A SciBath Detector for the Measurement of Neutral Particle Fluxes

Robert Cooper


March 13, 2012
Physics Motivation

- $s$-quark contributes to proton spin structure ($\Delta s$)
- $\Delta s \approx \sigma(\text{NCell}) / \sigma(\text{CCQE})$
- Fine-grained detector to track outgoing $\sim 200$ MeV proton
- FINeSSE proposal $O(10)$ ton tracker

\[ \begin{array}{c}
\text{CCQE} \\
\text{NCell}
\end{array} \]
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Neutron Backgrounds

- $n$ scattering a NCell background
- $\mu \rightarrow n$ in rock
  - 1-100 MeV energy spectra
  - $n$ production not well known*
- Cosmogenic $\mu$ sources
- Accelerator $\nu_\mu \rightarrow \mu$ sources
- Good detector must be able to measure neutron flux

Neutrons from Energetic Muons

Design Concept

- Usual tracker is crossed scintillation bars (SciBar)
- High-$\rho_T$ scatters are hard
- Bath of liquid scintillator 3D array of crossed fibers
- SciBath has $4\pi$ uniform tracking efficiency
- Many readout channels
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New SciBath
The SciBath Detector

- 80 L liquid scintillator (LS)
  - 88% mineral oil
  - 11% pseudocumene
  - 1% PPO

- 768 (3-16x16) array wavelength-shifting fibers (x,y,z axes)
  - 1.5 mm diameter
  - 2.5 cm spacing
  - UV → blue
The SciBath Detector

- Pulsed LED calibration
The SciBath Detector

- $N_2$ and LS plumbing
The SciBath Detector

- Electronics readout & PMTs
The SciBath Detector

- Electronics readout & PMTs
Low-Cost Digitization Solution

- 64-channel Integrated Readout Module
  - 12-bit flash ADCs
  - FPGA logic
  - ARM-9 micro-controller with embedded Linux kernel
  - Shaped oscillator input
  - 6U VME form factor (no VME backplane power)
  - Ethernet transmission
  - Built custom “in-house”
  - $70 / channel

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Anticipated Sensitivity ($n$ events)

- MC response to $n$ reconstruction
- MC uses $n(p,d)\gamma$ capture reaction as tag
- 2.2 MeV gamma above threshold
- Other techniques?
NuMI Beam Hall Deployment

- 24/7 operation, 100% duty factor; remote monitoring
- 100 meter rock overburden
- 5 mrad off-axis

- 1 GeV $\nu$ mode on horn
- 6 wks. 0.5 PE threshold data
- 6 kHz data rate $\rightarrow$ 6.5 TB total data collected
- $\sim$90% total live time.
Anticipated Sensitivity

- For 5 mrad off-axis, 1 GeV ν, $6.41 \times 10^{19}$ POT
- Anticipate 350 CC-Inclusive, 65 CCQE events
- Cosmogenic neutron rate 20 n / day
- Total ~ 800 cosmogenic neutrons in this run
- Beam-correlated neutron rate is being studied
- Analysis underway
Primary Analysis → “Energy”

- Beam-correlated “regions”
Primary Analysis → “Energy”

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![Graphs showing PE spectra for in-beam and transition regions with candidate muons and neutron captures highlighted.]

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Secondary Analysis → Timing

- Beam-correlated “regions”
- Primary “in-beam” → prompt neutron
- Secondaries > 10 µs
- ~100 µs thermalize / capture time scale

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- Beam-correlated “regions”
- Primary “in-beam” → stopping muon
- Secondaries < 10 µs
- ~2.2 µs muon lifetime → Michel electrons
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Sample Event – Muon

Selected Event Num: 44432
Raw Event Num: 1023824
Multiplicity: 189
Total PEs: 439.3
PEs -- X-fibers: 107.2
PEs -- Y-fibers: 156.8
PEs -- Z-fibers: 175.3
T0: 273.6180107 s
Time to last BIB: 0.0002228 s
\[ x = 0.2 \pm 9.5 \text{ cm} \]
\[ \bar{y} = -13.3 \pm 4.7 \text{ cm} \]
\[ z = -8.7 \pm 5.9 \text{ cm} \]
Sample Event - Neutron

Selected Event Num: 22877
Raw Event Num: 525812
Multiplicity: 96
Total PEs: 273.8
PEs -- X-fbers: 80.6
PEs -- Y-fbers: 87.1
PEs -- Z-fbers: 106.0
T0: 141.3253560 s
Time to last BIB: 0.0002196 s
\(x = 10.0 \pm 3.7\) cm
\(y = -16.2 \pm 3.5\) cm
\(z = 12.9 \pm 2.6\) cm

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Next Steps – MI-12 Target Bldg.

- Deployed ~10 m from Booster Neutrino Beam target
- Background for coherent neutrino scattering
- Externally triggered

Proton target 7 m below

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Summary

• SciBath is an efficient 3D charged particle tracking detector → reconstruct neutral events
• Desire to measure neutron backgrounds to NCcl events (cosmogenic and beam-related)
• Measure neutrino interactions
• Deployed at NuMI (near Minos), above ground at Minos Service Bldg., and now at MI-12.
• Analysis continues!
Backup Slides
Low-Cost Digitization Solution

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Counts vs. Time (PE ≥ 5)

Timing spectra (PE ≥ 5)
Primary Analysis → Timing

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