Light Water Data Extraction

P. Skensved and B.C. Robertson
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Introduction

In SNO-STR-91-06 we investigated the response from the D_2O in the SNO detector for three different Δm^2, $\sin^2 2\theta$ scenarios and for the case of vacuum oscillations. In each case spectra simulating a light water fill, a heavy water fill and finally a heavy water plus NaCl fill were generated. Each counting period was taken to be one year and total data sets (signals plus all known backgrounds) were created. The data was sorted with respect to energy, angle and reconstructed radius and we showed that it was possible to prove the existence of neutrino oscillations in most cases.

In this report we extend the analysis to the light water surrounding the D_2O.

Extraction of data

The detector contains approximately 1,645 tonnes of H_2O which is sensitive to the elastic scattering reaction (ES). However due to the limited solid angle of the reflectors only a fraction of this is effectively visible (about 600 tonnes). This is still enough to work with at least for some neutrino oscillation scenarios and it will provide some information on the time dependence of the ν_e flux.

The data sets generated for [1] were re-analyzed with a radial cut of 600 to 850 cm for the four different oscillation scenarios and total 3 year data sets were created.

Figure 1a shows a typical energy spectrum in the H_2O for year 3 for the case assuming $\Delta m^2 = 10^{-6}$ and $\sin^2 2\theta = .01$ (suppression of low energy ν_e's). Figures 1b through 1f shows the angular projections (the cosine of the angle between reconstructed direction and direction to the sun). The ES signal is clearly visible above 45 hits and it is clear that one can use a lower threshold of between 50 and 70 hits. Above that the number of ES events is too small.

As in [1] we fit the angular projections above some energy threshold to the no-oscillation spectrum for ES plus a constant to see how well we can detect the presence of oscillations. Fits (dashed lines) for $N_{hit} = 50$, 60 and 70 are presented in figures 2a, 2b and 2c for the case of $\Delta m^2 = 10^{-6}$. As the threshold is increased both the signal and the background gets smaller. The optimum is somewhere just below 50 hits.

The next set of figures (3 to 6) shows the fits for the 3 neutrino vacuum oscillation case, $\Delta m^2 = 10^{-6}$, 10^{-5} and 10^{-4} for years 1,2 and 3. The corresponding values of $\sin^2 2\theta$ are .01, .03 and .01 and the threshold is kept fixed at 50 hits. In terms of the effect on the ν_e spectrum these corresponds to uniform suppression to one third the standard model, suppression of low energy ν_e's, suppression of all ν_e's independent of energy and suppression of high energy ν_e's respectively.

Tables 1 through 4 lists the results. Listed are both the fitted numbers and the input Monte Carlo numbers plus the total χ^2. The same results (in ratio form) can be found in table 5.

Due to the fact that we use 600 cm as the inner radial cut there are a number of misreconstructed CC (and NC) events in the H_2O. Consequently the fits were repeated adding a CC term ($1 - \frac{1}{3} \times \cos\theta$) to the angular distribution. The inclusion of the CC term only has a minor effect on the error of the ES component but it does affect the uncertainty on the 'background' which is of no concern here. Most of these CC and NC events would disappear if one were to use a slightly larger inner cut.

The expected rates based on the high statistics multi year spectra for the Standard Solar Model with a ν_e flux of 5.8×10^6 cm^{-2} s^{-1} and a radial cut of 600 to 850 cm are listed in table 6 and finally, the ratios of the fitted numbers to the expected ones for the SSM can be found in table 7. There is good agreement between this table and table 7 in SNO-STR-91-06 which is what one would expect since we are measuring the same flux but the uncertainties here are slightly higher. This is primarily due to the smaller light water fiducial volume and to a lesser degree due to the higher backgrounds.

Conclusions

We have shown that if the backgrounds can be kept to the levels assumed in [2] measurement of the elastic scattering signal in the light water surrounding the acrylic vessel is indeed possible except if there are no high energy electron neutrinos or if the overall ν_e flux is depressed. The quality of the signal is slightly worse than the one from the D_2O but it can, based on a simple analysis, yield a 10% number in a year for cases where the ν_e flux is of the order of one third of the number predicted by the SSM.

References

[1] SNO-STR-91-06

[2] SNO-87-12

Year	Thres.	ES		CC		Background + NC		χ^2
	N_{hit}	Fit	M.C.	Fit	M.C.	Fit	MC	(40 pts.)
1	50	201 (22)	196	-	-	1140 (38)	1145	40.7
	60	115 (14)	120	-	-	261 (18)	256	56.4
	70	80 (10)	80	-	-	52 (8)	52	23.5
2	50	202 (23)	216	-	141	1276 (40)	1110 + 29	55.8
	60	105 (14)	117	-	109	369 (22)	239 + 9	39.1
	70	66 (10)	69	-	66	127 (13)	54 + 4	43.2
2	50	219 (28)	216	-2 (254)	141	1279 (273)	1110 + 29	55.8
	60	112 (17)	117	118 (138)	109	244 (148)	239 + 9	38.0
	70	76 (12)	69	86 (82)	66	31 (87)	54 + 4	41.1
3	50	258 (25)	230	-	122	1471 (43)	1108 + 269	33.1
	60	135 (16)	145	-	85	536 (26)	246 + 195	29.0
	70	83 (12)	85	-	57	226 (17)	57 + 110	36.4
3	50	269 (30)	230	179 (273)	122	1281 (293)	1108 + 269	32.6
	60	149 (19)	145	228 (166)	85	294 (176)	246 + 195	26.7
	70	82 (14)	85	15 (108)	57	213 (116)	57 + 110	36.1

Table 1: Year 1 through 3 data (vacuum oscillations) for 600$\leq$ r $\leq$850 cm . Angular distribution fitted to ES(θ) + constant or ES(θ) + [1 - $\frac{1}{3}$ cos θ] + constant.

Year	Thres.	ES		CC		Background + NC		χ^2
	N_{hit}	Fit	M.C.	Fit	M.C.	Fit	MC	(40 pts.)
1	50	373 (26)	380	-	-	1152 (38)	1145	49.1
	60	238 (18)	240	-	-	258 (19)	256	59.4
	70	163 (14)	161	-	-	50 (9)	52	22.0
2	50	357 (27)	369	-	180	1331 (41)	1110 + 29	49.9
	60	201 (18)	224	-	130	401 (23)	239 + 9	46.1
	70	123 (13)	142	-	83	162 (15)	54 + 4	36.4
2	50	351 (32)	369	-88 (264)	180	1425 (285)	1110 + 29	49.9
	60	214 (21)	224	171 (149)	130	218 (160)	239 + 9	43.6
	70	140 (15)	142	110 (94)	83	35 (100)	54 + 4	34.1
3	50	398 (28)	366	-	200	1545 (44)	1108 + 269	37.6
	60	224 (20)	241	-	148	606 (28)	246 + 195	42.5
	70	164 (16)	166	-	109	278 (19)	57 + 110	43.6
3	50	420 (34)	366	333 (286)	200	1189 (307)	1108 + 269	36.0
	60	249 (23)	241	381 (180)	148	200 (192)	246 + 195	36.0
	70	183 (18)	166	296 (124)	109	-37 (131)	57 + 110	37.9

Table 2: Year 1 through 3 data ($\Delta m^2 = 10^{-6}$, $\sin^2 2\theta = .01$) for $600 \leq r \leq 850$ cm . Angular distribution fitted to ES(θ) + constant or ES(θ) + [1 - $\frac{1}{3}$ cos θ] + constant.

Year	Thres.	ES		CC		Background + NC		χ^2
	N_{hit}	Fit	M.C.	Fit	M.C.	Fit	MC	(40 pts.)
1	50	46 (17)	49	-	-	1148 (37)	1145	45.0
	60	20 (9)	30	-	-	266 (18)	256	60.6
	70	16 (5)	20	-	-	56 (8)	52	39.7
2	50	57 (17)	46	-	17	1145 (37)	1110 + 29	57.6
	60	27 (9)	33	-	12	266 (18)	239 + 9	38.4
	70	24 (6)	20	-	7	61 (9)	54 + 4	40.7
2	50	51 (28)	46	-94 (231)	17	1245 (247)	1110 + 29	57.5
	60	31 (11)	33	64 (112)	12	198 (119)	239 + 9	38.0
	70	27 (7)	20	51 (57)	7	7 (60)	54 + 4	37.8
3	50	59 (18)	21	-	21	1360 (40)	1108 + 269	38.1
	60	11 (10)	12	-	16	458 (23)	246 + 195	32.4
	70	14 (7)	9	-	9	171 (14)	57 + 110	39.1
3	50	69 (23)	21	181 (252)	21	1170 (269)	1108 + 269	37.5
	60	21 (12)	12	227 (143)	16	221 (151)	246 + 195	29.2
	70	17 (8)	9	35 (88)	9	133 (93)	57 + 110	38.9

Table 3: Year 1 through 3 data ($\Delta m^2 = 10^{-5}$, $\sin^2 2\theta = 0.3$) for 600≤ r ≤850 cm . Angular distribution fitted to ES(θ) + constant or ES(θ) + [1 - $\frac{1}{3}\cos\theta$] + constant.

Year	Thres.	ES		CC		Background + NC		χ^2
	N_{hit}	Fit	M.C.	Fit	M.C.	Fit	MC	(40 pts.)
1	50	102 (19)	100	-	-	1143 (37)	1145	41.3
	60	36 (10)	45	-	-	265 (18)	256	57.6
	70	11 (5)	16	-	-	57 (8)	52	24.2
2	50	138 (20)	133	-	43	1177 (38)	1110 + 29	55.4
	60	59 (11)	69	-	20	278 (19)	239 + 9	29.7
	70	31 (7)	30	-	6	63 (9)	54 + 4	39.0
2	50	130 (25)	133	-119 (240)	43	1305 (257)	1110 + 29	55.2
	60	61 (13)	69	39 (118)	20	237 (126)	239 + 9	29.6
	70	35 (8)	30	17 (57)	6	43 (61)	54 + 4	39.5
3	50	129 (21)	98	-	36	1382 (41)	1108 + 269	38.5
	60	33 (11)	46	-	11	465 (24)	246 + 195	32.6
	70	20 (7)	20	-	3	170 (14)	57 + 110	34.3
3	50	134 (26)	98	82 (258)	36	1295 (276)	1108 + 269	38.4
	60	40 (14)	46	140 (147)	11	318 (156)	246 + 195	31.1
	70	23 (9)	20	35 (89)	3	132 (94)	57 + 110	34.2

Table 4: Year 1 through 3 data ($\Delta m^2 = 10^{-4}$, $\sin^2 2\theta = .01$) for $600 \leq r \leq 850$ cm . Angular distribution fitted to ES(θ) + constant or ES(θ) + [1 - $\frac{1}{3}\cos\theta$] + constant.

Δm^2/	Thres.	Year 1	Year 2		Year 3	
$\sin^2 2\theta$	N_{hit}	ES	ES	ES (with CC)	ES	ES (with CC)
vac.	50	1.03 (.11)	0.94 (.11)	1.01 (.13)	1.12 (.11)	1.17 (.13)
	60	0.96 (.12)	0.90 (.12)	0.96 (.15)	0.93 (.11)	1.03 (.13)
	70	1.00 (.13)	0.96 (.14)	1.10 (.17)	0.98 (.14)	0.96 (.16)
10^{-6}	50	0.98 (.07)	0.97 (.07)	0.95 (.09)	1.09 (.08)	1.15 (.09)
0.01	60	0.99 (.08)	0.90 (.08)	0.96 (.09)	0.93 (.08)	1.03 (.10)
	70	1.01 (.09)	0.87 (.09)	0.99 (.11)	0.99 (.10)	1.10 (.11)
10^{-5}	50	0.94 (.35)	1.24 (.37)	1.11 (.46)	2.81 (.86)	3.3 (1.1)
0.3	60	0.67 (.30)	0.82 (.27)	0.94 (.33)	0.92 (.83)	1.8 (1.0)
	70	0.80 (.25)	1.20 (.30)	1.35 (.35)	1.56 (.78)	1.89 (.89)
10^{-4}	50	1.02 (.19)	1.04 (.15)	0.98 (.19)	1.32 (.21)	1.37 (.27)
0.01	60	0.80 (.22)	0.86 (.16)	0.88 (.19)	0.72 (.24)	1.13 (.30)
	70	0.69 (.31)	1.03 (.23)	1.17 (.27)	1.00 (.35)	1.15 (.45)

Table 5: Ratios of fitted numbers to Monte Carlo input numbers for 600$\leq$ r $\leq$850 cm. Data for year 2 and 3 is fitted with and without a [1 - $\frac{1}{3}$ cos θ] term.

Threshold		ES	CC	NC	
N_{hit}	E(MeV)			D_2O	NaCl
50	5.3	683.4	356.2	20.6	133.5
60	6.3	443.3	263.8	9.5	100.1
70	7.3	281.6	175.7	3.0	66.3

Table 6: Expected rates based on multiyear distributions for 600$\leq$ r $\leq$850 cm for Standard Solar Model with 5.8 $\times$ 10^6 ν_e per cm^2 per sec. Note that the the energies quoted are based on the calibration in the D_2O. No geometrical correction has been applied.

Δm^2/ $\sin^2 2\theta$	Thres. N_{hit}	Year 1	Year 2		Year 3	
		ES	ES	ES (with CC)	ES	ES (with CC)
vac.	50	0.29 (.03)	0.30 (.03)	0.32 (.04)	0.38 (.04)	0.39 (.04)
	60	0.26 (.03)	0.24 (.03)	0.25 (.04)	0.30 (.04)	0.34 (.04)
	70	0.28 (.04)	0.23 (.04)	0.27 (.04)	0.29 (.04)	0.29 (.05)
10^{-6}	50	0.55 (.04)	0.52 (.04)	0.51 (.05)	0.58 (.04)	0.61 (.05)
0.01	60	0.54 (.04)	0.45 (.04)	0.48 (.05)	0.51 (.05)	0.56 (.05)
	70	0.58 (.05)	0.44 (.05)	0.50 (.05)	0.58 (.06)	0.65 (.06)
10^{-5}	50	0.07 (.02)	0.08 (.02)	0.07 (.04)	0.09 (.03)	0.10 (.03)
0.3	60	0.05 (.02)	0.06 (.02)	0.07 (.02)	0.02 (.02)	0.05 (.03)
	70	0.06 (.02)	0.09 (.02)	0.10 (.02)	0.05 (.02)	0.06 (.03)
10^{-4}	50	0.15 (.03)	0.20 (.03)	0.19 (.04)	0.19 (.03)	0.20 (.04)
0.01	60	0.08 (.02)	0.13 (.02)	0.14 (.03)	0.07 (.02)	0.09 (.03)
	70	0.04 (.02)	0.11 (.02)	0.12 (.03)	0.07 (.02)	0.08 (.03)

Table 7: Ratios of fitted numbers to expected numbers from SSM based on multiyear distributions for $600 \leq r \leq 850$ cm. Data for year 2 and 3 is fitted with and without a [$1 - \frac{1}{3} \cos\theta$] term.

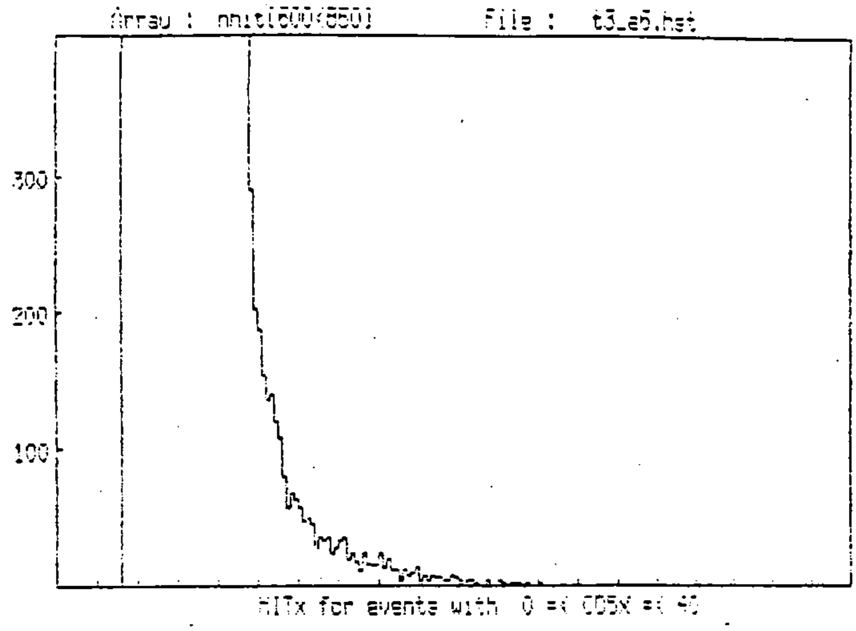
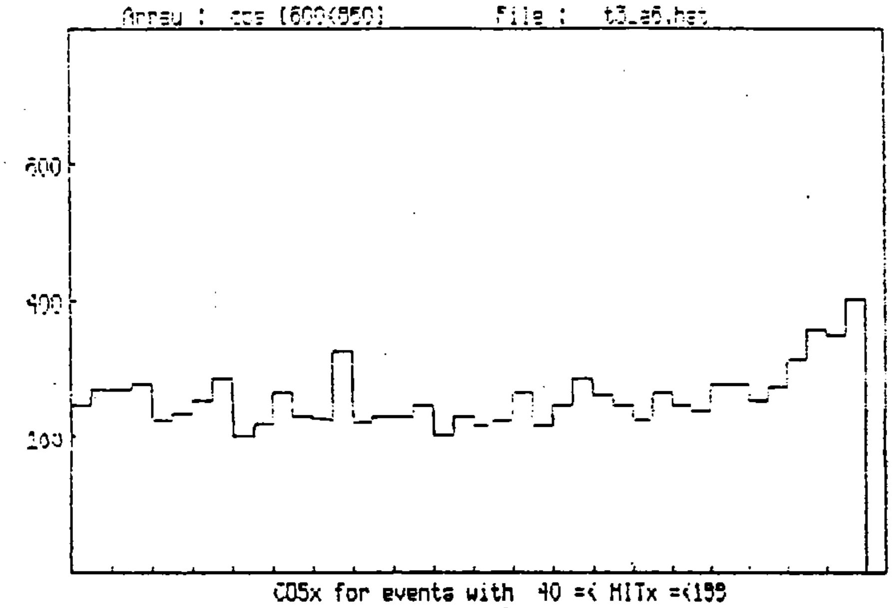
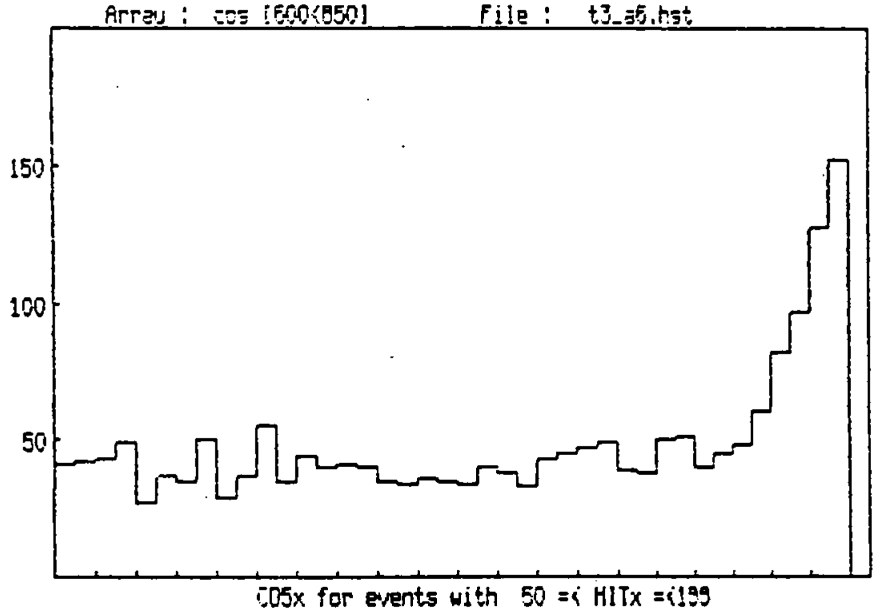


Figure 1a.



1b



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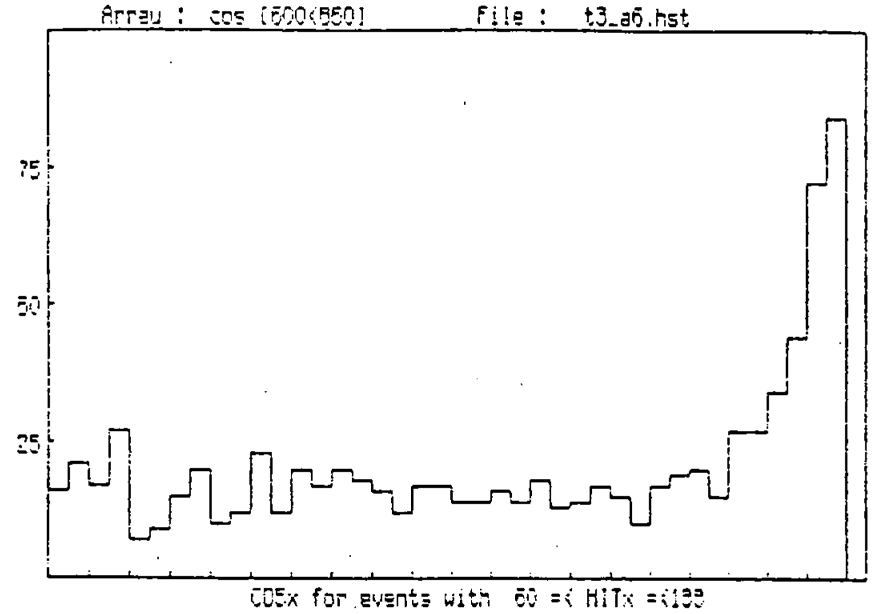
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25
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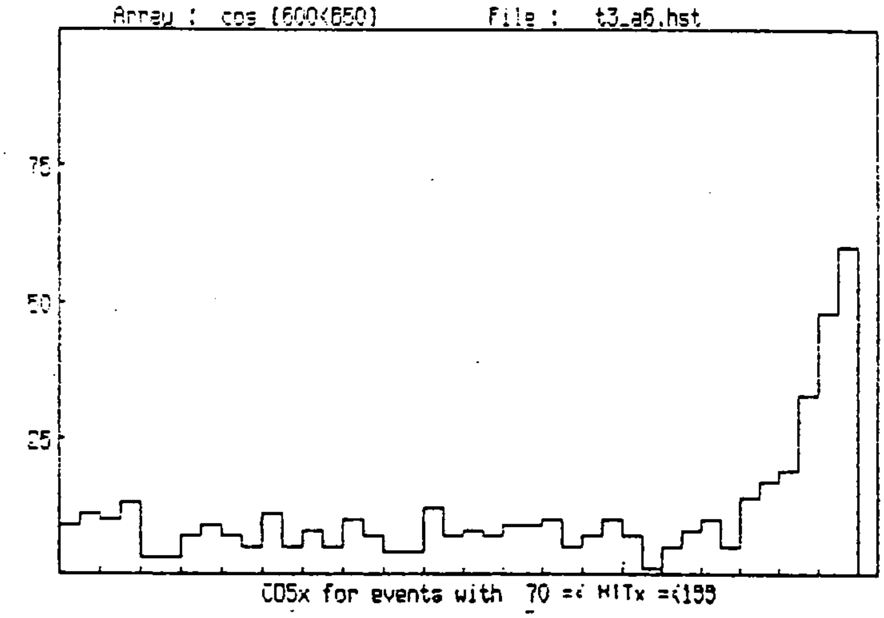
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25
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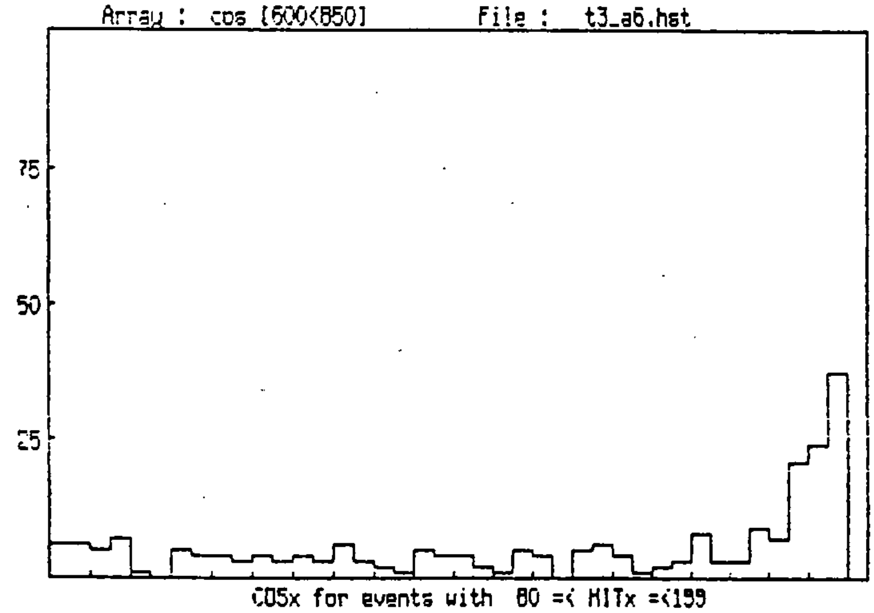
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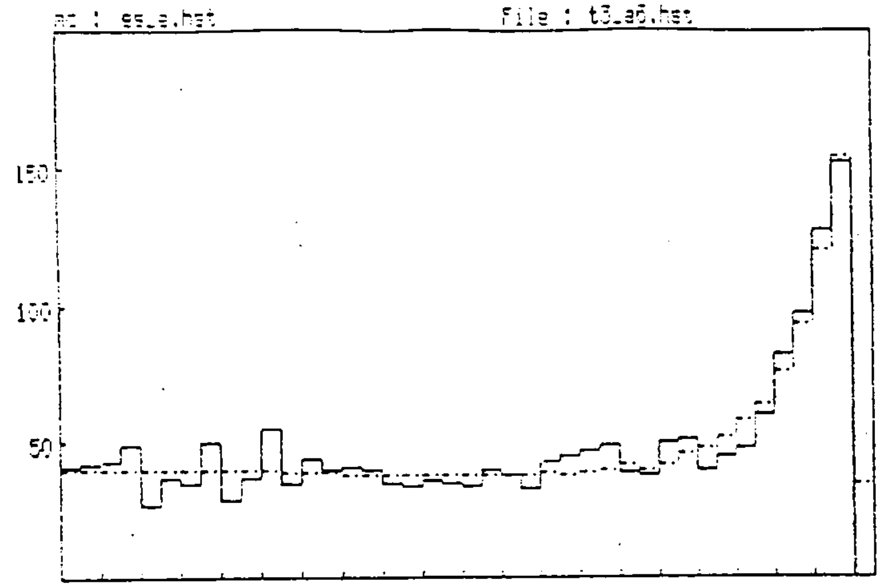
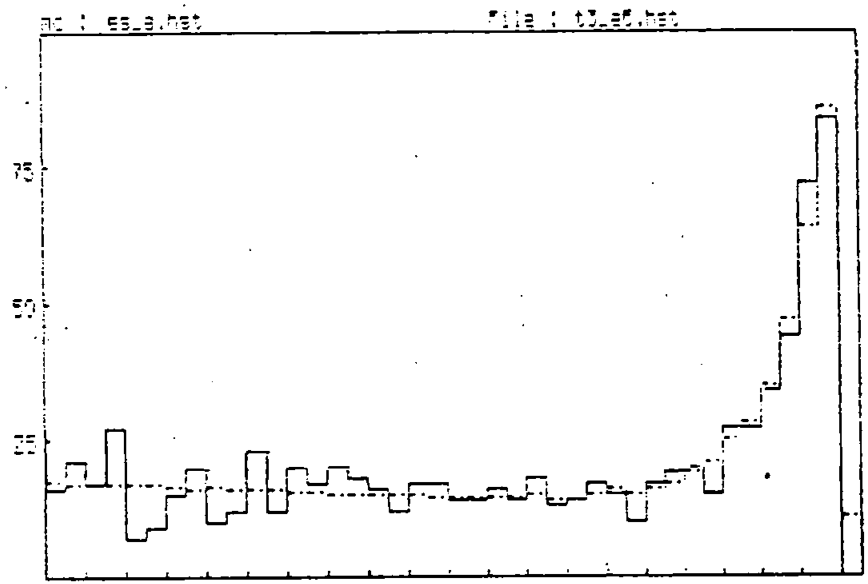
1 f

Figure 2a



C05x[600<850] for events with 50 =< HITx =< 199

2b



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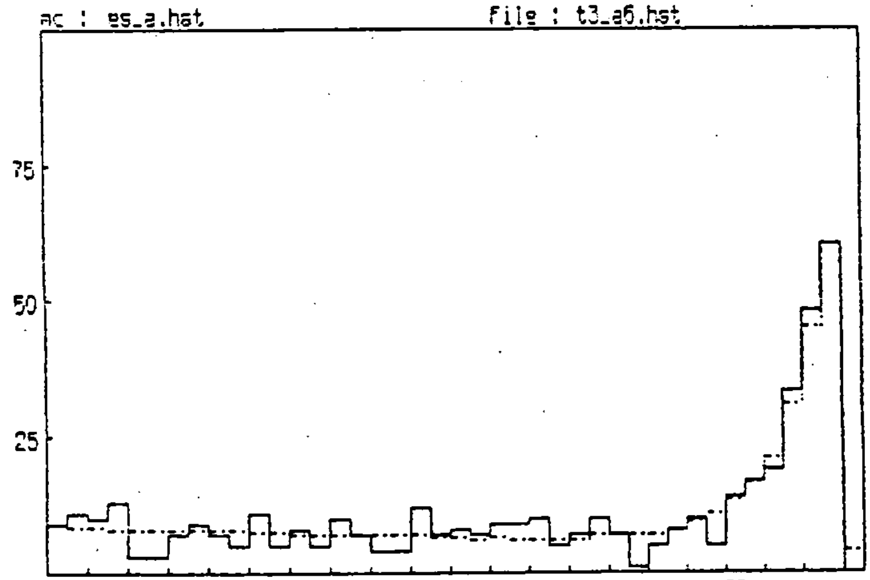

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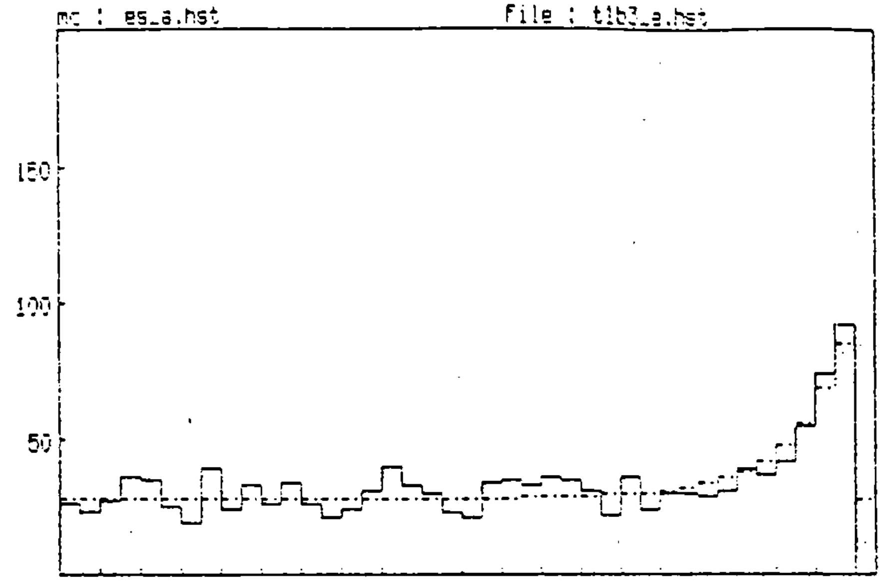
Figure 3



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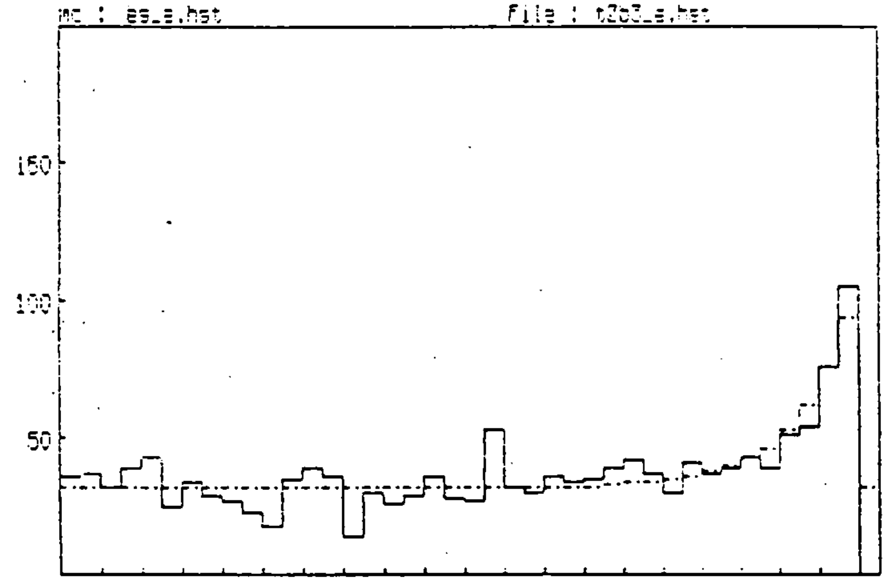

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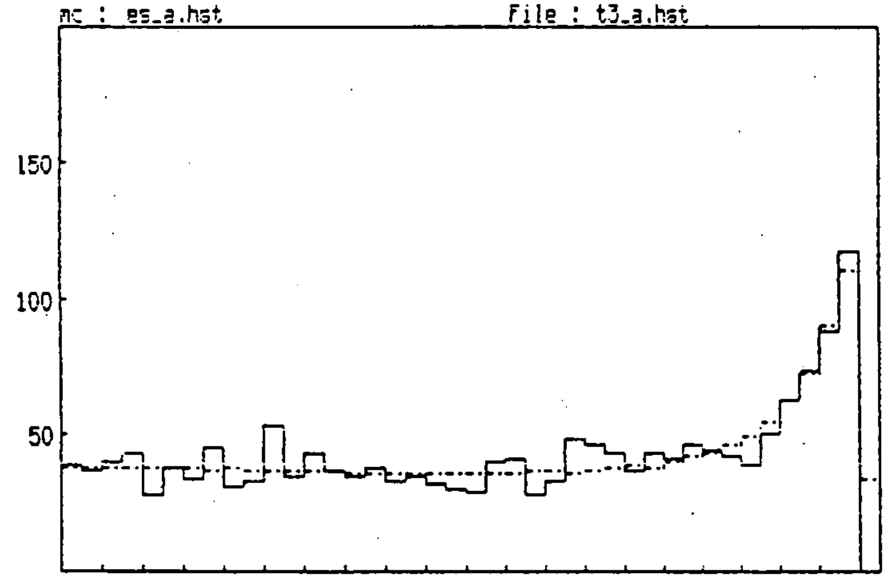

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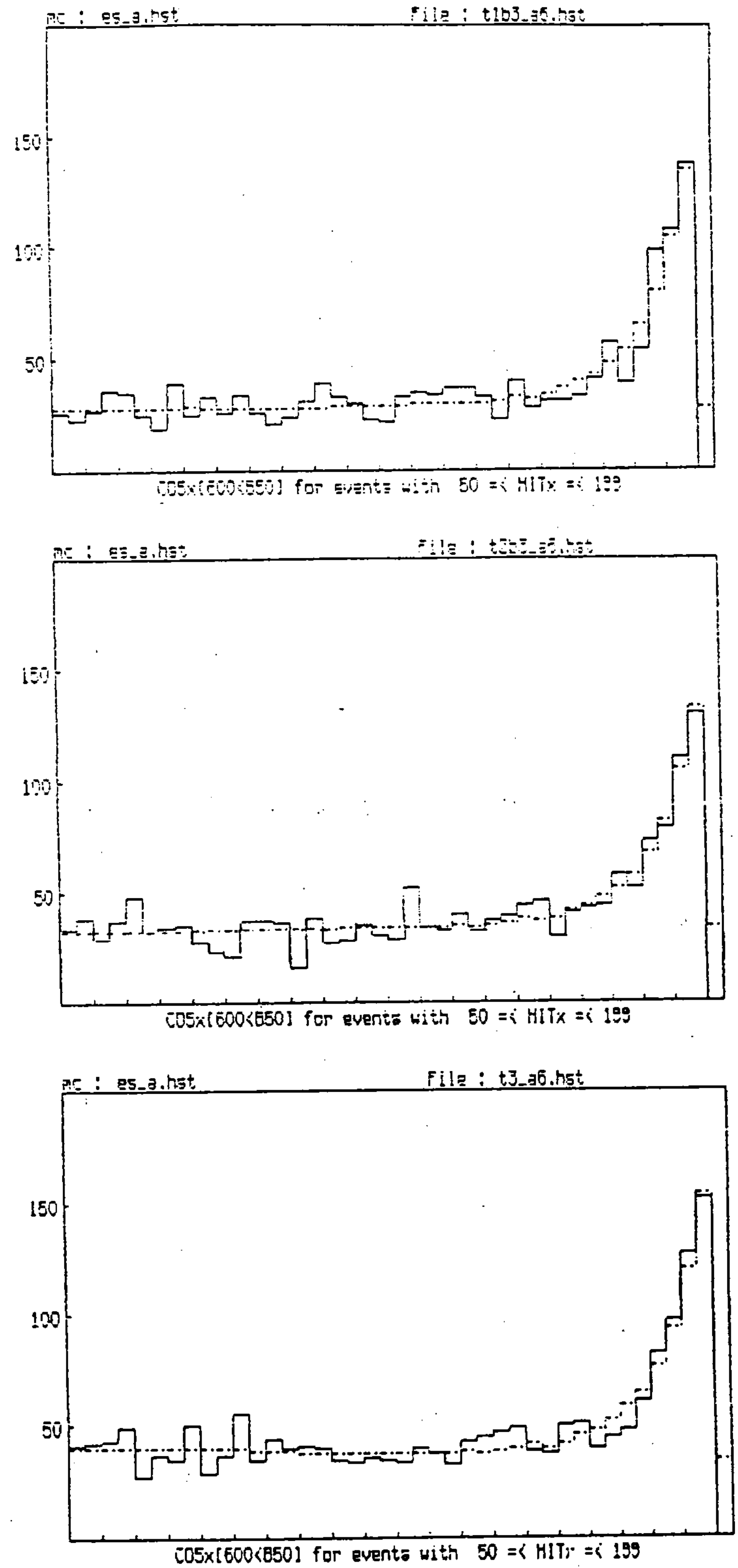
Figure 4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100
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File : t2b3_a6.hst
150
100
50
C05x[600<850] for events with 50 =< HITx =< 199
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File : t3_a6.hst
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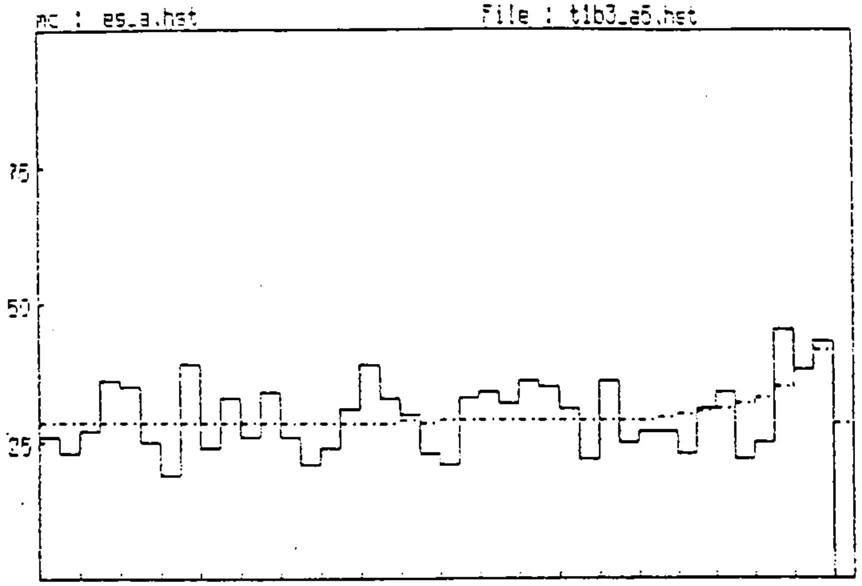
100
50
C05x[600<850] for events with 50 =< HITx =< 199

Figure 5



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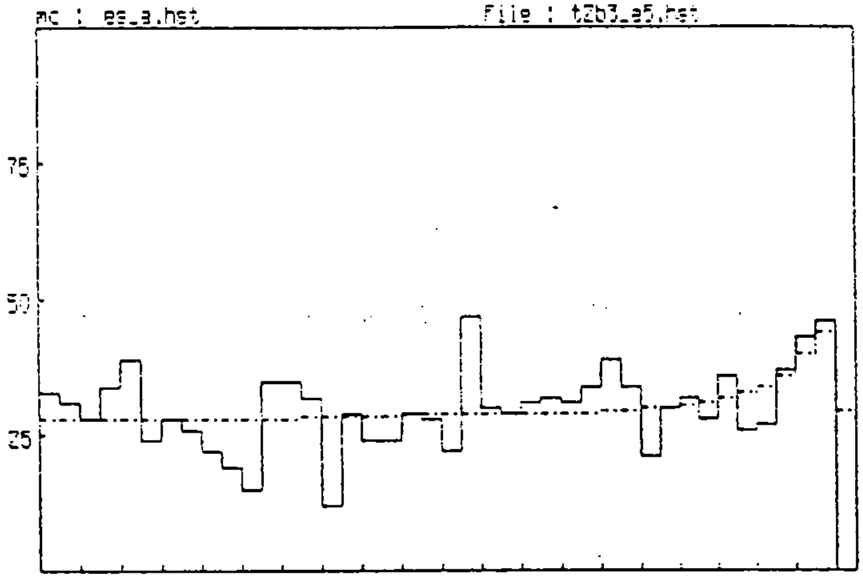

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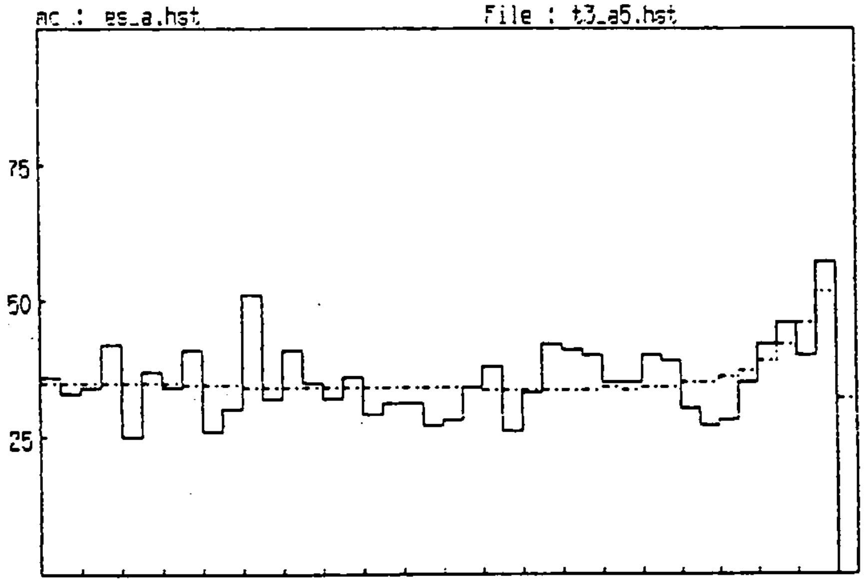

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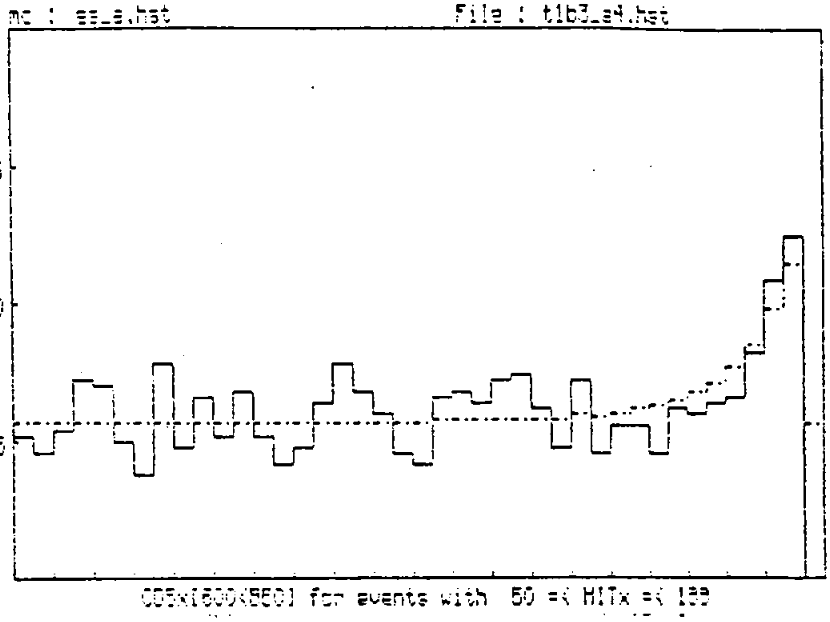
Figure 6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25
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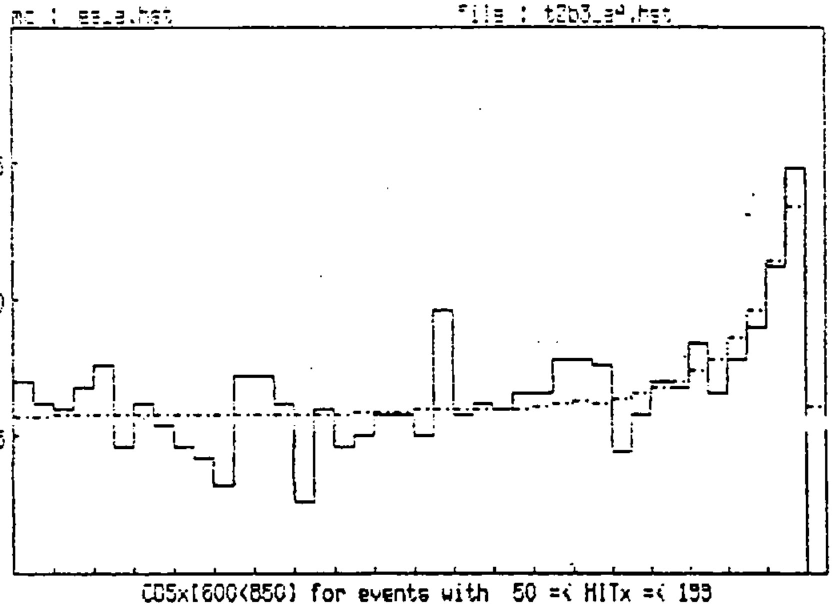
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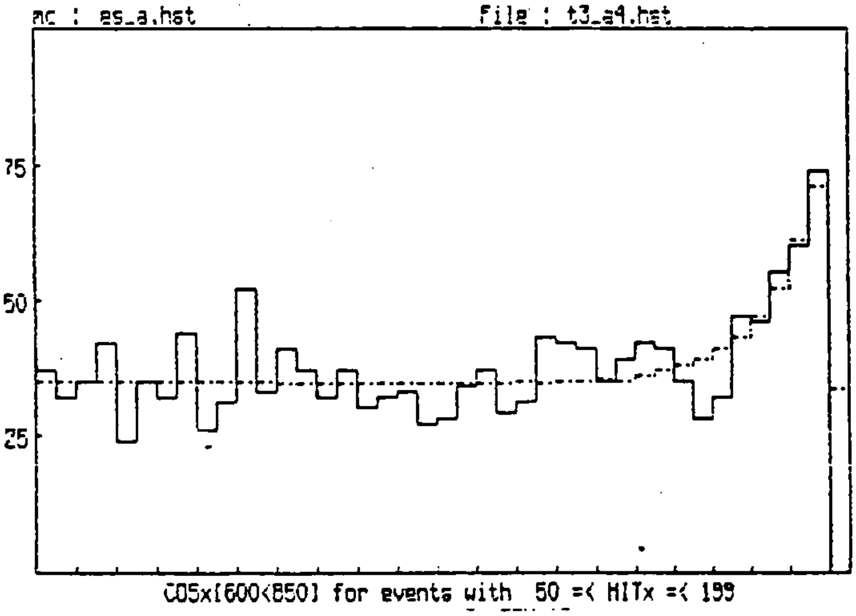
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COSx[600<850] for events with 50 =< HITx =< 199