Physics with a detector at Homestake

Milind Diwan (BNL)
2/21/2008
SLAC P5 meeting

Total event rate with 300 kT and 2 MW is ~200,000 cc evts/yr (no oscillations, raw events)

The Study: http://nwg.phy.bnl.gov/fnal-bnl

yr-2\times10^7 \text{ sec}
• Proposal for an Experimental Program in Neutrino Physics and Proton Decay in the Homestake Laboratory

Department of Physics, Brookhaven National Laboratory, Upton, NY

R. Lanou
Department of Physics, Brown University, Providence, RI

W. Leland, K. Lesko
Department of Physics, University of California, Berkeley, CA

Karsten Heeger, W. Y. Lee
Lawrence Berkeley Laboratory, Physics Division, Berkeley, CA

W. Frati, K. Lunde, A. K. Mann, R. Van Berg
Department of Physics and Astronomy, University of Pennsylvania Philadelphia, PA

K. T. McDonald
Department of Physics, Princeton University, Princeton, NJ

D. B. Cline
Department of Physics and Astronomy, University of California, Los Angeles, CA

P. Huber, V. Barger
Department of Physics, University of Wisconsin, Madison, WI

D. Marfatia
Department of Physics and Astronomy, University of Kansas, Lawrence, KS

T. Kirk
Department of Physics, University of Colorado, Boulder, CO

Renato Potenza
Instituto Nazionale di Fisica Nucleare, Dipartimento de Fisica e Astronomia, Universita di Catania, 64, Via S. Sofia, I-95123 Catania, Italy
Outline

- Scientific/Technical issues for a new long baseline experiment regarding CP violation.
- Ultimate reach with a detector at DUSEL and a conventional beam from FNAL.
- Implementation with the first 100 kT detector.
Scientific strategy

- The Study: A very large detector is needed for the next steps for $\theta_{13}$, mass ordering, and CP violation coming from the standard 3-generation scenario.

- The Study: Program should have broad physics capability: nucleon decay, supernova detection, astrophysical neutrinos.

- Conventional wisdom: Experimental set up with a large matter effect, such as for 1300 km, is more sensitive to possible new physics.

- For neutrino mixing the experiment must have internal redundancy to check 3-gen CP violation and get hints of new physics if they are there.
Technical issues

- Program should lead to measurement of 3-generation parameters without ambiguities. (recall: CP measurement is approximately independent of $\theta_{13}$). Need large detector independent of $\theta_{13}$ value.

- An off-axis program cannot overcome ambiguities easily.

300 kT water Cherenkov detector @DUSEL

Measurement of CP phase and $\sin^2 2\theta_{13}$ at several points. All ambiguities and mass hierarchy are resolved.
\[ \sin^2 2\theta_{13} = 0.04, \] 300 kT, 1300 km, -2MW @ 60 GeV 3yrs neutrinos
\[ (\delta_{CP} = -45^\circ, \quad \delta_{CP} = +45^\circ) \]

Spectra with 300 kT detector and 2MW beam from FNAL

Background issues examined by FNAL/BNL study.

Mark Dierckxsens\textit{(UChicago)}, Mary Bishai\textit{(BNL)}
Ultimate Reach
60 GeV, 2MW, 3+3 yrs, 300kT
Mass ordering

$\theta_{13}$

$\nu + \bar{\nu}, \text{1300km}$
$120+120 \times 10^{20} \text{ PoT}$

$\delta_{CP}$

3$\sigma$ ($\Delta m^2_{31} > 0$)
5$\sigma$ ($\Delta m^2_{31} > 0$)
3$\sigma$ ($\Delta m^2_{31} < 0$)
5$\sigma$ ($\Delta m^2_{31} < 0$)

$\sin^2 2\theta_{13}$

50% coverage at 3 sigma

stat + 5% syst

Mark Dierckxsens (UChicago), Mary Bishai (BNL)
Intermediate proposal

- 100 kT fiducial detector at Homestake with rock mechanics studies starting in fall of 2008. (Homestake Interim Lab. now exists, SuperK and SNO experience and success gives confidence in feasibility and performance.)

- New wide band beam from FNAL (pre-Project x)

- Focus on \( \theta_{13} \), and mass hierarchy.

- Get started on CP violation, p-decay, Supernovae.
\[ \sin^2 2\theta_{13} = 0.04, \, 100\, kT, \, 1300 \, km, \, -1 \, MW \, 60\, GeV \, 3\, yrs \, neutrinos \]
\[ \text{and} \, 3\, yrs \, antineutrinos \]
\[ (-\delta_{CP} = -45^\circ, \, -\delta_{CP} = +45^\circ) \]

Spectra with 100 kT detector and 1 MW beam from FNAL

\[ \sin^2 2\theta_{13} = 0.04, \, 100\, kT, \, 1300 \, km, \, -1 \, MW \, 60\, GeV \, 3\, yrs \, neutrinos \]
\[ \text{and} \, 3\, yrs \, antineutrinos \]

Normal

Reversed

Total rate of events
-30k/yr
noosc/raw evts
Reach with 100 kT water Cherenkov

$\theta_{13}$

$60 \text{ GeV, } 1 \text{MW, 3+3 yrs, 100kT}$

Mass ordering

$\sin^2 2\theta_{13}$ coverage at 3 sigma: 0.008

Stat+5% syst: 0.025
Same plots detail

$\theta_{13}$

Mass ordering @ 2 sigma

$\Delta m^2_{31}, > 0$

$\Delta m^2_{31}, < 0$

$\delta_{CP}$

$3 \sigma$ discovery:

3 yrs for $\nu$ and $\bar{\nu}$ each

100kt WCh

95% CL observ.:

$\Delta m^2_{31}, > 0$

$\Delta m^2_{31}, < 0$

$\sin^2 2\theta_{13}$

$\sin^2 2\theta_{13}$

$\times 10^7$ sec as previous plot
MEGATON MODULAR MULTI-PURPOSE NEUTRINO DETECTOR

✓ Chamber Design

180' (55M) Mined outside
174' (53M) Finished Inside
DIAMETER

50' BETWEEN
TANK AND RAMP

RAMP CROSSCUTS INTO TANK
EVERY 20 VERTICAL FEET

7' DIAMETER
BOREHOLE IN

TOP VIEW

Controlled Blasting in Chamber

RAMP, 1243'
@ -14% GRADE

Cable bolt 60 ft long
on a 8'x8' pattern

Could use Instrumented Cables
for Engineering / Geotechnical
Study

SIDE VIEW

VENTILATION

VENTILATION

4850

Mark A. Laurenti (Former Homestake Chief engineer)
MEGATON MODULAR MULTI-PURPOSE NEUTRINO DETECTOR

✓ Modular Configuration

muon rate/cavern~1/10 Hz

180 ft dia

Rock removal at 5000L (new)

Parallel Access tunnel at 4850L (new)

Mark A. Laurenti

November 2007
Technically limited schedule for a single 100 kT fiducial detector

- Tube production is slowed to match excavation. Tube production is NOT the limiting factor.
- For simplicity, water system, PMT testing, electronics, etc. are not shown.
- For 300 kT the time need not be tripled.

Comments: Phototube production is slowed down to match construction of 1 module only.
Schedule is strictly technical. Does not account for review process. See KTLesko talk. PMT testing facility, water system procurement and installation, and other items are not shown here.
One time costs over next 3 yrs

- 100kT estimate on next page does not include R&D and one time costs that are needed to establish the entire facility for the megaton-class detector.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber design and coring</td>
<td>$0.76M</td>
<td>Laurenti</td>
</tr>
<tr>
<td>Access tunnels</td>
<td>$4.5M</td>
<td>Laurenti</td>
</tr>
<tr>
<td>Contingency</td>
<td>$2.6M</td>
<td>50% of above</td>
</tr>
<tr>
<td>Mining + other equip.</td>
<td>$10.0M</td>
<td>Laurenti</td>
</tr>
<tr>
<td>PMT+Elec. R&amp;D</td>
<td>$4.0M</td>
<td>Prel. Eng.+Subcontracts</td>
</tr>
<tr>
<td>Water/materials R&amp;D</td>
<td>$2.0M</td>
<td>Preliminary</td>
</tr>
<tr>
<td>Contingency (non-civil)</td>
<td>$3.2M</td>
<td>Equip. has quotes</td>
</tr>
<tr>
<td>Total</td>
<td>$27.1M</td>
<td>FY2007</td>
</tr>
</tbody>
</table>
### Summary cost for 100kT (do not triple for 300kT)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Cavity construction</td>
<td>$28.1M*</td>
<td>Laurenti</td>
</tr>
<tr>
<td>contingency 30%</td>
<td>$8.4M</td>
<td>Preliminary Reviews</td>
</tr>
<tr>
<td>PMT (50000 chan)</td>
<td>$46.7M</td>
<td>Auger, NNN05, etc.</td>
</tr>
<tr>
<td>Electronics, cables</td>
<td>$10.65M</td>
<td>UPenn+SNO</td>
</tr>
<tr>
<td>Installation</td>
<td>$8.75M</td>
<td>Conceptual</td>
</tr>
<tr>
<td>Water, DAQ, testing, etc.</td>
<td>$11.4M</td>
<td>Quote, made for 300kT</td>
</tr>
<tr>
<td>Contingency (non-civil)</td>
<td>$25.0M</td>
<td>&gt;30% for some items</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$139M</strong></td>
<td>FY2007</td>
</tr>
</tbody>
</table>

*Cost and schedule reviewed by RESPEC, does not have rock disposal*
Conclusion

• 100kT detector could be ready for physics by mid decade (~2015).

• Unique physics capability in the world. Excellent sensitivity for $\theta_{13}$ and mass ordering.

• Get started on much larger program for CP violation, Nucleon decay, and Supernova physics.

• Subsequent caverns could house different technology: better PMTs, Liquid Scintillator, Liquid Argon ...
Excavation costs do not include

- General operations: mine, shaft, pumps, ventilation
- Overhead functions: office, property maintenance, water consumption, power.
- Mobilization/demobilization
- Waste handling
- EDIA
- Do not triple for 3 caverns.
Collaboration requesting funds from DUSEL R&D

One time costs

From Mark Laurenti
# Capital Investment

**MINING EQUIPMENT**

<table>
<thead>
<tr>
<th>Units</th>
<th>Price Ea</th>
<th>Total $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Face Drill (2 Boom)</td>
<td>2</td>
<td>$860,000</td>
</tr>
<tr>
<td>Bench Drill</td>
<td>2</td>
<td>$425,000</td>
</tr>
<tr>
<td>Bolter</td>
<td>1</td>
<td>$800,000</td>
</tr>
<tr>
<td>Cable Bolter</td>
<td>1</td>
<td>$1,245,000</td>
</tr>
<tr>
<td>Load Haul Dump</td>
<td>4</td>
<td>$800,000</td>
</tr>
<tr>
<td>Haul Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosive Truck</td>
<td>1</td>
<td>$300,000</td>
</tr>
<tr>
<td>Sissor Lift</td>
<td>2</td>
<td>$250,000</td>
</tr>
<tr>
<td>Utility Lift</td>
<td>1</td>
<td>$200,000</td>
</tr>
<tr>
<td>Transport</td>
<td>3</td>
<td>$75,000</td>
</tr>
<tr>
<td>Jacklegs</td>
<td>6</td>
<td>$6,000</td>
</tr>
</tbody>
</table>

**OTHER EQUIPMENT**

<table>
<thead>
<tr>
<th>Units</th>
<th>Price Ea</th>
<th>Total $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explosive Mag</td>
<td>2</td>
<td>$100,000</td>
</tr>
<tr>
<td>Vent Fan</td>
<td>6</td>
<td>$30,000</td>
</tr>
<tr>
<td>Shop Equipment</td>
<td>1</td>
<td>$500,000</td>
</tr>
<tr>
<td>Fuel Tanks</td>
<td>1</td>
<td>$100,000</td>
</tr>
</tbody>
</table>

**TOTAL** $10,020,000

From Mark Laurenti
100kT water Cherenkov CP reach
Nucleon decay and Supernova

- Large body of work by HyperK, and UNO.
- Background levels for the positron+Pion mode
  - 3.6/MTon-yr (normal)
  - 0.15/MTon-yr (tight)

Sensitivity on K-nu mode is about $\sim 8 \times 10^{33}$ yr

Galactic Supernova in 300kT: 100000 evts/10sec

Ref: Shiozawa (NNN05) 300kTX10yrs => $7 \times 10^{34}$ yrs