

Monte Carlo Status Report

P. Skensved and B.C. Robertson
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MSW

A systematic study of the detector response for various MSW parameters has been completed. Survival probabilities for neutrinos produced at the center of the sun were calculated by integrating the MSW equations [1] for a range of $\Delta m^2/E$ (10^{-9} to 3×10^{-5}) and $\sin^2 2\theta$. Figure 1 shows a typical set of $P(\nu_e \rightarrow \nu_e)$ curves for neutrinos produced at the center of the sun as function of solar radius. The effect of resonant conversion is clearly visible. In the calculations we use solar densities taken from the work of Bahcall [2]. In figure 2 we show the survival probability at earth as a function of $\Delta m^2/E$ for $\sin^2 2\theta = 0.01$. The results are in agreement with those of Haxton [3]. No correction was made for the finite size of the source as it only affects a small region of the MSW plot near $\Delta m^2 = 10^{-4}$. In all other cases the critical density occurs outside the source region ($R_{\odot B} / R_{Sun} \lesssim 0.1$). Finally in figures 3 to 7 we show the detector response for $\sin^2 2\theta = 0.7, 0.3, 0.1, 0.01$ and 0.01 for selected values of $-\log_{10}(\Delta m^2)$ ranging from 3.0 to 8.5 (the plots are labeled with the mass difference and the mixing angle in the form $mm-aa$). Each figure represents a vertical slice (ranging from non-adiabatic to adiabatic) through the 'interesting' region of the MSW triangle and we assume one full year of detector livetime for each. No

other signals (ES and NC) or backgrounds are included in the figures. A reasonable threshold would be approximately 50 hits. Below that the β - γ background will dominate.

Code Development

The basic Monte Carlo code has been extended to handle all neutrino interactions in the detector below $E_\nu = 40$ MeV. The total cross sections were taken from Doi et al. [4] for the four $\nu + d$ reactions. The corrections due to the p-p (n-n) relative motion have been re-evaluated using a more realistic deuteron wave function. We now interpolate in the ratio of the overlap integral to the 'zero charge' overlap integral as opposed to doing it in the integral itself. The ratio varies much more slowly as a function of the relative momentum and the 'zero charge' integral can be evaluated analytically. Additionally, a Fermi factor for the outgoing electron was added (a 4% correction at 6 MeV). The overall effect of these changes is small however when the basic detector resolution is folded in.

In the case of $\bar{\nu}_e + p$ the cross section can be evaluated analytically as function of neutrino energy and scattering angle. Due to the kinematics this reaction has an angular distribution.

Figure 8 shows the detector response (the D₂O) to a thermal spectrum of $\bar{\nu}_e$'s ($T = 3$ MeV) and figure 9 shows the signal from the H₂O to the same spectrum.

SuperNova

Preliminary estimates have been made of backgrounds and signals due to a 'standard' supernova at a distance of 10 kpc. Spectra were calculated for the initial $\bar{\nu}_e$ burst, the first second and the following two seconds of the cooling phase. In such a three second period the only contribution to the background comes from the PMT β - γ . Five of these events reconstructed in the detector and all of them below 2 MeV.

A large number of different reactions (mostly elastic scattering) compete during the cooling phase with relatively few events from each. This will give us a 'background' which will be difficult to sort out. The largest signal is from the neutron captures followed by $\bar{\nu}_e + d$ and $\nu_e + d$ in the D_2O and $\bar{\nu}_e + p$ in the H_2O .

If the neutron detection method is the default one (NaCl additive) then approximately half the non-neutron events occur above 10 MeV so that a clean signal is obtained for those. However, in order to determine the temperature it is necessary to observe the peak of the distribution.

Some of the neutron events (from $\bar{\nu}_e + d$) have a distinct signature; a positron followed a few milliseconds later by two neutron captures. A program to study these triple coincidences is about to be launched. This will also enable us to put a limit on high energy cosmic ray neutrinos.

9500 versus 7600 tubes

In preparation for the ARC meeting a set of simulations were done for both the default 9500 tube configuration and for a scaled down version with only 7600 tubes. This latter number gives us a detector which is roughly equivalent to the 'Temple Review' one where we specified 30% 'hard' photocathode coverage. Both calculations were done with the actual R1408 quantum efficiency as measured by Hamamatsu and Oxford. Since the Schott glass transmits more photons at low wavelength than the standard Pyrex glass, an increase in observed backgrounds originating outside the acrylic is expected. Figures 10 and 11 shows the standard plots for 9500 tubes ($D_2O + NaCl$ and pure D_2O) of events reconstructed inside 600 cm per year per MeV. Similar figures with 7600 tubes are shown in figures 12 and 13. In figures 14 and 15 we repeat figures 10 and 12 plotted on a linear scale. It is quite obvious that cutting the number of tubes or reducing the light collection in any other way (reducing the reflector size) results in a significantly poorer detector.

PMT β - γ 's

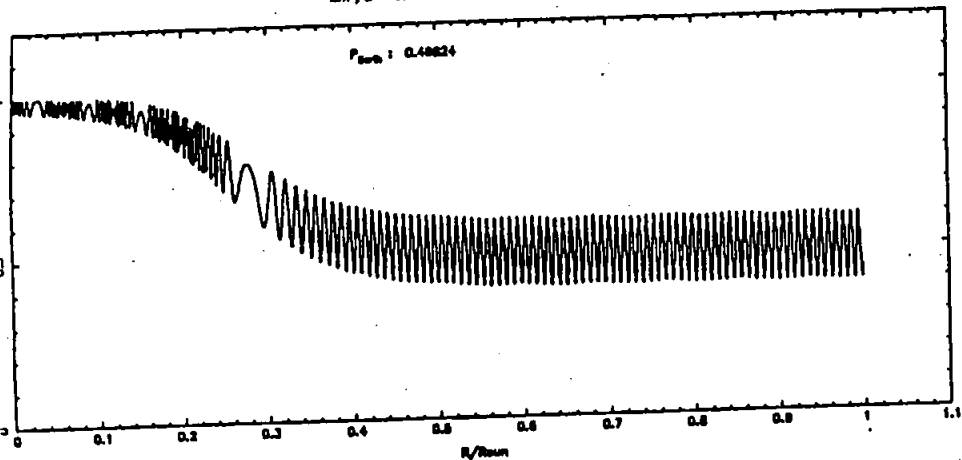
A high statistics data set containing some 50,000,000 events is currently being put together. It will be used for further investigation into fitter systematics and detector response in the central D₂O volume.

References

- [1] S.P. Rosen and J.M. Gelb, Phys. Rev. D, vol. 34, 969 (1986)
- [2] J.N. Bahcall, Neutrino Astrophysics, Cambridge Univ. Press.
- [3] W.C. Haxton, Phys. Rev. D, vol. 35, 2353 (1987)
- [4] M. Doi and K. Kubodera, Private Communication. (Submitted to Phys. Rev. D)

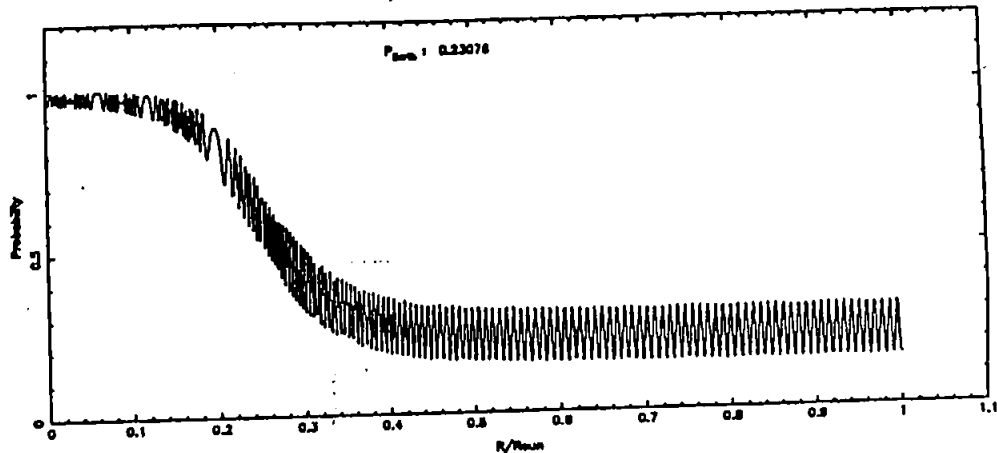
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$P_{Surv} = 0.48824$



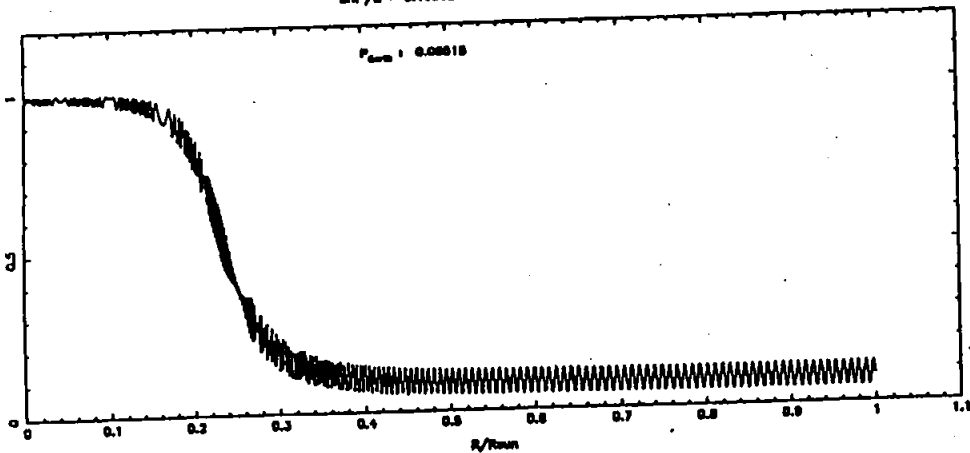
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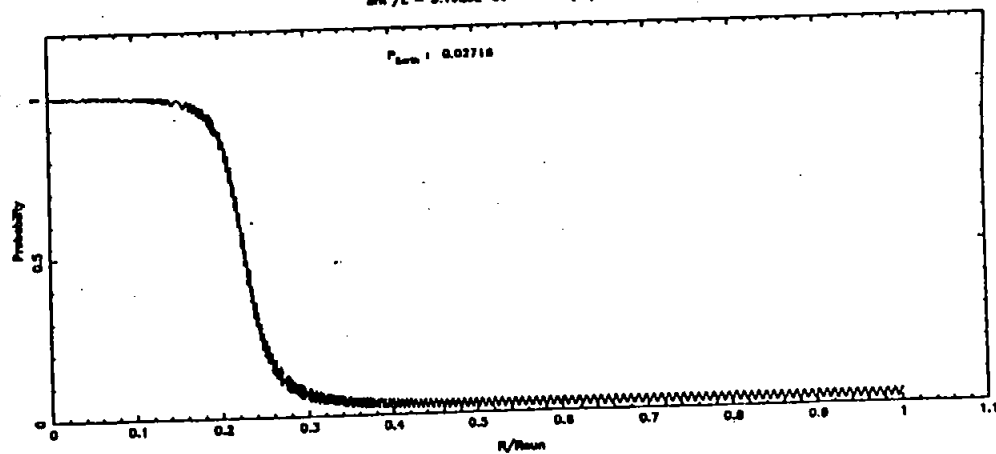
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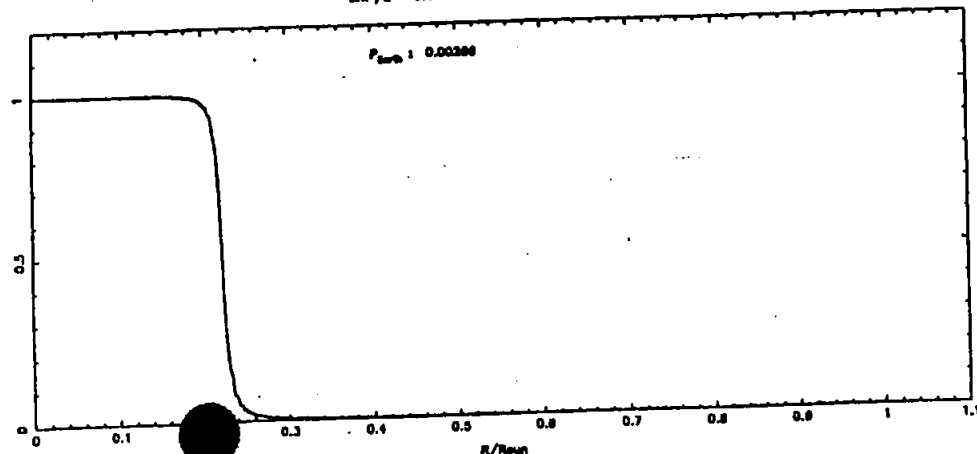
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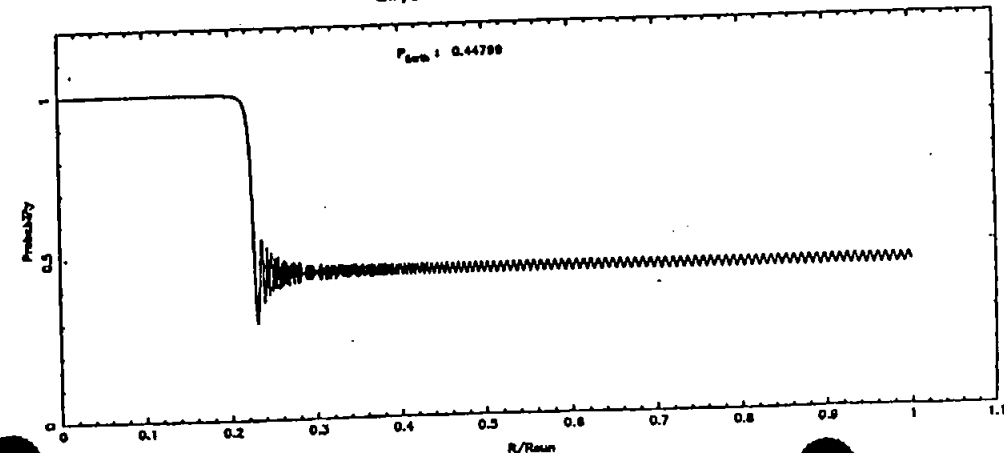
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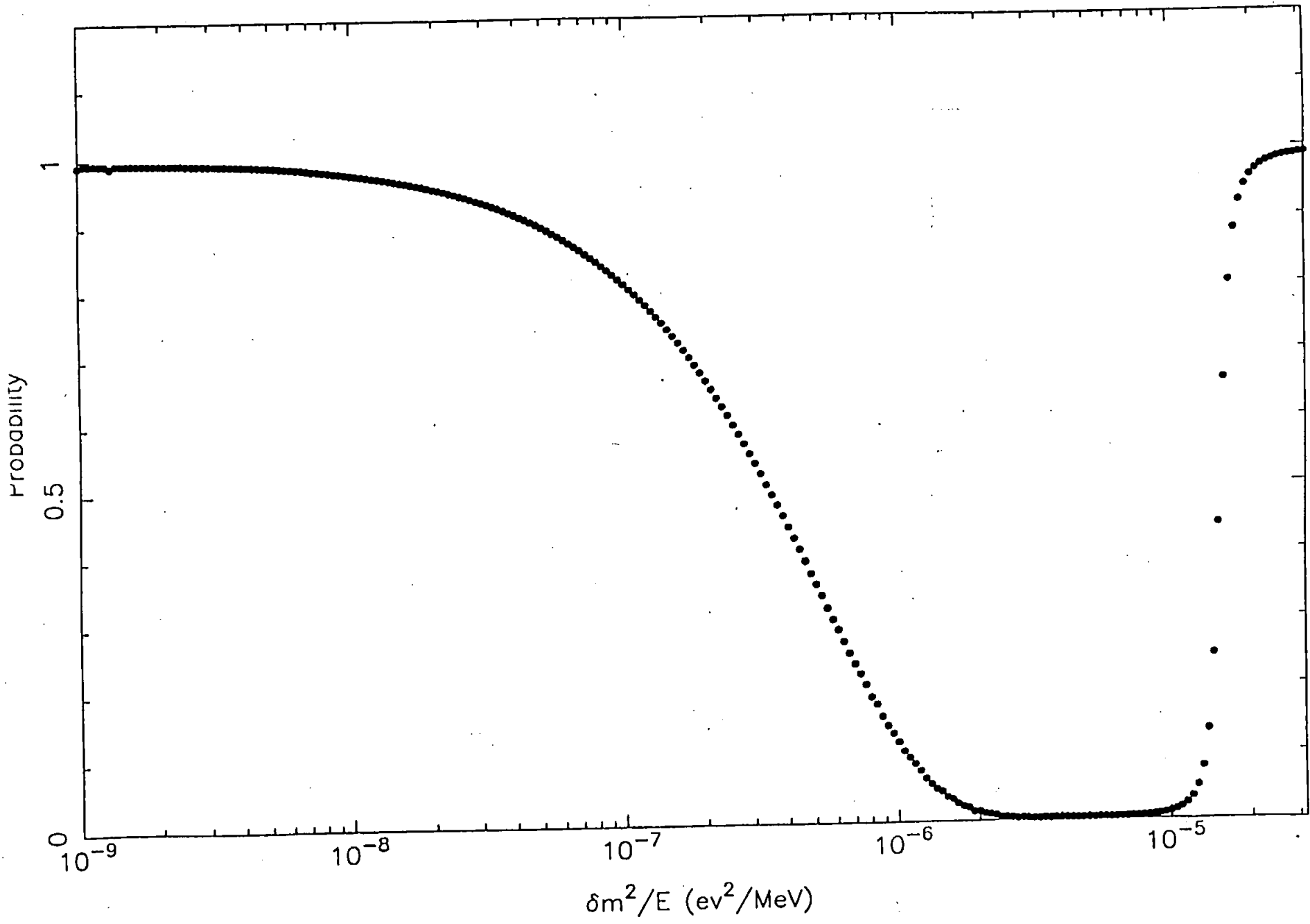
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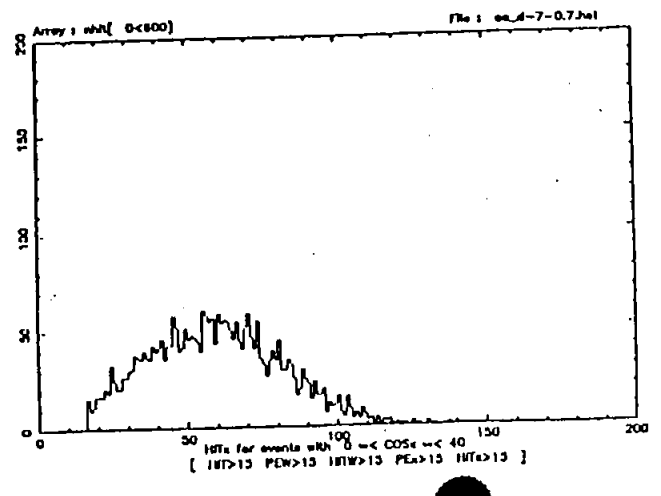
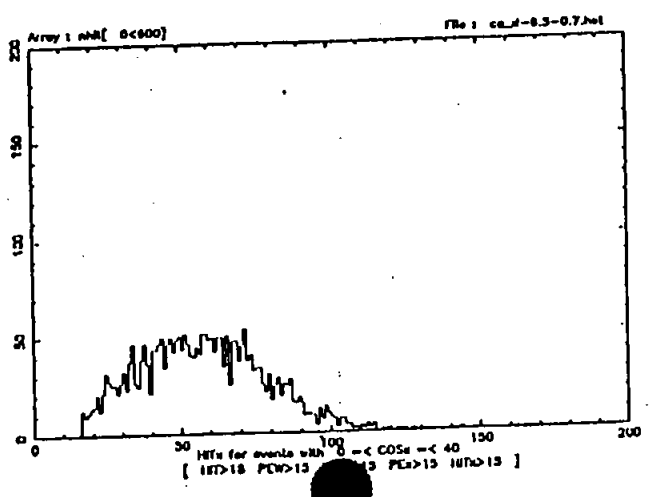
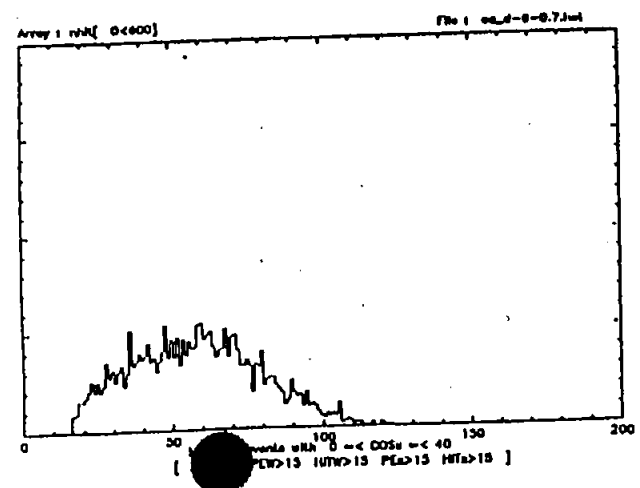
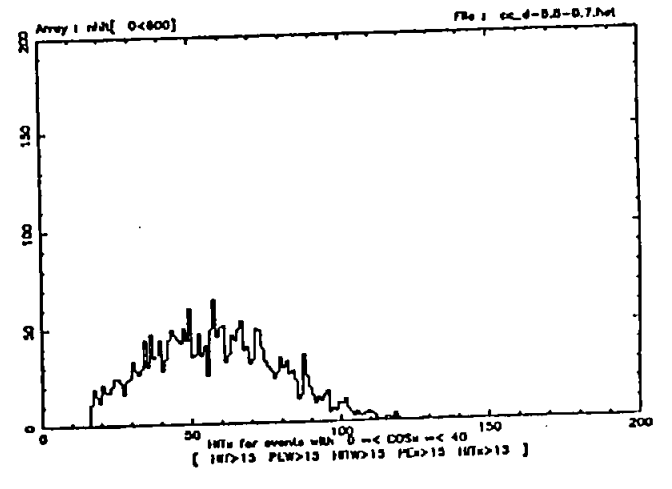
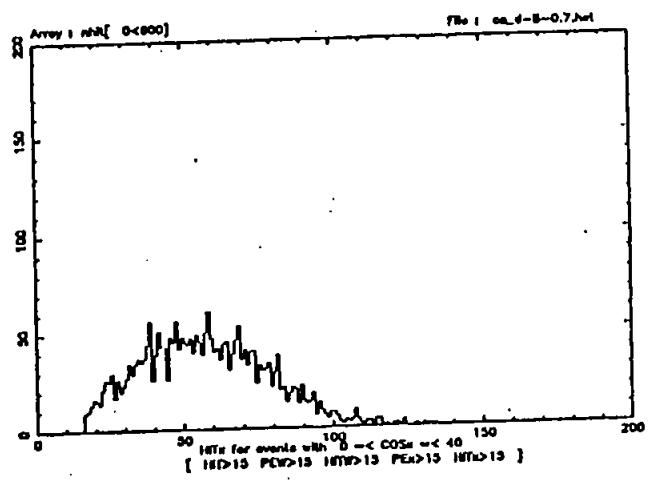
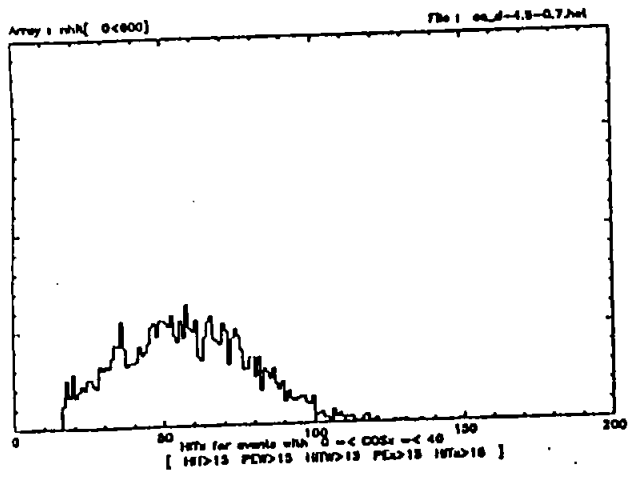
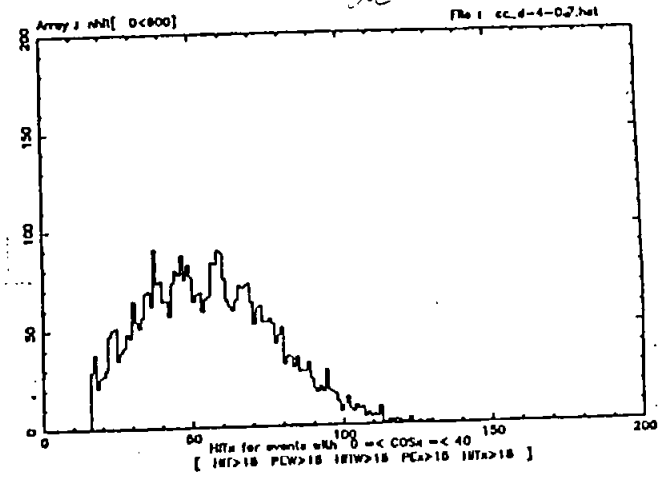
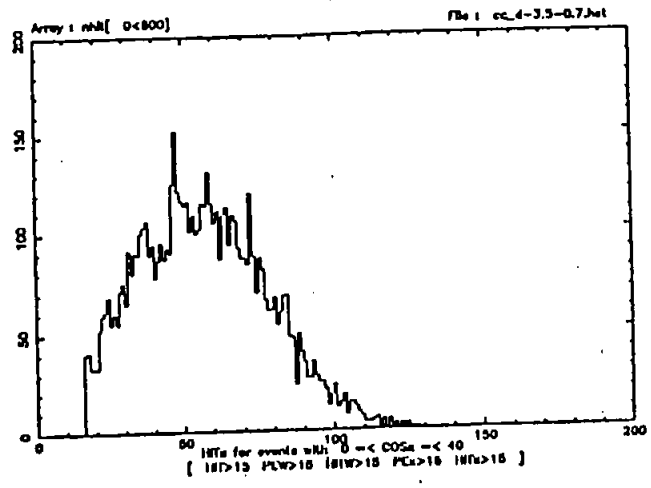
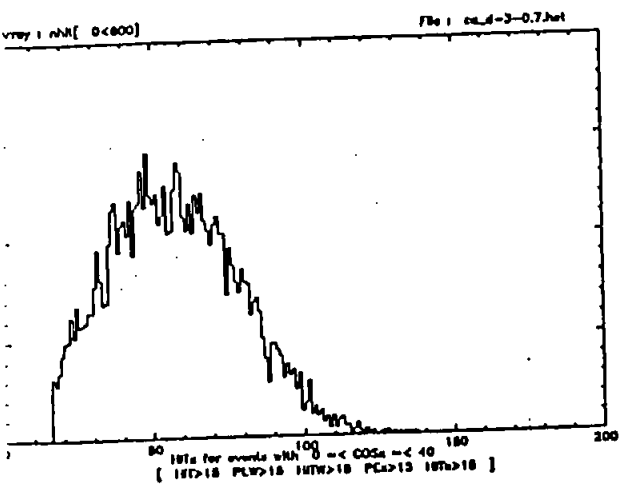
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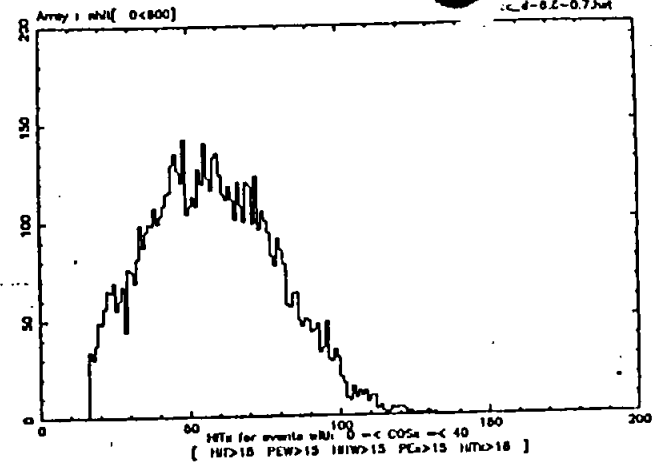
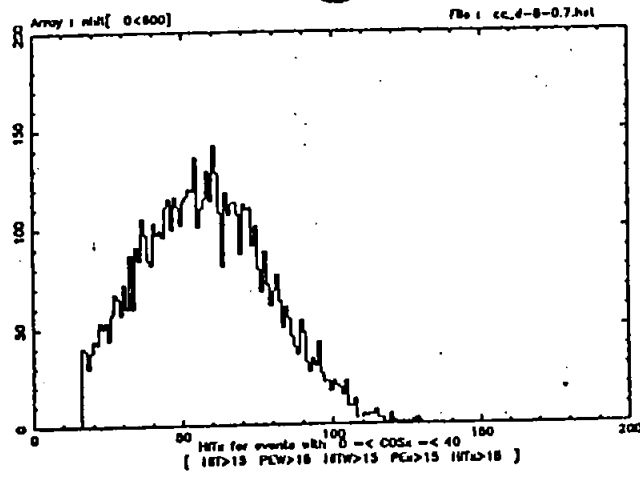
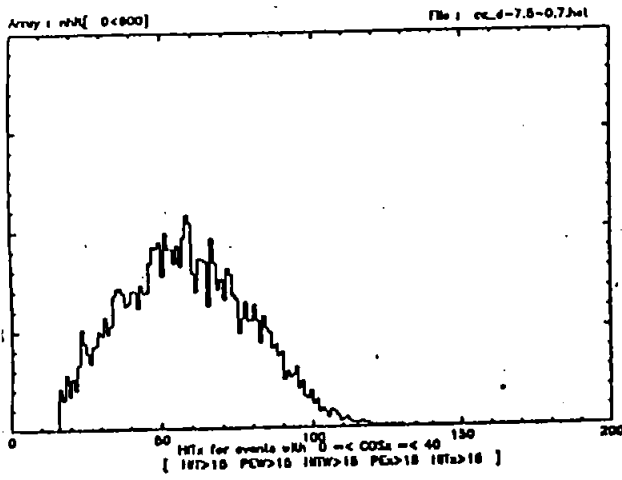


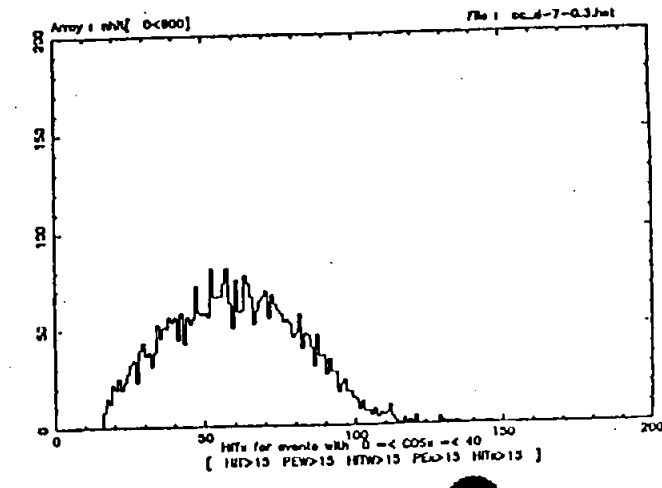
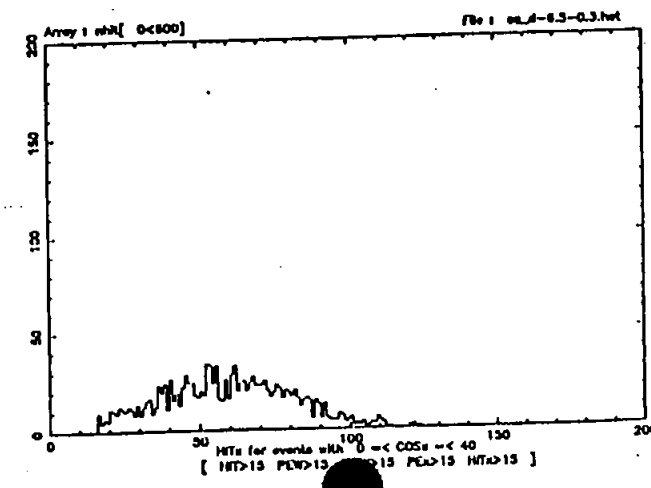
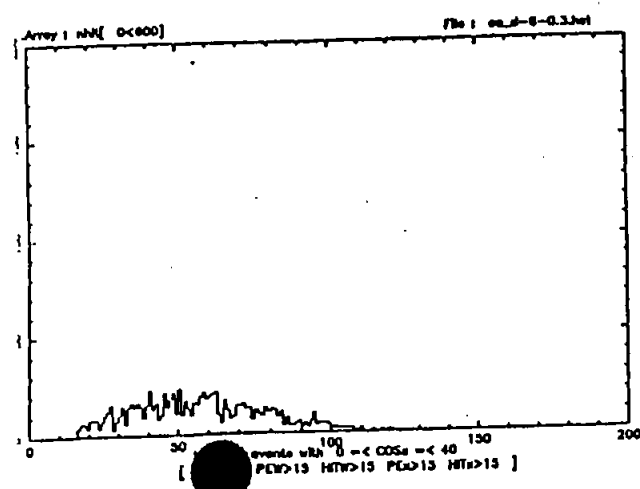
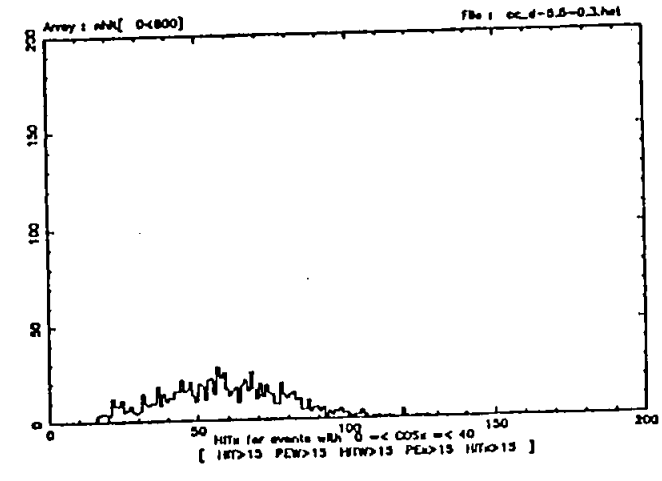
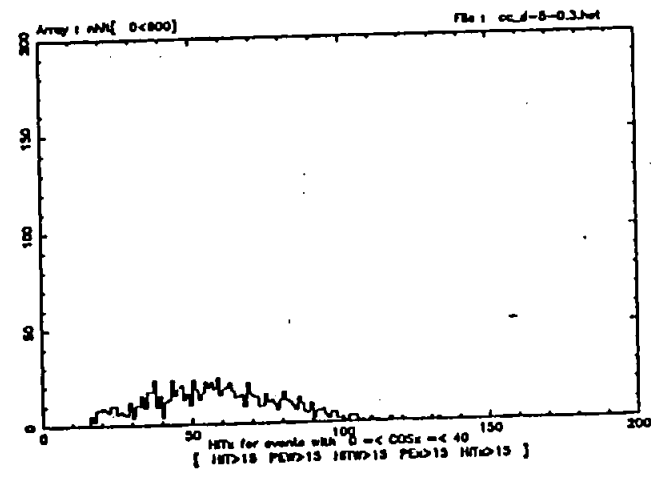
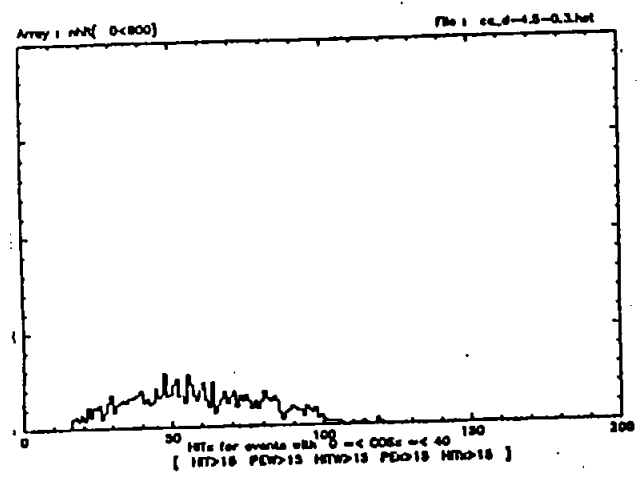
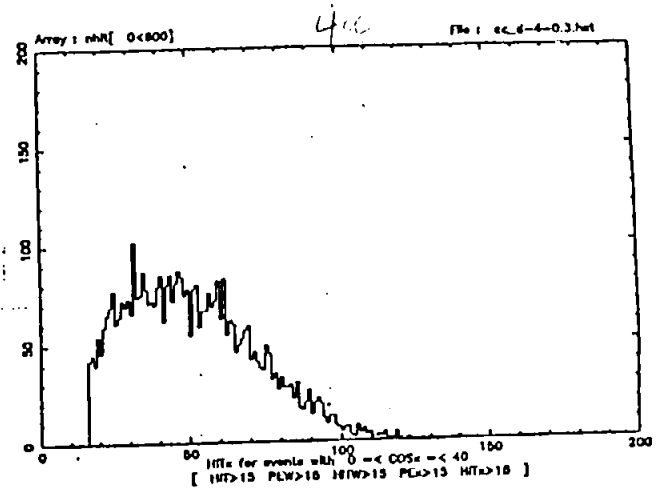
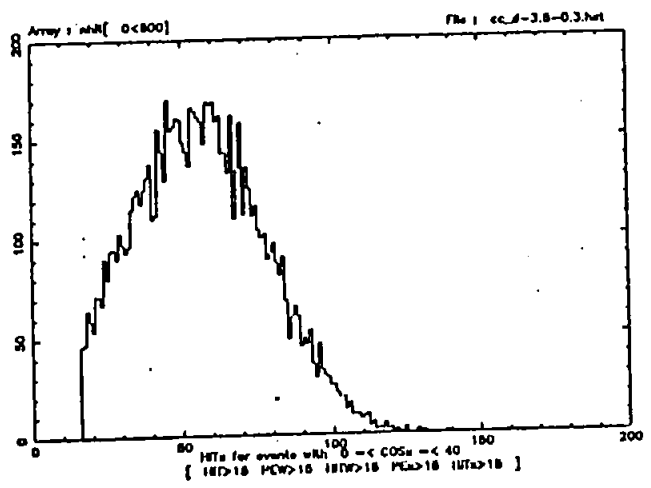
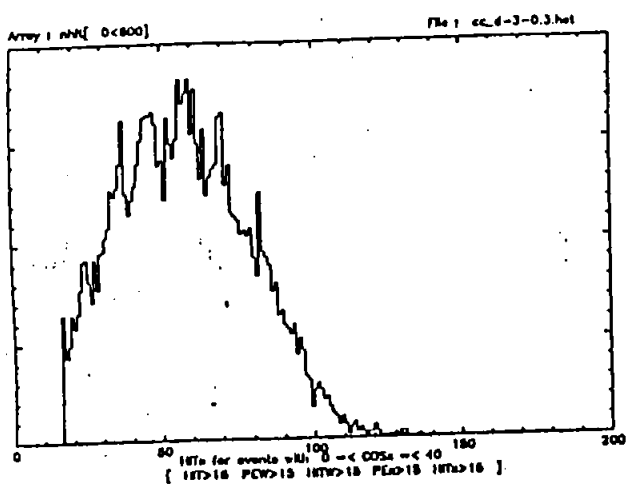
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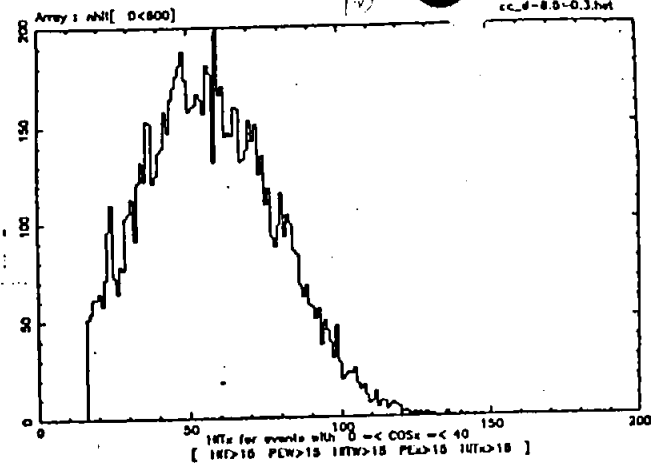
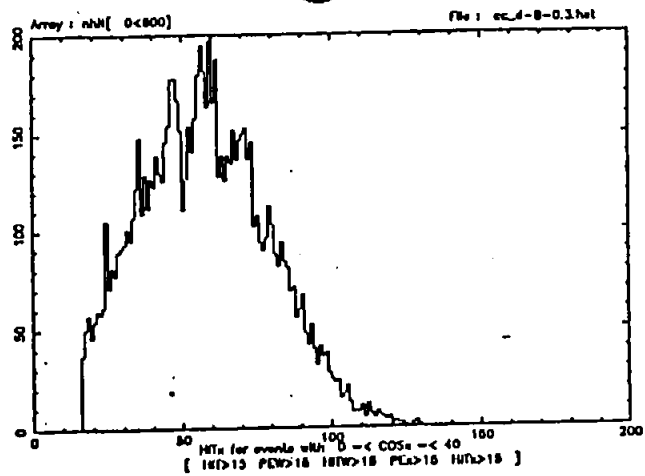
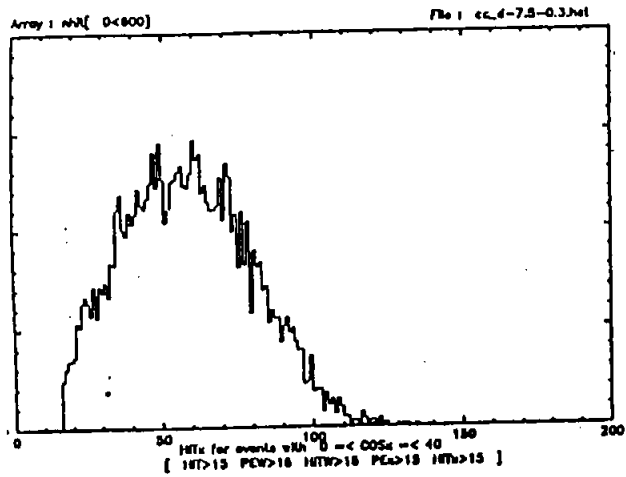
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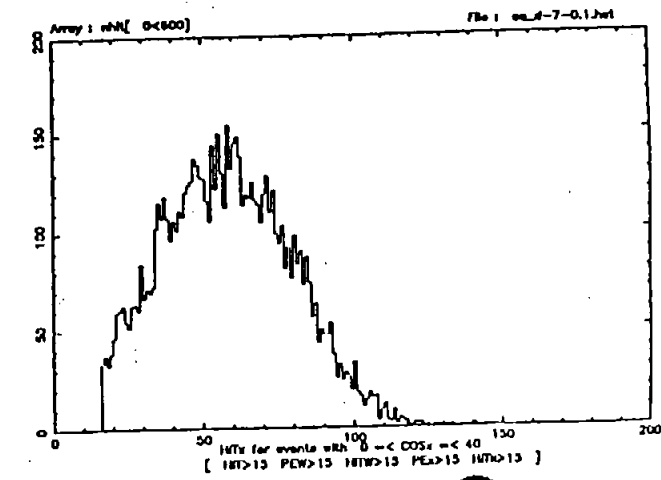
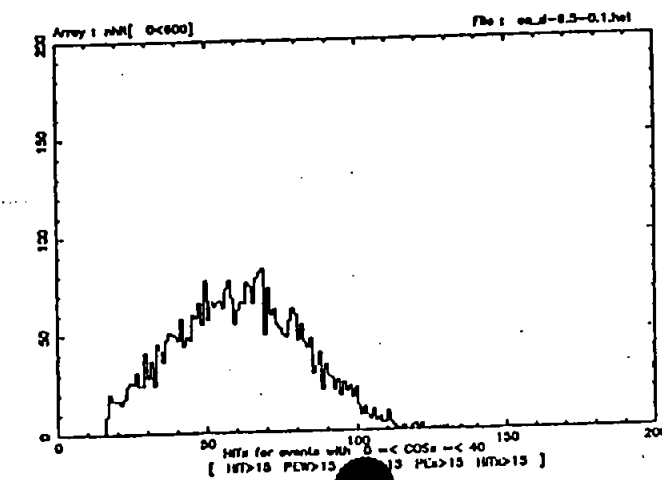
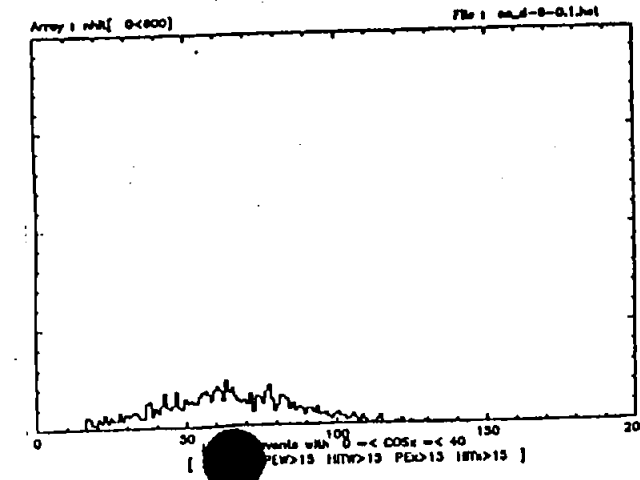
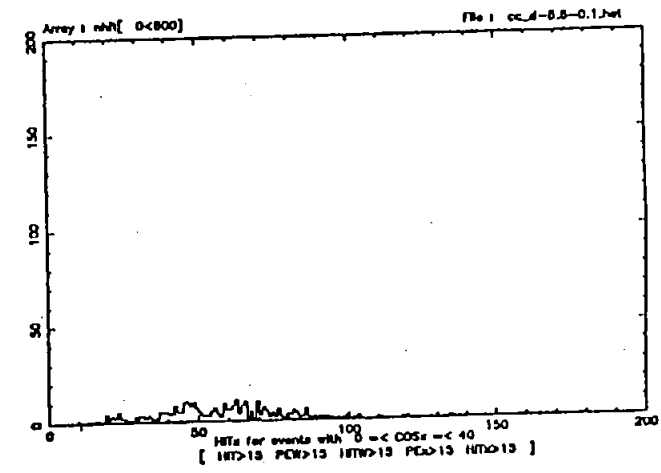
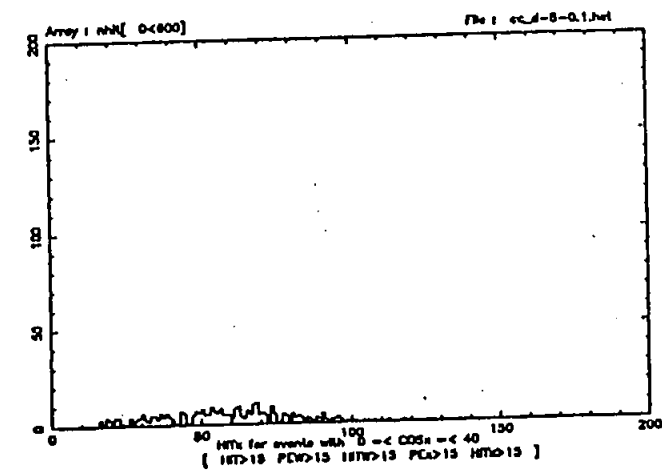
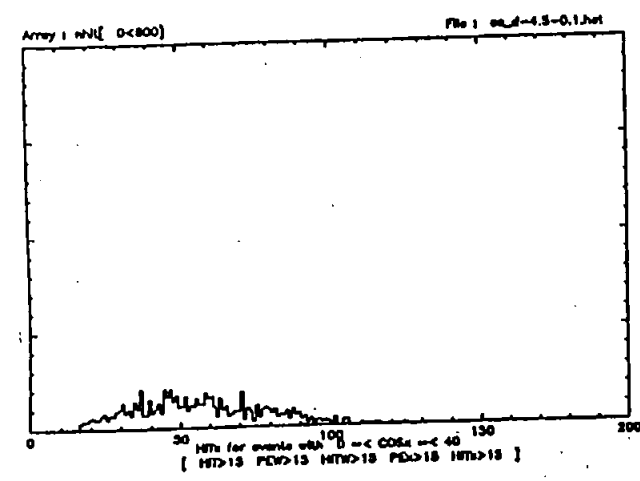
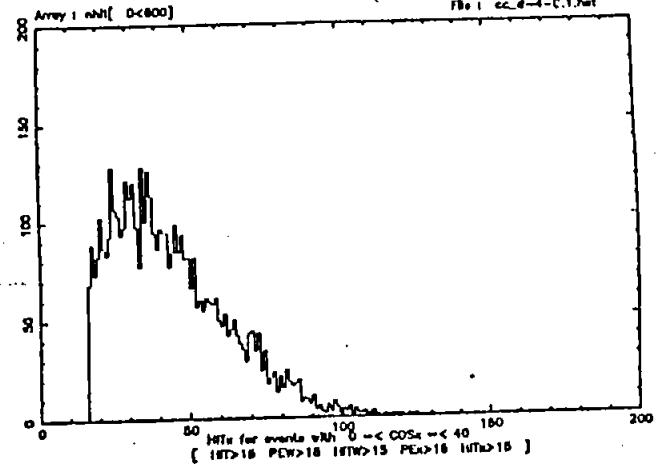
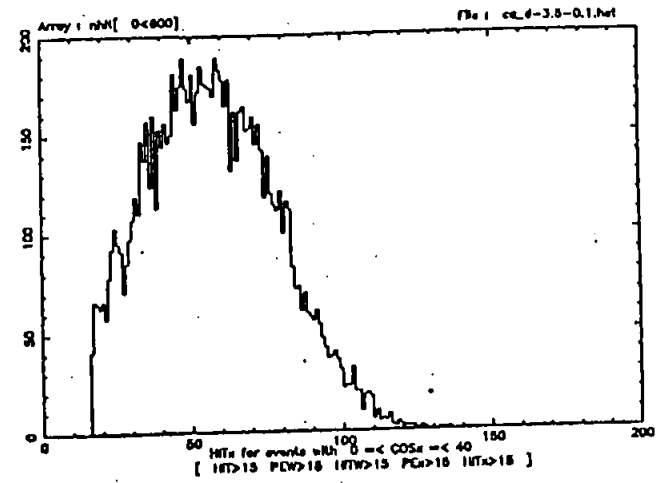
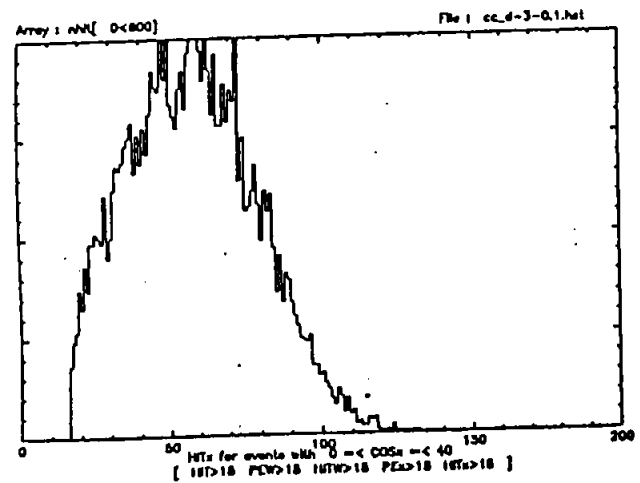


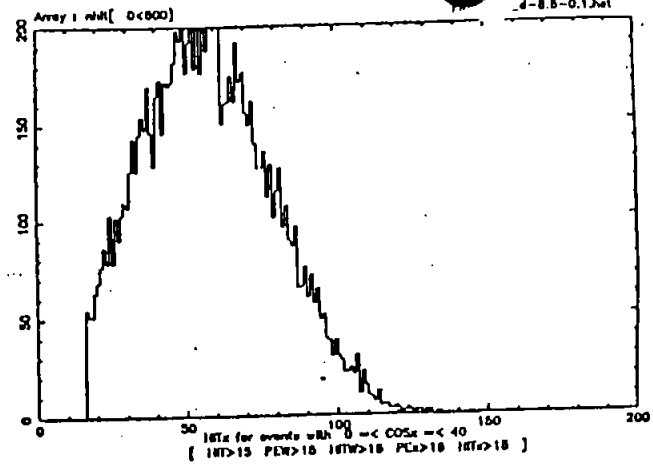
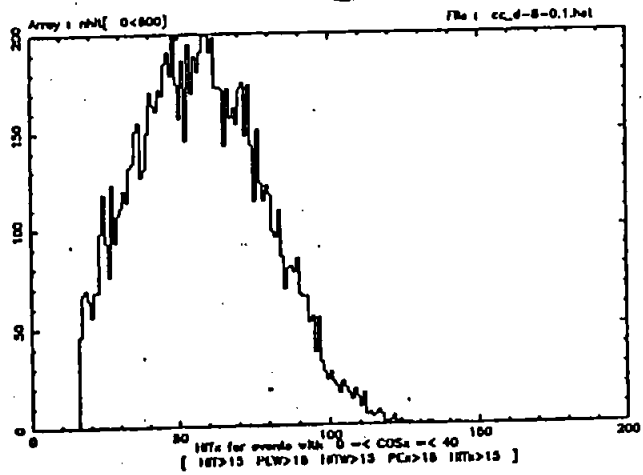
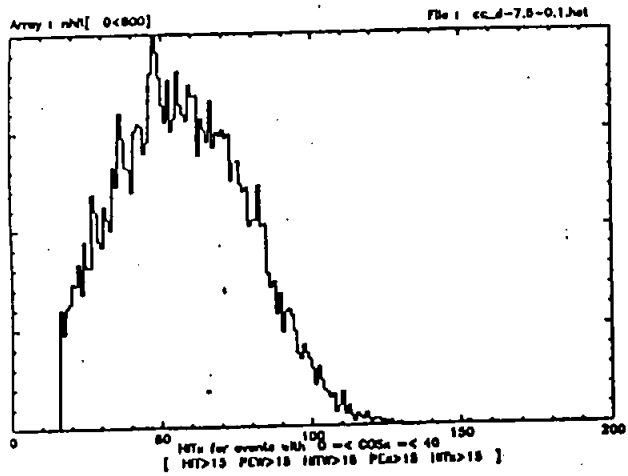


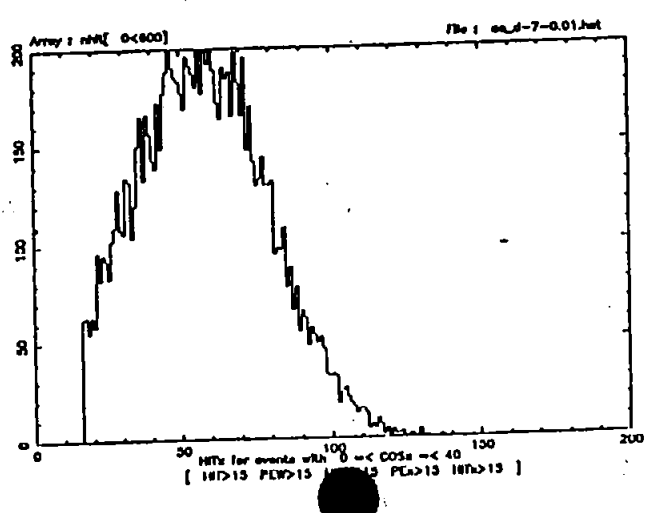
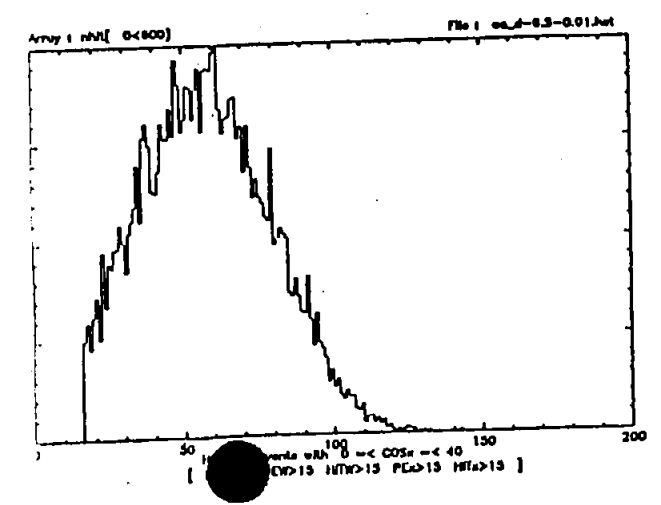
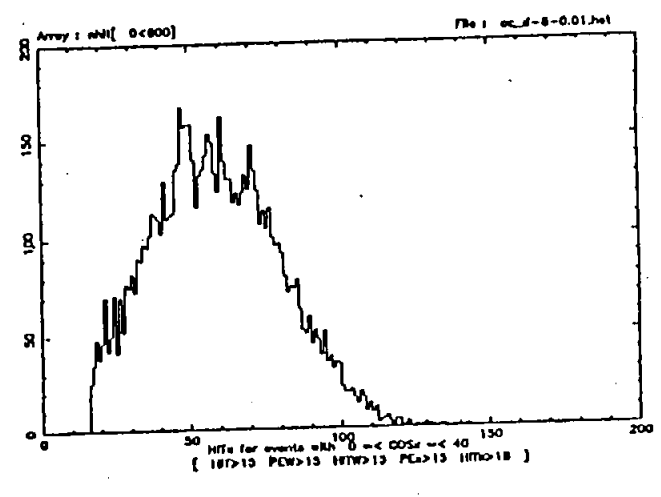
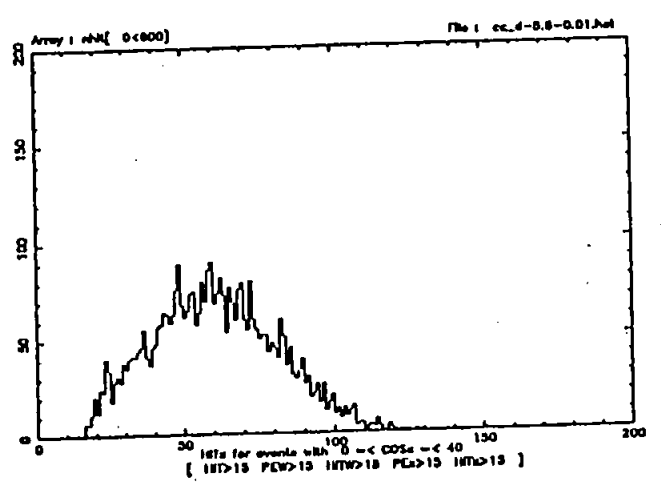
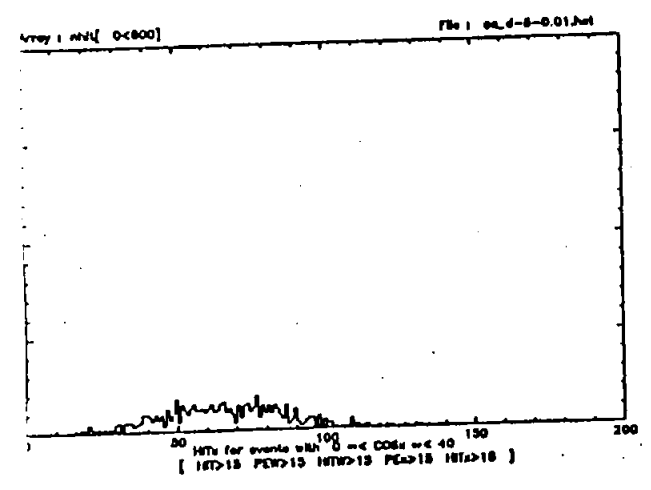
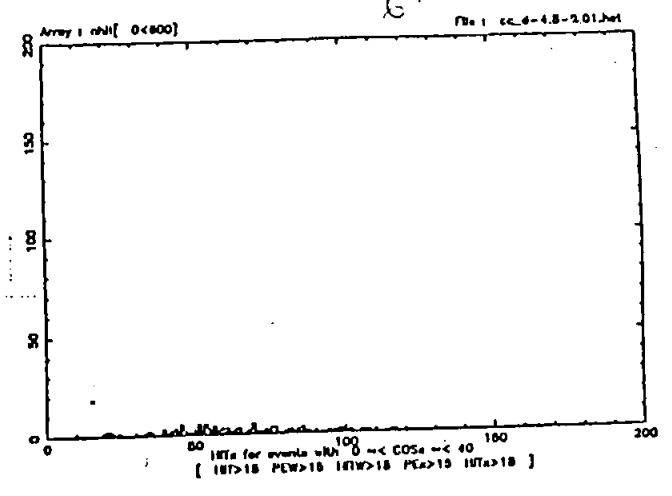
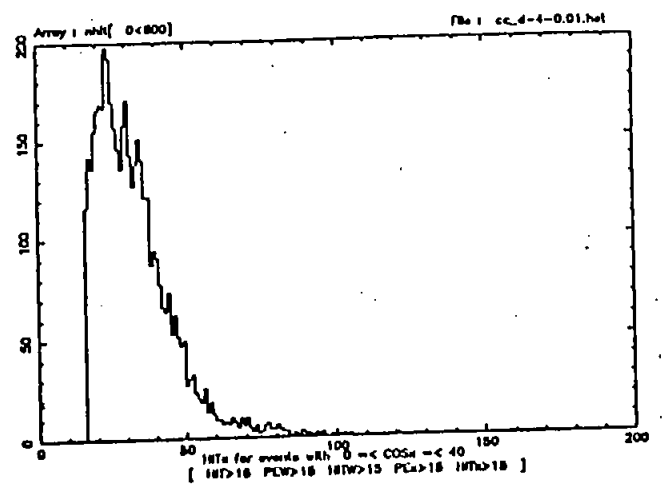
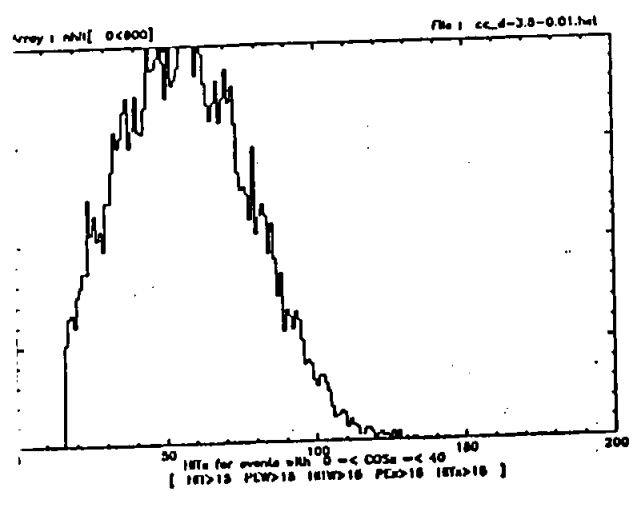












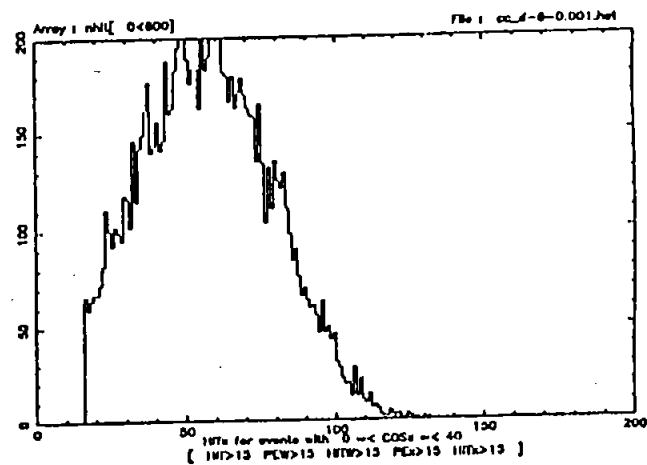
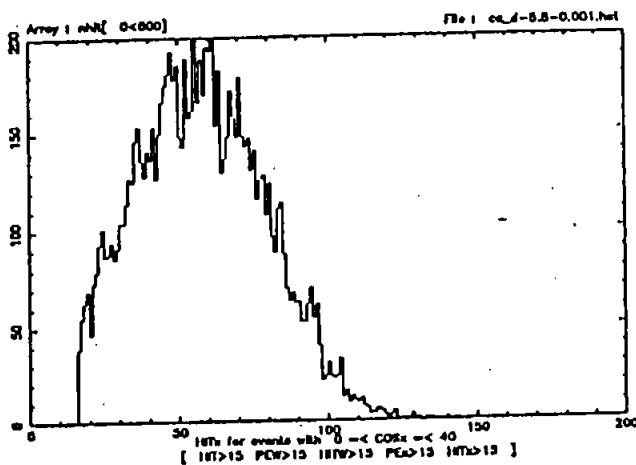
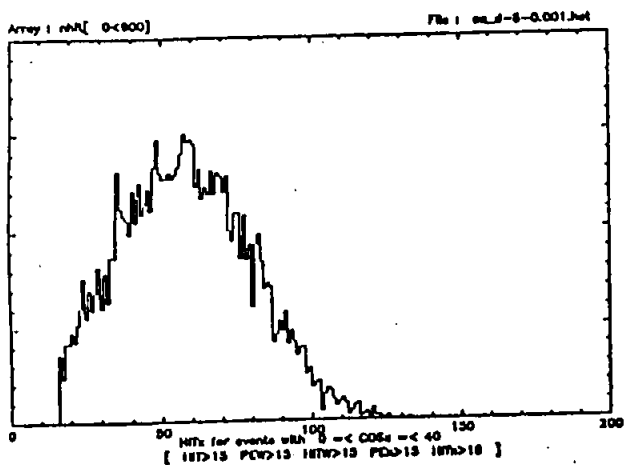
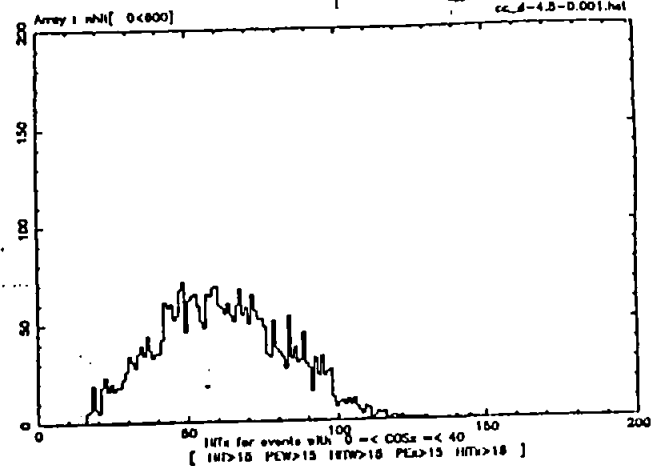
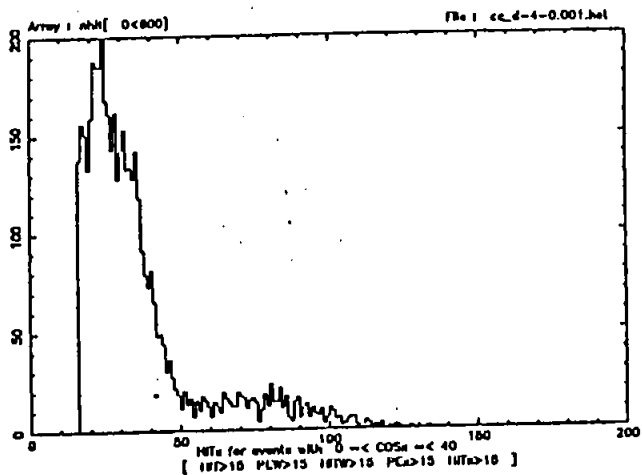
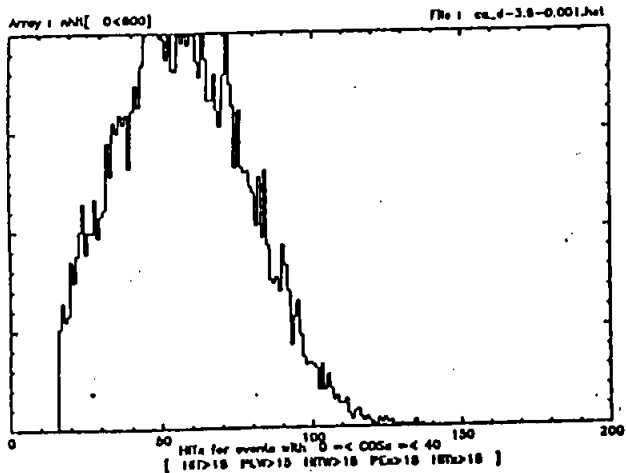
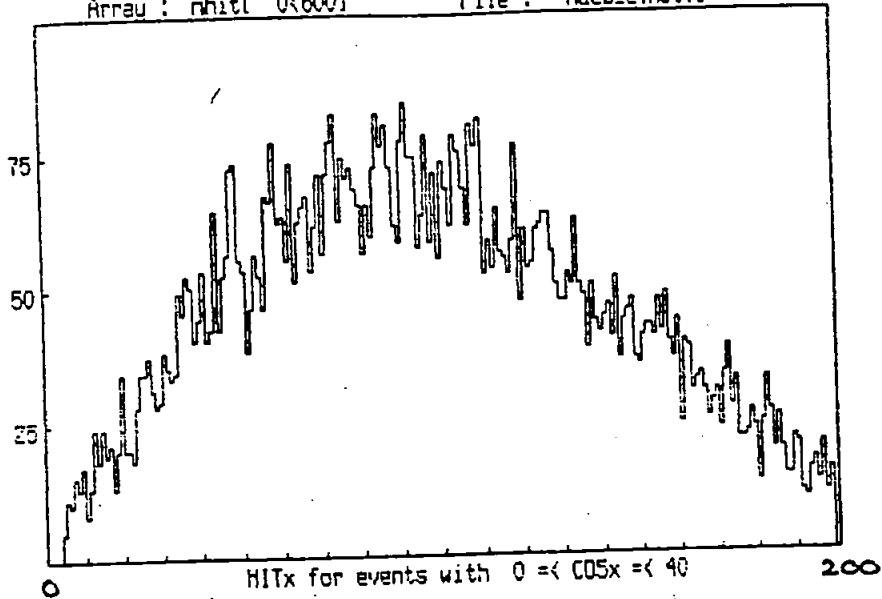


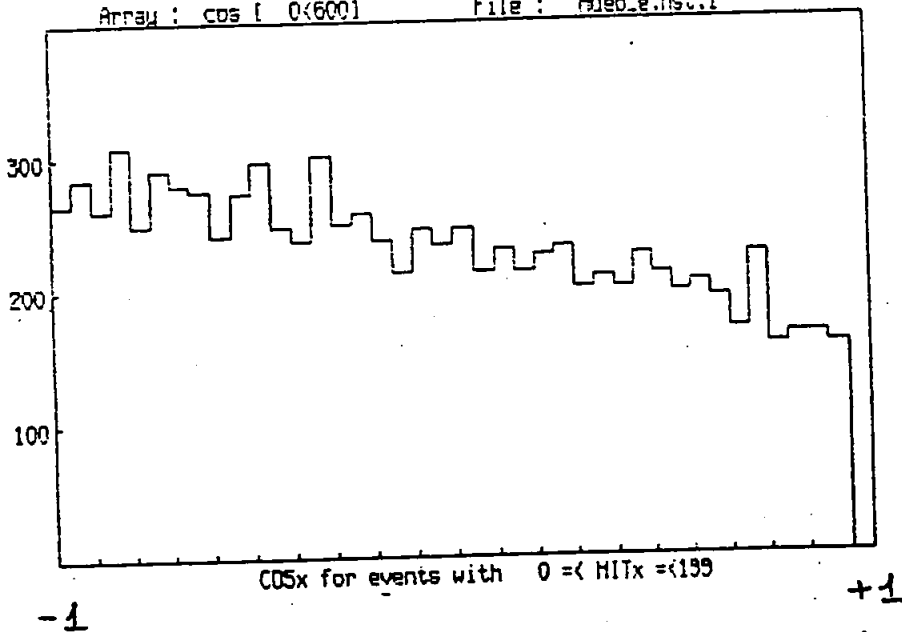
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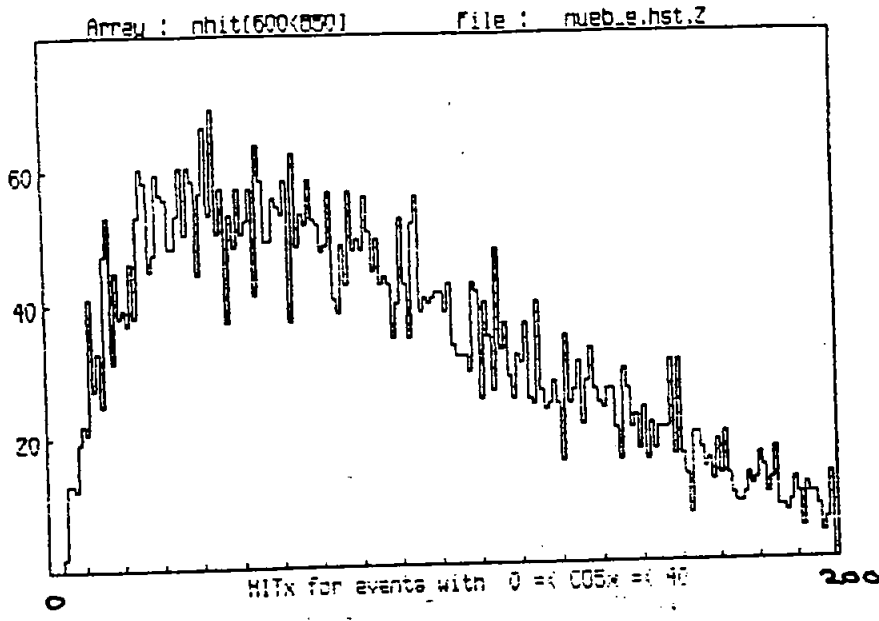


$$\bar{\nu}_e + d \rightarrow n + n + e^+$$

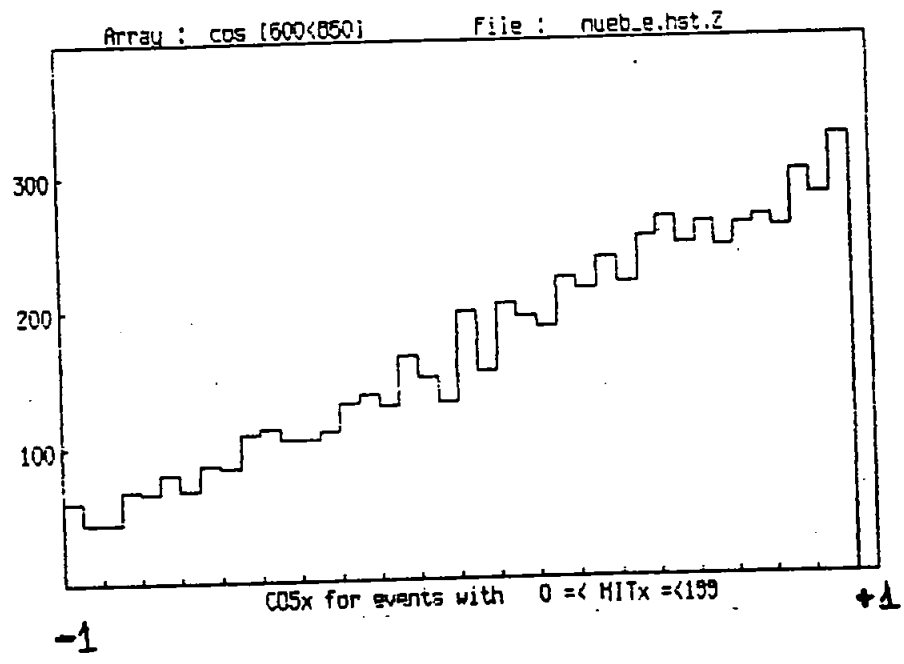
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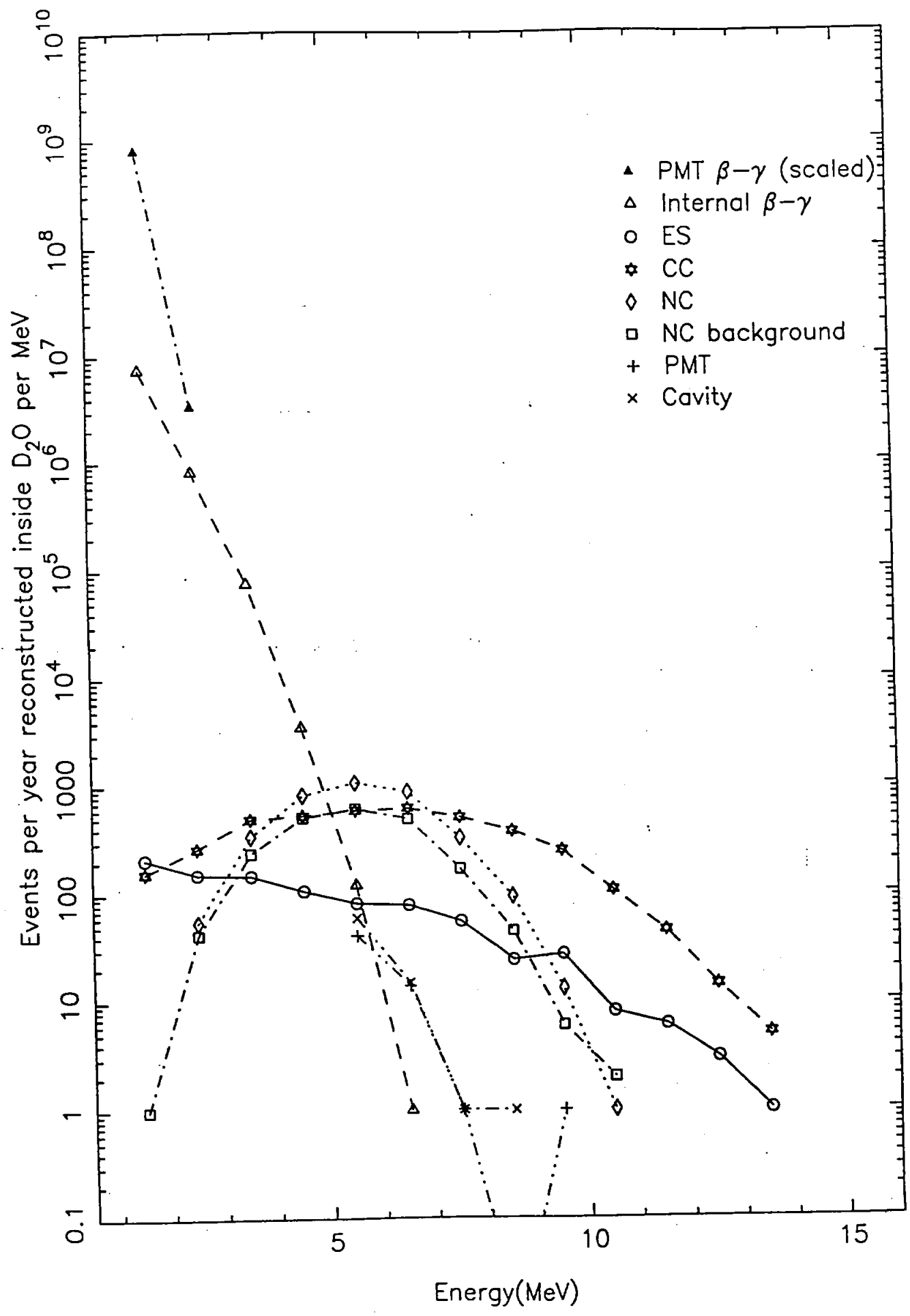
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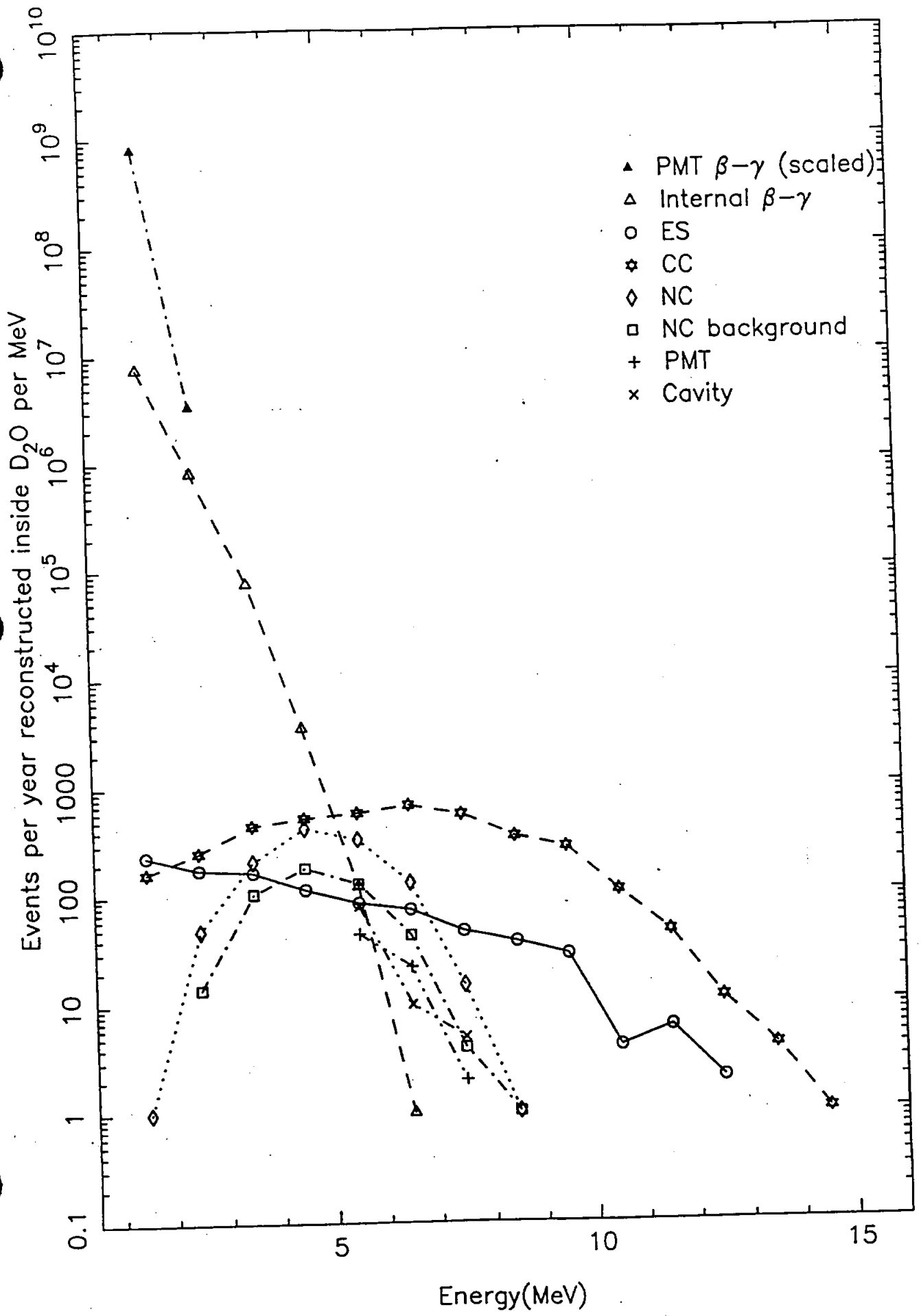
$$\bar{\nu}_e + p \rightarrow n + e^+$$

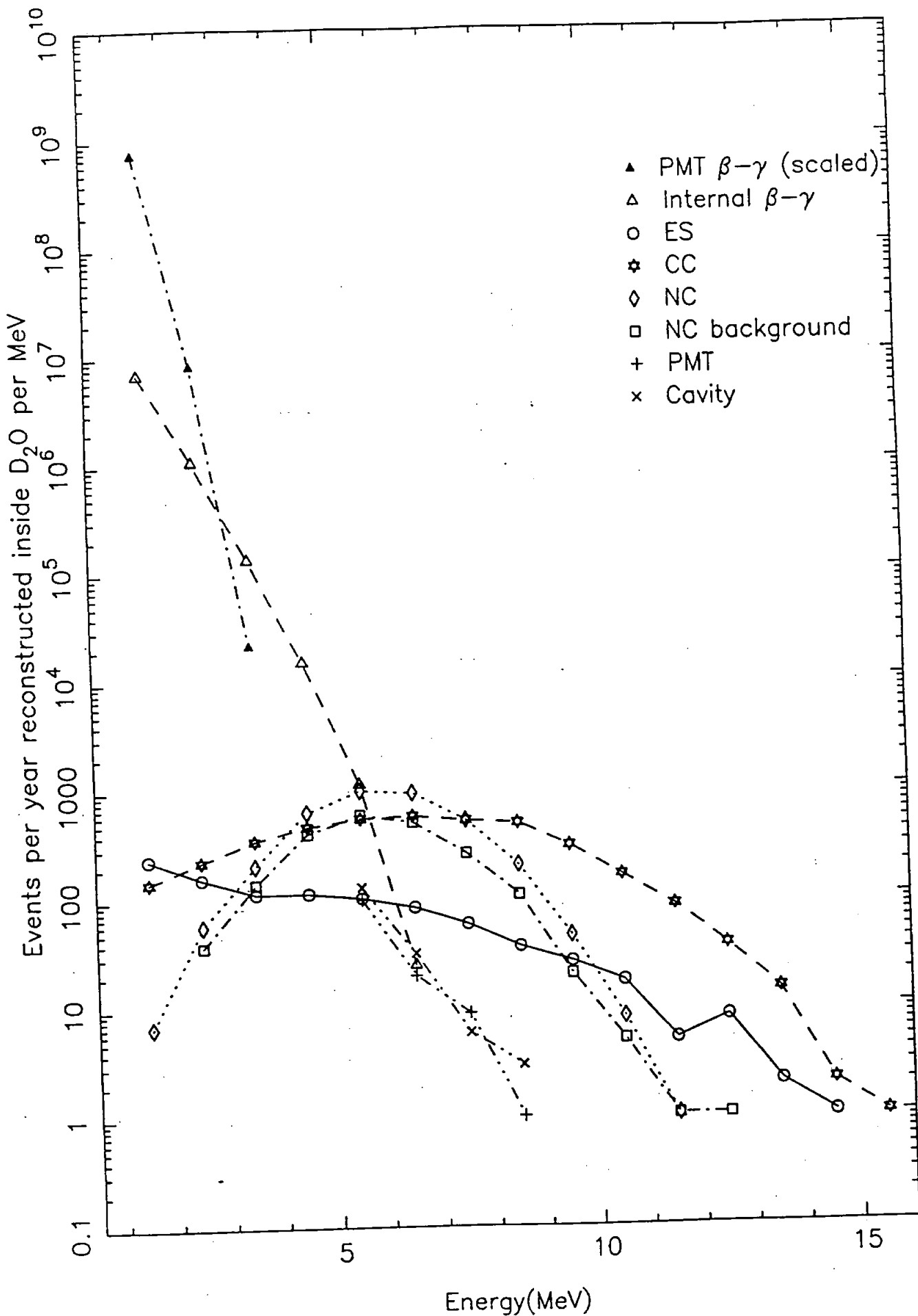


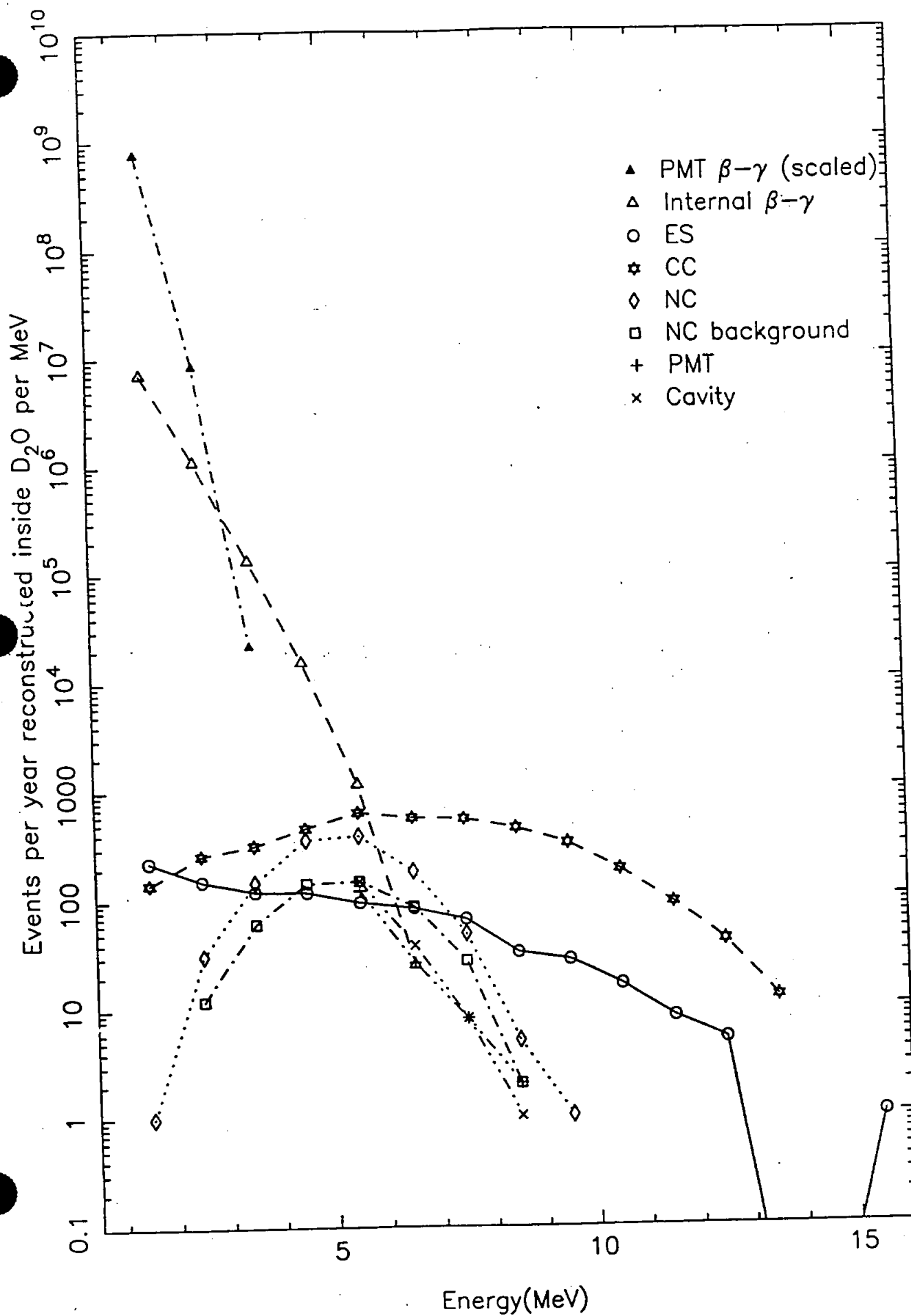
9418 Hamamatsu 8" , 3.8 ns , D₂O + NaCl



9418 Hamamatsu 8" , 3.8 ns , D₂O

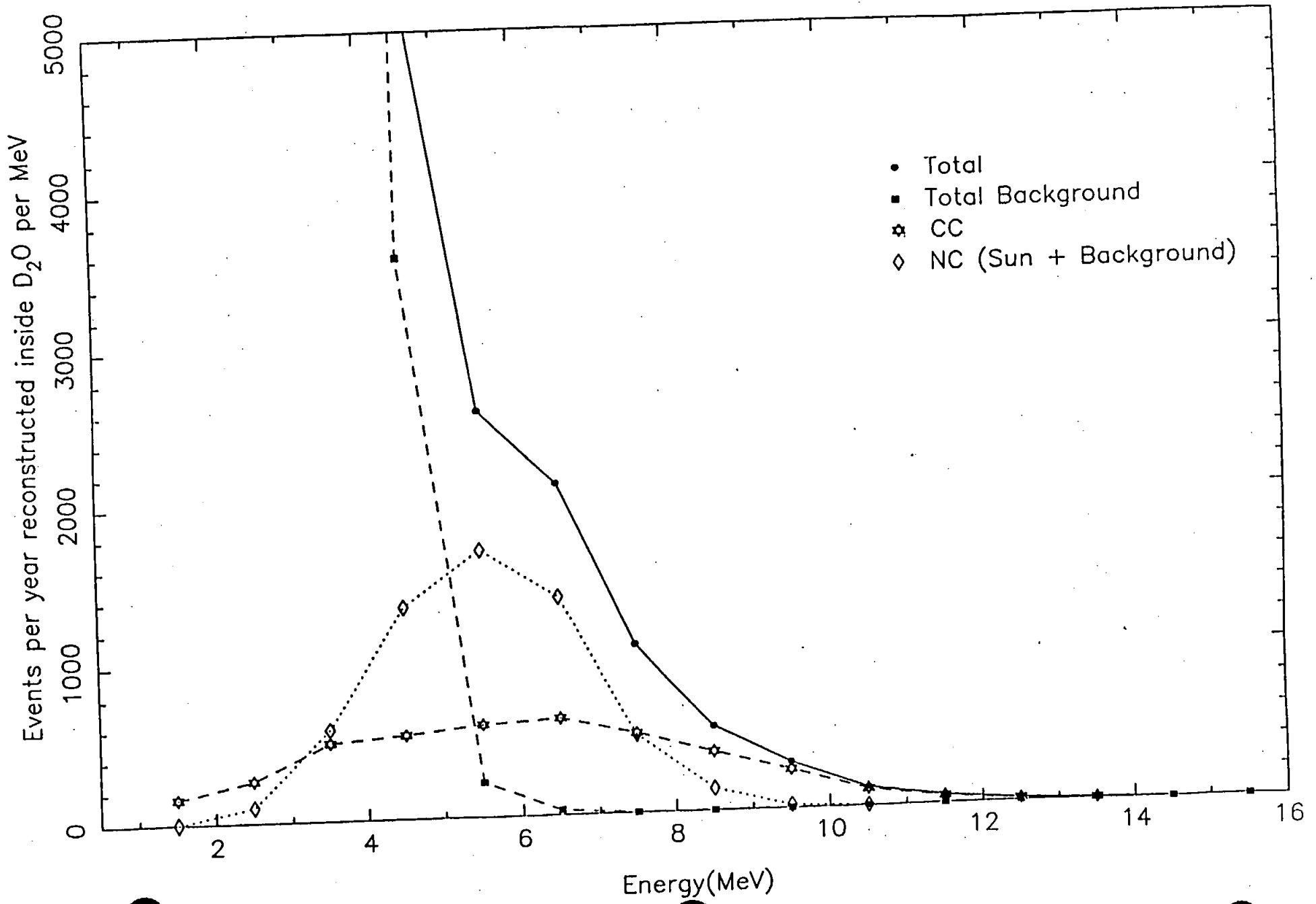






9418 Hamamatsu 8" , 3.8 ns , D₂O + NaCl

14



7600 Hamamatsu 8" , 3.8 ns , D₂O + NaCl