The Short Baseline Neutrino Oscillation Program at Fermilab

Matt Bass - University of Oxford

ICHEP 2016

The Short Baseline Neutrino (SBN) Oscillation Program at Fermilab

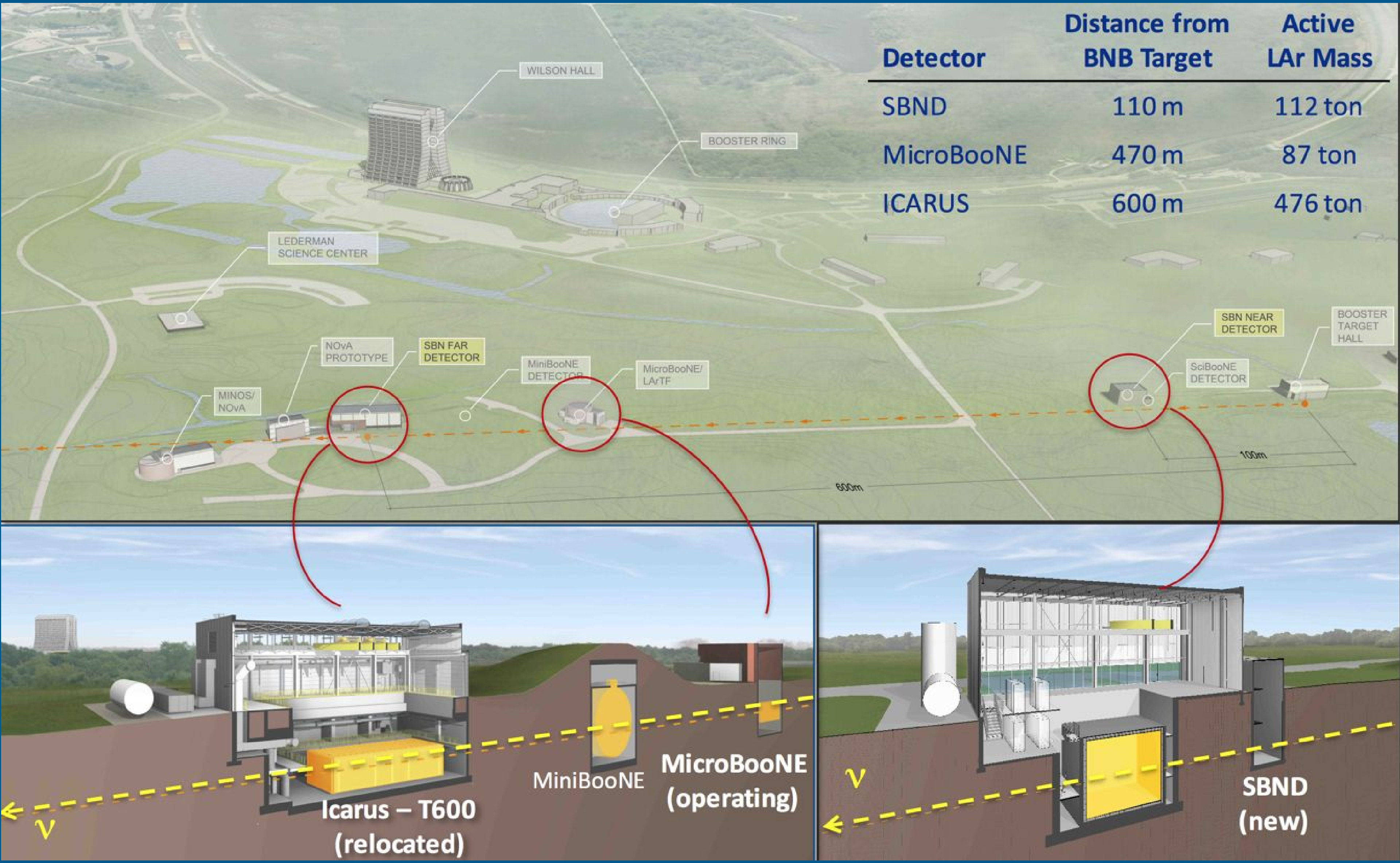
Overview

Goals

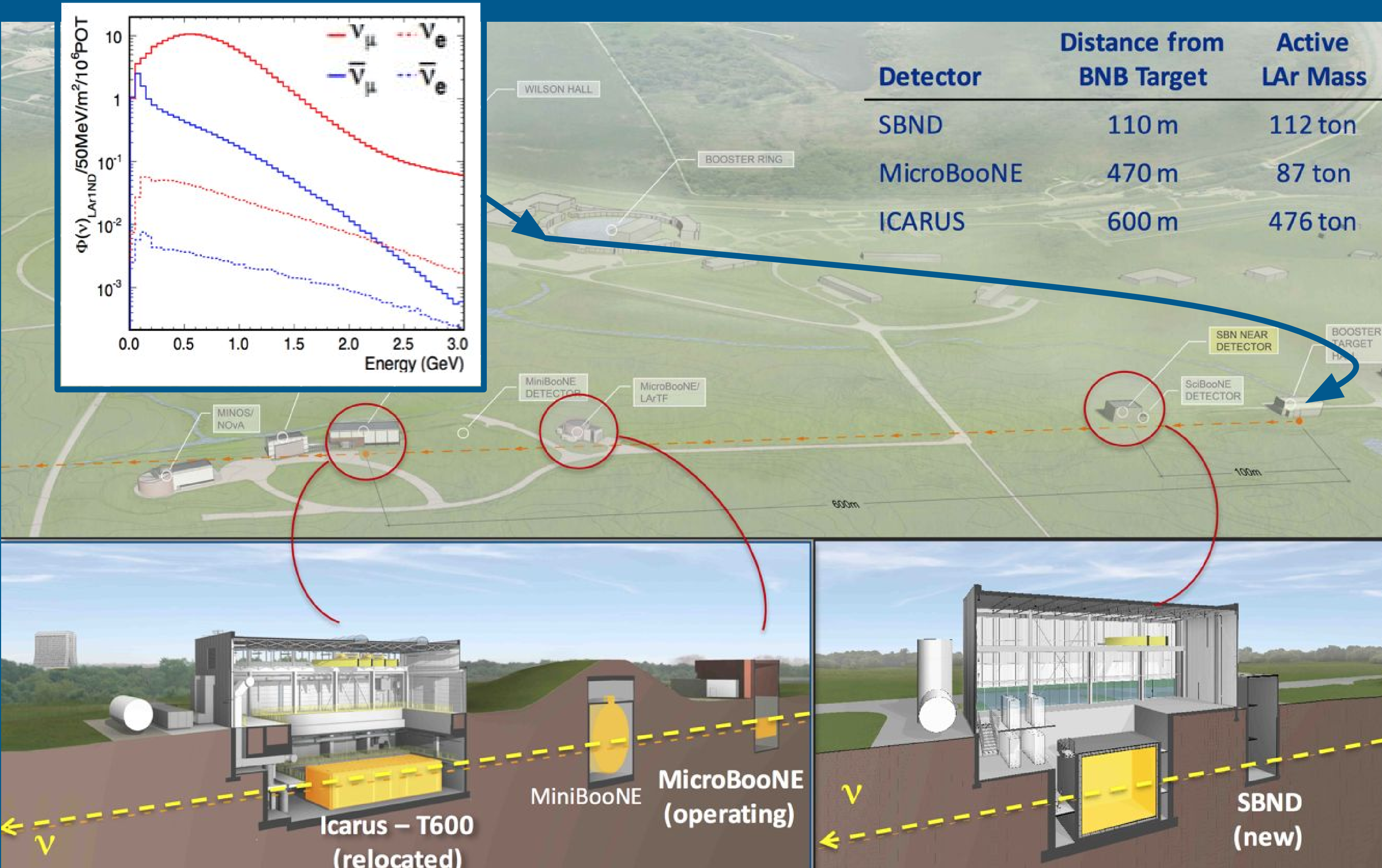
Status

Outlook

Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton



SBN Program Detectors - LAr TPCs



Detector	Distance from BNB Target	Active LAr Mass
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SBN Program Detectors – LAr TPCs

ICARUS

Argonne National Lab, USA
Brookhaven National Lab, USA
CERN, Switzerland
Colorado State University, USA
Fermi National Lab, USA
INFN Sez. di Catania and University, Catania, Italy
INFN GSSI, L'Aquila, Italy
INFN LNGS, Assergi (AQ), Italy
INFN Sez. di Milano Bicocca, Milano, Italy
INFN Sez. di Napoli, Napoli, Italy
INFN Sez. di Padova and University, Padova, Italy
INFN Sez. di Pavia and University, Pavia, Italy
H. Niewodniczanski Inst. of Nucl. Phys., Polish Academy of Science, Krakow, Poland
Institute for Nuclear Research (INR),
Institute of Physics, University of Silesia, Katowice, Poland
Inst. for Radio-Electronics, Warsaw University of Technology, Warsaw, Poland
Los Alamos National Lab, USA
National Centre for Nuclear Research, Warsaw, Poland
University of Pittsburgh, USA
Russian Academy of Science, Moscow, Russia
SLAC, USA
Texas University at Arlington, USA

MicroBooNE

University of Bern, Switzerland
Brookhaven National Lab, USA
University of Cambridge, UK
University of Chicago, USA
University of Cincinnati, USA
Columbia University, USA
Fermi National Lab, USA
Illinois Institute of Technology, USA
Kansas State University, USA
Lancaster University, UK
Los Alamos National Lab, USA
University of Manchester, UK
MIT, USA
University of Michigan, USA
New Mexico State University, USA
Oregon State University, USA
Otterbein University, USA
University of Oxford, UK
University of Pittsburgh, USA
Pacific Northwest National Laboratory, USA
Princeton University, USA
Saint Mary's University of Minnesota, USA
SLAC, USA
Syracuse University, USA
University of Texas at Arlington, USA
Tubitak Space Tech. Research Inst., Turkey
Virginia Tech, USA
Yale University, USA

SBND

Argonne National Lab, USA
University of Bern, Switzerland
Brookhaven National Lab, USA
University of Cambridge, UK
University of Campinas – UNICAMP, Brazil
CERN, Switzerland
University of Chicago, USA
Columbia University, USA
Federal University of ABC – UFABC, Brazil
Federal University of Alfenas – UFAL, Brazil
Fermi National Laboratory, USA
Illinois Institute of Technology, USA
Indiana University, USA
Kansas State University, USA
Lancaster University, UK
University of Liverpool, UK
Los Alamos National Lab, USA
University of Manchester, UK
University of Michigan, USA
MIT, USA
University of Oxford, UK
Pacific Northwest National Lab, USA
University of Pennsylvania, USA
University of Puerto Rico
University of Sheffield, UK
Syracuse University, USA
University of Texas, Arlington, USA
University College London, UK
Virginia Tech, USA
Yale University, USA

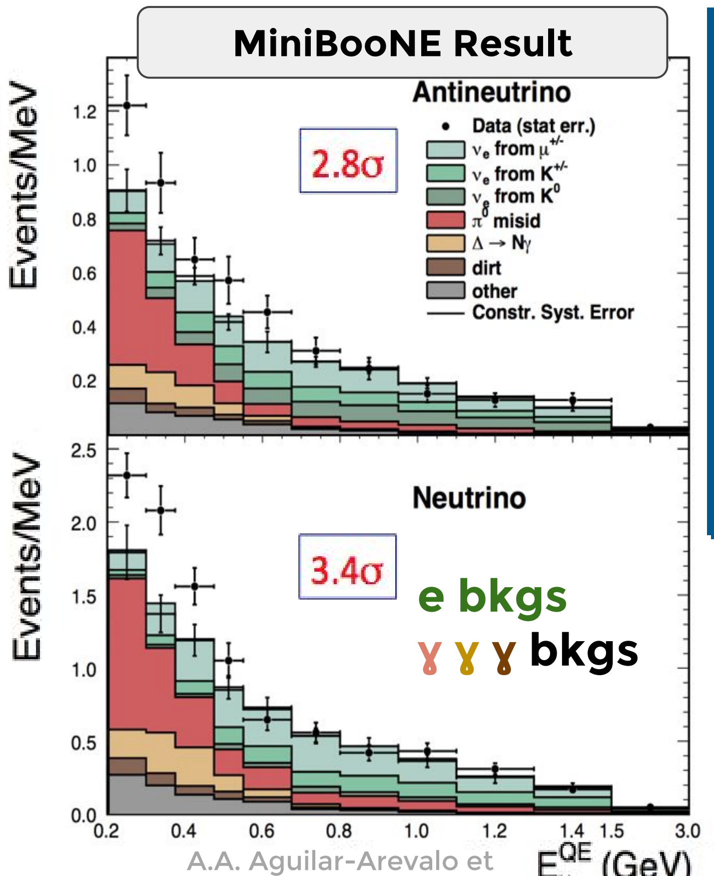
SBN Program Collaborations – Institutions (July 2016)

SBN Program Goals

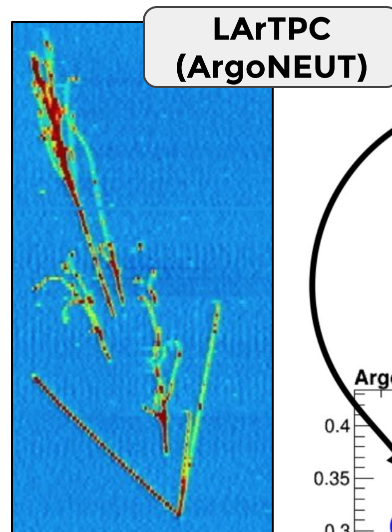
1. MiniBooNE Follow-up

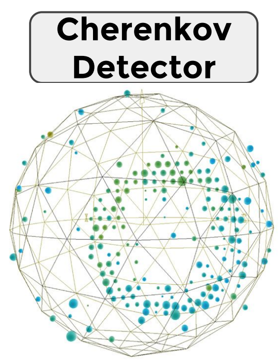
Follow up on the excess of EM events seen in MiniBooNE

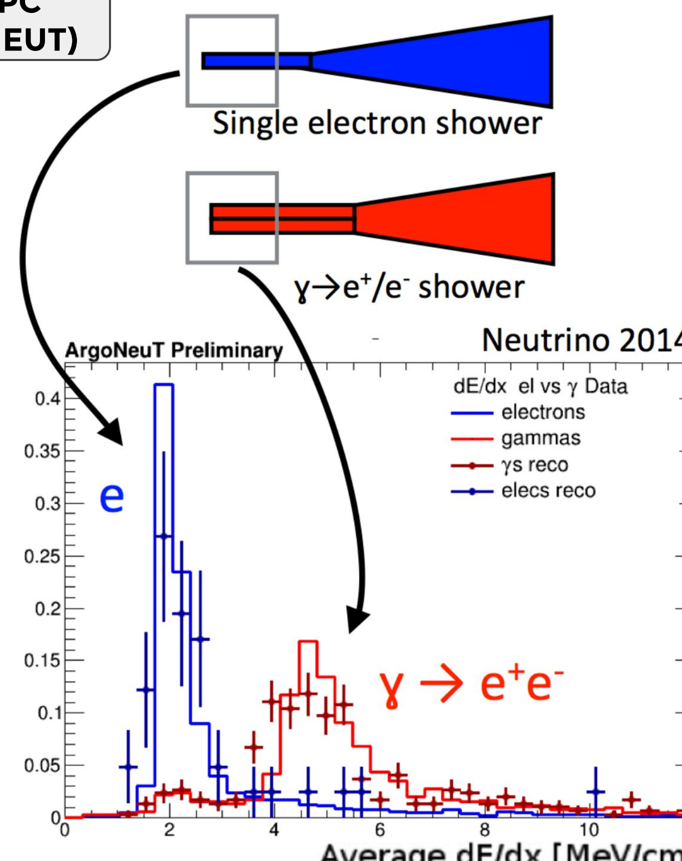
Liquid Argon Time Projection Chambers (LAr TPCs) can distinguish between **electrons** and **photons**



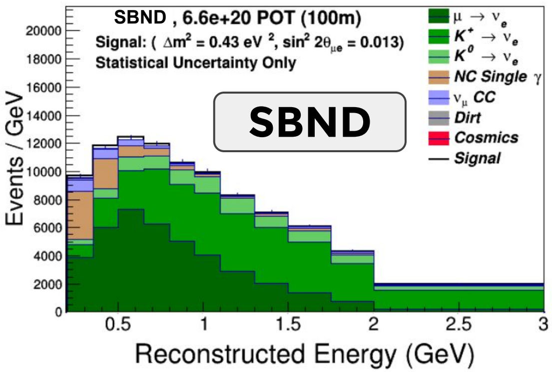
A.A. Aguilar-Arevalo et al., PRL 110, 161801 (2013)

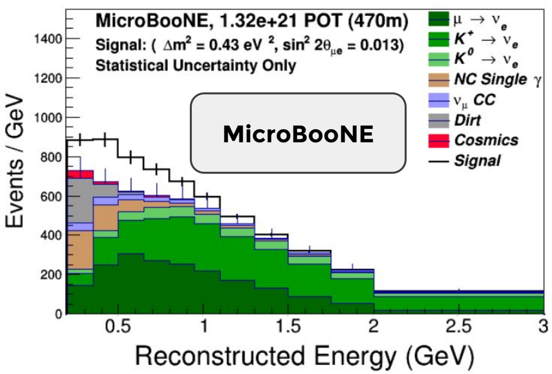


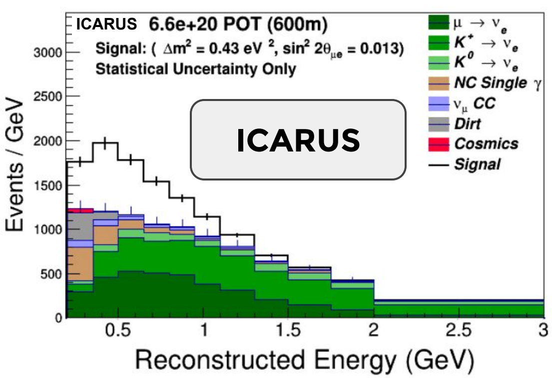




2. Explore Sterile ν Oscillations



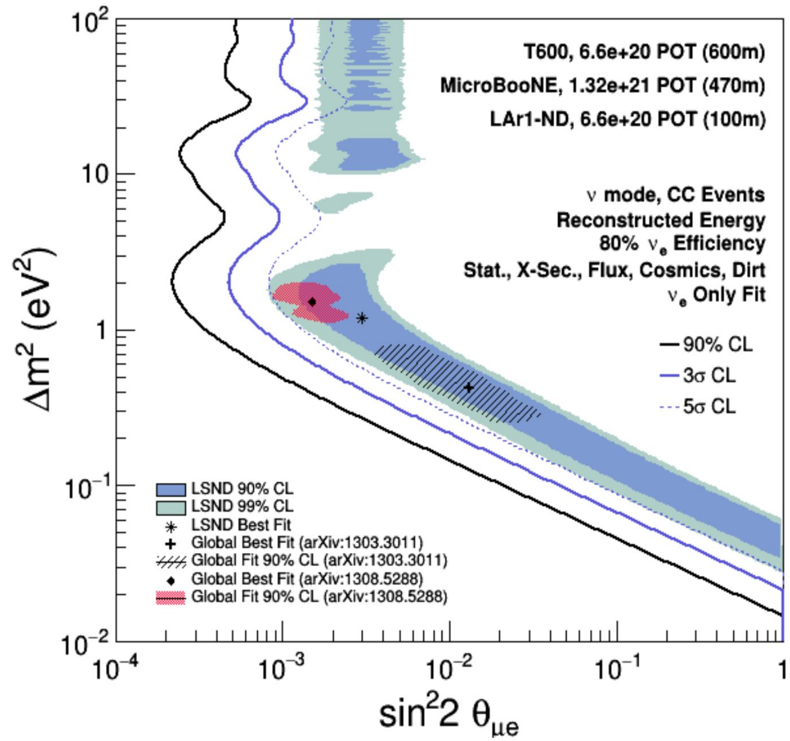




Detailed **sensitivity analysis** includes cosmogenic backgrounds, correlated flux & cross section systematics, and beam backgrounds.

The SBN program will exclude the LSND 99% CL region at 5σ in 3 years of taking data in the BNB

arXiv:1503.01520v1

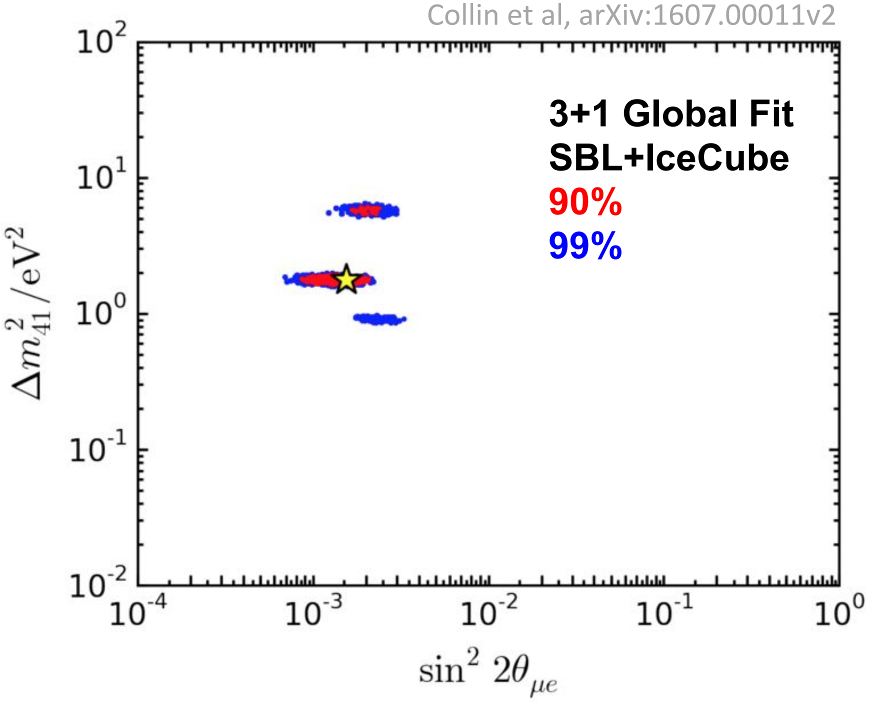


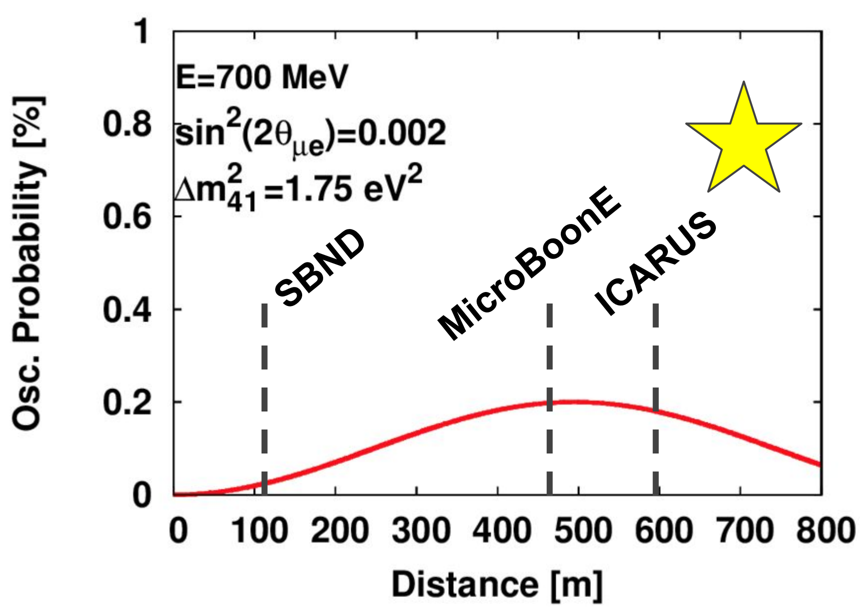
2. Explore Sterile ν Oscillations

Recent 3+1 global fits, e.g. short-baseline + IceCube, have further limited the range of allowed values for the oscillation parameters governing active to sterile oscillations

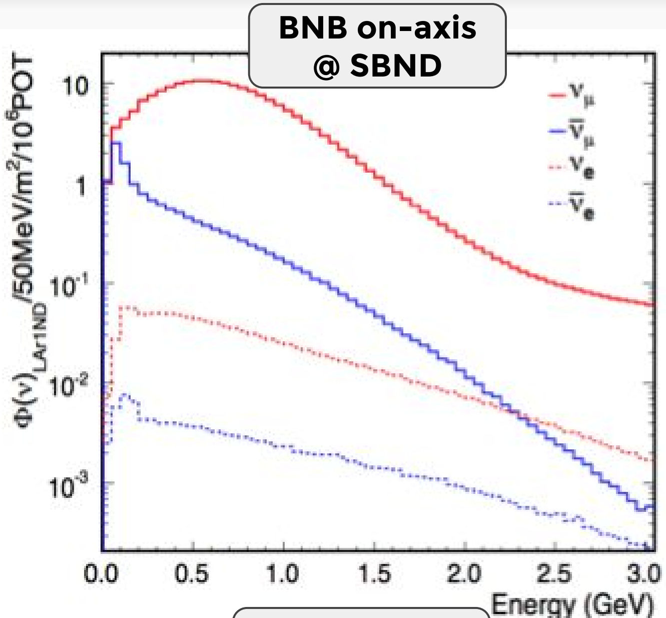
SBN setup provides unique ability to measure SBL oscillations over a wide range of parameter values

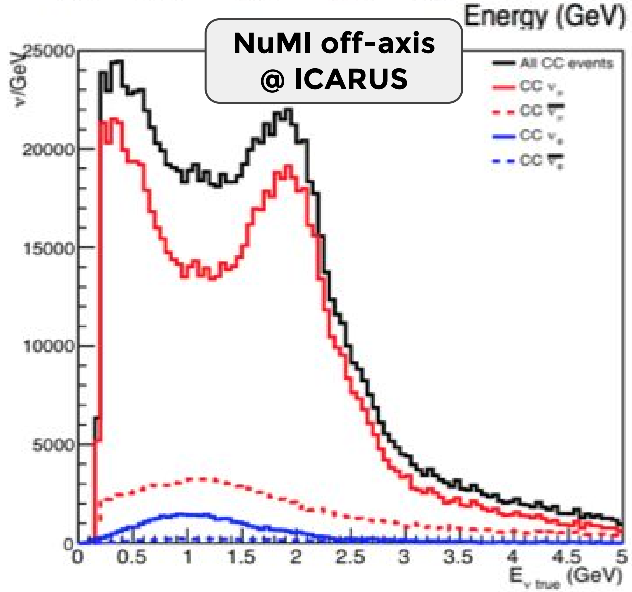
Collin et al, arXiv:1607.00011v2





3. High Precision ν-Ar Measurements





MicroBooNE will lead the way with its numerous cross section measurements; now in progress!

(See Xiao Luo's talk earlier today.)

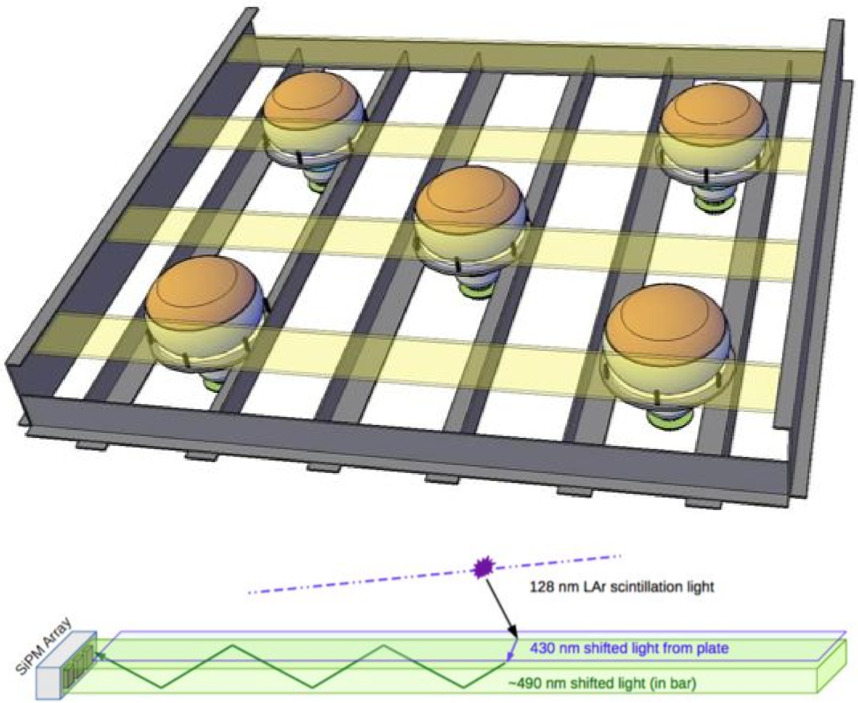
SBND sees a large flux from the **BNB** beam-line, enabling high precision ν-Ar measurements;
$1.5\text{x}10^6$ ν_μCC and $1.2\text{x}10^4$ ν_eCC interactions/year)

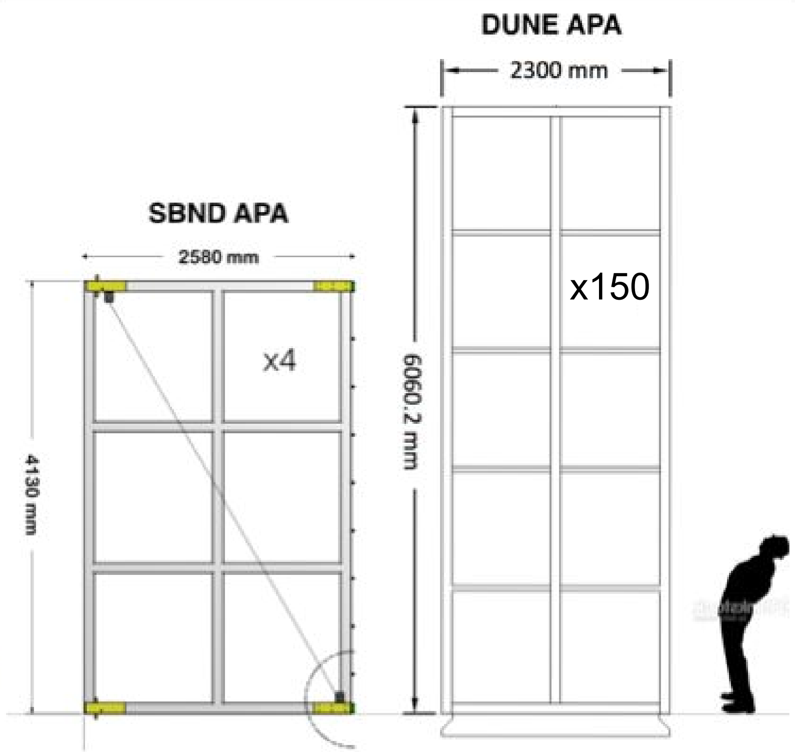
The SBN detectors also see the **NuMI** beam-line at off-axis angles. (ICARUS especially; 10^5/year)

6.6e20 POT (~3 years)

	numu	numubar	nue	nuebar
CC Total	173302	1407	1469	36
NC Total	64661	1002	502	17

4. R&D for Future Large LAr TPCs





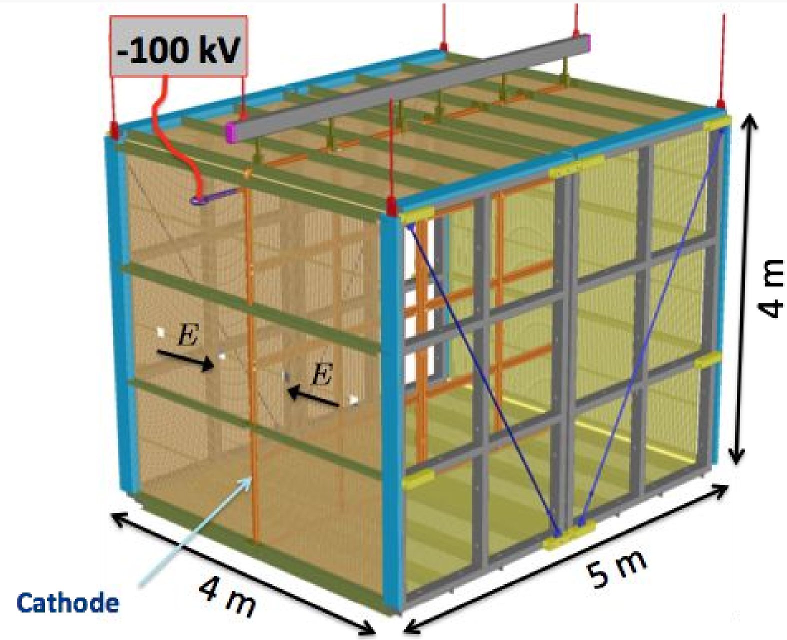
SBND design shares similar features and components that are critical for the Deep Underground Neutrino Experiment (**DUNE**)

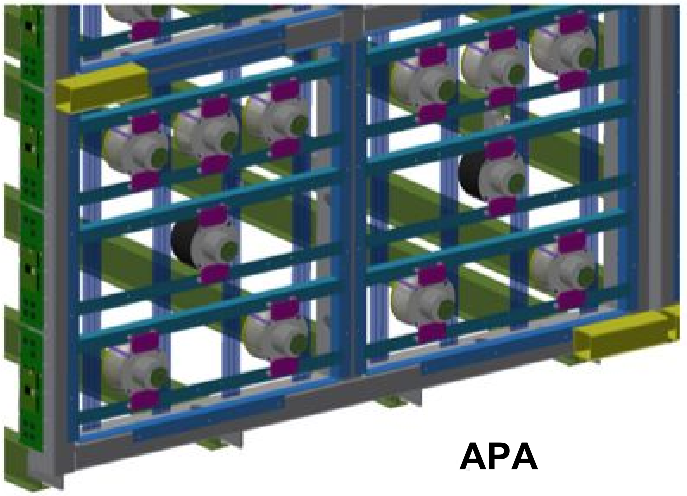
Photon detection systems in SBND will provide feedback for DUNE designs

Overview & Status of the SBN Detectors

SBND Overview

- 260 t LAr (112 t active)
- Membrane cryostat
- Two **TPCs**
  - 2 m drift distance
  - 3 wire planes (vert, ±60°)
  - 3 mm pitch
- 120 8” **PMTs** coated with TPB
  - Acrylic light guides; SiPM readout
  - Reflective foils under study
- **Laser** calibration system
- External **cosmic ray tracker** (nearly full coverage)



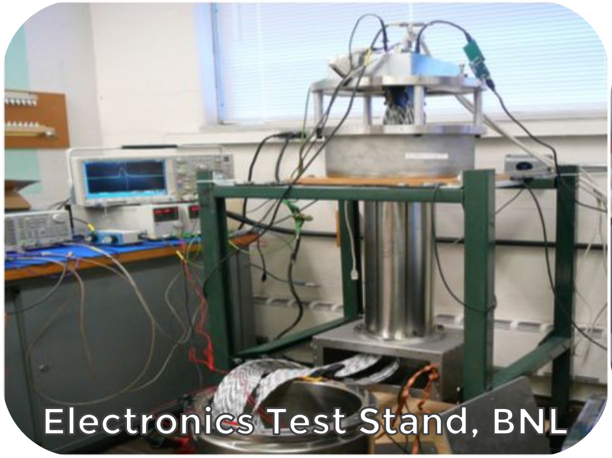


APA

SBND Status

- SBND detector systems being finalized now
- **APA frames** being built
- Front-end **electronics** with cold ADC under development at BNL
- SBND **cosmic ray tracker** being built and tested at BERN
- **TPC assembly** will begin at Fermilab in 2017
- Plan to **install in cryostat** in 2018
- **Commission**: late 2018
- **Operations**: 2019

APA Frames, Sheffield



Electronics Test Stand, BNL

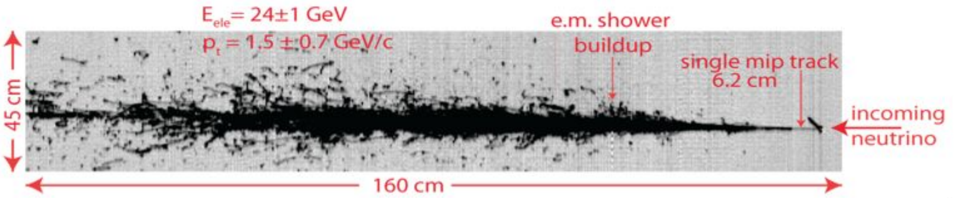
SBND CRT, BERN

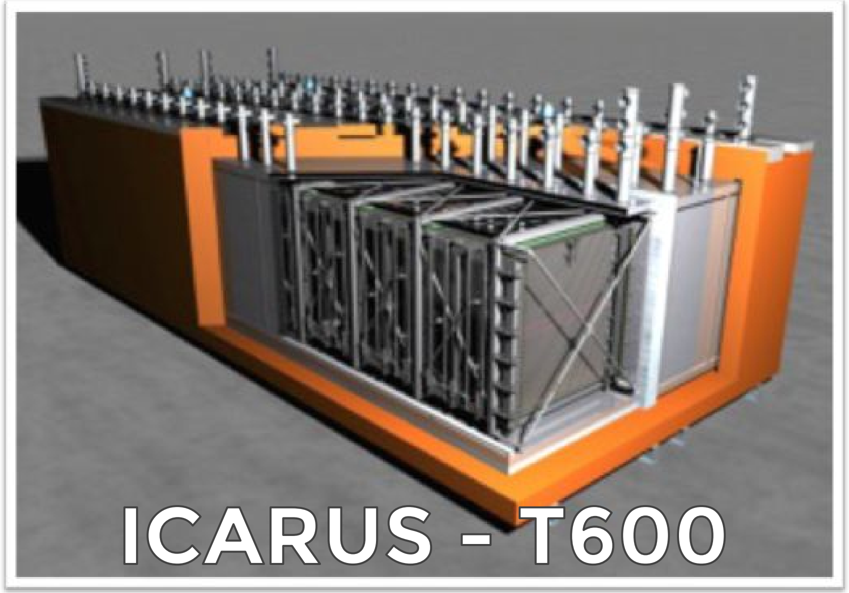
See SBND poster during Saturday's poster session!

Near Detector Civil Construction Underway - 1 July 2016

ICARUS Overview

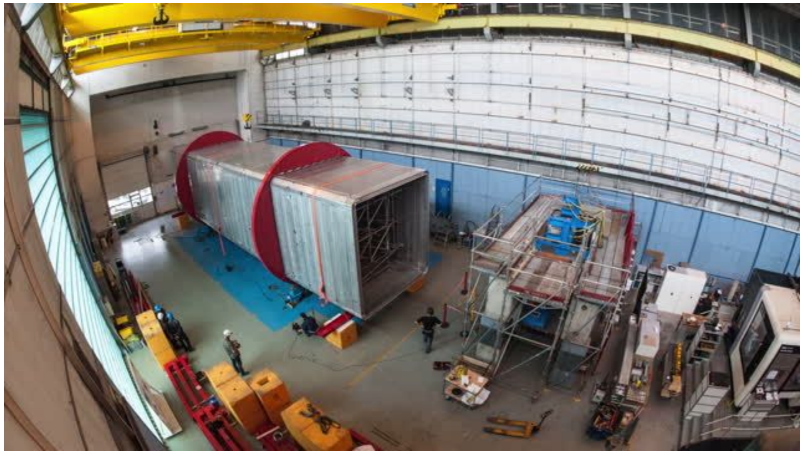
- **Operated** in CNGS beam in Italy for 3 years
- Currently being **refurbished** & **upgraded** at CERN
- 760 t **LAr** (476 t active)
- Four **TPCs**
  - 1.5 m drift distance
  - 3 wire planes
  - 3 mm wire pitch
- 360 8” **PMTs**; TPB-coated
- **Cosmic Ray Tracker**





ICARUS Status

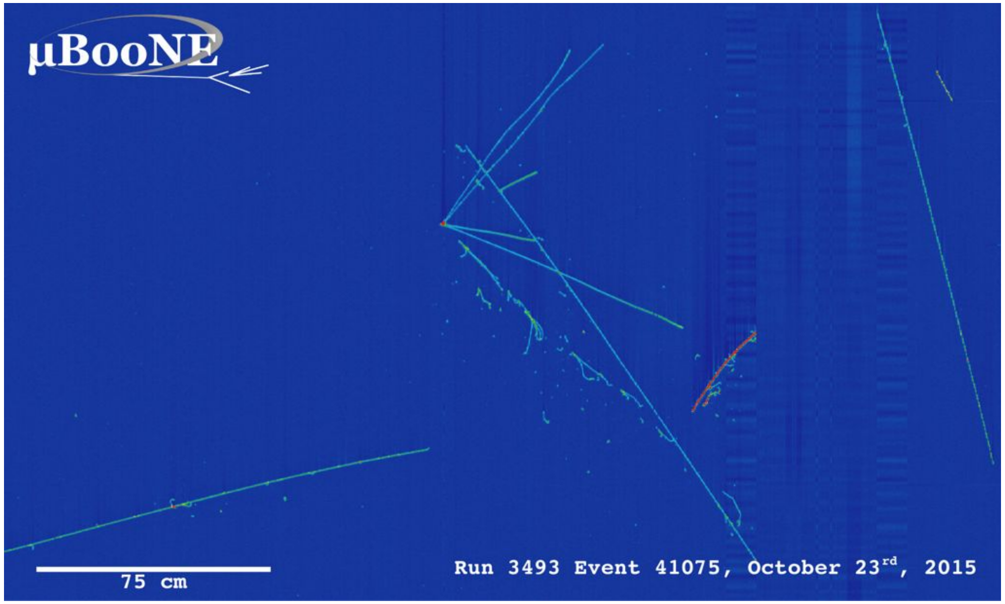
- New aluminum cryostat vessels under construction
- ICARUS **overhaul** @ CERN
  - Planarity of cathode
  - Enlarged PMT system
  - New readout electronics
  - Refurbished cryogenics
- 1st TPC module nearing completion
- **Broke ground** on Far Detector building in July 2015
- Building **complete** by end of **2016**
- Two detector modules delivered to Fermilab in early **2017**
- **Commissioning** in 2018



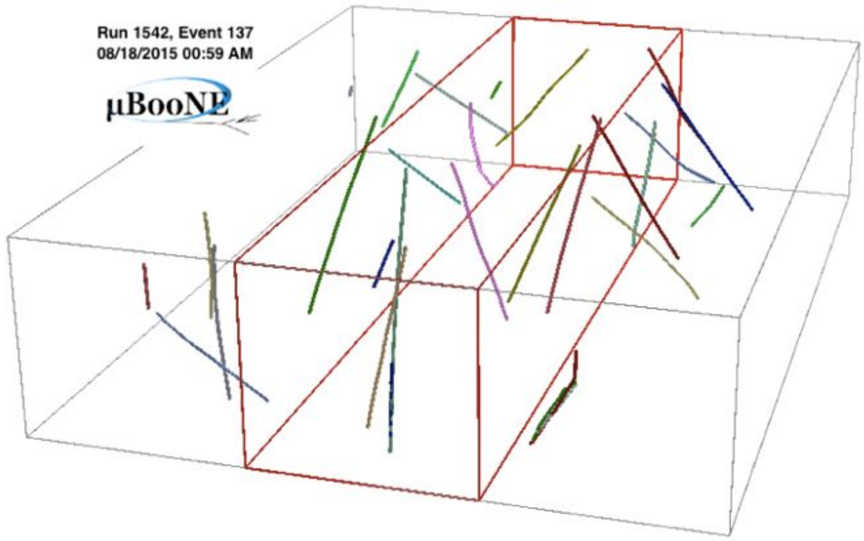
Far Detector Building Civil Construction Underway
(left) 9 June 2016, (right) 20 July 2016

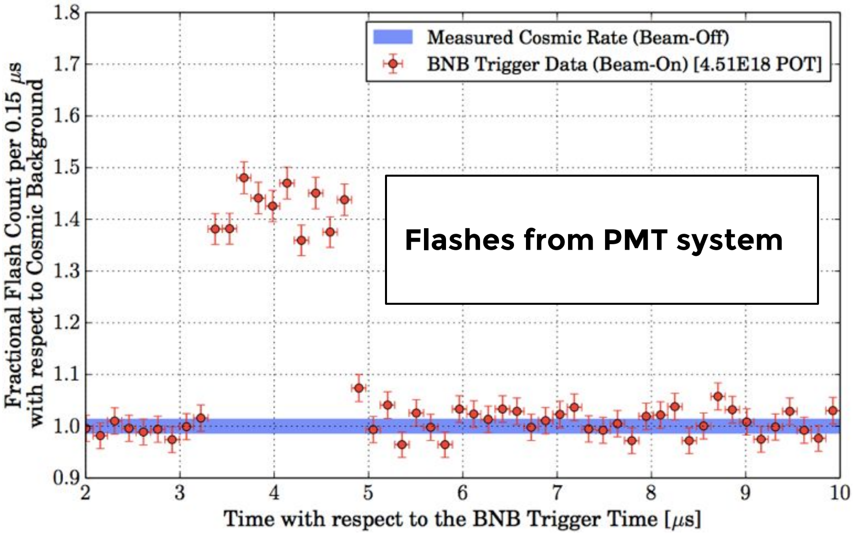
MicroBooNE Overview

- Currently **operating** in BNB at Fermilab
- Has recorded **3.4×10^{20} POT** so far; plan to collect 6.6×10^{20} POT by 2018
    - Will collect another 6.6×10^{20} in SBN program
- 170 t LAr (87 active)
- Single **TPC**
    - 2.5 m drift
    - 3 wire planes
    - 3 mm wire pitch
- **2 UV lasers**
- **32 8” PMTs**
- **Cosmic Ray Tagger** being installed over the Summer



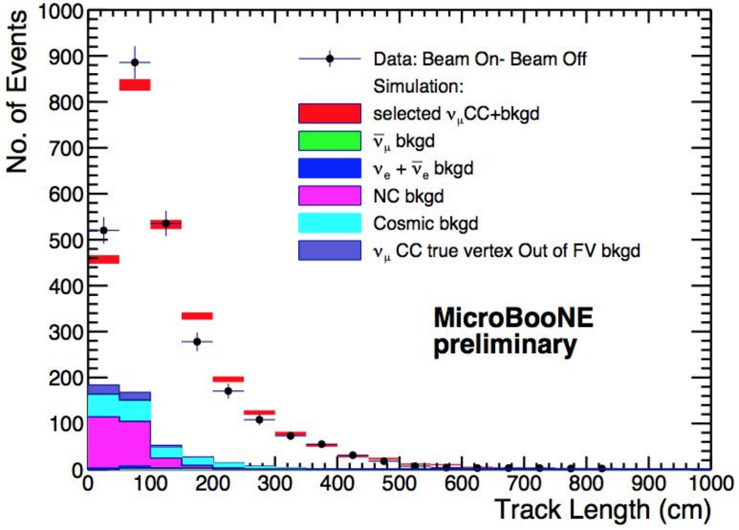
First Results from MicroBooNE





Flashes from PMT system

First ν_μ CC distributions from MicroBooNE data (Neutrino 2016)



Summary

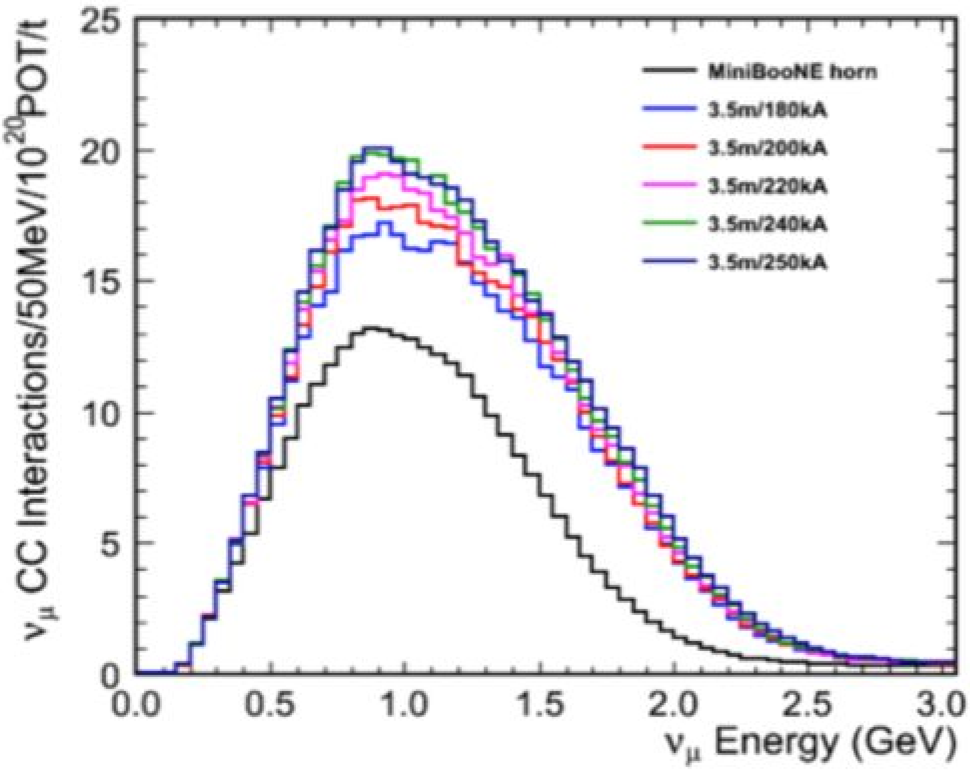
- The SBN Program consists of three LAr TPCs that will sit in the Booster Neutrino Beamline at Fermilab and will
  - Follow up on hints of new physics, in particular the LSND allowed region will be covered at > 5σ
  - Make high precision measurements of ν-Ar cross sections
  - Develop LAr TPC technology & expertise further in preparation for DUNE

- Significant recent progress:
  - BNB operating with high rates
  - MicroBooNE running with beam; 3.4e20 POT recorded!
  - Civil construction underway for ICARUS & SBND facilities
  - ICARUS refurbishment is underway @ CERN
  - SBND TPC design being finalized; components being built

Extra Slides

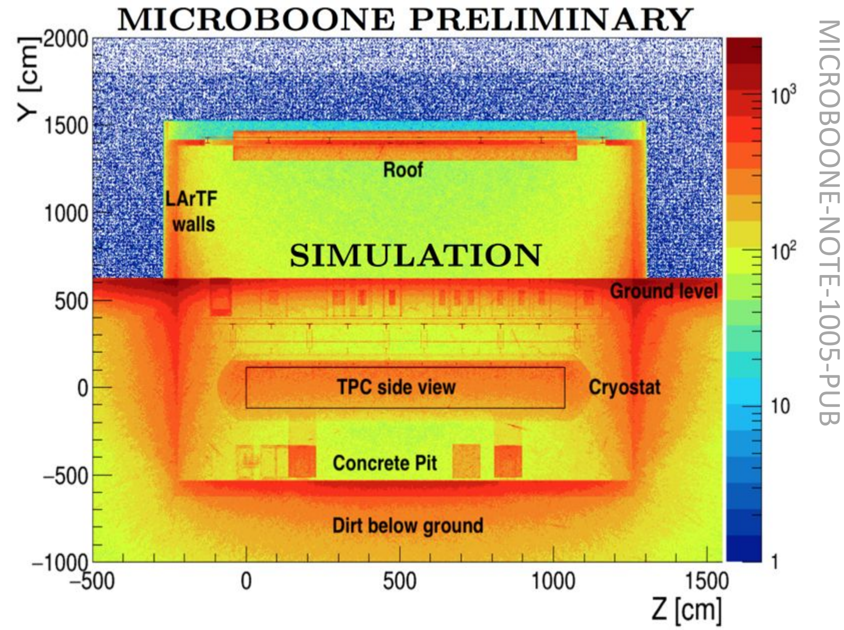
Beam Upgrades

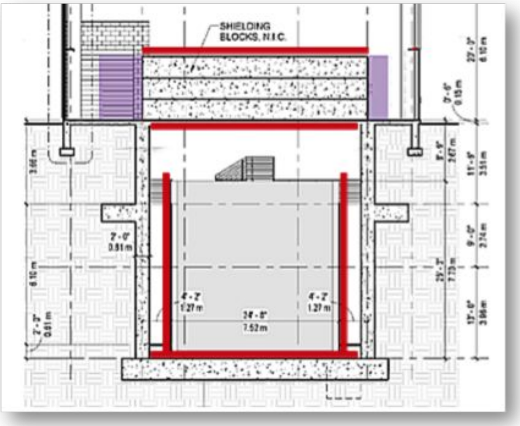
- Upgrades being considered for BNB
  - Increased focusing efficiency of target/horn
  - Increase max repetition rate from current of 5 Hz
  - Design studies indicate possible improves of 1.8x in event rate

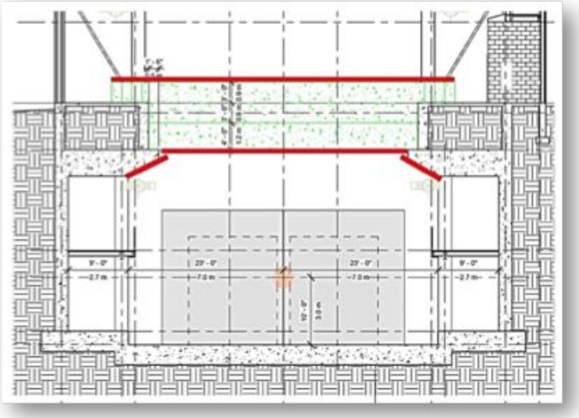


Cosmogenic Backgrounds

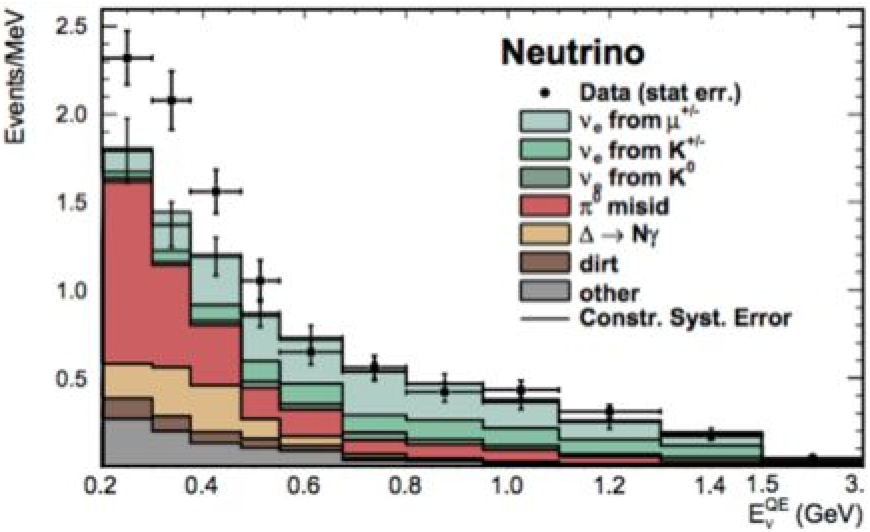
- SBN program detectors are located on surface and see large cosmogenic rate
  - E.g. 5 kHz muon rate in MicroBooNE
- **Overburden** for SBND and ICARUS removes non-muon primaries
- **Cosmic Ray Tracker** systems in all three will help to reduce backgrounds further
- BNB->PMT **timing** improvements can reduce out-of-time events further
  - Dirt muons

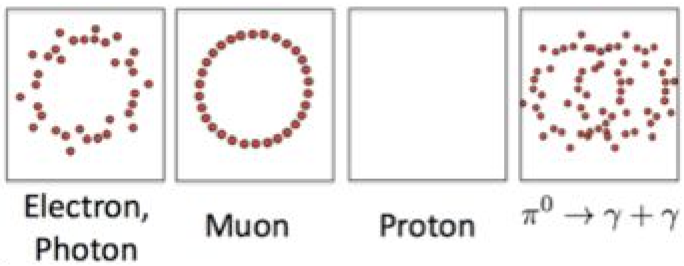






Context: MiniBooNE

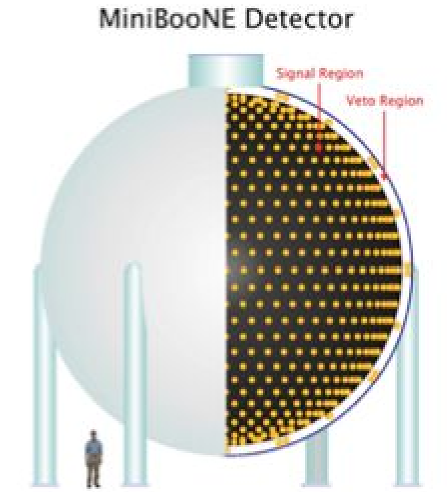




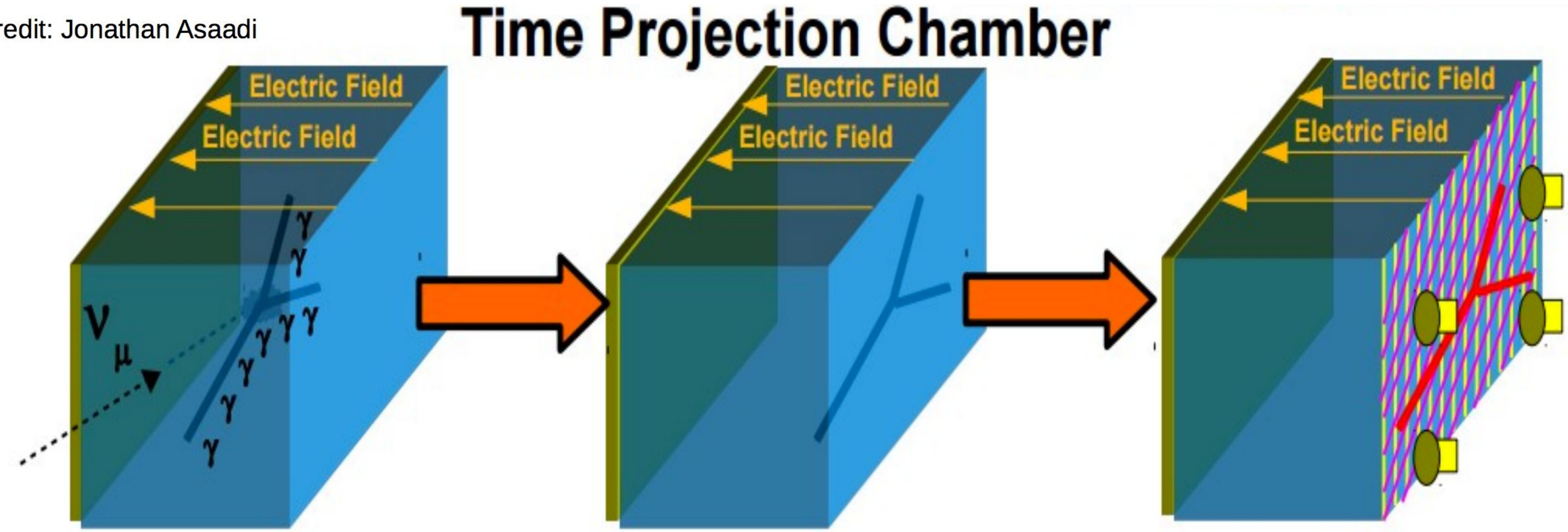
MiniBooNE is a Cherenkov detector that ran in the BNB:

- Operated 2003-2014
- 800 t liquid scintillator
- 540 m from BNB target

Observed excess of EM-like events, but unable to determine if electron or gamma in origin.



Credit: Jonathan Asaadi



- **Electric field**, ~500 V/cm, is setup by **cathode plane**
- **Interactions** in **LAr** produce **ionization electrons** and photons
- Prompt **scintillation light** (128 nm) reaches the **PMTs** first
  - Wavelength shift (fibers, plates, coating on walls of TPC, etc) to readout in PMTs
- Due to **electric field**, electrons drift, at mm/us, to anode plane where they induce charge in the **induction planes** and are collected on the **collection plane**
  - No charge amplification -> charge readout is proportional to deposited energy
- This is the single phase approach