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SciBar Detector for SciBooNE

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Abstract. SciBooNE is an experiment for measurements of neutrino-nucleus interaction cross-sections using the Booster Neutrino Beam at Fermilab. The SciBar detector in SciBooNE is a fully-active, finely segmented tracking and calorimetric detector. The SciBar detector can identify neutrino interactions by detecting charged particles. The design, performance, calibration and operation of SciBar are presented.

1. Introduction

SciBooNE [1] is an experiment for measurements of neutrino-nucleus interaction cross-sections. Precise knowledge of neutrino-nucleus interactions cross-sections is important for neutrino oscillation measurements to determine oscillation parameters. Figure 1 shows the ν_μ energy spectrum at SciBooNE. SciBooNE measures neutrino and anti-neutrino cross-sections at energies around 1 GeV. There are experimental data of low statistics of neutrino-nucleus and anti-neutrino-nucleus interaction cross-sections from previous experiments at energies below 1 GeV. SciBooNE helps the neutrino oscillation experiment T2K [2] since it uses the same neutrino energy region as SciBooNE. SciBooNE also helps MiniBooNE [3], which is on the axis of the same neutrino beam, as a near detector.

Charged current quasi-elastic (CCQE) scattering is the signal reaction in ν_μ disappearance oscillation measurement. The background comes from charged current single pion production (CC 1π) in which the pion is not observed; this happens because of pion absorption inside the nucleus or insufficient pion energy to be detected.

Neutral current pion production (NC $1\pi^0$) is the major ν_μ background of ν_e appearance measurement with a Cherenkov detector. Two γ's from a π^0 decay are detected as two Cherenkov rings. They can be mis-identified as a ν_e event if the opening angle between them is too small or they have highly asymmetric energies. SciBar can identify π^0's with higher momentum by looking at tracks of electro-magnetic showers. The measurement of these interactions enables oscillation experiments to know fractions of signals and backgrounds.

Neutrino-nucleus scattering gives us knowledge also about nucleon spin structure. The cross-section for neutral current elastic (NC elastic) scattering contains electro-magnetic form factors and axial form factor of the nucleon. Each form factor includes strange quark contribution. The strange quark axial form factor is proportional to the strange component of nucleon spin in the $Q^2 \to 0$ limit. Strange quark spin contribution to the nucleon spin can be determined from the NC elatic cross-sections as a function of Q^2. A previous experiment, E734 [5] at BNL in the 1980's, measured NC elastic cross-section with Q^2 down to 0.4 GeV^2. SciBooNE can measure cross-section with Q^2 downt to 0.2 GeV with more statistics.

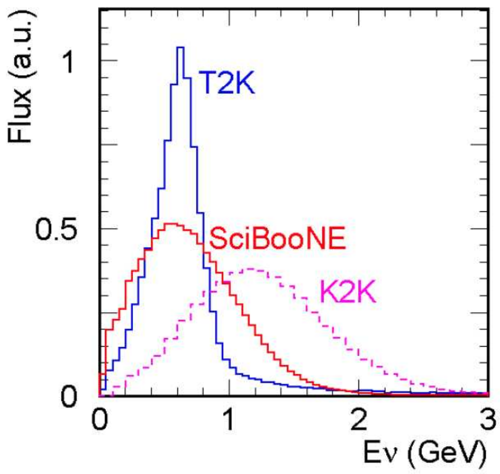

Figure 1. The ν_μ energy spectrum at K2K, T2K and SciBooNE. All curves are normalized by area.

SciBooNE uses the FNAL Booster Neutrino Beam (BNB) with a peak energy of 0.7 GeV. 8 GeV protons from the Booster hit a beryllium target surrounded by the magnetic focusing horn and produce mesons, primarily pions and kaons. The produced mesons are focused, and decay into neutrinos inside the 50 m decay volume. The polarity of the magnetic focusing horn can be changed to select the neutrino or anti-neutrino mode which enables us to study both neutrino and anti-neutrino cross-sections. SciBar, an electro-magnetic calorimeter (EC) [7], and a muon range detector (MRD) [8] are detectors for SciBooNE. They are located 100m downstream of the proton target.

The SciBar detector was used as a near detector in the neutrino oscillation experiment K2K [4] at KEK in Japan from 2003 to 2004. It was then moved from KEK to FNAL and re-assembled. We started commissioning with the neutrino beam in May 2007. Projected statistics are 1×10^{20} protons on target (POT) for both neutrino and anti-neutrino mode in one year. We completed collecting projected POT for neutrino data. We will complete data taking for anti-neutrino in August 2008.

2. SciBar Detector

The SciBar detector [6] is a fully-active neutrino detector with finely segmented structure. Carbon and hydrogen in the plastic scintillators are the target nuclei. Its volume is $3{\times}3{\times}1.7$ m^3 and weight is 15 tons. The SciBar detector consists of 14,336 plastic scintillator bars (Figure 2). Dimensions of each plastic scintillator bar are $1.3{\times}2.5{\times}300$ cm^3. The SciBar detector consists of 64 layers arranged perpendicular to the beam direction. Each layer has a vertical plane and a horizontal plane. One plane consists of 112 bars of plastic scintillator arranged vertically or horizontally. The scintillator bars are made of polystyrene, infused with PPO (1%) and POPOP (0.03 %) with 0.25 mm thickness TiO_2 coating. The emission wave length is 420 nm (at peak). One wave length shifting (WLS) fiber is inserted in each plastic scintillator bar. The diameter of the WLS fiber is 1.5 mm. The attenuation length of each WLS fiber is measured, and is about 350 cm on average. The scintillation light from the plastic scintillators is sent to a 64-channel multi-anode photo-multiplier tube (MAPMT) through the WLS fibers. In total, 224 of MAPMT (H8804 made by Hamamatsu Photonics K.K.) are used in the SciBar detector. Each has 64 anodes with $2{\times}2$ mm^2 area. The typical gain is $6{\times}10^5$ with a linear response up to $\sim$200 photoelectrons (p.e.); the gain uniformity over all channels is 20% in RMS. The fibers and the MAPMT are connected using a dedicated jig, called a "cookie" (Figure3) to align the fibers to the anodes. There is cross-talk mainly caused by light entering adjacent channels on the surface of the MAPMT. The average level of the cross-talk from an adjacent channel is measured to be 3.5%.

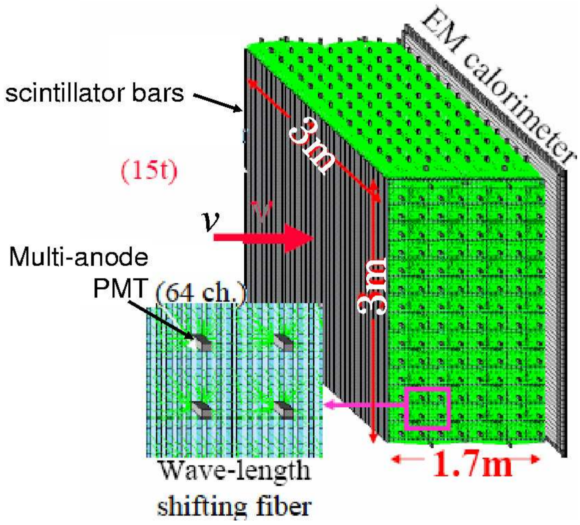

Figure 2. The SciBar detector consists of 14,336 of the combination of plastic scintillator bar and wave-length shifting (WLS) fiber. Volume of the detector is 3×3×1.7 m^3, weight is 15 tons.The Scintillator bars are arranged vertically and horizontally. Each WLS fiber is attached to one anode of a multi-anode PMT.

The gains of all the SciBar channels are monitored using a gain monitoring system which consists of LEDs, clear fibers, and light injection modules. The light from four LEDs is sent via clear fibers to each light injection module located between the plastic scintillators and every MAPMT. The light injection modules are designed to uniformly distribute light from the clear fibers to each WLS fiber. PIN-photo diodes are located near each LED to monitor the LED luminosity. The gain and pedestal data for each MAPMT channel are taken between every beam spill to monitor the detector stability.

Light yield and timing resolution of the SciBar detector are evaluated using cosmic-ray muons. Light yield is $\sim$20 p.e./1.3cm for minimum ionizing particles at the detector edge close to the MAPMT. Timing resolution is $\sim$1.6 ns. The number of dead channels of the SciBar detector is one out of 14,336.

Each MAPMT is mounted on a front-end board as shown in Figure 3. Each front-end board has two sets of Application Specific Integrated Circuit (ASIC), called “VA/TA”. The VA is an ASIC with a preamplifier, a shaper and a multiplexer which serialize charge from 32 channels of the MAPMT to a single output. The TA is an ASIC which provides inclusive timing information for the 32 channels. The front-end boards process signals from the MAPMTs, and send them to VME-9U backend electronics boards. They process the charge and timing information from the MAPMT with 12-bit flash ADCs and 64-ch multi-hit TDCs.

Charged particles whose track length exceeds 8 cm inside the detector are reconstructed with 99% efficiency.

3. Neutrino Events in the SciBar Detector

Figures 4 and 5 show CCQE event candidates. The area of dots is propotional to the ADC count (i.e. energy deposit). Boxes represent TDC hit information by their colors. The track penetrating the MRD in Figure 4 is identified as muon (Figure 4). One of the tracks in Figure 5 is identified as muon which decayed inside the SciBar using the multi-hit TDC information. Existence of muon is the sign of charged current events. Difference in dE/dx between muons and protons can be seen. dE/dx distributions of muons and protons are shown in Figure 6. Protons are separated from muons with $\sim$90% efficiency.

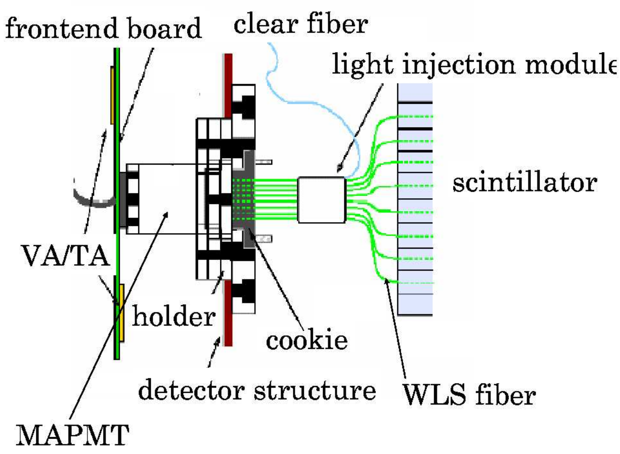

Figure 3. The WLS fibers are attached to the MAPMT by the cookie. The light injection module is located between the scintillators and the MAPMT. Each MAPMT is mounted on the front-end board.

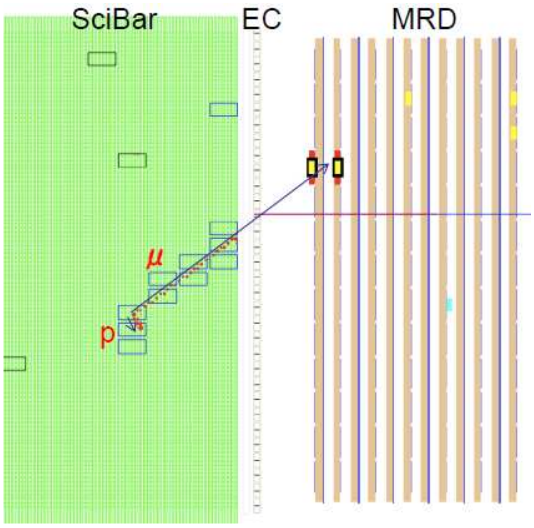

Figure 4. Event displays of CCQE candidate. the area of dots is propotional to ADC counts. Boxes represent TDC hit information. Tracks penetrating the MRD are identified as a muon.

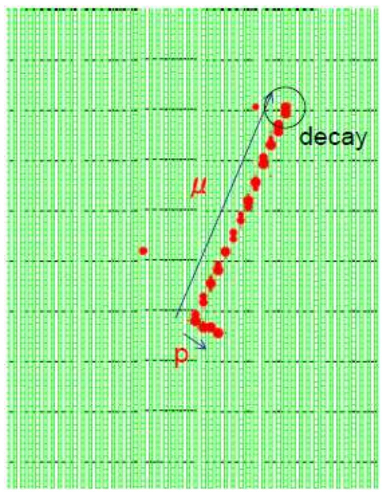

Figure 5. Event displays of charged current quasi-elastic candidate. The decay of the muon is tagged by multiple TDC hits.

CC 1π production can be categorized into three different groups: coherent interaction $\nu A \rightarrow \mu A \pi$, neutron scattering $\nu n \rightarrow \mu n \pi$ and proton scattering $\nu p \rightarrow \mu p \pi$. As shown in Figure 7, scattering on neutrons or coherent interactions appears as two charged tracks with common vertex in the SciBar, while scattering on proton appears as three charged tracks as in Figure 8. If one of the tracks is not long enough to be tracked in the proton interaction event, i.e., the proton track in Figure 8, the event can be separated from the neutron or coherent scattering events by looking at large energy deposit near the vertex.

There is no muon in the final state of neutral current events. Figure 9 shows a candidate of neutral current elastic scattering. The signature of this event is a single proton track. The proton is identified using dE/dx information. Figure 10 shows a candidate of neutral current

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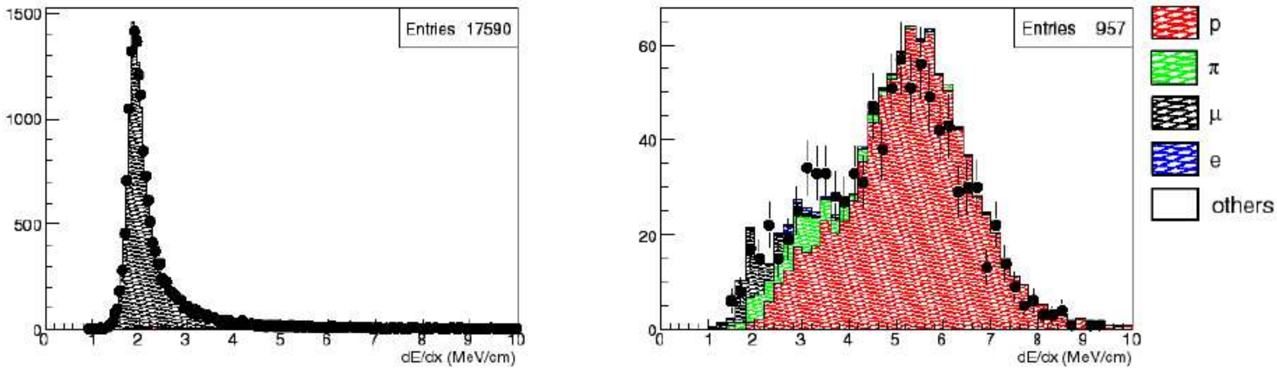

Figure 6. dE/dx distributions of muons (left plot) and protons (right plot). Protons are separated from muons with ∼90% efficiency.

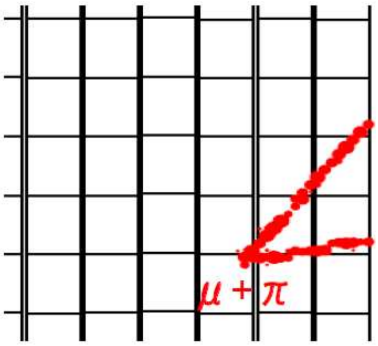

Figure 7. CC 1π coherent or $\nu n \to \mu n \pi$ candidate. Muon and pion are visible.

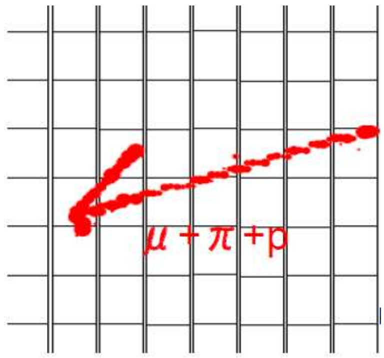

Figure 8. CC 1π $\nu p \to \mu p \pi$ candidate. Muon, pion and proton are visible.

π^0 production event. The 2 γ's from a π^0 decay produce electro-magnetic showers, which can be detected in SciBar. These features of SciBar enable us to make precise measurements of neutrino-nucleus interactions in the region of neutrino energy below 1 GeV. Analyses of these interactions are on going.

4. Event Rate

The number of CC event candidates is evaluated from tracks starting inside the SciBar every week during the data taking period. With the obtained number, one can monitor the SciBar status. Figure 11 shows number of CC event candidate normalized by POT. The flat shape for each mode and same values for two anti-neutrino mode periods shows that the SciBar took data stably since we started data taking. Neutrino event rate is ∼4.5 times of anti-neutrino event rate because of difference between cross-sections of neutrino-nucleus and anti-neutrino-nucleus scattering, and production cross-sections of π^+ and π^- that are parent particles of neutrino and anti-neutrino. We started data taking in Jun. 2007, switched to neutrino mode in Oct. 2007. We completed taking data of projected POT with neutrino mode in April 2008, then switched back to anti-neutrino mode. We will complete taking data of anti-neutrino mode in August 2008.

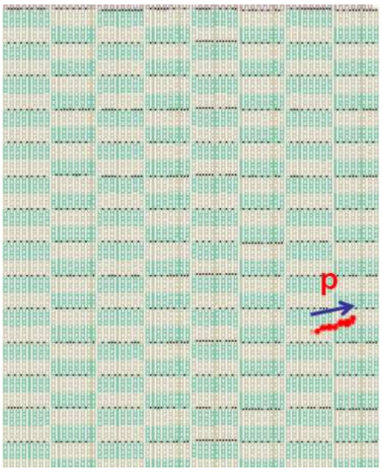

Figure 9. Candidate of neutral current elastic scattering. Signature of this event is single proton track. The proton is identified using dE/dx information.

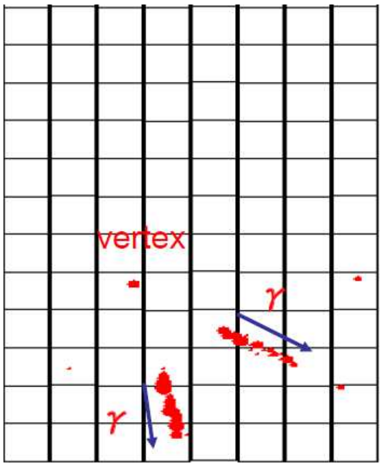

Figure 10. Candidate of neutral current π^0 production event. The 2 γ's from a π^0 decay produce electro-magnetic showers, which can be detected in the SciBar.

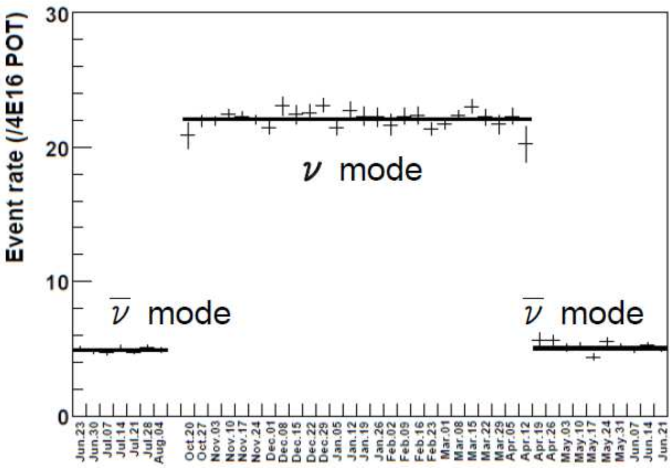

Figure 11. Number of CC event candidates normalized by POT. The flat shape for each mode and same values for two anti-neutrino mode periods shows that the SciBar took data stably since we started data taking.

Acknowledgments

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