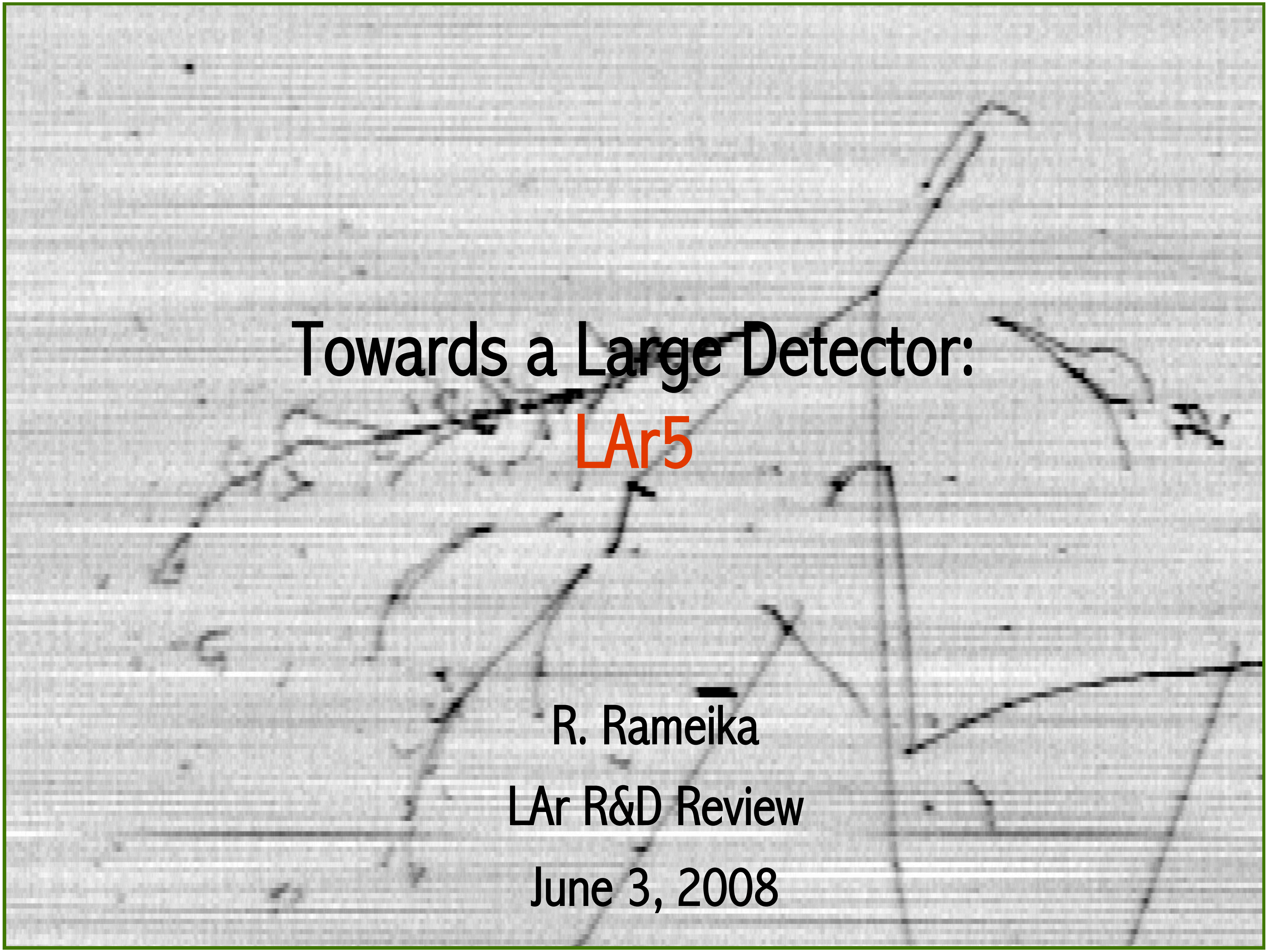


Towards a Large Detector:
LAr5

R. Rameika

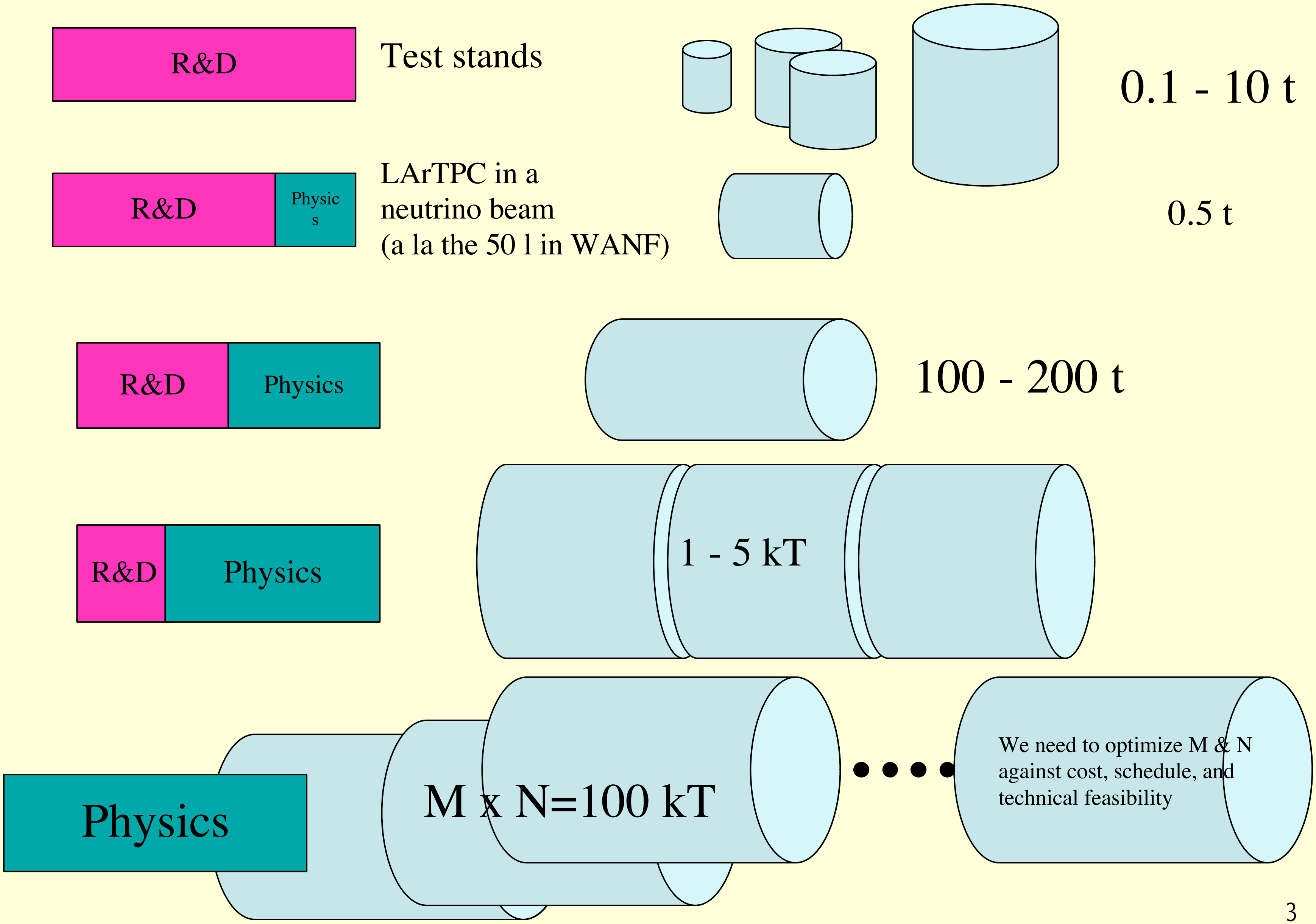
LAr R&D Review

June 3, 2008

Outline

- Why a 5 kiloton step?
- Siting Options
  - NuMI
  - DUSEL
- Technical Issues
  - Evolution from MicroBooNE
  - Unique to larger detectors
- Schedule Considerations
- Conclusion

Evolution of a Liquid Argon Physics Program

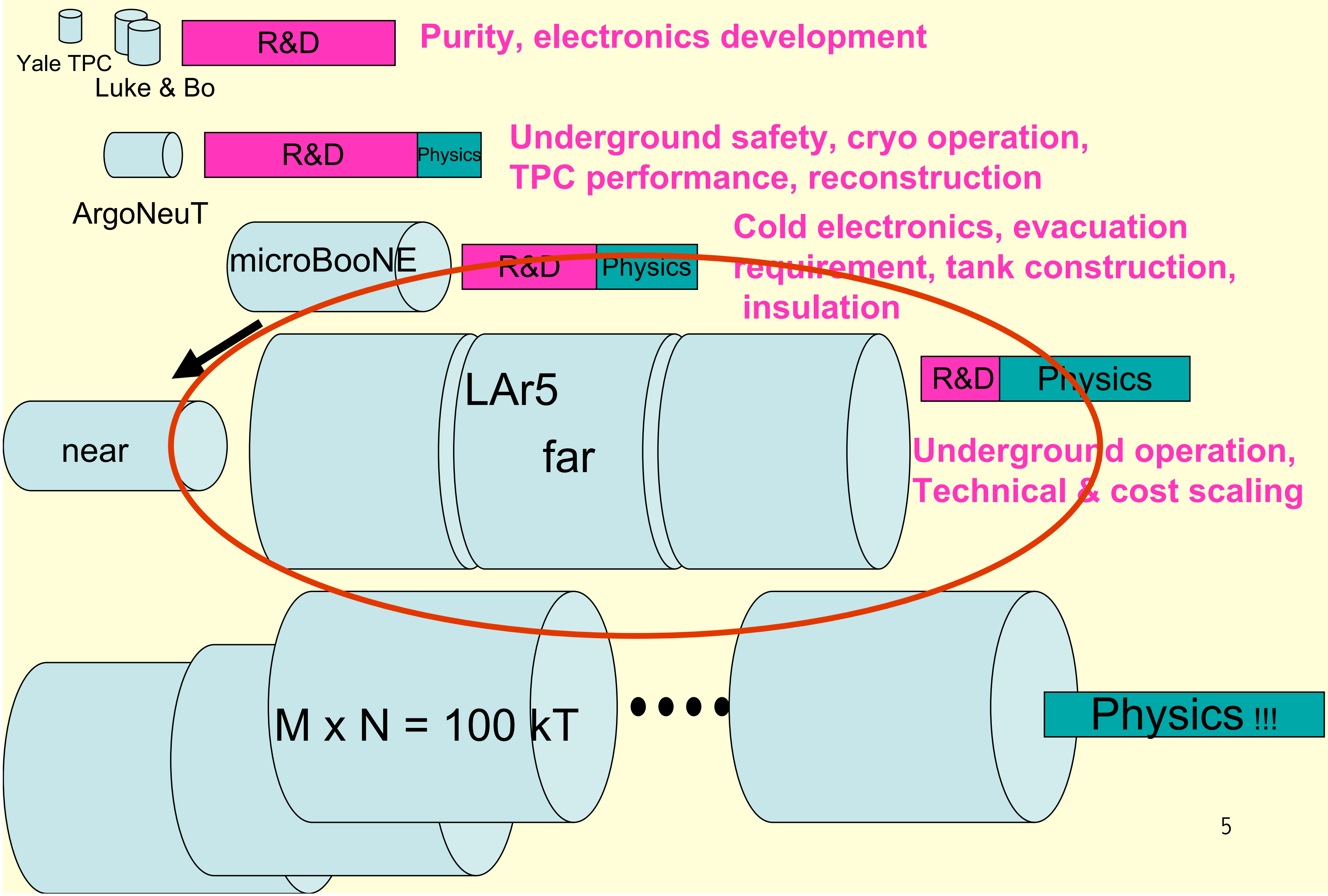


Why a 5 kiloton step?

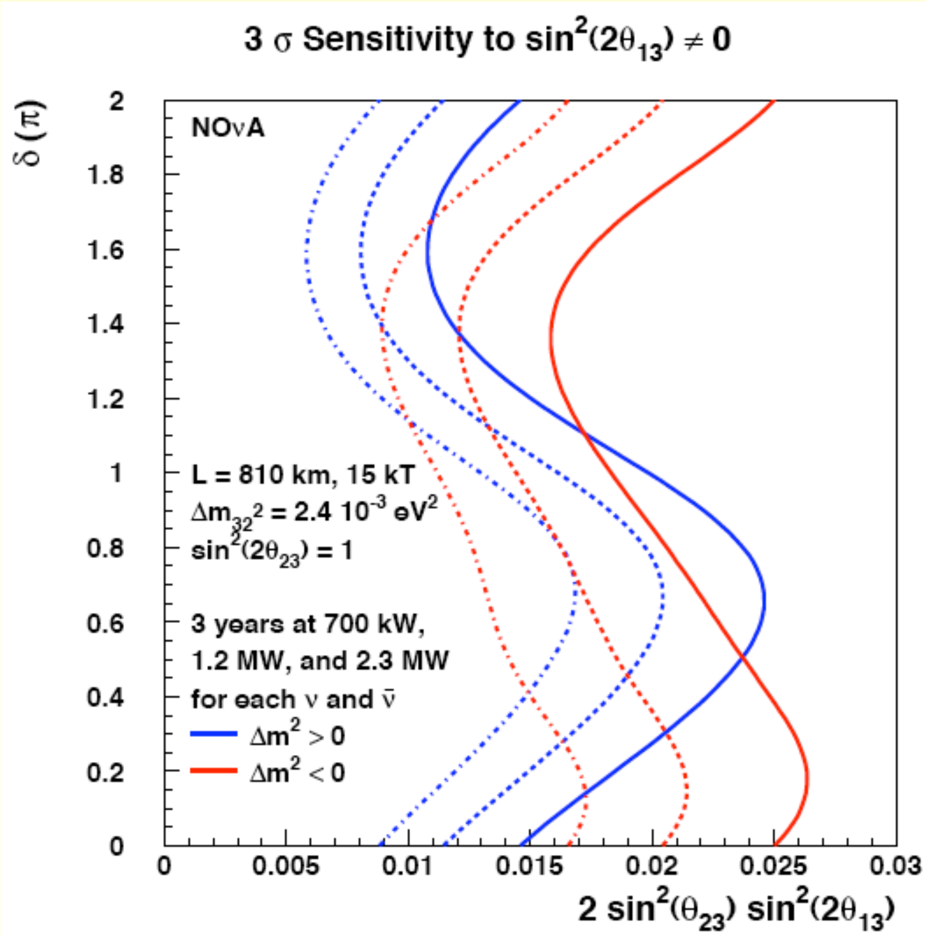
- From a purely technical point of view, the step after the 100 - 200 t detector, could be 1 to 5 kilotons
  - The main technical purpose of this step is to determine construction techniques and the scaling laws, especially in regards to cost
- Location of 1 - 5 kilotons
  - 1 kT in a near location gets lots of events; does near detector physics - no oscillation physics
  - 5 kT in a far location is about the smallest one can build and have decent sensitivity to physics measurements

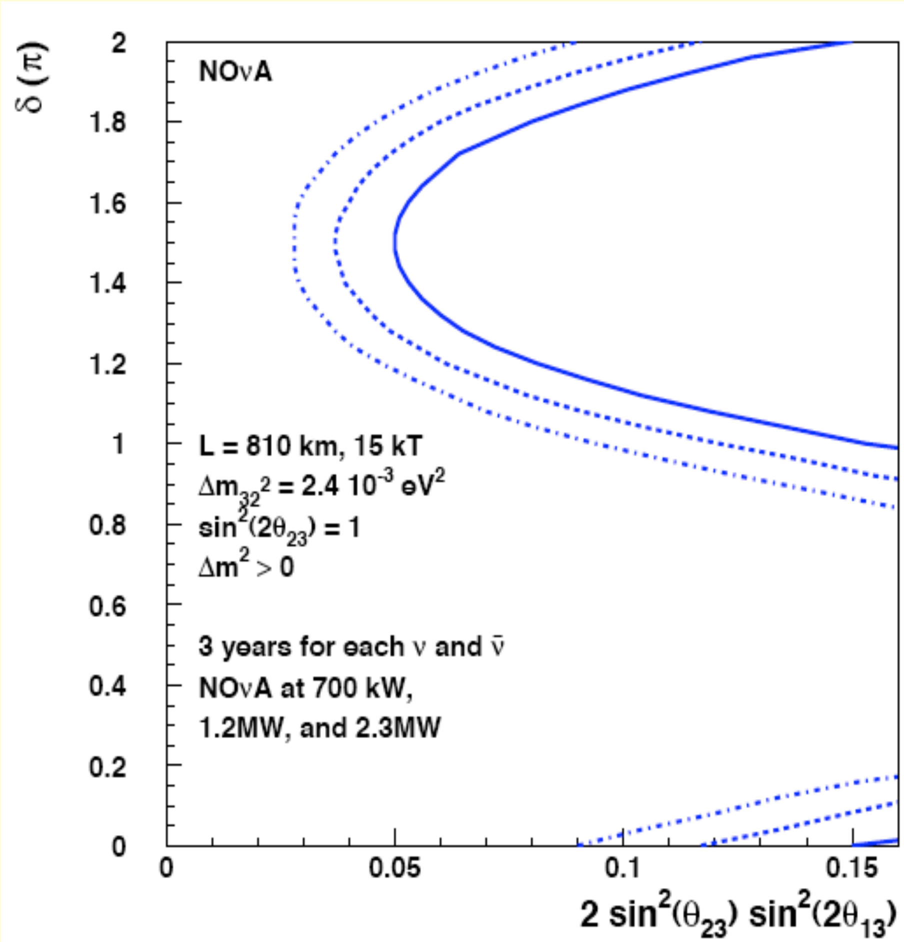
5kT is an appropriate step in mass and has compelling physics potential

Evolution of the Liquid Argon Physics Program

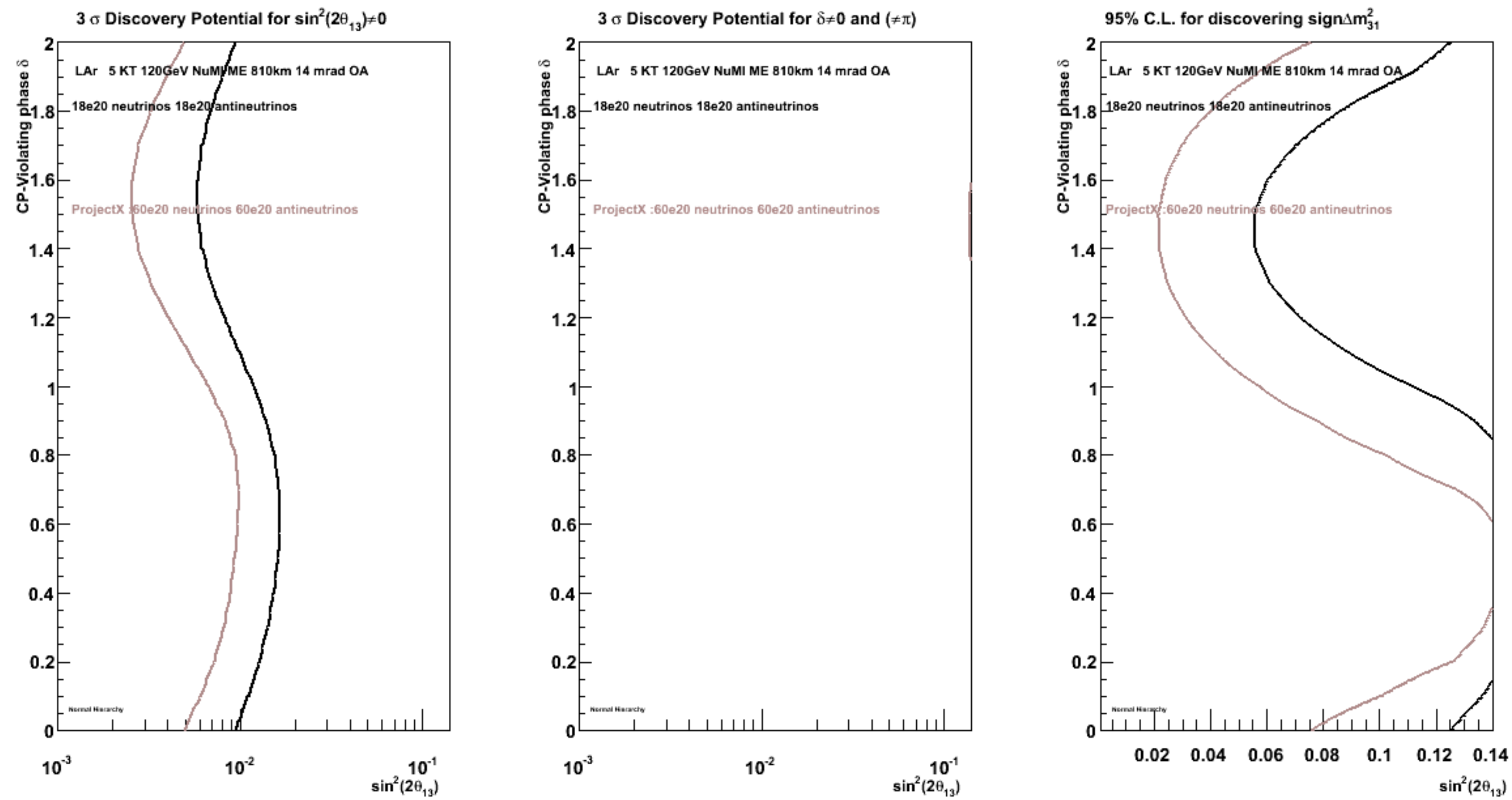


NOvA sensitivity (P5)



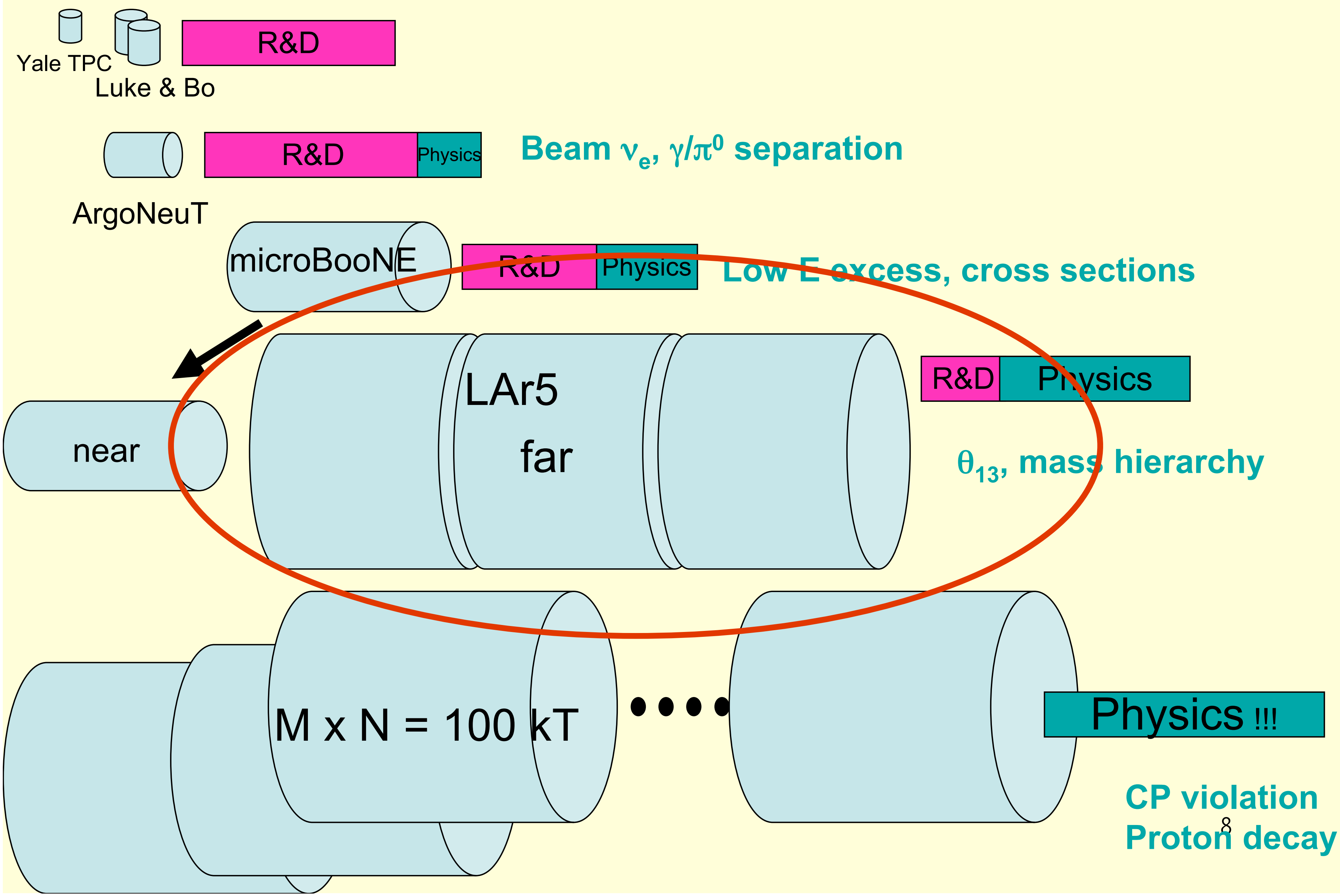


LAr5 @ Ash River (ME)

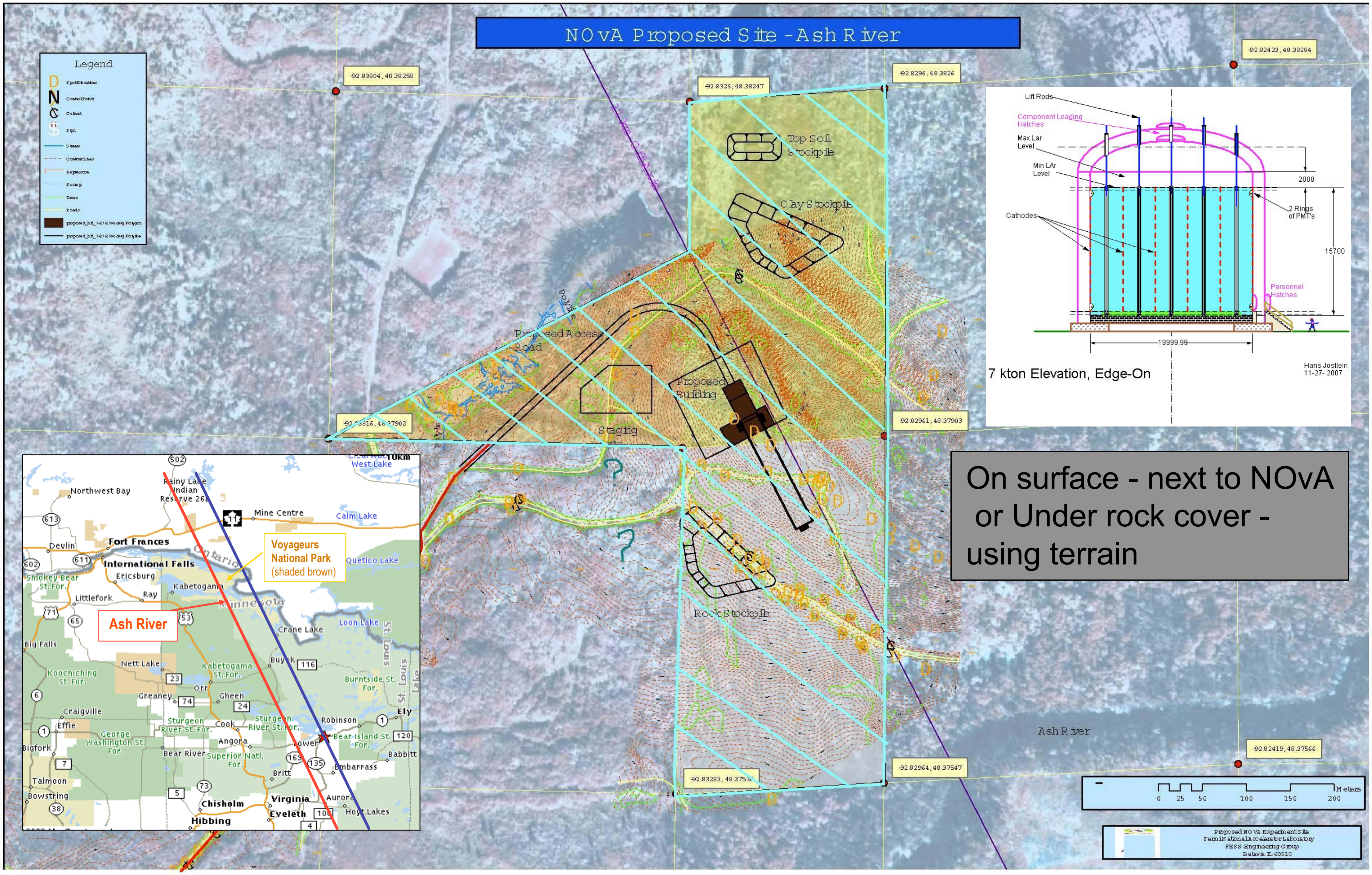


Sensitivity studies by N. Saoulidou

Evolution of the Liquid Argon Physics Program

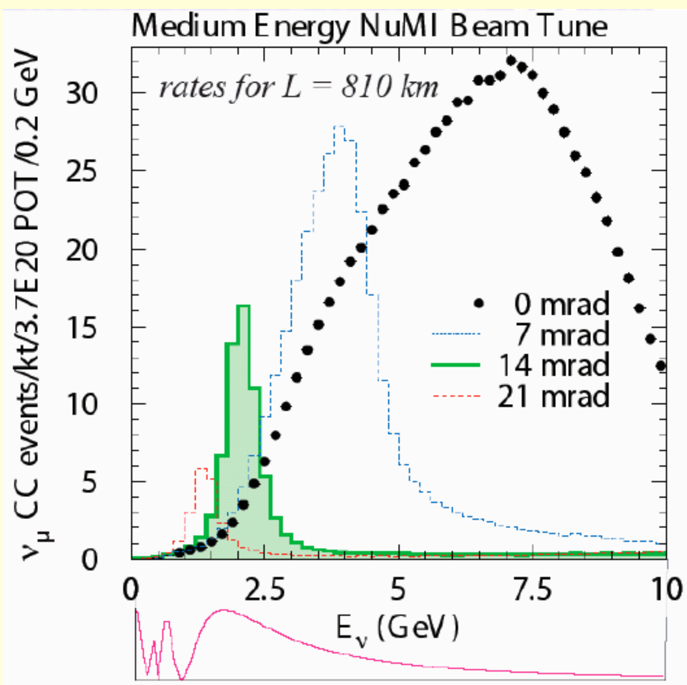


Siting options at Ash River

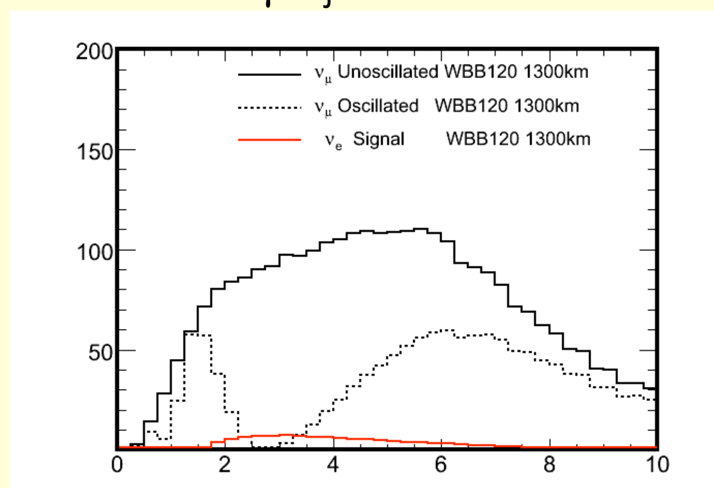


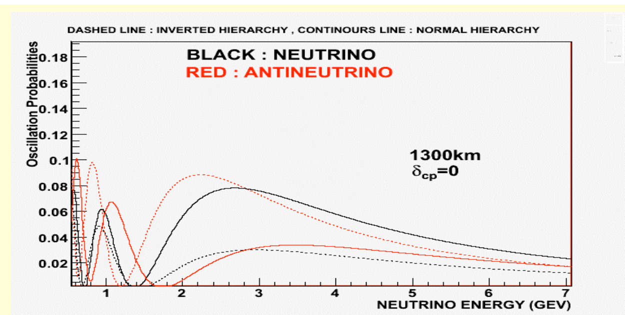
Detector Siting Options

- Off-axis neutrinos
  - Reduced backgrounds from neutral current interactions
    - Reason for NOvA choice
  - Lower the energy to get closer to the oscillation maximum
    - Reason for the MODULAr choice

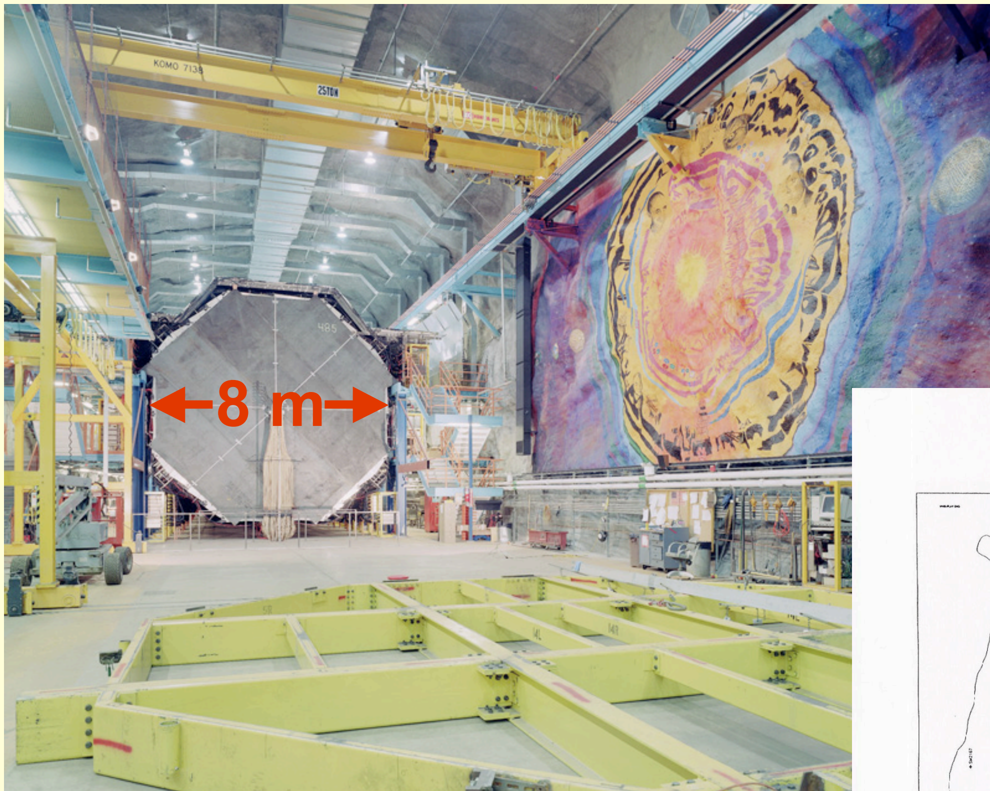


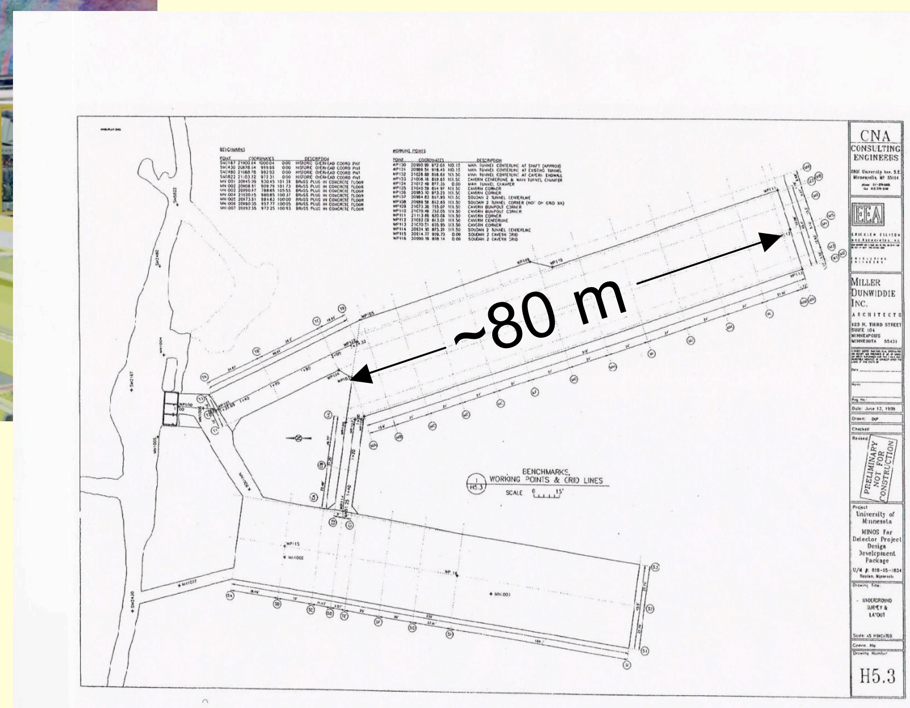
- On-axis neutrinos
  - Broadband beam : more events, both signal and background
  - On-axis option can be considered if the detector has excellent NC π^0/γ rejection



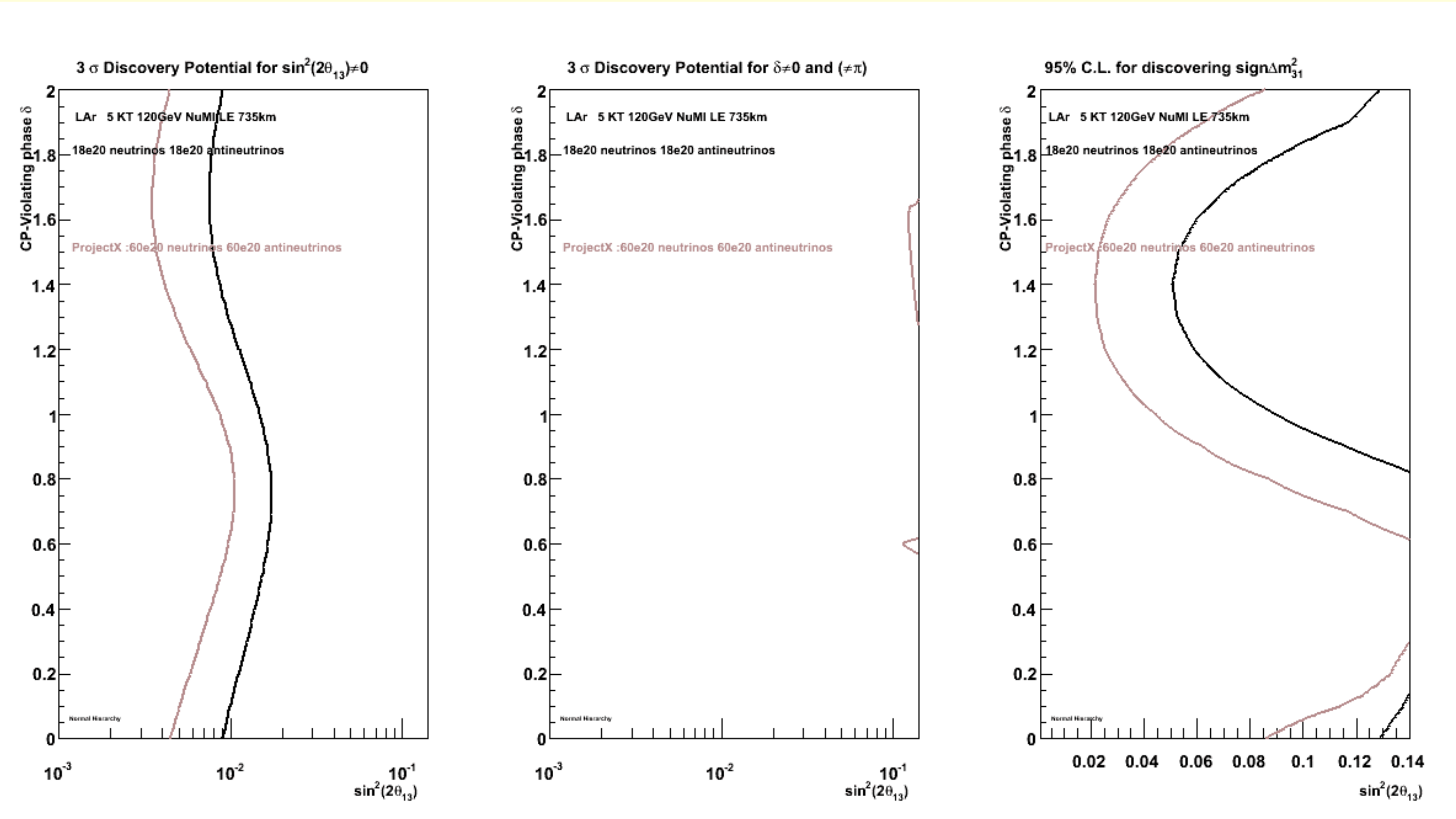


The MINOS Cavern
at the Soudan Underground Laboratory

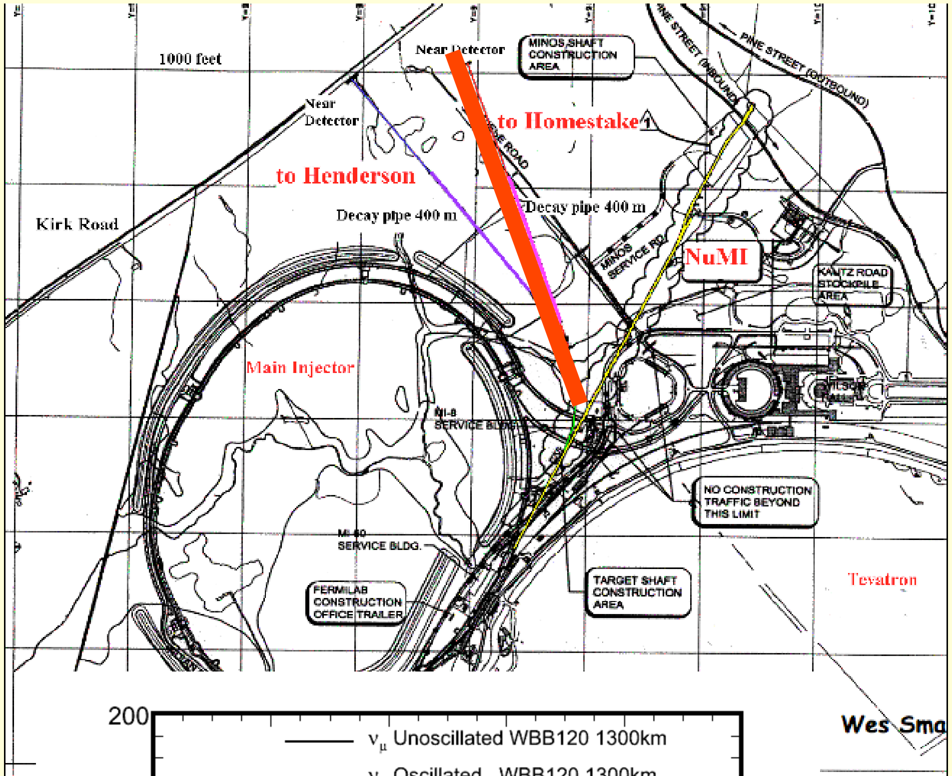


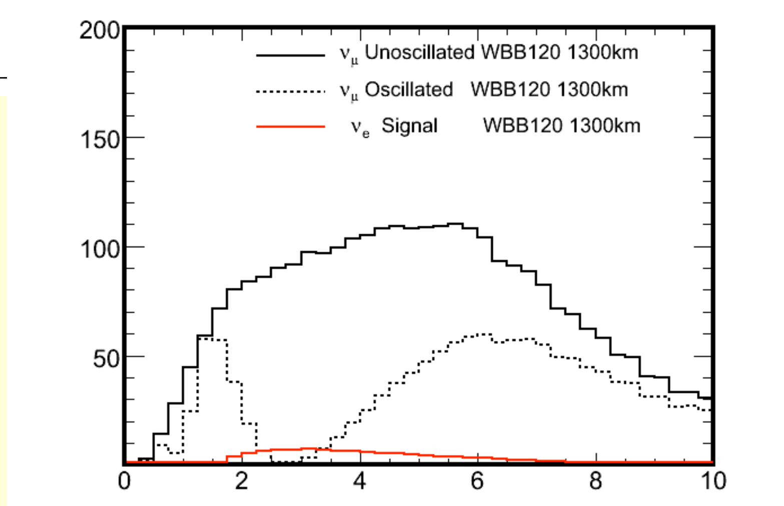


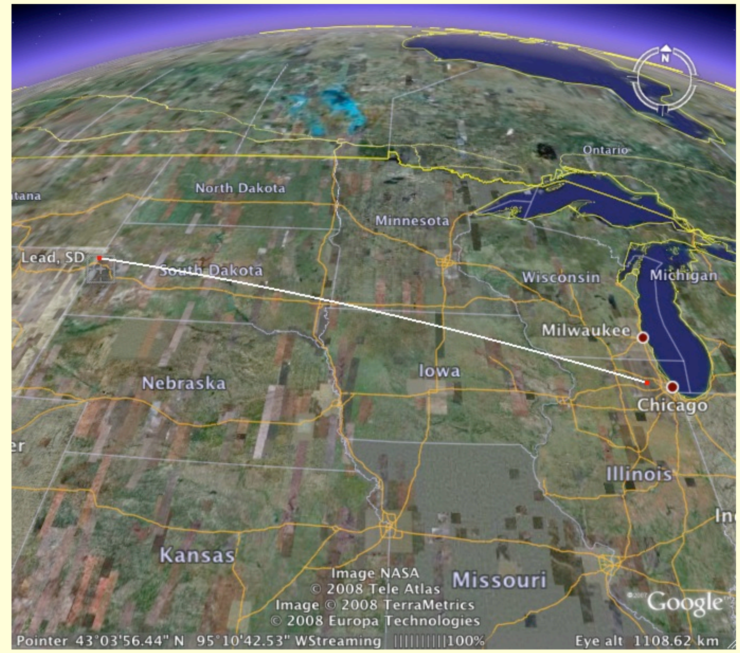
LAr5 @ SOUDAN (LE)



The DUSEL Option





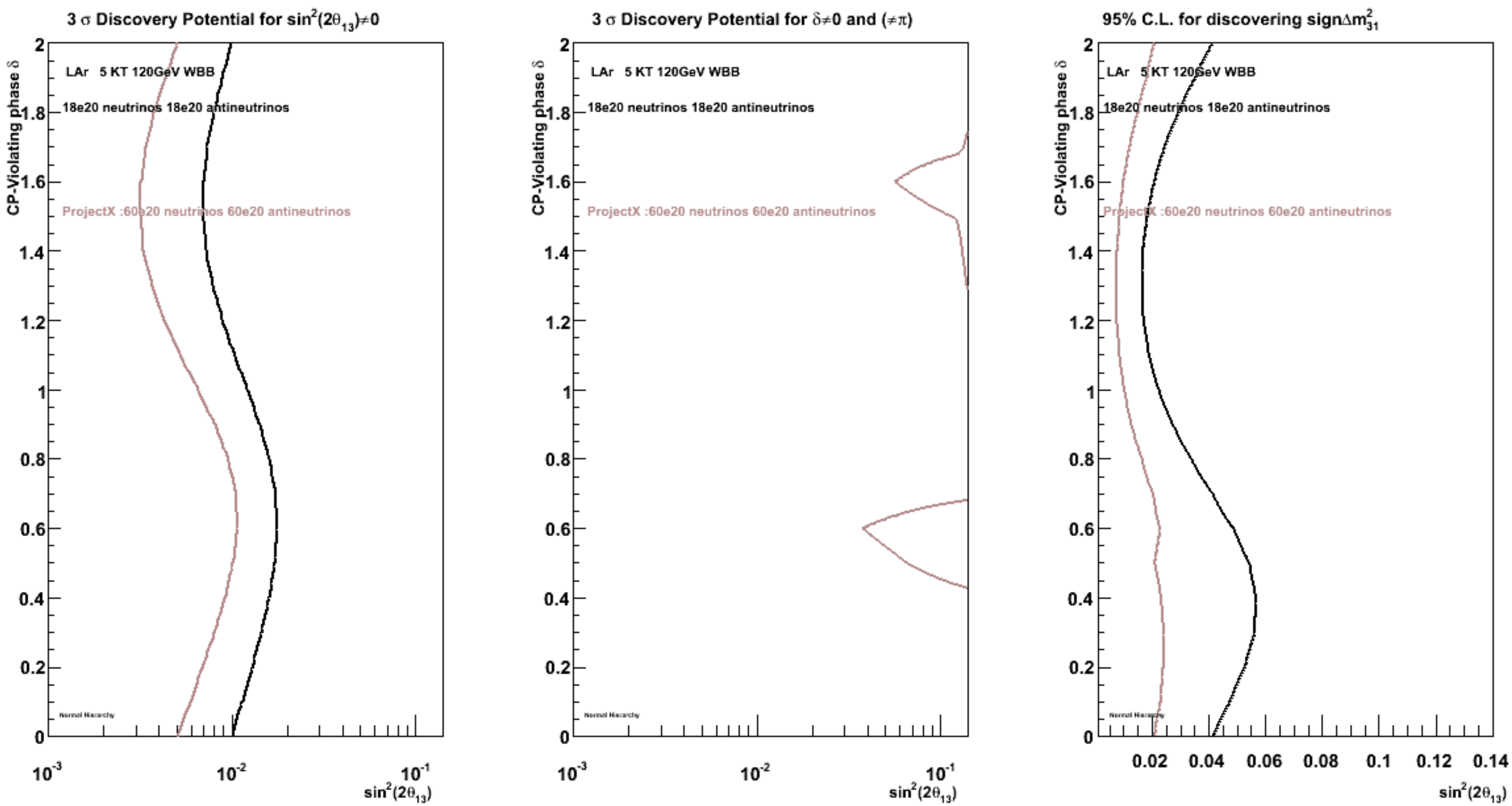


L = 1300 km (more matter effect in the oscillations)

Oscillation maximum at higher energies

Broad band beam can cover 1st and 2nd maximum

LAr5 @ L = 1300 km



Pros and Cons of the NuMI Options

- Cons :
  - The NuMI beam exists; the baseline is limited to 735km on axis and 810 km off-axis; the decay pipe geometry is optimized for high energy
  - The Ash River site is being developed for NOvA; additional site development might not be practical on a fast time scale
  - The Soudan cavern holds a maximum of ~5kT : no upgrade path
  - Physics reach is comparable to NOvA : good for θ_{13}, limited for mass hierarchy

Pros and Cons of the NuMI Options

- Pros :
  - The NuMI beam exists; it will be upgraded to 700kW for NOvA
  - Ash River
    - The Ash River site will be developed for NOvA; LAr5 could benefit from the infrastructure
  - Soudan
    - The SOUDAN cavern + laboratory infrastructure exists; MINOS will complete its running ~2011; disassembly and removal of MINOS was built into the planning
    - The cavern holds a maximum of ~5kT : no scope creep!
    - Requires us to address underground construction & operation
    - The underground location eliminates the concern about surface operation (which in principle is possible, but likely to lead to additional challenges)
      - Any detector constructed for proton decay will need to be at depth
      - This 5kT may be able to make a contribution to the $p \rightarrow K\nu$ search
  - Physics reach is comparable to NOvA → ~doubling the mass

Pros and Cons of the DUSEL Option

- Cons :
  - The DUSEL beam doesn't exist; minimum 5 year, >$200M construction project
  - DUSEL caverns do not exist, even for 5 kT; preliminary estimate at 300' level ~$25M
- Pros :
  - The DUSEL beam doesn't exit : we can design an optimized beam
  - The cavern doesn't exist ; can be planned for future expansion
  - Two options for depth : 300' drive-in, 4850' to be developed
  - The underground location eliminates the concern about surface operation (which in principle is possible, but likely to lead to additional challenges)
    - Any detector constructed for proton decay will need to be at depth
    - This 5kT may be able to make a contribution to the $p \rightarrow K\nu$ search
  - Plans for an early implementation in progress (SUSEL) [April Workshop]
  - Physics reach for θ_{13} is comparable to NOvA; better for mass hierarchy
  - Eventually sensitivity to CP Violation

Technical Issues

Many technical issues will be addressed directly in the design, construction, and operation of the MicroBooNE detector, however for the larger scale there are many more unique issues

- Design Considerations
  - Liquid Argon purity → maximum drift → channel count
  - Thermal insulation → Operation cost
  - Location : surface/underground
    - Cryostat design
    - Cryogenic Safety
    - Cosmic ray backgrounds
    - Cavern/enclosure design
- Scaling considerations
  - Modularity
  - Shape
  - Total-Fiducial-Active volume ratio
  - Number of electronic channels
  - Surface-to-volume ratio (heat input and wall outgassing)
  - Cryostat thermal insulation techniques
  - Materials and construction techniques

Technical Issues

Many technical issues will be addressed directly in the design, construction, and operation of the MicroBooNE detector, however for the larger scale there are many more **unique** issues

- Design Considerations
  - Liquid Argon purity → maximum drift → channel count
  - Thermal insulation → Operation cost
  - Location : surface/underground
    - **Cryostat shape**
    - **Cryogenic Safety**
    - Cosmic ray backgrounds
    - **Cavern/enclosure design**
- Scaling considerations
  - Modularity
  - Shape
  - Total-Fiducial-Active volume ratio
  - Number of electronic channels
  - Surface-to-volume ratio (heat input and wall outgassing)
  - Cryostat thermal insulation techniques
  - Materials and construction techniques

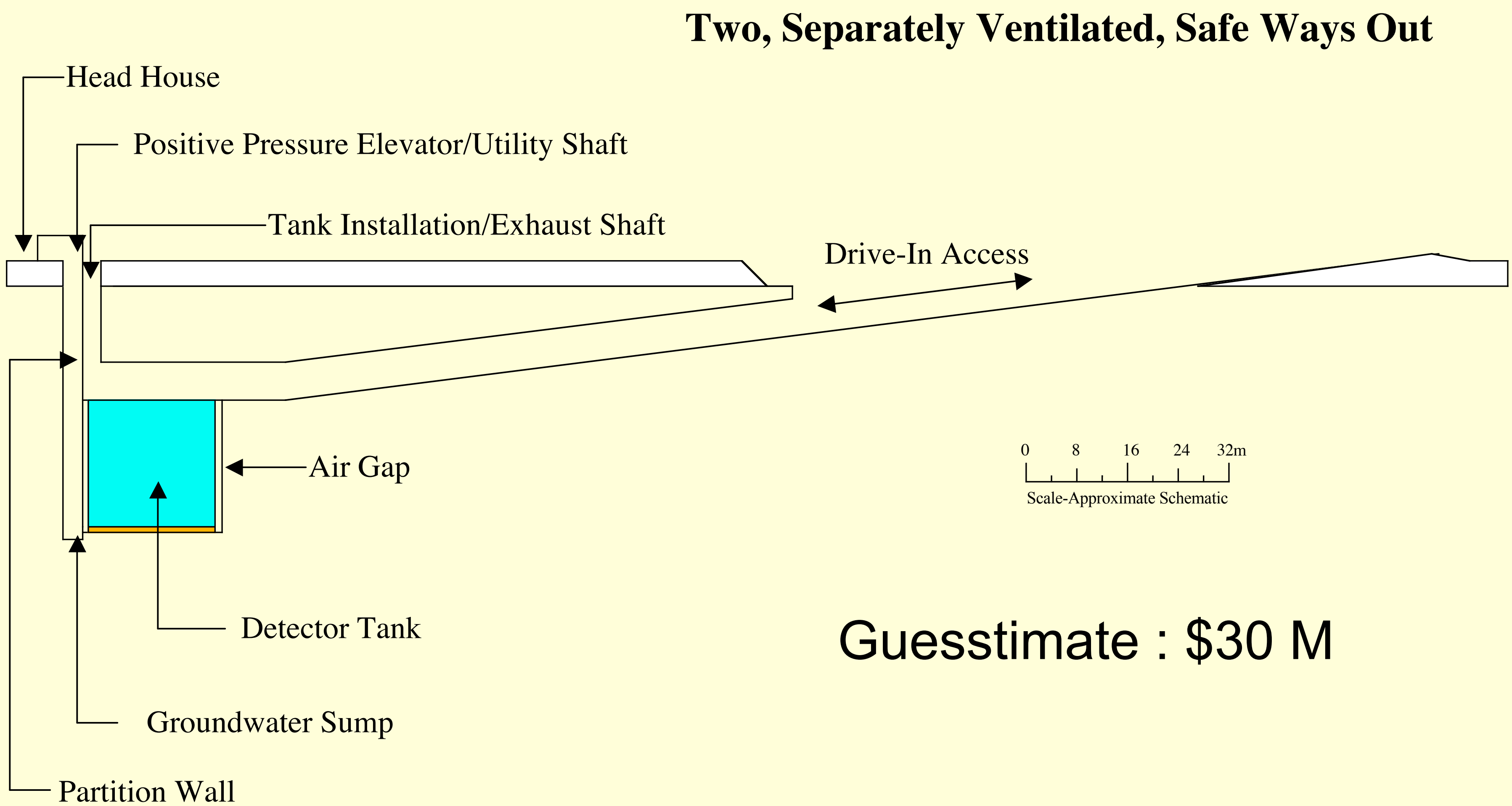
Cavern/enclosure design (work by Chris Laughton)

- Technical Consideration : Cavern span : width AND height
  - 15 - 20 m : conservative, cost effective (up to 30 possible)
  - Favorable towards longitudinal cylinders or rectangles

Table 3. Examples of cavities in hard rock with volumes over 200,000 cubic meters, unsupported spans of 24 meters or more, and depths of 100 meters or more (from *Hoek and Brown, 1980; Hoek, 1989*, and Appendix II).

Country	Cavern Name/Use	Rock Type	Est.Vol.m^3	Dimensions (LWH), depth
Nepal	Chisipani (proposed)	Sedimentary	900,000	700 x 28 x 50 at depth??
Gr. Britian	Bulk Storage Facility	unknown	788,000	900 x 25 x 35 at depth??
Canada	La Grande Pwr. Sta.	Gneiss	600,000	483 x 27 x 47 at 100 m
China	Ertan Hydro Power	Syenite, Basalt	421,000	240 x 27 x 65 at 250 m
Tadjikistan	Rogun Turbine Rm.	Sandstone	381,000	200 x 28 x 68 at 351 m
Canada	Kimano Power Sta.	Granitic	360,000	347 x 25 x 42 at 300 m
Finland	Vihanti mine	Dolomite	350,000	150 x 40 x 160 at 200 m
Canada	Churchill Mach. Hall	Gneiss	348,000	296 x 25 x 47 at 294 m
Indonesia	Cirata Hydro. Pwr.	Breccia, Andesite	320,000	253 x 35 x 49.4 at 109 m
Mozambiq.	CaboraBassa PwrSta	Gneiss	300,000	220 x 27 x 57 at 160 m
Canada	Mica Dam Power Sta.	Gneiss	250,000	237 x 24 x 44 at 200 m
Japan	Shintakasegawa Pwr.	Granite	240,000	163 x 27 x 55 at 250 m
Gr. Britian	Dinorwic Power Sta.	Slate	225,000	180 x 24 x 52 at 300 m
Japan	Imaichi Power Sta.	Sandstone, breccia	220,000	160 x 33 x 51 at 400 m

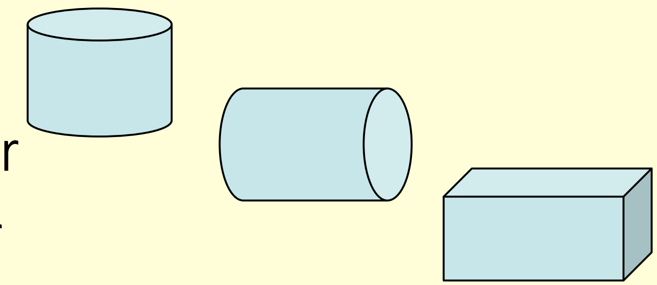
Shallow drive in option (Ash River, DUSEL shallow)



Guesstimate : $30 M

Cryostat Shape

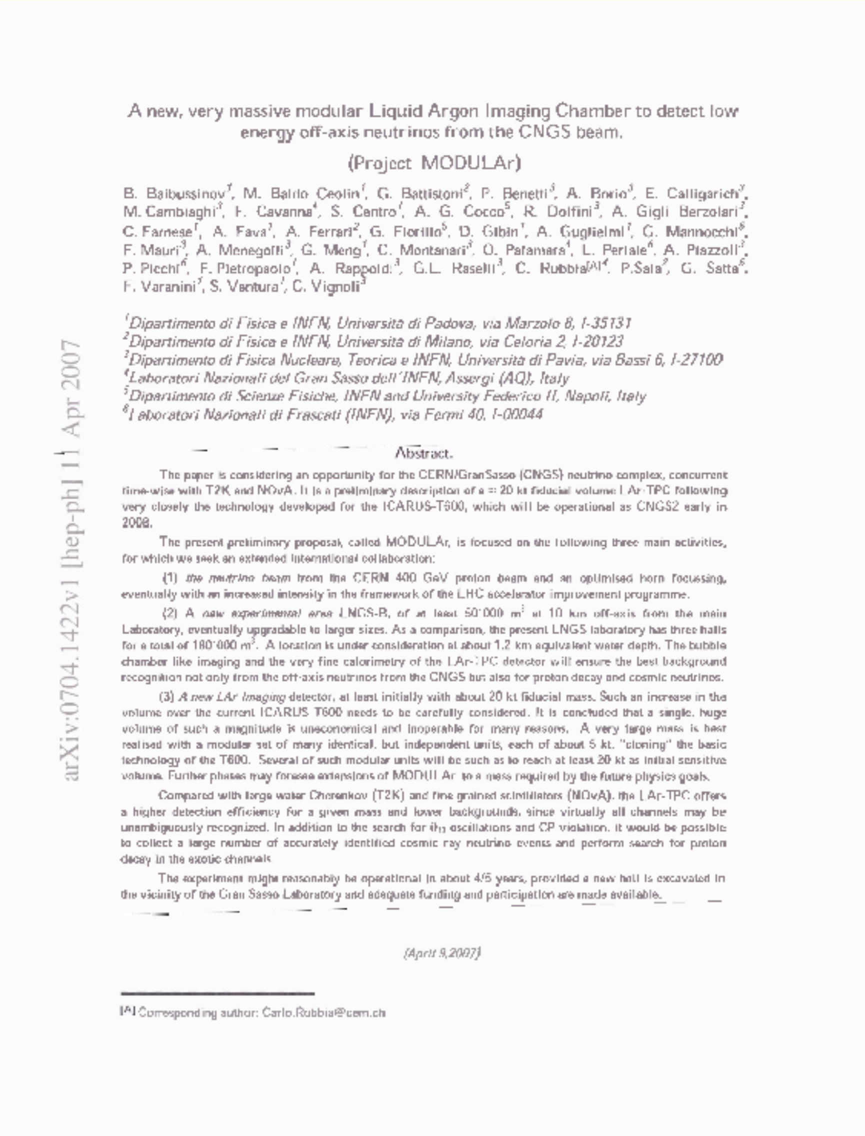
- Three options to consider :
  - 1) Upright cylinder
  - 2) Longitudinal cylinder
  - 3) Square/Rectangular



- Mechanical Engineering input :
  - Option 1 is the most straight forward and economical for the tank
  - Not clear if it is optimized for efficient fiducial/total volume
- Cavern engineering input :
  - Options 2 and 3 are more favorable

- Essential studies in progress to evaluate the cost and technical tradeoffs

ICARUS concept evolution : Project MODULAr



A new, very massive modular Liquid Argon Imaging Chamber to detect low energy off-axis neutrinos from the CNGS beam.

(Project MODULAr)

B. Baibussinov[1], M. Baldo Ceolin[1], G. Battistoni[2], P. Benetti[3], A. Borio[3], E. Calligarich[3], M. Cambiaghi[3], F. Cavanna[4], S. Centro[1], A. G. Cocco[5], R. Dolfini[3], A. Gigli Berzolari[3], C. Farnese[1], A. Fava[1], A. Ferrari[2], G. Fiorillo[5], D. Gibin[1], A. Guglielmi[1], G. Mannocchi[6], F. Mauri[3], A. Menegolli[3], G. Meng[1], C. Montanari[3], O. Palamara[4], L. Periale[6], A. Piazzoli[3], P. Picchi[6], F. Pietropaolo[1], A. Rappoldi[3], G.L. Raselli[3], C. Rubbia[A][4], P.Sala[2], G. Satta[6], F. Varanini[1], S. Ventura[1], C. Vignoli[3]

[1]*Dipartimento di Fisica e INFN, Università di Padova, via Marzolo 8, I-35131*
[2]*Dipartimento di Fisica e INFN, Università di Milano, via Celoria 2, I-20123*
[3]*Dipartimento di Fisica Nucleare, Teorica e INFN, Università di Pavia, via Bassi 6, I-27100*
[4]*Laboratori Nazionali del Gran Sasso dell'INFN, Assergi (AQ), Italy*
[5]*Dipartimento di Scienze Fisiche, INFN and University Federico II, Napoli, Italy*
[6]*Laboratori Nazionali di Frascati (INFN), via Fermi 40, I-00044*

Abstract.

The paper is considering an opportunity for the CERN/GranSasso (CNGS) neutrino complex, concurrent time-wise with T2K and NOvA. It is a preliminary description of a ≈ 20 kt fiducial volume LAr-TPC following very closely the technology developed for the ICARUS-T600, which will be operational as CNGS2 early in 2008.

The present preliminary proposal, called MODULAr, is focused on the following three main activities, for which we seek an extended international collaboration:

(1) *the neutrino beam* from the CERN 400 GeV proton beam and an optimised horn focussing, eventually with an increased intensity in the framework of the LHC accelerator improvement programme.

(2) A *new experimental area* LNGS-B, of at least 50'000 m^3 at 10 km off-axis from the main Laboratory, eventually upgradable to larger sizes. As a comparison, the present LNGS laboratory has three halls for a total of 180'000 m^3. A location is under consideration at about 1.2 km equivalent water depth. The bubble chamber like imaging and the very fine calorimetry of the LAr-TPC detector will ensure the best background recognition not only from the off-axis neutrinos from the CNGS but also for proton decay and cosmic neutrinos.

(3) *A new LAr Imaging* detector, at least initially with about 20 kt fiducial mass. Such an increase in the volume over the current ICARUS T600 needs to be carefully considered. It is concluded that a single, huge volume of such a magnitude is uneconomical and inoperable for many reasons. A very large mass is best realised with a modular set of many identical, but independent units, each of about 5 kt, "cloning" the basic technology of the T600. Several of such modular units will be such as to reach at least 20 kt as initial sensitive volume. Further phases may foresee extensions of MODULAr to a mass required by the future physics goals.

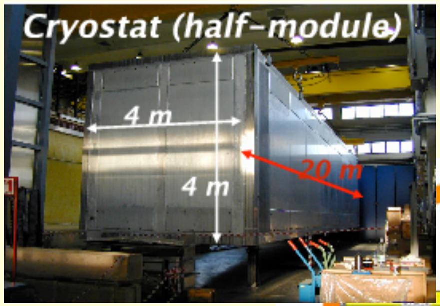
Compared with large water Cherenkov (T2K) and fine grained scintillators (NOvA), the LAr-TPC offers a higher detection efficiency for a given mass and lower backgrounds, since virtually all channels may be unambiguously recognized. In addition to the search for [illegible] oscillations and CP violation, it would be possible to collect a large number of accurately identified cosmic ray neutrino events and perform search for proton decay in the exotic channels.

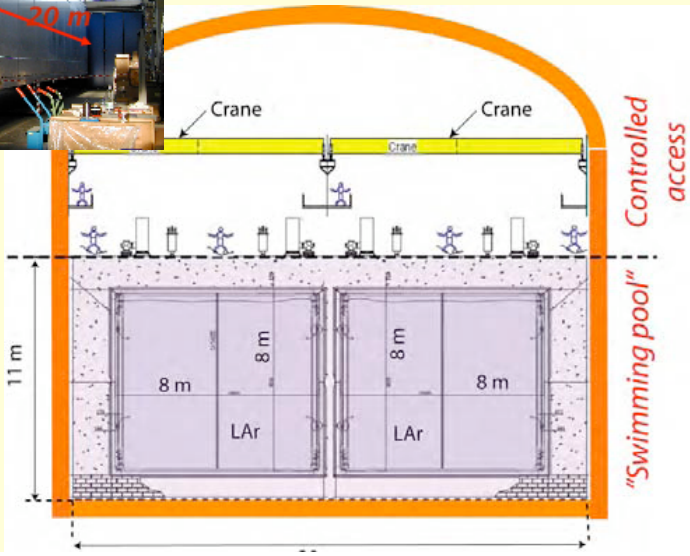
The experiment might reasonably be operational in about 4/5 years, provided a new hall is excavated in the vicinity of the Gran Sasso Laboratory and adequate funding and participation are made available.

(April 9,2007)

[A] Corresponding author: Carlo.Rubbia@cern.ch

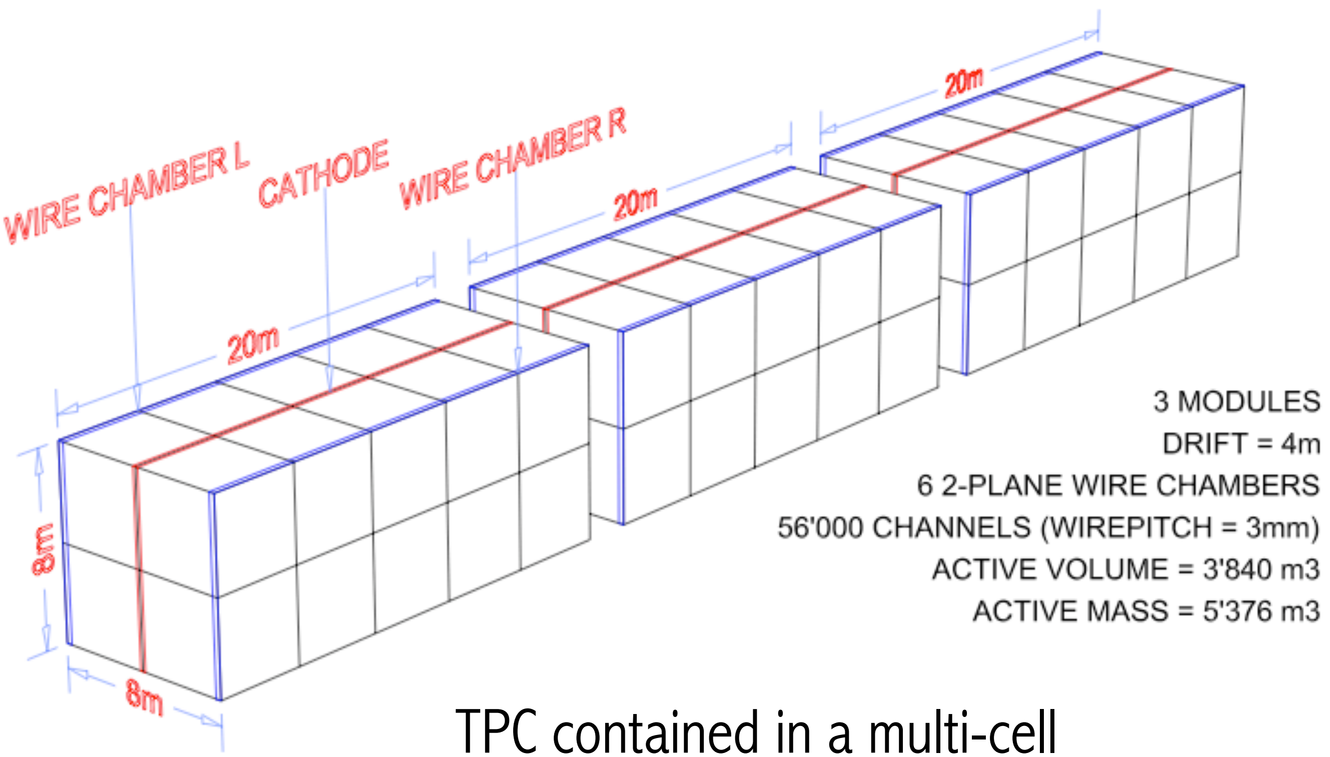
- ~20kT fiducial volume, modeled after ICARUS T-600
  - Upgraded neutrino beam from the 400 GeV CERN SPS
  - New experimental area 10 km off-axis of CNGS neutrino beam
  - Multiple 5kT LArTPCs
    - ($8x8x60m^3$ per 5kT unit)





LANNDD Modular Concept

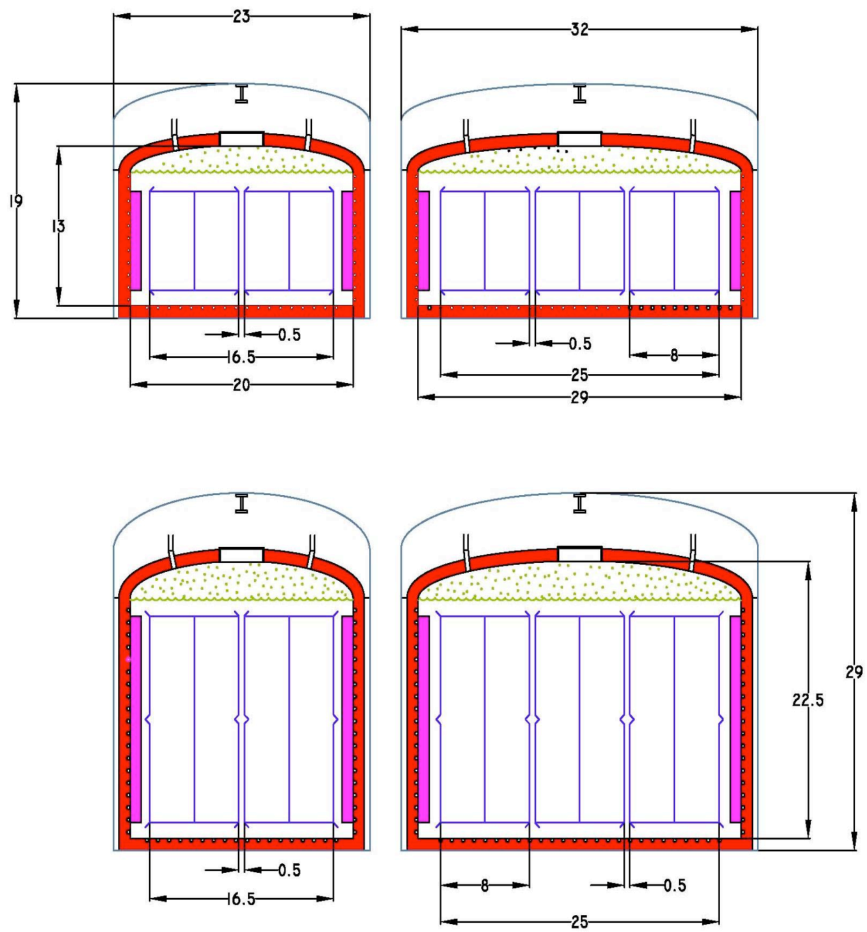
5 kT is 8 x8 x 60 m^3



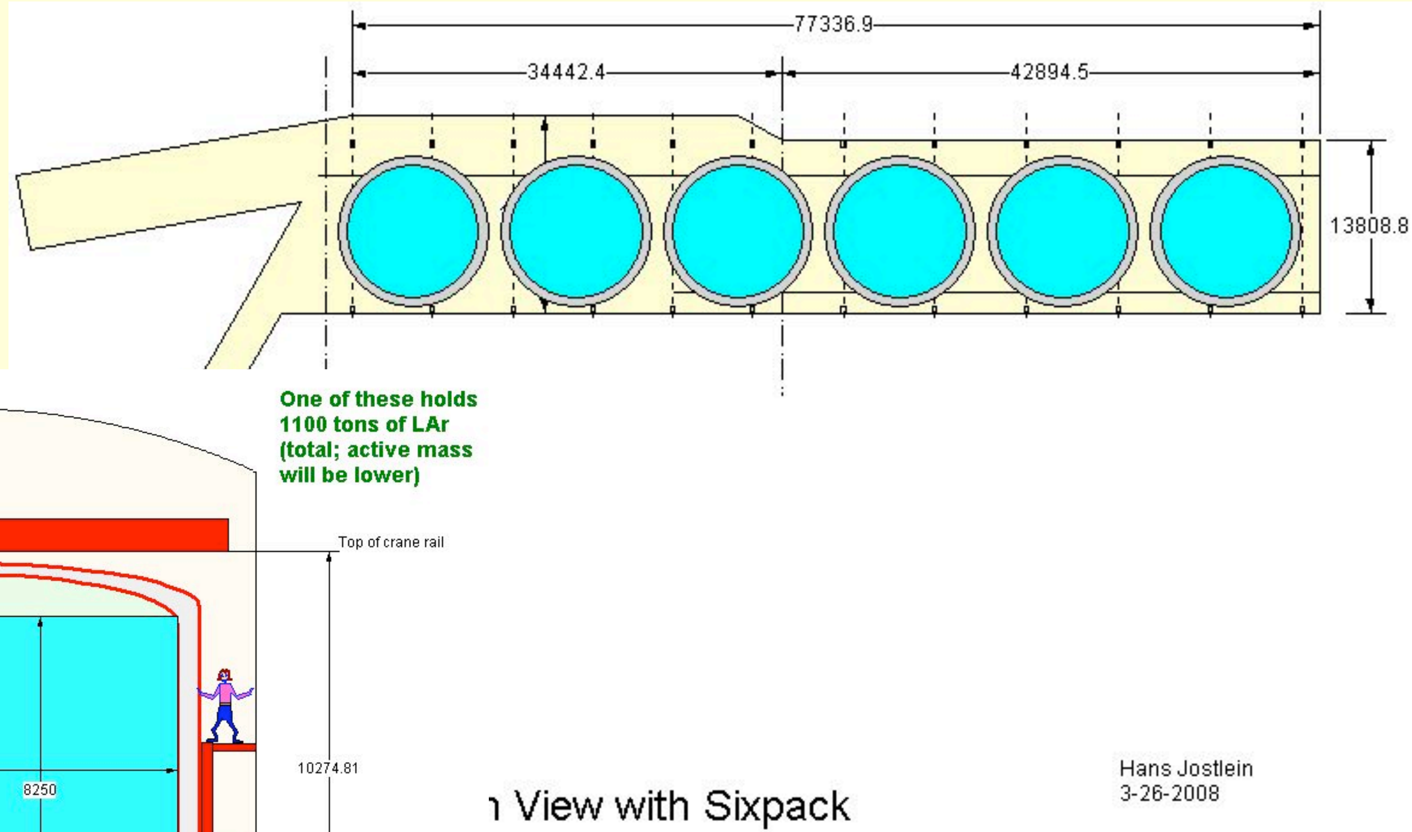
TPC contained in a multi-cell mechanical structure

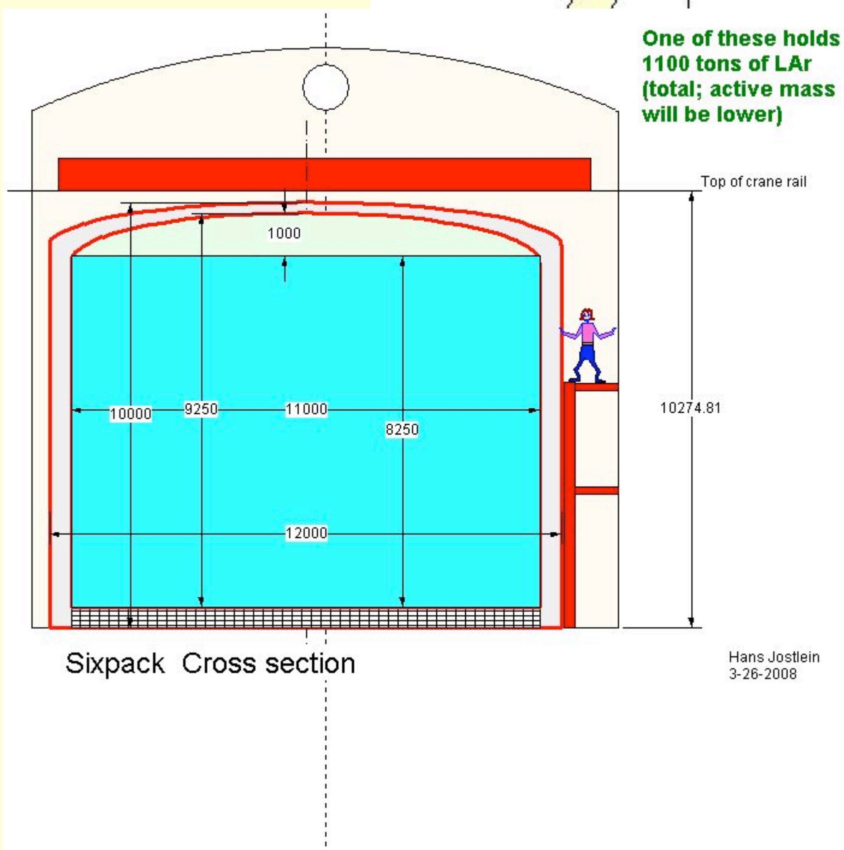
Drawing courtesy of D. Cline and F. Sergiampietri

Strawmans for multiple modules at DUSEL

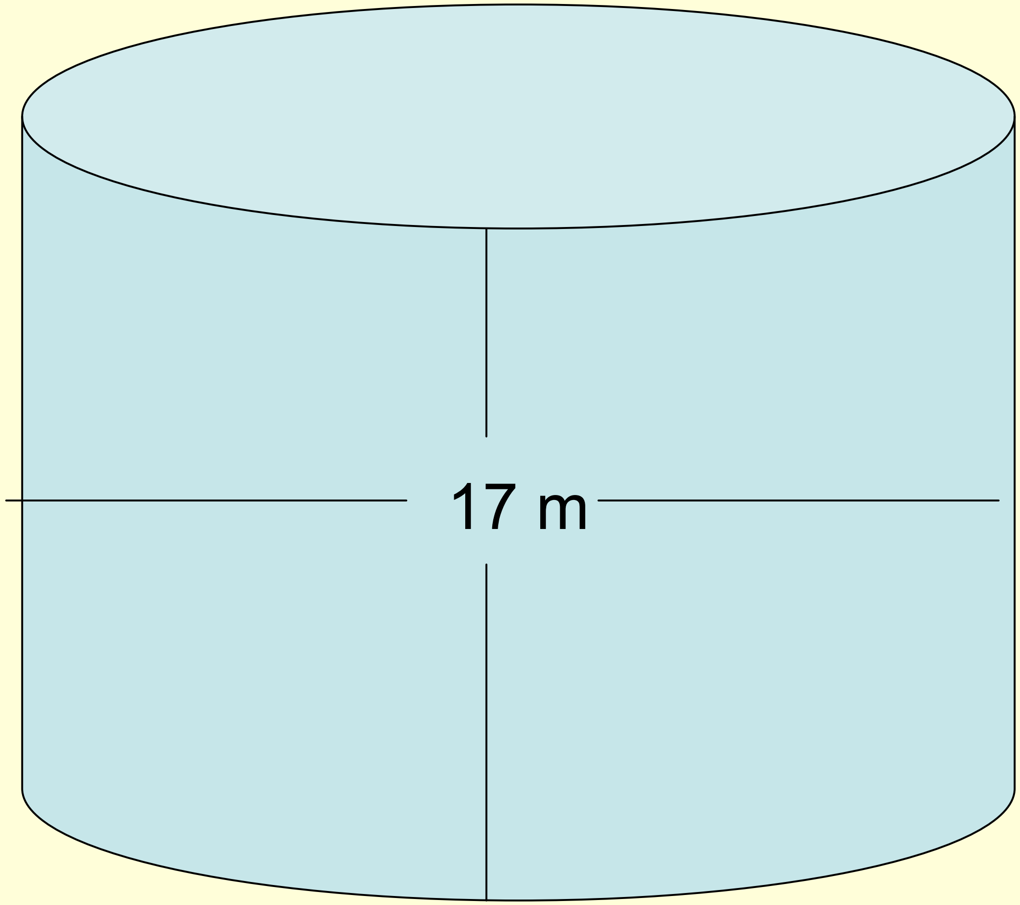


Upright cylinder concept : fit into MINOS Soudan Cavern





5 kT Single Vessel



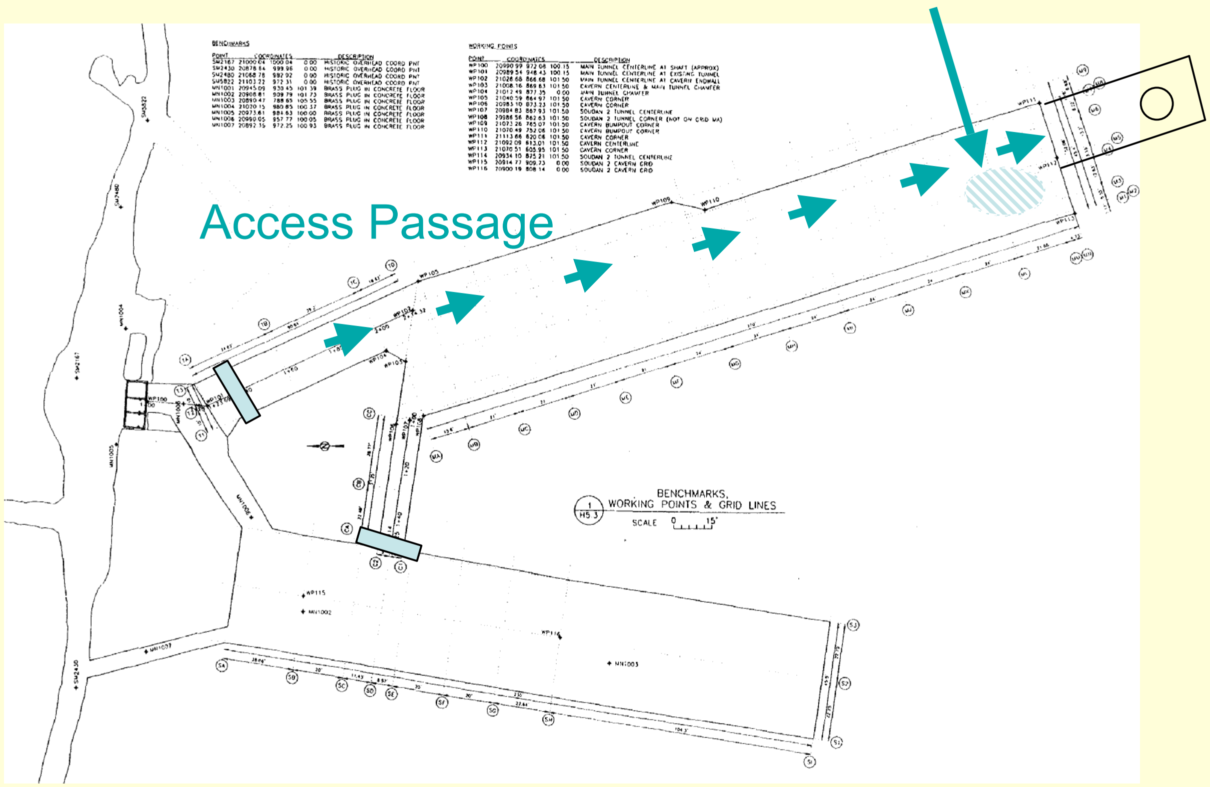
Doesn't fit in Soudan, but would work in a conservative Cavern span at DUSEL

Cryogenic Safety (work by Rich Schmitt - PPD Mechanical)

- Preliminary ODH analysis completed for 5kT @ SOUDAN (methodology applicable for DUSEL caverns)
  - Considered a model of 3- 1.7kT vessels
- Failure Modes considered :
  - Severed vent line
  - Severed drain line
  - Vessel leak or rupture

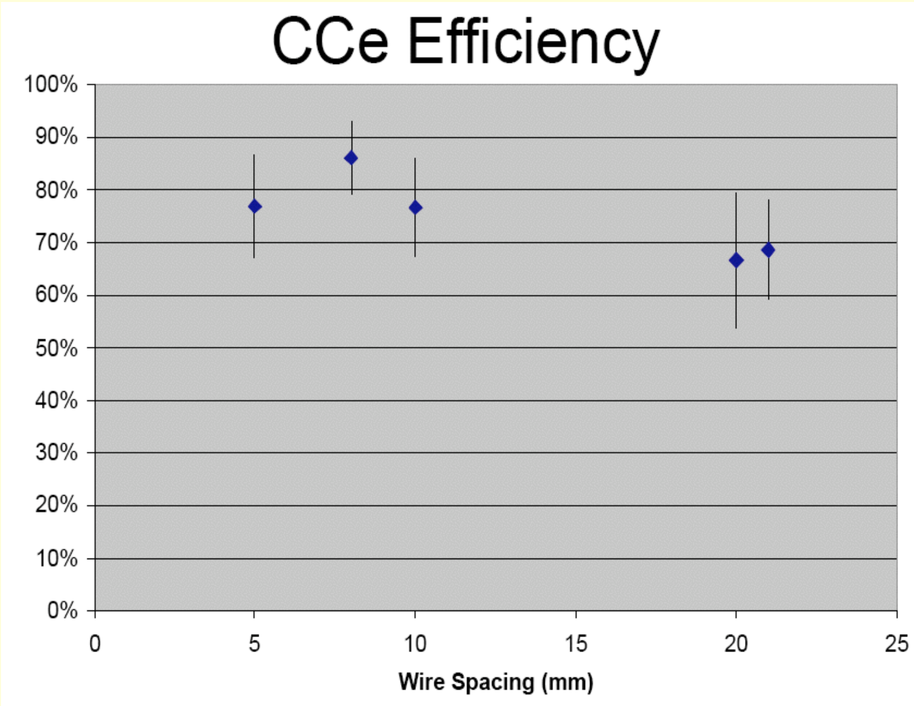
- Assumptions
  - Relief valve and vent line runs to the surface
  - Single wall, foam insulated vessels
  - 60 in diameter ventilation shaft from cavern to surface
  - Refrigeration equipment is underground (nitrogen in refrigeration is too small to present a hazard)
  - No liquid nitrogen supply from surface
  - Refrigeration is water cooled
  - Only the largest leaks are considered (smaller leaks handled by the ventilation system)
  - Crane use is limited when vessels are filled
  - Vessels are made to high quality requirements : ASME Section VIII or higher, 100% radiograph, conservative in design
  - Industrial oxygen sensors and alarms are generously located and regularly calibrated
  - A substantial bulkhead barrier separates the experiment from the public areas; doors and ventillation ports into the cavern are equipped with closures to prevent argon gas from entering public areas; doors are maintained tested and not blocked open; presure rating 5psig.

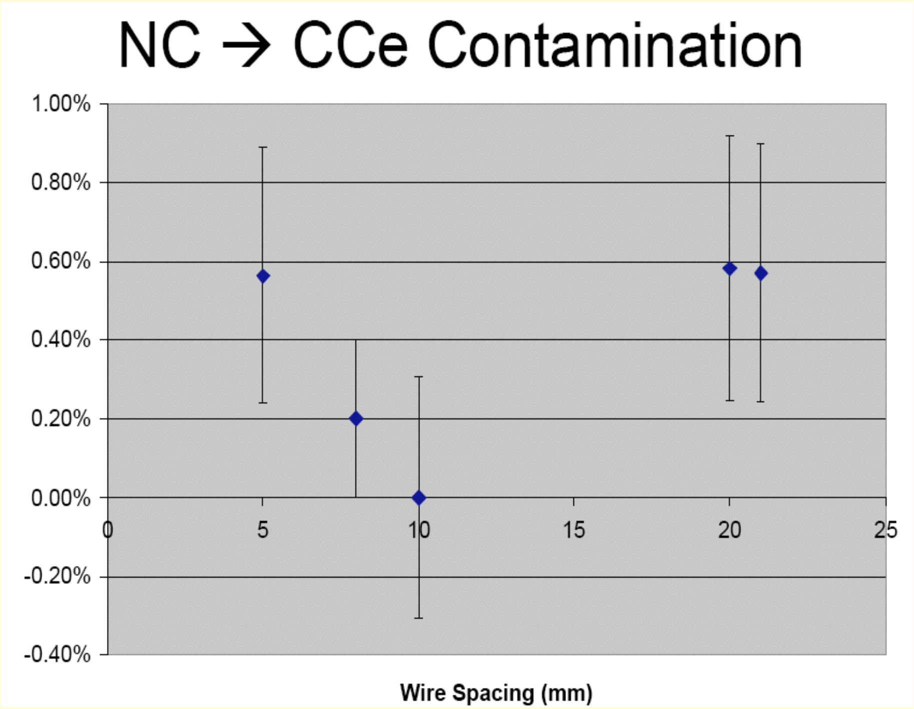
- Given these assumptions, cavern and detector volumes : ODH Class 0 for all three failures
    - A total spill of one vessel would fill the cavern to a depth of four feet, but vaporize quickly; A pressure of 3.1 psi would push the gas into the ventilation shaft ; the bulkhead doors which can sustain this pressure keeps the rest of the complex suitably isolated.



MC Studies for detector optimization

- PRELIMINARY study of detector performance as a function of wire spacing (Bruce Baller).





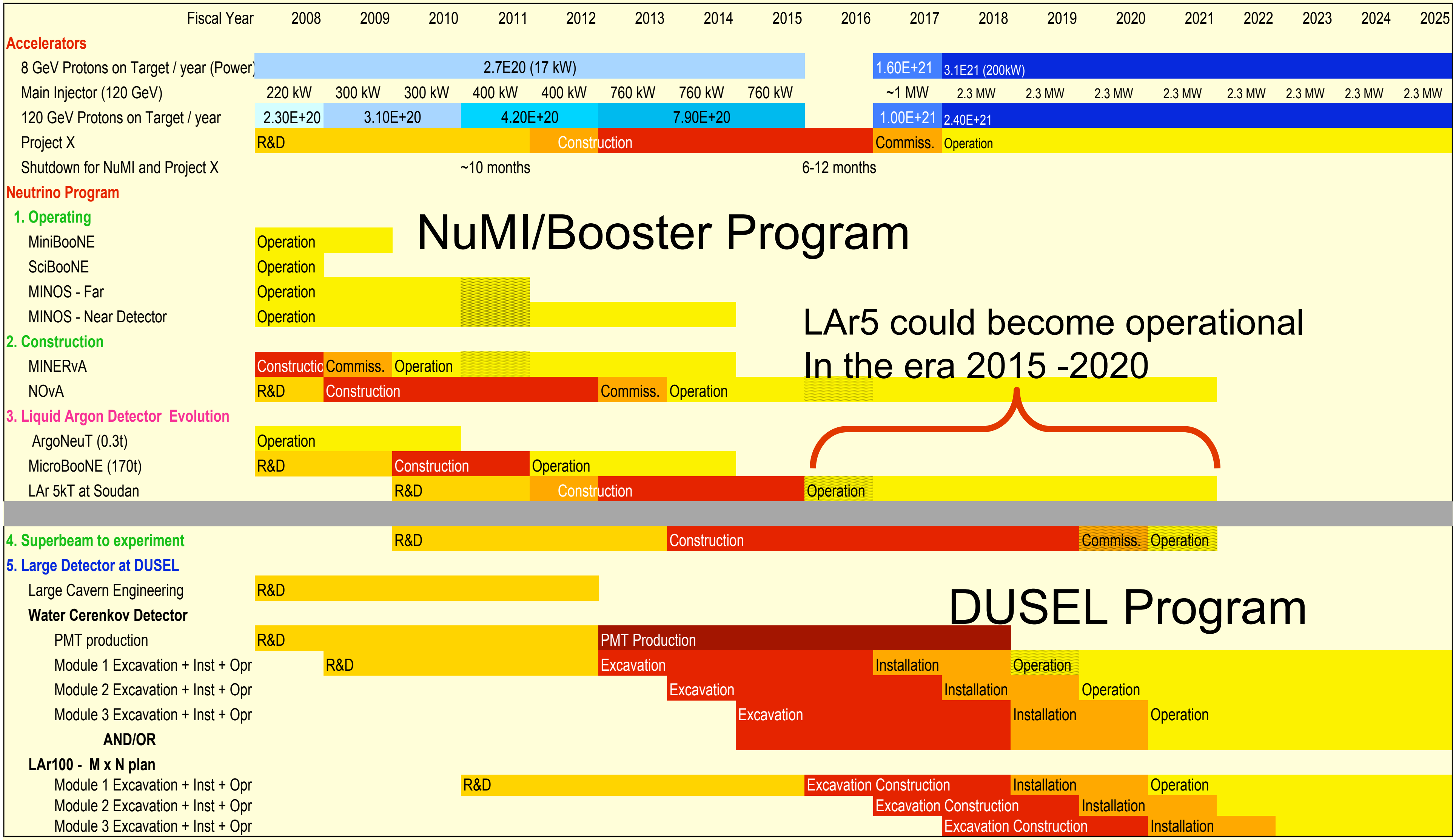
Wire spacing → channel count;
want to optimize against cost and performance

Goal : reduce channel count

- LE CCe scanning efficiency = 76% ± 4%
  - Does not include event location and vertex location efficiency
- LE NC π^o rejection = 99.6% ± 0.1%
- LE CCmu π^o rejection = 99.9% ± 0.1%
- Efficiency & purity are ~independent of the wire spacing (< 2 cm wire spacing)

Will use MC + data from ArgoNeuT to complete studies

Schedule considerations



Conclusions

- We believe that a 5 kiloton liquid argon neutrino detector is the appropriate size to plan for the next step (after MicroBooNE) in developing this detector technology
- A 5kT detector has powerful physics potential, in either the NuMI or DUSEL locations
- The major technological design issues that will be addressed in the R&D program are :
  - Cryostat/TPC configuration
  - Installation/construction techniques
  - Mitigation of safety issues (containment, egress)
  - Per channel cost of electronics
  - Total Project Cost estimate
- The PAC has encouraged the laboratory to provide **engineering and design support** to work on the technical issues
- We believe we can address most of the issues over the next two years

P-982 LOI

Contributors and Potential Collaborators

B. Baller, D. Finley, D. Jensen, H. Jostlein, C. Laughton, B. Lundberg,
R. Plunkett, S. Pordes, R. Rameika[1], N. Saoulidou, R.Schmitt
Fermi National Accelerator Laboratory

M. D. Messier, J. Musser, J. Urheim
Indiana University

C. Bromberg, D. Edmunds
Michigan State University

K. Heller, M. Marshak, E. Peterson
University of Minnesota

T. E. Coan
Southern Methodist University

S. Kopp, K. Lang
University of Texas, Austin

H. Gallagher, W. A. Mann, J. Schneps
Tufts University

B. Fleming
Yale University

[1]Contact : rameika@fnal.gov

Backup Slides

Large LAr Detector - on surface

From

DRAFT

LOI for

LAr5 @

Ash
River

Task	per unit estimate
Liquid Argon procurement & delivery	$1 Million per kiloton
Cryogenic Tank fabrication	$3.75 M + 0.4M/kiloton
Cryogenic Tank Roof customizing	$4500/m^2
Purification and Cryo System fabrication	$4M
TPC and Cathode System	$50K/panel
Electronics, Data Acquisition and Slow Control	$200K + $50/channel
Cables in and out of cryostat	$50/channel
Photmultiplier Tubes and Readout	$7.5K/pmt
Detector Installation and Integration	$200K/month
Engineering and Engineering Support	$150K per person-year

Table 1: *Preliminary* estimates of per unit cost drivers.

Parameter	5 kT	7 kT	10 kT
Cryogenic Tank diameter(m)	15	19	24
Cryogenic Tank height (m)	14	15	16 m
Cryogenic Tank volume (m^3)	2500	4250	7235
Tank roof area (m^2)	177	283	452
TPC sense panels (#)	20	29	44
Sense wires per panel (30^0) (#)	2700	2700	2700
TPC interleaved cathode panels (#)	18	28	40
TPC circumferential gradient panels (#)	20	24	36
Electronics channels (#)	54,000	78,300	118,800
Photomultiplier tubes (#)	48	60	72

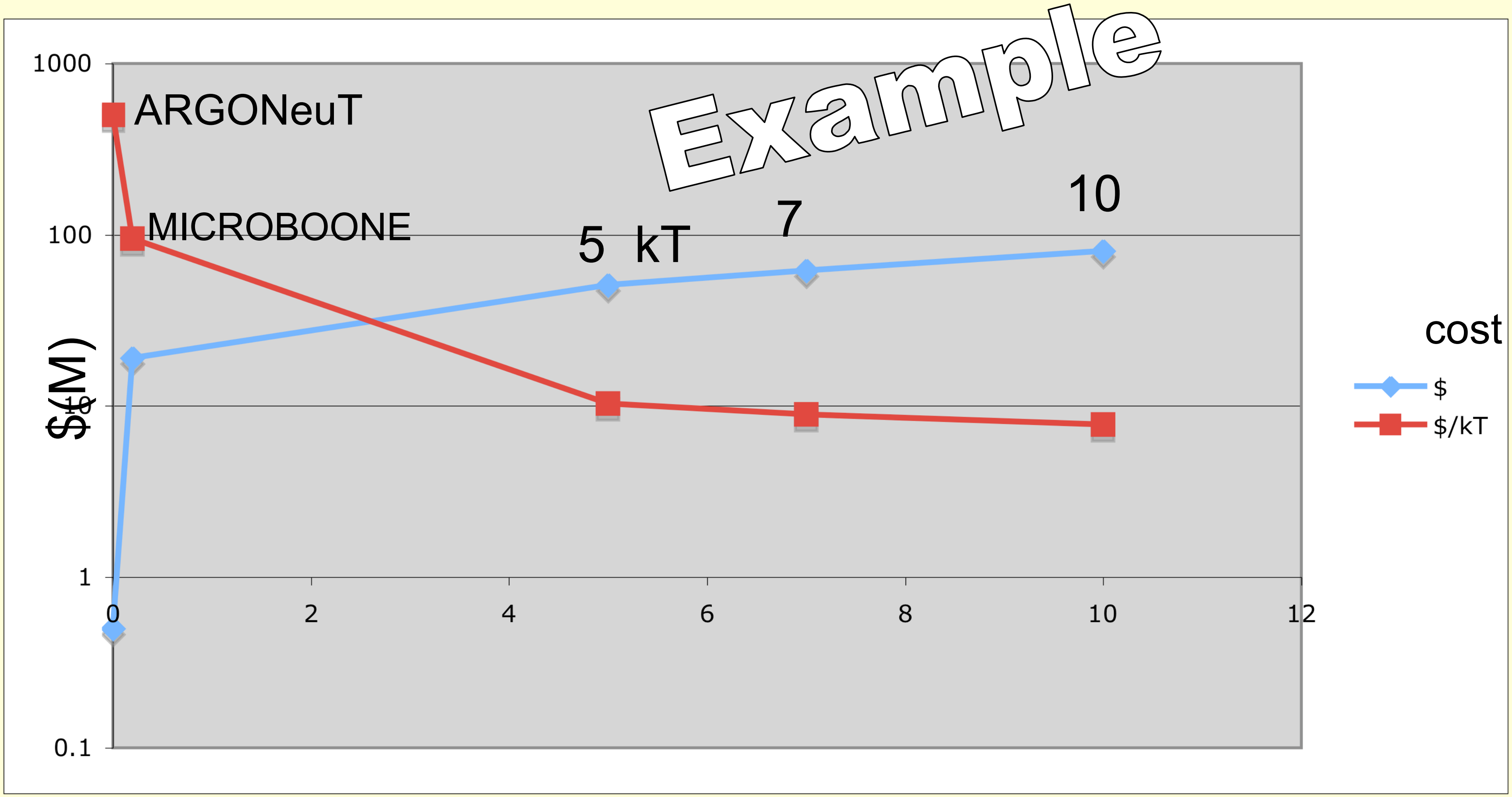
Table 2: Detector parameters used for estimating the cost range of a Liquid Argon detector in the 5-10 kiloton mass range.

WORK IN PROGRESS

	5 kton	7 kton	10 kton
Site Preparation and Infrastructure	[illegible]		
Liquid Argon Procurement and Delivery	[illegible]	$7,000,000	$10,000,000
Tank	[illegible]	$6,550,000	$7,750,000
Tank Customizing	[illegible]	$1,273,500	$2,034,000
Argon Purification and and Cryo Syste[illegible]	[illegible]	$4,000,000	$4,000,000
TPC Panels	$2,900,000	$4,050,000	$6,000,000
Electronics & Readout	$5,600,000	$8,030,000	$12,080,000
Photomultiplier Tubes	$360,000	$450,000	$540,000
Installation and Integration	$2,400,000	$2,800,000	$3,200,000
Engineering	$7,500,000	$7,500,000	$7,500,000
Base Cost	**$34,306,500**	**$41,653,500**	**$53,104,000**
Cost per kiloton	$6,861,300	$5,950,500	$5,310,400
Contingency (50%)	$17,153,250	$20,826,750	$26,552,000
Total	$51,459,750	$62,480,250	$79,656,000

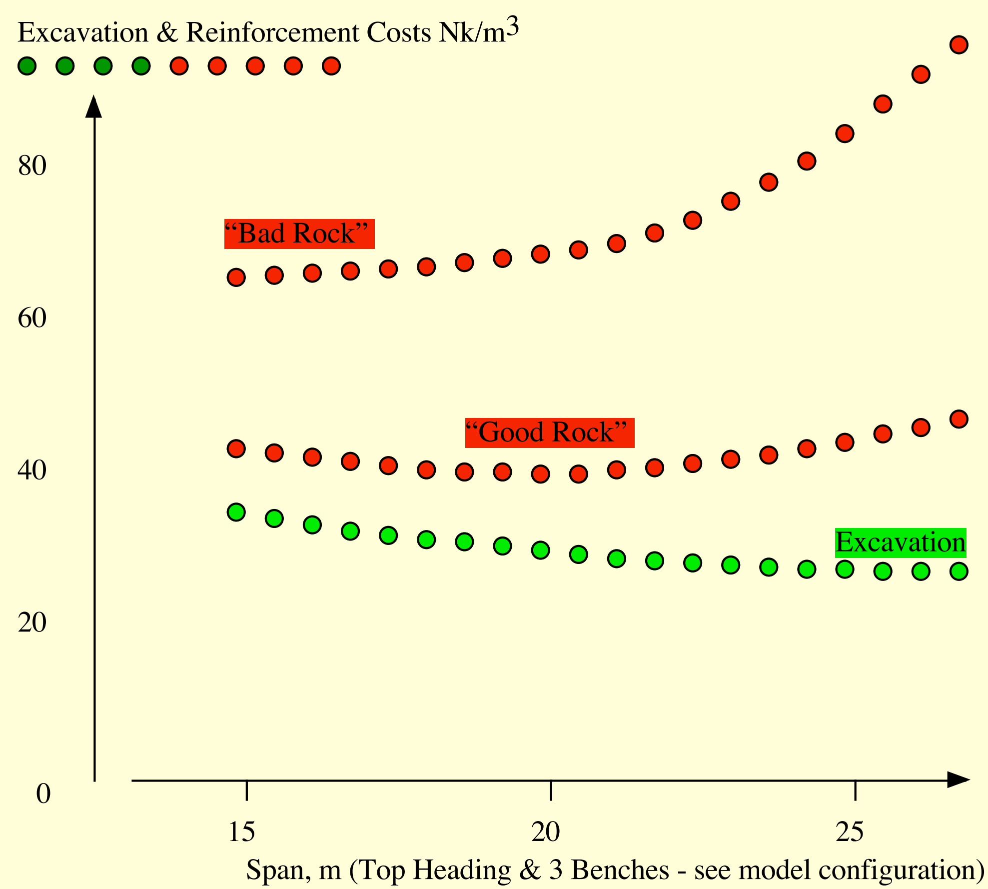
Preliminary

What we know about cost scaling



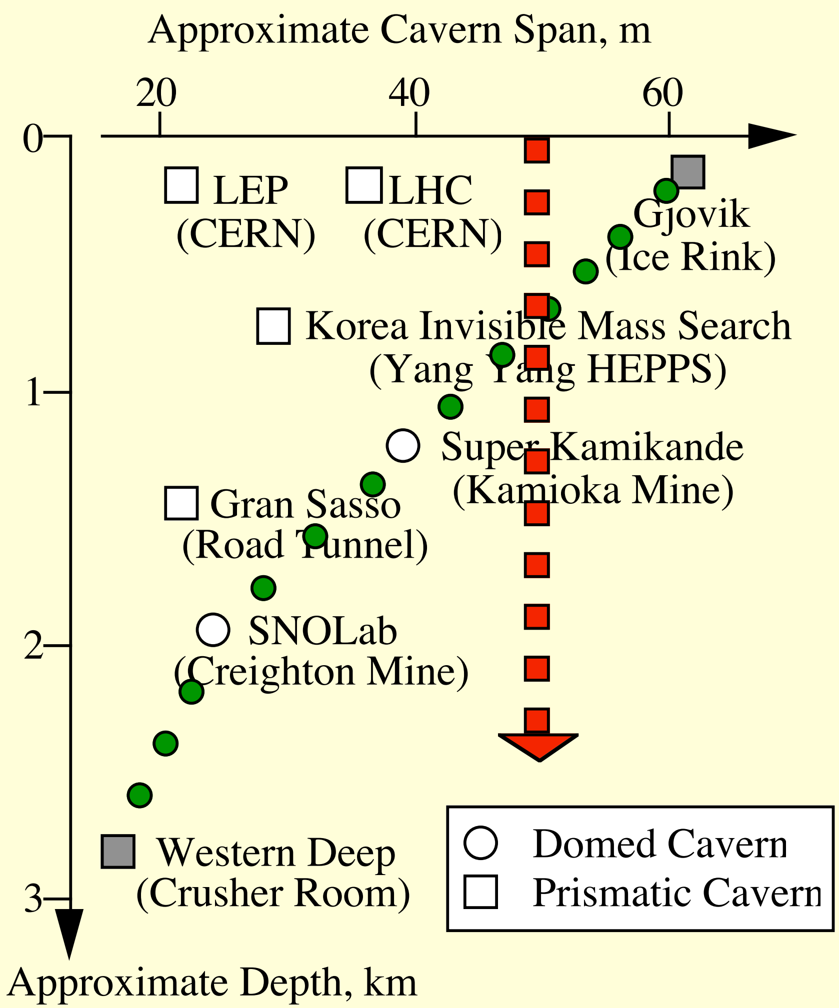
Cavern Cost Study - Findings

- Excavation Costs
  - Unit cost (Nk/m^3) reduced as span increased
  - Reduction most marked in the 10-20m span range
- Reinforcement Costs
  - In good rock - slight drop in unit cost (Nk/m^3) calculated with increased span (10-20 m range)
  - When rock conditions are less favorable, the costs of reinforcement can increase rapidly with increasing span.



Cavern Cost Study - Conclusions

- Rock Caverns with Spans > 20m
  - Reductions in excavation cost ~ relatively small compared to potential for increase in reinforcement cost
  - Many 20m+ caverns have been built, but
    - Reinforcement needs can increase rapidly
    - Designers and builders perception of risk will be critical to affordability -> how good is the ground?, how well are its characteristics known?
    - Reserve detailed design until the ground is adequately characterized - conduct trade-off design/cost studies before committing to a large span design
- Choosing a span greater than the rock mass can reasonably allow is the greatest error a designer can make, after Johansen



Unit Price Sources

- Based on Unit Costs Developed from Diablo Canyon Estimate (Feb. '04)
- Lump Sums for
  - Mobilization/Demobilization..
  - Portal Development..
- Excavations..
  - Tunnel at $15k/linear meter and 5m/day
  - Cavern/Pit/Shaft at $500/bank cubic meter
  - Assumed to be equivalent to Diablo Canyon Class I Rock Mass Material ~ same methods and means