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Fast Ring Recognition Algorithm for the RICH Detector of the CBM Experiment at FAIR

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The Compressed Baryonic Matter (CBM) experiment at the future FAIR facility at Darmstadt will measure dileptons emitted from the hot and dense phase in heavy-ion collisions. Measuring di-electron, a high purity of identified electrons is required in order to suppress the background. Electron identification in CBM will be performed by a Ring Imaging Cherenkov (RICH) detector and Transition Radiation Detectors (TRD).

In this contribution we will present algorithms which were developed for event reconstruction in the RICH detector. Efficient and fast ring recognition is based on the Hough Transform method which was accelerated considerably compared to a standard implementation. Ring quality selection is done using an Artificial Neural Network. Ellipse fitting algorithm was developed for RICH ring fitting. These reconstruction methods allow for a high purity and efficiency of reconstructed electron rings.

Key words and phrases: CBM, RICH detector, ring recognition, ring finding, ANN, Artificial Neural Network.

1. Introduction

The Compressed Baryonic Matter (CBM) experiment [1] is designed to investigate nucleus-nucleus collisions from 10-45 *A*GeV beam energy at the future international FAIR project.

The experimental task is to identify both hadrons and leptons and to detect rare probes such as dileptons and charm production. The challenge is to select these rare events with charged particle multiplicities of about 800 per central event at reaction rates of up to 10 MHz. Such measurements require fast and radiation hard detectors, fast and self-triggered read-out electronics, a high-speed data acquisition system, online event selection based on track reconstruction, and fast offline tracking and event reconstruction routines as well.

The core of the CBM detector is a Silicon Tracking System (STS) in a magnetic dipole field. The STS provides track and vertex reconstruction and momentum determination. Detectors for particle identification will be placed upstream of the magnet: a Ring Imaging Cherenkov (RICH) detector together with Transition Radiation Detectors (TRD) for electron identification and a time-of-flight (TOF) wall for hadron identification. The setup will be completed by an Electromagnetic CALorimeter (ECAL) for the measurement of direct photons and a Projectile Spectator Detector (PSD) for the determination of collision centrality and of the reaction plane.

2. The RICH Detector

The RICH detector in CBM [2] will serve for electron identification from lowest momenta up to 10 GeV/c needed for the study of the dielectronic decay channel of vector mesons.

Currently two different RICH designs are under discussion [2]. Both designs provide about 22 hits/ring but differ in length due to different choices of radiator gas.

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The larger option would be run with nitrogen as radiator, has a radiator length of 2.25 m and a resulting ring radius for electrons of about 6 cm. In the smaller option CO_2 would be used as radiator gas and the ring radius of electrons would be about 5 cm due to a smaller mirror curvature and reduced radiator length of 1.5 m. As photodetector MAPMTs from Hamamatsu (H8500-03) are implemented in the simulation. The dimensions of the sensitive pads for H8500-03 are appr. 0.6x0.6 cm^2, which is of the order of 10% of the ring radius. The ring and hit density on the photodetector plane is non-uniform. The inner part which is closer to the beam pipe has the highest ring densities. Fig. 1 illustrates the layout of the RICH detector in the GEANT simulations of CBM and a typical part of a RICH event for central Au+Au collisions at 25 AGeV beam energy.

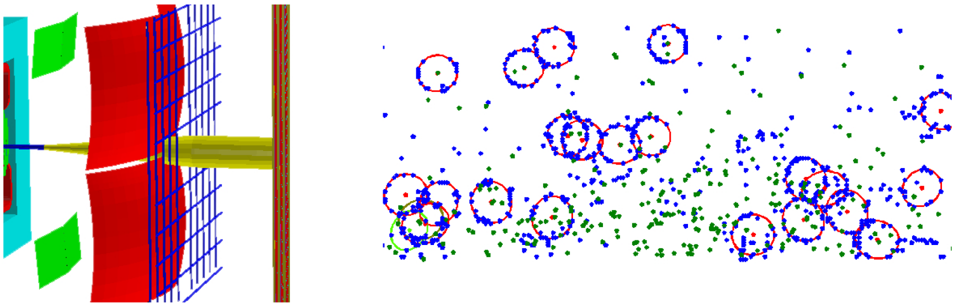

Figure 1. **Left: Sketch of the smaller CO_2-RICH setup as used in simulations (outer gas box omitted). Right: Part of one typical event: RICH hits, found rings, track projections form the STS**

3. Ring Recognition in the CBM RICH Detector

The main challenge of the ring recognition in the CBM RICH detector results from the large multiplicity in heavy-ion collisions. This high charged particle multiplicity leads to a high ring density in the RICH detector (appr. 100 rings per event). Most measured electrons are electrons produced in the STS detector or magnet yoke. The resolution of the Cherenkov angle, i.e. ring resolution is determined to approximately similiar magnitude by multiple scattering, distortions from the residual magnetic field and detector granularity. Rings are slightly distorted to ellipses with about 10% difference in the length of major and minor half axis, because the flat photodetector can only be approximately placed in the focal plane.

The developed ring recognition algorithm is standalone, i.e the input data is only an array of RICH hits without information from other detectors. It consists of two steps. First, a local search of ring-candidates based on localized Hough Transform (HT) is performed. The second step is a global search, in which mainly the quality of rings is determined using an artificial neural network (ANN). This step is used as filter: collecting information about all ring-candidates, the algorithm compares them and chooses only high quality rings, rejecting repeatedly found rings and wrongly found rings.

The first step in the ring recognition procedure is to determine the local area, in which a ring is located. Instead of combining all possible hit triplets in the photodetector plane, we use the fact that the RICH rings have a maximum radius $R_{\max}$ because of the limiting Cherenkov angle. Hit triplets are only combined within this distance plus a safety margin, e.g. within $2R_{\max} = D_{\max}$. The recognition procedure then starts from the first hit in this hit array, which defines the preliminary position of the first ring. Then all hits are collected lying whithin the predefined region around the initial hit (see Fig. 2, left).

In the next step center and radius are calculated using HT equations from every triplet of selected hits. The calculated values are filled in the histograms of ring parameters. In our approach two independent histograms are used: a 2D histogram

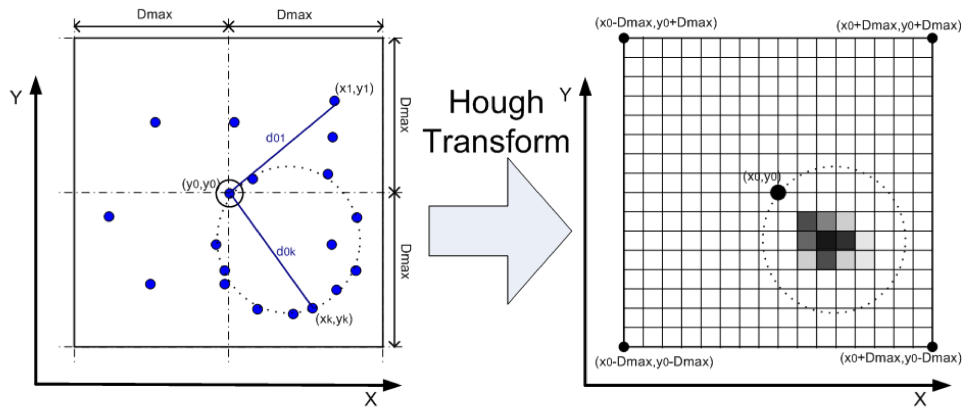

Figure 2. **Preliminary local hit selection in a region defined by the maximum ring diameter plus a safety margin(left). Schematic view of the 2D histogram of ring centers (right)**

for ring centers (see Fig. 2, right) and a 1D histogram for the radii. Note that the 2D histogram is created only in the same local area, thus it has small dimensions (here: 15 by 15 bins), this significantly reduces memory consumption and computational time. When the histograms are built, strong peaks in each histogram should correspond to the supposed positions of ring centers (2D histogram) and radii (1D histogram). If the peak is higher than a prescribed cut this ring-candidate is accepted and shifted to the ring-candidate array, otherwise rejected.

The above described local ring-candidate search algorithm finds not only correct rings but also wrong rings which are formed by random combinations of hits. In order to reliably reject these fake rings, a set of ring characteristics was selected which is used for a quality estimation of found rings. The selected properties differ significantly for wrongly and correctly found rings. After a statistical analysis nine parameters were selected: the number of hits per ring; χ^2 of the ellipse fitting; the position of the ring in the RICH detector, etc. An ANN has been trained for the ring quality calculation using these nine input parameters. The output values of the ANN concentrate around ± 1 thus providing ring quality measure or probability whether a ring-candidate was correctly found or not.

The final selection of good rings from the array of found ring-candidates is based on this ring quality. A selection algorithm compares the ring quality choosing good rings and rejecting repeatedly found rings (clones) and wrongly found rings. First, the array of rings is sorted by the ring quality, thus starting with the highest quality rings. When filling the output ring array, the algorithm checks for shared hits with all other ring-candidates. If the ring shares more than 30% of its hits with better quality rings it is rejected.

In the RICH reconstruction both a circle fitter and an ellipse fitter are used. Because of its simplicity circle fitting is used in the ring recognition algorithm. The main requirement to this algorithm is a very high computational speed while keeping reasonable accuracy. The algorithm which is known as COP (Chernov-Ososkov-Pratt) is used [3]. As the rings in the CBM RICH detector have a slight elliptic shape, an ellipse fitting method based on the Taubin method [4] was implemented for more precise parameter determination.

4. Results

The algorithm was developed and tested using simulated data within the CBM software framework [5]. About 100 rings per event are seen in the RICH detector. As mentioned above two different RICH designs are under discussion. In the larger N_2-RICH efficiencies are as high as 95% while dropping by 2% for the smaller CO_2-RICH with higher ring densities. Overall, typically 4% of the approximately 100 found rings are fake rings and 2% clone rings.

5. Summary

A fast and efficient algorithm for ring recognition in the CBM RICH detector was developed. The ring recognition is based on the Hough Transform method with a local selection of hits. An ellipse fitting algorithm has been implemented for precise estimation of ring parameters. A global ring search algorithm was developed for good ring selection. The time of the reconstruction of one event in the RICH detector with typically more than 100 rings is from 10 ms to 80 ms on a Pentium4 2GHz. The variation of time depends on selected parameters in the ring reconstruction trading efficiency vs. speed. The algorithm has shown a very good performance in terms of ring finding efficiency and is robust towards a high ring multiplicity environment.

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Алгоритм быстрого поиска колец в RICH детекторе эксперимента CBM на FAIR

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В эксперименте CBM (Compressed Baryonic Matter) на строящемся в институте GSI (Дармштадт, Германия) ускорительном комплексе FAIR планируется изучение ди-лептонов, образующихся в соударениях тяжёлых ядер при энергиях от 10 до 45 АГэВ. Для этого требуется очень чистая идентификация электронов, чтобы их выделить из шума. Идентификация электронов будет производиться с помощью RICH детектора (Ring Imaging Cherenkov) и TRD детектора (Transition Radiation Detectors).

В данной работе представлены алгоритмы, которые были разработаны для реконструкции событий в детекторе RICH. Алгоритм поиска колец основан на преобразовании Хафа, которое было существенно ускоренно по сравнению со стандартной реализацией. Алгоритм выбора хороших колец и отсева неправильно найденных основан на использовании искусственной нейронной сети. Для подгонки колец был реализован алгоритм подгонки эллипсом. Разработанные алгоритмы позволяют с высокой эффективностью распознавать кольца RICH.

Ключевые слова: CBM, RICH детектор, распознавание колец, поиск колец, искусственные нейронные сети.