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 Hamamatsu 5” PMTs(R4144) attached to the detector through Pyrex glass windows.
Energy – Position independent?

\[
\begin{align*}
L_{\text{left}} &= 0.5 L_{\text{tot}} e^{-(D/2-x)/l} \\
L_{\text{right}} &= 0.5 L_{\text{tot}} e^{-(D/2+x)/l} \\
\ln \sqrt{\frac{L_{\text{left}}}{L_{\text{right}}}} &= x/l \\
\sqrt{L_{\text{left}} L_{\text{right}}} &= 0.5 L_{\text{tot}} e^{-D/2l} \propto E_{\text{tot}}
\end{align*}
\]
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 can only be separated in narrow slices along the tube. The n/g separation is getting better when the position is closer to ends.
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 $\sim 1$ MeV.
• 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

- Calibration Curve
- Justified Line

- Calibrated Data
- Justified Data
- Muon Simulation

- X/l < -0.5
- X/l > 0.5

- Energy (MeV)

- Energy Calibration at High Energy

- Delayed0/a0

- Delayed1/a1
• Reconstructed muon flux: 0.016 /cm²/s which is 11.7% higher than sea level from Gaisser’s formula (0.0137/cm²/s).
• USD campus elevation: 1221 feet.
Visible V.S recoil energy by assuming NY neutron spectrum
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

- Satellite data at Soudan Mine area. Coordinates: (-92.24125400833333, 47.82034835833334) 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.

<table>
<thead>
<tr>
<th>Compound</th>
<th>%</th>
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<tbody>
<tr>
<td>SiO₂</td>
<td>50.6</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.0</td>
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<tr>
<td>CaO</td>
<td>9.0</td>
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<tr>
<td>FeO</td>
<td>8.6</td>
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<tr>
<td>MgO</td>
<td>6.5</td>
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<tr>
<td>H₂O</td>
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<tr>
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<tr>
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<tr>
<td>MnO</td>
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<tr>
<td>P₂O₅</td>
<td>0.1</td>
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</table>
Absolute Flux from the simulation:
Muon: $1.54 \times 10^{-7}$/cm$^2$/s
Neu: $3.76 \times 10^{-9}$/cm$^2$/s

Mean Energy:
Muon: 215.3 GeV
Neu: 82.7 MeV

Phi:
0 -> muon coming from easting
90-> muon coming from north
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

![Graph showing neutron flux versus energy](image-url)
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.