Collection of Photoelectrons from a CsI Photocathode in Triple GEM Detectors

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***Abstract*—A study has been made of the parameters affecting the extraction and collection of photoelectrons from the surface of a CsI photocathode in a triple GEM detector. The purpose of this study was to optimize the photoelectron collection efficiency and GEM operating conditions for the PHENIX Hadron Blind Detector (HBD) at RHIC. The parameters investigated include the electric field at the surface of the photocathode, the voltage across the GEM, the electric field below the GEM, the medium into which the photoelectrons are extracted (gas or vacuum), and the wavelength dependence of the extraction efficiency. A small, calibrated light source, or "scintillation cube", was used to measure the photoelectron yield from the CsI photocathode using ^{241}Am particles to produce scintillation light in CF_4 and an ^{55}Fe source to measure the GEM gas gain. The absolute scintillation light yield (photons/MeV) in CF_4 gas was also determined using a CsI photocathode GEM detector. Results will be presented on the study of the parameters affecting the photoelectron collection efficiency, the construction and calibration of the scintillation cube, and the measurement of the absolute scintillation light yield in CF_4.**

I. Summary

THE quantum efficiency and photoelectron collection efficiency for CsI photocathodes has been studied by a number of authors [1-5]. However, the measurements have shown conflicting results, particularly regarding the maximum number of photoelectrons that can be extracted from a CsI photocathode surface into various gases and subsequently transported into the gain region of a GEM detector. This process is of great importance for the performance of the PHENIX Hadron Blind Detector (HBD), which uses CsI photocathode GEM detectors to detect Cherenkov photons produced by relativistic particles in a CF_4 radiator in heavy ion collisions at RHIC [6]. The purpose of this study was to investigate the parameters affecting the photoelectron collection efficiency for CsI photocathode GEM detectors operated in pure CF_4 in order to better understand this process and to optimize the performance of the HBD.

The HBD utilizes an array of triple GEM detectors where the top GEM has a ~ 200 nm thick CsI photocathode layer deposited on its top surface. A mesh electrode above this surface is used to control the field above the photocathode. It can be biased such that charge produced in gap between the mesh and the top GEM is collected by the GEM (Forward Bias) or by the mesh (Reverse Bias). The detector is operated in pure CF_4, where the CF_4 acts as both the Cherenkov radiator and as the operating gas for the GEMs.

The main factor affecting the production of photoelectrons from the photocathode is the quantum efficiency. This can be measured in vacuum in a parallel plate configuration where all photoelectrons are collected by the mesh. Fig. 1 shows the quantum efficiency measured as a function of wavelength for our typical CsI photocathodes.

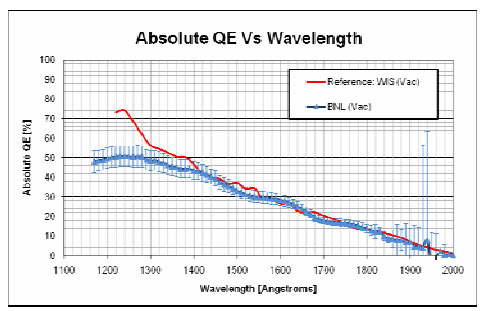

Fig. 1. Quantum efficiency of typical CsI photocathodes measured in vacuum in parallel plate collection mode.

The photoelectron collection efficiency depends on the electric field in the collection gap, and quickly reaches 100% in vacuum, as shown in Fig 2. However, in the presence of gas, the collection efficiency is reduced due to the backscattering of electrons off gas molecules. Fig 2 shows that in CF_4, the collection efficiency reaches a plateau value of ~ 80% at a field of ~2 kV/cm, whereas for Ar, the collection efficiency is lower and there is no plateau for fields less than 2.5 kV/cm. This is believed to be due to the effect of the vibrational modes of excitation of CF_4 molecules at low electron energies [5]. We note that the same efficiency is measured for different drift gaps distances, indicating that the loss of electrons takes place close to the photocathode surface and is therefore not due to attachment or recombination of electrons during transport.

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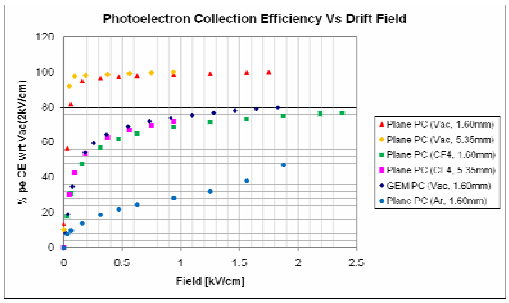

Fig. 2. Photoelectron collection efficiency as a function of electric field in parallel plate collection mode for vacuum, CF_4 and argon.

The process of backscatter and transport losses and its effect on the photoelectron collection efficiency in CF_4 and other gases has also been investigated using a detailed Monte Carlo simulation [5]. They predict that the collection efficiency depends not only on the field, but also on the wavelength of the incident light. Our measurements agree qualitatively with these predictions, as shown in Fig. 3, which indicates that the collection efficiency decreases with increasing photon energy.

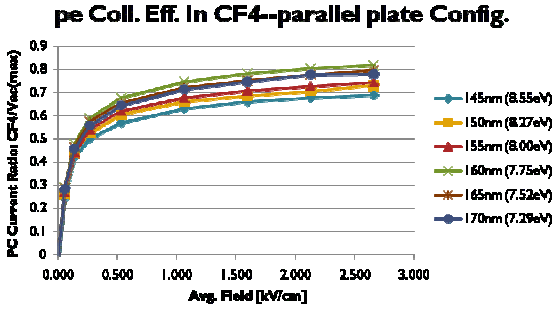

Fig. 3. Photoelectron collection efficiency for different incident wavelengths.

In order to better understand the electric field at the photocathode surface and the distribution of field lines that carry photoelectrons into the gain region inside the holes of the GEM, we have developed a 3D model of the field using Maxwell [7]. Fig 4 shows a visualization of the field in the region of a hole for the reverse bias mode of the HBD, where the mesh is at a lower negative potential than the photocathode. The red lines indicate field lines that carry photoelectrons to the mesh and the blue lines are field lines that carry photoelectrons to the lower surface of the top GEM. In principle, both of these could result in the loss of photoelectrons reaching the gain region and subsequently being transferred to the next stage of the GEM. However, this loss will be reduced due to diffusion and the gain process inside the holes.

The main goal of this study is to determine the overall efficiency for producing photoelectrons on the photocathode surface, collecting them into the gain region inside the holes of the first GEM, and then transferring them to subsequent stages of the GEM. We have been able to measure this experimentally using a calibrated light source, or "Scintillation Cube", which produces scintillation light in CF_4 using ^{241}Am alpha particles and an ^{55}Fe source to simultaneously measure the gas gain of the GEM. A calibrated CsI photocathode PMT was used to determine the light flux from the cube which is then used to illuminate a CsI photocathode GEM. Knowing the quantum efficiency of the photocathode allows us to determine the number of photoelectrons produced, and measuring the total charge produced by the GEM, along with a knowledge the gas gain and the calibration of the charge output in terms of electrons, allows us to determine the number of photoelectrons that were collected and amplified. Our initial measurements indicate that this fraction is greater than 80% and only weakly dependent on such parameters as the voltage across the GEM and the field in the transfer gap below the top GEM. We will make a systematic study of how this efficiency depends on all of these parameters and present the results at the conference.

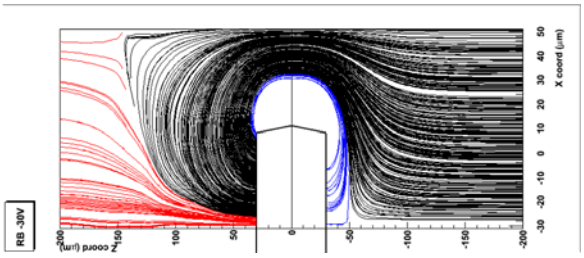

Fig. 4. Visualization of electric field lines in the region of a hole of a GEM in reverse bias mode of the HBD. The mesh electrode is to the left and is at a lower negative potential than the photocathode. Red lines indicate losses to the mesh and blue lines indicate electrons that would be collected on the lower surface of the GEM neglecting effects of diffusion.

As an additional result, we are able to determine the absolute scintillation light yield in CF_4 using both a calibrated PMT and a CsI photocathode GEM detector. We have reported on these results at last year's conference [8], but we will present a more detailed measurement which includes the effect of the photoelectron collection efficiency as measured in this study at this year's meeting.

II. References

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