SBN Program

Angela Fava

49th Annual Fermilab Users Meeting

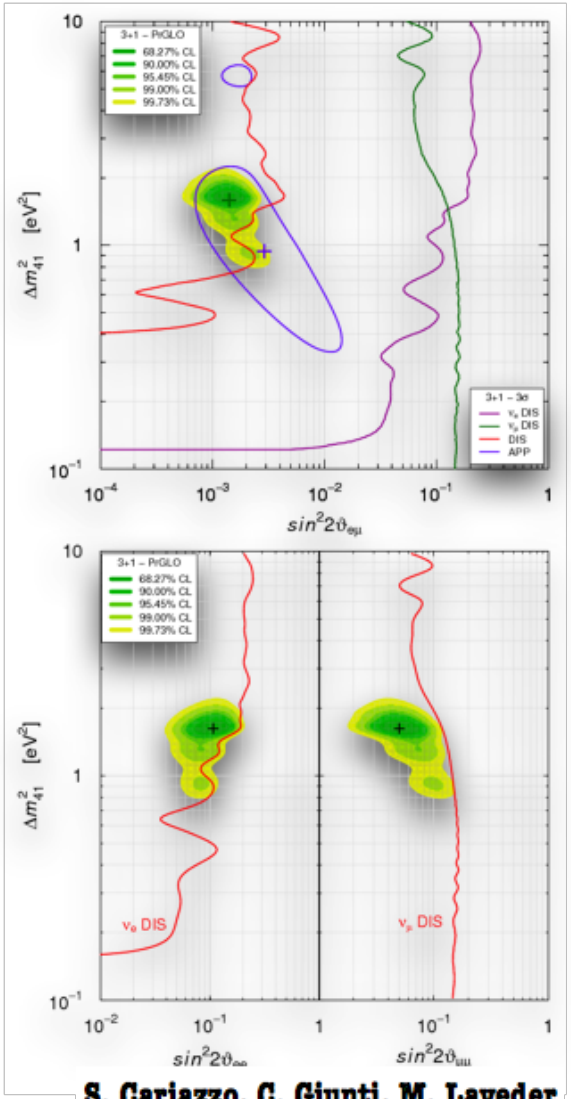
June 16th, 2016

The puzzling picture of short baseline ν oscillations

Three independent classes of anomalous experimental results are not fitting into the "standard" landscape of 3-flavour ν mixing:

- disappearance in anti-ν_e events detected from near-by nuclear reactors (R = 0.938 ± 0.023 ratio between observed and predicted event rates);
- disappearance in ν_e events from Mega-Curie k-capture calibration sources in solar ν experiments (R = 0.86 ± 0.05);
- appearance of ν_e/anti-ν_e in ν_μ/anti-ν_μ beams at particle accelerators, with 3.4 σ (MiniBooNE) / 3.8 σ (LSND) evidence for oscillations.

Each of these measurements lacks the significance to claim a discovery, but together they point to the possible existence of non standard heavier "sterile" neutrino state(s) driving oscillations at small distances: $\Delta m^2_{new} \approx 1$ eV^2, relatively small $\sin^2(2\vartheta_{new})$.

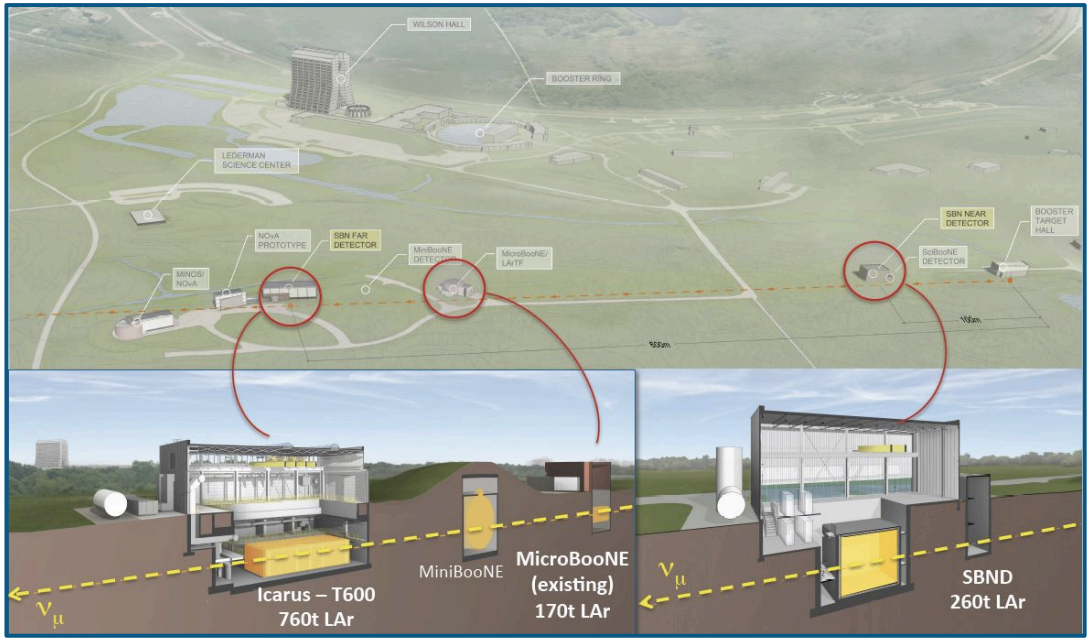


S. Cariazzo, C. Giunti, M. Laveder
arXiv:1507.08204

Short Baseline Neutrino Program at Fermilab

An ultimate experiment with multiple LAr-TPCs exposed to FNAL Booster ν beam has been proposed to FNAL PAC on Jan 15th 2015 as definitive answer to the "sterile neutrino puzzle", getting Stage-1 approval.

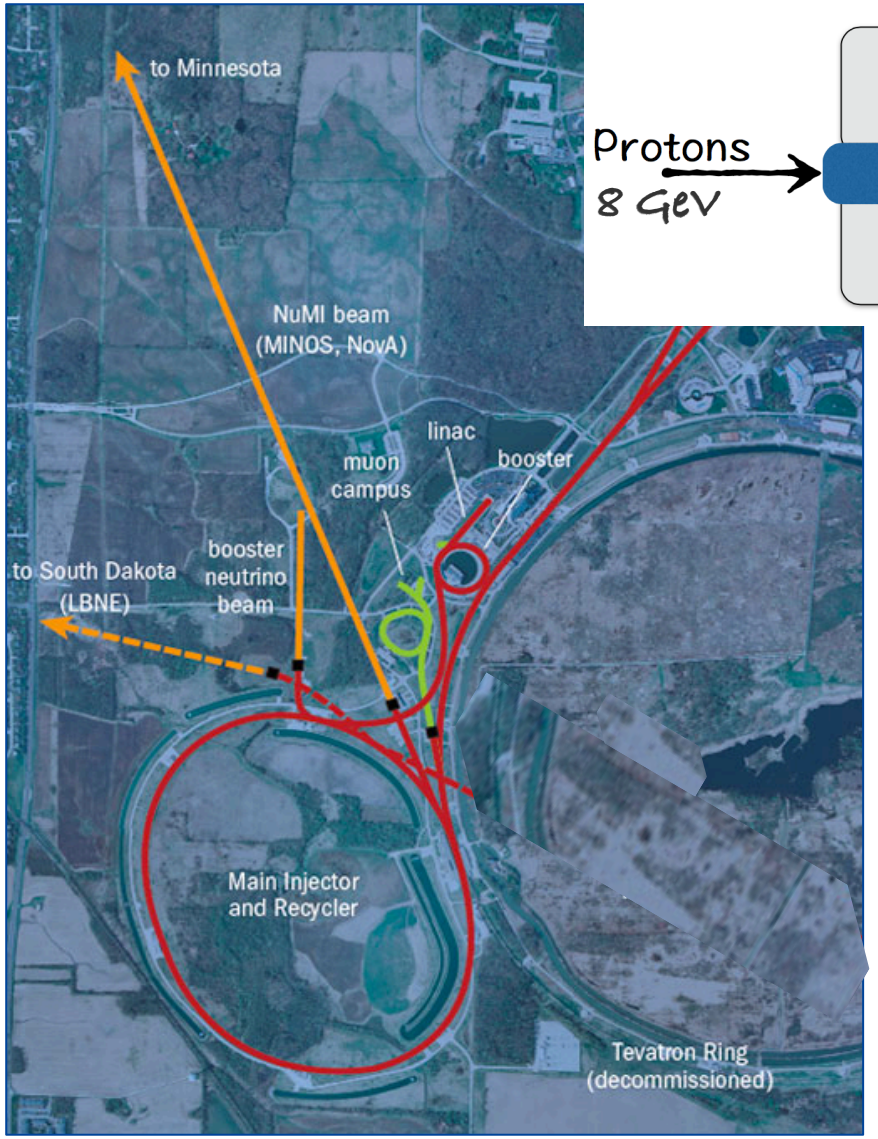
- **SBND** detector to be built anew, with 112 t LAr active mass, at 110 m from target;
- **MicroBooNE** detector (87 t), installed at 470 m and taking data;
- **ICARUS T600** (476 t), presently at CERN for refurbishing, at 600 m.

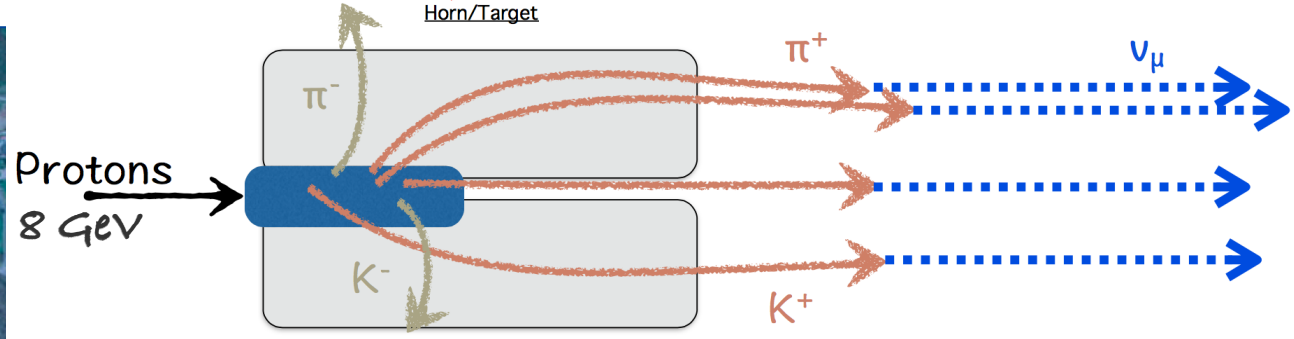


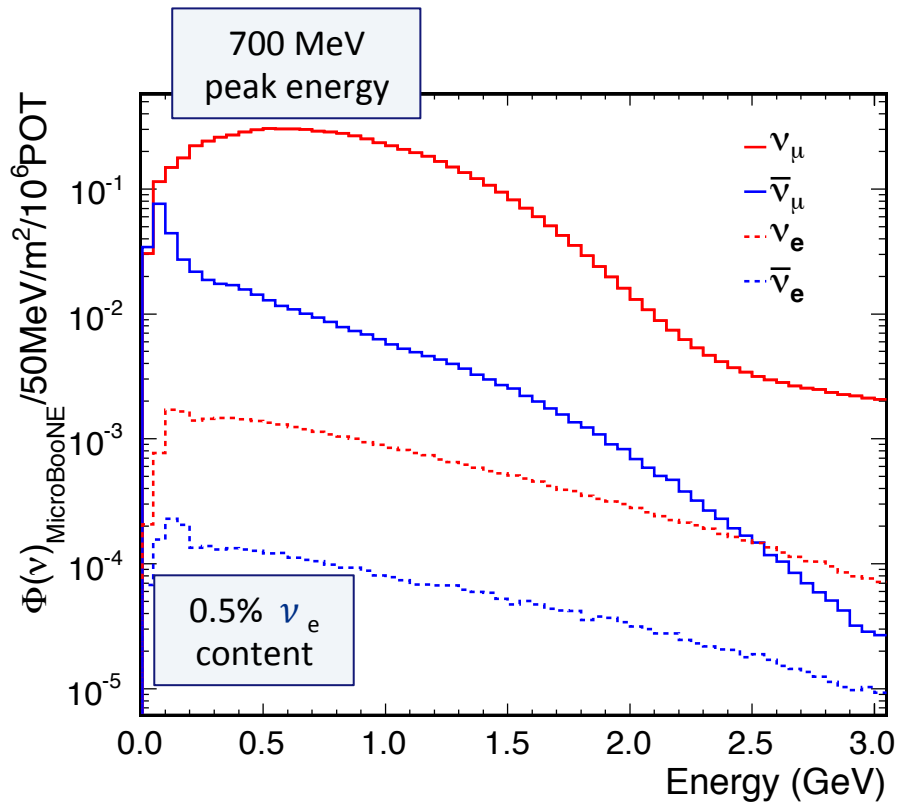
Both ν_e appearance and ν_μ disappearance will be independently measured by comparing the event spectra recorded with the three detectors.

The exploitation of the same ν beam and detection technique will allow for the cancelation of many systematic errors.

The Booster Neutrino Beam

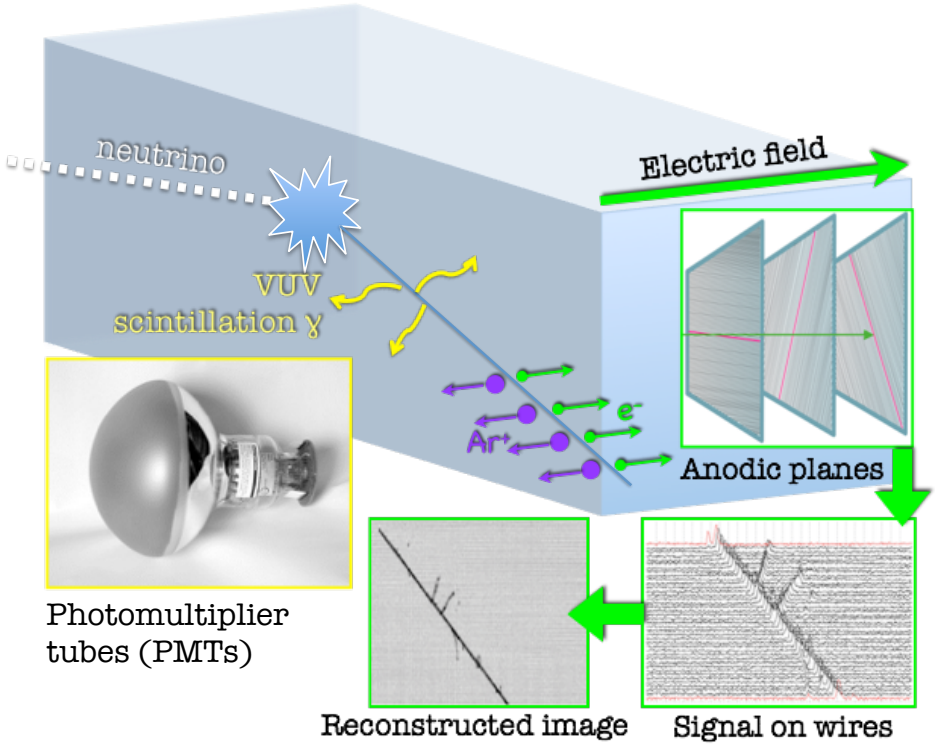






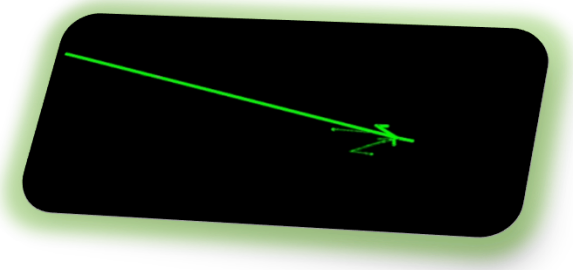
Liquid Argon TPC detection technique

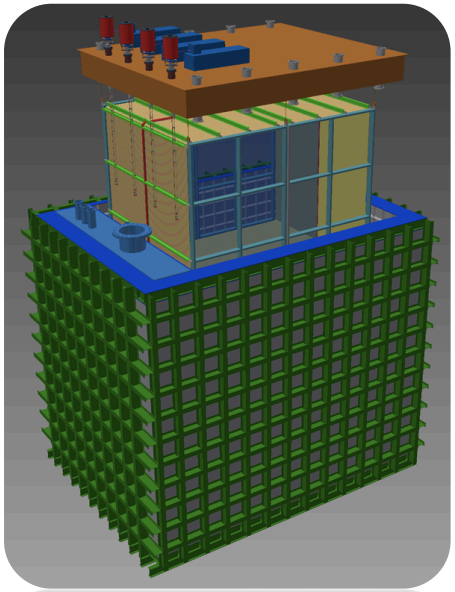
- Liquid Argon Time Projection Chamber (LAr-TPC) detectors are very well suited for the experimental study of Neutrino Physics, combining a massive yet homogeneous target with excellent tracking and calorimetric capabilities.
- First idea: H. Chen (1976) [FNAL P-496], C. Rubbia (1977) [CERN-EP/77-08]



λ = 128 nm scintillation light:
40000 γ/MeV wo electric field.
Response time ~ 6 ns ÷ 1.8 μs.

Ionisation electrons:
42000 e^-/MeV.
Drifted (E) toward planes of wires on which they induce a signal.
Response time = drift time (~ ms).
3D image reconstruction by combining coordinates on different wire planes at the same drift time.

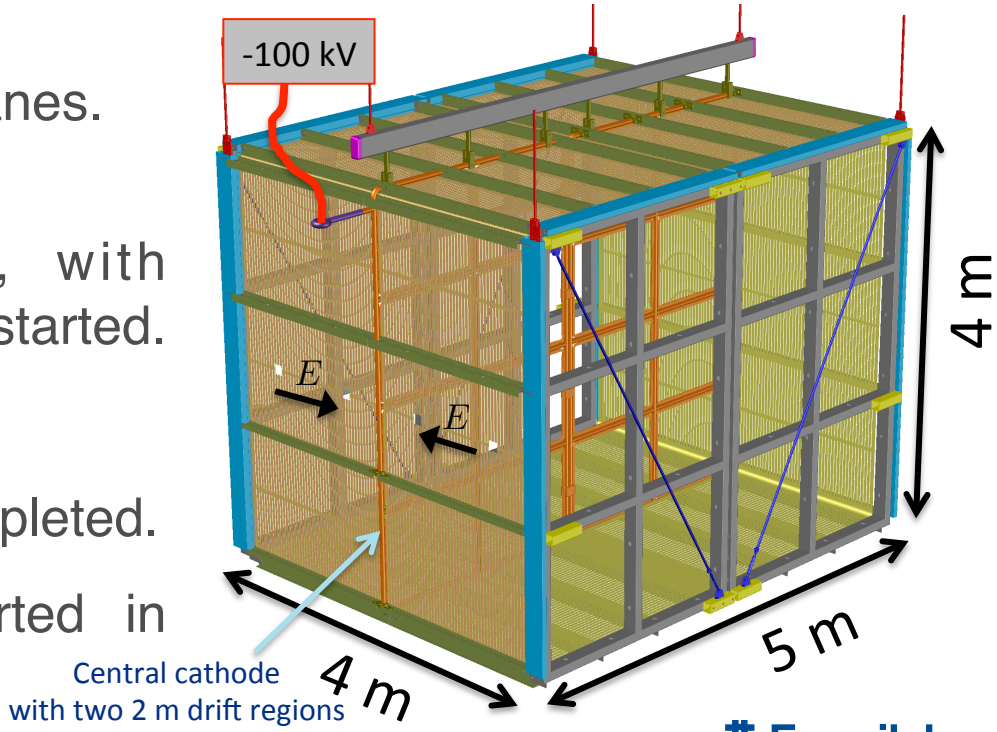




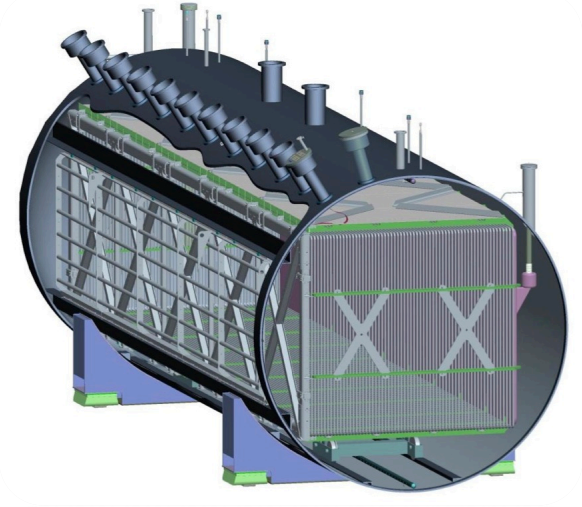
SBND

- 260 t of LAr, 112 t active mass.
- Located at 110 m from the source, it will characterize the neutrino beam before the onset of oscillations.
- 1.5 x 10^6 ν_μCC and 12 x 10^3 ν_eCC/ year expected
  ➔ excellent platform for studying cross sections of ν-Ar interactions.

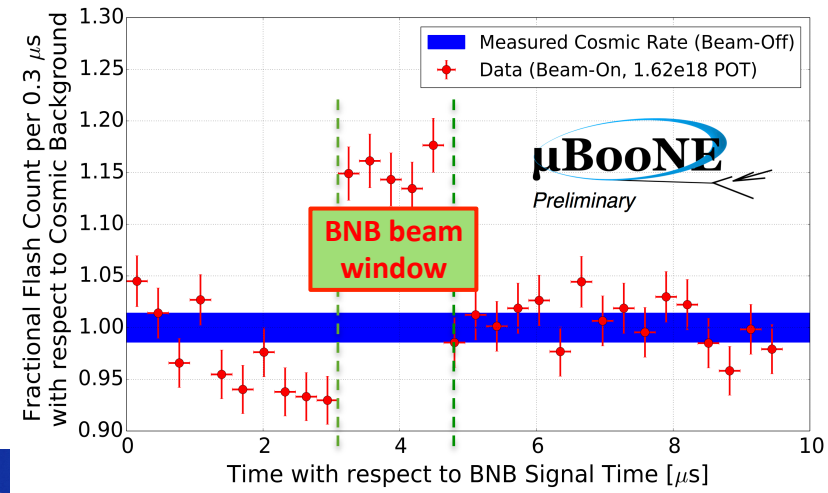
- 4 TPCs with 2 m drift and 3 wire planes.
  112 8” PMTs coated with TPB.
- TPC in final design stages, with production of anode plane frames started.
  PMTs ordered.
  Cosmic ray tagger final design.
  Cryostat design (membrane) ~ completed.
- Construction of the building started in March 2016.



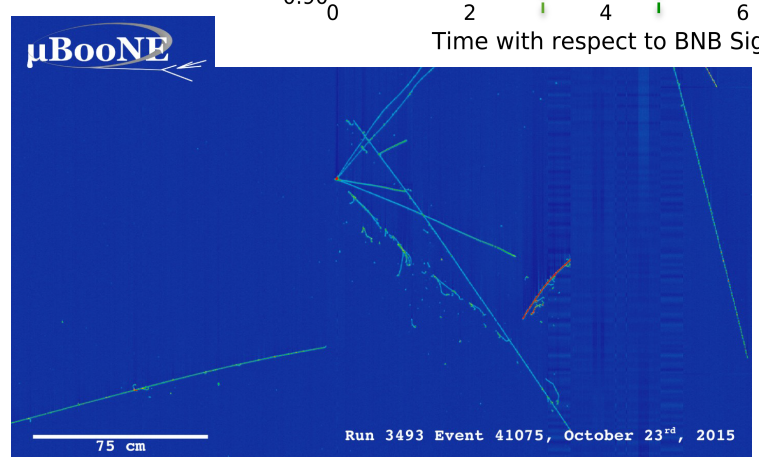
MICROBOONE



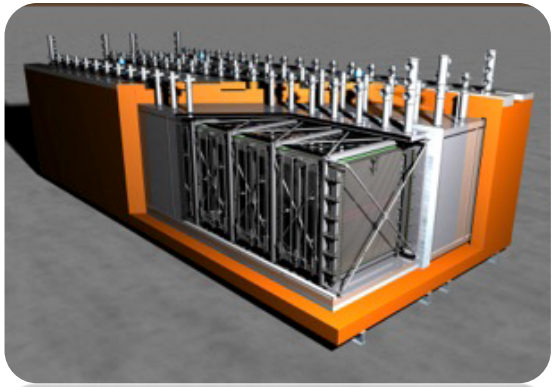
- 170 t of LAr, 87 t active mass.
- Located at 470 m from the source, it is presently addressing the MiniBooNE low energy excess and will contribute to SBN as far detector.



- 1 TPC with 2.5 m drift and 3 wire planes with 3 mm pitch.
  32 8” PMTs coated with TPB.
- Installation completed by December 2014.
  First ν interactions on October 2015, 3.2 x 10^{20} pot in 6 months.
- Measurements of ν-Ar cross section in preparation.
  First results in this year.

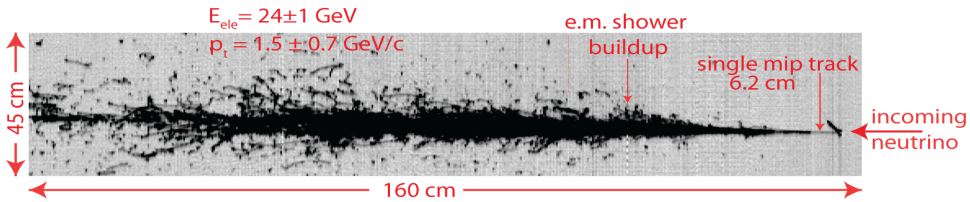


ICARUS

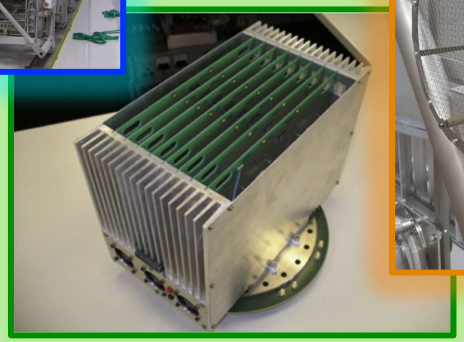


- 760 t of LAr, 476 t active mass.
- Located at 600 m from the source, will contribute to SBN as far detector.
  Additional ~ 10^5 NuMI off-axis events/year expected.

- 4 TPCs with 1.5 m drift and 3 wire planes with 3 mm pitch.
  360 8” PMTs coated with TPB.



- Operated underground in Italy in 2010 ÷ 2012 with CNGS ν beam.
- Overhauling at CERN:
  - new cold vessels & passive insulation;
  - refurbishing of cryogenics;
  - flattening of cathode;
  - upgrade of light collection system;
  - new readout electronics.
- Building construction started in August 2015.



Laying the groundwork: SBND

June 10th

June 16th

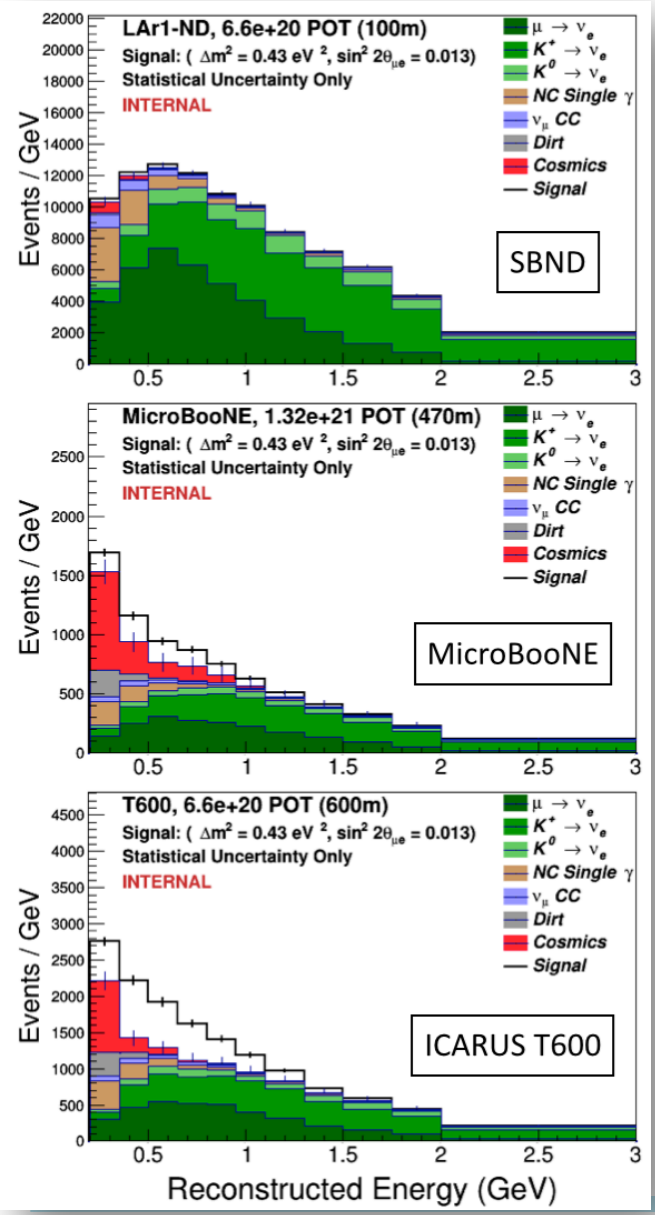
Fermilab

Laying the groundwork: ICARUS

June 14th

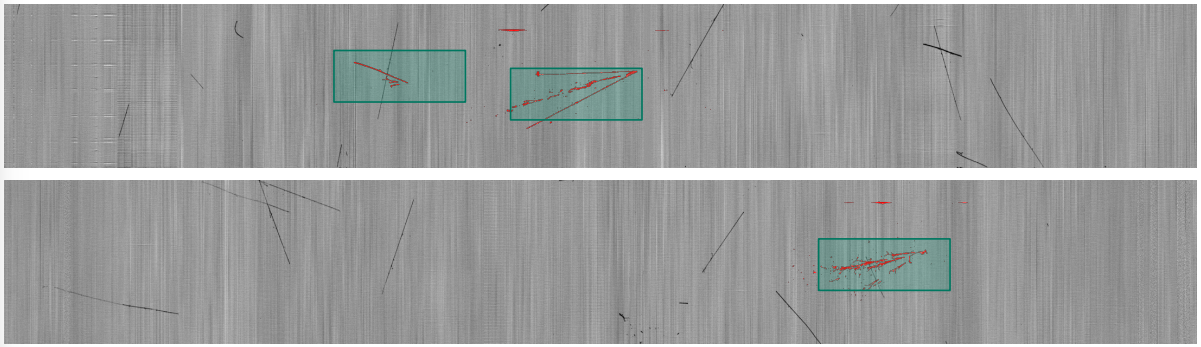
June 16th

Analysis of sensitivity to oscillations



- Correlations between detectors (same beam and experimental technique) allow for cancelations in systematic uncertainty.
- The analysis leveraged MiniBooNE expertise in simulating BNB neutrino fluxes.
- Major background source related to cosmic rays:
  - spurious triggers;
  - several uncorrelated c-rays in LAr active volume during drift window recording.

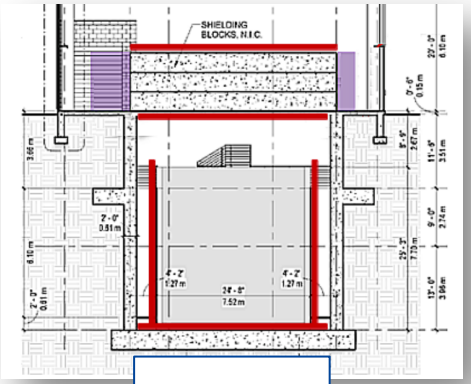
Detector	ν every N spills	Cosmic μ in spill every N spills
SBND	25	300
MicroBooNE	800	200
ICARUS-T300	500	100



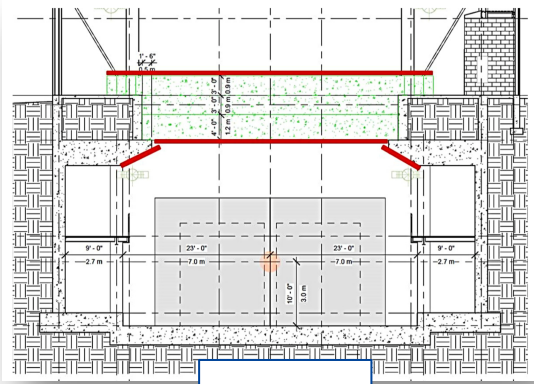
Cosmic rays (PV) + low energy CNGS beam events

Mitigation of cosmogenic background

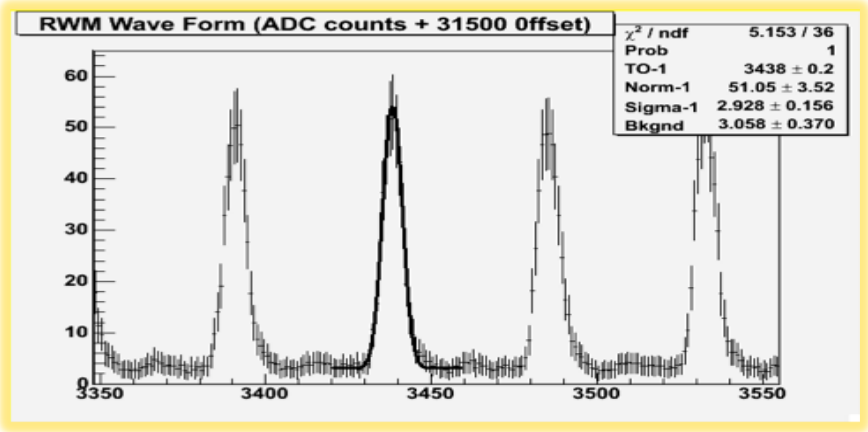
- 3 m of concrete overburden guarantees ~100% reduction of primaries other than muons, with only few percent increase in secondaries.
- γ generated by cosmic μ close to the detector remain the main background for ν_e appearance search.
- It can be mitigated:
  - 1-to-1 match of ionization charge with scintillation light signals, requiring high resolution of PMT system both in space and time;
  - external cosmic ray tracker system capable of tagging muons passing near the detector.
- Further rejection of spurious triggers possible by exploiting the bunched structure of the Booster proton beam (2 ns wide bunches every 19 ns).



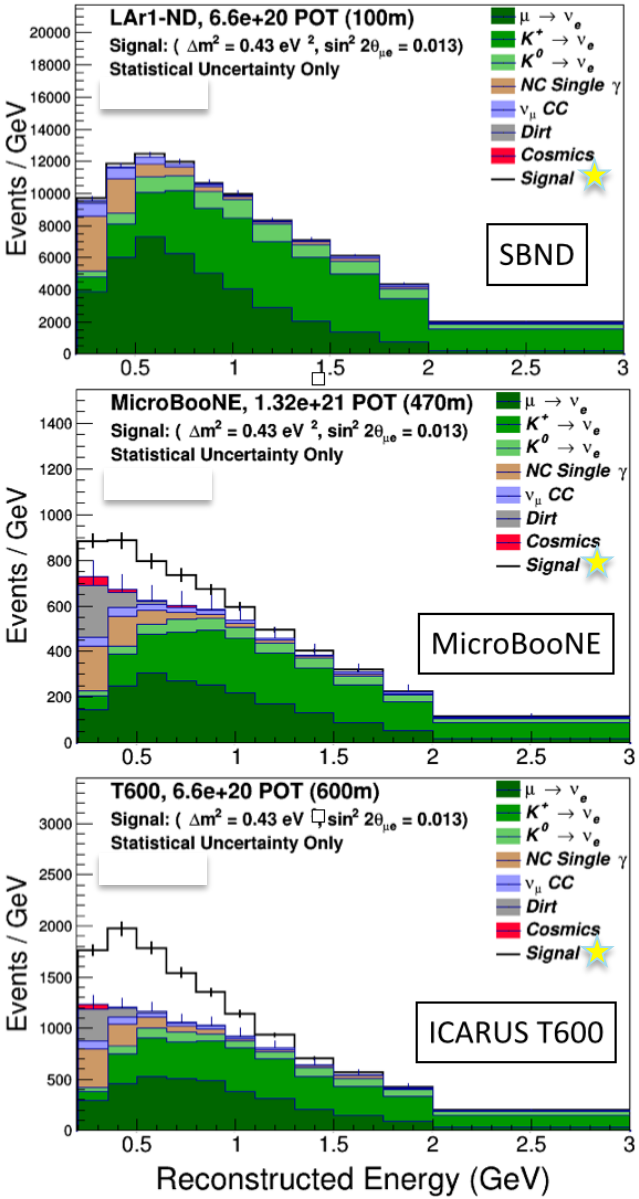
SBND

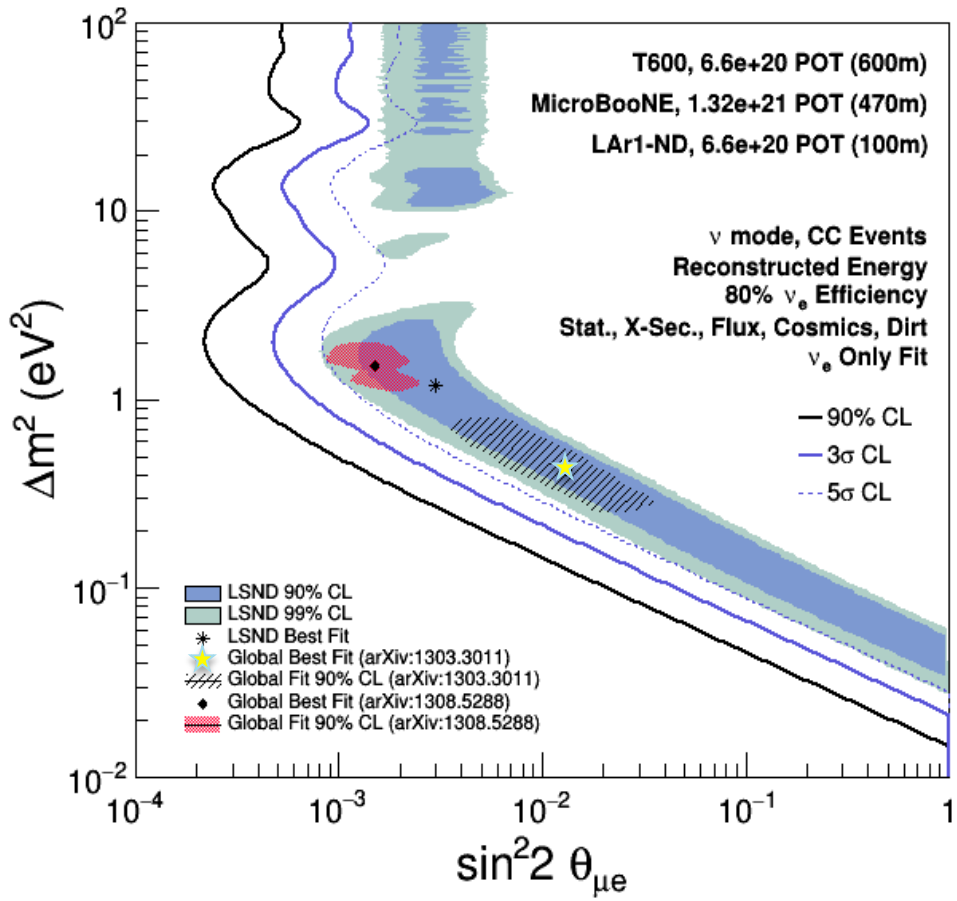


T600



Sensitivity of SBN program in appearance channel





The LSND 99% C.L. region will be covered at ~ 5 σ – level in 3 years of data taking with positive focusing of the BNB (~ 6.6 x 10^{20} pot).

Relevance of ν_μCC disappearance measurement

- In the framework of 3+1 model (only 1 light sterile neutrino), three mixing angles are introduced describing ν_μ disappearance ($\theta_{\mu x}$), ν_e disappearance (θ_{ex}) and appearance ($\theta_{\mu e}$) cross-related through the relation

$$\sin^2(2\theta_{\mu e}) = 1/4 \sin^2(2\theta_{\mu x}) \sin^2(2\theta_{ex})$$

- Therefore, a possible ν_e excess due to the existence of sterile neutrinos will be due to the combined effect of ν_e appearance and disappearance

$$S = R\nu_\mu(E)\left[\frac{1}{4}\sin^2(2\theta_{\mu x}) - \frac{R\nu_e}{R\nu_\mu}(E)\right]\sin^2(2\theta_{ex})\sin^2(1.27\,\Delta m_{41}\,L/E)$$

- The interplay between these 2 effects can be disentangled by independently measuring ν_μ disappearance (or measuring ν_e appearance varying the intrinsic ν_e contamination of the beam).

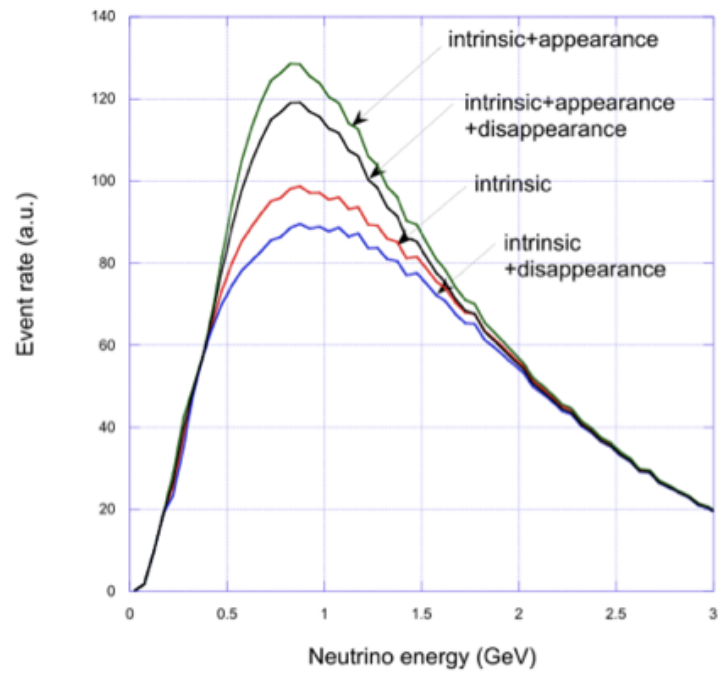
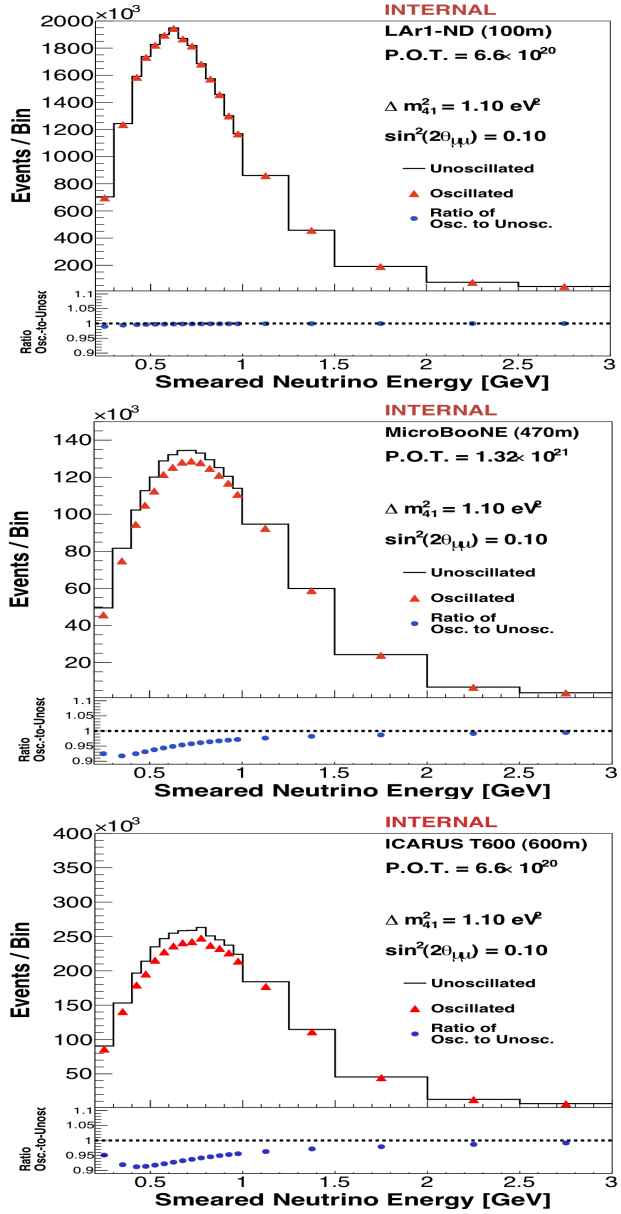
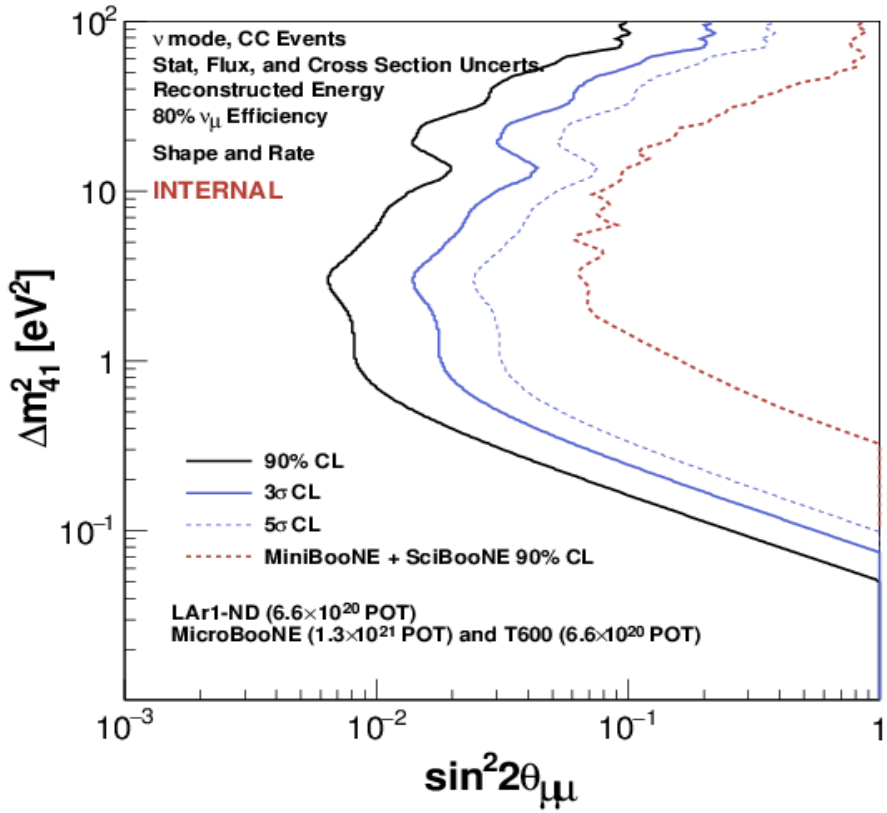


FIGURE 1. Contribution to the ν_e excess in the Booster neutrino spectrum in case of a detector placed at ~ 600 m from the beam target, as foreseen for the ICARUS T600, for the best fit of Giunti-Laveder 3+1 neutrino model (arxiv1308.5288) predicting $\Delta m^2_{41} \sim 1.5\ eV^2/c^2$ and $\sin^2(2\theta_{\mu e}) \sim 1.25\ 10^{-3}$, $\sin^2(2\theta_{ex}) \sim 10^{-1}$, $\sin^2(2\theta_{\mu x}) \sim 5\ 10^{-2}$.

Sensitivity of SBN program in disappearance channel

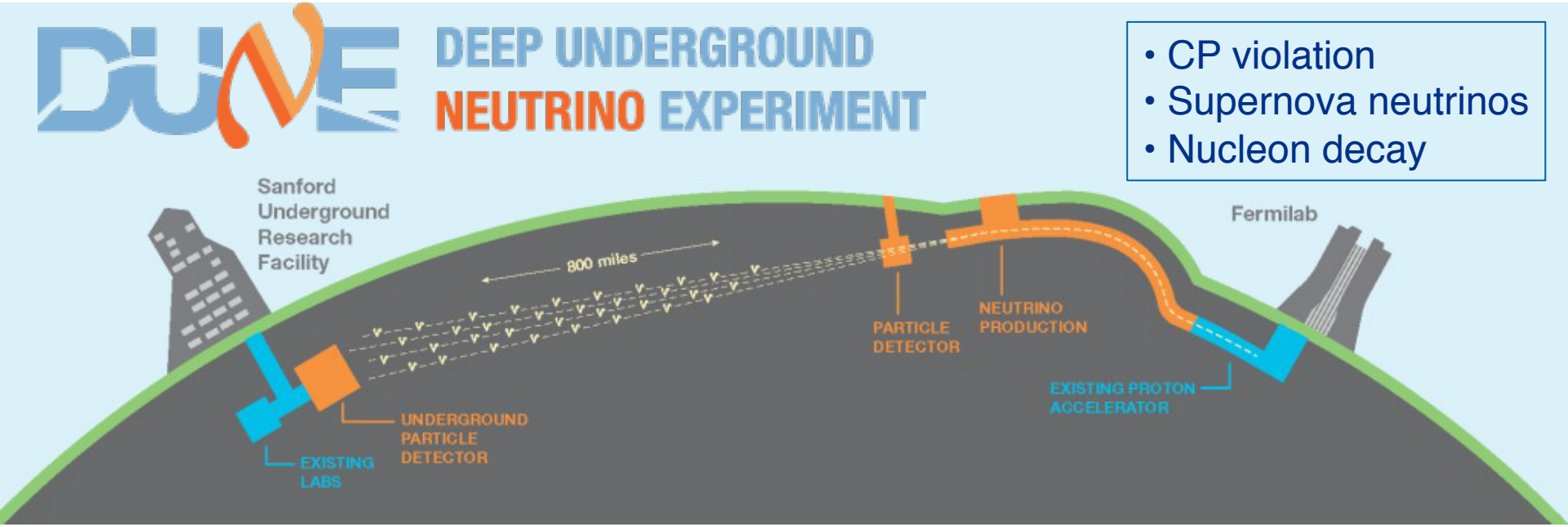




Sensitivity to ν_μ disappearance will be extended by 1 order of magnitude beyond SciBooNE + MiniBooNE limits in 3 years of data taking with positive focusing of the BNB (~ 6.6 x 10^{20} pot).

Ties to the Long-Baseline Program

- The SBN Program, beyond its physics scope, serves also as a platform in view of the Long-Baseline Program DUNE:
  - technological developments of LAr-TPCs;
  - measurement of GeV scale ν-Ar cross sections;
  - design and validation of automatic event reconstruction and analysis tools;
  - gathering together of a large community of experts from all over the world.



µBooNE
Fermilab