Massive Observatory for Neutrino Oscillations or Limits on their Existence

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Physics goals

✓ Prove neutrino oscillations through observation of the oscillation pattern discriminate amongst alternative hypotheses (decay, decoherence, extra dimensions etc.)

✓ Improve the measurement of parameters affecting $\nu_\mu$ oscillations (if oscillations)

✓ Test mixing with sterile (now disfavored) and electron neutrinos (stringent upper bound now) searching for matter-induced effects

Overcome the limitations of current atmospheric neutrino detectors:

High L/E resolution
Systematic-free analysis of the oscillation pattern
Focus on $\nu_\mu$ disappearance
Here we are...

Superkamiokande opened a new era of precision measurements

H. Sobel
Neutrino2000
Measurement of disappearance

The disappearance probability can be measured with a single detector and two equal sources:

\[
L(\theta_{up}) = 2R\cos(\theta_{up}) \quad \quad L'(\theta_{down}) = L(\pi - \theta_{down})
\]

\[
\frac{N_{up}(L/E)}{N_{down}(L'/E)} = P(\nu_\mu \rightarrow \nu_\mu; L/E) = 1 - \sin^2 (2\Theta) \sin^2 (1.27 \Delta m^2 L/E)
\]

\[
\Delta m^2 = 0.0035 \text{ eV}^2 \quad \sin^2 (2\Theta)
\]

Fitted parameters:
\[
\sin^2 (2\Theta) = 1 \\
\Delta m^2 = 0.34 \times 10^{-2} \text{ eV}^2
\]
A detector for precision measurements of L/E

The L/E resolution is determined by the capability of the experiment to reconstruct the neutrino energy and the neutrino direction of flight:

\[
\frac{\sigma_{L/E}^2}{(L/E)^2} = \frac{\sigma_E^2}{E^2} + \frac{\sigma_L^2}{L^2} \approx \frac{\sigma_{E_\mu}^2}{E_{\mu}^2} (1 - y)^2 + \frac{\sigma_{E_h}^2}{E_h^2} y^2 + \tan^2 \theta \sigma_\theta^2
\]

Events near the horizon are of no use: resolution is spoiled by the tan^2\theta term

Low L/E values must be obtained with high E

Extend the detector efficiency toward the high energy component of the neutrino spectrum and provide a good momentum resolution for muons

**Magnetized tracking calorimeter**

- \( E_\mu \) by range measurement for fully contained events
- \( E_\mu \) by tracking in magnetic field for partly-contained events
- \( \theta_\mu \) by tracking
- Up/Down discrimination by time of flight (plus vertex identification)
- \( E_h \) by calorimetric measurement
The Monolith Detector

Large mass       ~ 35 kton
Space resolution ~ 1 cm (rms on X-Y coordinates)
Time resolution  ~ 1 ns  (for up/down discrimination)
Magnetized Fe spectrometer      $B = 1.3$ Tesla
Momentum resolution $\sigma_{p/p} \sim 20\%$ from track curvature for outgoing mu
                     $\sim 6\%$ from range for stopping muons
Hadron E resolution $\sigma_{E_h/E_h} \sim 90\%/\sqrt{E_h} \oplus 30\%$

$8.0 \times 3000 \times 1500 \text{ cm}^3 \times 7.87 \text{ g/cm}^3 = 285 \text{ ton/plane} \quad 120 \text{ planes}$

$\sim 54000 \text{ m}^2$ of detector: Glass Spark Counters
Efficiencies and resolutions

Selected $\nu_\mu$ CC after 4 years of data taking (no oscillation):

- Fully contained: 931
- Partially contained: 259
- Total: 1190
Expected L/E distributions (1)

Expected L/E distributions for $\Delta m^2 = 7 \times 10^{-4}$ eV$^2$ (top) and $2 \times 10^{-3}$ eV$^2$ (bottom)

Central value in each bin is obtained with a 26 y statistics
Error bars and event rates correspond to 4 years

Contours are obtained from a maximum likelihood procedure, which accounts for statistical errors after 4 years
They correspond to:
99% C.L.
90% C.L.
68% C.L.
Expected L/E distributions (2)

\[ \Delta m^2 = 0.5 \times 10^{-3} \text{ eV}^2 \quad \sin^2 2\theta = 1 \]

\[ \Delta m^2 = 8 \times 10^{-3} \text{ eV}^2 \]

\[ \Delta m^2 = 5 \times 10^{-3} \text{ eV}^2 \]

\[ \Delta m^2 = 0.8 \times 10^{-2} \text{ eV}^2 \quad \sin^2 2\theta = 1 \]

\[ \Delta m^2 = 0.77 \times 10^{-2} \text{ eV}^2 \]
Detection of the oscillation pattern

Four simulated experiments of 4 years
$\Delta m^2 = 0.003 \text{ eV}^2$

It is shown:
- best parametric fit
- best fit to oscillation
- best fit to decay
Many other physics topics...

\[ \nu_\tau / \nu_s \text{ separation:} \]

- Matter effect + muon charge
- NC enriched samples

Cosmic rays studies in the multi-TeV energy range

A possible detector for future neutrino factories...
Conclusions

The superior $L/E$ resolution will allow detection of the first oscillation period. MONOLITH will thus prove (or disprove) oscillations.

It will also highly improve the measurement of the oscillation parameters.

These qualitative and quantitative improvements qualify MONOLITH as a next generation neutrino oscillation detector.
Monolith Sensitivity – 4 years

The oscillation pattern as seen in SuperKamiokande and expected in Monolith for $\Delta m^2 = 3.2 \times 10^{-3} \text{ eV}^2$

$L/E$ distributions and oscillation pattern for $\Delta m^2 = 5 \times 10^{-3} \text{ eV}^2$

The superior $L/E$ resolution will allow detection of the first oscillation period. It will also result in a substantial improvement in the measurement of $\Delta m^2$. 
The oscillation pattern as seen in SuperKamiokande and expected in Monolith for $\Delta m^2 = 3.2 \times 10^{-3}$ eV$^2$.

The superior $L/E$ resolution will allow detection of the first oscillation period. It will also result in a substantial improvement in the measurement of $\Delta m^2$. 