Deep Underground Science and Engineering Laboratory at Homestake

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UC Berkeley
May 2008
Outline of Presentation

• The U.S. Deep Underground Science and Engineering Laboratory at Homestake
  – Status of the NSF’s Proposal
    • Scope
    • Timetable
    • Recent Milestones
  – DUSEL’s Physics Programs

• The Sanford Laboratory
  – Current Status of Facility Reentry
  – Early Implementation Science Program
Homestake DUSEL Proposal

• NSF’s Major Research Equipment and Facility Construction Effort
  – Facility
  – Initial Suite of Experiments
    • Facility Requirements

• Multidisciplinary
  – Physics
  – Geology
  – Biology
  – Engineering
  – Education
DUSEL Progress

- **DUSEL Three-Step Process**
  - S-1 Assess the Science -- DeepScience
  - S-2 Project Science onto Sites -- CDRs
  - S-3 Select a site -- Homestake
    - $15M, 3 year planning grant with UCB

- **DUSEL as an MREFC (Major Research Equipment and Facilities Construction)**
  - Recommendation to Advance to Readiness
  - ~$500 - 600M
    - ~$250M Facility
    - ~$250M Initial Suite of Experiments
  - Physics Driven, but Multidisciplinary Facility
Community DUSEL Activities

- **S-1**: culminated in **Deep Science**
- **November 07 Town Meetings**
- **DEDC** follows on from S-1
  - Steve Elliott (LANL) Phy
  - **Derek Elsworth** (Penn State) Geo/Eng
  - Daniela Leitner (LBNL) Phys
  - Larry Murdoch (Clemson) Geo/Eng
  - T.C. Onstott (Princeton) Geo/Bio
  - Hank Sobel (UCI) Phy

- **April Homestake Workshops** to begin defining Initial Suite Experiments Proposals -- **S-4**
The Next Round of Solicitations

- **S-4 Develop Superset of Experiments**
  - Provide $15M over 3 years to develop ISE plans
  - Any day now...
  - All disciplines

- **S-5 Select Initial Suite of Experiments**
  - S-4 is neither necessary nor sufficient for ISE
  - There are additional “on ramps” for experiments other than NSF “S-x” solicitations
Significant Milestone for Initial Suite of Experiments

- November 2007 Town Meeting
- April 2008 Lead Workshops
  - Late Spring S-4 Solicitation Announcement
  - July 2008 Internal Review of DUSEL
  - Fall 2008 S-4 Funds for Experiment PDRs
  - December 2008 NSF Review of DUSEL
  - Summer 2009 Review of ISE by NSF Panel
  - Summer/Fall 2009 Integration ISE and Facility
  - Fall 2009 Completion of DUSEL PDR & Review
  - Winter 2009-10 Presentation to and Review by NSF
  - March 2010 Presentation to NSB
  - FY2012 MREFC funding (projected)
### Proposed Timeline for Sanford Laboratory and DUSEL

<table>
<thead>
<tr>
<th>Event</th>
<th>Start</th>
<th>Finish</th>
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<tbody>
<tr>
<td>Sanford Laboratory at Homestake</td>
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<tr>
<td>Ross Shaft Rehab and Pumping Column Commissioning</td>
<td>Jan-07</td>
<td>May-08</td>
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<tr>
<td>Yates Shaft Rehab</td>
<td>Mar-08</td>
<td>Dec-08</td>
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<tr>
<td>Gain safe access to 4850L for EIP construction start, and hold water level at 5000L</td>
<td>May-08</td>
<td>Jun-08</td>
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<tr>
<td>Install facility infrastructure for Davis Lab early experiments</td>
<td>May-08</td>
<td>Sep-08</td>
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<tr>
<td>Install and commission research instrumentation in Davis Lab</td>
<td>Jul-08</td>
<td>Dec-08</td>
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<td>Early experiments in Davis Lab ready for operation</td>
<td>Jun-08</td>
<td>Dec-08</td>
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<tr>
<td>Continued rehabilitation and infrastructure upgrades for Sanford Lab</td>
<td>Dec-08</td>
<td>Dec-11</td>
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<tr>
<td>Transition from Sanford Lab to DUSEL Operations</td>
<td>Jan-12</td>
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<tr>
<td>NSF Deep Underground Science and Engineering Laboratory at Homestake</td>
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<tr>
<td>Homestake site selection announcement</td>
<td>Jul-07</td>
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<tr>
<td>DUSEL Preconstruction Planning and Development (R&amp;RA)</td>
<td>Oct-07</td>
<td>Dec-11</td>
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<tr>
<td>Preliminary Design Phase to develop Baseline Cost and Schedule</td>
<td>Oct-07</td>
<td>Dec-09</td>
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<tr>
<td>Preliminary Design Review and National Science Board Recommendation</td>
<td>Mar-10</td>
<td>Dec-11</td>
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<tr>
<td>Final Design Phase</td>
<td>Mar-10</td>
<td>Dec-11</td>
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<tr>
<td>Final Design Review and Authorization for Construction Start</td>
<td>Dec-11</td>
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<tr>
<td>DUSEL Facility - Construction and Commissioning (MREFC)</td>
<td>Jan-12</td>
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<tr>
<td>Construction Start</td>
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<tr>
<td>Near-Surface Campus Construction at 300L</td>
<td>Jan-12</td>
<td>Dec-13</td>
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<tr>
<td>300L Laboratories and Education and Outreach Facilities</td>
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<tr>
<td>Mid-Level Campus Construction at 4850 Level</td>
<td>Jan-12</td>
<td>Jan-14</td>
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<tr>
<td>4850L Common Facilities and Lab Module #1 (Excavation &amp; Lab Build-out)</td>
<td>Jan-12</td>
<td>Oct-12</td>
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<tr>
<td>4850L Lab Modules #2, #3 and #4</td>
<td>Jan-12</td>
<td>Jul-17</td>
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<tr>
<td>Deep-Level Campus Construction at 7400 Level</td>
<td>Jan-14</td>
<td>Dec-15</td>
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<td>7400L Common Facilities and Lab Module #1 (Excavation &amp; Lab Build-out)</td>
<td>Jan-14</td>
<td>Jun-15</td>
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<td>7400L Lab Modules #2 and #3</td>
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<td>Jul-17</td>
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<tr>
<td>Surface Campus Construction</td>
<td>Jan-12</td>
<td>Sep-13</td>
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<tr>
<td>Infrastructure to support Underground Construction and Operations</td>
<td>Jan-12</td>
<td>Mar-13</td>
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<tr>
<td>Phase 1 Offices and Laboratories</td>
<td>Jul-12</td>
<td>Oct-14</td>
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<tr>
<td>Phase 2 Offices and Laboratories</td>
<td>Jul-12</td>
<td>Sep-16</td>
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<tr>
<td>DUSEL Initial Suite of Experiments - Construction and Commissioning</td>
<td>Jan-12</td>
<td>Sep-18</td>
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**Fiscal Years**

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Physics Motivations: Long Baseline Neutrinos

Program Highlights include significant reach and discovery potential with long baseline neutrinos including:

**Mass Hierarchy**

**CP violation**

Requires Large Detectors, Modest Depths (~ 100 - 1000 m) and Long Distances from ν Sources (> 1000 km)
Physics Motivations: Nucleon Decay

Nonzero Baryon Number and assumptions of $B=0$ at $T=0$ suggest proton decay

In the framework of GUTs

$M_p = \text{proton mass}$

$M_U = \text{Unification Mass Scale}$

$a_U \sim 1/30$

$\therefore \tau_p \sim 10^{36} \text{ years}$

$$\frac{1}{\tau_p} = a_U^2 \frac{M_p^5}{M_U^4}$$
Limits for Various Decay Channels

Requires Very Large Detectors, Modest Depths (~ 1500 m), Stable and Long-term Excavations

from Hank Sobel
Program: FNAL to Homestake ~ 1290 km

FNAL (L~1290 km) 700 kW @ 120 GeV ➞ 6 \times 10^{20} \text{ POT /yr}
by ~ 2012

Then Project X: 2.3 MW @ 60 - 120 GeV as early as 2016
Physics with 100-kt Water Cherenkov Detector & 700kW Beams @ 120 GeV 3 years each $\nu + \bar{\nu}$

$1\text{kt} LAr \approx 3\text{kt} H_2O$

Mass Hierarchy

Determination of CP Phase

from Mark Dierckxsens
Milind Diwan
Mary Bishal

$18 \times 10^{20}$ POT each

$\Theta_{13}$

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

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

$95\% \text{ CL observ.}$

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

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

$100\text{kt WCh}$

3 years at 700 kW for $\nu$ and $\bar{\nu}$ each

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

$18 \times 10^{20}$ PoT

true value

$68\% \text{ CL}$

$95\% \text{ CL}$

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

$\sin^2 2\theta_{13}$
Physics with 300-kt Water Cherenkov Detector & 2 MW Beams @ 120 GeV 3 years each $\nu+\overline{\nu}$

Exclusion of CP Violation

Mass Hierarchy

$\Theta_{13}$

$\nu+\overline{\nu}$, WCh
60+60 $10^{20}$ PoT

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

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

$\Delta m^2_{31}$

60$\times$10$^{20}$ POT each

Double Chooz 2012
Daya Bay 2013
T2K 2012
NOvA 2014

100kt LAr DUSEL
Modular Approach to Megaton

Initial coring

Single 130,000 ton Module construction

Multiple module layout
Oscillation experiments indicate $\nu$s are massive, set relative mass scale, and minimum absolute mass

$\beta$ decay + cosmology set maximum for absolute mass

$\therefore$ One $\nu$ in the mass range: $\sim 45$ meV $< m_\nu < \sim 2200$ meV

$0\nu\beta\beta$ experiments may determine absolute mass scale

$0\nu\beta\beta$ may establish mass hierarchy, synergistic when combined with accelerator neutrino measurements

$0\nu\beta\beta$ only way to establish if Dirac or Majorana

Even null results are now interesting and useful
Physics Motivations: Neutrinos - Neutrinoless Double Beta Decay

\[ 2\nu \beta \beta \]

\[ 2n \Rightarrow 2p + 2e^- + 2\bar{\nu}_e \]

\[ 0\nu \beta \beta \]

\[ n \Rightarrow p + e^- + \bar{\nu}_e \]

\[ \nu_e + n \Rightarrow p + e^- \]

\[ [T_{0\nu 1/2}]^{-1} = G^{0\nu}(E_0,Z) |<m_\nu>|^2 |M^{0\nuF} - (g_A/g_V)^2 M^{0\nuGT}|^2 \]
Physics Motivations: Neutrinoless Double Beta Decay

- Well Motivated by ν Oscillation Experiments & Theory
  - Absolute ν mass scale
  - ν mass hierarchy
  - Dirac or Majorana Nature of ν
  - Even null results are valuable

\[ [\mathbf{T}^{\nu}_{1/2}]^{-1} = G^{\nu} (E_0, Z) |<m_\nu>|^2 \quad |M^{0\nu}_F - (g_A/g_V)^2 M^{0\nu}_{GT}|^2 \]

ReQUIRES Shielding (great depth ~ 2500 m), Experimental Support, Access, Stability, Environmental Control

\[ n \Rightarrow p + e^- + \nu_e \quad (RH \nu_e) \]
\[ \nu_e + n \Rightarrow p + e^- \quad (LH \nu_e) \]

\[ \nu_e \]

\[ Z \]

\[ Z+1 \]

\[ Z+2 \]
Physics Motivations: Dark Matter

- Strong science motivation for discovery
  - Convergence of particle and astrophysics theory/experiment

- Significant recent advancements in sensitivity
  - US is current world leader in field

- Direct searches testing physics complementarity to accelerator work
  - Also indirect/astro signal searches

- Flagship science at DUSEL
  - DUSEL will ensure continued leadership

WIMP Mass [GeV/c^2]
Cross-section [cm^2] (normalised to nucleon)

figures from Town Meeting DM working group
Physics Motivations: Dark Matter

Requires Shielding (great depth ~ 2500 m), Experimental Support, Access, Stability, Environmental Control

FOM: 1 ct/T/year
Physics Motivations: Nucleosynthesis

- $A>60$ formation in Supernovae, $\nu$ interactions
- Sources of neutrons for s-, r- processes
- Details of Lower Mass Nucleosynthesis
- pp chain
- CNO

\[ ^3\text{He}(^3\text{He},2p)^4\text{He} \]
\[ ^3\text{He}(\alpha,\gamma)^7\text{Be} \]
\[ D(^3\text{He},p)^4\text{He} \]
\[ D(p,\gamma)^3\text{He} \]
\[ ^7\text{Be}(p,\gamma)^8\text{B} \]
\[ ^{14}\text{N}(p,\gamma)^{15}\text{O} \]
\[ ^{12}\text{C}(\alpha,\gamma)^{16}\text{O} \]

\[ ... \]
Research in Targeted Fields of Opportunity

- Solar Neutrinos
- Gravity Waves
- Geoneutrinos
- Nucleon-oscillations
- ...

\[
i\hbar \frac{\partial}{\partial t} \left( \frac{n}{\bar{n}} \right) = \left( \begin{array}{cc} m + V_1 & \delta \\ \delta & m + V_2 \end{array} \right) \left( \frac{n}{\bar{n}} \right)
\]
<table>
<thead>
<tr>
<th>Dark Matter (6-8)</th>
<th>Low Energy Solar ν (2)</th>
<th>Neutrinoless ββ Decay (2 - 3)</th>
<th>Gravity Waves (1)</th>
</tr>
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<tbody>
<tr>
<td>Sanford Lab 4850L</td>
<td>4850L 7400L</td>
<td>Sanford Lab 7400L</td>
<td>2000L</td>
</tr>
<tr>
<td>Neutrinoless ββ Decay (2 - 3)</td>
<td>300L 4850L 7400L</td>
<td>Long Baseline ν &amp; Nucleon Decay (2)</td>
<td>Engineering and Excavation Research 4850L 7400L</td>
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<tr>
<td>Nuclear Astrophysics (2)</td>
<td>4850L 7400L</td>
<td>Geoneutrinos (1)</td>
<td>Scale Effects 4850L 7400L</td>
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<td>Geobiology</td>
<td>Active Processes 4850L 7400L</td>
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<td>Low Background Assay &amp; Materials 300L 4850L</td>
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<td>Geoneutrinos (1)</td>
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<td>Geobiology</td>
<td>R&amp;D Efforts Surface 300L 4850L 7400L</td>
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<tr>
<td>Geoneutrinos (1)</td>
<td>4850L</td>
<td>Geobiology</td>
<td>Education &amp; Outreach Surface 300L</td>
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</table>

- Concepts for Initial Suite of Experiments - to be revised with community based program
- Low Background Assay & Materials 300L 4850L
- R&D Efforts Surface 300L 4850L 7400L
- Education & Outreach Surface 300L
Research Campuses

Details of the Conceptual Design at www.lbl.gov/nsd/homestake
Progress at the Sanford Lab

- $115M state-funded effort
- Jose Alonso Lab Director
- Focusing on stabilizing facility and starting early science as Sanford Lab
- Pumped 3.5M G in April & May
- Routine pumping by June
- Access to 4850L by Sept
- Science at 4850L by Dec
Approximate boundary of transferred property:
186 acres (surface) 7700 (u/g)
Phased approach to building DUSEL

A dedicated science facility without competition or interference from mining, transportation, etc.
Summary

- World-class Programs
- Unique Capabilities in the World
- Transformational Experiments Identified
  - Dark Matter
  - Neutrinoless Double Beta Decay
  - Long Baseline Neutrinos + Nucleon Decay
  - Other Topics and Disciplines
- Efforts underway at Sanford Lab to prepare the site ($126M) parallel to DUSEL efforts
  - phased program for experiments
- Long-term, Reduced Risk, Well-known Site
  - tailored access
  - 30+ year horizon providing critical u/g space
  - no competition with other interests