Preliminary Calculation of Geometry Factors for Helium-3 Wire Chamber, Pt. I

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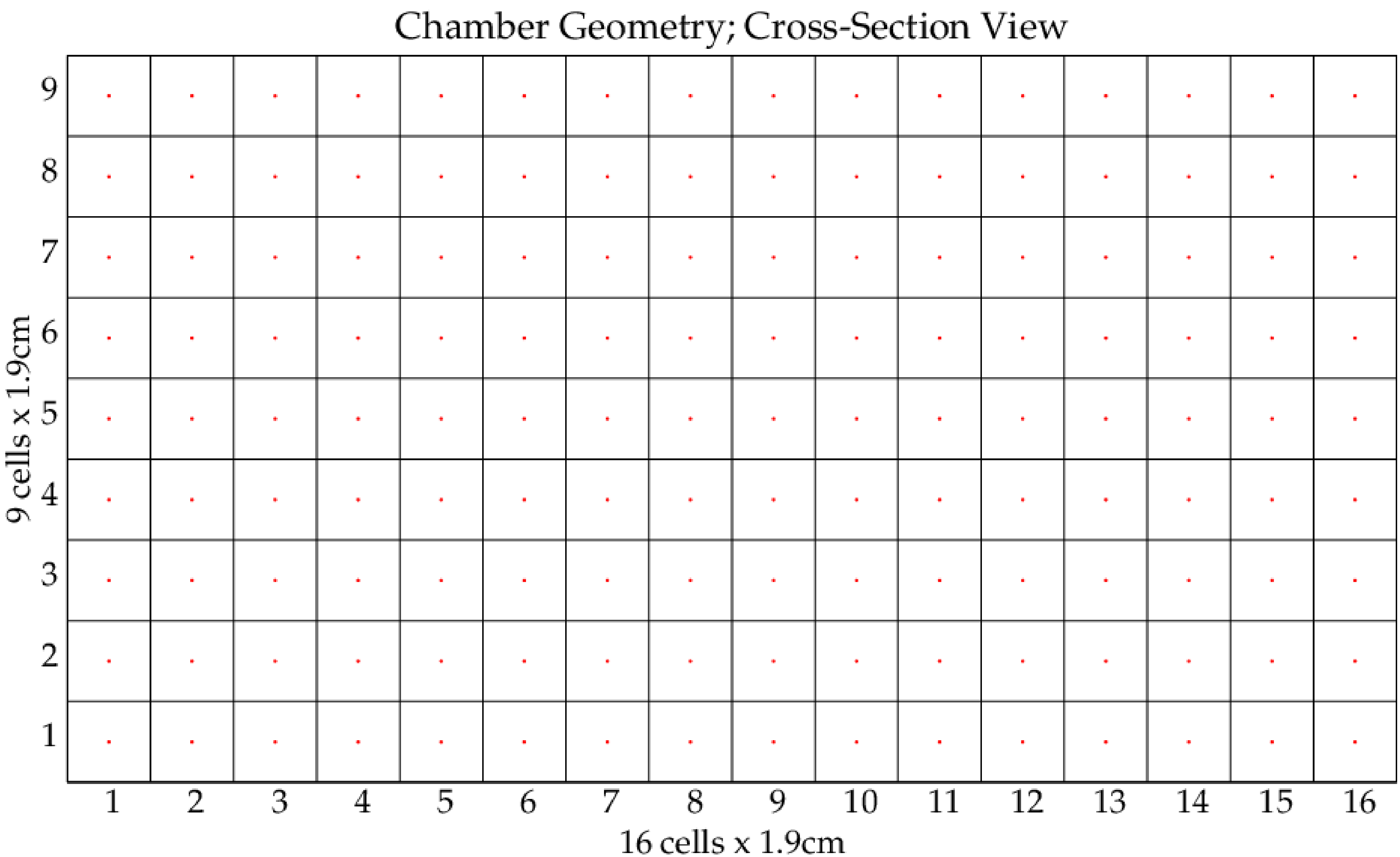
Cell Model

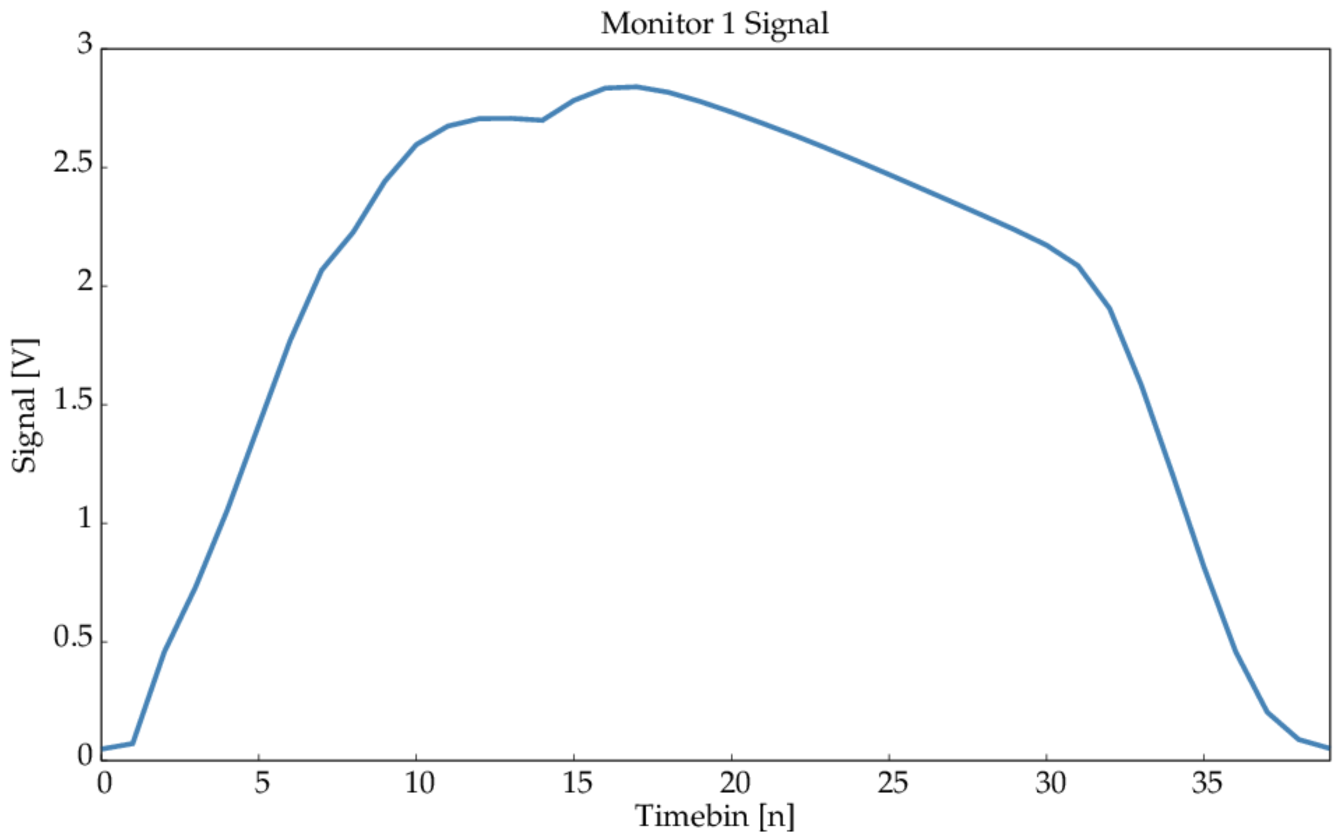
1. Model the wire chamber as 144 “cells” which collect all charge deposited in a parallelepiped set by the surrounding high voltage wires.

2. Each cell is 1.9 cm x 1.9cm x 17.1 cm. (There will be a small correction to the volume of the top and bottom row of cells).

3. Assume the 3He is contained inside the total cell volume. (There is a buffer in front of the first column of cells of about 2.2cm that will shift the physics in the -z direction by about 1 cell).

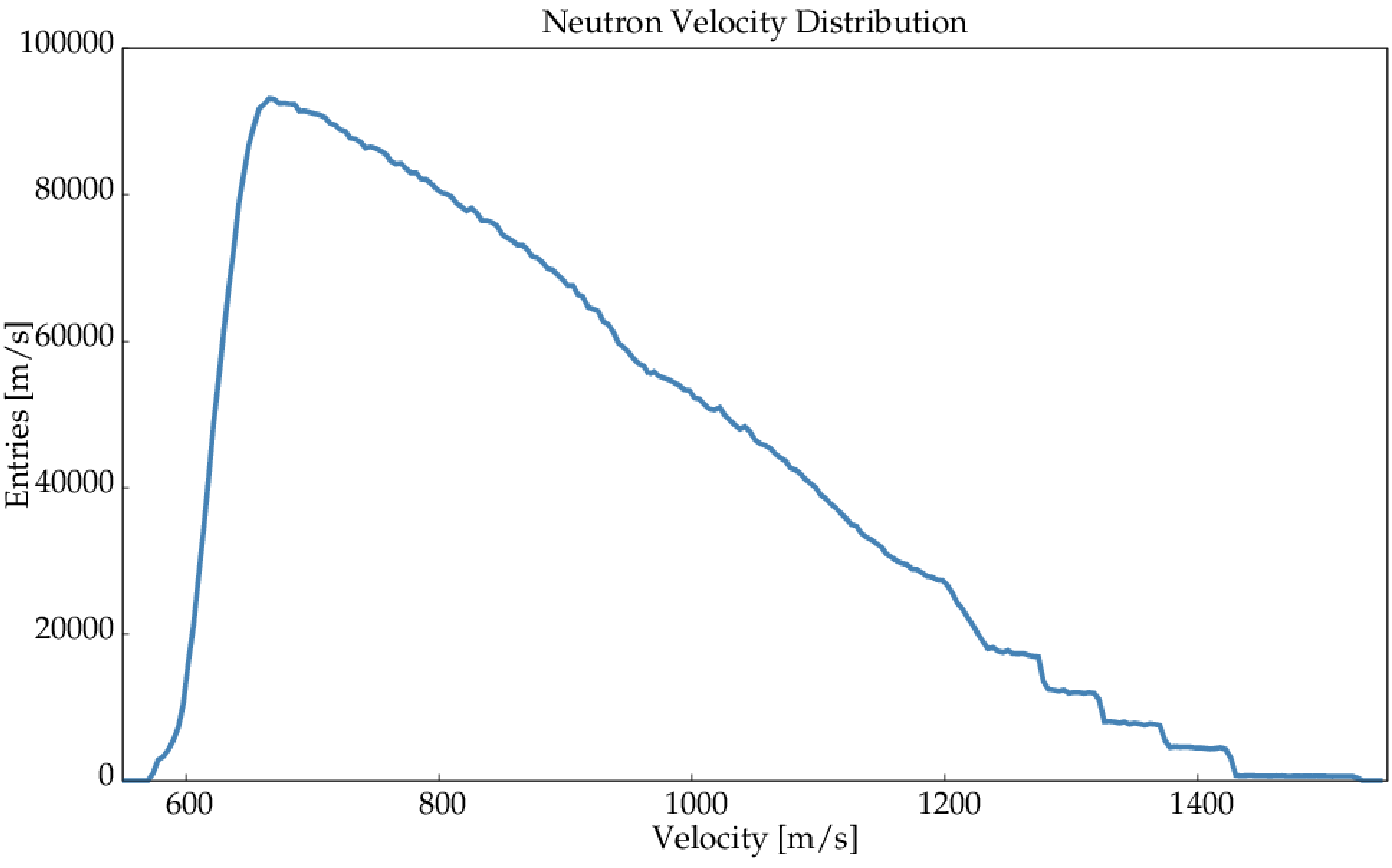

Chamber Geometry; Cross-Section View
9 cells x 1.9cm
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
16 cells x 1.9cm

Neutron Velocity

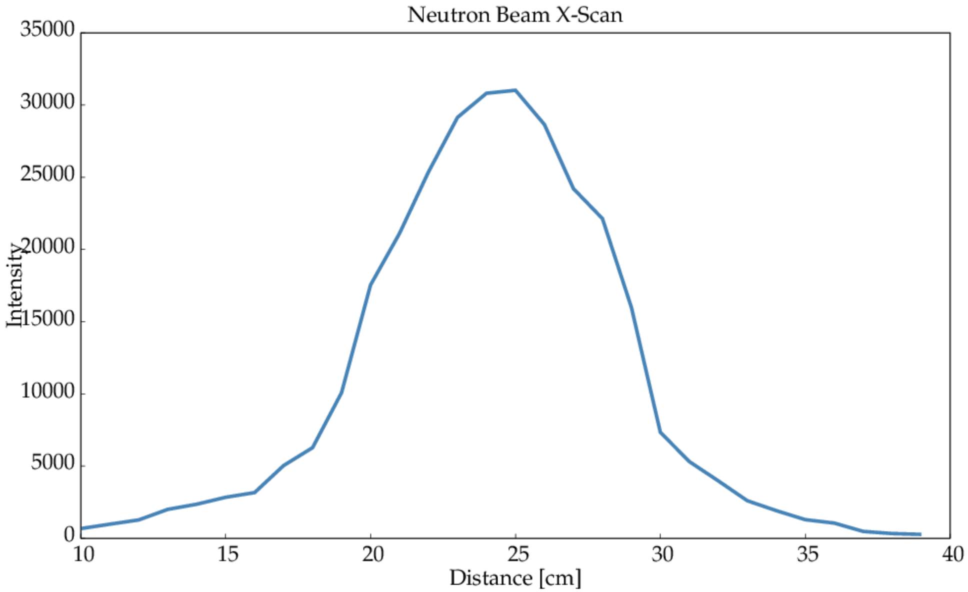


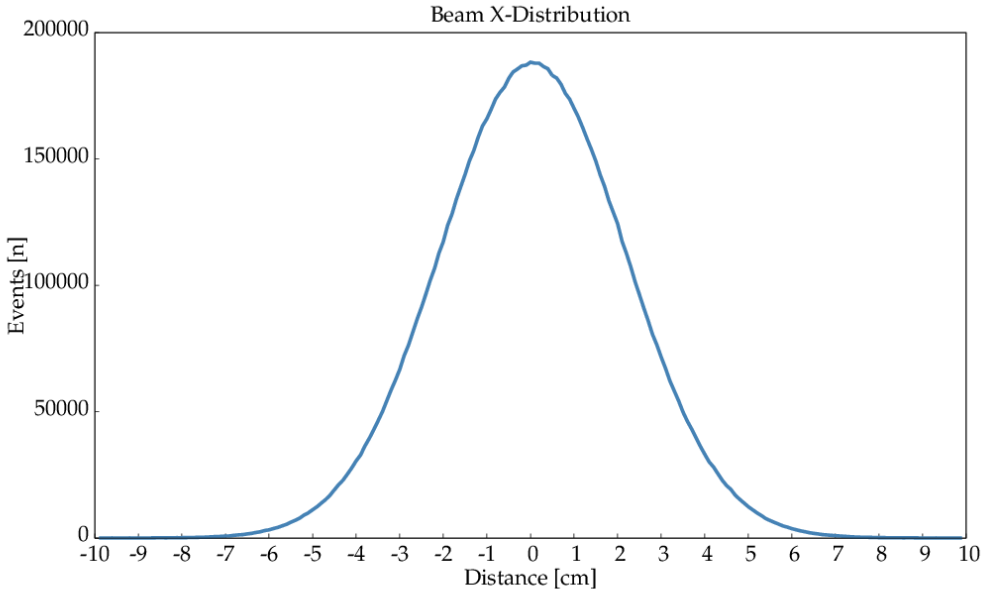
To get neutron velocities, use time-of-flight calculation to transform monitor signal into a velocity distribution. 4.05Å bragg edge used to fix the absolute time:

$$v_n = \frac{15.15\text{m}}{\left(.00979 + \frac{tbin}{2400}\right) ms}$$


Neutron Velocity Distribution
100000
80000
60000
40000
20000
0
Entries [m/s]
600
800
1000
1200
1400
Velocity [m/s]

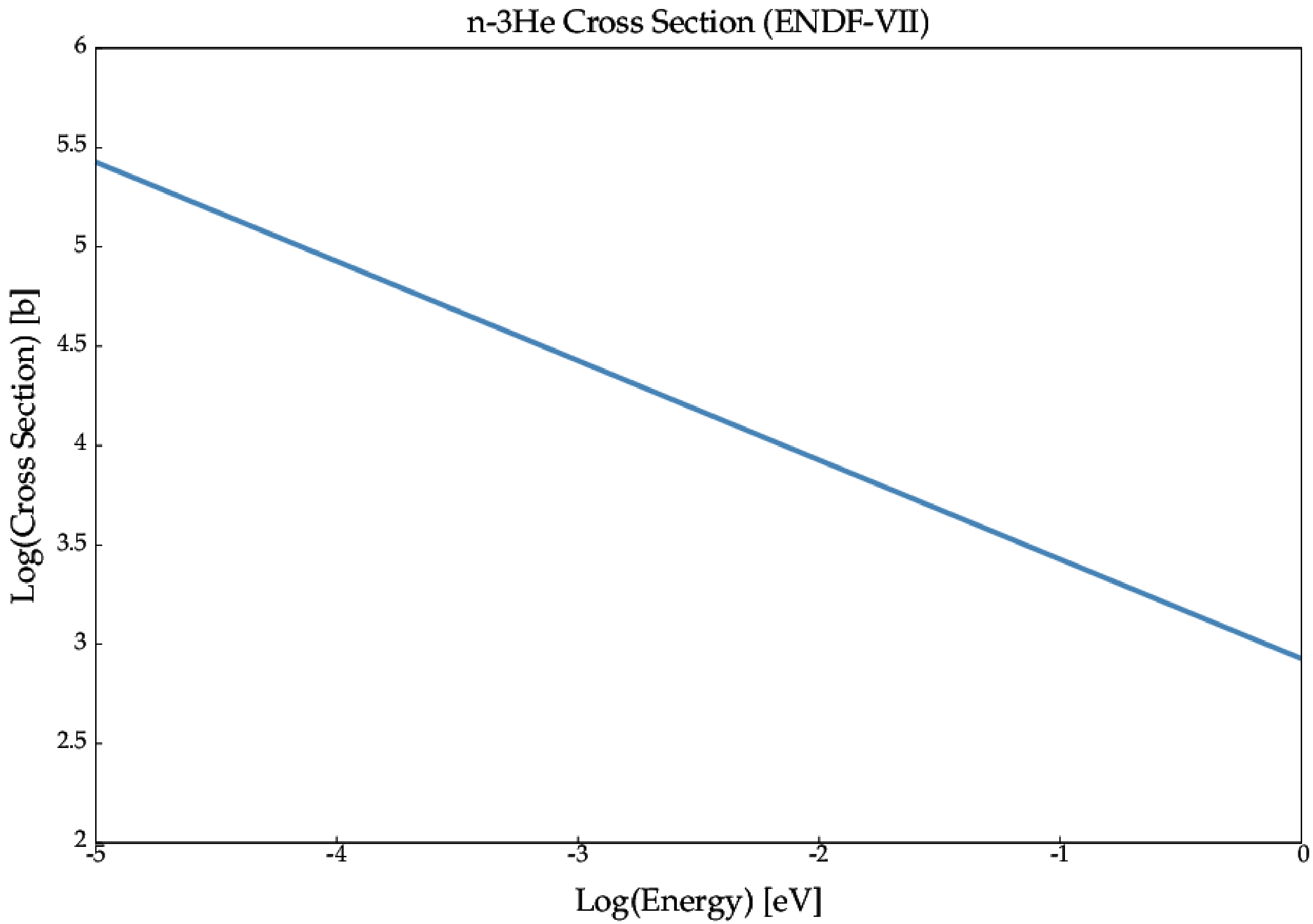
Beam Profile



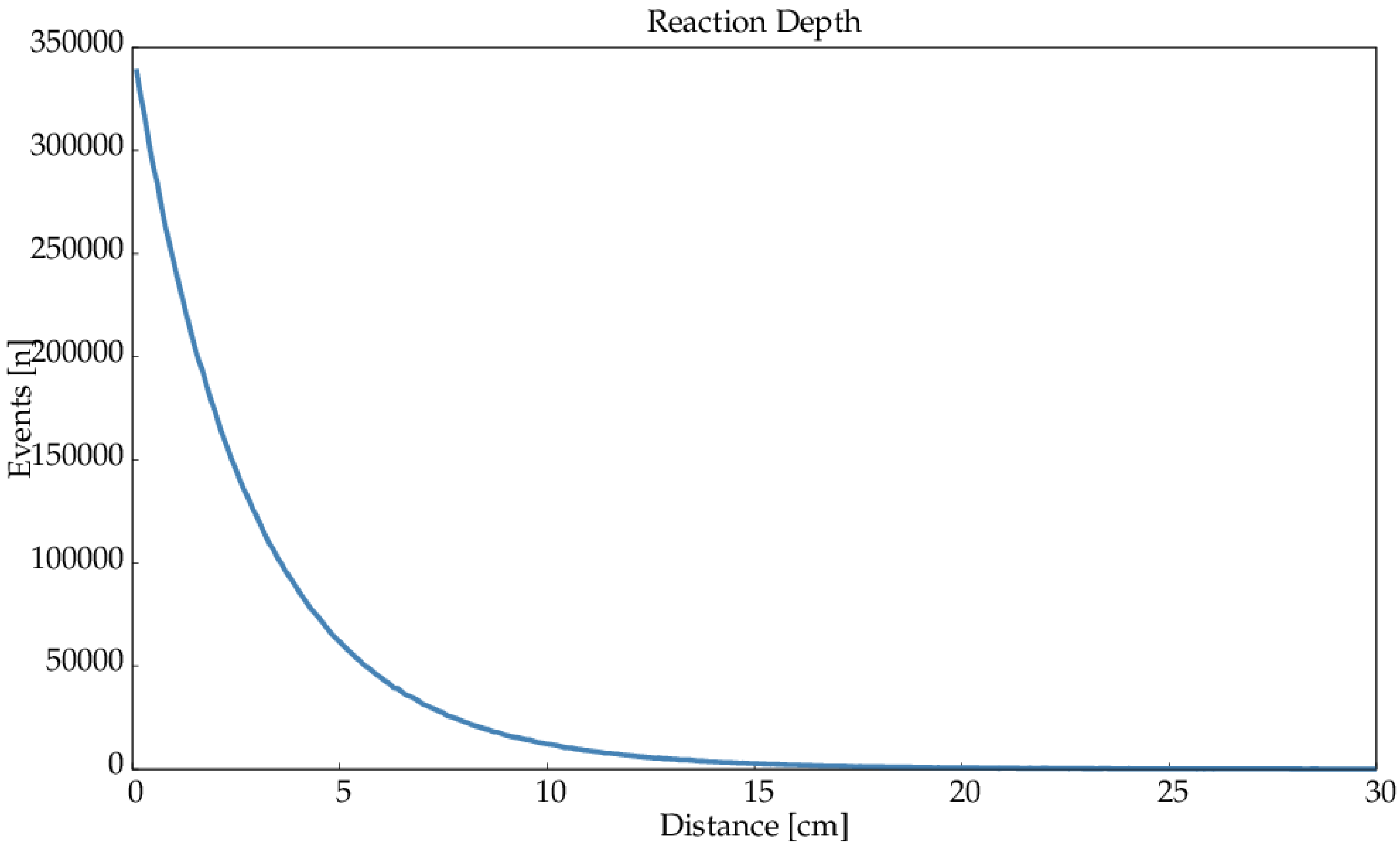


Fit the 2011 beam scan to a gaussian and find the sigma value. Assume both x and y distributions are in the form of gaussians with the same sigma.

Reaction Depth

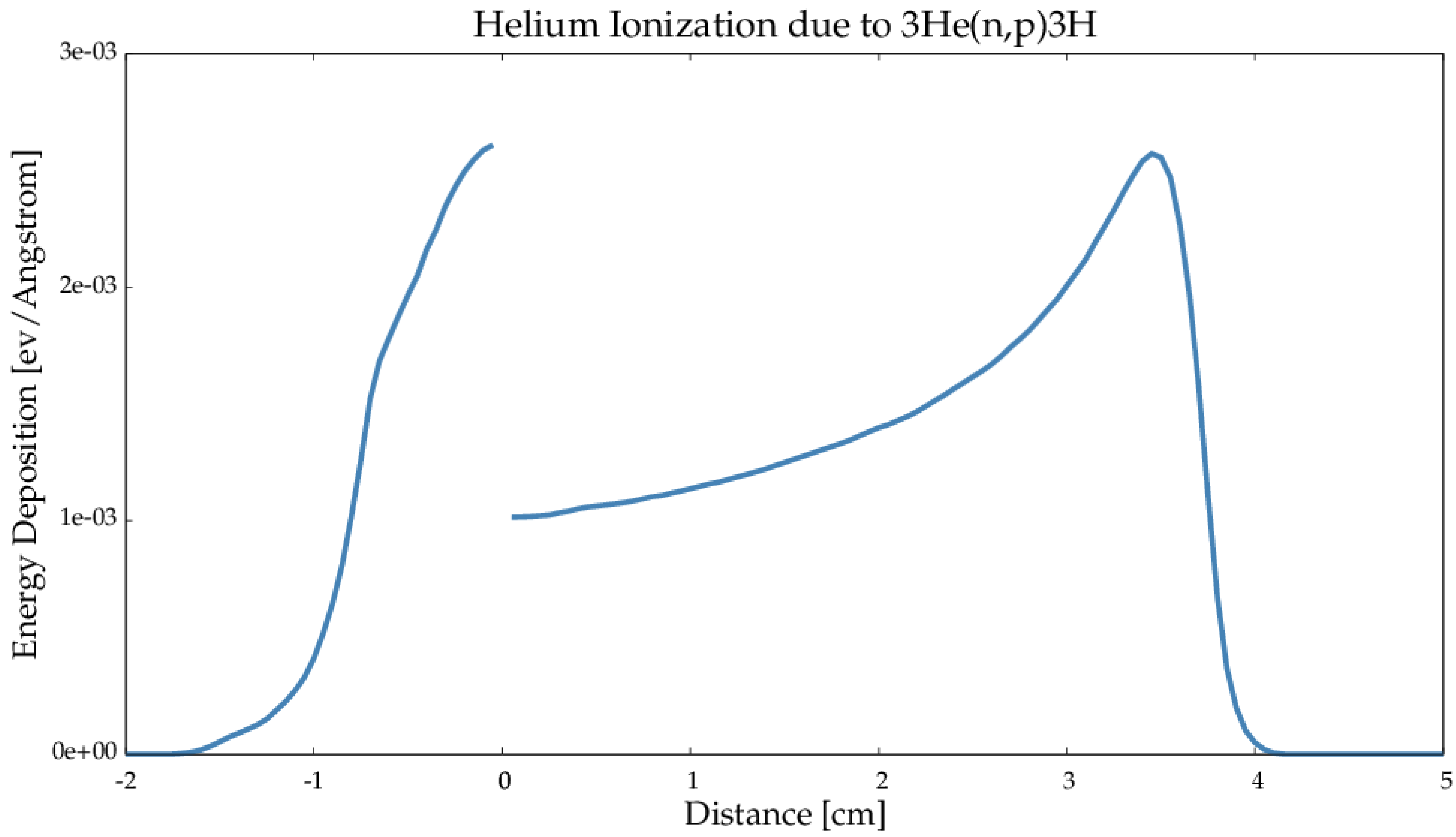


For computational speed, fix linear parameter at -0.5 and curve fit over the relevant region to find the constant coefficient ≈ 2.92709.



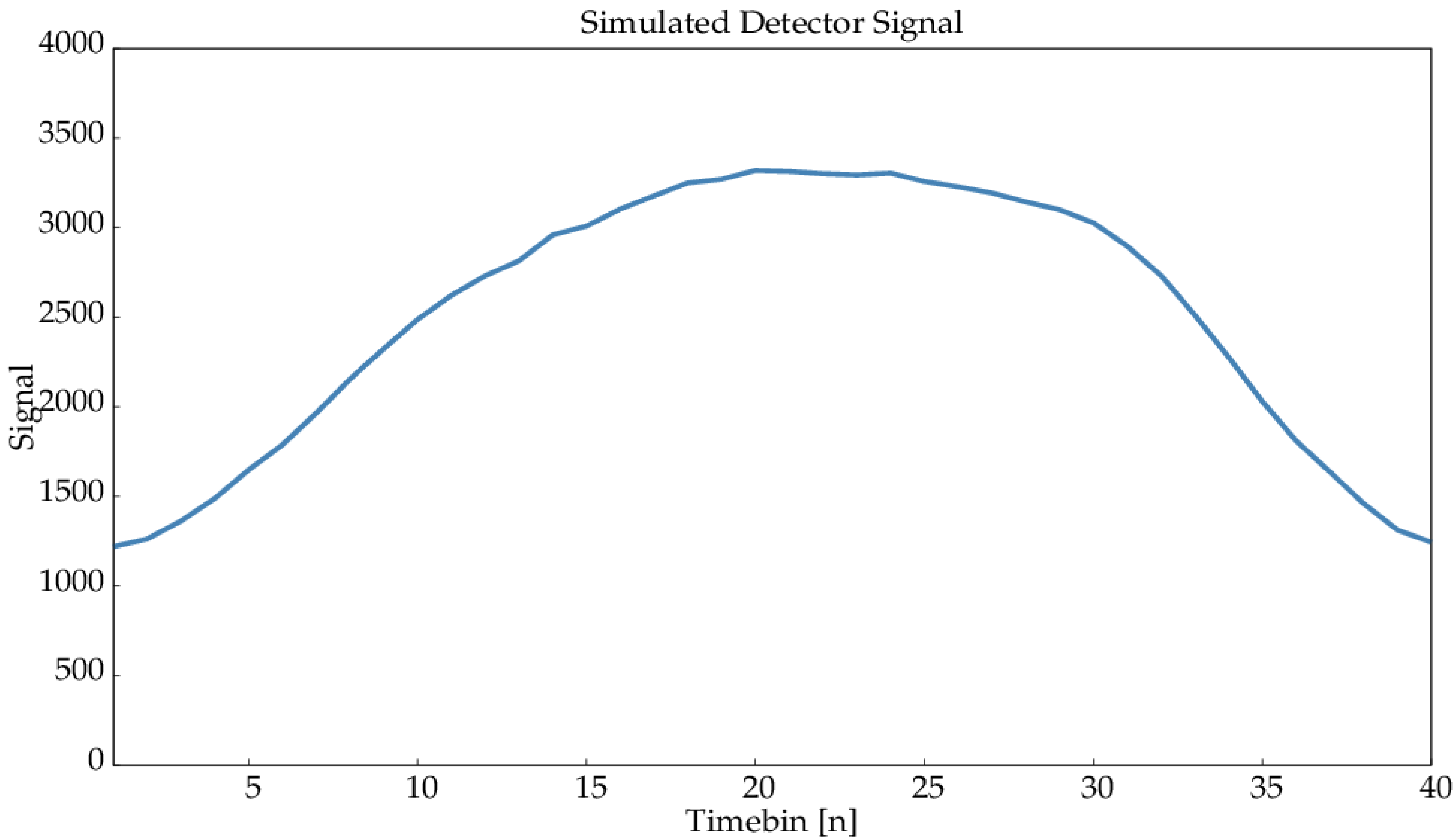
For computational speed, assume F=0 and generate a reaction depth instead of propagating the neutron into the chamber. For a 5Å neutron, 95% of reactions take place within 8cm.

Energy Deposition



Calculation of energy deposition curves with SRIM (srim.org)

Frame Shifting

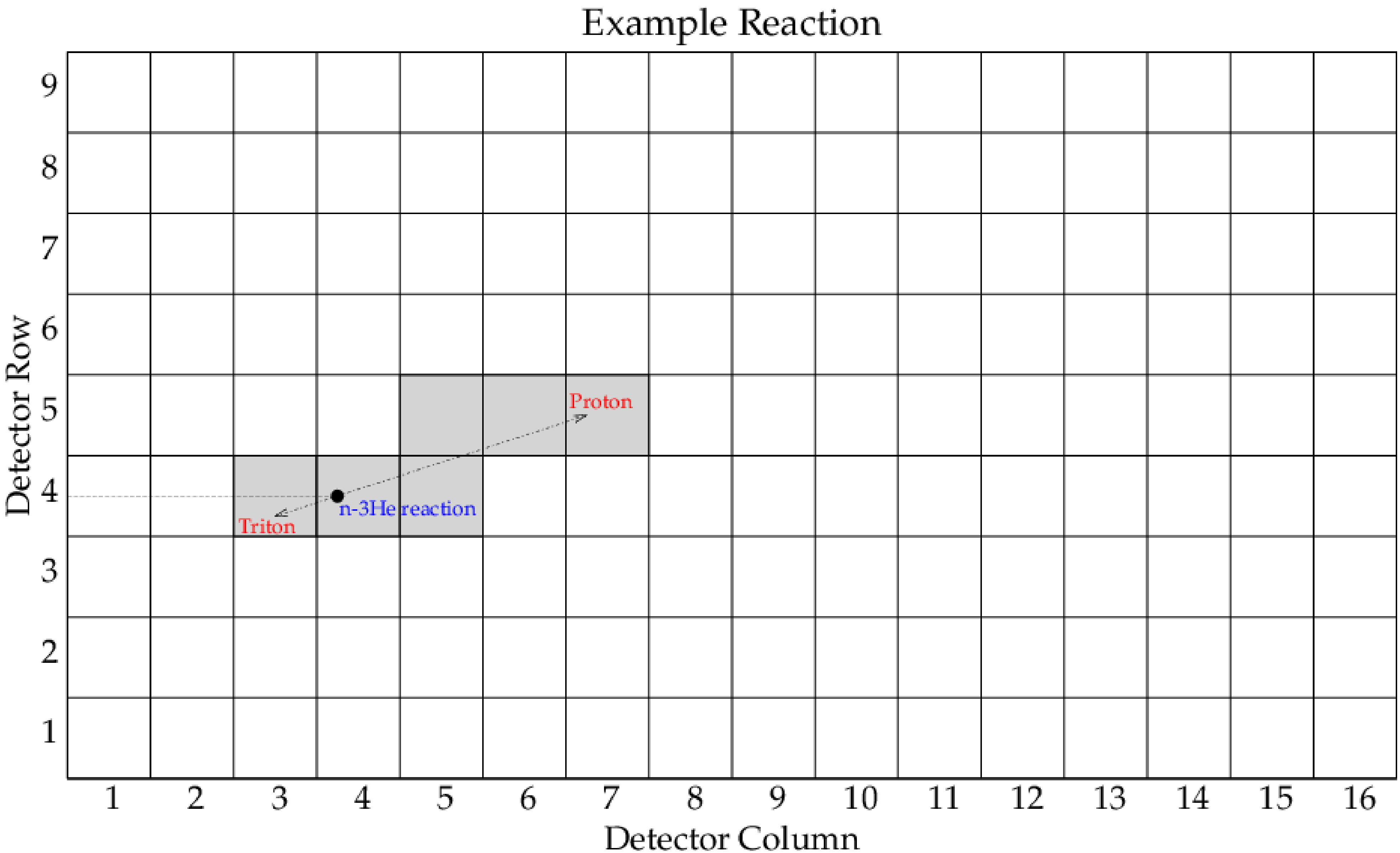


Signal overlap due to pulse broadening. Frame shifts 1.6ms.

Proton emitted isotropically with 573 keV. Triton given opposite velocity and 191 keV.

Particles are tracked until they stop or leave the chamber. The energy depositions in each cell are recorded.

For computational speed, integrate deposition curves to get cumulative deposition, and then subtract at crossing points.


Example Reaction
Detector Row
Detector Column
Proton
Triton
n-3He reaction
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Definition of Geometry Factors

Detectors are given one spatial index k. Choose ordering

$$k = 16(m-1) + n$$

Energy depositions are also indexed by time, t.

The set of depositions due to the i^{th} neutron are given event index i.

In addition, each deposition is dependent on the reaction depth and emission angles of the products:

$$E^{h}_{i,k,t}(z_i, \theta_i, \varphi_i)$$

Note that each event i has a unique set of reaction coordinates.

Neutron events will have a known helicity, h.

Define the “monte carlo average” to be the average of N events:

$$\langle E_{k,t} \rangle = \frac{1}{N} \sum_{i=1}^{N} E_{i,k,t}$$

These are the simulated signals from each cell. So our predicted value for the energy of a cell k at time t is:

$$\langle E_{k,t} (1 + \alpha\, h \cos\theta_{k,t}) \rangle$$

We will compare this predicted value to the experimental yield from a detector with cell index k, at time bin t, measuring the signal from reactions due to neutron beam helicity h:

$$Y_{k,t}^{h}$$

More specifically, we will need a comparison to the arithmetic mean of cell yields for positive and negative helicities:

$$\frac{Y_{k,t}^{+1} - Y_{k,t}^{-1}}{Y_{k,t}^{+1} + Y_{k,t}^{-1}} = \Delta Y$$

Form the corresponding quantity from our predicted values by taking the sum and difference of theoretical yields with opposite helicities:

$$\langle E_{k,t}(1+\alpha h \cos\theta_{k,t})\rangle - \langle E_{k,t}(1-\alpha h \cos\theta_{k,t})\rangle = 2\alpha \langle E_{k,t} \cos\theta_{k,t}\rangle$$
$$\langle E_{k,t}(1+\alpha h \cos\theta_{k,t})\rangle + \langle E_{k,t}(1-\alpha h \cos\theta_{k,t})\rangle = 2\langle E_{k,t}\rangle$$

Now divide the right side to obtain

$$\alpha \frac{\langle E_{k,t} \cos\theta_{k,t}\rangle}{\langle E_{k,t}\rangle}$$

Note the physics asymmetry is an unknown constant.

The term multiplying the alpha is our geometry factor:

$$\alpha \frac{\langle E_{k,t} \cos\theta_{k,t} \rangle}{\langle E_{k,t} \rangle} = \alpha G_{k,t}$$

Along with the arithmetic mean of the yields, this is what we will use with least-squares fit to determine alpha:

$$\chi^2 = \sum_{k,t} \left(\frac{\Delta Y_{k,t} - \alpha G_{k,t}}{\sigma_{k,t}} \right)^2$$

Uncertainties will be explained in Pt II.

Meaning of Geometry Factors

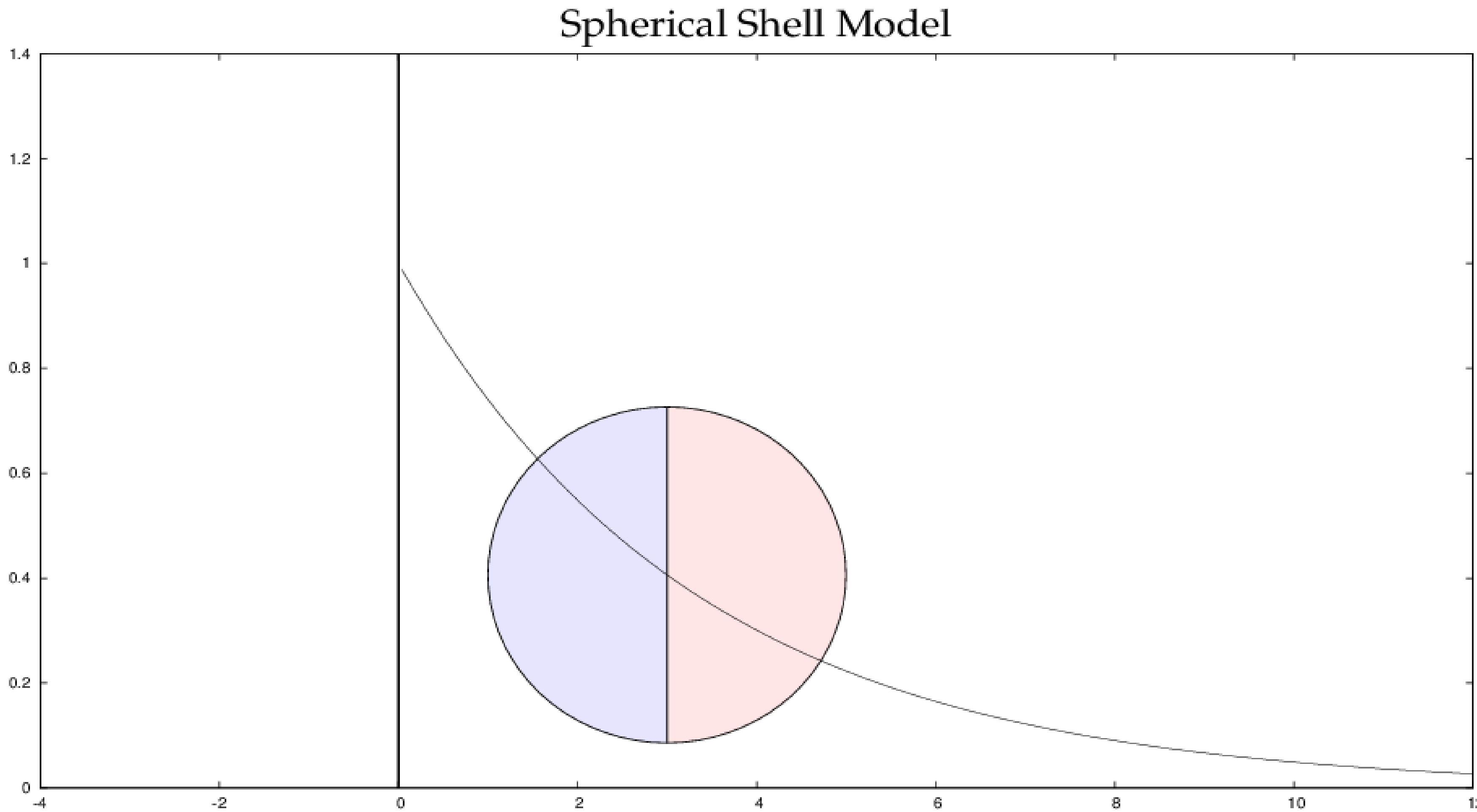
G is a weighted average of Cos(θ) for the energy deposited in cell k at time bin t, where the weights are the associated energies:

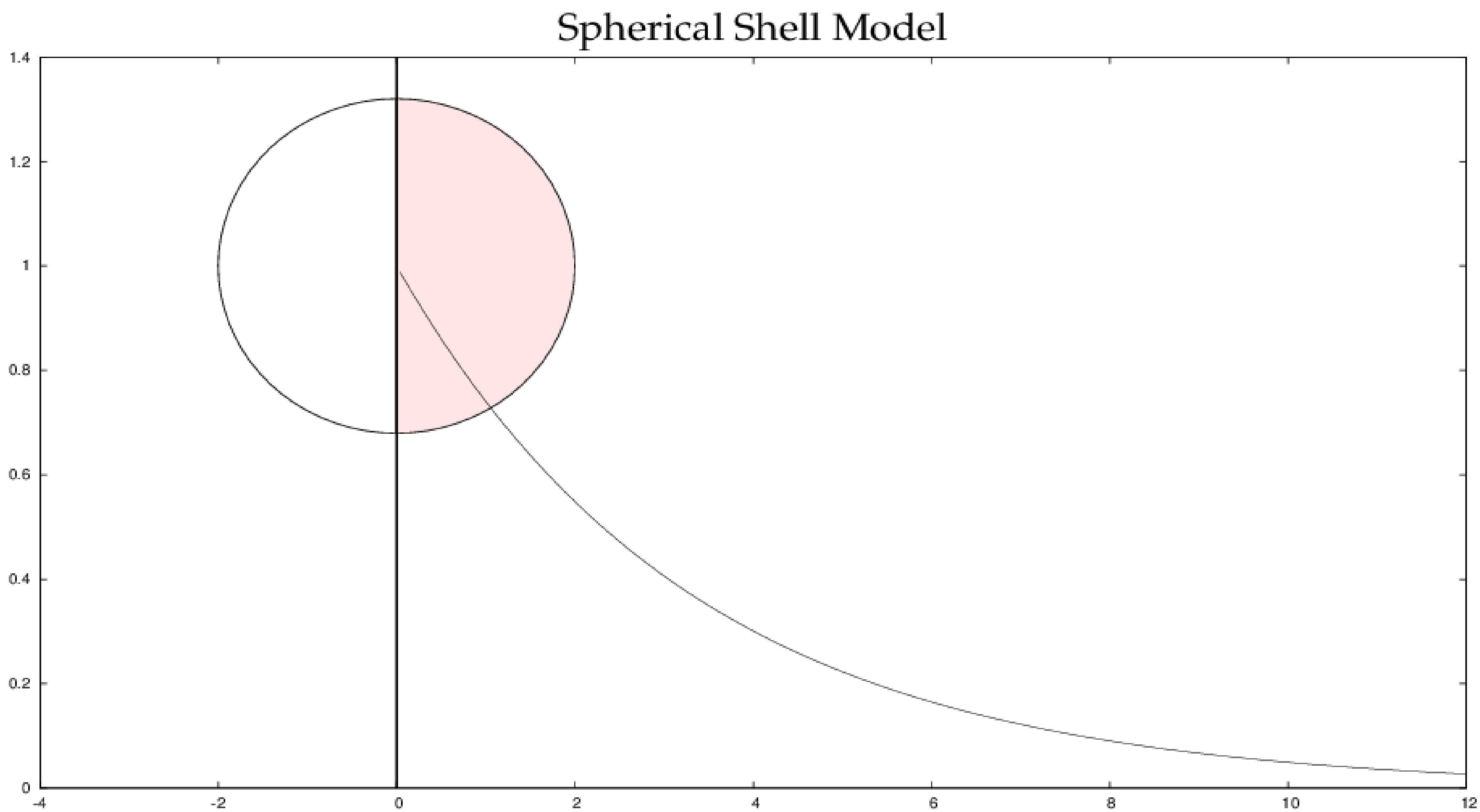
$$G_{k,t} = \frac{\sum_{i=1}^{N} \cos\theta_{i,k,t} \, w_{i,k,t}}{\sum_{i=1}^{N} w_{i,k,t}}$$

$$w_{i,k,t} = E_{i,k,t}$$

G is the ratio of the observables to the physics asymmetry.

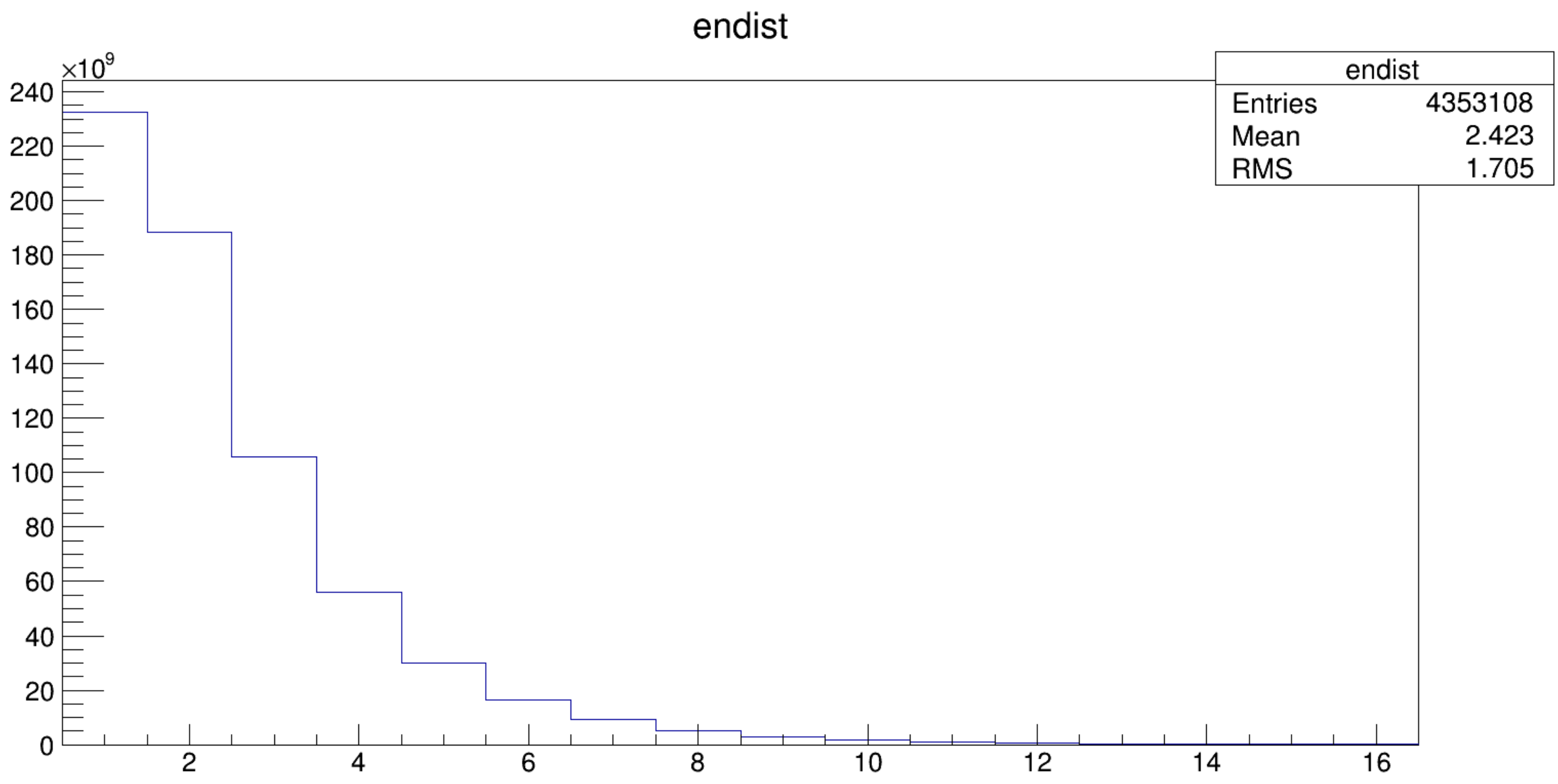
Attenuation and Deposition Volume





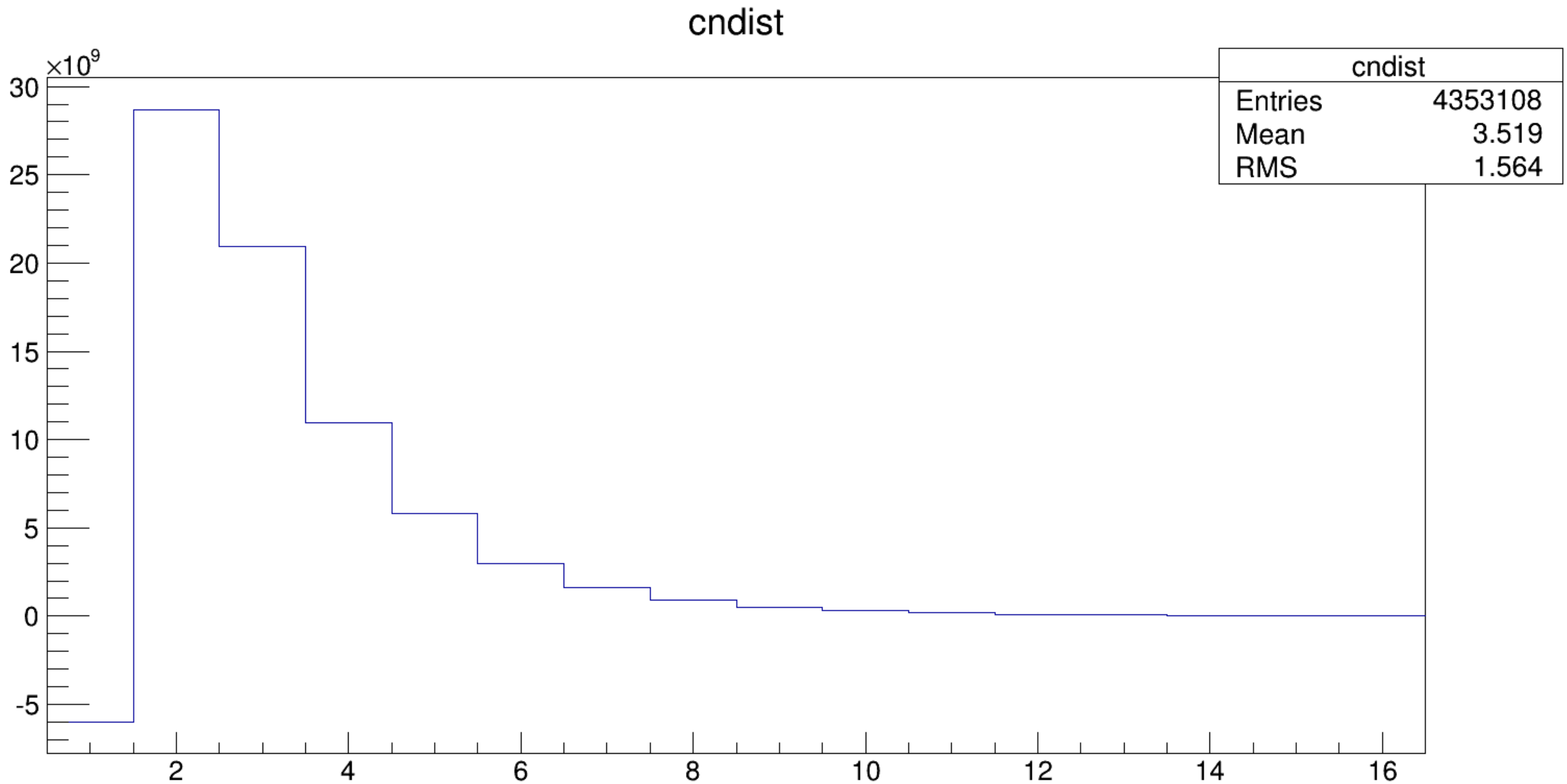
This can also be used to estimate how much reaction energy escapes the Helium chamber. Spherical shell model 16%, Simulations ~15%

Energy per Column



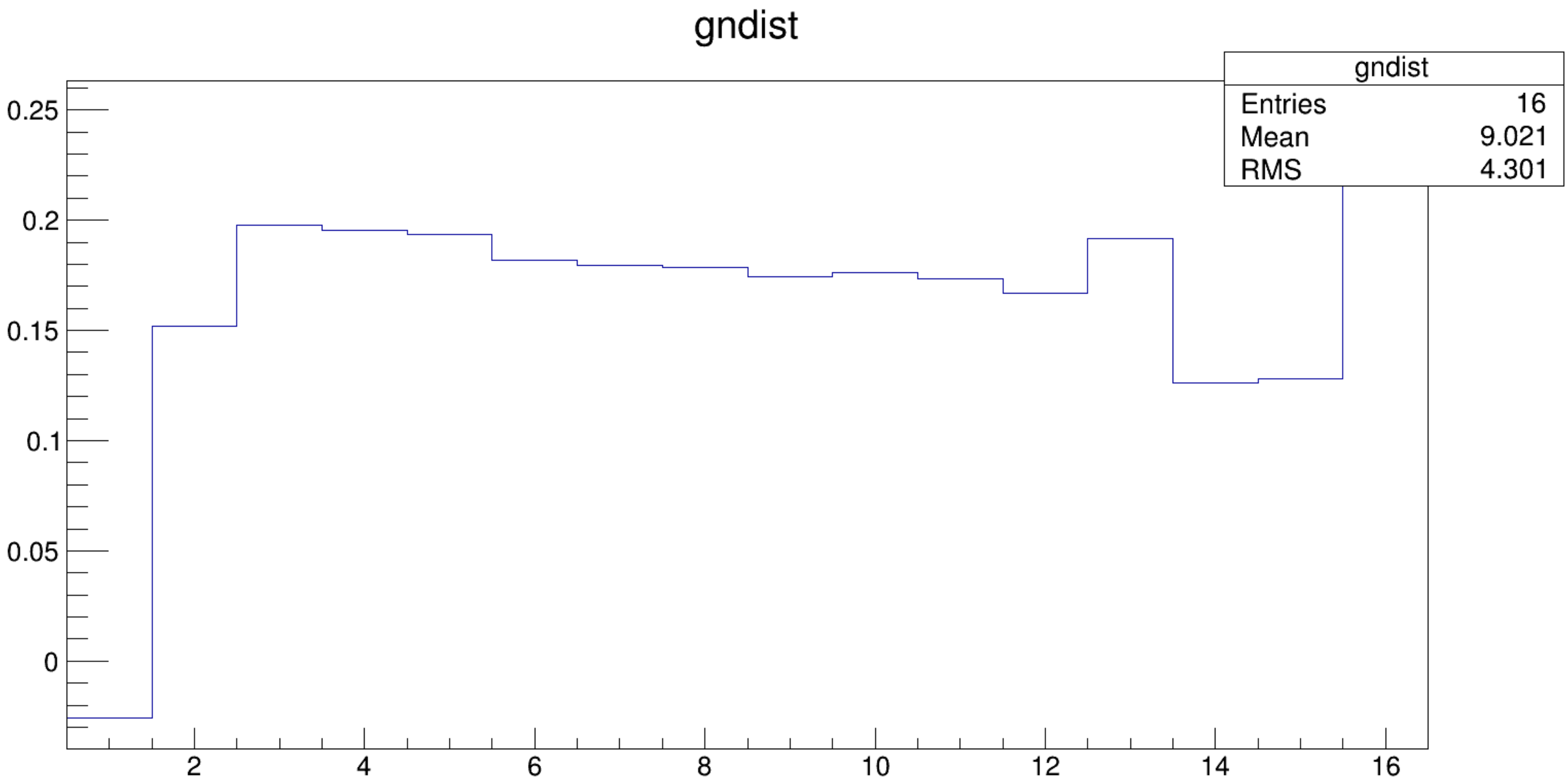
Front cells have 10^3 times more energy than those in the rear.

Energy·Cos(θ) per Column

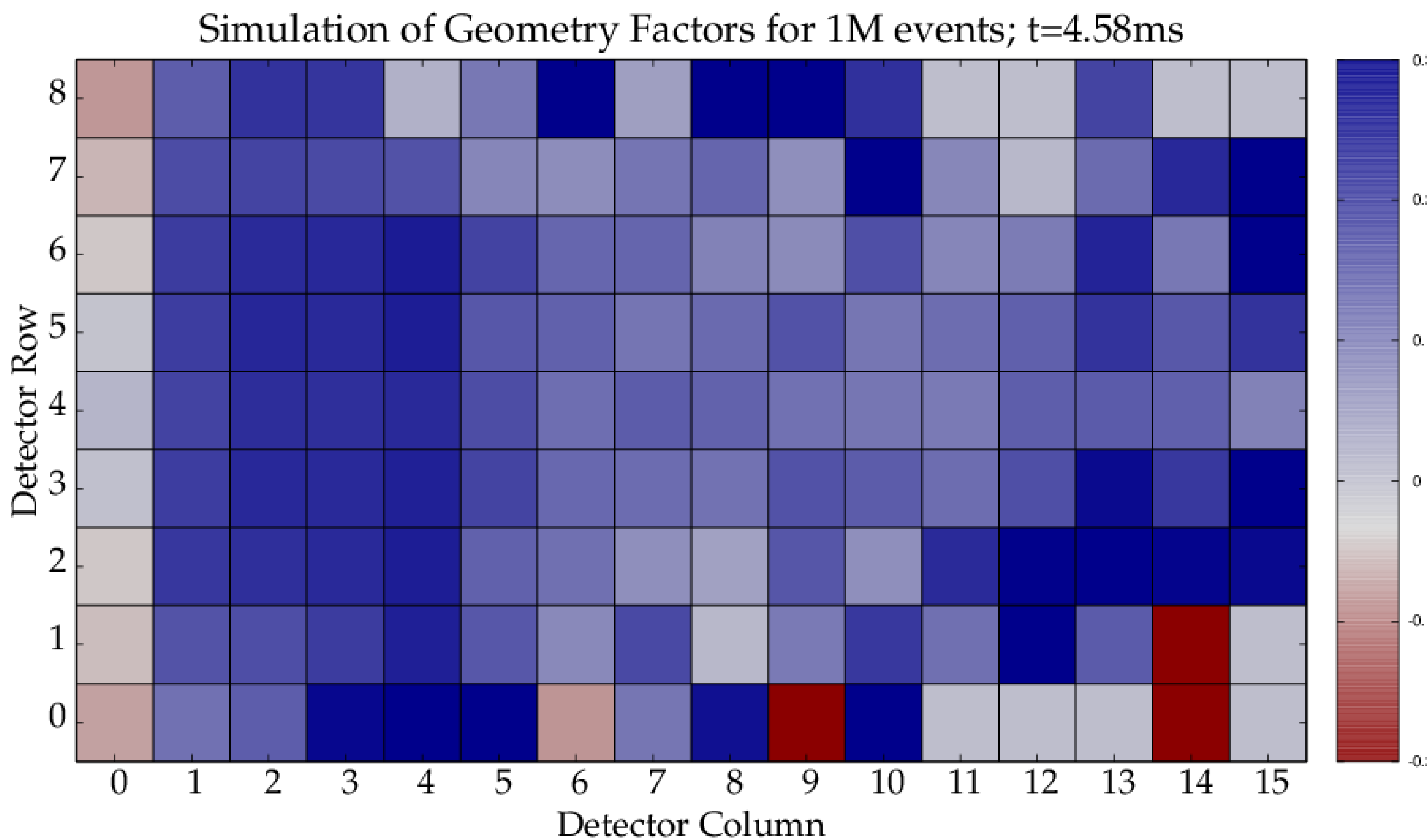


Edge effect causes negative weighted deposition in first ~2cm.

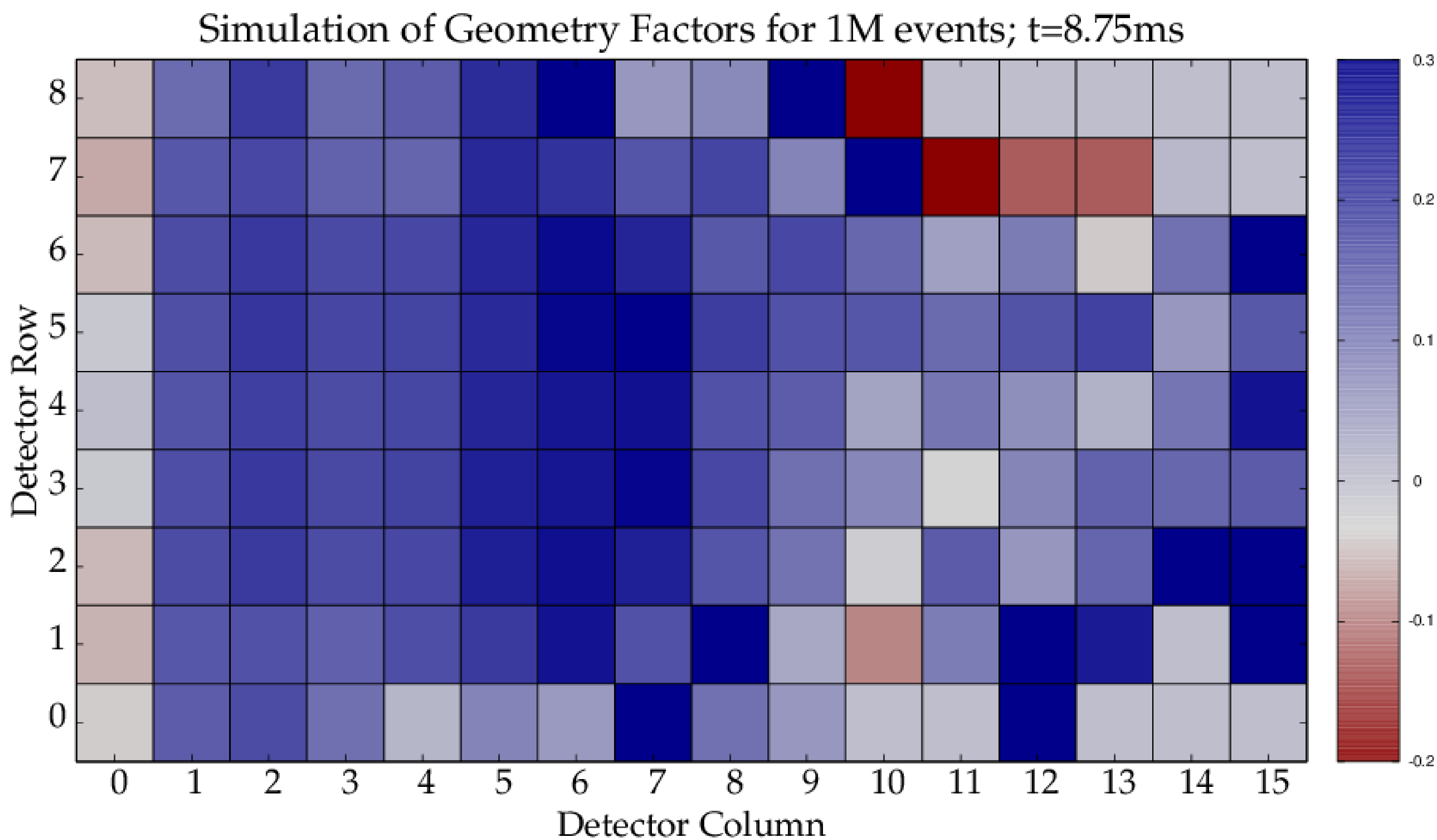
Weighted Average of Cos(θ) per Column



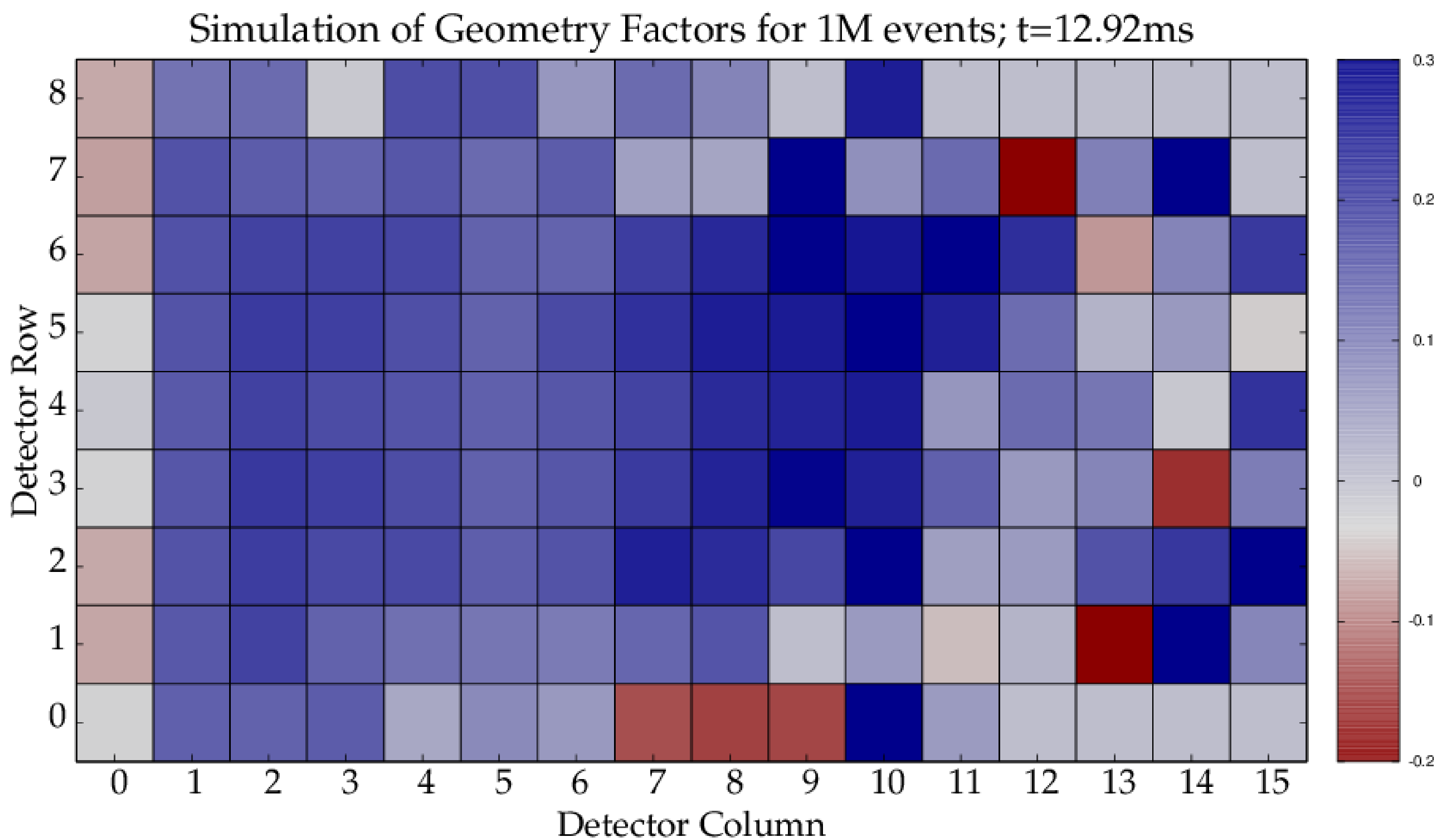
These are like G_n.



Simulation of Geometry Factors for 1M events; t=4.58ms
Detector Row
Detector Column
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.3
0.2
0.1
0
-0.1
-0.2



Simulation of Geometry Factors for 1M events; t=8.75ms
Detector Row
Detector Column
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.3
0.2
0.1
0
-0.1
-0.2


Simulation of Geometry Factors for 1M events; t=12.92ms
Detector Row
Detector Column
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.3
0.2
0.1
0
-0.1
-0.2

Conclusions

Simulated geometry factors match basic analytic comparisons. Adding the extra ~2cm of 3He will shift the -G regions out of the chamber.

It is likely possible to reduce uncertainty in the measured asymmetry by reducing pressure in the chamber (simulation uses 1 atm). A lower pressure would spread the reactions deeper into the chamber and distribute the energies over more cells. There will be some additional energy leakage out of the sides of the chamber, so an optimization calculation could find the pressure which produces the smallest uncertainty in alpha.

The next talk will include an explanation of statistical analysis.