Bonnie T. Fleming
July 11th, 2006
LAr nu physics workshop

FNAL/BNL Long Baseline Study

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Description and purpose of the study

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Scope of the study: direction of long baseline community in the future....

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How LArTPCs fit into this picture

FNAL/BNL Joint Study on Long Baseline Neutrinos

S. Dawson (BNL)

Report to NuSag (5/20/2006)

- Study is jointly sponsored by BNL (S. Dawson) and FNAL (H. Montgomery)
- Study is led by Gina Rameika (FNAL) and Milind Diwan (BNL)

S. Dawson, NuSAG mtg, 2006

Charge to study

- Consider as a function of θ_{13} the ability to establish a finite θ_{13}, determine the mass hierarchy, and to search for CP violation using a broad band technique and an off-axis technique
  - For each measurement, what are the limiting systematic uncertainties?
- Consider the precision with which each of the oscillation parameters can be measured
  - What is the ability to discriminate between neutrino mass concepts?
- Consider the available experimental design concepts
  - What is the optimum proton beam energy; optimum geometry, detector technology, cost guesstimate?

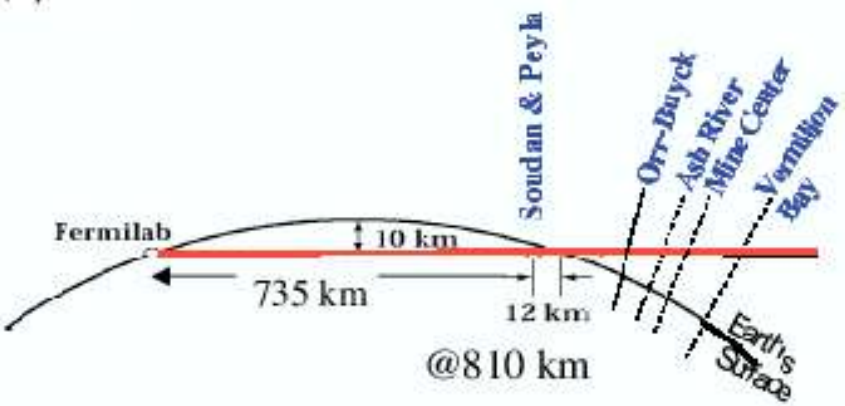
S. Dawson, NuSAG mtg, 2006

Timelines

- Off-axis community is considering a follow-up experiment to Nova (G. Rameika)
- Broad band community sees interface with DUSEL process (M. Diwan)
- EPP2010 recommends proceeding with an international study to understand the possibilities in a worldwide context

S. Dawson, NuSAG mtg, 2006

The Experimental Approach : "NuMI North"



@810 km

12 km off-axis

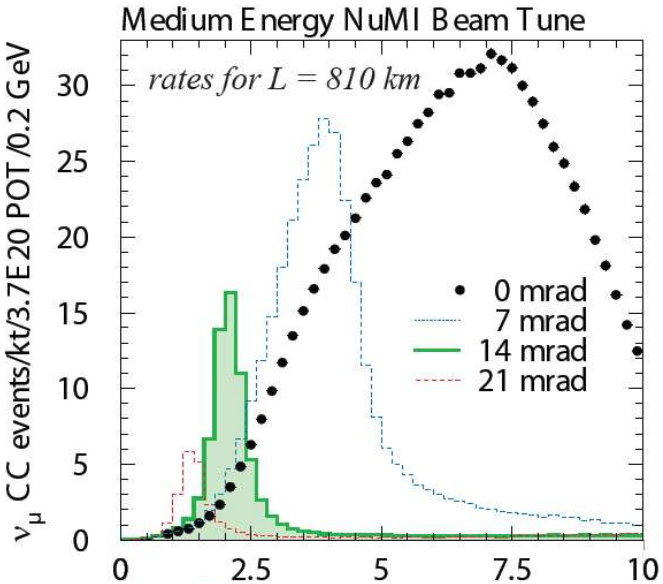
~ 14 mrad

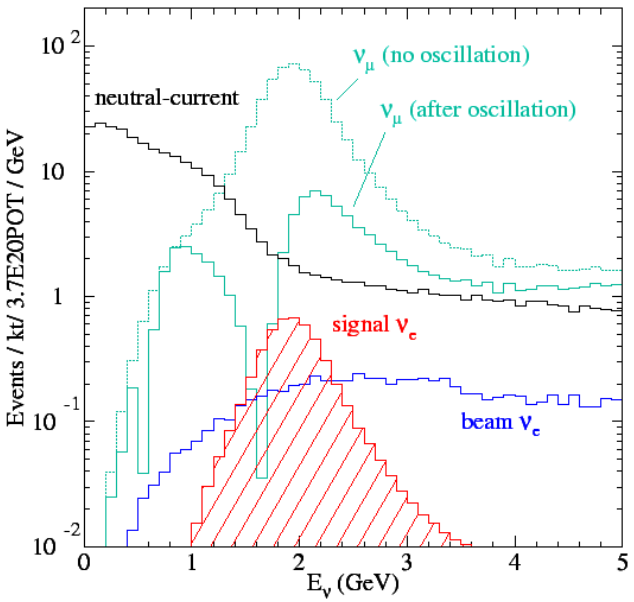
Presentation to NuSAG
May 20, 2006

G. Rameika, NuSAG mtg, 2006

• Off axis NuMI beam

1st oscillation maxima





2nd oscillation maxima

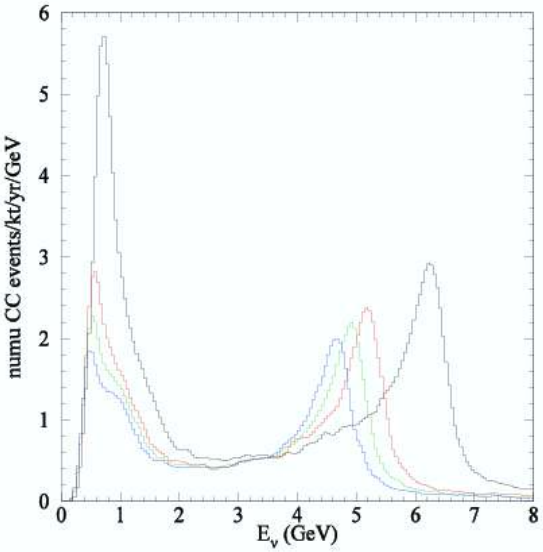
Mark has produced beam spectra that peak near the second maximum (525 MeV at 810 km)

30 km off-axis

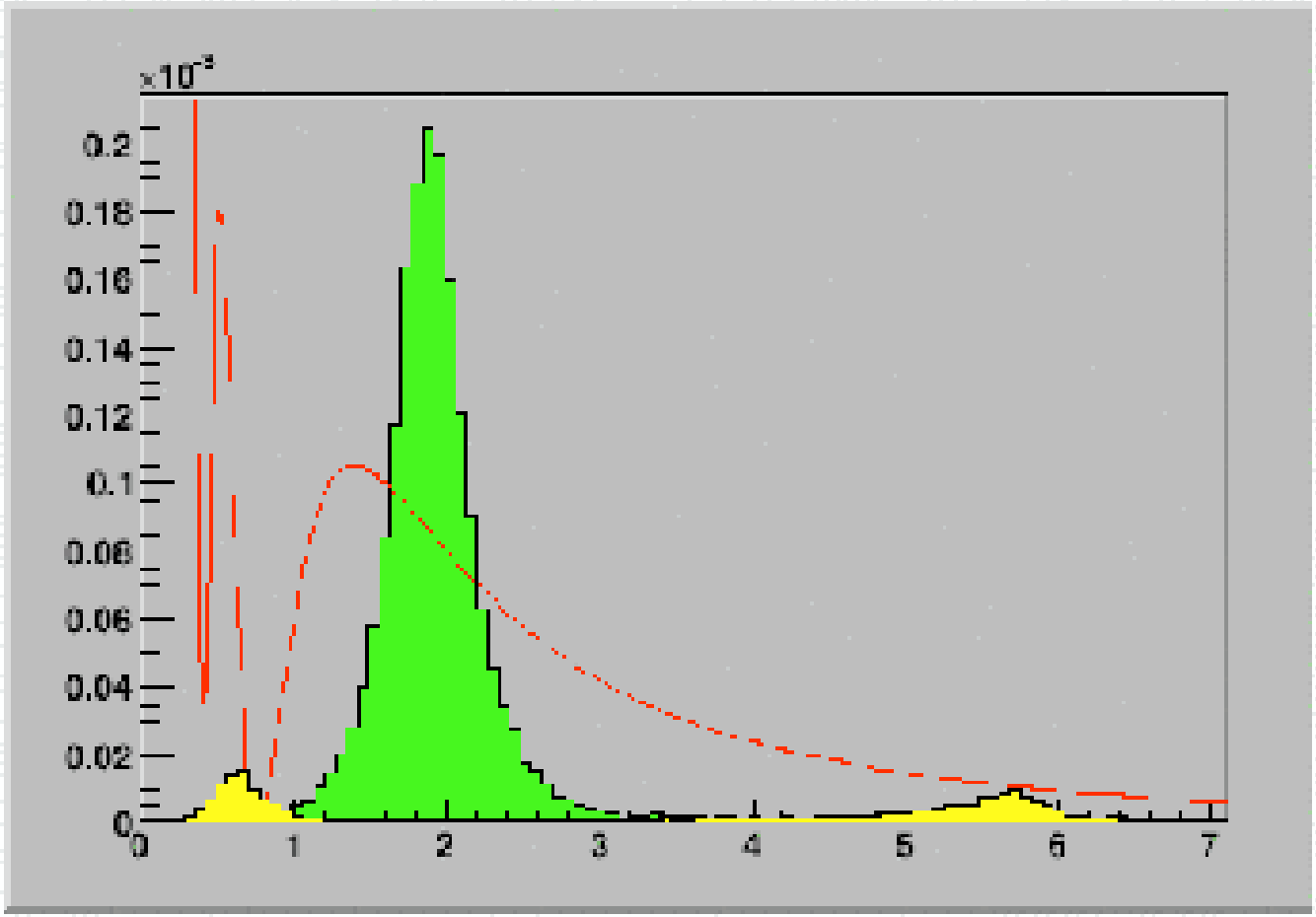
36 km off-axis

38 km off-axis

40 km off-axis



$\nu_\mu \rightarrow \nu_e$ appearance



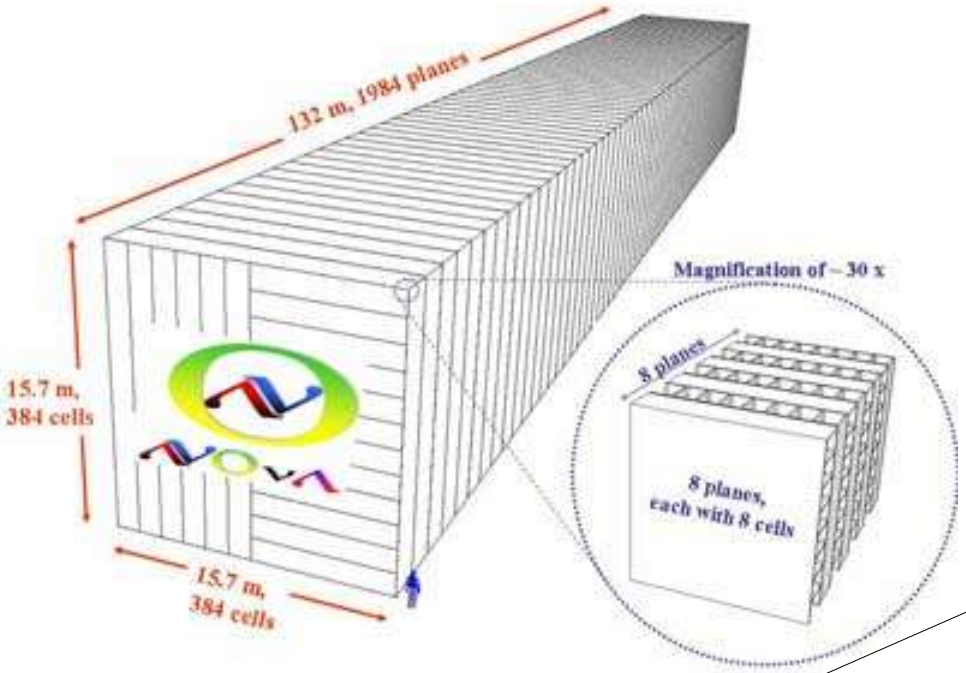
Presentation to NuSAG
May 20, 2006

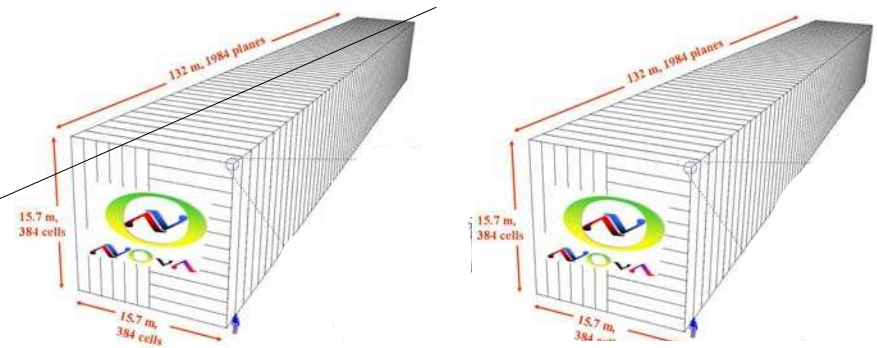
Example : L = 810 km
$\Delta m^2_{23} = 0.0025$

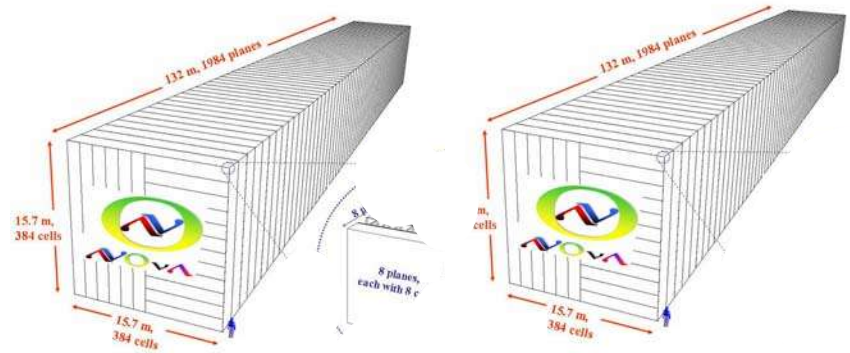
G. Rameika, NuSAG mtg, 2006

NOvA at the 2nd maxima:

- alternating xy cells of liquid scintillator
- cells: 15.7m x 3.87cm x 6.0 cm
- 0.8mm looped WLS fiber in each cell for light collection
- WLS fibers read-out by APDs
- 80% active material





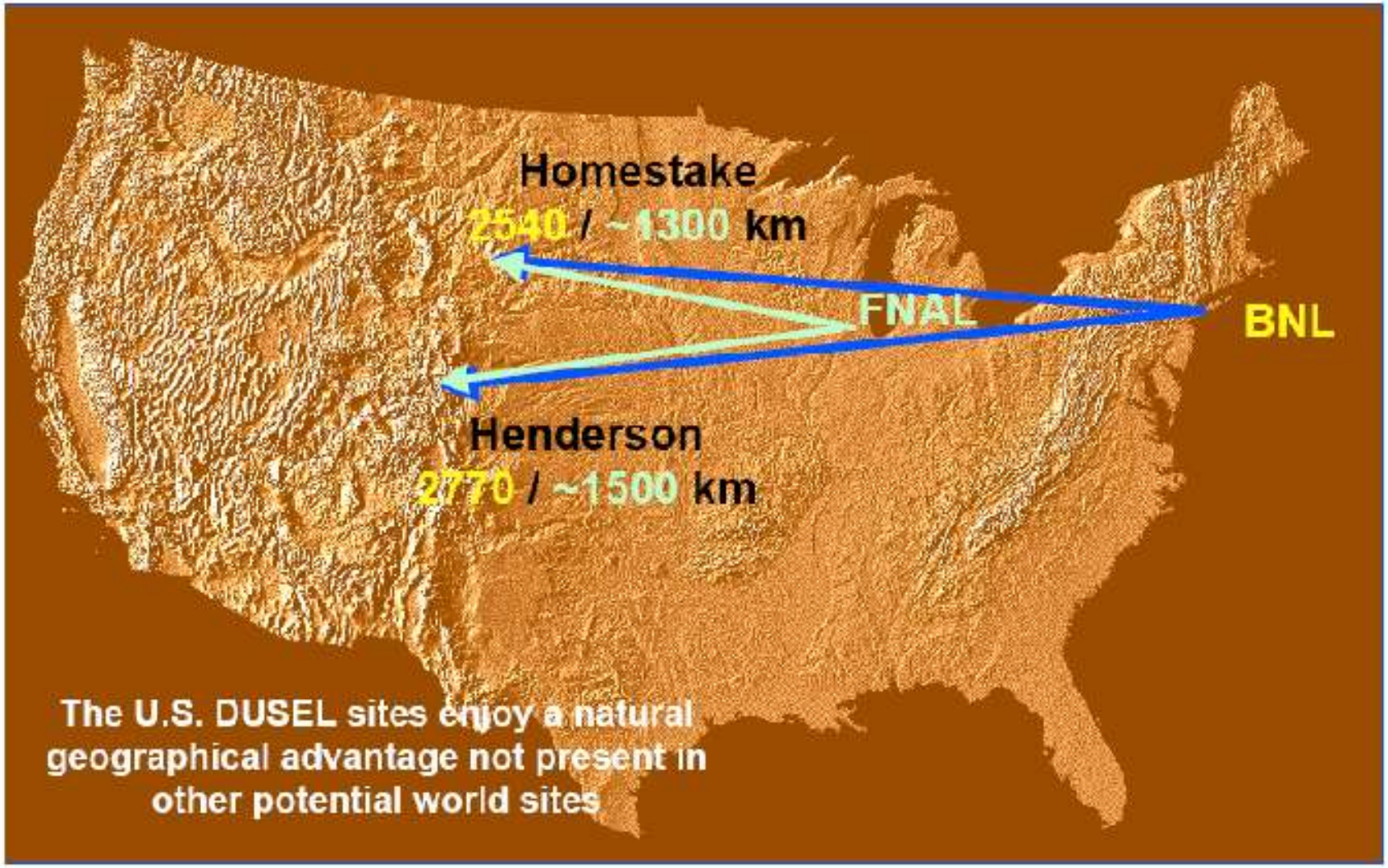


for 2nd detector location:

- scale to 100kton
- detector at 735km
- 5 year neutrino run

Still...signal/background make this option impossible....need LArTPCs

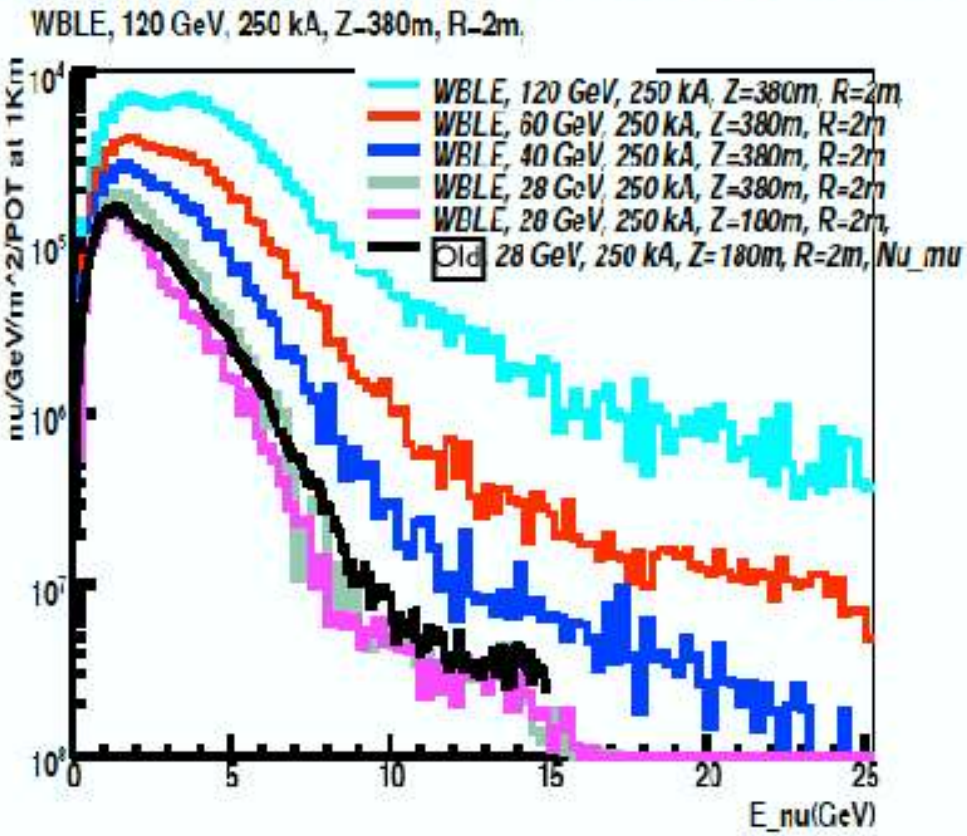
Super Neutrino Beam to DUSEL Candidate Sites

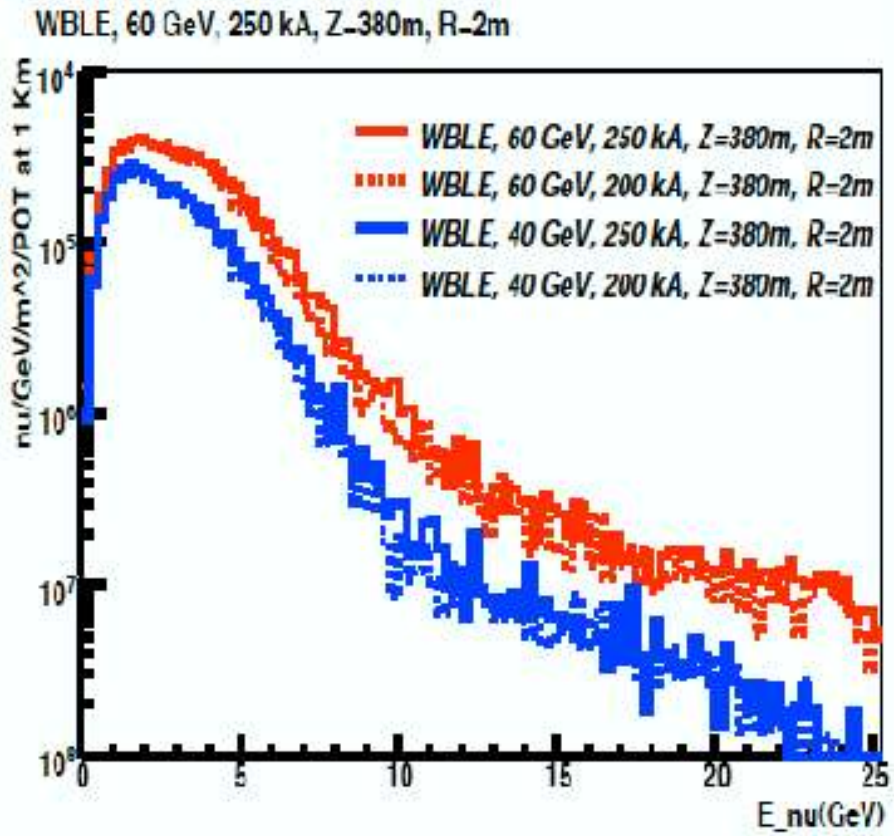


WBLE Optimization - FLUKA05

Decay pipe radius chosen to be 2m.

Siting restrictions ⇒ decay pipe is < 400 m in length

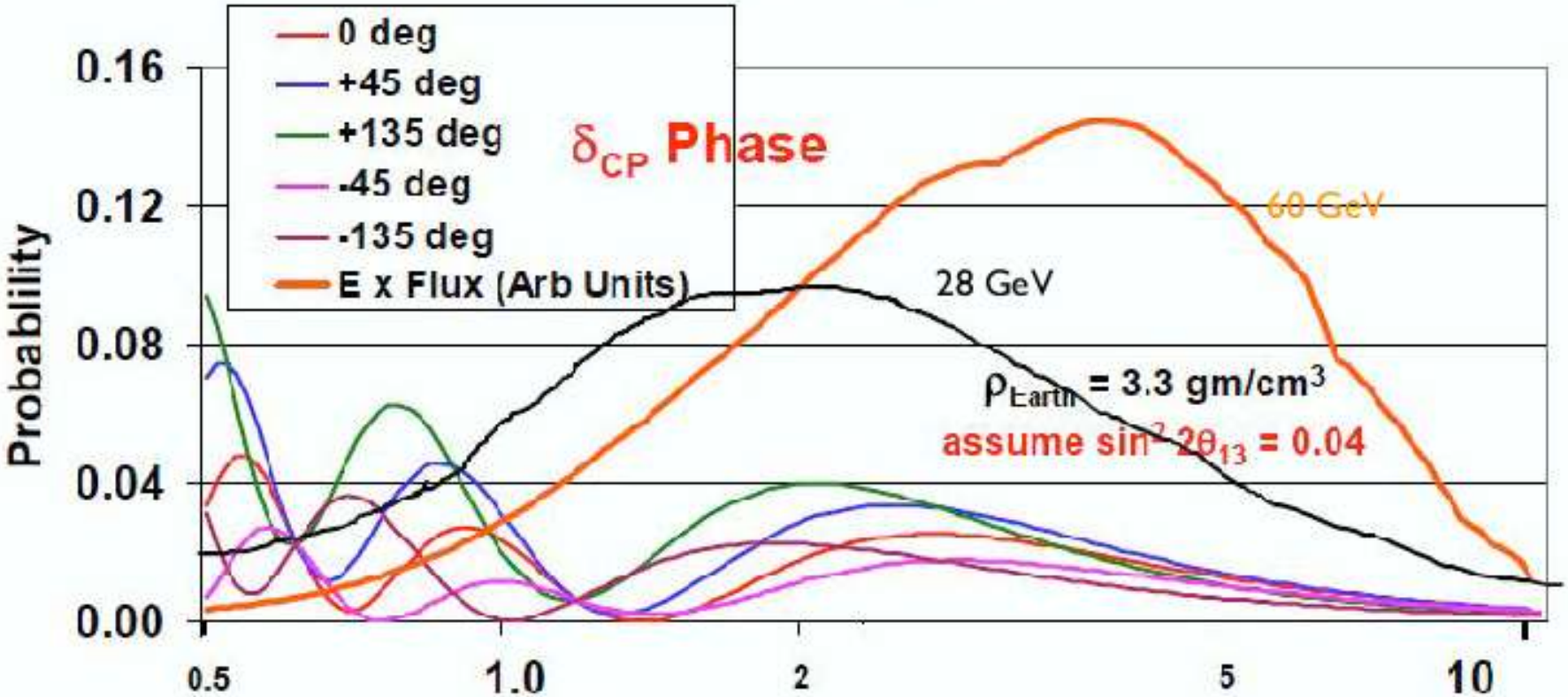




From M. Bishai

$\nu_\mu \rightarrow \nu_e$ CP Phase Effects - VLBNO

L = 1300 km – FNAL to Homestake

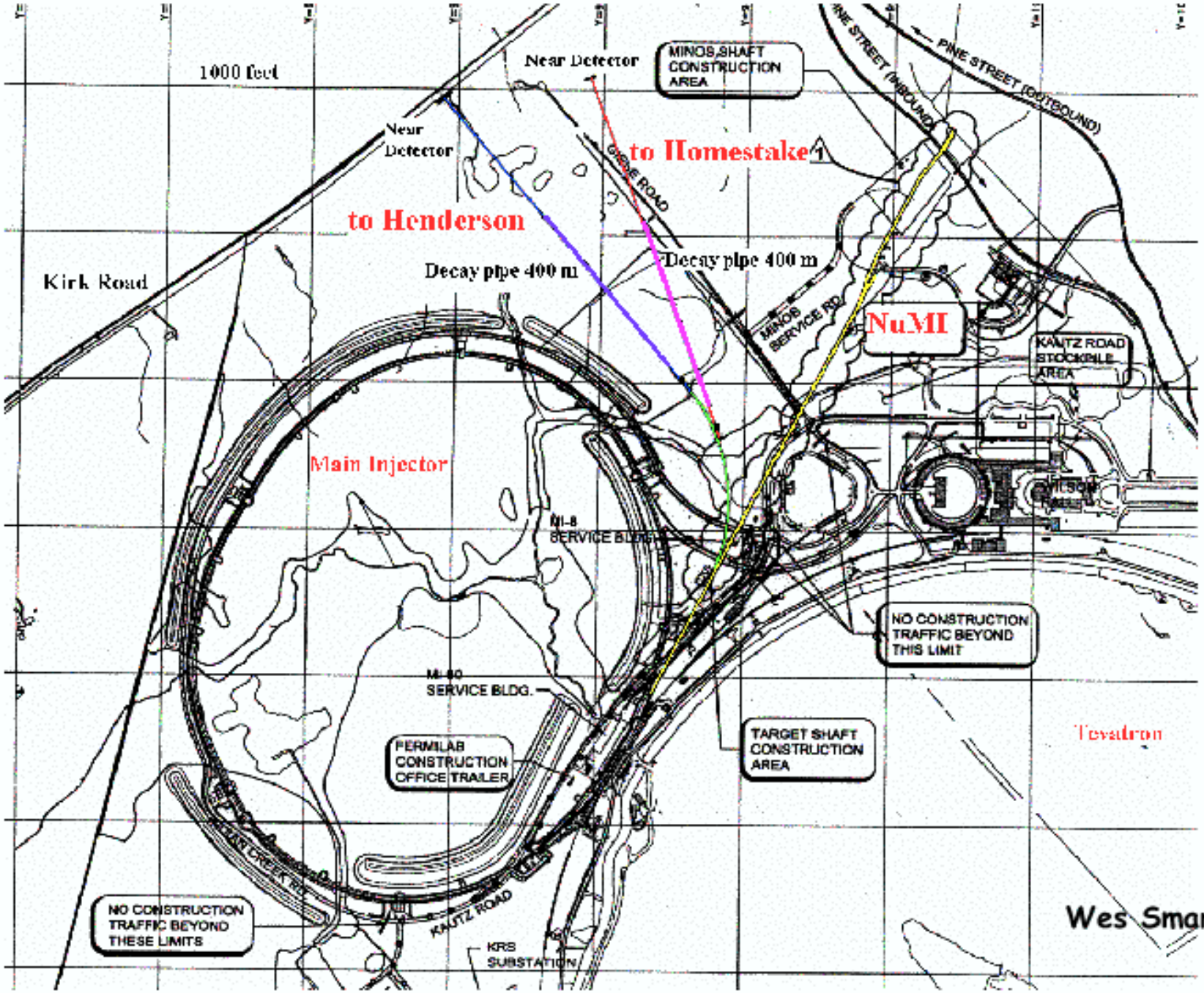


Δm^2_{21} = 0.000080 eV^2

Δm^2_{23} = 0.0025 eV^2

$\sin^2 2\theta_{12}$ = 0.84

$\sin^2 2\theta_{23}$ = 0.95


1000 feet
Near Detector
MINOS SHAFT CONSTRUCTION AREA
PINE STREET (INBOUND)
PINE STREET (OUTBOUND)
Near Detector
to Homestake
GROVE ROAD
to Henderson
Decay pipe 400 m
Decay pipe 400 m
Kirk Road
MINOS SERVICE RD
NuMI
KANTZ ROAD STOCKPILE AREA
Main Injector
MI-8 SERVICE BLDG.
NO CONSTRUCTION TRAFFIC BEYOND THIS LIMIT
MI-60 SERVICE BLDG.
FERMILAB CONSTRUCTION OFFICE TRAILER
TARGET SHAFT CONSTRUCTION AREA
Tevatron
NO CONSTRUCTION TRAFFIC BEYOND THESE LIMITS
KANTZ ROAD
KRS SUBSTATION
Wes Smart

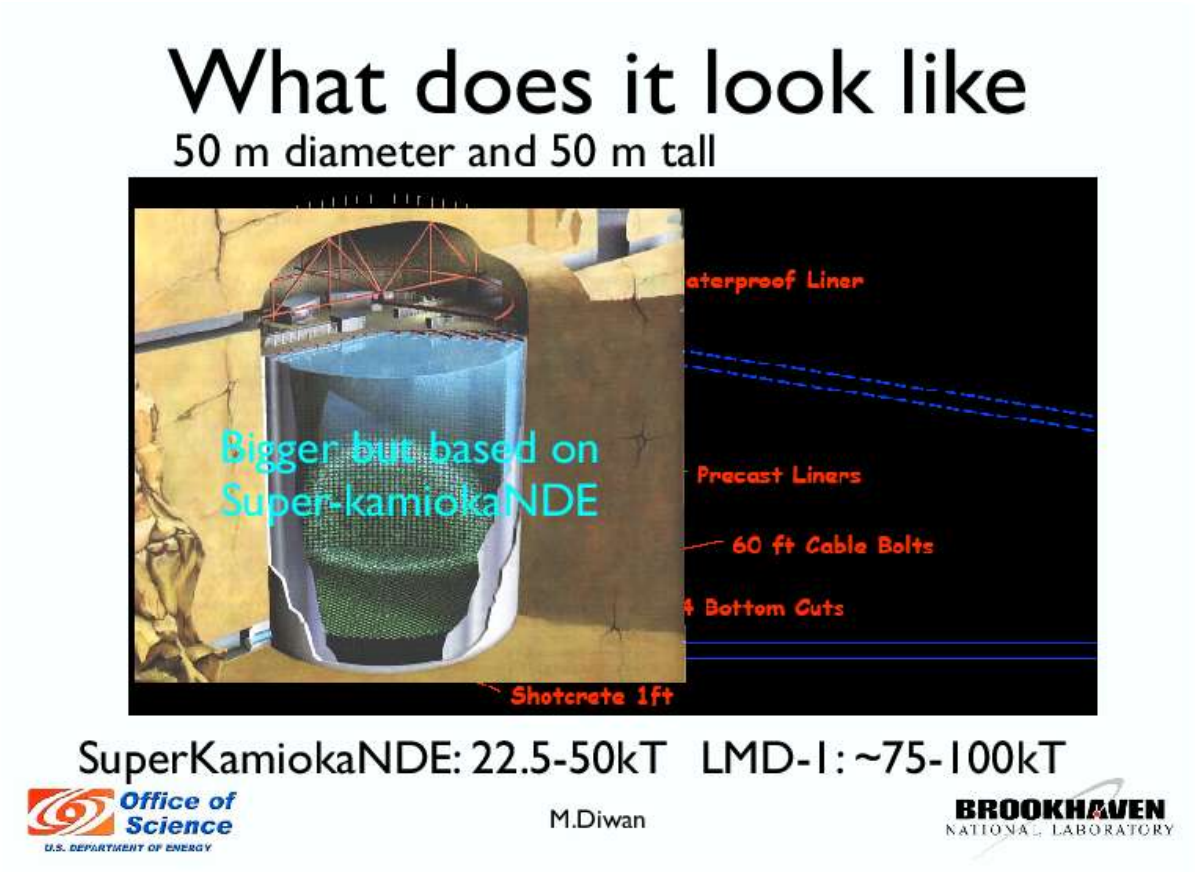
Detector options:

- modularized Water Cerenkov detector (100 kton units
- One large Water Cerenkov detector (UNO-like)
- Liquid Argon TPC

Underground
at DUSEL

Possibilities
at DUSEL

- no overburden
- minimal overburden (ie: 300ft drive in site at Homestake)
- up to ~4800 ft deep



Event rates and optimization

For NuMI (735 km): 1st osc max is at 1.5 GeV, 2nd osc max is at 0.5 GeV

For FNAL-Homestake (1297 km): 1st osc max is at 2.6 GeV, 2nd osc max is at 0.8 GeV

Beam scenario	Tunnel	numu CC /10^20 POT*kT	Total rate 5e7 sec	CC(nue/ numu)
WBLE 60GeV	R=2m L=380	13 (1300km)	202800 (300kT*1MW)	0.9%
WBLE 40GeV	R=2m L=380	6 (1300km)	140400 (300kT*1MW)	0.9%
WBLE 28GeV	R=2m L=380	3.4 (1300)	114240 (300kT*1MW)	0.8%
WBLE 28GeV	R=2m L=180	2.4 (1300)	80640 (300kT*1MW)	0.6%
NUMI-ME -120GeV 12km offaxs	R=1m L=677	20.3 (810km)	15625 (30kT*1MW)	2.2% (integrated)
NUMI-ME -120GeV 40 km offaxs	R=1m L=677	0.9 (810 km)	1170 (50kT*1MW)	5.5% (integrated)

$$\text{Total POT}(10^{20}) = \frac{\text{Beam power(kW)}}{1.6E_p(\text{GeV})} \times \text{time}(10^7\text{sec})$$

Office of Science
U.S. DEPARTMENT OF ENERGY

M.Diwan

BROOKHAVEN NATIONAL LABORATORY

Work list for Study

- Detectors:
  - Liquid Argon simulation studies with off-axis and wide band beam
    - How deep does it need to be?
  - Water Cherenkov Detector
    - Resolution and Background Reduction
    - Interface with DUSEL
- Beam:
  - Simulations of beam spectrum to DUSEL
  - Sensitivity using 2nd off-axis detector

S. Dawson, NuSAG mtg, 2006

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S. Dawson, NuSAG mtg, 2006

Long Baseline Study: LAr

Simulation Studies:

- Scenarios
  - Off axis NuMI beam at 14 mrad, 810 km
  - at 40 mrad, 810km, and 200km
  - Wide-band beam

efficiencies and resolutions for signal and background

↓

sensitivity studies

Technical Issues:

- Depth vs background
- energy threshold for different channels

  physics beyond accelerator neutrino oscillations
- Technical feasibilty vs detector size
- R&D towards massive detectors

→ Costing

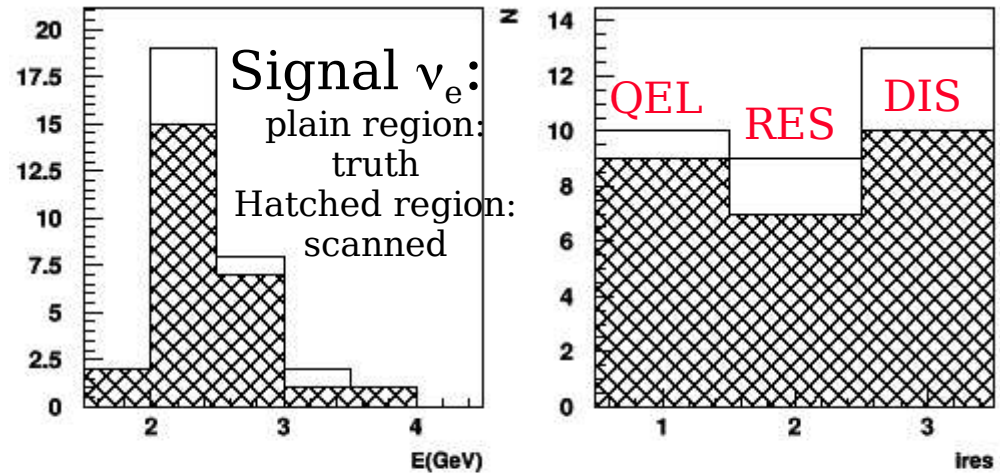
B. T. Fleming, NuSAG 2006

Efficiencies, purities and resolutions from existing work...

Tufts University Group

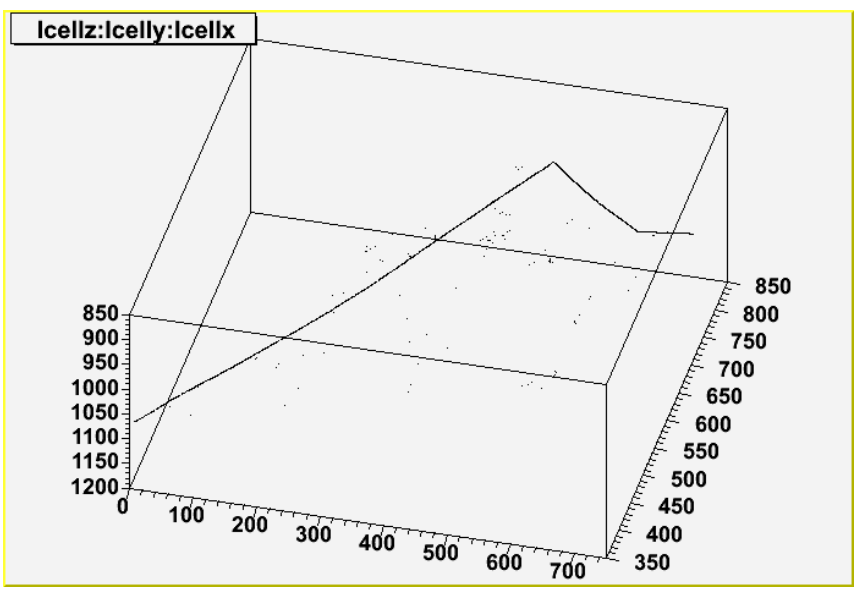
Efficiencies from hand scan excercise

90% 77% 70%



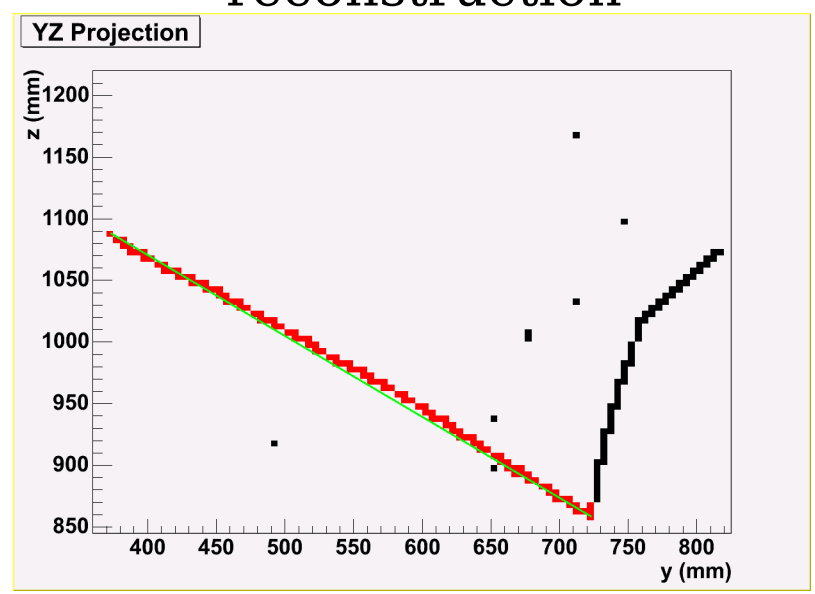
Developing tools for refined sensitivity calculations...

GEANT3 simulation



Steve Linden

Automated hough transform reconstruction



Colin Anderson

LArTPC at NOvA location.....

Assuming 90% ν_e efficiency and NC background rejection well below ½ of the intrinsic ν_e beam backgrounds, how sensitive are these detectors?

Sensitivity = detector mass x detector efficiency x protons on target/yr x # of years

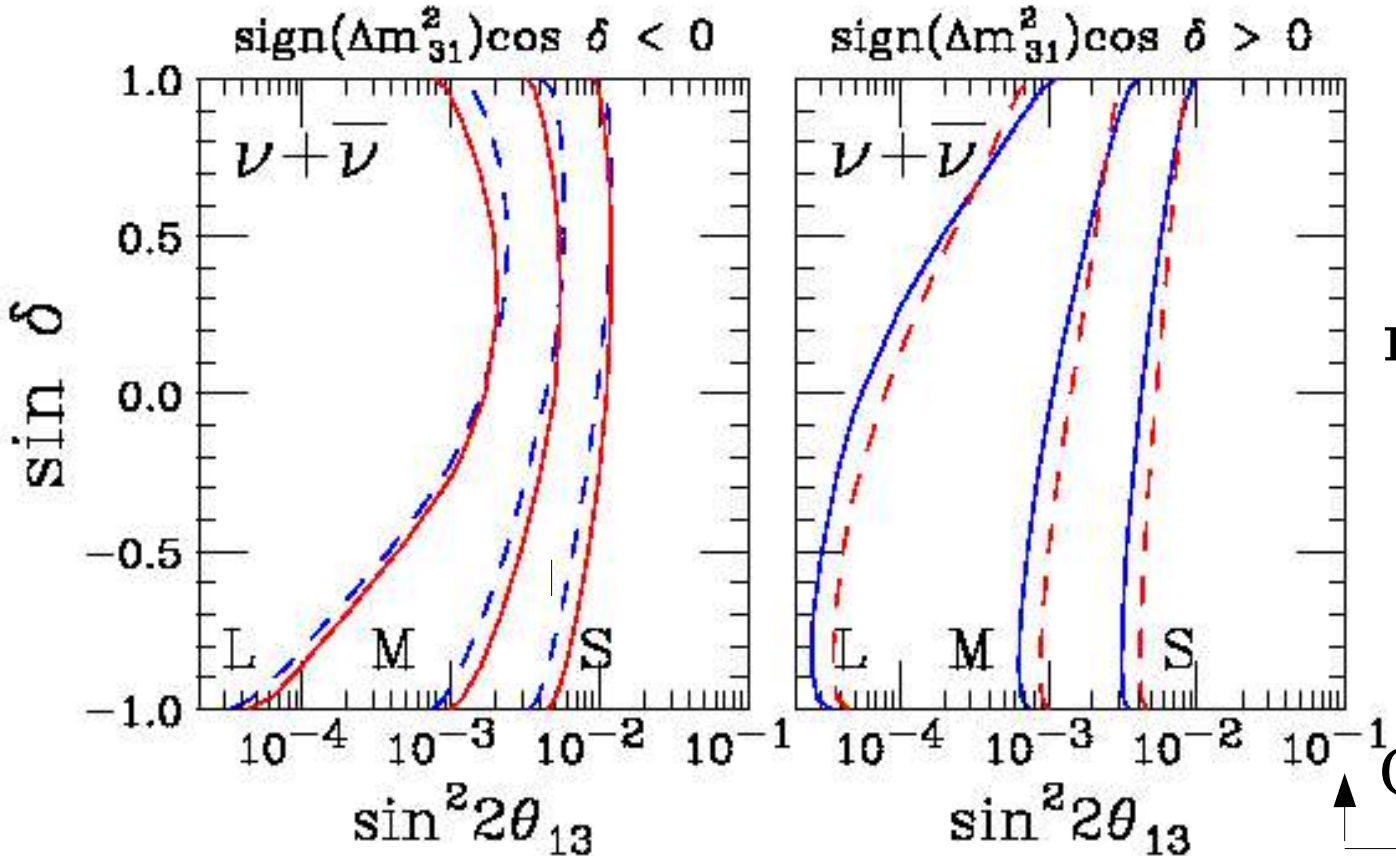
"Equivalent" detectors

	Small	Medium	Large
NOvA	30kTon	30kton + PD or x5 mass or exposure	30kton + PD + x5 mass or exp.
LArTPC (90% ν_e eff.)	8kton	40kton	40kton + PD or exposure

hep-ph/0505202

B. T. Fleming, NuSAG 2006

Sensitivity to CP phase(sin δ) vs $\sin^2 2\theta_{13}$ for



Sensitivities assume 3 years running each in ν and $\bar{\nu}$ mode

CHOOZ limit

most restrictive:

cos δ <0, normal hierarchy

cos δ >0, inverted hierarchy

least restrictive:

cos δ >0, normal hierarchy

cos δ <0, inverted hierarchy

B. T. Fleming, NuSAG 2006

Long Baseline Study: LAr

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- Scenarios
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  - Wide-band beam

efficiencies and resolutions for signal and background

sensitivity studies

for 2nd osc max and wide-band beam -> in progress

Technical Issues:

- Depth vs background
- energy threshold for different channels

  physics beyond accelerator neutrino oscillations
- Technical feasibilty vs detector size
- R&D towards massive detectors

Costing

B. T. Fleming, NuSAG 2006

Long Baseline Study: LAr

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efficiencies and resolutions for signal and background

↓

sensitivity studies

S. Pordes: Surface rates talk tomorrow

Technical Issues:

- Depth vs background
- energy threshold for different channels

  physics beyond accelerator neutrino oscillations
- Technical feasibilty vs detector size
- R&D to get to necessary sizes (brief)

→ Costing

What is gained from going underground?

How far underground?

Cosmic backgrounds primarily from

- crossing muons and decay products
- neutrons
- photons

Effect on

- beam physics
- nucleon decay searches
- Atmospheric neutrinos
- Solar neutrinos
- Supernovae searches

What are the added challenges of going underground?

-underground construction

-how deep underground is deep?

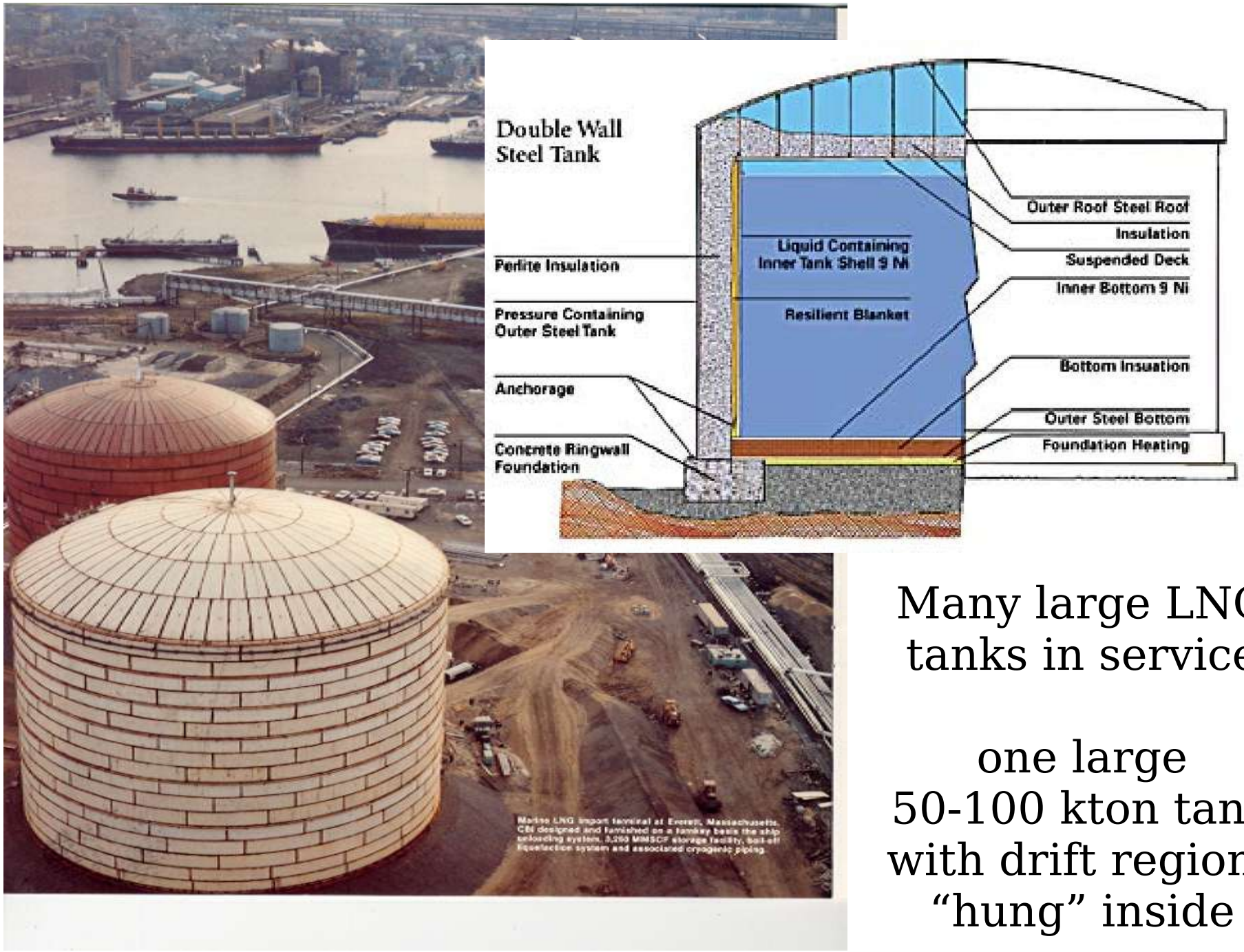
-how large a cavern is needed?

-safety considerations

-how deep is deep?

-LAr spill containment

-cost.....

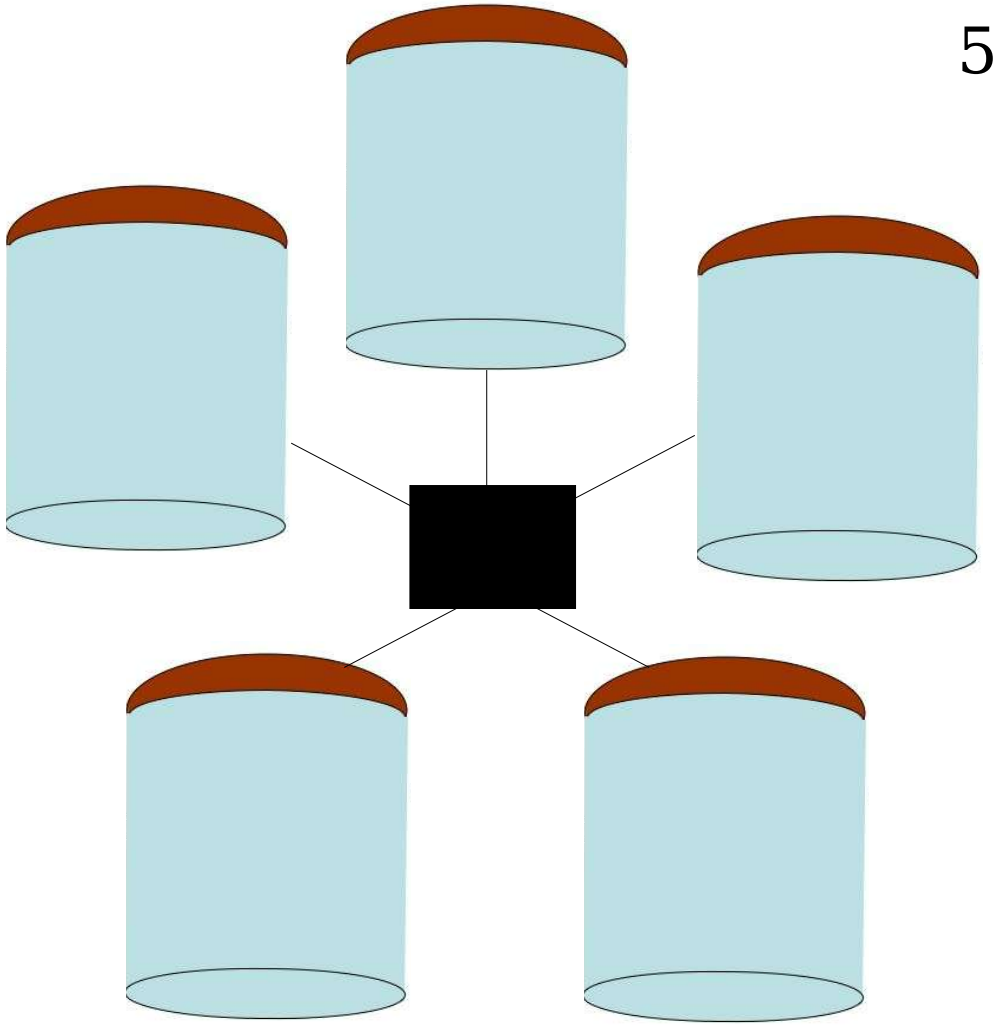


Many large LNG tanks in service

one large 50-100 kton tank with drift regions "hung" inside

Is 50-100 ktons the right size?

Modularize: build 5 10-20 kton detectors



what do you gain?
-phased construction
-reduction of systematics
-ease of engineering?

what do you lose?
-cost (pedestal cost)
-fiducial volume

Goal of Study

- Preliminary report, July 15, 2006
- Final report, October 1, 2006
- Hope for a consensus statement of advantages/disadvantages of off-axis and broad band techniques along with a discussion of the unresolved questions

S. Dawson, NuSAG mtg, 2006