

# Neutrinos and Intensity Frontier Physics

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DOE review

6/9/2009



# Program at BNL

- E787/E949: analysis of past rare kaon decay data.
- MINOS: running of the MINOS experiment and analysis
- LBNE project: search for CP violation and precision measurements of neutrino parameters with a very large detector.
- MicroBooNE and development of large liquid argon TPC as part of LBNE.

# People

Project	BNL personnel
E787/949	Diwan, Jaffe, Frank, Kettell, Littenberg, Viren, (Zhe Wang)
MINOS	Bishai, Jaffe, Diwan, Viren, (Kevin Zhang, Lisa Whitehead)
LBNE	Bishai, Diwan, Kettell, Littenberg, Stewart, Viren
MicroBooNE/ LArTPC	Lanni, Lissauer

Postdocs in parenthesis

# Collaborators

Project	Collaborating Institutions	Recent collaborative work with BNL participation (partial list)
E787/949	NDA(Yokosuka), Osaka, Fukui, Alberta, INR(Moscow), IHEP(Protvino), KEK(Japan), Kyoto, FNAL, BritishColumbia, TRIUMF, New Mexico, Princeton, BNL	Analysis of PNN2 (PRL101.191802) PRD pnn1 PRD pnn2
MINOS	Argonne, Athens, Benedictine, CalTech, Cambridge, IF-UNICAMP, Paris-7, FNAL, Harvard, Illinois, Indiana, ITEP, Lebedev, LLNL, London, Minnesota, Oxford, Pittsburgh, RAL, Sao Paulo, South Carolina, Stanford, Sussex, Texas A&M, UT-Austin, Tufts, Warsaw, Western Washington, William & Mary, BNL	Systematics of beam, Muon disappearance analysis, Electron appearance analysis, anti-numu analysis offaxis miniboone
LBNE	Wisconsin, FNAL, Michigan State, Yale, Boston, StonyBrook, Colorado, UPenn, LBL, Columbia, Minnesota, Kansas, York, Princeton, Indiana, Utah, Catania, Iowa, Colorado-state, Wurzburg, William&Mary, UCLA, LLNL, Orsay-LAL, Orsay-IPN, Tokyo, Irvine, Davis, Duke, Drexel, Maryland, RPI, BNL... and Growing	US longbaseline study, proposal for Homestake Water Cherenkov Detector, Depth report
MicroBoone/ LAR	Yale, FNAL, LANL, Columbia, MIT, Michigan State, Princeton, St. Mary's, UCLA, Cincinnati, UT-Austin, BNL	MicroBoone Proposal. CDR prep. Electronics development.

# E787/E949

- All analysis on  $K^+ \rightarrow \pi^+ \nu \bar{\nu}$  anti- $\nu$  is now complete.
- One of the most important tests of the Standard Model. (GIM suppressed FCNC process)
- We have found 7 events with varying levels of backgrounds. The probability that all events are backg. is  $10^{-3}$
- Branching ratio measurement

$$\mathcal{B}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) = (1.73_{-1.05}^{+1.15}) \times 10^{-10}$$

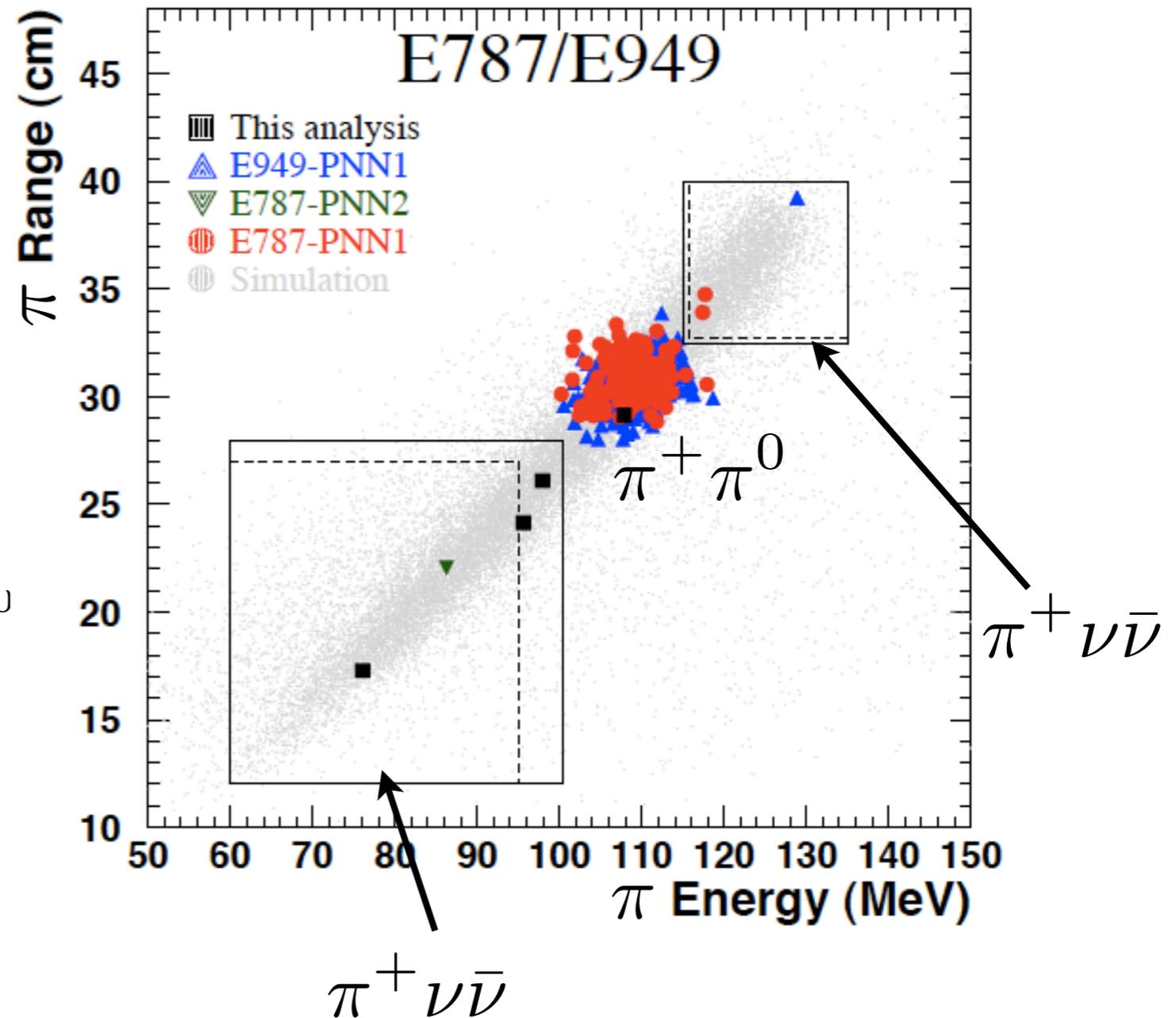
PRL 101: 1918021, 2008

PRD 77: 052003, 2008

arXiv:0903:0030, 2009

3 recent Ph.D. thesis

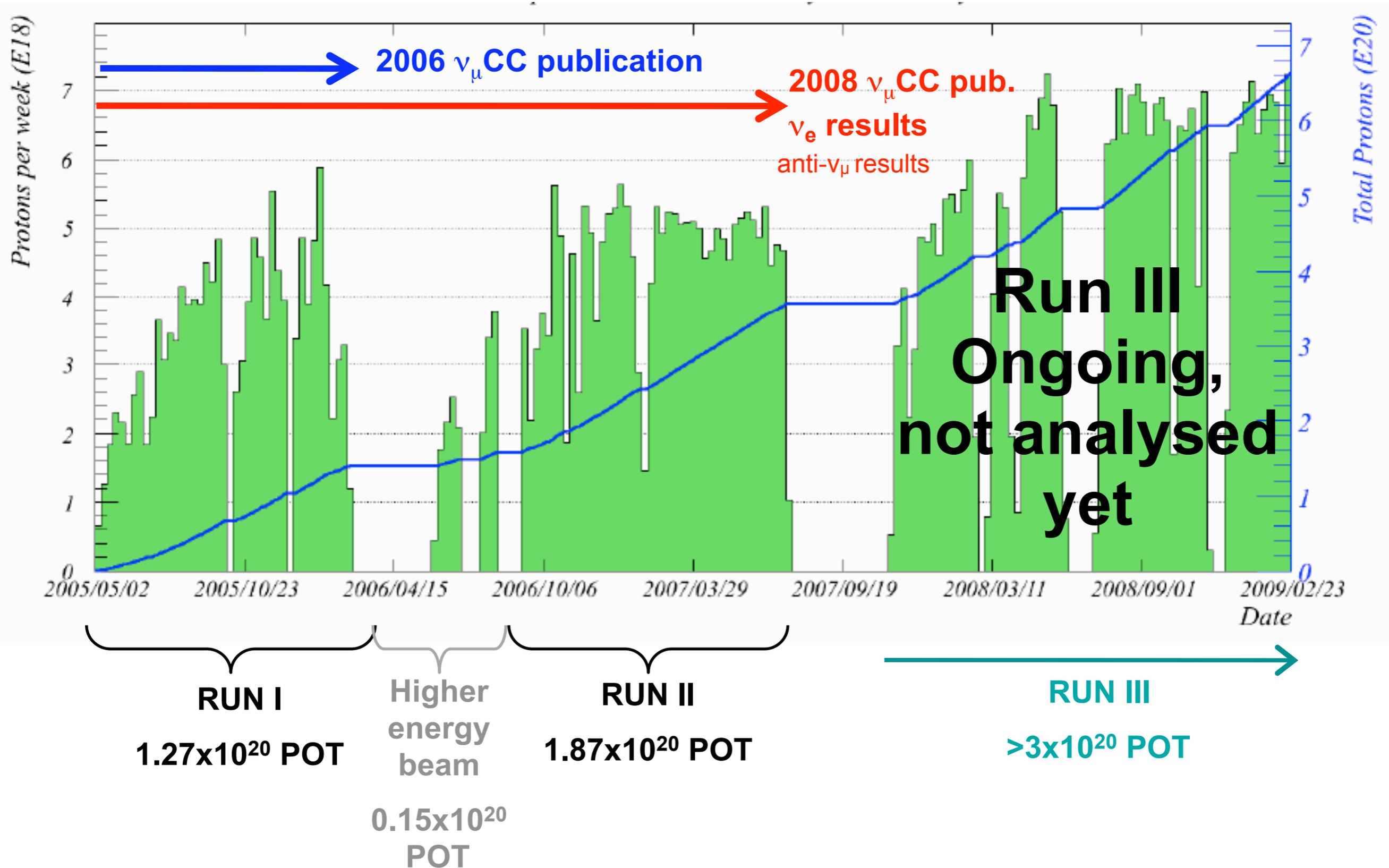
Referee: ... surely the most relevant experimental result in kaon physics in the past ten years.



# MINOS 2006-2009

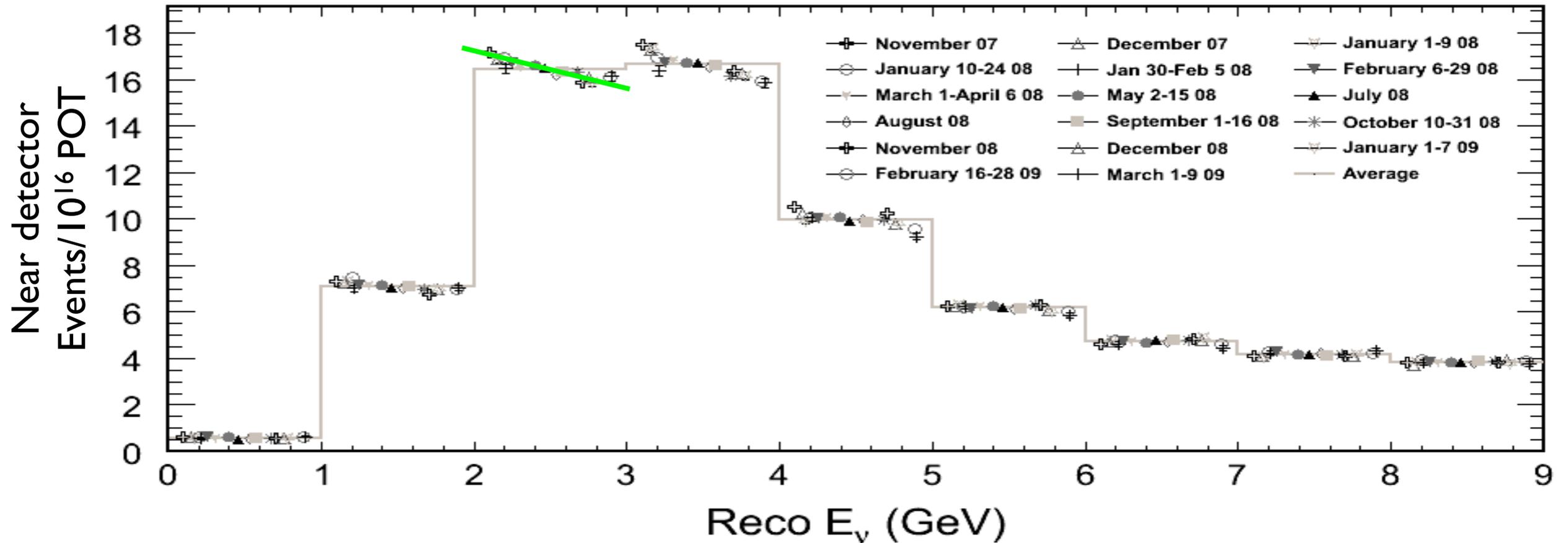
- We were very active in the commissioning of MINOS.
- We are key repository of knowledge on the experiment's software structure and beam monitoring.
- We have participated in many analysis groups, including leadership of the beam systematics group and the nue analysis group.
- Papers on nue and anti-numu being prepared.

# Accumulated Beam Data



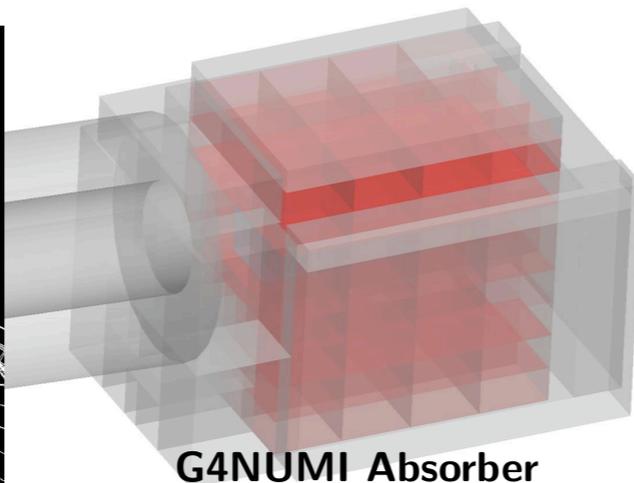
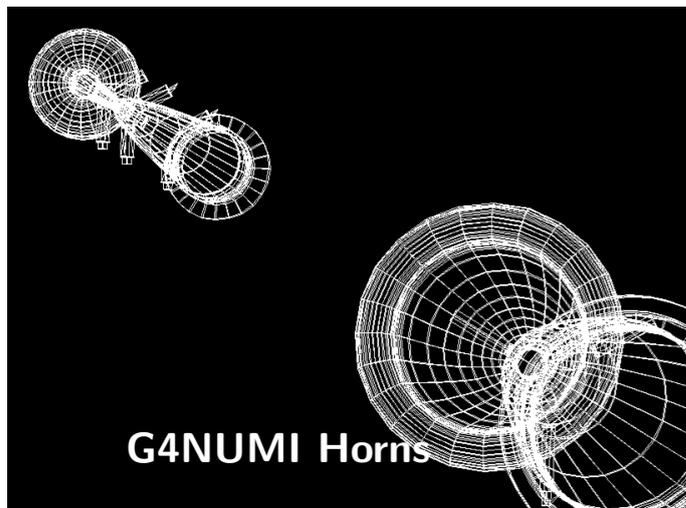
# MINOS Beam Work

## Neutrino Energy Spectrum Stability



FLUGG = G4NuMI geometry + FLUKA08 unified interaction/focusing simulation

- Slow decrease in event rate seen at the peak, perhaps due to target degradation.
- Extremely precise simulation work now in progress.
- Will be based on data
- Will have broad applicability.



Mary Bishai is co-convener of this group

# $\nu_\mu$ disappearance result

- See strong energy dependent distortion of spectrum
- Prediction using near detector data. No osc.: 1065 $\pm$ 60
- Observation is 848
- Energy spectrum fit with the

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2(2\theta) \sin^2\left(\frac{1.27\Delta m^2 L}{E}\right)$$

Best measurement with 1/2 the expected data.

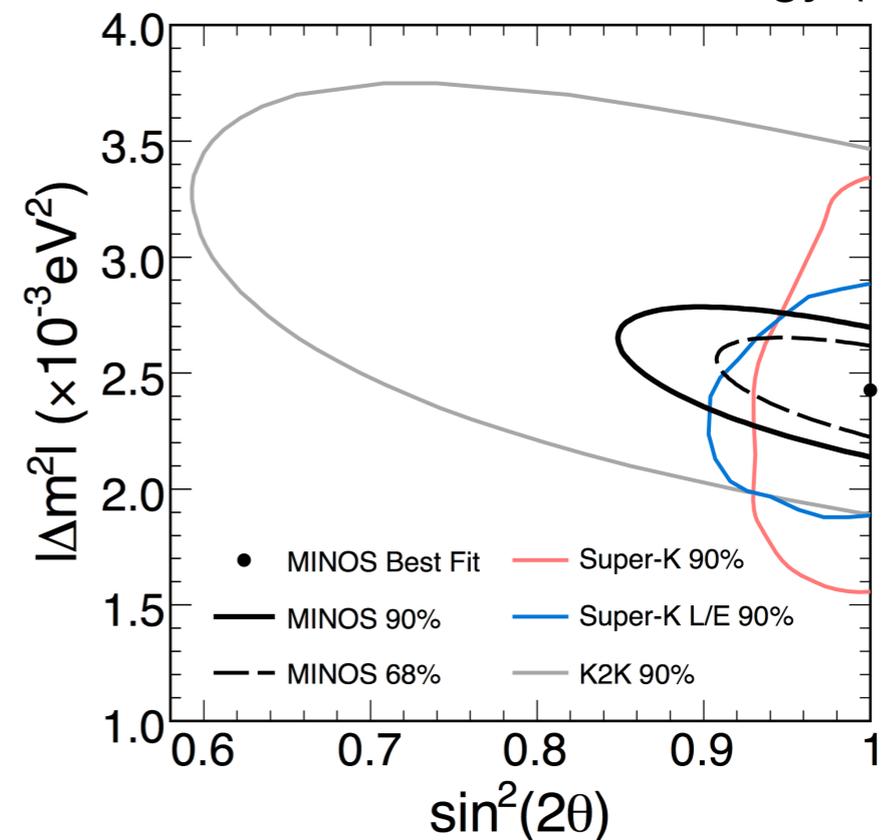
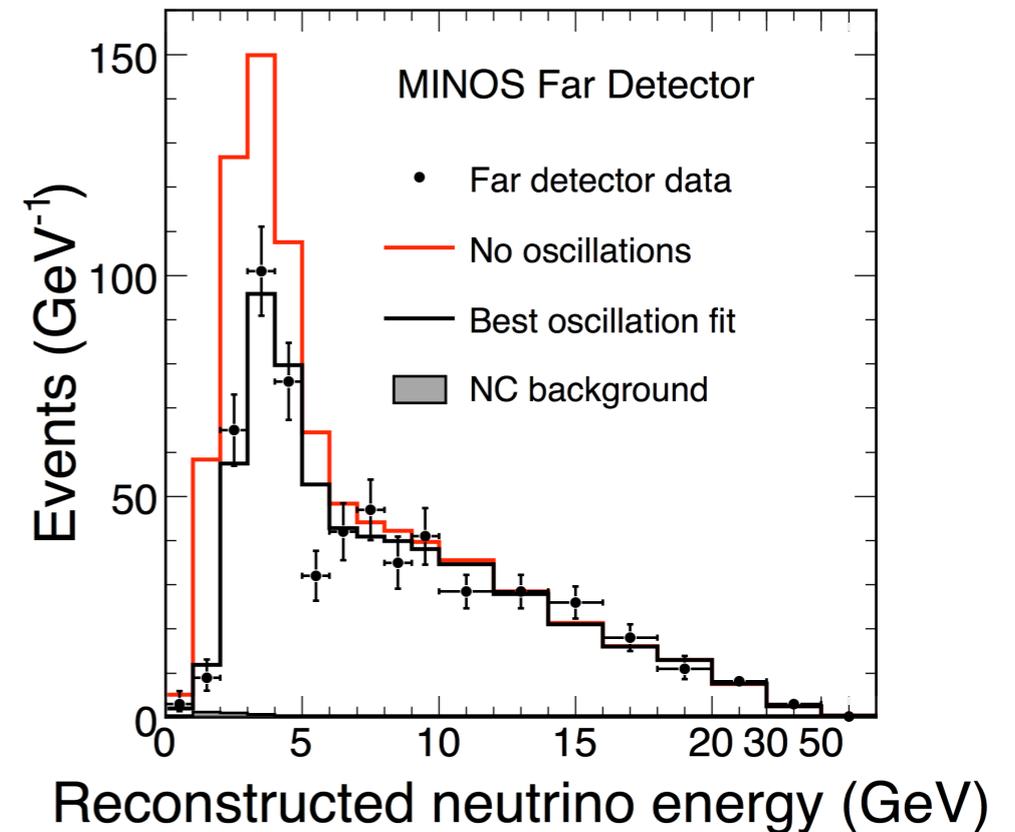
$$|\Delta m^2_{32}| = (2.43 \pm 0.13) \times 10^{-3} \text{ eV}^2$$

at 68% C.L.

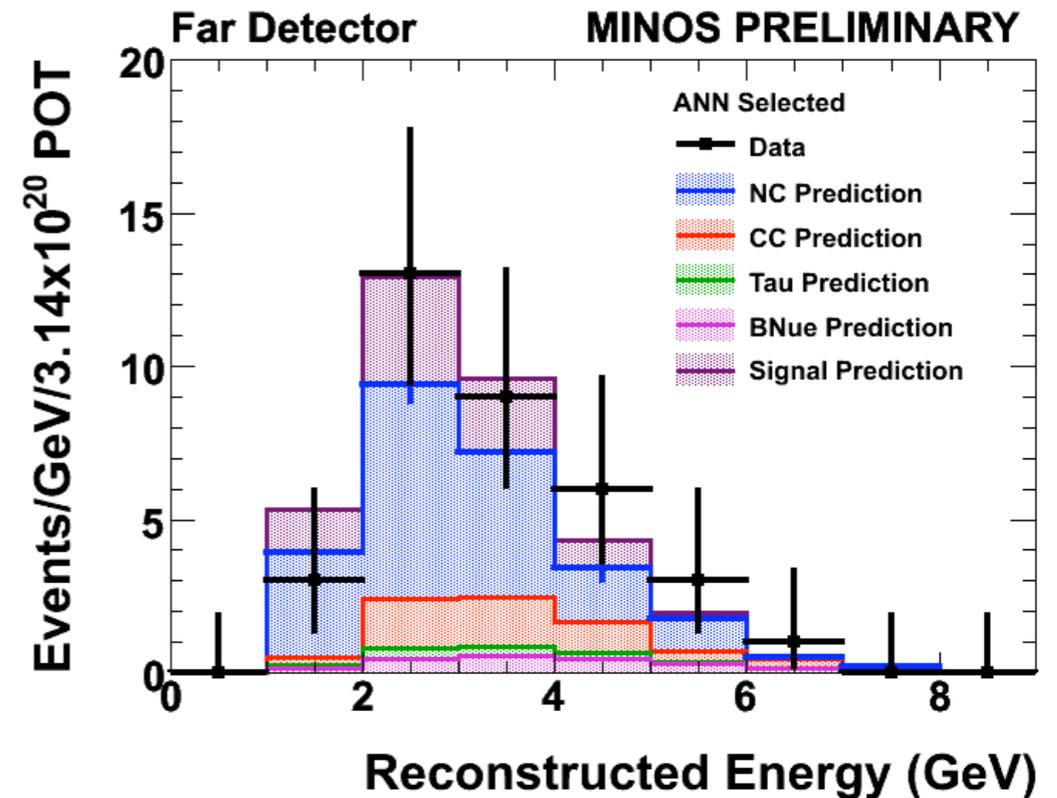
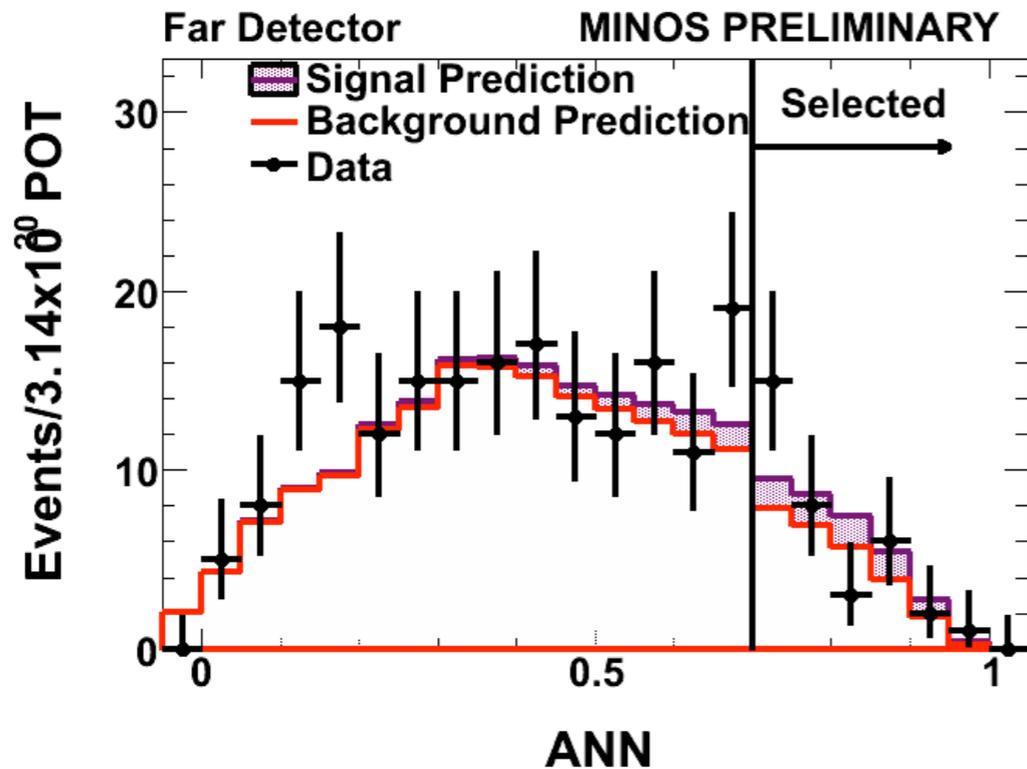
$$\sin^2(2\theta_{23}) > 0.90$$

at 90% C.L.

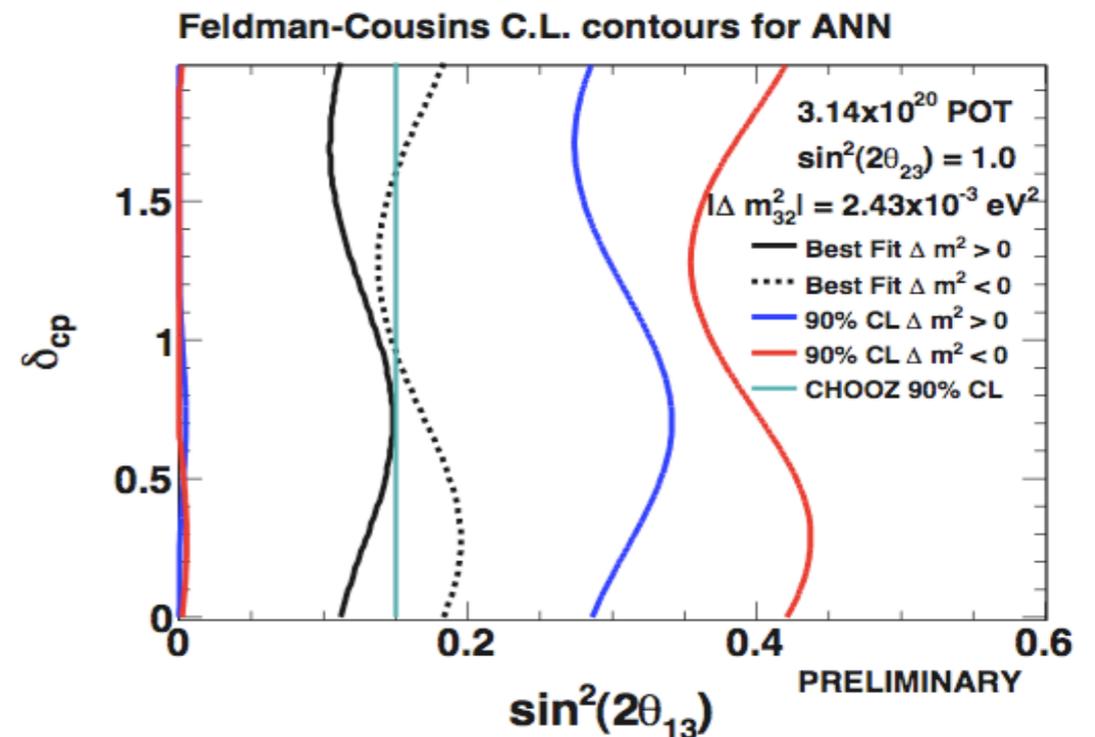
PRL 101 131802. Credit goes to the entire MINOS team, esp. FNAL acc. division.



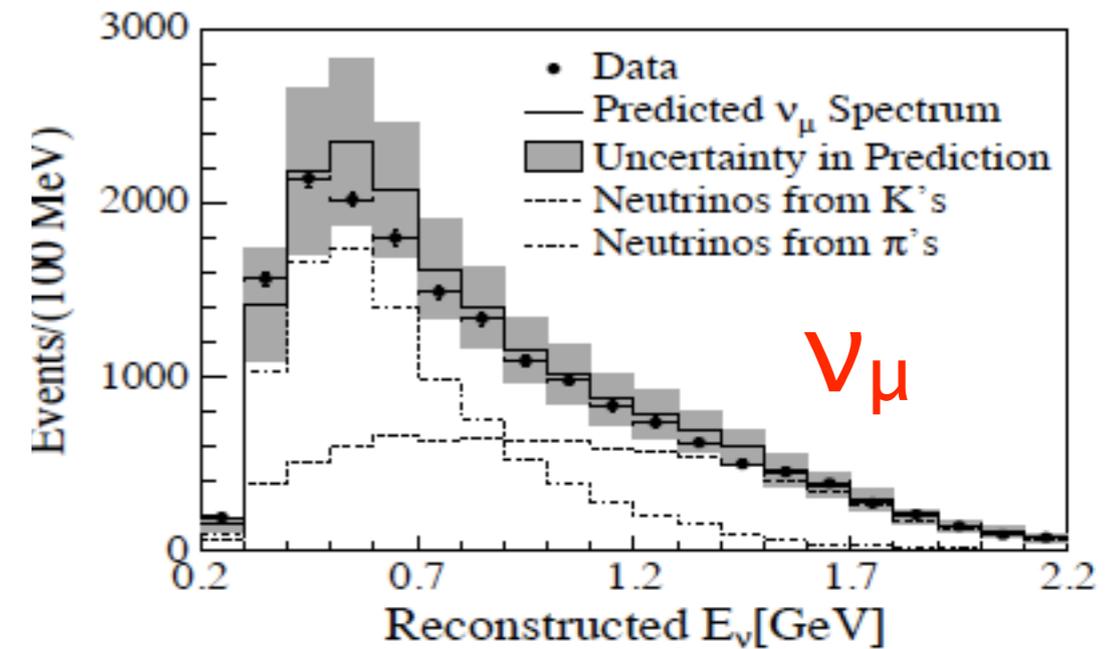
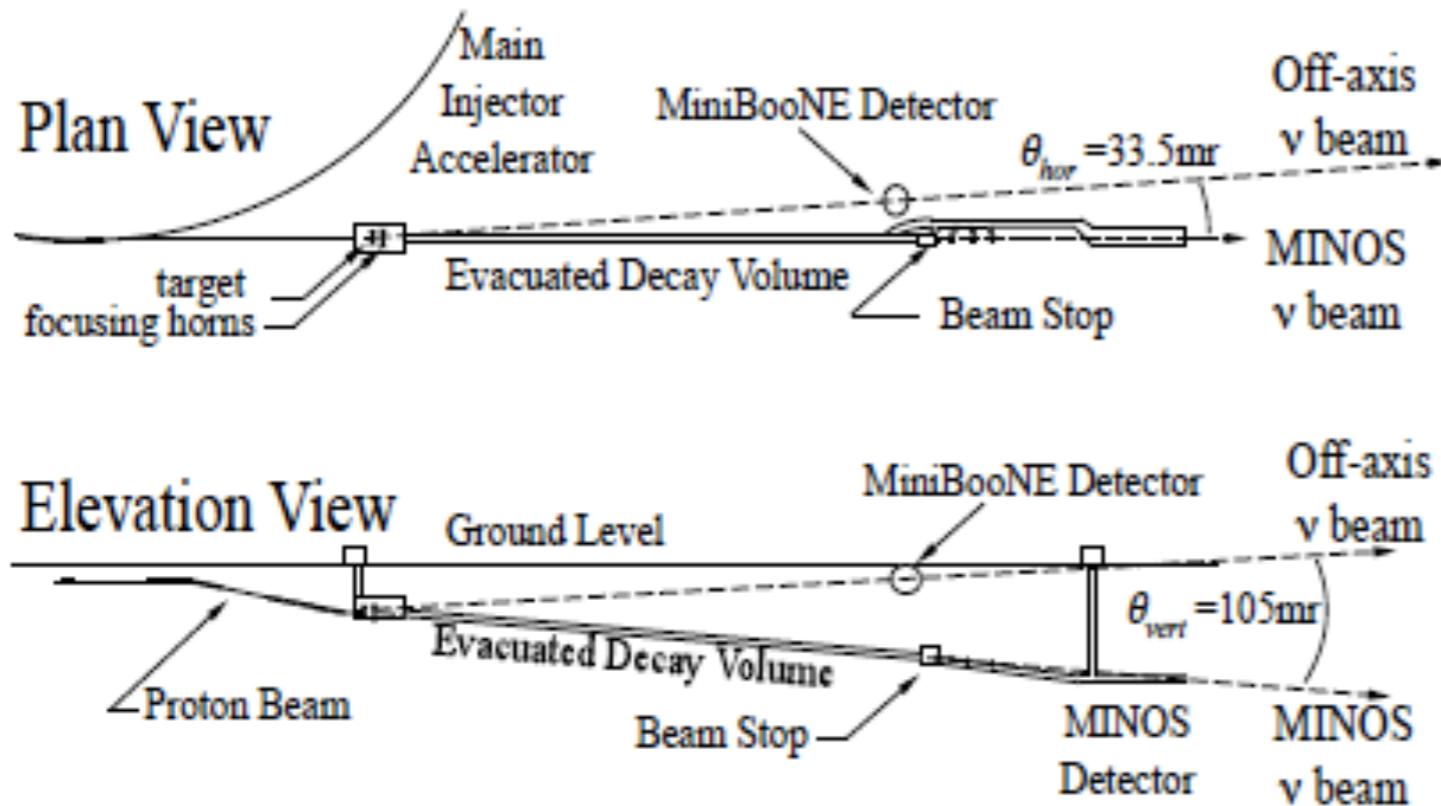
# MINOS $\nu_e$ appearance



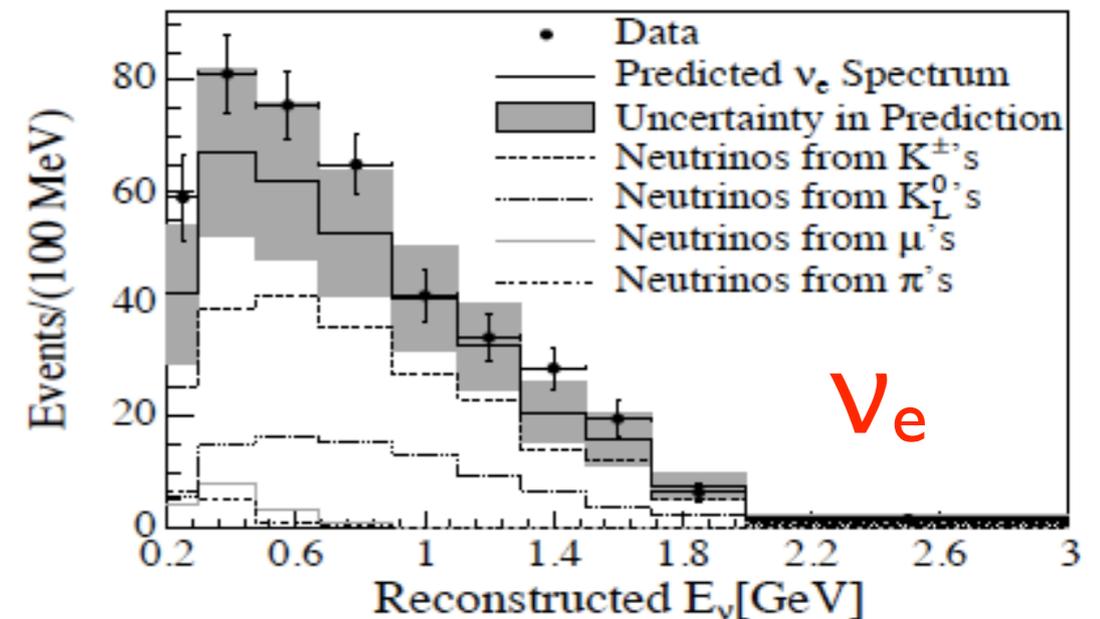
- Analysis on 1/2 of the MINOS data is complete. Paper in preparation.
- Analysis has generated a number of new and unique ideas. 5-6 theses with unique intellectual contributions.
- More data and further improvements are expected.
- Diwan has been involved in this analysis since the beginning. (co-convenor 2003-2008).
- Lisa Whitehead is a key person in the analysis from BNL.



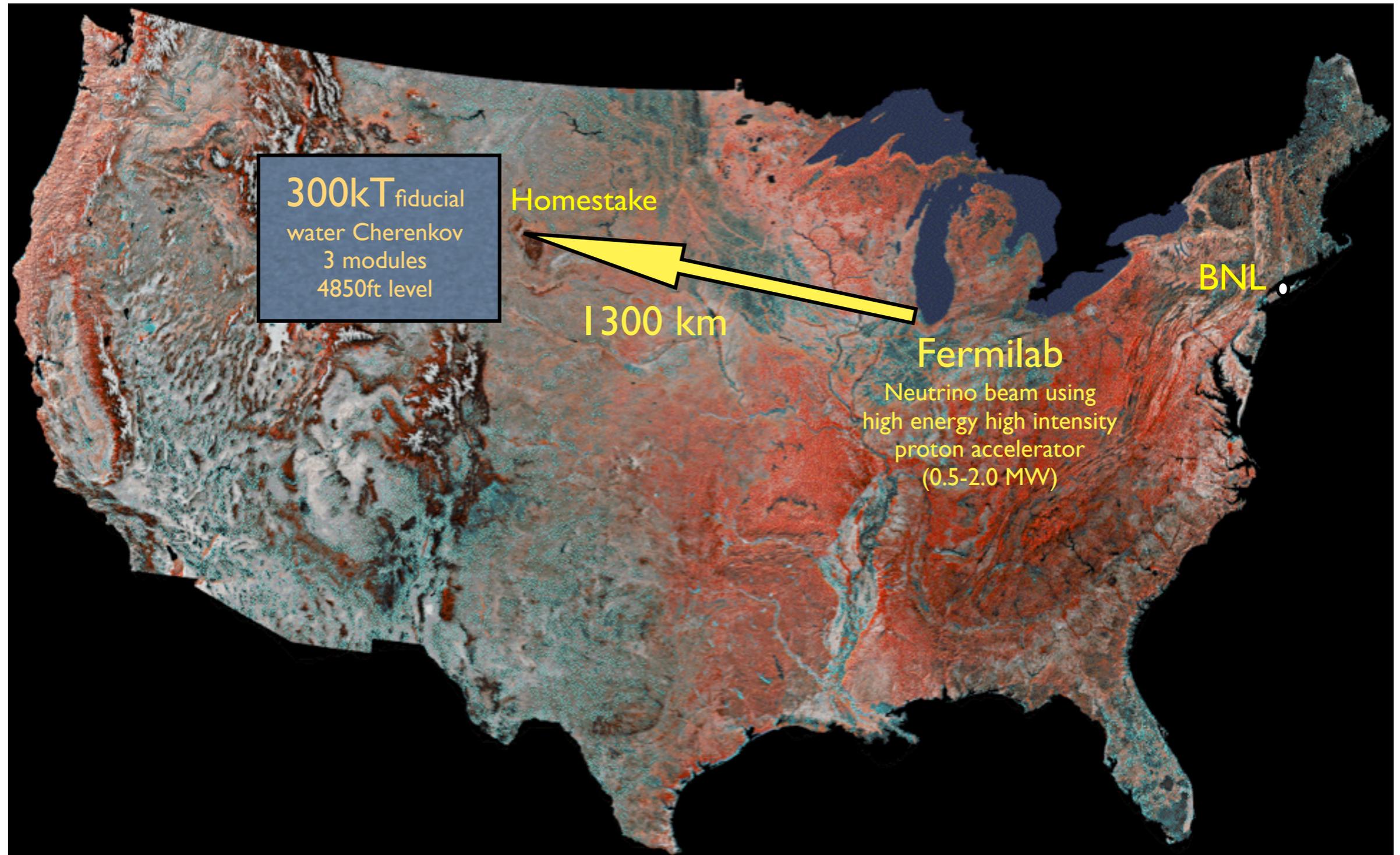
# Off-axis miniboone



- Opportunistic physics. Neutrinos at  $\sim 110 \text{ mrad}$ .
- BNL contribution to this analysis was the beam information including timing and normalization.
- PRL102 211801.
- First analysis of such off-axis neutrinos.
  - Off-axis technique was first proposed for BNL-E889 in 1995 BNL-52459, April 1995.



# New Initiative: Long Baseline Neutrino Experiment (LBNE)



# LBNE development

Documents	Workshops and reviews
<p> <a href="#">NNN99</a> proceedings, editors C.K. Jung and M. Diwan  <a href="#">Extra longbaseline...</a>, V.Marciano, <a href="#">arXiv:hep-ph/0108181</a>, Aug2001            D. Beavis, et al., <a href="#">hep-ex/0205040</a>, 2002  <a href="#">Very longbaseline...</a>, M. Diwan, et al., <a href="#">BNL69395</a>, <a href="#">hep-ex/0211001</a>            Megaton Modular..detector, M. Diwan, <a href="#">hep-ex/0306053</a>, 2003            Int. J. Mod. Phys. A18:4039,2003            Phys. Rev. D 68: 012002,2003         </p>	<p>           NNN99, <a href="#">NUSL workshop in Lead Oct2001</a>,  <a href="#">NESS2002</a>, <a href="#">StonyBrook 2002</a>, <a href="#">HQL2004</a> <b>Initial ideas</b>            Presentation to SAGENAP, March 12, 2002         </p>
<p> <a href="#">The AGS based superneu...</a>, Alessi et al., <a href="#">BNL-73210-2004-IR</a>,2004            The case for a superneu..., M.Diwan, <a href="#">hep-ph/0407047</a>            Spectrum...,S.Kahn, <a href="#">PAC-2005-RPPT059</a>, 2005.            FNAL Proton driver, <a href="#">hep-ex/0509019</a>            Neutrino Matrix Report, 2004.            Backg. study..., Yanagisawa et al., <a href="#">AIP conf. proc. 944:92-106</a>, 2007.         </p>	<p>           PAC2003, NuFACT05, FNAL proton driver workshop 2004            APS multi-divisional study: Joint BNL/UCLA/APS workshop,            Snowmass2004,            BNL/UCLA workshop 2004, 2005. <b>Development</b>            PAC2005            HEPAP Future Facilities Subcommittee, Feb. 2003         </p>
<p>           Preliminary cost &amp; design..., <a href="#">BNL-76798-2006-IR</a>, <a href="#">hep-ex/0608023</a>  <a href="#">US longbaseline study...</a> <a href="#">FNAL-0801</a>, <a href="#">BNL-77973</a>, <a href="#">arXiv:0705.4396</a>            NSF Homestake S1, S2, S3 proposals.            NSF S4 proposal for detector development.            Report on depth..., <a href="#">BNL-81896-IR</a>, <a href="#">FNAL-TM-2424</a>, <a href="#">LBNL-1348E</a>  <a href="http://nwg.phy.bnl.gov/fnal-bnl">http://nwg.phy.bnl.gov/fnal-bnl</a> </p>	<p>           NNN series of workshops, NUFACT workshops,            UDIG 2008 workshop,            DUSEL workshops, US long baseline study meetings,  <a href="#">Homestake PAC, 2006</a>, <a href="#">BNL PAC 2006</a>  <a href="#">NUSAG, 2006</a>, <a href="#">HEPAP 2006, 2007</a>            P5 committee Feb, 2008 <b>Proposal</b> </p>

**BNL group has had a leading role at every stage**

Not a complete list

# Work on Oscillation Sensitivity

*Physics sensitivity with WCe,  $3\sigma$  for all  $\delta_{cp}$  ( $\theta_{13}$ , hier)/50%  $\delta_{cp}$  (CPV)*

Beam	Det size (FIDUCIAL)	Exposure $\nu + \bar{\nu}$	bkgd uncert	$\sin^2 2\theta_{13}$	$\text{sign}(\Delta m_{31}^2)$	CPV
NuMI/HStake 120 GeV 9mrad off-axis	100kT	700kW 2.6+2.6yrs	5%	0.018	0.044	> 0.1
	100kT	1MW 3+3yrs	5%	0.014	0.031	> 0.1
	300kT	1MW 3+3yrs	5%	0.008	0.017	0.025
	300kT	1MW 3+3yrs	10%	0.009	0.018	0.036
	300kT	2MW 3+3yrs	5%	0.005	0.012	0.012
	300kT	2MW 3+3yrs	10%	0.006	0.013	0.015

**NB: Flux at 1st oscillation maximum has increased by 25% since these calculations**

- Detector has a broad science agenda. BNL will continue to refine the long baseline science plan.
- Physics can start with 100 kT and 0.7 MW (for mass hierarchy)
- But CP studies need the full detector and high power.
- The scale of the experiment does not depend on the exact distance or value of  $\theta_{13}$ , as long as it is high enough to beat background.

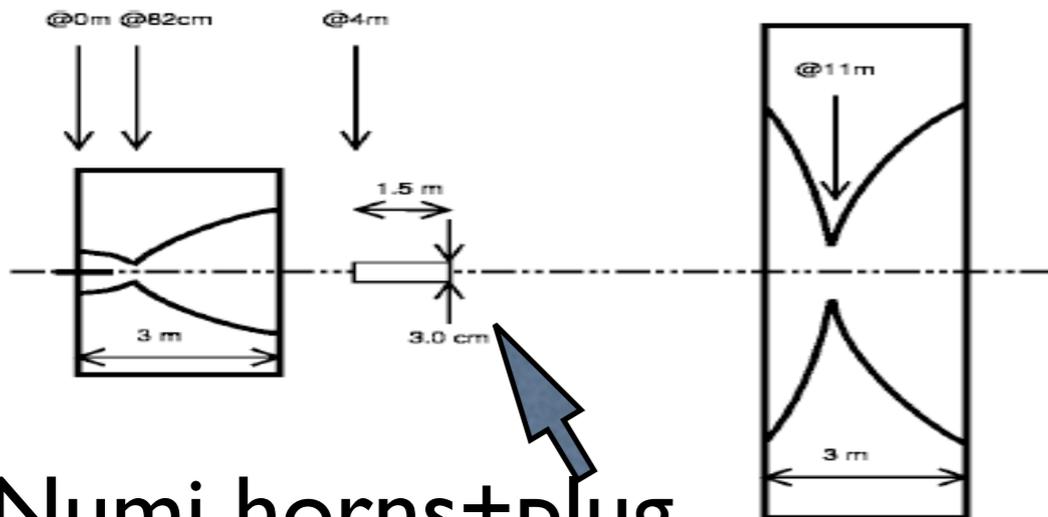
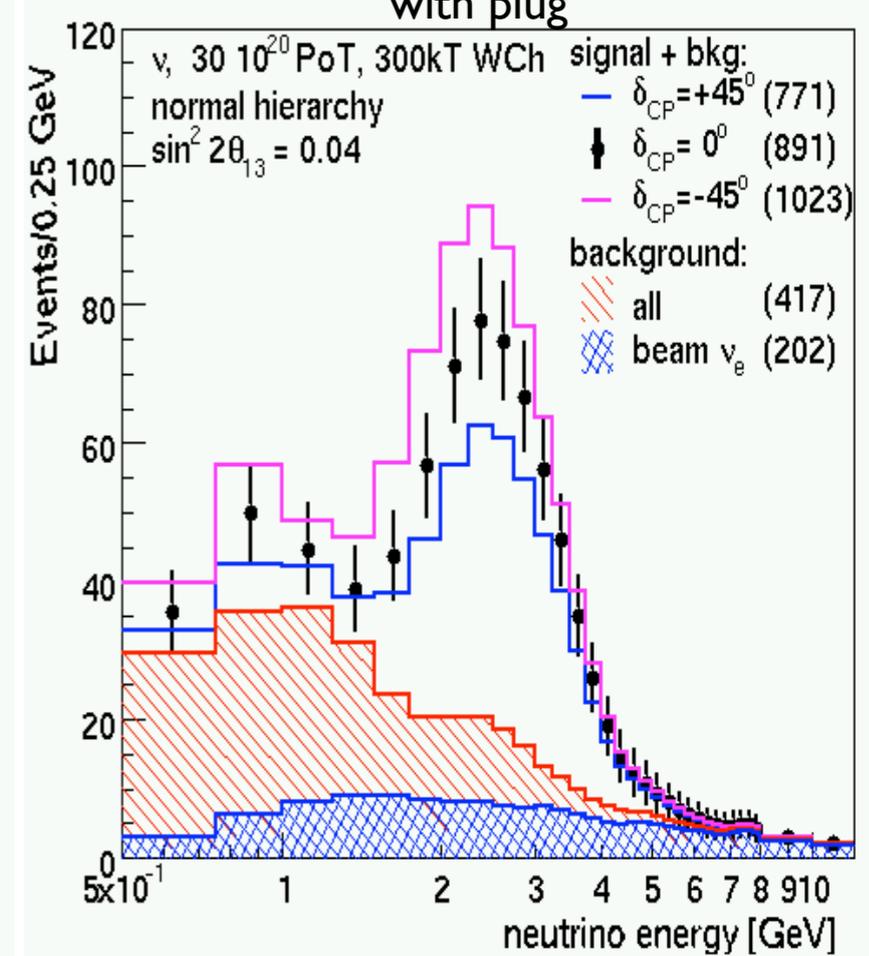
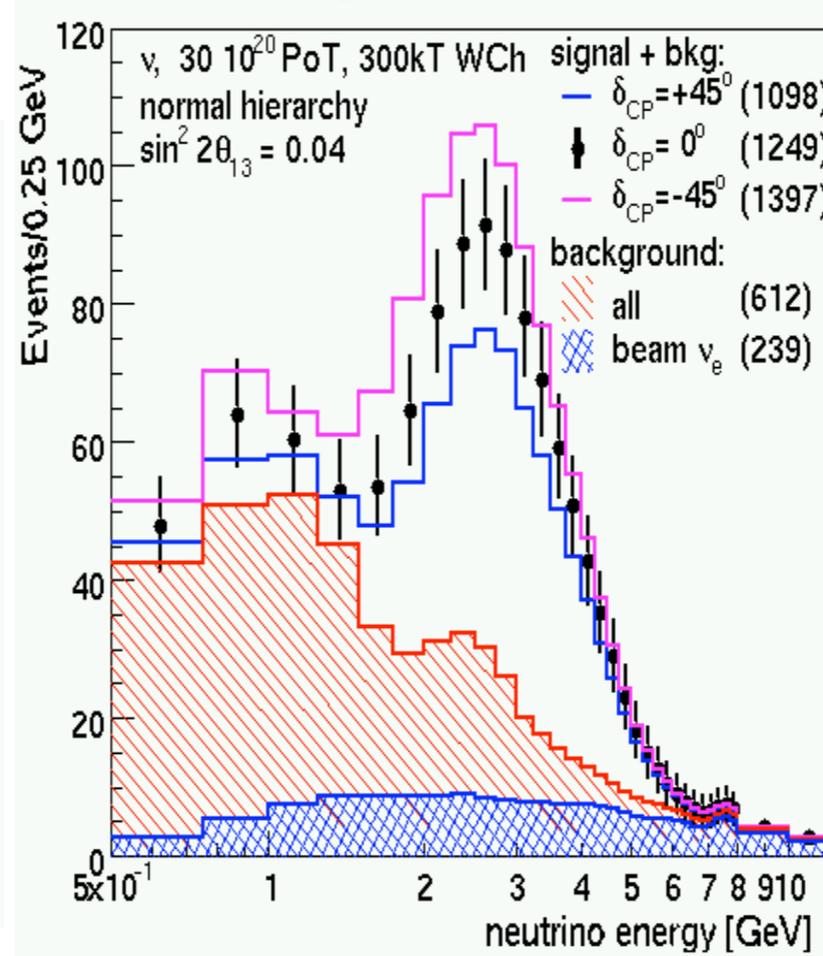
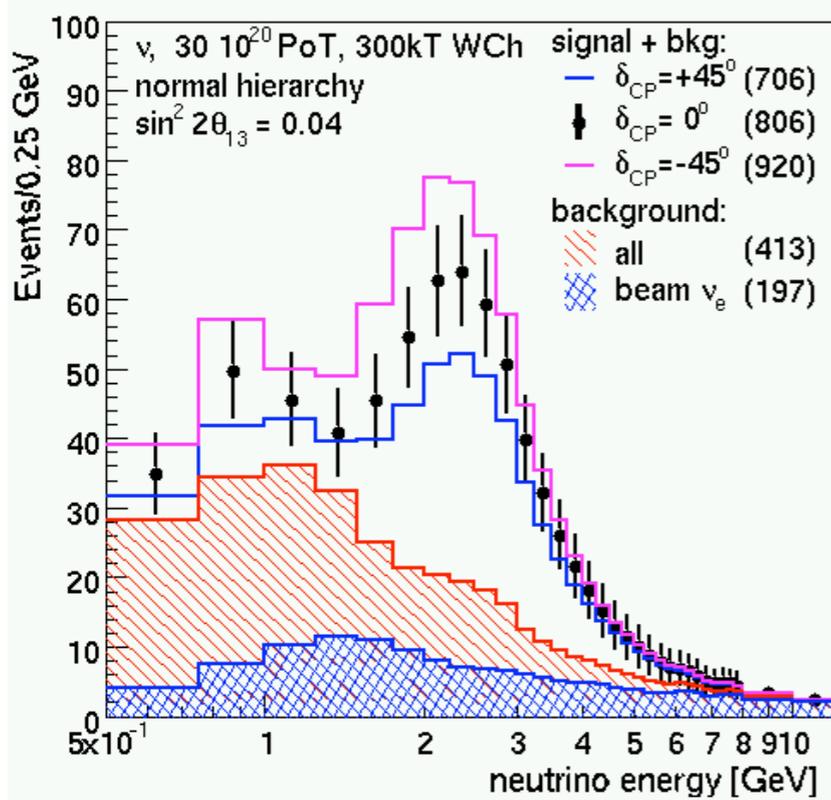
# DUSEL beam optimization

New NuMI based on axis designs  
and shorter beampipe

Old design  
0.5 deg. off. presented  
last year

High horn current

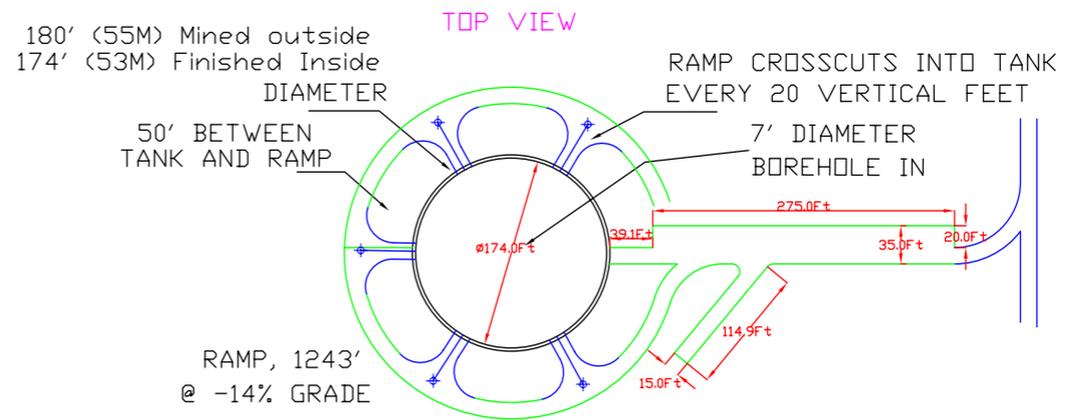
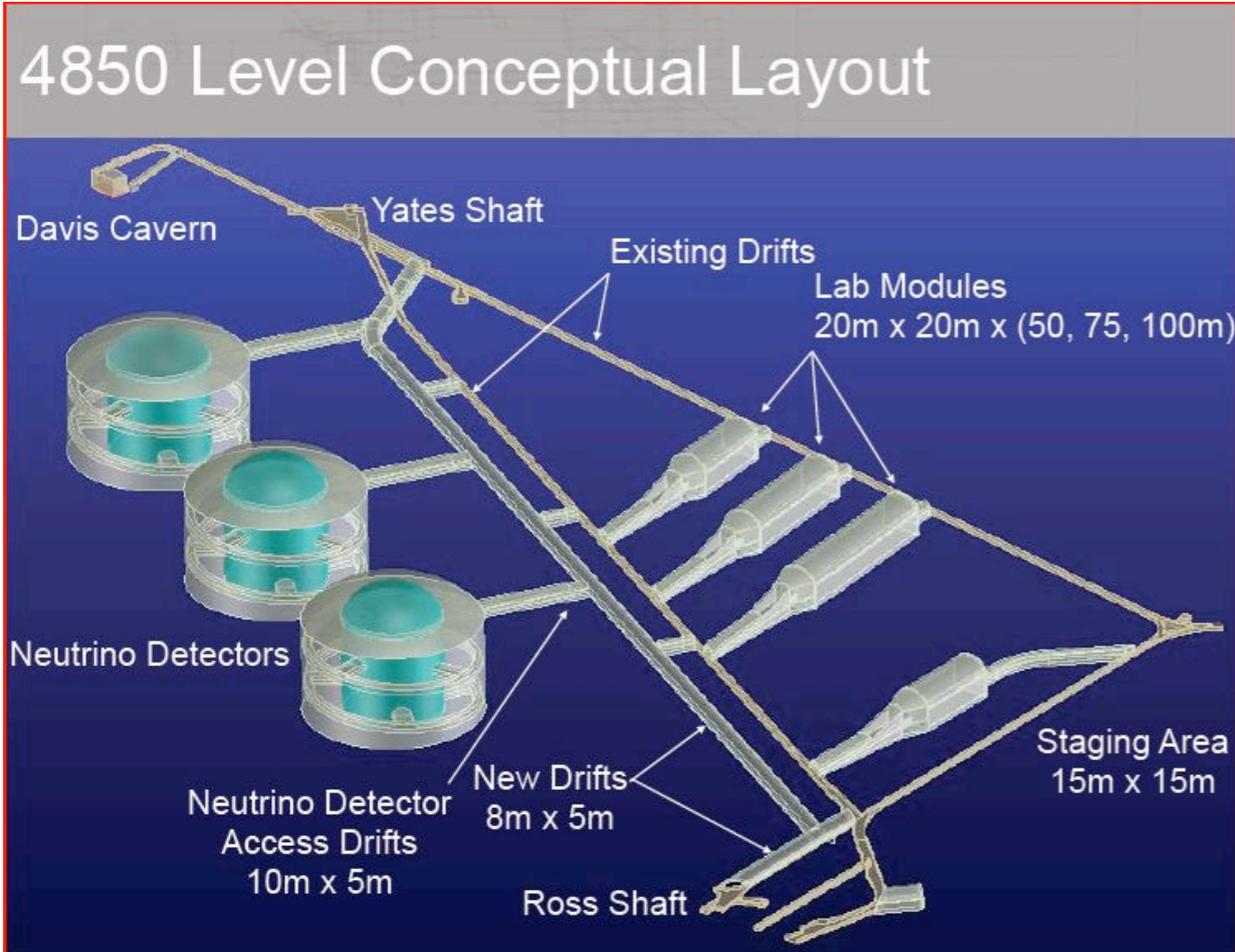
normal current  
with plug



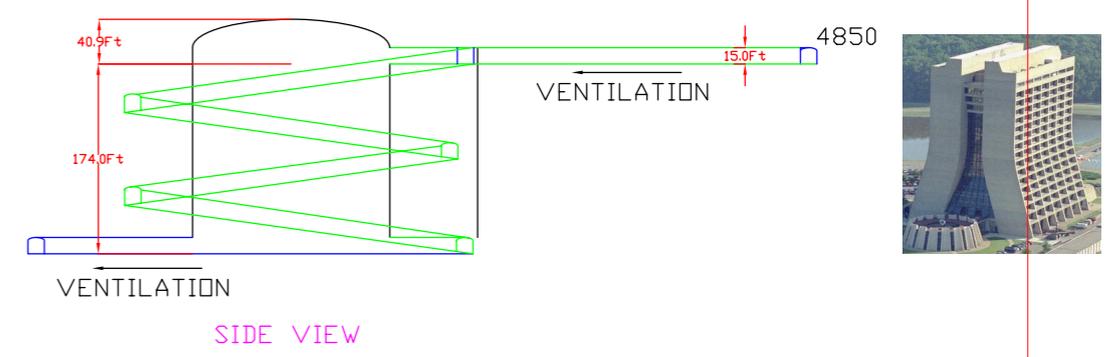
NuMI horns+plug

Signal/background enhanced by ~20%.  
Other optimizations (proton beam energy) under investigation in the beam working group.

# BNL/LDRD funded 3-cavern design and initial cost and schedule



muon rate ~0.1 Hz/cavern



Engineering & access	\$5.3M
I chamber	labor \$13.0M eqpnt ops. \$6.5M supplies \$9.4M
equipment ownership	\$10.0M
skipping&disposal	\$7.0M
ovrhd&markup	\$15.4M
contingency	\$26.6M
<b>Total</b>	<b>\$93M</b>

reported in detail

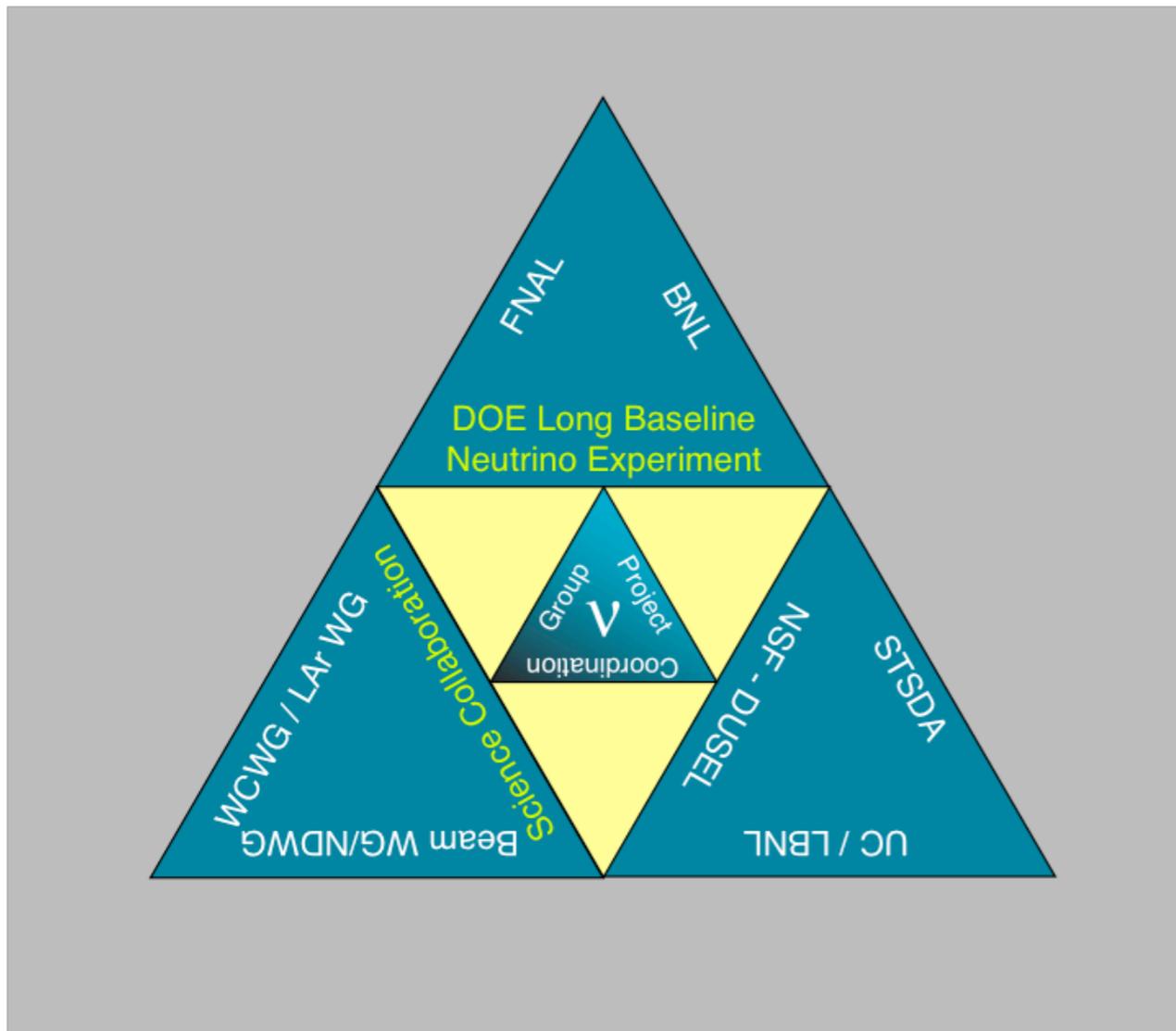
\$51M

guess

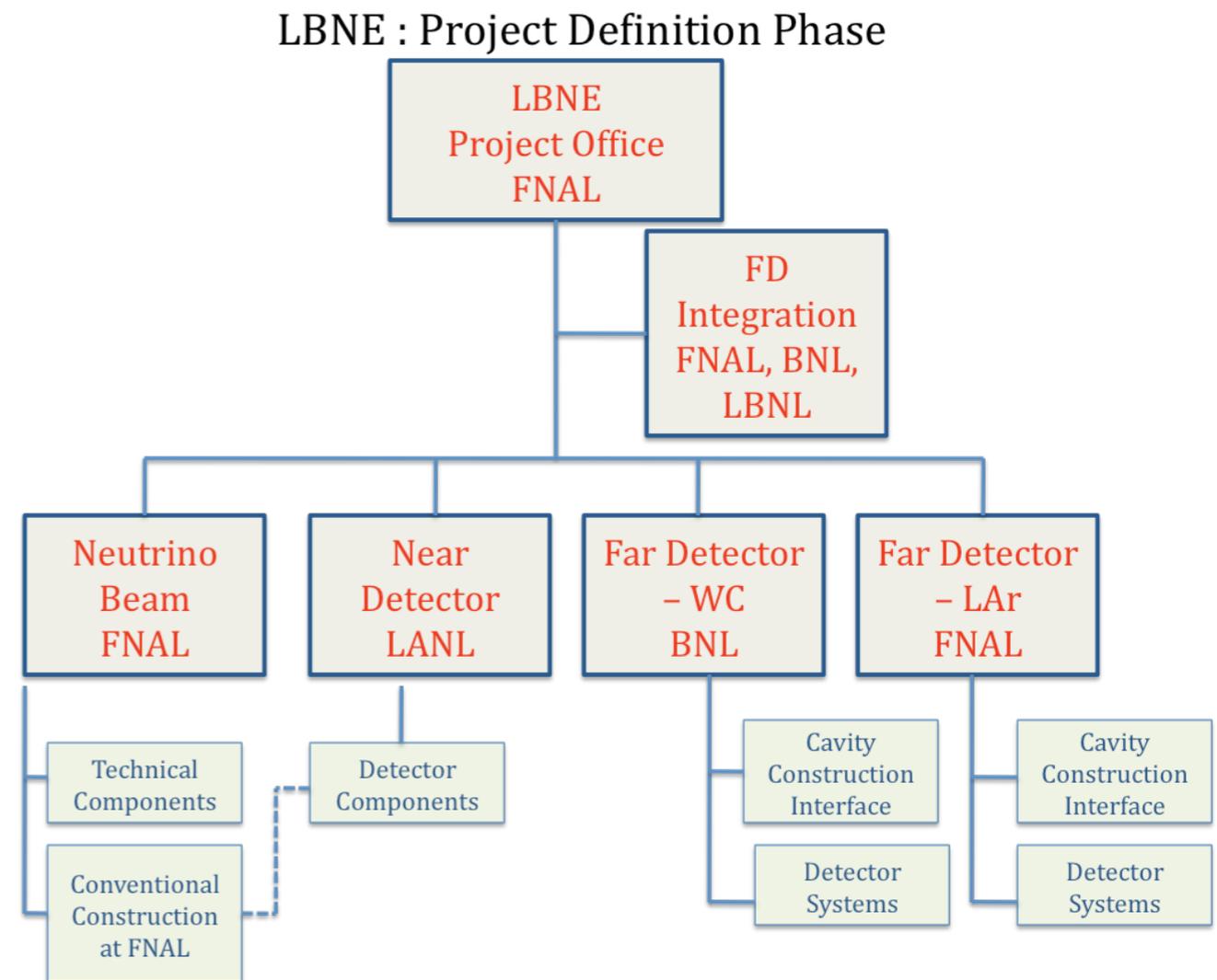
- 5 year schedule
- 1 year for dome
- Excavation by safer method
- 3 chambers can be done in parallel
- Work done in collaboration with Ken Lande at the University of Pennsylvania

2007 costs for chamber part of many DOE, NSF reviews including P5

# LBNE project organization



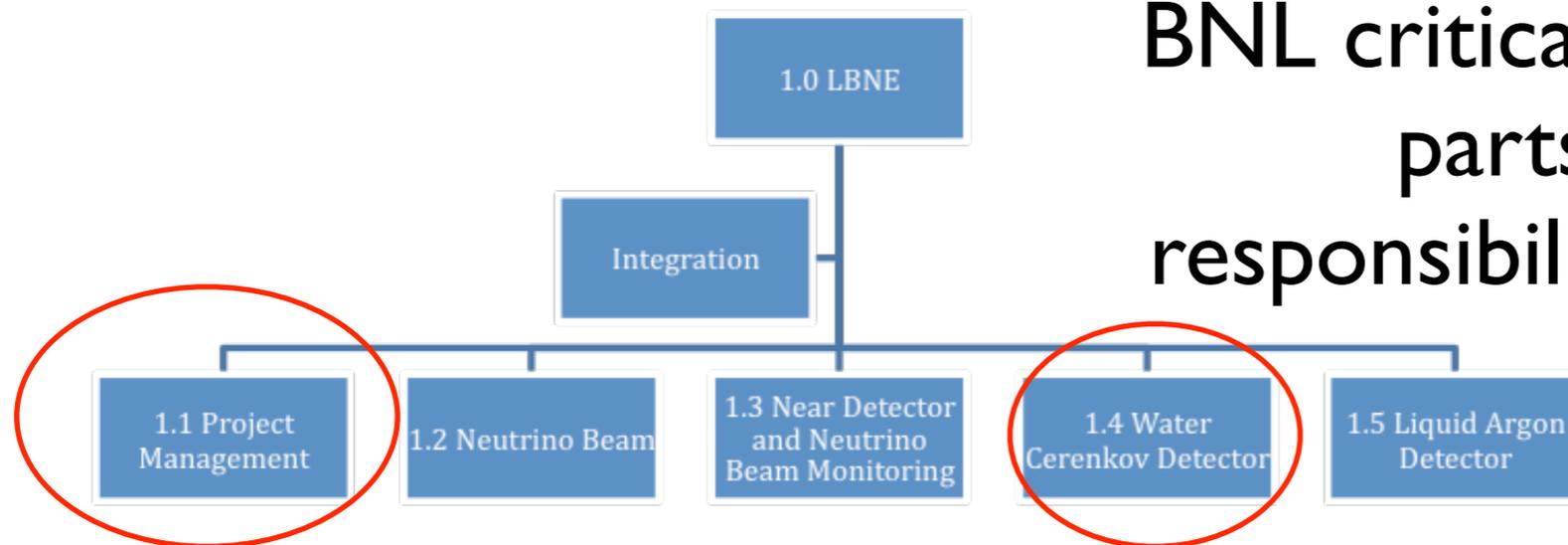
Project Coordination



Jim Stewart at BNL is onboard

# Coordination for CDI for water Cherenkov

BNL critical involvement in all parts with major responsibility to I.1.4 and I.4



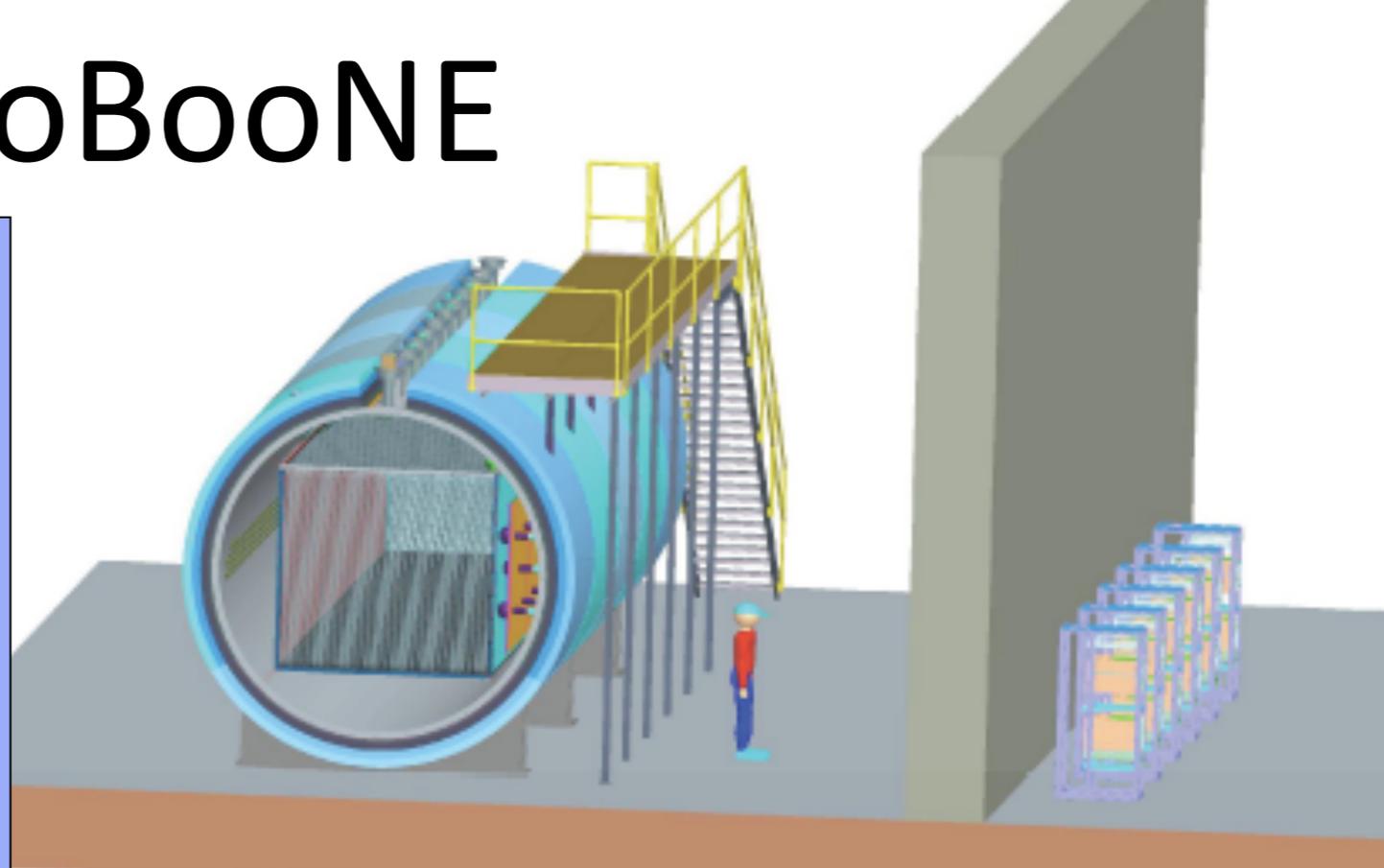
Water Cherenkov WBS element	DOE LBNE	NSF S4 (PI at Davis)
I.1.4 Project Management	BNL	
I.4.1 Vessel/Liner	BNL	UW/PSL/RPI/Duke
I.4.2 Photomultipliers	BNL	Upenn/UW/PSL/Drexel/Davis/Caltech/USC
I.4.3 Electronics/online		BU/Penn/Maryland
I.4.4 Calibration	LBL	Davis
I.4.5 Water Systems	BNL/LLNL	Irvine/Davis/LLNL
I.4.6 Civil Integration	BNL/FNAL	LBL
I.4.7 Offline/simulations	BNL	Duke/BU/Penn/Maryland/Davis
I.4.8 Installation	BNL	

# R&D on neutrino detectors at BNL

- Liquid Argon R&D
- Water Cherenkov R&D

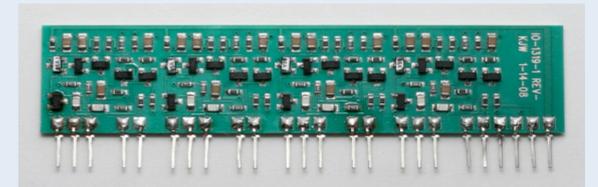
# MicroBooNE

- A 70 ton fiducial volume LAr TPC on the BNB at FNAL
  - Collaboration formed in 2007
  - 10 univ+labs/50 phys+eng.
  - Under design phase and DOE CD-1 later this year
- <http://www-microboone.fnal.gov>
- Low energy phenomena and excess observed by miniBooNE
- Precision measurements of “golden”  $\nu_\mu$  CCQE channel:
- Possibility of CCQE measurements from intrinsic  $\nu_e$
- Background for oscillation searches:  $N\pi^0$ , photonuclear events



- 2.5 m drift @ 500V/cm
- **3 Readout planes**
  - 2 induction planes (U,V at  $\pm 60^\circ$  from vertical)
  - 1 collection plane (vertical wires, 2.5m long)
- 30 PMT for T0 determination
- **Evacuatable Single vessel containment**
  - No expansion vessel (8% ullage)
- **Readout based on “cold” preamplifiers**
  - JFET based discrete
  - 10,000 channels
  - Warm Feedthroughs
- Bi-phase purification system

BNL Roles



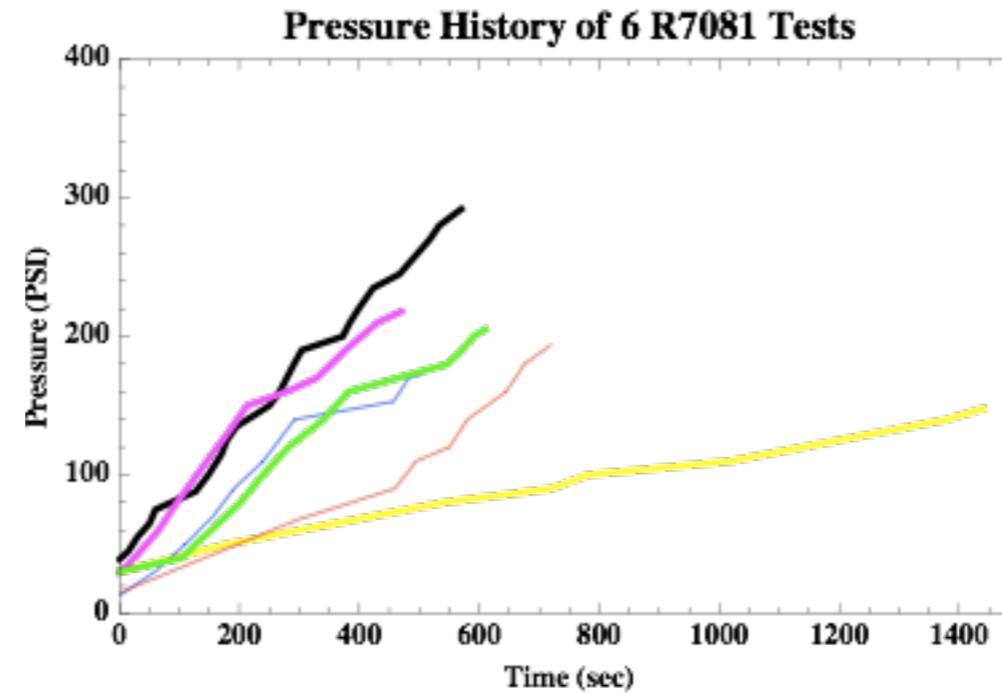
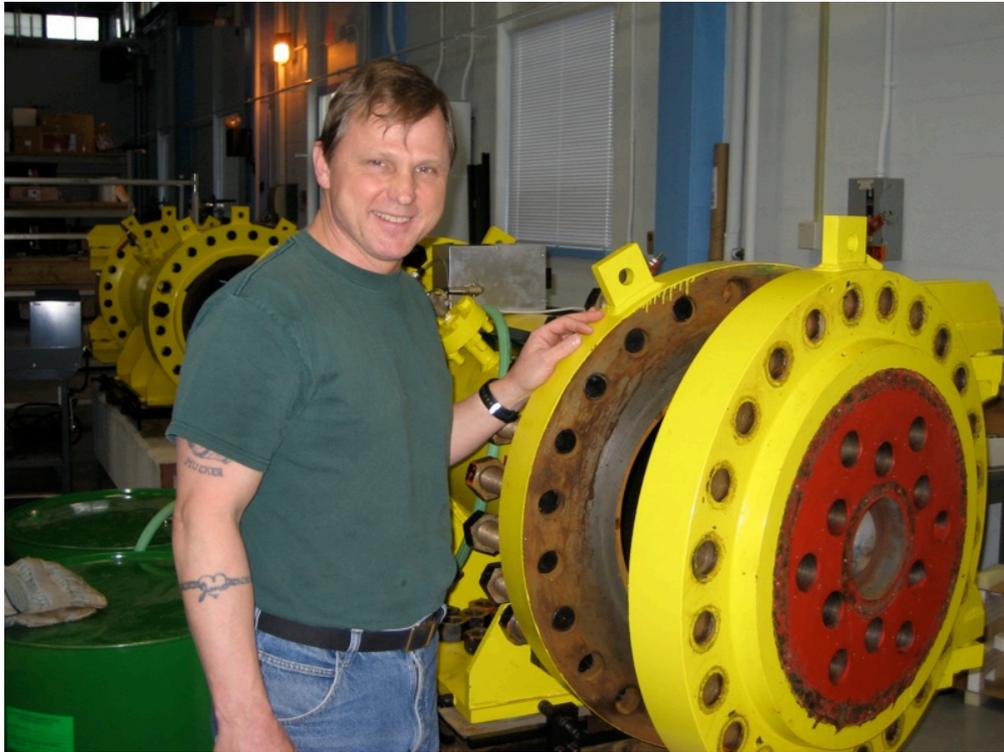
# LArTPC R&D Challenges

- Scalability to very large volumes (100ktons) is yet to be proved
  - ICARUS T600 detector at Gran Sasso (Italy)
- Critical aspect is the development of readout electronics operating at LAr temperatures
- Our main goal is to demonstrate the feasibility, performance and reliability of the cryogenic electronics
- We will work with the LBNE LAr detector project being formed at FNAL aiming at leadership role in detector and readout optimization.

# Water Cherenkov R&D support so far

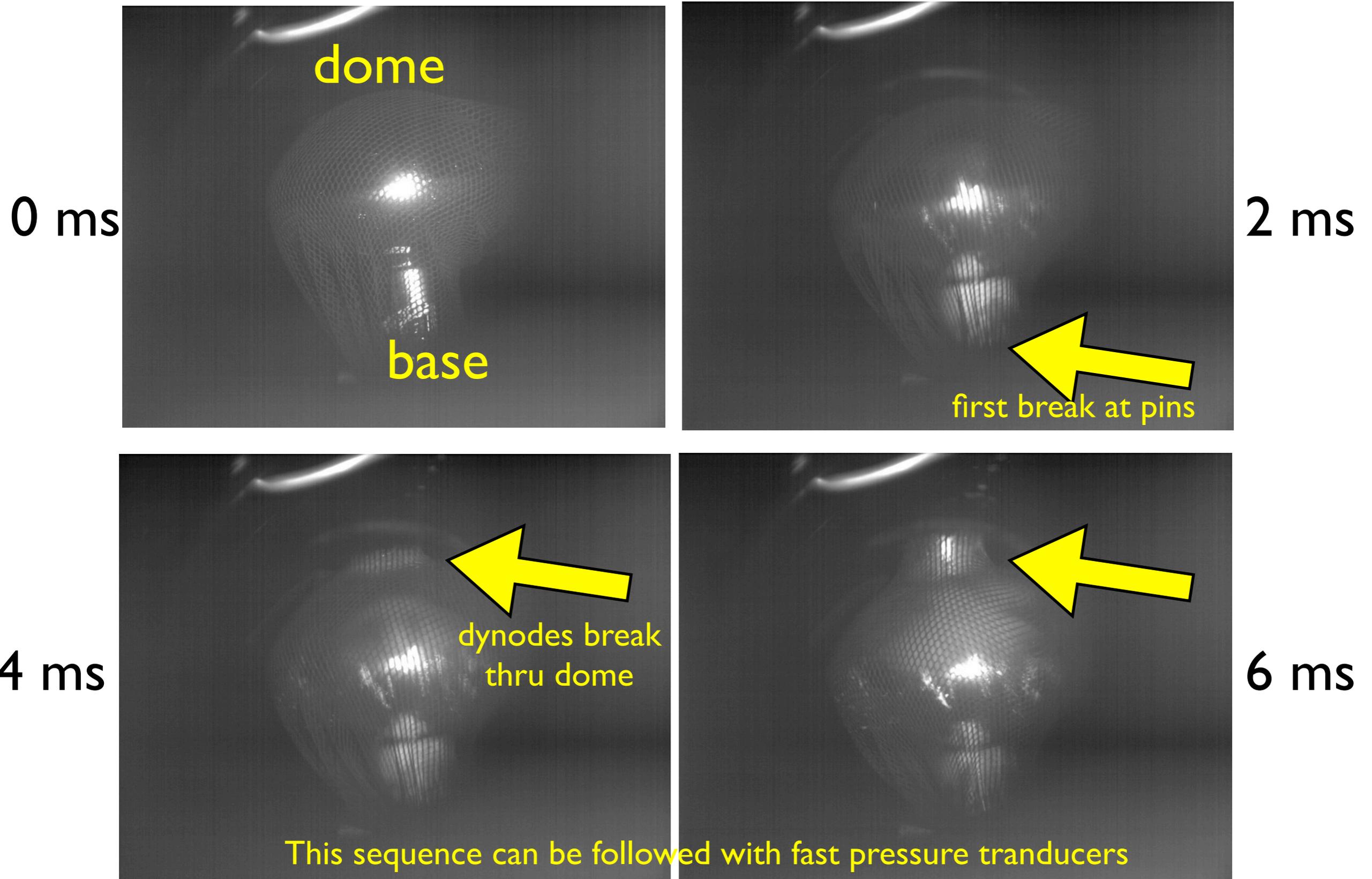
- **BNL/LDRD funds used for several tasks**
  - Preliminary pressure testing of photo-multiplier tubes
  - Initial cavern excavation engineering and cost and schedule estimates.
  - Simulation work to understand backgrounds and performance (postdoc, university visitors, partial support for scientist, and workshops).
  - Other efforts on optics, materials, in collaboration with BNL-Chemistry.

# Development of pressure testing at BNL (Diwan, Goett, Sexton)



- What have we learned
  - Manufacturers have tubes with very distinct characteristics
  - Failure mode in Hamamatsu hemispherical tubes is at the pins. 7 atm is o.k.
  - Other manufacturers failure may occur at the dome in much more damaging way.
  - Data includes motion picture and recorded pressure pulses.
  - Funded mostly out of LDRD which is finished.

# Typical R708I failure (TA3085 failed at 13.4 bar)



# People plan

	2009	2010	2011	2012
<b>Physicists</b>				
E949	0.3	0.0	0.0	0.0
MINOS	0.7	0.7	0.1	0.0
MicroBooNE/LArTPC	0.0*	0.5	1.0	1.0
LBNE	1.5	1.7	3.2	3.7
<b>Sum</b>	<b>2.5</b>	<b>2.9</b>	<b>4.2</b>	<b>4.7</b>
<b>Postdocs</b>				
E949	0.5	0.0	0.0	0.0
MINOS	0.8	0.5	0.7	0.7
MicroBooNE/LArTPC	0.0	0.5	1.0	1.0
LBNE	0.0	0.1	0.5	1.1
<b>Sum</b>	<b>1.3</b>	<b>1.1</b>	<b>2.2</b>	<b>2.8</b>
<b>Total</b>	<b>3.8</b>	<b>4.0</b>	<b>6.4</b>	<b>7.5</b>
Moved from LBNE project	1.2#	5.0	5.0	5.0
<b>New total</b>	<b>5.0</b>	<b>9.0</b>	<b>11.4</b>	<b>12.5</b>

# as reflected in the FY09 supplement request.

- Staffing plan as presented at the Mar. budget briefing
  - \*current work on LAR under KA15
  - E949 transitioned to LBNE
  - MINOS transitioned to LBNE
- Recent guidance from OHEP changes this plan by shifting some scientific effort from project to Core funding.



# Summary

- BNL weak-interactions efforts has undergone a successful transition in the last few years.
- BNL has played an important role in forming the national priorities at the intensity frontier.
- The LBNE plan is being developed in collaboration with other national labs, and the science community.
- The national plan is for BNL to take on a major leadership role on a large detector for LBNE, which will require a modest increase in Core support.
- To properly execute the LBNE plan a similar modest increase is needed across the collaboration.