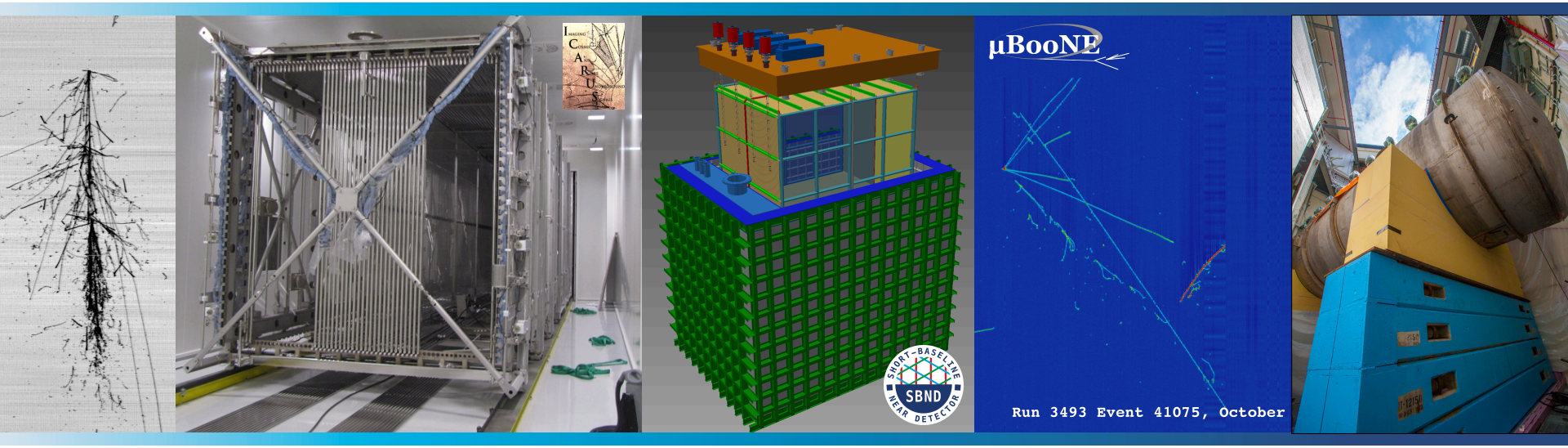
The Short-Baseline Neutrino (SBN) Physics Program at Fermilab



HEPAP Meeting, Newport Beach, CA

December 9-11, 2015

David Schmitz, University of Chicago

for the SBN Collaborations

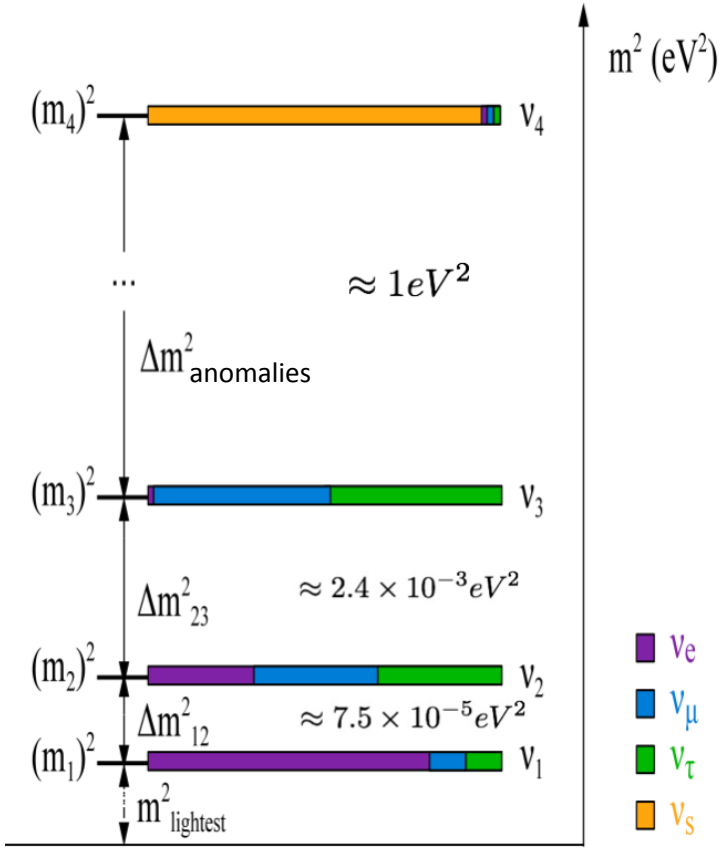
Outline: SBN Progress and Status

- Introduction to the SBN physics program
  - *Motivations and scientific capabilities of the three detector program*
- On-going analysis efforts and SBN coordination
  - *Analysis efforts: surface operation and cosmic background mitigation*
  - *Software development: requirements for a common LAr software environment*
  - *Technical coordination: electronics, DAQ, cosmic ray taggers, photon detectors*
- Technical progress of the SBN experimental program
  - *MicroBooNE progress (SBN phase-I now operational!)*
  - *Near detector (SBND) progress*
  - *Far detector (ICARUS) progress*
  - *Infrastructure at Fermilab*
  - *Beam improvements*
- SBN-DUNE coordination and synergies

The SBN Physics Program

Physics Beyond the 3-ν SM?

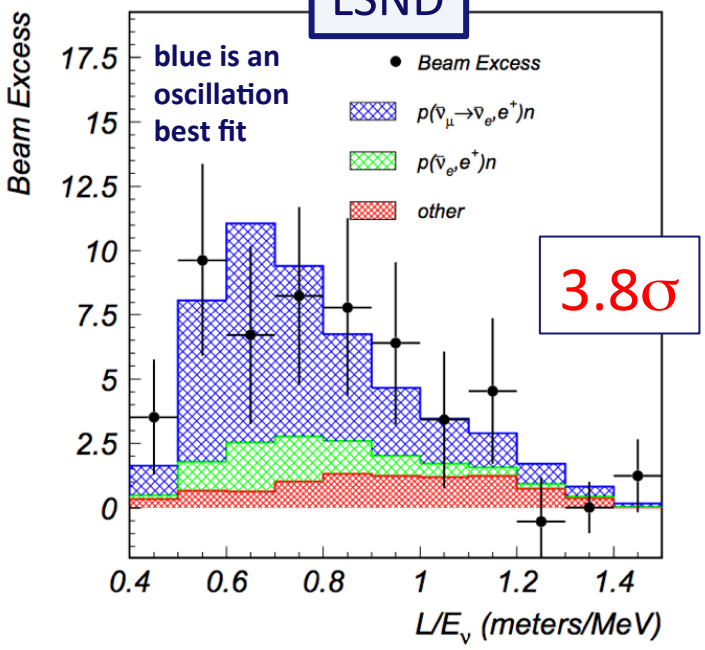
- In principle, oscillations can provide a window into particle sectors not accessible through SM interactions
  - *i.e. no strong, EM, or weak interactions*
  - *e.g. 'sterile' neutrinos*
- Turns out anomalies are present in some existing data
  - *While each of the measurements alone lack the significance to claim a discovery, together they could be hinting at important new physics*
- The SBN program will contribute directly to this question either by making a significant discovery or by ruling out oscillations in a range hinted at by previous results



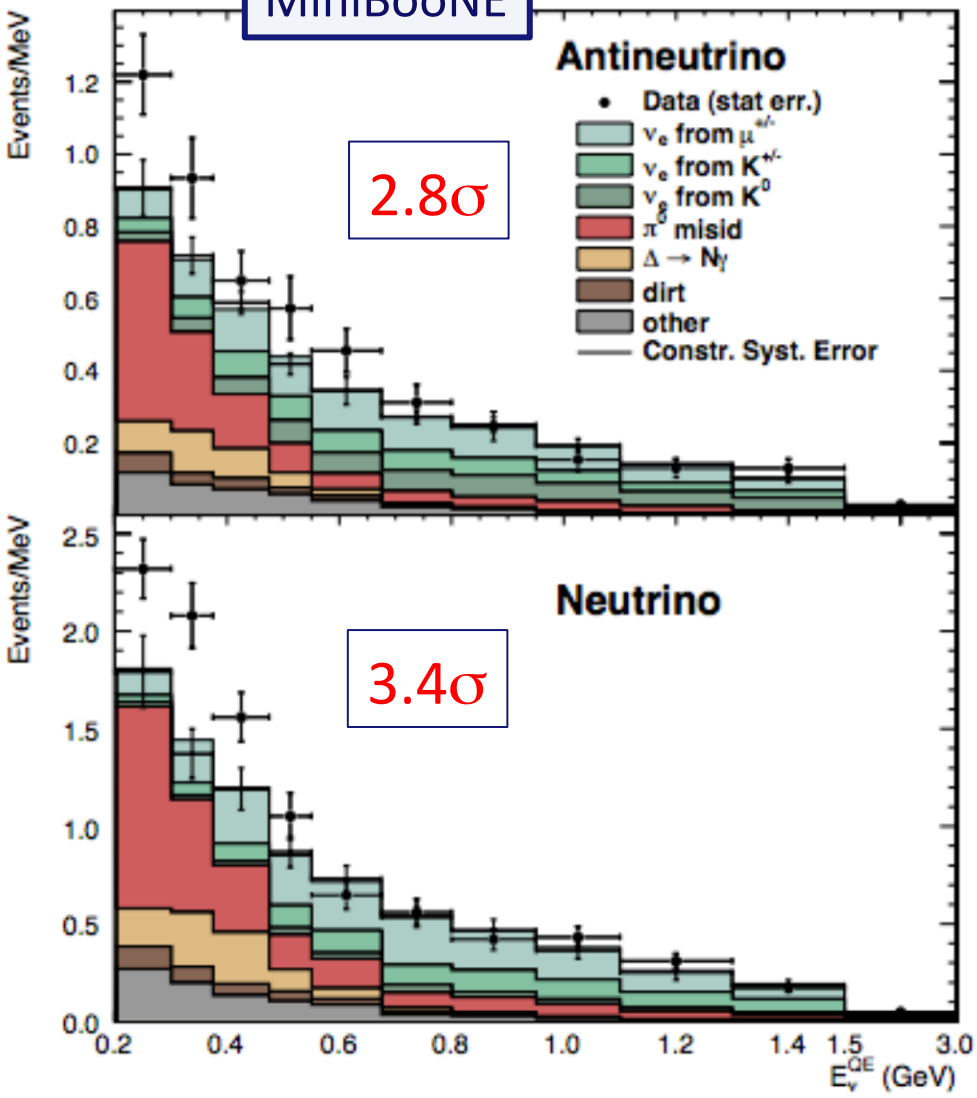
Very sensitive experiments are needed. Factor 10 smaller $\nu_\mu \rightarrow \nu_e$ oscillation probabilities than for θ_{13}!

Existing SBL (high-Δm^2) Anomalies (Accelerators)

LSND



MiniBooNE

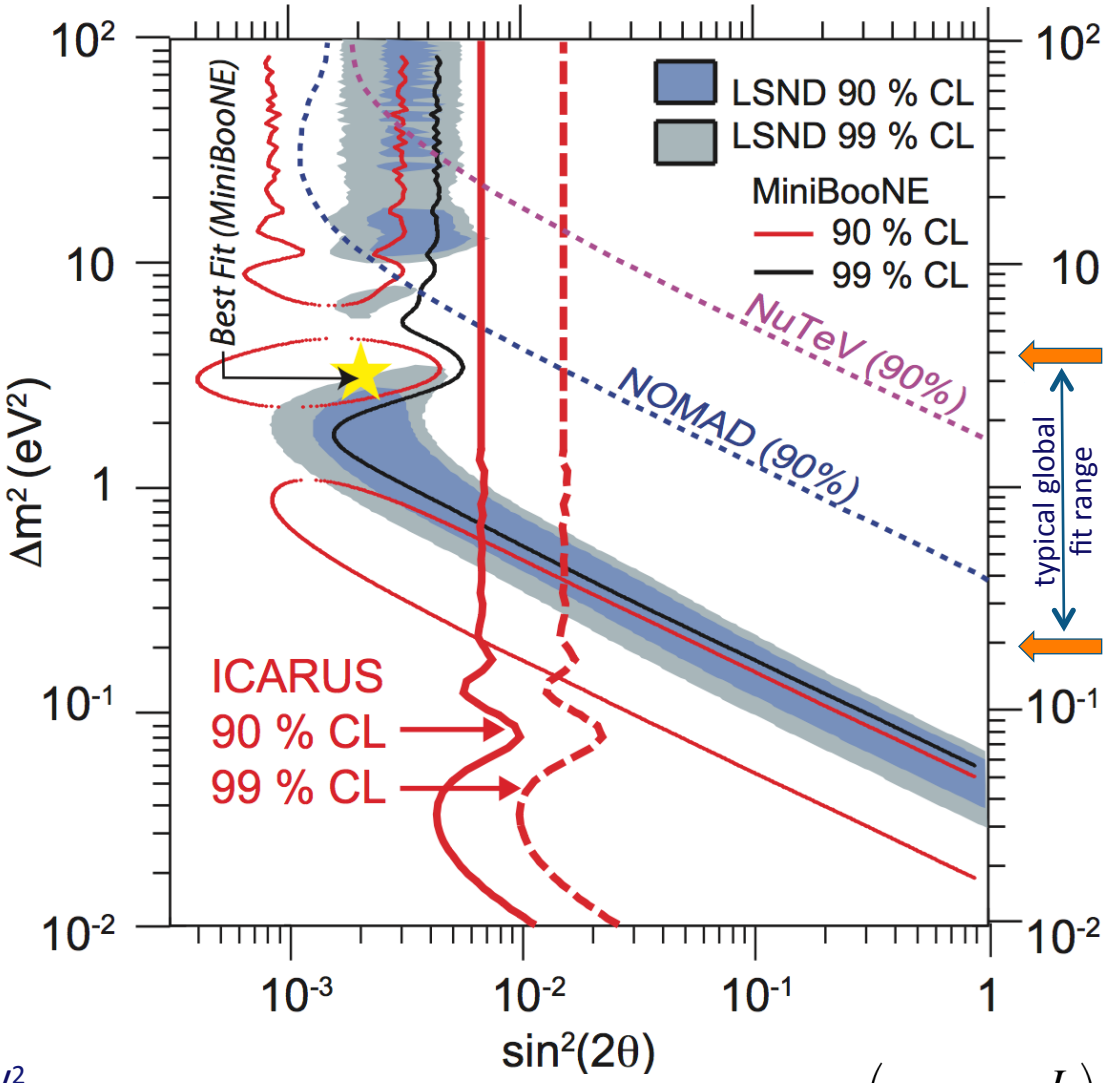


Are these results evidence of new physics or caused by challenging SM backgrounds? Could be important either way.

Unexplained results also from reactors and radioactive sources

Where to Look: Possible Sterile Neutrino Parameters

- Many global analyses that incorporate the positive and null results available
  - *Kopp et al.*
  - *Conrad et al.*
  - *Giunti et al.*
  - *others*
- Positive signals in $\nu_\mu \rightarrow \nu_e$ (and antineutrino) and ν_e disappearance (and antineutrino)
- No evidence for ν_μ disappearance



Recall the standard active neutrino mass splittings are down here at 10^{-3} and 10^{-5} eV^2

$$\ldots * \sin^2\left(1.27\Delta m^2_{ij}\frac{L}{E}\right)$$

Science Goals of the SBN Program

- Directly follow-up on the **MiniBooNE neutrino anomaly** by utilizing the LArTPC technology to determine the composition of the observed excess as electrons or photons (Phase I)

- Apply the advantages of the LArTPC technology and *multiple detectors at different baselines* to the question of high-Δm^2 **sterile neutrino oscillations**, testing current allowed oscillation parameters at $\geq 5\sigma$ (Phase II)

- Study ν-Argon interaction physics using **millions of events** from both the Booster and Main Injector neutrino beams at Fermilab

- Further **develop the LArTPC technology** toward the aim of applying it at very large scales for long-baseline physics in DUNE

SBN Program, A Brief History

- At the January 2014 meeting of the Fermilab Physics Advisory Committee (PAC), two new proposals were put forward:
- P-1052: ICARUS@FANL
  - *Proposal to relocate the existing ICARUS-T600 LArTPC detector to the BNB and to construct a new one-fourth scale detector based on the same design to serve as a near detector for oscillation searches*
- P-1053: LAr1-ND
  - *Realizing the physics program enabled in a first phase with a near detector in combination with MicroBooNE, LAr1-ND was proposed as the next phase in the BNB program (to possibly be followed by 1kton scale far detector later, LAr1).*

"The PAC encourages the [groups] to formulate a common Short-Baseline Neutrino Experimental program for FNAL."

- Soon after, proponents of the LAr1-ND and ICARUS proposals, members of the MicroBooNE collaboration, as well as representatives from Fermilab, INFN, and CERN started working together to develop a plan for a coherent SBN physics program

2014 P5 Recommendations

P5 Report, May 2014

Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.

Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.

The SBN Proposal

- Returned to the PAC in January 2015 with a scientific proposal and conceptual design report for the program:

A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

Submitted jointly by ICARUS, MicroBooNE and SBND (LAr1-ND)
http://arxiv.org/abs/1503.01520

Part I: SBN Physics Program

Part II: Near Detector Conceptual Design

Part III: T600 Design and Refurbishing

Part IV: Infrastructure and Civil Construction

Part V: Booster Neutrino Beam

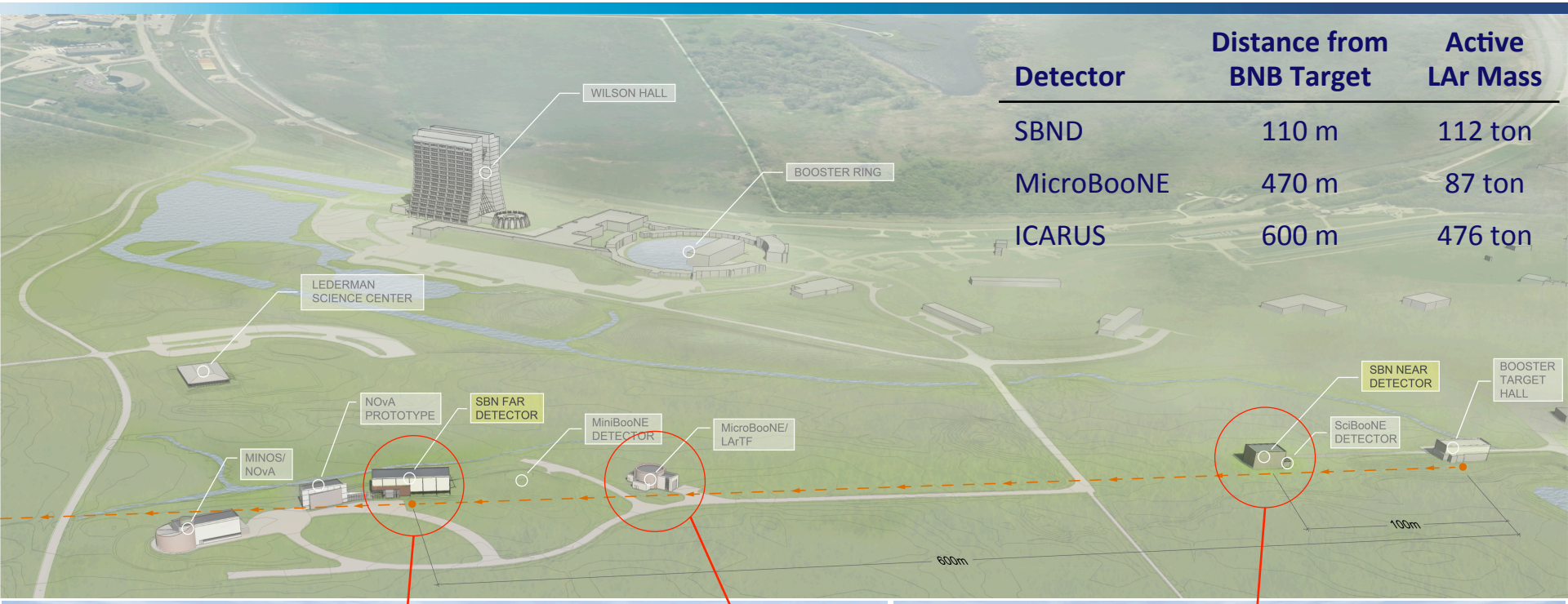
Part VI: Coordination and Schedule

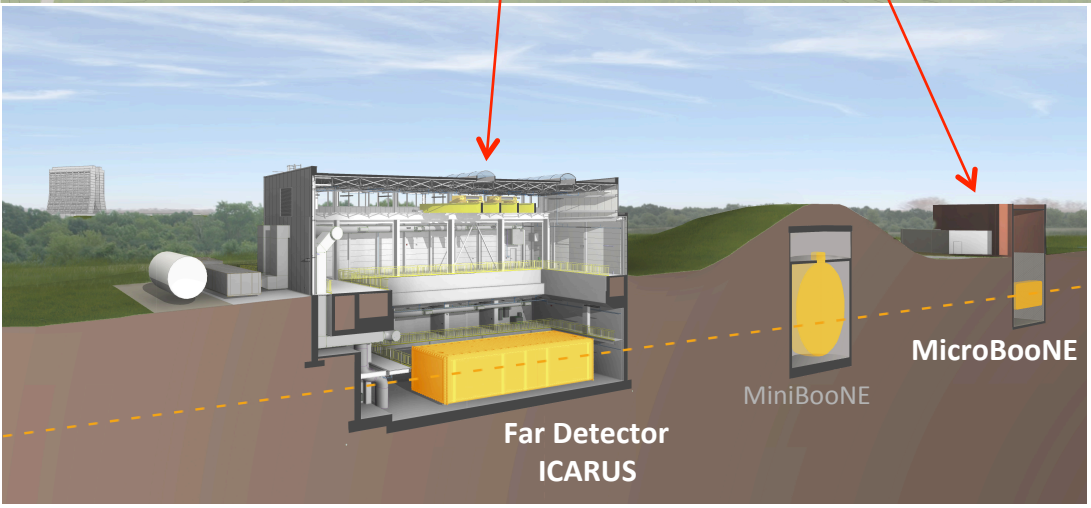
218 authors from 22 US and 23 non-US institutions

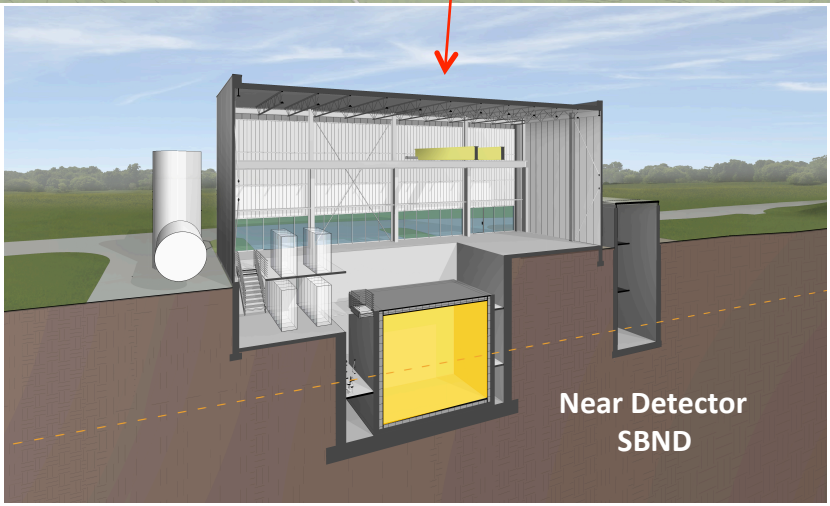
Collaborations have all continued to grow through 2015

The Three-Detector SBN Program

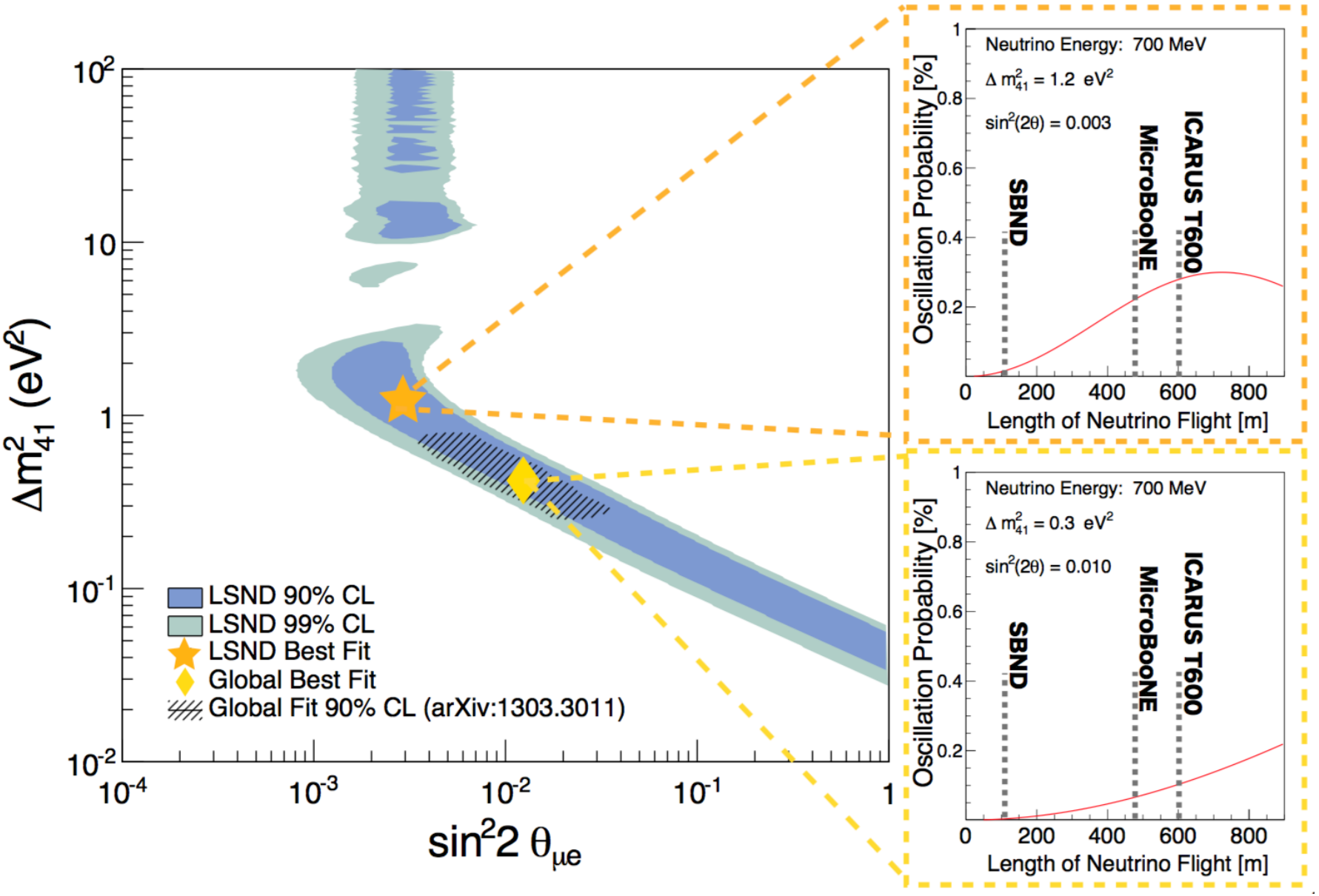
Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton



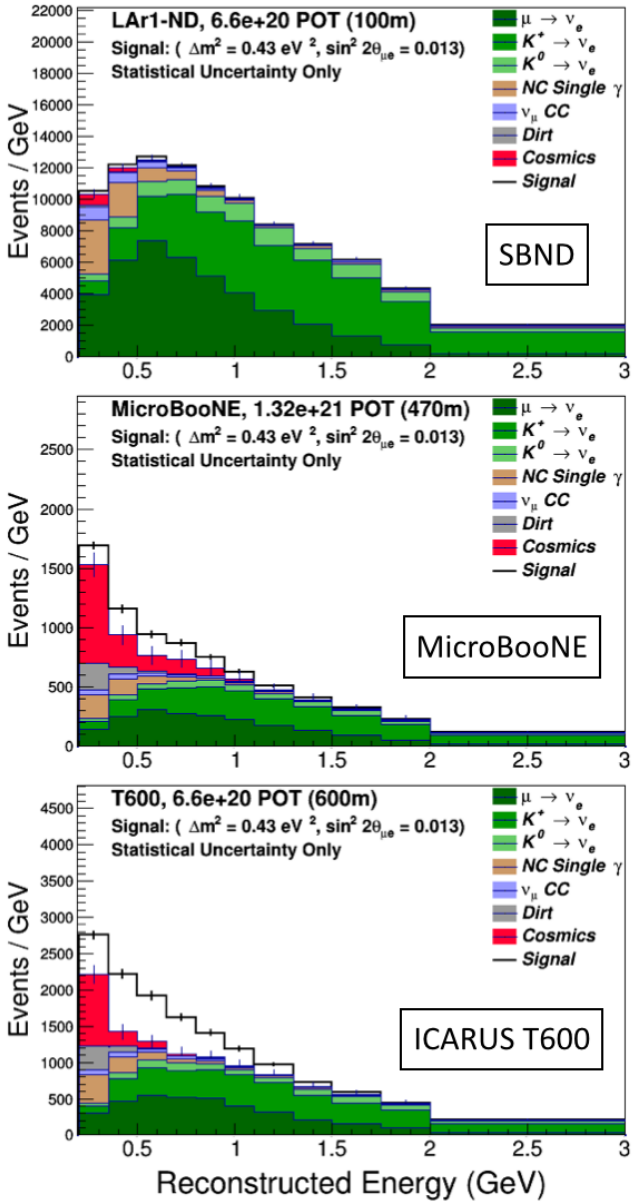




Sample 3+1 Oscillation Signals in SBN

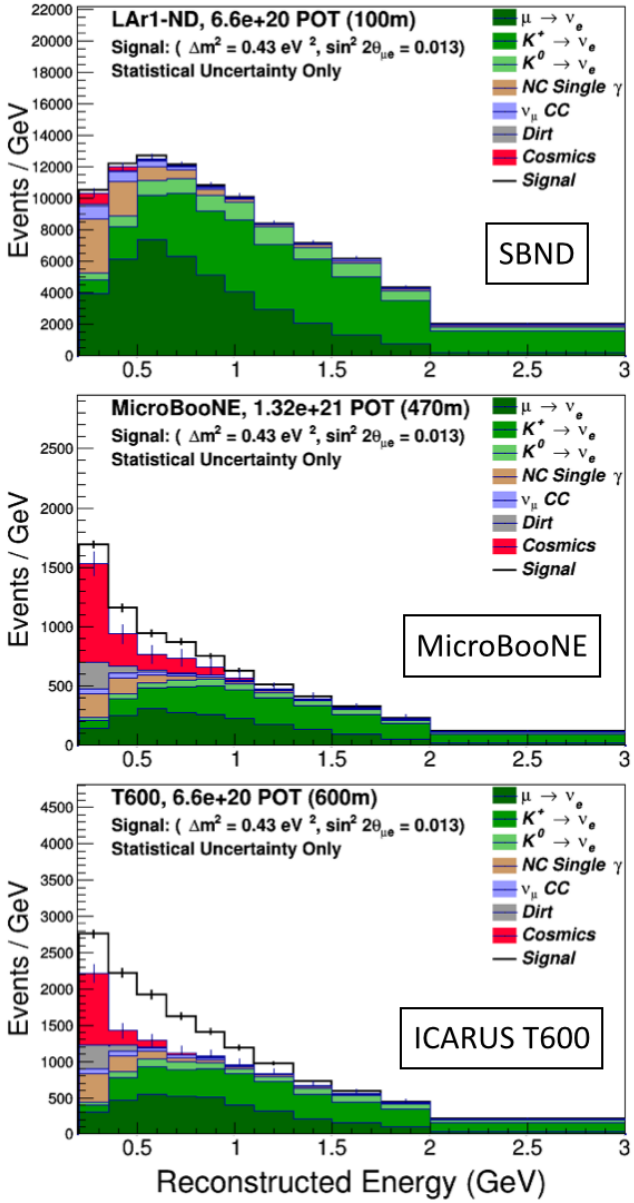


SBN Oscillation Sensitivity Analysis

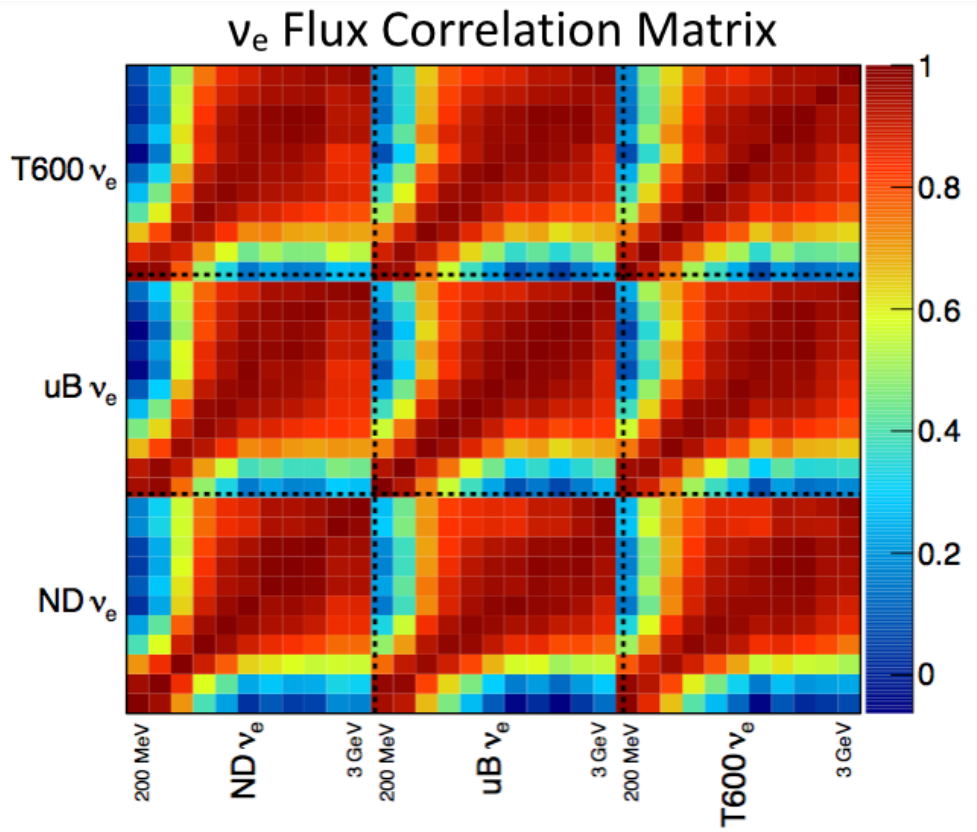


- For sensitivity calculations, event samples were generated in all three detectors using common simulation tools, and…
- Datasets analyzed simultaneously in a common framework in order to properly account for correlations (the key to systematic uncertainty cancelations)
- Advanced simulation tools were used:
  - *Applied the full G4 simulation of BNB neutrino fluxes developed over ~10 years by MiniBooNE and based on dedicated hadron production data from HARP*
    - **Phys. Rev. D79, 072002 (2009)**
  - *Used a standard neutrino interaction event generator (GENIE) that many experiments have used to analyze and publish data (MINERvA, T2K, etc.)*
    - **Nucl.Instrum.Meth. A614 (2010) 87-104**

Flux and Cross Section Systematics

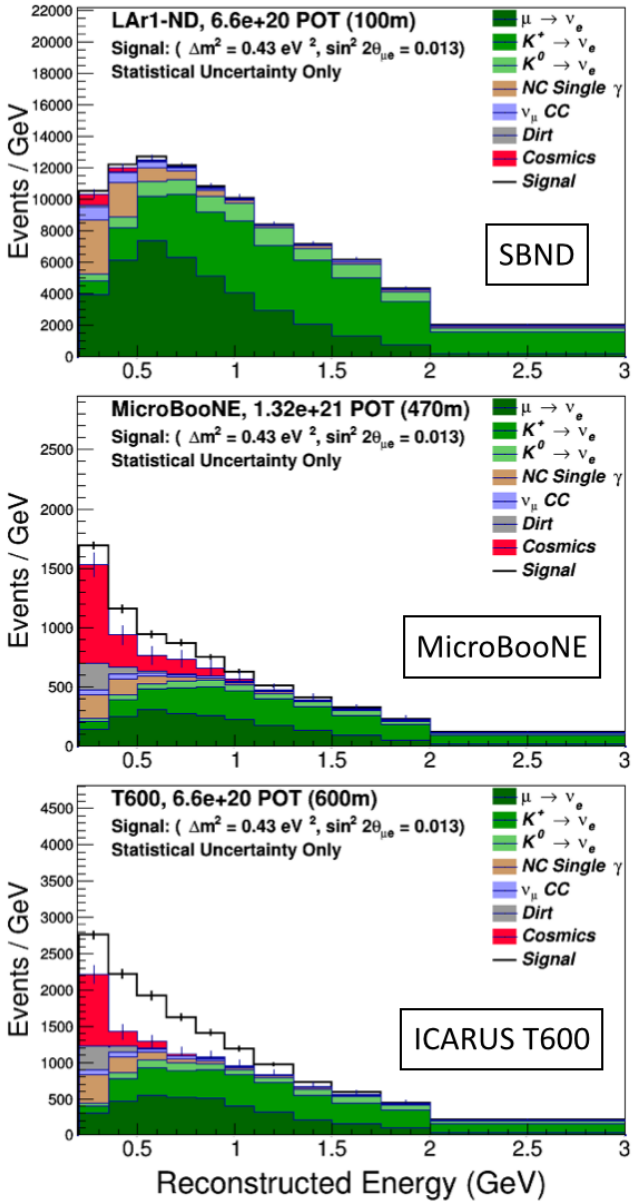


- Systematics utilities within G4 flux simulation and GENIE used to quantify the correlations between data samples



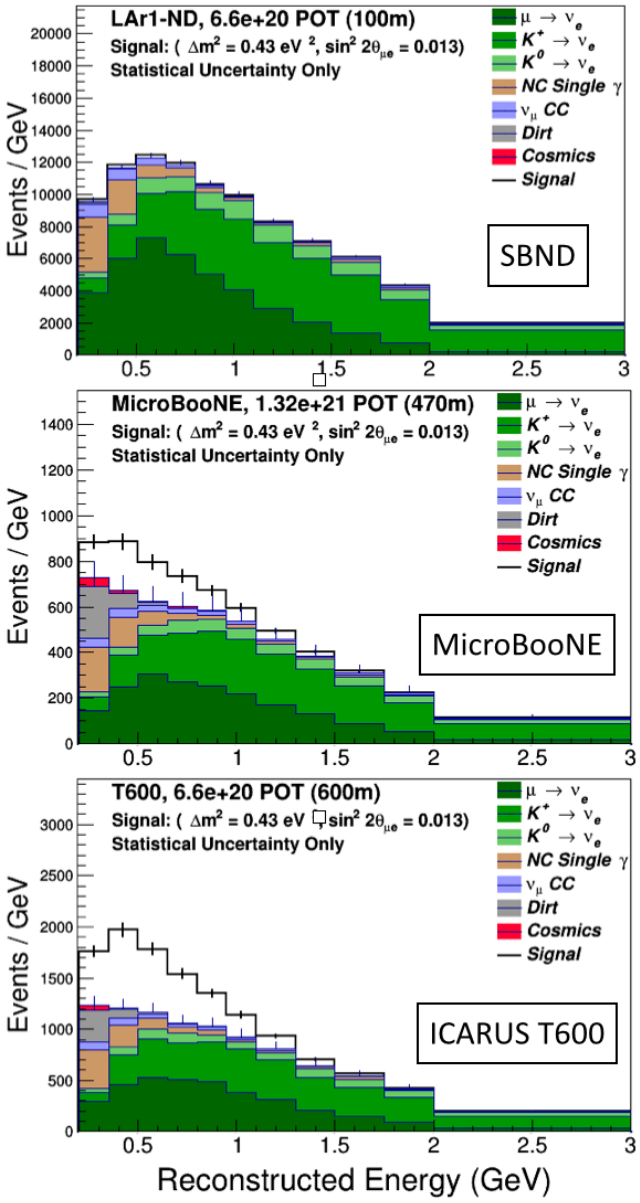
Similar matrix for neutrino interaction systematics
Similar matrices for ν_μ

Cosmogenic Backgrounds

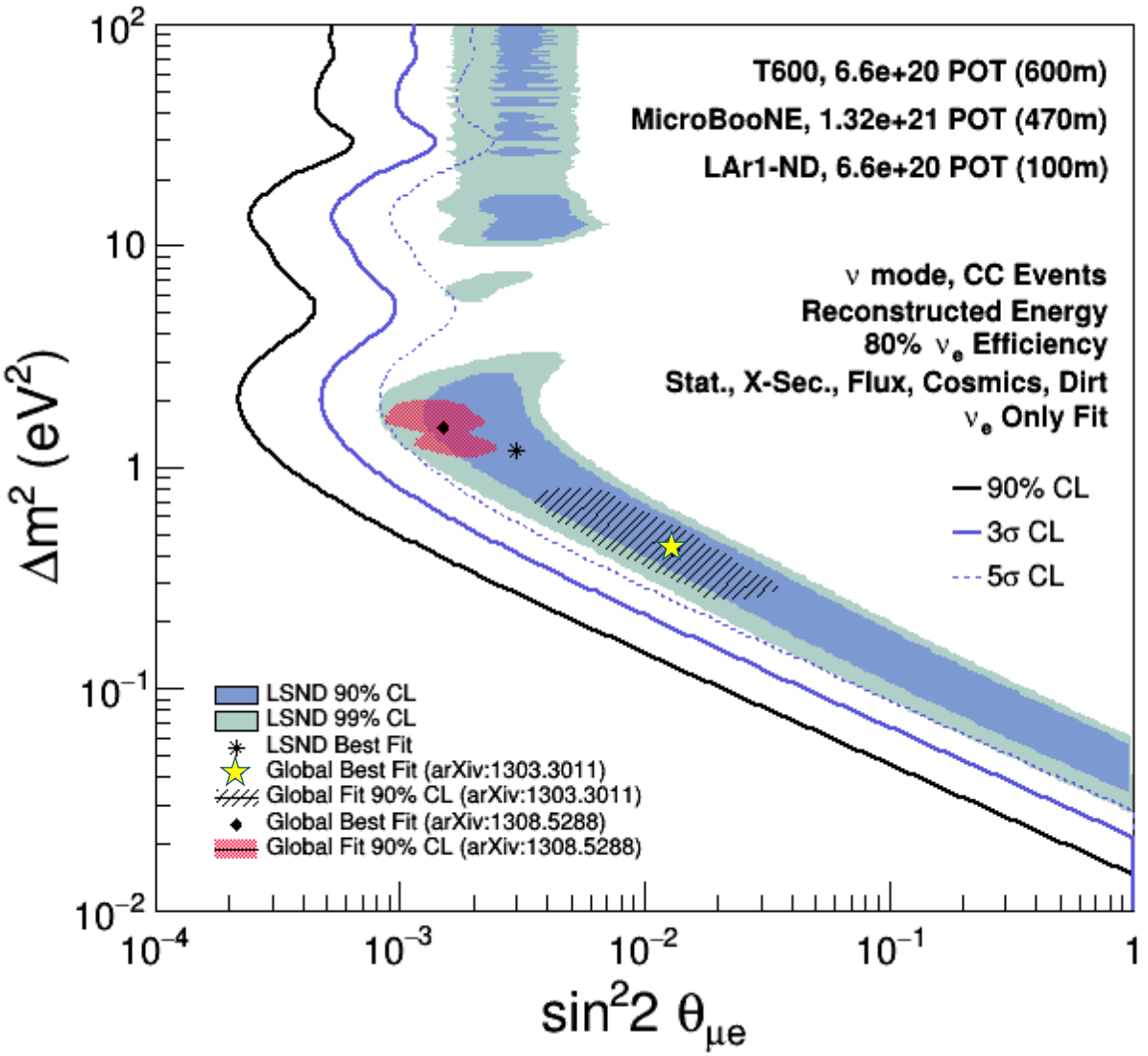


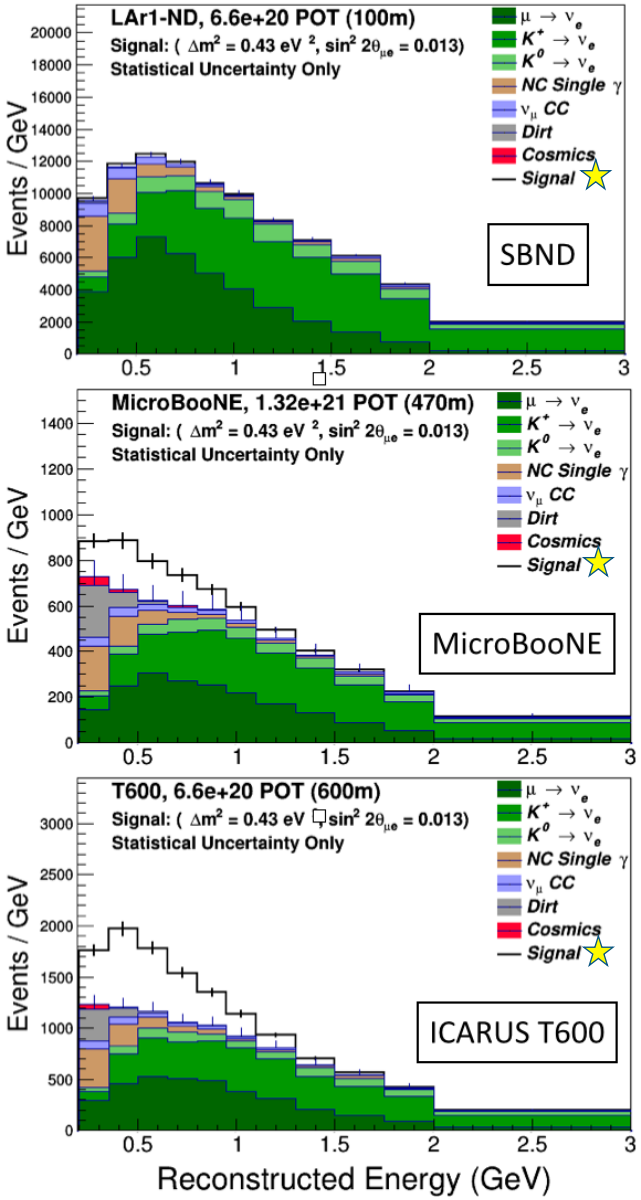
External cosmic ray tagger (CRT) systems can be employed to identify contaminated beam spills

Off-beam triggers can be used to measure cosmic backgrounds to high precision so small systematic uncertainties - all about statistics

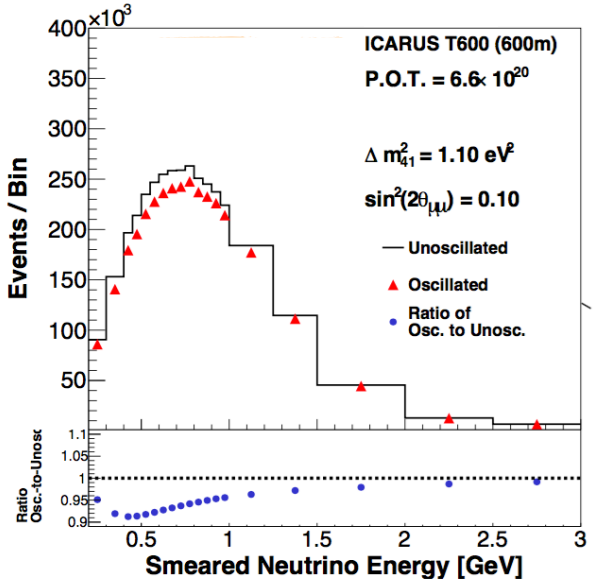


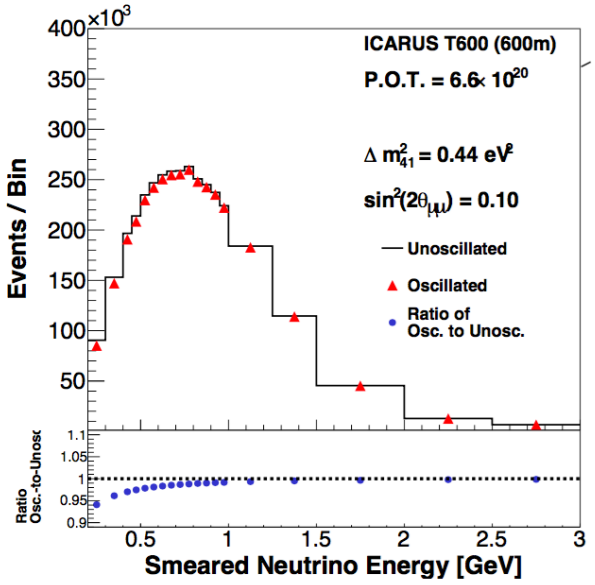
SBN $\nu_\mu \rightarrow \nu_e$ Oscillation Sensitivity

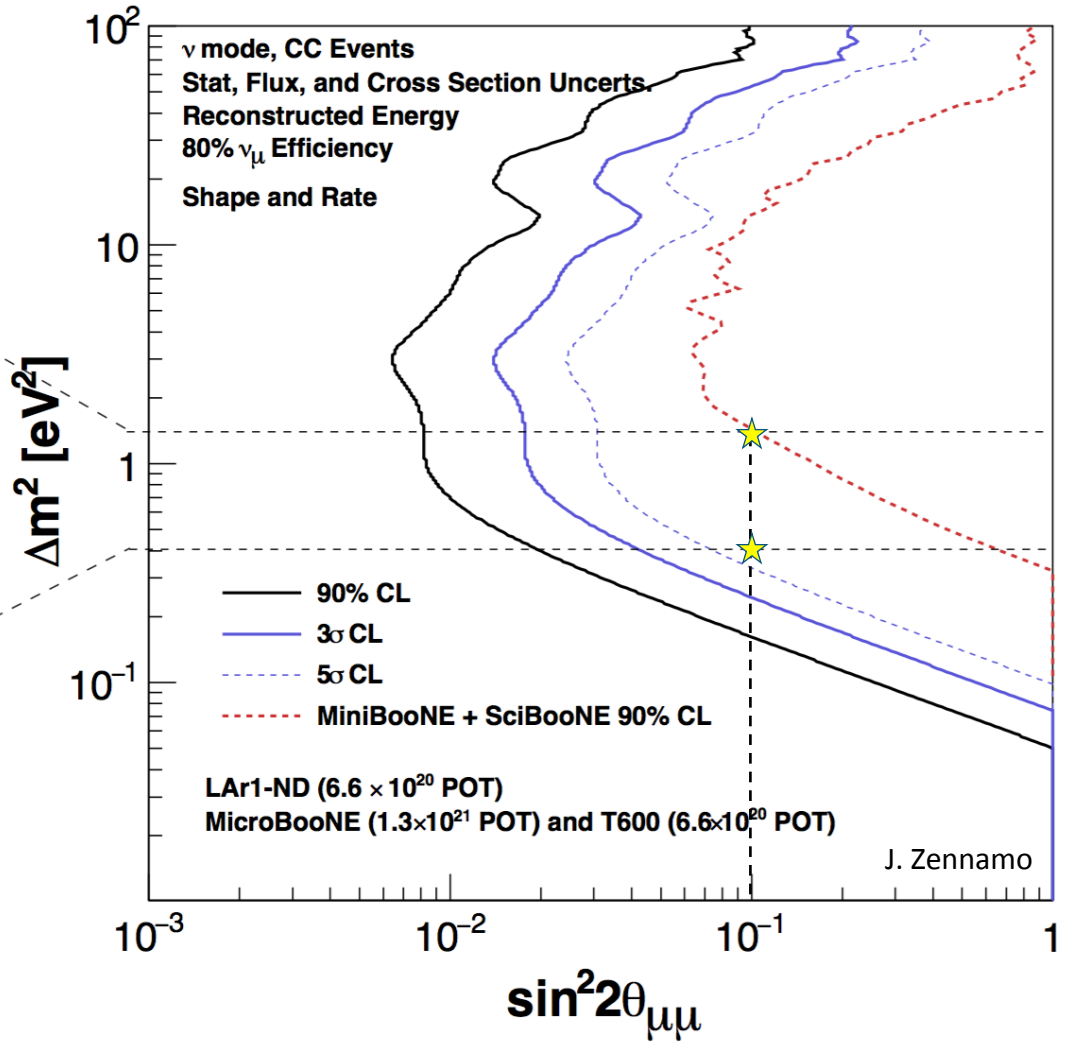




SBN ν_μ Disappearance Oscillation Sensitivity

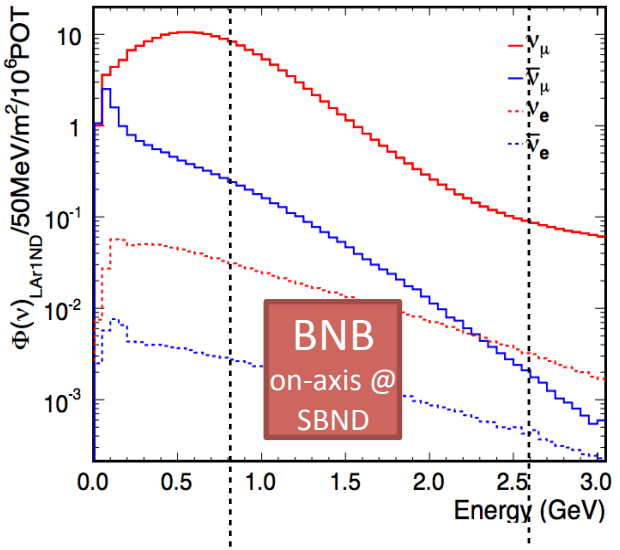






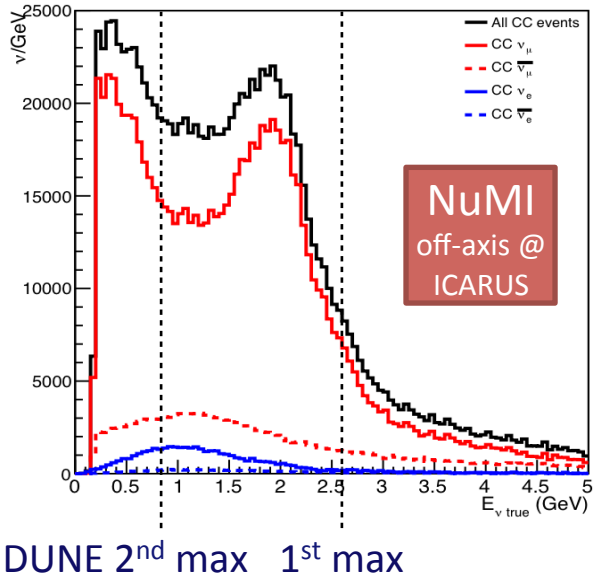
Neutrino Cross Sections, Analysis Dev.

- SBN detectors will collect **huge data sets on argon** from the BNB on-axis and the NuMI off-axis fluxes
  - *SBND will record ~1.5M neutrino interactions (7,000 ν_e) in the fiducial volume per 2.2e20 POT (~year running)*
  - *Large complementary samples in T600 and MicroBooNE (already started!)*
  - *Order 100k NuMI off-axis events in the T600 per year*



- Precision studies of neutrino-argon interaction physics
  - *Even rare channels like coherent scattering, strange production, ν-e elastic scattering, etc.*

- Large data sets will push development of LAr reconstruction and analysis techniques, having direct impact for long-baseline physics using LAr in the future



Continuing Analysis Efforts and SBN Coordination

SBN Program Coordination

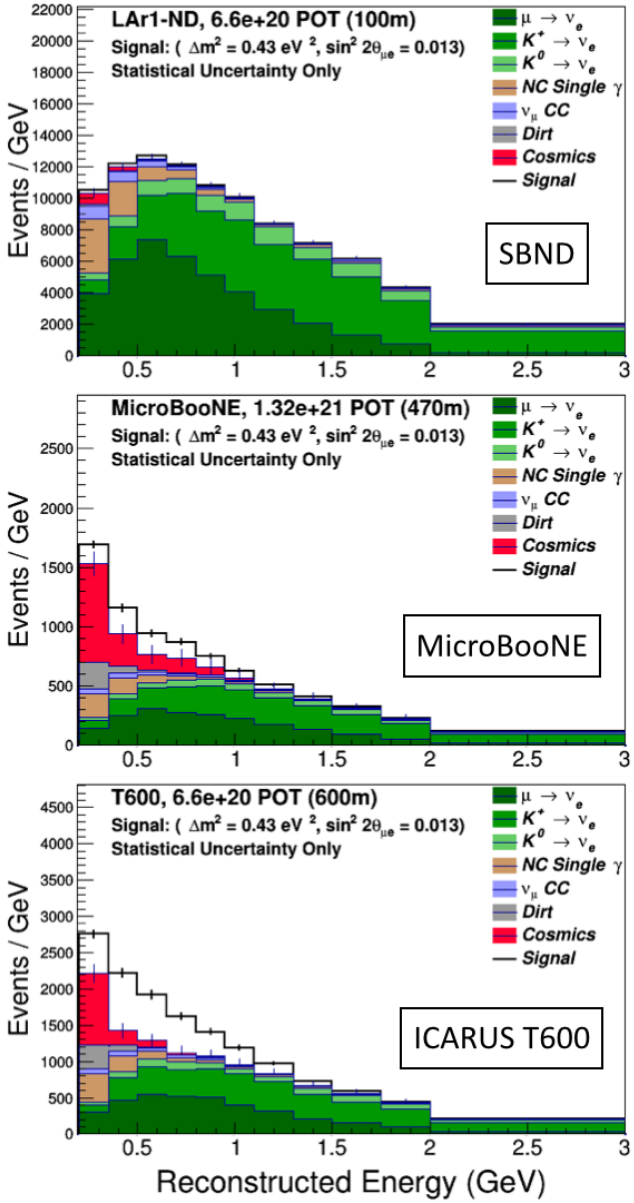
- Program benefited enormously by a dedicated **SBN Program Office** within Neutrino Division at Fermilab
  - *Coordinator: Peter Wilson*
  - *Deputy Coordinator: Cat James*
  - *Program mechanical and electrical engineers*
  - *Program-wide project controls for cost and schedule*
- Program managed as a combination of in-kind contributions and Fermilab managed DOE funded deliverables
  - *Major infrastructure contributions by FNAL (civil design and construction, electrical design, detector installations, etc.) and CERN/FNAL (cryostats and cryogenics)*
- Also assist coordination between collaborations, plan reviews, etc.

http://sbn.fnal.gov/

Since January 2015

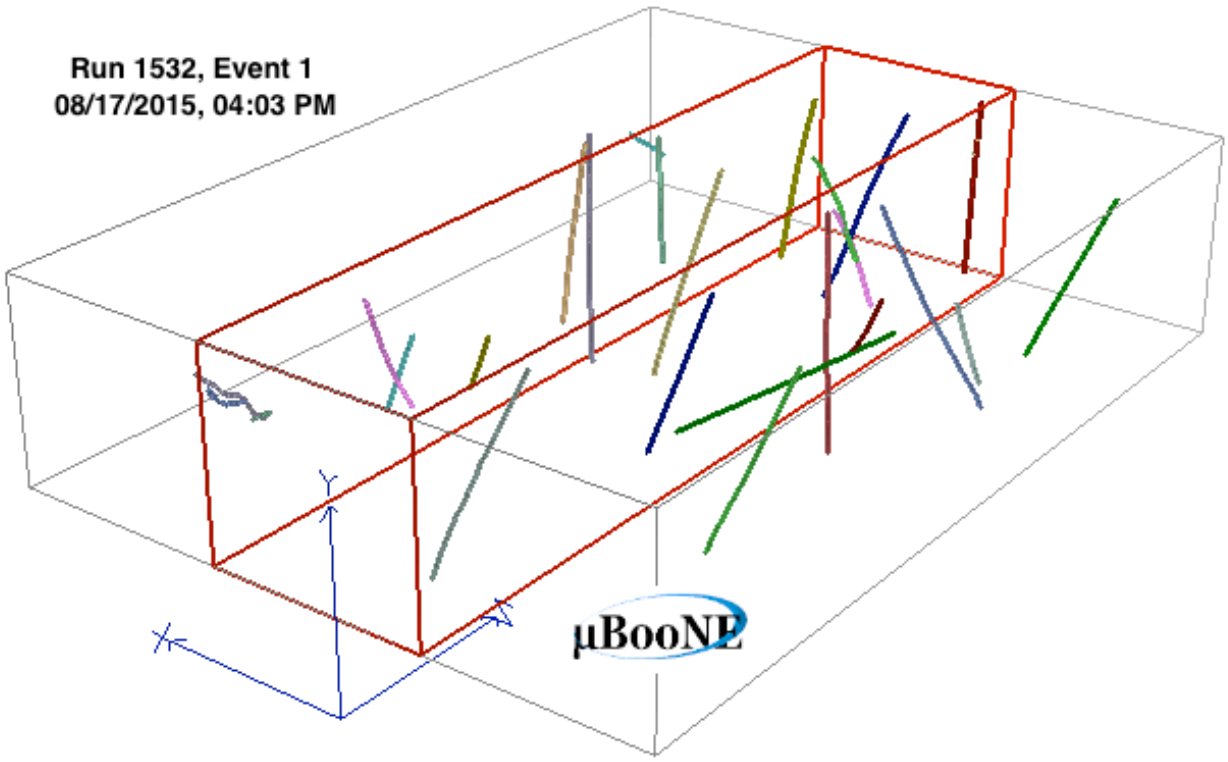
- Development of the SBN physics proposal was spearheaded by a five member Task Force representing FNAL, CERN, and the three collaborations as well as a set of Working Groups with co-conveners and members drawn from each of the collaborations
  - *4 WGs: flux and systematics, cosmics, cryogenic infrastructure, civil construction*
- Following the proposal, SBN Executive Board consisting of collaboration spokespersons and SBN Program Coordinator formed to facilitate continued communication
- With Stage 1 approval granted after the January 2015 PAC, focus of collaborations has been on detector design, construction, and operation - Excellent technical progress in 2015!
- Analysis and software development has continued in parallel with both short- and long-term aims
  - *Emphasis tends to be where input is needed for detector or program design… e.g.→*

Mitigation of Cosmogenic Backgrounds



- The problem: 1000x longer charge drift time than the beam spill time!

1.6 μs beam spill vs. 1-2 ms TPC drift time



MicroBooNE cosmic data with 3D reconstruction!

Mitigation of Cosmogenic Backgrounds

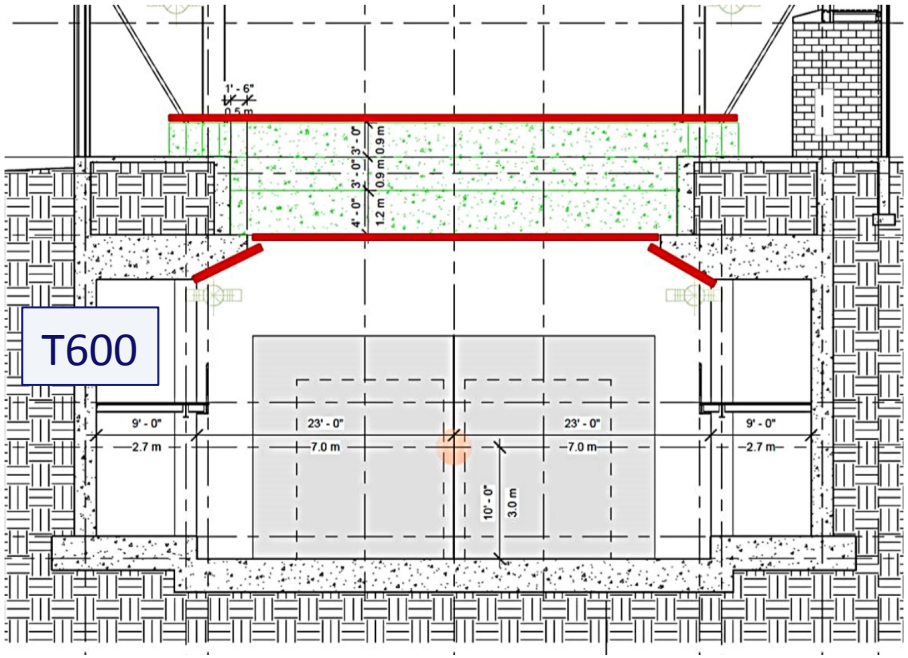
- Both the near and far detector buildings have been designed to accommodate up to 3m of concrete shielding directly above the detectors

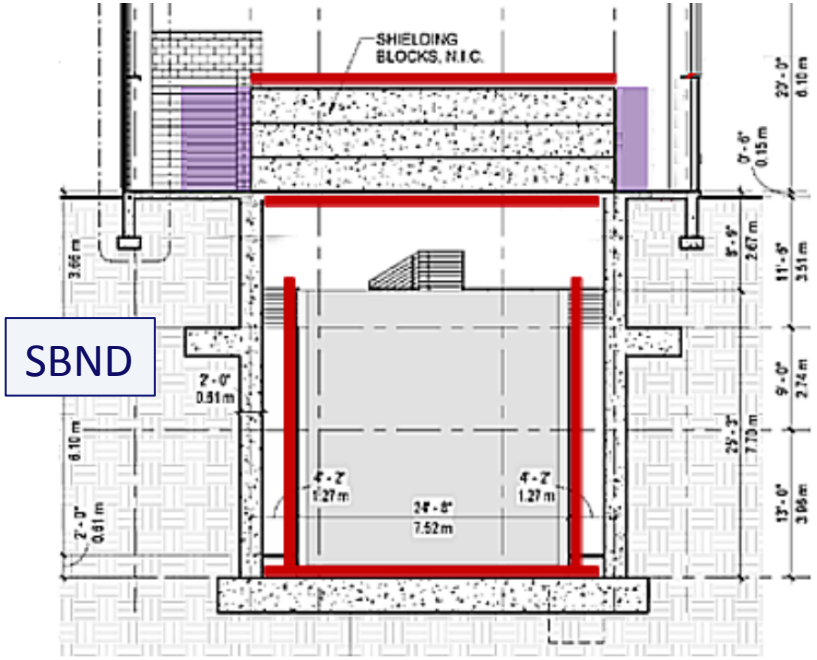
- Overburden provides significant rejection power for many ν_e-like backgrounds induced by cosmic rays other than muons
  - *Near 100% reduction of **primary** protons, neutrons, pions, and gammas that enter the TPCs without OB*
  - *Modest increase in **secondaries** generated in OB (e.g. 1% increase in secondary protons and 7% increase in secondary neutrons with 3m concrete OB according to a recent SBND simulation study)*

- This leaves photons generated by cosmic muons near or inside the detector as the primary source of cosmogenic backgrounds in the ν_e analysis

Cosmic Ray Tagger Design

- Significant analysis effort has continued by the collaborations
  - *What is the optimal configuration of the CRT systems for tagging the most problematic muons?*
  - *What are the requirements on spatial and time resolutions, number of layers?*
  - *What is the level of inadvertent vetoing of FV neutrino interactions?*





SBN Cosmogenic Task Force

Fermilab

SBN Program
Neutrino Division
630.840.2156 (phone)

Memorandum

29-Nov-2015

To: SBN Spokespeople

From: Peter Wilson, SBN Program Coordinator

Subject: Task Force on Cosmic Ray Mitigation for SBN Detectors

A Cosmic Ray Background taskforce is being created to more clearly define the requirements and implementation of the overburden and cosmic ray tagger systems for the SBN detectors. The taskforce membership will consist of experts and interested parts from all three SBN experiments. The conveners will consist of one representative from each of the experiments. A preliminary report from the task force should be provided by January 31, 2016.

• • •

Joint Task Force *charged with assimilating available information and performing any new analysis needed to address specific questions related to overburden and CRT systems including: OB thickness, CRT design and performance requirements, identification of areas where common technical solutions could be used for multiple detectors.*

Analysis Software Coordination

- LArSoft provides a common software infrastructure for the sharing of reconstruction and simulation codes used by different liquid argon TPC experiments
  - *MicroBooNE, SBND, DUNE, ArgoNeuT, LArIAT, etc. users of LArSoft framework*
  - *ICARUS, of course, developed their own analysis software for their Gran Sasso physics run before start of the LArSoft project*
  - *ICARUS reconstruction workshop held at CERN in July included LArSoft experts from Fermilab and reconstruction developers from MicroBooNE*
- Steering Group of experiment spokespeople formed over the past 12 months meets with LArSoft team ~monthly to drive developments, prioritize work, and plan for the future
- LBNC Chair, David MacFarlane, also working with the groups – to receive reports on assessment, planning and future work for software and analysis for the LArTPC-based experiments

Analysis Software Coordination

- Software workshop with all stakeholders held at Fermilab in October
  - *Organized and attended by Fermilab and CERN computing experts together with representatives from SBN (MicroBooNE, ICARUS, and SBND), DUNE, and LArIAT, the LAr test beam experiment at Fermilab*
  - *Reviewed status of reconstruction development among the groups*
  - ***Primary goal**: To define requirements for a LArTPC software platform that will support the analysis needs of LArTPC experiments over the next ~decade*
  - *Requirements document now in draft, authored by workshop participants*
    - https://cdcvs.fnal.gov/redmine/projects/lartpc-requirements/repository/revisions/master/entry/new-document/requirements.pdf
  - *Some examples: **i)** physics algorithm performance, **ii)** ability to use multiple physics algorithms in end-to-end analysis of data, **iii)** increased functionality of event visualizations, **iv)** enable effective use of multi-core and new computer hardware technologies, **v)** ease of use and distribution for international collaborations, **vi)** inclusion of new external software components such as event generators and hadronic simulation codes*
- Next step is to plan future work based on published requirements – again to involve all participants

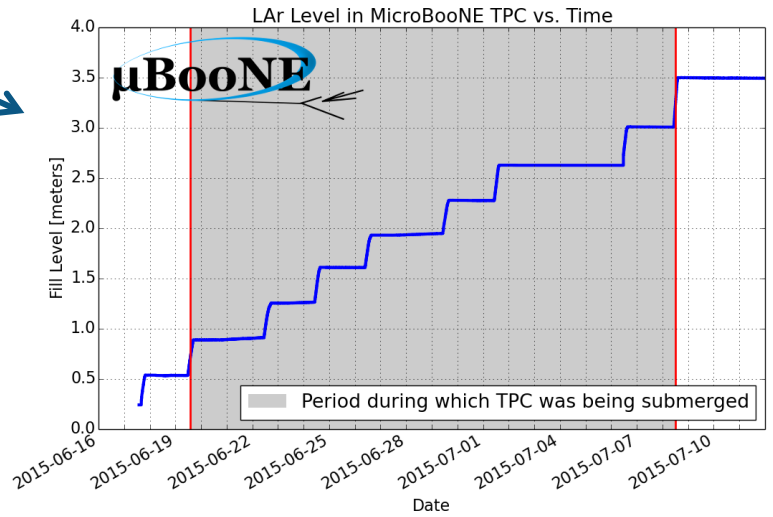
Detector Hardware Coordination

- Cosmic Ray Tagger Systems
  - *Common solutions in scintillator tracker design and readout electronics*
- DAQ
  - *Lots of activity involving SBND, MicroBooNE, and ICARUS DAQ experts to consider common DAQ software solutions, data formats, etc.*
  - *One-day SBN-DUNE workshop held in November to explore possible synergies within DAQ and readout electronics.*
- Photon Detection
  - *SBND working with ICARUS on PMT-based photon detection system*
  - *SBND to use same PMTs, 8" Hamamatsu R5912*
  - *Plan to send SBND PMTs to CERN for wavelength shifter coating and performance testing/characterization in same facility used for ICARUS tubes*
  - *Working together to decide on similar electronics and DAQ system*

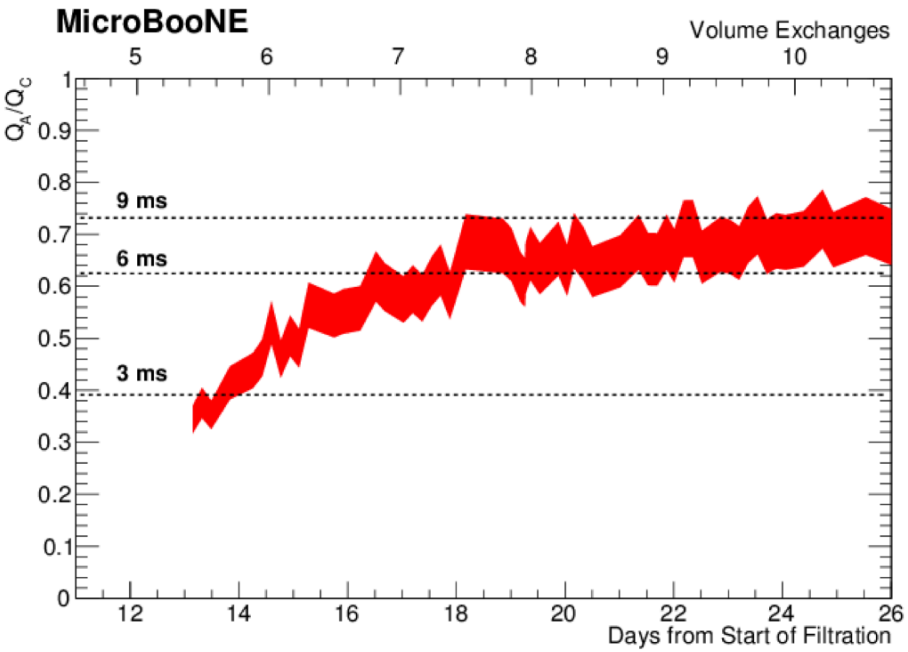
The Three SBN Detectors: Technical Progress in 2015

MicroBooNE LAr Fill (June-July 2015)

9 trucks to fill

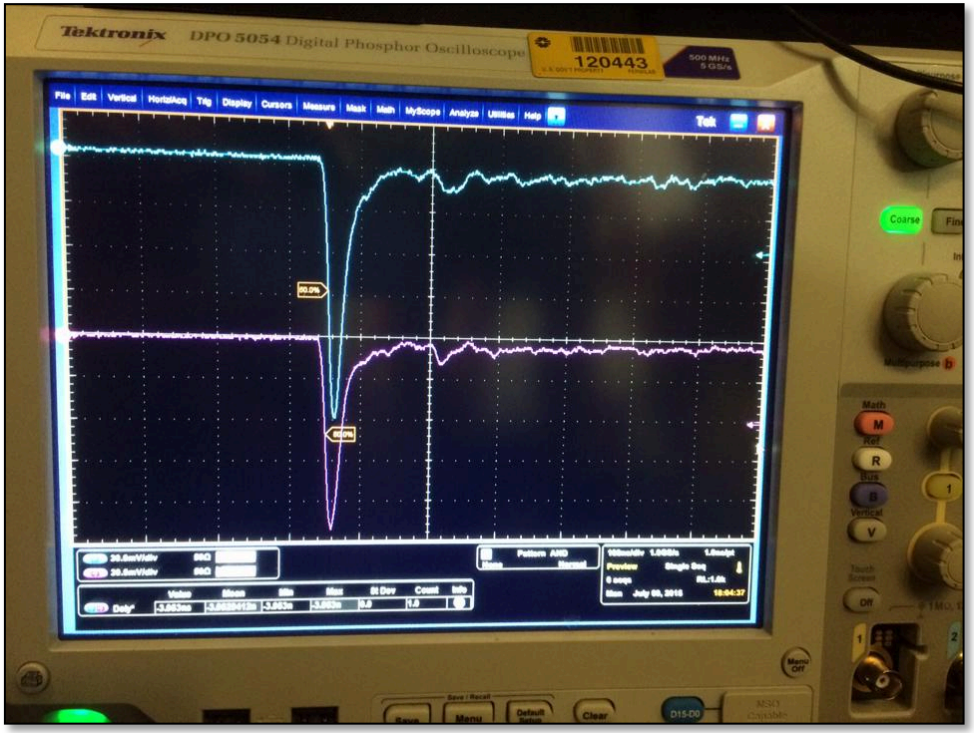


- Argon purity more than a factor 2 better than design
  - *> 6 ms e lifetime, < 50 ppt O_2*
- Detector fully commissioned and reviewed twice
  - *Sept 24-35: MicroBooNE internal commissioning review*
  - *Nov 23-24: Fermilab Operational Readiness Review*



MicroBooNE PMTs - Day After Fill

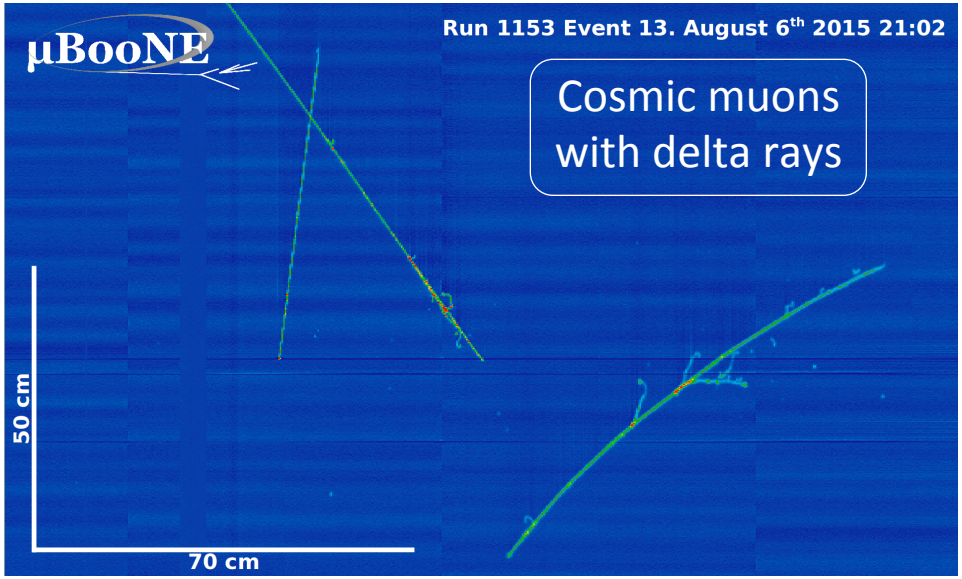
- PMT system turned on

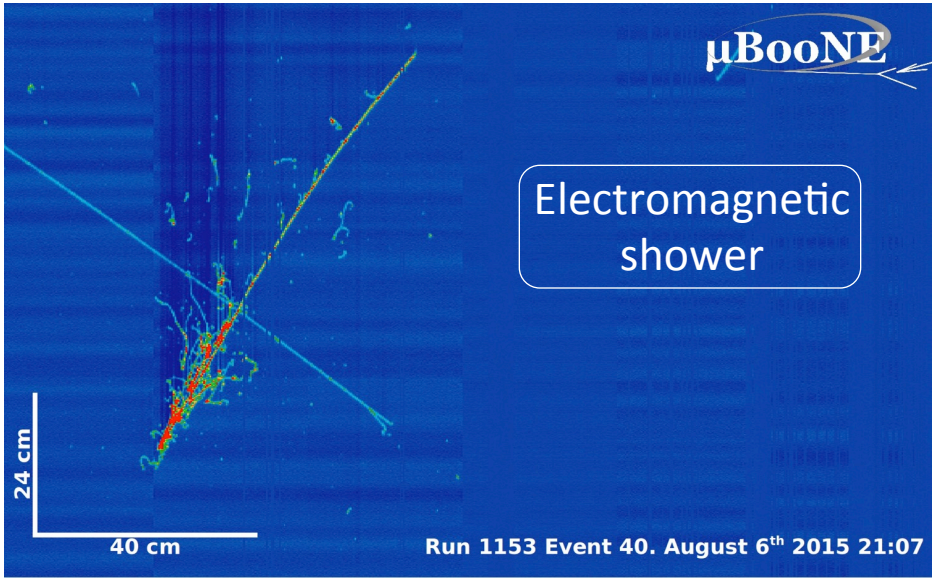


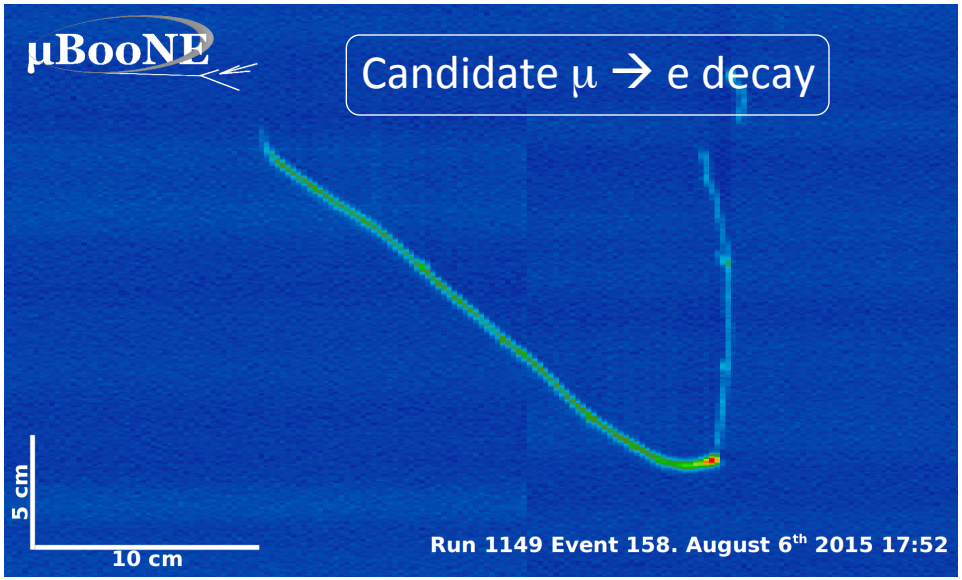
Coincident pulses seen on adjacent PMTs

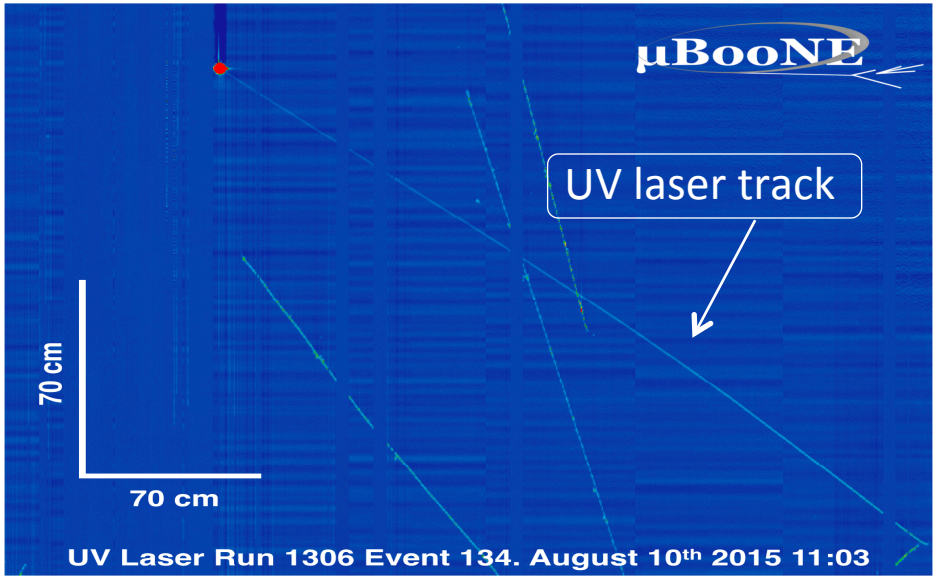
→ cosmic muon candidate!

First Cosmic Tracks in August 2015

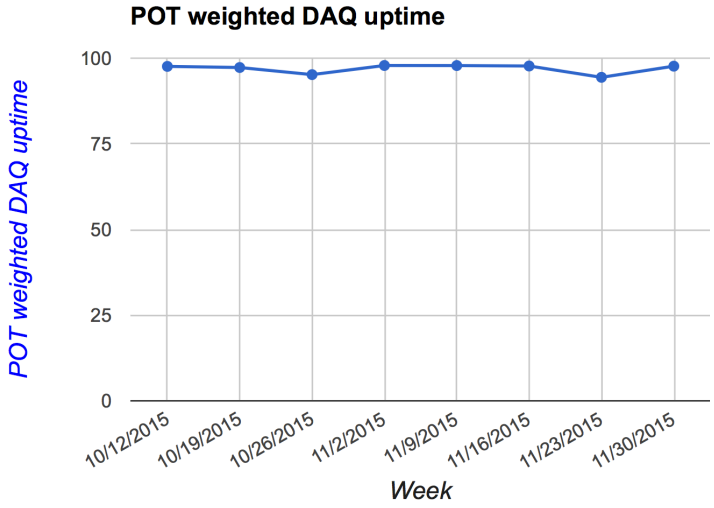








Neutrino Beam Since October!



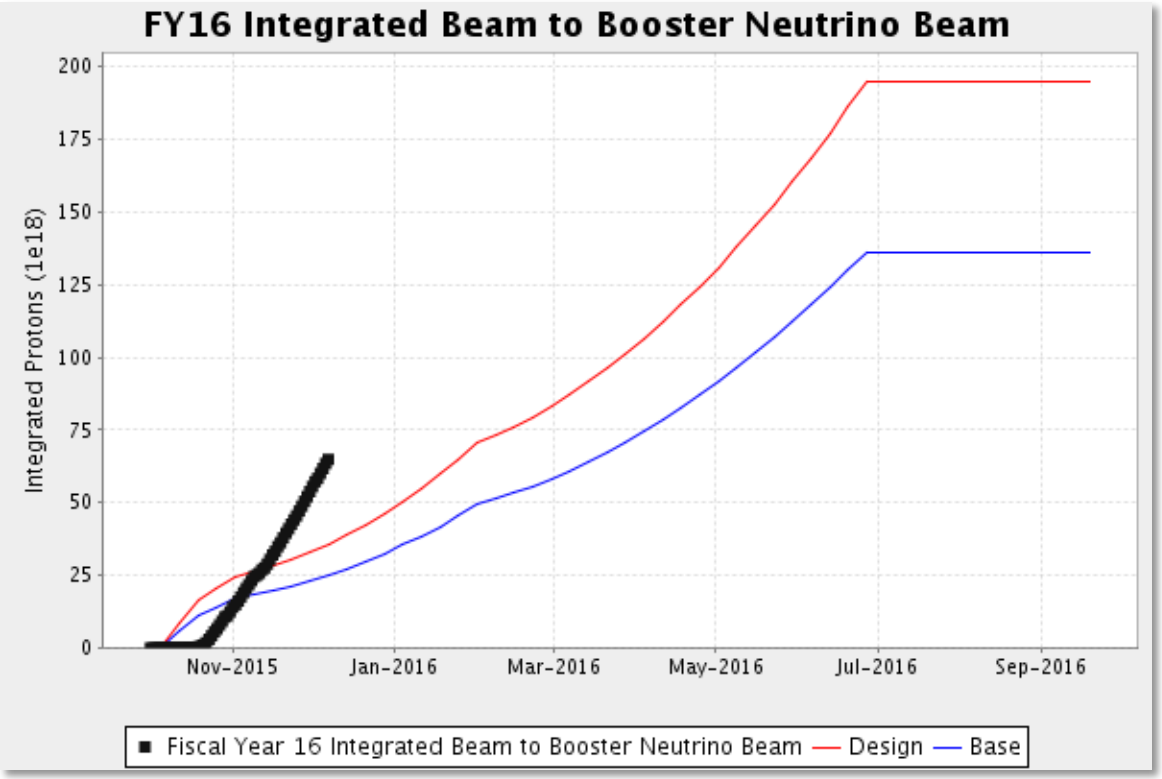
MicroBooNE DAQ uptime has been consistently >97%

MicroBooNE has accumulated

0.67 × 10^{20} POT

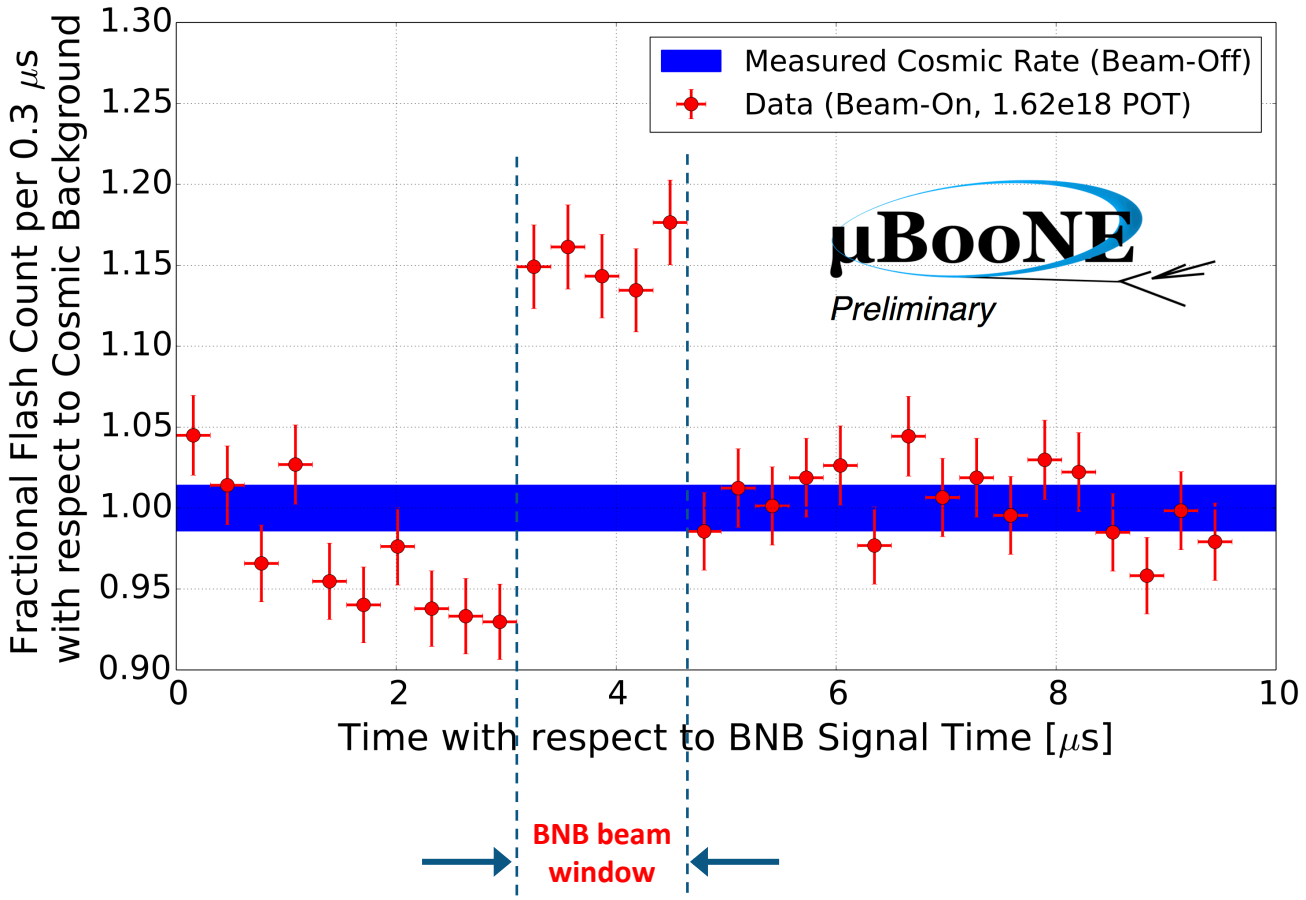
from the BNB since October 15, 2015!

On track to collect ~1-2 × 10^{20} POT by summer 2016



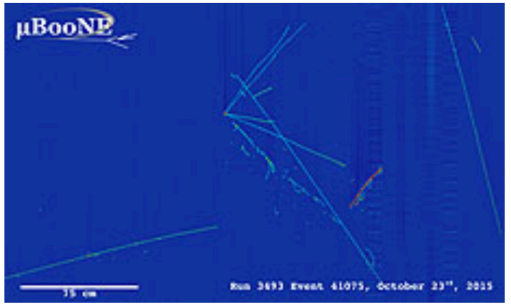
MicroBooNE's First Neutrinos

- More than "just a few event displays" → neutrino events are selected via automated 2D and 3D reconstruction algorithms making full use of the detector (both TPC and PMT systems)



Feature

MicroBooNE sees first accelerator-born neutrinos

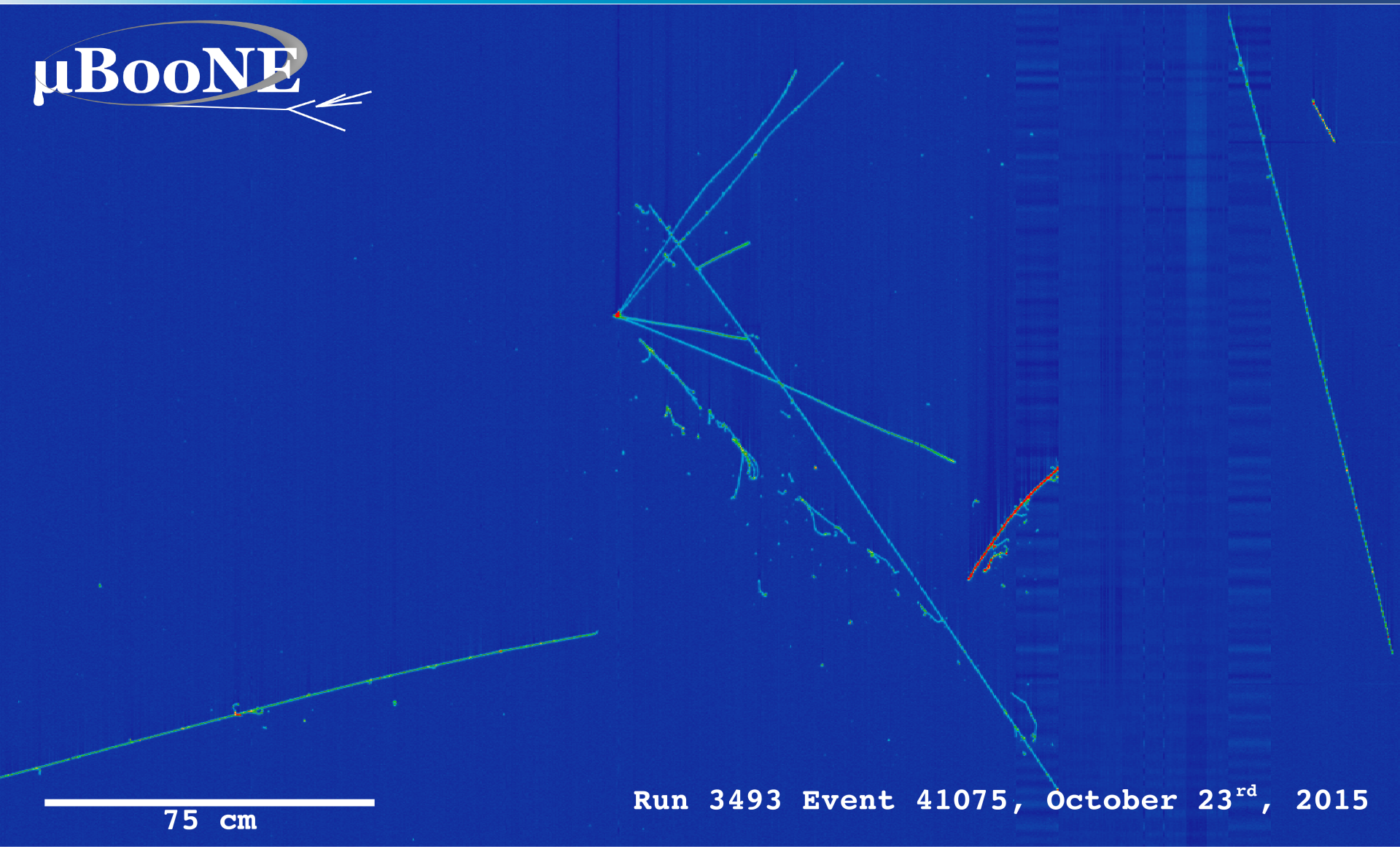


This display shows a neutrino event candidate in the MicroBooNE detector. *Image: MicroBooNE*

Today the MicroBooNE collaboration announced that it has seen its first neutrinos in the experiment's newly built detector.

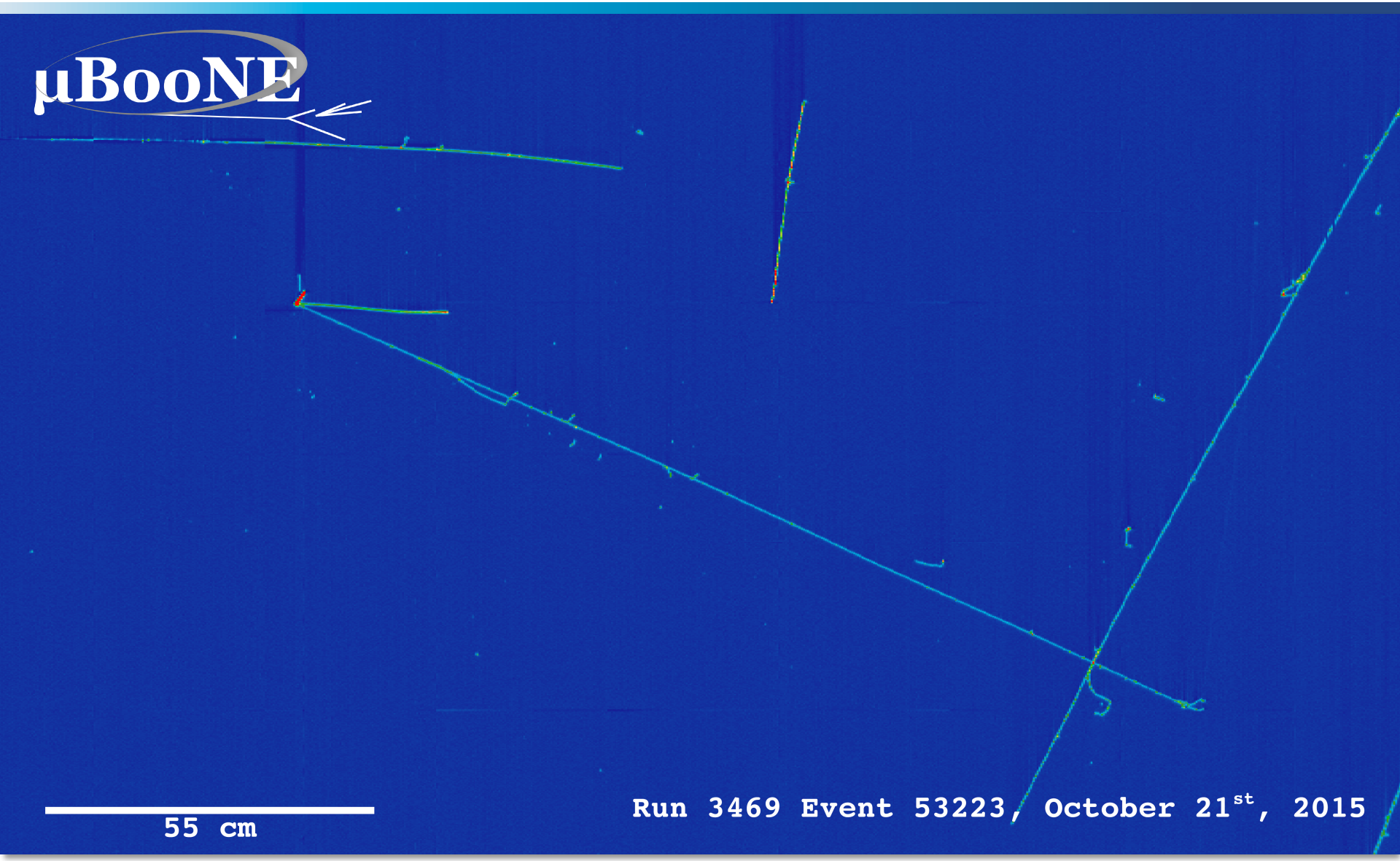
Fermilab Today, 11/02/2015

First Neutrino Events!



more images here: http://www-microboone.fnal.gov/first-neutrinos/index.html

First Neutrino Events!



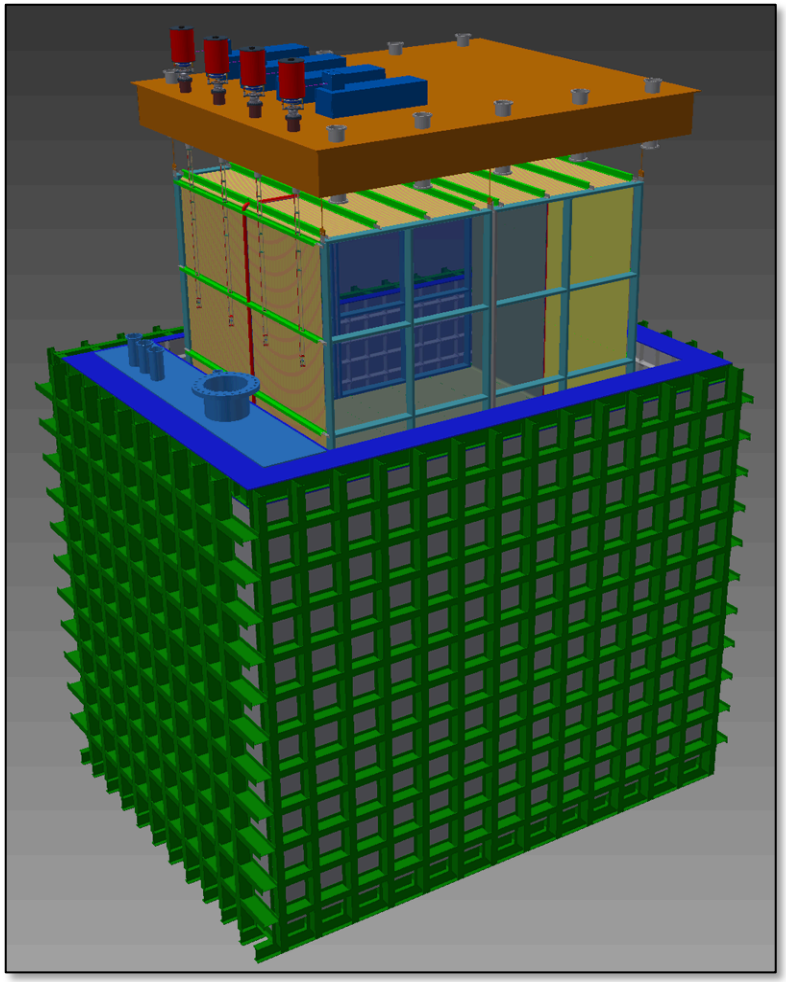
more images here: http://www-microboone.fnal.gov/first-neutrinos/index.html

Public Results from MicroBooNE

- MicroBooNE has been putting out a steady stream of results this year using both detector data and simulation

Active	Analysis	Group	Team	EB	Date created	Public Note / Publication	Shown at:
	NumuCC inclusive cross section study based on simulation	Xsec	Anne S.	Xin Q., Mike S.	Oct 2015	DocDB-4994	NuInt 2015
	Electronegative concentration and electron lifetime		Ben C., M. Zuckerbrot	Josh S, Brian R.	Sept 2015	DocDB-4928	NNN 2015
	First neutrino events	Reco	Anne S., Andy F.	Dave S., Andrzej	Sept 2015	DocDB-4903	NuInt 2015
	Nuceon Decay	APE	Elena G.	Jen R., Eric C.	Aug 2015	DocDB-4765	TAUP 2015
	Noise vs. Fill Level	Commissioning	David C.	Bryce L., Vittorio P.	July 2015	DocDB-4717	TAUP 2015

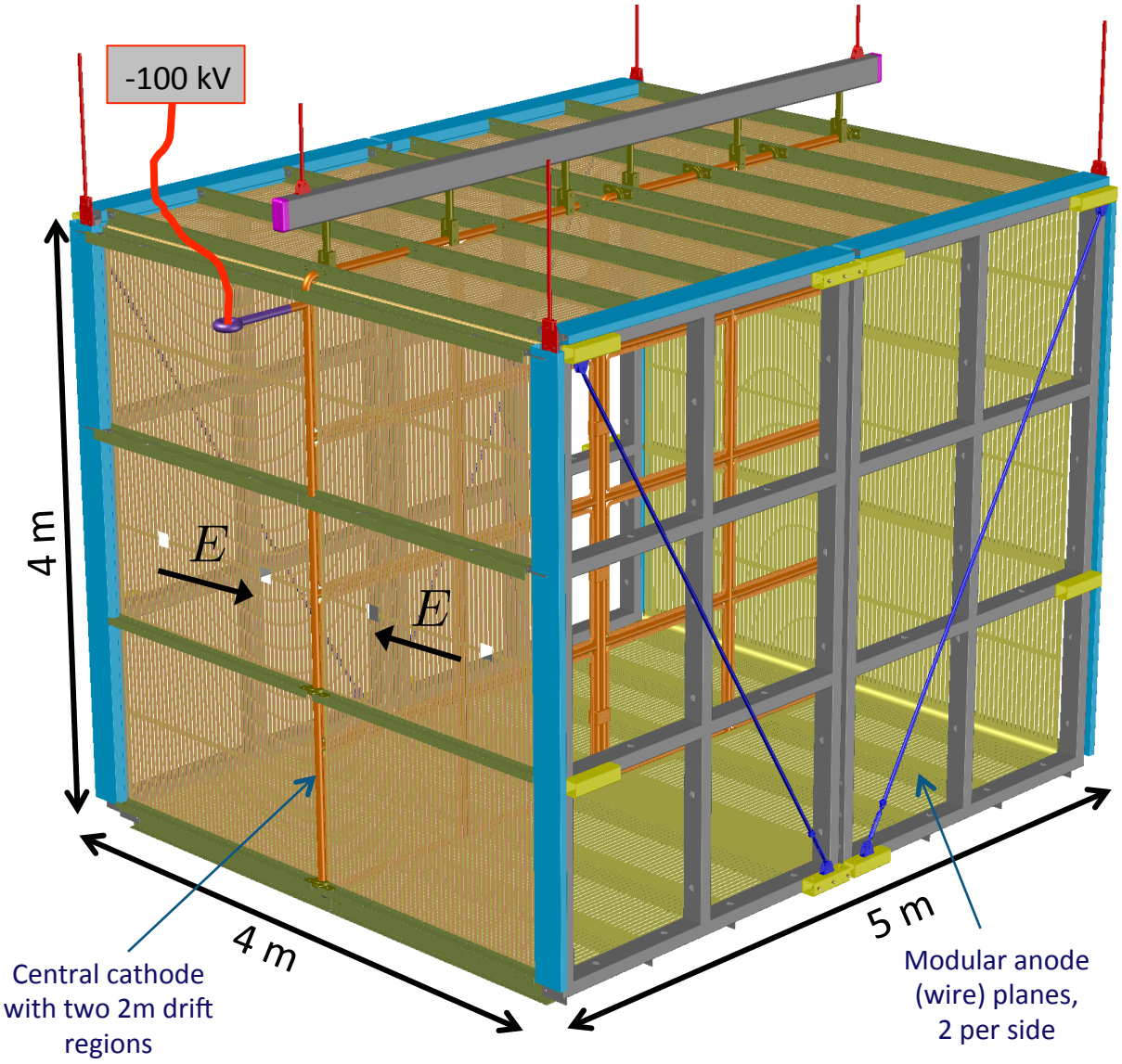
The Short-Baseline Near Detector



SBND is a 4m (W) x 4m (H) x 5m (L) 112 ton LArTPC.

Only 110 m from the BNB source, will see more than **1.5 million neutrino interactions per year**.

The SBND TPC



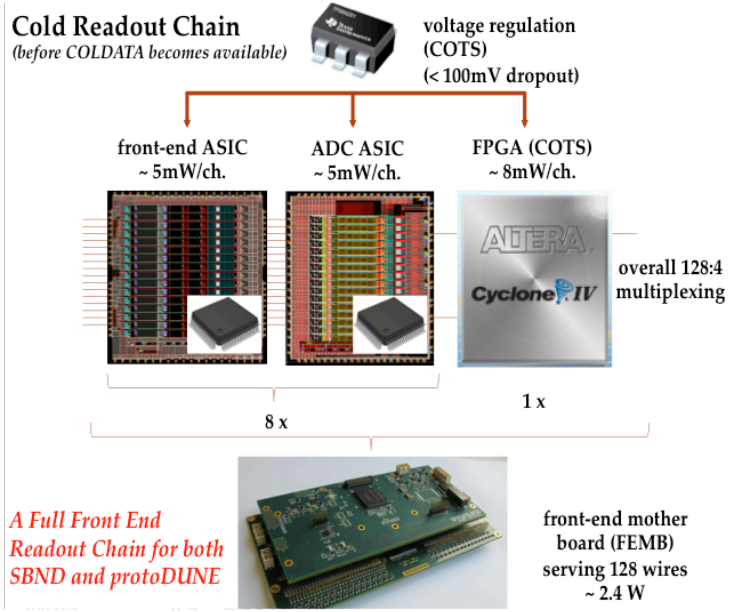
*SBND TPC design and construction is a joint **US-NSF** and **UK-STFC** project*

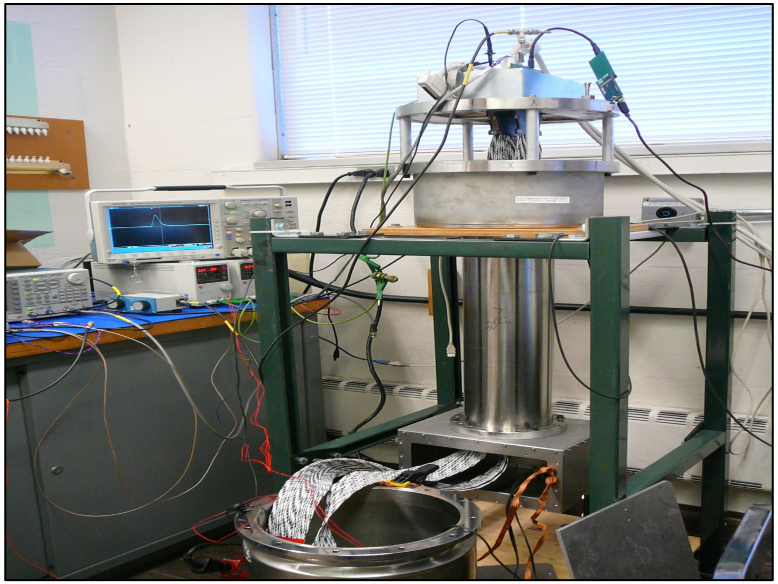
TPC Component	Institutions
Anode frames	Chicago, Sheffield
Anode wiring	Manchester, Syracuse
Cathode plane	Liverpool
Field cage	BNL, Yale
High voltage feed-through	UCL, Yale
APA testing	Lancaster
Integration, assembly, and installation	Chicago, BNL, Fermilab

TPC now in final design phase
Component construction in 2016
Assembly at Fermilab in 2017

SBND TPC Electronics

- Cold front-end & warm readout electronics will be upgrades from components used in MicroBooNE system
  - *Signal digitization moves into the cold*
- FE/ADC ASIC design now a **joint SBND-DUNE effort**
  - *Coordination meeting Aug 20 at BNL*
  - *Cost and resource sharing agreed*
  - *2 prototype ASIC runs scheduled for 2016*
  - *Production run early 2017*
- Involving collaboration institutes in QA/QC test-stand efforts





SBND Cryostat, CRT, and Photon Detectors

- Cryostat design being developed at CERN following WA105 experience

- Cosmic Ray Tagger in final design and prototyping at University of Bern (Swiss NSF)

- Photon detection in SBND
  - *112 8" PMTs (as in ICARUS & MicroBooNE) mounted to backside of APA frames directly behind wires*
    - LANL LDRD funding secured in 2015
  - *Pursuing also a complimentary light-guide-based system with SiPM readout as R&D toward a DUNE photon system*

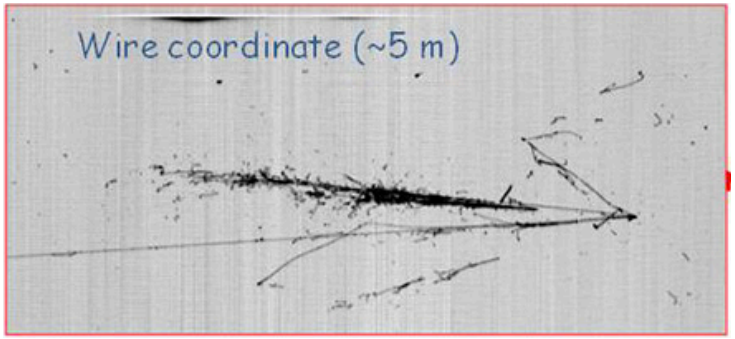

WA105 @ CERN

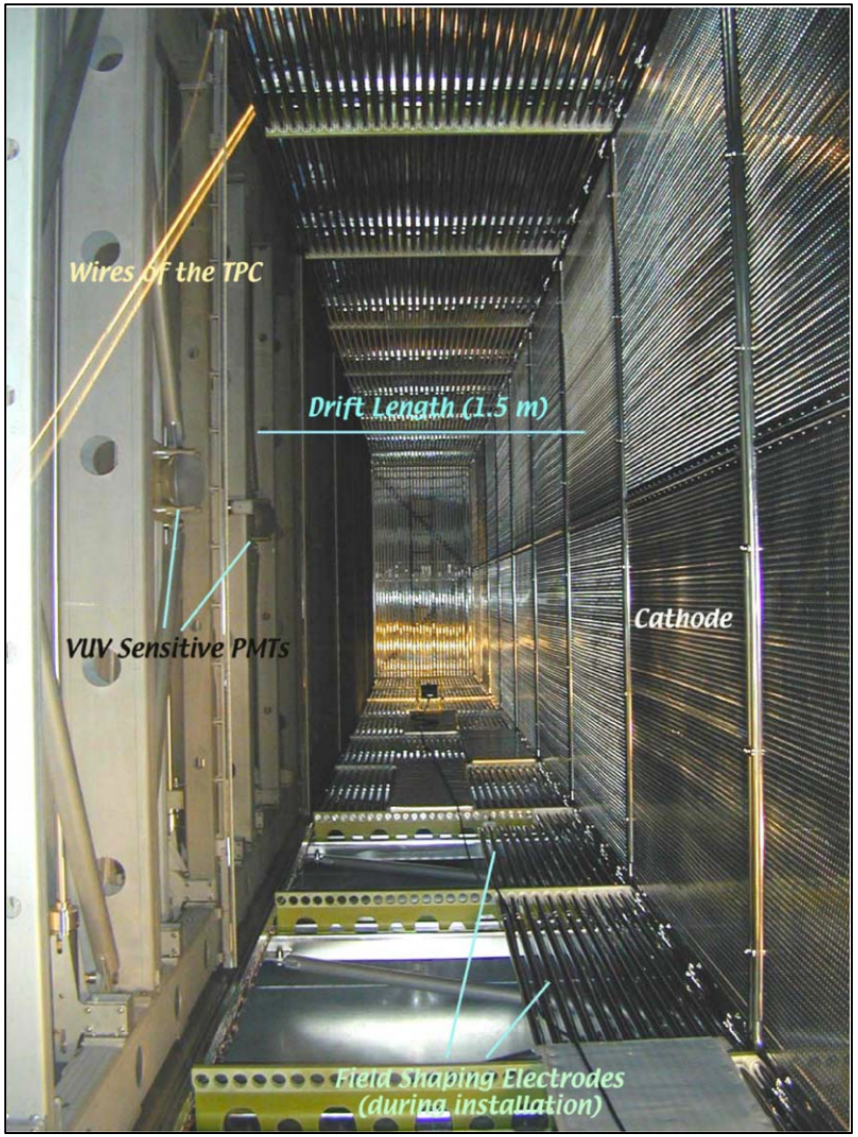

WA105 @ CERN


SBND CRT @ BERN

The ICARUS-T600

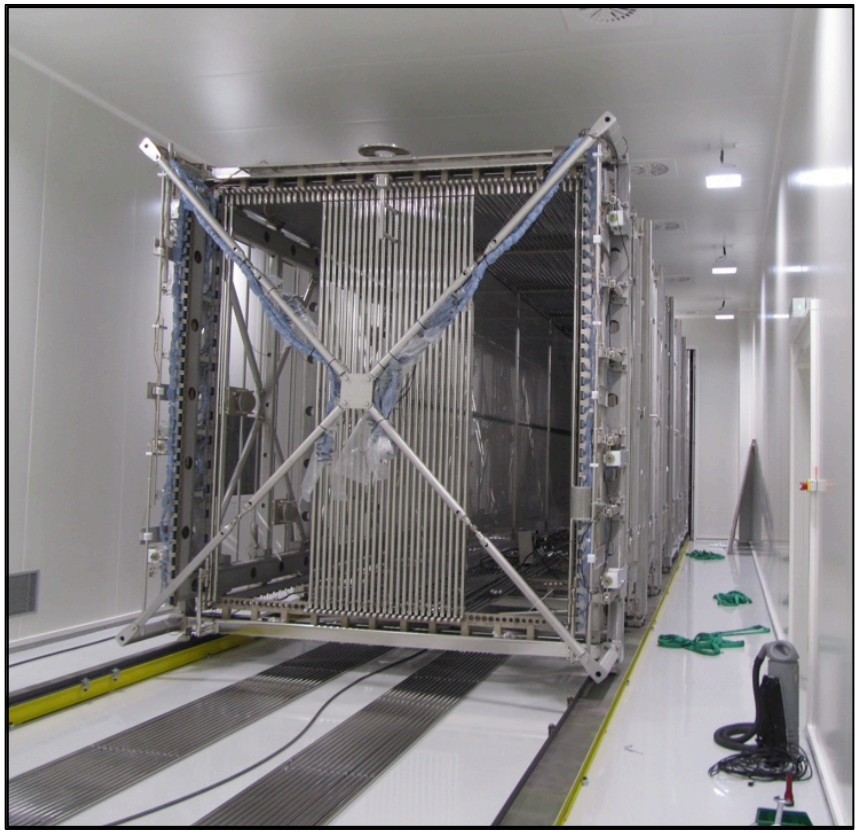
- The T600 is the first and the largest LArTPC ever built
  - *Three-year physics run in the CNGS neutrino beam at the Gran Sasso Laboratory*
- Currently the detector is at CERN for refurbishment (INFN and CERN project, WA104) in preparation for transport to Fermilab
  - *First module complete end of 2015*
  - *Second module prepared in 2016*
  - *Installation at Fermilab in 2017*





ICARUS Refurbishment Activities

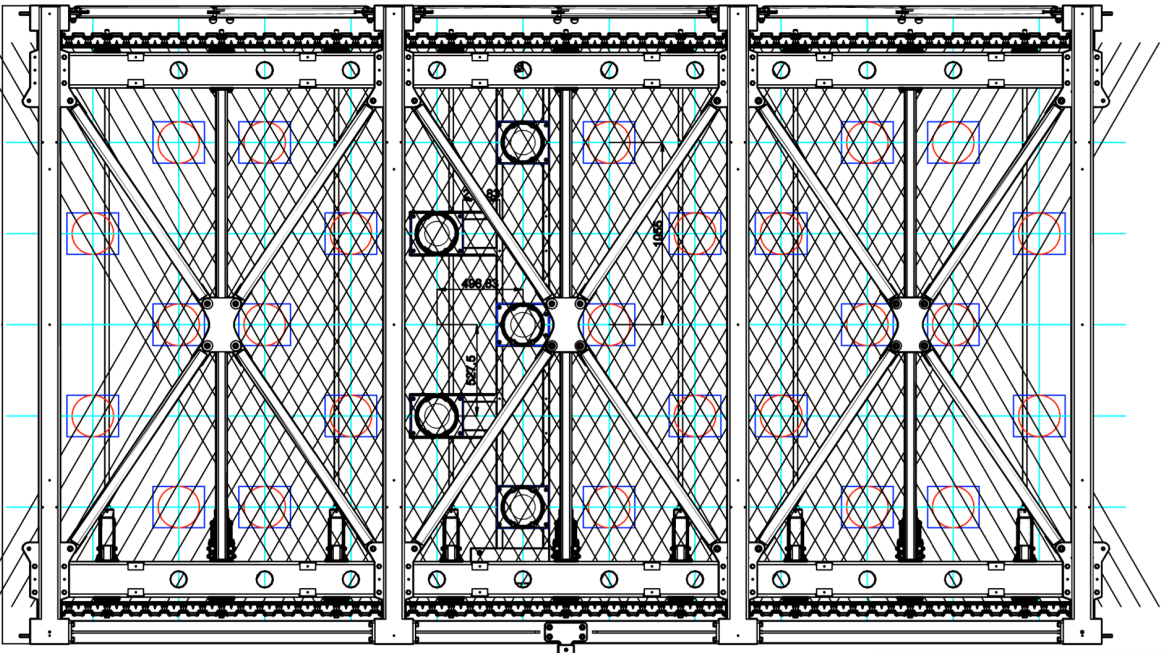
- New PMT system deployment
- Cathode flattening
- Updated TPC electronics
- Detector re-cabling
- New cold vessel construction
- New thermal insulation
- Maintenance and partial replacement of cryogenics and purification systems
- Construction of Cosmic Ray Tagger

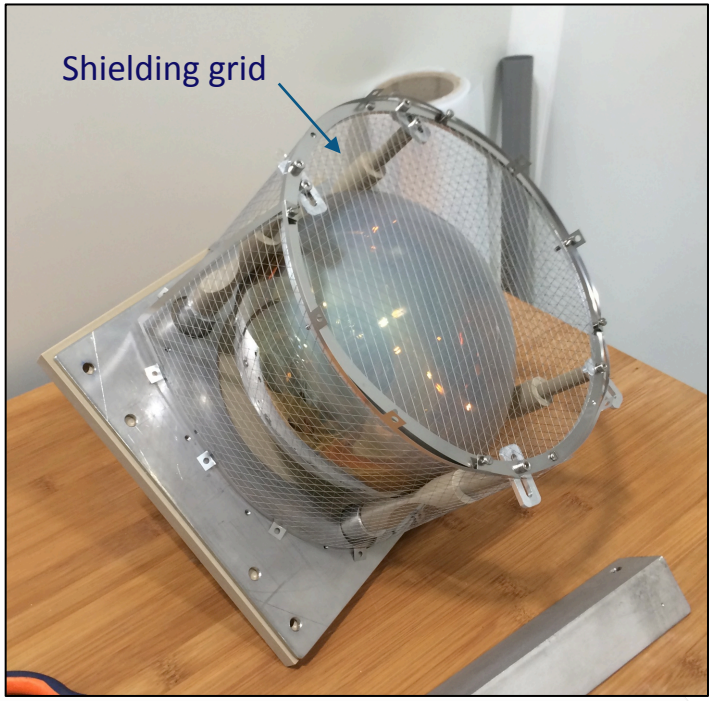


One T-300 in the clean room at CERN

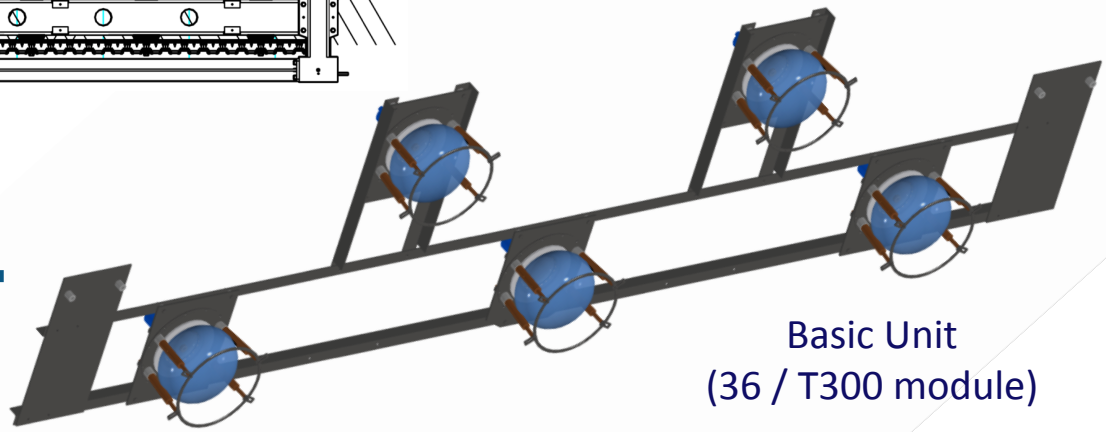
ICARUS PMT System

- Photon detection being enhanced for **surface operation** in SBN





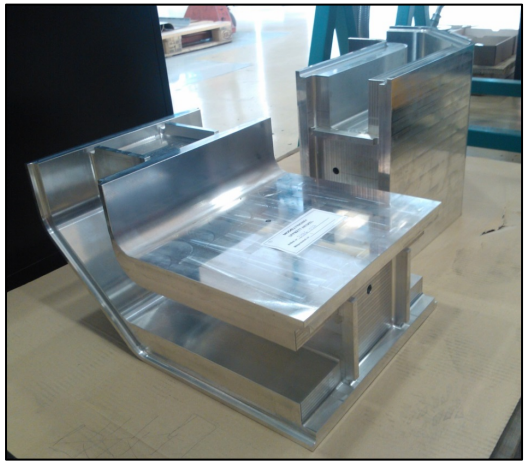
x10 increase in PMT coverage to enable better event matching within a readout

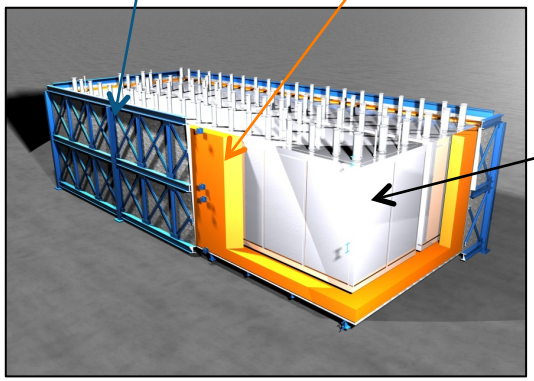


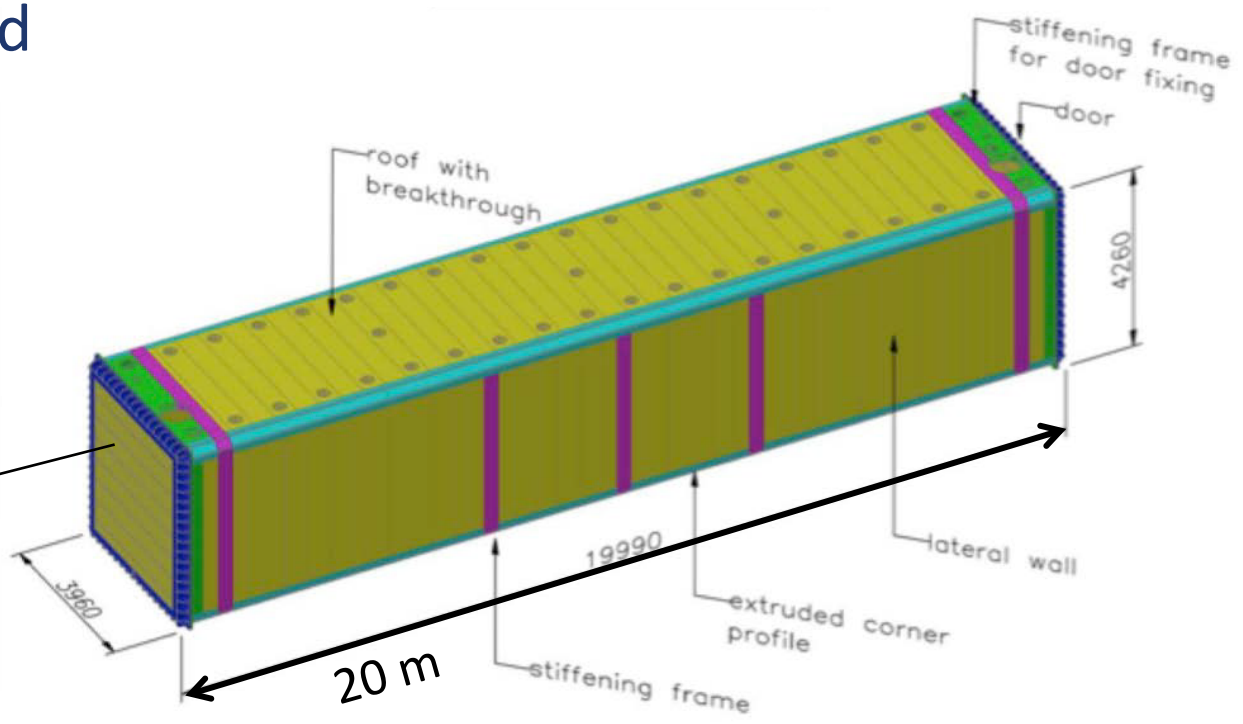
Basic Unit
(36 / T300 module)

New Cold Vessels Construction

- First extrusions produced and delivered to CERN for welding tests
- Panel pre-assemblies ordered and expected by end of 2015
- Assembly strategy defined, required tools being procured

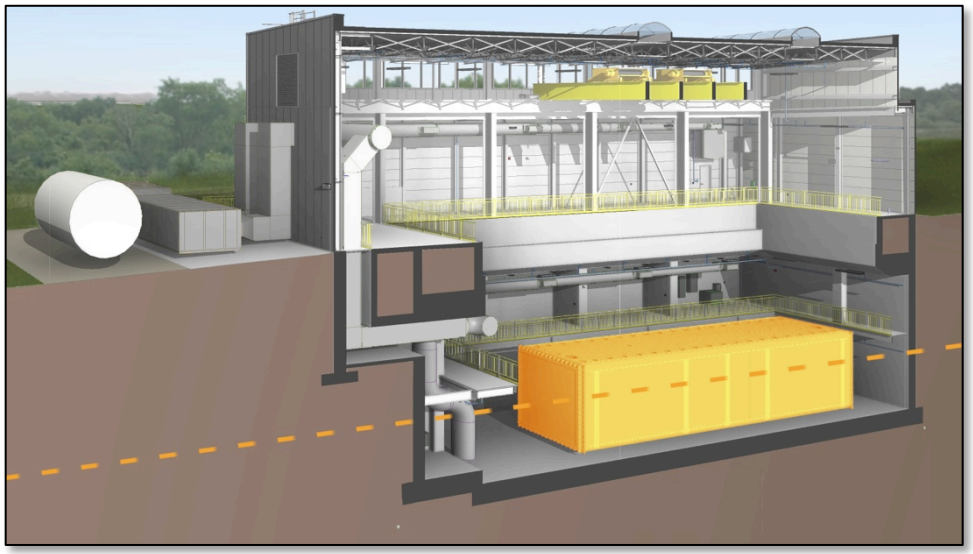






Civil Construction - Far Detector Building

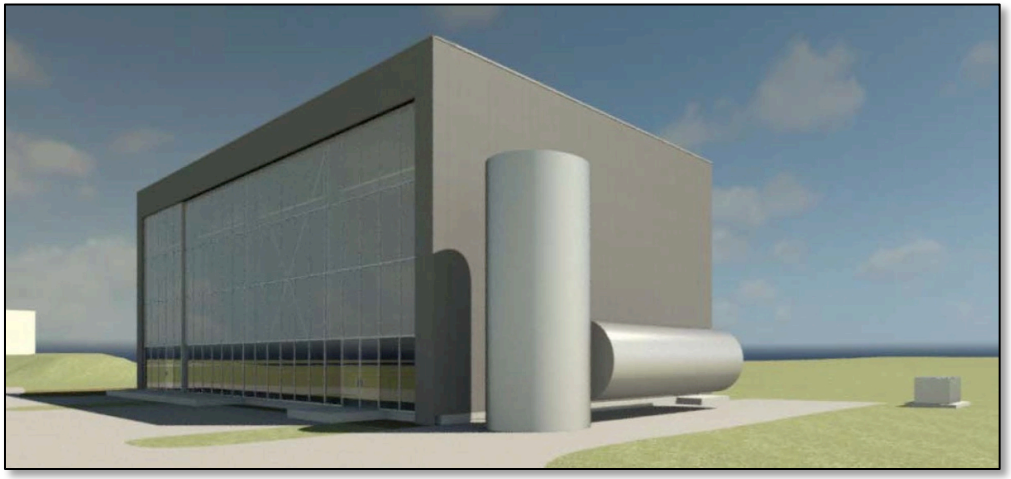
- Close cooperation between ICARUS, CERN and Fermilab on design requirements and review.
- Designed for 3m concrete overburden directly over detector
- Milestones:
  - ✓ *Aug 2015 – Start preliminary design*
  - ✓ *March 2015 - Design complete*
  - ✓ *April 2015 - Construction contract bidding*
  - ✓ *July 2015 – Construction Start*
  - ✓ *Sept 2015 – Excavation complete*
  - *Jan 2016 – Concrete complete*
  - *June 2016 – Building envelope complete*
  - ***Oct 2016*** *- Complete*

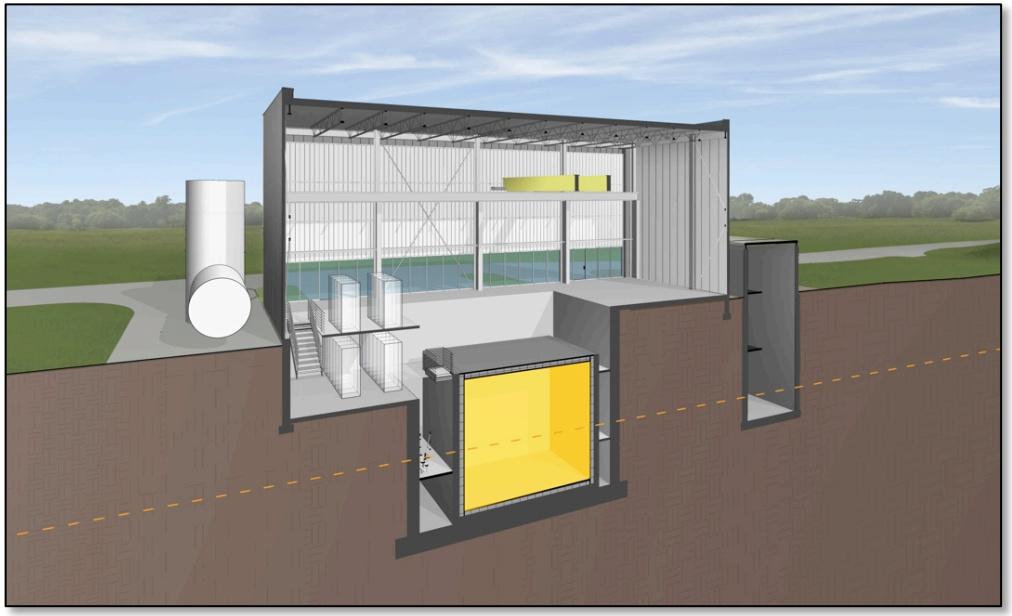


Far Detector Building Progress

Civil Construction - Near Detector Building

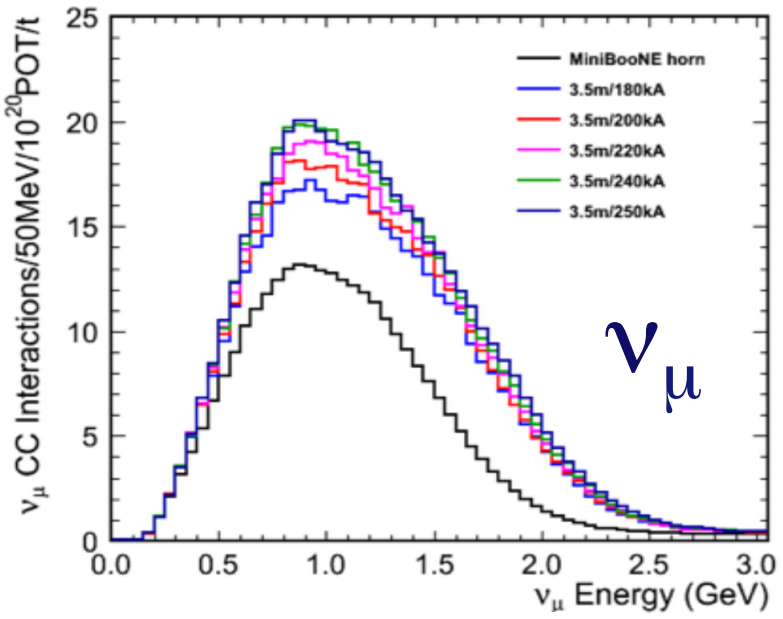
- Designed for 3m concrete overburden directly over detector
- Milestones:
  - ✓ *Jan 2015 – Design start*
  - ✓ *May 2015 - 60% Design complete*
  - ✓ *July 2015 – Final design review*
  - ✓ *Aug 2015 - Design complete*
  - ✓ *Sept 2015 - Bidding*
  - • *Nov 2015 - Construction start*
  - • ***Dec 2016*** *- Complete*

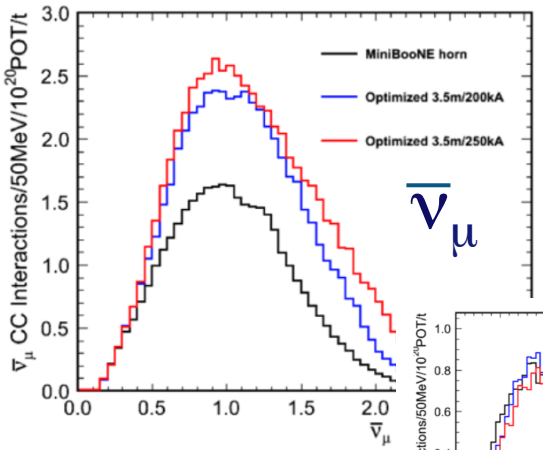




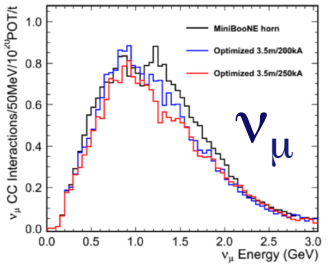
Booster Neutrino Beam Improvements

- Far detector statistics are key to ν_e appearance sensitivity
  - *(Detector mass) x (Neutrino flux) x (Time)*
- Possible BNB upgrade paths:
  1. *Increase focusing efficiency of target/horn system*
     - Optimize horn length, inner conductor, and current
  2. *Increase rate at which horn system is capable of running*
     - Booster can operate at 15 Hz, existing horn at 5 Hz (limited by mechanical integrity and power supply)
- Detailed study carried out by design team at FNAL; conclusion: gains up to **~1.8× in event rate** possible with longer horn design and upgraded power supply





antineutrino mode running



SBN-DUNE Coordination and Synergies

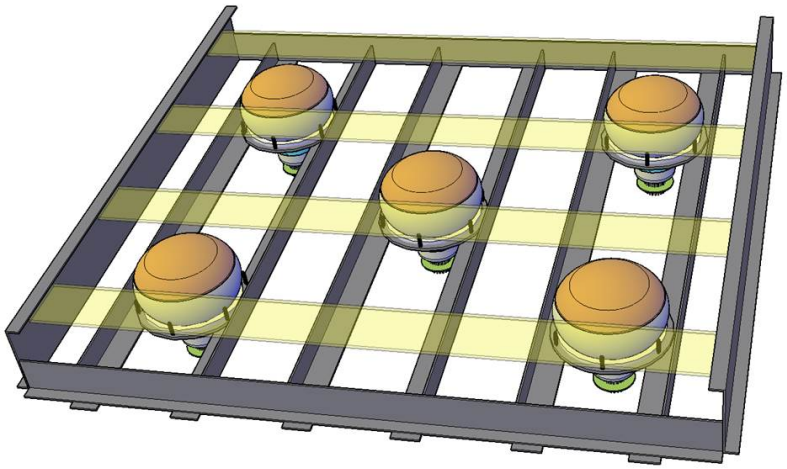
SBN-DUNE Coordination and Synergies

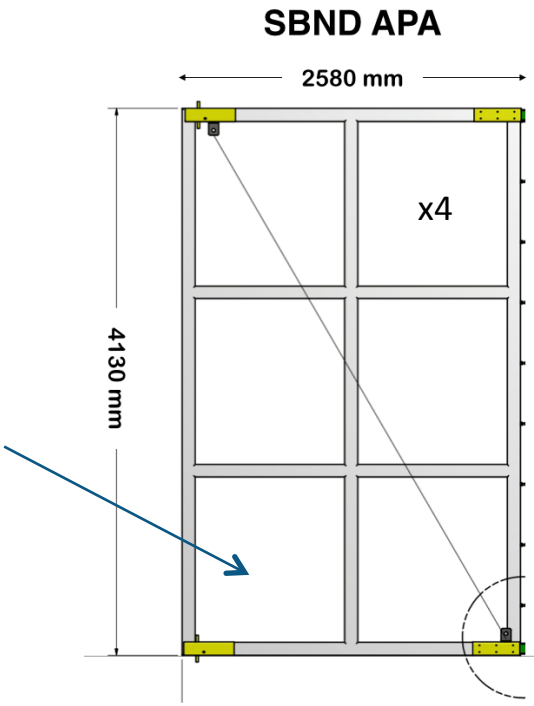
- On-going efforts to explore and exploit synergies between the detectors and physics of SBN and DUNE/proto-DUNE
  - *Development of cold front-end electronics for SBND/proto-DUNE now fully aligned*
  - *First SBND-DUNE TPC workshop in September: covered electronics, APAs, photon detection.*
  - *SBN-DUNE DAQ and readout electronics workshop in November*
  - *LArTPC analysis software development in the same platform, regular LArSoft stakeholder meetings involving all groups, joint software workshops*
- Communication happens at multiple levels
  - *Spokespersons, technical coordinators*
  - *SBND presentations at both the TPC and Photon Detector DUNE working group meetings in recent months*
  - *Overlap in SBN/DUNE collaborations further facilitates communication*

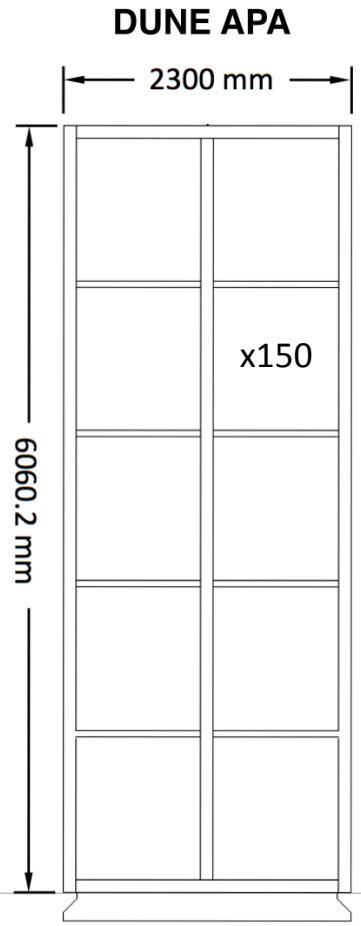
SBND ⇔ DUNE

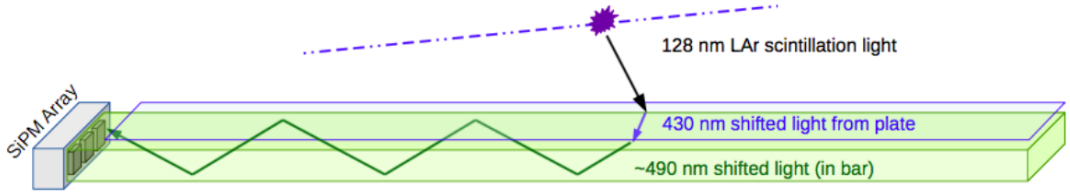
- SBND design based on technologies/solutions similar to those planned for DUNE

Development of photon detection technologies









Similar scale wire planes. Collaboration on engineering, wire stringing, QA procedures, etc.

SBN ⇔ LBN Physics Goals

- The physics goals of SBN are complementary to the goals of DUNE-LBNF and extend the overall reach of the neutrino physics program:
  - *A major physics goal of DUNE-LBNF is to "test the 3-ν paradigm"*
  - *SBN will contribute directly to this question through either a major discovery that breaks the paradigm or by ruling out additional light neutrinos in a range hinted at by previous anomalies*
  - *Precision measurements of neutrino+argon cross sections in the relevant energy range are an important component for reaching systematics at level of 1% in DUNE-LBNF*
  - *SBN will study these interactions in detail with millions of events in the few hundred MeV to few GeV energy range*

Summary: SBN Progress and Status

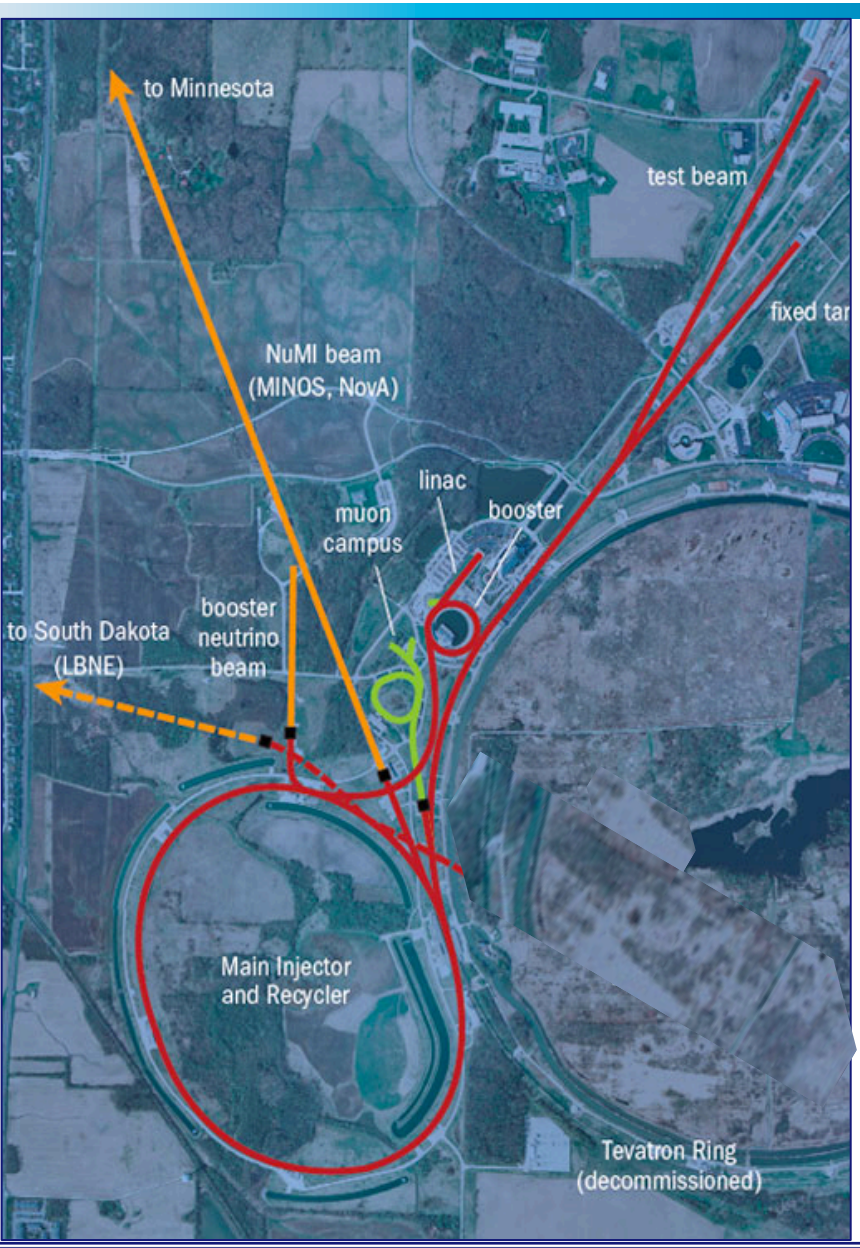
- The SBN Program of three LArTPC detectors located along the Booster Neutrino Beam was granted Stage 1 approval by Fermilab in February 2015 to:
  - *Explore the anomalous hints of new physics in the neutrino sector and confirm or rule out the LSND allowed oscillation parameters in neutrinos at >5σ*
  - *Measure neutrino-argon cross sections with high precision in an important energy range*
  - *Further develop the LArTPC technology for neutrino physics and help build expertise of the global neutrino community working toward DUNE*
- SBN detectors have made enormous technical progress in 2015
  - *MicroBooNE is running with beam!*
  - *ICARUS T600 refurbishment is progressing well and on schedule at CERN*
  - *SBND TPC is entering final design phase, construction to begin in early 2016*
  - *Civil construction on-going and improved beam designs being explored*
- SBN Director's Progress Review at Fermilab next week (15-17)

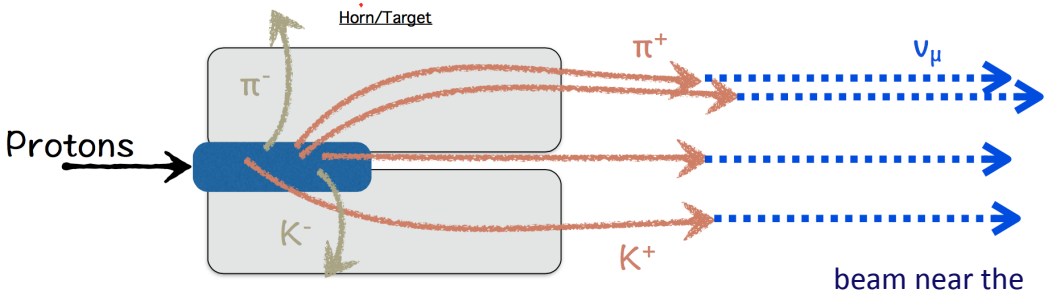
Well on our way to an exciting SBN physics program!

Thank You!

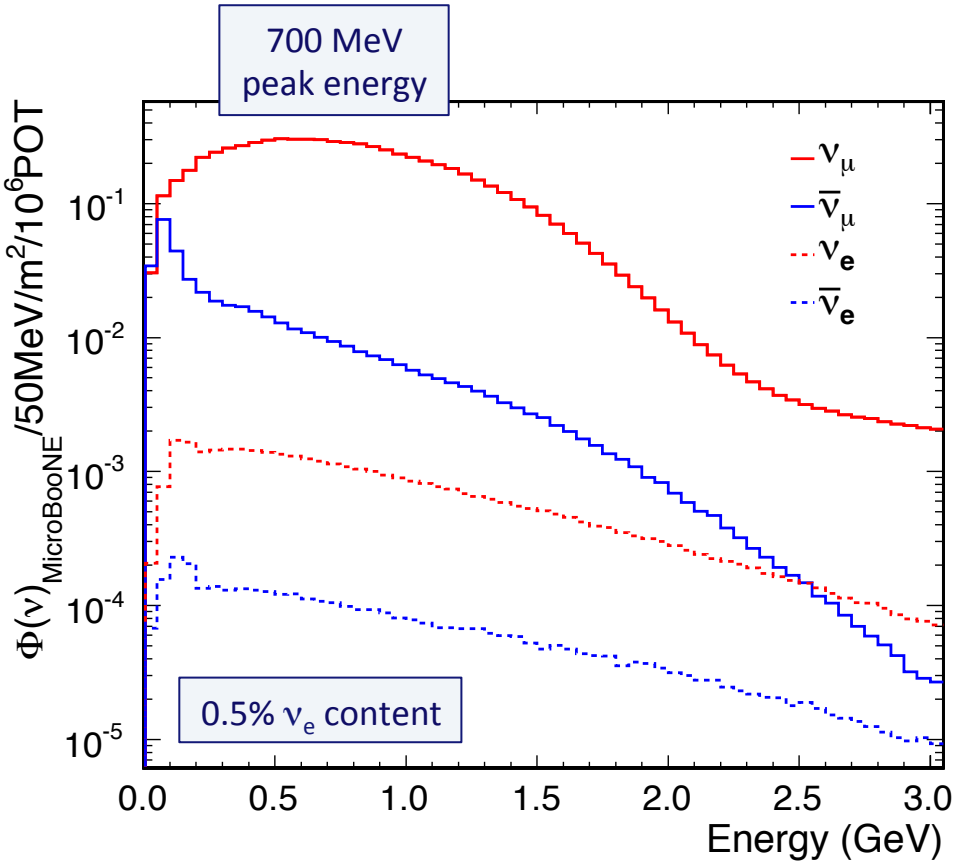
Extras

The Booster Neutrino Beam



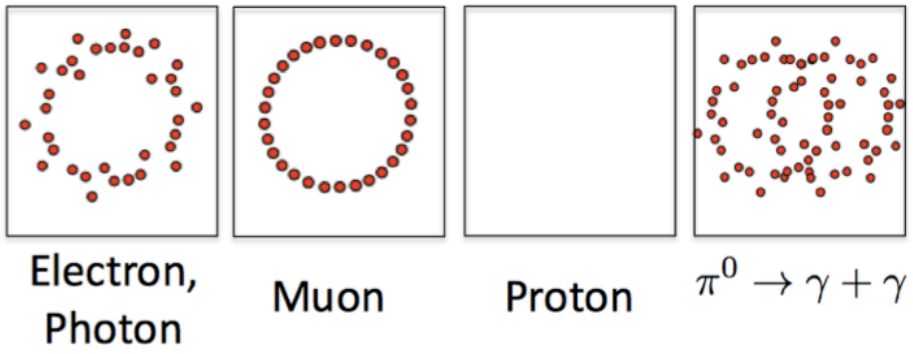


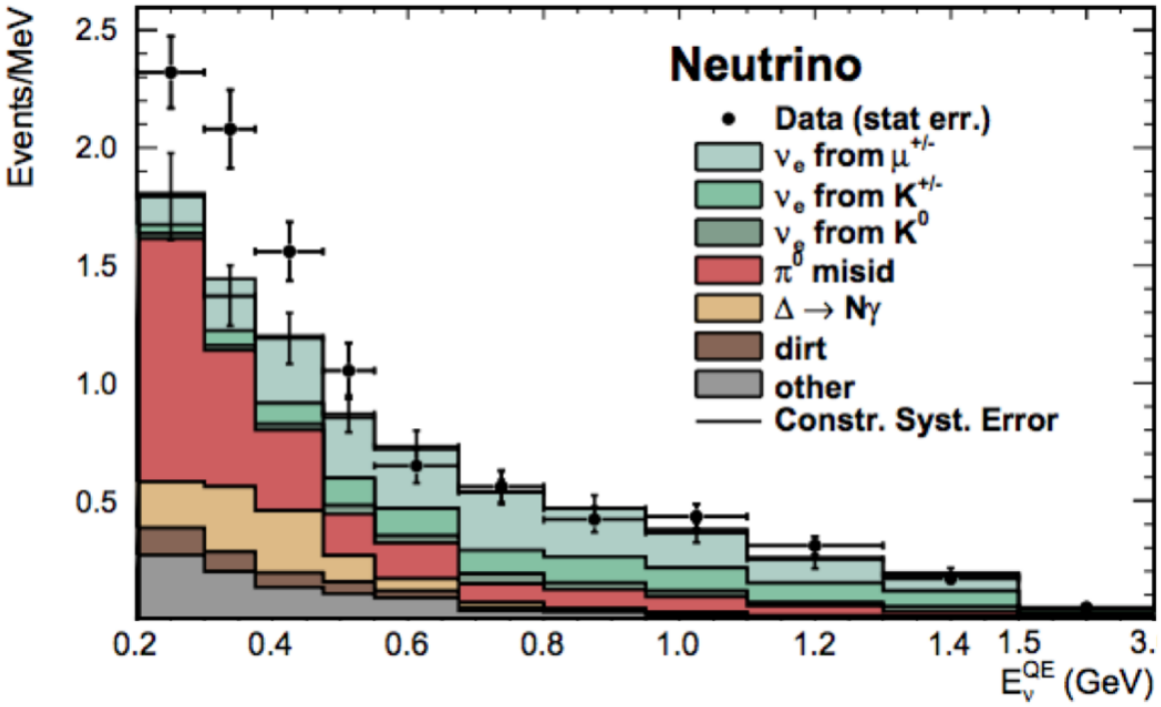
beam near the surface, parallel

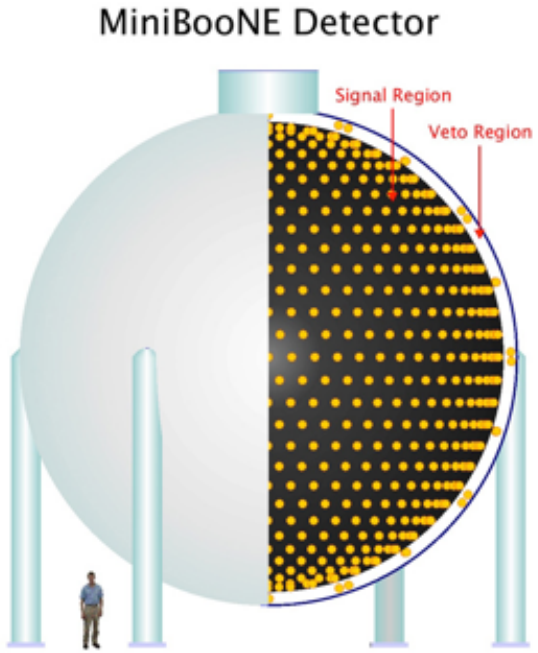


MiniBooNE (2003-2014)

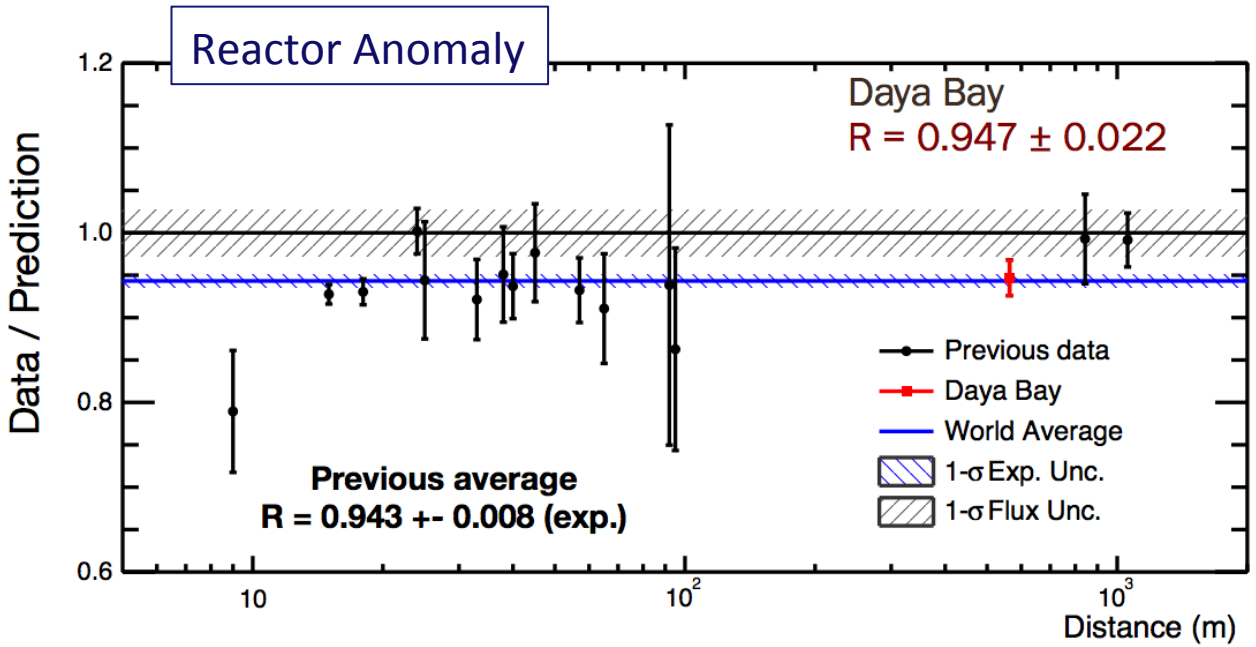
- MiniBooNE was a Cherenkov detector
- Single electron indistinguishable from single gamma
- 800 ton liquid scintillator detector
- 540 m from the beam target







Some of the Existing SBL (high Δm^2) Anomalies



Current anomalies from:
accelerator beams
radioactive sources
reactor neutrinos

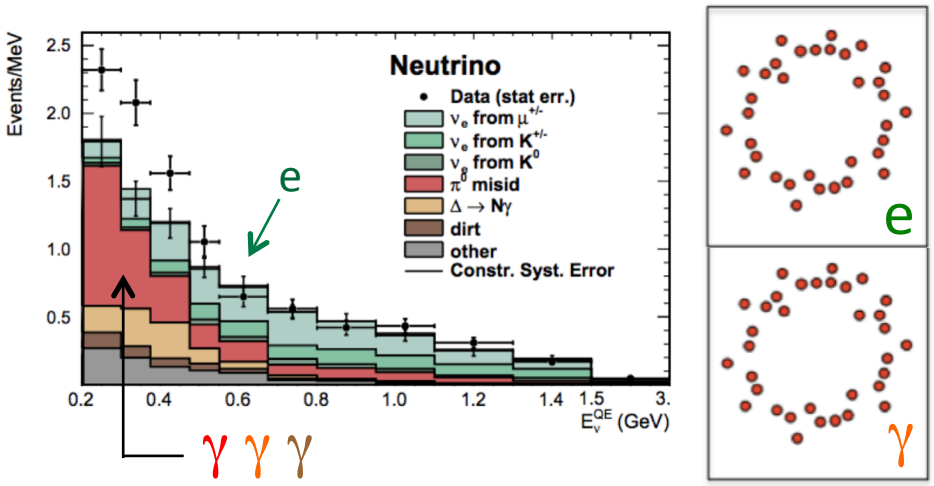
Experiment	Type	Channel	Significance
LSND	DAR	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	3.8σ
MiniBooNE	SBL accelerator	$\nu_\mu \to \nu_e$ CC	3.4σ
MiniBooNE	SBL accelerator	$\bar{\nu}_\mu \to \bar{\nu}_e$ CC	2.8σ
GALLEX/SAGE	Source - e capture	ν_e disappearance	2.8σ
Reactors	Beta-decay	$\bar{\nu}_e$ disappearance	3.0σ

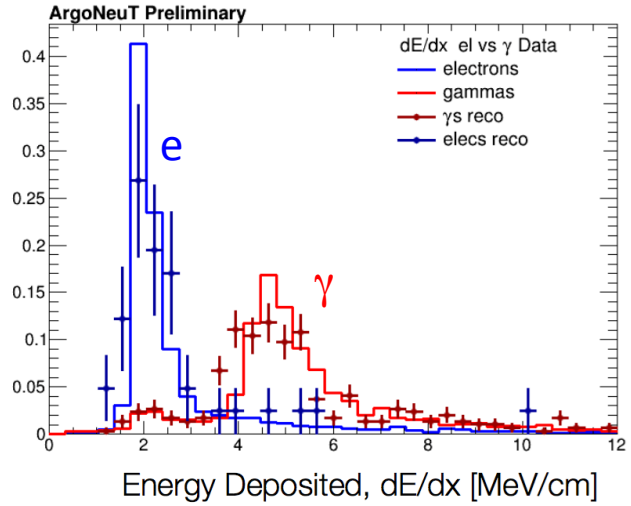
K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

Phase I: MiniBooNE → MicroBooNE

- MiniBooNE was a Cherenkov detector
- Single electron indistinguishable from single photon
- 800 ton mineral oil detector
- 540 m from the beam target

- MicroBooNE is a LArTPC
- Single electron distinguishable from single photon
- 170 ton liquid argon detector
- 470 m from the beam target

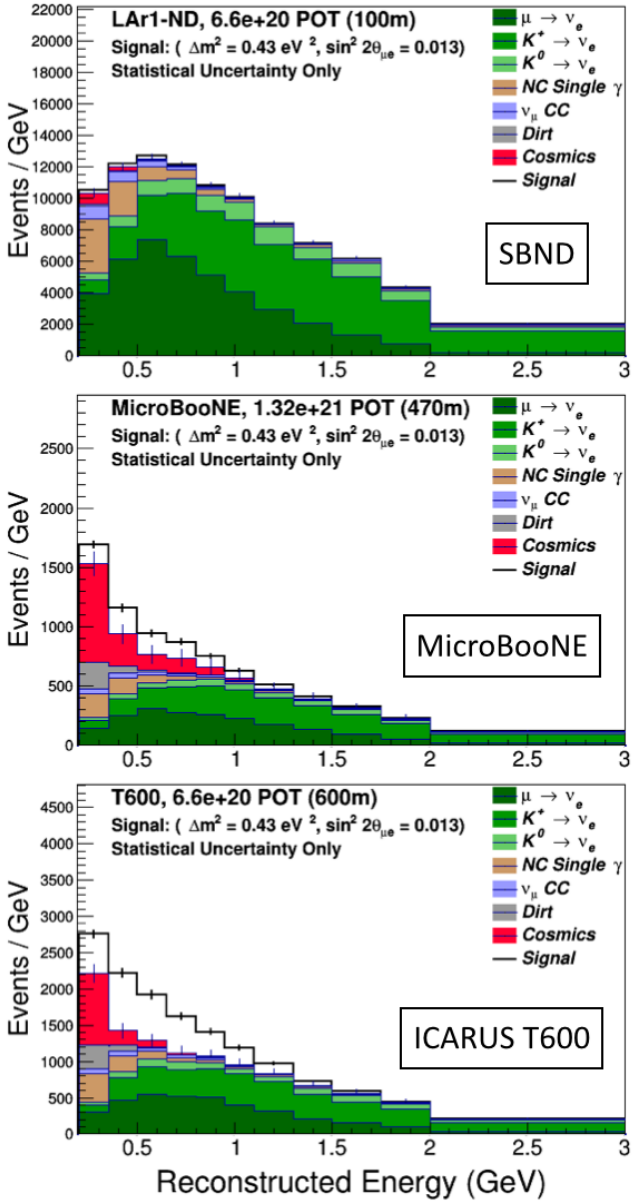




MicroBooNE's core mission is to follow up on the anomalous excess of electromagnetic events observed by MiniBooNE and determine its composition as electrons or photons

MicroBooNE parameters (mass, run plan, etc.) were chosen to observe the specific MiniBooNE excess with ~5σ significance over expected backgrounds

Backgrounds & Oscillation Signals in SBN

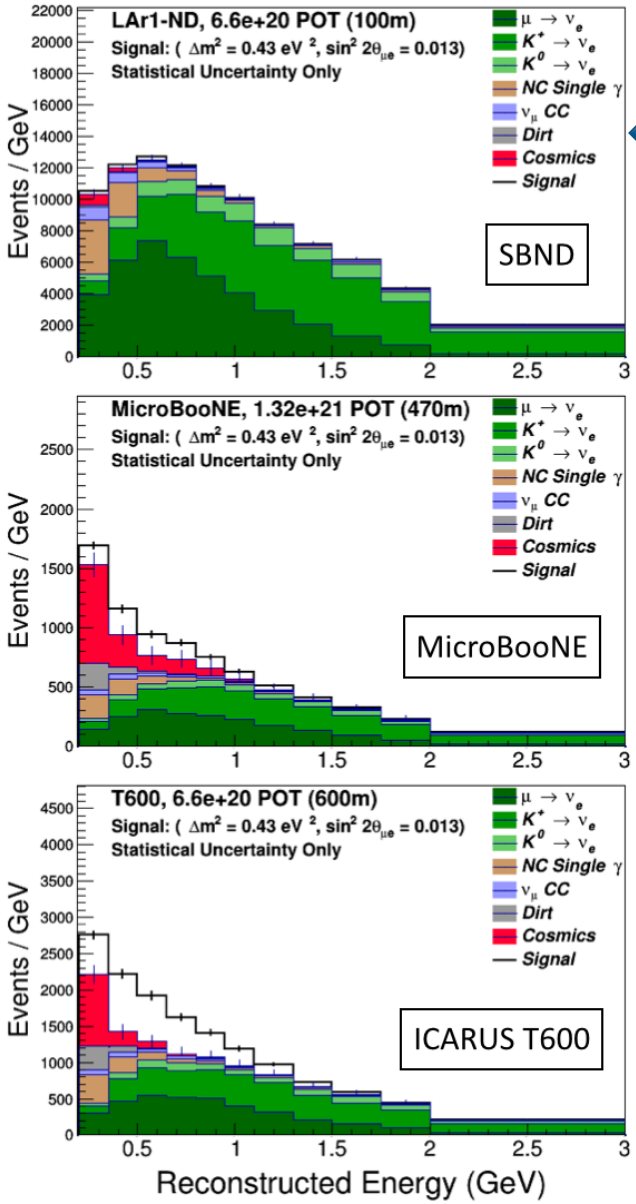


- Electron neutrino CC interactions
  - $\pi \rightarrow \mu \rightarrow \nu_e$
  - $K^+ \rightarrow \nu_e$
  - $K^0 \rightarrow \nu_e$

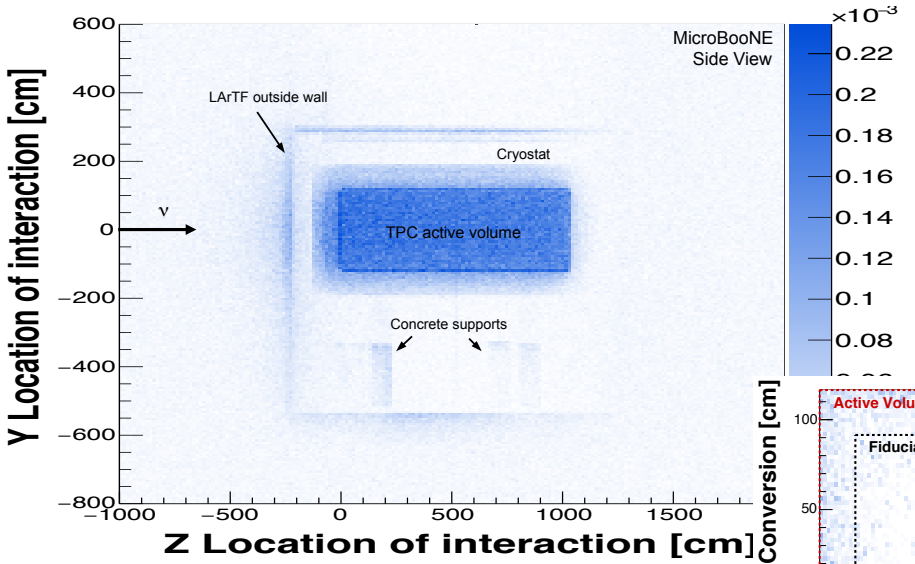
  → Intrinsic beam ν_e
  - Sample appearance signal

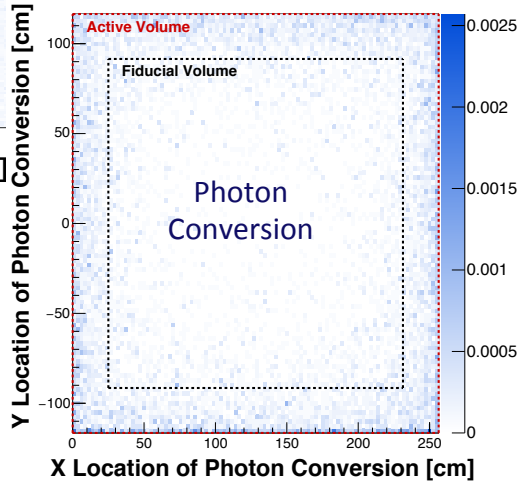
- Photon-induced e.m. shower backgrounds
  - NC misIDs
  - ν_μ CC misIDs
  - "Dirt" Backgrounds: beam-related but out-of-detector interactions
  - Cosmogenic photon sources

“Dirt” Backgrounds



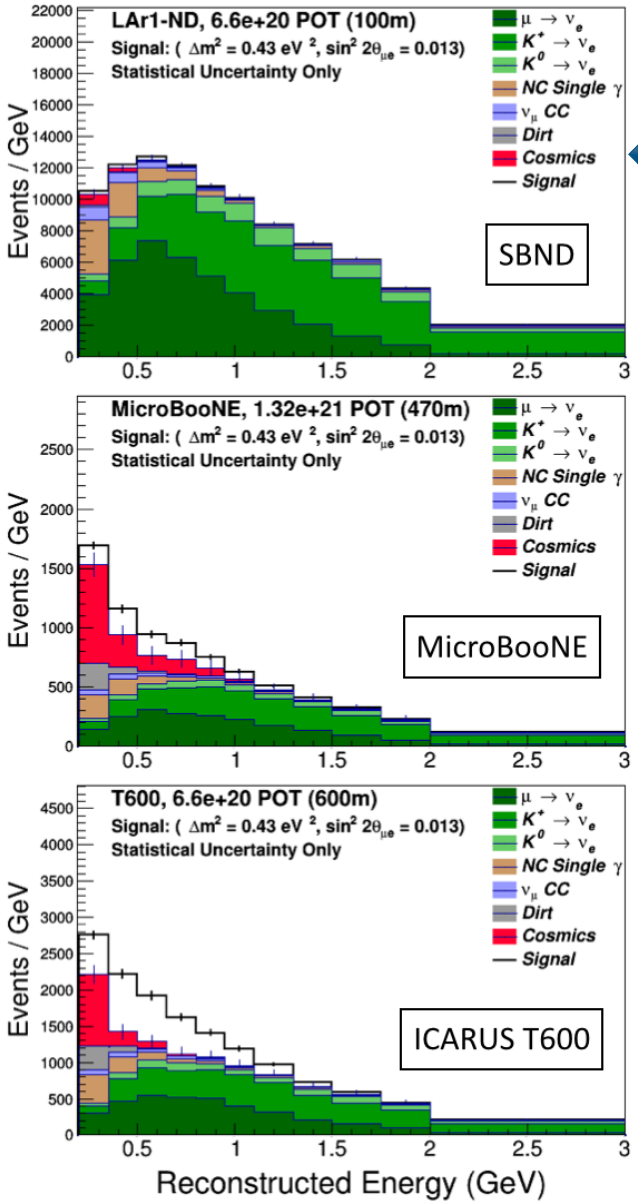
- “Dirt” backgrounds
  - *Detailed model of the MicroBooNE detector, equipment, and building*
  - *Study beam-induced backgrounds that sneak **into the active volume from outside***





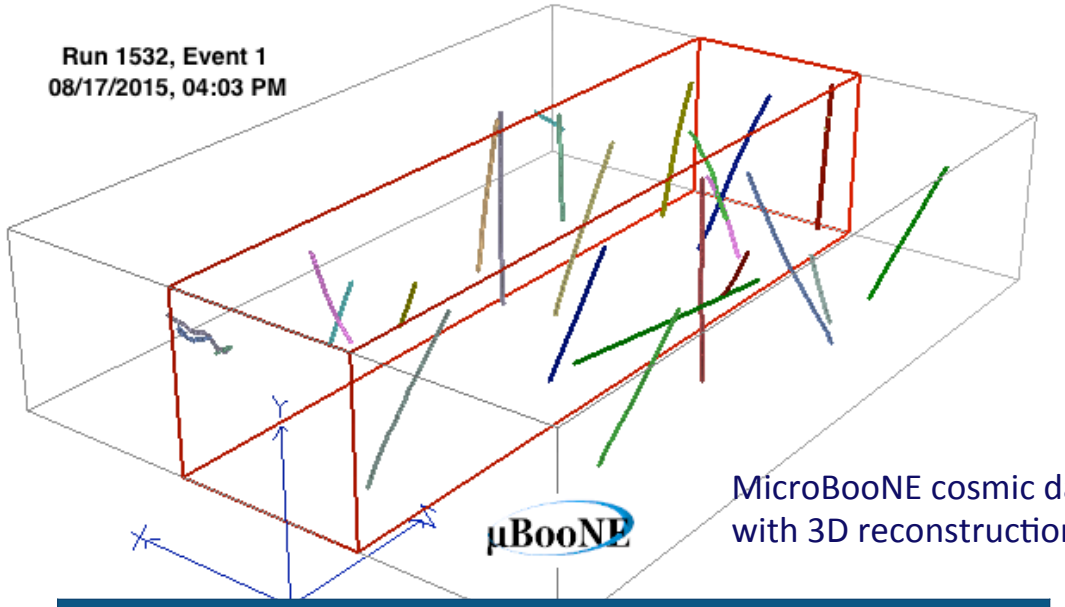
Applied a tight 25cm FV buffer to keep this background limited

Mitigation of Cosmogenic Backgrounds



- The problem: 1000x longer charge drift time than the beam spill time!

1.6 μs beam spill vs. 1-2 ms TPC drift time

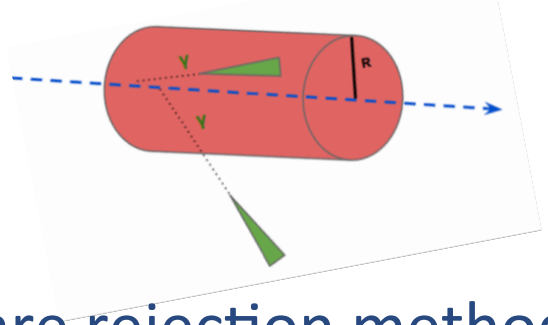


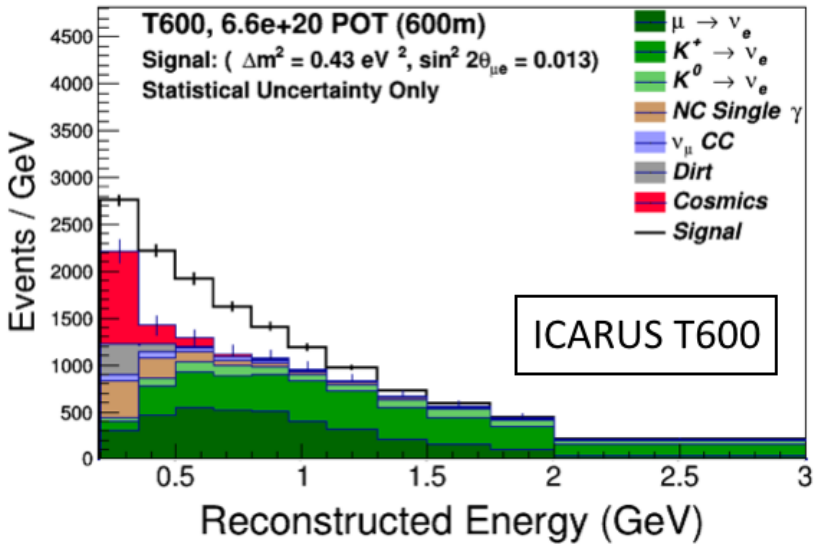
MicroBooNE cosmic data with 3D reconstruction!

Detector	Neutrino interaction every N spills	Cosmic muon in beam spill time every N spills
SBND	20	250
MicroBooNE	600	200
ICARUS-T300	350	100

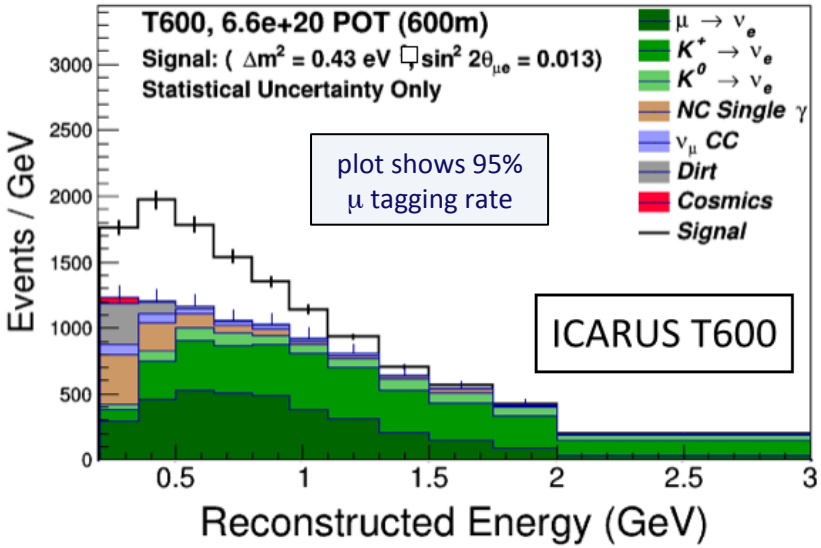
Mitigation of Cosmogenic Backgrounds

- Software rejection methods:
  - *dE/dx at initial part of showers → factor ≈10*
  - *Fiducial volume for photons produced outside*
  - *Shower distance from parent muon track → 15 cm radius rejects >99% of γ > 200 MeV*

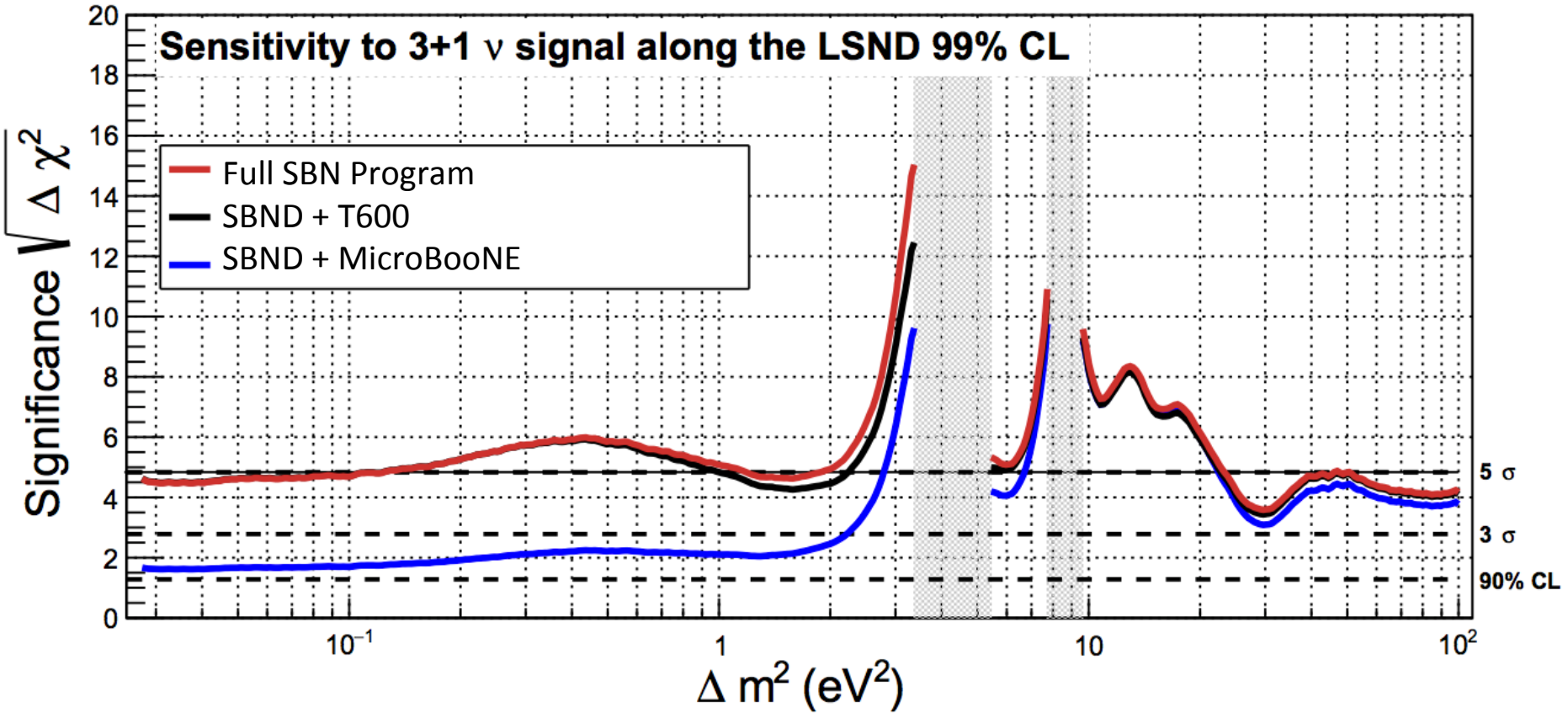




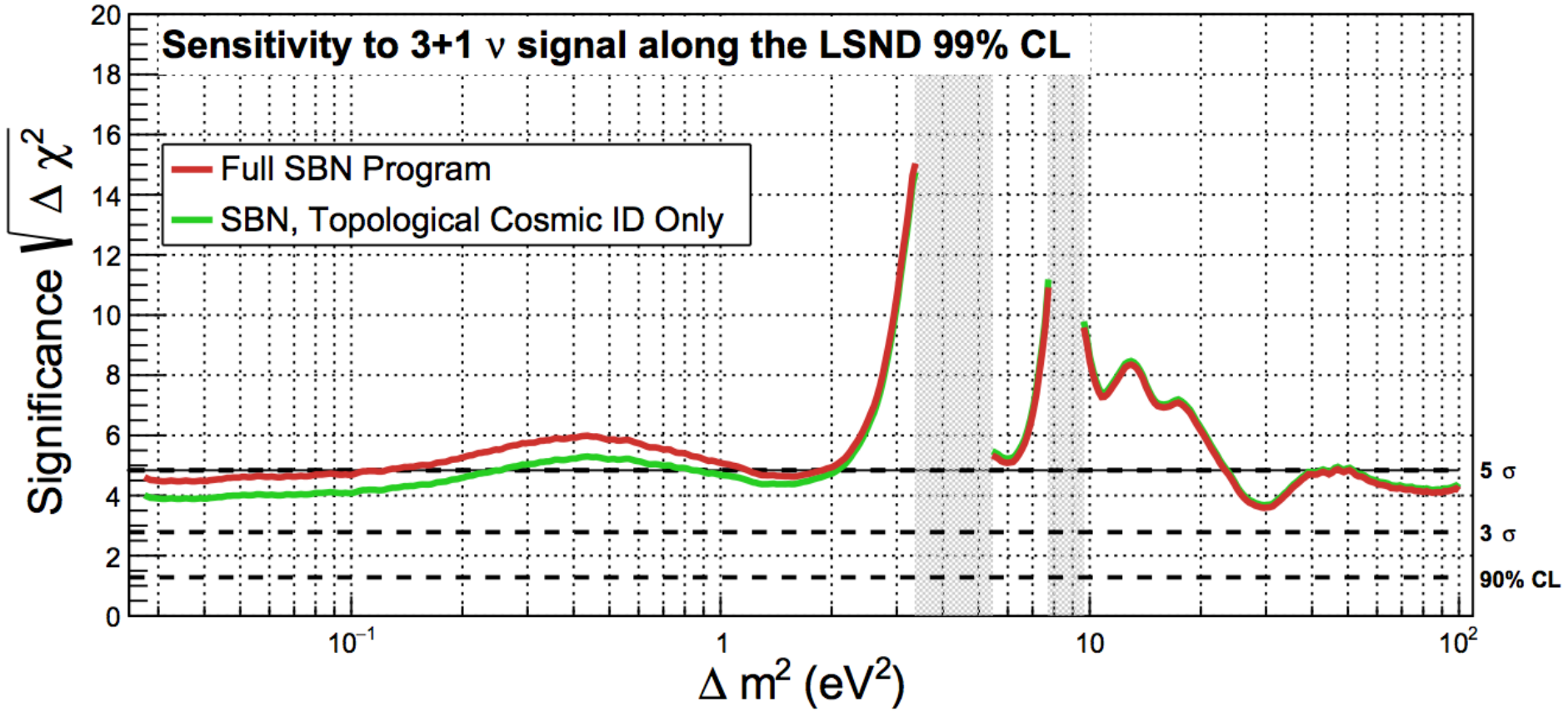
- Hardware rejection methods:
  - *Internal photon detectors*
    - Performance depends on position-time matching resolution of system
  - *External cosmic ray tagging system*
    - Reject beam triggers with in-time signals in the CRT, suppressing cosmogenic backgrounds with a small and measurable efficiency loss on ν events (3%)



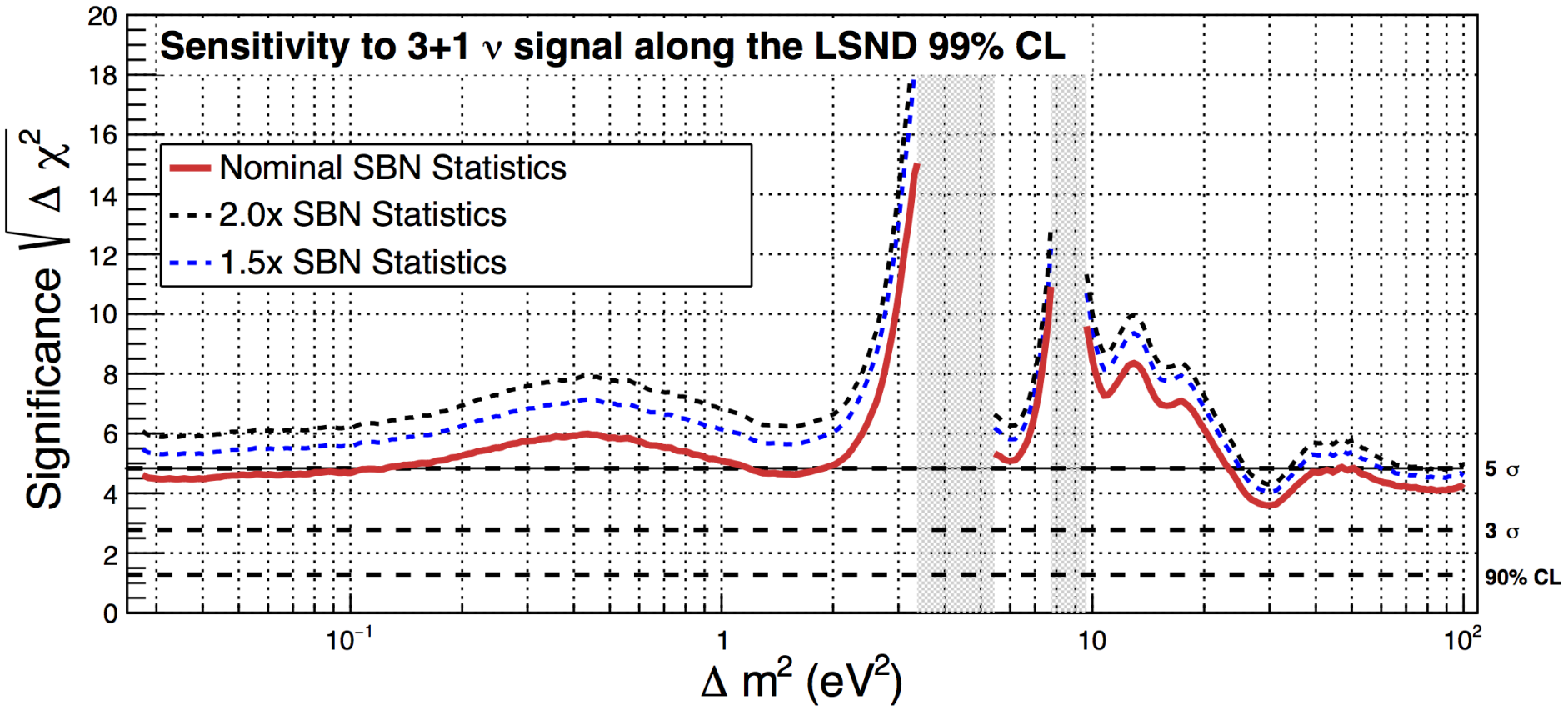
Impact of Three Detectors



Impact of Cosmics

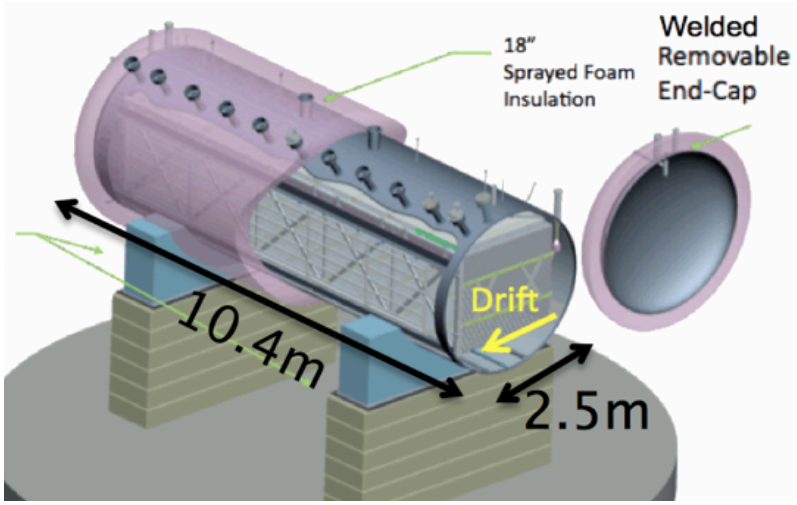


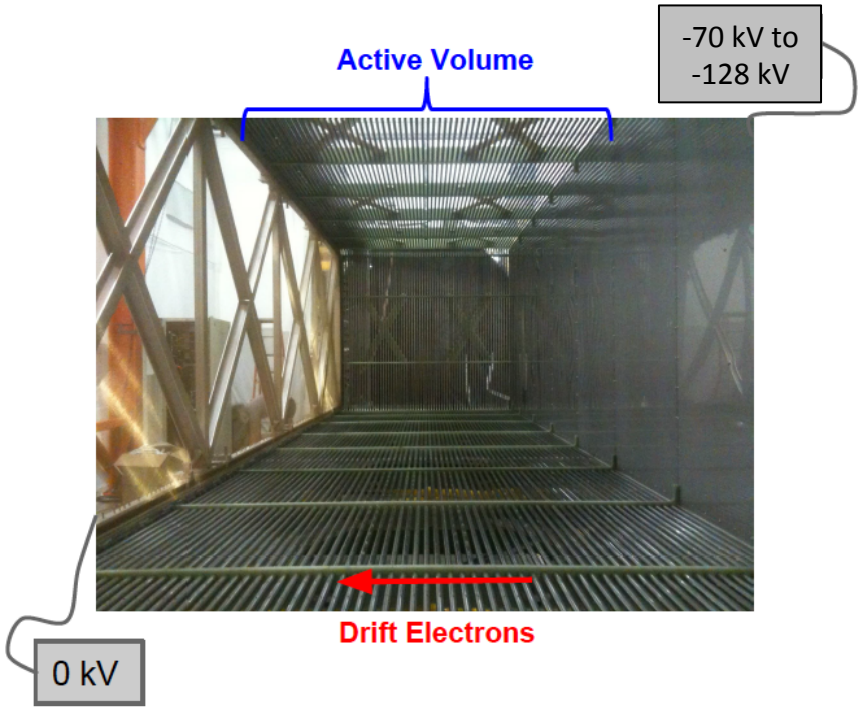
Impact of Additional Beam Statistics



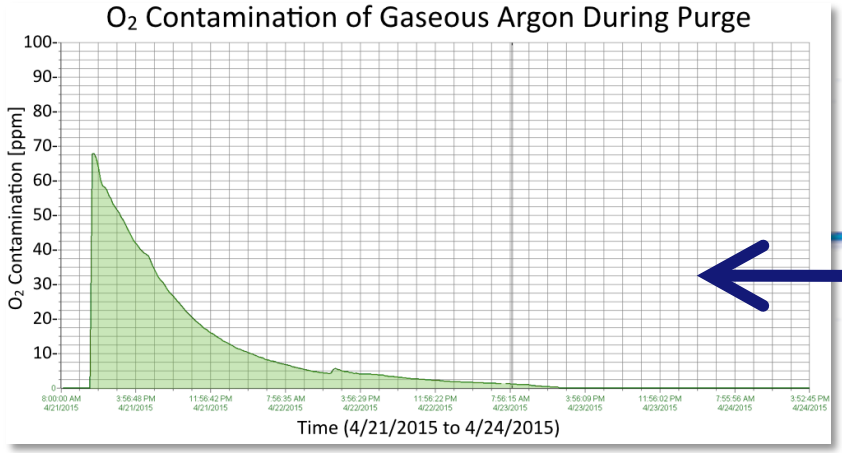
The MicroBooNE Detector

- 170 ton LArTPC (total mass)
- 8256 wires (3 mm pitch)
  - *3456 collection channels (vertical)*
  - *4800 induction channels (±60˚)*
- Cold front-end TPC electronics
- 32 8” Cryogenic PMTs to collect scintillation photons
- UV laser calibration system
  - *2 ports: upstream, downstream (maneuverable heads)*
- LAr purity monitors
- HV required depends on purity
  - *purity is excellent; -128 kV nominal, begin operations at -70 kV*

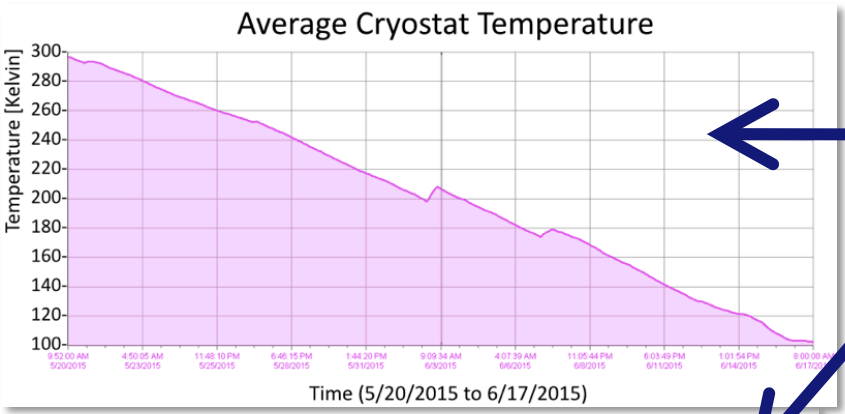




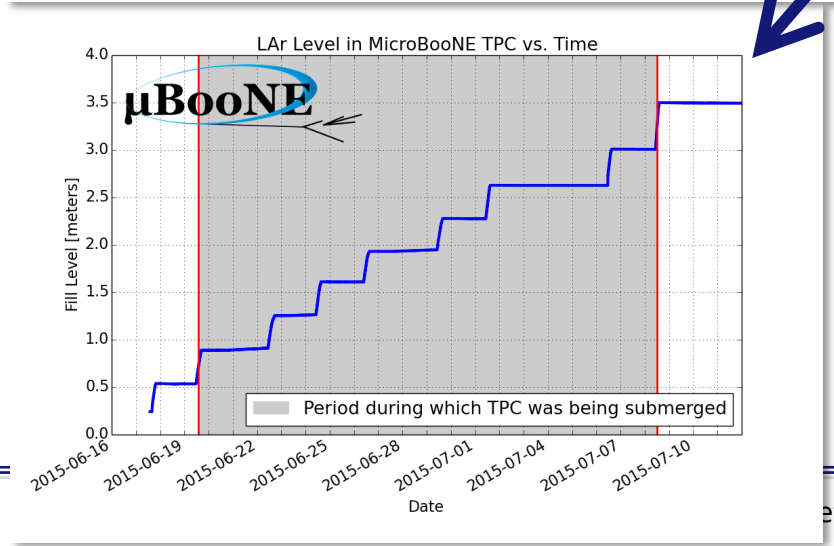
Liquid Argon

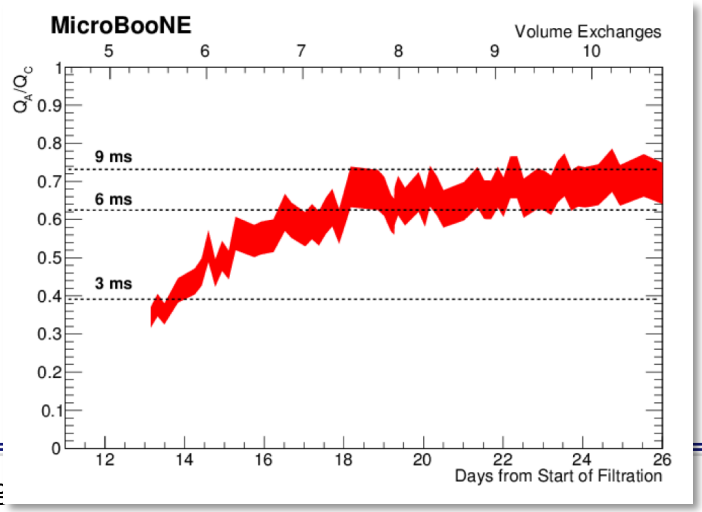


- step 1: purge with gaseous argon
  - *first demonstration of this technique in a fully instrumented physics experiment*
  - → *vessel evacuation not necessary*

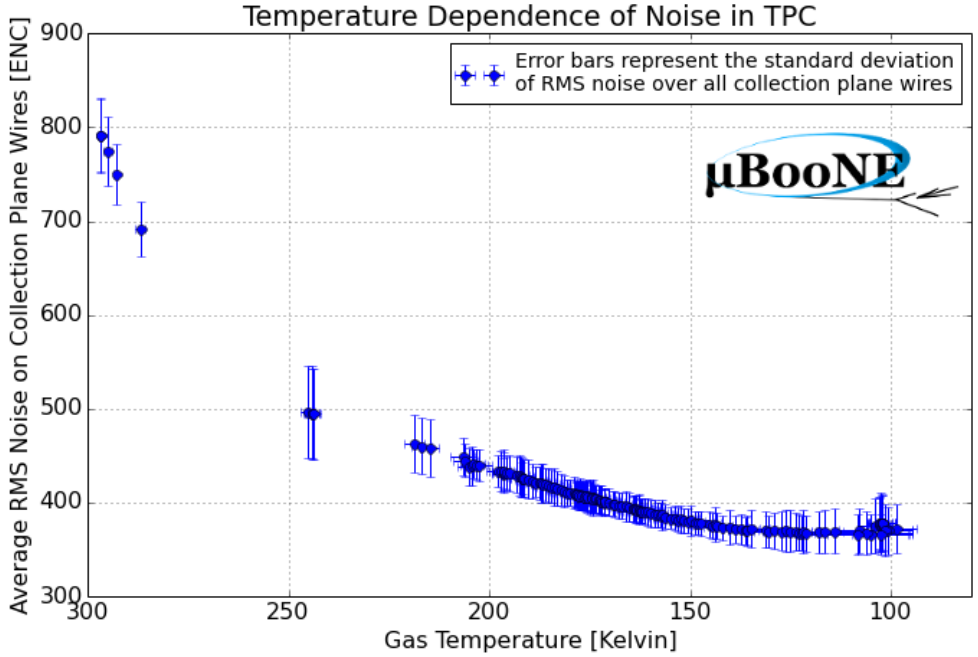


- step 2: cool to LAr temperatures
- step 3: liquid argon fill *(170 tons)*
- step 4: purification *(>2x design purity)*





Cold Electronics



Noise Dependence on Temperature and LAr Fill Level in the MicroBooNE Time Projection Chamber

David Caratelli*
for the MicroBooNE Collaboration

Nevis Laboratories, Columbia University, New York, NY

August 28th 2015

Abstract

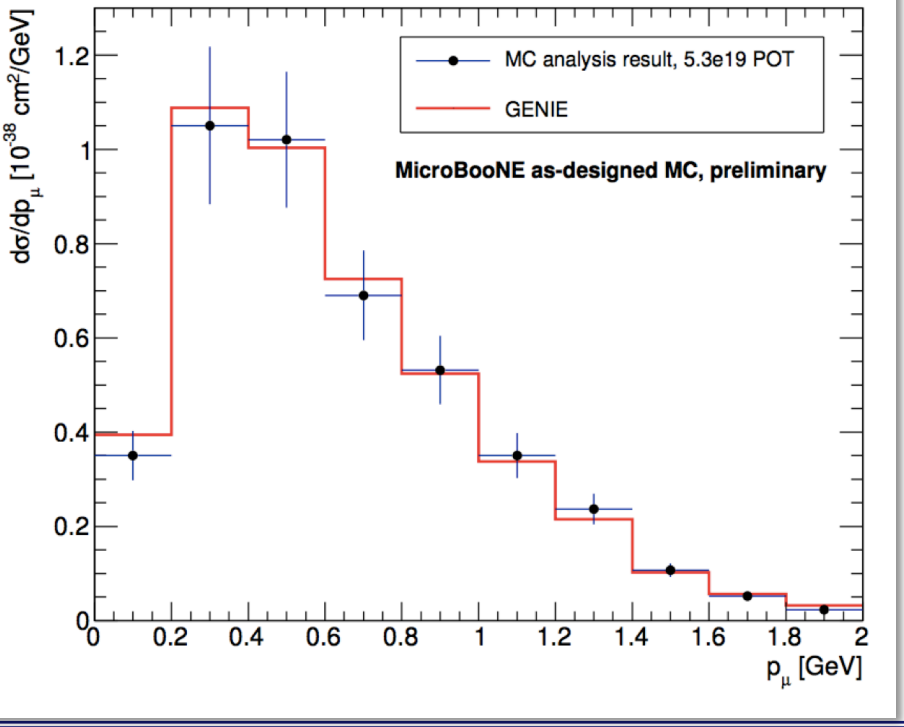
MicroBooNE is a liquid argon time projection chamber (LArTPC) in the Fermilab Booster Neutrino Beamline. In Summer of 2015 the detector was filled with liquid argon and commissioned. In this note we present the temperature and fill-level dependence of the noise measured on the wire signals. We observe the expected decrease of noise for the CMOS ASIC and the increase in wire noise due to the change in dielectric when submerged in liquid argon.

- 90% of channels are operational *(out of a total of 8,256 channels in 3 planes)*
- signal/noise is 40:1 *(ICARUS = 10:1)*

Neutrino Cross Sections

- end-to-end fully automated muon neutrino CC inclusive cross section analysis completed, based on simulation

  - includes all basic ingredients for a ν_μ cross section analysis



MC performance study for an early ν_μ charged-current inclusive analysis with MicroBooNE

The MicroBooNE Collaboration

November 6, 2015

Abstract

This note describes an analysis performed on Monte Carlo data to evaluate the sensitivity of MicroBooNE for an early ν_μ charged-current inclusive cross section measurement. Such an analysis is intended to be done using the first three months of Booster Neutrino Beam data. The event selection is entirely based on an automated event reconstruction. The Monte Carlo prediction for a flux-integrated and single differential cross section measurement with an approximate estimation of statistical and systematic uncertainties for the MicroBooNE detector as designed is presented. This allows the comparison of the sensitivity of MicroBooNE to theory and other experiments.

- projections were shown at the NuInt conference last month

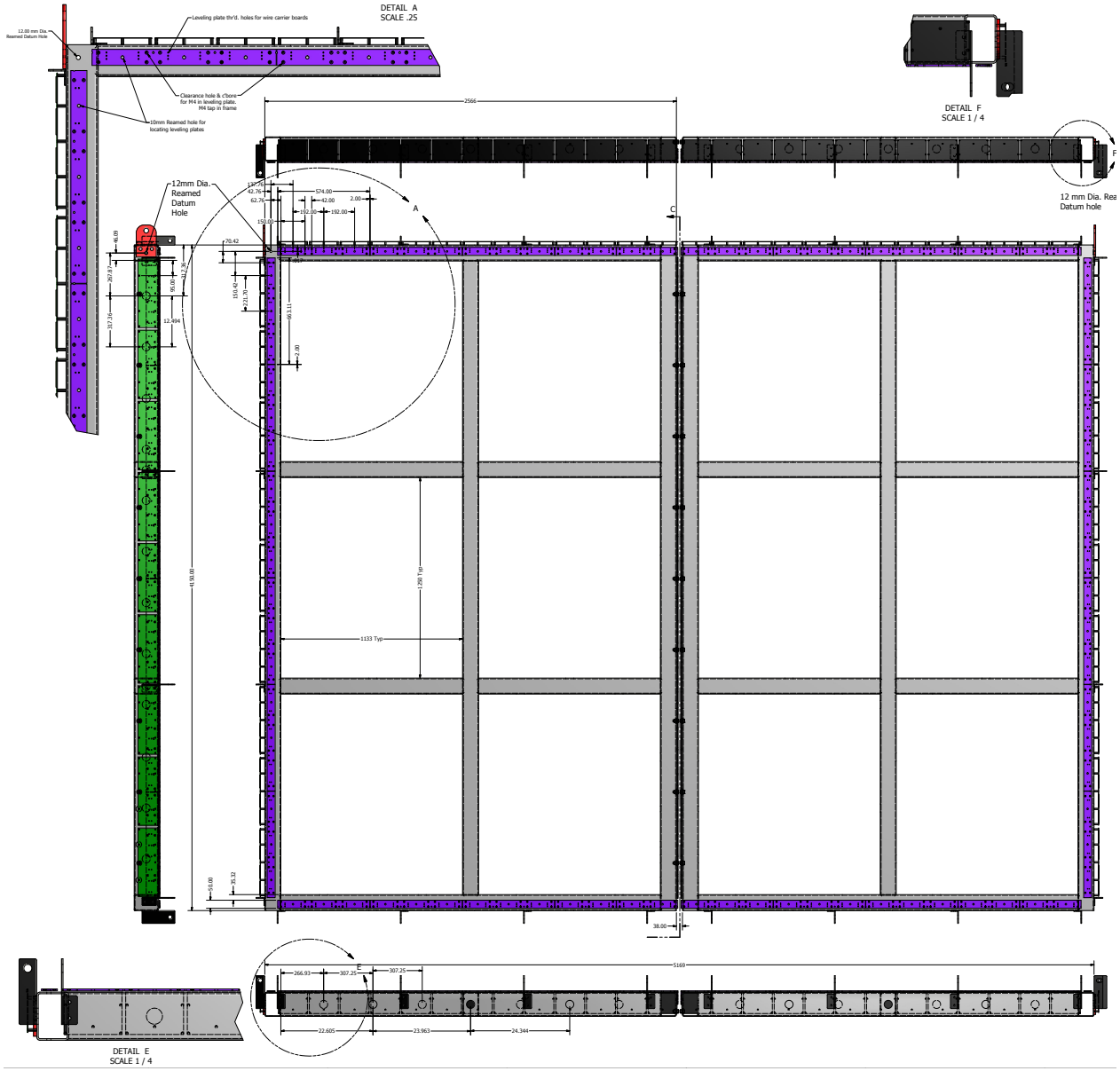
Publications

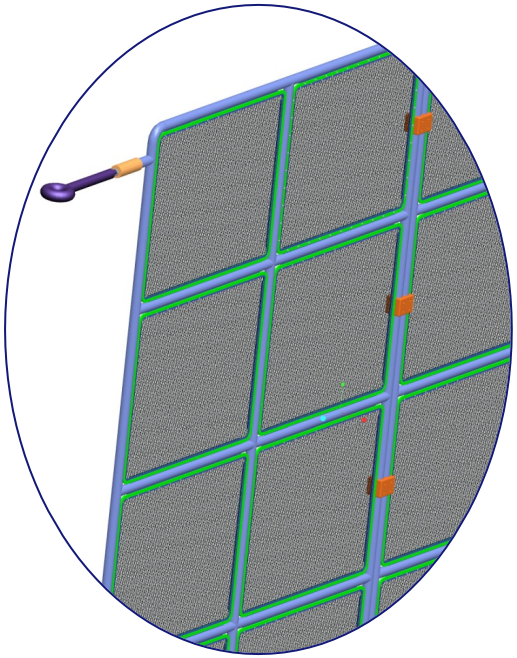
Related Publications by MicroBooNE Collaborators:

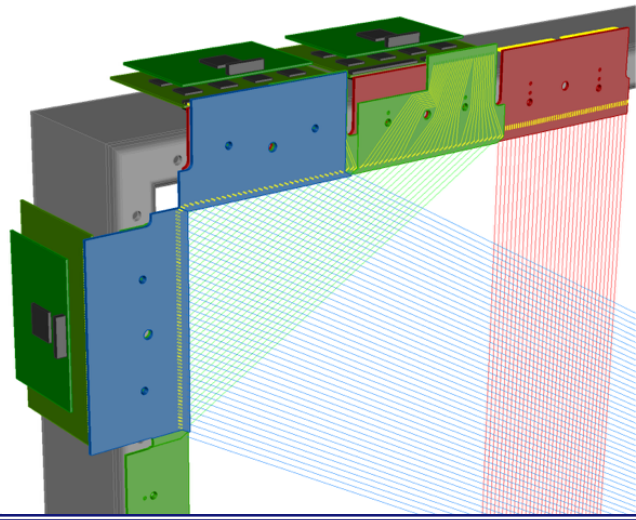
- B. Carls *et al.*, "Design and Operation of a Setup with a Camera and Adjustable Mirror to Inspect the Sense Wire Planes of the TPC Inside the MicroBooNE Cryostat", JINST 10, T08006 (2015)
- J. Conrad *et al.*, "The Photomultiplier Tube Calibration System of the MicroBooNE Experiment", JINST 10, T06001 (2015)
- L.F. Bagby *et al.*, "Breakdown Voltage of Metal Oxide Resistors in Liquid Argon", JINST 9, T11004 (2014)
- R. Acciarri *et al.*, "Liquid Argon Dielectric Breakdown Studies with the MicroBooNE Purification System", JINST 9, P11001 (2014)
- A. Ereditato *et al.*, "First Working Prototype of a Steerable UV Laser System for LAr TPC Calibrations", JINST 9, T11007 (2014)
- J. Asaadi *et al.*, "Testing of High Voltage Surge Protection Devices for Use in Liquid Argon TPC Detectors", JINST 9, P09002 (2014)
- M. Auger *et al.*, "A Method to Suppress Dielectric Breakdowns in Liquid Argon Ionization Detectors for Cathode to Ground Distances of Several Millimeters", JINST 9, P07023 (2014)
- A. Blatter *et al.*, "Experimental Study of Electric Breakdown in Liquid Argon at Centimeter Scale", JINST 9, P04006 (2014)
- T. Briese *et al.*, "Testing of Cryogenic Photomultiplier Tubes for the MicroBooNE Experiment", JINST 8, T07005 (2013)
- B.J.P. Jones *et al.*, "Photodegradation Mechanisms of Tetraphenyl Butadiene Coatings for Liquid Argon Detectors", JINST 8 P01013 (2013)
- B.J.P. Jones *et al.*, "A Measurement of the Absorption of Liquid Argon Scintillation Light by Dissolved Nitrogen at the Part-Per-Million Level", JINST 8 P07011 (2013)
- C.S. Chiu *et al.*, "Environmental Effects on TPB Wavelength-Shifting Coatings", JINST 7, P07007 (2012)
- A. Ereditato *et al.*, "Design and Operation of ARGONTUBE: a 5m Long Drift Liquid Argon TPC", JINST 8, P07002 (2013)

- 13 papers during the construction and installation of MicroBooNE

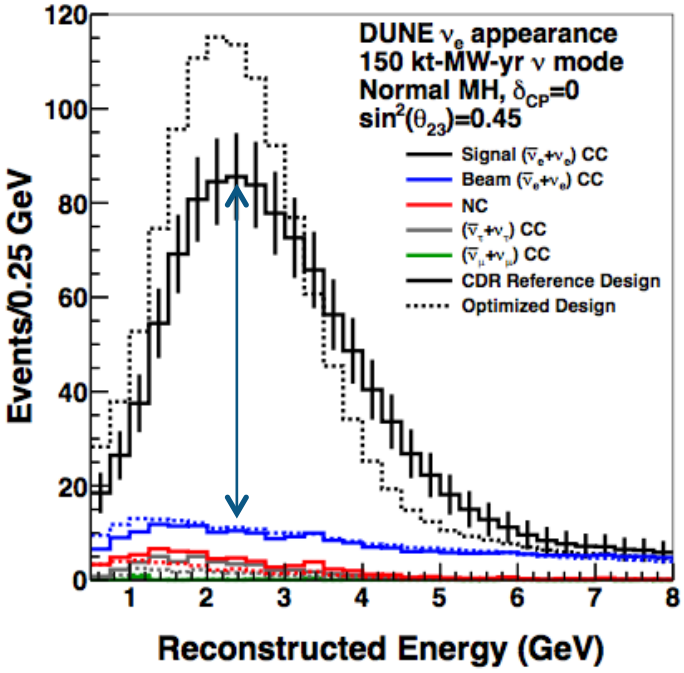
Currently In Final Design Phase for TPC

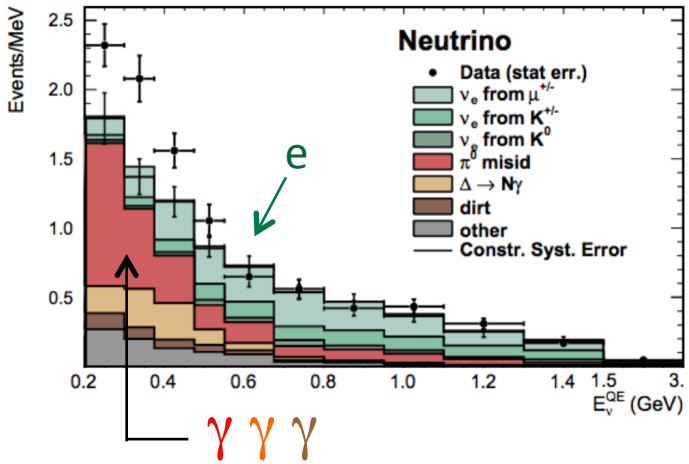






LBL & SBL Detector Requirements

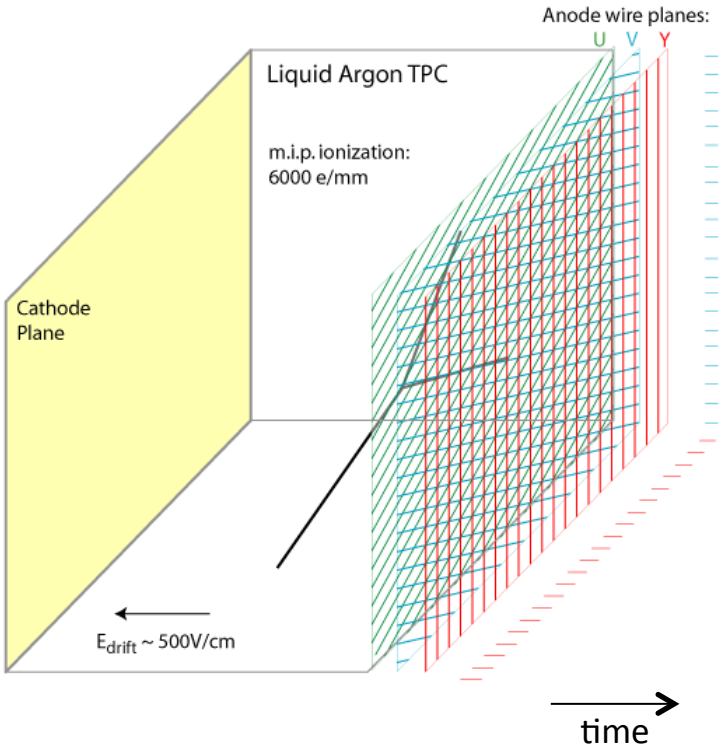




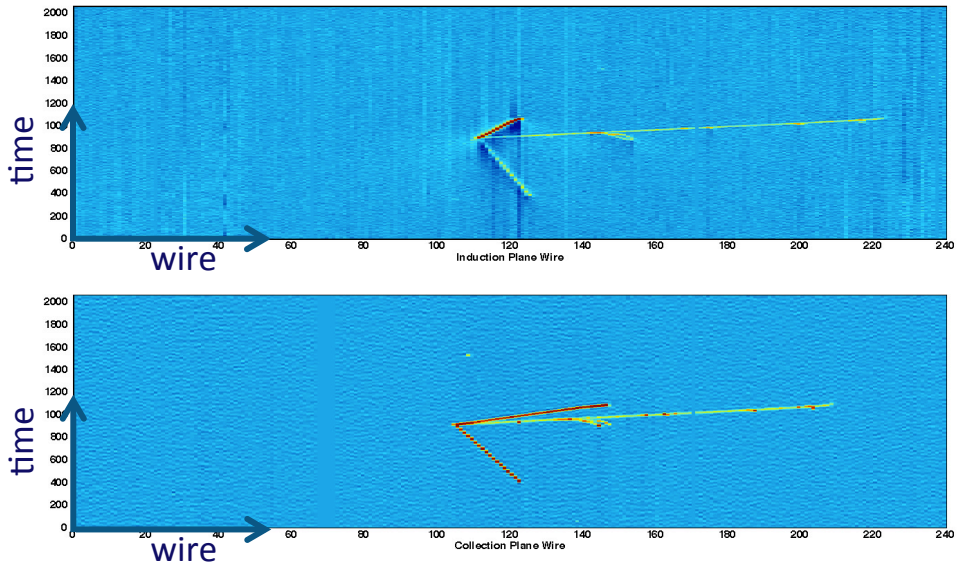
- Common detector requirements for next generation neutrino physics
  - *Excellent muon AND electron identification*
  - *Powerful rejection of NC backgrounds where gammas can fake electron showers*
  - *Excellent energy measurement capabilities*
  - *Good performance from few-MeV (for SN physics) to few-GeV (for beam physics)*
  - *Scalable to tens of thousands of tons*
- Liquid argon time projection chamber
  - *Monolithic, totally active calorimeter*
  - *Exquisite imaging capability in 3D (mm scale)*
  - *dE/dx sampling enables e/γ separation*

Liquid Argon TPCs

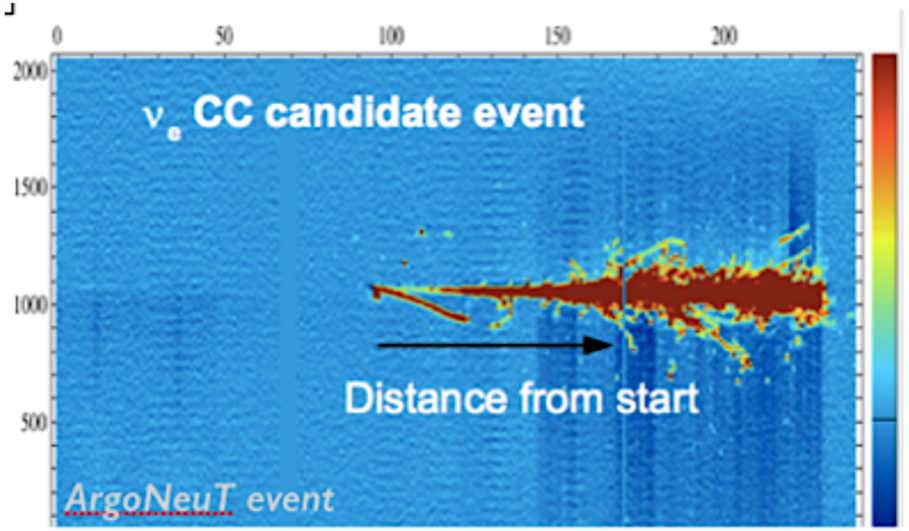
- Propagating charged particles ionize the argon
- Electric field drifts free electrons ~meters to wire chamber planes
- Induction/Collection planes image charge, record dE/dx
- Argon purity of prime importance to avoid signal attenuation

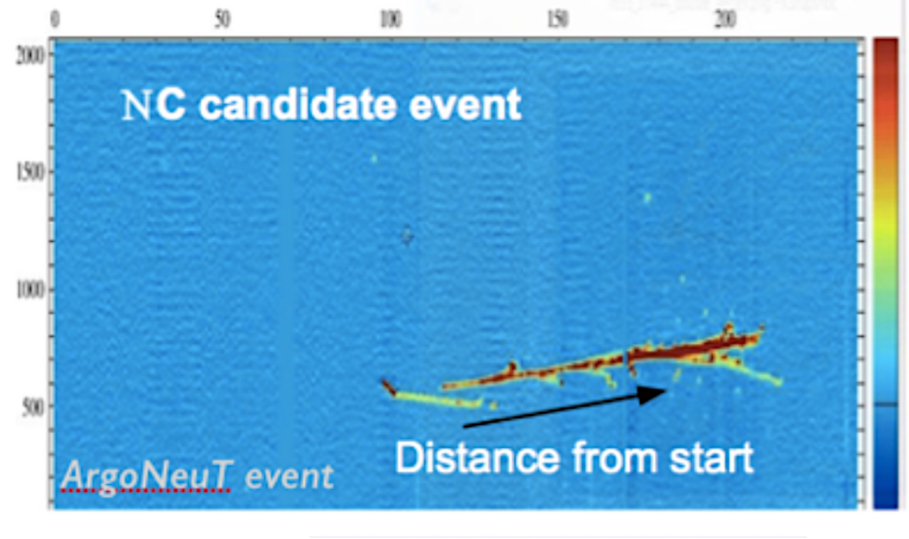


Neutrino interaction in the ArgoNeuT LArTPC at Fermilab



Electron/Gamma ID in LArTPCs

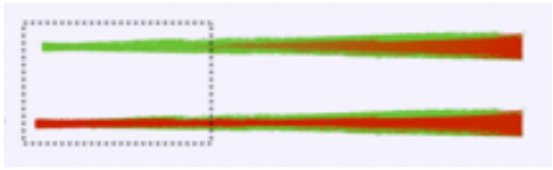




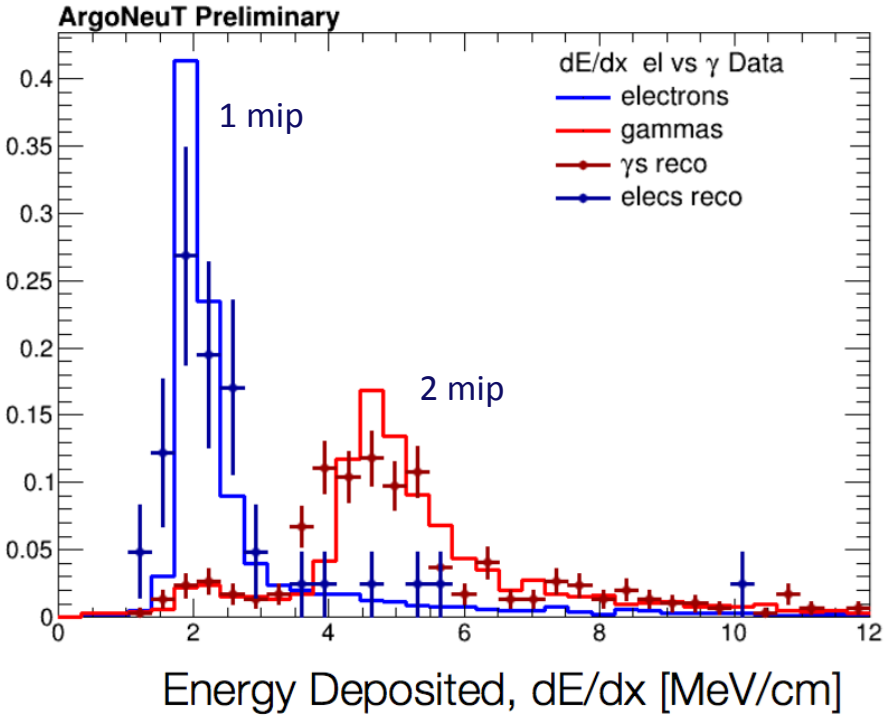
1 mip

Electron

$\gamma \rightarrow e^+ + e^-$

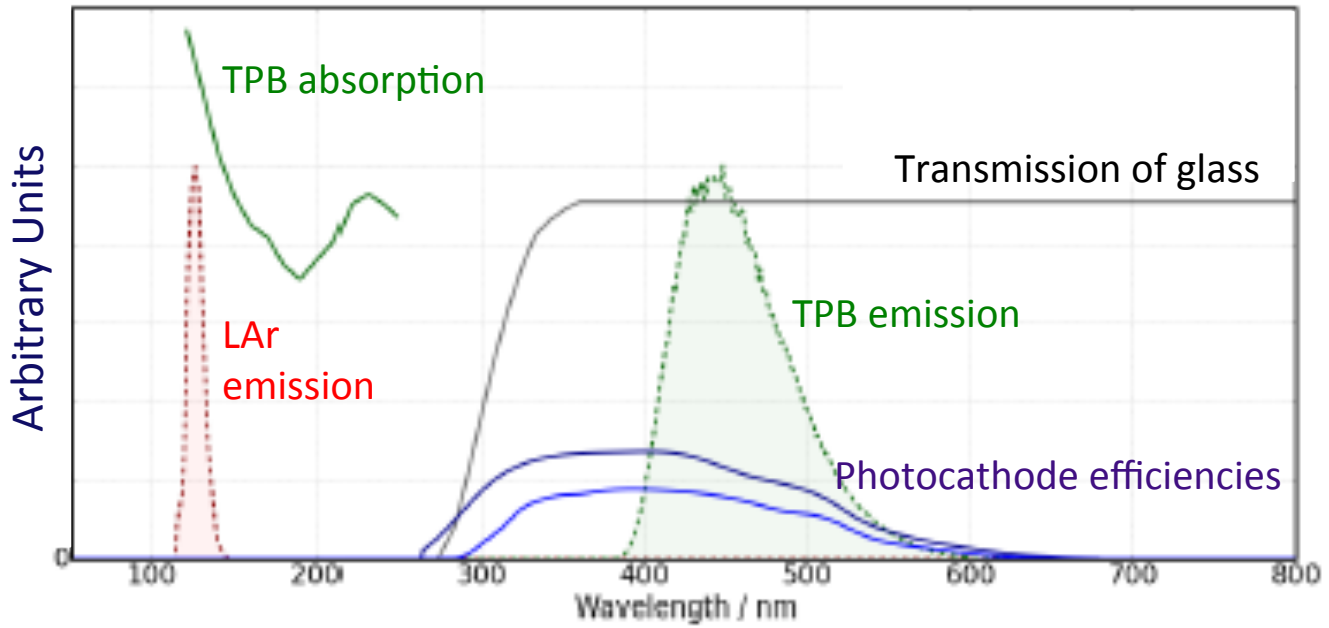


2 mip



Scintillation Light in LArTPCs

- Ionized LAr creates large amounts of scintillation light as well
  - *~40k photons per MeV at 0 electric field*
- Valuable for fast-timing information and, potentially, calorimetry
- The problem is that the light is at 128 nm (VUV)
  - *Shift the light from UV to Visible, typically using Tetraphenyl Butadiene (TPB)*



Three Collaborations ➔ One Program

Jan 2015 proposal author list

The ICARUS-WA104 Collaboration

M. Antonello[16], B. Baibussinov[31], V. Bellini[5], P. Benetti[32], S. Bertolucci[6], H. Bilokon[15], F. Boffelli[32], M. Bonesini[17], J. Bremer[6], E. Calligarich[32], S. Centro[31], A.G. Cocco[19], A. Dermenev[20], A. Falcone[32], C. Farnese[31], A. Fava[31], A. Ferrari[6], D. Gibin[31], S. Gninenko[20], N. Golubev[20], A. Guglielmi[31], A. Ivashkin[20], M. Kirsanov[20], J. Kisiel[38], U. Kose[6], F. Mammoliti[5], G. Mannocchi[15], A. Menegolli[32], G. Meng[31], D. Mladenov[6], C. Montanari[32], M. Nessi[6], M. Nicoletto[31], F. Noto[6], P. Picchi[15], F. Pietropaolo[31], P.Płoński[42], R. Potenza[5], A. Rappoldi[32], G. L. Raselli[32], M. Rossella[32], C. Rubbia*[6,11,16], P. Sala[18], A. Scaramelli[18], J. Sobczyk[44], M. Spanu[32], D. Stefan[18], R. Suley[43], C.M. Sutera[5], M. Torti[32], F. Tortorici[5], F. Varanini[31], S. Ventura[31], C. Vignoli[16], T. Wachala[12], and A. Zani[32]

The LAr1-ND Collaboration

C. Adams[45], C. Andreopoulos[23], A. Ankowski[41], J. Asaadi[40], L. Bagby[10], B. Baller[10], N. Barros[33], M. Bass[30], S. Bertolucci[6], M. Bishai[3], A. Bitadze[25], J. Bremer[6], L. Bugel[26], L. Camilleri[9], F. Cavanna[a,10], H. Chen[3], C. Chi[9], E. Church[10], D. Cianci[7], G. Collin[26], J.M. Conrad[26], G. De Geronimo[3], R. Dharmapalan[1], Z. Djurcic[1], A. Ereditato[2], J. Esquivel[40], J. Evans[25], B.T. Fleming[45], W.M. Foreman[7], J. Freestone[25], T. Gamble[37], G. Garvey[24], V. Genty[9], D. Göldi[2], H. Greenlee[10], R. Guenette[30], A. Hackenburg[45], R. Hänni[2], J. Ho[7], J. Howell[10], C. James[10], C.M. Jen[41], B.J.P. Jones[26], L.M. Kalousis[41], G. Karagiorgi[25], W. Ketchum[24], J. Klein[33], J. Klinger[37], U. Kose[6], I. Kreslo[2], V.A. Kudryavtsev[37], D. Lissauer[3], P. Livesly[22], W.C. Louis[24], M. Lu□thi[2], C. Mariani[41], K. Mavrokoridis[23], N. McCauley[23], N. McConkey[37], I. Mercer[22], T. Miao[10], G.B. Mills[24], D. Mladenov[6], D. Montanari[10], J. Moon[26], Z. Moss[26], S. Mufson[14], M. Nessi[6], B. Norris[10], F. Noto[6], J. Nowak[22], S. Pal[37], O. Palamara*[b,10], J. Pater[25], Z. Pavlovic[10], J. Perkin[37], G. Pulliam[40], X. Qian[3], L. Qiuguang[24], V. Radeka[3], R. Rameika[10], P.N. Ratoff[22], M. Richardson[37], C. Rudolf von Rohr[2], D.W. Schmitz*[7], M.H. Shaevitz[9], B. Sippach[9], M. Soderberg[40], S. Söldner-Rembold[25], J. Spitz[26], N. Spooner[37], T. Strauss[2], A.M. Szelc[25,45], C.E. Taylor[24], K. Terao[9], M. Thiesse[37], L. Thompson[37], M. Thomson[4], C. Thorn[3], M. Toups[26], C. Touramanis[23], R.G. Van De Water[24], M. Weber[2], D. Whittington[14], T. Wongjirad[26], B. Yu[3], G.P. Zeller[10], and J. Zennamo[7]

The MicroBooNE Collaboration

R. Acciarri[10], C. Adams[45], R. An[13], A. Ankowski[41], J. Asaadi[40], L. Bagby[10], B. Baller[10], G. Barr[30], M. Bass[30], M. Bishai[3], A. Blake[4], T. Bolton[21], C. Bromberg[27], L. Bugel[26], L. Camilleri[9], D. Caratelli[9], B. Carls[10], F. Cavanna[a,10], H. Chen[3], E. Church[10], G.H. Collin[26], J.M. Conrad[26], M. Convery[39], S. Dytman[34], B. Eberly[39], A. Ereditato[2], J. Esquivel[40], B.T. Fleming*[45], W.M. Foreman[7], V. Genty[9], D. Göldi[2], S. Gollapinni[21], M. Graham[39], E. Gramellini[45], H. Greenlee[10], R. Grosso[8], R. Guenette[30], A. Hackenburg[45], O. Hen[26], J. Hewes[25], J. Ho[7], G. Horton-Smith[21], C. James[10], C.M. Jen[41], R.A. Johnson[8], B.J.P. Jones[26], J. Joshi[3], H. Jostlein[10], D. Kaleko[9], L. Kalousis[41], G. Karagiorgi[25], W. Ketchum[24], B. Kirby[3], M. Kirby[10], T. Kobilarcik[10], I. Kreslo[2], Y. Li[3], B. Littlejohn[13], D. Lissauer[3], S. Lockwitz[10], W.C. Louis[24], M. Lu□thi[2], B. Lundberg[10], A. Marchionni[10], C. Mariani[41], J. Marshall[4], K. McDonald[35], V. Meddage[21], T. Miceli[28], G.B. Mills[24], J. Moon[26], M. Mooney[3], M.H. Moulai[26], R. Murrells[25], D. Naples[34], P. Nienaber[36], O. Palamara[b,10], V. Paolone[34], V. Papavassiliou[28], S. Pate[28], Z. Pavlovic[10], S. Pordes[10], G. Pulliam[40], X. Qian[3], J.L. Raaf[10], V. Radeka[3], R. Rameika[10], B. Rebel[10], L. Rochester[39], C. Rudolf von Rohr[2], B. Russell[45], D.W. Schmitz[7], A. Schukraft[10], W. Seligman[9], M. Shaevitz[9], M. Soderberg[40], J. Spitz[26], J. St. John[8], T. Strauss[2], A.M. Szelc[25,45], N. Tagg[29], K. Terao[9], M. Thomson[4], C. Thorn[3], M. Toups[26], Y. Tsai[39], T. Usher[39], R. Van de Water[24], M. Weber[2], S. Wolbers[10], T. Wongjirad[26], K. Woodruff[28], M. Xu[13], T. Yang[10], B. Yu[3], G.P. Zeller*[10], J. Zennamo[7], and C. Zhang[3]

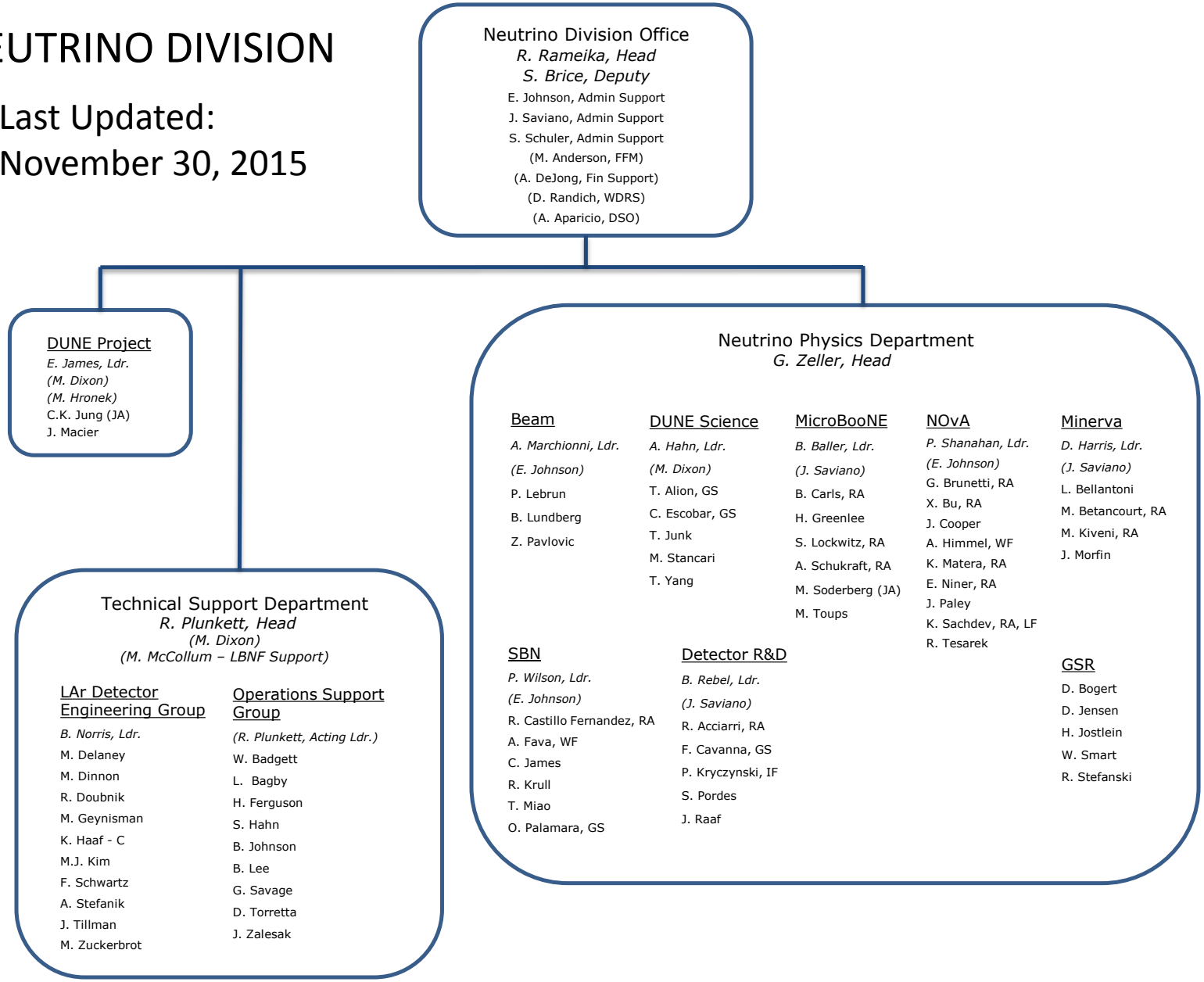
Additional Fermilab Contributors

W. Badgett[10], K. Biery[10], S. Brice[10], S. Dixon[10], M. Geynisman[10], E. Snider[10], and P. Wilson[10]

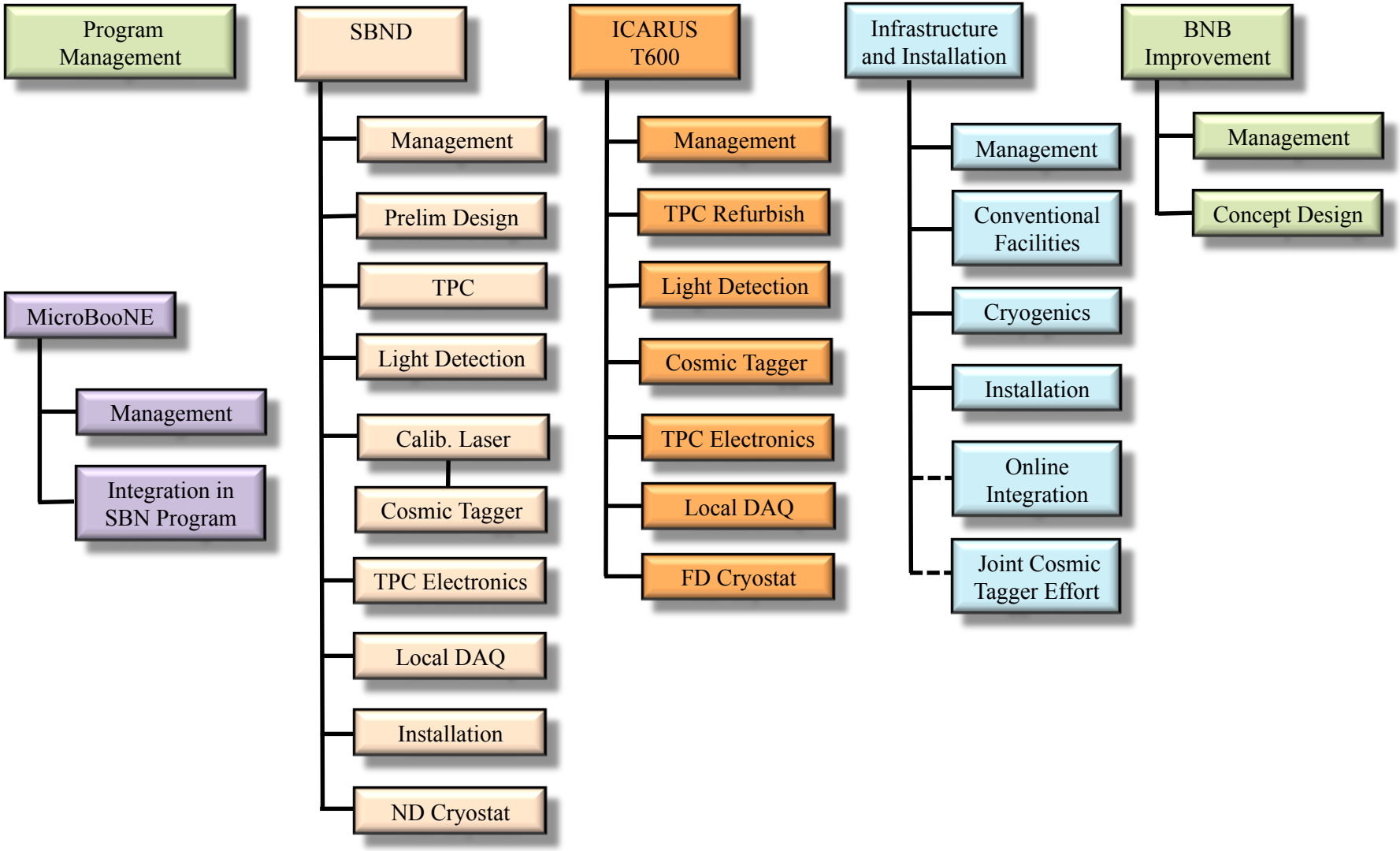
Collaboration spokespeople
Fermilab SBN Program Coordinator

NEUTRINO DIVISION

Last Updated:
November 30, 2015



SBN Work Breakdown



SBN Work Breakdown