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A hadron blind detector for the PHENIX experiment at RHIC

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Abstract. A hadron blind detector (HBD) is to be installed in the PHENIX experiment for Run7, starting in fall 2006. The HBD is a threshold Čerenkov detector designed to measure electrons in a field free region surrounding the collision vertex. The HBD's primary purpose is to tag background electrons originating from photon conversion and Dalitz decays. These background electrons can subsequently be excluded from a dilepton analysis, thereby reducing the combinatorial background by up to a factor of 100. The detector is realized by a proximity-focus windowless Čerenkov detector operating with pure CF_4 and read out by a reflective photocathode consisting of a stack of Gas Electron Multipliers (GEM), the first of which is coated with 300 nm of CsI. The avalanche charge from the GEM stack is collected on a PCB with pads having similar size to the Čerenkov blob. Dalitz and photon conversions are tagged by having twice the amplitude of a single blob. An excellent Quantum Efficiency of the photocathode is thus crucial to the success of the device. Outstanding results have been accomplished using a vacuum evaporation facility on loan from INFN Rome. We will give an overview of the experimental methods to identify blobs and techniques developed for photocathode production.

1 Introduction

A Hadron Blind Detector (HBD) has been developed as an upgrade to the PHENIX detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). This upgrade will assist the measurement of electron-positron pairs from the decay of light vector mesons (ρ, ω and ϕ). The low-mass di-electron continuum may yield information about chiral symmetry restoration; an enhancement of low-mass di-electron pairs has been interpreted as thermal radiation from pion annihilation mediated by a ρ meson which might suffer in-medium modification [1]. Results from the CERES experiment [2] at CERN SPS and NA60 [3] show this enhancement.

This low-mass di-electron spectrum is a very challenging analysis due to a signal/background ratio of $\sim$1/500 [4]. This background is mainly a result of associating uncorrelated electron-positron pairs in the mass spectrum. The problem is exacerbated by a high multiplicity of γ beam pipe conversions and π^0 Dalitz decays in conjunction with the limited acceptance of PHENIX. In di-electron reconstruction, typically one of the two pair partners is lost. The resulting combinatorial background necessitates this upgrade to the PHENIX detector.

2 The HBD concept

In order to differentiate between γ-conversions/π^0-Dalitz-decays and light vector meson decays, the opening angle of the decay pair can be measured. Since Dalitz decays and photon conversions typically produce pairs with very small opening angles, the direction of the momentum is sufficient to tag electrons originating from these sources. However, this necessitates having a magnetic-field-free region in which to operate. Fortunately, the inner coil of PHENIX can cancel the field within a 60 cm radius of the beam pipe thereby providing a zero-field region. Fig. 1 shows the location of the HBD with respect to the PHENIX central magnets.

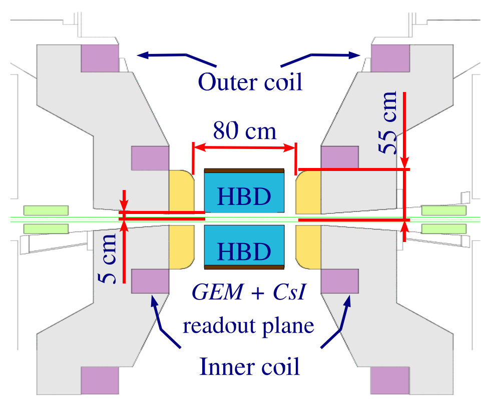

Fig. 1. Layout of the inner part of the PHENIX detector showing the location of the HBD and the inner coil.

Based on Monte Carlo simulations, when the HBD is run in reverse-bias mode (hadron-blind mode), miminum ionizing particles (MIPs) will generally result in a signal comparable to ∼1 Čerenkov-induced photoelectron. These ionization electrons are nearly always confined to a single pad. Conversely, the Čerenkov photons from a single signal-electron should yield an average of ∼35 photoelectrons distributed across 2-3 pads. Charged pions are easily distinguished from signal-electrons both by signal height and the number of fired pads. The main HBD specifications are: electron identification with a very high efficiency ($> 90\,\%$), double hit recognition at a comparable level and a moderate π rejection factor of ∼100.

Potential design ideas for this detector were analyzed and the following scheme was adopted: a windowless Čerenkov detector, operated with pure CF_4 and directly coupled to a triple Gas Electron Multiplier (GEM) [5] detector with a CsI photocathode evaporated on the top face of the first GEM foil and with pad readout. (Fig. 2)

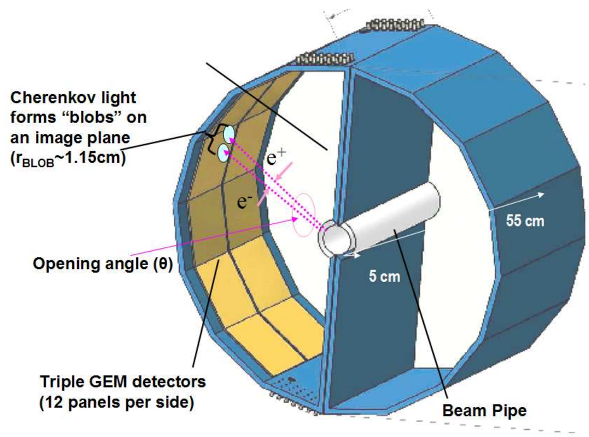

Fig. 2. 3-D depiction of the HBD.

A GEM is made of two 24 x 30 cm conducting foils (Cu for non-CsI coated GEMs, Au for photocathodes) separated by a layer of kapton. The GEMs are chemically pierced with 80 μm diameter holes which are separated 150 μm apart. A high voltage (∼500 V) is applied across the GEM foil which creates regions of extremely high electric field density within the center of the holes (See Fig. 3). As Čerenkov photons strike the photocathode surface, photoelectrons are ejected. The field lines catch the photoelectrons and direct them through the GEM holes creating an electron avalanche in the CF_4. The avalanche process occurs across three layers of GEMs, in series, to create a measurable signal on ∼6.5 cm^2 pads. (Fig. 4)

The triple GEM stacks line the interior wall of the HBD vessel (See Fig. 2), giving the e^+e^- pairs ∼55 cm of CF_4 radiator to traverse yielding an expected figure of merit N_0=822 cm^{-1}; the primary photoelectron yield per decay electron is expected to be ∼35. In addition to providing gain on the order of 10^4, the three-step avalanche process minimizes photon-feedback from the CF_4 avalanches. The gamma threshold for Čerenkov light in CF_4 is ∼28.3 so that pions with momentum <4 GeV do not radiate.

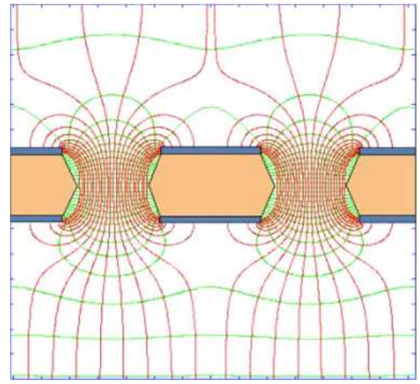

Fig. 3. Cross-section of a GEM showing electric field lines passing through the holes creating regions of high E-field density.

Since charged particles from the collision will ionize the CF_4 creating overwhelming noise, the triple GEM stack avalanche process must be shielded from this ionization. Therefore, a wire mesh is placed above the top GEM with a slightly positive voltage with respect to the top of the photocathode GEM (See Fig. 4). Only those ionization electrons liberated within a 150 μm gap above the top GEM get pulled through the triple GEM stack. Therefore, the HBD rejects virtually the entire ionization trail while still capturing nearly all of the photoelectrons, in effect making it blind to hadrons yet still measuring Čerenkov-induced photoelectrons efficiently.

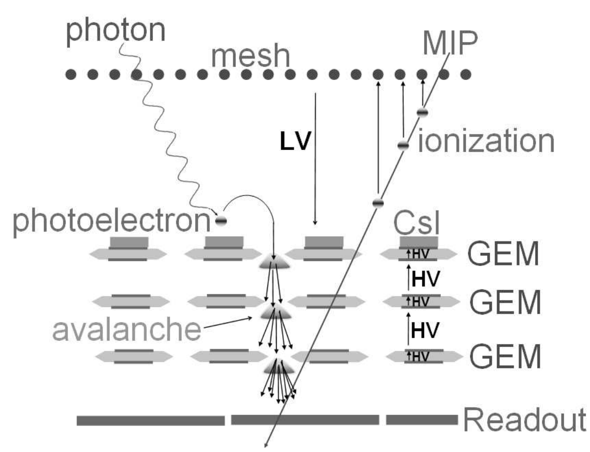

Fig. 4. The schematic cross-section of a triple GEM stack. The top GEM has a ∼300 nm coating of CsI. Čerenkov-induced photoelectrons are accelerated through the holes while ionization electrons from MIPs are "swept" upwards towards the wire mesh. (not to scale)

3 The CsI evaporation in Stony Brook

The production facility for CsI deposition and GEM installation into the HBD vessel at Stony Brook University is inside a dust-free clean tent (typically class 40). The production line consists of three major components: 1) a laminar flow hood, where the GEMs are prepared for the CsI deposition; 2) an evaporator, where both the CsI deposition occurs and the quantum efficiency is measured; and 3) a high-purity dry nitrogen atmosphere glovebox, where the assembly of the GEMs into the HBD vessel takes place.

The laminar flow table surpasses class 1 specifications for clean areas and is used as a staging ground to inspect the GEMs as well as to test for any shorted GEMs (by applying ∼400 volts across the GEM). The GEMs are then mounted, four at a time, into a transport box (Fig. 5), which both secures the GEMs and facilitates the ability to move the GEMs inside the evaporator.

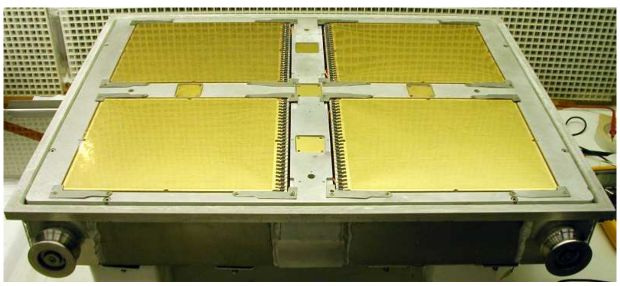

Fig. 5. The transport box which holds the 4 GEMs and 5 smaller, gold-coated photocathodes.

The evaporator consists of a cylindrical stainless steel vessel (110 cm in height, 120 cm in diameter) on loan from INFN Roma. This vessel is directly coupled to a station with the ability to measure the quantum efficiency (QE) of the photocathode before it leaves vacuum. (Fig. 6)

The purity of the CsI layer is vital to the quantum efficiency of the photocathodes. In particular, H_20 severely affects the photocathode's performance and therefore, all precautions are taken to minimize humidity levels in the presence of the CsI.

The deposition of CsI is performed in vacuum ($\sim 10^{-7}$ mbar) achieved by a scroll/turbo pump combination in addition to a cryopump. Prior to the evaporation, the GEMs are heated to 40°C for ∼24 hours in vacuum. The GEM's are located ∼50 cm above the CsI crystals to ensure a variation of less than 10% in the CsI thickness. Four symmetrically positioned molybdenum "boats" (crucibles), each filled with 0.8 grams of CsI crystal, are heated to evaporate a ∼300 nm coating of CsI onto the GEM foils. The CsI is cut from the center of a high quality scintillation crystal and evaporates at a temperature of ∼500°C at a deposition rate of 2 nm/s.

After the evaporation, the transport box can be rolled into the quantum efficiency measuring station, while sustaining vacuum, in order to monitor the quality and uniformity of the evaporation. A deuterium lamp is used as a source of UV light and is shined through a bandpass filter (25 nm FWHM spread) to isolate wavelengths of 160, 185 and 200 nm wavelengths. A rotating mirror is utilized to direct the light either onto the CsI coated GEM or onto a reference photo multiplier tube (PMT). A small (5 x 5 cm) wire mesh located 2 mm away from the photocathode is held at ≈130 volts with respect to the GEM surface. When the light is directed onto the photocathode, the resulting photocurrent can be measured with a picoammeter. Comparing this measurement to the photocurrent from the reference PMT, used in diode mode, whose quantum efficiency is known, a QE mapping of the GEM can be established. This provides an online, detailed QE measurement as a function of position primarily to demonstrate uniformity.

In addition to the four GEMs, every evaporation also includes 5 small (~ 15 cm^2) gold coated photocathodes (See Fig. 5). These small photocathodes are transported to Brookhaven National Laboratory (BNL) for a measurement using a vacuum monochromator over the wavelength range from 120 nm to 200 nm (Fig. 7). This offline measurement is necessary because the online system is limited in wavelength range and the low wavelength QE is vital to the HBD's operation.

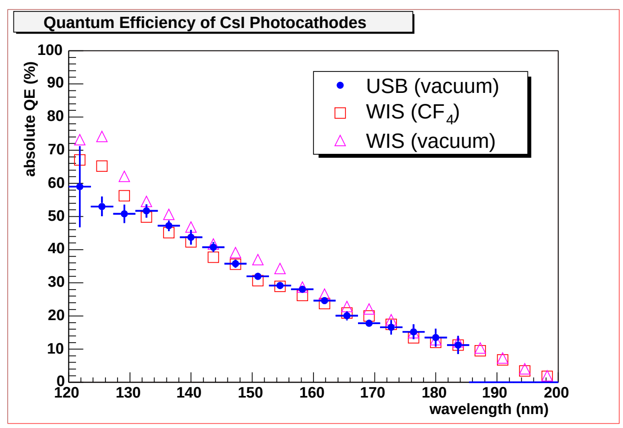

Fig. 7. Quantum Efficiency of small gold coated photocathodes plotted as a function of wavelength (measured at BNL).

Finally, the evaporator is back-filled with Ar and a lid is secured on the transport box in order to maintain an argon atmosphere during transport of the GEMs into the glovebox. The transport box containing the GEMs is placed into an airlock antechamber which is flushed with nitrogen gas before being opened to the glovebox atmosphere.

Inside the glovebox, the gain of each triple GEM stack is measured in an Ar/CO_2 (70%/30%) atmosphere with 5.9 keV gamma rays from an ^{55}Fe source. This system allows a full positional gain mapping (7 x 8 grid) of the triple GEM stack. Fig. 8 shows the uniformity of the gain for one stack. Since these gain maps are not taken under PHENIX operating conditions (ie. Ar/CO_2 instead of CF_4, ^{55}Fe source instead of Au+Au collisions, etc), they will not be used as the final gain map calibrations for the

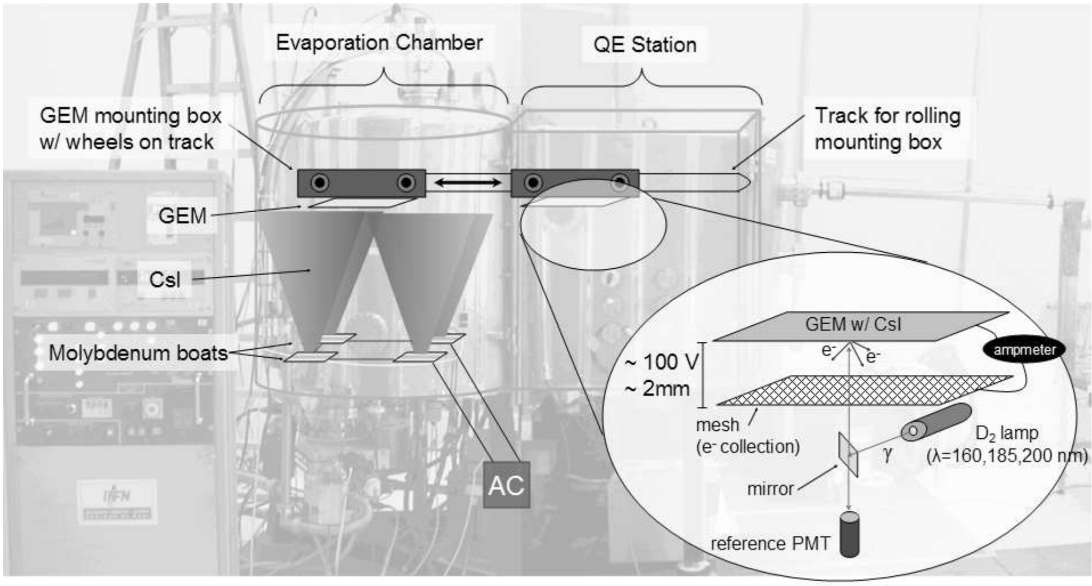

Fig. 6. A picture of the evaporator and quantum efficiency station overlayed with a scematic drawing of the inside of the vessel. The transport box can roll back and forth between the two stations. Highlighted in the lower right is the quantum efficiency station.

HBD. Their primary purpose is to verify the gain uniformity of a triple stack as compared to the predicted gain uniformity of 3 single GEMs. The predicted triple GEM stack's gain is based on measurements of single GEMs made prior to their arrival at Stony Brook. Final gain maps will be determined under operating conditions by measuring the MIP peak after the detector is installed in PHENIX.

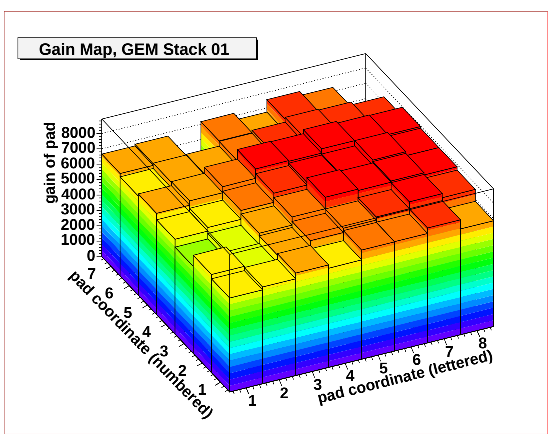

Fig. 8. Gain Map of a triple GEM stack presently installed in the HBD.

The HBD vessel also resides inside the glovebox and the gain-tested triple GEM stacks are then immediately transferred directly into the detector.

4 Status

Presently, the first HBD vessel is installed in the west arm of PHENIX. The second vessel (for the east arm) is being prepared for the the installation of its triple GEM stacks. Final installation and commissioning are foreseen for the fall of 2006.

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