The LAr1-ND experiment

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The LAr1-ND Collaboration

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10 US institutions
- 3 DOE National Laboratories
- 6 NSF institutions

7 European institutions
- CERN
- 1 Swiss institution
- 5 UK institutions

Outline

- A Short-Baseline Neutrino Programme at FNAL
  - Motivations
  - Description of the programme
- The LAr1-ND experiment
- Physics reach
  - MiniBooNE low-energy excess
  - Sensitivity to SBL neutrino *anomalies*
  - Cross-section measurements

Motivations

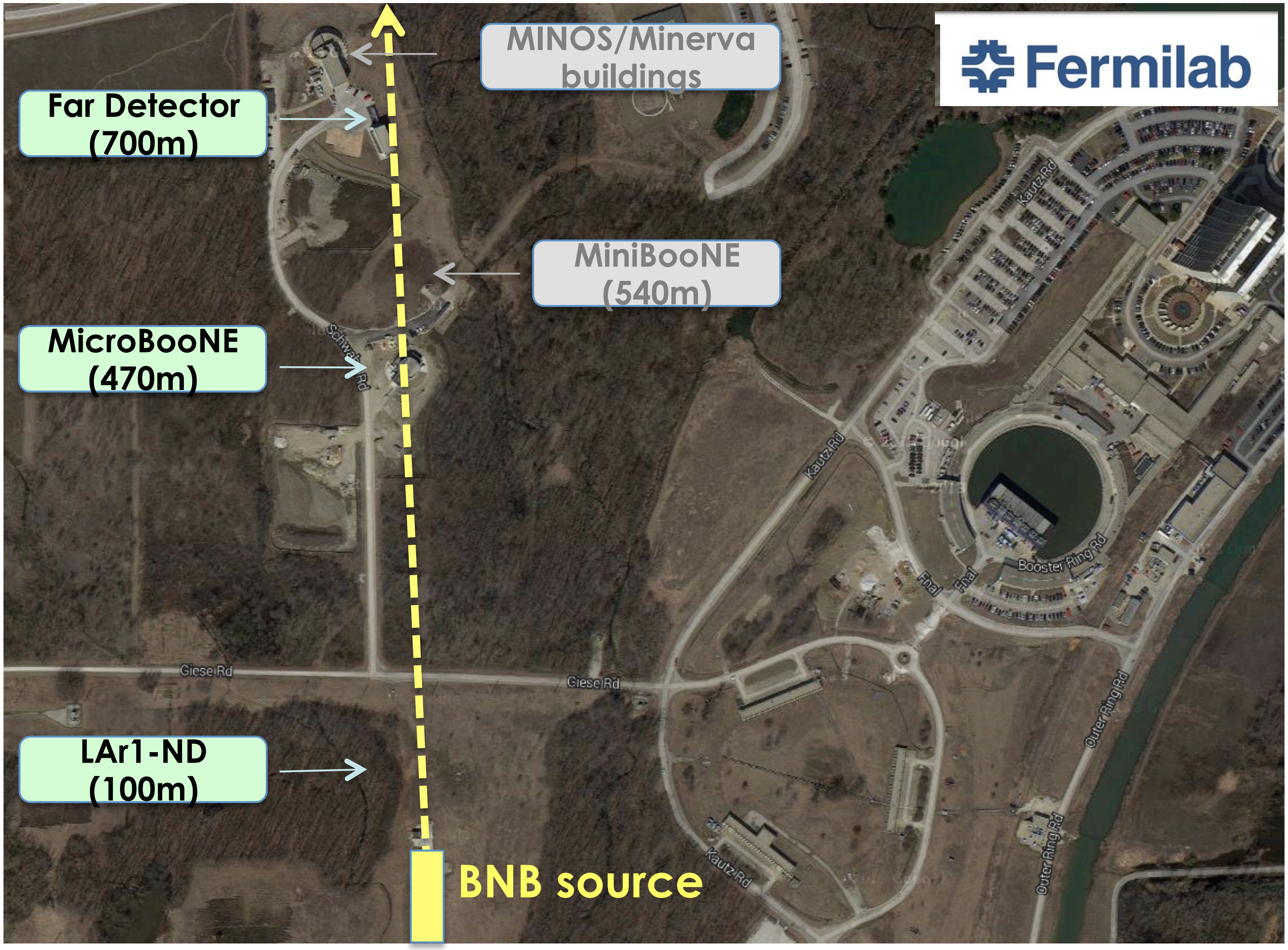
Current anomalies from:
accelerator beams
radioactive sources
reactor neutrinos

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)

- Control of systematic uncertainties
- Cross-section measurements
- Test bench for LAr R&D for future experiments

A staged Multi-LAr detector Programme

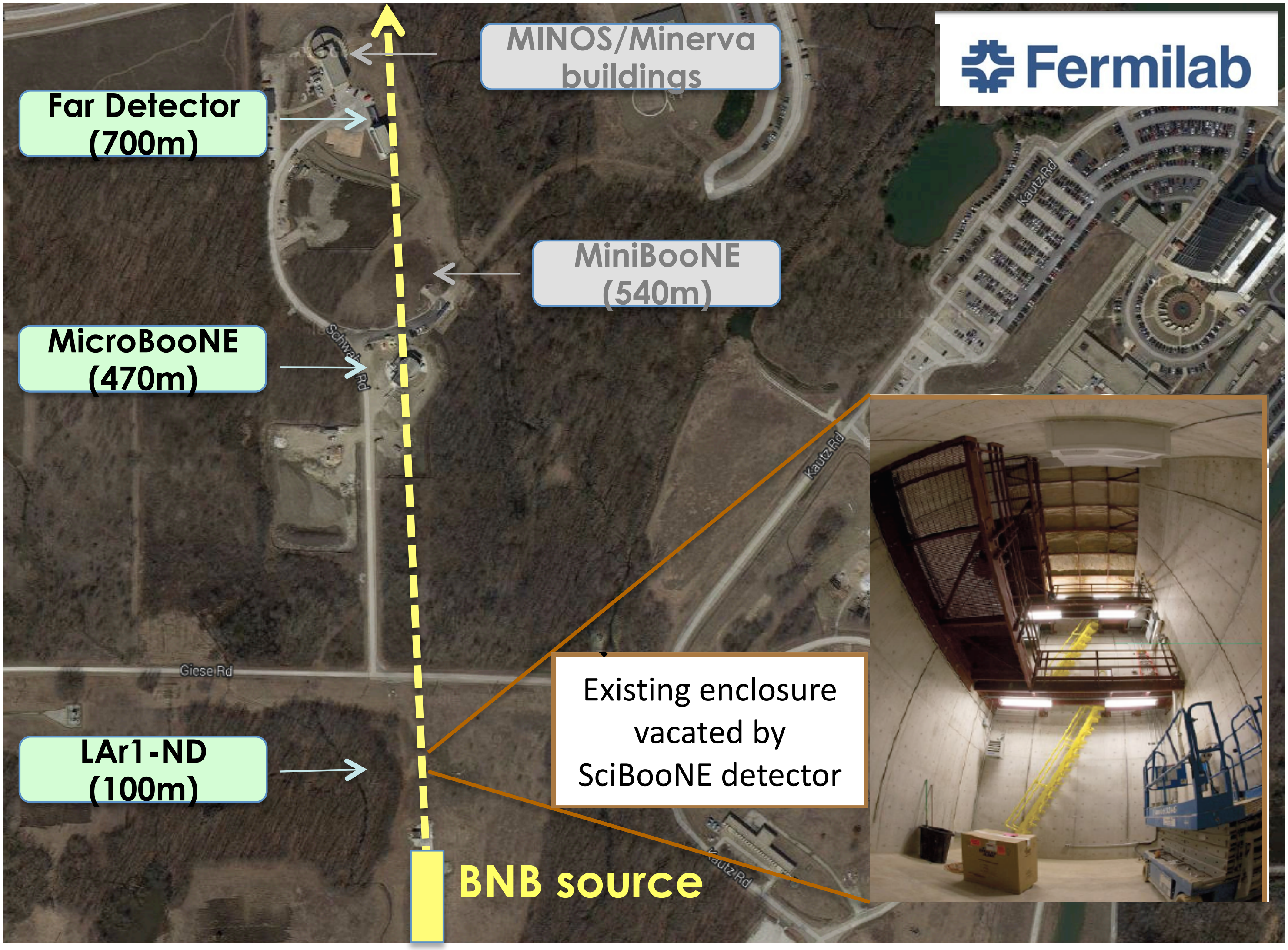


Phase 0: MicroBooNE
86 t active volume TPC
L = 470 m
start in 2014

Phase 1: LAr1-ND
82 t active volume TPC
L = 100 m
2017-2018

Phase 2: Far Det.
1000 t active volume TPC
L = 700 m
2020+

A staged Multi-LAr detector Programme



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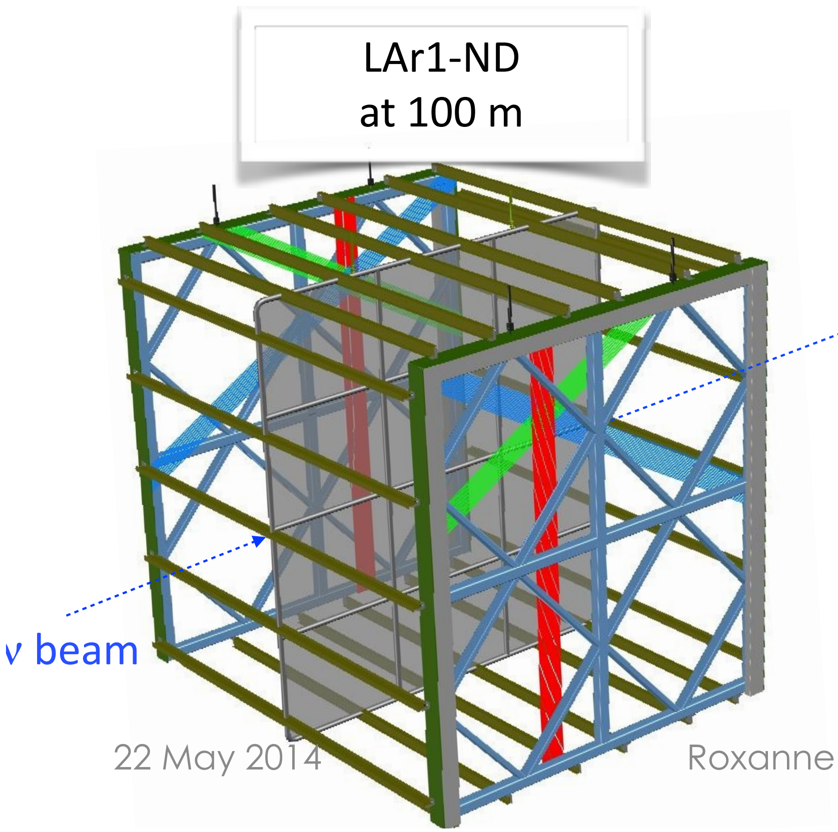
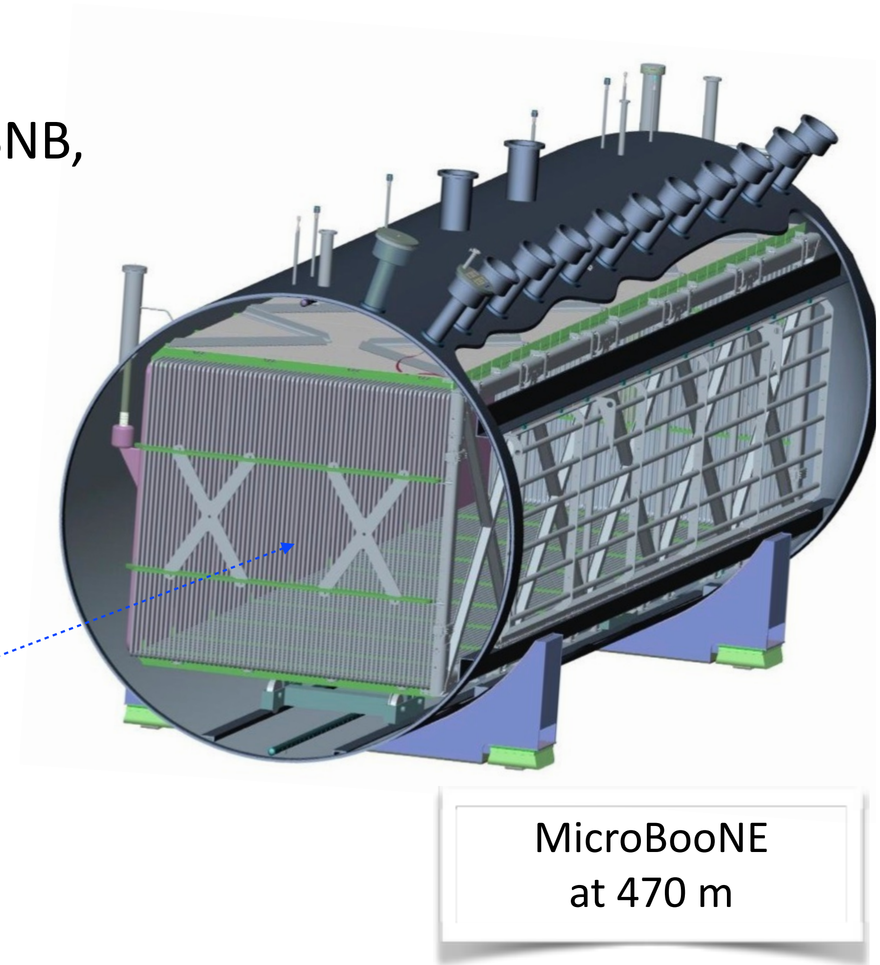
2020+

Phase 1: LAr1-ND

A LArTPC Near Detector
(82 t active mass) in the SciBooNE hall,
to run in conjunction with MicroBooNE on the BNB,
for an exposure of 2.2×10^{20} POT
(in the last year of the MicroBooNE run)

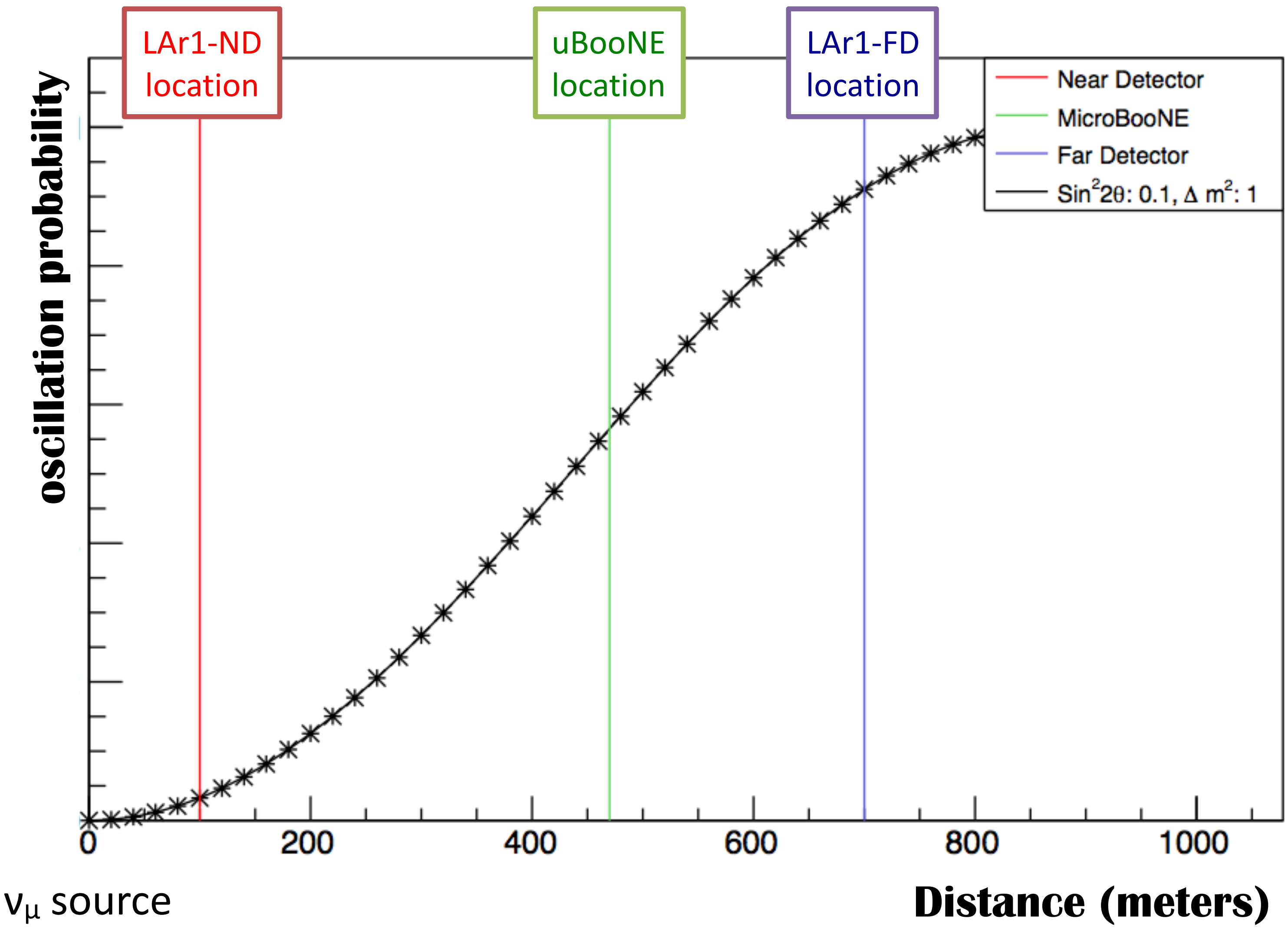




Why a Near detector?

- A Near Detector close to the BNB source is a key element in each phase
  - ➡ Sample the beam before the onset of L/E dependent physics
  - ➡ Provide a high statistics constraint on intrinsic event rates

ν_μ disappearance probability (E = 700MeV)

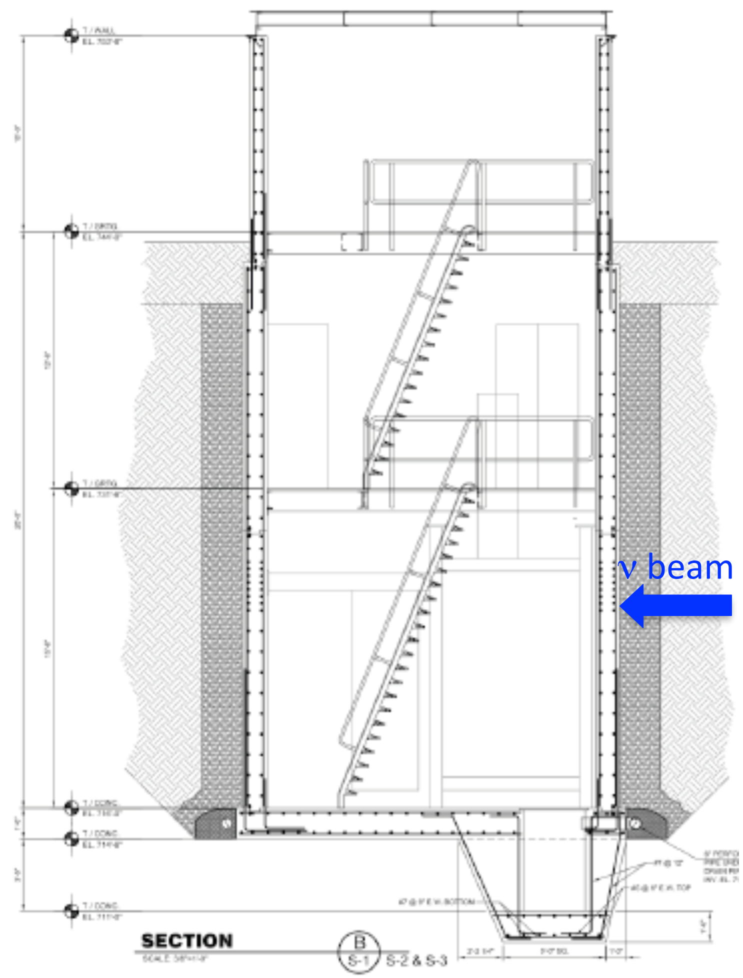


C. Adams' talk from Monday

The LAr1-ND location
(SciBooNE experimental hall)

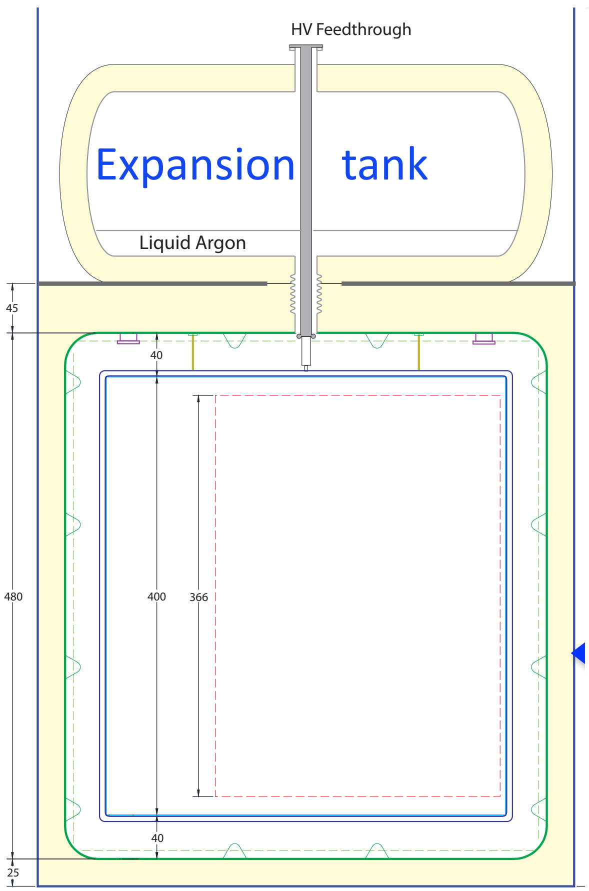
- SciBooNE enclosure (on-axis at 100m from BNB target) is currently empty and is an ideal, ready to use, location

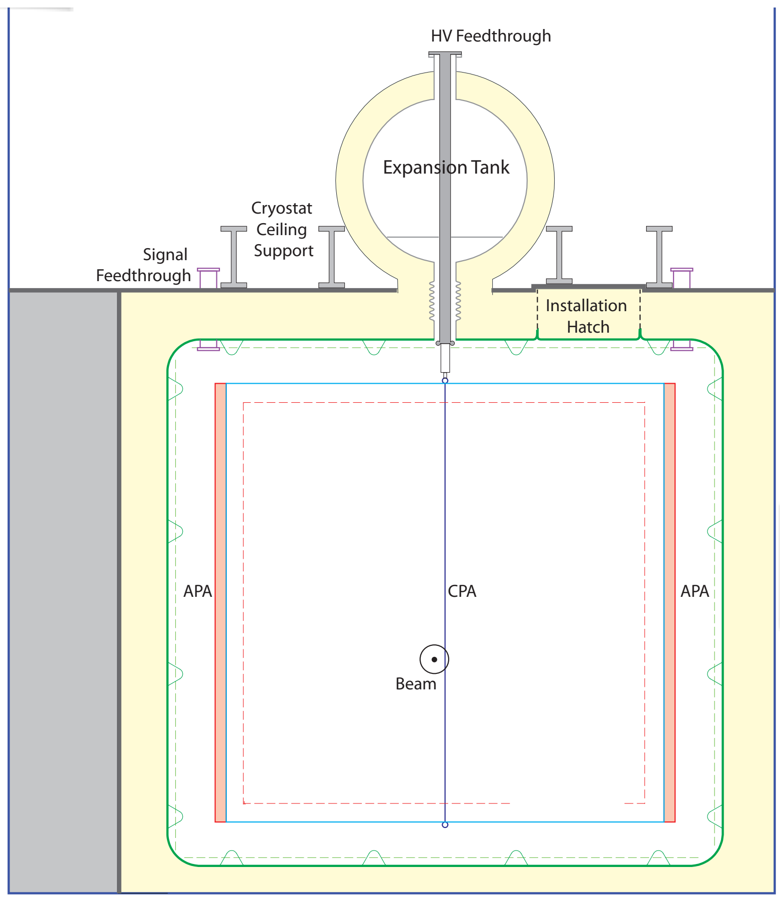
Length *(beam direction) = 4.9 m*
Width *= 7.0 m*
Depth*: floor-grade = 8.5 m,*
floor-ceiling = 11.6 m

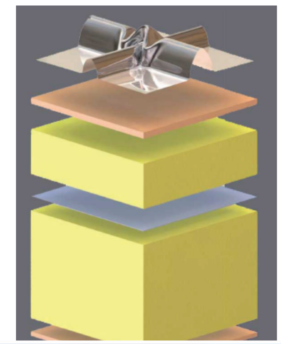


LAr1-ND detector design

- Membrane cryostat (supported by outer walls) (5.1m(w) x 4.8m(h) x4.4m(l))







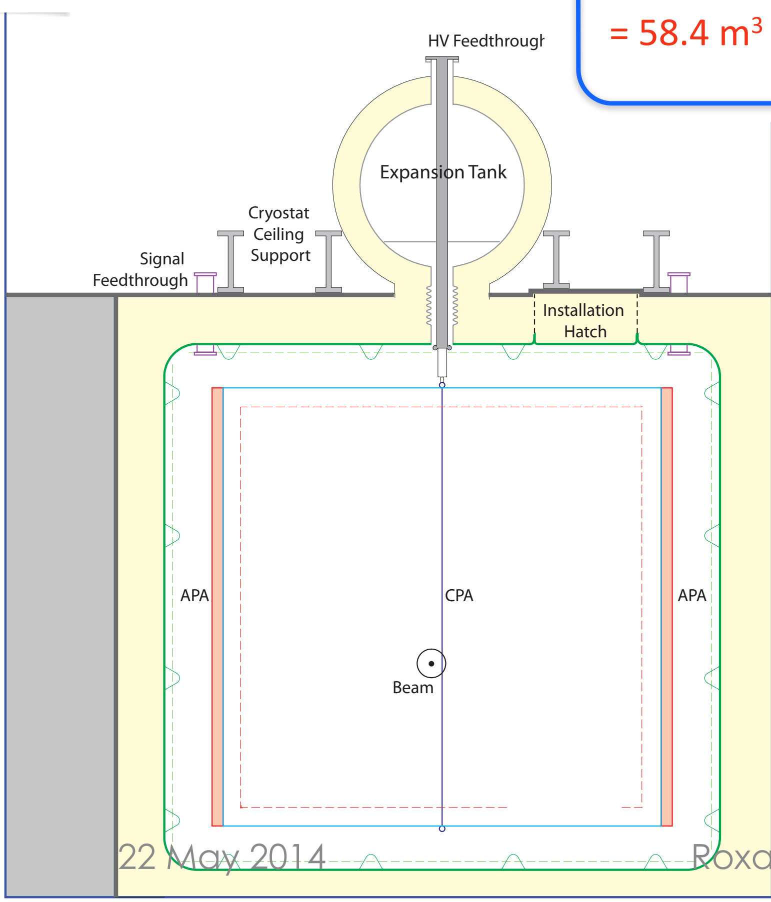
35 ton membrane cryostat prototype constructed and successfully filled and operated at Fermilab

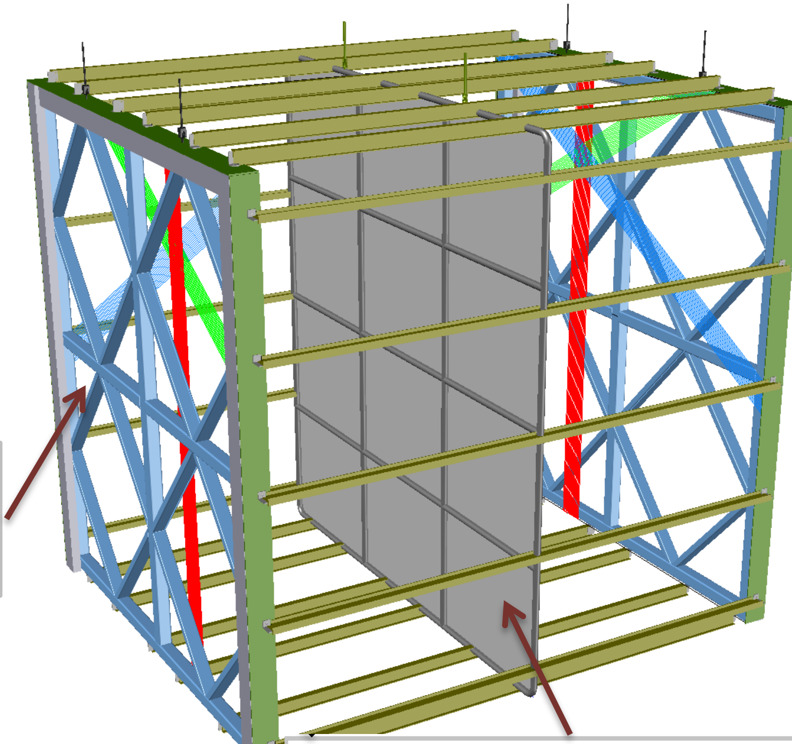
LAr1-ND detector design

- TPC: 2 APAs near the walls and 1 CPA in center

The TPC active volume:

3.65 m *(beam direction)* x
4.0 m *(wide)* x
4.0 m *(tall)*
= 58.4 m^3 (82 tons of argon)





APA
active area:
3.65 m wide and 4 m tall

Each pair of facing CPA and APA forms an electron-drift region

CPA is made of a stainless-steel framework, with an array of stainless-steel sheets mounted over the frame openings

At a 500 V/cm drift field and 2 m drift distance, the cathode plane is biased at -100 kV (< than MicroBooNE HV)

LAr1-ND physics Goals

- **MiniBooNE low-energy excess**
  - Directly test the anomalous excess of electron neutrino events reported by MiniBooNE
- **Oscillations: $\nu_\mu \rightarrow \nu_e$ appearance**
  - In combination with MicroBooNE, much improved sensitivity with a near detector (ND)
- **Oscillations: ν_μ disappearance**
  - Only possible with a ND
- **Oscillations: Neutral-current disappearance**
  - Direct test for sterile neutrino content. Only possible with a ND
- **Neutrino-argon interactions**
  - 15x the rate compared to MicroBooNE. ~1M events per year.
  - If low-energy excess determined to be a Standard Model photon production mechanism, LAr1-ND can make measurements of the rate and kinematics with 100s of events per year
- **Dark matter search with beam off-target running**
  - Requires future beam off-target running.

Sensitivity to MiniBooNE low-energy excess

MicroBooNE will tell if the excess is electrons or gammas

LAr1-ND increases the significance AND will determine if the excess is inherent to the beam or to oscillations

Process	Events (μB)	Events (LAr1-ND)	MiniBooNE unc.	dE/dx unc.	Total unc.	Error (μB)	Error (LAr1-ND)
$\mu \to \nu_e$	21.5	171.3	0.26	0.1	0.28	6.0	47.7
$K^+ \to \nu_e$	6.4	51.3	0.22	0.1	0.24	1.55	12.4
$K^0 \to \nu_e$	1.8	14.7	0.38	0.1	0.39	0.73	5.79
ν_μ CC	4.9	38.9	0.26	0.0	0.26	1.27	10.1
$\nu_\mu e \to \nu_\mu e$	3.8	30.7	0.25	0.1	0.27	1.03	8.26
NC π^0	6.7	53.4	0.13	0.1	0.16	1.10	8.77
Dirt	0.9	6.9	0.16	0.1	0.19	0.16	1.31
$\Delta \to N\gamma$	2.5	19.8	0.14	0.1	0.17	0.43	3.40
Other	0.9	7.6	0.25	0.1	0.27	0.26	2.04
Total	49.4	322.1				6.55	52.23

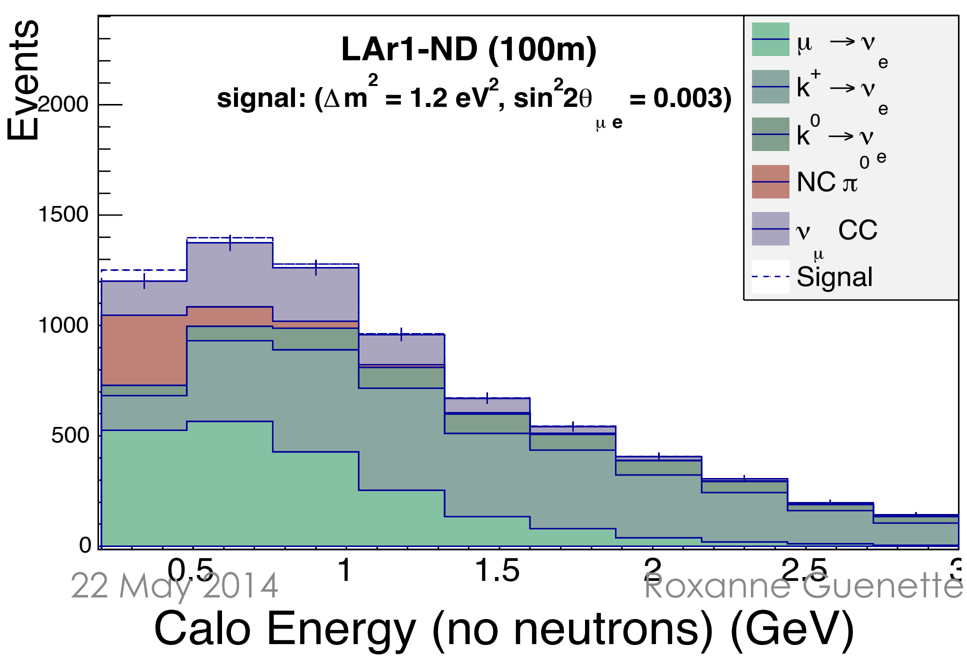
	MicroBooNE	LAr1-ND
Total Events	97	775
"Low-energy Excess"	47.6	380
Background	49.4	394.6
Statistical Error	7.0	19.9
Systematic Error	6.6	52.2
Total Error	9.6	55.9
Statistical Significance of Excess	6.8 σ	19.1 σ
Total Significance of Excess	**5.0** σ	**6.8** σ

An estimate of systematics based on MiniBooNE analysis indicates a **>6.5σ** observation of a MiniBooNE-like excess

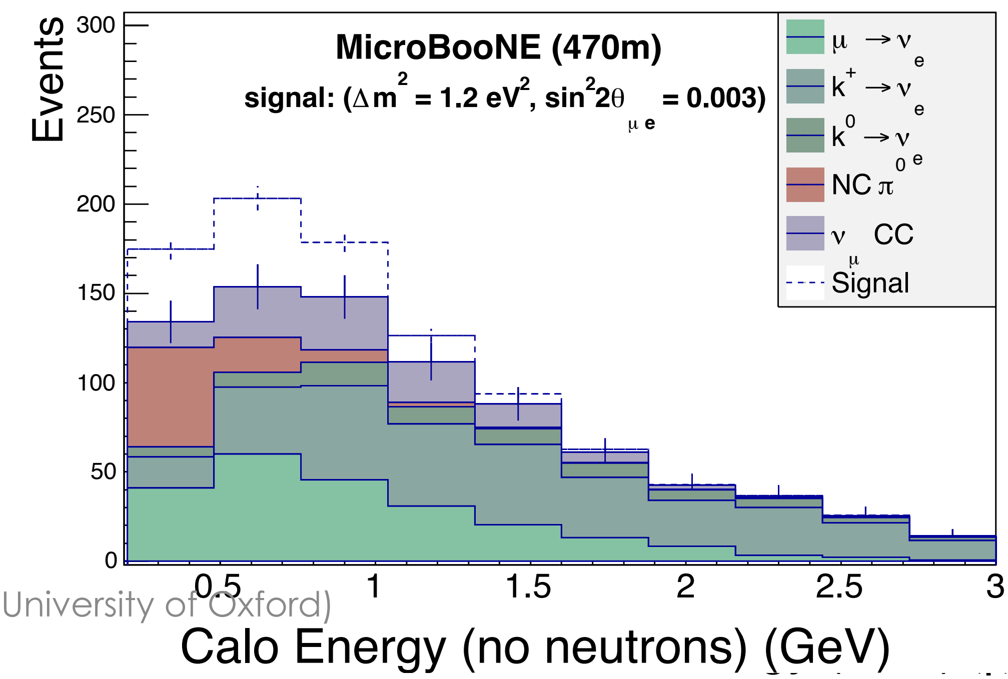
Sensitivity to neutrino anomalies
$\nu_\mu \rightarrow \nu_e$ Appearance

- Testing $\nu_\mu \rightarrow \nu_e$ appearance in the context of a 3 active + 1 sterile neutrino model (3+1)
- Predicted event rates come from full Geant4 Monte Carlo and expected e/γ shower separation in a LAr TPC, not flat scaling of generator level event topologies
- Produce realistic reconstructed neutrino energy spectrum using calorimetric reconstruction
- The observed electron candidate event rate in LAr1-ND at 100m is used to constrain the expected rate (in the absence of oscillations) in MicroBooNE at 470m

2.2×10^{20} POT exposure for LAr1-ND



6.6×10^{20} POT exposure for MicroBooNE



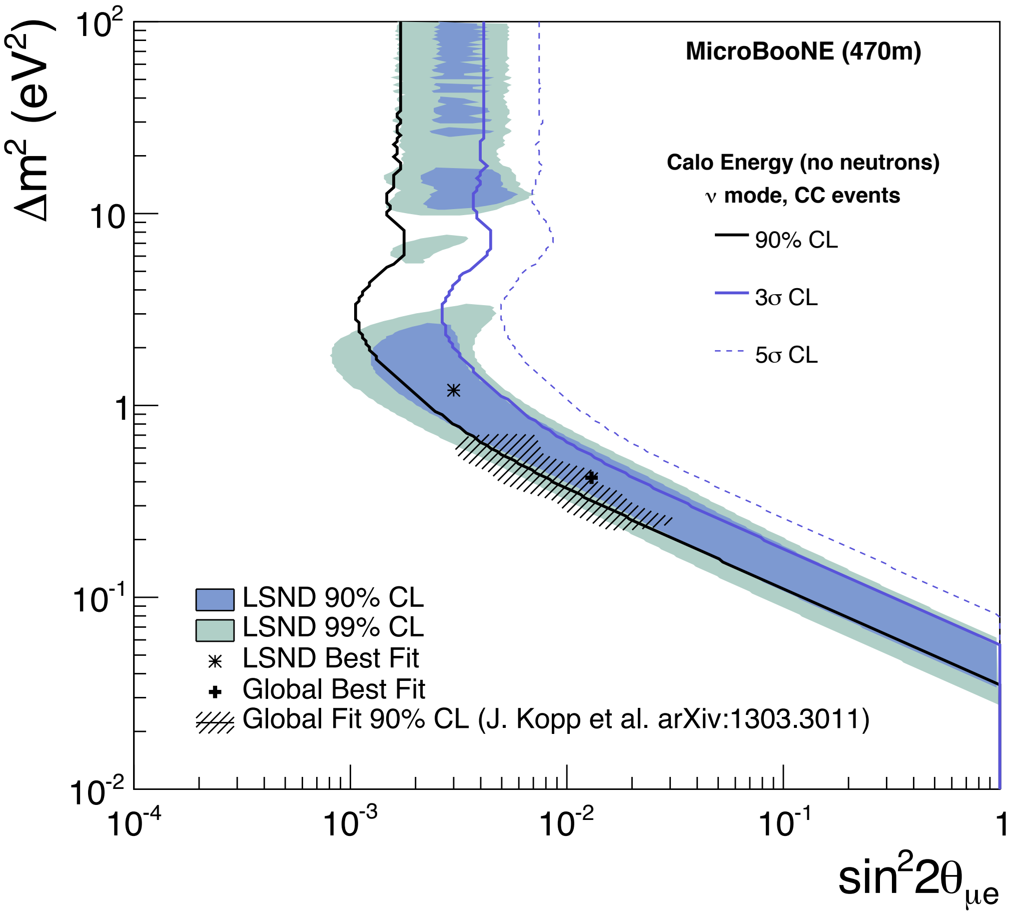
Sensitivity to neutrino anomalies

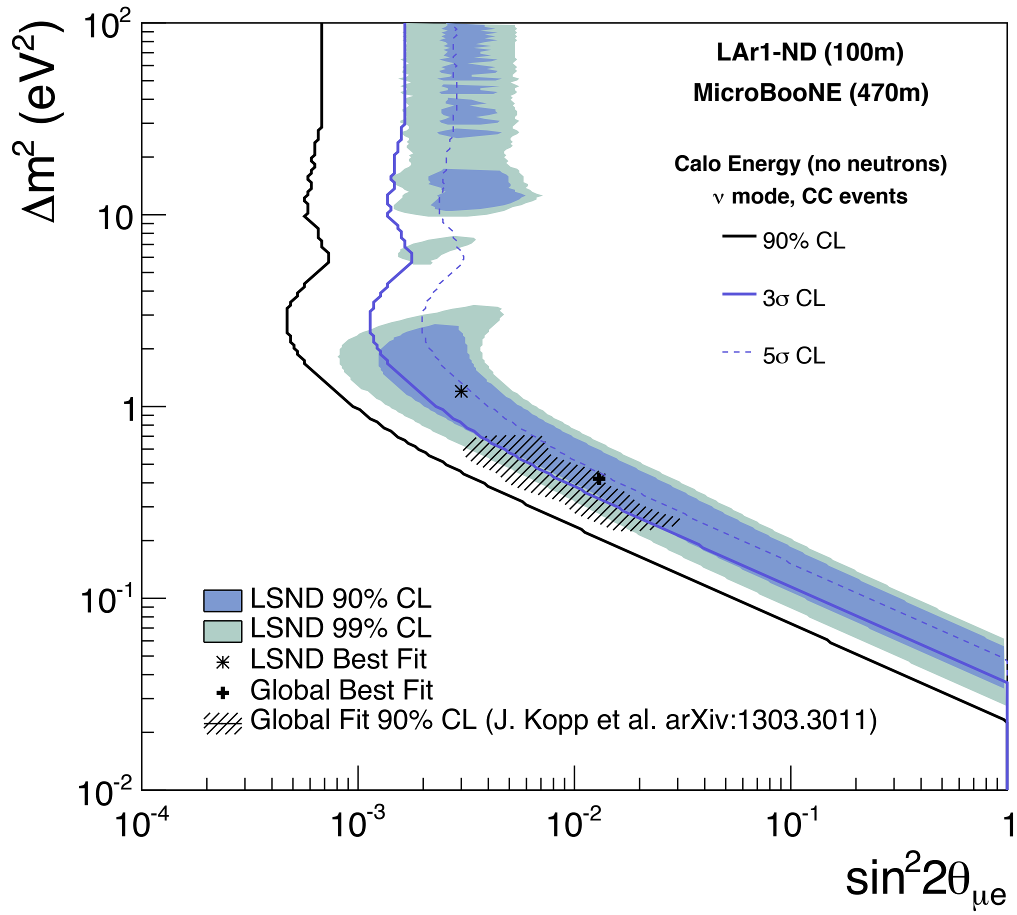
$\nu_\mu \rightarrow \nu_e$ Appearance

6.6x10[20] POT exposure for MicroBooNE alone, assuming 20% systematic uncertainties on ν_e background prediction

+ND

Same MicroBooNE exposure + 2.2x10[20] POT exposure for LAr1-ND to constrain background prediction



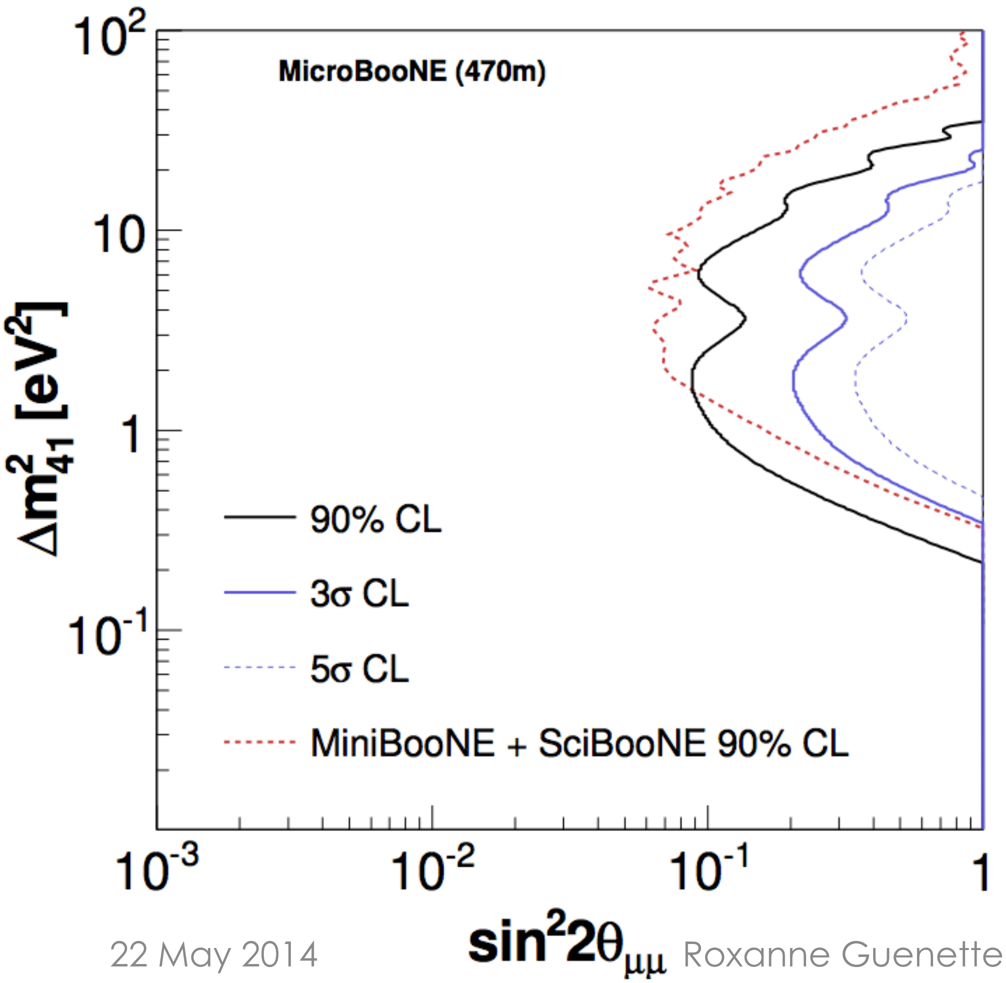


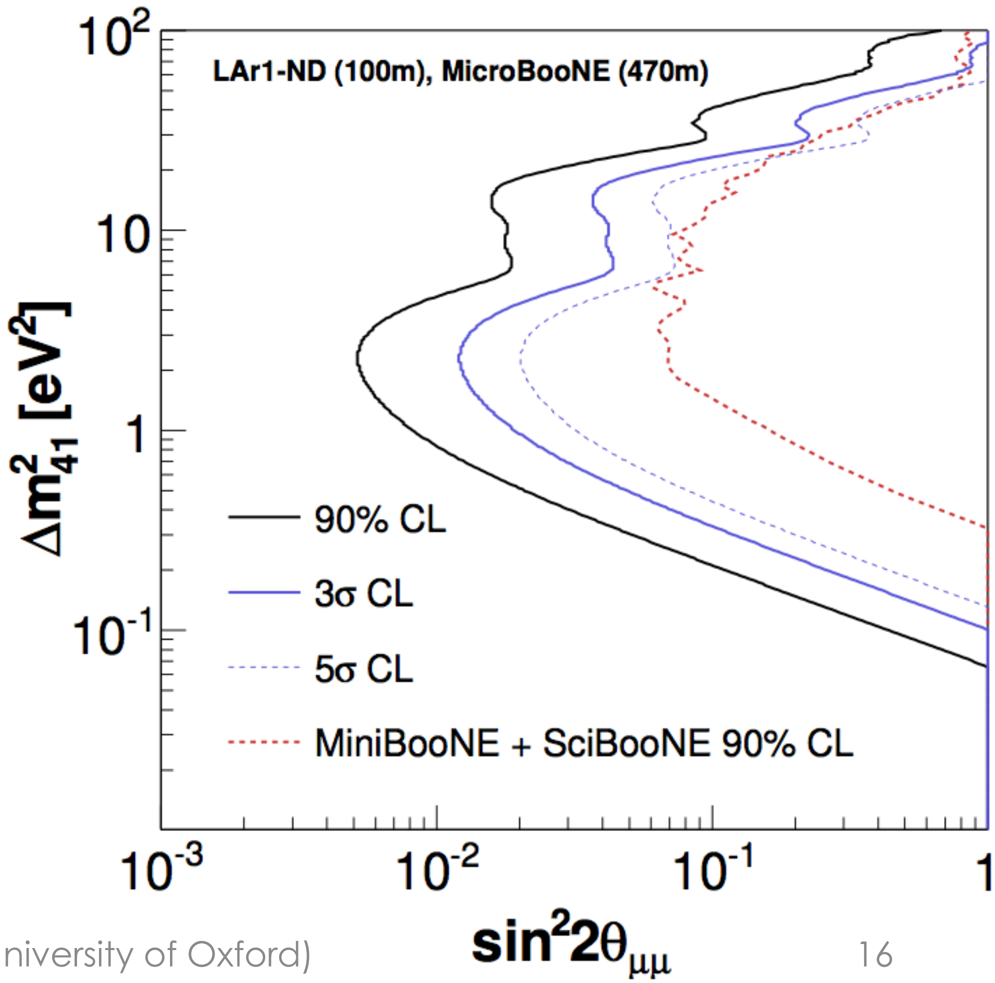
Sensitivity to neutrino anomalies
ν_μ Disappearance

6.6x10[20] POT exposure for MicroBooNE alone, assuming 15% systematic uncertainties on the absolute ν_μ event rate

+ND

Same MicroBooNE exposure + 2.2x10[20] POT exposure for LAr1-ND to measure unoscillated ν_μ





Neutrino-Argon Interactions

GENIE estimated event rates

2.2×10^{20} POT exposure for LAr1-ND

Process		No. Events
	ν_μ Events (By Final State Topology)	
CC Inclusive		787,847
CC 0 π	$\nu_\mu N \to \mu + Np$	535,673
	$\cdot\ \nu_\mu N \to \mu + 0\text{p}$	119,290
	$\cdot\ \nu_\mu N \to \mu + 1\text{p}$	305,563
	$\cdot\ \nu_\mu N \to \mu + 2\text{p}$	54,287
	$\cdot\ \nu_\mu N \to \mu + \geq 3\text{p}$	56,533
CC 1 $\pi^\pm$	$\nu_\mu N \to \mu + \text{nucleons} + 1\pi^\pm$	176,361
CC $\geq 2\pi^\pm$	$\nu_\mu N \to \mu + \text{nucleons} + \geq 2\pi^\pm$	14,659
CC $\geq 1\pi^0$	$\nu_\mu N \to \text{nucleons} + \geq 1\pi^0$	76,129
NC Inclusive		300,585
NC 0 π	$\nu_\mu N \to \text{nucleons}$	206,563
NC 1 $\pi^\pm$	$\nu_\mu N \to \text{nucleons} + 1\pi^\pm$	39,661
NC $\geq 2\pi^\pm$	$\nu_\mu N \to \text{nucleons} + \geq 2\pi^\pm$	5,052
NC $\geq 1\pi^0$	$\nu_\mu N \to \text{nucleons} + \geq 1\pi^0$	54,531
	ν_e Events	
CC Inclusive		5,883
NC Inclusive		2,098
Total ν_μ and ν_e Events		1,096,413
	ν_μ Events (By Physical Process)	
CC QE	$\nu_\mu n \to \mu^- \text{p}$	470,497
CC RES	$\nu_\mu N \to \mu^- N$	220,177
CC DIS	$\nu_\mu N \to \mu^- X$	82,326
CC Coherent	$\nu_\mu Ar \to \mu Ar + \pi$	3,004

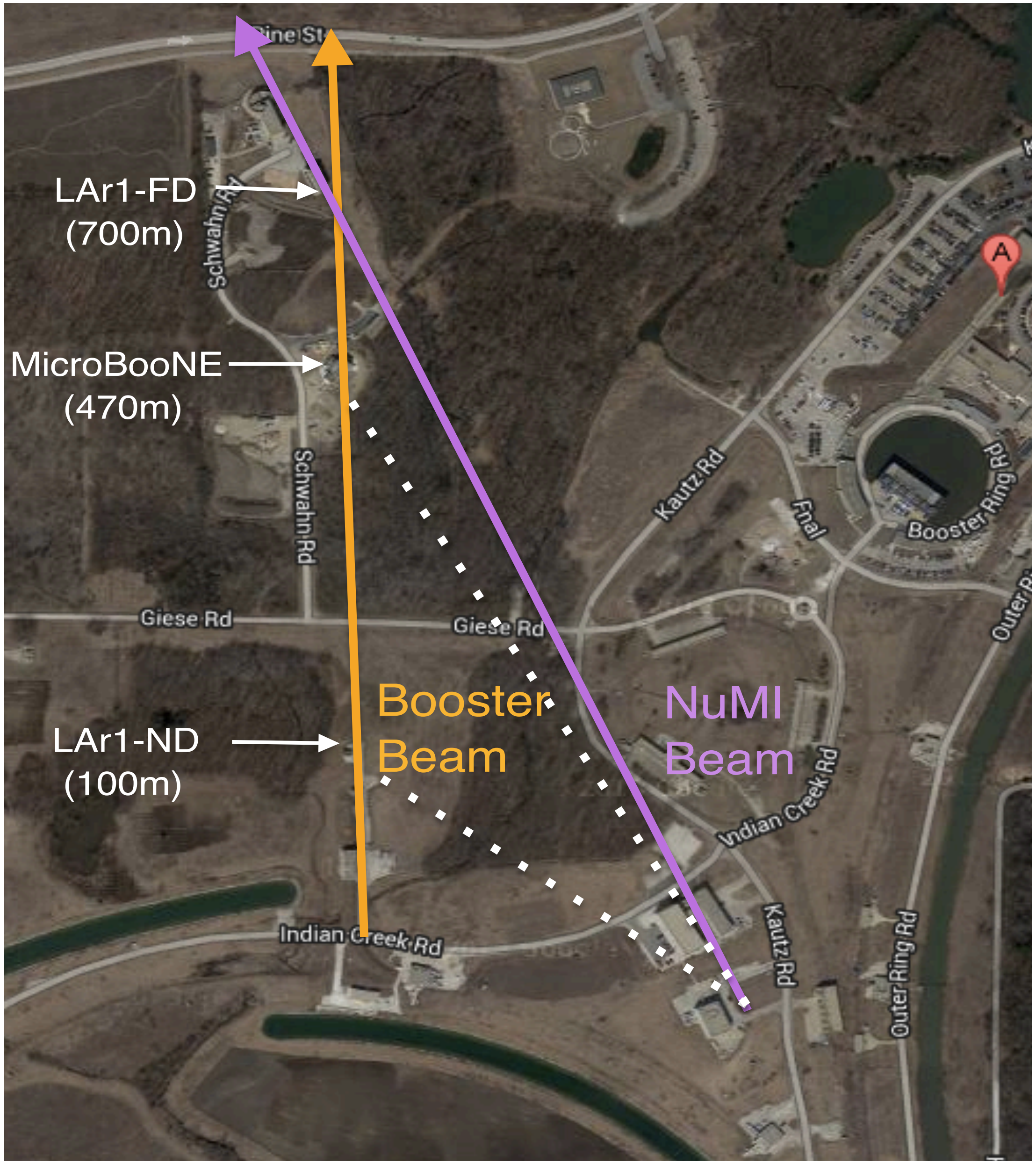
LAr1-ND provides a great venue to conduct high statistics precision cross section measurements in the 1 GeV energy range

Event rates based on categorization in terms of exclusive experimental topologies

← total events per ~year

Energy threshold on protons: 21 MeV. The 0π topologies include any number of neutrons in the event.

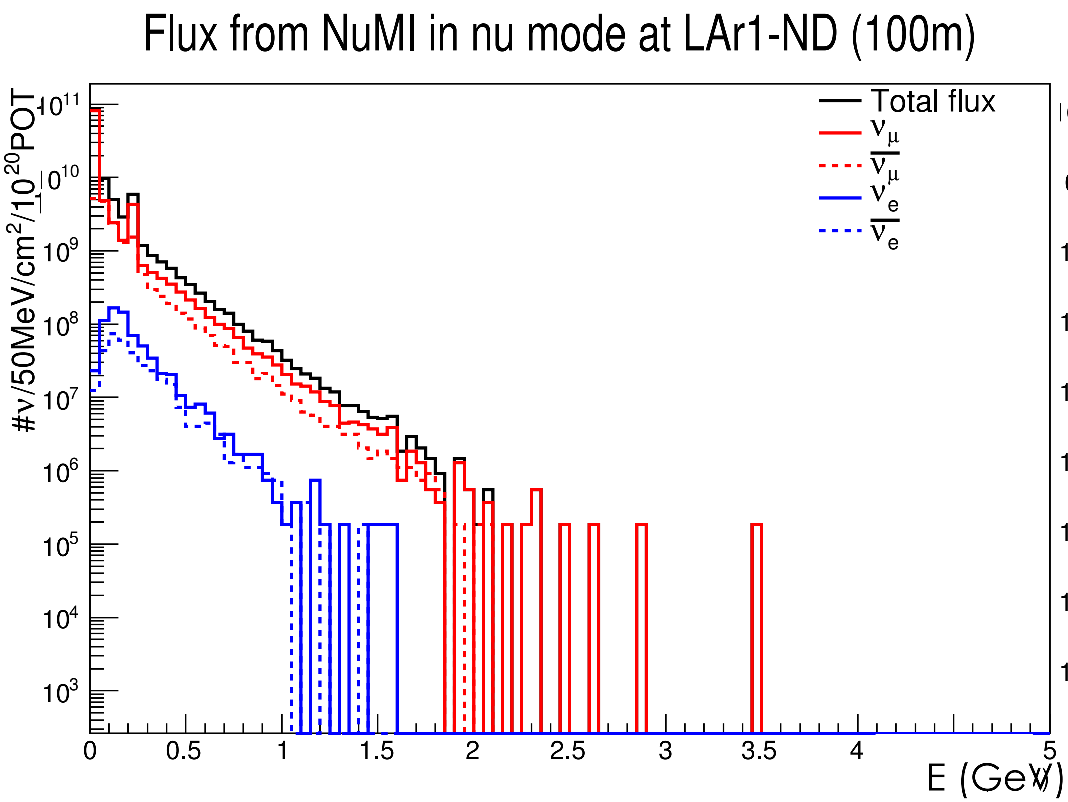
There's more! NuMI events

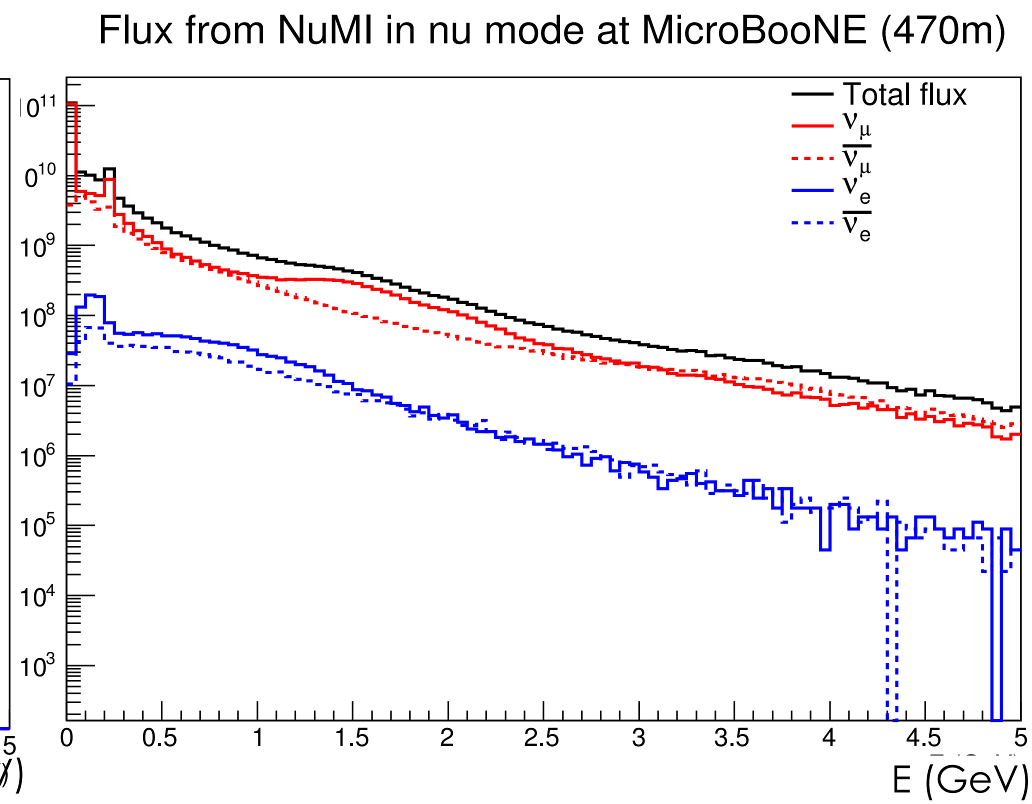


<u>NuMI Off-Axis Angles</u>

- To LAr1-ND: ~30°
- To MicroBooNE: ~8°

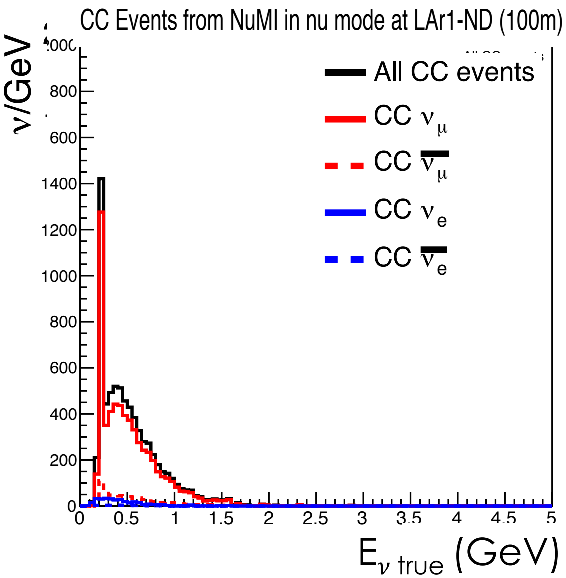
There's more! NuMI events

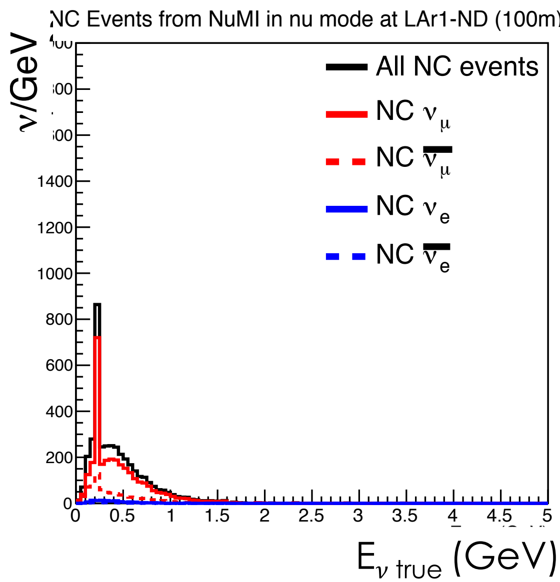




There's more! NuMI events

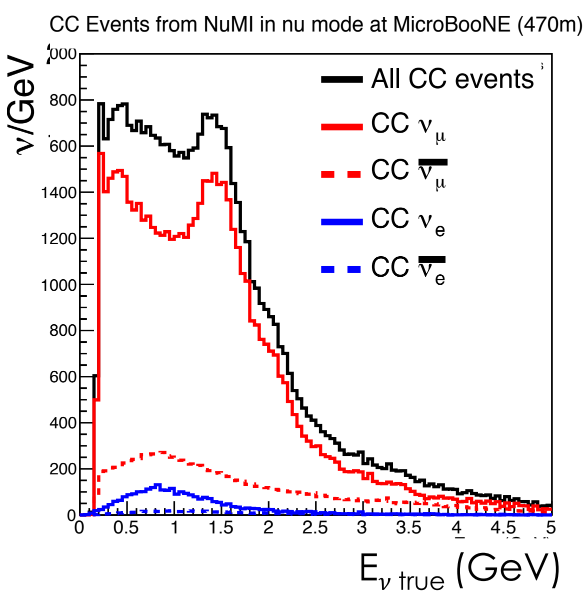
NuMI Event Rates

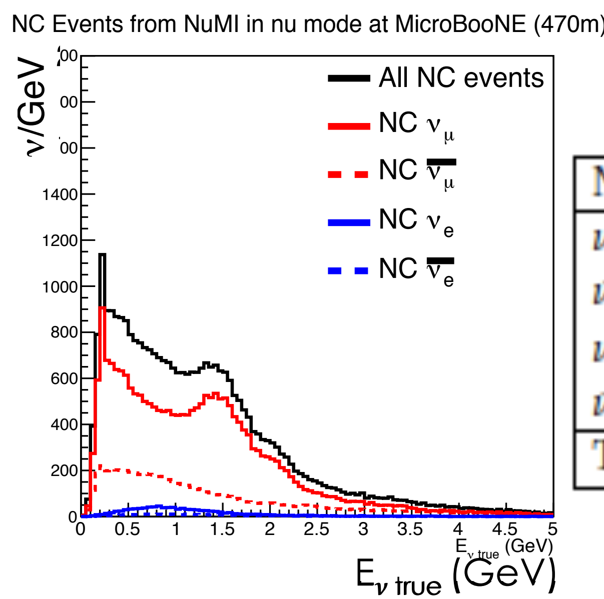




LAr1-ND

Neutrino flavor	All events	CC events	NC events
ν_μ	9,148	6,143	3,005
$\bar{\nu}_\mu$	1,498	720	778
ν_e	430	311	119
$\bar{\nu}_e$	74	41	33
Total	11,150	7,215	3,935



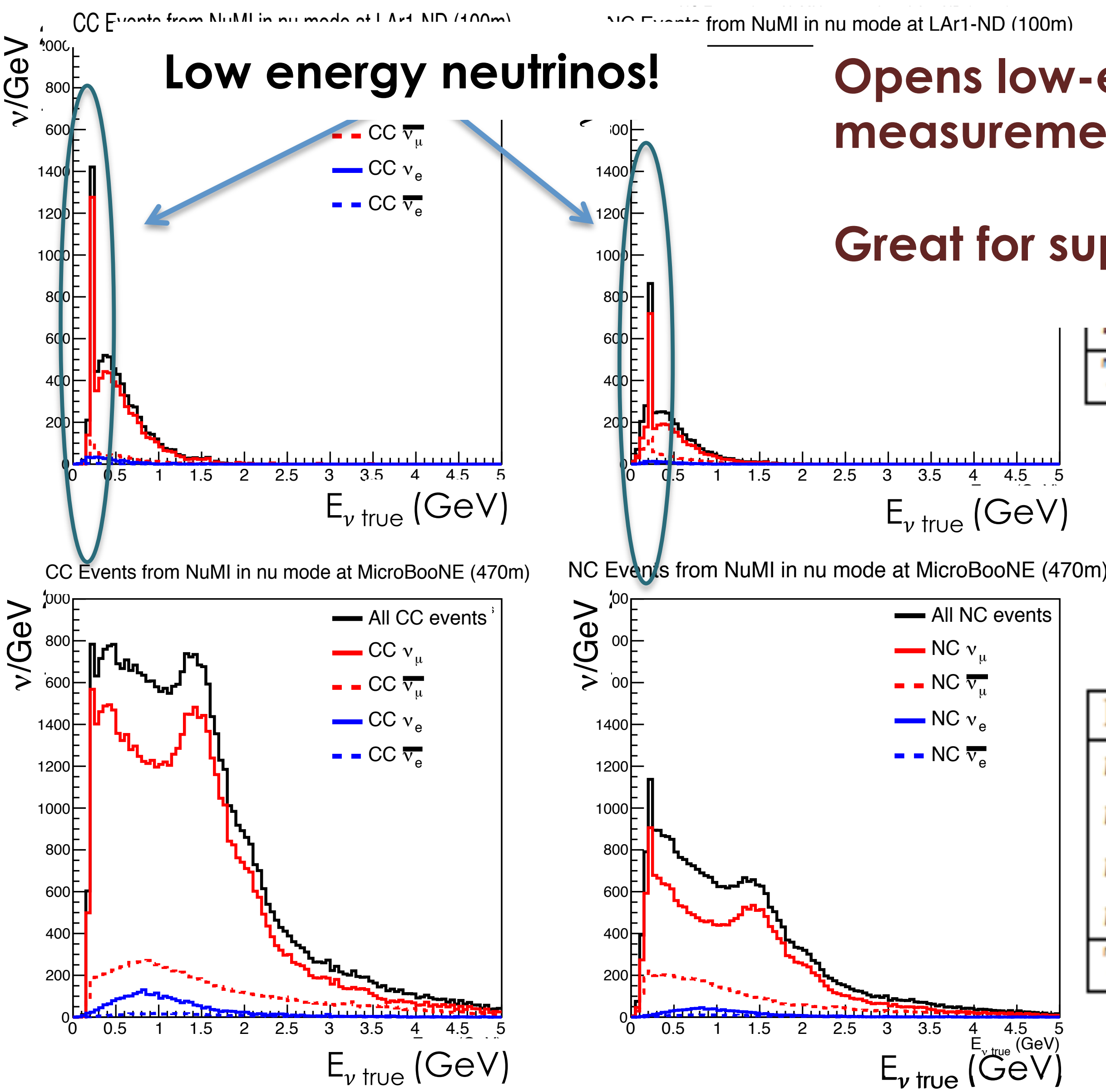


MicroBooNE

Neutrino flavor	All events	CC events	NC events
ν_μ	78,955	56,751	22,204
$\bar{\nu}_\mu$	17,769	10,946	6,823
ν_e	3,834	2,828	1,006
$\bar{\nu}_e$	888	569	319
Total	101,446	71,095	30,351

There's more! NuMI events

Low energy neutrinos!



Opens low-energy cross-section measurements

Great for supernova studies

			NC events
			3,005
			778
			119
			33
Total	11,150	7,215	3,935

MicroBooNE

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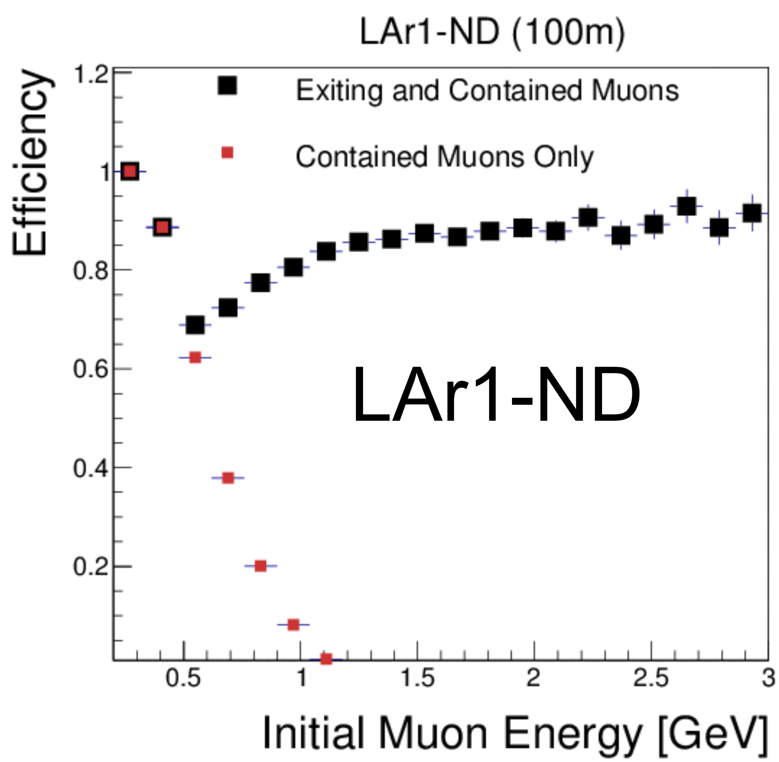
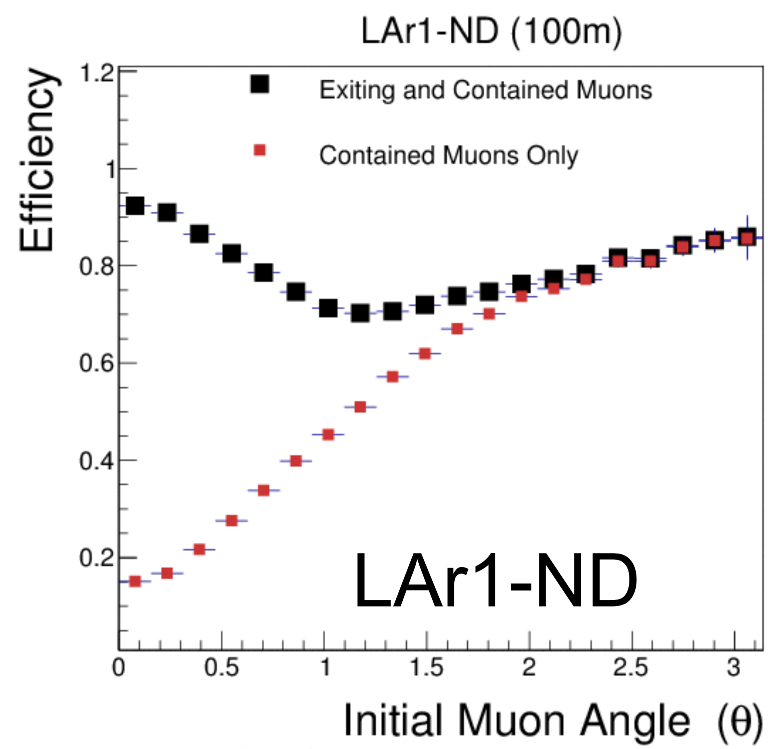
We are still optimising

- We have studied (and are studying) many design details, systematics effects, and physics models
- Example: muon containment study



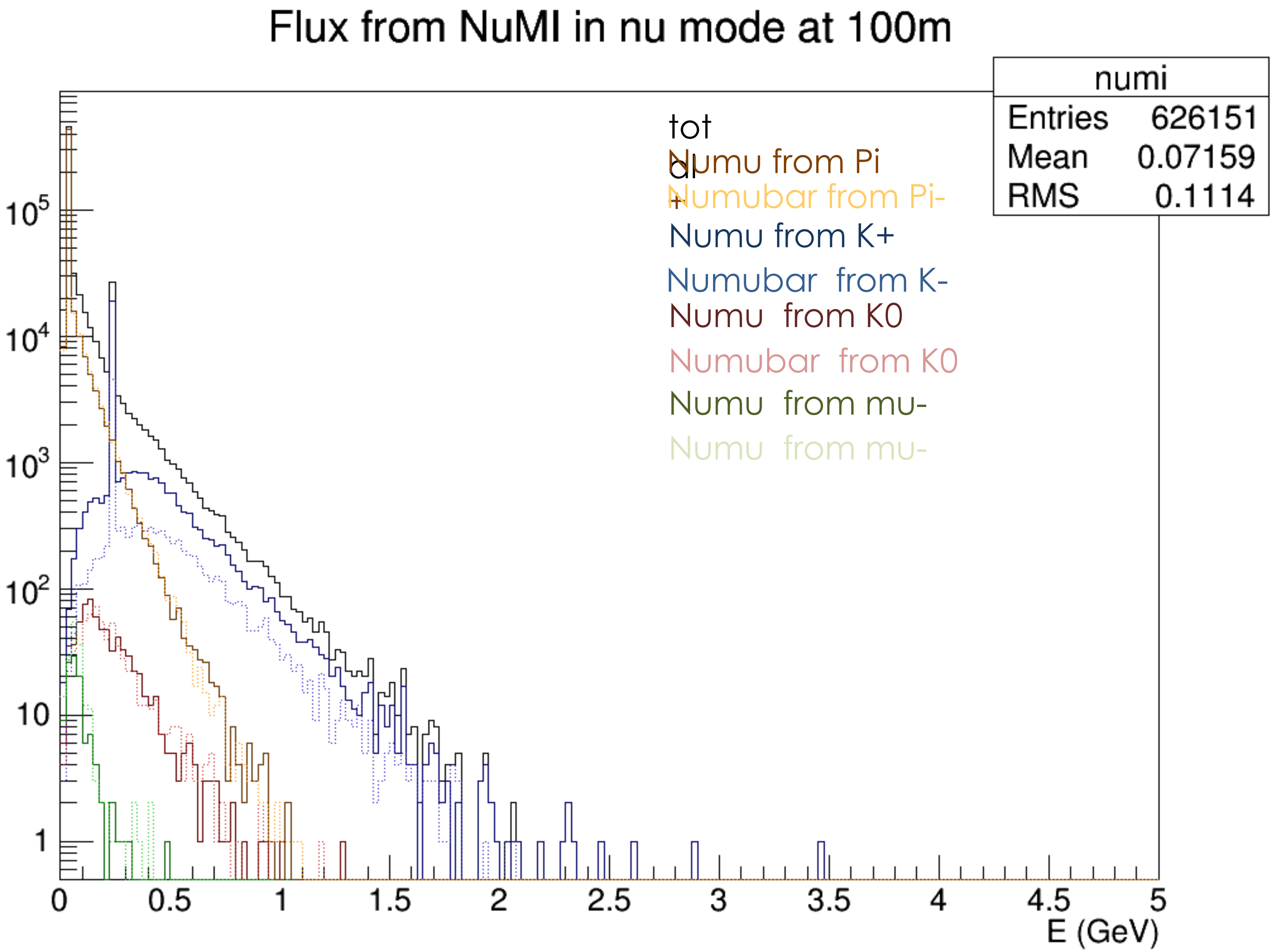


Conclusion

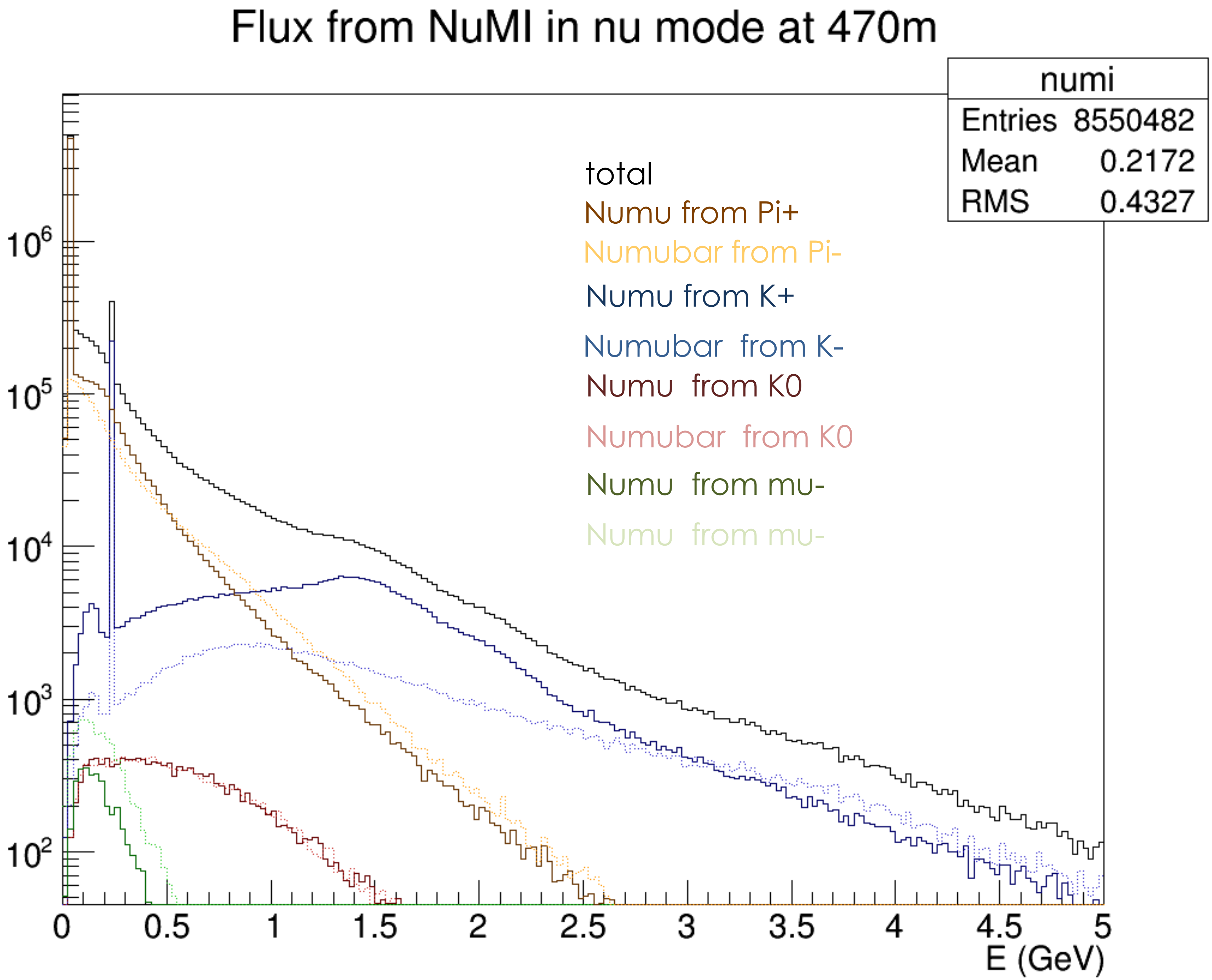
- Clear scientific motivations for a Near Detector in the BNB
- Great statistics available for cross-section measurements
- It gives a test bench for R&D and for expertise expansion
- It opens the door for definitive answer to the SBL anomalies with a 3 detector experiments

Backup

Fluxes at LAr1 in nu mode (100m)



Fluxes (nu mode MicroBooNE)



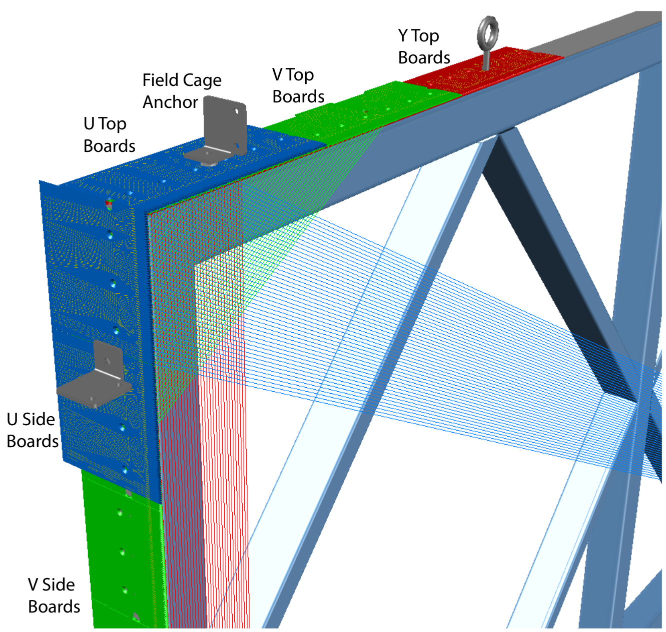
Anode Plane Assembly

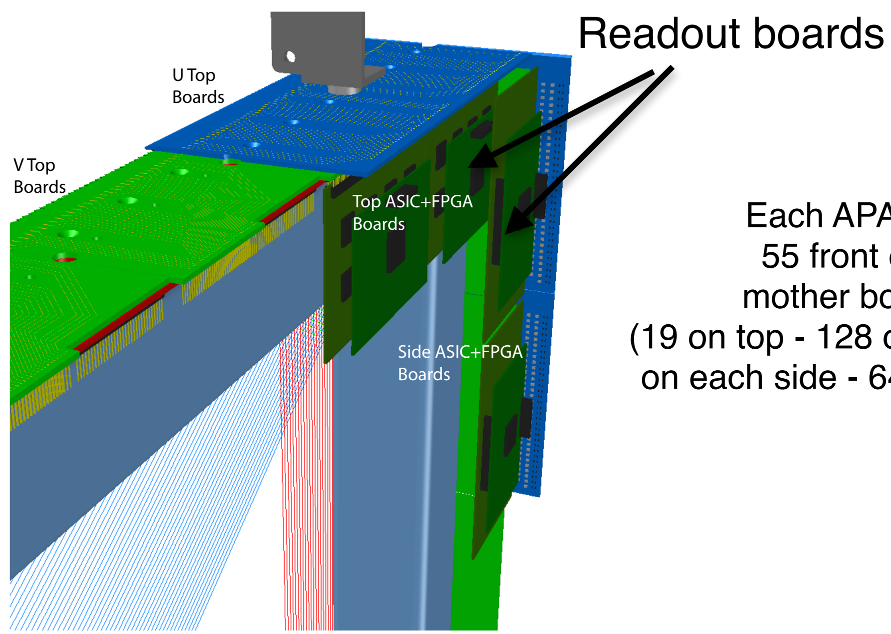
➢ Each APA holds three planes of wires (U, V and Y) on one side. The wire pitch (3 mm) and angles (0^0 and $\pm60^0$ from vertical) are identical to that of MicroBooNE

Single sided APA: uses the same wire bonding method developed for the LBNE APAs, but without the continuous helical wrapping, to minimize ambiguities in track reconstruction.

Each wire is connected to a front-end readout channel. The wire readout arrangement is also identical to MicroBooNE, with cold electronics boards at the top and vertical sides of each APA

The total number of readout channels is 4736 per APA (9472 in the entire detector)



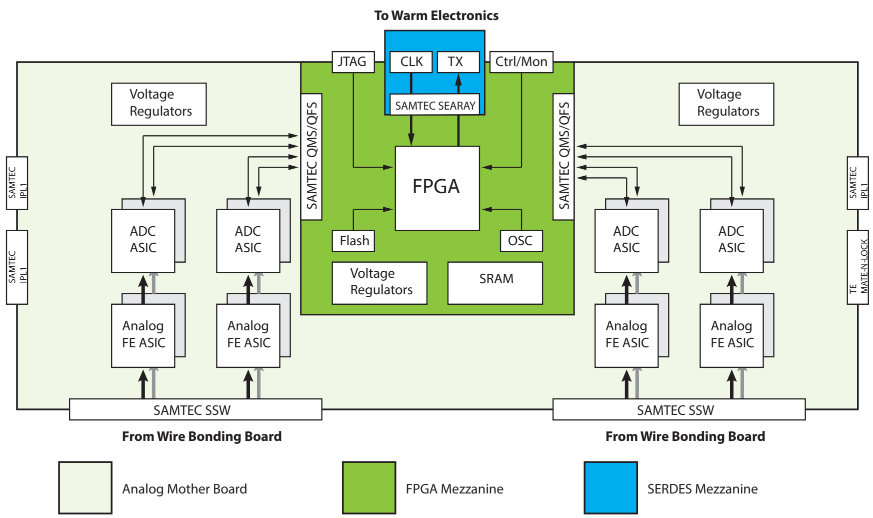


Each APA has 55 front end mother boards (19 on top - 128 channels, 18 on each side - 64 channels)

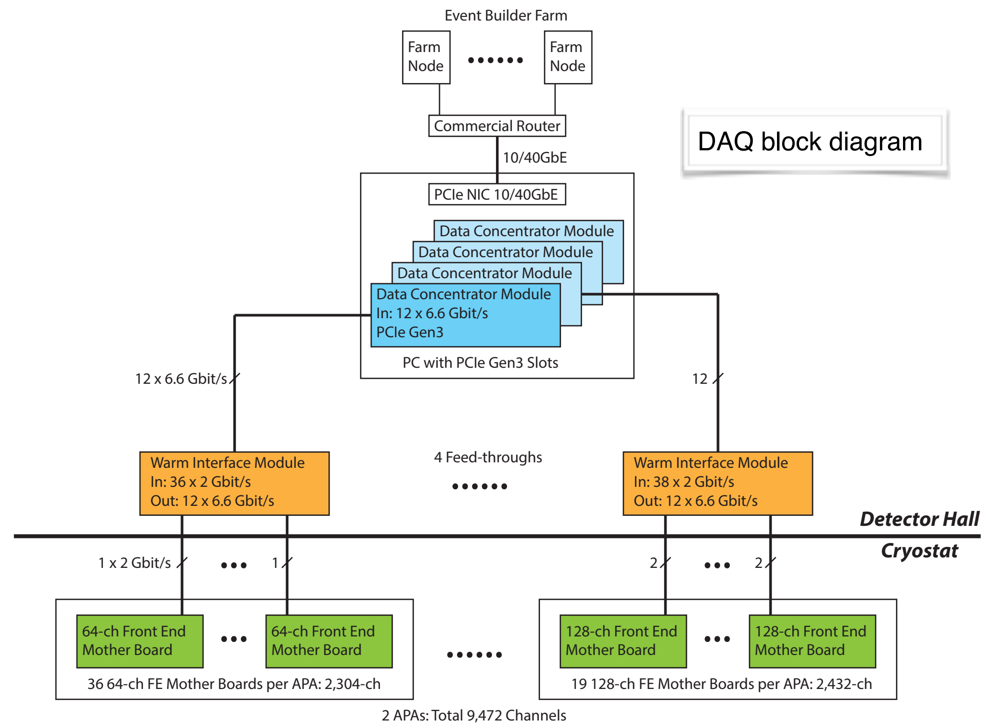
Corner view of an APA. Wires at 0^0 (collection plane) and $\pm60^0$ from vertical (2 induction planes) are attached to wire bonding boards at the sides and ends of the APA.

Readout Electronics & DAQ

- ➢ The electronic readout chain is implemented as CMOS ASICs designed for operation in LAr, and commercial FPGAs (multiplexing). *Both analog Front End (FE) ASIC and ADC ASIC have already been developed for LBNE, and analog FE ASIC is being used in MicroBooNE*
- ➢ 8 FE, 8 ADC plus a FPGA comprise a single 128-channel front end mother board



Front End Mother board



DAQ block diagram

- ➢ The FPGA on each motherboard transmit data out of the cryostat through a feedthrough to the DAQ system.
- ➢ The DAQ system is located external to the cryostat vessel, with components in the detector hall and in an on-site control room. It consists of the Warm Interface Module (WIM), timing system, and commodity Data Concentrator Modules (DCM), network switch and computing farm

Trigger - Light Collection

- Detection of scintillation light plays several important roles in LAr TPCs:
  - For a surface detector in a beam, like LAr1-ND, the scintillation light provides a tag of events in-time with the beam pulse, allowing rejection of cosmic rays;
  - The light also provides the T_0 for non-accelerator events (such as supernova events);
  - If a suitable <u>high efficiency light collection system</u> is in use, energy deposited into light can be related to energy deposited into charge for an improved calorimetric reconstruction.

- A compact light-guide-based system has been proposed as Photon Detector (PD) for LBNE *(acrylic bars read out by silicon photomultipliers, SiPMs*). The results of an R&D program show that, while more development is still necessary, the system works properly and is proposed as the basic design for light collection in the LAr1-ND detector

However, the relatively small volume of LAr1-ND provides an <u>excellent test-bed for light collection systems</u> being designed and optimized for LBNE and for studies of the light collection efficiency as a function of the photocathode coverage

Estimation of Costs

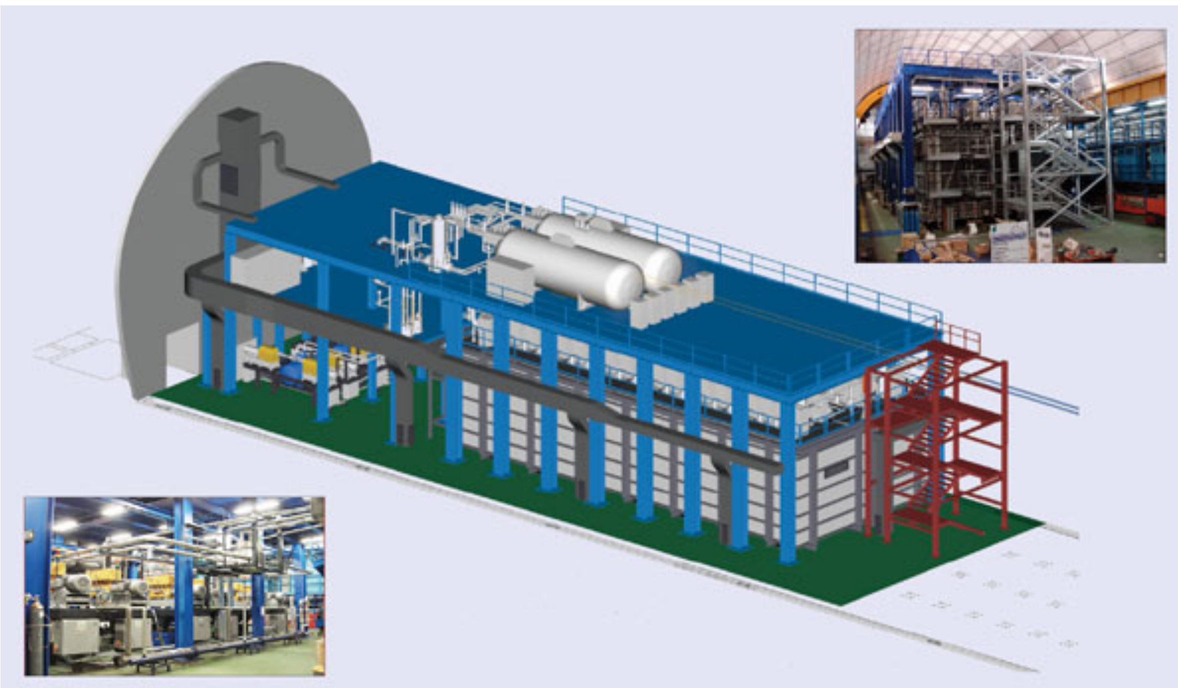
➢ The construction costs for LAr1-ND are estimated based on recent experience at Fermilab from building related LAr projects including MicroBooNE, the LBNE 35 ton membrane cryostat, and the Liquid Argon Purity Demonstrator (LAPD)

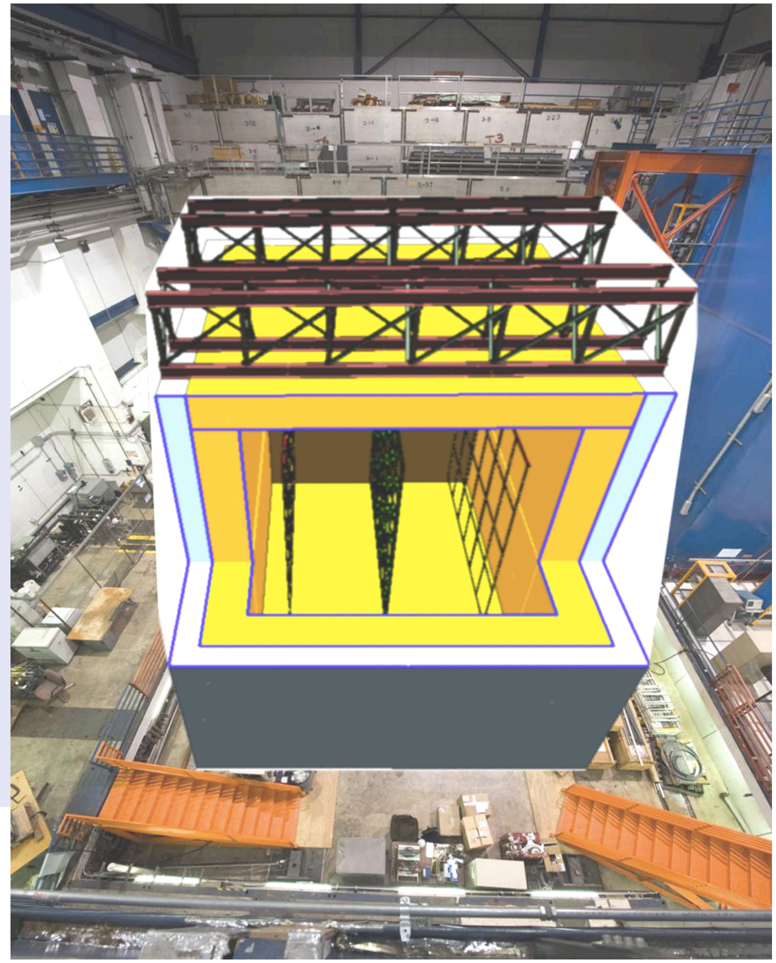
➢ The total project cost for the detector, modifications to the conventional facilities, and project management is estimated at $13M

Item	Estimated Cost*
1. Enclosure	$0.3M
2. Cryostat	$2.5M
3. Cryogenic System	$3.0M
4. Time Projection Chamber (TPC)	$2.0M
5. Front-end TPC Electronics	$1.5M
6. Light Detection System	$0.5M
7. Readout, Trigger and DAQ	$0.5M
8. Integration and Installation	$1.0M
Total Construction Costs	$11.3M
Project Management at 15%	$1.7M
Project Total	$13M

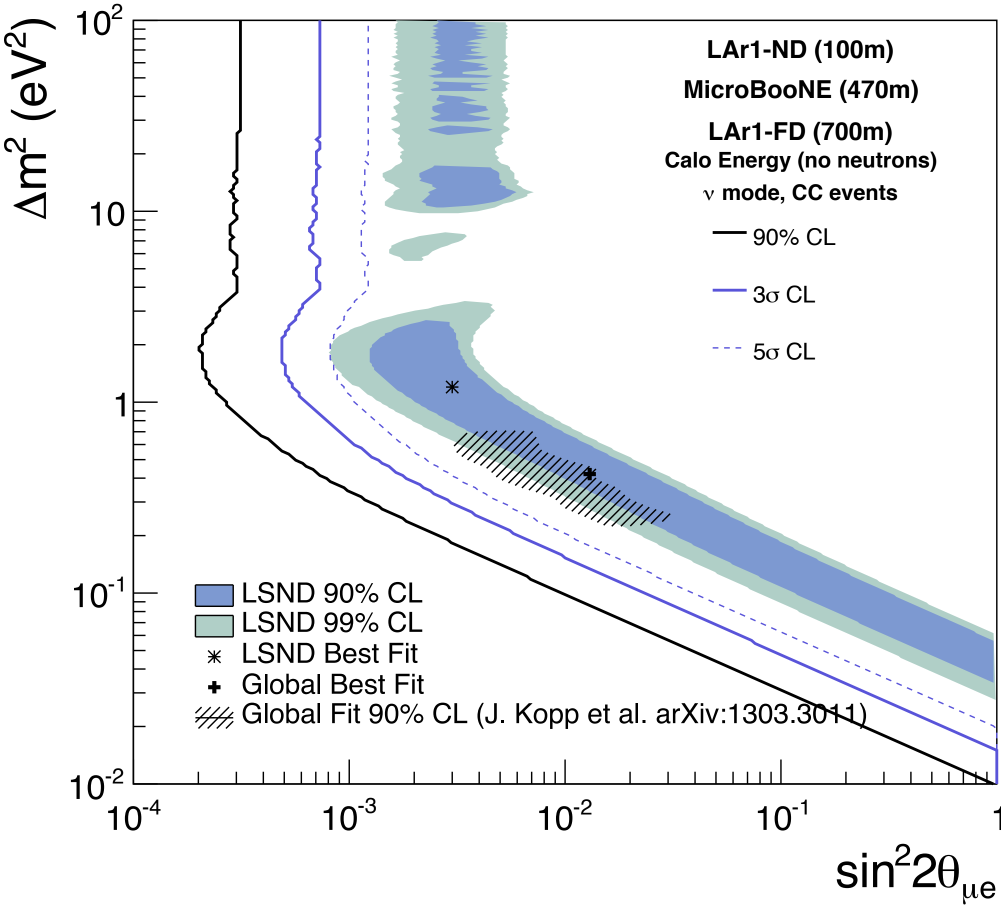
*not including contingency

Phase 2: LAr1-FD

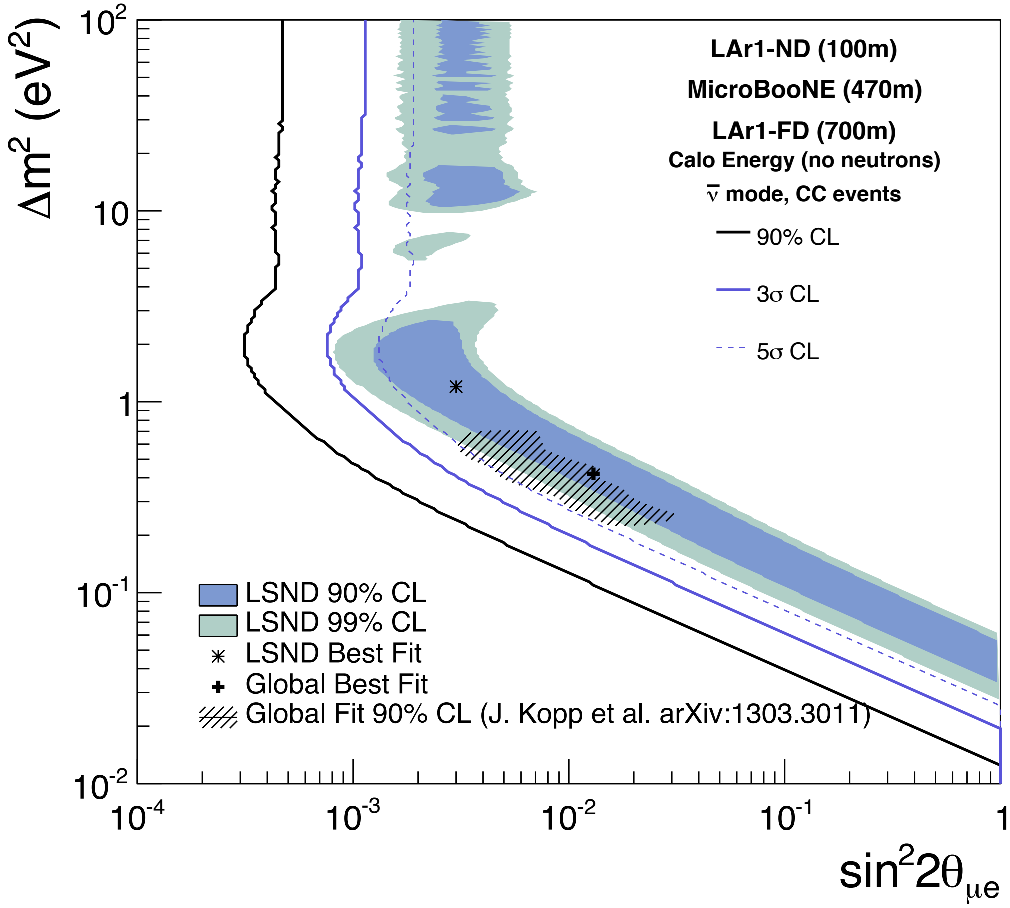




Full programme sensitivity



6.6x10^{20} POT exposure
neutrino mode



10x10^{20} POT exposure
anti-neutrino mode
(assumes both neutrinos and anti-neutrinos oscillate)