Simulation and Exercise Report

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Compton Scattering

Purpose

To determine the optimal distance for detector placement to detect Compton events from a gamma beam passing through a thin copper plate.

Geometry

Symmetric Compton events were looked at in this simulation. The simulated apparatus used consisted of a sodium iodide crystal with dimensions 25.4 x 25.4 x 25.4 cm. The crystal was housed in an aluminum casing with thickness 0.16 cm on the incident beam face and 0.64 cm on the other surfaces. A NE102 plastic detector was placed in front of the NaI detector package at a distance of 5 cm. The NE102 detector had thickness of 0.32 cm along the beam direction and 26.68 cm in the other dimensions. An iron collimator was place 2 cm in front of the NE102 detector and was 10.16 cm thick in the beam direction and 26.68 cm thick in the other dimensions. A cylindrical hole through the center of the collimator had a diameter of 17.78 cm. A copper target of thickness 0.3175 cm in the beam direction and 15.0 cm in the other dimensions was used. The detector packages were placed originally symmetrically about the beam line. One was positioned above the beam line at 17.5 degrees measured from the beam line at the point of the target with a distance of 3 m from the target. Another detector package was placed symmetrically below the beam line at -17.5 degrees and 3 m distance. A third detector package was placed in the beam line when data collection of the beam was necessary. The incident beam had 10.0 MeV or 5.0 MeV gamma rays.

Data collection

Histograms were made for particle energy deposition in the detectors and the apparatus parts. The sharp peak in the NE102 detector between the energies of 0.4 - 1.0 MeV made by electrons passing through this detector was used to determine particle type as either a gamma ray or an electron. Compton events were counted whenever an electron hit in a NE102 detector was coincidence with a gamma hit in the other, with energy deposition in both NaI crystals exceeding 1 MeV.

Histograms were made to record the energy deposition in the NaI crystals for Compton events. When the NE102 detector recorded a electron, energy deposition between 0.4 - 1.0 MeV, or a gamma ray, energy deposition less then 0.4 MeV, the energy deposited in the NaI crystal was measured.

The theta and phi angles of particles were recorded for two cases. The first case was when a gamma ray hit one of the detector packages, any electrons in the same event had their theta and phi values plotted on a histogram. Next, whenever a electron hit a detector package the theta and phi values of all the electrons in that event would have their theta and phi values recorded in a histogram. This histogram would serve as a check that the theta and phi values were being calculated properly as the angular position of the detectors should create a peak in this theta and phi plot.

Results

Table 1.1 lists several simulations at different detector distances and beam energy. All of the simulations have the same angular position of the detectors at 17.5 degrees. Each of the following listings corresponds to a 5 million event simulation.

Table 1.1

	UPPER ARM		LOWER ARM			
Energy (MeV)	Angle (degrees)	Distance (cm)	Angle (degrees)	Distance (cm)	Compton Events (#)	Rate (1/MHz)
10.0	17.5	300	17.5	300	5	1.0

10.0	17.5	200	17.5	200	7	1.4
10.0	17.5	100	17.5	100	48	9.6
5.0	17.5	300	17.5	300	0	0.0
5.0	17.5	200	17.5	200	0	0.0
5.0	17.5	100	17.5	100	0	0.0
10.0	17.5	200	17.5	100	14	2.8
5.0	17.5	200	17.5	100	1	0.2
10.0	17.5	100	17.5	200	17	3.4
5.0	17.5	100	17.5	200	0	0.0

Table 1.2 lists simulations where the electron and gamma ray energy deposited in the NaI crystal is examined for Compton events. For the gamma ray energy deposition a clear normal distribution could be seen so a Gaussian fit was done. The mean value and standard deviation are listed by the energy range for these. The electron energy deposition plot had a more uniform distribution and the energy range of the main deposition block is listed. All the listings are for a beam energy of 10.0 MeV, with 75 million event runs.

Table 1.2

Upper Arm distance (cm)	Lower Arm distance (cm)	Electron Energy Range +/- 0.2 (MeV)	Gamma Energy Range +/- 0.2 (MeV)	Mean Energy (MeV)	Standard deviation (10^-3)
300	300	1.2 - 3.6	3.5 - 5.6	-	-
200	200	1.8 - 4.0	3.5 - 5.8	4.69	0.977
100	100	1.6 - 4.4	3.0 - 6.4	4.75	0.826
200	100	1.8 - 4.1	3.2 - 6.1	4.64	0.740
100	200	1.6 - 4.5	3.4 - 6.0	4.77	0.602

The electron plot of electron hits on a detector confirmed that the angles were being calculated properly as the histogram plots of these events had peaks at the angular lactation of the detector packages and a small uniform distribution over all other angles. Table 1.3 lists the theta and phi for paths of electrons that occurred in the same event that a gamma ray hit one of the detector packages. The angular distribution for several runs at 10.0 MeV energy, and 75 million events are listed below. Note that the upper column corresponds to the upper arm detecting a gamma hit, and similarly for the lower column.

Table 1.3

Upper Arm distance (cm)	Lower Arm distance (cm)	Electron Theta Angular Distribution +/- 5 (degrees)		Electron Phi Angular Distribution +/- 5 (degrees)	
		Upper	Lower	Upper	Lower
300	300	13 - 28	8 - 26	-110 - -70	60 - 120
200	200	10 - 29	8 - 24	-120 - -65	60 - 110
100	100	7 - 29	7 - 27	-125 - -60	60 - 115
200	100	10 - 28	6 - 30	-115 - -70	55 - 130
100	200	9 - 31	8 - 26	-135 - -70	70 - 110

He-3 Disintegration Simulation

Motivation

To determine the viability of detecting protons and deuterons from the photo disintegration of He-3 for incident gamma energies between 10 - 30 MeV.

Procedure

The simulation was done using Geant version 3.21. There are four different geometries. The first and most simple geometry consisted of a mylar cylindrical target with Helium-3 gas at STP inside. A delta-E, E detector package was placed perpendicular to the z axis of the cylindrical target (see Figure A.1, Appendix 1.1). The thickness of the mylar target cells walls was varied between 0.5 mm, 0.25mm and 0.125mm. The Silicon Delta-E detector consisted of a gold plated ring with outer radius 3.16 cm, an inner radius of 1.95 cm, and a length of 0.76 cm. The silicon depletion depth was 0.01 cm. The E silicon detector had an outer radius of 2.86 cm, an inner radius of 1.95 cm, and was 1.23 cm in length. The silicon depletion depth of the E was 0.1 cm thick. These parameters were based on some of the EG & G ORTEC silicon detectors available (see Figure A.2, Appendix 1.1). In the code for particle kinematics a routine was added to uniformly distribute particles in a cone. This kinematic code is in all the other simulations as well.

The next geometry contains ten delta-E, E detector packages distributed radially around the target five above and five below. The detectors are positioned 16.3 cm from the center of the target to the face of the detector package (see Figure A.3, Appendix 1.2).

The next geometry has again ten detector packages only in this case there are five above and five to the right of the target (see Figure A.4, Appendix 1.3).

In the last geometry there is a more detailed target cell and a subroutine was added in the particle kinematics to move the cone of uniform particles in the z-y plane. The subroutine is called ROTATEZY (see Appendix 1.4). The target cell here now consists of a 4 cm long 2 cm wide cylindrical volume for liquid helium with 150 micrometer thick walls along the sides of the target with 2 mm thick mylar plates on the top and bottom of the cell. Around this is a vacuum chamber with 5 cm between the target wall and the vacuum chamber wall. The vacuum chamber wall is 50 micrometers thick (see Figure A.5, Appendix 1.4).

Data

Three simulations were done to determine to lower bound on the kinetic energy of a proton which could still be detected in the delta-E, E configuration.(See Tables 1.1, 1.2, 1.3 in appendix A)

The probability of interaction was done to determine differences between a STP he-3 target and liquid he-3 target. (See Table 1.4 in appendix A)

Simulations were done with an adapted target cell to be more physically realistic which had a cryostat cell and vacuum chamber. Two simulations were done with protons and deuterons of different energies to determine their minimum detection kinetic energy and bend back point. A third simulation was done with the same apparatus set up but with an STP target to see the difference in minimum detection energy.(See Tables 1.5, 1.6, 1.7 in appendix A)

A program was used to calculate values of a he-3 disintegration for the p,d case. The energy range of 10 - 30 MeV for incident gamma energies was looked at and the angles and energies of out going particles recorded.(See Table 1.8, 1.9 in appendix A)

Results

The data tabulated in Table 1.5 show that protons need an energy over 8 MeV to be detected in both the DE and E efficiently. From Table 1.6 it can be seen that deuterons need an energy over 10 MeV to be detected in the DE and E efficiently.

Tables 1.8 and 1.9 have the results of the simulated particle disintegration for the region of interest, energies of 10 - 30 MeV gammas. The results in the tables show a minimum kinetic energy value of 2.765 MeV and a maximum of 17.82 MeV for protons. Protons cross the detection minimum of 8 MeV with 20 MeV gammas.

For deuteron the minimum and maximum values for kinetic energy are 1.283 MeV and 9.888 MeV. The deuterons in the region of interest do not go over the 10 MeV deuteron detection threshold.

Conclusion

From the results of simulating the energy deposition and efficiency of protons and deuterons for Helium-3 disintegration using a target cell and vacuum chamber set up, and delta-E, E detector package that would be required to run the experiment, it would not be possible to detect deuterons in the incident gamma region of 10 -30 MeV. Further, protons from the disintegration could only be seen for gamma energies in the region of 20 - 30 MeV.

The following are simulation results to determine the lower bound on kinetic energy for particle detection with a delta-E, E detector system. Three different thickness of mylar are used for the target wall. These efficiency simulations were done before the vacuum chamber was added to the geometry file.

Table 1.1

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 1.8 cm
Mylar Thickness, Ends = 2.0 mm, wall = 0.125mm
Detector Distance = 15.0 cm
DE = 100 micrometers, E = 1 mm, silicon

Detector Angle (degrees)	Proton Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
75	10	0.01237	0.00019	4631	4101
	9	0.01055	0.00018	4413	3498
	8	0.00536	0.00013	3608	1778
	7	0.00024	0.00003	2172	81
60	10	0.04936	0.00039	18225	16369
	9	0.04843	0.00038	18011	16060
	8	0.04796	0.00038	17977	15904
	7	0.04609	0.00037	18009	15286
	6	0.01121	0.00018	17625	3717
45	10	0.06412	0.00044	23685	21266
	9	0.06356	0.00044	23645	21079
	8	0.06323	0.00044	23541	20970
	7	0.06192	0.00043	23419	20535
	6	0.05995	0.00043	23259	19882
	5	0.00003	0.00001	23999	10
30	10	0.07231	0.00047	26814	23979
	9	0.07208	0.00047	26805	23903
	8	0.07040	0.00046	26387	23346
	7	0.07072	0.00046	26686	23453
	6	0.06937	0.00046	26540	23005
	5	0.02841	0.00029	26392	9422
15	10	0.07706	0.00048	28657	25556
	9	0.07610	0.00048	28454	25236
	8	0.07756	0.00048	29004	25723
	7	0.07596	0.00048	28594	25190
	6	0.07419	0.00047	28406	24605
	5	0.06521	0.00044	28536	21626
0	10	0.07829	0.00049	29247	25962
	9	0.07946	0.00049	29669	26352
	8	0.07942	0.00049	29509	26340
	7	0.07844	0.00049	29504	26015
	6	0.07696	0.00048	29314	25524
	5	0.07062	0.00046	29275	23420

Table 1.2

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 1.8 cm

Mylar Thickness, Ends = 2.0 mm, wall = 0.25mm
Detector Distance = 15.0 cm
DE = 100 micrometers, E = 1 mm, silicon

Detector Angle (degrees)	Proton Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
75	10	0.00134	0.00006	1728	445
	9	0.00006	0.00001	764	21
	8	0.00000	0.00000	50	0
60	10	0.04853	0.00038	18257	16094
	9	0.04373	0.00036	18380	14504
	8	0.01251	0.00019	14627	4150
45	10	0.06391	0.00044	23825	21196
	9	0.06208	0.00043	23218	20589
	8	0.06150	0.00043	23433	20395
	7	0.02370	0.00027	23873	7860
30	10	0.07107	0.00046	26472	23568
	9	0.07094	0.00046	26500	23525
	8	0.06949	0.00046	26294	23045
	7	0.06881	0.00046	26833	22819
	6	0.00001	0.00000	26431	2
15	10	0.07696	0.00048	28635	25521
	9	0.07693	0.00048	28664	25512
	8	0.07474	0.00047	28132	24788
	7	0.07413	0.00047	28474	24585
	6	0.00364	0.00010	28407	1206
0	10	0.07810	0.00049	29091	25902
	9	0.07757	0.00048	29117	25725
	8	0.07725	0.00048	29153	25618
	7	0.07727	0.00048	29548	25624
	6	0.01752	0.00023	29250	5811

Table 1.3

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 1.8 cm
Mylar Thickness, Ends = 2.0 mm, wall = 0.5mm
Detector Distance = 15.0 cm
DE = 100 micrometers, E = 1 mm, silicon

Detector Angle (degrees)	Proton Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
75	10	0.00000	0.00000	19	0
	9	0.00000	0.00000	0	0
60	10	0.00019	0.00002	2801	63
	9	0.00000	0.00000	343	0
45	10	0.05156	0.00039	23460	17099
	9	0.00112	0.00006	13761	370
30	10	0.07074	0.00046	26709	23460
	9	0.05570	0.00041	26666	18473

	8	0.00000	0.00000	18744	0
15	10	0.07521	0.00048	28288	24943
	9	0.07310	0.00047	28200	24242
	8	0.00400	0.00011	28284	1327
0	10	0.07752	0.00048	29264	25707
	9	0.07612	0.00048	29041	25245
	8	0.02136	0.00025	29422	7083

Table 1.4

The probability of interaction and the total number of particles scattered into all angles was determined for liquid and gaseous helium-3. A cross section of 1 millibarn was used for the calculation along with a target length of 4 cm, a beam flux of 1 MHz, and the density of liquid and gaseous helium of 0.0575 g/cm^3 and 0.000134 g/cm^3 respectively.

		Liquid	Gaseous
Density of centers	=	1.1534 x10^22 cm^-3	2.6880 x10^19 cm^-3
Probability of Interaction	=	4.6138 x10^-5	1.0752 x10^-7
Total scattered into all angles	=	46.14	0.1075

(See Appendix 1.5)

Table 1.5

The following simulation was with the target cell and vacuum chamber configuration. Liquid helium-3 is used as the target. Bendback of protons start to occur at 15 MeV.

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 2.0 cm
Mylar Thickness Target, Ends = 2.0 mm, wall = 0.015 mm
Vacuum chamber thickness = 0.005 mm
Detector Distance = 15.0 cm
DE = 100 micrometers, E = 1 mm, silicon

Proton Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
11	0.07348	0.00047	29382	24369
10	0.05147	0.00039	26202	17069
9	0.02282	0.00026	16794	7567
8	0.00462	0.00012	8346	1533

Table 1.6

The following simulation was with the target cell and vacuum chamber configuration. Liquid helium-3 is used as the target. Bendback of deuterons start to occur at 20 MeV.

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 2.0 cm
Mylar Thickness Target, Ends = 2.0 mm, wall = 0.015 mm
Vacuum chamber thickness = 0.005 mm
Detector Distance = 15.0 cm

DE = 100 micrometers, E = 1 mm, silicon

Deuteron Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
22	0.07923	0.00049	29164	26276
20	0.07923	0.00049	29166	26275
18	0.07906	0.00049	29136	26219
16	0.07822	0.00049	28936	25939
14	0.05849	0.00042	27520	19398
12	0.02204	0.00026	15887	7310
10	0.00058	0.00004	3764	191

Table 1.7

The following simulation was with the target cell and vacuum chamber configuration. Gaseous helium-3 at SPT is used as the target. Bendback of deuterons start to occur at 18 MeV.

Triggers 1 x 10^6
Target length = 4.0 cm
Radius = 2.0 cm
Mylar Thickness Target, Ends = 2.0 mm, wall = 0.015 mm
Vacuum chamber thickness = 0.005 mm
Detector Distance = 15.0 cm
DE = 100 micrometers, E = 1 mm, silicon

Proton Energy (MeV)	Efficiency (x10^-2)	Efficiency Error (x10^-2)	Raw DE Hits	Raw E Hits
18	0.07915	0.00049	29148	26248
16	0.07954	0.00049	29233	26378
14	0.07958	0.00049	29320	26393
12	0.07909	0.00049	29174	26229
10	0.07898	0.00049	29384	26194
8	0.05801	0.00042	29278	19238

Table 1.8

The following tables have calculated values for the photo disintegration of He-3 into a proton and a deuteron. The subroutine Otherpart was used.(See Appendix 1.6) The first table takes the gamma energy and the angle of one of the particles as input. The second table has the gamma energy and the deuteron angle as inputs.

Inputs		Outputs		
Energy Gamma (MeV)	Proton Angle (degrees)	Proton Energy (MeV)	Deuteron Angle (degrees)	Deuteron Energy (MeV)
10	30	3.226	145.9	1.283
10	60	3.122	113.1	1.387
10	90	2.987	82.4	1.523
10	120	2.857	53.7	1.653
10	150	2.765	26.5	1.744
15	30	6.814	145.7	2.695
15	60	6.589	112.9	2.920
15	90	6.293	82.2	3.216
15	120	6.010	53.5	3.499

15	150	5.812	26.4	3.697
20	30	10.45	145.4	4.061
20	60	10.08	112.3	4.434
20	90	9.588	81.5	4.921
20	120	9.124	53.0	5.385
20	150	8.799	26.1	5.710
25	30	14.12	145.0	5.389
25	60	13.58	111.7	5.931
25	90	12.87	80.9	6.638
25	120	12.20	52.5	7.308
25	150	11.73	25.8	7.775
30	30	17.82	144.6	6.684
30	60	17.09	111.0	7.416
30	90	16.14	80.3	8.366
30	120	15.25	52.0	9.264
30	150	14.62	25.5	9.888

Table 1.9

Inputs		Outputs		
Energy Gamma (MeV)	Deuteron Angle (degrees)	Deuteron Energy (MeV)	Proton Angle (degrees)	Proton Energy (MeV)
10	30	1.735	146.0	2.774
10	60	1.626	113.2	2.884
10	90	1.487	82.4	3.022
10	120	1.360	53.5	3.149
10	150	1.275	26.3	3.235
15	30	3.677	145.9	5.832
15	60	3.438	113.0	6.071
15	90	3.136	82.1	6.373
15	120	2.861	53.3	6.648
15	150	2.675	26.2	6.834
20	30	5.674	145.6	8.836
20	60	5.277	112.5	9.232
20	90	4.780	81.5	9.730
20	120	4.329	52.8	10.18
20	150	4.027	25.9	10.48
25	30	7.719	145.2	11.79
25	60	7.140	111.9	12.37
25	90	6.417	80.9	13.09
25	120	5.768	52.3	13.74
25	150	5.335	25.6	14.17
30	30	9.807	144.8	14.70
30	60	9.022	111.3	15.49
30	90	8.049	80.2	16.46
30	120	7.181	51.8	17.33
30	150	6.607	25.3	17.90

Appendix A

- 1.1

The directory with the simple geometry is ˜/geant/he. For a picture of the geometry go to Figure A.1 in the appendix A. The silicon detector arrangment is Figure A.2 of appendix A.

- 1.2

The directory with the ten radialy distributed detectors is ˜/geant/he3. A picture of the detector is Figure A.3 of appendix A.

- 1.3

The directory with the detectors aligned to the right and above the target is ˜/geant/hemult. A picture of this geometry is Figure A.4 of appendix A.

- 1.4

```
      SUBROUTINE ROTATEZY(DETANG,THEOLD,PHIOLD,THENEW,PHINEW)

      IMPLICIT NONE

      REAL*4 DETANG

      REAL*4 THEOLD,PHIOLD
      REAL*4 THENEW,PHINEW

      REAL*4 XOLD,YOLD,ZOLD
      REAL*4 XNEW,YNEW,ZNEW

      IF(ABS(DETANG) .LT. 0.02)THEN
        THENEW = THEOLD
        PHINEW = PHIOLD
      ELSE
        XOLD = COS(THEOLD)*SIN(PHIOLD)
        YOLD = SIN(THEOLD)*SIN(PHIOLD)
        ZOLD = COS(PHIOLD)

        XNEW = XOLD
        YNEW = YOLD*COS(DETANG) + ZOLD*SIN(DETANG)
        ZNEW = -YOLD*SIN(DETANG) + ZOLD*COS(DETANG)

        PHINEW = ACOS(ZNEW)
        THENEW = ATAN2(YNEW,XNEW)
      ENDIF
      RETURN
      END
```

The directory with the more detailed target cell and single detector is ˜/geant/eff. All of the code for angluar effieciencies of the apparatus are in this directory. For a picture of the geometry turn to Figure A.5 of the appendix A.

- 1.5

```
      Program Totscat

      real*4 dens,deltax,sigma,flux
      real*4 N,prob,scatt,KHz
      real*4 avag,atmass,barn

      parameter (avag = 6.022e23)
      parameter (atmass = 3.002)
      parameter (barn = 1.00e-24)
      parameter (KHz = 1000.0)

      write(*,'(" ")')
```

```
      write(*,'("Give target length in cm : ",$)')
      read(*,*) deltax
      write(*,'("Give Helium density in g/cm^3 : ",$)')
      read(*,*) dens
      write(*,'("Give cross section in barns : ",$)')
      read(*,*) sigma
      write(*,'("Give beam flux in KHz : ",$ )')
      read(*,*) flux

      write(*,'(" ")')
      N = (dens*avag/atmass)
      write(*,100) N
100   format("Density of centers              = ", 1pg10.4, " cm^-3")

      prob = N*deltax*sigma*barn
      write(*,110) prob
110   format("The probability of interaction          = ",1pg10.4)

      scatt = flux*KHz*prob
      write(*,120) scatt
120   format("Total number scattered into all angles  = ",1pg10.4)
      write(*,'(" ")')

      end
```

- 1.6

```
      Program OtherParticles

      integer*4 kintyp
      real*4 gamma,ang3,mass(4),ke3(2),ke4(2),ang4(2)

      write(*,'(" ")')
      write(*,'("Type 1 for 2-body or 2 for 3-body : ",$)')
      read(*,*) kintyp

      if(kintyp.eq.1)then

        write(*,'("Input gamma energy in MeV: ",$)')
        read(*,*) gamma
        write(*,'("Input angle of particle 3 in degrees: ",$)')
        read(*,*) ang3
c       write(*,'("Input mass of particle 1 in MeV/c^2: ",$)')
c       read(*,*) mass(1)
c       write(*,'("Input mass of particle 2 in MeV/c^2: ",$)')
c       read(*,*) mass(2)
c       write(*,'("Input mass of particle 3 in MeV/c^2: ",$)')
c       read(*,*) mass(3)
c       write(*,'("Input mass of particle 4 in MeV/c^2: ",$)')
c       read(*,*) mass(4)
        mass(1) = 0
        mass(2) = 2808.414
        mass(3) = 1875.625
        mass(4) = 938.28
        call kin_2body(gamma,ang3,mass,ke3,ke4,ang4)
        write(*,'("solution one")')
        write(*,100) ke3(1)
100   format("Kinetic energy of particle 3 = ",1pg10.4, " MeV")
        write(*,110) ke4(1)
110   format("Kinetic energy of particle 4 = ",1pg10.4, " MeV")
        write(*,120) ang4(1)
120   format("Angle of particle 4          = ",1pg10.4, " degrees")
        write(*,'("solution two")')
        write(*,100) ke3(2)
        write(*,110) ke4(2)
        write(*,120) ang4(2)
```

```
        endif

        if(kintyp.eq.2)then
          write(*,'("Sorry this option is not yet avalible")')
        endif

        if((kintyp.ne.1).and.(kintyp.ne.2))then
        endif

        end

        subroutine kin_2body(t1, a3, m, t3, t4, a4)
        parameter(PI=3.14159265)
        real*4 t1, a3, m(4), t3(2), t4(2), a4(2)

        real*4 p3(2), p4(2), e3(2), e4(2)

c       general 2 body kinematics (Lab Frame)
c       m(1) + m(2) -> m(3) + m(4)
c
c       INPUTS
c               t1      KE of incident particle (1)
c                       target is particle 2 (stationary)
c               a3      angle of outgoing particle (3)
c               m(4)    masses of particles (1,2,3,4)
c                       Units: degrees, MeV, MeV/c^2
c
c       OUTPUTS
c               t3(2)   KE of outgoing particle (3)
c               t4(2)   KE of outgoing particle (4)
c               a4(2)   angle of particle 4
c                       Two possible solutions for above

        e1 = t1 + m(1)
        et = e1 + m(2)
        et2 = et*et
        ct = cos(PI/180.*a3)
        ct2 = ct*ct
        m32 = m(3)*m(3)
        p1 = sqrt(e1*e1 - m(1)*m(1))
        aa = p1*p1 - et2 - m32 + m(4)*m(4)
        a = 4.*(et2 - p1*p1*ct2)
        b = 4.*aa*p1*ct
        c = 4*et2*m32 - aa*aa

        det = b*b - 4.*a*c
        if(det .lt. 0.) then
                write(6,*)'kin_2body(): determinant < 0.'
                t3(1) = -1.
                t4(1) = -1.
                a4(1) = 0.
                t3(2) = -1.
                t4(2) = -1.
                a4(2) = 0.
                return
        end if

        p3(1) = (-b + sqrt(det))/2./a
        p3(2) = (-b - sqrt(det))/2./a

        do i = 1,2

        if(p3(i) .ge. 0.) then
                e3(i) = sqrt(p3(i)*p3(i) + m32)
                t3(i) = e3(i) - m(3)
```

```
                det = p1*p1 - 2.*p1*p3(i)*ct + p3(i)*p3(i)
                if(det .lt. 0.) then
                        p3(i) = -1.
                else
                        p4(i) = sqrt(det)
                        if(p4(i) .gt. 0.) then
                                c = (p1 - p3(i)*ct)/p4(i)
                                if(abs(c) .le. 1.) then
                                        a4(i) = 180./PI*acos(c)
                                else
                                        a4(i) = 0.
                                end if
                        else
                                a4(i) = 180.
                        end if
                        e4(i) = sqrt(p4(i)*p4(i) + m(4)*m(4))
                        t4(i) = e4(i) - m(4)
                end if
        end if

        end do

c       make first solution be valid if there are valid solutions
        if(p3(1) .lt. 0.) then
                p3(1) = p3(2)
                t3(1) = t3(2)
                t4(1) = t4(2)
                a4(1) = a4(2)
                p3(2) = -1.
        end if
c       make invalid solution energies = -1.
        do i = 1,2
                if(p3(i) .lt. 0.) then
                        t3(i) = -1.
                        t4(i) = -1.
                        a4(i) = 0.
                end if
        end do
        return
        end
```

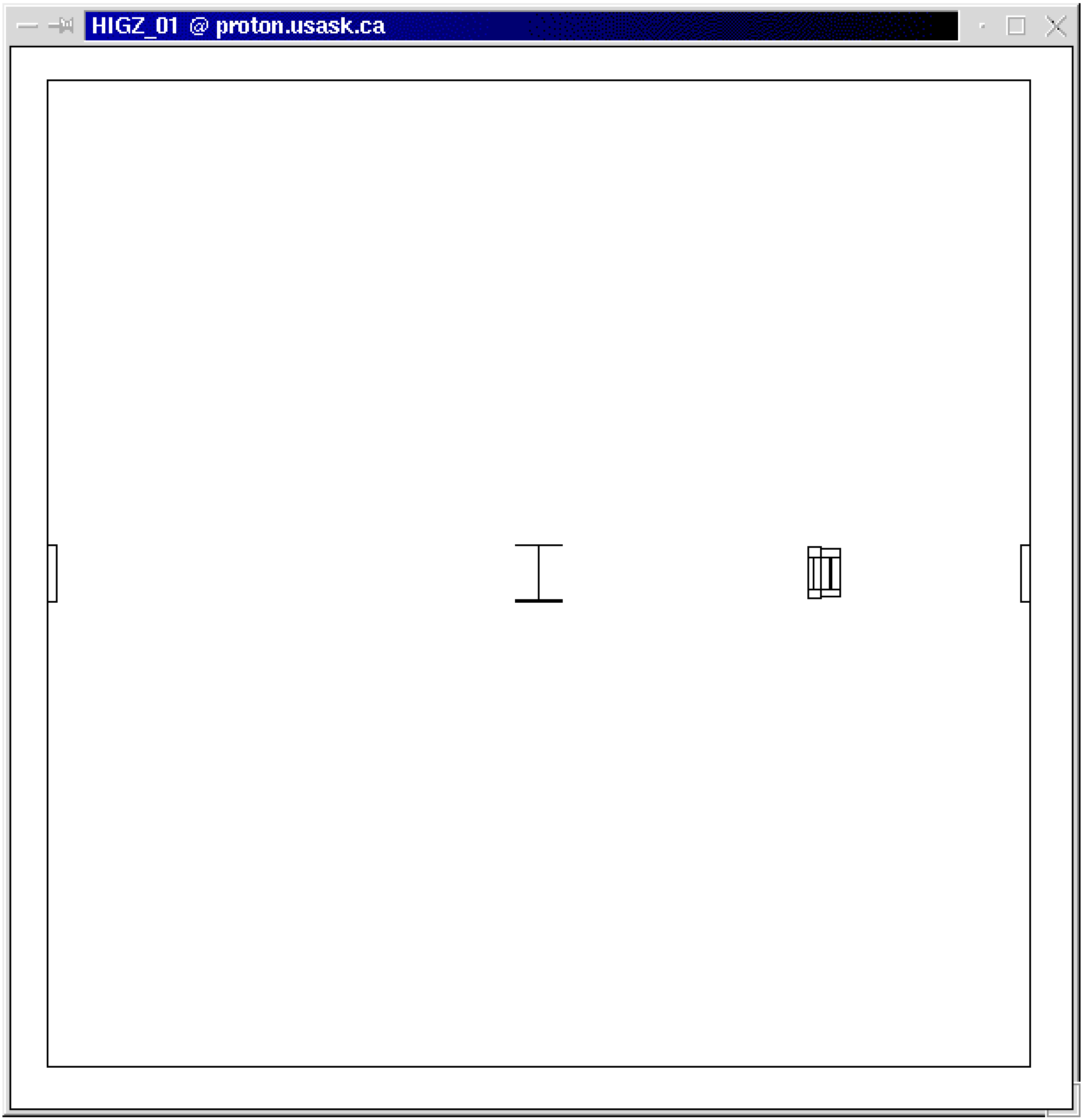

Figure A.1

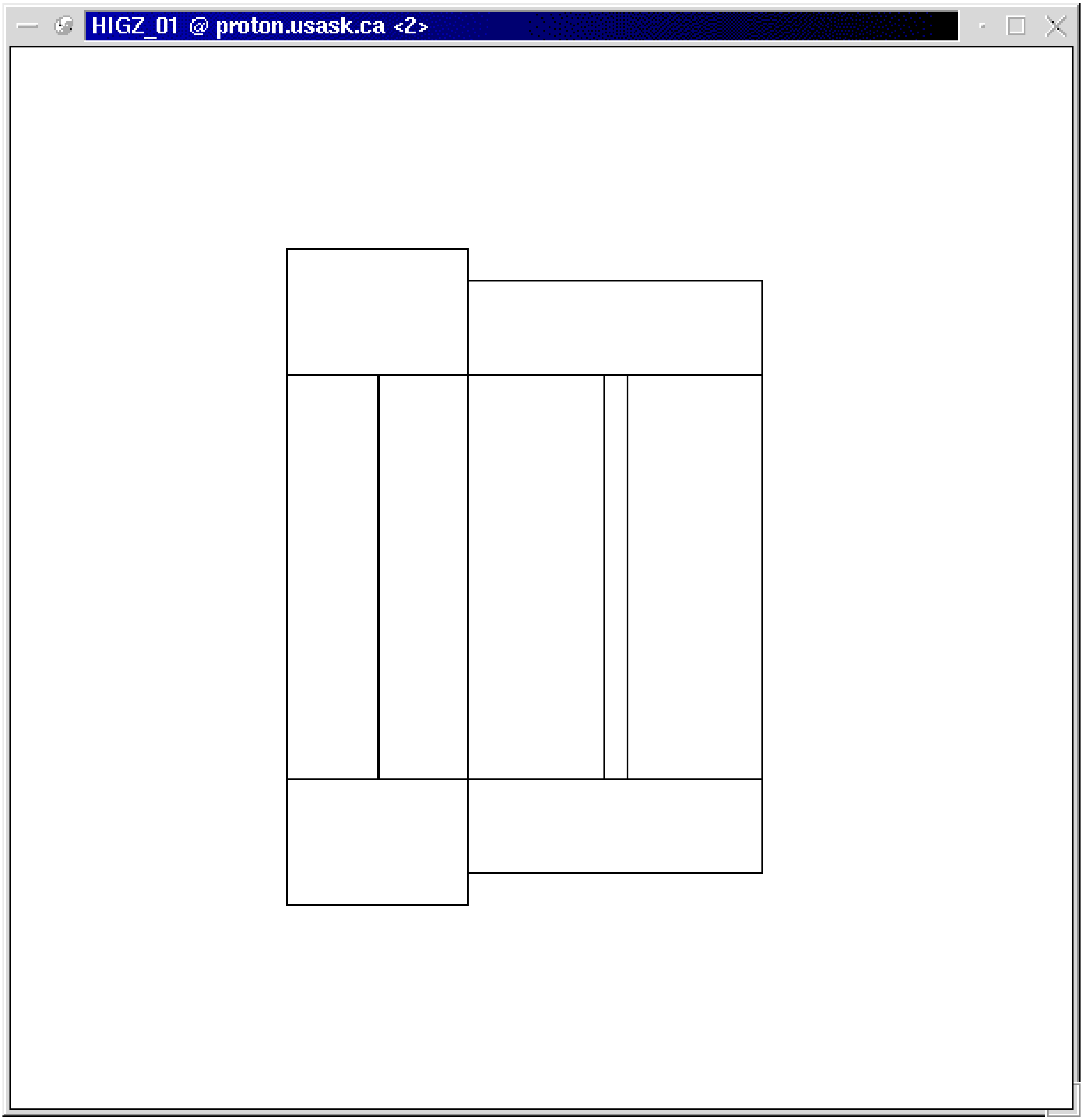

Figure A.2

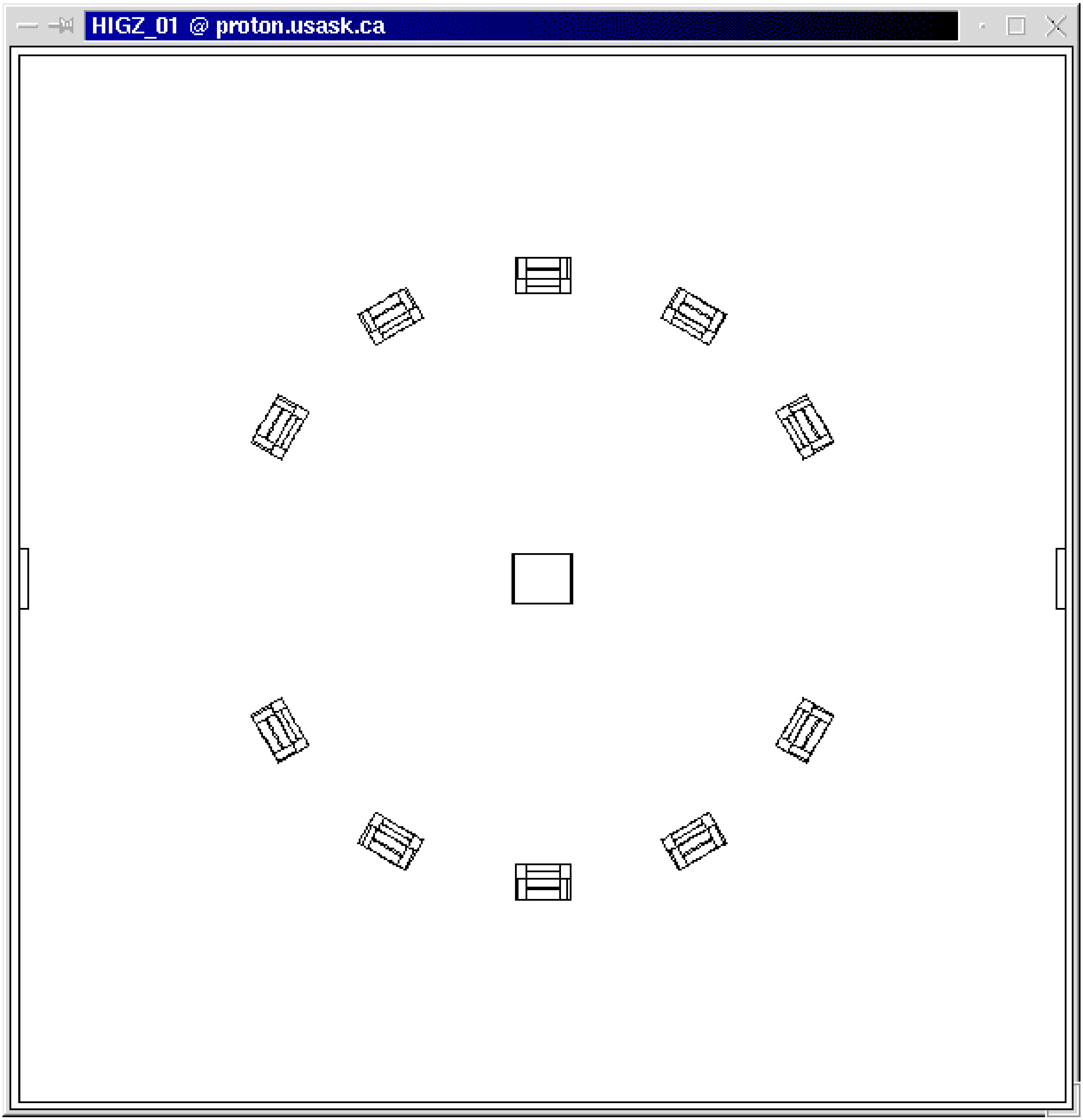

Figure A.3

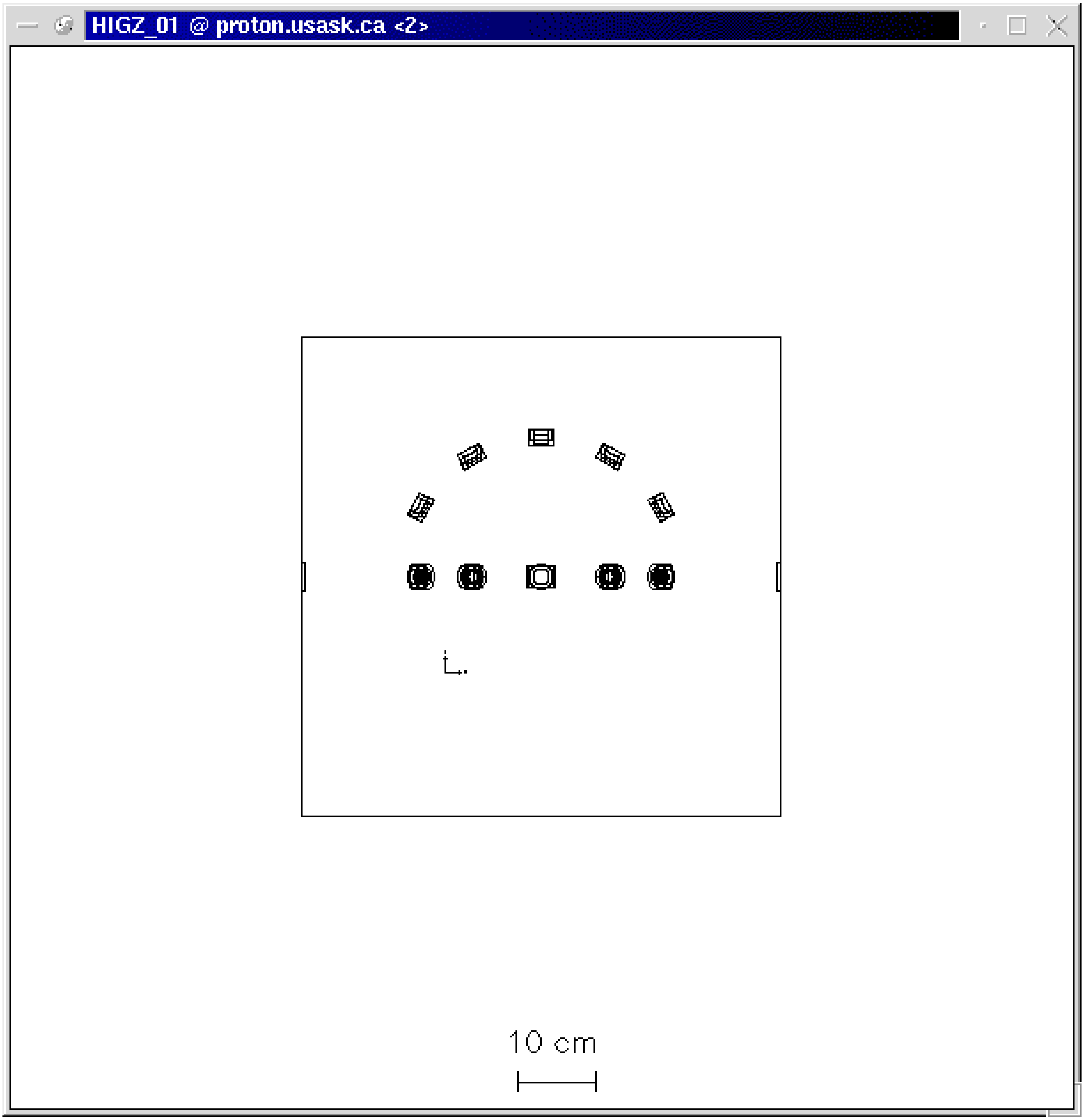

Figure A.4

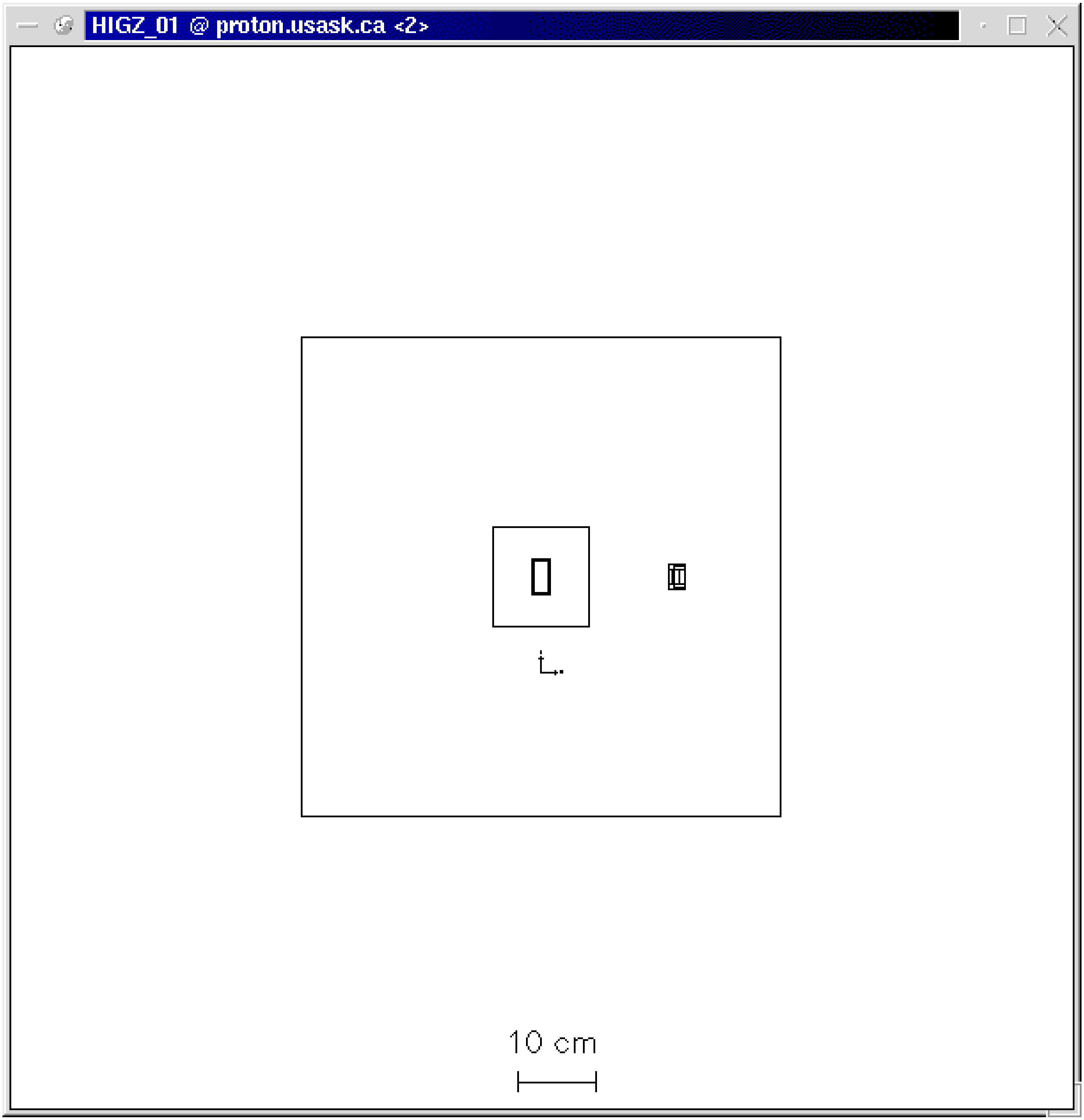

Figure A.5

He-4 Disintegration Efficiency Simulation

Motivation

To determine the efficiency of the apparatus used for detecting He-4 disintegration so that the cross sections may be determined from the analyzed data from the experiment.

Procedure

The simulation was done using Geant version 3.21. The simulated equipment includes six telescope detectors and a bar detector for the purpose of detecting ionized particles, and several bar detectors for the purpose of detecting neutrons. All of the detectors were made of NE102 plastic scintillator. The angular positions of the telescopes were radial about the target with distance of 23.5 cm from the edge of the vacuum camber to the front of the collimator, the angular positions in degrees were 38.8, 55.0, 81.0, 98.1, 115.1, 132.2 (see Figure B.1, Appendix 2.1). The telescopes consisted of a E block detector dimensions 10 x 10 x 7.6 cm. A delta-E detector 10 x 10 x 0.2 cm. A conic collimator was used, the block dimensions were 10 x 10 x 3.5 cm, the conic hole had an outer radius of 3.35 cm and an inner radius of 3.72 cm. The collimator was made out of lead (see Figure B.2, Appendix 2.2). The bar and paddle detector system had 14 paddle DE detectors in front of the bar detector. The angular locations of the paddles in degrees were 20.8, 23.4, 26.8, 31.2, 37.2, 45.3, 56.6, 71.3, 90.0, 108.3, 123.4, 134.7, 142.8, 148.8. The paddle at 90 degrees had a distance from the target cell of 18.3 cm. The dimensions of the paddles are the same as the delta-E’s for the telescopes. The bar has dimensions 150 x 15 x 7.6 cm. There is a thin layer of PVC over the paddles and bar which has a thickness of 0.025 cm. The dimensions of the neutron bars are the same as the paddle bar. There is a thin detector behind the paddle bar and in front of the neutron bars with dimensions 150 x 15 x 0.2 cm at a distance of 1.5 cm (see Figure B.3, Appendix 2.3).

Data collection

To determine the detection efficiency of the telescopes and paddles additional code was added to the kinematics file to send particles uniformly in all directions (see Appendix 2.4). A delta-E vs. E plot was made for each telescope and paddle to determine particle type. The proton band was then fitted in a curve fitting program and placed into geant (see Appendix 2.5). For a given E value the delta-E value would be calculated and then compared to the energy deposition recorded in the delta-E. If the recorded value was within a small error, which was set by the user, then the particle would be accepted as a proton and counted as a hit. Light output from energy deposition in the NE102 was then done. The efficiency of each of the detectors was then determined (see Appendix 2.6). A similar process was done for the neutron bar detectors.

Results

The efficiencies for the telescope and paddle detectors were done for proton energies between 20 and 100 MeV in 10 MeV steps. The data files from these simulations are in appendix B. Each simulation was run with 10 million events. The efficiencies for the neutron detectors were simulated for neutron energies between 10 and 100 MeV in 10 MeV increments. The data files from these simulations are in appendix B. Each of the neutron simulations was run with 5 million events.

Conclusion/Remarks

The efficiencies listed in the data files from the proton simulations could be refined further for better accuracy. For the proton efficiency the scalar that records the number of proton hits which was used in the calculation for the efficiency could be triggered by the light output rather then the energy deposition. This would require the light output histogram to be curve fitted like the energy deposition histogram was, and the equation put into geant were each particle would be tested and either passed or failed as a valid particle hit (see appendix 2.7).

For the neutron bar efficiencies, there was a small amount of absorption noted for lower energy neutrons. For neutrons in the energy range of 10 - 50 MeV some absorption was noted as the top bar scalers are less then the bottom scalar. For neutron energies of 60 - 100 MeV the scalar values for all the bars become similar (see Appendix B for data sheets). The bottom bar of the neutron detector is the only one with a direct line to the target not intersected by the proton bar (see Figure B.4, Appendix 2.8). It is therefore the best gauge of how much absorption is taking place.

Appendix B

- 2.1

A figure of the experimental set up is Figure B.1 of appendix B.

- 2.2

A figure of the telescope apparatus is Figure B.2 of appendix B.

- 2.3

A figure of the paddle detector system is Figure B.3 of appendix B.

- 2.4

The code is in the gukine.f file in the directory ˜/geant/rice.

- 2.5

The program xmgrace was used for the curve fitting.

- 2.6

The efficiencies were calculated in guout.f on the last event of the simulation and then written into a file.

- 2.7

The code for the particle band testing is in guout.f, all scalers and histograms for this data is incremented here.

- 2.8

A figure of the simulated apparatus from the side is Figure B.4 of appendix B.

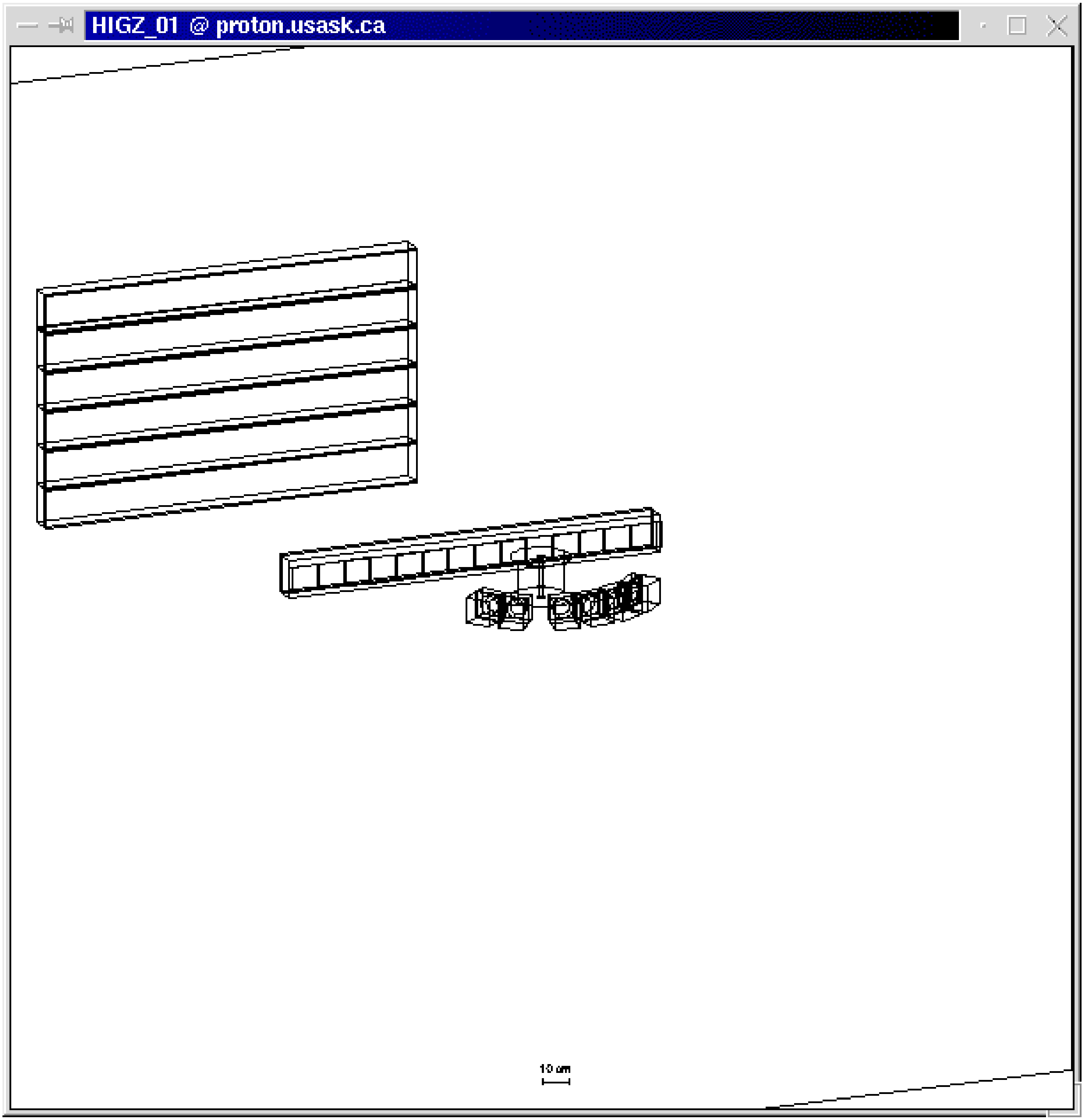

Figure B.1

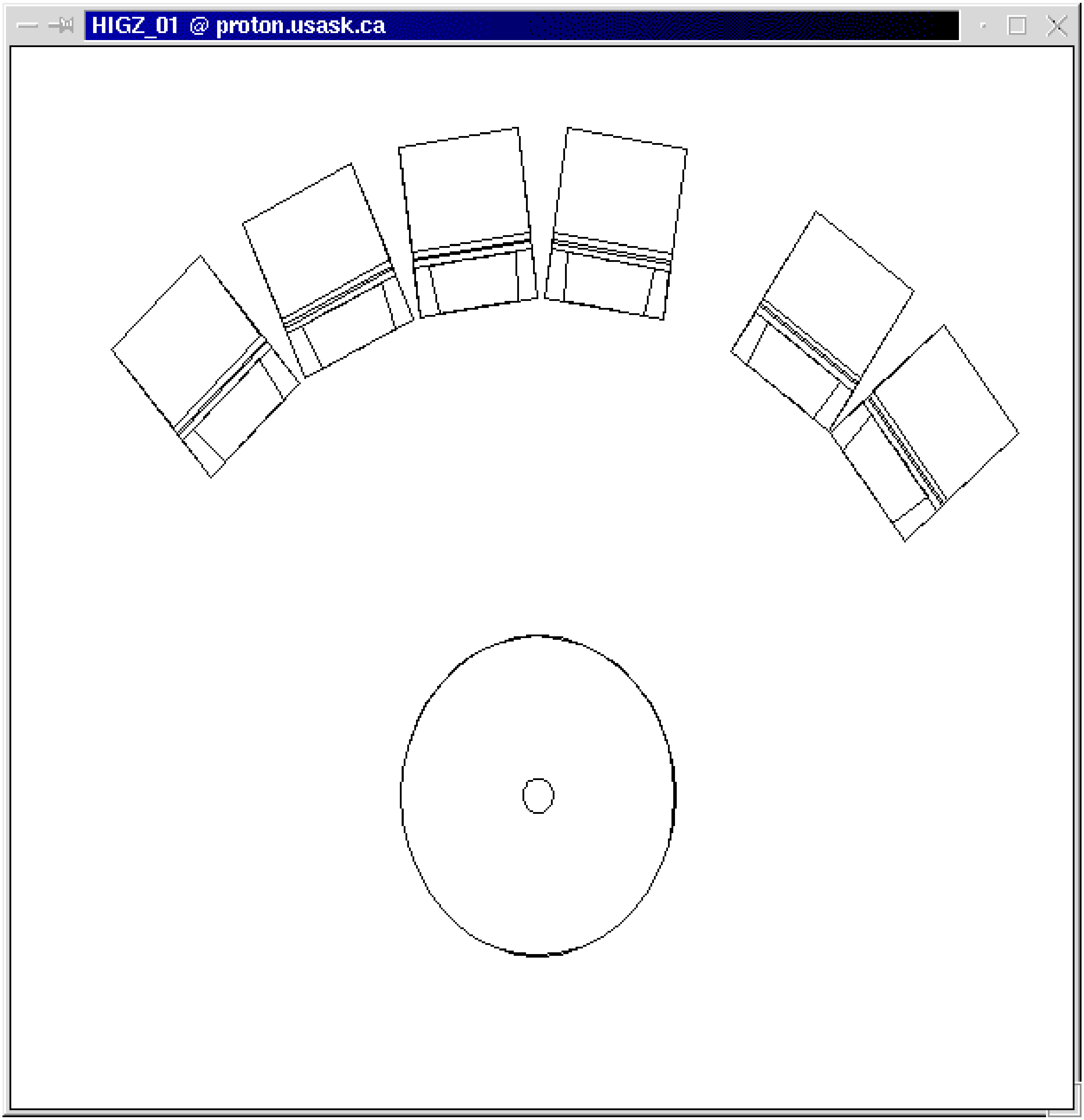

Figure B.2

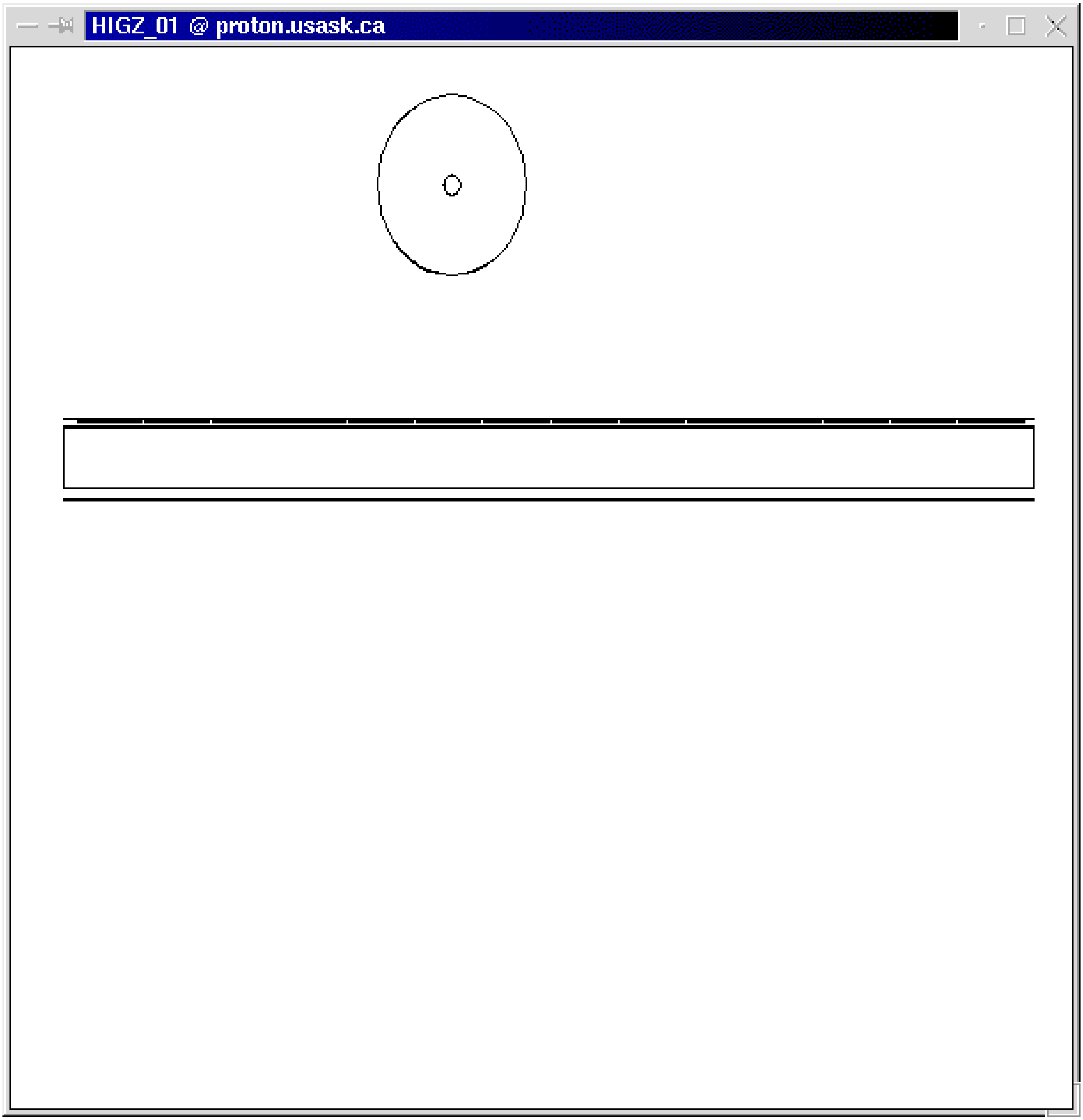

Figure B.3

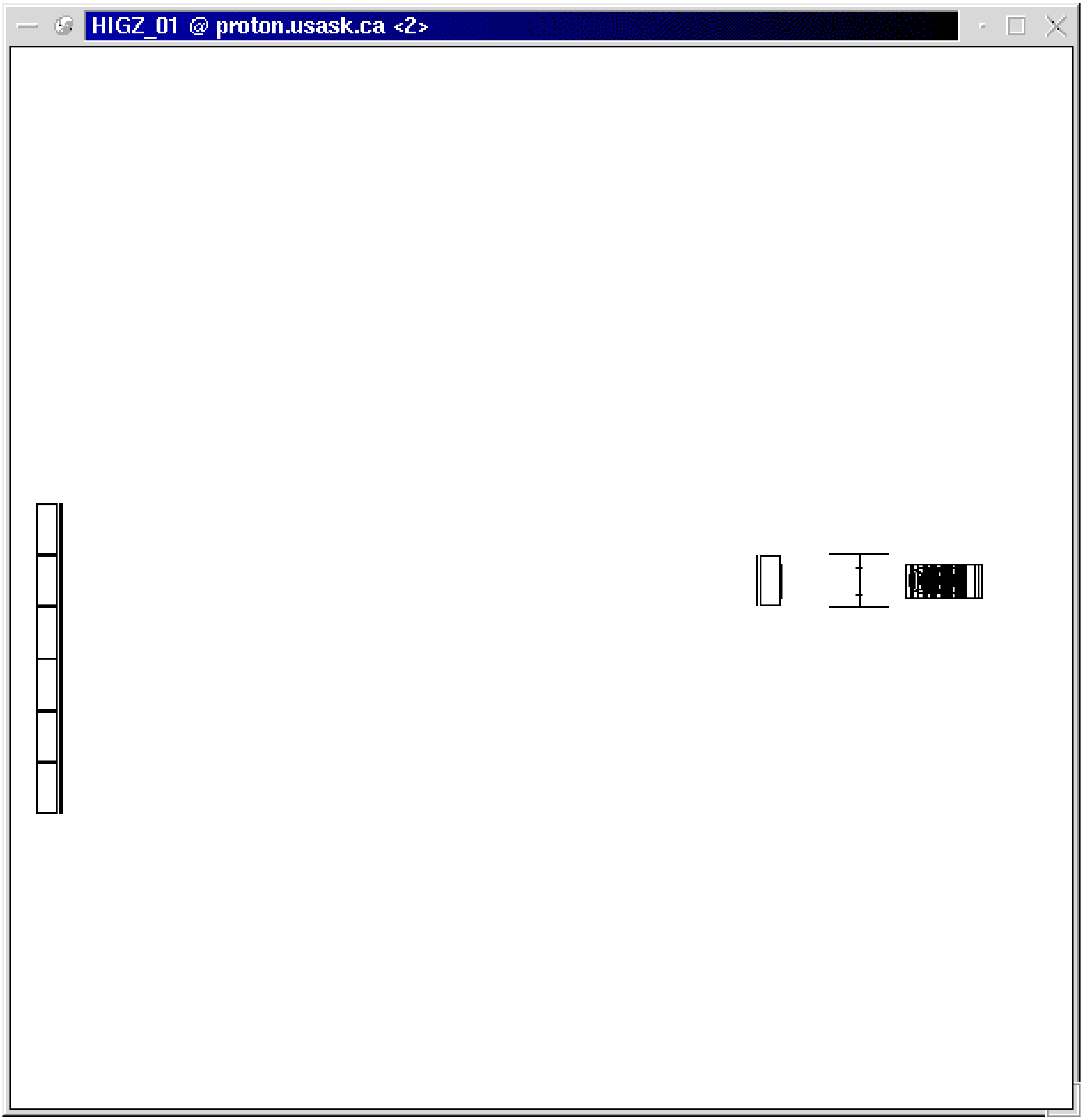

Figure B.4

```
  PROTON COUNTS  (20 MeV)
 TELE 1 DE :              22149.0
 TELE 1 E  :               9491.0
 TELE 1 CUT:                 6946
 TELE 1 EFFICIENCY       .0006946
 TELE 1 EFFICIENCY ERROR .0000083
 TELE 2 DE :              21987.0
 TELE 2 E  :               9432.0
 TELE 2 CUT:                 7457
 TELE 2 EFFICIENCY       .0007457
 TELE 2 EFFICIENCY ERROR .0000086
 TELE 3 DE :              22110.0
 TELE 3 E  :               9612.0
 TELE 3 CUT:                 7896
 TELE 3 EFFICIENCY       .0007896
 TELE 3 EFFICIENCY ERROR .0000089
 TELE 4 DE :              22248.0
 TELE 4 E  :               9595.0
 TELE 4 CUT:                 7809
 TELE 4 EFFICIENCY       .0007809
 TELE 4 EFFICIENCY ERROR .0000088
 TELE 5 DE :              21928.0
 TELE 5 E  :               9359.0
 TELE 5 CUT:                 7540
 TELE 5 EFFICIENCY       .0007540
 TELE 5 EFFICIENCY ERROR .0000087
 TELE 6 DE :              22038.0
 TELE 6 E  :               9337.0
 TELE 6 CUT:                 7208
 TELE 6 EFFICIENCY       .0007208
 TELE 6 EFFICIENCY ERROR .0000085
 TELE EFF SUM 0.0044856 +/- 0.0000519
 PADDLE  1    :                3277.0
 PADDLE  1 CUT:                     0
 PADDLE  1 EFFICIENCY       .0000000
 PADDLE  1 EFFICIENCY ERROR .0000000
 PADDLE  2    :                5047.0
 PADDLE  2 CUT:                     0
 PADDLE  2 EFFICIENCY       .0000000
 PADDLE  2 EFFICIENCY ERROR .0000000
 PADDLE  3    :                7448.0
 PADDLE  3 CUT:                     0
 PADDLE  3 EFFICIENCY       .0000000
 PADDLE  3 EFFICIENCY ERROR .0000000
 PADDLE  4    :               11465.0
 PADDLE  4 CUT:                     0
 PADDLE  4 EFFICIENCY       .0000000
 PADDLE  4 EFFICIENCY ERROR .0000000
 PADDLE  5    :               18441.0
 PADDLE  5 CUT:                     0
 PADDLE  5 EFFICIENCY       .0000000
 PADDLE  5 EFFICIENCY ERROR .0000000
 PADDLE  6    :               30324.0
 PADDLE  6 CUT:                     3
 PADDLE  6 EFFICIENCY       .0000003
 PADDLE  6 EFFICIENCY ERROR .0000002
 PADDLE  7    :               50251.0
 PADDLE  7 CUT:                    14
 PADDLE  7 EFFICIENCY       .0000014
 PADDLE  7 EFFICIENCY ERROR .0000004
 PADDLE  8    :               74530.0
 PADDLE  8 CUT:                  7751
 PADDLE  8 EFFICIENCY       .0007751
 PADDLE  8 EFFICIENCY ERROR .0000088
 PADDLE  9    :               85956.0
```

```
PADDLE  9 CUT:                15364
PADDLE  9 EFFICIENCY       .0015364
PADDLE  9 EFFICIENCY ERROR .0000124
PADDLE 10    :              71926.0
PADDLE 10 CUT:                 6620
PADDLE 10 EFFICIENCY       .0006620
PADDLE 10 EFFICIENCY ERROR .0000081
PADDLE 11    :              48105.0
PADDLE 11 CUT:                   13
PADDLE 11 EFFICIENCY       .0000013
PADDLE 11 EFFICIENCY ERROR .0000004
PADDLE 12    :              28664.0
PADDLE 12 CUT:                    1
PADDLE 12 EFFICIENCY       .0000001
PADDLE 12 EFFICIENCY ERROR .0000001
PADDLE 13    :              17420.0
PADDLE 13 CUT:                    0
PADDLE 13 EFFICIENCY       .0000000
PADDLE 13 EFFICIENCY ERROR .0000000
PADDLE 14    :              10979.0
PADDLE 14 CUT:                    0
PADDLE 14 EFFICIENCY       .0000000
PADDLE 14 EFFICIENCY ERROR .0000000
PAD EFF SUM 0.0029766 +/- 0.0029766
BAR     :                   50861.0
BAR CUT :                     29766
```

```
  PROTON COUNTS  (30 MeV)
 TELE 1 DE :              22012.0
 TELE 1 E  :              21841.0
 TELE 1 CUT:                21704
 TELE 1 EFFICIENCY       .0021704
 TELE 1 EFFICIENCY ERROR .0000147
 TELE 2 DE :              22361.0
 TELE 2 E  :              22200.0
 TELE 2 CUT:                22033
 TELE 2 EFFICIENCY       .0022033
 TELE 2 EFFICIENCY ERROR .0000148
 TELE 3 DE :              22443.0
 TELE 3 E  :              22258.0
 TELE 3 CUT:                22110
 TELE 3 EFFICIENCY       .0022110
 TELE 3 EFFICIENCY ERROR .0000149
 TELE 4 DE :              22314.0
 TELE 4 E  :              22149.0
 TELE 4 CUT:                21977
 TELE 4 EFFICIENCY       .0021977
 TELE 4 EFFICIENCY ERROR .0000148
 TELE 5 DE :              22059.0
 TELE 5 E  :              21886.0
 TELE 5 CUT:                21713
 TELE 5 EFFICIENCY       .0021713
 TELE 5 EFFICIENCY ERROR .0000147
 TELE 6 DE :              22397.0
 TELE 6 E  :              22240.0
 TELE 6 CUT:                22063
 TELE 6 EFFICIENCY       .0022063
 TELE 6 EFFICIENCY ERROR .0000149
 TELE EFF SUM 0.0131600 +/- 0.0000889
 PADDLE  1    :                3561.0
 PADDLE  1 CUT:                     0
 PADDLE  1 EFFICIENCY        .0000000
 PADDLE  1 EFFICIENCY ERROR .0000000
 PADDLE  2    :                4966.0
 PADDLE  2 CUT:                    62
 PADDLE  2 EFFICIENCY        .0000062
 PADDLE  2 EFFICIENCY ERROR .0000008
 PADDLE  3    :                7406.0
 PADDLE  3 CUT:                  2480
 PADDLE  3 EFFICIENCY        .0002480
 PADDLE  3 EFFICIENCY ERROR .0000050
 PADDLE  4    :               11375.0
 PADDLE  4 CUT:                  7275
 PADDLE  4 EFFICIENCY        .0007275
 PADDLE  4 EFFICIENCY ERROR .0000085
 PADDLE  5    :               18310.0
 PADDLE  5 CUT:                 12645
 PADDLE  5 EFFICIENCY        .0012645
 PADDLE  5 EFFICIENCY ERROR .0000112
 PADDLE  6    :               30399.0
 PADDLE  6 CUT:                 23957
 PADDLE  6 EFFICIENCY        .0023957
 PADDLE  6 EFFICIENCY ERROR .0000155
 PADDLE  7    :               49988.0
 PADDLE  7 CUT:                 44517
 PADDLE  7 EFFICIENCY        .0044517
 PADDLE  7 EFFICIENCY ERROR .0000211
 PADDLE  8    :               74337.0
 PADDLE  8 CUT:                 71811
 PADDLE  8 EFFICIENCY        .0071811
 PADDLE  8 EFFICIENCY ERROR .0000268
 PADDLE  9    :               86581.0
```

```
PADDLE  9 CUT:                84541
PADDLE  9 EFFICIENCY       .0084541
PADDLE  9 EFFICIENCY ERROR .0000291
PADDLE 10    :              72675.0
PADDLE 10 CUT:                70100
PADDLE 10 EFFICIENCY       .0070100
PADDLE 10 EFFICIENCY ERROR .0000265
PADDLE 11    :              48300.0
PADDLE 11 CUT:                42972
PADDLE 11 EFFICIENCY       .0042972
PADDLE 11 EFFICIENCY ERROR .0000207
PADDLE 12    :              28730.0
PADDLE 12 CUT:                21818
PADDLE 12 EFFICIENCY       .0021818
PADDLE 12 EFFICIENCY ERROR .0000148
PADDLE 13    :              17374.0
PADDLE 13 CUT:                11282
PADDLE 13 EFFICIENCY       .0011282
PADDLE 13 EFFICIENCY ERROR .0000106
PADDLE 14    :              10799.0
PADDLE 14 CUT:                 6594
PADDLE 14 EFFICIENCY       .0006594
PADDLE 14 EFFICIENCY ERROR .0000081
PAD EFF SUM 0.0400054 +/- 0.0400135
BAR     :                  454790.0
BAR CUT :                    400054
```

```
  PROTON COUNTS  (40 MeV)
TELE 1 DE :              22439.0
TELE 1 E  :              22290.0
TELE 1 CUT:                21880
TELE 1 EFFICIENCY       .0021880
TELE 1 EFFICIENCY ERROR .0000148
TELE 2 DE :              22367.0
TELE 2 E  :              22225.0
TELE 2 CUT:                21810
TELE 2 EFFICIENCY       .0021810
TELE 2 EFFICIENCY ERROR .0000148
TELE 3 DE :              22373.0
TELE 3 E  :              22205.0
TELE 3 CUT:                21820
TELE 3 EFFICIENCY       .0021820
TELE 3 EFFICIENCY ERROR .0000148
TELE 4 DE :              22358.0
TELE 4 E  :              22194.0
TELE 4 CUT:                21829
TELE 4 EFFICIENCY       .0021829
TELE 4 EFFICIENCY ERROR .0000148
TELE 5 DE :              22312.0
TELE 5 E  :              22157.0
TELE 5 CUT:                21772
TELE 5 EFFICIENCY       .0021772
TELE 5 EFFICIENCY ERROR .0000148
TELE 6 DE :              22551.0
TELE 6 E  :              22386.0
TELE 6 CUT:                21987
TELE 6 EFFICIENCY       .0021987
TELE 6 EFFICIENCY ERROR .0000148
TELE EFF SUM 0.0131098 +/- 0.0000887
PADDLE  1    :               3560.0
PADDLE  1 CUT:                 1658
PADDLE  1 EFFICIENCY       .0001658
PADDLE  1 EFFICIENCY ERROR .0000041
PADDLE  2    :               5152.0
PADDLE  2 CUT:                 3095
PADDLE  2 EFFICIENCY       .0003095
PADDLE  2 EFFICIENCY ERROR .0000056
PADDLE  3    :               7591.0
PADDLE  3 CUT:                 5165
PADDLE  3 EFFICIENCY       .0005165
PADDLE  3 EFFICIENCY ERROR .0000072
PADDLE  4    :              11614.0
PADDLE  4 CUT:                 8901
PADDLE  4 EFFICIENCY       .0008901
PADDLE  4 EFFICIENCY ERROR .0000094
PADDLE  5    :              18089.0
PADDLE  5 CUT:                14944
PADDLE  5 EFFICIENCY       .0014944
PADDLE  5 EFFICIENCY ERROR .0000122
PADDLE  6    :              30297.0
PADDLE  6 CUT:                26650
PADDLE  6 EFFICIENCY       .0026650
PADDLE  6 EFFICIENCY ERROR .0000163
PADDLE  7    :              50310.0
PADDLE  7 CUT:                47016
PADDLE  7 EFFICIENCY       .0047016
PADDLE  7 EFFICIENCY ERROR .0000217
PADDLE  8    :              74418.0
PADDLE  8 CUT:                71620
PADDLE  8 EFFICIENCY       .0071620
PADDLE  8 EFFICIENCY ERROR .0000268
PADDLE  9    :              86359.0
```

```
PADDLE  9 CUT:                83683
PADDLE  9 EFFICIENCY       .0083683
PADDLE  9 EFFICIENCY ERROR .0000289
PADDLE 10    :              72181.0
PADDLE 10 CUT:                69312
PADDLE 10 EFFICIENCY       .0069312
PADDLE 10 EFFICIENCY ERROR .0000263
PADDLE 11    :              48028.0
PADDLE 11 CUT:                43891
PADDLE 11 EFFICIENCY       .0043891
PADDLE 11 EFFICIENCY ERROR .0000210
PADDLE 12    :              28928.0
PADDLE 12 CUT:                24620
PADDLE 12 EFFICIENCY       .0024620
PADDLE 12 EFFICIENCY ERROR .0000157
PADDLE 13    :              17432.0
PADDLE 13 CUT:                13743
PADDLE 13 EFFICIENCY       .0013743
PADDLE 13 EFFICIENCY ERROR .0000117
PADDLE 14    :              11015.0
PADDLE 14 CUT:                 8084
PADDLE 14 EFFICIENCY       .0008084
PADDLE 14 EFFICIENCY ERROR .0000090
PAD EFF SUM 0.0422382 +/- 0.0422472
BAR     :                  466727.0
BAR CUT :                    422382
```

```
  PROTON COUNTS  (50 MeV)
TELE 1 DE :               22531.0
TELE 1 E  :               22385.0
TELE 1 CUT:                 21798
TELE 1 EFFICIENCY       .0021798
TELE 1 EFFICIENCY ERROR .0000148
TELE 2 DE :               22552.0
TELE 2 E  :               22390.0
TELE 2 CUT:                 21814
TELE 2 EFFICIENCY       .0021814
TELE 2 EFFICIENCY ERROR .0000148
TELE 3 DE :               22648.0
TELE 3 E  :               22510.0
TELE 3 CUT:                 21919
TELE 3 EFFICIENCY       .0021919
TELE 3 EFFICIENCY ERROR .0000148
TELE 4 DE :               22742.0
TELE 4 E  :               22586.0
TELE 4 CUT:                 21999
TELE 4 EFFICIENCY       .0021999
TELE 4 EFFICIENCY ERROR .0000148
TELE 5 DE :               22689.0
TELE 5 E  :               22551.0
TELE 5 CUT:                 21953
TELE 5 EFFICIENCY       .0021953
TELE 5 EFFICIENCY ERROR .0000148
TELE 6 DE :               22593.0
TELE 6 E  :               22436.0
TELE 6 CUT:                 21850
TELE 6 EFFICIENCY       .0021850
TELE 6 EFFICIENCY ERROR .0000148
TELE EFF SUM 0.0131333 +/- 0.0000888
PADDLE  1    :                3616.0
PADDLE  1 CUT:                  2168
PADDLE  1 EFFICIENCY       .0002168
PADDLE  1 EFFICIENCY ERROR .0000047
PADDLE  2    :                5222.0
PADDLE  2 CUT:                  3647
PADDLE  2 EFFICIENCY       .0003647
PADDLE  2 EFFICIENCY ERROR .0000060
PADDLE  3    :                7597.0
PADDLE  3 CUT:                  5919
PADDLE  3 EFFICIENCY       .0005919
PADDLE  3 EFFICIENCY ERROR .0000077
PADDLE  4    :               11583.0
PADDLE  4 CUT:                  9413
PADDLE  4 EFFICIENCY       .0009413
PADDLE  4 EFFICIENCY ERROR .0000097
PADDLE  5    :               18398.0
PADDLE  5 CUT:                 15841
PADDLE  5 EFFICIENCY       .0015841
PADDLE  5 EFFICIENCY ERROR .0000126
PADDLE  6    :               30563.0
PADDLE  6 CUT:                 27552
PADDLE  6 EFFICIENCY       .0027552
PADDLE  6 EFFICIENCY ERROR .0000166
PADDLE  7    :               50176.0
PADDLE  7 CUT:                 46823
PADDLE  7 EFFICIENCY       .0046823
PADDLE  7 EFFICIENCY ERROR .0000216
PADDLE  8    :               75179.0
PADDLE  8 CUT:                 71771
PADDLE  8 EFFICIENCY       .0071771
PADDLE  8 EFFICIENCY ERROR .0000268
PADDLE  9    :               86921.0
```

```
PADDLE  9 CUT:                 83492
PADDLE  9 EFFICIENCY        .0083492
PADDLE  9 EFFICIENCY ERROR .0000289
PADDLE 10    :               72473.0
PADDLE 10 CUT:                 69130
PADDLE 10 EFFICIENCY        .0069130
PADDLE 10 EFFICIENCY ERROR .0000263
PADDLE 11    :               48174.0
PADDLE 11 CUT:                 44332
PADDLE 11 EFFICIENCY        .0044332
PADDLE 11 EFFICIENCY ERROR .0000211
PADDLE 12    :               28877.0
PADDLE 12 CUT:                 25464
PADDLE 12 EFFICIENCY        .0025464
PADDLE 12 EFFICIENCY ERROR .0000160
PADDLE 13    :               17545.0
PADDLE 13 CUT:                 14683
PADDLE 13 EFFICIENCY        .0014683
PADDLE 13 EFFICIENCY ERROR .0000121
PADDLE 14    :               10862.0
PADDLE 14 CUT:                  8577
PADDLE 14 EFFICIENCY        .0008577
PADDLE 14 EFFICIENCY ERROR .0000093
PAD EFF SUM 0.0428812 +/- 0.0428905
BAR     :                   469437.0
BAR CUT :                     428812
```

```
  PROTON COUNTS  (60 MeV)
TELE 1 DE :              22815.0
TELE 1 E  :              22680.0
TELE 1 CUT:                21921
TELE 1 EFFICIENCY       .0021921
TELE 1 EFFICIENCY ERROR .0000148
TELE 2 DE :              22902.0
TELE 2 E  :              22767.0
TELE 2 CUT:                21983
TELE 2 EFFICIENCY       .0021983
TELE 2 EFFICIENCY ERROR .0000148
TELE 3 DE :              22518.0
TELE 3 E  :              22393.0
TELE 3 CUT:                21597
TELE 3 EFFICIENCY       .0021597
TELE 3 EFFICIENCY ERROR .0000147
TELE 4 DE :              22362.0
TELE 4 E  :              22238.0
TELE 4 CUT:                21438
TELE 4 EFFICIENCY       .0021438
TELE 4 EFFICIENCY ERROR .0000146
TELE 5 DE :              22383.0
TELE 5 E  :              22275.0
TELE 5 CUT:                21514
TELE 5 EFFICIENCY       .0021514
TELE 5 EFFICIENCY ERROR .0000147
TELE 6 DE :              22371.0
TELE 6 E  :              22215.0
TELE 6 CUT:                21452
TELE 6 EFFICIENCY       .0021452
TELE 6 EFFICIENCY ERROR .0000146
TELE EFF SUM 0.0129905 +/- 0.0000883
PADDLE  1    :                3622.0
PADDLE  1 CUT:                  2119
PADDLE  1 EFFICIENCY       .0002119
PADDLE  1 EFFICIENCY ERROR .0000046
PADDLE  2    :                5061.0
PADDLE  2 CUT:                  3848
PADDLE  2 EFFICIENCY       .0003848
PADDLE  2 EFFICIENCY ERROR .0000062
PADDLE  3    :                7509.0
PADDLE  3 CUT:                  6019
PADDLE  3 EFFICIENCY       .0006019
PADDLE  3 EFFICIENCY ERROR .0000078
PADDLE  4    :               11496.0
PADDLE  4 CUT:                  9621
PADDLE  4 EFFICIENCY       .0009621
PADDLE  4 EFFICIENCY ERROR .0000098
PADDLE  5    :               18165.0
PADDLE  5 CUT:                 15681
PADDLE  5 EFFICIENCY       .0015681
PADDLE  5 EFFICIENCY ERROR .0000125
PADDLE  6    :               30537.0
PADDLE  6 CUT:                 27539
PADDLE  6 EFFICIENCY       .0027539
PADDLE  6 EFFICIENCY ERROR .0000166
PADDLE  7    :               50369.0
PADDLE  7 CUT:                 46807
PADDLE  7 EFFICIENCY       .0046807
PADDLE  7 EFFICIENCY ERROR .0000216
PADDLE  8    :               74880.0
PADDLE  8 CUT:                 71020
PADDLE  8 EFFICIENCY       .0071020
PADDLE  8 EFFICIENCY ERROR .0000266
PADDLE  9    :               86352.0
```

```
PADDLE  9 CUT:                  82233
PADDLE  9 EFFICIENCY       .0082233
PADDLE  9 EFFICIENCY ERROR .0000287
PADDLE 10    :              72929.0
PADDLE 10 CUT:                68957
PADDLE 10 EFFICIENCY       .0068957
PADDLE 10 EFFICIENCY ERROR .0000263
PADDLE 11    :              48312.0
PADDLE 11 CUT:                44318
PADDLE 11 EFFICIENCY       .0044318
PADDLE 11 EFFICIENCY ERROR .0000211
PADDLE 12    :              28961.0
PADDLE 12 CUT:                25641
PADDLE 12 EFFICIENCY       .0025641
PADDLE 12 EFFICIENCY ERROR .0000160
PADDLE 13    :              17564.0
PADDLE 13 CUT:                14782
PADDLE 13 EFFICIENCY       .0014782
PADDLE 13 EFFICIENCY ERROR .0000122
PADDLE 14    :              11063.0
PADDLE 14 CUT:                 8465
PADDLE 14 EFFICIENCY       .0008465
PADDLE 14 EFFICIENCY ERROR .0000092
PAD EFF SUM 0.0427050 +/- 0.0427142
BAR     :                  469660.0
BAR CUT :                    427050
```

```
  PROTON COUNTS  (70 MeV)
TELE 1 DE :               22902.0
TELE 1 E  :               22749.0
TELE 1 CUT:                 21752
TELE 1 EFFICIENCY       .0021752
TELE 1 EFFICIENCY ERROR .0000147
TELE 2 DE :               22710.0
TELE 2 E  :               22552.0
TELE 2 CUT:                 21536
TELE 2 EFFICIENCY       .0021536
TELE 2 EFFICIENCY ERROR .0000147
TELE 3 DE :               22553.0
TELE 3 E  :               22405.0
TELE 3 CUT:                 21422
TELE 3 EFFICIENCY       .0021422
TELE 3 EFFICIENCY ERROR .0000146
TELE 4 DE :               22889.0
TELE 4 E  :               22759.0
TELE 4 CUT:                 21737
TELE 4 EFFICIENCY       .0021737
TELE 4 EFFICIENCY ERROR .0000147
TELE 5 DE :               22930.0
TELE 5 E  :               22817.0
TELE 5 CUT:                 21747
TELE 5 EFFICIENCY       .0021747
TELE 5 EFFICIENCY ERROR .0000147
TELE 6 DE :               22617.0
TELE 6 E  :               22482.0
TELE 6 CUT:                 21517
TELE 6 EFFICIENCY       .0021517
TELE 6 EFFICIENCY ERROR .0000147
TELE EFF SUM 0.0129711 +/- 0.0000882
PADDLE  1    :                3613.0
PADDLE  1 CUT:                  1941
PADDLE  1 EFFICIENCY       .0001941
PADDLE  1 EFFICIENCY ERROR .0000044
PADDLE  2    :                5028.0
PADDLE  2 CUT:                  3935
PADDLE  2 EFFICIENCY       .0003935
PADDLE  2 EFFICIENCY ERROR .0000063
PADDLE  3    :                7628.0
PADDLE  3 CUT:                  6177
PADDLE  3 EFFICIENCY       .0006177
PADDLE  3 EFFICIENCY ERROR .0000079
PADDLE  4    :               11697.0
PADDLE  4 CUT:                  9888
PADDLE  4 EFFICIENCY       .0009888
PADDLE  4 EFFICIENCY ERROR .0000099
PADDLE  5    :               18404.0
PADDLE  5 CUT:                 15963
PADDLE  5 EFFICIENCY       .0015963
PADDLE  5 EFFICIENCY ERROR .0000126
PADDLE  6    :               30511.0
PADDLE  6 CUT:                 27355
PADDLE  6 EFFICIENCY       .0027355
PADDLE  6 EFFICIENCY ERROR .0000165
PADDLE  7    :               50474.0
PADDLE  7 CUT:                 46609
PADDLE  7 EFFICIENCY       .0046609
PADDLE  7 EFFICIENCY ERROR .0000216
PADDLE  8    :               74970.0
PADDLE  8 CUT:                 70614
PADDLE  8 EFFICIENCY       .0070614
PADDLE  8 EFFICIENCY ERROR .0000266
PADDLE  9    :               86309.0
```

```
PADDLE  9 CUT:                 81774
PADDLE  9 EFFICIENCY       .0081774
PADDLE  9 EFFICIENCY ERROR .0000286
PADDLE 10    :              72611.0
PADDLE 10 CUT:                 68308
PADDLE 10 EFFICIENCY       .0068308
PADDLE 10 EFFICIENCY ERROR .0000261
PADDLE 11    :              48089.0
PADDLE 11 CUT:                 43964
PADDLE 11 EFFICIENCY       .0043964
PADDLE 11 EFFICIENCY ERROR .0000210
PADDLE 12    :              29047.0
PADDLE 12 CUT:                 25699
PADDLE 12 EFFICIENCY       .0025699
PADDLE 12 EFFICIENCY ERROR .0000160
PADDLE 13    :              17492.0
PADDLE 13 CUT:                 14797
PADDLE 13 EFFICIENCY       .0014797
PADDLE 13 EFFICIENCY ERROR .0000122
PADDLE 14    :              10902.0
PADDLE 14 CUT:                  7761
PADDLE 14 EFFICIENCY       .0007761
PADDLE 14 EFFICIENCY ERROR .0000088
PAD EFF SUM 0.0424785 +/- 0.0424873
BAR     :                  470018.0
BAR CUT :                    424785
```

```
  PROTON COUNTS  (80 MeV)
 TELE 1 DE :               22688.0
 TELE 1 E  :               22549.0
 TELE 1 CUT:                 21300
 TELE 1 EFFICIENCY        .0021300
 TELE 1 EFFICIENCY ERROR .0000146
 TELE 2 DE :               22876.0
 TELE 2 E  :               22757.0
 TELE 2 CUT:                 21507
 TELE 2 EFFICIENCY        .0021507
 TELE 2 EFFICIENCY ERROR .0000147
 TELE 3 DE :               22915.0
 TELE 3 E  :               22780.0
 TELE 3 CUT:                 21562
 TELE 3 EFFICIENCY        .0021562
 TELE 3 EFFICIENCY ERROR .0000147
 TELE 4 DE :               22700.0
 TELE 4 E  :               22598.0
 TELE 4 CUT:                 21409
 TELE 4 EFFICIENCY        .0021409
 TELE 4 EFFICIENCY ERROR .0000146
 TELE 5 DE :               22789.0
 TELE 5 E  :               22682.0
 TELE 5 CUT:                 21416
 TELE 5 EFFICIENCY        .0021416
 TELE 5 EFFICIENCY ERROR .0000146
 TELE 6 DE :               22945.0
 TELE 6 E  :               22804.0
 TELE 6 CUT:                 21596
 TELE 6 EFFICIENCY        .0021596
 TELE 6 EFFICIENCY ERROR .0000147
 TELE EFF SUM 0.0128790 +/- 0.0000879
 PADDLE  1    :               3677.0
 PADDLE  1 CUT:                 1764
 PADDLE  1 EFFICIENCY       .0001764
 PADDLE  1 EFFICIENCY ERROR .0000042
 PADDLE  2    :               5121.0
 PADDLE  2 CUT:                 4078
 PADDLE  2 EFFICIENCY       .0004078
 PADDLE  2 EFFICIENCY ERROR .0000064
 PADDLE  3    :               7530.0
 PADDLE  3 CUT:                 6143
 PADDLE  3 EFFICIENCY       .0006143
 PADDLE  3 EFFICIENCY ERROR .0000078
 PADDLE  4    :              11425.0
 PADDLE  4 CUT:                 9701
 PADDLE  4 EFFICIENCY       .0009701
 PADDLE  4 EFFICIENCY ERROR .0000098
 PADDLE  5    :              18225.0
 PADDLE  5 CUT:                15964
 PADDLE  5 EFFICIENCY       .0015964
 PADDLE  5 EFFICIENCY ERROR .0000126
 PADDLE  6    :              30445.0
 PADDLE  6 CUT:                27410
 PADDLE  6 EFFICIENCY       .0027410
 PADDLE  6 EFFICIENCY ERROR .0000166
 PADDLE  7    :              50285.0
 PADDLE  7 CUT:                46454
 PADDLE  7 EFFICIENCY       .0046454
 PADDLE  7 EFFICIENCY ERROR .0000216
 PADDLE  8    :              75274.0
 PADDLE  8 CUT:                70601
 PADDLE  8 EFFICIENCY       .0070601
 PADDLE  8 EFFICIENCY ERROR .0000266
 PADDLE  9    :              86483.0
```

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PADDLE  9 CUT:                 81465
PADDLE  9 EFFICIENCY       .0081465
PADDLE  9 EFFICIENCY ERROR .0000285
PADDLE 10    :              73423.0
PADDLE 10 CUT:                 68676
PADDLE 10 EFFICIENCY       .0068676
PADDLE 10 EFFICIENCY ERROR .0000262
PADDLE 11    :              47894.0
PADDLE 11 CUT:                 43985
PADDLE 11 EFFICIENCY       .0043985
PADDLE 11 EFFICIENCY ERROR .0000210
PADDLE 12    :              29180.0
PADDLE 12 CUT:                 26067
PADDLE 12 EFFICIENCY       .0026067
PADDLE 12 EFFICIENCY ERROR .0000161
PADDLE 13    :              17750.0
PADDLE 13 CUT:                 15240
PADDLE 13 EFFICIENCY       .0015240
PADDLE 13 EFFICIENCY ERROR .0000123
PADDLE 14    :              11078.0
PADDLE 14 CUT:                  7287
PADDLE 14 EFFICIENCY       .0007287
PADDLE 14 EFFICIENCY ERROR .0000085
PAD EFF SUM 0.0424835 +/- 0.0424920
BAR     :                  471357.0
BAR CUT :                    424835
```

```
  PROTON COUNTS  (90 MeV)
 TELE 1 DE :              22918.0
 TELE 1 E  :              22754.0
 TELE 1 CUT:                21216
 TELE 1 EFFICIENCY       .0021216
 TELE 1 EFFICIENCY ERROR .0000146
 TELE 2 DE :              23077.0
 TELE 2 E  :              22951.0
 TELE 2 CUT:                21420
 TELE 2 EFFICIENCY       .0021420
 TELE 2 EFFICIENCY ERROR .0000146
 TELE 3 DE :              22928.0
 TELE 3 E  :              22782.0
 TELE 3 CUT:                21282
 TELE 3 EFFICIENCY       .0021282
 TELE 3 EFFICIENCY ERROR .0000146
 TELE 4 DE :              23083.0
 TELE 4 E  :              22965.0
 TELE 4 CUT:                21453
 TELE 4 EFFICIENCY       .0021453
 TELE 4 EFFICIENCY ERROR .0000146
 TELE 5 DE :              23252.0
 TELE 5 E  :              23122.0
 TELE 5 CUT:                21581
 TELE 5 EFFICIENCY       .0021581
 TELE 5 EFFICIENCY ERROR .0000147
 TELE 6 DE :              23052.0
 TELE 6 E  :              22905.0
 TELE 6 CUT:                21446
 TELE 6 EFFICIENCY       .0021446
 TELE 6 EFFICIENCY ERROR .0000146
 TELE EFF SUM 0.0128398 +/- 0.0000878
 PADDLE  1    :                3600.0
 PADDLE  1 CUT:                  1428
 PADDLE  1 EFFICIENCY       .0001428
 PADDLE  1 EFFICIENCY ERROR .0000038
 PADDLE  2    :                5011.0
 PADDLE  2 CUT:                  3926
 PADDLE  2 EFFICIENCY       .0003926
 PADDLE  2 EFFICIENCY ERROR .0000063
 PADDLE  3    :                7613.0
 PADDLE  3 CUT:                  6226
 PADDLE  3 EFFICIENCY       .0006226
 PADDLE  3 EFFICIENCY ERROR .0000079
 PADDLE  4    :               11620.0
 PADDLE  4 CUT:                  9805
 PADDLE  4 EFFICIENCY       .0009805
 PADDLE  4 EFFICIENCY ERROR .0000099
 PADDLE  5    :               18405.0
 PADDLE  5 CUT:                 16001
 PADDLE  5 EFFICIENCY       .0016001
 PADDLE  5 EFFICIENCY ERROR .0000126
 PADDLE  6    :               30675.0
 PADDLE  6 CUT:                 27438
 PADDLE  6 EFFICIENCY       .0027438
 PADDLE  6 EFFICIENCY ERROR .0000166
 PADDLE  7    :               50387.0
 PADDLE  7 CUT:                 46195
 PADDLE  7 EFFICIENCY       .0046195
 PADDLE  7 EFFICIENCY ERROR .0000215
 PADDLE  8    :               74964.0
 PADDLE  8 CUT:                 69942
 PADDLE  8 EFFICIENCY       .0069942
 PADDLE  8 EFFICIENCY ERROR .0000264
 PADDLE  9    :               86890.0
```

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PADDLE  9 CUT:                81188
PADDLE  9 EFFICIENCY       .0081188
PADDLE  9 EFFICIENCY ERROR .0000285
PADDLE 10    :              72594.0
PADDLE 10 CUT:                67510
PADDLE 10 EFFICIENCY       .0067510
PADDLE 10 EFFICIENCY ERROR .0000260
PADDLE 11    :              48021.0
PADDLE 11 CUT:                43924
PADDLE 11 EFFICIENCY       .0043924
PADDLE 11 EFFICIENCY ERROR .0000210
PADDLE 12    :              28789.0
PADDLE 12 CUT:                25648
PADDLE 12 EFFICIENCY       .0025648
PADDLE 12 EFFICIENCY ERROR .0000160
PADDLE 13    :              17645.0
PADDLE 13 CUT:                15244
PADDLE 13 EFFICIENCY       .0015244
PADDLE 13 EFFICIENCY ERROR .0000123
PADDLE 14    :              11032.0
PADDLE 14 CUT:                 6387
PADDLE 14 EFFICIENCY       .0006387
PADDLE 14 EFFICIENCY ERROR .0000080
PAD EFF SUM 0.0420862 +/- 0.0420942
BAR     :                  470987.0
BAR CUT :                    420862
```

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  PROTON COUNTS ( 100 MeV )
TELE 1 DE :              23108.0
TELE 1 E  :              23012.0
TELE 1 CUT:                21173
TELE 1 EFFICIENCY       .0021173
TELE 1 EFFICIENCY ERROR .0000146
TELE 2 DE :              23176.0
TELE 2 E  :              23045.0
TELE 2 CUT:                21275
TELE 2 EFFICIENCY       .0021275
TELE 2 EFFICIENCY ERROR .0000146
TELE 3 DE :              23205.0
TELE 3 E  :              23063.0
TELE 3 CUT:                21300
TELE 3 EFFICIENCY       .0021300
TELE 3 EFFICIENCY ERROR .0000146
TELE 4 DE :              23211.0
TELE 4 E  :              23121.0
TELE 4 CUT:                21330
TELE 4 EFFICIENCY       .0021330
TELE 4 EFFICIENCY ERROR .0000146
TELE 5 DE :              23114.0
TELE 5 E  :              22998.0
TELE 5 CUT:                21191
TELE 5 EFFICIENCY       .0021191
TELE 5 EFFICIENCY ERROR .0000146
TELE 6 DE :              23248.0
TELE 6 E  :              23120.0
TELE 6 CUT:                21274
TELE 6 EFFICIENCY       .0021274
TELE 6 EFFICIENCY ERROR .0000146
TELE EFF SUM 0.0127543 +/- 0.0000875
PADDLE  1    :                3602.0
PADDLE  1 CUT:                  1090
PADDLE  1 EFFICIENCY       .0001090
PADDLE  1 EFFICIENCY ERROR .0000033
PADDLE  2    :                4971.0
PADDLE  2 CUT:                  3923
PADDLE  2 EFFICIENCY       .0003923
PADDLE  2 EFFICIENCY ERROR .0000063
PADDLE  3    :                7472.0
PADDLE  3 CUT:                  6048
PADDLE  3 EFFICIENCY       .0006048
PADDLE  3 EFFICIENCY ERROR .0000078
PADDLE  4    :               11537.0
PADDLE  4 CUT:                  9647
PADDLE  4 EFFICIENCY       .0009647
PADDLE  4 EFFICIENCY ERROR .0000098
PADDLE  5    :               18487.0
PADDLE  5 CUT:                 16046
PADDLE  5 EFFICIENCY       .0016046
PADDLE  5 EFFICIENCY ERROR .0000127
PADDLE  6    :               30636.0
PADDLE  6 CUT:                 27288
PADDLE  6 EFFICIENCY       .0027288
PADDLE  6 EFFICIENCY ERROR .0000165
PADDLE  7    :               50273.0
PADDLE  7 CUT:                 45807
PADDLE  7 EFFICIENCY       .0045807
PADDLE  7 EFFICIENCY ERROR .0000214
PADDLE  8    :               75060.0
PADDLE  8 CUT:                 69458
PADDLE  8 EFFICIENCY       .0069458
PADDLE  8 EFFICIENCY ERROR .0000264
PADDLE  9    :               86685.0
```

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PADDLE  9 CUT:                80348
PADDLE  9 EFFICIENCY       .0080348
PADDLE  9 EFFICIENCY ERROR .0000283
PADDLE 10    :              72905.0
PADDLE 10 CUT:                67317
PADDLE 10 EFFICIENCY       .0067317
PADDLE 10 EFFICIENCY ERROR .0000259
PADDLE 11    :              48071.0
PADDLE 11 CUT:                43698
PADDLE 11 EFFICIENCY       .0043698
PADDLE 11 EFFICIENCY ERROR .0000209
PADDLE 12    :              29305.0
PADDLE 12 CUT:                25955
PADDLE 12 EFFICIENCY       .0025955
PADDLE 12 EFFICIENCY ERROR .0000161
PADDLE 13    :              17697.0
PADDLE 13 CUT:                15224
PADDLE 13 EFFICIENCY       .0015224
PADDLE 13 EFFICIENCY ERROR .0000123
PADDLE 14    :              10883.0
PADDLE 14 CUT:                 5259
PADDLE 14 EFFICIENCY       .0005259
PADDLE 14 EFFICIENCY ERROR .0000073
PAD EFF SUM 0.0417108 +/- 0.0417181
BAR     :                  471639.0
BAR CUT :                    417108
```

NEUTRON COUNTS (10 MeV)

BAR 0 : 14896
EFFICIENCY .0029792 +/- .0000244

BAR 1 : 15527
EFFICIENCY .0031054 +/- .0000249

BAR 2 : 15949
EFFICIENCY .0031898 +/- .0000253

BAR 3 : 15852
EFFICIENCY .0031704 +/- .0000252

BAR 4 : 15661
EFFICIENCY .0031322 +/- .0000250

BAR 5 : 17032
EFFICIENCY .0034064 +/- .0000261

NEUTRON COUNTS (20 MeV)

BAR 0 : 15758
EFFICIENCY .0031516 +/- .0000251

BAR 1 : 16336
EFFICIENCY .0032672 +/- .0000256

BAR 2 : 16299
EFFICIENCY .0032598 +/- .0000255

BAR 3 : 16806
EFFICIENCY .0033612 +/- .0000259

BAR 4 : 16198
EFFICIENCY .0032396 +/- .0000255

BAR 5 : 17774
EFFICIENCY .0035548 +/- .0000267

NEUTRON COUNTS (30 MeV)

BAR 0 : 15916
EFFICIENCY .0031832 +/- .0000252

BAR 1 : 16667
EFFICIENCY .0033334 +/- .0000258

BAR 2 : 16850
EFFICIENCY .0033700 +/- .0000260

BAR 3 : 16484
EFFICIENCY .0032968 +/- .0000257

BAR 4 : 16780
EFFICIENCY .0033560 +/- .0000259

BAR 5 : 17645
EFFICIENCY .0035290 +/- .0000266

NEUTRON COUNTS (40 MeV)

BAR 0 : 18591
EFFICIENCY .0037182 +/- .0000273

BAR 1 : 18447
EFFICIENCY .0036894 +/- .0000272

BAR 2 : 18943
EFFICIENCY .0037886 +/- .0000275

BAR 3 : 18995
EFFICIENCY .0037990 +/- .0000276

BAR 4 : 19195
EFFICIENCY .0038390 +/- .0000277

BAR 5 : 19372
EFFICIENCY .0038744 +/- .0000278

NEUTRON COUNTS (50 MeV)

BAR 0 : 18846
EFFICIENCY .0037692 +/- .0000275

BAR 1 : 19367
EFFICIENCY .0038734 +/- .0000278

BAR 2 : 19269
EFFICIENCY .0038538 +/- .0000278

BAR 3 : 19775
EFFICIENCY .0039550 +/- .0000281

BAR 4 : 19765
EFFICIENCY .0039530 +/- .0000281

BAR 5 : 20103
EFFICIENCY .0040206 +/- .0000284

NEUTRON COUNTS (60 MeV)

BAR 0 : 19357
EFFICIENCY .0038714 +/- .0000278

BAR 1 : 20121
EFFICIENCY .0040242 +/- .0000284

BAR 2 : 19875
EFFICIENCY .0039750 +/- .0000282

BAR 3 : 20839
EFFICIENCY .0041678 +/- .0000289

BAR 4 : 19787
EFFICIENCY .0039574 +/- .0000281

BAR 5 : 20069
EFFICIENCY .0040138 +/- .0000283

NEUTRON COUNTS (70 MeV)

BAR 0 : 20055
EFFICIENCY .0040110 +/- .0000283

BAR 1 : 20471
EFFICIENCY .0040942 +/- .0000286

BAR 2 : 20636
EFFICIENCY .0041272 +/- .0000287

BAR 3 : 20580
EFFICIENCY .0041160 +/- .0000287

BAR 4 : 20904
EFFICIENCY .0041808 +/- .0000289

BAR 5 : 20589
EFFICIENCY .0041178 +/- .0000287

NEUTRON COUNTS (80 MeV)

BAR 0 : 20214
EFFICIENCY .0040428 +/- .0000284

BAR 1 : 20520
EFFICIENCY .0041040 +/- .0000286

BAR 2 : 20857
EFFICIENCY .0041714 +/- .0000289

BAR 3 : 20985
EFFICIENCY .0041970 +/- .0000290

BAR 4 : 20829
EFFICIENCY .0041658 +/- .0000289

BAR 5 : 20964
EFFICIENCY .0041928 +/- .0000290

NEUTRON COUNTS (90 MeV)

BAR 0 : 21012
EFFICIENCY .0042024 +/- .0000290

BAR 1 : 21778
EFFICIENCY .0043556 +/- .0000295

BAR 2 : 21944
EFFICIENCY .0043888 +/- .0000296

BAR 3 : 21930
EFFICIENCY .0043860 +/- .0000296

BAR 4 : 21738
EFFICIENCY .0043476 +/- .0000295

BAR 5 : 21550
EFFICIENCY .0043100 +/- .0000294

NEUTRON COUNTS (100 MeV)

BAR 0 : 21259
EFFICIENCY .0042518 +/- .0000292

BAR 1 : 21631
EFFICIENCY .0043262 +/- .0000294

BAR 2 : 21649
EFFICIENCY .0043298 +/- .0000294

BAR 3 : 21898
EFFICIENCY .0043796 +/- .0000296

BAR 4 : 22119
EFFICIENCY .0044238 +/- .0000297

BAR 5 : 21830
EFFICIENCY .0043660 +/- .0000295

Review of Geant Exercises

Exercise 1 : Manipulation of basic variables

- during the step by step commands it should be mentioned that using the kumac file to reset the picture display will also reset several other things like particle type, kinetic energy, and other controls like bremstralung radiation.
- another couple of lines could be included to have the user try changing the angles and starting point of a particle using the kine command.

Exercise 2 : Energy loss measurement

- it may be useful to mention how to put in, and where to put user global variables and how to pass them trough the different files, gustep.f, guout.f, and gukine.f. (ie. COMMON/USER/VARIABLE_NAME)

Exercise 3 : Absorption Measurement

- a little bit should be said on making histograms particularly on two-D histograms, the function call used, and the additional variables.

- a note could be put in on how to access the internal Geant cross sections from the command line if the Motif interface is not working.

Exercise 4 : Energy deposition, etc

- another line could be included on the hi/fit options including the types of fits that can be done and the variables that need to be passed in, such as the bin numbers or axis values.

Exercise 5 : Change direction of beam

- may want to included a description of the vector array and the seven values that it holds.

Exercise 6 : Reducing the acceptance

- a note how to include a new material iron, lead, etc would be useful, perhaps for earlier exercises as well.

Exercise 7 : Finite beam spot

- perhaps note that sampling in polar coordinates would make the simulation more efficient where as sampling in Cartesian and then passing or failing the random selected numbers through the formula r^2 = sqrt(x^2 + y^2) would lengthen simulation times. But with polar coordinates sample along r^2 and theta the numbers will always be good.

Exercise 8 : Finite beam divergence

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Exercise 9 : Beam monitor feasibility study

- a note should be made that when embedding objects with in each other the volume number of the most emidieate outer volume should be used in the function call not the main mother volume for all objects.
(ie. when making a colliminator the cylindrical hole should have a mother volume number corresponding to the block it is going into not the main mother volume)

Deuteron Disintegration

At Higgs deuteron disintegration was looked at using a D2O target. The detection apparatus was 88 liquid scintillator cells positioned spherically around the target on eight detector arms called "Blow fish". The angular cross section of disintegration was being measured. During the research collaboration at Duke University the following things were done during the course of the experiment.

- Changing the thresholds on the CF8000 to allow the detection of lower energy particles.

- Filling the Germanium detector tank with liquid nitrogen to lower the temperature to the necessary level for proper operation of the detector.

- Monitoring histograms to detect any problems, and noting the beam flux level to determine when the ring needs to be re-injected. This was to determine when to start and stop a data run.

- Measurement of the background radiation levels to subtract off of experimental data.

- Drawing a detailed geometry of the experimental apparatus for calculations and repositioning.

- Fixing light leaks to prevent unwanted signals in the photo tubes.

- Rotating the detector array for different angular measurements.

- Na-22 source detector tests for calibration and systems checks.

- Updating the log book to keep a record of the experiment

- Wrote subroutines to filer through the data files from the runs and pull out the inhibited counts for the detector arms and passed those numbers to statistic analysis routines.