Error Analysis

Monte Carlo Technique

02 October 2013

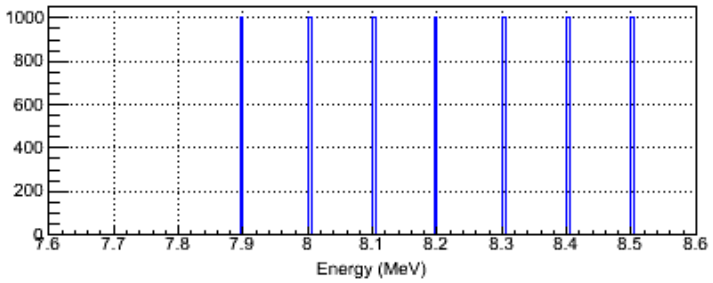
Statistical Errors

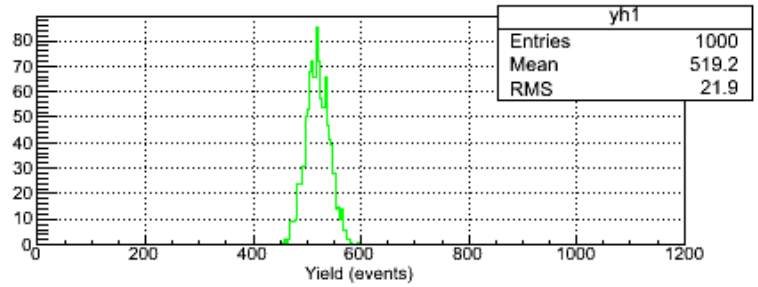
Statistical Error – No Background

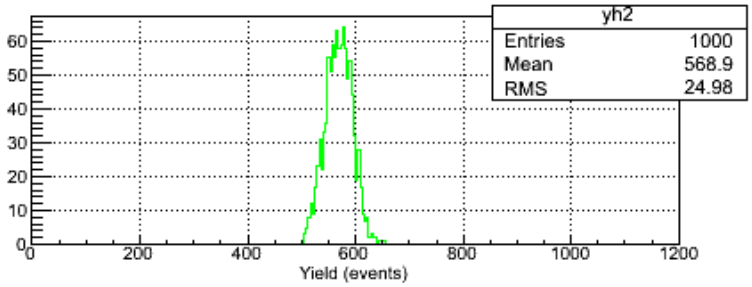
I. Calculate the yield
II. Allow for statistical fluctuations:

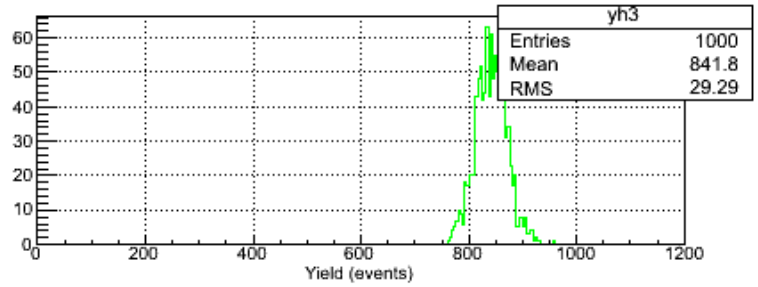
$$y_i = gRandom\text{->}Gaus(y_i, Sqrt(y_i))$$

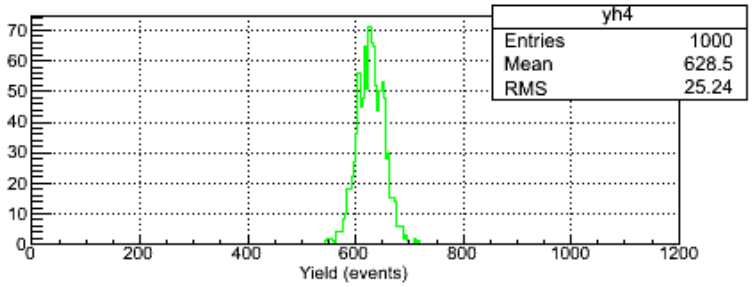
III. Unfold cross section
IV. Repeat for 1000 tries

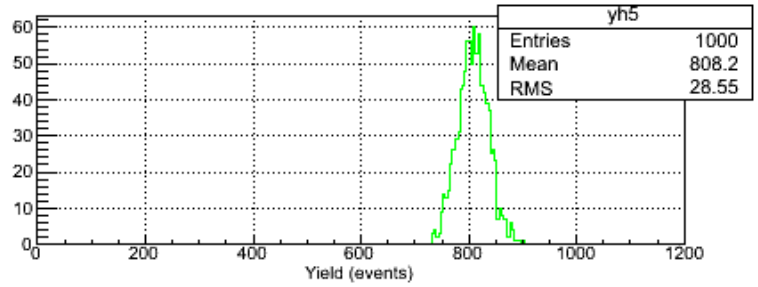

Energy (MeV)

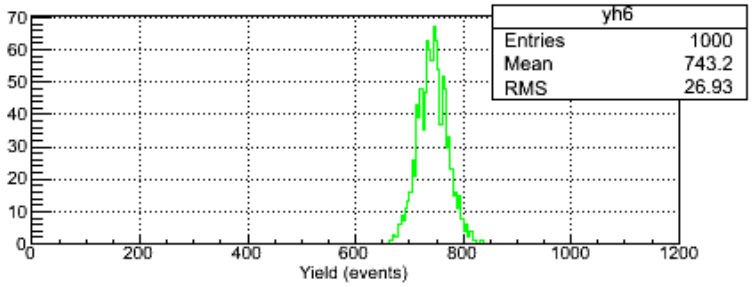

yh1
Entries 1000
Mean 519.2
RMS 21.9
Yield (events)

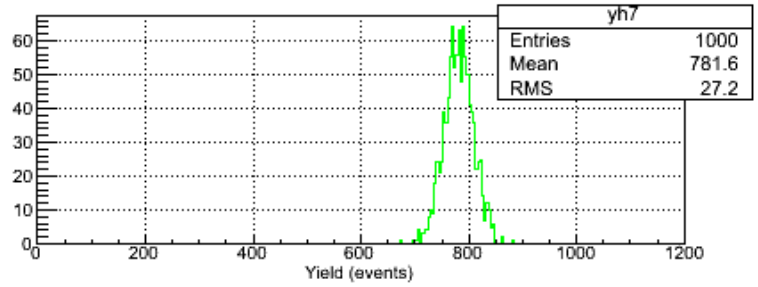

yh2
Entries 1000
Mean 568.9
RMS 24.98
Yield (events)

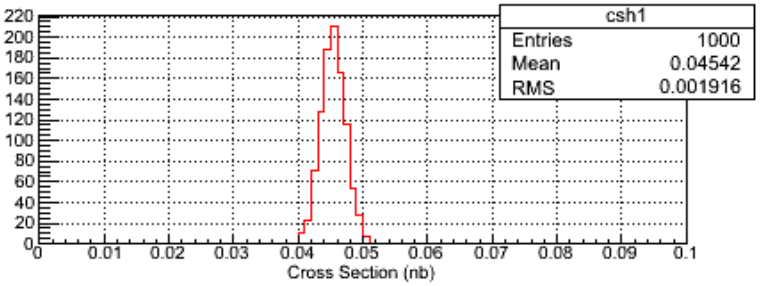

yh3
Entries 1000
Mean 841.8
RMS 29.29
Yield (events)

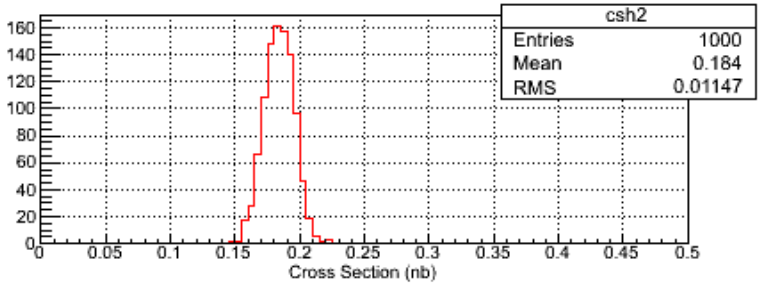

yh4
Entries 1000
Mean 628.5
RMS 25.24
Yield (events)

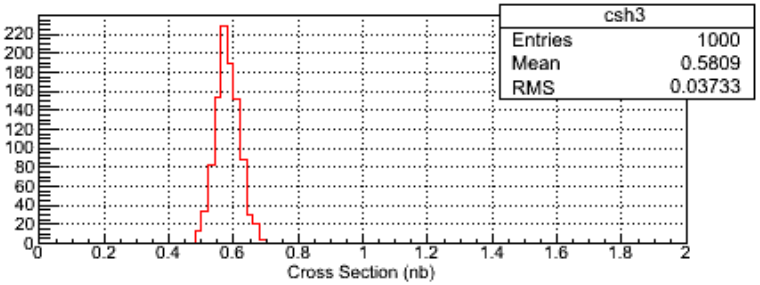

yh5
Entries 1000
Mean 808.2
RMS 28.55
Yield (events)

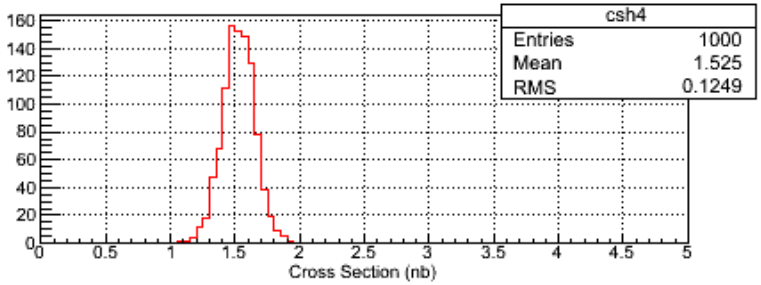

yh6
Entries 1000
Mean 743.2
RMS 26.93
Yield (events)

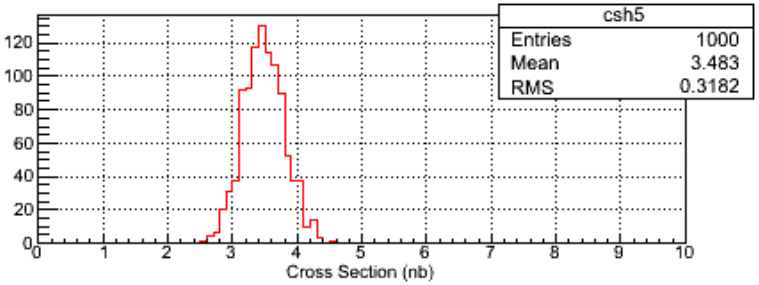

yh7
Entries 1000
Mean 781.6
RMS 27.2
Yield (events)

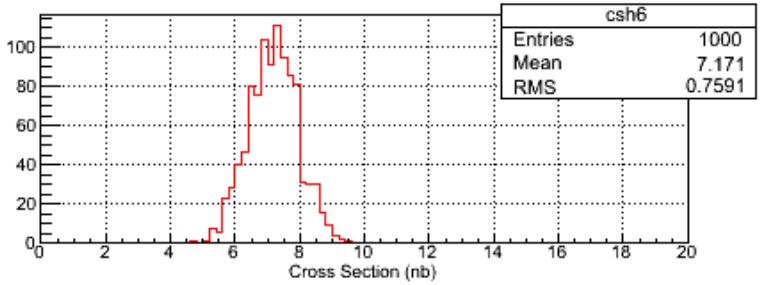

csh1
Entries 1000
Mean 0.04542
RMS 0.001916
Cross Section (nb)

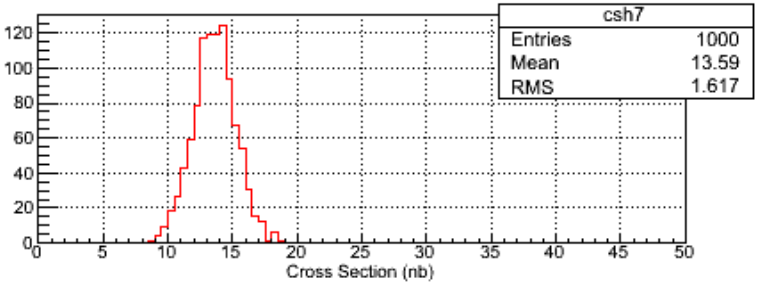

csh2
Entries 1000
Mean 0.184
RMS 0.01147
Cross Section (nb)


csh3
Entries 1000
Mean 0.5809
RMS 0.03733
Cross Section (nb)


csh4
Entries 1000
Mean 1.525
RMS 0.1249
Cross Section (nb)


csh5
Entries 1000
Mean 3.483
RMS 0.3182
Cross Section (nb)


csh6
Entries 1000
Mean 7.171
RMS 0.7591
Cross Section (nb)


csh7
Entries 1000
Mean 13.59
RMS 1.617
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i (no bg)	dy_i/y_i (no bg, %)
7.9	100	100	519	22	4.2
8.0	100	20	569	25	4.4
8.1	80	10	842	29	3.5
8.2	20	10	629	25	4.0
8.3	10	10	808	29	3.5
8.4	4	10	743	27	3.6
8.5	2	10	782	27	3.5

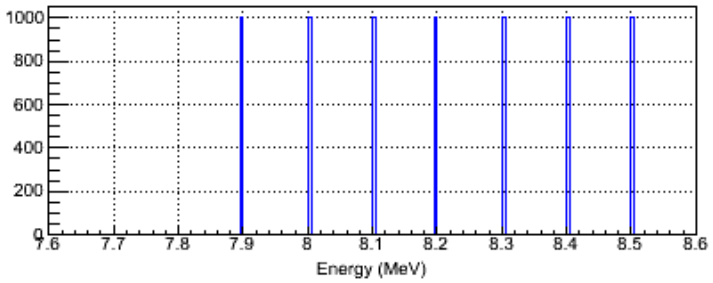
Electron Beam K. E.	Cross Section (nb)	Stat Error (no bg, %)
7.9	0.045	4.2
8.0	0.184	6.2
8.1	0.58	6.4
8.2	1.53	8.2
8.3	3.48	9.1
8.4	7.2	10.6
8.5	13.6	11.9

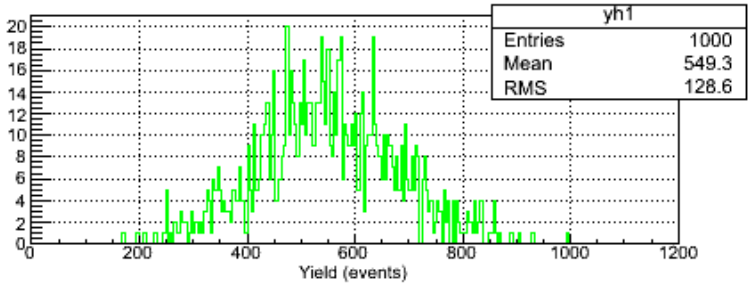
Statistical Error – With Background

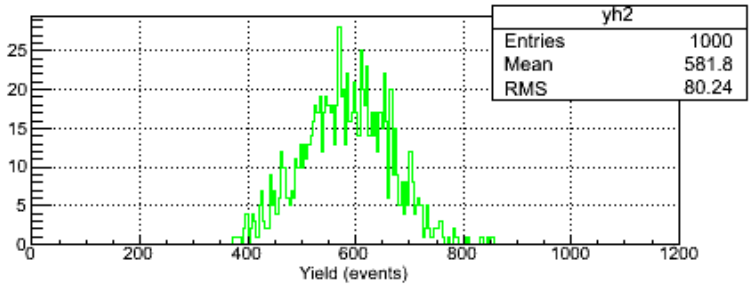
I. Calculate the yield
II. Calculate the background yield from ^{18}O
III. Allow for statistical fluctuations:

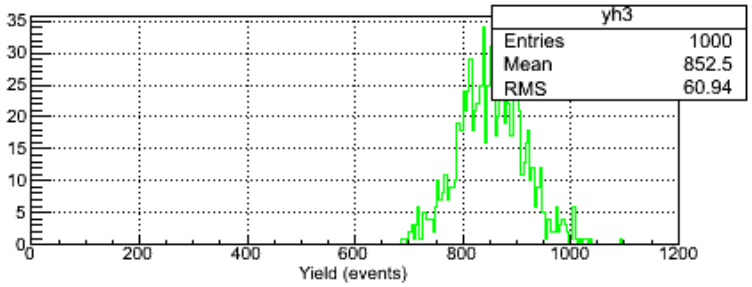
$$y_i = gRandom\text{->}Gaus(\ y_i,\ Sqrt(y_i + 2y_i^{\ bg})\ )$$

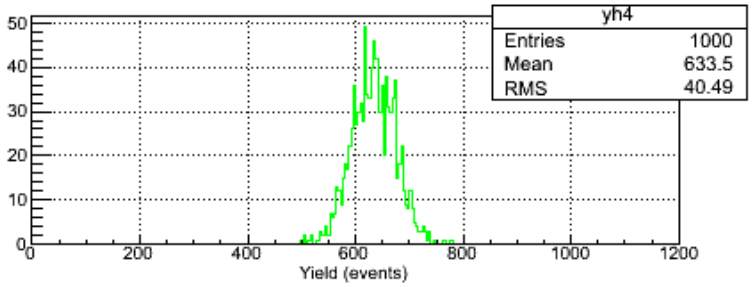
IV. Unfold cross section
V. Repeat for 1000 tries

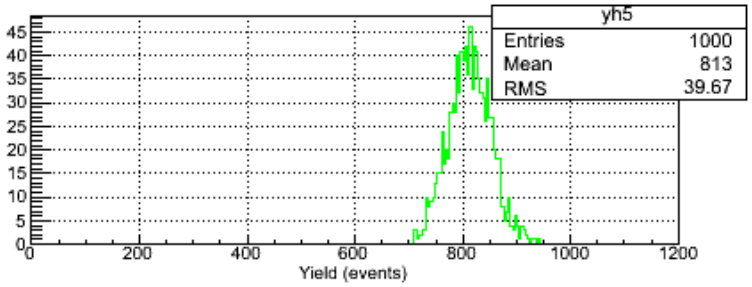

Energy (MeV)

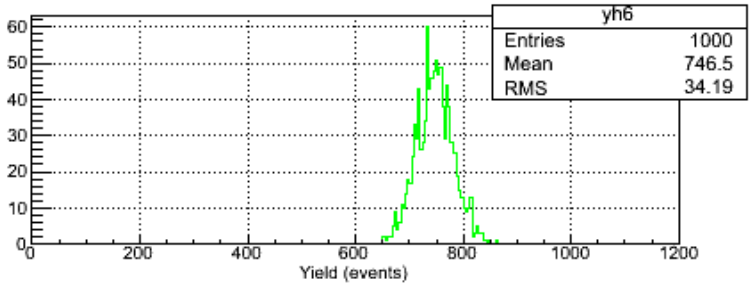

yh1
Entries 1000
Mean 549.3
RMS 128.6
Yield (events)

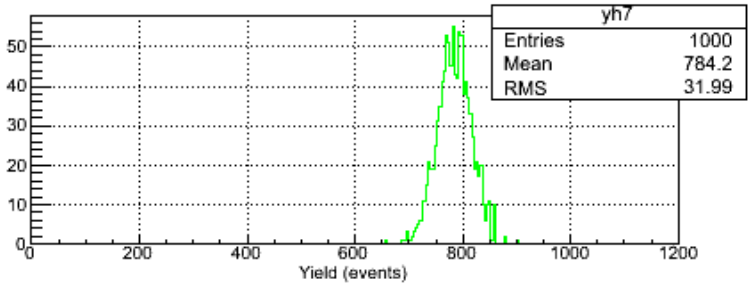

yh2
Entries 1000
Mean 581.8
RMS 80.24
Yield (events)

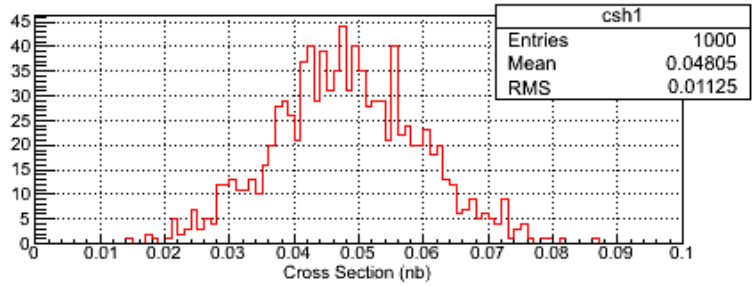

yh3
Entries 1000
Mean 852.5
RMS 60.94
Yield (events)

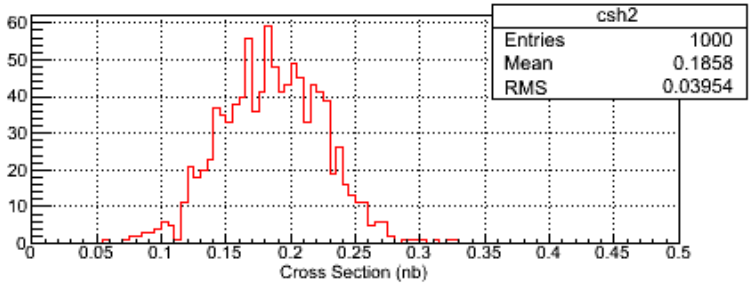

yh4
Entries 1000
Mean 633.5
RMS 40.49
Yield (events)

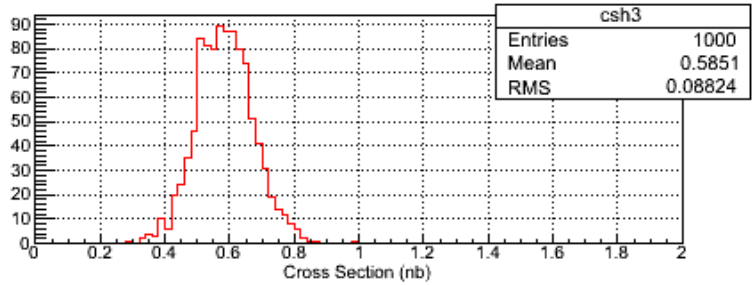

yh5
Entries 1000
Mean 813
RMS 39.67
Yield (events)

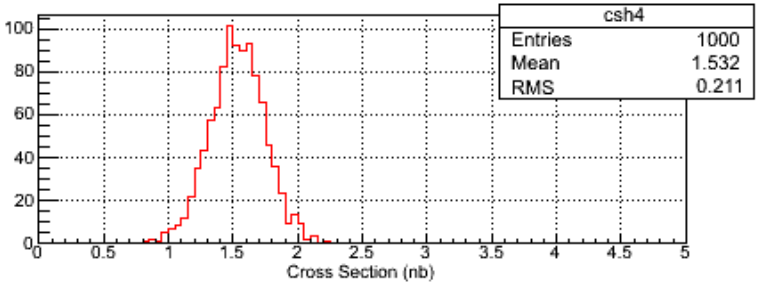

yh6
Entries 1000
Mean 746.5
RMS 34.19
Yield (events)

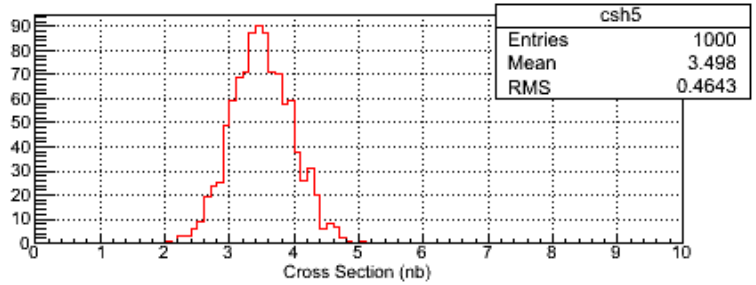

yh7
Entries 1000
Mean 784.2
RMS 31.99
Yield (events)

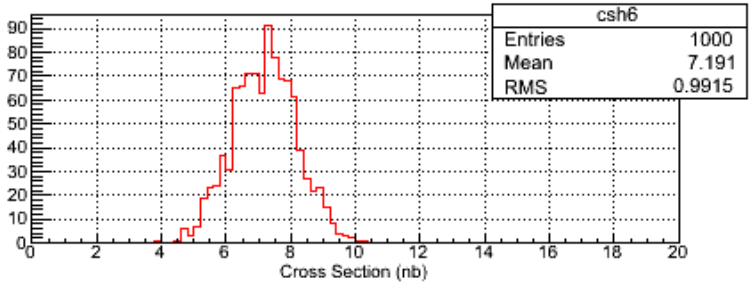

csh1
Entries 1000
Mean 0.04805
RMS 0.01125
Cross Section (nb)

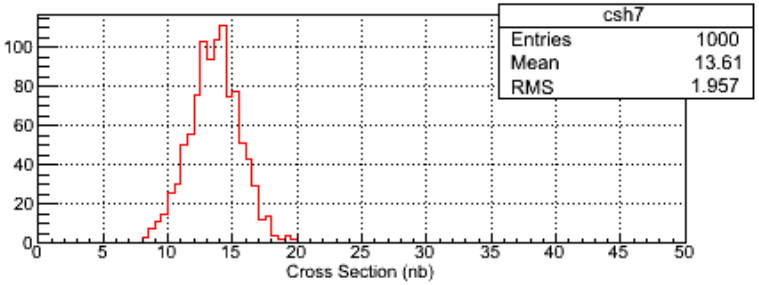

csh2
Entries 1000
Mean 0.1858
RMS 0.03954
Cross Section (nb)


csh3
Entries 1000
Mean 0.5851
RMS 0.08824
Cross Section (nb)


csh4
Entries 1000
Mean 1.532
RMS 0.211
Cross Section (nb)


csh5
Entries 1000
Mean 3.498
RMS 0.4643
Cross Section (nb)


csh6
Entries 1000
Mean 7.191
RMS 0.9915
Cross Section (nb)


csh7
Entries 1000
Mean 13.61
RMS 1.957
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i (with bg)	dy_i/y_i (with bg, %)
7.9	100	100	549	129	23.4
8.0	100	20	582	80	13.8
8.1	80	10	852	61	7.1
8.2	20	10	633	40	6.4
8.3	10	10	813	40	4.9
8.4	4	10	747	34	4.6
8.5	2	10	784	32	4.1

Electron Beam K. E.	Cross Section (nb)	Stat Error (with bg, %)
7.9	0.048	23.4
8.0	0.186	21.3
8.1	0.59	15.1
8.2	1.53	13.8
8.3	3.50	13.3
8.4	7.2	13.8
8.5	13.6	14.4

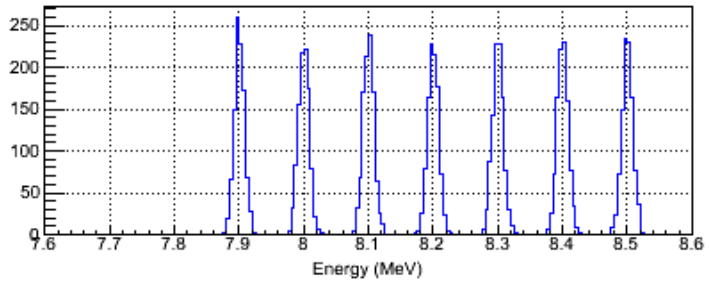
Absolute Systematic Errors

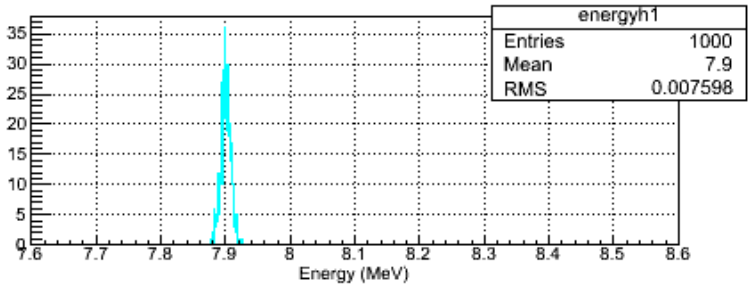
Absolute Beam Energy

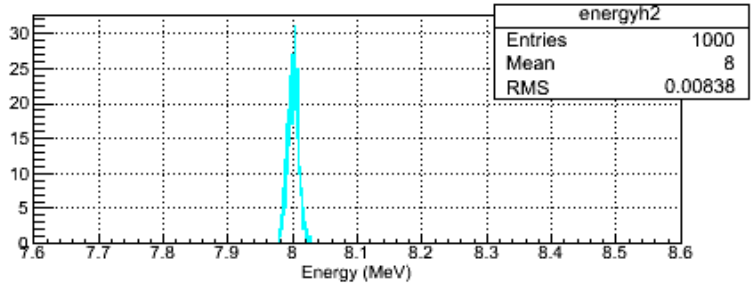
I. Calculate the N_{ij} for each nominal beam energy, E_i (since we will use GEANT4)
II. Allow for absolute beam energy to change by:

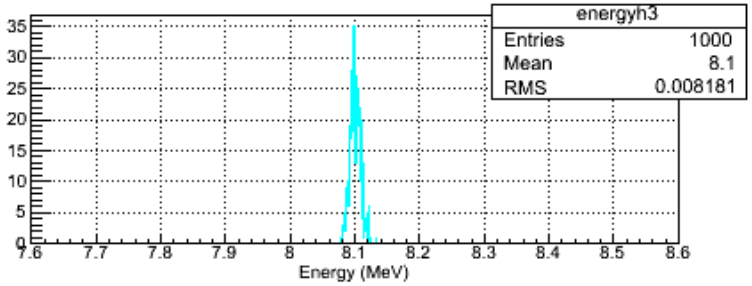
$$E_i = E_i * gRandom->Gaus(1, 0.001)$$

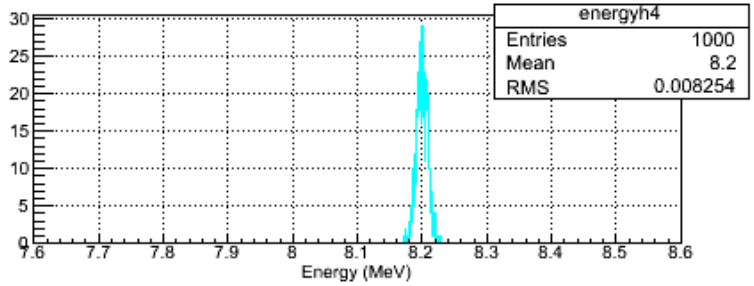
III. Calculate the yield
IV. Unfold cross section
V. Repeat for 1000 tries

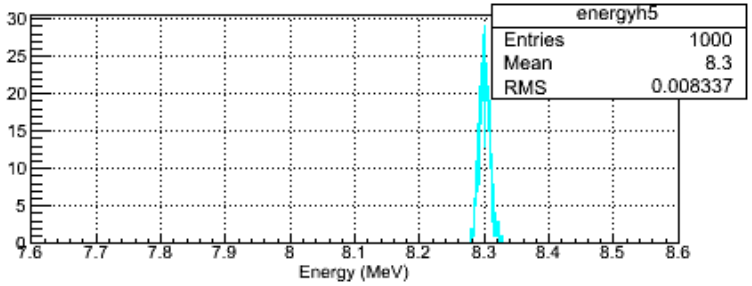

Energy (MeV)

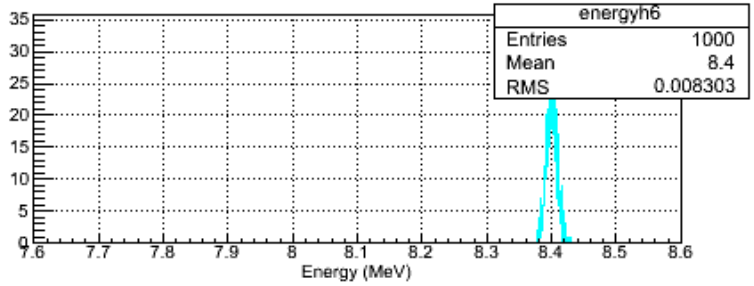

energyh1
Entries 1000
Mean 7.9
RMS 0.007598
Energy (MeV)

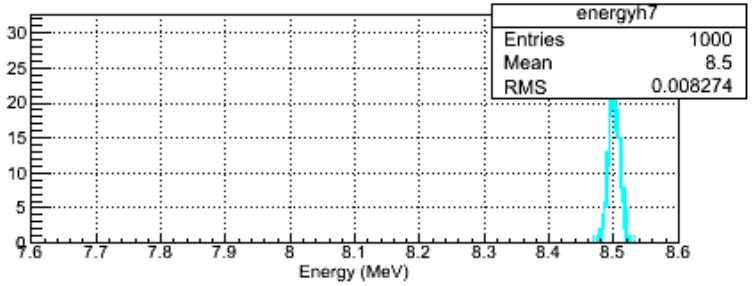

energyh2
Entries 1000
Mean 8
RMS 0.00838
Energy (MeV)

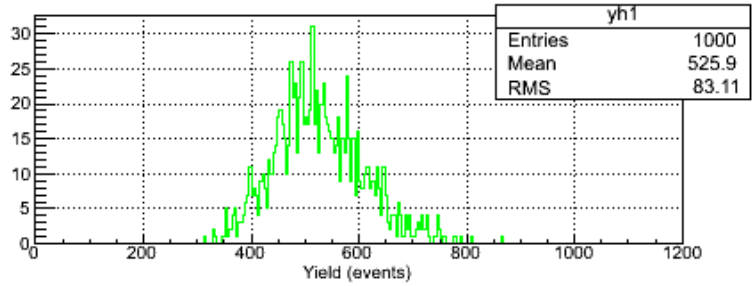

energyh3
Entries 1000
Mean 8.1
RMS 0.008181
Energy (MeV)

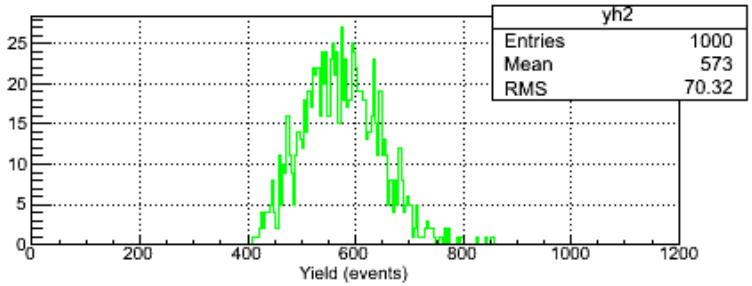

energyh4
Entries 1000
Mean 8.2
RMS 0.008254
Energy (MeV)

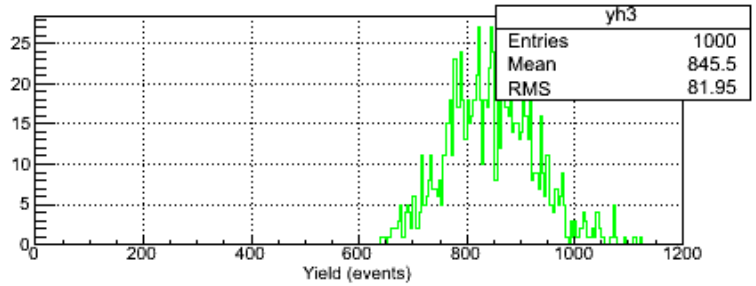

energyh5
Entries 1000
Mean 8.3
RMS 0.008337
Energy (MeV)

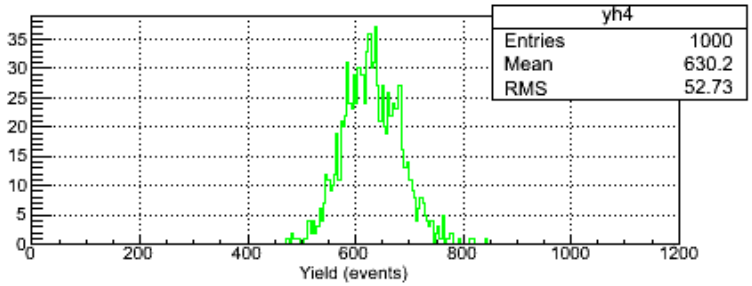

energyh6
Entries 1000
Mean 8.4
RMS 0.008303
Energy (MeV)

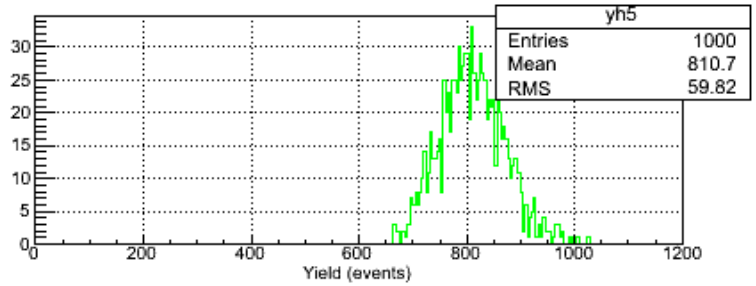

energyh7
Entries 1000
Mean 8.5
RMS 0.008274
Energy (MeV)

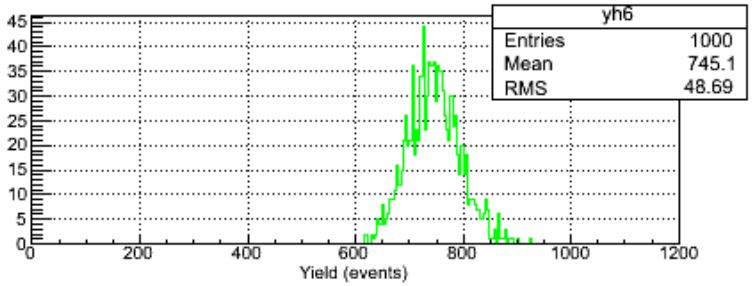

yh1
Entries 1000
Mean 525.9
RMS 83.11
Yield (events)

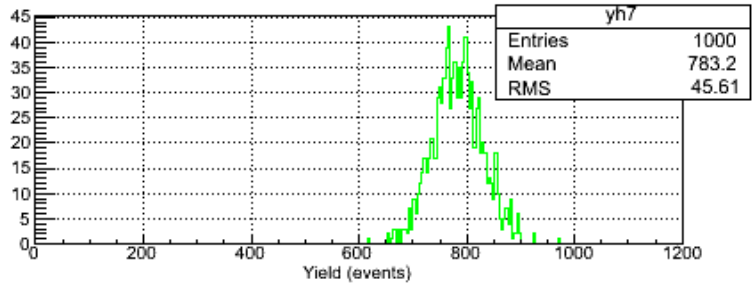

yh2
Entries 1000
Mean 573
RMS 70.32
Yield (events)

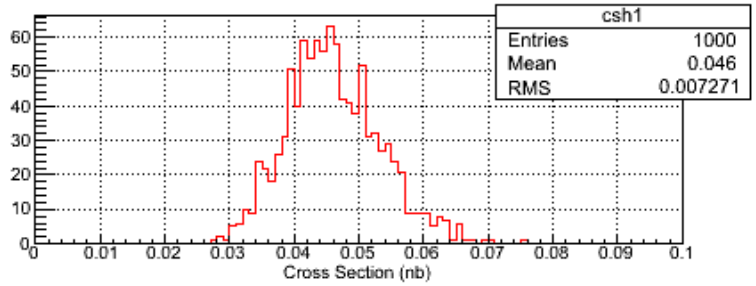

yh3
Entries 1000
Mean 845.5
RMS 81.95
Yield (events)

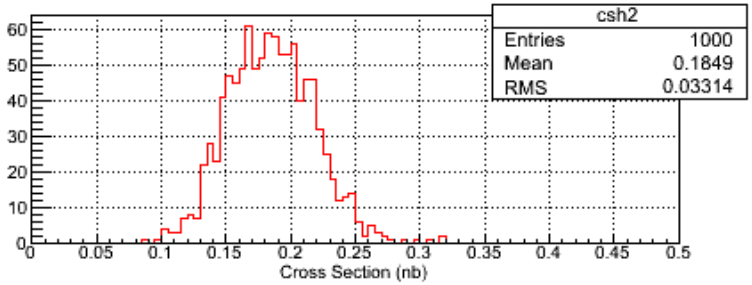

yh4
Entries 1000
Mean 630.2
RMS 52.73
Yield (events)

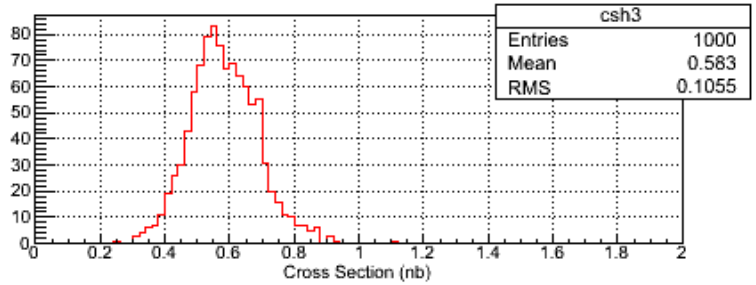

yh5
Entries 1000
Mean 810.7
RMS 59.82
Yield (events)

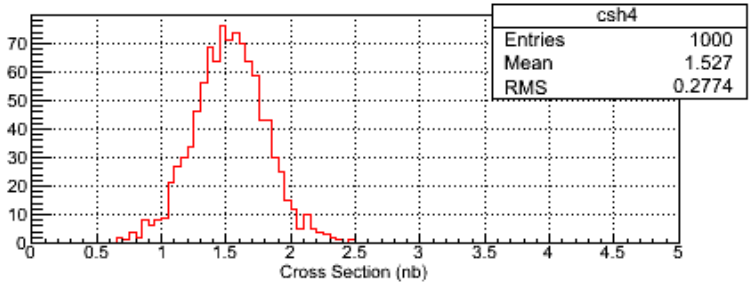

yh6
Entries 1000
Mean 745.1
RMS 48.69
Yield (events)

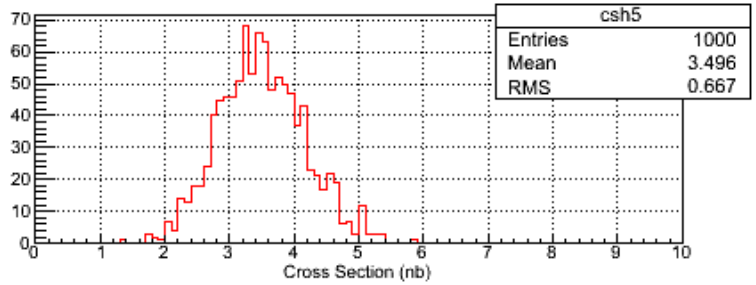

yh7
Entries 1000
Mean 783.2
RMS 45.61
Yield (events)

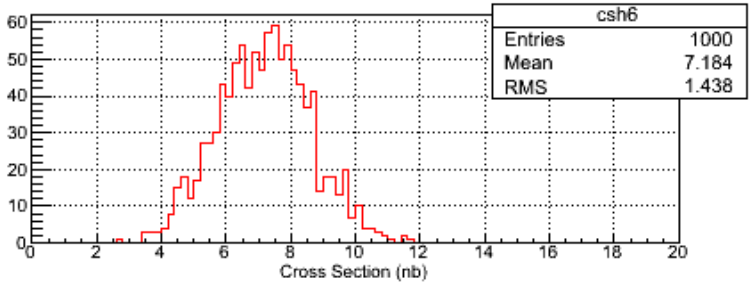

csh1
Entries 1000
Mean 0.046
RMS 0.007271
Cross Section (nb)

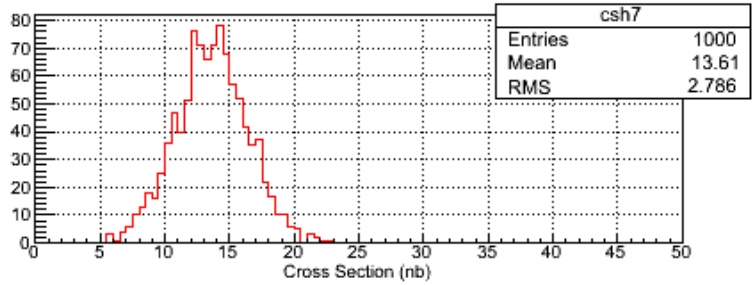

csh2
Entries 1000
Mean 0.1849
RMS 0.03314
Cross Section (nb)


csh3
Entries 1000
Mean 0.583
RMS 0.1055
Cross Section (nb)


csh4
Entries 1000
Mean 1.527
RMS 0.2774
Cross Section (nb)


csh5
Entries 1000
Mean 3.496
RMS 0.667
Cross Section (nb)


csh6
Entries 1000
Mean 7.184
RMS 1.438
Cross Section (nb)


csh7
Entries 1000
Mean 13.61
RMS 2.786
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i/y_i (%)
7.9	100	100	526	15.8
8.0	100	20	573	12.3
8.1	80	10	846	9.7
8.2	20	10	630	8.4
8.3	10	10	811	7.4
8.4	4	10	745	6.5
8.5	2	10	783	5.8

Electron Beam K. E.	Cross Section (nb)	Sys Error (Energy, %)
7.9	0.046	15.8
8.0	0.185	17.9
8.1	0.58	18.1
8.2	1.53	18.2
8.3	3.50	19.1
8.4	7.2	20.0
8.5	13.6	20.5

Other Absolute Systematic Errors

I. Calculate the N_{ij} for each nominal beam energy, E_i (since we will use GEANT4)

II. Allow for absolute beam energy to change by:

$$E_i = E_i * gRandom->Gaus(1, 0.001)$$

III. Calculate the yield

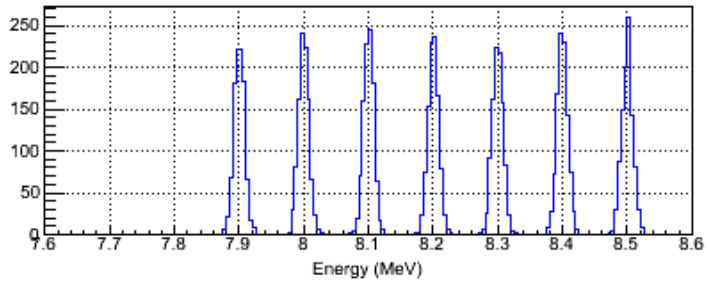
IV. Include other absolute systematic errors:

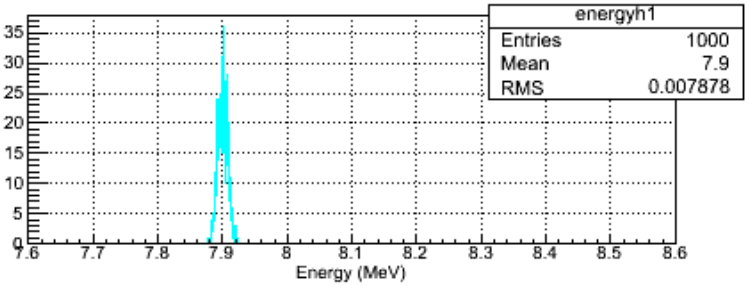
$$N_{ij} = N_{ij} * gRandom->Gaus(1, \delta\varphi/\varphi)$$

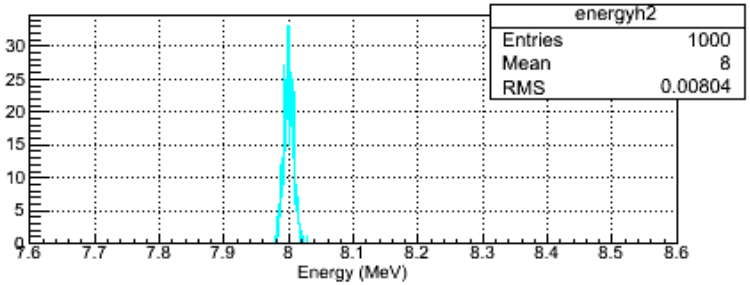
$$y_i = y_i * gRandom->Gaus(1, Sqrt((\delta I/I)^2 + (\delta R/R)^2 + (\delta T/T)^2 + \varepsilon^2)$$

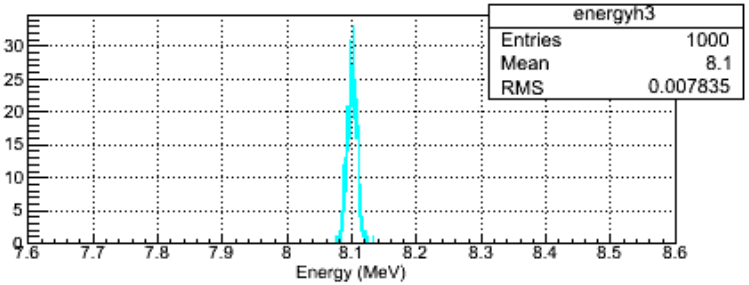
V. Unfold cross section

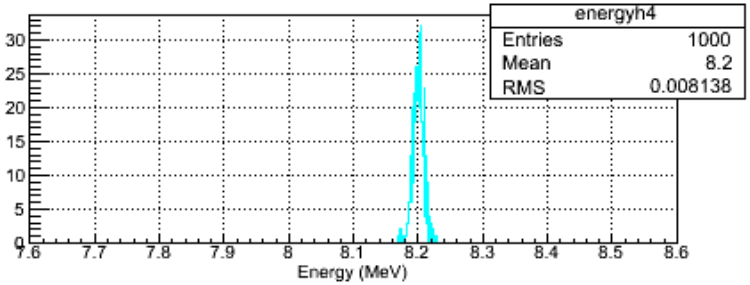
VI. Repeat for 1000 tries

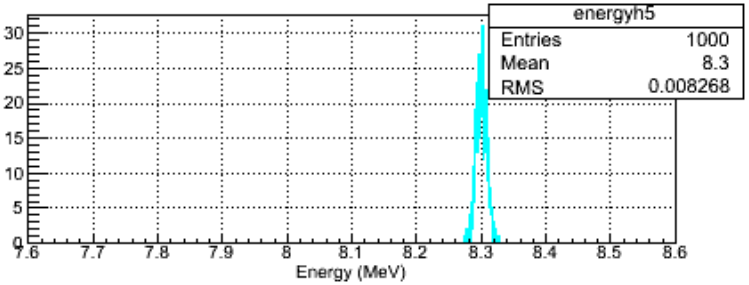

Energy (MeV)

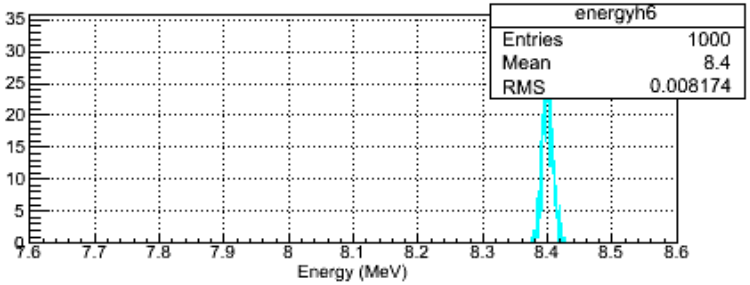

energyh1
Entries 1000
Mean 7.9
RMS 0.007878
Energy (MeV)

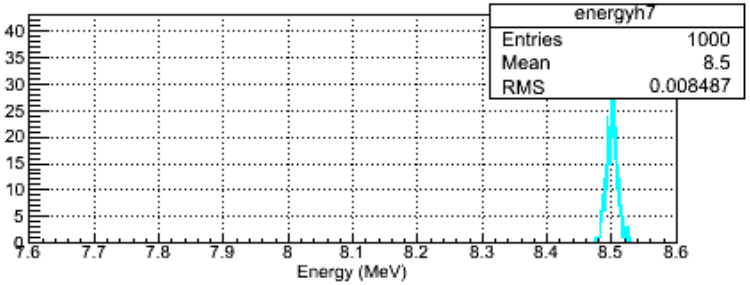

energyh2
Entries 1000
Mean 8
RMS 0.00804
Energy (MeV)

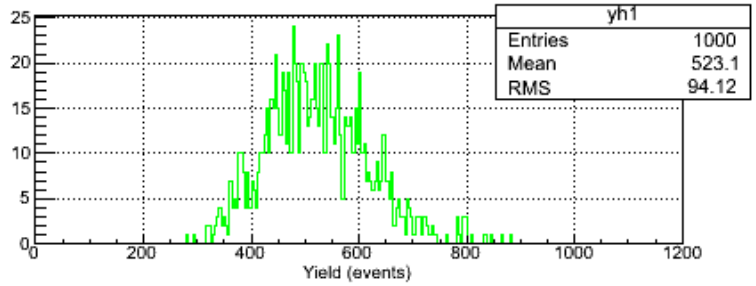

energyh3
Entries 1000
Mean 8.1
RMS 0.007835
Energy (MeV)

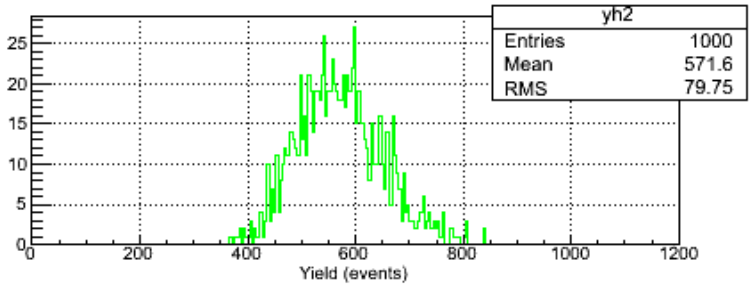

energyh4
Entries 1000
Mean 8.2
RMS 0.008138
Energy (MeV)

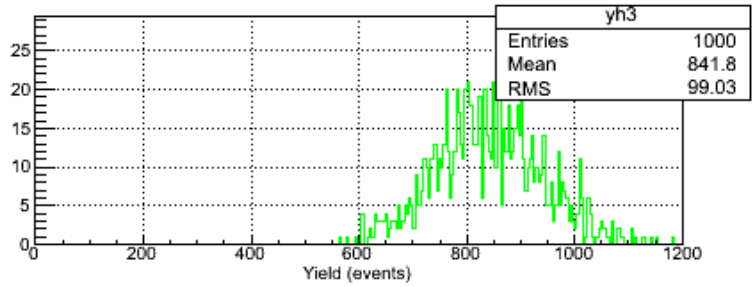

energyh5
Entries 1000
Mean 8.3
RMS 0.008268
Energy (MeV)

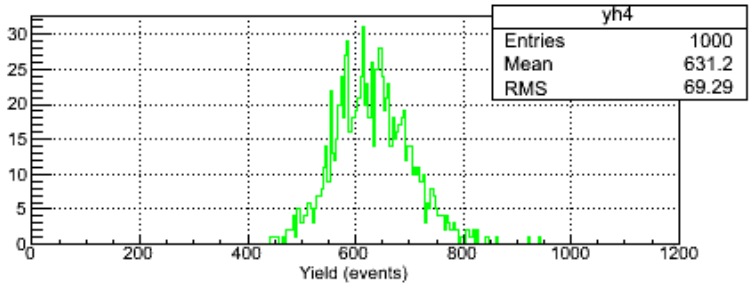

energyh6
Entries 1000
Mean 8.4
RMS 0.008174
Energy (MeV)

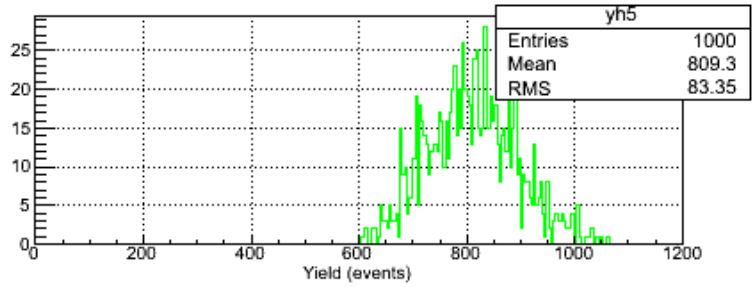

energyh7
Entries 1000
Mean 8.5
RMS 0.008487
Energy (MeV)

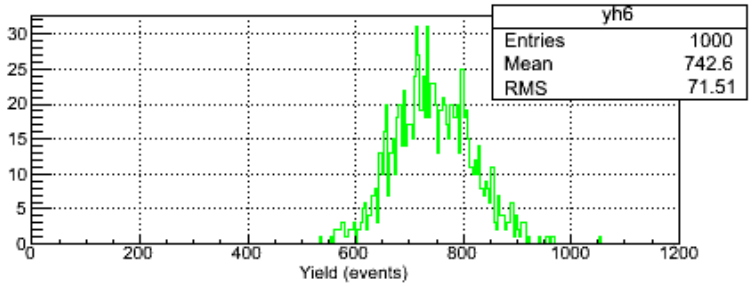

yh1
Entries 1000
Mean 523.1
RMS 94.12
Yield (events)

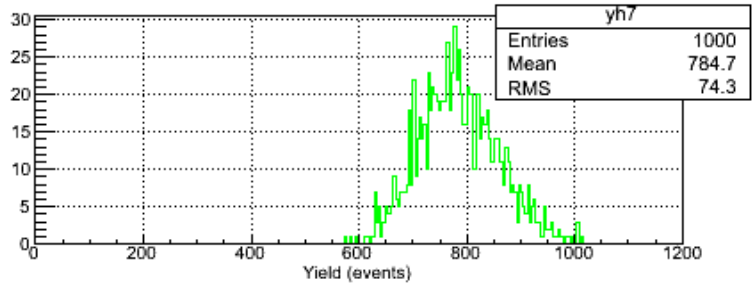

yh2
Entries 1000
Mean 571.6
RMS 79.75
Yield (events)

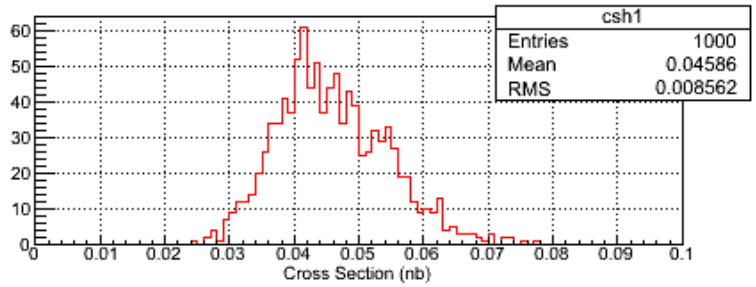

yh3
Entries 1000
Mean 841.8
RMS 99.03
Yield (events)

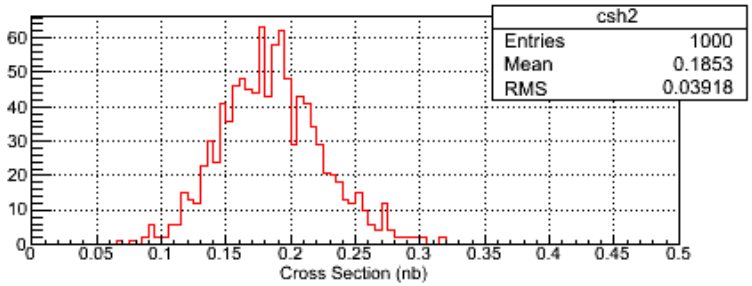

yh4
Entries 1000
Mean 631.2
RMS 69.29
Yield (events)

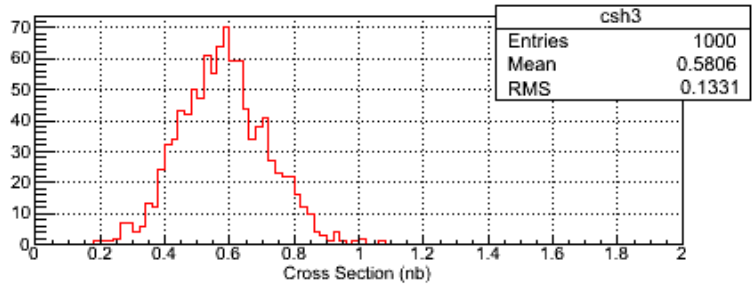

yh5
Entries 1000
Mean 809.3
RMS 83.35
Yield (events)

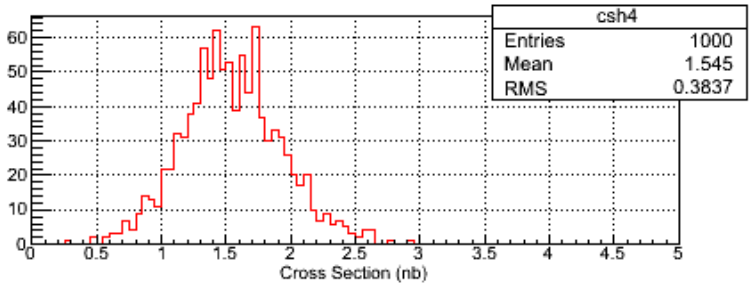

yh6
Entries 1000
Mean 742.6
RMS 71.51
Yield (events)

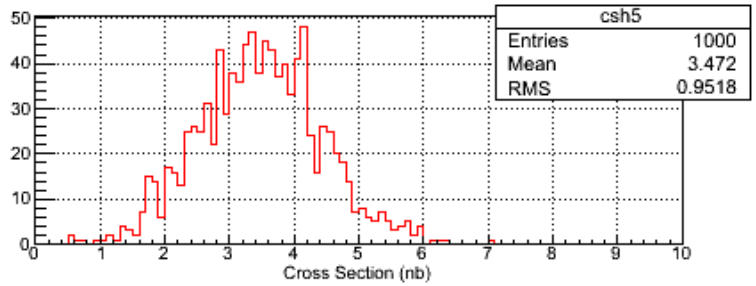

yh7
Entries 1000
Mean 784.7
RMS 74.3
Yield (events)

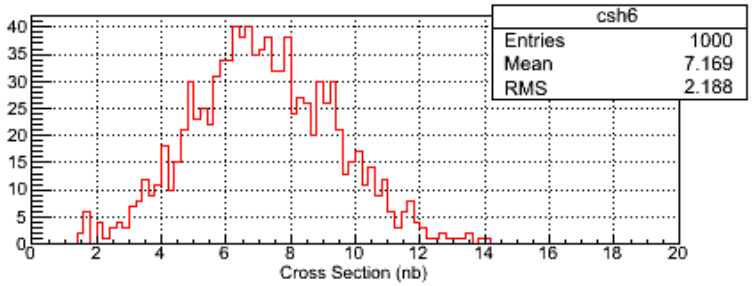

csh1
Entries 1000
Mean 0.04586
RMS 0.008562
Cross Section (nb)

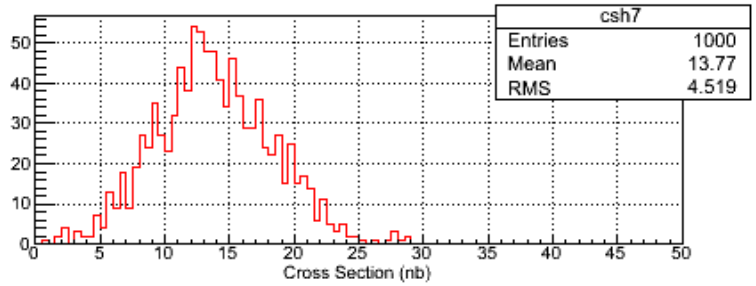

csh2
Entries 1000
Mean 0.1853
RMS 0.03918
Cross Section (nb)


csh3
Entries 1000
Mean 0.5806
RMS 0.1331
Cross Section (nb)


csh4
Entries 1000
Mean 1.545
RMS 0.3837
Cross Section (nb)


csh5
Entries 1000
Mean 3.472
RMS 0.9518
Cross Section (nb)


csh6
Entries 1000
Mean 7.169
RMS 2.188
Cross Section (nb)


csh7
Entries 1000
Mean 13.77
RMS 4.519
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i/y_i (%)
7.9	100	100	523	18.0
8.0	100	20	572	14.0
8.1	80	10	842	11.8
8.2	20	10	631	11.0
8.3	10	10	809	10.3
8.4	4	10	743	9.6
8.5	2	10	785	9.5

Electron Beam K. E.	Cross Section (nb)	Sys Error (Total, %)
7.9	0.046	18.7
8.0	0.185	21.1
8.1	0.58	22.9
8.2	1.54	24.8
8.3	3.48	27.4
8.4	7.2	30.5
8.5	13.8	32.8

Relative Systematic Errors

Relative Beam Energy

I. Calculate the N_{ij} for each nominal beam energy, E_i (since we will use GEANT4)

II. Allow for absolute beam energy 7.8 MeV to change by:

$$E_0 = 7.8 * gRandom->Gaus(1, 0.001)$$

III. Higher energies has same relative error,

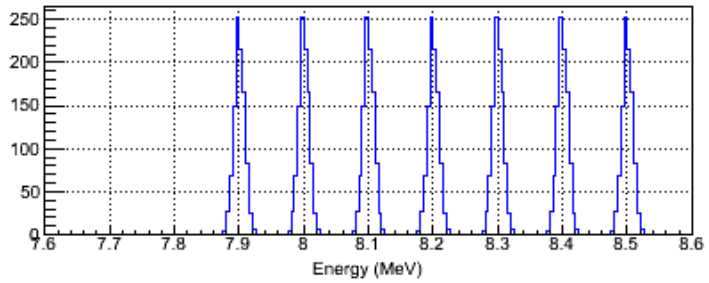
$$E_i = E_0 + i\Delta$$

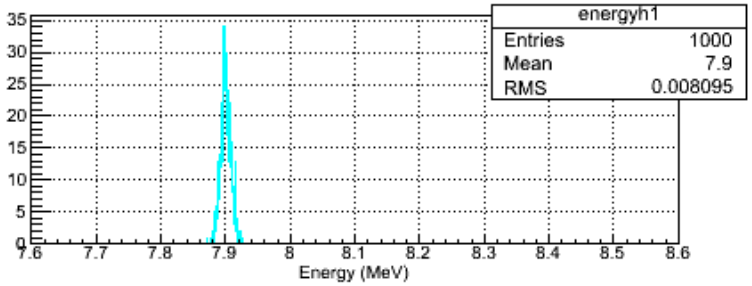
IV. Calculate the yield

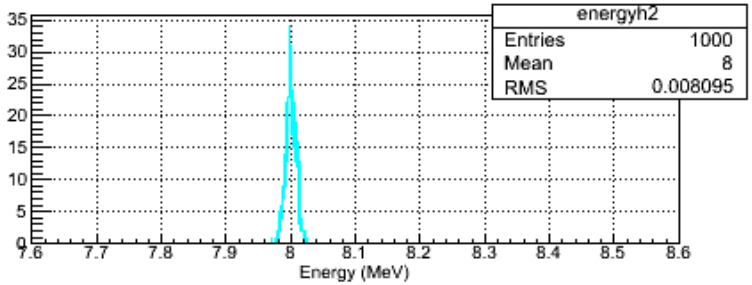
V. Unfold cross section

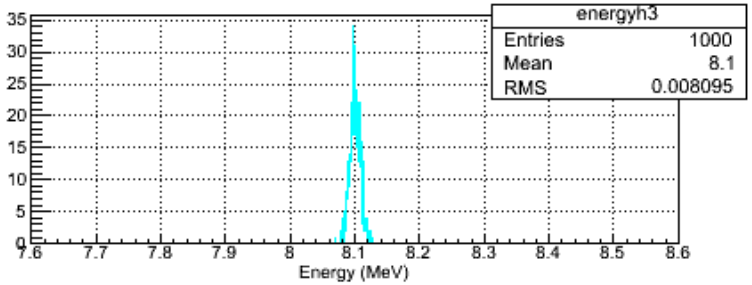
VI. Repeat for 1000 tries

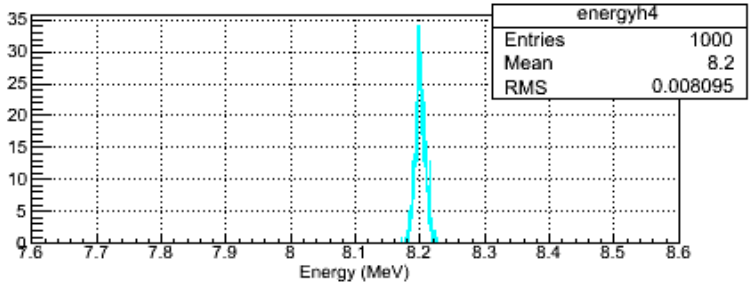
Now, we have to worry about beam stability (RF stability). Need injector FFB system to maintain relative beam stability

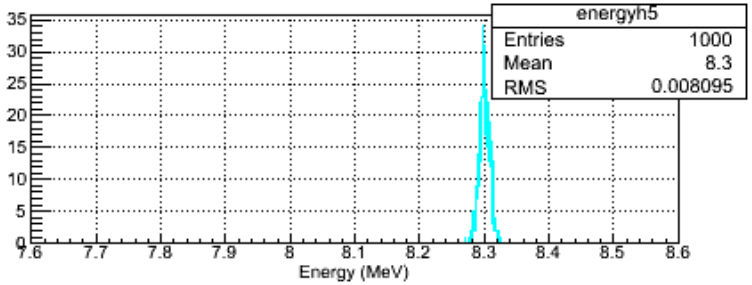

Energy (MeV)

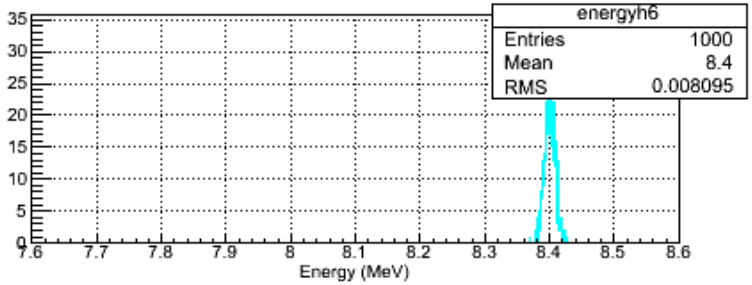

energyh1
Entries 1000
Mean 7.9
RMS 0.008095
Energy (MeV)

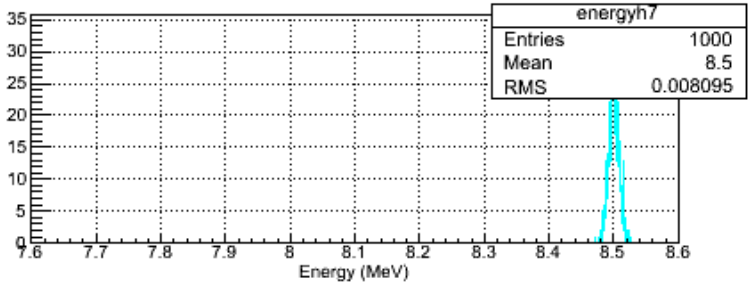

energyh2
Entries 1000
Mean 8
RMS 0.008095
Energy (MeV)

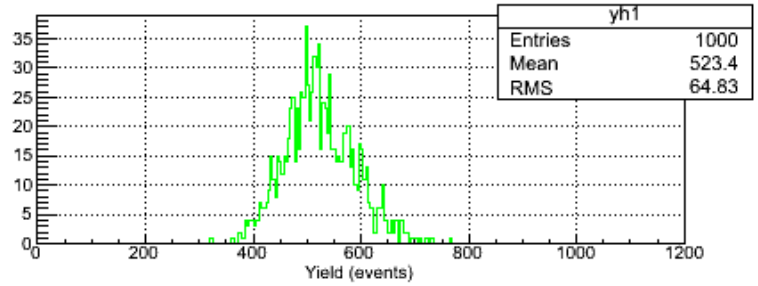

energyh3
Entries 1000
Mean 8.1
RMS 0.008095
Energy (MeV)

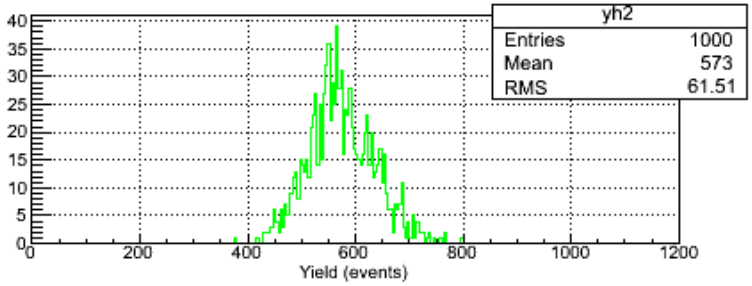

energyh4
Entries 1000
Mean 8.2
RMS 0.008095
Energy (MeV)

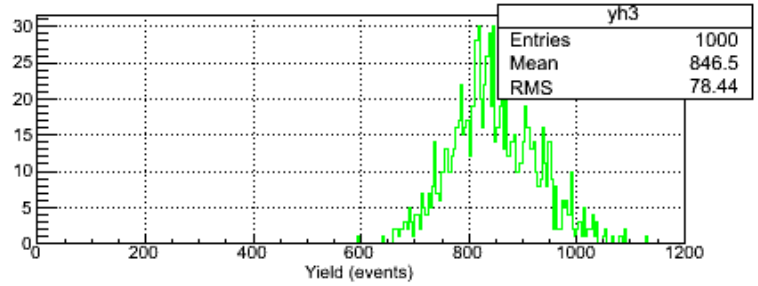

energyh5
Entries 1000
Mean 8.3
RMS 0.008095
Energy (MeV)

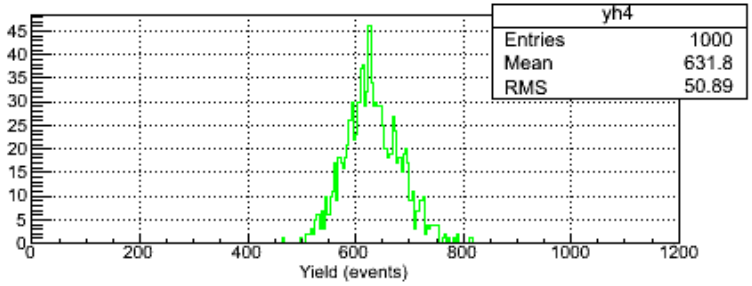

energyh6
Entries 1000
Mean 8.4
RMS 0.008095
Energy (MeV)

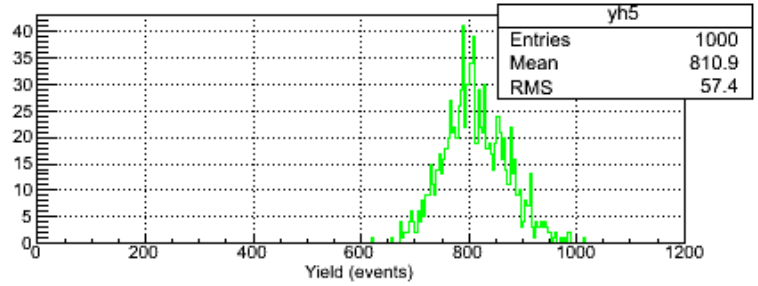

energyh7
Entries 1000
Mean 8.5
RMS 0.008095
Energy (MeV)

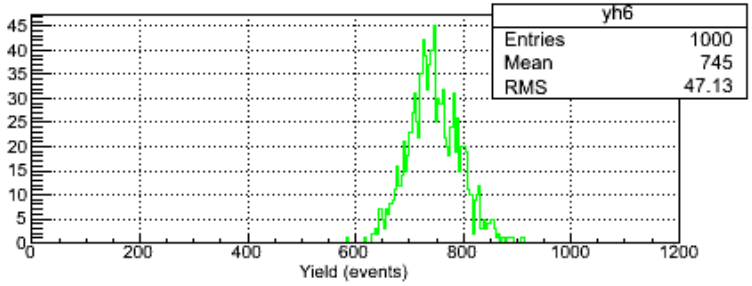

yh1
Entries 1000
Mean 523.4
RMS 64.83
Yield (events)

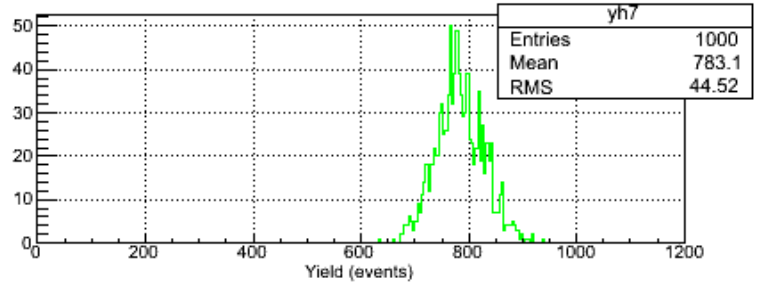

yh2
Entries 1000
Mean 573
RMS 61.51
Yield (events)

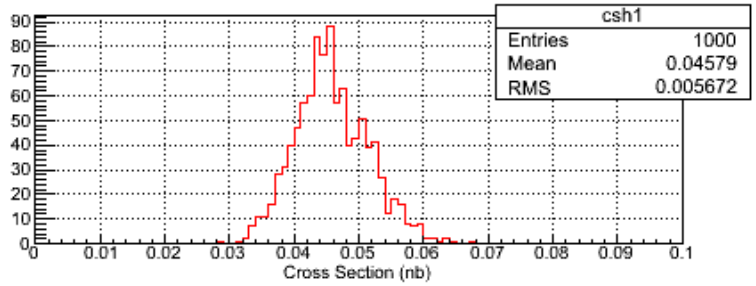

yh3
Entries 1000
Mean 846.5
RMS 78.44
Yield (events)

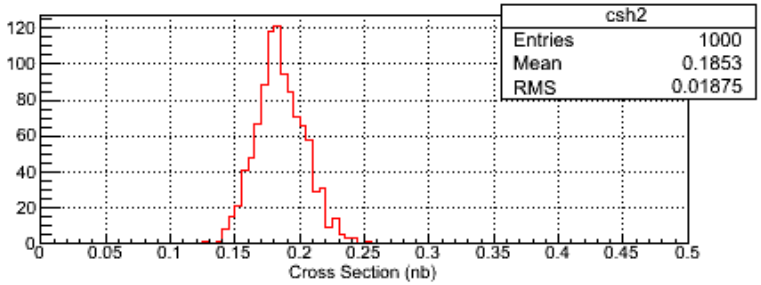

yh4
Entries 1000
Mean 631.8
RMS 50.89
Yield (events)

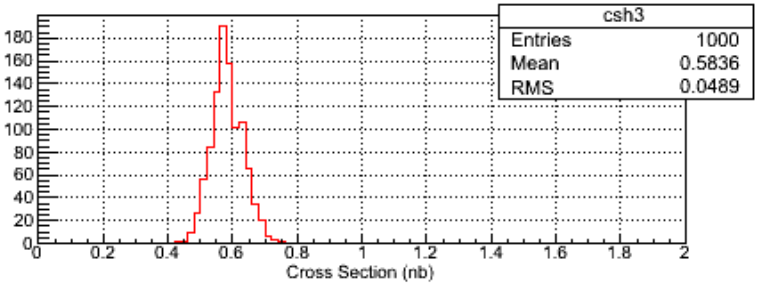

yh5
Entries 1000
Mean 810.9
RMS 57.4
Yield (events)

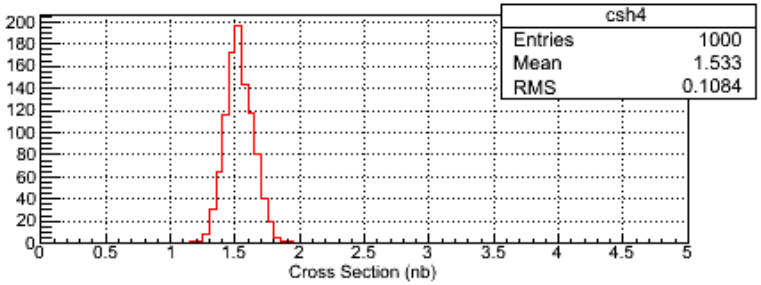

yh6
Entries 1000
Mean 745
RMS 47.13
Yield (events)

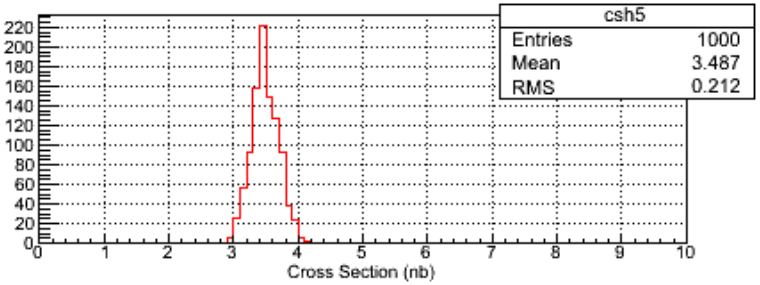

yh7
Entries 1000
Mean 783.1
RMS 44.52
Yield (events)

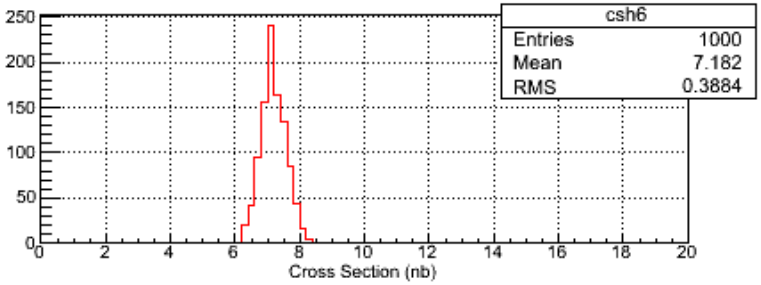

csh1
Entries 1000
Mean 0.04579
RMS 0.005672
Cross Section (nb)

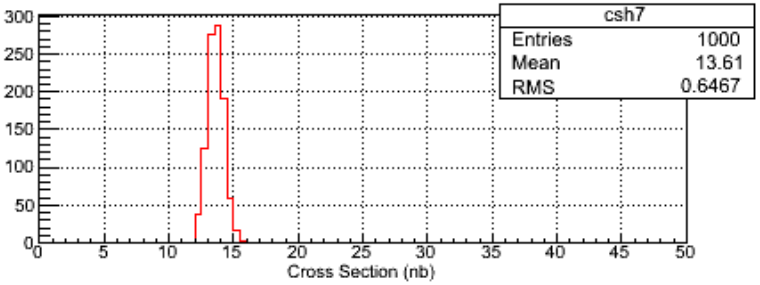

csh2
Entries 1000
Mean 0.1853
RMS 0.01875
Cross Section (nb)


csh3
Entries 1000
Mean 0.5836
RMS 0.0489
Cross Section (nb)


csh4
Entries 1000
Mean 1.533
RMS 0.1084
Cross Section (nb)


csh5
Entries 1000
Mean 3.487
RMS 0.212
Cross Section (nb)


csh6
Entries 1000
Mean 7.182
RMS 0.3884
Cross Section (nb)


csh7
Entries 1000
Mean 13.61
RMS 0.6467
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i/y_i (%)
7.9	100	100	523	12.4
8.0	100	20	573	10.7
8.1	80	10	846	9.3
8.2	20	10	632	8.1
8.3	10	10	811	7.1
8.4	4	10	745	6.3
8.5	2	10	783	5.7

Electron Beam K. E.	Cross Section (nb)	Sys Error (Energy, %)
7.9	0.046	12.4
8.0	0.185	10.1
8.1	0.58	8.4
8.2	1.53	7.1
8.3	3.49	6.1
8.4	7.2	5.4
8.5	13.6	4.8

Other Relative Systematic Errors

I. Calculate the N_{ij} for each nominal beam energy, E_i (since we will use GEANT4)

II. Allow for absolute beam energy 7.8 MeV to change by: $E_0 = 7.8 * gRandom->Gaus(1, 0.001)$

III. Higher energies has same relative error, $E_i = E_0 + i\Delta$

IV. Calculate the yield

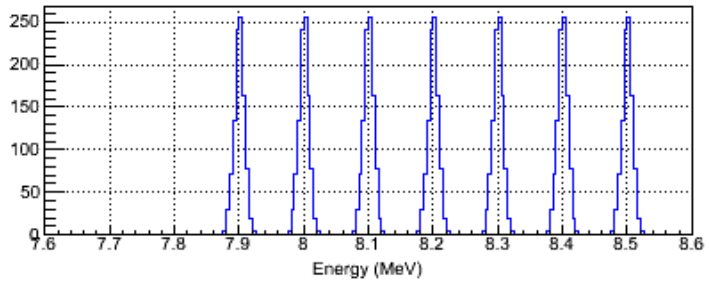
V. Include other relative systematic errors:

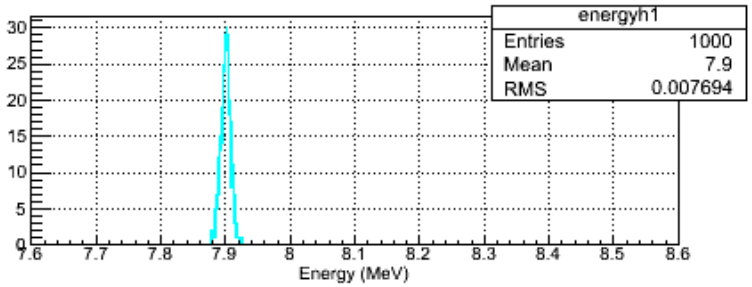
$N = N * gRandom->Gaus(1, \delta\varphi/\varphi)$

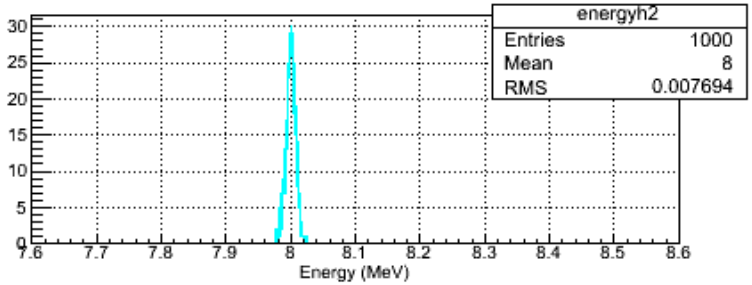
$y = y * gRandom->Gaus(1, Sqrt((\delta I/I)^2 + (\delta R/R)^2 + (\delta T/T)^2 + \varepsilon^2)$

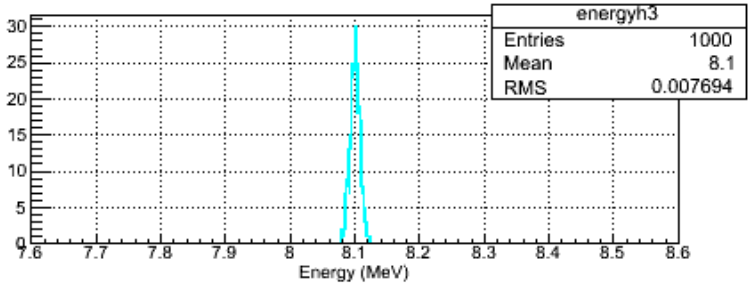
VI. Unfold cross section

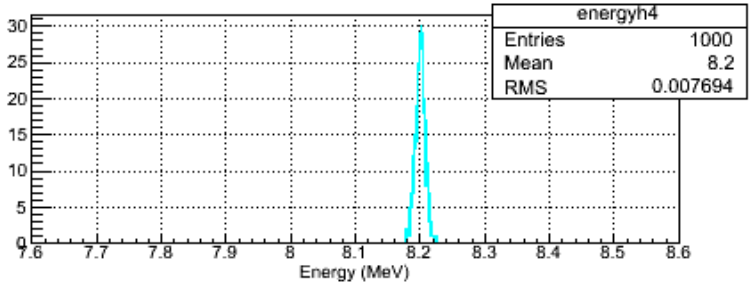
VII. Repeat for 1000 tries

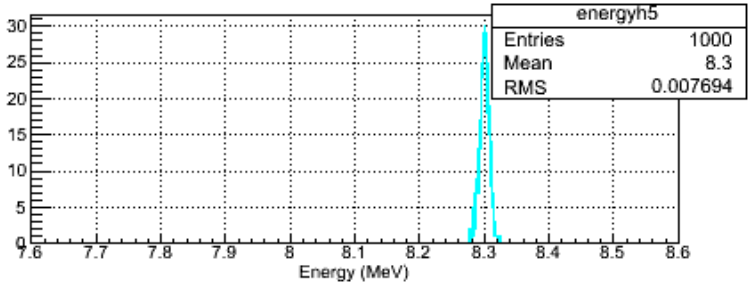

Energy (MeV)

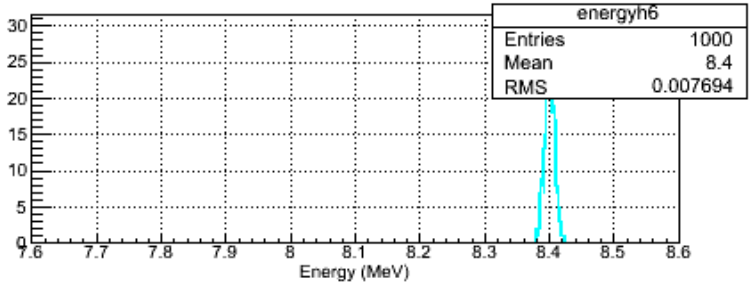

energyh1
Entries 1000
Mean 7.9
RMS 0.007694
Energy (MeV)

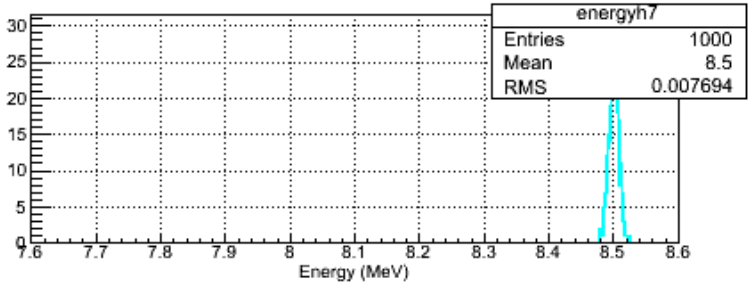

energyh2
Entries 1000
Mean 8
RMS 0.007694
Energy (MeV)

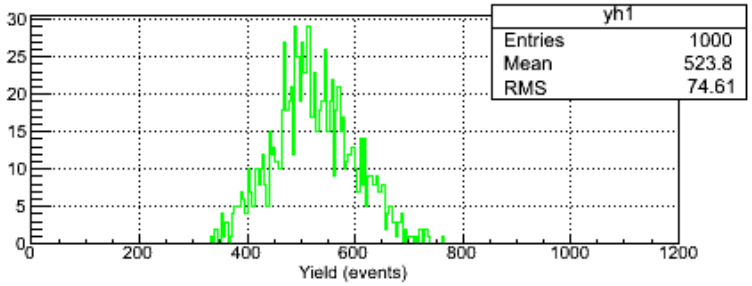

energyh3
Entries 1000
Mean 8.1
RMS 0.007694
Energy (MeV)

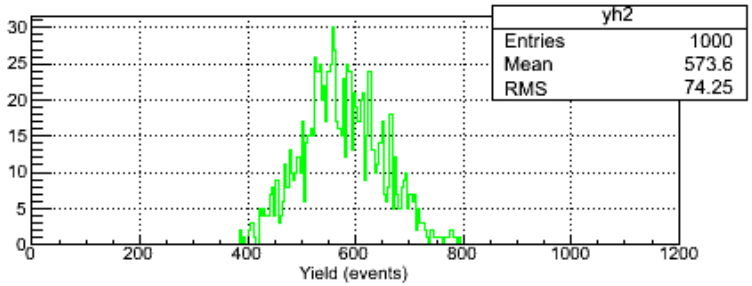

energyh4
Entries 1000
Mean 8.2
RMS 0.007694
Energy (MeV)

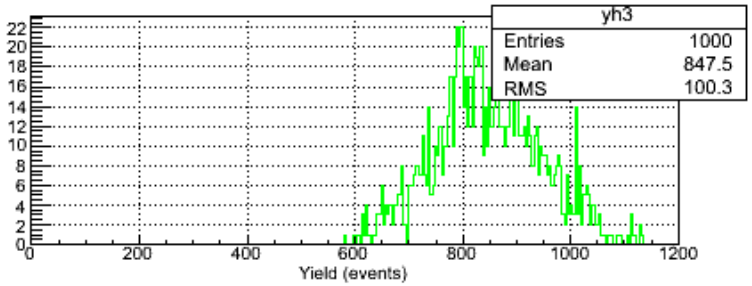

energyh5
Entries 1000
Mean 8.3
RMS 0.007694
Energy (MeV)

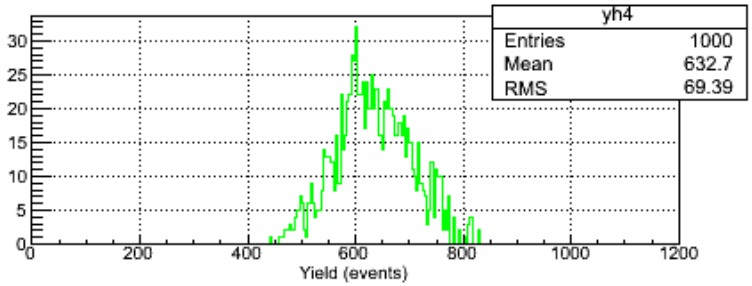

energyh6
Entries 1000
Mean 8.4
RMS 0.007694
Energy (MeV)

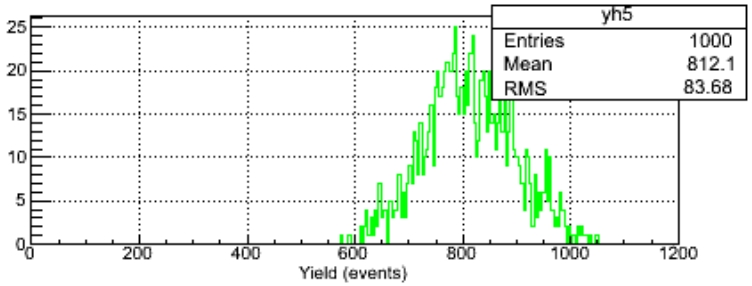

energyh7
Entries 1000
Mean 8.5
RMS 0.007694
Energy (MeV)

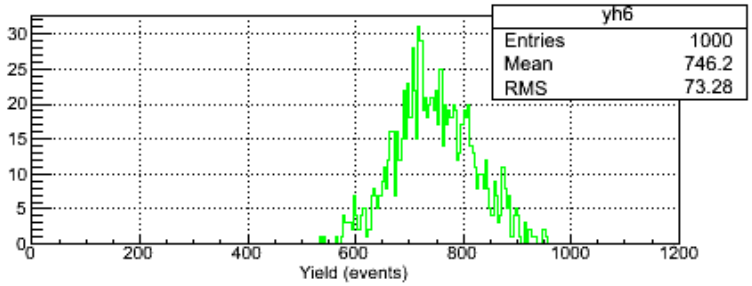

yh1
Entries 1000
Mean 523.8
RMS 74.61
Yield (events)

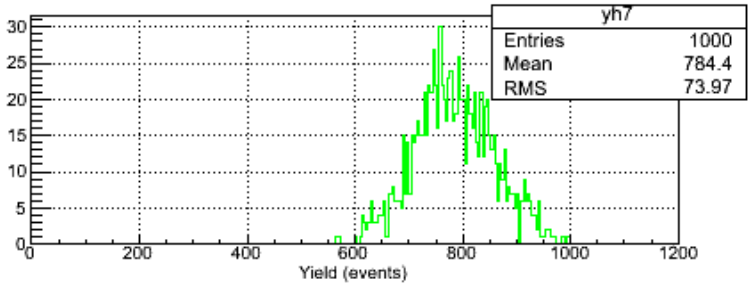

yh2
Entries 1000
Mean 573.6
RMS 74.25
Yield (events)

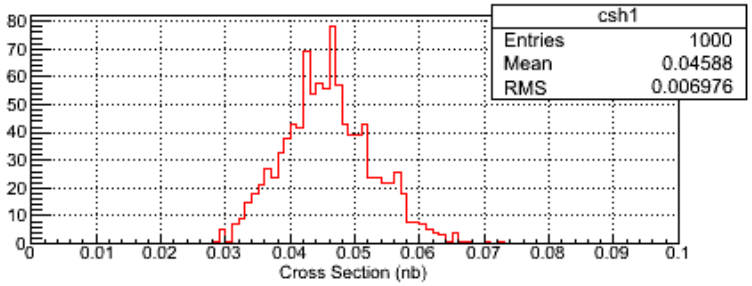

yh3
Entries 1000
Mean 847.5
RMS 100.3
Yield (events)

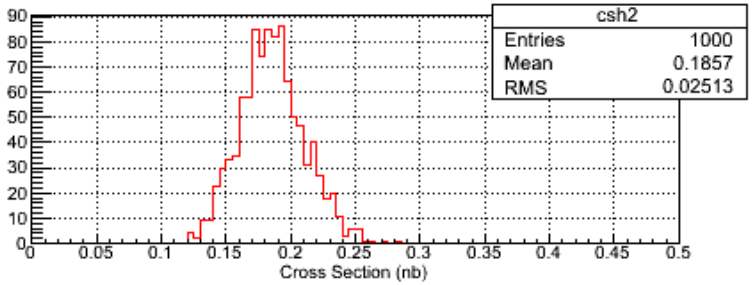

yh4
Entries 1000
Mean 632.7
RMS 69.39
Yield (events)

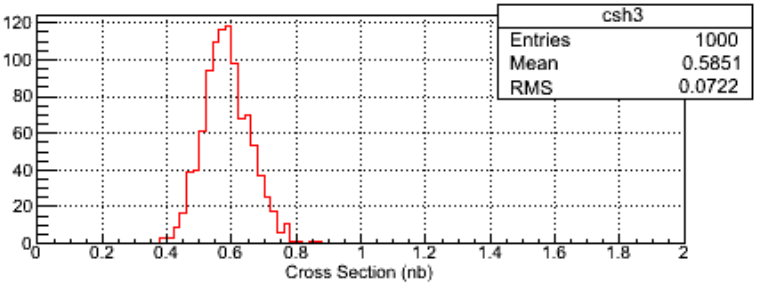

yh5
Entries 1000
Mean 812.1
RMS 83.68
Yield (events)

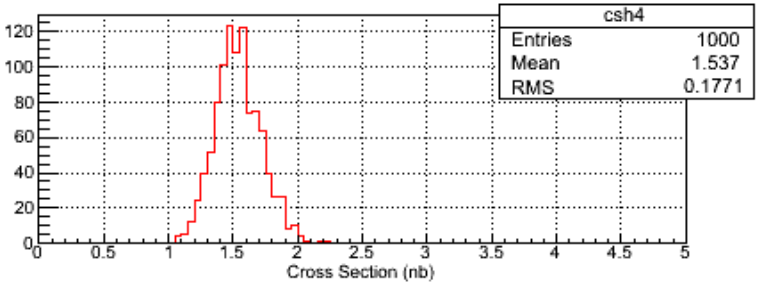

yh6
Entries 1000
Mean 746.2
RMS 73.28
Yield (events)

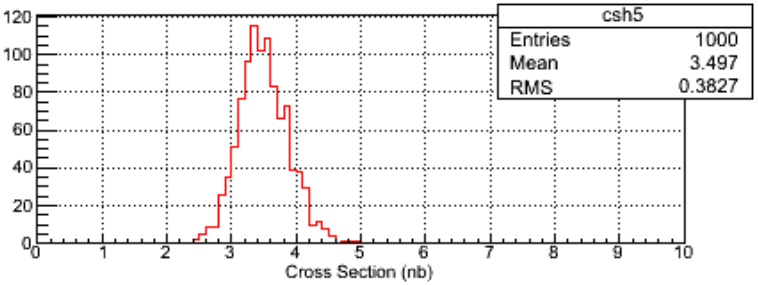

yh7
Entries 1000
Mean 784.4
RMS 73.97
Yield (events)

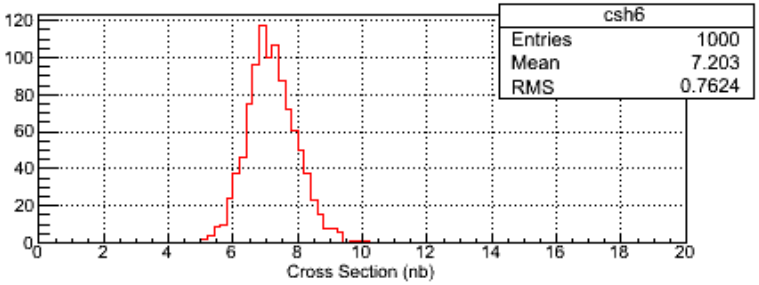

csh1
Entries 1000
Mean 0.04588
RMS 0.006976
Cross Section (nb)

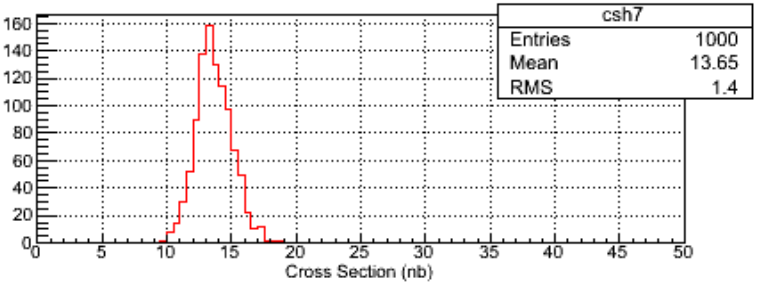

csh2
Entries 1000
Mean 0.1857
RMS 0.02513
Cross Section (nb)


csh3
Entries 1000
Mean 0.5851
RMS 0.0722
Cross Section (nb)


csh4
Entries 1000
Mean 1.537
RMS 0.1771
Cross Section (nb)


csh5
Entries 1000
Mean 3.497
RMS 0.3827
Cross Section (nb)


csh6
Entries 1000
Mean 7.203
RMS 0.7624
Cross Section (nb)


csh7
Entries 1000
Mean 13.65
RMS 1.4
Cross Section (nb)

Electron Beam K. E.	Beam Current (μA)	Time (hour)	y_i	dy_i/y_i (%)
7.9	100	100	524	14.2
8.0	100	20	574	12.9
8.1	80	10	848	11.8
8.2	20	10	633	11.0
8.3	10	10	812	10.3
8.4	4	10	746	9.8
8.5	2	10	784	9.4

Electron Beam K. E.	Cross Section (nb)	Sys Error (Total, %)
7.9	0.046	15.2
8.0	0.186	13.5
8.1	0.59	12.3
8.2	1.54	11.5
8.3	3.50	10.9
8.4	7.2	10.6
8.5	13.6	10.3