Potential of Neutron Gun as A New Calibration source

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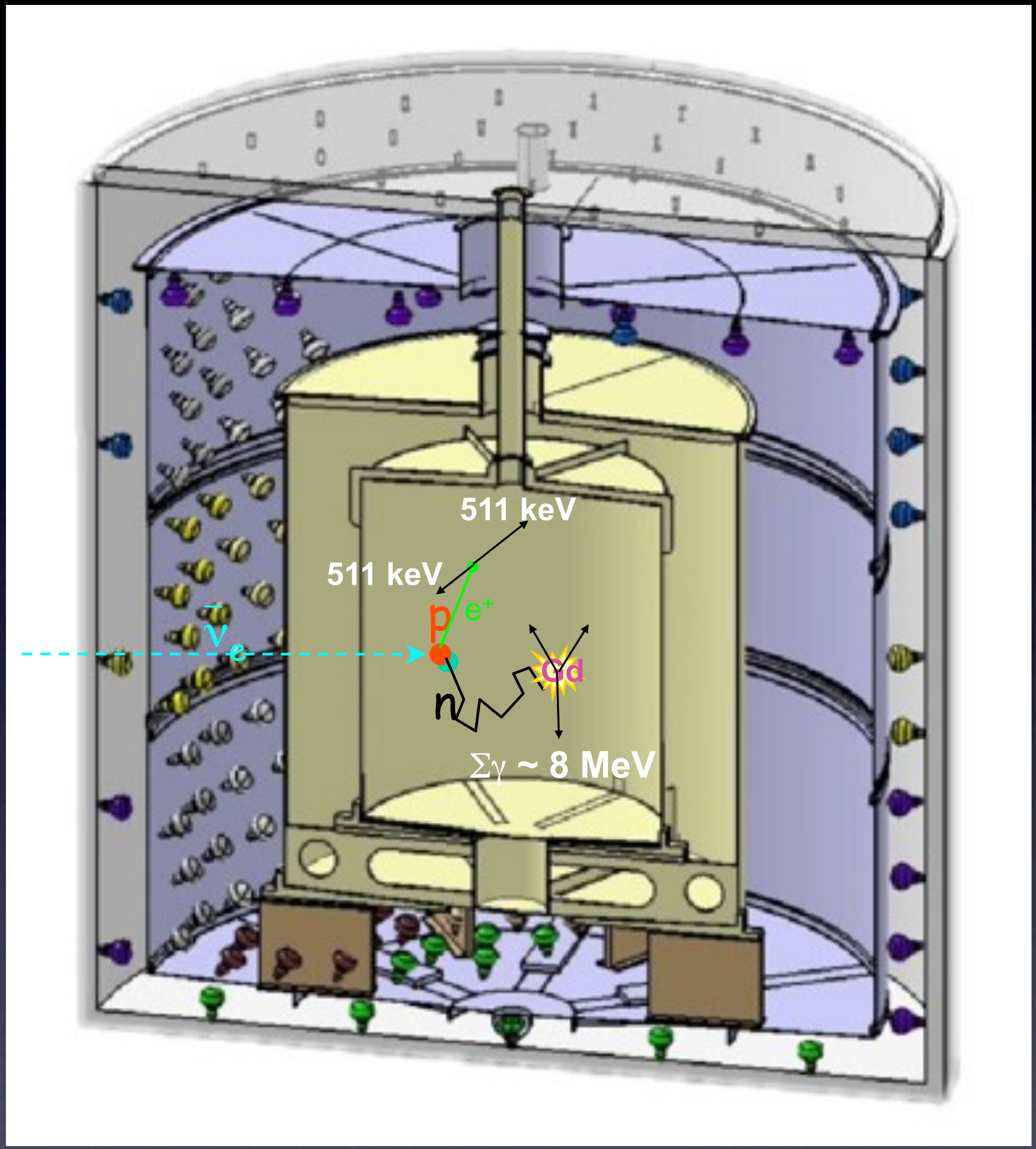
Detector Review

Target Volume (LS + Gd) 10.3m^3

LS = proton rich target to induce inverse beta decay + Gd to achieve high efficiency on neutron capture. Acrylic vessel.



Gamma Catcher (LS) 22.6m^3

To contain capture gamma inside the target volume. Made of an acrylic vessel.

Buffer (natural oil) 110m^3

To keep low singles due to radioactivity of PMTs.

Inner muon veto (cheap LS) 90m^3

Inner muon detector to veto cosmic ray muons

Outer muon tracking veto system

Outer muon tracking system using plastic scintillator based trigger system.

What's on the Neutron's path?

Top

Stainless Steel Shielding (150mm)

IV Stainless Steel Tank (10mm)

IV LS (576mm)

Buffer Stainless Steel Tank (3mm)

Buffer Natural Oil (1051mm)

Gamma Catcher LS (551mm)

Target LS+Gd (2458mm)

Bottom

≈ 2.28m of natural oil
to reach the target

Before presenting my work...

Words from a Nuclear Reactor expert, Prof. Richard Lanza at MIT...

"Wow, this detector is one of the best shielding for fast neutrons I have ever seen!
I would be surprised to see enough statistics inside the target volume to conclude any physics..."

→ If it works, it's great. But we should investigate very, very carefully and make sure it works. Also, most likely, we must be smarter about where/how to install the gun for this project to work.

Neutron Gun Simulation

and

Sanity Check
for
DCGLG4sim Neutron Simulation

Motivation

Investigate whether a neutron gun can be useful or not

How To Simulate

First, we use DCGLG4sim, Geant4 based simulation software with Double CHOOZ geometry loaded.

What Can We Use a Simulation For?

1. Basic study of neutron diffusion in oil

2. Check the validity of low energy (≤MeV) neutron simulation in Geant4.

3. Full simulation of neutron transport from the top to the bottom of the detector.

Part 1

Simulation of 2.4 MeV Neutrons

in

Target (LS+Gd)

G-Catcher (LS)

Buffer (Natural Oil)

Motivation

Simulate 2.4MeV neutrons in each region and see how far they travel. Basically a simulation out of the box.

Simulation Setup

1e4 neutrons with 2.4MeV K.E. and isotropic momentum distribution are produced in each regions...

- Target (LS + Gd) produced at (0,0,0)
- G-Catcher (LS) produced at (1400,0,0)
- Buffer (natural oil) produced at (2200,0,0)

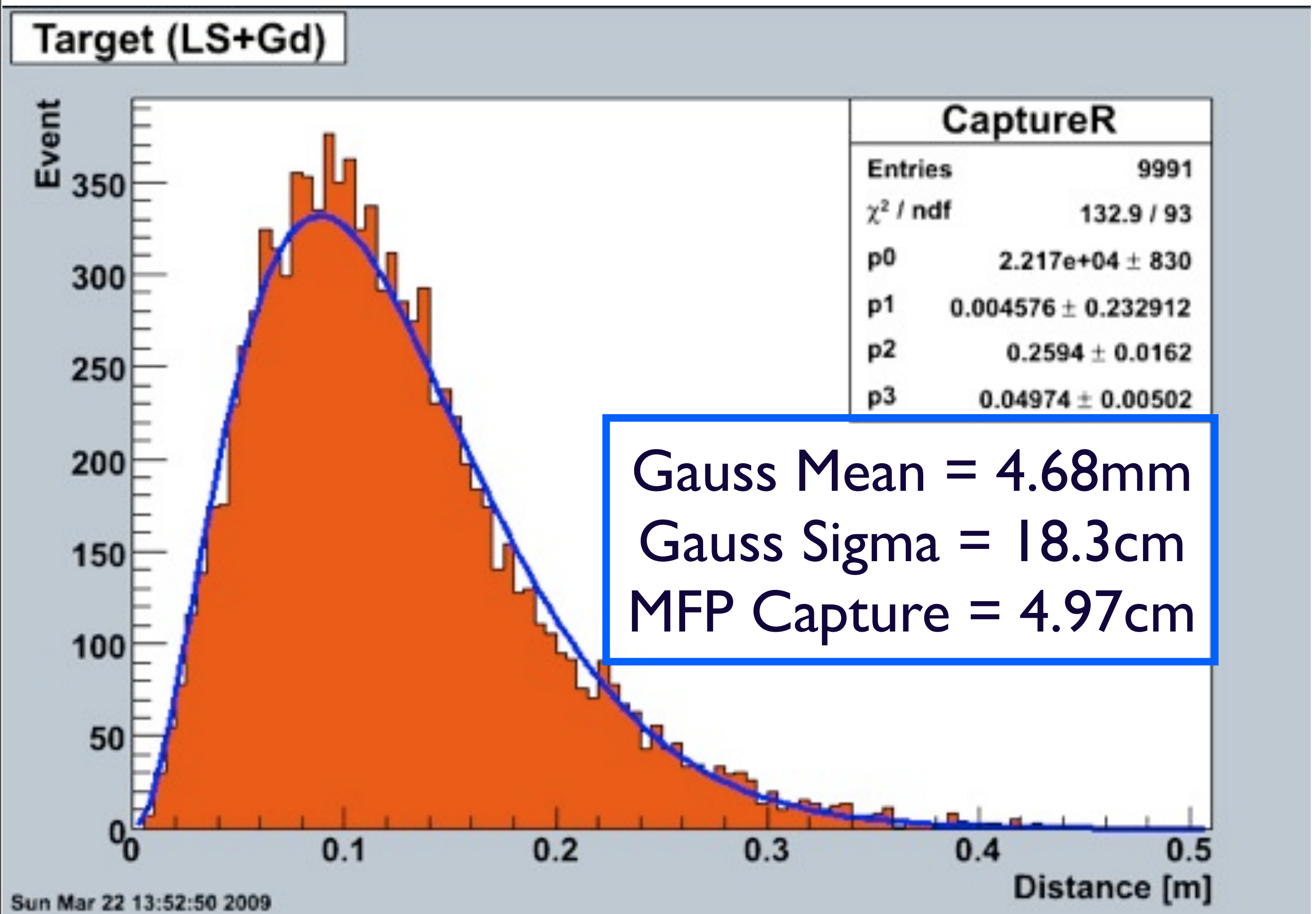
What's Plotted?

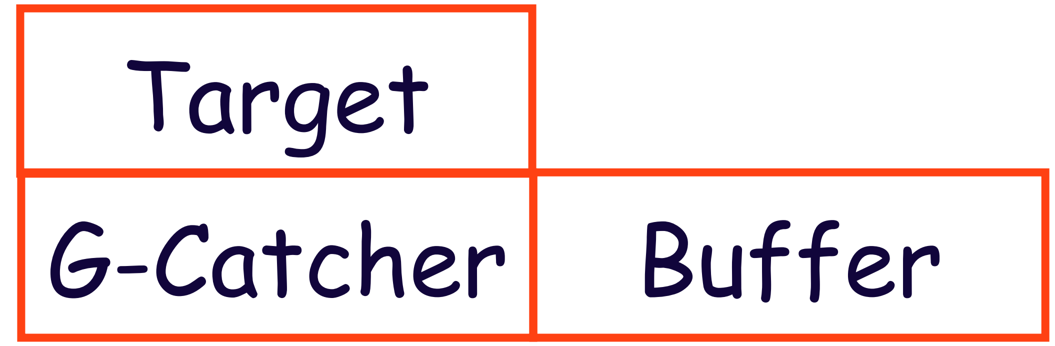
Diffusion ΔR [m] and Capture Time [us] (for a check)

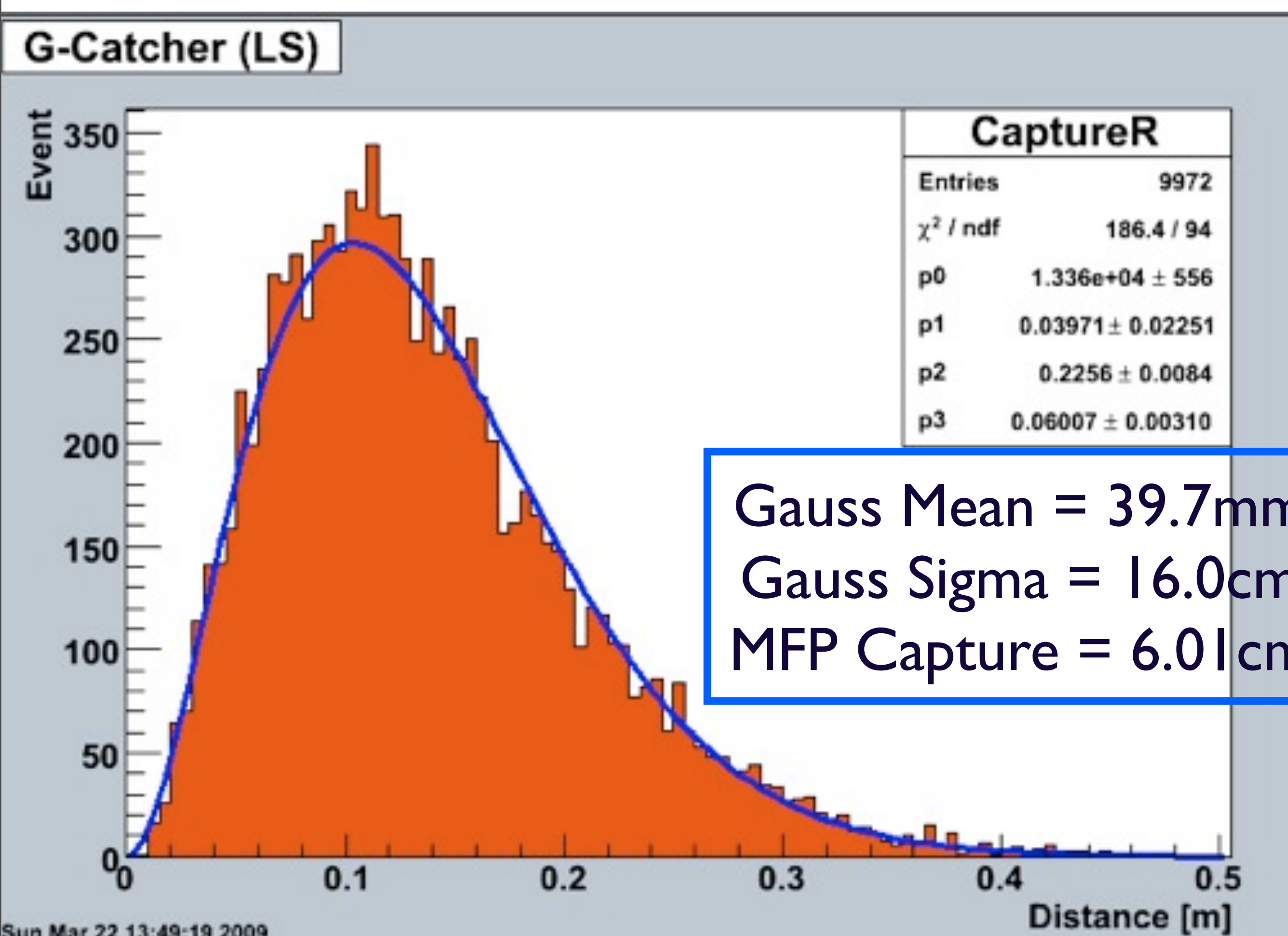
Fitted function:

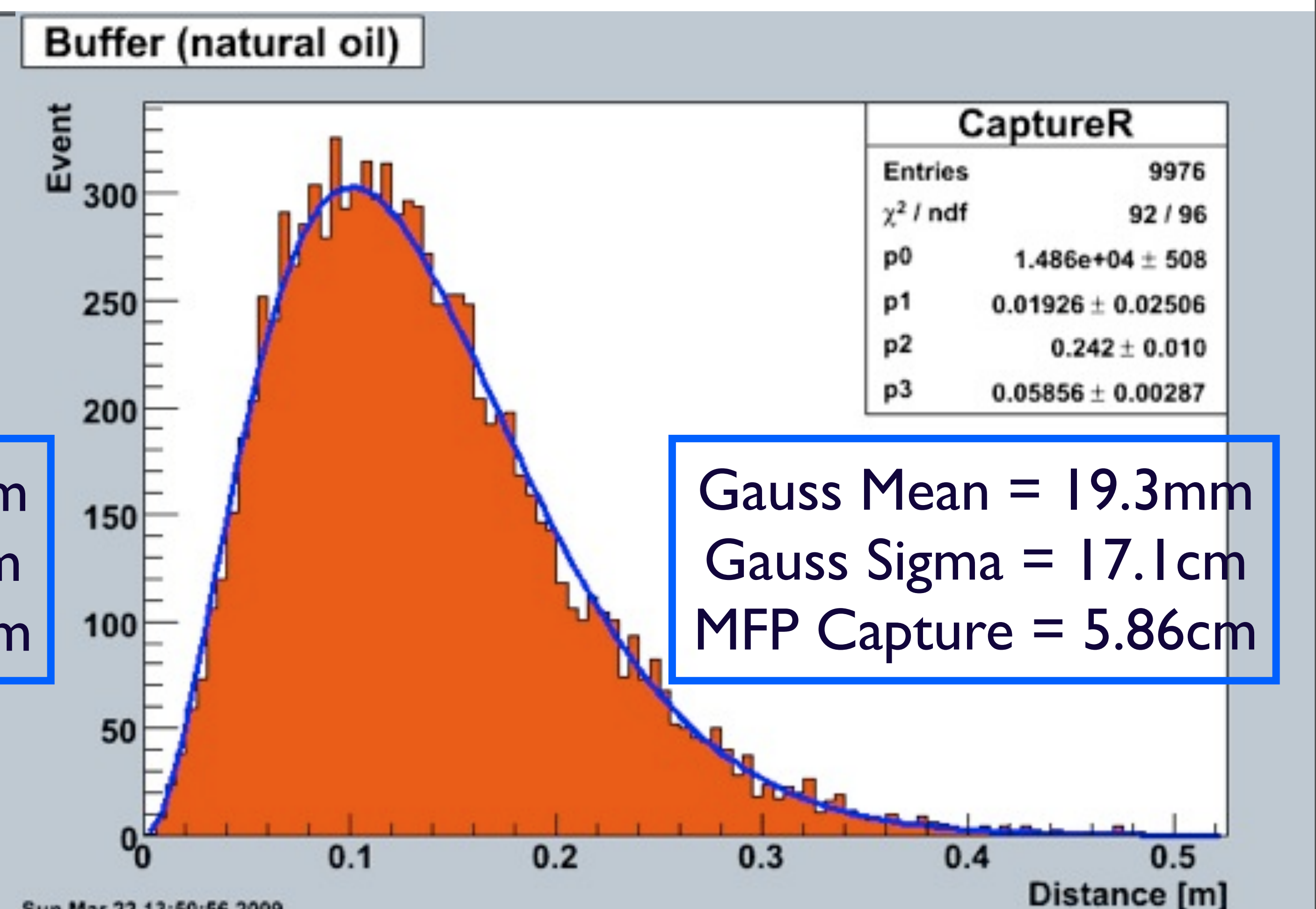
$$\frac{dN(x)}{dx} = 4\pi x^2\,[p0]\exp\left[-\frac{(x-[p1])^2}{[p2]^2} - \frac{x}{[p3]}\right]$$

- Center of the gaussian $x_0 = p1$
- Width of the gaussian $\sigma = p2$
- Characteristic capture length $\lambda = p3$


Target (LS+Gd)
CaptureR
Entries 9991
χ² / ndf 132.9 / 93
p0 2.217e+04 ± 830
p1 0.004576 ± 0.232912
p2 0.2594 ± 0.0162
p3 0.04974 ± 0.00502
Gauss Mean = 4.68mm
Gauss Sigma = 18.3cm
MFP Capture = 4.97cm
Event
Distance [m]
Sun Mar 22 13:52:50 2009


Target
G-Catcher
Buffer

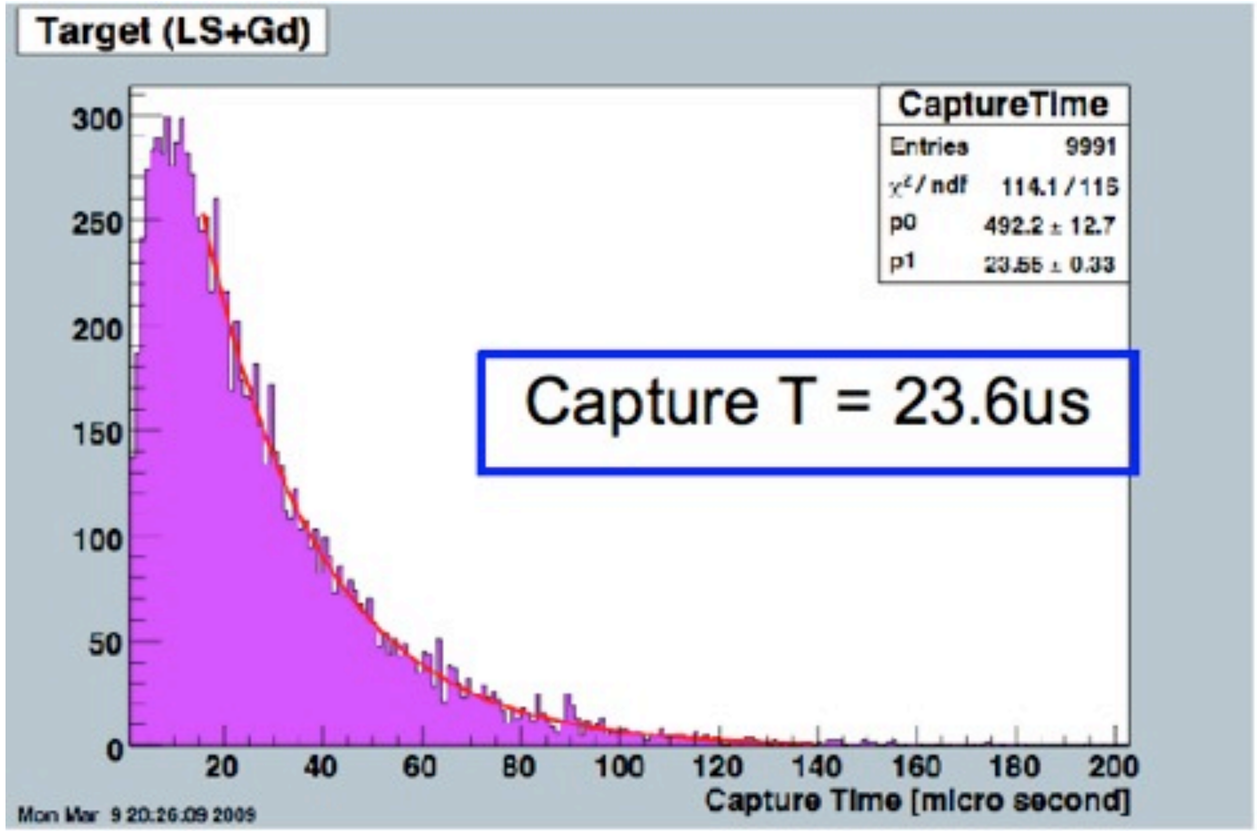

G-Catcher (LS)
CaptureR
Entries 9972
χ² / ndf 186.4 / 94
p0 1.336e+04 ± 556
p1 0.03971 ± 0.02251
p2 0.2256 ± 0.0084
p3 0.06007 ± 0.00310
Gauss Mean = 39.7mm
Gauss Sigma = 16.0cm
MFP Capture = 6.01cm
Event
Distance [m]
Sun Mar 22 13:49:19 2009


Buffer (natural oil)
CaptureR
Entries 9976
χ² / ndf 92 / 96
p0 1.486e+04 ± 508
p1 0.01926 ± 0.02506
p2 0.242 ± 0.010
p3 0.05856 ± 0.00287
Gauss Mean = 19.3mm
Gauss Sigma = 17.1cm
MFP Capture = 5.86cm
Event
Distance [m]
Sun Mar 22 13:50:56 2009

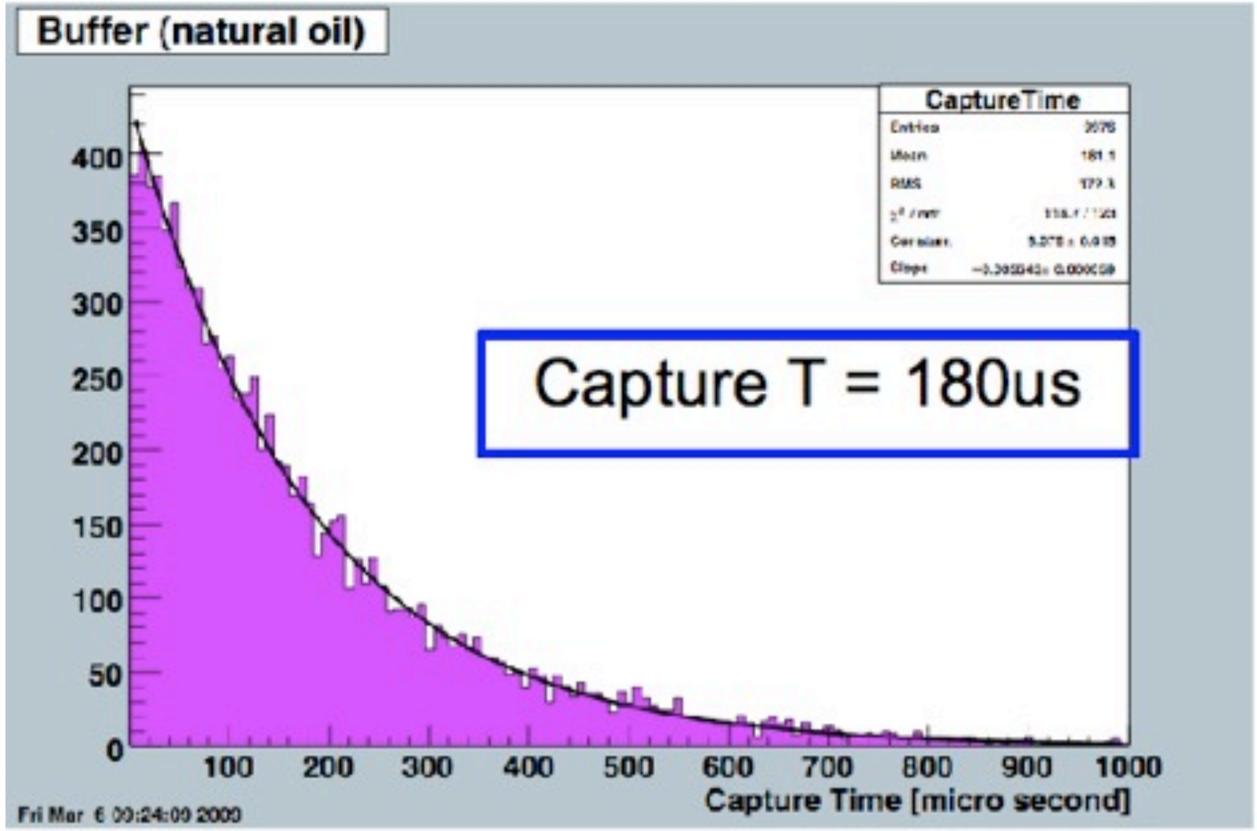
In above plots...

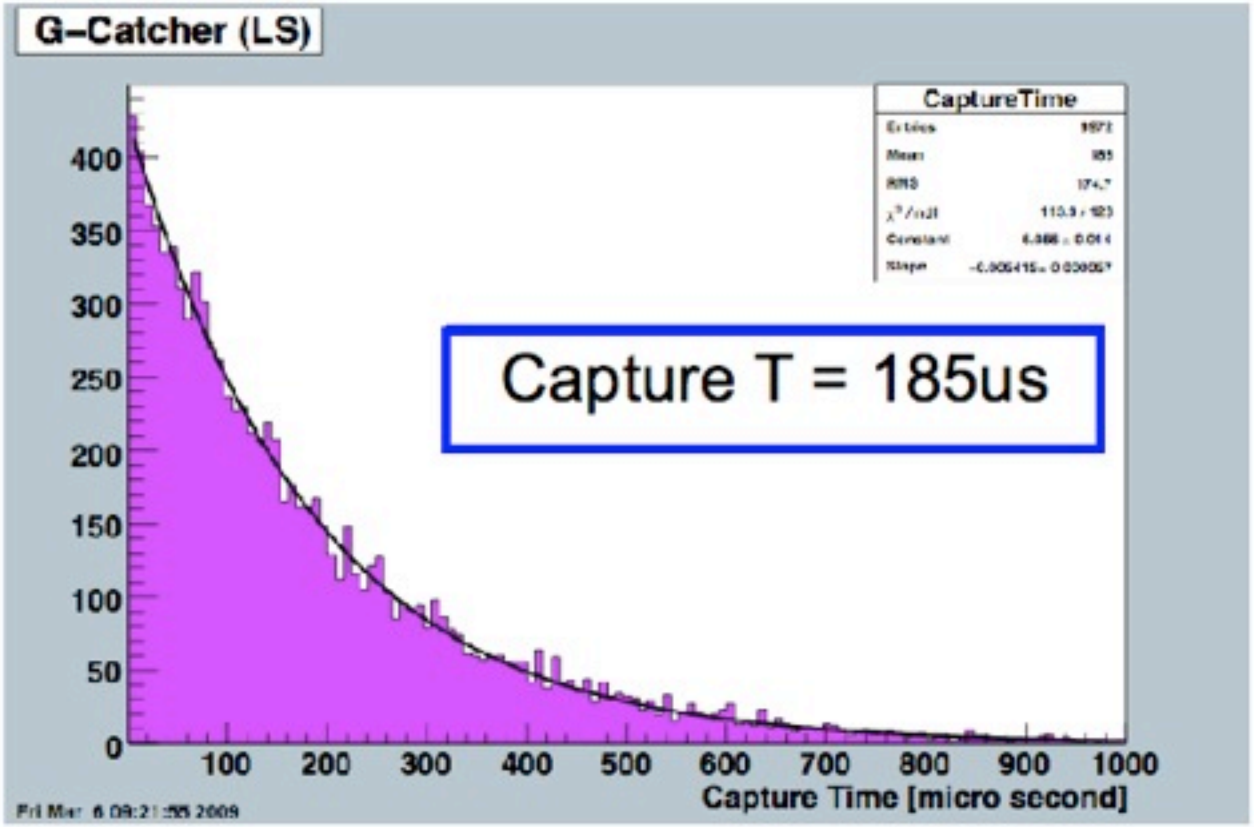
- In all regions, almost all neutrons get captured within ΔR=0.5m with 2.4MeV initial K.E.
- What is an explanation for a large difference in the mean position of the gaussian peak between three plots? (This could be simply a statistics)
- Should we install a gun inside Inner Veto? Or should we use D-T source from outside? Currently we are thinking of D-T source outside...

To make sure the simulation is working fine, capture time distribution for the same set of simulation is plotted in next page.


Target (LS+Gd)
CaptureTime
Entries 9991
χ^2 / ndf 114.1 / 116
p0 492.2 ± 12.7
p1 23.55 ± 0.33
Capture T = 23.6us
Capture Time [micro second]
Mon Mar 9 20:26:09 2009


Target
Buffer
G-Catcher


Buffer (natural oil)
CaptureTime
Capture T = 180us
Capture Time [micro second]


G-Catcher (LS)
CaptureTime
Capture T = 185us
Capture Time [micro second]

In above plots...

- Gd is effective in the target volume. The capture time by handwritten calculation yields 22us in the target with Gd.

- In both Buffer and G-Catcher region, hand written calculation yields 209us of capture time. A slight difference might be due to proton density difference in each volume.

Thoughts...

- Diffusion plot is not quite promising for a neutron gun to be installed at the outside top of the detector.

- The diffusion distance is determined by the thermalization process. We also need to check the validity of the simulation.

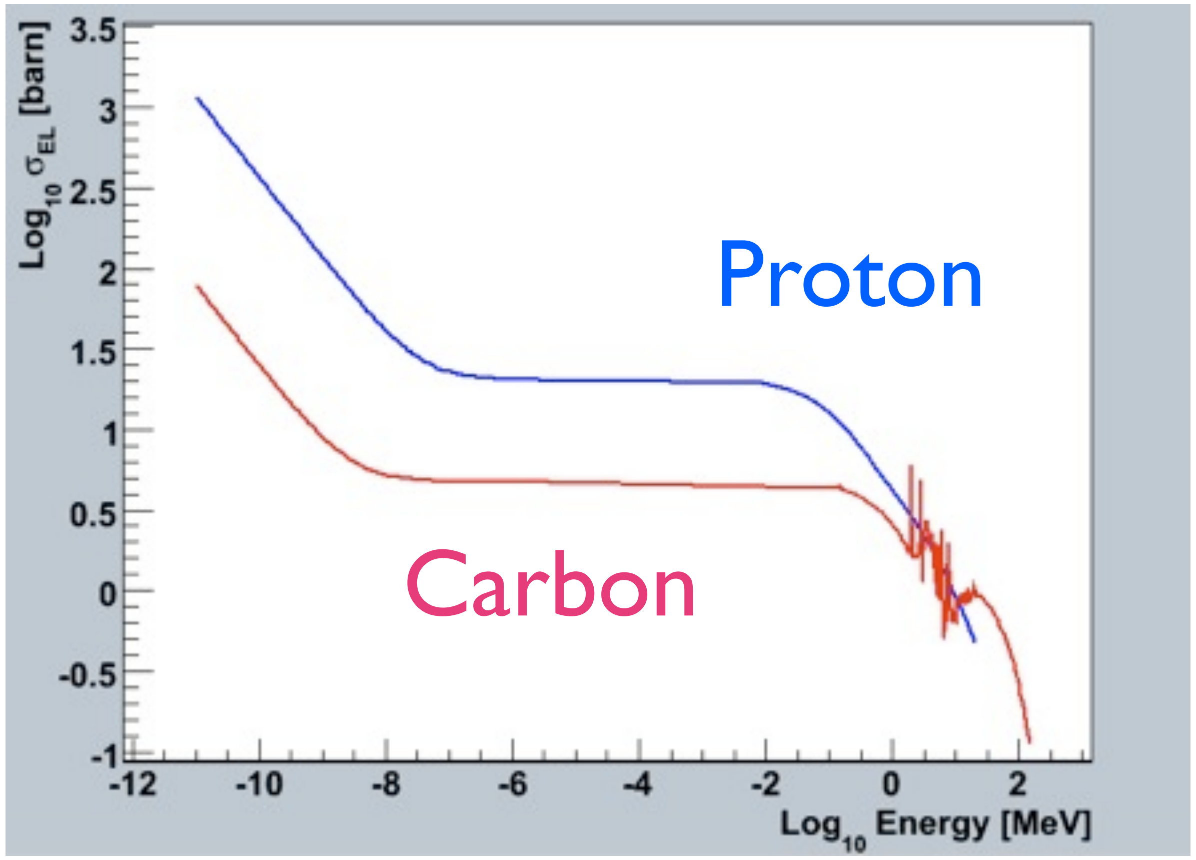
Must check the validity of simulation result

Part 2

How to check the validity
of
DCGLG4sim neutron simultion?

Why Do We Check DCGLG4sim Validity?

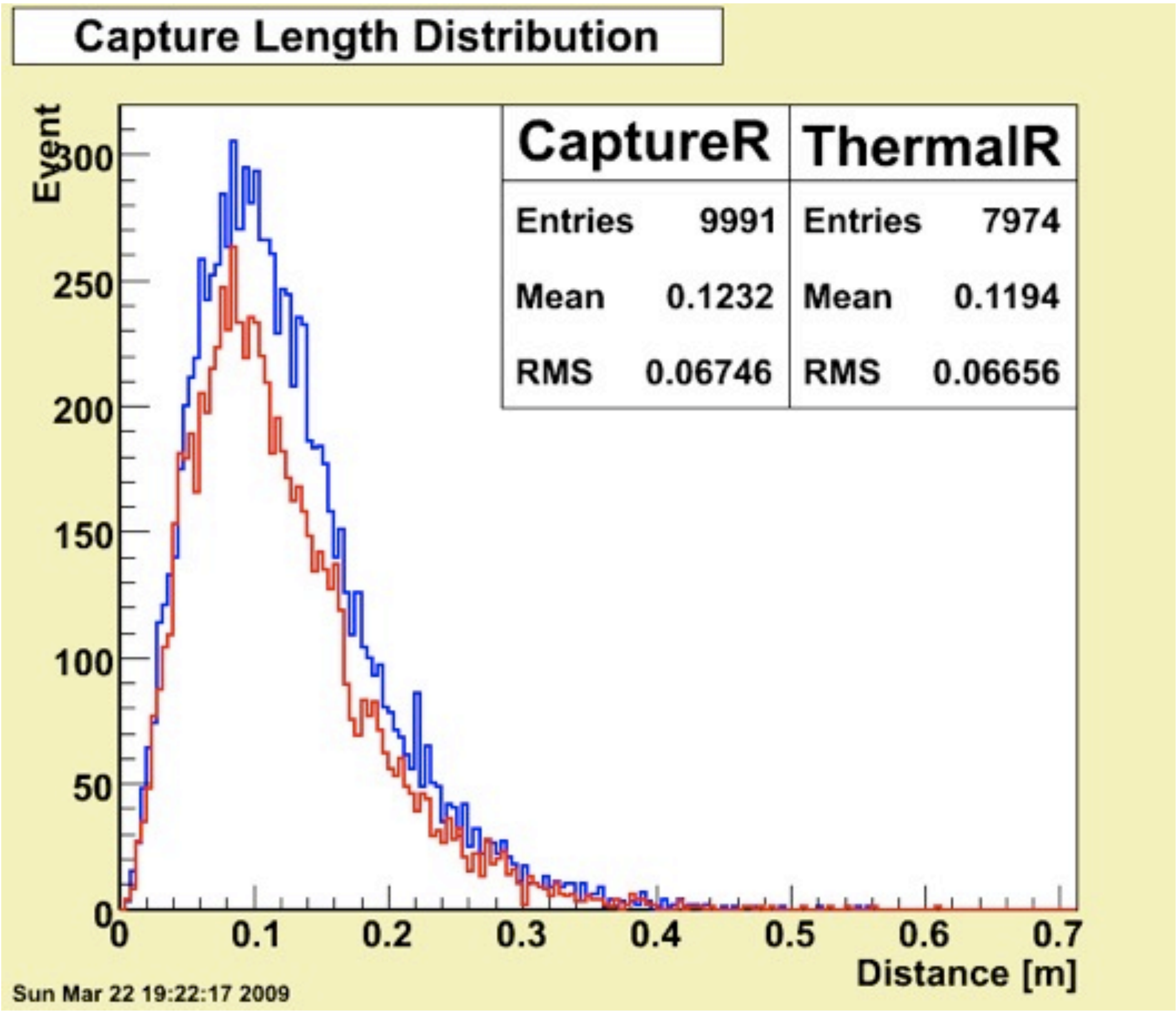
- To make sure things before we pay >$80k
- Geant4 is known to be weak on low energy neutron simulation. Cross check is needed anyway.
- How far neutrons can travel depends on the simulation of complicated thermalization process. Actual measurement is required whether we do well or not on the simulation.



Energy dependent elastic scattering cross section for H and C, which are dominant nuclei for neutron to be scattered from.

First a few steps are taken at much lower scattering cross section, indicating the dominancy of first a few steps in contribution to the diffusion.

If not intuitive, plots below show the dominancy of thermalization process for the diffusion process.



The blue line shows the diffusion ΔR for capture events while the red line shows the diffusion ΔR when thermalization is achieved.

The red line has a smaller peak because capture events are excluded for the sake of comparison. Functional form is same between two plots.

Ways for DCGLG4sim sanity check

- Compare DCGLG4sim with analytical model (Kazu)
- Compare with other softwares; MCNPX and FLUKA are known to be much more reliable for low energy neutron simulation.
- Perform an actual measurement (Kazu)

What's done so far

- Analytical modeling of neutron diffusion has been studied. Need to do hand-written calculation for comparison.
- Lindey might be able to make FLUKA simulation.
- A simple measurement of neutron flux change through LS is on its way at MIT using Jocelyn's neutron detector.

0th order DCGLG4sim Sanity Check

and

Comparison w/ Analytical Model

... and

Measurement of Neutron Flux Through LS

0th order Sanity Check

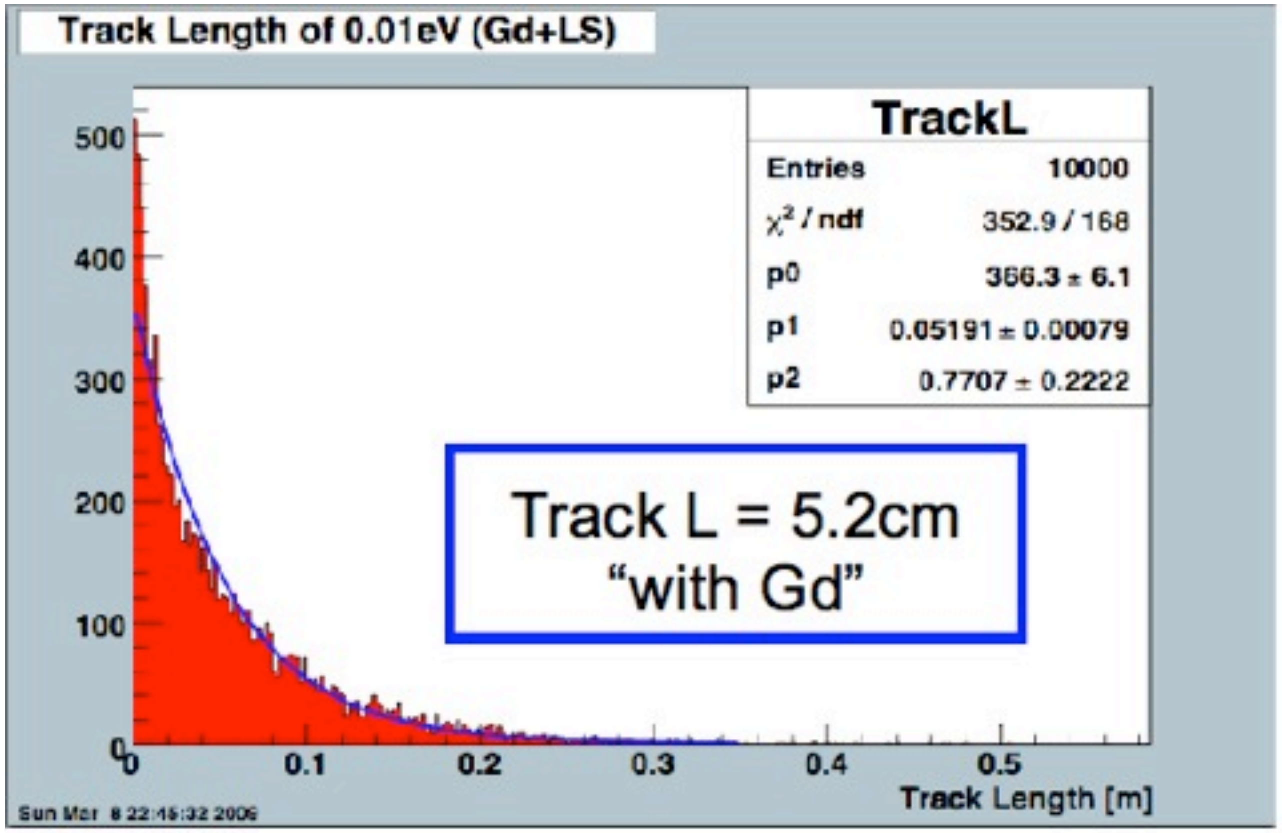
We make sure that all physics are same for “with Gd” and “without Gd” configuration inside the target volume.

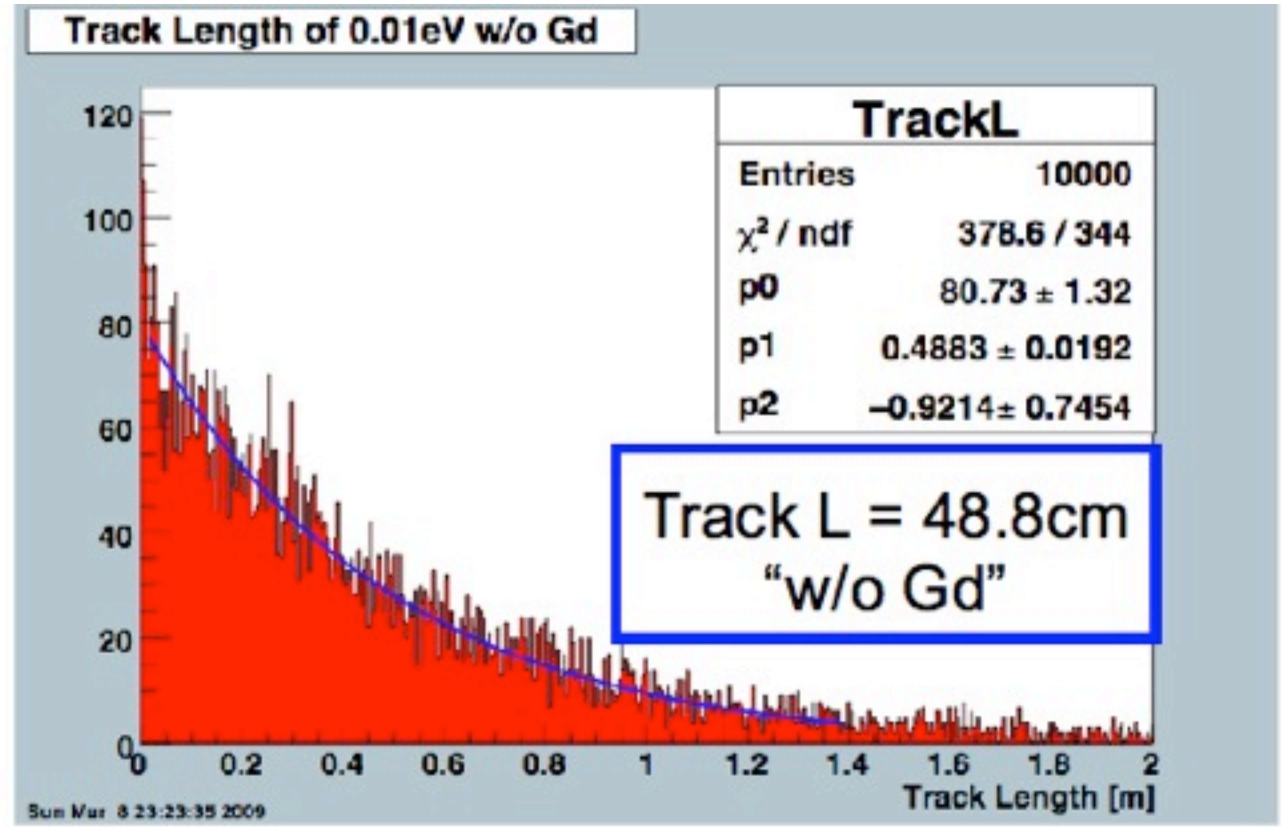
Simulation Setup

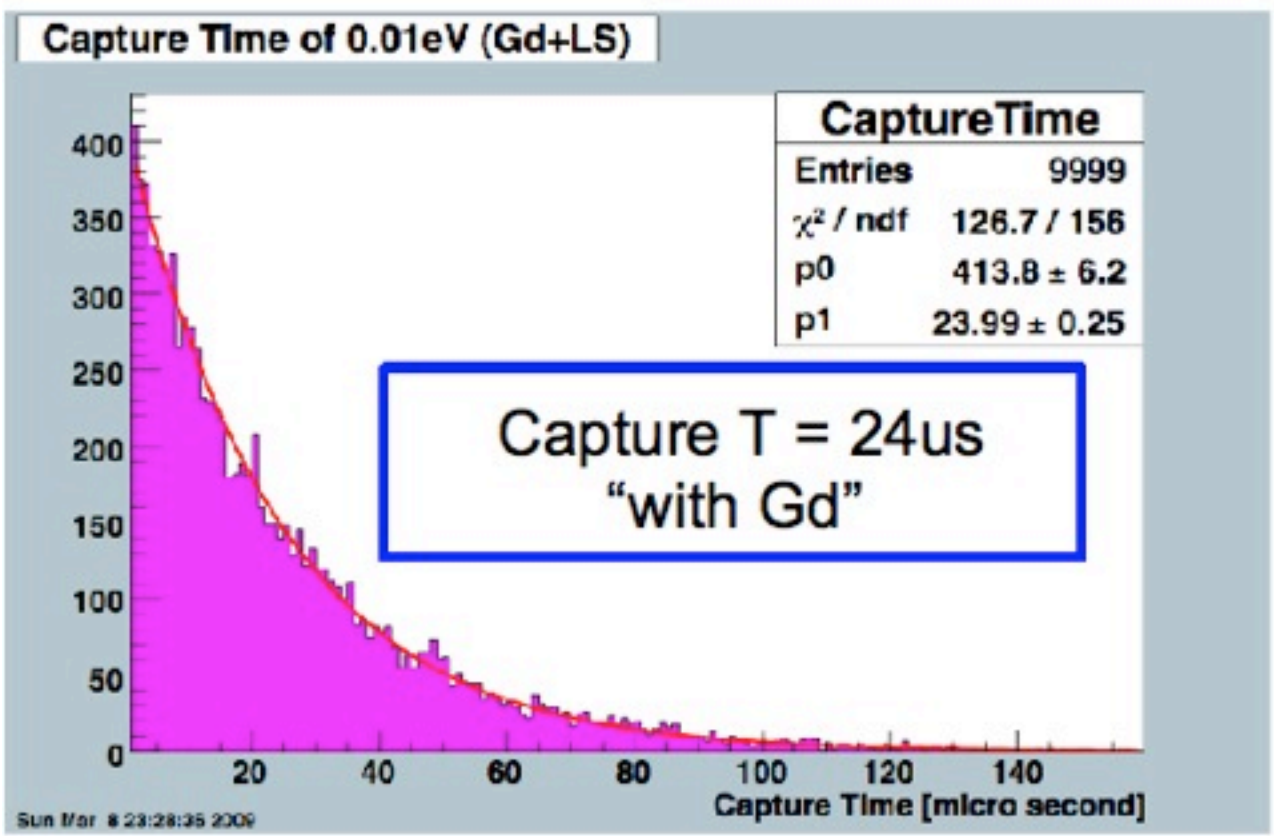
- 1e4 neutrons simulated inside the target volume with 0.01 eV (thermal level) K.E. override.
- For one simulation run, turn off Gd in the target by modifying “fluid_cards.dat” geometry file.

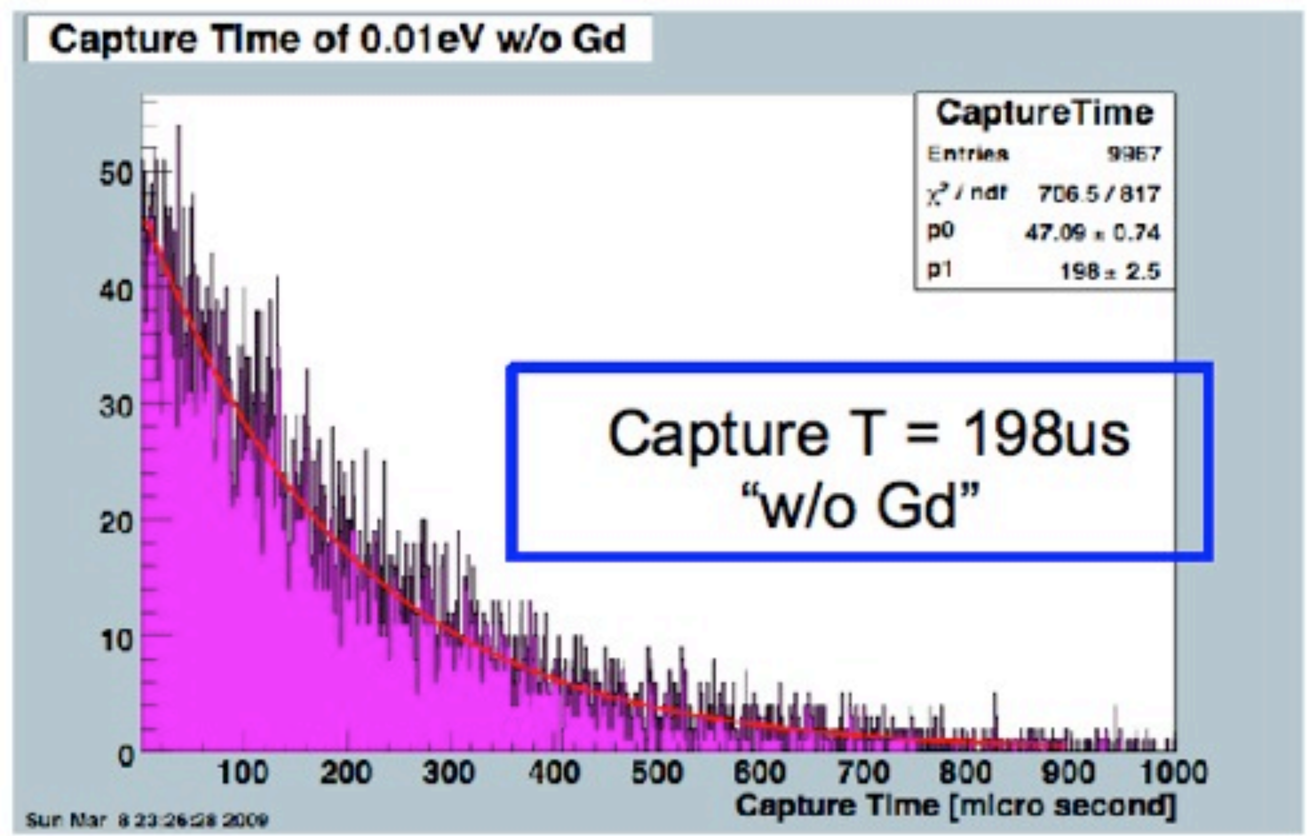
What do we expect?

- No thermalization process, thus 2200m/s neutron random walk until get captured.
- “With” and “without” Gd configuration should give the same result.


Track Length of 0.01eV (Gd+LS)
TrackL
Entries 10000
χ² / ndf 352.9 / 168
p0 366.3 ± 6.1
p1 0.05191 ± 0.00079
p2 0.7707 ± 0.2222
Track L = 5.2cm
"with Gd"
Track Length [m]


Track Length of 0.01eV w/o Gd
TrackL
Entries 10000
χ² / ndf 378.6 / 344
p0 80.73 ± 1.32
p1 0.4883 ± 0.0192
p2 −0.9214± 0.7454
Track L = 48.8cm
"w/o Gd"
Track Length [m]


Capture Time of 0.01eV (Gd+LS)
CaptureTime
Entries 9999
χ² / ndf 126.7 / 156
p0 413.8 ± 6.2
p1 23.99 ± 0.25
Capture T = 24us
"with Gd"
Capture Time [micro second]


Capture Time of 0.01eV w/o Gd
CaptureTime
Entries 9967
χ² / ndf 706.5 / 817
p0 47.09 ± 0.74
p1 198 ± 2.5
Capture T = 198us
"w/o Gd"
Capture Time [micro second]

Previous plots look consistent w/ expectation

- Neutrons in target "with Gd" travel at 5.2cm/24us = 2167m/s .
- Neutrons in target "w/o Gd" travel at 48.8cm/198us = 2464m/s.
- Both seem close enough to 2200m/s thermal velocity.

Total track length and capture time scaled with more-or-less a same factor btw "with Gd" and "w/o Gd" conditions. This makes sense since a thermal neutron only does random walk until it gets captured w/o change in its K.E. energy.

Also,,,

Hand-written calculation yields (ΔR, T) to be about (4.8cm, 22us) for "with Gd" condition and (45.9cm, 208us) for "w/o Gd". These values are calculated by Lindley's macro (Thanks Lindley!) with similar number density of target volume content.

These results all make sense and thus valid!

~~0th order DCGLG4sim Sanity Check~~

and

Comparison w/ Analytical Model

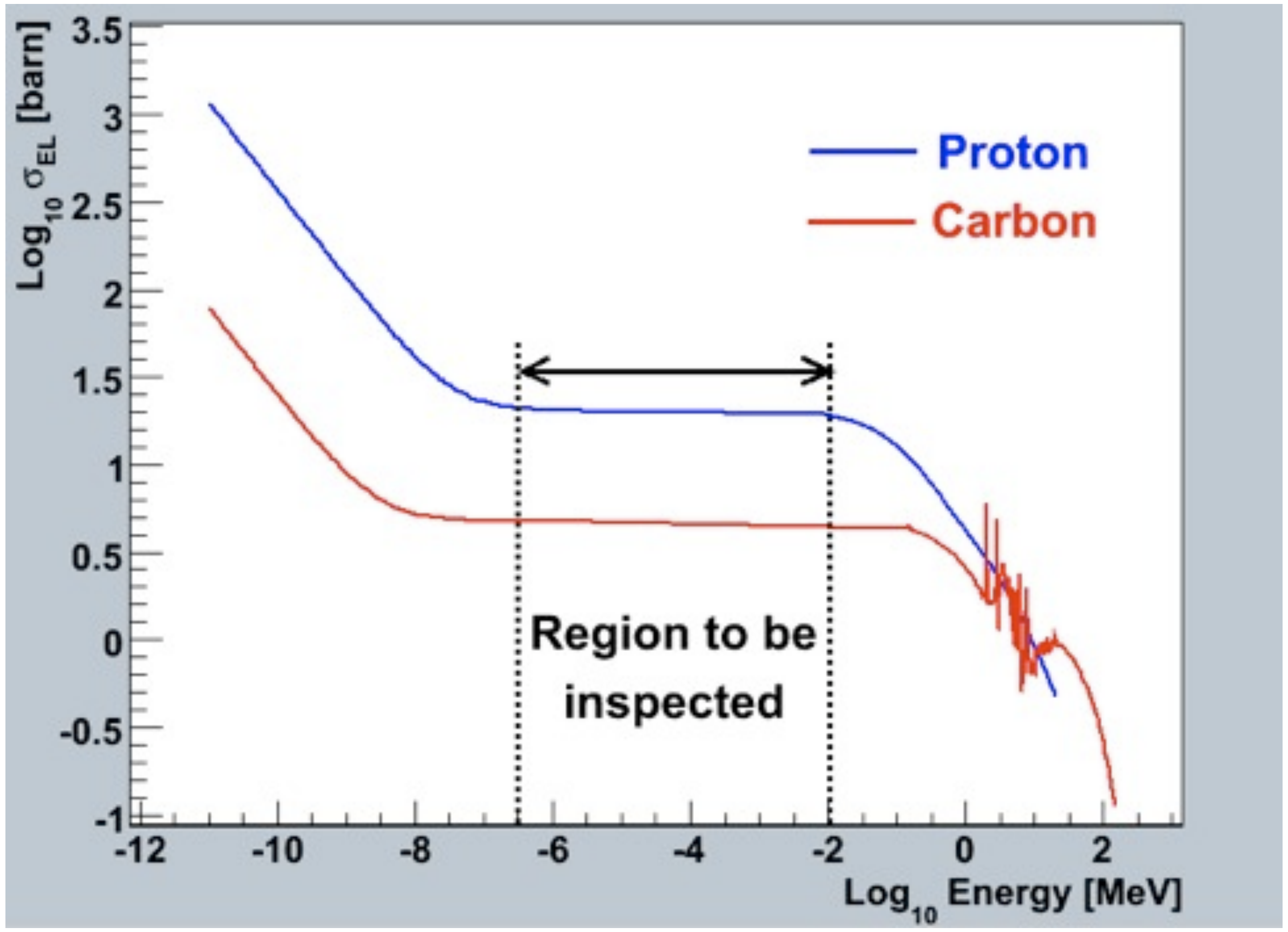
... and

Measurement of Neutron Flux Through LS

Analytical Modeling of Neutron Thermalization

Sanity check is two folds:

- Check the used cross section of neutron-proton and neutron-carbon elastic scattering.
- Algorithm and modeling of neutron energy loss per scattering in the LS.



Algorithm should be checked for the region between two dashed lines where the complication of the scattering cross section due to its energy dependence is negligible. ≈ 1eV to 10keV

Three ways to check algorithm

- Inspect how neutrons' slowing down
- Inspect neutron step length per scattering
- Inspect the average of total track length

Modeling of Slowing Down Neutrons

Energy of neutron after n elastic scatterings;

$$\langle E_n \rangle = E_i \exp\left[-\xi n\right] \qquad \text{where} \qquad \xi = 1 + \frac{\alpha}{1-\alpha}\log\alpha$$

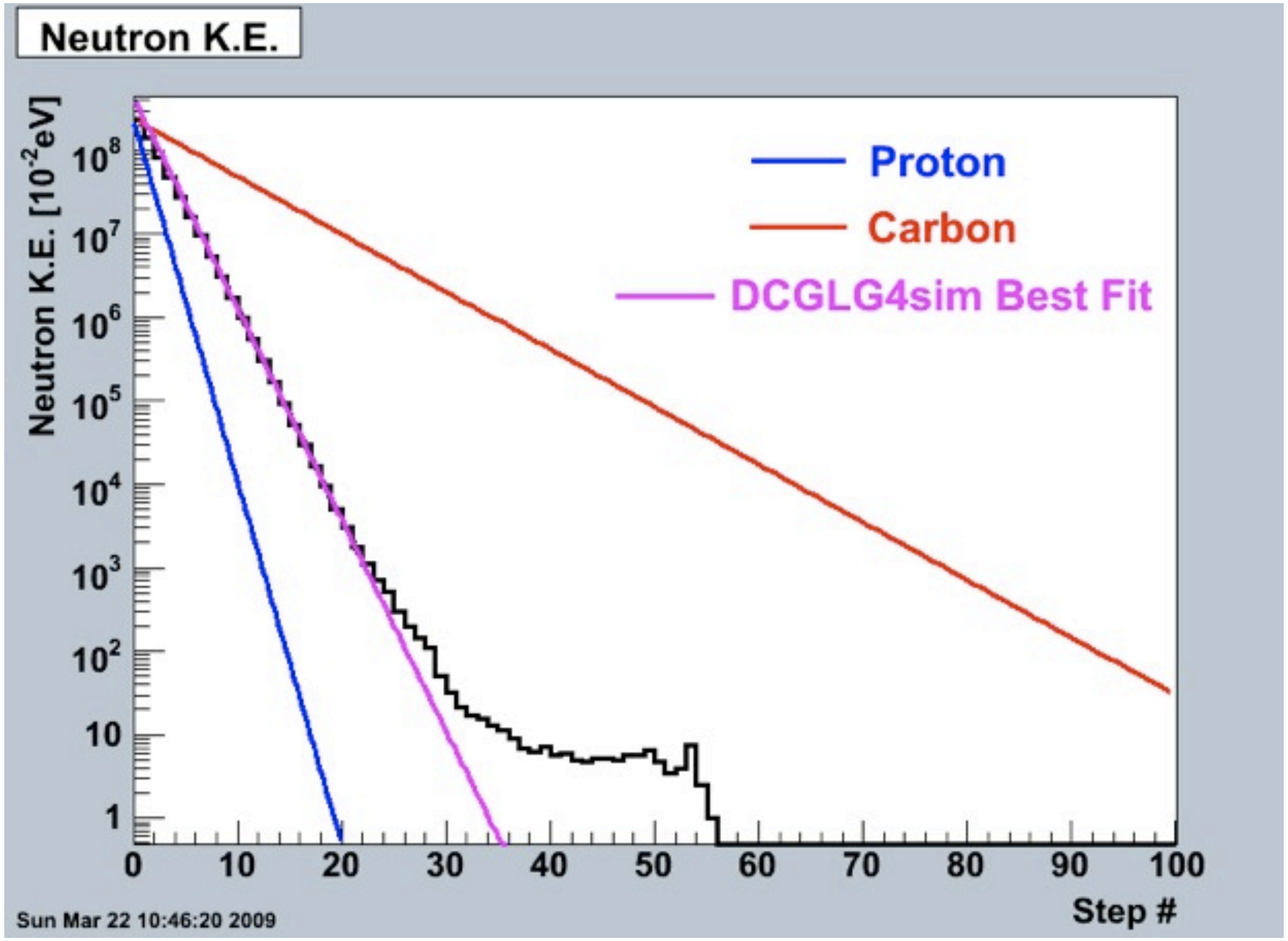
With characteristic constant for a moderator; $\alpha \equiv \left(\frac{M_T - m_n}{M_T + m_n}\right)^2$

Element	Gram/Mole	ξ	Collision $N(\xi)$
Hydrogen	1.01	1.000	18.4
Carbon	12.01	0.159	115.6

Table: Parameters calculated for pure-H / C moderator

Knowing the H and C target fraction as well as ratio of elastic scattering cross section in the specified range, we can estimate the characteristic constant ξ specific to the DC target volume.

How the modeling is done? See: http://www2.lns.mit.edu/~kazuhiro/MyDC/NeutronThermalization.pdf (work in progress)

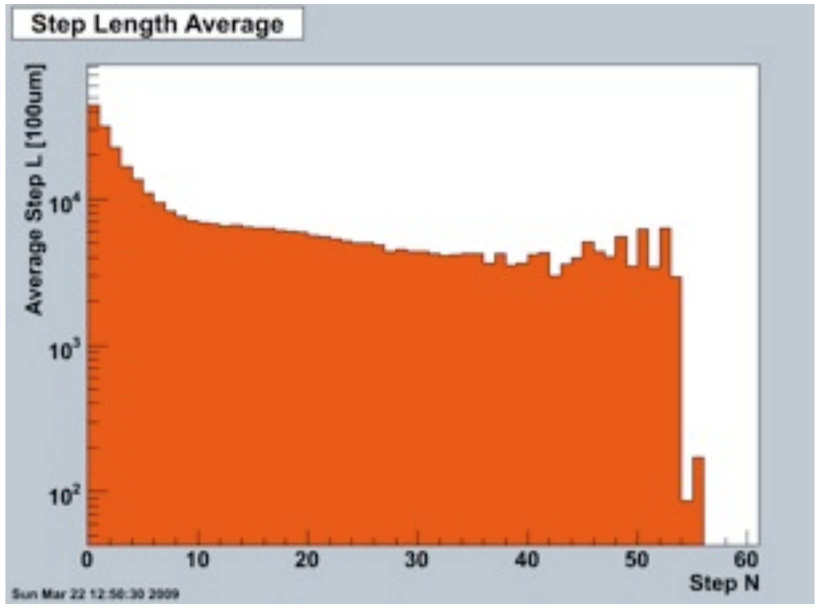


Histogram of a neutron energy at each step averaged over 1e4 neutrons by DCGLG4sim. The pink line shows the best fit in the energy region from 10eV to 10keV, satisfying the range in which σ_{el} is approximately constant. Characteristic constant from the fit is ξ=-0583 and is to be confirmed with hand written calculation. The red line is for pure-Carbon moderator, and the blue line is for pure-H moderator.

Calculation not yet done....

Investigating the Average Step Length

Work under progress... This is to be done after inspecting the algorithm for slowing down neutrons.

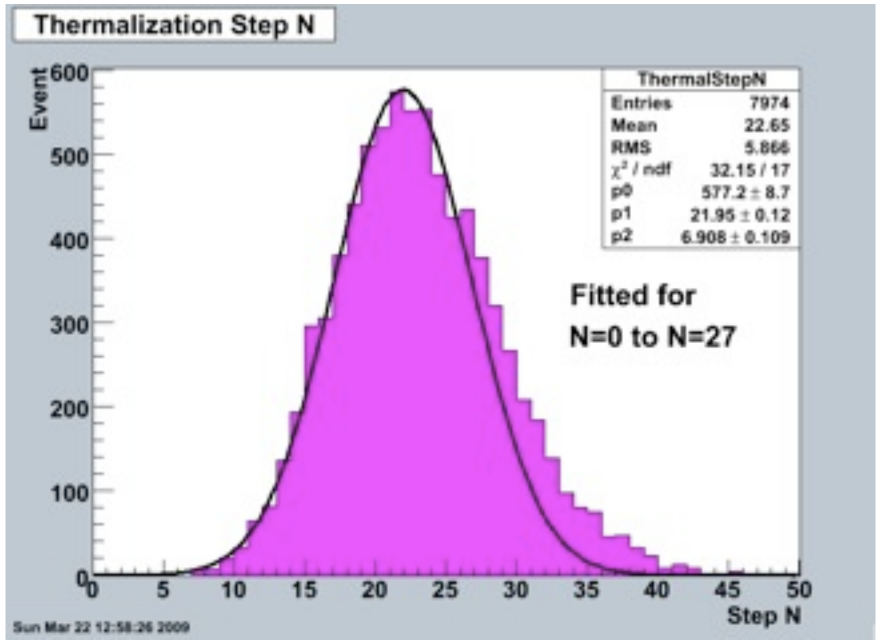


Investigating the average of total track L

Work in progress. Complicated analytical model (Fermi aging effect). Maybe not necessarily to go this far.

Random question for you!

What's shown in right hand side is an number of steps it took for 1e4 neutrons to get thermalized. The distribution has a tail and it's definitely not a gaussian. Do you see why??



~~0th order DCGLG4sim Sanity Check~~

and

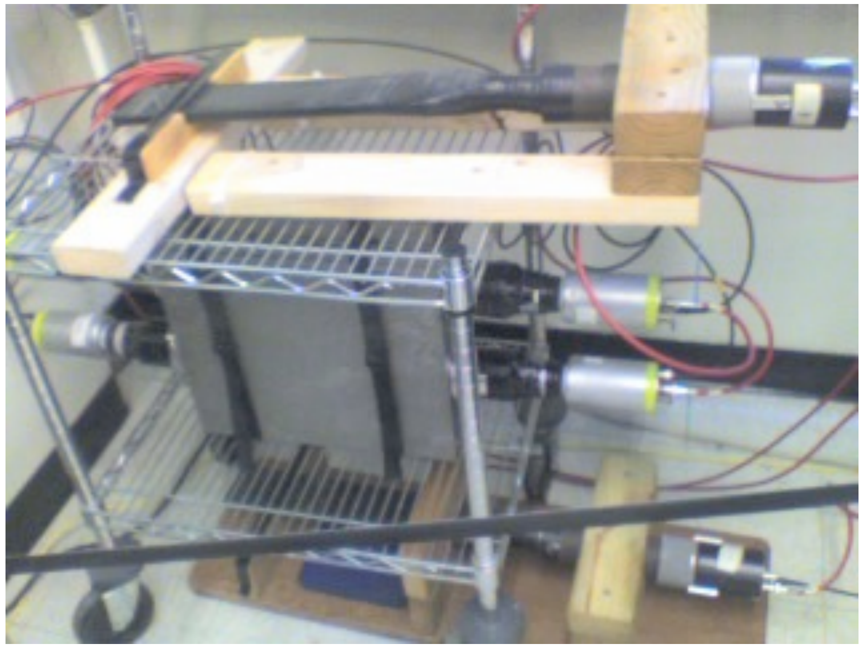
~~Comparison w/ Analytical Model~~

... and

Measurement of Neutron Flux Through LS

Measurement of Neutron Flux Through LS

Conducted at MIT building NW-13 dungeon lab using Dr. Jocelyn Monroe's neutron detector, an original of her dark matter proto-type detector.



Neutron gun (left) will be set with a neutron detector (right) which looks at scintillation light from neutron elastic scattering with 4PMTs.

Basic Setup of the Measurement

• Stainless steel box filled with LS (dodecane, PXE, PPO... nice!) 4PMTs looking at scintillation photons from N-P elastic scatterings.

• Two plastic scintillator based trigger for muon veto

• D-D fast neutron source that can mimic our neutron gun

• Borax shielding to avoid events from unexpected scattered neutrons from the surroundings. This should be signed carefully...

• We measure neutron flux from the source for the first run.

• We put a small container of LS between the source and the target to measure the change in neutron flux from the source for the second run.

→ Although sounds simple, neutron attenuation length measurement is known to be tricky... Any suggestion or advice is very much appreciated!