

The Long Baseline Thrust

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DOE Laboratories Intensity Frontier Program Review

May 21, 2013

Outline

- The physics case for long-baseline experiments
- Fermilab's Support of the Long Baseline Thrust
 - MINOS/MINOS+
 - NOvA
 - LBNE
- Summary

Neutrino Oscillations in the Future

- We have learned a lot about neutrino oscillations - measured 2 mass splittings and 3 mixing angles
- Future questions to answer about oscillations
 - Is the PMNS matrix sufficient to explain oscillations?
 - Are there more neutrinos than the 3 active flavors?
 - Is the CP violating phase non-zero?
 - What is the mass hierarchy?



Neutrino Oscillations in the Future

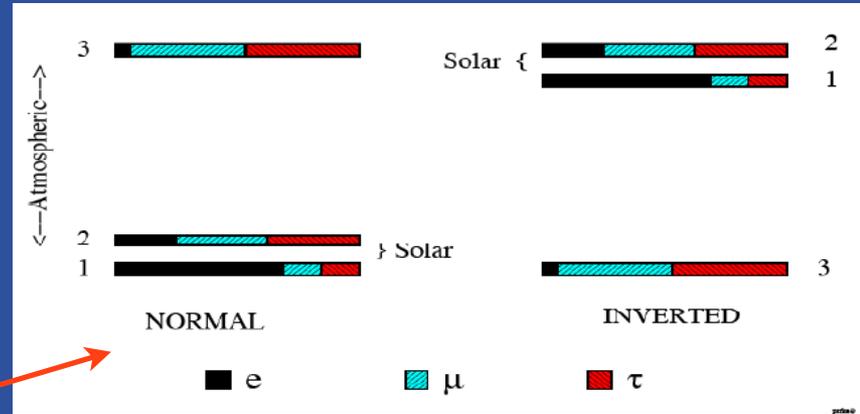
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- Future questions to answer about oscillations

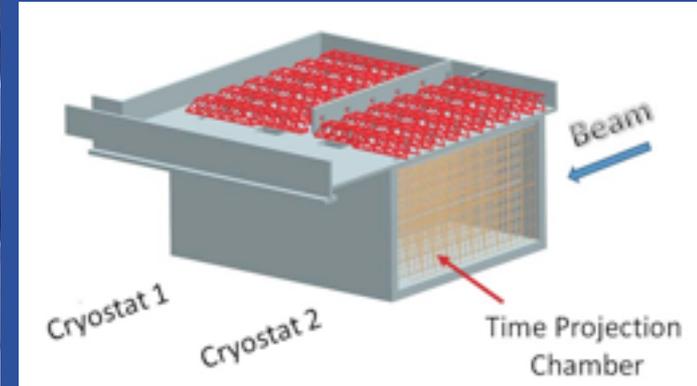
- Is the PMNS matrix sufficient to explain oscillations?
- Are there more neutrinos than the 3 active flavors?
- Is CP violated?
- What is the mass hierarchy?

$\nu_4, \nu_5, \dots ?$

$$P(\nu_\alpha \rightarrow \nu_\beta) \neq P(\bar{\nu}_\alpha \rightarrow \bar{\nu}_\beta)$$



Long Baseline Program



MINOS/MINOS+
32 Institutions,
124 Collaborators
ND: 1kt, FD: 5kt
8 Fermilab Scientists

Measures:

θ_{23}, θ_{13}

Δm^2_{32}

NOvA
35 Institutions,
180 Collaborators
ND: 210t, FD: 14kt
18 Fermilab Scientists

Measures:

θ_{13}, θ_{23}

Search for δ

Δm^2_{32}

Mass hierarchy

LBNE
67 Institutions,
384 Collaborators
FD: 10+kt
24 Fermilab Scientists

Measures:

θ_{13}, θ_{23}

δ

Δm^2_{32}

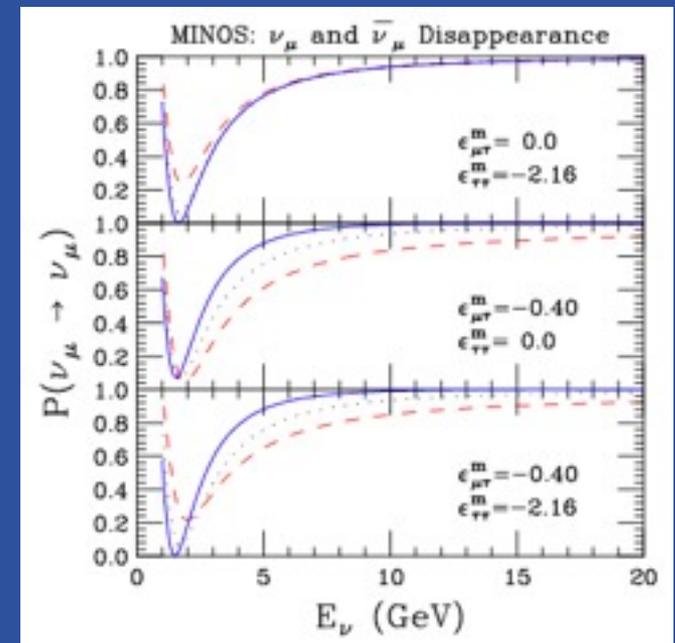
Mass hierarchy

Fermilab's Support of the Long Baseline Thrust

- Fermilab scientists play strong leadership roles in the long baseline program
 - Wealth of experience in data analysis, beam line design, and detector construction from MINOS through NOVA to LBNE
 - Operate the current generation of experiments while building the next
- Fermilab scientists facilitate and enhance participation of other labs and university groups in the long baseline program
 - Provide resources and facilities for university groups to develop new technologies
 - Mentor students and postdocs from university groups while in residence at Fermilab

MINOS/MINOS+

- Made the most precise measurement of Δm^2_{32}
- Measured appearance of ν_e , cross sections with the ND
- Searched for sterile neutrinos, Lorentz violation, NSI
- MINOS+ is the continuation in the NOvA era
- MINOS+ tests exotic models and expands search for sterile neutrinos in a new region of L/E

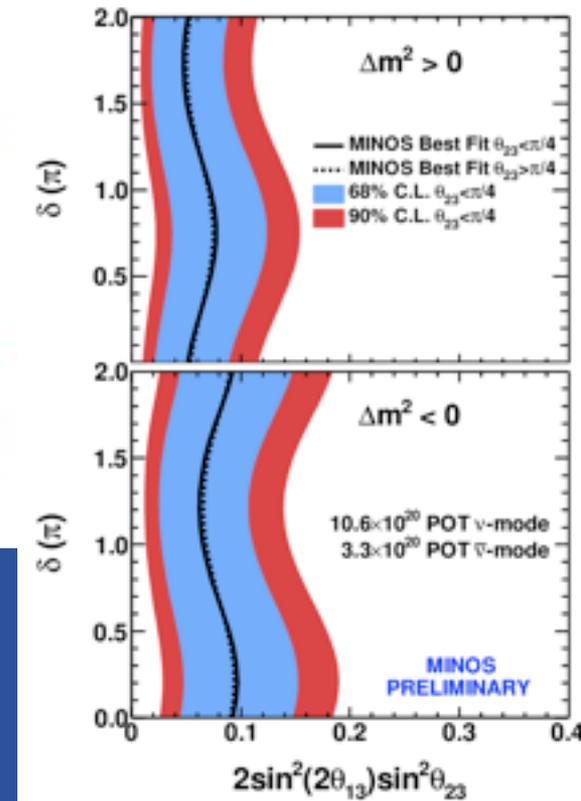
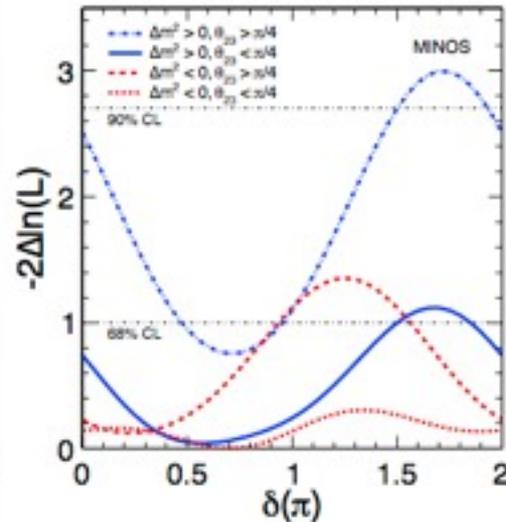
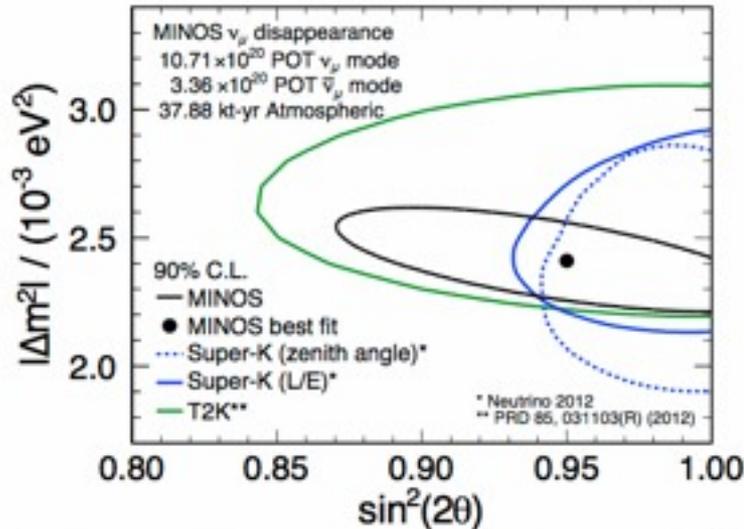


(Kopp, Machado, Parke)

Current Fermilab Leadership in MINOS(+)

Staff Member	Role
Plunkett	Co-spokesperson
Rebel	Publication Committee Chair, Neutral Current Group Co-Convener (2007-2010)
Adamson	Main Injector Group, Beam Systematics Convener, Time of Flight convener, Elected Executive Committee member
Pahlka (RA)	Run Coordinator (2011), Disappearance Analysis
Moed-Sher	Time of Flight Analysis, Energy Scale Calibration Supervisor

MINOS Recent Results



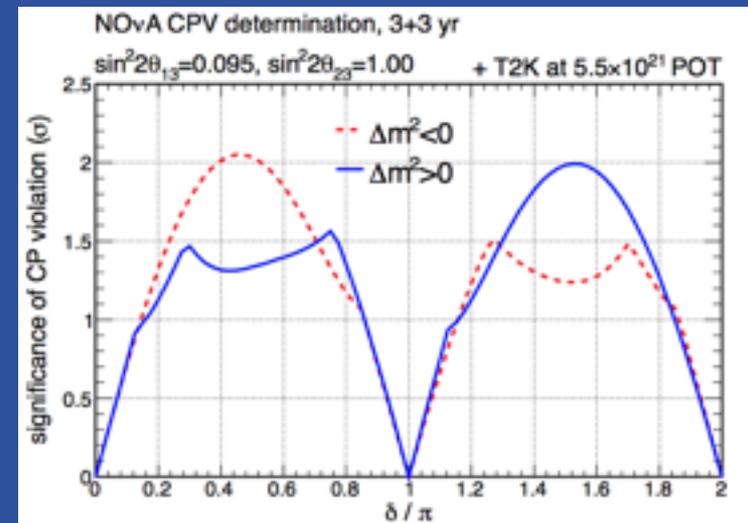
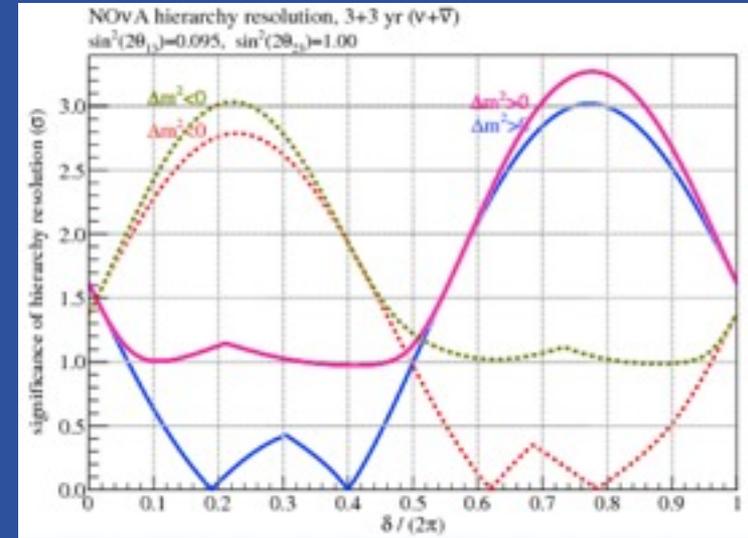
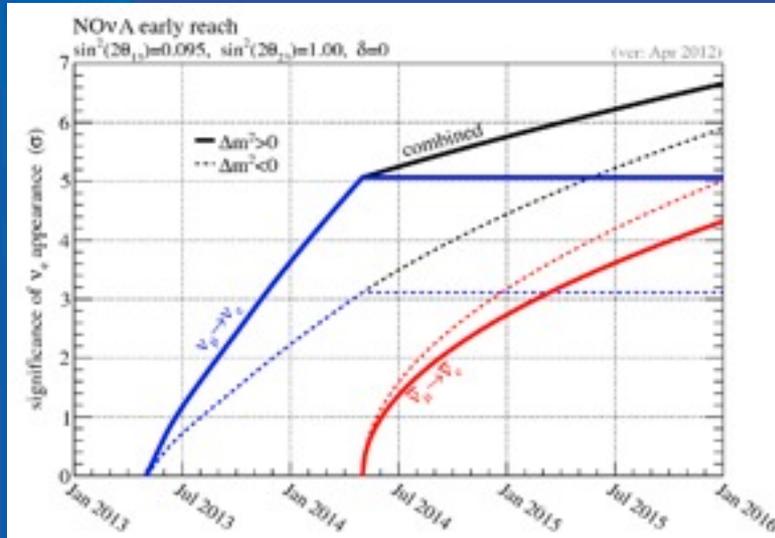
- Updated ν_μ disappearance to combine beam and atmospheric neutrino data
- ν_e appearance analysis excludes $\theta_{13} = 0$ at 90% CL
- Recent paper proposes techniques to determine hierarchy, octant of θ_{23}
- 18 papers published since 2009, Fermilab scientists played major roles for 11 of them (Adamson, Harris, Moed-Sher, Pahlka (RA), Plunkett, Rebel, Shanahan, Zwaska)

NOvA

- 15kt far detector with 700 kW narrow band beam
- NOvA's primary physics goals include
 - Measure $\nu_{\mu} \rightarrow \nu_e$ and $\bar{\nu}_{\mu} \rightarrow \bar{\nu}_e$ oscillations, measurement of θ_{13}
 - Mass hierarchy
 - Search for CP violation
 - Precision measurement of θ_{23}



NOvA Physics Reach



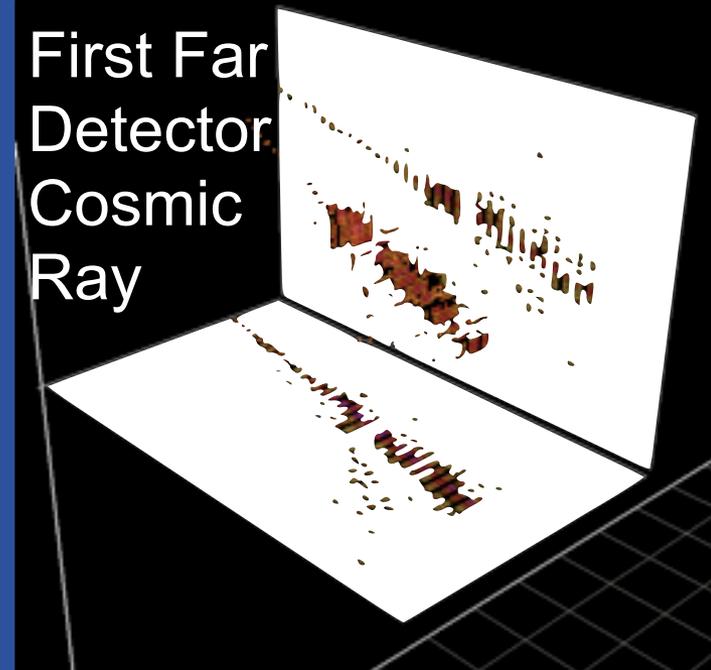
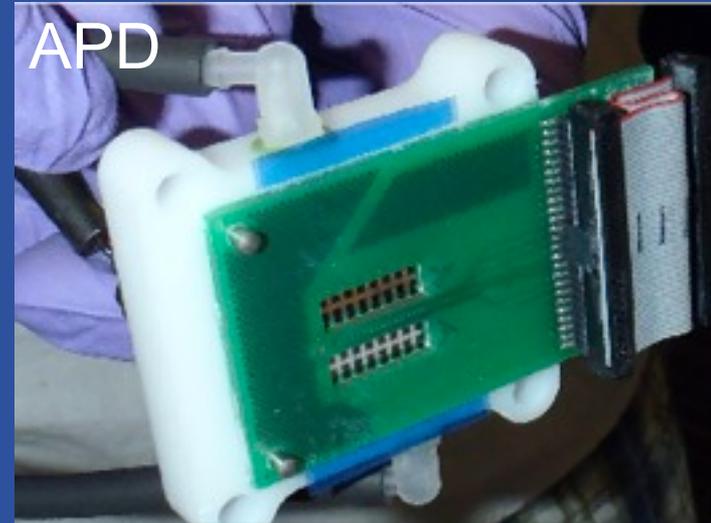
- Reach 5σ significance for ν_e appearance within a year of beam turning on
- Right plots shows mass hierarchy resolution/CP violation vs δ , including combination with T2K
- Doubling NuMI beam power to reach these goals (Adamson, Derwent, Madrak, Schlabach, Zwaska)

Current Fermilab Leadership in NOvA

Staff Member	Role
Cooper	Project Manager
Tesarek	Deputy Project Manager
Derwent	Associate Project Manager for Accelerator Upgrades
Lukens	L2 Far Detector Assembly
Miao	L2 Near Detector Assembly
Shanahan	Elected Executive Committee Member, Reconstruction Coordinator
Rebel	Elected Executive Committee Member, Calibration Co-Convener
Muether (RA)	Elected Executive Committee Member, Run Coordinator (2012)
Zwaska	Beam Systematics Co-Convener
Norman	Data Driven Trigger Coordinator
Group	NOvA Computing Co-Convener

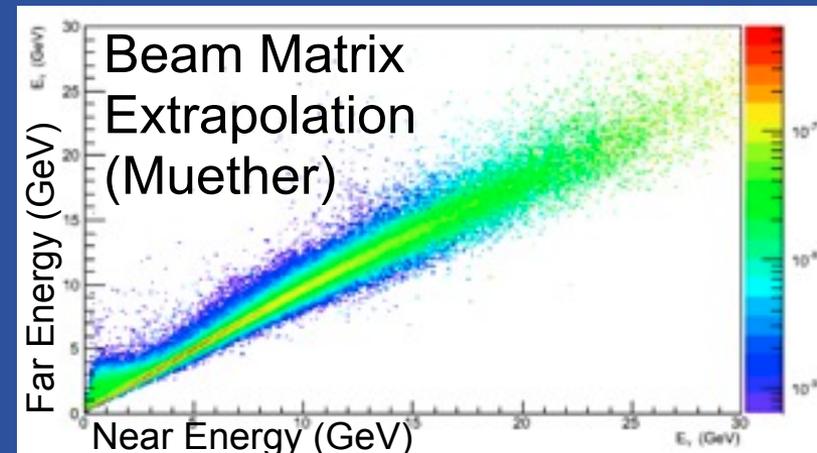
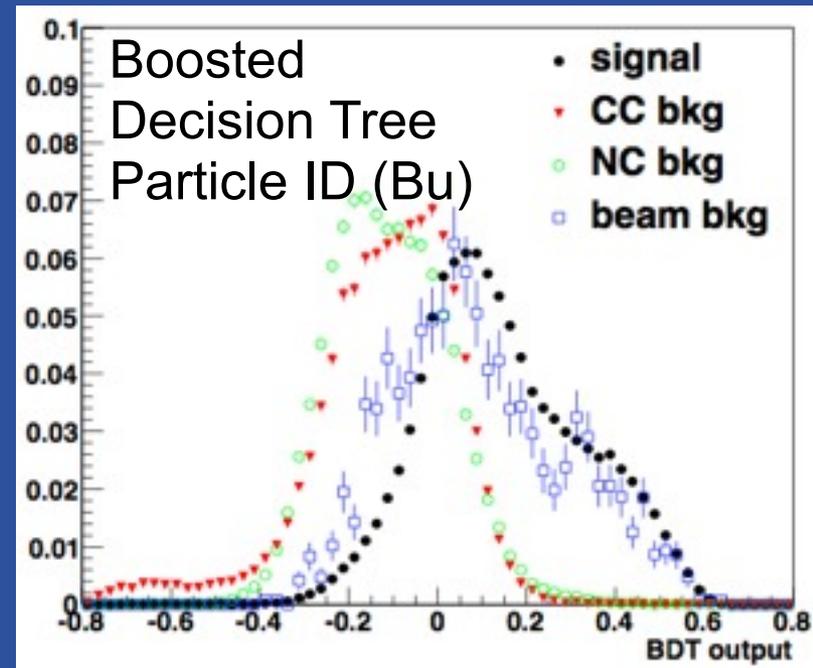
Construction and Commissioning

- Fermilab scientists are key players in construction and commissioning
- Major effort installing prototype detector from the entire group
- **Shanahan** leading DAQ effort including **Norman**, **Muether (RA)**, **Perevalov (RA)**, **Adamson**, **Zalesak** and universities
- **Muether (RA)** was key in making APDs function, worked closely with Caltech
- **Lukens** and **Tesarek** leading FD construction, **Bu (RA)** and **Miao** leading efforts with ND
- These efforts combined to detect the first cosmic ray muon 20 minutes after APD installation at the FD



Analysis

- Fermilab scientists are major contributors to data analyses
- **Shanahan** is the offline reconstruction coordinator, **Rebel** is co-convenor of Calibration and Alignment group
- **Bu (RA)**, **Muether (RA)**, and **Perevalov (RA)** contributing vital components to the oscillation analysis working groups
- **Rameika**, **Rebel**, **Shanahan**, **Norman**, **Tesarek** actively mentoring RAs on the analyses
- NOVA chose the Fermilab developed ART framework for analysis and reconstruction code rather than maintain its own

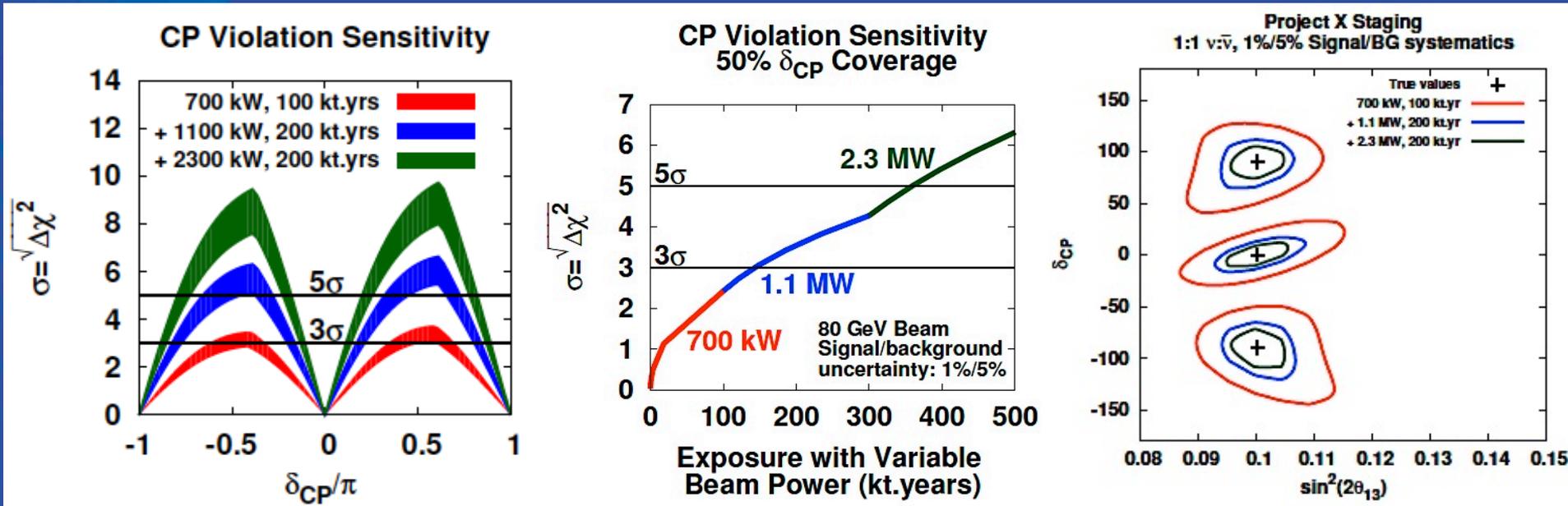


LBNE and LArTPC R&D



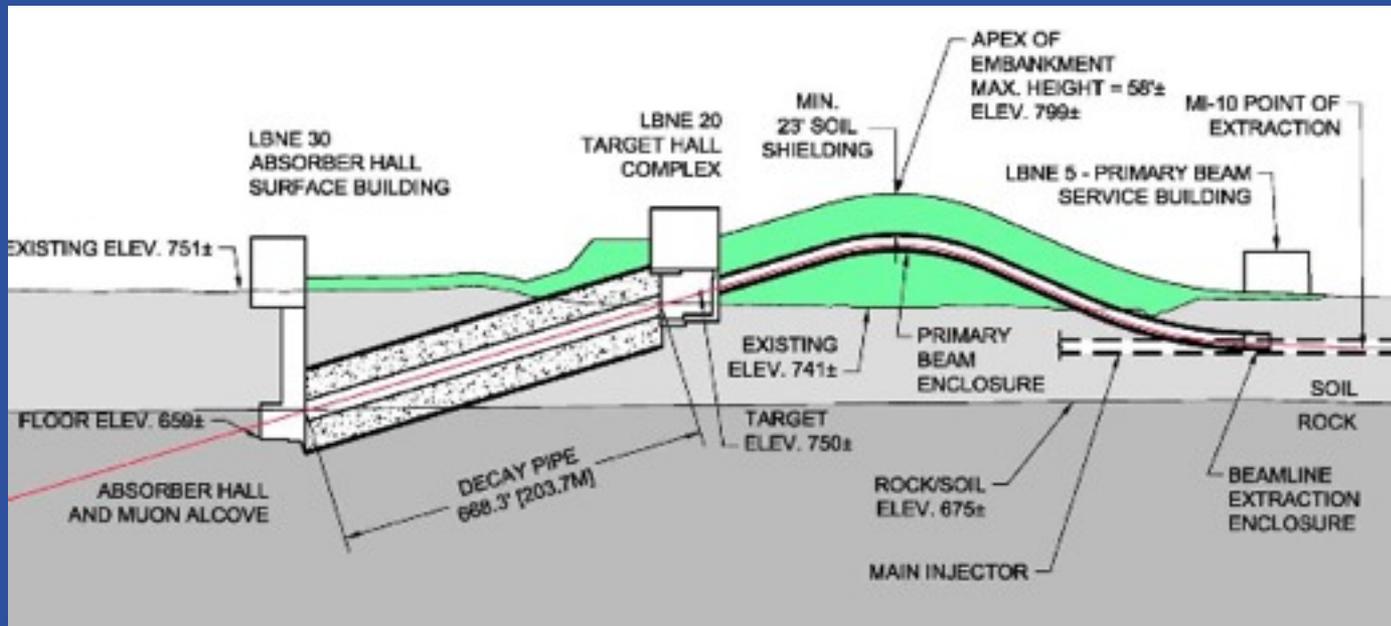
- LBNE will be a world leading long baseline experiment
- Builds on the measurements of NOvA and MINOS/MINOS+
- Mass hierarchy and CPV
- Goal is to add proton decay and astrophysical neutrinos to the program
- Far detector will be first multi-kiloton (10+) liquid argon time projection chamber

LBNE Physics Reach with Project X



- **Zeller** is a co-leader with Bishai (BNL) of the working group studying physics reach and developing oscillation analyses with significant contributions from **Rameika** and **Lundberg**
- Bands indicate 1σ variations of θ_{13} , θ_{23} , and Δm^2_{31}
- Project X adds 5σ discovery potential for CPV, enables precision measurements of ν_e appearance

LBNE Beam Line



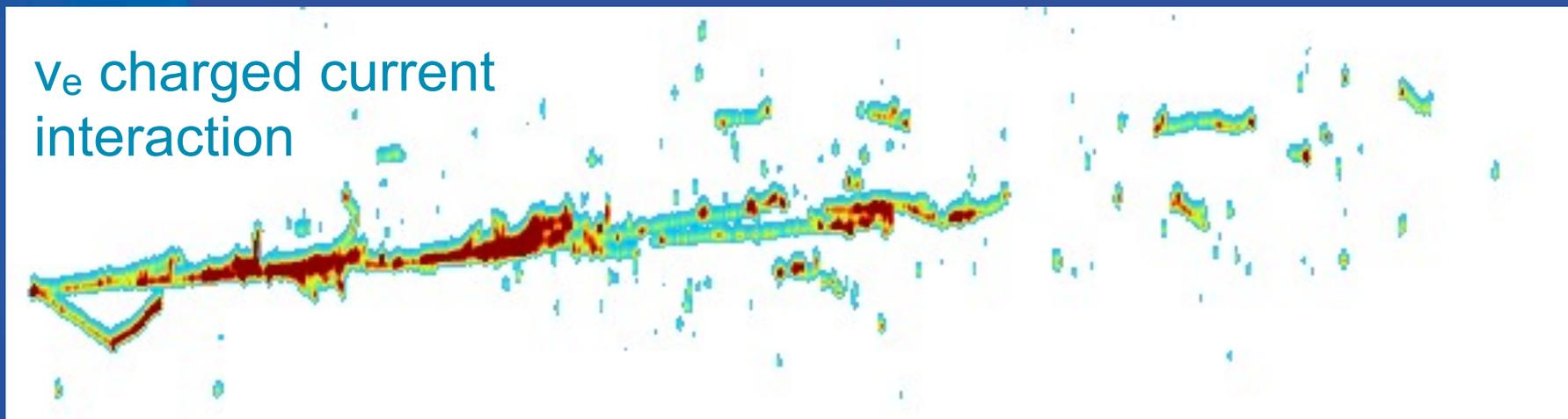
- Significant experience from the NuMI and ANU projects in this group
- LBNE beamline group led by Papadimitriou and includes Childress, Hylan, Lundberg, Marchionni, Plunkett, and Zwaska
- Plan extensive simulation of the optics, target, losses, horns, absorber and decay pipe over next few years

Fermilab Leadership in LBNE and LAr R&D

Staff Member	Role
Strait	LBNE Project Director, LBNE Executive Committee
McCluskey	LBNE Project Manager, LBNE Executive Committee
Papadimitriou	LBNE L2 Beam, LBNE Executive Committee
Baller	LBNE L2 Far Detector (2009-2012)
Hahn	LBNE Prototype Coordinator
Junk	LBNE Physics Tools Coordinator
Zeller	Co-Leader of LBNE Physics Working Group, LBNE Executive Committee, Reconfiguration Committee
Rameika	LBNE Project Scientist (2010-11), Reconfiguration Committee, LBNE Project Manager (2008-2009)
Raaf	Co-spokesperson of LArIAT
Pordes	R&D Infrastructure Coordinator
Rebel	Lead of Liquid Argon Purity Demonstrator, Co-spokesperson of LArIAT, LArSoft Leader
Soderberg	ArgoNeuT Spokesperson

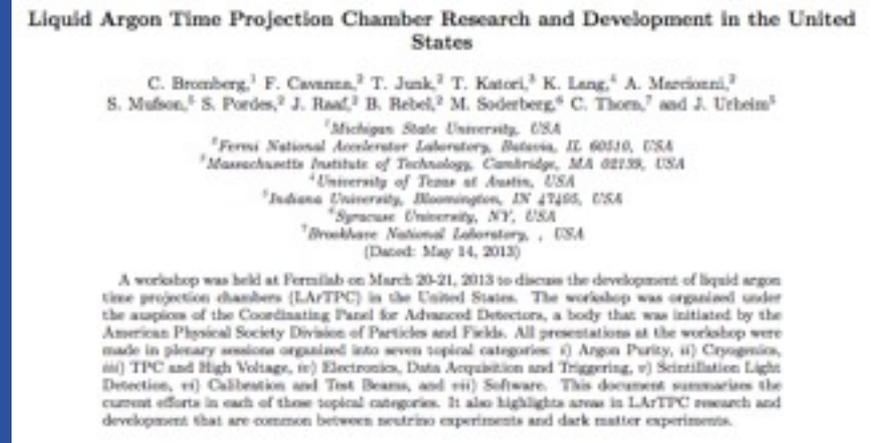
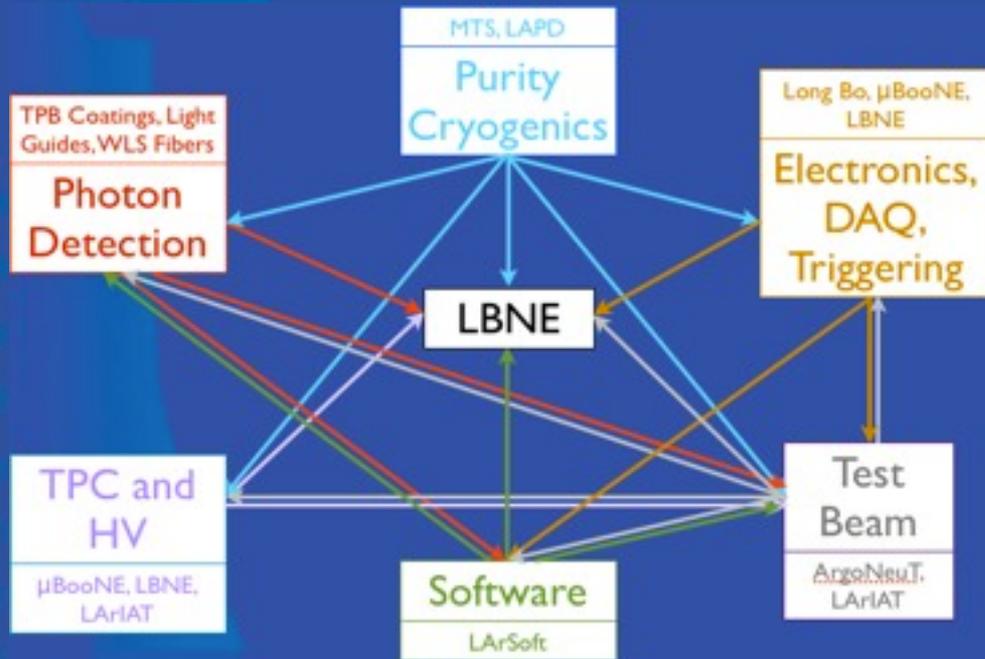
Support for LArTPC Development toward LBNE

ν_e charged current
interaction



- Liquid argon TPCs are exciting detectors for the next generation of neutrino physics
- Fermilab scientists are leaders in the development of LArTPCs
 - Broad program developing argon purity, electronics, high voltage, photon detection, test beam experiments, simulation and reconstruction
- Fermilab facilities and resources enable participation from the community
- This work makes LBNE possible

Enabling Community Involvement

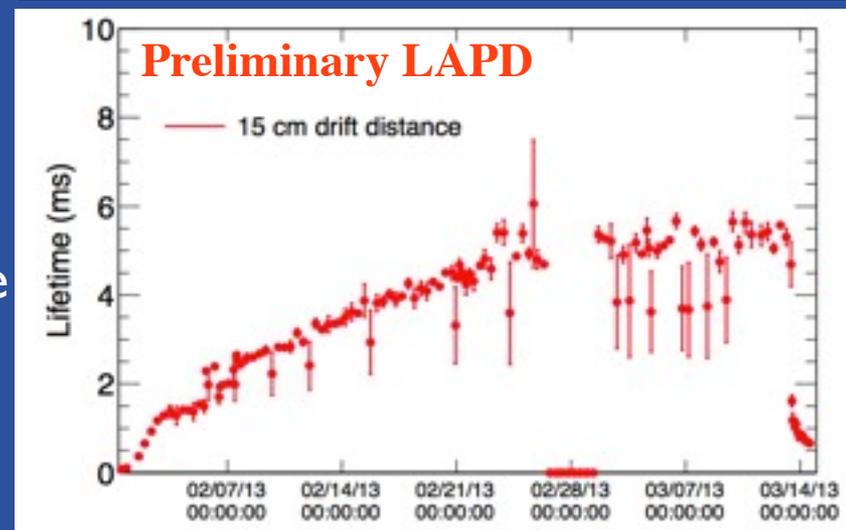
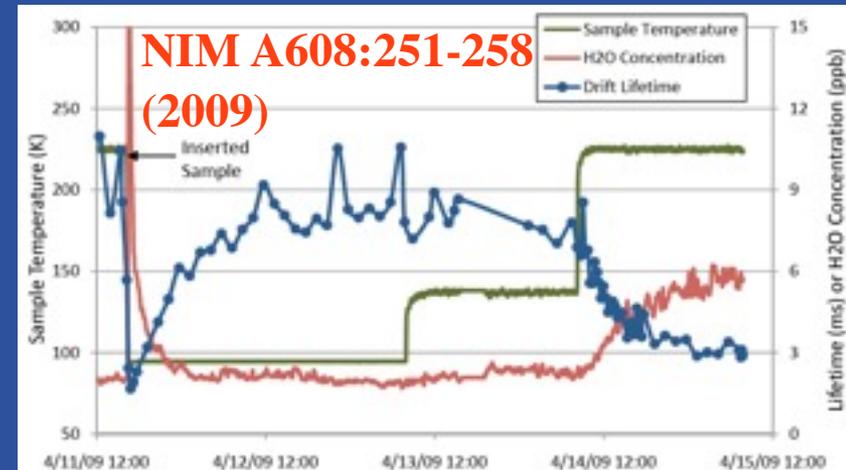


- Many interconnections between areas required to build LBNE
- **Rebel** co-organized a workshop on LArTPC R&D as part of CPAD/Snowmass process to bring community together
- 72 participants from 32 institutions came to discuss work and learn where new contributions would make the most impact
- Producing summary document, workshop will be an annual event

Development toward LBNE: Argon Purification

- Two test stands to understand electronegative contamination in Argon
- Materials test stand (MTS) is the workhorse for vetting materials that are considered for use in LArTPCs
- Liquid argon purity demonstrator (LAPD) showed the electron lifetimes necessary to operate LBNE can be achieved without evacuation
- MTS will continue operating, LAPD system will be used for LBNE membrane cryostat prototype

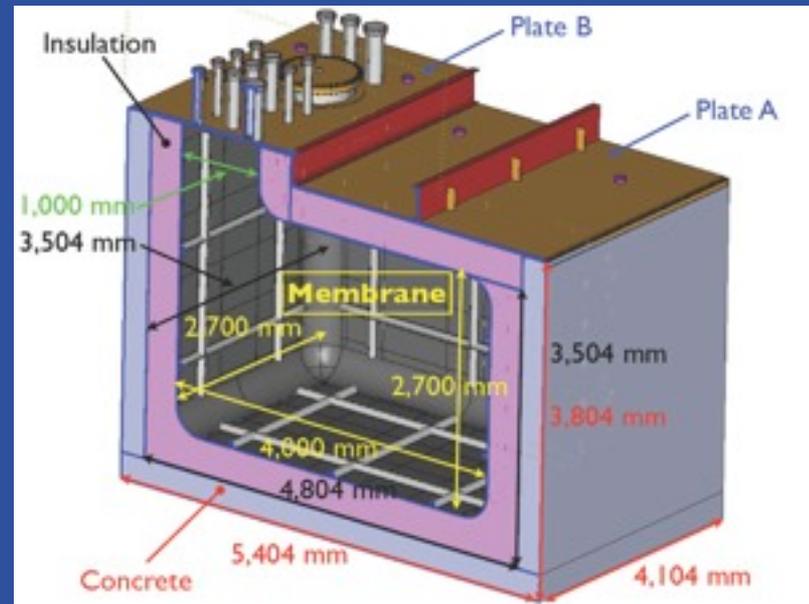
Carls (RA), Hahn, Jostlein, Lockwitz (RA), Pahlka (RA), Pordes, Plunkett, Rebel, Stancari, Yang (RA)



Development toward LBNE: Argon Purification

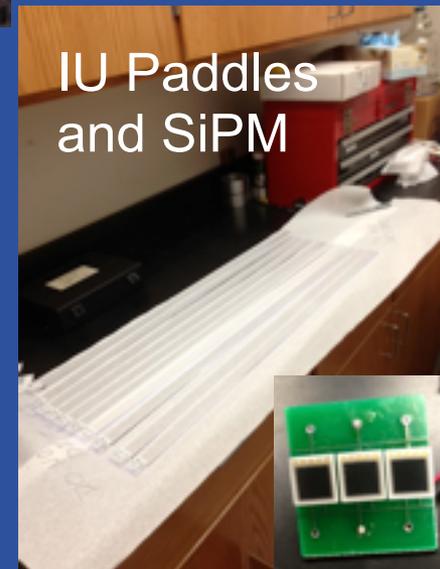
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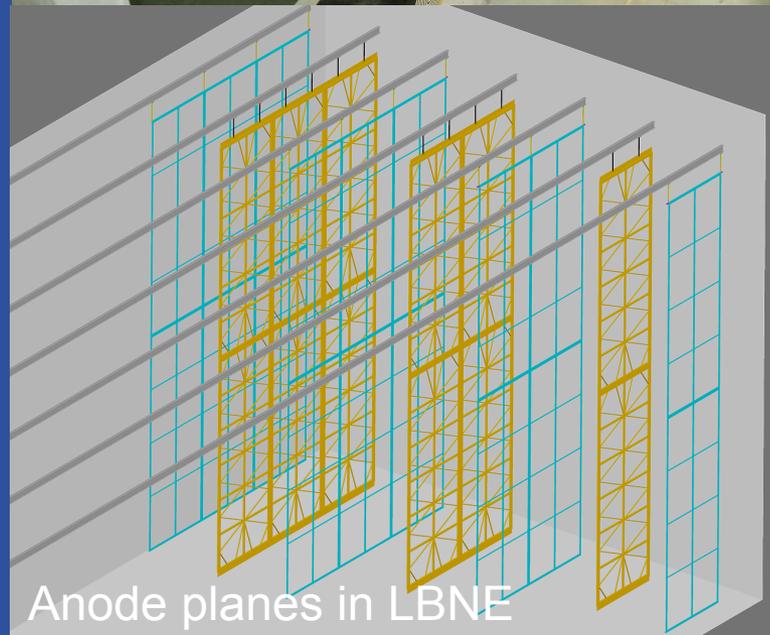
Development toward LBNE: Light Collection

- Fermilab hosts efforts to develop light collection techniques for MicroBooNE and LBNE
- **Pordes** and **Rebel** maintain the facility and organize university use
- MIT and St. Mary's groups have tested PMTs and related electronics for MicroBooNE; Indiana University will test paddles and SiPMs for LBNE
- **Escobar** is developing QA methods for accepting SiPMs for LBNE



Development toward LBNE: High Voltage and TPC

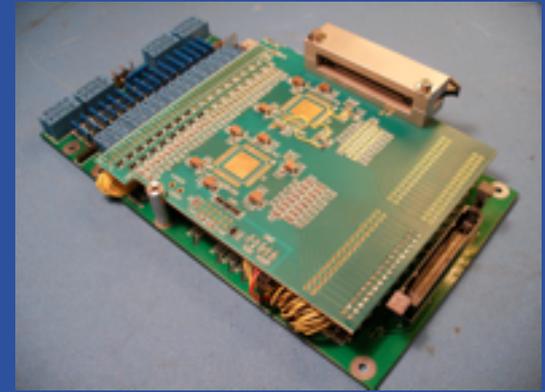
- Electric fields of 500V/cm means 25kV for each 50 cm of drift distance
- Development of HV feed throughs is a high priority for LArTPCs
- **Jostlein** and **Lockwitz (RA)** developing a stable feed through for use with Long Bo and MicroBooNE
- **Velev** and **Prokofiev** developing anode planes for LBNE, first tests will be in prototype detector



LArTPC Development: Electronics

- Fermilab collaborated with Michigan State University to develop electronics warm first, then cold
- Initial tests were on small TPC, expanded to 2 m TPC placed in LAPD (Long Bo)
- This new TPC is also using a version of the ASIC developed by BNL for MicroBooNE and LBNE
- Example of how the program continues to build on the existing infrastructure to get to the goal of multi-kiloton detector

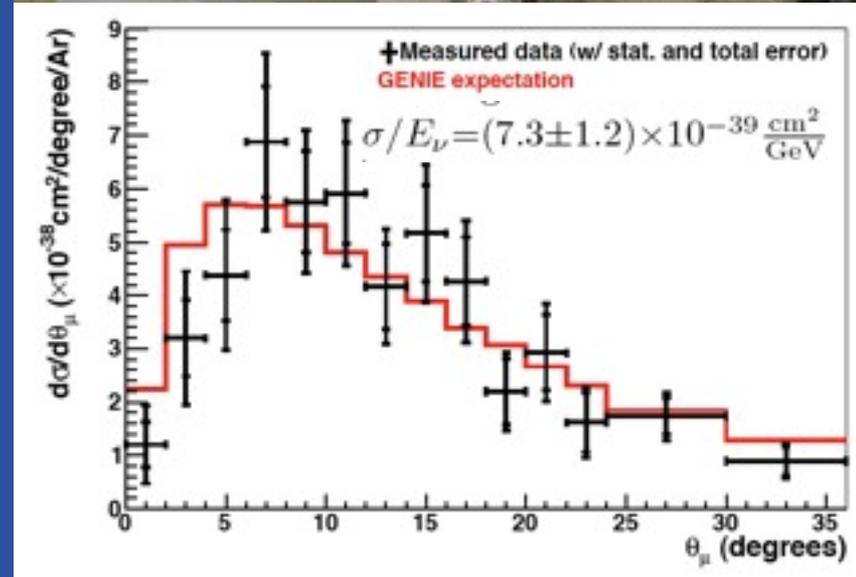
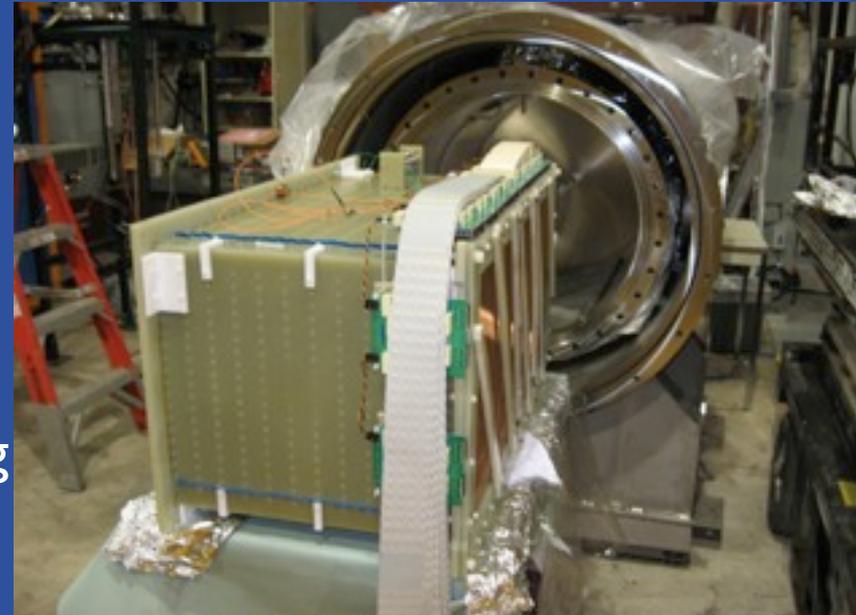
Carls (RA), Hahn, Jostlein, Lockwitz (RA), Pahlka (RA), Pordes, Rebel, Stancari, Yang (RA)



LArTPC Development: Test Beam and Calibration

- ArgoNeuT was first LArTPC in low energy neutrino beam, joint effort with Yale, Syracuse, MSU and others
- Major contributions from **Baller, James, Jostlein, Rameika, and Pordes** - enabled future R&D and experiments
- **Yang (RA), Baller and Zeller** contributing to analysis of ν -Ar cross sections
- **Raaf and Rebel** leading effort with Yale (Cavanna) and William and Mary (Kordosky) colleagues to initiate a test beam experiment - LArLAT
- Fills the need for understanding EM and hadronic shower energy resolutions
- Collaboration has 49 members from 19 institutions

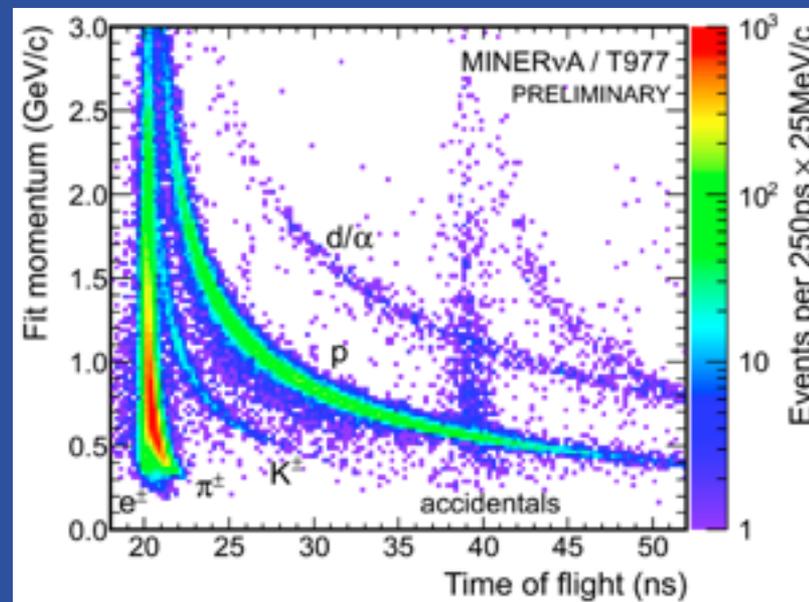
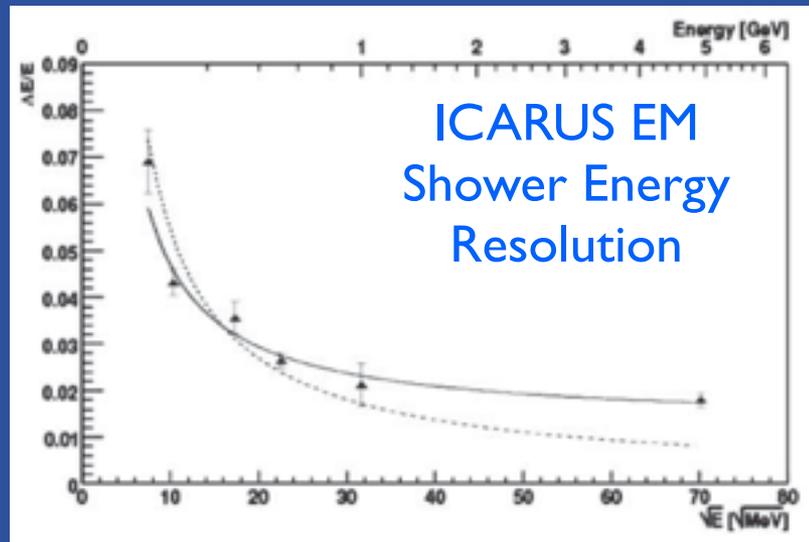
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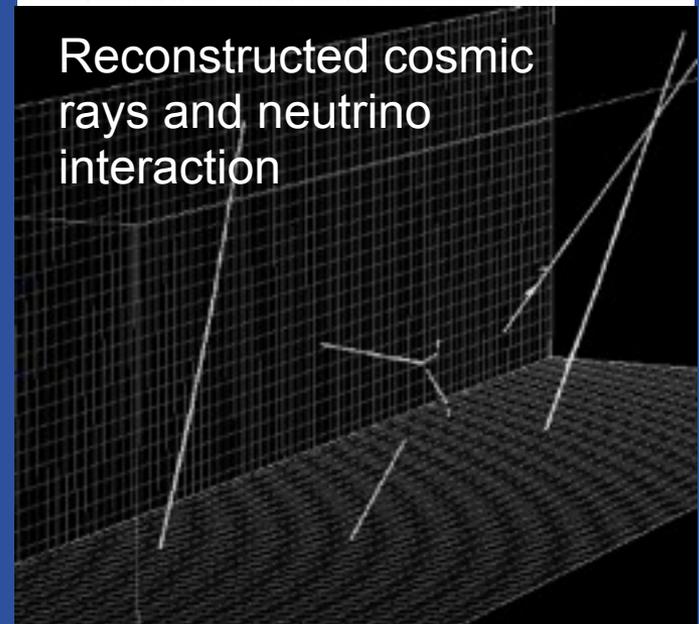
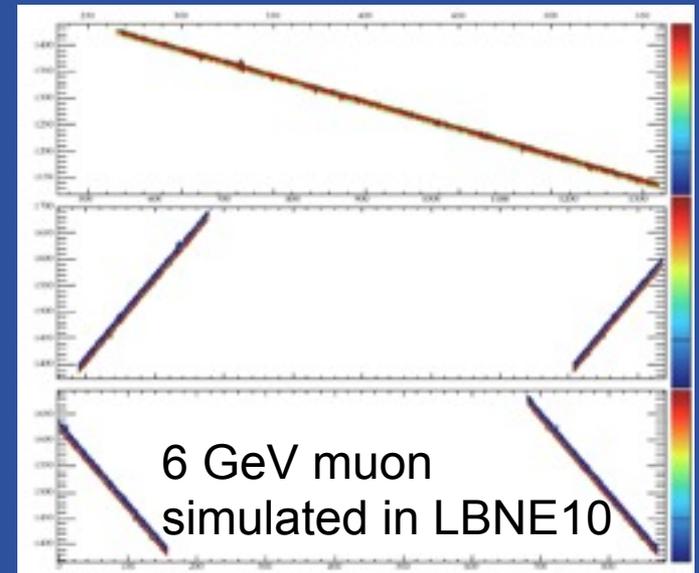
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LArTPC Development: Software

- LArSoft is simulation, reconstruction, and analysis software for any LArTPC experiments
- Contributions to LArSoft come from 36 collaborators spread over all LArTPC collaborations
- Makes use of the ART framework
- Led by **Rebel** and Church (Yale) until 2013
- **Snider** now managing the LArSoft project and building team to provide schedule, build system, and testing services
- Significant contributions from **Baller, Kirby, Greenlee, Junk, Yang (RA), Carls (RA), Lockwitz (RA)**

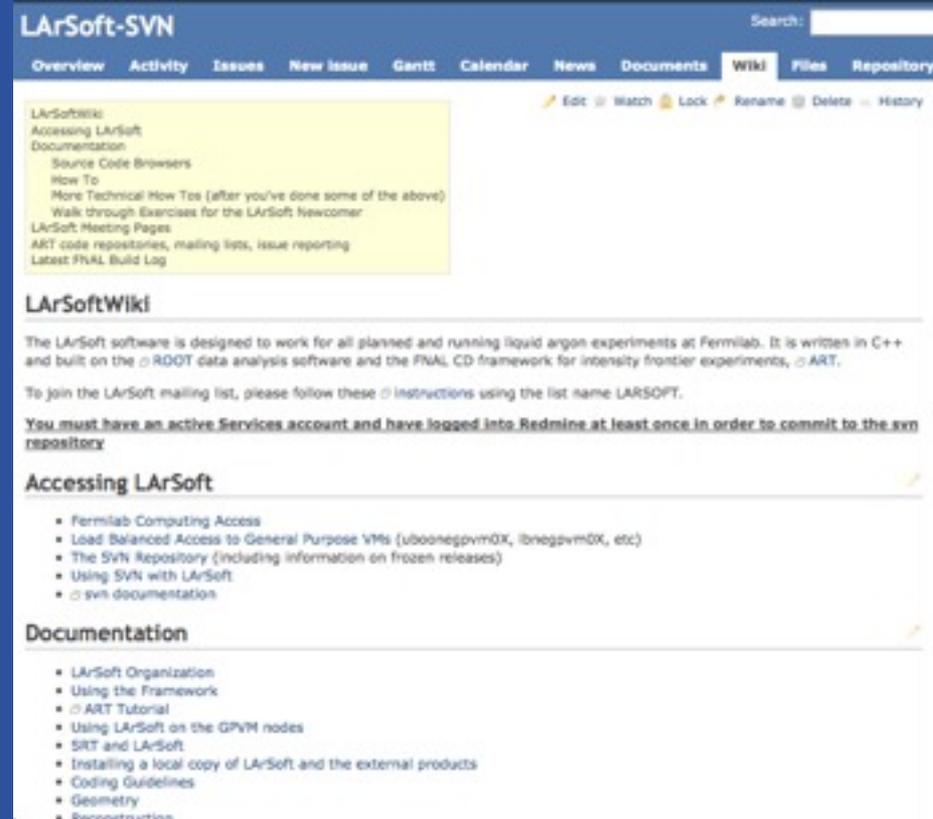


Summary

- Fermilab scientists play strong leadership roles in the long baseline program
- Wealth of experience in all areas of long baseline experiments: beam design and operation, detector construction, data analysis
- This experience makes it possible to operate the current generation of experiments while building the next
- Fermilab scientists facilitate and enhance participation of other labs and university groups in the long baseline program
- NOVA prototype experience crucial to making detectors work, Fermilab scientists key to making it happen
- LArTPC development facilities enable university groups to contribute to LBNE

Enabling LArSoft Contributions

- LArSoft is open source and available via svn repository
- Documentation is available from wiki hosted at Fermilab
- Precompiled versions of external packages available for users of SLF 5 and SLF 6 - also works with SLC
- Build scripts for all required packages provided to users not using SL, discussions of other operating systems to support is on-going
- Successfully installed at over 10 institutions; most prefer to work on Fermilab machines for access to data
- Extra support given to those that ask



The screenshot shows the LArSoft-SVN website interface. At the top, there is a navigation bar with tabs for Overview, Activity, Issues, New Issue, Gantt, Calendar, News, Documents, Wiki, Files, and Repository. A search bar is located in the top right corner. Below the navigation bar, there is a yellow box containing links for LArSoft documentation, including Source Code Browsers, How To, More Technical How Tos, Walk through Exercises for the LArSoft Newcomer, LArSoft Meeting Pages, ART code repositories, mailing lists, issue reporting, and Latest FNAL Build Log. Below this box, there is a section titled LArSoftWiki with introductory text about the software's design and build environment, and instructions for joining the mailing list. A warning message states: "You must have an active Services account and have logged into Redmine at least once in order to commit to the svn repository". Below this, there is a section titled Accessing LArSoft with a bulleted list of links: Fermilab Computing Access, Load Balanced Access to General Purpose VMs, The SVN Repository, Using SVN with LArSoft, and svn documentation. Finally, there is a section titled Documentation with a bulleted list of links: LArSoft Organization, Using the Framework, ART Tutorial, Using LArSoft on the GPVM nodes, SRT and LArSoft, Installing a local copy of LArSoft and the external products, Coding Guidelines, Geometry, and Reconstruction.