BNL at the Intensity Frontier: Accelerator Neutrinos

DOE IF Comparitive Review, May 21 2013

Mary Bishai
Brookhaven National Laboratory

1 νs at BNL
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3 MicroBooNE
4 LBNE
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Neutrino History at BNL

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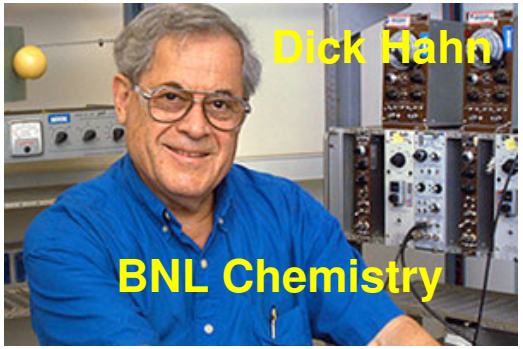
1957
Neutrino helicity discovered

1962
Discovery of neutrino flavor (1988 Nobel)

1960's–1980's
Solar neutrino disappearance at Homestake (2002 Nobel)

1987
Supernova neutrinos in IMB

1990's–mid 2000
GALLEX
SNO: Proof of neutrino flavor oscillations



Long Baseline Neutrino Oscillations at BNL

BNL at the Intensity Frontier: Accelerator Neutrinos
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νs at BNL
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MicroBooNE
LBNE
Summary

April 1995:

Long Baseline Neutrino Oscillation Experiment at the AGS
Approved by the HENPAC as AGS Experiment 889 Report No. BNL-52459, April 1995

*D. Beavis, A. Carroll, I. Chiang, M. Diwan †, J. Frank, S. Kahn, M. Marx *, S. McCorkle, M. Murtagh, J. Sondericker III, H. Takai, P. Yamin*
Brookhaven National Laboratory, Long Island, NY

with UCSB, LSU, Louisiana Tech, U. Montreal, UNM, U.Penn, Southern University, UT Austin, TRIUMF, Valparaiso, Yale.

E889 introduces the off-axis concept

Feb-April 1995: MINOS Proposal P-875 at Fermilab

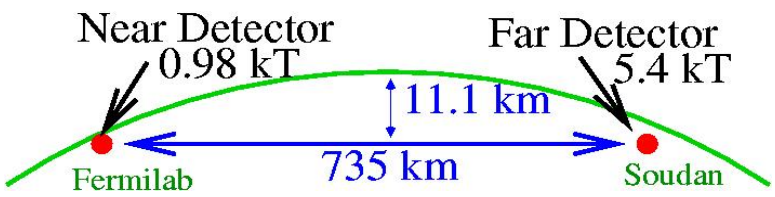
1998: SuperK demonstrates atm ν_μ oscillations

1999-2004: Planning, design and construction of MINOS.

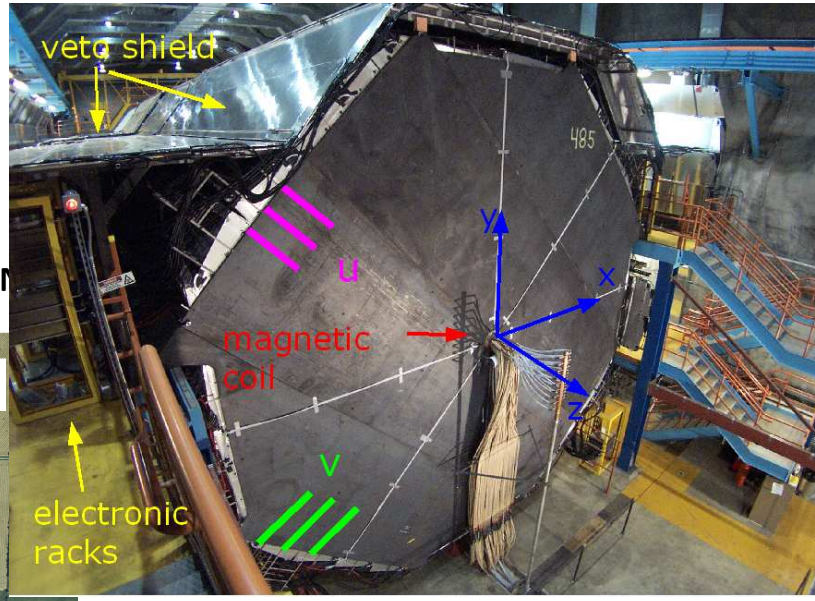
2000: BNL joins MINOS

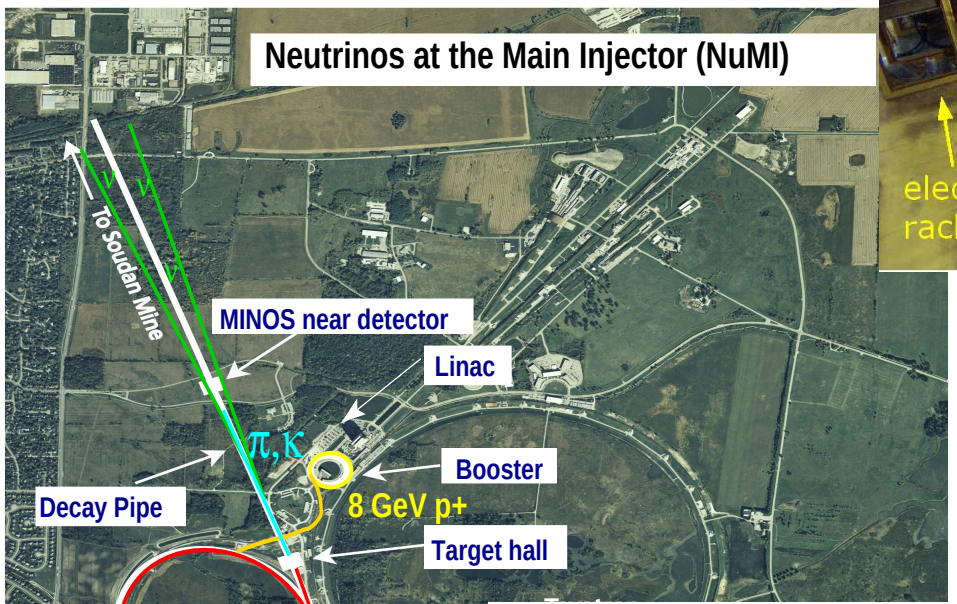
The NuMI/MINOS Accelerator ν_μ Experiment.

Observe $\nu_\mu/\bar{\nu}_\mu$ disappearance, ν_e appereance, atmospheric $\nu/\bar{\nu}$ oscillations, search for ν_s

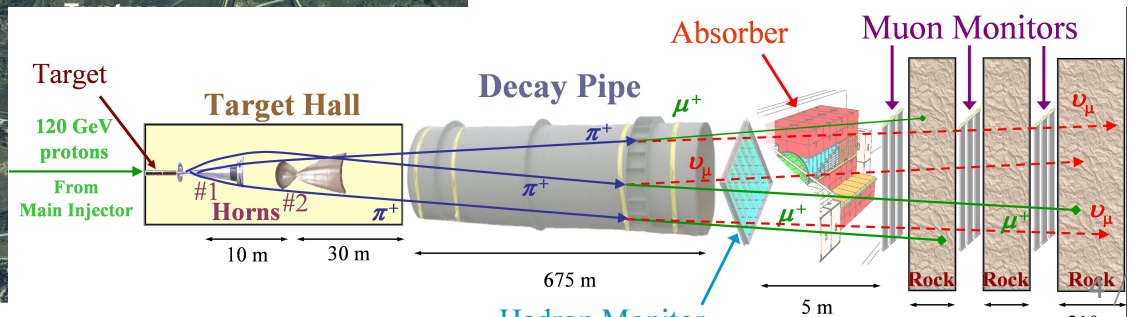


Fermi Natl. Lab., IL **Soudan Underground Lab, MN**



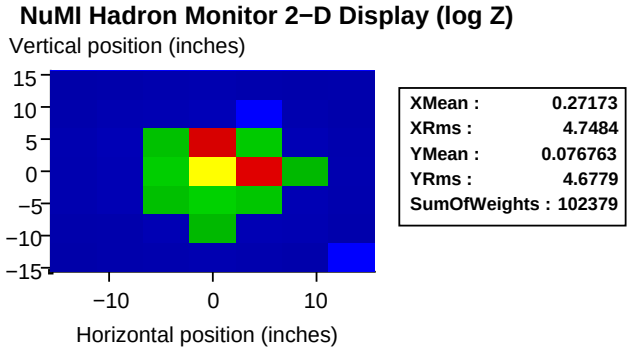


MINOS far detector
Magentized iron-scint calorimeter

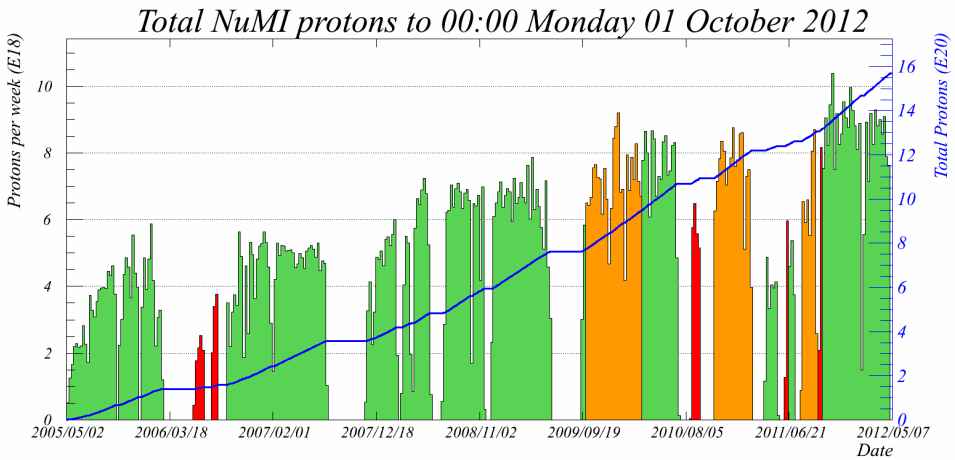


MINOS 2005-2012

First pulses in NuMI recorded by the online JAS-based NuMI monitoring software developed by Mary Bishai, BNL:



MINOS running 2005-2012:

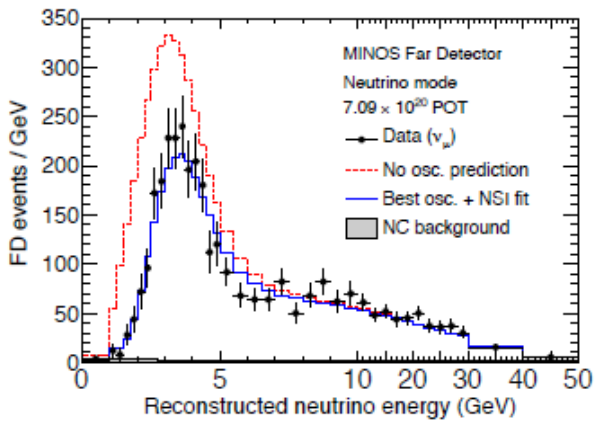


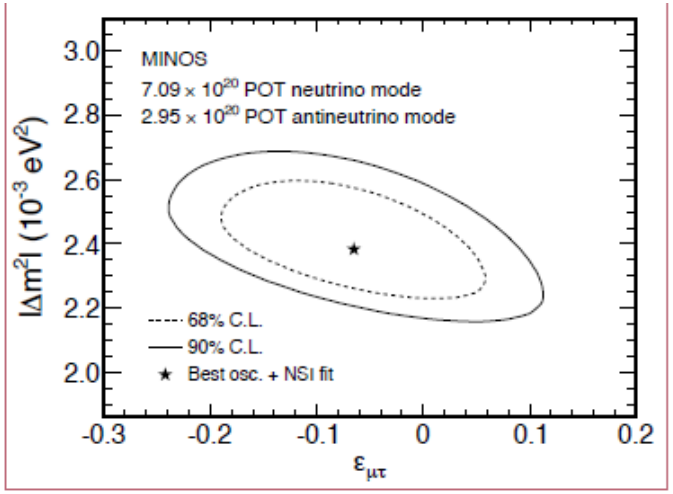
M. Bishai, M. Dierckxsens, B. Viren at BNL developed online NuMI-MINOS beam data logging and monitoring: NuMI spill-by-spill data incoporated into MINOS offline analysis, for absolute proton-on-target normalization, and beam data quality selection

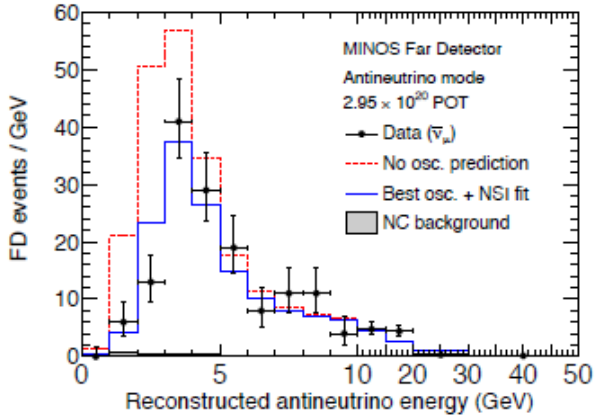
BNL People and Activities 2010-2013

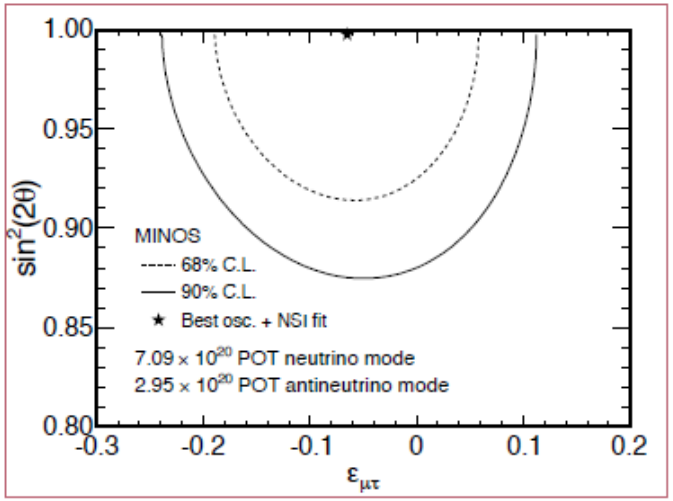
Person	MINOS activities
Mary Bishai, Physicist	Beam systematics co-convener 2009-2011
Milind Diwan, Physicist	Former ν_e analysis co-convener 2005-2008 MINOS internal reviewer.
David Jaffe, Physicist	Member $\bar{\nu}_\mu$ oscillation analysis team 2005-2009 MINOS internal reviewer.
Brett Viren, Physicist	Beam data software development 2005-2011
Lisa Whitehead, postdoc	ν_e analysis co-convener 2010-present 2010 ν_μ analysis internal reviewer. Joined U. Houston faculty Aug 2011
Jiajie Ling, postdoc	ν_μ flux measurements, ν_e particle ID optimization. joined BNL Aug 2010
Zeynep Isvan, postdoc	Leads non-standard interactions anaylsis joined BNL Jan 2012

Latest results on Non-Standard Interactions: Z. Isvan (BNL)









- Three-parameter fit, incorporates systematics as penalty terms
- Submitted to PRL in March, arXiv: 1303.5314

$$\varepsilon_{\mu\tau} = -0.07 \pm 0.08$$

- Δm^2, $\sin^2 2\theta$ consistent with standard oscillation results.

MINOS+ Proposal 2011

DocDB-7923
May 13, 2011

MINOS+

A Proposal to FNAL to run MINOS with the medium energy NuMI beam

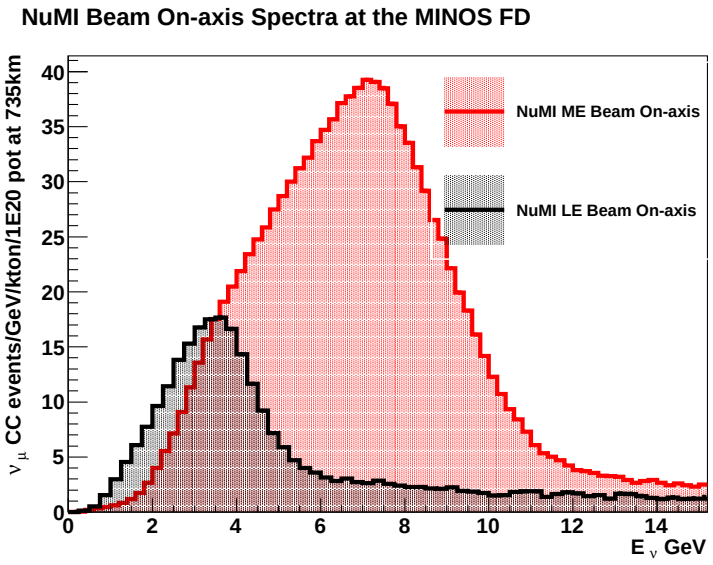
The MINOS+ Collaboration

G. Tzanakos
University of Athens, Athens, Greece

M. Bishai, M. Diwan
Brookhaven National Laboratory, Upton, New York 11973, USA

in addition to many of the MINOS collaboration

MINOS+ Future Plans at BNL



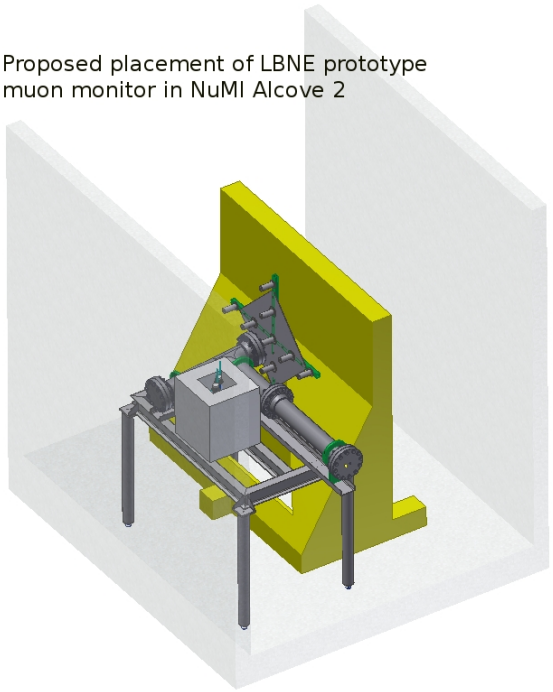
- **NuMI medium-energy beam is much wider than low-energy $\Rightarrow$ larger range of L/E to look for non-standard interactions: Z. Isvan, M. Bishai.**

- **D. Jaffe (BNL) and P. Ochoa (CalTech) developed a technique for extracting the ν_e content of the beam in the oscillation region with a precision of better than $\leq$ 20% by measuring the $\bar{\nu}_\mu$ signal from $\pi^+ \rightarrow \nu_\mu \mu^+$, $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ in different beam tunes. The MINOS+ ME running would allow the BNL group to complete this analysis.**
  Provides important constraints on the ν_e background in LBNE. M. Bishai.

MINOS+ $\longrightarrow$ LBNE

- **NuMI is the model for the LBNE beamline. Continue studies of the NuMI performance and beam systematics with the MINOS ND for LBNE optimization.**
- **LBNE studies indicate mass hierarchy sensitivity significantly improved using lower energy beams. Explore the impact of lowering the Main Injector beam energy on the neutrino spectrum using MINOS ND.**

Proposed placement of LBNE prototype muon monitor in NuMI Alcove 2



- **LANL group is prototyping the LBNE near site muon flux monitors in the NuMI beam - MINOS+ ND data can be used to correlate μ flux with ν interactions.**

MINOS Summary

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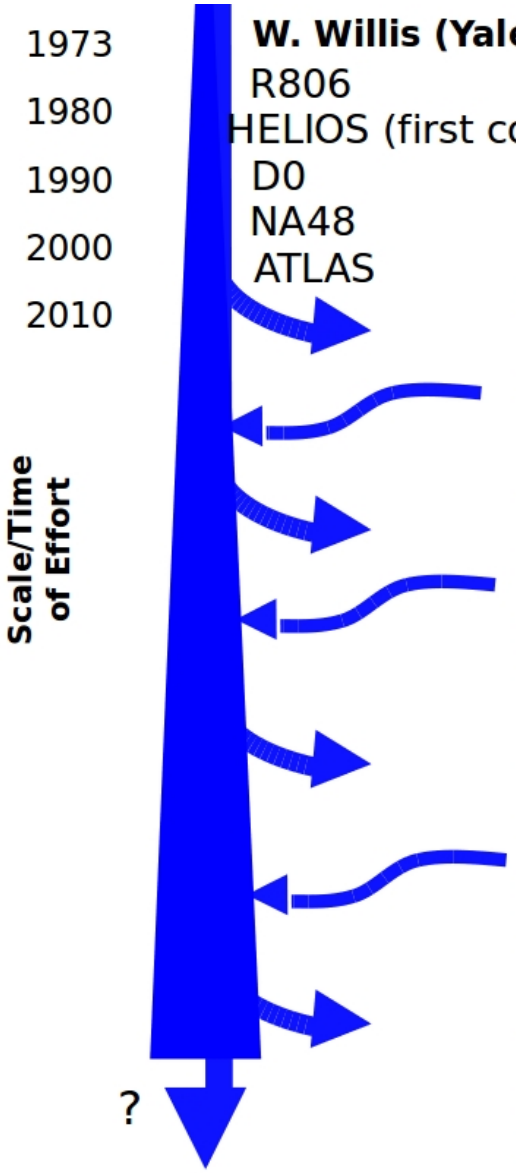
BNL MINOS/MINOS+ effort is severely undermanned!

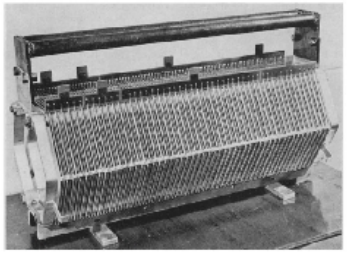
- **The BNL MINOS group has been involved in a wide variety of successful MINOS analysis efforts: $\bar{\nu}_\mu$ oscillation, $\nu_\mu \rightarrow \nu_e$ appearance search, measurement of the atmospheric ν_e flux in the FD, beam modeling systematics.**
- **The BNL MINOS group's expertise on NuMI/MINOS analysis and beam simulations has been critical in producing the first LBNE beam designs and making the physics case.**
- **Continuing involvement in MINOS+ will allow us to continue extracting useful information for optimizing LBNE designs and to play a leading role in the MINOS+ non-standard interaction analysis. Extremely valuable data on the road to LBNE!!**

BNL Development of Noble Liquid Detectors → Giant LAr-TPCs



W. Willis (Yale), V. Radeka (BNL), Nucl. Instr. Methods, 120 (1974) 221

R806
HELIOS (first cold electronics)
D0
NA48
ATLAS



- **LAr Generic Detector R&D**
  LAr properties measurements, cold electronics development, TPC construction, device prototyping
- **MicroBooNE Experiment**
  Resolve miniBooNE low-E excess, precision neutrino cross section measurements of E, QE, 1p, NCp0, LAr technology development
- **LAr1 Experiment**
  "Far" detector for microBooNE, short baseline physics, backgrounds, development of giant LAr technologies (membrane cryostat, modular TPCs)
- **LBNE LArTPC**
  Mass hierarchy, q13, CPV in lepton sector, PDK, supernovae, ...

The MicroBooNE Experiment

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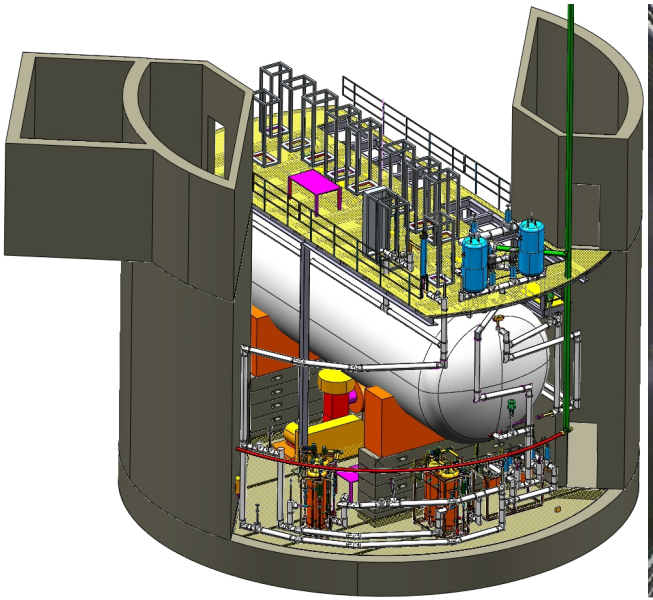
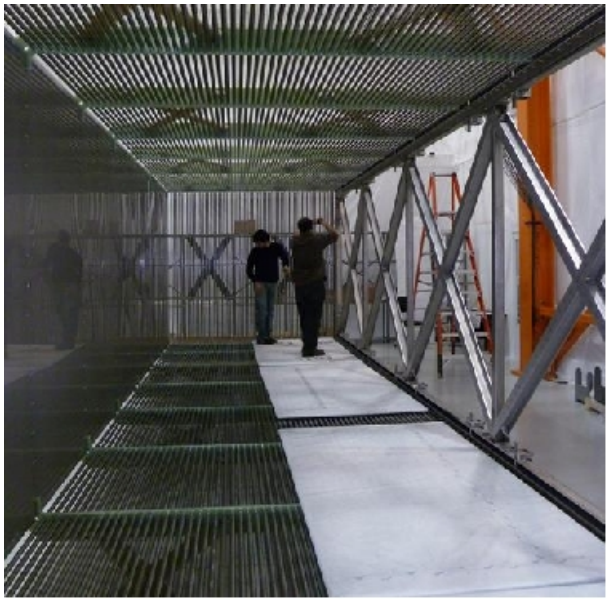
circa 2007: A LAr-TPC at the FNAL booster neutrino beam concieved by W. Willis (Columbia), D. Lissauer (BNL), B. Fleming (yale).

CD-0 Oct 2009, CD-1 June 2010, CD-2/3a Sep 2011, CD-3b March 2012





19 Institutions in 3 countries: Italy, Switzerland, USA. 3 US National Labs. 12 US Research Universities. 2 All-undergraduate Universities.

MicroBooNE Personnel at BNL: H. Chen, S. Duffin, J. Farrell, F. Lanni, D. Lissauer, G. Mahler, D. Makowiecki, J. Mead, V. Radeka, S. Rescia, J. Sondericker, C. Thorn, B. Yu, Y. Li.

The BNL Team on MicroBoooNE

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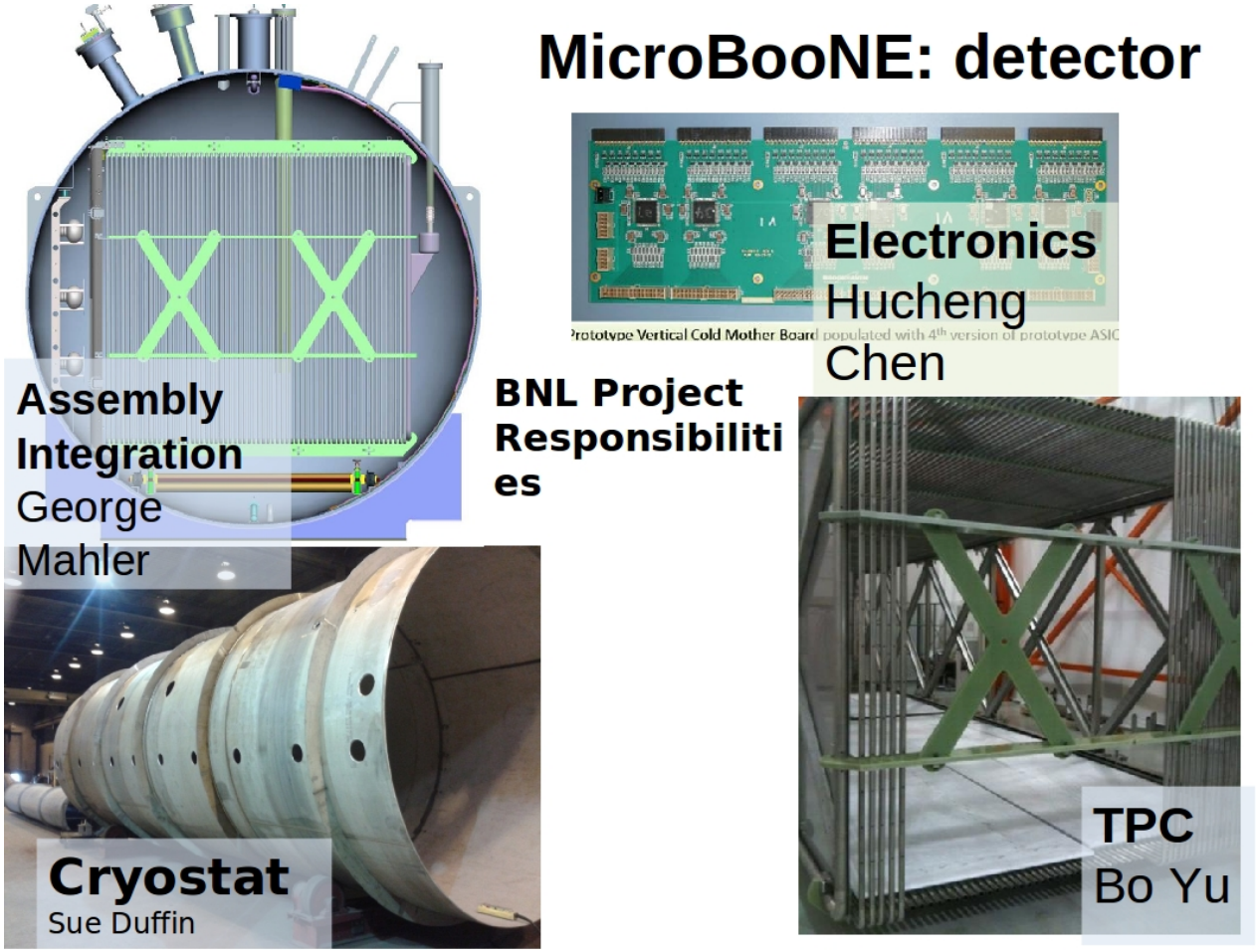
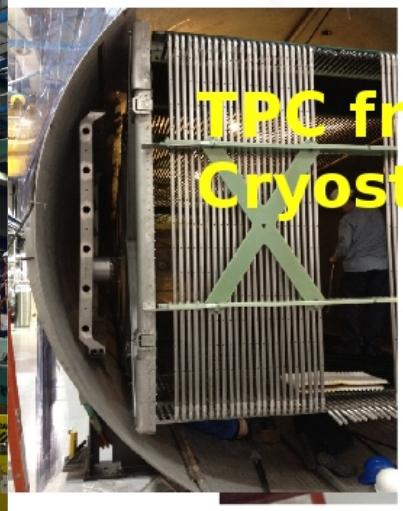
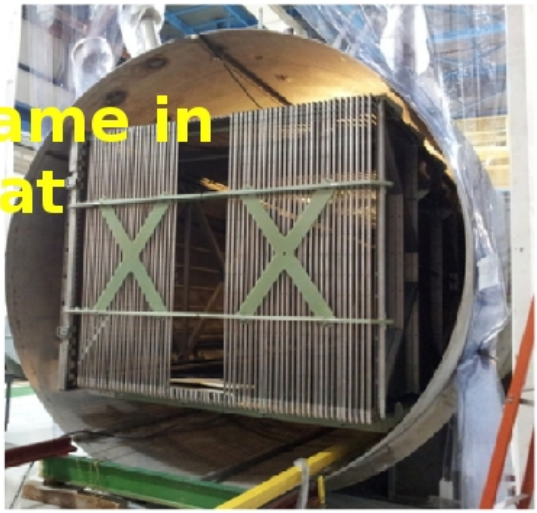
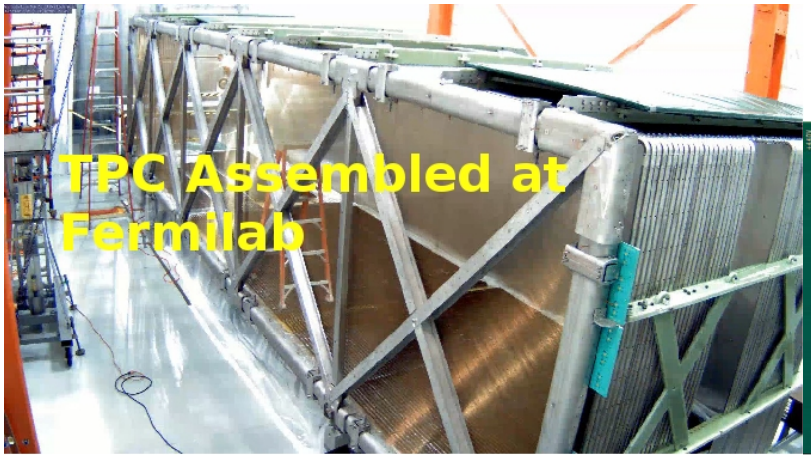


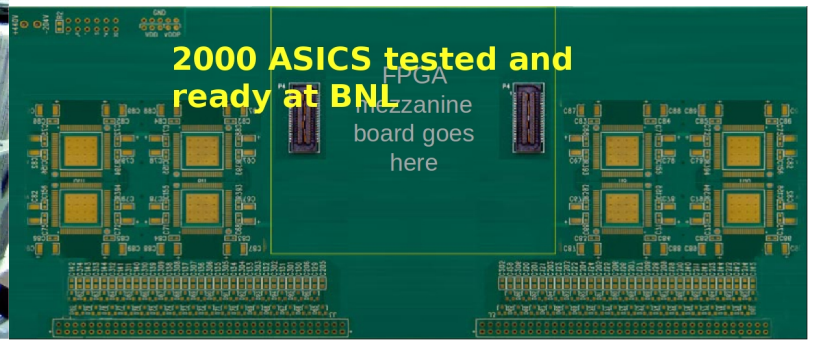
Craig Thorn Deputy Project Manager - Active Detector
Also: Jason Farrell Designer, cryostat and electronics
Andres Ruga Designer, TPC
Yichen Li Postdoc, electron & photon transport

Recent Results from BNL MicroBooNE Team









MicroBoooNE Future Plans at BNL

The BNL group plans to capatilize on its large institutional investment in MicroBooNE by expanding the scientific effort with the involvement of additional scientific staff and postdocs. Plans are under discussion with the collaboration.

	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^o	8k	3k
ν_e CCQE	0.4k	1.2k
POT	6×10^{20}	8×10^{20}

Expected Event Rates for MicroBooNE.

Commisioning/Operations activities 2013-2014

- LAr properties R&D: (Harry Themann), Craig Thorn
- Electronics installation and commisioning: (Harry Themann)
- Operations: Yichen Li, (Harry Themann)

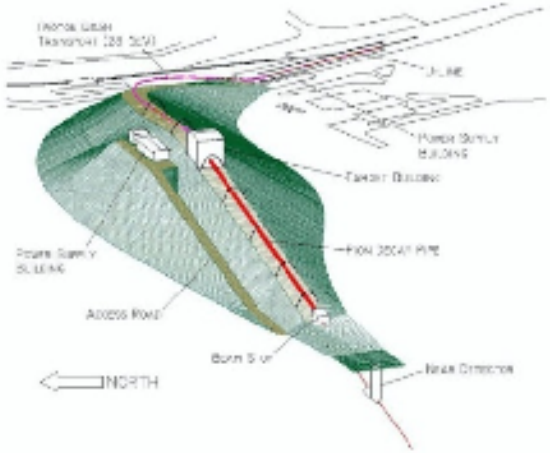
Initiation of new effors on simulations and analysis:

- Incorporation of realistic transport/electronics response into simulation and reconstruction: Y. Li, C. Thorn
- Simulation of neutrino interactions and nuclear models: (M. Bishai), (X. Qian)
- Anti-neutrino interactions and cross-sections: (M. Bishai), (Z. Isvan).
- Study of cosmic ray backgrounds on the surface: C. Thorn, (M. Bishai), (X. Qian), (Z. Isvan).

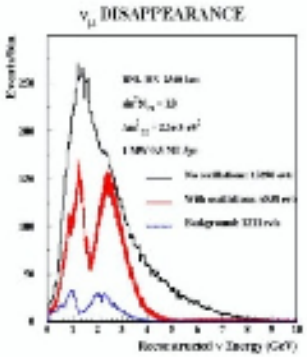
Long Baseline Neutrino History at BNL

Proposal to HEPAP Future Facilities 2003:

Super Neutrino Beam (Proton Driver)
Brookhaven National Laboratory
Upton, NY 11973



Submitted to the
HEPAP Future Facilities
Subcommittee
15 February 2003



Joint BNL-FNAL U.S. Long Baseline Study 2007:

Fermilab-0801-AD-E
BNL-77973-2007-IR

Report of the US long baseline neutrino experiment study

V. Barger,[1] M. Bishai,[2] D. Bogert,[3] C. Bromberg,[4] A. Curioni,[5] M. Dierckxsens,[2] M. Diwan,[2] F. Dufour,[6] D. Finley,[3] B. T. Fleming,[5] J. Gallardo,[2] J. Heim,[2] P. Huber,[1] C. K. Jung,[7] S. Kahn,[2] E. Kearns,[6] H. Kirk,[2] T. Kirk,[8] K. Lande,[9] C. Laughton,[3] W.Y. Lee,[10] K. Lesko,[10] C. Lewis,[11] P. Litchfield,[12] A. K. Mann,[9] A. Marchionni,[3] W. Marciano,[2] D. Marfatia,[13] A. D. Marino,[3] M. Marshak,[12] S. Menary,[14] K. McDonald,[15] M. Messier,[16] W. Pariseau,[17] Z. Parsa,[2] S. Pordes,[3] R. Potenza,[18] R. Rameika,[3] N. Saoulidou,[3] N. Simos,[2] R. Van Berg,[9] B. Viren,[2] K. Whisnant,[19] R. Wilson,[20] W. Winter,[21] C. Yanagisawa,[7] F. Yumiceva,[22] E. D. Zimmerman,[8] and R. Zwaska[3]

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[4]*Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA*
[5]*Department of Physics, Yale University, New Haven, CT 06520, USA*
[6]*Department of Physics, Boston University, Boston, MA 02215, USA*
[7]*Stony Brook University, Department of Physics and Astronomy, Stony Brook, NY 11794, USA*
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[13]*Department of Physics and Astronomy, University of Kansas, Lawrence, KS 66045, USA*
[14]*Department of Physics and Astronomy, York University, Toronto, Ontario M3J1P3, Canada*
[15]*Department of Physics, Princeton University, Princeton, NJ 08544, USA*
[16]*Department of Physics, Indiana University, Bloomington, IN 47405, USA*
[17]*Deapartment of Mining Engineering, University of Utah, Salt Lake City, UT 84112, USA*
[18]*Instituto Nazional di Fisica Nucleare,*

arXiv:0705.4396v1 [hep-ph] 30 May 2007

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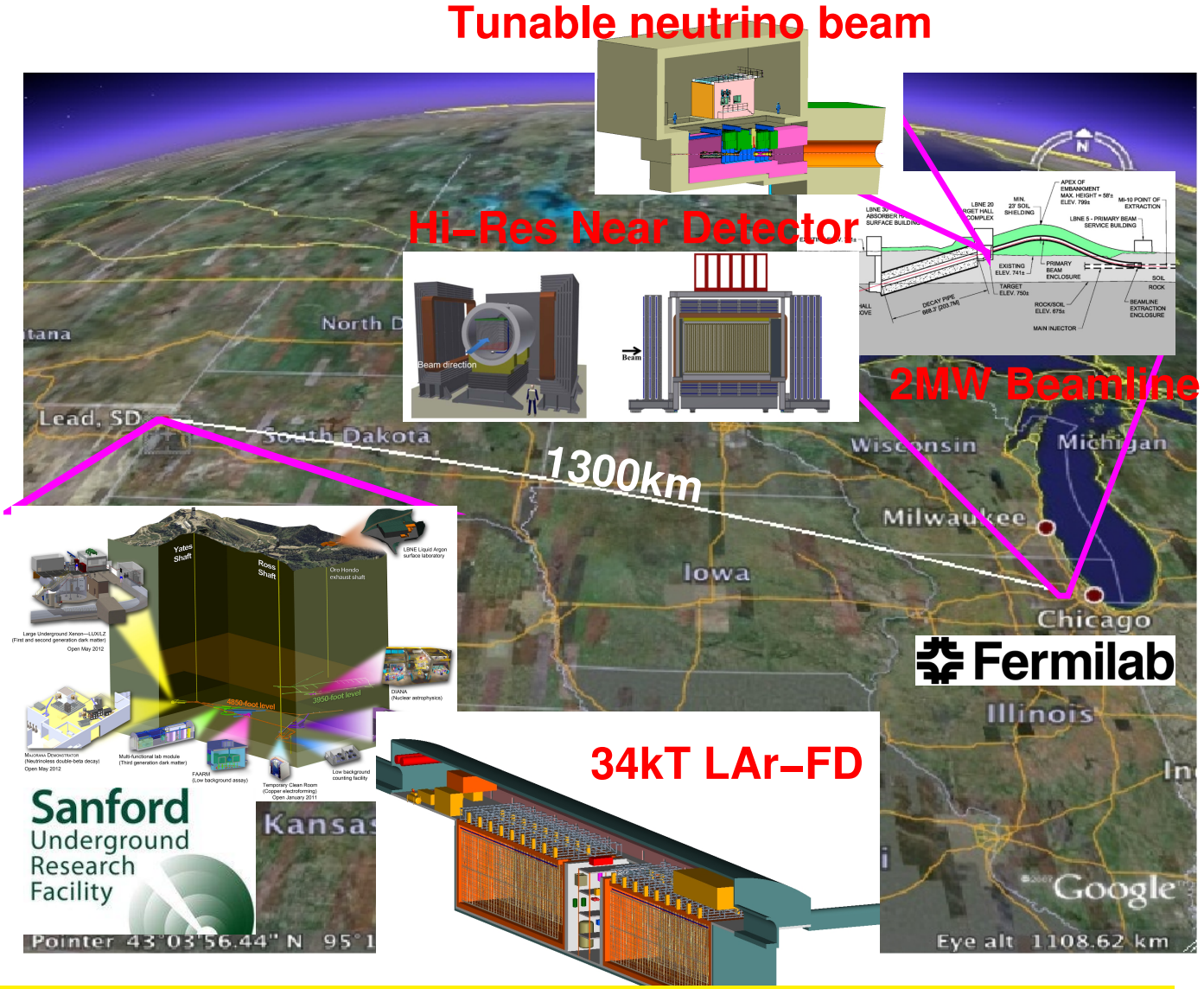
DOE CD 0 for long-baseline ν expt. $>$ 1000 km granted in Jan 2010

The Long Baseline Neutrino Experiment. CD-1 for Phase I granted Dec 2012



$\sim$ 350 people, 60 institutions from US, India, Italy, Japan, UK

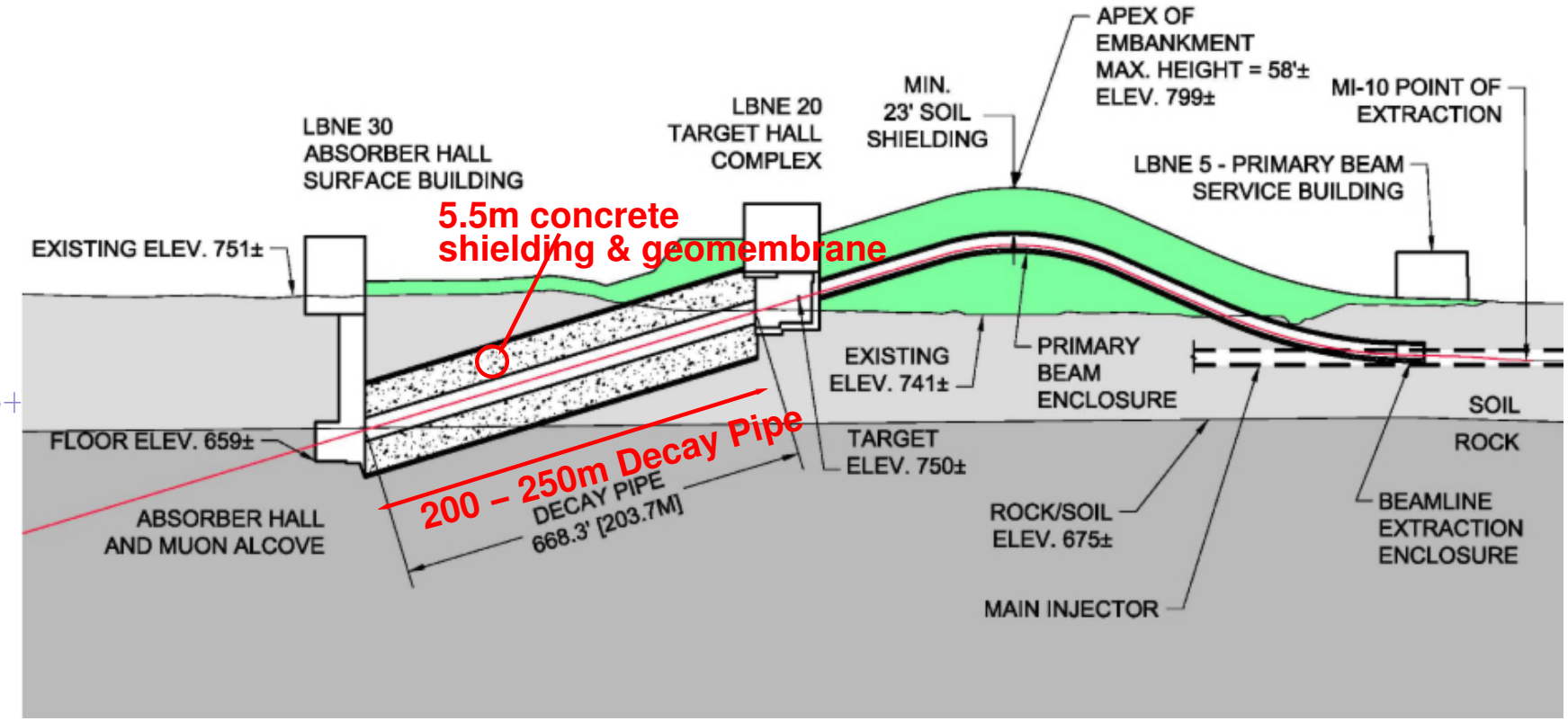
LBNE at BNL

Key Personnel at BNL

Senior Scientific Staff	
M. Diwan	Co-spokesperson
M. Bishai	Project Scientist, Physics Working Group, Beam Simulations co-convener
Jim Stewart	LAr-TPC Far Detector L2 Project Manager.
Craig Thorn, Bo Yu	L3s for cold electronics and TPC
V. Radeka	Former head of ID, cold electronics developer
M. Potekhin, B. Viren	LBNE software infrastructure and simulation
N. Samios	Former BNL lab director, senior advisor to the BNL project
B. Marciano	Neutrino theory, key theoretical concepts
S. Kettell	Water Cherenkov Detector CDR editor
R. Hackenburg	35 ton prototype development
M. Yeh (chemistry)	LAr properties, cleanliness
N. Simos (NSLSII)	Proton target irradiation R&D, PMT mechanical simulations
Research Associates	
E. Worcester	Physics capabilities studies and LBNE reconfiguration
Z. Isvan	Beam simulations, 35 ton simulations
J. Ling	WCD PMT mechanical studies
C. Zhang, J. Ling	Study of mass hierarchy sensitivities
X. Qian (new hire)	LAr physics sensitivities, nuclear effects
Y. Li, H. Themann	fundemantal LAr properties R&D
Technical/Project Staff	
J. Dolph	LBNE Systems Engineer
P. Novakova	Project controls specialist
R. Sharma	TPC static analysis, field cage development, WCD PMT mechanical R&D
G. Mahler, A. Ruge	Lead TPC field cage development
H. Chen	Cold electronics development
De Geronimo, S. Li, J. Fried	
N. Nambiar, E. Vernon	Instrumentation division cold electronics development

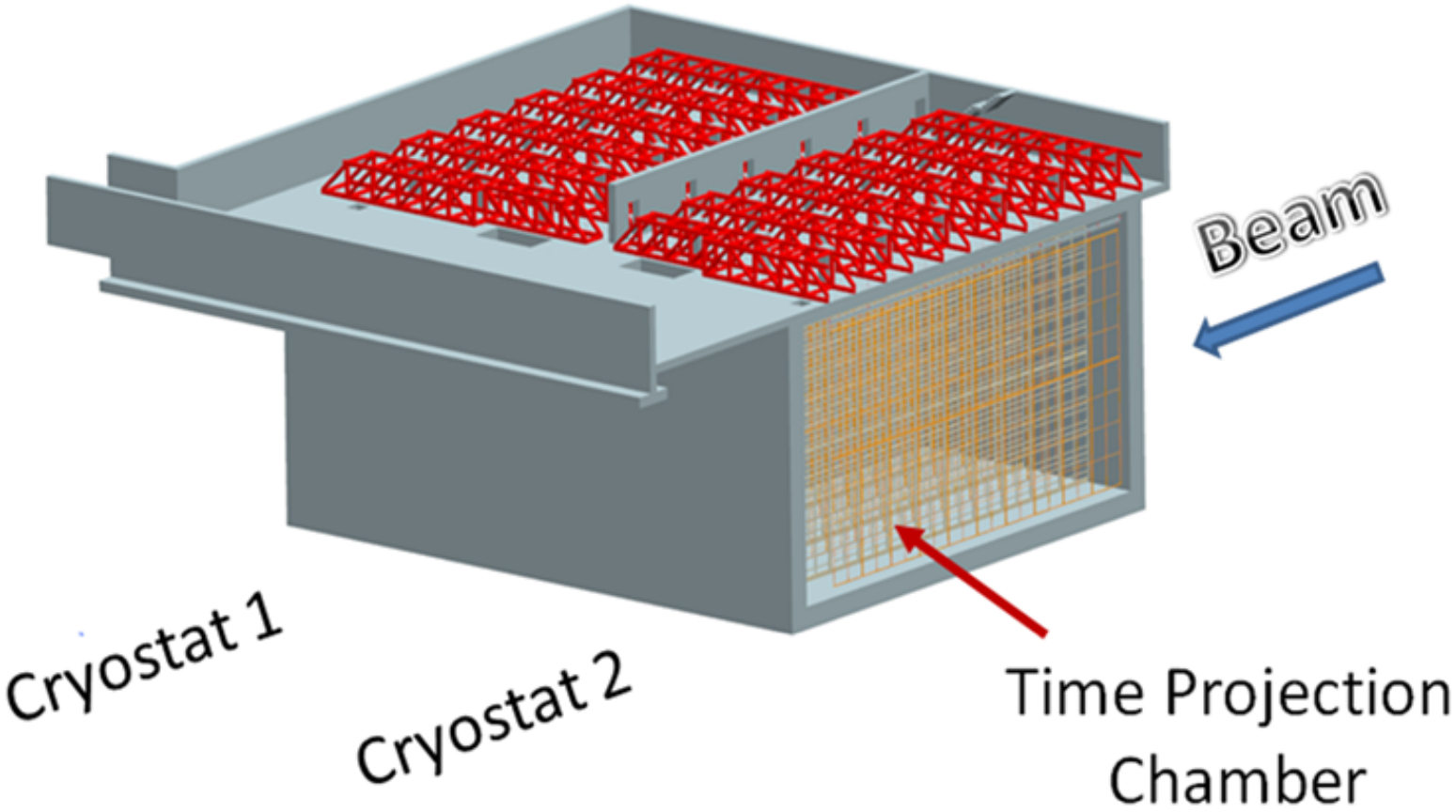
The LBNE Beamline

Novel beam-on-a-hill construction for 2.3MW from 60-120GeV



The beam-on-hill concept proposed by BNL. **NuMI based focusing design and optimized decay pipe geometry for LBNE developed by M. Bishai (and summer interns) working with FNAL team.** **Proton target material irradiation studies at BLIP facility : N. Simos with FNAL team**

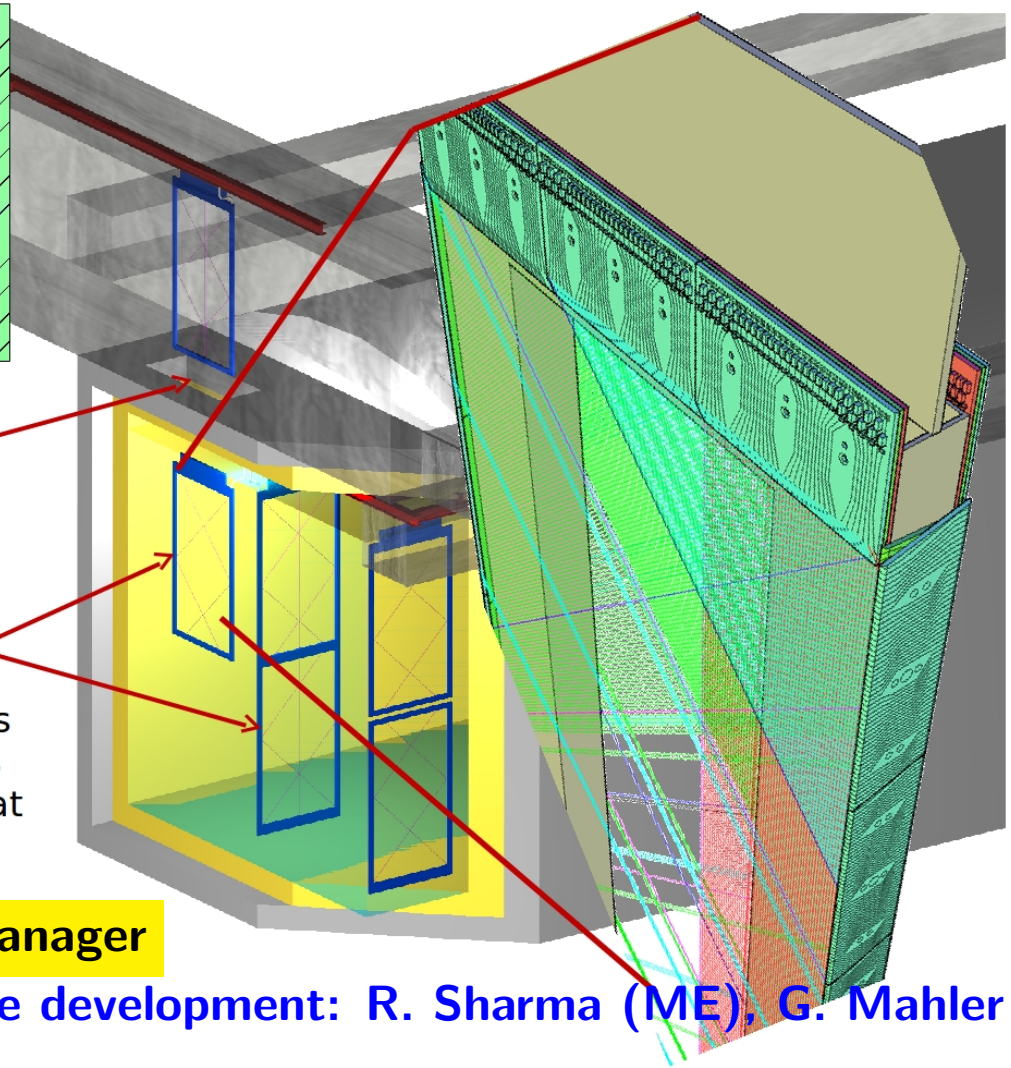
Conceptual design of CD1 10 kTon



Jim Stewart: L2 project manager for far detector
Craig Thorn: L3 for FD electronics
Bo Yu: L3 for TPC

Modular TPC Development at BNL

Anode and Cathode Modules can be manufactured, tested, transported, and installed in cryostat to form a TPC of arbitrary size



Cryostat access hatch, plugged when cryostat is filled

Anode Plane Assemblies and Cathode Plane Assemblies are transported in halves which are joined in cryostat

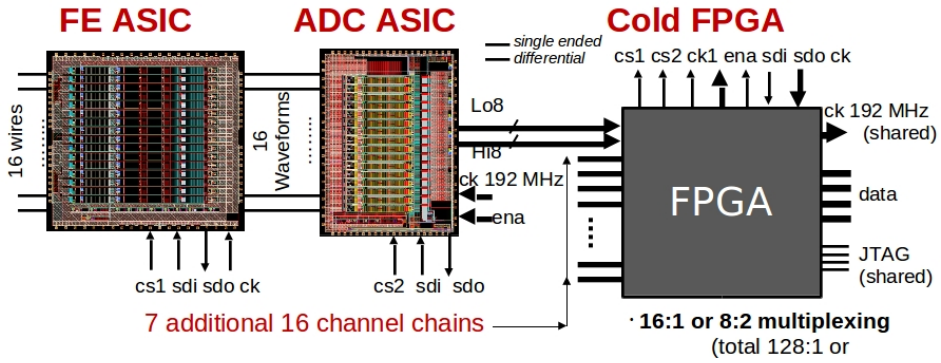
Bo Yu: L3 TPC Manager

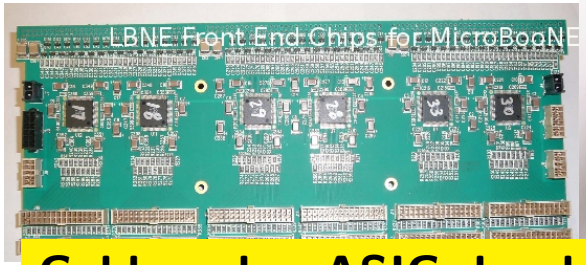
BNL leads field cage development: R. Sharma (ME), G. Mahler (ME) and A. Ruga (MD)

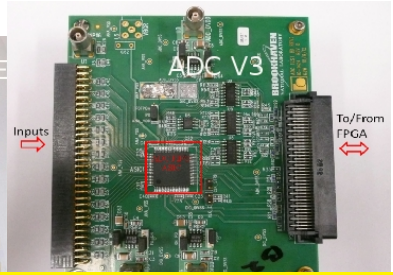
TPC static analysis: R. Sharma

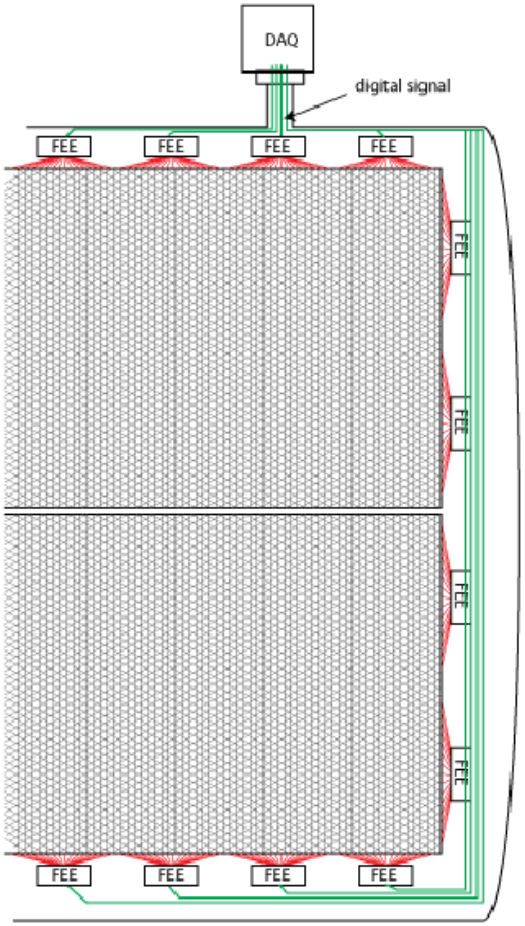
Cold Electronics for LBNE

Cryogenic highly multiplexed electronics with few digital output lines = reduced penetrations, enables modular TPC arrays with feedthroughs decoupled from electronics location.







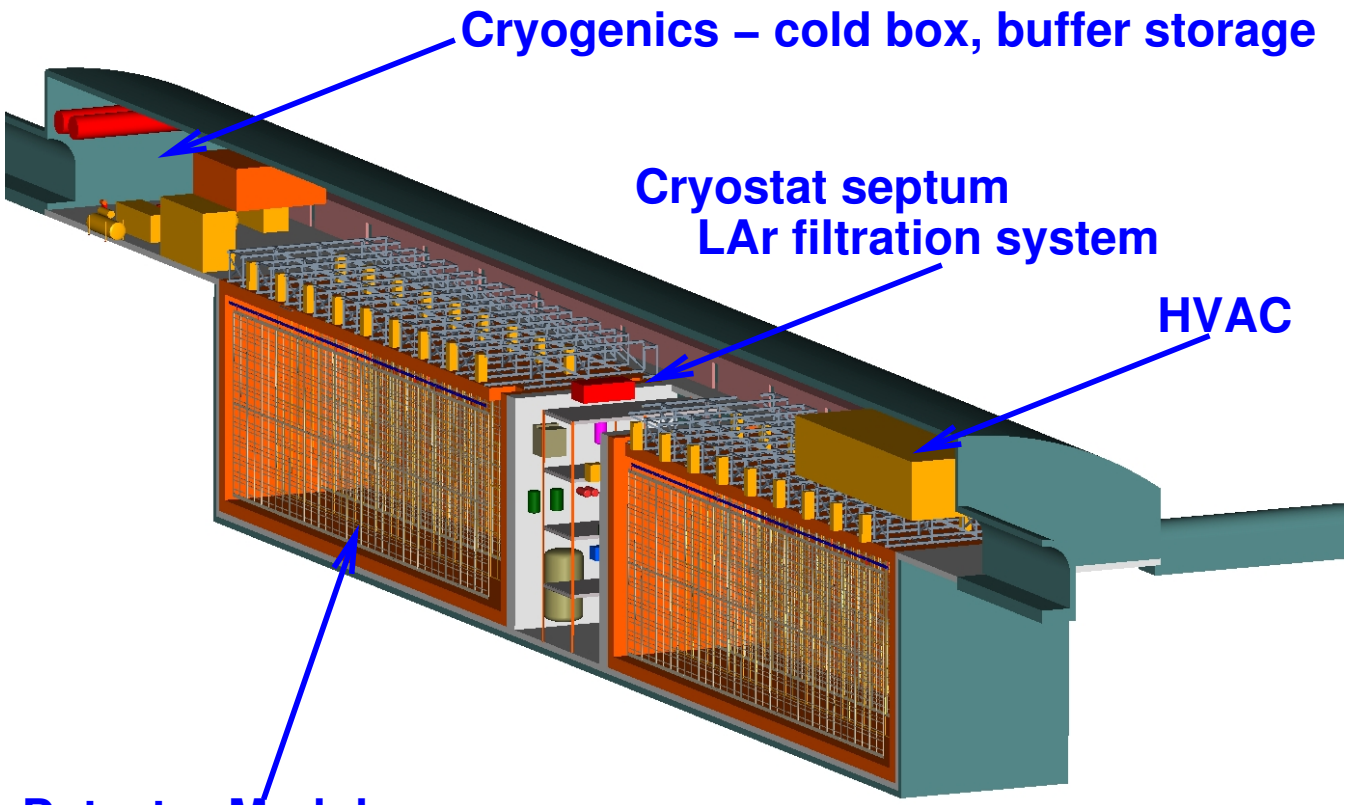


Cold analog ASIC development at BNL critical for LBNE

GOAL: produce FEE+ADC+FPGA prototype board this summer

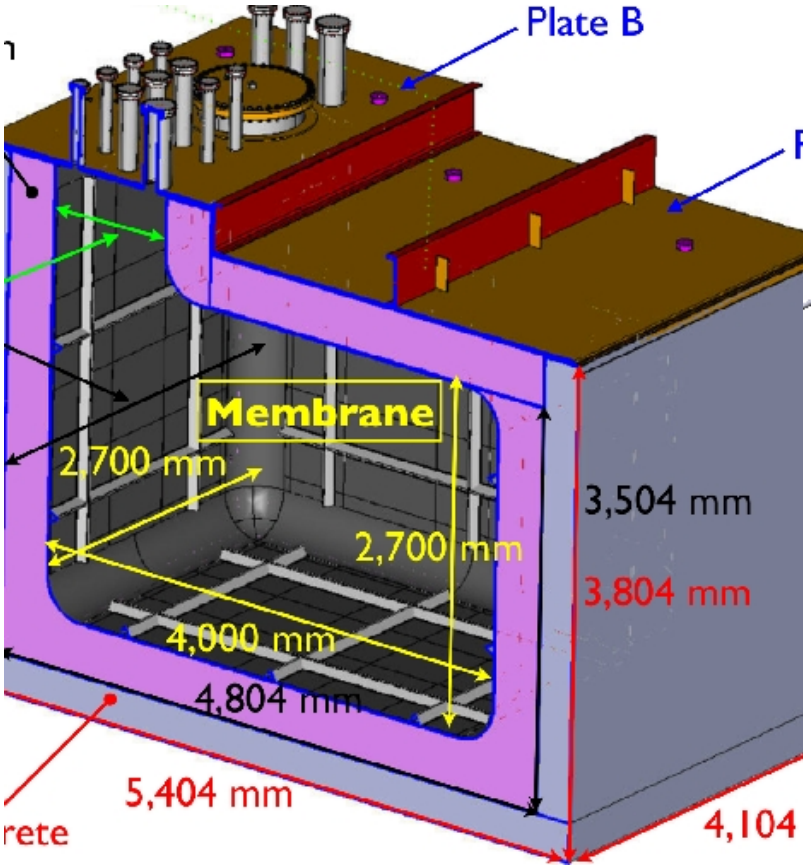
BNL Instrumentation: V. Radeka, G. De Geronimo, S. Li, N. Nambiar, J. Fried, E. Vernon. BNL Physics: H. Chen, C. Thorn

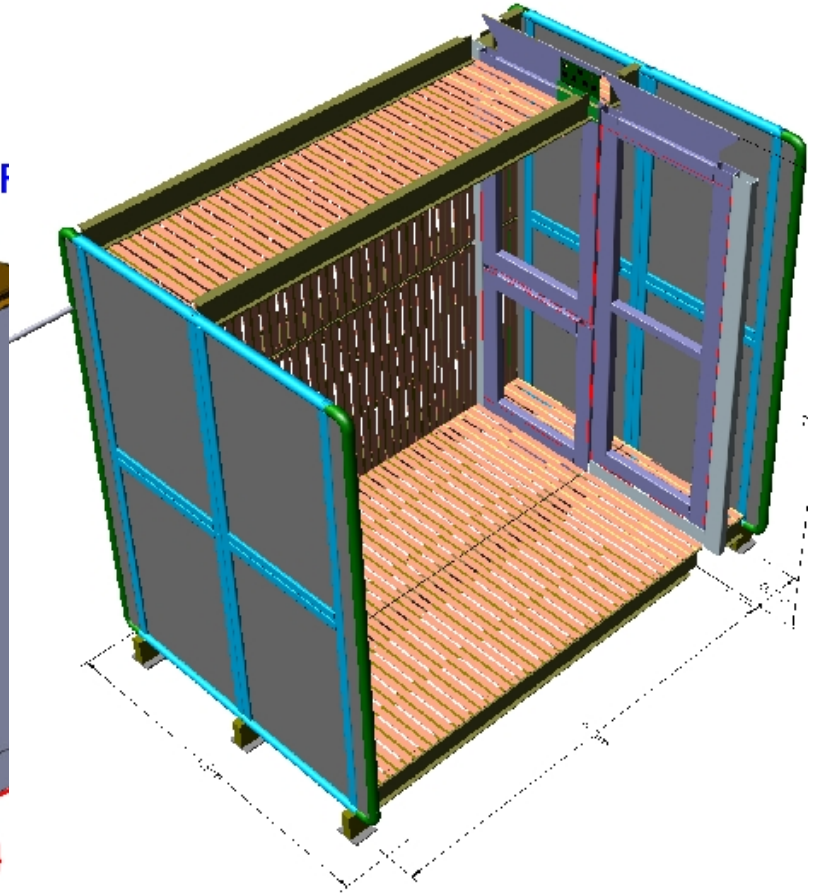
Conceptual design of 35 kTon Underground Detector



BNL modular TPC designs scaled up to LBNE full FD design

LBNE 35 Ton Prototype. Ready for data with cosmics late 2014





BNL responsible for TPC oversight, field cage construction and cold electronics.

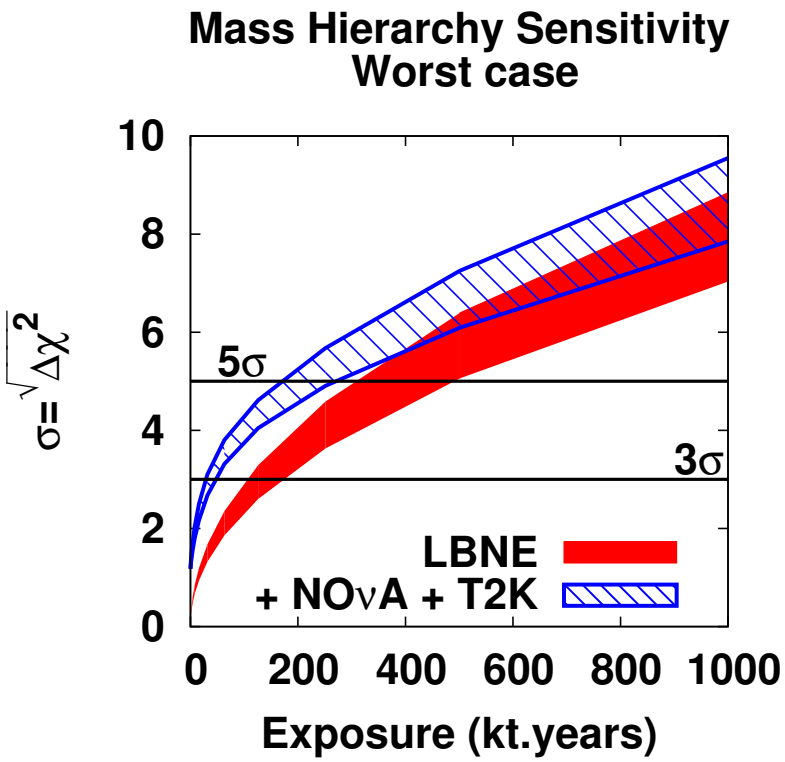
BNL scientific team (B. Viren, M. Potekhin, Z. Isvan, R. Hackenburg) assuming major roles in modeling, simulation and data analysis

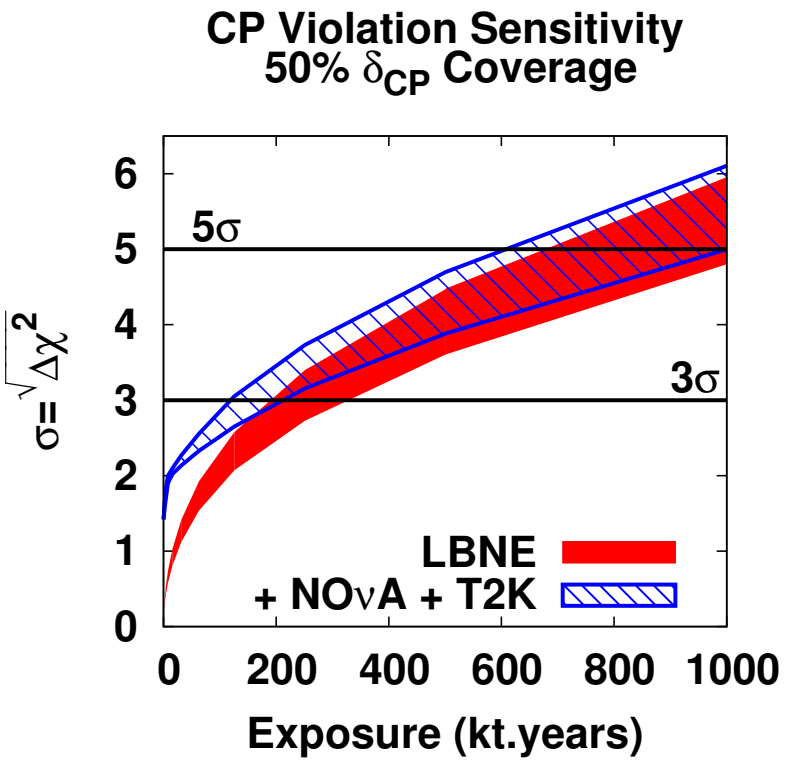
Co-ordinating with university groups

LBNE MH/CPV Sensitivities with 700kW Beam

E. Worcester, M. Bishai (BNL), M. Bass, W. Wilson, D. Cherdack (CSU)

NEW: modest beam improvements (band) = big impact on sensitivities





Need 100kt.yrs at 700kW to resolve MH with $\geq 3\sigma$

Need 200kt.yrs at 700kW to resolve CPV with $\geq 3\sigma$ for 50% δ_{cp}

M. Bishai (BNL) and S. Zeller (FNAL) long baseline physics working group co-conveners

Mass Hierarchy Studies

From BNL: J.J. Ling, C. Zhang, E. Worcester, (X. Qian joined BNL May 2013)

Statistical Evaluation of Experimental Determinations of Neutrino Mass Hierarchy

X. Qian,[1,*] A. Tan,[2,†] W. Wang,[3,‡] J. J. Ling,[4] R. D. McKeown,[5,3] and C. Zhang[4]
[1] *Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA*
[2] *Department of Statistics and Actuarial Science, University of Iowa, Iowa City, IA*
[3] *Physics Department, College of William and Mary, Williamsburg, VA*
[4] *Brookhaven National Laboratory, Upton, NY*
[5] *Thomas Jefferson National Accelerator Facility, Newport News, VA*
(Dated: December 6, 2012)

Statistical methods of presenting experimental results in constraining the neutrino mass hierarchy (MH) are discussed. Two problems are considered and are related to each other: how to report the findings for observed experimental data, and how to evaluate the ability of a future experiment to determine the neutrino mass hierarchy, namely, sensitivity of the experiment. For the first problem where experimental data have already been observed, the classical statistical analysis involves constructing confidence intervals for the parameter Δm^2_{32}. These intervals are deduced from the parent distribution of the estimation of Δm^2_{32} based on experimental data. Due to existing experimental constraints on $|\Delta m^2_{32}|$, the estimation of Δm^2_{32} is better approximated by a Bernoulli distribution (a Binomial distribution with 1 trial) rather than a Gaussian distribution. Therefore, the Feldman-Cousins ap
intervals.
constructe
supported
that quant
probability
mental resu
Illustration
the MH de

3 [hep-ph] 5 Dec 2012

Snowmass whitepaper

A Second Detector at an Off-axis Location to Enhance the Mass Hierarchy Discovery Potential in LBNE

X. Qian[1], J. J. Ling[2], R.D. McKeown[3], W. Wang[3], E. Worcester[2], C. Zhang[2]
[1]Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA
[2]Physics Department, Brookhaven National Laboratory, Upton, NY
[3]Colleage of William and Mary, Williamsburg, VA

NEW: Octant Sensitivity in LBNE

E. Worcester (BNL), J. Kopp (FNAL)

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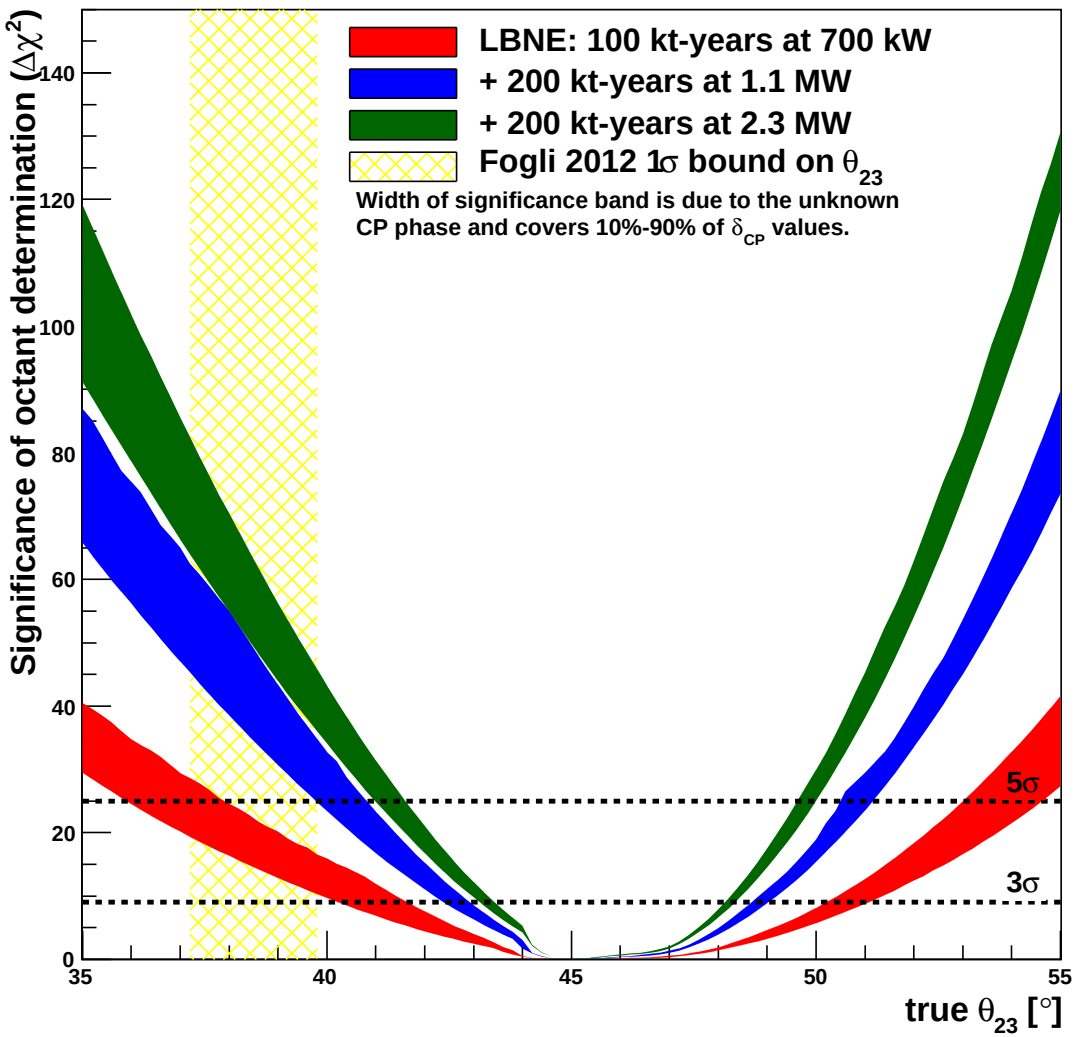
νs at BNL
MINOS/MINOS+
MicroBooNE
LBNE
Summary

Octant Sensitivity



Resolution of δ_{cp}: Comparison with other Proposals

M. Bishai, CSS2013 subgroup co-convener

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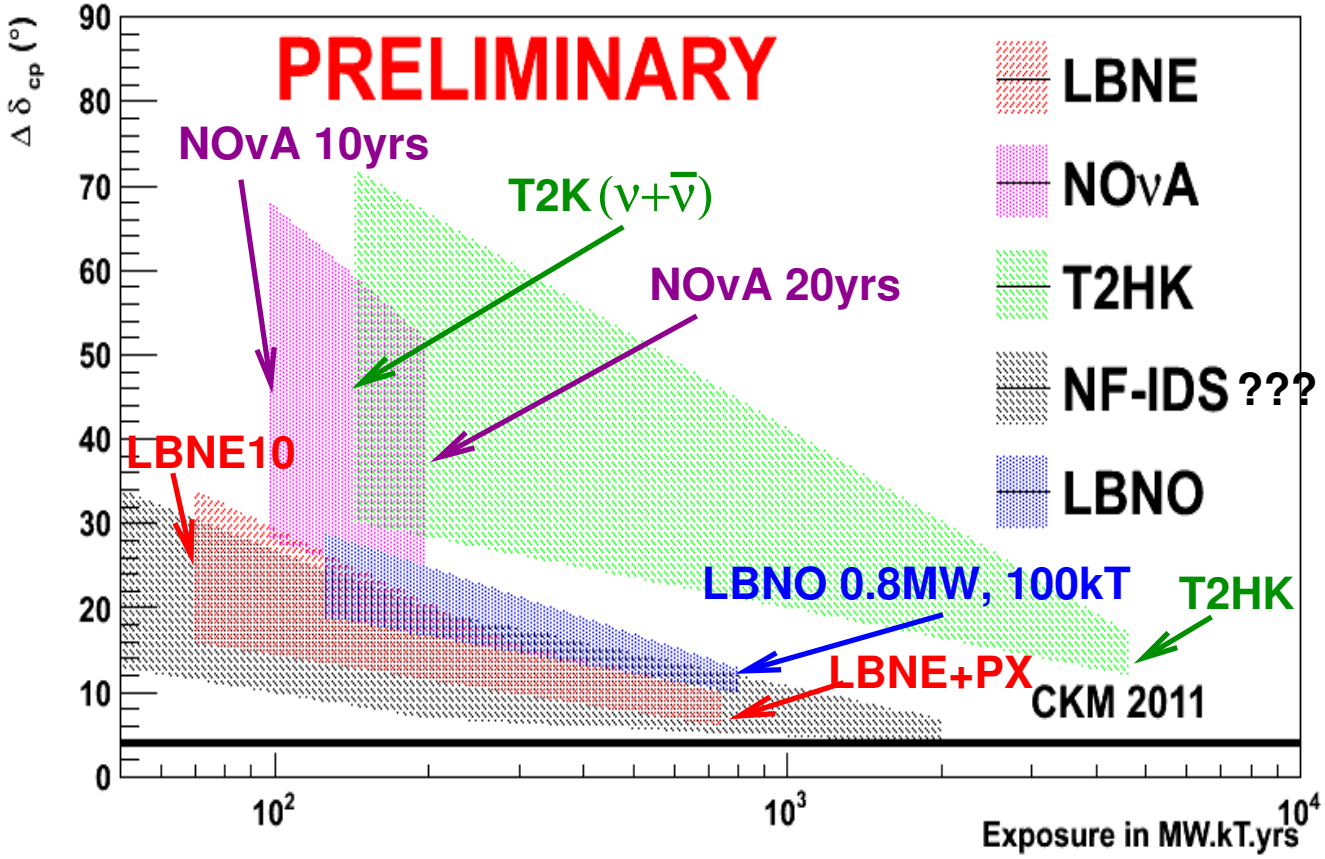
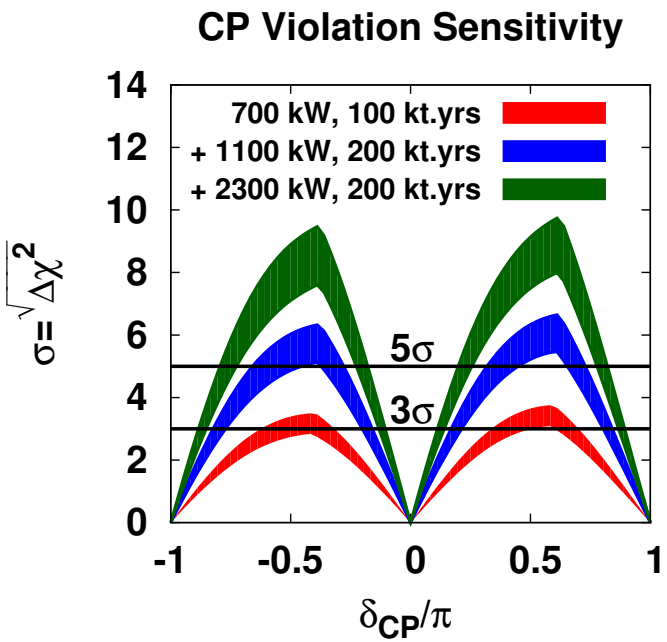
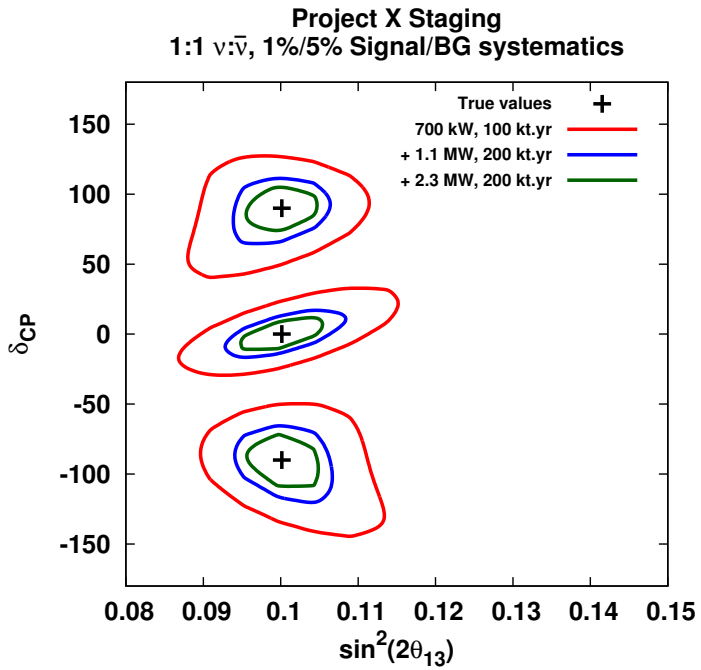
For Community Summer Study (AKA Snowmass) 2013:



Very long baseline superbeams (or NF) with MT.MW.yrs = CKM precision

LBNE and Project X





With sufficient exposure we can reach 5 – 10° resolution on δ_{cp}.

New initiatives with Project X: "Precision Neutrino Oscillation Measurements using Simultaneous High-Power, Low-Energy Project-X Beams" M.Bishai, M.Diwan, S.Kettell, J.Stewart, B.Viren, L.Whitehead, E.Worcester, BNL arXiv 1203.4090

Work is progressing at BNL on 2nd maximum CP measurements

Evolution of the Intensity Frontier at BNL

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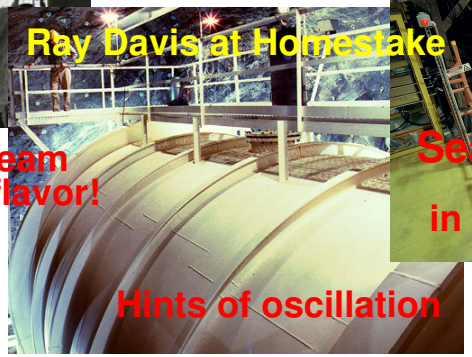
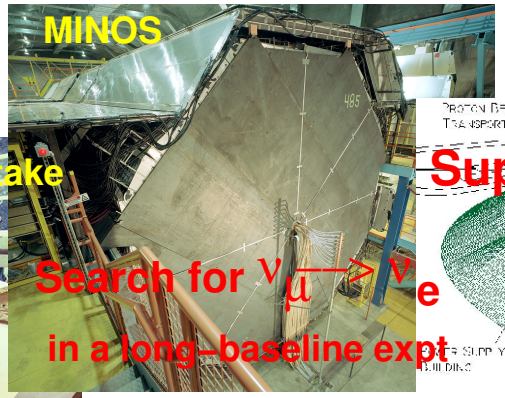
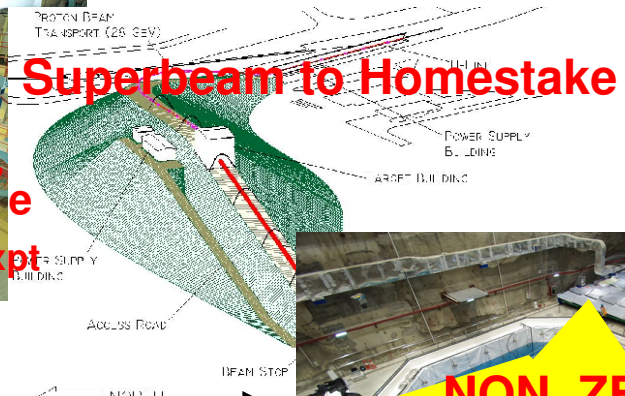
First neutrino beam
Neutrinos have flavor!



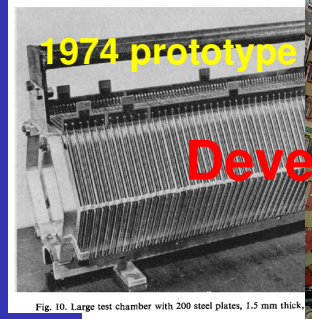
Hints of oscillation

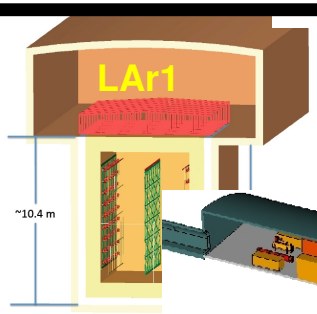


Search for $\nu_\mu \rightarrow \nu_e$ in a long–baseline expt

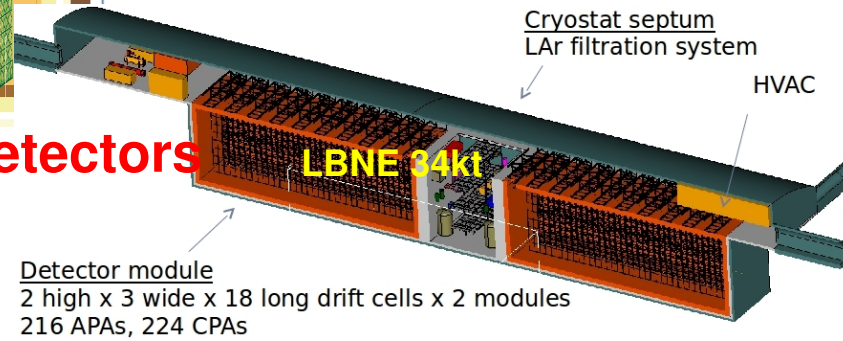


1960's → 2012





Development of massive LAr detectors



Intellectual and technical pioneers of ν experiments

Evolution of the Intensity Frontier at BNL

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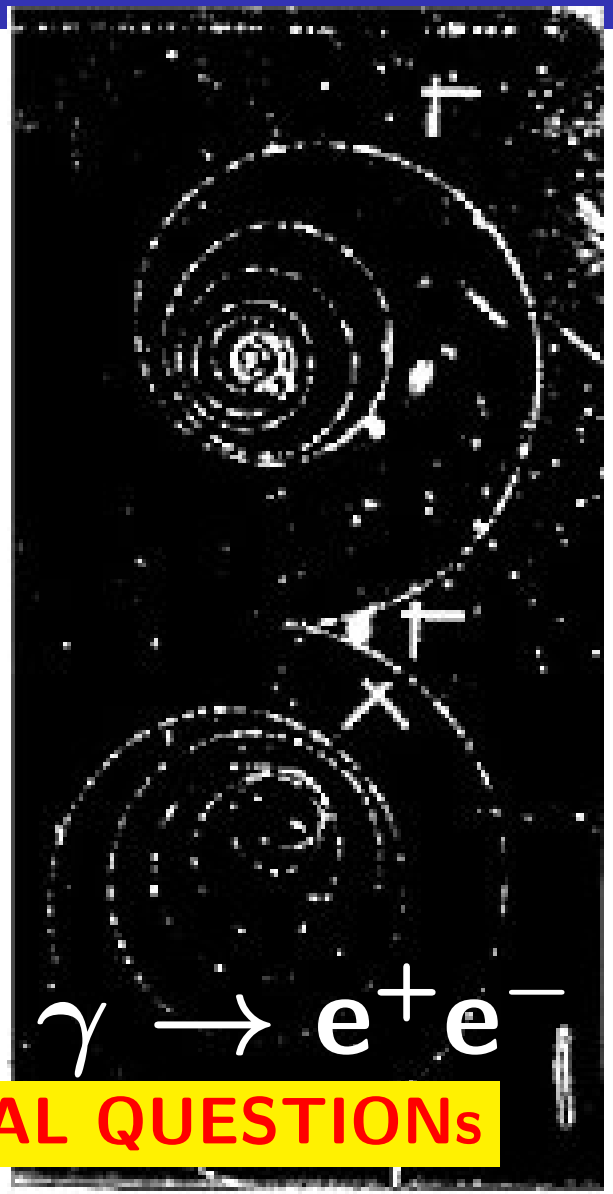
Is CP violated in the leptonic sector??



TO ANSWER FUNDEMENTAL QUESTIONs

BACKUP

NSIs and MINOS+

BNL at the Intensity Frontier: Accelerator Neutrinos
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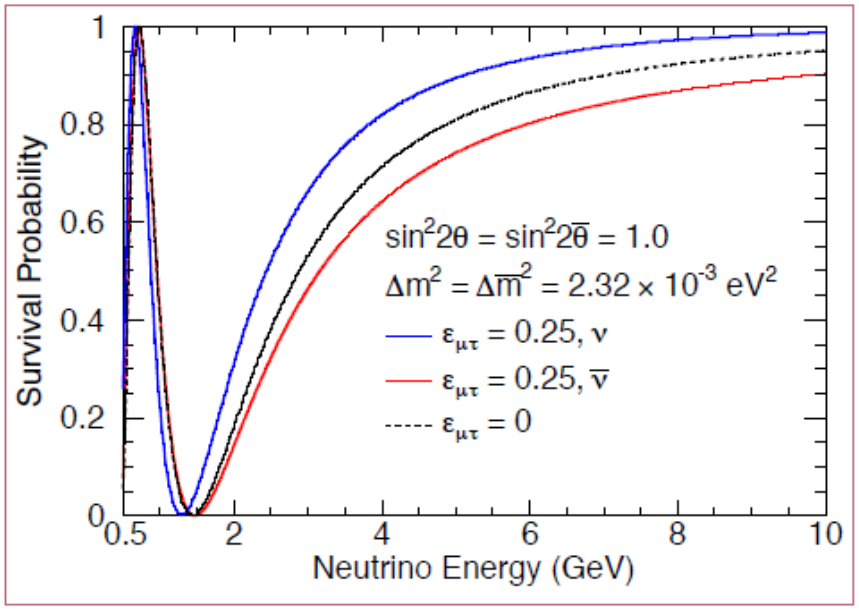
νs at BNL
MINOS/MINOS+
MicroBooNE
LBNE
Summary

- MINOS detectors will keep collecting data during NOvA operation.
- NuMI 'medium energy' beam ~5GeV
- Detectors are on axis and see a wide band.
- First two years, neutrino-mode: 10×10^{20} POT neutrino mode; antineutrino mode running to follow.
- With this data MINOS+ can improve standard oscillation results and NSI limits.

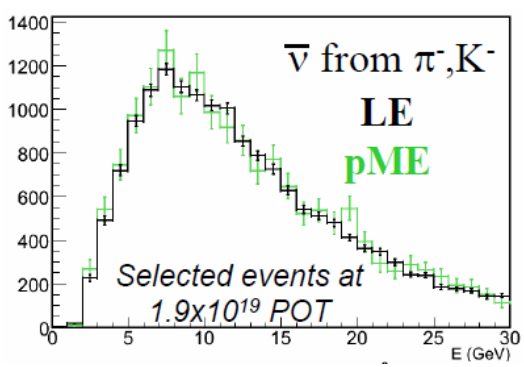


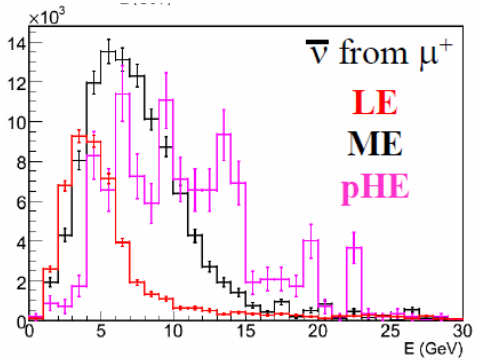
Measuring the beam ν_e using $\bar{\nu}_\mu$ in MINOS+

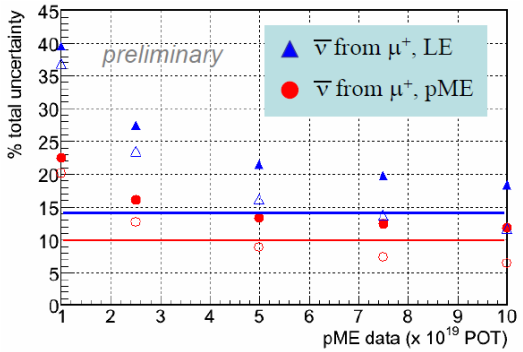
Technique developed by D. Jaffe (BNL) and P. Ochoa (Caltech) for MIN

- **The beam ν_e contamination in conventional ν_μ beams ultimately limits the sensitivity of ν_e appearance experiments.**
- **The ν_e contamination in the MINOS and LBNE signal region comes from $\pi^+ \rightarrow \nu_\mu \mu^+ \quad \mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$**
- **Constraining the $\bar{\nu}_\mu$ from μ constrains the beam ν_e flux.**

Difference in $\bar{\nu}_\mu$ between LE and pME are dominated by the $\bar{\nu}_\mu$ from μ







MINOS+ = enough ME stats. for a $< 20\%$ measurement of ν_e from μ^+

Will provide valuable info for constraining LBNE beam ν_e bkgd.

MINOS+ and LBNE

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νs at BNL
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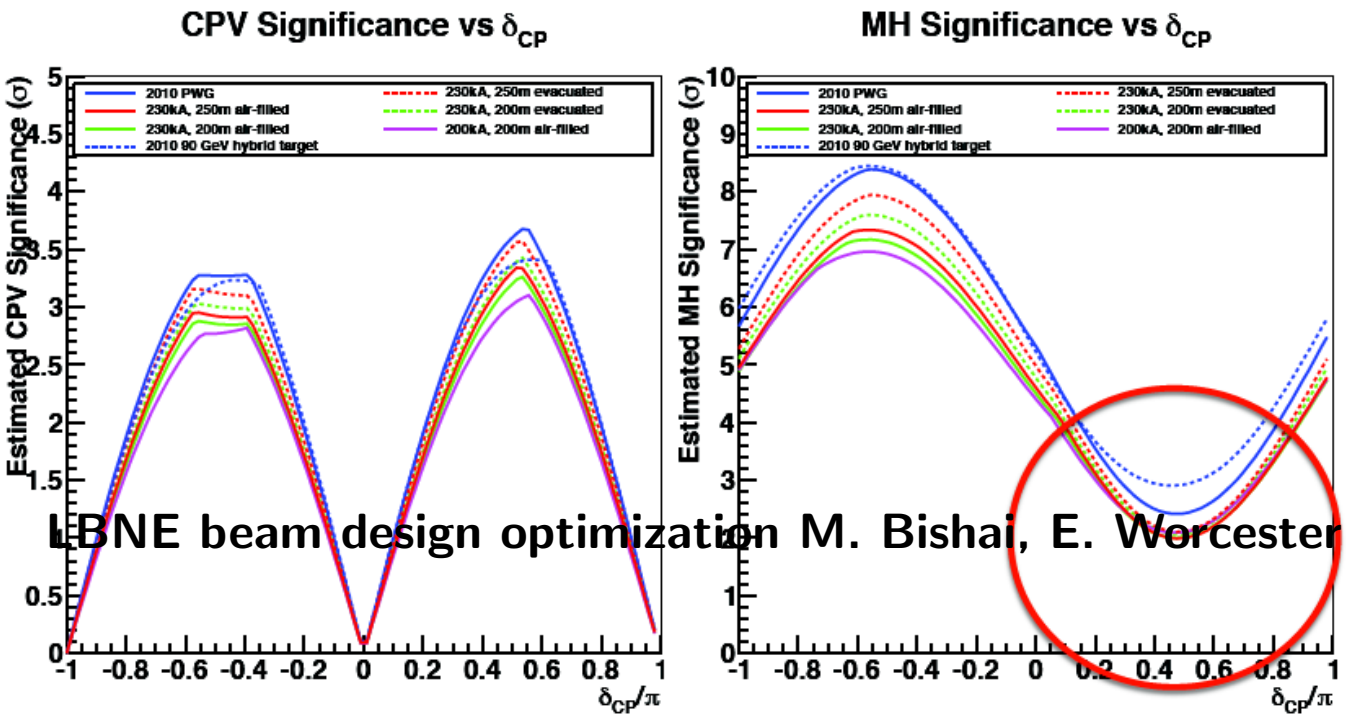
Summary

- **NuMI is the model for the LBNE beamline. Continue studies of the NuMI performance and beam systematics with the MINOS ND for LBNE optimization. Explore the impact of lowering the Main Injector beam energy on the neutrino spectrum:**



LBNE beam design optimization M. Bishai, E. Worcester

*90 GeV beam (with hybrid target) improves MH sensitivity for $\delta_{CP} > 0$ with small loss of CPV sensitivity