Short Baseline Neutrino Program @ Fermilab (MicroBooNE et al)

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Overview

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- Strong physics case for SBL neutrino experiments
- Neutrino physics is now also precision physics
- Precision detectors (LArTPC) are available
- Timeliness (experiments, strategies, education)

Interesting signals from short baseline experiments (<1km)

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

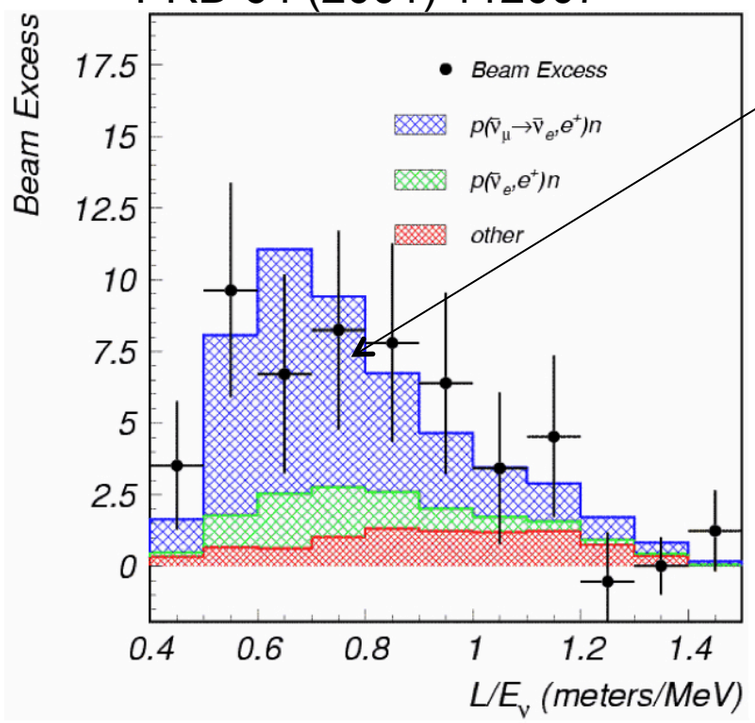
K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

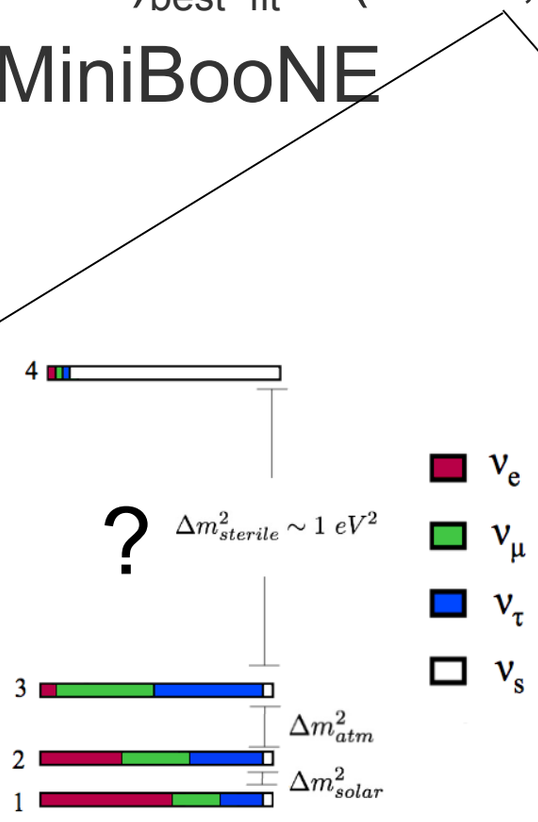
- Physics case for Short Base-Line experiments
- No discovery if taken separately,
  but together they could be a hint at something new
- Most common interpretation: evidence for high mass-squared neutrino oscillations
  - existence of additional, mostly “sterile” neutrino states with masses at or below a few eV ?
- Tension for global fits
  - signal vs. exclusions, nu vs. nubar, appearance vs. disappearance

High Δm^2 results

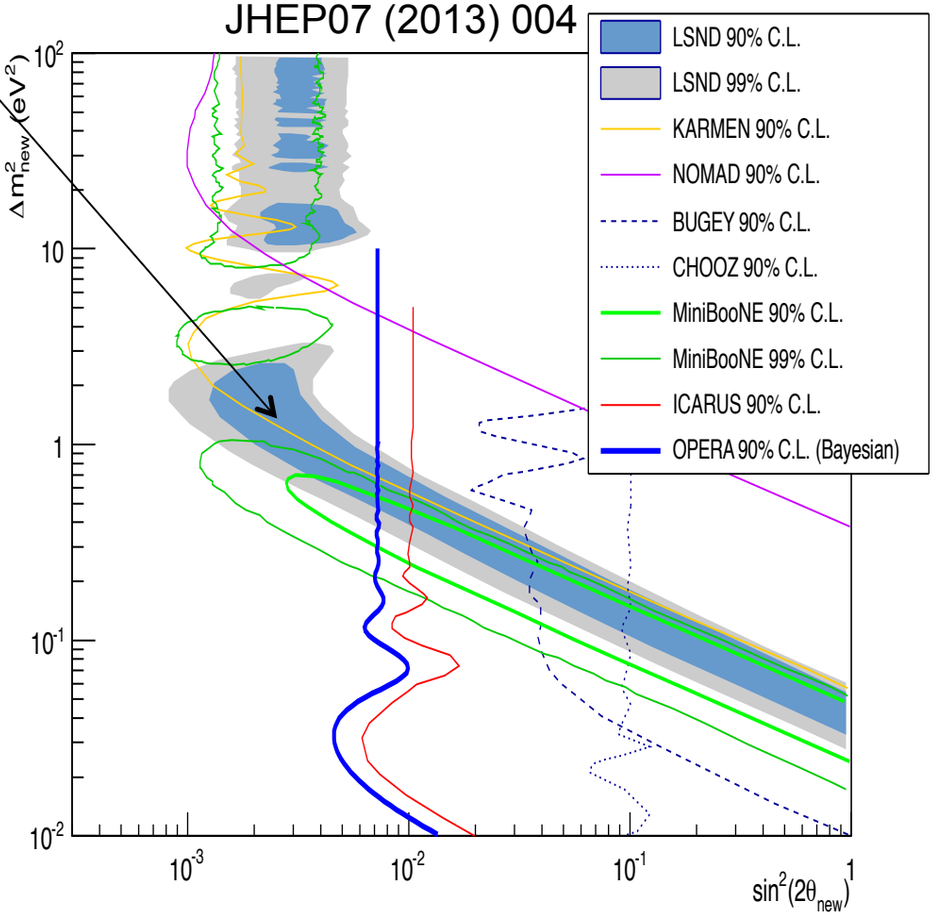
- LSND most significant excess (anti-ν_e in an anti-ν_μ beam)
  - High Δm^2 $(\sin^2 2\theta, \Delta m^2)_{\text{best-fit}} = (0.003, 1.2 eV^2)$
- Further excess by MiniBooNE

PRD 64 (2001) 112007





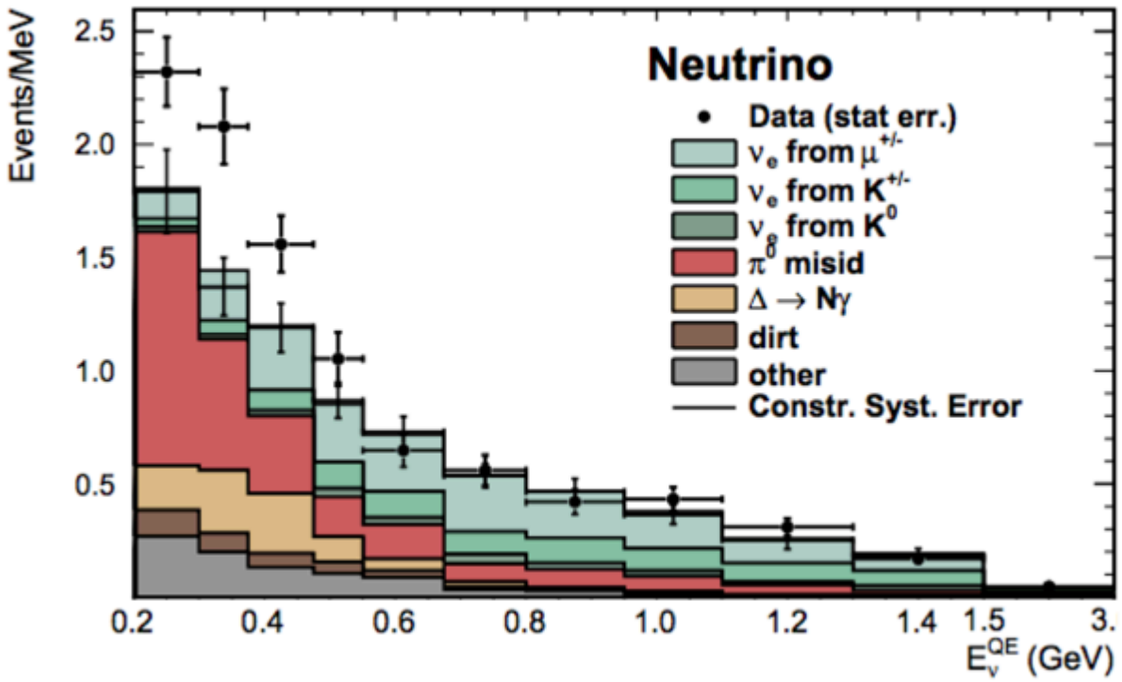
JHEP07 (2013) 004

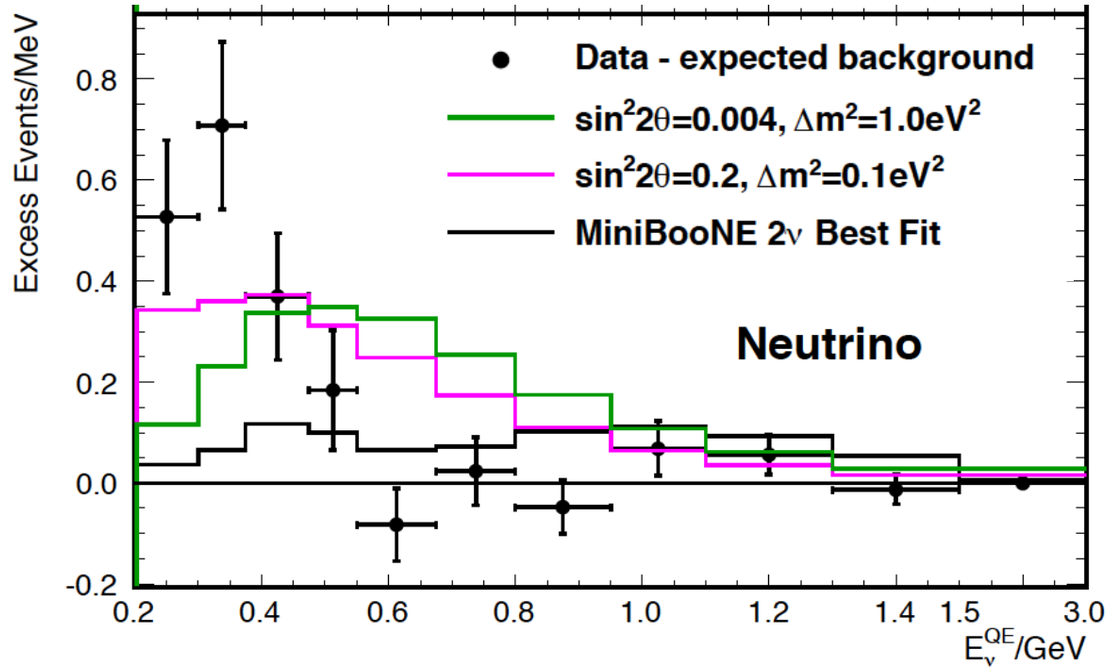


- Based on 2-neutrino oscillation: $P = \sin^2 2\theta \cdot \sin^2 \frac{\Delta m^2 L}{4E}$

More from MiniBooNE

Phys. Rev. Lett. 110 161801 (2013)



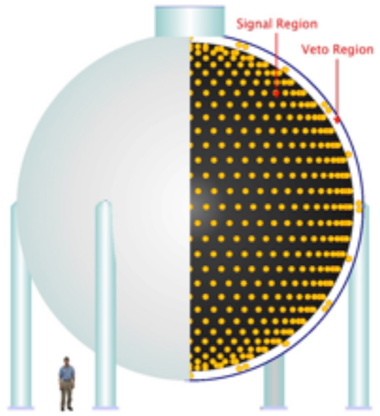


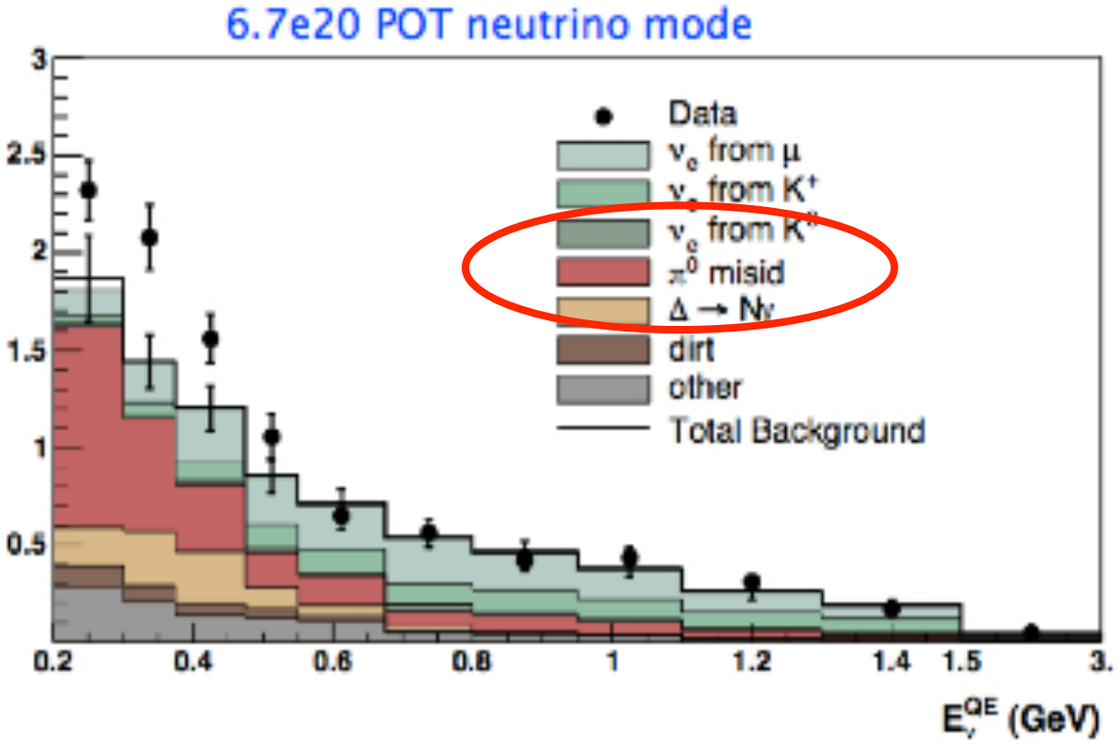
- Excess of ν_e in ν_μ beam **at low energy**
- Similar excess for anti-neutrinos
- No easy global fit for oscillations

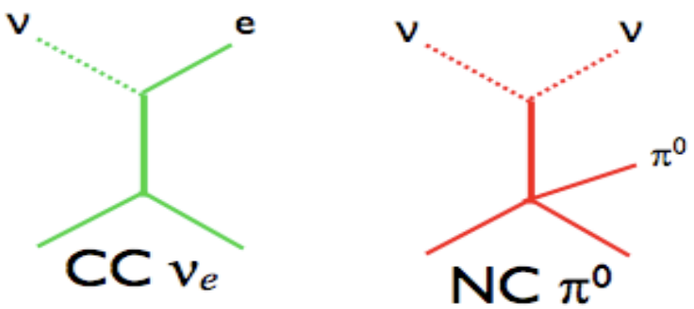
Conclusion -> Need more experimental input !

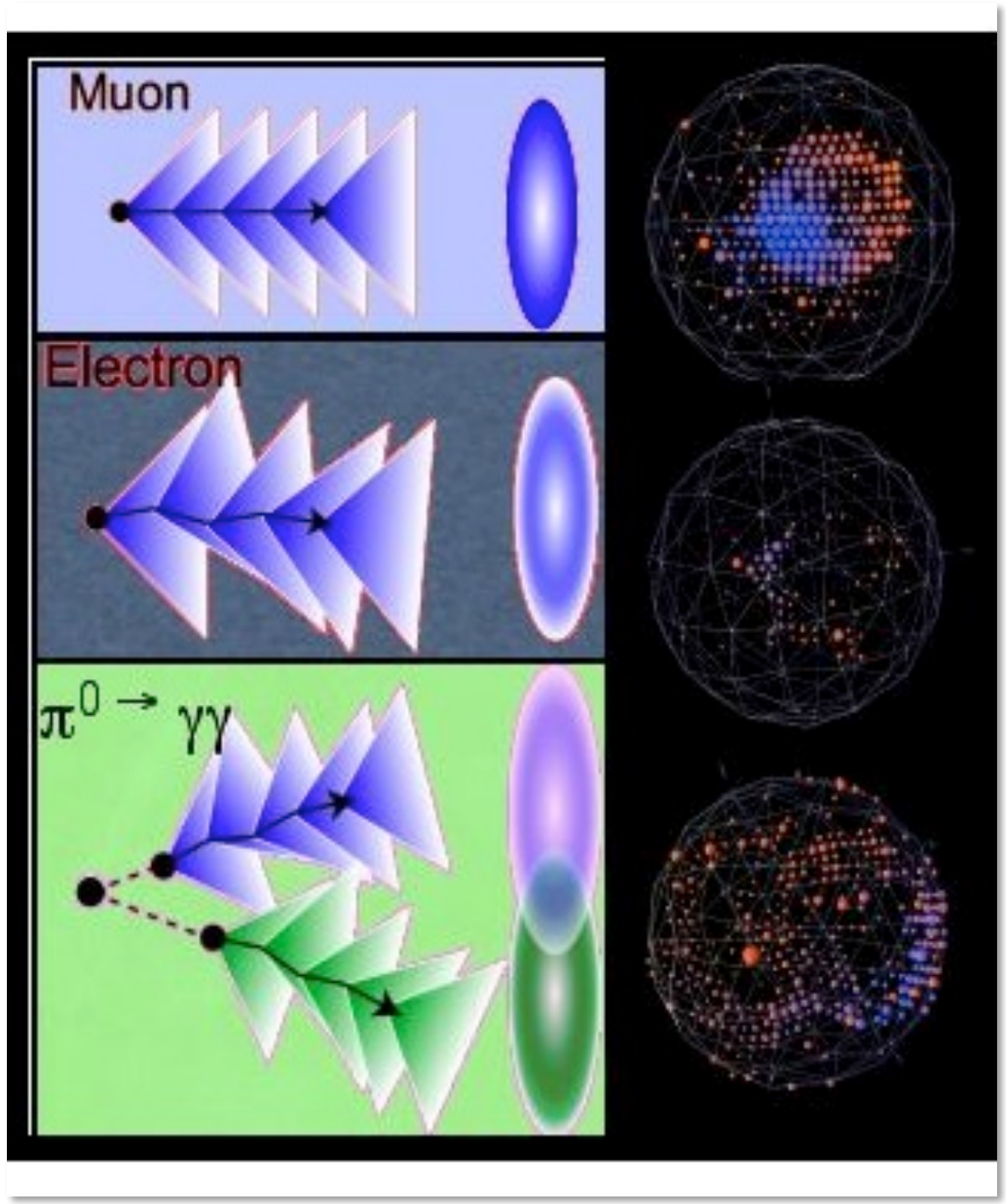
For the low energy excess: stay as close as possible to the MiniBooNE conditions

MiniBooNE Detector









- A better measurement needs to address this largest background

C. Rubbia,
CERN-EP, 77-08, 1977

Liquid Argon TPC

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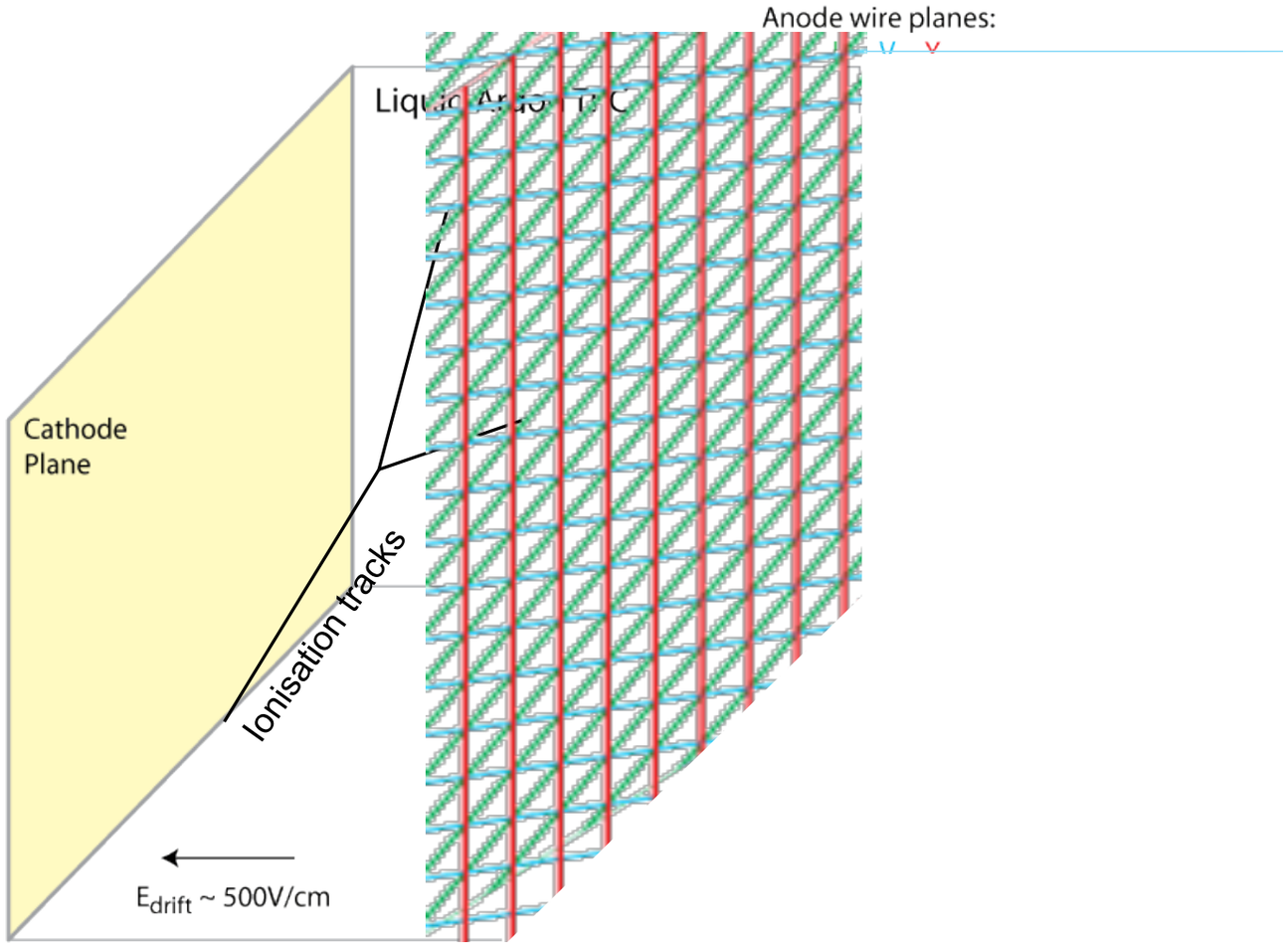
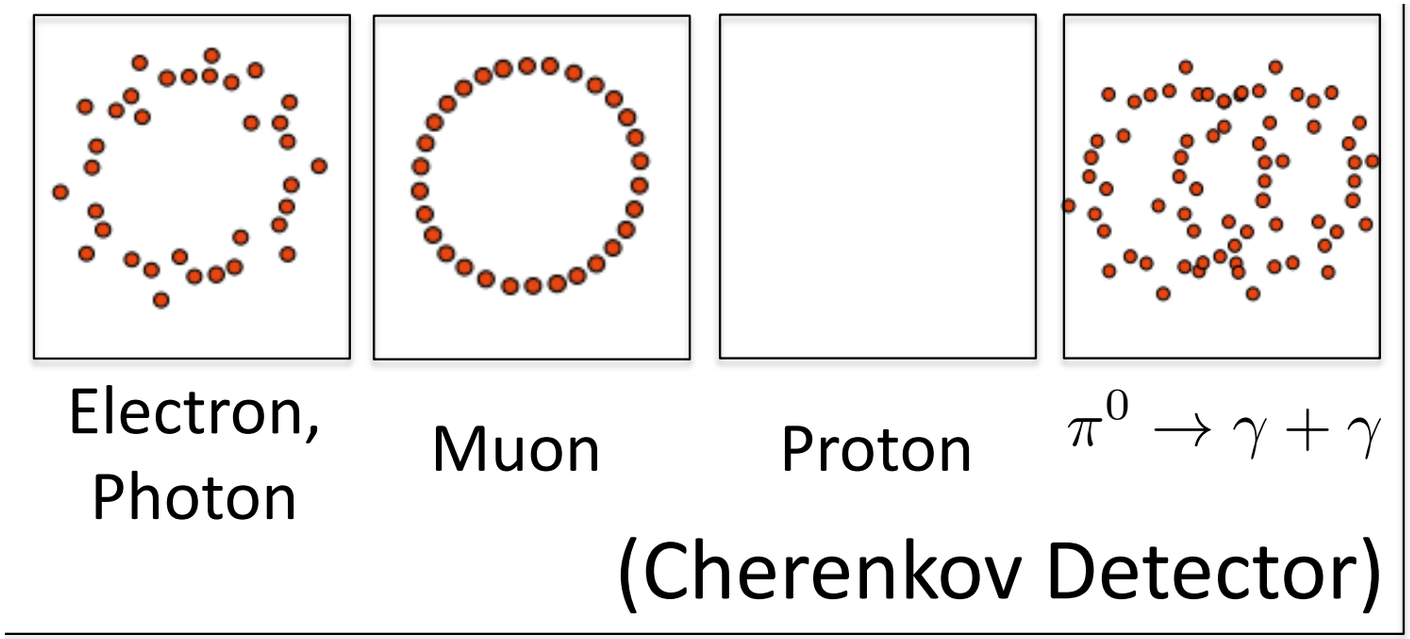
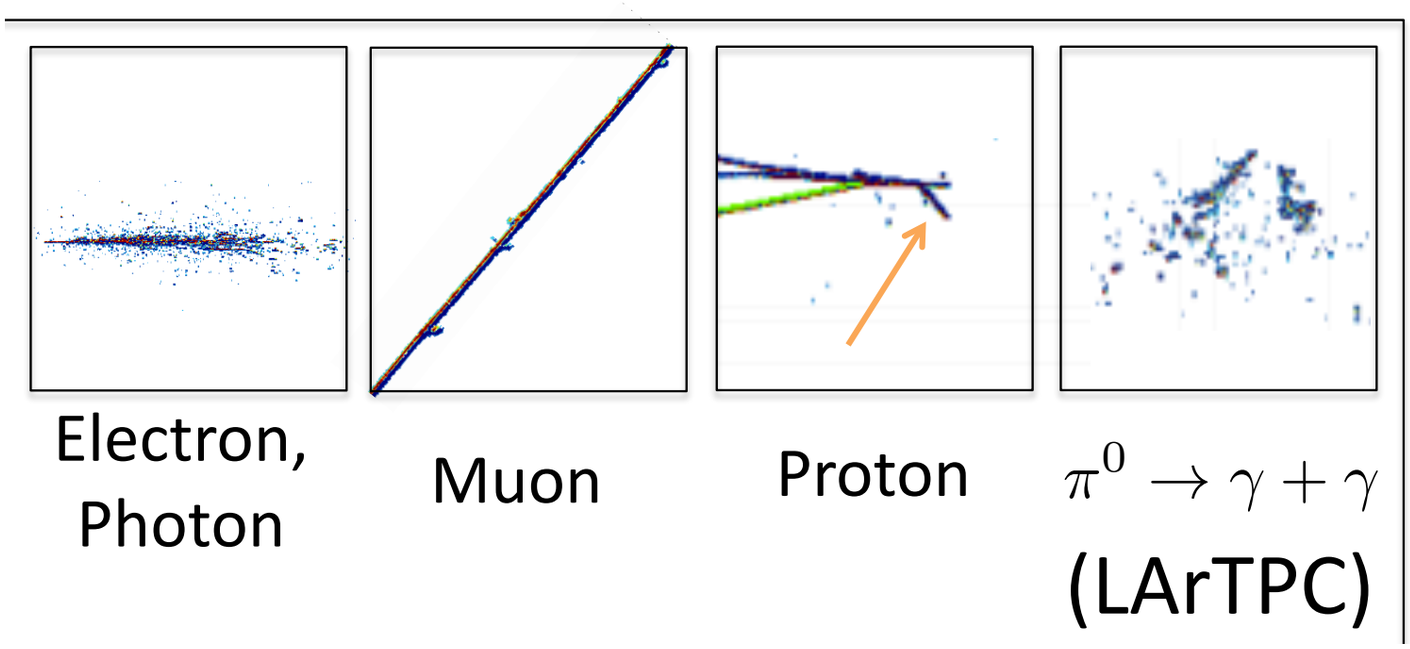


Liquid argon:

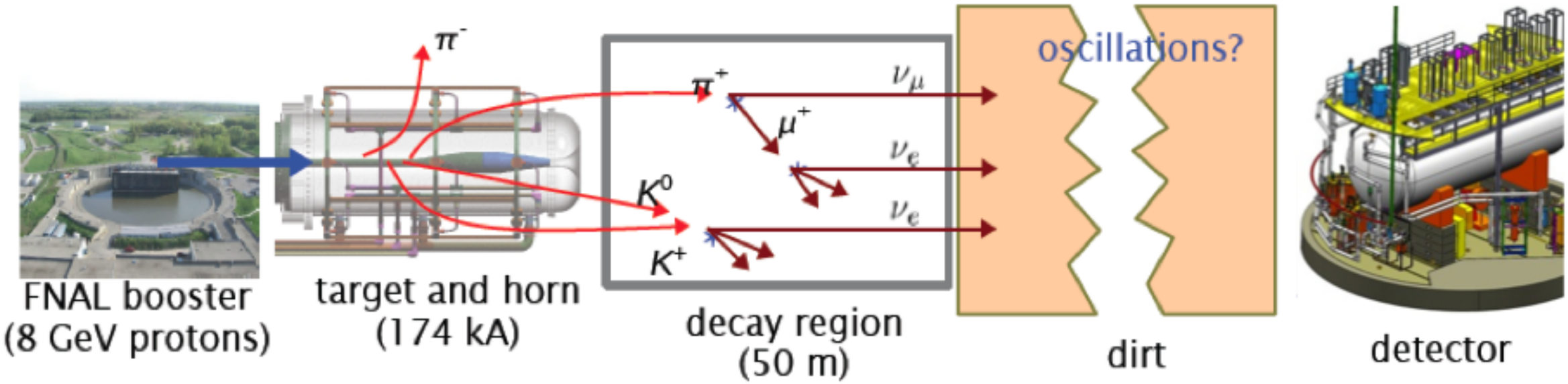
→ dense (1.4 g/cm^3), liquid at 87K
→ abundant (1% of the atmosphere)
→ ionization yield of 55,000 e/cm for a MIP
→ high electron mobility (545 (cm/s)/(V/cm) at 87 K)
→ scintillates and is transparent to the produced light

LArTPCs can see the interactions

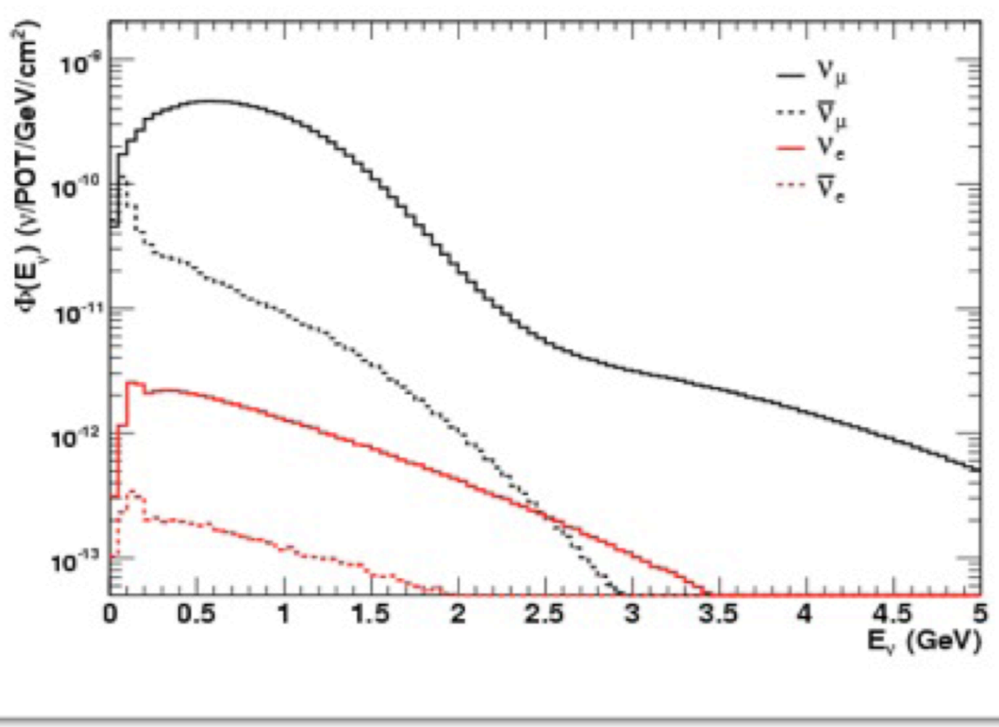




MicroBooNE:
A “classical” short baseline experiment

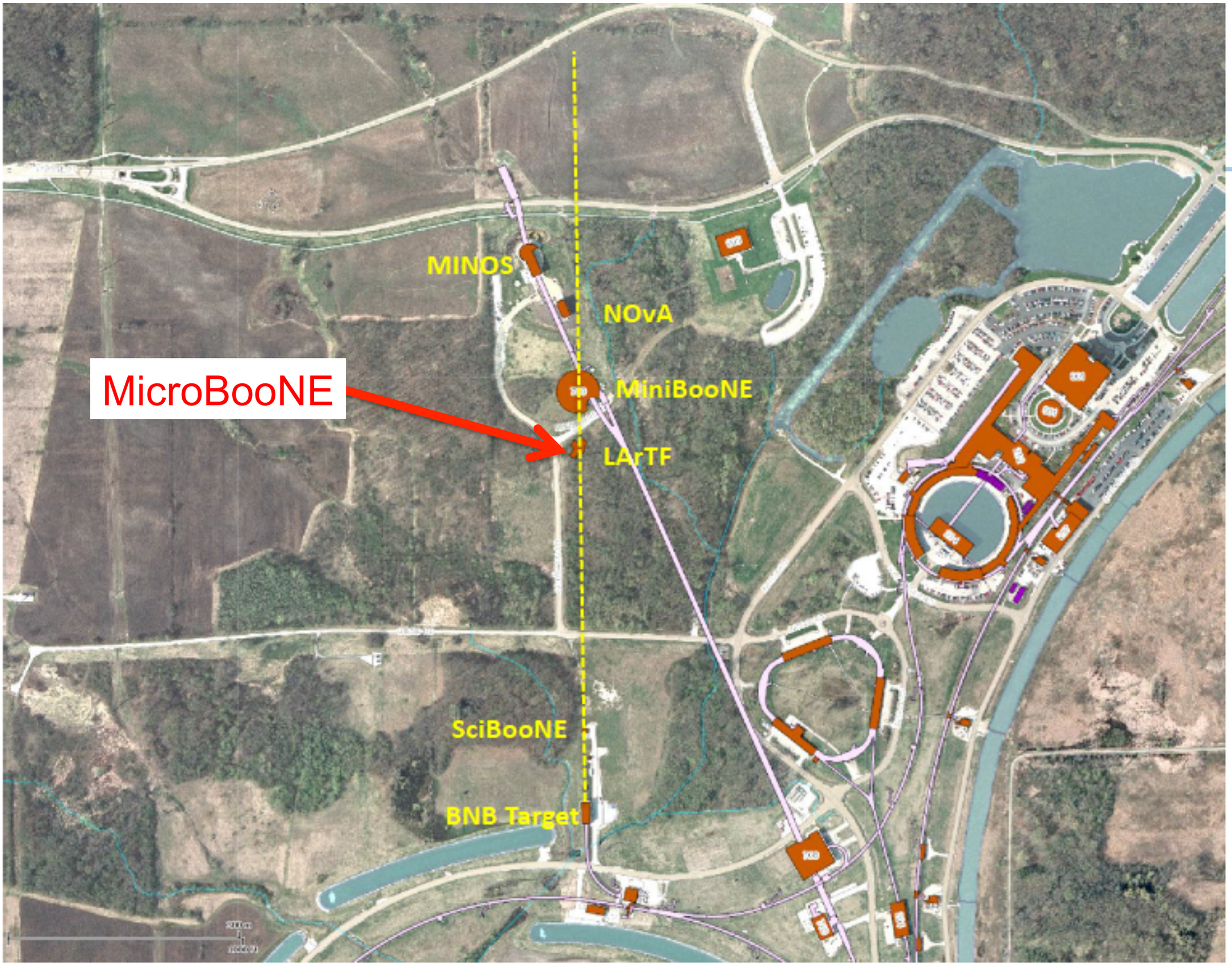


Booster Neutrino Beam



(@470 m from the source)

- Planned experiment turn-on **this year**
- Well known Booster Neutrino Beam
- In 3 years expect
  - 6.6×10^{20} Protons On Target
  - ~140 k events (Booster Neutrino Beam)


MINOS
NOvA
MiniBooNE
MicroBooNE
LArTF
SciBooNE
BNB Target

Electron / Photon separation

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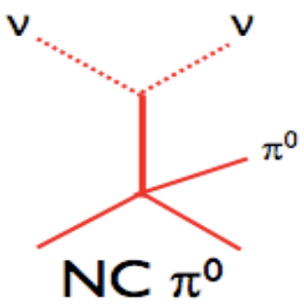
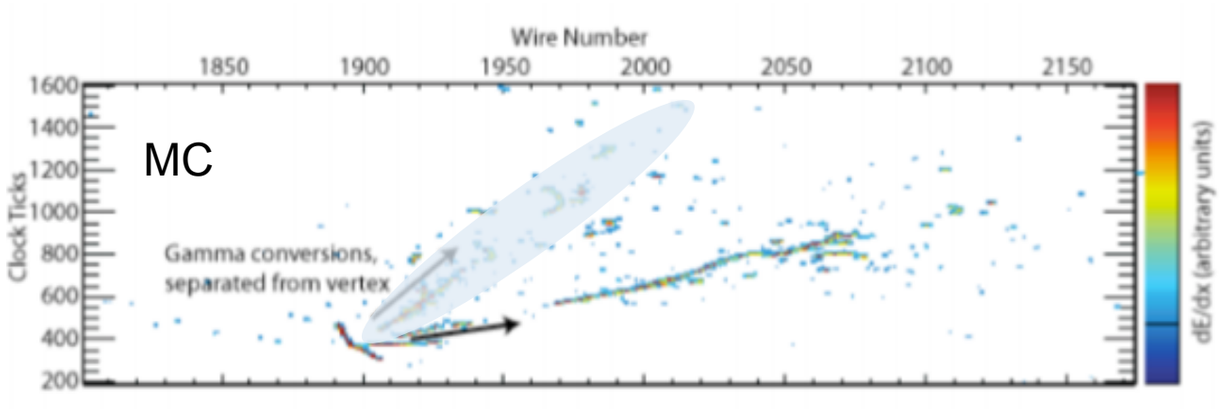
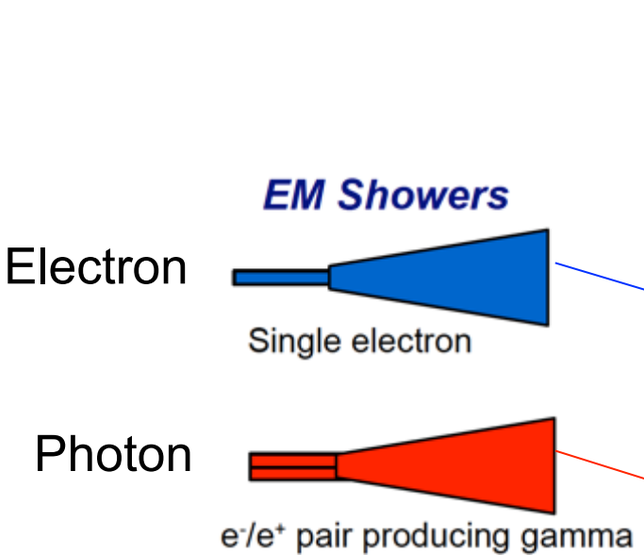
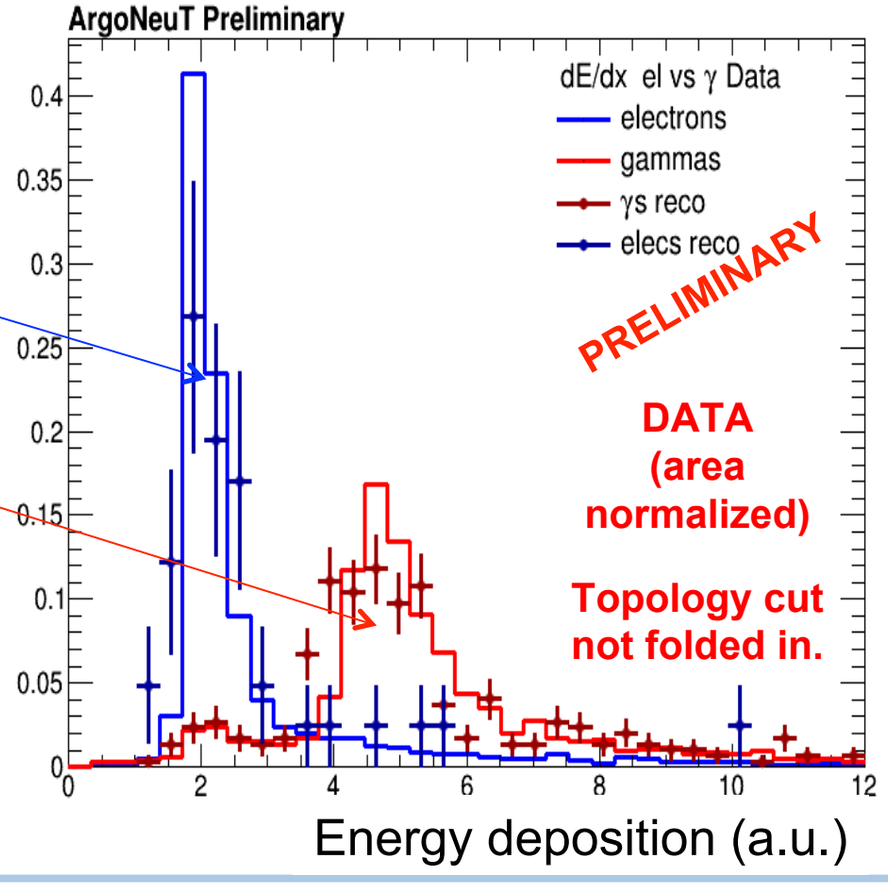




In about 1% of the events one photon from Pi0 is not seen

Large background in MiniBooNE

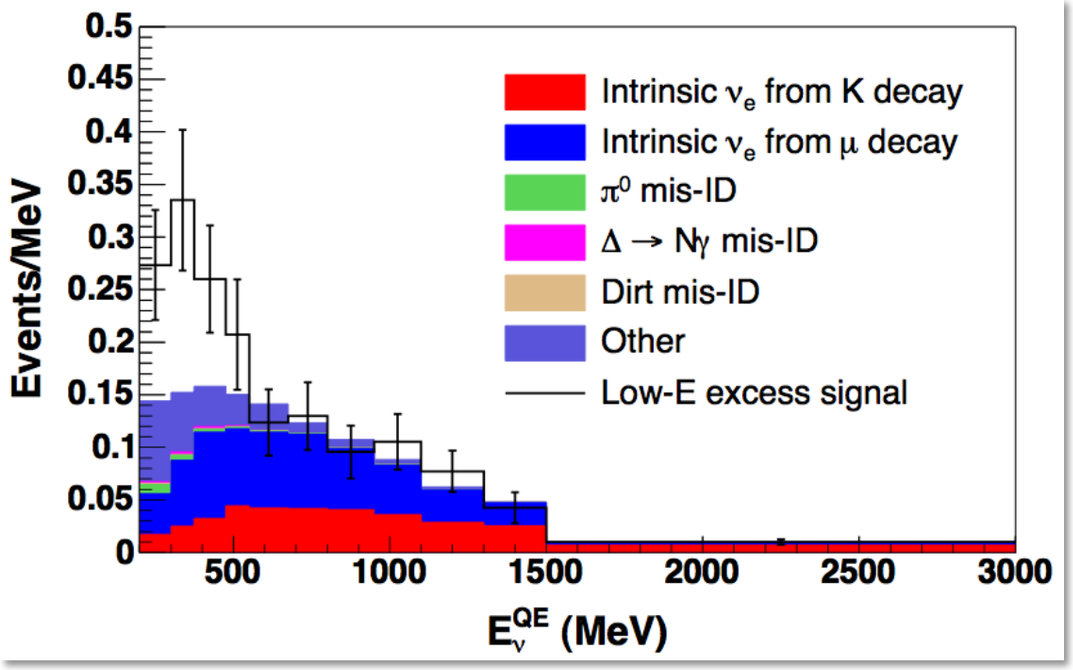




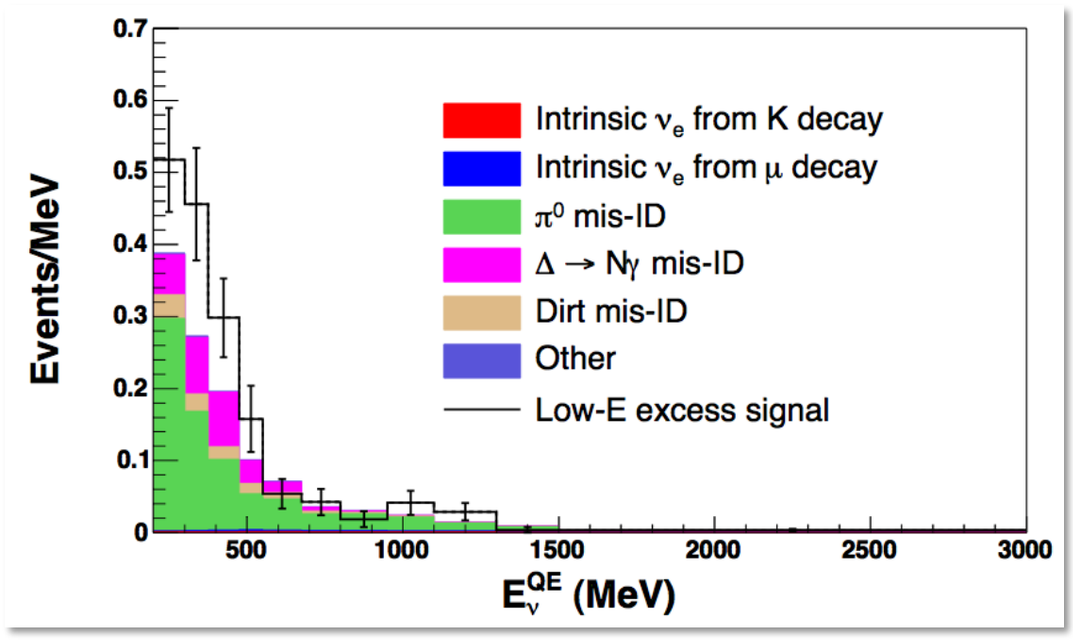
Less background in a LArTPC because photons and electrons can be separated

ArgoNeuT data vs. MC

Sensitivity to the low energy excess



Confirm an electron source: >5σ significance

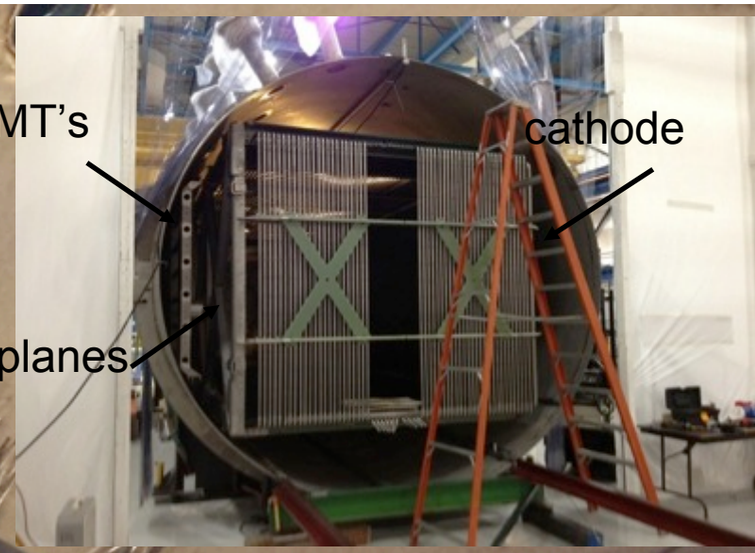


Confirm a photon source: >4σ significance

170 tons LAr (~60t fiducial)
Foam insulated cryo-volume

(2.5 x 2.3 x 10.4) m^3 TPC
2.5m charge drift
U,V,Y wire planes
Signal pre-amplification in liquid (cold)

PMT system (32 x 8”)



UV laser calibration system

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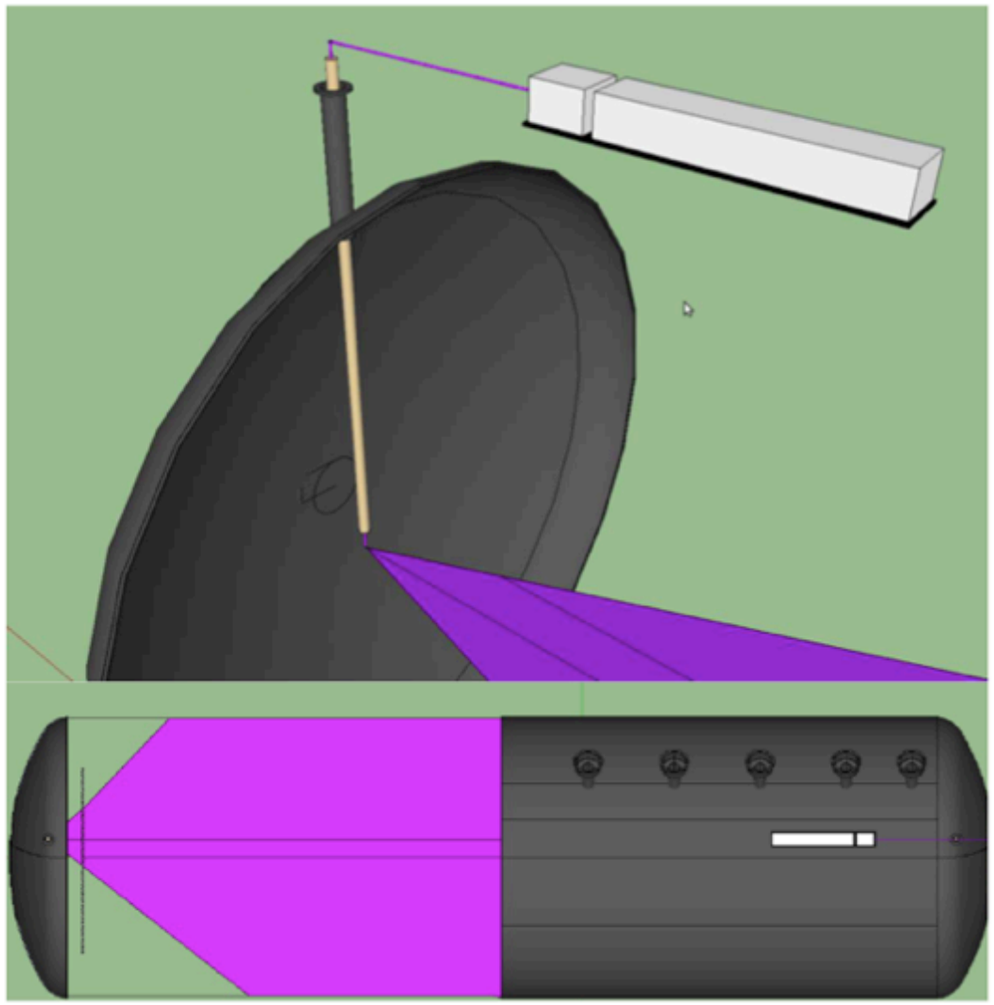
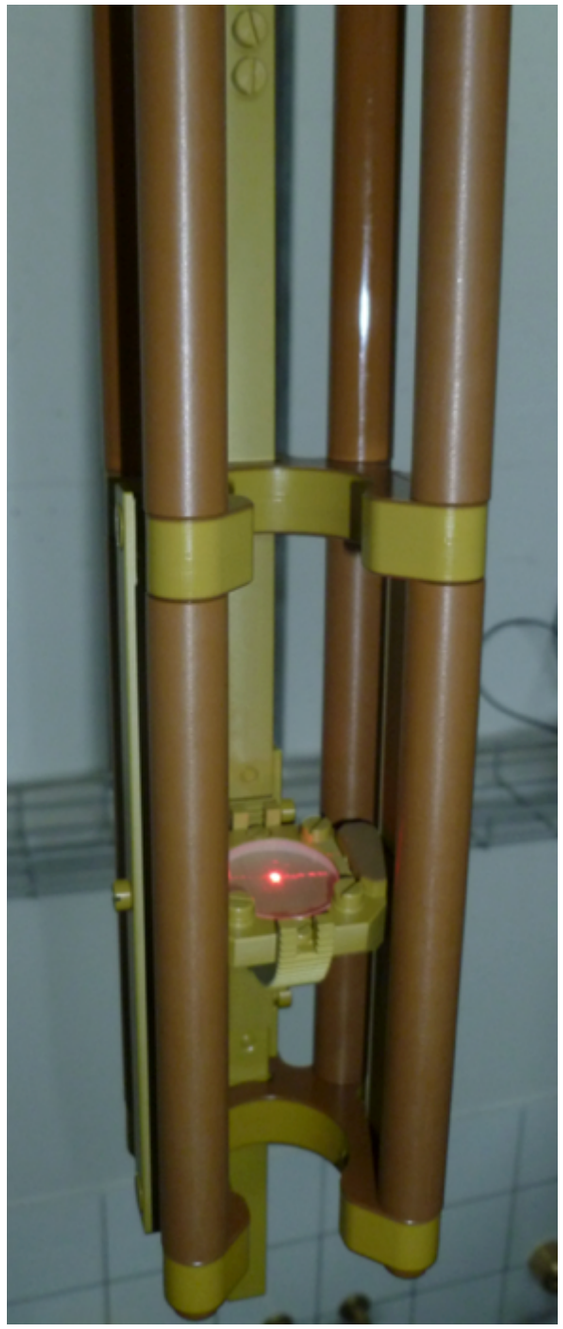


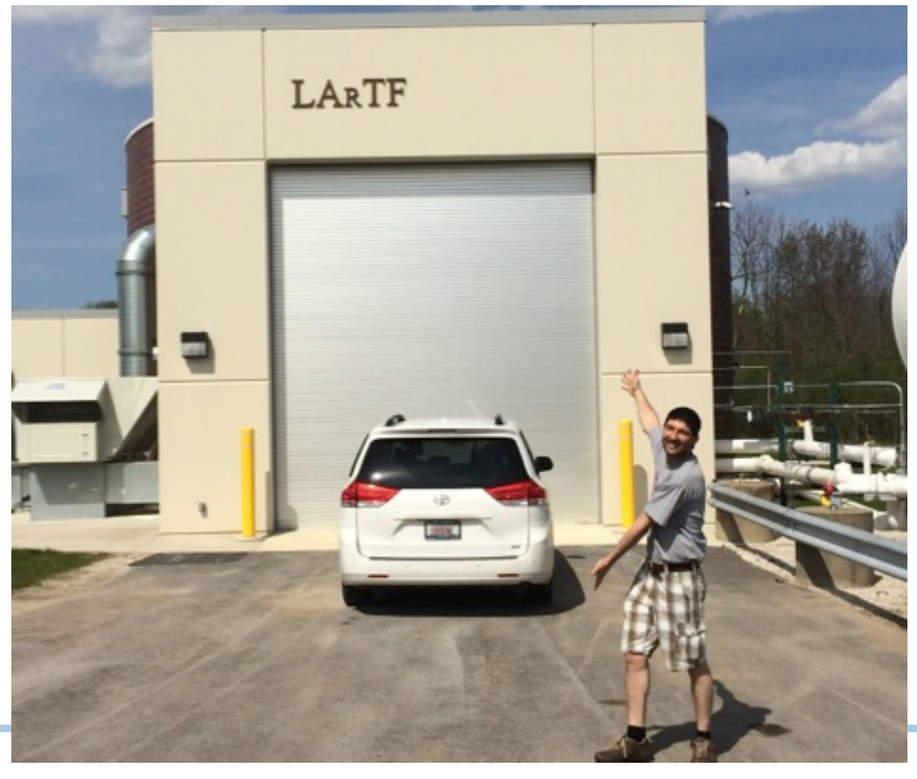
SWISS MADE



Detector “completed” May 30th 2014

Near Future – the move to LArTF

- The building is ready
- After final tests of all subsystems the Cryostat will move to the detector hall (week of June 23rd)
- Need to apply insulating foam and connect and test cryo and readout
- Then cooldown, filling and start data taking



Booster Neutrino Beam (BNB) and NUMI Beam

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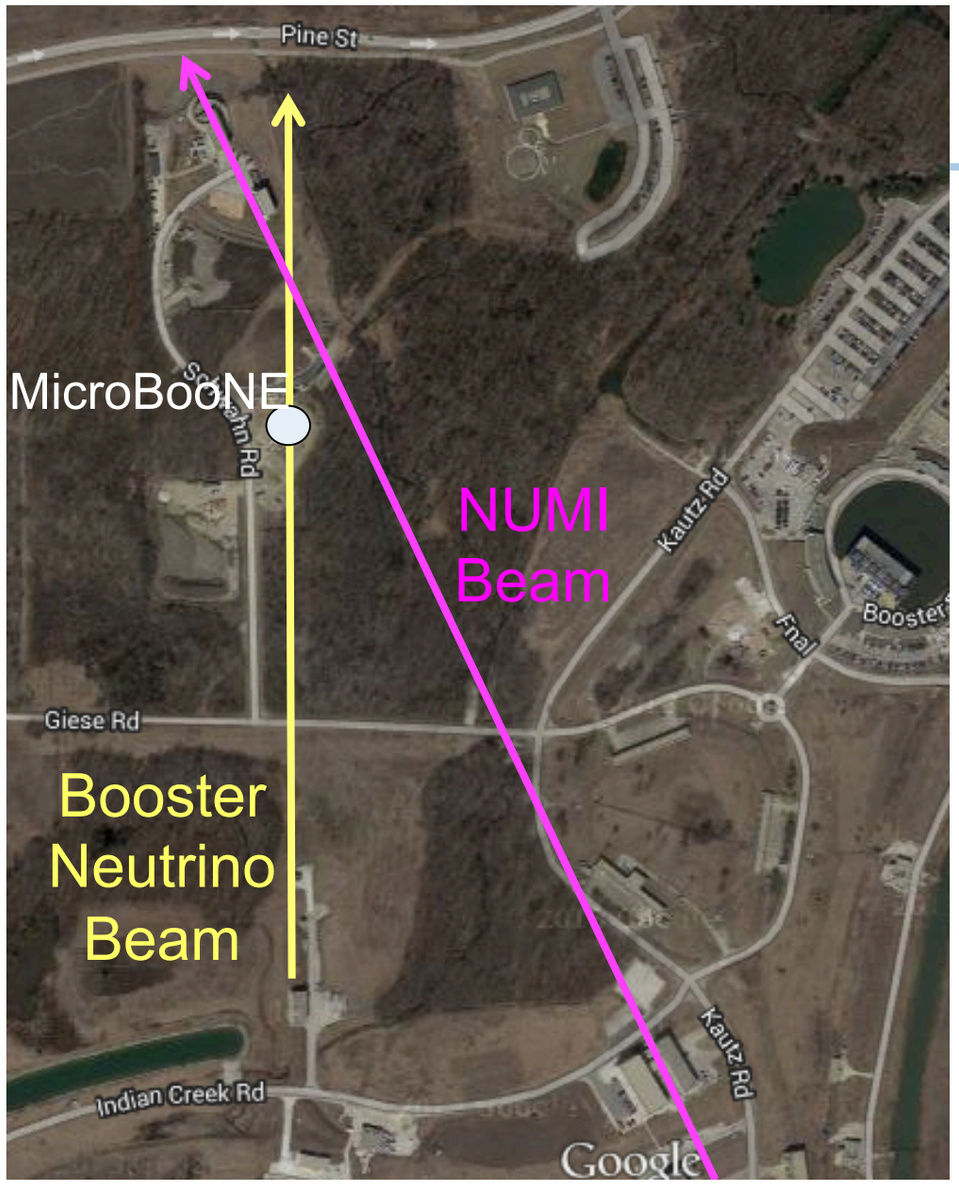
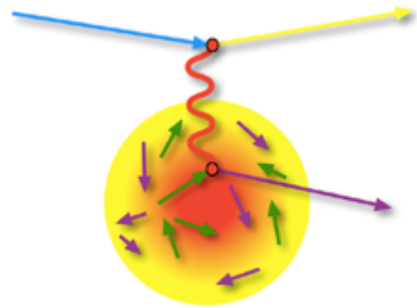
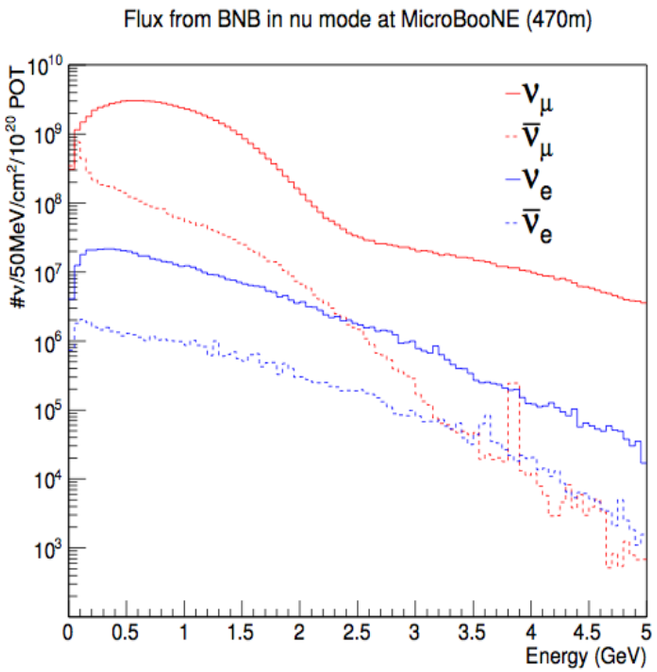
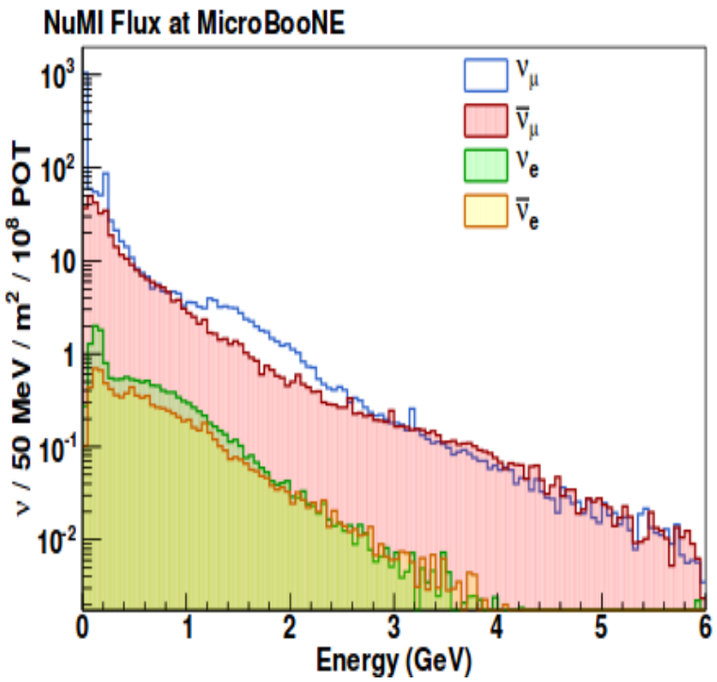


- Will be able to perform cross section measurements over a wide range of energy to develop and study nuclear interaction models
- Profit from 10 years of experience/knowledge of the BNB



6.6E20 POT	BNB	NuMI
Total Events	145k	60k
ν_μ CCQE	68k	25k
NC π^0	8k	3k
ν_e CCQE	0.4k	1.2k
POT	6×10^{20}	8×10^{20}





ArgoNeuT: LArTPC in a neutrino beam

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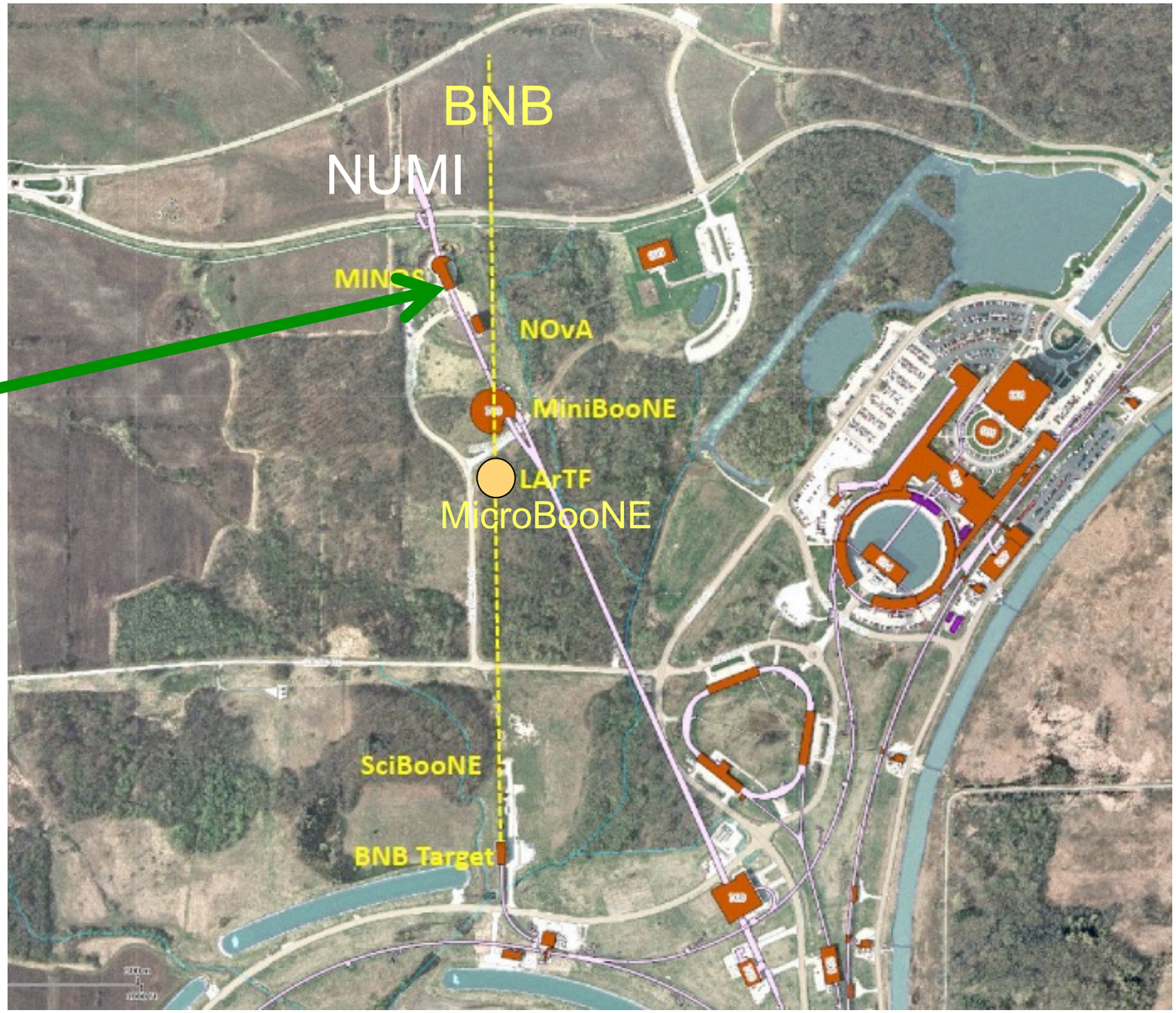

ArgoNeuT

ArgoNeuT

JINST 7 (2012) P10019

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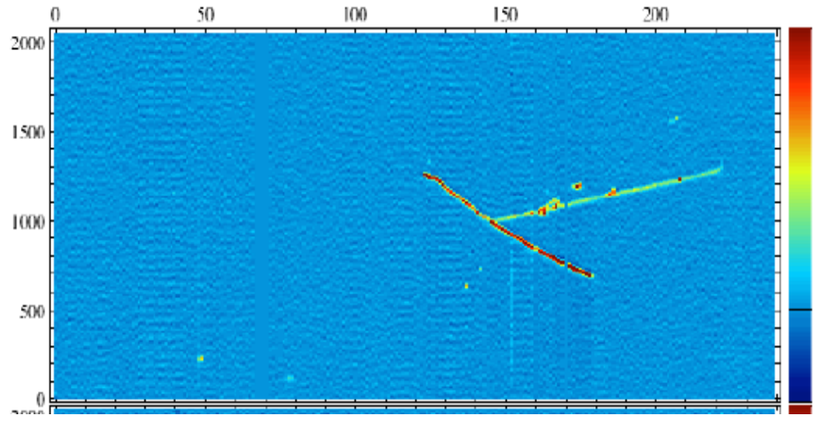
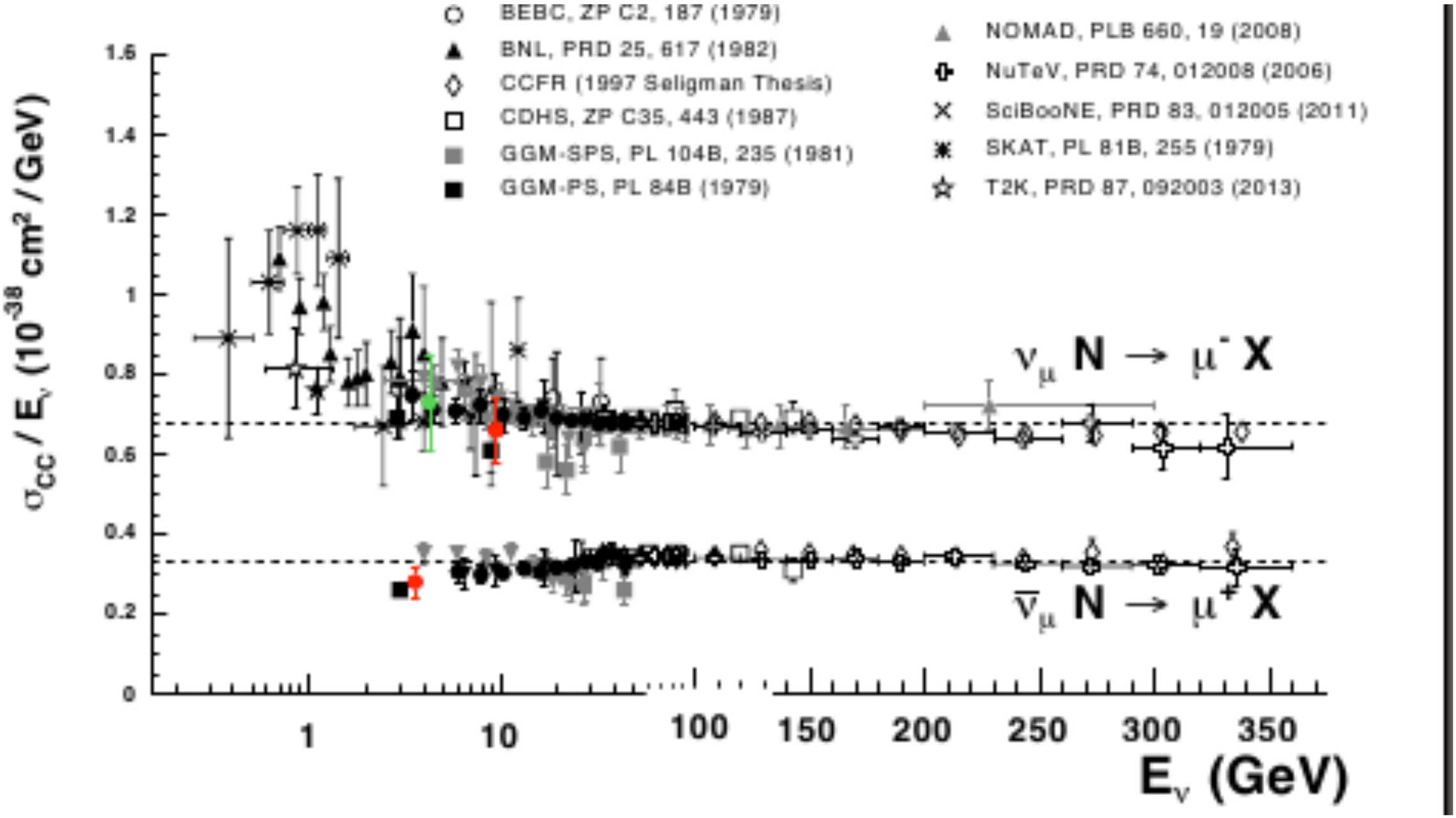
- Test **LAr TPC** put in the NUMI beam **at Fermilab** 2009-2010
- In front of MINOS-ND, from which the muon reconstruction was used
- **JINST 7 (2012) P10020**
  - Analysis of a large sample of neutrino-induced muons
- **JINST 8 (2013) P08005**
  - Study of electron-ion recombination
- **Phys. Rev. Lett. 108 (2012) 161802**
  - First neutrino cross-section measurement on Argon
  - Uses two weeks of neutrino beam data
- **Phys. Rev. D 89 (2014) 112003**
  - Differential cross sections for neutrino and anti-neutrino from 5 months of data
- **ArXiv:1405.4261 (submitted to PRD)**
  - Observation of back-to-back proton events (short range nuclear correlations)

Physics !



ArgoNeuT

Phys. Rev. D 89 (2014) 112003, published June 9th, 2014



Embedding in a Short Baseline Program

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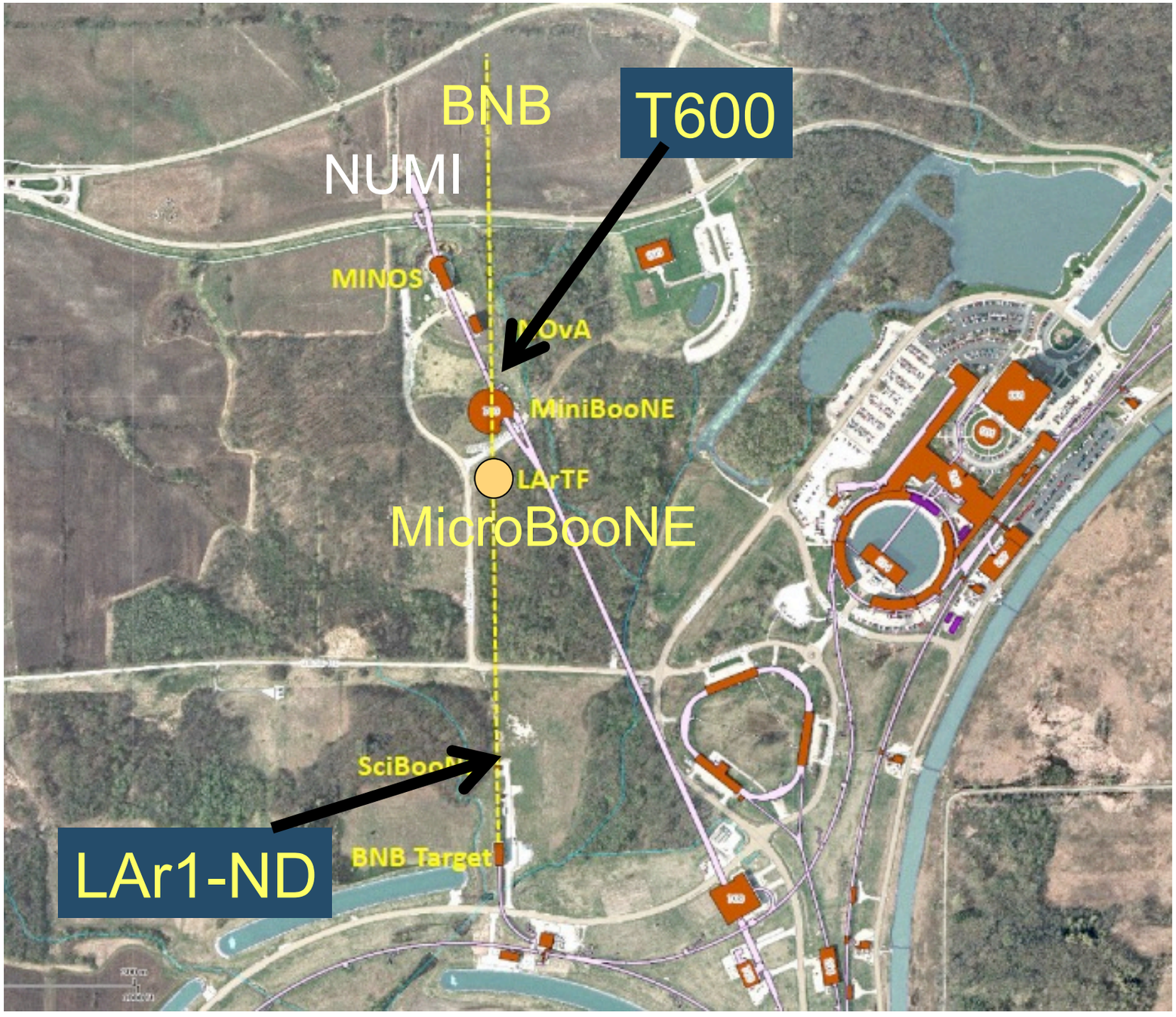
P5
5 “physics drivers”

http://science.energy.gov/~/media/hep/hepap/pdf/May202014/P5MayHEPAP-Ritz.pdf

- **Recommendation 12: In collaboration with international partners, develop a coherent short- and long-baseline neutrino program hosted at Fermilab.**
- **Recommendation 15: Select and perform in the short term a set of small-scale short-baseline experiments that can conclusively address experimental hints of physics beyond the three-neutrino paradigm. Some of these experiments should use liquid argon to advance the technology and build the international community for LBNF at Fermilab.**

SBN infrastructure at Fermilab: add detectors

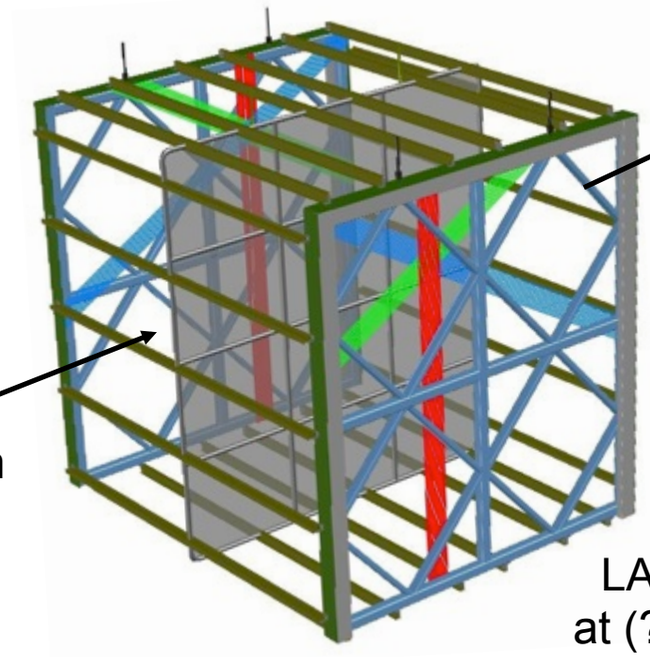


Oscillation and sterile neutrinos: multiple detectors

- LAr1-ND: a LAr TPC near detector with 82 t active mass
- Move ICARUS to Fermilab
- Run in conjunction with MicroBooNE on the BNB

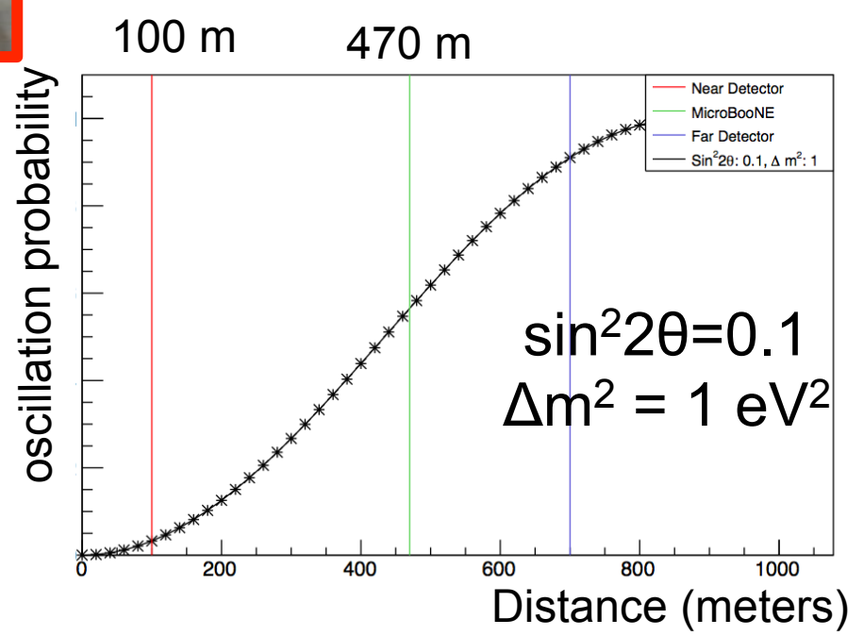
ICARUS
at (?)600m

MicroBooNE
at 470 m



v beam

LAr1-ND
at (?)100 m



LAr1-ND extension to MicroBooNE

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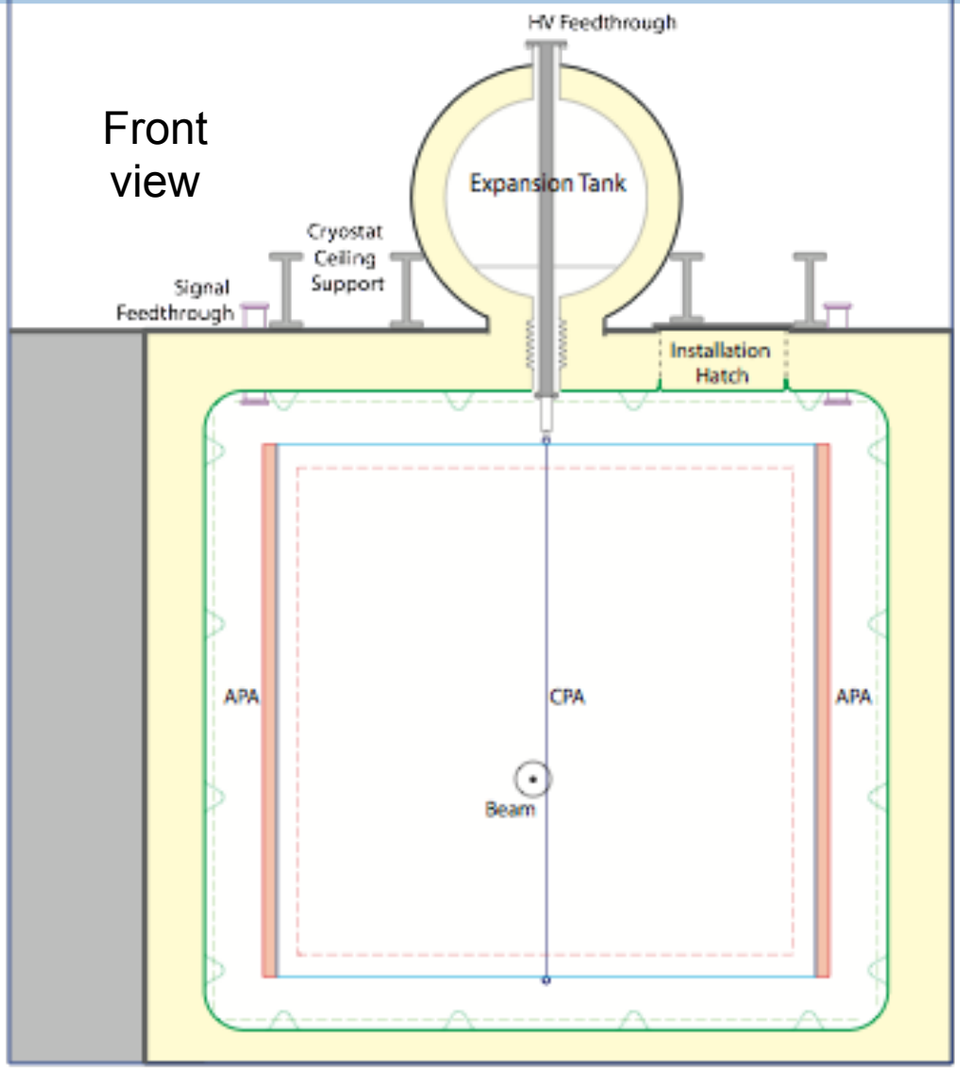
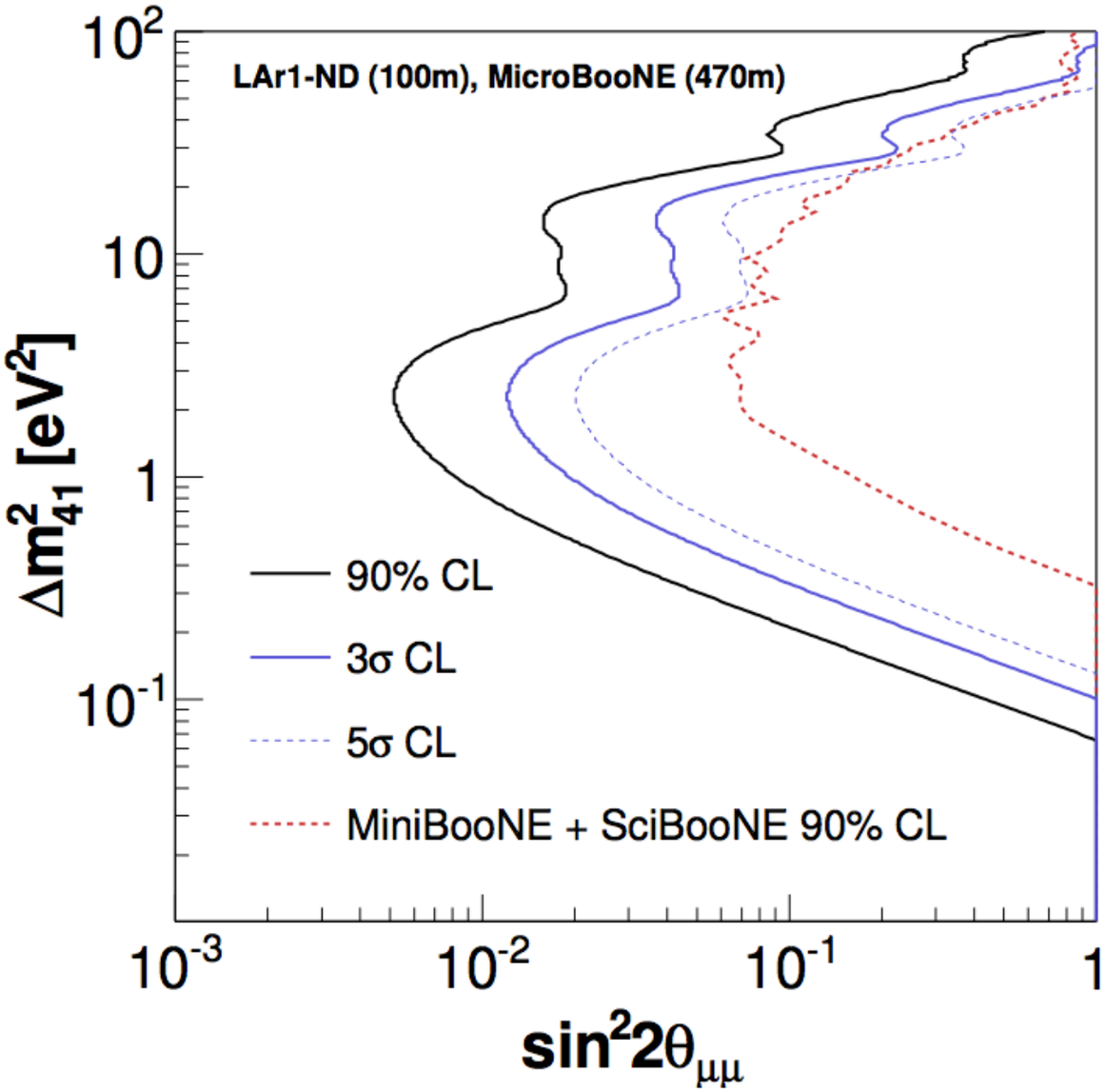
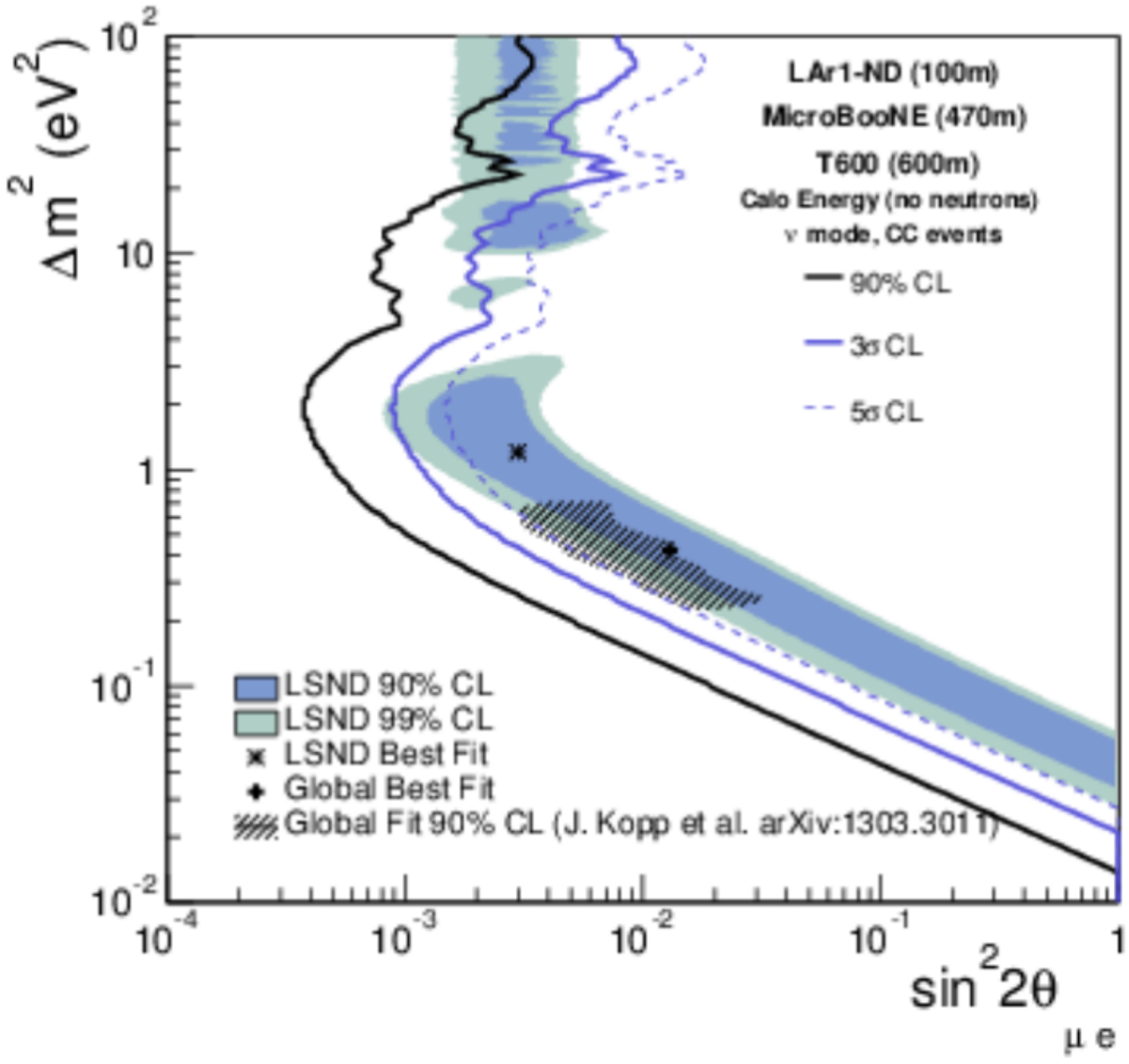


4.4 m (beam direction) x
4.1 m (wide) x
4.8 m (tall)
= 150 t LAr (82 t active)

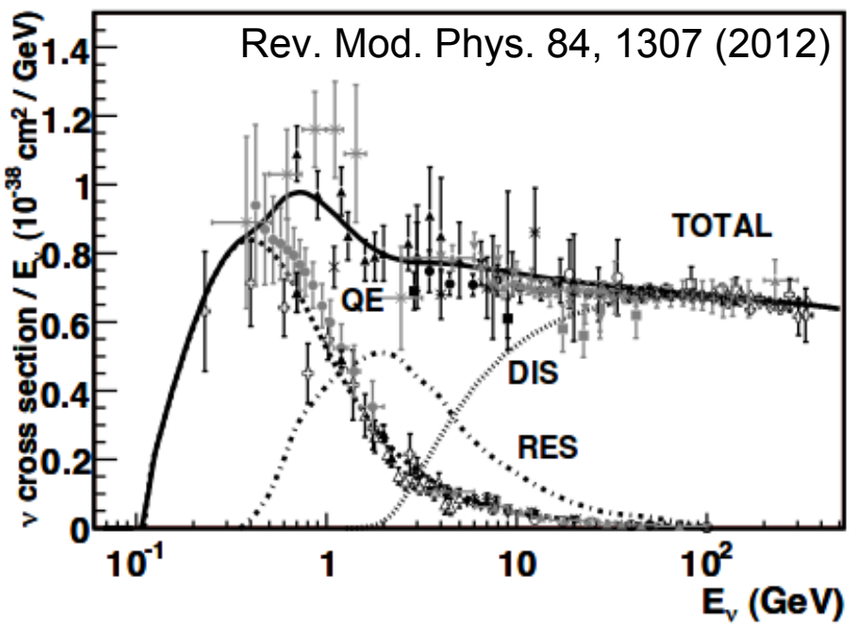
- Bulk of the cryostat surface is wetted with liquid (i.e. signal feedthrough immersed in liquid, to limit outgassing from signal cables)
- Membrane cryostat
- Single cathode plane, two readout anode plane assemblies
- Collaboration:
  - 3 US National Labs
  - 6 US Institutions
  - CERN
  - 1 Swiss Institution (BERN)
  - 5 UK institutions
- Building site to be decided (existing SciBooNE enclosure or a new building)

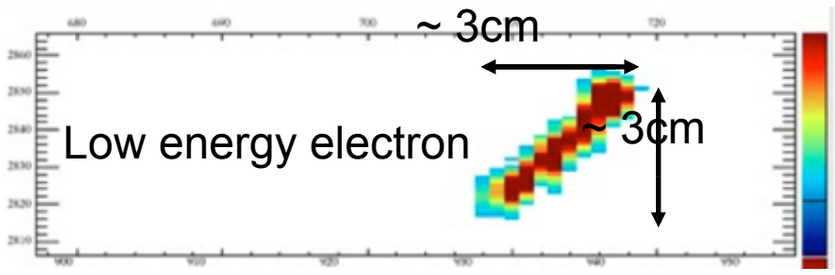
Sensitivity to oscillations

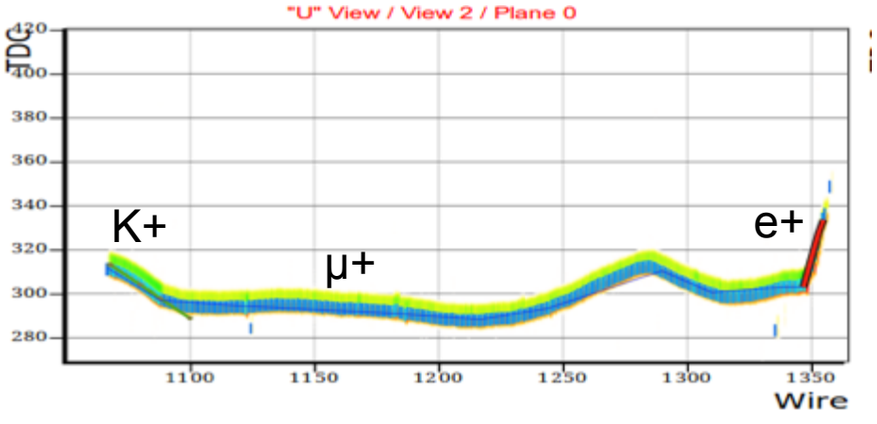




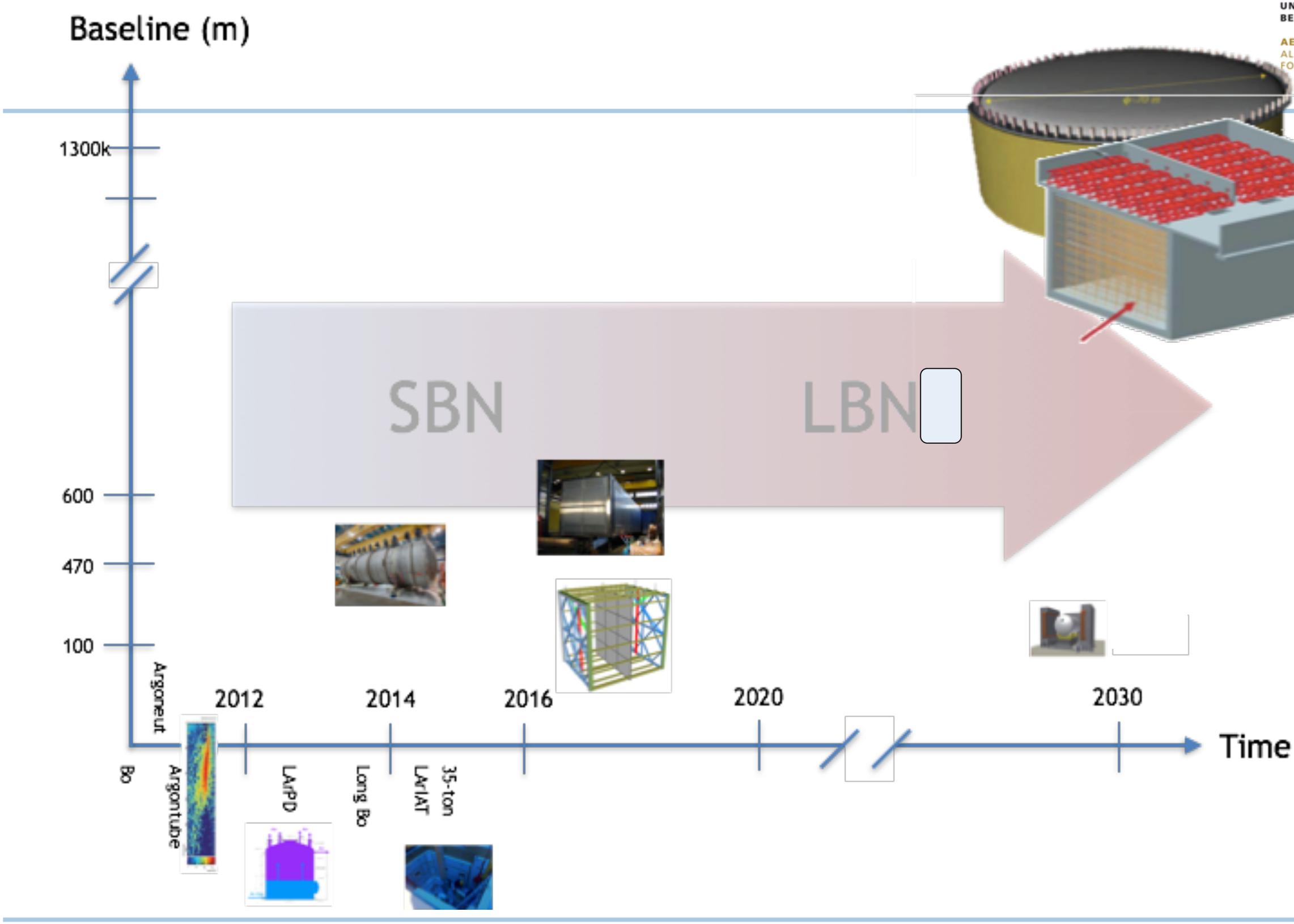
More physics goals







- Cross-section physics
  - Nuclear models
  - Understanding low energy cross-sections crucial to oscillation experiment (present and future)
  - MicroBooNE will see the NuMI and BNB beam, covering great energy range
  - LAr1-ND will see a large statistics of events
- Supernovae
  - Low energy electron reconstruction
- Proton decay (background)
  - Study Kaon decays as background to “golden” channel p→K+ν



C. Adams, M. Weber, J. Zennamo

Conclusions

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- Strong physics case for SBL neutrino experiments
- Neutrino physics is now also precision physics
- Precision detectors (LArTPC) are available
- Timeliness
  - MicroBooNE about to start running in the neutrino beams at Fermilab
  - Great involvement by young people ! Building the up the next generation
  - Switzerland is involved !
  - Strategy to expand this SBN program by adding multiple detectors
  - This program is a path to a future long baseline program
- More physics in terms of cross sections, understanding of beams, studies for future detectors in-situ (e.g. Supernova, proton decay)
- More in terms of detector improvements (laser calibration, HV, cold electronics, purity) and possibly more R&D -> Antonio's talk

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