DUSEL Project Overview

- Preliminary Design
  - Facility Design
    - Design Milestones
  - Science Integration
    - LBNE Integration
- Program Advisory Committee
- Recent Activities and Plans for 2011
- Neutrinoless Double Beta Decay
- Nuclear Astrophysics
DUSEL is extensively addressed by the Scientific Communities, Agencies, National Academy Reports

- Bahcall Committee Report 2001
- Nuclear Physics Long Range Plan 2002
- Connecting Quarks to the Cosmos
- HEPAP Long Range Plan 2003
- Neutrinos and Beyond
- EarthLab
- Physics of the Universe
- The Neutrino Matrix
- Earth Scope
- Discovering the Quantum Universe
- Deep Science
- Nuclear Physics Long Range Plan 2007
- 2008 P5 Report
- 2009 PASAG
- 2010 NRC Study is underway
Why Are We Developing DUSEL?

To enable the Science, exploit synergisms, maximize the benefits of a dedicated facility, and integrate Education and Outreach functions

- Neutrinos - discover new physics, known-unknown physics
- Dark Matter - identify ~25% of the known-unknown universe
- Dark Life - limits of life, life in extremes, life in isolation, new life
- Origin of the Elements - how, where did the elements originate
- Symmetries and High Energy Scale Physics - matter/antimatter asymmetry, the universe at extreme energies and physics of the early universe -- the Intensity Frontier
- Natural Resources - understanding, probing & predicting
- Engineering - safer, deeper, larger & faster
- Energy and Carbon Research - imperative societal questions
- Education and Outreach - welcome, attract, excite & engage
Reviewing the DUSEL Project

• DUSEL will be a Major Research Equipment and Facility Construction (MREFC) Project
  – Facility
  – Suite of Compelling Multidisciplinary Experiments

• Updated Agency Guidance - FY14 start
  – Facility (NSF Stewardship)
  – Long Baseline Neutrinos + Proton Decay (DOE HEP Stewardship)
    • CD0 - Jan. 2010, LBNE Project Team Senior Leadership Established
  – Neutrinoless Double Beta Decay (DOE NP Stewardship)
  – Dark Matter (NSF Stewardship)
  – Additional experiments (NSF Stewardship)
  – More on the stewardship model later...

• Proposal & CDR championed Early Implementation Program
  – Requires operational EH&S program while DUSEL’s full programs are being crafted - Project working closely with SD to realize this
Facility Design Refined Following Interactions with the Collaborations and LBNE

• World-Class Facility
  – Research Campuses
    • Surface Campus (~27,000 m²/1100 m² total/assembly)
    • 4850L (~25,000 m²/10,000 m² total/science)
    • 7400L (~5000 m²/1800 m² total/science)
    • Other Levels and Ramps (~30 km: ~50/50 ops/sci)
  – Dual Access to Research Campuses
  – Best-practices Life Safety Systems and Programs
  – Experimental Support
  – Design Enabling Future Expansion
  – Project Enabling Participation by Other Agencies

• Suite of Transformational Scientific Experiments
  – Diverse and Compelling Suite of Experiments
  – Integral Education and Outreach Efforts
Facility Design Refined Following Interactions with Collaborations

- **Surface Campus**
  - 2 Simultaneous Installations

- **0 to ~1700L** (Vertical Expts)

- **4850L**
  - 1 Large Cavity (+ Options)
  - 4 - 5 Physics Experiments
  - Earth Science Experiments

- **7400L**
  - 2 Physics Experiments
  - Earth Science Expts

- **Other Levels & Ramps**
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• Other Levels & Ramps
MREFC Project Scope: On-going Iterations

- Draft Multidisciplinary Generic Suite of Experiments
- Developed Facility supporting this GSE based on concepts, parametric estimates and scaling arguments
- Iterate and Value Engineering on the Facility Design work with science collaborations
- Factor in Agency discussions and assumptions
- Working with the Agencies to understand the Science support within the NSF and between NSF and DOE
- Science is recognized to require additional support

<table>
<thead>
<tr>
<th>NSF MREFC Scope</th>
<th>Targets including Contingency</th>
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</thead>
<tbody>
<tr>
<td>DUSEL Project Office</td>
<td>$48M</td>
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<tr>
<td>Surface Campus* (+ $5M from Sanford)</td>
<td>$50M</td>
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<td>Underground Infrastructure and Laboratories*</td>
<td>$480M</td>
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<td>LBNE Science Contribution</td>
<td>$123M</td>
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<td>Other Science Contributions</td>
<td>$50M</td>
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* including LBNE support
The DUSEL Organization Nearly Complete: ~55 Staff Members
Advancing DUSEL’s Preliminary Design and Maintaining Project Schedule

• Golder Excavation Design
  60% Report 16 June 2010 ✓

• HDR Surface Campus
  100% Report 13 May 2010 ✓

• Arup Laboratory Design
  60% Report - 01 June 2010 ✓

• Arup Laboratory Infrastructure
  60% Report - 07 June 2010 ✓

• Golder Geological/Geotechnical Assessment
  4850L Synthesis Report - 8 April 2010 ✓
Completed Critical Geotechnical Investigations

- 4850 Level Mapping - Completed
- Geological Model - Developed
- Coring and Logging - Completed
  - holes 1, 2, 3: Sanford Lab
  - holes 3, M, N: LC 1
  - holes B, C: LC 2, LC3
  - holes D, J: 4850 Lab Modules
  - 4363.1 feet of core
  - enough geotech for Preliminary design - Large Cavity Advisory Board
- In situ testing - Completed
- Laboratory testing - Completed

Good news: Little Water, Good to Very Good Rock Quality
# Milestone Schedule to Complete Preliminary Design

<table>
<thead>
<tr>
<th>Design Packages and Design Activities</th>
<th>April</th>
<th>May</th>
<th>June</th>
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- **2010**
  - **60% Preliminary Design**
    - Input to 90% Documents
    - Consolidated 60% Packages
  - **90% Preliminary Design**
    - Consolidated 90% Packages
    - Consolidated 90% Estimate
  - **100% PDR**
    - Advancing Design Elements and Integrating Experiments

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<tr>
<th>Design Packages and Design Activities</th>
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<td>DUSEL Construction Management and Project Team</td>
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<td>DUSEL, LBNE, Science Collaboration Reviews, Agency Meetings</td>
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- **2011**
  - **Transition to New M&O**
  - NSB Meeting

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NSAC July 30, 2010

Homestake DUSEL
Stewardship Model: Sharing DUSEL Responsibilities Between the Agencies

- **steward verb**: supervise arrangements, keep order, manage or look after (another person’s) property

- NSF & DOE are working closely together to steward DUSEL’s science

- Physics Efforts Coordinated through the Joint Oversight Group (JOG), Working Groups Established for:
  - Long Baseline Neutrinos
  - Neutrinoless Double Beta Decay
  - Nuclear Astrophysics
  - Dark Matter Searches

- JOG will negotiate and mediate major decisions parsing scope, funding, timing between the agencies and projects.

- Integration of LBNE with DUSEL efforts serves as an effective model for other major experiments
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<tr>
<th>Program</th>
<th>Steward Agency</th>
<th>Collaborating Agency</th>
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<td>DUSEL Facility</td>
<td>NSF</td>
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<td>Dark Matter</td>
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<td>DOE-OHEP</td>
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<td>DOE-ONP</td>
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<td>Long Baseline Neutrinos &amp; Proton Decay</td>
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<td>Nuclear Astrophysics</td>
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<td>Advanced low background &amp; assay</td>
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<td>Bio/Geo/Eng</td>
<td>NSF</td>
<td>DOE(-BES, BER)</td>
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"The Committee also recognizes the recommendation made in the 2008 report of the Particle Physics Project Prioritization Panel to develop a world-leading program of neutrino science to understand the role neutrinos play in the evolution of the universe. The United States has unique capabilities and infrastructure at Fermilab to advance this area of science. The Committee supports design work for two new potential construction projects – the Long Baseline Neutrino Experiment and the Muon to Electron Conversion Experiment. However, the Committee directs the Office of Science to submit a report not later than 180 days after enactment of this act that lays out (1) the expected benefits of intensity frontier science, (2) a strategy for maintaining the U.S. lead, and (3) the funding needs over the next 10 years, including construction activities, of implementing the proposed strategy. The Committee also is concerned about the status of the Deep Underground Science and Engineering Laboratory [DUSEL] funded by the National Science Foundation [NSF]. The neutrino program relies on the construction of DUSEL and any delays in the DUSEL program would impact advances in this area of science. The Committee urges the Office of Science to coordinate its neutrino program research efforts with NSF to avoid unnecessary delays."
Agency Guidance

• Initial Guidance (late 2009)
  – FY14 construction start
  – MREFC Cost estimated at $750M, including:
    – Comprehensive Deep Facility supporting transformational research
      • including 7400L campus
  – Four Pillars of the Physics Program
    • Long Baseline Neutrinos
    • Proton Decay
    • Neutrinoless Double Beta Decay
    • Dark Matter
  – Additional well-motivated experiments
    • Bio/Geo/Eng
    • Nuclear Astrophysics
    • Additional Physics Opportunities
Project Milestone Schedule through Construction

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<td>Access to and Maintenance of the Facility during Construction</td>
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*these are 30% PD, non-optimized Beneficial Occupancy Estimates
Integrating the Suite of Science Experiments into the Facility Design: Program Advisory Committee

Mike Witherell, UCSB
Physics Chair

Mark Zoback, Stanford
Earth Science Chair

Allen Caldwell, MPI

Boris Kayser, FNAL

Hitoshi Murayama, IPMU & UCB

Peter Parker, Yale

Michael Ramsey-Musolf, U. Wisconsin

Heidi Schellman, Northwestern

Abe Seiden, UCSC

Yoichiro Suzuki, U. Tokyo

Don DePaolo, UCB and LBNL

Steve Hickman, USGS

Art McGarr, USGS

Patricia Sobecky, U. Alabama

Provide an independent assessment of DUSEL’s proposed Generic Suite of Experiments 27-28 July 2010
Safety Program Timeline Discussed with NSF and DOE

Safety Review
21-22 June

DUSEL Early Science Re-Start Plan

<table>
<thead>
<tr>
<th>Time Scale</th>
<th>April</th>
<th>May</th>
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**DUSEL Safety**
- Develop EHS Program elements specific to supporting Early Science
- Peer ESH Review June 21-23
- Address Improvement Opportunities
- Ferguson ESH Committee Review Sep 13-15

**DUSEL Infrastructure**
- Electrical System Upgrade completed / Lighting for Majorana
- Ground Control Enhanced at Science Station Entrances
- VOIP & Analog Phones Installed
- Replacement of Shaft Studs
- Tety Group Agrees 25% complete
- Dewar Light System Installation Completed

**Majorana**
- Experiment Safety Assessment process evolved
- Open ESH Item Addressed
- Open ESH Item Addressed
- EHS Meeting Confirm Jan Review Items Addressed
- Deliver Temp Clean Room (TCR) U/G
- Build TCR
- Install Hardware in TCR
- Ready Review
- Final Walk Down
- Authorize Start

**LUX**
- Hoisting & Rigging Plan Approved
- Electrical Components Approved
- Cryo / OOH Approved
- Open ESH Item Addressed
- EHS Review
- Charge Cryo system
- Final Walk Down
- Authorize Start

**BIO/GEOL**
- BGE - Transparent Earth
- BGE - DUSL (LOGO)
- BGE - Crystal Growth
- BGE - Fiber Sensor
- BGE - Vertical Characterization
- BGE - Hydrology
- Authorize Re-Start

Note: Critical Path Elements
Sanford Laboratory Science Research Groups and Efforts

**Physics**
- **LUX-350** – Dark Matter
- **MAJORANA DEMONSTRATOR** – 0νββ
- **CUBED** – Crystal growth
- Bkgd Characterization – μ, n, γ, Rn
- Vertical Facility – Magnetic field

**Biology**
- Microbiology – Bang, Anderson
- Lignocellulose – Bleakley
- Manifold Sampling – Onstott, Pfiffner
- Microbiology – Sani

**Geology**
- CO₂ Sequestration – Environment
- DUGL – Seismic characterization
- Fiber Sensors – Ext, Temp
- Hydrology – SDSMT/Sanford/DUSEL
- PODS – Geology (pet, ore dep, structure)
- Tiltmeter – Water, Budker arrays
- Transparent Earth – Seismic

**Engineering**
- Signal Prop – Anagnostou
- DUSEL Design Teams - Multiple

**Others**
- Cummingtonite – Geology (Berman)
- THMCB – Geology (DUSEL S4)
- Vertical Array – Geology (Dahlgren)
- Submersible – Engineering (McGough)

Total Active = ~18 groups (plus others)

Slide Adapted from Jaret Heise

Homestake DUSEL
Physics Users at Sanford Lab: **MAJORANA DEMONSTRATOR (0νββ)**

- **Leadership:**
  - Wilkerson (UNC) CPM, Elliott (LANL) Spokesman

- **Collaboration:**
  - ~93 researchers (including students)
  - 18 institutions + Sanford Lab

- **Milestones:**
  - Jun/Aug 09: Pb, Cu onsite
  - Dec 09: TCR work begins
  - Sep 10: Electroforming begins
  - Aug 11: Bene. Occ. Davis Campus

- **Implementation:**
  - **EHS:** Hazard = ORNL, waste, developing training matrix, NEPA
  - **DOE Pre-Readiness:** Oct 2009 (TCSM)
  - **Readiness Review:** Jan 2010
  - **DOE CD1-like Review:** May 2010
  - **MOU:** Signed May 11, 2010
  - **Insurance:** Evidence from ORNL

---

**Initial Occupancy Ross Shops area 4850L**

---

*Slide Adapted from Jaret Heise*
Physics Users at Sanford Lab: Large Underground Xenon (LUX-350)

- PIs:
  - Gaitskell (Brown), Shutt (Case)
- Collaboration:
  - ~52 researchers (including students)
  - 10 institutions + Sanford Lab
- Milestones:
  - Sep 09: Grad student onsite
  - Dec 09: Surface Lab activity
  - Aug 10: Detector operations
  - Aug 11: Davis Campus
- Implementation:
  - EHS: Hazard = LLNL, review Mar 2010, training matrix/OSHA
  - Pre-Readiness: Dec 2008
  - Readiness Review: Aug 2010
  - MOU: Being Developed
  - Insurance: Not determined

Adapted from Jaret Heise
The Sanford Laboratory: Davis Campus to Support Majorana Demonstrator and LUX

4850L

Davis Cavity

New 130 x 50 ft hall
Preparing for FY 11

• On May 6 the Congressional Delegations from South Dakota, California and Illinois requested a Briefing from OSTP, NSF & DOE

• FY11 Funding for DUSEL and continued good interagency cooperation were discussed at length during the Briefing

• Based on this briefing the Project remains confident that the NSF will work with OMB & OSTP to obtain an adequate level of funding in FY11 and understand of the Project needs beyond this period

• Following recommendations from the February and April 2010 NSF Reviews the Project has prepared a proposal to provide bridge funding between April 2011 - May 2012

• The proposal will fund continued Project Team activities including 1) critical design activities, 2) continued experimental integration including the DOE’s LBNE efforts, and 3) ensure safe access underground for design and pumping activities
Summary - Advancing the Preliminary Design and Preliminary Facility Baseline

• Building the Health & Safety Program remains a highlighted focus for Project – facility maintenance and upgrades - plans and implementation – additional Health and Safety Personnel

• Aggressively advancing the Preliminary Design and Integrating activities – Project added Systems Engineering and Construction Management Contractors – Lab Design, Excavation Design, Surface Design Interim Reports Received, contracts continue on-schedule, developing 90% reconciled design – Significant progress in establishing good relationships with LBNE
  • Long-lead design
  • Facility requirements
  • Review and sharing of design information

• Project is on schedule for completing Preliminary Design Report in 2010
Neutrinoless Double-Beta Decay Experiments

Kevin Lesko for Ryan Martin and Jason Detwiler (Science Liaisons for Double-Beta Decay Experiments)

Homestake DUSEL
NSAC Summary

Homestake DUSEL
NSAC meeting,
July 30th 2010

Figure Courtesy PDG and LBNL
Neutrinoless Double-Beta Decay

Certain isotopes can undergo 2-neutrino double beta decay, a very rare process.

- Neutrinoless double beta decay would be even more rare and is only allowed if neutrinos are Majorana particles.
- Extremely good energy resolution is required to observe the $0\nu\beta\beta$ events.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Q(MeV)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{48}\text{Ca} \rightarrow ^{48}\text{Ti}$</td>
<td>4.271</td>
<td>0.187</td>
</tr>
<tr>
<td>$^{76}\text{Ge} \rightarrow ^{76}\text{Se}$</td>
<td>2.040</td>
<td>7.8</td>
</tr>
<tr>
<td>$^{82}\text{Se} \rightarrow ^{82}\text{Kr}$</td>
<td>2.995</td>
<td>9.2</td>
</tr>
<tr>
<td>$^{96}\text{Zr} \rightarrow ^{96}\text{Mo}$</td>
<td>3.350</td>
<td>2.8</td>
</tr>
<tr>
<td>$^{100}\text{Mo} \rightarrow ^{100}\text{Ru}$</td>
<td>3.034</td>
<td>9.6</td>
</tr>
<tr>
<td>$^{110}\text{Pd} \rightarrow ^{110}\text{Cd}$</td>
<td>2.013</td>
<td>11.8</td>
</tr>
<tr>
<td>$^{116}\text{Cd} \rightarrow ^{116}\text{Sn}$</td>
<td>2.802</td>
<td>7.5</td>
</tr>
<tr>
<td>$^{124}\text{Sn} \rightarrow ^{124}\text{Te}$</td>
<td>2.228</td>
<td>5.64</td>
</tr>
<tr>
<td>$^{130}\text{Te} \rightarrow ^{130}\text{Xe}$</td>
<td>2.533</td>
<td>34.5</td>
</tr>
<tr>
<td>$^{136}\text{Xe} \rightarrow ^{136}\text{Ba}$</td>
<td>2.479</td>
<td>8.9</td>
</tr>
<tr>
<td>$^{150}\text{Nd} \rightarrow ^{150}\text{Sm}$</td>
<td>3.367</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Isotopes, Q-values and natural abundances
Experimental sensitivity to $0^{\nu}\beta\beta$

Phase Space

$T_{1/2}^{0\nu} = \left( G^{0\nu} | M^{0\nu} |^2 \langle m_{\beta\beta} \rangle^2 \right)^{-1}$

Nuclear Matrix Element

$\langle m_{\beta\beta} \rangle \equiv U_{e1}^2 m_1 + U_{e2}^2 m_2 e^{i\phi_2}$

$+ U_{e3}^2 m_3 e^{i\phi_3}$

PMNS Matrix

Majorana Phases

Background rate

Energy resolution

$\langle m_{\beta\beta} \rangle \propto \left( \frac{b\Delta E}{M_{\text{live}}} \right)^{\frac{1}{4}}$ (sensitivity)

Active mass

Live-time

The half life for $2^{\nu}\beta\beta$ is of order $10^{20}$ years

A tonne scale experiment is required to probe $m_{\beta\beta}$ of order the atmospheric neutrino mass-squared difference

Background rates are critical in attaining a good sensitivity
Implications of observing $0\nu\beta\beta$ decay

- Neutrinos are, therefore, Majorana particles
- Lepton number is violated
- The scale of neutrino masses is determined
- The hierarchy of neutrino masses may be determined

With these conclusions, one would gain substantial insight into understanding neutrino masses (eg. see-saw mechanism for Majorana neutrinos) 
Through lepton number violation, one could explain the matter/anti-matter asymmetry of the Universe using leptogenesis
Experiments Overview

- Two experiments are being proposed at DUSEL and have S4 funding (other R&D efforts as well):
  
  - The **1TGe Experiment** will look for $0\nu\beta\beta$ in approximately 1 tonne of Germanium (enriched in $^{76}\text{Ge}$)
  
  - Technologies are being explored/demonstrated by the MAJORANA DEMONSTRATOR and GERDA collaborations

  - The **Enriched Xenon Observatory (EXO)** will look for $0\nu\beta\beta$ in 1-10 tonnes of liquid or gaseous Xenon (enriched in $^{136}\text{Xe}$)

  - Technologies are being explored/demonstrated by the EXO-200 and EXO-Gas projects
The 1TGe Experiment

- Two different approaches being investigated by MAJORANA and GERDA
- Ton-scale version will combine the best features of the two experiments

**The GERDA experiment in LNGS:**
- Cryostat is stainless steel with copper plate shielding around Ge
- Will use up to ~35kg of enriched Ge s immersed in Liquid Argon (LAr) shielding + water tank
- Operate between 2010-2014

**The MAJORANA DEMONSTRATOR in Sanford lab:**
- 2 Cryostats made of electroformed copper, in conventional shielding
- Will use up to 40kg of Ge (20kg enriched)
- Operate between 2011-2014
The EXO Experiment

**EXO-200 LXe** low-background TPC with APD readout; currently being deployed at WIPP (2010-2013) - expected to measure the $2\nu\beta\beta$ mode for the 1st time

Design of high-pressure **GXe** test-bed detector: electroluminescence light readout with photocathodes and electron gas amplification

The ton-scale experiment will involve **Ba-tagging** to significantly remove backgrounds. Ba-tagging research is underway in parallel with EXO-200
Obtaining Requirements

- Requirements from the experiments have been collected via regular phone calls and face to face meetings.
- DUSEL has defined a schedule for obtaining required deliverables that the experiments have followed.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>DUSEL Science</th>
<th>DUSEL Engineering</th>
<th>Experiment Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>1TGe</td>
<td>Ryan Martin</td>
<td>Bob Altes</td>
<td>David Steele (LANL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Matthew Busch (TUNL, Engineer)</td>
</tr>
<tr>
<td>EXO</td>
<td>Jason Detwiler</td>
<td>Bob Altes</td>
<td>Giorgio Gratta (Stanford)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>John Ku (SLAC, Engineer)</td>
</tr>
</tbody>
</table>

Points of contact
**Document Summary**

- Summary of documentation that has been provided to DUSEL in Docushare

<table>
<thead>
<tr>
<th>Document</th>
<th>1TGe</th>
<th>EXO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science Goals</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Layout</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Depth Requirements</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Infrastructure requirements database (utilities, EH&amp;S)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cost and Schedule</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>S4 Proposal</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Layout for Cu/Pb Shield 1TGe

- Layout is on 2 levels; does not fit in 7400L experimental installation envelope (too long)
- Current design assumes they provide their own assembly space, as well as break room, gowning and bathroom – sharing some of these with another experiment would shrink the layout’s length
The Cu/Pb version of 1TGe will require large amounts of electroformed copper (shield and cryostats use the most)

The process will require space at 4850:

- **Electroforming lab** (14mx9mx3m) will fit in the current MAJORANA DEMONSTRATOR electroforming lab, need to add 4 larger baths to the existing 16 (20 total)

- **Cleaning and passivation lab** (6mx10mx3m), will re-use the MAJORANA DEMONSTRATOR facility

- **Machine shop** (12mx5mx3m), will need some new space for 1-2 larger machine tools and welding facility
Layout for LAr-style 1TGe

- Layout is on 3 levels
- Current design does not fit in module – the water tank requires “bulges” in side walls as well as a 2m excavation (15m diameter, 14.5m tall)
- On-going R&D will determine if tank can be smaller (worst case scenario shown)
• EXO’s preferred layout for detector + support building
• Does not fit in 7400L lab module (requires ~4m excavation + ~2m widening on each side)
Both experiments have submitted documents requesting to be at the 7400 level.

In both cases, the argument is made that the risk of fast neutron backgrounds at 4850 is high.

The R&D of the ongoing smaller scale experiments will help to quantify the risks better.
• Investigate assembly challenges for a real case

**Transport Modes**
- Lifts, winze, and ramps
- Planned load designs
- Number of trips required
  → Ramp transport would dramatically reduce the number of trips (243 → 85)

**Assembly**
- Process Planning
- Tooling and Fixtures
- Staging
- Rigging
- Weld fabrication methods
- Cleanliness issues

**Safety**
- Trade-related
- Confined space issues
- Temporary structures / rigging
Outlook

• Both experiments are in the process of vetting their proposed technologies which will determine the final implementations of their design (~2014-15)

• DUSEL is actively working with them to review and iterate on the information to refine the PDR

• So far, both experiments are proposing layouts that require a slight increase in the 7400 lab module size
International DIANA Collaboration has been growing steadily over the last three years

**DIANA Collaboration:**
- **Michael Wiescher (U. Notre Dame) PI**
- **Matthaeus Leitner (LBNL) Project Manager**
- Arthur Champagne (U. North Carolina)
- Philippe Collon (U. Notre Dame)
- Manoel Couder (U. Notre Dame)
- Michael Famiano (West Michigan U.)
- Frederick Gray (Regis U.)
- Uwe Greife (Colorado School of Mines)
- Christian Iliadis (U. North Carolina)
- Daniela Leitner (LBNL)
- Alberto Lemut (LBNL)
- Edward Stech (U. Notre Dame)
- Paul Vetter (LBNL)

**New team members (since 2010):**
- Maria Luisa Aliotta (U. Edinburgh, UK)
- Frank Strieder (RU Bochum, Germany)
- Lucio Gialanella (Federico II Naples, Italy)
- Gianluca Imbriani (Federico II Naples, Italy)

several graduate & undergraduate students associated with the project

Communication with LUNA & Canfranc as well as Felsenkeller team in Dresden

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S-4 Review 2010
Washington, DC
July 12-15, 2010
Astrophysics Underground Accelerator DIANA
Addresses two key questions identified in the nuclear science long range plan

• What is the origin of the elements in the cosmos?

• What are the nuclear reactions that drive stars and stellar explosions?

NP long range plan identifies a opportunity for a DIANA type facility at DUSEL:

‘The direct measurement of reaction rates on stable nuclei that require high-intensity beams, and are needed to model stars and novae, also presents enormous challenges. The largest handicap is the small cross section coupled with large natural background, which prohibits the detection of the characteristic reaction signals. The use of underground based low-energy accelerator facilities, as demonstrated by LUNA at the European Gran Sasso underground laboratory, significantly reduces cosmic-ray-induced background by several orders of magnitude. This approach is complemented by the development of active background-reduction techniques based on event identification or inverse kinematic techniques to reduce the natural radiation and beam induced background. DUSEL will provide an opportunity for the development of such a facility in the United States.’
Scientific Motivation

Stellar Neutrino Sources in the sun & massive stars
- Probe the properties of the sun (standard solar model, core temperatures, metallicity)
- Provide necessary precision cross section data for the next generation neutrino detectors.

Origin of the Elements in early & present Universe
- Neutron Sources
- Heavy Ion burning
Why going underground?

For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!

S-4 Review 2010
Why going underground?

For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!

S-4 Review 2010
Why going underground?

For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!
DIANA facility is a next generation facility that will support a vibrant 30 year+ science program

Two coupled accelerators allow consistent measurements of resonant structures and expand the physics program to helium burning reactions and late stellar evolution reaction.

**Hydrogen Burning**
- $^3\text{He}(\alpha,\gamma)^7\text{Be}$
- $^2\text{H}(\alpha,\gamma)^6\text{Li}$
- $^3\text{He}(^3\text{He},2p)^4\text{He}$
- $^7\text{Be}(p,\gamma)^8\text{B}$
- $^{12}\text{C}(p,\gamma)^{13}\text{N}$
- $^{14}\text{N}(p,\gamma)^{15}\text{O}$
- $^{15}\text{N}(p,\gamma),(p,\alpha)^{16}\text{O},^{12}\text{C}$
- $^{17}\text{O}(p,\gamma),(p,\alpha)^{18}\text{F},^{14}\text{N}$
- $^{18}\text{O}(p,\gamma),(p,\alpha)^{19}\text{F},^{15}\text{N}$
- $^{19}\text{F}(p,\gamma),(p,\alpha)^{20}\text{Ne},^{16}\text{O}$

**Helium Burning**
- $^{12}\text{C}(\alpha,\gamma)^{16}\text{O}$
- $^{16}\text{O}(\alpha,\gamma)^{20}\text{Ne}$
- $^{20}\text{Ne}(\alpha,\gamma)^{24}\text{Mg}$
- $^{18}\text{O}(\alpha,\gamma)^{22}\text{Ne}$
- $^{22}\text{Ne}(\alpha,\gamma)^{26}\text{Mg}$
- $^{24}\text{Mg}(\alpha,\gamma)^{28}\text{Si}$
- $^{13}\text{C}(\alpha,n)^{16}\text{O}$
- $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$
- $^{25}\text{Mg}(\alpha,n)^{28}\text{Si}$
- $^{26}\text{Mg}(\alpha,n)^{29}\text{Si}$

**Neutron sources**
- $^{13}\text{C}(\alpha,n)^{16}\text{O}$
- $^{22}\text{Ne}(\alpha,n)^{25}\text{Mg}$
- $^{25}\text{Mg}(\alpha,n)^{28}\text{Si}$
- $^{26}\text{Mg}(\alpha,n)^{29}\text{Si}$

**Heavy Ion Burning**
- $^{12}\text{C}^{+^{12}}\text{C}$
- $^{12}\text{C}^{+^{16}}\text{O}$
- $^{16}\text{O}^{+^{16}}\text{O}$
- $^{17}\text{O}(\alpha,n)^{20}\text{Ne}$
- $^{28}\text{Si}(\alpha,\gamma)^{32}\text{S}$
- ...
The two coupled accelerators cover a wide range of ion beam energies and intensities for consistent cross section measurements with identical target and detector set-up.
LOW ENERGY ACCELERATOR AND TARGET STATION

ION SOURCE
50 kV BEAM EXTRACTION GAP
50 kV BEAM EXTRACTION GAP
MAIN ACCELERATION COLUMN (0 TO 400 kV)
ANALYZING MAGNET
1 TESLA FOCUSING SOLENOIDS
HIGH DENSITY GAS JET TARGET
HIGH VOLTAGE PLATFORM

Milestone 12/30/2010
Ion optics completed
Low Energy Accelerator Challenges and R&D items

Unique Features

- high intensity from 50kV-400kV (up to 100 mA proton and 20 mA helium beam)
- beam focus < 1 cm
- energy Distribution: +/- 0.05 % of beam energy
- unique high density jet gas target
- coupled target with the high energy accelerator
- open-air high voltage platform for easy access

Unique Challenges

- preserving the beam properties on target over the whole energy range at high beam intensities
- beam diagnostics
- beam energy stabilization
- jet gas target design
- beam dump design

Up to 2 orders of magnitude higher beam current than presently available at state of the art facilities (to address the low count rates close to the Gamow window energies.)
Technical Progress: Low energy beam optics and design

By adjusting the accelerator gap lengths and the focusing strength in the solenoids the beam diameter on target is less than 6mm on target over the whole energy range. Further optimization and integration with target and diagnostics is in progress.
High Energy Accelerator And Target Stations

Commercial accelerator with some unique features:

- High intensity from 350kV to 3MV (≥ 1mA)
- Coupled targets with the low energy accelerator
- 2 independent target station for simultaneous experiments and future expansion

The high energy accelerator allows consistent measurements of resonant structures and expands the physics program to helium burning reactions and late stellar evolution reaction
Technical Progress: High energy ion beam optics

16 identical Quadrupoles (8 duplets)  
3 Dipole magnets

Image slits of the high energy accelerator (energy stabilization)

High energy gas jet target

Solid target/extended gas target

Coupled low and high energy gas jet target

Milestone 12/30/2010  Ion optics completed
Integration into DUSEL

Interface with Facility
• All the requirements for the DUSEL baseline definition for DIANA have been gathered (power, weights, utilities, surface and underground spaces, shielding, occupancy, EH&S)
• Strong ties with the DUSEL facility teams have been established
• Unique experimental facility, will ensure US leadership in this area
• Next generation facility that ties low and high energy data consistently together, 30 year+ science program
• Will deliver precision data needed for astrophysics modeling
• Growing international collaboration
• Technical progress is on track
• Low energy commissioning 2015
• DIANA will be ready for installation in 2017 (as soon as Lab module is available)