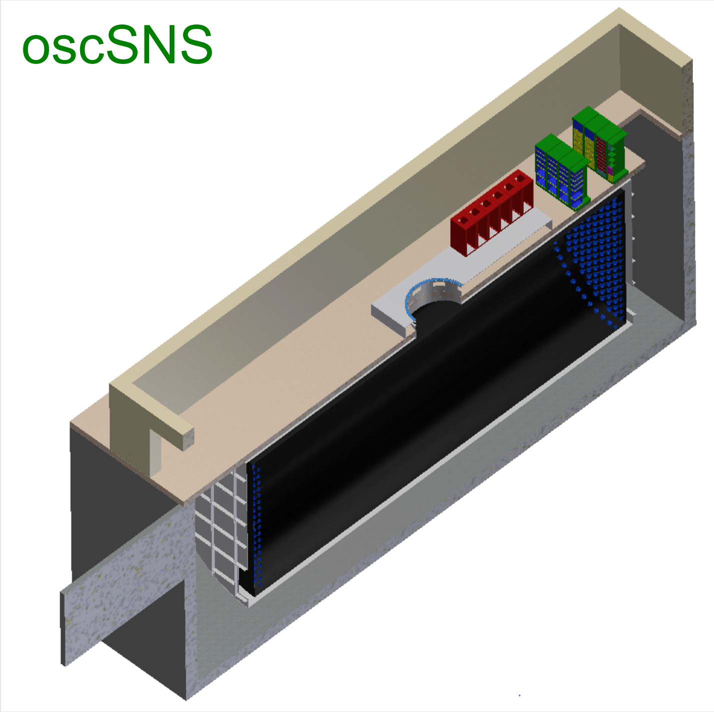
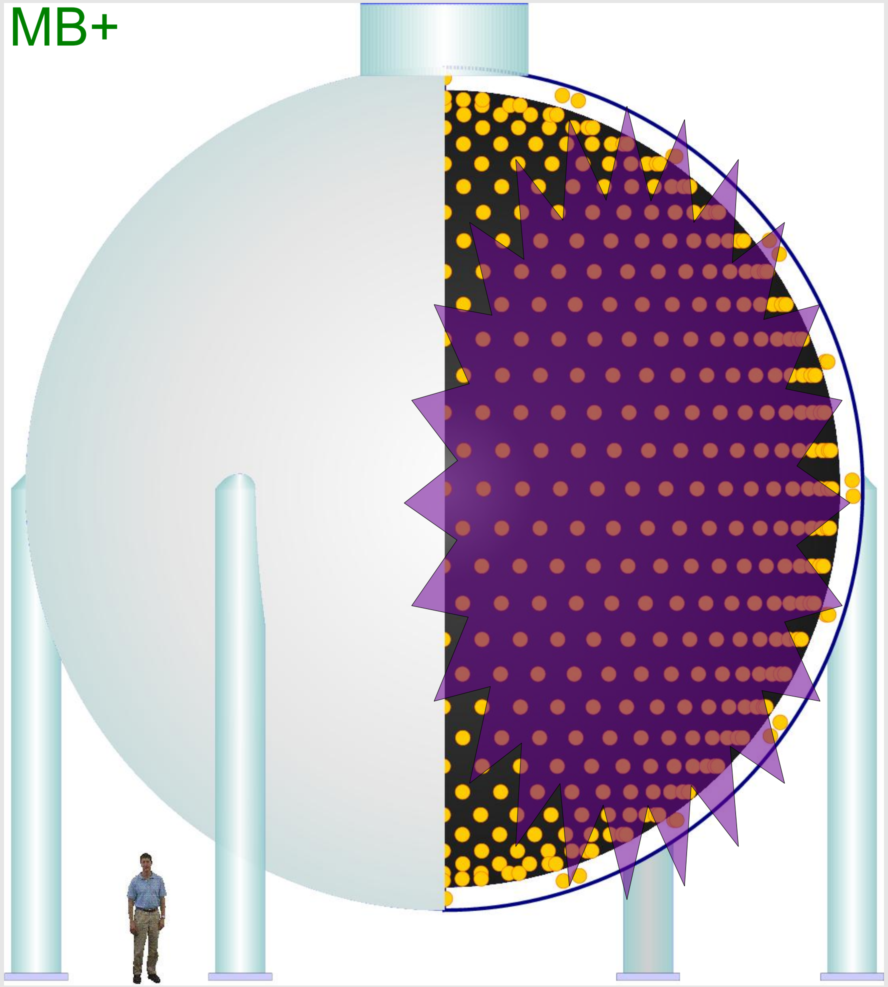
Seaching for sterile neutrinos with MiniBooNE+ and oscSNS

Outline:
- Motivation
- Latest MB results
- MB+
- OscSNS
- summary

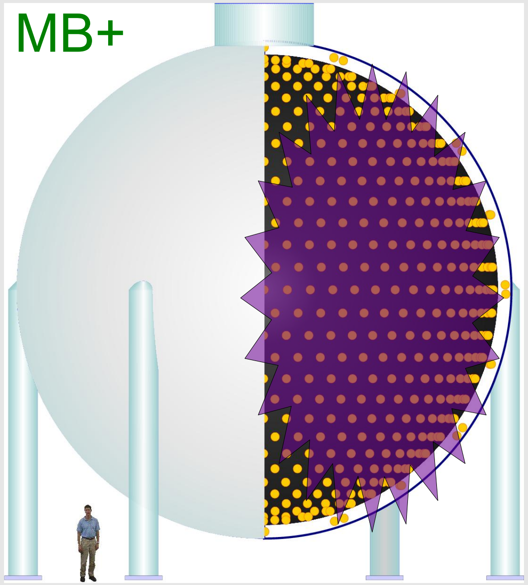




Motivation

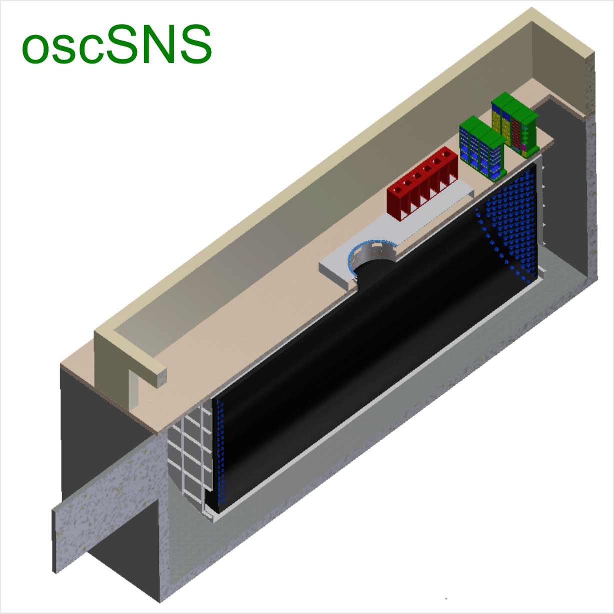
Several hints for sterile neutrinos in $\Delta m2 \sim 1\ eV^2$ exist

– Radioactive source ν_e disappearance
– Reactor ν_e disappearance ("Reactor Anomaly")
– Short-baseline LSND / MiniBooNE ν_e , $\bar{\nu}_e$ appearance



MB+ (MiniBooNE +scintillator):

- A test of CC signal vs NC background hypothesis in a new ν_e search with MiniBooNE+scintillator.



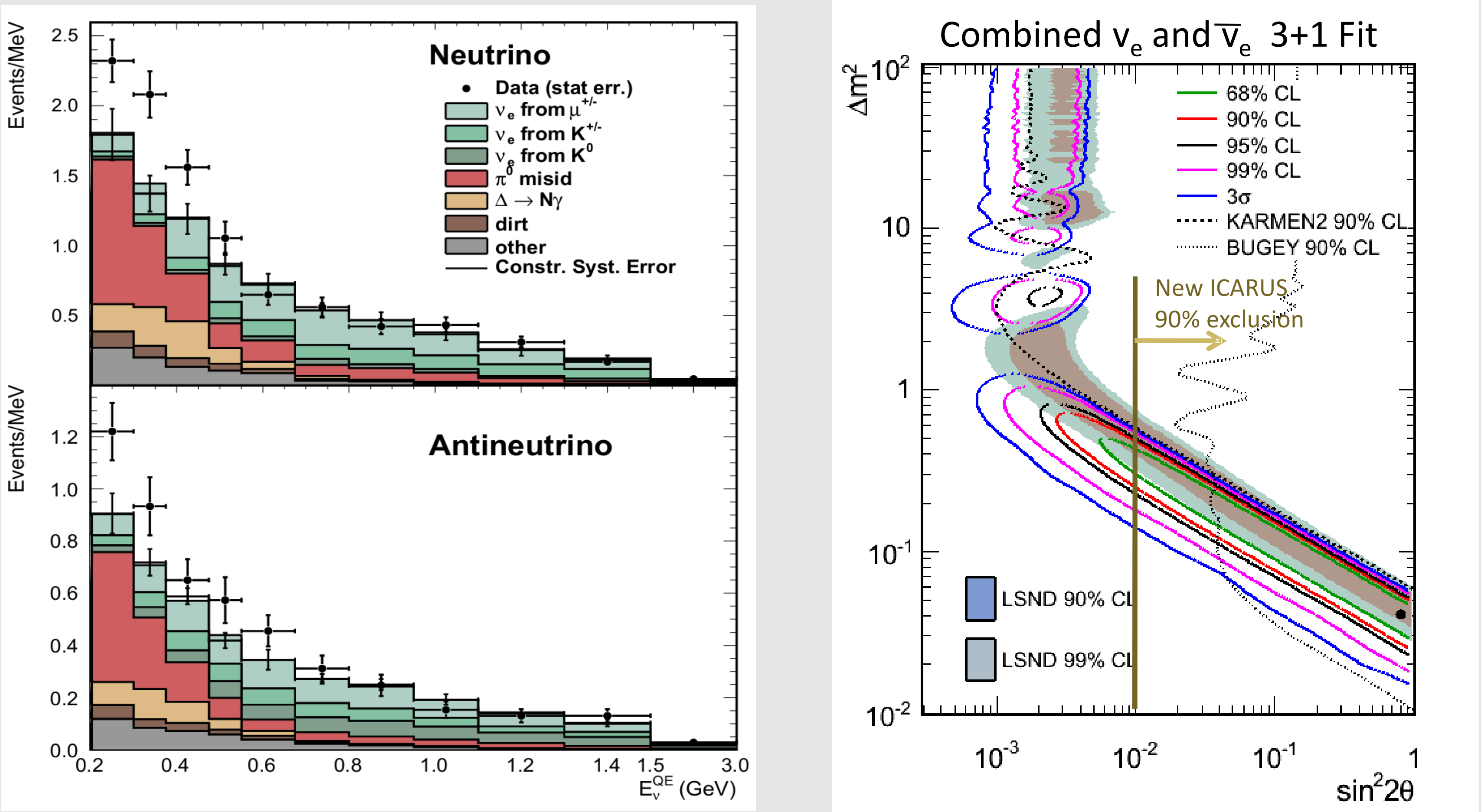
OscSNS:

- A short-baseline ($\Delta m2 \sim 1\ eV^2$) measurement of
  - $\bar{\nu}_e$ appearance ,
  - ν_e / ν_μ disappearance
  - ν_e / ν_μ / $\bar{\nu}_e$ NC disappearance

  in a pion DAR beam at the SNS.

MiniBooNE oscillation excess:

- The combined $\nu / \bar{\nu}$ data set (including all $\bar{\nu}$ data to date) yields a combined excess of 240.3±62.9 events (3.8σ) and is consistent with LSND.

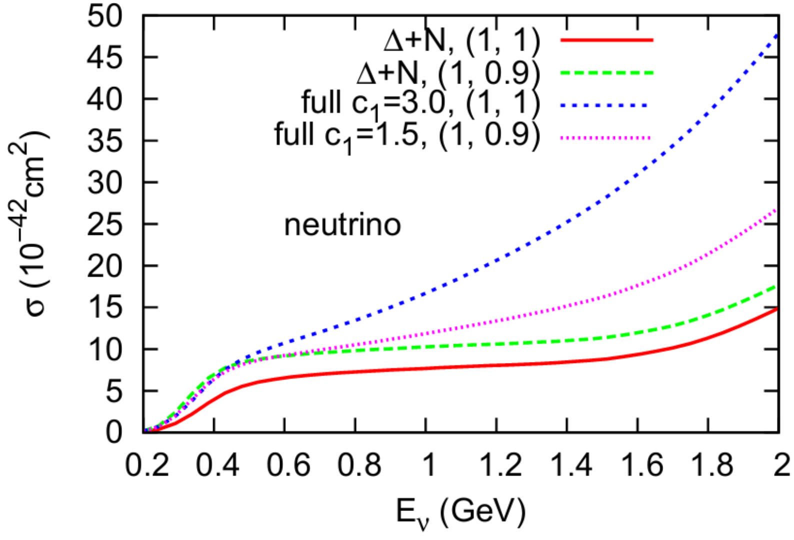


- Excess occurs mostly at low-energy where NCγ and $NC\pi^0$ are dominant. Natural to examine these backgrounds further.

MiniBooNE oscillation NC backgrounds:

- Both NCγ and NCπ^0 are constrained with additional MB measurements.
  - NCπ^0 directly measured in MB
  - NCγ constrained to NCπ^0 (due to dominance of Δ, Δ→Nγ)

NCγ production cross section



From Zhang and Serot, arXiv:1210.3610

- Recent theoretical calculations agree with MB calculations

B. D. Serot and X. Zhang, arXiv:1110.2760 [nucl-th].

B. D. Serot and X. Zhang, Phys. Rev. C **86**, 015501 (2012) [arXiv:1206.3812 [nucl-th]].

X. Zhang and B. D. Serot, arXiv:1208.1553 [nucl-th].

X. Zhang and B. D. Serot, arXiv:1206.6324 [nucl-th], accepted to Physical Review C.

J. A. Harvey, C. T. Hill and R. J. Hill, Phys. Rev. Lett. **99**, 261601 (2007) [arXiv:0708.1281 [hep-ph]].

R. J. Hill, Phys. Rev. D **81**, 013008 (2010) [arXiv:0905.0291 [hep-ph]].

X. Zhang and B. D. Serot, in Press.

R. J. Hill, Phys. Rev. D **84**, 017501 (2011) [arXiv:1002.4215 [hep-ph]].

E_{QE}(GeV)	[0.2 , 0.3]	[0.3 , 0.475]	[0.475 , 1.25]
coh	1.3 (2.4)	6.4 (9.9)	2.4 (9.3)
inc	9.5 (10.5)	27.6 (31.3)	16.7 (27.1)
H	3.0 (3.3)	10.6 (11.7)	5.4 (7.4)
Total	13.8 (16.2)	44.6 (52.9)	24.5 (43.8)
MiniBN	19.5	47.3	19.4
Excess	42.6 ± 25.3	82.2 ± 23.3	21.5 ± 34.9

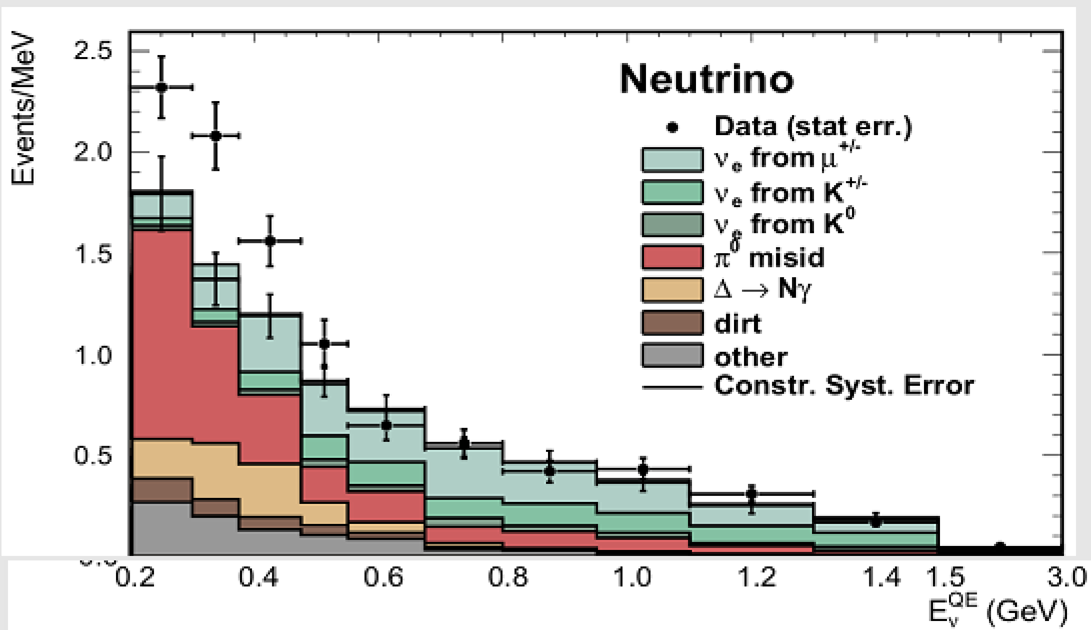
TABLE II: E_{QE} distribution of the NC photon events in the MiniBooNE neutrino run, comparing our estimate to the MiniBooNE estimate [1].

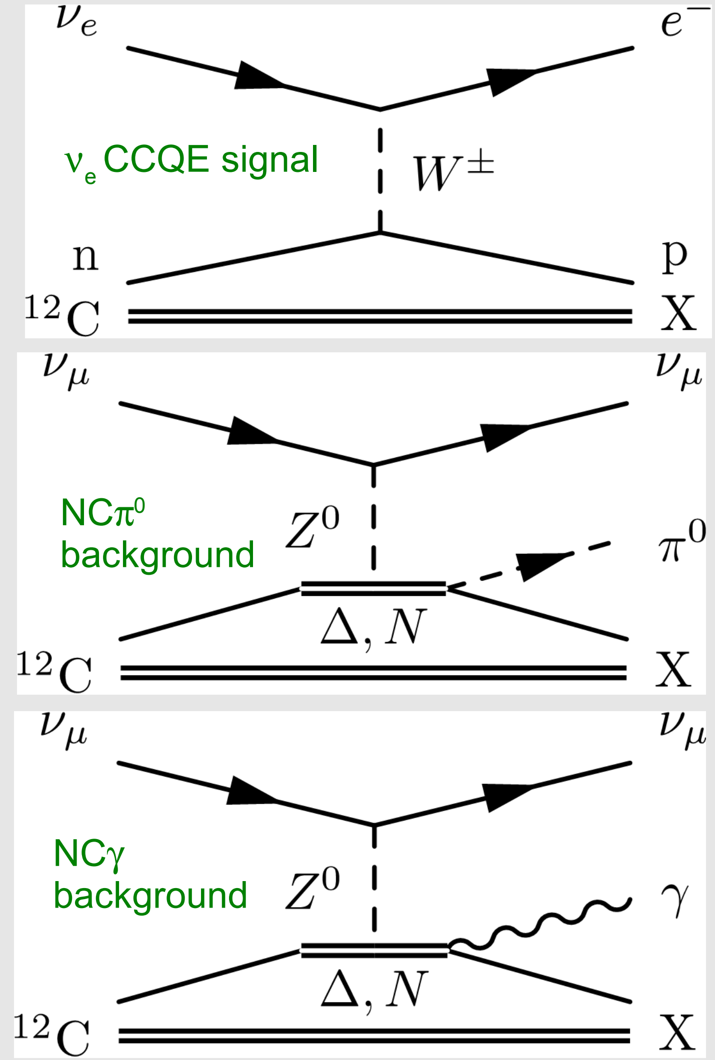
- However, additional experimental tests called for...
  - important to resolve the MB low-energy excess
  - may be important for other future experiments in this energy range (eg: T2K)

MiniBooNE+scintillator

- Add scintillator to MB to enable reconstruction of 2.2 MeV n-capture photons
- rerun MB $\nu_\mu \rightarrow \nu_e$ search

The n-capture (np→dγ) signal will enable separation of CC oscillation signal events from NC backgrounds for an improved test of the low-energy MiniBooNE oscillation excess.



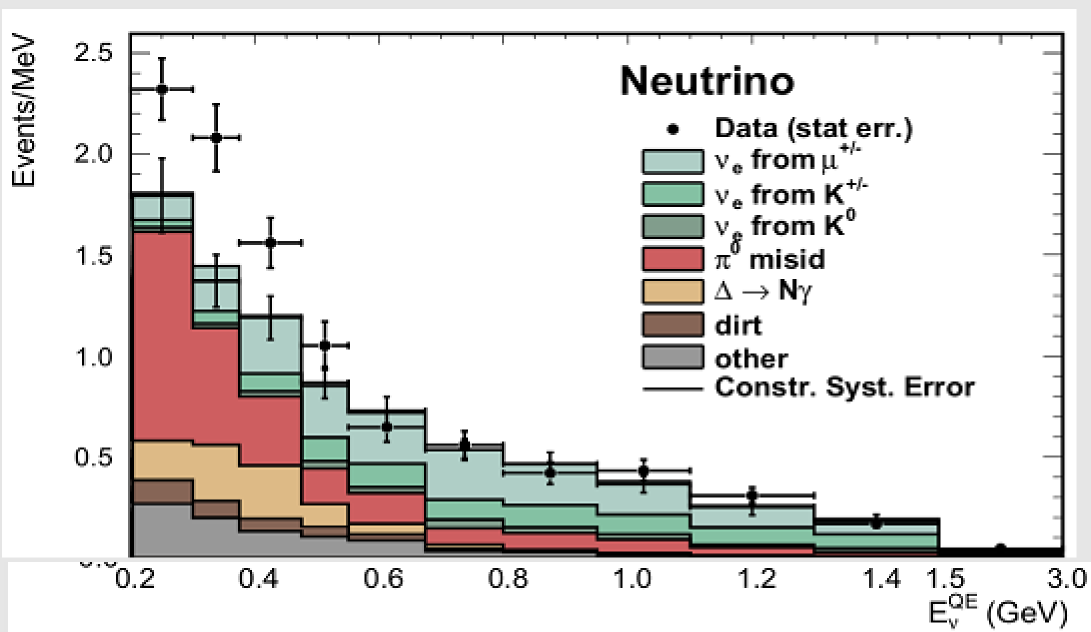


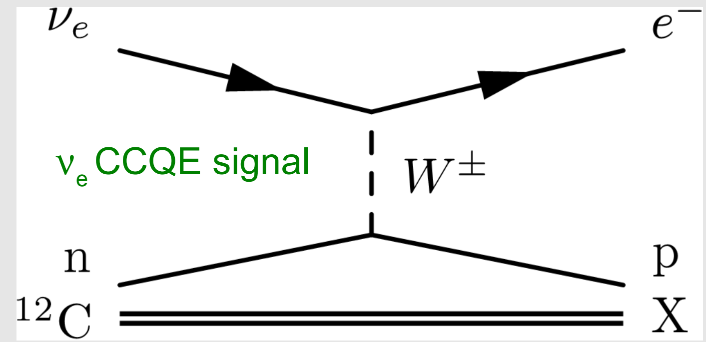
Physics: $\nu_\mu \rightarrow \nu_e$ search with NC tag

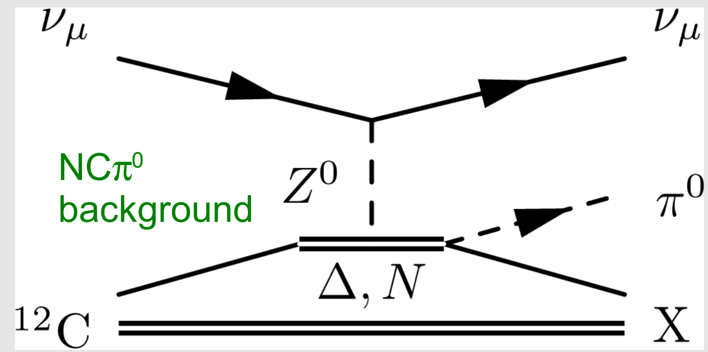
Select oscillation candidates with an associated n-capture "tag".
If event excess (at low energy) is:

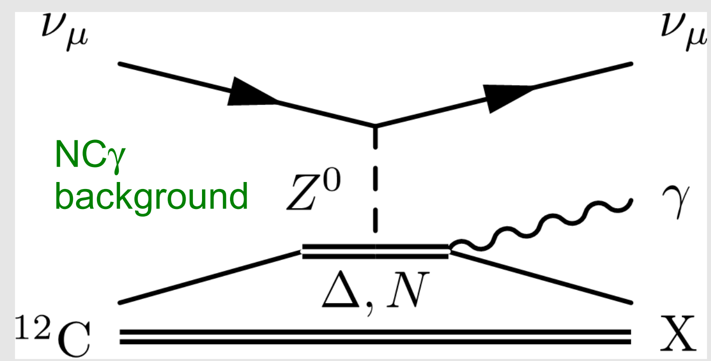
- CC oscs: excess will disappear since it is mostly CCQE (with only 1-10% neutrons)

- NC bckgd: excess will not disappear since it will contain 50% neutrons. This is because of dominance of NC Δ with equal branch to p/n decay









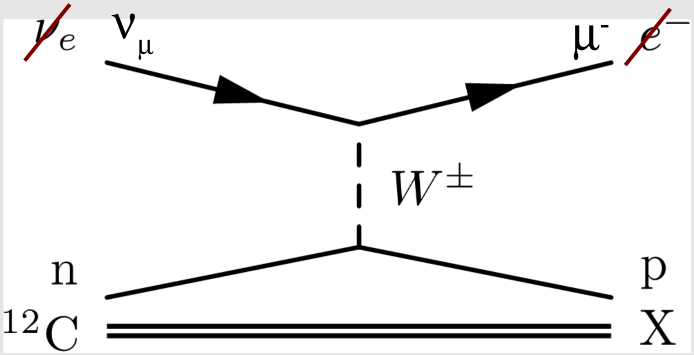
Calibration of signal/background n-fraction

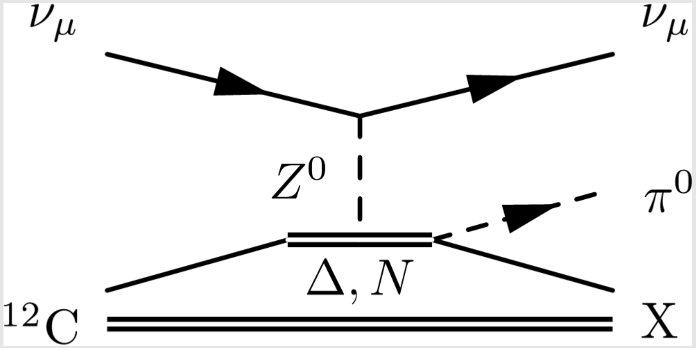
Assumed n-fraction in CC/NC is very important component of this analysis.
Numbers here have been estimated from previous data and model guidance.

In actual experiment they will be *measured.*

- For ν_e CCQE interactions, can measure n-fraction in ν_μ CCQE events

- For ν_μ NC backgrounds, ν_μ NCπ^0 events (with well-identified) π^0 will be used





Results in measured n-fraction for both CC signal and NC background, bin-bin in reconstructed ν energy.
These measurements include final state effects.

Simulated Analysis

A new oscillation analysis of MB with scintillator has been simulated:

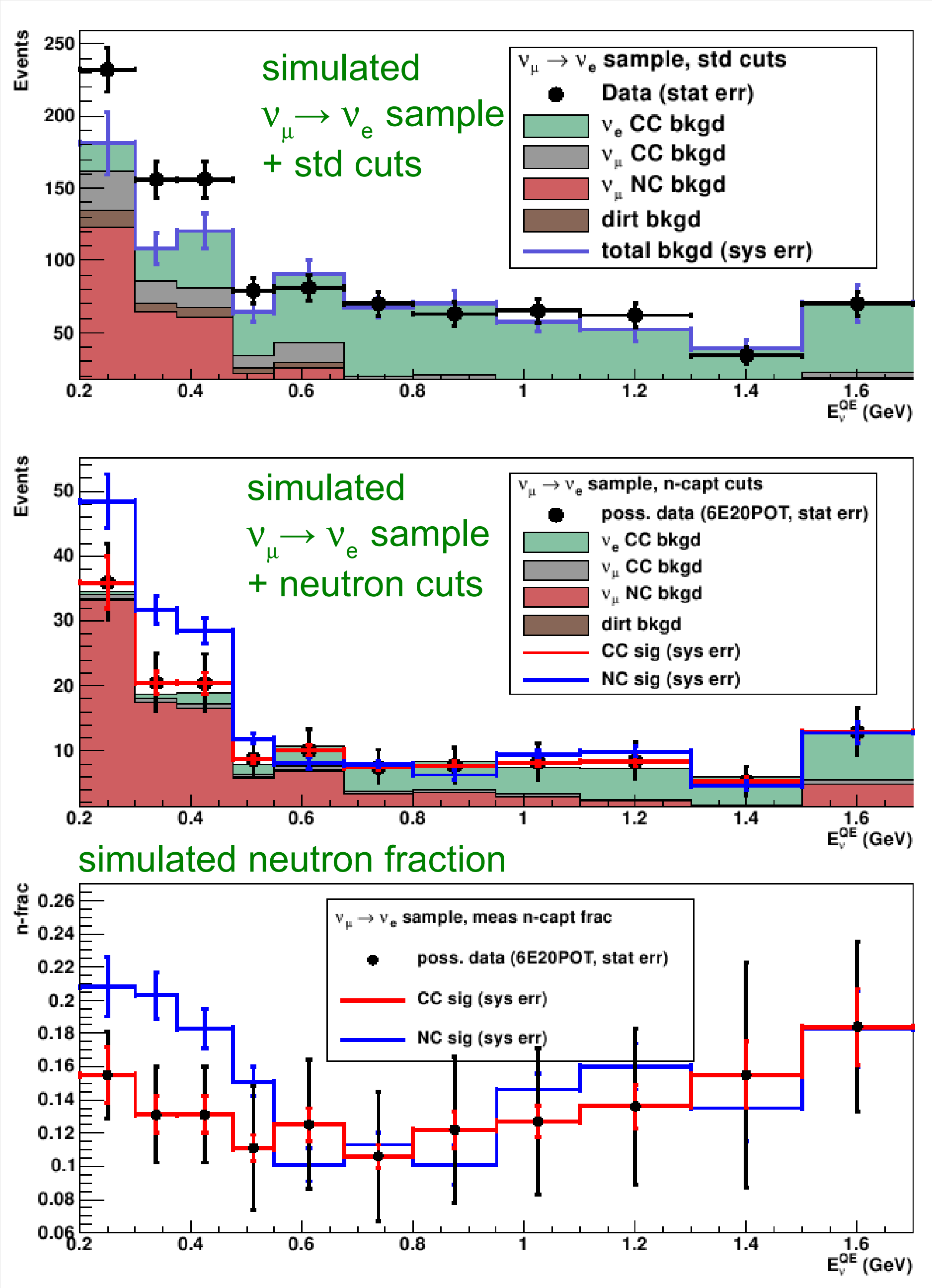
Assumptions:
- Previous ν oscillation experiment performed with same cuts and same statistics (6.5E20POT)
  - reconstruction performance same as previous
  - same excess is seen in this analysis (top plot)

- Then n-capture events are required and a reduced data set is obtained (middle plot)

Note that data excess disappears in middle plot and is same as CC prediction (red lines). If excess due to NC background (blue lines), then excess remains.

If excess is CC oscillation signal, then NC/CC separation is 3.5σ for this test. Combined with independent neutrino-mode excess in 1st stage analysis (of 3.4σ)

Yields a ~5σ test of MB excess.



MiniBooNE+ and MicroBooNE

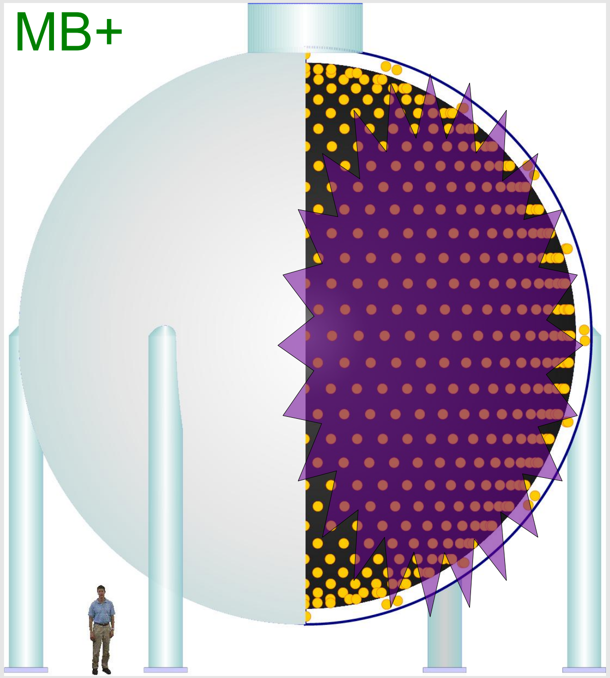
This would be a complementary effort to that of MicroBooNE which also has a goal of understanding MB excess...

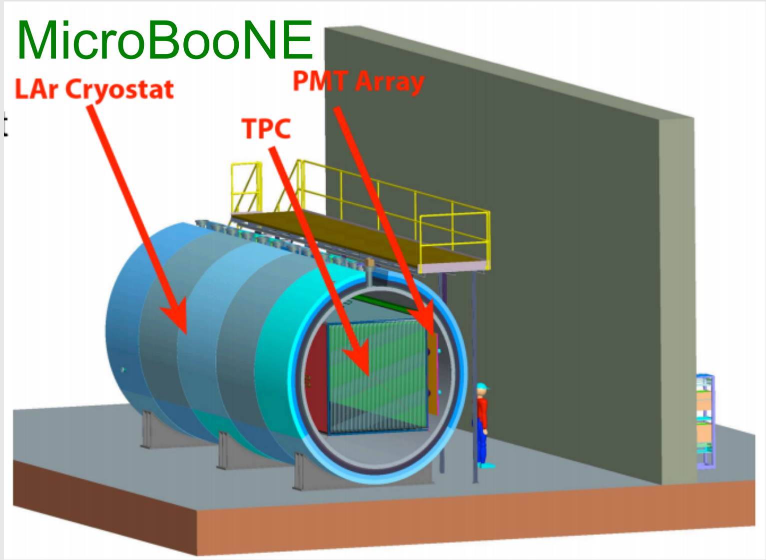
- Different nuclei: Carbon vs Argon

- MicroBooNE goal is to differentiate CC/NC via γ/e separation.
  MB+ will focus on nucleons, in particular neutrons with no energy threshold

- MicroBooNE will have precision tracking, but low event counts.
  MB+ cerenkov/calormetric reconstruction, higher event rates.

- The MiniBooNE excess is important to resolve, best to have two detectors looking at it, esp since nucleus changes in MicroBooNE





More physics w/MB+scintillator

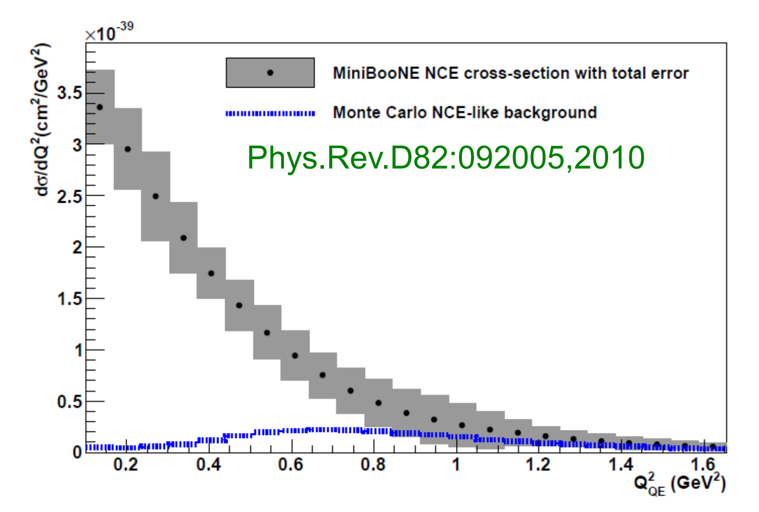
NC elastic scattering and Δs :

- MiniBooNE has measured ν – nucleon NC elastic scattering in both ν and $\bar{\nu}$ channels.
- Addition of scintillator allows for n/p separation and measurement of Δs (s-quark contribution to nucleon spin) via:

$$R(NCp/NCn) = \frac{\sigma(\nu_\mu p \to \nu_\mu p)}{\sigma(\nu_\mu n \to \nu_\mu n)}$$

for more input to ongoing proton spin puzzle.

MiniBooNE NC elastic differential cross section



$$\frac{d\sigma}{dQ^2}(\nu N \to \nu N) \propto (-\tau_z G_A + G_A^s)^2$$

$$G_A^s(Q^2=0) = \Delta s$$

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s$$
$$\Delta q = q\uparrow - q\downarrow + \bar{q}\uparrow - \bar{q}\downarrow$$

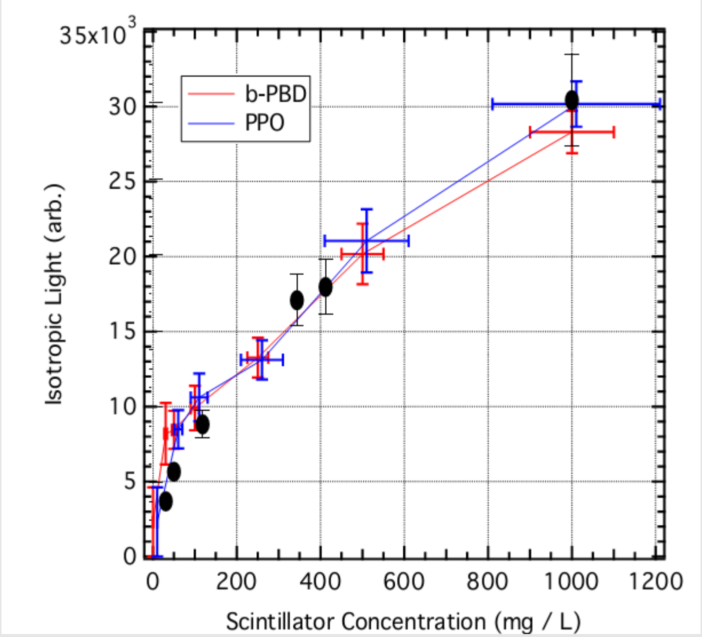
- Measurement of $\nu_\mu C \to \mu^- N_{g.s.}$
  - tagged with $N_{g.s.}$ β decay (~15MeV endpoint, enabled with scintillator)
  - cross section known to ~2% near threshold allows a low-E flux test

- Test of E_ν^{QE} in ν energy reconstruction
  - addition of scintillator will allow total energy of event to be measured and compared with E_ν^{QE}, the current method of reconstruction that assumes quasielastic ν–nucleon scattering.

MB+scintillator: some details

From MC studies combined with lab tests:
- 300kg of PPO (~$75k) added to the 800 tons of MiniBooNE mineral oil (0.3g/l) will increase light to enable reconstruction of 2.2 MeV γ

scintillation light vs scintillant concentration

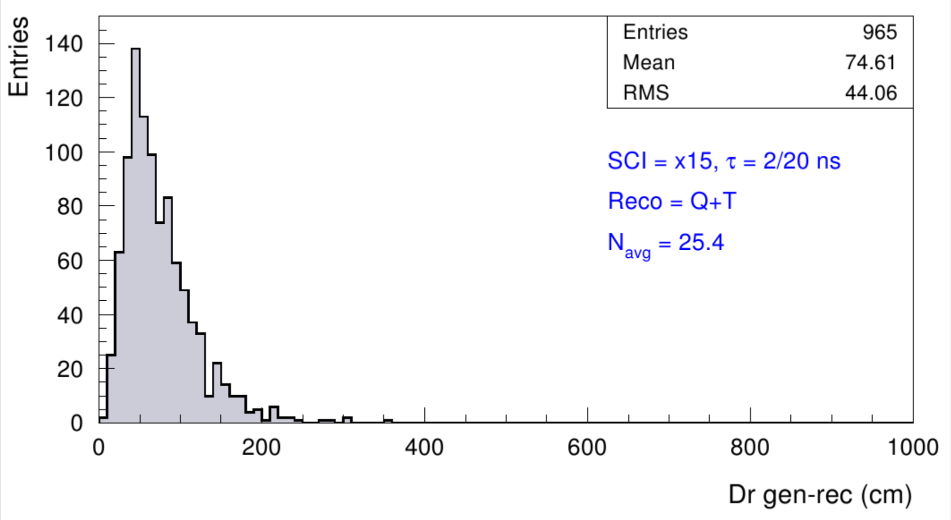


- LOI to FNAL in Fall'12.
  Proposal for June '13 PAC.

Letter of Intent: A new investigation of $\nu_\mu \rightarrow \nu_e$ oscillations with improved sensitivity in an enhanced MiniBooNE experiment

arXiv:1210.2296

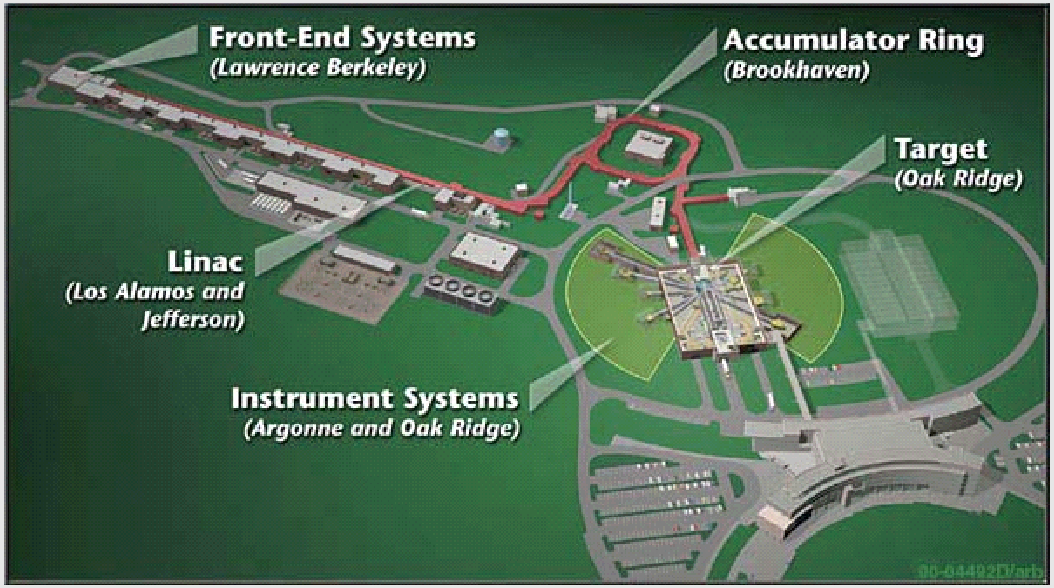
position reconstruction of n-capt phtons



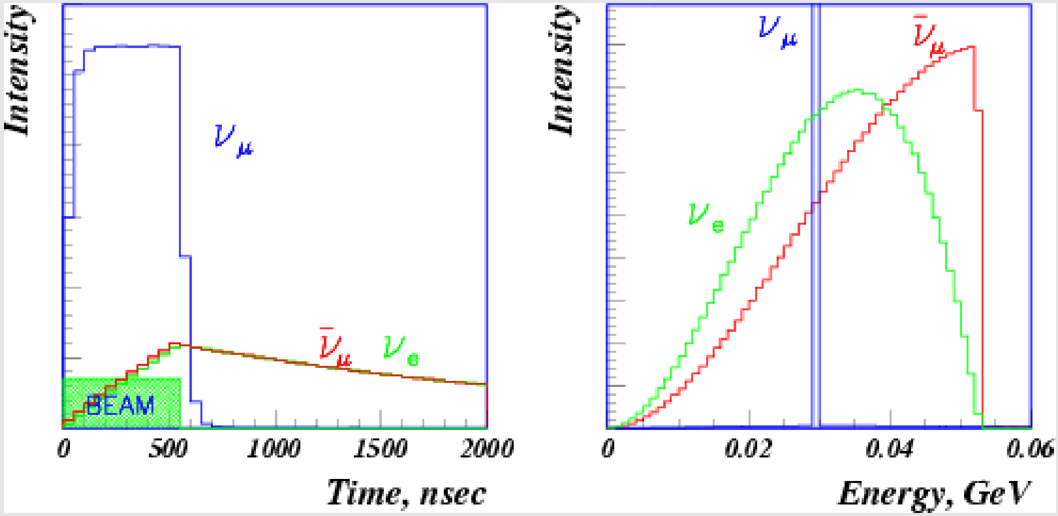
OscSNS: beam

- A short-baseline sterile neutrino search in a pion DAR beam at the SNS.

- Spallation neutron source at ORNL
- 1.4MW of 1GeV protons on Hg target



- well understood flux of ν_e / ν_μ / $\bar{\nu}_e$
- low duty-factor for low beam-unrelated backgrounds
- useful time structure



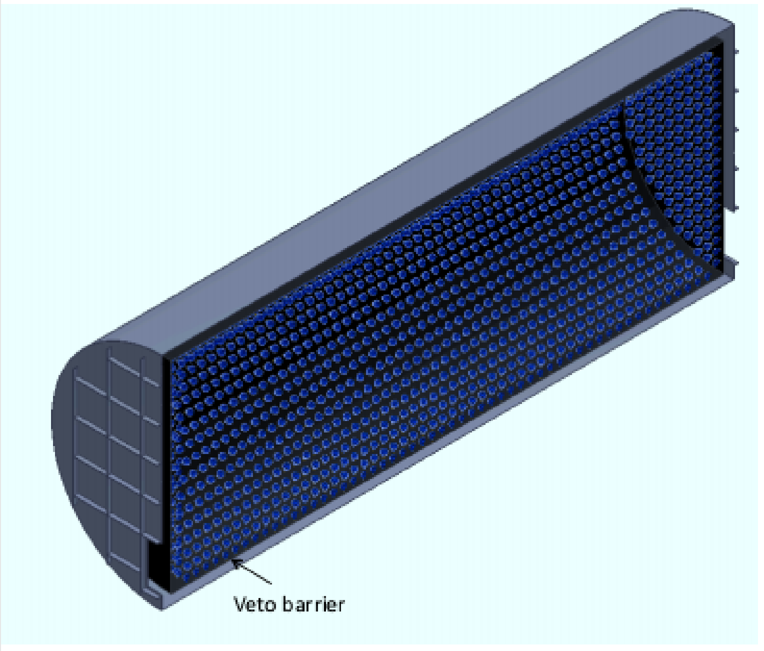
OscSNS: detector

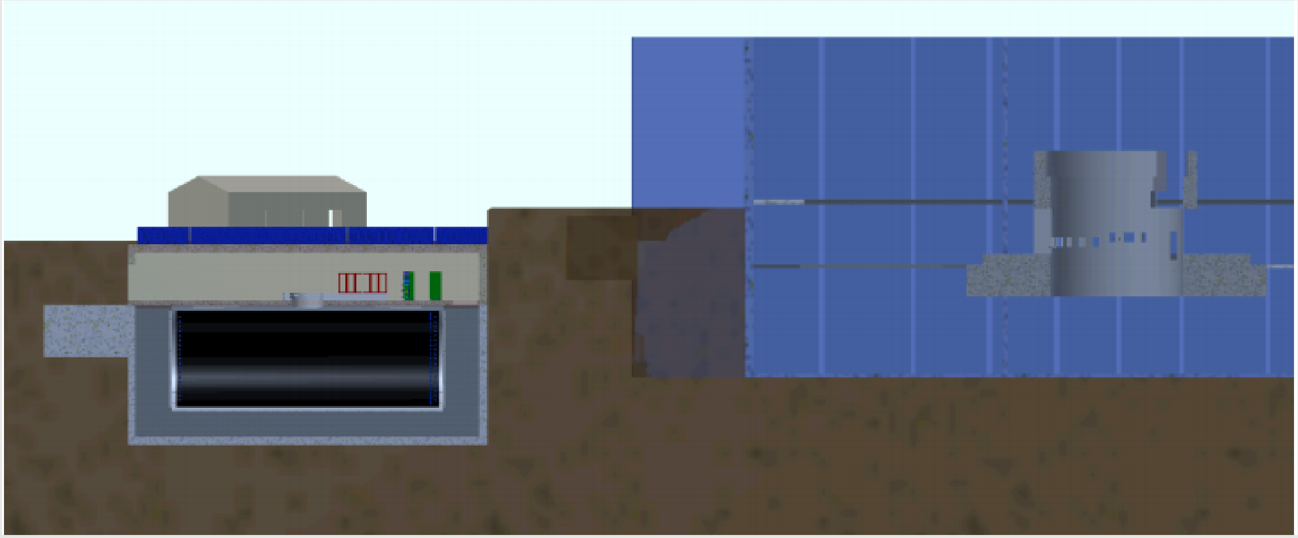
Assumed detector location

OscSNS: detector

- 886 tons liquid scintillator
- ~4700 8-inch PMT (25% photocathode coverage
- ~2m steel overburden
- 60m from source

- cerenkov and calormetric reconstruction
- neutron-capture via (np→dγ)

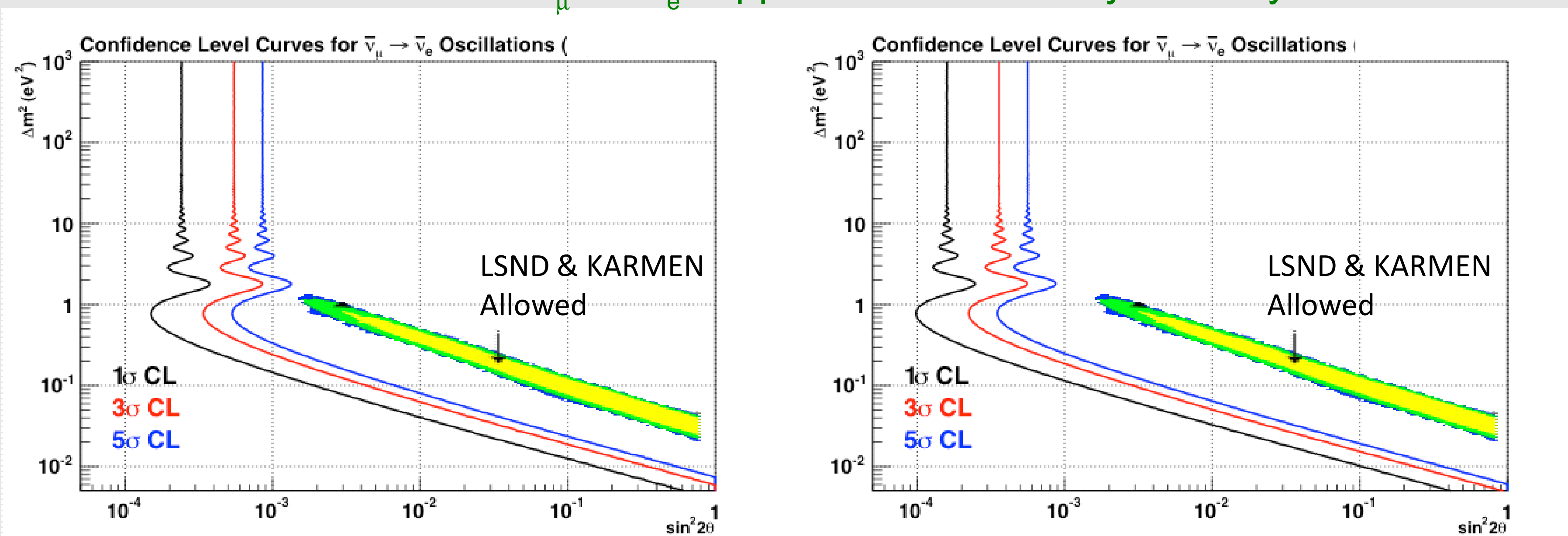




OscSNS: $\bar{\nu}_e$ appearance

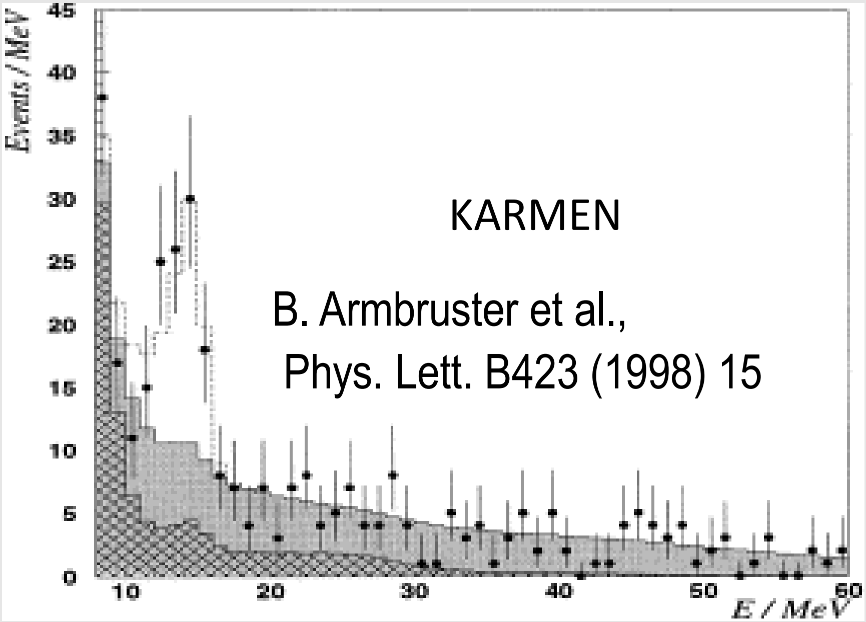
– $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance via
  $\bar{\nu}_e\ p \rightarrow e^+\ n;\ np \rightarrow d\gamma$ (2.2 MeV)

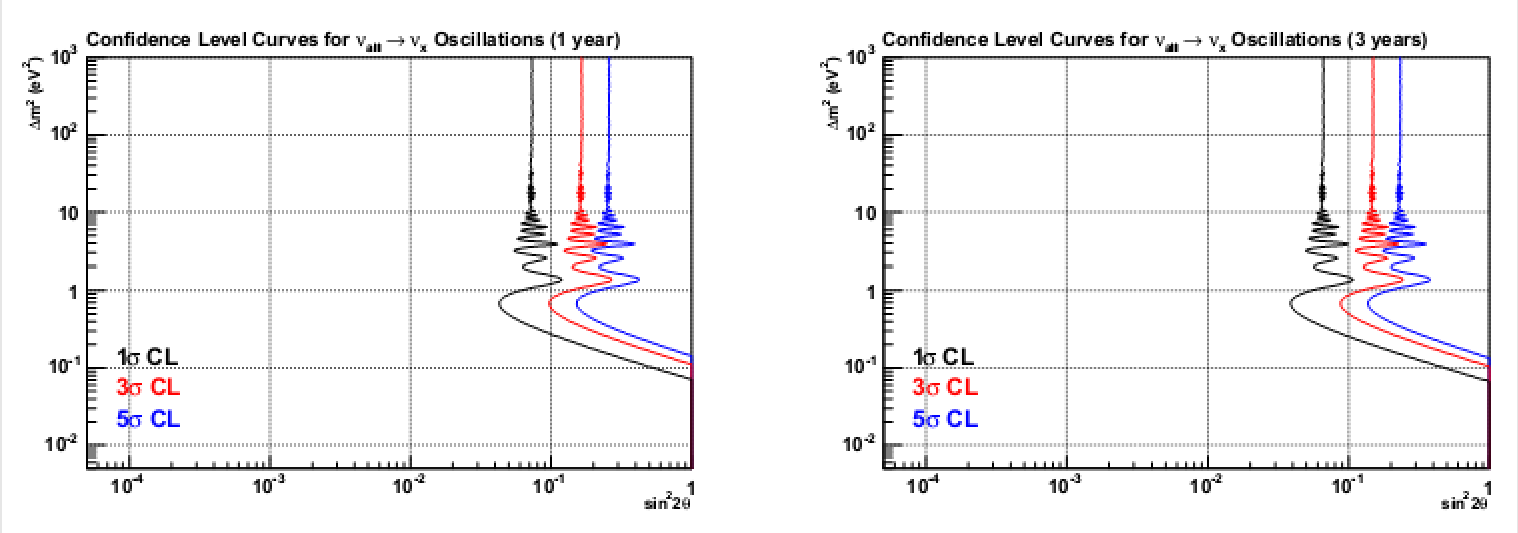
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance sensitivity for 2/6 years of runtime



OscSNS: NC disappearance

- ν_μ disappearance via
  - ν_μ C $\rightarrow$ ν_μ C*(15.11)
  - ν_μ, ν_μ, $\bar{\nu}_e$ C $\rightarrow$ ν_μ, ν_μ, $\bar{\nu}_e$ C*(15.11)





OscSNS: event rates

events/yr

- event rates and other channels

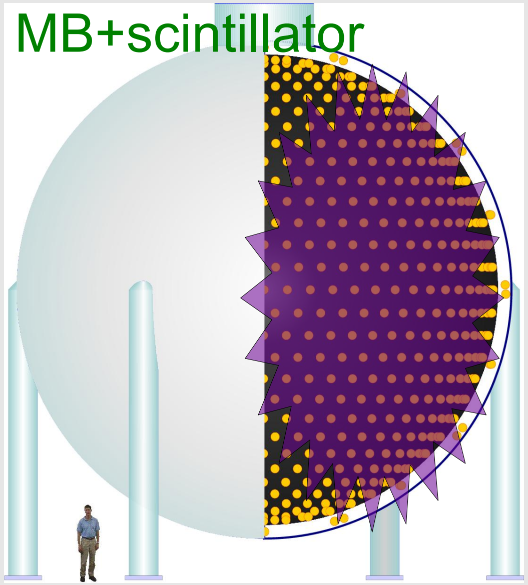
Channel	Background	Signal
Disappearance Search		
$\nu_\mu\ ^{12}C \rightarrow \nu_\mu\ ^{12}C^*$ $\nu_e\ ^{12}C \rightarrow \nu_e\ ^{12}C^*$ $\bar{\nu}_\mu\ ^{12}C \rightarrow \bar{\nu}_\mu\ ^{12}C^*$	1060 ± 36	3535 ± 182
$\nu_\mu\ ^{12}C \rightarrow \nu_\mu\ ^{12}C^*$	224 ± 75	745 ± 42
$\nu_e\ ^{12}C \rightarrow e^-\ ^{12}N_{gs}$	24 ± 13	2353 ± 123
Appearance Search		
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$: $\bar{\nu}_e\ ^{12}C \rightarrow e^+\ ^{11}B\ n$ $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$: $\bar{\nu}_e\ p \rightarrow e^+\ n$	42 ± 5	120 ± 10
$\nu_\mu \rightarrow \nu_e$: $\nu_e\ ^{12}C \rightarrow e^-\ ^{12}N_{gs}$	12 ± 3	3.5 ± 1.5

Summary

Can check the MiniBooNE evidence for sterile nu oscillation:

MB+ (MiniBooNE +scintillator):

- A test of CC signal vs NC background hypothesis in a new ν_e search with MiniBooNE+scintillator.
- low-cost, short timescale

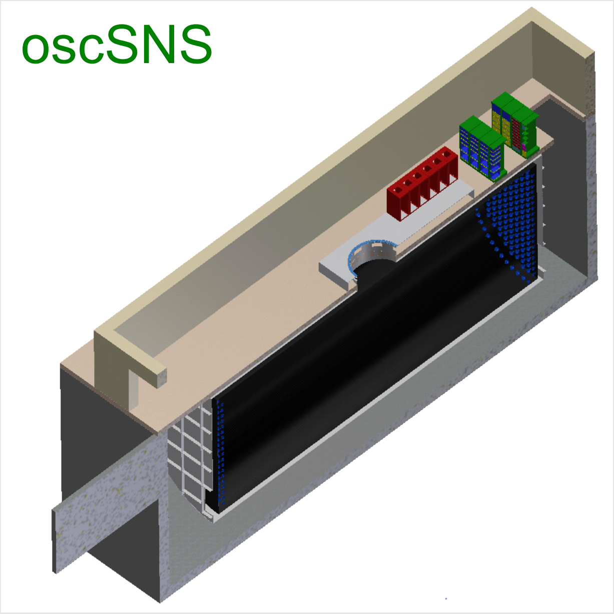


OscSNS:

- A short-baseline (Δm2 ~ 1 eV^2) measurement of
  - $\bar{\nu}_e$ appearance ,
  - ν_e / ν_μ disappearance
  - ν_e / ν_μ / $\bar{\nu}_e$ NC disappearance

  in a pion DAR beam at the SNS.

- reasonable cost/timescale
- high sensitivity



Summary

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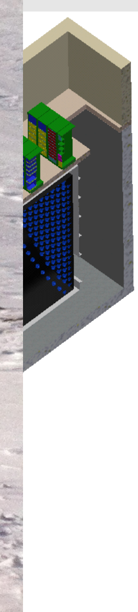


Backup slides

Simulated Analysis: details

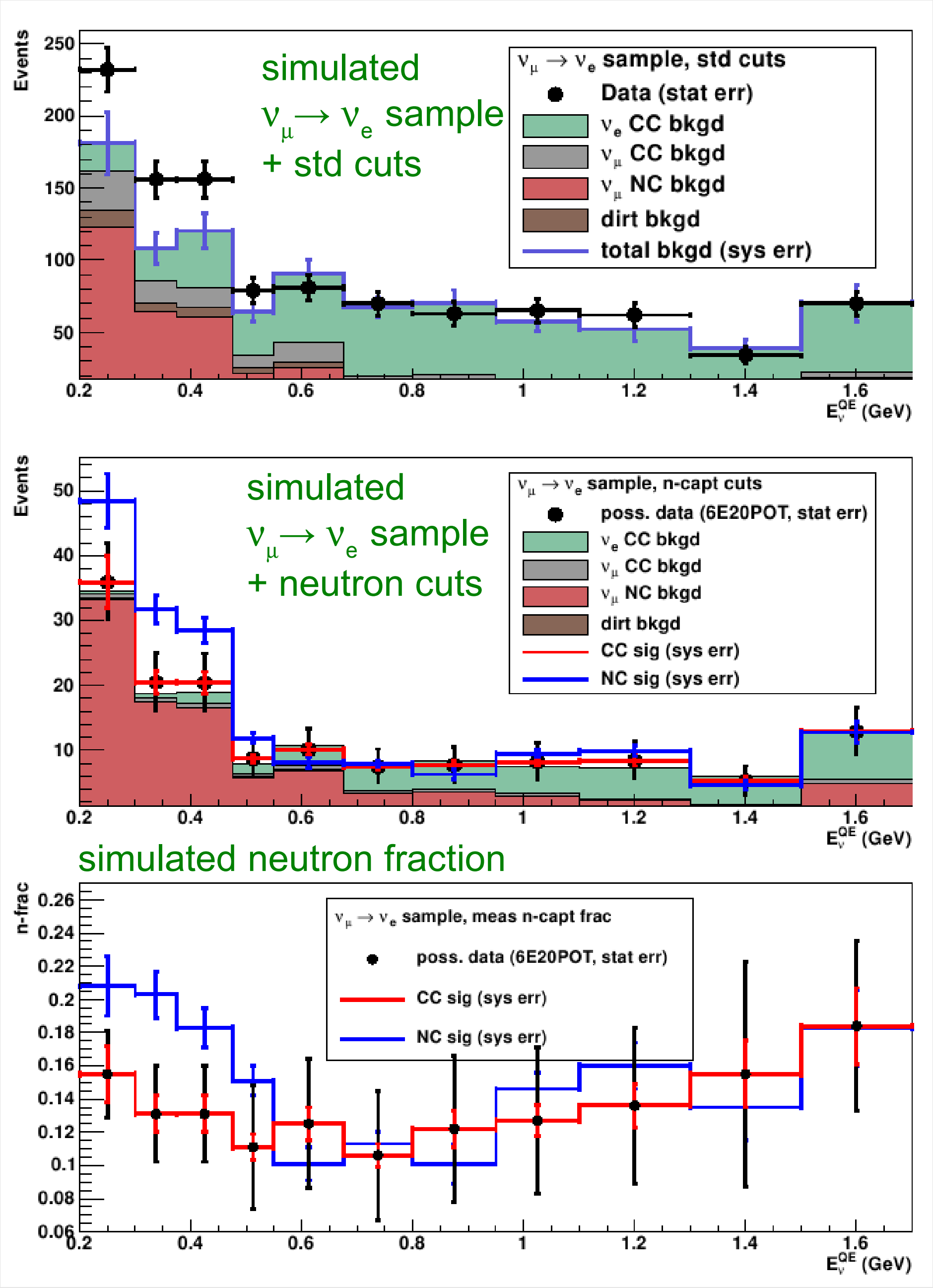
A new oscillation analysis of MB with scintillator has been simulated:

Assumptions:
- Previous ν oscillation experiment performed with same cuts and same statistics (6.5E20POT)
  - reconstruction performance same as previous
  - same excess is seen in this analysis (top plot)

- Then n-capture events are required and a reduced data set is obtained (middle plot)

Assumptions:
  - excess is due to oscillations (CCQE events)
  - CC event n-fraction = 1%(250 MeV) - 10%(1GeV), includes final state effects and has been measured.
  - NC event n-fraction = 50%. From Δ dominance in both NCγ and NCπ^0
  - 50% n-capture efficiency
  - 2% accidental n-capture probability
  - systematic errors assigned to all these and variational studies performed.

Note that data excess disappears in middle plot and is same as CC prediction (red lines). If excess due to NC background (blue lines), then excess remains.



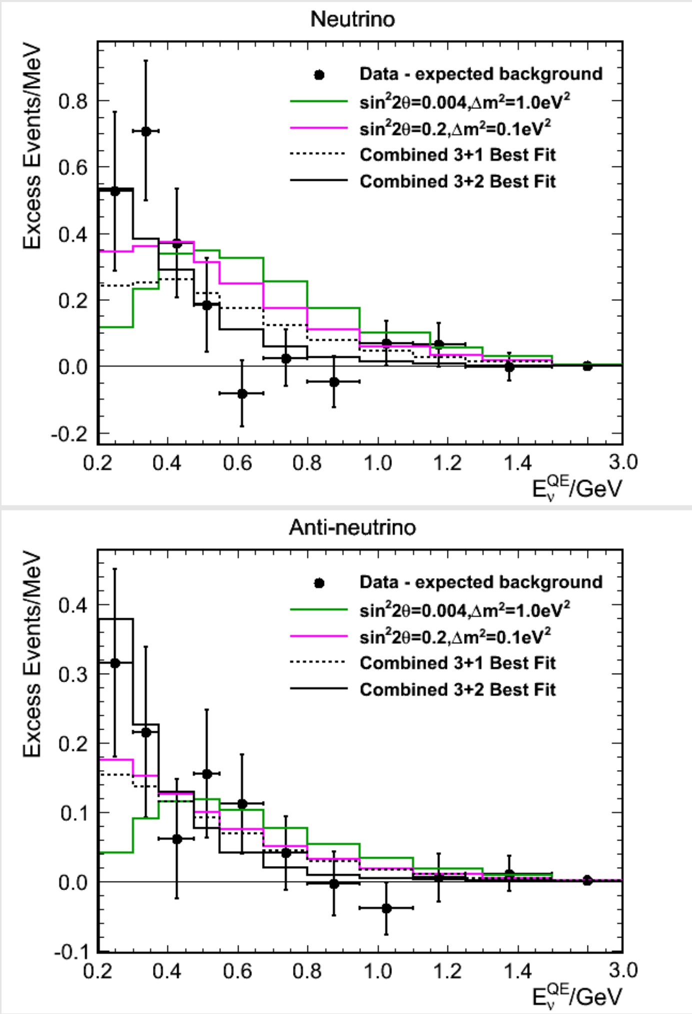
Simulated Analysis

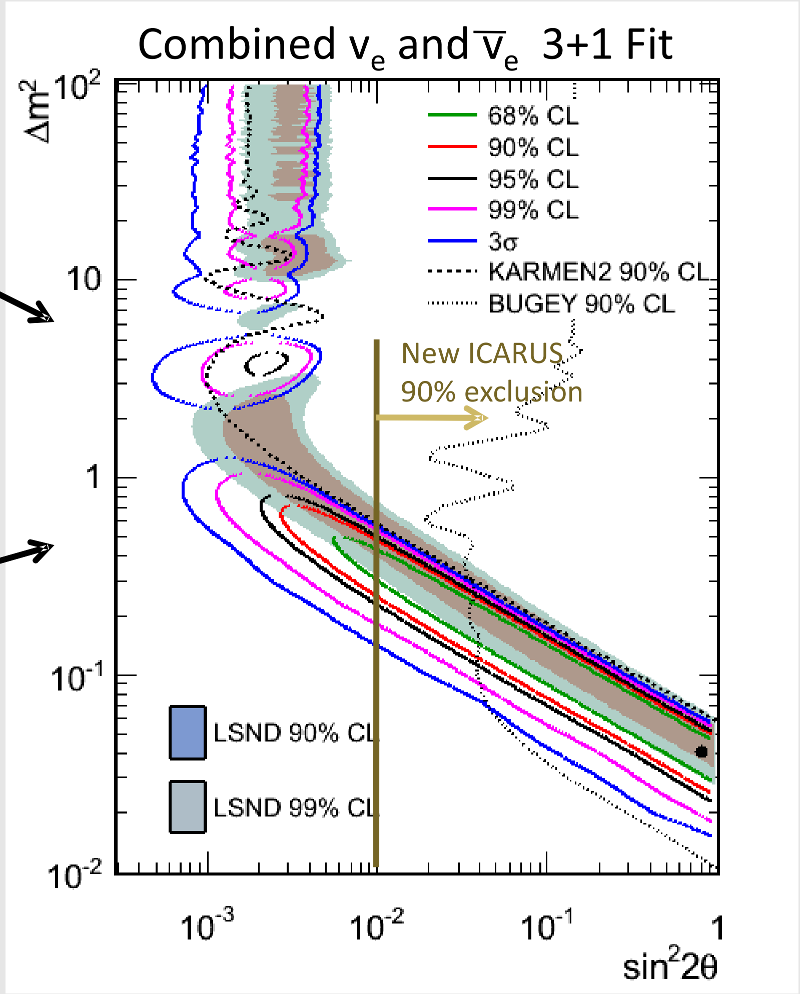
If excess is CC oscillation signal, then separation from NC hypothesis is 3.5σ for this NC/CC test. Combined with expected neutrino-mode excess in 1st stage analysis (of 3.4σ) yields ~5σ

Variations of study assumptions performed.
- POT, statistics limited study, need 6.5E20POT
- background rejection important to achieve sensitivity.

	neutron fraction			
configuration	NC prediction	fake data	difference	$n\sigma$
standard	0.191 ± 0.008	0.134 ± 0.015	0.057 ± 0.016	**3.48**
4E20POT	0.191 ± 0.008	0.134 ± 0.018	0.057 ± 0.019	2.95
2E20POT	0.191 ± 0.008	0.134 ± 0.026	0.057 ± 0.027	2.16
(bckgnd error)×0.5	0.191 ± 0.005	0.134 ± 0.015	0.057 ± 0.015	3.73
(n-capture efficiency)=0.75	0.277 ± 0.012	0.191 ± 0.018	0.086 ± 0.021	4.13
(accidental efficiency)×2	0.211 ± 0.008	0.154 ± 0.016	0.057 ± 0.017	3.29
(CC n-fraction)×2	0.191 ± 0.008	0.137 ± 0.015	0.054 ± 0.017	3.26
(low-E CC n-fraction)=0.06	0.199 ± 0.008	0.147 ± 0.015	0.051 ± 0.017	3.00
(NC n-fraction error)×2	0.191 ± 0.010	0.134 ± 0.015	0.057 ± 0.017	3.31
dirt n-fraction=0.5	0.203 ± 0.008	0.145 ± 0.015	0.057 ± 0.017	3.32
(NC bckgnd)×2	0.215 ± 0.011	0.175 ± 0.014	0.040 ± 0.017	2.29
(NC bckgnd)×2 + ∞ POT	0.215 ± 0.011	0.175 ± 0.000	0.040 ± 0.010	3.81
(NC n-fraction)= 0.42	0.165 ± 0.006	0.117 ± 0.014	0.048 ± 0.015	3.17
∞ POT	0.191 ± 0.008	0.134 ± 0.000	0.057 ± 0.008	7.63

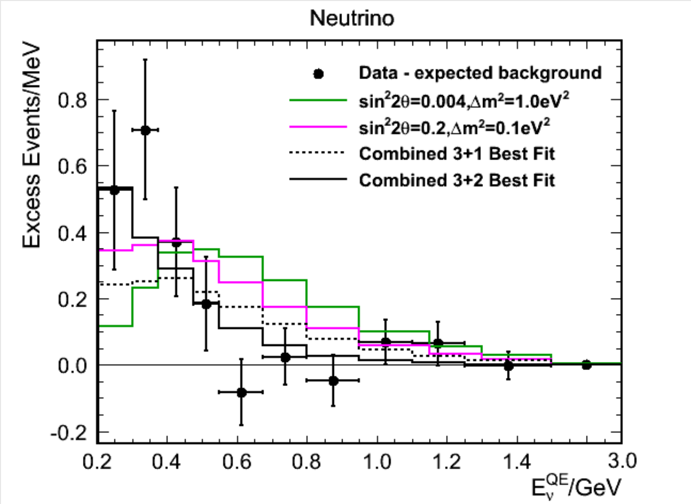
Ten Years of MiniBooNE Running: Oscillation Results





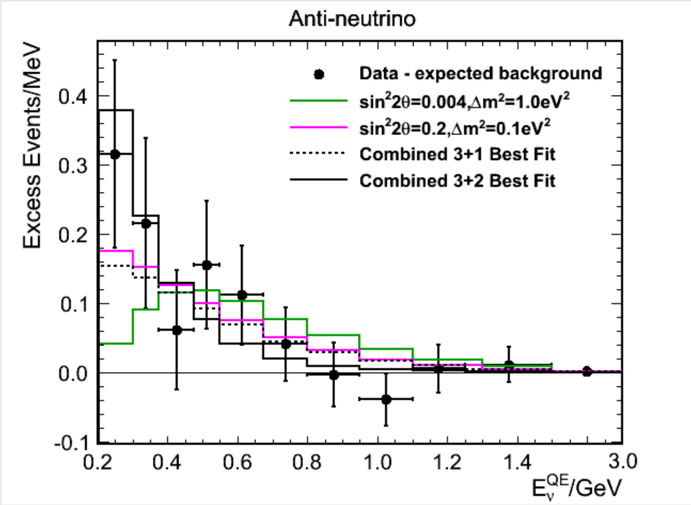
- Combined ν_e and $\bar{\nu}_e$ Event Excess from 200-1250 MeV = 240.3+-34.5+-52.6 (3.8σ)

Ten Years of MiniBooNE Running: Oscillation Results



6.7e20 POT neutrino mode

ν mode	E > 200 MeV	E > 475 MeV
χ^2(null)	22.81	6.35
Prob(null)	0.5%	36.6%
χ^2(bf)	13.24	3.73
Prob(bf)	6.12%	42.0%

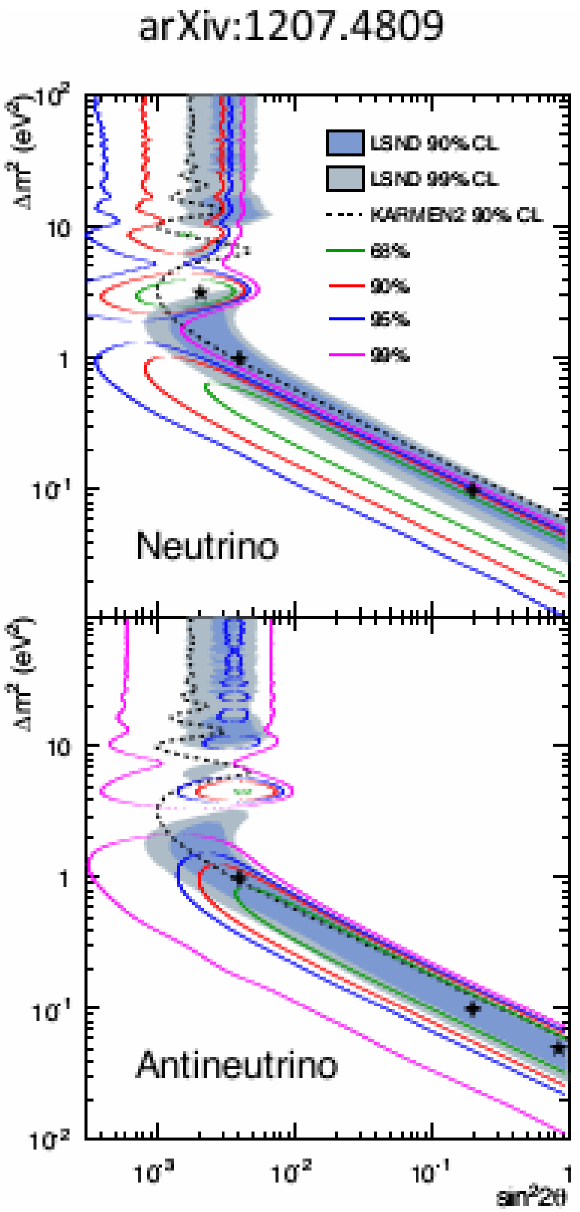


11.3e20 POT anti-neutrino mode

$\bar{\nu}$ mode	E > 200 MeV	E > 475 MeV
χ^2(null)	16.3	7.59
Prob(null)	5.8%	26.4%
χ^2(bf)	4.76	3.23
Prob(bf)	67.5%	50.2%

MiniBooNE Allowed Regions

arXiv:1207.4809



Neutrino

$P_{bf} = 6.1\%$, $P_{null} = 1.6\%$

Antineutrino

$P_{bf} = 67.5\%$, $P_{null} = 0.5\%$