DUSEL Water Cherenkov Experiment

R. Svoboda, NNN09
A Large Neutrino Detector for DUSEL

Note: the DUSEL detector will likely be realized in 2-3 modules

The muon rate in the DUSEL detector will be $1/30^{th}$ that of Super-Kamiokande

IMB

Super-Kamiokande

DUSEL

300 ktons

22 ktons

3 ktons
Long Baseline Neutrino Experiment
(Project)

- NSF
- DOE
- DUSEL
- LBNE Office (FNAL)
- S4 Office (universities)
- NEAR DET (LANL?)
- WCh Detector Office (BNL)
- BEAM
- LAr Detector Development
Long Baseline Neutrino Experiment
(Science Collaboration)

- ~180 people
- Science Goals: We want a broad program!
- Neutrino Mass Hierarchy & CP violation
- Supernovae
- Relic Supernovae
- Proton Decay
- neutrino physics
Sensitivities for various NuMI-like beam options with a 280m DP length

\[ \sin^2 2\theta_{13} \neq 0 \]

**mass hierarchy**

\[ \delta_{CP} \neq 0, \pi \]

**Mark Dierckxsens**

Default: 120 GeV, 250kA, no plug, 3+3 MW yr
300 kTon + 2.4 MW

Mass Hierarchy
M. Dierckxsens

CP violation
5% background uncertainty
120 GeV 0.5 OA

R. Svoboda, 3 November 2008
Cosmic ray induced neutrinos

Would pass Super-K in statistics after \(~1.5\) years.

Issues:
1. improved sensitivity to $\nu_\mu \rightarrow \nu_\tau$
2. oscillation mixing angle
3. “exotic” phenomenon
Supernova Burst

- Huge signal for a galactic supernova
- More importantly: very precise knowledge of the cross-section (~0.2%) for $\bar{\nu}_e + p \rightarrow e^+ + n$ makes the statistics meaningful!
- Double coincidence: zero background (need Gd)
- Positron spectrum mirrors neutrino spectrum

<table>
<thead>
<tr>
<th></th>
<th>10 kpc with 300 ktons</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC $\bar{\nu}_e$</td>
<td>70,000 events</td>
</tr>
<tr>
<td>NC $\nu_x$</td>
<td>3,000 events</td>
</tr>
<tr>
<td>ES $\nu_e$</td>
<td>3,000 events</td>
</tr>
</tbody>
</table>
The feeble signal of all SNe

- Sum over the whole universe:

\[ \sum \Phi^*_\nu \]

Note: DUSEL has at least an order of magnitude less reactor antineutrino flux

Gadolinium Doping

- Sensitivity to neutron capture via 8 MeV gamma cascade (e.g. M.Vagins, NNN08)
- Inexpensive, low risk. Could be implemented after construction completed, no schedule risk.
- Technical challenges:
  - material compatibility. Chose materials that do not contaminate the water.
  - water treatment. Remove impurities but leave gadolinium in solution.

R.Svoboda, 3 November 2008
Status of theory: anti-$\nu_e$ flux

- Differences due to different inputs/methods

For a **Gd-loaded** 300 kton WC detector, estimates range from 6-60 events/year.


SK background of $\sim$20/year significantly reduced by neutron tagging. (Beacom and Vagins)
Nucleon Decay

- Neutrinos, electrons, photons, and protons are the only known stable particles
- Stable over what time scale?
- Lifetime of universe $10^{10}$ years
- Many theories that try and unite the known forces of nature into a “Grand Unified Theory” (GUT) predict that free protons will decay with lifetimes of $10^{30}$ years or longer
Proton Decay Limits

GOAL: push this Sensitivity forward
By factor of 13
Water Cherenkov Detector Design Group

- Argonne NL
- Boston University*
- Brookhaven NL
- Caltech*
- Univ. of California, Davis*
- Univ. of California, Irvine*
- Drexel University*
- Duke University*
- Fermi NL
- Iowa State Univ.
- Univ. of Hawaii
- Lawrence Livermore NL*
- Univ. of Maryland*
- Univ. of Minnesota
- Univ. of Pennsylvania*
- Rensselaer Poly. Inst.*
- Univ. of South Carolina*
- Univ. of Wisconsin*

* Funded through NSF S4
Major Project Components

• Neutrino Beam. Plan initially for 700 kw beam with potential for up to 3 MW later. Project Office at FNAL.

• Near Detector: for characterization of the beam. LANL proposed to have a major role.

• Far Detector. Project Office at BNL and S4 proposal from NSF for Water Cherenkov detector development. LAr detector development through FNAL.
Excavation Plans
October 09

- Davis Cavern
- Yates Shaft
- Ross Shaft
- Existing Drifts
- Lab Modules
- Large Cavities
- Excavation Drifts at 5040L
- New Winze to 7400L
- Access Drifts at 4850L
- #6 Winze
Excavation Plans
Large Cavities

Yates Shaft

Large Cavities

New Winze to 7400L
Large Cavity, Water Cerenkov Detector
Water: 53m Dia. x 54m vertical, Fiducial Volume: 50m Dia. x 51m vertical

- Utility Rooms
- Entrance Drift at 4850L
- Excavation Ramp to Mid-Levels
- Water Level
- Large Cavity
- Excavation Drift at Lower Level, 5040L
The Big Hole

- One large cavity is included in the scope of DUSEL. DOE will also cost one cavity.
- Large Cavity Board report: a large 100 kton detector could be built safely and economically. 150 kton cavities may also be possible.
- Three independent cost estimates
- We want 300 ktons total
Excavation Plans

Large Cavity Excavation Sequencing (LCAB)

Stage 1
• Excavate Top Heading Concurrent with Bottom Heading
• Excavation and support needs to proceed sequentially from the center of the cavern out to the perimeter of the cavern.
• The top drift into the center of the cavern should be approximately 5 meters or less in width with the permanent rock support installed as the drift progresses.
• The sequence could be in approximately 5 meter rings or in pie shaped wedges, but always proceeding from the center of the cavern towards the perimeter.
Excavation Plans

Large Cavity Excavation Sequencing (LCAB)

Stage 2

• Excavate Center Borehole
• Borehole dimension – 10 – 14 ft diameter
• Provides conduit for muck removal as well as relief for blasting
Excavation Plans

Large Cavity Excavation Sequencing (LCAB)

**Stage 3**
- Long hole drilling and blasting of the center portion of the cavern.
- The dimension of the un-blasted perimeter ring should be determined by numerical modeling of stress conditions and assessment of rock joint patterns.
- The key parameter in defining the perimeter ring is confining the predicted rock fracture resulting from ground relaxation to within the ultimate excavated perimeter of the cavern.
- Other considerations, such as drilling equipment dimensions, may increase the width of the perimeter ring but the minimum width needs to be determined and adhered to.
Excavation Plans

Large Cavity Excavation Sequencing (LCAB)

Stage 4
• The perimeter ring is to be excavated in benches deep enough to be reasonably economical but not deep enough to create failure in the surrounding rock mass due to stress relaxation at the cavern wall. It is imperative that the wall excavation support be installed in a timely manner.
• In all of the excavation sequences proper controlled blasting techniques must be employed. The intent of the controlled blasting is to limit the loosening of the remaining rock mass. This maximizes the long term stability of the remaining rock mass under changed stress conditions and decreases the likelihood of rock falls.
Water Containment

- Keep Rock out
- Keep water in
- Keep costs down
**Possible Solutions**

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Steel self supporting</th>
<th>Concrete blocks</th>
<th>Unitary post-stressed concrete vessel self supporting</th>
<th>Liner on shotcrete</th>
<th>Cast concrete against rock</th>
<th>Pressure balanced wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiducial Radius</td>
<td>m</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Gap between fiducial radius and PMT module</td>
<td>m</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PMT module thickness</td>
<td>m</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.2</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Gap between PMT module and tank wall</td>
<td>m</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sealing/coating layer thickness</td>
<td>m</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.005</td>
<td>0.01</td>
</tr>
<tr>
<td>Tank water radius</td>
<td>m</td>
<td>26.51</td>
<td>26.51</td>
<td>26.51</td>
<td>27.21</td>
<td>27.01</td>
<td>27.21</td>
</tr>
<tr>
<td>Tank wall thickness top</td>
<td>m</td>
<td>0.05</td>
<td>0.5</td>
<td>1</td>
<td>0.1</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Tank wall thickness bottom</td>
<td>m</td>
<td>0.12</td>
<td>0.5</td>
<td>1.0</td>
<td>0.1</td>
<td>1</td>
<td>0.0</td>
</tr>
<tr>
<td>Tank wall thickness average</td>
<td>m</td>
<td>0.09</td>
<td>0.50</td>
<td>1.00</td>
<td>0.10</td>
<td>1.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Tank outer radius</td>
<td>m</td>
<td>26.63</td>
<td>27.01</td>
<td>27.51</td>
<td>27.31</td>
<td>28.01</td>
<td>27.22</td>
</tr>
<tr>
<td>Access/drainage/balance gap</td>
<td>m</td>
<td>2</td>
<td>0.2</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Rock wall radius</td>
<td>m</td>
<td>28.63</td>
<td>27.21</td>
<td>30.51</td>
<td>27.31</td>
<td>28.01</td>
<td>27.72</td>
</tr>
<tr>
<td>Tank wall mass</td>
<td>tonne</td>
<td>5989</td>
<td>11453</td>
<td>23331</td>
<td>2316</td>
<td>23755</td>
<td>231</td>
</tr>
<tr>
<td>Fiducial volume</td>
<td>cu m</td>
<td>100000</td>
<td>100000</td>
<td>100000</td>
<td>100000</td>
<td>100000</td>
<td>100000</td>
</tr>
<tr>
<td>Fiducial height</td>
<td>m</td>
<td>51</td>
<td>51</td>
<td>51</td>
<td>51</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>Tank water height</td>
<td>m</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Tank floor thickness</td>
<td>m</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Excavation height</td>
<td>m</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>56</td>
</tr>
<tr>
<td>Excavation volume (without upper part)</td>
<td>cu m</td>
<td>144155</td>
<td>130207</td>
<td>163712</td>
<td>131166</td>
<td>137978</td>
<td>135184</td>
</tr>
<tr>
<td>Normalized</td>
<td></td>
<td>1.04</td>
<td>0.94</td>
<td>1.19</td>
<td>0.95</td>
<td>1.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

**SK**

**miniBooNE**

**IMB, SNO**

**KamLAND**
Photon Economics

- About 50% of the detector cost is expected to be in photosensors
- Even small improvements can make a big impact
- Development of light enhancement techniques underway
- New high QE PMTs are now available – will be tested in a statistically large sample this year
- Prevention of implosion chain reaction (BNL+U.S. Navy). This is a possible point for international cooperation.
- Developments outside Project: waveshifting dyes, MCP development
78 high quantum efficiency 10” PMT successfully tested for use in IceCube

- More than 4000 sensors with standard 10” PMT (R7081-02) integrated and tested in IceCube
- 78 high quantum efficiency PMT (10”) tested with IceCube standard production test program.
- Result:
  - Quantum efficiency ~38% higher (405 nm, -40C)
  - No problems found
  - Low temperature (-40C) noise behavior scales with quantum efficiency as expected.
- Plan to use high QE PMT on 6 Deep Core strings for enhanced sensitivity at low energies (<100GeV, dark matter)
- Sensors already at the South Pole

A. Karle, UW-Madison
Example data R7081 (10 inch)

- High QE Type
  - Champion Data
  - 35% at 380 nm
- Standard
  - 26% at 380 nm

Samples: 22 pcs
Average: 31.6%

Goal of development is 43%
M. Diwan
Other Experiment Components

- Electronics: conceptual designs in progress. Would like further international cooperation.
- Water transparency: facilities at UCI, LLNL
- Gadolinium loading: UC Irvine, LLNL, BNL
- Calibrations: specifications being developed
- PMT’s: FNAL
- Project Integration: BNL/DUSEL/S4
- Safety: BNL
- Environmental Impact: ANL
S4 Work

- Deck Design Concept (Duke)
- Thermal Control (RPI/LLNL)
- Cranes and movement infrastructure (Duke)
- Magnetic Field Compensation (RPI/UC Davis)
- PMT characterization (Penn/Drexel)
- Water System (Gadolinium) development (UC Irvine/LLNL)
- Light Collector evaluation (Caltech/Drexel/S.Carolina)
- PMT QA, mobilization planning (Wisconsin)
- Simulations for Engineering Specifications (Duke+all)
- Electronics (BU/Penn)
- Calibration Planning (UC Davis – temp)
- Outreach (UC Davis)
Schedule

- Initial design and costing complete by Fall, 2010
- DOE CD-1, December 2010
- National Science Board, Spring 2011
- Preliminary Design (~CD-2), end of 2012
- DUSEL construction start, 2013
- Large Cavity construction, 2016-2017 (this could be earlier)
Backup slides
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Dewater Construction Commences</td>
<td>0 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50STA Science</td>
<td>658 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop Lux and Majorana projects</td>
<td>16 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yates Shaft</td>
<td>4496 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary rehab 2000L - 4850L</td>
<td>9 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yates utilized as emergency egress</td>
<td>55 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strip and re-equip shaft</td>
<td>24 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yates utilized as Science access</td>
<td>53 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC drive upgrade - production host</td>
<td>3 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install new auxiliary host</td>
<td>9 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ross Shaft</td>
<td>4294 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ross used as primary access shaft</td>
<td>41 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC drive upgrade - service host</td>
<td>3 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft infrastructure rehab</td>
<td>8 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ross utilized as lining shaft</td>
<td>71 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 5 Egress Shaft</td>
<td>2976 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install 2nd hand egress host</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strip and re-equip (rope guide)</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 5 utilized as emergency egress</td>
<td>02 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 6 Shaft</td>
<td>2666 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install new production host</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install new service hotel</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft infrastructure rehab</td>
<td>8 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 6 utilized as lining shaft to 7400L</td>
<td>71 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 8 Shaft (new)</td>
<td>2077 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Re bore 4850L to 6000L</td>
<td>10 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install automatic service host</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install shaft infrastructure</td>
<td>11 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 8 utilized as Science shaft to 7400L</td>
<td>46 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste transfer to pit</td>
<td>558 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rehab tramway level</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install overland conveyor</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Install pit waste handling system</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4850 Lab Construction</td>
<td>992 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Access development</td>
<td>12 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 1 development</td>
<td>4 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 2 development</td>
<td>7 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 3 development</td>
<td>10 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large cavern development</td>
<td>19 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7400 Lab Construction</td>
<td>682 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Develop 2000H (10fps) to No. 8 Shaft bottom</td>
<td>6 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Division 2000H South Access</td>
<td>7 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab 1 development (130,000 tons@500fps)</td>
<td>9 mons</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Water Cherenkov particle identification
Continuously Improving $\pi^0/e$ separation in SK

- 2-R e-like tag (old ring-finder)
- $\pi^0$ fitter (improved ring-finder)
100 kTon + 700 KW

Hierarchy

M. Dierckxsens

5% background uncertainty
120 GeV 0.5 OA
Preliminary Data (i.e. taken last week):

Tagged muon spectrum:

Downward travelling muons are tagged in scintillator paddles.
Chromatic Dispersion in Water

The Cherenkov photons will propagate at the group velocity given by:

\[ v_g = \frac{d\omega}{dk} = c \left[ \frac{1}{n(\lambda)} + \frac{\lambda}{n^2(\lambda)} \frac{dn}{d\lambda} \right] \]

Higher energy photons will propagate slower. This becomes increasingly significant at sub 300nm wavelengths where detection sensitivities are already becoming very small.
Cherenkov Radiation: \[
\frac{d^2 N}{dx d\lambda} = \frac{2\pi \alpha z^2}{\lambda^2} \left(1 - \frac{1}{\beta^2 n^2(\lambda)}\right)
\]

Cherenkov spectrum is dominated by UV photons. Typical PMT Quantum Efficiencies are poor in most of this range.

Idea: Absorb UV photons and re-emit them at longer wavelengths.
Spectrum fitting in SK-I

- $N_{\text{data}}(i)$: real Data spectrum
- $N_{\text{relic}}(i)$: SRN MC spectrum
- $N_{\nu_e}(i)$: atmospheric $\nu_e$ spectrum
- $N_{\nu_\mu}(i)$: atmospheric $\nu_\mu$ spectrum

Courtesy Iida, ICRR
\( \nu_e \) appearance in a \( \nu_\mu \) beam

\[
P(\nu_\mu \rightarrow \nu_e) = (2c_{13}s_{13}s_{23})^2 \sin^2\Phi_{31} \\
+8c_{13}^2s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23})\cos\Phi_{32}\sin\Phi_{31}\sin\Phi_{21} \\
-8c_{13}^2c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta\sin\Phi_{32}\sin\Phi_{31}\sin\Phi_{21} \\
+4s_{12}^2c_{13}(c_{12}^2c_{23}^2 + s_{12}^2s_{23}^2s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta)\sin^2\Phi_{21} \\
-8c_{13}^2s_{13}^2s_{23}^2(1 - 2s_{13}^2)(aL/4E)\cos\Phi_{32}\sin\Phi_{31}
\]

\( a = \text{constant} \times n_eE \)

\( \text{CP: } a \rightarrow -a, \ \delta \rightarrow -\delta \)
Why DUSEL?

• 1300 km distance is significant for determination of neutrino mass hierarchy
• Deep underground site allows rich physics program in addition to LB neutrinos
Spectra FNAL to DUSEL (WBLE: wide band low energy)

numu cc (param) 1300 km / 0 km

numu cc (param) 1300 km / 12 km

- 60 GeV at 0 deg: CC rate: 14 per (kT*10^20 POT)
- 120 GeV at 0.5 deg: CC rate: 17 per (kT*10^20 POT)

Work of M. Bishai and B. Viren using NuMI simulation tools.
<table>
<thead>
<tr>
<th></th>
<th>10 inch R7081</th>
<th>20 inch R3600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number (25% cov)</td>
<td>~50000</td>
<td>~14000</td>
</tr>
<tr>
<td>QE</td>
<td>25%</td>
<td>20%</td>
</tr>
<tr>
<td>CE</td>
<td>~80%</td>
<td>~70%</td>
</tr>
<tr>
<td>rise time</td>
<td>4 ns</td>
<td>10 ns</td>
</tr>
<tr>
<td>Tube length</td>
<td>30 cm</td>
<td>68 cm</td>
</tr>
<tr>
<td>Weight</td>
<td>1150 gm</td>
<td>8000 gm</td>
</tr>
<tr>
<td>Vol.</td>
<td>~5 lt</td>
<td>~50 lt</td>
</tr>
<tr>
<td>pressure rating</td>
<td>0.7Mpa</td>
<td>0.6Mpa</td>
</tr>
<tr>
<td>$\Theta$ coverage/pmt</td>
<td>0.6 deg</td>
<td>1.1 deg</td>
</tr>
<tr>
<td>$\Theta$ granularity</td>
<td>1.0 deg</td>
<td>2.1 deg</td>
</tr>
</tbody>
</table>
Water Purification system:

Beakers are illuminated by a fluorescent UV light.

- Tap Water
- 1ppm 4-MU

- Tap Water
- 1ppm 4-MU after ~5min in DI system
Large-area Micro-Channel Plate Panel “Cartoon”

Front Window and Radiator

Photocathode

Pump Gap

High Emissivity Material

Gold Anode

Low Emissivity Material

`Normal` MCP pore material

50 Ohm Transmission Line

Capacitive Pickup to Sampling Readout

Rogers PC Card

8/13/2009

13-15, 2009, OHM

N.B.- this is a `cartoon`- working on workable designs-