Physics, Astrophysics, Dark Life, Restless Earth, and Ground Truth in Initial Suite of Experiments

Harry Nelson and Derek Elsworth

Homestake DUSEL

April 20, 2007

Synopsis of Science Plan

- The PAC Process
- 2. DUSEL Science
  - 2.1 Underground Universe (Physics and Astrophysics)
  - 2.2 Dark Life (Biology)
  - 2.3 Restless Earth (Geoscience)
  - 2.4 Ground Truth (Geoengineering)
- 4. Homestake Project Goals and Requirements
  - 4.1 Homestake Early Implementation Plan and Early R&D
  - 4.2 DUSEL Initial Suite of Experiments

Evolution of DUSEL Collaborations

- DUSEL Development Promotes Multi-Disciplinary, Multi-Investigator Collaborations
- Homestake Phased Approach Offers Opportunities of Systematic Growth

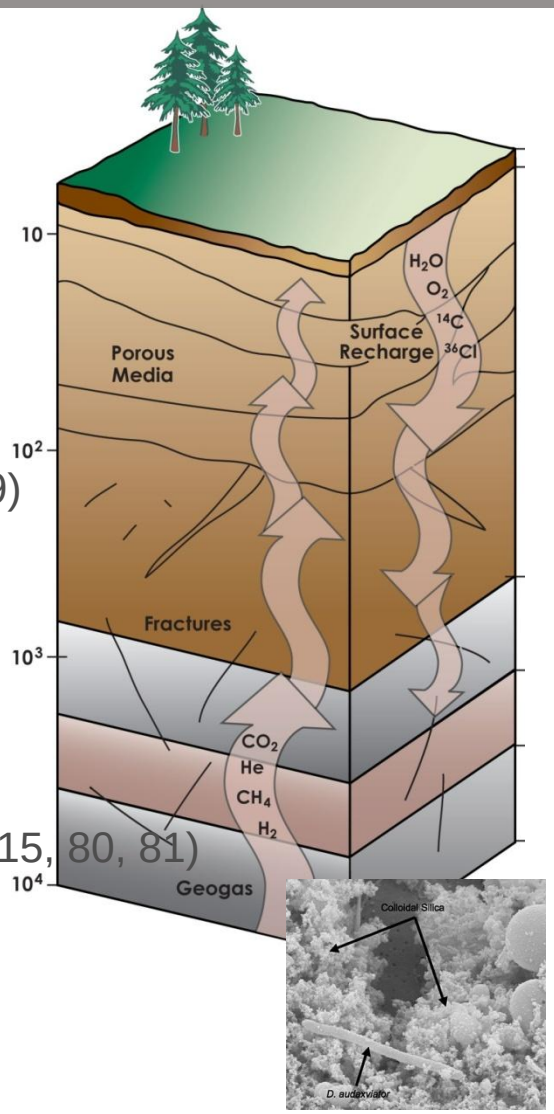
➢ 2000: Mine closure announcement, Bahcall/Lesko mtg. with earth science and physics communitities
➢ 2001: Underground Science Meetings; Earth science, physics and geomicrobiology workshops
➢ 2002: NSF visit, ARMA/NRC and NeSS mtg.
➢ 2003: ARMA-NSF and EarthLab reports, first site announcement, pump stoppage
➢ 2004: NSF S-process announcement, S-1 workshops
➢ 2005: S-2 applications, H-H selection, AGU townhall, S-2 workshops
➢ 2006: Letters of Interest, PAC recommendation, CDR-100 submitted
➢ 2007: CDR-250 for S-3, NSF Site Visits, Homestake S-3 workshops

The Geo-Universe – Science Questions

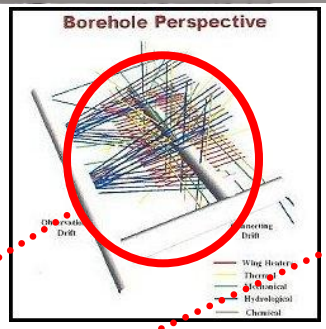
- Dark Life (Biology)
  - How deep does life go?
  - Do biology and geology interact to shape the world underground?
  - How does subsurface microbial life evolve in isolation?
  - Did life on earth originate beneath the surface?
  - Is there life on earth as we don't know it?
- Restless Earth (Geosciences)
  - What are the interactions among subsurface processes?
  - Are underground resources of drinking water safe and secure?
  - Can we forewarn of earthquakes?
  - Can we view complex underground processes in action?
- Ground Truth (Geoengineering)
  - What lies between boreholes?
  - How can technology lead to a safer underground?
  - How do water and heat flow deep underground?

Dark Life - Geomicrobiology (>15 LOIs)

- **Early Reentry LOI's**
  - Bioprospecting (LOI 28)
  - Robotic sampling (LOI 25)
  - Mine soil weathering (LOI 29)
  - Microbial ecology + geomicrobiology (LOI 38, 53a)
  - Corrosion of mining structure (TCO3+LOI38, 53a)
- **4850 Level LOI's**
  - Microbial ecology + geomicrobiology (LOI 3, 53a, 83)
  - Deep Biogeochemical Cycles (LOI 70, 38, 83)
  - Transition biogeochemistry and impact on geology (LOI 75, 79)
  - Intermediate Coupled Processes Laboratory (LOI 38, 53a, 76)
    - Bioprospecting (LOI 28)
    - Robotic sampling (LOI 25)
    - Mine soil weathering (LOI 29)
    - Corrosion of mining structure (LOI 38, 53a, 77)
- **DUSEL – deep level – LOI's**
  - Limits of life (3+ km borehole array) from 8,000 level (LOI 38, 15, 80, 81)
  - Deep Coupled Processes Laboratory (LOI78, 83)
  - Deep Biogeochemical Cycles (LOI 70&38)*
    - Bioprospecting (LOI 28)
    - Robotic sampling (LOI 25)
    - Mine soil weathering and corrosion (LOI 29, 38, 53, 77)



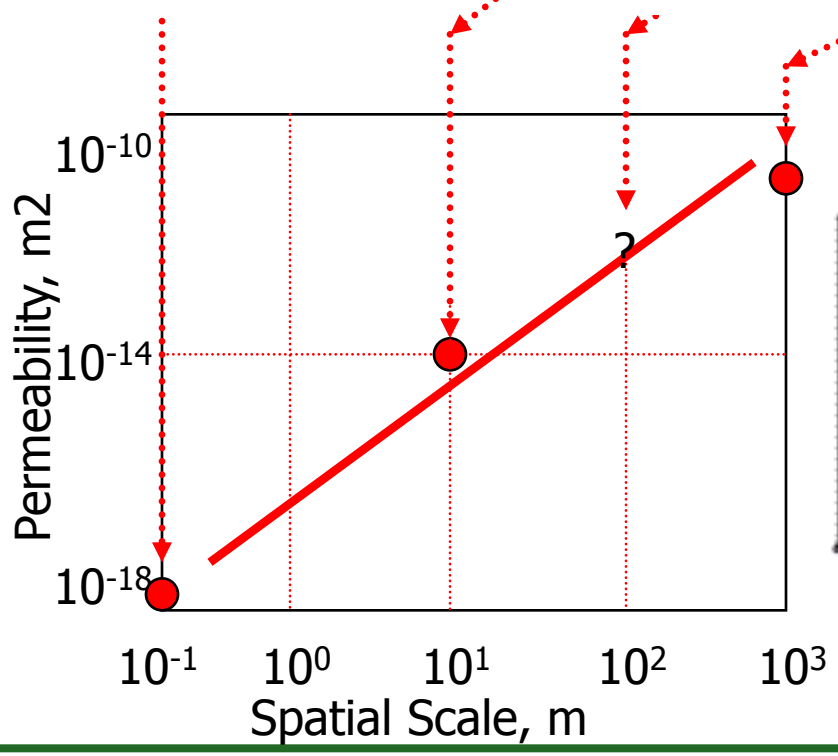
Scale Effects in Hydrology – Space and Time

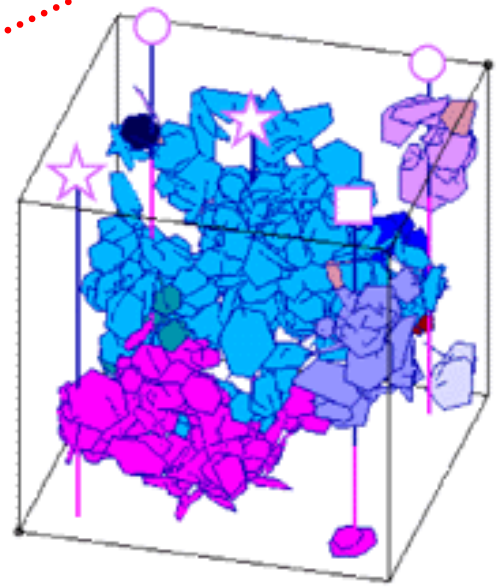


Lab scale

Field scale

Regional scale

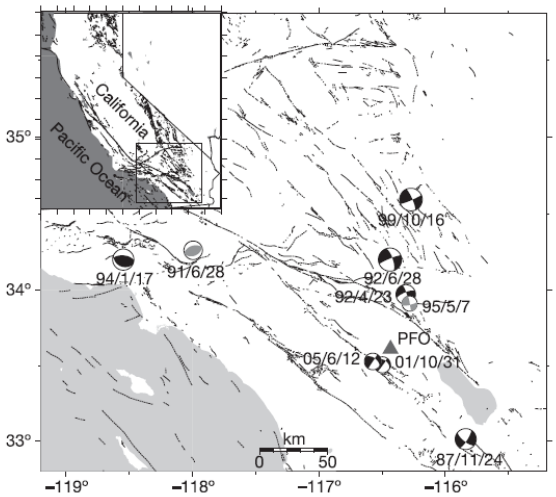


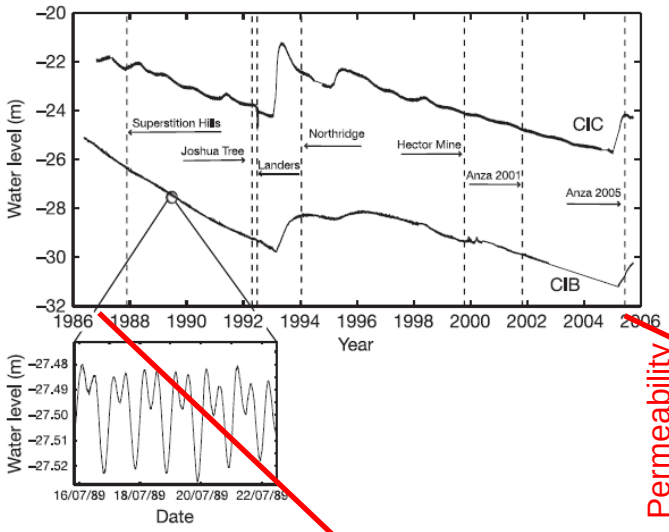


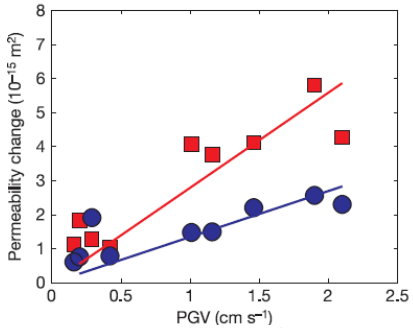
Production

- Excellent - Major compartments intersected
- Significant - Interference from wells sharing compartments
- Poor - No major compartments intersected

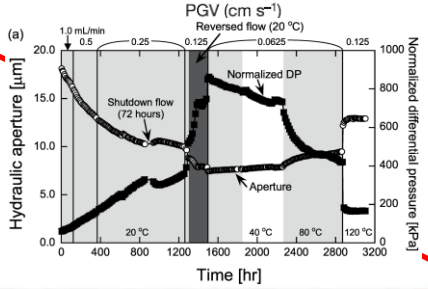
Scale Effects in Hydrology – Space and Time





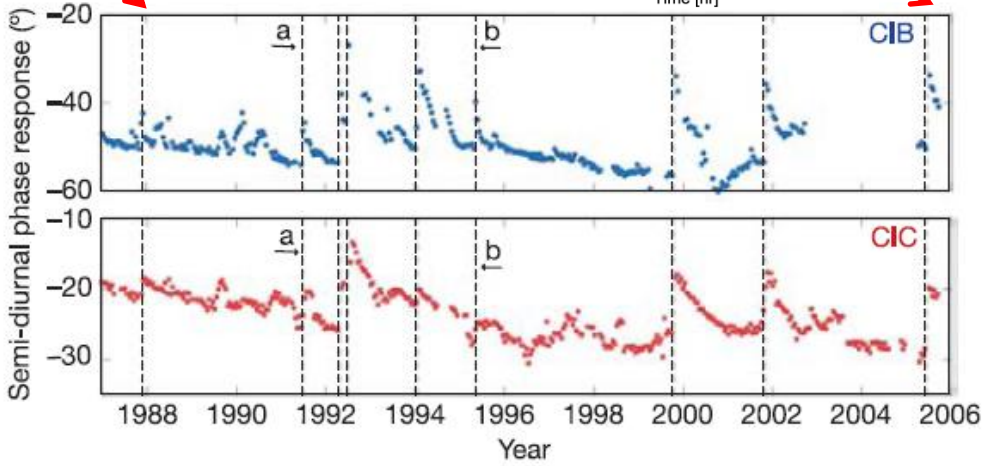


Permeability

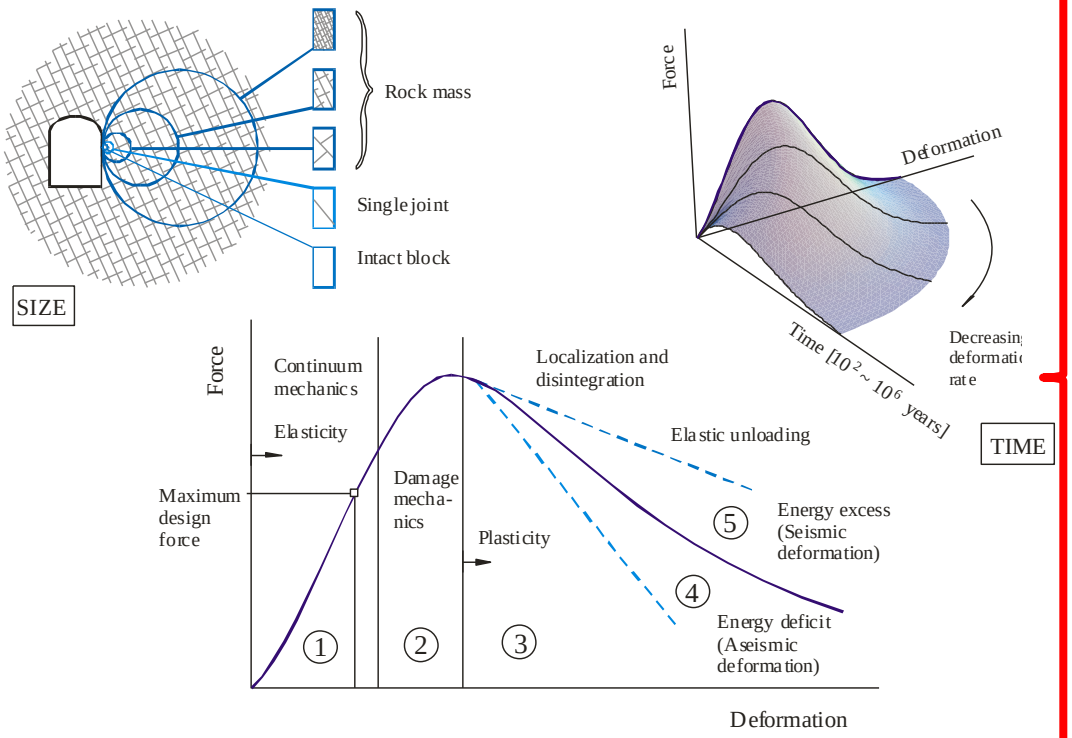


- Remote earthquakes trigger dynamic changes in permeability
- Unusual record transits ~8y
- Sharp rise in permeability followed by slow “healing” to background
- Sales of observations:
  - Field scale
  - Laboratory scale
  - Missing intermediate scale with control

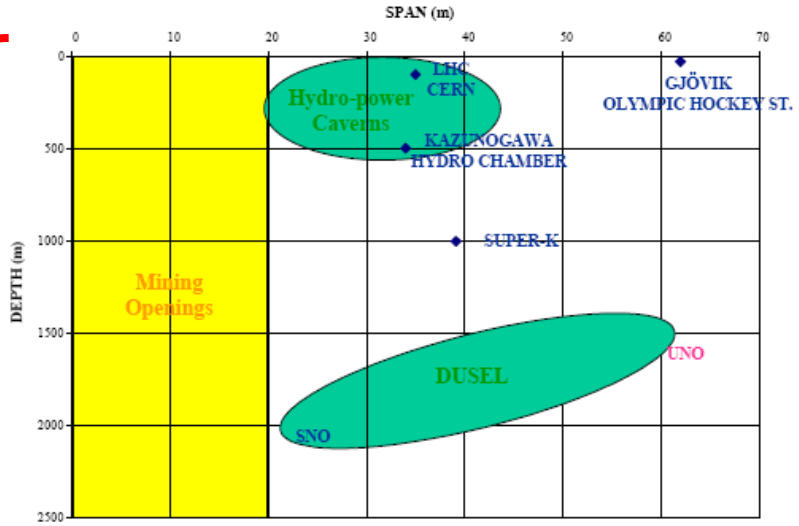
Permeability



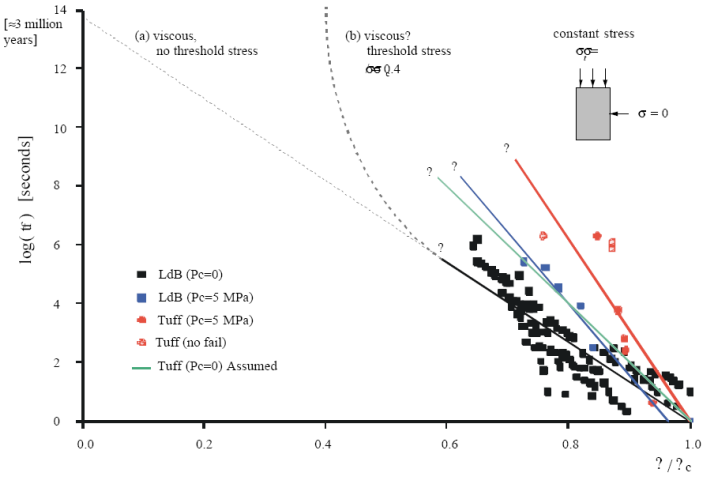
Scale Effects in Geomechanics – Space and Time



Complete Load-Deformation Behavior



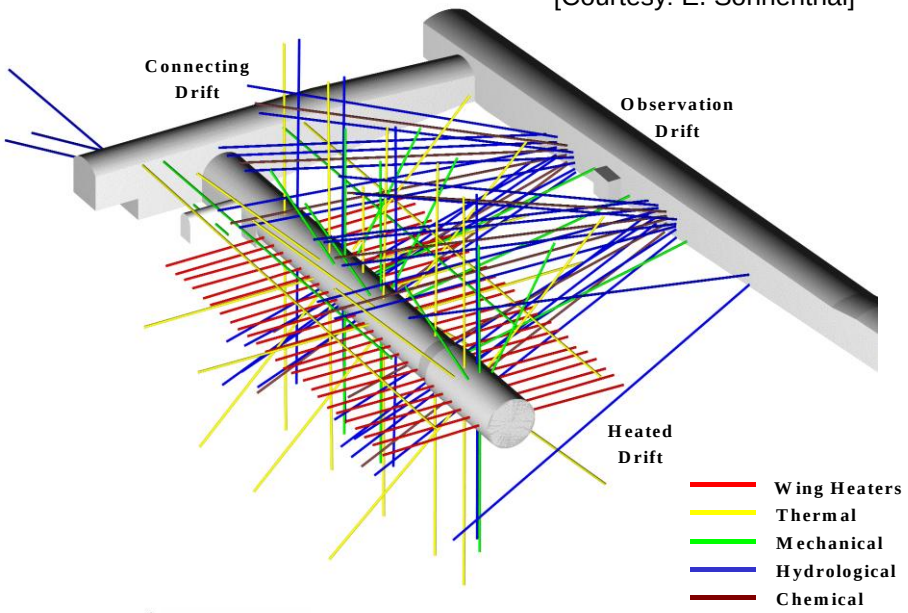
[Elsworth and Fairhurst, NSF-S1, 2007]

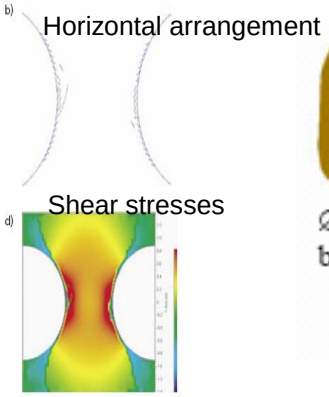


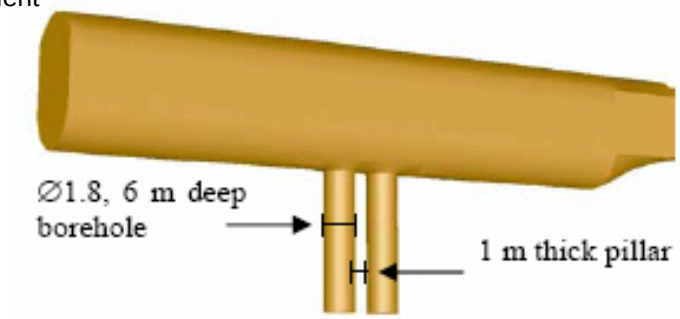
Coupled Thermal, Hydrological, Mechanical and Chemical Processes

- Purpose of the test is to evaluate coupled thermal, hydrological, mechanical and chemical processes surrounding the potential repository
- Dimensions: ~ 50 meters long by 5 meters in diameter
- Electric heaters activated Dec. 1997, turned off Jan. 2002
- Maximum drift wall temperature reached ~ 200°C
- Water, gas, and rock samples collected from boreholes for geochemical and isotopic studies
- Reaction-transport modeling performed prior to and during test (examples on following slides)

[Courtesy: E. Sonnenthal]



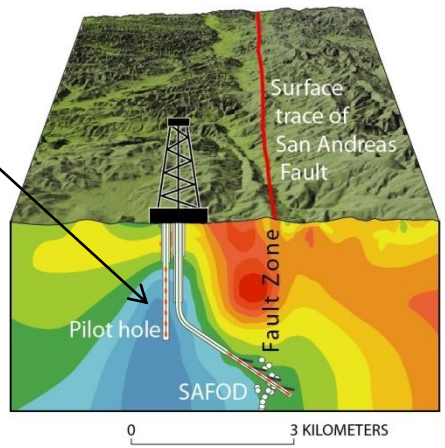


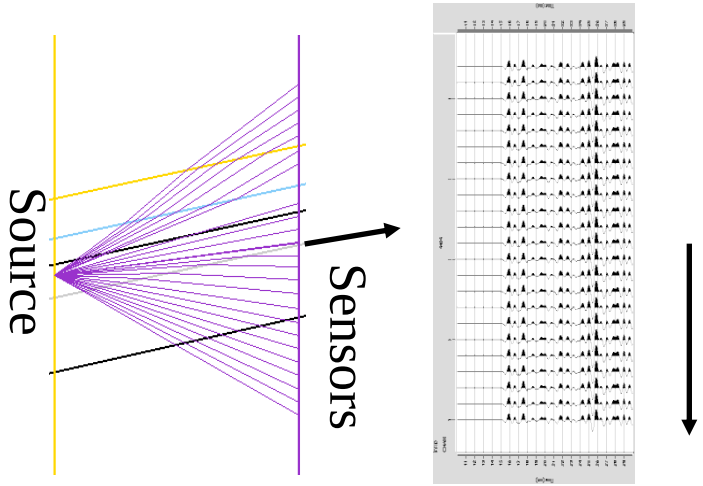


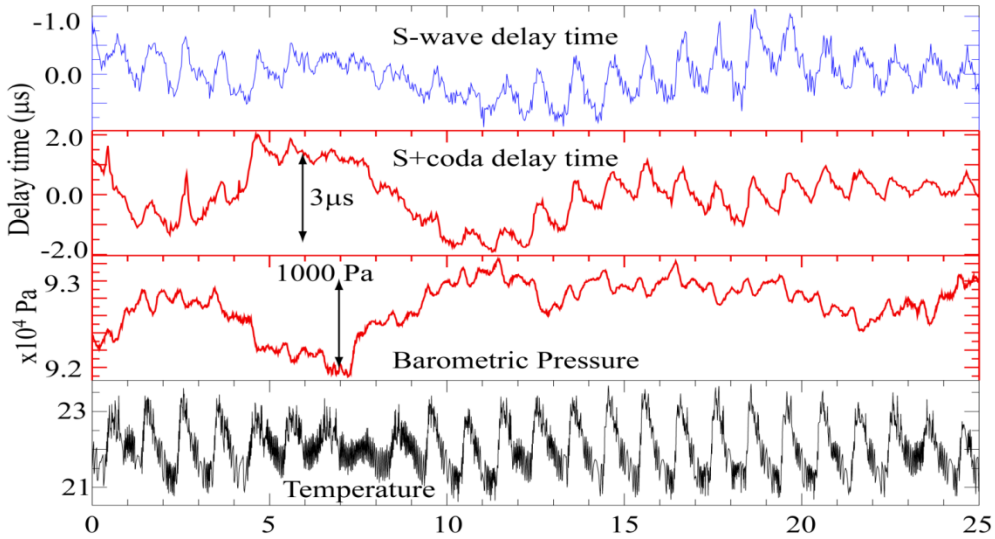
[Rinne et al., SKB, R-04-04, 2004]

Imaging for Constitutive Behavior

Crosswell:
1.1 km deep
~12 m apart







Result: Velocity change: 3.0E-4;
Stress sensitivity: 3.0E-7 Pa^{-1}

- Goal: In-situ monitoring of stress changes using seismic travel time change
- Motivation:
  - Earthquake 'Prediction'
    - Tectonic stress change
  - Reservoir Management
    - Fluid Pressure via effective stress
    - Subsidence via stress and strain changes
- Need calibration signal to determine stress sensitivity: Barometric Pressure or Earth Tides

Dark Life and Geobiology

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
How do biology and geology interact to shape the world underground?	Ecology/geomicrobiology – LBNL (38); Geomicrobiology on geochemistry, transport, corrosion – Princeton (75, 76, 77); Coupled Process, near surface to deep – Oak Ridge Nat. Lab. (78, 79)	Low radiation on human – Brookhaven Nat. Lab (14); Microbial evolution –U Tennessee (15); Soil, health physics, microbial population – SDSU (29, 30, 32); Microbiological analysis – U. Wisconsin (70)
How does subsurface microbial life evolve in isolation?	(38); Limits of life – New Mexico Tech. (80)	Microbial diversity – SDSMT (53)
Did life on earth originate beneath the surface?	(38); (80)	Autotrophy – SDSU (81)
Is there life underground as we don't know it?	(38); (80)	Bioprospecting – SDSU (28)

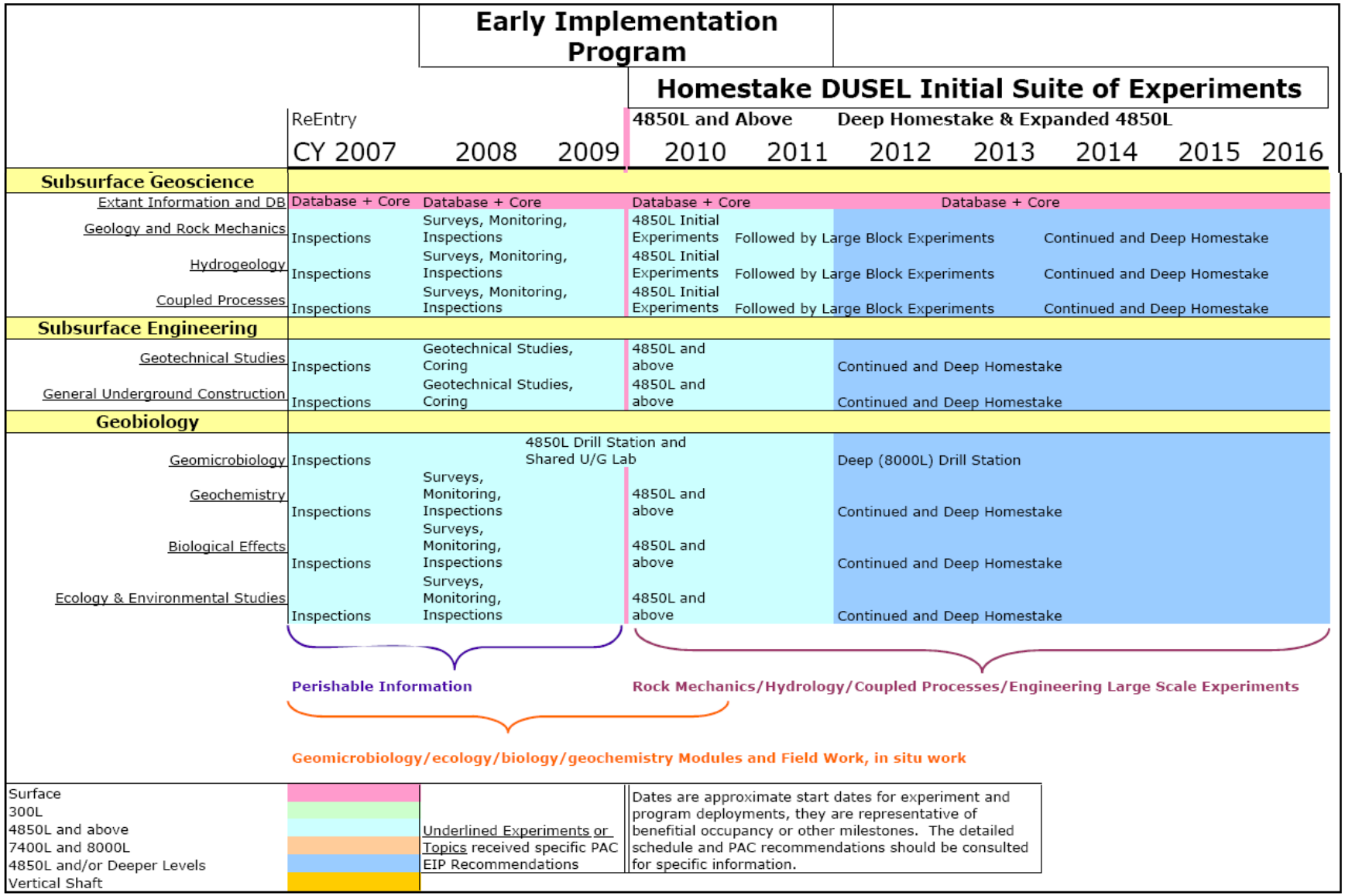
Restless Earth and Geosciences

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
What are the interactions between the various processes controlling the subsurface environment?	Coupled process – LBNL (41); Block test of rock failure – Penn. State (55); Hydro/Mechanical - U. Wisconsin (65); (78)	Partitioning between hinges - Montana Tech. (10); Gold mineralization, role of iron, thermal history, breccia evolution, volatile in dikes – SDSMT (18, 20, 21, 44, 68); Faulting and fracture – U. Hawaii (43); Stress-Fluid Monitoring - Freie U. Berlin (60)
Are underground resources of drinking water safe and secure?	Hydrogeology, geochemistry – LBNL (36, 37)	
Can we reliably predict and control earthquakes?	Sensors – UCB (13); Geophysics – LBNL (39); (55)	
Can we make the Earth "transparent" and observe underground processes in action?	(39)	Cosmic Ray – LBNL (42)

Ground Truth and Geoengineering

Goals/Questions	Collaborations for experiments that will address this issue (LOIs)	Specific approaches to implement required tasks (LOIs)
What are the mechanical properties of rock?	Mining Engineering - SDSMT (4)	Deformation, scaling, and stress in Yates - U Utah (1, 2, 3); Fracture network - Virginia Tech. (34)
What lies between the boreholes?	(13); (39)	Mapping/surveying-Montana Tech (9); Geological model, mapping - U. Minnesota (45, 46); Mapping – Virginia Tech. (47) Database, acoustic mapping – SDSMT (11, 62)
How does rock respond to human activity?	Rock mechanics geotechnical – LBNL (40)	(1)
How does water flow deep underground?	(36)	Dewatering, hydrological instrumentation, footprint – SDSMT (6, 12, 24)
How can technology lead to a safer underground?	Risk assessment – Virginia Tech. (35); (40)	(1); Robotics – SDSMT (25); Rock Bolting and Backfills - Mon


Bio- Geo- Early Implementation Plan Timeline



Physics and Astrophysics Questions

- Why study the Universe from 1-2 miles underground?
  - Surface `noisy'… physics signals of interest are like a whisper in Manhattan traffic
  - Interesting particles of astrophysical origin easily penetrate… $1/10^{13}$ interact when passing through the *whole earth* !
- Detectors as pure and massive as possible

Physics and Astrophysics Questions

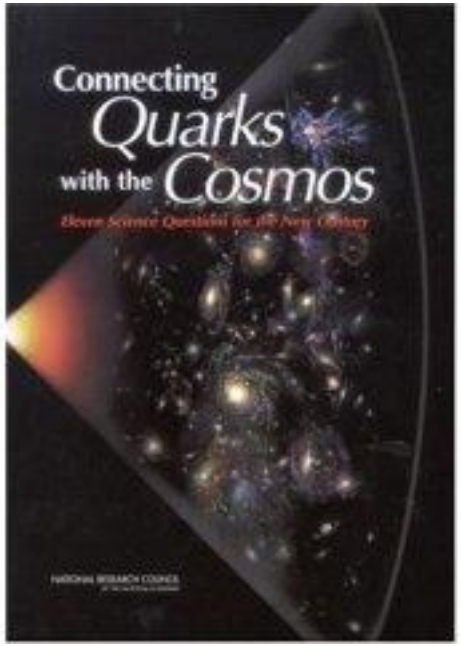
- Scientific Questions… called for Letters of Interest… due 8 December 2005
- 22 Submissions (Physics/Astrophysics)
- PAC Analyzed, Jan.-May 2006… Report… not parties to the Homestake Proposal
  - Frank Sciulli (co-chair), Columbia
  - Ed Kearns, Boston University
  - Josh Klein, U. Texas, Austin
  - Bill Marciano, Brookhaven NL
  - Hank Sobel, Univ. Calif. Irvine
  - Harry Nelson, Univ. Calif. Santa Barbara
- Charge: develop scientific roadmap, with an eye toward early implementation.

Physics Letters of Interest Categories

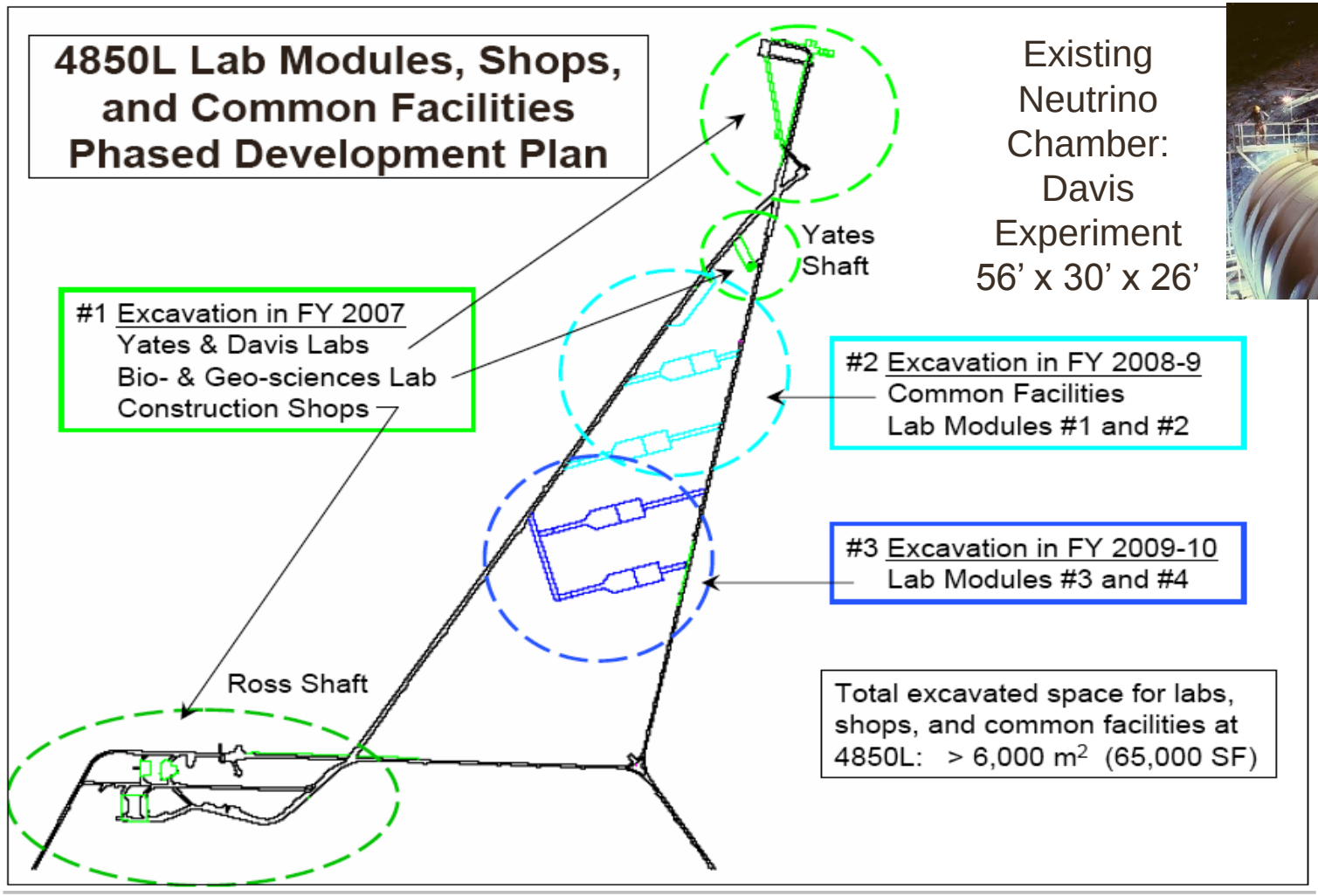
- Neutrinos – 9 LOI's
  - 3: neutrino mass/solar astrophysics… source is the sun
  - 1: particle accelerator for nuclear astrophysics
  - 2: neutrino mass… `long baseline', source is an accelerator (also does proton decay)
  - 2: neutrino mass… `double beta decay', source is an isotope in the detector
  - 1: Geoneutrinos
- Dark Matter – 7 LOI's
- Speculative – 3 LOI's
- Common Facilities – 3 LOI's
- Education/Outreach – 1 LOI

Physics Grand Questions

- Coverage of the grand questions
  - What is the Dark Matter?
  - Exploration and exploitation of neutrinos to uncover the origin of mass and matter, and to understand the sun
  - Are protons really stable?
  - Origins of the Elements?
- PAC Scrutinized, Analysed Suitability for Early Implementation – 2008/9

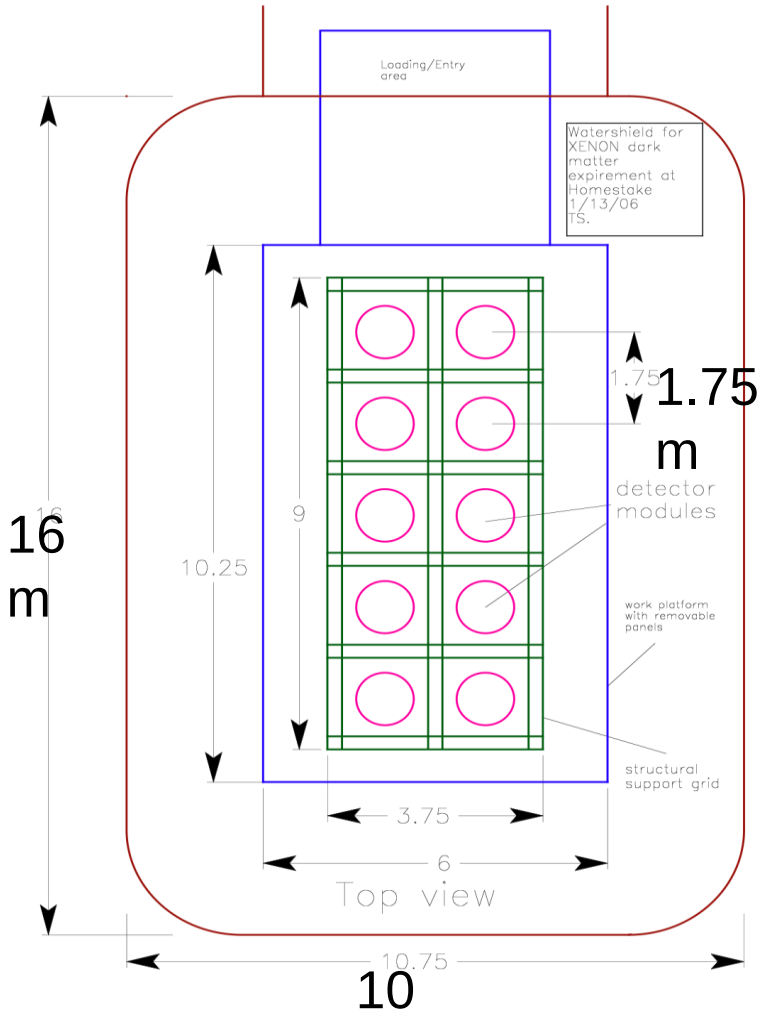


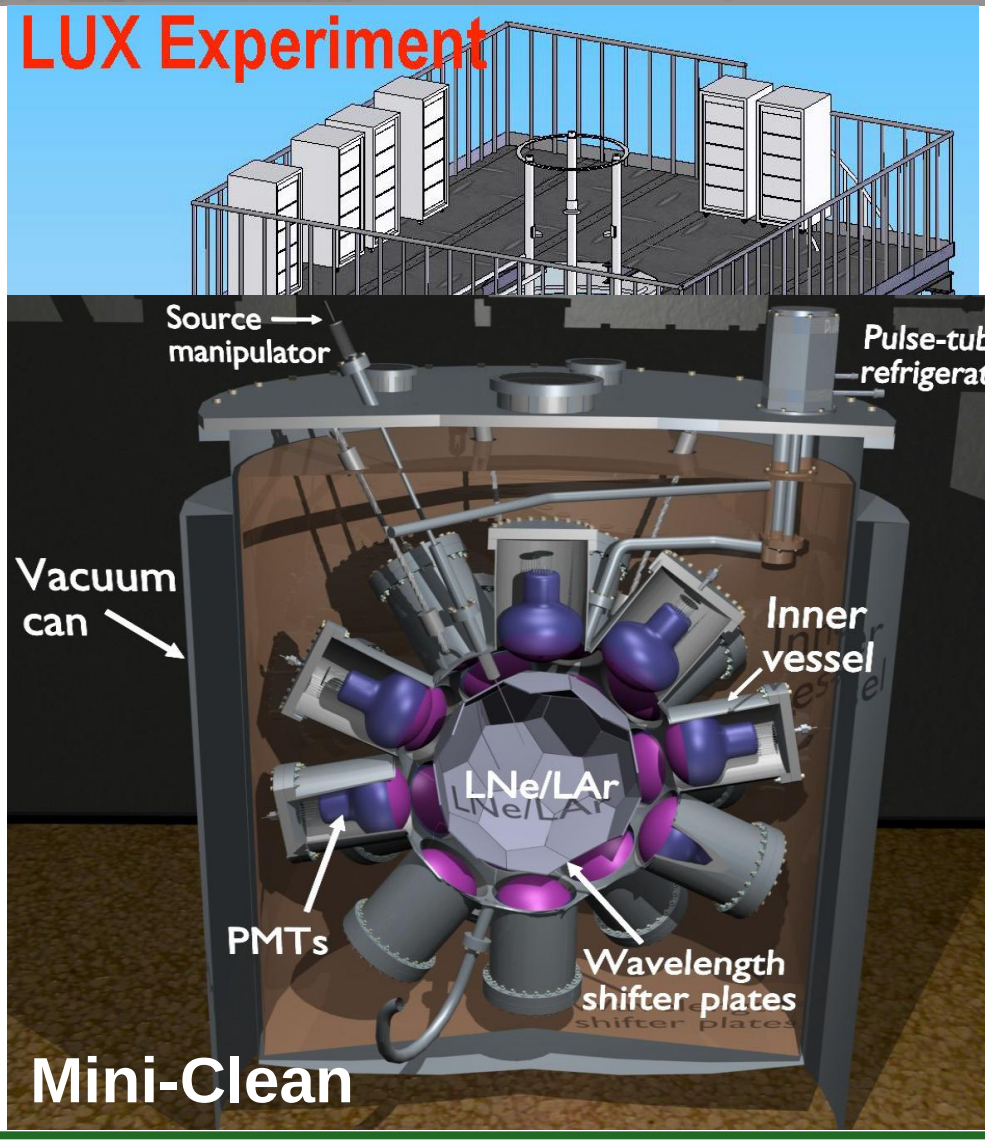
Early Implementation – 4850ft/4100 mwe



Existing Neutrino Chamber: Davis Experiment 56' x 30' x 26'

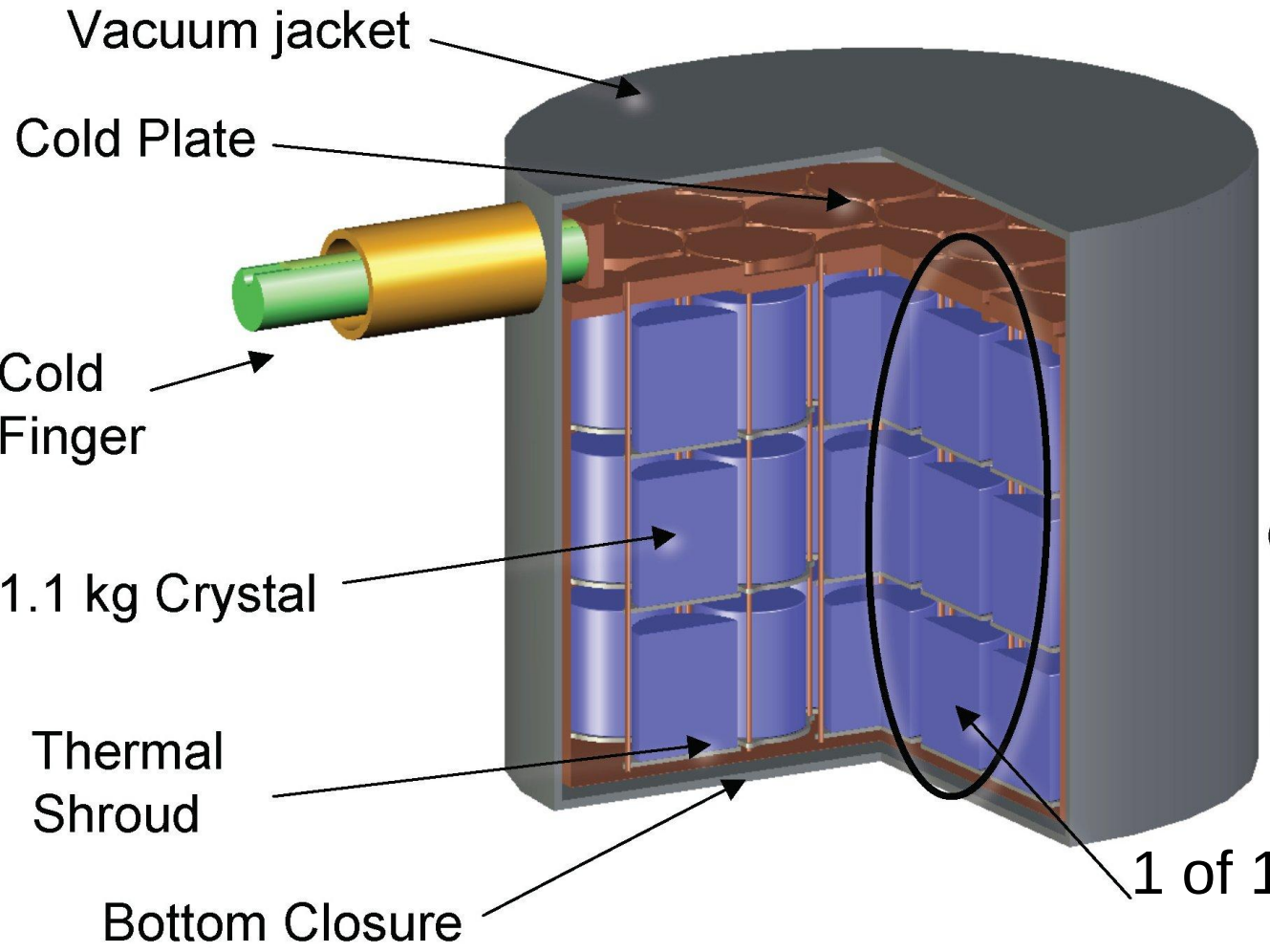
Davis Lab – Early Implementation

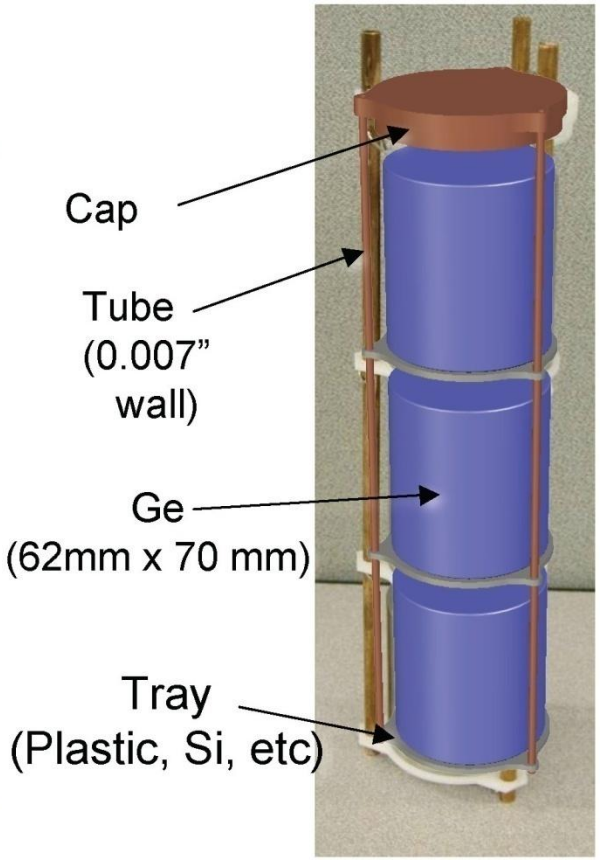




Shutt nOI talk

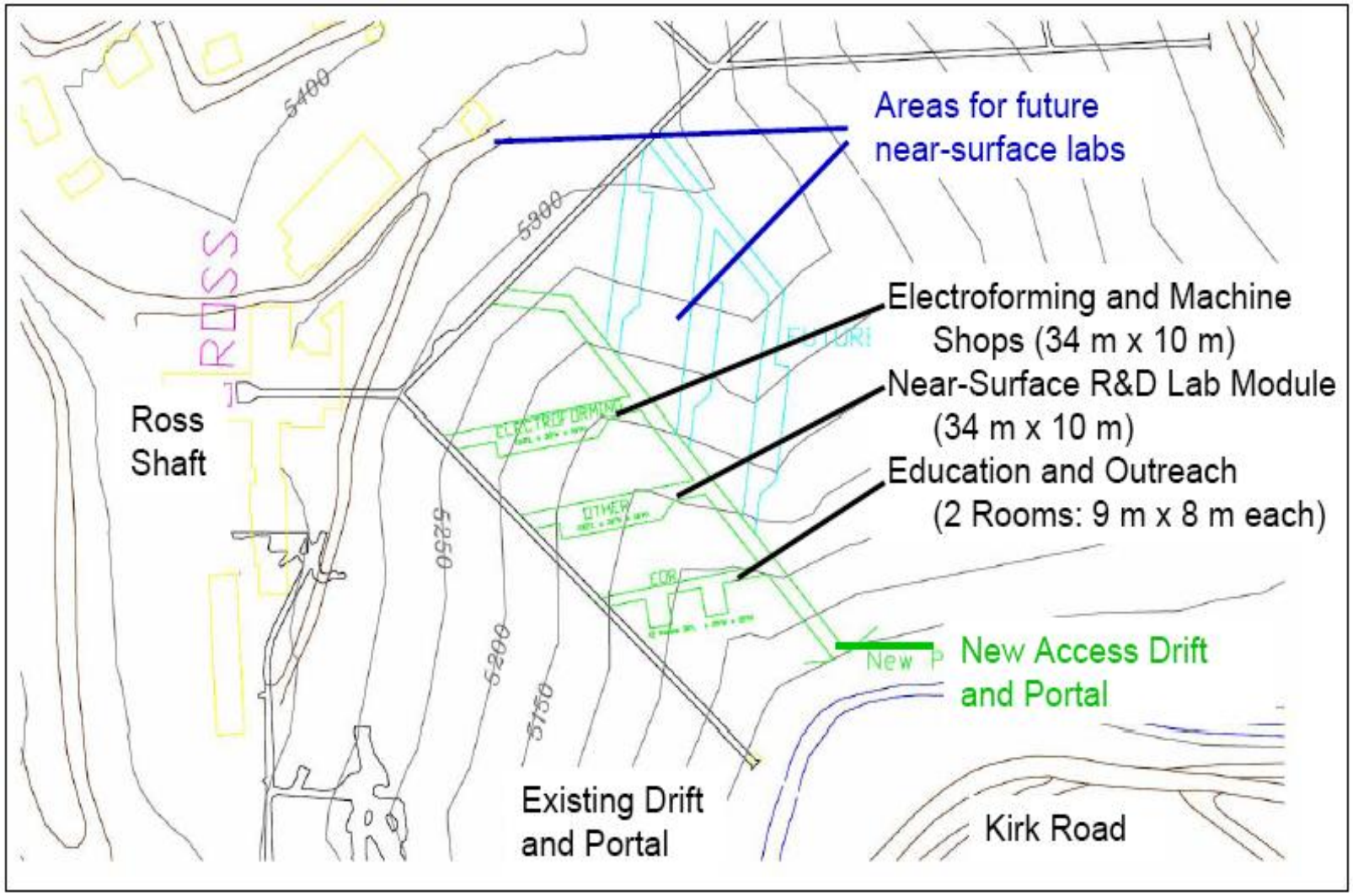
Majorana - ββ - Phased



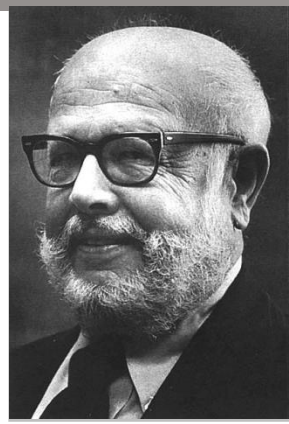


Common with DM … screening/fabrication

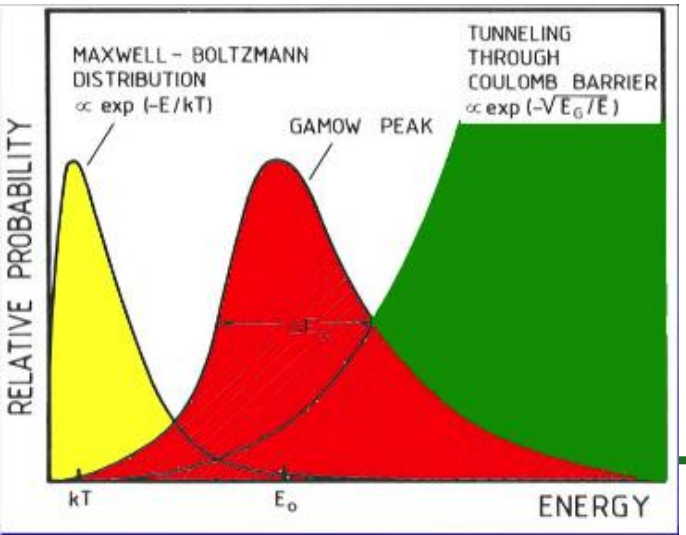
Common Facility – 300ft/233 mwe

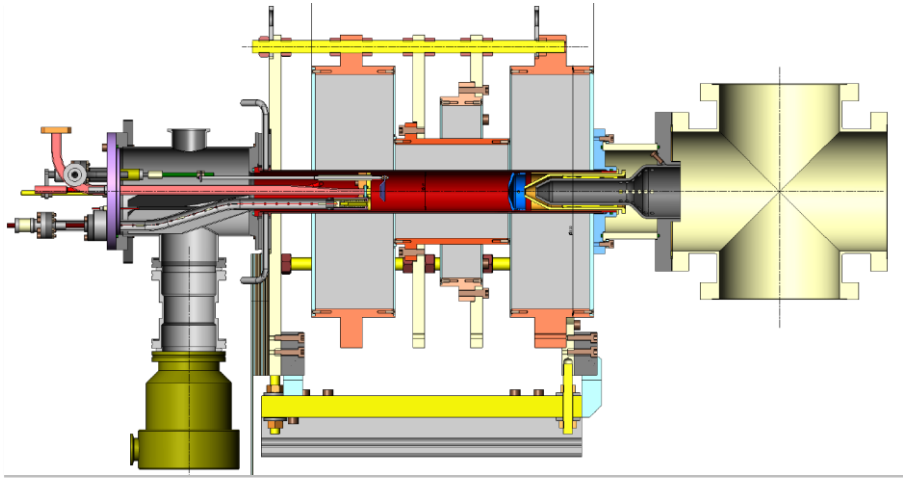


Nuclear Astrophysics



- High Current Accelerator (LOI 64)
- LUNA (Gran Sasso) looking for space in coming year or two to expand and adapt their facility, working with US physicists on joint programs.
- Nuclear Astrophysics could move in rapidly at Homestake, current plans and R&D suggest 2008 or 2009 - fits ISE





Early Implementation – 4850ft/4100 mwe

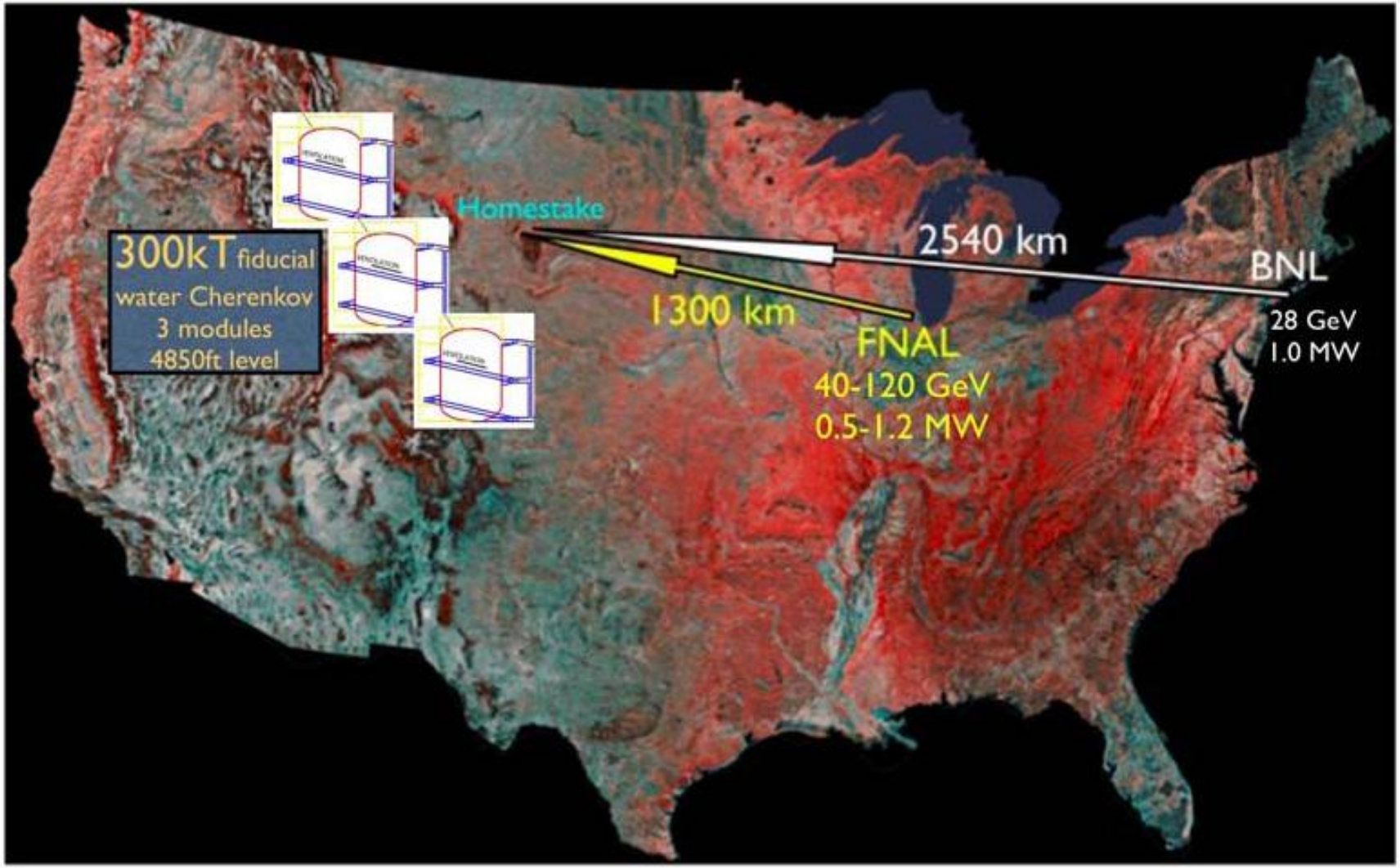
LONGSECTION OF THE HOMESTAKE MINE

Early Implementation Program

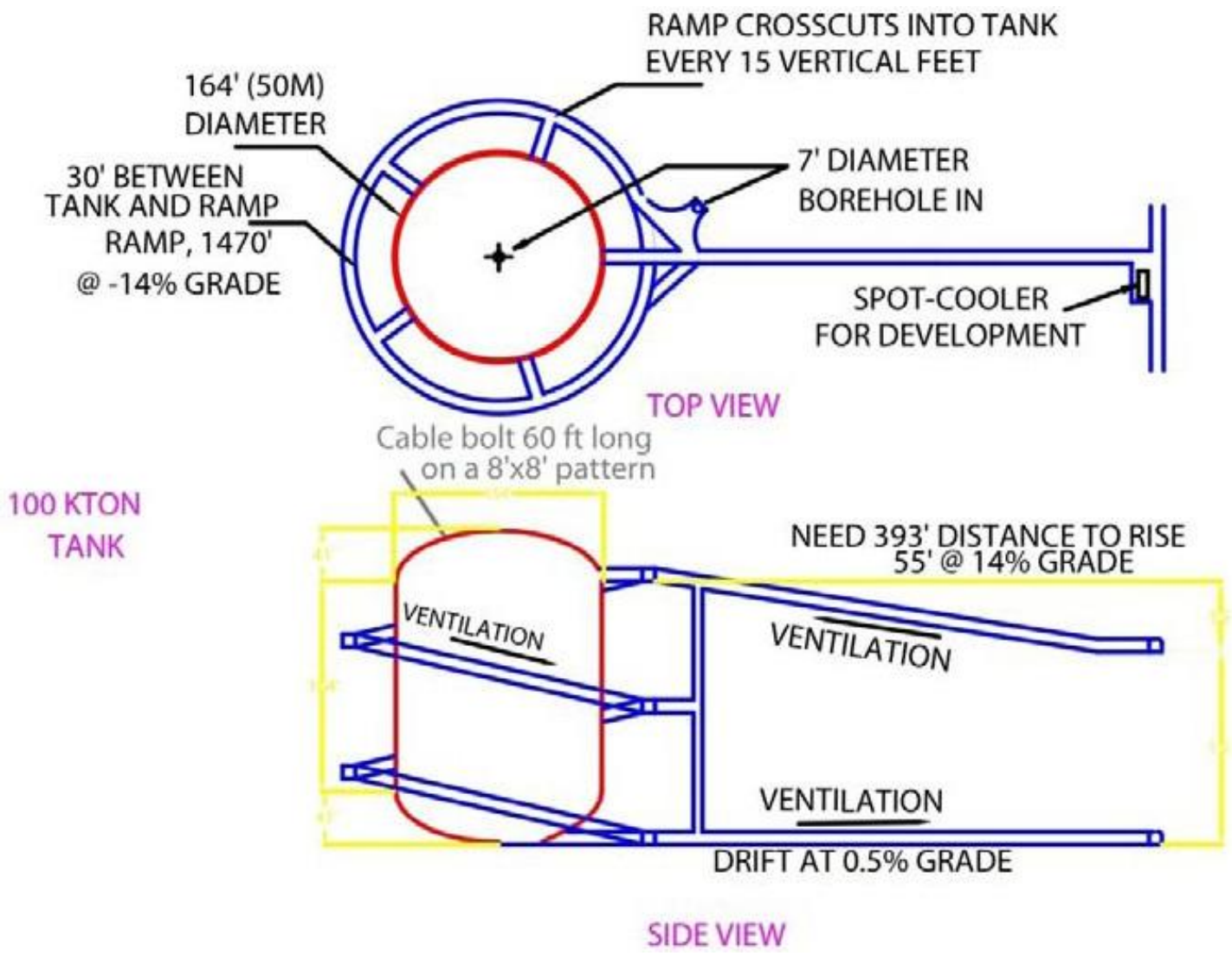
Homestake DUSEL Initial Suite of Experiments

	ReEntry CY 2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Common Infrastructure										
Surface and Underground Laboratory Modules and Support Services	Title, Insurance, Indemnification, Rehab. Plans									
Surface Support Facilities Phase I	Rehab Existing Buildings for EIP			Phase I Expansion						
Surface Support Facilities Phase II					Phase II Expansion					
300L				Rehab U/G	Prepare 300L					
4850L	Rehab U/G	Rehab U/G	Prepare 4850L	Lab Mod. 1	Lab Mod. 2		Lab Mod. 3	Lab Mod. 4		
7400L + 8000L					Rehab Deep U/G	Deep Lab Module 1	Deep Lab Module 2 & 3			
Ultralow Background Materials Manufacture and Storage				300L Outfit / Production	300L Operation					
Well shielded "Water Room" for Assay and Experiments		4850L Outfit	4850L Operation							
Sanford Lab and Bio/Geo Lab		4850L Outfit	4850L Operation							
Low Background Counting				300L Outfit	Operation					
		4850L Outfit	4850L Operation							
Education and Outreach										
	Surface		**Sanford Science Education Center**							
				300L Outfit / Production	300L Operation					
		4850L Outfit	4850L Operation							
							7400L Outfit			
Physics										
Dark Matter										
XENON/LUX		R&D and Lab Outfit	R&D and Deployment	Continued 4850L Operation			Continued or Deep Labs			
ZEPLIN		At Boulby		R&D Potential		Potential Deployment	Potential Deep Deployment			
miniCLEAN		R&D and Lab Outfit	R&D and Deployment	4850L Continued Operation			Deep Homestake (plus solar neutrinos)			
DRIFT		At Boulby		R&D Potential			Potential Homestake Deployment			
TPC			R&D	R&D	R&D then Expt @4850L		Continued or Deep Labs			
SIGN			R&D	4850L Deployment			Continued or Deep Labs			
SuperCDMS						Potential Deployment	Deep Deployment			
Neutrinoless Double Beta Decay										
Majorana		R&D Outfit and Storage	R&D / Deployment	4850L Deployment	Operate 1st Phase Majorana		Outfit Deep Lab	MJ at Deep Homestake with add'l Mass		
EXO			*R&D EXO200 @ WIPP*	EXO 4850L			Continued or Deep Labs			
Long Baseline Neutrinos + PDK										
Large Cavity Geotechnical Studies, Siting		Cavity Geotechnical Studies,		Design	Cavity Construction 100kT Module(s)			Long Baseline Neutrino Program		
LAr, HSD & Water Cerenkov Detector R&D				300L Outfitting	300L R&D		300L R&D			
			4850L R&D				4850L R&D			
Solar Neutrinos										
LENS R&D		R&D Program			4850L Deployment		Continued or Deep Homestake			
							Advanced R&D 300L and 4850L			
Other Science										
Nuclear Astrophysics				Nuclear Astrophysics Program at 4850L						
Cloud Physics		Collaboration & Proposal Development					Potential Vertical Shaft Experiment			
Neutron-Antineutron Oscillations		Engineering & Feasibility Studies					Potential Vertical Shaft Experiment			
Long Baseline Gravity Wave		Engineering & Feasibility Studies					Possible Deployment			
Joint Physics & Earth Science Research										
Geoneutrinos			R&D		4850L Deployment					
Carbon Sequestration Geothermal Energy					4850L and Above Deployment					
				R&D						
Diural Earth Rotation		Collaboration & Proposal Development					Potential Vertical Shaft Experiment			

Large Chamber / Neutrino Beam / Proton Decay



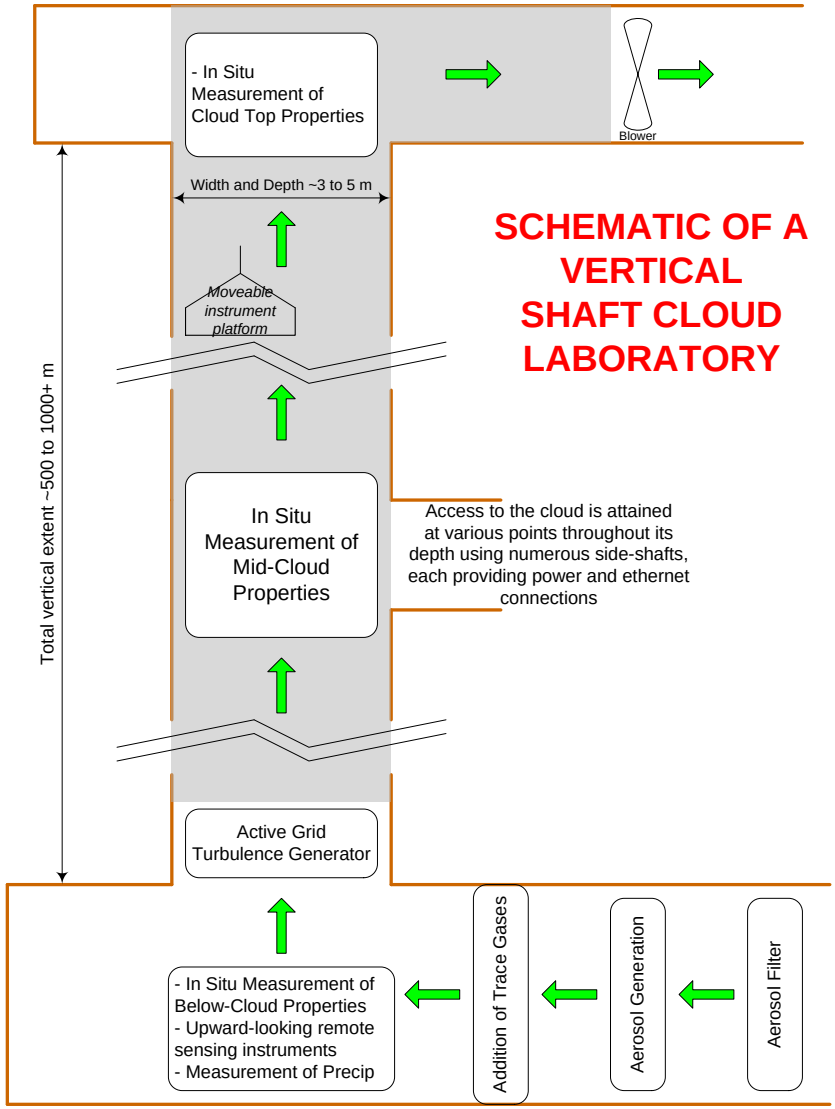
Large Water Cerenkov Detector



PAC…
Extremely
Compelling,
Flagship
Experiment

External
Challenges

Beyond the Core…Speculative



PAC…
Intriguing…

To really implement, need more review/expertise.

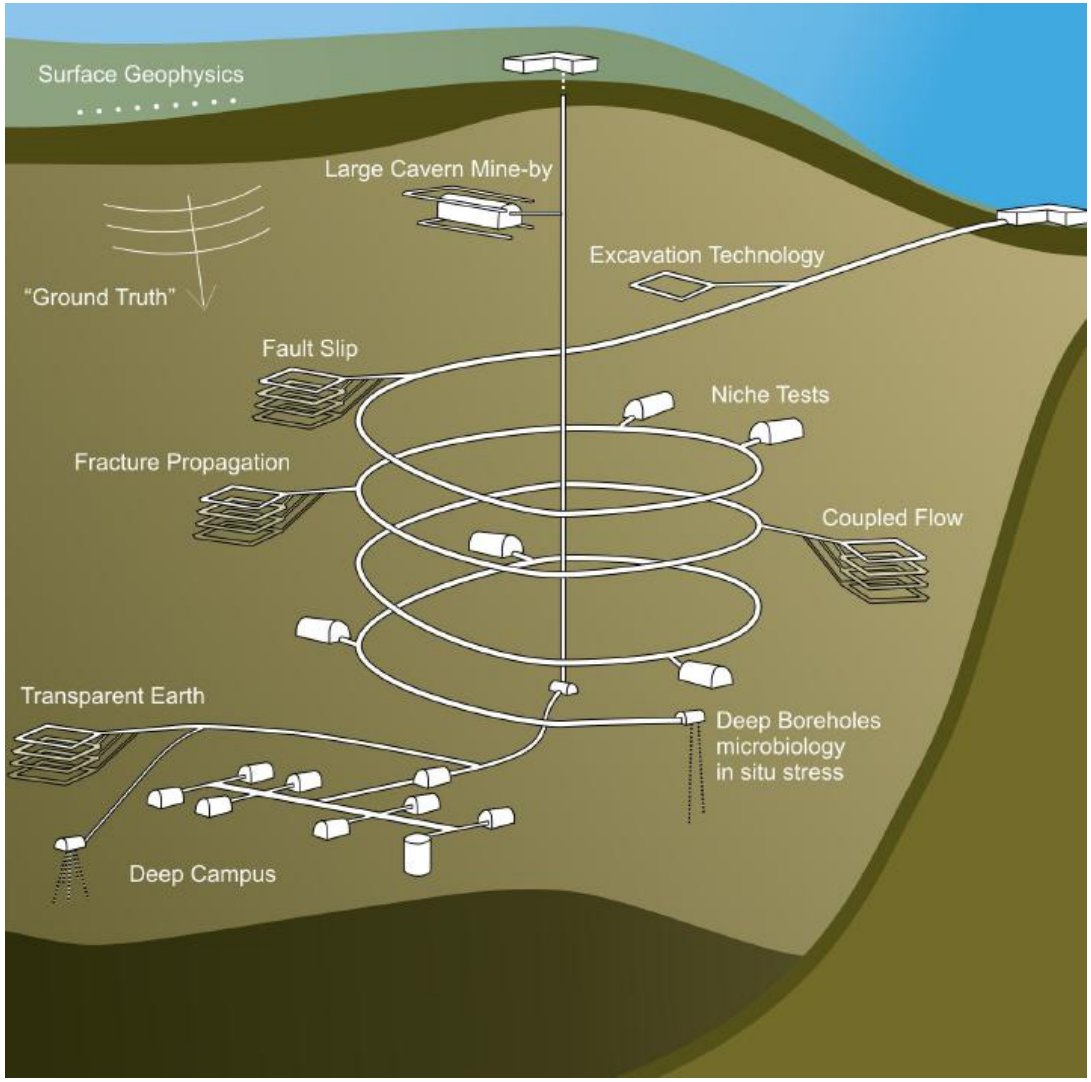
Also… n-nbar oscillations, earth's rotation

Education/Outreach

- `Chicken and Egg'… relative remoteness of site
  - Joint Appointments
  - Named postdoctoral fellowships
  - Summer visitors
  - Summer Institutes

Match to Proposed S-1 ISE

- Ability to accommodate…"as large a program as can be envisaged being supported over the foreseeable future."
- Extensive network of existing workings
- Large lateral extent ~5km
  - Isolated laboratories
  - Large run-of-mine/lab
- Extensive suite of boreholes
- Seismically quiet
- Early/immediate access to 4850 level and bays
- Moderate-term access to 7000+ level



Updates for Early Implementation 2007-2009 for DUSEL Initial Suite of Expt. 2010-2015

- **Space for Physics R&D**
  - Water Room for multiple experiments at 4850L (LUX, DEAP/MiniCLEAN, Gd in water, …)
  - Low background counting facility for detector components (Majorana, …)
  - Coring, design, site selection (LBL, …)
- **Reentry with Earth Science Team**
  - Bio-Geochemical sampling (ecology, bio-prospecting, …)
  - Geophysical monitoring (surface bores, 2000L, 2600L, …)
  - Dewatering (in-drift moisture, transducers from 4850L, …)
  - CO_2 Injections along sandholes, …

Supplemental Slides