LAr1-ND

Overview & Physics Updates

Short-baseline Neutrino Program Working Meeting

FNAL, April 30th 2014

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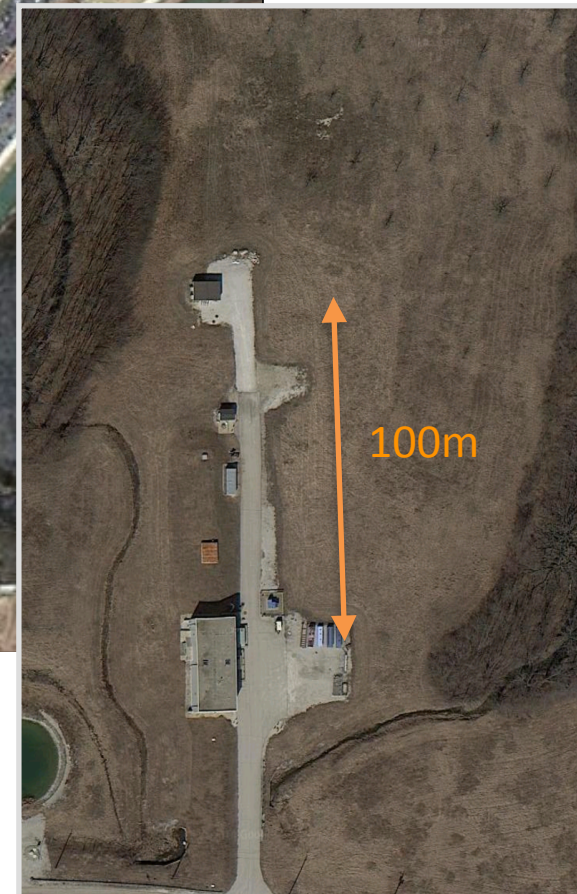
for the LAr1-ND Collaboration

Outline

❖ Motivations for the LAr1-ND Proposal

❖ Physics Reach of LAr1-ND

❖ Studies of containment and acceptance in LAr1-ND

❖ Neutrino fluxes along the BNB
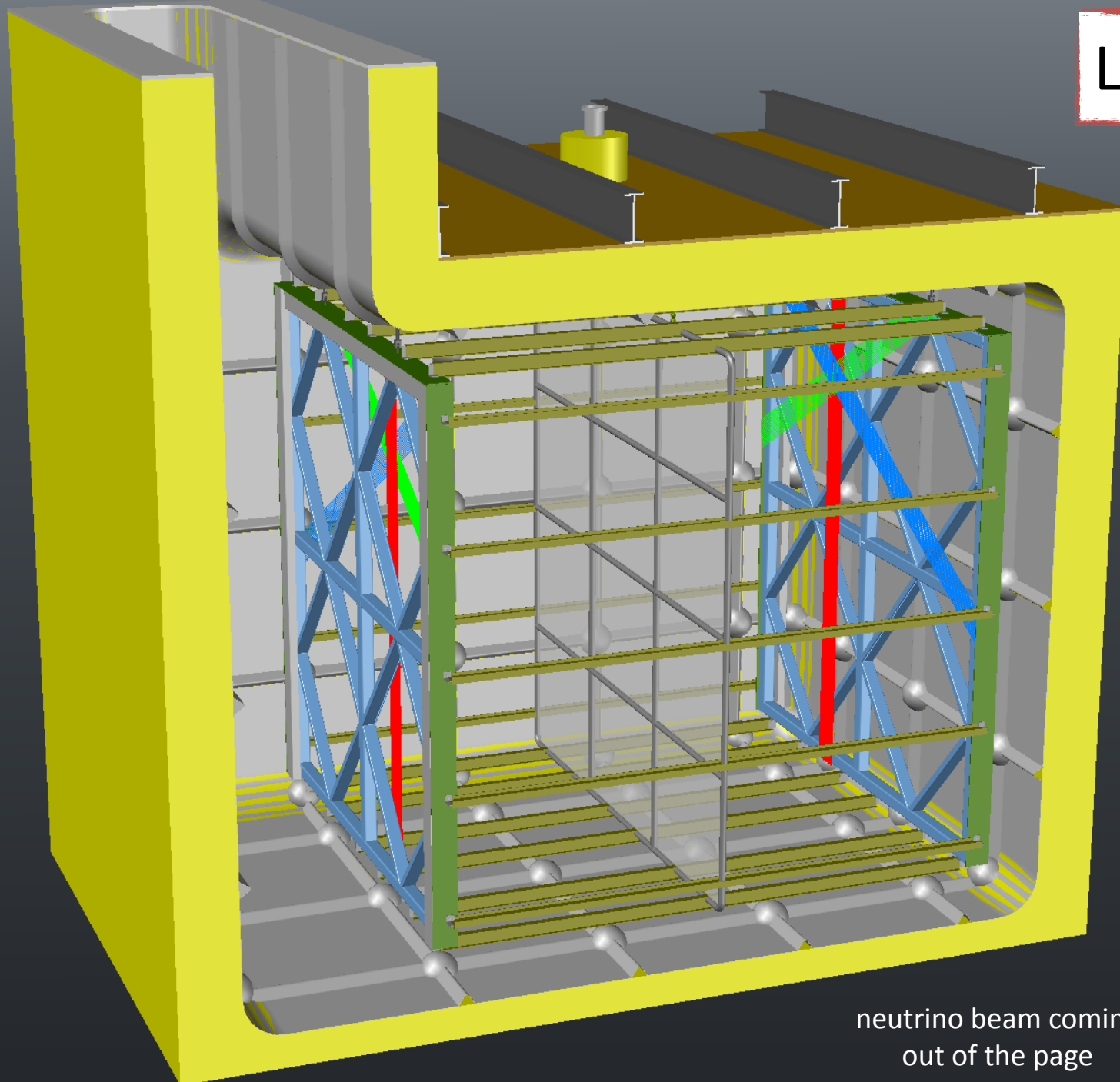
❖ Conclusions

The LAr1-ND Proposal, P-1053

❖ Recall our approach was to consider a staged short-baseline neutrino program that builds upon the existing FNAL Booster Neutrino Beam and the MicroBooNE detector

  ❖ There are important physics questions to be answered

  ❖ The SBL program builds upon existing infrastructure, investments, expertise, and physics interests within the neutrino physics community

  ❖ The SBL program offers an ideal opportunity for continued development of the liquid argon TPC technology, combining timely neutrino physics measurements with vital experience in detector development for a community working toward LBNE

❖ LAr1-ND was proposed as the next step in this program

  ❖ In our studies, we considered a first phase with LAr1-ND + MicroBooNE, which already enables a compelling and important physics program

  ❖ We also considered (including sensitivities) LAr1-ND as ND for the overall SBL program

  ❖ We focused on a detector design that is time- and cost-effective and would allow LAr1-ND to run near the end of the already approved MicroBooNE neutrino-mode run of 6.6×10^{20} POT

  ❖ Important R&D role on path to LBNE LAr detectors
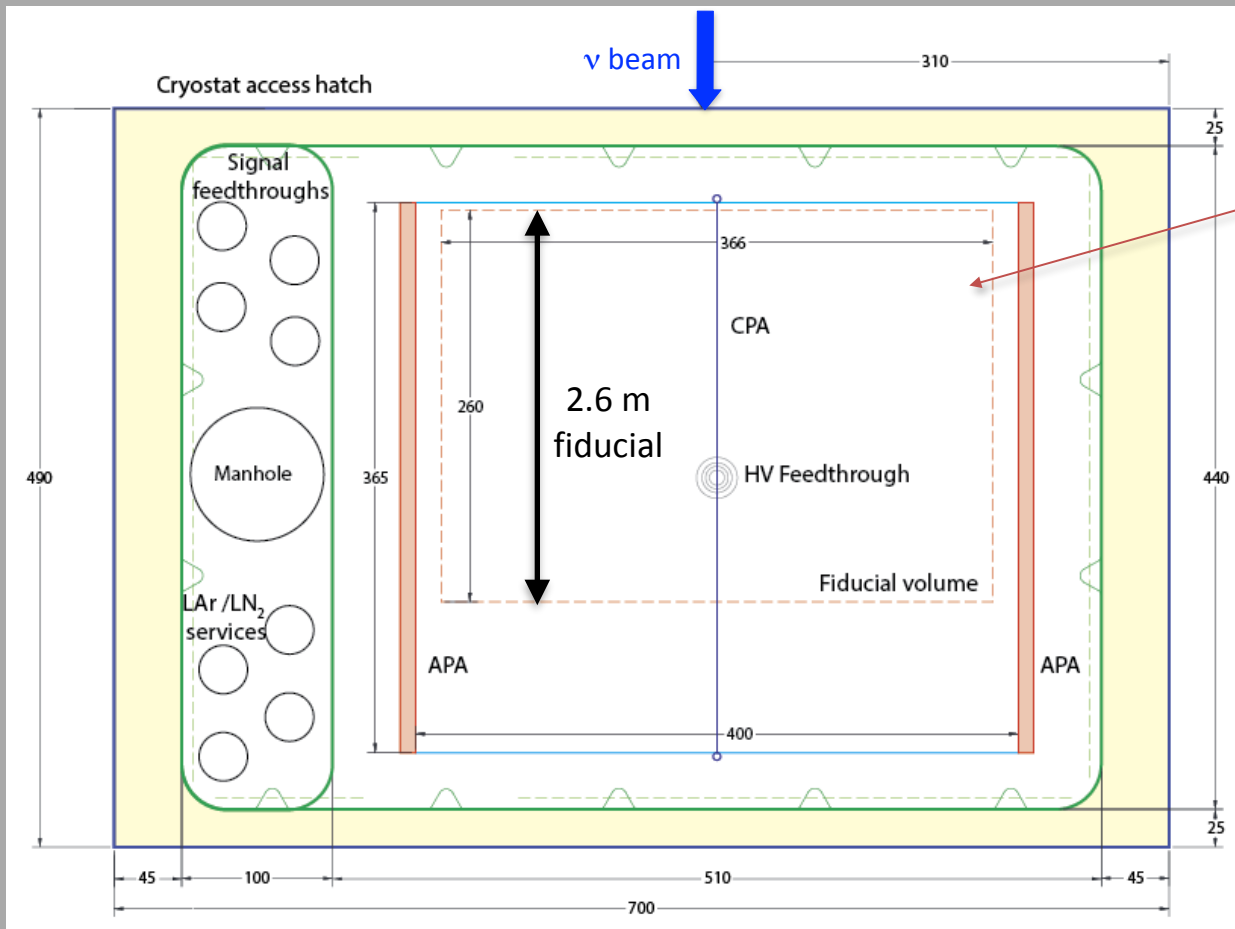
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Fermilab Short-Baseline Neutrino Program

MINOS/MINERvA surface building

SBNE FD (700m)

Fermilab

MicroBooNE (470m)

Booster Neutrino Beam

LAr1-ND (100m)

BNB Source

100m

The SciBooNE Experimental Hall

LAr1-ND

neutrino beam coming
out of the page

LAr1-ND

ν beam

Cryostat access hatch

Signal feedthroughs

Manhole

LAr /LN₂ services

APA

CPA

HV Feedthrough

Fiducial volume

APA

50t fiducial volume

2.6 m fiducial

3.65 m active

4.0 m active

LAr1-ND Physics Goals

❖ **MiniBooNE low-energy excess**

   ❑ Directly test the anomalous excess of electron neutrino events reported by MiniBooNE with very high significance (>5σ)

❖ **Oscillations: $v_\mu \to v_e$ appearance**

   ❑ In combination with MicroBooNE, much improved sensitivity with a near detector (ND)

❖ **Oscillations: v_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 and "Physics R&D"**

   ❑ 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
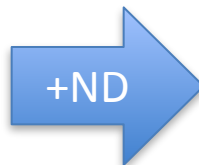
❖ **Dark matter search with beam off-target running**
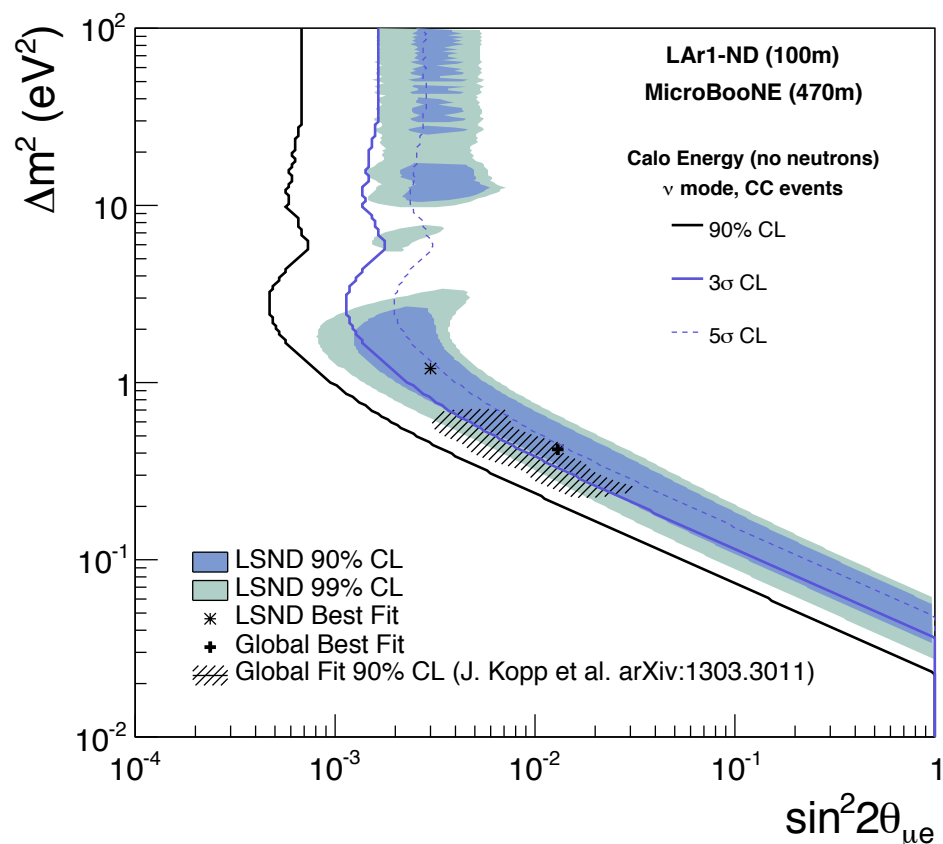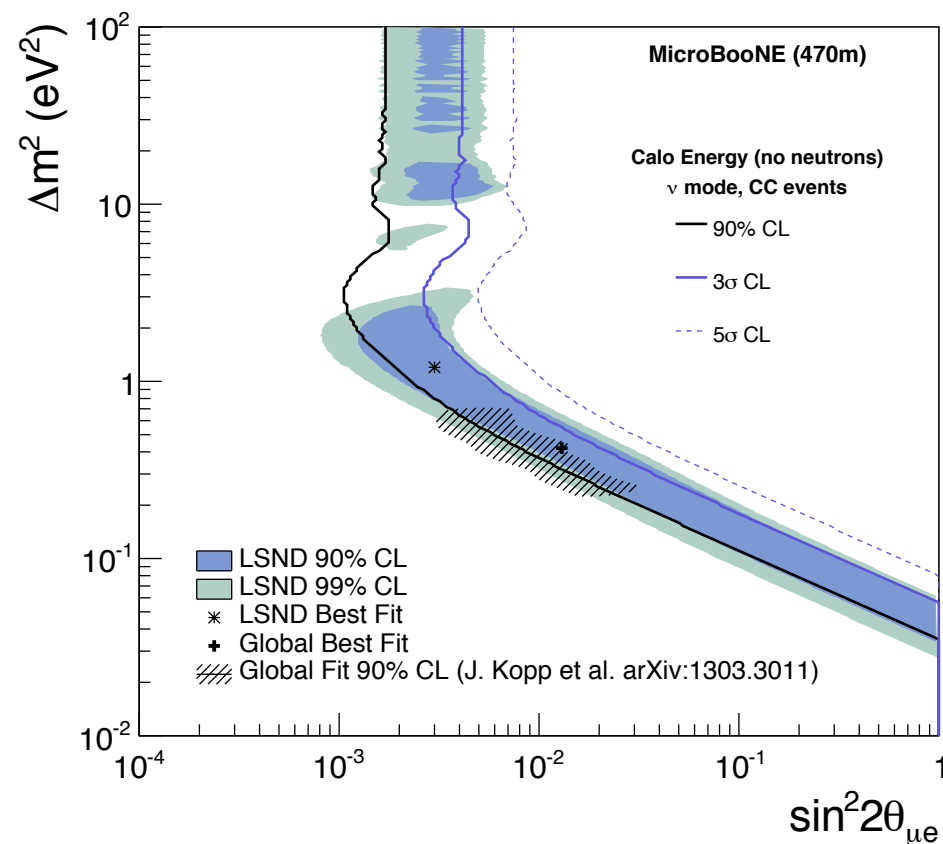
   ❑ Requires future beam off-target running.

$\nu_\mu \rightarrow \nu_e$ Appearance

Our standard "Phase 1" that is LAr1-ND running in a final year of MicroBooNE running.

6.6×10^{20} POT exposure for MicroBooNE alone, assuming 20% systematic uncertainties on ν_e background prediction
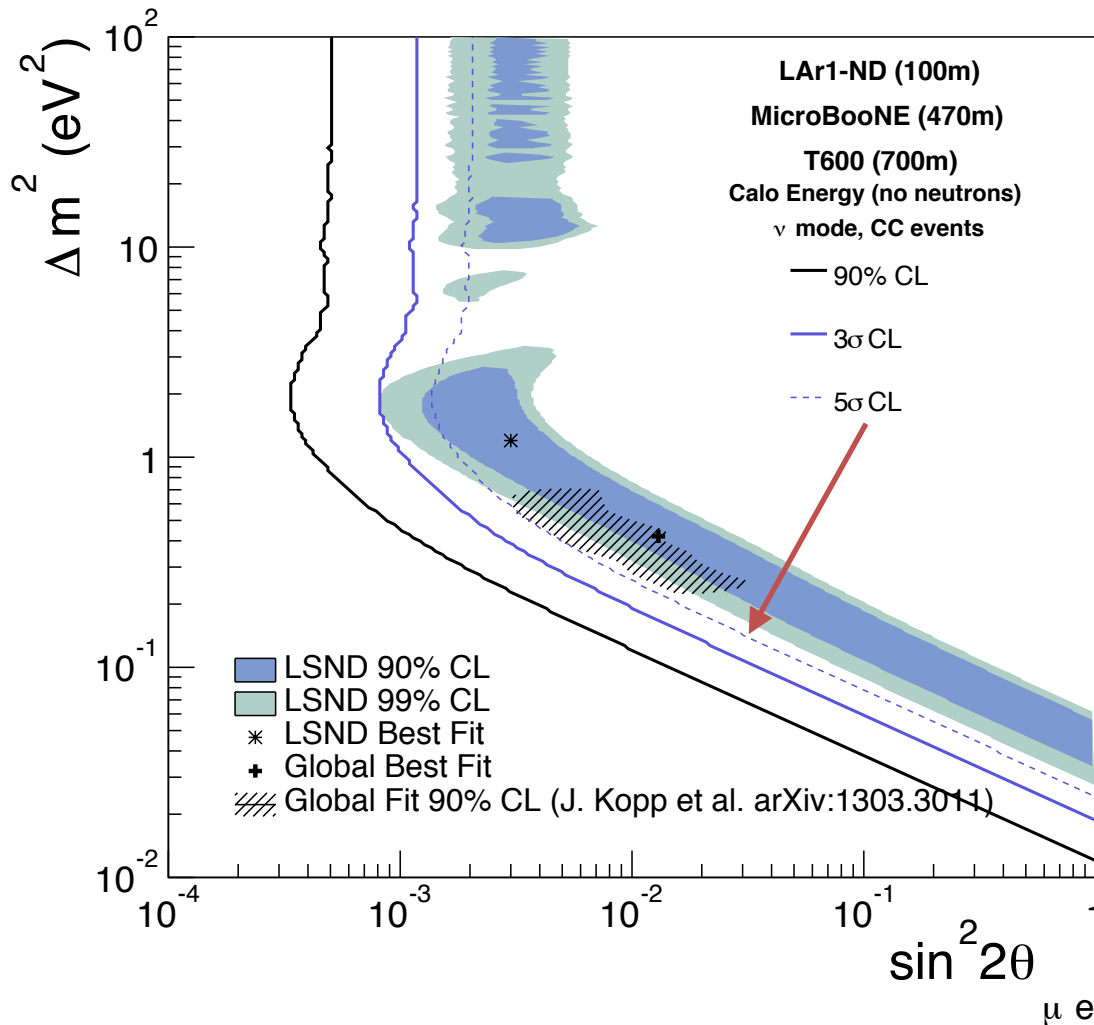
+ND

Same MicroBooNE exposure + 2.2×10^{20} POT exposure for LAr1-ND to constrain background prediction

MicroBooNE (470m)

Calo Energy (no neutrons)
ν mode, CC events
— 90% CL
— 3σ CL
- - - 5σ CL

LSND 90% CL
LSND 99% CL
* LSND Best Fit
+ Global Best Fit
/// Global Fit 90% CL (J. Kopp et al. arXiv:1303.3011)

LAr1-ND (100m)
MicroBooNE (470m)

Calo Energy (no neutrons)
ν mode, CC events
— 90% CL
— 3σ CL
- - - 5σ CL

LSND 90% CL
LSND 99% CL
* LSND Best Fit
+ Global Best Fit
/// Global Fit 90% CL (J. Kopp et al. arXiv:1303.3011)

$\nu_\mu \rightarrow \nu_e$ Appearance

With a large detector at 700m location.

6.6x10²⁰ POT exposure for all detectors
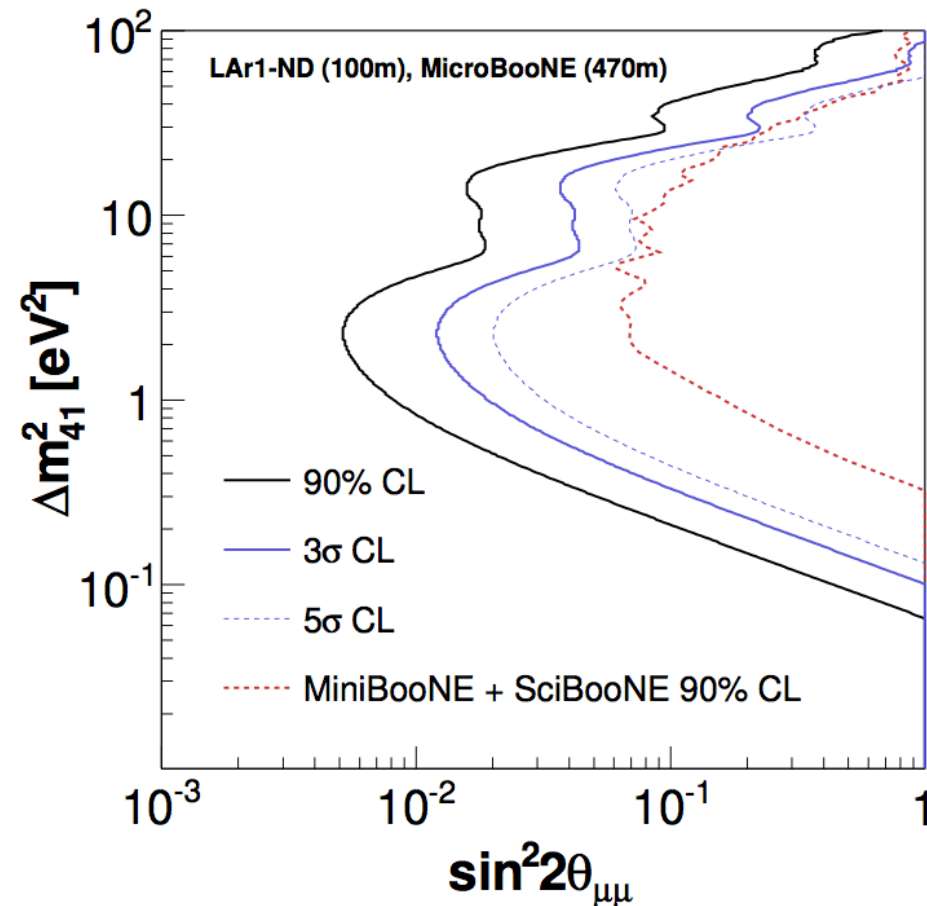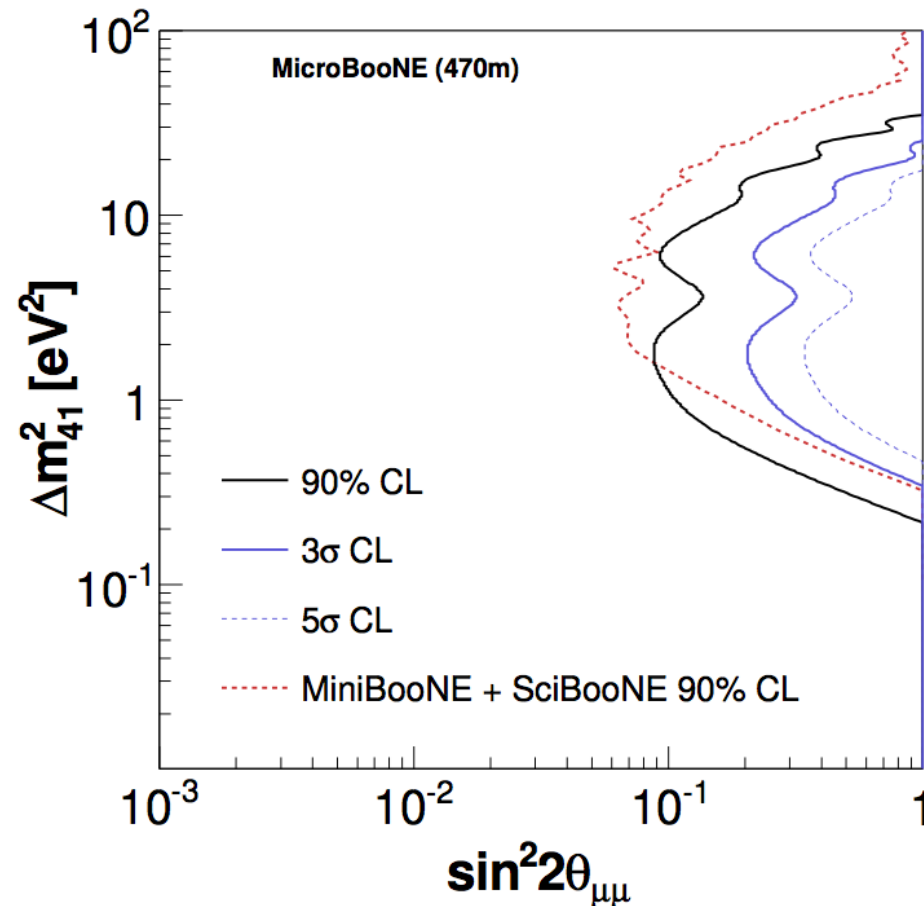

LAr1-ND (100m)

MicroBooNE (470m)

T600 (700m)
Calo Energy (no neutrons)
ν mode, CC events

— 90% CL
— 3σ CL
--- 5σ CL

LSND 90% CL
LSND 99% CL
∗ LSND Best Fit
+ Global Best Fit
▨ Global Fit 90% CL (J. Kopp et al. arXiv:1303.3011)

LAr1-ND + MicroBooNE + T600

100m   470m   700m

Our proposal included studies with a 1kt far detector, LAr1-FD (LOI to PAC in 2012), at 700m.

Straightforward to replace with a geometry representing mass and aspect ratio of the T600 detector at 700m (on-axis).

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ν_μ Disappearance

Our standard "Phase 1" that is LAr1-ND running in a final year of MicroBooNE running.

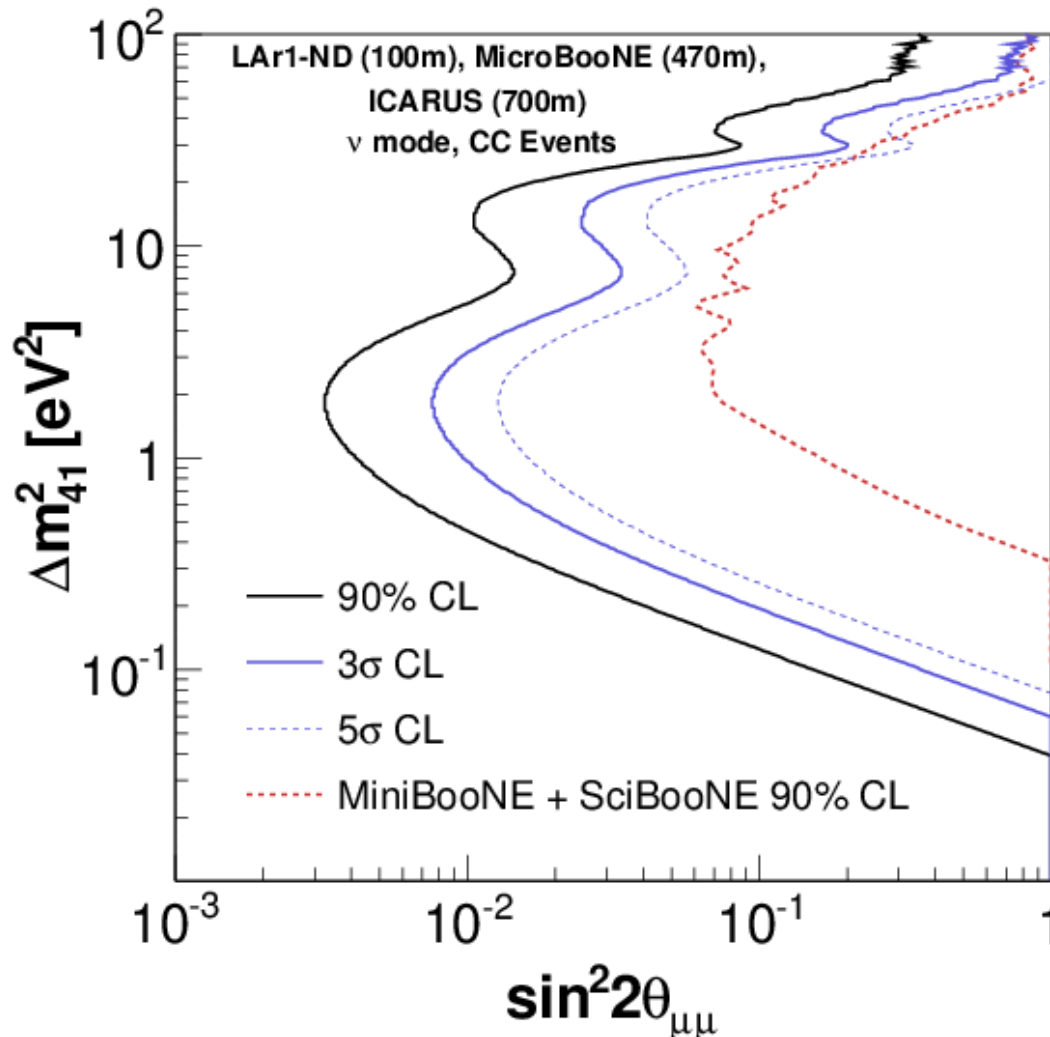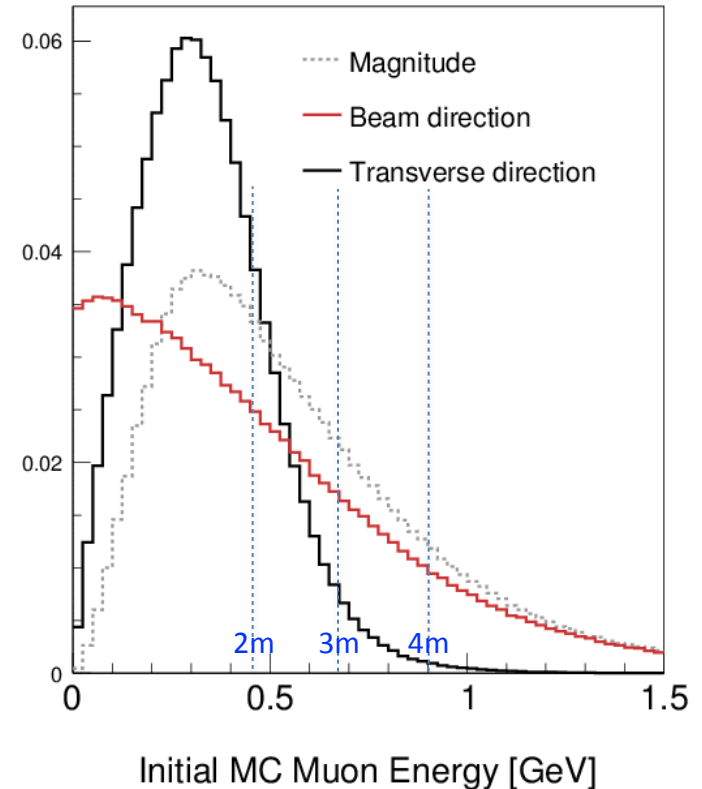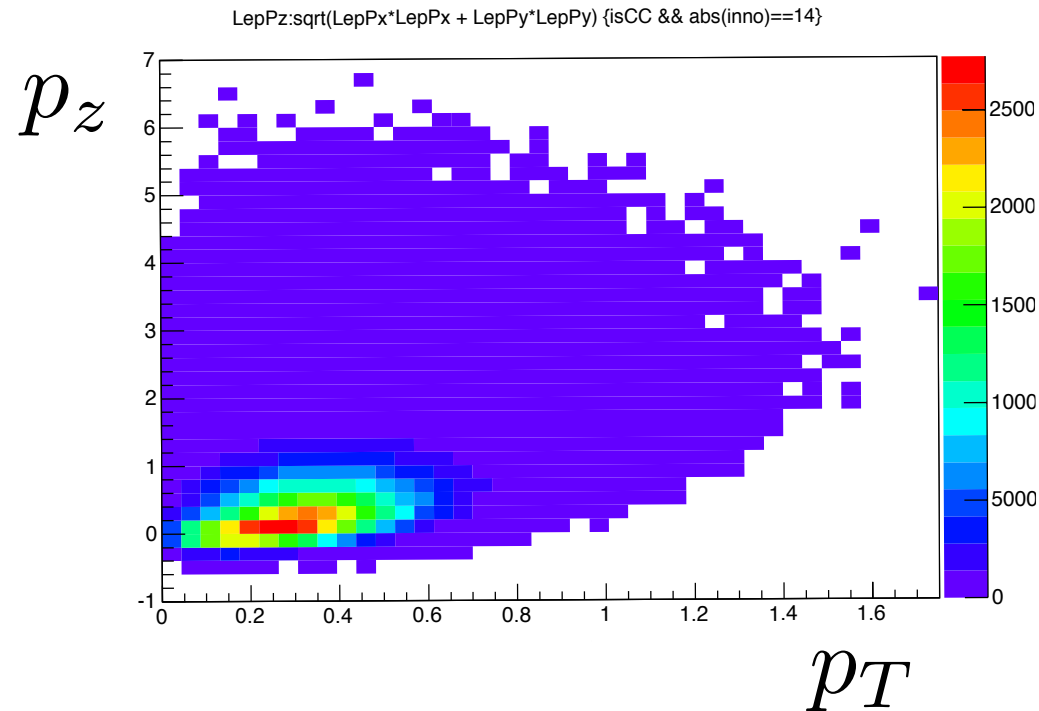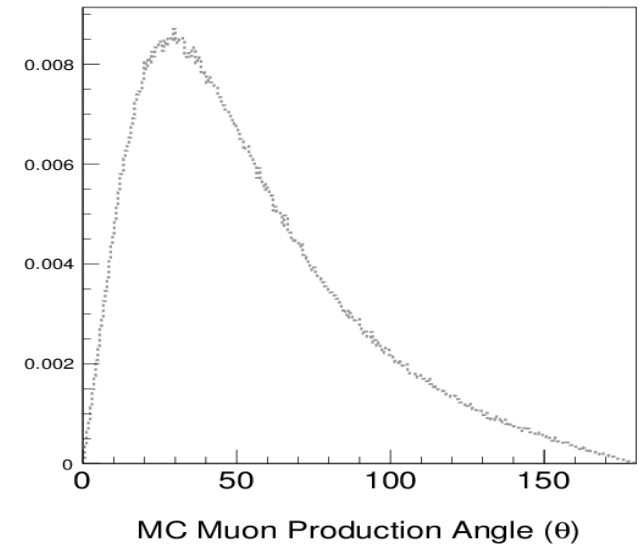6.6×10^{20} POT exposure for MicroBooNE alone, assuming 15% systematic uncertainties on the absolute ν_μ event rate

+ND
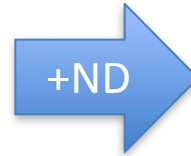
Same MicroBooNE exposure + 2.2×10^{20} POT exposure for LAr1-ND to measure unoscillated ν_μ

MicroBooNE (470m)

- —— 90% CL
- —— 3σ CL
- ---- 5σ CL
- ---- MiniBooNE + SciBooNE 90% CL

LAr1-ND (100m), MicroBooNE (470m)

- —— 90% CL
- —— 3σ CL
- ---- 5σ CL
- ---- MiniBooNE + SciBooNE 90% CL

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ν$_\mu$ Disappearance

6.6x10^{20} POT exposure for all detectors

LAr1-ND (100m), MicroBooNE (470m), ICARUS (700m)
ν mode, CC Events

— 90% CL
— 3σ CL
- - - 5σ CL
- - - MiniBooNE + SciBooNE 90% CL

LAr1-ND + MicroBooNE + T600

100m	470m	700m

Our proposal included studies with a 1kt far detector, LAr1-FD (LOI to PAC in 2012), at 700m.

Straightforward to replace with a geometry representing mass and aspect ratio of the T600 detector at 700m (on-axis).

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Acceptance and Containment in LAr1-ND

Muons in LAr1-ND

The low-energy Booster Beam makes large angle leptons, both transverse and longitudinal containment are important.

MC Muon Production Angle (θ)

LepPz:sqrt(LepPx*LepPx + LepPy*LepPy) {isCC && abs(inno)==14}

p_z

p_T

- - - - Magnitude
—— Beam direction
—— Transverse direction

2m 3m 4m

Initial MC Muon Energy [GeV]

Fates of Muons in LAr1-ND

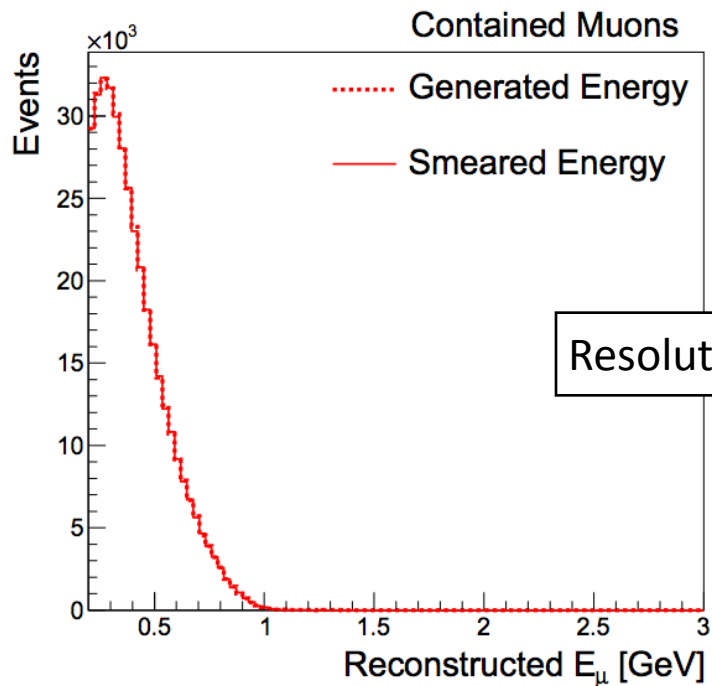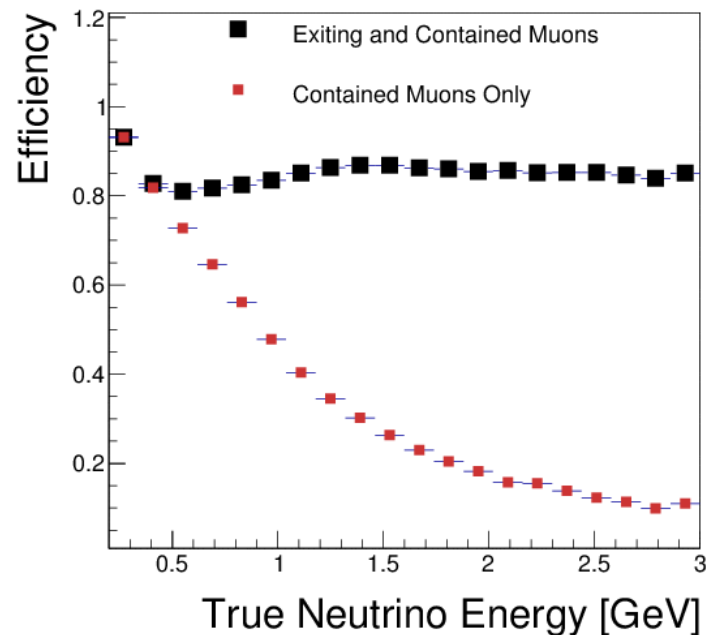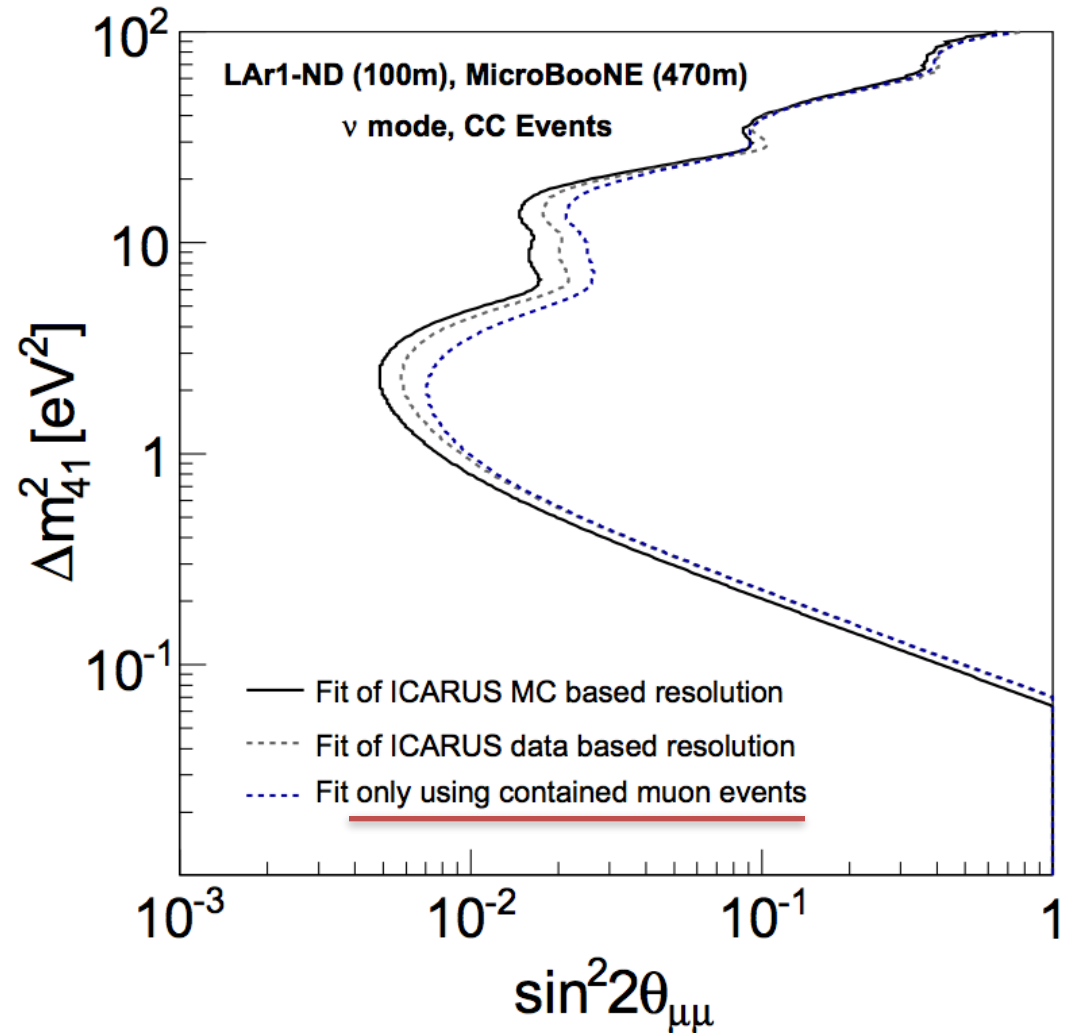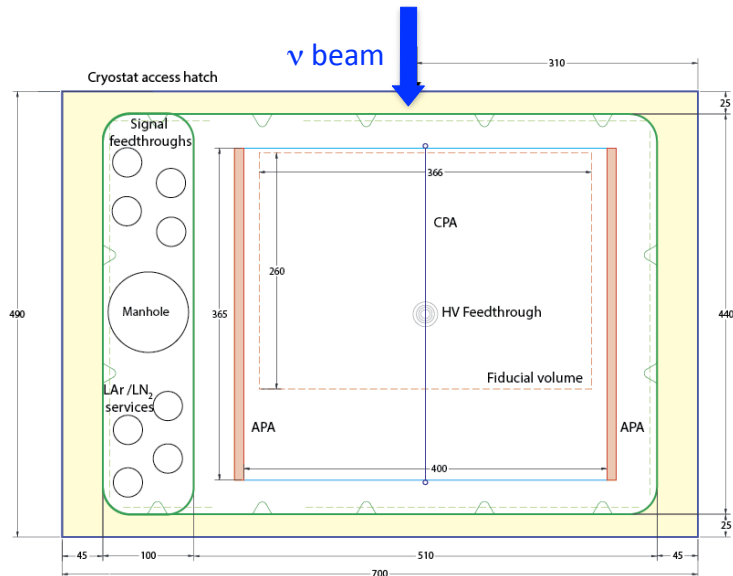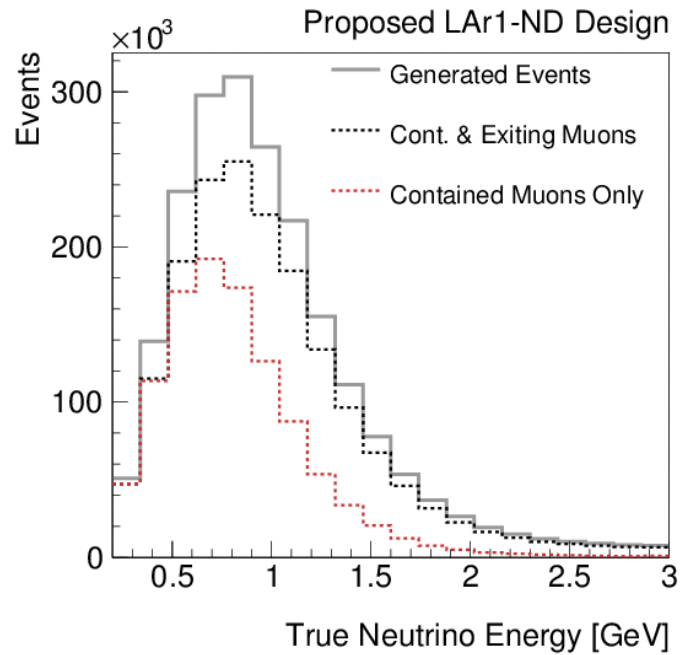| Muon fate for FV CC events	Fraction of total CC muons
Contained inside active volume	*49.9%*
> 1m track length in active volume, then exit side	*11.4%*
> 1m track length, then exit back	*22.5%*
< 1m track length, exit side	*13.5%*
< 1m track length, exit back	*1.6%*

83.8%

50t fiducial volume

3.65 m
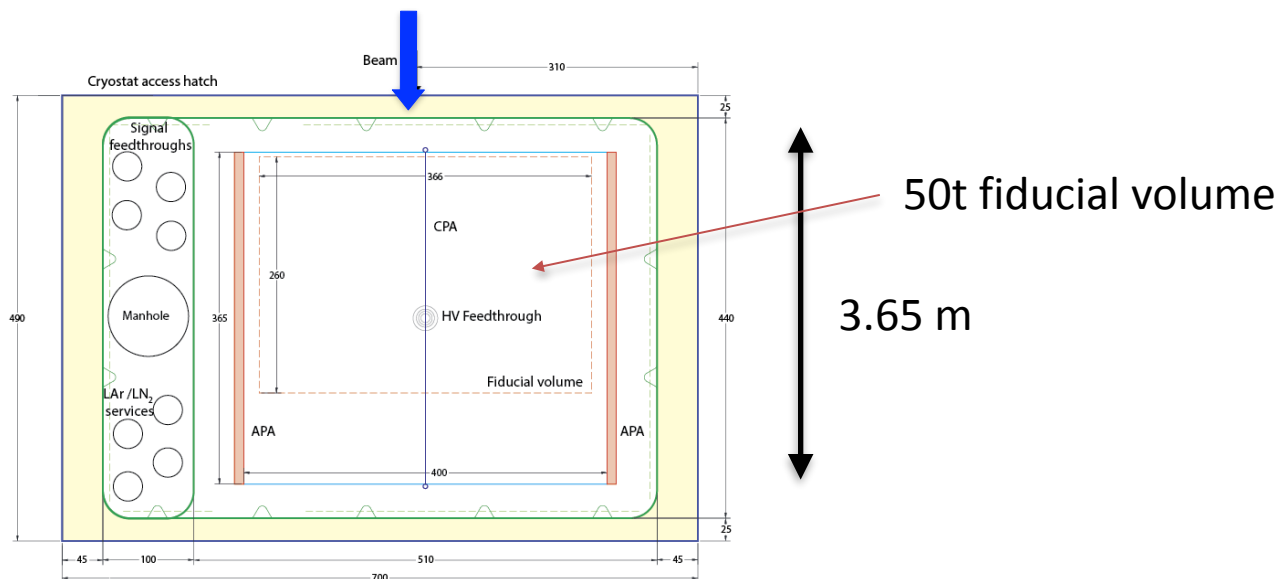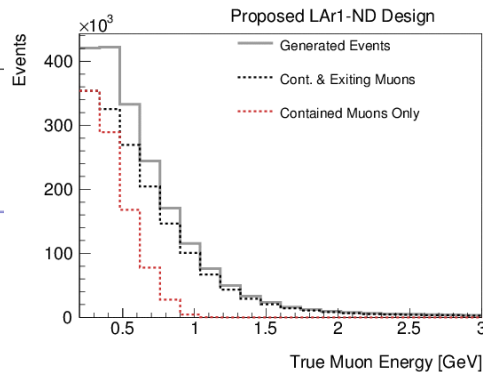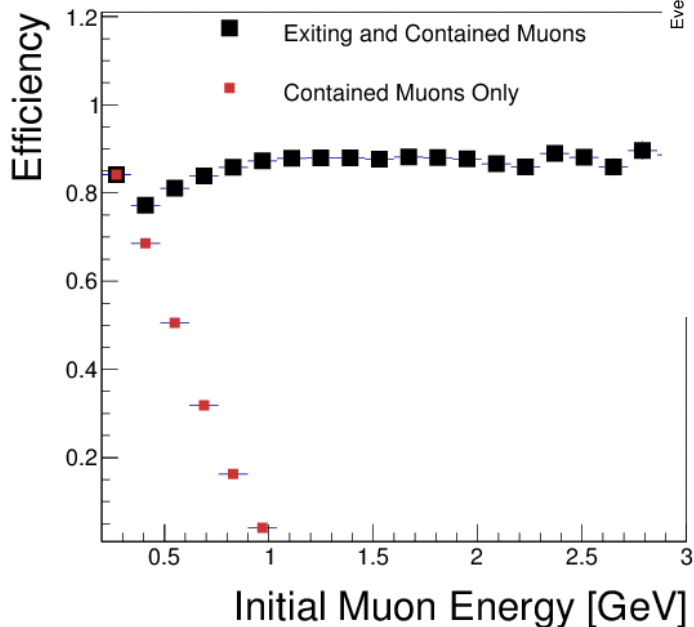
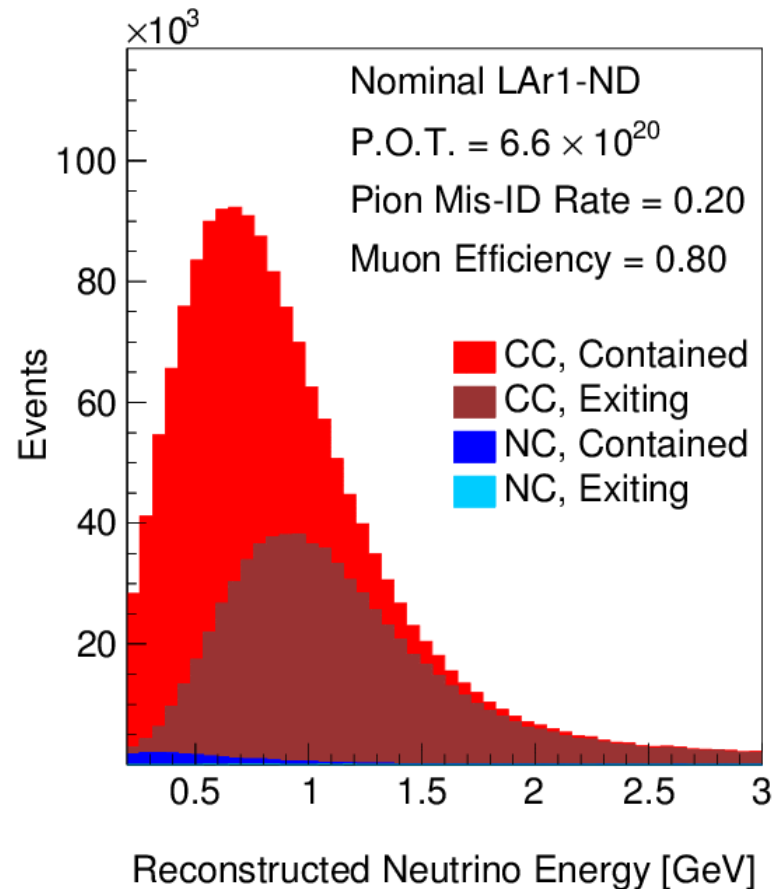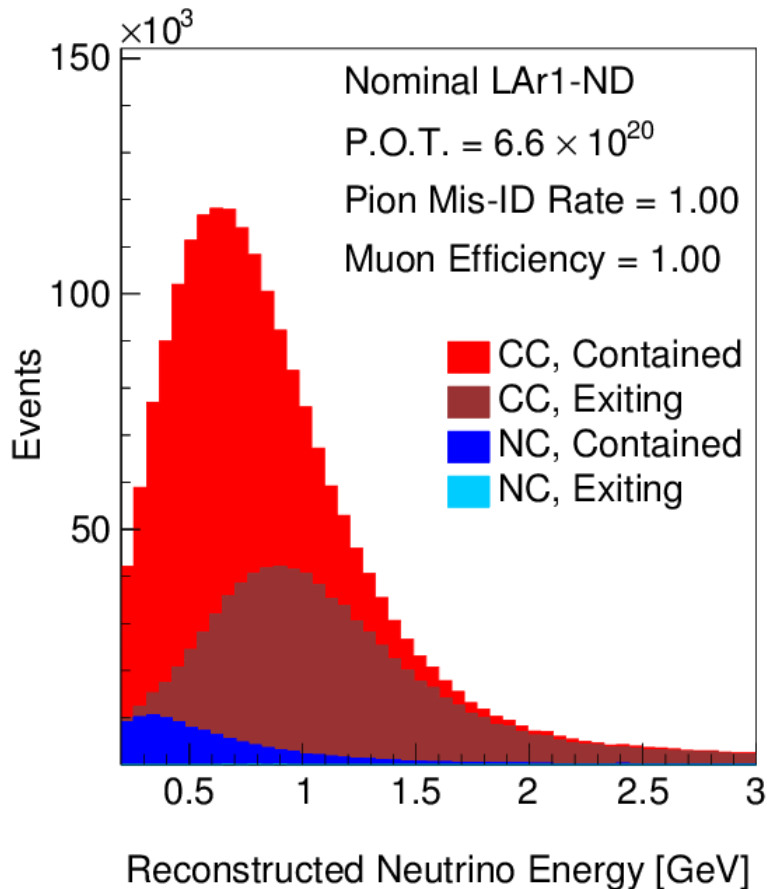Proposed LAr1-ND Design

Acceptance

Resolutions
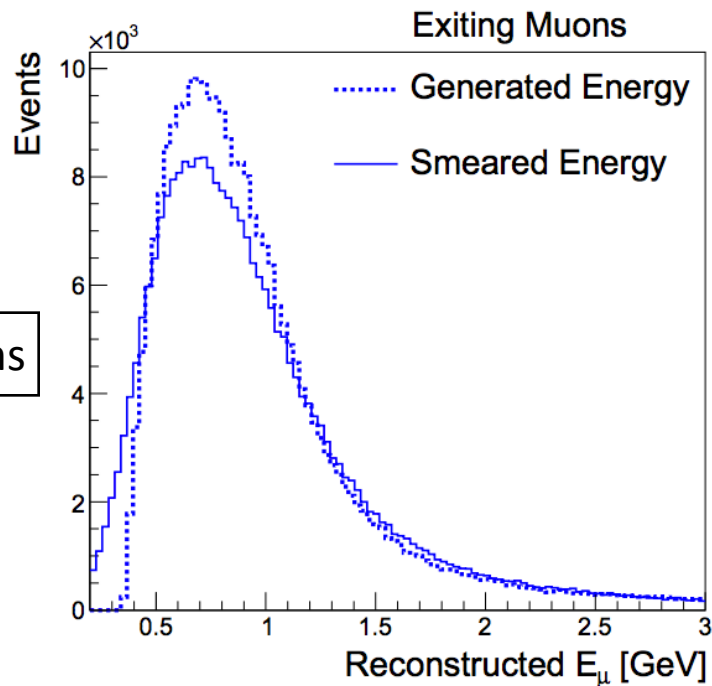
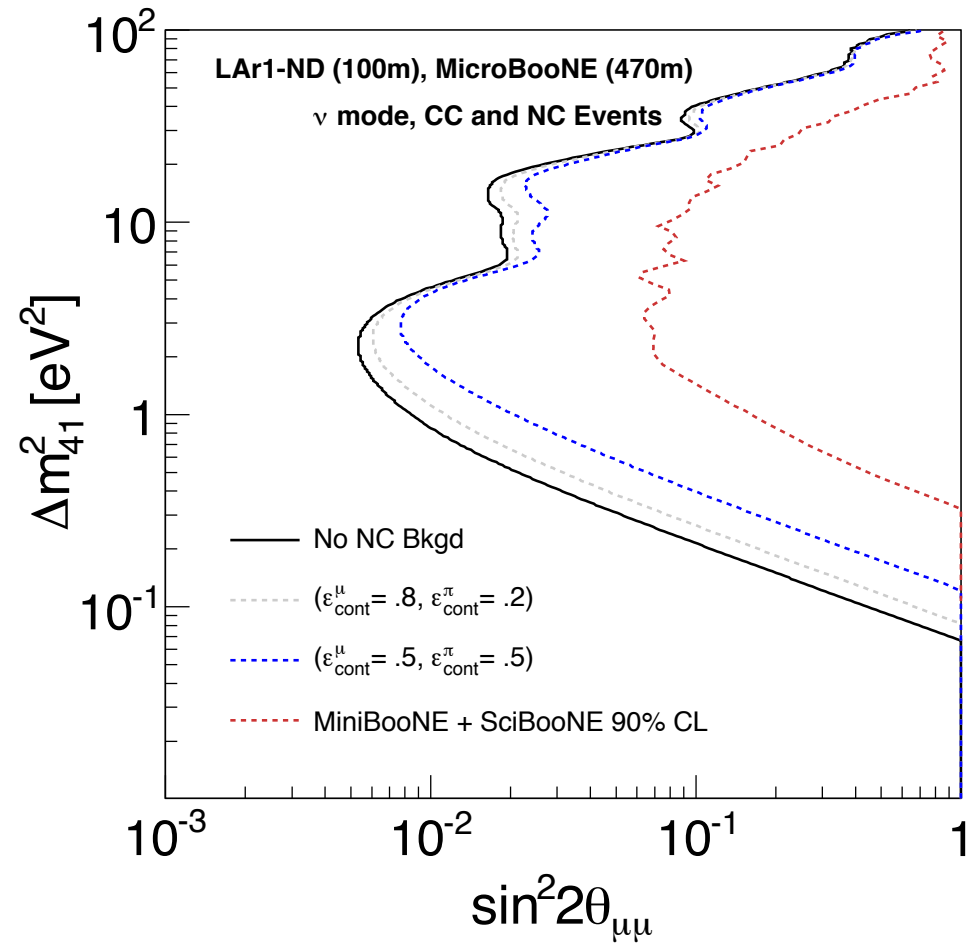# ν_μ Disappearance with different sub-samples of Muons

ν$_\mu$ Disappearance: Neutral Current Backgrounds

- Charged pions and muons which exit the detector cannot be distinguished, but very few charged pions exit.

- Contained tracks may be distinguishable, but the precise efficiency/purity is an area of active study.

ν_μ Disappearance: Neutral Current Backgrounds

- Plot shows sensitivity for two different efficiency/purity assumptions

- When determining the sensitivity we assume that the NC events do not oscillate

- The uncertainty on the fraction of NC events is set at 30%

LAr1-ND (100m), MicroBooNE (470m)

ν mode, CC and NC Events

—— No NC Bkgd

- - - (ε^μ_{cont}= .8, ε^π_{cont}= .2)

- - - (ε^μ_{cont}= .5, ε^π_{cont}= .5)

- - - MiniBooNE + SciBooNE 90% CL

Δm^2_{41} [eV^2]
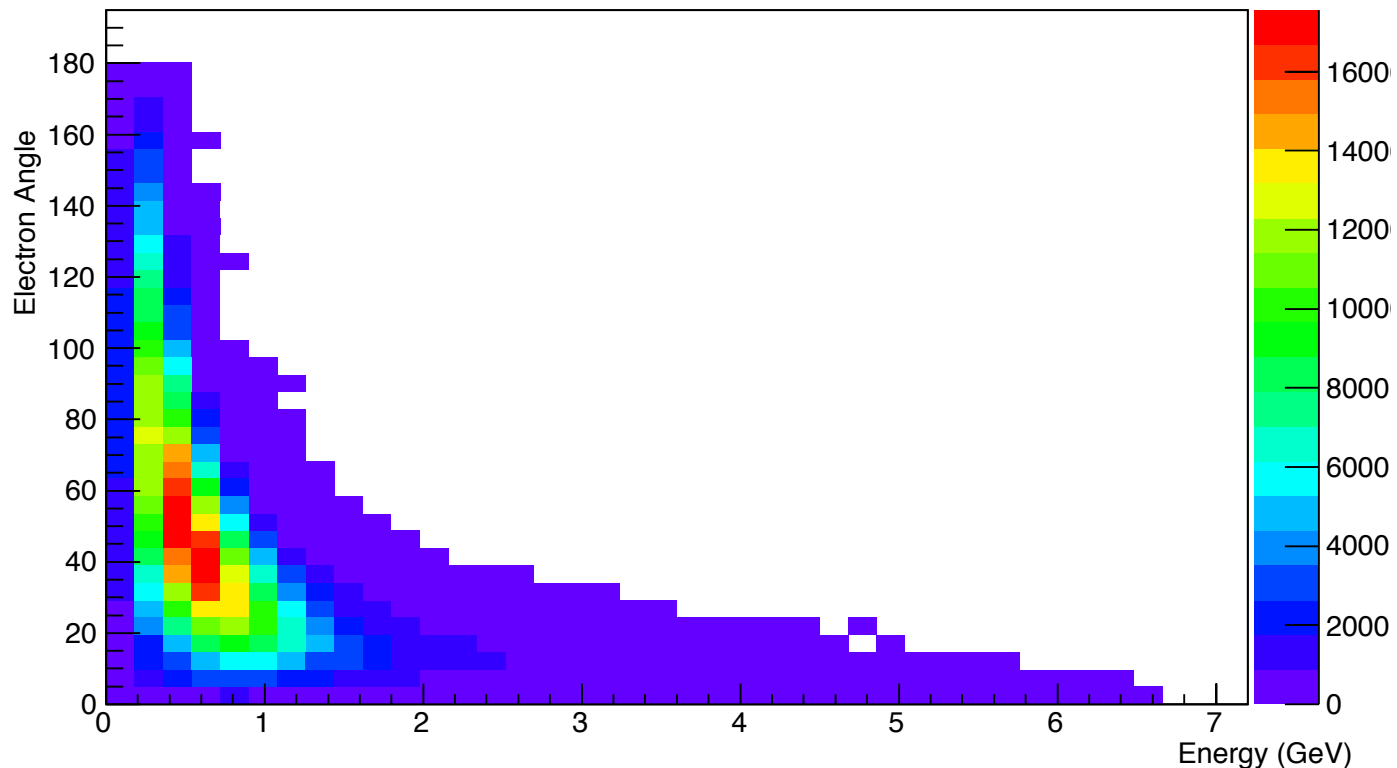
$\sin^2 2\theta_{\mu\mu}$

Electromagnetic shower containment

Electron angle w.r.t. the beam vs Energy

BNB neutrinos are at low energy, electrons in CC events also at large angles ($<\theta>=54^0$)
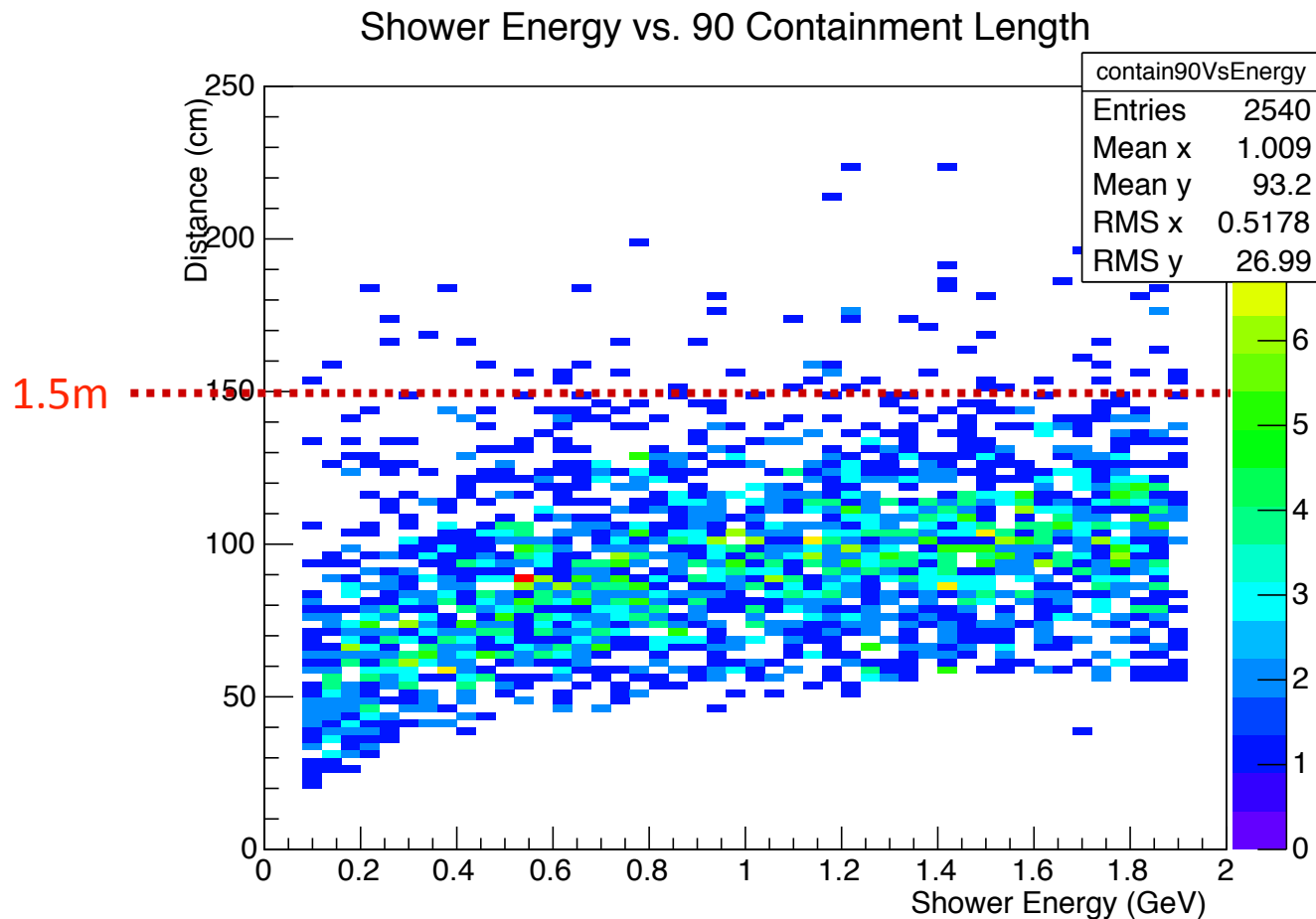
Electron Angle Vs. Electron Energy

Electromagnetic shower containment

Longitudinal shower containment vs Energy

Longitudinal distance to contain 90% of the energy deposited by the shower

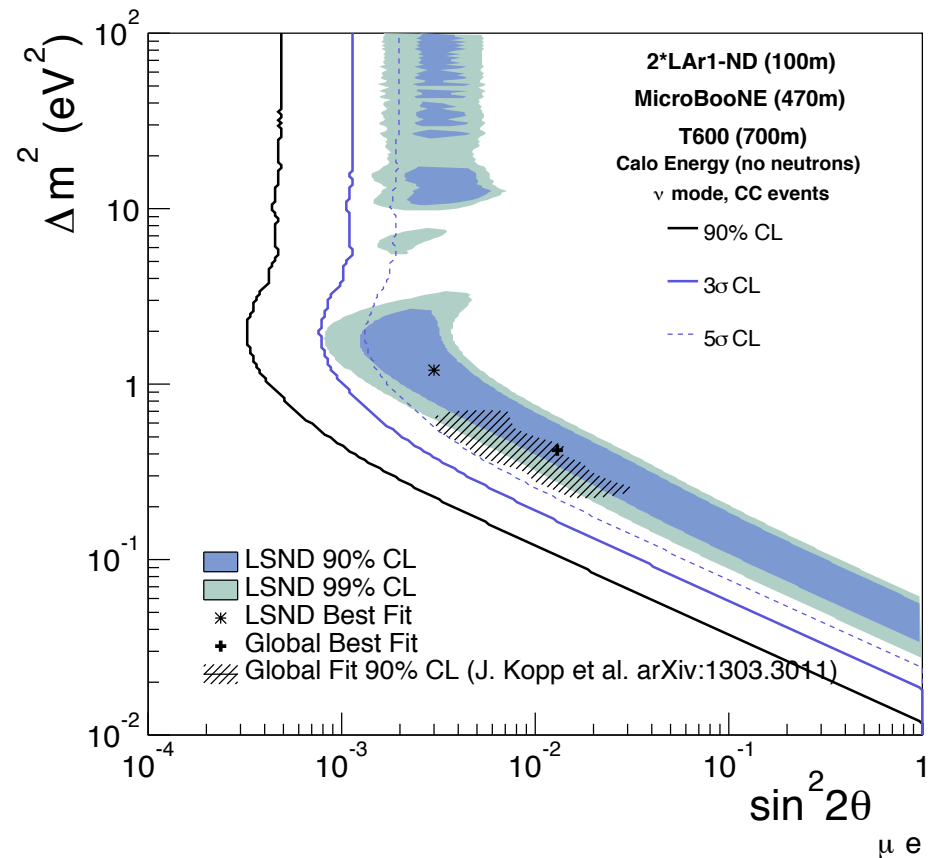# Increasing the Size of LAr1-ND

- There have been some discussions about the potential benefits of lengthening the ND in the beam direction

- First, the gain in <u>statistics</u> in the near detector has zero impact

Impact on ν_e Appearance
ND + uBoone + T600

LAr1-ND

2*LAr1-ND

Fates of Muons in 2*LAr1-ND

Muon fate for FV CC events	Fraction of total CC muons	
Contained inside active volume	59%	85%
> 1m track length in active volume, then exit	26%	

2 × LAr1-ND Design

- ■ Exiting and Contained Muons
- ■ Contained Muons Only

Efficiency vs Initial Muon Energy [GeV]

2 × LAr1-ND Design

- ■ Exiting and Contained Muons
- ■ Contained Muons Only

Efficiency vs True Neutrino Energy [GeV]
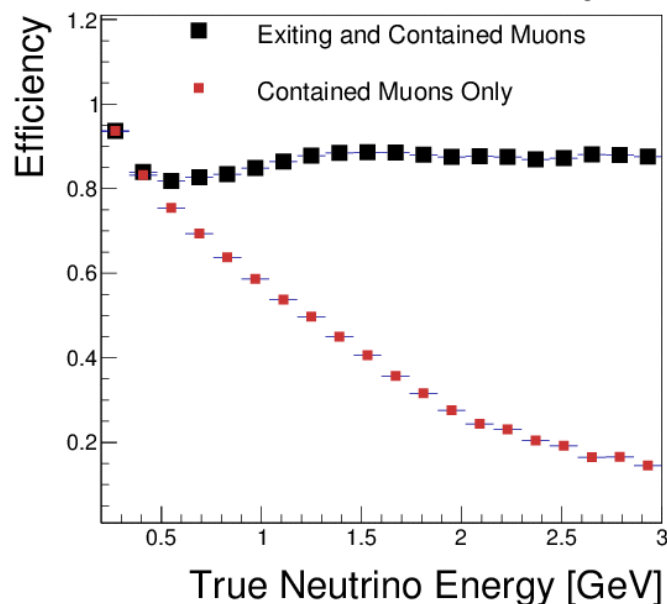
Impact on ν_μ Disappearance
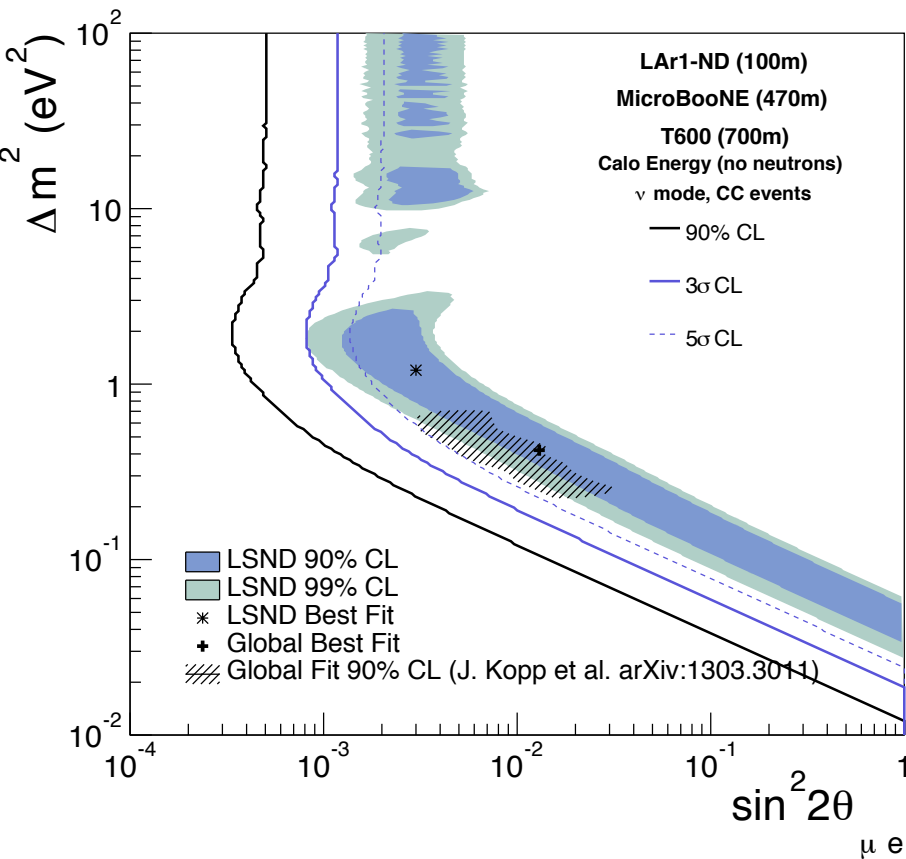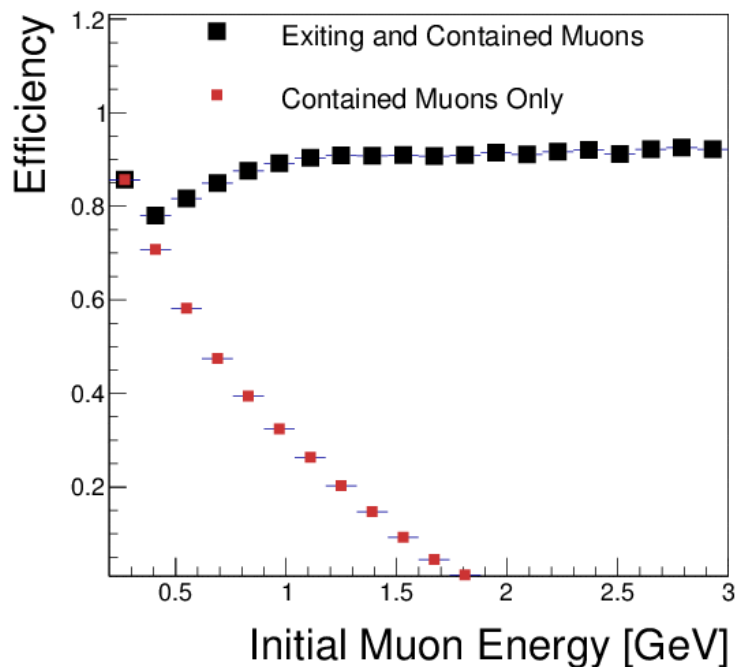## ND + uBoone + T600

Increasing the Size of LAr1-ND

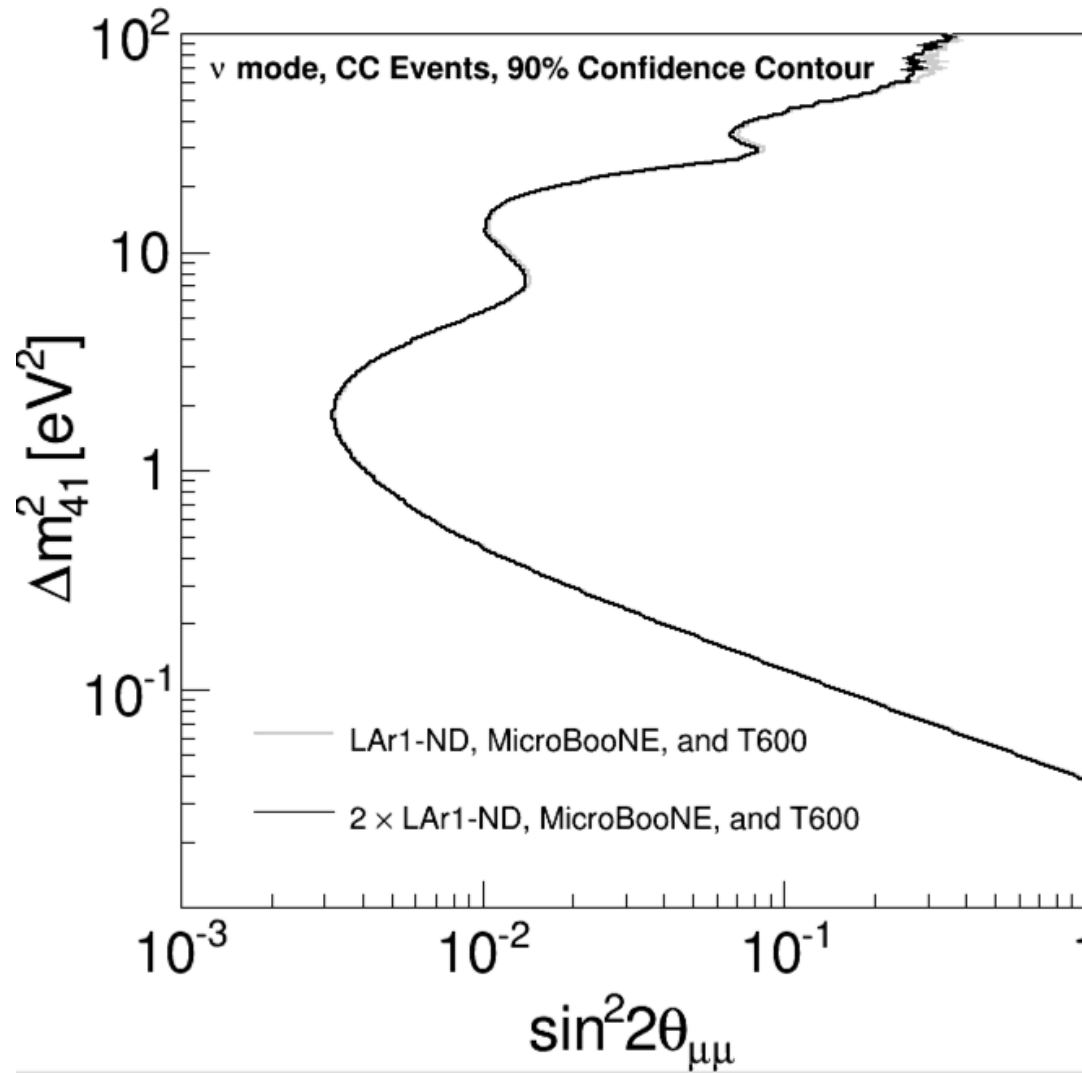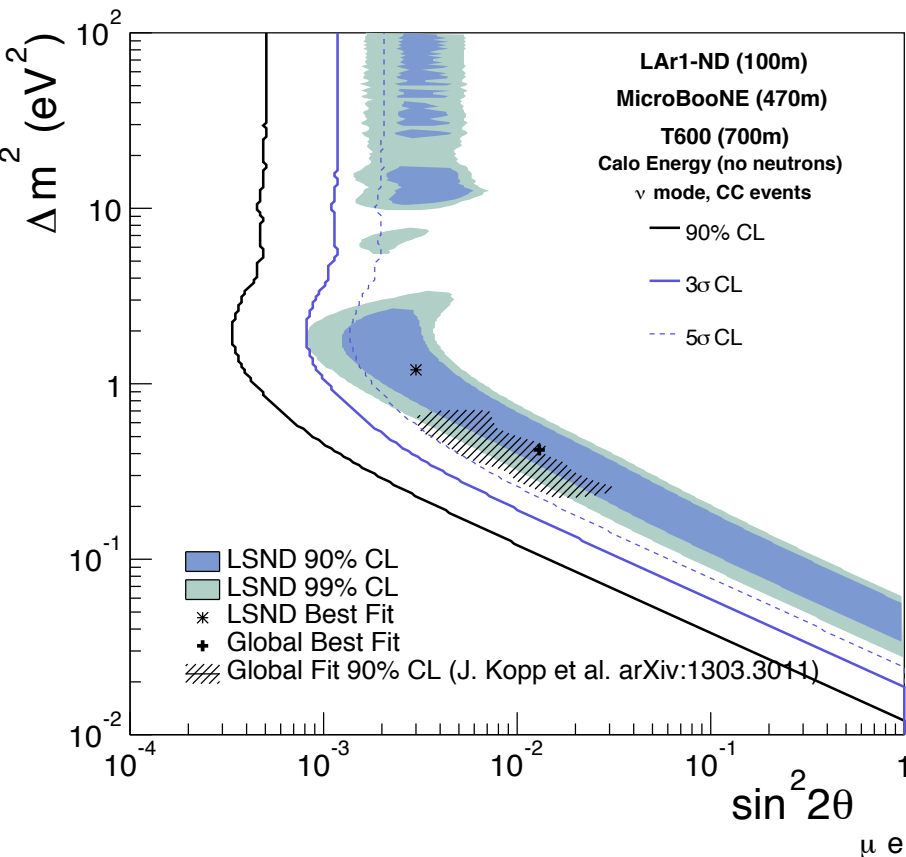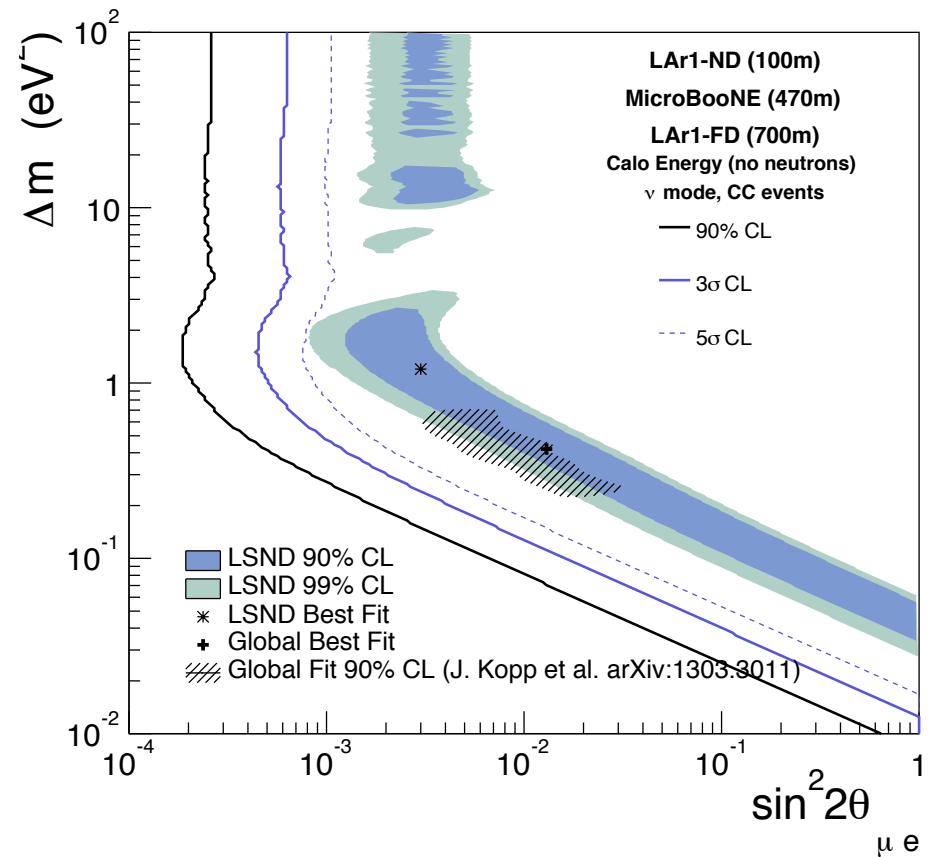- There have been some discussions about the potential benefits of lengthening the ND in the beam direction

- First, the gain in <u>statistics</u> in the near detector has zero impact

- Are there more subtle, second order advantages to a bigger detector, perhaps improving <u>systematics</u>?

  - With longer detector, would have some efficiency to reconstruct the high energy tail with contained muons.

  - Enlarge sample where can potentially use endpoint of muon tracks to determine muon charge?

  - "Dirt" backgrounds: larger active volume enables selection of a more "insulated" fiducial volume, reducing contamination from interactions outside of the detector.

- Why wouldn't we want this?!

  - The impact on cost and schedule for the project must be considered very carefully. Are the risks to cost and schedule worth any potential gains?

Impact on ν_e Appearance

LAr1-ND + uB + ICARUS

LAr1-ND + uB + 1000t FV FD

Neutrino Fluxes along the BNB

SBNE FD (700m)

MicroBooNE (470m)

Booster Neutrino Beam

LAr1-ND (100m)

ν_e
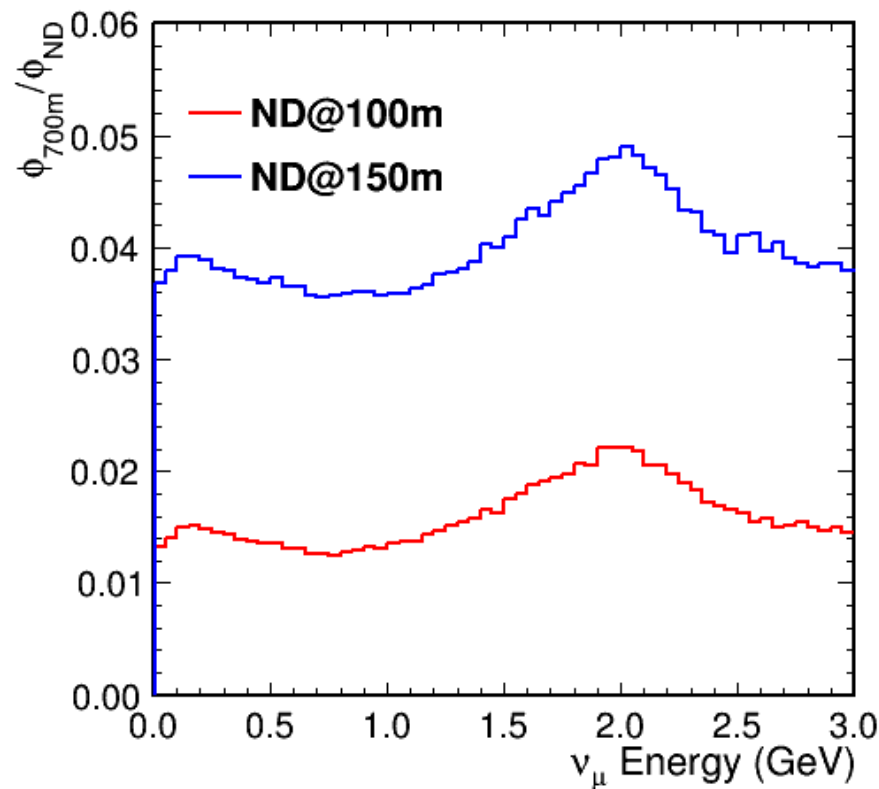
$$R = \frac{\Phi_{700m}}{\Phi_{ND}}$$

ν_μ
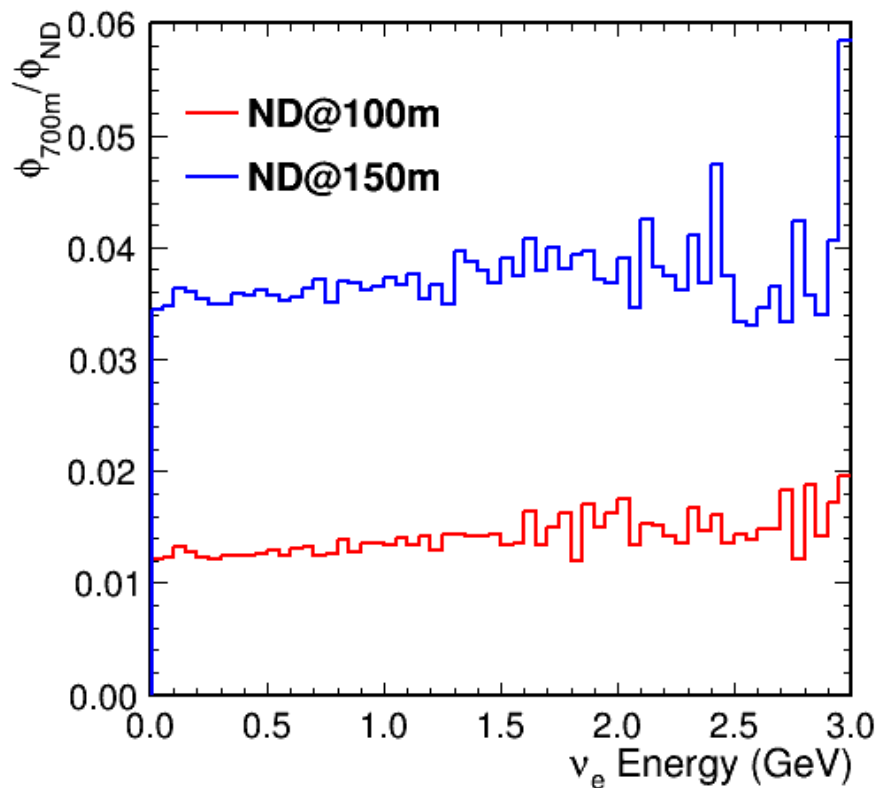
Shape of F/N ratio similar when ND
located at 100m or 150m,
but ND event rate reduced by 2-3x.

End

Neutrino-Argon Interactions

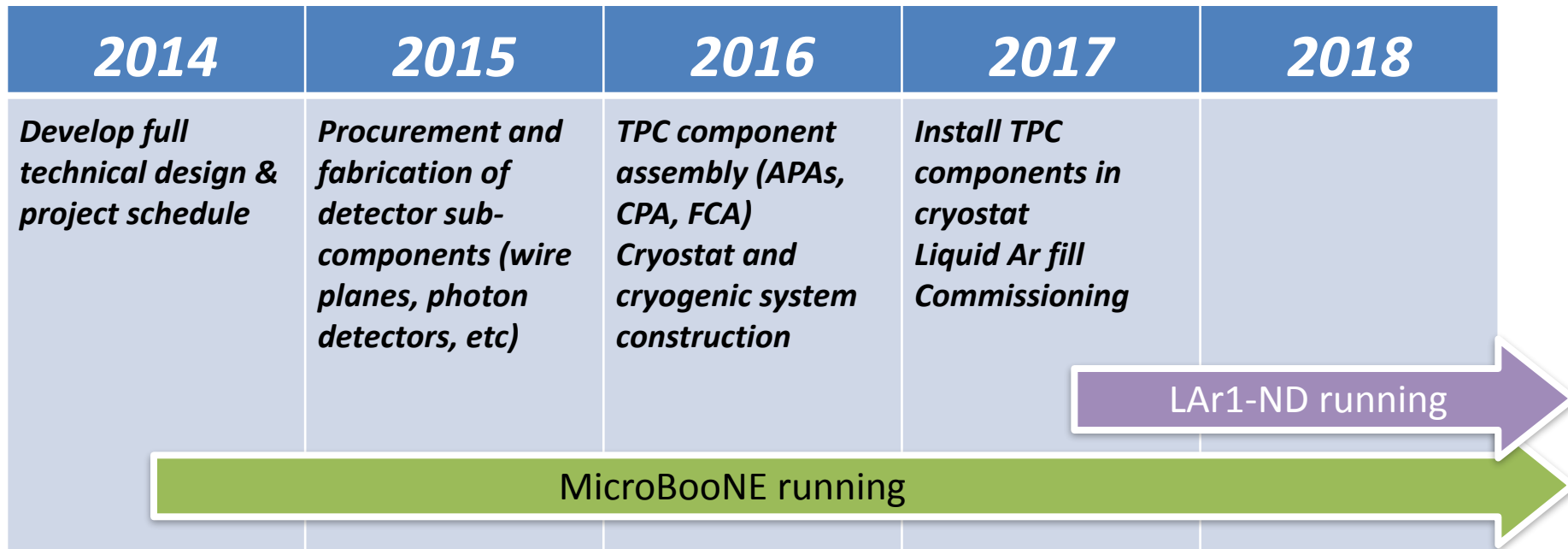| Process	GENIE estimated event rates 2.2x10²⁰ POT exposure for LAr1-ND	No. Events
	ν_μ Events (By Final State Topology)	
CC Inclusive		787,847
CC 0 π	$\nu_\mu N \rightarrow \mu + Np$	535,673
	· $\nu_\mu N \rightarrow \mu + 0p$	119,290
	· $\nu_\mu N \rightarrow \mu + 1p$	305,563
	· $\nu_\mu N \rightarrow \mu + 2p$	54,287
	· $\nu_\mu N \rightarrow \mu + \geq 3p$	56,533
CC 1 $\pi^\pm$	$\nu_\mu N \rightarrow \mu + \text{nucleons} + 1\pi^\pm$	176,361
CC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow \mu + \text{nucleons} + \geq 2\pi^\pm$	14,659
CC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 1\pi^0$	76,129
NC Inclusive		300,585
NC 0 π	$\nu_\mu N \rightarrow \text{nucleons}$	206,563
NC 1 $\pi^\pm$	$\nu_\mu N \rightarrow \text{nucleons} + 1\pi^\pm$	39,661
NC $\geq 2\pi^\pm$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 2\pi^\pm$	5,052
NC $\geq 1\pi^0$	$\nu_\mu N \rightarrow \text{nucleons} + \geq 1\pi^0$	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	$\nu_\mu n \rightarrow \mu^- p$	470,497
CC RES	$\nu_\mu N \rightarrow \mu^- N$	220,177
CC DIS	$\nu_\mu N \rightarrow \mu^- X$	82,326
CC Coherent	$\nu_\mu Ar \rightarrow \mu Ar + \pi$	3,004

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

almost 6,000 ν_e events

1M total events per ~year
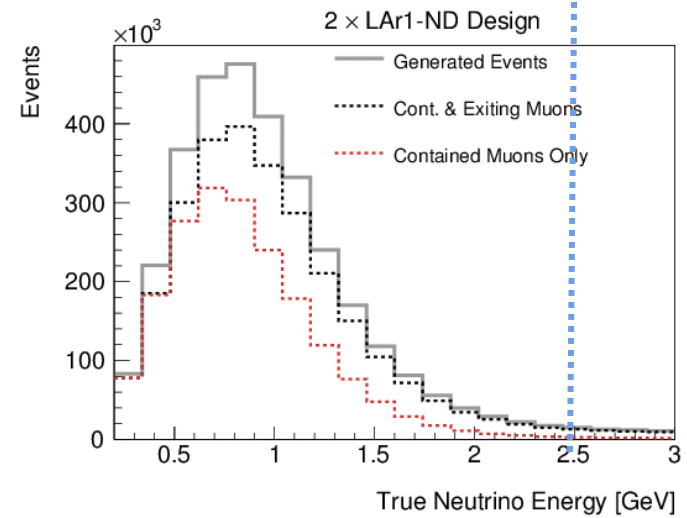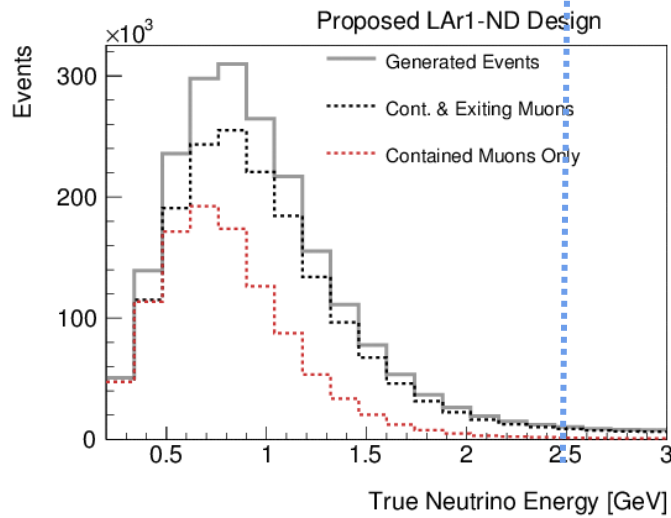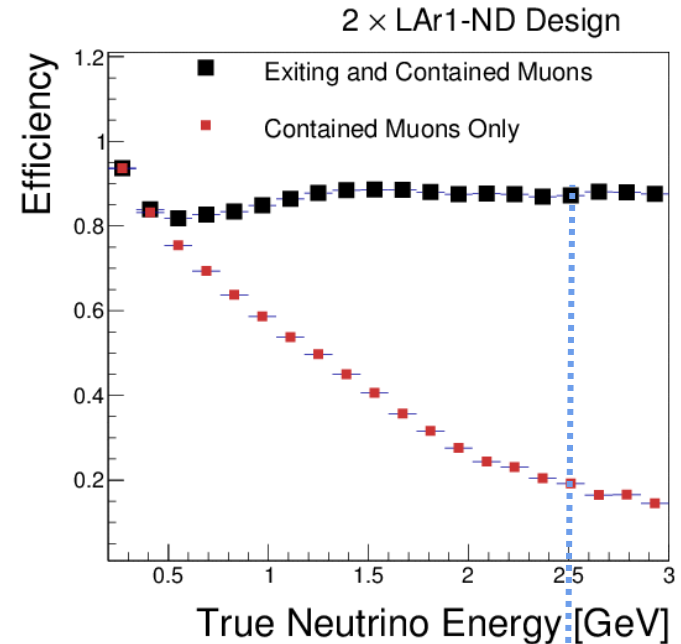
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LAr1-ND Timeline

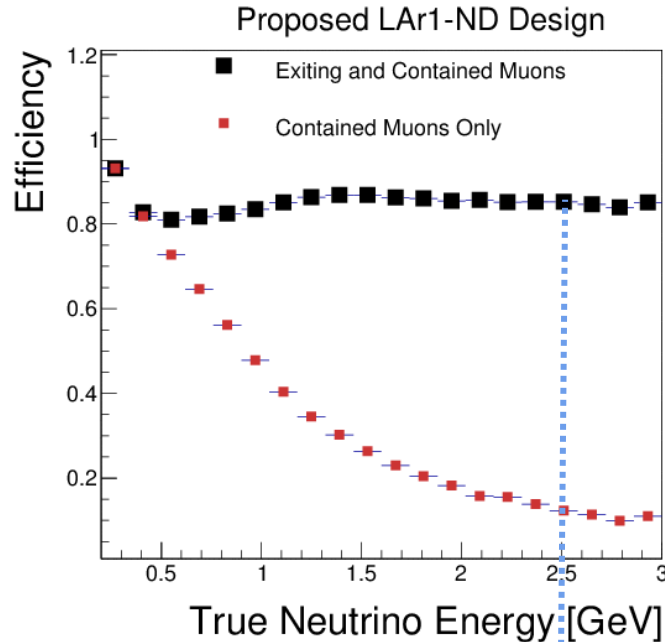Based on experience in constructing LAr TPC detectors, the <u>LAr1-ND detector construction</u> could be <u>completed in about two years</u>

2014	2015	2016	2017	2018
Develop full technical design & project schedule	*Procurement and fabrication of detector sub-components (wire planes, photon detectors, etc)*	*TPC component assembly (APAs, CPA, FCA) Cryostat and cryogenic system construction*	*Install TPC components in cryostat Liquid Ar fill Commissioning*	

LAr1-ND running

MicroBooNE running

A construction start on the 2015 time scale

maximizes the <u>physics potential within the existing Fermilab program</u>,

making it possible to <u>run the LAr1-ND detector concurrently with MicroBooNE</u>

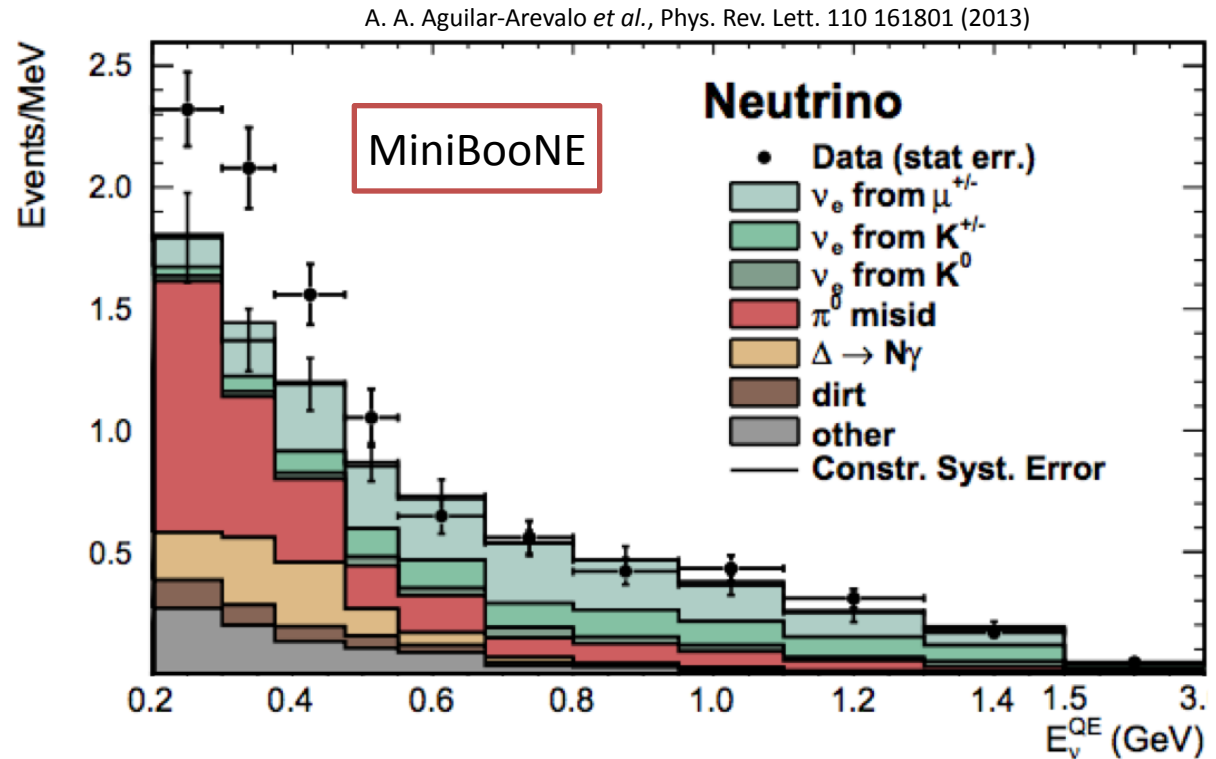toward the end of the already planned neutrino-mode running

Neutrino Energy Acceptance

The increase in the muon energy acceptance will then carry through to the neutrino energy

A. A. Aguilar-Arevalo *et al.*, Phys. Rev. Lett. 110 161801 (2013)

Is the excess of electromagnetic events observed in MiniBooNE due to **ν_e** or photon final states?

Neutrino

- Data (stat err.)
- ν_e from $\mu^{+/-}$
- ν_e from $K^{+/-}$
- ν_e from K^0
- π^0 misid
- $\Delta \to N\gamma$
- dirt
- other
- Constr. Syst. Error

MicroBooNE will determine the nature of the MiniBooNE excess reported at ~500 m.

In either scenario (electrons or photons) LAr1-ND can address the obvious next question:

__Does the excess appear over a distance or is it intrinsic to the beam?__

Sensitivity to MiniBooNE Low-Energy ν_e Excess

A. A. Aguilar-Arevalo *et al.*, Phys. Rev. Lett. 110 161801 (2013)
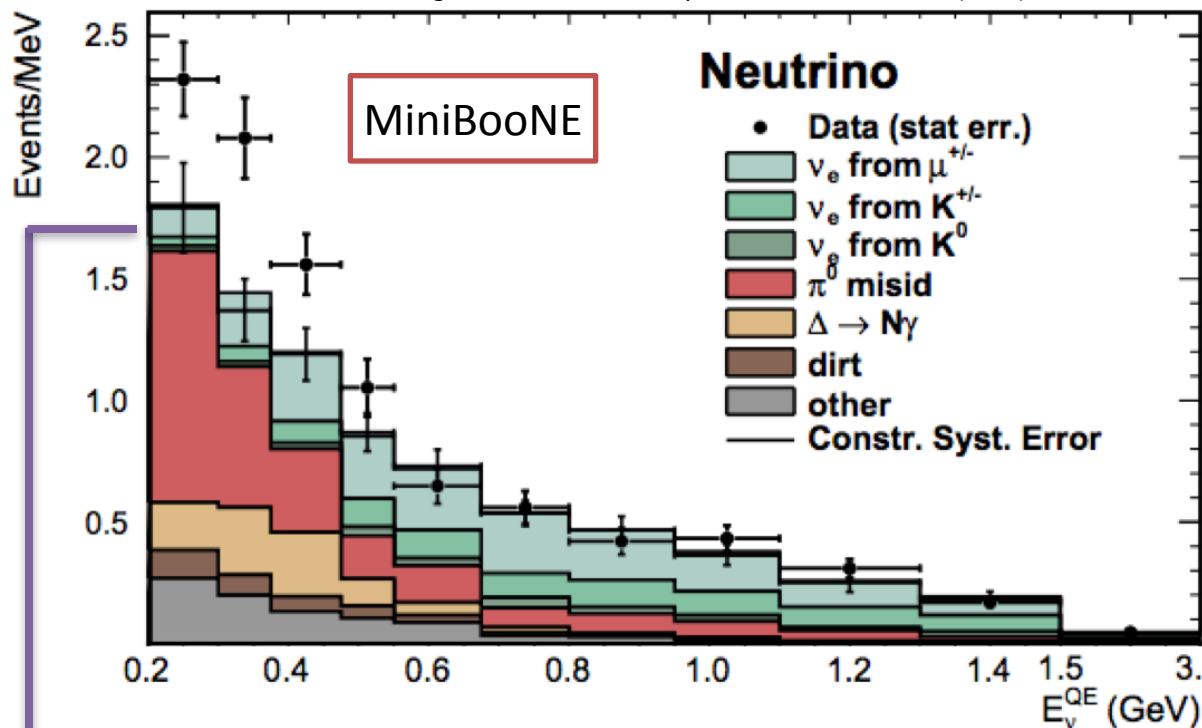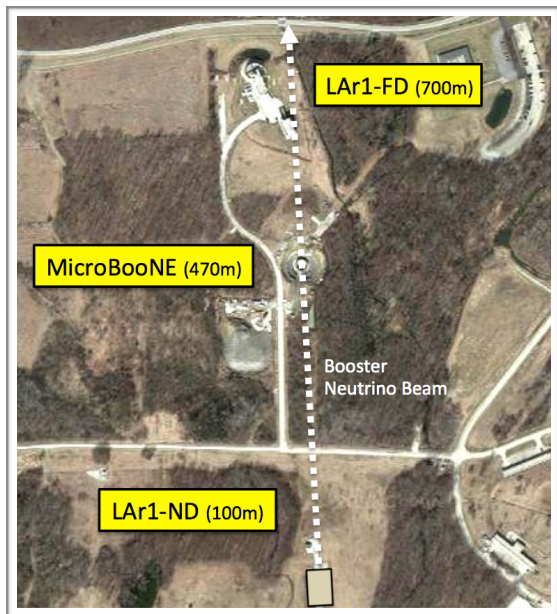
By scaling directly from observed rates in MiniBooNE, MicroBooNE expects to see ~50 background and 50 excess events in 6.6x10^20 POT run

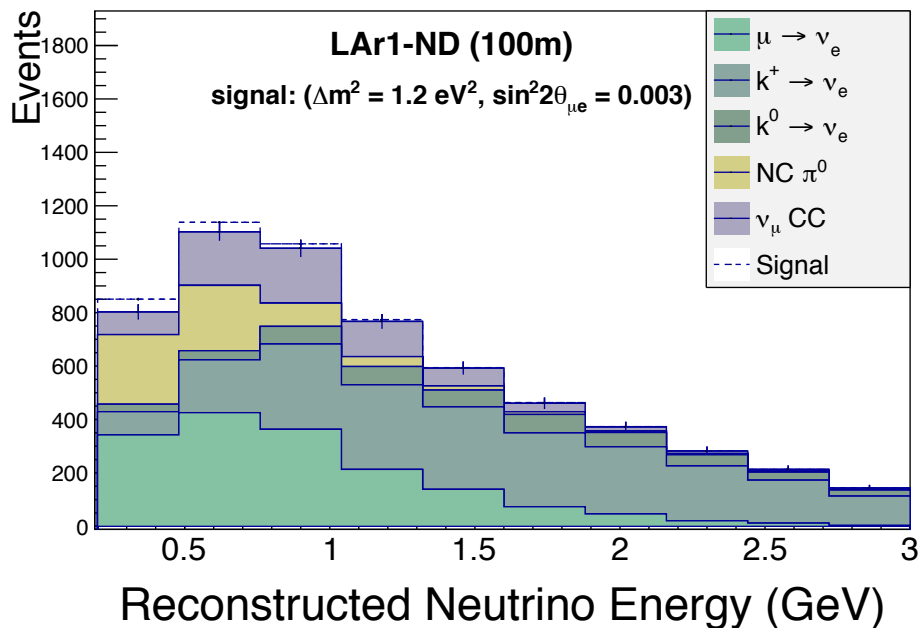*Assuming NO L/E dependence LAr1-ND would expect to see ~320 background and 300 excess events in 2.2x10^20 POT run*

An estimate of systematics based on MiniBooNE analysis indicates a **>6.5σ** observation of a MiniBooNE-like excess
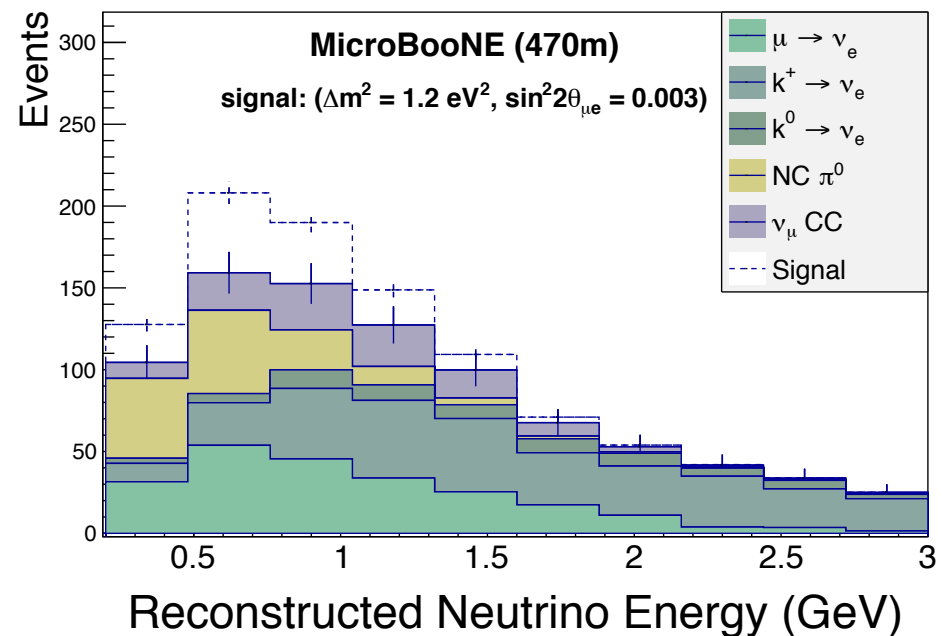
35

ν$_\mu$ → ν$_e$ Appearance

Our standard "Phase 1" that is LAr1-ND running in a final year of MicroBooNE running.

❖ Testing ν$_\mu$ → ν$_e$ appearance in the context of a 3 active + 1 sterile neutrino model (3+1)

❖ 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
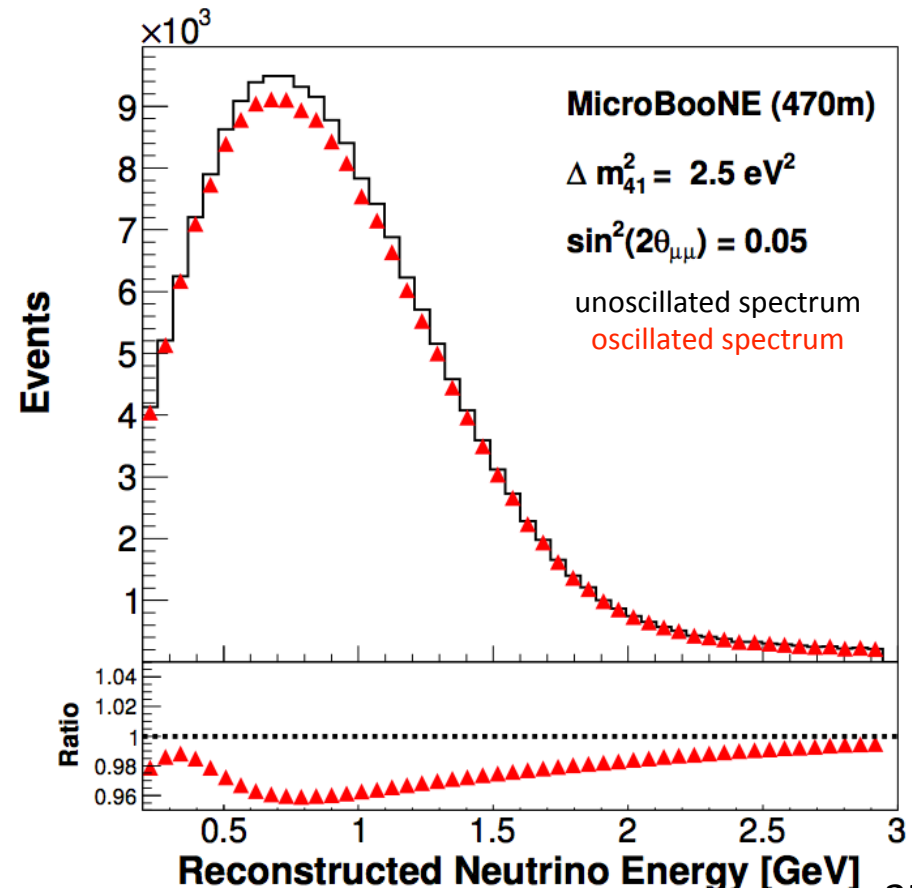
2.2x10^{20} POT exposure for LAr1-ND

6.6x10^{20} POT exposure for MicroBooNE

ν$_\mu$ Disappearance

❖ Testing ν$_\mu$ disappearance only enabled with near detector constraint

    ❖ Flux and cross section errors of 15-20% conceal a disappearance signal in MicroBooNE alone, but using an observed LAr1-ND spectrum to normalize the expected rate at MicroBooNE makes it observable

37
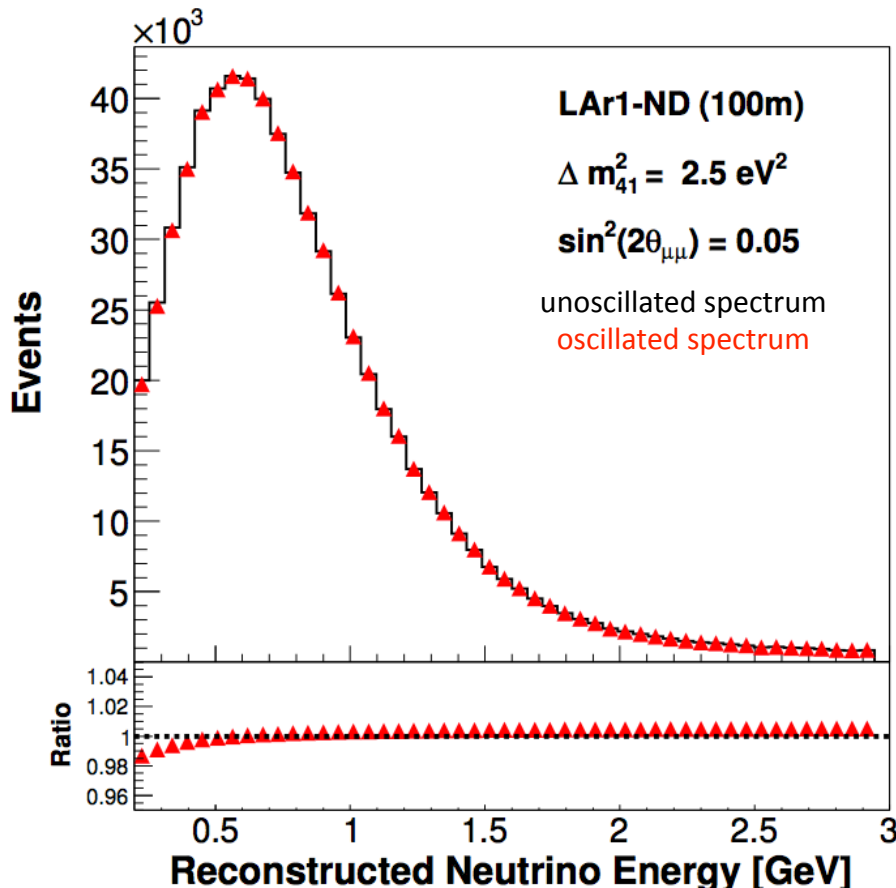
Monte Carlo simulation

To estimate physics sensitivities of the experiment, a <u>full Monte Carlo simulation</u> is used:

1. Beam simulation (verified against the MiniBooNE beam Monte Carlo) —> Booster Neutrino Beam flux in the target hall.

2. Flux propagated *(GSimple package)* to the detectors at 100 m, 470 m, as well as 700 m.

3. Neutrino interactions are simulated using the *GENIE neutrino event generator*.

4. Particles exiting a nucleus after the neutrino interaction are passed on to the *LArSoft framework (Geant4* to propagate in the LAr detector volumes). Geometry descriptions are provided for each detector.

5. Full reconstruction in the LArSoft framework is not applied (yet), but we assume efficiencies based on studies (using the reconstruction tools in the LArSoft framework):

   ‣ For example, we use a <u>94% rejection rate of single photon background</u> coming from π^0 decays or other sources (using the **dE/dx** tag in the first few centimeters of the electromagnetic shower)

6. *Calorimetric energy reconstruction*: the incoming neutrino energy in CC events is estimated by summing the energy of the lepton and all charged hadronic particles (above observation thresholds) present in the final state.

With the *full simulation of the neutrino events* we can accurately model realistic backgrounds for the multiple channels in which we are sensitive to sterile neutrino signals instead of assuming, e.g. flat distributions.
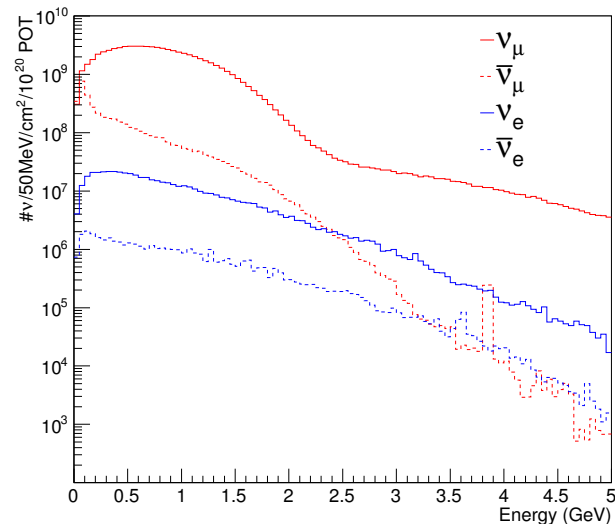
Neutrino beams (I)

On axis Booster Neutrino Beam fluxes @ different detector locations
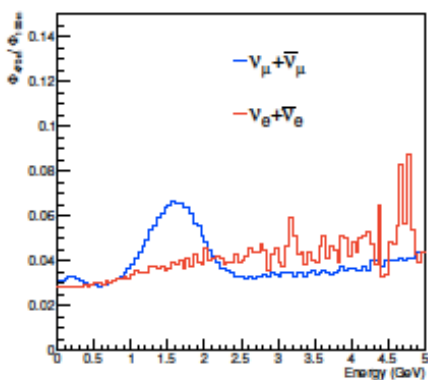

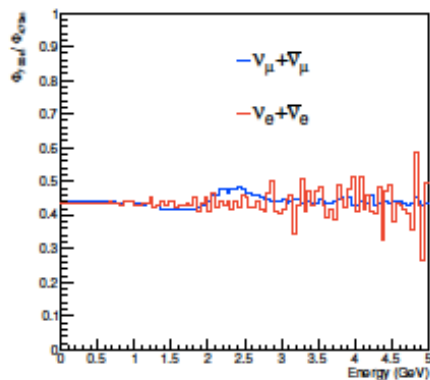
Flux from BNB in nu mode at LAr1-ND (100m)
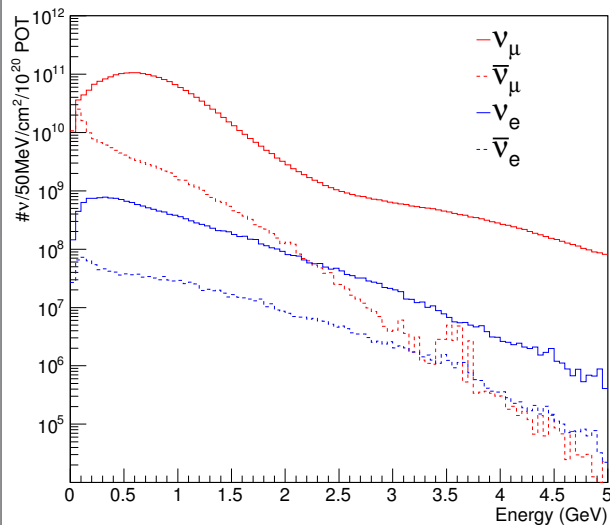
Flux from BNB in nu mode at MicroBooNE (470m)

Ratios of the fluxes at different detector locations.
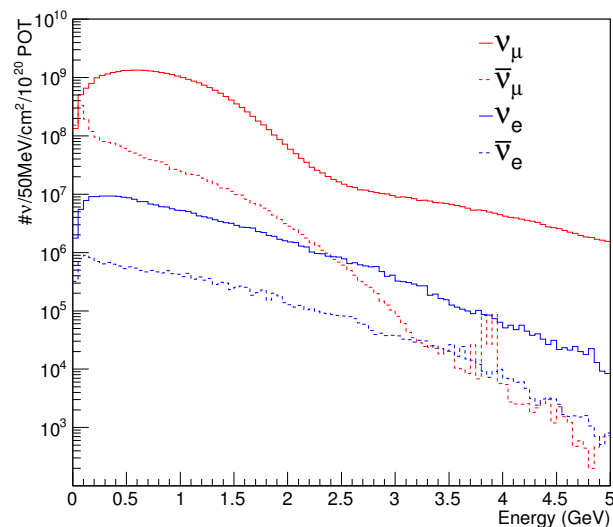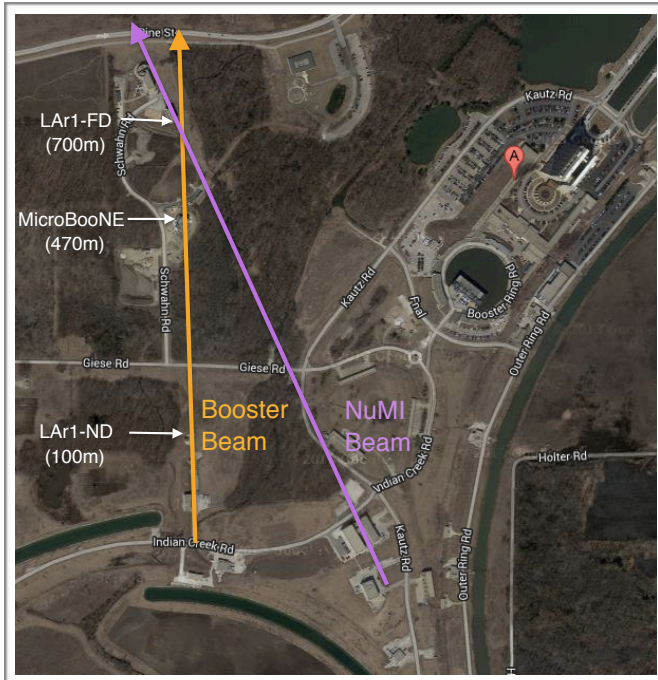

Flux at MicroBooNE vs. flux at LAr1-ND

Flux at MicroBooNE vs. flux at LAr1-FD
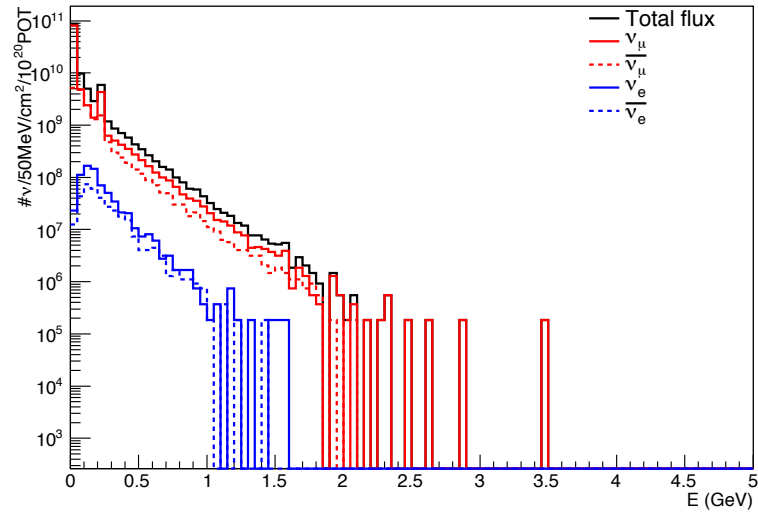
Flux from BNB in nu mode at LAr1-FD (700m)

Neutrino beams (II)
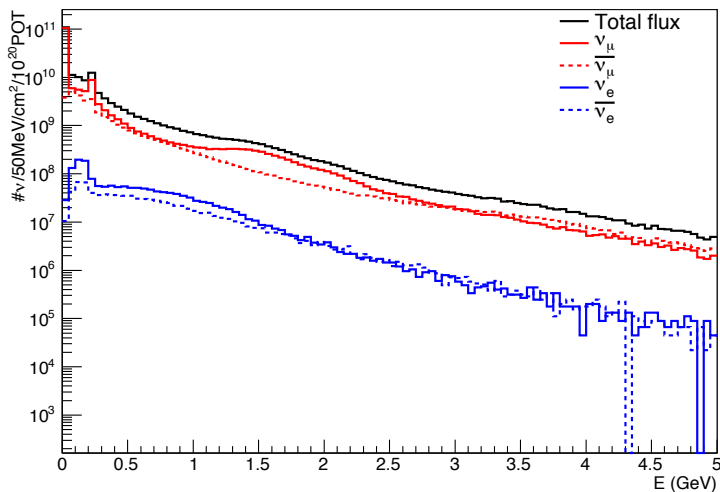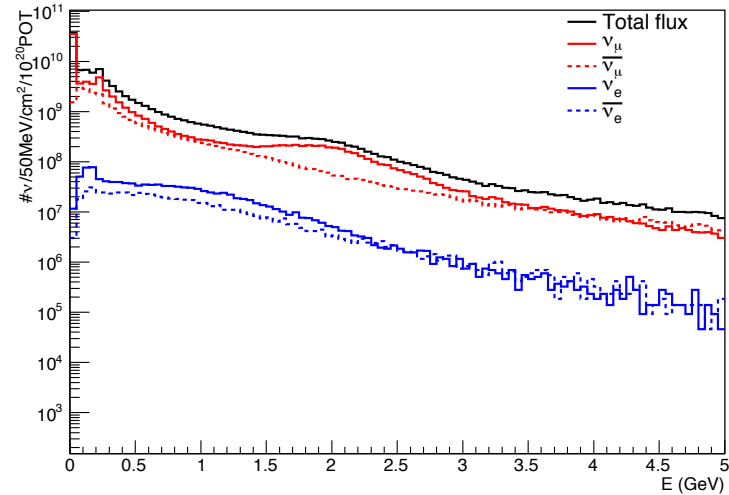
Off-axis NuMI fluxes @ different detector locations

Flux from NuMI in nu mode at LAr1-ND (100m) **~30⁰ off-axis**

Flux from NuMI in nu mode at MicroBooNE (470m) **~8⁰ off-axis**

Flux from NuMI in nu mode at LAr1-FD (700m) **~6⁰ off-axis**

The LAr1-ND Collaboration

C. Adams[1], C. Andreopoulos[2], J. Asaadi[3], B. Baller[4], M. Bishai[5], L. Bugel[6], L. Camilleri[7], F. Cavanna[1], H. Chen[5], E. Church[1], D. Cianci[8], G. Collin[6], J.M. Conrad[6], G. De Geronimo[5], A. Ereditato[9], J. Evans[10], B. Fleming*[1], W.M. Foreman[8], G. Garvey[11], R. Guenette[12], J. Ho[8], C.M. Ignarra[6], C. James[4], C.M. Jen[13], B.J.P. Jones[6], L.M. Kalousis[13], G. Karagiorgi[7], W. Ketchum[11], I. Kreslo[9], V.A. Kudryavtsev[14], D. Lissauer[5], W.C. Louis[11], C. Mariani[13], K. Mavrokoridis[2], N. McCauley[2], G.B. Mills[11], Z. Moss[6], S. Mufson[15], M. Nessi[16], O. Palamara*[1], Z. Pavlovic[11], X. Qian[5], L. Qiuguang[11], V. Radeka[5], R. Rameika[4], C. Rudolf von Rohr[9], D.W. Schmitz*[8], M. Shaevitz[7], M. Soderberg[3], S. Söldner-Rembold[10], J. Spitz[6], N. Spooner[14], T. Strauss[9], A.M. Szelc[1], C.E. Taylor[11], K. Terao[7], L. Thompson[14], M. Thomson[17], C. Thorn[5], M. Toups[6], C. Touramanis[2], R.G. Van De Water[11], M. Weber[9], D. Whittington[15], B. Yu[5], G. Zeller[4], and J. Zennamo[8]

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*Contact person

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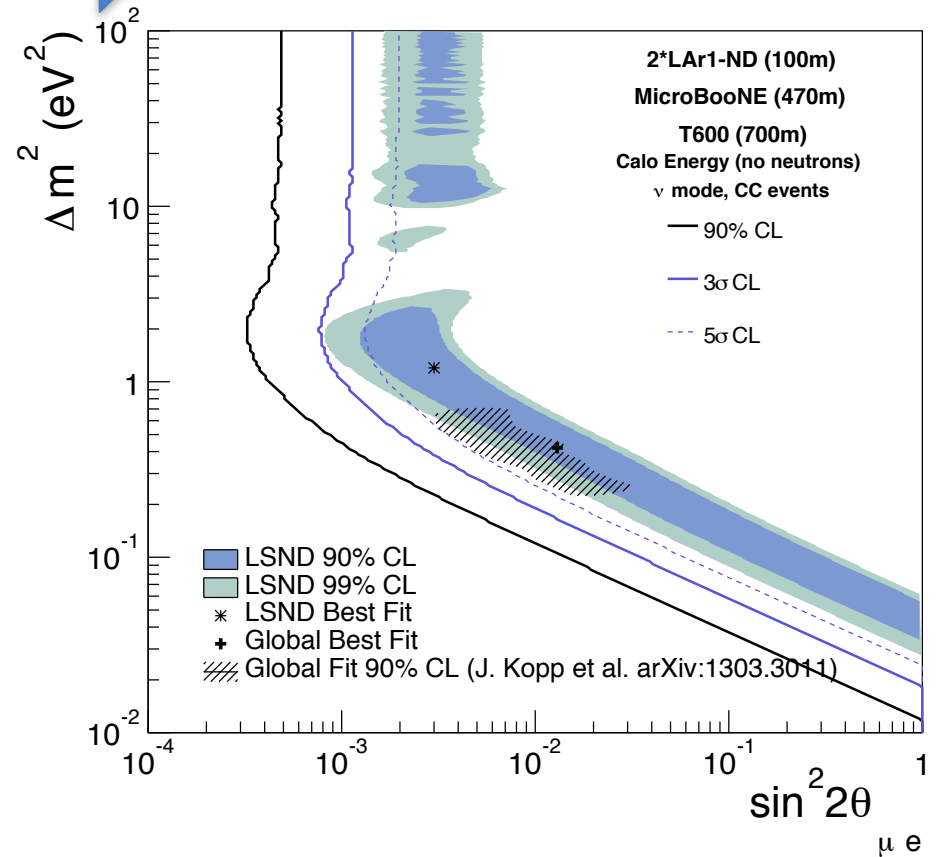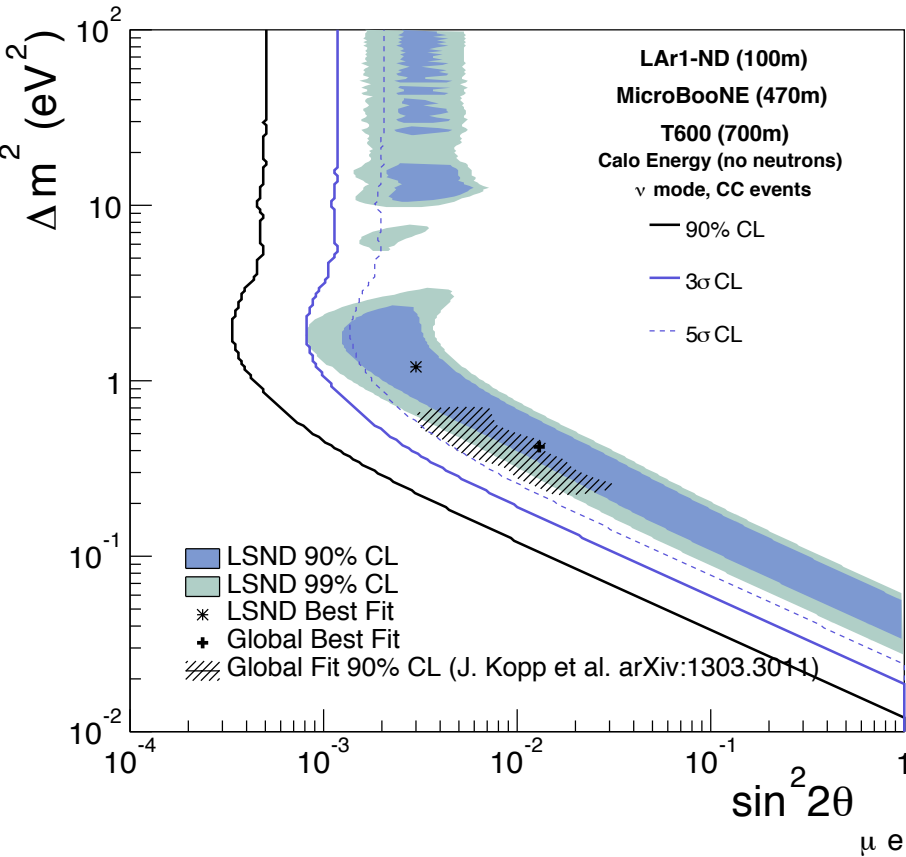- 6 NSF institutions

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

11 institutions also on MicroBooNE
Nearly all interested in longer term
long-baseline FNAL program

$\nu_\mu \rightarrow \nu_e$ Appearance

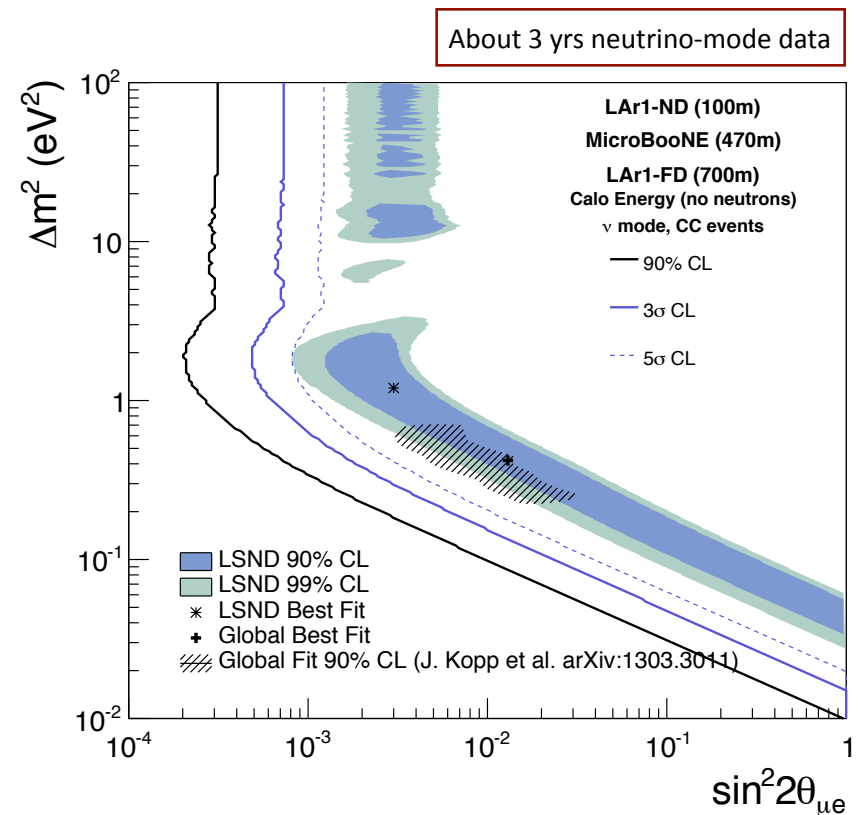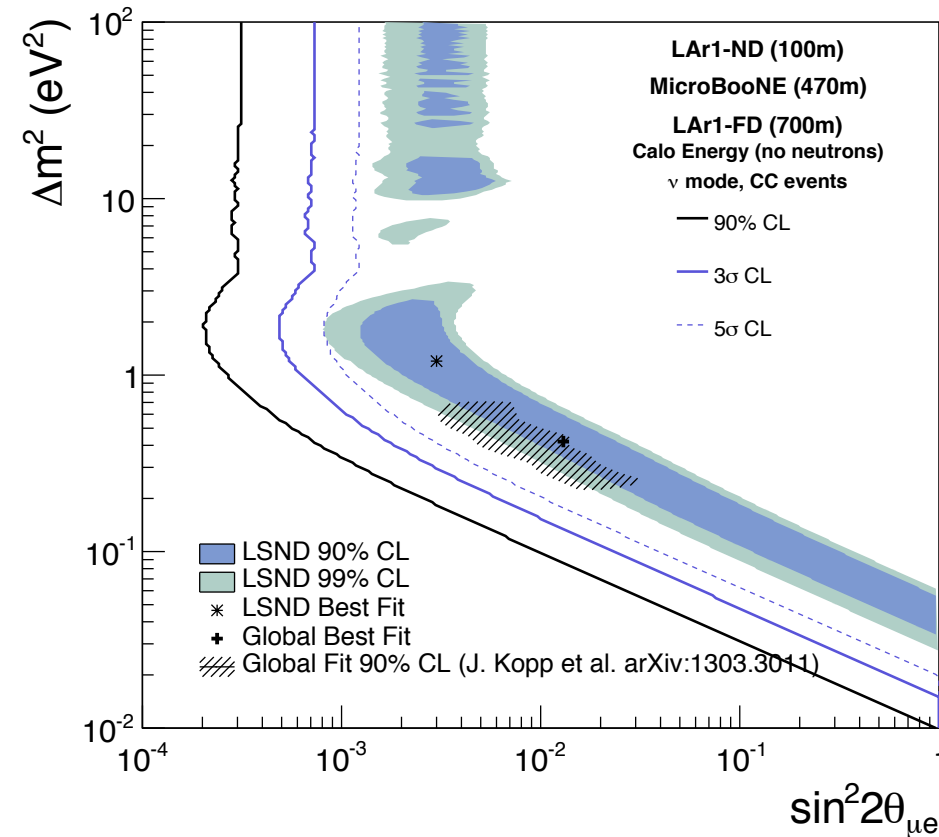6.6x10^{20} POT exposure

2*ND

LAr1-ND+MicroBooNE+T600 @ 700 m

Phase-2 Short-Baseline Neutrino Program at FNAL

❖ LAr1-ND + MicroBooNE already presents a significant extension of the physics program, but LAr1-ND can also be thought of as the next step in the development of a program of short-baseline accelerator-based neutrino physics at Fermilab

❖ The addition of a large (kiloton-scale) detector at longer baseline (~700 m) could address oscillations in anti-neutrino mode and make precision measurements of sterile neutrino oscillations if they are discovered

❖ 5σ level coverage of the null hypothesis for the oscillation parameter space indicated by existing experimental anomalies

❖ Three detector configuration provides a powerful confirmation of the interpretation of any results as an oscillation signal

❖ Have calculated sensitivities, more available in backup slides

About 3 yrs neutrino-mode data

LAr1-ND (100m)
MicroBooNE (470m)
LAr1-FD (700m)
Calo Energy (no neutrons)
ν mode, CC events

— 90% CL
— 3σ CL
-- 5σ CL

LSND 90% CL
LSND 99% CL
* LSND Best Fit
+ Global Best Fit
▨ Global Fit 90% CL (J. Kopp et al. arXiv:1303.3011)

Δm^2 (eV^2)
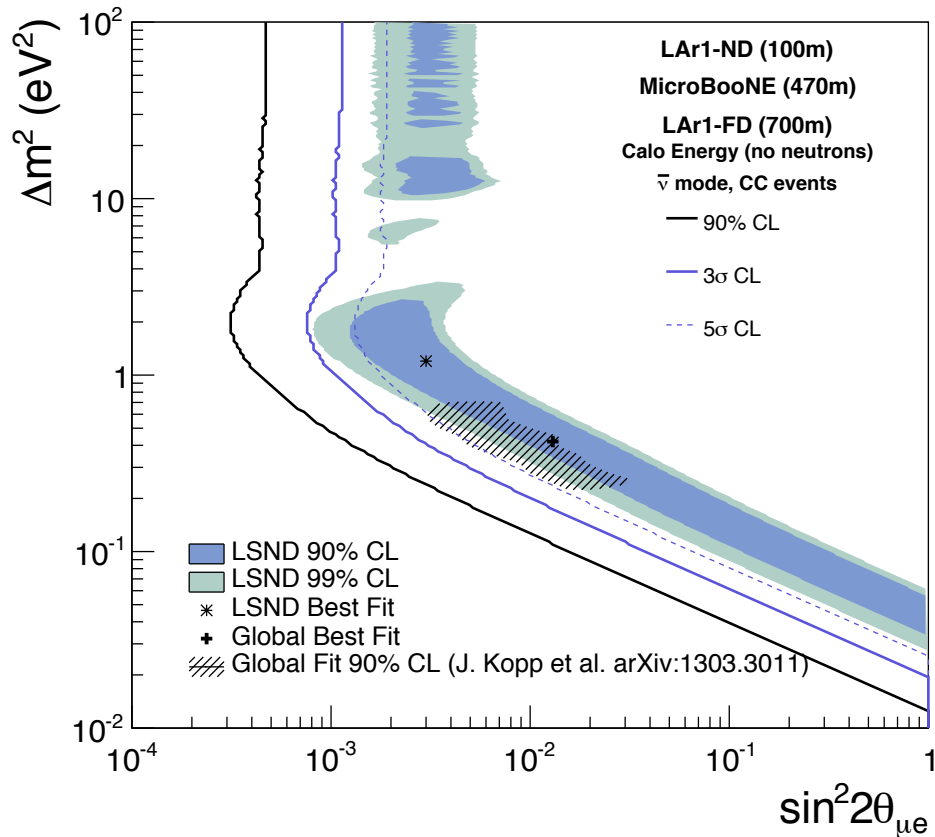
$\sin^2 2\theta_{\mu e}$

43

$\nu_\mu \rightarrow \nu_e$ Appearance (3-det)

❖ LAr1-ND + MicroBooNE + 1 kiloton Far Detector at 700m

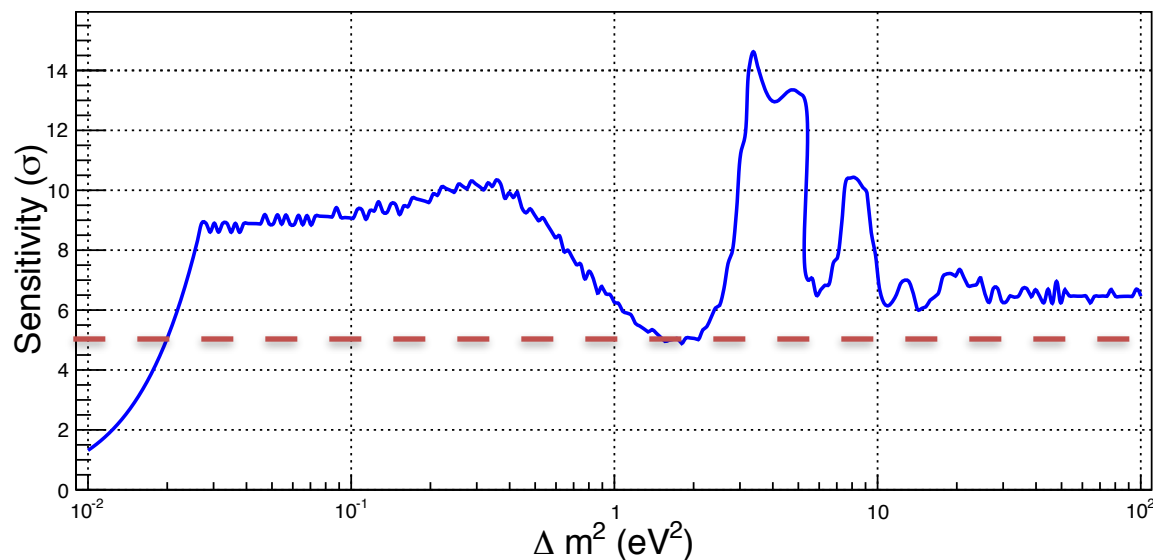6.6x10²⁰ POT exposure
neutrino mode

10x10²⁰ POT exposure
anti-neutrino mode
(assumes both neutrinos and anti-neutrinos oscillate)

$\nu_\mu \rightarrow \nu_e$ Appearance (3-det)

Sensitivity to 3+1 ν signal along the lsnd edge.

neutrino mode

5σ
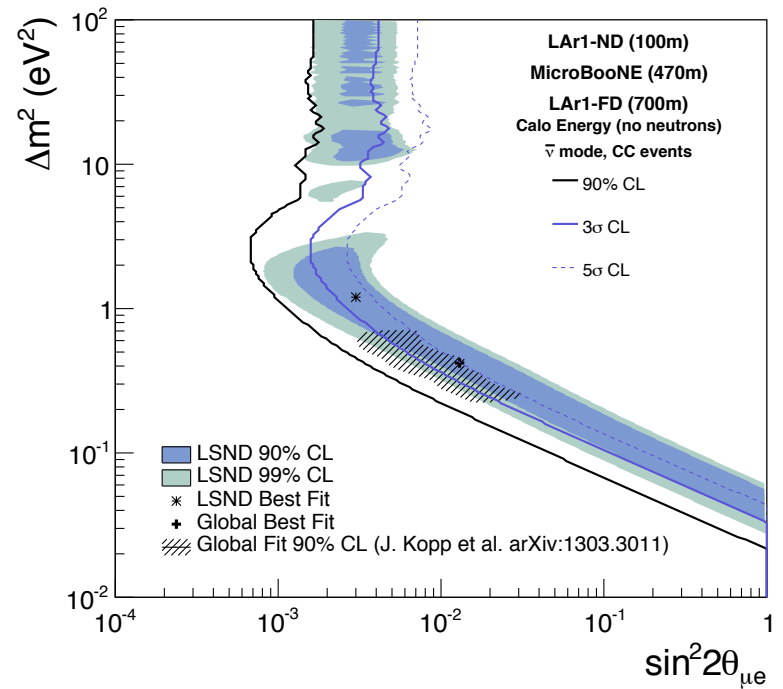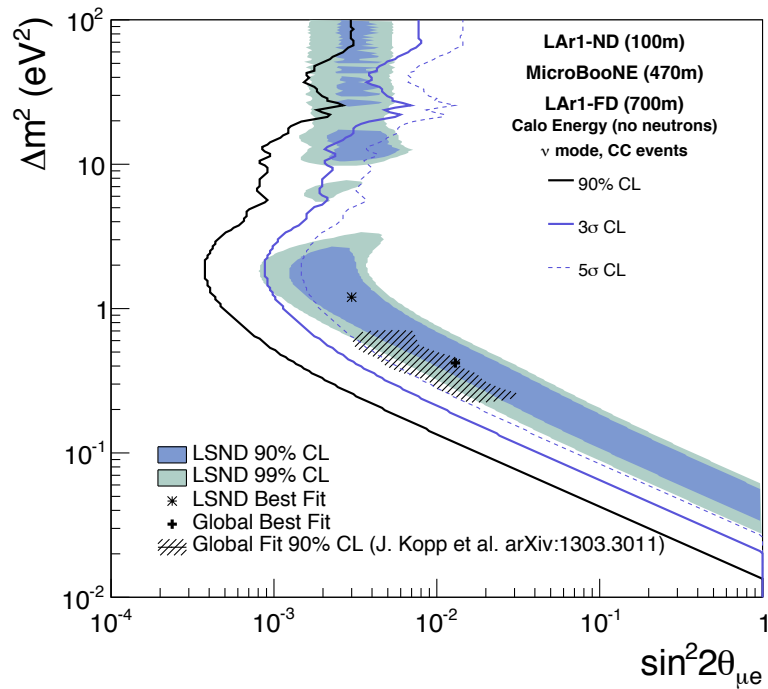
Sensitivity to 3+1 $\bar{\nu}$ signal along the lsnd edge.
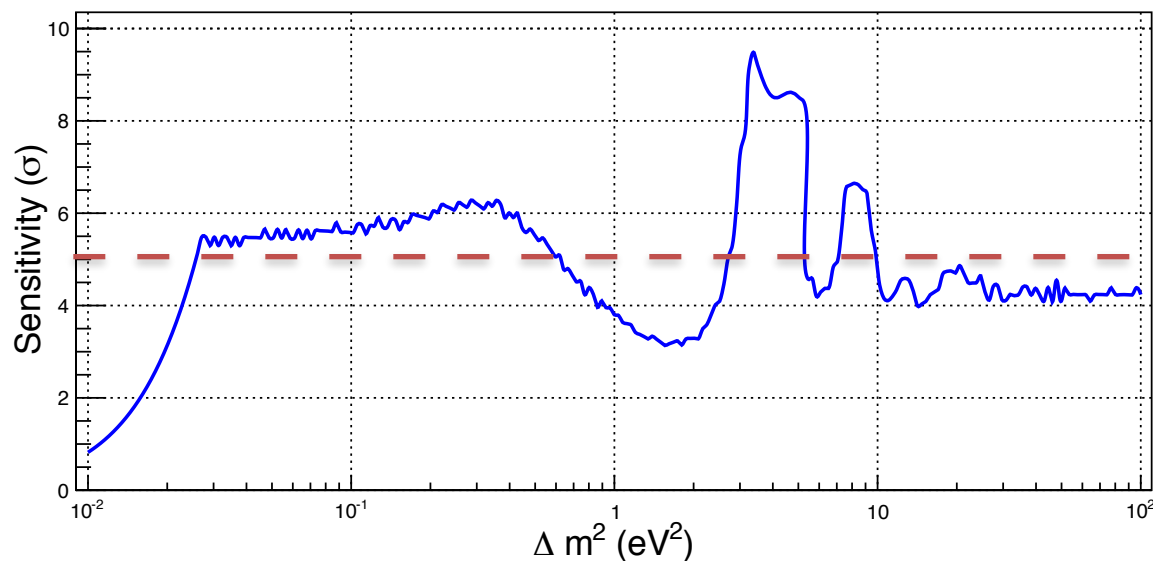
anti-neutrino mode

5σ

$\nu_\mu \to \nu_e$ Appearance (shape only)
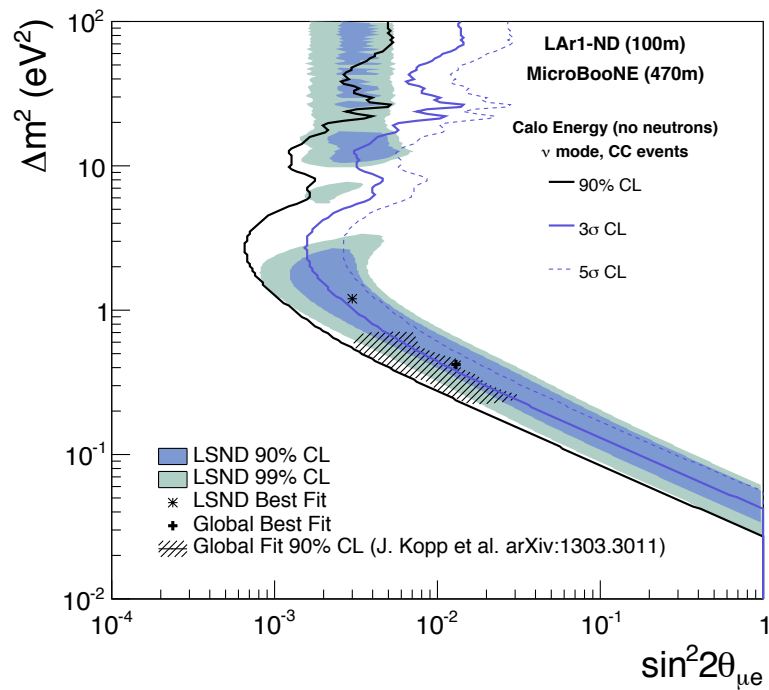
ν_μ Disappearance (3-det)

❖ LAr1-ND + MicroBooNE + 1 kiloton Far Detector at 700m
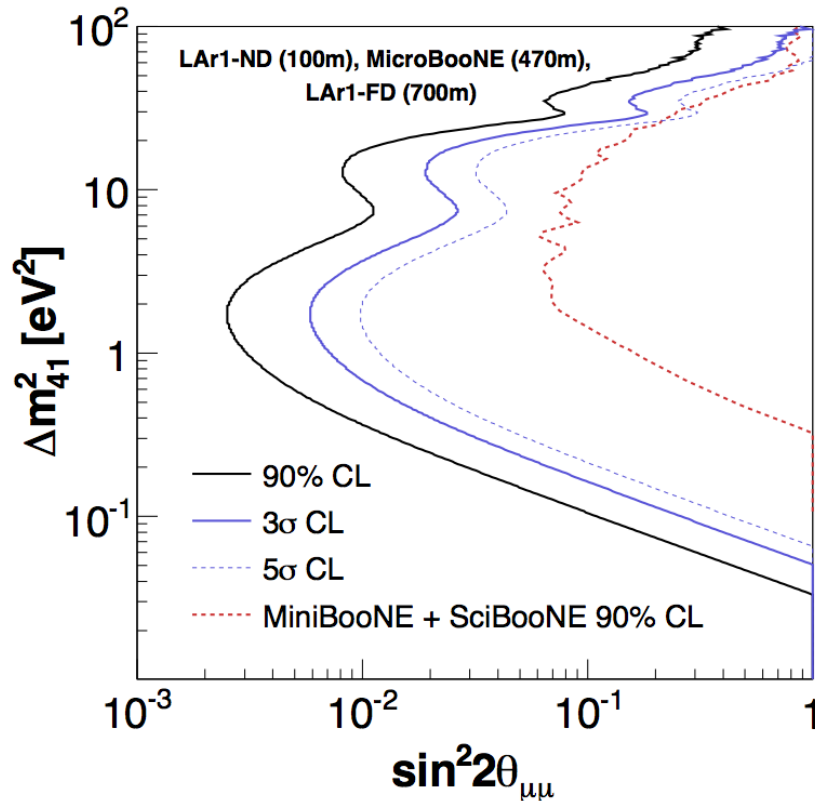
6.6x10^{20} POT exposure
neutrino mode
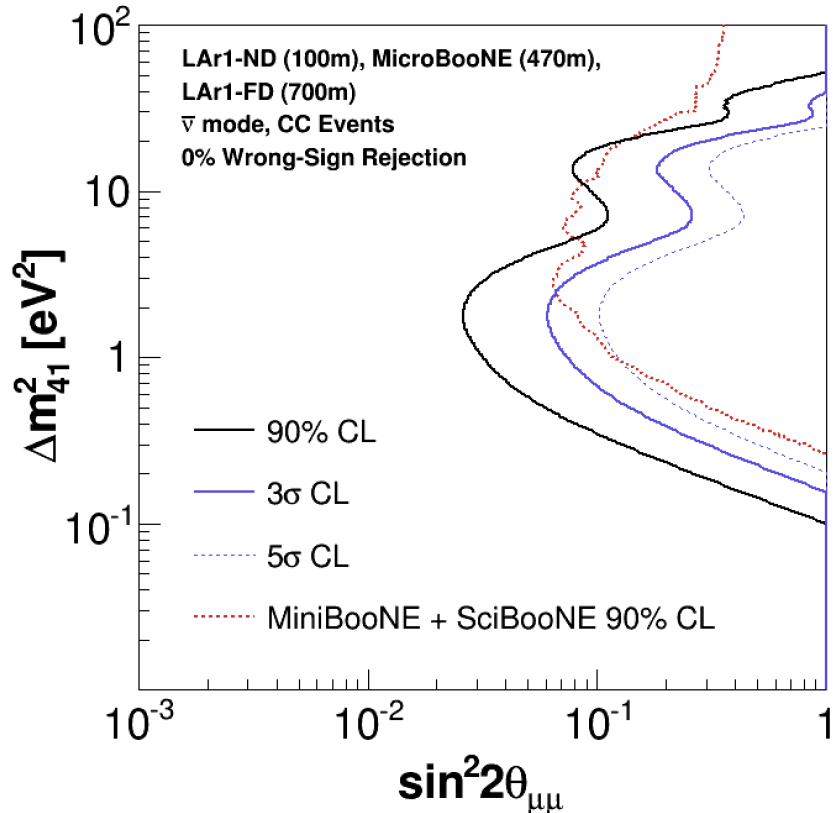
10x10^{20} POT exposure
anti-neutrino mode
(assumes only anti-neutrinos oscillate with WS background)

LAr1-ND detector

LAr1-ND: Detector Location

➤In choosing a location for the LAr1-ND detector, our strategy was to look into taking advantage of an existing, empty detector hall along the Booster Neutrino Beam, formerly used by the SciBooNE experiment

> ➤Reduce costs

> ➤Minimize time to physics in phase-1

➤The "SciBooNE Enclosure" was built to house the SciBooNE neutrino detector

> ➤"Concrete elevator shaft"

➤This space could be used for a membrane cryostat LAr detector built to fit against the concrete walls of this space

> ➤Dimensions essentially determined

The SciBooNE Experimental Hall

➢ The SciBooNE enclosure is a below grade rectangular concrete structure 100m from the Booster Neutrino Beam target, 50m from the end of the decay region:

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

ground level

ν beam
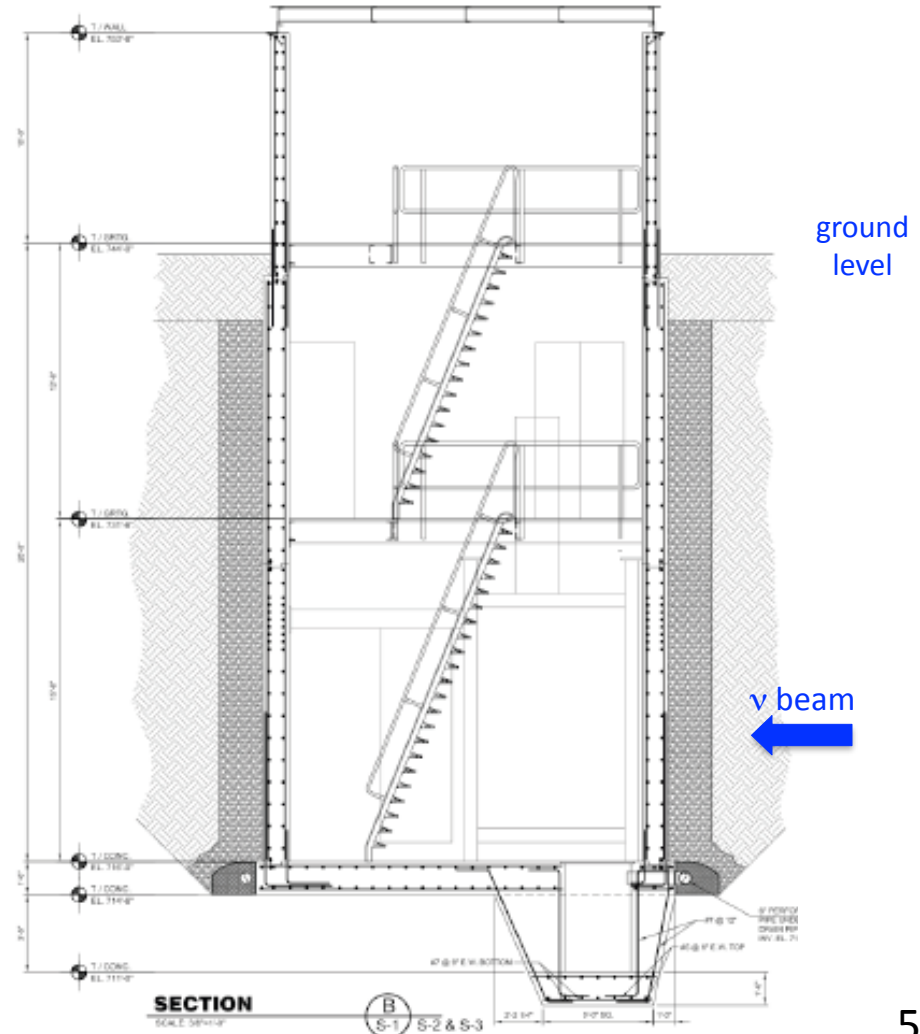
LAr1-ND Detector Overview

➢ The LAr1-ND detector design is based on:

▸ Implementing technology that builds upon the current experience from the T600, MicroBooNE and the 35 ton prototype

▸ Utilizing as many of the design elements developed for the LBNE Far Detector as feasible

➢ Brief overview of the design:

▸ A foam insulated, corrugated stainless steel membrane cryostat supported by outer concrete walls of the existing SciBooNE enclosure.

▸ The interior dimensions of the cryostat are 4.4 m long in the neutrino beam direction, 6.1 m wide and 4.8 m tall, amounting to 180 tons total of liquid argon

▸ The TPC consists of two APAs (Anode Plane Assemblies) near the walls of the cryostat (beam left and beam right), and one CPA (Cathode Plane Assembly) centered between the two APAs

▸ Analog front-end, analog-to-digital conversion, and FPGA for multiplexing performed with cold electronics

LAr1-ND: Time Projection Chamber Layout

APA
active area:
3.65 m wide x 4.0 m tall

APA

Each pair of facing CPA and APA forms a 2.0 m electron-drift region

For 500 V/cm drift field, cathode plane biased at -100 kV

Open sides between each APA and the CPA are surrounded by 4 FCA (Field Cage Assemblies) modules, constructed from FR4 printed circuit panels with parallel copper strips to create a uniform drift field

3.65 m *(beam)* x
4.0 m *(wide)* x
4.0 m *(tall)* =
58.4 m³
(82 tons of argon
in active volume)

drift distance - 2 m

CPA made of a stainless-steel framework, with an array of stainless-steel sheets mounted over the frame openings
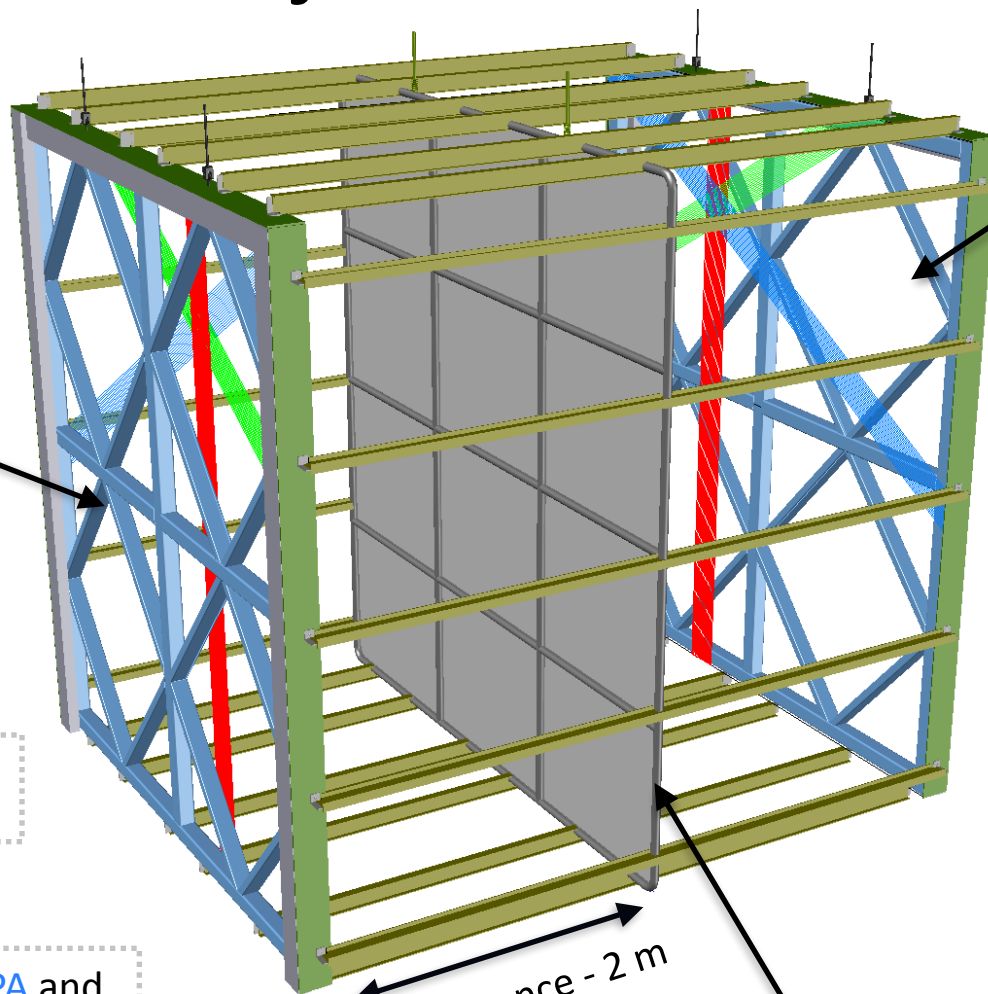
LAr1-ND: Anode Plane Assemblies

Each APA holds three planes of wires on one side

- ➤ Wire pitch = 3 mm
- ➤ Wire angles = 0^0 and $\pm 60^0$ from vertical

Cold readout boards at the top and vertical sides of each APA. Total <u>4736 channels per APA</u>.
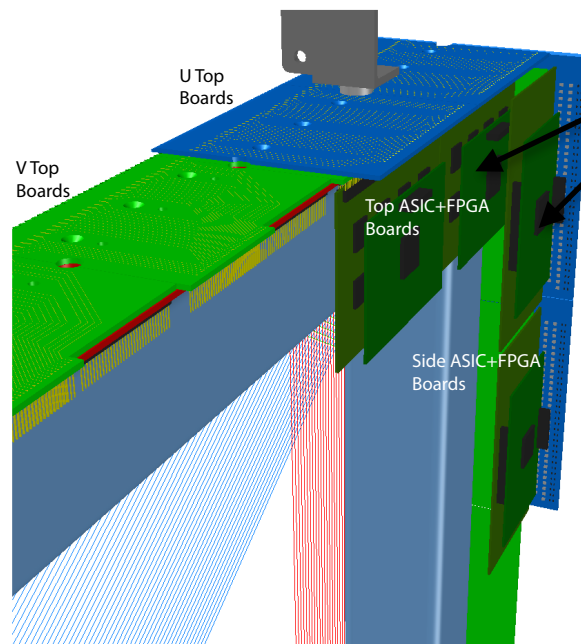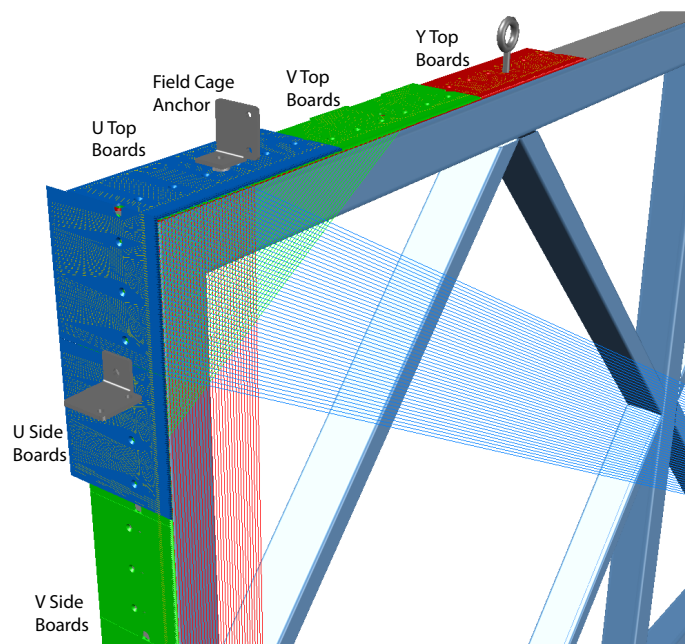
Readout boards

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 $\pm 60^0$ from vertical (2 induction planes) are attached to wire bonding boards at the sides and ends of the APA.

LAr1-ND vs LBNE Design: TPC

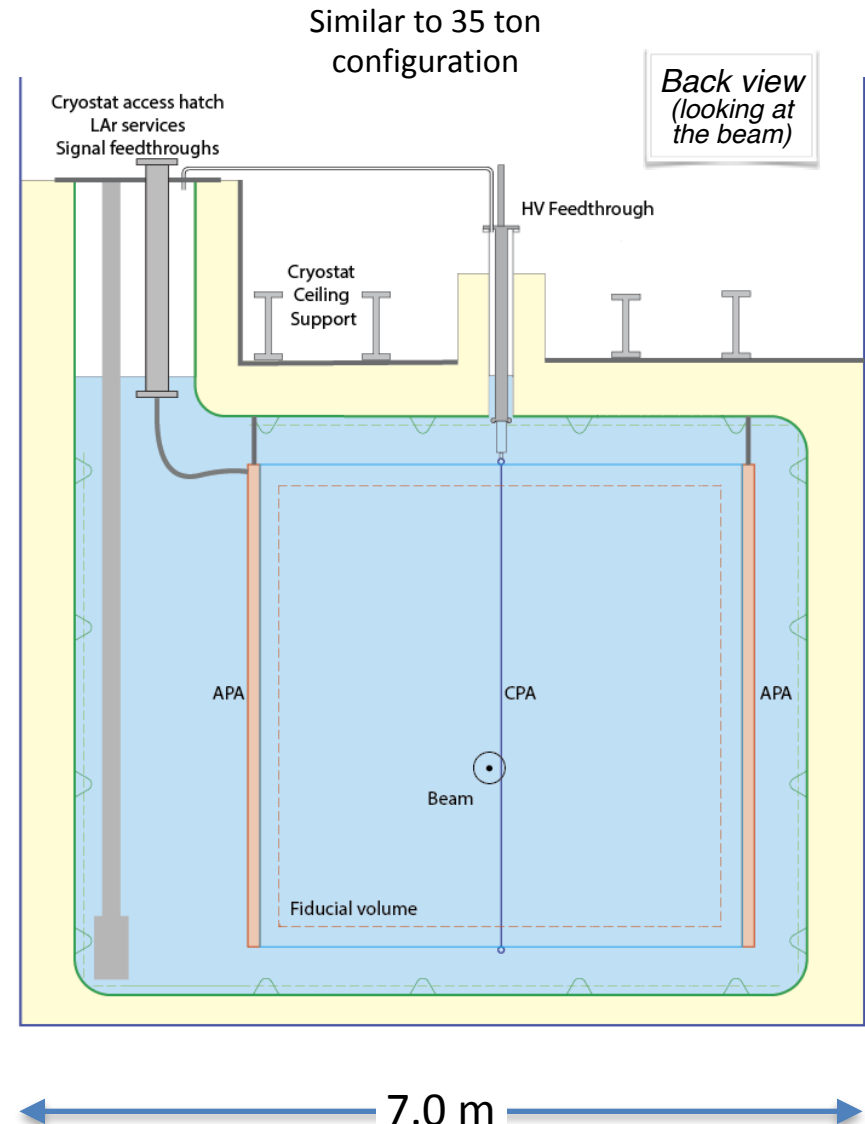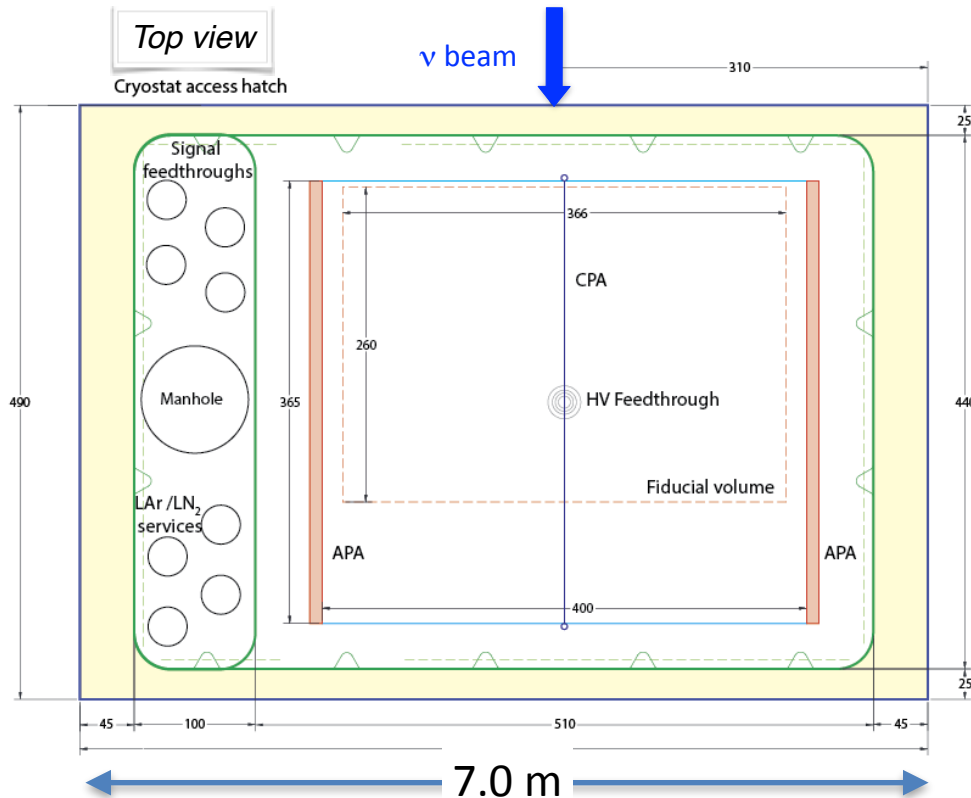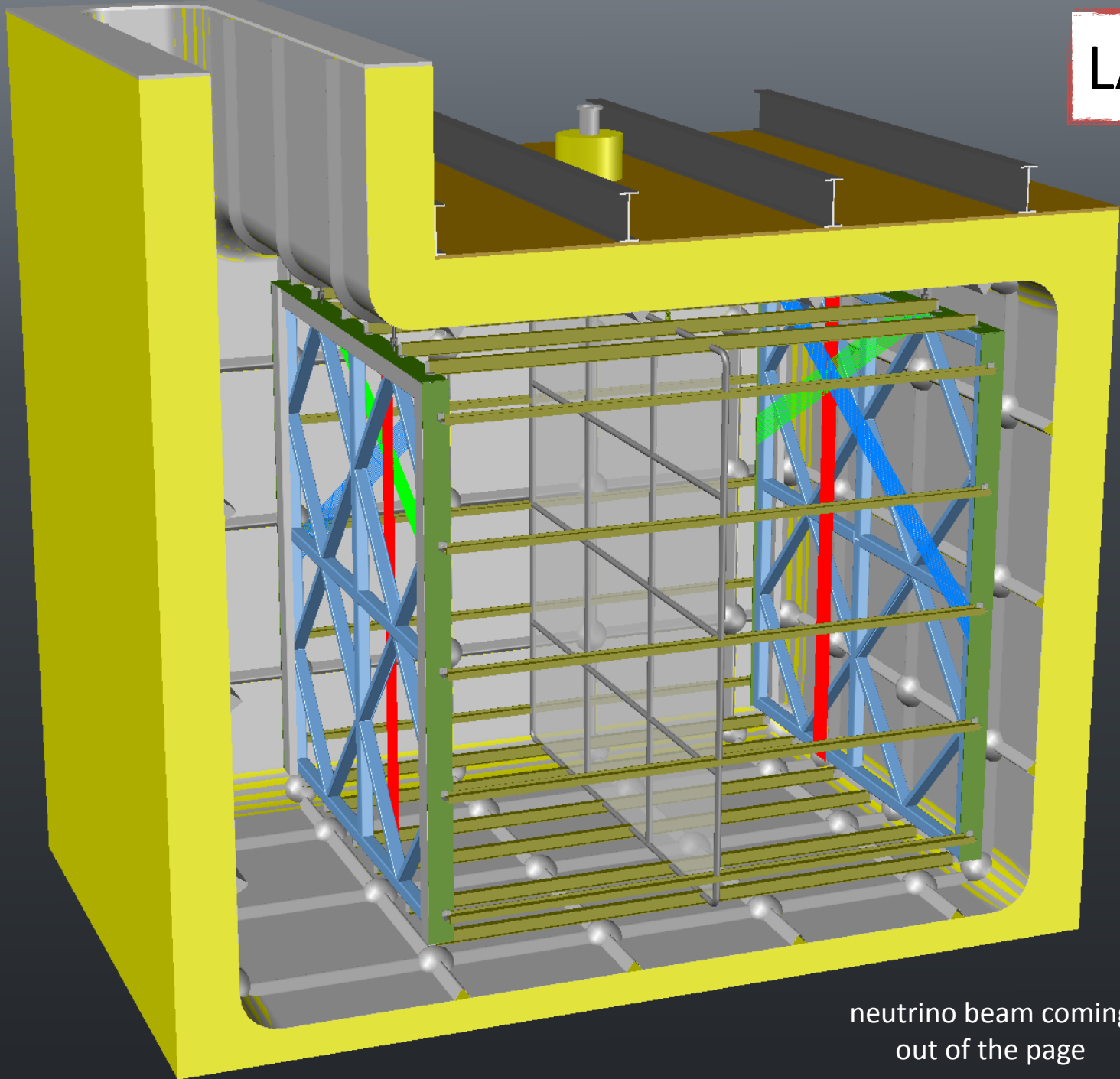| TPC	LAr1-ND	LBNE	Comparison
Construction	Pre-fabricated/tested modules assembled in cryostat	Pre-fabricated/tested modules assembled in cryostat	Same concept, different implementation
TPC Support	Suspended under cryostat roof	Suspended under cryostat roof	Same concept, different implementation
TPC configuration	CPA in the middle, single sided APAs against the walls	CPAs against the walls, double sided APAs in the middle	LAr1-ND's TPC configuration avoids a costly fiducial cut around the non-active thickness of the APA in the center of the active region. The APAs can be placed closer to the cryostat walls to maximize active region in the limited available space. For LBNE, it is cheaper to build fewer APAs if they are double sided and in the middle.
APA configuration	single sided, no helical wire wrapping, readout on 3 edges	double sided, helical wire wrapping on two induction planes, readout on one edge	LBNE's wire wrapping design allows the APAs to be tiled on 3 sides, but raised concerns about the reconstruction efficiency. LAr1-ND's APA design avoids the wire wrapping, while allowing APA tiling on all 4 sides. If the LBNE 35 ton TPC shows that the wrapped wires do not work well, the LAr1-ND design provides a verified alternative to the LBNE APAs.
APA wire configuration	3 sense wire planes, +/- 60 degree, 3mm wire pitch, identical to MicroBooNE	3 sense wire planes, +/- 45 degrees, 4.5-5mm wire pitch	LAr1-ND's wire configuration is set to be identical to MicroBooNE to avoid additional systematic errors when running together. LBNE's wire angles are supposed to be better suited for beam neutrino events. The large wire pitch is compatible with the larger diffusion over longer drift.
APA wire bonding	CuBe wires epoxyed and soldeded to PCB with notched edges	CuBe wires epoxyed and soldeded to PCB with notched edges	Same design
CPA design	stainless steel frame + conductive sheet	stainless steel frame + conductive sheet	Same design concept, light transmission TBD.
Field cage design	Cu strips on FR4 panels	Cu strips on FR4 panels	Similar design.

LAr1-ND: Membrane Cryostat

- Main volume wetted on all sides to minimize outgassing. Also, long "cold" signal feed-throughs an option to conceal cables.

Similar to 35 ton configuration

Shielding blocks removed in favor of an access region over LAr but not the active area

LAr1-ND

neutrino beam coming
out of the page

LAr1-ND vs LBNE Design: Cryostat

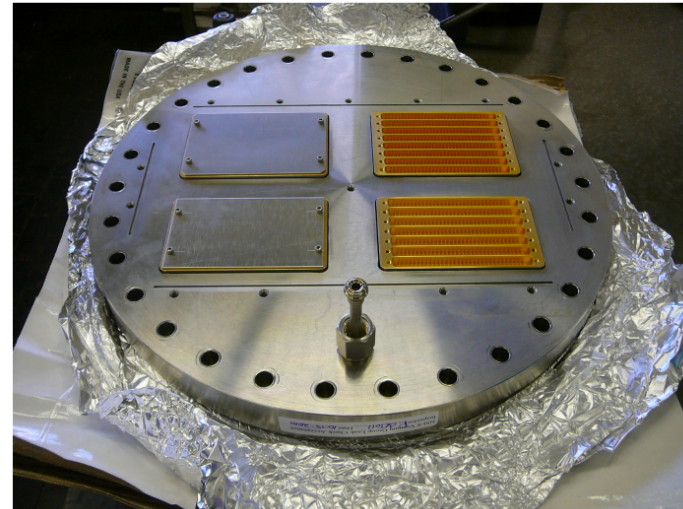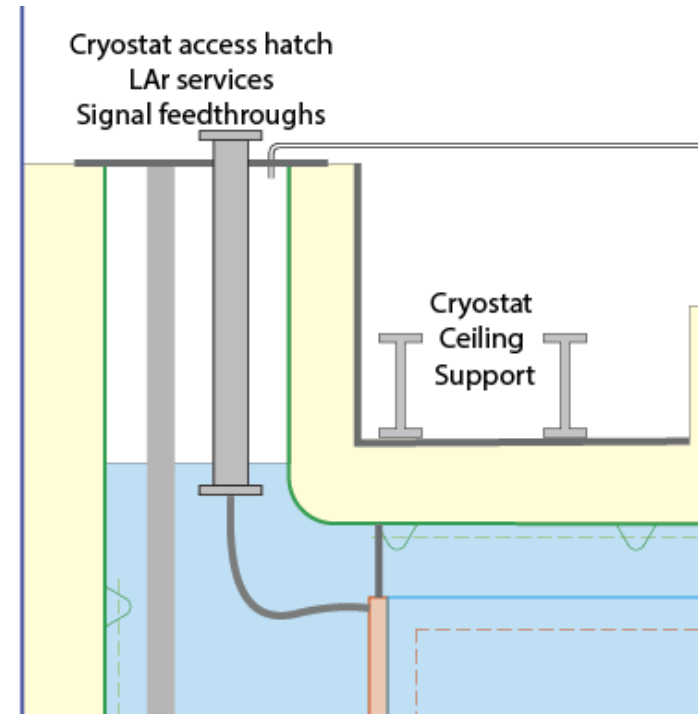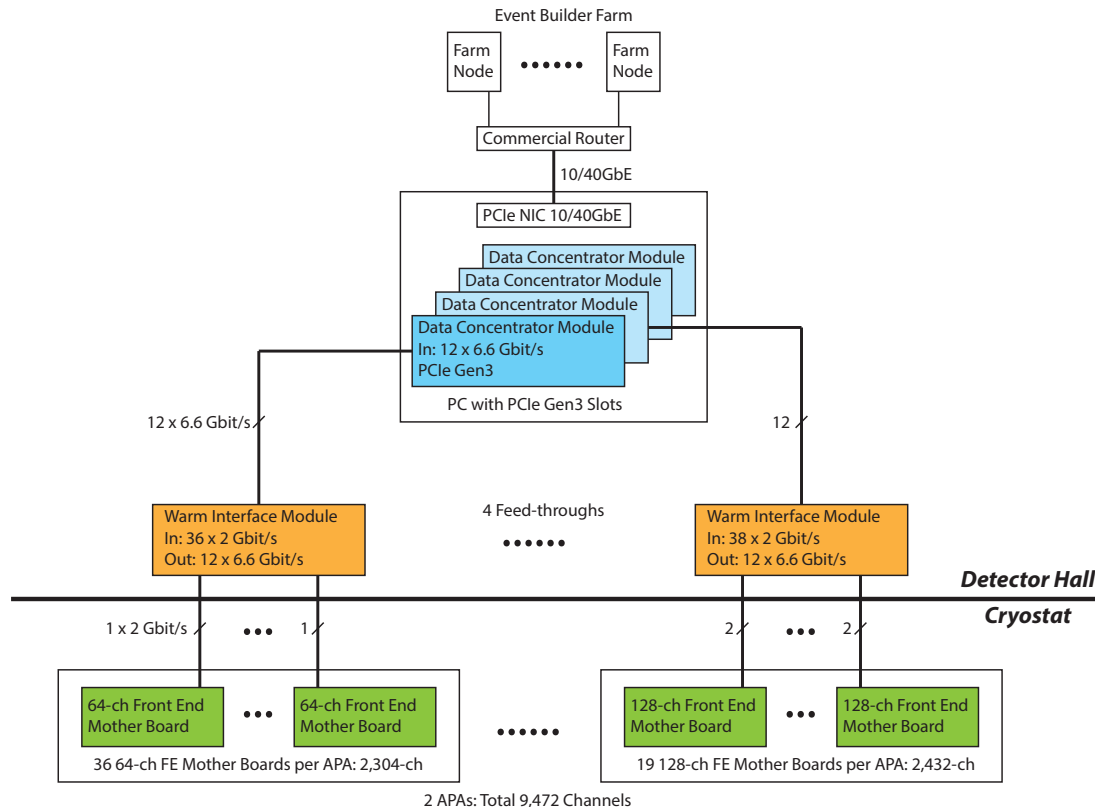| Cryostat/ Cryogenic	LAr1-ND	LBNE	Comparison
Cryostat Technology	Membrane	Membrane	Similar commercial technology using passive foam insulation
LAr pump	Inside cryostat	Inside cryostat	Similar design. May not pump LAr continuously in LAr1-ND.
Ullage space	Confined to a region over inactive region	In the cryostat	An isolated expansion region in LAr1-ND allows the main cryostat to be completely filled with LAr, eliminates outgassing from warm surfaces inside the cryostat
Purification	Dual phase during filling, gas phase thereafter	Dual phase throughout	With the warm ullage in a separate area in LAr1-ND, a much smaller scale purification system can be used in the small gas volume during the normal operation of the TPC
Cooling	Heat exchanger inside cryostat	Heat exchanger outside cryostat	LAr1-ND uses cooling panels inside the cryostat, results in better stability in LAr temperature and convection. The lower convection simplifies the prediction and correction of the positive ion distribution on a surface detector.

Readout Electronics

➢ Analog Front End ASIC and ADC ASIC have been developed for LBNE; Analog Front End ASIC is being used in MicroBooNE; Commercial FPGAs for multiplexing in the cold; similar to that used in 35 ton, with opportunity for longer term running and large data samples.

➢ After on-board multiplexing, 4 cold cable bundles to 4 signal feed-throughs

Front End Mother Board
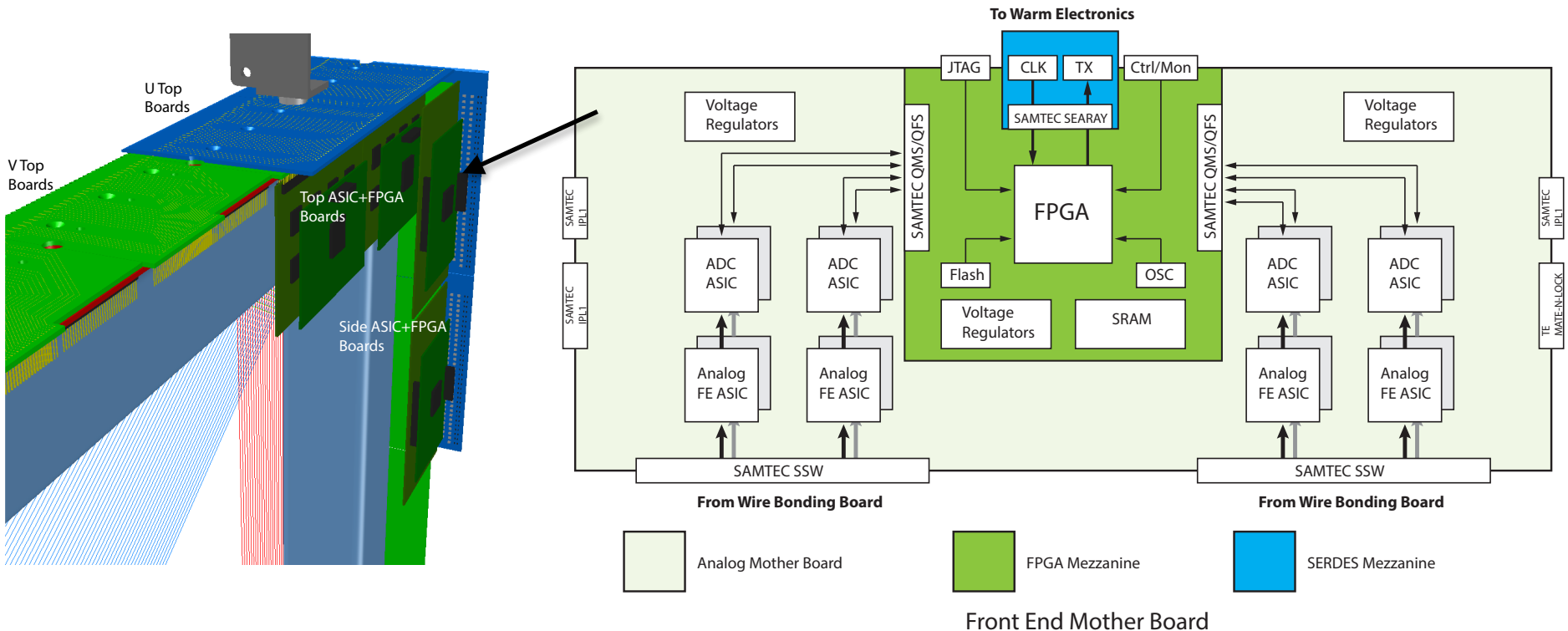
Signal Feed-throughs, warm Electronics & DAQ

- Considering long "cold" feed-throughs that dip into the liquid.

- Eliminates exposed cables in the gas region

- Reliability and hermetic seals are concerns

- ATLAS has developed such a FT designed for both warm and cold flanges. MicroBooNE used for warm FTs.

- External to the cryostat is the Warm Interface Module (WIM), timing system, and commodity Data Concentrator Modules (DCM), network switch and computing farm

LAr1-ND vs LBNE Design: Electronics

Electronics Elements	LAr1-ND	LBNE	Comparison
Analog Front-End	ASIC	ASIC	Same design
ADC	ASIC	ASIC	Same design
FE Digital Processing	FPGA	FPGA or ASIC	LAr1-ND will use FPGA to meet fast schedule; LBNE will make decision later, with inputs and experience from LAr1-ND
Front End Board	Analog Mother Board + Digital	Analog Mother Board + Digital Mezzanine	Similar design, different mechanical dimension and channel density
Cold Cable	Twinaxial Cable	Twinaxial Cable	Same design
Signal Feed-through	ATLAS Pin Carrier	Flange Board or ATLAS Pin Carrier	LAr1-ND will use already developed technology ATLAS pin carrier; LBNE will make decision later, with inputs and experience from LAr1-ND. LAr1-ND will use a double feedthrough configuration to accommodate both the cold cables inside the cryostat and the warm cables outside.
Warm Interface Board	FPGA + Optical Transceiver	Optical Transceiver and/or FPGA	LAr1-ND will use FPGA to study data compression and trigger algorithm, and keep the capability to stream all data out; LBNE will make decision later, with inputs and experience from LAr1-ND.
Data Concentrator Board	Commercial PCIe Card	SLAC RCE	LAr1-ND will use commodity hardware in DAQ system, focus efforts on algorithm, firmware and software development

LAr1-ND vs. LBNE Design: Light Collection System

➤ A compact light-guide-based system like what has been proposed for LBNE *(acrylic bars read out by silicon photomultipliers, SiPMs)* is the starting design concept for LAr1-ND.

Photodetection System	LAr1-ND	LBNE	Comparison
Construction	Extruded light guides coated with wavelength-shifter assembled into "paddles" inserted behind APAs	Extruded light guides coated with wavelength-shifter assembled into "paddles" inserted between APAs	Same design
Photodetector	SiPM	SiPM	Same design

➤ 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 as well as for studies of the light collection efficiency as a function of photocathode coverage