

## Feasibility Studies for Di-Electron Spectroscopy with CBM

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The Compressed Baryonic Matter experiment (CBM) at FAIR is designed to explore the QCD phase diagram at high net baryon densities and moderate temperatures by means of heavy ion collisions with energies from 2-11 AGeV beam energy (Au+Au collisions) and interaction rates up to 10 MHz, provided by the SIS100 accelerator. Leptons as penetrating probes not taking part in the strong interaction leave the fireball without being modified, thus carrying information from the hot and dense phase. However, di-leptons are rare probes, therefore calling for high efficiency and high purity identification capabilities. In CBM, electron identification will be performed by a Ring Imaging Cherenkov Detector (RICH), a Transition Radiation Detector (TRD) and a Time-of-Flight detector (ToF). In this contribution, feasibility studies of di-electron spectroscopy from low mass vector meson decays will be presented. Special emphasis is put on the application of fast simulations to achieve high statistics for the rare di-electrons in order to evaluate the feasibility of e.g. temperature measurements through di-leptons in the intermediate mass region beyond  $1 \text{ GeV}/c^2$ .

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## 1. Motivation

Quarks are strongly bound into hadrons at low net-baryon densities and temperatures. At zero chemical potential and a critical temperature of  $T_c \approx 155$  MeV lattice QCD calculations show an analytic crossover to a deconfined state, the quark gluon plasma [1]. From model calculations a first-order phase transition is suggested at zero temperature and finite chemical potential  $\mu_B$  [1]. Hence, a critical end-point (CP) between smooth crossover and first-order phase transition is assumed to exist. The CBM experiment at FAIR will investigate the QCD phase diagram with A+A collisions at center-of-mass energies of  $\sqrt{s_{NN}} = 2.3 - 5.3$  GeV, corresponding to  $\mu_B = 785 - 520$  MeV. This range is of particular interest, because the CP could be located therein [2].

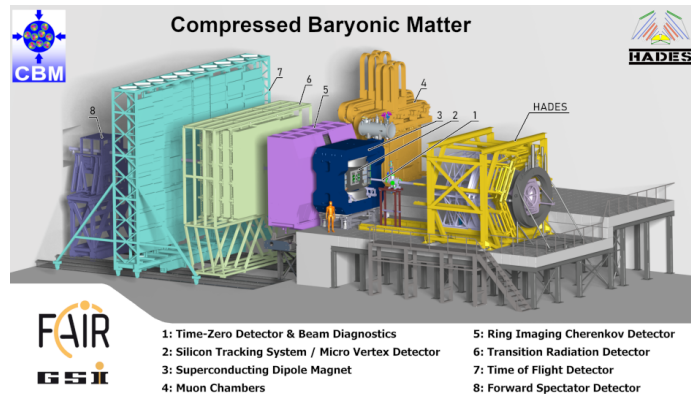
By means of di-electron spectroscopy lifetimes and average temperatures of the fireball created in these collisions can be determined. Di-electrons don't interact via the strong interaction but escape the fireball nearly undisturbed, thus being direct probes for the hot and dense matter.

The temperature can be calculated via the inverse slope of the invariant di-electron mass spectrum in the intermediate mass region (IMR) [3]. In this presentation, the feasibility to extract a temperature by means of di-electron spectroscopy at CBM is presented.

## 2. The CBM Experiment

CBM is a future fixed target experiment that is designed to explore the QCD phase diagram with special focus on rare probes. It will be located at the SIS100 accelerator ring at FAIR in Darmstadt/Germany and aims to start data taking in 2029. The CBM detector (Fig.1) is designed to record heavy ion collisions with highest interaction rates, up to 10 MHz [2]. These high rates require very fast readout electronics and online event selection procedures.

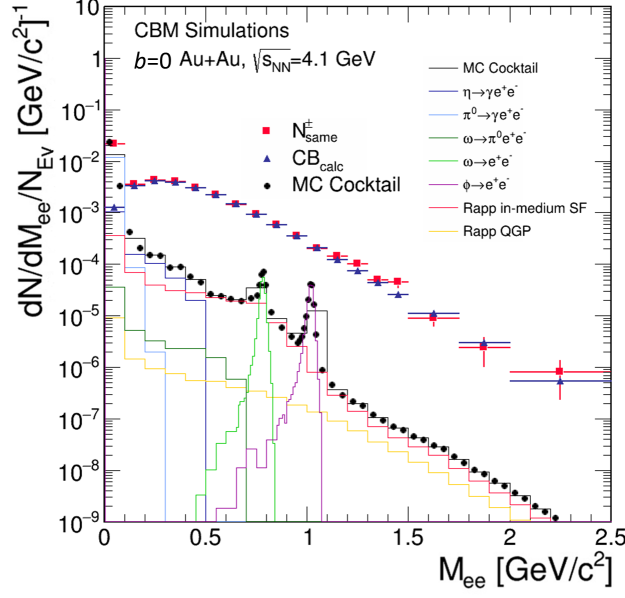
For electron identification the Ring Imaging Cherenkov Detector (RICH) [5–7] and Transition Radiation Detector (TRD) are essential. In addition the Time-of-Flight detector (TOF) and the Silicon Tracking System (STS) are used to separate electrons from other particles, as e.g. pions and protons.



**Figure 1:** Sketch of the future CBM detector with the existing HADES detector at GSI. Figure taken from [4].

## 3. Feasibility Studies for Di-Electron Spectroscopy

The feasibility studies are performed with simulated central ( $b = 0$  fm) Au+Au collisions from UrQMD with a center-of-mass energy of  $\sqrt{s_{NN}} = 4.1$  GeV and a statistics of  $5 \times 10^6$  events. Into each event one meson ( $\eta$ ,  $\omega$ ,  $\rho$ ,  $\phi$ ) with a thermal distribution generated by PLUTO and QGP radiation is embedded. Reconstructed tracks that are identified as electrons in RICH, TRD and



**Figure 2:** Invariant mass spectrum of di-electrons for  $5 \times 10^6$  central Au+Au collisions at  $\sqrt{s_{NN}} = 4.1$  GeV.  $N_{\text{same}}^{\pm}$  will be measured in the experiment. The calculated combinatorial background is indicated with  $CB_{\text{calc}}$ . The MC Cocktail is the sum of the meson contributions and QGP radiation.

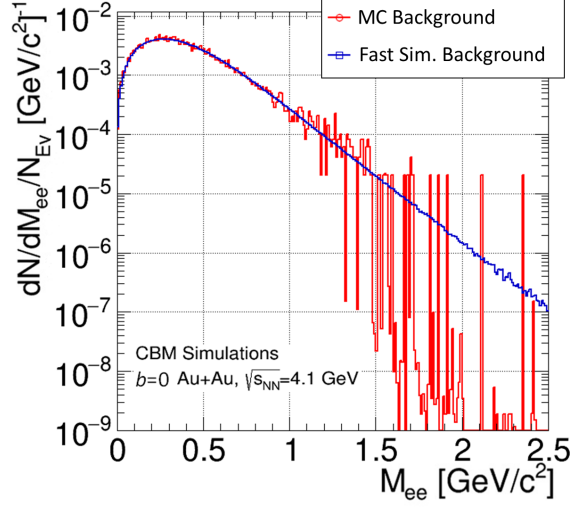
TOF are further processed for di-electron spectroscopy. A sequence of cuts on the opening angle of track pairs is applied in order to reject physical background which is mainly caused by the large number of  $\pi^0$  that are created in A+A collisions. These pions are mostly decaying into  $2\gamma$  (98.8 %) or into  $\gamma e^+ e^-$  ( $\lesssim 1.2$  %) [8]. Many electrons from subsequent  $\gamma$  conversions due to the material in front of the RICH detector and the Dalitz decays leave no reconstructable tracks in the detectors. Secondary electrons leave rings in the RICH and can easily be matched to tracks of charged hadrons as e.g. pions or protons and hence lead to misidentifications. In Fig. 2 the invariant mass spectrum of di-electrons is shown for an analysis of  $5 \times 10^6$  events including a CBM setup consisting of all detectors except the MVD. Here  $N_{\text{same}}^{\pm}$  represents the total  $e^+ e^-$  yield that will be measured in the experiment. For each mass bin, the amount of the combinatorial background can be estimated via

$$CB_{\text{calc}} = 2k\sqrt{B^{++}B^{--}}, \quad k = \frac{b^{\pm}}{\sqrt{b^{++}b^{--}}}, \quad (1)$$

where  $B^{\pm\pm}$  is the total like-sign pair yield from same events and  $b^{\pm\pm}$  the like-sign yield from mixed events. The factor  $k$  is a correction factor that accounts for acceptance (and efficiency) difference between like-sign and unlike-sign pairs and is calculated through the mixed-event technique. At higher invariant masses ( $M > 0.4$  GeV/ $c^2$ ), the same event like-sign yields are replaced by normalised mixed event like-sign yields. The signal is then calculated as

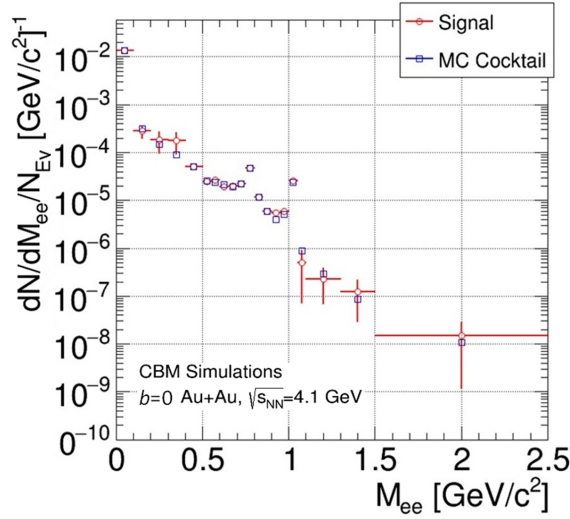
$$S = N_{\text{same}}^{\pm} - CB_{\text{calc}} \quad (2)$$

for each mass bin. In simulations, the signal can be compared to the MC input in order to verify the background calculation procedure. In order to artificially enhance the event statistics a fast



**Figure 3:** Di-lepton spectra for background contributions only from  $5 \times 10^6$  UrQMD events (red) and  $20 \times 10^9$  events using the fast simulation technique (blue).

simulation procedure was developed. The events created by the fast simulation procedure are based on the output yields of the conventional UrQMD events and appropriately scaled signal electrons provided by the PLUTO generator. For this, the multiplicity and 3D-momentum distributions of



**Figure 4:** Signal ( $S = B_{FS} + \text{Cocktail} - CB_{\text{calc}}$ ), calculated by means of fast simulation techniques, compared to the input MC Cocktail (blue).

identified UrQMD and PLUTO electrons are used as probability distributions in order to create new events for fast simulations. Both di-lepton spectra, UrQMD with a statistics of  $5 \times 10^6$  events and the yield obtained by the fast simulations are shown in Fig. 3. For both spectra no signal is included. The number of events from fast simulations is set to  $20 \times 10^9$ . This number is expected to

be achieved in the first year of an energy scan with the CBM detector for each of 5-6 energy values. Based on this statistics, the signal can now be extracted. Since the fast simulation events are not correlated, the total  $e^+e^-$  yield  $N_{\text{same}}^\pm$  is split up into a part with uncorrelated pairs ( $B_{\text{FS}}$ ) from fast simulations and a part with true pairs ("Cocktail"). The signal now is calculated as

$$S = B_{\text{FS}} + \text{Cocktail} - \text{CB}_{\text{calc}}. \quad (3)$$

In Fig. 4 the such obtained signal is shown in comparison to the MC input Cocktail.

#### 4. Temperature Estimation

The temperature averaged over the lifetime of the fireball can be extracted from the slope of the di-electron mass distribution for masses  $M > 1 \text{ GeV}/c^2$ . In this region, the following relation between the excess yield  $\frac{dN}{dM}$  and the temperature is given [3]:

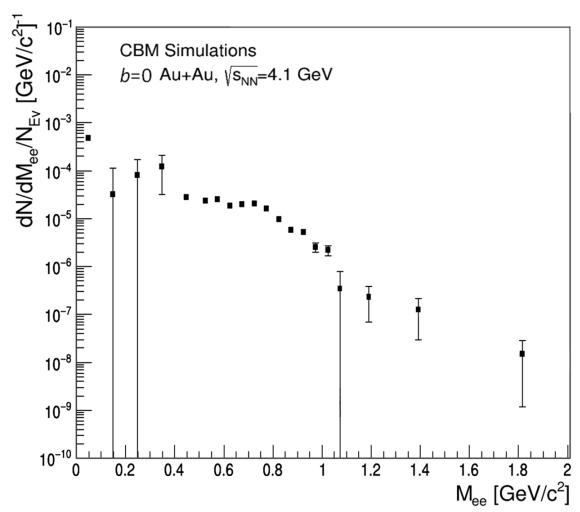
$$\frac{dN}{dM} \propto (MT)^{3/2} \exp(-M/T). \quad (4)$$

To apply this, at first, contributions from all freeze-out hadrons have to be subtracted from the calculated signal. These are di-electrons stemming from decays of  $\pi^0$ ,  $\eta$ ,  $\omega$  and  $\phi$  mesons. The remaining spectrum (reduced signal) should contain di-electron yields from the in-medium rho ( $\rho_{\text{i.m.}}$ ) and QGP radiation only. Fig. 5 shows this reduced signal. Due to the large bins for masses  $M > 1 \text{ GeV}/c^2$  a correction of the bin position in mass is applied [9].

Errors are dominated by event statistics in combination with the signal-to-background ratio. Still, a temperature estimate will be possible for the anticipated first data sets of CBM.

#### 5. Conclusion and Outlook

A fast simulation technique was implemented to generate large statistics of the rare di-electron signal. Results obtained show good agreement with the MC Cocktail. The simulated statistics was chosen according to the planned number of events for the first data sets of the CBM energy scan. In the intermediate mass region, the error is dominated by a small signal-to-background ratio  $S/B$  and the available statistics. Taking into account the current setup and a statistics of  $20 \times 10^9$  events with  $S/B \approx \frac{1}{300}$  in the IMR, the last bin ( $1.5 < M \leq 2.5 \text{ GeV}/c^2$ ) has  $N \approx 60,000$  entries. Hence the size of the statistical error  $\Delta N$  is in the order of magnitude of the signal:  $\Delta N = \sqrt{N} \approx 245$  and  $S = N \cdot \frac{S}{B} = 200$ . For the first year, a quick energy scan with 4-5 days data taking for each 5-6 energy values is planned. Thorough measurements for each energy will follow. Improvements in order to get a higher rejection rate of physical background and decrease misidentifications are ongoing. We thus expect overall a better performance than presented here.



**Figure 5:** Reduced signal: Signal minus contributions from known sources that will be fitted with the temperature relation in Eq. 4 in order to determine the temperature.

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