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Measuring Photons and Neutrons at Zero Degrees in CMS

O.A.Grachov, B.Metzler, M. Murray, J.Snyder, L.Stiles, J.Wood, V.Zhukova
University of Kansas, Lawrence, KS, 66045, USA

W.Beaumont, S.Ochesanu
Universiteit Antwerpen, Wilrijk, Belgium

P.Debbins, D.Ingram, E.Norbeck, Y.Onel
University of Iowa, Iowa City, IA, USA

E.Garcia
University of Illinois at Chicago, Chicago, IL, USA

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The CMS Zero Degree Calorimeters, ZDCs, will measure photons and neutrons emitted with $|\eta| \geq 8.6$ from Pb+Pb, p+Pb and p+p collisions at $\sqrt{s_{NN}} = 5.5$, 8.8 and 14 TeV respectively. The calorimeter consists of an electromagnetic part segmented in the horizontal direction and an hadronic part segmented into four units in depth. In addition CMS will have access to data from a segmented shower maximum detector being built for luminosity measurements. We will present detailed results from tests beam measurements taken at the CERN SPS. These data will be used to extrapolate the utility of the ZDCs to measure photons, and possibly π_0 s in p+p and ultra-peripheral heavy-ion collisions. Data from the hadronic section can be used to estimate the number of participants in heavy ion-collisions. In addition we will discuss plans to use the detector to measure the reaction plane, thereby extending the sensitivity of the central detectors in CMS.

1. Introduction

The Compact Muon Spectrometer (CMS) [1] consists of a tracking system, electromagnetic and hadronic calorimeters and muon detectors. A solenoidal magnet provides a 4 T magnetic field surrounding the tracking and calorimetric systems. The tracking system covers the pseudorapidity region $|\eta| < 2.5$. The combination of electromagnetic and hadronic calorimeters provides coverage of the rapidity region $|\eta| < 5$. The muon detector covers the region $|\eta| < 2.4$. A set of two zero degree calorimeters (ZDCs) [2], with pseudorapidity coverage of $|\eta| \geq 8.6$ for neutral particles, have been proposed to complement the existing CMS detector, especially, for heavy ion studies. Each ZDC has two independent parts: the electromagnetic (EM) and hadronic (HAD) sections. Two identical ZDCs will be located between the two LHC beam pipes at 140 m on each side of the CMS interaction region at the detector slot of 1 m length, 96 mm width and 607 mm height inside the neutral particle absorber TAN [3].

In order to meet the goals of the CMS forward physics program the energy resolution of the EM section must be on the level of 10% for 50 GeV photons. During heavy ion running the combined (EM + HAD) calorimeter should allow one to reconstruct the energy of 2.75 TeV spectator neutrons with a resolution of $10-15\%$.

2. Zero degree calorimeter

Sampling calorimeters using tungsten and quartz fibers have been chosen for the detection of the energy in the ZDCs. A significant advantage of this technology is that the calorimeter will be very compact, extremely fast and radiation hard. Quartz fibers were chosen as the active media of the ZDC calorimeters because of their unique radiation hardness features and intrinsic speed of the Cherenkov effect. The quartz-quartz fibers can withstand up to 30 GRad with only a few percent loss in transperency in the wavelength range of 300-425 nm.
The HAD section consists of 24 layers of 15.5 mm thick tungsten plates and 24 layers of 0.7 mm diameter quartz fibers ($6.5\lambda o$). The tungsten plates are tilted by 45^0. The EM section is made of 33 layers of 2 mm thick tungsten plates and 33 layers of 0.7 mm diameter quartz fibers (19Xo). The tungsten plates are oriented vertically. The fibers were laid in ribbons. The hadronic section of each ZDC requires 24 fiber ribbons. After exiting the tungsten plates the fibers from 6 individual ribbons are grouped together to form a read - out bundle. This bundle is compressed and glued with epoxy into a tube. From there, an optical air-core light guide will carry the light through radiation shielding to the photomultiplier tube. The full hadronic section will consist of four identical towers divided in the longitudinal direction. For the electromagnetic section, fibers from all 33 fiber ribbons will be divided in the horizontal direction into five identical fiber bundles. These 5 bundles will form five horizontal towers, each fiber bundle will be mounted with a 0.5 mm air gap from the photocathode of a phototube. EM and HAD sections will be instrumented with the same type of phototube. The phototubes are Hamamatsu R7525 phototubes with bi - alkali photocathode.

Figure 1 shows a side view of the ZDC with the EM section in front and the HAD section behind. The configuration includes 9 mm Cu plates in the front and back of each section. For the TAN's final detector configuration a luminosity monitor[4] will be mounted in the 10 cm space between the ZDC's calorimetric sections.

3. Experimental set-up

The main goal of the test beam measurements was to study the performance of the zero degree calorimeter. Secondary goals included tests of the full electronic chain to be used in CMS and real data data transfer to Fermi National Accelerator

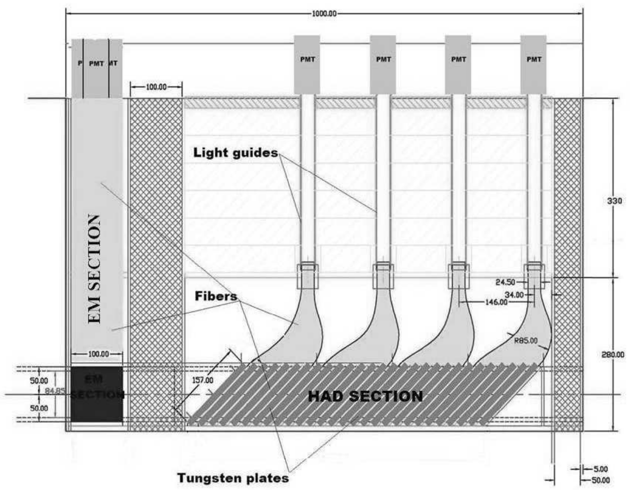

Fig. 1. The side view of the ZDC with EM section in front and HAD section behind. A luminosity monitor will be mounted in the 10 cm space between the ZDC's calorimetric sections

Lab for online monitoring. Measurements were carried out in the SPS H2 beam at CERN. A 400 GeV/c proton beam was extracted from the SPS accelerator and steered onto the primary target. The intensity of this primary beam was 5×10^{12} protons per burst. Downstream from the primary target, a secondary hadron or electron (positron) beam were made with momenta from 10 to 350 GeV/c. The beam then passed through a gas threshold Cherenkov counter; two multi - wire proportional chambers MWPCs, of size $(10 \times 10)cm^2$; four 1cm thick scintilators with sizes $(14 \times 14)cm^2$, $(4 \times 4)cm^2$, $(2 \times 2)cm^2$, and $(14 \times 14)cm^2$ and finally two more wire chambers (WC-D and WC-E), before hitting the calorimeter. The calorimeter sat on table that could be moved horizontal and vertical directions under remote control. This made it possible to direct the beam anywhere in the calorimeter front face.

The trigger system required a coincidence from the scintillaters and the appropriate signal in the cerenkov. The normal beamspot condition exposed an calorimeter area of about $(2 \times 2)cm^2$. The MWPCs were used to extrapolate the particle trajectory to the calorimeter front face.

The high-voltage for the phototubes was provided by a commercial unit LeCroy4032 [8]. Each tube was pre-calibrated. Based on pr-ecalibration data and simple calculations we set the same gain of 10^5 for each PMT. The electrical signals from the phototubes were transmitted through a 204 m long coaxial cables type C-50-11-1 to charge integrater and encoder (QIE) for digitization and buffering. All of the digital electronics ran at 40 MHz, the clock speed that will be used at the LHC.

3.1. *Response to Electrons*

The characteristics of the EM section were measured with 20, 50, 100 Gev positrons. The momentum spread of the beam was 0.1-0.2%. To equalize each tower the center of each tower was irradiated by 50 GeV positron beams. The peak position obtained from a Gaussian fit of the amplitude distribution for each tower was used to determine the calibration coefficients.

Figure 2 shows the sum of the response of the central tower and its two neighbours

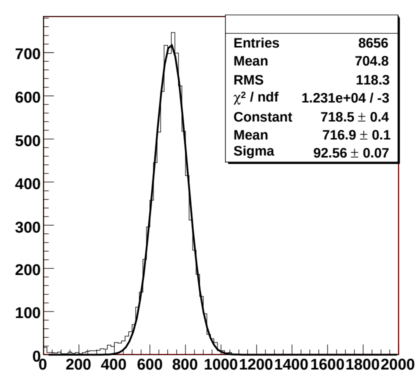

Fig. 2. The sum of the gain corrected signals in the central tower irradiated by 50 Gev/c positrons and the two neighbouring towers.

to 50 Gev/c positrons. The energy resolution for the different positron energies measurements was obtained by Gaussian fits and can be parametrized as,

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{70\%}{\sqrt{E}}\right)^2 + (8\%)^2 \qquad (1)$$

The linearity of the EM section response is defined as the ratio of the fitted mean energy to the nominal beam energy. The relative deviation from a straight line as a function of beam momentum have been measured and the calorimeter is found to be linear over a range of from 20 GeV to 100 GeV to within 2%. The GEANT4 simulations reproduces well the EM section test beam data.

3.2. *Response to pions*

Positive pions with energies of 150 GeV and 300 GeV were used to measure the response of the EM + HAD combined system. The total depth of combined system is 7.5 hadronic interaction lengths (λ).

The total energy:

$$E_{TOT} = \alpha E_{EM} + E_{HAD} \tag{2}$$

is defined as the sum of energy in EM section:

$$E_{EM} = E_{EM1} + E_{EM2} + E_{EM3} + E_{EM4} + E_{EM5} \tag{3}$$

and energy in HAD section:

$$E_{HAD} = E_{HAD1} + E_{HAD2} + E_{HAD3} + E_{HAD4}, \tag{4}$$

when the central tower (EM3) was irradiated by beam. The energy dependent

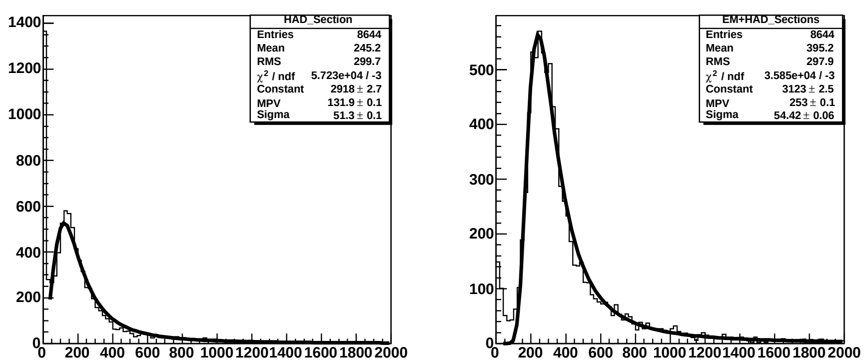

Fig. 3. HAD section and combined EM+HAD system response to 300 GeV pions

intercalibration parameter between the EM and HAD section (α) is determined by minimizing the energy resolution of 300 GeV pions. In our case, α is equal 1 at 300GeV. The analysis did not included any corrections for dead material, leakage and the non-compensation nature of calorimter's sections. Figure 3 shows an example of HAD section and combined EM+HAD system response to 300 GeV pions. The energy resolution was obtained by a Landau fit and can be parametrized as,

$$\frac{\sigma}{E} = \frac{138\%}{\sqrt{E}} + 13\% \tag{5}$$

4. Flow detector up-grade

The study of directed flow has been one of the main tools used to study the strongly interacting matter created at RHIC. It has been suggested that if a quark gluon plasma is created the directed flow, as measured by v_1, should oscillate, or wiggle, as one moves from central to forward rapidities [5, 6]. At forward rapidities the plasma may expand in the direction opposite the reaction plane. The STAR collaboration has searched for this effect at $\sqrt{s_{NN}} = 62.4$ GeV/c using their shower maximum detector, imbedded in the Zero Degree Calorimeters to reconstruct the reaction plane [7]. So far the "wiggle" has not been seen in data, possibly because we have not yet reached the softest point of the equation of state. The CMS experiment has the largest (psuedo)-rapdity coverage of any experiment at the LHC. The complete azimuthal coverage and fine granularity of the detectors make it ideal to study the rapidity dependence of flow. We propose to augment these capabilities by adding a flow detector to the CMS Zero Degree Calorimeters. These devices will consist of two 8cm by 8cm hodoscopes inserted just behind the electromagnetic sections of the left and right ZDCs. We are currently investigating a variety of technologies to address the technical challanges involved in this project.

5. Summary

The ZDC has sufficient energy resolution and linearity to meet our physics goals. The response also agrees well with GEANT4 simulations. The electromagnetic section has a non-linearity $\leq 2\%$ from 20 to 100GeV. EM section, as an independent detector, significantly improves the energy resolution for hadrons with energy between 150 and 300 GeV. The combined resolution of electromagnetic and hadronic sections is approximately twice that of the hadronic section alone.

6. Acknowledgements

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