Homestake DUSEL
Nuclear Science Advisory Committee

DUSEL Project Overview

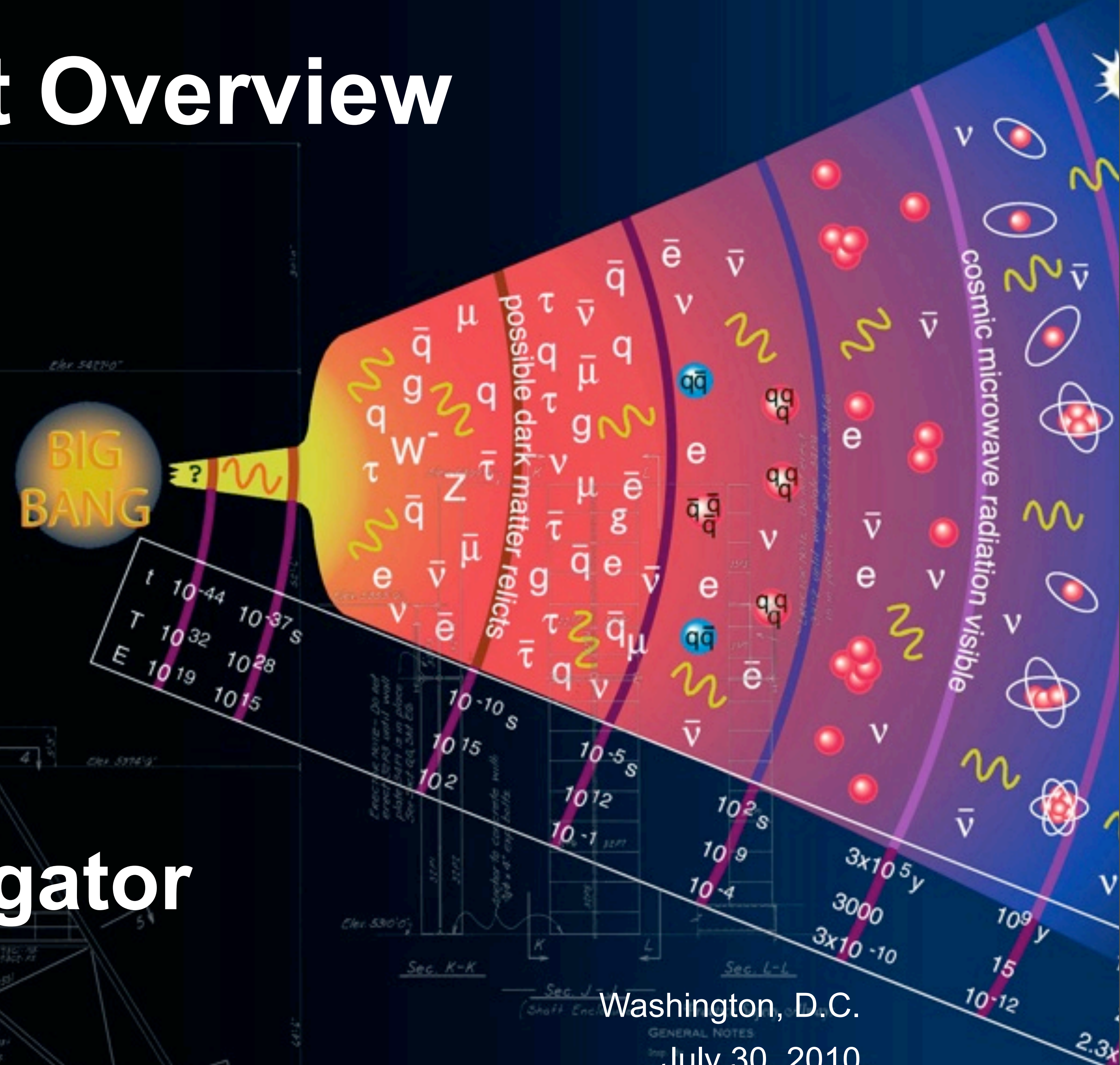
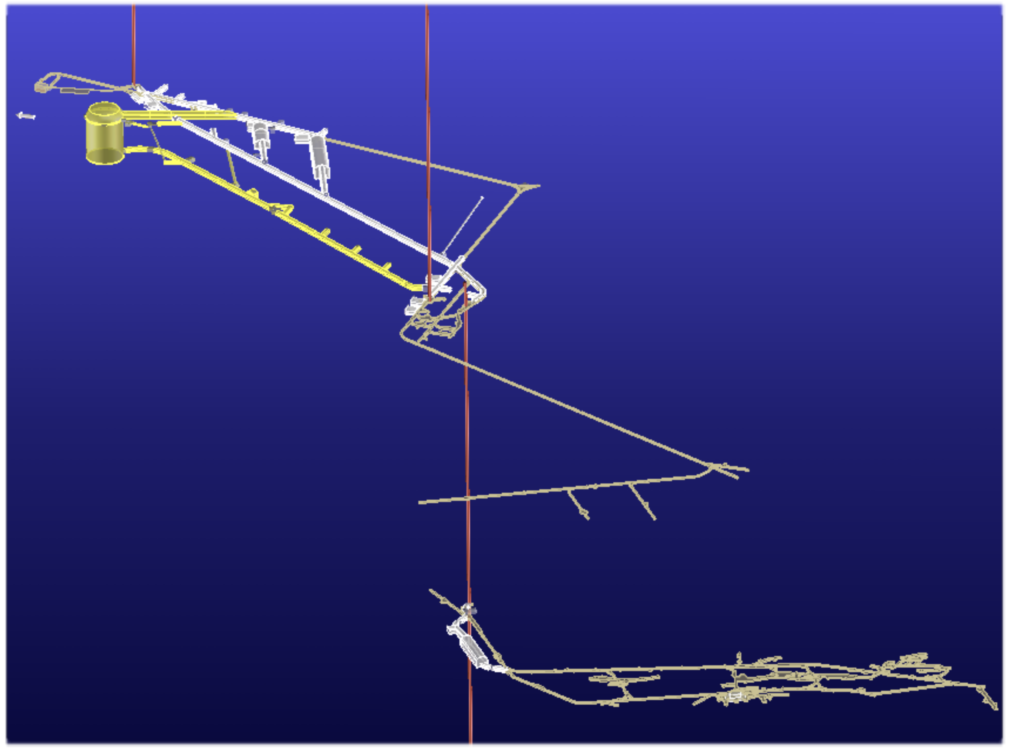


Figure Courtesy PDG and LBNL

Kevin T. Lesko
Principal Investigator

Washington, D.C.
July 30, 2010

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

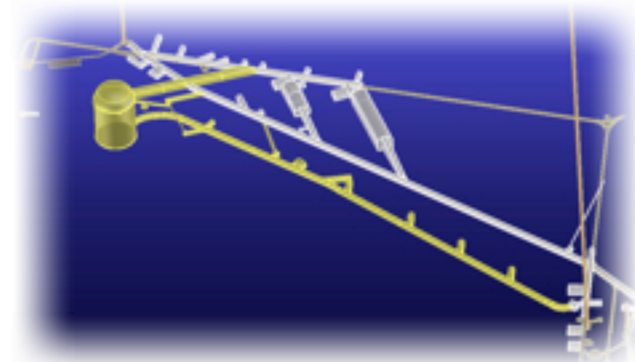
- Bahcall Committee Report 2001
- Nuclear Physics Long Range Plan 2002
- Connecting Quarks to the Cosmos
- HEPAP Long Range Plan 2003
- Neutrinos and Beyond
- EarthLab
- Physics of the Universe
- The Neutrino Matrix
- Earth Scope
- Discovering the Quantum Universe
- Deep Science
- Nuclear Physics Long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

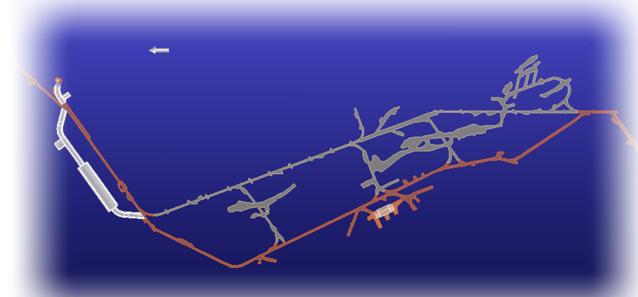
Why Are We Developing DUSEL?

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

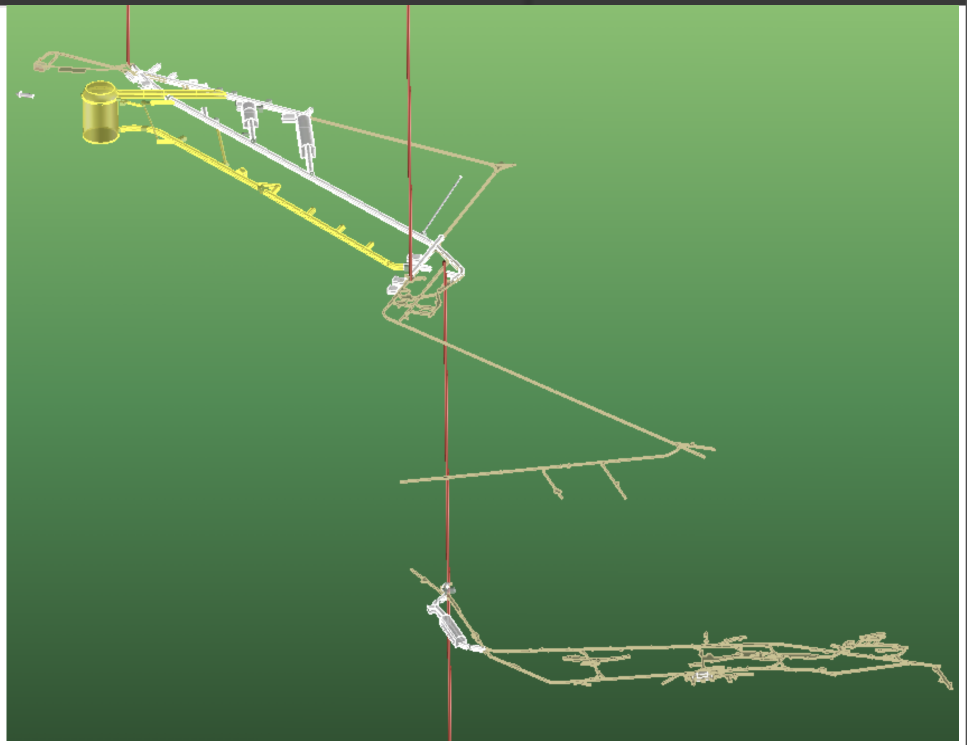
Reviewing the DUSEL Project





- 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 m^2/ 1100 m^2 total/assembly)
    - 4850L (~25,000 m^2 /10,000 m^2 total/science)
    - 7400L (~5000 m^2 /1800 m^2 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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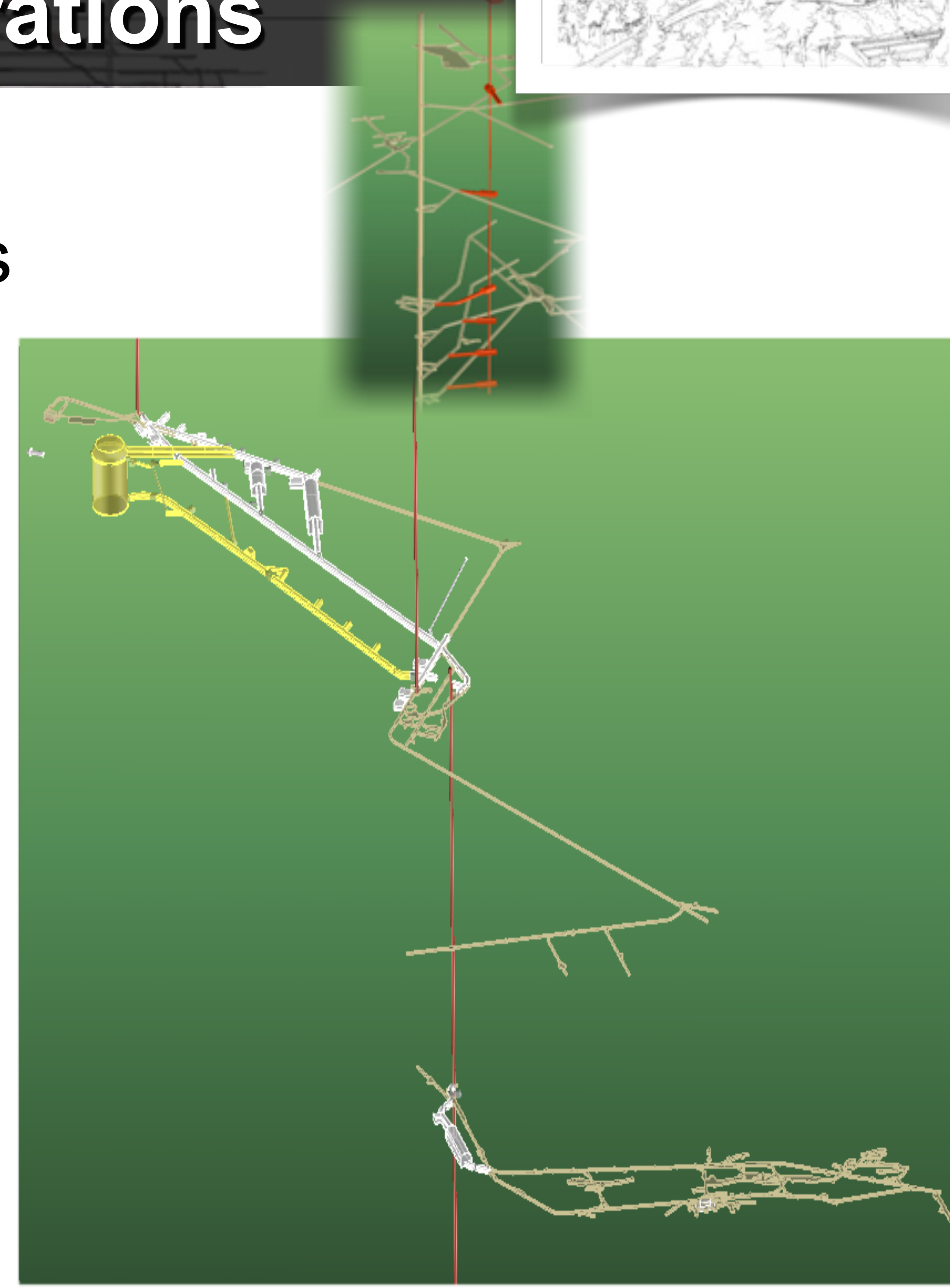

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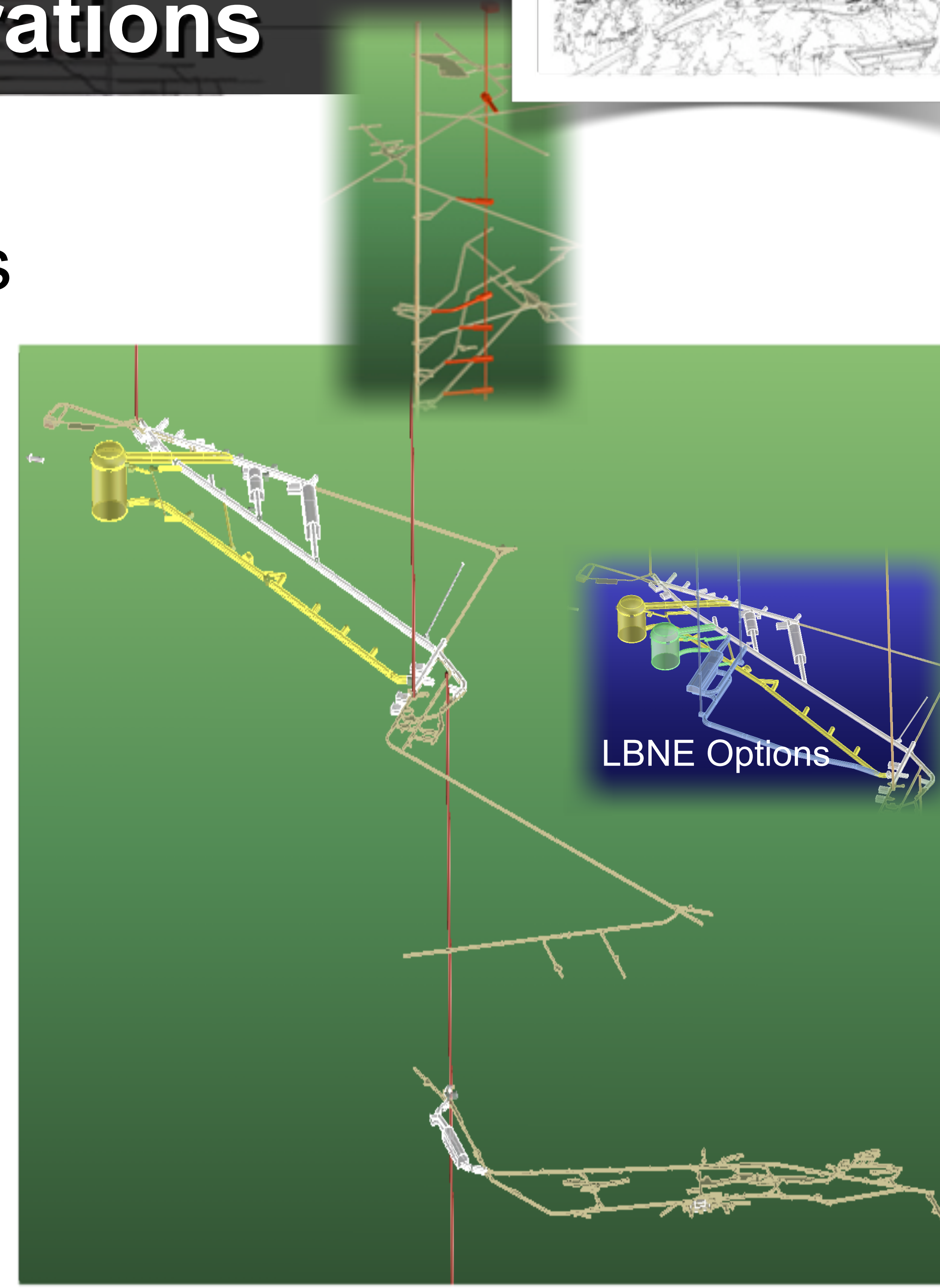

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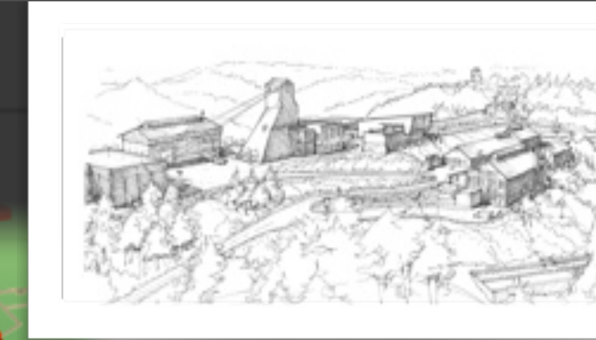

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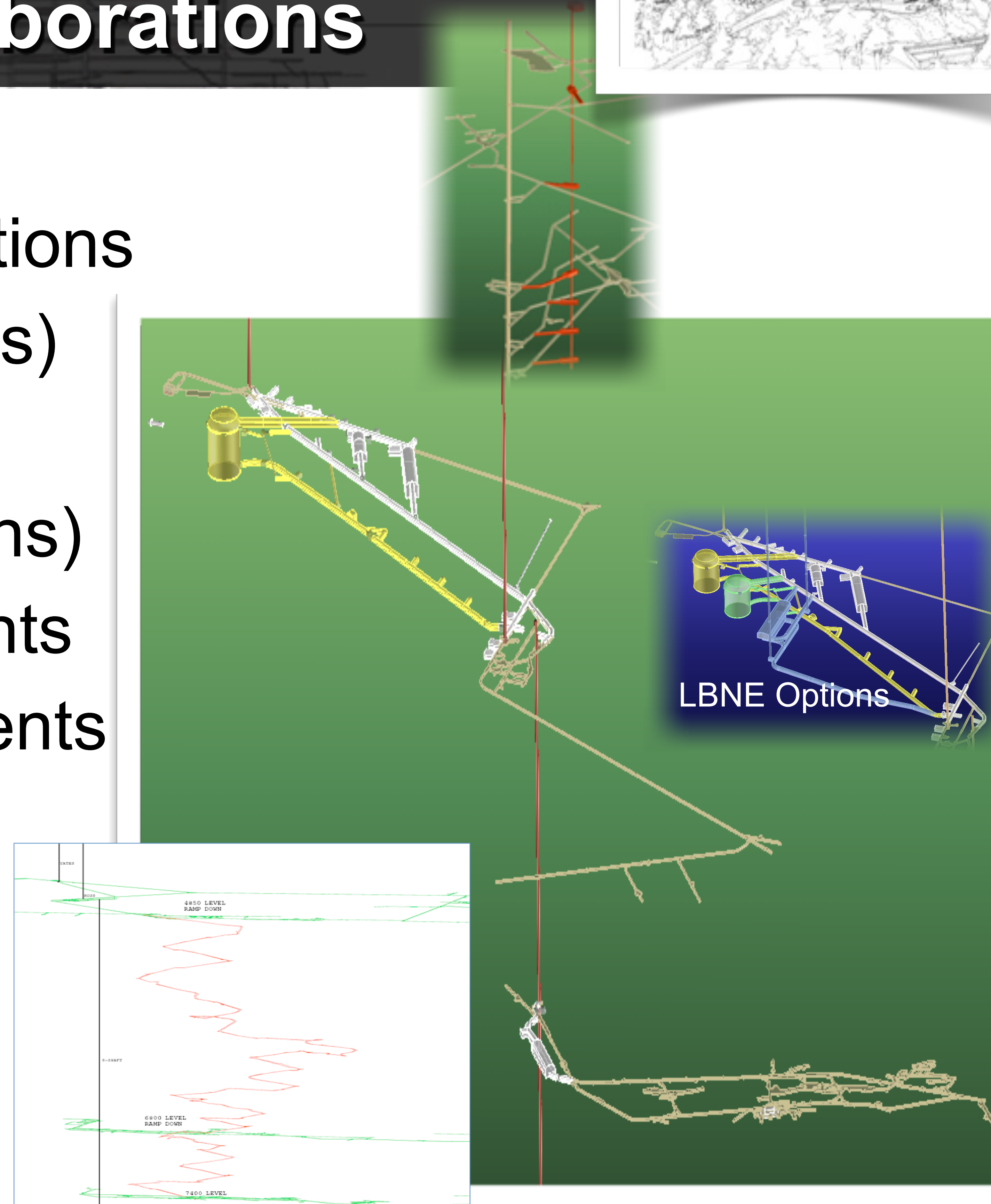


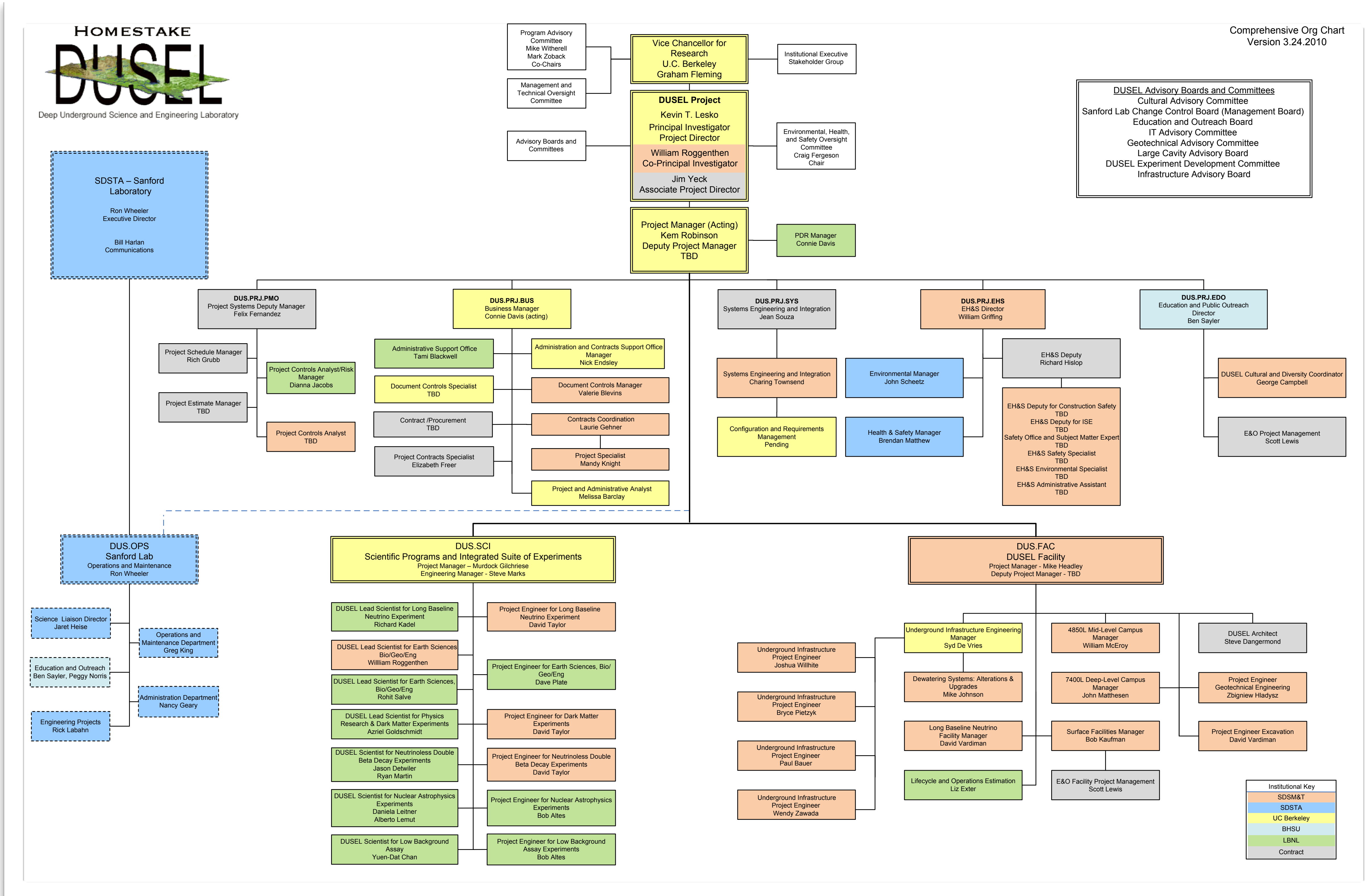
MREFC Project Scope: On-going Iterations

- 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

NSF MREFC Scope	Targets including Contingency
DUSEL Project Office	$48M
Surface Campus* (+ $5M from Sanford)	$50M
Underground Infrastructure and Laboratories*	$480M
LBNE Science Contribution	$123M
Other Science Contributions	$50M
	$750M

* including LBNE support

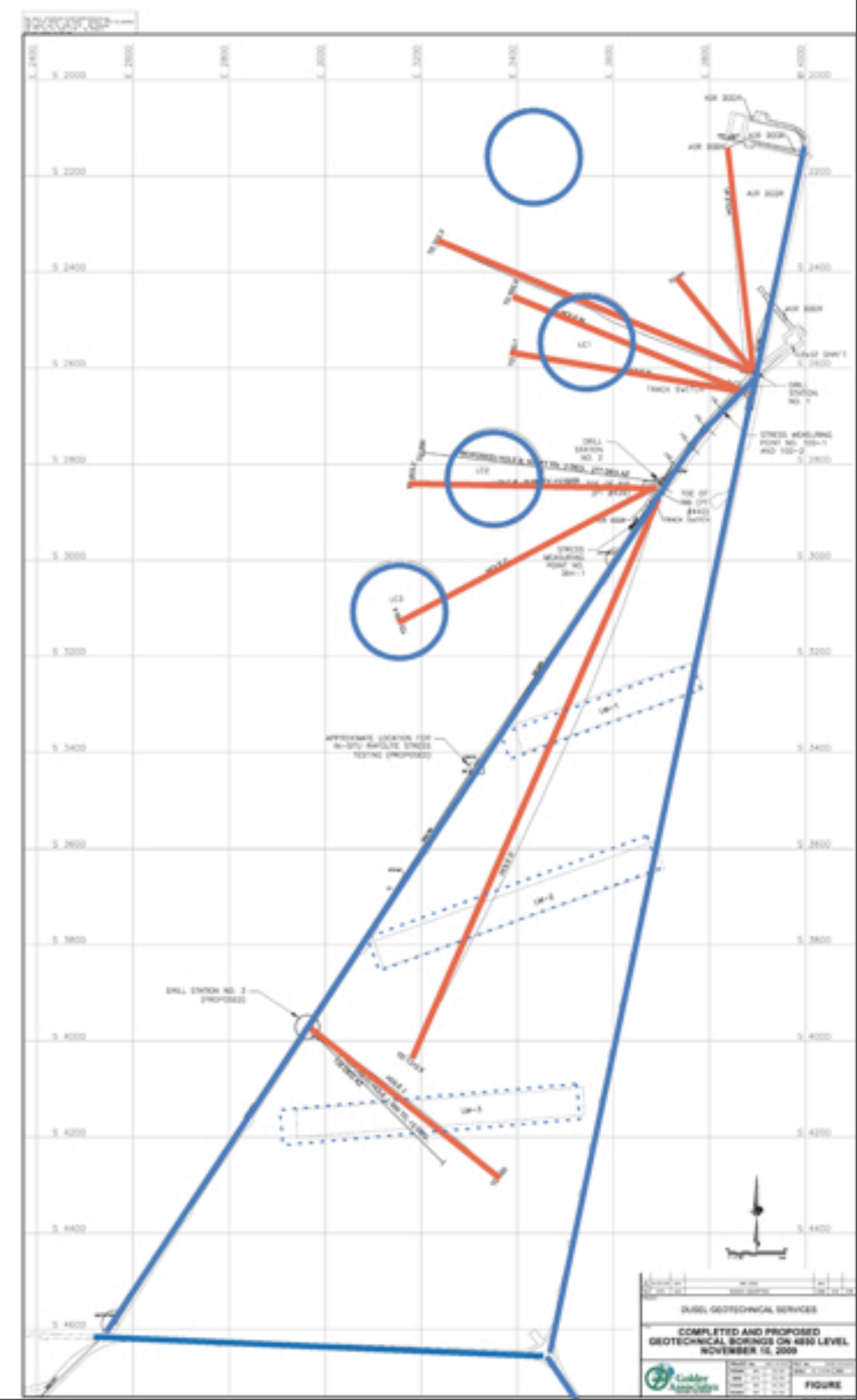
The DUSEL Organization Nearly Complete: ~55 Staff Members



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 ✓

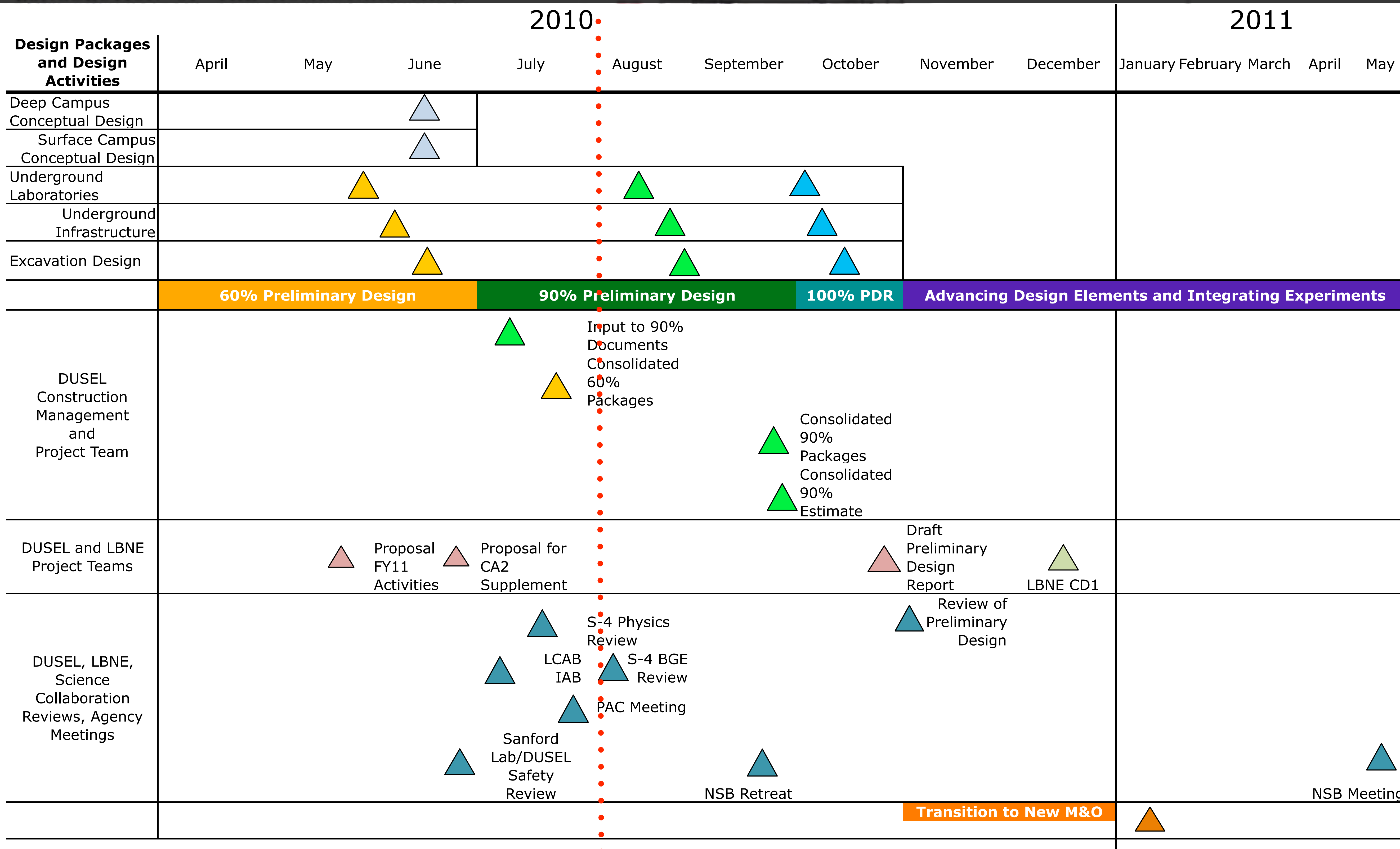
Completed Critical Geotechnical Investigations



- 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



Stewardship Model: Sharing DUSEL Responsibilities Between the Agencies

- **<u>steward</u> *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

Stewardship Model, *continued*

Program	Steward Agency	Collaborating Agency
DUSEL Facility	NSF	DOE
Dark Matter	NSF	DOE-OHEP
$0\nu\beta\beta$	DOE-ONP	NSF
Long Baseline Neutrinos & Proton Decay	DOE-OHEP	NSF
Nuclear Astrophysics	NSF	DOE-ONP
Advanced low background & assay	NSF	DOE
Bio/Geo/Eng	NSF	DOE(-BES, BER)

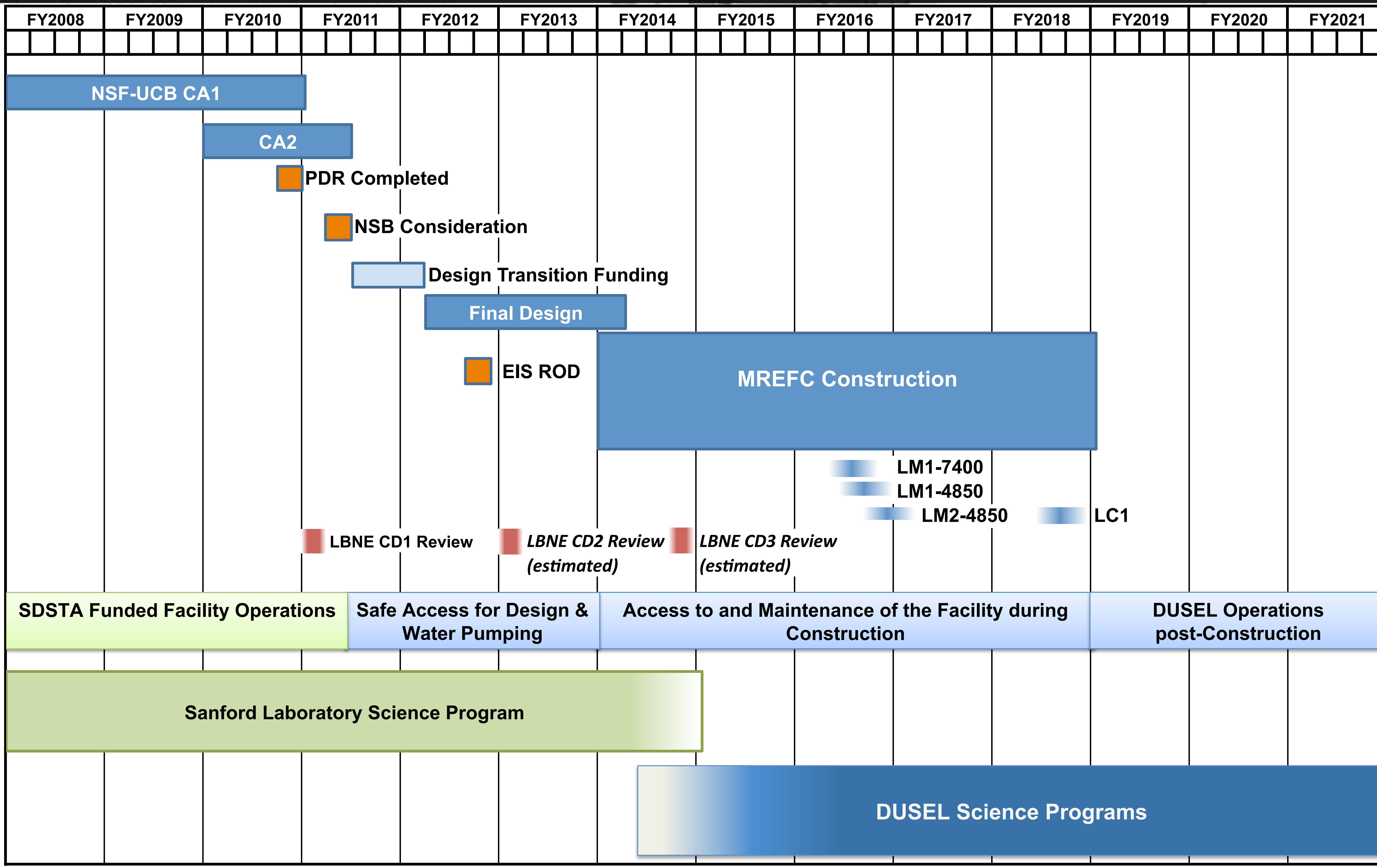
Senate Appropriations Committee Report Language Details DOE Funding Bill

- "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



*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

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*

Mark Zoback, Stanford

Earth Science Chair

Don DePaolo, *UCB and LBNL*

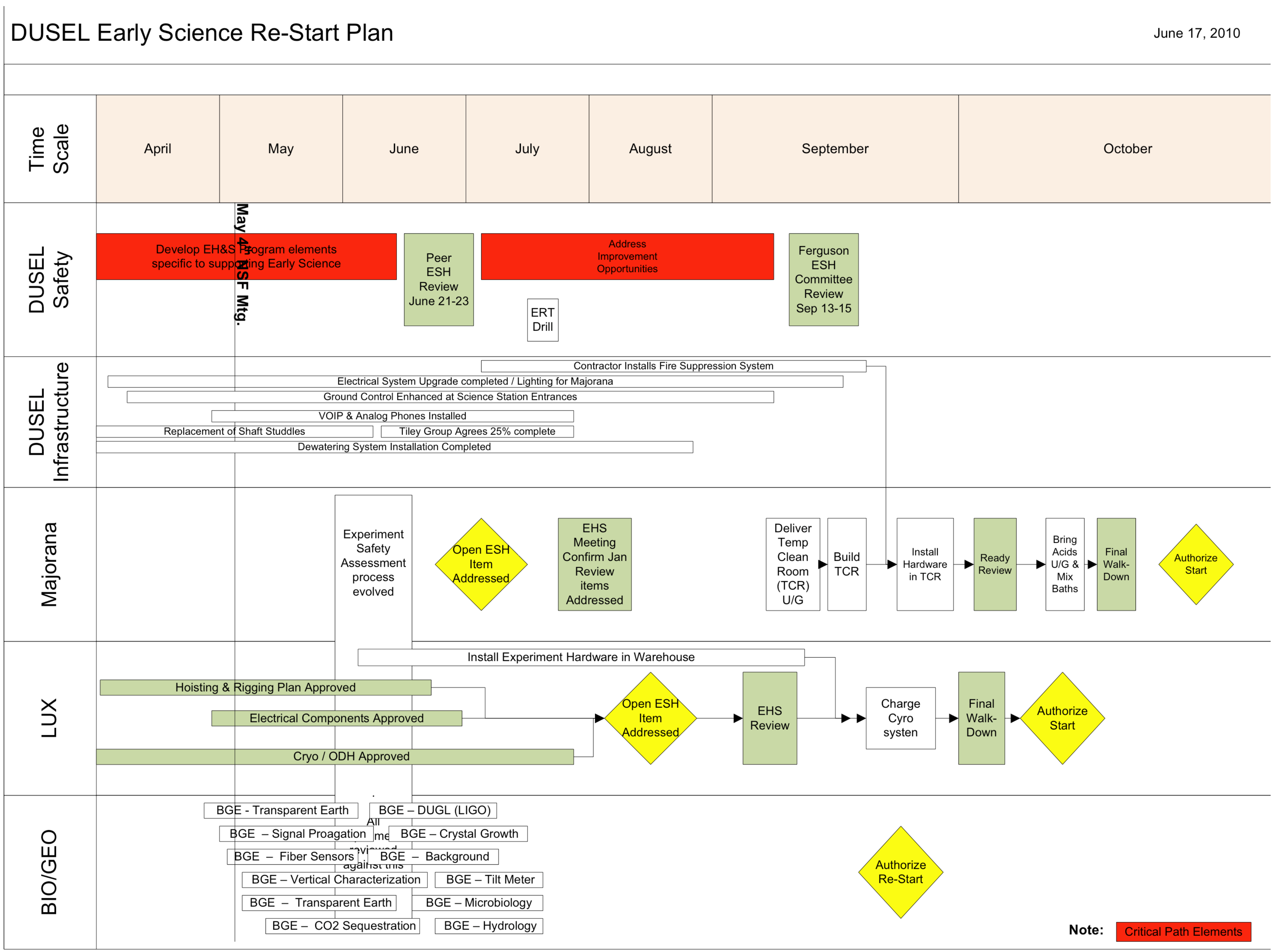
Steve Hickman, *USGS*

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

Sanford Laboratory Science Research Groups and Efforts

LONGSECTION OF THE HOMESTAKE MINE

Physics
- **LUX-350** − Dark Matter
- **MAJORANA DEMONSTRATOR** − $0\nu\beta\beta$
- **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
- CO_2 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

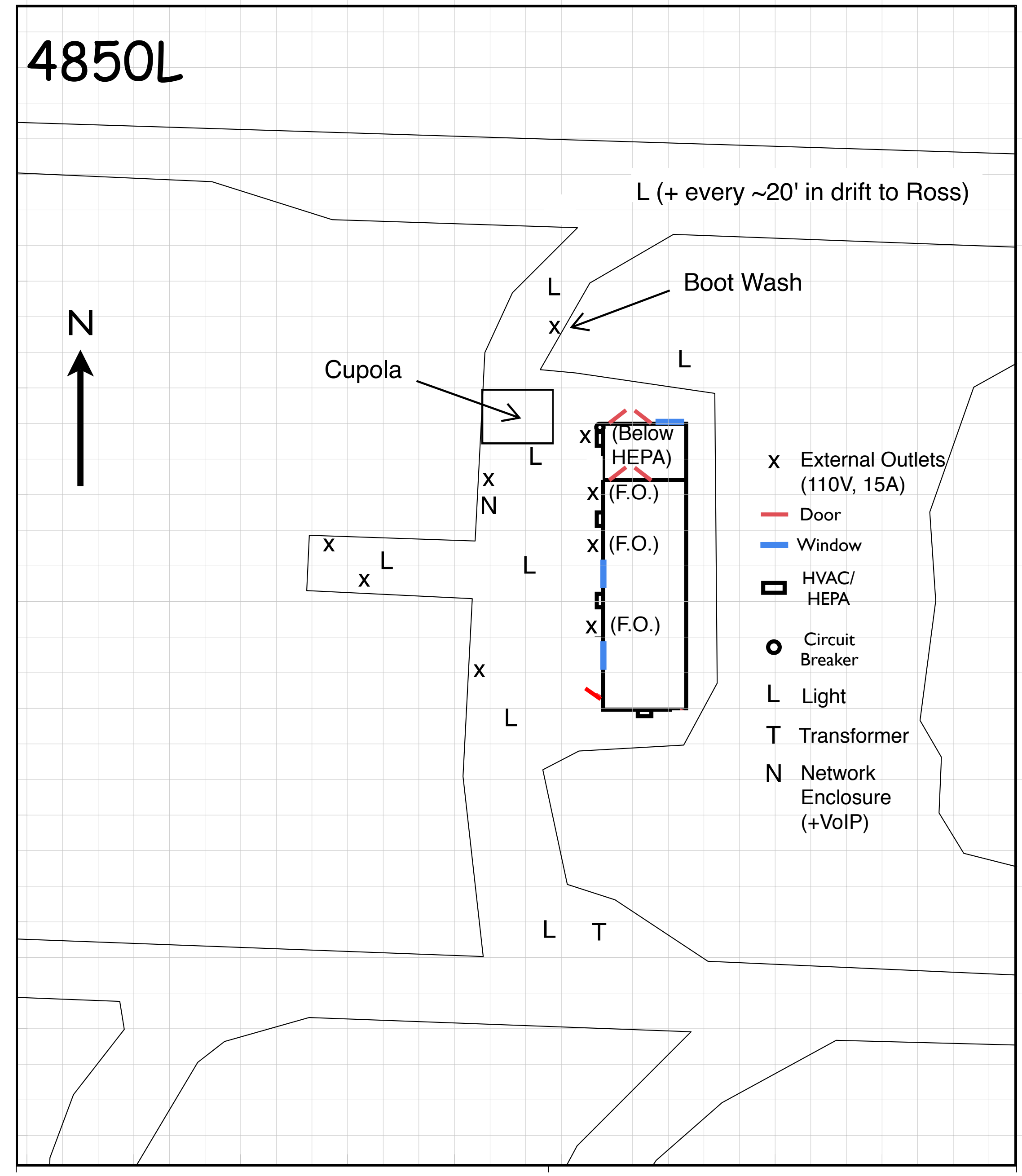
Engineering
- Signal Prop − Anagnostou
- DUSEL Design Teams - Multiple

Others (Site Selection Only)
- Cummingtonite − Geology (Berman)
- THMCB − Geology (DUSEL S4)
- Vertical Array − Geology (Dahlgren)
- Submersible − Engineering (McGough)

Total Active = ~18 groups
(plus others)

Physics Users at Sanford Lab: MAJORANA DEMONSTRATOR ($0\nu\beta\beta$)

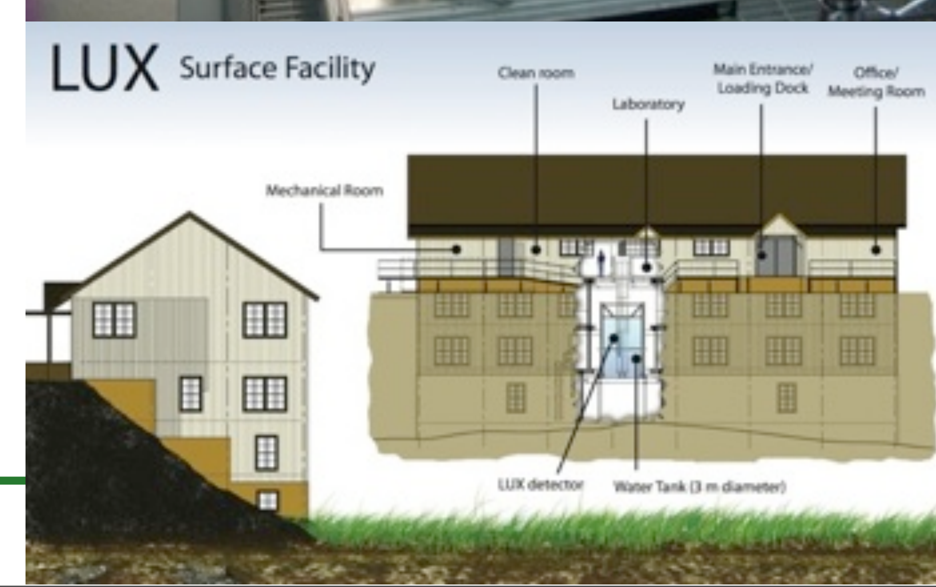
- Leadership:
  - → Wilkerson (UNC) CPM, Elliott (LANL) Spokesman
- Collaboration:
  - → ~93 researchers (including students)
  - → 18 institutions + Sanford Lab
- Milestones:
  - → Jun/Aug 09: Pb, Cu onsite
  - → Dec 09: TCR work begins
  - → Sep 10: Electroforming begins
  - → Aug 11: Bene. Occ. Davis 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



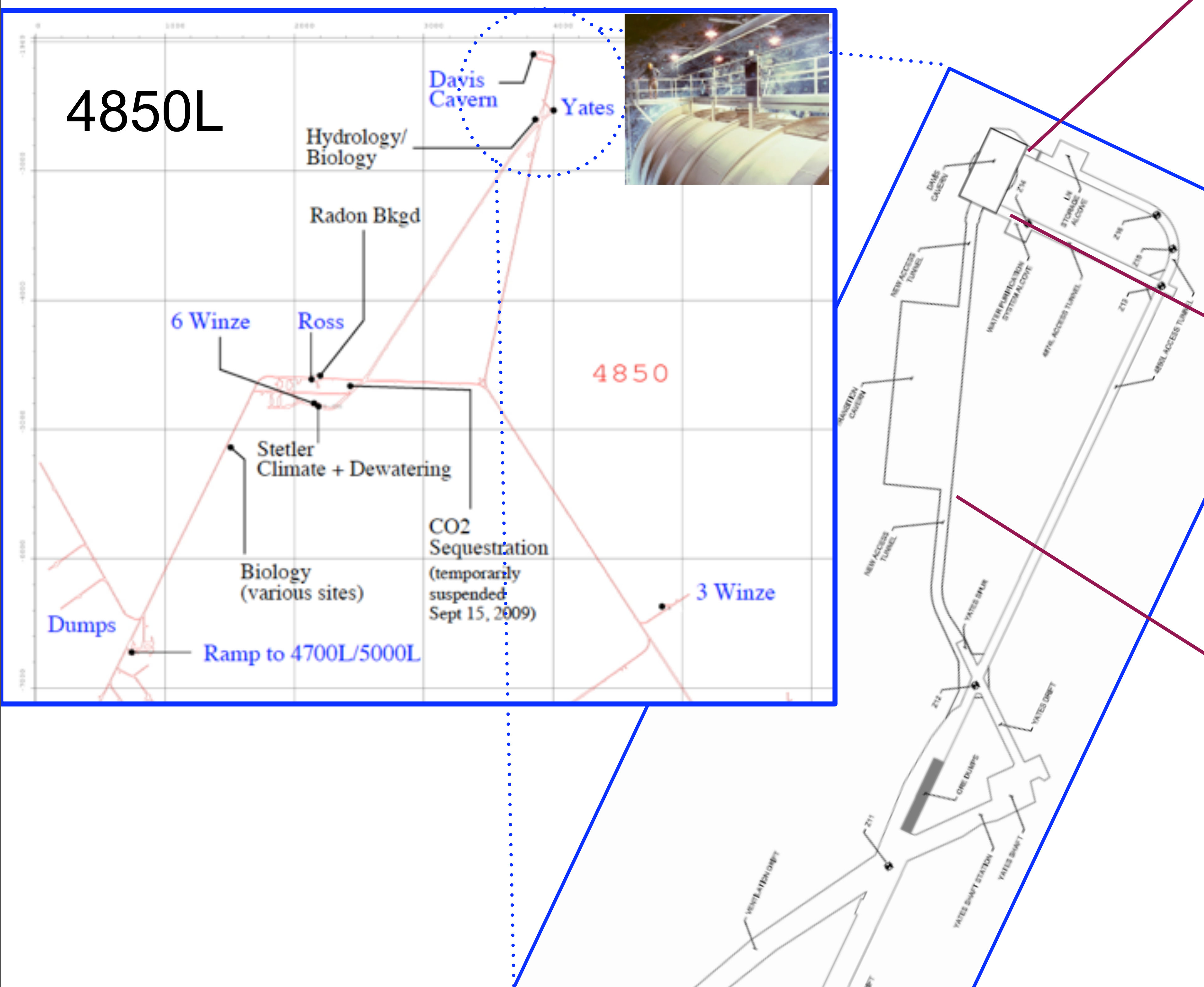
Initial Occupancy Ross Shops area 4850L

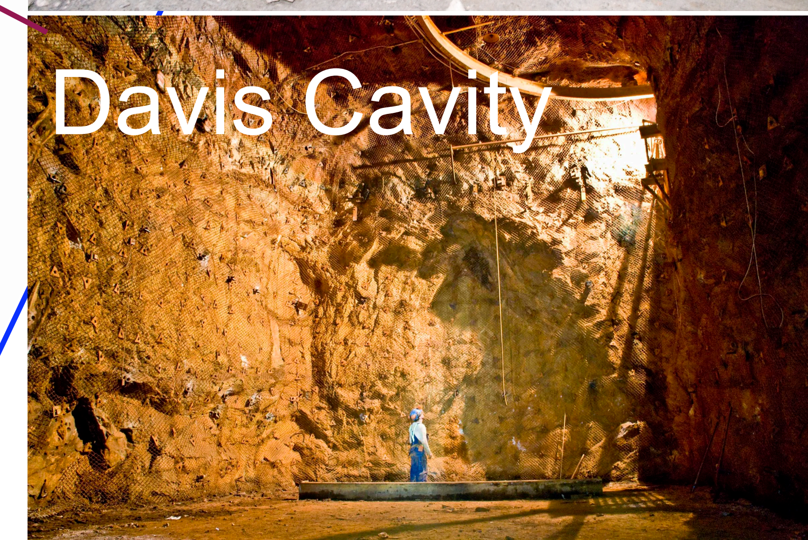
Physics Users at Sanford Lab: Large Underground Xenon (LUX-350)

- 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



The Sanford Laboratory: Davis Campus to Support Majorana Demonstrator and LUX



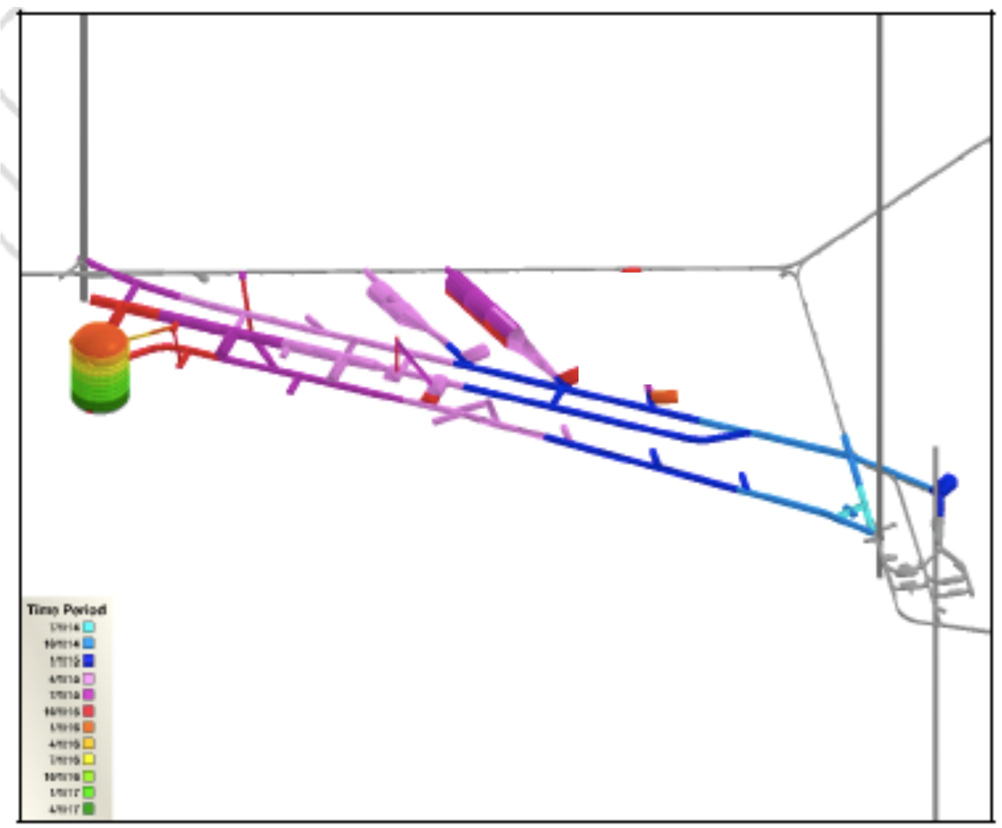


Preparing for FY 11

- 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

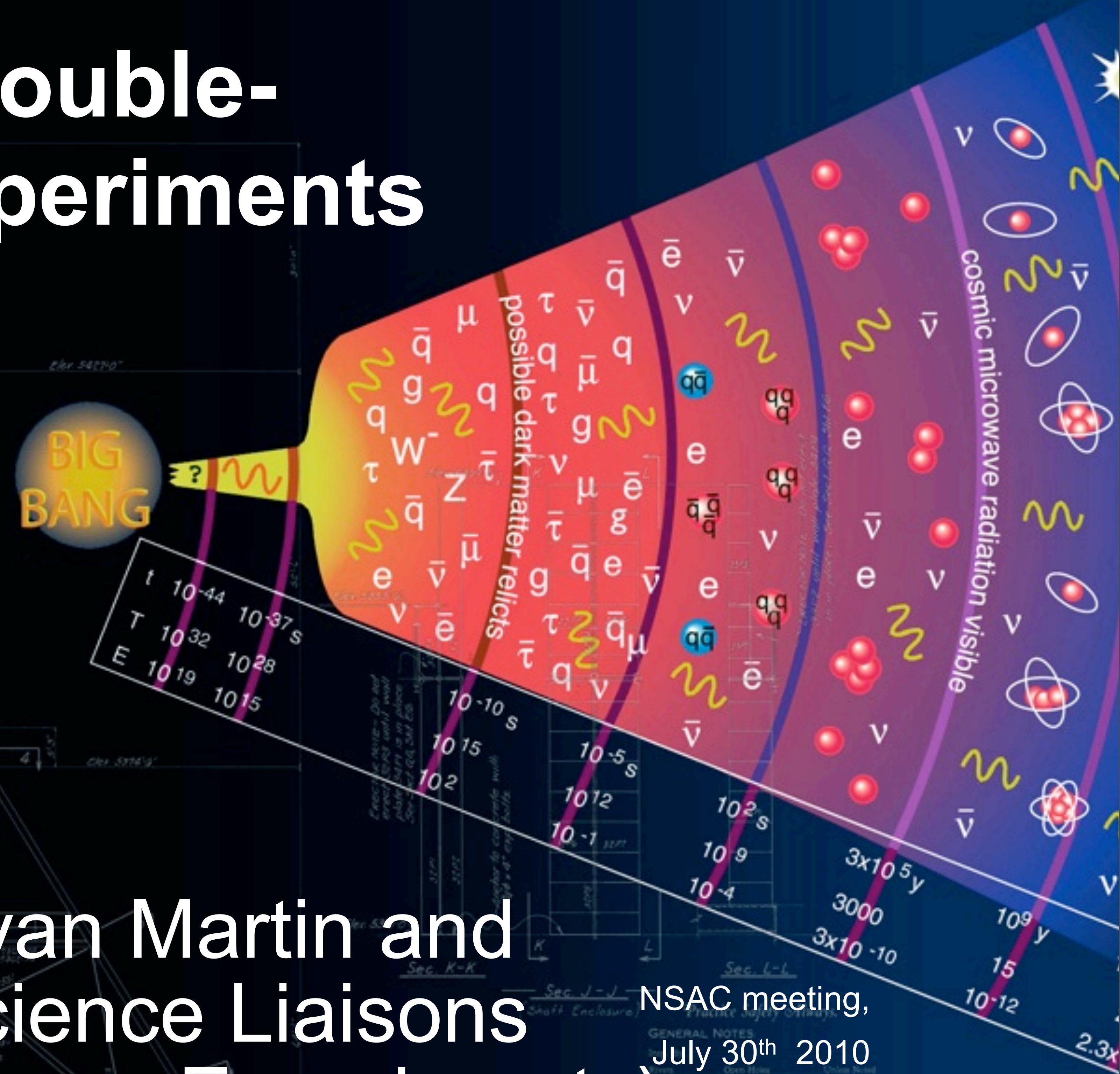
- Building the Health & Safety Program remains a highlighted focus for Project
  - facility maintenance and upgrades - plans and implementation
  - additional Health and Safety Personnel
- Aggressively advancing the Preliminary Design and Integrating activities
  - Project added Systems Engineering and 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**

Homestake DUSEL
NSAC Summary

Neutrinoless Double-Beta Decay Experiments

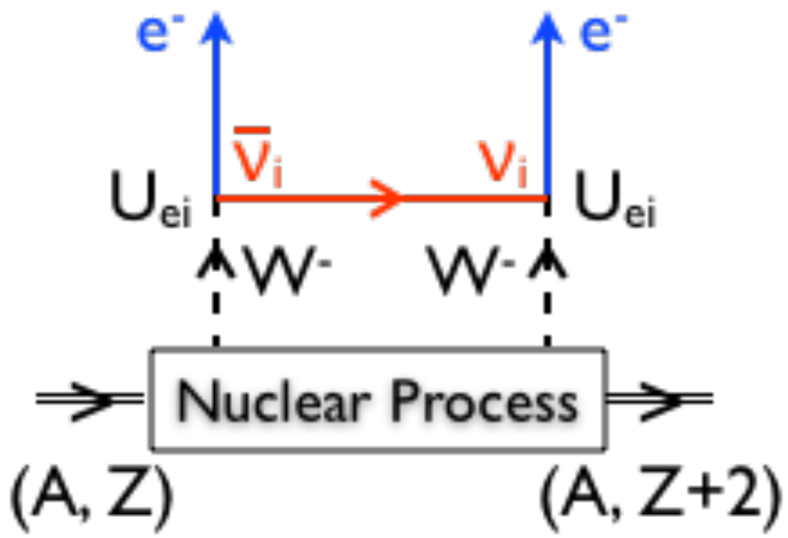


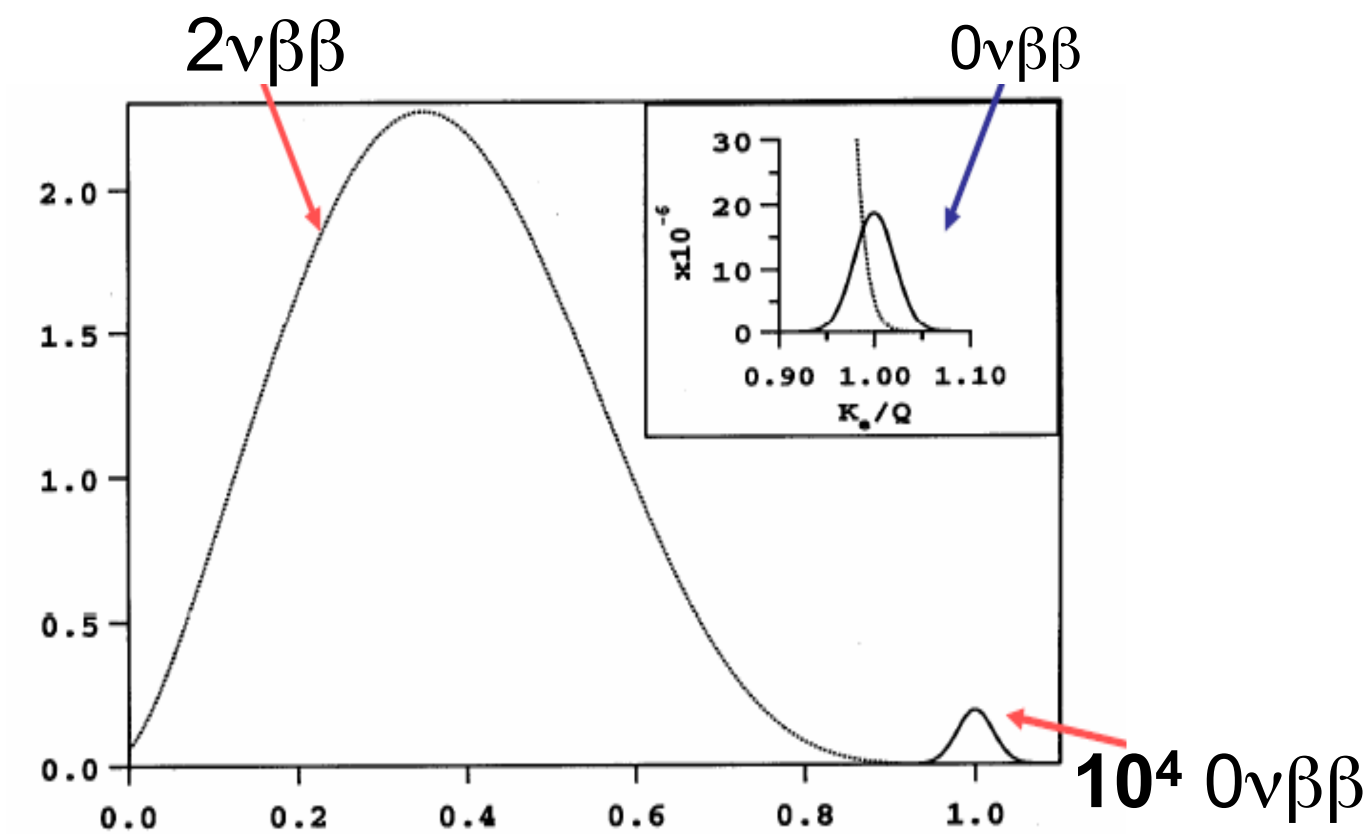
Kevin Lesko for Ryan Martin and Jason Detwiler (Science Liaisons for Double-Beta Decay Experiments)

NSAC meeting,
July 30th 2010

Figure Courtesy
PDG and LBNL

Neutrinoless Double-Beta Decay





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

G. Gratta

Isotopes, Q-values and natural abundances

- 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 0νββ events

Experimental sensitivity to 0νββ

Phase Space

Nuclear Matrix Element

$$T_{½}^{0\nu} = \left(G^{0\nu} \, |M^{0\nu}|^2 \, \langle m_{\beta\beta} \rangle^2 \right)^{-1}$$

$$\langle m_{\beta\beta} \rangle \equiv U_{e1}^2 m_1 + U_{e2}^2 m_2 e^{i\phi 2} + U_{e3}^2 m_3 e^{i\phi 3}$$

PMNS Matrix

Majorana Phases

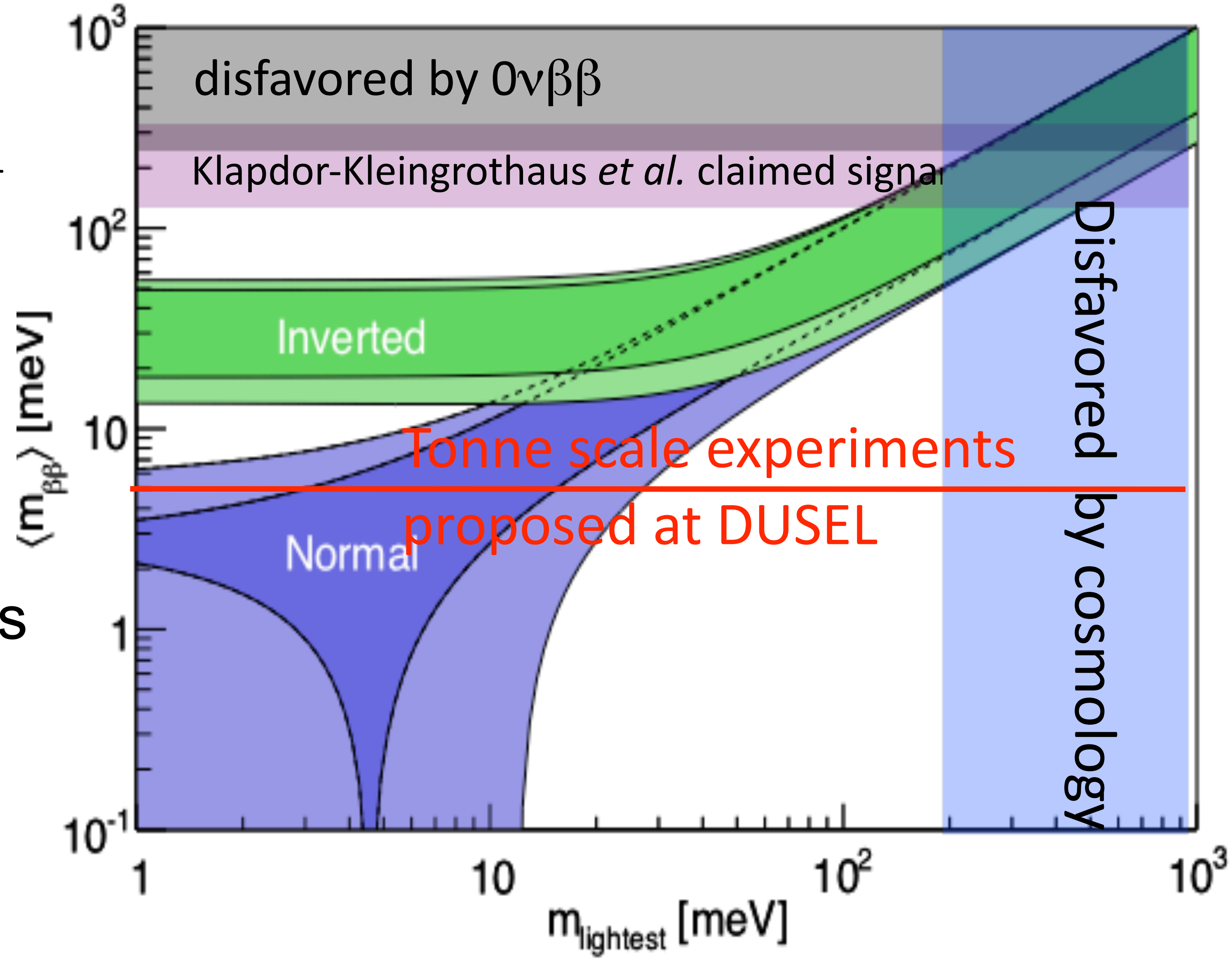
background rate

energy resolution

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

active mass

live-time



- The half life for 2νββ 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

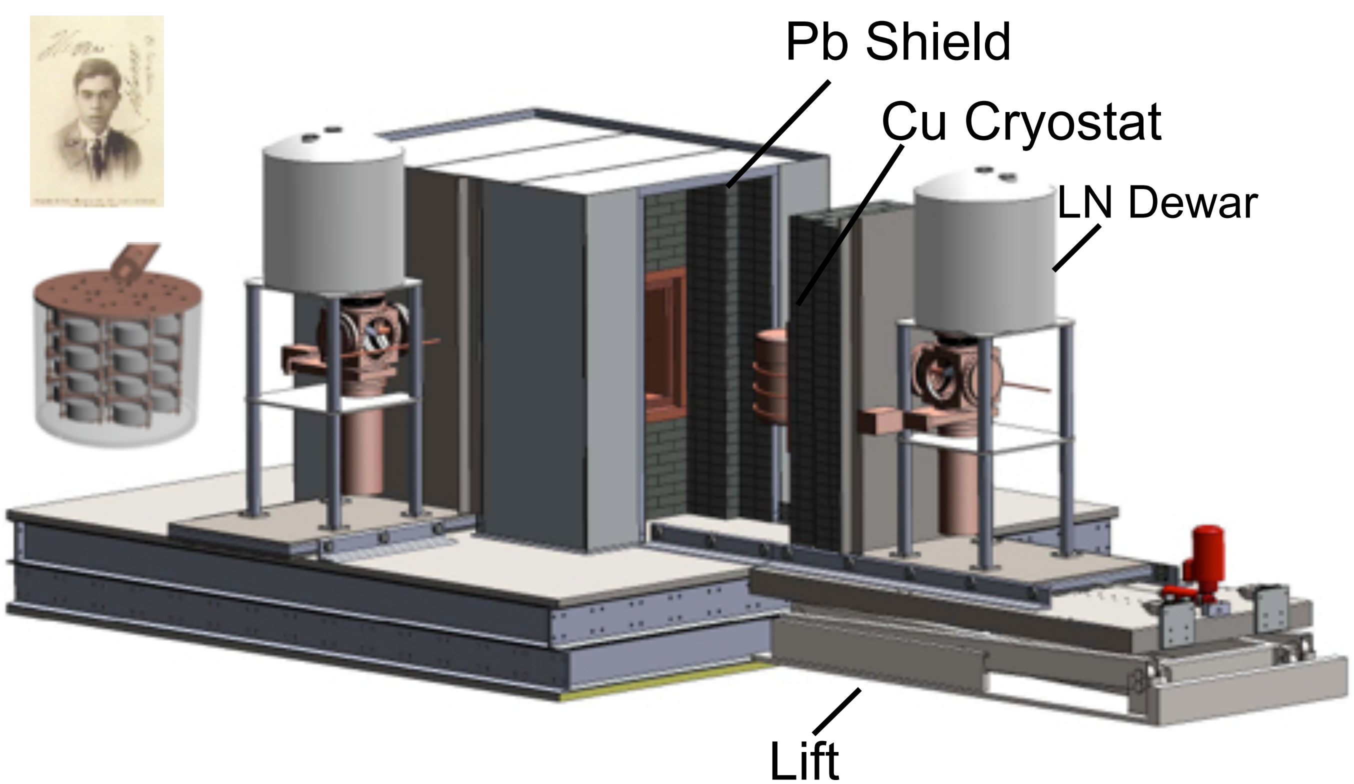
- Two experiments are being proposed at DUSEL and have S4 funding (other R&D efforts as well):

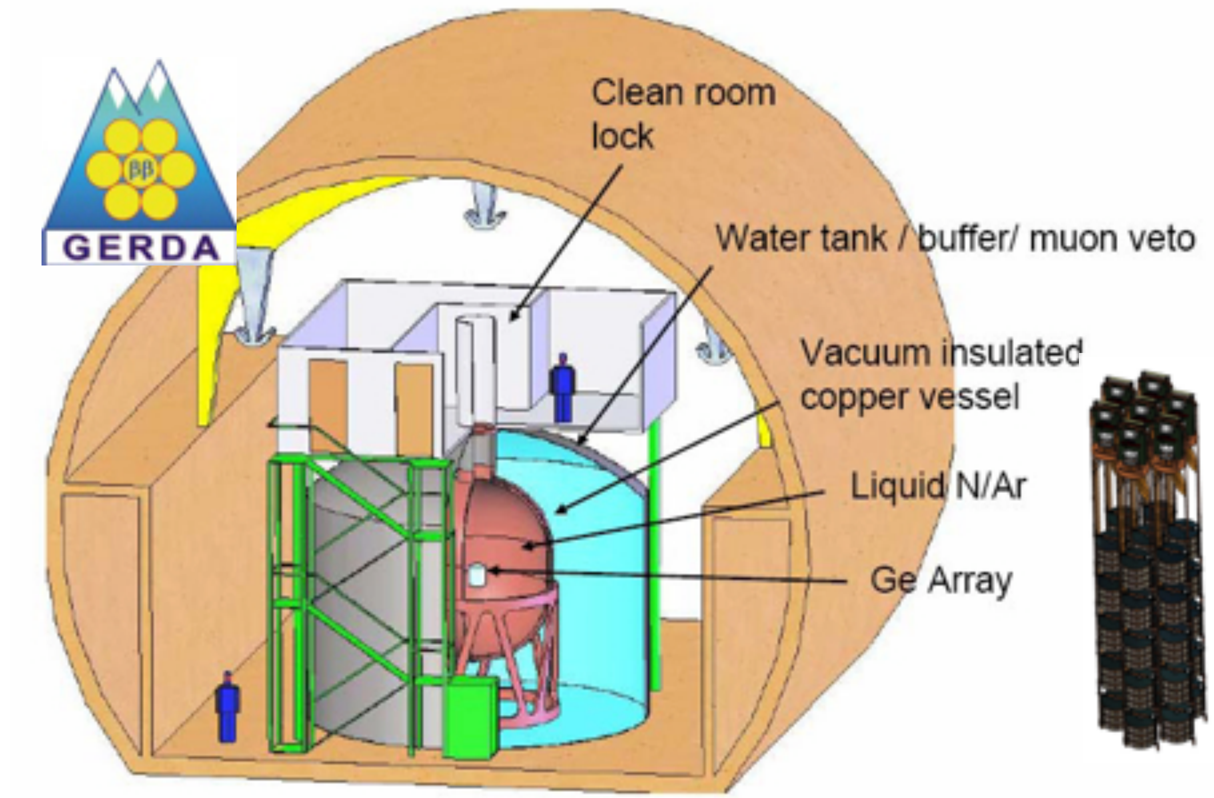
- The **1TGe Experiment** will look for $0\nu\beta\beta$ in approximately 1 tonne of Germanium (enriched in ^{76}**Ge**)
- Technologies are being explored/demonstrated by the MAJORANA DEMONSTRATOR and GERDA collaborations

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



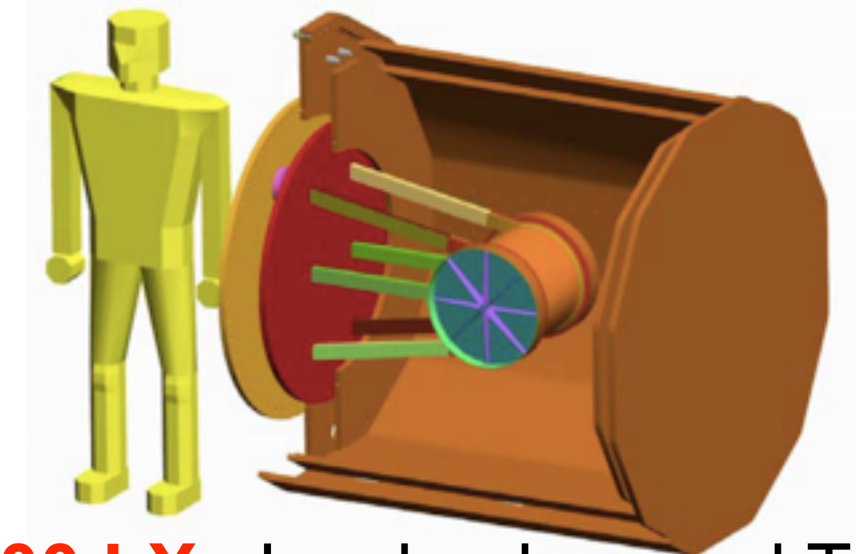


http://ilias.in2p3.fr/ilias_site/meetings/documents/ILIAS_3rd_Annual_Meeting/Parallel_DBD_Exp_Zuzel.pdf

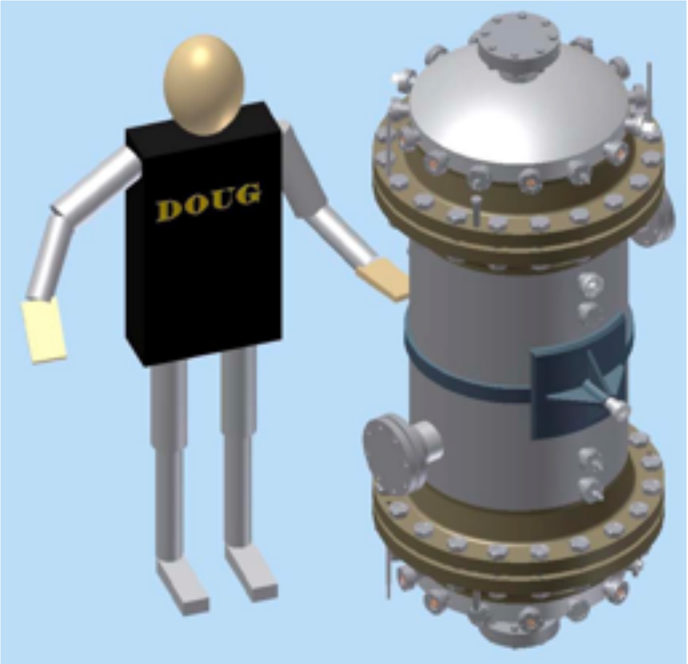
The MAJORANA DEMONSTRATOR in Sanford lab:
•2 Cryostats made of electroformed copper, in conventional shielding
•Will use up to 40kg of Ge (20kg enriched)
•Operate between 2011-2014

The 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

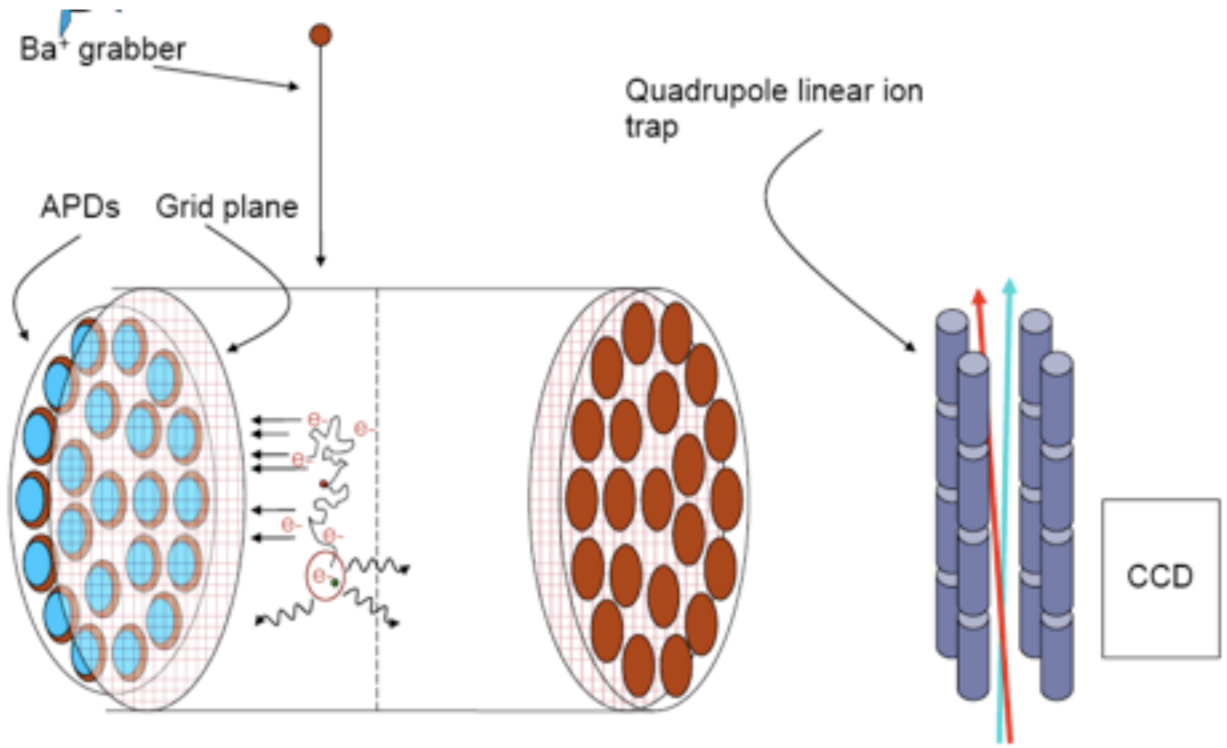
The EXO Experiment



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

Experiment	DUSEL Science	DUSEL Engineering	Experiment Contact
1TGe	Ryan Martin	Bob Altes	David Steele (LANL) Matthew Busch (TUNL, Engineer)
EXO	Jason Detwiler	Bob Altes	Giorgio Gratta (Stanford) John Ku (SLAC, Engineer)

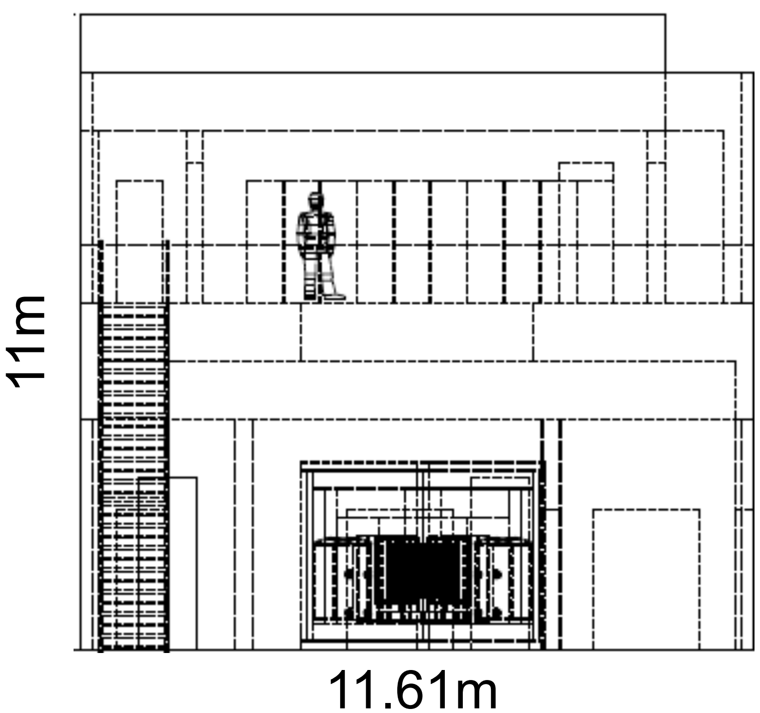
Points of contact

Documentation Summary

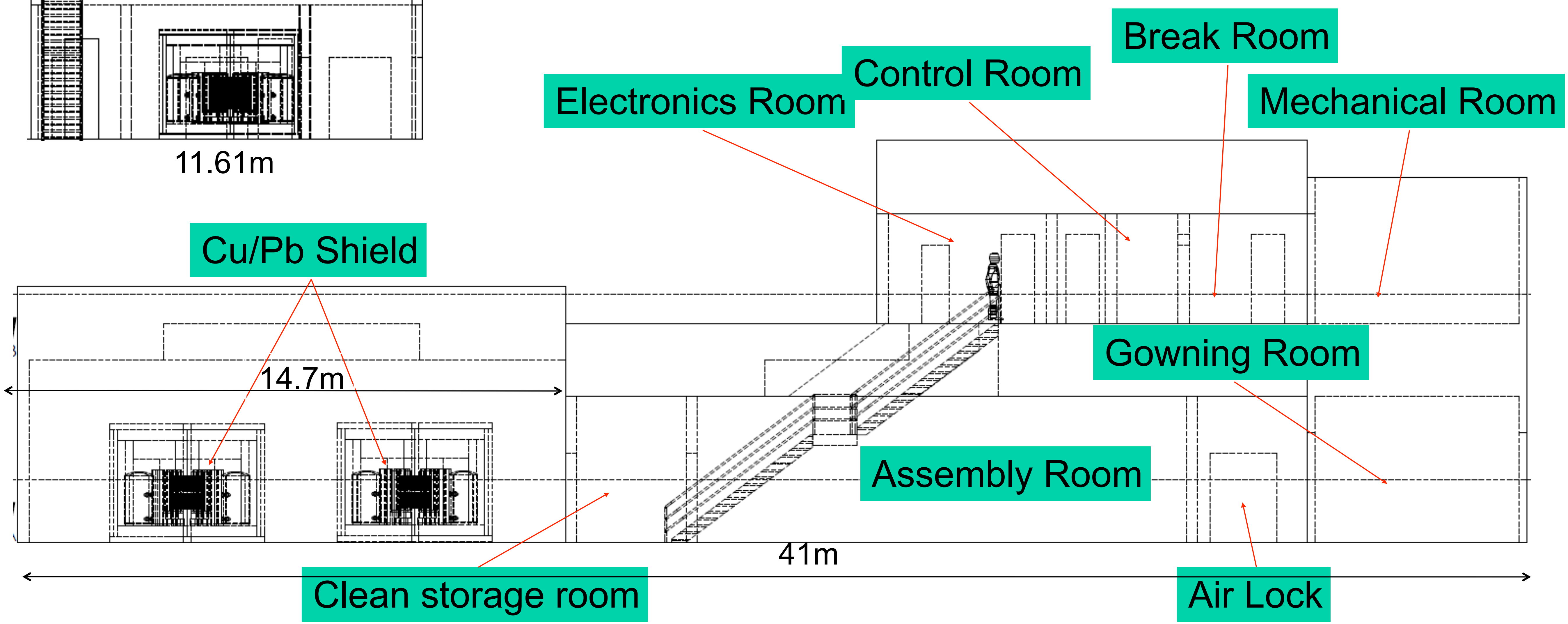
- Summary of documentation that has been provided to DUSEL in Docushare

Document	1TGe	EXO
Science Goals	✓	✓
Layout	✓	✓
Depth Requirements	✓	✓
Infrastructure requirements database (utilities, EH&S)	✓	✓
Cost and Schedule	✓	✓
S4 Proposal	✓	✓

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

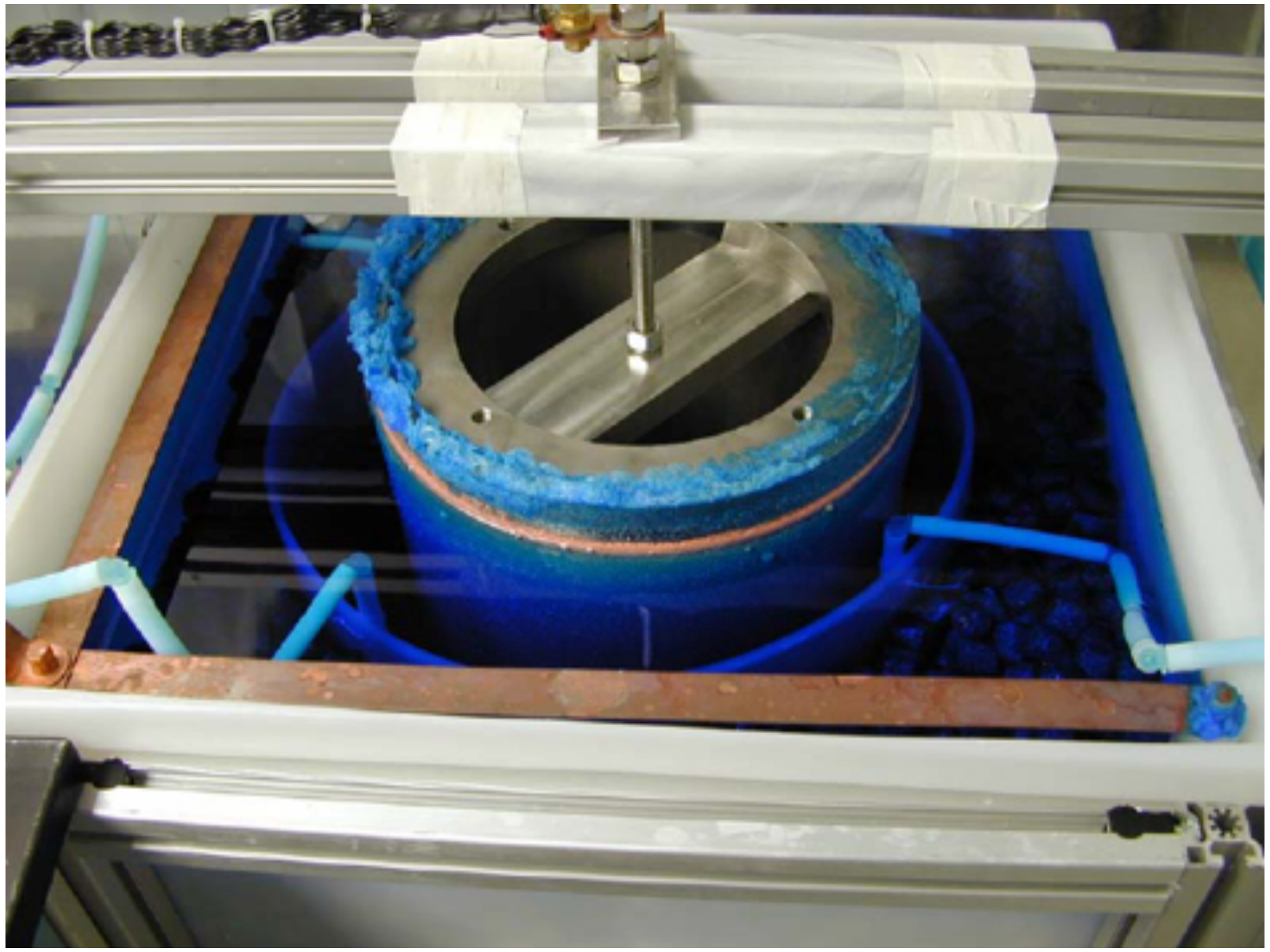


Electroforming lab for 1TGe Cu

•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:

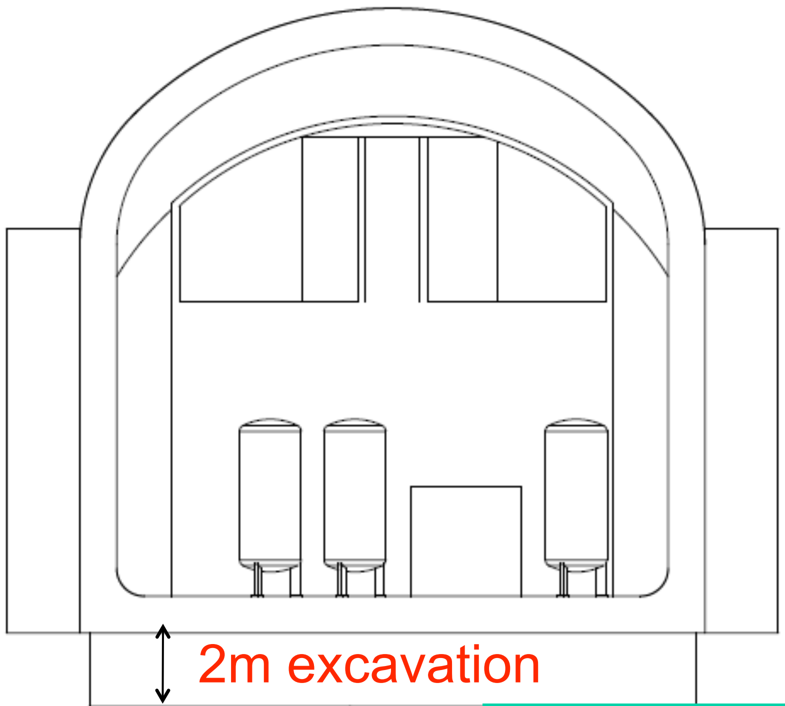
- **Electroforming lab** (14mx9mx3m) will fit in the current MAJORANA DEMONSTRATOR electroforming lab, need to add 4 larger baths to the existing 16 (20 total)
- **Cleaning and passivation lab** (6mx10mx3m), will re-use the MAJORANA DEMONSTRATOR facility
- **Machine shop** (12mx5mx3m), will need some new space for 1-2 larger machine tools and welding facility

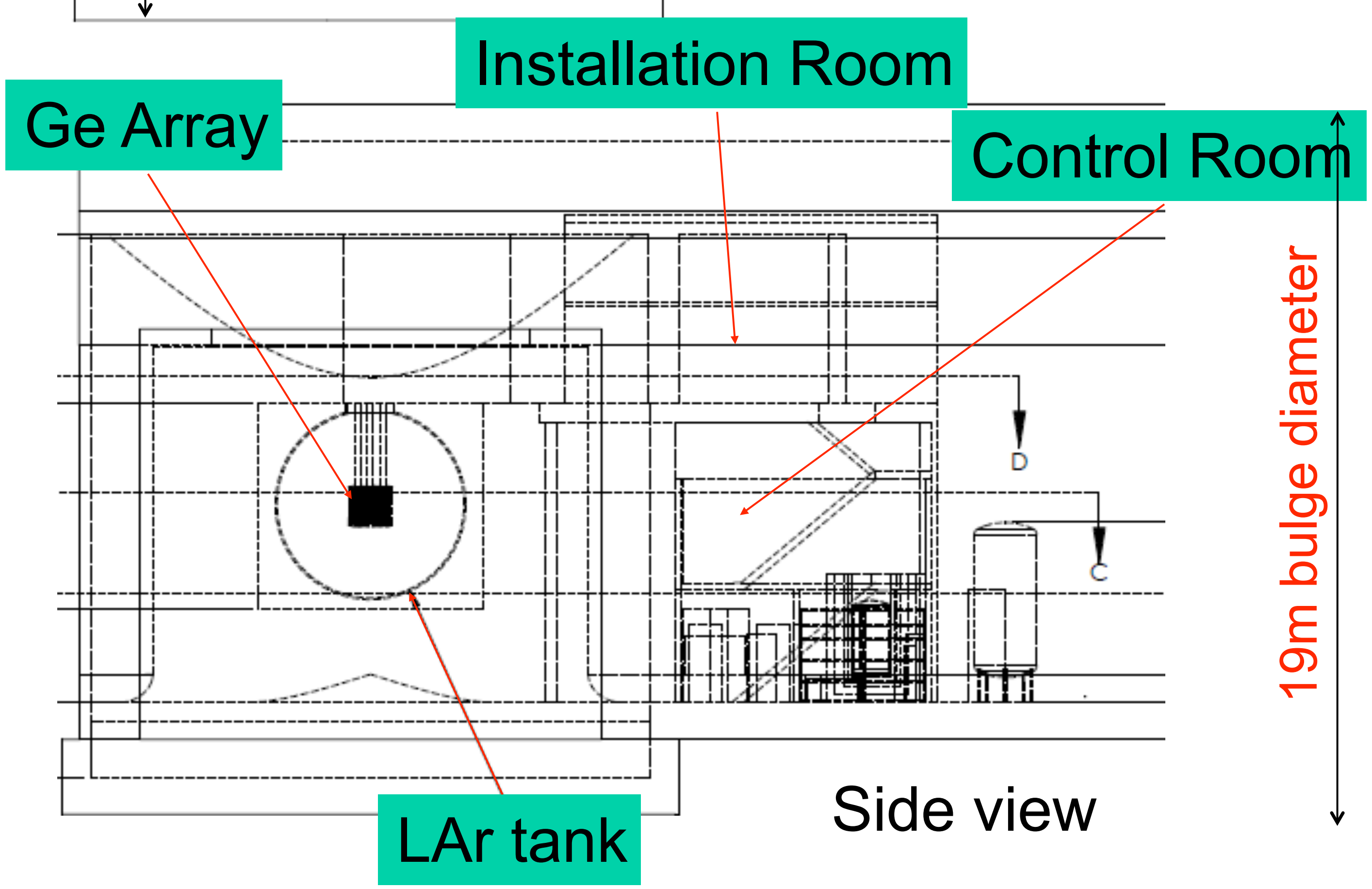


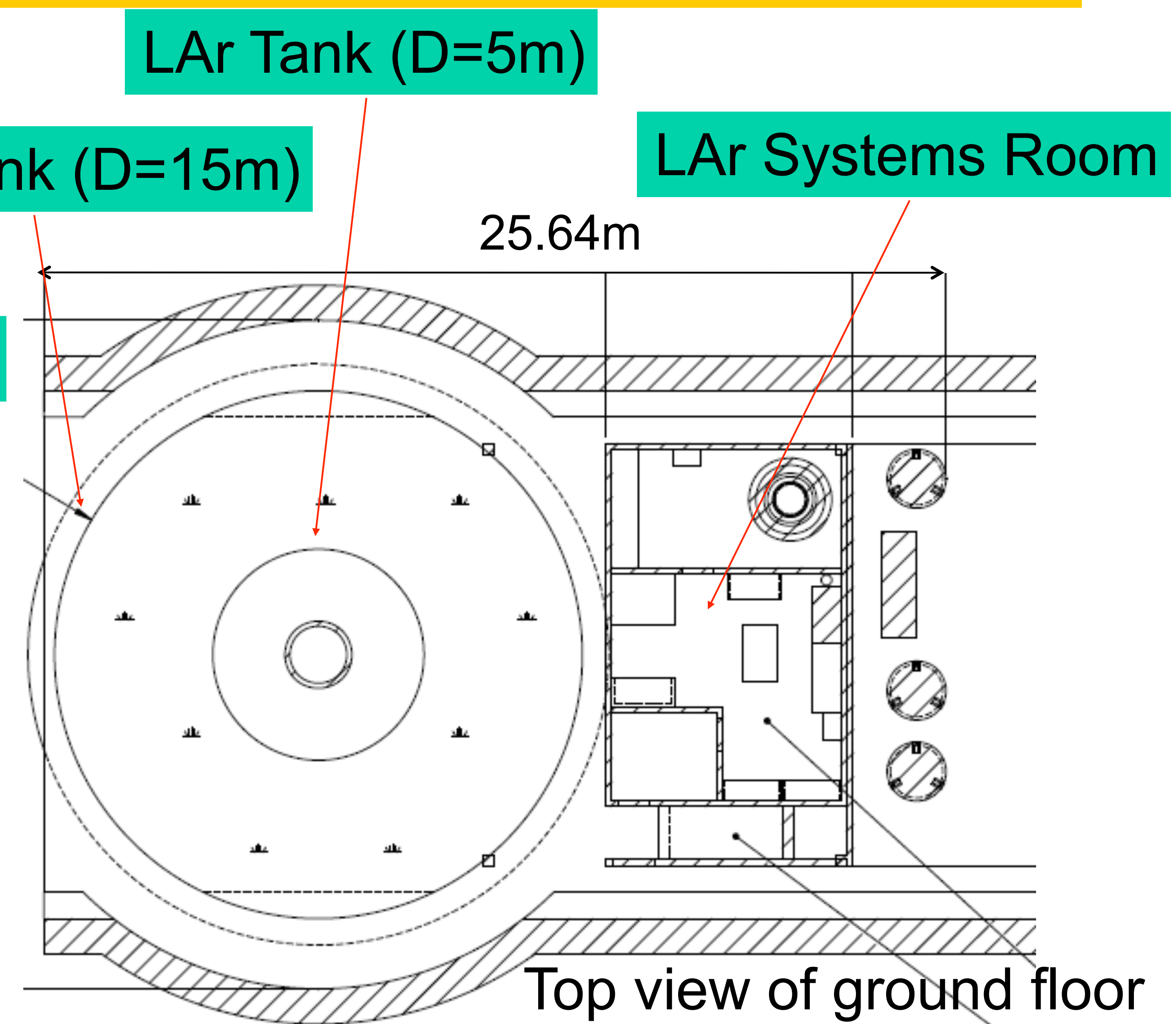
Electroforming bath prototype for the MAJORANA DEMONSTRATOR

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)

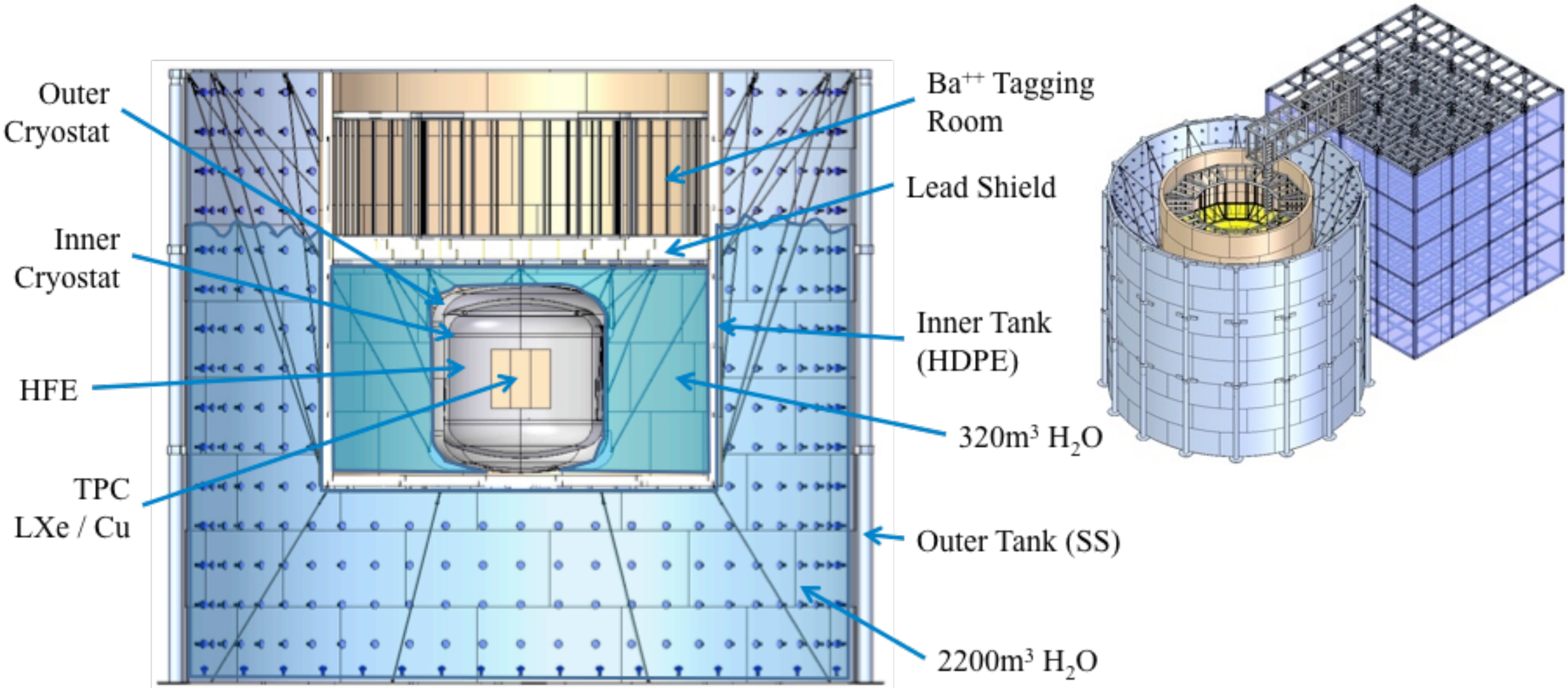






Layout for EXO

- EXO's preferred layout for detector + support building
- Does not fit in 7400L lab module (requires ~4m excavation + ~2m widening on each side)



Depth

- 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

EXO Assembly Study

- 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

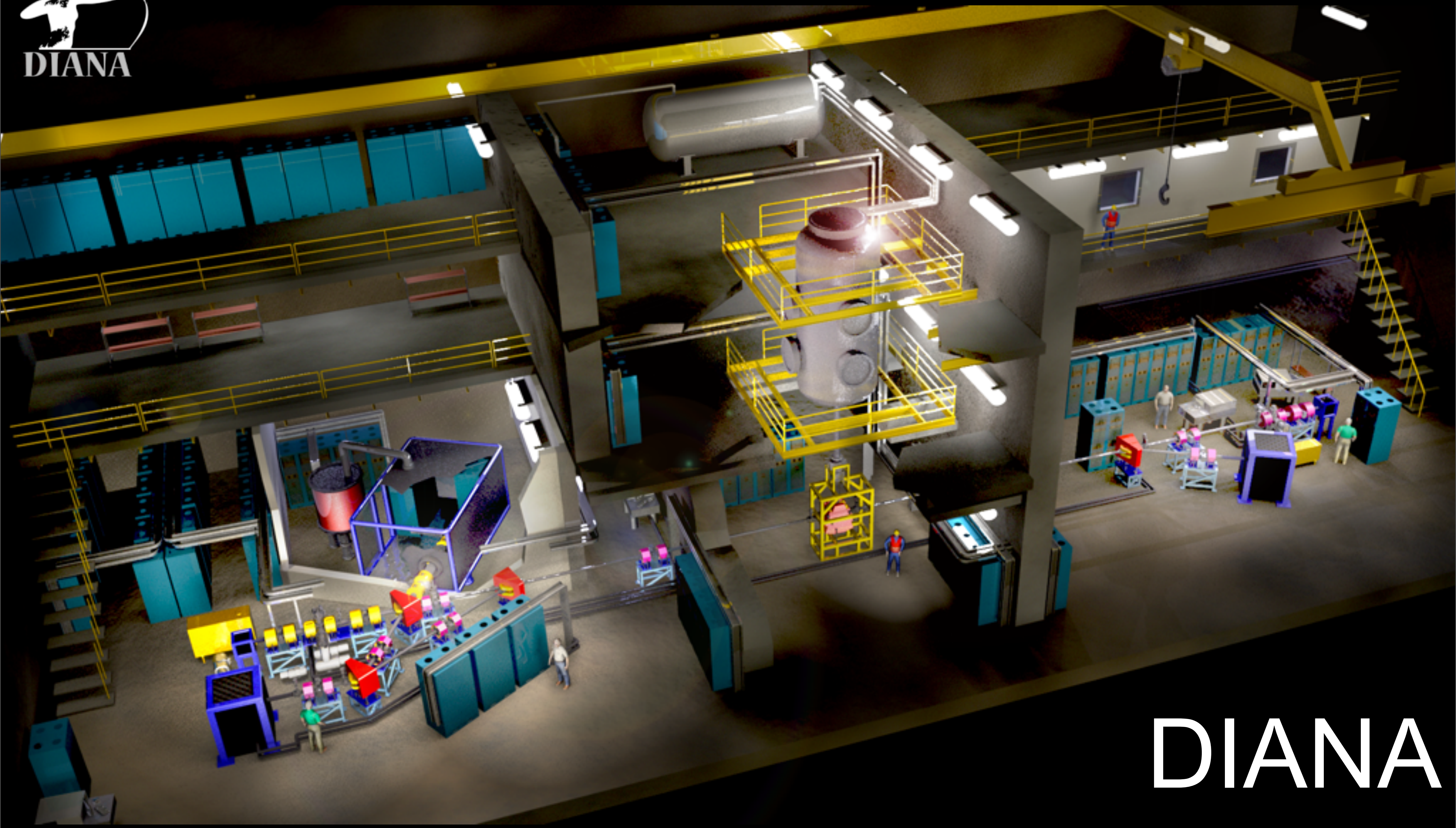
- Trade-related
- Confined space issues
- Temporary structures / rigging

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



DIANA

Dakota Ion Accelerators for Nuclear Astrophysics

Kevin Lesko for Alberto Lemut - DUSEL Liaison

nternational 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)

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

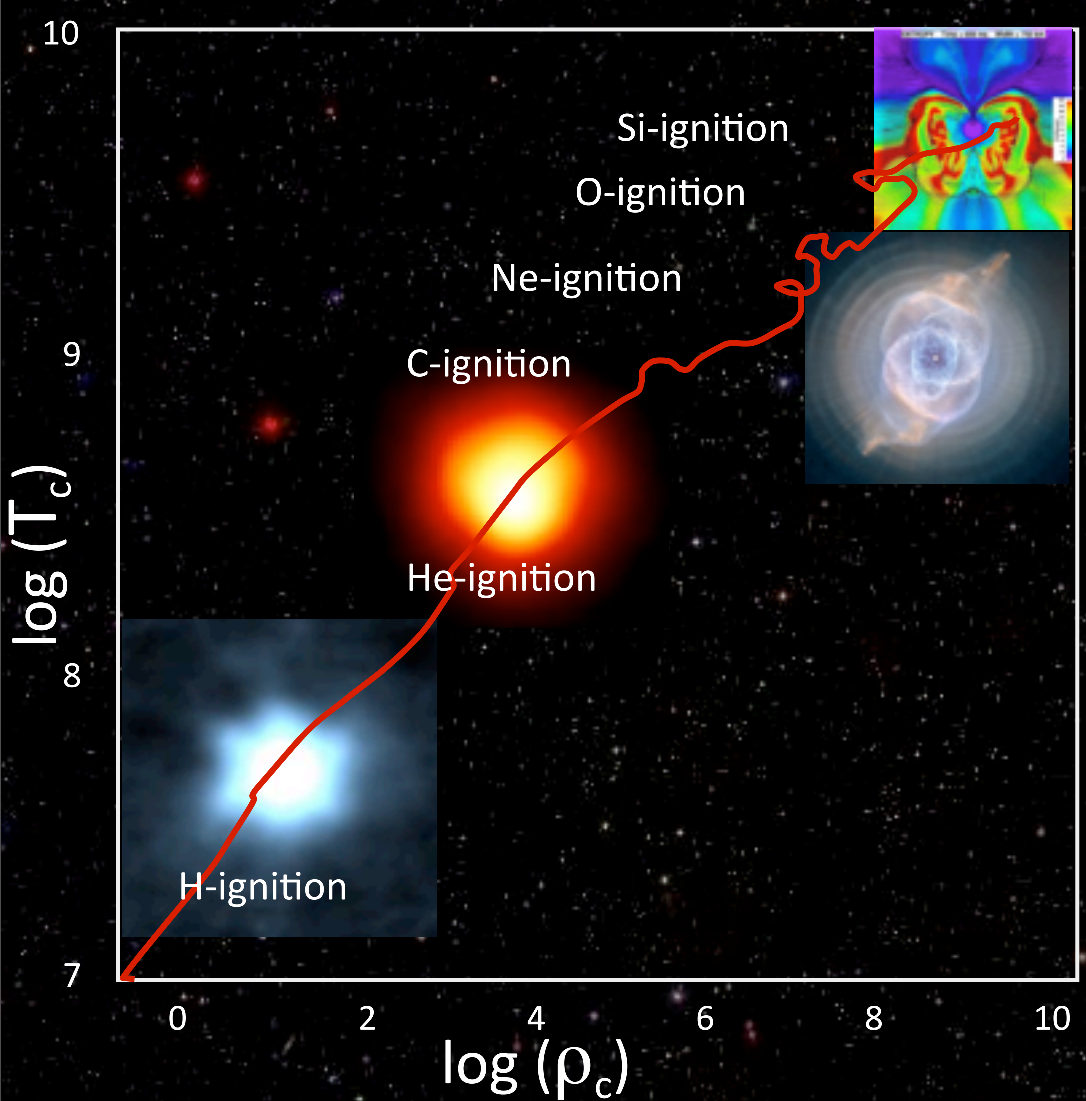
New team members (since 2010):

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

Astrophysics Underground Accelerator DIANA

Addresses two key questions identified in the nuclear science long range plan

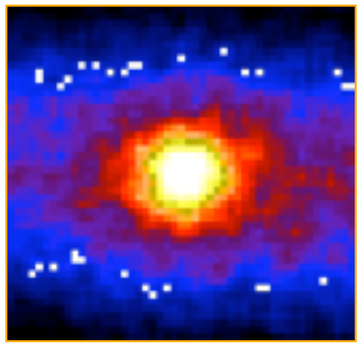


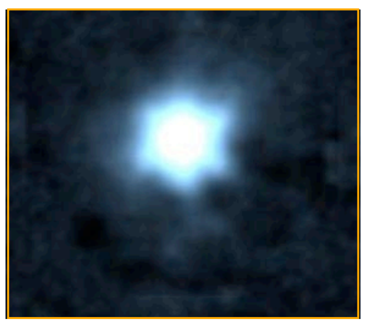
- **What is the origin of the elements in the cosmos?**
- **What are the nuclear reactions that drive stars and stellar explosions?**

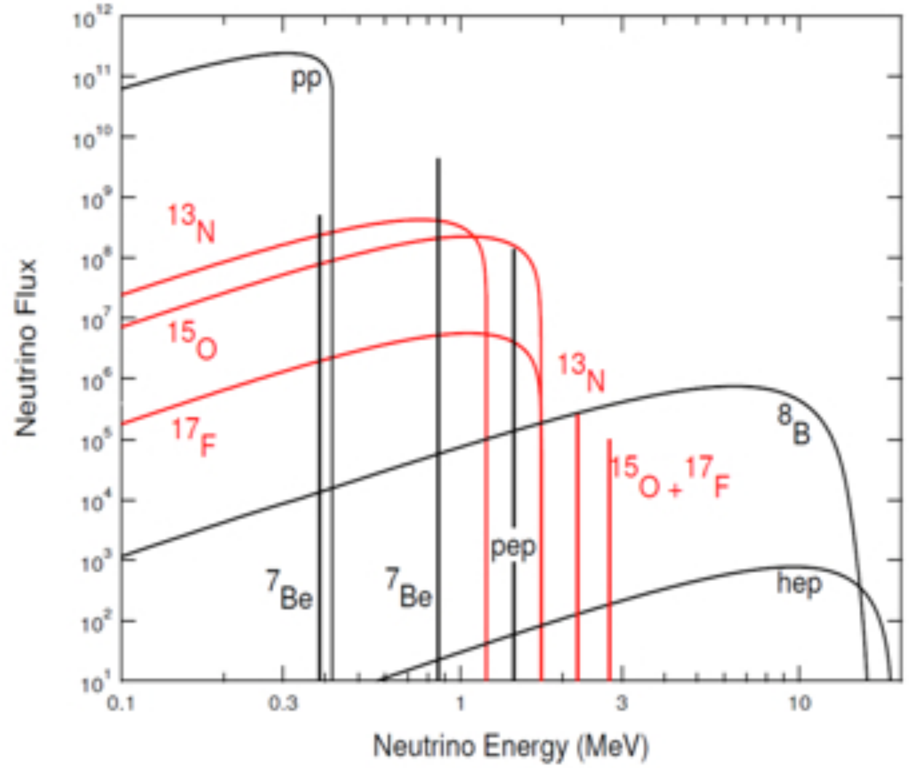
NP long range plan identifies a opportunity for a DIANA type facility at DUSEL:

‘The **<u>direct measurement of reaction rates on stable nuclei</u>** that **<u>require high-intensity beams</u>**, 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 **<u>underground based low-energy accelerator facilities</u>**, as demonstrated by LUNA at the European Gran Sasso underground laboratory, **<u>significantly reduces cosmic-ray-induced background by several orders of magnitude</u>**. 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. **<u>DUSEL will provide an opportunity for the development of such a facility in the United States.</u>**’

Scientific Motivation



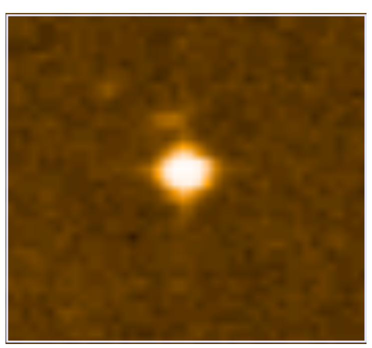


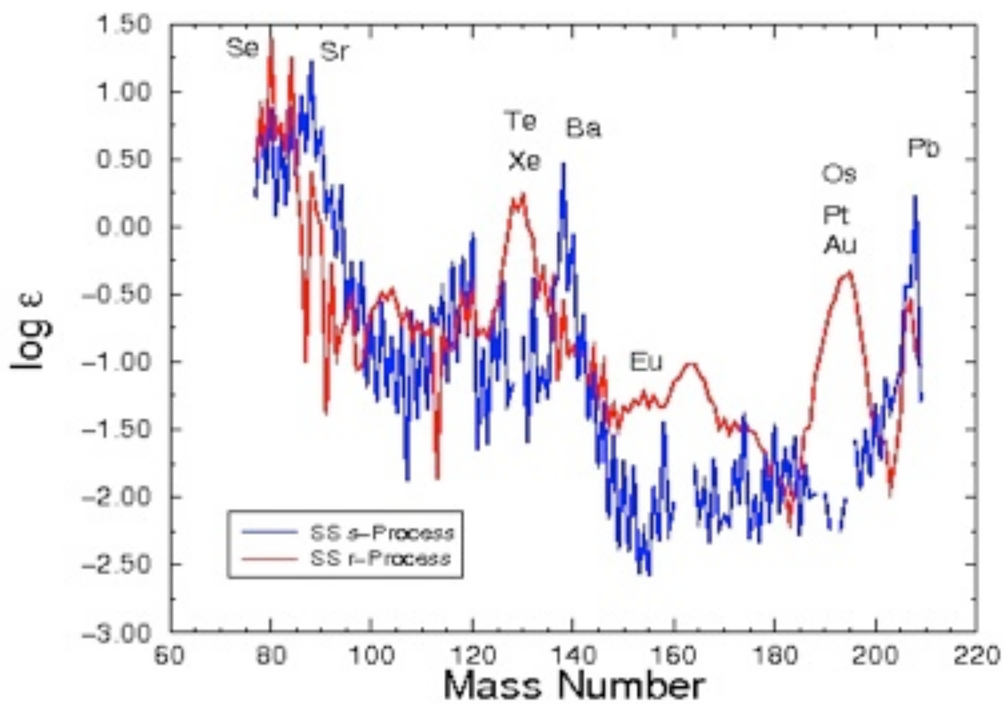


Stellar Neutrino Sources

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.



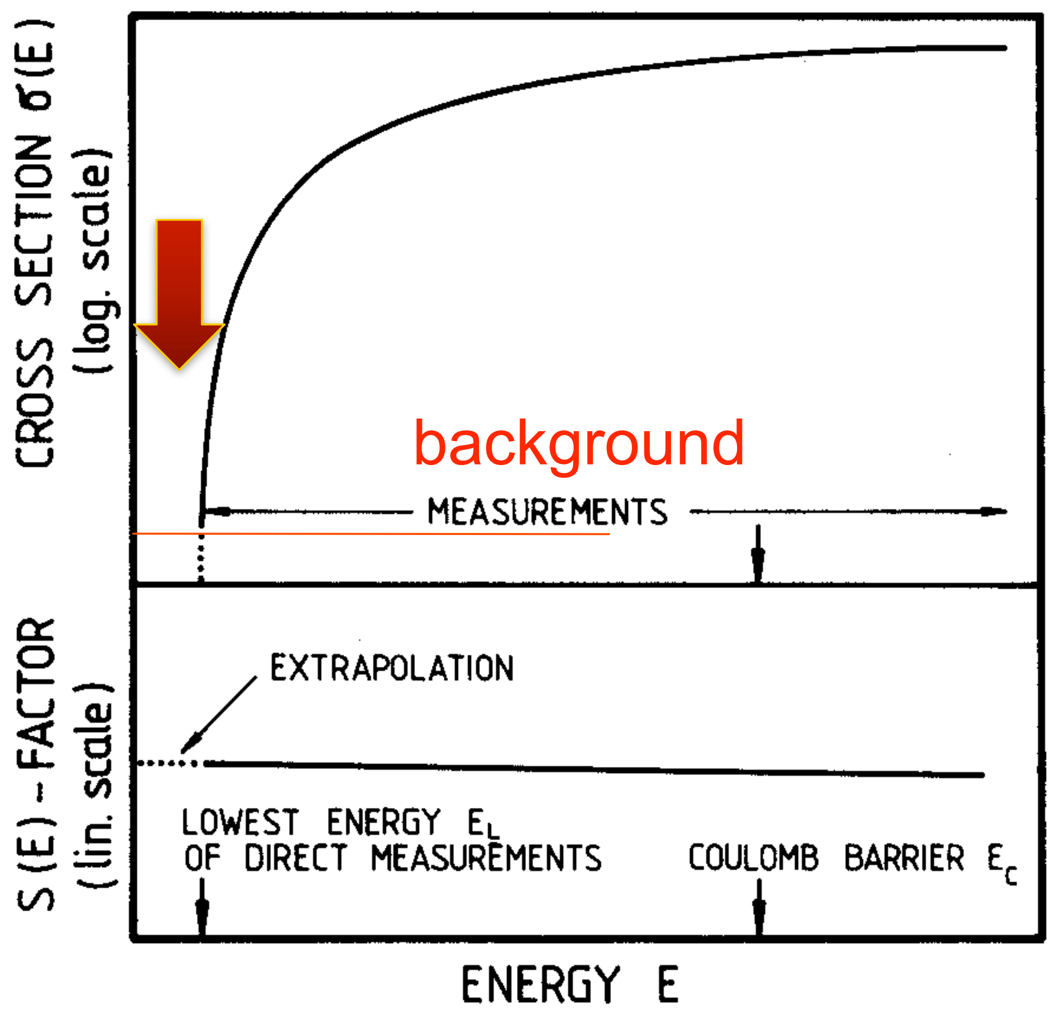


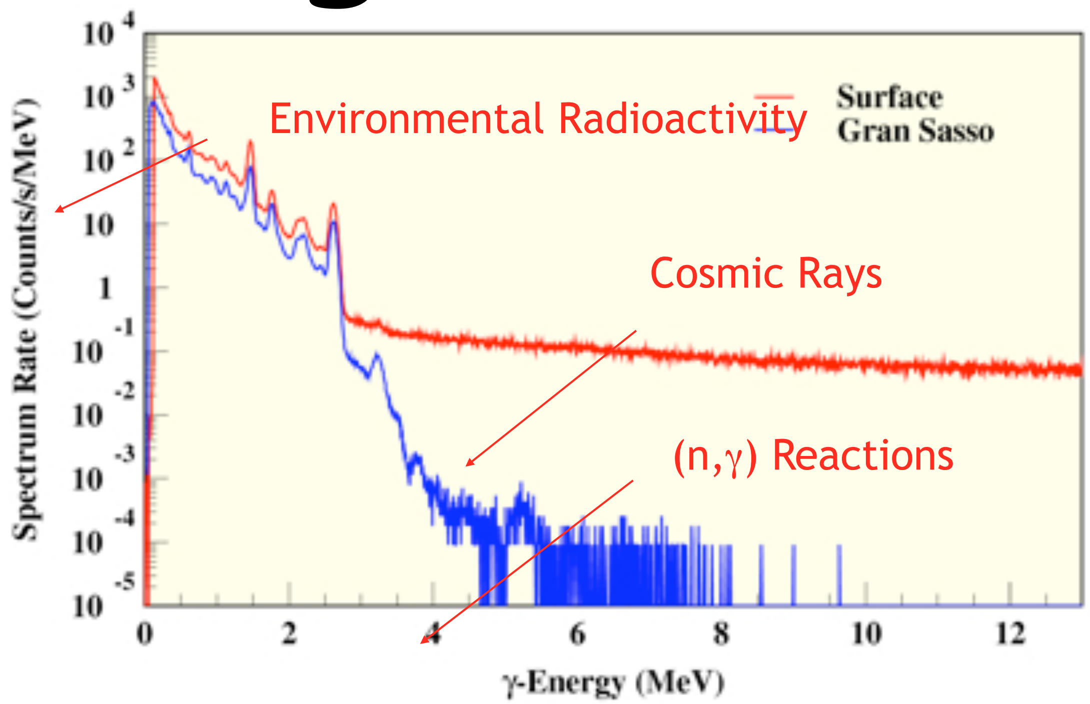
Origin of the Elements

in early & present Universe

- Neutron Sources
- Heavy Ion burning

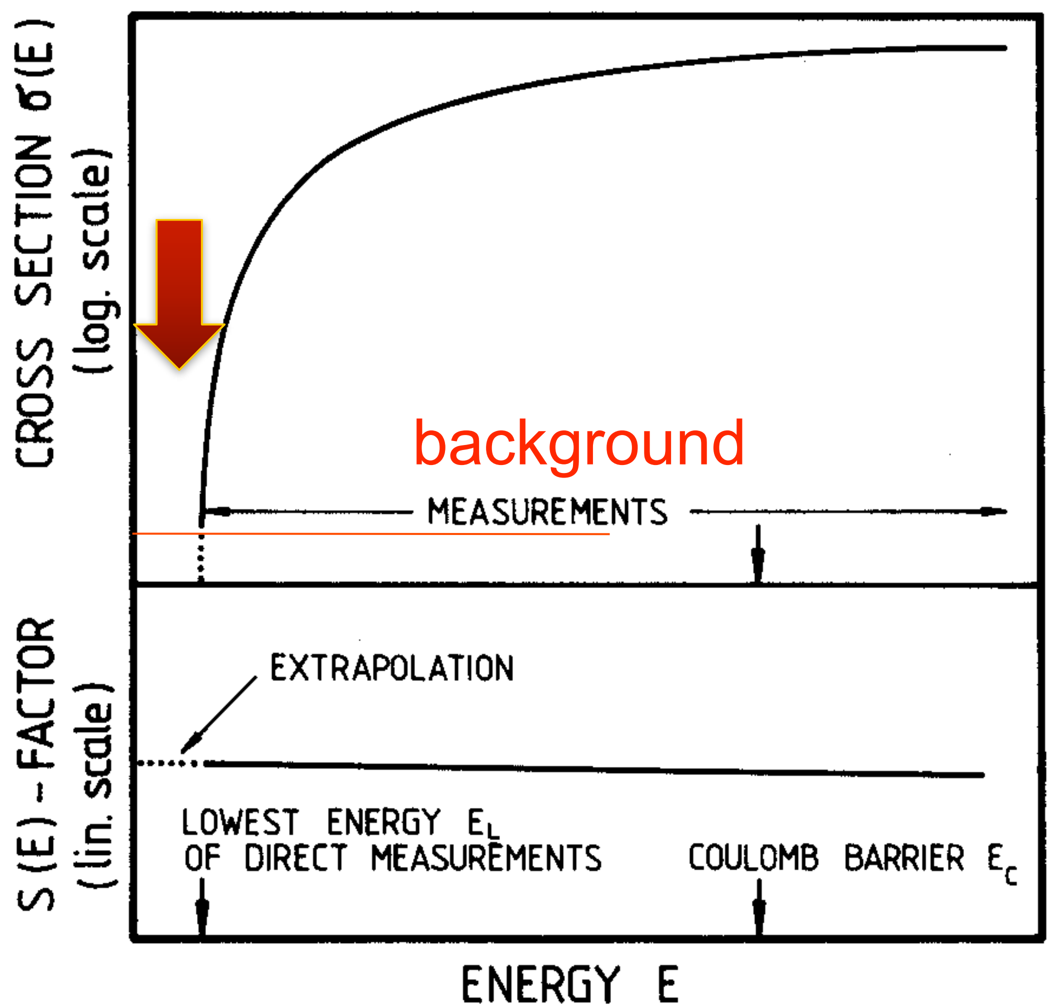
Why going underground?

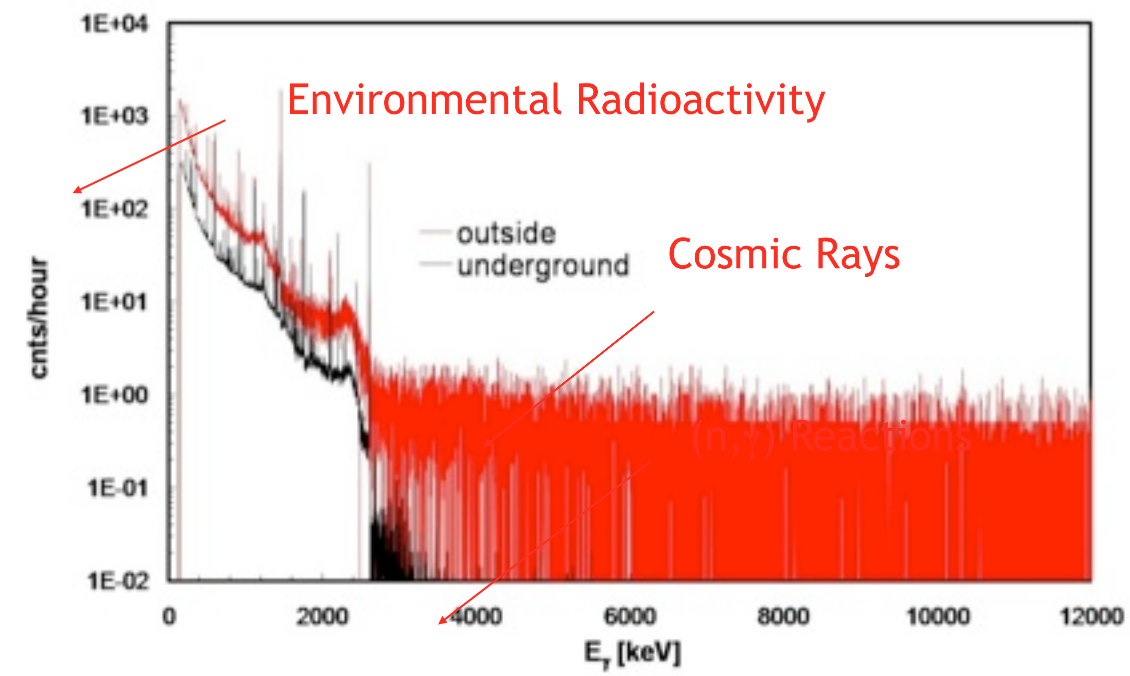




For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!

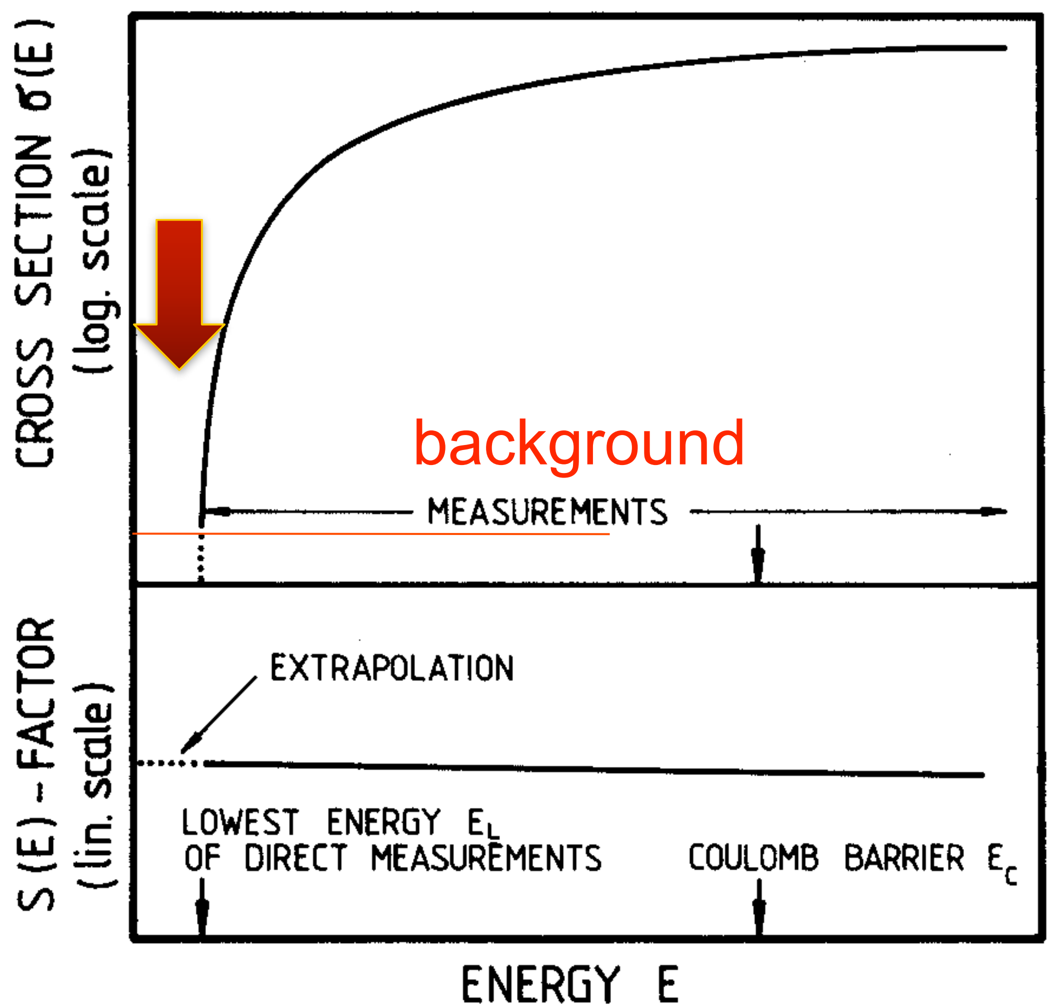
Why going underground?

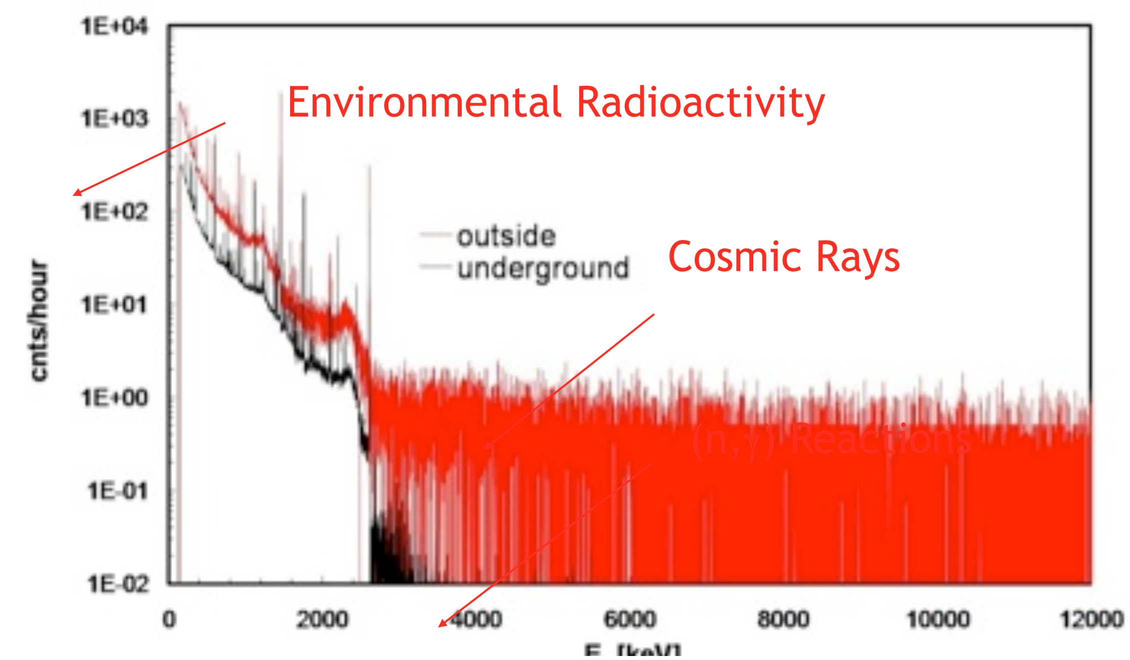


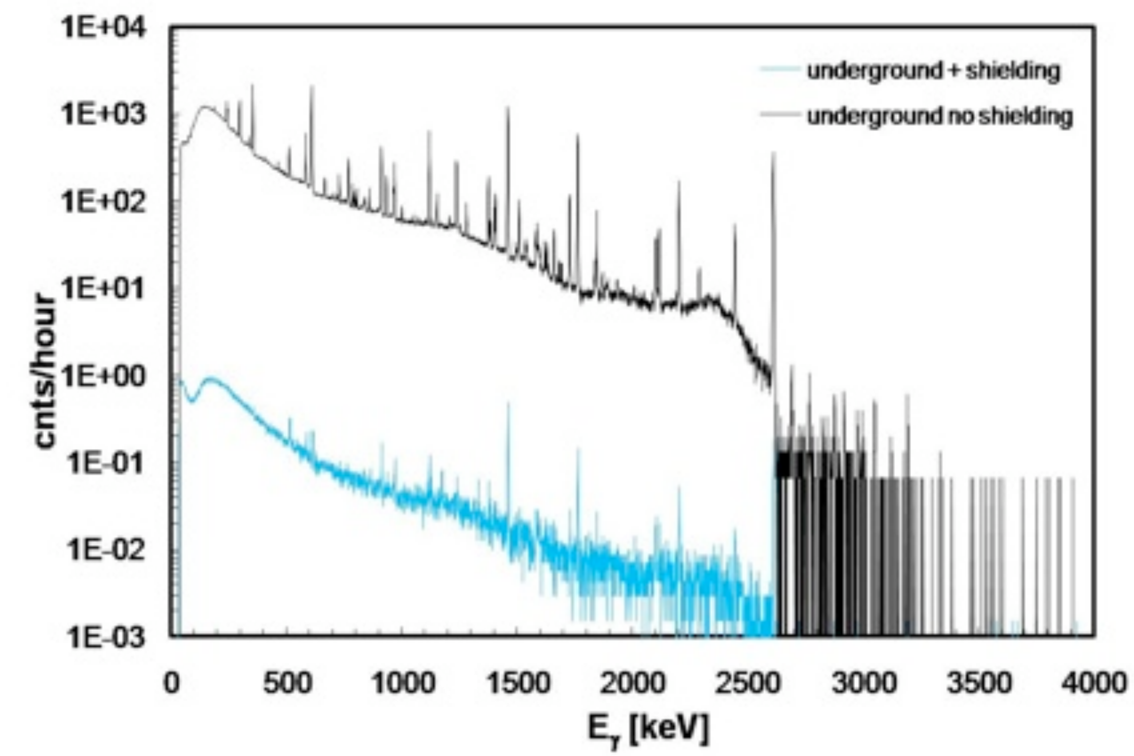


For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!

Why going underground?

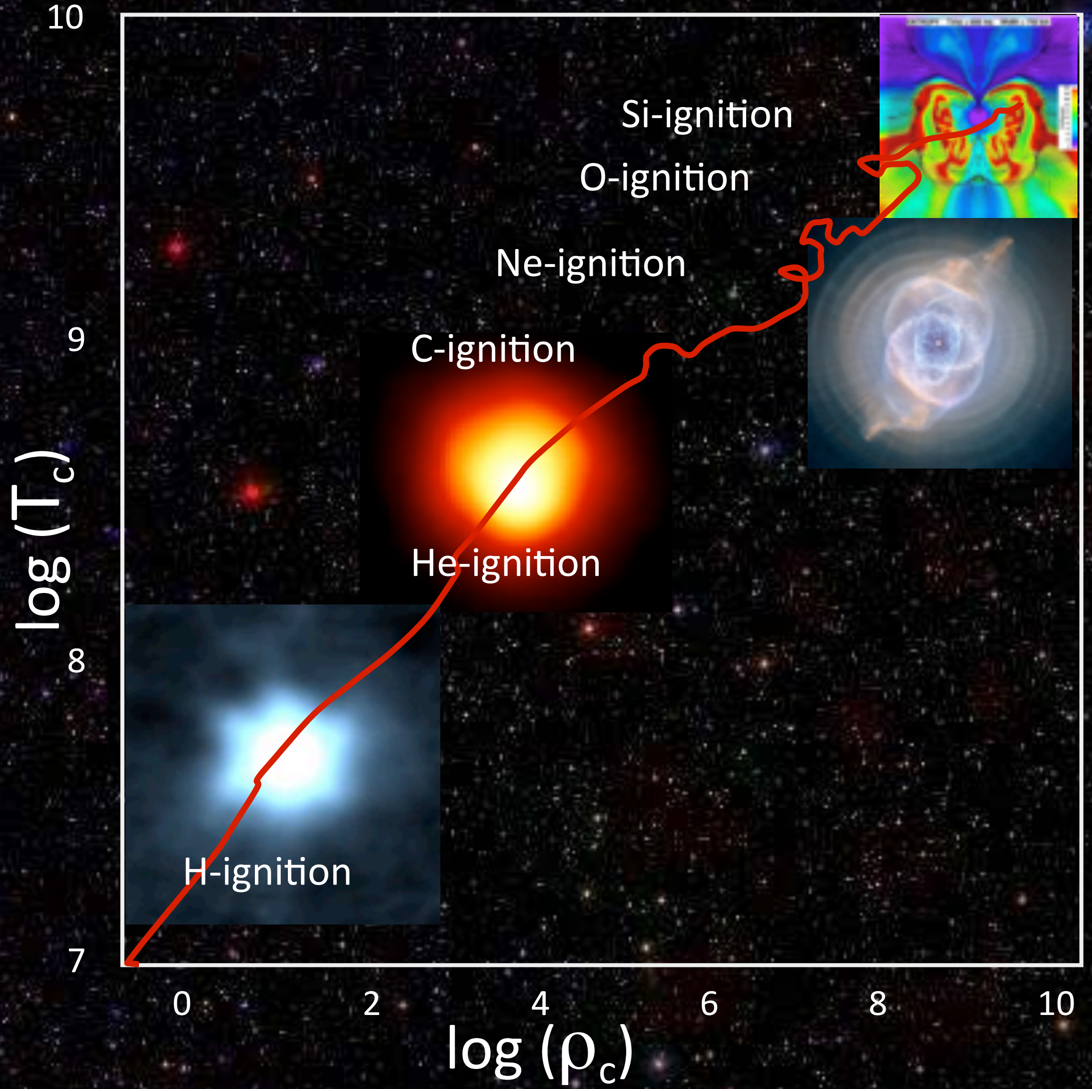






For low Q-value reaction: Local shielding (Pb) is more effective when the muon flux is reduced!

DIANA facility is a next generation facility that will support a vibrant 30 year+ science program



Hydrogen Burning

$^{3}He(\alpha,\gamma)^{7}Be$
$^{2}H(\alpha,\gamma)^{6}Li$
$^{3}He(^{3}He,2p)^{4}He$
$^{7}Be(p,\gamma)^{8}B$

$^{12}C(p,\gamma)^{13}N$
$^{14}N(p,\gamma)^{15}O$
$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$
$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$
$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

Helium Burning

$^{12}C(\alpha,\gamma)^{16}O$
$^{16}O(\alpha,\gamma)^{20}Ne$
$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
$^{24}Mg(\alpha,\gamma)^{28}Si$

Neutron sources

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

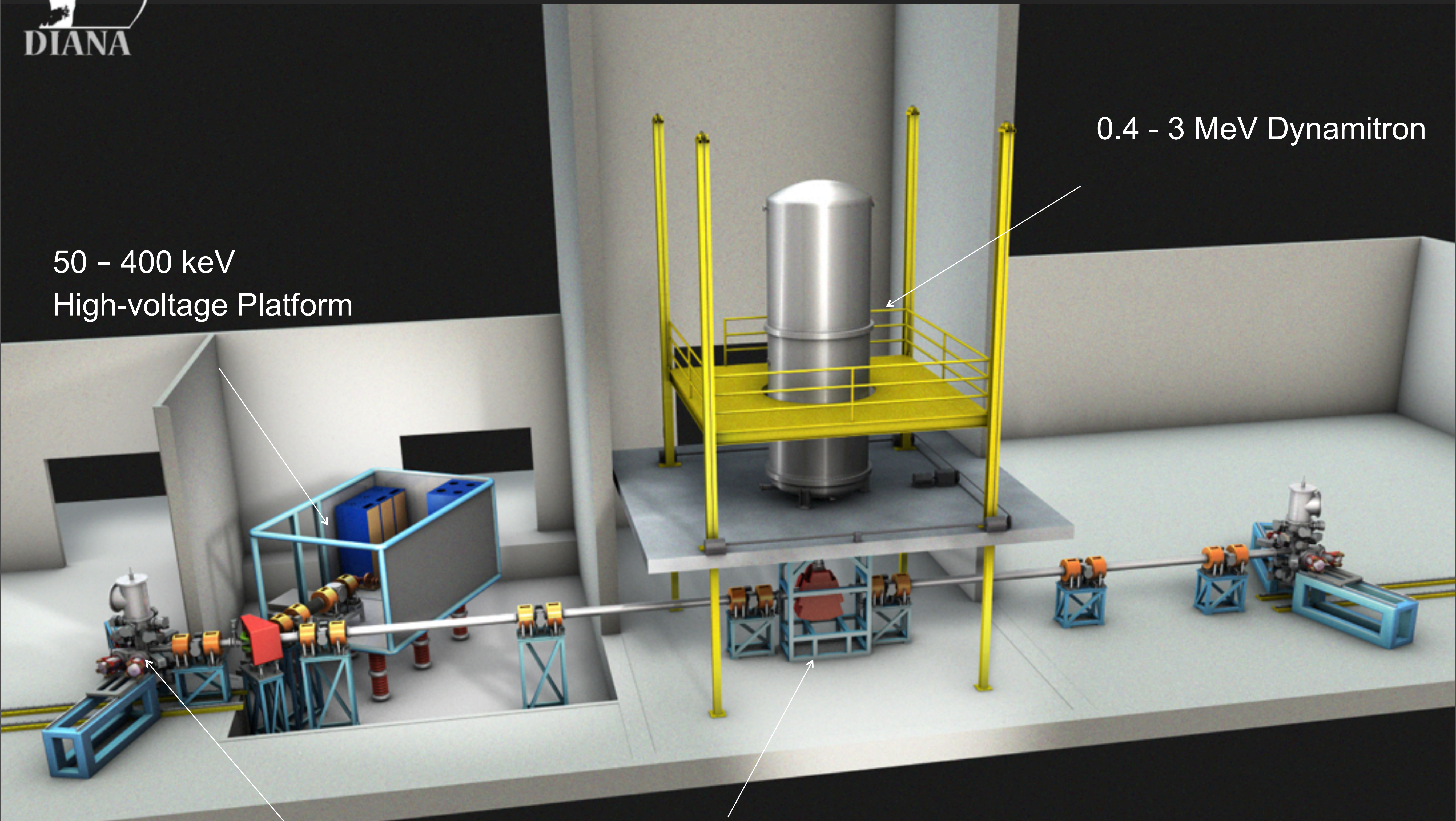
Two coupled accelerators allow consistent measurements of resonant structures and expand the physics program to helium burning reactions and late stellar evolution reaction

Heavy Ion Burning

$^{12}C+^{12}C$
$^{12}C+^{16}O$
$^{16}O+^{16}O$

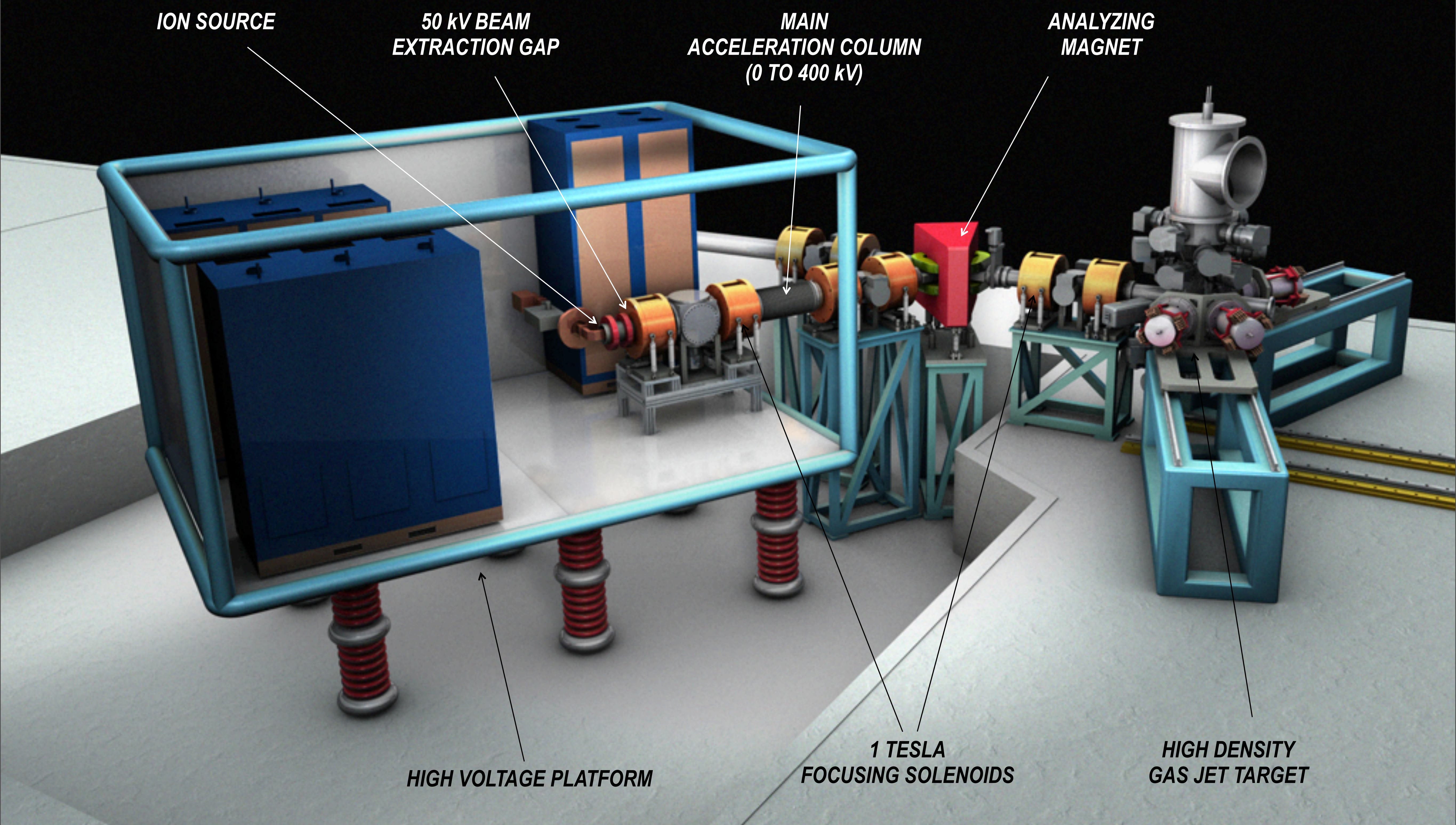
$^{17}O(\alpha,n)^{20}Ne$
$^{28}Si(\alpha,\gamma)^{32}S$
⋮

Unique Features of the DIANA Facility



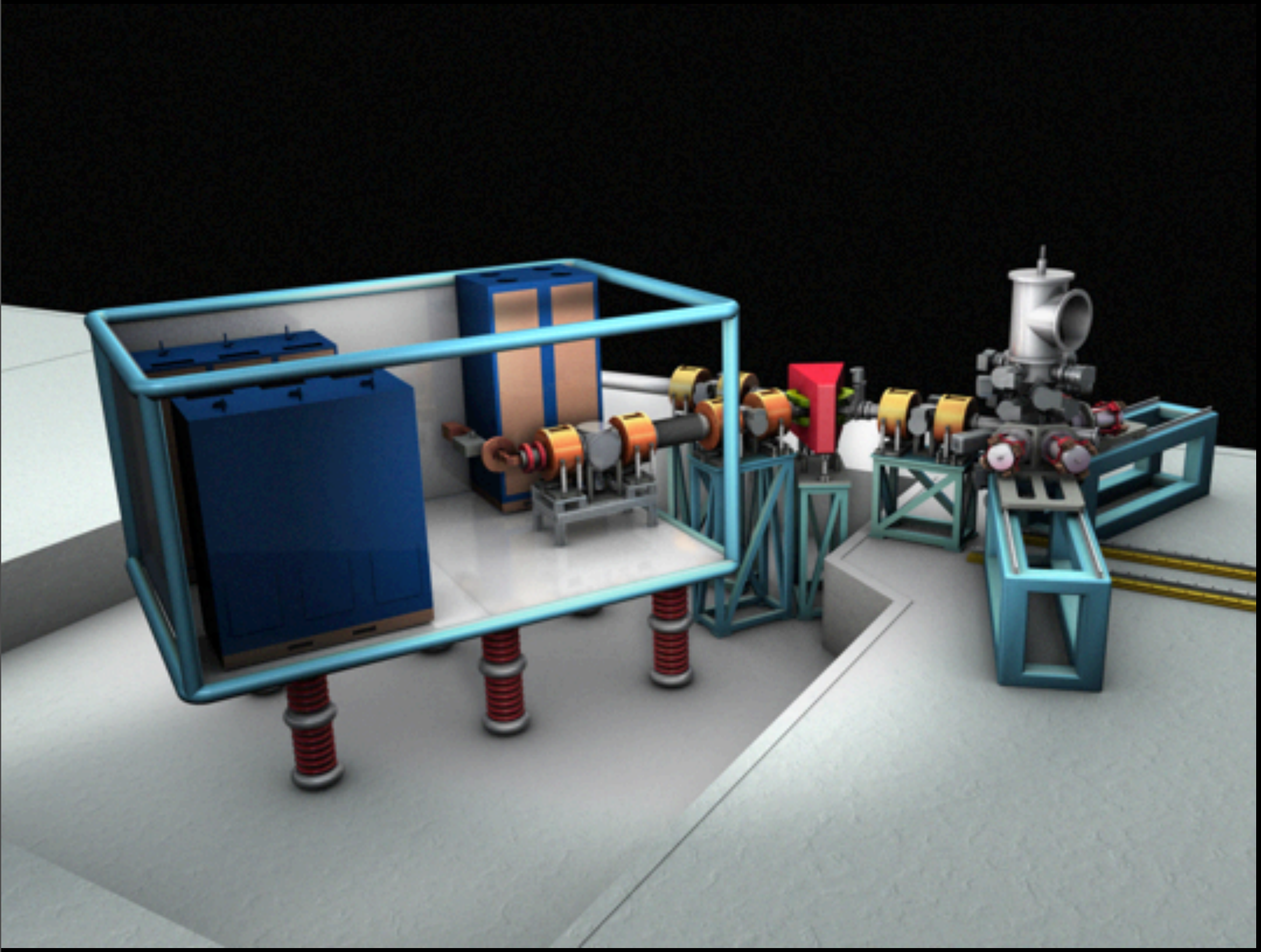
The two coupled accelerators cover a wide range of ion beam energies and intensities for consistent cross section measurements with identical target and detector set-up.

LOW ENERGY ACCELERATOR AND TARGET STATION



Milestone 12/30/2010 Ion optics completed

Low Energy Accelerator Challenges and R&D items



Unique Features

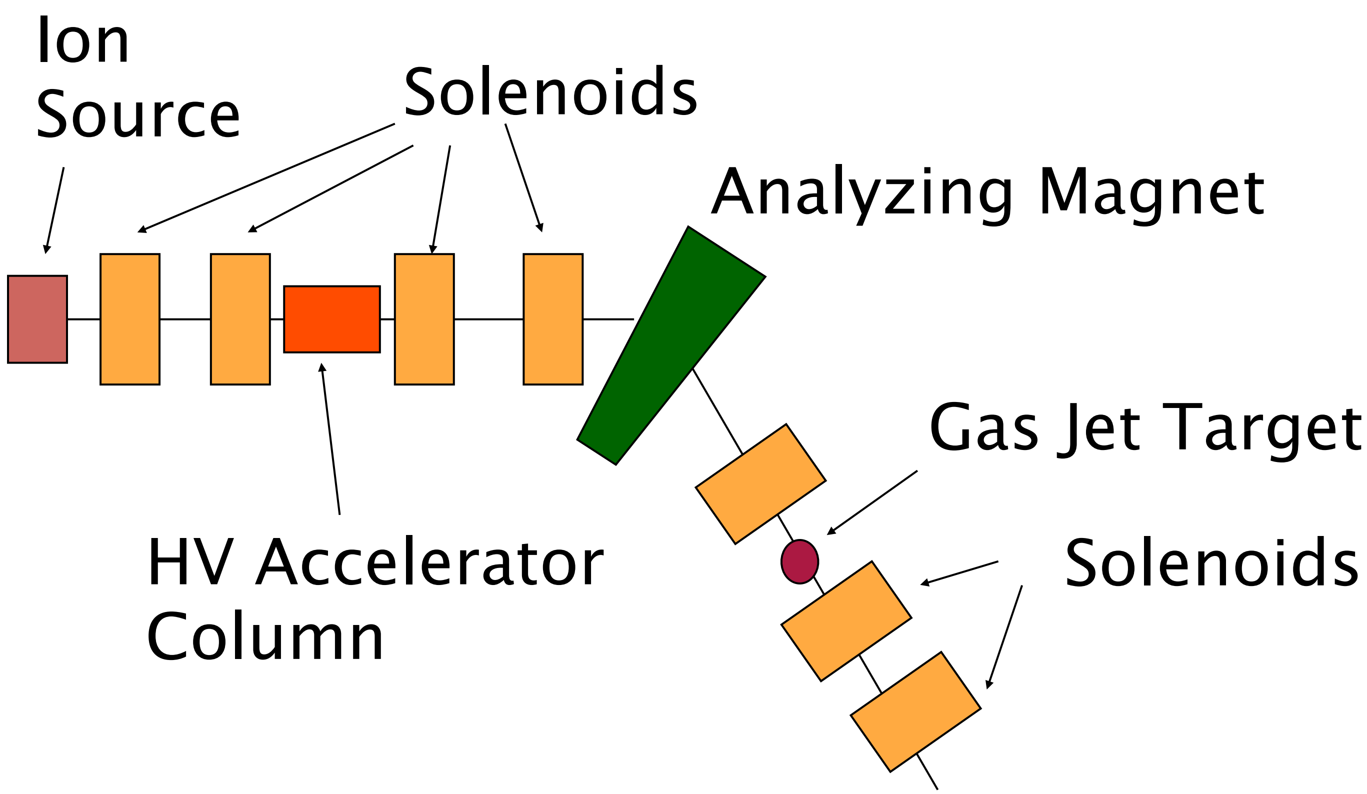
- high intensity from 50kV-400kV (up to 100 mA proton and 20 mA helium beam)
- beam focus < 1 cm
- energy Distribution: +/- 0.05 % of beam energy
- unique high density jet gas target
- coupled target with the high energy accelerator
- open-air high voltage platform for easy access

Unique Challenges

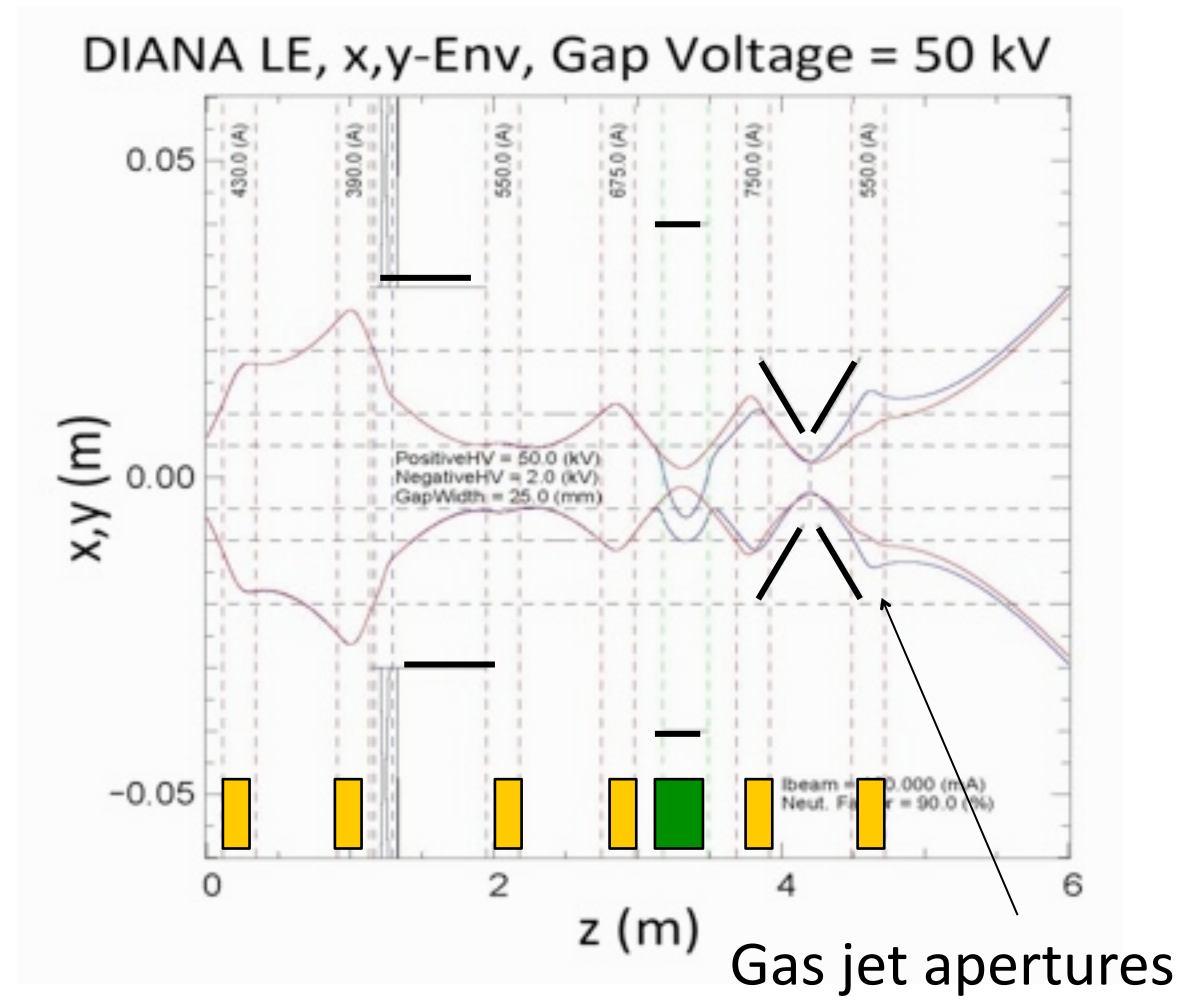
- preserving the beam properties on target over the whole energy range at high beam intensities
- beam diagnostics
- beam energy stabilization
- jet gas target design
- beam dump design

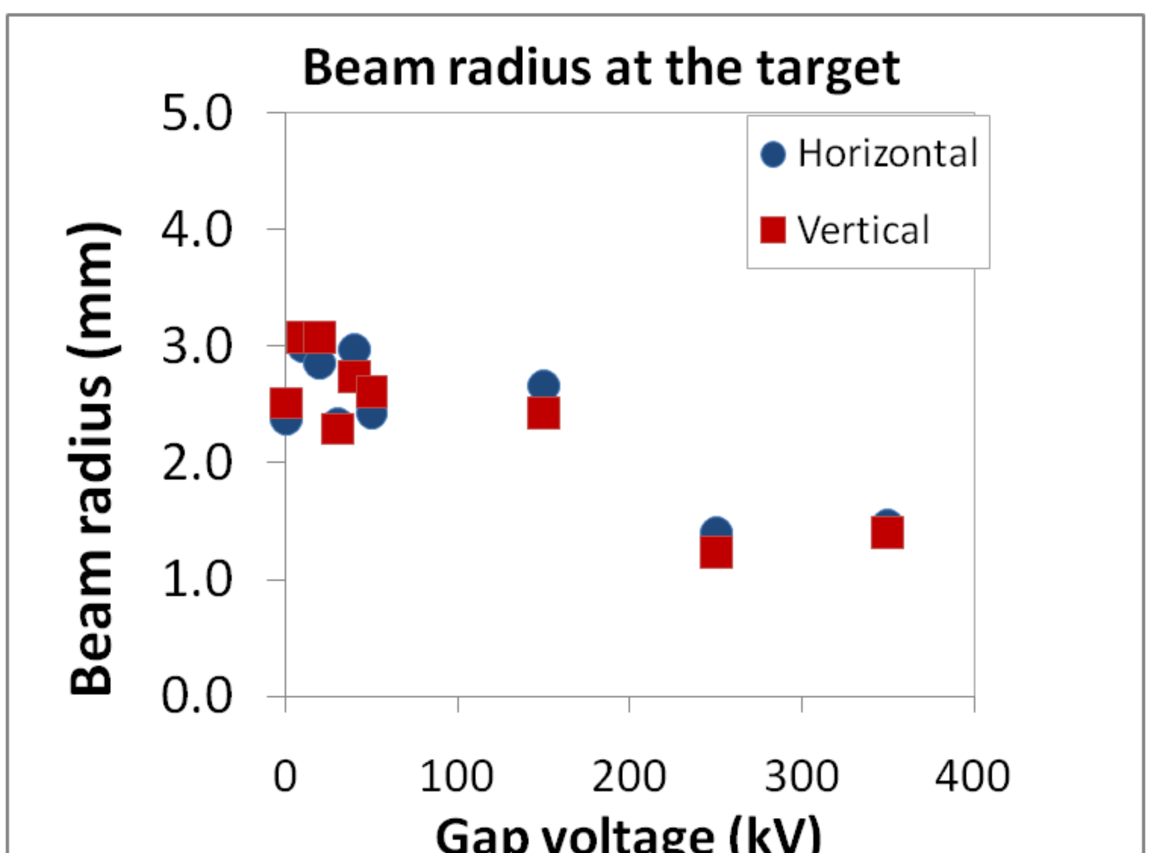
Up to 2 orders of magnitude higher beam current than presently available at state of the art facilities (to address the low count rates close to the Gamow window energies.)

Technical Progress: Low energy beam optics and design



Beam envelope

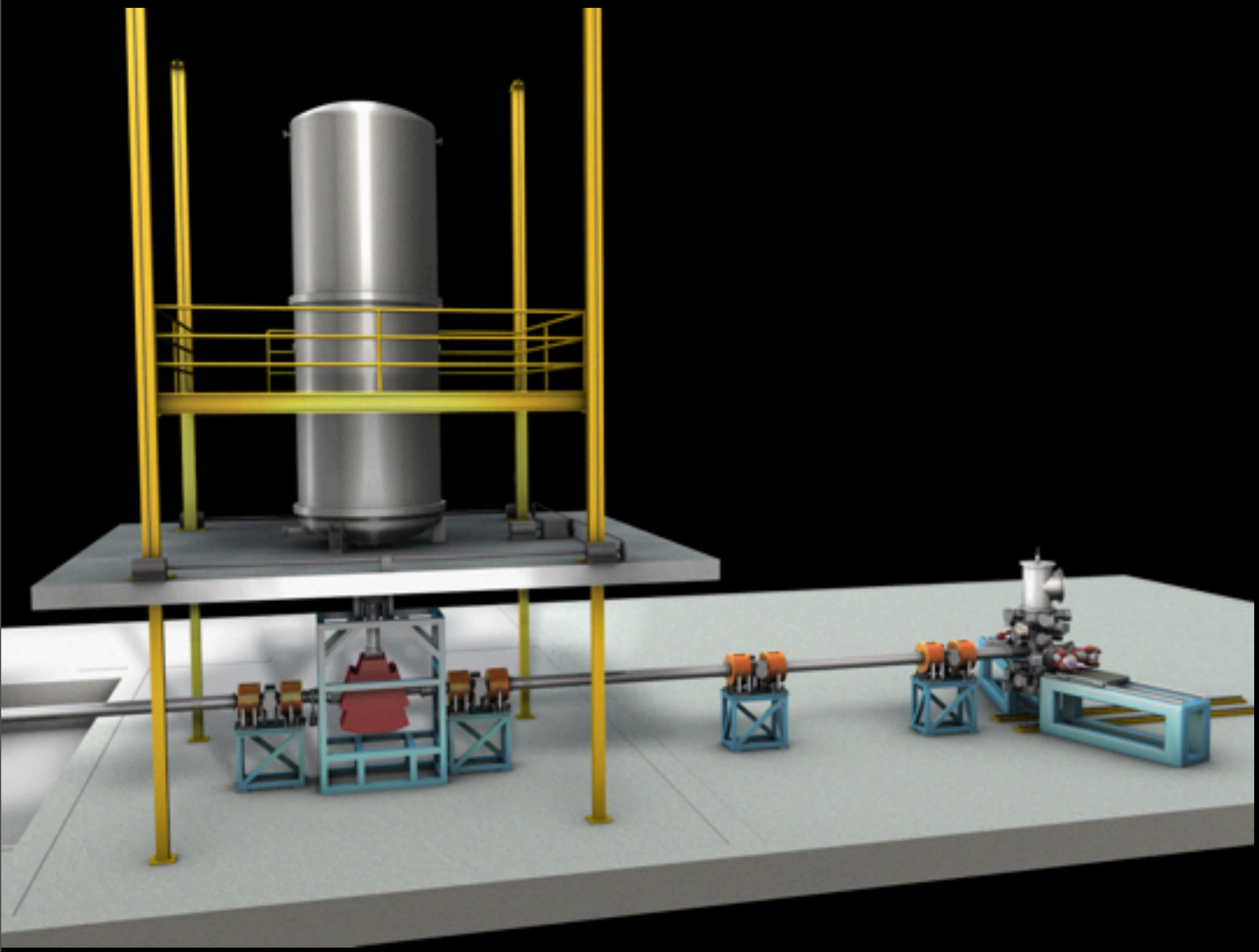




By adjusting the accelerator gap lengths and the focusing strength in the solenoids the beam diameter on target is less than 6mm on target over the whole energy range

Further optimization and integration with target and diagnostics is in progress.

High Energy Accelerator And Target Stations



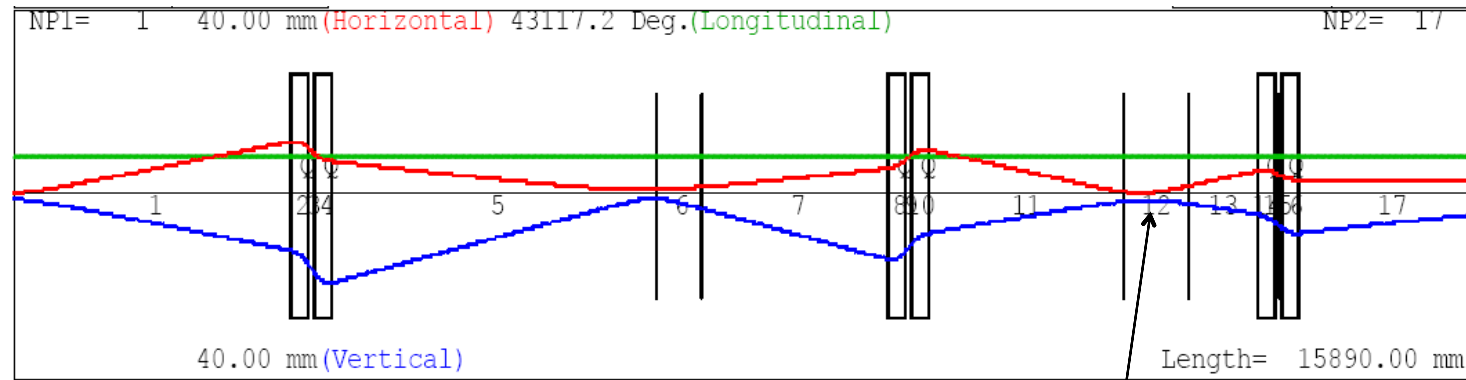
Commercial accelerator with some unique features:

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

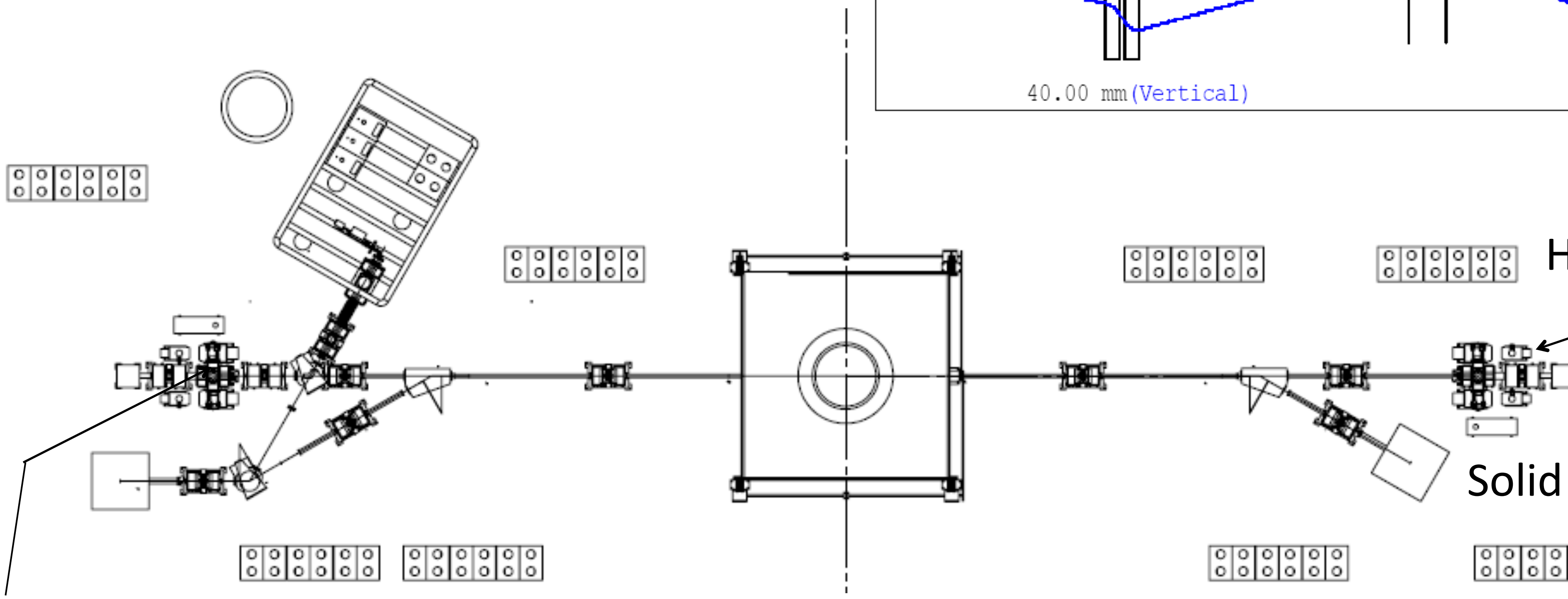
The high energy accelerator allows consistent measurements of resonant structures and expands the physics program to helium burning reactions and late stellar evolution reaction

Technical Progress: High energy ion beam optics

16 identical Quadrupoles (8 duplets)
3 Dipole magnets



High energy gas jet target



Solid target/extended gas target

Coupled low and high energy gas jet target

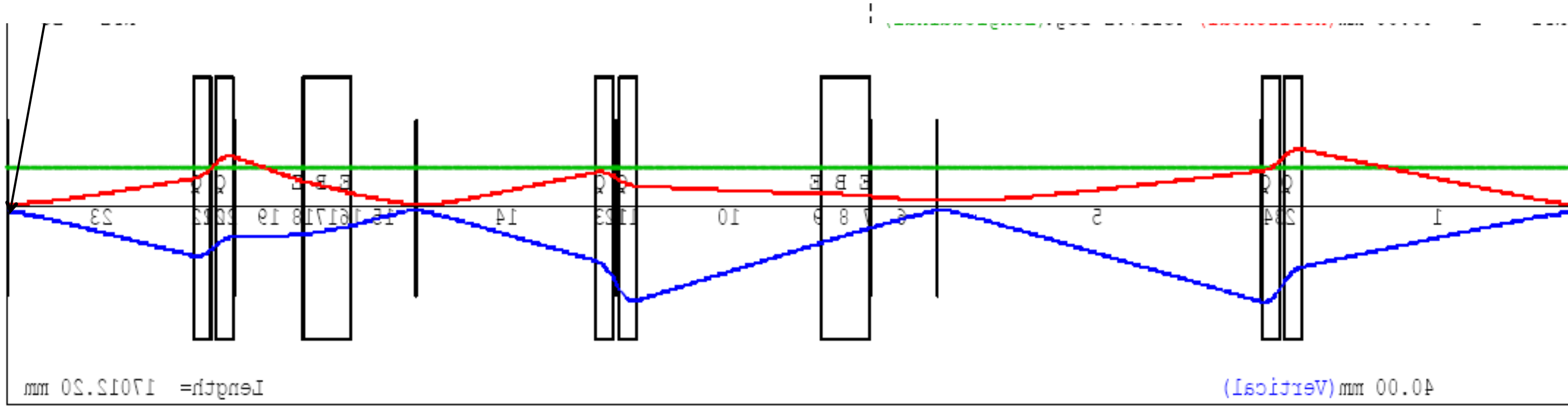
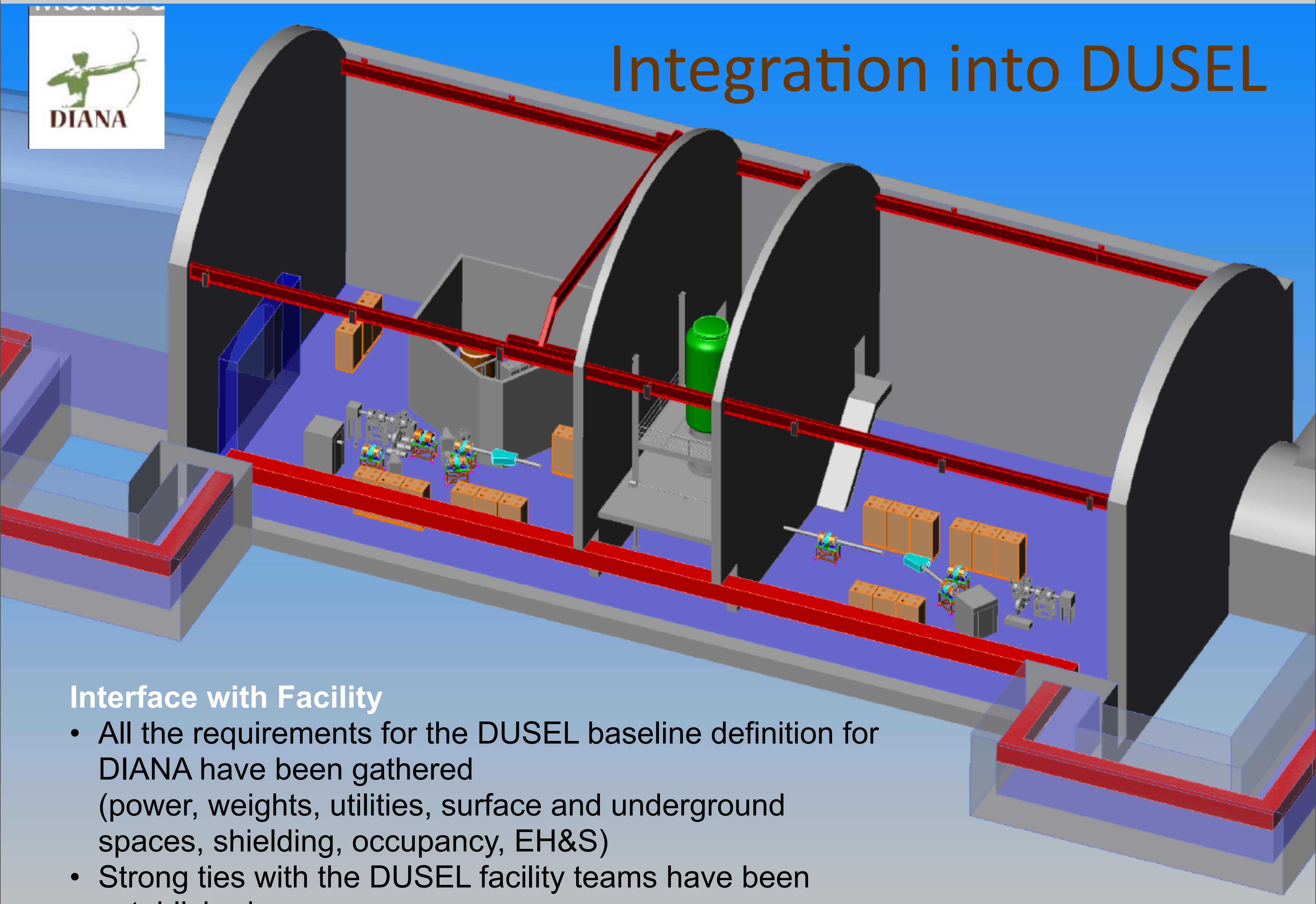


Image slits of the high energy accelerator (energy stabilization)

Milestone 12/30/2010 Ion optics completed

Integration into DUSEL

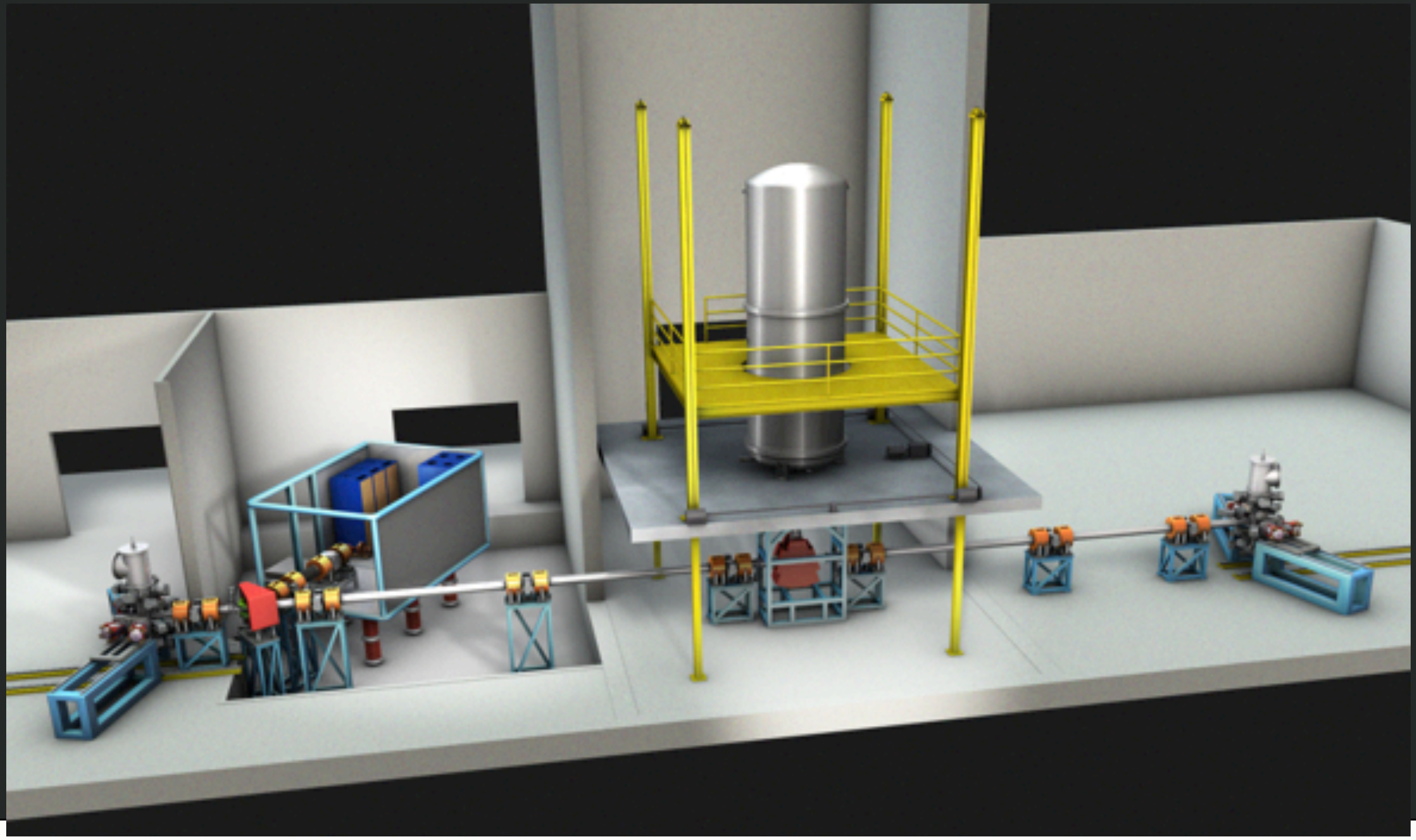


Interface with Facility

- 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

Summary

- 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)



UNIVERSITY OF NOTRE DAME · THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL · COLORADO SCHOOL OF MINES EARTH ENERGY ENVIRONMENT · REGIS UNIVERSITY · WESTERN MICHIGAN UNIVERSITY · BERKELEY LAB ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY