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External Background Characterization of Homestake Mine for Sanford Lab and DUSEL

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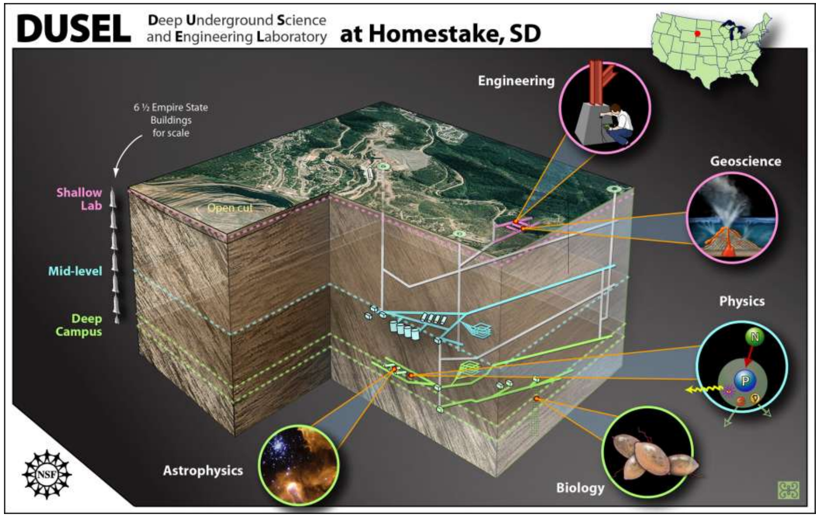
External Backgrounds at Homestake

- **Measuring external sources of radioactivity at the DUSEL site is key to success in low-energy neutrino and dark matter (WIMP searches) experiments**
  - **Shielding design, radon mitigation, and active veto**
- **The Sources of External Background**
  - **Radioactivity in the rock**
    - **Gamma-rays, (alpha, n) neutrons, radon**
  - **Muon-induced processes**
    - **Muon-induced neutrons**
    - **Muon bremsstrahlung**
- **How the measurements are being pursued**
  - **NaI detectors for measuring gamma-rays**
  - **Plastic scintillators for measuring muons**
  - **Liquid scintillators for measuring neutrons**
  - **RAD 7 and AlphaGuard for measuring radon levels**



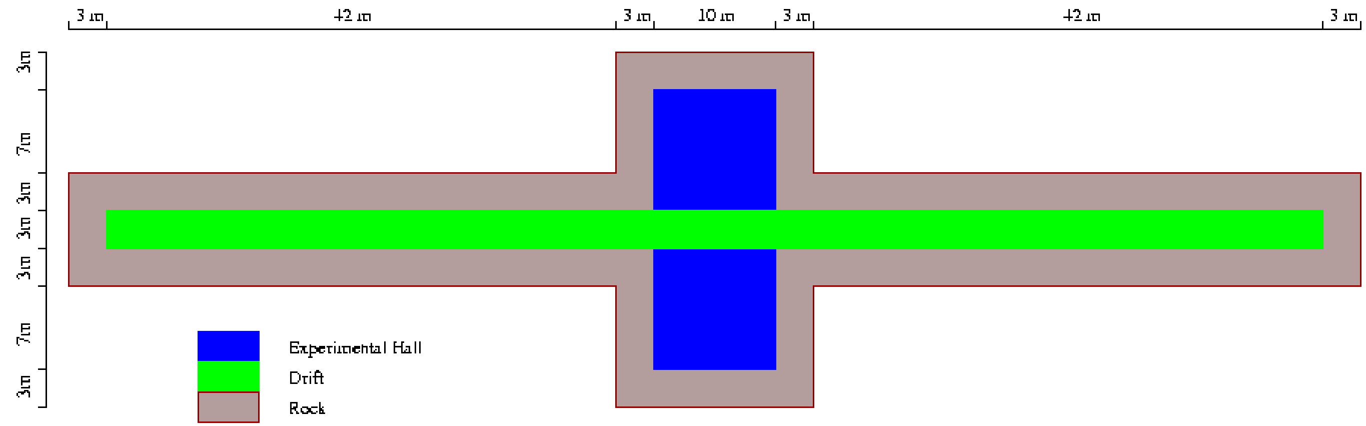
Rock Composition

Produced primarily through the radioactive decay processes of U^{238}, Th^{232}, and K^{40} present in the host rock.

Sample	Core #	Note	U (ppm)	Th (ppm)	K (%)
HST-05A	15532	7300-7450L, Poorman	0.080	0.25	0.104
HST-05B	15532	7300-7450L, Poorman	0.085	0.25	0.125
HST-06	11537	4850L, Poorman/Yates	0.160	0.20	0.154
HST-07	15532	4850L, Poorman	0.55	0.30	2.12
HST-12	11553-352	4850L, Yates	0.21	0.30	1.12
HST-13	11553-218	4850L, Yates	0.19	0.19	0.920
HST-14	18627-3461	7400L, Yates	0.18	0.24	1.01
HST-15	18627-3461	7400L, Yates	0.49	0.20	0.57
HST-08	15680-820	4850L vicinity (Rhyolite)	9.4	12.2	3.98
HST-09	17581-822	7400L vicinity (Rhyolite)	8.3	10.1	3.31
HST-10	11553-059	4850L vicinity (Rhyolite)	8.0	8.6	2.80
HST-11	11537-180	4850L vicinity (Rhyolite)	8.6	12.2	1.69
HST-16		1250L Pump Rm.(Rhyolite)	8.71	10.9	6.86

W. Roggenthen and A.R. Smith. “Uranium, Thorium, Potassium Contents of Materials in the Homestake Underground, Lead SD.” 2008 AGU Fall Meeting, San Francisco, CA.

Background Simulation



Rock Component (Sample 278-2)	Composition (% weight)
SiO_2	43.7
TiO_2	1.22
Al_2O_3	13.6
FeO	12.7
MnO	0.13
MgO	7.0
CaO	7.9
Na_2O	2.87
K_2O	0.21
P_2O_5	0.07
H_2O	10.7
$^{232}Th(\alpha,n)$ Yield	0.34/g/ppm/y
$^{238}U(\alpha,n)$ Yield	0.86/g/ppm/y

http://neutronyield.usd.edu

NIM A 606(2009)651-660 (arXiv:0812.4307)

Table 1: The equilibrium yields from ^{238}U, ^{232}Th and Samarium($E_n > 0.1MeV$).

Element	^{232}Th $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$	^{238}U $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$	Samarium $(n \cdot ppm^{-1} \cdot g^{-1} \cdot y^{-1})$
Boron	1.32e+01	5.00e+01	8.32e-03
Carbon	1.13e-01	3.78e-01	
Oxygen	4.53e-02	1.45e-01	2.57e-06
Neon	1.65e+00	5.02e+00	
Sodium	1.75e+00	5.43e+00	
magnesium	1.47e+00	4.14e+00	
Aluminum	2.04e+00	4.95e+00	
Silicon	2.12e-01	5.54e-01	1.49e-08
Phosphorus	2.01e-06	5.63e-07	
Argon	3.06e+00	6.12e+00	
Potassium	2.84e-02	5.36e-02	
Calcium	1.90e-02	3.54e-02	
Titanium	8.60e-01	1.38e+00	
Manganese	4.03e-01	4.61e-01	
Iron	1.71e-01	1.61e-01	
Copper	3.77e-02	1.77e-02	
Xeon	6.07e-07	1.33e-08	

- We developed a web database to calculate (a,n) neutron yield in all possible element/compound/mixture.
- The result of neutron energy spectrum is taken as an input for MC simulation.

Background Simulation

- The gamma ray flux in the experimental hall induced by radioactive elements in the rocks.

Range (MeV)		0 − .1	.1 − .2	.2 − .3	.3 − .4	.4 − .5	.5 − .6	.6 − .7	.7 − .8	.8 − .9	.9 − 1	Sum
E_γ	Source	γ-ray flux ($ppm^{-1}cm^{-2}s^{-1}$)										
0	^{238}U	9.1e-2	1.4e-1	6.5e-2	4.1e-2	1.6e-2	1.1e-2	2.5e-2	7.6e-3	5.0e-3	5.2e-3	4.0e-1
	^{232}Th	3.5e-2	5.5e-2	3.3e-2	1.2e-2	6.7e-3	1.2e-2	3.0e-3	5.3e-3	2.7e-3	7.5e-3	1.7e-1
	^{40}K	6.6e-2	1.4e-1	7.1e-2	3.4e-2	2.3e-2	1.9e-2	1.5e-2	1.2e-2	1.2e-2	1.1e-2	4.0e-1
1	^{238}U	5.7e-3	1.1e-2	7.4e-3	6.1e-3	4.1e-3	1.7e-3	1.0e-2	1.4e-2	1.5e-3	2.2e-4	6.2e-2
	^{232}Th	5.0e-3	1.4e-3	5.8e-4	5.1e-4	4.3e-4	1.4e-3	8.0e-4	2.2e-4	2.9e-4	1.4e-4	1.1e-2
	^{40}K	1.2e-2	1.3e-2	9.4e-3	8.7e-3	1.6e-1	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	2.0e-1
> 2	^{238}U	0.0e+00	1.5e-3	3.5e-3	0.0e+00	4.4e-4	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	5.5e-3
	^{232}Th	2.9e-4	6.5e-4	2.2e-4	4.3e-4	1.4e-4	7.2e-4	9.3e-3	0.0e+00	0.0e+00	0.0e+00	1.2e-2
	^{40}K	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00	0.0e+00

- The neutron flux in the experimental hall induced by ^{238}U and ^{232}Th radioactivity in the rocks.

The neutron flux induced by ^{238}U and ^{232}Th radioactivity in the simulated experimental hall.

Source	Thermal Neutron E_n <1 eV ($ppm^{-1}cm^{-2}s^{-1}$)	Slow Neutron E_n in [1 eV, 0.1 MeV] ($ppm^{-1}cm^{-2}s^{-1}$)	Fast Neutron E_n >0.1 MeV ($ppm^{-1}cm^{-2}s^{-1}$)
^{238}U (α, n)	1.17e-6	6.79e-7	6.46e-7
^{232}Th (α, n)	4.19e-7	2.48e-7	2.64e-7
^{238}U fission	5.73e-7	3.26e-7	3.04e-7

- Predictions based on the radioactive concentration, i.e., for the 4850-ft level, 238U: 0.55ppm, 232Th: 0.3ppm and 40K: 2.21%; for the7400-ft level, 238U: 0.49ppm, 232Th:0.20ppm and K: 0.57%.

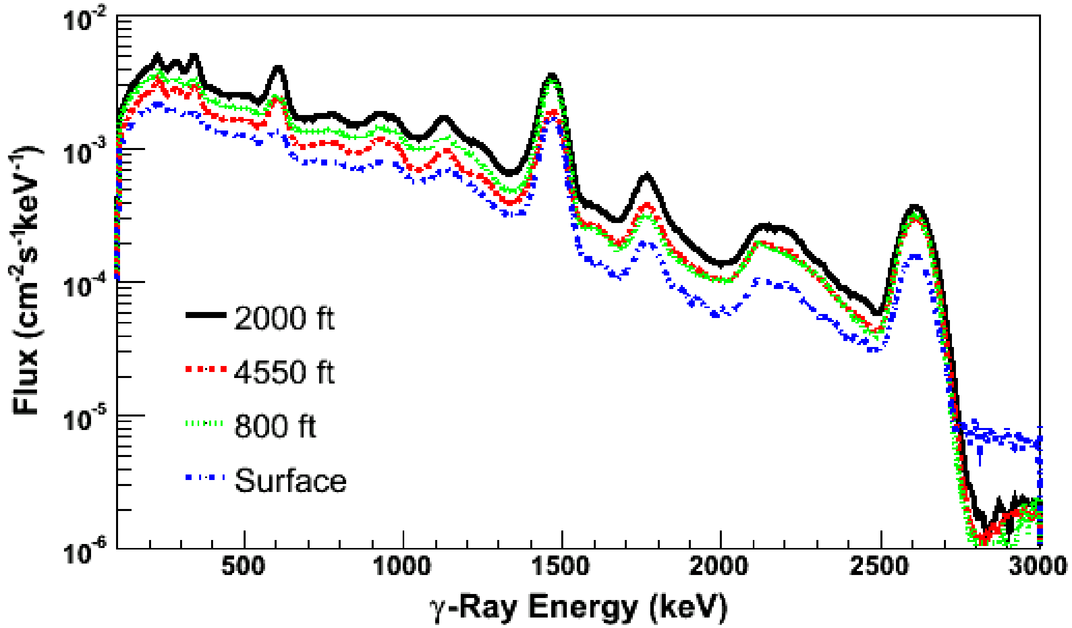
Predicted γ-ray and neutron fluxes for the 4850-ft and 7400-ft levels.

Depth	γ-ray flux ($ppm^{-1}cm^{-2}s^{-1}$)		Neutron flux ($ppm^{-1}cm^{-2}s^{-1}$)
	From ^{238}U and ^{232}Th	^{40}K	
4850 ft	0.318	1.46	2.3×10^{-6}
7400 ft	0.271	0.38	2.0×10^{-6}

Gamma Ray Background

arXiv:0912.0211

Levels surveyed thus far include locations on the surface, 800L, 2000L, and 4550L. Results depend most upon local geology. More measurements are planned for the 4850L soon when appropriate areas become available.

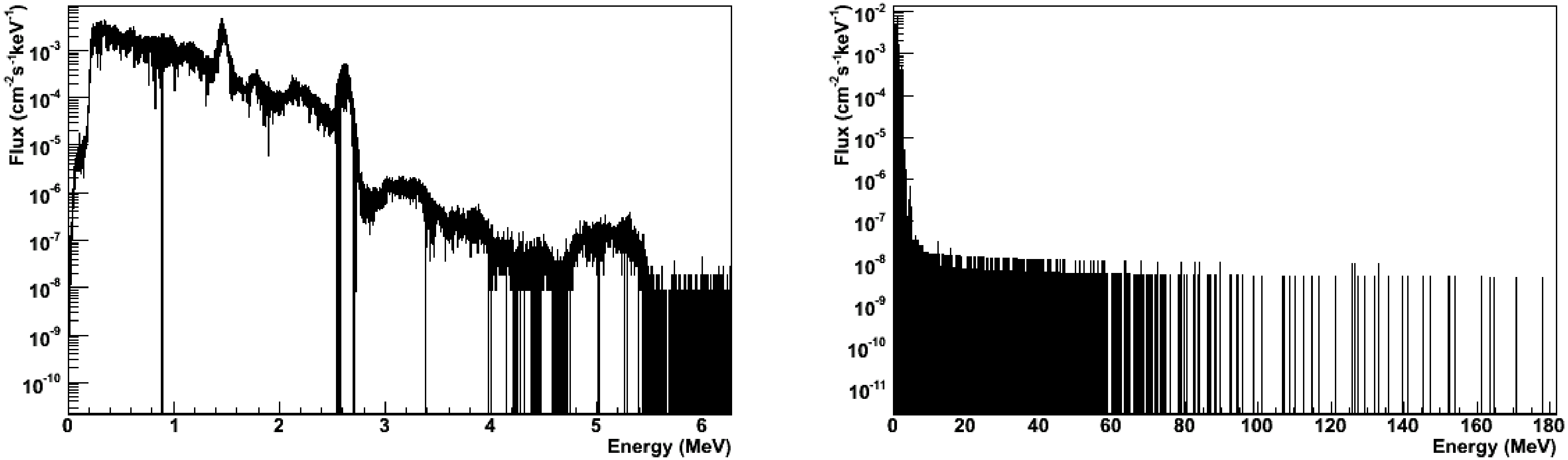


The measured γ-ray flux ($cm^{-2}s^{-1}$)

	E>0.1 MeV	E>1 MeV	E>2 MeV	E>3 MeV
Surface	1.56	4.63×10^{-1}	5.52×10^{-2}	1.09×10^{-3}
800 ft	2.65	7.97×10^{-1}	9.49×10^{-2}	4.81×10^{-4}
2000 ft	3.42	1.04	1.26×10^{-1}	7.05×10^{-4}
4550 ft	2.16	6.32×10^{-1}	9.64×10^{-2}	6.01×10^{-4}

Gamma Ray Background

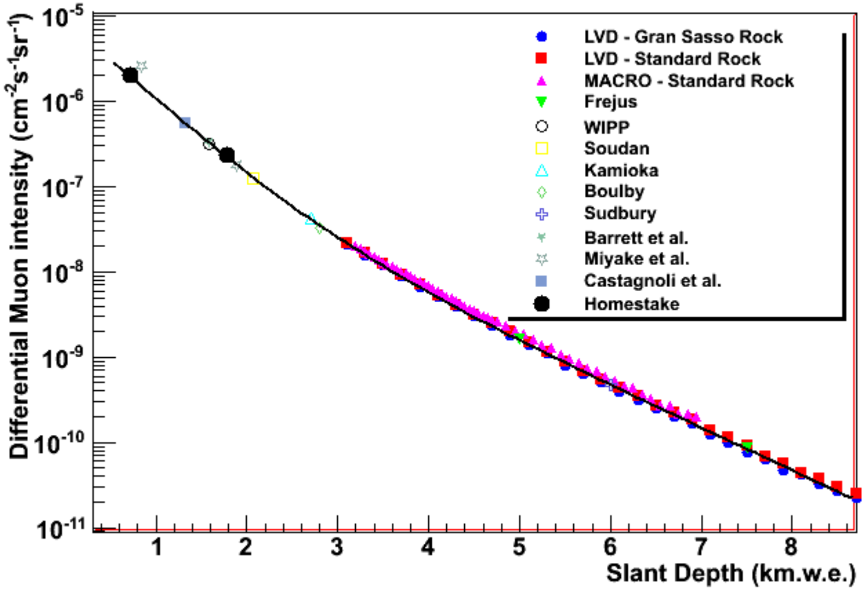
Long-term measurements are being conducted in an effort to characterize the higher energy gamma ray flux, as a result of muon bremsstrahlung. This has been done on the 800L and it is currently operating on the 2000L with plans to relocate to the 4850L soon.



~30 day background spectrum from the 800 ft Level.

Muons

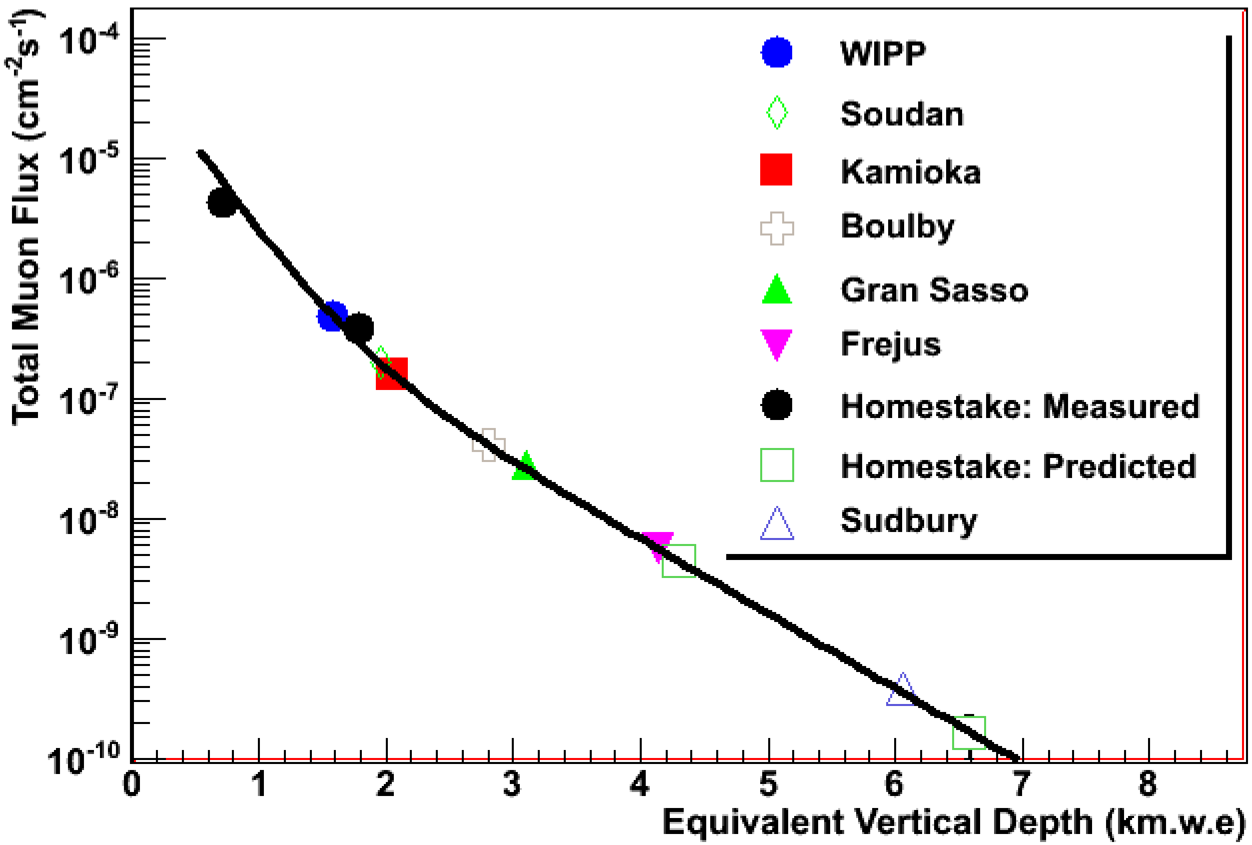
Muon detector system on the 2000L



Muon measurements conducted thus far have been consistent with what was predicted in Mei & Hime's paper: PRD 73, 053004 (2006)

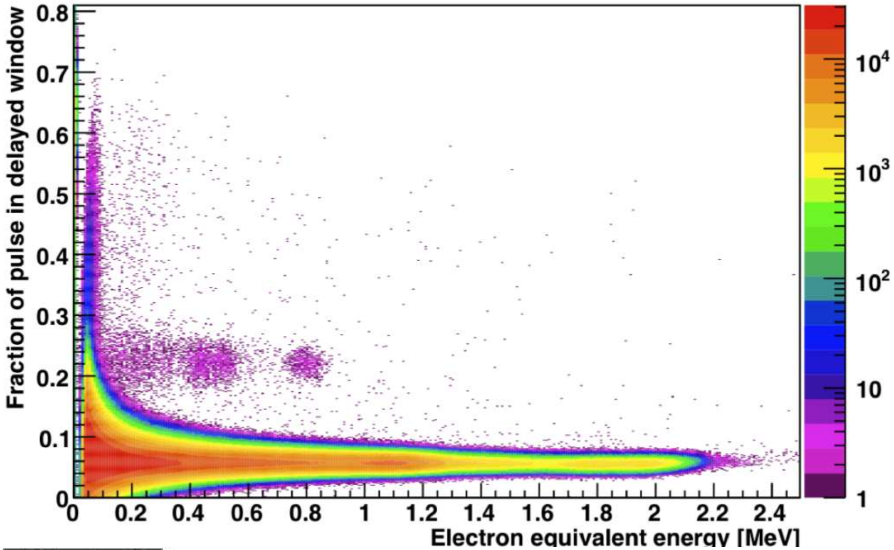
Surface	$(1.15 \pm 0.01) \times 10^2$ s^{-1} m^{-2} sr^{-1}
800L	$(2.67 \pm 0.06) \times 10^2$ s^{-1} m^{-2} sr^{-1}
2000L	$(3.05 \pm 0.34) \times 10^2$ s^{-1} m^{-2} sr^{-1}

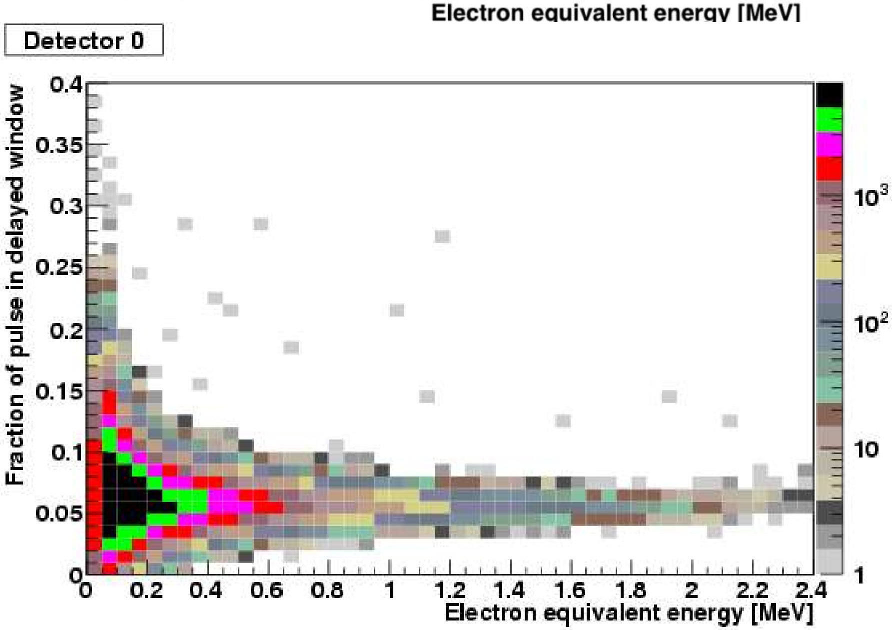
Muons



Total Muon Flux (cm^{-2}s^{-1})
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
0
1
2
3
4
5
6
7
8
Equivalent Vertical Depth (km.w.e)
WIPP
Soudan
Kamioka
Boulby
Gran Sasso
Frejus
Homestake: Measured
Homestake: Predicted
Sudbury

Neutrons

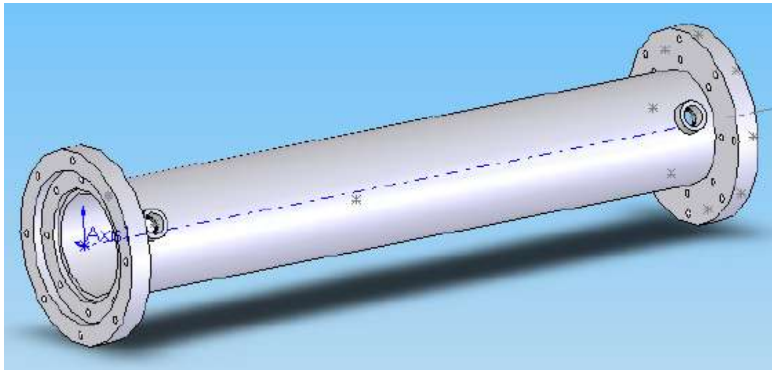




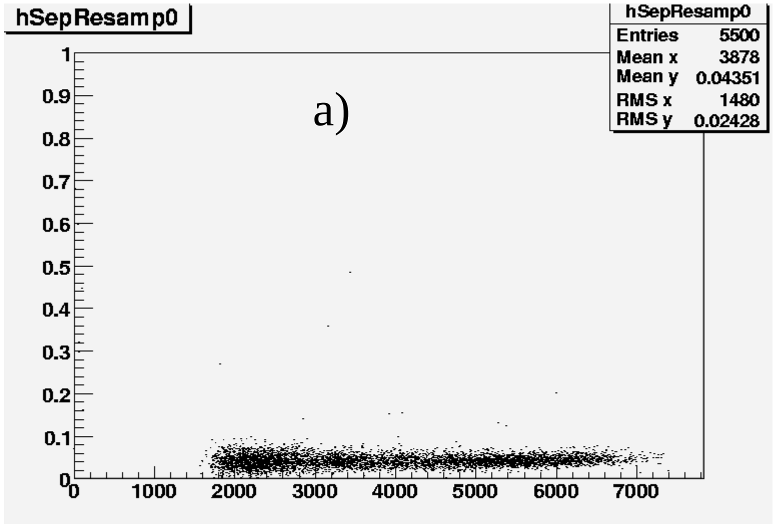
- Neutrons are produced in rock through (a, n) reactions, spontaneous fission, and muon-induced process.
- Current measurements are being conducted with approximately a 1L scintillation cell containing Eljen Technologies EJ301 Liquid Scintillator, chosen for its pulse shape discrimination.
- Alpha backgrounds in the small scintillator are dominant, so that we will need a coincidence technique.

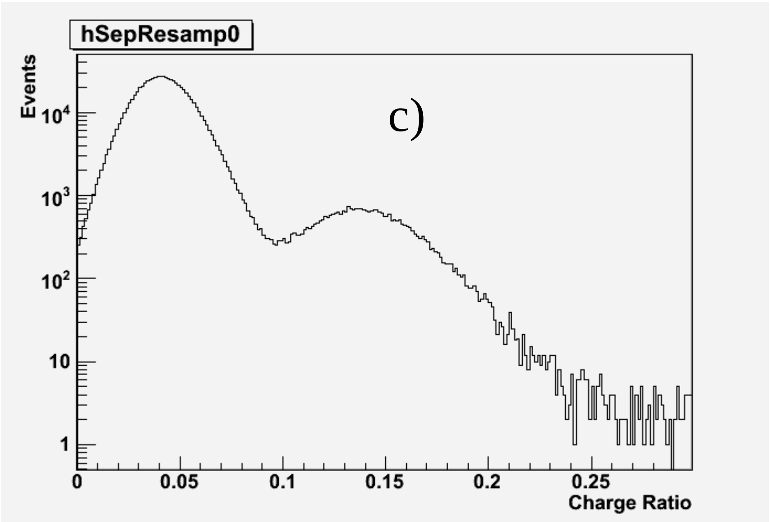
Big Neutron Detector

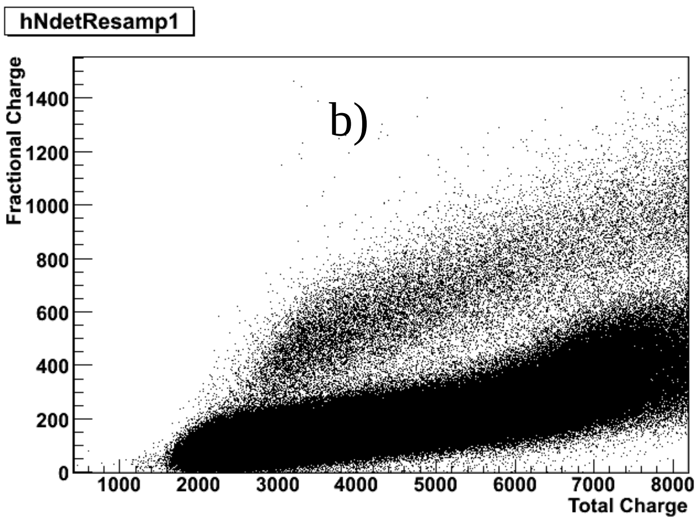
- A 10L liquid scintillation counter has been built and tested in the lab.
- it's a 5" in diameter, 1 meter in length Aluminum tube filled with EJ-305 liquid scintillators. EJ-520 reflective paint is uniformly painted on the inner surface of the tube.
- Two PMTs (R4144 , hamamatsu) installed at the both ends of the counter.



Big Neutron Detector







a) ^{60}Co source.

b) AmBe source.

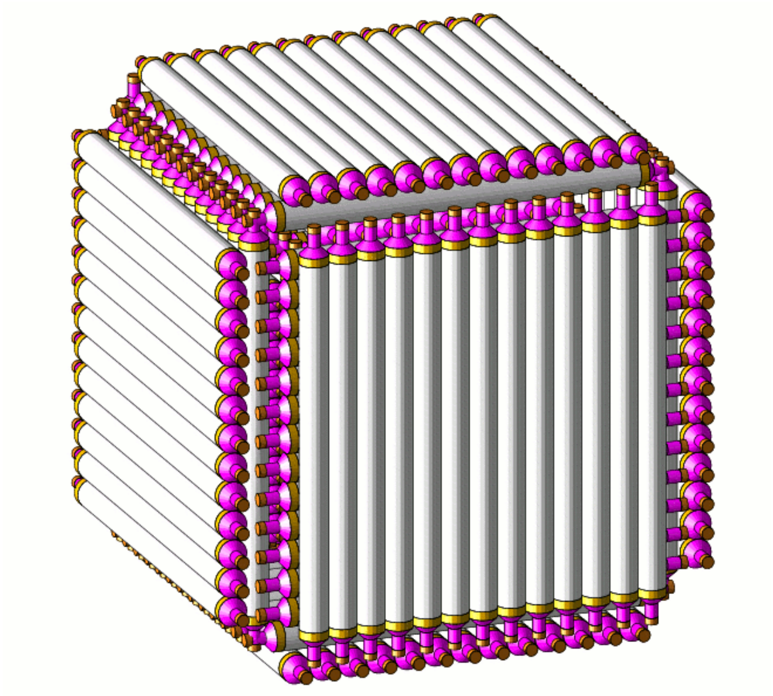
c) Pulse shape discriminations.

Big Neutron Detector

Upcoming Events

- Phase I: this 10L liquid scintillation counter will be deployed at 2000 ft level underground for test soon.

- Phase II: a detector system which surrounds inner and outer four layers liquid scintillators together with the muon tracking detectors above and below the target will be replaced.



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Status

- Gamma flux measured on surface, 800L, 2000L, and 4550L.
- High energy gamma's are being measured right now underground on the 2000ft level. System will be relocated to the 4850L soon.
- Muon measurements have been made on the surface, 800L and 2000L. Results agree with predictions/measurements taken in past. The setup will relocate soon to the 4850L.
- Neutrons are currently being measured on the 800L, and will soon incorporate a 10L detector.
- The simulation results agree with the measured results on muons and gamma rays pretty well. Prediction can be done for levels/areas temporarily inaccessible.