DUSEL Experiment Development and Coordination (DEDC)

Internal Design Review

July 16-18, 2008

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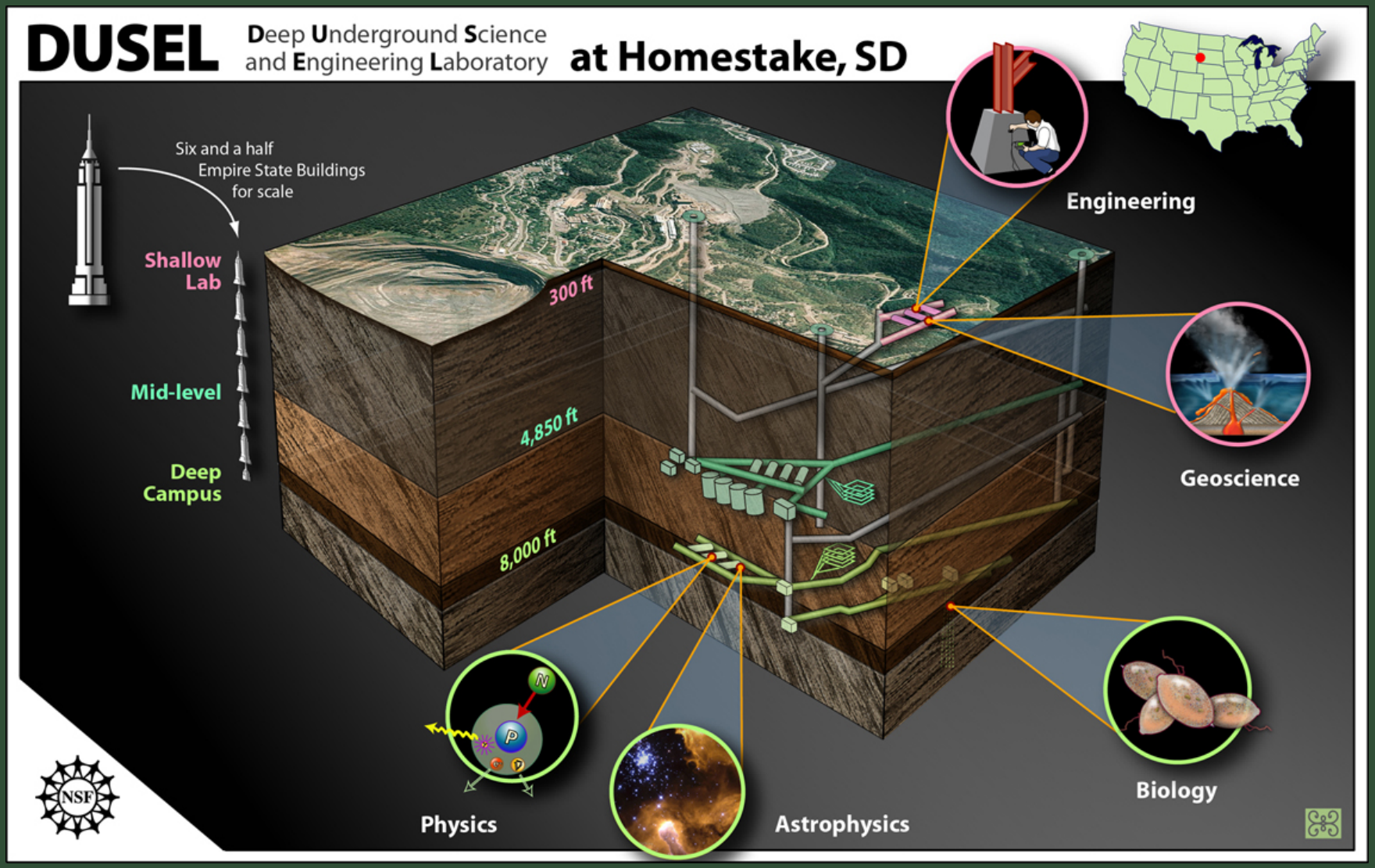


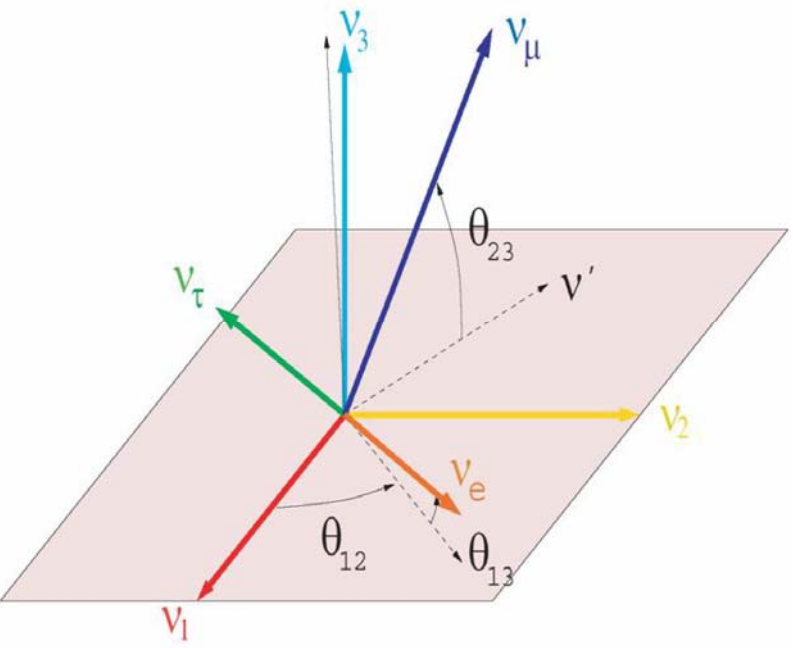
Physics Experiments at DUSEL

- Long Baseline Neutrino Beam/Nucleon Decay
- Dark Matter
- Neutrino-less Double Beta Decay
- Solar Neutrinos
- Nuclear Astrophysics
- Energetic particle effects

Exploratory programs

- Gravity Waves
- 1- km Vertical Space

Three Neutrino Picture



The physical neutrino eg. ν_μ is a mixture of eigenstates such that:

$$\nu_\mu = U_{\mu 1}\nu_1 + U_{\mu 2}\nu_2 + U_{\mu 3}\nu_3 \quad \text{etc.}$$

Flavor States — MNS Maki-Nakagawa-Sakata mixing matrix — Mass eigenstates

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

3 independent parameters
+ 1 complex phase
θ_{12}, θ_{23}, θ_{13}, δ

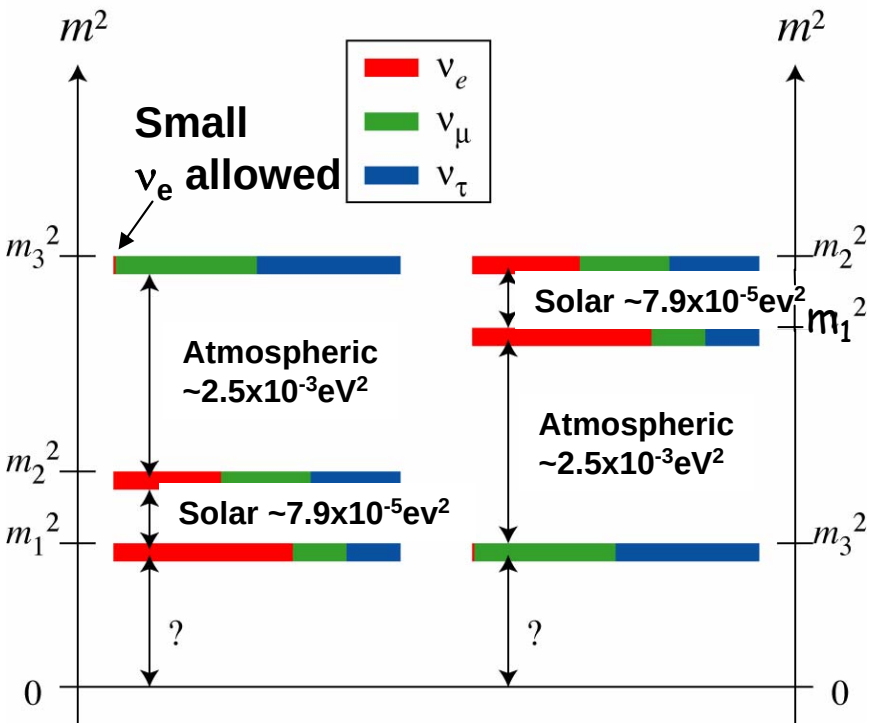
Remaining Questions

LB-L

- Mass hierarchy?
- How small is θ_{13}?
- CP Violation?

ββ

- Absolute mass scale?
- Dirac or Majorana?



Neutrino Beam From Fermilab
(Strongly indorsed by P5)

Long Baseline Physics Program
Why DUSEL?

Can probe remaining unknown neutrino parameters.

- Neutrino interactions in the Earth probe the hierarchy.

  Need long travel distance

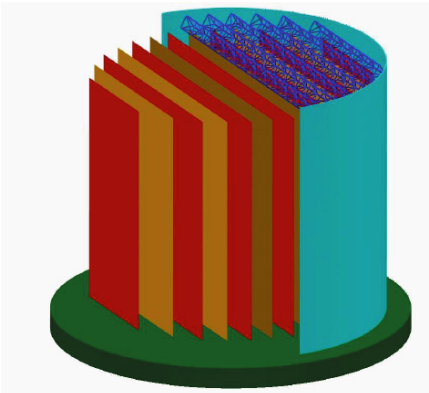
  1300 km distance offers a ***significant improvement.***
- CP violation may be observable with intense neutrino and anti-neutrino beams.
  - **CP violation may explain matter/anti-matter asymmetry of the Universe**

  Rates are low, need very large detectors.
- Large detectors and great depth allows additional rich physics program.

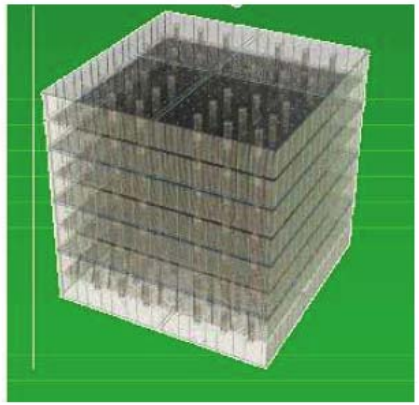
  Nucleon decay, Relic supernovae detection, Solar neutrinos

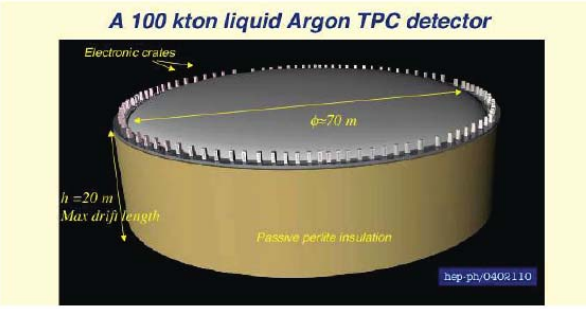
Water Cherenkov/Liquid Argon

LArTPC: Modularized drift regions in one large (10-50kton) tank (un-evacuated)



LAANDD: modular cubic evacuated

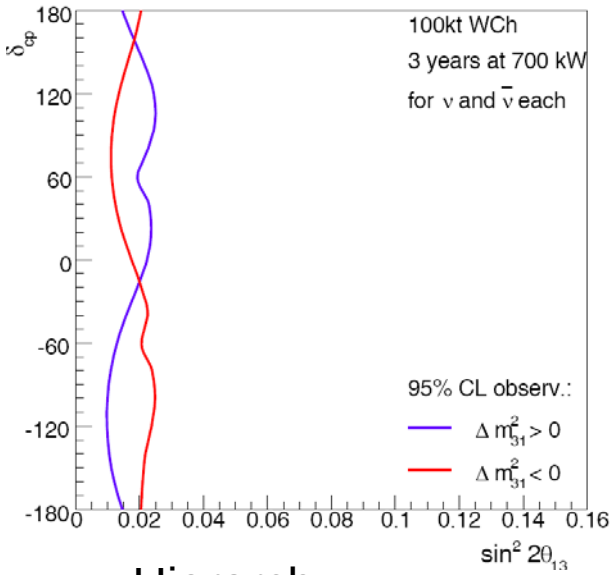




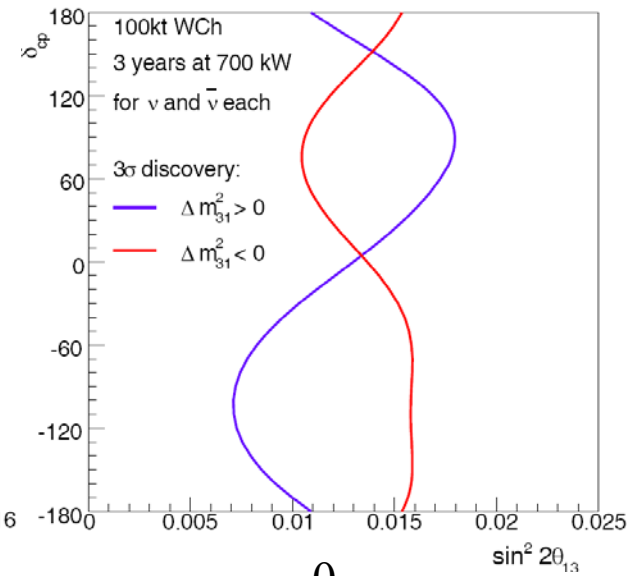
GLACIER: Combination of charge and light collection, single large drift area

- Scale existing water detector up to >100kt modules
- Initial Argon proposal is for 5kt
- Staged approach investigating development issues
  - Triggering, purification, TPC design, vessel design, electronics, depth

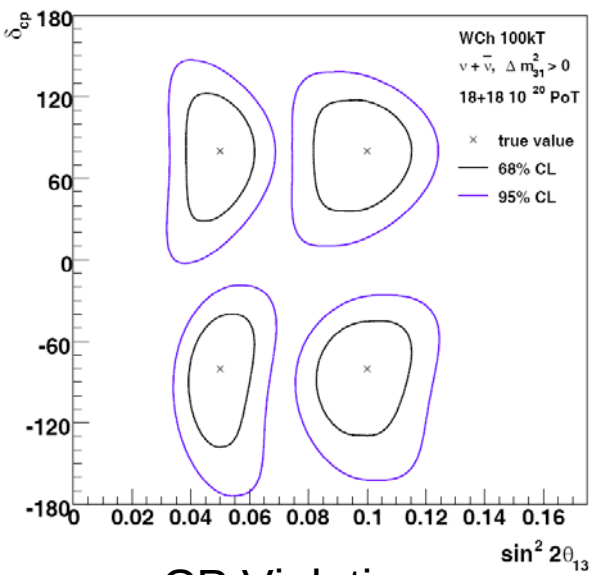
Sensitivity



Hierarchy



θ_{13}



CP Violation

Initial sensitivity of 100 kt water detector

The DUSEL 100kt detector is almost an order of magnitude better than NOνA for mass hierarchy determination for same running.

Additionally, High Precision (~1%) Measurement of $Sin^2 2\theta_{23}$, δm^2_{23} with Muon CC Events

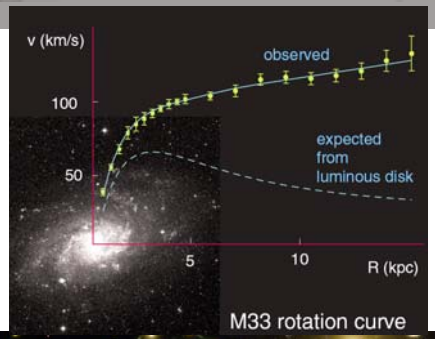
S-4 Issues / Facility Needs

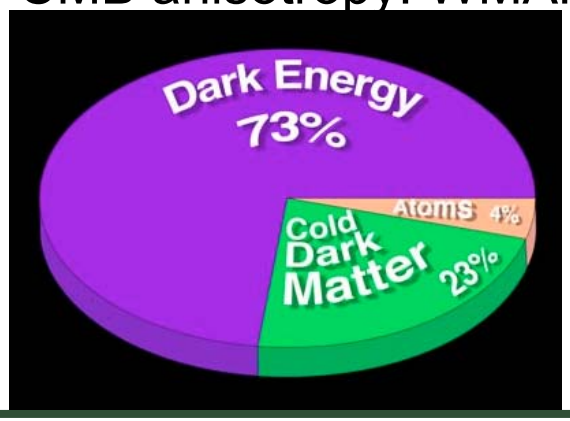
- Most important is identifiable rock mass for excavation. This information drives the designs. Need coring & engineering.
- For LAr:
  - Risk analysis for underground siting.
  - Ventilation
  - Controlled release studies
  - Freeze-thaw mitigation
  - Egress plan
  - Vessel/cavern configuration
- For Water:
  - Shape and size optimization
  - Geo-textile design
  - PMT size/number optimization
  - PMT pressure testing
  - PMT mounting
- Top down power estimate for water detector- First module: 50,000 channels at 10 W/channel, plus 40% for HVAC and 20% other power, for total of 840kW.

The Direct Detection of Dark Matter

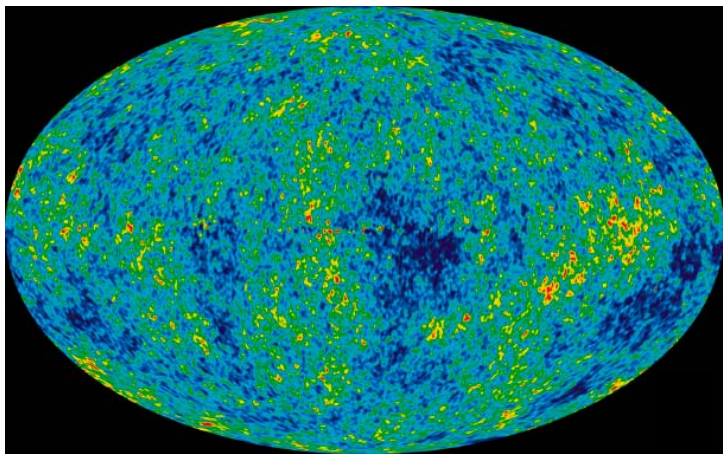
Breakthroughs in cosmology have transformed our understanding of the Universe.

- Spiral galaxies
  - rotation curves
- Clusters & Superclusters
  - Weak gravitational lensing
  - Strong gravitational lensing
  - Galaxy velocities
  - X rays
- Large scale structure
  - Structure formation
- CMB anisotropy: WMAP





Evidence for Dark matter now overwhelming – amount becoming precisely known



Despite this progress, the identity of dark matter remains a mystery

- Constraints on dark matter properties ⇨ the bulk of dark matter cannot be any of the known particles.
  - One of the strongest pieces of evidence that the current theory of fundamental particles and forces, is incomplete.
- Because dark matter is the dominant form of matter in the Universe, an understanding of its properties is essential to attempts to determine how galaxies formed and how the Universe evolved.
  - Dark matter therefore plays a central role in both particle physics and cosmology, and the discovery of the identity of dark matter is among the most important goals in basic science today.

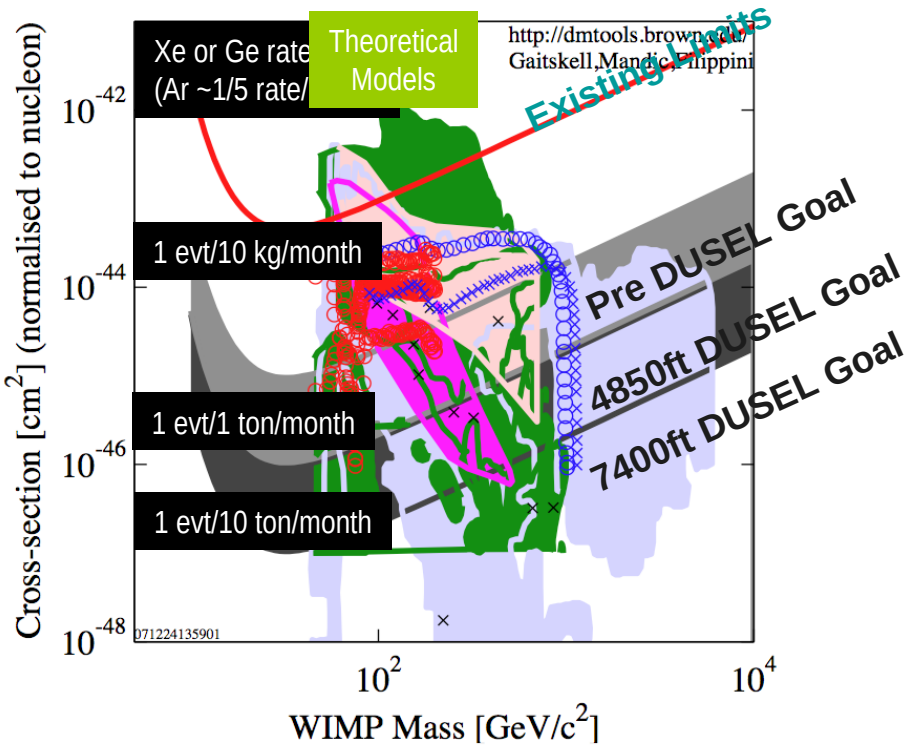
Experimental Challenges

In many supersymmetric models, the lightest supersymmetric particle is, stable, neutral, weakly-interacting, mass ~ 100 GeV. All the right properties for WIMP dark matter!

The WIMP "signal" is a low energy (10-100 keV) nuclear recoil.

Overall expected rate is very small

- Large low-threshold detector to discriminate against various background
  - WIMPs and neutrons scatter off nuclei.
  - Photons scatter off electrons.
- Minimize radioactive contamination.
- Minimize external incoming radiation.
  - **Deep underground location**



Dark Matter Working Group (DMWG)

Co-Chairs: Akerib, Gaitskell + Sadoulet

For list of groups associated with each experiment see presentations posted at http://dmtools.brown.edu/DMWiki/index.php/DMWG_DUSEL_Lead_Meeting_080424

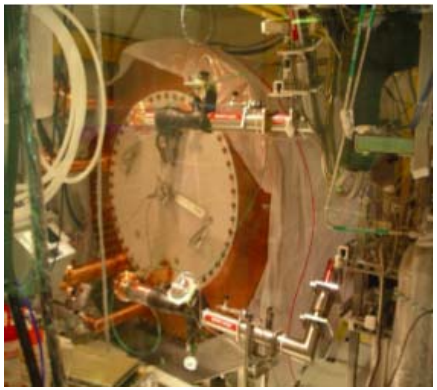
Candidate Experiments

LUX/ZEPLIN	4850	20 tonne liquid Xe TPC
SuperXENON	4850	20 tonne liquid Xe TPC
CLEAN	4850	50 tonne liquid Ar or Ne
Depleted Argon TPC	4850	10 tonne Ar TPC
Low Temperature Ge	7400	1-2 tonne Ge
COUP	4850	Freon Bubble Chamber (Not S4, but may enter S5)
Gas - Hi Pressure & Low Pressure (Directional)	R&D 4850 TPC 7400	Not ISE, but require R&D space underground

Double Beta Decay

requires massive Majorana neutrinos

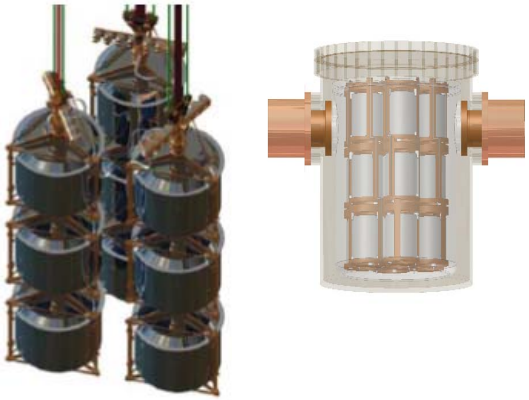
EXO



$$\Gamma_{0\nu} = G_{0\nu} \left| M_{0\nu} \right|^2 m_\nu^2$$

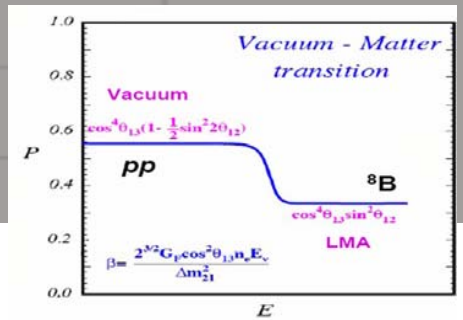
At least one neutrino has a mass >50 meV. These experiments will have a sensitivity below 50 meV.

1-tonne Ge



- **Two detectors proposed for DUSEL: EXO and GERDA/MAJORANA, which use isotopes of ^{136}Xe and ^{76}Ge with very different and complementary techniques. More than one experiment is required because:**
  - **backgrounds are different**
  - **possible gamma lines will not produce false detection in multiple isotopes**
  - **Nuclear matrix elements are different for different isotopes**
  - **The underlying physics of neutrinoless double beta decay can only be elucidated by studying more than one isotope**

Solar Neutrinos

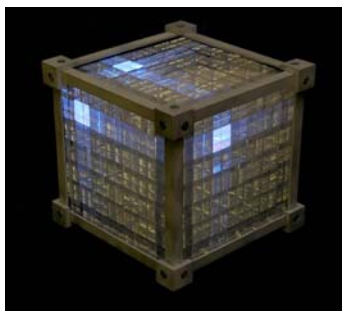


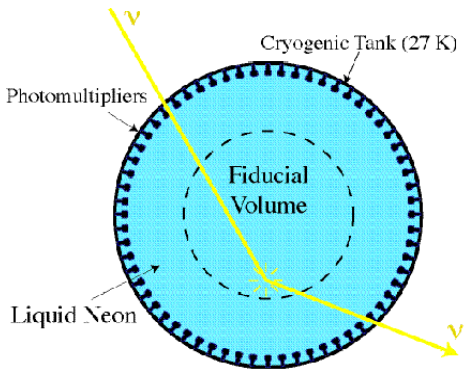
Is θ_{13} different from zero?
Time dependencies in the Sun's opacity or energy production?
Is there a subdominant energy source in the sun?
Is the MSW mechanism correct?
Do nuclear reactions fully account for the Sun's energy output today?

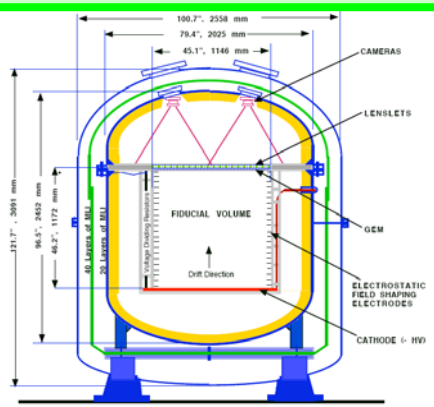
LENS
125 t Liquid scint.
10 t In
Scintillation readout
10 tons for CC study

CLEAN
Liquid Ne
Scintillation readout
10 tons for pp search

eBubble
40-atm Ne gas
Low-E track readout
S4 proposal for prototype
20 tons for pp search







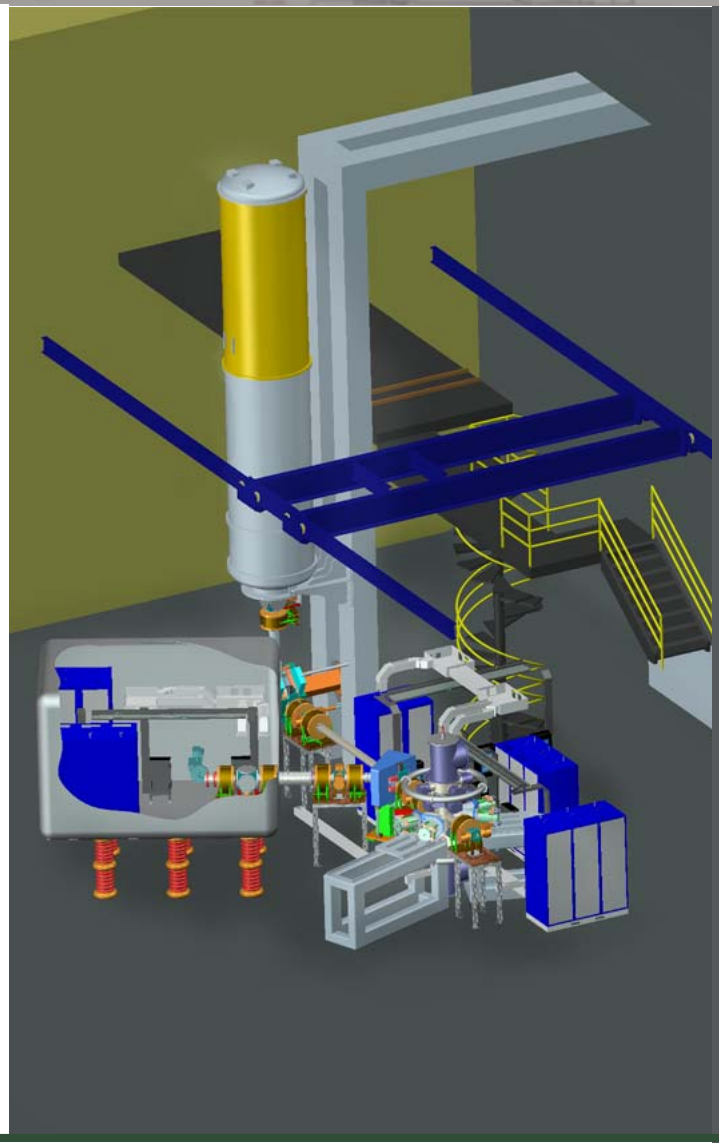
Accelerator Laboratory for Nuclear Astrophysics (ALNA)

Collaborators

Matthaeus Leitner	LBNL
Paul Vetter	LBNL
Peggy McMahan	LBNL
Daniela Leitner	LBNL
Damon Todd	LBNL
Ani Aprahamian	Notre Dame
Philippe Collon	Notre Dame
Manoel Couder	Notre Dame
Joachim Goerres	Notre Dame
Francesco Raiola	Notre Dame
Daniel Schuermann	Notre Dame
Ed Stech	Notre Dame
Michael Wiescher	Notre Dame
Xiao-Dong Tang	Notre Dame
Jose Alonso	Sanford Lab
Arthur Champagne	UNC
Claudio Ugalde	UNC
Michael Famiano	WMU
Peter Parker	Yale

International interest

Pietro Corvisiero	INFN Genova, IT
Paulo Prati	INFN Genova, IT
Heide Costantini	INFN Genova, IT
Lucio Gialanella	Naples, IT
Gianluca Imbriani	Naples, IT
Christina Bordenau	HH-NIPNE, RO



Two accelerators

400 kV CLAIRE
350 kV-3 MV
(Dynamitron, other option being studied)

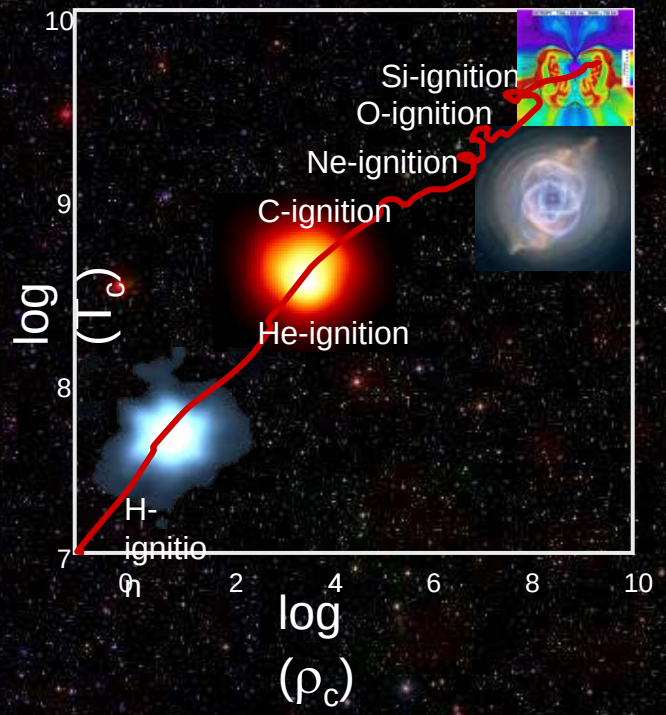
ECR ion source for extended energy range (1MeV/u)

Energy overlap allows to consistently measure cross section over a wide energy range and allow reliable extrapolations

Address a wide range of nucleosynthesis cross sections

Flexibility would make it a unique facility world wide

Science Stellar evolution, Origin of Elements, Stellar Neutrino Sources, Nucleosynthesis



Challenge: Reaction rates at stellar energy are tiny, Extrapolation carry substantial uncertainties

Underground
Shields cosmic ray backgrounds
Unprecedented beam intensities will allow to push level of accuracy

Proposed initial experiments

$^{3}He(\alpha,\gamma)^{7}Be$ stringent benchmark of the facility

- Constrain "invisible energy production"
- Constrain solar metallicity and temperature

Determines solar neutrino flux measured by current and proposed neutrino oscillation experiments

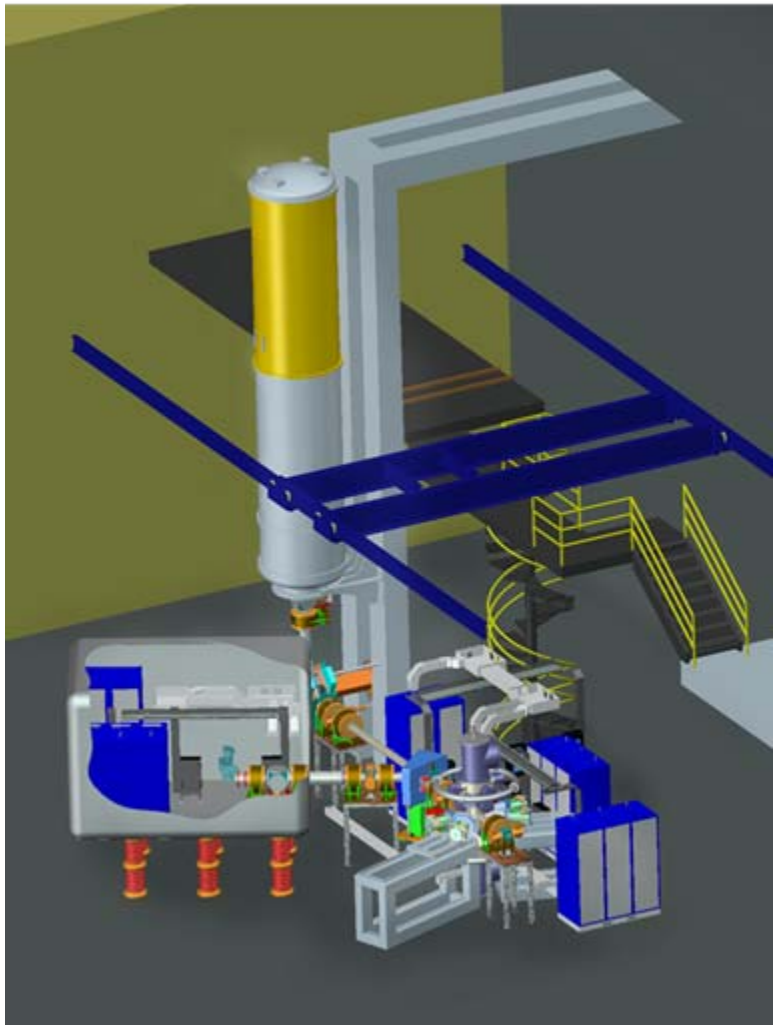
Neutron sources

Large uncertainty in s-process element production and subsequent nucleosynthesis

e.g. $^{22}Ne(\alpha,n)^{25}Mg$, $^{25}Mg(\alpha,n)^{28}Si$…

- Cannot be addressed in the LUNA facility

Astrophysics facility requirements

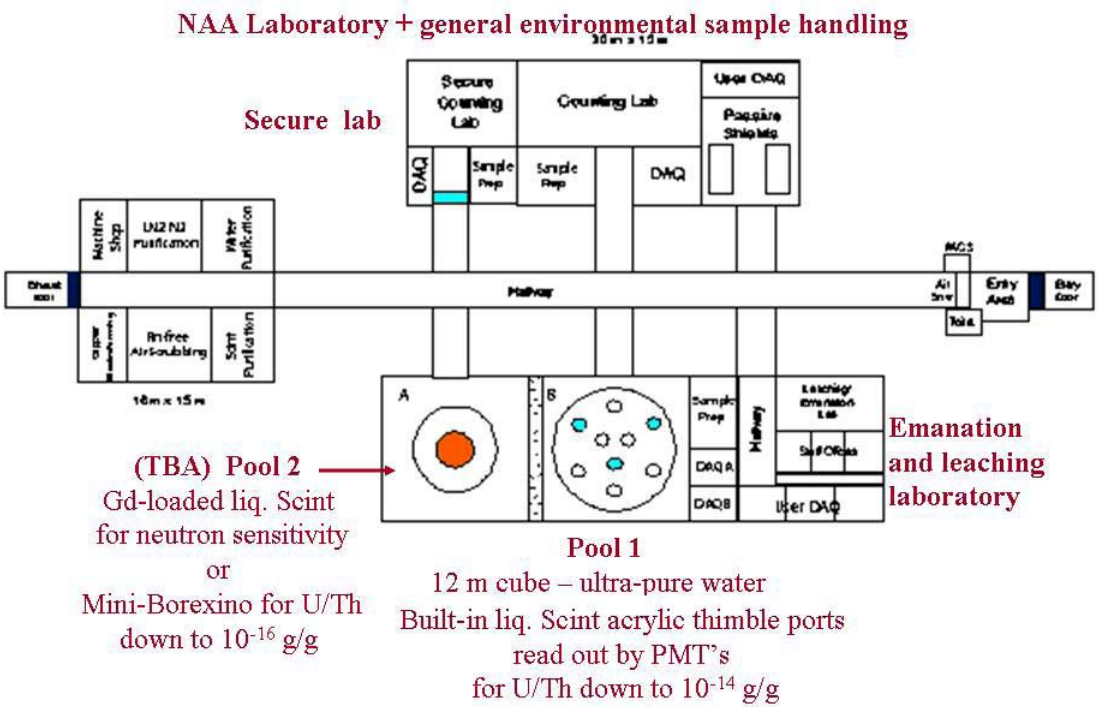


- **Facilities Underground (4850 ft level) Standard Experimental Cavity of 45x20x20m^3, low background rock, external shielding**
  - 2 Accelerators with energy overlap (50keV to 3MeV), auxiliary beams lines and power supplies
  - Experimental hall, control area, counting area
  - Target preparation and low background counting
- **Utilities**
  - Power estimate about 500 kW
  - SF_6 storage, LCW Cooling water, Cryogenic equipment/cryogenics
  - Climate control of the cave environment (humidity)
- **Above ground areas**
  - Machine shop area
  - Above ground office space and counting areas
  - Laboratory space for general use (experiment and target preparation, detector testing)

Science: Low Background Counting

A Dedicated Facility for the Assay, Control, and Production of Low Radioactivity Materials has been recognized as an essential shared task from the beginning of the DUSEL process.

Figure E-16 from the Homestake Reference Design



Facility will need to be defined and supported by the various experiments

S-4 Process will further define the facility

Exploratory ISE proposals 1km Vertical Space

Extensive feasibility studies are still to be done

- **Gravity Wave**
  Exploring 1-Hz region (outside the LIGO frequency band) of gravitational waves (merger of white dwarfs and massive black hole)
  - **Why Underground? Seismic noise and gravity gradient noise are among the major obstacles for reaching 1-Hz scale.**

Unique vertical Laboratory space

- **Evacuated tube required**
  - **NNbar Collaboration**
  - **Gravity waves by Atomic Interferometry**
  - **Mirror Matter Transition Search**
  - **Study of Diurnal Earth rotation**

- **1km Vertical Space (clean room and climate control required)**
  - **Facility for physics of Cloud Formation**

Final Thoughts – The Physics program is very rich and requires a deep underground laboratory

- DUSEL is a vital component of a continuing neutrino program.
  - The distance from Fermilab and the depth make for a world-leading program.
- The mega-tonne scale detector will significantly advance the search for nucleon decay and evidence for grand unification.
- Dark Matter experiments are growing larger and more sensitive. DUSEL depth, space and infrastructure are necessary components in this program.
- Double-beta decay experiments will be sensitive to the atmospheric neutrino mass scale.
- Solar neutrinos provide a unique window into the Sun.
- A Nuclear astrophysics underground accelerator experiment will help us to understand the origin of the elements.