Testing the Maxwell-Boltzmann Relationship for Thermal Neutron Velocities

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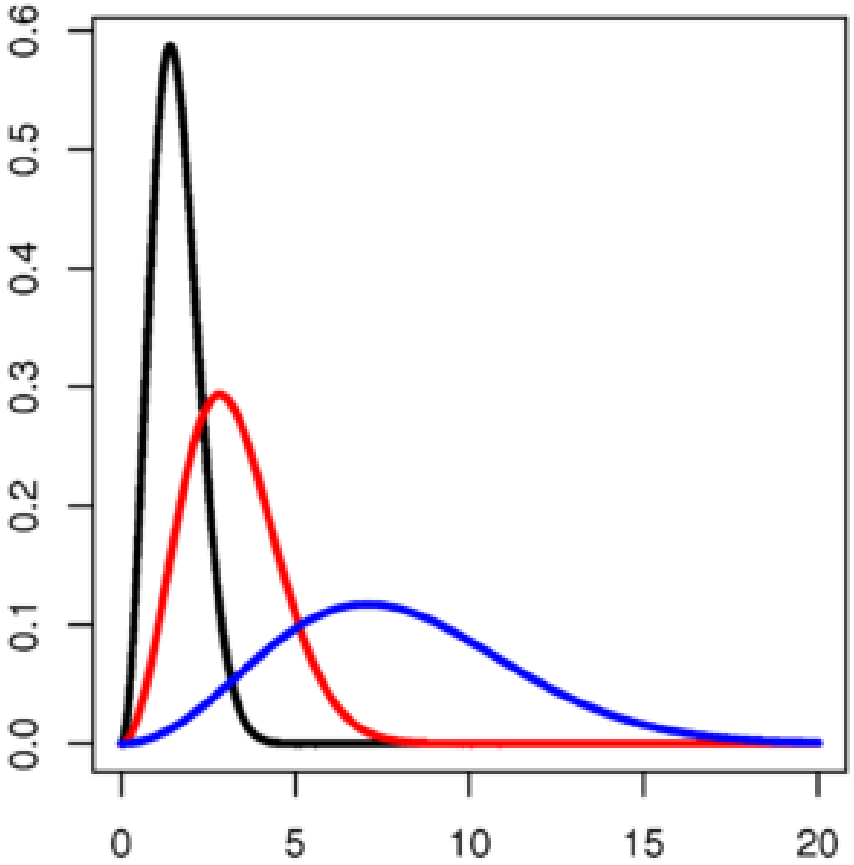
Experimental Goals

- **Overlying Question:** What is the thermal neutron velocity distribution?
- Test the Maxwell-Boltzmann prediction of the velocity distribution for thermodynamic particles
- Determine the energy and temperature of thermal neutrons

Neutron Energies

Fast	>1 eV
Slow	≤ 0.4 eV
Hot	0.2 eV
Thermal	0.025 eV
Cold	5×10^{-5}–0.025 eV
Ultra Cold	$< 3\times10^{-6}$ eV

The Maxwell-Boltzmann Distribution



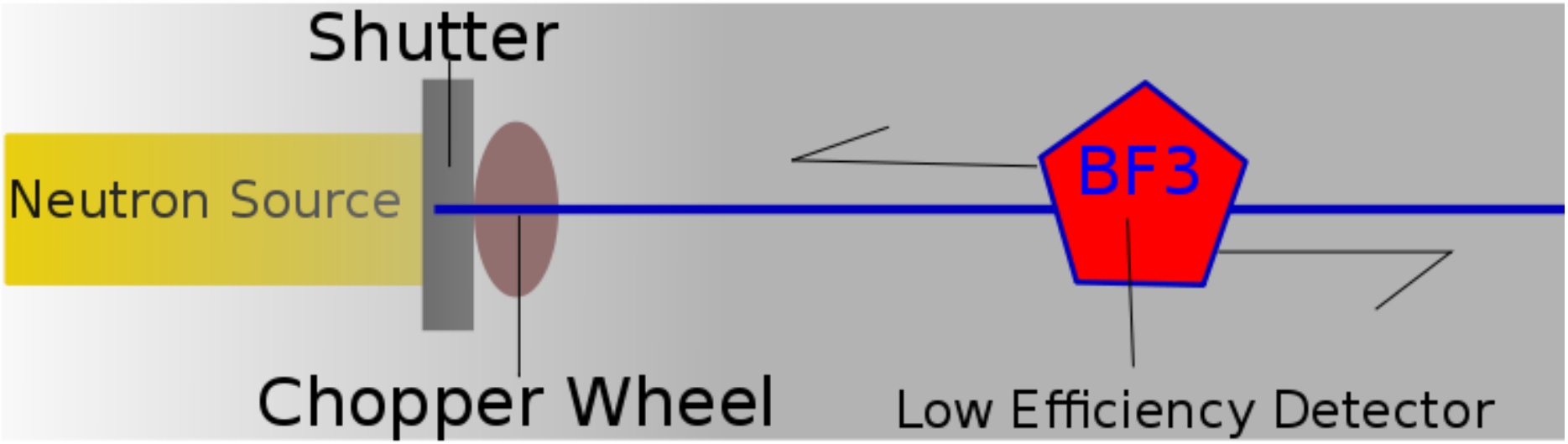
- $\frac{N_i}{N} = \frac{g_i \exp\left(-\frac{E_i}{kT}\right)}{\Sigma_j g_j \exp\left(-\frac{E_j}{kT}\right)}$
- $E = \frac{mv^2}{2}$

Maxwell-Boltzmann Velocity Distribution

$$f(v) = 4\pi \left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 \exp\left(-\frac{mv^2}{2kT}\right)$$

http://en.wikipedia.org/wiki/File:Maxwell-Boltzmann_distributionPDF.png

Experimental Setup



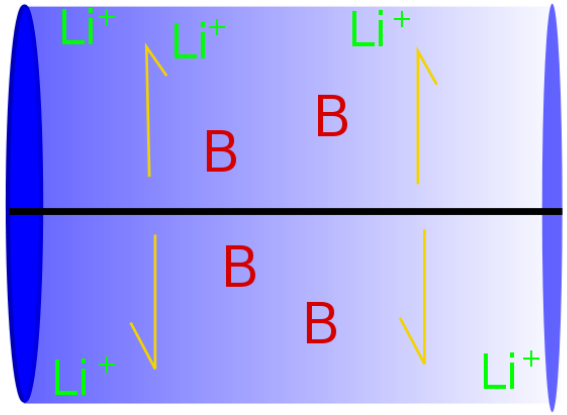
- Detector sends signal to counter which stores data on computer
- Efficiency of detector $\approx 1\%$

Neutron Detection

BF_3 Detector Reaction

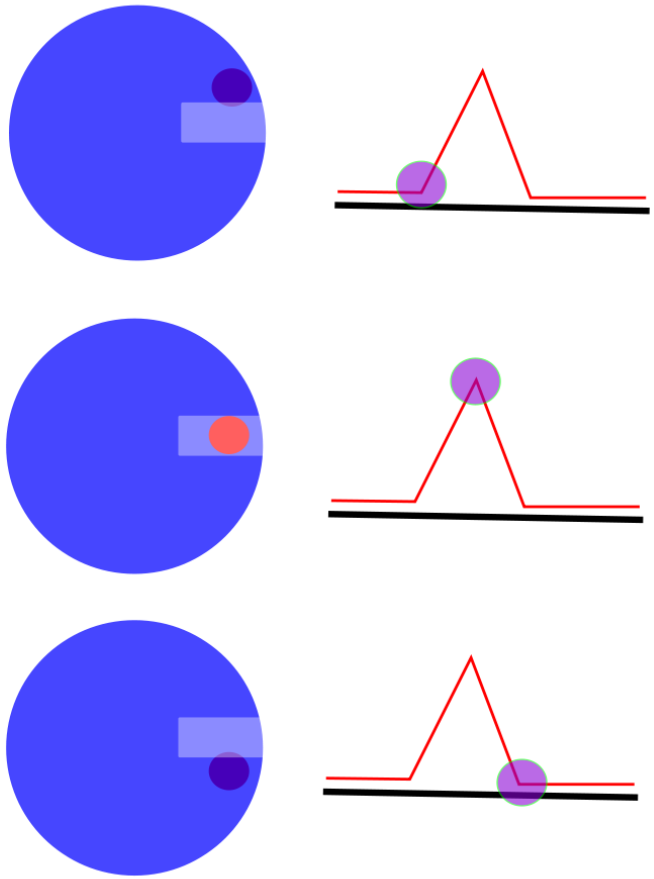
$$ {}^{1}_{0}n + {}^{10}_{5}B \rightarrow {}^{7}_{3}Li + {}^{4}_{2}He \tag{1} $$

- Electric field in detector collects ionized nuclei



Chopper Wheel

To determine the flux change as the chopper wheel moves past the beam, consider the convolution:



Observations

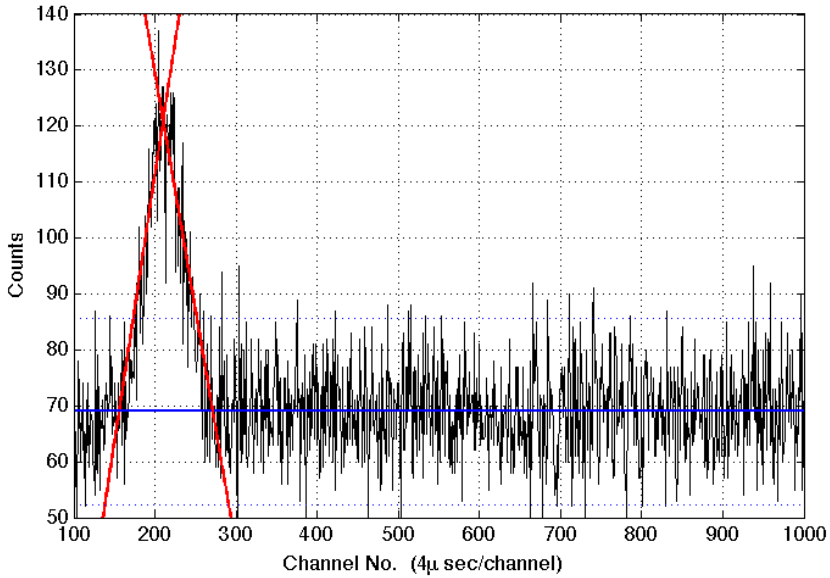


Figure: Time of flight measurement .08 meters away from source

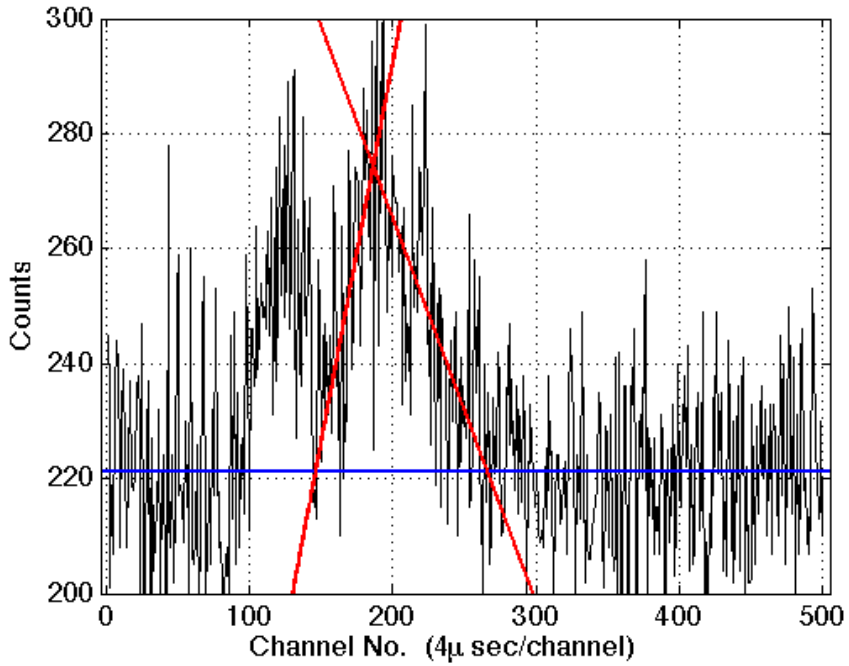
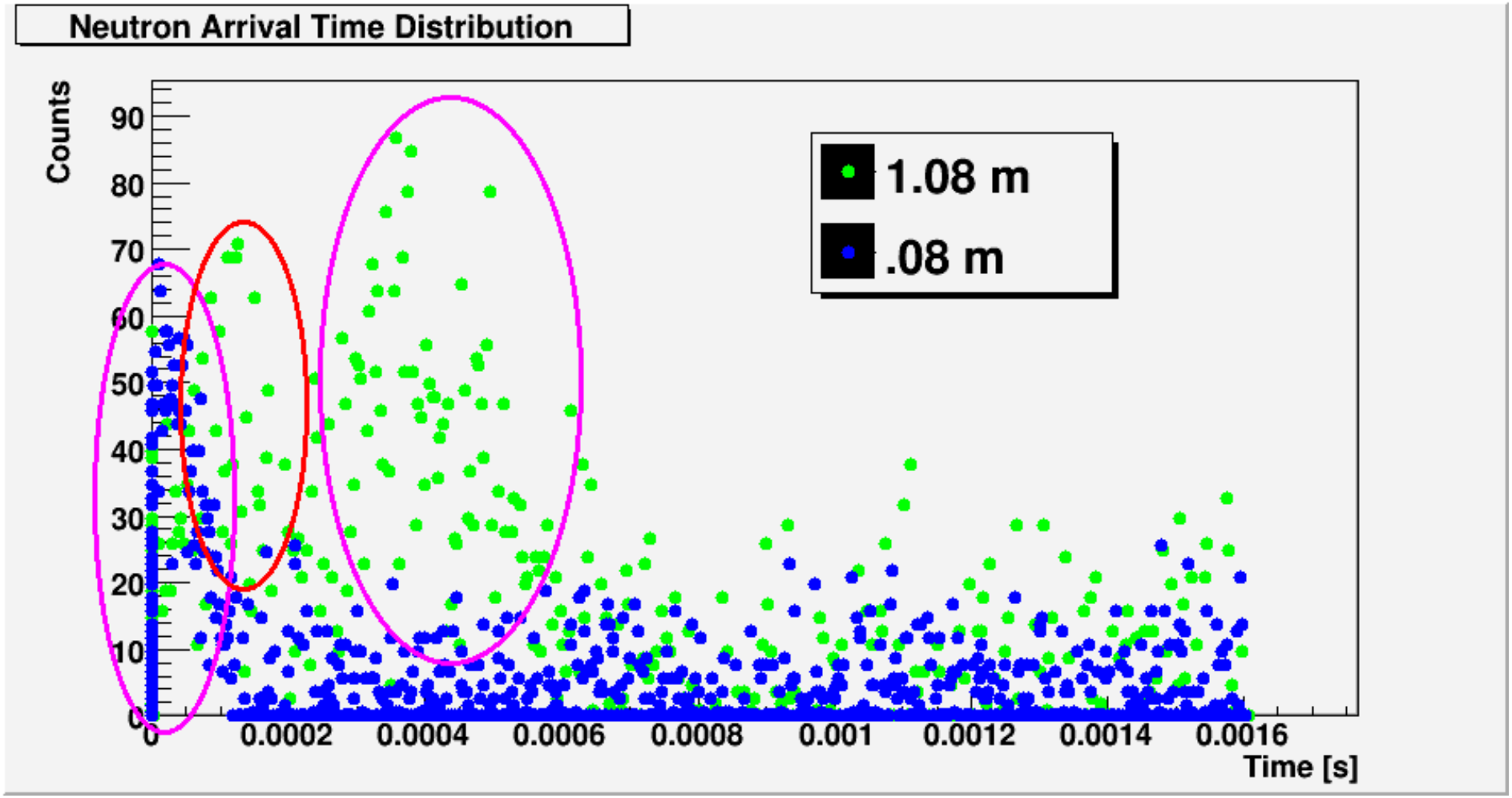


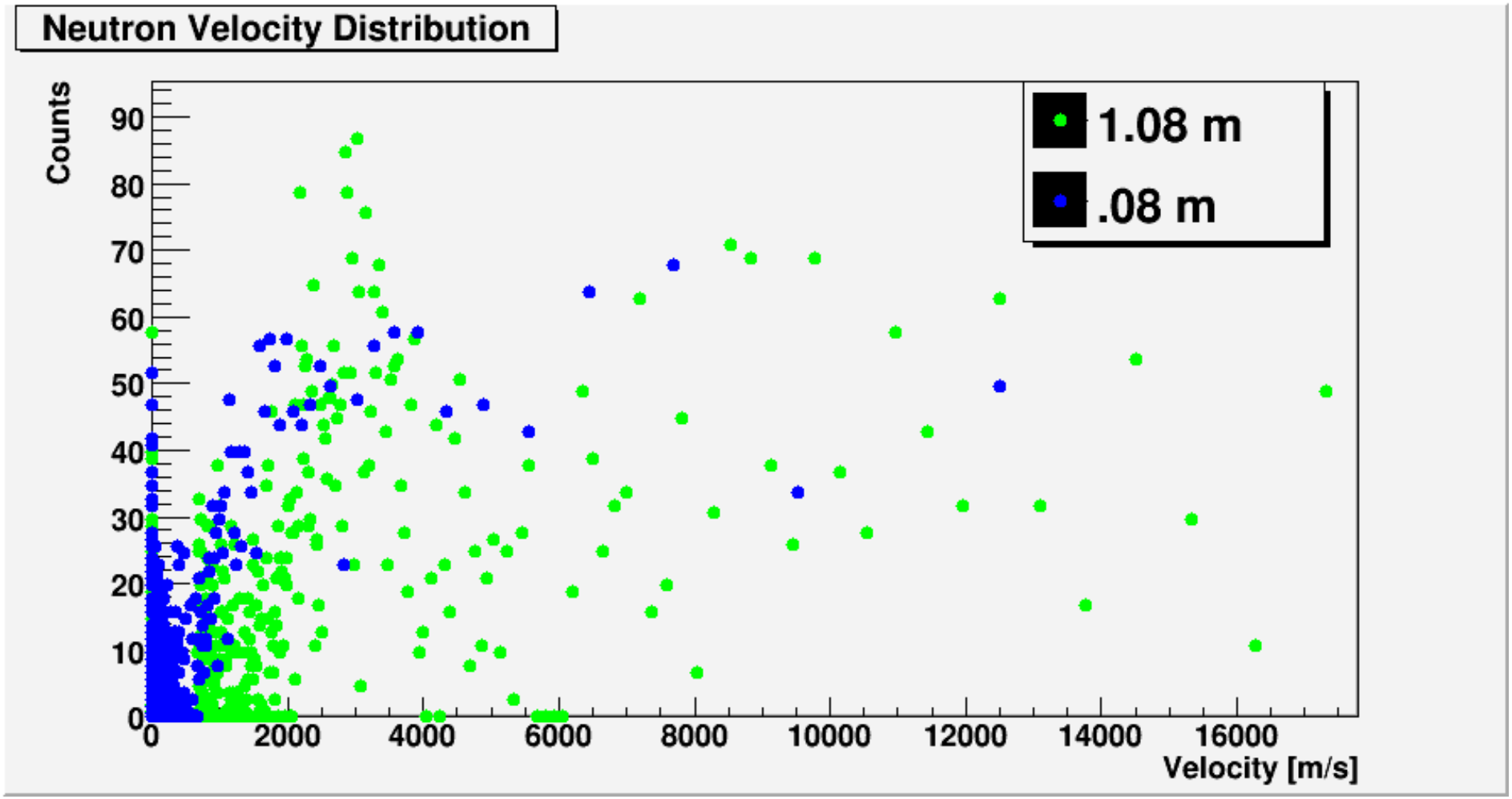
Figure: Time of flight measurement 1.08 meters away from source

Time Scale


Neutron Arrival Time Distribution
Counts
90
80
70
60
50
40
30
20
10
0
0
0.0002
0.0004
0.0006
0.0008
0.001
0.0012
0.0014
0.0016
Time [s]
1.08 m
.08 m

Velocity Distribution

Results



Velocity Distribution

Comparison

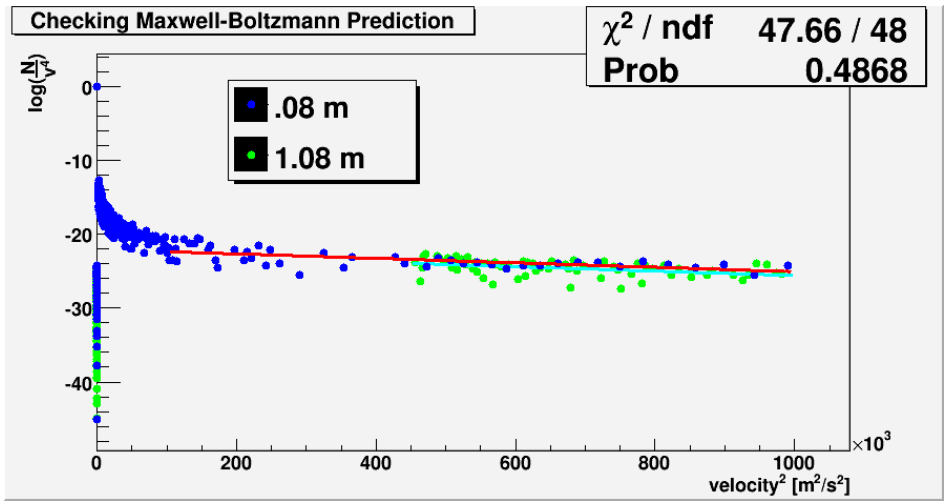


Figure: Fixing $v_{0,1.08m}$ and $v_{0,.08m}$ to 2300 m/s

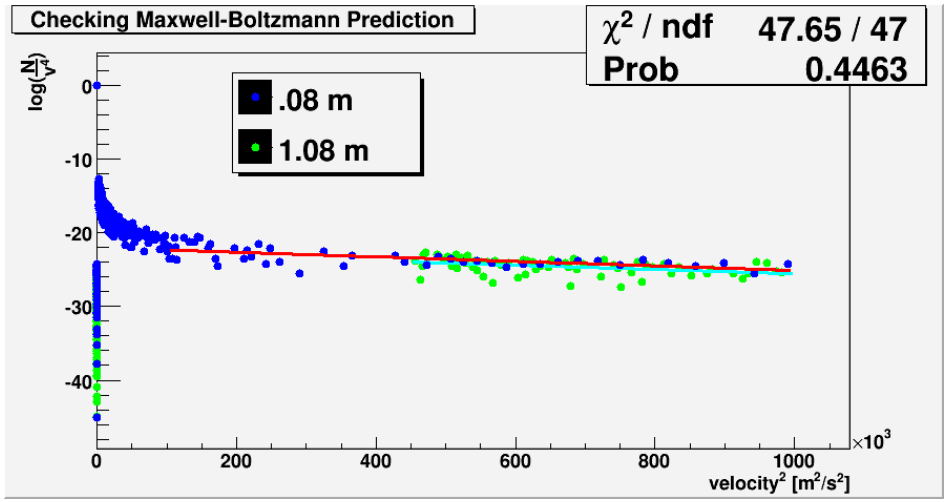


Figure: $v_{0,1.08m} = 585.7 \pm 105$m/s, $v_{0,.08m} = 570.0 \pm 57.6$

Results

Quantity	Predicted	Measured	σ
v_0 [m/s]	≈ 2300	585.7	105
E_0 [eV]	0.027	.002	.005
T_0 [K]	320.4	20.7	8.1

Error Analysis

- Random Error
  - Noise: There is a significant noise of $\approx 50\%$ the peak
  - Fitting Errors: Fitting errors amounted to $\approx 20\%$ for v_0 calculations and 5% for time–adjustment measurements
  - Statistical Error: Inherent 68% chance that results will fall outside Maxwell-Boltzmann predictions
- Systematic Error
  - Distance uncertainty: Distance measurements were all precise to the millimeter, so uncertainty ($.5 \times 10^{-3}$m) is small
  - Overlap with fast neutrons: Regions overlap $\approx .0001$ second and fast neutron data was rejected in analysis.

Conclusions

- The neutron velocity distribution follows a Maxwell-Boltzmann distribution
- Measured neutron energies did not match the expected energies, but were still within range of being thermal
- Expected values fit observations

Acknowledgements

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