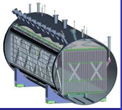
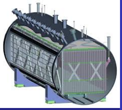


The Fermilab Short Baseline Program and Detectors

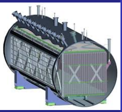
NNN 2016, 3-5 November 2016, IHEP Beijing

Mary Bishai
Brookhaven National Lab

November 3, 2016

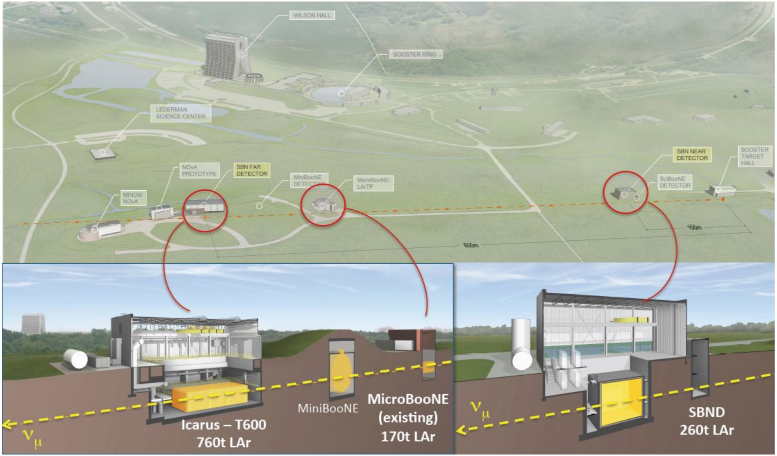


Outline

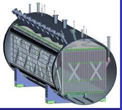


The Fermilab Short Baseline Program

3 detectors in the neutrino beam from the 8GeV Booster ($E_{\nu}^{\rm peak} \sim 800 MeV$):



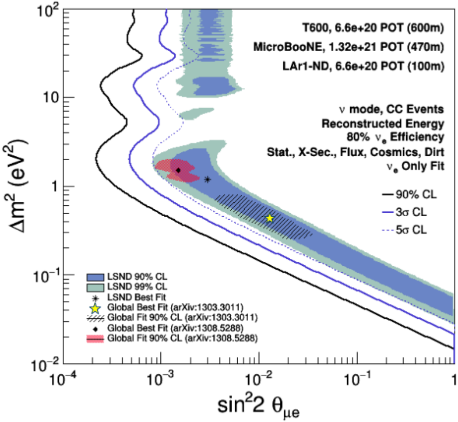
ICARUS (600m) **μBooNE (470m)** **SBND (100m)**

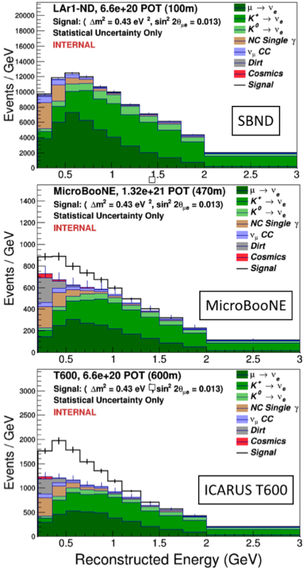


Physics Goals

see talk by A. Palazzo 2/11

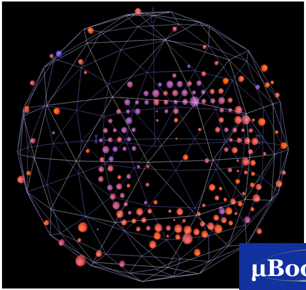
Search for new oscillation phenomena with MULTIPLE detectors/baselines!

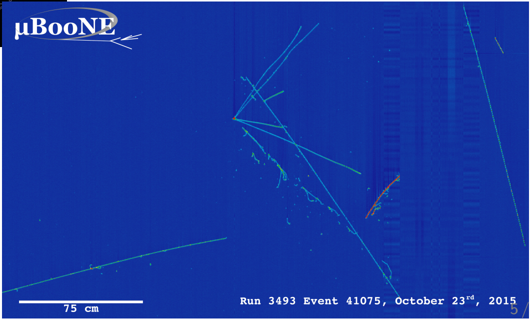




Physics Goals

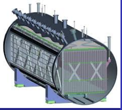
And with better neutrino imaging technology:

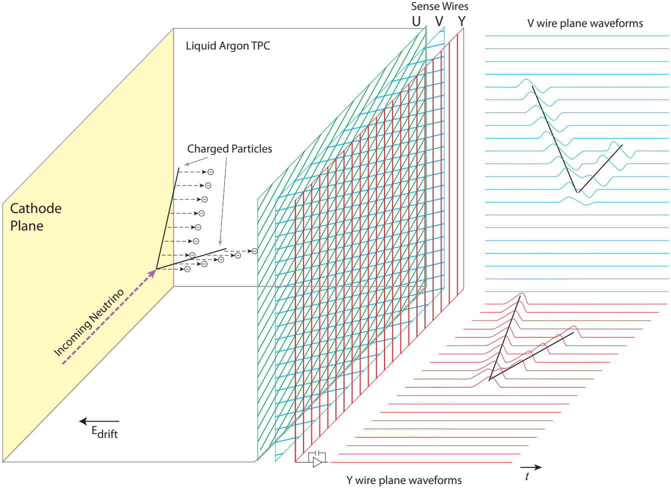


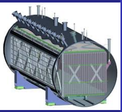


SBN/DUNE Technology: The Single Phase Liquid Argon TPC

see talk by J. Asaadi 2/11







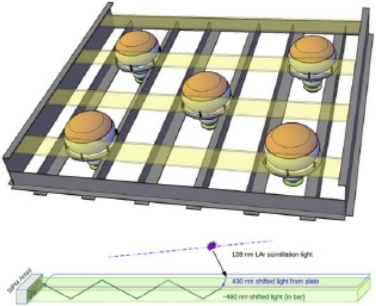
SBN/DUNE Technology: The Single Phase Liquid Argon TPC

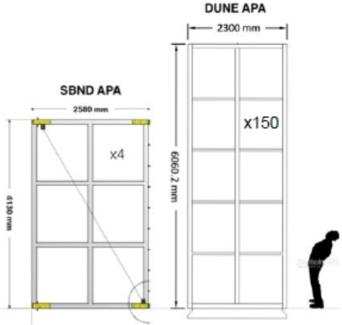
see talk by J. Asaadi 2/11

SBN Detector Parameters:

Detector Component	SBND	MicroBooNE	ICARUS@SBN
TPC Active Volume	4 × 4 × 5 m	2.5 × 2.3 × 10.4 m	3.6 × 3.9 × 19.6 m
TPC Active Mass	112	89	476
TPC Drift Time (at 500V/cm E-field)	1.28 ms	1.6 ms	0.95 ms
TPC Wire Orientation	0° (collection), $\pm 60^\circ$ (induction)		
Wire/plane spacing	3mm	3mm	3mm
Number of wires	11264	8192	53248
Nominal Drift HV	100 kV	128 kV	75 kV
Analog readout electronics	cold CMOS	cold CMOS	warm
Digital readout electronics	ADC cold, FPGA cold	warm	warm
Light collection	120 8" PMTs & scint. bars	32 8" PMTs	360 8" PMTs

SBND/DUNE Synergies

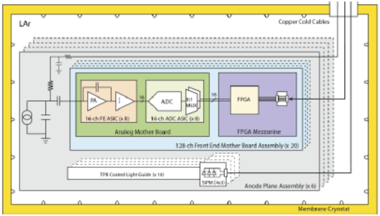




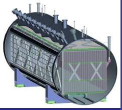
Modular TPC design with large anode plane assemblies

Test scintillator bar photon detector design

Cold electronics readout chain



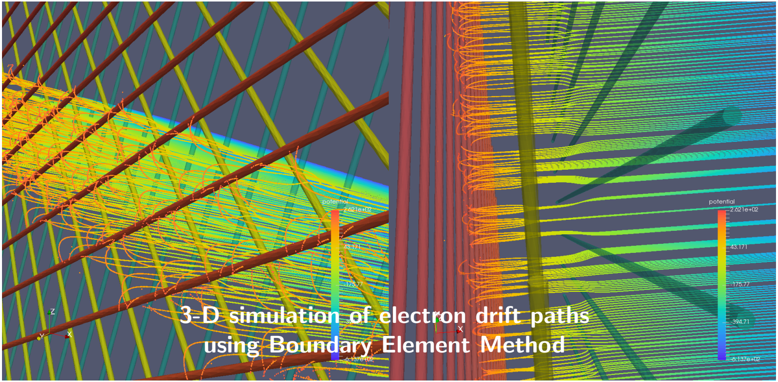
see talk by S. Gao 2/11



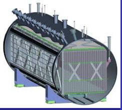
LArTPC Signal Formation

In a LArTPC ionization charges drifts towards the wire planes. Charge is induced on the U and V planes as the charge drifts towards and away from the plane. Most of the charge is collected on the Y plane.

A MIP produces around 14,000 electrons in a 3mm cell



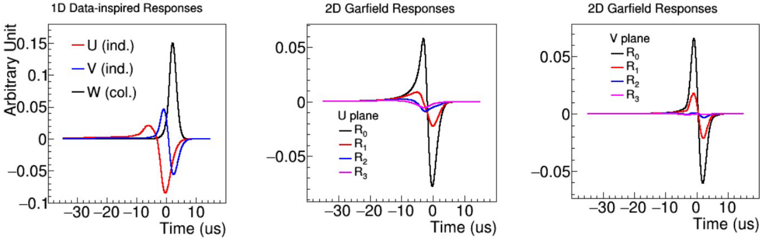
3-D simulation of electron drift paths using Boundary Element Method



LArTPC Signal Processing

see talk by M. Mooney 2/11

In order to extract the charge distribution arriving at the planes from the measured current on the wire, the field response must be deconvoluted:

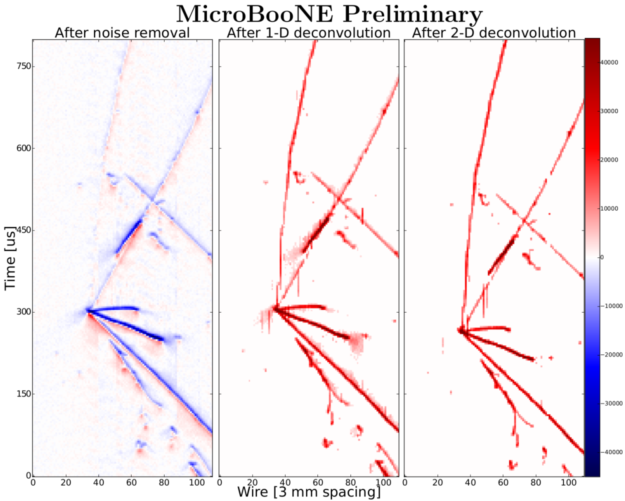


The signals on the induction plane are 2-3x smaller than the collection planes and *highly dependent on track angle*. The charge passing through the plane induces charge on MULTIPLE wires.

Deconvolution has to be in 2-D. Noise needs to be v. low to enable deconvolution of induction plane signals particularly for tracks ⊥ wire.

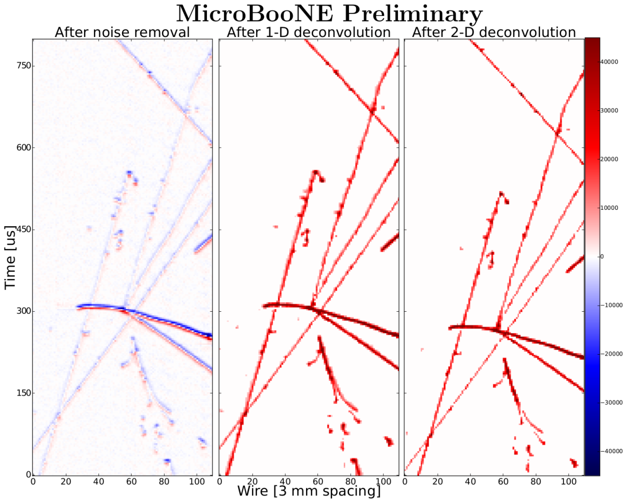
LArTPC Signal Processing

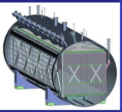
U plane signal processing



LArTPC Signal Processing

V plane signal processing





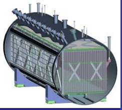
Basic Noise Theory: Sources of Noise in ICs

- **The series "white" noise in the input transistor described by a spectral density, e_n in $\mathrm{V}/\sqrt{\mathrm{Hz}}$, which can be calculated by a simple approximate formula as: $e_n^2 = 4\ \mathrm{k_B}\ \mathrm{T}\ \mathrm{R_s}$**
- **The low frequency series noise $\propto 1/f$ due to charge trapping and de-trapping in the input transistor.**
  for $t_p > 1\mu$s, the $1/f$ noise is dominant
- **The "f parallel" noise which arises from thermal fluctuations in the dielectric components such as the circuit boards. Appears as a series $1/f$ noise component in addition to transistor $1/f$.**
- **The parallel "white" noise due to the transistor bias current and wire bias resistors**

$$\mathrm{ENC}^2 \approx \underbrace{\frac{e_n^2 C_{in}^2}{t_p}}_{\text{series white}}$$

ENC: Equivalent Noise Charge. t_p: shaper peaking time.
C_{in}: sum of detector, cable and preamp input capacitances.

A_f: Measurement constant for $1/f$ noise $\mathcal{O}(10^{-13})\mathrm{V}^2$



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$$\mathrm{ENC}^2 \approx \underbrace{\frac{e_n^2 C_{in}^2}{t_p}}_{\text{series white}} + \underbrace{\pi C_{in}^2 A_f}_{\text{series 1/f}}$$

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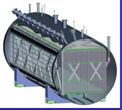

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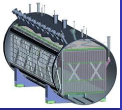

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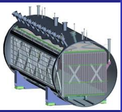
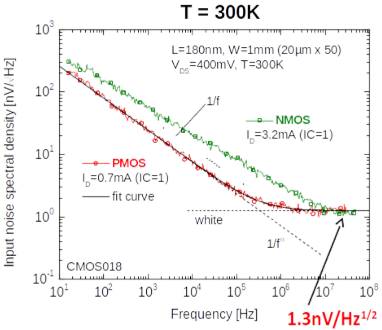
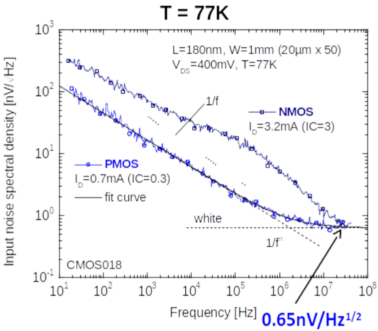


CMOS Performance in the Cold

see talk by S. Gao 2/11





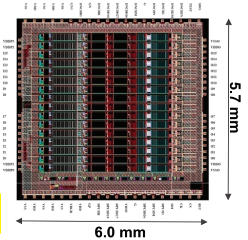
For SBND, μBooNE, DUNE an analog front-end ASIC with preamplifier and shaper operated in LAr reduces noise.

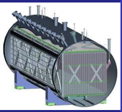
4 gain settings: 4.7, 7.8, 14, 25 mV/fC

4 t_p settings: 0.5, 1.0, 2.0, 3.0 μs

Shaping time good for noise

matches detector response $v_e = 1.6 mm/\mu s$

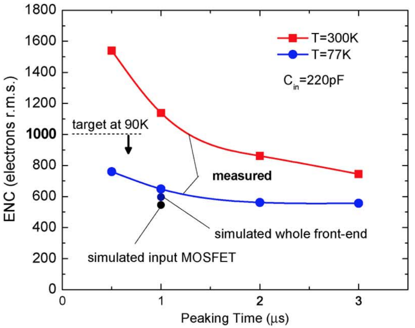


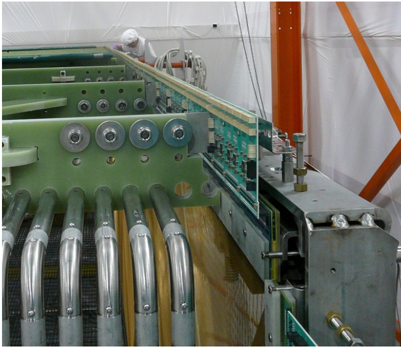


CMOS Performance in the Cold

see talk by S. Gao 2/11

Cold CMOS Analog ASIC for μBooNE and SBND:





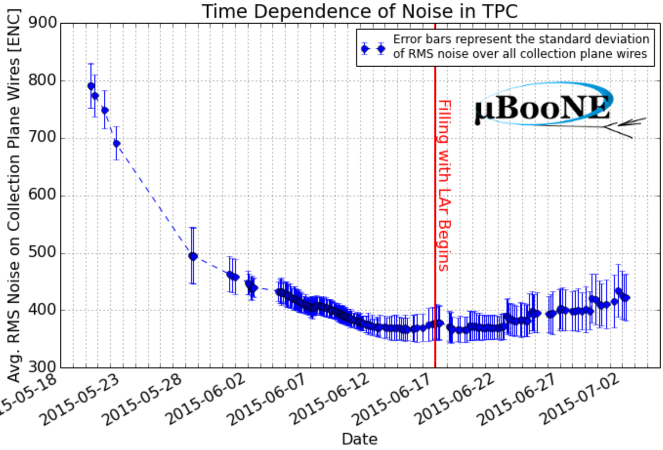
Reduce C_{in} by mounting cold electronics directly on TPC wire frame.

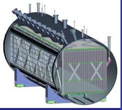
For μBooNE: $C_{in} \approx \underbrace{25\mathrm{pF}}_{\text{circuit boards}} + \underbrace{18\frac{\mathrm{pF}}{m} x L_{\mathrm{wire}}}_{\text{wires}}$

$\Rightarrow$ **ENC is $\mathcal{O}(400)$ electrons for longest wire (4.7m) at $t_p = 2\mu s$**

MicroBooNE Detector Status: Operational Oct '15

TPC noise readout during filling

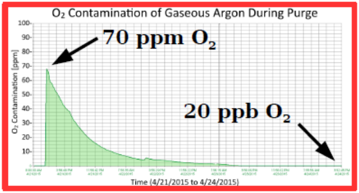


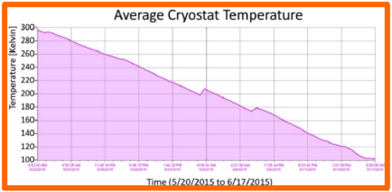


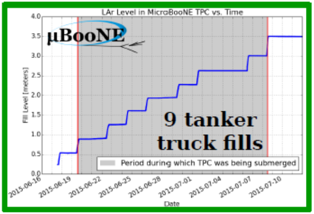
MicroBooNE Detector Status: Operational Oct '15

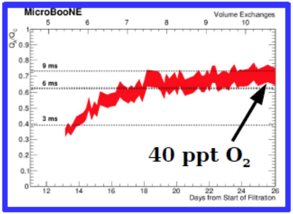
Cryogenics commisioning:

- Four stages: (1) purge (2) cool-down (3) LAr fill (4) recirculation and purification → **operating at least 2-3 times design purity!**









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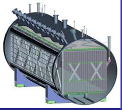
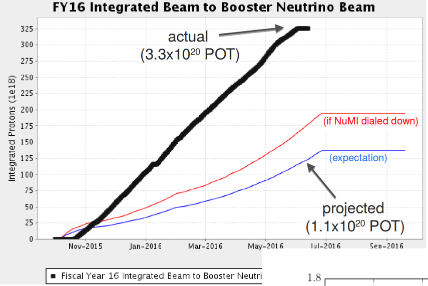
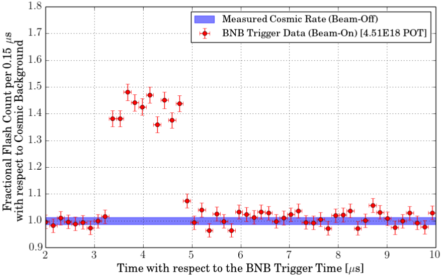
Cryostat operated w/o evacuation. *e* lifetime > 6 ms achieved quickly



MicroBooNE Detector Status: Operational Oct '15

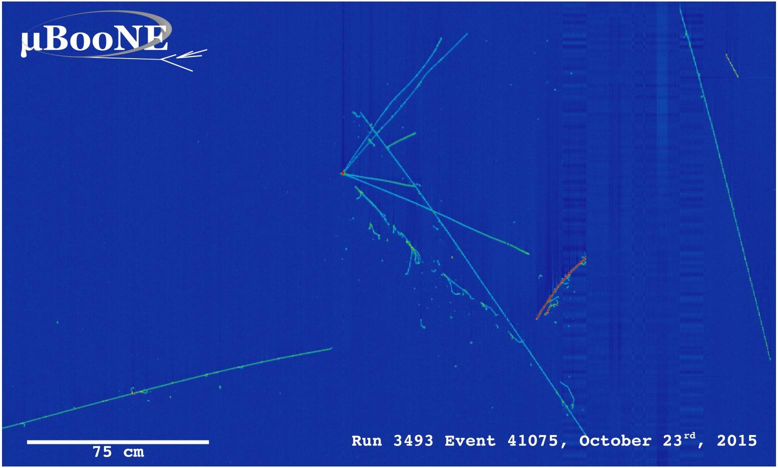
BNB Performance

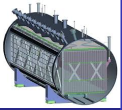




MicroBooNE Detector Status: Operational Oct '15

First neutrino images

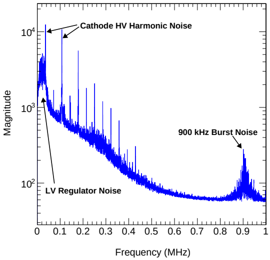




MicroBooNE TPC Noise

see talk by M. Mooney 2/11

Summary of Excess Noise



MicroBooNE Preliminary

Dominant sources of noise are:

Coherent noise (10-30 kHz) from the low-voltage filter outside the cryostat supplying the ASICs on the front-end mother board

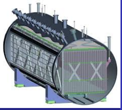
Odd harmonics of 36 kHz traced to ripple in the drift HV power supply

Software noise filter removed the excess TPC noise from raw wire signals :

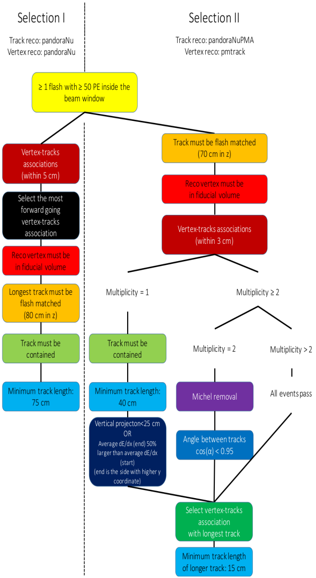
Noise	U (4.7m)	V (4.7m)	Y (2.3m)
ENC (e rms) before s. filter	1600	1400	660
ENC (e rms) after s. filter	430	420	330

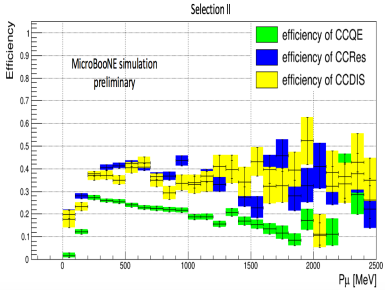
Oct ’16: Hardware fixes implemented for LV filter and HV supply.

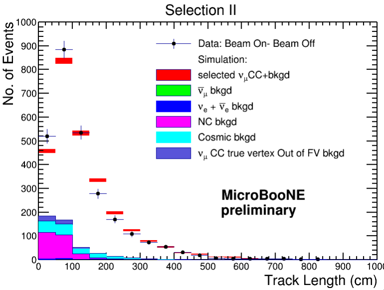
Removed $\sim$ 70% of the unfiltered noise



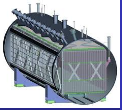
Fully automated ν_μ CC selection

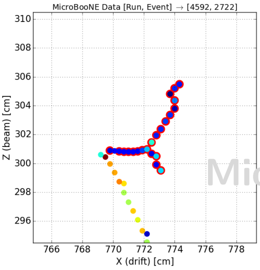


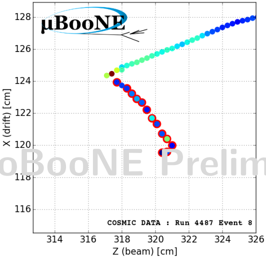


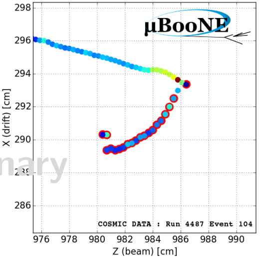


Michel Electron Reconstruction







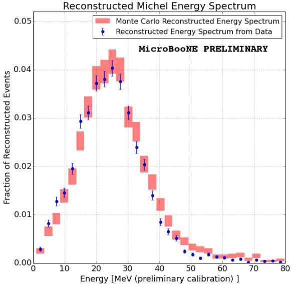


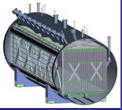
MicroBooNE Preliminary

Fully automated reconstruction using collection plane signal only

Michel electrons identified by a Bragg peak and a kink in the track.

Energy calibration based on charge injection calibration signal.





Preliminary π^0 reconstruction

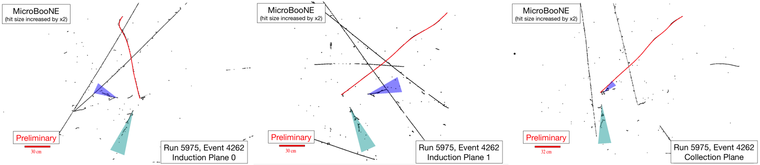
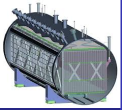


TABLE I: *Event-per-event reconstructed shower properties for our two reconstruction passes. These include the collected energy, E^{Coll}, the angle between the two showers, $\theta_{\gamma\gamma}$, and the reconstructed diphoton masses. These values also contain uncertainties discussed in the text.*

(Run, Subrun, Event)	Shower Reconstruction	$E_1^{Coll} \pm \sigma_{E_1}$ [MeV*]	$E_2^{Coll} \pm \sigma_{E_2}$ [MeV*]	$\theta_{\gamma\gamma} \pm \sigma_{\theta_{\gamma\gamma}}$ [°]	$m_{\gamma\gamma} \pm \sigma_{m_{\gamma\gamma}}$ [MeV*]
(6145, 16, 814)	3D-Based	62 ± 22	59 ± 21	120 ± 14	105 ± 28
	2D-Based	58 ± 20	61 ± 21	112 ± 5	99 ± 25
(6058, 94, 4706)	3D-Based	95 ± 34	41 ± 15	103 ± 14	97 ± 27
	2D-Based	94 ± 33	41 ± 14	87 ± 5	85 ± 22
(6058, 177, 8877)	3D-Based	64 ± 23	55 ± 20	156 ± 14	116 ± 30
	2D-Based	63 ± 22	54 ± 19	134 ± 5	107 ± 27
(5975, 85, 4262)	3D-Based	117 ± 42	96 ± 35	81 ± 14	138 ± 40
	2D-Based	-	-	-	-



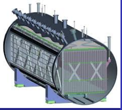
Lots more results from MicroBooNE

See public notes page

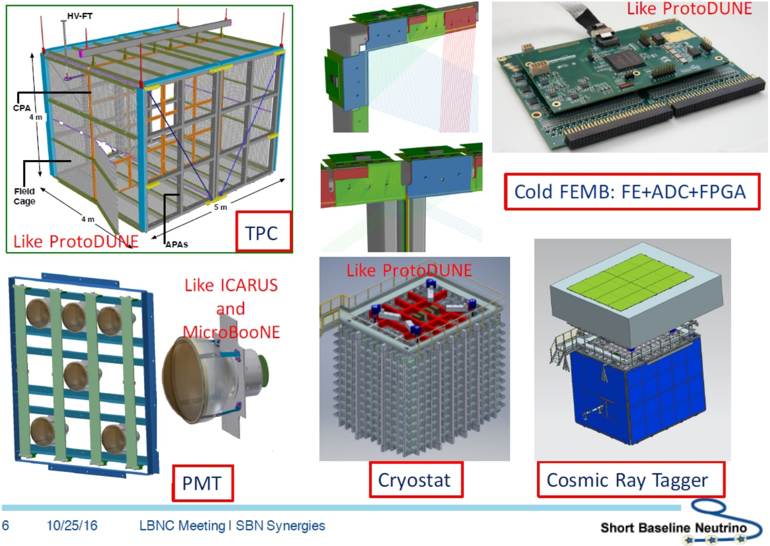
MicroBooNE Public Notes Page

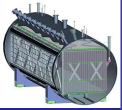
Back to the Publications Page

- 7/4/16 MICROBOONE-NOTE-1019-PUB
  Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber
- 7/4/16 MICROBOONE-NOTE-1017-PUB
  A Method to Extract the Charge Distribution Arriving at the TPC Wire Planes in MicroBooNE
- 7/4/16 MICROBOONE-NOTE-1016-PUB
  Noise Characterization and Filtering in the MicroBooNE TPC
- 7/4/16 MICROBOONE-NOTE-1015-PUB
  The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors
- 7/4/16 MICROBOONE-NOTE-1014-PUB
  A Comparison of Monte-Carlo Simulations and Data from MicroBooNE
- 7/4/16 MICROBOONE-NOTE-1013-PUB
  MicroBooNE Detector Stability
- 7/4/16 MICROBOONE-NOTE-1012-PUB
  Demonstration of 3D Shower Reconstruction on MicroBooNE Data
- 7/4/16 MICROBOONE-NOTE-1010-PUB
  Selection and kinematic properties of numu charged-current inclusive events in 5E19 POT of MicroBooNE data
- 7/1/16 MICROBOONE-NOTE-1008-PUB
  Michel Electron Reconstruction Using the MicroBooNE LArTPC Cosmic Data
- 5/3/16 MICROBOONE-NOTE-1006-PUB
  Study Towards an Event Selection for Neutral Current Inclusive Single Pi0 Production in MicroBooNE
- 5/30/16 MICROBOONE-NOTE-1005-PUB
  Cosmic Shielding Studies at MicroBooNE
- 11/6/15 MICROBOONE-NOTE-1004-PUB
  MC performance study for an early numu charged-current inclusive analysis with MicroBooNE
- 5/29/16 MICROBOONE-NOTE-1003-PUB
  Measurement of the Electronegative Contaminants and Drift Electron Lifetime in the MicroBooNE Experiment
- 11/2/15 MICROBOONE-NOTE-1002-PUB
  First neutrino interactions observed with the MicroBooNE Liquid-Argon TPC detector



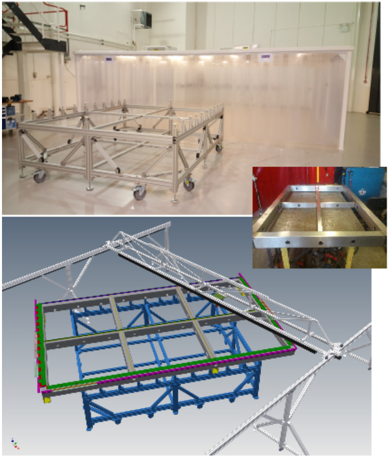
The Short Baseline Near Detector Status



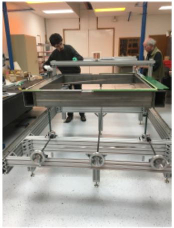


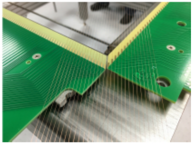
The Short Baseline Near Detector Status

Daresbury lab at UK



Wright lab at Yale of US

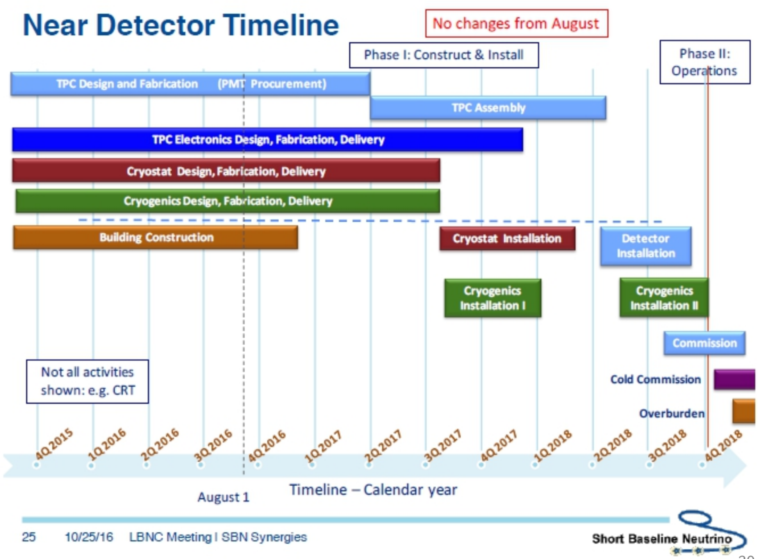


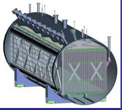


US winding prototype

11 10/20/2016 Ting Miao | SBN PMG

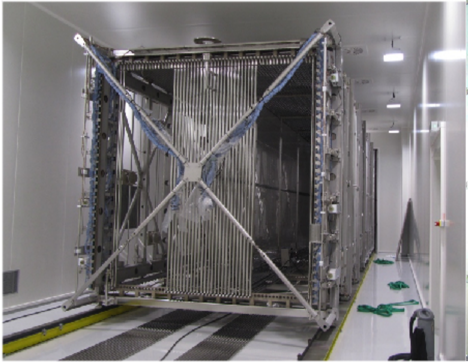
The Short Baseline Near Detector Status

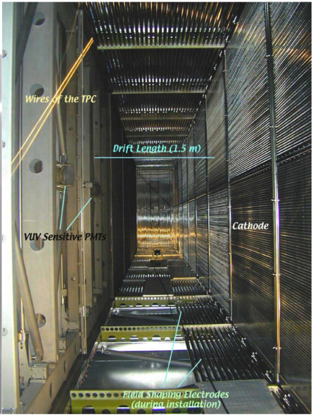




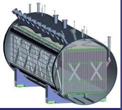
ICARUS@SBN

ICARUS TPC refurbishment at CERN





New low-noise warm electronics developed at INFN **see talk by G. Meng 2/11**

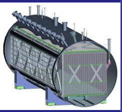


ICARUS@SBN

ICARUS buildings at Fermilab

Broke ground on the Far Detector building in July 2015

Ready for installation end of 2016



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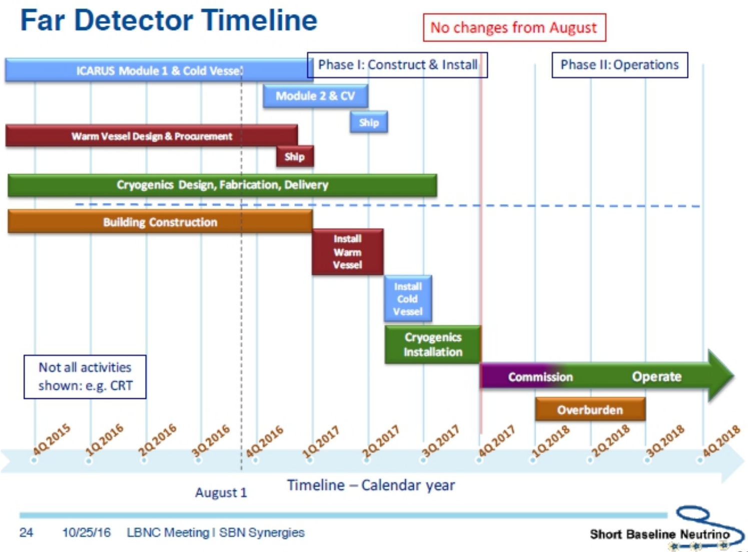
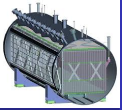

Far Detector Timeline
No changes from August
Phase I: Construct & Install
Phase II: Operations
ICARUS Module 1 & Cold Vessel
Module 2 & CV
Ship
Warm Vessel Design & Procurement
Ship
Cryogenics Design, Fabrication, Delivery
Building Construction
Install Warm Vessel
Install Cold Vessel
Cryogenics Installation
Commission
Operate
Overburden
Not all activities shown: e.g. CRT
4Q2015
1Q2016
2Q2016
3Q2016
4Q2016
1Q2017
2Q2017
3Q2017
4Q2017
1Q2018
2Q2018
3Q2018
4Q2018
August 1
Timeline – Calendar year
24
10/25/16
LBNC Meeting I SBN Synergies
Short Baseline Neutrino



Summary and Conclusions

- **MicroBooNE has been taking data since Oct '15:**
  - **Record beam intensity - integrated $> 3 \times 10^{20}$ p.o.t**
  - **Stable running with drift HV of 70kV with electron lifetime of > 6ms.**
  - **After hardware fixes in Oct '16, noise performance is at expectation and significantly improved over previous generation of massive LArTPC.**
  - **New sophisticated signal processing techniques coupled with low noise due to cold electronics have enabled extraction of induction plane images with unprecedented fidelity.**
  - **Fully 3-D reconstructed ν events and 1^{st} data results.**
- **SBND TPC and field cage construction is proceeding on schedule. Cold ADC ASIC still needs work.**
- **ICARUS refurbishment at CERN and new membrane cryostat being built. Building at Fermilab also proceeding on schedule.**

SBND/ICARUS begin operations end of 2018