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Physics Impact of the Acrylic Vessel Thickness

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1. INTRODUCTION

Recent discussions on the vessel design haven't included any detailed study on the physics impact of an increased vessel thickness. This note aims to correct that omission as well as to present other domains of the light collection where changes/improvments might be expected.

The discontinuous increase in light collection efficiency at the D2O-H2O interface (Fig. 1) magnifies the low energy background originating from the vessel and in the nearby H2O since a fraction of these events will be reconstructed in the D2O with apparent higher energy (Ref. 1). It is reasonable to assume that most of the low energy beta-gamma background follows that scheme since, according to the MC, 85% of the 4 to 6MeV beta-gamma background events reconstructed in the D2O originate from the acrylic vessel (Ref. 2). As a consequence, a decrease in acrylic light transmission corresponds in fact to an increase of similar magnitude of the energy scale of the internal beta-gamma background spectrum: from the slope of the internal beta-gamma background wall around 5 MeV one deduces that a 1% reduction in light transmission is equivalent to a 17% low-energy background increase at a given apparent energy.

2. VESSEL THICKNESS

It has been established (Ref. 3) that 0.1" increase in vessel thickness corresponds to a drop of 1% in light collection. Following the above arguments, one can therefore quantify the physics impacts of a thicker vessel as summarized in Table 1. for a thickness change from 5cm to 6cm. The vessel being the major source of background, its change in mass has also been taken into account. The 5cm and 6cm are semi-realistic values to set up the scale. Thicknesses mentioned in recent discussions are given in Table 2. for comparison.

Table 1. Physics impacts of a 5cm to 6cm thickness change

Additional light losses	4%
Low-energy background increase	225%
Shift in detection threshold	280 keV
Loss in NC statistics (5 MeV threshold)	11.6%
Loss in NC statistics (6 MeV threshold)	20.7%
Loss in CC statistics (5 MeV Threshold)	6.2%

Table 2. Thicknesses of current interest

(cm)	(inch)	
	1.97"	Value used in MC background calculations
[illegible].08	2"	Value assumed during most of '92
5.33	2.1"	Value to accommodate a buckling safety factor of 20
5.46	2.15"	Value to accommodate an 10oC operating temperature
5.97	2.35"	Nominal value so that the minimal thickness is 2.15"
6.21	2.44"	Nominal value after thermoforming (4% increase)

3. DISCUSSION

a. Table 1. summarizes the physics impacts of an acrylic vessel thickness increase. This estimate is uniquely based on rather simple, straightforward assumptions. The performances of the SNO detector depend on the vessel thickness and specially its ability to detect the NC signal since its spectrum overlaps significantly with the internal beta-gamma background (Fig. 2). A significant fraction of the NC statistic might be lost due to a vessel thickness increase. The losses are threshold dependent, the present best estimate of the NC threshold being 5.3MeV. Other qualitative aspects of the NC detection such as the confidence in NC extraction and the believability of the NC signal (Fig. 2) have been widely debated over the last two years and should also be considered here.

b. Recent results on the 4" production from one supplier suggests that they succeeded to optimize the optical quality of their material by trying different recipes and production processes. Negotiations are in progress to initiate a short term R$D program aiming to further improve the optical quality of their acrylic.

c. The light collection not only depends on acrylic light transmission but also on many other parameters such as the light transmissions in D2O, H2O, reflectivity of the light concentrators and PMTs quantum efficiency. Table 3. gives a non-exhaustive list of these parameters as well as radioactivity values that might affect the overall light collection and/or the NC detection efficiency/threshold.
Present estimates of the NC threshold come from MC simulations. The SNO MC code is based on detector parameters that are realistic at a given point in time and that are periodically updated. Many of those parameters that might have a direct effect on the NC extraction threshold or/and on the NC background are not yet precisely measured/designed/finalized.
The ability to univoquely detect the NC signal and to further push down the background wall to lower energy depends on the optimization of each of these parameters.

Table 3.
Detector parameters affecting the light collection or the NC threshold

Detector parameter	MC value	Status	Expectations
Acrylic vessel radioactivity	1.9ppt	< 1ppt	<.5ppt (?)
Rope radioactivity	0.4ppb	?	
D2O radioactivity	.011ppt	?	0.001ppt(?)
H2O radioactivity	.022ppt	0.1ppt	
Acrylic light transmission	5cm F=0.708	5cm F=0.724 6cm F=0.695	even better material(?)
D2O light transmission	16% losses	?	8% losses
H2O light transmission	7% losses	?	7% losses
concentrators reflectivity	25% discont.	21% discont.	

A wavelength dependent MC treatment of the dielectric reflectivity of the light concentrators has been recently initiated by Mike Lowry and shows that the magnitude of the D2O-H2O discontinuity decrease by 3.5% by comparison to the standard MC. More detailed informations are presented in Annex A.
The present MC estimates at 16% the light losses in D2O, based on measurements performed on samples stored for 9 years. Better purity can be expected in SNO, and based on comparison with light water measurements on deionized

double-distilled samples, the light losses in D2O can be reasonably estimated at 8%. More details are presented in Annex B.

The last word belongs to E.D.Earle : " The vessel must be as thin as possible consistent with good engineering ".

References:

1. E.Bonvin, Impact of the acrylic vessel on light collection, 17-June-1991, SNO-STR-91-046.
2. Peter's MC calculations.
3. E.Bonvin and E.D.Earle, Evaluation of Optical Properties of acrylic samples from different suppliers, 13-Aug-1992.
4. S.Gil et al. Progress Report on the Characterization of dielectric coated aluminum samples, UBC, 11-May-1992, SNO-STR-92-034.
5. M.Lowry, private communication.
6. L.P.Boivin et al., Appl.Opt.25,877,1986.
7. T.I.Quikenden and J.A.Irvin,J.Chem.Phys.72,4416,1980.

Figures:

1. The D2O-H2O discontinuity: Level of detectable light as a function of the generated vertex along the detector radius, as obtained by the MC code described in (Ref. 1). The relative amplitude of the discontinuity taken at 5.9m and 6.1m is 26% in good agreement with the standard SNO MC (25%). The drop from detector center to 5.5m and 5.9m is respectively 4% and 9%.

2. Linear distribution of reconstructed events (NC, CC and background) as simulated by the standard SNO Monte Carlo code.

3. Light spectrum from 10MeV electrons generated at 4m, 5.9m and 6.1m as simulated by the standard MC code (from Ref. 5).

4. Light spectrum from 10MeV electrons generated at 4m, 5.9m and 6.1m as simulated by a modified MC code containing a wavelength dependent treatment of the dielectric light concentrators (from Ref. 5).

ANNEX A : LIGHT CONCENTRATORS

The wavelength dependence of the dielectric reflectivity of the light concentrators is not incorporated in the present standard MC code, the indices of refraction at 400nm are simply assumed over the whole spectrum. The light concentrators collect almost half of the total light observed and a non-correct MC treatment of their reflectivity might affect our understanding of the detector response.
The D2O-H2O discontinuity is a direct result of the difference between D2O and H2O light spectra (Fig. 3) A reduction of the D2O-H2O discontinuity is expected from dielectric reflectivity measurements performed at UBC (Ref. 4), since these reflectivity data exhibit a sharp cut-off around 300nm that will affect higher frequencies

of the H2O spectrum but will have no or little effect on the D2O spectrum. Mike Lowry has parametrized the UBC data over the whole range of reflection angles, has incorporated the wavelength dependence in his MC code and has studied the effect of different dielectric coating thicknesses on light collection and particularly on the D2O-H2O discontinuity. His results show (Fig.3 and Fig. 4) that a wavelength dependent treatment of the reflectivity decreases the magnitude of the D2O-H2O discontinuity by 3.5% by comparison to the standard MC (Ref. 5). This effect on light collection (and its physics impact) is almost of the same magnitude as the effect of a 5cm to 6cm vessel thickness increase but, fortunately, in the opposite direction.
UBC is presently extending its measurements to different reflection angles. A wider set of data will allow a finer tuning of the reflectivity parametrization and a better understanding of the overall detector response.

ANNEX B : D2O AND H2O LIGHT TRANSMISSIONS

The standard SNO MC parametrizes the light transmissions through D2O and H2O according to measurements performed at NRC (Ref. 6) and shows that respectively 16% and 7% of the useful light is absorbed through D2O and H2O.
The H2O measurements were performed on double-distilled, deionized water and agree well with the literature data (Ref. 7). In the UV-range, the measured H2O absorption coefficients are a factor 2.5 higher than expected from Rayleigh scattering alone. The D2O measurements were performed on water directly sampled out of a SS drum in which the heavy water was stored for 9 years. The D2O samples were not filtered, distilled or purified in any way prior to measurement and presence of impurities collected over the storage period has not been ruled out. Measured D2O absorption coefficients in UV are 7.5 times the Rayleigh scattering component.
The primary purpose of these measurements was to prove the feasibility of the SNO detector and to rule out previous data that reported stronger absorption in the visible, and not to determine the lowest possible absorption values, the authors commenting that further progress in lowering the absorption hinges on improving the water purity.

While no quantitative statement can be made on the D2O and H2O light transmissions that are going to be effectively achieved in SNO, one expect similar purity levels in D2O and H2O (or possibly slightly more impurities in H2O due to material leaching). Assuming that D2O absorption coefficients that are 3 times the UV-Rayleigh scattering could be obtained in D2O (as it has been observed in H2O), one expects a reduction from 16% to 8% of useful light losses in D2O by comparison to the values presently assumed by the standard MC, while no change will affect the H2O light losses. Such a reduction in D2O light losses won't affect the magnitude of the D2O-H2O discontinuity, the events occurring near the acrylic wall don't have much pathlength in D2O. It will however increase by 8% the overall light level detected from D2O and that can only be beneficial to the detector performance.

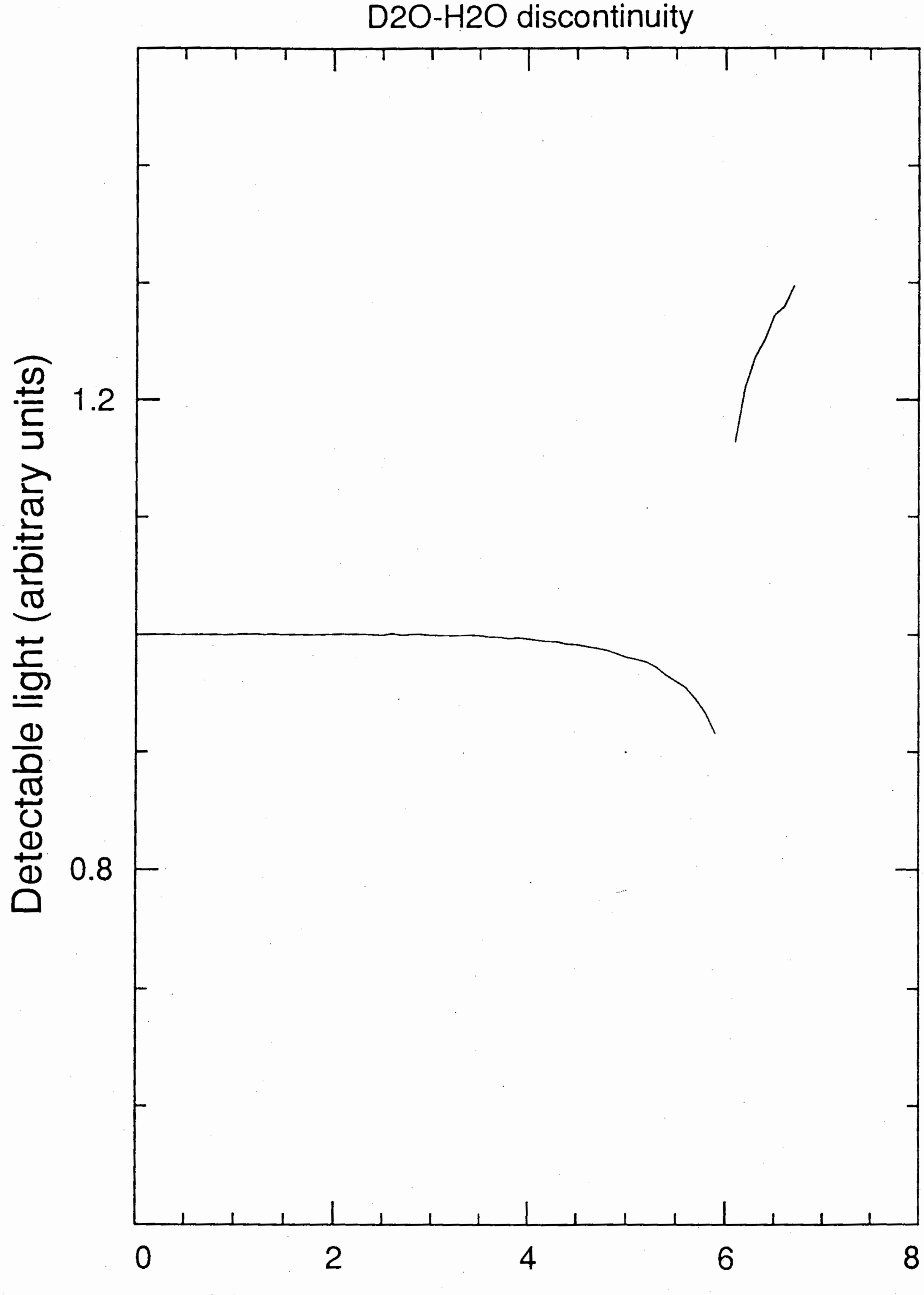

D2O-H2O discontinuity
Detectable light (arbitrary units)
1.2
0.8
0
2
4
6
8
Vertex position along the radius (m)

Figure 1.

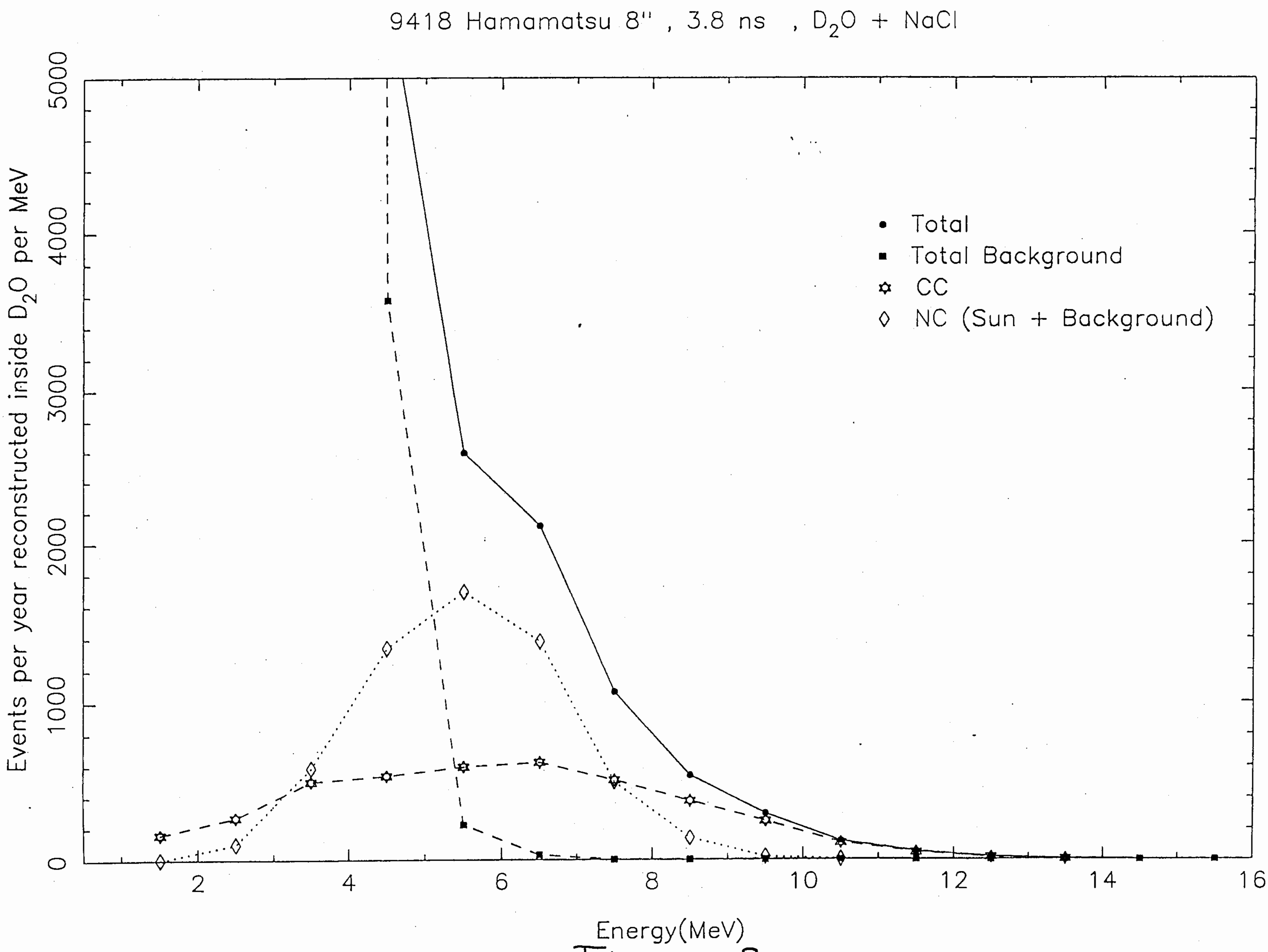
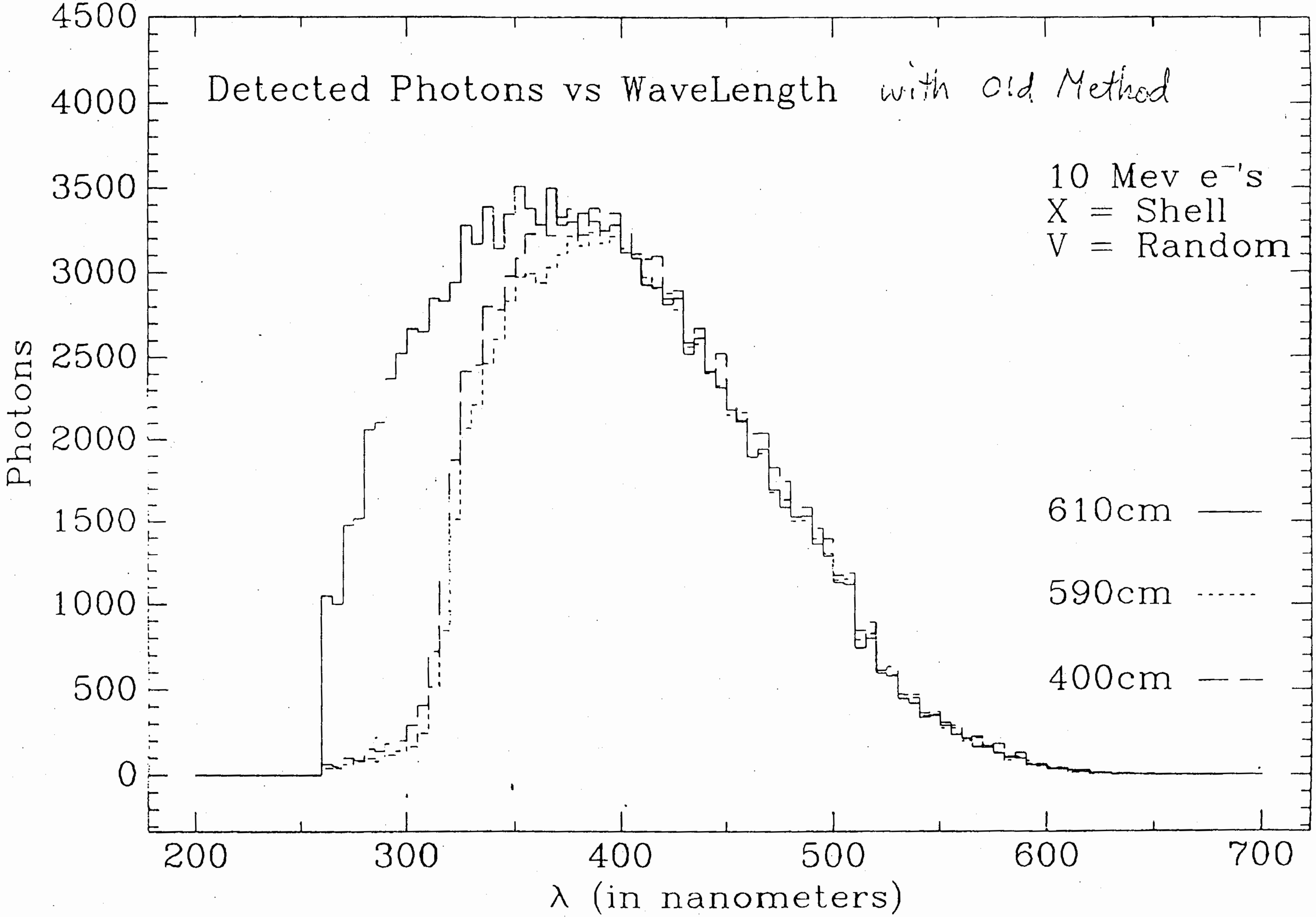
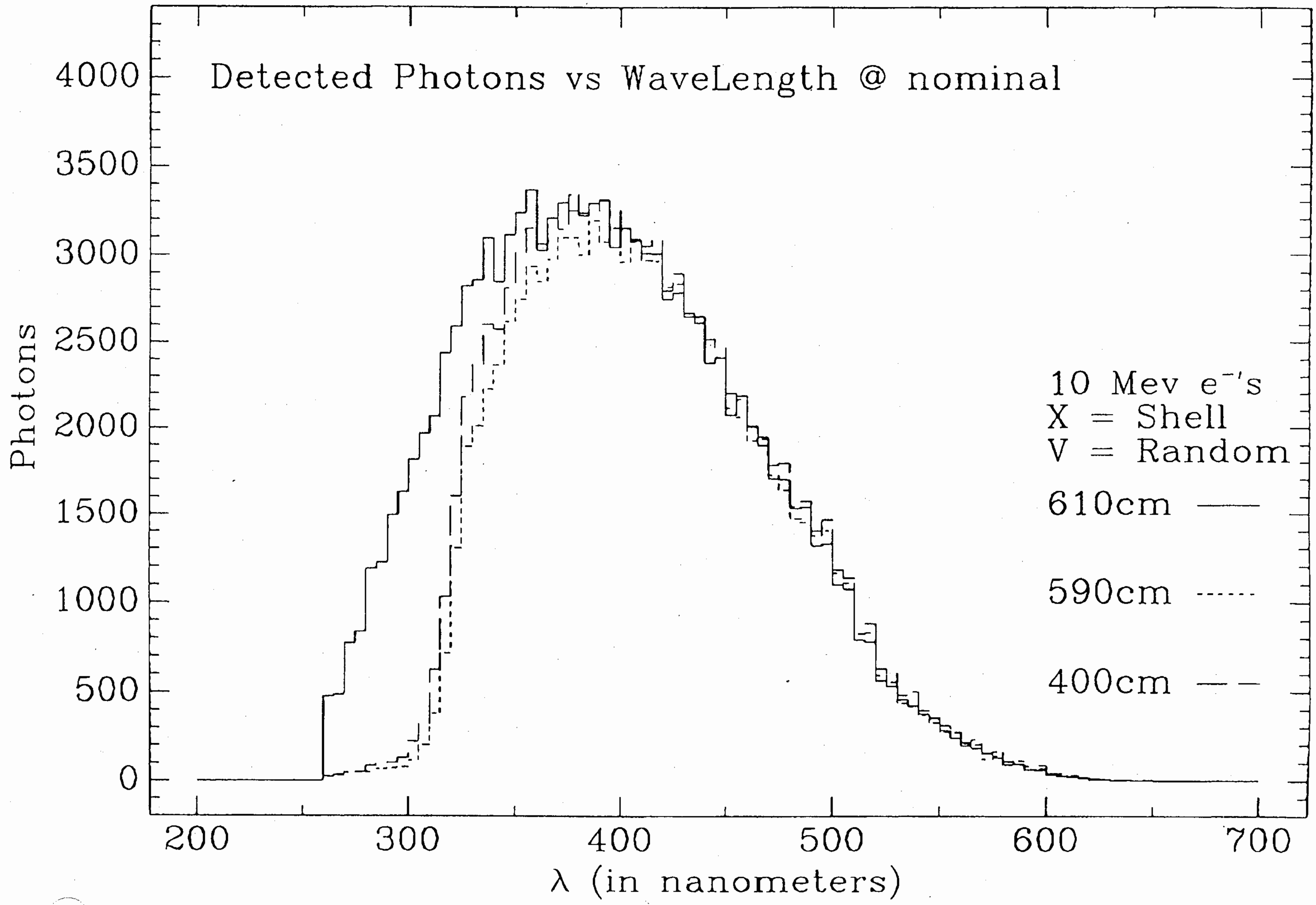

9418 Hamamatsu 8" , 3.8 ns , D2O + NaCl
Events per year reconstructed inside D2O per MeV
Energy(MeV)
Total
Total Background
CC
NC (Sun + Background)
0
1000
2000
3000
4000
5000
2
4
6
8
10
12
14
16

Figure 2.



Detected Photons vs WaveLength with Old Method
10 Mev e⁻'s
X = Shell
V = Random
610cm
590cm
400cm
Photons
4500
4000
3500
3000
2500
2000
1500
1000
500
0
200
300
400
500
600
700
λ (in nanometers)

Figure 3.


Detected Photons vs WaveLength @ nominal
Photons
4000
3500
3000
2500
2000
1500
1000
500
0
200
300
400
500
600
700
λ (in nanometers)
10 Mev e⁻'s
X = Shell
V = Random
610cm
590cm
400cm
Figure +.