

# A hadron blind detector\* for the PHENIX experiment at RHIC

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A novel Hadron Blind Detector (HBD) has been developed for an upgrade of the PHENIX experiment at RHIC. The HBD will allow a precise measurement of electron-positron pairs from the decay of the light vector mesons and the low-mass pair continuum in heavy ion collisions. The detector consists of a 50 cm long radiator filled with pure CF<sub>4</sub> and directly coupled in a windowless configuration to a triple Gas Electron Multiplier (GEM) detector with a CsI photocathode evaporated on the top face of the first GEM foil.

## 1. INTRODUCTION

In this paper we present a summary of the R&D results and expected performance of a Hadron Blind Detector (HBD) which has been developed as an upgrade of the PHENIX detector at the Relativistic Heavy Ion Collider (RHIC) at BNL. The HBD will allow the measurement of electron-positron pairs from the decay of the light vector mesons ( $\rho$ ,  $\omega$  and  $\phi$ ) and the low-mass ( $m_{e^+e^-} \leq 1 \text{ GeV}/c^2$ ) pair continuum in Au+Au collisions. Dileptons are valuable probes to diagnose the hot and dense matter formed in relativistic heavy ion collisions. The physics potential of this probe is fully confirmed by results from lower energy experiments. The most prominent result is the strong enhancement of low-mass electron pairs observed by the CERES experiment [1] at the CERN SPS and recently confirmed by the NA60 results [2]. This enhancement triggered a wealth of theoretical activity and was quantitatively reproduced only by invoking the thermal radiation from a

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high density hadron gas ( $\pi^+\pi^- \rightarrow e^+e^-$ ) with in-medium modification of the intermediate  $\rho$  meson which could be linked to chiral symmetry restoration [3].

However, the measurement of electron pairs is a very challenging one. The main difficulty arises from the huge combinatorial background, *i.e.* uncorrelated pairs formed by tracks from unrecognized  $\gamma$  conversions and  $\pi^0$  Dalitz decays. For example, the analysis of Run-4 data taken with the present PHENIX configuration [4] shows that the signal to background ratio, S/B, at the invariant mass of  $m_{e^+e^-} \sim 500$  MeV/ $c^2$  is approximately 1/500, making the measurement of the low-mass pair continuum practically impossible. An upgrade of the PHENIX detector is therefore necessary for this measurement. The present paper is focused on the comprehensive R&D program that we have carried out over the past two years to develop such an upgrade [5,6].

## 2. THE HBD CONCEPT

The upgrade consists of two elements: a) installation of an inner coil (foreseen in the original design of PHENIX) which results in an almost field-free region close to the vertex, extending out to  $\sim 60$  cm in the radial direction; b) the major and challenging element of the upgrade is a hadron-blind detector (HBD) located in this field free region. Fig. 1 shows the layout of the inner part of the PHENIX detector together with the location of the coils and the proposed HBD. The main task of the HBD is to recognize and reject  $\gamma$  conversions and  $\pi^0$  Dalitz decays. The strategy is to exploit the fact that the opening angle of electron pairs from these sources is very small compared to the pairs from light vector mesons. In the field-free region, this angle is preserved and by applying an opening angle cut one can reject more than 90% of the conversions and  $\pi^0$  Dalitz decays, while preserving most of the signal.

Based on Monte Carlo simulations, the main HBD specifications are: electron identification with a very high efficiency ( $> 90\%$ ), double hit recognition at a comparable level and moderate  $\pi$  rejection factor of  $\sim 100$ . We analyzed possible realizations of the HBD detector and finally adopted the following scheme: a windowless Čerenkov detector, operated with pure  $\text{CF}_4$  in a proximity focus configuration and directly coupled to a triple Gas Electron Multiplier (GEM) [7] detector with a CsI photocathode evaporated on the top face of the first GEM foil and with pad readout.

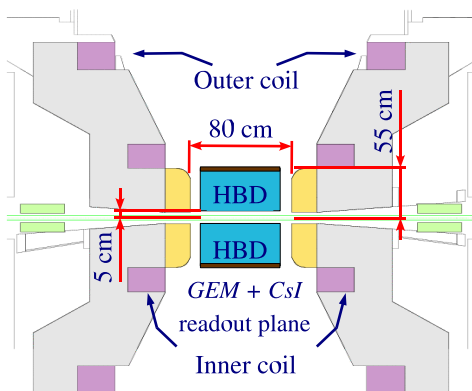


Figure 1. Layout of the inner part of the PHENIX detector.

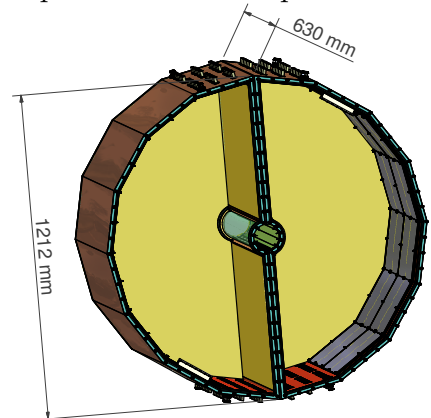


Figure 2. 3D view of the HBD final design.

### 3. SUMMARY OF R&D RESULTS

The concept described in the previous section exhibits a number of very attractive features. a) The choice of  $\text{CF}_4$  both as radiator and detector gas in a windowless geometry results in a very large bandwidth (6-11.5 eV) and consequently in a very large figure of merit  $N_0$  ( $\sim 800 \text{ cm}^{-1}$ ). With these unprecedented numbers, the number of photoelectrons  $N_{pe}$  is expected to be of the order of 35 for a 50 cm long radiator. b) The readout scheme foresees the detection of the Čerenkov photoelectrons in a pad plane with hexagonal pads of size slightly smaller than the blob size ( $\sim 10 \text{ cm}^2$ ) such that the probability of a single-pad hit by an electron entering the HBD is negligibly small. On the other hand, whenever a hadron gives a signal in the HBD, it will produce a single pad hit with an almost 100% probability. This will provide a strong handle on the hadron rejection factor of the HBD. c) The relatively large pad size results also in a low granularity and therefore a low cost detector. In addition, since the photoelectrons produced by a single electron will be distributed between at most three pads, one can expect a primary charge of at least 10 electrons/pad, allowing operation of the detector at a relatively moderate gain of a few times  $10^3$ . This is a crucial advantage for the stable operation of a UV photon detector. However, many elements of the proposed HBD were new and had not been tested before in the laboratory. A number of issues and questions were raised which required dedicated investigation. To address these questions and to demonstrate the concept validity, a comprehensive R&D program was needed. The results of this effort are summarized below [5,6].

- We have shown that a triple GEM detector with a reflective CsI photocathode operates in a stable mode at gains up to  $10^4$  in pure  $\text{CF}_4$ .
- A charge saturation effect occurring in  $\text{CF}_4$  when the total charge in the avalanche reaches  $4 \times 10^7$  electrons makes the HBD relatively robust against discharges.
- We carried out a test of a triple GEM detector operated with pure  $\text{CF}_4$  at the proposed location inside the PHENIX central arm spectrometer. The detector performed smoothly in the presence of Au+Au collisions exhibiting no discharges or gain instabilities.
- We have studied the basic parameters which determine the HBD performance. In particular, we measured the device response to minimum ionizing particles and to electrons. Large hadron rejection factors, well in excess of 100, can be achieved while preserving an electron detection efficiency larger than 90%.
- We confirmed measurements of the CsI quantum efficiency over the bandwidth 6-8.3 eV and extended them up to 10.3 eV. Extrapolation to the expected operational bandwidth of the device (6-11.5 eV) gives a figure of merit  $N_0=822 \text{ cm}^{-1}$ .
- Aging studies of the GEM foils as well as the CsI photocathode revealed that there is no significant deterioration of the detector for irradiation levels corresponding to  $\sim 10$  years of normal PHENIX operation at RHIC.

These results demonstrated the validity of the proposed HBD concept and paved the way to the incorporation of such a device in the PHENIX experiment.

#### 4. DETECTOR DESIGN AND SYSTEM PERFORMANCE

The mechanical design of the HBD has been developed and construction procedures have been exercised and optimized on a full-scale prototype. The HBD consists of two identical arms (see Fig. 2), each one covering  $135^\circ$  in azimuth and  $\pm 0.45$  units of pseudorapidity. In each arm the detector element is subdivided in 12 detector modules, 6 along the  $\phi$  axis  $\times 2$  along the  $z$  axis, with a module size of  $\sim 23 \times 27$  cm<sup>2</sup>. The signals are collected in the anode plane consisting of 1152 hexagonal pads in each arm. The detector vessel has a polygonal shape made of panels glued together.

The full-scale prototype design has been integrated into the PHENIX standard simulation package. Realistic simulations have been performed using HIJING central Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV with embedded  $\phi$  mesons. We chose a very narrow centrality window: impact parameter  $b < 2$ fm (top 2%) which corresponds to an average charged particle rapidity density of  $dN_{ch}/dy = 940$ . Fig. 3 shows the reconstructed clusters after clean-up of such a central collision. The clean-up is optimized for electron identification and hadron rejection. It requires: a) a pad amplitude  $> 1$  p.e.; b) a cluster amplitude  $> 20$  p.e.; c) a cluster size with  $N_{pads} \geq 2$ . Out of the huge number of hadrons ( $\sim 400$ ) going through the HBD only two are reconstructed demonstrating excellent hadron rejection. Electrons reconstructed in the central arms and matched to a cluster in the HBD are rejected as a) likely conversions if the cluster amplitude is larger than 60 p.e.; b) likely  $\pi^0$  Dalitz decays if there is another electron cluster in the HBD within a distance of 200 mrad. For the mass region around the  $\phi$  meson, this results in a reduction of the combinatorial background from these two sources by a factor larger than 100, compared to the present performance without the HBD. At this level of rejection the quality of the low-mass pair measurement is not limited anymore by this background but rather by the combinatorial background from the semi-leptonic decays of charmed mesons.

The HBD is presently under construction with installation and commissioning foreseen in 2006.

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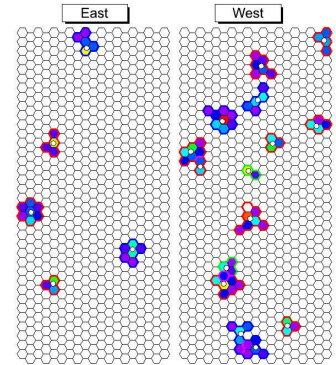


Figure 3: HBD event display of a central HIJING event.