The ALICE PHOS calorimeter

2009 J. Phys.: Conf. Ser. 160 012045

(http://iopscience.iop.org/1742-6596/160/1/012045)

The ALICE PHOS Calorimeter

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Abstract. The ALICE PHOton Spectrometer (PHOS) is designed to detect photons in nucleus-nucleus collisions at the Large Hadron Collider (LHC). The basic design and the measured performance with the first constructed module are shown. The installation schedule and the future construction plan are reported.

1. Introduction

The ALICE detector has been designed to study the strongly interacting matter created in nucleus-nucleus collisions at the Large Hadron Collider (LHC). Measurement of direct photons is probing the initial state of the interactions. In the heavy ion collisions program at LHC, it is very critical to measure thermal radiated photons, which is known to carry the temperature information of created hot medium, with very fine energy and position resolution.

The ALICE PHOton Spectrometer (PHOS) [1] consists of 17920 PWO crystals to each having size of $22 \times 22 \times 180mm$ and Avalanche Photo Diode (APD) for readout of scintillation light. The performance result of prototype modules for the PHOS calorimeter has been reported earlier[2]. First PHOS module consisting of 3584 crystals was constructed and tested by utilizing 2GeV/c electron beam in the summer of 2006 and cosmic rays in 2007. The HV bias for APDs were calibrated in order to obtain equal gain for better trigger performance. Second PHOS module is under construction and installed for the first p+p collisions at LHC. Further research and development program for improved performance of PHOS as a electro-magnetic calorimeter are under studying.

In this paper, we will present the construction and installation status of the PHOS modules and performance results. In addition, physics potential with the PHOS module during the first physics run of LHC will be discussed.

2. PHOton Spectrometer (PHOS) in ALICE Experiment

Figure 1 depicts the ALICE setup consisting of two arms; a central arm inside the L3 magnet and a muon arm shown in the right part of the figure. The PHOS detector is placed below of the collision vertex at 460cm distance and covers 100deg in the azimuthal angle and pseudo-rapidity of between -0.12 and 0.12. It designed to measure photons in the heavy-ion collisions at LHC.

Several measurements of photons in heavy-ion collisions were reported at the several accerellator, AGS, SPS, and RHIC. One of the most interesting physics is the thermal photon measurement since it is expected to be probing the initial state of the strongly interacting matter, Quark Gluon Plasma (QGP), created in nucleus-nucleus colisions.

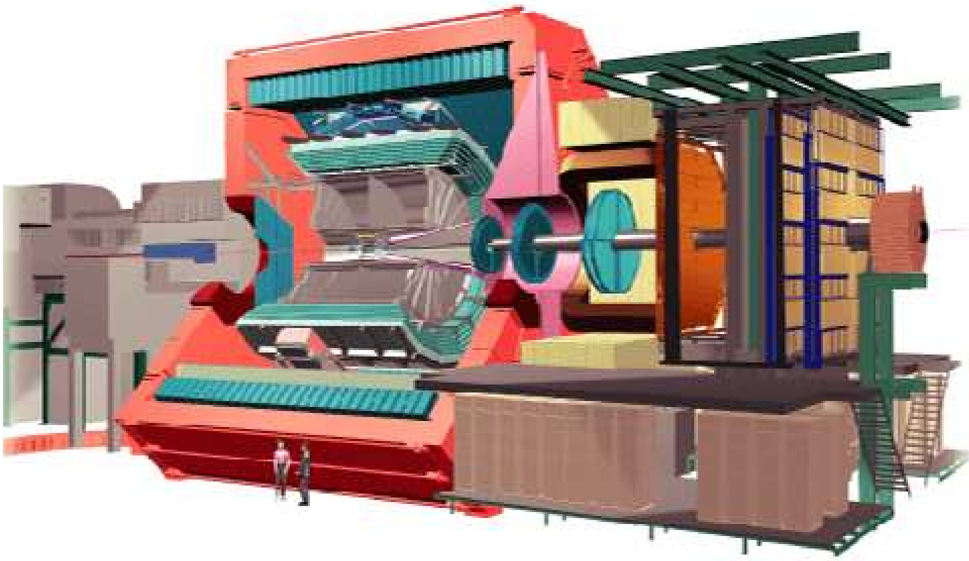

Figure 1. ALICE Setup

At the LHC energy in heavy-ion collisions, several theoretical predictions for thermal photon production [1][2][3]. Also see more compilation of general photon physics in heavy ion collisions at the LHC [4]. According to the predictions, the thermal photons are expected to be measurable in the energy range between 1 and 10GeV depending on the temperature of the medium and the strength of the background photons. One of the two major requirements on PHOS is to have good energy resolution down to the energy range of a couple of 100MeV. At the LHC energy, we expect that the heavy ion collisions produce about 8000 charged particles in a unit of rapidity. In order to survive the high multiplicity condition, another requirement is the segmentation size. The PHOS detector is specially designed to fulfill these both requirements by focussing the geometrical coverage at very small region. In addition, the high energy photon is one of good tools to study the QCD process. Especially, the jet measurement in the opposite direction of the photon is interesting physics process in the heavy-ion collisions in terms of the jet modification in hot medium.

All electro-magnetic calorimeters which are under construction at three LHC experiments; ATLAS, CMS, and ALICE are listed in Table 1. The rapidity and azimuthal coverage of PHOS is smaller than that of others, however PHOS is designed to fulfill the requirements for the thermal photon measurement; fine segmentation, good energy resolution and dynamic range to lower energy.

3. Basic Design

In this section, an overview of the PHOS structure is described. See ALICE Technical Design Report[5] for further detail.

3.1. $PbWO_4$ Crystal + Avalanche Photon Diode

The PHOS consists of combination of $PbWO_4$ (PWO) crystals and Avalanche Photon Diode (APD). In total, 17920 channels covers 100deg in azimuthal angle and ± 0.12 in pseudo-rapidity. Total weight is 12.5ton.

The PWO crystal is known as its characteristics of the fast signal and the small Moliere radius of about 2cm. Each crystal of the PHOS detector has $22 \times 22 \times 180$mm dimention, which

Exp.	ATLAS		CMS		ALICE	
Name	LAr Barrel	LAr Endcap	ECAL(EB)	ECAL(EE)	PHOS	EMCal
Structure	Liquid Ar		PWO + APD		PWO + APD	Pb + APD
Coverage	0<|η|<1.4, 2π	1.4<|η|<3.2, 2π	0<|η|<1.5, 2π	1.5<|η|<3.0, 2π	0<|η|<0.12, 0.6π	0<|η|<0.7, 0.6π
Granularity ΔηxΔφ	0.003x0.100 0.025x0.025 0.025x0.050	0.025x0.100 0.025x0.025 0.025x0.050	0.0174x0.0174	0.0174x0.0174 to 0.05x0.05	0.004x0.004	0.0143x0.0143
Res.	10%/√E ⊕0.5%	10%/√E ⊕0.5%	2.7%/√E ⊕0.55%	5.7%/√E ⊕0.55%	3.3%/√E⊕ 1.1%	7%/√E⊕ 1.5%

Table 1. Comparison of Electro-Magnetic Calorimeter at ATLAS, CMS, and ALICE.

corresponds to $20X_0$ radiation length in the longitudinal direction. The crystals are kept at the temperature of -25deg, where the light yield is enhanced to be 230 photo-electron per MeV. The scintillation light has the wave length of 400nm to 500nm.

The APD of Hamamatsu S8664-55 type is employed for detecting the scintillation light from PWO. Its advantage is the high quontum efficiency of 60% to 80% depending on the light wave length. With the PWO crystal and the APD active surface of 5×5mm, 4.5 photo-electron per MeV is expected at the temperature of -25deg. Another advantage is its capability to be operational in magnet field. Each APD is mounted on one preamplifier board where the integration of charge is done.

3.2. Front-End Electronics and Trigger System

The front-end electronics (FEE) are designed to fit the compactness of the PHOS module. The research and development has started since 2004. Two 10-bit 10MHz sampling ADCs for two different dynamic ranges are implemented. The dynamic range in total is from 5MeV to 80GeV. The electronic noise is 615 electron, which is equivalent to 3.1MeV. One FEE board covers 32 APD reading and has 32 APD bias regulators.

The sum of 2x2 analog signals are processed through a fast shaper amplifier on the FEE board and transfered into Trigger Region Unit (TRU) for the purpose of triggering energy activities in PHOS. 12-bit sampling ADC are used for the digitization at the rate of 40MHz. The energy sum of overlapping 4x4 crystals are taken and transfered into Trigger OR (TOR) board with a programmable FPGA, where sophisticated decision for physics trigger can be performed for enhancing isolated photons or jet for example.

3.3. Control and Monitoring

The slow control and monitoring of the PHOS modules are implemented in an ALICE standard framework, Detector Control System (DCS). The six different parts, FEE, FEE cooling, PWO cooling, LV power supply, HV power supply, LED calibration system are controled and monitored by three computers. All are accesible from one computer together with the other detectors by a shift leader as for a global control in ALICE.

We also have a monitoring system of the data stream obtanied by the DAQ system. The same data stream is monitored through the High Level Trigger (HLT) system, where we check the quality of the data, export information for the online monitoring display, and perform compression of the raw data.

4. PHOS Performance

In this section, we will describe the measured performance with the constructed PHOS module consisting of 64×56 xtals in addtion to previous reports on 8x8 prototype [6], 16x16 prototype [8] and expected performance [7][9][10].

4.1. Test Beam in 2006

A construction of first PHOS module out of five modules was finished in the spring of 2006 and was tested at at a beam line. The test was done at T10 beam line of CERN-PS in the summer of 2006. As described in Fig. 2, several beam counters and electron identification gas counter are used in the beam line. The first PHOS module was put on a moving stage so that the beam can be irradiated into any positions of the PHOS module surface. Electrons with 2GeV/c momentum are irradiated into most of channels in order to calibrate the relative energy. During the beam time, the APD bias was successfully adjusted for equalized gain by accuracy of 4% . In addition, electrons with 1-5GeV/c and π^- with 5GeV/c were used to investigate the energy resolution and the shower shape.

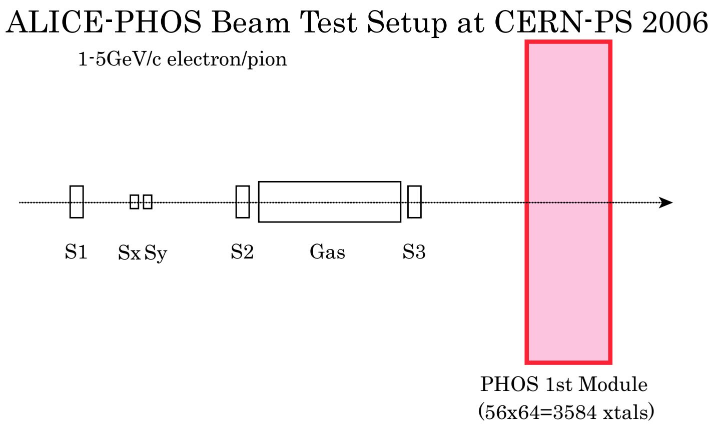

Figure 2. Test beam setup at T10 beam line of CERN-PS in the summer of 2006

Figure 3 shows the obtained energy resolution as a function of photon energy together with previous results from the prototypes [6][8] and a fitting result by following formula;

$$\frac{\sigma}{E(GeV)} = \sqrt{\frac{0.018}{E} \oplus \frac{0.033}{\sqrt{E}} \oplus 0.011}.$$

We concluded that the measured energy resolution of the first 64×56 module is consistent with previous results from prototypes and all can be described by a single formula. Also all results fulfill the requirements on the PHOS performance as shown in the figure.

4.2. Cosmic Ray in 2007

The first constructed PHOS module is also tested by cosmic rays during summer in 2007. The PHOS module was rotated so that the vertical cosmic-ray penetrates longer path (18cm) of

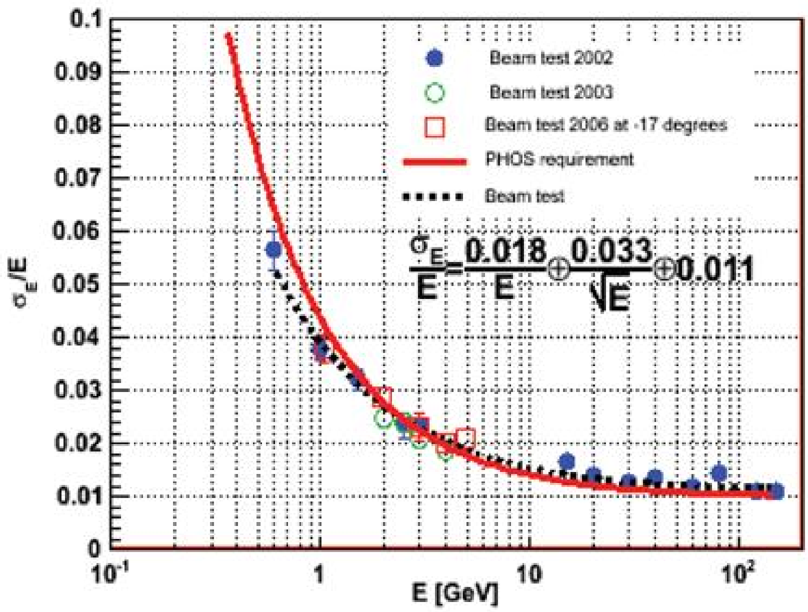

Figure 3. Energy resolution measured in 2006 for first PHOS module together with the measured resolution for prototypes [6][8]. All results can be described by a single fitting as shown in a dotted line.

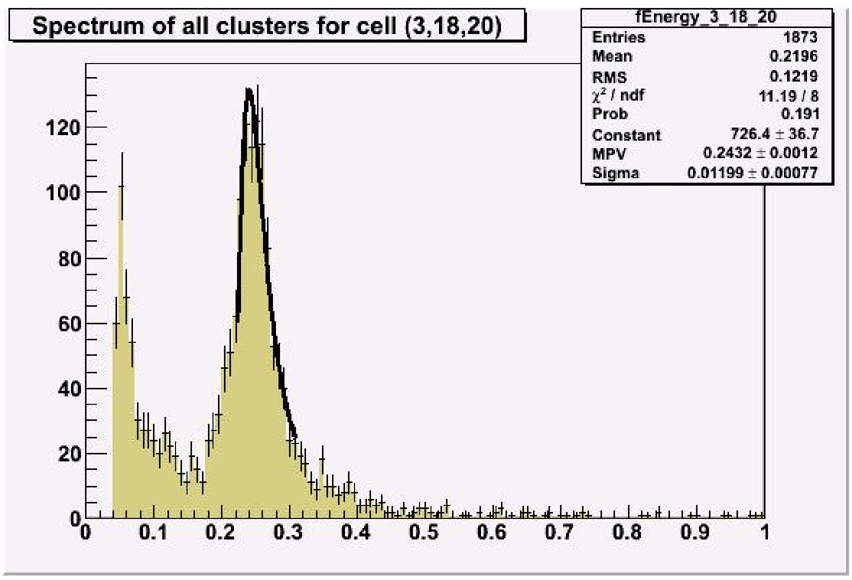

Figure 4. Cluster energy distribution by cosmic-rays in the summer of 2007 together with a fitting result.

xtals. By utilizing a prototype of the cooling system, the PWO crystals were cooled at the temperature of about -17deg. A scintillator of $40 \times 80 \times 2cm^3$ was set by 61cm distance from another scintillator of $50 \times 100 \times 4cm^3$. The bottom one was put just on the PHOS module

Journal of Physics: Conference Series **160** (2009) 012045 doi:10.1088/1742-6596/160/1/012045

and covered about 1107 (27x41) xtals. In order to cover all xtals, they needed to be moved on the PHOS surface several times. The analog signals from both were discriminated by thresholds of 300mV and used for starting the data taking. The trigger rates after coincidence was about 10Hz, which is consistent with an expectation.

Same APD bias as the test beam in 2006 was applied during this test, where we expect the gain of all channels were equalized by 4%. On the other hand, there was clearly seen that $> 10\%$ gain unbalance so that they were corrected in the analysis. Figure 4 shows the cluster energy distribution after the relative energy are calibrated. A clear peak at around 250MeV was observed together with an exponential background. These data were used for an initial calibration and also for quality check of all channels.

5. Installation Schedule

First p+p collisions at LHC is scheduled in 2008 summer at the center of mass energy of 900GeV and 10TeV. Secondly constructed PHOS module was succesfully constructed and installed on May 2008 and is operated at normal room temperature. First and third constructed modules are basically ready and they are under mechanical upgrade now to fulfill the air-tightness reuirement. They will be tested in the lab in 2008 with cosmic and electron beam and will be installed in ALICE during shutdown after first LHC beam and before the first Pb+Pb collisions, which is scheduled after second year of LHC.

The construction of fourth and fifth modules are scheduled after the installation of the other three modules. All five modules are scheduled to be ready before the full luminosity run of Pb+Pb collisions at LHC.

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