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ELASTIC NEUTRINO-ELECTRON SCATTERING:
A Progress Report on Exp734 at Brookhaven

BNL-Brown-KEK-Osaka-Penn-Stony Brook-Tokyo (INS) Collaboration*

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ELASTIC NEUTRINO-ELECTRON SCATTERING

A PROGRESS REPORT ON EXPERIMENT 734 AT BROOKHAVEN

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presented by

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ABSTRACT

I will report preliminary results on elastic neutrino-electron scattering from data taken with the 200-ton segmented liquid scintillator - proportional drift-tube neutrino detector at Brookhaven. Features of the detector (such as the active target and long radiation length) permit a uniquely clean signal. Prospects of results from the completed analysis and further data taking are discussed.

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1. Introduction

The elastic scattering of muon neutrinos and antineutrinos on electrons,

$$\overset{(-)}{\nu}_\mu e \rightarrow \overset{(-)}{\nu}_\mu e \qquad (1)$$

is a purely leptonic process that allows a direct observation of the weak neutral current. With data from this process one can make a direct determination of the neutral current coupling constants g_V, g_A . These numbers can be interpreted within a given model to provide clean measurements of parameters such as $\sin^2\Theta_W$ or ρ .

To study elastic neutrino-electron scattering we have built a new neutrino detector[1] at Brookhaven National Lab. Operation of the detector at the Brookhaven AGS has a number of advantages relative to FNAL or the SPS despite the lower cross section. Indeed, with 10^{13} protons/pulse and 1.4 pulses/second the event rate at the AGS is comparable to that at other labs. The real difference in experiments at Brookhaven has to do with background: neutrino interactions at 1 GeV rather than 20 GeV have low multiplicities and have been well studied. Correspondingly, the backgrounds are simpler and easier to calculate and recognize. A recent development has been the recognition of the importance of coherent π^0 production:

$$\nu N \rightarrow \nu N \pi^0 \qquad (2)$$

Calculations(2) and experiments(3,4) suggest that this process could be a serious background in the elastic neutrino-electron signal. With increasing energy the cross section for this process grows rapidly and becomes more sharply peaked in the forward direction, so low energy experiments have a decided advantage.

2. The Detector

The anticipated signal for elastic neutrino electron scattering is that of an isolated electromagnetic shower, constrained to be in the forward direction by the kinematic relation:

$$E\Theta^2 \leq 2m_e \qquad (3)$$

Typically at Brookhaven energies the electron energy E is around 400 MeV, with the electron angle Θ then less than 50 milliradians. The total cross section for the elastic scattering is roughly

$$\sigma_{\nu_\mu e \to \nu_\mu e} \sim 1.5E_\nu \times 10^{-42}\text{cm}^2 \tag{4}$$

Reactions which can also give forward showers, like

$$\nu_\mu n \to \nu_\mu n\pi^0 \tag{5}$$

or

$$\nu_e n \to e^- p \tag{6}$$

and which have cross sections three orders of magnitude larger, can be serious sources of background.

With these considerations in mind we have designed and built a new detector at Brookhaven. Its basic design is to combine an active target with multiple measurements of position and energy loss on a distance scale short compared to a radiation length. The target is liquid scintillator, contained within 4m long acrylic extrusions and packaged into planes 4m x 4m in area and 8.9 cm thick. As shown in the insert on Figure 1, each scintillator plane (16 cells each with a phototube at both ends) is followed by 2 planes of thin-walled proportional drift tubes (54 wires/plane), with alternating horizontal and vertical wires. Over 80% of the mass of the detector is liquid scintillator, permitting observation of energy deposits at the vertex as well as allowing approximately 75% of the total energy to be visible. The radiation length is 5 modules (one module = 1 scintillator plus 2 PDT planes), so multiple measurements of dE/dx in both the scintillator calorimeter and the PDTs are possible at an early stage in the growth of an electron shower. This aspect of the detector enables good separation of electron tracks from photon showers. Together with energy loss measurements, the PDTs (with spatial resolution of 1.5mm) provide a determination of the electron angle [important because of eqn. (3)] with an accuracy approximately

$$\Delta\Theta \sim \frac{12\text{mrad}}{\sqrt{E}} \tag{7}$$

This number is derived from early prototype tests; measurements are in progress in a test beam to study fully this and other aspects of the detector.

The complete detector is shown in Figure 1. The total of 112 modules as described above (calorimeter and 2 PDT planes), 172 metric tons, is followed by

10 modules or 30 metric tons of alternating scintillator planes and 1 radiation length Pb sheets. This "gamma catcher" provides an energy measurement for showers which begin late in the detector, allowing a fiducial region for shower vertex position that extends through module 102. A spectrometer, using PDT planes, permits a determination of the momentum spectrum of a sample of quasi-elastic events to check the neutrino (anti neutrino) spectrum and $(\nu, \bar{\nu})$ composition of the beam. The total detector occupies a volume of 4m x 4m x 24m and is instrumented by approximately 4000 phototubes and 14,000 PDT wires.

The detector data collection is designed to be deadtimeless. A 10 μsec. electronic gate enables all elements shortly before the arrival of the 2.5 μsec neutrino burst. Both time and charge are recorded for every element with a signal above threshold. In data analysis, then, one can "time cluster" the hits and cleanly separate interactions (or delayed μdecays) within this gate. Additionally, all elements have multihit capability. Data readout procedes in parallel through four microprocessors[5]; these also handle elaborate calibration and monitoring tasks between bursts.

3. Status of the Experiment

We have had two data taking periods, with the flux as summarized in Table 1. The early data, taken with 1/2 the number of modules installed and without the "gamma catcher" or spectrometer, was summarized at Balaton[6]. I will discuss the analysis of the neutrino electron elastic scattering data from our major run, with the full detector.

TABLE 1. EXP 734 Running Periods

		protons on target:	
period	detector	(ν beam)	($\bar{\nu}$ beam)
June-July 1981	1/2	6.3×10^{18}	5.0×10^{17}
Dec.-Feb. 1982	full	8.8×10^{18}	9.1×10^{18}

The raw data from the ν running with the full detector consisted of recorded (time, charge) for all hit elements for each of 1.25×10^{6} bursts. This data was first passed through a conservative software filter designed to eliminate beam muons and neutrino interactions without electromagnetic shower characteristics. The sample surviving, 4×10^{4} "time clusters", was then scanned by physicists to select single showers within a 15° cone of the forward direction and eliminating events with extra tracks at the vertex, with multiple showers, or with associated side or front entering particles. The remaining 1575 events were subjected to a fiducial cut (vertex within modules 6 to 102 and PDT wire numbers 7-50) and an energy cut (visible energy > 150 MeV).

The above selection process eliminated all but 1048 events. Of these events, 257 were found to have an energy deposit of at least 5 MeV correlated in time but upstream of the vertex. As discussed below this feature is suggestive of a π^0 decay; subtracting this data left 791 events, predominantly single electromagnetic showers. Using the PDT positions in the first 3 to 5 modules of the shower (within 1 radiation length) we calculated the angle of the candidate electron; requiring this angle to be less than 180 milliradians reduced the sample to 392 events. Finally, to tag "electrons" and "protons" we made a separation based on the energy deposited in the PDT and calorimeter cells within the first three modules after the vertex. At this stage the signal was already relatively clean, so we were able to apply this cut loosely, retaining 95% of the electron signal while eliminating 50% of the photon-like background. This separation left 265 "electron" events and 127 "photon" events.

We handle the π^0 and e^-p backgrounds (Eqns 5 and 6) remaining in our sample by making a cut based on the measured shower energy. Studies indicate that the electron from e^-p events has much higher energy than from elastic neutrino electron scattering; we require then that the visible shower energy be less than 1500 MeV. Forward photon showers from π^0 producton, on the other hand, have energies that peak around 100 MeV. To reduce this contamination, we require that the visible shower energy E_{vis} be at least 150 MeV, and we study separately the regions $150 < E_{vis} < 300$ and $300 < E_{vis} < 1500$.

Using the energy selections mentioned above, the data tagged by dE/dx measurements as "electron" or "photon" events has a dependence on Θ^2 as shown in Figures 2 and 3. Note that the kinematic constraint, Eqn. 3, puts a restriction on Θ^2 that varies with E such that electrons at $E_{vis} = 1500$ MeV should fall within the first .001 bin of Figure 2, while at $E_{vis} = 150$ MeV the signal extends out to $\Theta^2 = .005$ (radians)^2. On the other hand, photons from reaction (5) should be isotropic in the forward direction or flat in Θ^2. Clearly in both energy regions there is a strong signal in the "election" sample with an essentially flat background having the same shape as the "photon" events. Shown also in Figs. 2 and 3 are the same distributions for events with associated upstream energy deposit. The Θ^2 distribution of these showers is consistent with their being photons from π^0 decay, as mentioned earlier. In figure 4, a plot of $E\Theta^2$, we see for the full region $150 < E_{vis} <$ 1500 MeV the pronounced signal in the "electron" sample. Note that although the background is also peaked near zero (due to the predominantly low energy of forward π^0 photons) the signal to noise is better than 2/1.

Using Figures 2 and 3 we can estimate the number of elastic neutrino-electron events in our sample; these numbers are given in Table 2. Together with the early data reported previously[6], our signal for neutrino-electron scattering totals 69 events. This sample should be compared with the 46 neutrino-electron and 77 antineutrino-electron events reported by the CHARM group[7].

TABLE 2. Preliminary $\nu_\mu e \rightarrow \nu_\mu e$ data

Run	Signal + Background	Est. Background	Signal
June-July '81	23	10	13
Dec-Feb '82			
$150<E_{vis}<300$	26	9	17
$300<E_{vis}<1500$	55	16	39
$150<E_{vis}<1500$	81	25	56
			total 69

Studies are now in progress of the detector performance with test beam electrons. Our signal/background ratio for elastic neutrino electron events, already outstanding, should improve as we understand and optimize our angular and energy resolutions. Analysis of the anti-neutrino data is now underway as is the normalization of the events to a measured quasi-elastic rate. With new data from running later this year we expect to have approximately 120 events of the process $\nu_\mu e \rightarrow \nu_\mu e$ and an equal number of the anti-neutrino electron scattering $\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$. Analysis of this data should provide a direct measurement of $\sin^2\Theta_W$ to better than .02.

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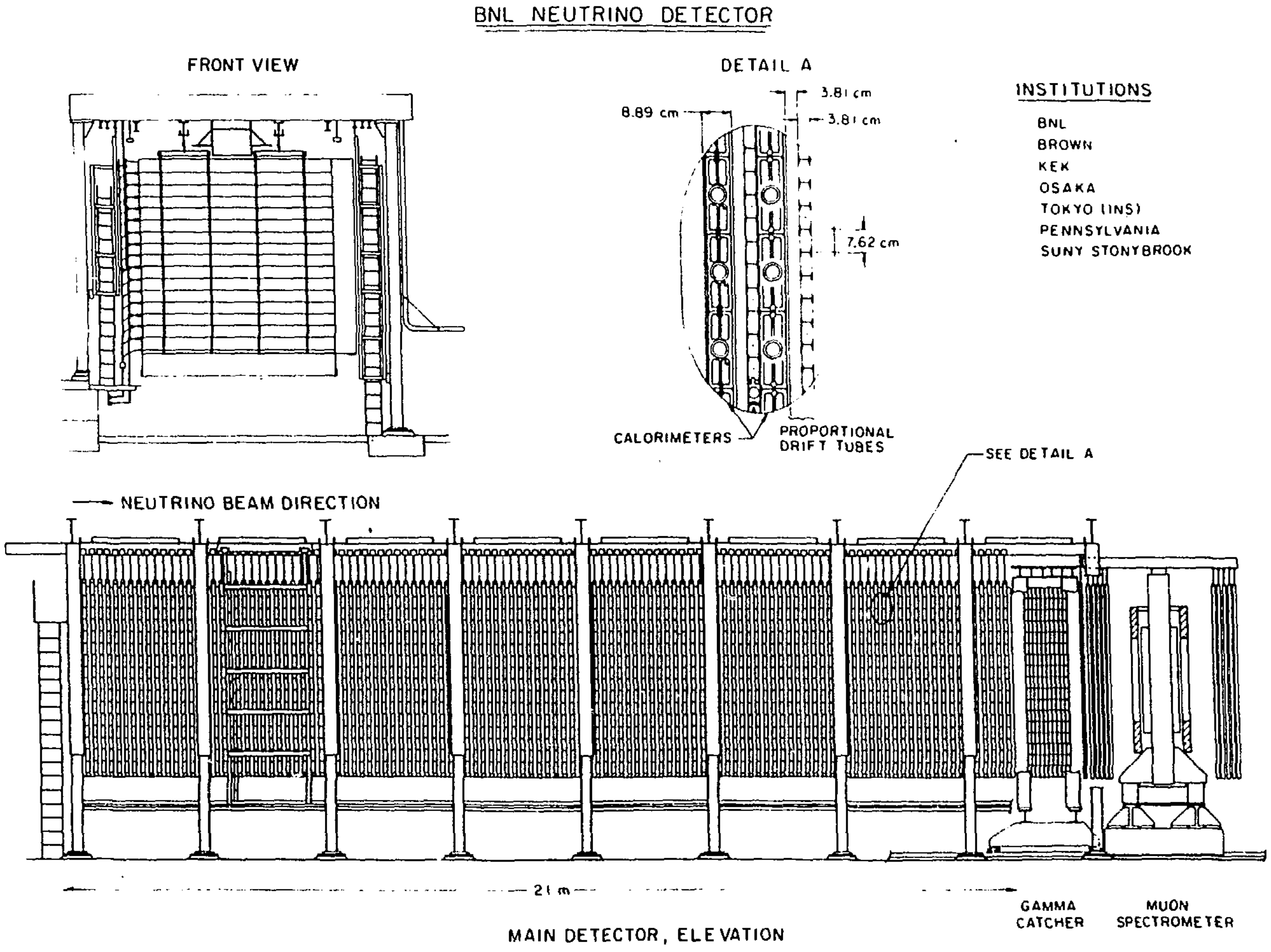

Figure 1. Diagram of the Brookhaven Neutrino Detector.

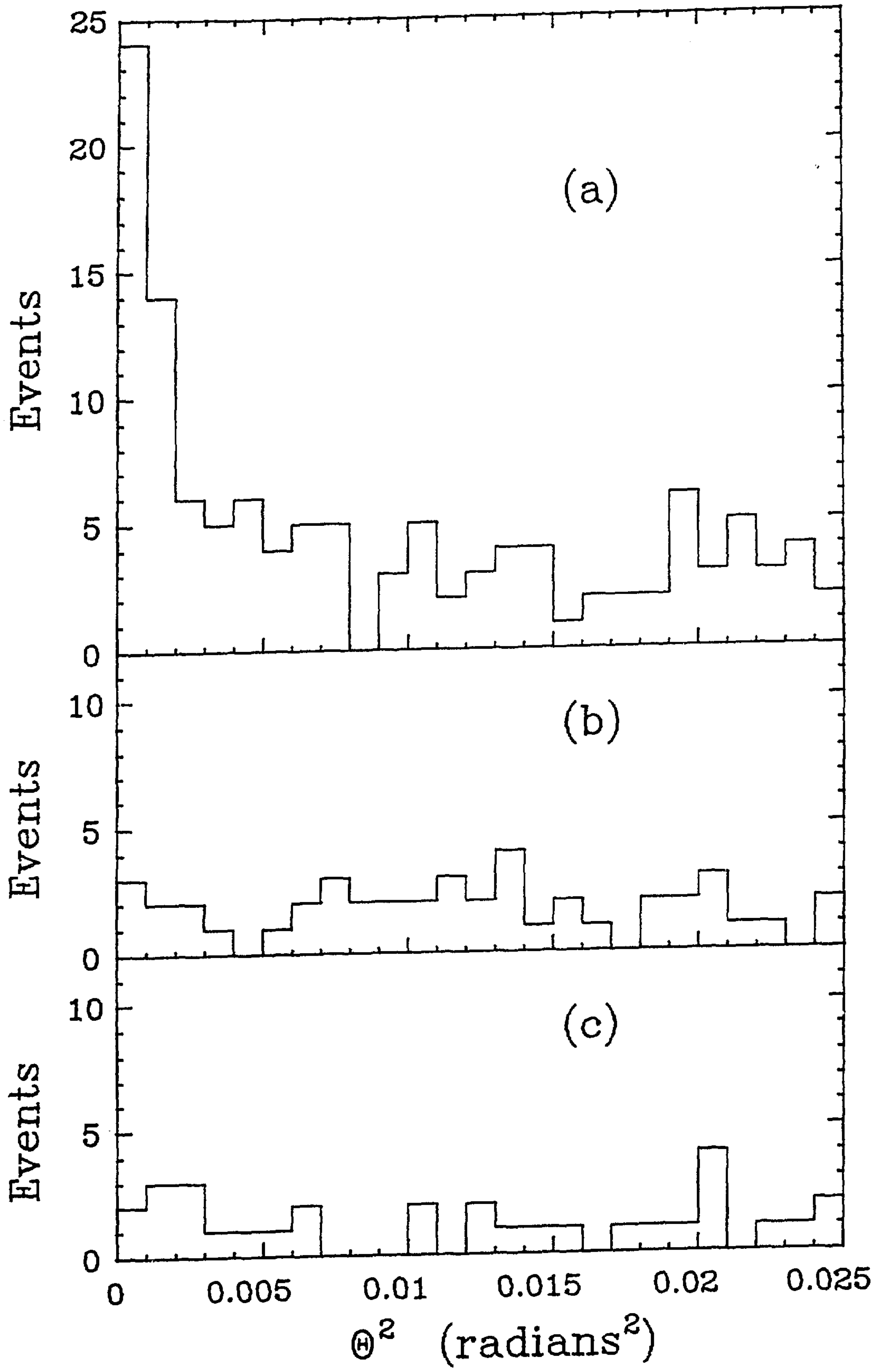

Figure 2. Distribution in θ^2 for events with $300 < E_{vis} < 1500$ MeV, and (a) tagged as "electrons", (b) tagged as "photons", and (c) with associated upstream energy deposit.

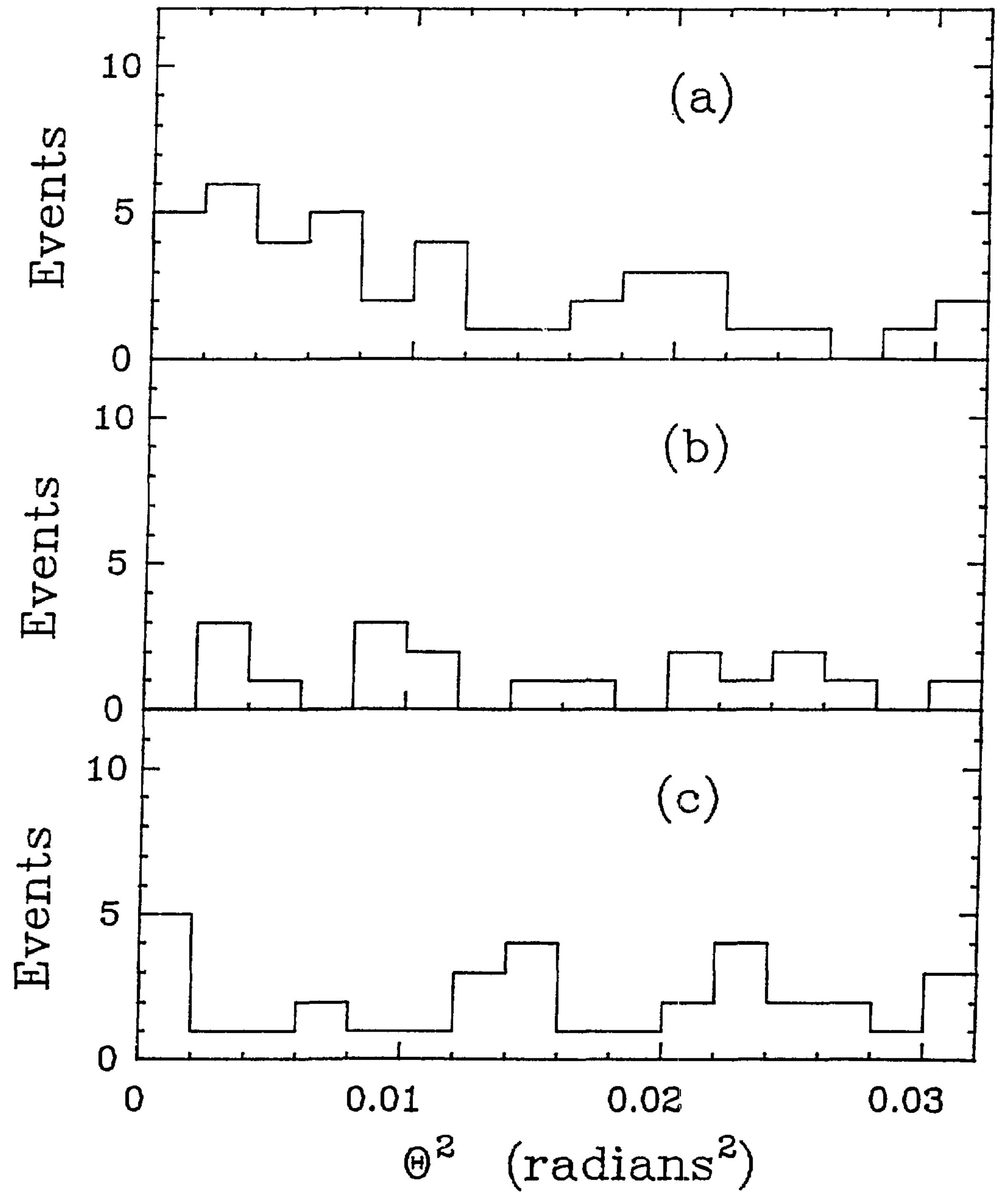

Figure 3. Distribution in Θ^2 for events with $150 < E_{vis} < 300$ MeV, and (a) tagged as "electrons", (b) tagged as "photons", and (c) with associated upstream energy deposit.

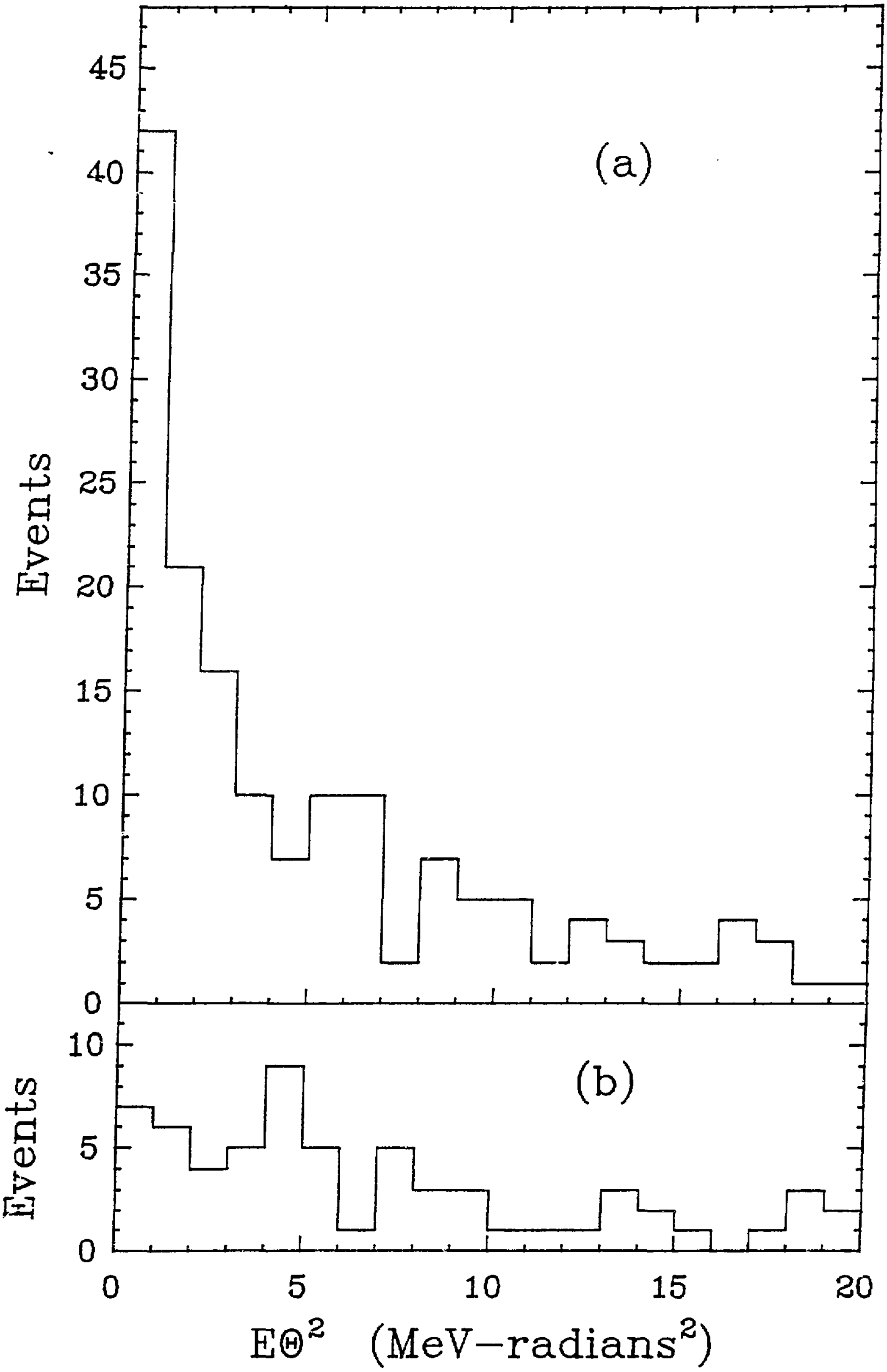

Figure 4. Distribution in $E\Theta^2$ for events with $150 < E_{vis} < 1500$ MeV, and (a) tagged as "electrons" or (b) tagged as "photons".