Status Of The Compressed Baryonic Matter (CBM) Experiment At FAIR

Kshitij Agarwal

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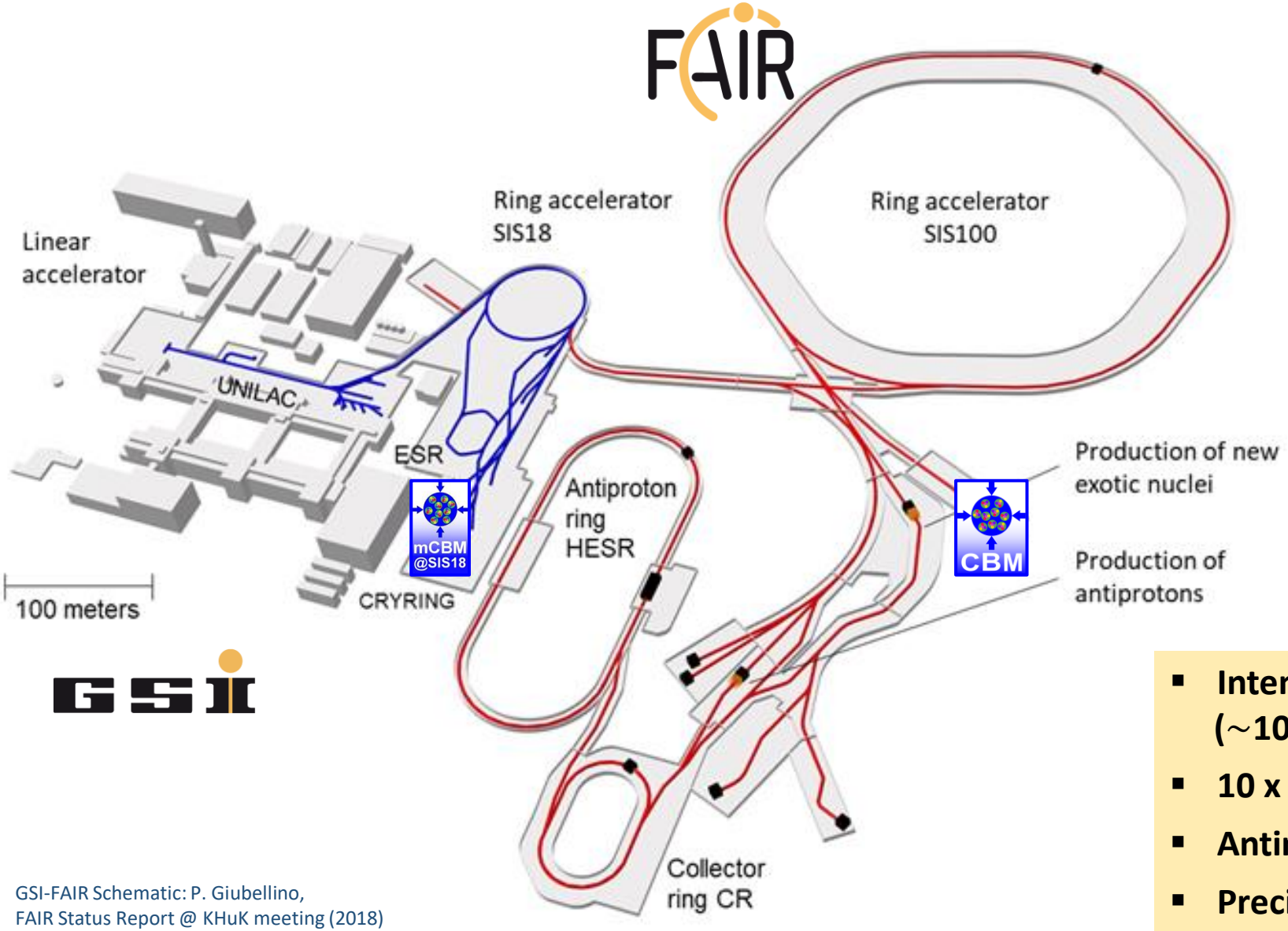
Eberhard-Karls-Universität Tübingen (DE)

- For the CBM Collaboration –

29th International Conference on Ultra-relativistic Nucleus-Nucleus Collisions (Quark Matter 2022)

Krakow, Poland, April 04 – 10, 2022

Facility For Anti-Proton And Ion Research (FAIR)



GSI-FAIR Schematic: P. Giubellino, FAIR Status Report @ KHuK meeting (2018)

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^{13}/s for p; ~10^{10}/s for Au)**
- **10 x energy (compared to SIS-18@GSI)**
- **Antimatter: antiproton beams**
- **Precision: System of storage and cooler rings**

Jens Stadlmann (GSI)

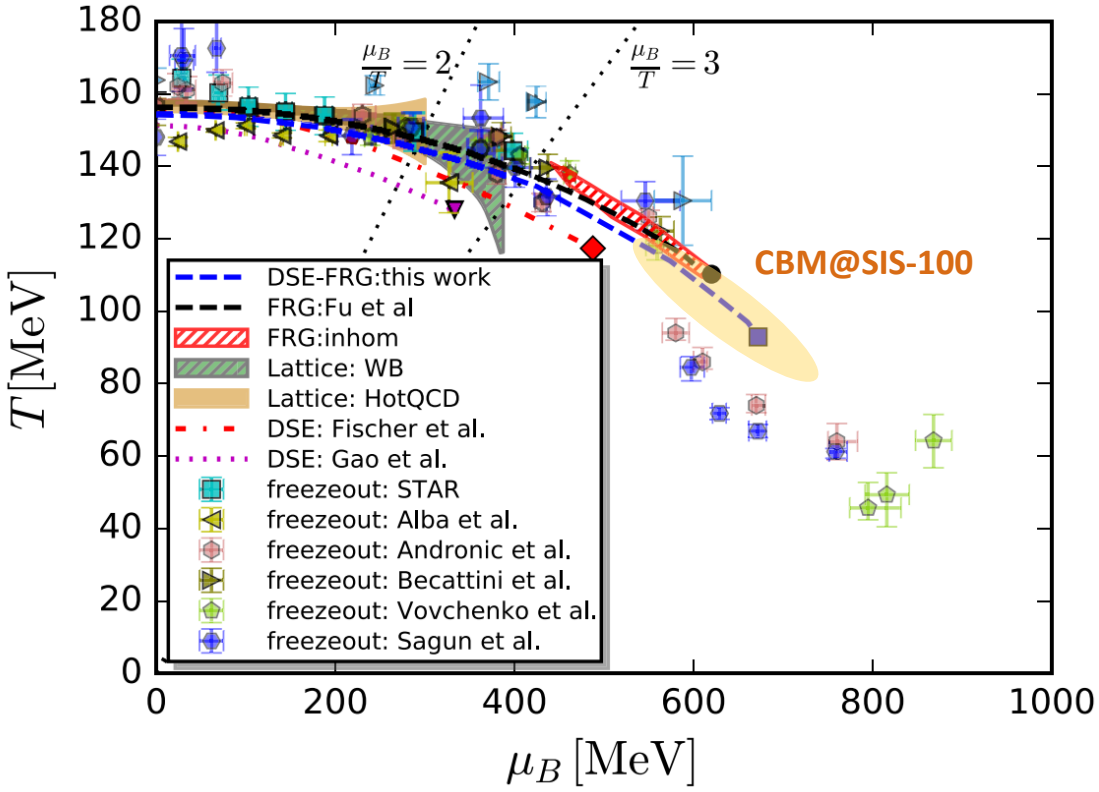
Update On FAIR Construction (December 2021)

- **Interior work on SIS-100 tunnel ongoing**
- **CBM Building's construction is on schedule and is ready for 'heavy installation' from 2022-23**
- **Consequence of the war in Ukraine and sanctions imposed on Russia are currently being evaluated**
- **Updates on construction available at: GSI Webpage | YouTube | …**

CBM Physics Goals

CBM Physics Goals

F. Gao, J.M. Pawlowski, Phys.Rev.D 102 (2020) 3, 034027



Most promising range to find the Critical End Point (CEP):

$$(135, 450)\mathrm{MeV} \lesssim (\mathrm{T}, \mu_\mathrm{B})_\mathrm{CEP} \lesssim (100, 650)\mathrm{MeV}$$

fRG:	$(\mathrm{T}, \mu_\mathrm{B})_\mathrm{CEP} = (107, 635)$ MeV	W.J. Fu et al., Phys.Rev.D 101 (2020) 5, 054032
DSE:	$(\mathrm{T}, \mu_\mathrm{B})_\mathrm{CEP} = (109, 610)$ MeV	F. Gao et al., Phys.Lett.B 820 (2021), 136584
	$(\mathrm{T}, \mu_\mathrm{B})_\mathrm{CEP} = (112, 636)$ MeV	P.J. Gunkel et al., Phys.Rev.D 104 (2021) 5, 054022
LQCD:	$\mathrm{T}_\mathrm{CEP} < \mathrm{T}_\mathrm{C} = 132^{+3}_{-6}$MeV	F. Karsch, PoS CORFU2018 (2019) 163
		[HotQCD], Phys.Rev.Lett. 123 (2019) 6, 062002
	$\mu_\mathrm{B}/\mathrm{T} \lesssim 3.5$	S. Borsányi et al., Phys.Rev.Lett. 126 (2021) 23, 232001

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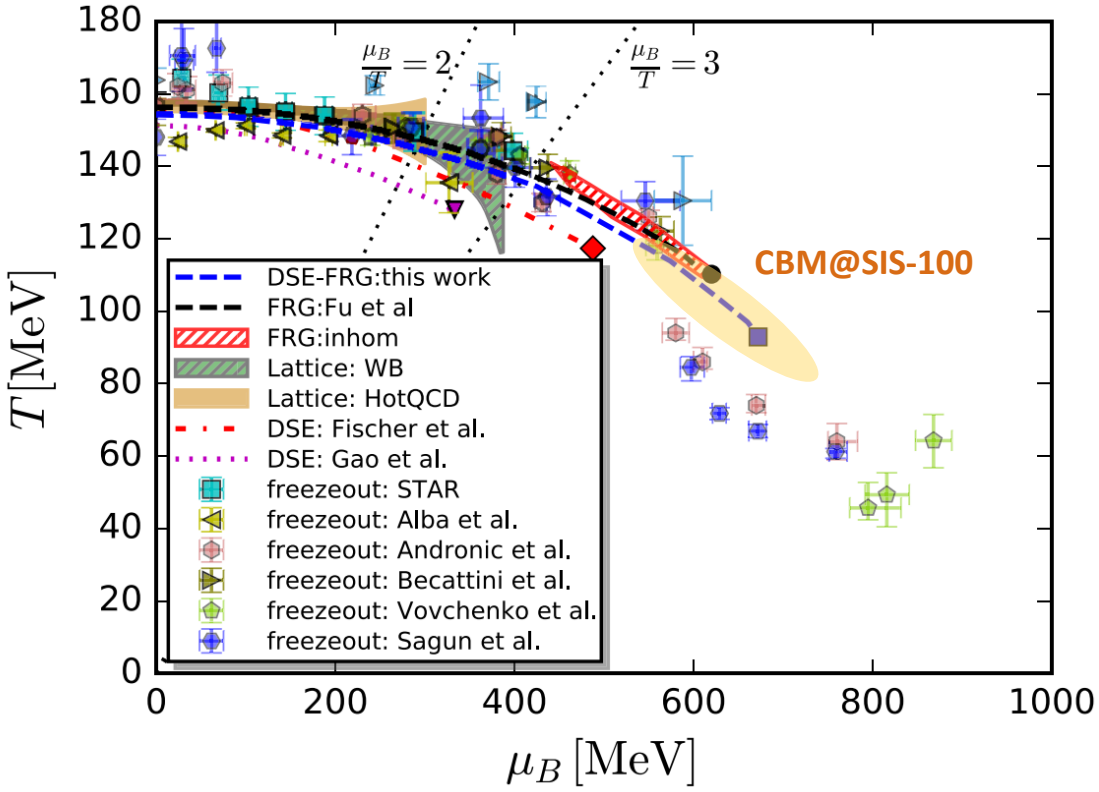

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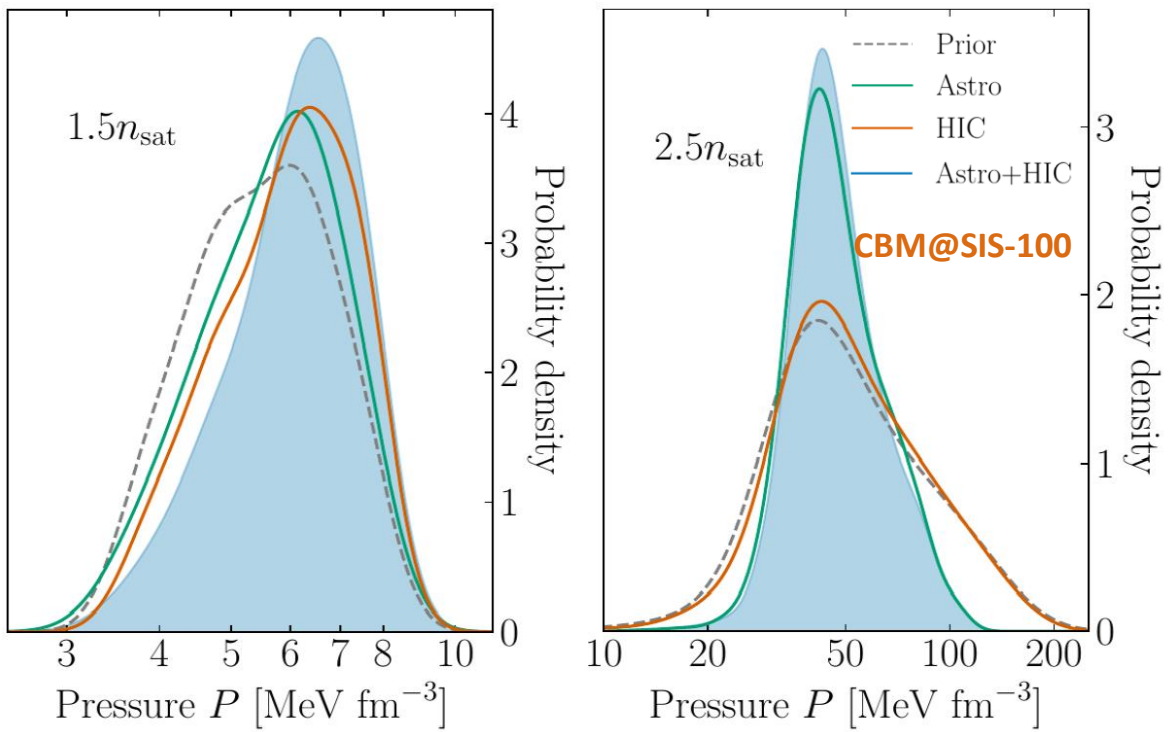
S. Huth, P.T.H. Pang et al., arXiv:2107.06229 [nucl-th]



K. Agarwal, 08.04.22, Poster Session 3 T10

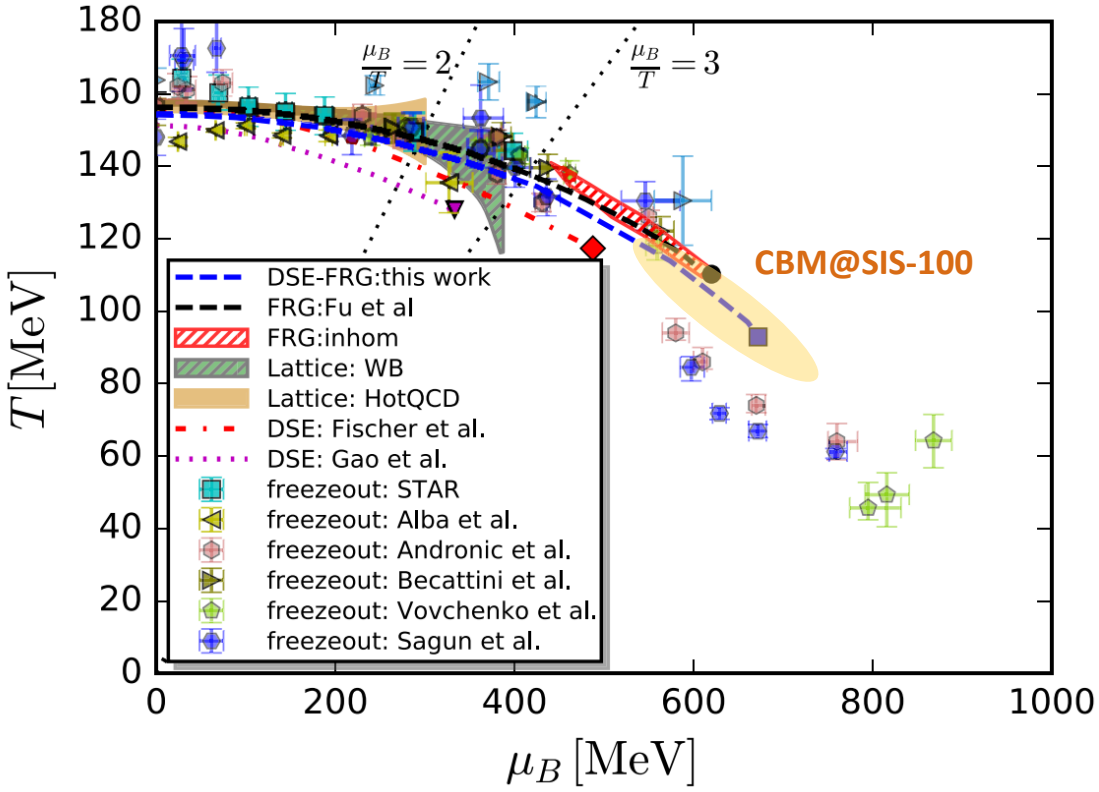
Bayesian interference to show that constraints on Pure Neutron Matter (PNM) EoS obtained by heavy-ion collisions (HIC) are consistent with multi-messenger astrophysics at lower densities

Symmetric Nuclear Matter:	[FOPI], Nucl.Phys.A 945 (2016) 112-133
	[KaoS], Phys.Rev.Lett. 86 (2001) 39-42
	P. Danielewicz et al., Science 298 (2002) 1592-1596
Symmetry Energy:	[ASY-EOS], Phys.Rev.C 94 (2016) 3, 034608
	[SπRIT], Phys.Rev.Lett. 126 (2021) 16, 162701

CBM Physics Goals

The CBM research program aims to decipher dense QCD matter properties
Microscopic (CBM) + Macroscopic Collisions (Astro) = New Multi-Messenger Physics

F. Gao, J.M. Pawlowski, Phys.Rev.D 102 (2020) 3, 034027



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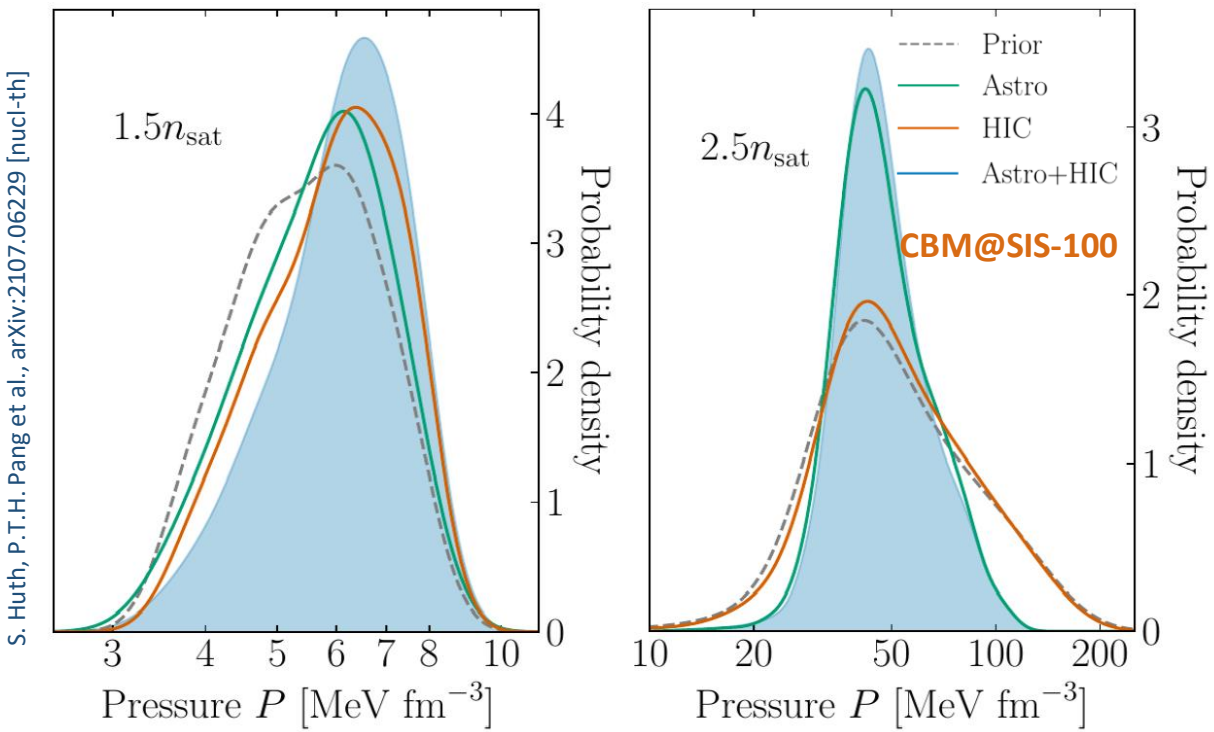

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CBM

Comprehensive roster of physics goals and observables

QCD equation-of-state and symmetry energy
- collective flow of identified particles
- particle production at threshold energies

Phase transition
- excitation function of hyperons
- excitation function of LM lepton pairs

Critical point
- event-by-event fluctuations of conserved quantities

Chiral symmetry restoration at large μ_B
- in-medium modifications of hadrons
- meson-baryon coupling
- dileptons at intermediate invariant masses

Strange matter
- (double-) lambda hyper-nuclei
- search for meta-stable objects (e.g., strange dibaryons)

Heavy flavor in cold and dense matter
- excitation function of charm production

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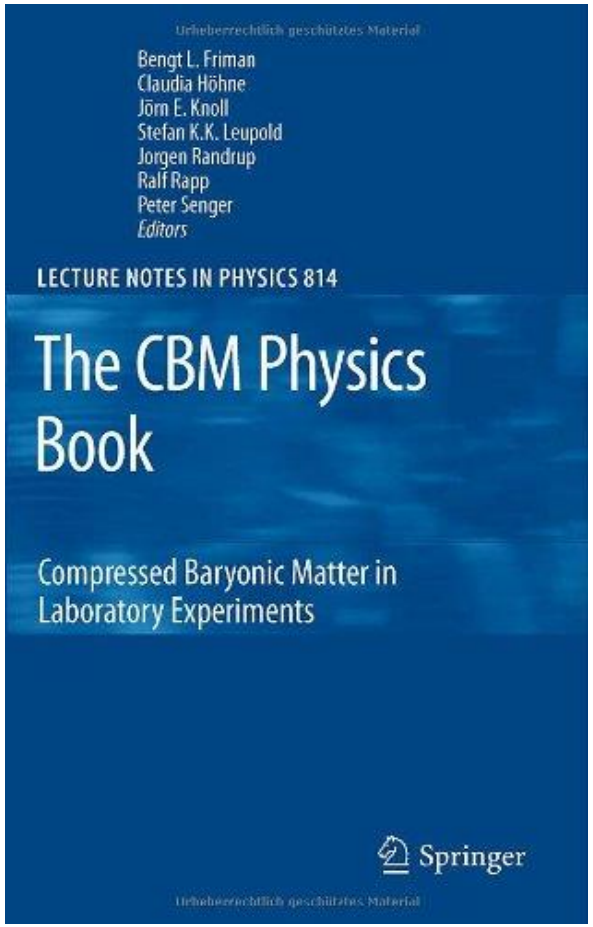
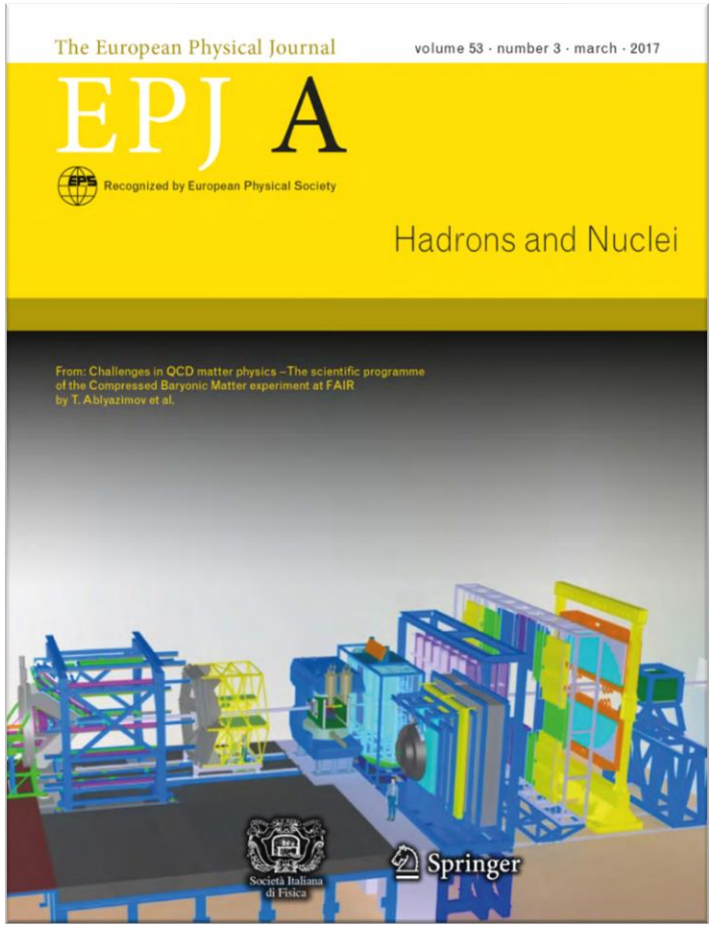
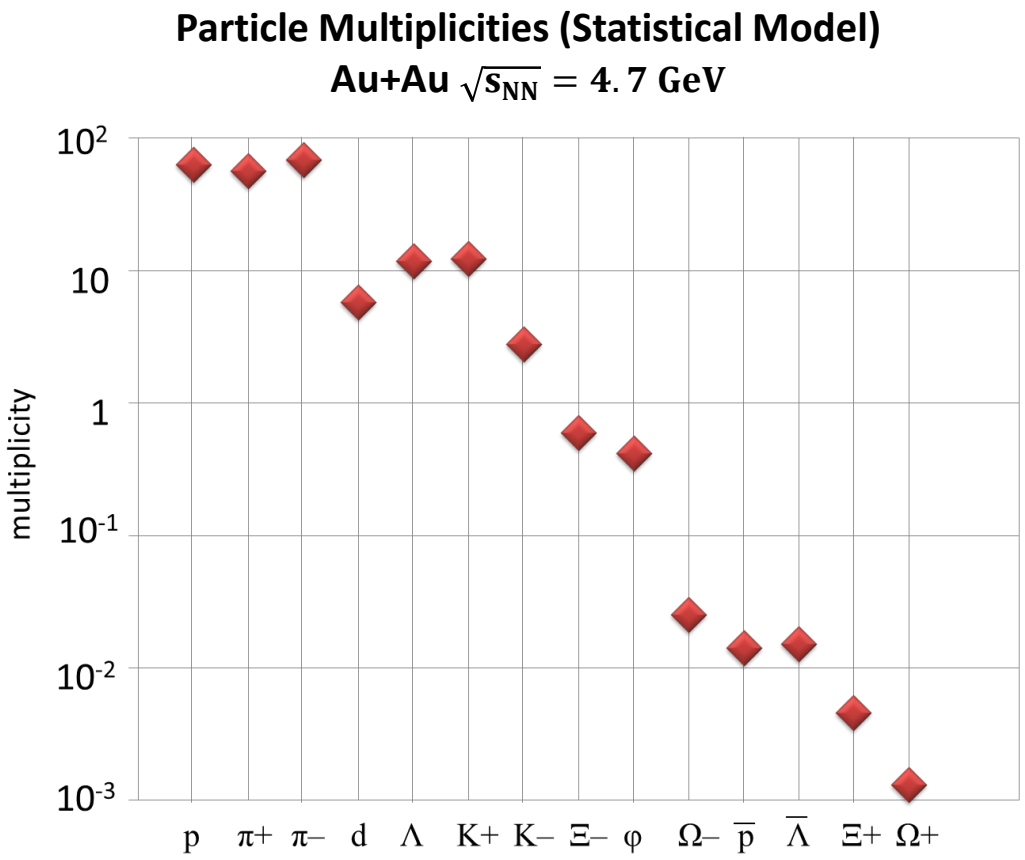


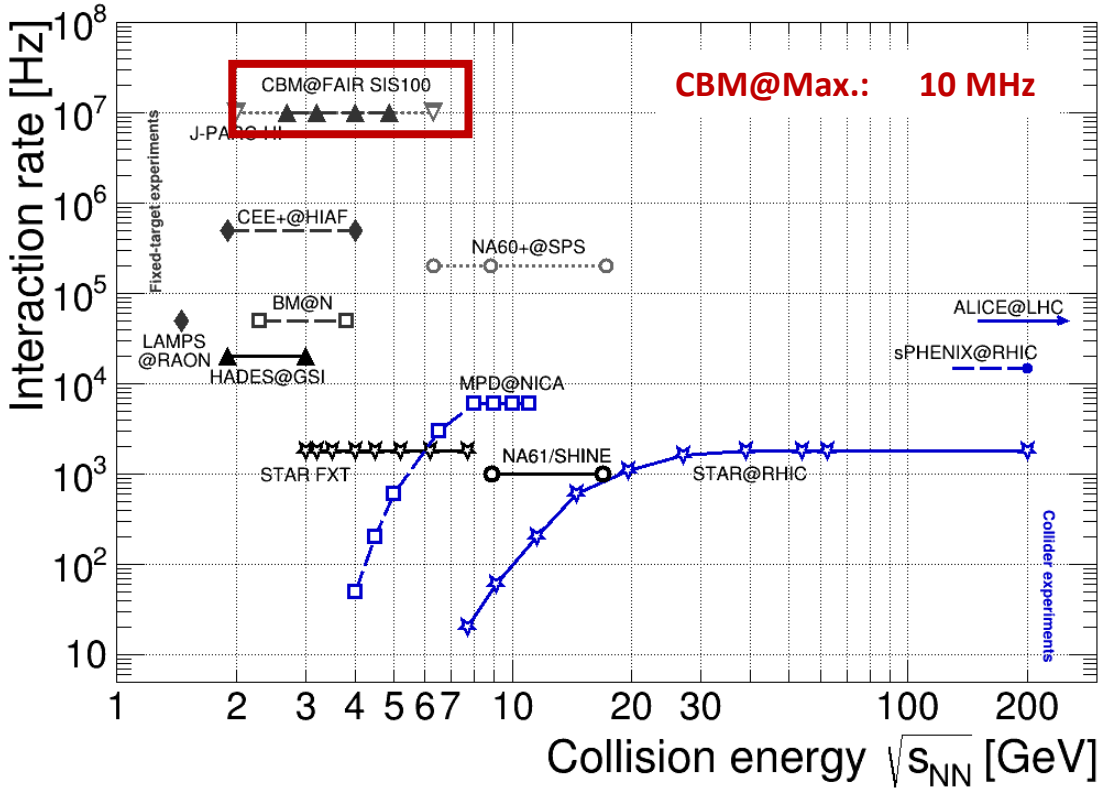
Lect. Notes Phys. 814 (2011) pp.1-980
DOI: 10.1007/978-3-642-13293-3



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

Beam-Target Interaction Rates And Rare Probes' Yields





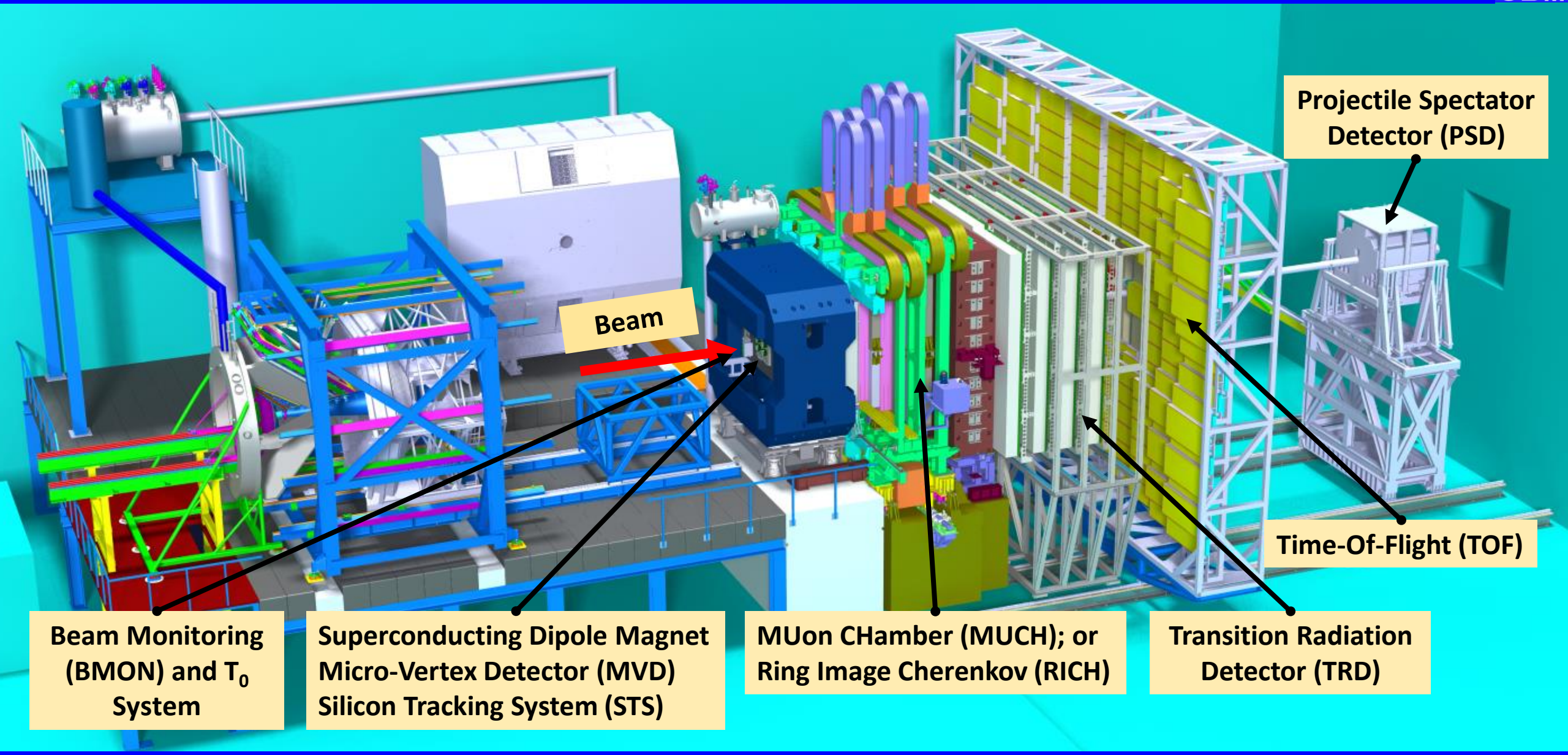
[CBM], Eur.Phys.J.A 53 (2017) 3, 60
T. Galatyuk, Nucl.Phys.A 982 (2019) 163-169, update (09/2021)

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'

Particle	$\sqrt{s_{NN}}$	Run time	e %	R_{int}	Duty F %	Yield
${}^{3}_{\Lambda}H$	4.7 GeV	1 wks	19	10 MHz	50	5.5×10^9
${}^{4}_{\Lambda}H$	4.7 GeV	1 wks	15	10 MHz	50	2.7×10^8
${}^{6}_{\Lambda\Lambda}He$	4.7 GeV	10 wks	1	10 MHz	50	146

T. Galatyuk, Quark Matter (2018)

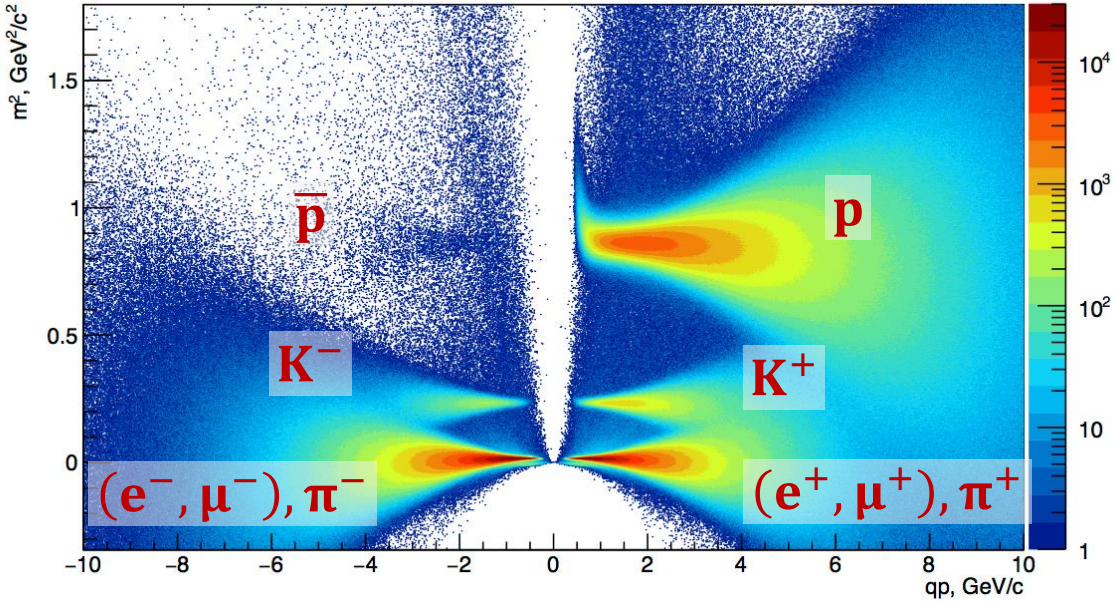
CBM Experimental Setup @SIS-100



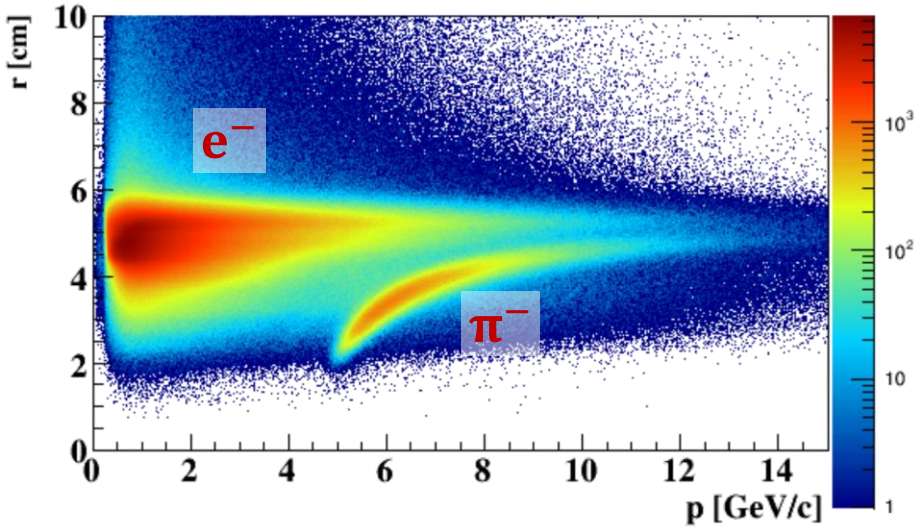
Particle Identification With CBM

CBM Simulations, central Au-Au@10AGeV

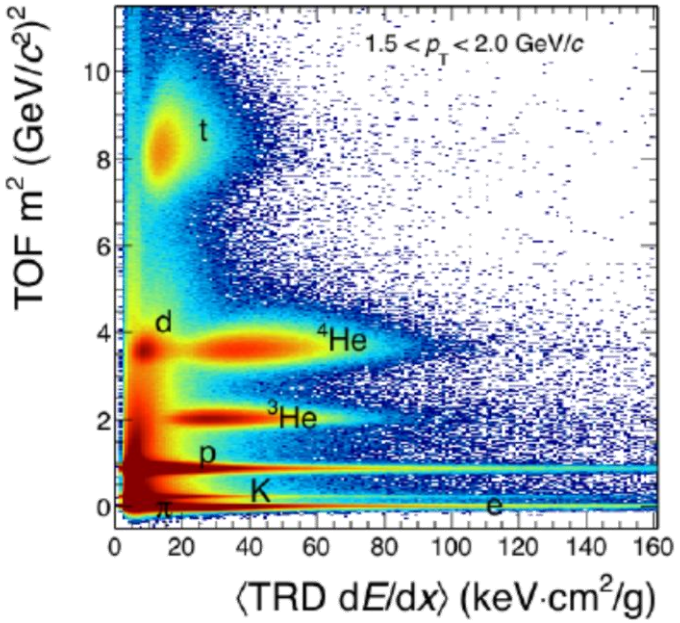
ToF - Hadron Identification



Clear separation between charged protons, pions and kaons



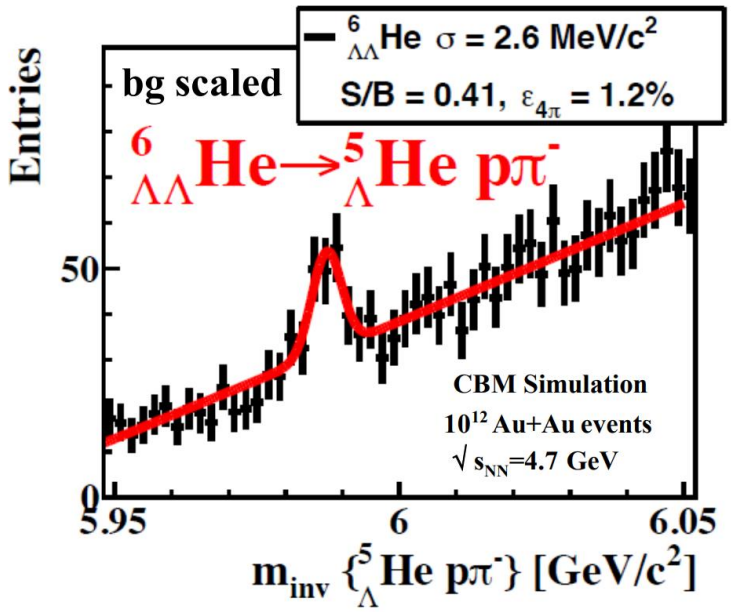
RICH - Electron ID



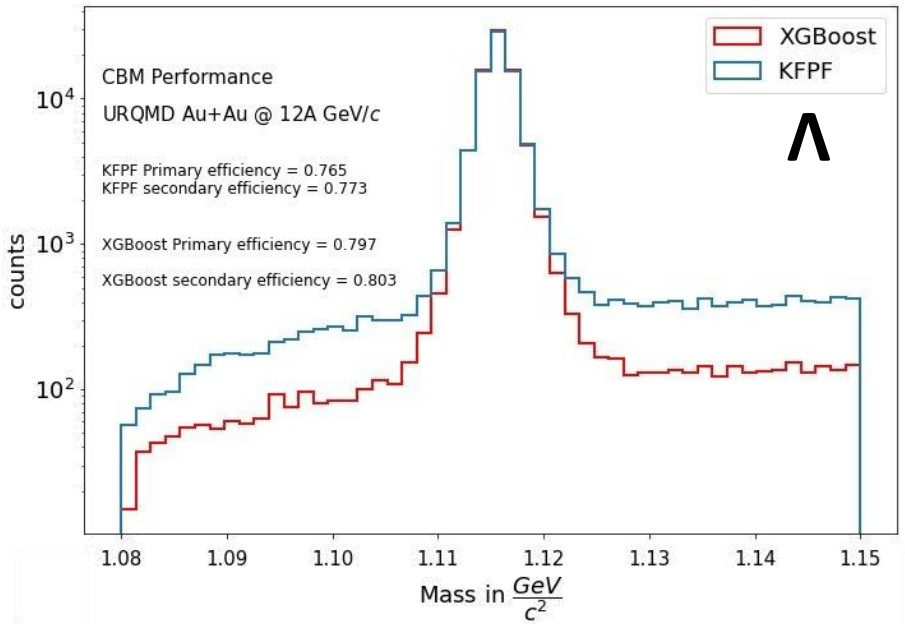
TRD + ToF - Electron, Light Nuclei, Heavy Fragments

Clear separation between pions and electrons, and light nuclei

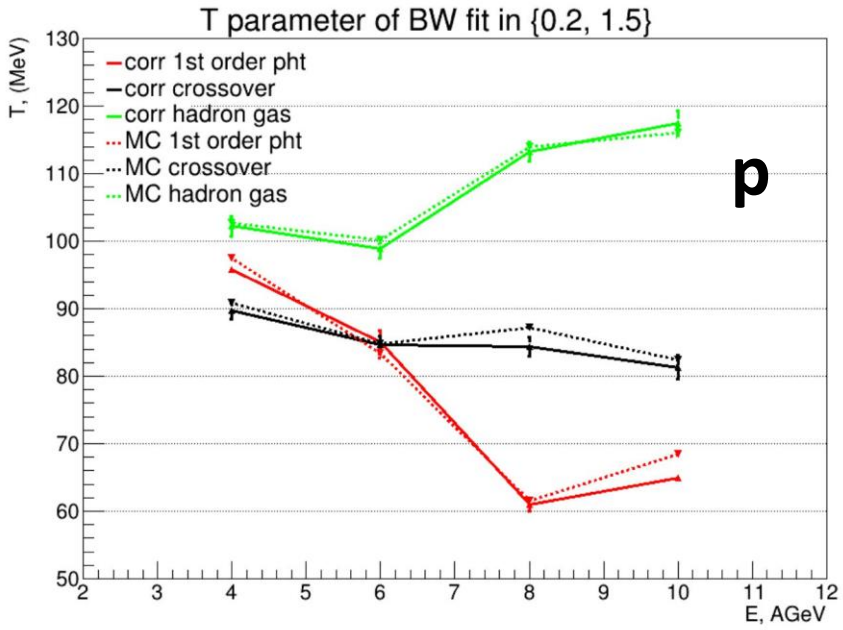
Physics Performance – Hadrons And Strangeness



I. Vassiliev, 08.04.22, Poster Session 3 T16



S. Khan, 08.04.22, Poster Session 3 T11_2



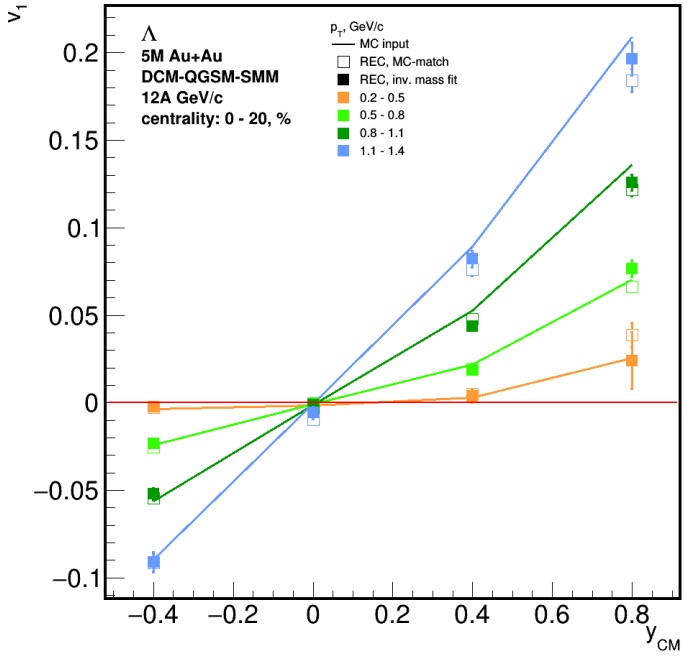
E. Volkova, 06.04.22, Poster Session 1 T14_2

- **Tools for the multi-differential physics analysis are prepared for strange hadrons and hypernuclei**
- **Reconstruction is based on the dedicated KFParticleFinder package**

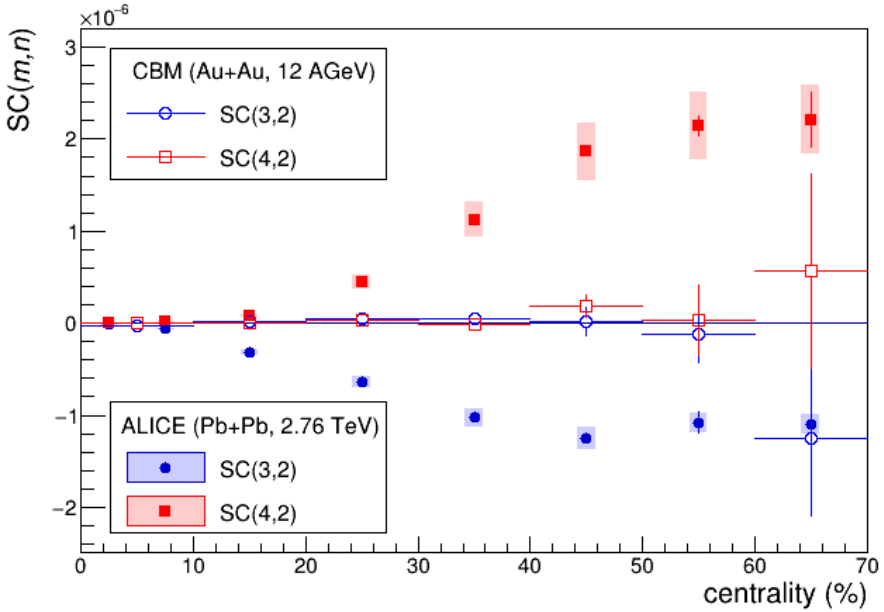
- **Yield improvements demonstrated with Λ by using Machine Learning techniques (XGBoost model)**
- **Further deployment on other (multi-)strange hyperons (K_0^S and Ξ^-)**

- **Studies to reconstruct the properties of different EoS in THESEUS event generator (3-fluid hydro)**
- **'Temperature' extraction within ~5% systematic error by using Blast-Wave and Boltzmann fitting**

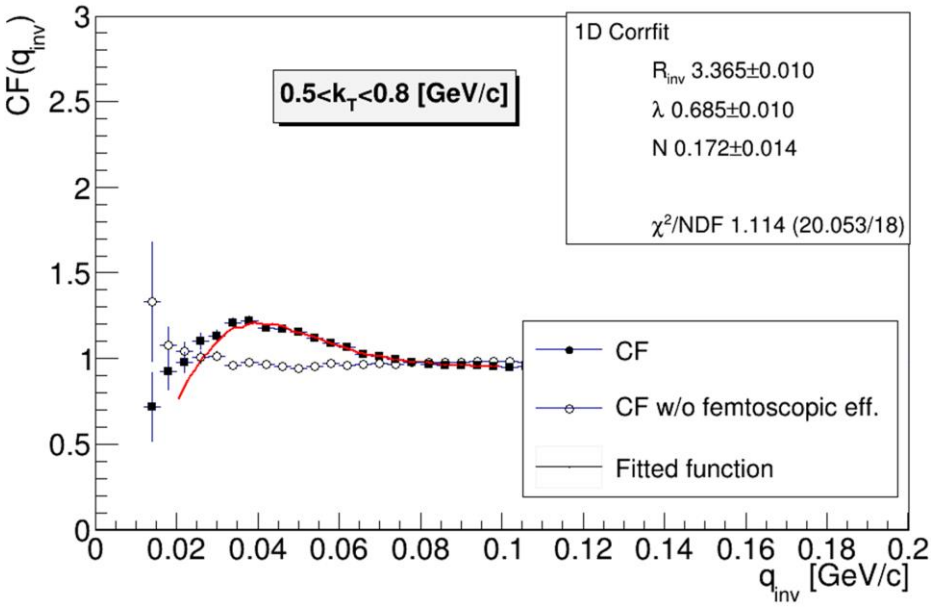
Physics Performance – Correlation, Flow, Fluctuations



O. Lubynets, 06.04.22, Poster Session 1 T14_2



A. Bilandzic, 08.04.22, Poster Session 3 T15_1



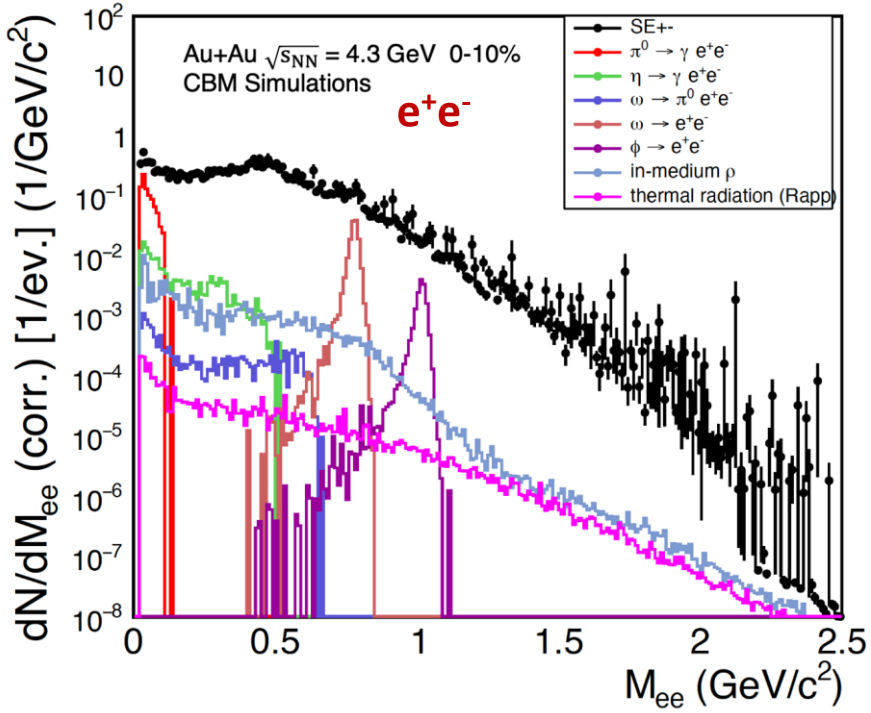
D. Wielanek, 06.04.22, Poster Session 2 T07_1

- **Multi-differential study of v_1 for (multi-)strange hyperons: Λ, K_0^S, and Ξ^-**
- **Input model v_1 is recovered using data-driven methods**

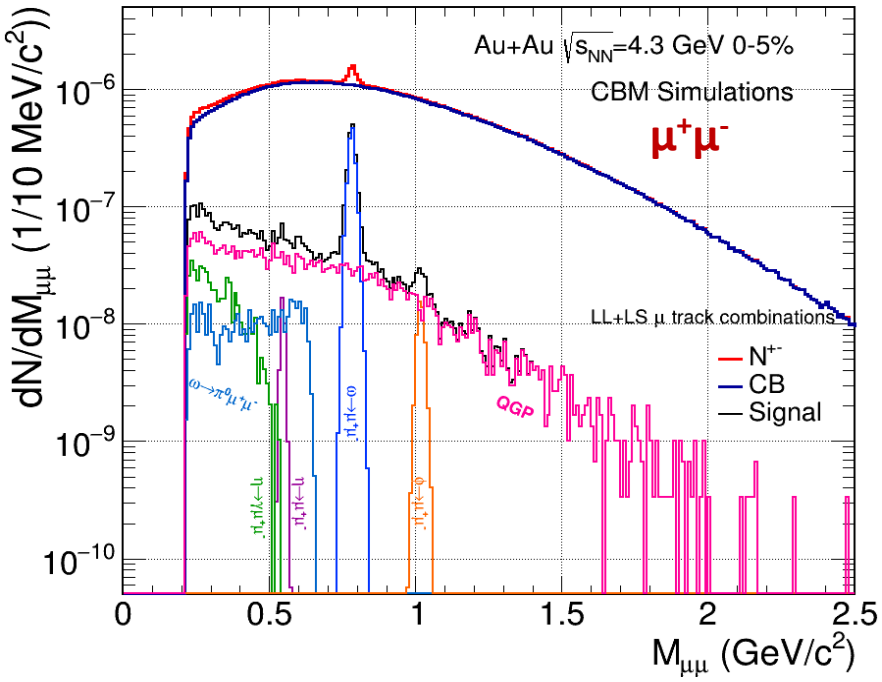
- **First feasibility studies of performing multi-particle azimuthal correlations in flow analyses (symmetric cumulants)**
- **Challenging due to CBM's fixed-target geometry at lower energies (non-uniform acceptance and low multiplicities), <u>BUT</u> possible**

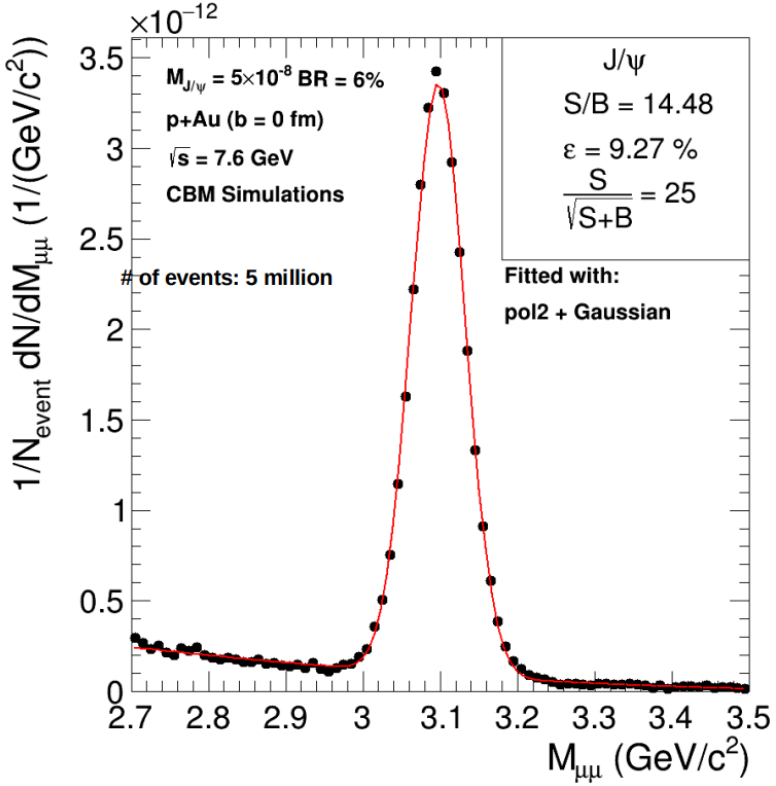
- **Feasibility studies to conduct measurements of proton-proton and pion-pion correlations**
- **Further analysis with higher statistics and cuts ongoing for precise reconstruction of source properties**

Physics Performance – Dileptons



C. Feier-Riesen, 08.04.22, Poster Session 3 T15/T16





S. Chatterjee, 06.04.22, Poster Session 2 T13

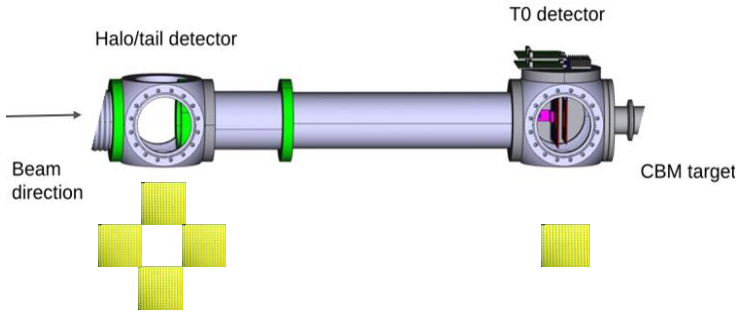
- **Clear peaks for the low mass vector mesons in both production channels, with negligible contribution from Drell-Yan**
- **Access to thermal signal is feasible with good background description; Improvements ongoing**

- **Prospects of charmonium measurements at sub-threshold energies (Au+Au) and to study cold nuclear matter effects (p+Au)**
- **Mass resolution of ~35 MeV, with good mid-rapidity coverage**

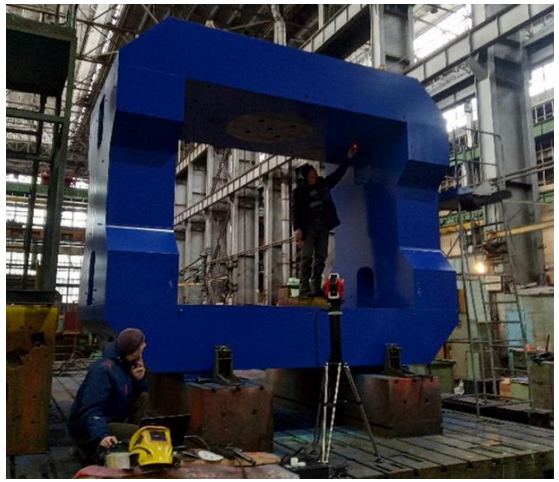
Recent (& Brief) Achievements In Detector Projects

More info in poster sessions 3 T15_1 , 3 T15_2 and backup slides

Beam Monitoring (BMON) Detector

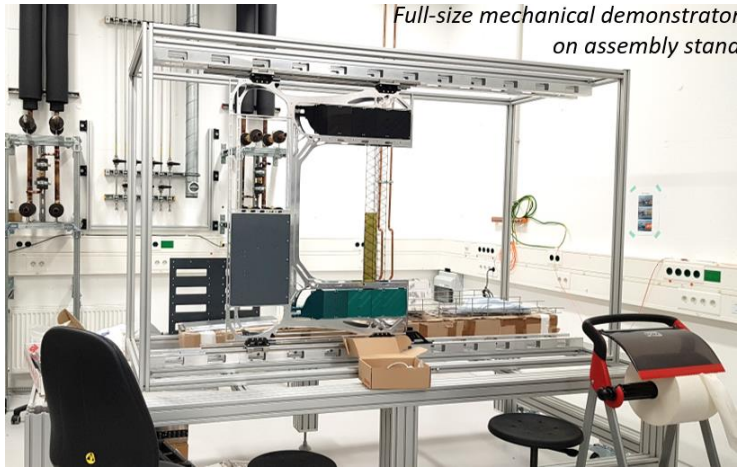


Superconducting Dipole Magnet



Micro-Vertex Detector (MVD)

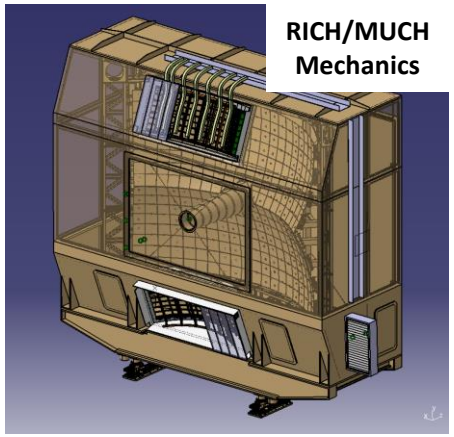
Silicon Tracking System (STS)



Muon Chambers (MUCH)

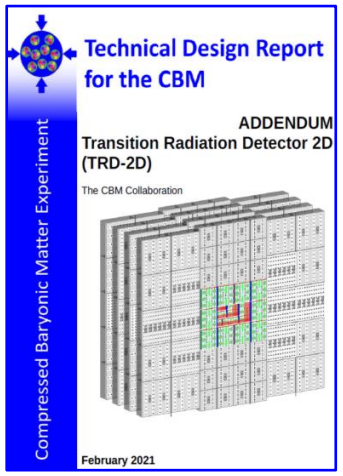
MUCH GEM at GIF++ (Nov.21)

Ring Imaging Cherenkov (RICH) Detector

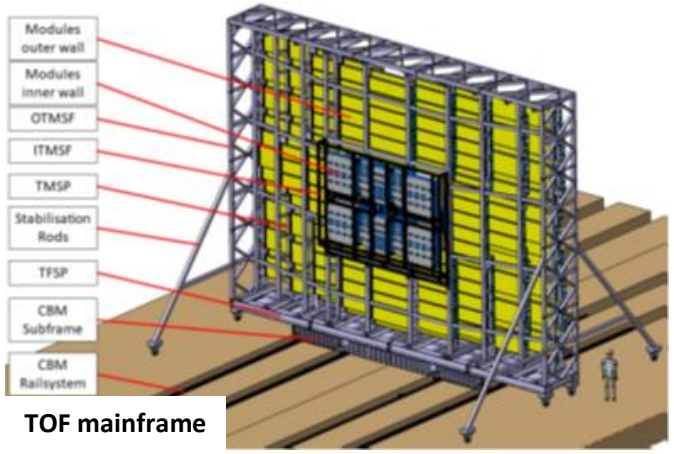


RICH/MUCH Mechanics

Transition Radiation Detector (TRD)



Time-of-Flight (ToF) Wall



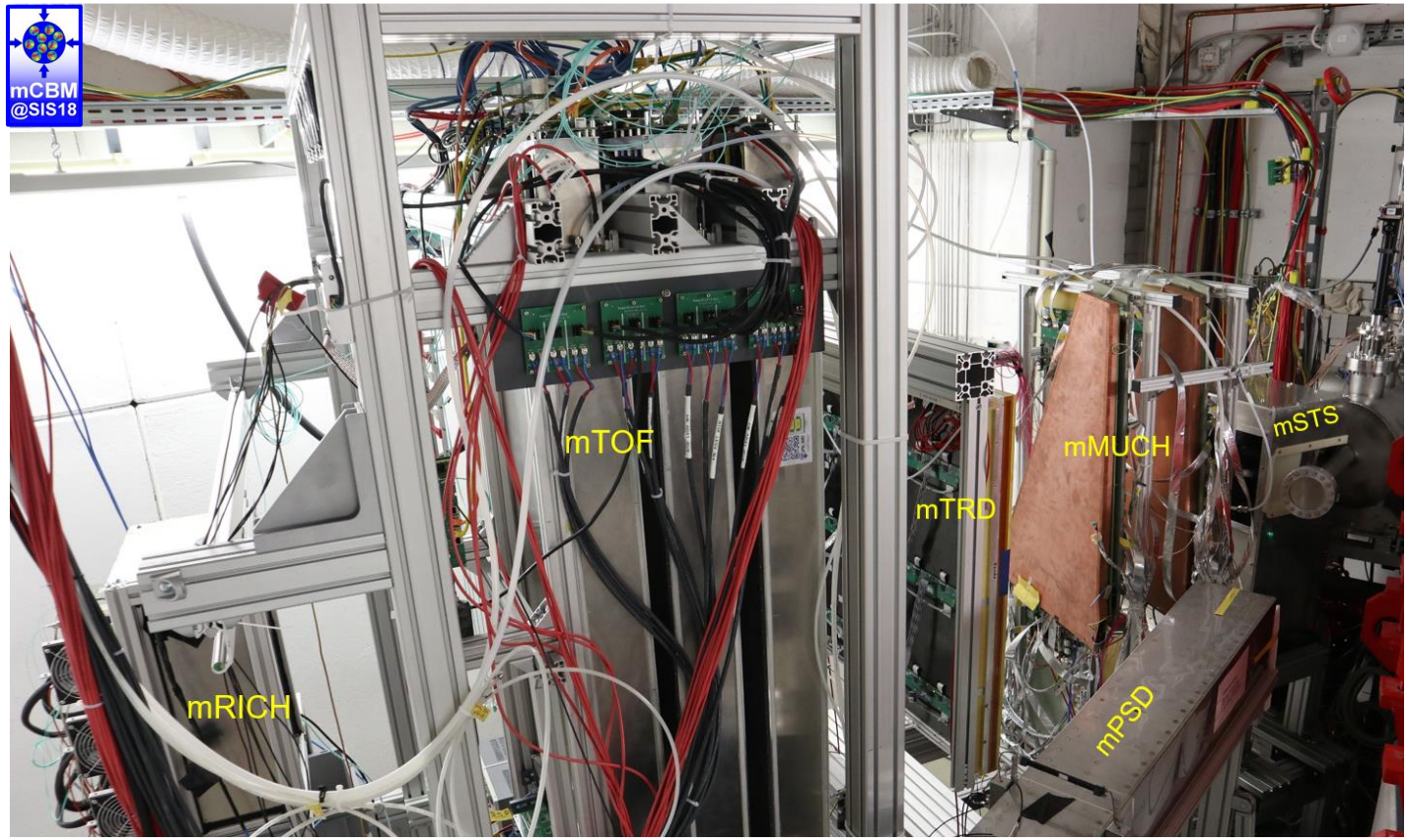
TOF mainframe

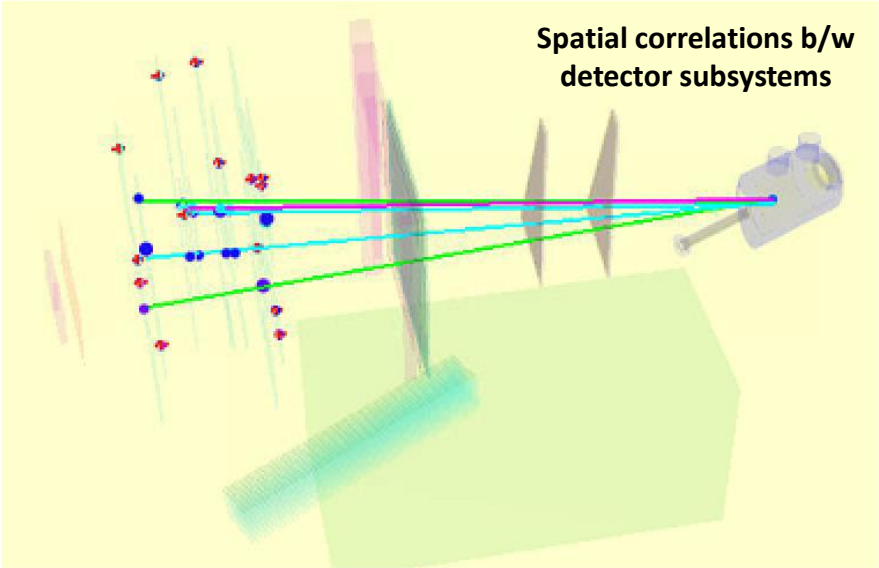
Projectile Spectator Detector (PSD)

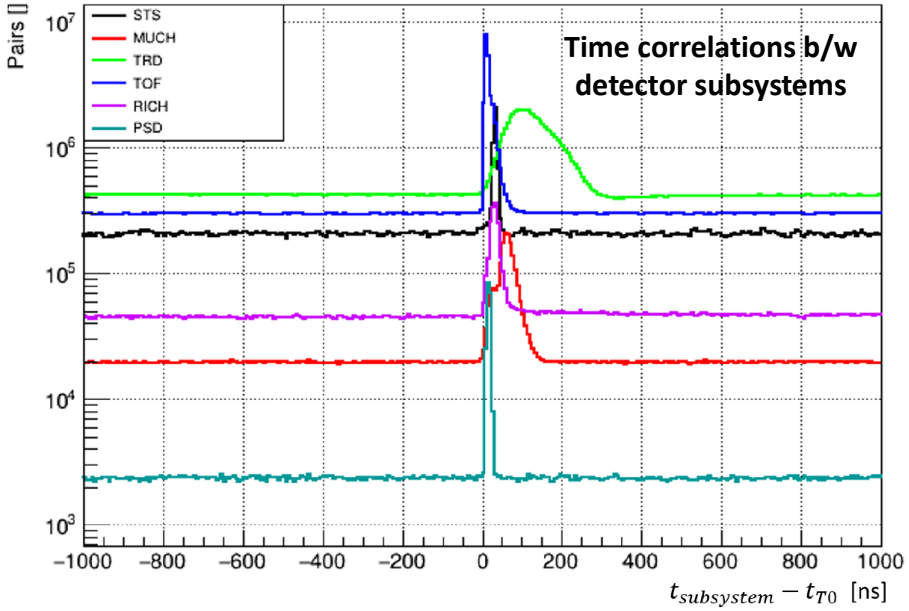
PSD support

mCBM @ SIS-18

D. Ramirez, 08.04.22, Poster Session 3 T15_2
E. Nandy, 08.04.22, Poster Session 3 T15_2
A. Weber, 08.04.22, Poster Session 3 T15/T16



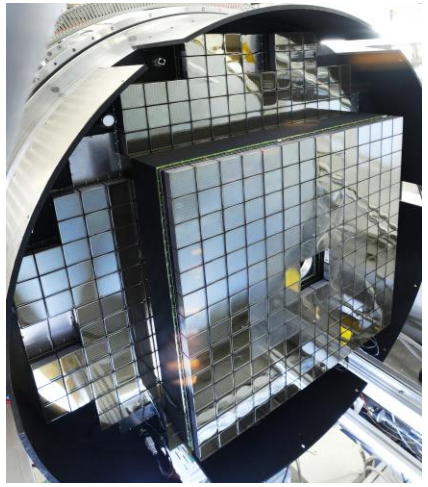


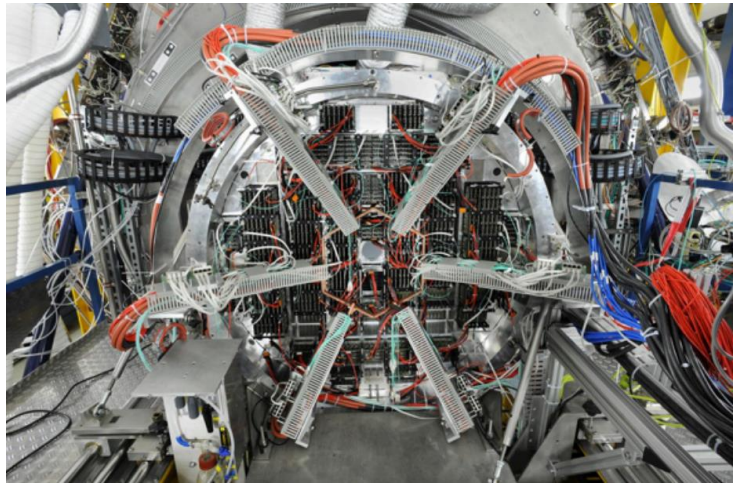


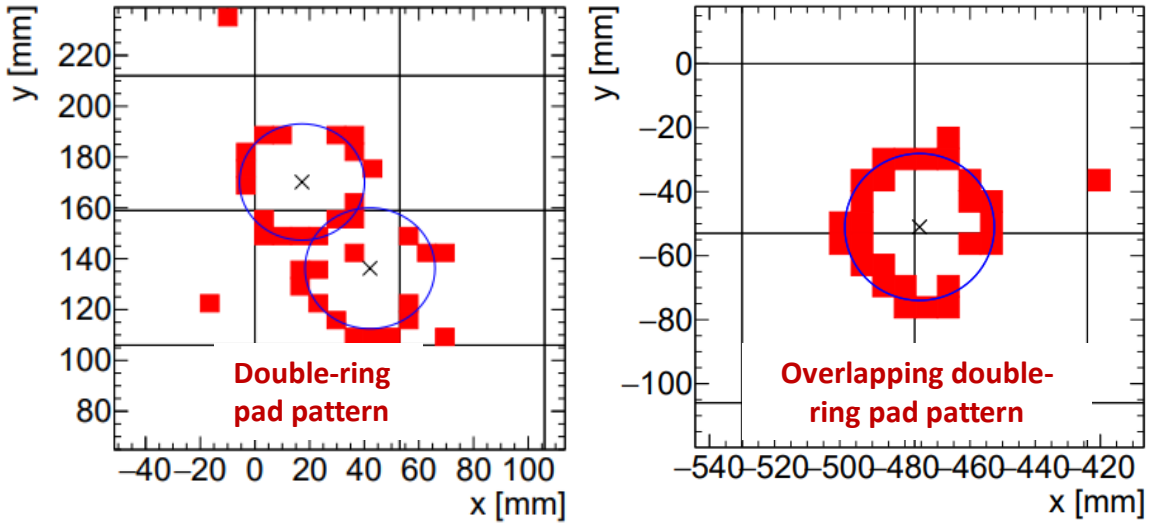
- **Conceptual verification of the triggerless-streaming read-out and data transport of CBM**
- **Detailed high-rate tests for validation of components' radiation tolerance**
- **Benchmark runs targeting Λ reconstruction in Au+Au collisions at 1.24 AGeV and Ni+Ni collisions at 1.93 AGeV in 2022**

CBM Contribution To FAIR Phase 0

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

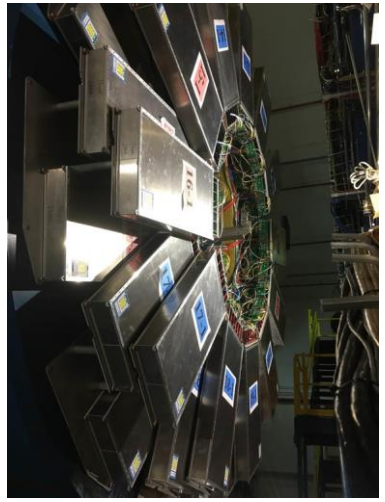


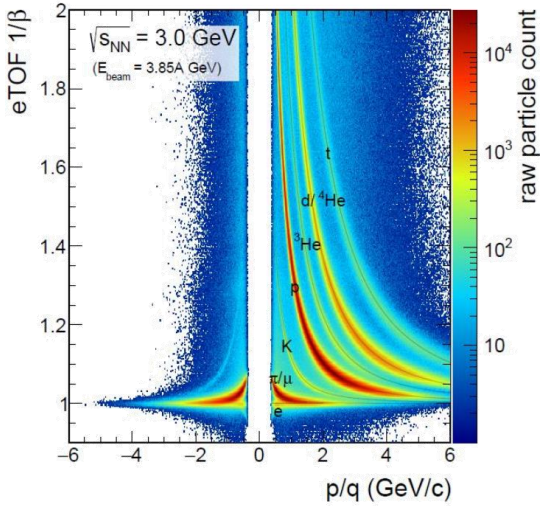


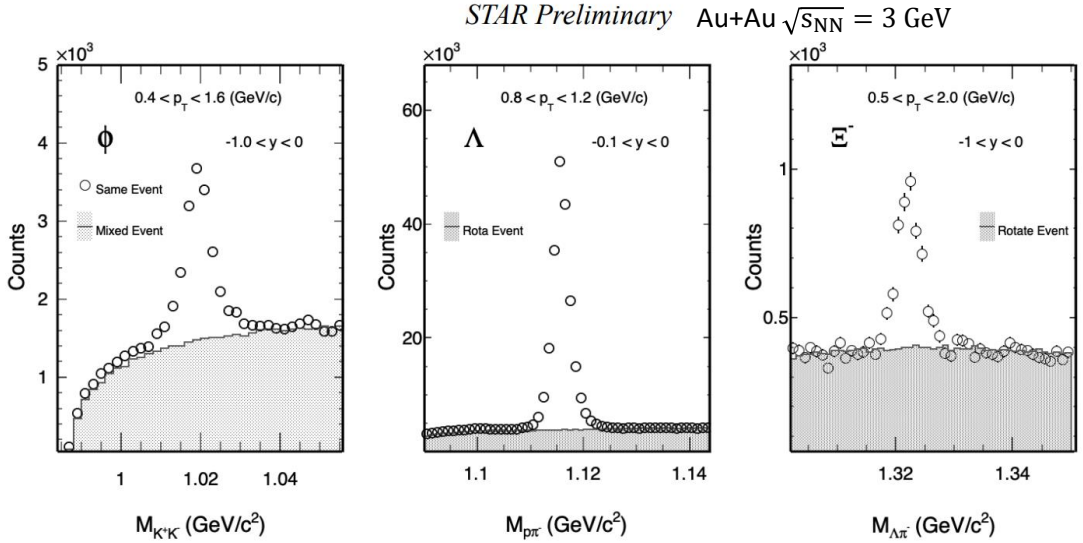


J. A-Musch et al., CBM Progress Report 2020

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







Guannan Xie, Strangeness in Quark Matter (2021)

Summary And Outlook

CBM@SIS-100 has significant discovery potential

- excitation function of hyperon production
- excitation function of di lepton production
- study of light hyper-nuclei

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)

- understanding of major components
- production of physics results with CBM devices

Consequence of the war in Ukraine and sanctions imposed on Russia are currently being evaluated

SUMMARY AND OUTLOOK

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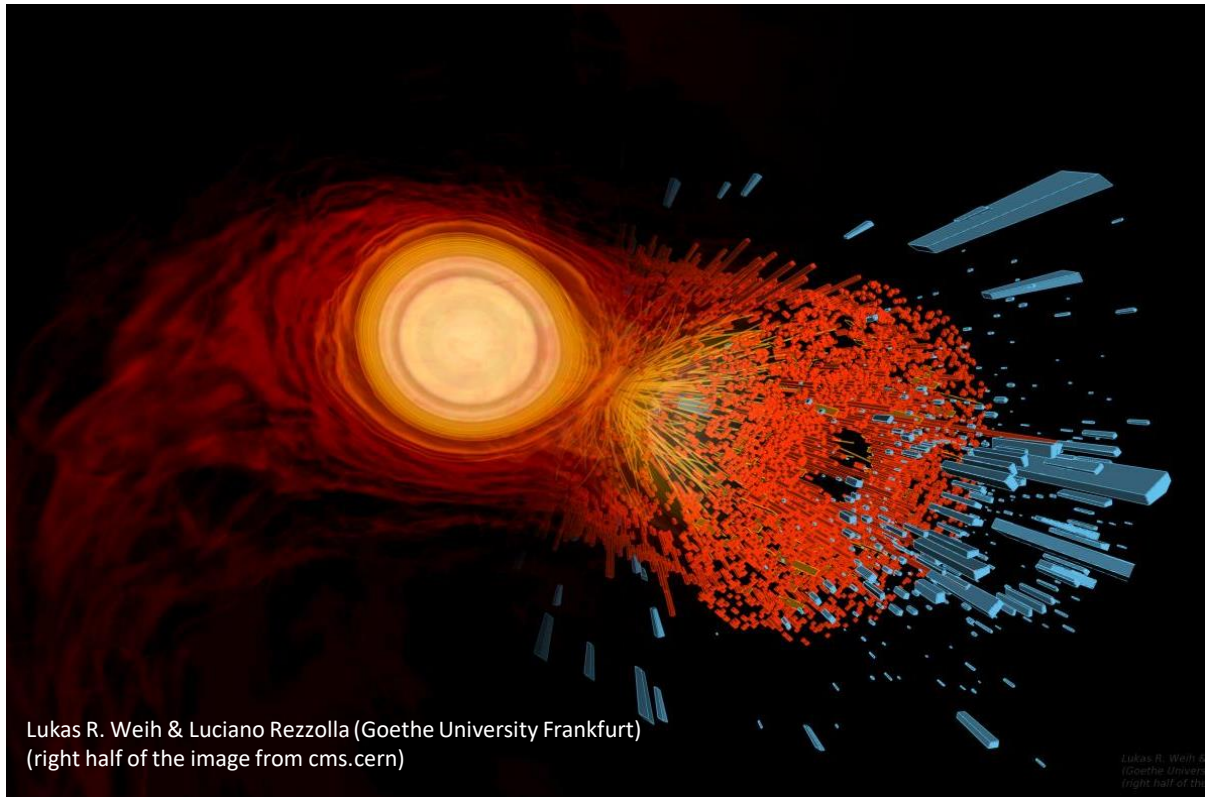


Lukas R. Weih & Luciano Rezzolla (Goethe University Frankfurt)
(right half of the image from cms.cern)

CBM@SIS-100 (2 – 11 AGeV Au-Au) 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

CBM Contributions At Quark Matter – 2022

Physics Working Groups

#466. CBM performance for anisotropic flow of charged hadrons and (multi)-strange hyperons in heavy-ion collisions, **O. Lubynets**, 06.04.22, Poster Session 1 T14_2

#506. Application of the Three-fluid Hydrodynamics-based Generator THESEUS in CBM at FAIR, **E. Volkova**, 06.04.22, Poster Session 1 T14_2

#573. Prospects of dilepton and charmonium measurements with CBM experiment, **S. Chatterjee**, 06.04.22, Poster Session 2 T13

#706. Performance studies of femtoscopy at CBM, **D. Wielanek**, 06.04.22, Poster Session 2 T07_1

#461. CBM performance for (multi-)strange hadron measurements using Machine Learning techniques, **S. Khan**, 08.04.22, Poster Session 3 T11_2

#503. Feasibility study of multiparticle correlations in flow analyses in CBM at FAIR, **A. Bilandzic**, 08.04.22, Poster Session 3 T15_1

#471. Perspectives on (multi-strange) hypernuclei physics with the CBM experiment at FAIR, **I. Vassilie**v, 08.04.22, Poster Session 3 T16

#966. Feasibility Studies of Di-Electron Spectroscopy with CBM at FAIR, **C. Feier-Riesen**, 08.04.22, Poster Session 3 T15/T16

Detector Working Groups and mCBM

#828. The powering scheme of the CBM Silicon Tracking System: concept and first implementations, **A. Lymanets**, 08.04.22, Poster Session 3 T15_2

#811. Performance of the mSTS detector in O+Ni collisions at 2 AGeV with the mCBM setup at SIS18, **D. Ramirez**, 08.04.22, Poster Session 3 T15_2

#454. Study of the material budget and data rates for the STS detector system of the CBM experiment, **M. Shiroya**, 08.04.22, Poster Session 3 T15_1

#451. Test and characterization of the final readout ASIC for the CBM Silicon Tracking System experiment, **O. Maragoto Rodriguez**, 08.04.22, Poster Session 3 T15_1

#691. Optimization of the calibration parameters for the font-end electronics of the Silicon Tracking System of the CBM experiment, **A. Rodriguez Rodriguez**, 08.04.22, Poster Session 3 T15_2

#689. Recent developments in the Silicon Tracking System of the CBM experiment towards starting system assembly, **A. Rodriguez Rodriguez**, 08.04.22, Poster Session 3 T15_2

#650. Solutions for humidity and temperature monitoring in the Silicon Tracking System of the CBM experiment: Sensors, Testing and DCS integration, **M. Bajdel**, 08.04.22, Poster Session 3 T15_2

#622. Performance study of CBM Muon Chamber detectors at the mCBM setup of SIS18 with Pb+Au collisions at 1.06 AGeV, **E. Nandy**, 08.04.22, Poster Session 3 T15_2

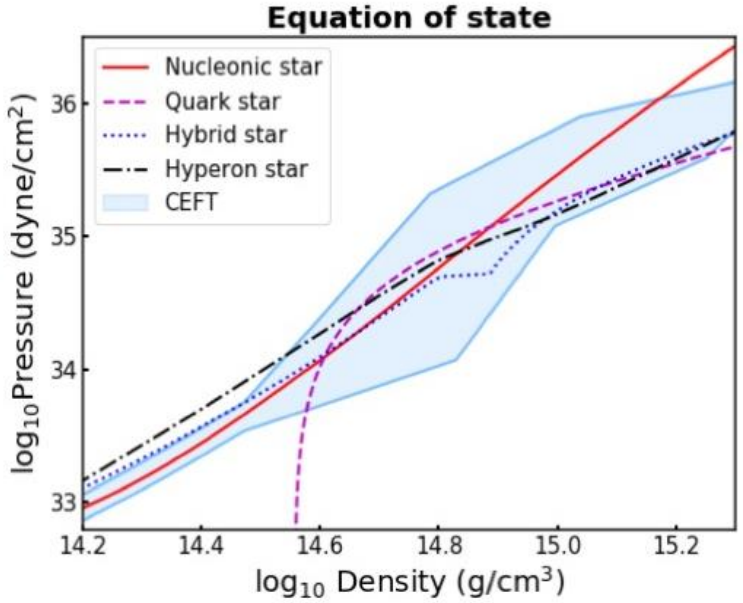
#900. The mCBM experiment at SIS18 of GSI/FAIR - a CBM precursor and demonstrator, **A. Weber**, 08.04.22, Poster Session 3 T15/T16

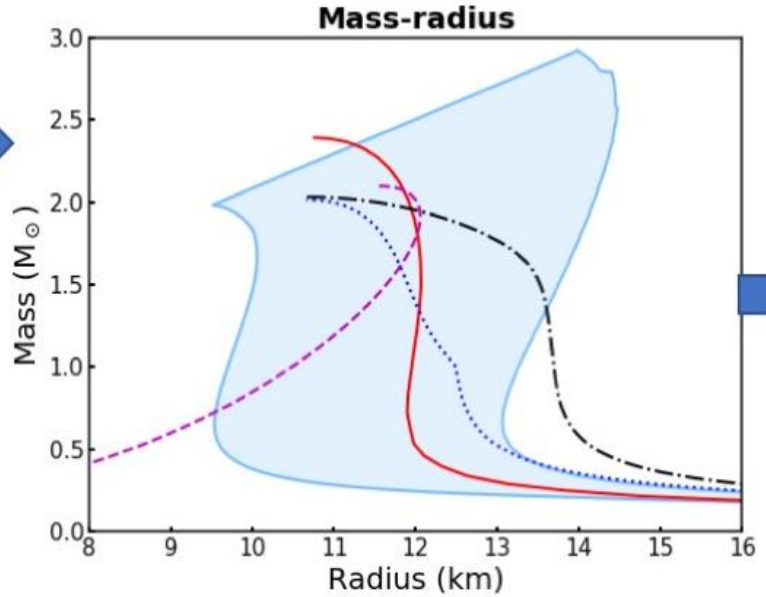
THANK YOU

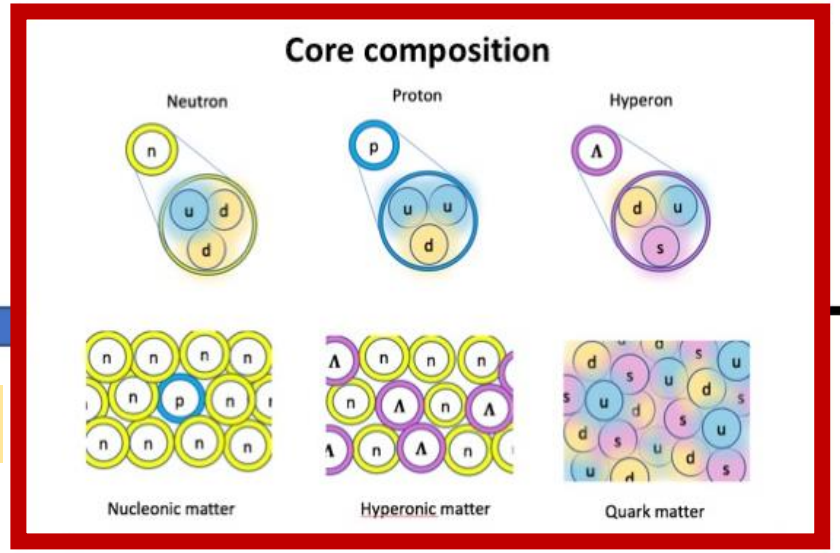
HELMHOLTZ GEMEINSCHAFT · GSI · FAIR · HFHF · ESCAPE · STRONG 2020 · Bundesministerium für Bildung und Forschung · Ministry of Science and Higher Education Republic of Poland · MINISTRY OF EDUCATION YOUTH AND SPORTS · MINISTERUL EDUCATIEI · GOVERNMENT OF INDIA · MINISTRY OF SCIENCE AND TECHNOLOGY · DST · DEPARTMENT OF SCIENCE & TECHNOLOGY

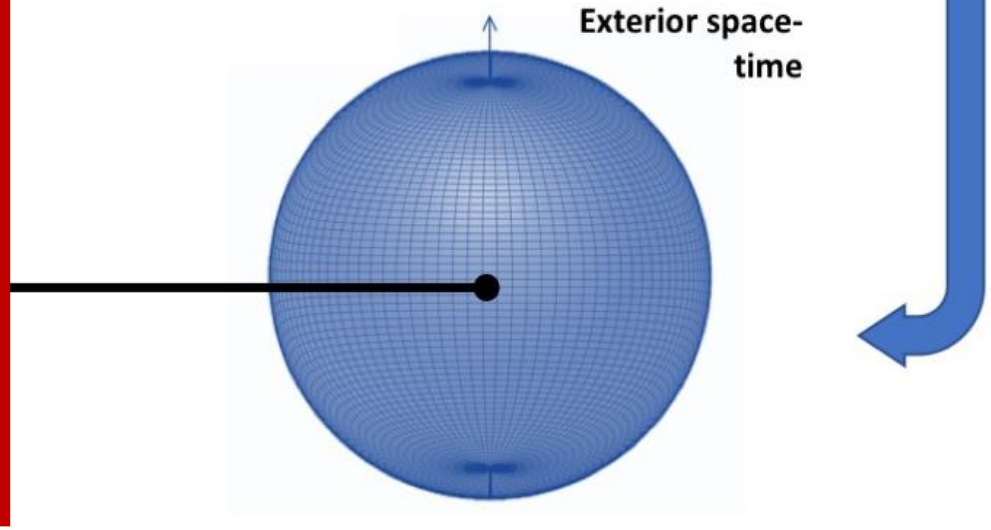
Physics Case 1: Equation Of State And Neutron Star Properties

P. Ray et al., STROBE-X: X-ray Timing and Spectroscopy on Dynamical Timescales from Microseconds to Years, arXiv:1903.03035









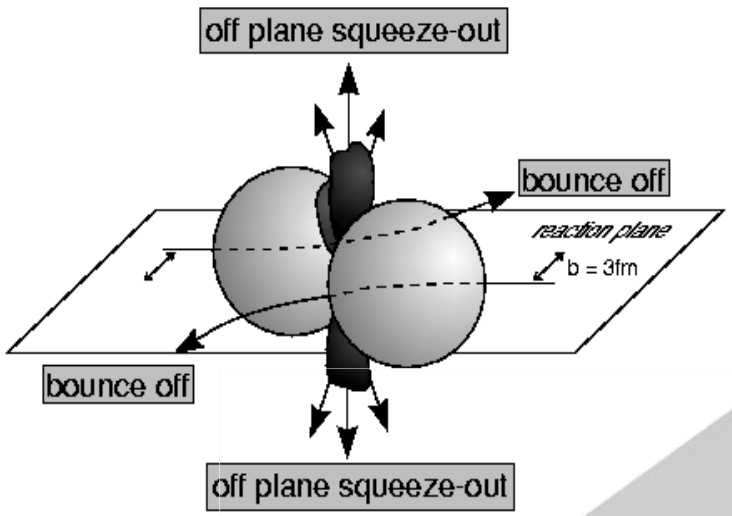
Heavy-Ion Collisions

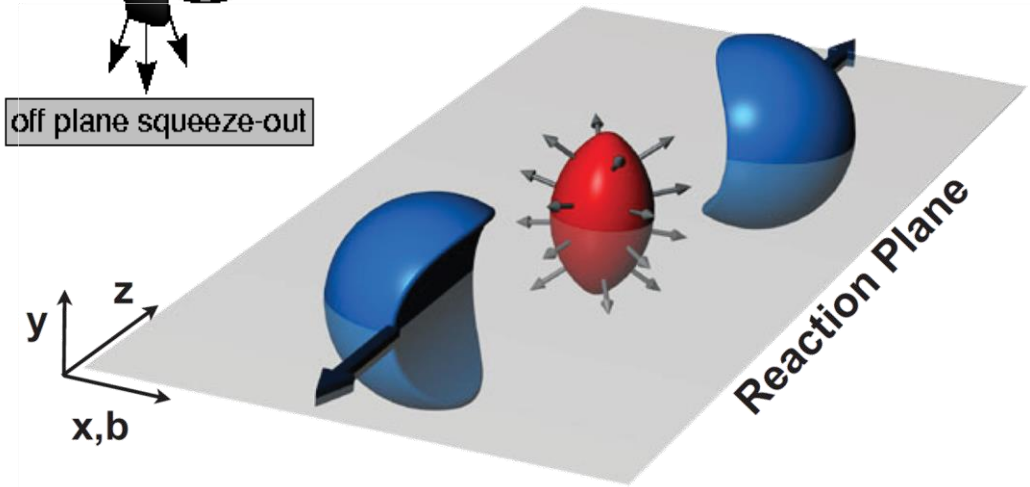
Physics Case 1: Equation Of State And Neutron Star Properties

ANISOTRPIC FLOW

Nucelar EoS ∝ '(In)Compressibility' of the nuclei ∝ 'Flow' direction of participants and spectators

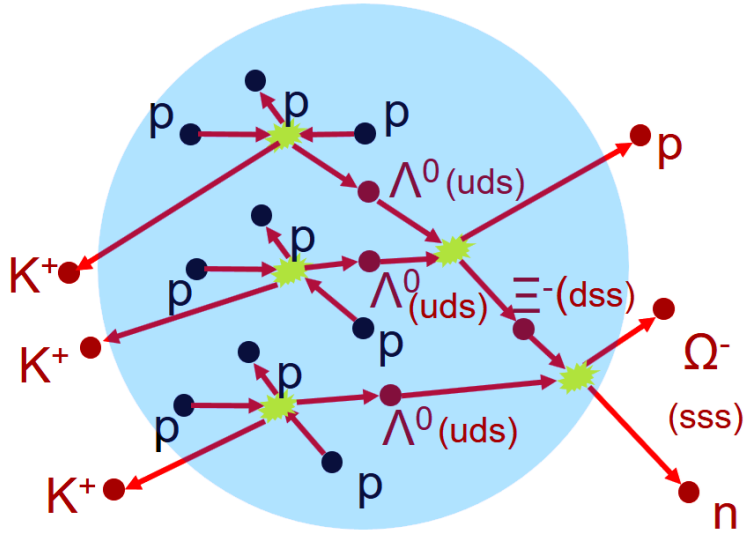
$$\frac{dN}{d\phi} \propto 1 + (2 \cdot v_1 \cdot \cos\phi) + (2 \cdot v_2 \cdot \cos 2\phi) + \cdots$$

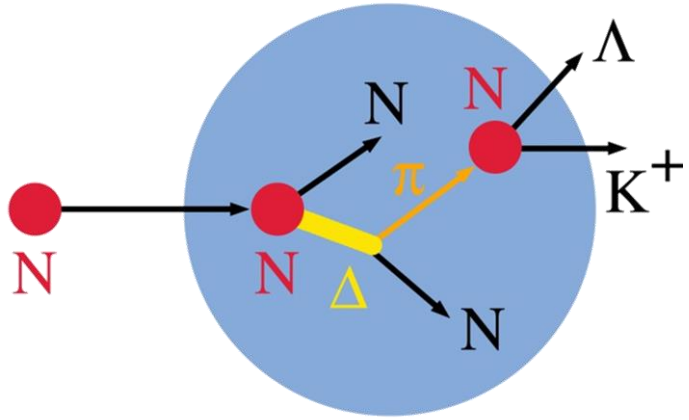


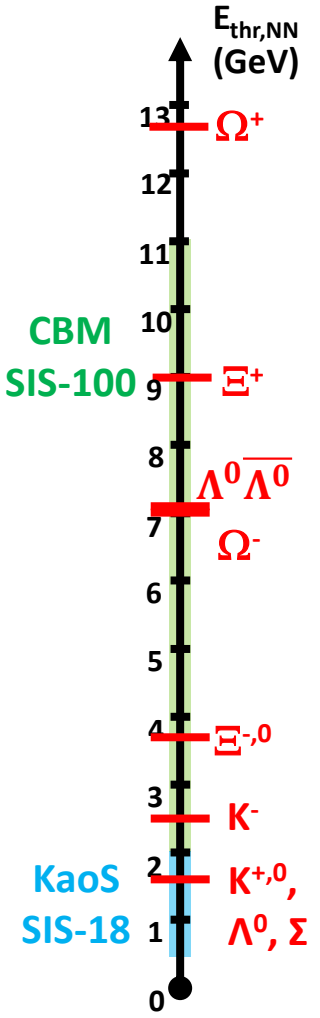


SUB-THRESHOLD STRANGENESS PRODUCTION

Nucelar EoS ∝ '(In)Compressibility' of the nuclei ∝ Density ∝ Strangeness Yield

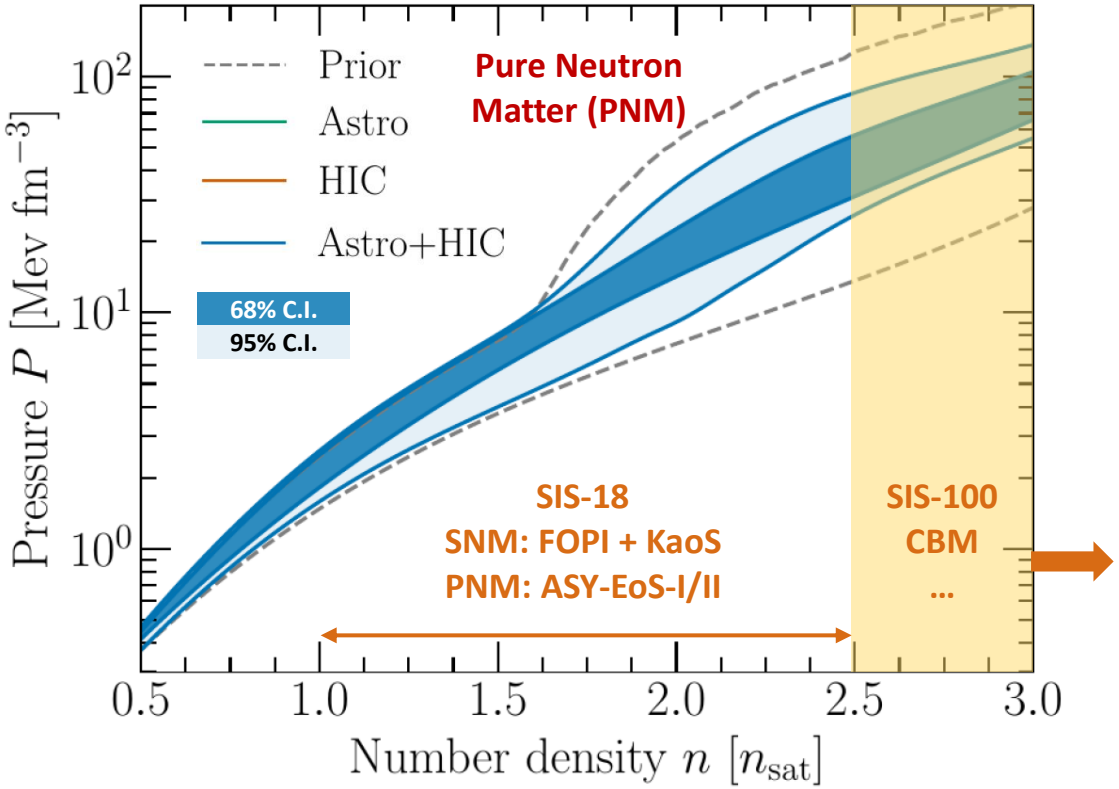


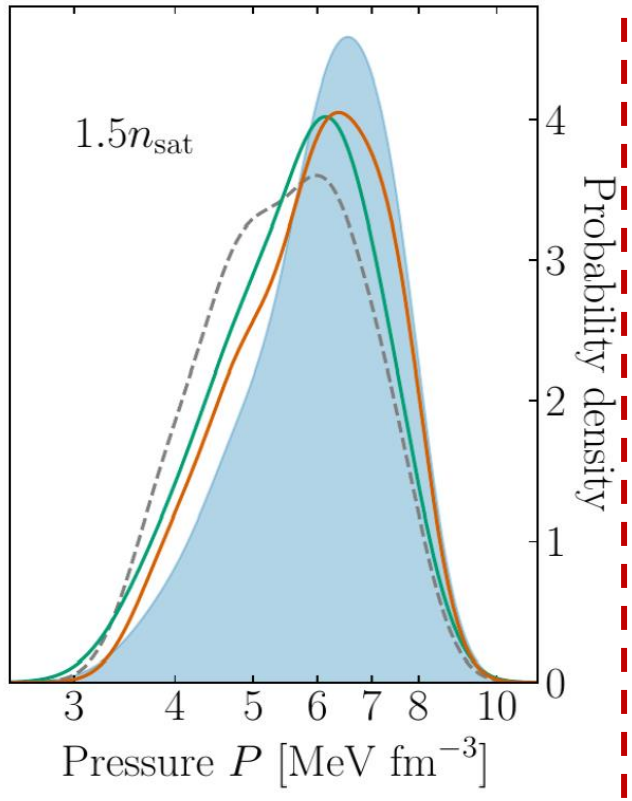


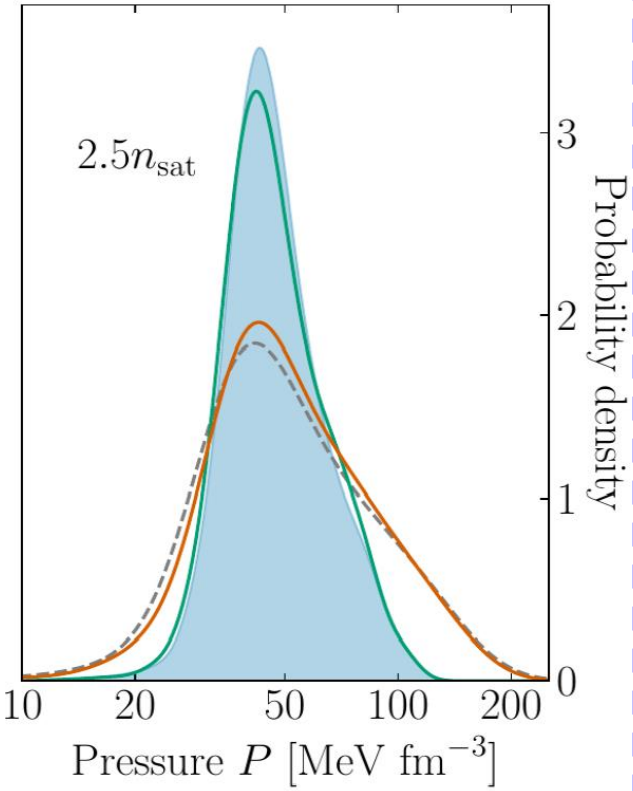


Physics Case 1: Equation Of State And Neutron Star Properties

S. Huth, P.T.H. Pang et al., arXiv:2107.06229 [nucl-th]







FOPI: Nucl. Phys. A 945, 112 (2016)
AGS, BEVALAC: Science 298, 1592 (2002)
KaoS: Phys. Rev. Lett. 86, 39 (2001)
J. Phys. G 28, 1615 (2002)
ASY-EOS-I: Phys. Rev. C 94, 034608 (2016)
SπRIT: Phys. Rev. Lett. 126, 162701 (2021)

CBM, with its capability with observables like particle flow and sub-threshold particle production, is in pole position to push our understanding of SNM and PNM at higher densities, thereby enhancing HIC's compatibility with astrophysical observations

HIC PRESENT (@SIS-18)

- **HIC constraints the EoS only where its sensitivity is highest ($\sim 1.5 n_{sat}$), where it favours stiffer EoS**
- **Constraints are consistent between HIC and astro**

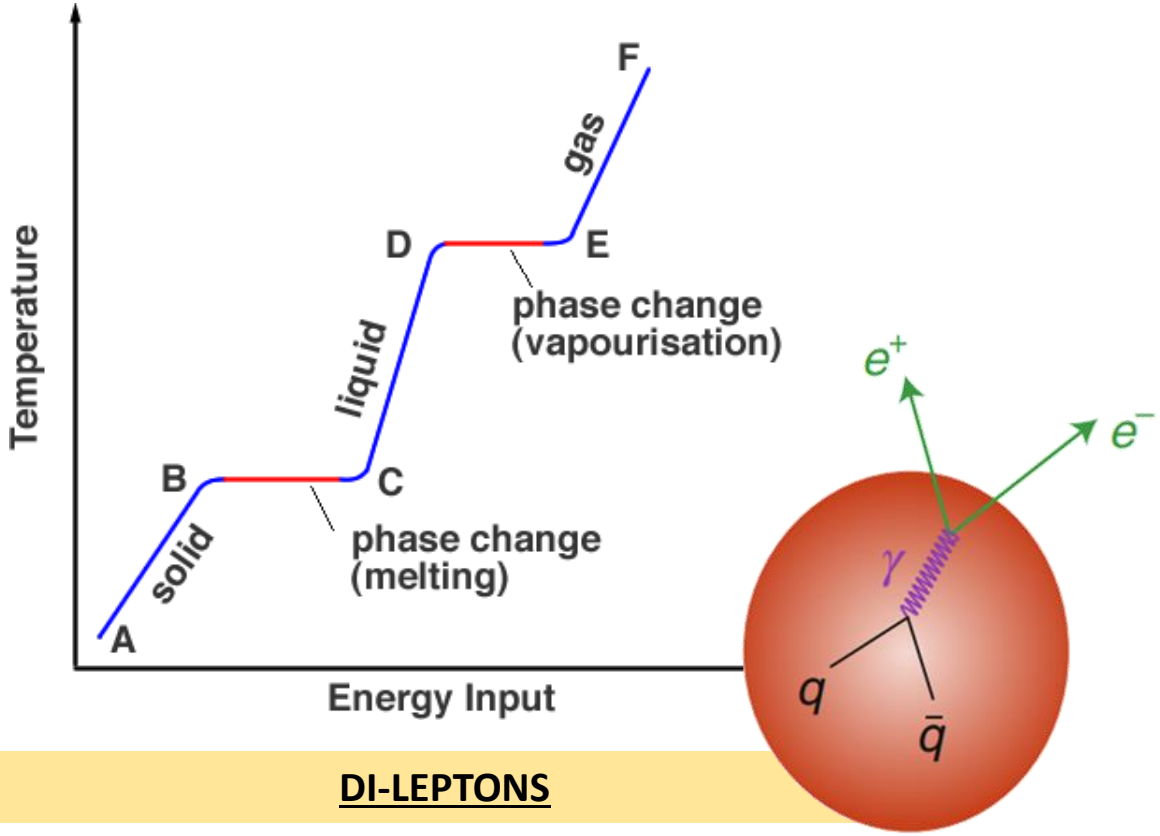
HIC FUTURE (@SIS-18, SIS-100, …)

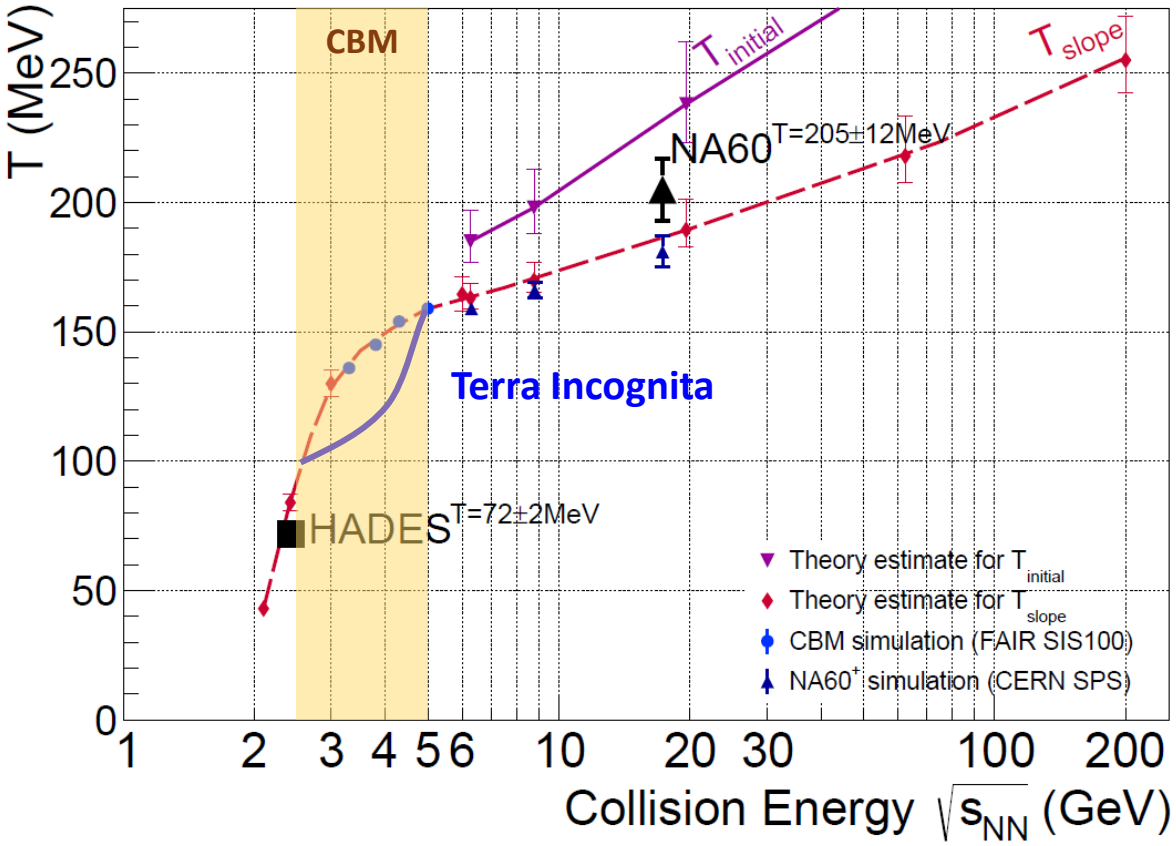
- **Higher density constraints are currently driven by Astro (which are limited in statistics)**
- **HIC has the potential to limit the constraints at higher densities**

Physics Case 2: Caloric Curve And Deconfinement

Image - http://www.splung.com/content/sid/6/page/latentheat
Liquid-Gas Phase Transition - [ALADIN] Phys. Rev. Lett. 75 (1995) 1040

Non-monotonous behaviour of the caloric curve potentially signals phase transition





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

Ralf Rapp, Nature Physics,
Volume 15, pg. 990–991 (2019)

DI-LEPTONS

Dileptons, being electromagnetic probes, act as a thermometer of the strong-interacting fireball medium

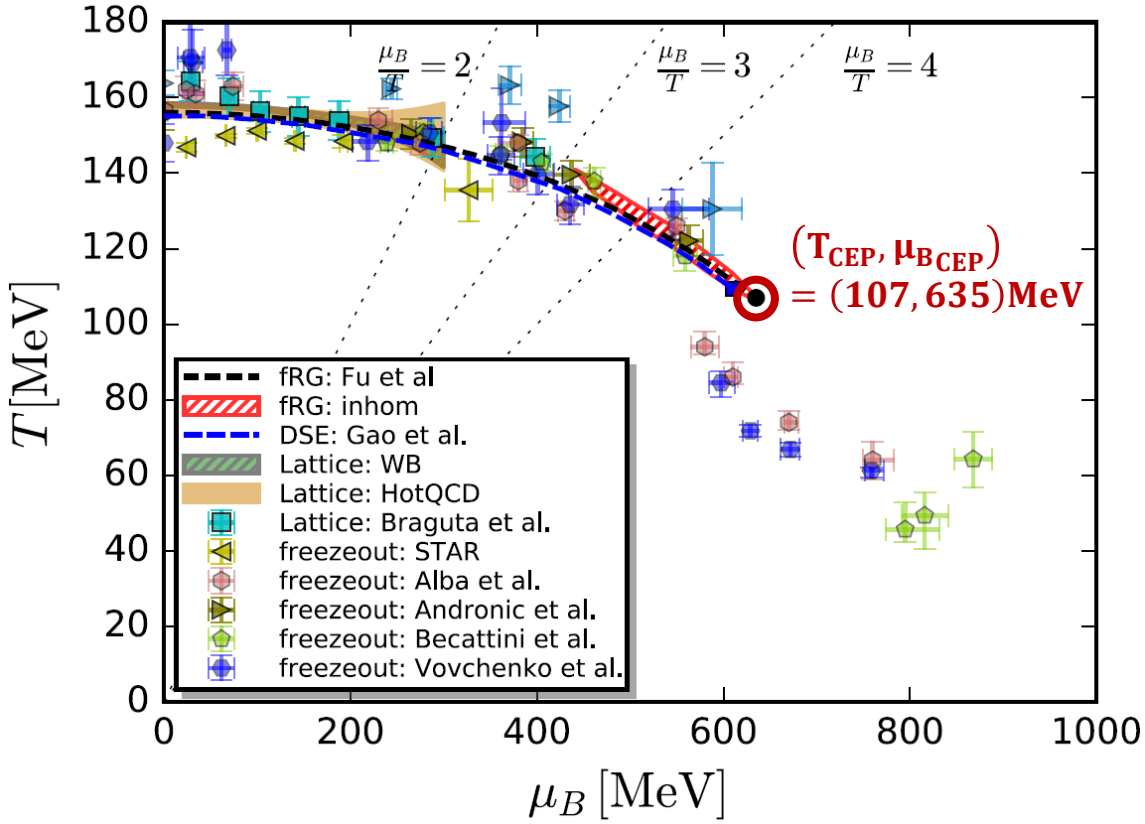
$$\frac{dN}{dM} \sim M^{3/2} \cdot \exp\left(-\frac{M}{T_S}\right)$$

Simplification of McLerran - Toimela formula,
Phys. Rev. D 31 (1985) 545

CBM will be the first experiment to use di-leptons for systematic measurements in both production channels (e^+e^- and $\mu^+\mu^-$) in the same coverage.

Physics Case 3: QCD Critical End Point

W.J. Fu, J.M. Pawlowski, F. Rennecke, Phys. Rev. D 101, 054032 (2020)

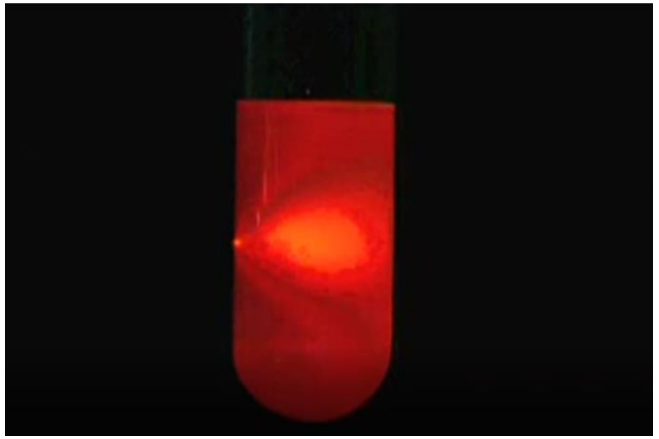


- **Based on the recent fRG and L-QCD results, there are no signs of criticality for $\mu_B/T \lesssim 4$**
- **Most promising range for finding the Critical End Point (CEP): $(135, 450)\text{MeV} \lesssim (T_{CEP}, \mu_{B_{CEP}}) \lesssim (100, 650)\text{MeV}$**

F. Karsch, arXiv:1905.03936
F. Karsch, RHIC Beam Energy Scan and Beyond 2021
A. Lahiri, LATTICE 2021
J.M. Pawlowski, CPOD 2021

EVENT-BY-EVENT FLUCTUATIONS

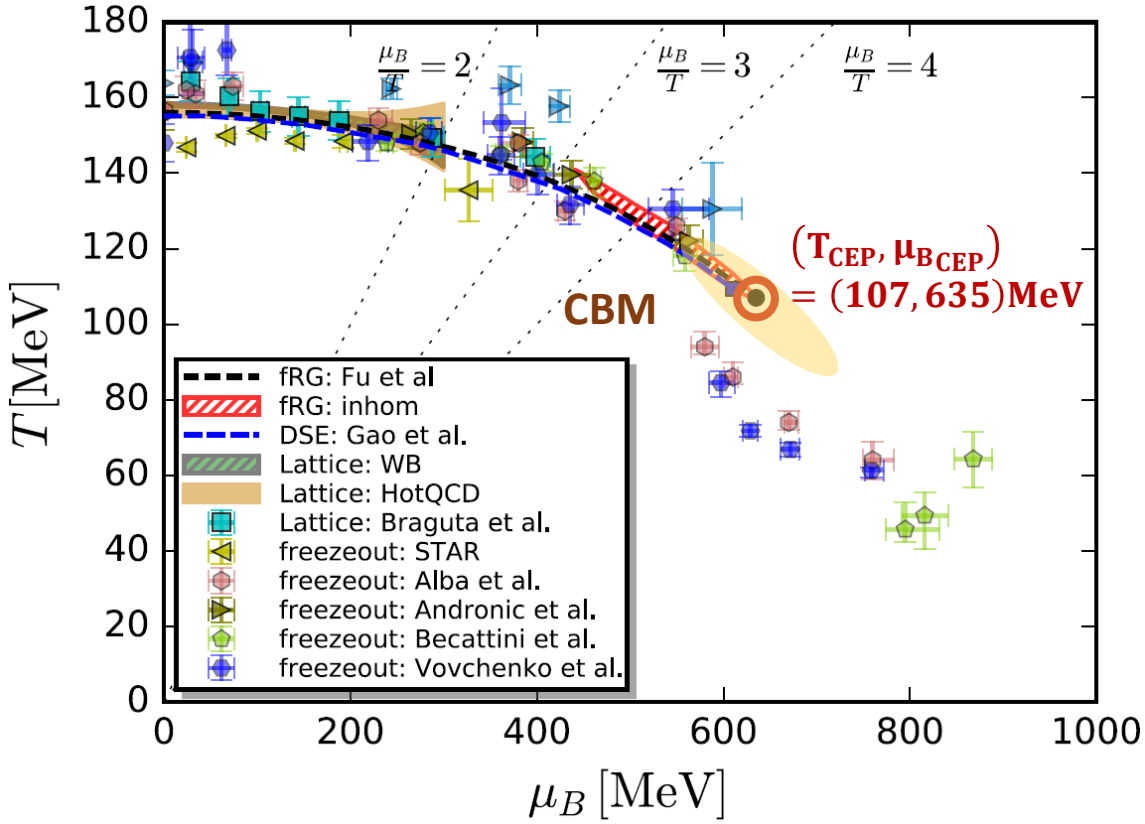
$T \neq T_{CEP}$



$T \approx T_{CEP}$

A vial containing a mixture of cyclohexane and aniline cooling from 35°C, has been filmed perpendicular to the direction of the laser light (left to right) - https://www.doitpoms.ac.uk/vidlib/full_record.php?id=58

Physics Case 3: QCD Critical End Point



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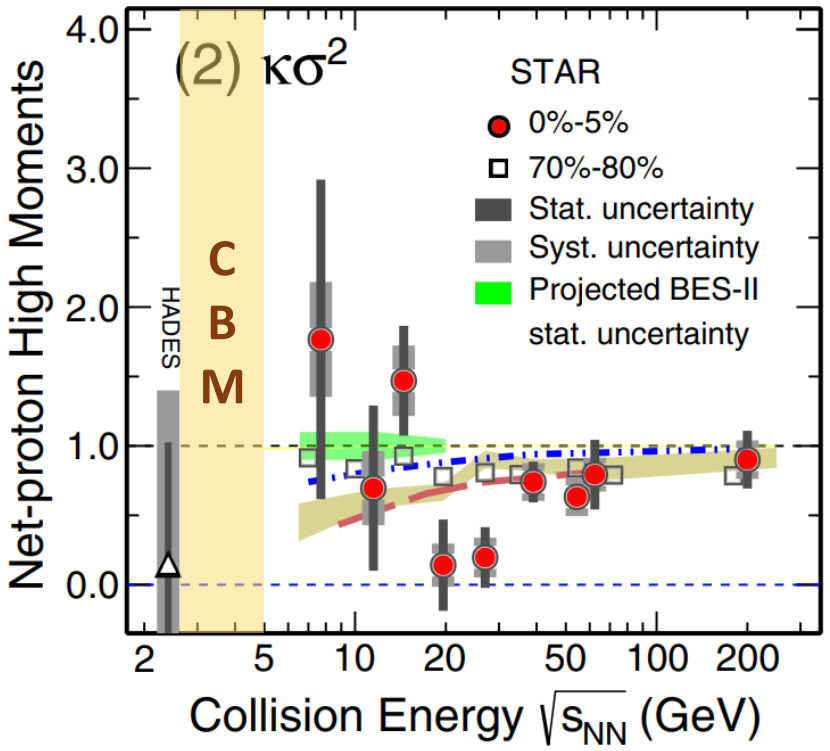
F. Karsch, RHIC Beam Energy Scan and Beyond 2021
A. Lahiri, LATTICE 2021
J.M. Pawlowski, CPOD 2021

EVENT-BY-EVENT FLUCTUATIONS

- **Higher-order cumulants and ratios of conserved quantities (B, Q, S) are sensitive to QCD CEP**

M.A. Stephanov, Phys. Rev. Lett. 102 032301 (2011)
J.W. Chen et al., Phys. Rev. D 95, 014038 (2017)



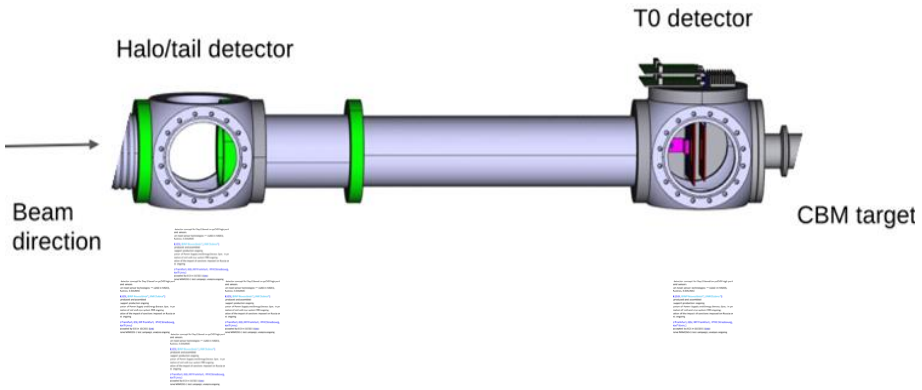
[STAR] Phys. Rev. Lett. 126, 092 (2021)
[STAR] arXiv:2101.12413 [nucl-ex]
[HADES] Phys. Rev. C 102, 024914 (2020)

CBM can systematically study the higher-order cumulants and ratios to contribute significantly to the search of QCD-CEP

Recent Achievements In Detector Projects – [I]

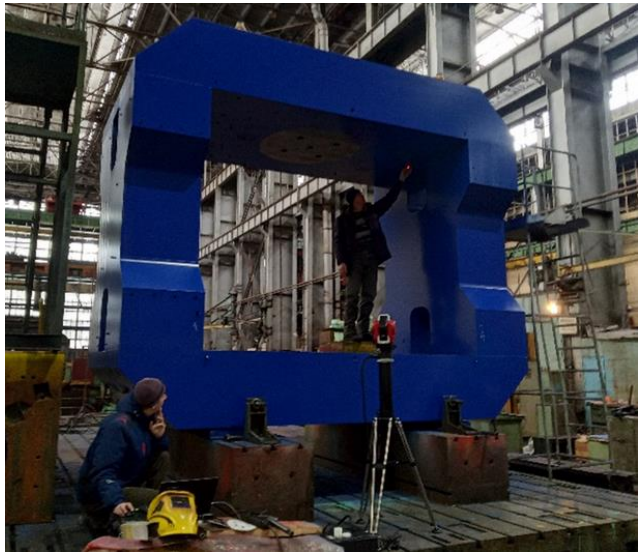
BMON (GSI, TU Darmstadt)

- BMON detector concept for CBM Day 1: two stations for HALO and T0 measurement
- Start detector concept for Day-1 based on pcCVD high purity diamond sensors
- R&D on novel sensor technologies → LGAD in HADES, MedAustron, S-DALINAC



Magnet (GSI, BINP Novosibirsk*, JINR Dubna*)

- Yoke produced and assembled
- Yoke support production ongoing
- Production of Power Supply and Energy Extract. Syst. in progress
- Finalization of coil and cryo system FDR ongoing
- Evaluation of the impact of sanctions imposed on Russia on the project ongoing



MVD (U Frankfurt, GSI, IKF Frankfurt, IPHC Strasbourg, Pusan Nat'l Univ.)

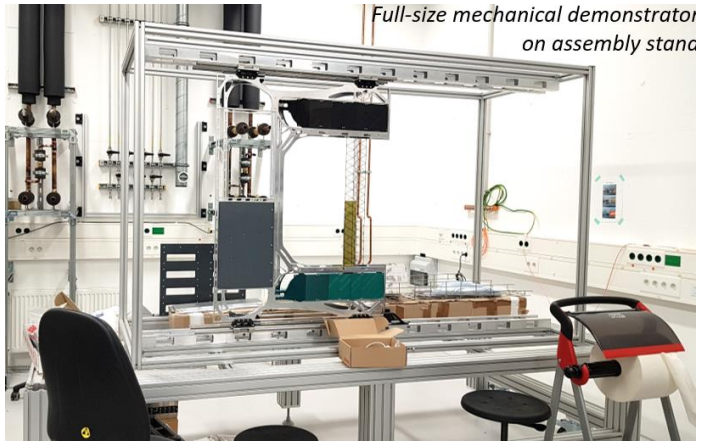
- TDR accepted by ECE in 10/2021 (link)
- Extensive MIMOSIS-1 test campaign; analysis ongoing
- MIMOSIS-2 submission (PRR in January 2022)

* Collaboration suspended

Recent Achievements In Detector Projects – [II]

STS (GSI Darmstadt, JINR Dubna*, KIT Karlsruhe, JU Cracow, AGH Cracow, KINR Kiev, Univ. Tübingen, Warsaw UT)

- Preparation of pre-series production and PRR
- STS Mechanics EDR successfully concluded
- STS-XYTER v2.2 series production, order placed through AGH
- FEB pilot production for module/ladder pre-production



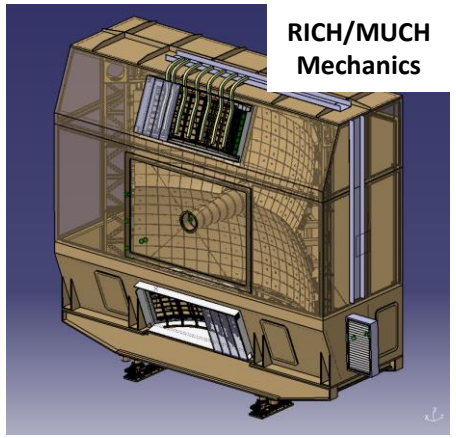
MUCH (Aligarh Muslim Univ., Bose Inst. Kolkata, Panjab Univ., Univ. of Jammu. , Univ. of Kashmir, Univ. of Calcutta, B.H. Univ. Varanasi, VECC Kolkata, IOP Bhubaneswar, NISER Bhubaneswar, IIT Kharagpur, IIT Indore, Guwahati Univ., PNPI Gatchina*)

- Built and tested the first GEM chamber for the 2nd station of MuCh
- Assembled and tested the real size RPC for the 3rd station of MuCh
- First HV supply crate assembled at VECC and tested with GEM
- CDR completed: MuCh gas system, GEM chambers, chamber mechanics

MUCH GEM at GIF++ (Nov.21)

RICH (Univ. Giessen, Univ. Wuppertal, PNPI Gatchina*, GSI Darmstadt)

- Mechanical design close to final
- Readout electronics – first of series available
- DIRICH frontend module tested up to 300 kHz/pixel (CBM full rate), no performance issues
- RICH photon camera design finalized, Mirror PRR in April ‘22



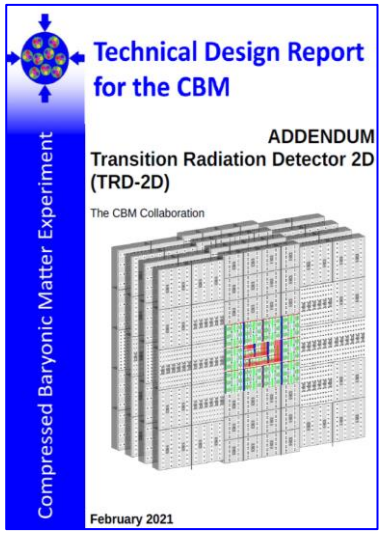
RICH/MUCH Mechanics

* Collaboration suspended

Recent Achievements In Detector Projects – [III]

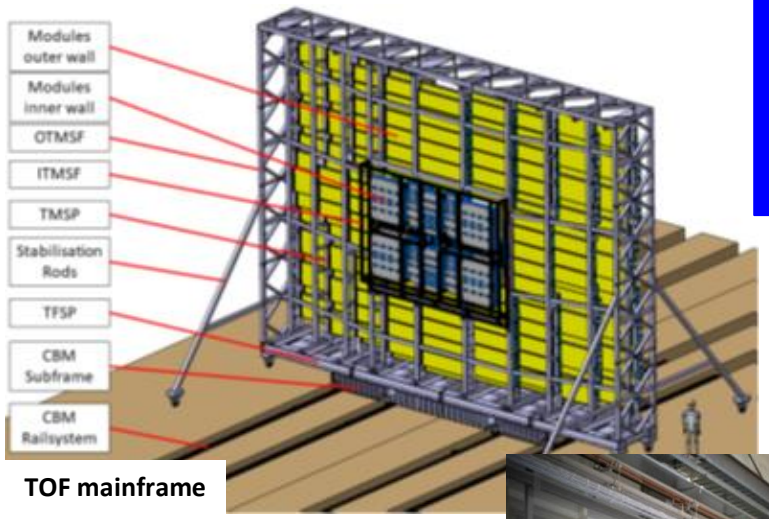
TRD (NIPNE Bucharest, Univ. Frankfurt, Univ. Heidelberg, Univ. Münster, IRI Frankfurt)

- Addendum to TRD TDR for TRD2D submitted to ECE
- Successful CRI-based data taking with SPADIC and FASP based readout
- Tests of SPADIC 2.3a/b continue, toward final submission of SPADIC 2.4



TOF (THU Beijing, NIPNE Bucharest, GSI Darmstadt, TU Darmstadt, USTC Hefei, Univ. Heidelberg, ITEP Moscow*, HZDR Rossendorf, CCNU Wuhan)

- Mitigation for observed aging ongoing, several sealed counter constructed for mCBM high rate running 2022
- FEE PRR in April '22
- Main frame CDR passed
- Gas system under development



TOF mainframe

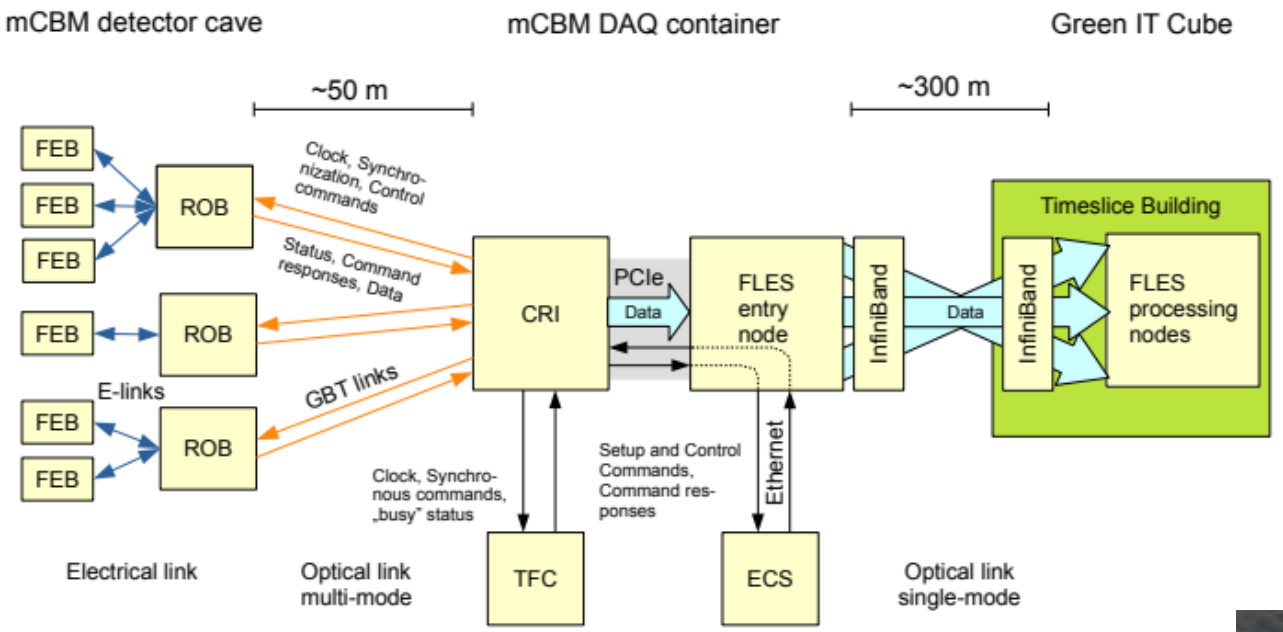
PSD (INR Moscow*, TU Darmstadt, CTU Prague, NPI Rez)

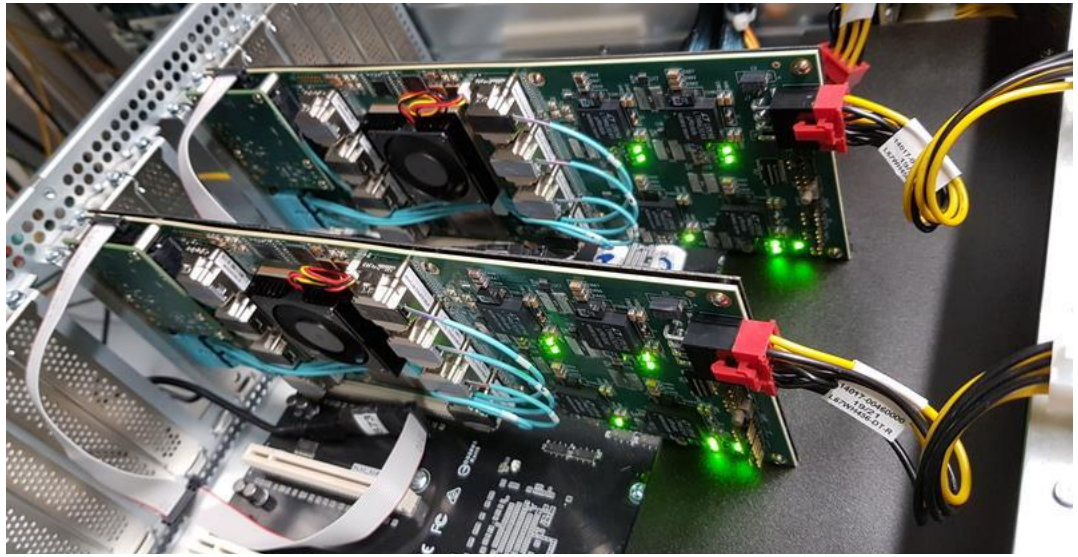
- All modules produced; upper support structure arrived at FAIR in 09.2020
- Commissioning of the FHCal at the BM@N during SRC run at the BM@N – Feb. 2022.
- Start of ordering and purchase of the PSD FEE and readout electronics, PRR concluded in Dec. 2022

PSD support SAT

* Collaboration suspended

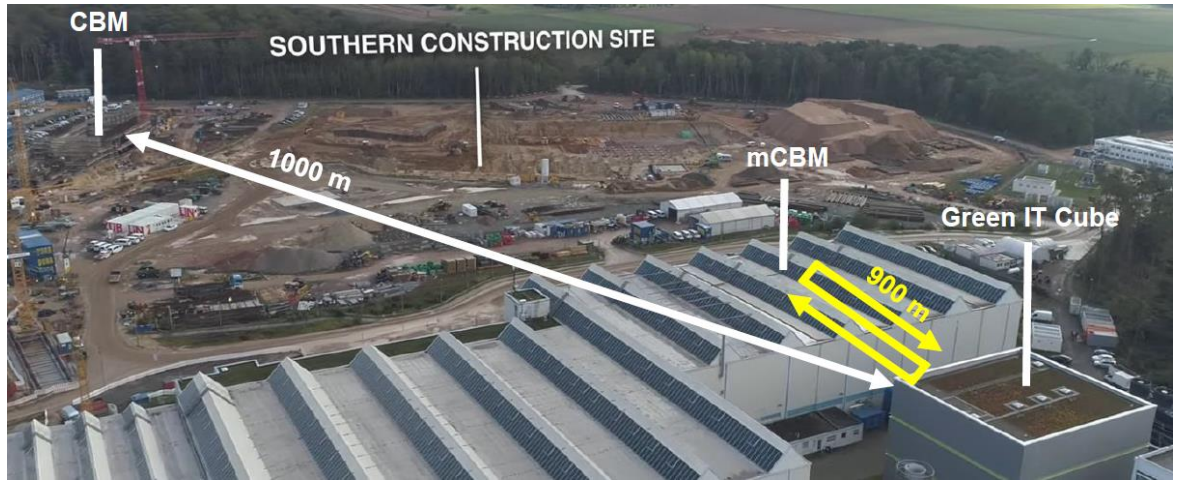
CBM-DAQ & mCBM@SIS-18





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

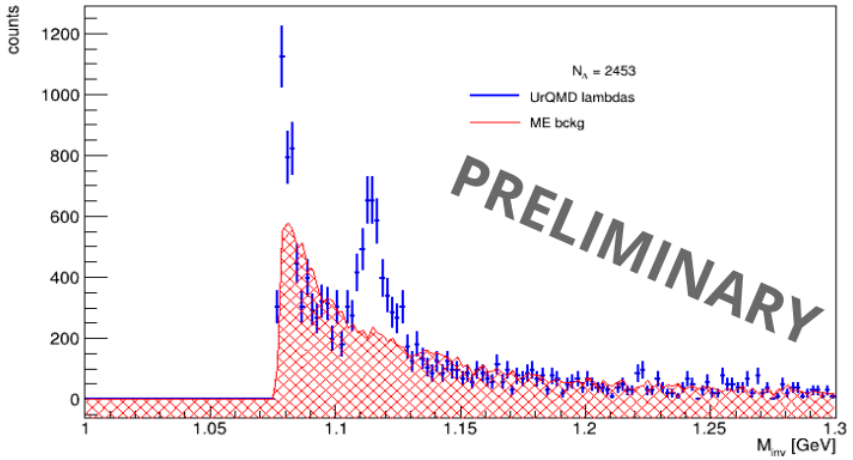
- DAQ nowadays utilizes common readout interface (CRI)
  - Dedicated FPGA board that connects the custom front end electronics to the commercial servers of the entry node
- Each detectors uses several CRI boards for its DAQ
- Entry nodes already connect to GreenCube
  - Timeslice building on FLES processing nodes
- mCBM readout chain is already small scale of future CBM readout



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

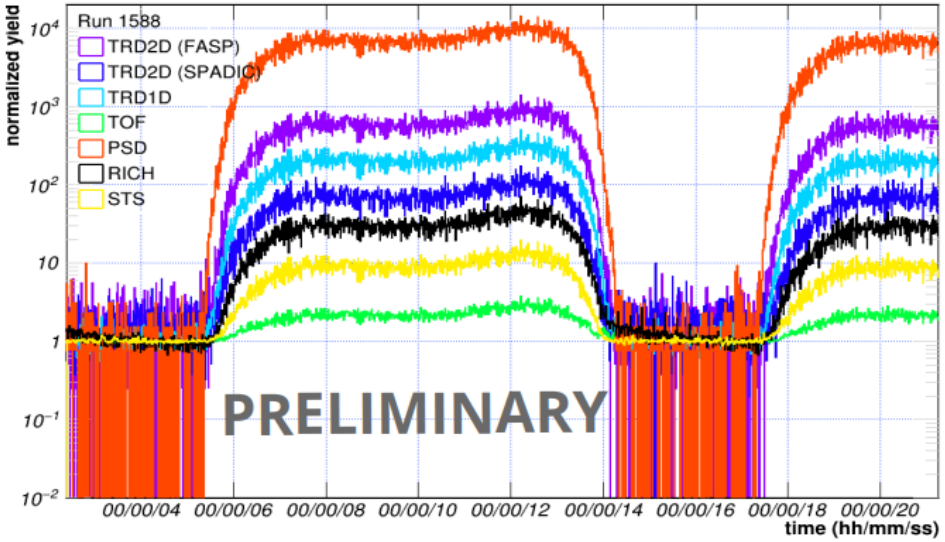
First Result With mCBM@SIS-18

- Aim of benchmark runs in 2022: Reconstruct Lambdas without magnetic field
- Reconstruction based on topology cuts
- Ni+Ni @ 1.93 AGeV is benchmark measurement with FOPI data as reference
  - Full lambda reconstruction without tracking and magnetic fields



Simulated reconstructed Lambdas for Ni+Ni @ 1.93AGeV

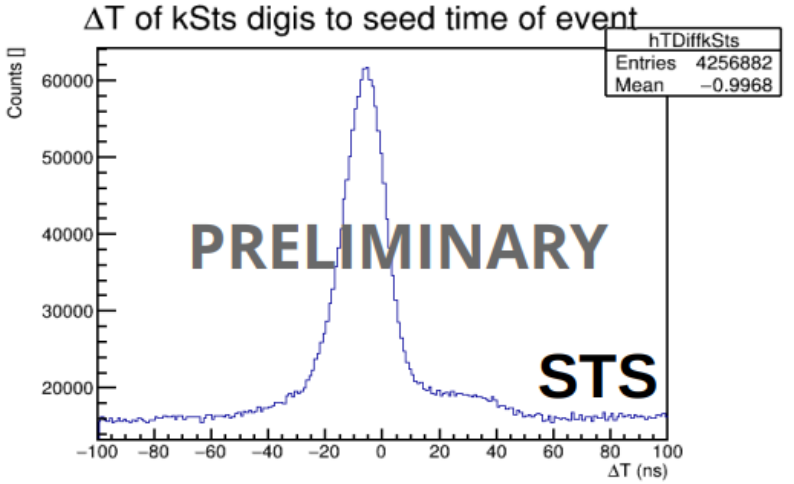
- Data yields in 10 ms intervals for all detectors taking part to the July 2021 mCBM campaign.
- Volumes of data for each system is in sync with the beam on/off structure
- Data correlation between ToF and all other systems.

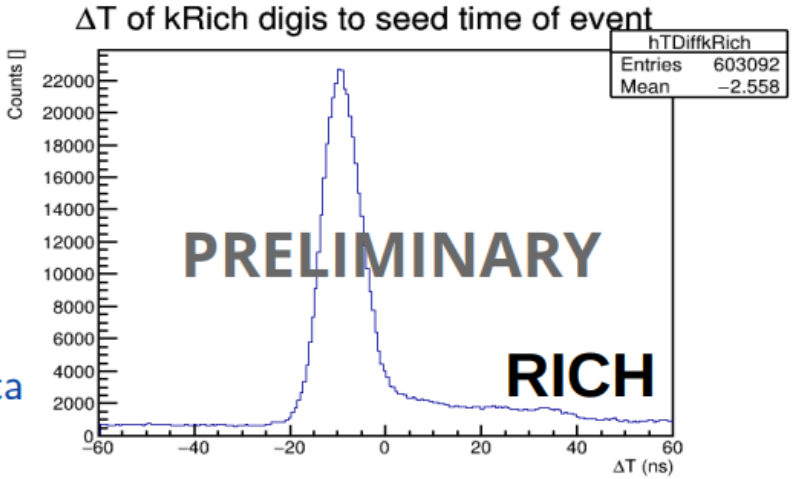


First Result With mCBM@SIS-18

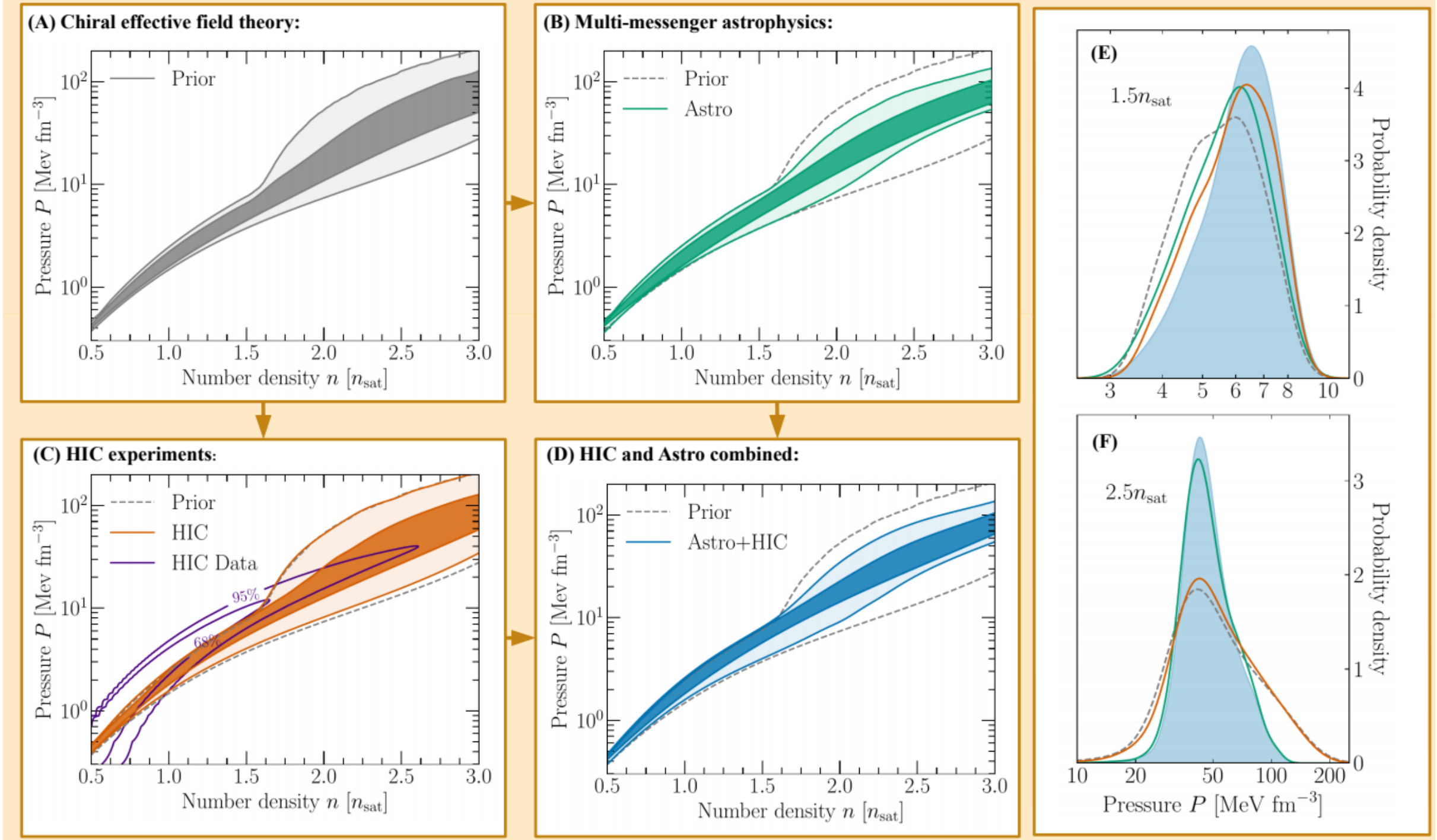
- Establishing of full readout chain with STS, TRD, TOF and RICH
- Handling of data from data stream
  - Full unpacking of data (digis: unpacked data)
    - Assigning of timestamp to each data point
  - Complete event building with unpacked data
  - Event selection
  - Archiving of events
- Demonstration of the full online data processing chain
- Extraction of time correlation between sub-detectors and seed time of an event from data stream

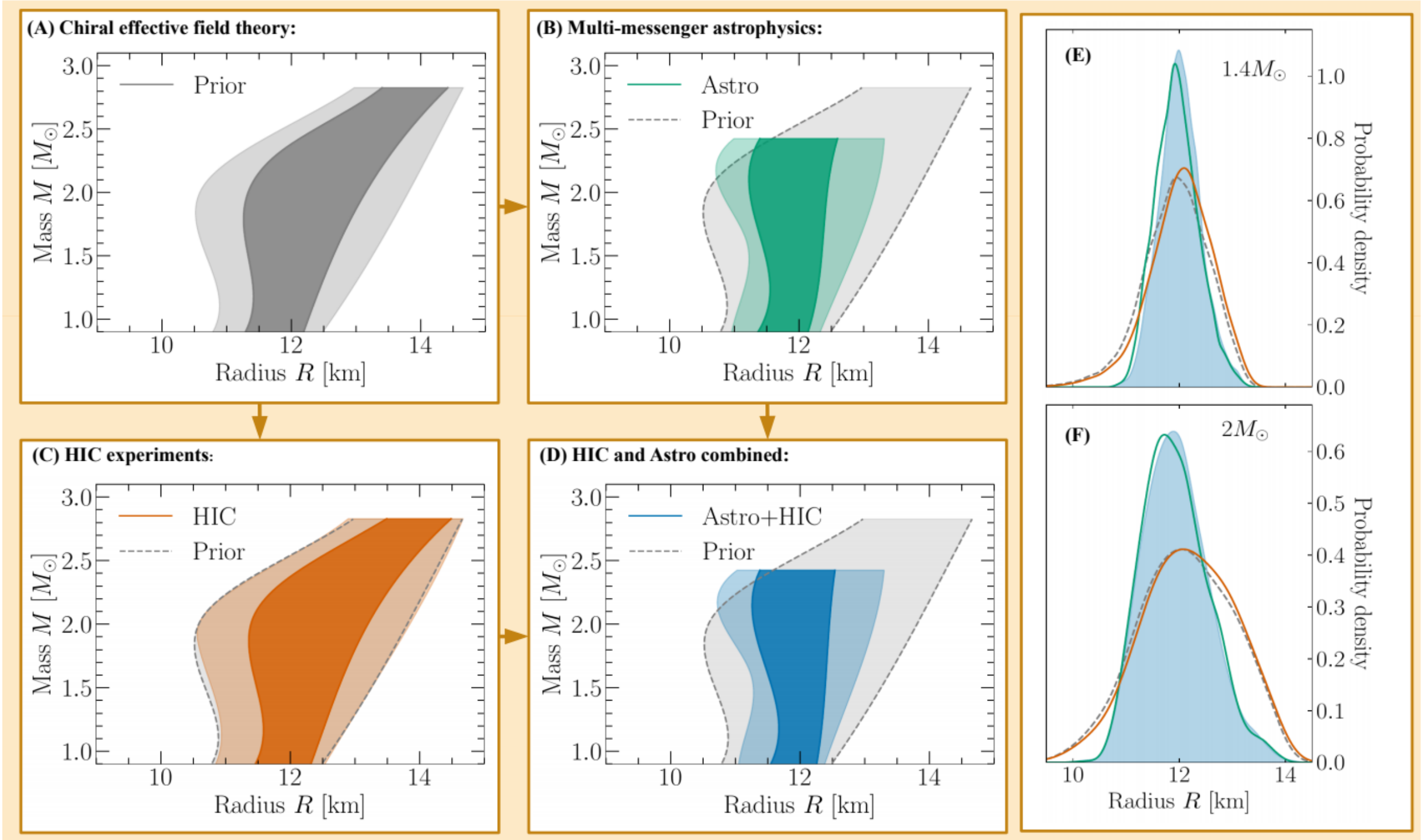
1st results from March 10, 2022, 3:36 am





Histograms created from streamed data in online histogram server


(A) Chiral effective field theory:
Prior
Pressure P [Mev fm^{-3}]
Number density n [$n_{\rm sat}$]
(B) Multi-messenger astrophysics:
Prior
Astro
Pressure P [Mev fm^{-3}]
Number density n [$n_{\rm sat}$]
(C) HIC experiments:
Prior
HIC
HIC Data
95%
68%
Pressure P [Mev fm^{-3}]
Number density n [$n_{\rm sat}$]
(D) HIC and Astro combined:
Prior
Astro+HIC
Pressure P [Mev fm^{-3}]
Number density n [$n_{\rm sat}$]
(E)
$1.5n_{\rm sat}$
Probability density
(F)
$2.5n_{\rm sat}$
Probability density
Pressure P [MeV fm^{-3}]


(A) Chiral effective field theory:
Prior
Mass M [$M_\odot$]
Radius R [km]
(B) Multi-messenger astrophysics:
Astro
Prior
Mass M [$M_\odot$]
Radius R [km]
(C) HIC experiments:
HIC
Prior
Mass M [$M_\odot$]
Radius R [km]
(D) HIC and Astro combined:
Astro+HIC
Prior
Mass M [$M_\odot$]
Radius R [km]
(E)
$1.4M_\odot$
Probability density
(F)
$2M_\odot$
Probability density
Radius R [km]