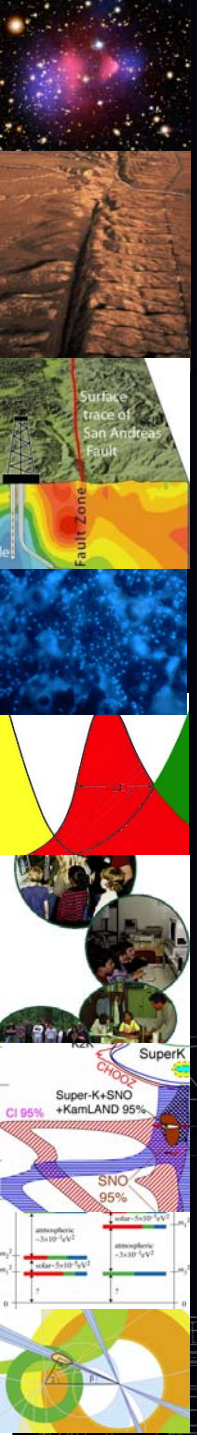
Homestake DUSEL
Large Cavity Detectors

Richard W. Kadel,

Physics Division, LBNL

FNAL, July 13, 2009



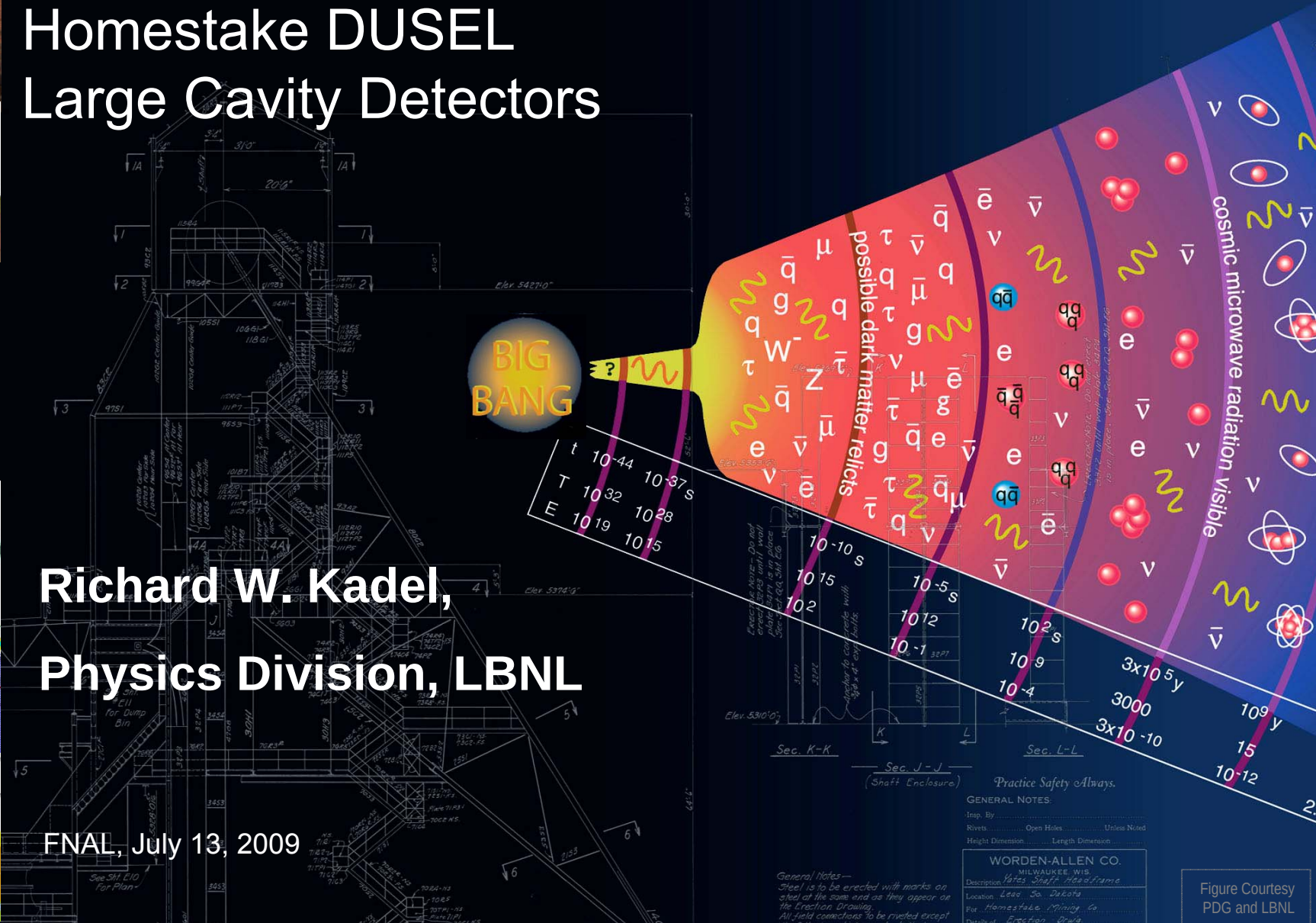
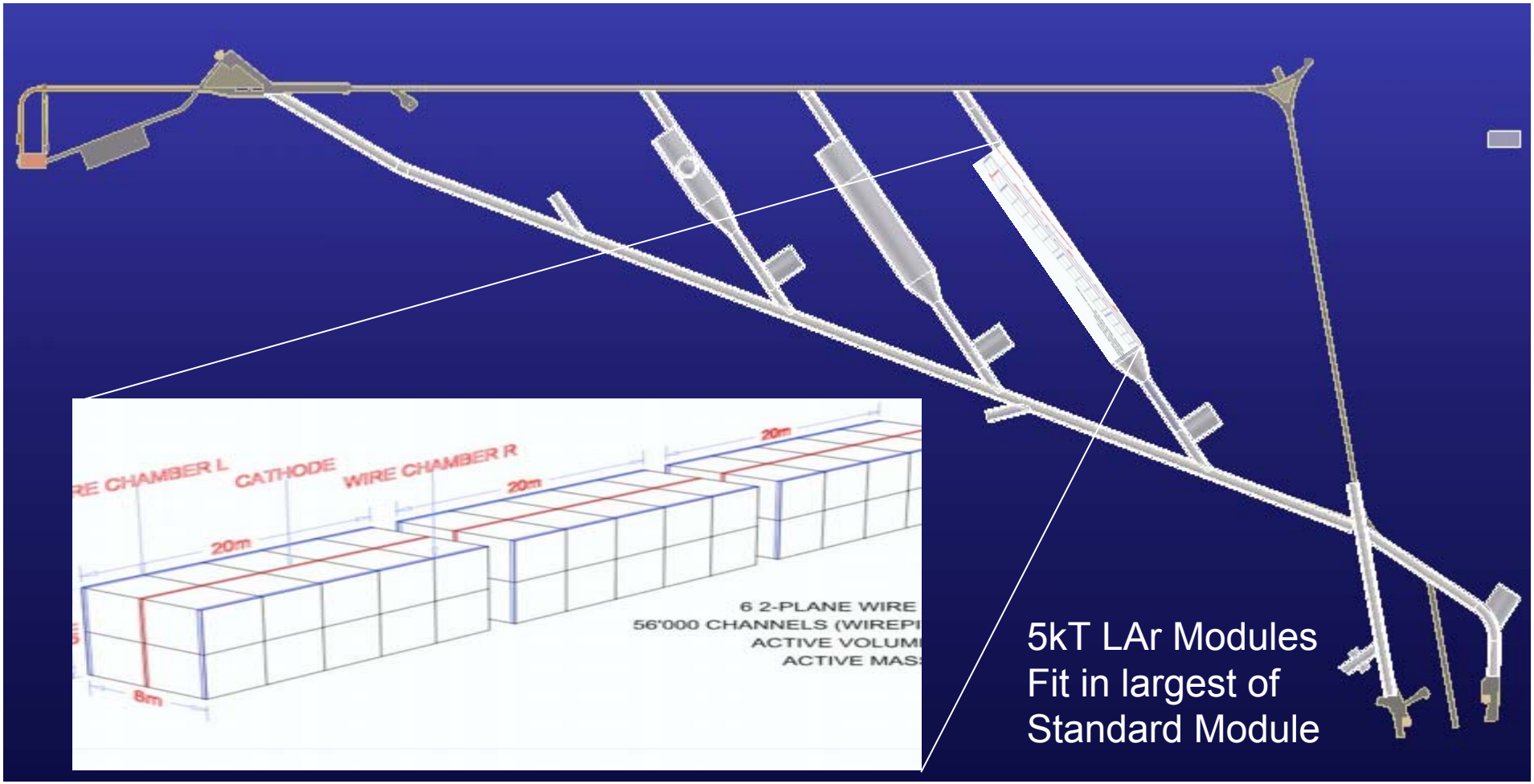


Figure Courtesy PDG and LBNL

Outline

- DUSEL Schedule
- Major Milestones and Contracts
- Dewatering progress
- Initial Cavern Specification for Water Cherenkov
- Isometric Drawings of Cavern
- LCAB meeting
- Conclusions

Liquid Argon S4 Proposal : 5kT



H_20 Cavern Spec Document

DUSEL

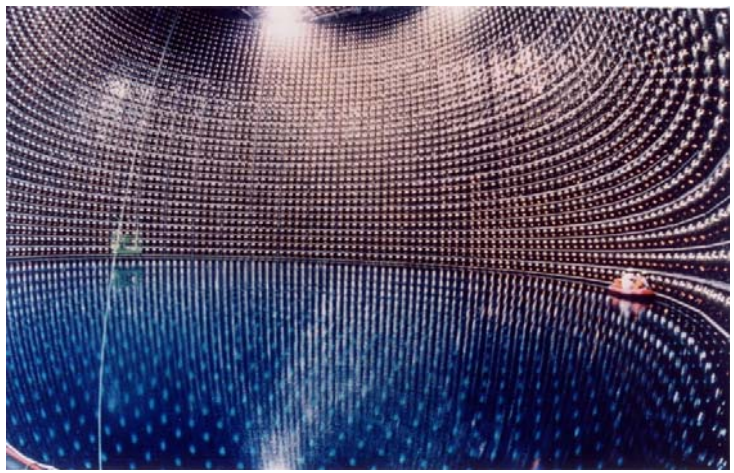
Long Base Line Neutrino Experiment
(LBNE)
Cavern Size Requirements

R. W. Kadel
LBNL
11-June- 2009

DUSEL Note # 73

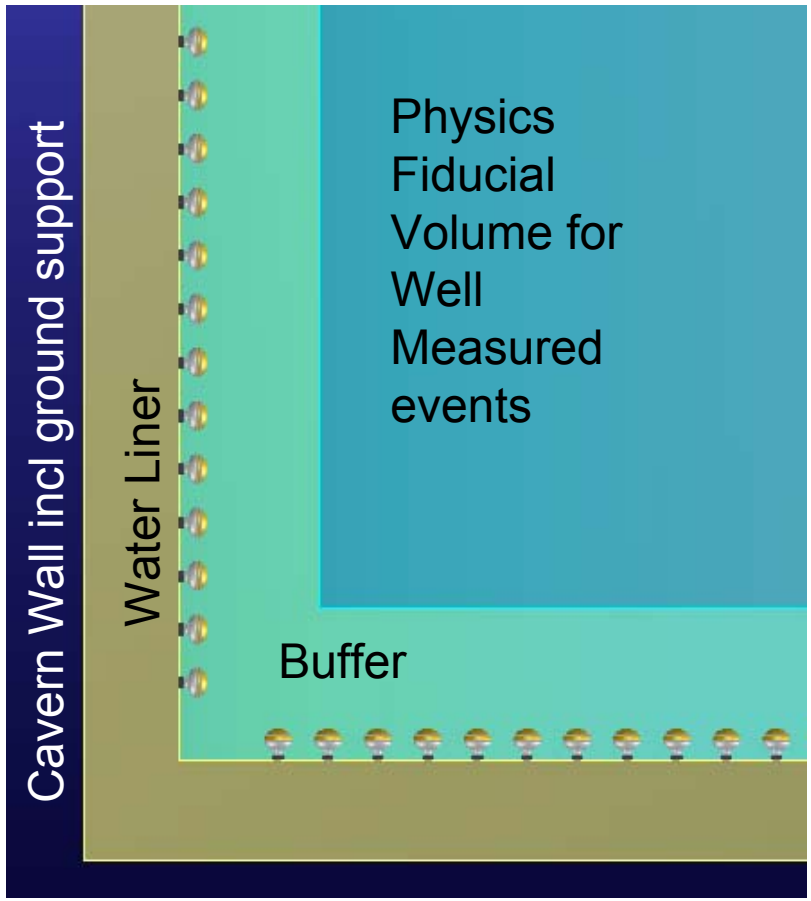
Abstract: This note describes the excavation necessary for a 100kT fiducial volume water Cherenkov detector. The necessary volume is a right cylinder, with a free diameter of 55 m and a free depth of 58 m deep below the 4850L.

Cross section at lower Corner of Cavity



Super-Kamiokande
22 kT F.V., 50kT total.

"Virtual" dividing line
Not a physical boundary



Courtesty D. Plate, S. DeVries

Requirements and Constraints

Item	Value	Reason
Total Volume of WCh detector	≥300kT	Neutrino Oscillation parameter measurement, Proton Decay,
Minimum fiducial Volume per Cavity	≥100kT	Scientific Competiveness
Maximum distance between cavities	5 km perpendicular to neutrino beam	Neutrino beam opening angle
Maximum Depth of Water above lowest PMT	60 m	PMT collapse under water pressure
Depth of Cavity below Surface	4850L	Cosmogenic background to proton decay
Maximum Distance between PMTs	80 m	Water attenuation length at peak PMT wavelength sensitivity when convoluted with Cherenkov light spectrum
Cavity Lifetime	≥30 years	Proton Decay, Neutrino Oscillation parameter measurement
Egress	Dual Egress from drifts and cavities during all phases of construction and operation	Personnel Safety
Water management	Inherently protect the remainder of the DUSEL facility from catastrophic failure of the water containment	Personnel, Equipment or facility safety
Code requirements	TBD	Personnel, Equipment or facility safety

Assumptions

Assumption	Value
Fiducial Volume	100kT
Shape	Right Cylinder
Minimum Diameter of Water (incl buffer)	53 m
Fiducial Volume cut	1 m
Buffer size (radially and axially)	1.5 m
Allowance for drainage and liner (sides and bottom)	1 m
Allowance for freeboard and deck (top only)	3 m combined
Top of deck	Level with 4850L

Specification

Item	Specification
Shape	An unobstructed right cylindrical volume free of rock outcroppings or ground support *
Free Diameter	55 m*
Top of right cylindrical	level with the 4850L
Free Height from [possibly virtual] flat floor to 4850L	58 m*
Lifetime	≥30 years

*This value follows from assumptions

Discussion

- Freeboard: The spec allows 3m vertical height between the top of the water and the 4850L (assumed level of deck)
- Crane access over full detector volume possible only at top of cylindrical volume, otherwise interference with dome.
- Full crane access may not be necessary for excavation.
- A 55 m span Deck may need support from above, either by cables, truss system, etc
- Support cables or truss for deck may interfere with crane for detector construction. A series of jib cranes around perimeter of the cavern may be adequate for the experiment.
- Final water temperature ≤ 15 degC (supress biologicals)

Temperature

- Final water temperature ≤ 15 degC (suppress biological activity)
- Estimate 70kW from rock.

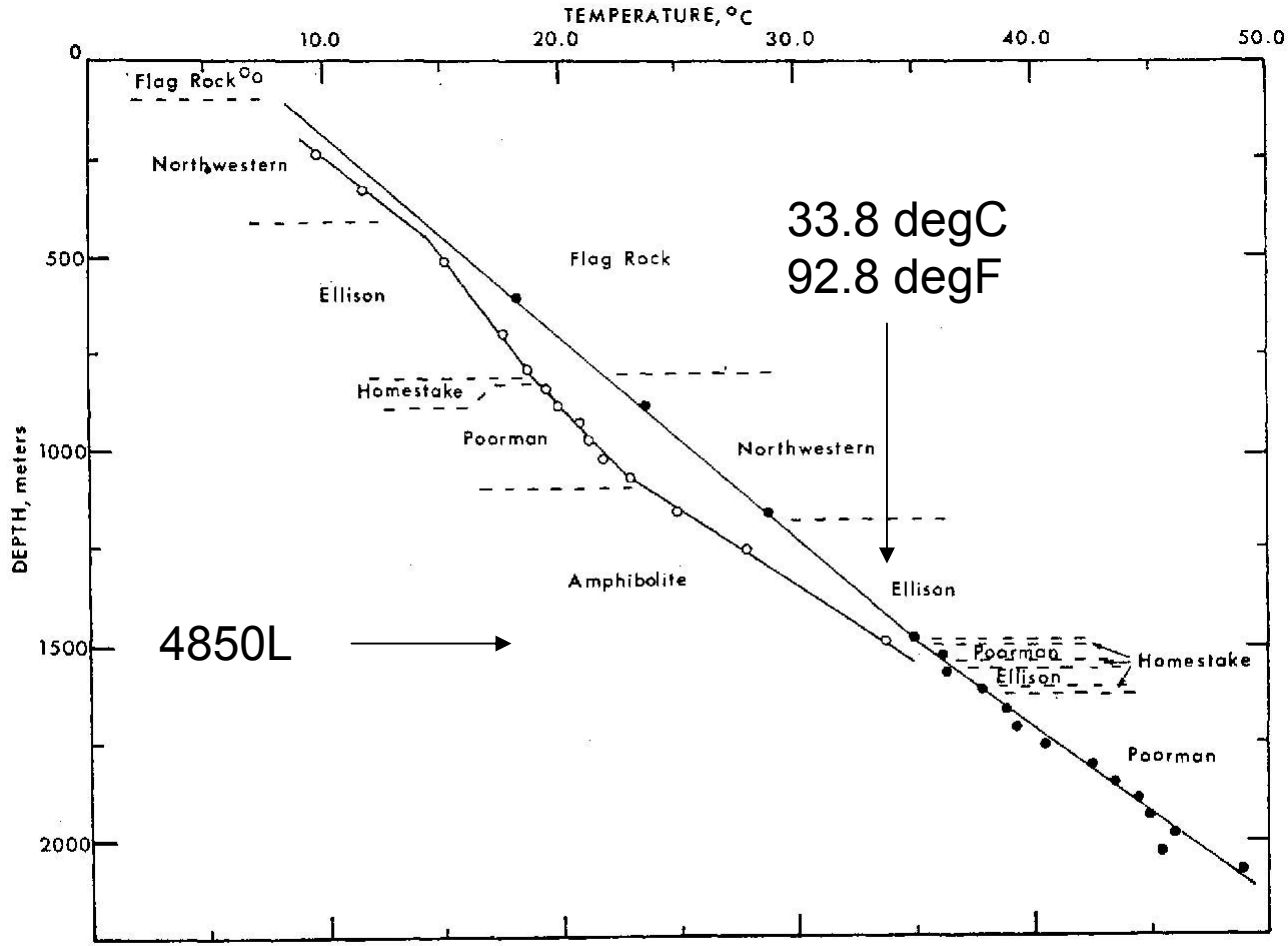


Fig. 2. Temperature-depth curves and rock units in Yates (open circles) and No. 4 and No. 5 (solid circles) Shafts, Homestake Mine, Lead, South Dakota.

D. Blackwell, PhD Thesis, Harvard 1967

Thermal Conductivity

Table 2. Thermal Conductivity, Gradient and Heat Flow
Homestake Mine, Lead, South Dakota

		Number of samples	Number of temperatures*	Average thermal conductivity**	Average gradient	Average heat flow
Flag Rock Formation	Yates	2	2	9.1	***	--
	#4	--	1	--	--	--
Northwestern Formation	Yates	1	2	10.9	20.4	(2.2)
	#4	--	2	--	--	--
Ellison Formation	Yates	3	3	16.4	12.8	2.10
	#4	3	--	11.2	--	--
Homestake Formation	Yates	--	--	--	****	--
	#4	4	--	7.9	--	--
Poorman Formation	Yates	8	7	10.8 ± 1.1	17.2 ± 3.4	1.86 ± .37
	#4	7	11	7.5 ± .5	24.4 ± 2.1	1.83 ± .28
Amphibolite	Yates	6	3	6.9 ± 1.1	26.4	1.82
		4		7.3 ± 2.0	26.4	1.93
	#4	--	--			

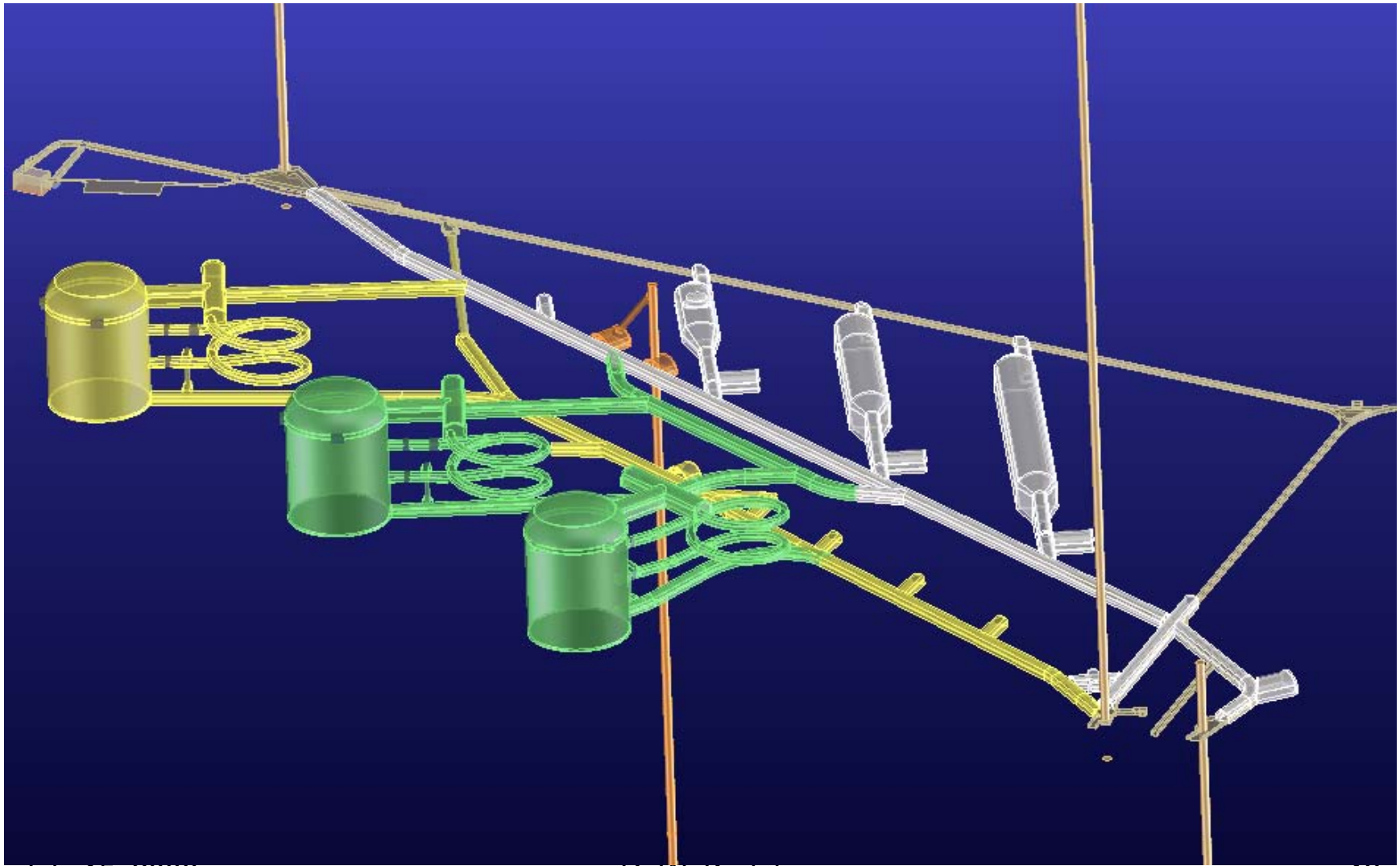
*The number of temperatures is the number of points within each unit.

**The average conductivity has been calculated for dip of 65°.

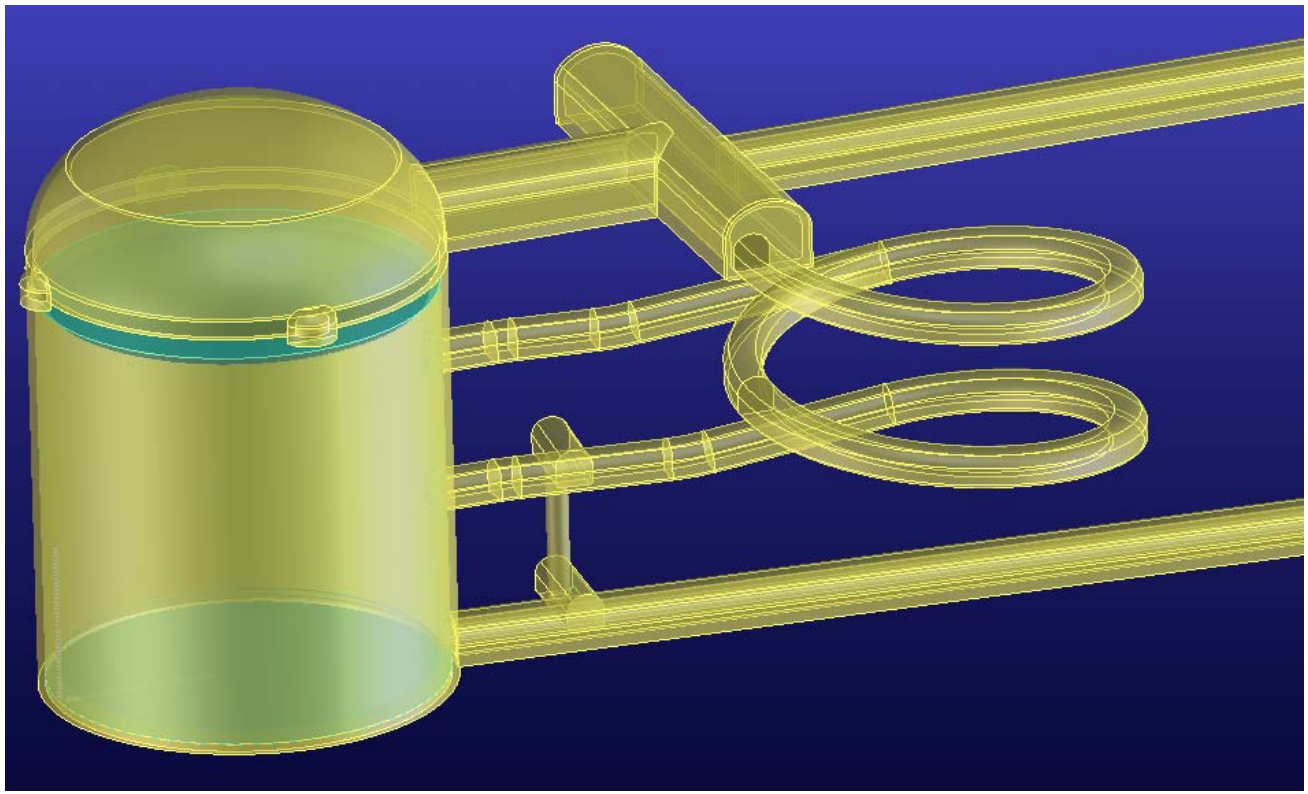
***No gradient calculated as both points are at less than 50 m. depth.

****The Homestake Formation is too thin and highly contorted to calculate a gradient

Cavity layout as of July 1

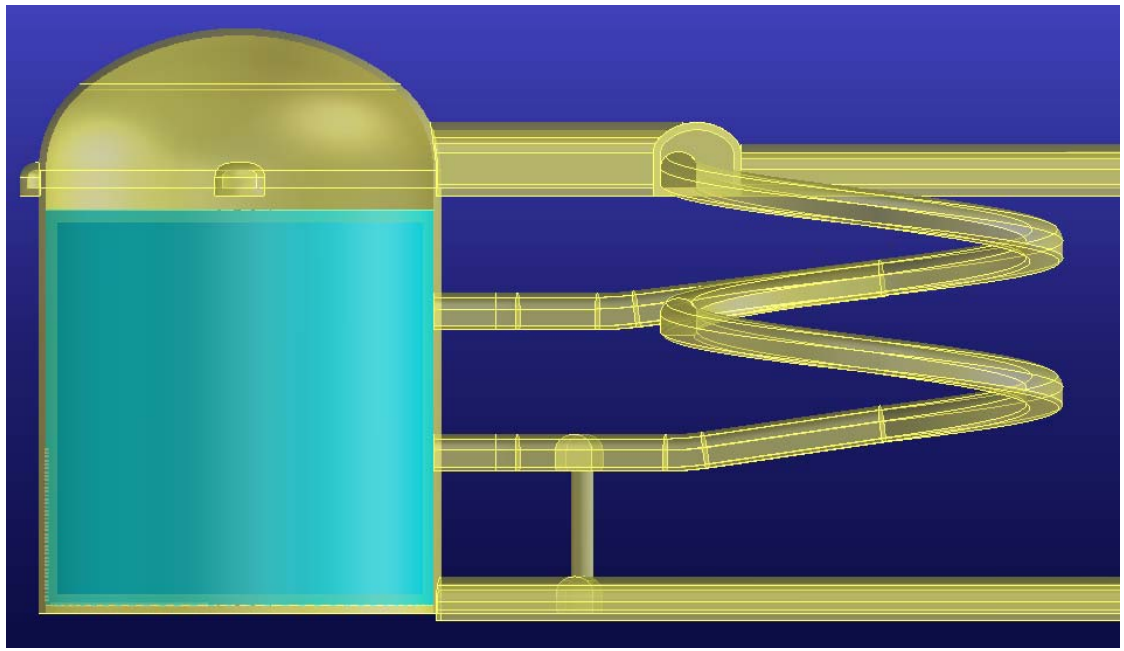


Isotropic view of Cavern, auxiliary spaces and excavation ramps



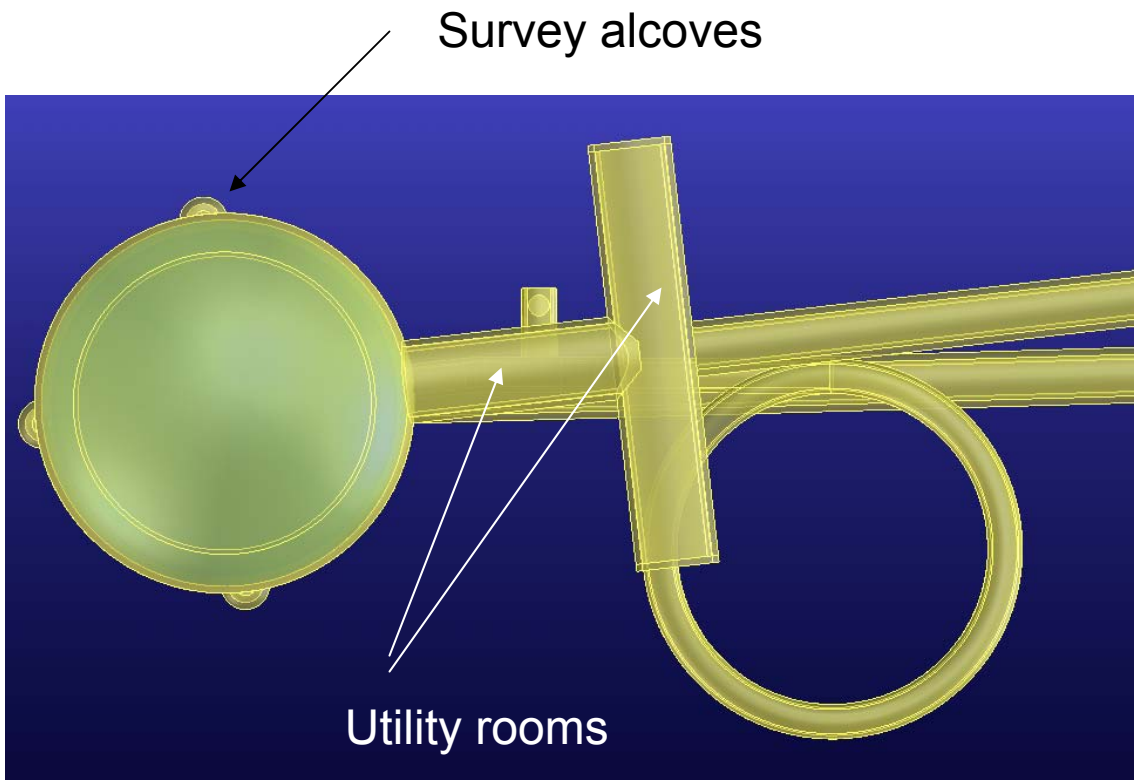
Courtesy D. Plate, S. DeVries

Side View of Cavern



Courtesy D. Plate, S. DeVries

Top View



Courtesy D. Plate, S. DeVries

LCAB meeting July 6-10, 2009 Lead, SD

- 2nd Meeting of the LCAB
- Agenda
  - Monday: Underground tour (20 people)
    - 4850L Triangle incl. Davis cavity (drained) & Ross shops
    - 4100L (Access to higher layer in Yates Anticline)
    - 2050L (VCR* stope in Poorman > 100ft dia)
  - Tuesday: Geology Reports
  - Wednesday:
    - Physics Cavern Spec
    - 2nd mine tour (5 people)
    - Discussion of mine tour results
  - Thrusday: Reports to NSF
  - Friday: Report writing & departure.

(L-R) Ed Cording, Evert Hoek, John MacDonald, Derek Martin

(*Vertical Crater Retreat)

LBNE Recommendations

- Avoid Poorman formation for large cavities
- Move cavities closer to drifts and each other
  - Typically one diameter separation
- Tentative location for LC1 (see next)
- After initial bore hole, drive exploratory drift through LC1 as soon as possible
- Controlled blasting is essential
  - should apply to all future drifts, including new drifts, spaces for Majorana and LUX
  - Key is accurate control of drill direction

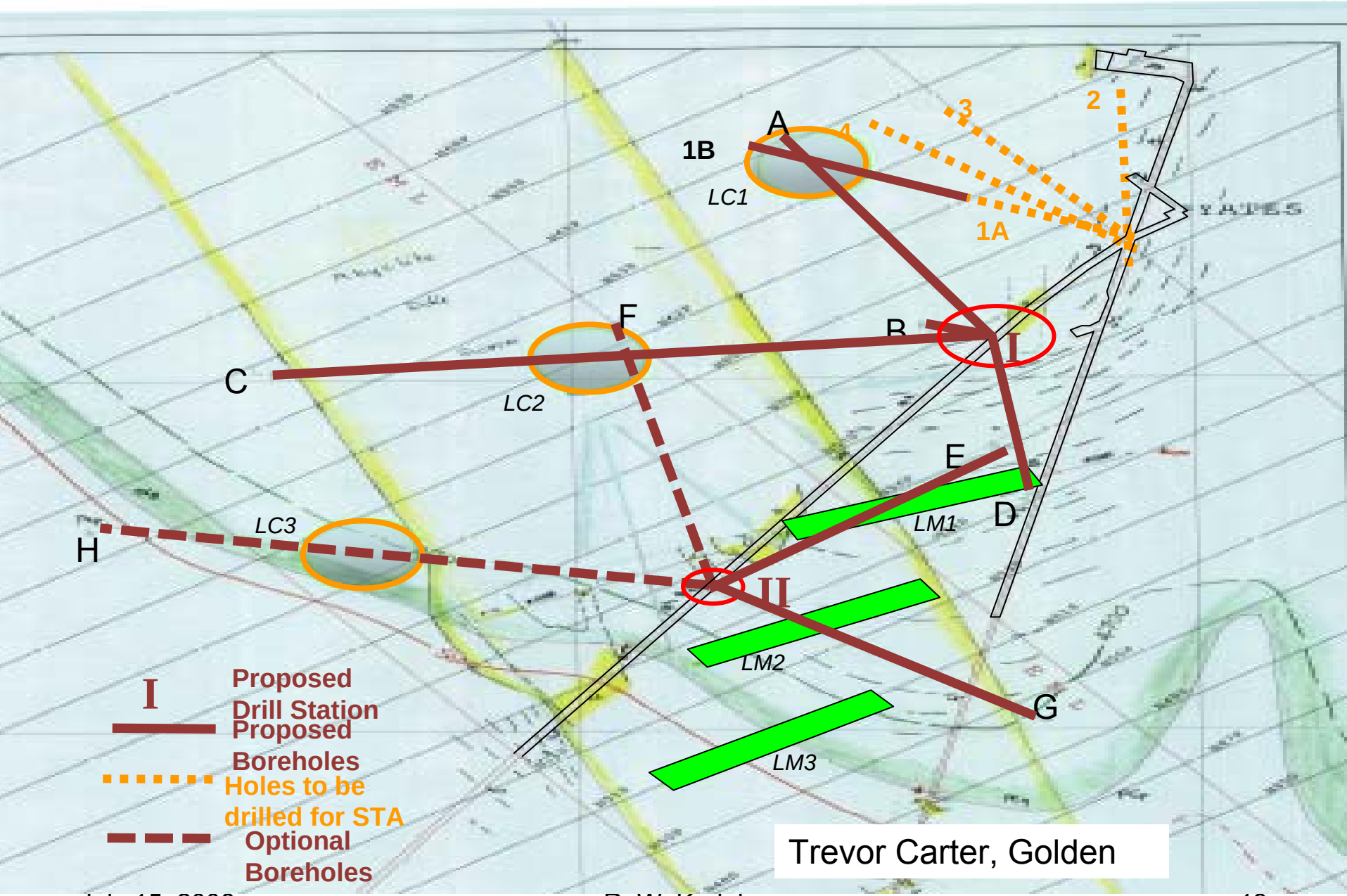


Figure 1. Proposed Borehole Locations on 4850 Level

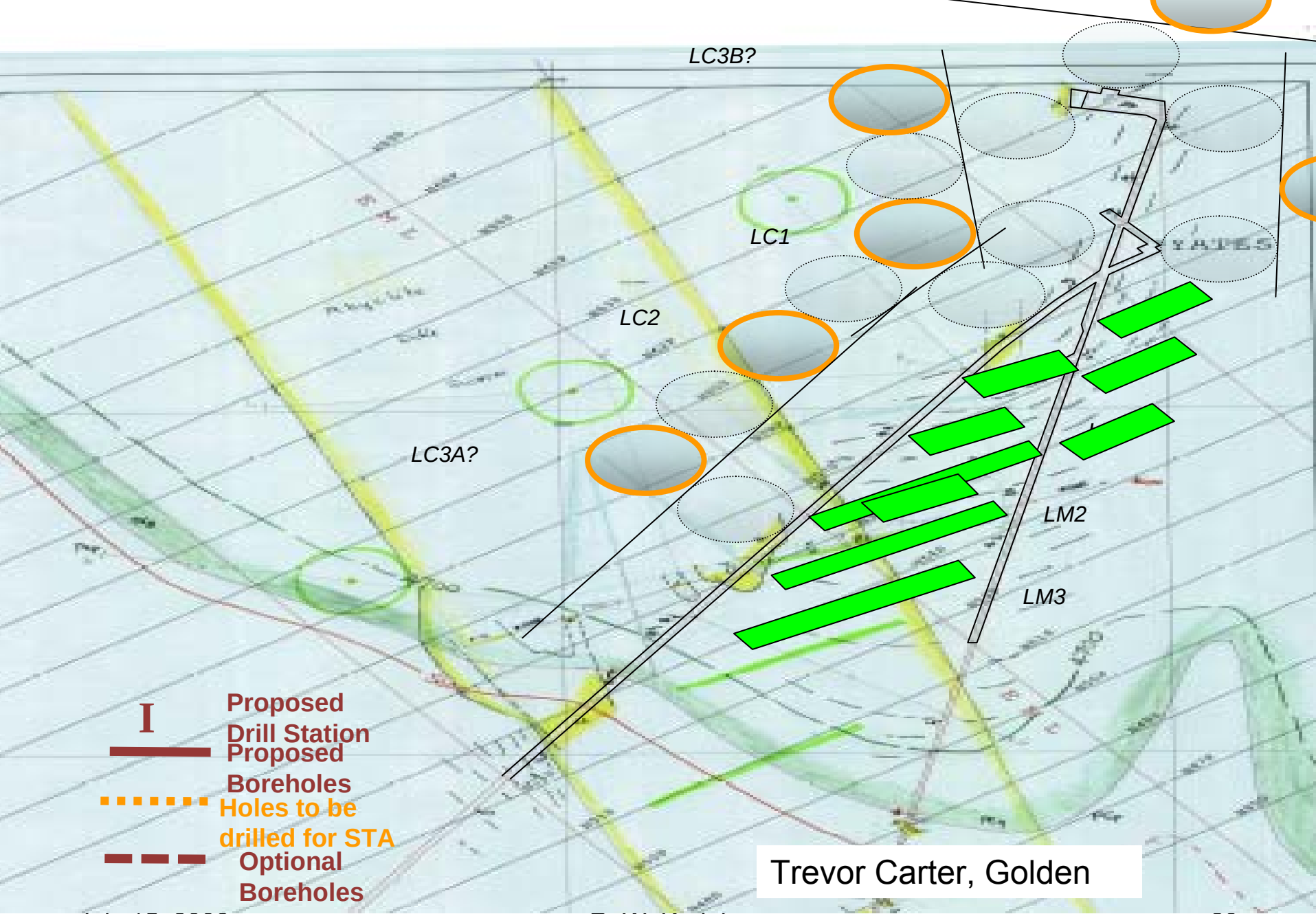


Figure 2A. Modified Cavern Layout on 4850 Level

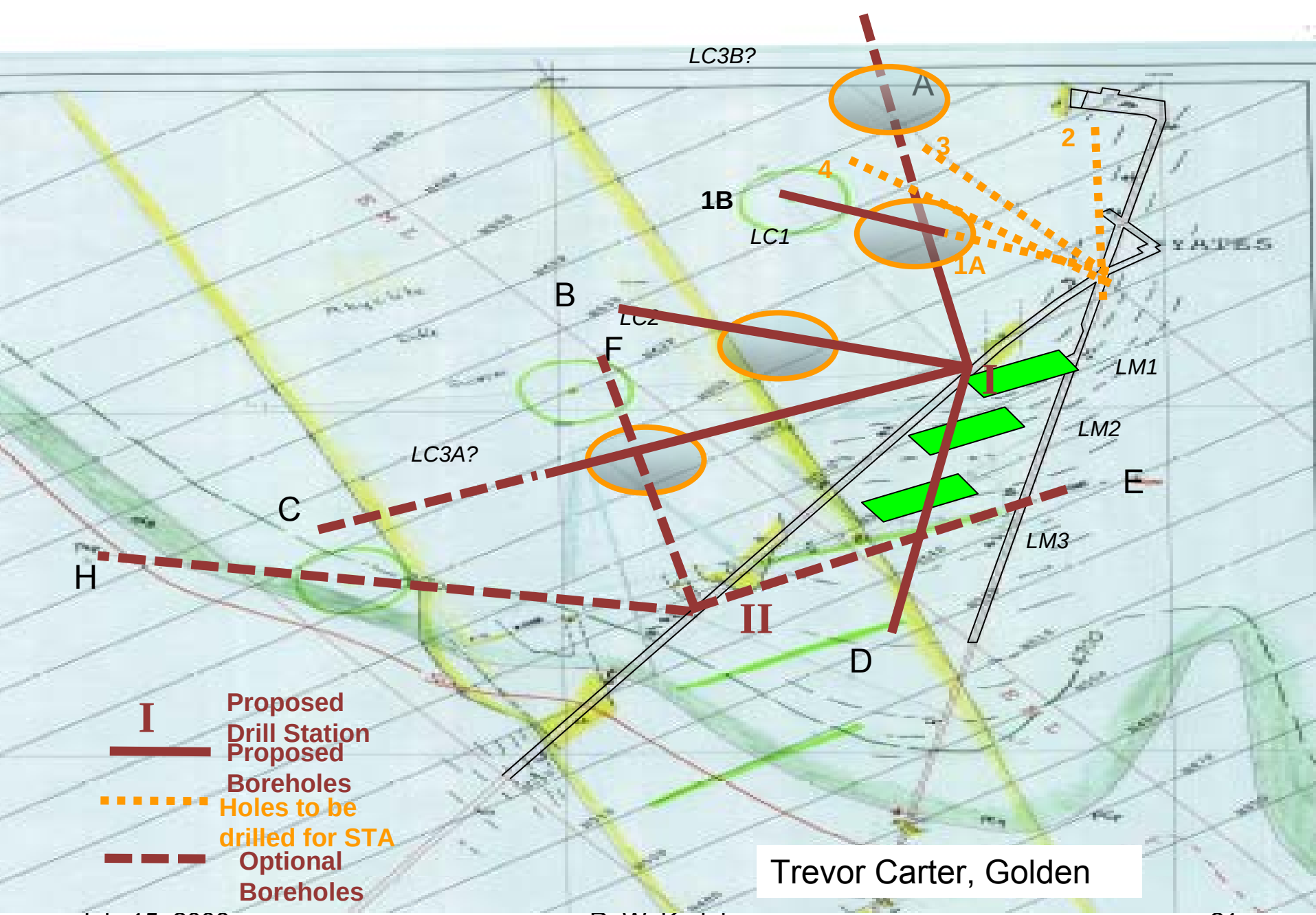
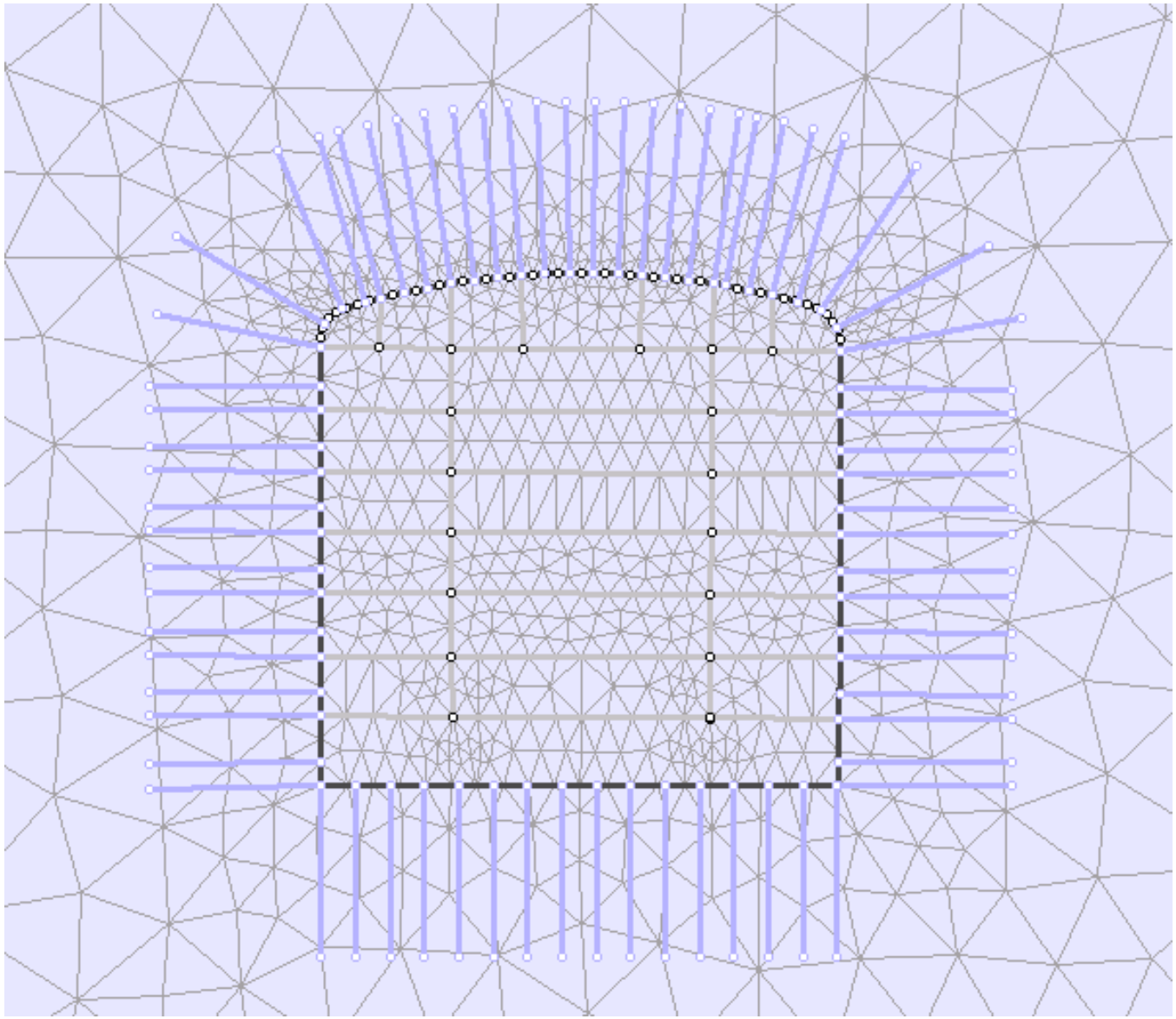
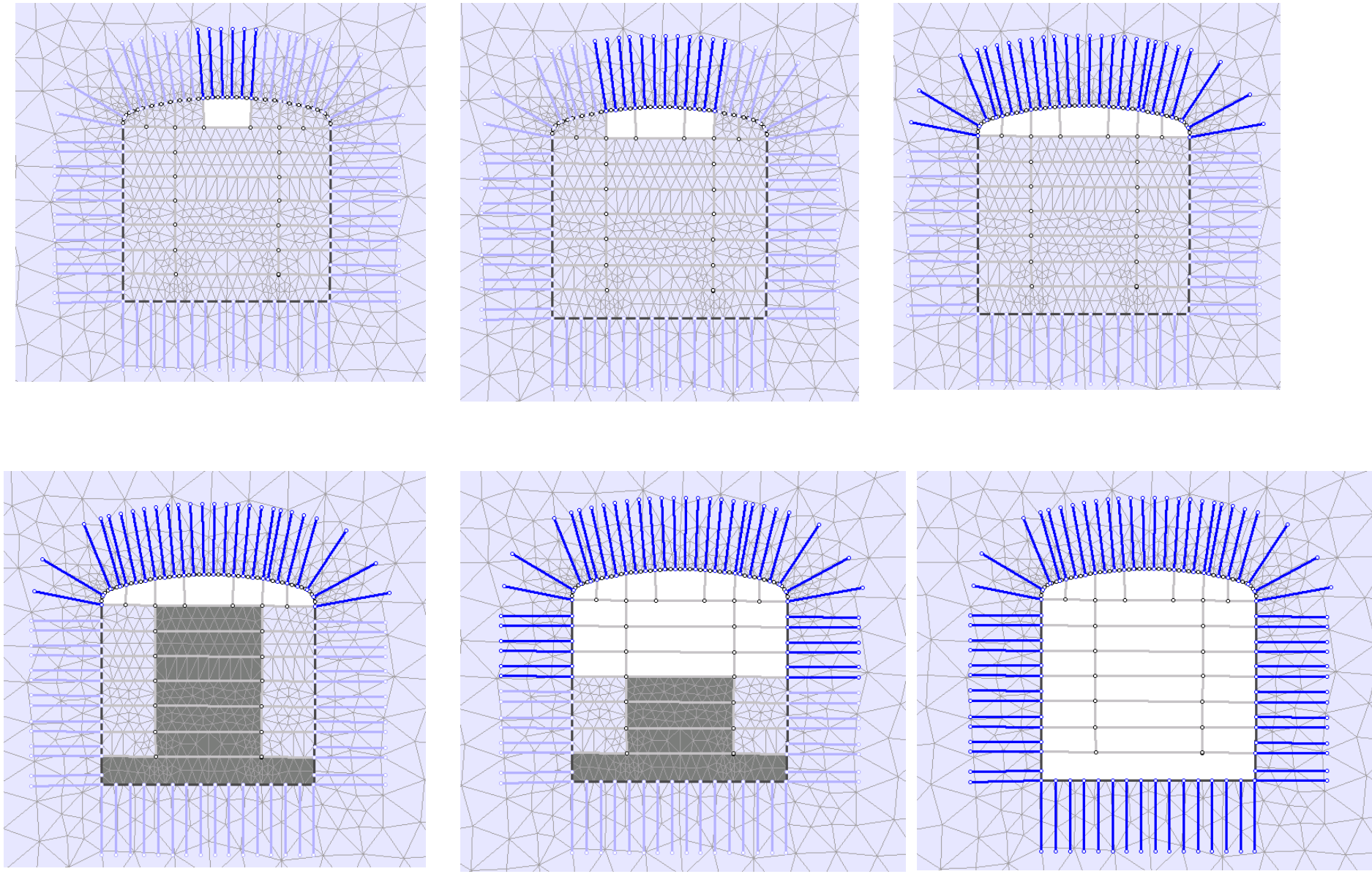


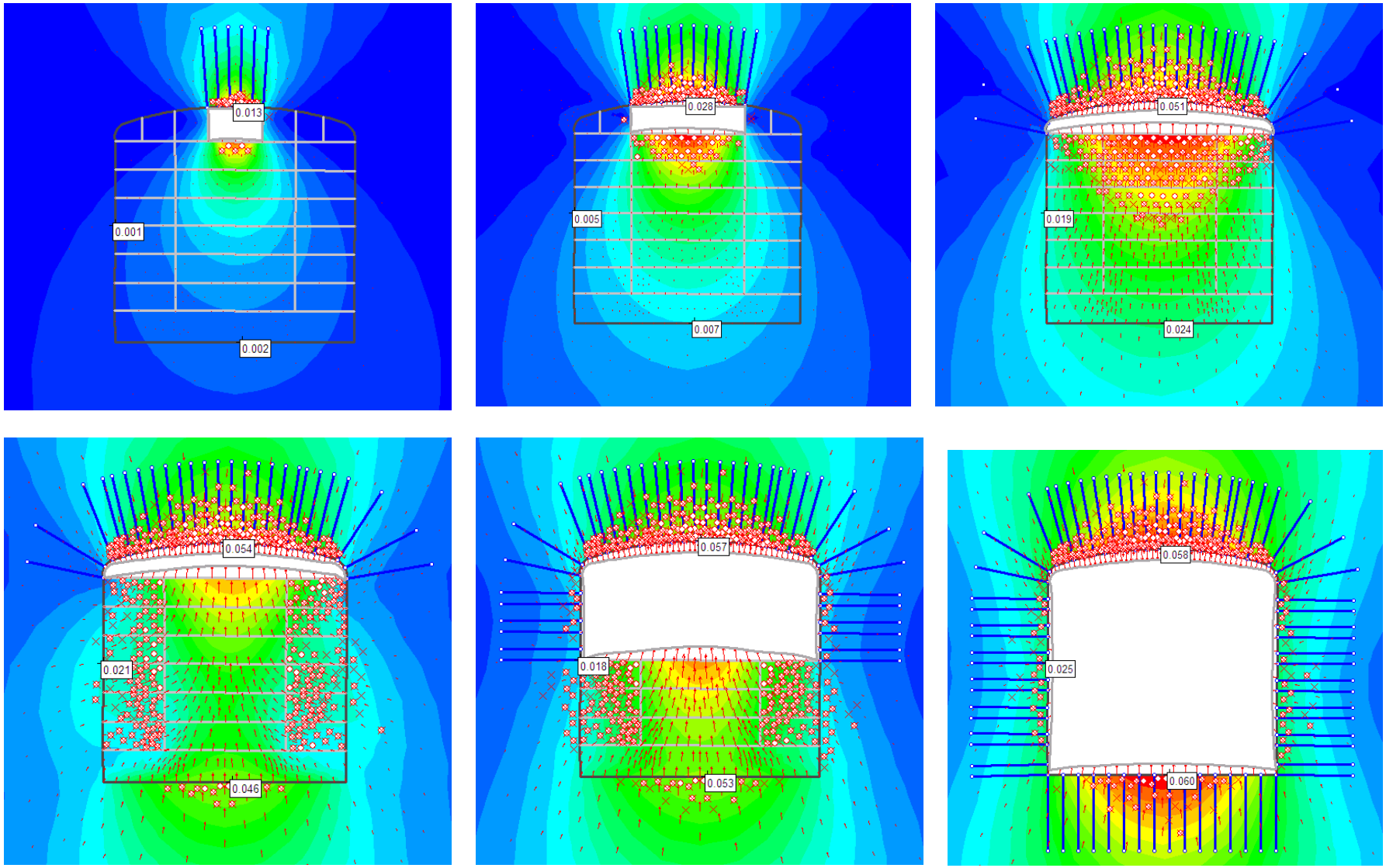
Figure 2B. Modified Borehole Locations on 4850 Level



Two-dimensional finite element model



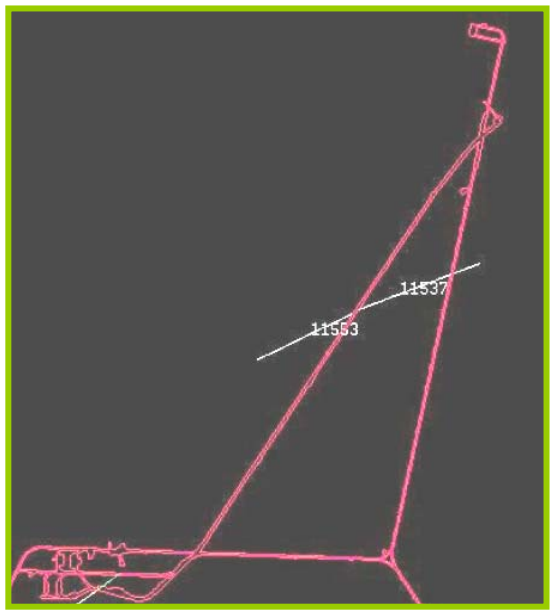
Sequential excavation and support



Induced displacements

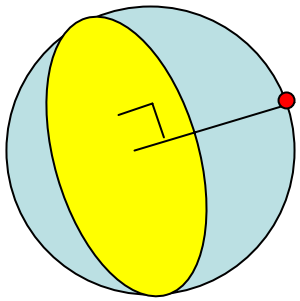
Existing Drill holes

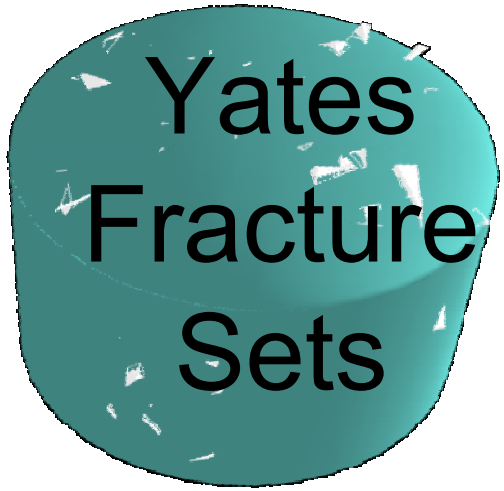
- 28,000 drill holes in the Homestake mine
- Cores available in old machine shop
- Only two drill holes in Yates Formation



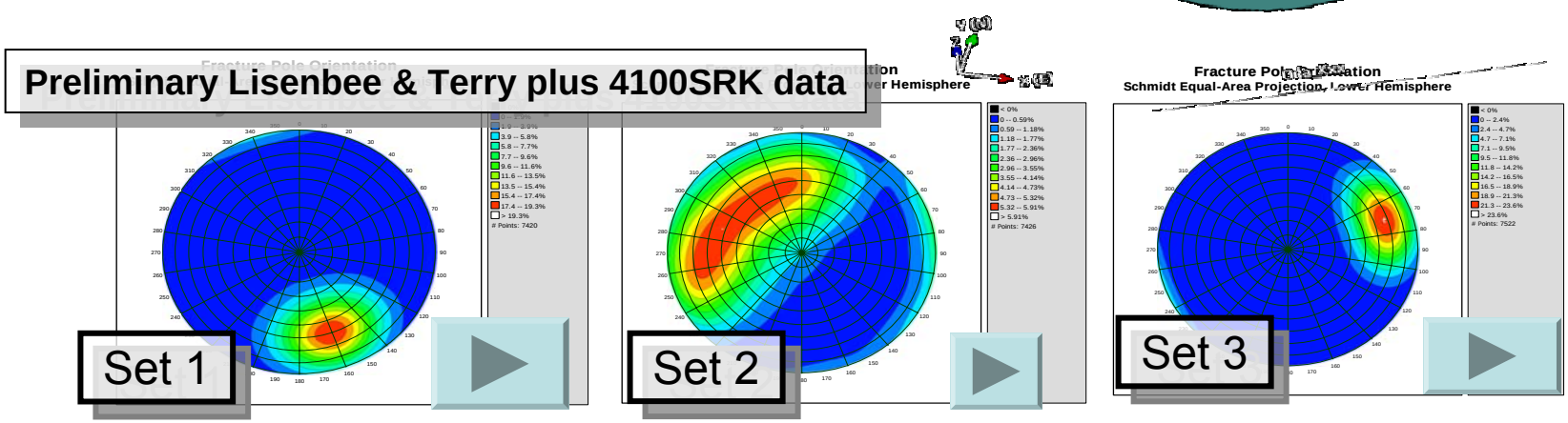
Inferred Joint Sets in Cavern Area (Trevor Carter, Golden)

Cut through a sphere





Preliminary Lisenbee & Terry plus 4100SRK data



Geotech Conclusions

- Work is moving well
- Existing data analysed, and incorporated into Vulcan model of mine
- Data use to MC joint sets in large cavity volume
- Major goal of Geotech work will be to drive drift to LC1, assuming no surprises with initial coring.

Water

- RWK Drafted specification for water for DUSEL
  - Supply water facts being checked at Homestake.
- Ultimate water quality comes from Cherenkov Water Group SOW for purification company.
- Water sources from DUSEL (many thanks to K. Lesko)
- Not too much controversy, except temperature requirements
  - LBNE will have to justify water temperture ≤ 15deg C
  - Should be data from IMB or SuperK.

Water Specification

DUSEL

Long Base Line Neutrino Experiment
(LBNE)
Water Requirements

R. W. Kadel
LBNL

7-July-2009
DUSEL Note xx

Abstract: This note describes the the water supply, purity and cooling requriemnts for the Large Cavity Water Cherenkov Detector. It is estimated that the detector will consume 1000l/min of water, and if supplied at 25 degC and chilled to 10degC, will require 1MW of cooling.

“Typical” Signature Page

Reviews, Acknowledgments & Approvals

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Acknowledged			
-	M. Diwan		
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S4 Proposal PI	R. Svoboda		
Approved by			
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DUSEL Senior Environmental Specialist	J. Scheetz		
DUSEL EH&S Director	S. Von Stein		
DUSEL operations Manager	G. King		
DUSEL Facility Integration	R. DiGennaro		
DUSEL Deputy Project Director	Kem Robinson		
DUSEL PI	K. T. Lesko		
DUSEL PI	W. Roggenthen		

Requirements from Water Group

Item	Requirement	Justification
Capacity	3 cavities having 120 kTon of water each, or 2 tanks having 180 kTon each.	Scientific Competitiveness
Quality	ASTM Type 1 and should include uranium removal and membrane final degasification.	Water transparency to Cherenkov light
Temperature	Achieve a water temperature of 13° C over a 6 month period, which should start at the beginning of the fill. The system should maintain the temperature of 13° C in the steady state operational period after the first 6 months.	Suppress biological growth to maintain transparency and reduce scattering
Disoloved oxygen	0.06 mg/liter.	Light transmission
Sterilization	UV treatment	Suppress biological growth
Fill Capacity	100kT per 4 months	Timeliness
Location of Water system	adjacent to the detector at the 4850 foot level in the Homestake mine.	Reduce system complication
Instrumentation	sufficient instrumentation so that its health and basic control functions can be accessed remotely	

DRAFT

Water Sources

Item	Value	Justification/Comment
Cost (untreated)	$0.35/thousand gal.	Lead Municipal (untreated surface) Water, $100/mo fee.
Onsite Supply lines	8” and 12”	
Historic Total Capacity (untreated)	1200 gpm of raw water	
Historic Total Capacity (treated)	200-400 gpm	
DUSEL needs (untreated)	300-600 gpm	Laboratory needs independent of LBNE and other experiments
Yates Shaft supply	4" raw and 2" potable lines exist, cascade system with ~ 300' drops	
Ross Shaft Supply	6" raw water system was rated at 5000 psi, typically ran at ~ 1200 psi, this system has large drops (surface to 2400, 2400 to 4000-ish, had power regeneration circuits)	These big drops introduce significant dissolved air into the wate
Outflow DUSEL Water Pruification system as a source	2000 gal/min	This is the outflow water from the mine (2000g/min) mixed with Barrick water from Grizzly gulch. See discussion below

DRAFT

Assumptions

Item	Value	Comment
LBNE capacity	1000 l/min	
DUSEL inlet temp	25 deg C	
LBNE output temp	10 deg C	
Water source	Lead municipal untreated water	
Leak rate	<100 l/min/cavity	Arbitrary assumption. Water from cronic leaks may require treatment, especially if load with Gd compounds.

DRAFT

Specification

Item	Value	Comment
LBNE capacity*	1200 l/min	Assumes filling one detector and replacing leaking water from two other cavities
Input water*	Lead untreated industrial	
DUSEL inlet temp*	25 deg C	
Inlet Pressure	TBD	
LBNE net cooling power for water	1 MW	Assumes output temperature of 10°C from cooling plant
Water Cooling method	TDB	
Pump-out	TDB	
Cooling system cost sharing	TDB	
Code Requirements	TDB	

DRAFT

*Follows from assumptions.

Conclusions

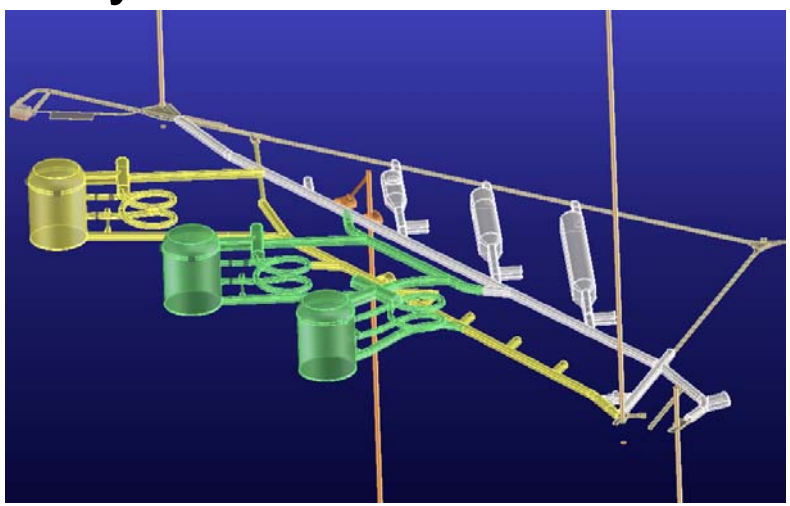
- DUSEL is moving quickly to establish contracts for underground and surface facilities design
- DUSEL will insist on specificaitons via design interface documents approved by LBNE project office(S)
- Geotech investigations at 4850L starting this week to determine best location and size of large cavities
- Size and shape of cavity will be determined by
  - Geology
  - Physics
  - Constructability
  - Cost

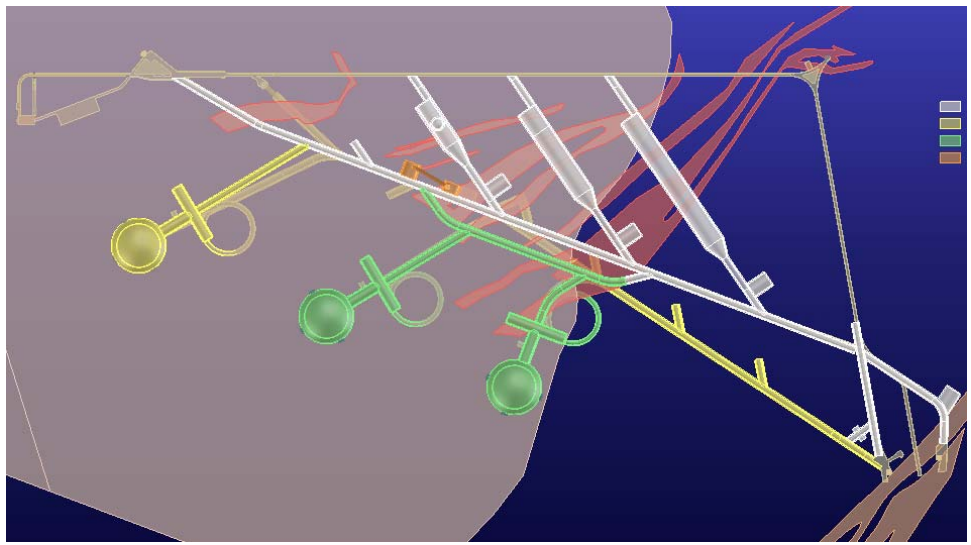
End/Backup

Detector Depth Conclusion

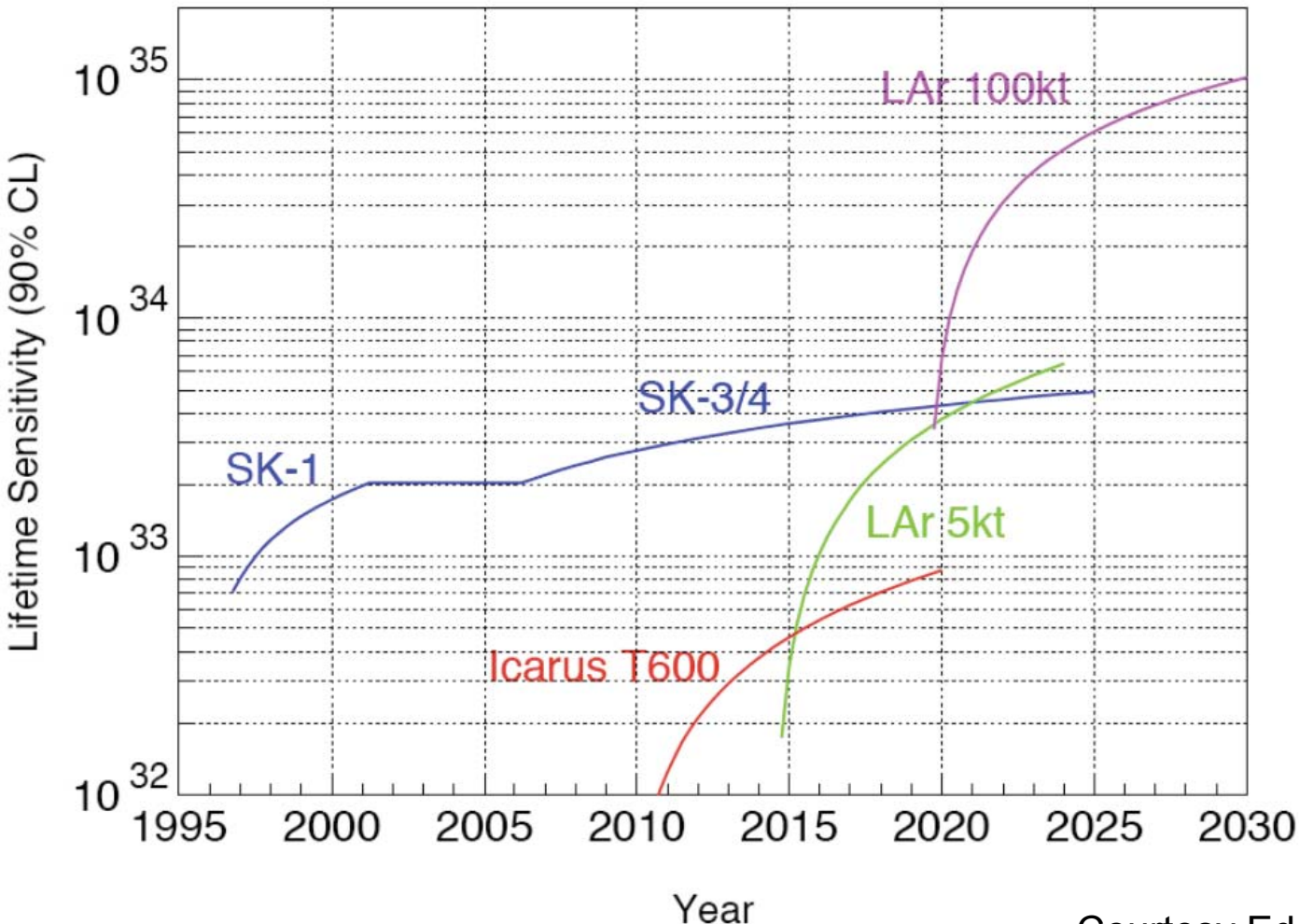
No physics goal requires a depth deeper than the 4850 Level

- Significant burden to go deeper (requires all material, equipment and personal change shafts)
- <u>Conclusion</u>: The depth required by physics goals weighed against the siting criteria suggest that the 4850L is the best location to search for candidate sites suitable for the large cavity detectors.



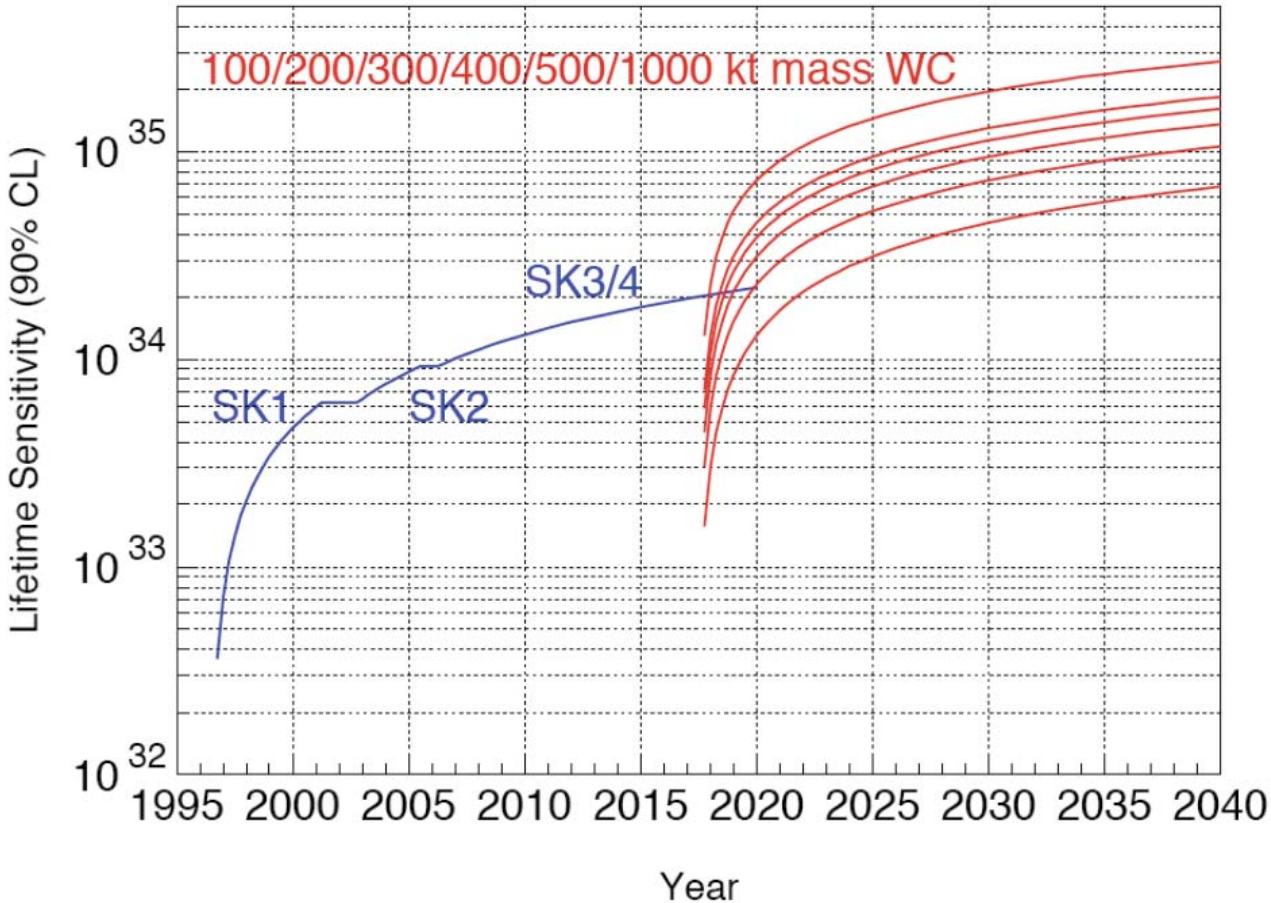


Proton Lifetime Sensitivity, LAr detector



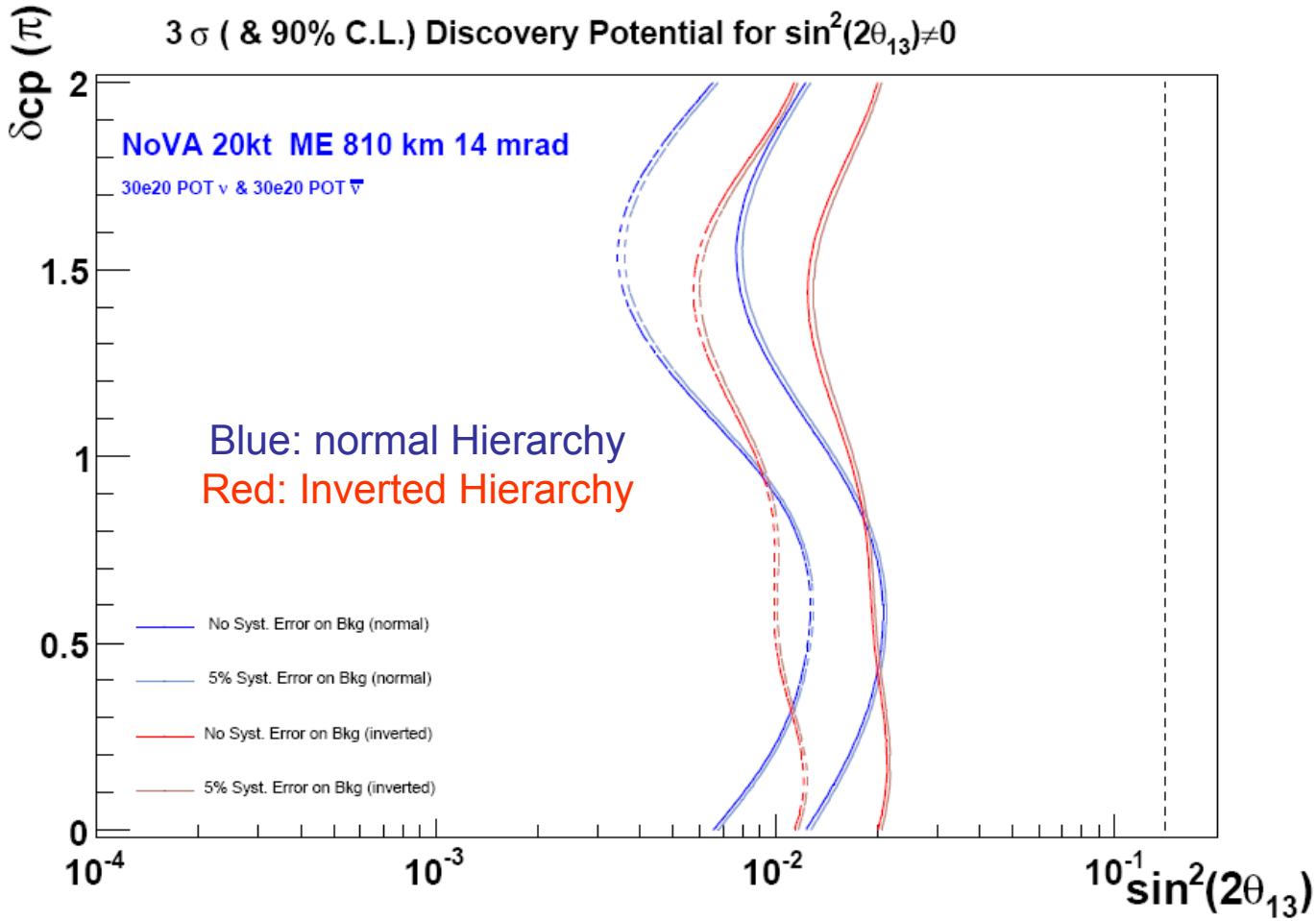
Courtesy Ed Kearns

Proton Life Time Sensitivity, Water Cherenkov



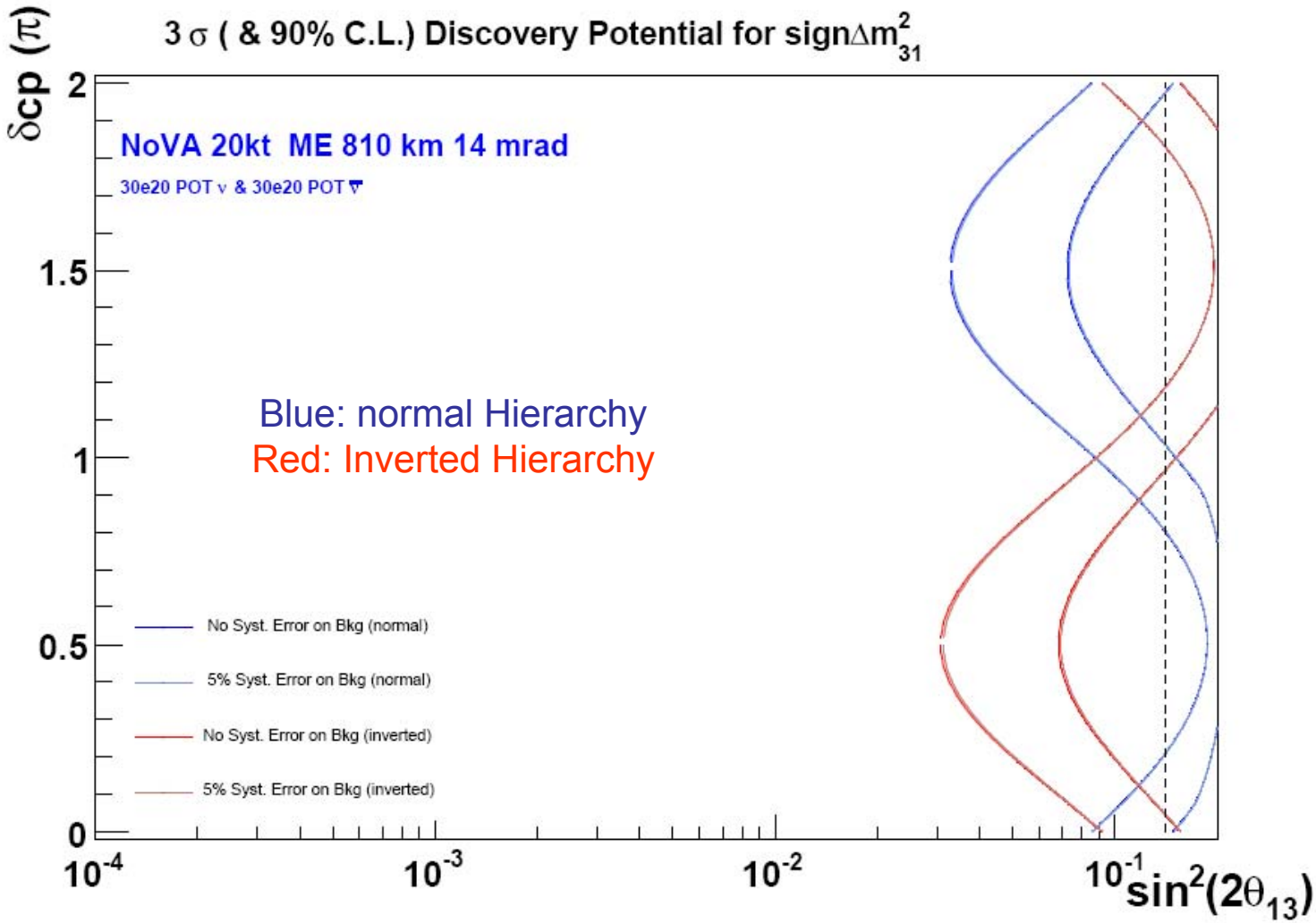
Courtesy Ed Kearns

NOVA, $\sin^2 2\theta_{13} \neq 0$



Report of the US long baseline neutrino experiment study, Fermilab-0801-AD-E

NOVA, Discovery Potential for



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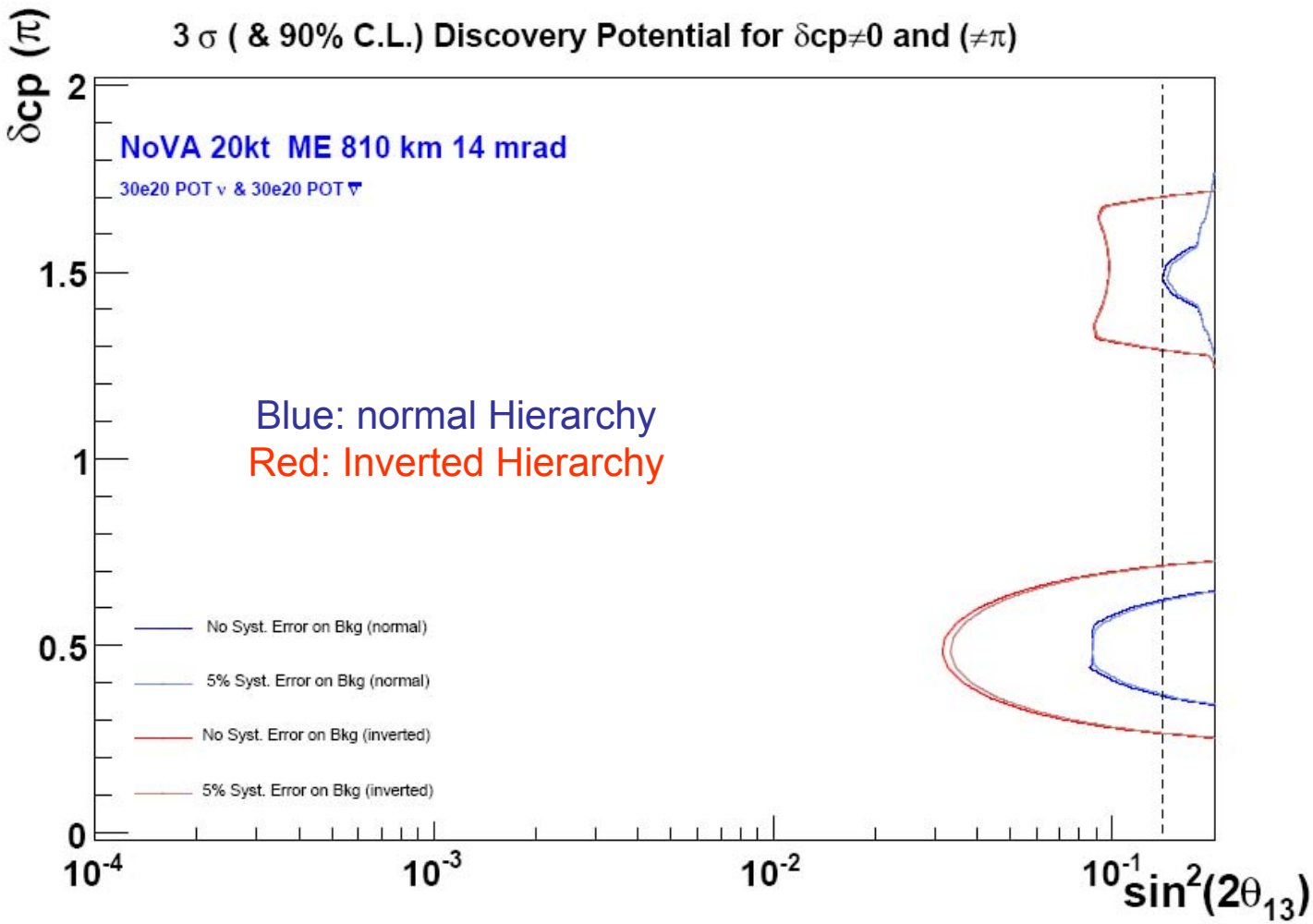
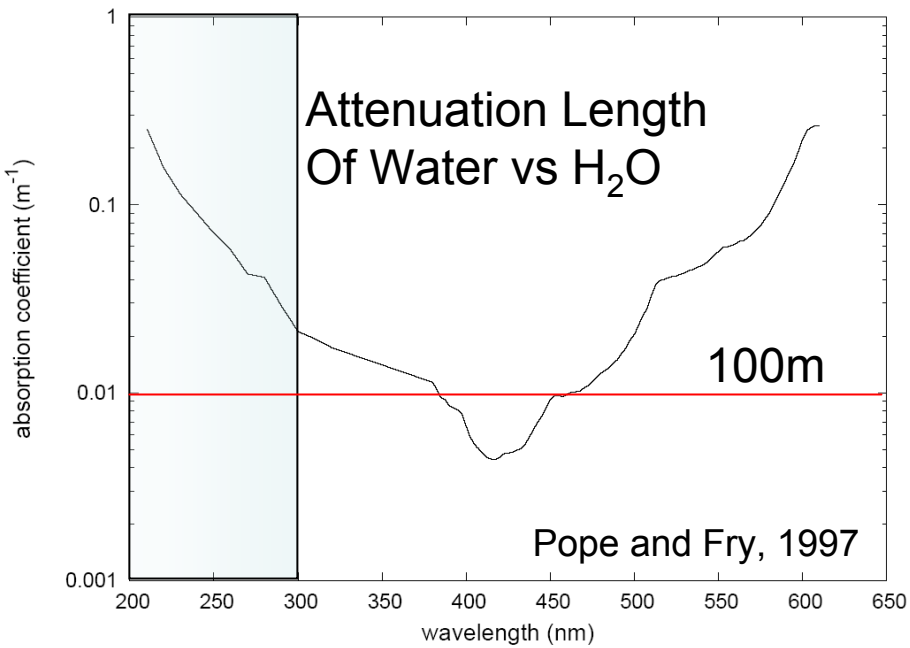
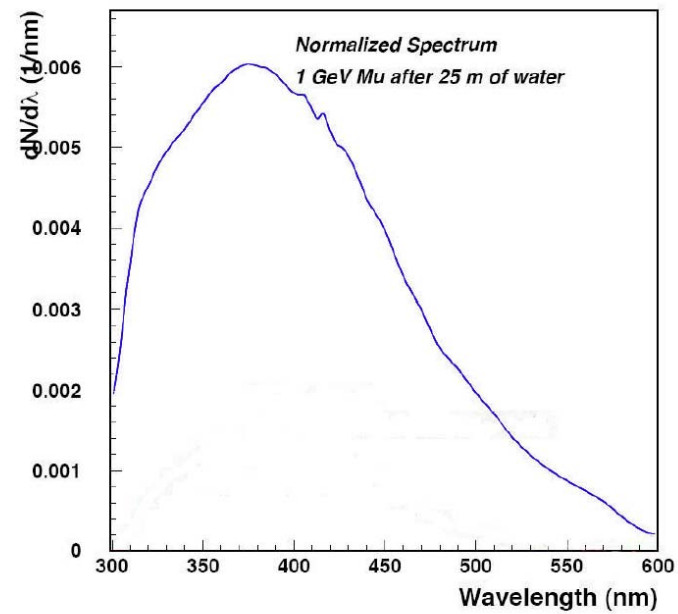
NOVA Discovery Potential for

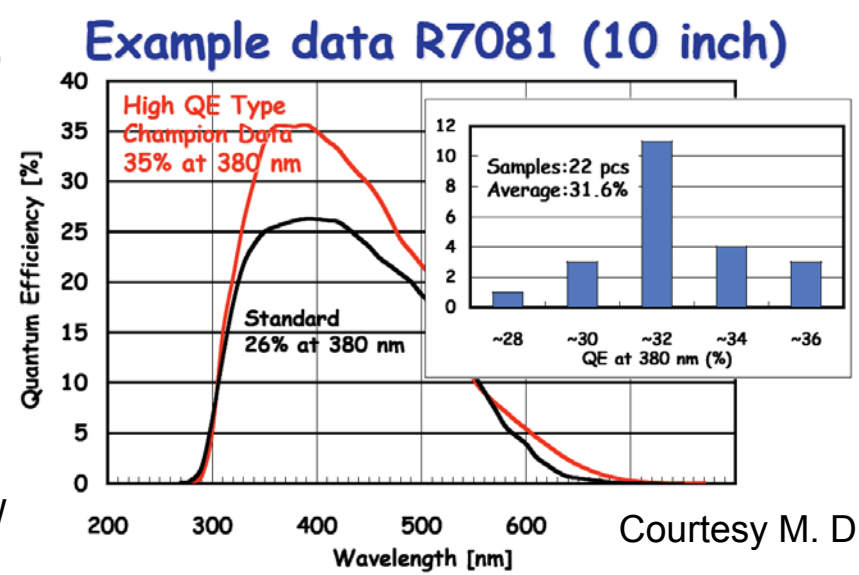


Report of the US long baseline neutrino experiment study, Fermilab-0801-AD-E

Requirements: Attenuation Length in H_20



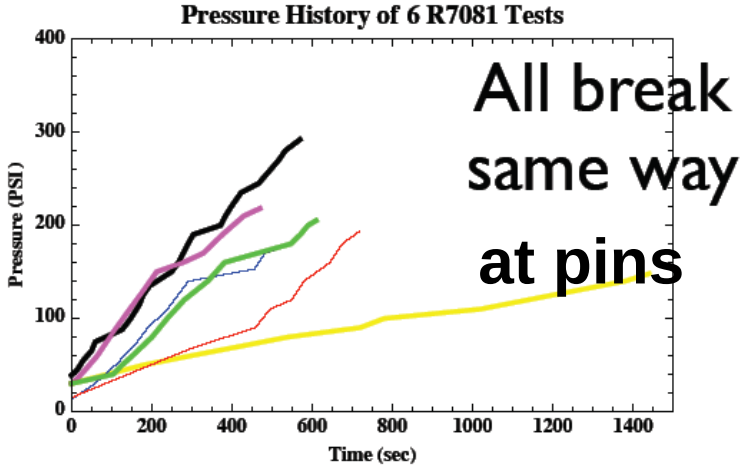


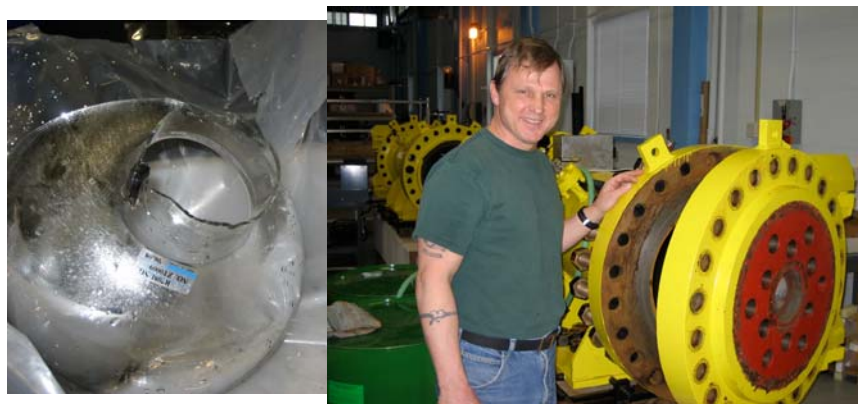


Courtesy M. Diwan

Requirements: PMT collapse Strength

- PMT's
  - collapse strength
  - QE. PMT's with 38% QE for available from Hamamatsu
  - Coverage >25%
- PMT's limit water depth to 60 m.
- PMT redesign or enclosures could improve performance.
- Pressure pulse

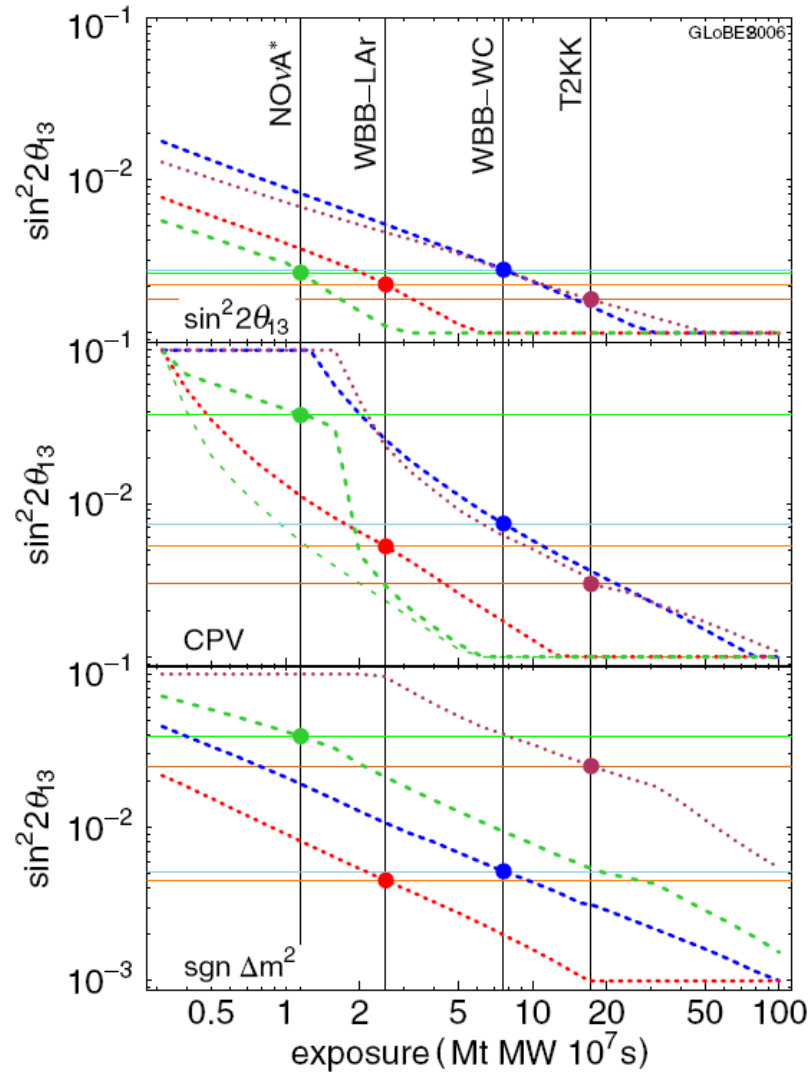




Courtesy M. Diwan

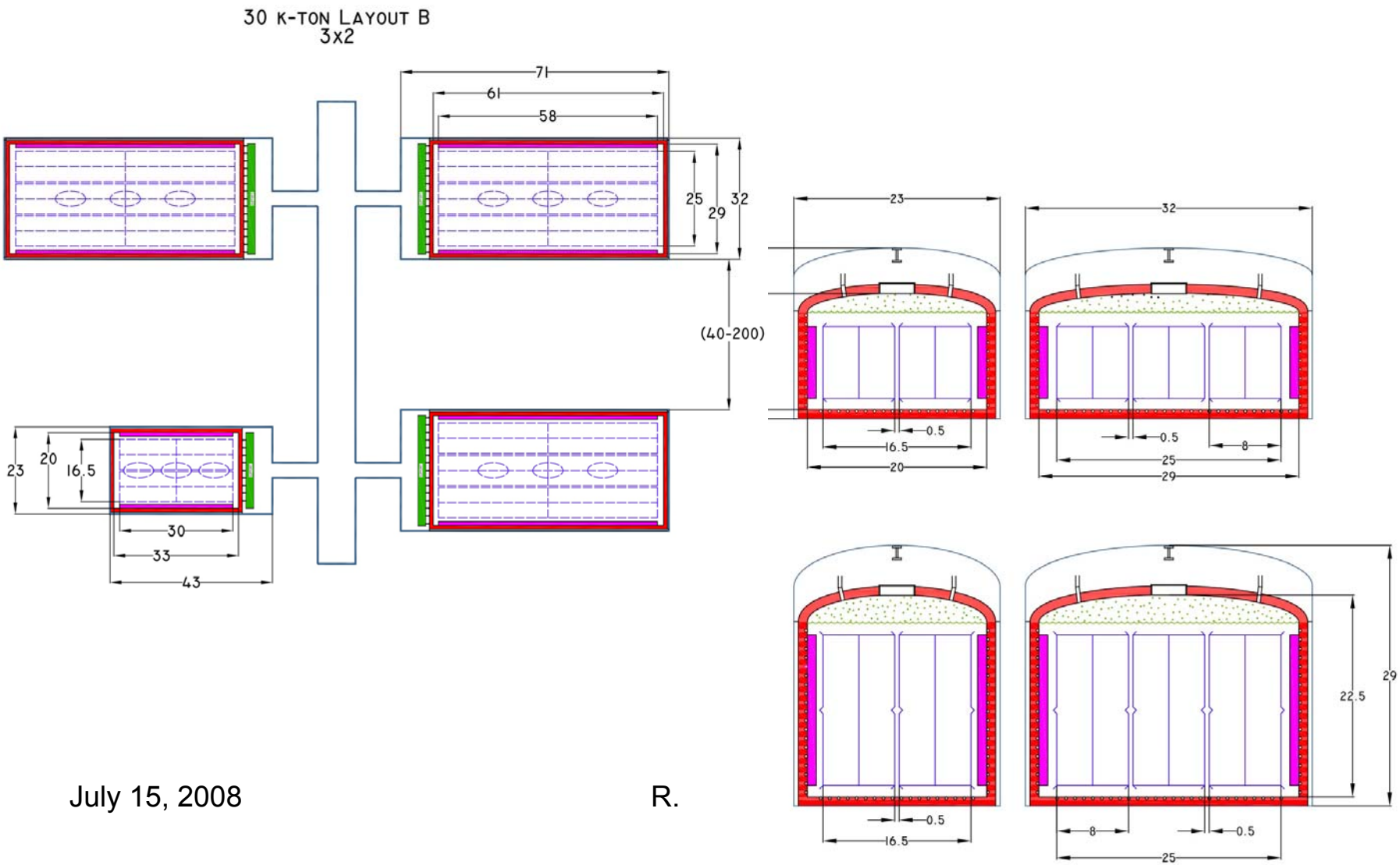
3σ Sensitivity
Future Long Base Line Experiments

Item	NOνA* LAr	WWB WCh	WWB LAr	T2KK WCh
POT/yr x10^{20} (ν)	10	22.5	22.5	52
POT/yr x10^{20} ($\bar{\nu}$)	10	45	45	52
Years ν + $\bar{\nu}$	3+3	5+5	5+5	4+4
Power (MW)	1.13	1 (ν) 2 ($\bar{\nu}$)	1 (ν) 2 ($\bar{\nu}$)	4
Baseline (km)	Ash River	1290	1290	295 + 1050
Mass (kT)	100	300	100	270 + 270
Exposure: (Mt-MW-10^7 sec)	1.15	7.65	2.55	17.85



Barger, et al, PRD 76, 031301 (2007)

Beyond 5kT LAr: Custom Cavities



Liner types

- Self supporting Steel can (PSL)
- Segmented Concrete blocks (Laurenti)
- Self supporting concrete vessel (BNL)
- Slip formed concrete from top or bottom
- No liner (ie water barrier over shotcrete) (LBNL./UCB)
- Pressure balanced wall

100 kT fiducial Volume Liners

	Unit	1 Steel self supporting	2 Concrete blocks	3 Unitary post-stressed concrete vessel self supporting	4 Liner on shotcrete	5 Cast concrete against rock	6 Pressure balanced wall
Fiducail Radius	m	25	25	25	25	25	25
Fiducial volume cut	m	1	1	1	1	1	1
PMT module thickness	m	0.5	0.5	0.5	1	1	1
Gap between PMT module and tank wall	m	0	0	0	0.2	0	0.2
Buffer size	m	1.5	1.5	1.5	2.2	2	2.2
Sealing/coating layer thickness	m	0.005	0.005	0.005	0.005	0.005	0.01
Tank water radius	m	26.51	26.51	26.51	27.21	27.01	27.21
Tank wall thickness top	m	0.05	0.5	1	0.1	1	0.01
Tank wall thickness bottom	m	0.12	0.5	1.0	0.1	1	0.0
Tank wall thickness average	m	0.09	0.50	1.00	0.10	1.00	0.01
Tank outer radius	m	26.63	27.01	27.51	27.31	28.01	27.22
Access/drainage/balance gap	m	2	0.2	3	0	0	0.5
Rock wall raidus	m	28.63	27.21	30.51	27.31	28.01	27.72
Tank wall mass	tonne	5989	11453	23331	2316	23755	231
Fiducial volume	cu m	100000	100000	100000	100000	100000	100000
Fiducial height	m	51	51	51	51	51	51
Tank water height	m	54	54	54	54	54	54
Tank floor thickness	m	2	2	2	2	2	2
Excavation height	m	56	56	56	56	56	56
Excavation volume (without upper part)	cu m	144155	130207	163712	131168	137978	135184
Normalized		1.04	0.94	1.19	0.95	1.00	1.00

55m < Free Cavity Diameter < 61m

130,000 m^3 < Excavated Volume < 164,000 m^3

Definitions

Cavern spec summarized from physics perspective in DUSEL note 73.

Free Diameter: Unobstructed diameter of finished cavern with ground support installed.

Free Height: Unobstructed distance from the top of the detector to a [possibly virtural] flat floor of the cavern.

Free board: distance between the top of the water and the next thing higher it should not touch.

Fiducial Volume: The allowance in meters, either radially or axially, between the maximum extent of photocathode and the volume of water used for physics analysis (see following pictures).

Buffer volume: volume of water immediately around PMTs including the volume need for their support and any fiducial volume cut