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Status of the CBM experiment at FAIR

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Abstract. The CBM experiment will explore dense baryonic matter at moderate temperatures with rare observables that could not be investigated so far for this type of matter. Experiments will be performed at the future FAIR facility with beams from SIS 100 exploring a range in $\sqrt{s_{NN}}$ from 2.3 - 5.3 GeV at interaction rates up to 10 MHz. Within the first few years energy scans in particular for dilepton and fluctuation observables are planned in order to search for the predicted first order phase transition and critical point. The status of the experimental preparations is reviewed in this contribution.

1 Experimental investigation of the QCD phase diagram

The investigation of the QCD phase diagram (fig. 1, left) since many years is in the focus of various experimental programs with heavy ion collisions. Just recently the ALICE collaboration has discussed in a review many details of QCD matter at highest temperatures and approximately zero net-baryon density [1]. Lattice QCD calculations have shown that at those conditions there is a crossover between deconfined and confined matter (e.g. [2]), in agreement with experimental observations. Scanning the QCD phase diagram towards higher net-baryon densities a critical endpoint is predicted, more recent calculations shift predictions to rather high μ_B of about 600 MeV [3, 4]. This region of the QCD phase diagram lies in the center of the experimental program of the CBM experiment at the future FAIR facility. The SIS 100 accelerator will provide proton and heavy ion beams in the range of $\sqrt{s_{NN}}$=2.3-5.3 GeV (A+A) corresponding to baryochemical potentials μ_B from 520 to 785 MeV [5]. The HADES experiment running at the SIS18 at GSI [6] extends the reach down to $\sqrt{s_{NN}}$=2 GeV, i.e. $\mu_B \approx 830$ MeV. In order to exploit this region of the QCD phase diagram beyond past and current efforts it will be indispensable to run at very high interaction rates (fig. 1, right) in order to access rare observables or to extend the statistical reach of certain measurements. It turns out that rare observables and ever more precise data will be key observables closely connected to characteristics of the produced dense matter such as the question for its phase structure, the equation-of-state or the properties of hadrons and limits of hadron existence [9]. Also, systematic investigations in dependence on energy or size of the system will be critical to understand the created matter.

2 Key observables

At the critical point or when crossing a 1st order phase transition fluctuations in the density occur. Measuring those are thus the most interesting signature, however experimentally difficult to realize. The most promising observable is the measurement of cumulants

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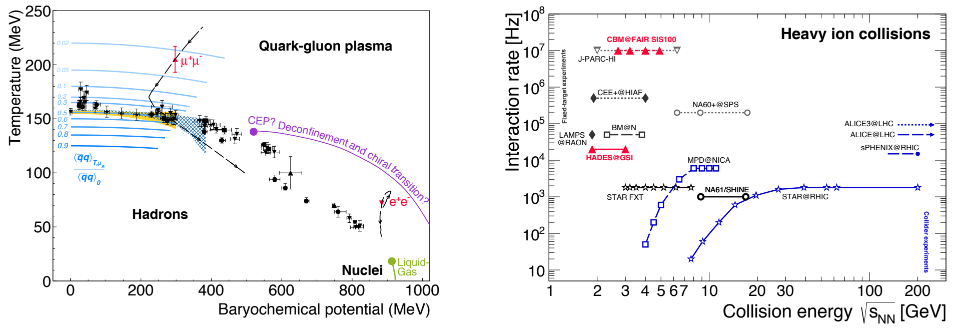

Figure 1. Left: QCD phase diagram with freeze-out points from various experimental programs including theoretical predictions [7] (and references therein). Right: Interaction rates for various experimental heavy-ion collision programs worldwide [8].

of baryon number as those measure derivatives in μ_B [10]. Experimentally, only protons can be measured, thus event-by-event the difference of the number of protons and antiprotons is recorded. Higher moments probe the tails, however this is a very statistics hungry measurement requiring high interaction rates. The measurement requires to systematically understand experimental effects such as acceptance, centrality, and - relevant for low center of mass energies - effects from baryon number conservation. The CBM experiment prepares for a centrality measurement with a forward calorimeter, independent on measuring the multiplicity in the event. The setup of CBM also ensures a wide acceptance for protons and antiprotons covering midrapidity by means of time-of-flight measurements. After three years of operation CBM aims at a measurement of the 4th order cumulants, i.e. the excitation function of $k\sigma^2 = \frac{\kappa_4}{\kappa_2}$ and first results on κ_6. Measurements already exist from the HADES [11] and STAR [12] experiments possibly indicating a change in the CBM energy range which so far remains unmeasured.

Another key observable CBM is aiming at is the measurements of electromagnetic probes, i.e. virtual photons. They are emitted throughout the full fireball evolution and their yield and energy are particularly sensitive to the temperature, duration and density of the dense phase. Within the first year of running CBM plans an energy scan covering 6 energies, having 5 days beam on target at 100 kHz interaction rate, thus collecting about $2 \cdot 10^{10}$ events each. This statistics will be sufficient to measure di-electron spectra extracting the excess yield in the low-mass region which is connected to the fireball lifetime. If the system crosses a phase transition, extra radiation due to latent heat is expected to be seen. Connected to this observable, a flattening of measured temperatures versus collision energy is predicted. A temperature measurement will be extracted from the invariant mass slope of di-electrons, both in the low and intermediate mass ranges. The measurement of the latter will be largely improved when the muon detector comes into place at CBM.

Strangeness production at CBM energies will also become a rare probe, as threshold energies for single, double or triple strange hadron production either lie slightly below or within the collision energy range of CBM. The silicon tracking system right after the target and within a large dipole magnet will allow for precise tracking, momentum determination and secondary vertex reconstruction. In particular strange baryons weakly decaying into charged tracks in the tracking system can be excellently reconstructed including the measurement of flow, correlations or polarization. For flow measurements, the forward calorimeter will not only measure centrality but also allow for event plane reconstruction. Beyond the measurement of Λ, Ξ and Ω baryons, the excellent tracking system of CBM will also allow for the reconstruction of $\Sigma^{\pm}$ baryons decaying into at least one neutral particle such as the neutron. Tracking algorithms will reconstruct the kink seen in the trajectory of the $\Sigma^{\pm}$ and combine this with a missing mass hypothesis for $\Sigma^{\pm}$ reconstruction. A measurement of the Σ^{-}/Σ^{+} ratio allows to access isospin dependences and is expected to carry information on the symmetry energy in the equation of state [13].

Hypernuclei production is predicted to have a maximum in the energy dependence of their cross sections at CBM energies [14, 15]. The silicon tracking system consequently can also reconstruct those decays, additional identification of light nuclei is provided by the TRD detector.

3 Experimental preparation

The construction of the FAIR facility is progressing continuously: The SIS 100 tunnel is available, technical installations are ongoing and the CBM cave is built and first user installations have been made. Thus, also CBM experimental preparations are progressing well targeting at first beams in 2028.

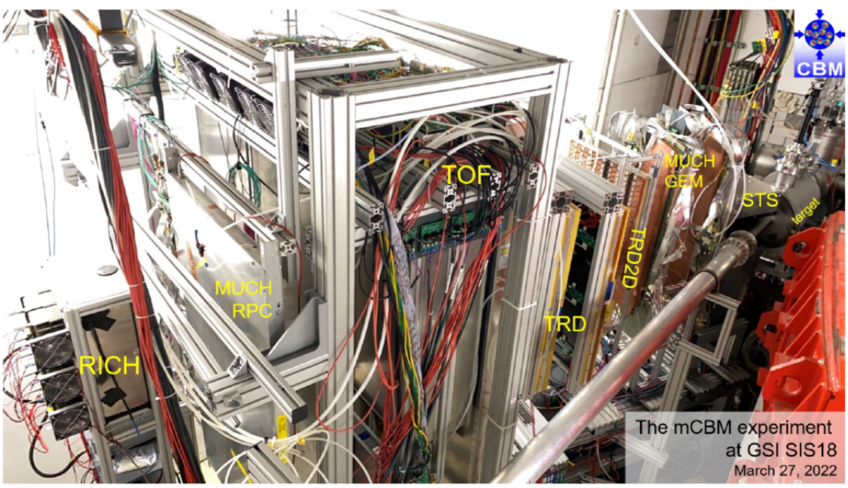

Figure 2. mCBM setup at SIS18 including prototypes of all subdetectors.

One major challenge of the CBM experiment will be to cope with the high interaction rates necessary to access rare and statistics hungry probes. In order to run and trigger the experiment at up to 10 MHz, a free-streaming readout concept with online event reconstruction and trigger decisions is foreseen [16]. In order to prepare for a smooth start of the CBM readout, the mCBM (mini CBM) experiment (see fig.2) has been constructed at the SIS 18 accelerator at GSI. Prototypes of the various detector components of CBM have been combined for a full system test and verification of the free-streaming readout relying on precise time stamps for detector signals and precise time synchronization of the CBM detector elements. The setup was run successfully at interaction rates up to 10 MHz delivering well synchronized signals, see e.g. [17]. The next milestone will be online reconstruction of Λ-baryons.

Preparation of the detectors is progressing well with first (pre-) series construction of various parts ongoing, see fig.3 for an impression.

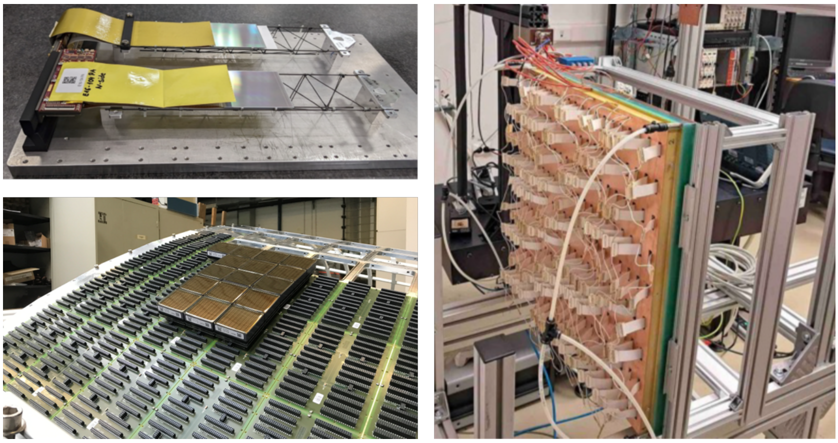

Figure 3. Top left: Pre-series STS modules. Bottom left: RICH photodetector plane. Right: Pre-series TRD modules.

4 Summary

The CBM collaboration prepares for first beams with the CBM detector at the FAIR SIS 100 accelerator in 2028, allowing for a detailed investigation of dense baryonic matter in the QCD phase diagram. The CBM collaboration will contribute to open QCD questions such as the phase structure of QCD at finite baryon density and the characterization of dense baryonic matter including the question of formation and correlation of hadrons and hypernuclei.

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