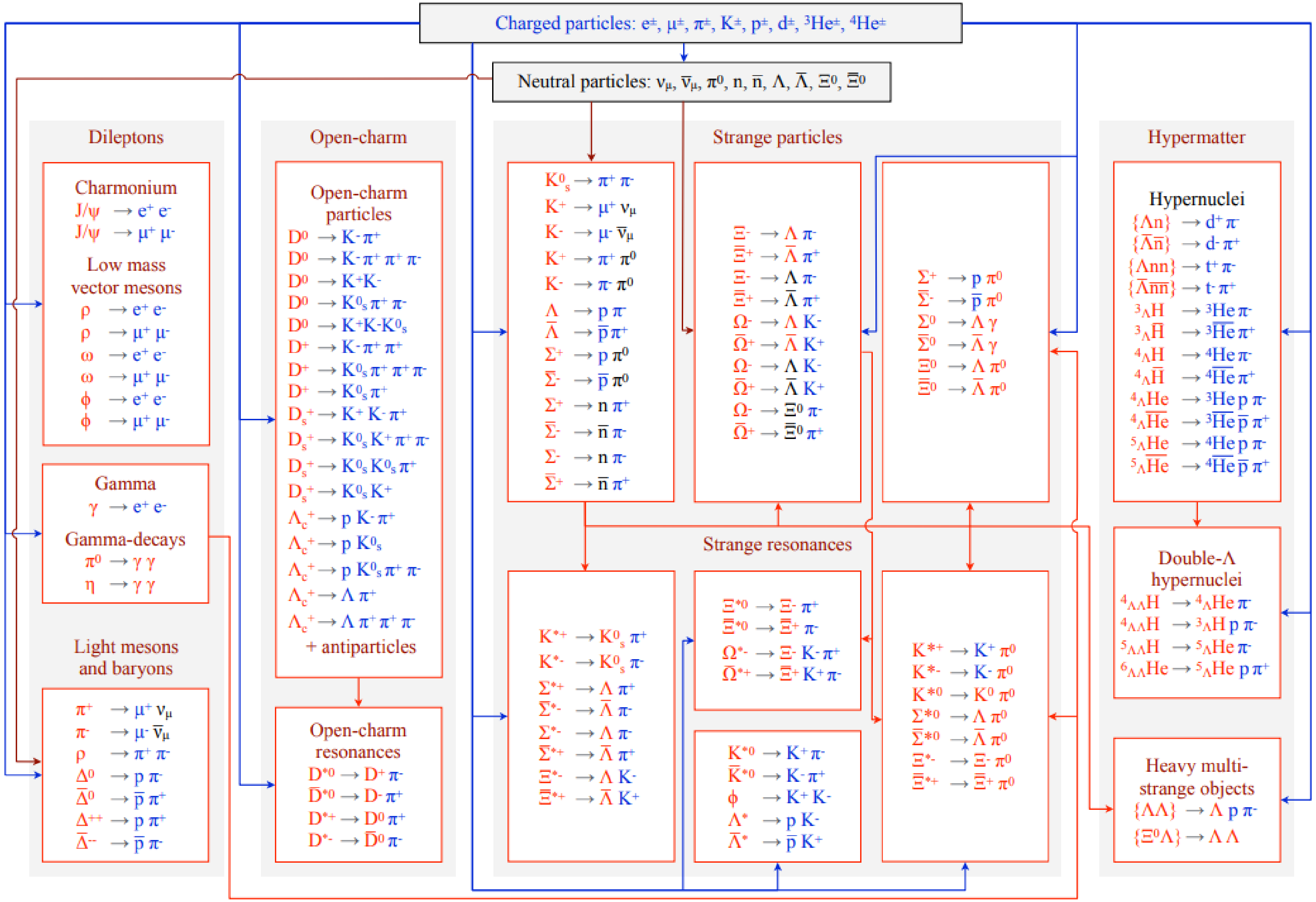


P. Kisel et al., EPJ Web Conf. 173 (2018) 04009



The vertexing and tracking detectors of CBM are located close to the interaction point, in conjunctions with novel track reconstruction methods enable high-statistics measurement of Σ hyperons to systematically study the isospin effects

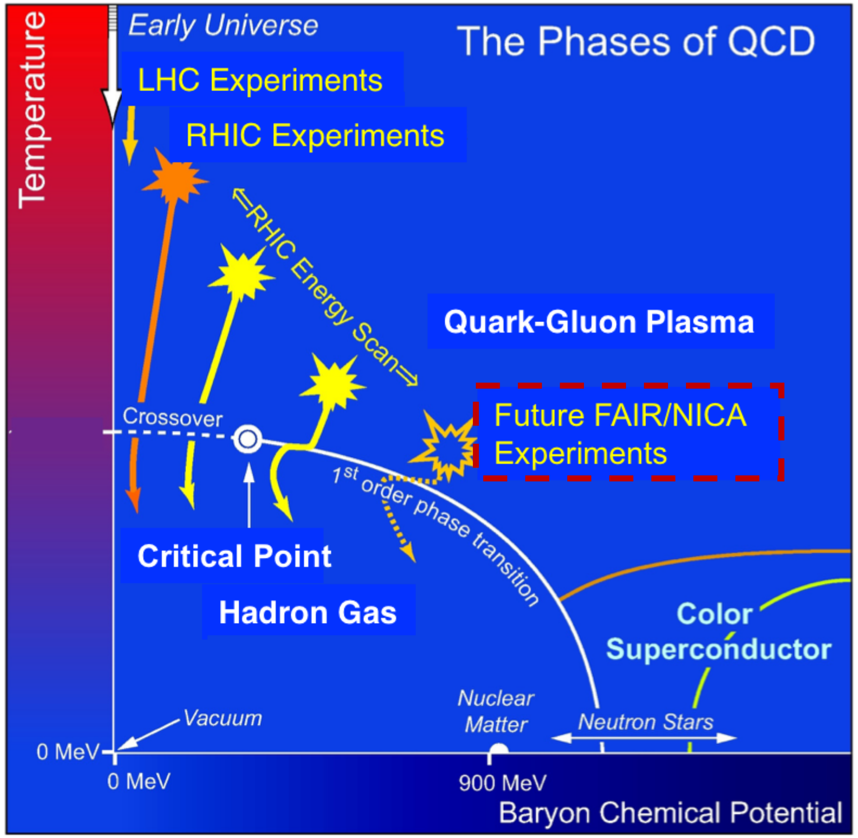
Are There More EOS Observables?



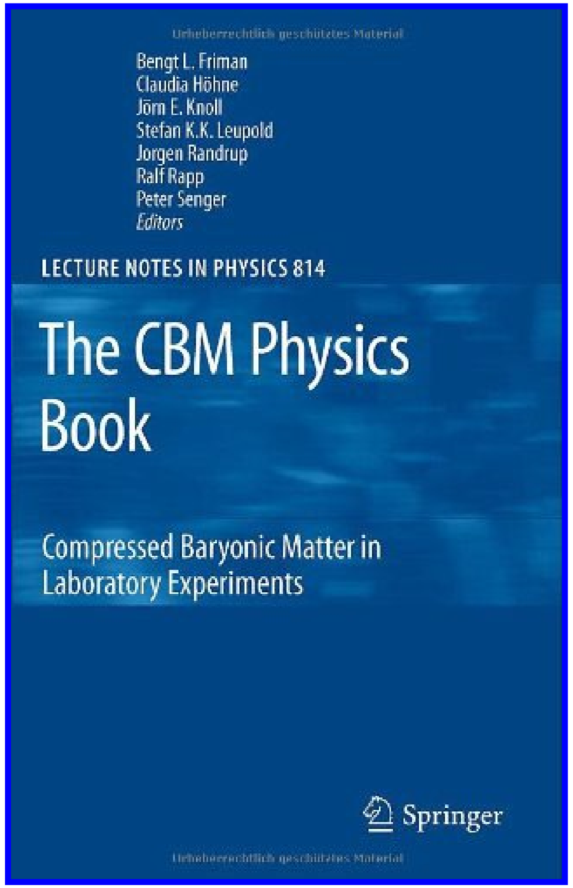
A food for thought, i.e., potential feedback and collaboration point:
Are there any other particles and/or observables amongst the CBM roster which are sensitive to the dense nuclear matter EOS?

CBM Physics Goals – Much More Than EOS Physics

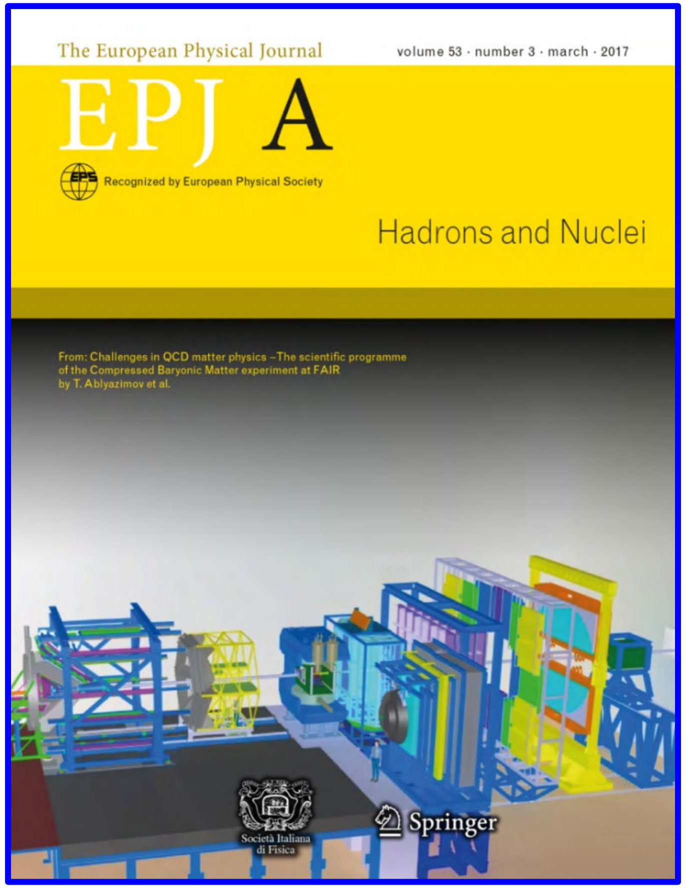
[STAR], Studying the Phase Diagram of QCD Matter at RHIC, STAR Note 598 (2014)



- Equation of State (EoS) of symmetric nuclear (and asymmetric neutron) matter at neutron star core densities
- Phase structure of QCD matter (1st-order phase trans.? critical point?)
- Chiral symmetry restoration at large μ_B
- Bound states with strangeness
- Charm in cold and dense matter



Lect. Notes Phys. 814 (2011) pp.1-980
DOI: 10.1007/978-3-642-13293-3



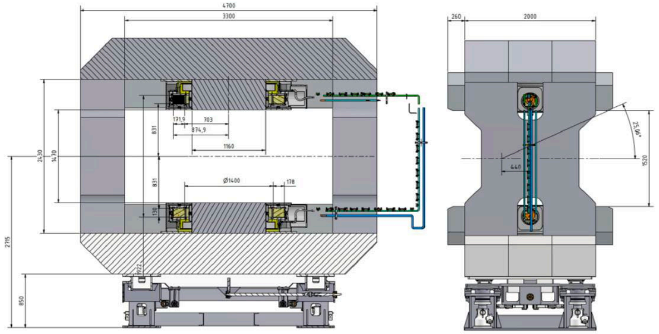
Eur.Phys.J.A 53 (2017) 3, 60
DOI: 10.1140/epja/i2017-12248-y

CBM has much wider physics goals, all centered to address the unanswered fundamental questions of QCD at high densities

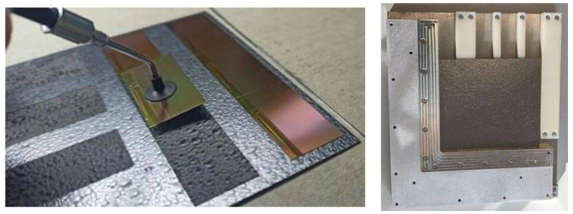
RECENT (& BRIEF) ACHIEVEMENTS IN DETECTOR PROJECTS

Accelerating towards series production and being ready for SIS-100 beams in 2028

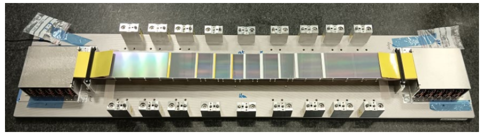
Superconducting dipole magnet
award of contract to Bilfinger Noell GmbH 20.12.2023



Micro Vertex Detector
sensor/module integration



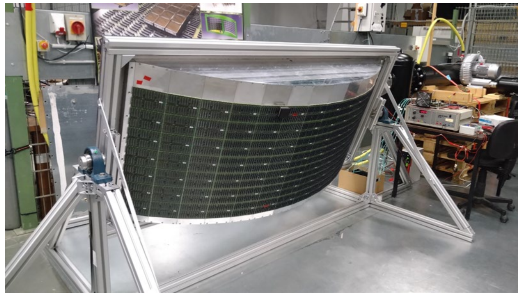
Silicon Tracking System



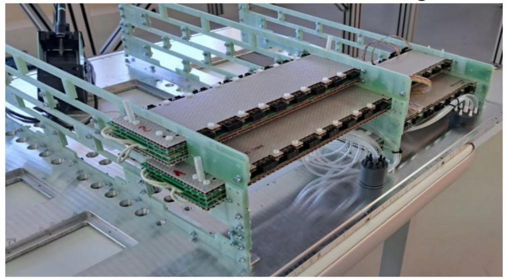
first STS series ladder

>25% modules assembled

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

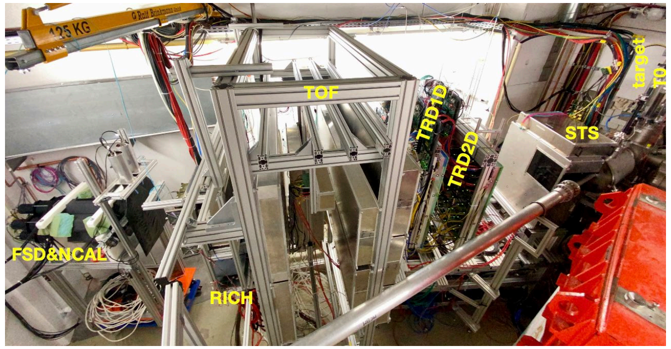


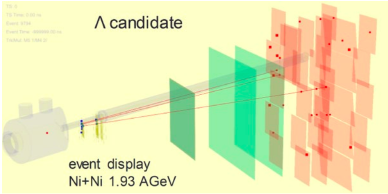
Time of flight detector

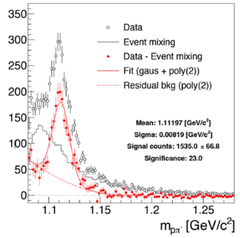


module pre-production concluded

Prototype of CBM online data processing tests with mCBM

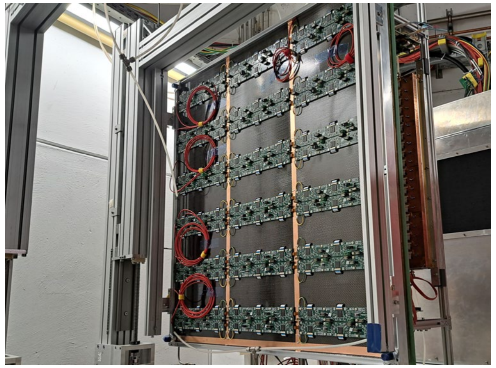






Beam monitoring system

Transition Radiation Detector

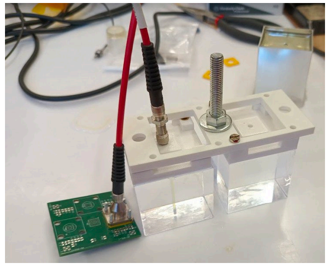


pre-production modules of 1D and 2D options ready

MUon CHamber system

test of full-size GEM and RPC prototypes

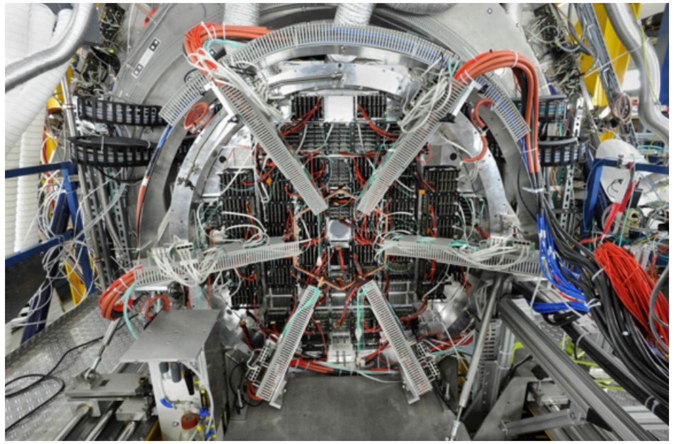
Forward Spectator Detector

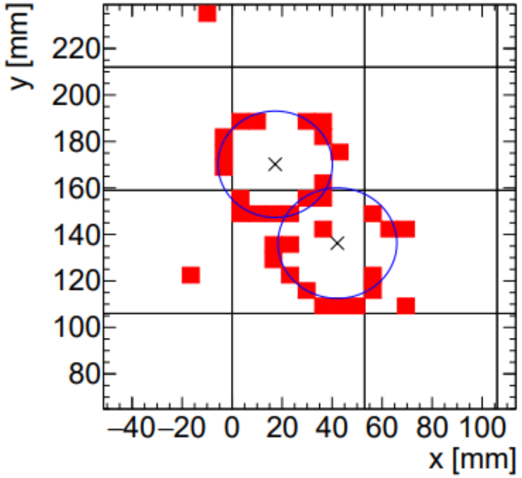


ZnS scintillators and LYSO crystals read-out via SiPM or/and PMT

"Large-Scale" Demonstrators With CBM Components

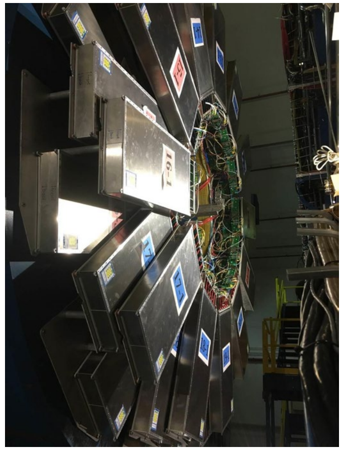
HADES-RICH: Already 1/2 (430 MAPMTs + FEE) of CBM-RICH

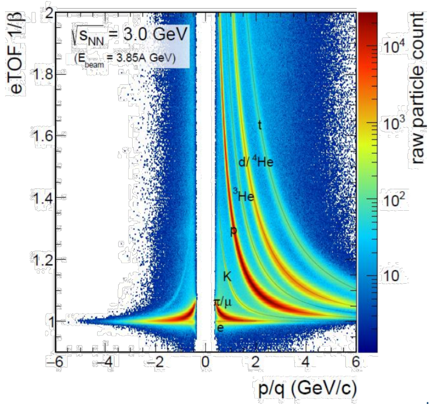


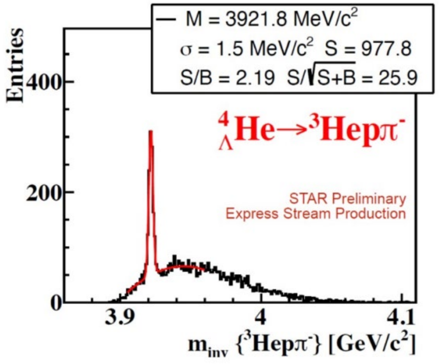


J. A-Musch et al., CBM Progress Report 2020

STAR-eTOF: 10% (108 MRPCs) of CBM-TOF
CBM Online Reconstruction Software for STAR-BES

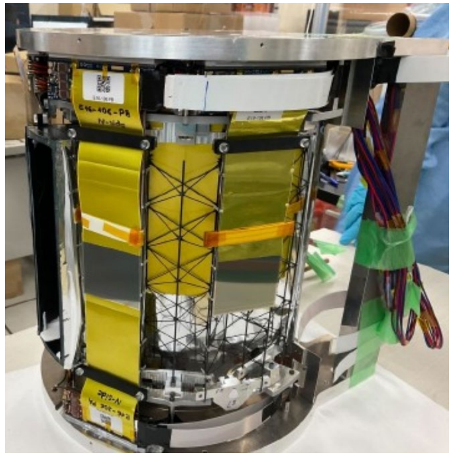


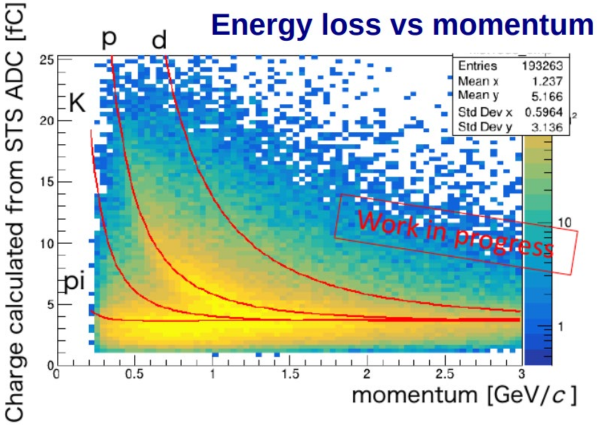




I. Deppner et al., JINST 15 (2020) 10, C10030
I. Vassiliev, Strangeness in Quark Matter 2024

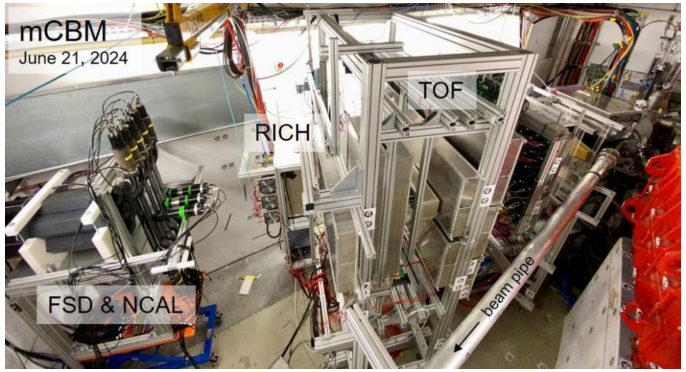
STS in E16 (J-PARC)
10 pre-production modules in magnetic field

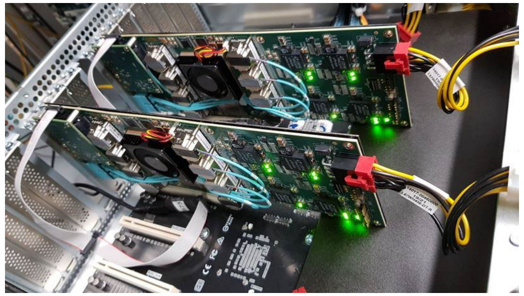




M. Teklishyn and A. Toia, CBM Collaboration Meeting, Fall 2024

mCBM-SIS18: Pre-production components from all CBM detector sub-systems
Conceptual verification of the triggerless-streaming read-out at $\mathcal{O}$ (1 MHz) interaction rates
Systematic high-rate studies performed for various detector subsystems
CBM software development – Λ reconstruction in 2024 data

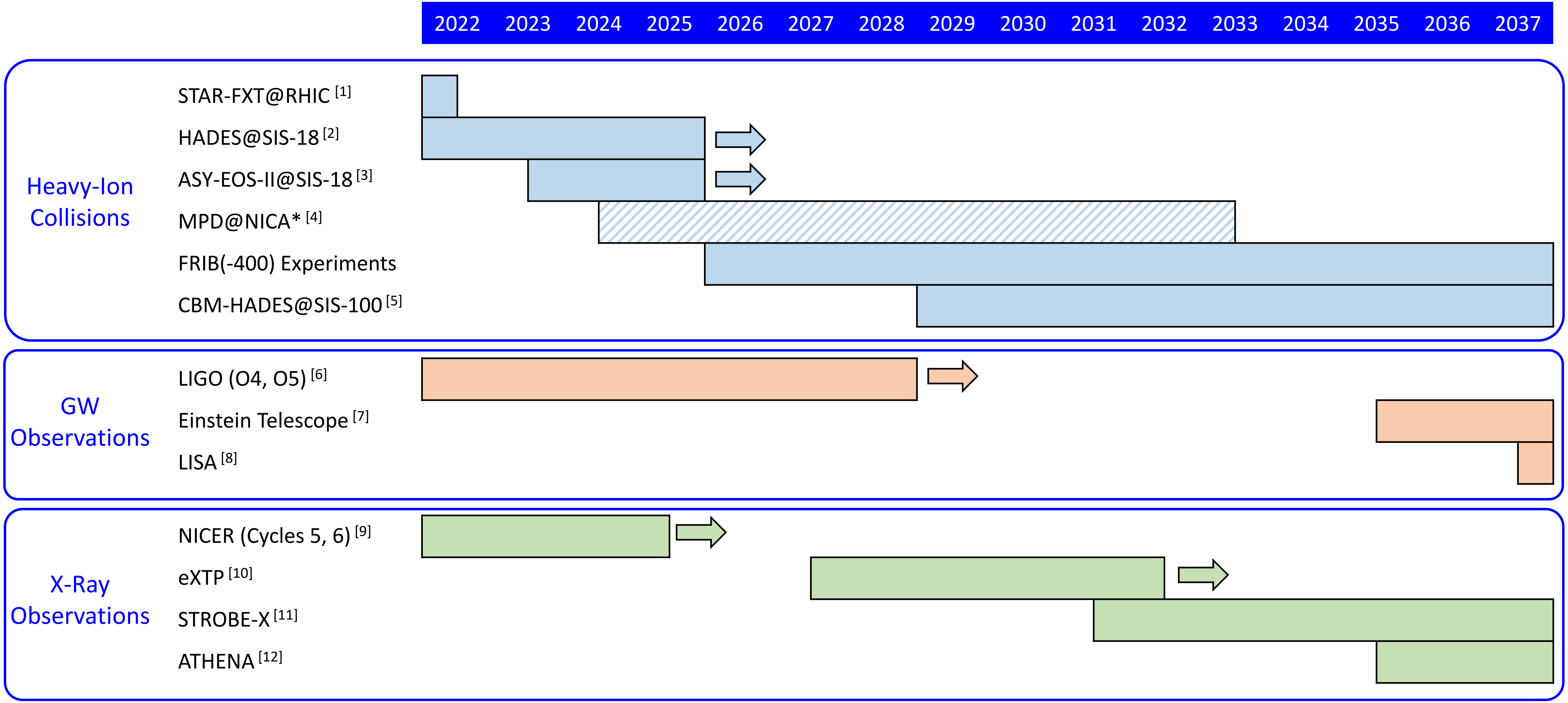




C. Sturm et al., CBM Progress Report 2022
C. Sturm et al., CBM Progress Report 2023

Growing Multi-Messenger Era (At Densities $\gtrsim \rho_0$)

Tools for leveraging this:
Morning Session (31.10)
N. Yao (30.10)



[1] D. Morrison, Quark Matter 2022 | Link
[2] Proposal for Beamtime in 2023-24, GSI G-PAC
[3] Proposal for Beamtime in 2023-24, GSI G-PAC
[4] I. Maldonado, A. Ayala, EuNPC 2022 | Link
[5] Staging Review of the FAIR Project (2022) | Link
[6] LIGO-Virgo-KAGRA Observing Run Plan | Link
[7] Einstein Telescope Homepage | Link
[8] LISA ESA Factsheet | Link
[9] NICER Proposals Guide – Cycle 5 | Link
[10] eXTP Homepage | Link
[11] STROBE-X White Paper | Link
[12] ATHENA ESA Factsheet | Link

SUMMARY AND OUTLOOK

CBM@SIS-100 has significant discovery potential

- Equation of State (EoS) of symmetric nuclear (and asymmetric neutron) matter at neutron star core densities
- Phase structure of QCD matter (1st-order phase trans.? critical point?)
- Chiral symmetry restoration at large μ_B
- Bound states with strangeness
- Charm in cold and dense matter

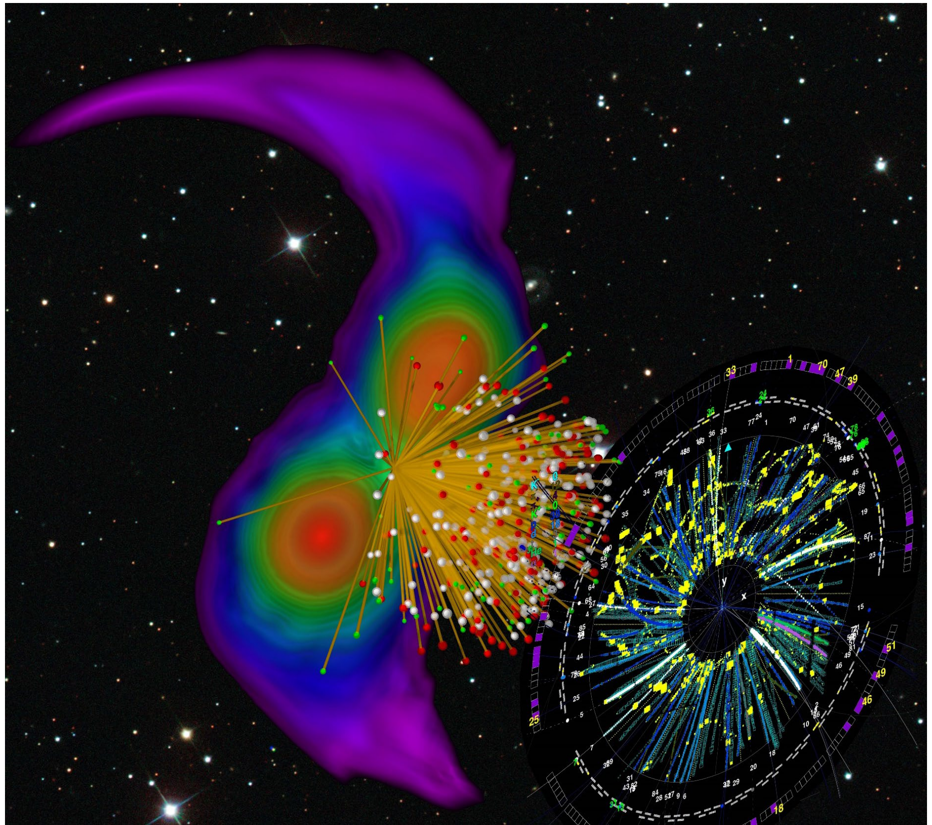
Pushing the high-rate capability frontier

- to achieve high precision of multi differential observables
- to enable rare processes as sensitive probes

CBM Phase 0 activities (HADES, STAR, mCBM)

- performance optimisation of major components
- production of physics results with CBM devices

CBM is open to new participation and collaborations



Tim Dietrich, Arnaud Le Fevre, Kees Huyser; Background: ESA/Hubble, Sloan Digital Sky Survey

CBM@SIS-100 (Au-Au at $\sqrt{s_{NN}} = 2.86 \; ... \; 4.93 \text{ GeV}$) provides unique conditions in lab to probe QCD matter properties at neutron star core densities, including the high-density EOS, and the search for new phases at higher densities

MOVING TOWARDS A NEW MULTI-MESSENGER PHYSICS ERA

Thank You

47 full member institutions
10 associated member institutions
from 10 countries, 315 full members

44th CBM Collaboration Meeting
Czech Technical University - Prague, September 15-20, 2024

Vote Of Confidence For CBM-FAIR

Report

from the Committee for

First-Science and Staging Review of the FAIR Project

Submitted to FAIR Council, October 2022

GSI Press Release – Link
Report PDF – Link

The committee came unanimously to the following recommendations in order to advance FAIR to science beyond Phase-0:

- First priority should be the completion of the S-FRS into the HEB cave for NUSTAR to carry out the Early Science program.
- Completion of SIS100 needs to have the next highest priority.
- If resources are tightly constrained, completing SIS100 with beams into the S-FRS and HEB cave, plus setting up and commissioning the CBM experiment offers an intermediate solution for developing world-class science at FAIR.
- Completing the infrastructure and instrumenting the APPA cave should have priority over instrumenting the additional area in LEB for NUSTAR.
- Tendering for civil construction of the West lot should be postponed, but a plan is needed for the time frame to implement PANDA.
- The orderly set of steps towards the IO, presented in this document, represents the most cost-effective plan for moving FAIR forward. In order to accomplish this, a yearly budget

- The Heuer-Tribble Committee suggests a stepwise approach for the realization of FAIR
- Completion of SIS-100 was noted to be "existential" to FAIR
- Further endorsement obtained that bringing CBM to life will extend FAIR's first science programme at a "minimal cost"

Accelerator Parameters And Comparisions

Table 4.1 Main parameters of accelerators around the world. Taken from [370]. In case of RAON linear accelerator, the length from the superconducting electron cyclotron resonance ion sources to the LAMPS experimental setup is given

	SIS18	SIS100	Nuclotron	NICA	HIAF	RAON	J-PARC
Circumference/length, m	216.72	1083	251.5	503.04	569.1	687	1567.5
Rigidity, Tm	18	100	25 – 43.25	45	36		160
Repetition rate, Hz	0.3 – 1	0.7			0.09		
Cycle duration, s		1.5	5		3 – 10		5.52
B-field ramp, T/s	10	4	1		4		
Accelerated ion	U^{73+}	Au^{79+}	Au^{79+}	Au^{79+}	U^{34+}	U^{79+}	U^{92+}
Extraction E ion, GeV	1	12	4.5	4.5	0.2 - 0.8	0.2	11.2 (19.5)
Extraction E proton, GeV	4.5	29	12.6	12.6		0.6	30 (50)
Intensity ion, ions/cycle	4×10^9	5×10^{10}	1×10^9	1×10^9	10^{11}	8.3 pμA	4×10^{11}
Intensity proton, p/cycle	10^{11}	2×10^{13}	1×10^{11}	1×10^{11}		660 μA	2×10^{14}
Extraction scheme	Fast, slow	Fast, slow	Single-turn, slow		Slow		Slow
Emittance, mm mrad		12/5			18/9		
Number of bunches/cycle				22			
β function, m				0.35		0.51 (SSR2)	
Rms bunch length, m				0.6			

Xiaofeng Luo, Qun Wang, Nu Xu, Pengfei Zhuang (Eds.), Properties of QCD Matter at High Baryon Density, Springer Singapore, eBook ISBN - 978-981-19-4441-3

Detector Parameters And Comparisions

Table 4.2 Running and planned high μ_B facilities. The facility and experiment, the anticipated year for data tacking, the range in μ_B and $\sqrt{s_{NN}}$ as well as capabilities of measuring hadrons, dileptons, and charm are listed. Taken from [370]

Facility	Experiment	Start	$\sqrt{s_{NN}}$, GeV	μ_B, GeV	Hadrons	Dileptons	Charm
RAON	LAMPS	>2027	$\leq$1.46	$\gtrsim$ 880	+		
HIAF	CEE+	2023	1.9 – 4	880 – 760	+		
Nuclotron	BM@N	2022 (Au)	2 – 3.5	880 – 670	+		
J-PARC-HI	DHS, D2S	>2025	2 – 6.2	880 – 430	+	+	(+)
SIS100	CBM / HADES	2025	2.7 – 5	760 – 500	+	+	(+)
NICA	MPD	2023	4 – 11	580 – 300	+	+	+
SPS	NA60+	> 2025	4.9 – 17.3	560 – 230	(+)	+	+
SIS18	HADES/mCBM	running	1.9 – 2.6	880 – 670	+	+	
RHIC	STAR	running	3 – 19.6	720 – 210	+	+	+
SPS	NA61	running	4.9 – 17.3	520 – 230	+		+

Xiaofeng Luo, Qun Wang, Nu Xu, Pengfei Zhuang (Eds.), Properties of QCD Matter at High Baryon Density, Springer Singapore, eBook ISBN - 978-981-19-4441-3

Planned mCBM-SIS18 Runs

2022	Projectile	T_{proj}	Beam intensity per spill (10s)	Av. collision rate	Objective
March 29 - April 1	^{238}U(73+)	1.00 AGeV	10^7 - 10^9	100 kHz - 10 MHz	high-rate studies TOF & MUCH
May 26	^{58}Ni(28+)	1.93 AGeV	$4{\cdot}10^7$	400 kHz	benchmark run I
June 16 - 18	^{197}Au(69+)	1.23 AGeV	$2 - 3{\cdot}10^7$	200 - 300 kHz	benchmark run II
June 19 - 20	^{197}Au(67+)	1.13 AGeV	$1{\cdot}10^7 - 4{\cdot}10^8$	100 kHz - 4 MHz	high-rate studies TOF & MUCH

Table 2.0.1: mCBM data taking in 2022.

Collision system	M_Λ, reconstr.	Av. collision rate	Beam intensity per spill (10s)	N_Λ reconstr. per 8h-shift
Ni + Ni 1.93 AGeV	$2.3{\cdot}10^{-5}$	400 kHz	$4{\cdot}10^7$	90k
Au + Au 1.24 AGeV	$2.2{\cdot}10^{-6}$	200 kHz	$2{\cdot}10^7$	4.4k
Ag + Ag 1.58 AGeV	$5{\cdot}10^{-6}$	300 kHz	$3{\cdot}10^7$	15k

Table 3.1.1: Rate estimate for Λ reconstruction with mCBM: the Λ yields for Ni + Ni collisions at 1.93 AGeV and for Au + Au at 1.24 AGeV are taken from simulations depicted in Fig. 3.1.1. Yields for Ag + Ag collisions at 1.58 AGeV were interpolated from above listed Ni and Au simulations (median in mass number and kinetic projectile energy). With a spill length of 10 s, 4 spills per minute and a duty cycle of about 0.5, approx. 1000 spills are taken per 8h-shift. The benchmark runs will be measured at moderate beam intensities resulting to 200 - 400 kHz averaged collision rate while using 10 % interaction probability targets.

	Year	Objective	Projectile	Intensity per spill	Extraction	User type	Shifts
(1)	2023	high-rate detector studies	ions 1 - 2 AGeV, preferably: Au, Pb, U	10^7 - 10^9	slow, 10 s	secondary	6
(2)	2023	commissioning for benchmark run	ions 1 - 2 AGeV, preferably: Ni 1.93 AGeV	10^7 - 10^8	slow, 10 s	secondary	3
(3)	2023	benchmark runs, Λ production excitation function	Ni 1.93, 1.58, 1.23, 1.0 AGeV	10^8	slow, 10 s	main	18
(4)	2024	high-rate detector studies	ions 1 - 2 AGeV, preferably: Au, Pb, U	10^7 - 10^9	slow, 10 s	secondary	6
(5)	2024	commissioning for benchmark run	ions 1 - 2 AGeV, preferably: Ag 1.58 AGeV	10^7 - 10^8	slow, 10 s	secondary	3
(6)	2024	benchmark runs, Λ production excitation function	Ag 1.58, 1.23, 1.0 AGeV	10^8	slow, 10 s	main	18

Table 3.1.2: Beam time application for the years 2023 and 2024 on SIS18 beam time for mCBM.

G-PAC Proposal for mCBM@SIS-18 (2023/24):

- https://indico.gsi.de/event/15266/contributions/64063/attachments/40205/55084/mcbm-proposal-23-24-final.pdf
- https://indico.gsi.de/event/15901/#38-mcbm-presentation-at-the-g

CBM RUNNING SCENARIOS

Year	CBM Setup	Colliding System	Beam Energies [A GeV]	Days on Target	Number of Events	Remarks
0	Electron-Hadron	Au + Au	2, 4, 6, 8, 10, 12	60 (total)		Commissioning
		Ag + Ag	2, 4, 6, 8, 10, 12			Commissioning
		C + C	2, 4, 6, 8, 10, 12			Commissioning
1	Electron-Hadron	Au + Au	2, 4, 6, 8, 10, 12	30 (5 each)	2×10^{10} each	EB + minBias
		C + C	2, 4, 6, 8, 10, 12	18 (3 each)	4×10^{10} each	minBias
		p + Be	3, 4, 8, 29	12 (3 each)	2×10^{11} each	minBias
2	Muon	Au + Au	2, 4, 6, 8, 10, 12	30 (5 each)	2×10^{11} each	minBias
		C + C	2, 4, 6, 8, 10, 12	18 (3 each)	4×10^{11} each	minBias
		p + Be	3, 4, 8, 29	12 (3 each)	2×10^{12} each	minBias
3	Hadron	Au + Au	2, 4, 6, 8, 10, 12	12 (2 each)	4×10^{11} each	EB + Selector(s)
	Hadron	C + C	2, 4, 6, 8, 10, 12	6 (1 each)	8×10^{11} each	
	HADES	Ag + Ag	2, 4	28 (14 each)	1×10^{10} each	
	Electron-Hadron	Ag + Ag	2, 4	8 (4 each)	2×10^{10} each	minBias

Table A.1.: CBM running scenario for the first three years. Table compiled by N. Herrmann (U. Heidelberg). Different CBM setups/configurations are tabulated in Tab. A.2.

CBM RUNNING SCENARIOS

CBM Setup	Detector Sub-Systems							
	BMON	MVD	STS	MuCh	RICH	TRD	TOF	FSD
Electron-Hadron	✓	✓	✓		✓	✓	✓	✓
Muon	✓		✓	✓		✓	✓	✓
Hadron	✓		✓		✓	✓	✓	

Table A.2.: CBM setups and the corresponding underlying detector sub-systems [236].

Colliding System	Beam Energies [A GeV]	Beam Intensity [ions/s]					
		Electron-Hardon		Muon		Hadron	
		Baseline	Max	Baseline	Max	Baseline	Max
Au + Au	2 ... 12	5×10^6	1×10^8	5×10^7	1×10^9	1×10^8	1×10^9
C + C	2 ... 12	1×10^7	1×10^8	1×10^8	1×10^9	1×10^9	1×10^9
Ag + Ag	2 ... 4	5×10^6	1×10^8				
p + Be	3 ... 29	1×10^8	1×10^{10}	1×10^9	1×10^{11}		

Table A.3.: Maximum beam intensities for different running scenarios, including colliding systems, collision energies and experimental setups (see Tab. A.2). "Baseline" corresponds to CBM run scenario for the first three years (see Tab. A.1), where "Max" corresponds to the maximum achievable interaction rate essentially limited by MVD's rate capability. Table compiled from [174].