Neutrino Cross-section Measurement Prospects with SBND

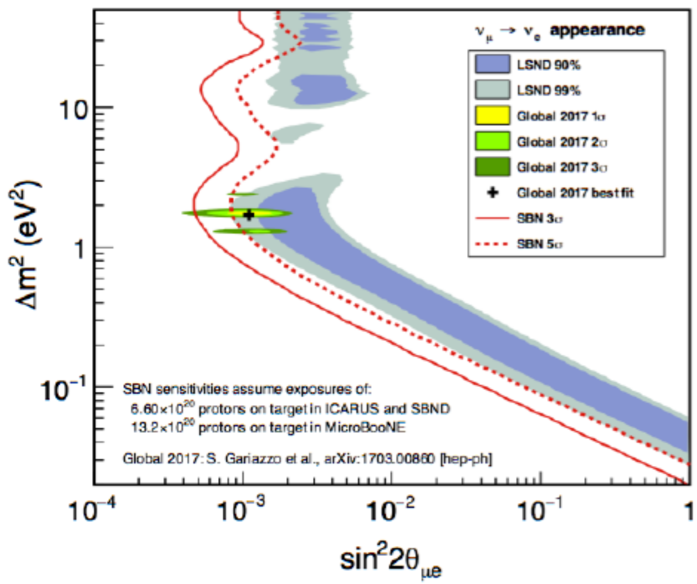
NuFact 2017

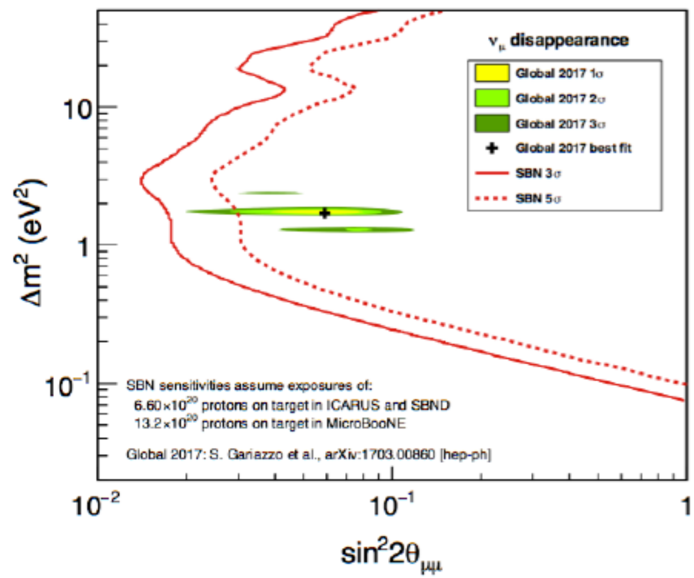
September 26th 2017

Nicola McConkey for the SBND Collaboration

Short Baseline Neutrino (SBN) program goals

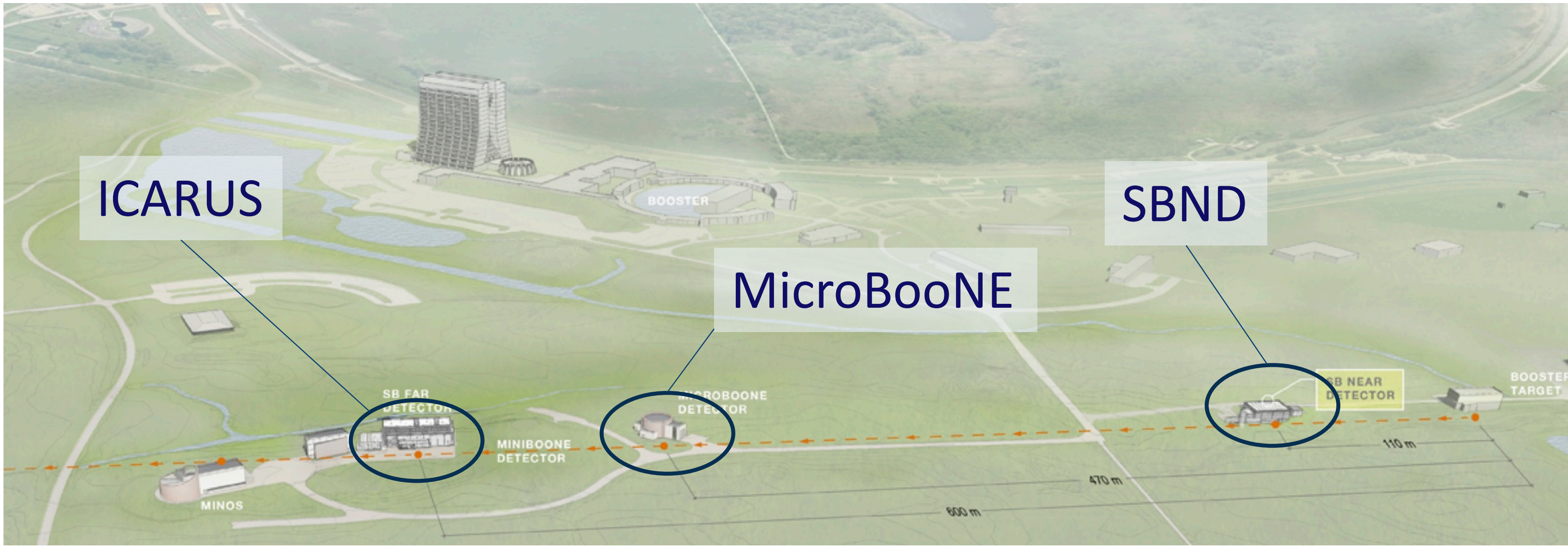
- Experimental anomalies have been observed in short baseline (< 1 km) neutrino experiments:
  - LSND: measured an 3.8σ excess in $\nu_\mu \rightarrow \nu_e$ appearance channel
  - MiniBooNE: measured a 3.4σ excess in $\nu_\mu \rightarrow \nu_e$ and a 2.4σ excess in $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ appearance channels
- Can be interpreted as a large Δm^2 oscillation
  - Requires the addition of a fourth "sterile" neutrino
  - $\Delta m^2_{41} \approx 1$ eV^2
- SBN will confirm or definitively refute these results at 5σ level, with major implications for neutrino physics





[S. Gariazzo et al, arXiv:1703.00860v3]

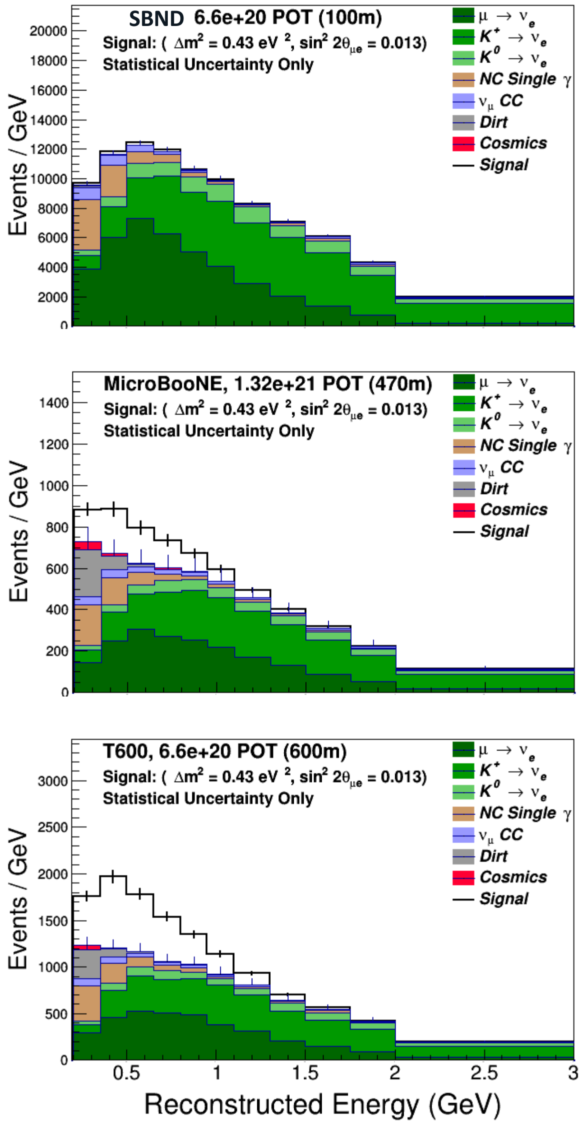
Short Baseline Neutrino Program



Detector	Baseline (m)	Active LAr mass (tonnes)
SBND	110	112
MicroBooNE	470	87
ICARUS T-600	600	476

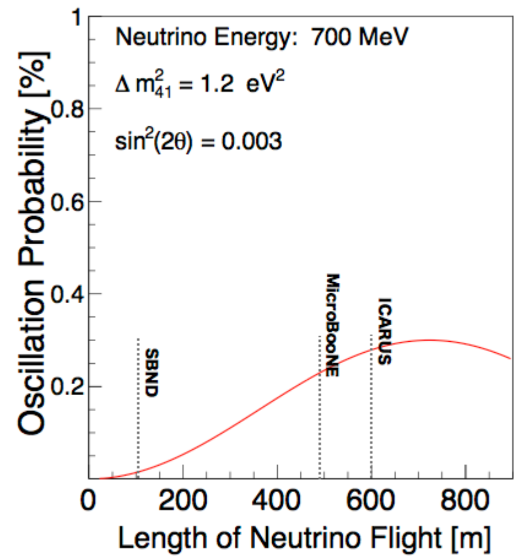
- Three detector measurement program in the Fermilab Booster Neutrino Beam (BNB)
- LAr TPC detectors
  - Same nuclear target and detector technology
  - Reducing effect of systematic uncertainties

SBN program goals



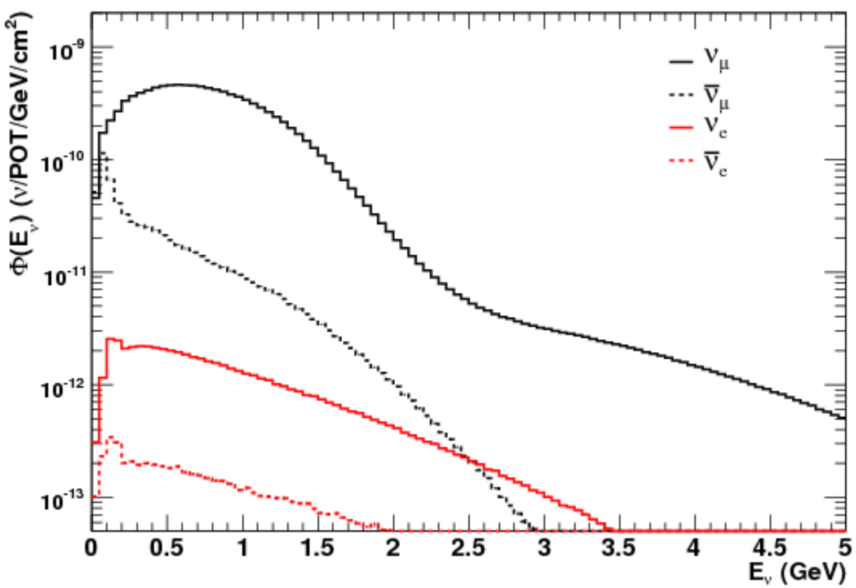
[SBN proposal, arXiv:1503.01520]

- SBN program will measure neutrino oscillations in the BNB
  - Both appearance and disappearance
  - Multiple detectors at different baselines



- Role of SBND is to measure the unoscillated neutrino flux
  - Extremely high statistics for ν_μ-CC *and* ν_e-CC and NC interactions
  - Tuning of flux and cross-section modelling to produce unoscillated predictions for MicroBooNE and ICARUS
  - Systematic error reduction for SBN

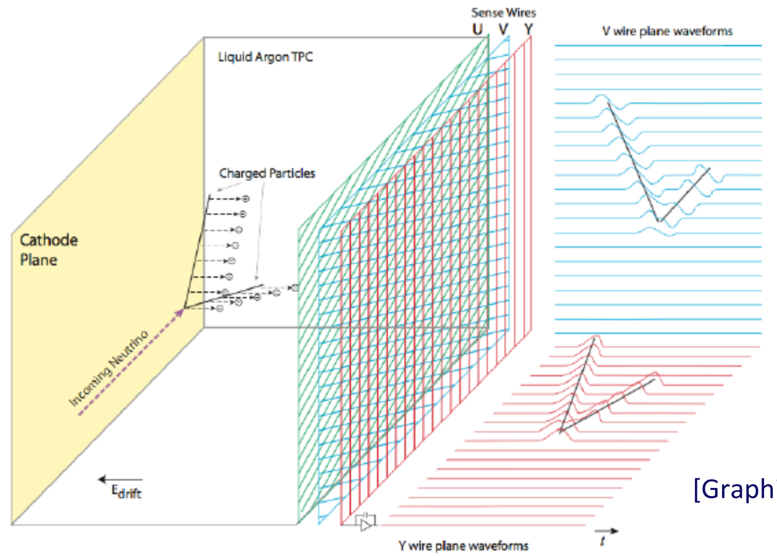
Booster Neutrino Beam



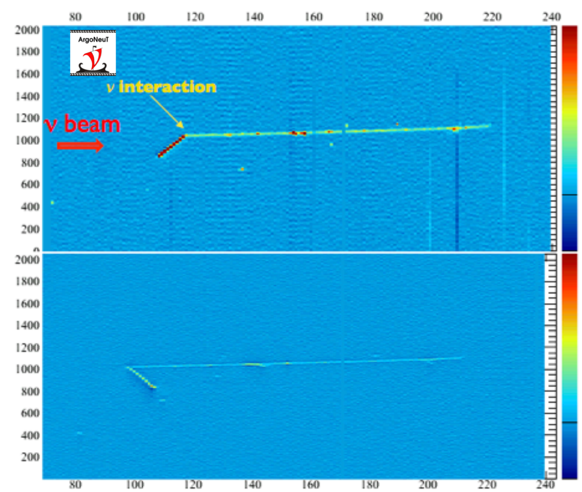
- 8 GeV protons on Beryllium target
- Low energy neutrino beam at Fermilab
- $\langle E_\nu \rangle \approx 700$ MeV
- Same beam as MiniBooNE
- Stably running for a decade
  - Well characterised
- Muon neutrinos with small electron neutrino contamination: <0.5%

Liquid Argon Time Projection Chamber

- Liquid argon:
  - Excellent scintillator
  - Good charge transport properties
- TPC – charge collection:
  - Electric field across active detector volume
  - Charged particles ionise argon atoms in the detector volume
  - Ionisation electrons drifted towards anode readout plane
  - Charge signal induced on wire readout planes
  - 2D projection of ionisation read out from 3 planes of wires
- TPC – photon collection:
  - Charged particles excite argon atoms
  - Prompt scintillation light
  - Allows event t_0 determination



[Graphic, Bo Yu]

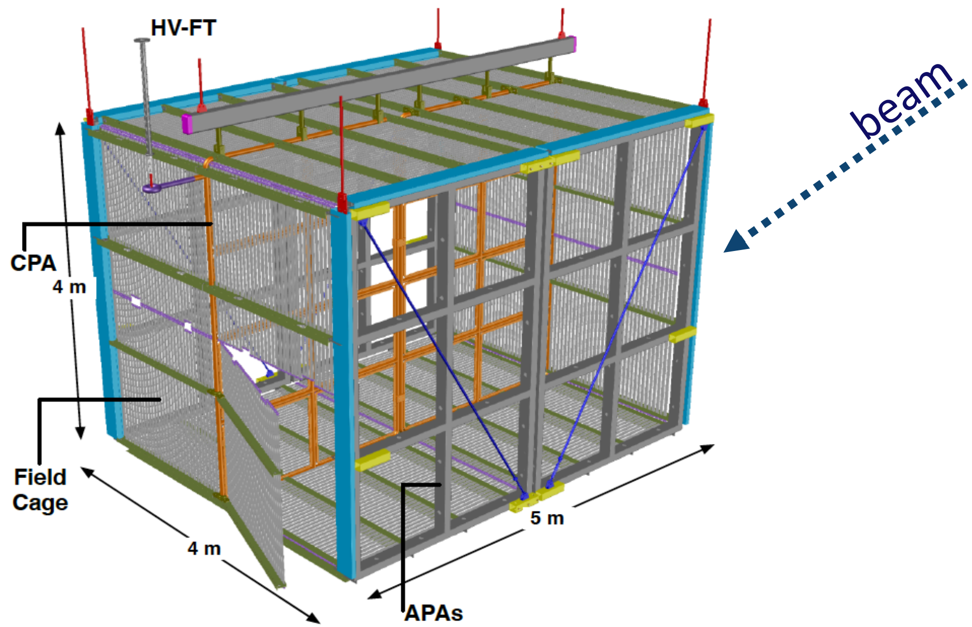


[C. Anderson et al, arXiv:1205.6747v2]

The SBND Detector

A time projection chamber with charge and light readout

- 112 tonnes of Liquid Argon (LAr)
- Active volume of 4m x 4m x 5m



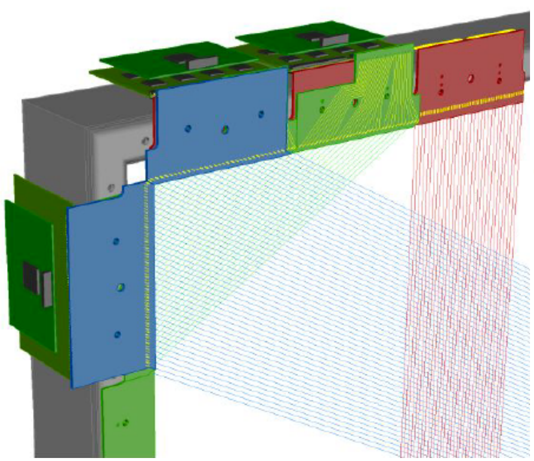
- ❑ TPC with central cathode and 2 drift volumes with wire plane readout
- ❑ Drift direction perpendicular to the neutrino beam direction

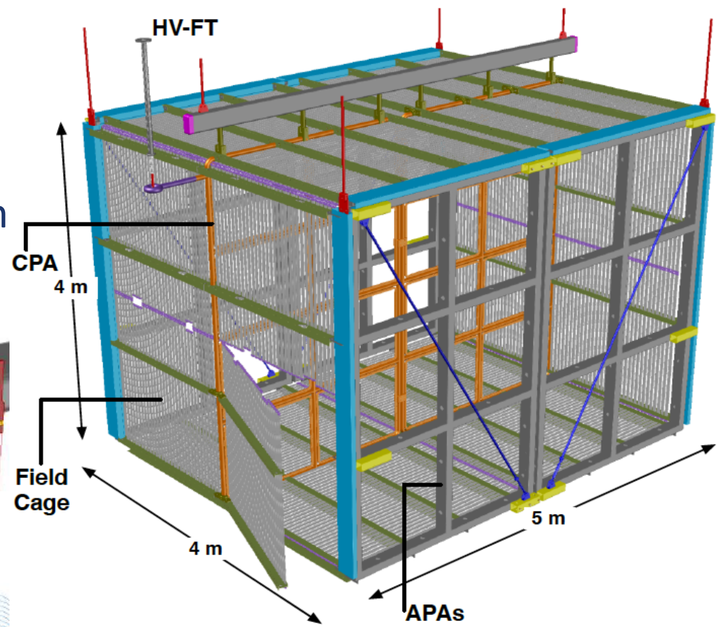
The SBND Detector

Anode Plane Assembly (APA)

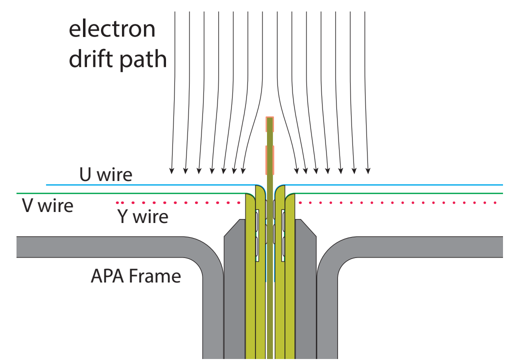
- ❑ Composed of two interconnected APA frames
- ❑ 3 planes of copper-beryllium wires:
  - Vertical (Y plane: red)
  - ± 60° to vertical

  (U plane: green, V plane: blue)
- ❑ Wire plane spacing: 3 mm
- ❑ Wire pitch: 3 mm





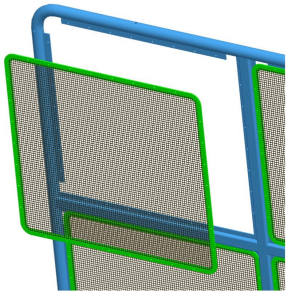
- ❑ Wire readout on outside edges
- ❑ Jumpered interconnect between U and V planes
- ❑ Voltage deflector concept under test: minimising charge loss in gap



The SBND Detector

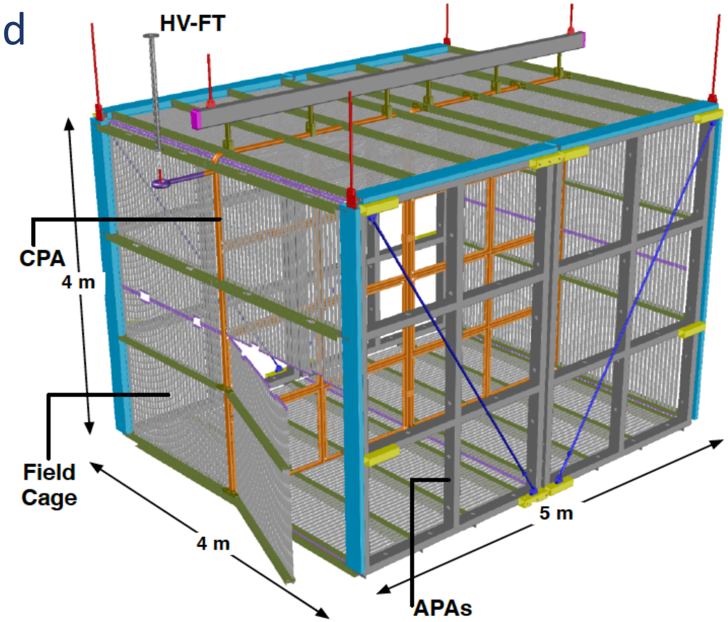
Cathode Plane Assembly (CPA)

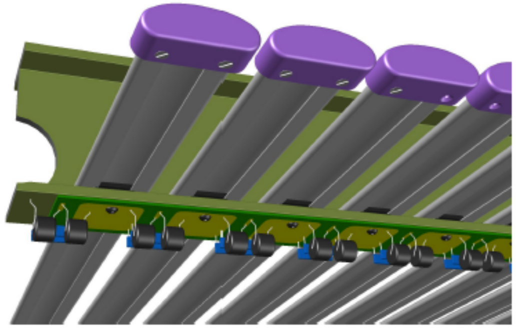
- Two stainless steel frames each holding 8 mesh frames
- Welded, electropolished frame assemblies



High Voltage Feedthrough

- Bias: -100 kV
- Coaxial design:
  - Polyethelene insulator
  - Stainless steel core and grounding sheath
  - Spring loaded tip for contact with HV cup





Field Cage

- Drift field 500 V/cm
- Roll formed Stainless steel profiles
- Polyethelene end caps
- Tested to 100 kV in LAr

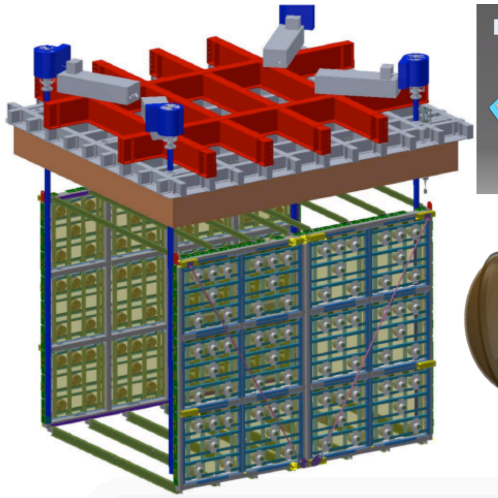
The SBND Detector

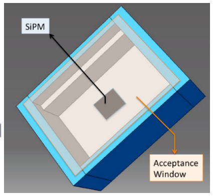
Photon detection system

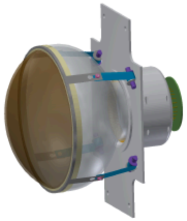
- ❑ Composite light collection system
  - Photomultiplier tubes (PMT) coated in wavelenght shifter
  - Acrylic wavelength shifting bars read out by SiPM
  - ARAPUCA – novel photon collection device using dichroic filters and SiPM

Cosmic ray tracker

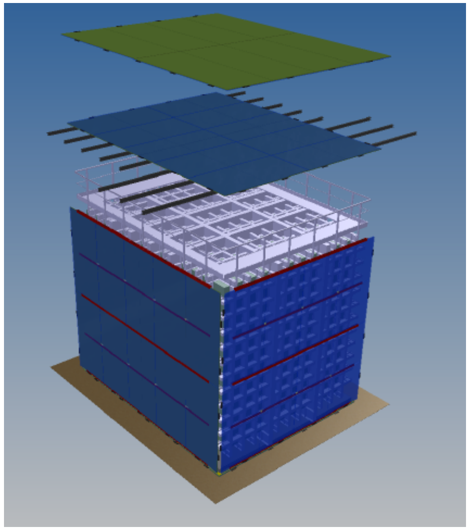
- ❑ Detector at surface with concrete overburden:
  - Tool to mitigate the Cosmic ray background in the detector
- ❑ Seven planes surrounding the detector
- ❑ Modules of extruded scintillator strips read out by MPPC photo-diodes





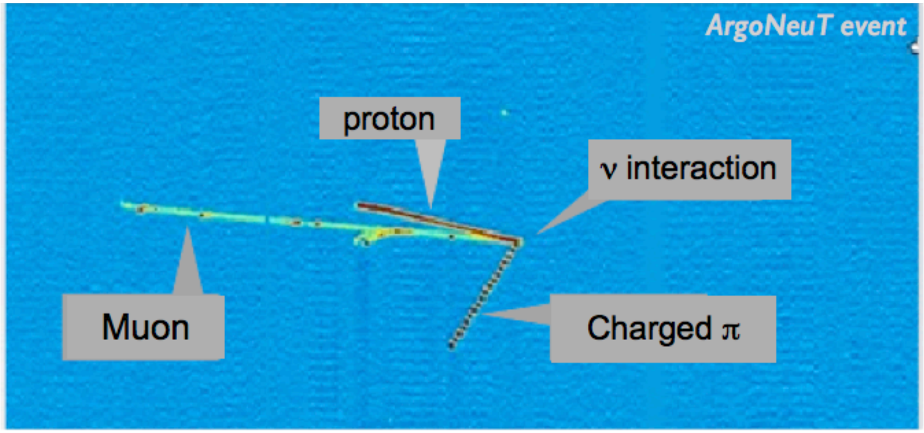


[A.A. Machado and E. Segreto, 2016 JINST 11 C02004]



SBND Physics Goals

- ❑ In addition to providing near detector measurements for SBN oscillation physics:
- ❑ SBND allows us to study neutrino-nucleus interactions on argon with unprecedented sensitivity



- ❑ LAr TPC gives
  - Full 3D imaging - good granularity
  - Precise calorimetric information
  - Topological information
- ❑ SBND has unprecedentedly high event rate
  - Exclusive topology measurements
  - Nuclear effects
- ❑ Entire 3-year MicroBooNE dataset in 2 months!

SBND Interaction rates

Process		No. Events	Events/ ton	Stat. Uncert.
	ν_μ Events (By Final State Topology)			
CC Inclusive		5,212,690	46,542	0.04%
CC 0 π	$\nu_\mu N \to \mu + Np$	3,551,830	31,713	0.05%
	$\cdot\ \nu_\mu N \to \mu + 0p$	793,153	7,082	0.11%
	$\cdot\ \nu_\mu N \to \mu + 1p$	2,027,830	18,106	0.07%
	$\cdot\ \nu_\mu N \to \mu + 2p$	359,496	3,210	0.17%
	$\cdot\ \nu_\mu N \to \mu + \geq 3p$	371,347	3,316	0.16%
CC 1 $\pi^\pm$	$\nu_\mu N \to \mu +$ nucleons $+ 1\pi^\pm$	1,161,610	10,372	0.09%
CC $\geq 2\pi^\pm$	$\nu_\mu N \to \mu +$ nucleons $+ \geq 2\pi^\pm$	97,929	874	0.32%
CC $\geq 1\pi^0$	$\nu_\mu N \to \mu +$ nucleons $+ \geq 1\pi^0$	497,963	4,446	0.14%
NC Inclusive		1,988,110	17,751	0.07%
NC 0 π	$\nu_\mu N \to$ nucleons	1,371,070	12,242	0.09%
NC 1 $\pi^\pm$	$\nu_\mu N \to$ nucleons $+ 1\pi^\pm$	260,924	2,330	0.20%
NC $\geq 2\pi^\pm$	$\nu_\mu N \to$ nucleons $+ \geq 2\pi^\pm$	31,940	285	0.56%
NC $\geq 1\pi^0$	$\nu_\mu N \to$ nucleons $+ \geq 1\pi^0$	358,443	3,200	0.17%
	ν_e Events			
CC Inclusive		36798	329	0.52%
NC Inclusive		14351	128	0.83%
Total ν_μ and ν_e Events		7,251,948	64,750	
	ν_μ Events (By Physical Process)			
CC QE	$\nu_\mu n \to \mu^- p$	3,122,600	27,880	
CC RES	$\nu_\mu N \to \mu^- \pi N$	1,450,410	12,950	
CC DIS	$\nu_\mu N \to \mu^- X$	542,516	4,844	
CC Coherent	$\nu_\mu Ar \to \mu Ar + \pi$	18,881	169	

[SBN proposal, arXiv:1503.01520]

World's highest statistics cross-section measurements on argon

←ν_μ-Ar
(7 million in 3 years)

←ν_e-Ar
(50,000 in 3 years)

Estimated event rates (GENIE) in the SBND active volume (112 ton) for a 6.6×10^{20} POT exposure

Exclusive topology measurements

Process		No. Events	Events/ ton	Stat. Uncert.
	ν_μ *Events (By Final State Topology)*			
CC Inclusive		5,212,690	46,542	0.04%
CC 0 π	$\nu_\mu N \rightarrow \mu + Np$	3,551,830	31,713	0.05%
	$\cdot\ \nu_\mu N \rightarrow \mu + 0p$	793,153	7,082	0.11%
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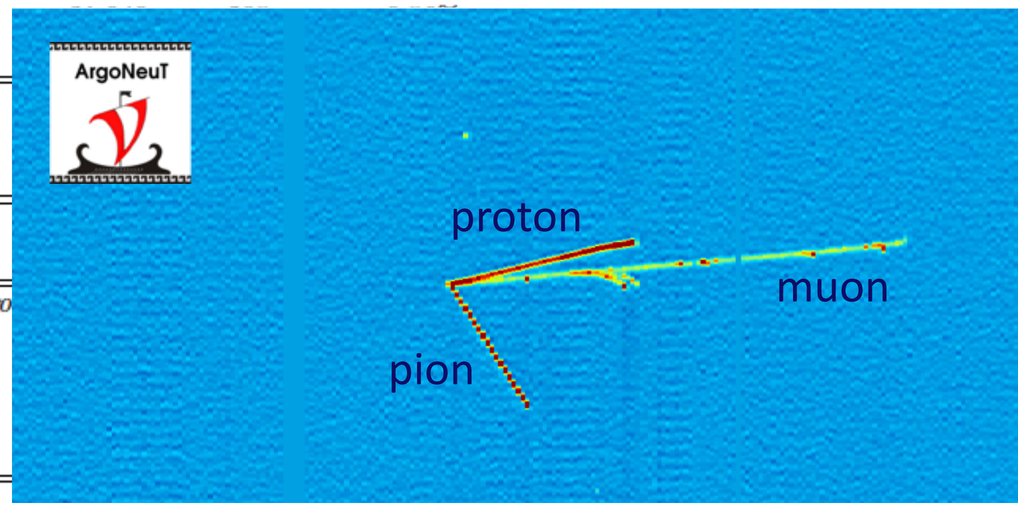
NC $\geq 1\pi^0$	$\nu_\mu N \rightarrow$ nucleons $+ \geq 1\pi^0$			
	ν_e *Events*			
CC Inclusive				
NC Inclusive				
Total ν_μ and ν_e Events				
	ν_μ *Events (By Physical Pro*			
CC QE	$\nu_\mu n \rightarrow \mu^- p$			
CC RES	$\nu_\mu N \rightarrow \mu^- \pi N$			
CC DIS	$\nu_\mu N \rightarrow \mu^- X$			
CC Coherent	$\nu_\mu Ar \rightarrow \mu Ar + \pi$			

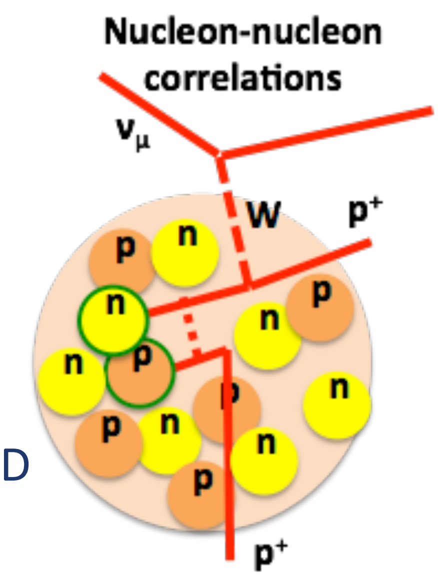


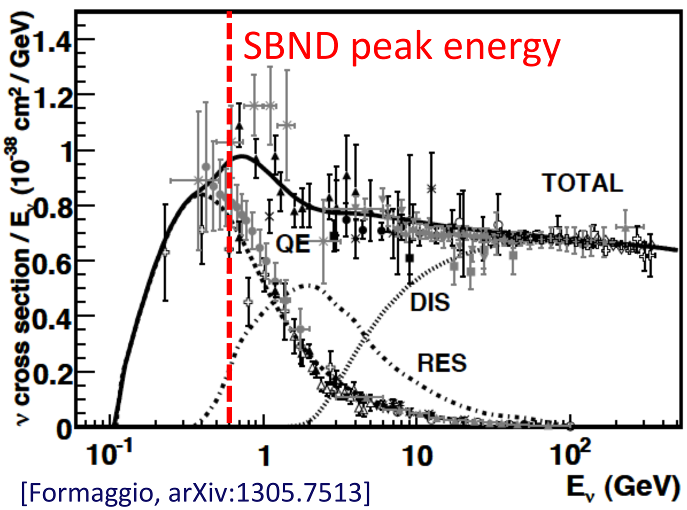
- Study of several exclusive topologies allows for disentangling neutrino-nuclear interaction phenomenology
- High statistics, detector granularity and good particle ID allows this

Final State interactions (FSI)

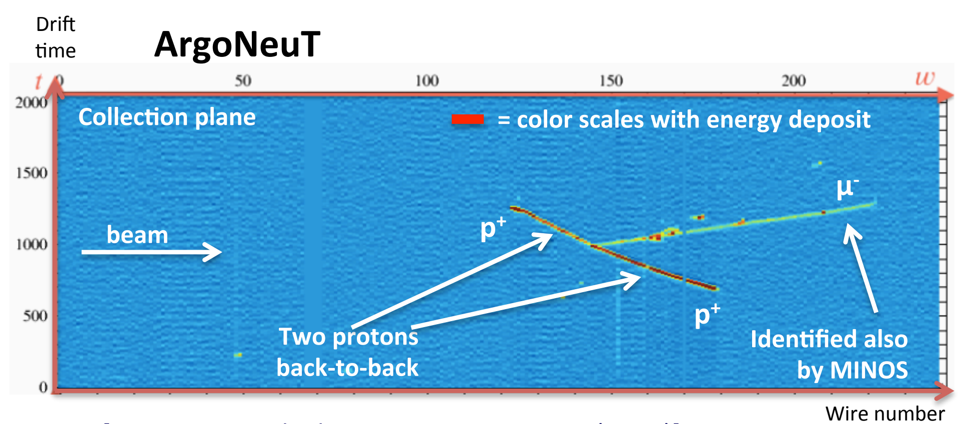
- At SBND CC 0π (no pions in the final state) is the dominant channel
- Can quantify nuclear effects in ν-Ar scattering with ν_μ and ν_e CC 0π
- Direct experimental investigation and quantification of nuclear effects and impact on rates, final states and kinematics
- SBND data will inform neutrino MC generators and discriminate between FSI models

- μ + 2p
- Correlated nucleon pairs
- 360,000 events per year in SBND





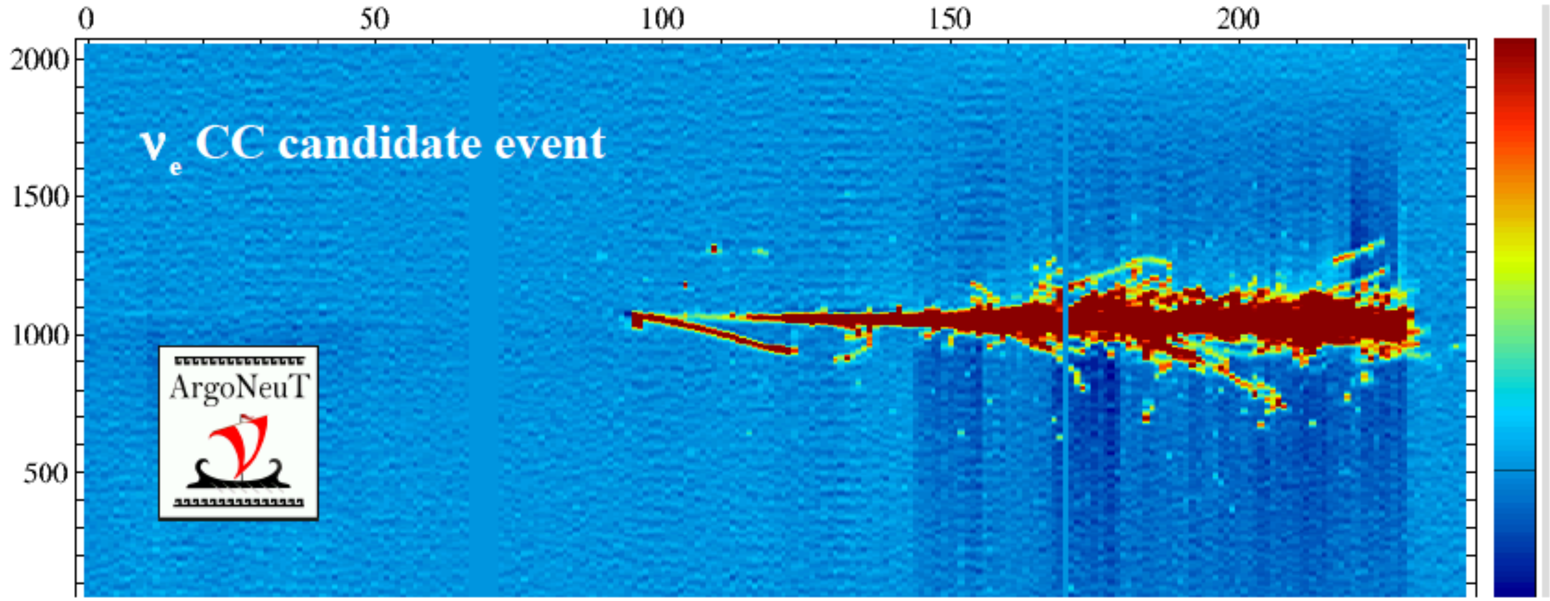
[Formaggio, arXiv:1305.7513]



[R. Acciarri et al, Phys. Rev. D 90, 012008 (2014)]

Electron neutrino interactions

- High statistics electron neutrino sample hugely beneficial for both SBN and DUNE physics programs
  - Measurement of both muon neutrino disappearance and electron neutrino appearance
  - Excellent opportunity to make inclusive *and* exclusive ν_e channel measurements!



[R. Acciarri et al, Phys. Rev. D **95**, 072005 (2017)]

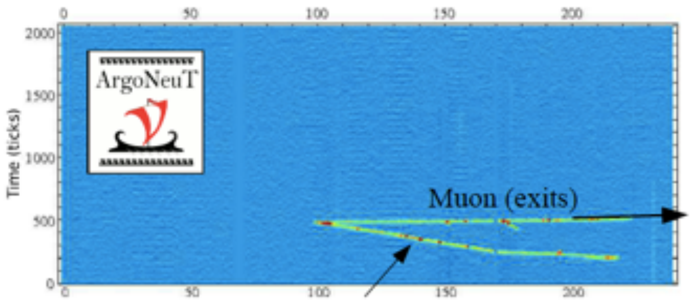
	1 month	1 year	3 years
CC ν_e events	1,000	12,000	37,000

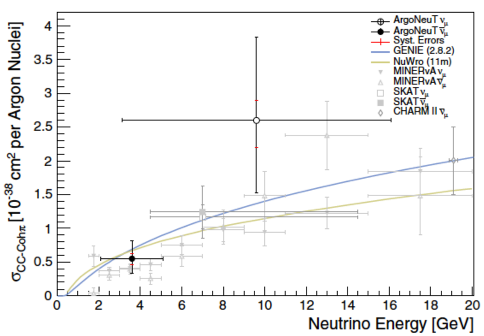
Rare channel searches

- High precision measurements of rare channels!
  - Some previously unmeasured on Argon!

Charged Current Coherent Pion Expectations (GENIE estimate, rounded)

	1 Month	1 Year	3 Years
CC Coherent	500	6,300	19,000



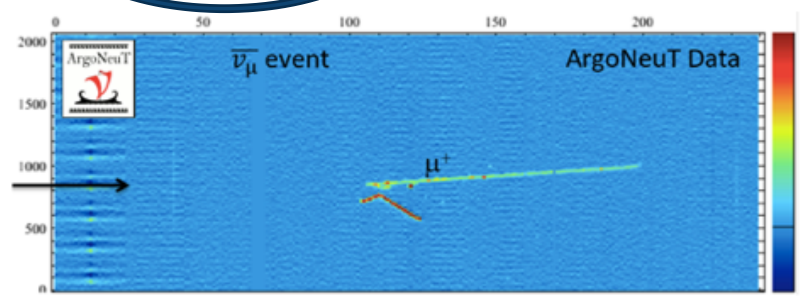


[R. Accarri et al, PRL 113, 261801 (2014)]

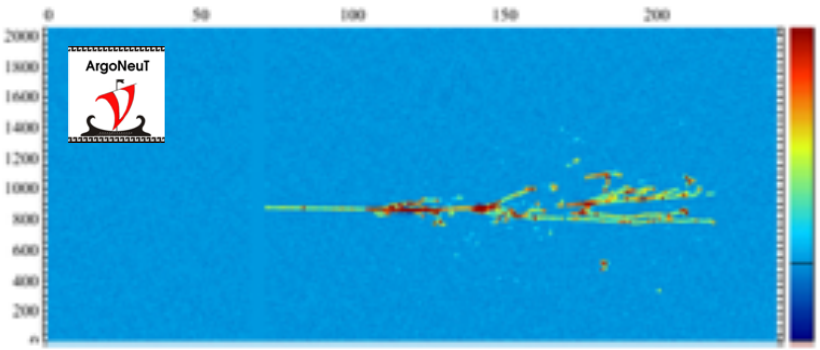
More detector interactions in one month than historical dataset

Hyperon Production Expectations (CC + NC) (GENIE Expectations)

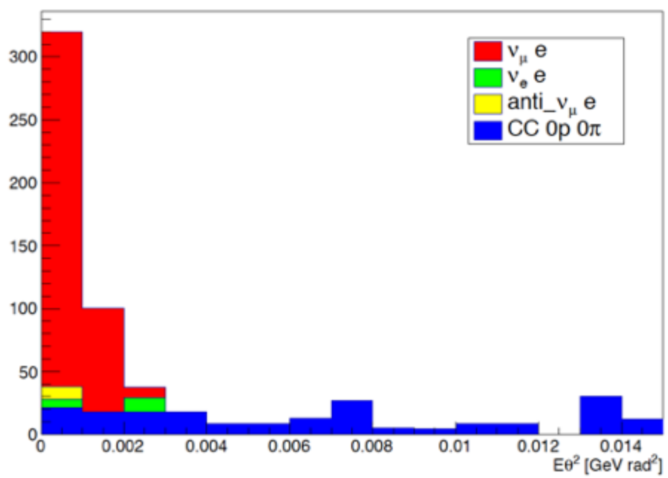
	1 Month	1 Year	3 Years
Λ^0 Production	200	2,600	8,000
Σ^+ Production	125	1,500	4,500



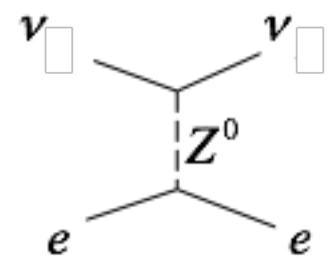
Electron-neutrino scattering



- Detector signature:
  - Very forward electron
  - No activity around vertex

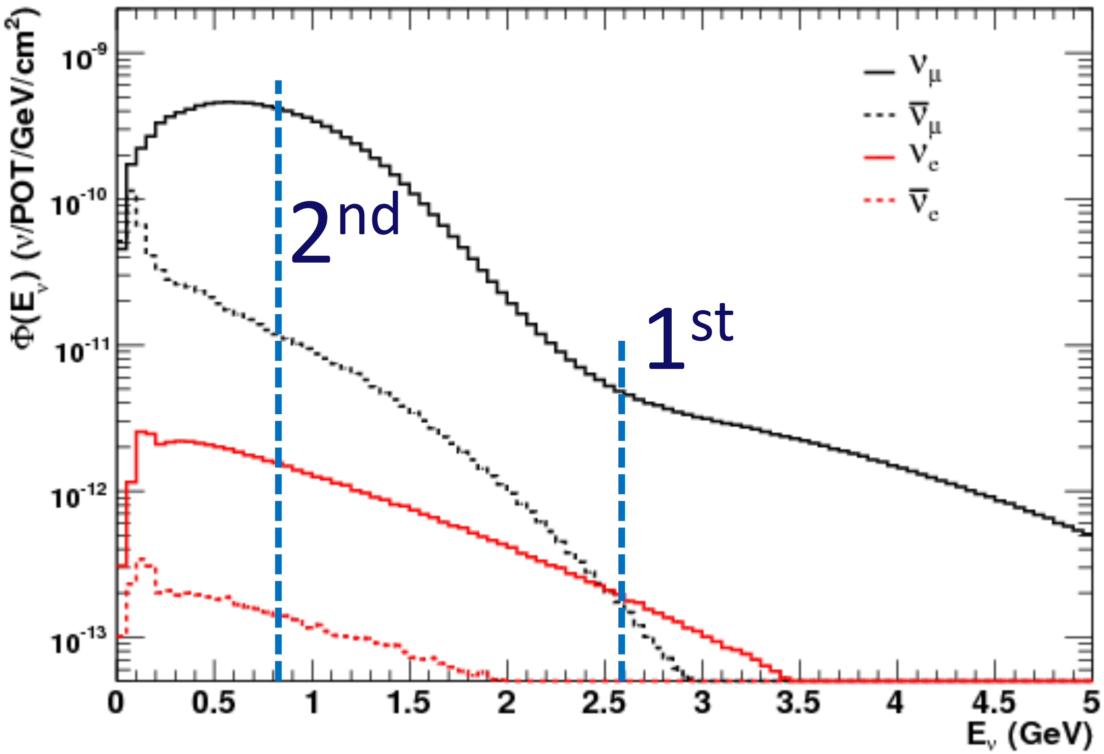


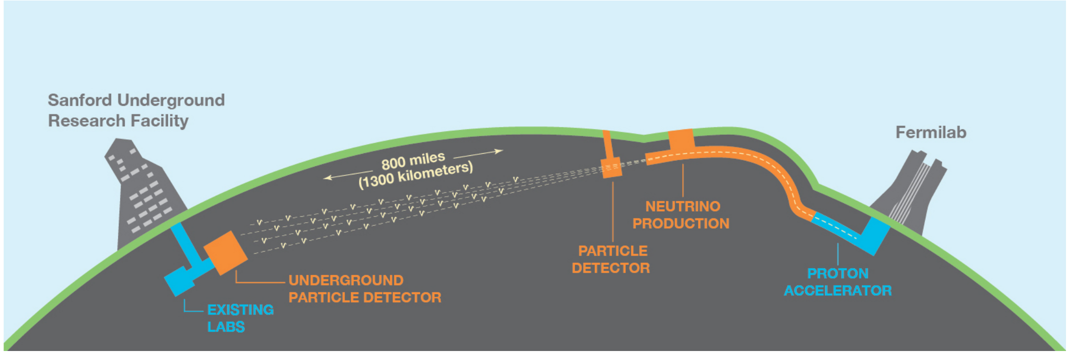
- Perfect position to make precision flux measurement
  - High event rate
  - Unoscillated signal
- Neutrino elastic scattering well known cross section



- LAr TPC is ideally suited to this measurement
  - 300 events expected

Relevance to DUNE





- BNB flux covers neutrino energy at both 1st and 2nd oscillation peak for Deep Underground Neutrino Experiment
- High statistics measurement of neutrino interactions at 2nd oscillation peak energy

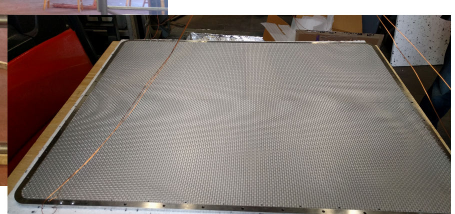
Physics overview

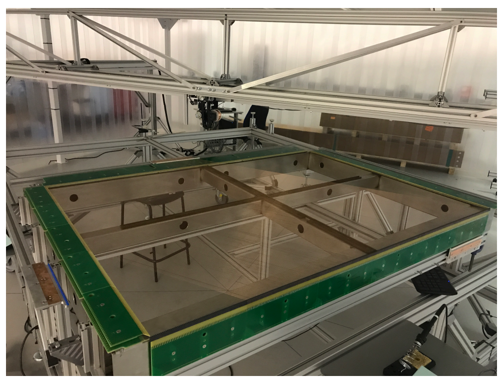
- SBND will contribute to the sterile neutrino search as a near detector for the SBN program, reducing systematic errors
- High statistics measurements of exclusive channels will lead to distinguish between nuclear models
  - Access to some unmeasured cross-sections on Argon
- Neutrino electron elastic scattering measurement will constrain the BNB flux
- Events at neutrino energy of DUNE 1^{st} and 2^{nd} oscillation maximum both measured at SBND

- SBND will have fully automated reconstruction
  - LArSoft framework (larsoft.org)
    - Used for physics simulation, detector response simulation, signal processing, hit reconstruction, pattern recognition, track and shower reconstruction, calorimetry
  - Development across collaborations: DUNE, MicroBooNE, LArIAT, ArgoNEUT

SBND Current Status

- The SBND detector is currently under construction!
  - APA frames welded, machined and assembled to flatness of 0.5mm
  - APA wiring of prototypes at advanced stages, final frame wiring to start imminently!
  - CPA frames welded, mesh frames in production

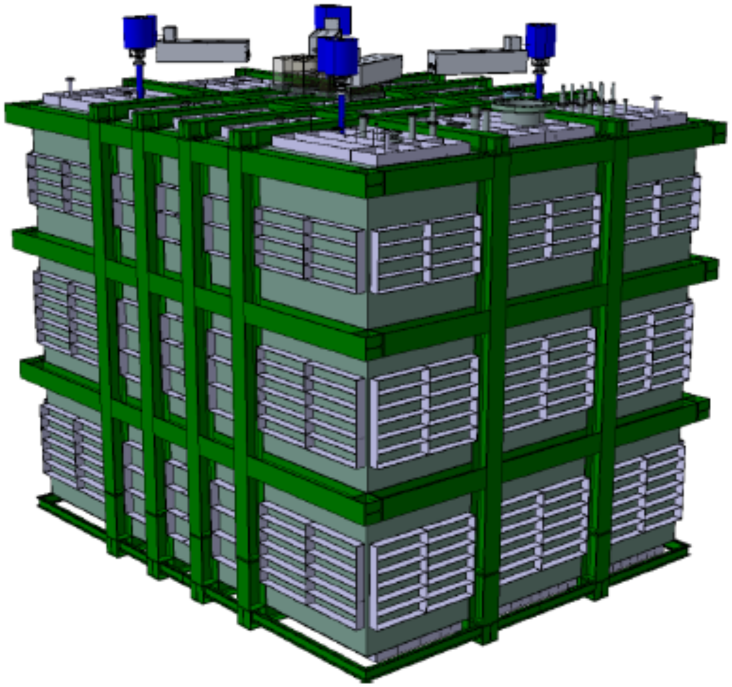




SBND Current Status

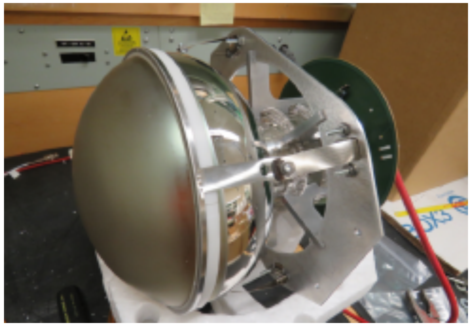
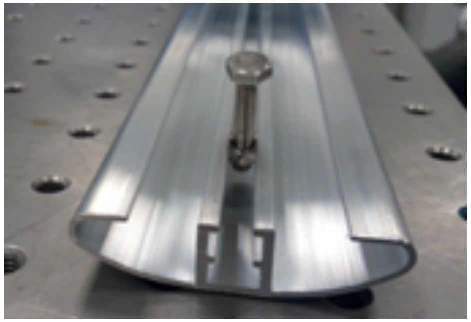
- SBND Building completed

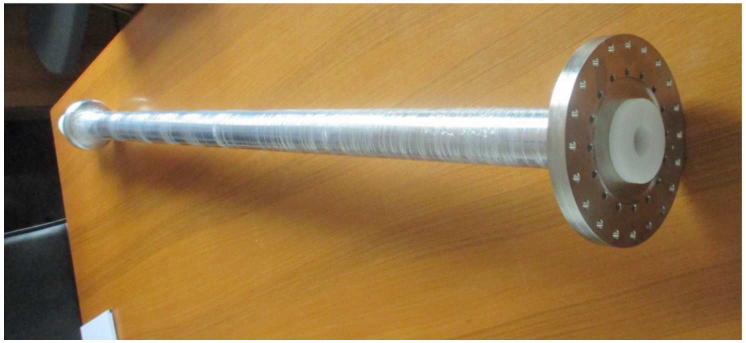
- Membrane Cryostat under design
  - Concrete with metal beams
  - 3rd generation prototype for DUNE



SBND Current Status

- High Voltage feedthrough prototypes in advanced stages
- Field cage components ready for testing and assembly
- Light collection system in production
- Detector cryogenic characterisation vessel commisioned



Future timeline

- ❑ Detector construction in progress!
- ❑ Software development synergies with other LAr experiments: use of LArSoft – mature development framework
- ❑ Detector assembly at Fermilab – early 2018
- ❑ Detector insertion into cryostat – late 2018
- ❑ Detector Commissioning – early 2019
- ❑ First neutrino data with TPC – mid 2019!

- ❑ Analysis work already ongoing – neutrino data from just 1 month's running is significant!

Summary

- SBND is the near detector for the Short Baseline Neutrino program at Fermilab
  - It will measure the unoscillated BNB flux
  - Significant contribution to systematic error reduction for the SBN sterile neutrino searches
- SBND will measure ν-Ar interactions with unprecedented precision due to excellent detector characteristics and high event rates
  - Transform our understanding of ν-Ar interactions in the low energy range
    - Exclusive topologies
    - Rare channels
    - Input to nuclear modelling
- SBND is currently under construction, and will begin taking neutrino data in 2019!
  - Exciting times ahead!

Thanks from SBND

188 Collaborators from 35 institutions