# Calibration of Double CHOOZ detector with Neutron Gun

Kazuhiro Terao

Neutrino/Dark Matter
Family Meeting

# Motivation: What neutron gun for?

➡ It is a fast neutron source for calibration of the detector.

## Systematics of Double CHOOZ

| | | Chooz | Double-Chooz | |
|---|---|---|---|---|
| Reactor-induced | $\nu$ flux and $\sigma$ | 1.9 % | <0.1 % | Two "identical" detectors, Low bkg |
| | Reactor power | 0.7 % | <0.1 % | |
| | Energy per fission | 0.6 % | <0.1 % | |
| Detector - induced | Solid angle | 0.3 % | <0.1 % | Distance measured @ 10 cm + monitor core barycenter |
| | Volume | 0.3 % | 0.2 % | Precise control of detector filling |
| | Density | 0.3 % | <0.1 % | Accurate T control (near/far) |
| | H/C ratio & Gd concentration | 1.2 % | <0.1 % | Same scintillator batch + Stability |
| | Spatial effects | 1.0 % | <0.1 % | Identical detectors and monitoring |
| | Live time | ----- | 0.1 % | Special electronic systems and monitoring |
| Analysis | From 7 to 3 cuts | 1.5 % | 0.2 - 0.3 % | Simplified cuts due to detector design |
| | Total | 2.7 % | < 0.6 % | |

# Why not a radioactive source ?

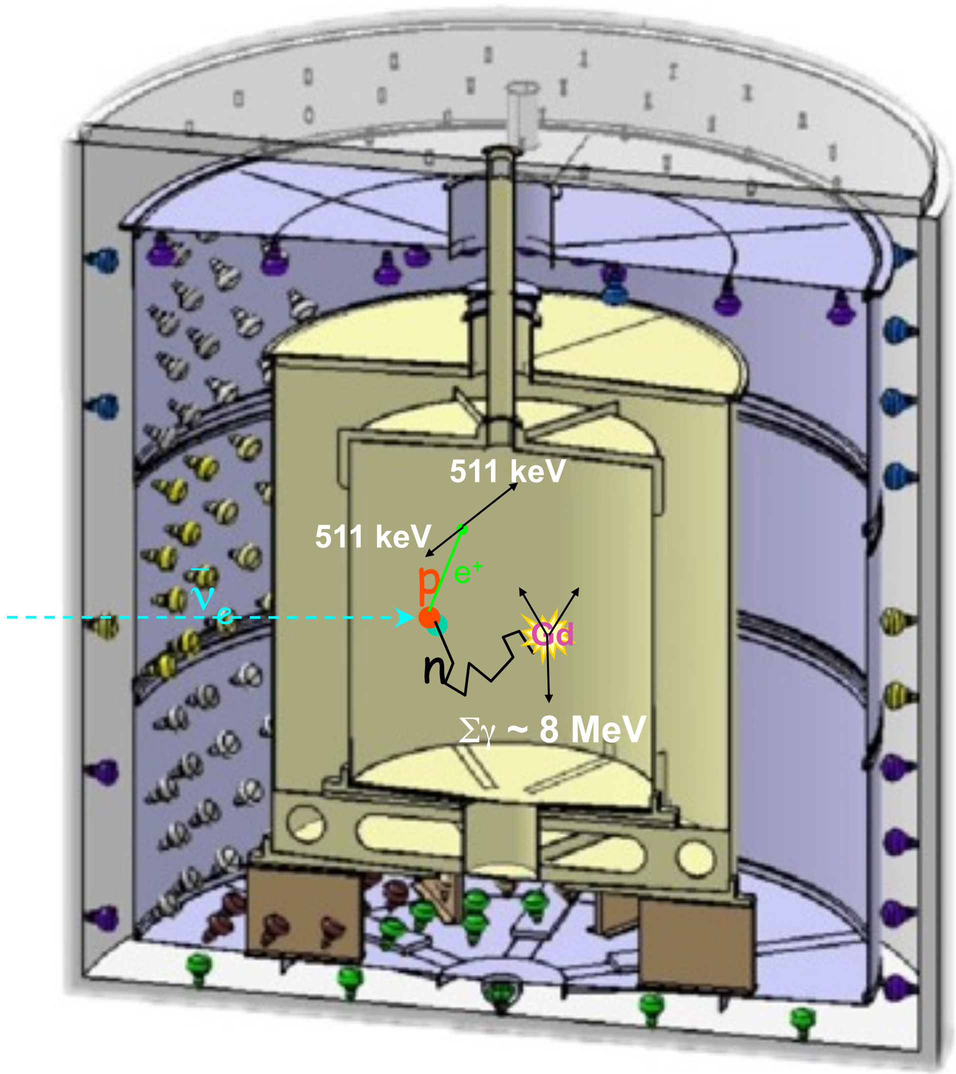
It has an advantage of higher neutron flux and calibration from outside the target volume.

# Neutron Gun from LBL

- D-D source
- 2.4MeV neutrons
- 26cm in diameter
- 28cm in length
- Rate of 1e6 to 1e12

Thanks to Dr. Ka-Ngo Leung !

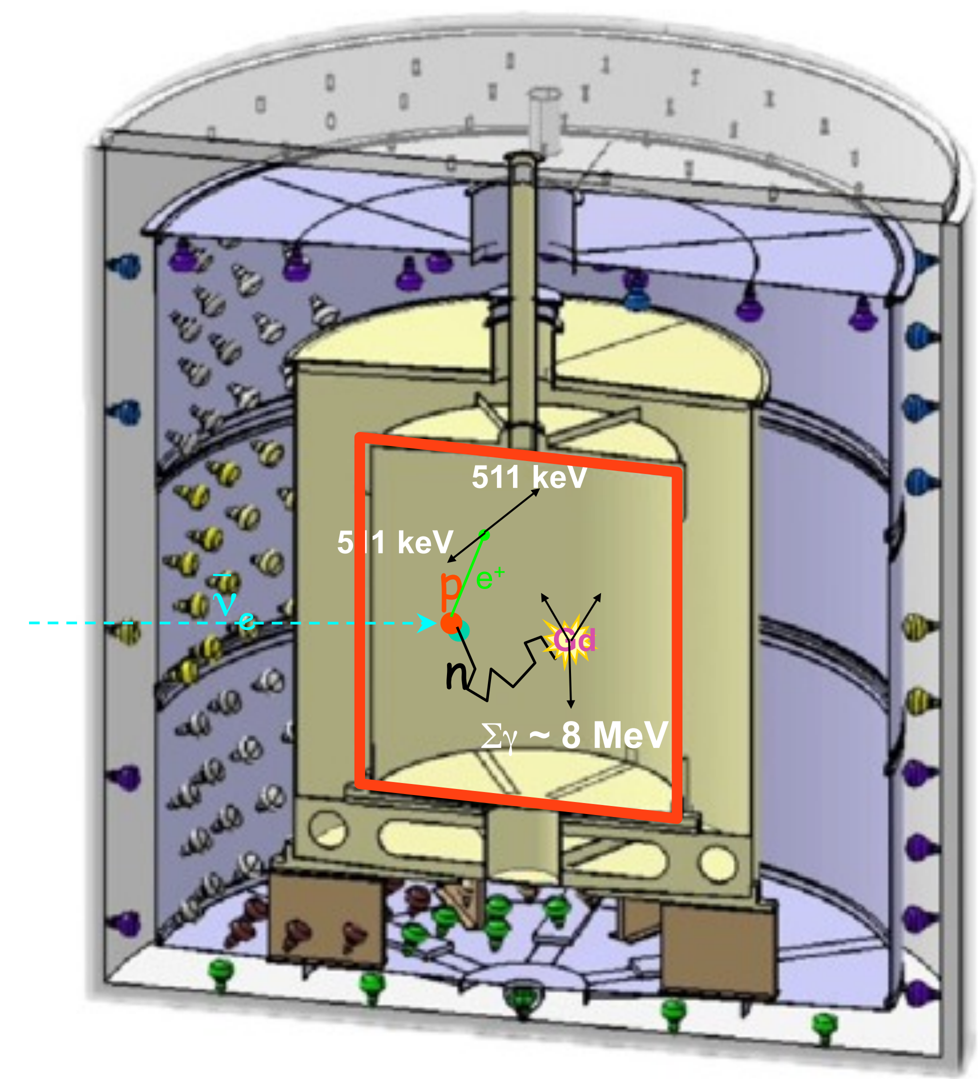
# Detector Review



# 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.



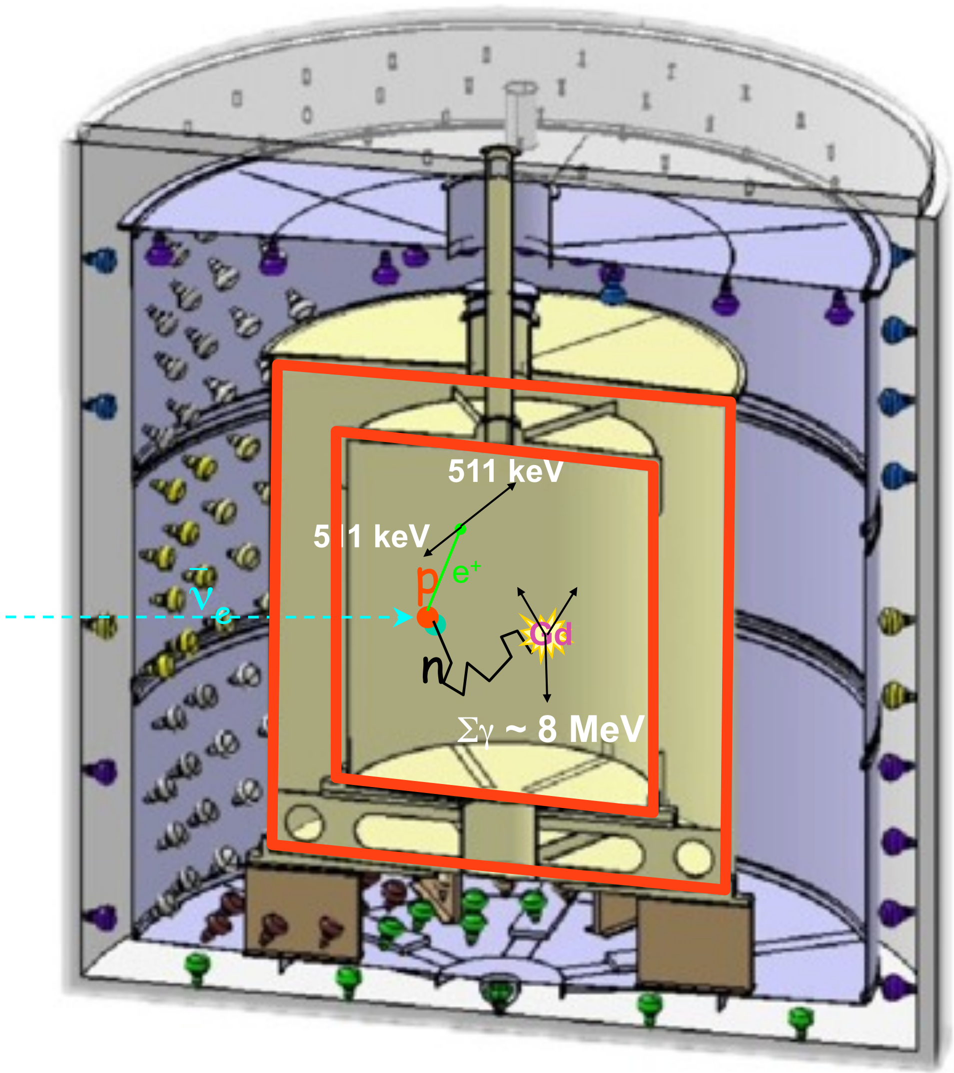
# Detector Review

## 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.



# Detector Review

## Target Volume (LS + Gd) $10.3m^3$

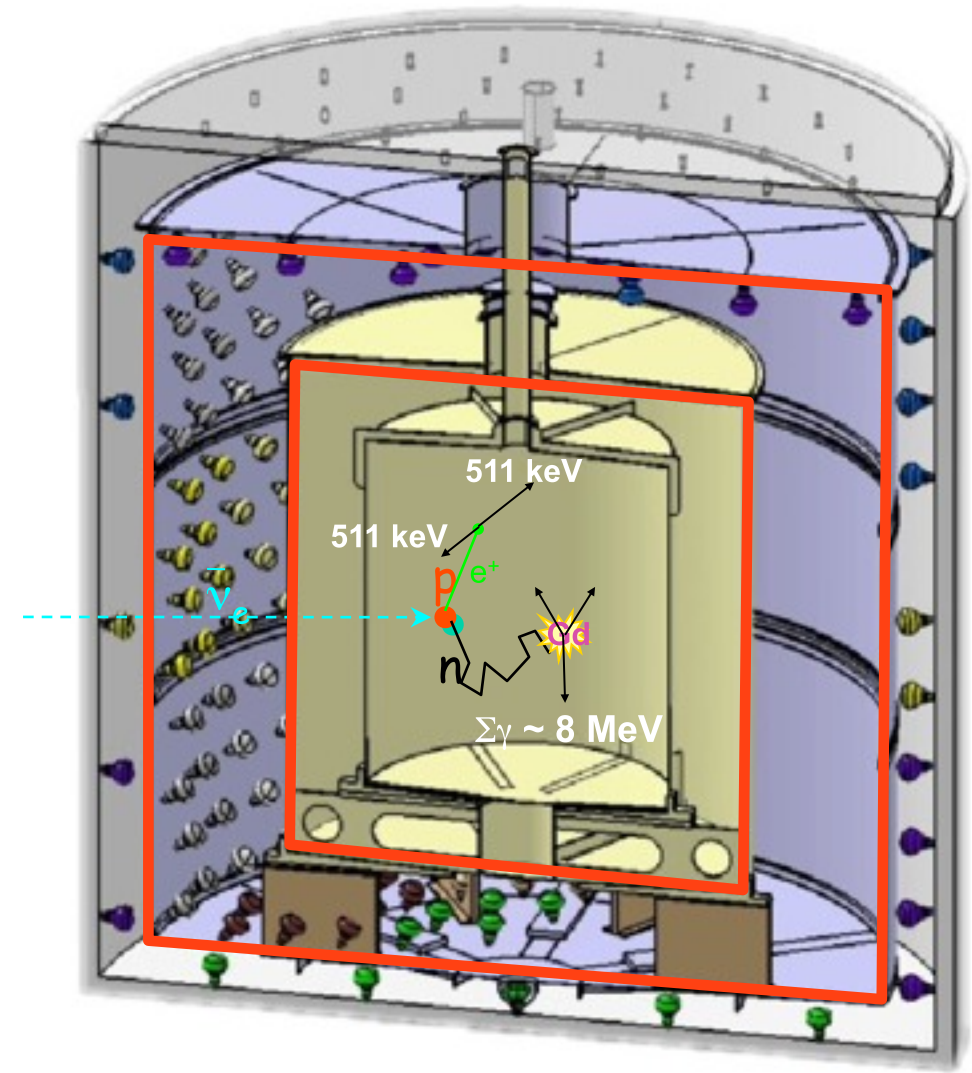
LS = proton rich target to induce inverse beta decay + Gd to achieve high efficiency on neutron capture. Acrylic vessel.

## 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.



# 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) $22.6m^3$

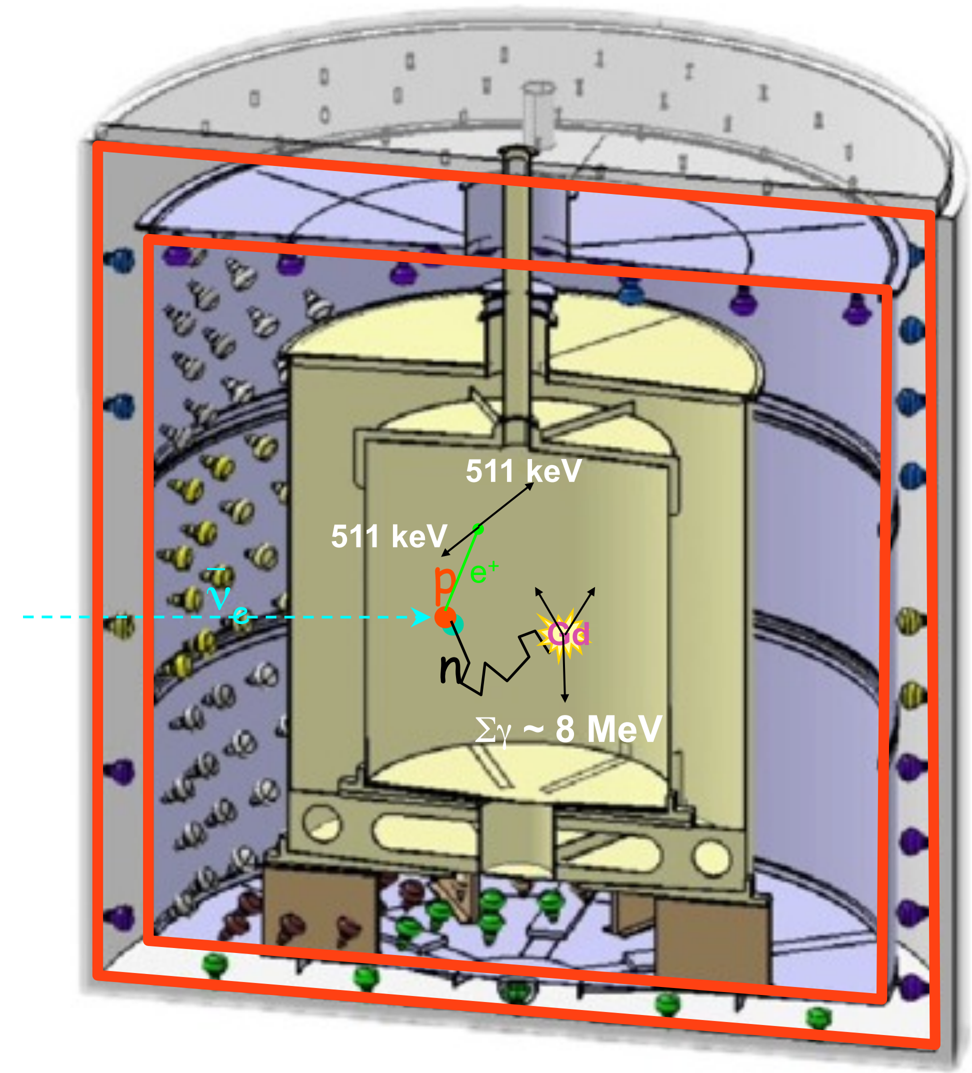
To contain capture gamma inside the target volume. Made of an acrylic vessel.

## Buffer (natural oil) $110m^3$

To keep low singles due to radioactivity of PMTs.

## Inner muon veto (cheap LS) $90m^3$

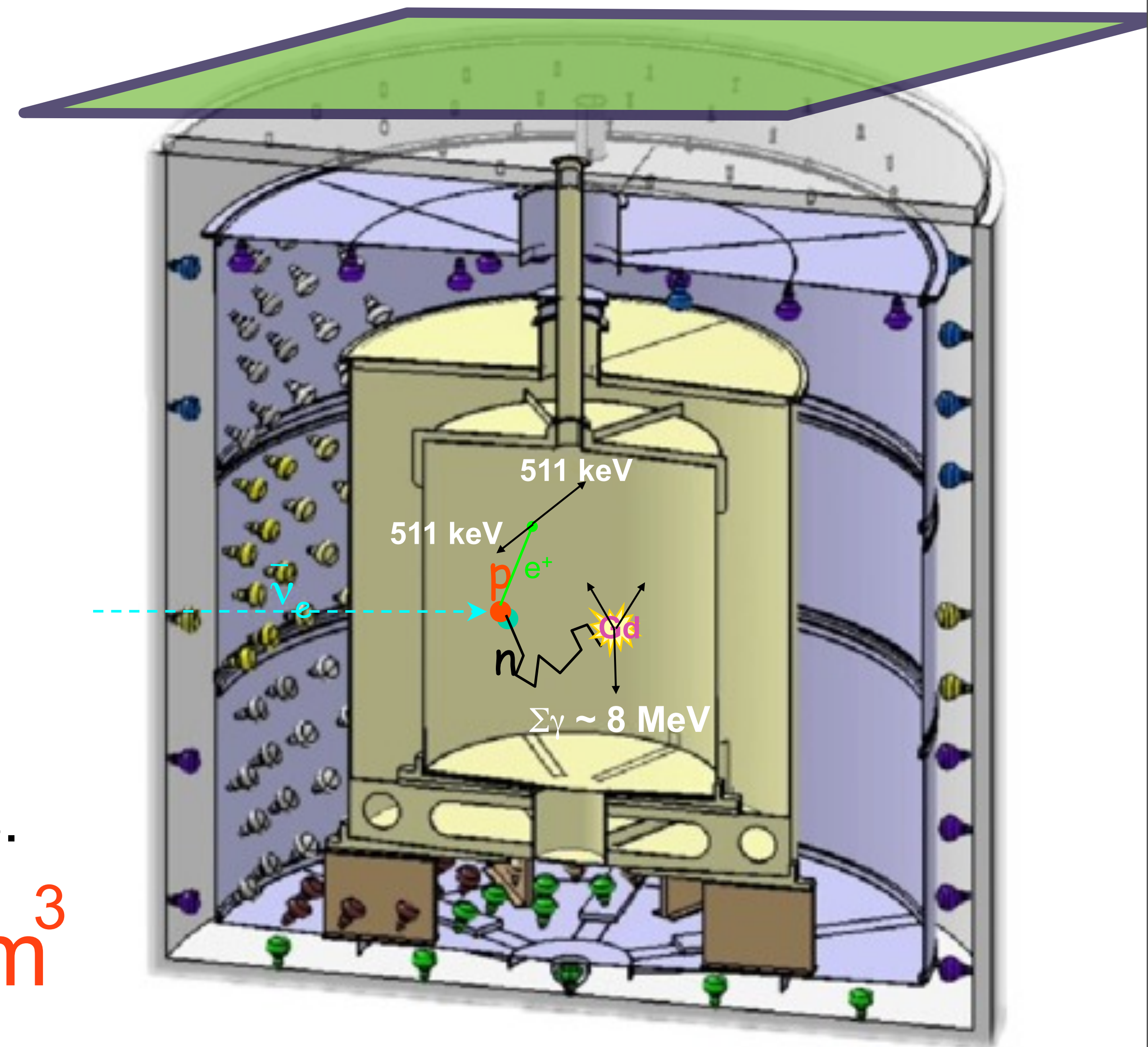
Inner muon detector to veto cosmic ray muons



# 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.

# Before neutrons reach the bottom

Roughly, it has to go through...

- Outer steel shielding (150mm)
- Buffer Stainless steel shielding (3mm)
- Buffer natural oil (1068mm)
- Acrylic G-catcher vessel (12mm)
- G-Catcher LS (542mm)
- Acrylic Target vessel (8mm)
- Target LS+Gd (2474mm)

... in respective order!

# Neutron Gun Simulation

# and

# Sanity Check
# for
# DCGLG4sim neutron simulation

# Motivation for 2.4 MeV Neutron Simulation

To simulate and investigate a potential of a neutron gun as a new calibration device. 2.4MeV is a typical energy level of neutrons we get out of a neutron gun.

# How to simulate?

We use DCGLG4sim, a software developed based on Geant4 with Double CHOOZ detector geometry composition.

# What's sanity check is for?

We are not sure whether DCGLG4sim simulates neutrons in LS correctly or not. We need to make sure the validity of simulation data we are using.

# What's in the following slides?

1. Results of 2.4MeV neutron simulation; $\Delta R$ (diffusion), capture time, and total track distribution are shown.

2. Results of high/low energy neutron simulation as the $1^{st}$ step sanity check of neutron simulation.

This presentation is to show where we stand now. I haven't had a conclusion for neither of a DCGLG4sim sanity check nor whether the attenuation length of 2.4MeV neutrons...

# Part 1

Simulation of 2.4 MeV neutrons

in

Target (LS + Gd)

G-Catcher (LS)

Buffer (natural oil)

## Motivation

Neutrons have to travel from outside to the target volume. We need to Investigate how far 2.4MeV neutrons can travel in each region.

## Simulation set up

1e4 neutrons with 2.4 MeV kinetic energy and isotropic momentum distribution are produced in different region...

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

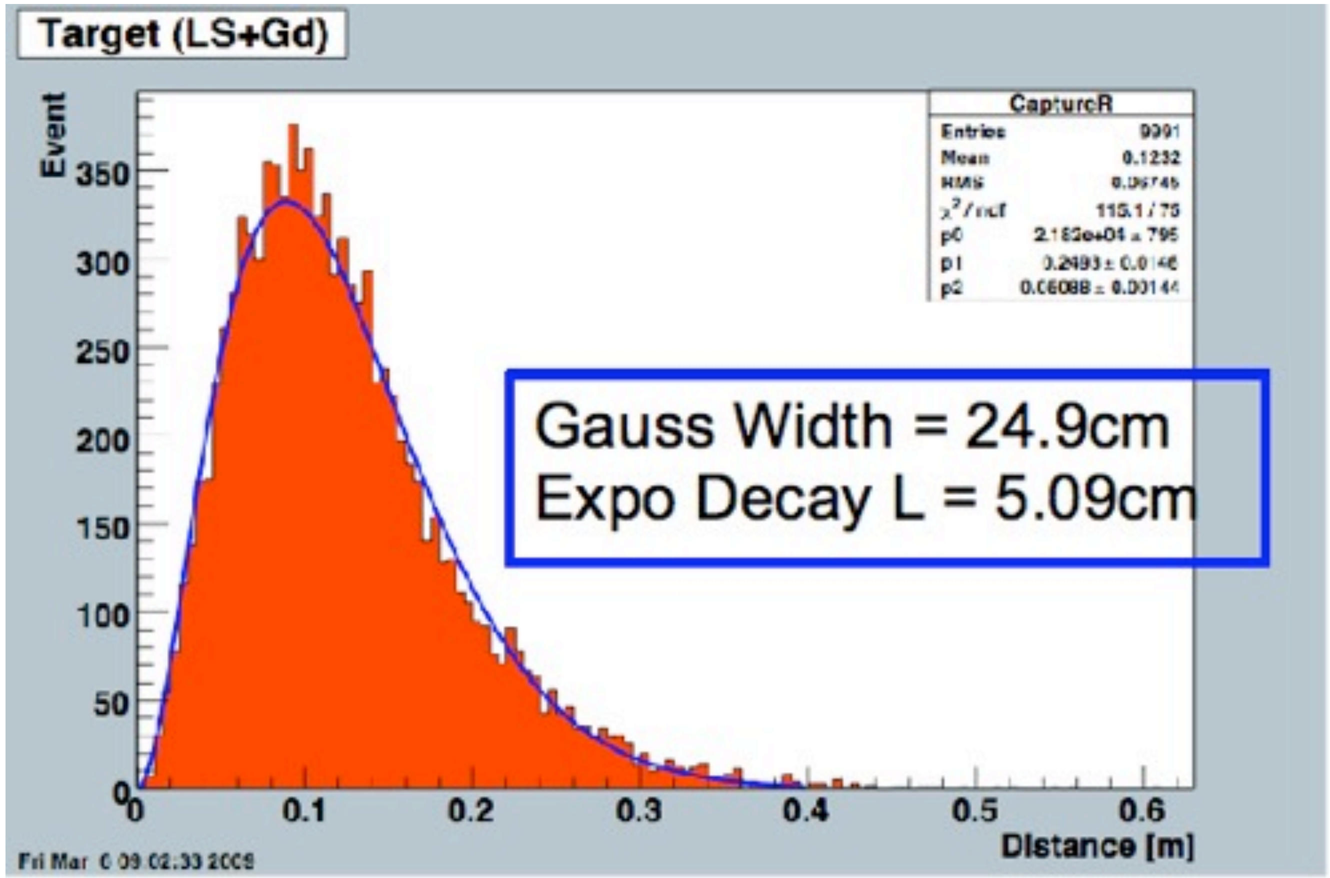
## What's plotted?

# capture event versus distance [m] ($\Delta R$) to the position of capture

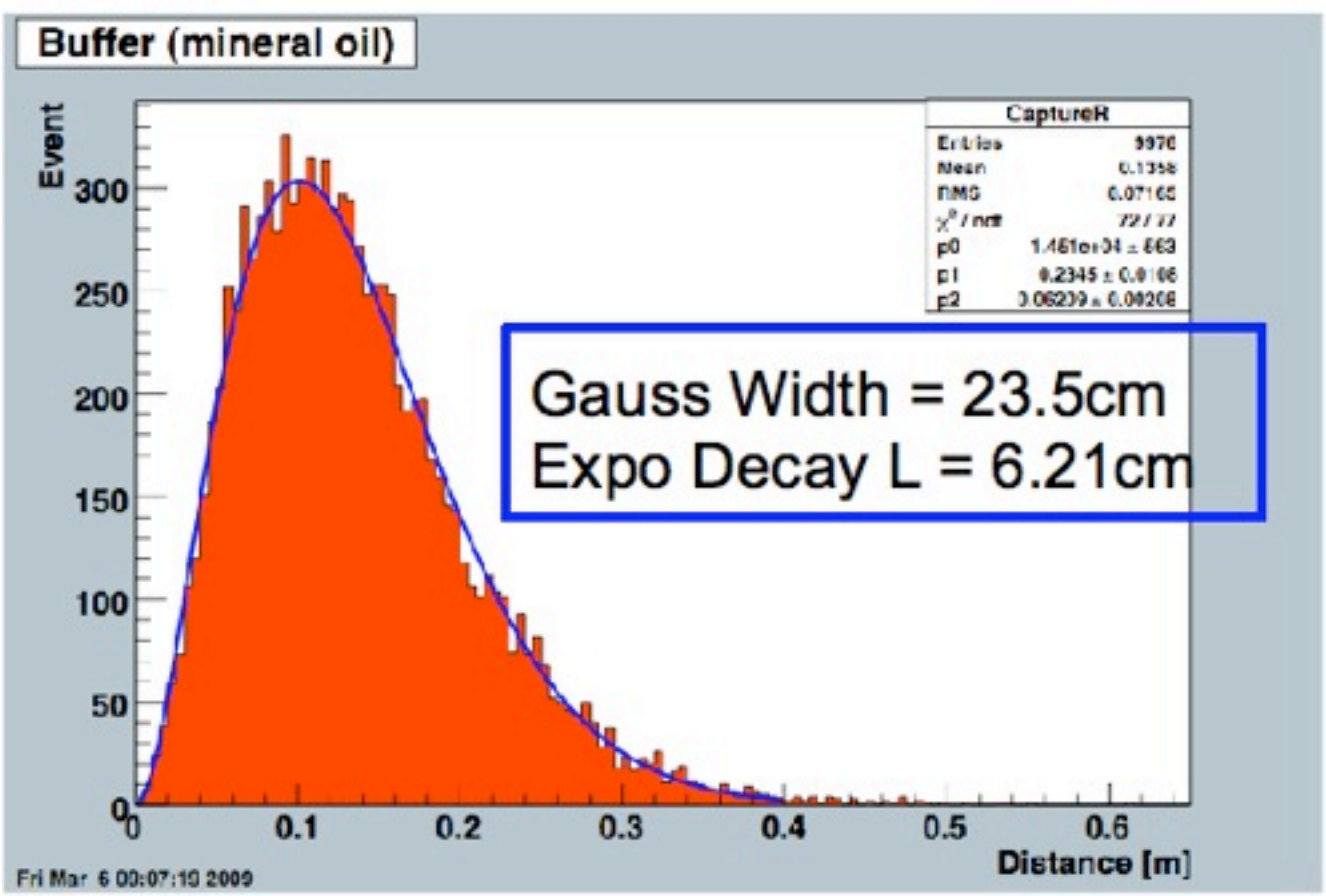
**Fitted function:**

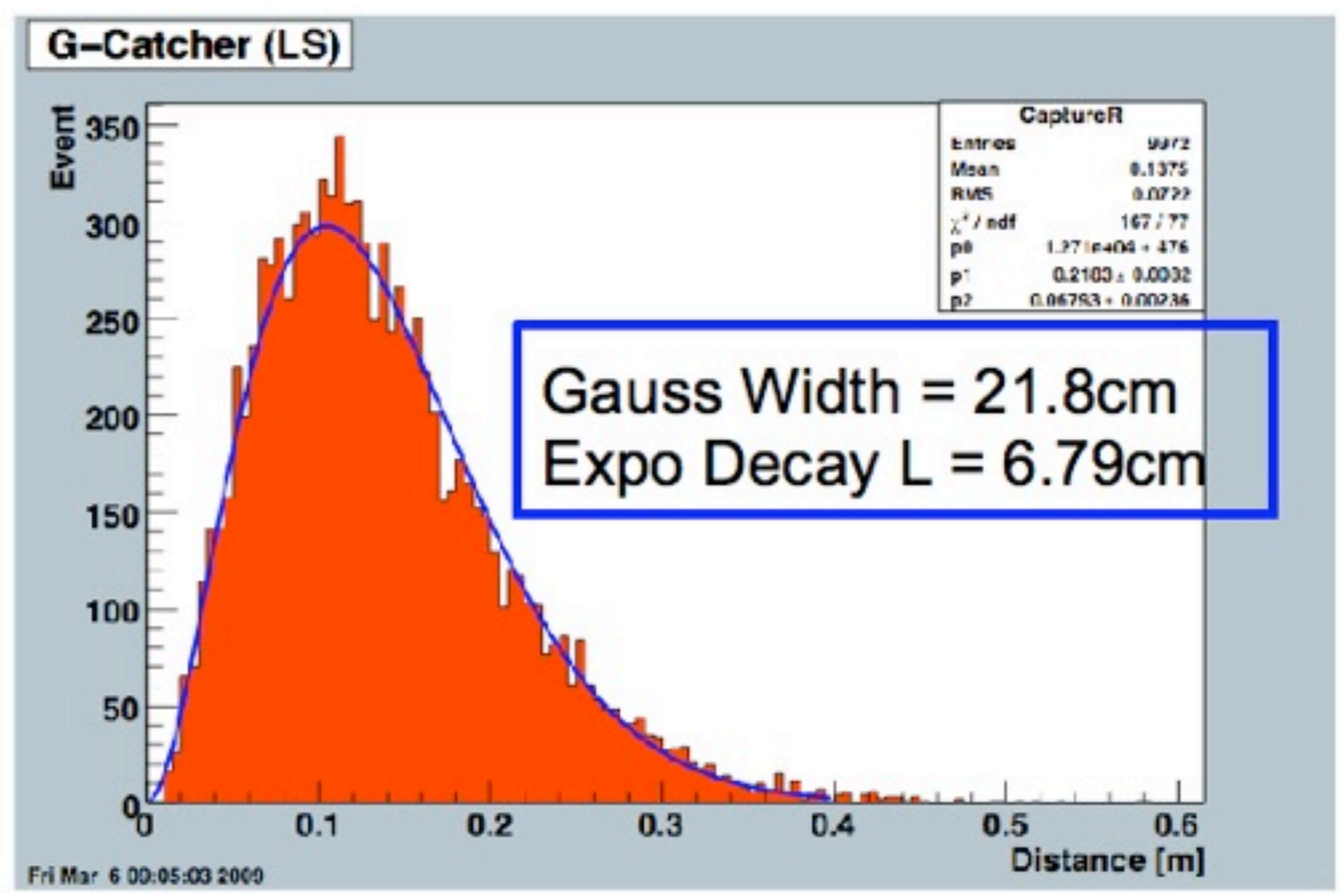
$$\frac{dN(x)}{dx} = 4\pi x^2 \, [p0] \exp\left[-\frac{x^2}{[p1]^2} - \frac{x}{[p2]}\right]$$

- Width of the gaussian $\sigma = p1$
- Characteristic decay length $\lambda = p2$


Target (LS+Gd)
Event
Distance [m]
Gauss Width = 24.9cm
Expo Decay L = 5.09cm


Target
Buffer
G-Catcher

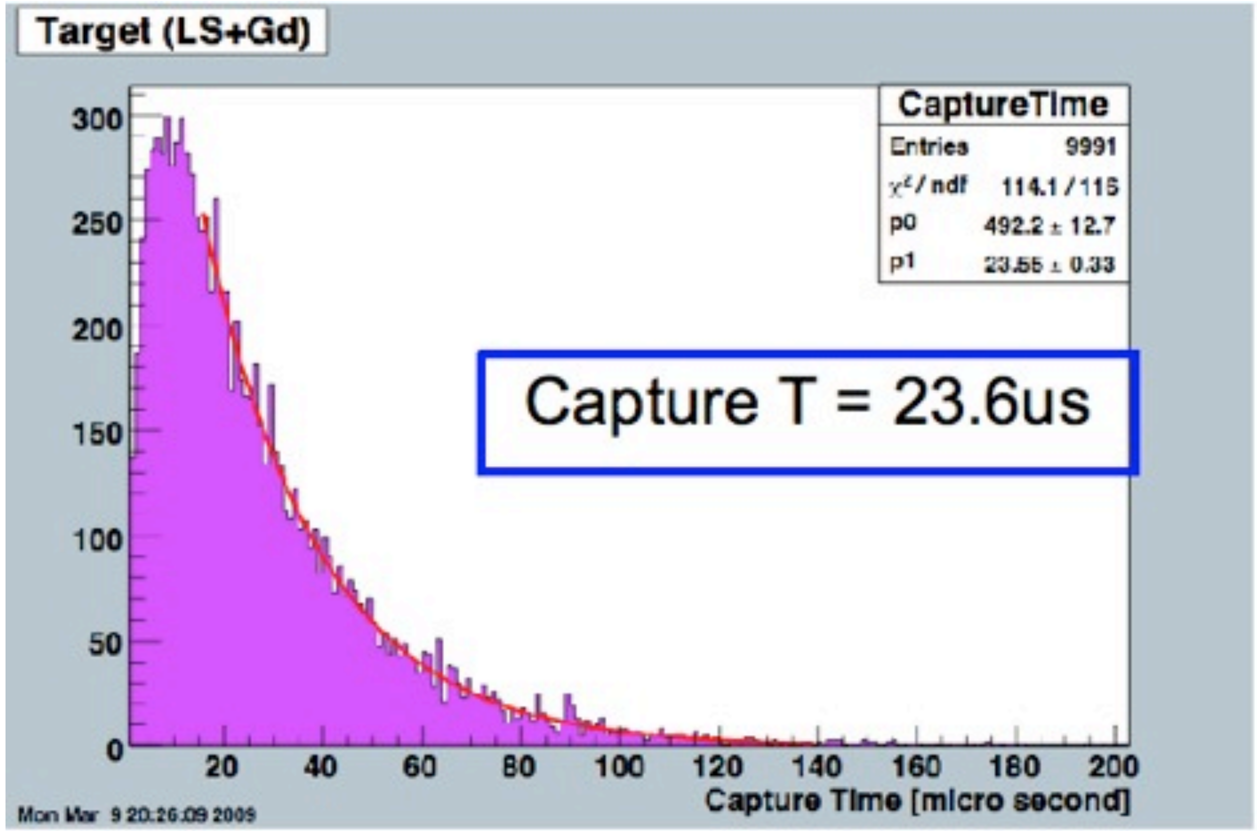

Buffer (mineral oil)
Event
Distance [m]
Gauss Width = 23.5cm
Expo Decay L = 6.21cm

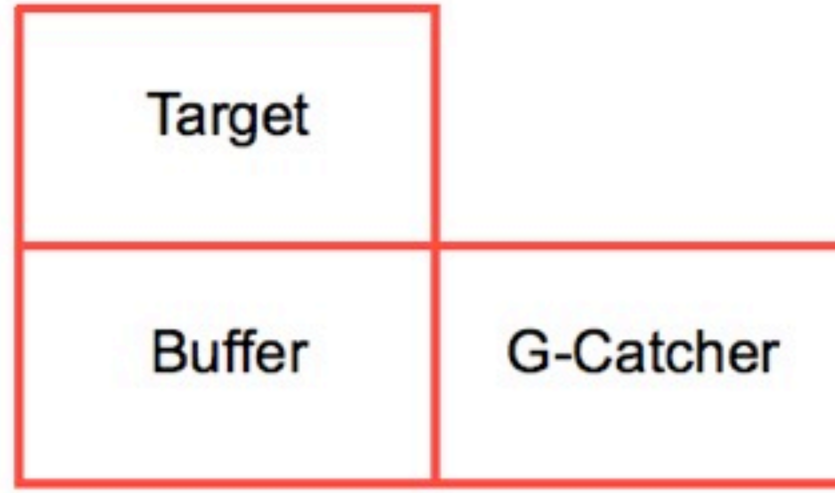

G-Catcher (LS)
Event
Distance [m]
Gauss Width = 21.8cm
Expo Decay L = 6.79cm

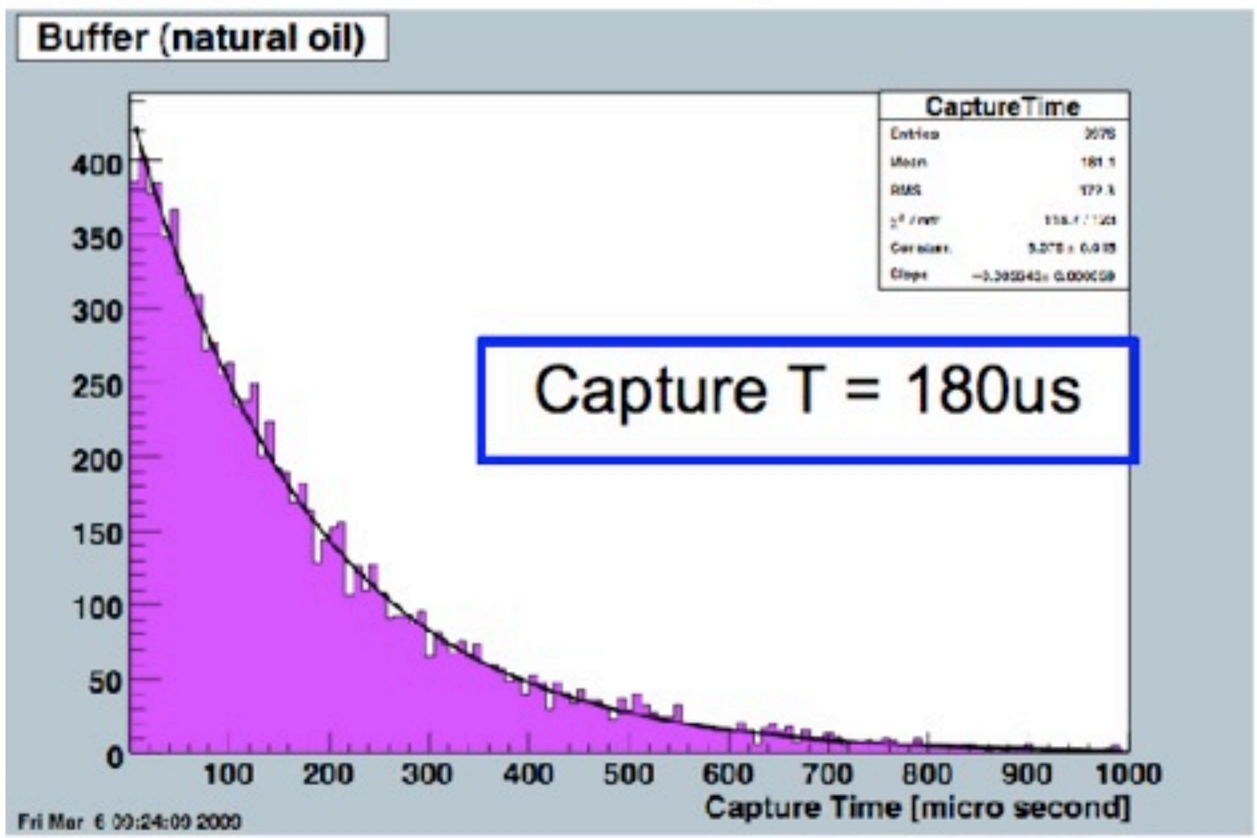
# In above plots...

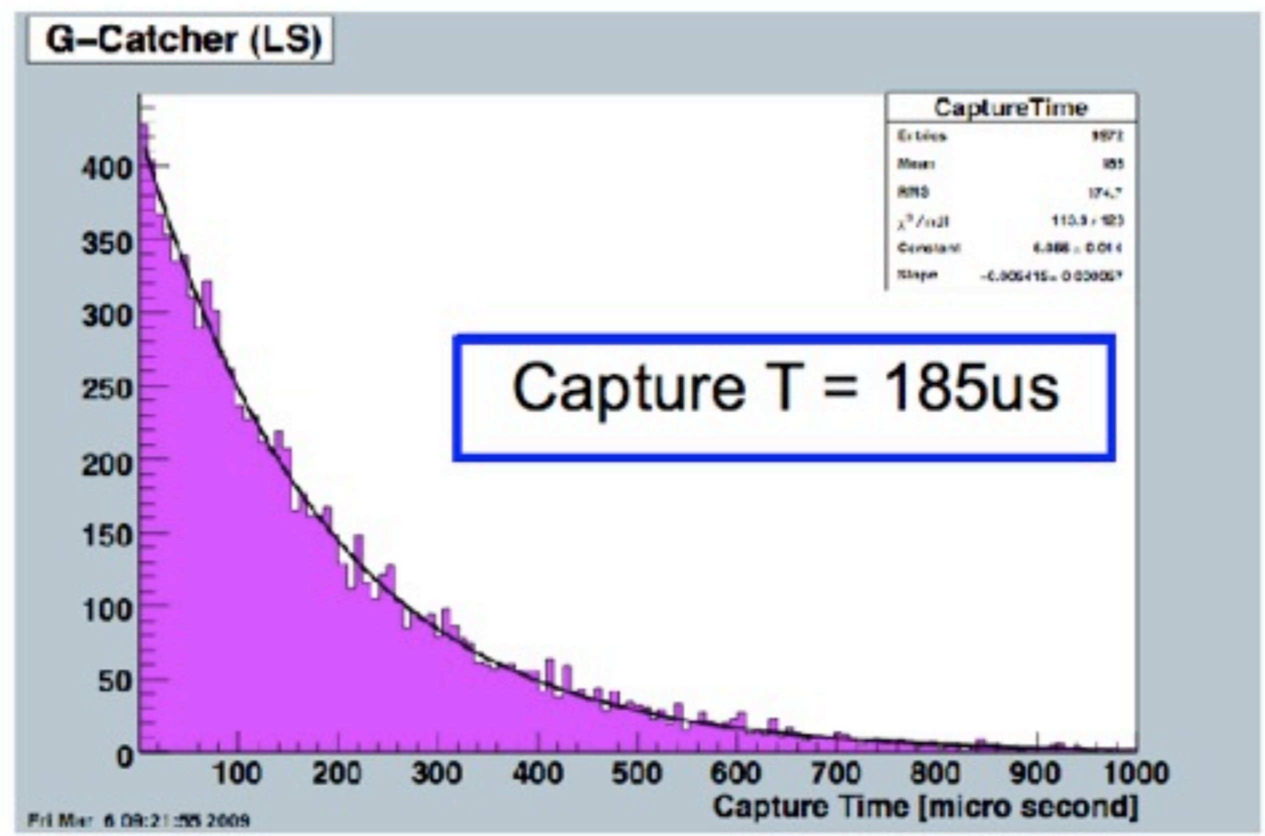
- In all regions, almost all neutrons get captured within $\Delta R=0.5m$ for 2.4MeV neutrons.
- These $\Delta R$ distribution are not very promising for a neutron gun.
- Distribution look very similar in all regions. We should look at capture time distribution and make sure Gd in the target volume is doing the right job.

Capture time distribution for the same simulation are shown in the next page


Target (LS+Gd)
CaptureTime
Entries 9991
χ²/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 is 22us in the target with Gd.

• Without Gd, the target volume should have 209us capture time. This is similar to what we saw in G-Catcher and Buffer region. A slight difference might come from proton density difference in each volume.

→ For neutron gun to be useful, neutrons must, at least, make it to the target volume when shot from outside the steel shielding.

→ $\Delta R$ distribution has a peak at around 10cm. Can this really be correct? Some people mentioned this peak to be 30cm...

We need a sanity check of DCGLG4sim

# Part 2

Comparison

"with Gd" v.s. "w/o Gd"

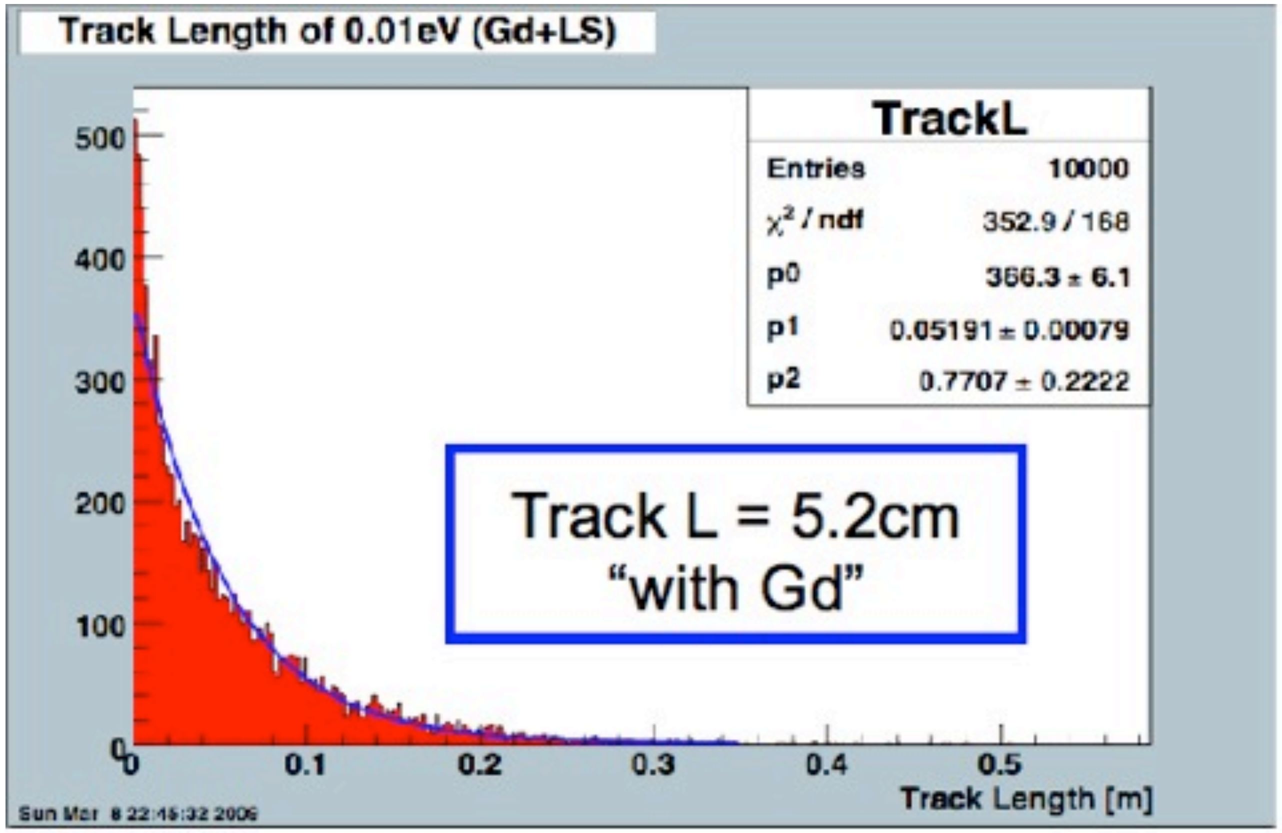
thermal neutrons

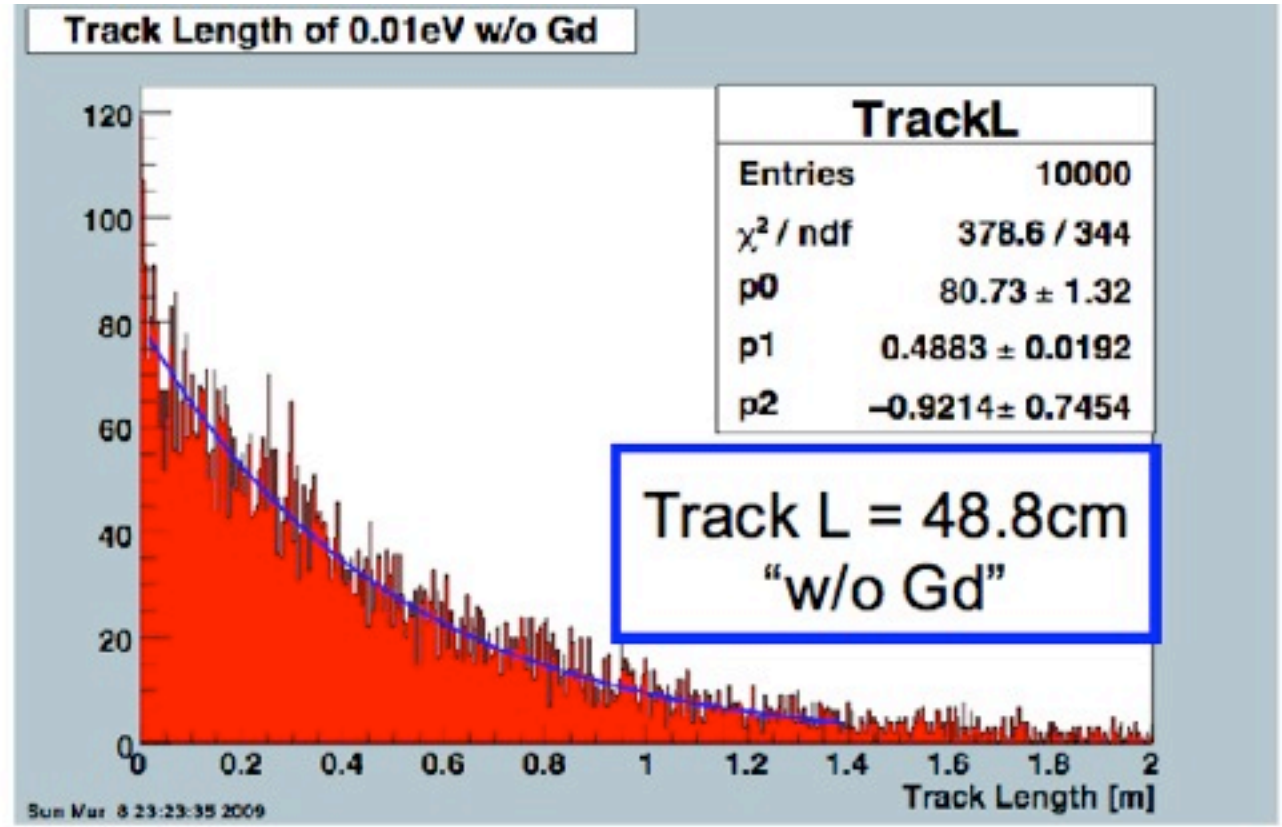
## Simulation set up

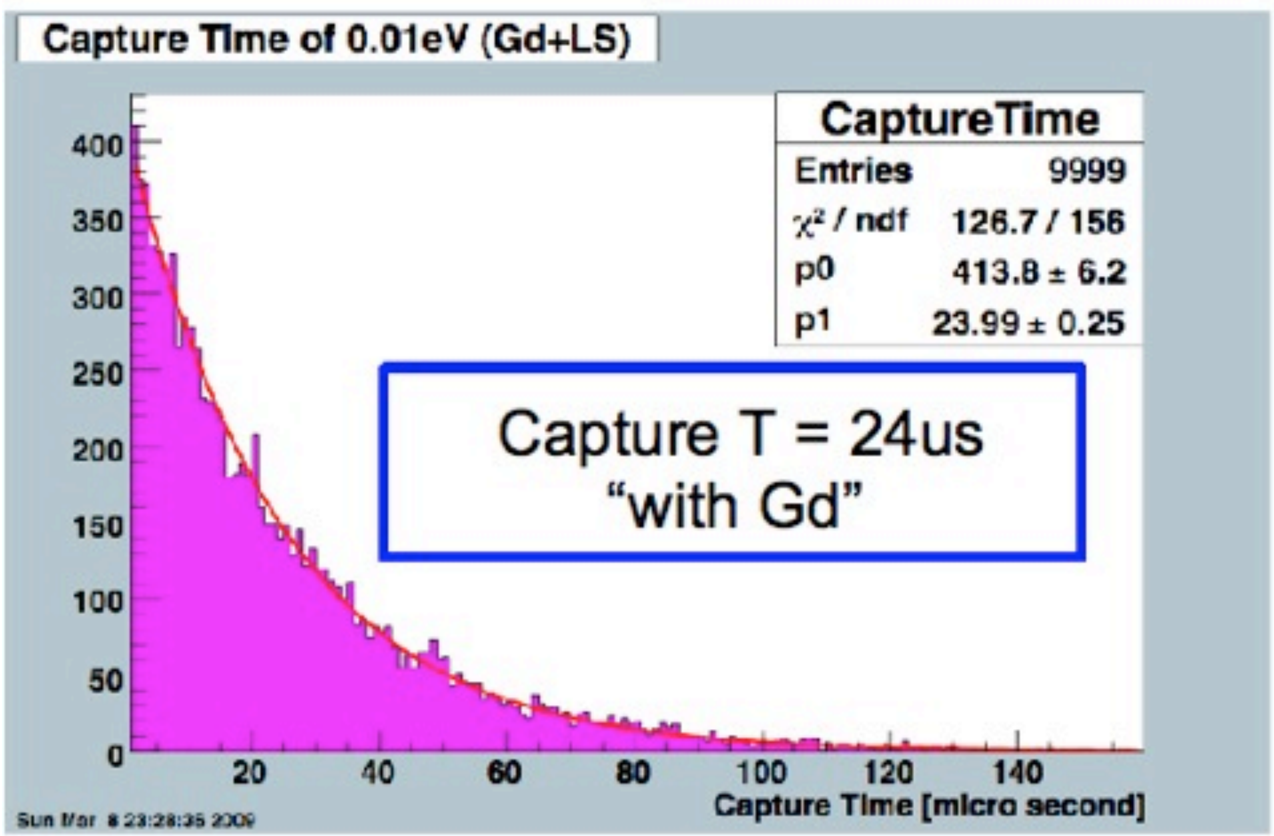
- 1e4 neutrons produced at center of the target volume
- 0.01eV kinetic energy override (thermal neutron energy) with isotropic momentum distribution

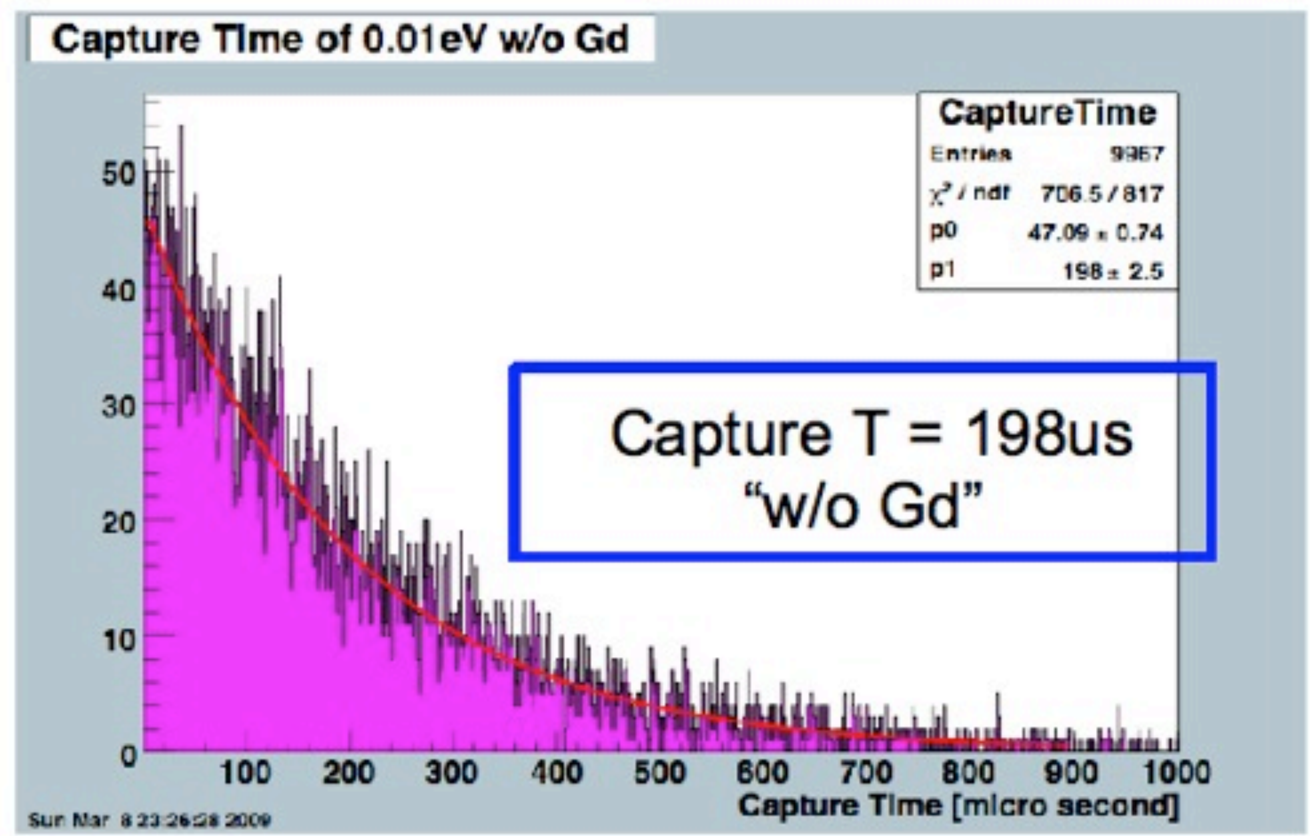
## What do we expect?

- There is no thermalization process since neutron energy is equal to thermal energy. We expect random walk of neutrons at thermal velocity (2200m/s) until they get captured.
- Random walk is due to elastic scattering upon protons, and nothing to do with Gd. Thus we expect the total track length to be scaled with capture time.


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]
Sun Mar 8 22:46:32 2009


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]
Sun Mar 8 23:23:35 2009


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]
Sun Mar 8 23:28:35 2009


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]
Sun Mar 8 23:26:28 2009

# 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 ($\Delta R$, 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.

# More To Do (No Conclusion Yet...)

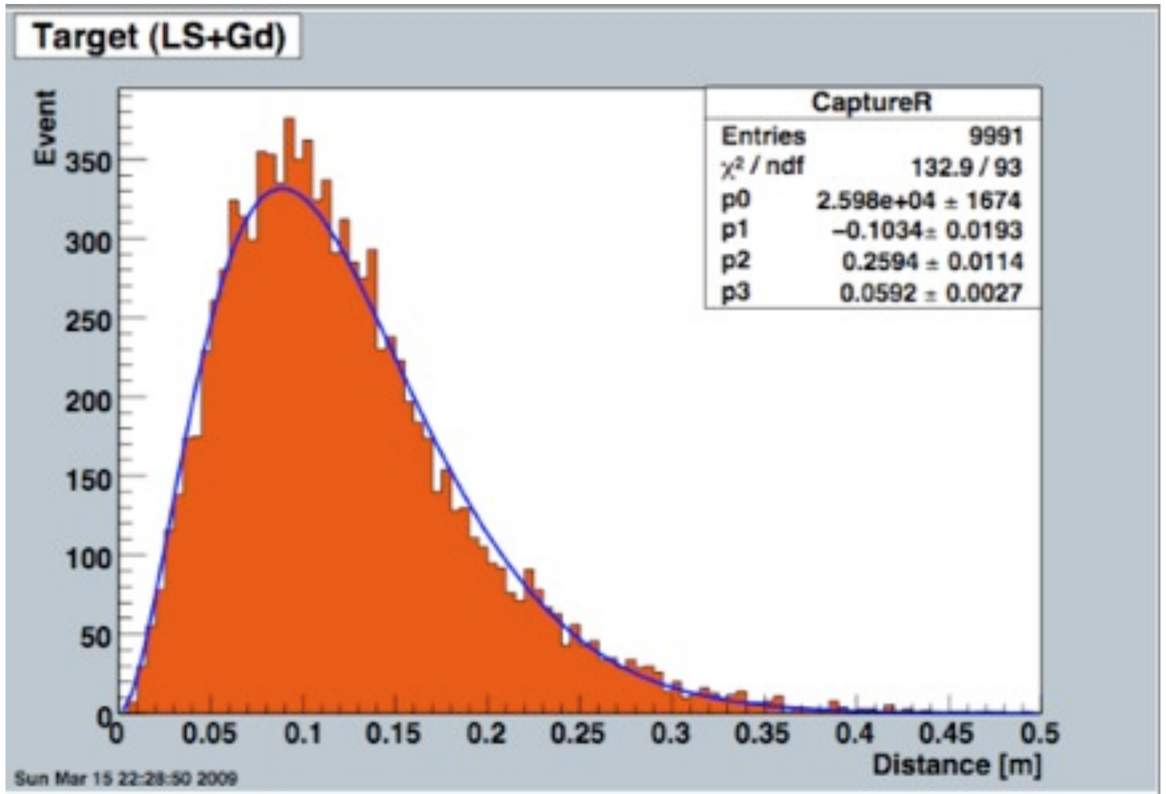
- We haven't found any clear fault of DCGLG4sim result yet.

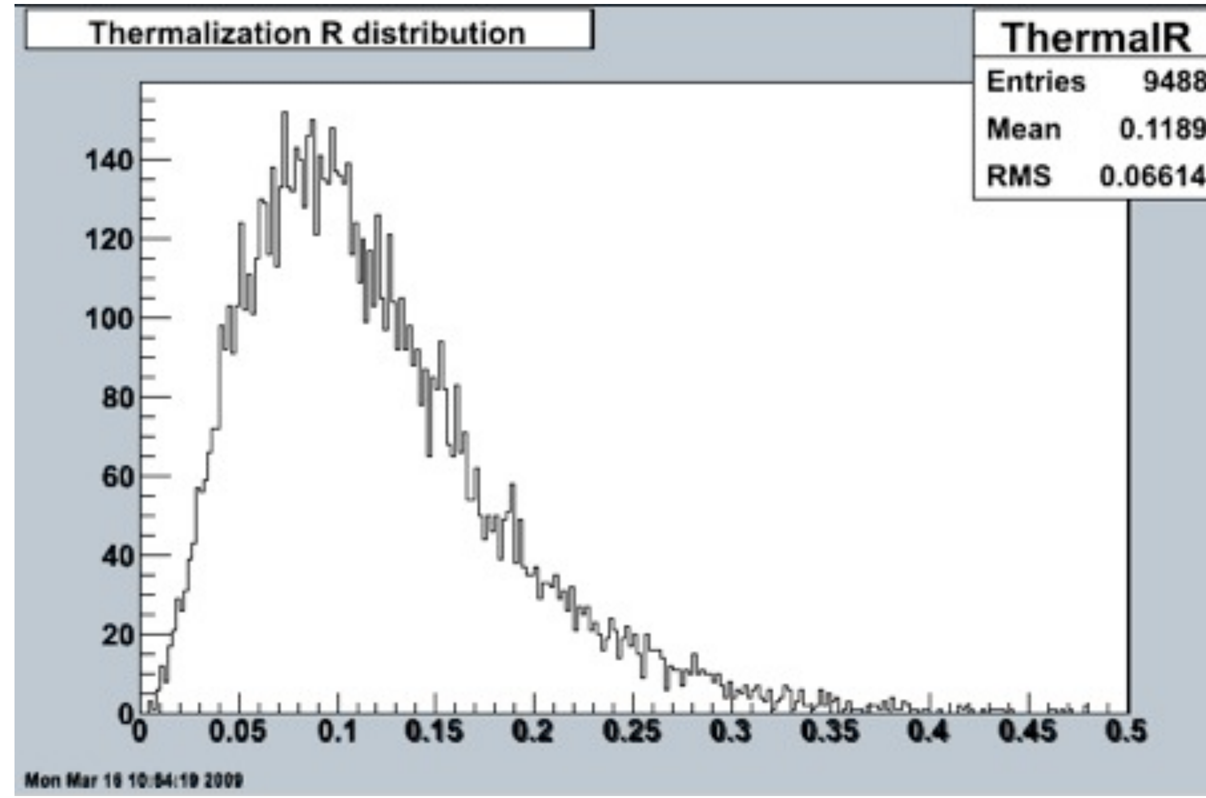
- Compare DCGLG4sim thermalization process with that of simulation run by toMC, MCNPX, and/or FLUKA.

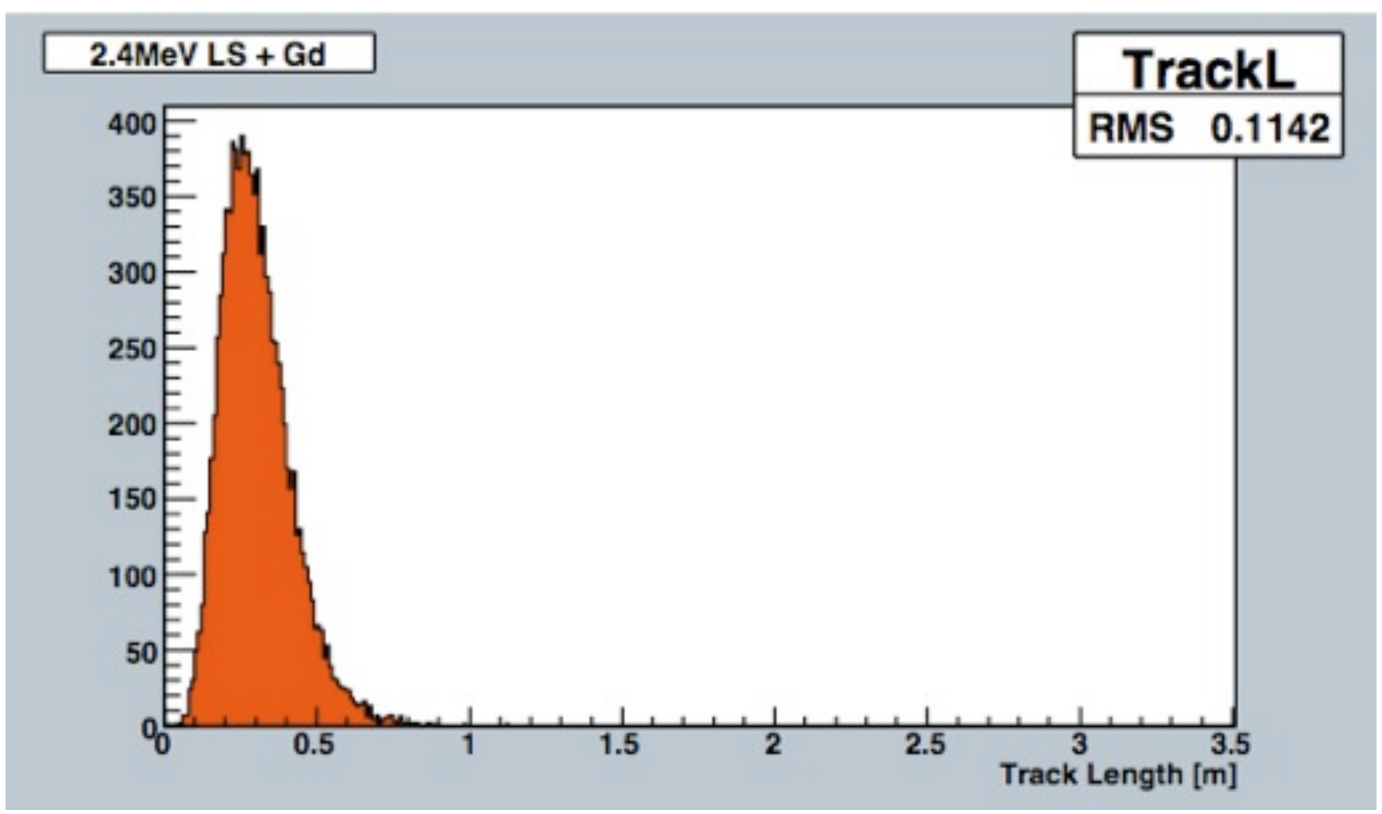
- Comparison of neutron energy as a function of a step between DCGLG4sim output and analytical function

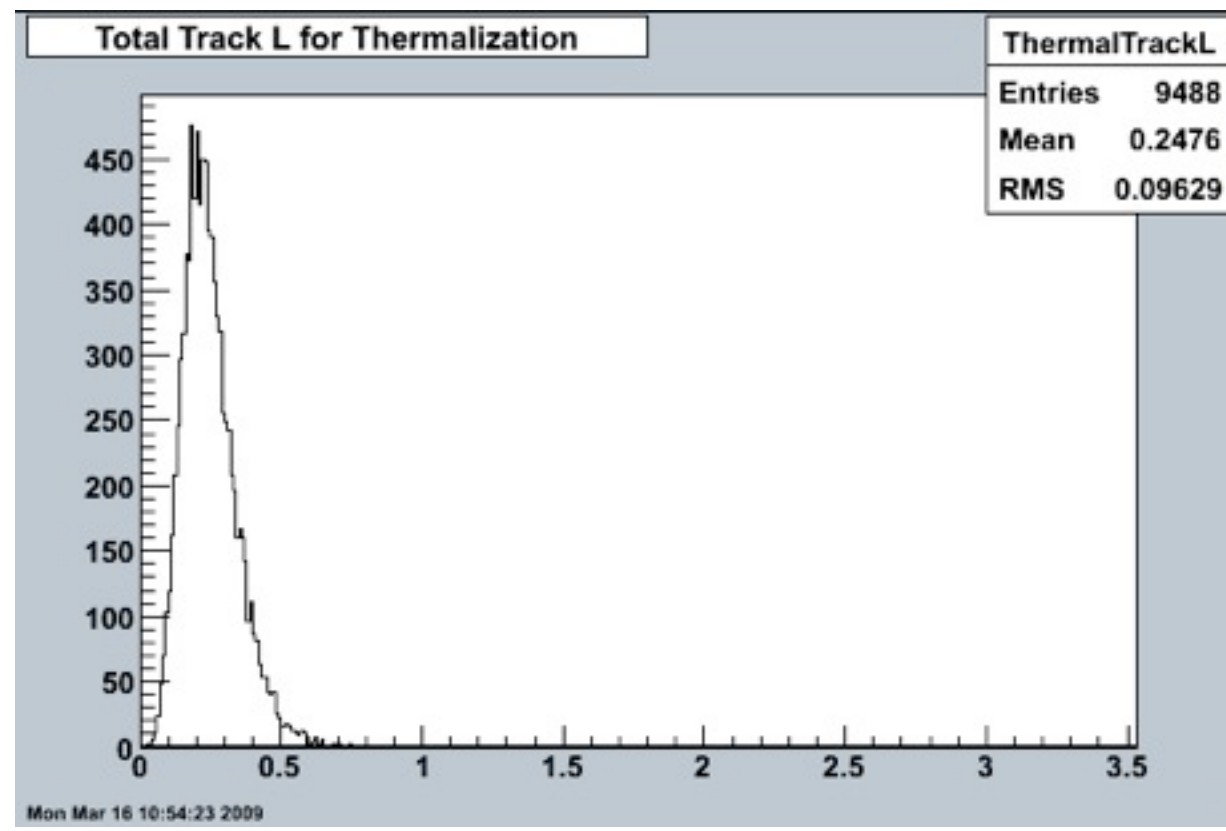
- I am going to measure neutron attenuation length in LS during next a few weeks in Jocelyn's danjon lab (Thanks to Jocelyn!)

Back Up


Target (LS+Gd)
CaptureR
Entries 9991
χ² / ndf 132.9 / 93
p0 2.598e+04 ± 1674
p1 −0.1034 ± 0.0193
p2 0.2594 ± 0.0114
p3 0.0592 ± 0.0027
Event
Distance [m]
Sun Mar 15 22:28:50 2009


Thermalization R distribution
ThermalR
Entries 9488
Mean 0.1189
RMS 0.06614
Mon Mar 16 10:54:19 2009


2.4MeV LS + Gd
TrackL
RMS 0.1142
Track Length [m]


Total Track L for Thermalization
ThermalTrackL
Entries 9488
Mean 0.2476
RMS 0.09629
Mon Mar 16 10:54:23 2009