Status of the CBM experiment at FAIR and results from the CBM demonstrator experiment

Claudia Höhne, University Giessen & GSI

for the CBM collaboration

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

GSI

FAIR

FAIR Phase 0 Research Program

HFHF Helmholtz Forschungsakademie Hessen für FAIR

Bundesministerium für Bildung und Forschung

QCD phase diagram

High T, low μ_B

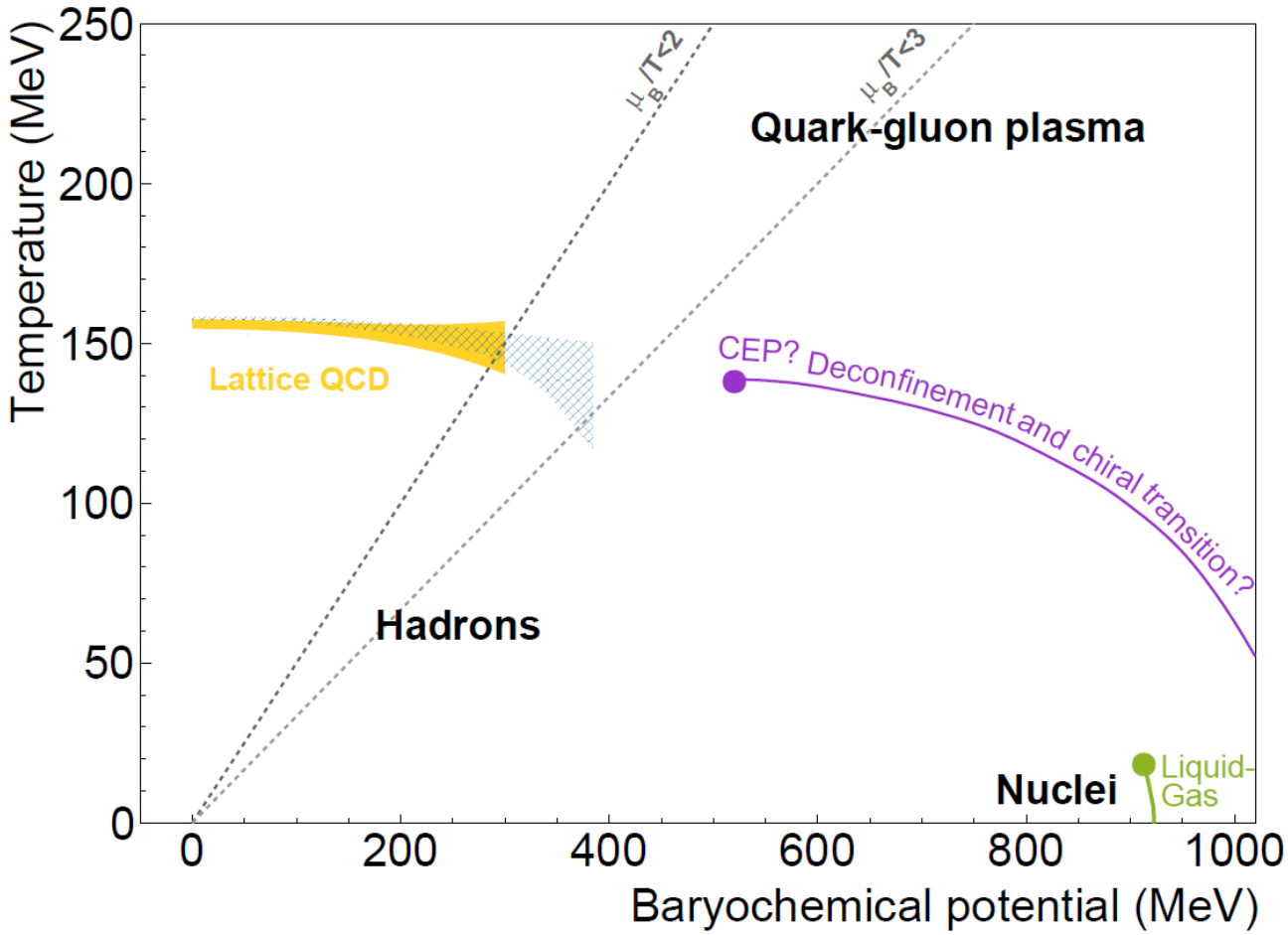
- Crossover to QGP

→ Detailed investigations on properties of QGP

- LQCD: no CEP indication for μ/T<3

Lower T, high μ_B

- Phase structure?
  - CEP?
  - 1st order phase transition?
  - New phases of QCD?
- Characterization of high-μ_B matter
- EOS?
- Properties of hadrons/ limits of hadron existence?



Bazavov *et al.* [HotQCD], PLB 795 (2019) 15-21
Ding *et al.*, [HotQCD], PRL 123 (2019) 6, 062002
Borsanyi *et al.*, PRL 125 (2020) 5, 052001
Isserstedt *et al*. PRD 100 (2019) 074011
Gao, Pawlowski, PLB 820 (2021) 136584

QCD phase diagram

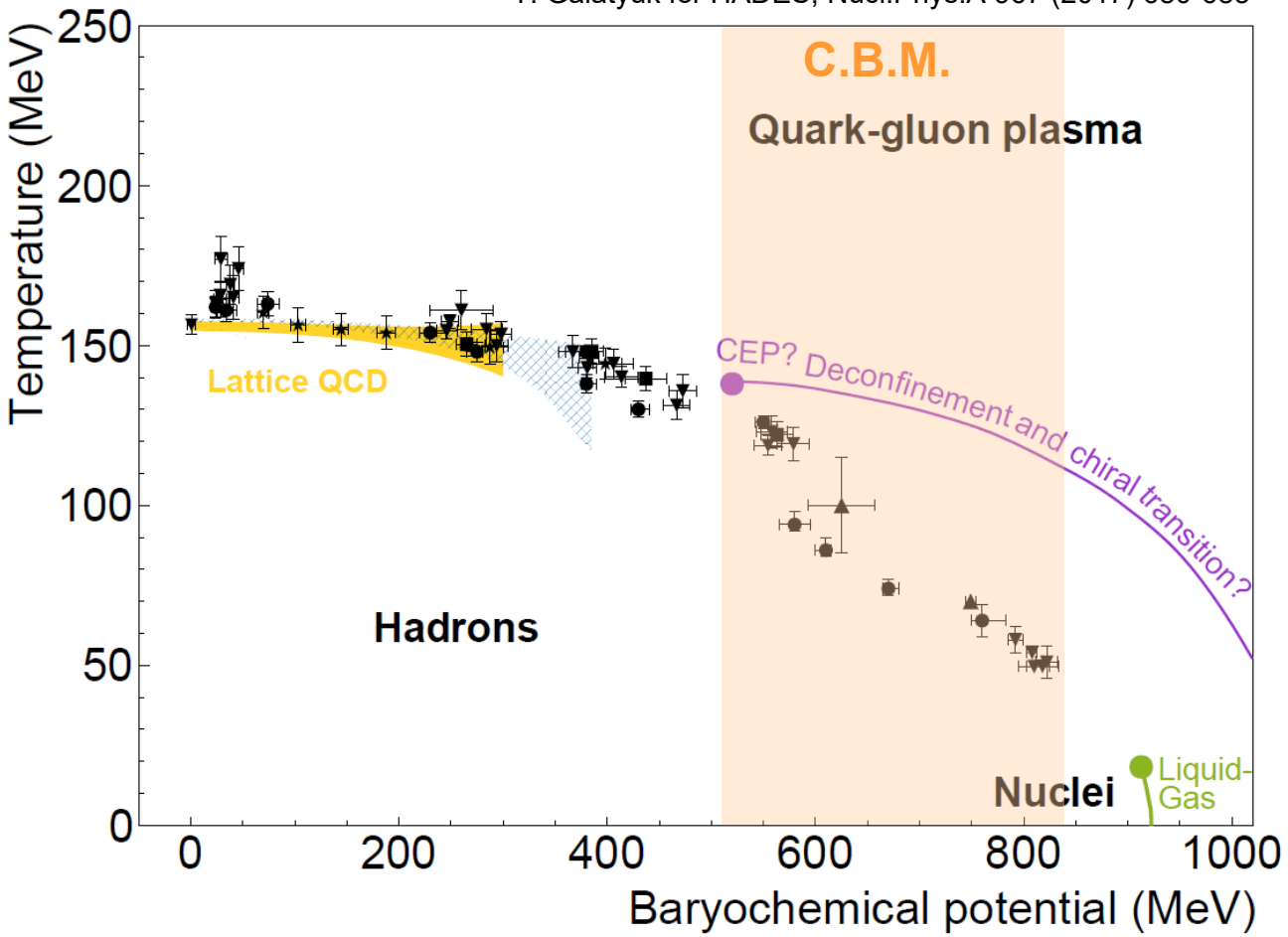
C.B.M. = CBM & HADES

- Experimental investigation of region with
  500 MeV < μ_B < 850 MeV

	$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]
SIS 18	2 – 2.5	830 – 760
SIS 100	2.3 – 5.3	785 – 520
SPS	5.1 – 17.3	530 – 220
STAR Collider	7.7 – 200	400 – 22
STAR FXT	3 – 13.7	700 – 265

$\mu_B(\sqrt{s_{NN}})$ from A. Andronic, P. Braun-Munzinger, K. Redlich and J. Stachel, Nature 561, no. 7723, 321 (2018)

HADES; Nature Physics 15 (2019) 10, 1040-1045
T. Galatyuk for HADES, Nucl.Phys.A 967 (2017) 680-683



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QCD phase diagram

C.B.M. = CBM & HADES

- Experimental investigation of region with
  500 MeV < μ_B < 850 MeV
- Recent theory predictions favor μ_B around 600 MeV and T around 100 MeV for CP

	$\sqrt{s_{NN}}$ [GeV]	μ_B [MeV]
SIS 18	2 – 2.5	830 – 760
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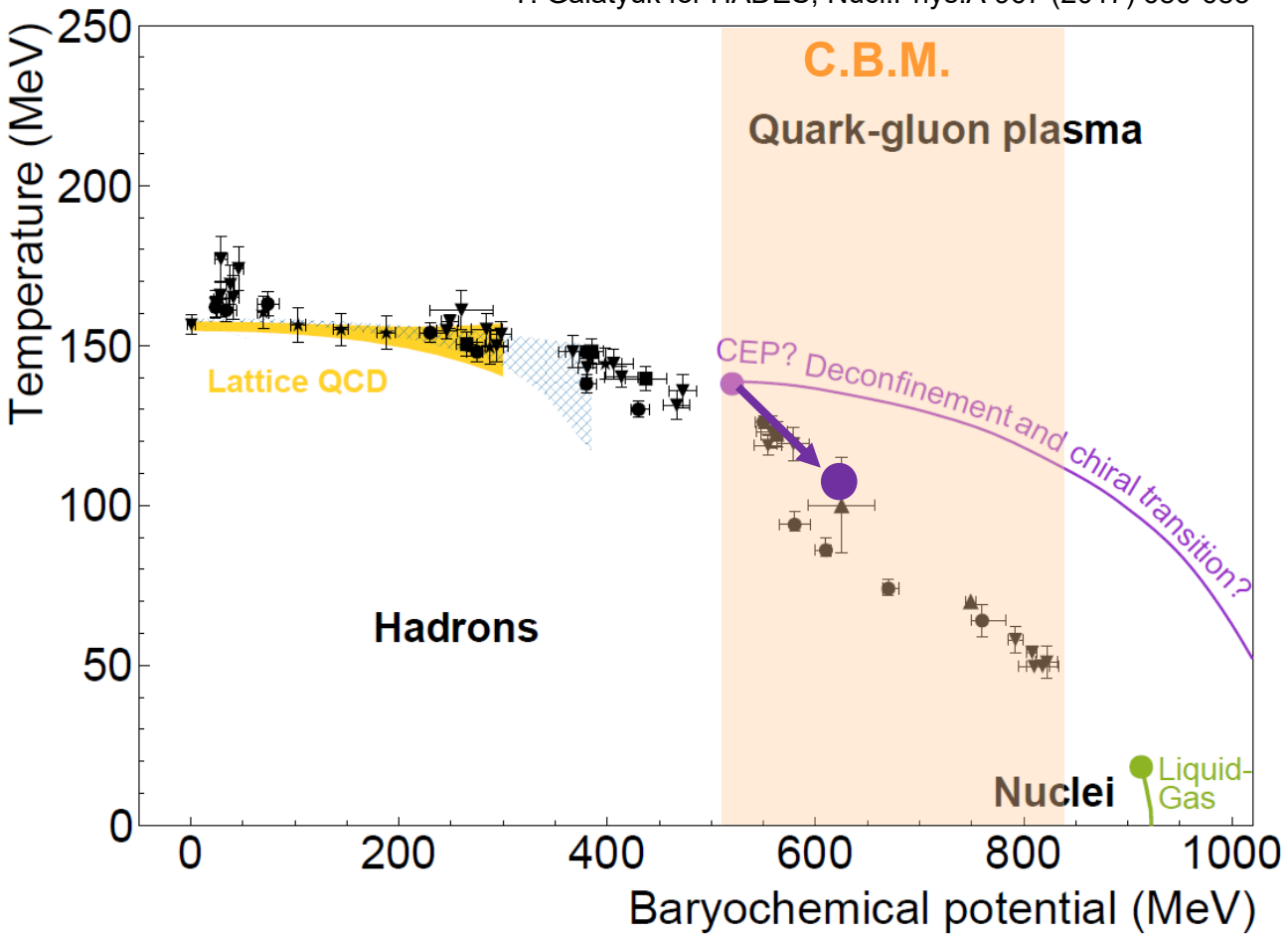

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Isserstedt *et al.* PRD 100 (2019) 074011
Gao, Pawlowski, PLB 820 (2021) 136584
Fu *et al.*, PRD 101 (2020), 054032
Gunkel, Fischer, PRD 104 (2021) 5, 054022
G. Basar, arXiv:2312.06952

(Key) observables

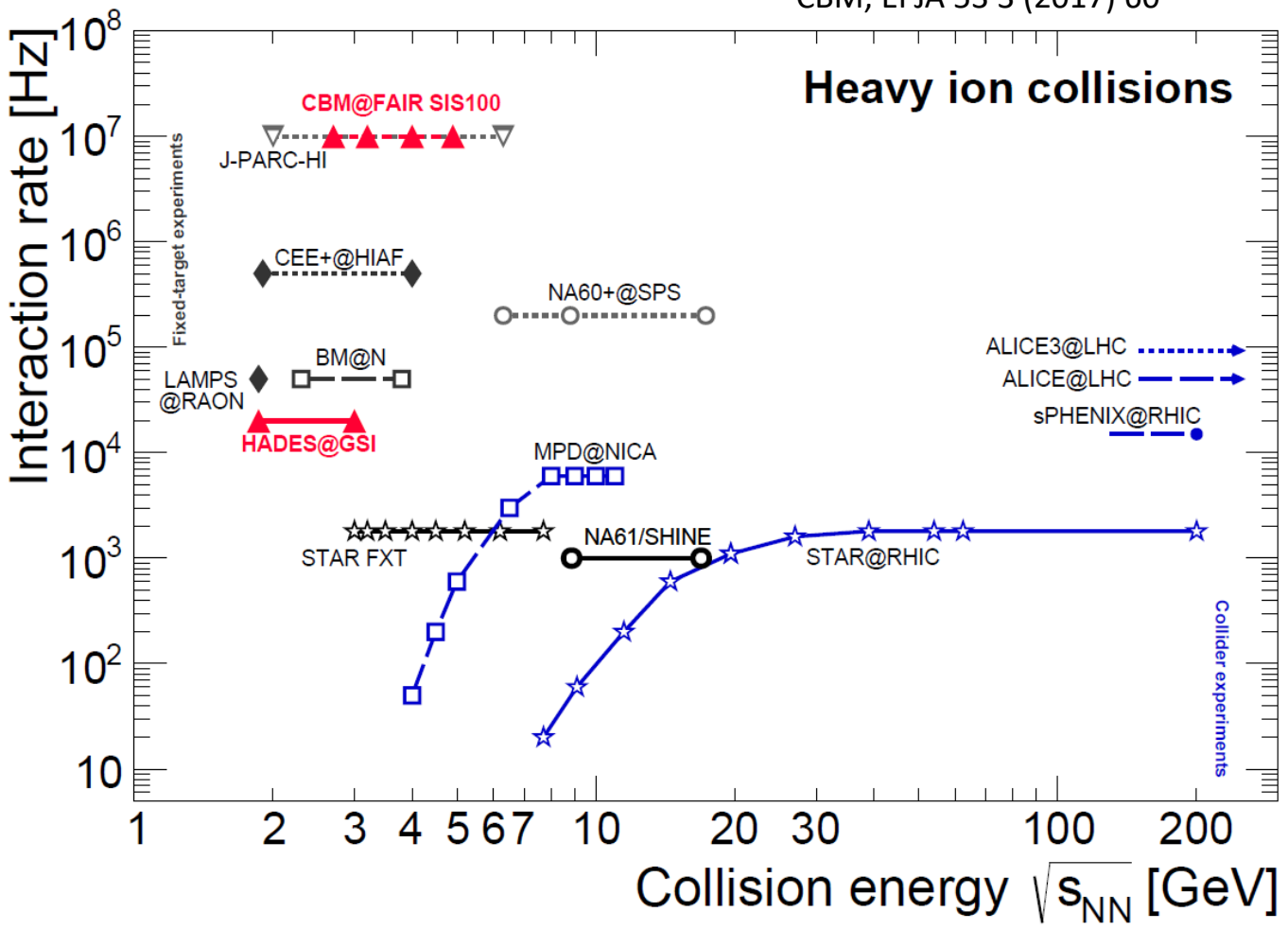
Worldwide effort to investigate high-μ_B region of the QCD phase diagram

T. Galatyuk, NPA 982 (2019), update 2023
https://github.com/tgalatyuk/interaction_rate_facilities,
CBM, EPJA 53 3 (2017) 60

Key observables are rare observables

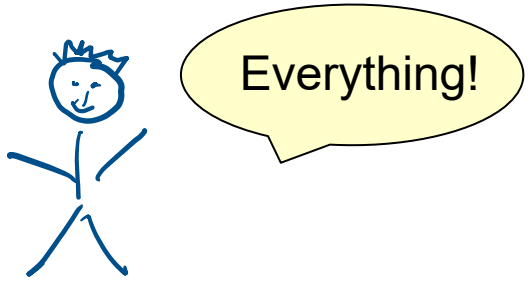
→ Program needs ever more precise data (statistics!) and sensitivity for rarest signals!

→ Systematic investigation in dependence on energy, size/centrality



(Key) observables

What to measure?



Key observables – systematic measurements! :

- Dileptons
  → Emissivity of dense baryonic matter: lifetime, temperature, density, in-medium properties

- Fluctuations
  → System transition via 1st order PT line, CEP

- Hadrons/ Strangeness/ Charm
  → System in equilibrium, Hypernuclei, Vorticity, Flow, EOS

- Correlations
  → Flow, Vorticity, YN & YNN interactions

(Key) observables

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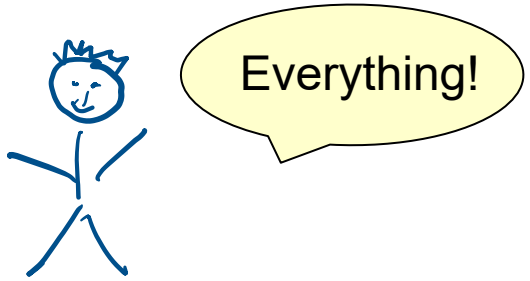

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Critical fluctuations

At CEP or when crossing a 1st order phase transition: density fluctuations/ jump in density
→ both yielding discontinuities/ fluctuations
→ Cumulants of baryon number measure derivatives of μ_B

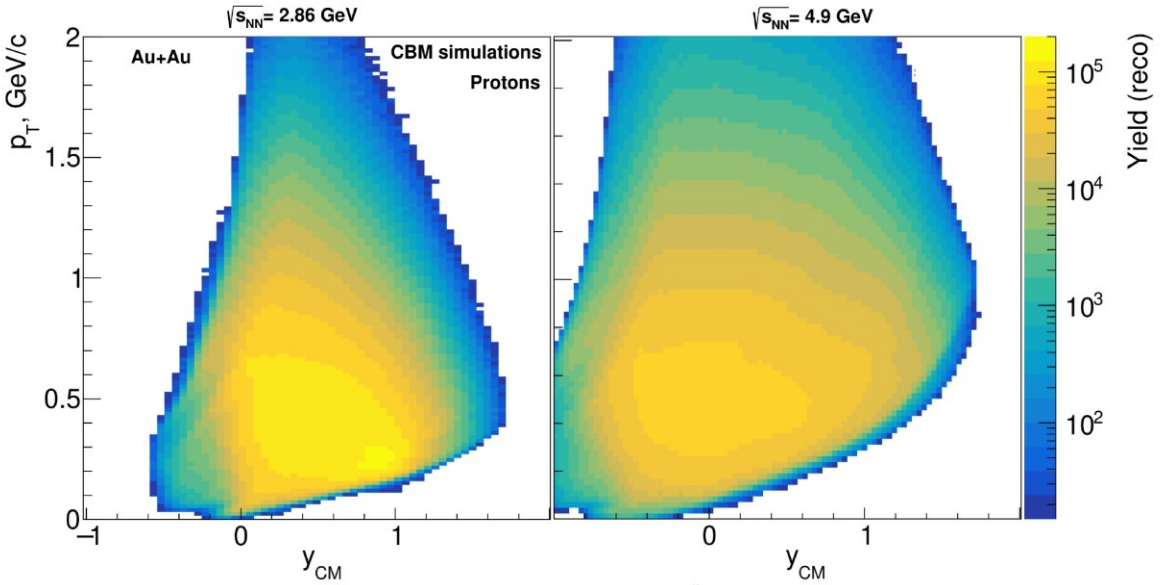
V. Vovchenko et al., *Phys.Lett.B* 811 (2020) 135868

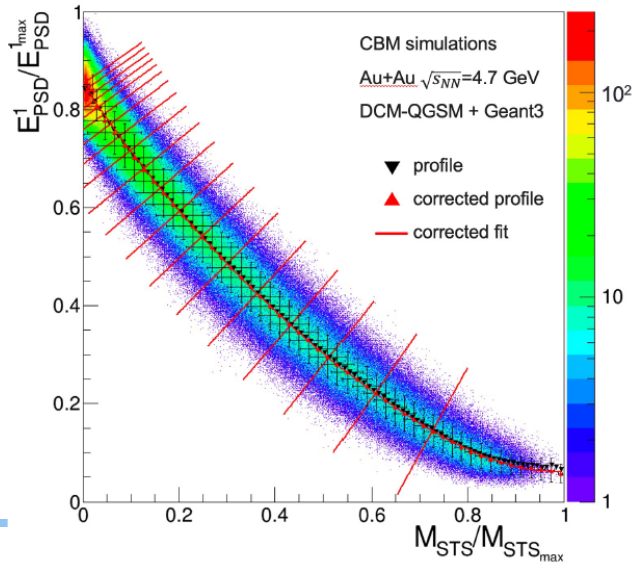
$$\chi_n^B \equiv \frac{\partial^n (p/T^4)}{\partial (\mu_B/T)^n} = \frac{\kappa_n[B]}{V\,T^3}$$

Ratios of cumulants independent on V

$$\frac{\chi_4}{\chi_2} = \frac{K_4}{K_2} = \kappa\sigma^2 \qquad K_2 = \langle N - \langle N \rangle \rangle^2 \text{ etc.}$$

Measure event-by-event net-proton number (p – anti-p)
→ higher moments (statistics hungry! but more sensitive) probe the tails!
→ Important to systematically understand experimental effects: acceptance, centraliy, barýon number conservation at high μ_B





Critical fluctuations

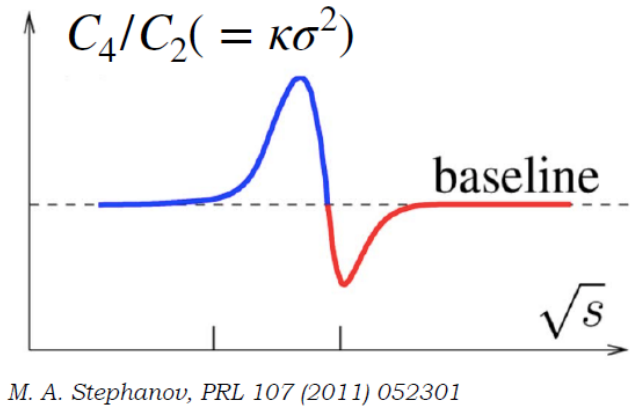
CBM after 3 years – (improve STAR stat. errors by factor of 10):

- Measure excitation function (p) for $k\sigma^2 = \frac{\kappa_4}{\kappa_2}$
- First results on κ_6(p)
- Extension to strangeness?

We hope to see:

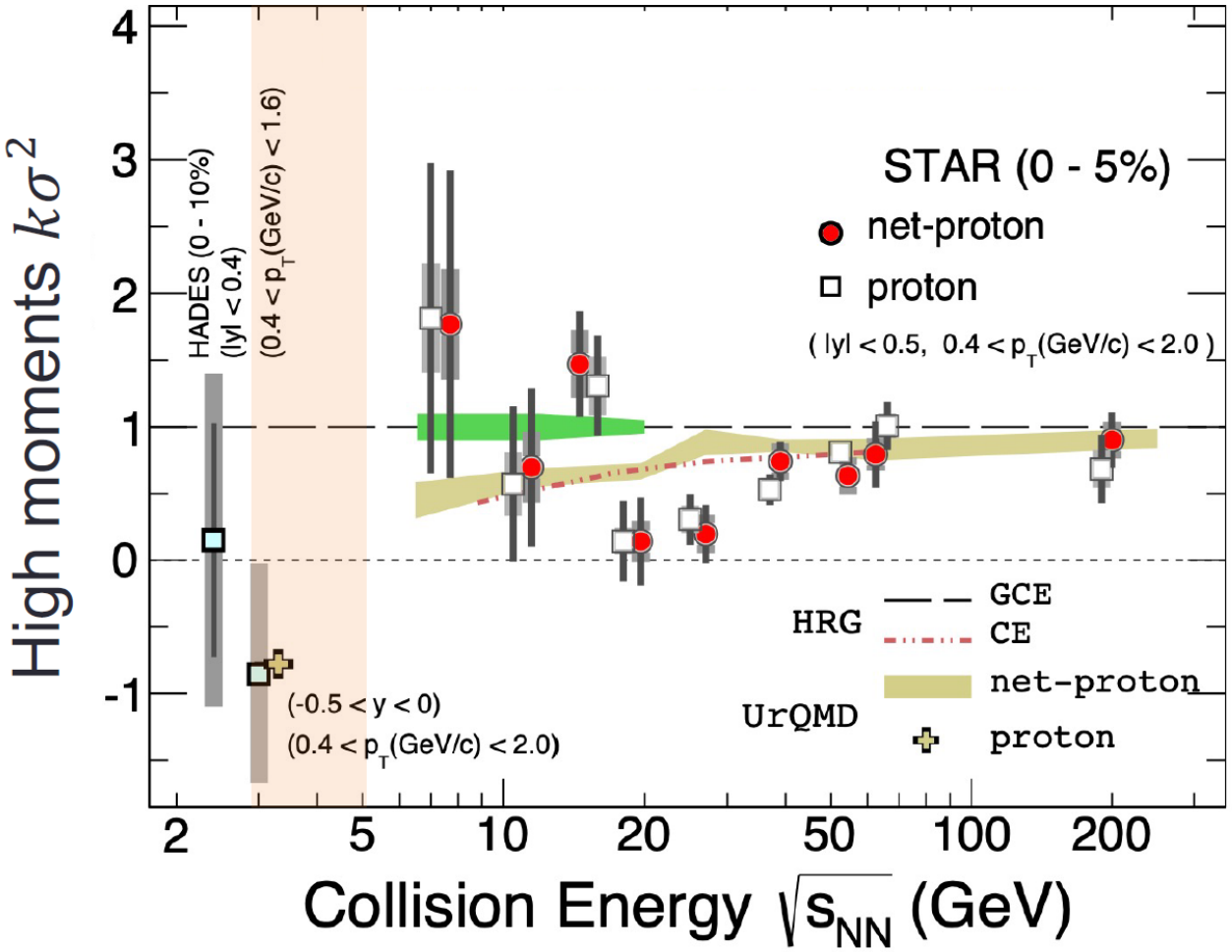
Discontinuity?!

… that extends to even higher moments?!



M. A. Stephanov, PRL 107 (2011) 052301

STAR, PRL 128 (2022) 20, 202303
HADES, PRC 102 (2020) 2, 024914



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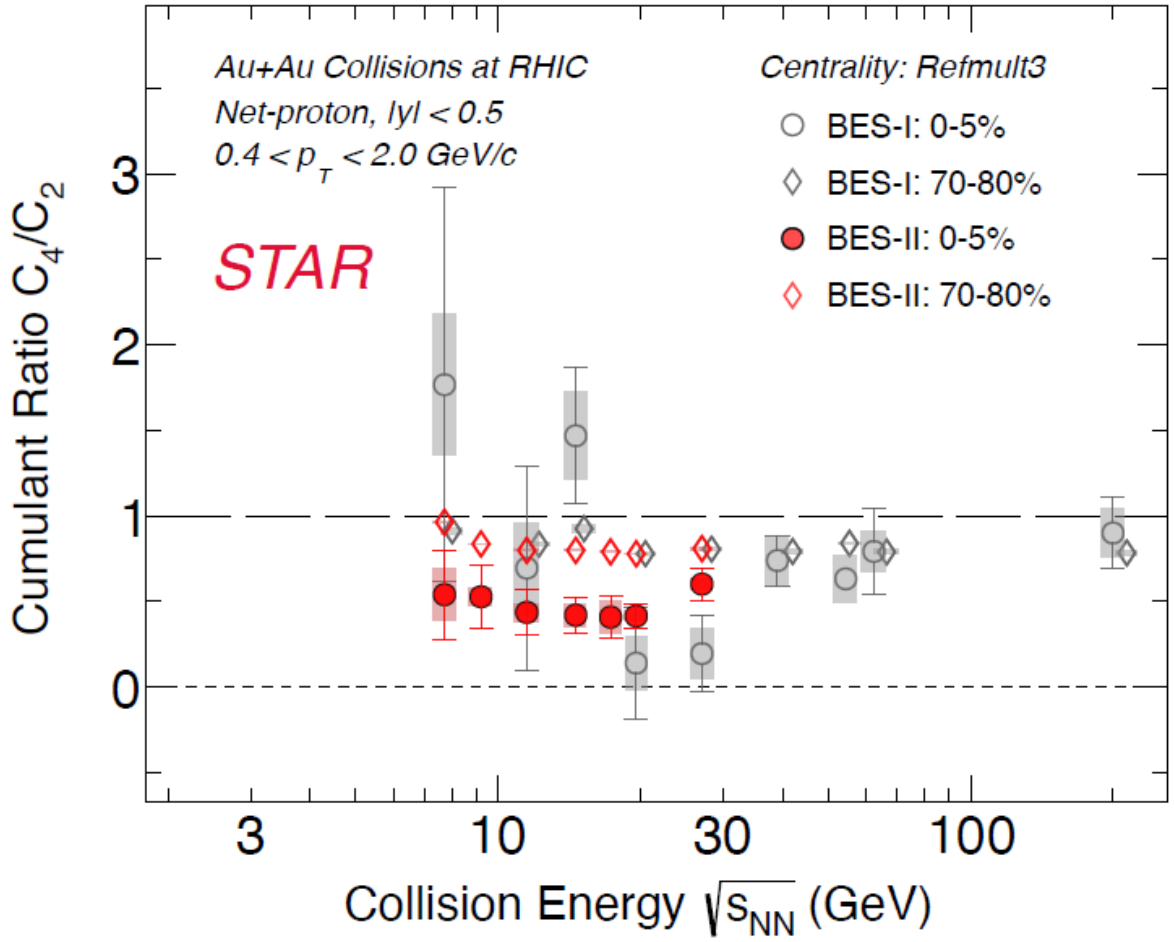
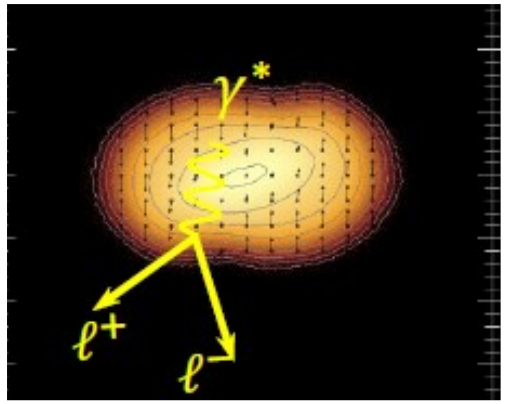


BES II results consisten with BES I
CPOD 2024, STAR, A. Pandav

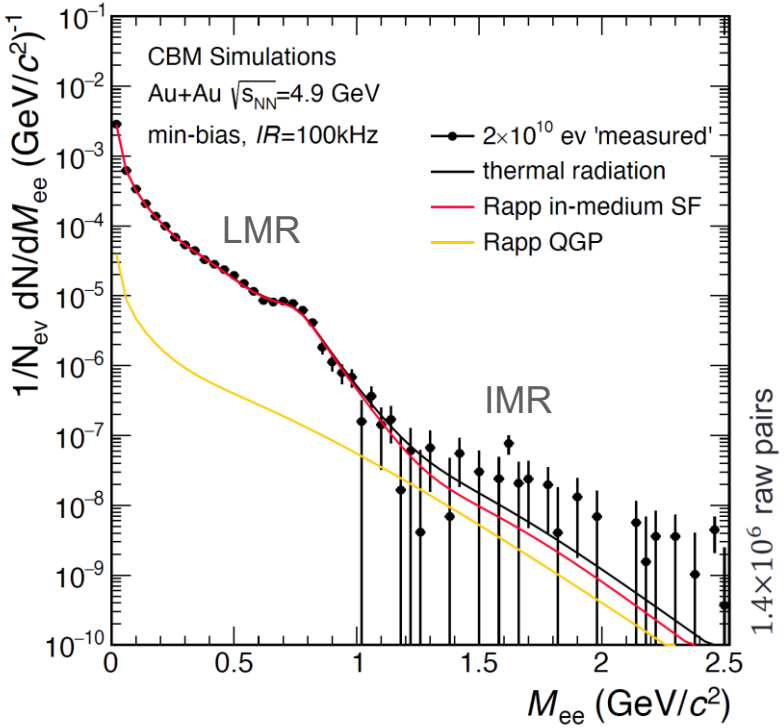
Dileptons

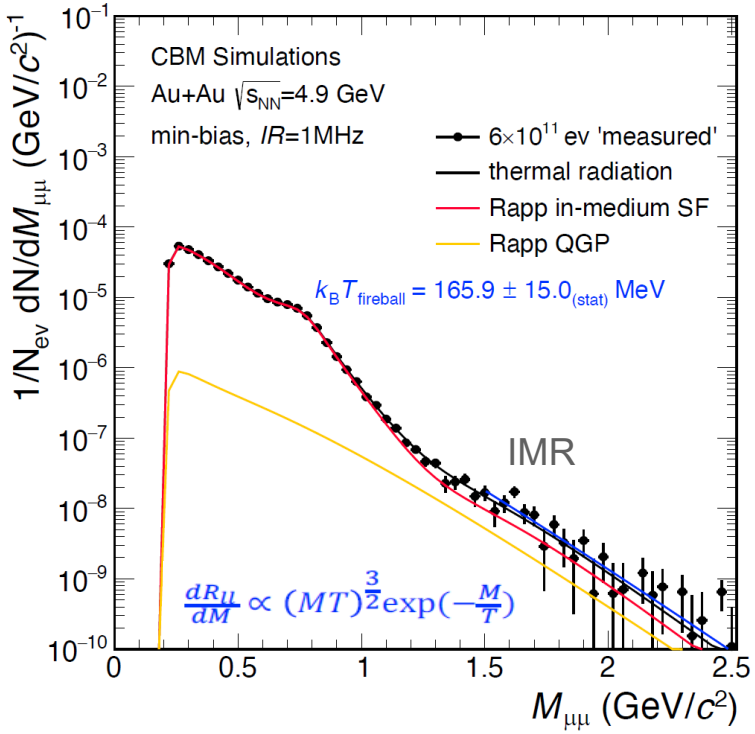
Em probes are sensitive to the full duration/evolution of the collision

- Emission of virtual photons from all stages
- Unique probe of temperature, duration, density, …



Expected **dielectron** performance
(first year, 5 days/ energy (6), 2x10^{10} events each = 5 days per energy)





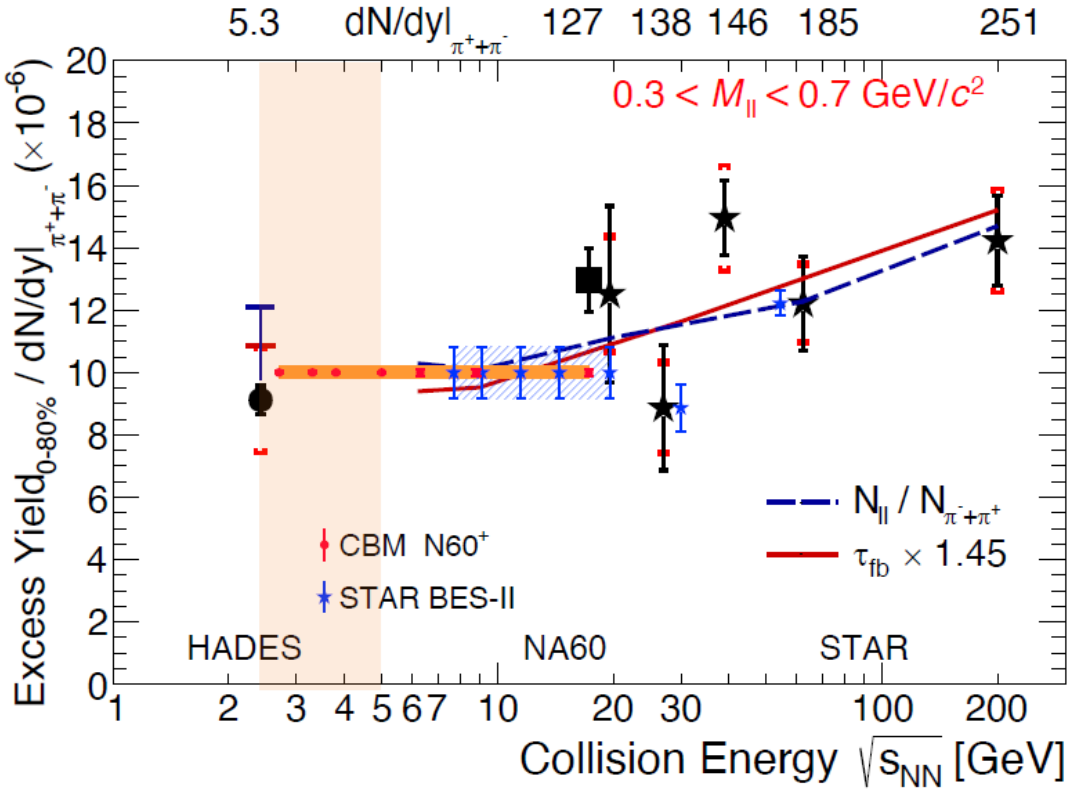
Expected **dimuon** performance
High statistics runs after first 3 years to access IMR range with <10% errrors on $T_{fireball}$

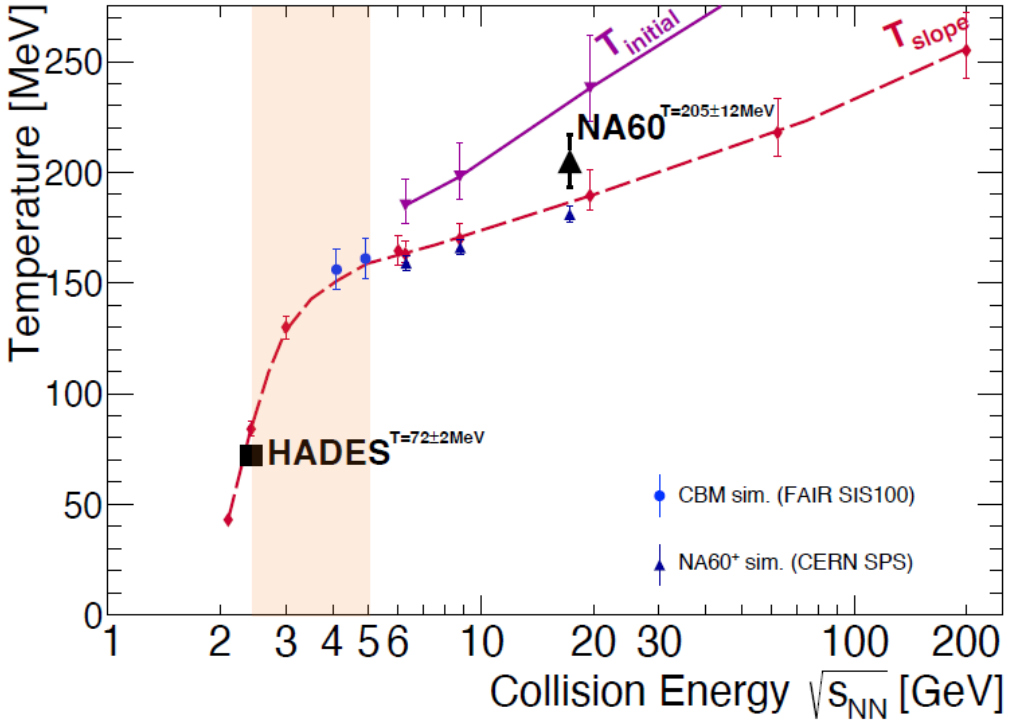
Dileptons

- Excess yield in LMR → fireball lifetime: extra radiation due to latent heat around PT (& CEP?)?
- Invariant mass slope (LMR & IMR) → flattening of caloric curve due to PT ?

* one year 5 days beam on target, 6 energies Au+Au, $2 \cdot 10^{10}$ ev. each, 100kHz

Tripolt et al., NPA 982 (2019) 775
Li and Ko, PRC 95 (2017) no.5, 055203
Seck et al., PRC (2022), arXiv:2010.04614 [nucl-th]
O. Savchuk et al., arXiv:2209.05267 [nucl-th]





T. Galatyuk, JPS Conf. Proc. 32 (2020) 010079k

Strangess & Σ prospects with CBM

- Tracking system allows for precise track and 2ndary vertex reconstruction, Δp=1%
- TOF for hadron ID

→ measure yields, flow, correlations, Λ polarization, …

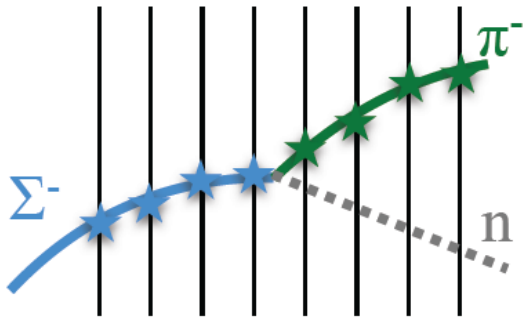
- **Identification of Σ^+ and Σ^- via their decay topology**: search for kink!

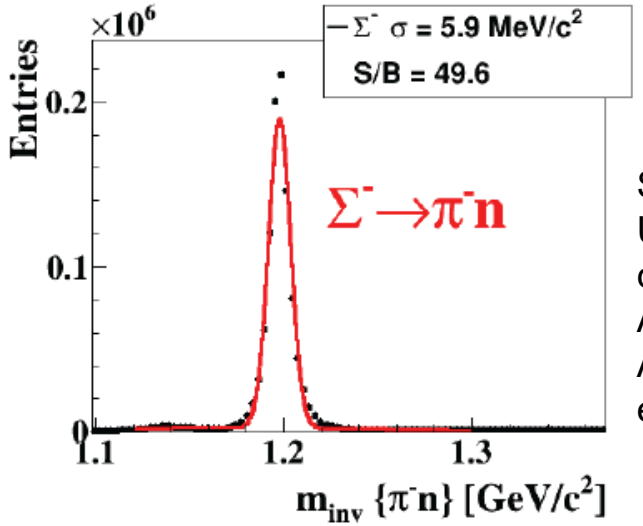
$\Sigma^+ \rightarrow p\pi^0$	$\bar{\Sigma}^+ \rightarrow \bar{p}\pi^0$	BR = 51.6%
$\Sigma^+ \rightarrow n\pi^+$	$\bar{\Sigma}^+ \rightarrow \bar{n}\pi^-$	BR = 48.3%
$\Sigma^- \rightarrow n\pi^-$	$\bar{\Sigma}^- \rightarrow \bar{n}\pi^-$	BR = 99.8%

→ (p/n) like ratios! → access to isospin dependence?

→ Σ^-/Σ^+ ratio is expected to carry $E_{sym}(\rho)$ information (stiff/soft)

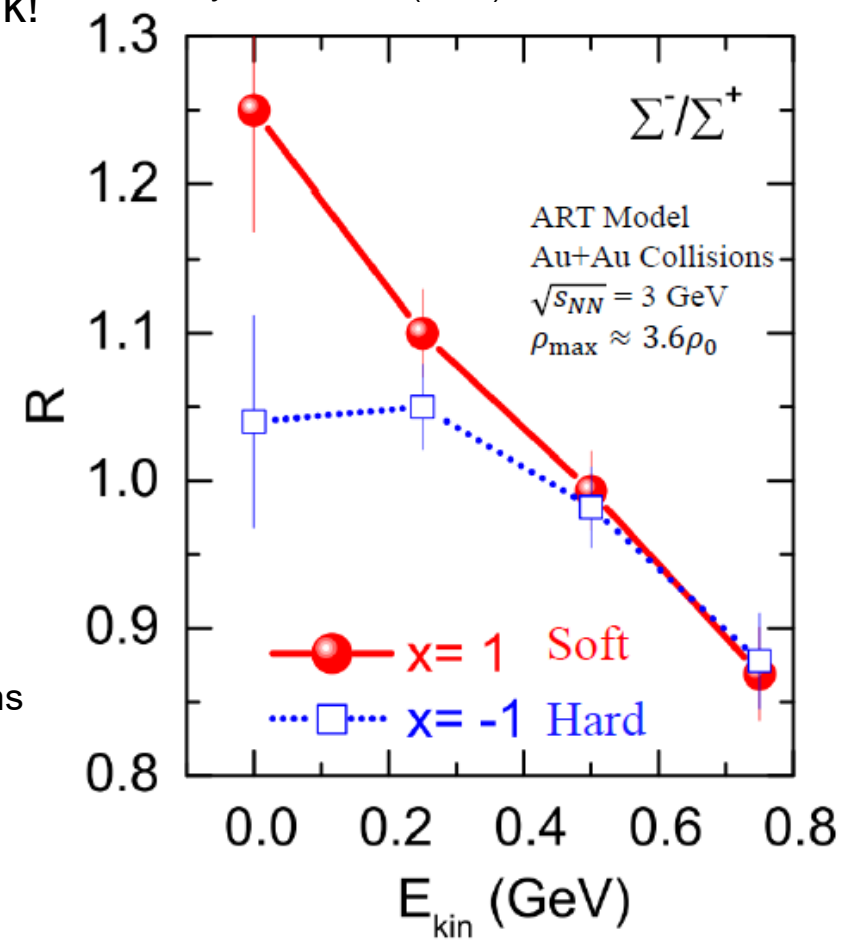
Find tracks of Σ and its charged daughter in STS and MVD





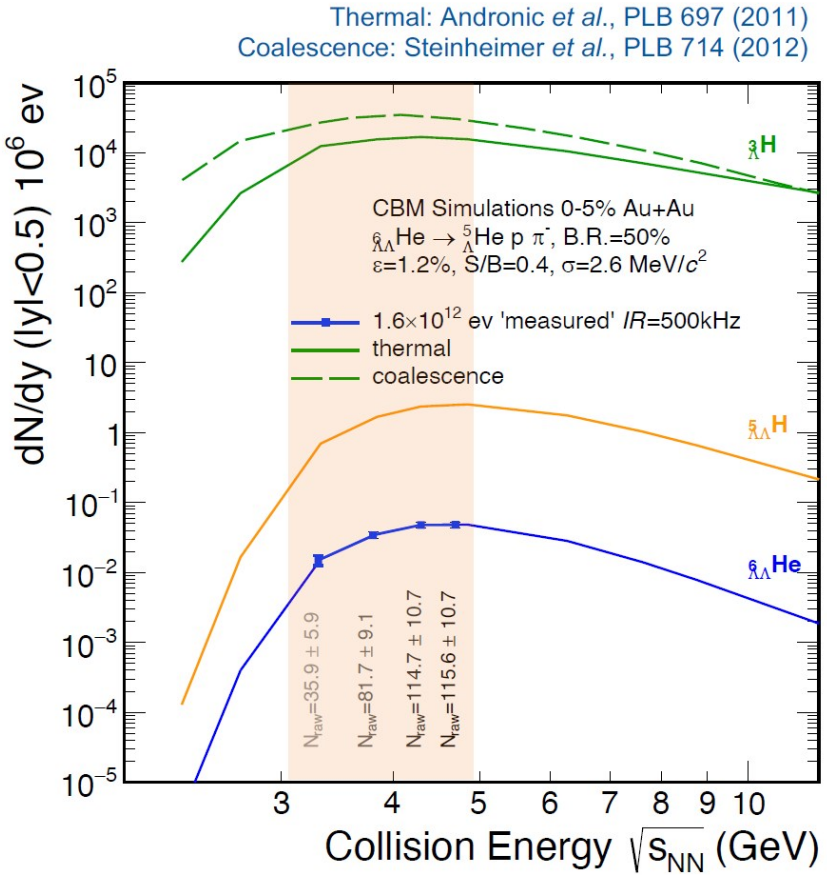
Simulations: UrQMD, 5M central collisions Au+Au, 10 AGeV beam energy

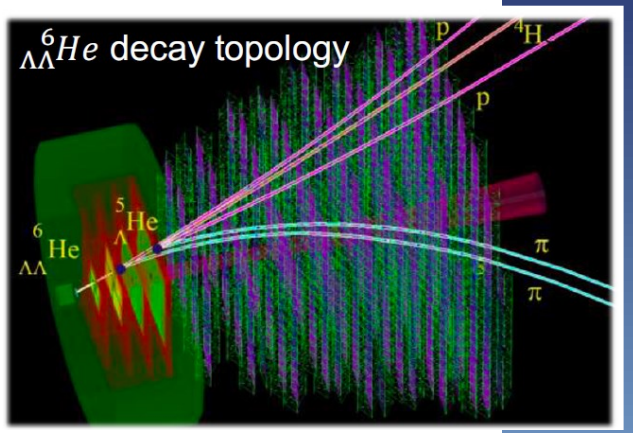
G.C. Yong et al, *Phys.Rev.C* 106 (2022) 2, 024902



Hypernuclei

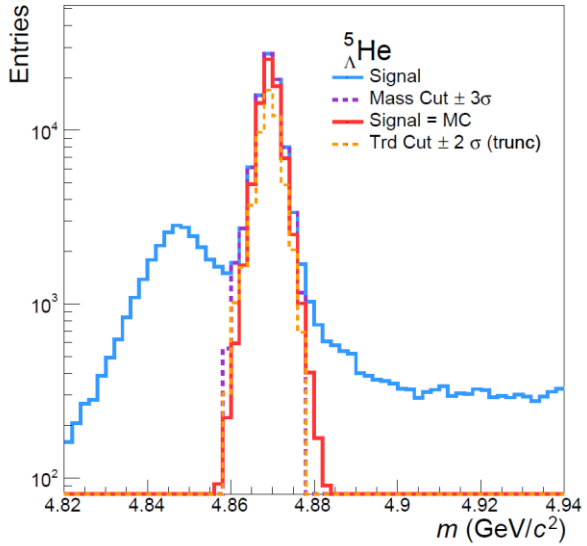
- Hypernuclei interesting/ important objects for neutron star descriptions
- Formation? YN and YY interactions? Influence on EOS for high densities?
- CBM energies optimum for production
- Reconstruction routines tested with STAR FXT data





$$^{5}_{\Lambda}He \rightarrow {}^{4}He + p + \pi^{-}$$

$$^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^{-}$$

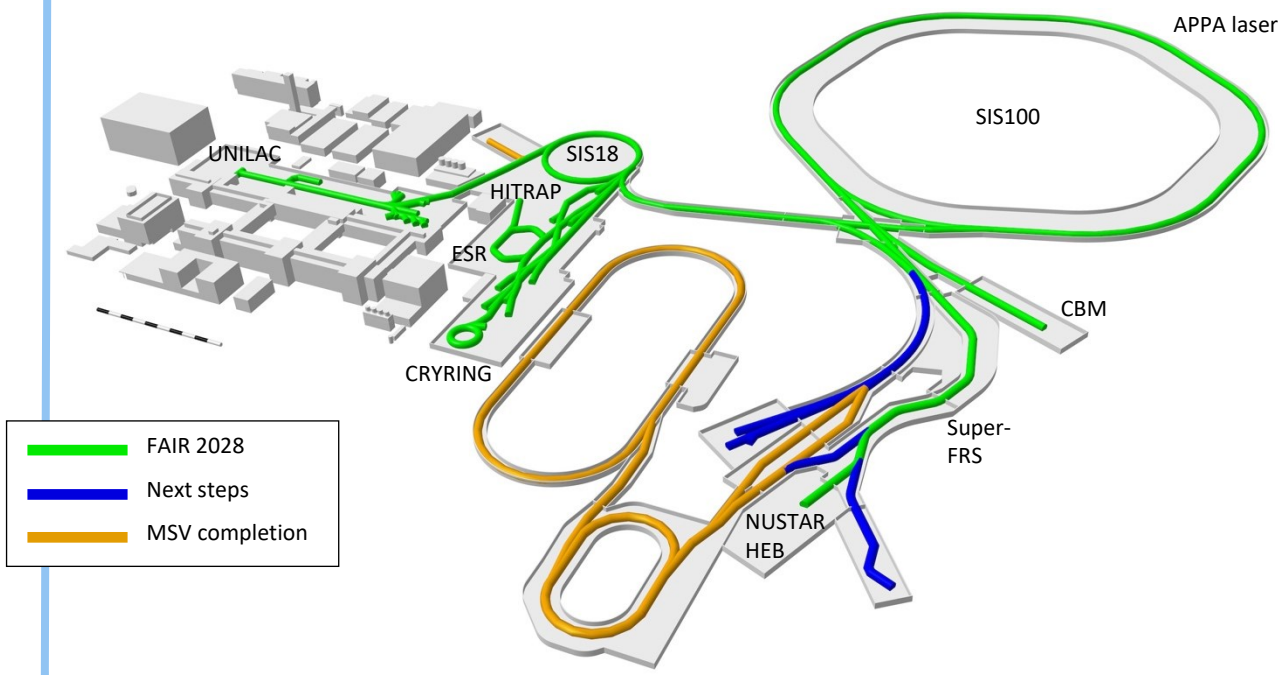


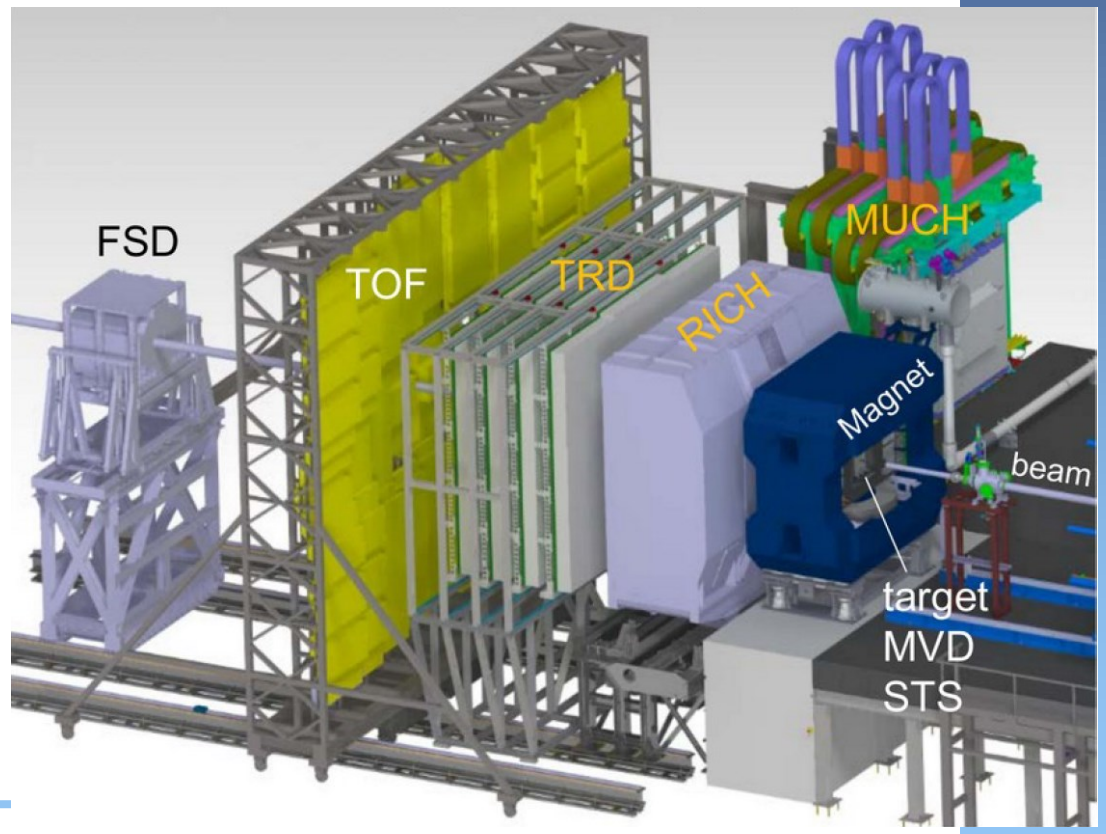
Master thesis S. Glässel, Univ. Frankfurt

FAIR & CBM

CBM @ FAIR

- 2.5° - 25° polar angle coverage, tracking in large gap dipole magnet, particle ID afterwards
- First beams in 2028/2029
  - Years 1-3: (first) energy scan, improved statistical errors of factor 10 with respect to STAR
  - Years 4-8: high statistics measurements → Dilepton IMR, ultra-rare probes





Status of FAIR & CBM

- FAIR construction progressing
  - ✓ SIS 100 tunnel ready, first installations ongoing
  - ✓ CBM cave ready
  - ✓ Upstream platform in CBM cave is installed – being the first user installations of FAIR!

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Status of FAIR & CBM

… and to make sure everybody visiting knows what will be installed here!!

Status of FAIR & CBM

… some more impressions!

CBM building

SIS100 tunnel

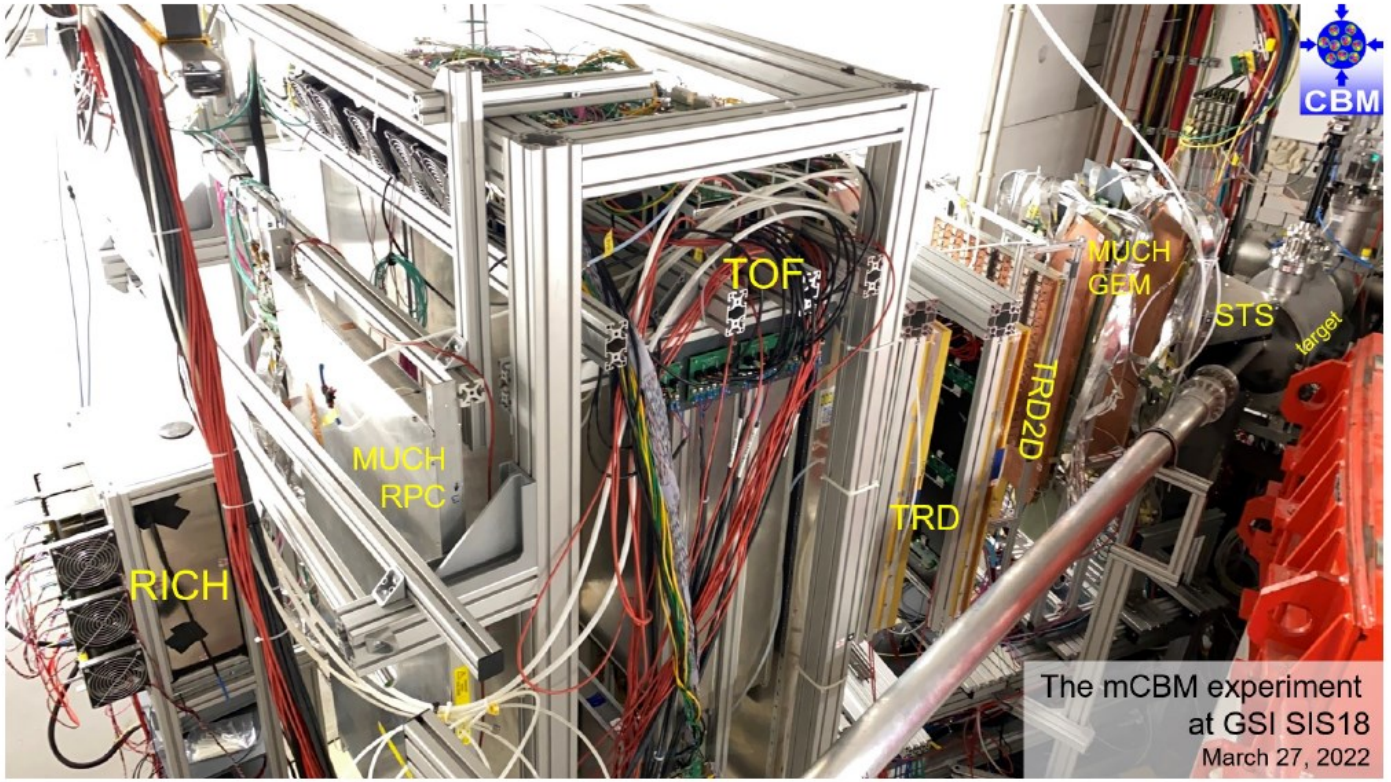
mCBM @ SIS18 (FAIR phase 0)

One major CBM challenge (& opportunity!) is the high rate:

- Free streaming readout
- Online reconstruction & trigger

Important milestone: mCBM @ SIS 18!

- Full system test
- Verification of triggerless-free-streaming readout
- Up to 10 MHz collision rates



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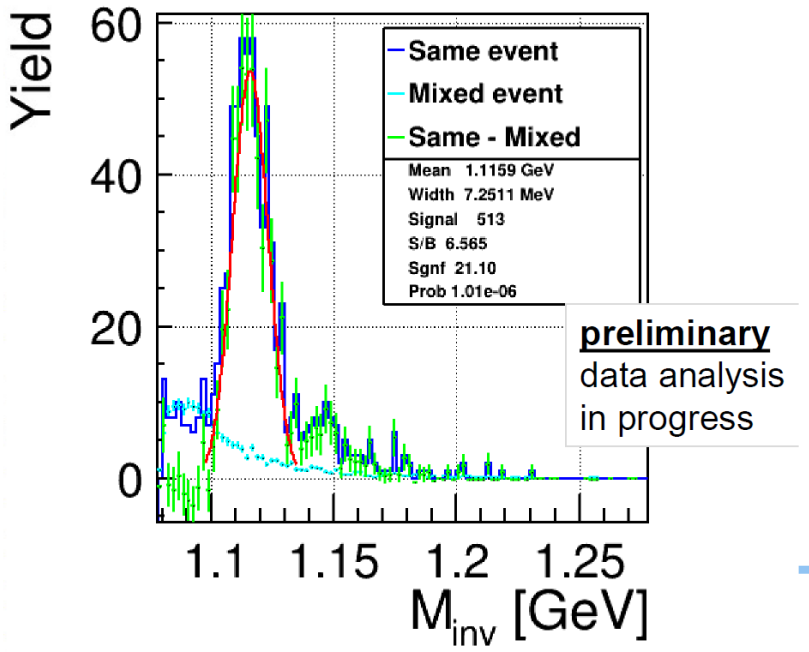
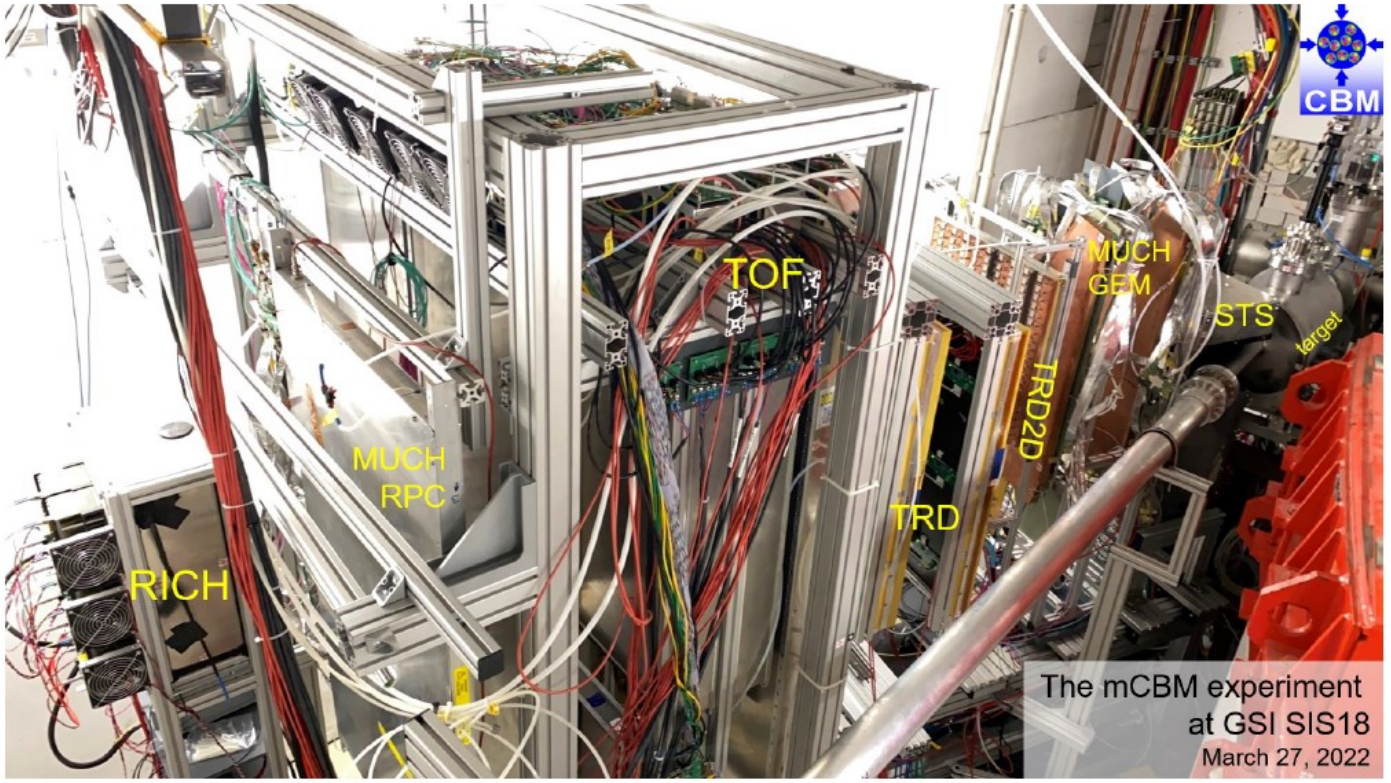


preliminary
data analysis
in progress



Λ reconstruction

400-500kHz average collision rate

Offline analysis

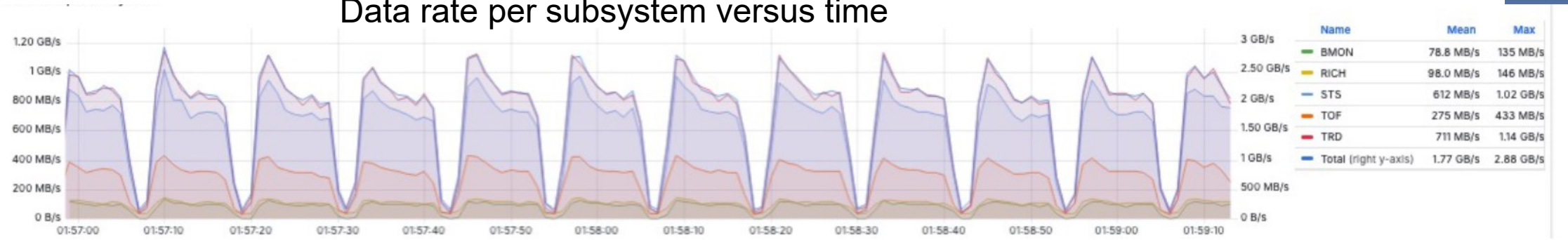
Next step: online reconstruction

mCBM @ SIS18 (FAIR phase 0)

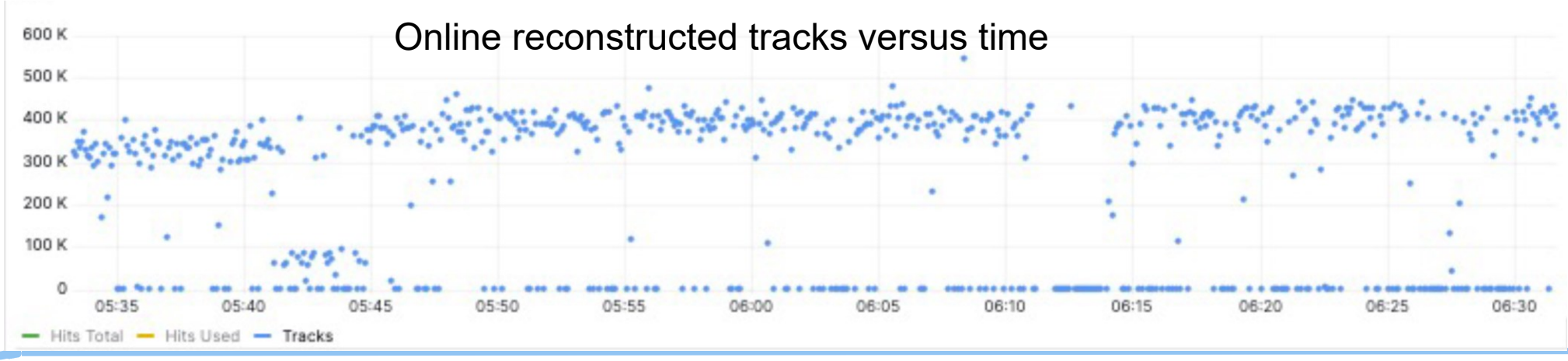
Late spring 2024: first beamtime with testing online trigger systems

- Multiplicity trigger: needs online unpacking and event building
- Online reconstruction and V0 topology trigger: needs online reconstruction and secondary vertex reconstruction on top
- Detailed evaluation ongoing

Data rate per subsystem versus time

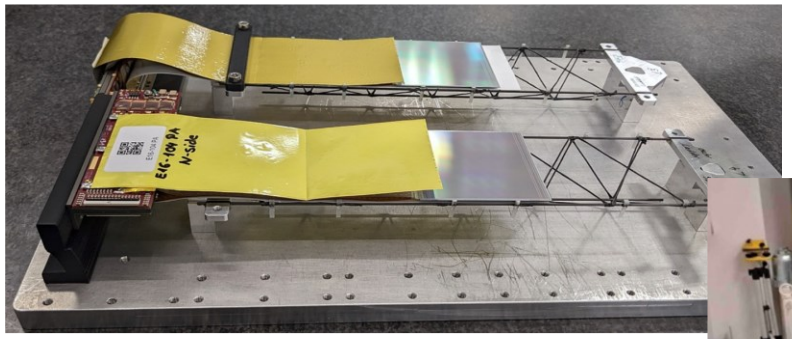


Online reconstructed tracks versus time

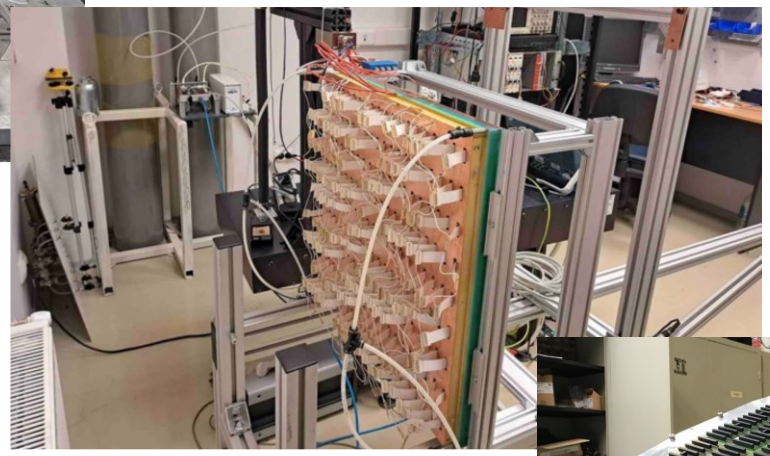


CBM construction

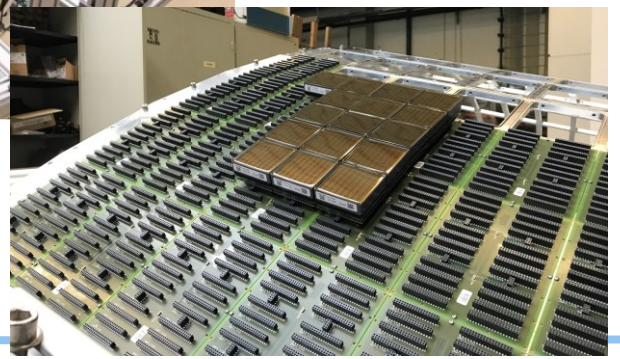
- Re-procurement of russian components ongoing
  - CBM magnet contract signed, production design review accomplished
  - New forward wall based on HADES concept in preparation
  - RICH, MUCH mechanics re-design/ re-procurement ongoing
- Detector (pre)-series production started



STS modules (pre-series)



TRD modules
(pre-series)



RICH photodetectorplane

Summary & Outlook

Future is bright!

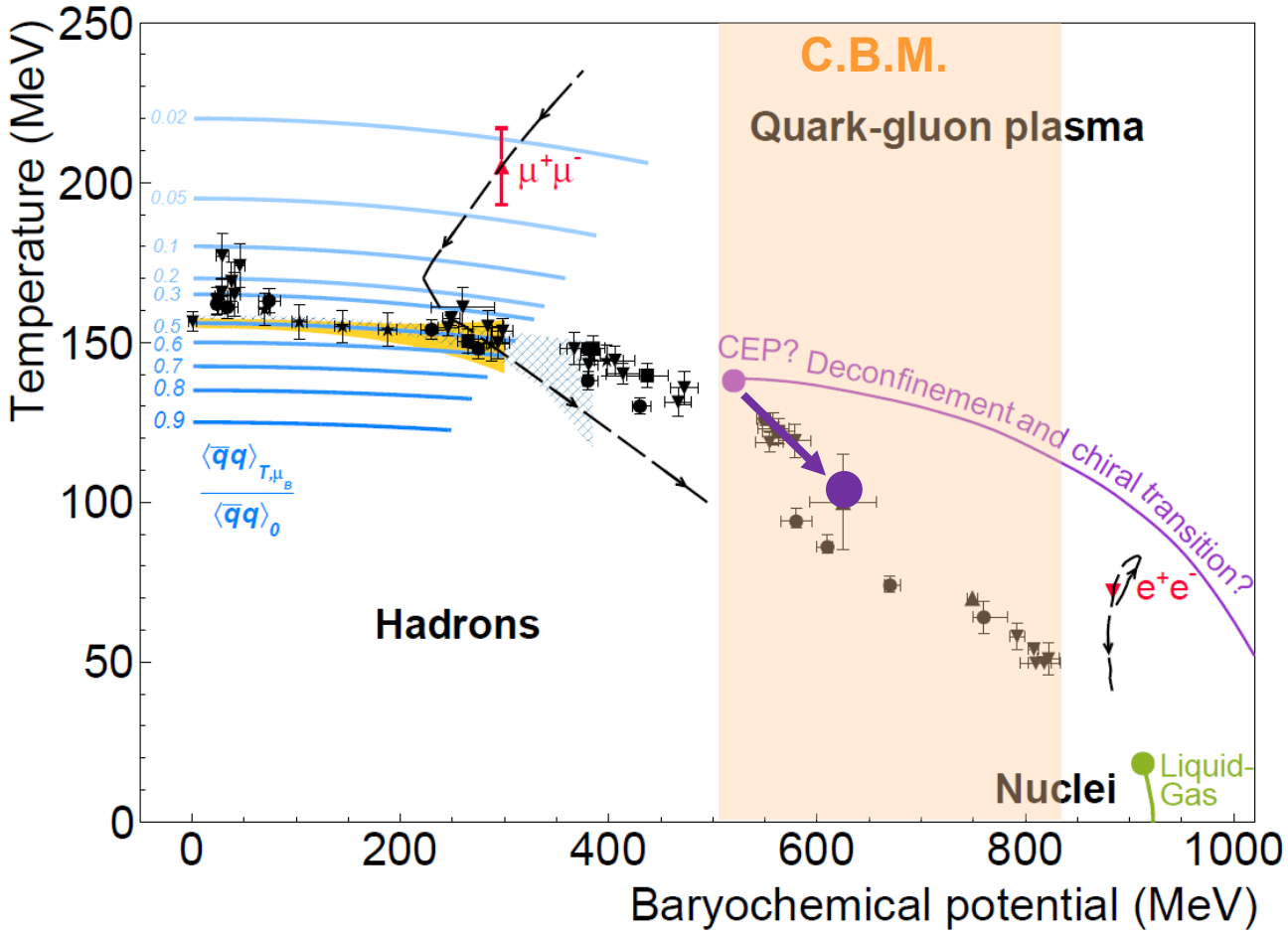
- (Pre)-series production of CBM started

→ Ready for first beams in 2028

→ Experimental data to contribute to open QCD questions:

- Phase structure of QCD at finite density
- Characterization of high μ_B matter
- Formation of hadrons, properties, interactions, correlations
- Formation of (hyper-)nuclei

HADES; Nature Physics 15 (2019) 10, 1040-1045
T. Galatyuk for HADES, Nucl.Phys.A 967 (2017) 680-683



That‘s us ….