Compressed Baryonic Matter (CBM) At FAIR
Role In Probing Dense Nuclear Matter EoS

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- For the CBM Collaboration –

Dense Nuclear Matter Equation of State from Heavy-Ion Collisions (INT Workshop 22-84W)

INT Seattle (Hybrid Format), December 05 – 09, 2022

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

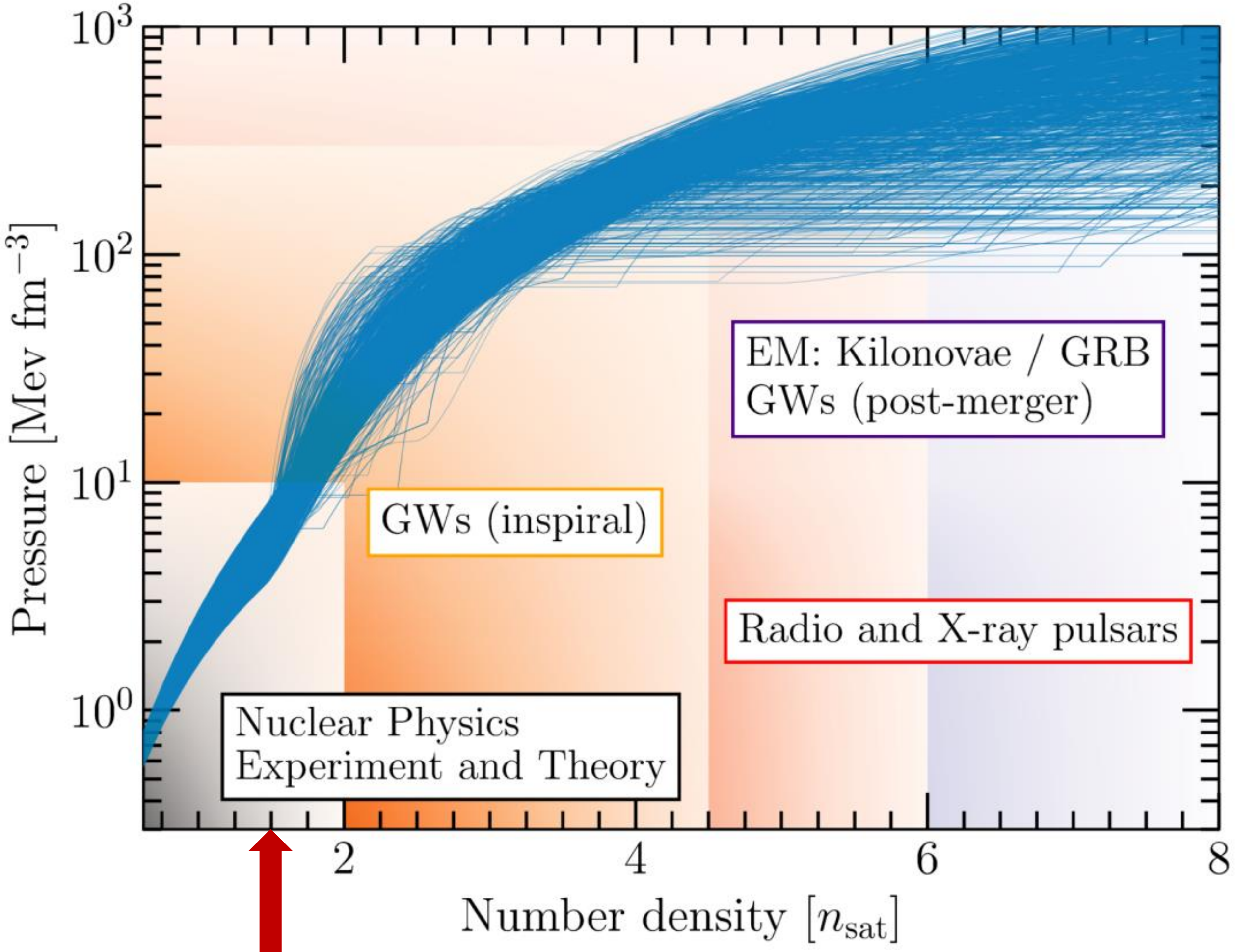
MATHEMATISCH-NATURWISSENSCHAFTLICHE FAKULTÄT
Physikalisches Institut

Current Landscape Of Nuclear Matter EoS At $\gtrsim \rho_0$

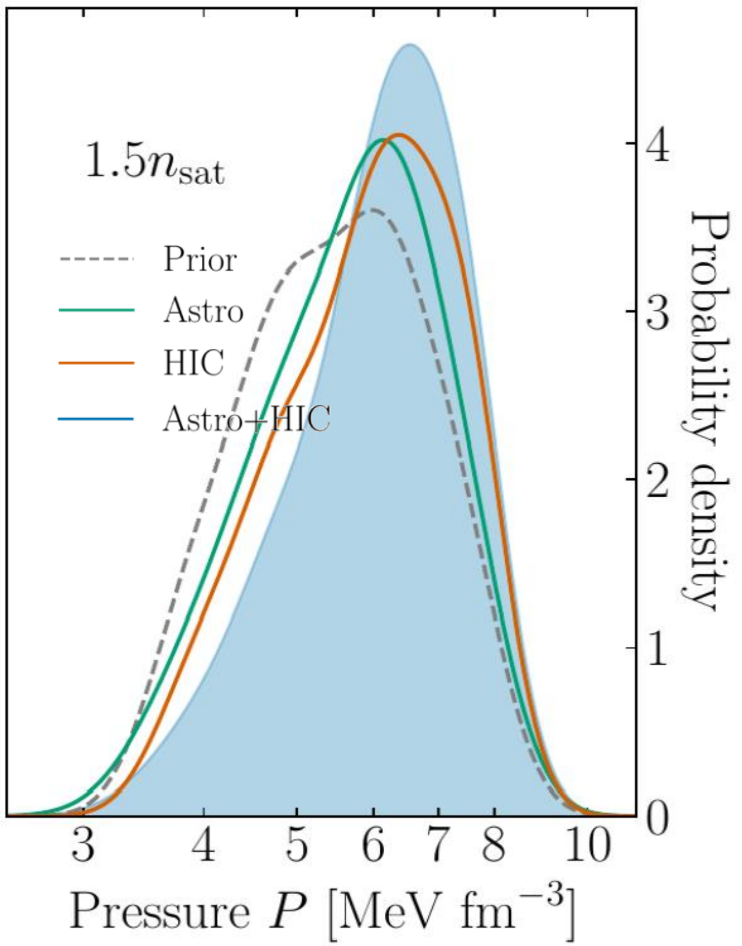
Landscape Of Nuclear Matter EoS At $\gtrsim \rho_0$

I. Tews (09.12.22)
R. Kumar (08.12.22)

EoS info from Heavy-Ion Collisions (Symmetric Nuclear Matter + Symmetry Energy) has shown remarkable compatibility at $1.5\rho_0$, i.e., where we have reliable data available especially from SIS-18 experiments



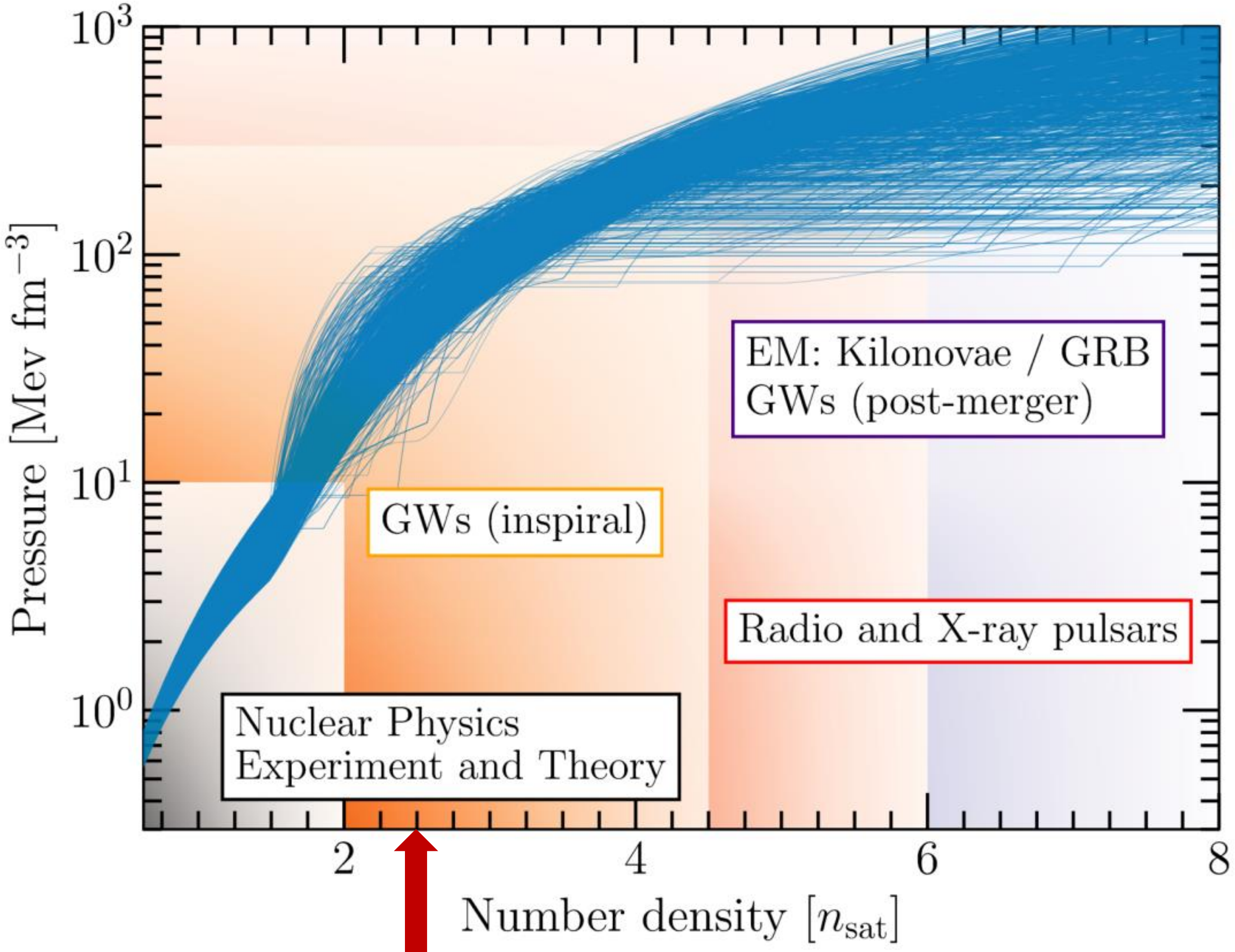
P.T.H. Pang et al., arXiv:2205.08513

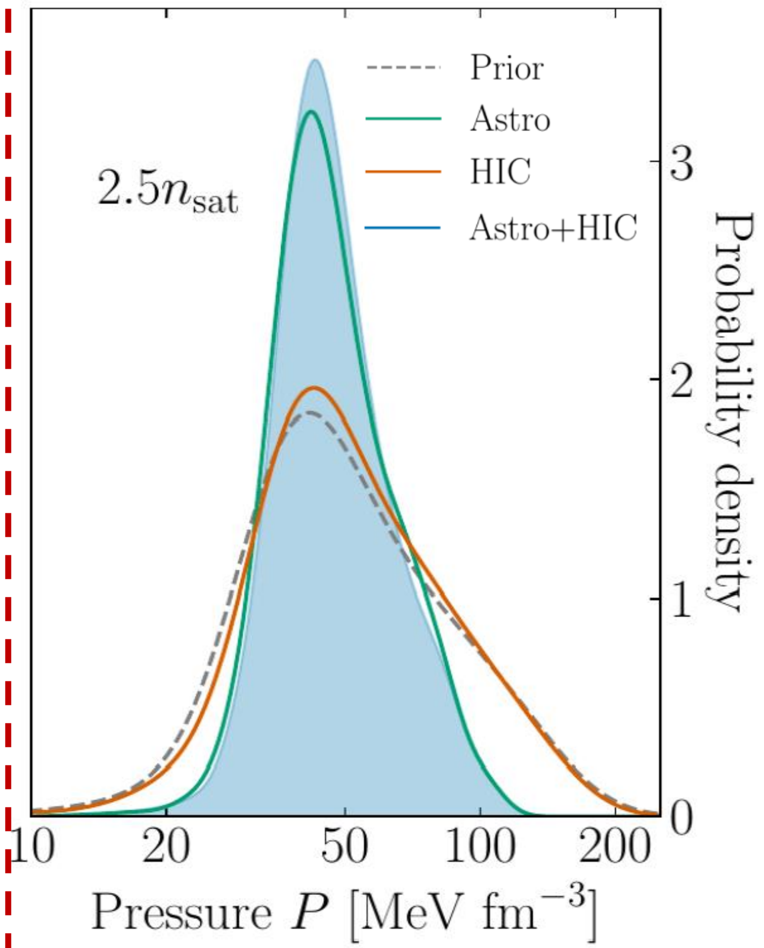


S. Huth, P.T.H. Pang et al., Nature 606, 276-280 (2022)

Landscape Of Nuclear Matter EoS At $\gtrsim \rho_0$

But this compatibility loosens at higher densities ($\sim 2.5\rho_0$) simply because no reliable experimental data is available yet, both for symmetric nuclear matter and symmetry energy





P.T.H. Pang et al., arXiv:2205.08513

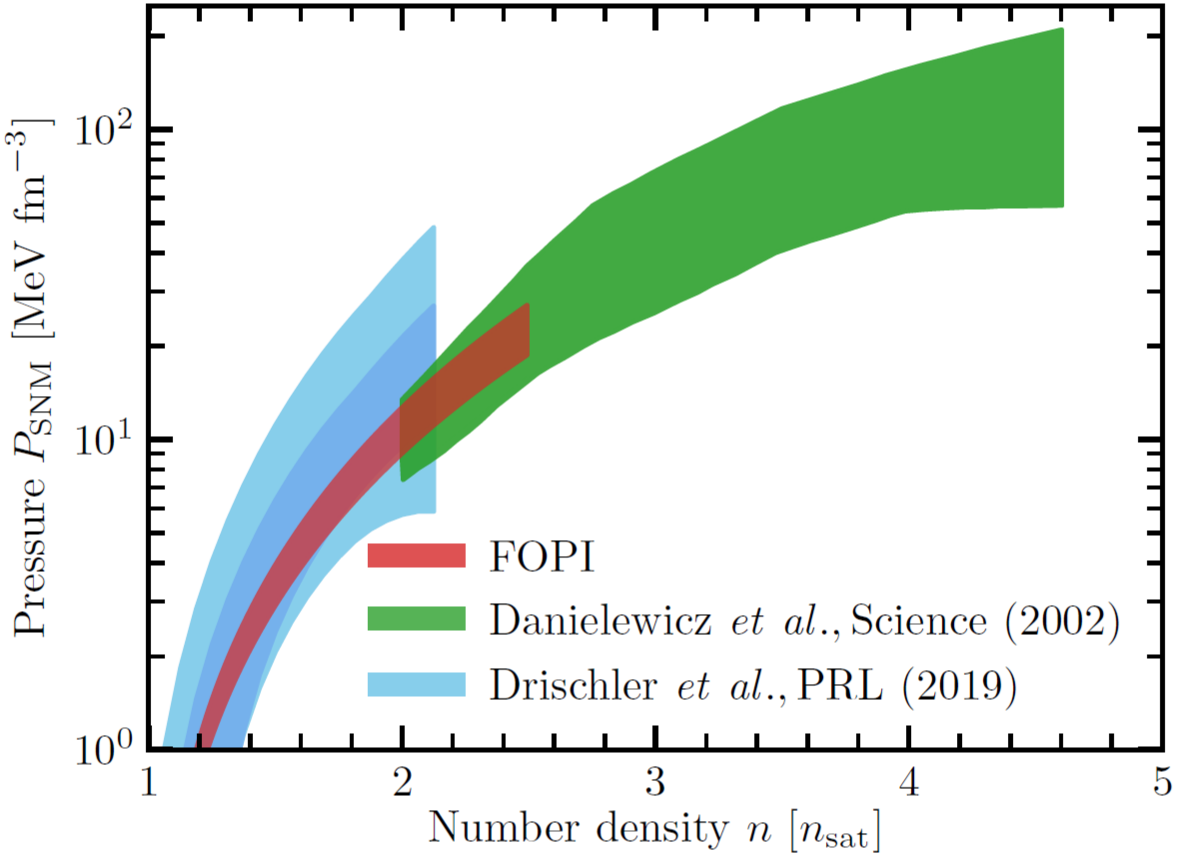
S. Huth, P.T.H. Pang et al., Nature 606, 276-280 (2022)

Current HIC EoS Data At $\gtrsim \rho_0$

P. Danielewicz (05.12)

SYMMETRIC NUCLEAR MATTER:

Still loosely constrained above $2.5\rho_0$ (2 AGeV Au+Au)

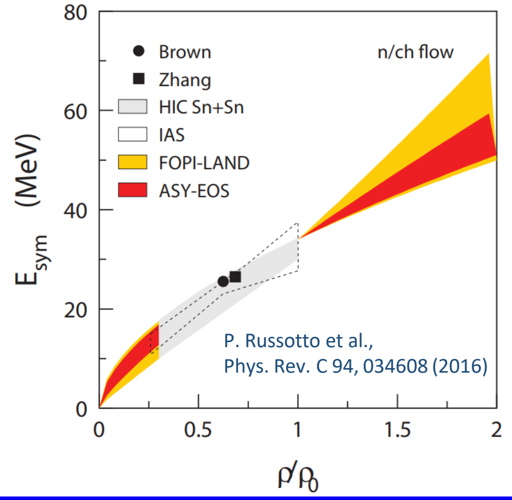


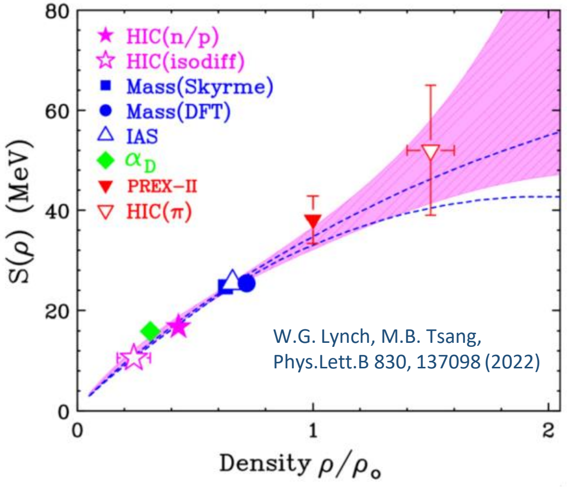
S. Huth, P.T.H. Pang et al., Nature 606, 276-280 (2022)

SYMMETRY ENERGY:

No data above $2\rho_0$ (0.4 AGeV Au+Au)

Constraint	τ	Inclination analyses ρ_s/ρ_0	Inclination analyses $S(\rho_s)$ (MeV)	Cross-over analyses ρ_s/ρ_0	Cross-over analyses $S(\rho_s)$ (MeV)	
Mass(Skyrme)	0.100 ± 0.006	0.63 ± 0.03	24.7 ± 0.8	0.63 ± 0.03	24.7 ± 0.8	
Mass(DFT)	0.079 ± 0.002	0.72 ± 0.01	25.4 ± 1.1			
IAS	0.092 ± 0.008	0.66 ± 0.04	25.5 ± 1.1			
HIC(isodiff)	0.256 ± 0.076	0.21 ± 0.11	10.1 ± 1.0	0.22 ± 0.07	10.3 ± 1.0	
	L_{01} MeV	L (MeV)	K_{sym}	From publications		P_{sym} (MeV/fm^3)
α_D				0.31 ± 0.03	15.9 ± 1.0	
HIC(n/p)				0.43 ± 0.05	16.8 ± 1.2	
PREX-II (^{208}Pb skin)	71.5 ± 22.6			0.67 ± 0		2.38 ± 0.75
PREX-II (^{208}Pb skin)				1 ± 0	38.1 ± 4.7	
HIC(π)		79.5 ± 38	47 ± 256	1.45 ± 0.2	52 ± 13	10.9 ± 8.7
HIC(n/p flow)		85 ± 32	96 ± 390	1.5 ± 0		12.1 ± 8.4
NICER-P_{SM}				2 ± 0		23.6 ± 13.7
NICER-P_{SM}				2.5 ± 0		72 ± 41
LIGO-P_{SM}				2 ± 0		10 ± 7
LIGO-P_{SM}				2.5 ± 0		22 ± 15

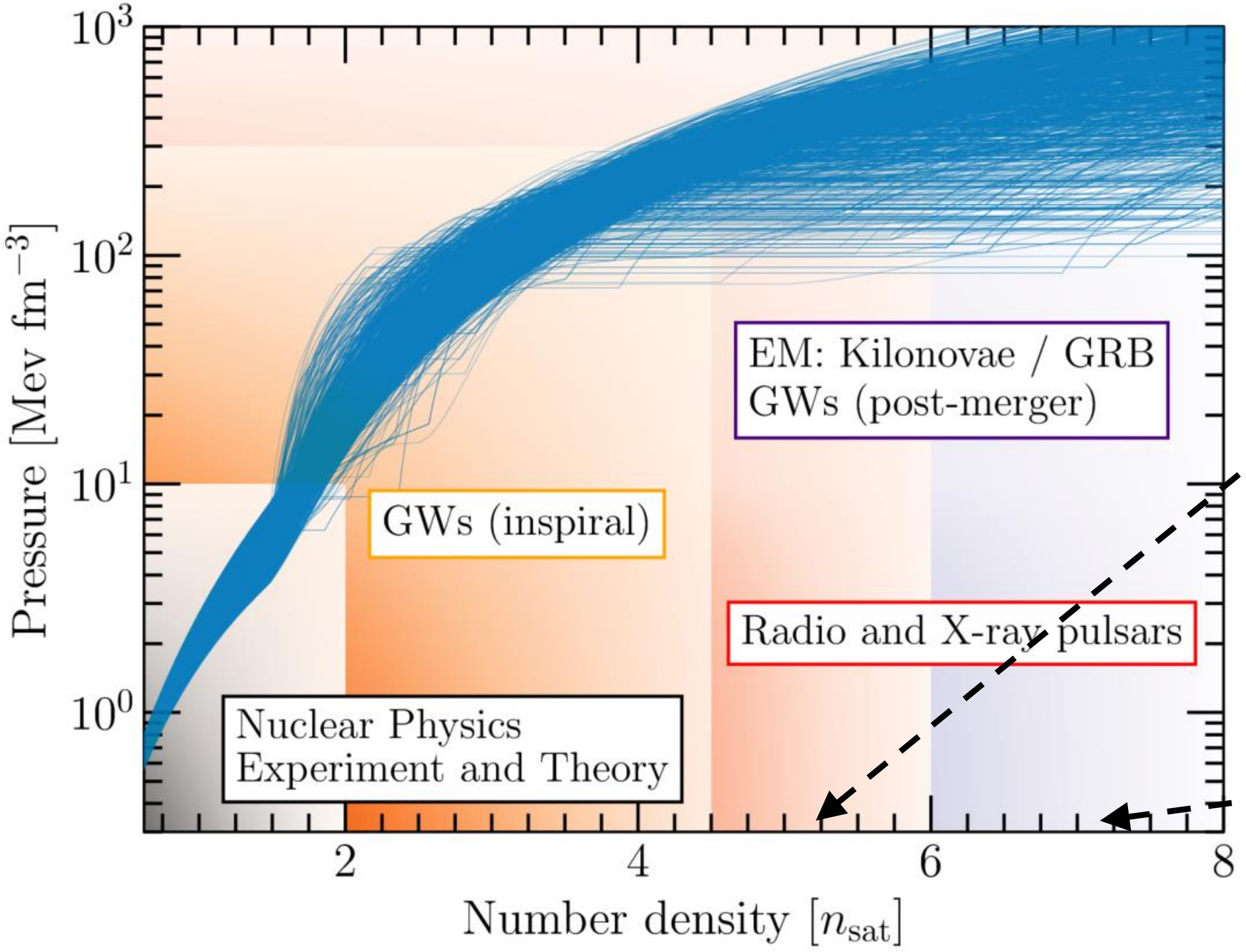




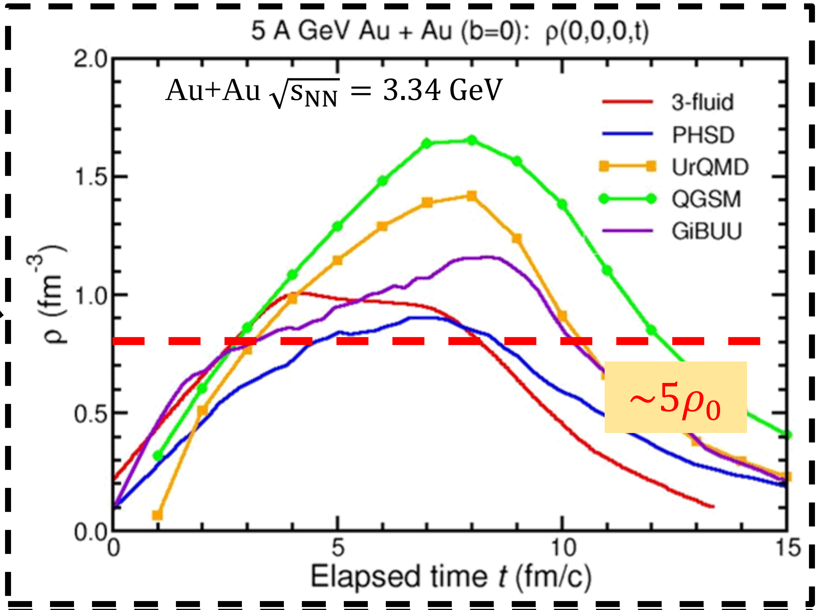
HIC Experimental Requirements To Probe $\gtrsim 3\rho_0$ (And How CBM-FAIR Fulfills Them)

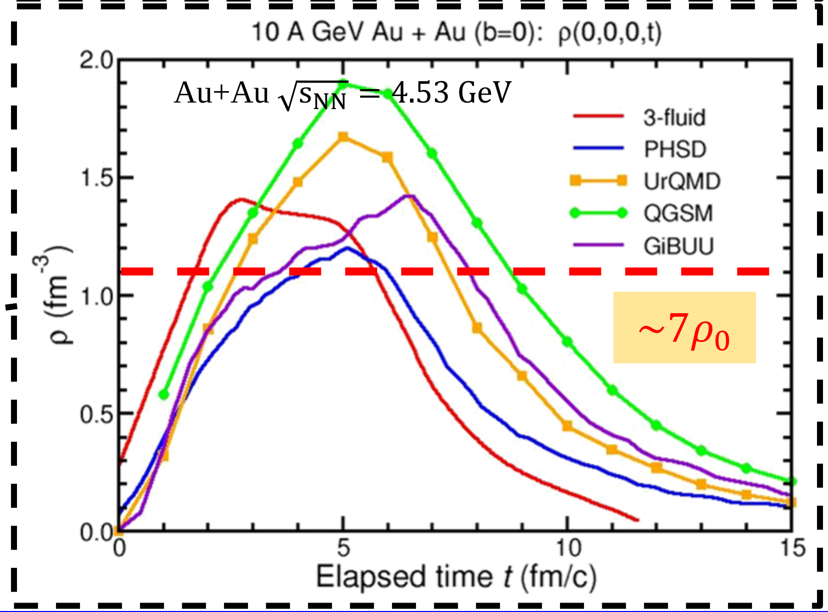
Higher Energies To Probe Higher Densities

Heavy-Ion Collisions at relatively higher energies (Au+Au $\sqrt{s_{NN}}$ > 3A GeV) will give us a possibility to explore EoS where currently, the only reliable info comes from MMA



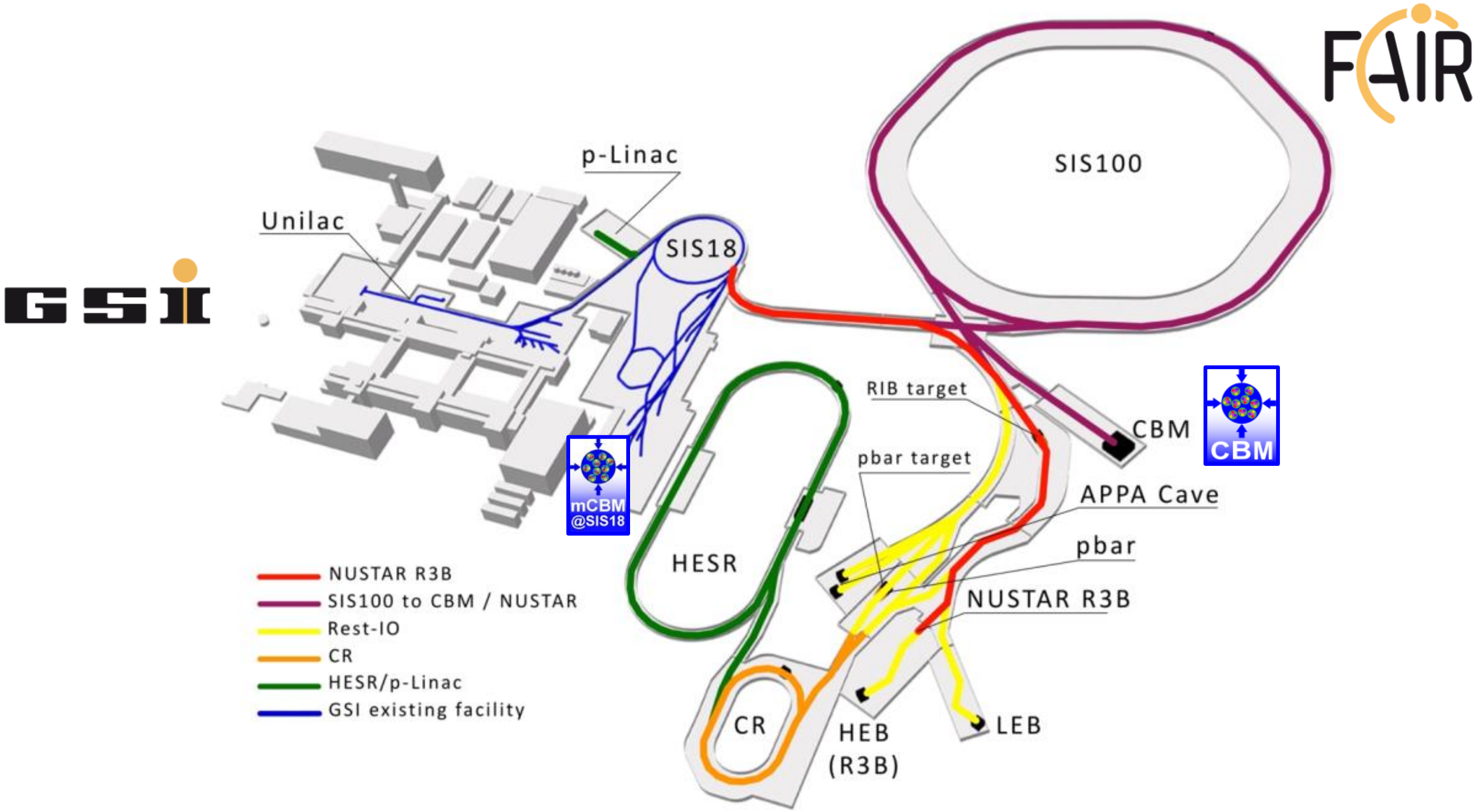
P.T.H. Pang et al., arXiv:2205.08513





I.C. Arsene et al., Phys.Rev.C 75 (2007) 034902

Facility For Anti-Proton And Ion Research (FAIR)



SIS-100 Capabilities			
Beam	Z	A	E_{max} [AGeV]
p	1	1	29
d	1	2	14
Ca	20	40	14
…			
Au	79	197	11
U	92	238	10.7

C. Höhne et al. (2011) CBM Experiment. In: B. Friman (eds) The CBM Physics Book. Lecture Notes in Physics, vol 814. Springer

M. Durante et al., Phys. Scr. 2019, 94, 033001

- Intensity gain: x 100 – 1000 (~10^9/s for Au)
- Energy gain: 10 x energy (compared to SIS-18@GSI)
- Antimatter: antiproton beams
- Precision: System of storage and cooler rings

- Current estimate: SIS100 commissioning with beams starts in 2028-29
- Recommendation from Heuer-Tribble Committee: downscale FAIR project (SIS100 & SFRS/R3B & CBM); Decision by FAIR council expected in Feb. 2023

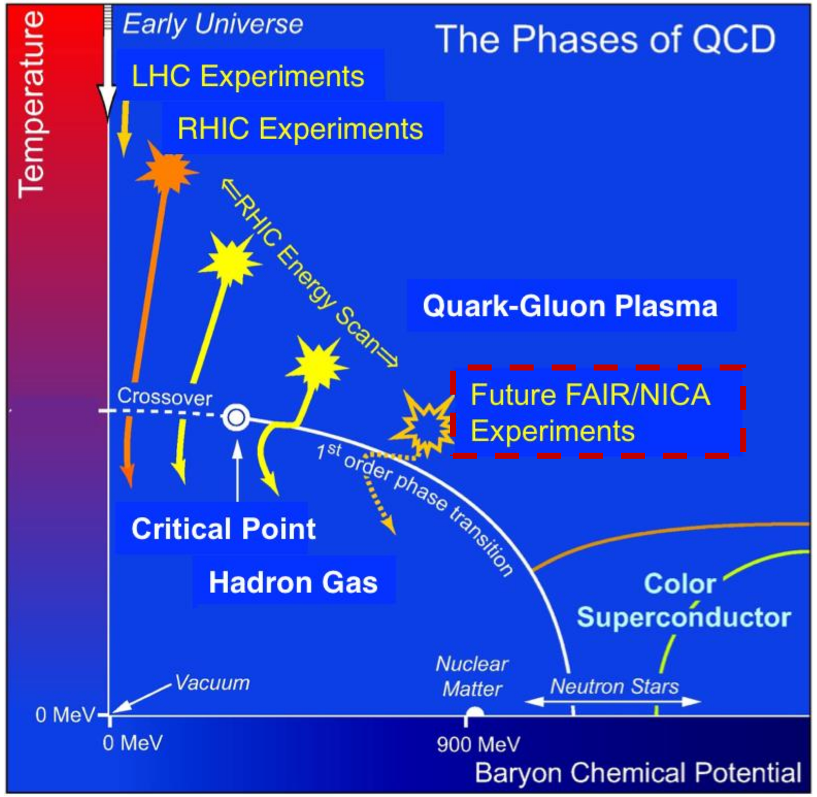
GSI Press Release – Link
Report PDF – Link

Update On FAIR Construction (October 2022)

- Interior work on SIS-100 tunnel ongoing - SIS100 ready for commissioning w/ beams 2028
- CBM Building's construction is on schedule and is ready for 'heavy installation' from 2022-23
- CBM ready for beam in 2027-28, ~12 months contingency for CBM global commissioning
- Updates on construction available at: GSI Webpage | YouTube | …

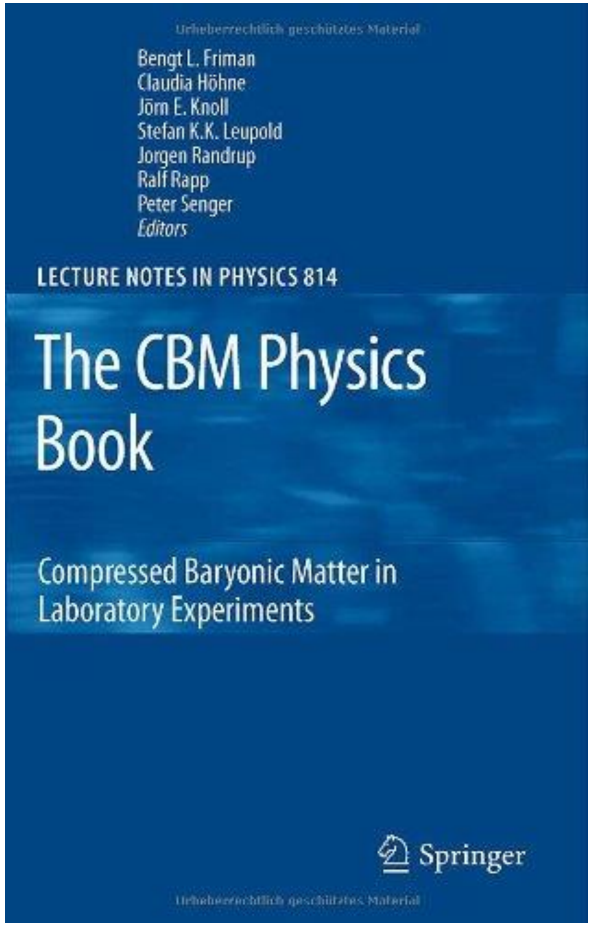
CBM Physics Goals

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

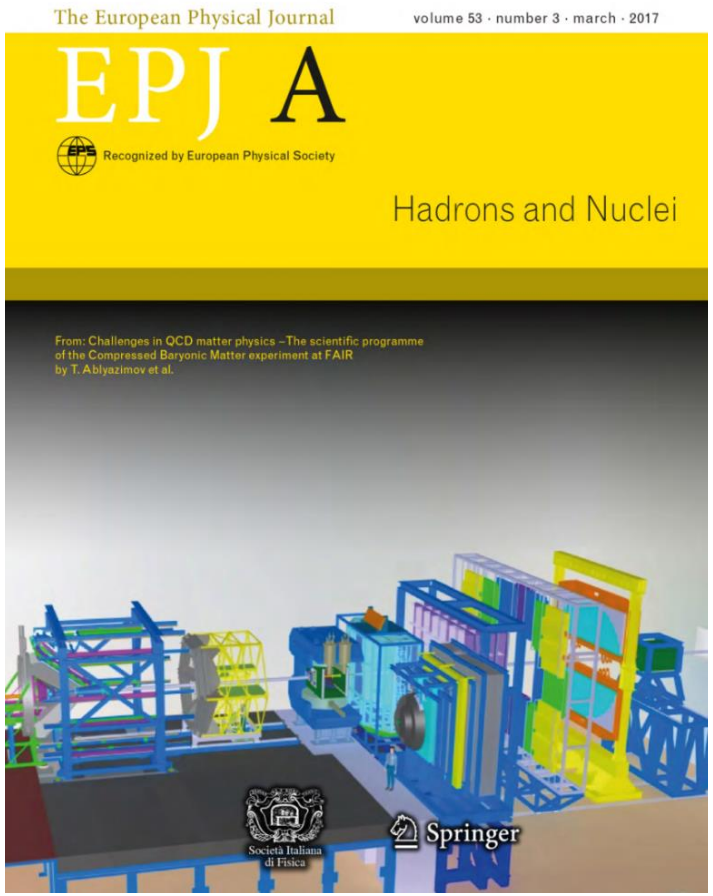


Unanswered fundamental questions for QCD at high densities

- 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



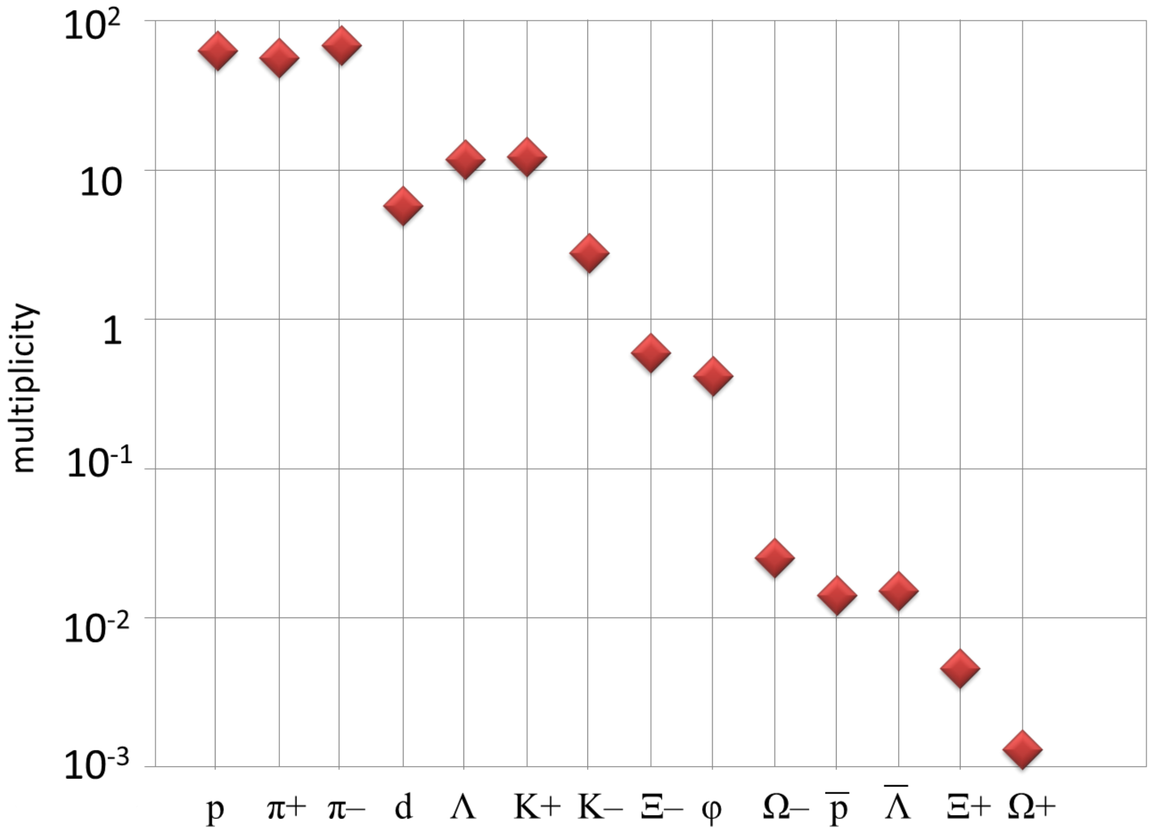
Lect. Notes Phys. 814 (2011) pp.1-980
DOI: 10.1007/978-3-642-13293-3

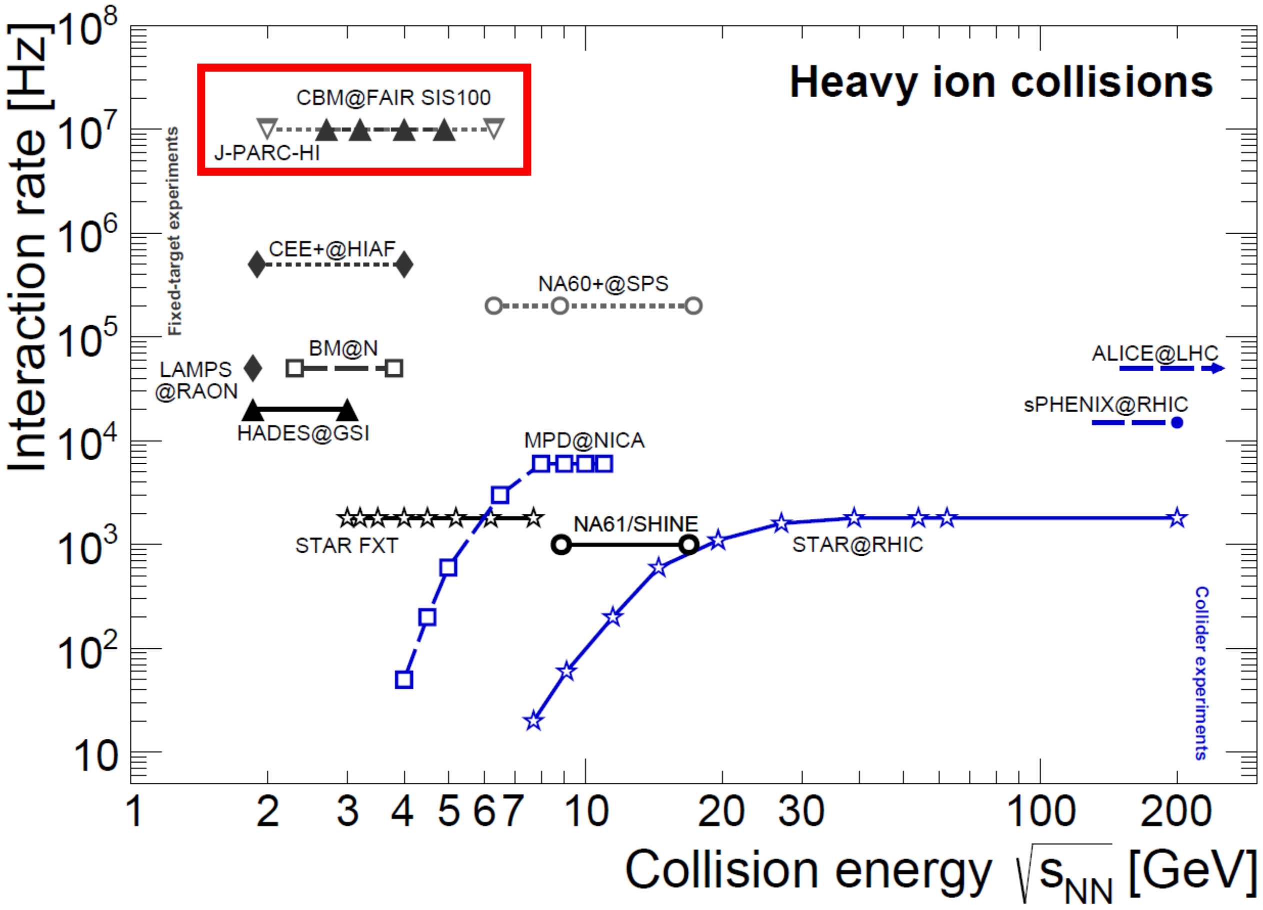


Eur.Phys.J.A 53 (2017) 3, 60
DOI: 10.1140/epja/i2017-12248-y

Beam-Target Interaction Rates And Rare Probes' Yields

Particle Multiplicities (Statistical Hadronisation Model)
Au+Au $\sqrt{s_{NN}} = 4.7$ GeV

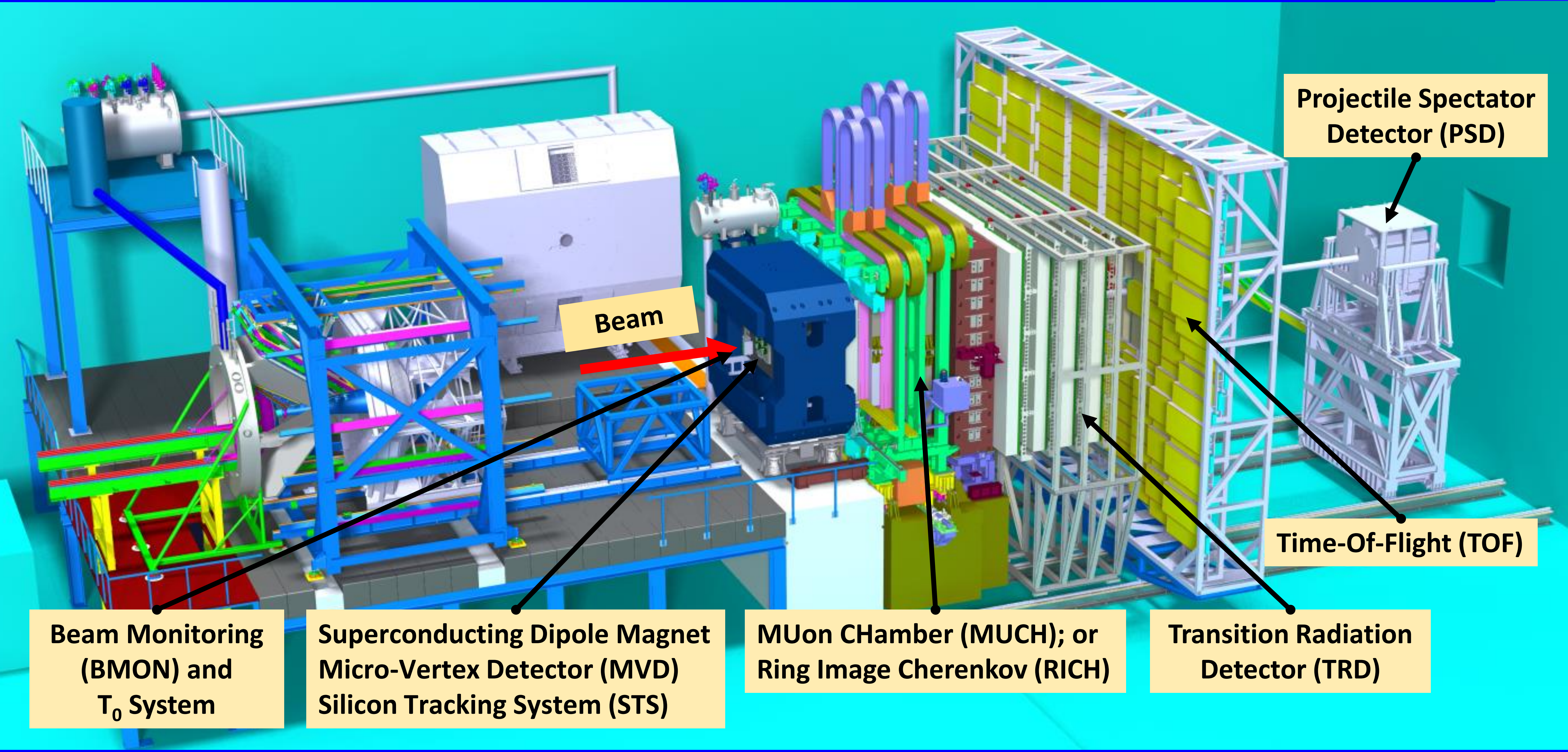




[CBM], Eur.Phys.J.A 53 (2017) 3, 60
T. Galatyuk, Nucl.Phys.A 982 (2019) 163-169, update (06/2022)

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

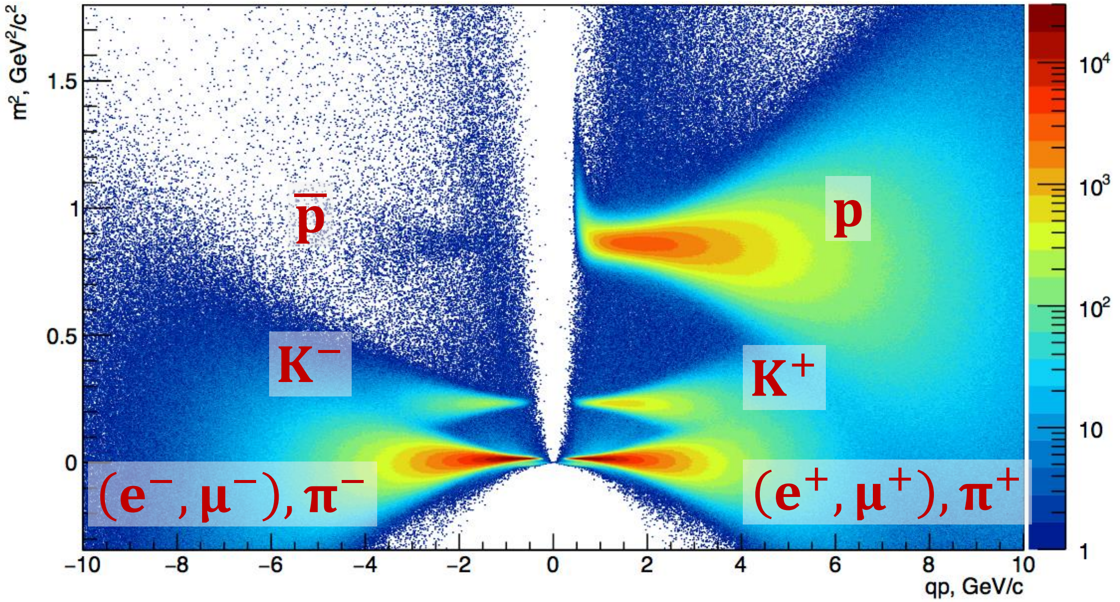
CBM Experimental Setup @SIS-100



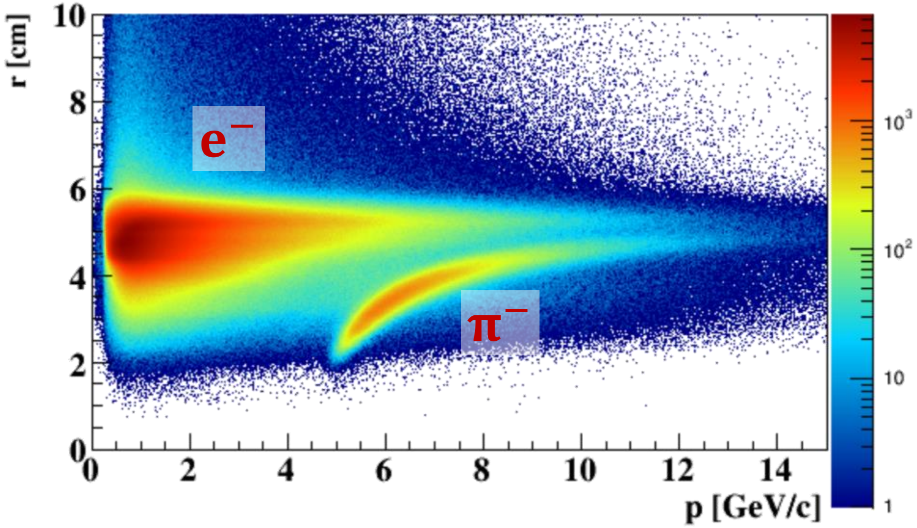
PARTICLE IDENTIFICATION WITH CBM

CBM Simulations
Central Au-Au Collisions @ $\sqrt{s_{NN}} = 4.53$ GeV

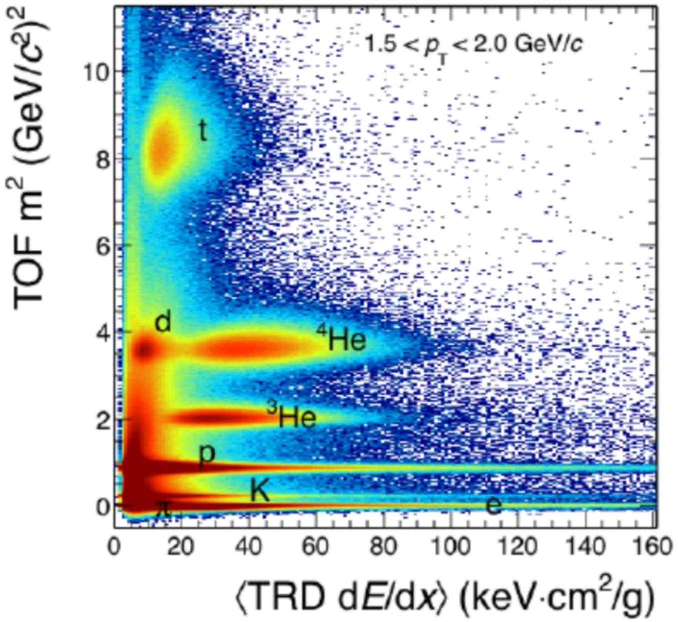
ToF - Hadron Identification



Clear separation between charged protons, pions and kaons



RICH - Electron ID

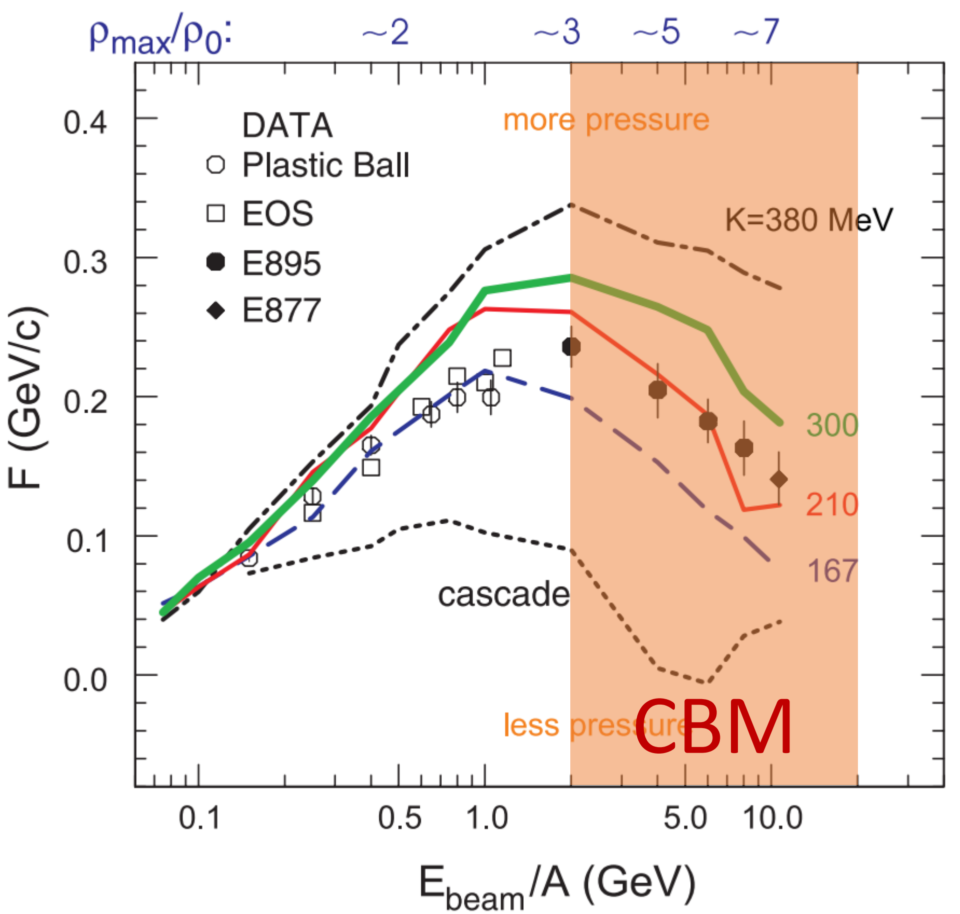


TRD + ToF - Electron, Light Nuclei, Heavy Fragments

Clear separation between pions and electrons, and light nuclei

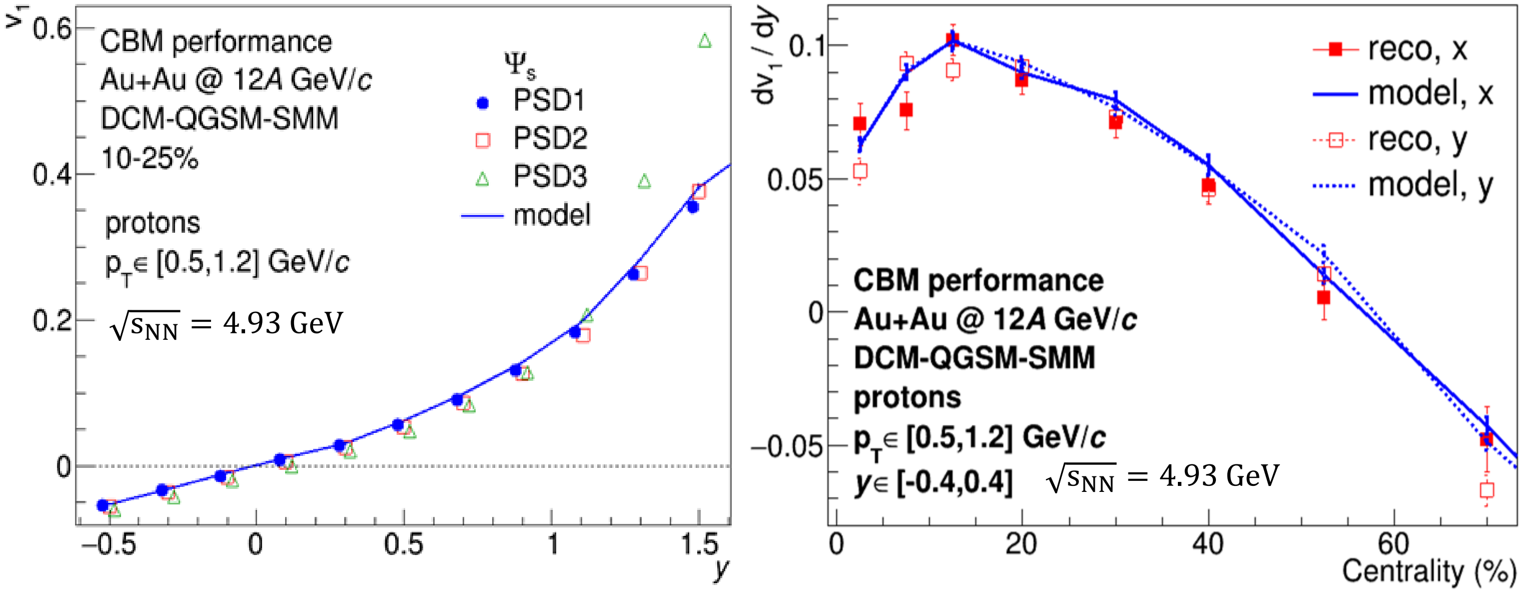
CBM Experimental Observables And Expected Physics Performance

OBSERVABLE #1: COLLECTIVE FLOW (v_1, …)



P. Danielewicz, Science 298 (2002) 1592-1596

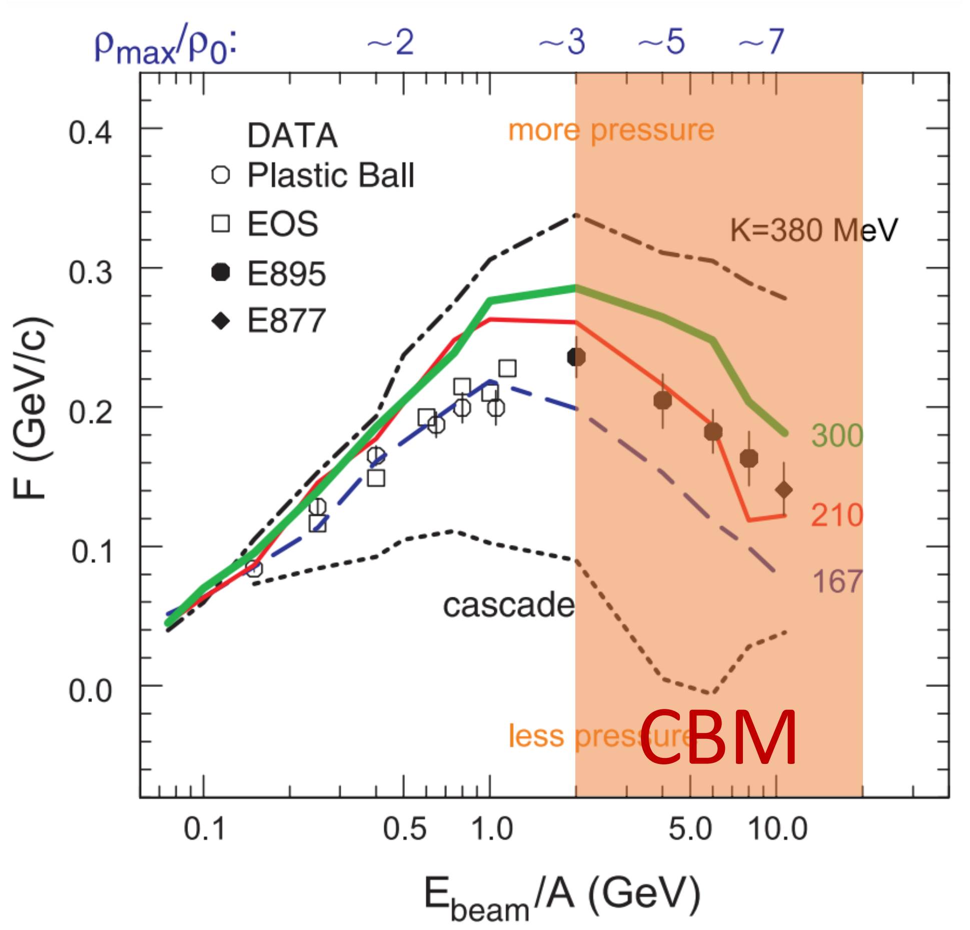
Collective flow driven by the pressure gradient in the fireball and thus carry the information about the underlying EOS



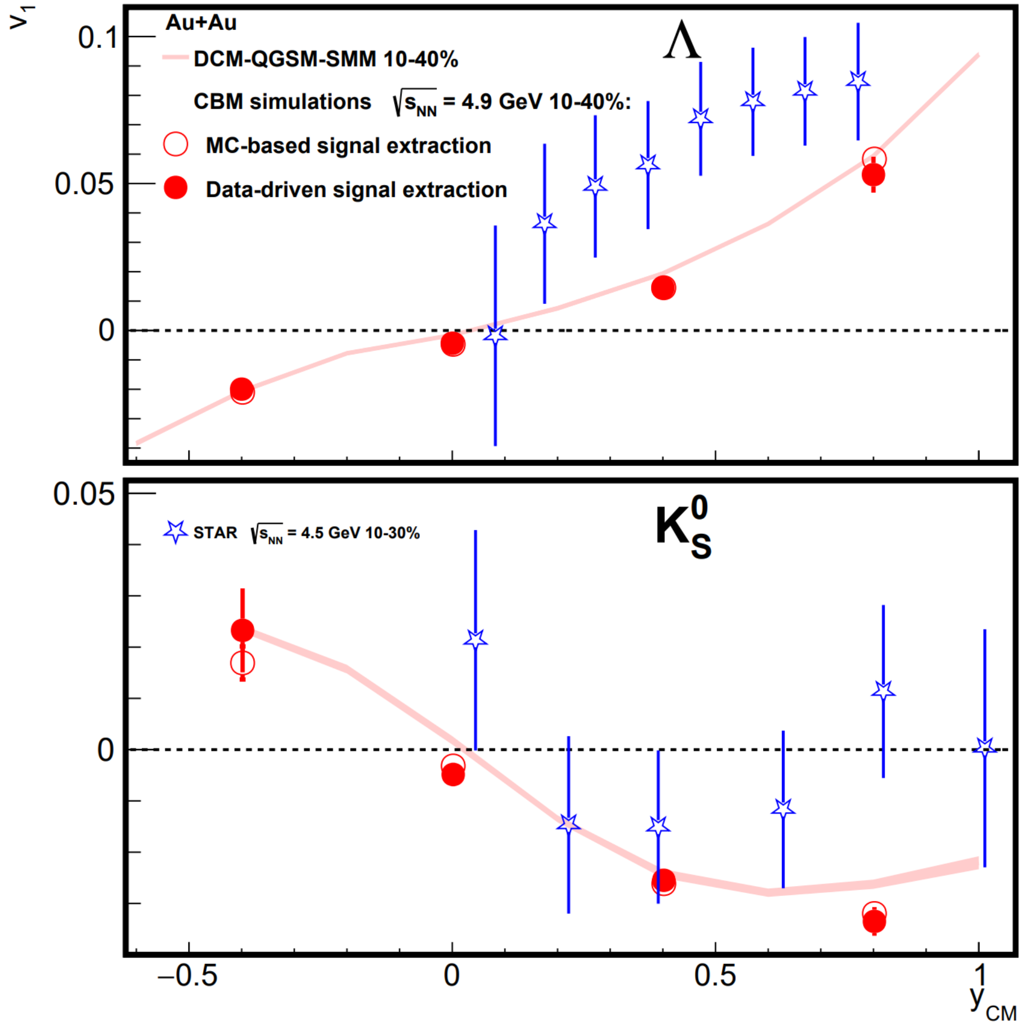
O. Golosov et al., CBM Progess Report 2020
O. Golosov et al., J.Phys.Conf.Ser. 1690 (2020) 1, 012104

- Data-driven methods to perform extensive multi-differential v_1 flow analysis for protons have been developed
- Procedures for centrality determination, particle identification and corrections for effects of detector's azimuthal non-uniformity are applied
- Input model v_1 from DCM-QGSM-SMM is recovered using data-driven methods with projectile spectators
- Ongoing – Higher harmonics (v_2, …) and energy scan

OBSERVABLE #1: COLLECTIVE FLOW (v_1, …)



P. Danielewicz, Science 298 (2002) 1592-1596

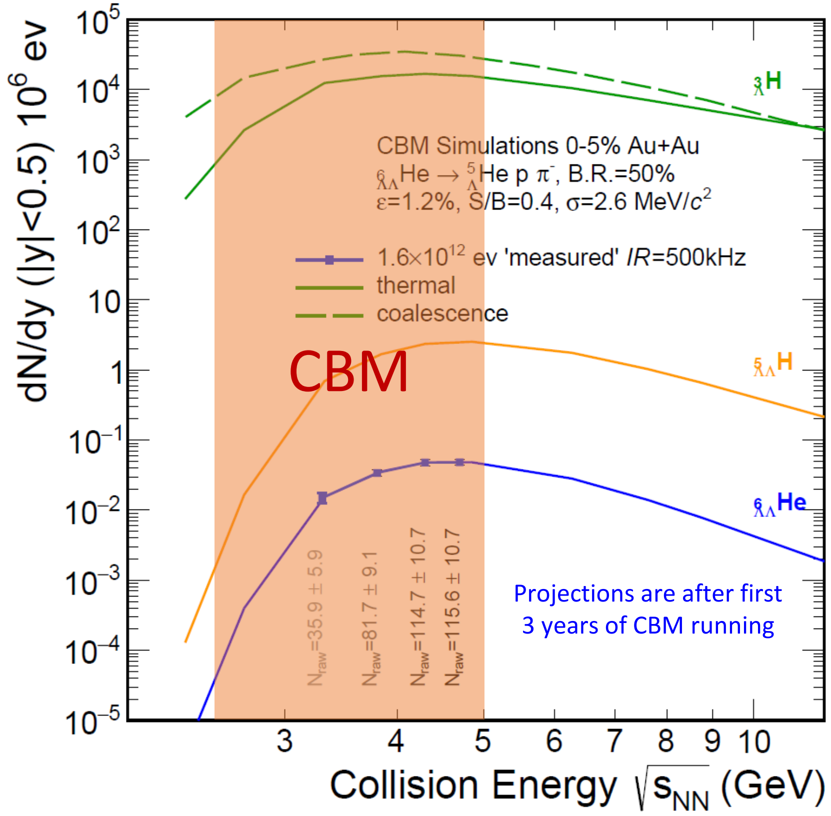


O. Lubynets, FAIRNESS 2022
[STAR], Phys. Rev. C 103, 034908 (2021)

Collective flow driven by the pressure gradient in the fireball and thus carry the information about the underlying EOS

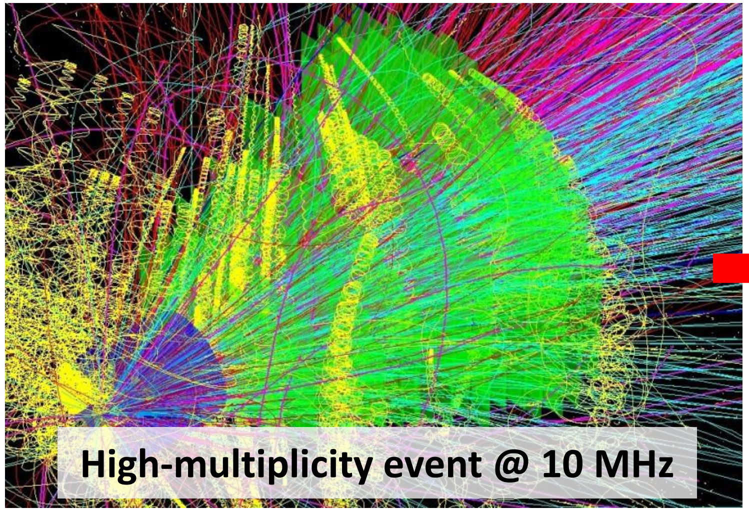
- v_1 calculated for strange hadrons (Λ, K^0_s) in data-driven mode reproduces MC-input
- Comparable v_1 predicted by DCM-QGSM-SMM for STAR-FXT at $\sqrt{s_{NN}}$ = 4.5 GeV

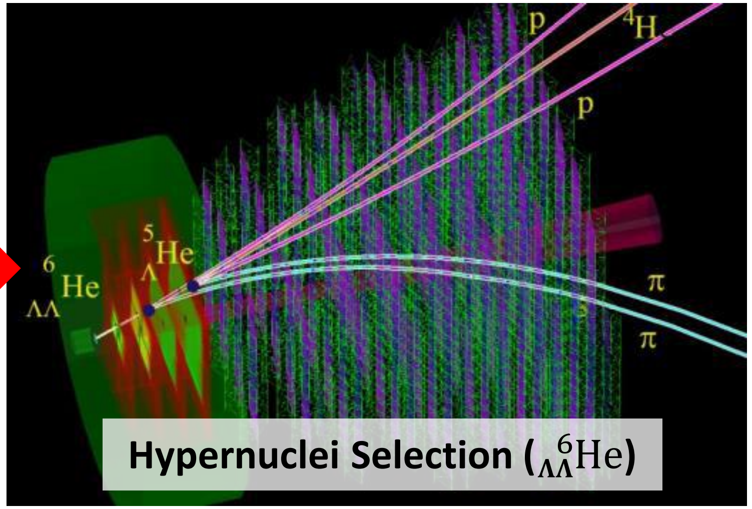
OBSERVABLE #2: HYPERNUCLEI



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

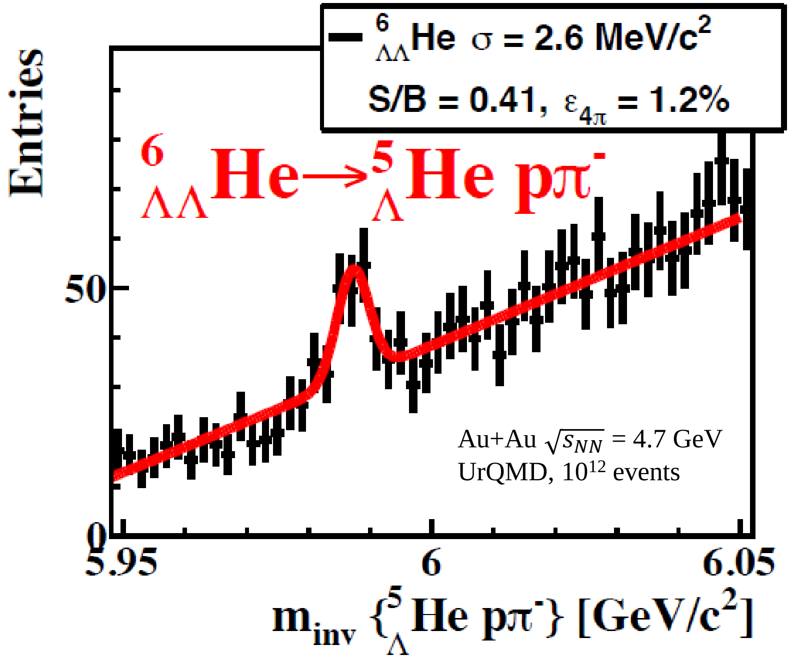
Hypernuclei carry essential information to study 2- and 3-body YN interactions and solve the 'Hyperon Puzzle'→
Yields maximum at CBM@SIS-100 regime!





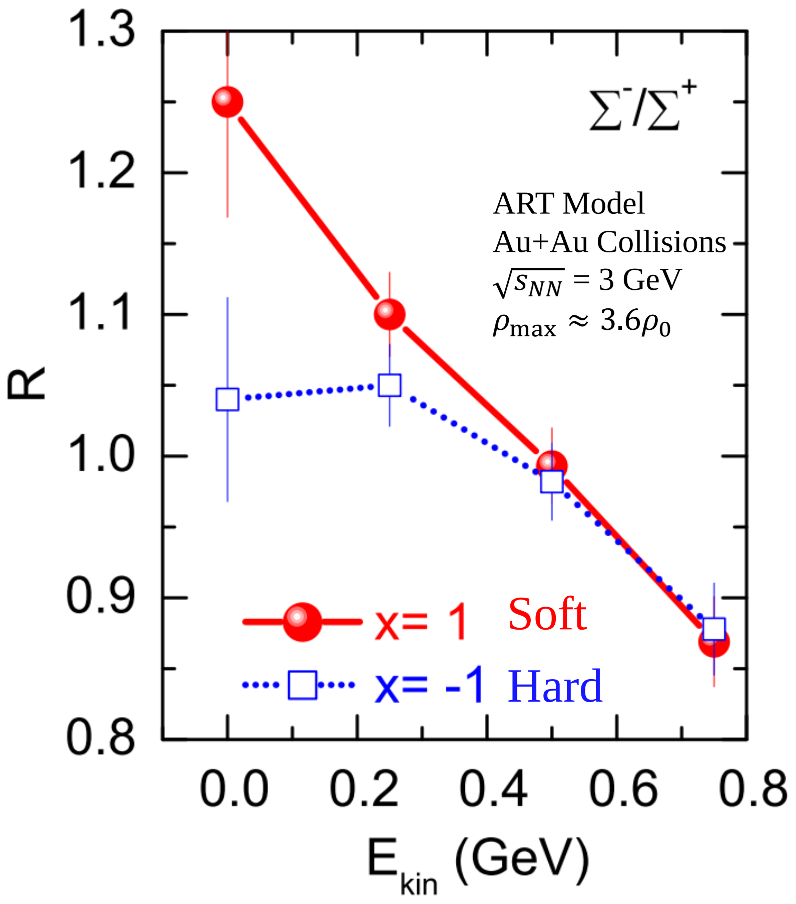
- Tools in place for the multi-differential physics analysis of strange hadrons and hypernuclei
- Reconstruction based on the dedicated KFParticleFinder package (efficiency and cuts optimization are ongoing)

I. Vassiliev, Quark Matter 2022
I. Kisel, J.Phys.Conf.Ser. 1070, 012015 (2018)



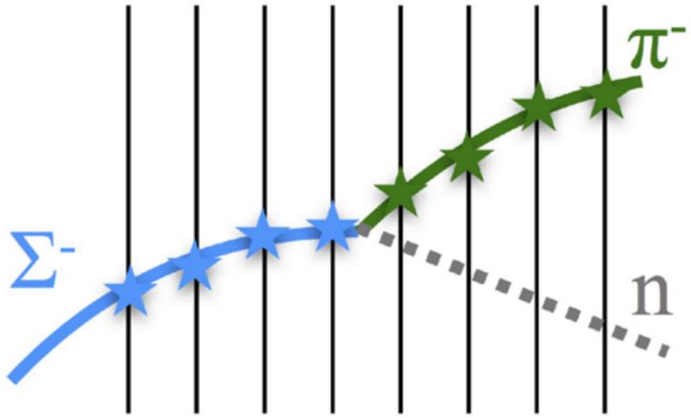
Observable #3: $(n/p)_{\text{like}}$ Particle Ratios

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



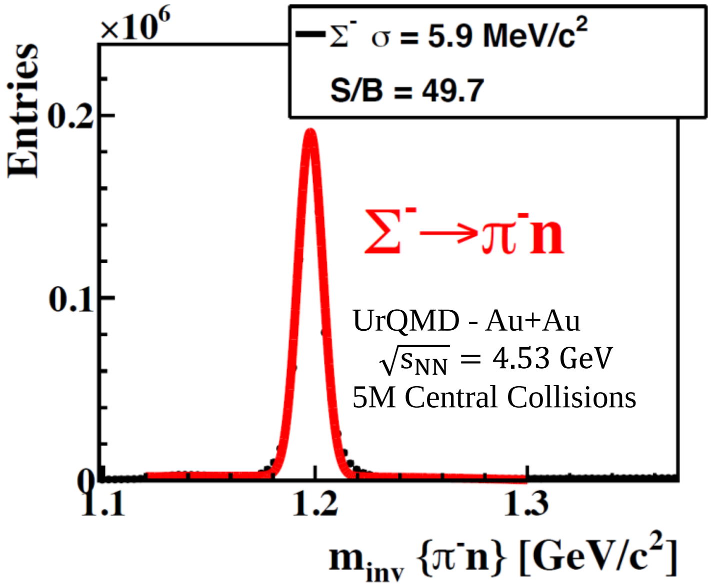
Σ^-/Σ^+ ratio is expected to carry the $E_{sym}(\rho)$ information since its production is dominated by primordial pions ($\pi + N \rightarrow \Sigma$)

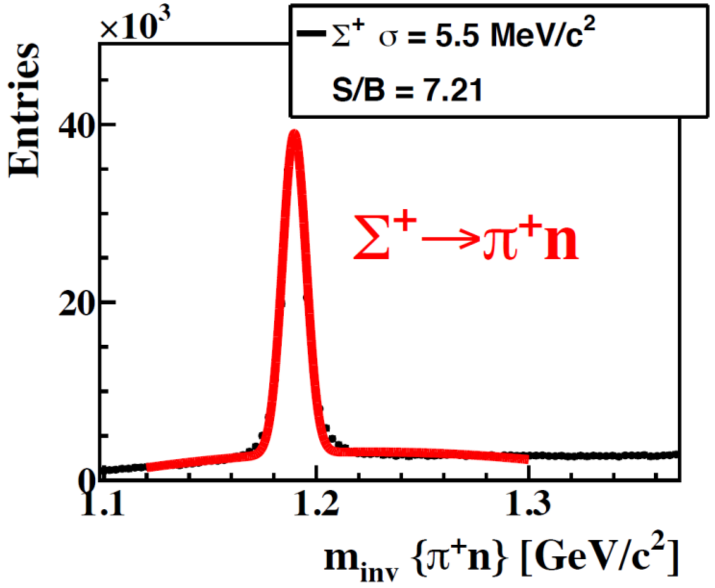
Q. Li et al., Phys. Rev. C 71, 054907 (2005)



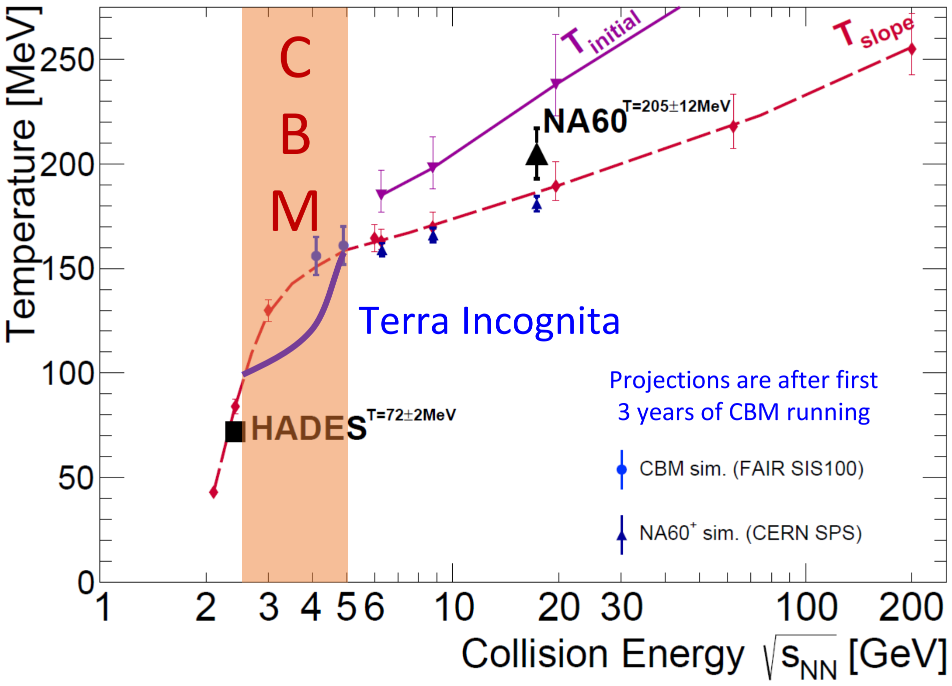
P. Kisel et al., EPJ Web Conf. 173 (2018) 04009

- Experimentally, Σ baryons are difficult to identify as they are short-lived ($c\tau_{\Sigma^+}$ = 2.4 cm and $c\tau_{\Sigma^-}$ = 4.4 cm) and decay with at least one neutral daughter particle
- 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





Observable #4: Fireball Caloric Curve Via Dileptons

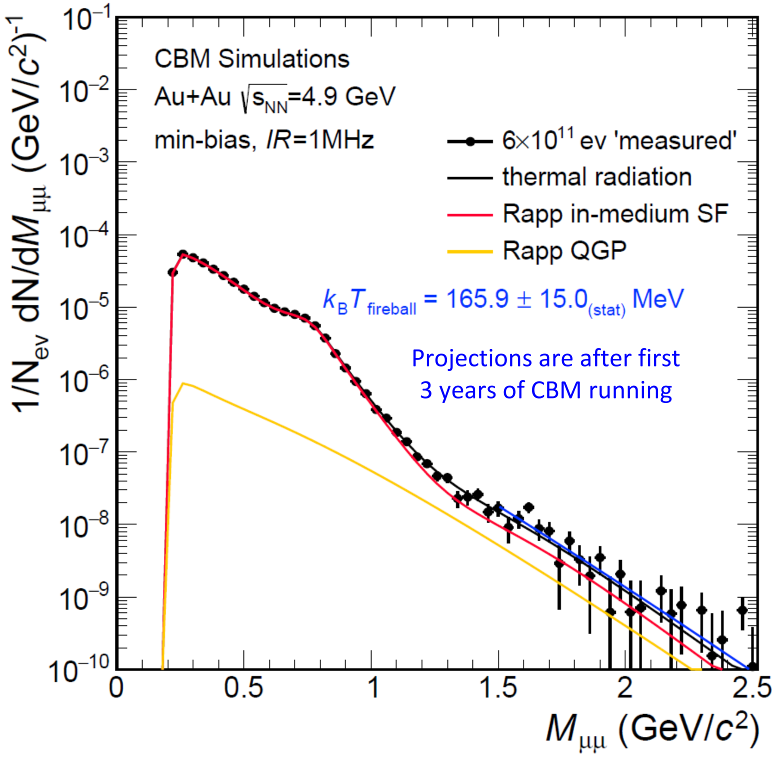


Nucl.Phys.A 1005 (2021) 121755
[NA60]: Eur. Phys. J. C 59 (2009) 607
[HADES]: Nature Physics 15 (2019) 1040

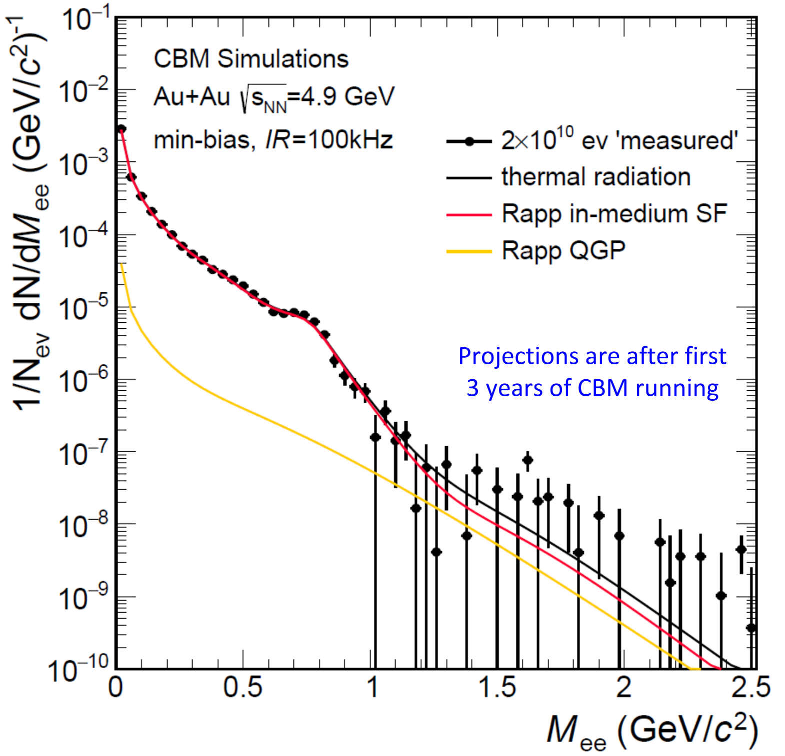
Theory: $\sqrt{s_{NN}} > 6$GeV - Phys. Lett. B 753 (2016) 586
$\sqrt{s_{NN}} < 6$GeV - Eur. Phys. J. A 52 (2016) 131

Any potential non-monotonous behaviour of fireball temperature within CBM energies would hint at a change of underlying degrees of freedom (hadronic to partonic)

Muon Setup ($\mu^+\mu^-$)
$R_{int} = \mathcal{O}$ (1 MHz)



Electron Setup (e^+e^-)
$R_{int} = \mathcal{O}$ (0.1 MHz)

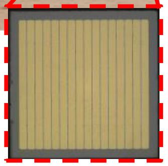


- Performance studies with realistic detector geometries, material budget, and response for both, muon ($\mu^+\mu^-$) and electron setup (e^+e^-)
- Access to thermal signal is feasible with good background description; Mass Resolution $\sigma_{M_{ll}}(\omega)$ = 14 MeV/c²

CBM Detector Subsystem Progress & FAIR Phase-0

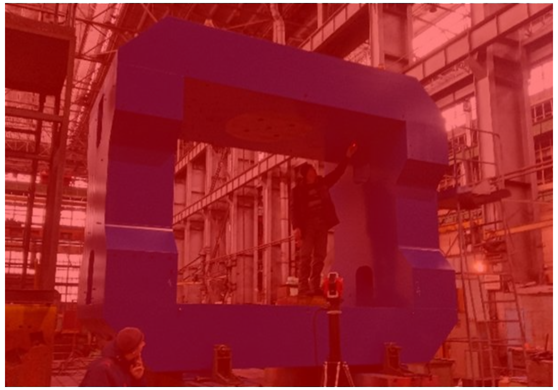
Recent (& Brief) Achievements In Detector Projects

Beam Monitoring (BMON) Detector

pcCVD diamond sensor (16-ch)
for high-intensity tests

Superconducting Dipole Magnet



Magnet Yoke housed in BINP (Russia).
Tendering for replacement started.

Micro-Vertex Detector (MVD)

MVD's TDR accepted.
Improved MIMOSIS-2 being submitted.

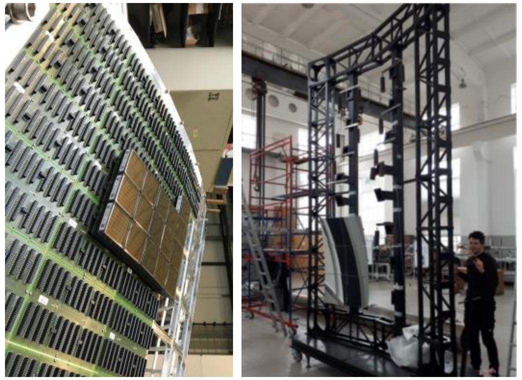
Silicon Tracking System (STS)

Pre-series STS module production for E16 (J-PARC) exp.

Muon Chambers (MUCH)

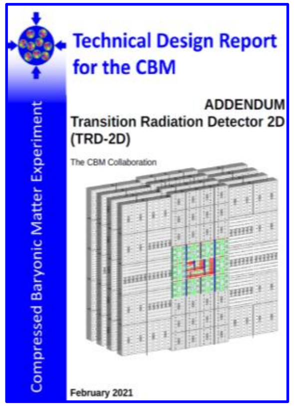
RPCs at tested at nominal
rates at GIF++ (Nov.21)

Ring Imaging Cherenkov (RICH) Detector



Photocamera and Mechanical
Prototypes (Mirror Wall)

Transition Radiation Detector (TRD)



TRD-2D-addendum submitted.
TRD-1D pre-production by Q1-2023.

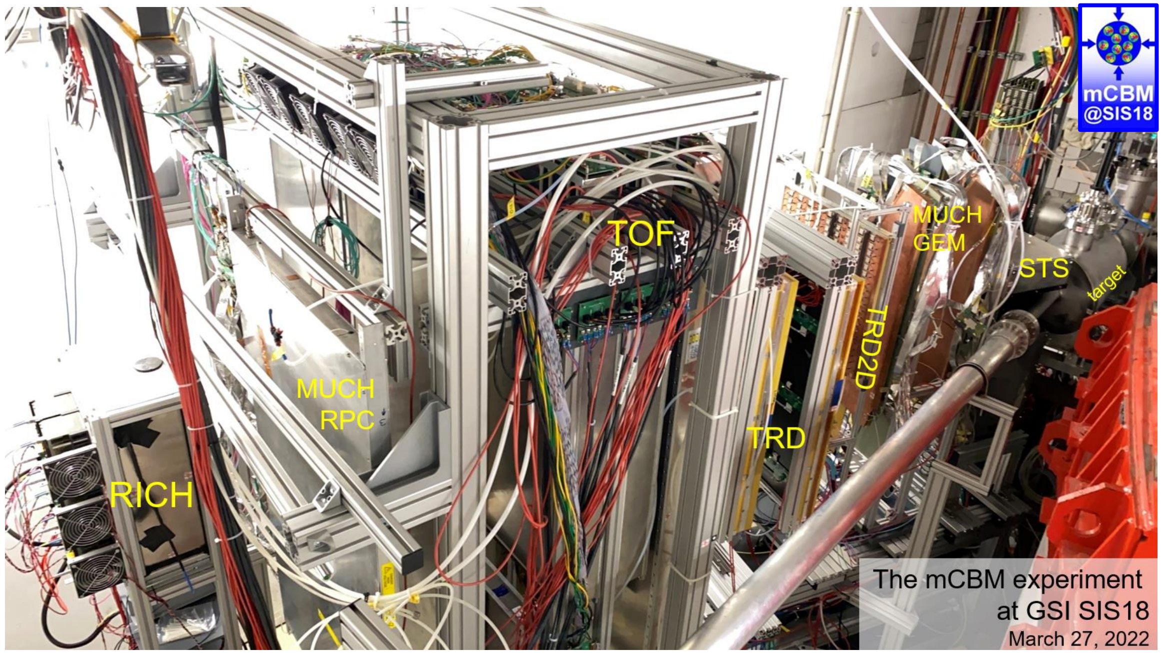
Time-of-Flight (ToF) Wall

Full-size counters (all types) built and tested
for high-rate and longer-term tests

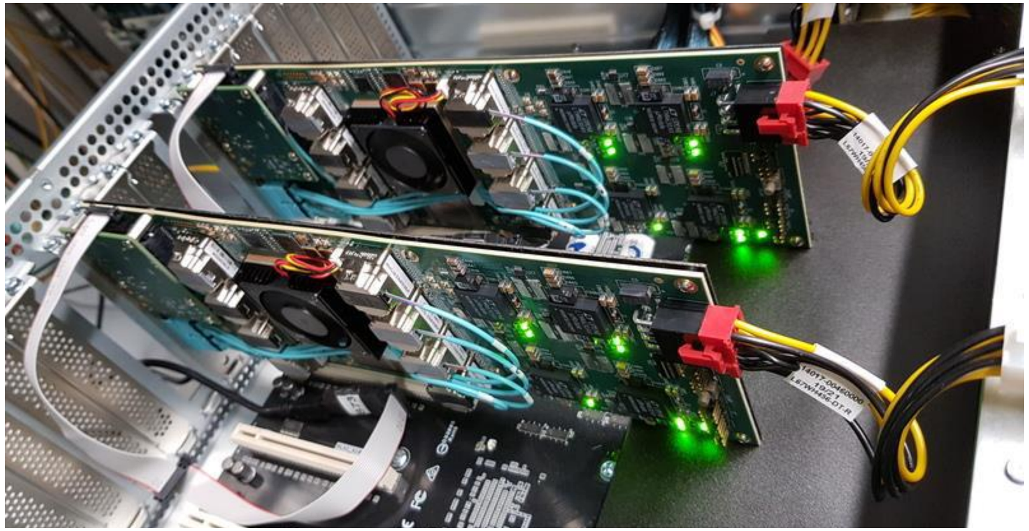
Projectile Spectator Detector (PSD)

Efforts to replace PSD with
HADES-like FWALL. Still open issue.

mCBM @ SIS-18



- Conceptual verification of the triggerless-streaming read-out and data transport of CBM at $\mathcal{O}$ (1 MHz) interaction rates
- Major effort put towards mimicking the final DAQ/data transport system by integrating all subsystems to the Common Readout Interface (CRI)
- Systematic high-rate studies performed for various detector subsystems and underlying components with up to 10 MHz collision rates during 2021-22 campaigns

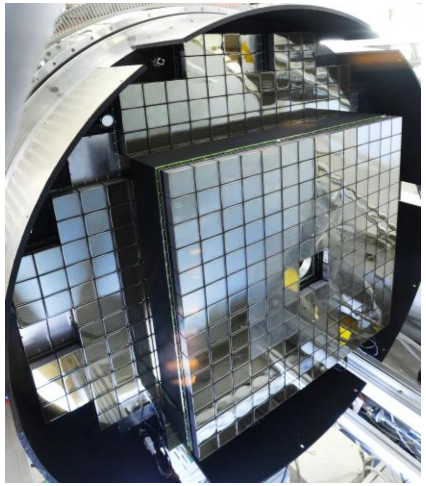


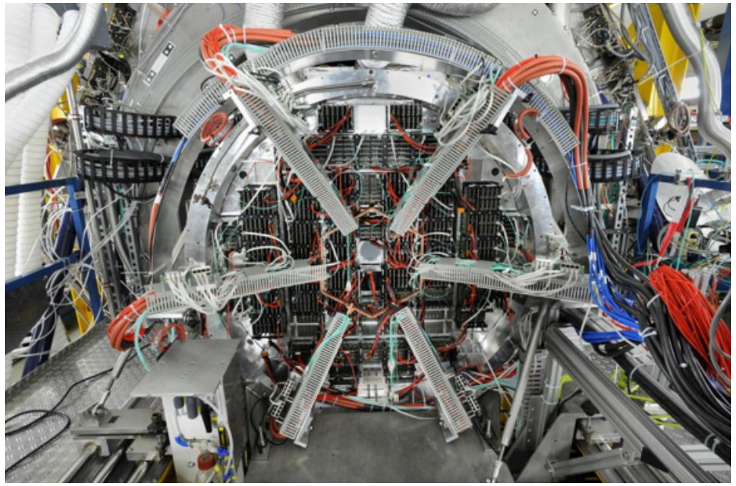
New mCBM DAQ with CRIs (prototype for CBM) in an entry node

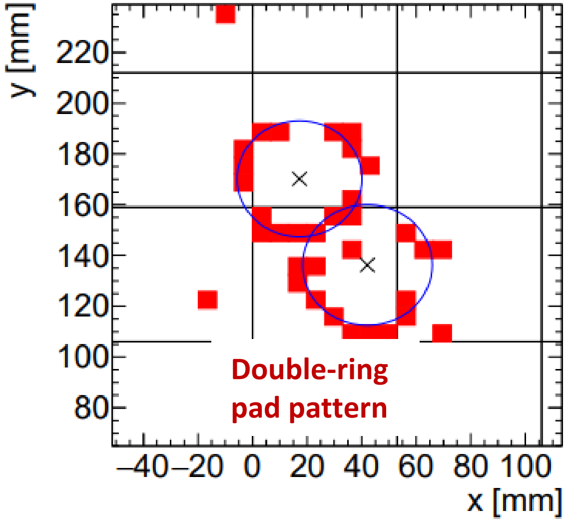
mCBM data sent forward, backward and forward to bridge a similar distance as later with CBM

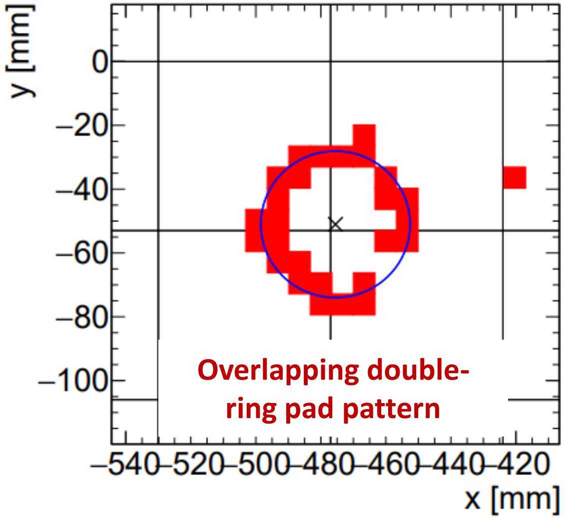
CBM Contribution To FAIR Phase 0

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



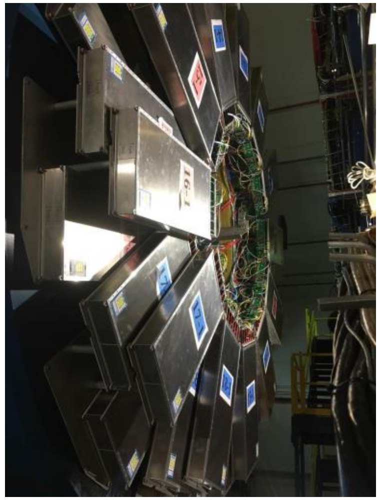


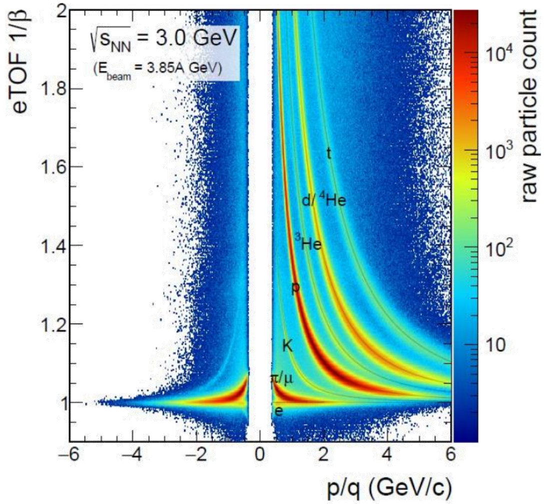


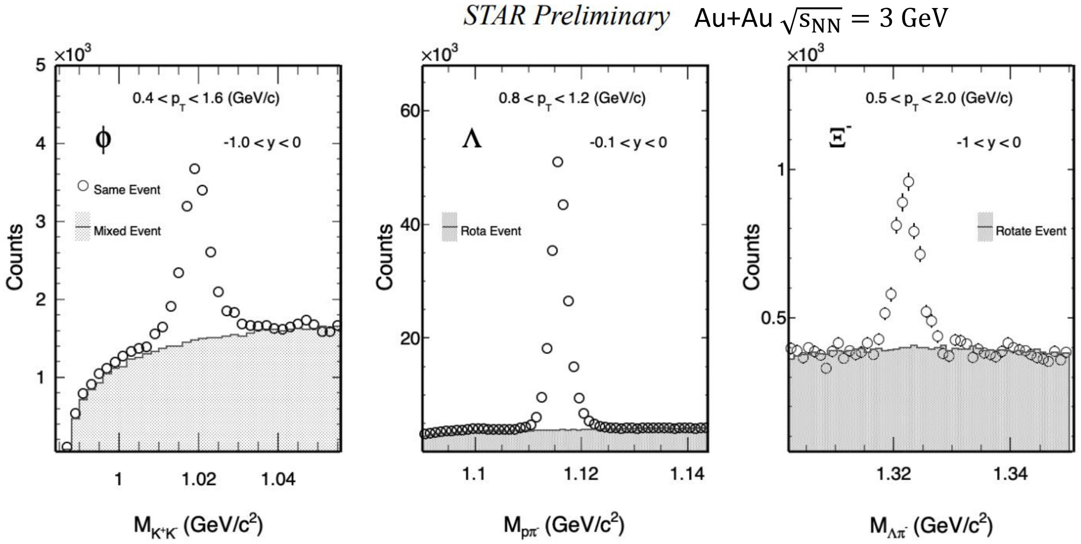


J. A-Musch et al., CBM Progress Report 2020

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



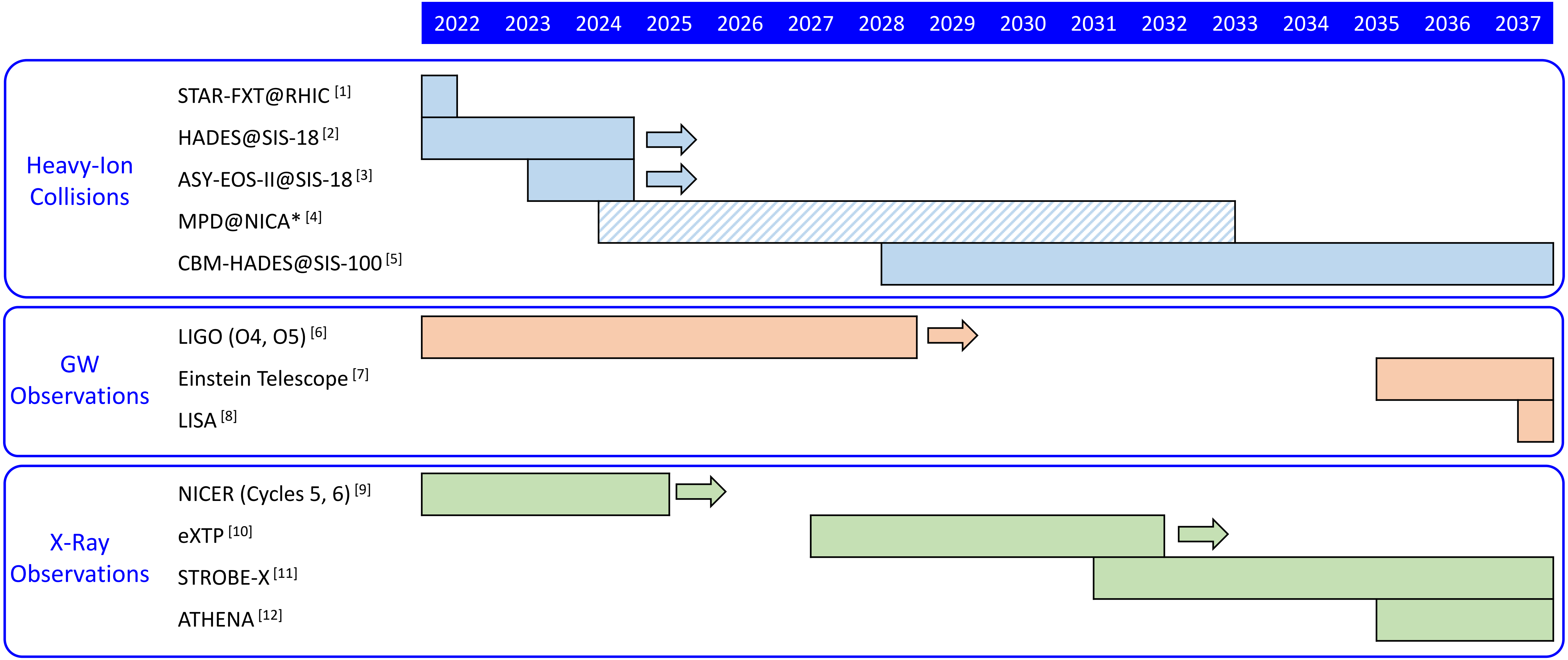




Guannan Xie, Strangeness in Quark Matter (2021)

A Look Into The Future
(Atleast Into One Of The Scenarios)

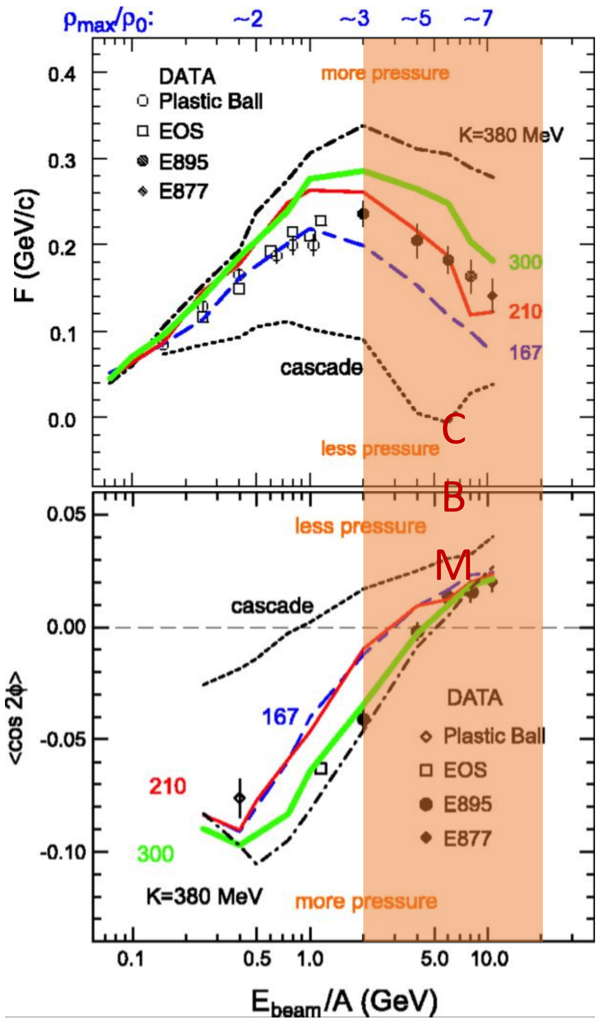
Growing Multi-Messenger Era (At Densities $\gtrsim \rho_0$)



[1] D. Morrison, Quark Matter 2022 | Link
[2] Proposal for Beamtime in 2023-24, GSI G-PAC (2022)
[3] Proposal for Beamtime in 2023-24, GSI G-PAC (2022)
[4] I. Maldonado, A. Ayala, EuNPC 2022 | Link
[5] First-Science and 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 for the Astro 2020 Decadal Survey | Link
[12] ATHENA ESA Factsheet | Link

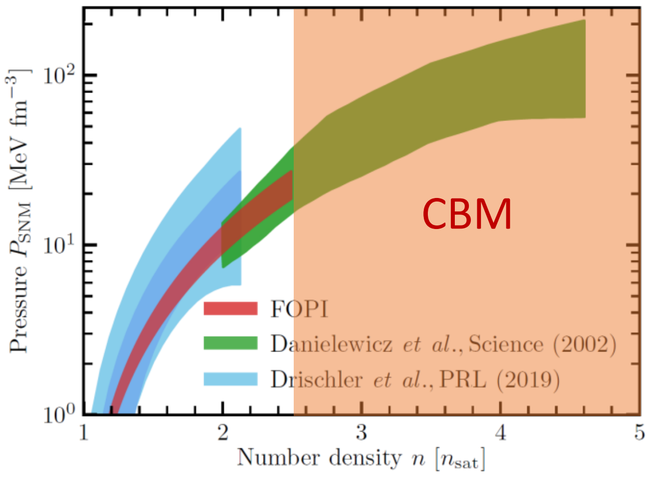
CBM'S ROLE VIS-À-VIS WORKSHOP OBJECTIVES

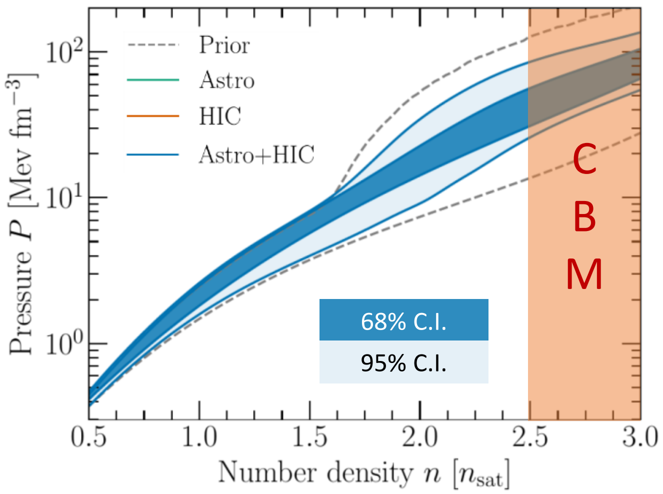
Can we reconcile data from current and previous experiments?



STAR BES-II/FXT (& AGS): D. Cebra (06.12)

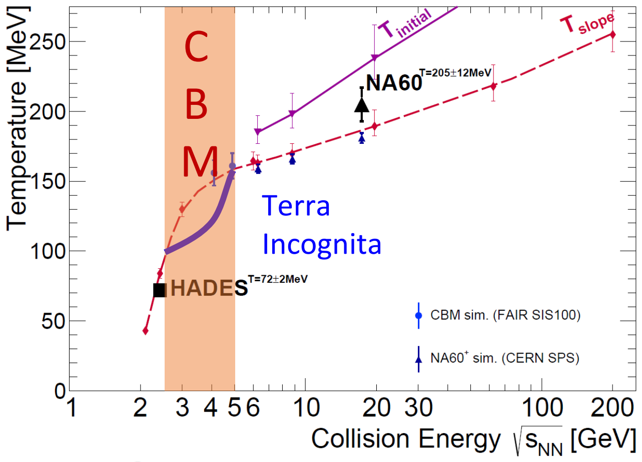
What improvements on the constraints on the EOS can we expect from future heavy-ion experiments?

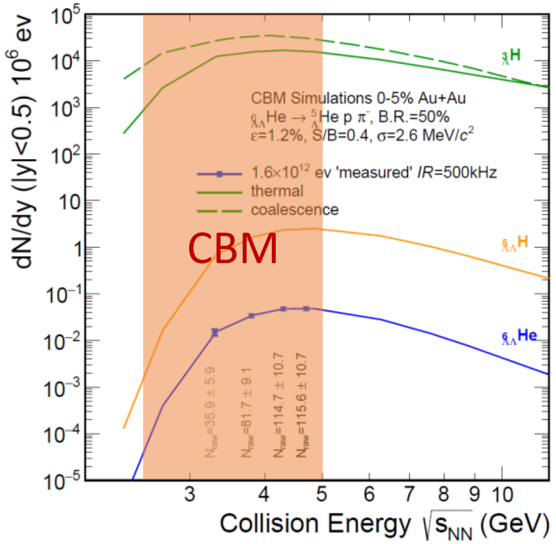




HADES Collective Flow: B. Kardan (06.12)
Reanalysis of FOPI Data: D. Cozma (05.12)

What other observables could enable the extraction of the EOS?





Correlations: M. Stefaniak, H. Zbroszczyk (06.12)
Fluctuations: V. Vovchenko (07.12)

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

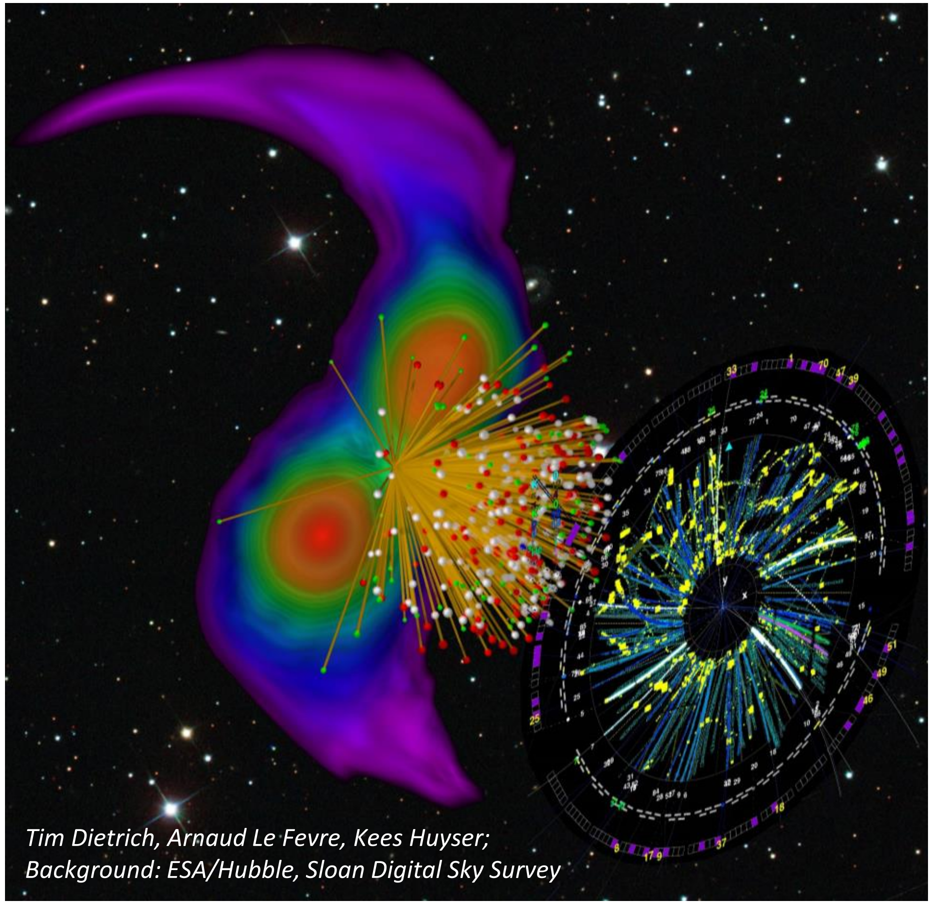
Pushing the high-rate capability frontier

- 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

Efforts are ongoing to compensate for the loss of Russian in-kind contributions to CBM due the war in Ukraine and sanctions imposed on Russia



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

CBM@SIS-100 (Au-Au at $\sqrt{s_{NN}} = 2.86 \ \ldots \ 4.93 \text{ GeV}$) 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

40th CBM Collaboration Meeting, Oct. 2022, WUT, Warsaw

VOTE OF CONFIDENCE FOR CBM-FAIR

CBM

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

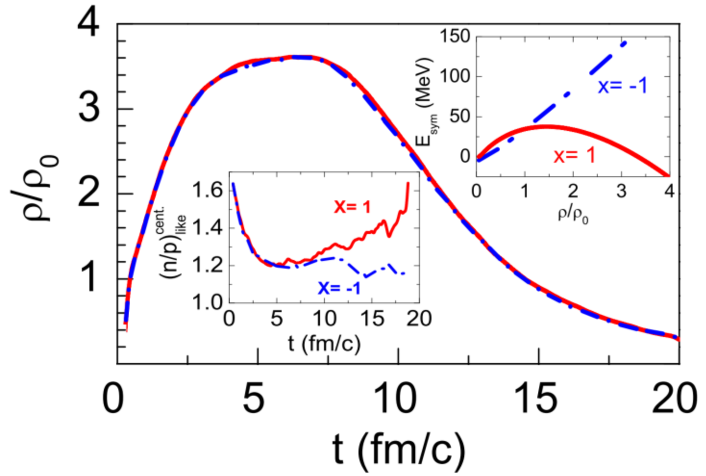
The committee came unanimously to the following recommendations in order to advance FAIR to science beyond Phase-0:

- 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”

OTHER SYMMETRY ENERGY OBSERVABLES AT ≳ $3\rho_0$

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



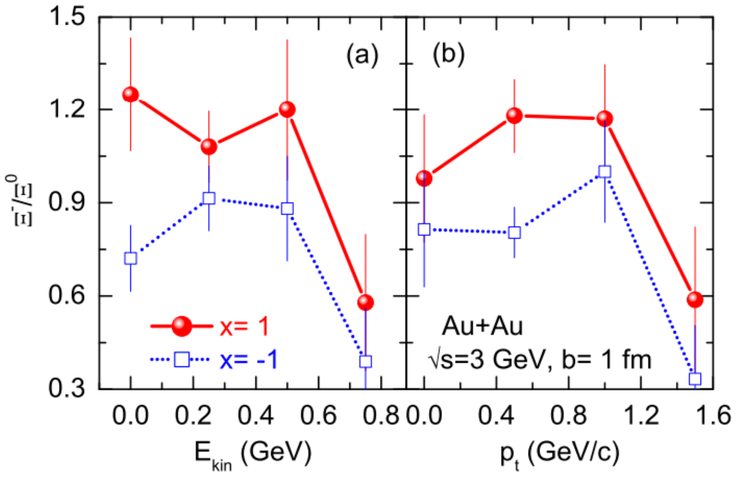


FIG. 2: Kinetic energy (a) and transverse momentum (b) distributions of the doubly strange baryon Ξ^-/Ξ^0 ratio in the central Au+Au reactions at $\sqrt{s_{NN}} = 3$ GeV with the stiff and soft symmetry energies, respectively. The curves are used to guide the eye and the error bars are statistical in nature.

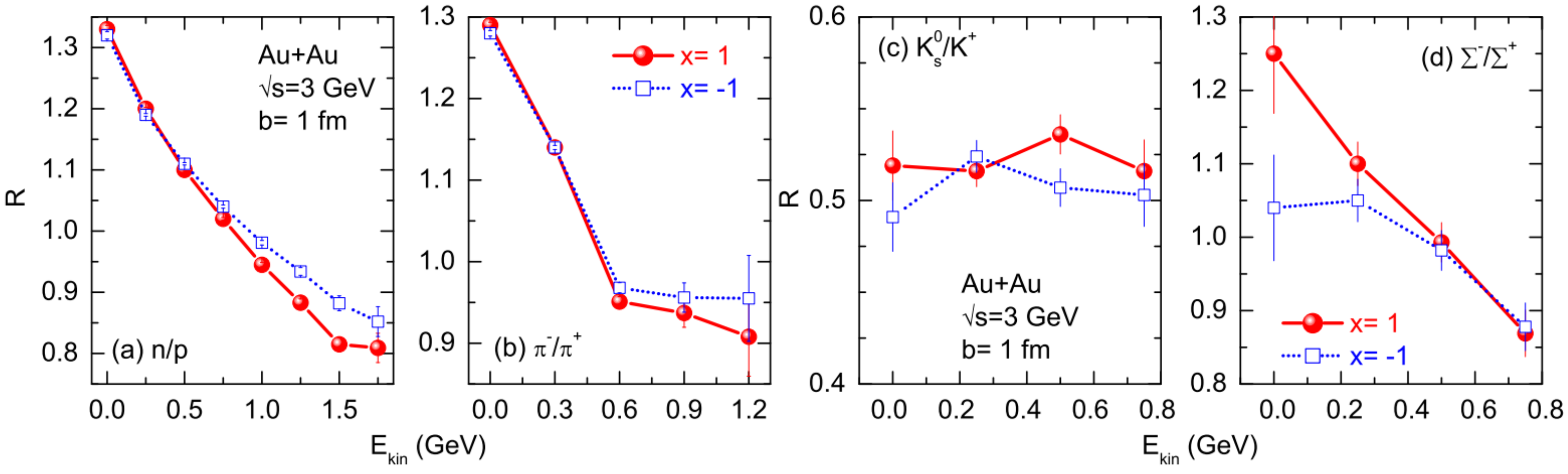
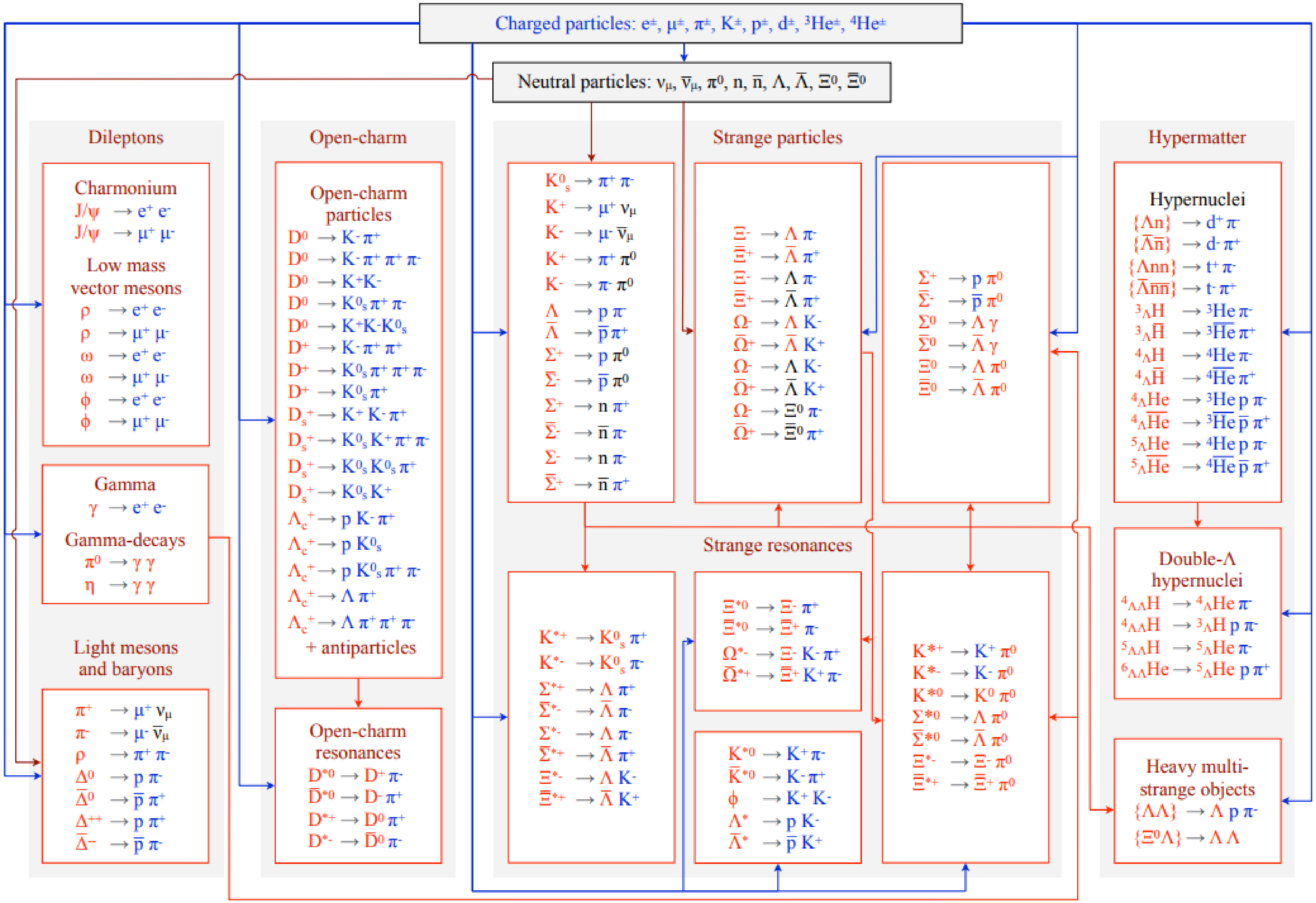


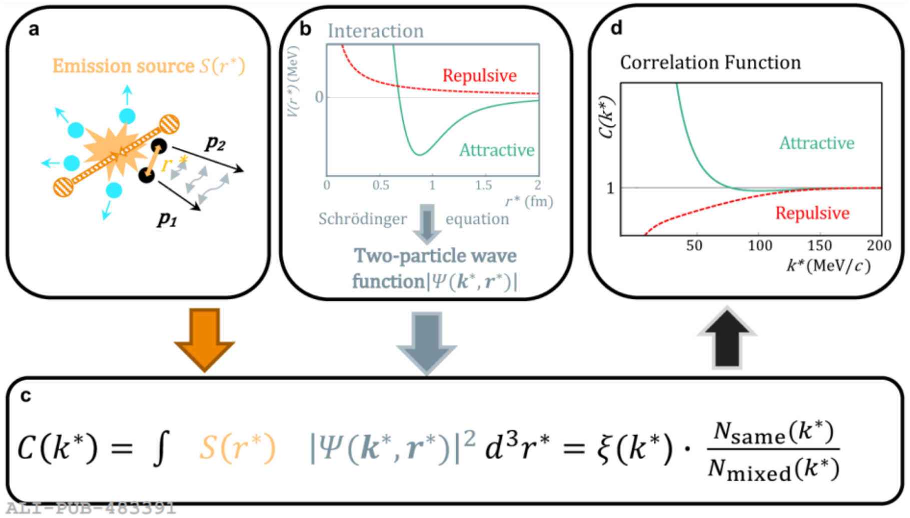
FIG. 3: The Kinetic energy distributions of n/p, π^-/π^+, K^0_s/K^+, and Σ^-/Σ^+ ratios in the central Au+Au reactions with stiff and soft symmetry energies at $\sqrt{s_{NN}} = 3$ GeV.

KF-PARTICLE FINDER



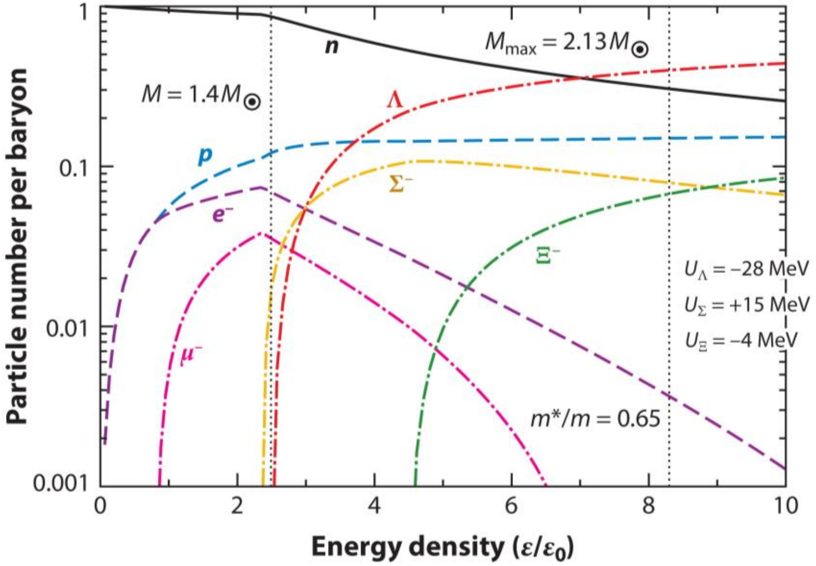
OBSERVABLE #5: FEMTOSCOPIC CORRELATIONS & YN INTERACTIONS

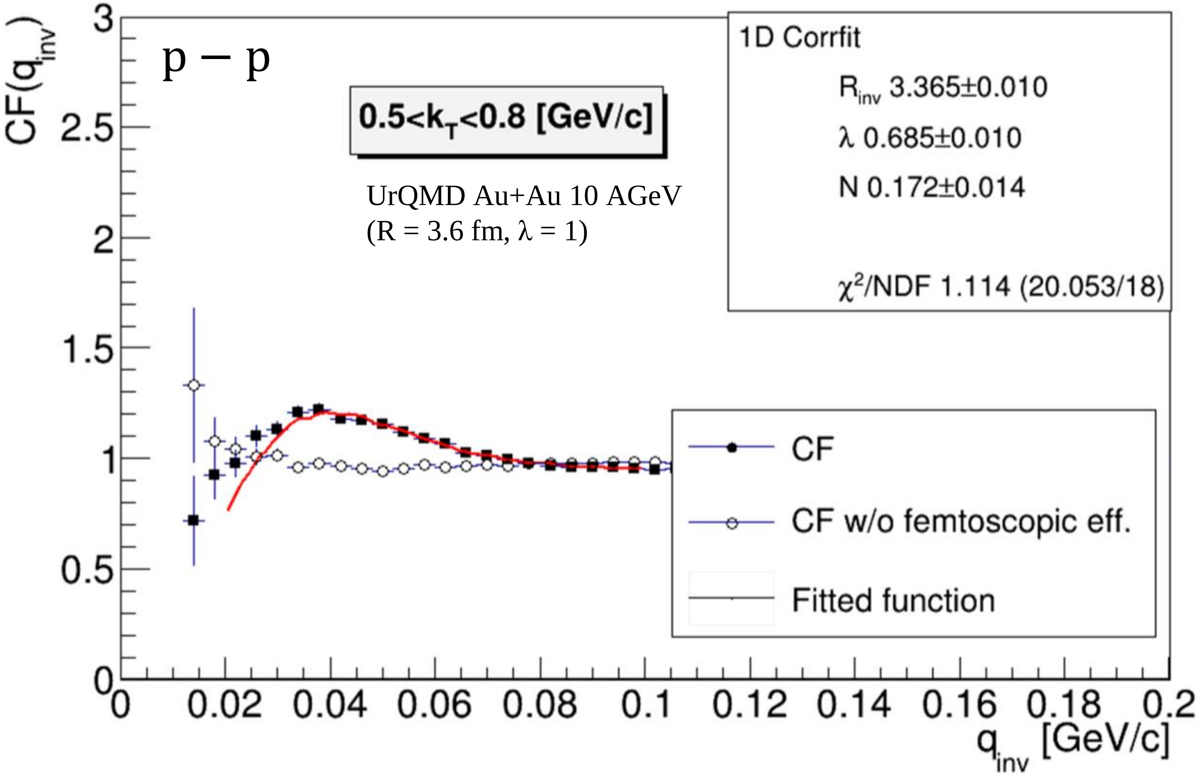
[ALICE], Nature 588, 7837 (2020)



Mean-Field Calculations + ALICE-LHC Measurements

L. Fabbietti et al., Ann.Rev.Nucl.Part.Sci. 71 (2021)
MF Calculations: D. Chatterjee, S. Gosh, J. Schaffner-Bielich
ALICE Data: Phys. Rev. Lett. 123:112002 (2019)





- Feasibility studies carried out to conduct measurements of proton-proton and pion-pion correlations

  D. Wielanek, Proc.SPIE Int.Soc.Opt.Eng. 11581 (2020) 115811E
  D. Wielanek, Quark Matter 2022

- Further analysis with higher statistics and improved cuts ongoing for precise reconstruction of source properties

Available STAR-RHIC Data

Table 1.2 Collision energy, event statistics, year of data taking, chemical freeze-out temperature, and baryon chemical potential for Au+Au collisions in BES-I and BES-II for STAR experiment at RHIC (Collider mode)

Au+Au Collisions at RHIC-STAR (2010–2021, Collider mode)				
$\sqrt{s_{NN}}$ (GeV)	Events ($\times 10^6$)	BES-II/BES-I	μ_B (MeV)	T_{ch} (MeV)
200	238	2010	25	166
62.4	46	2010	73	165
54.4	1200	2017	83	165
39	86	2010	112	164
27	560/30	2018/2011	156	162
19.6	538/15	2019/2011	206	160
17.3	250	2021	227	158
14.5	325/13	2019/2014	264	156
11.5	230/7	2020/2010	315	152
9.2	160/0.3	2020/2008	355	140
7.7	100/3	2021/2010	420	140

Table 1.3 Collision energy, event statistics, year of data taking, chemical freeze-out temperature, and baryon chemical potential for Au+Au collisions in BES-II for STAR experiment at RHIC (Fixed-target mode)

Au+Au Collisions at STAR (2018–2021, Fixed-target mode)				
$\sqrt{s_{NN}}$ (GeV)	Events ($\times 10^6$)	BESII/BESI	μ_B (MeV)	T_{ch} (MeV)
7.7	50/112	2019/2020	420	140
6.2	118	2020	487	130
5.2	103	2020	541	121
4.5	108	2020	589	112
3.9	117	2020	633	102
3.5	116	2020	666	93
3.2	200	2019	699	86
3	259/2000	2018/2021	720	80

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

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	≤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