Measuring fast neutrons with large liquid scintillator for ultra-low background experiments

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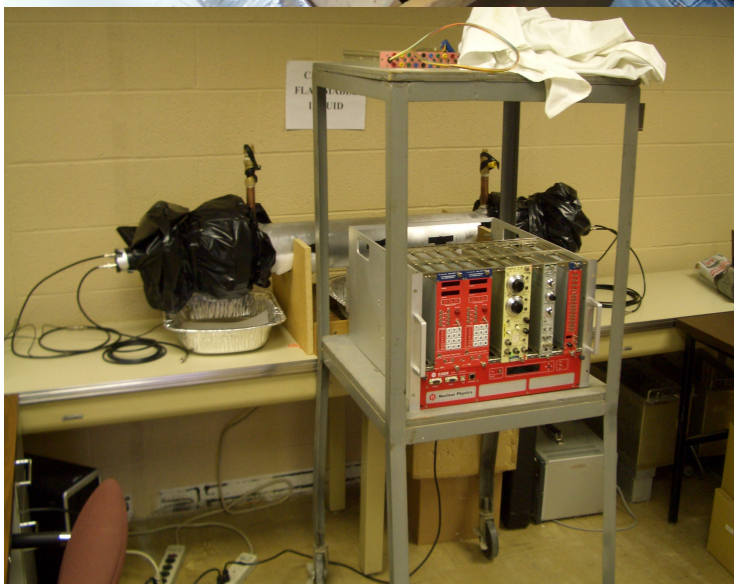
Outline

1. Fabrication of Big scintillation neutron detector at USD.
2. Energy & position calibration, n/γ discrimination.
3. Surface neutron measurement.
4. Soudan mine underground neutron measurement.

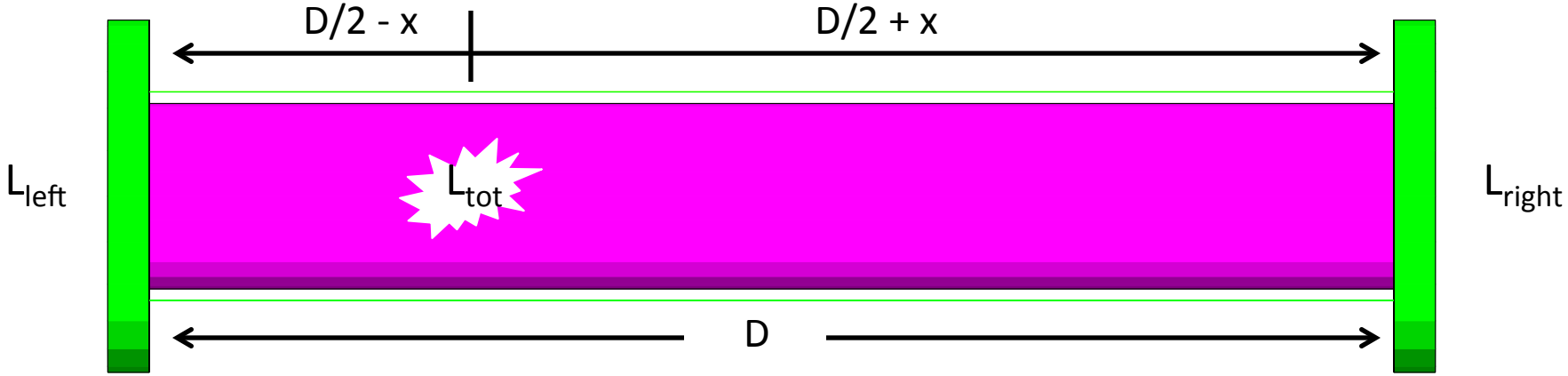
Large Liquid Scintillation Neutron Detector



Detector Design

- 1m long LS neutron detector filled with 12 liters LS EJ301.
- Internally covered with diffusive paint EJ520.
- 2 Hamamtsu 5” PMTs(R4144) attached to the detector through Pyrex glass windows.

Energy – Position independent?



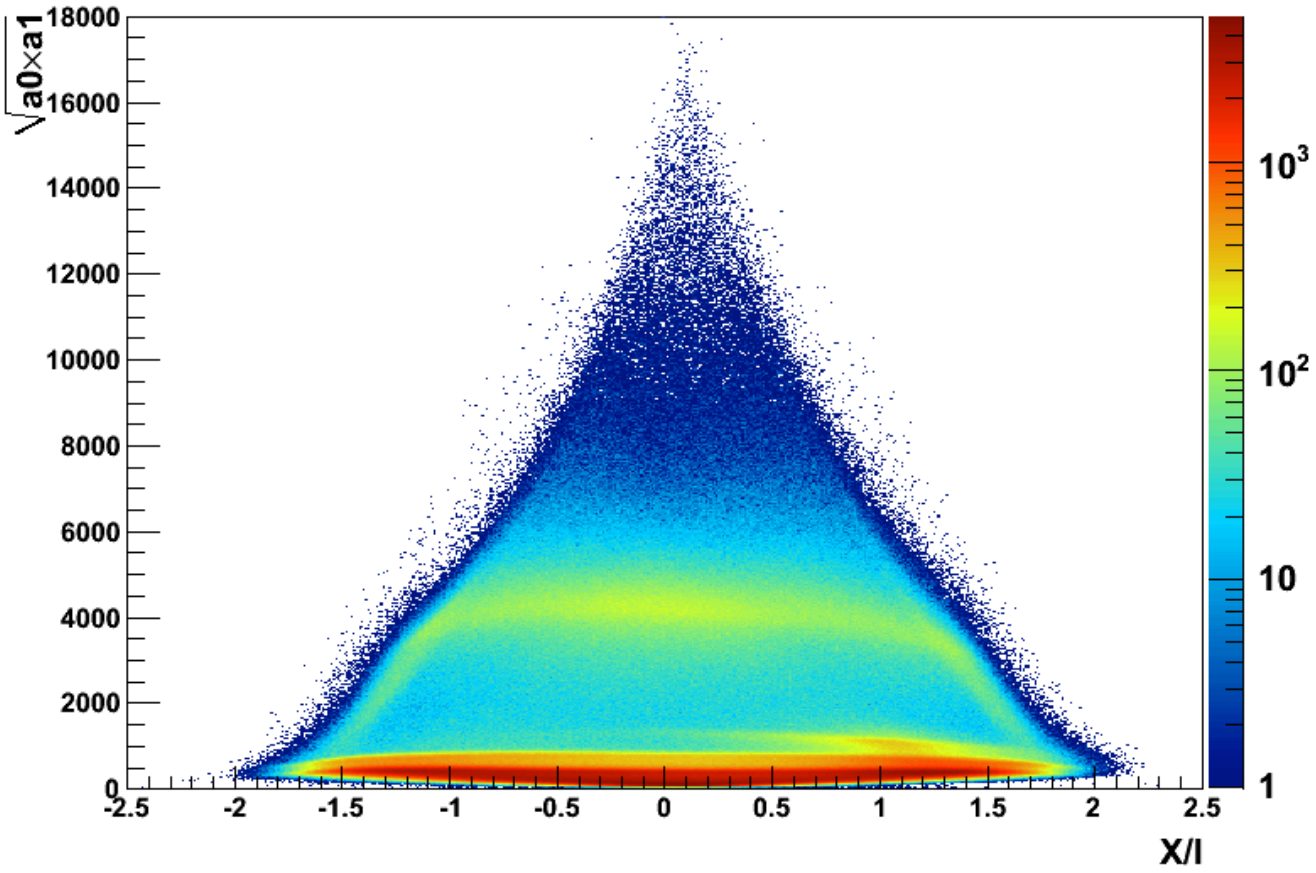
$$L_{left} = 0.5 L_{tot} e^{-(D/2-x)/l}$$

$$L_{right} = 0.5 L_{tot} e^{-(D/2+x)/l}$$

$$\ln \sqrt{\frac{L_{left}}{L_{right}}} = x/l$$

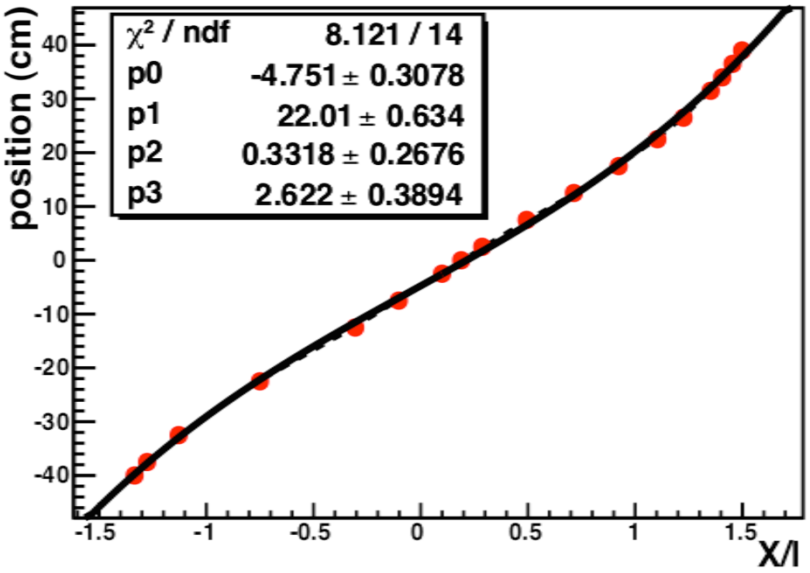
$$\sqrt{L_{left} L_{right}} = 0.5 L_{tot} e^{-D/2l} \propto E_{tot}$$

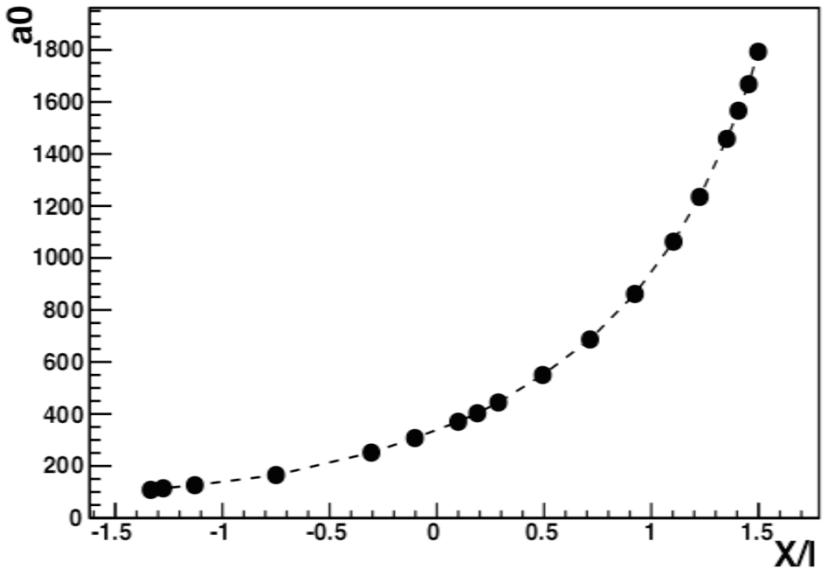
Energy - Position Independence



Three calibration source energy: Na22(1.27MeV), AmBe (4.4MeV) and muon minimum ionization peak(~20MeV)

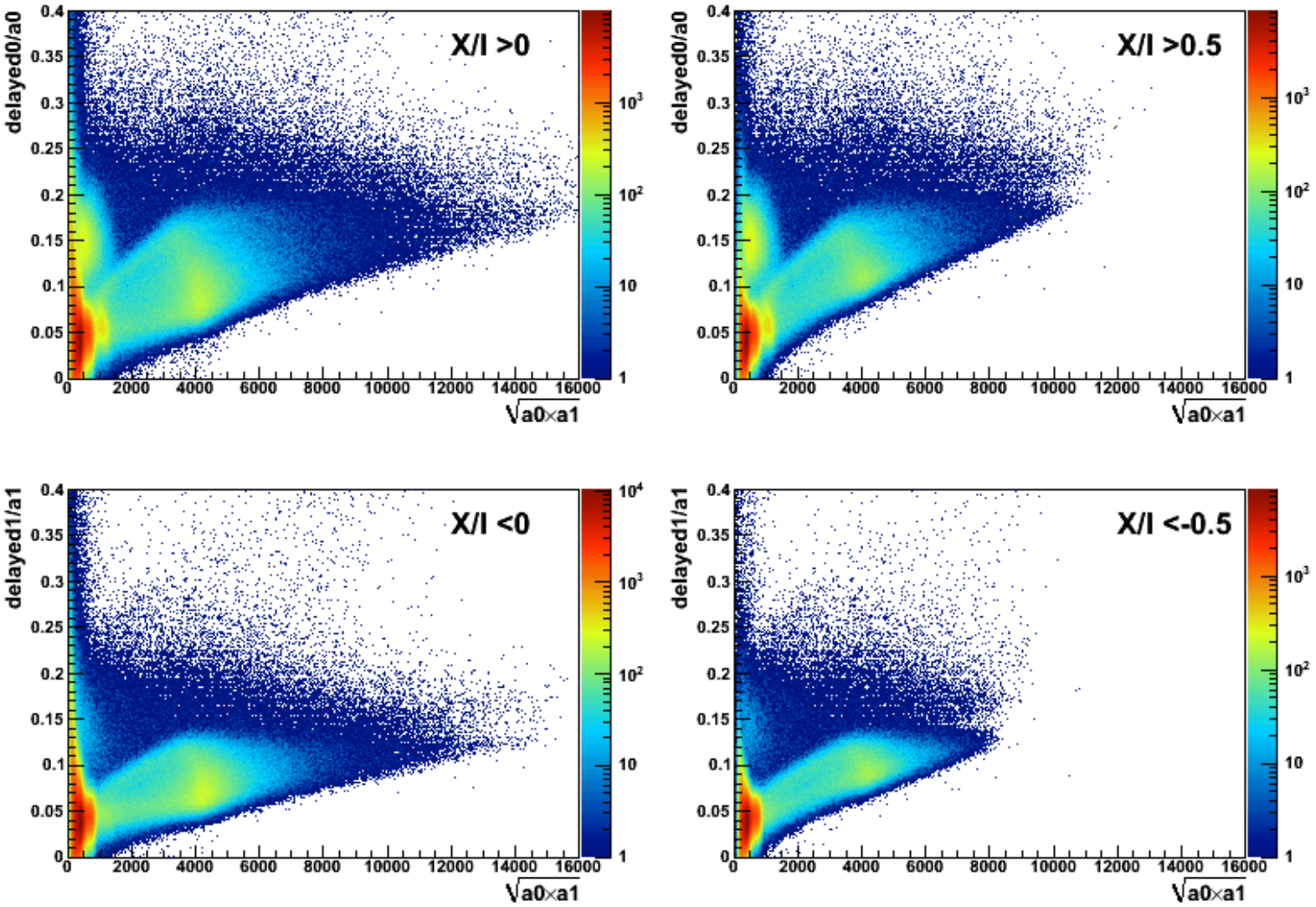
Position Calibration





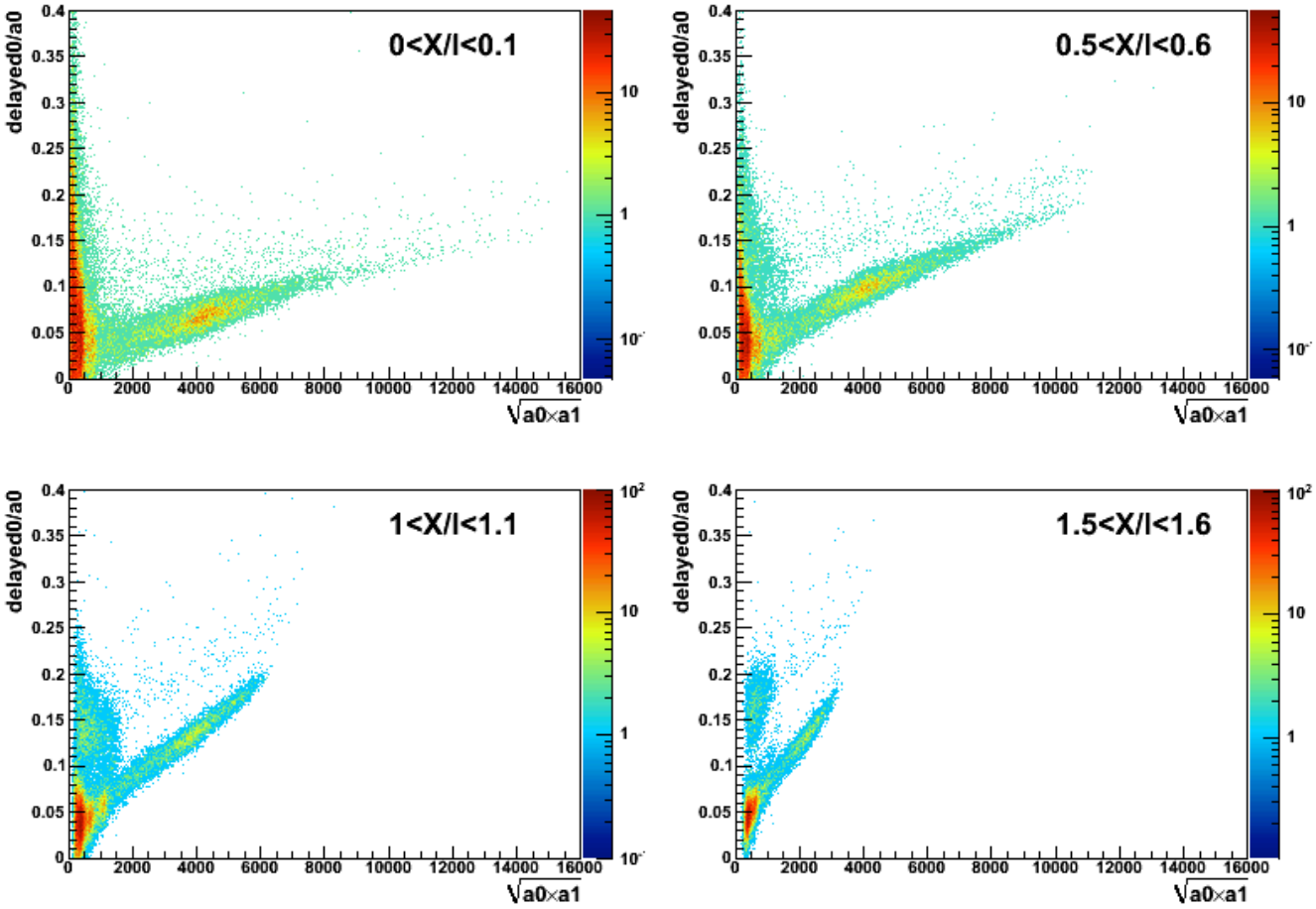
Calibration with Na22(1.27MeV). Place the source on the tube and change it each 2.5 cm.

n/g Discrimination



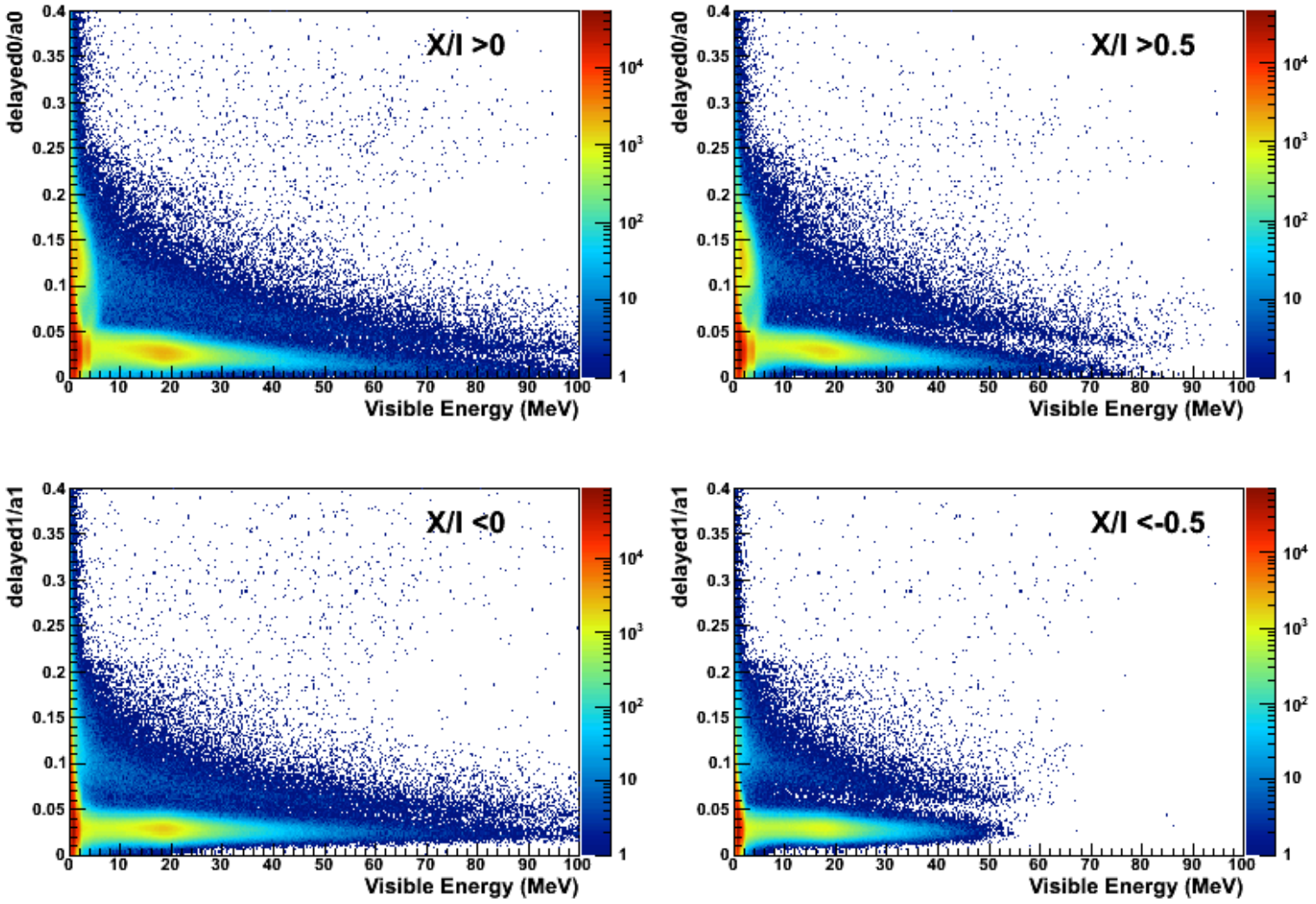
- AmBe source at surface about 68 hours data.
- n/g mixed together.

n/g Discrimination



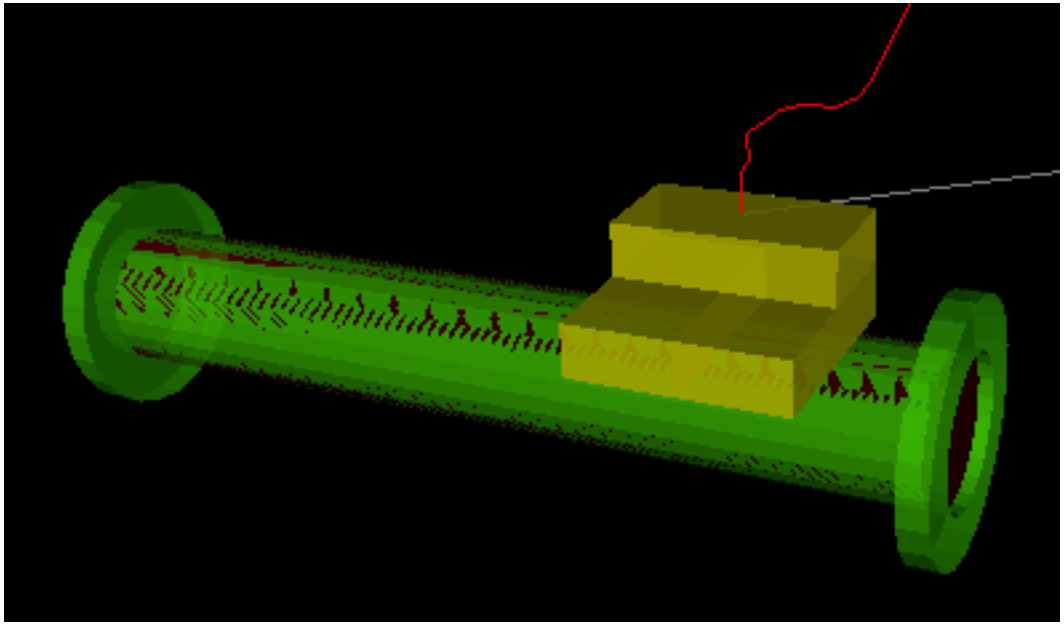
n/g can only be separated in narrow slices along the tube. The n/g separation is getting better when the position is closer to ends.

n/g Discrimination



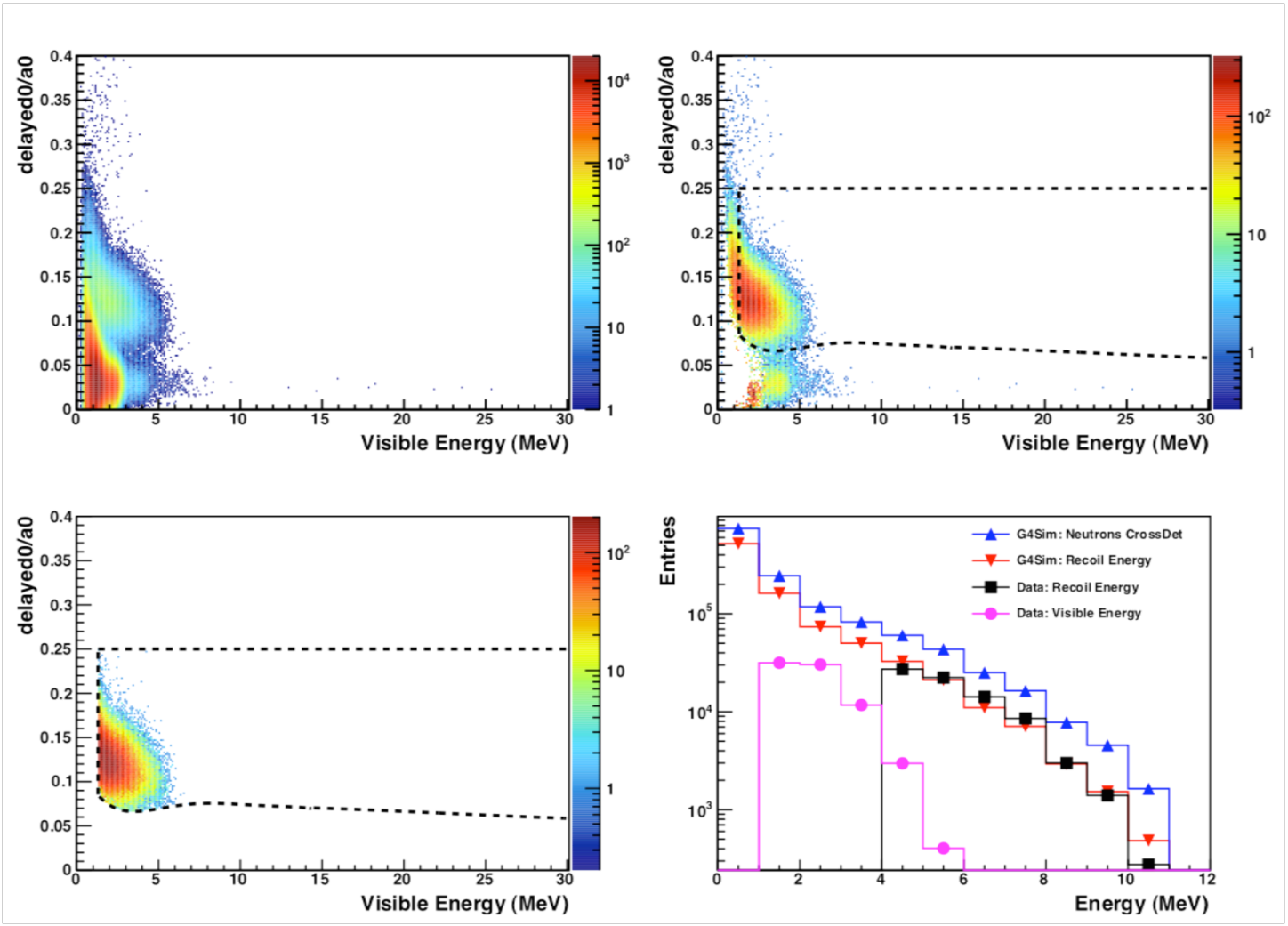
- All slices could be folded to the horizontal then summed up.

AmBe Calibration at Soudan Mine



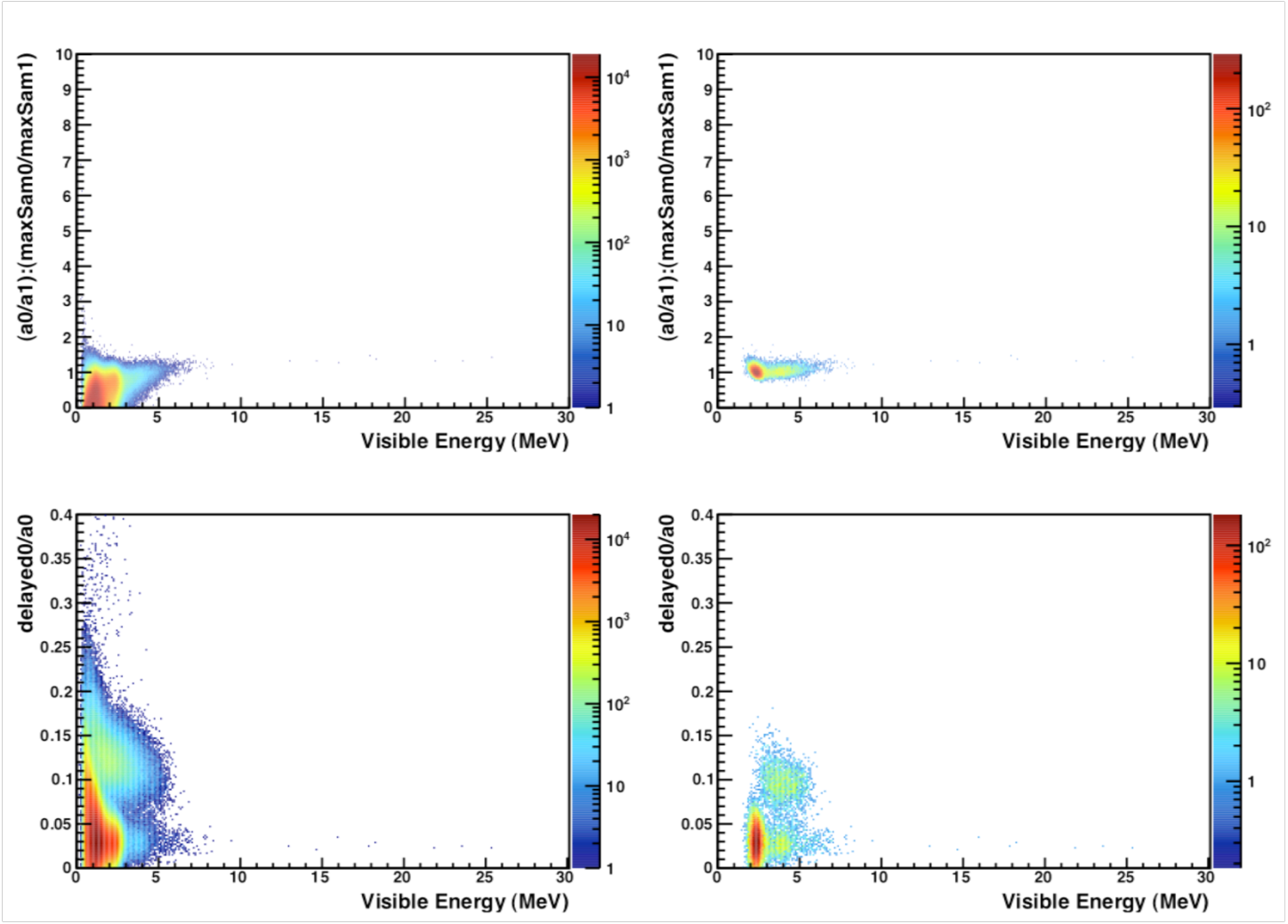
- In order to remove the effect of gamma ray contamination, two layer of lead bricks(4'' total) is place right above the tube and the AmBe source located on the top of it.
- We took about two days Ambe data and three days background data w/wo the source.

AmBe Run at Soudan Mine



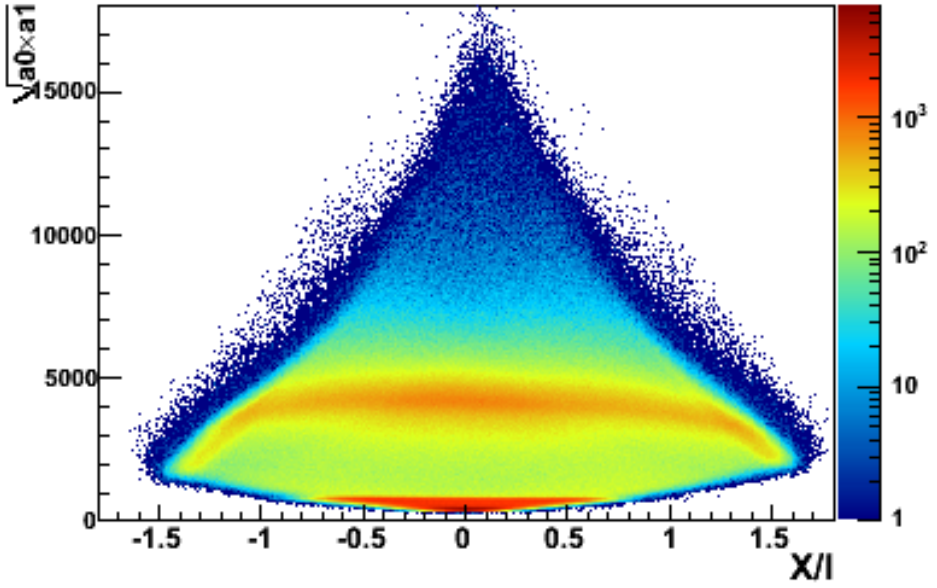
- Soudan AmBe Run: ~2 days

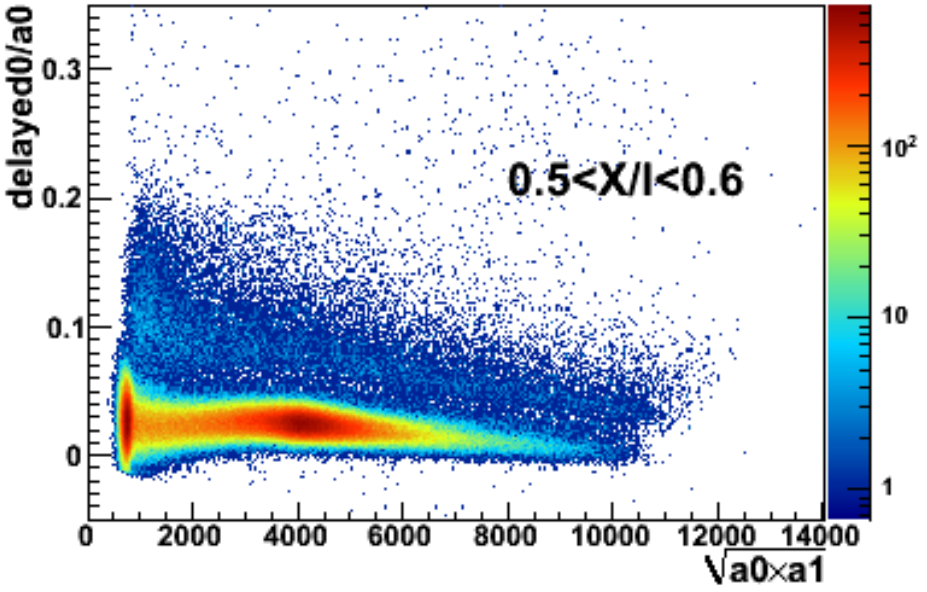
Raising the Threshold



- The energy threshold is set to ~1 MeV.

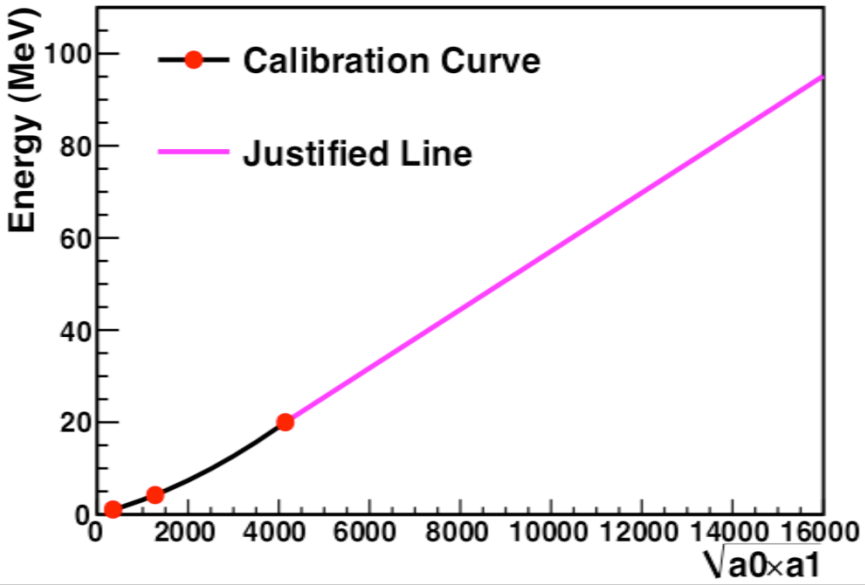
Neutrons at Surface

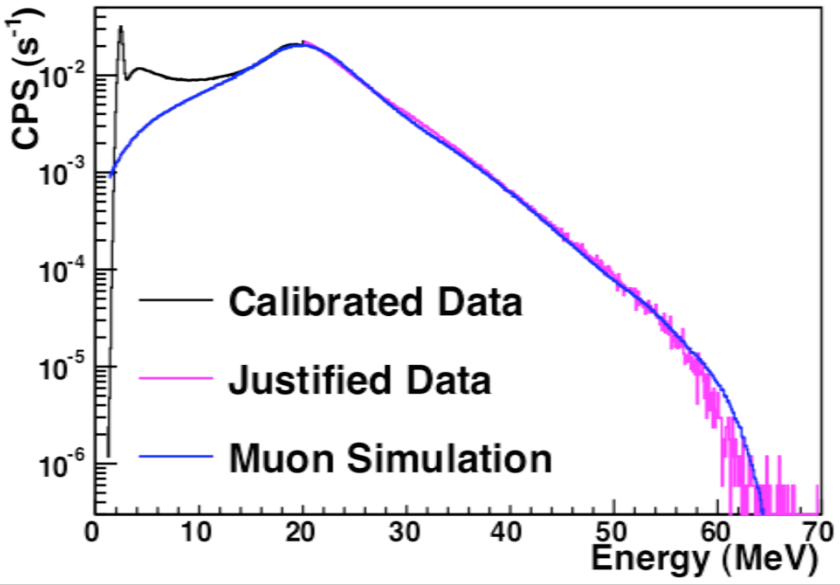


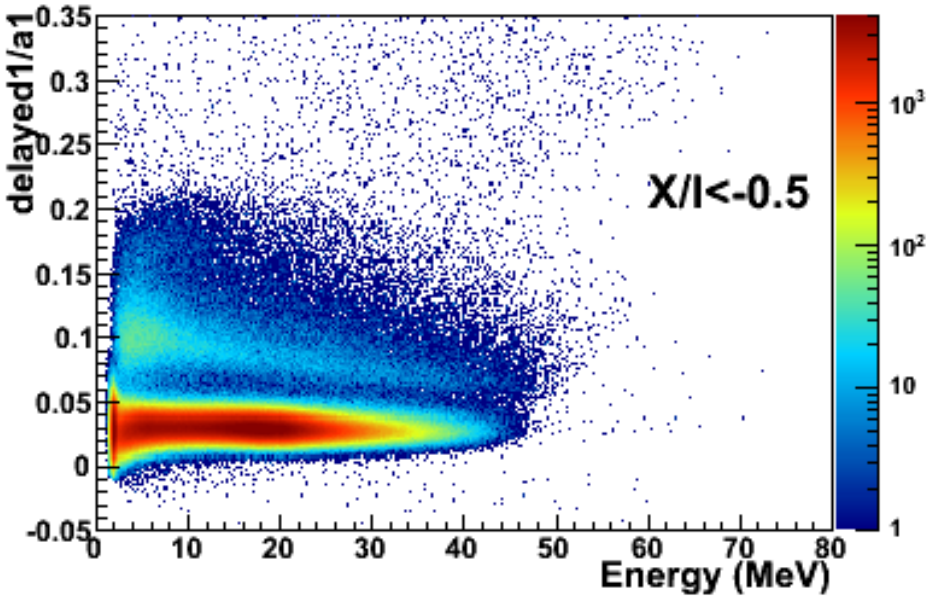


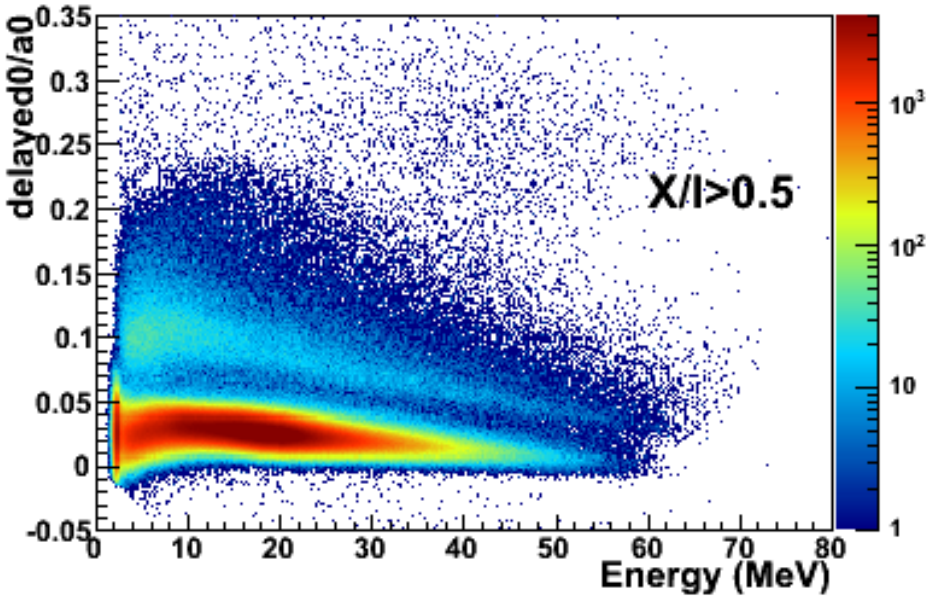
- Surface background data: 19.16 days
- Two issues need to be addressed:
  1. Energy calibration above 20MeV – correction by surface muon data.
  2. Quenching factor for high energy neutrons - ???

Energy Calibration at High Energy

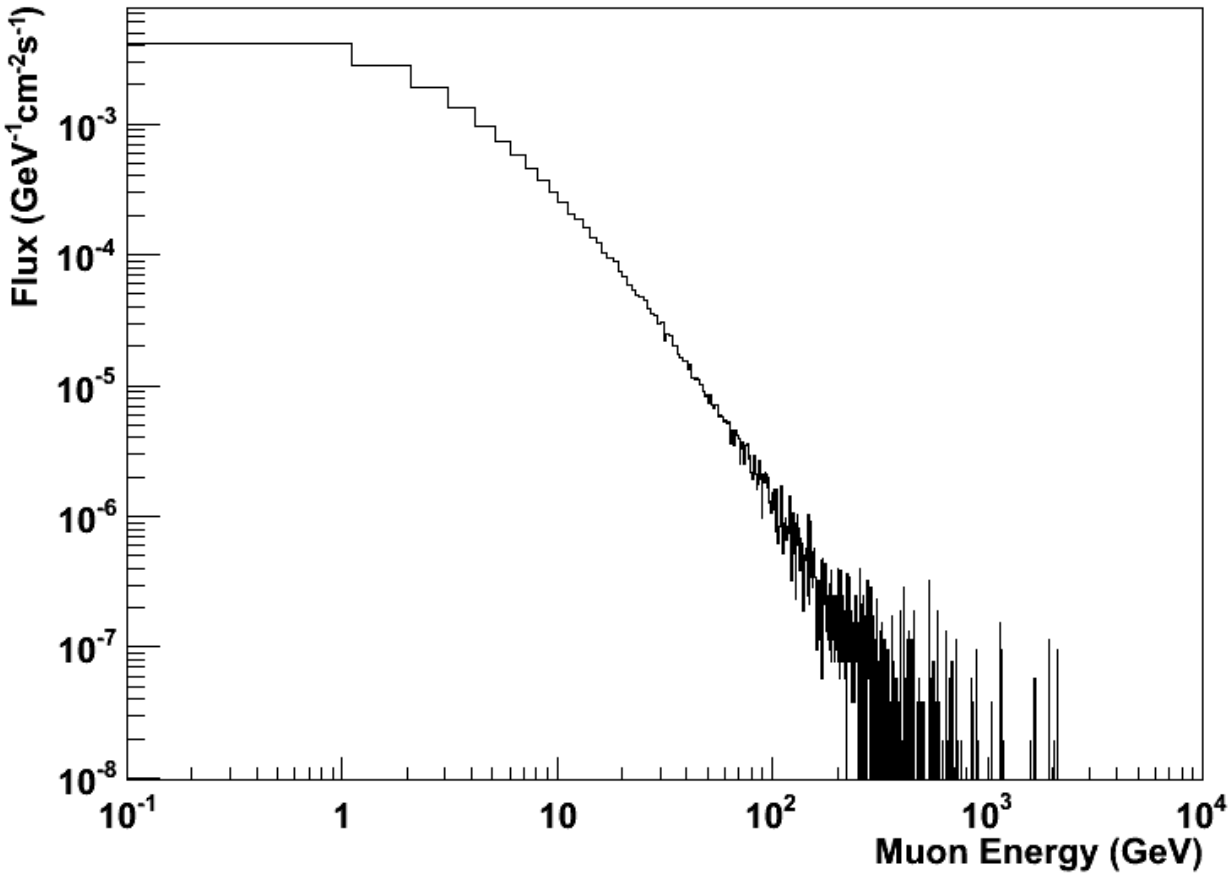








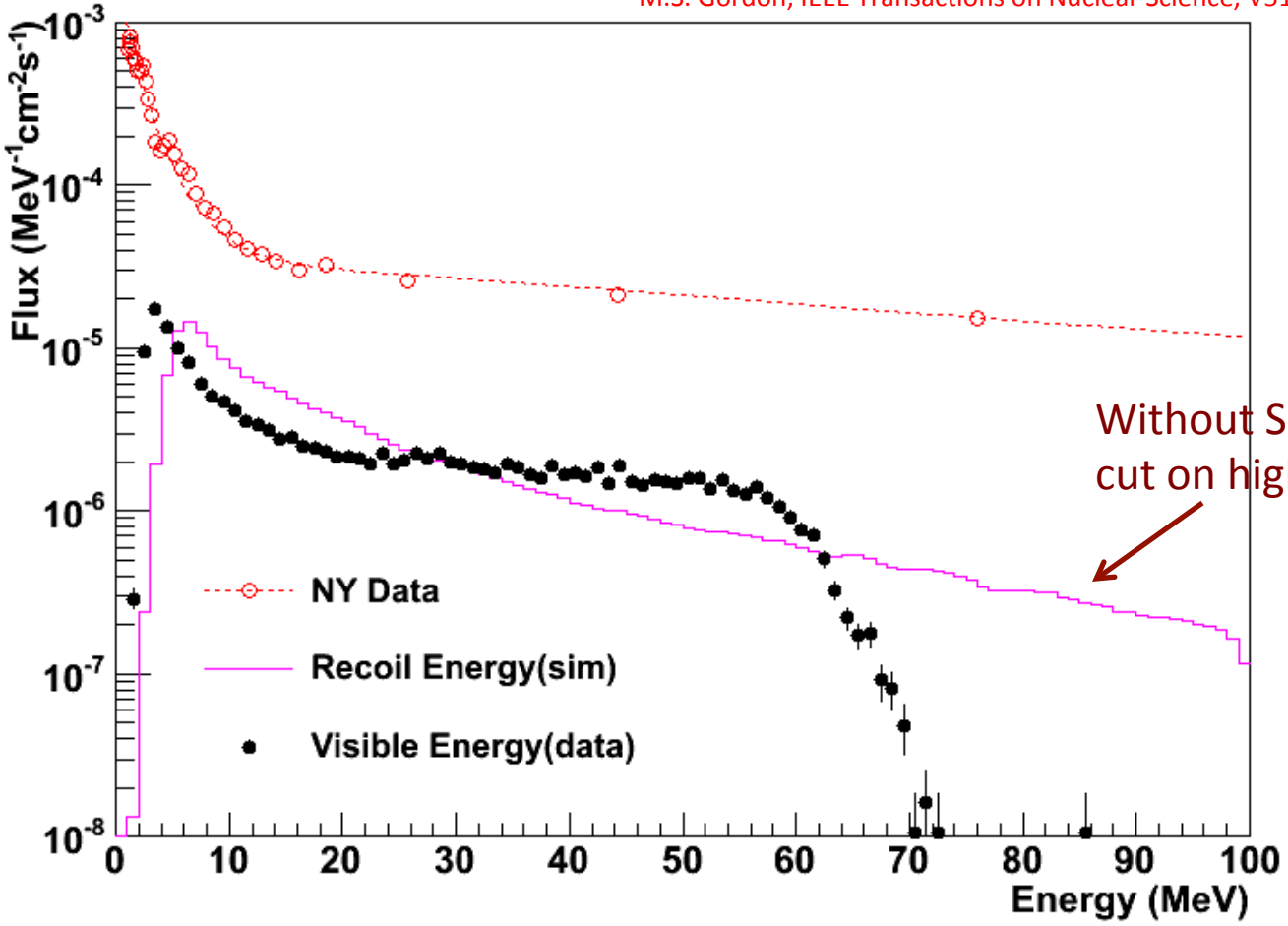
Muon Flux Measured at Surface



- Reconstructed muon flux: 0.016 /cm^2/s which is 11.7% higher than sea level from Gaisser's formula(0.0137/cm^2/s).
- USD campus elevation: 1221 feet.

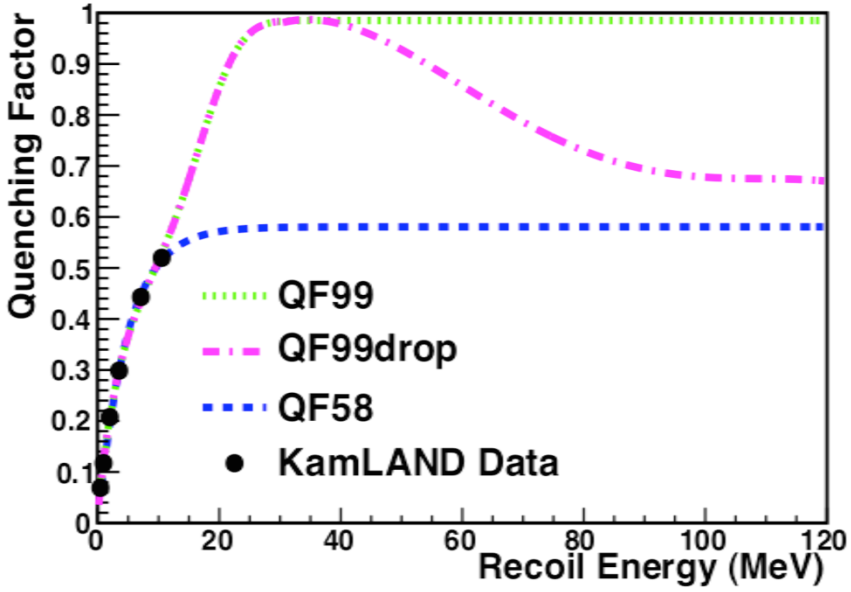
Quenching Factor Puzzle

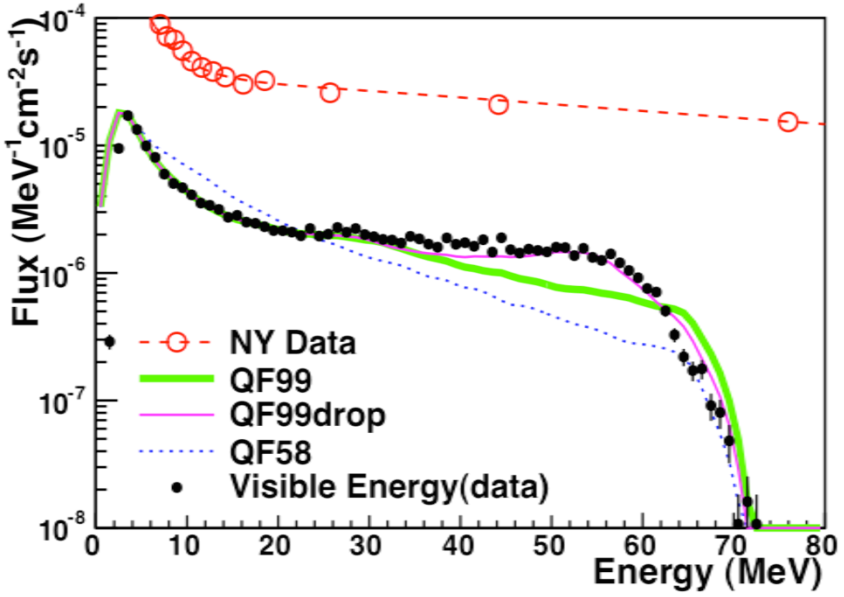
M.S. Gordon, IEEE Transactions on Nuclear Science, V51, No. 6, 2004



- Visible V.S recoil energy by assuming NY neutron spectrum

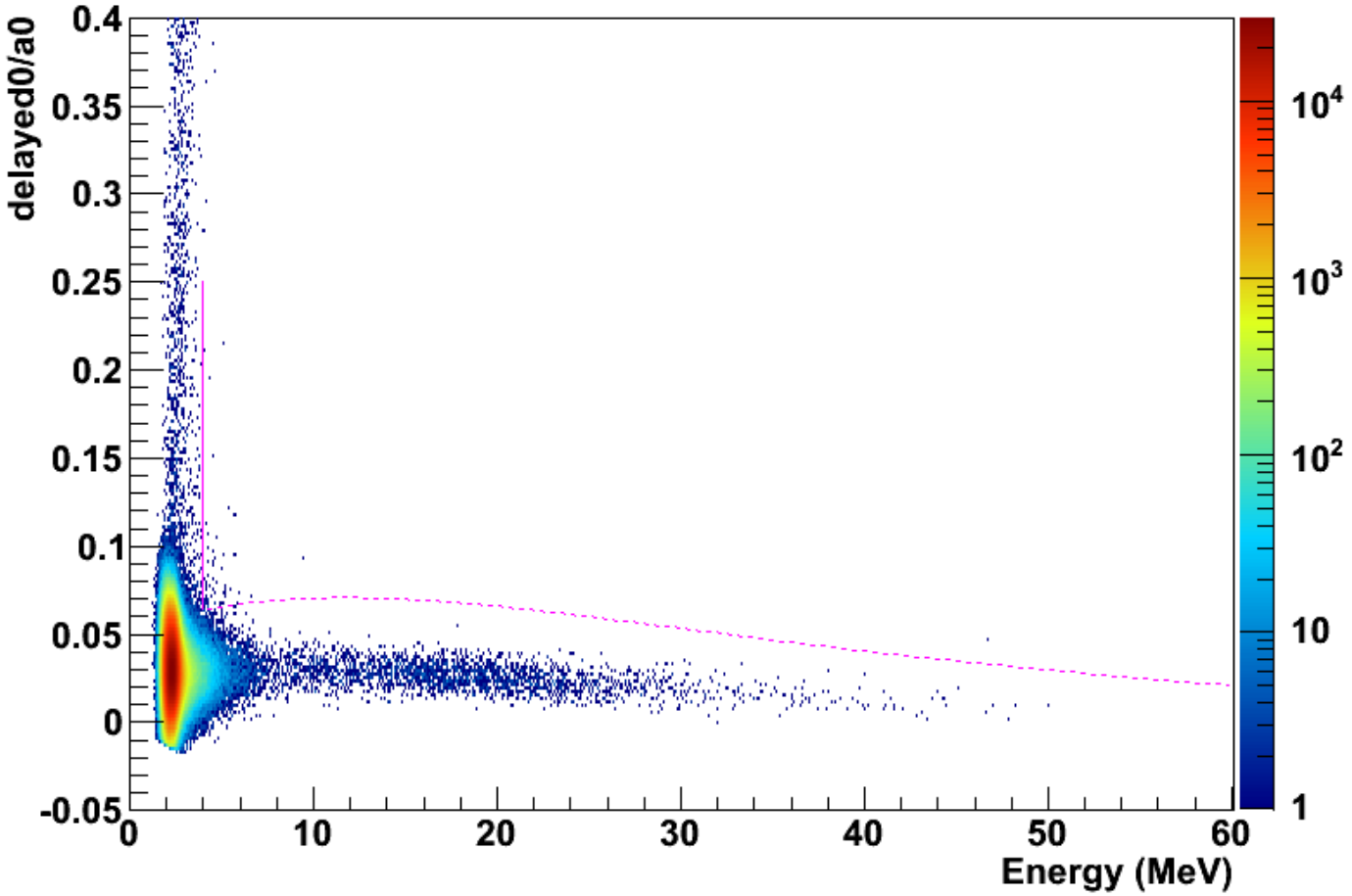
Neutron at Surface





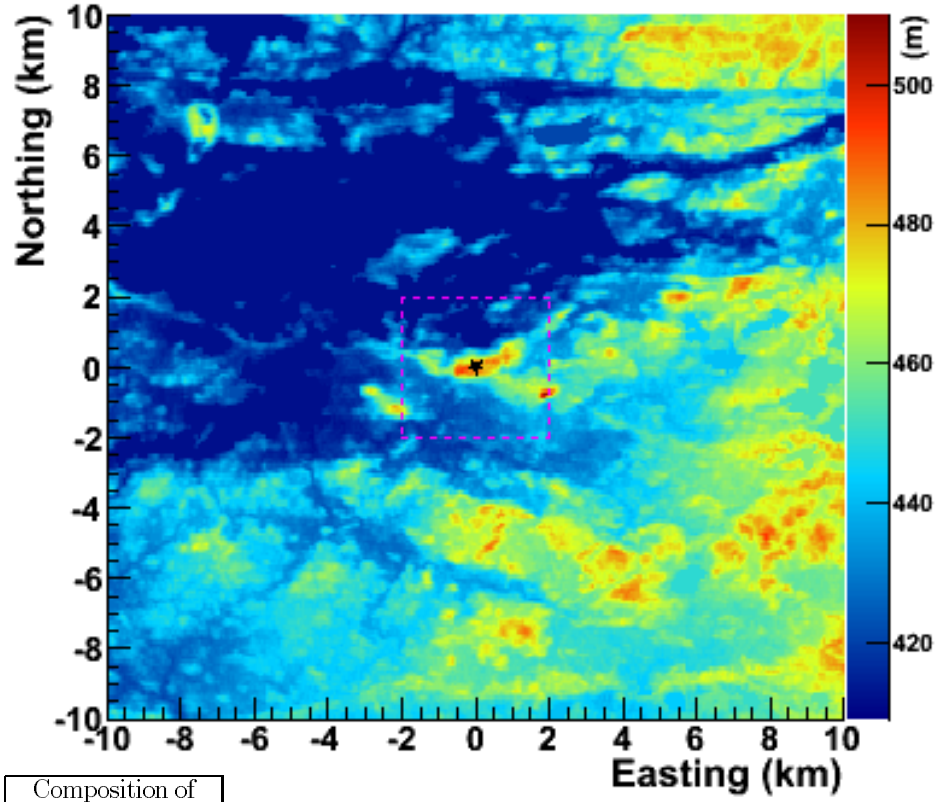
QF58 given by best fit from KamLAND:
visibleE=recoilE*0.5806*(1-exp(-0.2072*recoilE-0.00335))

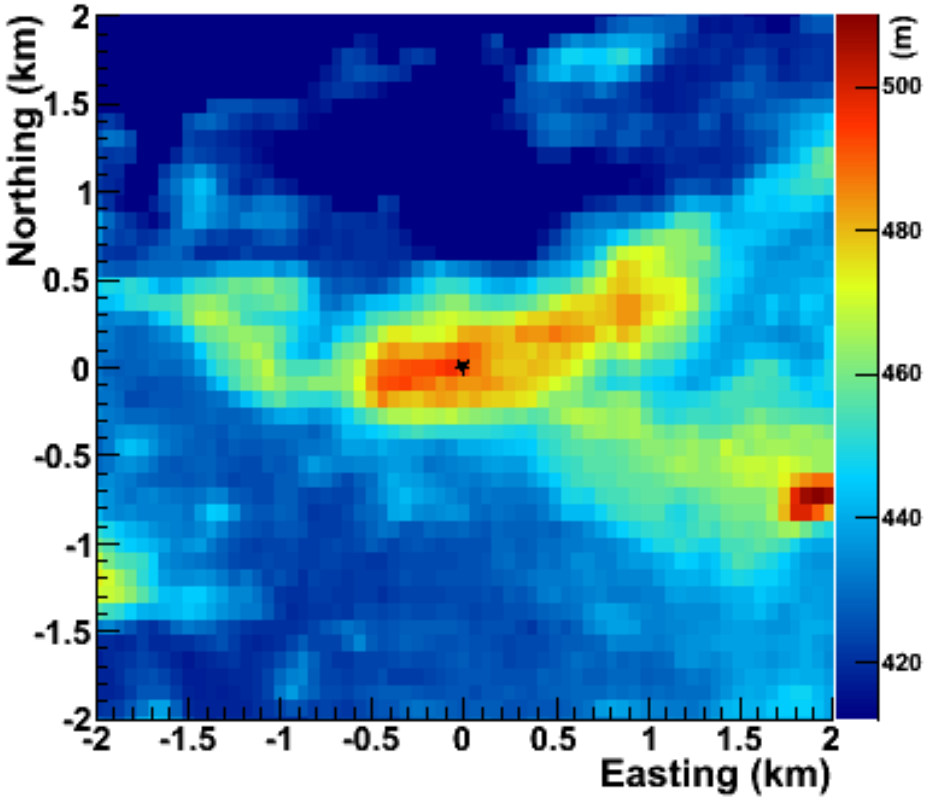
Muon Flux at Soudan Mine



- Soudan data: 373.1 days

Mountain Profile at Soudan Mine





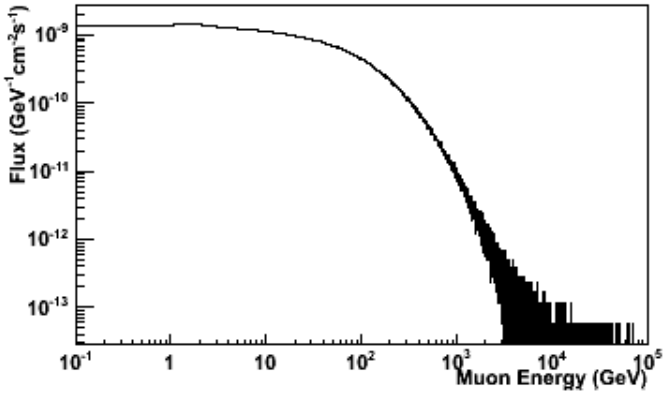
Composition of Ely Greenstone	
Compound	%
SiO_2	50.6
$Al_2 O_3$	15.0
CaO	9.0
FeO	8.6
MgO	6.5
$H_2 O$	2.7
$Fe_2 O_3$	2.6
$Na_2 O$	2.5
TiO_2	1.1
$K_2 O$	0.4
CO_2	0.3
MnO	0.2
$P_2 O_5$	0.1

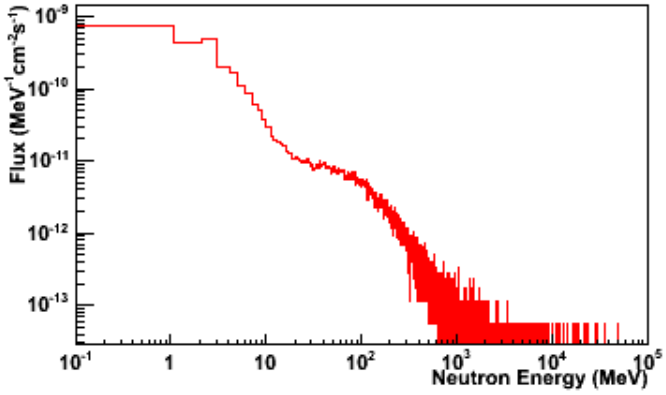
- Satellite data at Soudan Mine area. Coordinates: (-92.2412540083333, 47.820348358333334) with elevation: 492 meter above sea level.
- Cavern size 20m*20m*20m. Central cavern elevation: -217 meter.
- Rock composition refers to the Ely greenstone. The average rock density is taken as 2.85 g/cm3.
- Surface muons(Gaisser) are casting on 20km*20km mountain surface.

Absolute Flux from the simulation:

Muon:1.54e-7/cm2/s

Neu: 3.76e-9/cm2/s

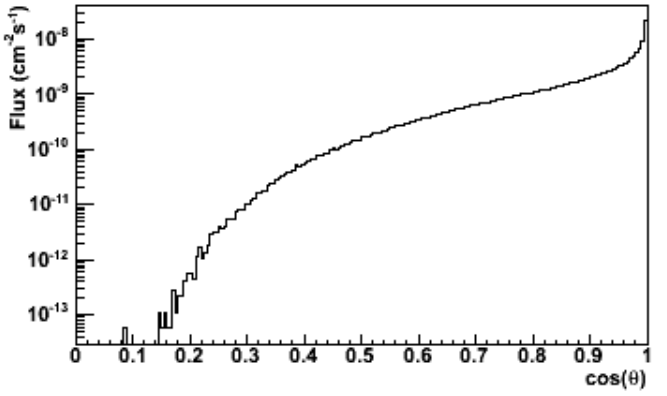


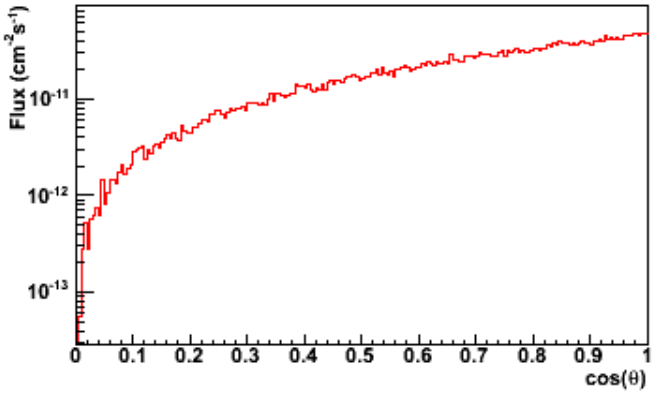


Mean Energy:

Muon: 215.3 GeV

Neu: 82.7 MeV

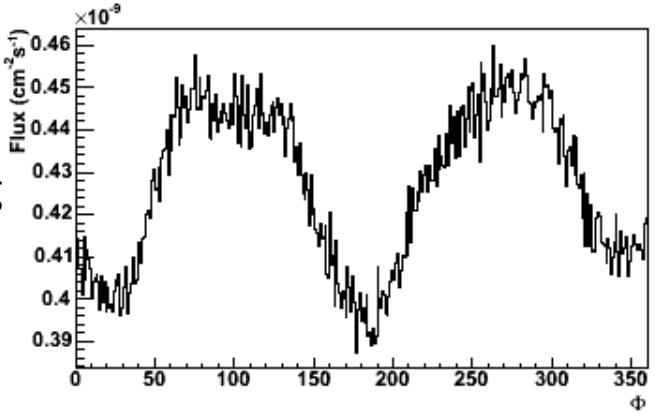


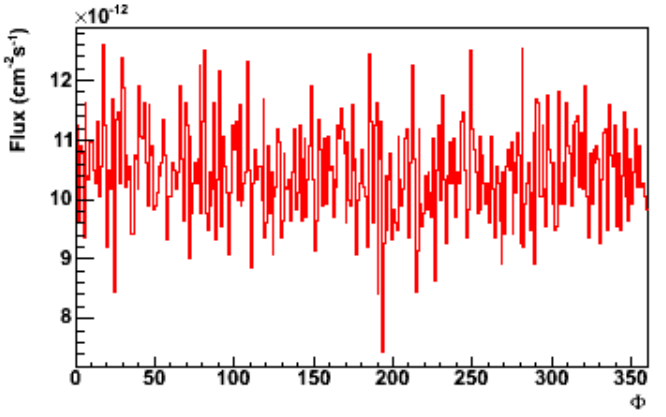


Phi:

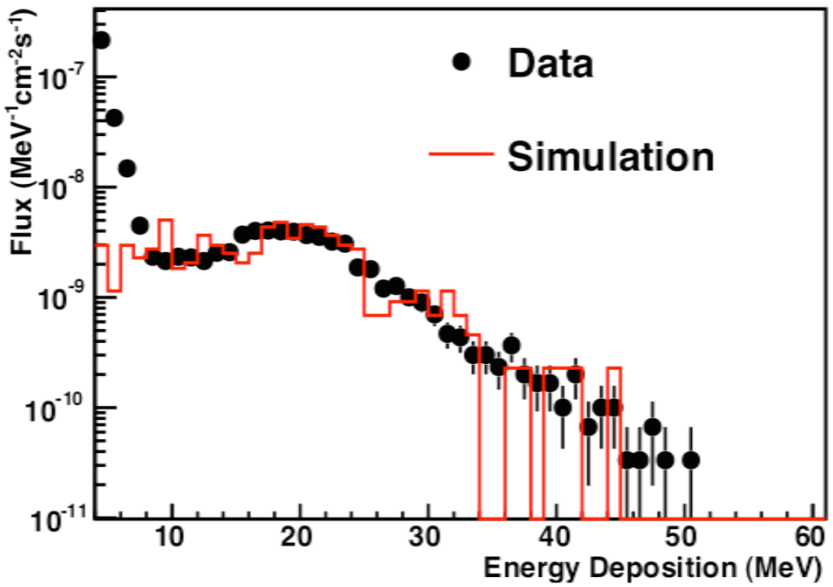
0 -> muon coming from easting

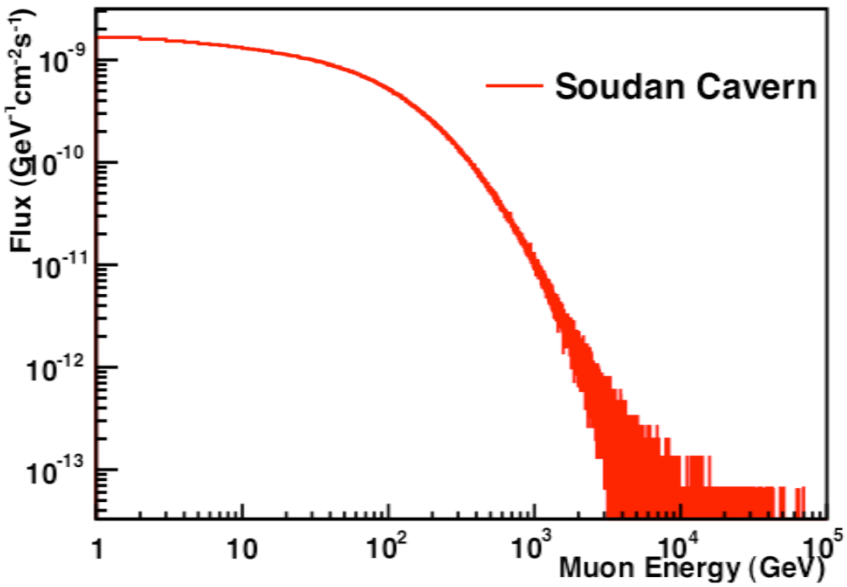
90-> muon coming from northing





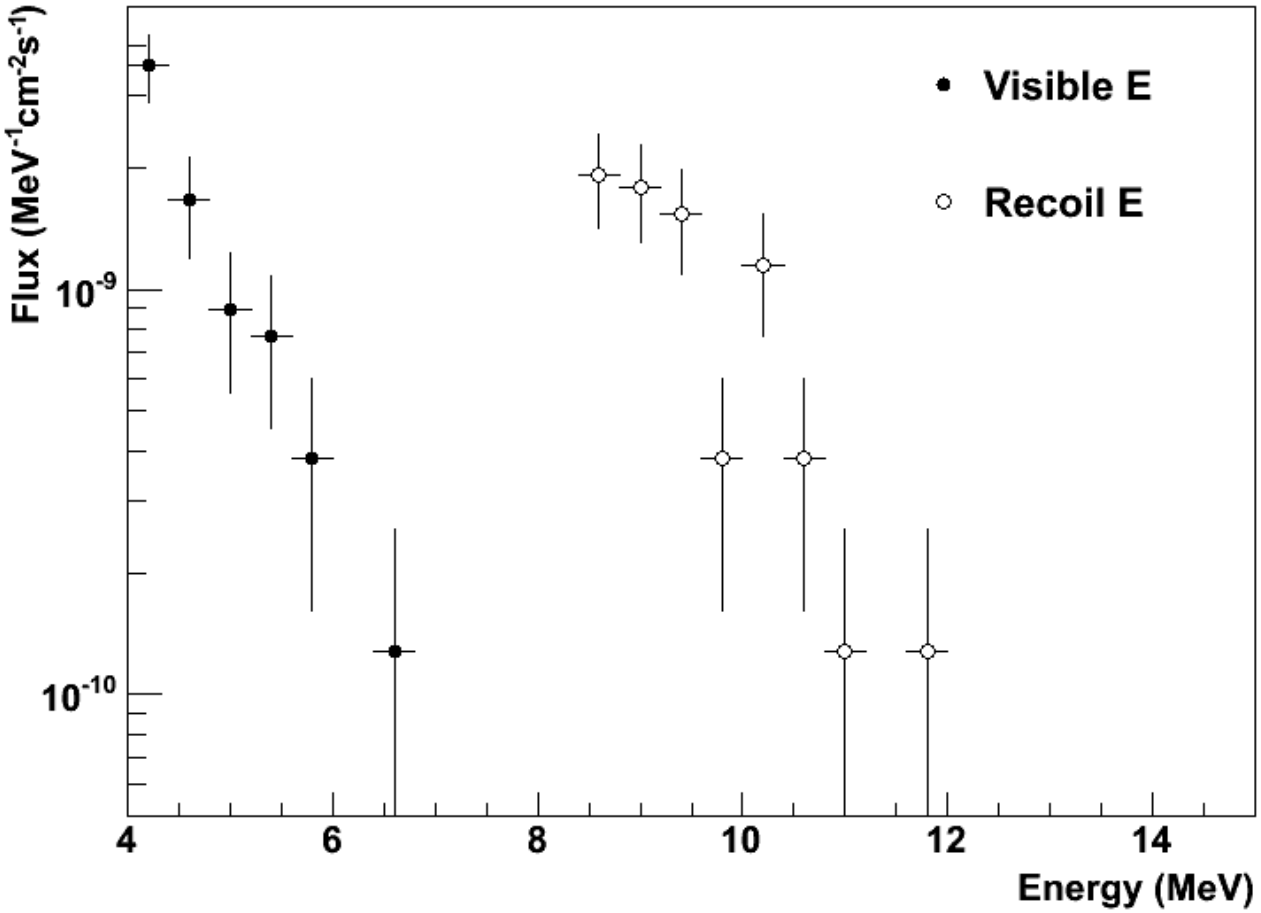
Muon Flux at Soudan Mine





- The statistics of the simulation is not sufficient (~2 months).
- The absolute Muon flux reconstructed at Soudan Mine: 1.786e-07/cm^2/s
- The shape of energy spectrum are taken from Geant4 simulation result which includes the hill effect at Soudan area.

Neutrons at Soudan Mine



Summary

- The simplified definitions of energy and position helped in understanding of the performance of the detector.
- Nature muon at the surface serve as an important calibration source for high energy above 20 MeV.
- The quenching factor at high energy need a better model to explain it.
- The random noise will affect the range with the visible energy below ~4 MeV. This seems cannot be avoid with the current design of the detector.
- For the Soudan measurement, more than one year data are collected. A full simulation with sufficient statistics is under taking.