The Ring Imaging Cherenkov detector for the CBM-Experiment

Christina Dritsa for the CBM collaboration
Justus-Liebig-Universität, Giessen
E-mail: Christina.A.Dritsa@exp2.physik.uni-giessen.de

Abstract. The mission of the future Compressed Baryonic Matter experiment, to be operated at the FAIR facility at GSI, Darmstadt, is the exploration of the properties of super-dense nuclear matter. In particular, the search for in-medium modifications of hadrons, the study of the transition from dense hadronic matter to quark-gluon matter, and the location of a critical endpoint in the phase diagram of strongly interacting matter are the principal physics goals of CBM. Detailed measurements of di-leptons and open charm probes are hoped to shed light to the existence of such effects.

The Ring Imaging Cherenkov detector of CBM aims at a clean and efficient electron identification. It is foreseen to have CO$_2$ as radiator gas and to be equipped with Hamamatsu multi-anode photomultiplier tubes. Herewith we present selected results of R&D studies and beam test measurements of the RICH prototype performed in October 2011 at the CERN/PS with negatively charged particles.

1. Introduction

The Compressed Baryonic Matter experiment (CBM) [1] will be one of the core experiments of the future FAIR facility at GSI, Darmstadt. CBM will study nuclear matter in the regime of highest net-baryon densities with various rare probes, among them low-mass vector mesons and charmonium. Low-mass vector mesons decay in leptons which have the particular property to leave the hot and dense fireball without undergoing any strong interactions. Therefore, their study is hoped to provide information on in-medium properties of vector mesons, as well as on charmonium production and propagation in hot and dense matter. Reconstructing these particles requires a set of high performance detectors. Among them is the Ring Imaging Cherenkov detector (RICH).

2. The RICH detector

The operation principle of RICH detectors is based on the fact that charged particles passing through a dielectric medium with a speed higher than the phase velocity of light in that medium emit electromagnetic radiation (cherenkov radiation). By measuring the angle of emission of the cherenkov radiation the identification of charged particles is achieved. The CBM-RICH is designed to provide electron identification for the CBM experiment in the momentum range of electrons from low-mass vector-meson decays, i.e. for $p \leq 8$ GeV/c. The detector will cover the full azimuthal angle and polar angles from 2.5° to 25°. For a sufficiently pure electron sample, a pion suppression factor in the order of 500 - 1000 is required for the RICH alone. The
electron identification in the RICH is complemented by several layers of TRDs. A combined pion suppression of $10^4$ will be achieved. Main challenges in the design of the RICH detector are set by the fact that it will be operated in a high track density environment: up to 1000 charged primary particles per event at interaction rates up to 10 MHz are expected in the detector acceptance for central Au+Au collisions if operated at the highest energies.

In order to cope with the high interaction rates, a vertically separated RICH detector is planned with CO$_2$ as radiator gas and MAPMTs with fast, self-triggered readout electronics as photodetector.

Given the high particle fluxes expected, a high electron-to-pion separation is needed. Assuming that pions can be separated from electrons up to 90% of the maximum Cherenkov opening angle, the choice of CO$_2$ is motivated by the need to separate electrons and pions with momenta up to $p \approx 10$ GeV/c. In CO$_2$ the transmittance of photons is limited by absorption to wavelengths $\lambda \geq 175$ nm.

Spherical glass mirrors with an Al+MgF$_2$ coating will be used to reflect the Cherenkov light cones on the 2.4 m$^2$ photodetector plane. Simulation studies have shown that the material budget of the mirrors is not crucial, therefore a thickness of 6 mm is tolerable. Several types of mirrors have been tested in the laboratory in terms of surface homogeneity and reflectivity (see Section 2.1). The photodetector plane is foreseen to be equipped with Hamamatsu H8500 multi-anode photomultiplier tubes (55000 channels). These are delivered from the factory with two different windows: borosilicate or UV enhanced window. The former exhibits an absorption edge at $\lambda \approx 270$ nm, the latter at $\lambda \approx 210$ nm. These limits are somewhat above the absorption limit for CO$_2$ (175 nm). Therefore, the option to use wavelength-shifting (WLS) films on top of the MAPMT windows in order to match the CO$_2$ absorption limit is under investigation. The usage of WLS films is based on their property to absorb deep UV photons and to re-emit them with longer wavelengths, where the transparency of the MAPMT window and the quantum efficiency of the photocathode is higher. Typical materials used for WLS are p-terphenyl (PT) and tetraphenyl-butadiene (TPB).

In order to cope with the high interaction rates (up to 10 MHz) required for the J/Ψ measurements in CBM, a fast, self-triggered readout electronics is foreseen. The data will be delivered to a large PC farm where they will be processed to allow for partial on-line event reconstruction.

2.1. Mirror tests
The Cherenkov photons are emitted in the form of light cones and a large fraction of the wavelengths lies in the UV region. These cones are focused with the use of spherical glass mirrors, forming rings on the photodetector plane. Detailed measurements were performed in cooperation with CERN for mirrors from different manufacturers: (i) FLABEG GmbH, Furth im Wald, Germany, (ii) Compas, Czech Republic, and (iii) JLO-Olomouc, Czech Republic. All mirrors are covered with an Al layer for best reflection of the UV photons and a MgF$_2$ layer to ensure protection from generation of aluminum oxidation layer which absorbs UV-photons. Table 1 summarizes all the important parameters of the tested mirrors: the radius of curvature $r_0$, the thickness of the glass substrate $d$, the area of the quadratic mirrors $A$, the thickness of the Al-and MgF$_2$ layer, $d$(Al) and $d$(MgF$_2$) (if measured), the results of $D_0$-measurements$^1$, as well as selected reflectivity data. Figure 1 summarizes the results on reflectivity measurements as a function of wavelength for all mirrors tested. The Flabeg mirrors (red rectangles) show the best reflectivity ($\geq 85\%$) for wavelengths above 250 nm. However, this performance drops significantly below 80\% for smaller wavelengths. The best compromise, i.e. very good reflectivity

$^1$ $D_0$ is defined as the diameter of the circle containing 95\% of the total light intensity reflected by the mirrors when being fully illuminated.
Table 1. Parameters of the mirrors tested in the laboratory. Not all quantities are measured (indicated by n.a.). For details see text.

| Producer | $r_0$ [mm] | $d$ [mm] | $A$ [cm$^2$] | $d$(Al) [nm] | $d$(MgF$_2$) [nm] | $D_0$ [mm] | R(200 nm) [%] | R(300 nm) [%] |
|----------|------------|----------|-------------|-------------|----------------|-----------|-------------|-------------|
| Flabeg   | 3200       | 6        | 40 x 40     | 55          | 120            | diffuse   | 78          | 90          |
| Compas   | 3000       | 6        | 20 x 20     | n.a.        | n.a.           | $\leq 3$  | 63          | 76          |
| JLO      | 3000       | 6        | 40 x 40     | 110         | 110            | $\leq 2$  | 82          | 85          |

Figure 1. Reflectivity measurements, performed at CERN or at University of Wuppertal (WU), as a function of wavelength for various mirrors. Additionally, the reflectivity of a mirror coated by Andre Braem (CERN) is shown for comparison.

for all wavelengths down to $\sim$ 200 nm, is given by the JLO-Olomouc mirror (blue circles) which also shows the best results in terms of $D_0$ (see Table 1). Thanks to these performances, this type of mirror is chosen to be used for the prototype measurements in beam.

2.2. The RICH-prototype
A CBM-RICH prototype has been built and tested in beam in 2011 at the CERN/PS, line T9 [2]. Figure 2 on the left, shows the technical drawing of the prototype and a photo can be seen on the right of the same figure. The radiator length is identical as for the final CBM-RICH, i.e. 1.7 m. The individual modules are large enough to allow for first studies of system integration issues. The Cherenkov light cone is projected on the photodetector by four high reflectivity UV spherical mirror tiles of 40 x 40 cm$^2$ with radius R=3 m. Each mirror is mounted on three points with holders including an actuator. This mounting scheme minimizes distortions and allows for mirror rotation and alignment. The complete mirror array is mounted on two frames which allow orienting the Cherenkov light on different areas of the photodetector. The latter consists of an array of 4 x 4 multianode photomultiplier tubes (MAPMTs). The gas system is computer controlled and aims at a clean and dry CO$_2$ flow. The evaluation of the prototype in this beam test mainly focuses in three topics: a) study of system integration issues (mirror, support, photodetector, electronics), b) test the ring finding and ring reconstruction algorithms and, c) study the detector performance under realistic conditions, i.e. in terms of number of photons per ring, noise levels, electron-to-pion separation, sensitivity to gas impurities, sensitivity to mirror distortions and misalignment.
3. Selected beam test results

A figure of merit for all RICH detectors is the ring hit multiplicity, i.e. the number of photons (hits) per ring. The latter was found between 19 and 22 photoelectrons without any correction for cross-talk. If correction for cross talk is applied, then the hit multiplicity varies between 16.7 and 19.4 photoelectrons, depending on the quantum efficiency of the MAPMTs. The WLS coated MAPMTs show enhanced hit multiplicities when compared to the non-coated ones. However, a detailed evaluation of this effect needs to take into account the efficiency of every MAPMT [3].

Figure 3 shows single and integrated rings from electrons of 6 GeV/c momentum (left to right) as obtained from the beam test. One also observes a high contrast between background noise and signal from electron rings. A very efficient shielding allowed reaching very low noise rates of the order of 10 Hz per channel (below 10 kHz for the whole photodetector).

The ring finding and fitting algorithms allowed fitting rings with ellipse or circle shapes. A 100% reconstruction efficiency was observed for rings with more than 8 hits (see Figure 4). Moreover, once a ring is found, it is successfully fitted providing thus the ring parameters such as the number of hits per ring, the radius (when fit as circle) and the major and minor half-axis (when fit as an ellipse). In order to have an electron sample as clean as possible for the CBM measurements, a good electron-to-pion separation for momenta up to 8 GeV/c is one of the major requirements of the CBM-RICH. It was found that for particles with momenta of 8 GeV/c the electron-to-pion separation is above 7σπ which is an excellent performance. It should be stressed here that this measured performance is achieved under beam test conditions and does not translate directly to the actual CBM environment.

The electron-to-pion separation can be expressed in terms of standard deviations (σπ) of the gauss fit of the distribution of pion ring radii.
Figure 4. Ring finding efficiency as a function of the number of hits in the event. The efficiency is 100% for rings with more than 8 hits. The different colors correspond to data taken from different runs.

not include effects such as the track reconstruction and the track-ring matching efficiencies. Figure 5 shows the distribution of ring radii for negative particles of 8 GeV/c momentum. One sees a clear separation between pions and electrons based on their ring radius. These measured results match very well the corresponding simulation results for the prototype.

Figure 5. Distribution (blue line) of ring radii for negative pions, muons and electrons of 8 GeV/c momentum. A gauss fit is shown with the red line.

4. Summary
A RICH detector for CBM at FAIR is being developed for efficient and clean electron identification. The different R&D activities include the development of self-triggered readout electronics and the re-evaluation of wavelength-shifting films for enhanced quantum efficiency in the UV-range. For the envisaged glass mirrors, prototypes from various industrial providers have been evaluated in terms of mirror reflectivity and surface homogeneity tests. A real size RICH prototype has been built and tested at the CERN/PS in October 2011. This test revealed very promising results on the number of photoelectrons per ring, the effect of WLS coating films, the ring fitting and finding efficiency as well as the electron-to-pion separation capability of the RICH.

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**References**

[1] C. Hühne, F. Rami, and P. Staszel, Nucl. Phys. News 310 16, 19 (2006).

[2] C. Bergmann et al., “Common CBM beam test of the RICH, TRD and TOF subsystems at the CERN PS T9 beamline”, GSI Scientific Report 2011

[3] J.Kopfer, “In-beam test of a real-size CBM-RICH prototype at CERN PS”, GSI Scientific Report 2011