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Charged-Current Neutral Pion production at SciBooNE

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Abstract.
SciBooNE, located in the Booster Neutrino Beam at Fermilab, collected data from June 2007 to August 2008 to accurately measure muon neutrino and anti-neutrino cross sections on carbon below 1 GeV neutrino energy. SciBooNE is studying charged current interactions. Among them, neutral pion production interactions will be the focus of this poster. The experimental signature of neutrino-induced neutral pion production is constituted by two electromagnetic cascades initiated by the conversion of the π^0 decay photons, with an additional muon in the final state for CC processes.

In this poster, I will present how we reconstruct and select charged-current muon neutrino interactions producing π^0's in SciBooNE

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SCIBOONE

SciBooNE [1] is a muon neutrino scattering experiment located at the BooNE neutrino beam at fermilab. The 0.8 GeV mean energy neutrino beam is produced with a 8 GeV proton beam. Protons hit a beryllium target producing charged pions that are selected and focused using a magnetic horn. The ability to switch the horn polarity allows to select π^+ to produce neutrino beam or π^- to produce anti-neutrino beam. Only neutrino beam is currently used in this analysis.

SciBooNE detector consists in three sub-detectors: the main detector SciBar, the electromagnetic calorimeter 'EC', and the muon range detector 'MRD'.

- SciBar[3] is a fully active and fine grained scintillator detector that consists in 14,336 bars arranged in vertical and horizontal planes. SciBar is capable to detect all charged particles and perform dE/dx based particle identification.
- The Electron Catcher (EC)[4], is a lead-scintillator calorimeter consisting in two planes, one vertical and one horizontal, with a width corresponding to 11 X_0.
- The MRD[5], consists in 12 steel plates sandwiched between vertical and horizontal planes of scintillator. The MRD has the capability to stop muons with momentum up to 1.2 GeV. The MRD detector is used in this analysis to define Charged Current events by tagging the outgoing muon.

The current analysis is covering SciBar contained events, which means that events with particles other than muons escaping from SciBar detector are not being considered. EC detector will be introduced in the analysis in the near future allowing us to use events with particles escaping from SciBar in the forward direction and reaching the EC.

NEUT [2] event generator is used in this analysis. The Rein-Sehgal model is implemented to simulate Charged Current resonant pion production with an axial mass $M_A = 1.2$ GeV/c^2. All resonances up to 2 GeV are taken into account. However $\Delta(1232)$ is the resonance that more largely contributes to the π^0 production.

CC-π^0 ANALYSIS

A CC-π^0 event is defined in this analysis as such event that contains at least a muon and a neutral pion coming out from the interaction vertex. This definition includes neutral pions generated by secondary interactions inside the target nucleus as, for instance, charge exchanges.

Though the π^0 decays almost immediately to two photons, and those produce EM cascades with an average flight distance of 25 cm, topologically a CC-π^0 SciBar contained event contains a muon reaching the MRD and two or more tracks contained in SciBar (see fig. 1). The non-muon tracks are considered gamma candidates and are used to, at the end, reconstruct the neutral pion.

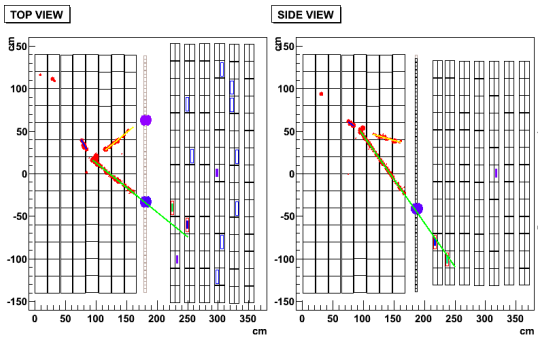

FIGURE 1. Typical CC-π^0 event. Muon track in green, reconstructed EM showers in yellow and blue.

TABLE 1. Event selection summary.

	DATA	MC*	Purity	Efficiency†
MRD matched sample	30161	30161	6.80%	23.9%
1 muon	28931	27223	6.00%	19.2%
veto	23457	24265	4.00%	11.4%
3 tracks	912	934	23.2%	2.54%
Time cut	846	903	23.8%	2.52%
dE/dx	433	447	27.5%	1.44%
Distance cut	141	137	45.5%	0.73%

* Normalized to CC-Inclusive
† Efficiency relative to all events produced in the SciBar fiducial volume.

CC-π^0 selection

Given the signal definition we can use some event topology and track property based cuts in order to reduce the background events in the sample (see table 1 for summary). The chosen filters are applied sequentially as follows:

- SciBar uses a CC event definition based on the muon tagging using the MRD[1]. Then, the first applied selection is over events that contains a track reaching the MRD tagged as a muon. Because we don't expect any other particle to reach the MRD, we also require only one tagged muon in the event.
- Given that we are selecting SciBar contained events, we use a veto filter to dismiss events with outgoing tracks. The veto filter applies to events with outgoing tracks either from the upstream or the sides of the detectors. The veto filter does not apply on tracks pointing to the EC because those tracks will be fully reconstructed once the EC information will be used. The veto filter is also useful in order to remove events with in-going tracks originated in interactions outside the detector (called DIRT interactions).
- As discussed before, we expect events with 3 tracks in SciBar, the muon and the 2 electromagnetic cascades from the pion decay. We thus use a filter to meet this topology.
- We also use a time based filter in order to avoid cosmic rays and DIRT generated tracks in our selected events. This filter requires that the photon candidates should match the muon time with a difference of 20 ns or less.
- As commented before, we use the SciBar dE/dx capability in order to separate minimum ionizing particles as muons or photons[2] from protons. Most protons are rejected using this filter.
- Finally, a cut is placed requiring that the photon tracks should be disconnected from the event vertex taking advantage of the larger photon flight distance. This cut is particularly useful to reject protons and charged pions, which track starts always from the event vertex.

[1] We are also performing analysis that uses Michel electrons to tag the muons that decays in SciBar without reaching the MRD.
[2] We use 'photon' and 'gamma' in this context to refer the EM cascades produced by photon interactions in SciBar.

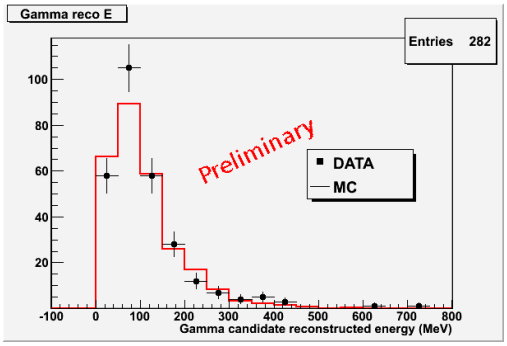

FIGURE 2. Reconstructed photon energy. MC normalized to CC-Inc.

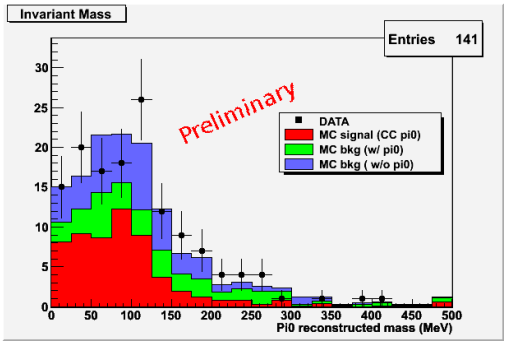

FIGURE 3. π^0 reconstructed mass. MC background broken in events with neutral pion and events without neutral pion. MC normalized to CC-Inc events.

Preliminary Results

After the above commented cuts, we get reconstructed photons with a typical energy between 50 and 200 MeV (see fig. 2). Also, for correctly associated photon candidates, the energy is reconstructed with 100 MeV resolution and small bias. The photons are reconstructed at all angles.

Once we have the 2 reconstructed gammas, we are able to reconstruct also the π^0 observables. In particular we reconstructed the invariant mass and also the momentum and angle. As you can see in fig. 4 neutral pions are produced at all angles with a momentum in 50 - 300 MeV/c range. It is also visible a peak in the invariant mass plot near the π^0 mass (fig. 3).

From the plots we can see that our NEUT-based MC reproduces well the π^0 observables.

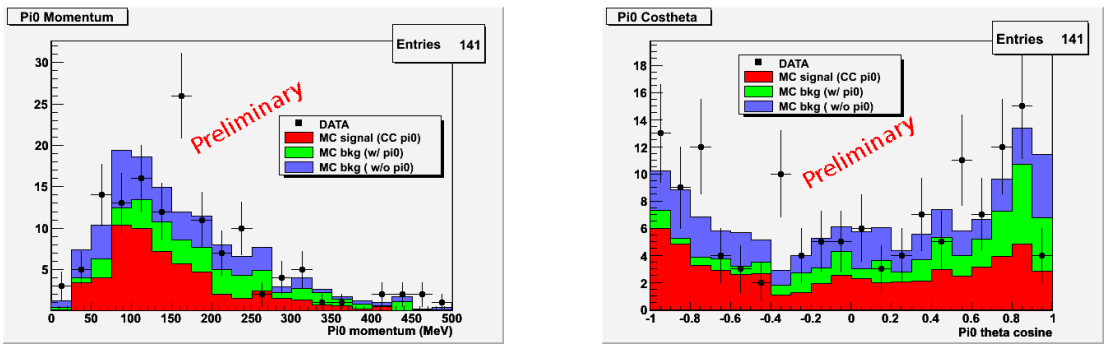

FIGURE 4. *Right plot:* π^0 reconstructed momentum. *Left plot:* Cosine of the angle of the π^0 with respect to the beam.

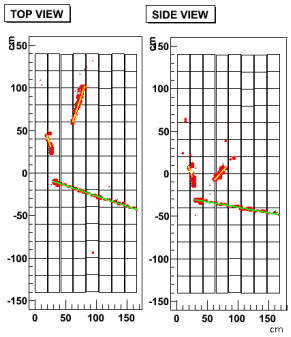

FIGURE 5. Event reconstructed using the improved track reconstruction algorithm. Muon track in green, reconstructed EM showers in yellow.

UPDATES

Since the poster was presented, some reconstruction improvements have been performed, in this section we are going to discuss them.

The track reconstruction in SciBar is performed by a cellular automaton which essentially travels among the beam direction connecting hits to create tracks. The first reconstruction improvement was to implement in the code a second run of the automaton but this time traveling in the transversal direction, that is perpendicular to the beam, and using the hits that are not associated to any track from the first processing. In this way we found abut a 10% more events containing 3 or more tracks and also we got the ability to reconstruct tracks at larger angle, close to 90 degrees like in fig. 5. This has been an important upgrade given the low statistics of the analysis mainly due to the lack of events with 3 or more reconstructed tracks.

A second improvement is to use a new algorithm that improves the reconstruction performance of the EM cascades. The EM cascades in SciBar are characterized by disconnected track segments and isolated hits, making difficult to recover and correctly associate all the photon visible energy. The new algorithm seeks for those disconnected track segments and merge them into a single extended track via an energy-flow algorithm. It also seeks for hits around the gamma candidate track in order to add the energy coming from those hits to the gamma track.

I this way, the photon energy reconstruction is improved and so is the π^0 observables. By using the new algorithm we find a narrower invariant mass peak with less low mass π^0 than in the fig. 3. Also, the bias in the π^0 momentum is reduced and it can be observed an increment of the high momentum pions.

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