EC Detector at SciBooNE

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Abstract. SciBooNE is an experiment to measure neutrino and anti-neutrino cross-sections on the Booster Neutrino Beam at Fermilab. The EC is an extruded lead sheets and scintillating fibers "spaghetti calorimeter" to provide longitudinal containment and energy measurement for electrons and photons.

1. SciBooNE
The name SciBooNE[1] comes from the merging of SciBar and BooNE. SciBar[2] is a fine grained detector, while BooNE stands for Booster Neutrino Experiment. MiniBooNE[3] (Scintillating Bar Detector) is a neutrino oscillation experiment taking data on the Booster neutrino beam at Fermilab, designed to access the neutrino oscillation parameters claimed by LSND[4] (the collaboration has recently published data which exclude the LSND signal[5] for muon neutrinos and is now running in anti-neutrino mode). The idea of SciBooNE is to install the SciBar+EC (Electromagnetic Calorimeter) detector very close to the source on the Booster neutrino beam. SciBooNE can act as near detector of the MiniBooNE experiment and its very good performance, coupled with the high intensity of the beam, allow important measurements of the beam composition and of neutrino and antineutrino cross-sections. The neutrino beam obtained from the 8 GeV protons extracted from the Fermilab Booster is quite similar to the T2K[6] neutrino beam and the SciBooNE measurements of beam composition and neutrino cross sections will also be very useful for the T2K oscillation experiment. The SciBar and EC detectors were used in the K2K near detector at KEK. After disassembling they were shipped to Fermilab at the end of July 2006. SciBar and EC were assembled and partially commissioned in a self-contained structure in parallel with the excavation of the experimental enclosure, where it was moved in May 2007. The detector is complemented by a new muon range detector (MRD) made of iron and scintillator planes, that was built at Fermilab. The installation of SciBooNE on the neutrino beam line at Fermilab was completed in the middle of May 2007. After a period of commissioning of the detectors at the end of May 2007, data taking in anti-neutrino mode started in June 2007. The SciBooNE measurements will provide significantly improved inclusive and exclusive neutrino and anti-neutrino cross-sections in the energy region below 1 GeV in the near future.

2. Electromagnetic Calorimeter (EC)
The EC detector is an electromagnetic calorimeter installed just downstream of SciBar with respect to incoming neutrinos (Fig.1). SciBar acts as a fully active target for neutrino interactions.
The main purpose of the EC is the longitudinal containment of the electromagnetic showers since the whole SciBar corresponds to only 4 radiation lengths. The EC provides 11 radiation lengths and has 85% energy containment at 3 GeV. It consists of one plane of 32 horizontal modules and one plane of 32 vertical modules. The two planes have both a cross sectional area of 2.7 m × 2.7 m. Each module is a sandwich of lead and scintillating fibers, built by piling up extruded sheets of grooved lead with scintillating fibers positioned in the grooves. A module consists of a stack of 21 lead sheets, 2,650 mm long, and 740 fibers of 1 mm diameter and 3,050 mm long (see Figure 2). The groove diameter is 1.1 mm and the sheet thickness is 1.9 mm. The sheet material is 99% lead with 1% antimony content to improve its mechanical properties. The stack is kept together by a welded steel case. An overall thickness non uniformity of less than 2% was achieved through the extrusion process. The fibers are manufactured by Kuraray (type SCSF81) and they have a 1 mm diameter polystyrene core, surrounded by a 30 µm thick acrylic cladding, with an emission maximum in the blue, around 420 nm. To improve the light collection uniformity an acrylic black paint is applied on the surface of the last 5 cm of fibers on each side. This has the effect of reducing the light coming from the cladding, which has a smaller attenuation length. In addition, to select the spectral component with a larger attenuation length a yellow filter (Kodak Wratten No. 3) is used. The attenuation length was about 500 cm when the modules were built in 1993 and was recently measured in SciBooNE to be 400 cm. The modules were originally produced for the CHORUS neutrino experiment at CERN[7]. At both ends of the readout cell (see Figure 3), fibers are grouped into two bundles with an hexagonal shape (22.2 mm apex to apex) and they are coupled to a plexiglas light guide, also with hexagonal cross section (24 mm apex to apex). The hexagonal shape and the length of the light guide were chosen to reduce non uniformities in the mixing of the light coming out of the individual fibers[8]. Each fiber bundle defines two independent readout cells of 42 × 42 mm² transverse cross section.

The light guides are coupled to 1-1/8 inch diameter photomultipliers, type R1355/SM from Hamamatsu, with a special green extended photocathode, of 25 mm useful diameter. The cathode material is Bialkali, with a quantum efficiency of 27% in the wavelength range 350-450 nm. The cathode is sensitive to wavelengths from 300 nm to 650 nm. A typical current amplification is $2.1 \times 10^6$ at the supply voltage of 1,600 V. The anode dark current is 10 nA. The PMT gain of each channel was measured before the installation. The non-linearity of the output signal vs input charge is 2% at 60 mA (corresponding to 600 photo electrons) at a gain $2 \times 10^6$. The pedestal width is approximately 0.7 photo electrons and the energy resolution was measured in a test beam as $14% / \sqrt{E(\text{GeV})}$ for electrons [7]. From each PMT a differential signal is produced using the outputs of the cathode and the last dynode, read via multipolar.
Figure 2. Cross section of one of the 64 electromagnetic calorimeter modules.

differential screened cables 100 m long.

Figure 3. Schematic view of one readout side of a module.

2.1. EC HV and DAQ
At the front-end the 256 analog channels of the detector are digitized using 8 QDC VME (CAEN V792). These boards support 32 channels charge analog to digital conversion (12 bits) in 5.7 $\mu$s. Impedance matching cards (CAEN A992 custom modified) are used to convert the 110 $\Omega$ differential signals into 50 $\Omega$ single ended signals and to decouple the PMT’s and the QDC grounds. The acquisition time for the EC DAQ is less than 1 ms. The EC DAQ can handle three types of trigger signal from the experiment: cosmic, pedestal and beam data. The HV system consists of two mainframes (CAEN SY527) each equipped with 9 HV distributor boards (CAEN A734N). The two CAEN mainframes are connected through a daisy chain to a PC that hosts the slow monitor and control system. The software uses the SMACS package[9] (see Figure 4), developed by INFN Roma for the CDF TOF system. The system performs cyclic read out of all the HV channels in less than 1 second to monitor the status of each voltage and current. Individual channel setting can be changed interactively and the status voltage, current and time plots are available for each channel through a tree browser interface. Fluctuations of the monitored voltage or current outside a user defined window around the set nominal value,
trigger alarms. The windows were set to $\pm 5$ V and $\pm 3$ $\mu$A. All HV events are logged to a local database and the same tree browser allows navigation of all the HV channels where a led represents the status of each channel (green=ok, yellow=warning, red=alarm). The system has a server and a client part. The server is hosted on a pc that sits in the SciBooNE enclosure while the client runs in one of the control room PCs. The client receives the status of each channel from the server through a TCP/IP socket and it shows the operational status of the detector HV in real time. All alarms and warnings are logged and displayed on the client window, notifying the experts via emails and calling the shifter pager when appropriate.

![Figure 4. EC HV server display.](image)

### 2.2. EC calibration and online monitoring

Before the transportation to the experiment enclosure, the detector was fully installed in an assembly area and partially commissioned with cosmic rays. During this commissioning the HV settings were tuned iteratively, achieving a spread of 10% in the pulse height distributions. The individual channel response was inter-calibrated by fitting the pulse heights with a Landau distribution convoluted with a gaussian to take into account resolution effects. Fig. 5 shows that the spread of the Landau most probable values after the HV tuning and applying the inter-calibration constants is better than 0.5%. Comparing the pulse height distribution for cosmics (most probable value and width) of the two PMTs in each readout cell, the number of photo-electron per MIP was measured to be 10.4 in average. The energy deposited in a read out cell is reconstructed from the geometrical average of the pulse heights of the two PMTs. The dependence on the longitudinal position along the cell due to the exponential attenuation of the light in the fibers factorizes out in the geometrical average. The energy deposited in a cell is given in Eq. 1.

$$
signal = \sqrt{\text{sig}_1} \times \sqrt{\text{sig}_2} \times \sqrt{C_{\text{inter-calib}_1} \times C_{\text{inter-calib}_2} \times \text{absolute calib} \times C_{\text{attenuation}}}
$$

where $\text{sig}_1$ and $\text{sig}_2$ are the ADCs of the two PMTs, $C_{\text{inter-calib}_i}$ are the inter-calibration constants of the two channels, $C_{\text{absolute}}[\text{GeV/ADC}]$ is the absolute calibration constant and $C_{\text{attenuation}}$ is the correction for the light attenuation.

Cosmic rays taken in between the neutrino spills during normal data taking are used to calibrate the detector, producing sets of inter-calibration constants. Random triggered events (pedestal events) are used to compute the pedestal absolute values and widths every 100 events.
(about 10 minutes). The response to cosmic ray muons is used to monitor the detector stability. In particular the shift crew monitor online the ADC hitmaps and the average deposited energy in each channel (see Fig. 6 for an example of the online monitor display).

Figure 5. PMT’s ADC response for the vertical and horizontal EC’s planes after applying the inter-calibration factors.

Figure 6. EC online monitor control.

2.3. EC MC simulation
In order to simulate the response of the EC detectors, the GEANT4[10] package is used to simulate the detector geometry and the tracking and interactions of particles. The energy loss of a particle in each individual EC sensitive fiber is simulated. The energy deposition in each cell is converted to a detector response value taking into account effects such as the light attenuation along the fibers, the poisson fluctuations of the number of photoelectrons, the PMT resolution and the pedestal fluctuations. The Bertini model in Geant4[10] is used to simulate the interactions of pions with the detector material. The input parameters of the detector simulation are derived from laboratory measurements and calibration data. The features of the simulation have been systematically compared and tuned with cosmic rays and neutrino data. The agreement between data and MC is shown in Figure 7. MC studies have been made of the energy measured for muons as a function of the true muon energy loss. The corresponding
resolution is well fitted by $\sigma_E/E = (6.6 \pm 0.1)\%/\sqrt{E(\text{GeV})}$. This resolution for the $dE/dx$ of a minimum ionizing particle corresponds to the pure sampling fluctuation. The resolution for electrons (and photons) will include also the shower fluctuations. In general the energy response to electrons of a calorimeter is different from the response to the same amount of energy released by muons. This effect is often called $e/\mu$ ratio and it is due to the fact that the physical mechanism of energy loss for electrons and muons is different. In our detector a smaller response to electron is expected since the photoelectric effect is larger in the (high-Z) lead absorber than in the (low-Z) active scintillator. Correspondingly, we expect $C_e/C_\mu > 1$ for the ratio of the absolute calibration constants for electrons and muons. Our result for the $e/\mu$ ratio is $C_e/C_\mu = 1.19 \pm 0.07$ and the energy resolution for electrons is $(12.8 \pm 0.1)\%/\sqrt{E(\text{GeV})}$, compatible with the one measured in a test beam at CERN by the CHORUS experiment[7].

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