MANCHESTER 1824

The University of Manchester

The Short Baseline Programme at Fermilab

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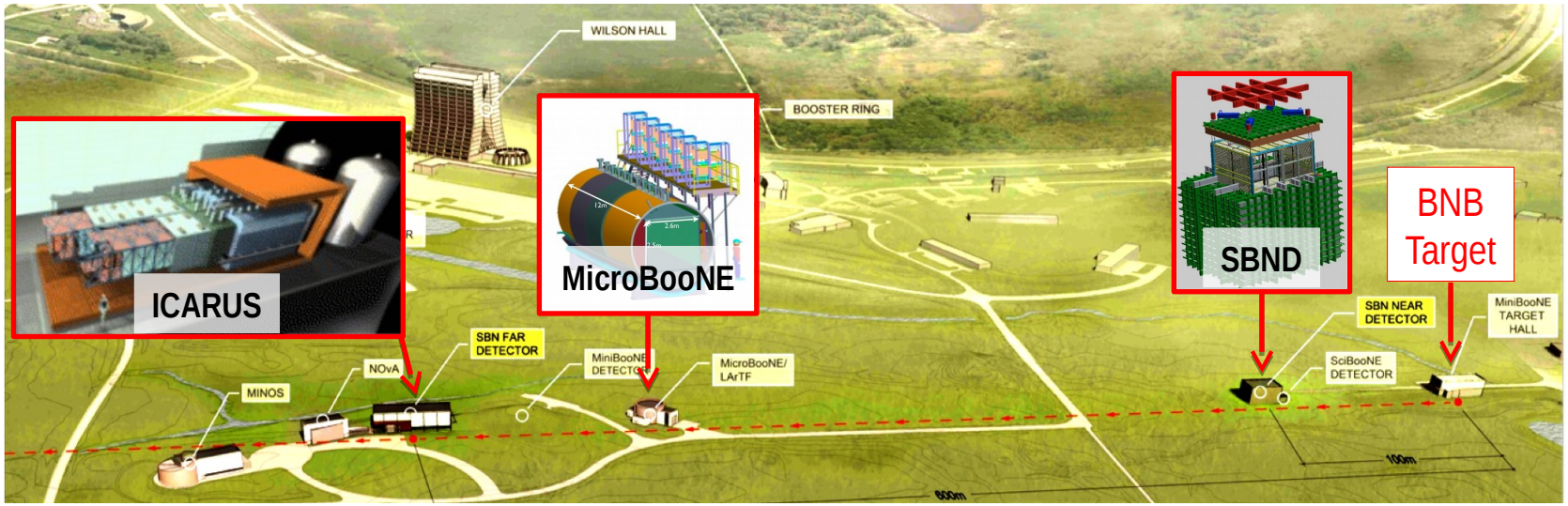
(University of Manchester)



Outline

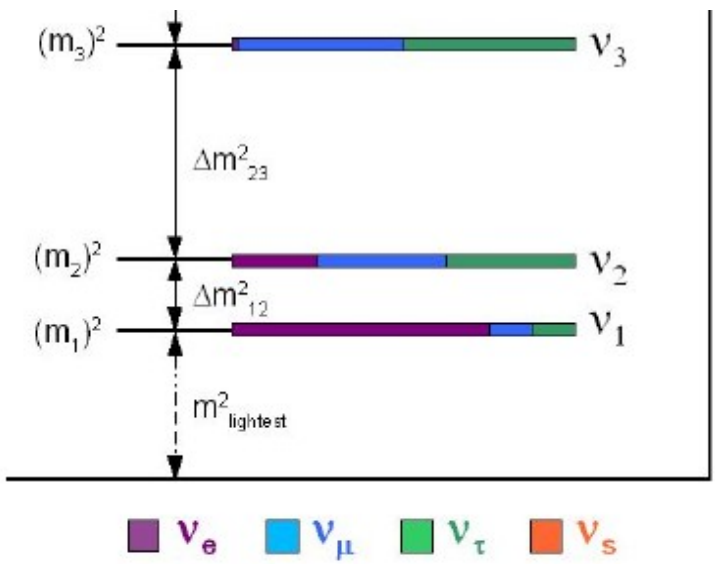
- Why sterile neutrinos?
- Detecting neutrinos with LArTPCs in the SBN programme
- Phase 1: MicroBooNE
- Phase 2: Full scale SBN
- Conclusions

The Current State of Neutrino Knowledge

Our picture of Neutrinos in the standard model is almost complete.

"Large" mixing angle θ_{13} opens the way to measurements of δ_{CP}. (and we already have hints that it is non-zero!).

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$



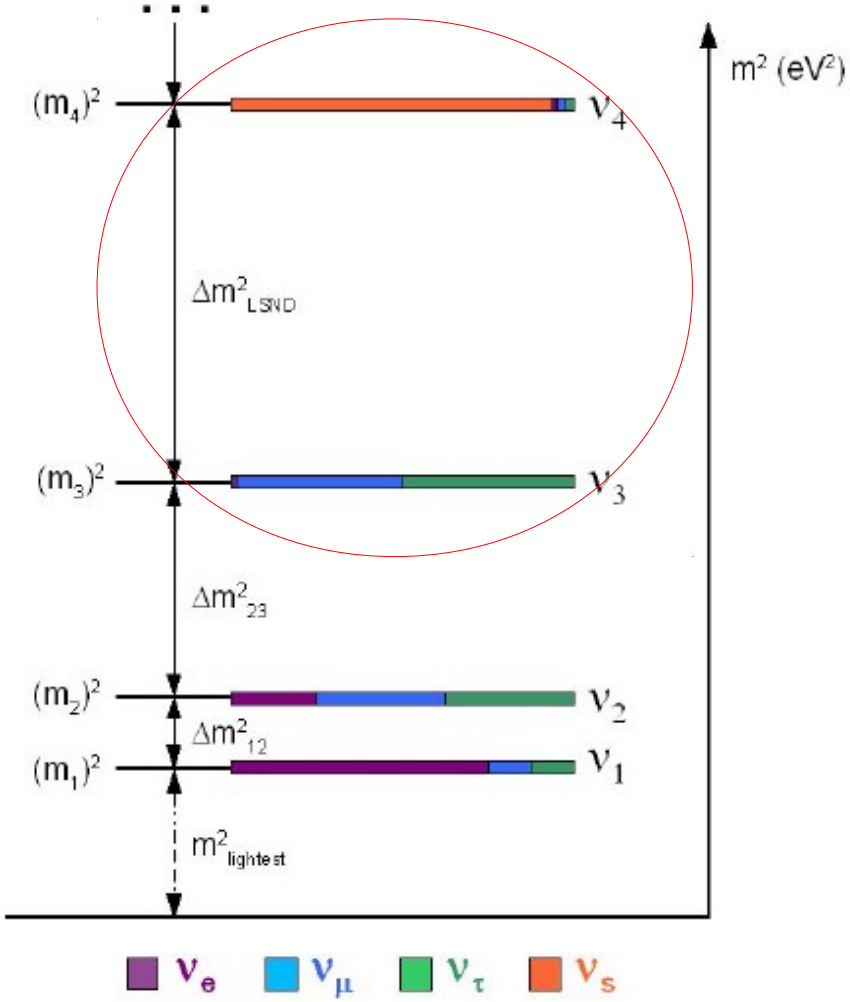
"Known" neutrino physics

Δm^2_{21} $[10^{-5}\mathrm{eV}^2]$	7.56 ± 0.19
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\mathrm{eV}^2]$ (NO)	2.55 ± 0.04
$\lvert\Delta m^2_{31}\rvert$ $[10^{-3}\mathrm{eV}^2]$ (IO)	2.49 ± 0.04
$\theta_{12}/^\circ$	$34.5^{+1.1}_{-1.0}$
$\theta_{13}/^\circ$	$8.44^{+0.18}_{-0.15}$
$\delta/^\circ$	252^{+56}_{-36}
$\sin^2\theta_{23}/10^{-1}$ (NO)	$4.30^{+0.20}_{-0.18}$
$\theta_{23}/^\circ$	41.0 ± 1.1
$\sin^2\theta_{23}/10^{-1}$ (IO)	$5.96^{+0.17}_{-0.18}$
$\theta_{23}/^\circ$	50.5 ± 1.0

Salas, Forero, Ternes, Tortola, Valle: 2017

SB Neutrino Anomalies

- Recalculation of reactor neutrino fluxes and analysis of sources in gallium experiments.
- LSND anomaly.
- MiniBooNE low energy excess.



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

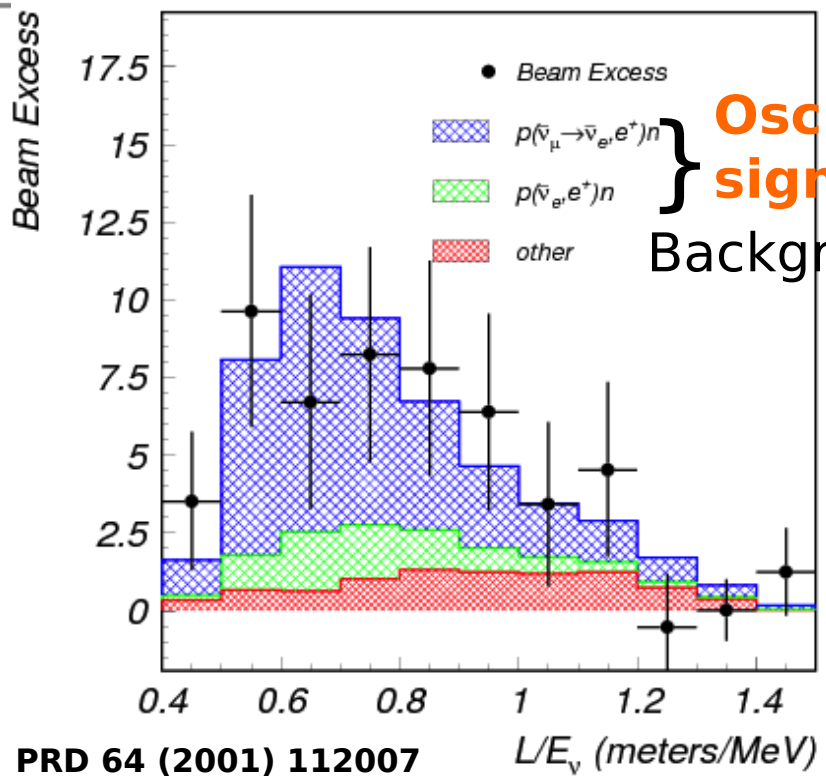
K. N. Abazajian et al. "Light Sterile Neutrinos: A Whitepaper", arXiv:1204.5379 [hep-ph], (2012)

- Very different experimental techniques are hinting at short baseline oscillations.
- Tension with other experiments, e.g. long-baseline.

Accelerator Anomalies

LSND

Baseline 30 m
E= [20 – 50] MeV
L/E ≈ 1 m/MeV
167 tons liquid scintillator



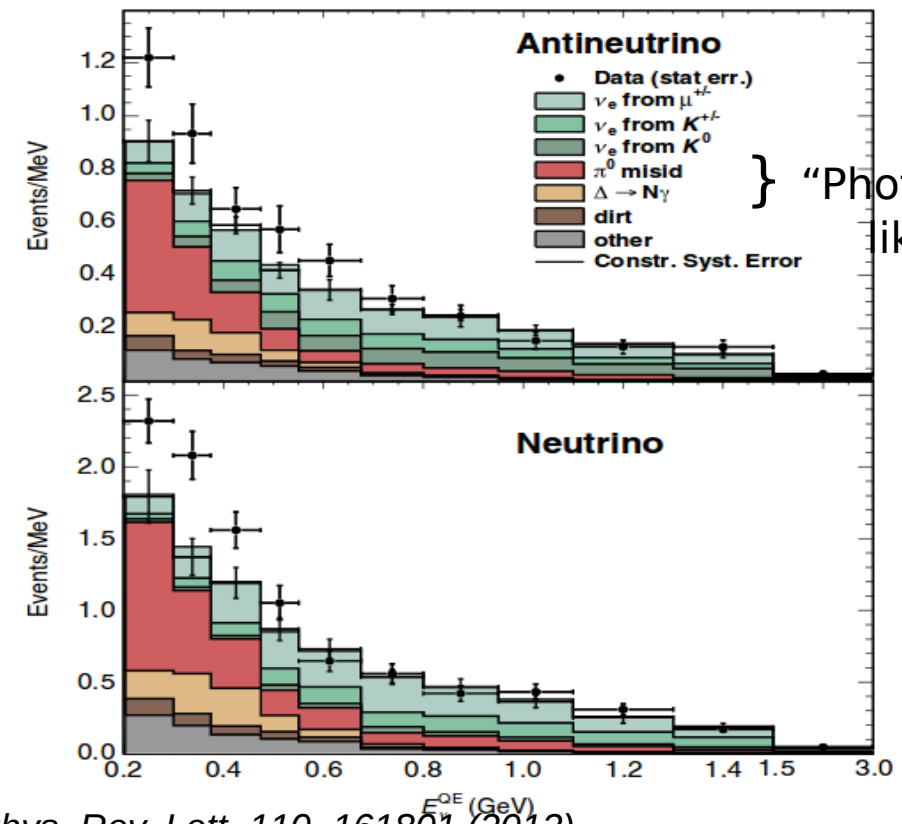
Oscillation signal?
Backgrounds

PRD 64 (2001) 112007

excess appearance of $\bar{\nu}_e$ - evidence for $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation at $\Delta m^2 \simeq 1$ eV^2 ?

MiniBooNE

Baseline 540 m
E=[0 - 2] GeV
L/E ≈ 1 m/MeV



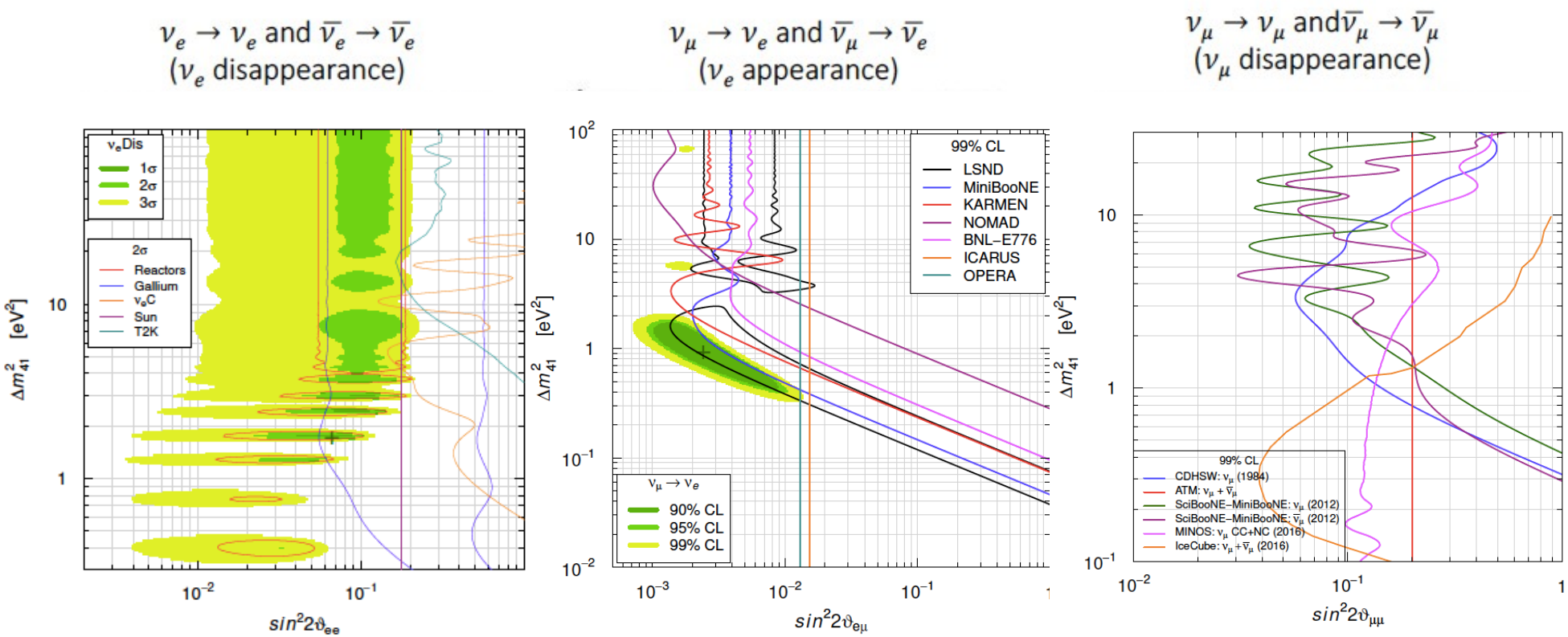
"Photon like"

Phys. Rev. Lett. 110, 161801 (2013)

excess appearance of $\bar{\nu}_e$ and ν_e:
So called low energy excess.
Cherenkov detector: e ~ γ

Global Fits

S. Gariazzo, C. Giunti, M. Laveder, Y.F. Li, arXiv:1703.00860, JHEP06(2017)135



Tension with experiments that observe no signal, e.g. recent measurements by **NEOS, IceCube and MINOS+** leads to significant constraints on possible sterile neutrino parameters.

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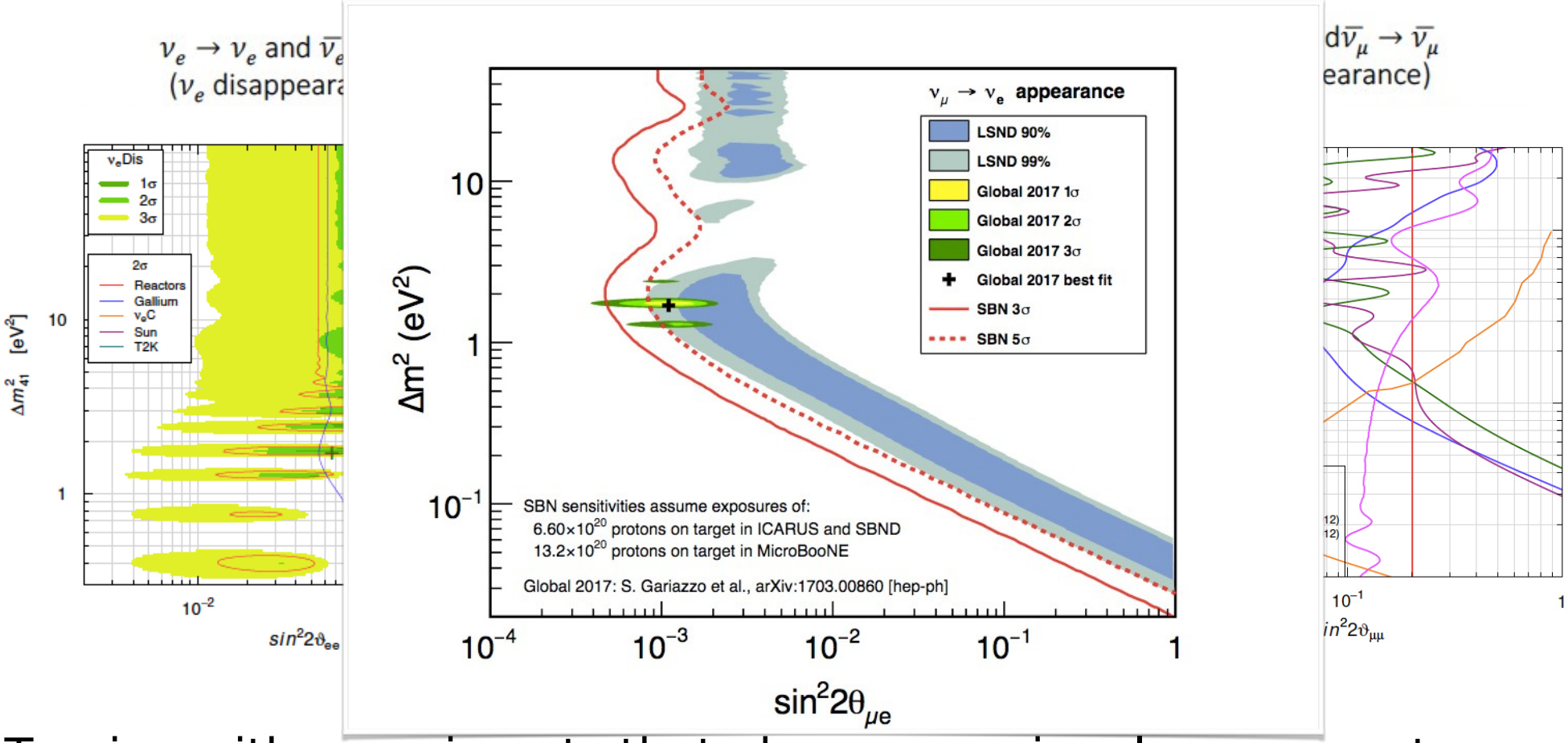

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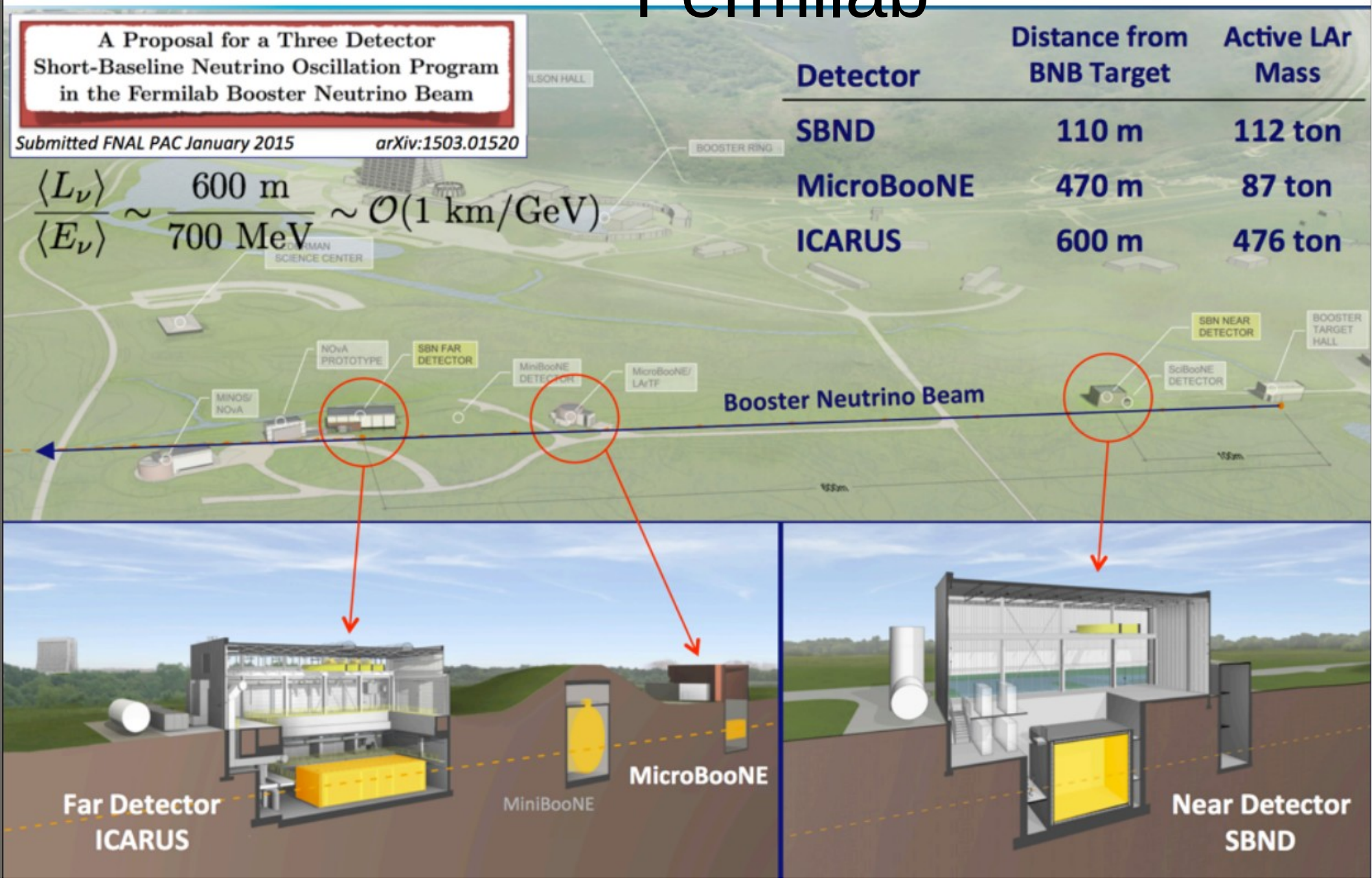
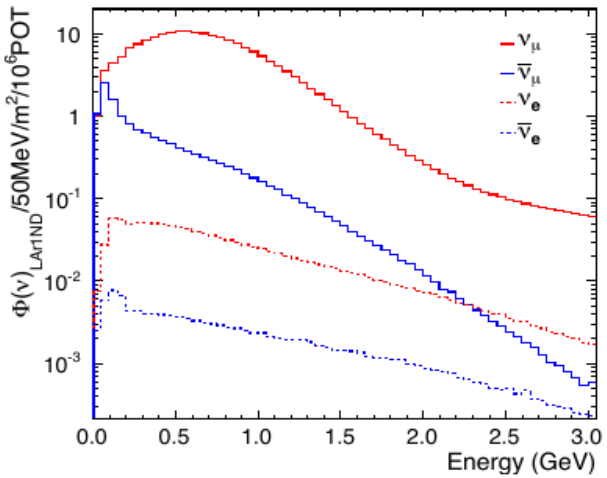
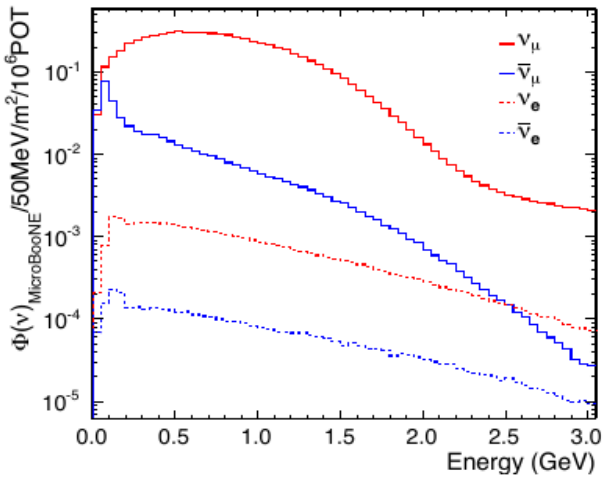
Enter SBN Programme at Fermilab



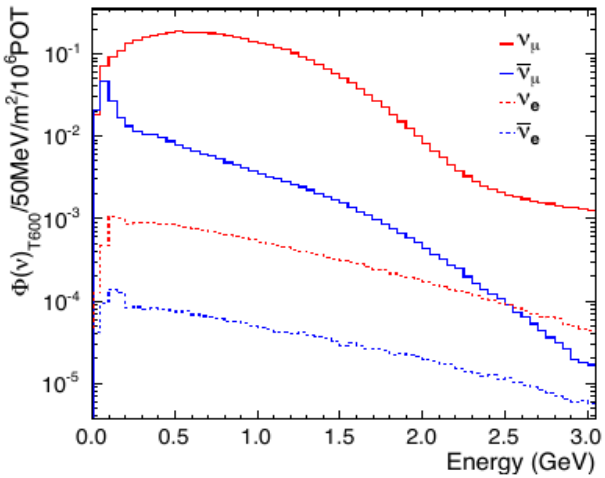
Booster Neutrino Beamline



at SBND

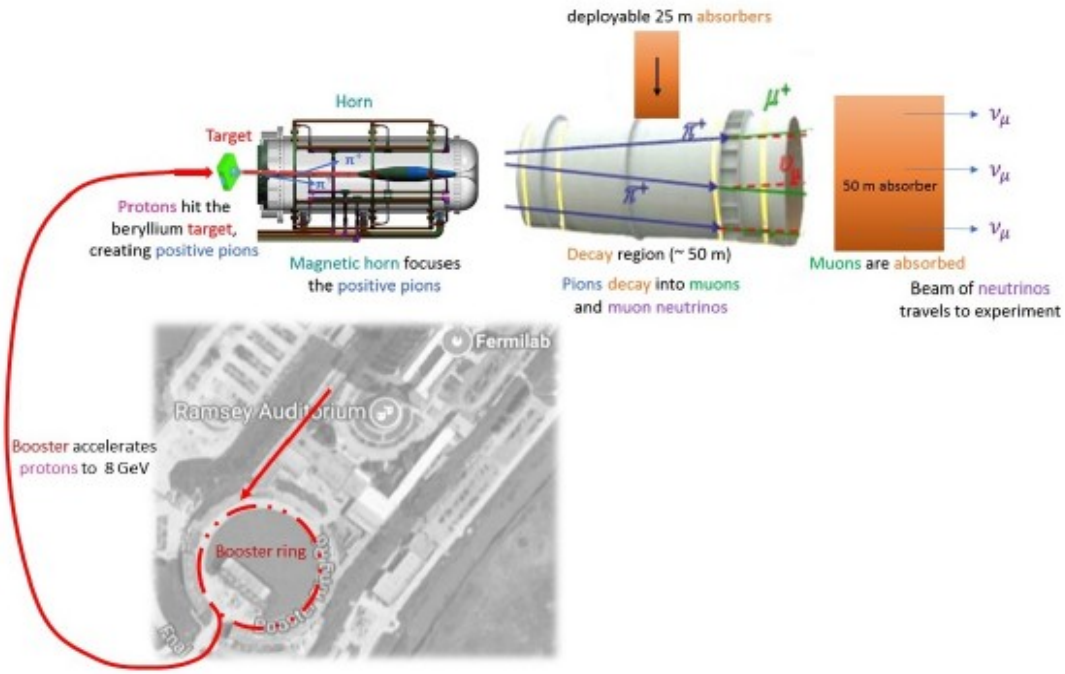


at MicroBooNE



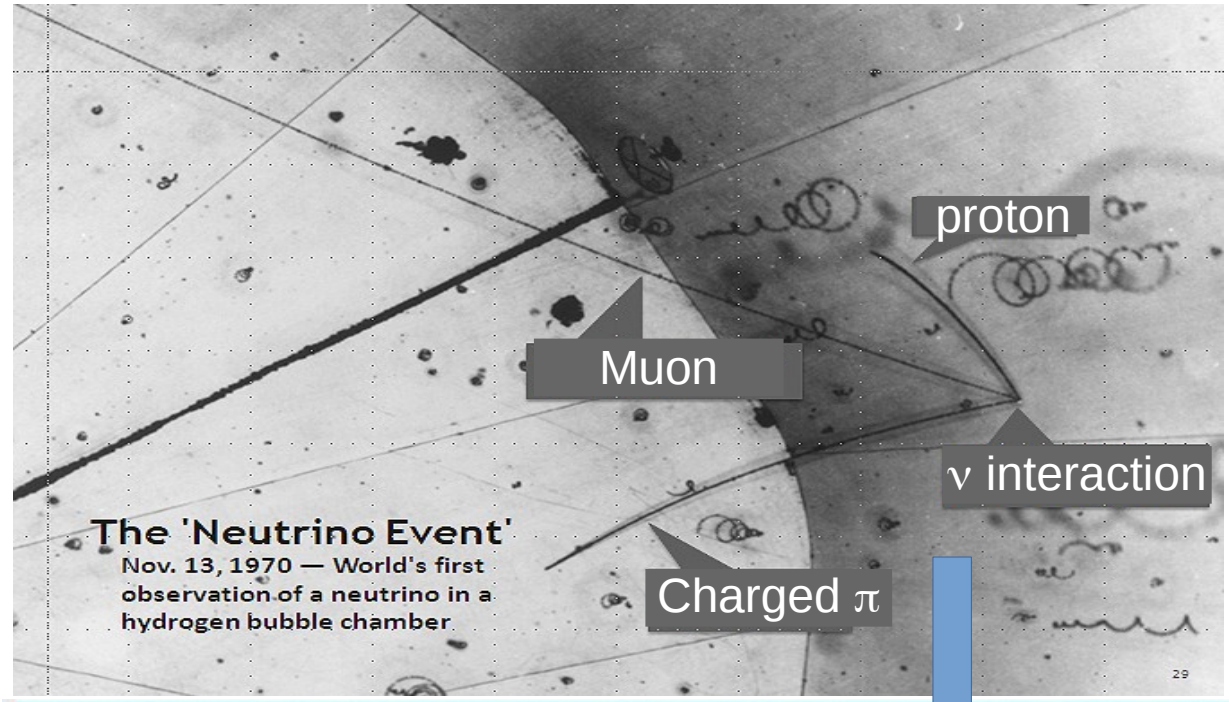
at ICARUS

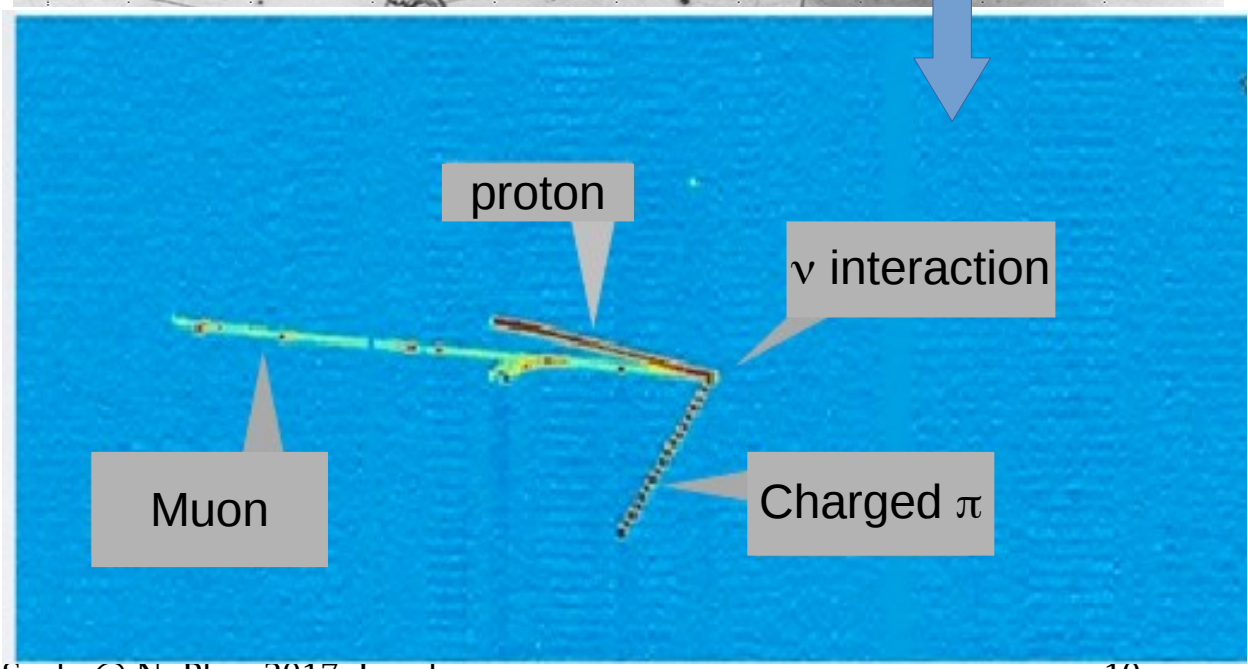
- Same beamline as MiniBooNE.
- A well known and understood system.



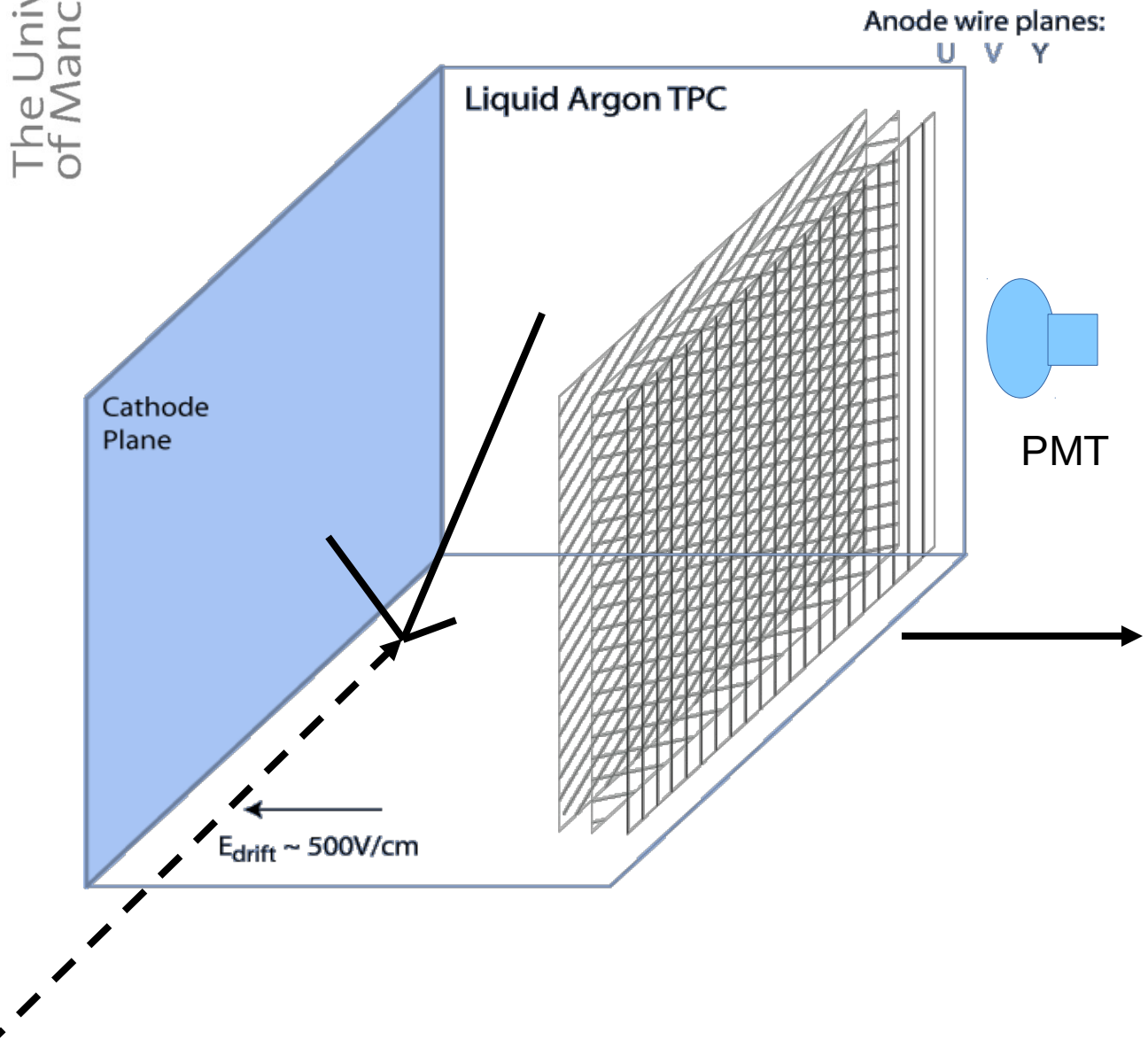
Detecting neutrinos in a LArTPC

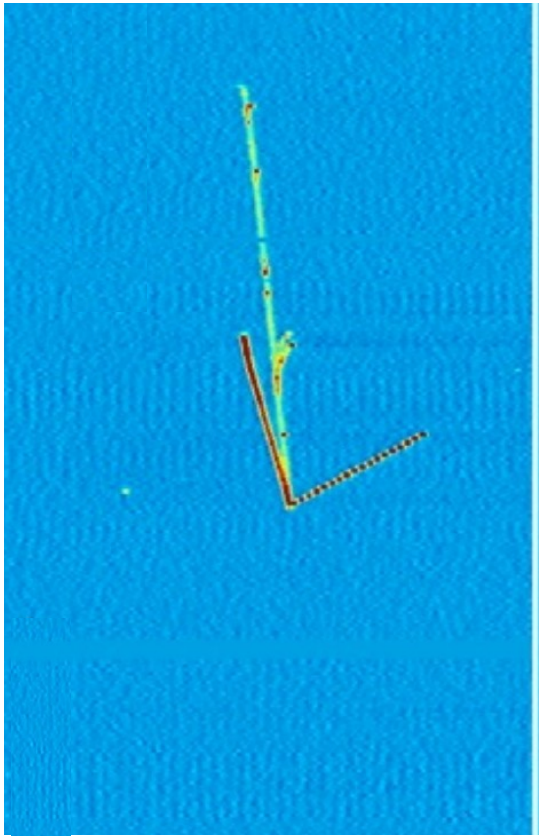
- The golden channel is ν_e appearance ($\nu_\mu \rightarrow \nu_e$)
- Photon backgrounds make ν_e appearance a particularly challenging game.
- The LArTPC and its bubble chamber-like data gives us strong background rejection tools.



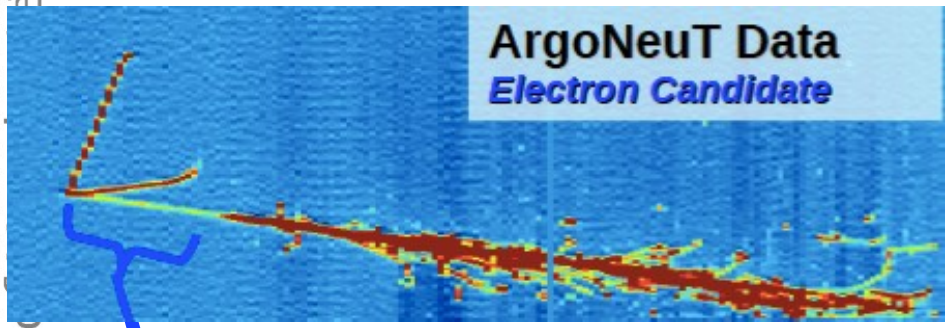


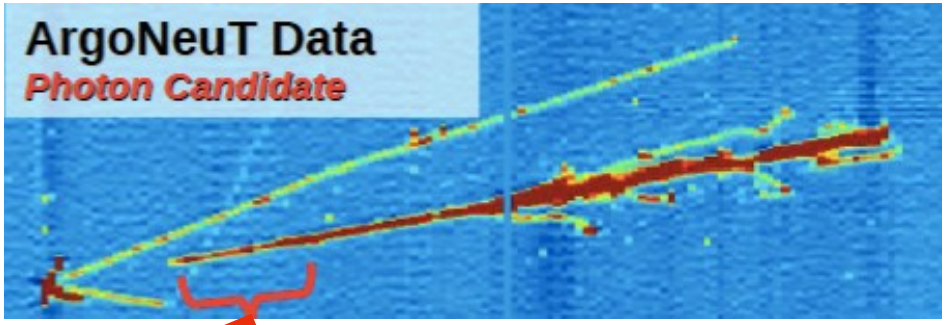
LArTPC Operation

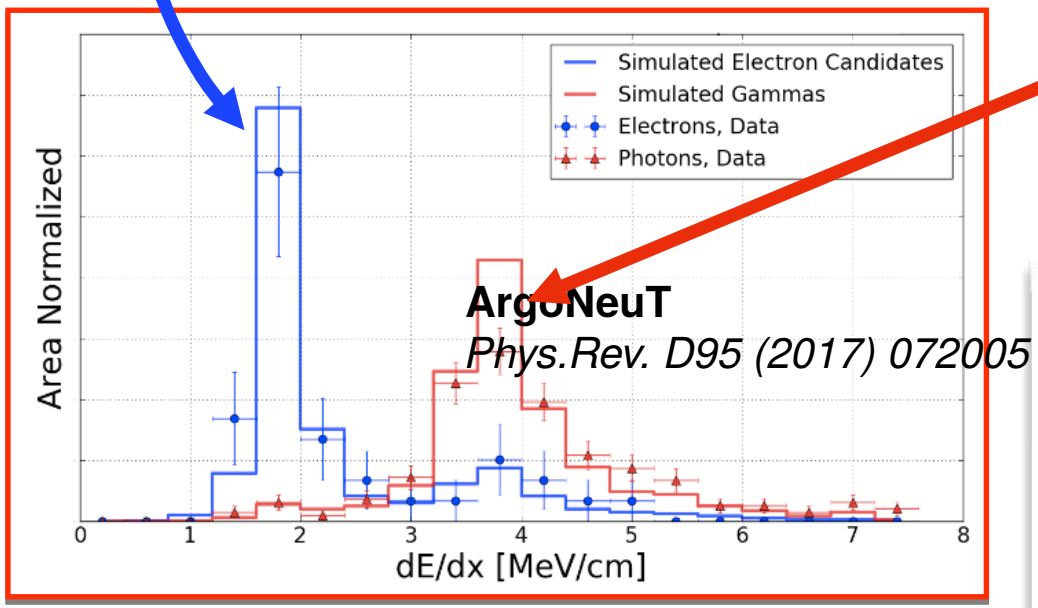




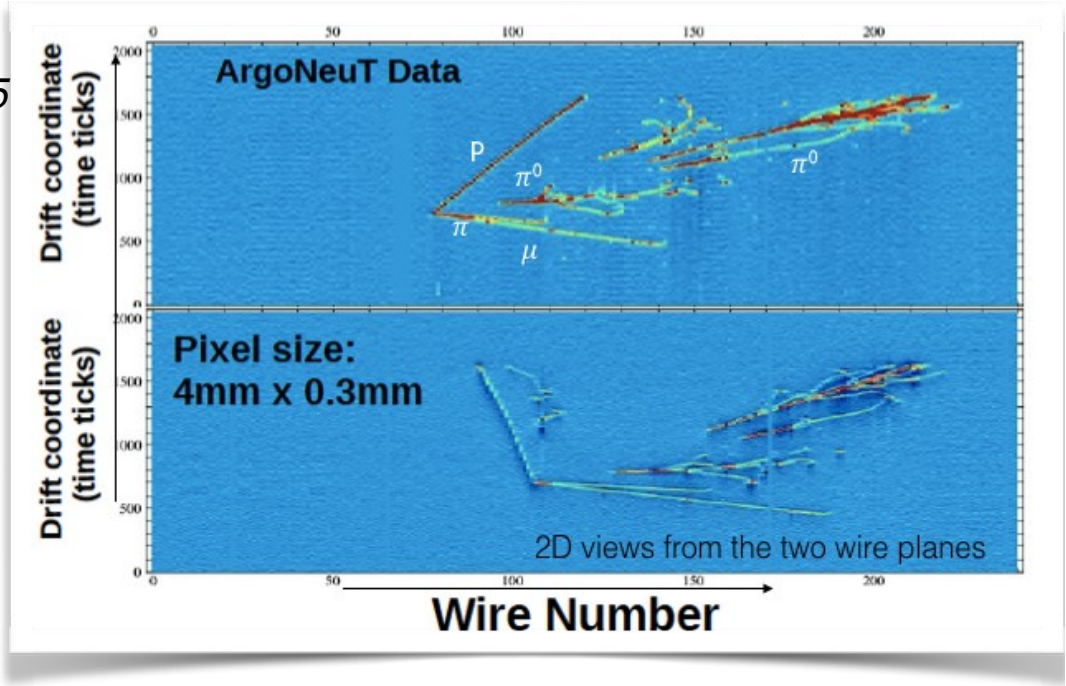
Electron-γ separation in LAr





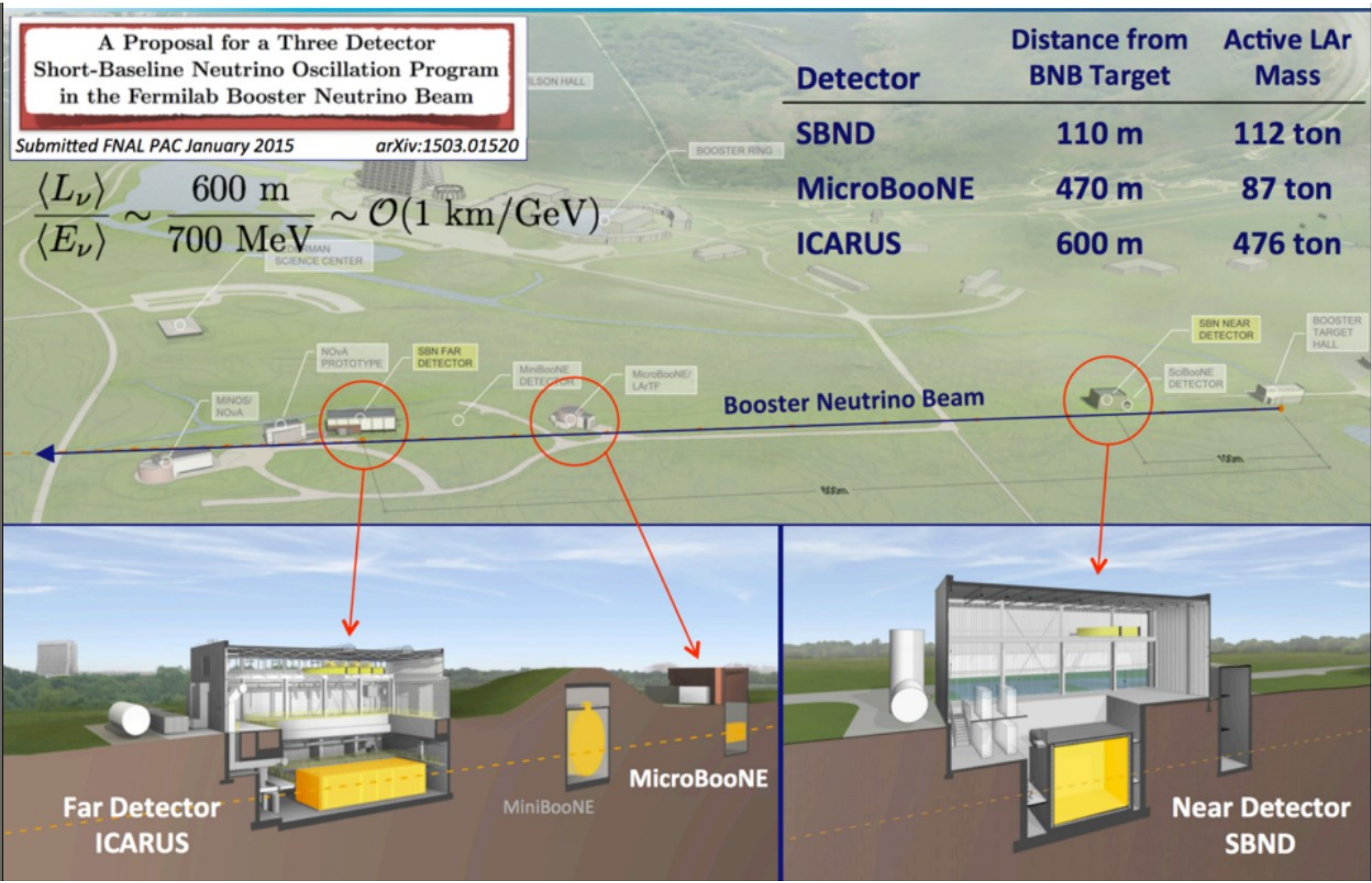


Double handle: topology and dE/dx



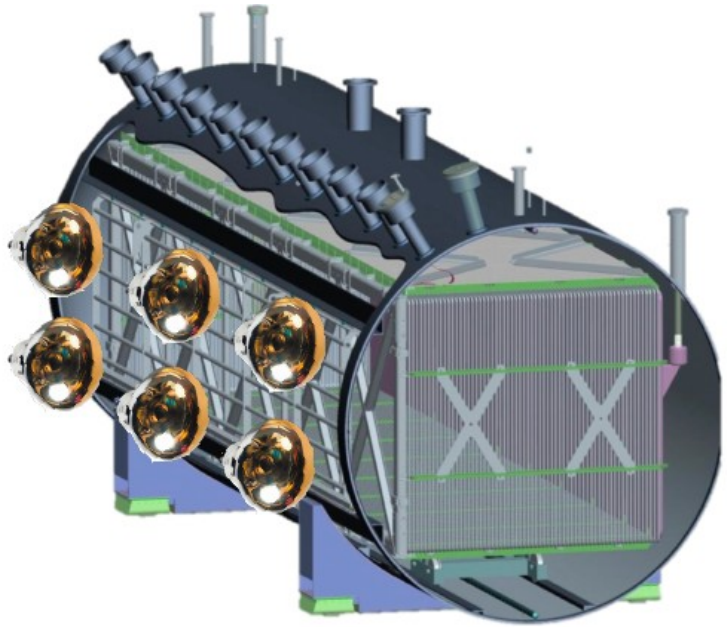
The LArTPC is an excellent tool for electron/photon separation

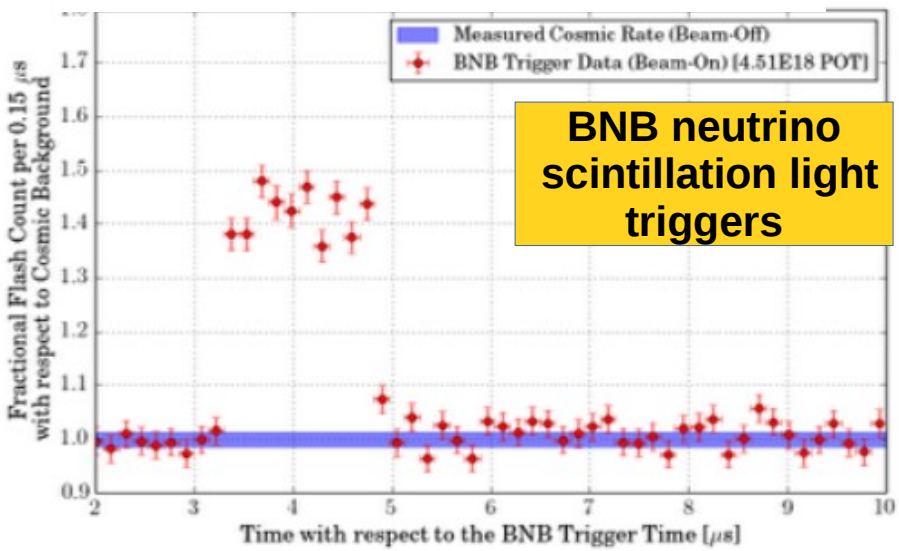
SBN Programme



Phase1: MicroBooNE

MicroBooNE





Running stably since 2015 (Largest running TPC in the World).

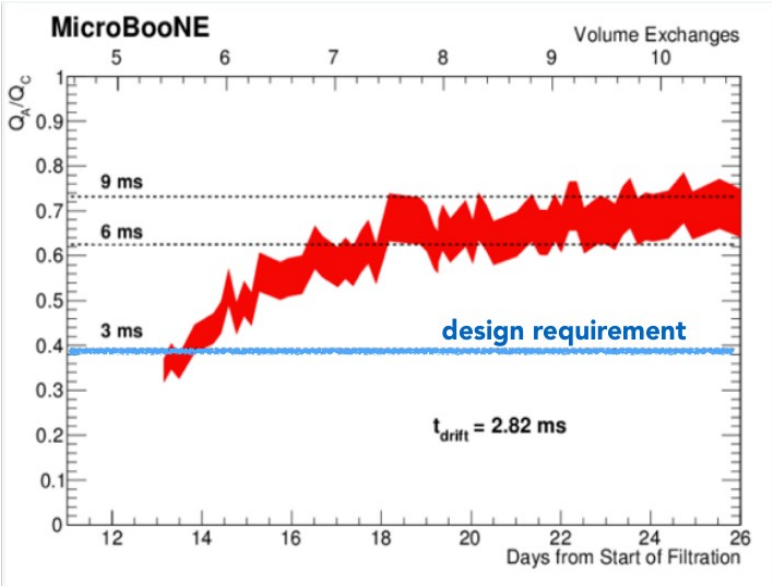
Physics goals: understand nature of MiniBooNE excess, cross-section measurements on argon.

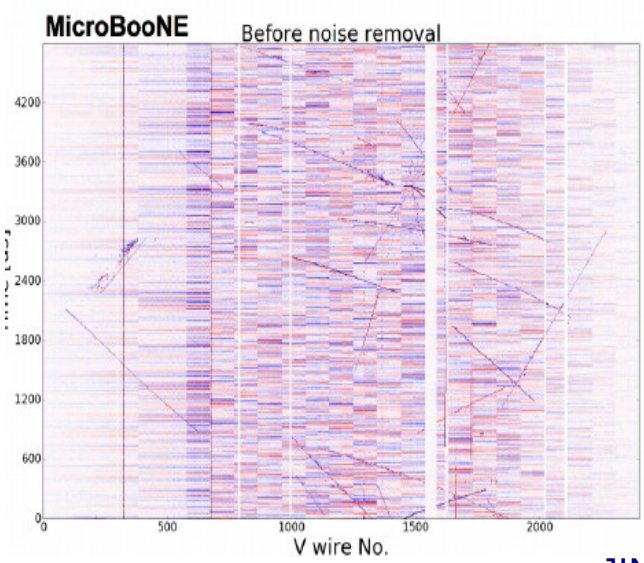
Development of LArTPC technology for future programme (DUNE).

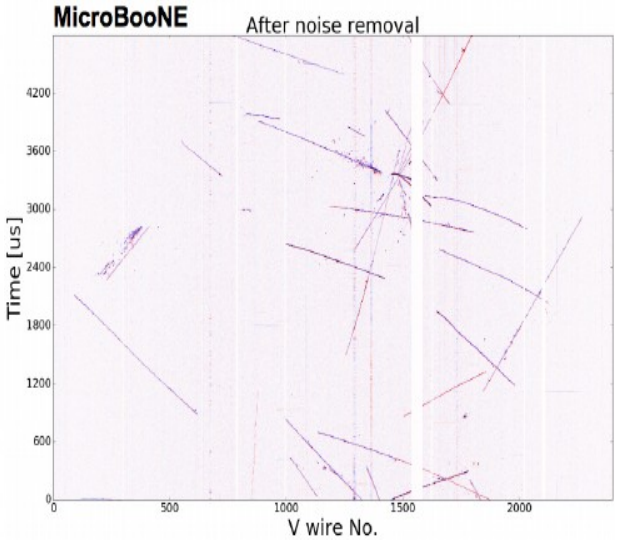
7 Publications, and more on the way:
https://www-microboone.fnal.gov/publications/index.html

Developing LArTPCs with MicroBooNE

- Extremely high purity obtained.
- Constructed CRT – important for cosmic backgrounds (and independent efficiencies).
- Understanding noise and signal formation in LArTPCs.

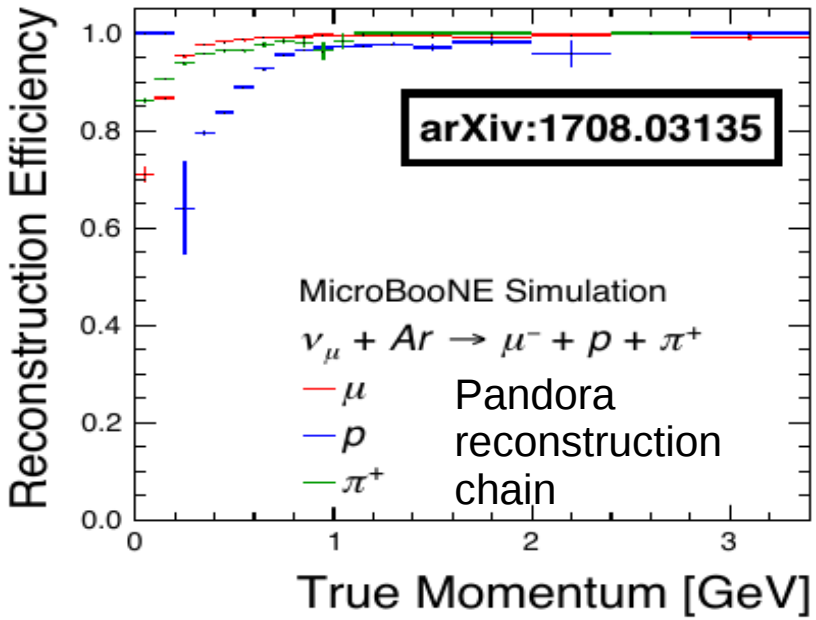


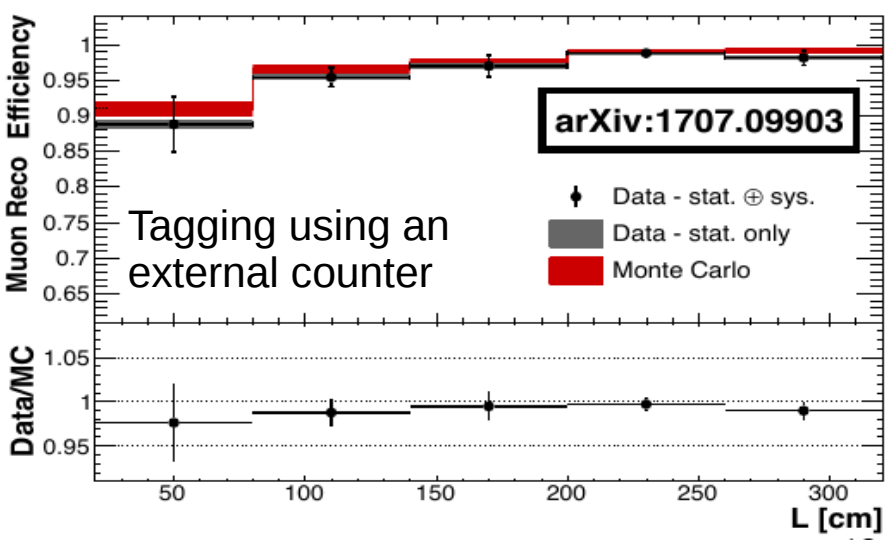


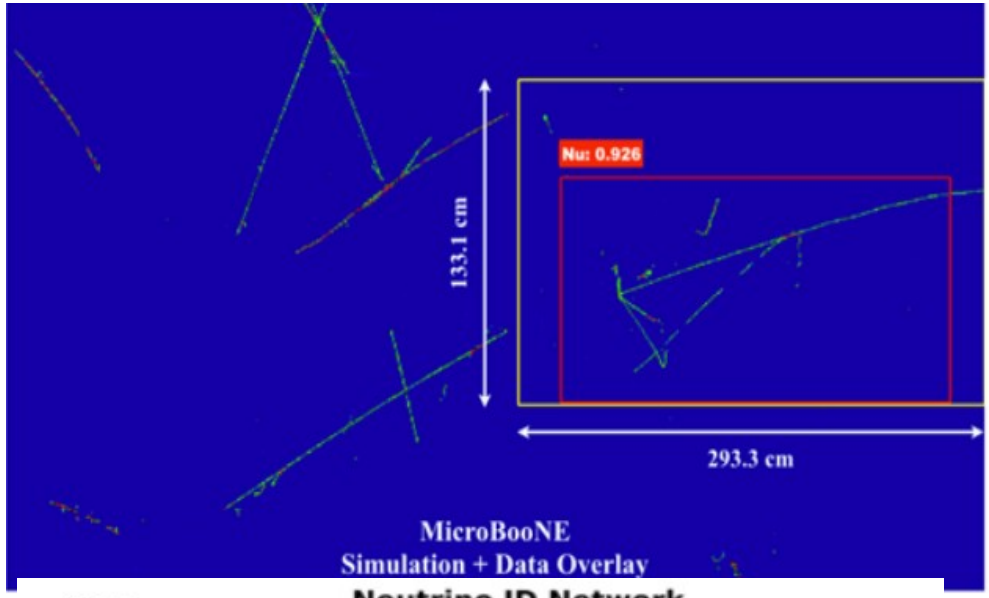


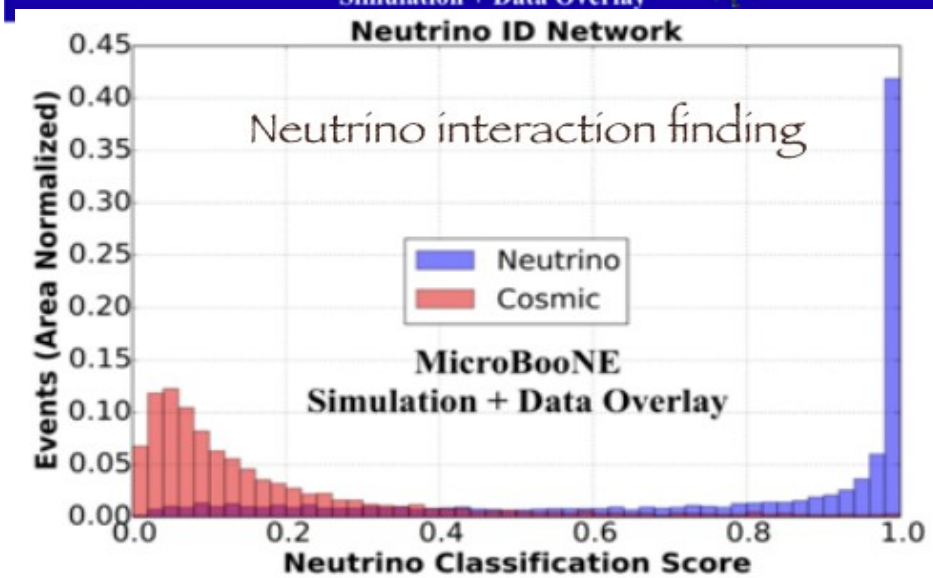
JINST 12, P08003 (2017)

Developing LAr reconstruction





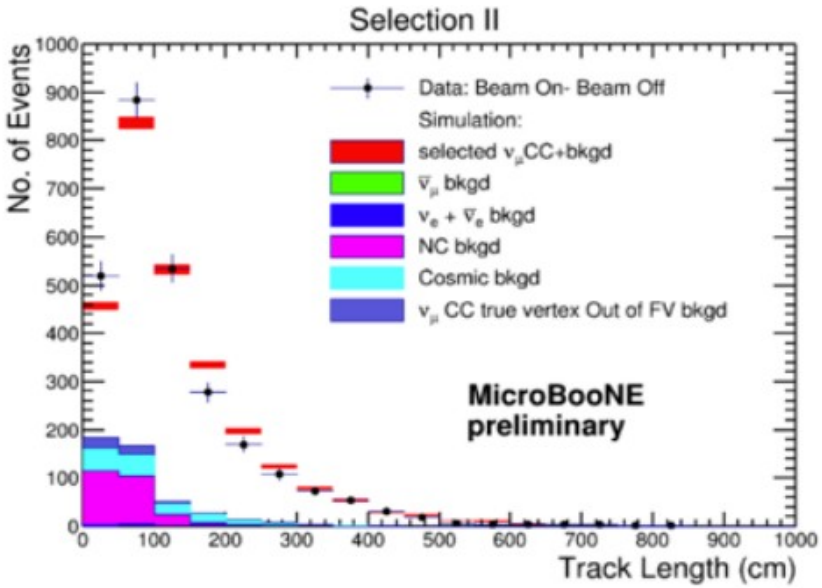


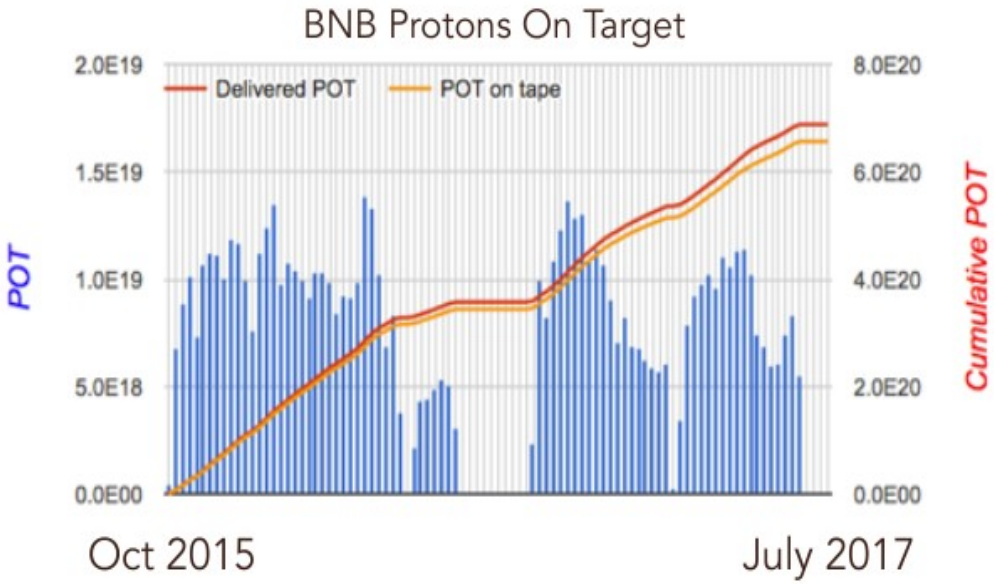


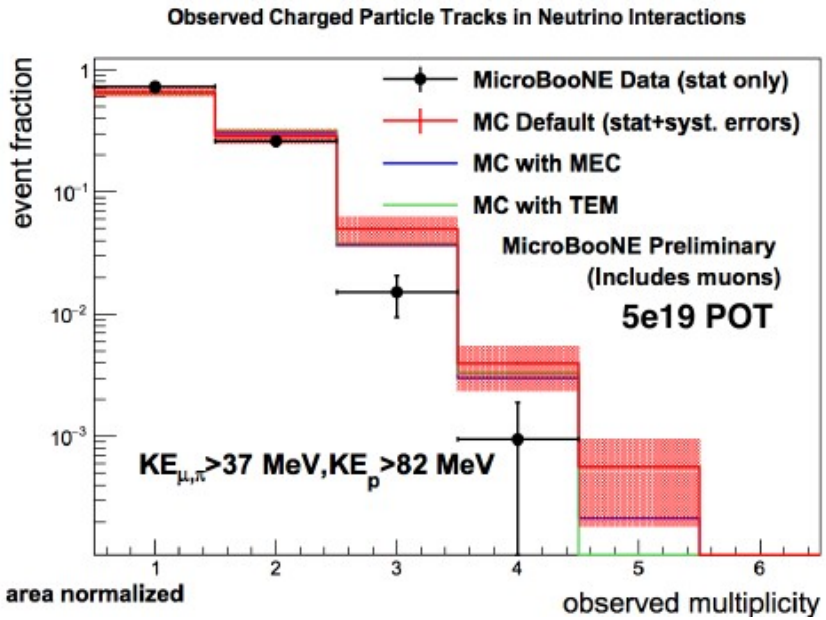
Event selection using Deep Learning
JINST 12, P03011 (2017)

Physics with tracks

- CC-inclusive measurement close to completion.
- In parallel studying the multiplicity of charged tracks – important for understanding nuclear models and energy reconstruction.

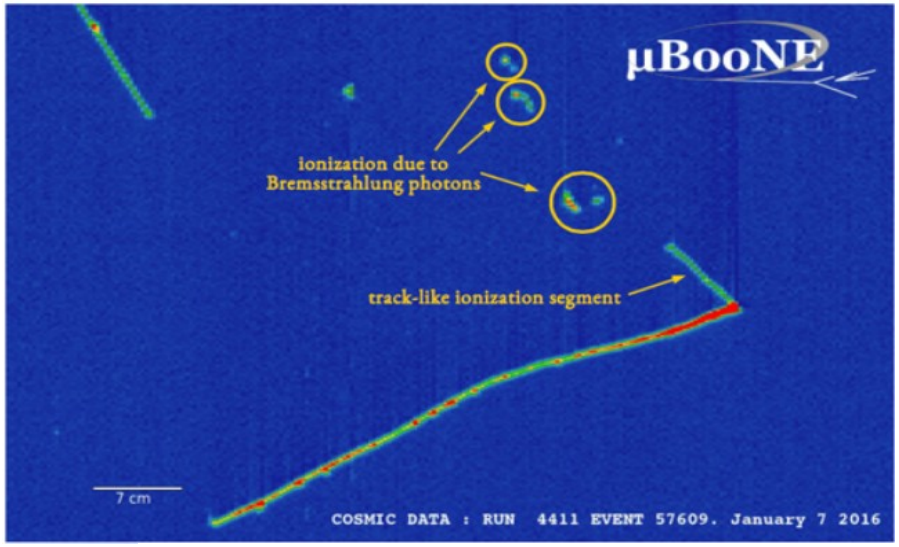


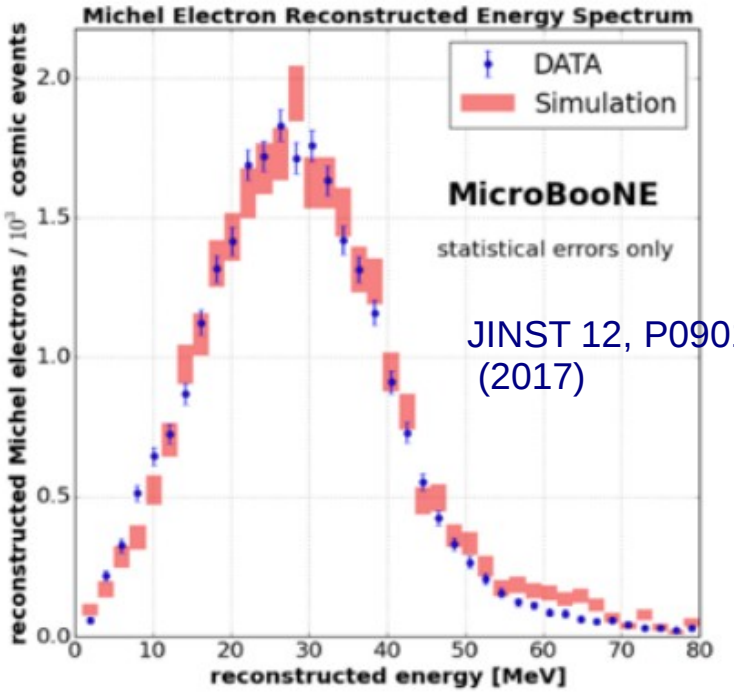




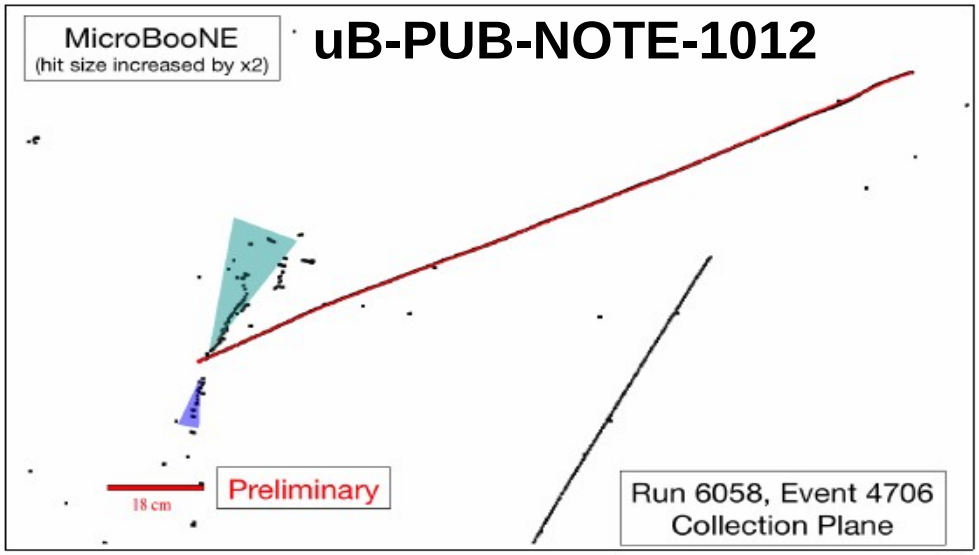
Physics with electrons and showers.

- Michel electrons are an excellent calibration source.
- Allows us to check that our modelling of EM processes is working well.
- Next step – π^0 from neutrino interactions.
  - A great sample to understand you EM shower reconstruction in energy, angles etc...



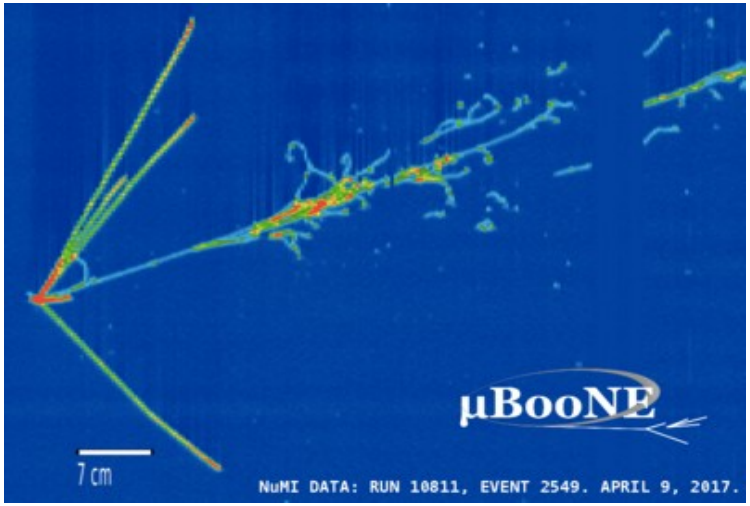


JINST 12, P09014 (2017)

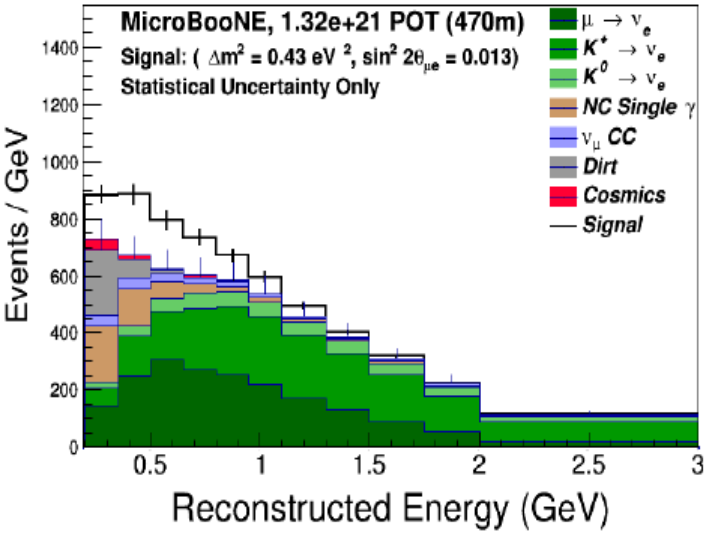


Towards Understanding the Low Energy Excess

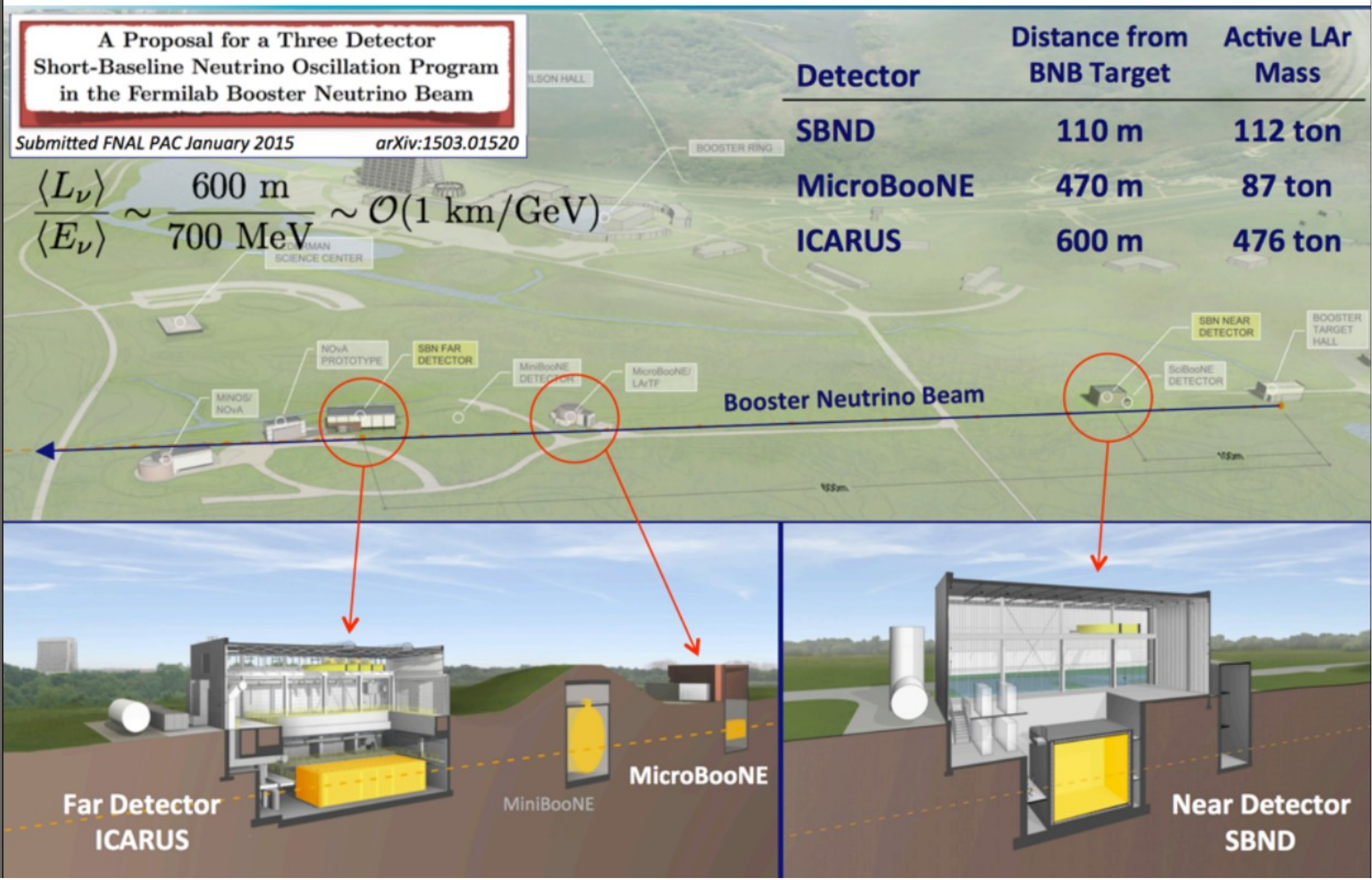
- Demonstrated:
  - Stable detector operation
  - Event selection
  - Tracking reconstruction
  - Proton multiplicity
  - Electron/photon discrimination
- Coming Soon:
  - First neutrino physics measurements
  - Shower energy reconstruction
  - Flux uncertainties



NuMI beam electron-neutrino candidate



SBN Programme



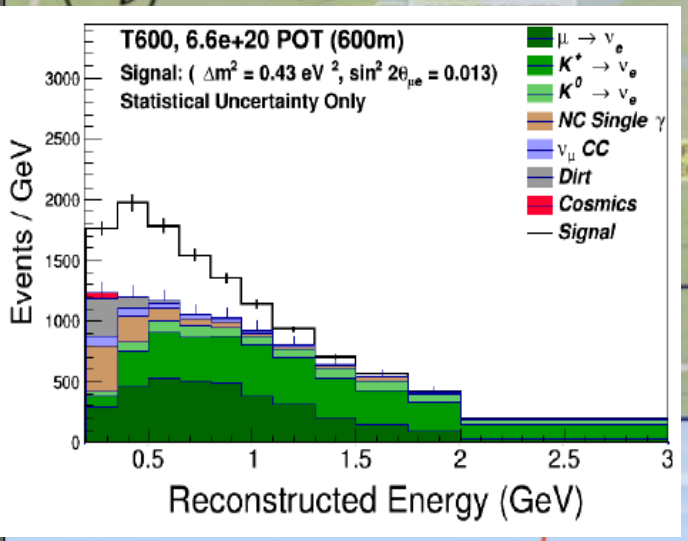
Phase II: full SBN running

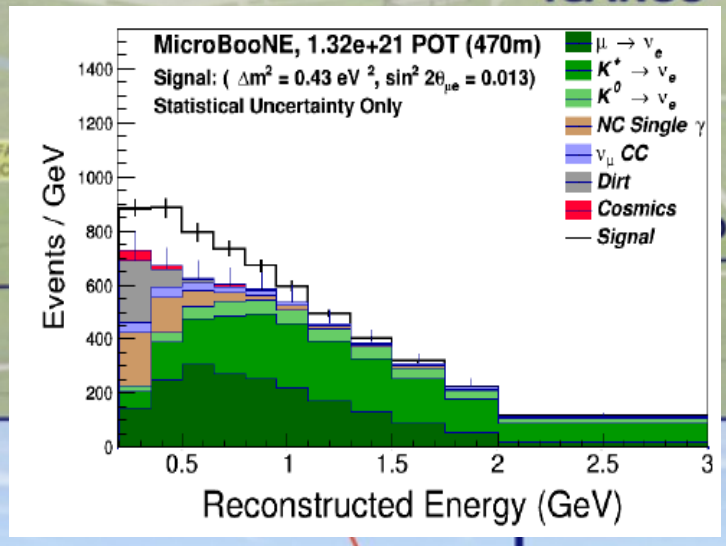
A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam

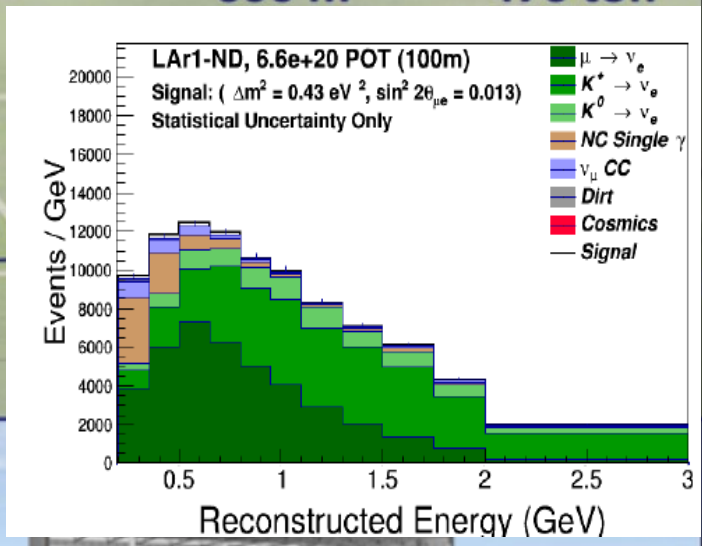
Submitted FNAL PAC January 2015 *arXiv:1503.01520*

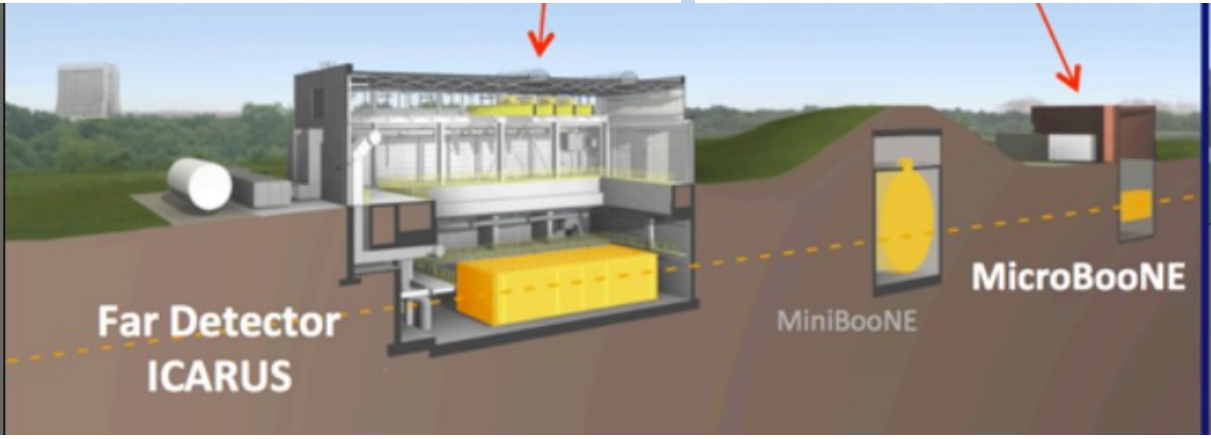
$$\frac{\langle L_\nu \rangle}{\langle E_\nu \rangle} \sim \frac{600\ \text{m}}{700\ \text{MeV}} \sim \mathcal{O}(1\ \text{km/GeV})$$

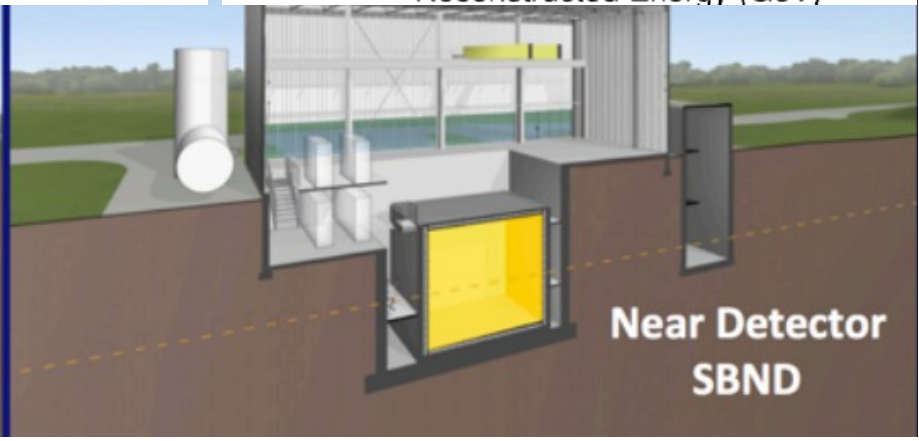
Detector	Distance from BNB Target	Active LAr Mass
SBND	110 m	112 ton
MicroBooNE	470 m	87 ton
ICARUS	600 m	476 ton









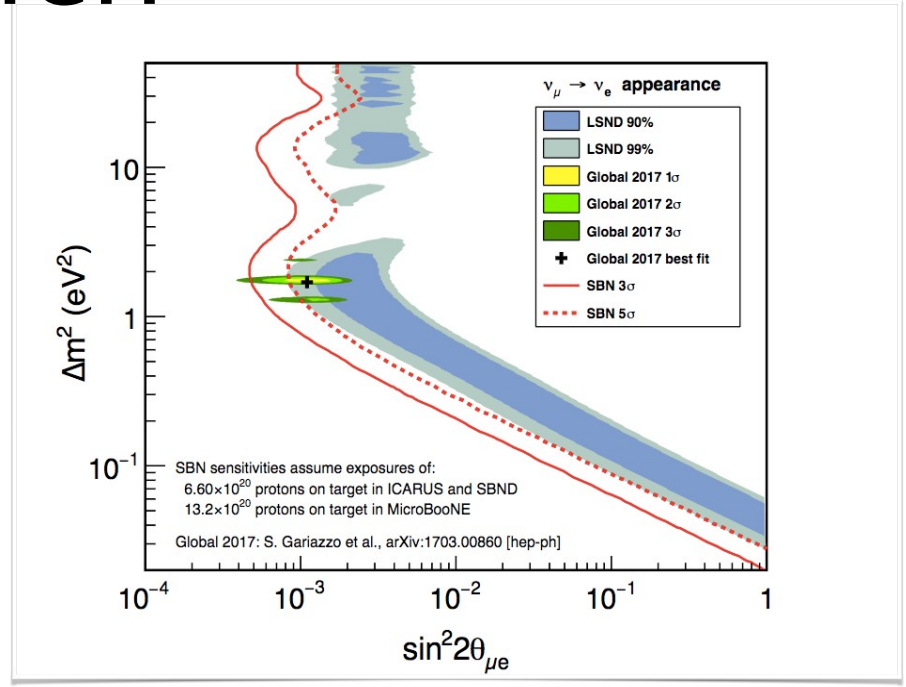


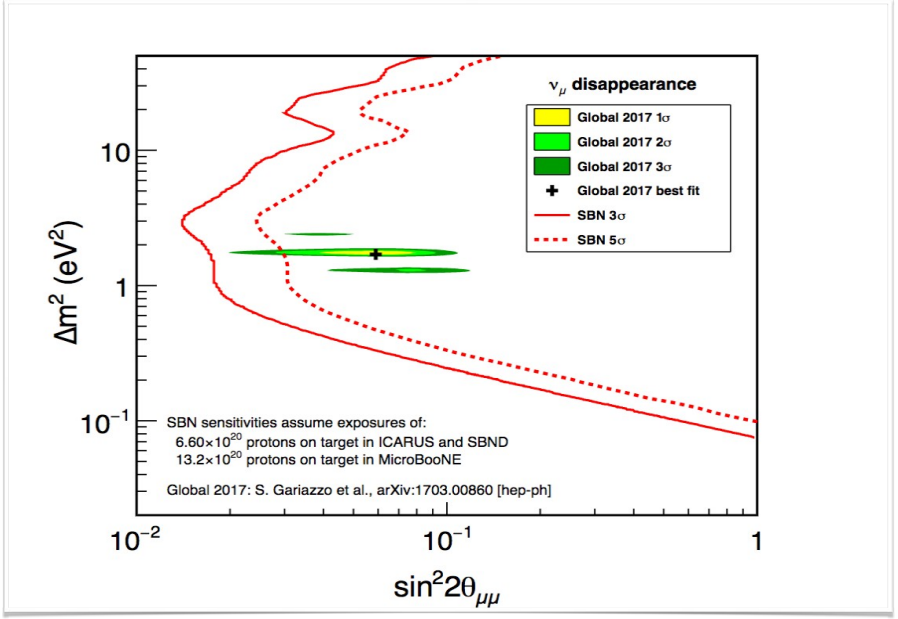
Physics reach

Constraints on the flux and cross-sections from the near detector lead to a powerful combined exclusion region.

LSND parameter space excluded at 5σ.

In addition, SBN can also perform ν_μ disappearance searches. Would confirm an oscillation interpretation of any observed ν_e appearance signal.





Fit from S. Gariazzo et al., arXiv:1703.00860

ICARUS – The far detector

Given its large mass and relatively large distance from the source the ICARUS-T600 will have high sensitivity to neutrino oscillation effects.

- Planned start of operation 2019.

ICARUS from Gran Sasso to CERN to Fermilab

The ICARUS T600, after a succesful Run at Gran Sasso on the CNGS beam Was transported to CERN for refurbishment.

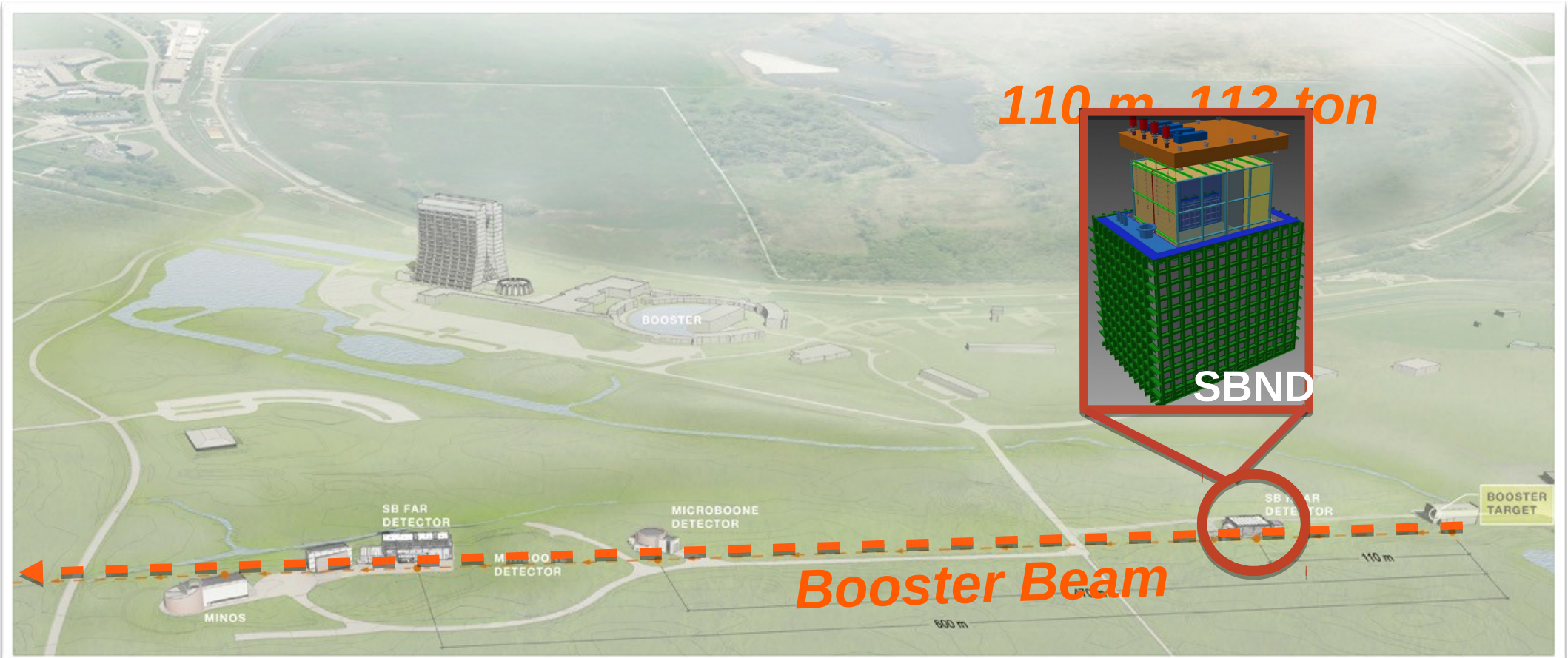
It then travelled to Fermilab over the Summer (#IcarusTrip).

Building to hold is ready, the cryostat Is under construction. Commissioning planned for 2018

ICARUS @ FNAL

ICARUS @ CERN

SBND – the near detector



The Short-Baseline Near Detector (SBND), will be located closest to the source of neutrinos.

It will characterize the beam before oscillations occur and address one of the dominant systematic uncertainties.

Planned start of operation 2019/2020.

SBND

SBND Liquid Argon Time Projection Chambers

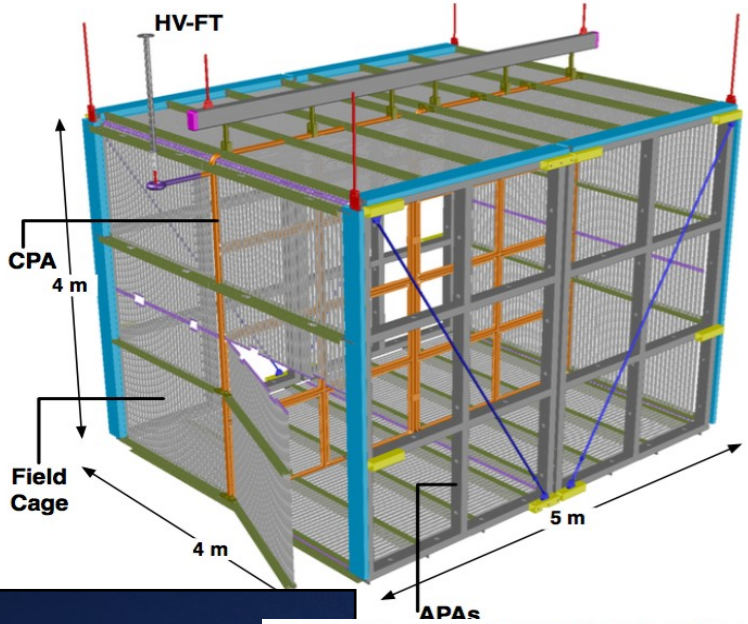
112-ton (active volume)

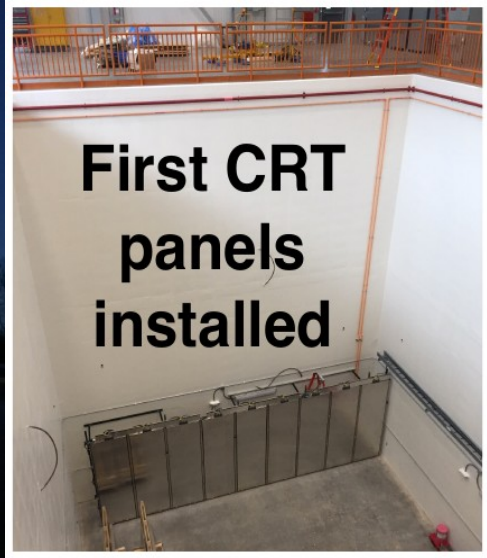
Four Anode Plane Assemblies and 2 Cathode Plane Assemblies

Cold readout electronics

Membrane Cryostat

Cosmic Ray Tagger

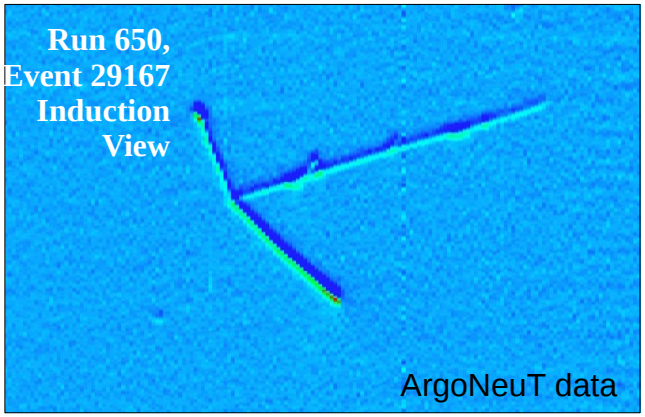




SBND cross-section physics

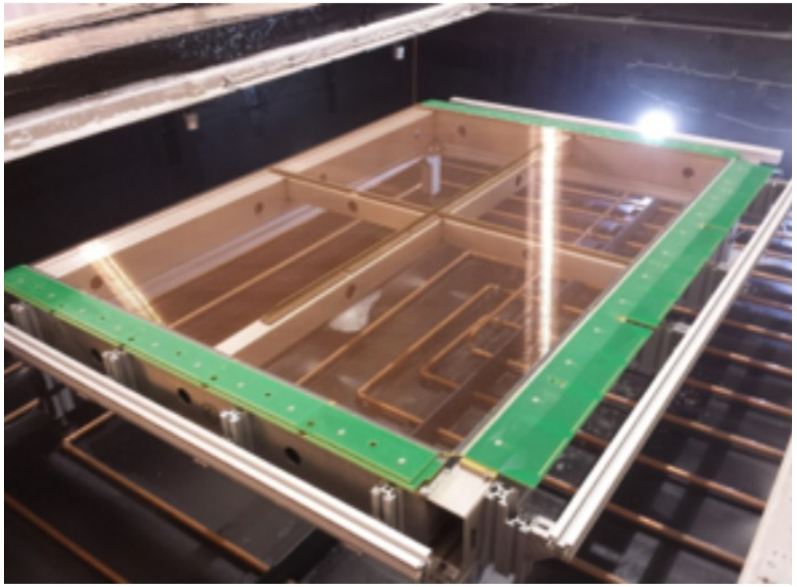
$\nu_\mu CC$, BNB/FHC, 6.6×10^{20} POT, 112 tonnes active mass		
	GENIE Model Configurations	
Hadronic Final State	**G17_01b**	**G17_02a**
Inclusive	5,389,168	5,329,241
$0\ \pi$	3,814,198	3,744,108
$0\ \pi + 0p$	27,269	34,696
$0\ \pi + 1p$ ($>$ 20 MeV)	1,629,252	2,235,338
$0\ \pi + 2p$ ($>$ 20 MeV)	1,150,368	637,535
$0\ \pi + 3p$ ($>$ 20 MeV)	413,956	229,239
$0\ \pi + >3p$ ($>$ 20 MeV)	396,212	263,727
$1\ \pi^+ + X$	942,555	1,021,212
$1\ \pi^- + X$	38,012	21,242
$1\ \pi^0 + X$	406,555	370,666
$2\ \pi + X$	145,336	131,308
$\geqslant 3\pi + X$	42,510	40,702
Physical Process		
QE	1,569,073	2,827,928
MEC	1,398,773	513,453
RES	1,816,570	1,539,159
DIS	581,905	441,057
Coherent	22,846	7642

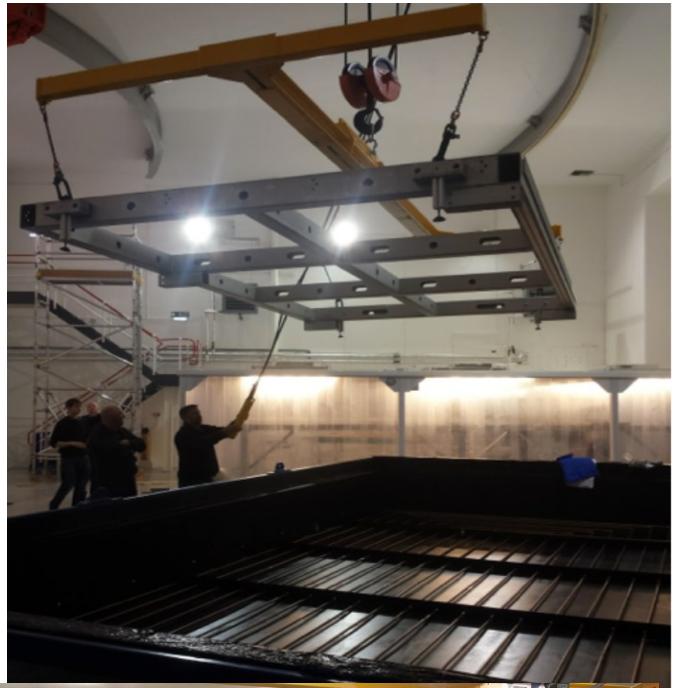
- SBND will see a huge event rate.
- Enables precision measurements of neutrino cross-sections and nuclear effects.
- Crucial for energy reconstruction.



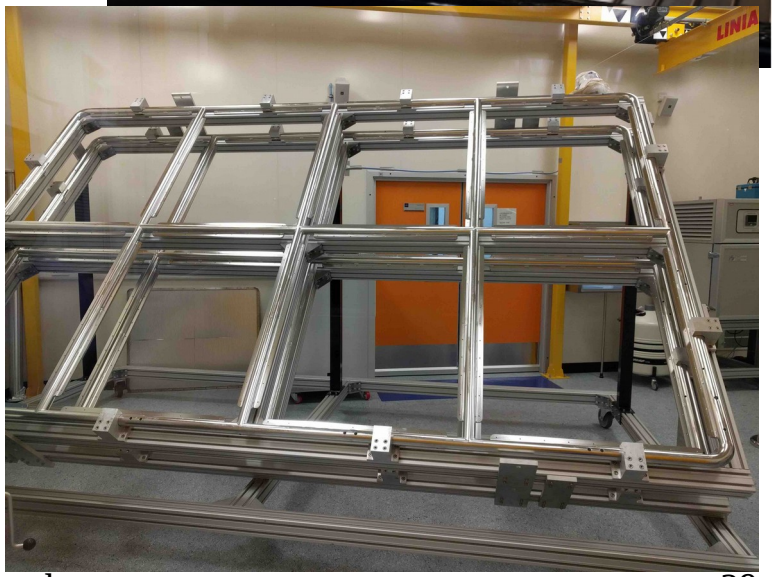
C. Andrepoulos, NuINT 17

SBND construction (UK-biased)



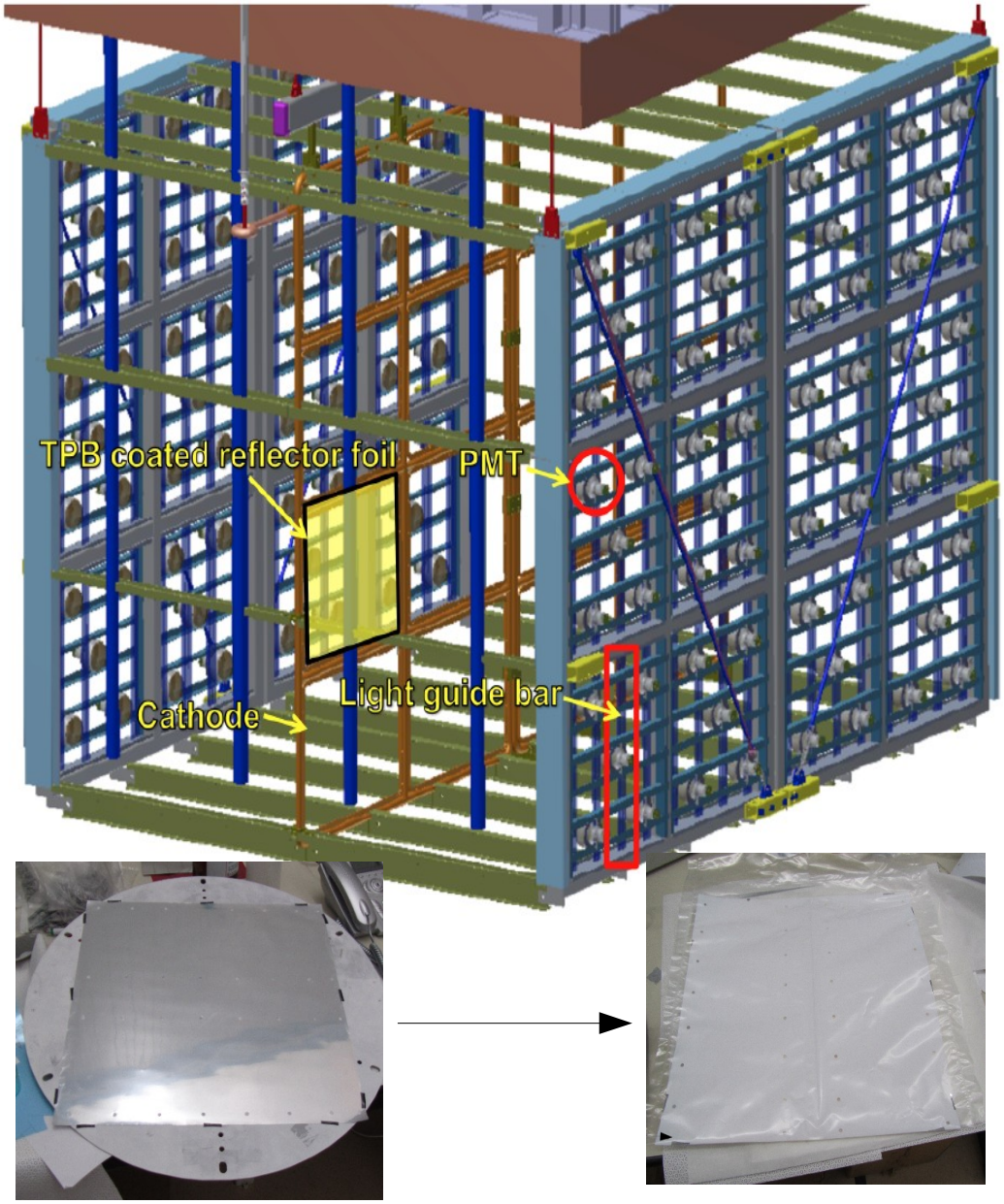


- Construction of field cage elements has started:
  - Cathode planes will be shipped to Fermilab in January (Liverpool).
  - Wire winding begins in January in Daresbury lab (test frame fully wound) – followed by US winding.
- Fieldcage assembly at Fermilab planned for August.



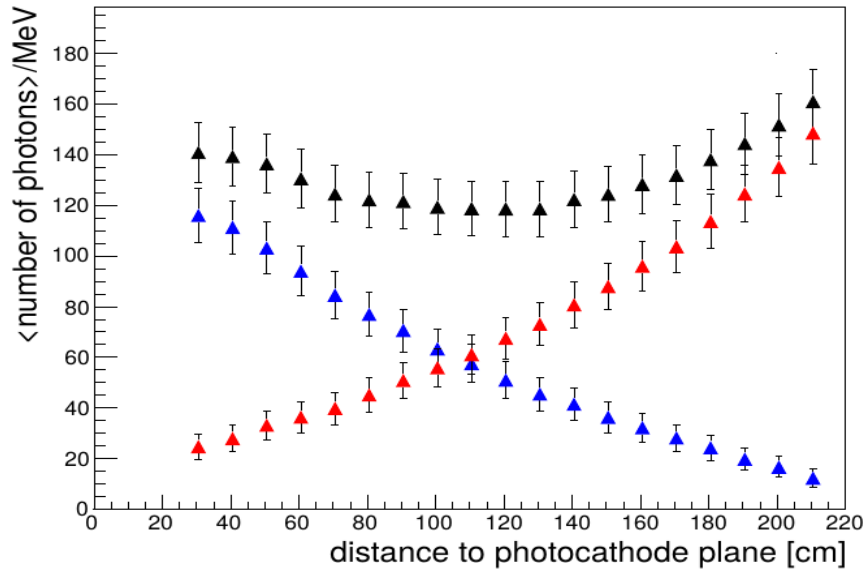
Light Detection in SBND

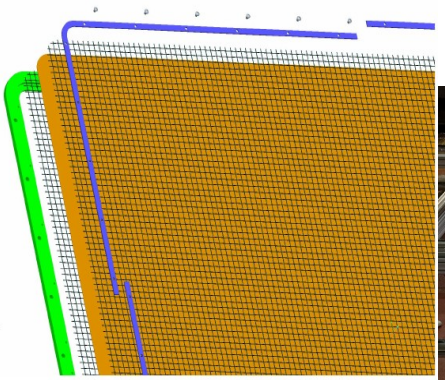
- Important R&D aspect
- Scintillation light applications:
  - trigger, t_0
  - background rejection
  - calorimetry, particle ID
- Mounted on anode planes:
  - PhotoMultiplier Tubes
  - Waveguide bars (proposed)
  - ARAPUCA light traps (proposed)
- Mounted on Cathode:
  - WLS-coated reflector foils to improve collection efficiency and uniformity.

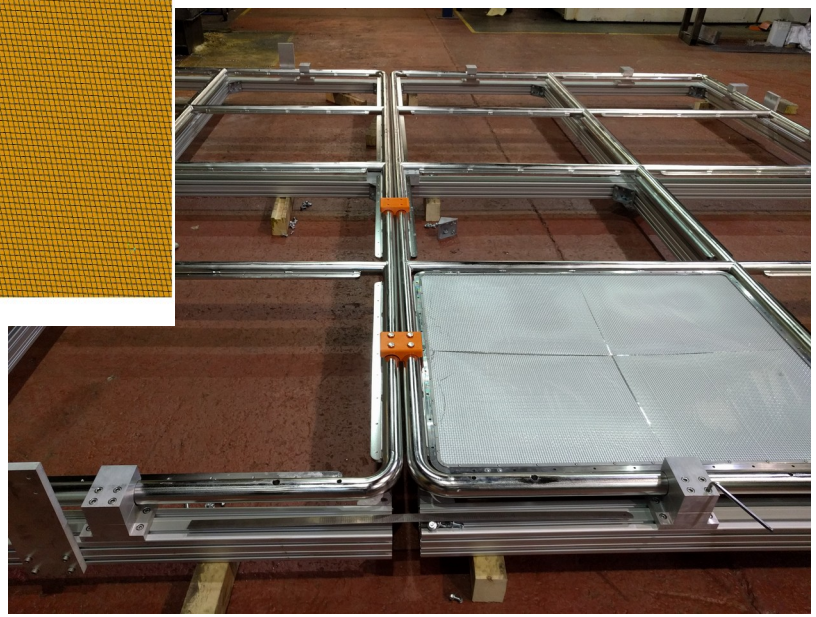


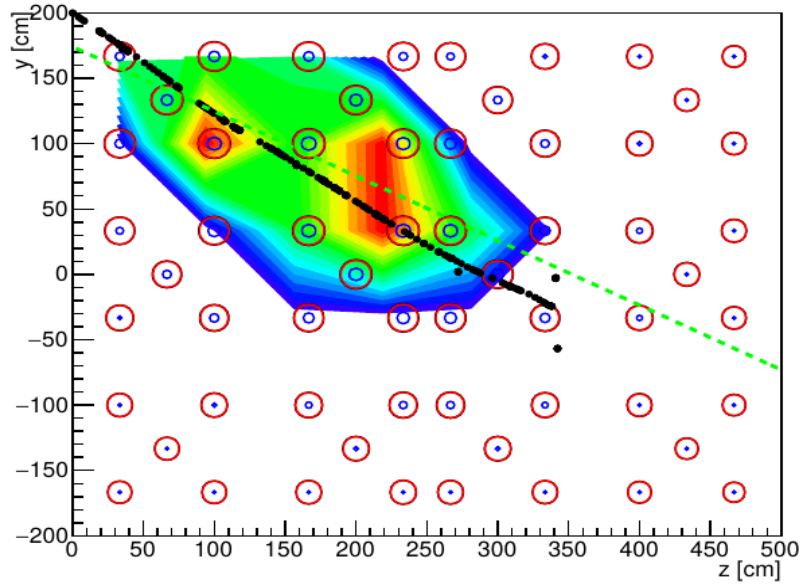
Boosting Light Collection

- Adding wavelength-shifting surface at the cathode recovers a large fraction of light that would normally be lost.
- The SBND LDS enables new applications of argon scintillation light – calorimetry, timing, drift position reconstruction.





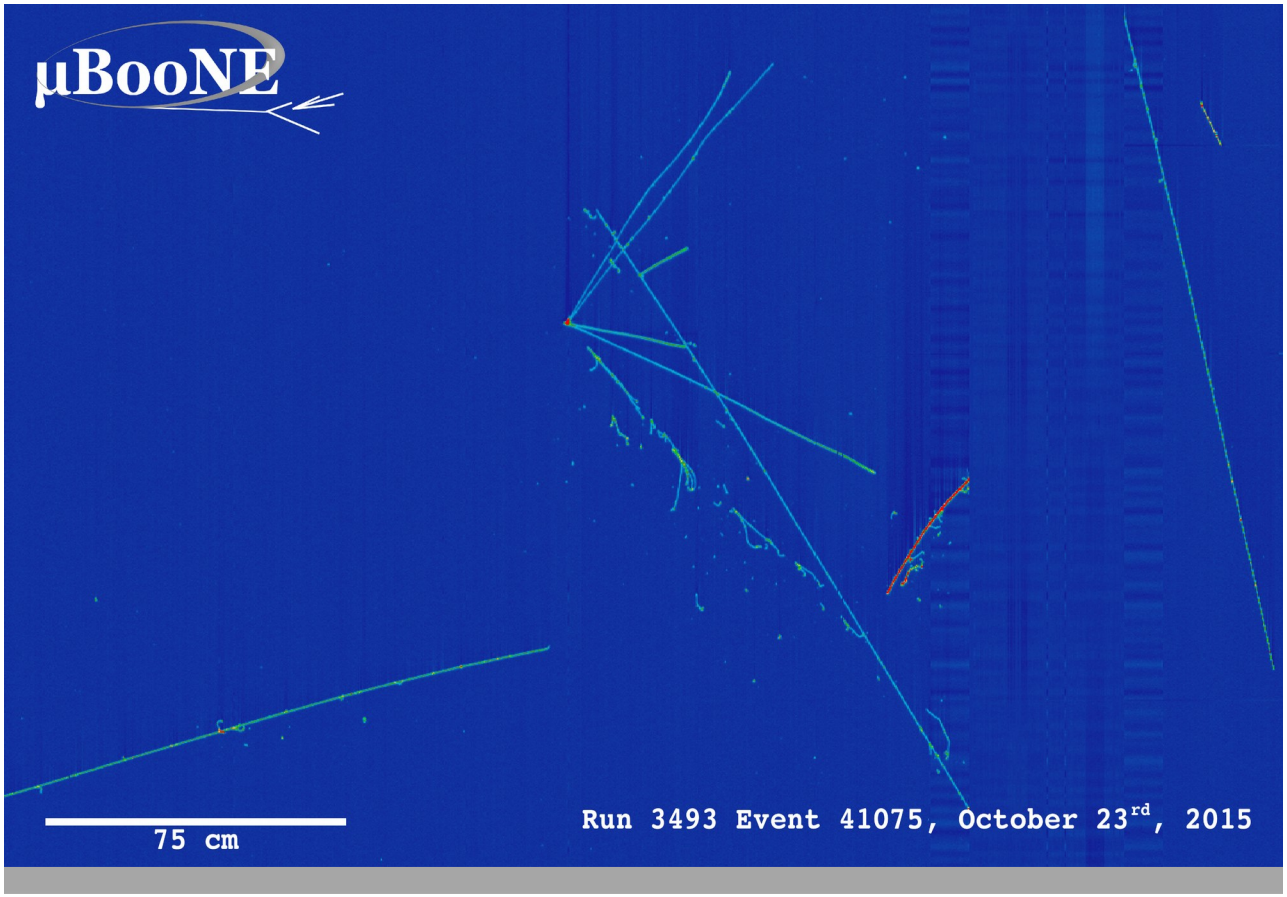




Summary

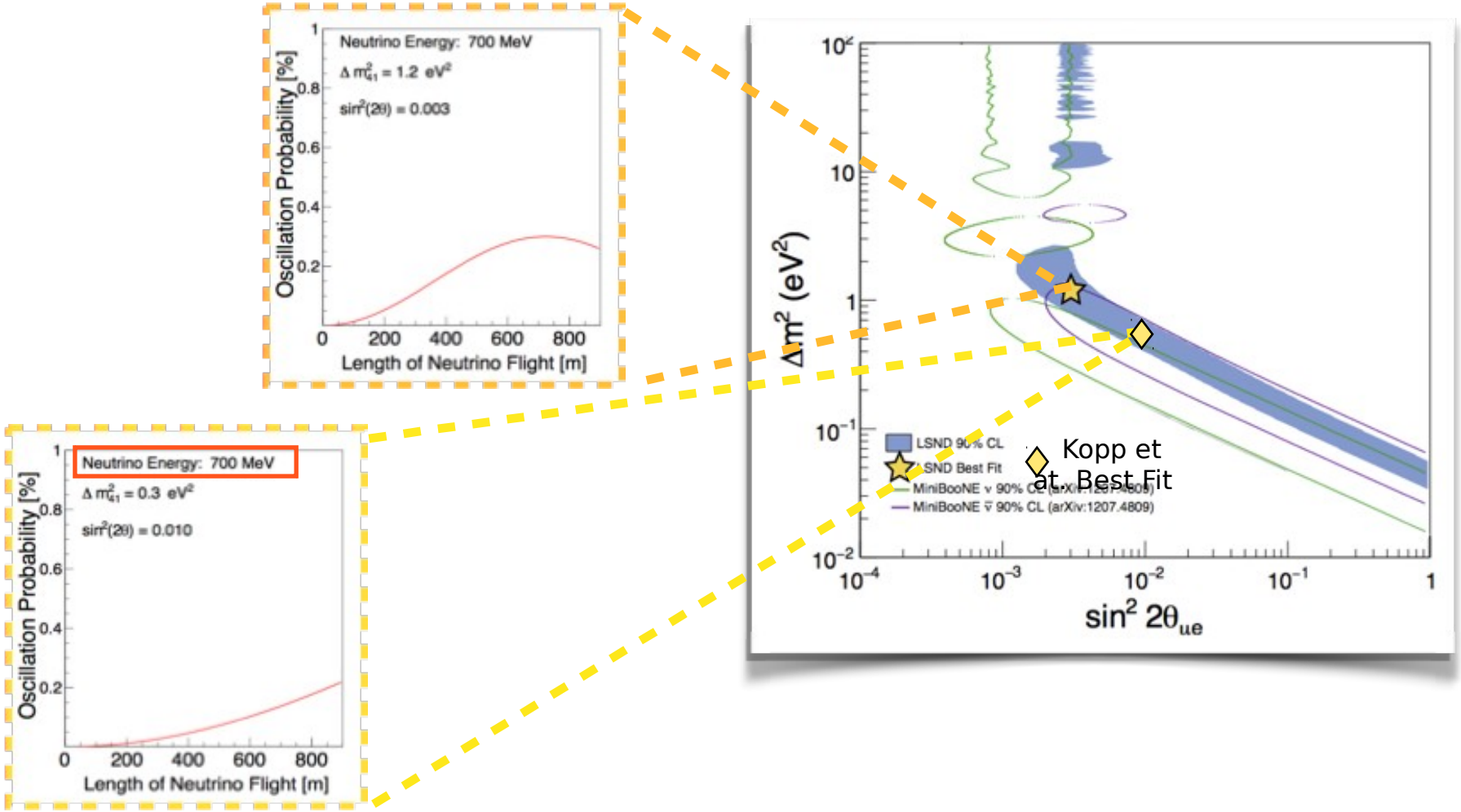
- The Short Baseline Programme at Fermilab will use three LArTPC detectors to resolve the question of the existence of sterile neutrinos.
- MicroBooNE is already running – first physics results coming soon.
- ICARUS and SBND will come online in the next two years enabling the full scale oscillation analysis.
- Stay tuned!

Thank You for your Attention



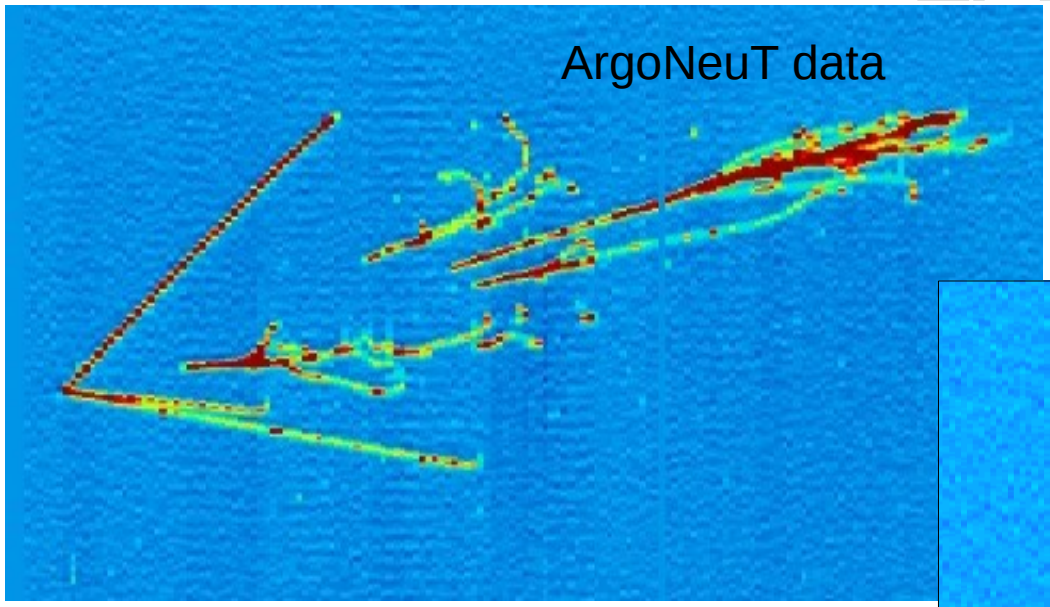
- SBN Posters:
- **W. Van De Pontseele**
  Flashmatching for the electron neutrino selection in MicroBooNE
- **D. Porzio**
  Searches for Heavy Sterile Neutrinos in MicroBooNE
- **V. Basque**
  Simulations of the SBND Light Collection System
- **O. Goodwin**
  Searches for light Dark Matter produced in neutrino beams with the SBN program
- **K. Mistry**
  Testing Cold Electronics Solutions for the SBND Experiment

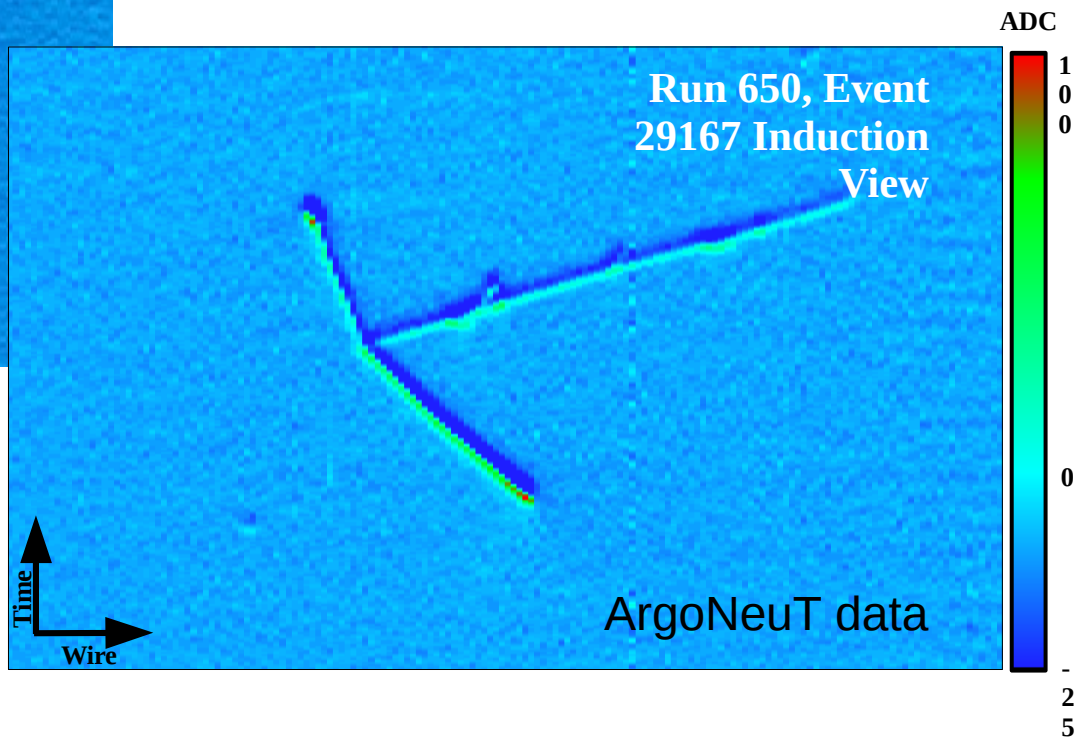
Covering the full LSND region

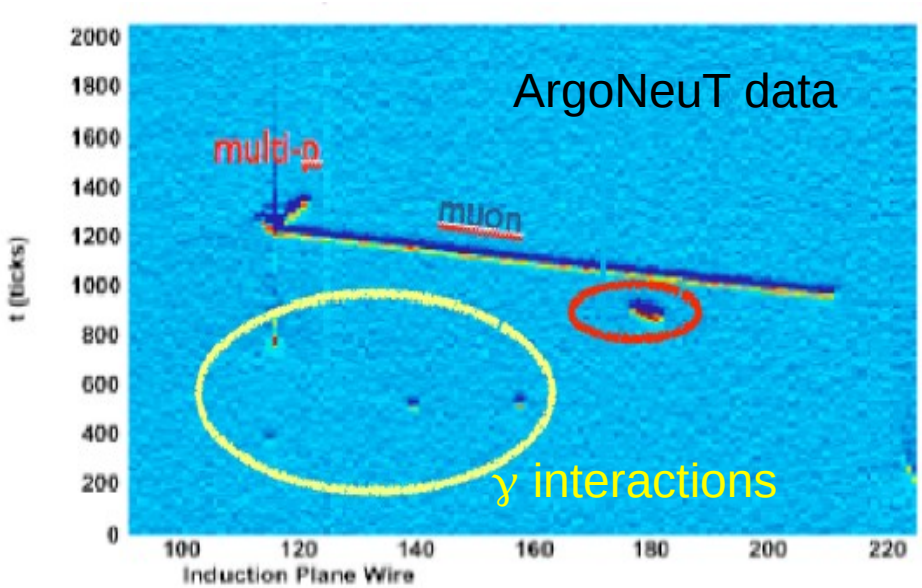


Multi-detector approach combined with a well understood beam (BNB) – minimizes systematics. Allows exclusion of LSND parameter space at 5σ.

Neutrino interactions in LArTPCs



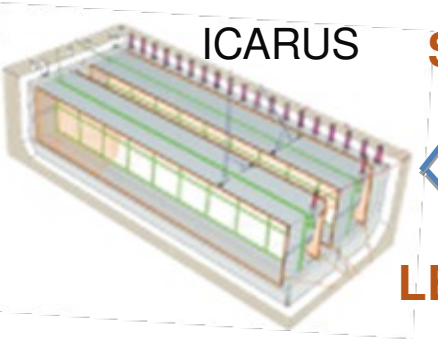




LArTPC development

Development and prototyping through the Fermilab SBN and CERN neutrino platform programmes

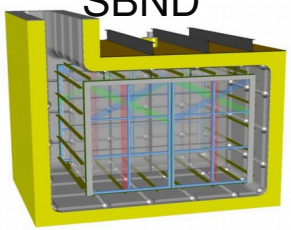
Single-Phase



SBL

MicroBooNE

SBND

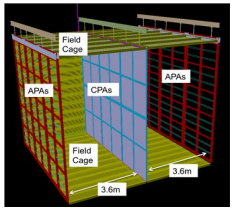


LBL

2015

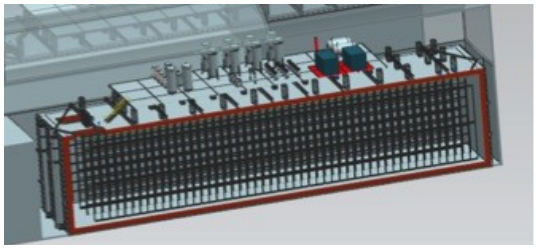
35-t prototype

2018



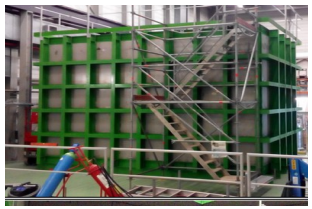
protoDUNE

DUNE Reference Design



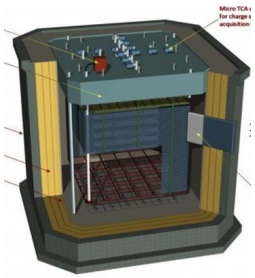
Dual-Phase

2016



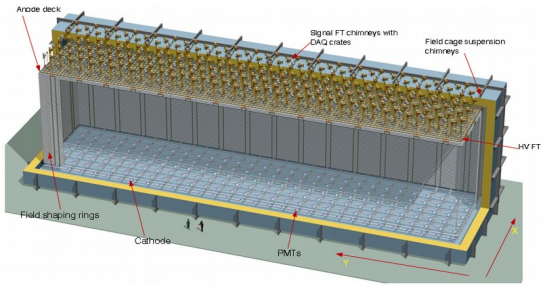
WA105: 1x1x3 m³

2018



ProtoDUNE
dbl phase

DUNE Alternative Design



This is a somewhat simplified drawing...