SBND: The Near Detector for the Short-Baseline Neutrino program at Fermilab

Costas Andreopoulos[1,2] for the SBND Collaboration

11th Intl' Workshop on Neutrino-Nucleus Scattering in the Few-GeV Region (NuINT17)

Toronto, 25-30 June 2017

[1]University of Liverpool, [2]STFC Rutherford Appleton Laboratory

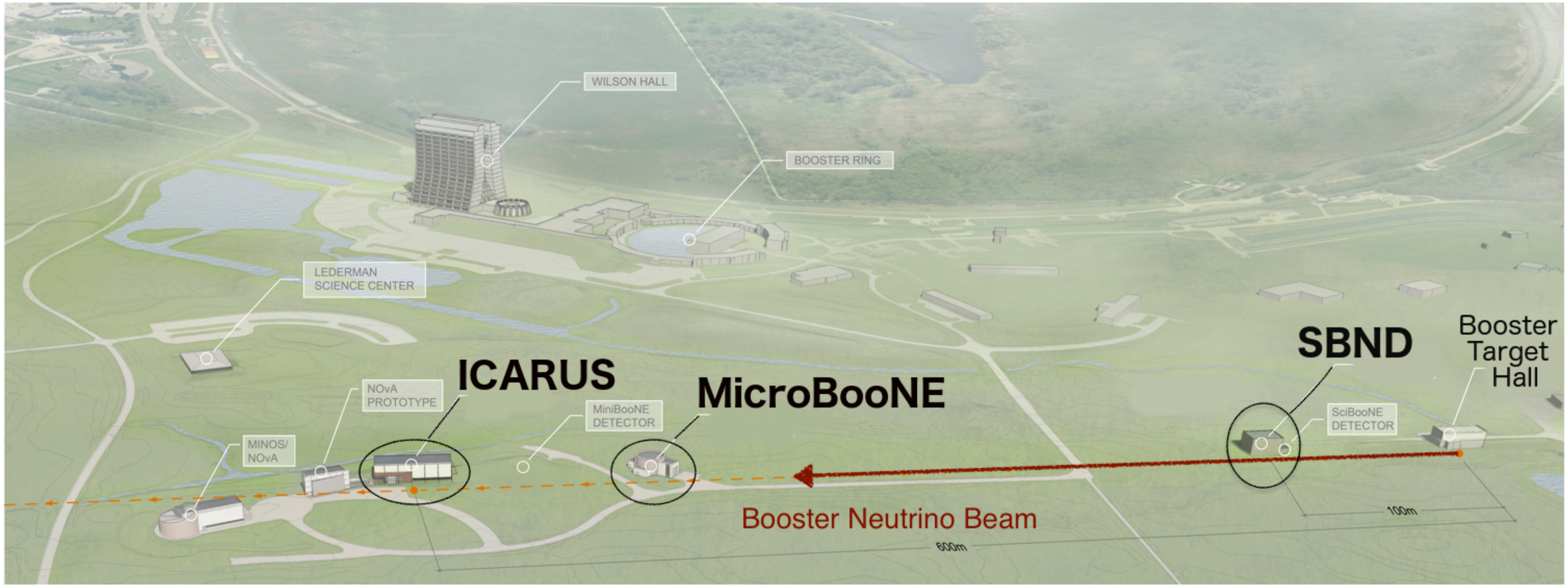
June 29, 2017

Outline

- The SBN program
- Tensions in the 3-flavour scheme / SBN primary science goals
- The role of the SBND
- The SBND detector and its main components
- Illustration of cross-section measurement capabilities
- SBND inputs towards a joint SBN oscillation analysis
- Summary

The SBN program

A Three LArTPC Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam [arXiv:1503.01520]



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

Same neutrino beam, nuclear target, detector technology: Reducing effect of systematic uncertainties.

Tensions in the 3-active-neutrino scheme

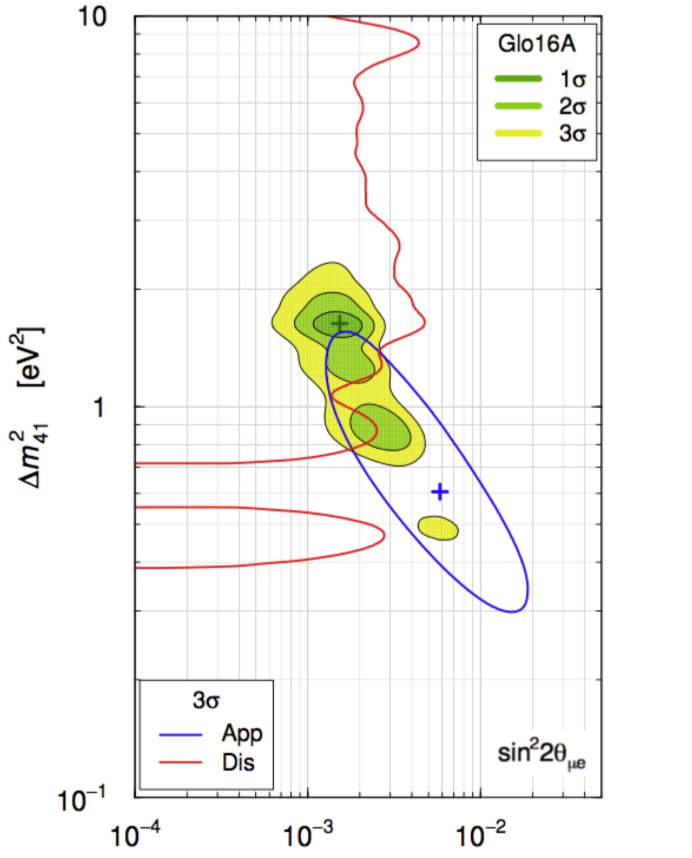
- **LSND anomaly**
  $\sim$50 MeV $\bar{\nu}_e$ appearance ($\sim 3.8\sigma$)
- **MiniBooNE anomaly**
  $\sim$1 GeV ν_e and $\bar{\nu}_e$ appearance ($\sim 3.8\sigma$)
- **Reactor anomaly**
  Few-MeV $\bar{\nu}_e$ disappearance ($\sim 3.0\sigma$)
- **Gallium anomaly**
  Sub-MeV ν_e disappearance ($\sim 2.7\sigma$)

Can be interpreted as large-Δm^2 oscillation, requiring the addition of new sterile neutrino(s).

- Severe tensions with null $\nu_\mu \to \nu_\mu$ results.
- Definite null result would settle a long-standing open question.
- Confirmation would be a major discovery.
- Implications for CPV searches.

Resuts of a global (3+1) $\nu_\mu \to \nu_e$ analysis

excluding recent MINOS, IceCuBE, NEOS results:



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

Tensions in the 3-active-neutrino scheme

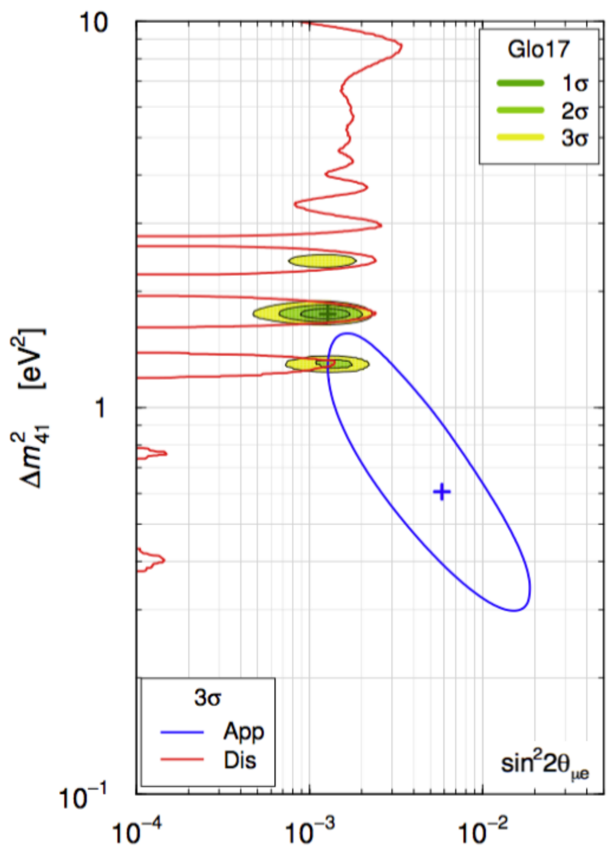
- **LSND anomaly**
  $\sim$50 MeV $\bar{\nu}_e$ appearance ($\sim 3.8\sigma$)
- **MiniBooNE anomaly**
  $\sim$1 GeV ν_e and $\bar{\nu}_e$ appearance ($\sim 3.8\sigma$)
- **Reactor anomaly**
  Few-MeV $\bar{\nu}_e$ disappearance ($\sim 3.0\sigma$)
- **Gallium anomaly**
  Sub-MeV ν_e disappearance ($\sim 2.7\sigma$)

Can be interpreted as large-Δm^2 oscillation, requiring the addition of new sterile neutrino(s).

- Severe tensions with null $\nu_\mu \rightarrow \nu_\mu$ results.
- Definite null result would settle a long-standing open question.
- Confirmation would be a major discovery.
- Implications for CPV searches.

Resuts of a global (3+1) $\nu_\mu \rightarrow \nu_e$ analysis

including recent MINOS, IceCuBE, NEOS results:



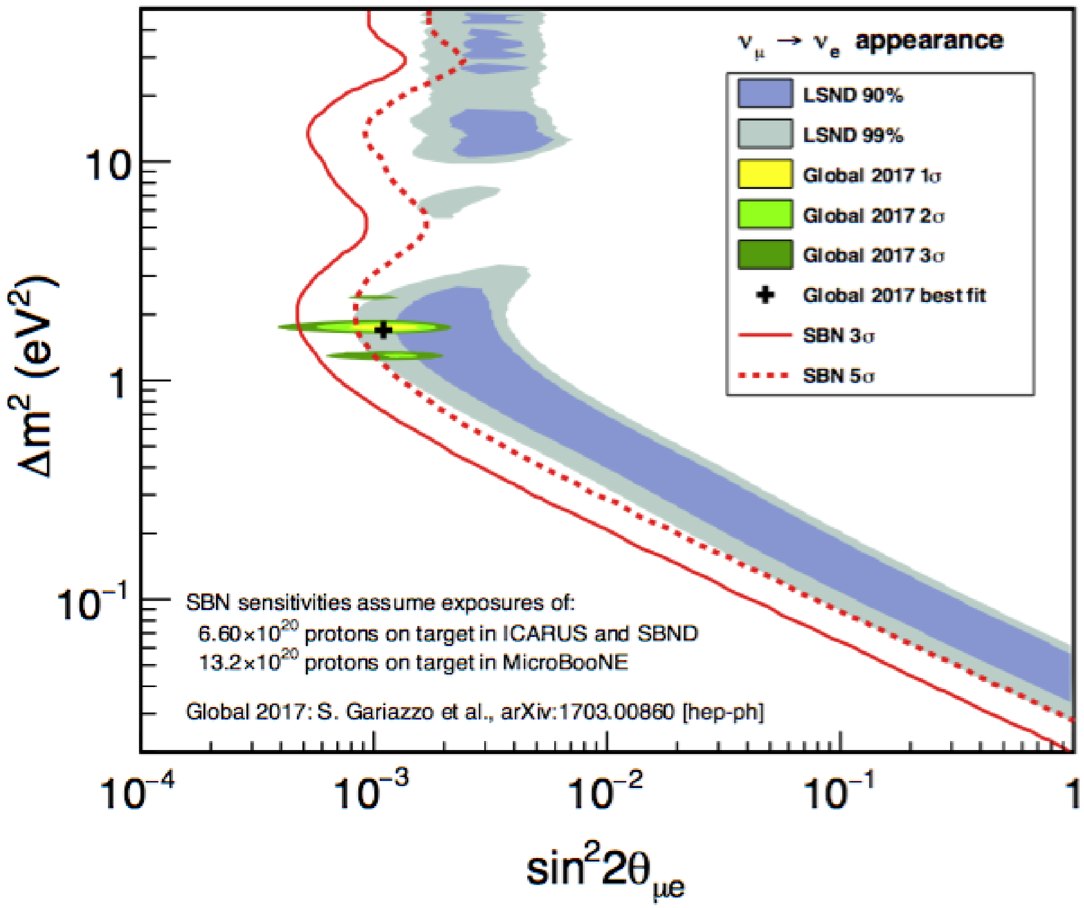
[S.Gariazzo et al., arXiv:1703.00860v3]

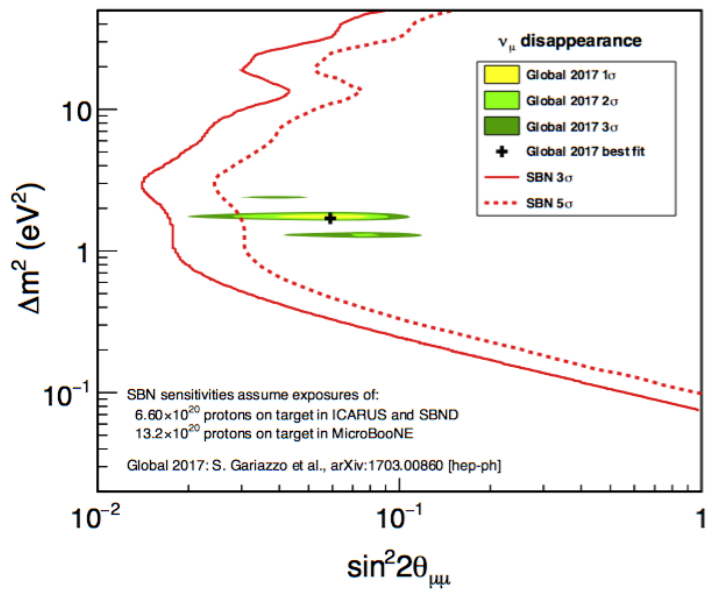
Primary science goal of the SBN

A definite test ($> 5\sigma$) of currently allowed oscillation parameter regions.

Small mixing angle ($sin^2 2\theta_{\mu e} \approx 10^{-3}$) requires a superbly sensitive experiment!

Enabled by the LArTPC technology and by use of multiple detectors at different baselines.





Complementarity between app. and disapp. (in a simple 3+1 scheme):

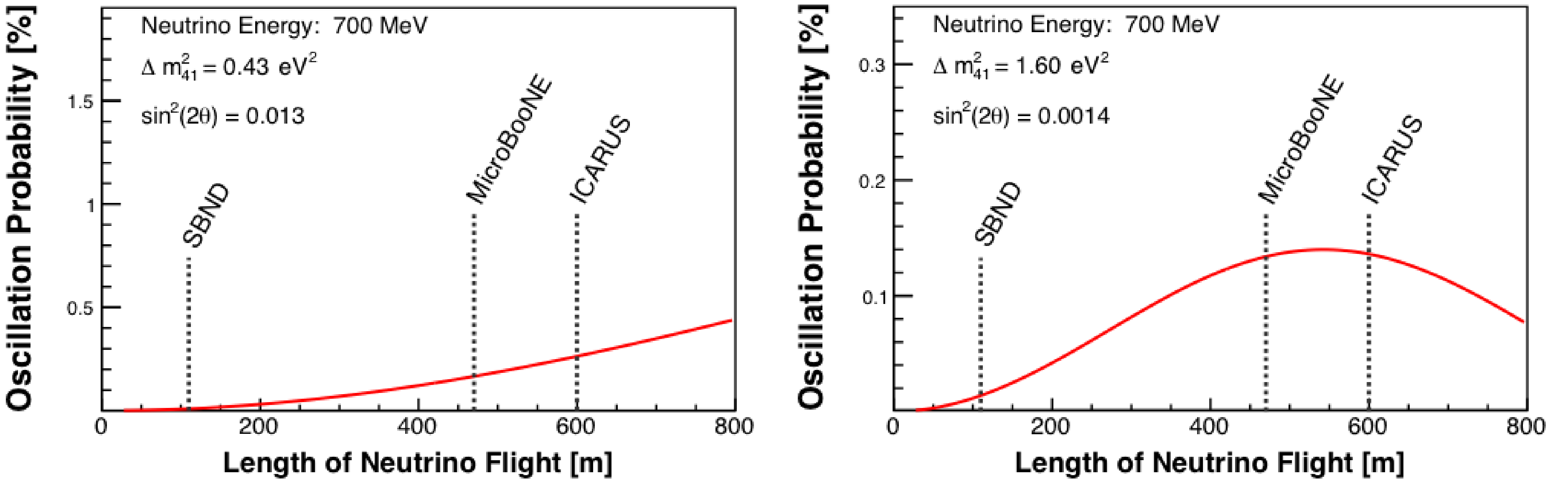
$sin^2 2\theta_{\mu e} = 4\ |U_{\mu 4}|^2 |U_{e4}|^2$

$sin^2 2\theta_{\mu\mu} = 4\ |U_{\mu 4}|^2 (1 - |U_{\mu 4}|^2)$

The role of the SBND

SBND samples the *unoscillated* neutrino flux with **very high statistics**.

- Record 3-yr MicroBooNE dataset in 2 months!

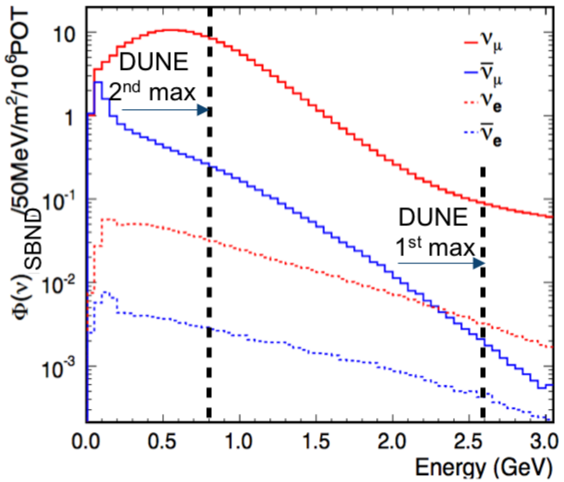


SBND data will enable tuning of flux and cross-section modelling, and produce unoscillated predictions for MicroBooNE and ICARUS.

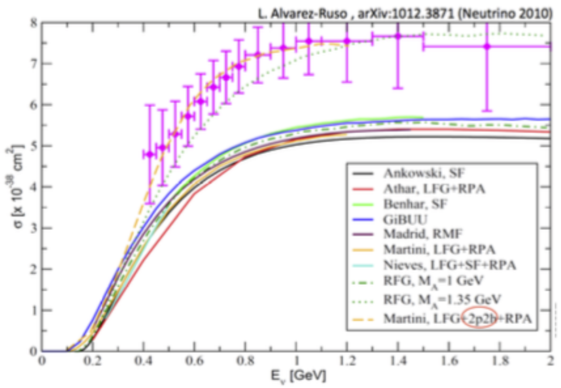
SBND carries the main burden for systematic error reduction in SBN.

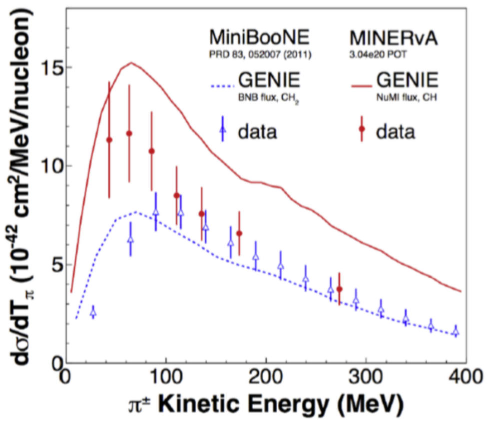
The role of the SBND

SBND carries the main burden for systematic error reduction in SBN.



- Flux covers DUNE 1st and 2nd osc. max
- $\sim$ 15% flux uncertainty.
- Mainly 0π and 1π interaction: QE and 1π puzzles.





[Phys.Rev.D92, 092008 (2015)]

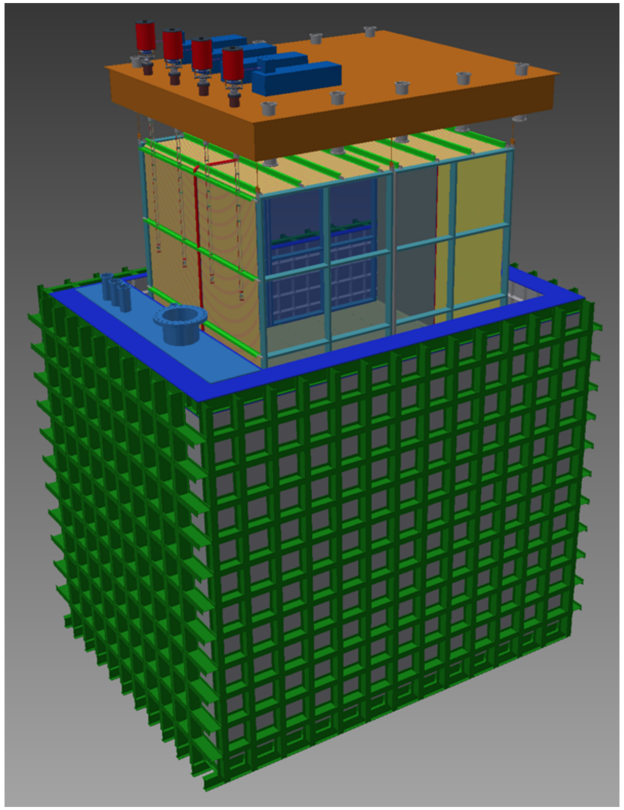
Source of Uncertainty	ν_μ	ν_e
π^+ production	14.7%	9.3%
π^- production	0.0%	0.0%
K^+ production	0.9%	11.5%
K^0 production	0.0%	2.1%
Horn field	2.2%	0.6%
Nucleon cross sections	2.8%	3.3%
Pion cross sections	1.2%	0.8%

[PRD79,072002 (2009)]

The SBND detector

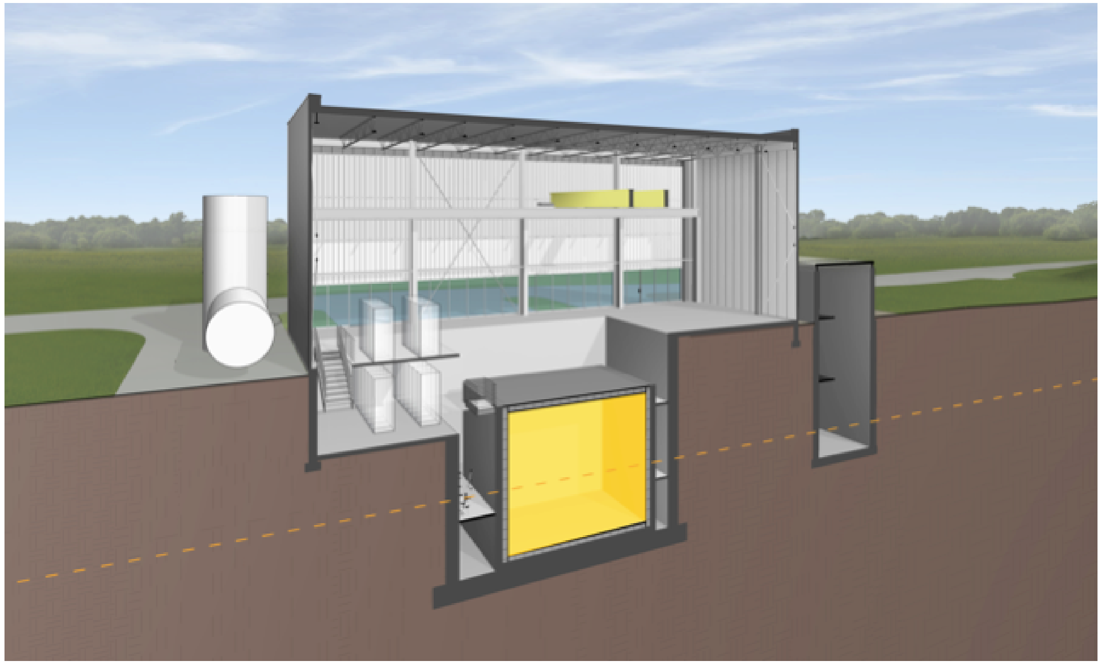
Liquid Argon Time Projection Chamber (LArTPC) detector in membrane cryostat.

A **key prototype for DUNE**. Similar design / construction procedures for many components.

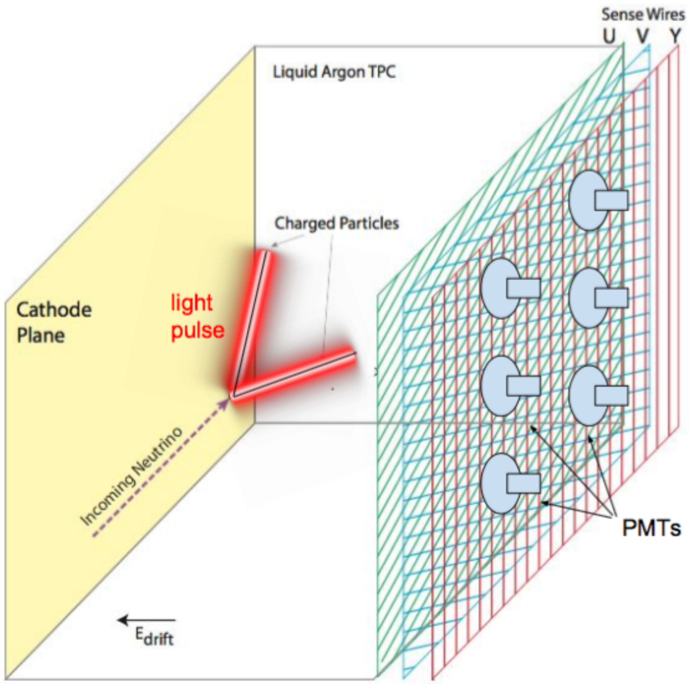


Membrane cryostat:
3rd generation DUNE prototype
with lighter support structure.

- SBND hall at O(100) m from the BNB target.
- 112 (270) tonnes active (total) LAr mass.
- Detector at shallow depth (3m of concrete overburden).
- Cosmic veto around cryostat (94% CR flux coverage).

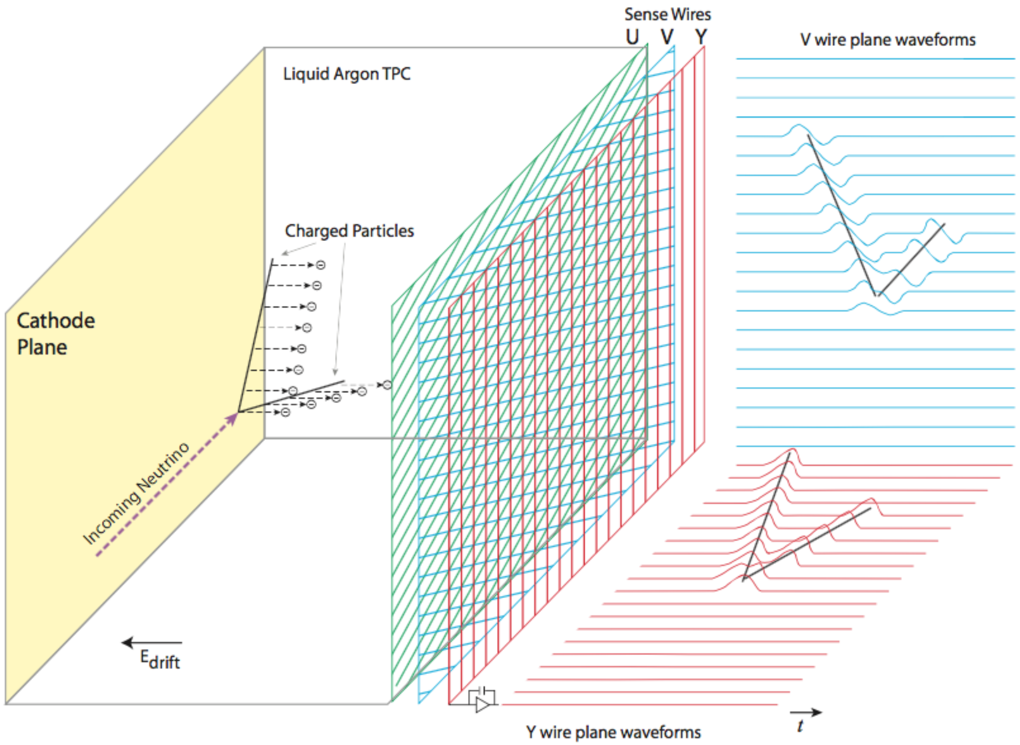


LArTPCs: Principle of operation



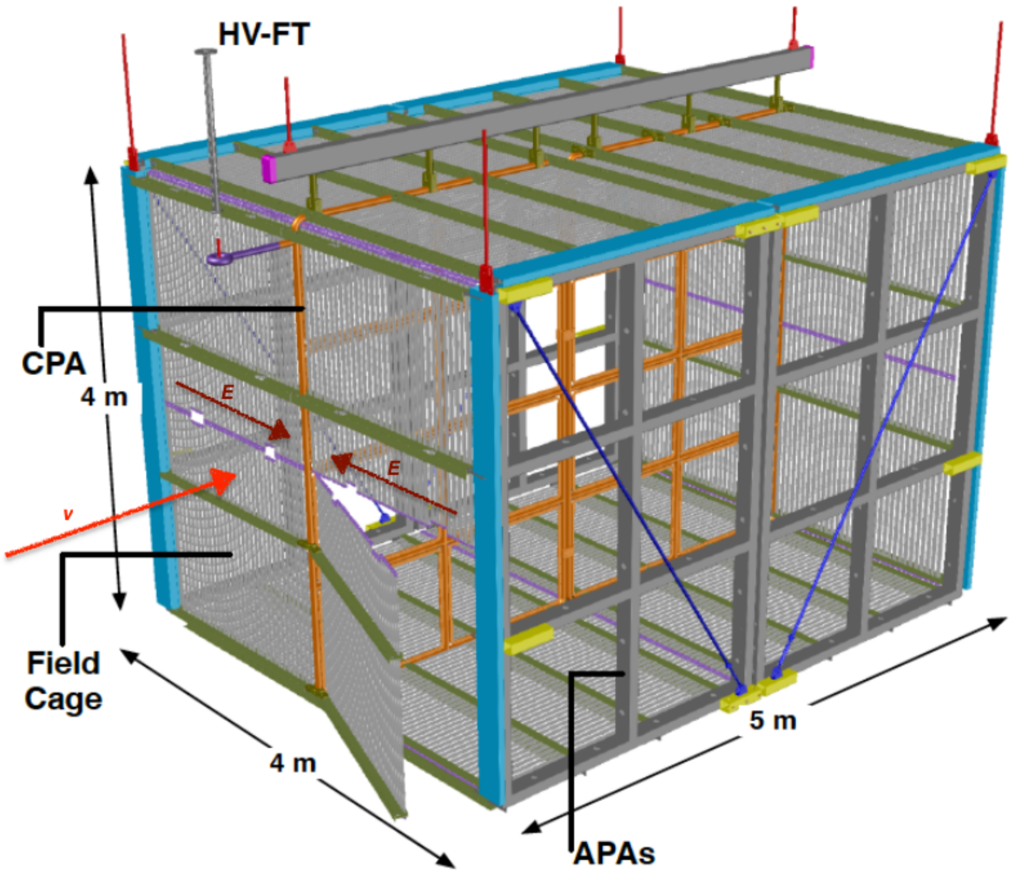
- Charged particles excite Argon atoms.
- Prompt scintillation light
  - 6 nsec characteristic time constant (fast component)
  - ≈ 40k photons/MeV (E=0)
  - emission at ≈ 128 nm (VUV)
- Allows determination of t_0

- Charged particles ionize Argon atoms.
- Charge drifts to segmented anode (wire planes)
  - Drift velocity ≈ 1.6 mm/μs at 500 V/cm
  - Max drift time at SBND ≈ 1.25 ms
- Projected (2-D) view of ionization tracks by each wire plane. Combination of multiple projected views (from wire planes of different orientations) forms stereoscopic images!



The SBND TPC

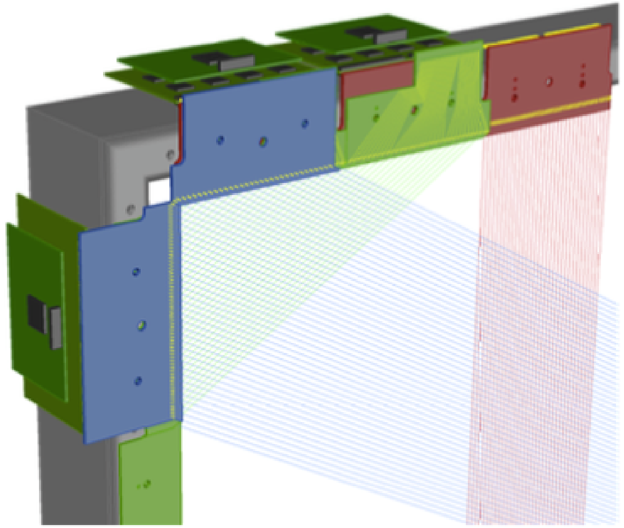
- Active LAr volume: 4m $\times$ 4m $\times$ 5m.
- Cathode Plane Assembly (CPA) in the middle (bias = -100 kV).
- Anode Plane Assemblies (APA) on beam left and right form **two ionization drift volumes**.
- Maximum drift distance: 2 m.
- Drift field $\approx$ 500 V/cm.
- Drift direction perpendicular to the beam direction.
- Charge and light readout.



The SBND TPC

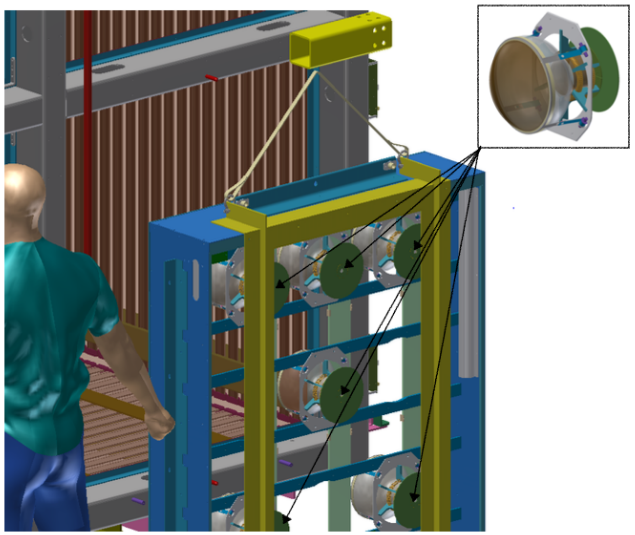
Charge readout:

- Two tiled 2.5m-wide Anode Plane Assemblies (APA) on each side of the TPC
- 3 wire planes: Y (vertical) and U/V ($\pm 60^o$).
- 3 mm wire plane spacing.
- 150 μm CuBe wires, 3 mm wire pitch.
- 11,263 channels
- Cold electronics mounted on 2 APA sides.
- S/N for M.I.Ps > 12



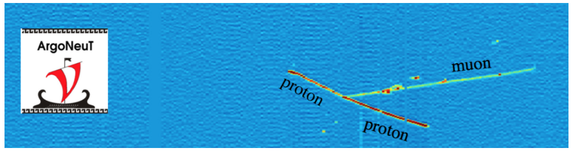
Light readout:

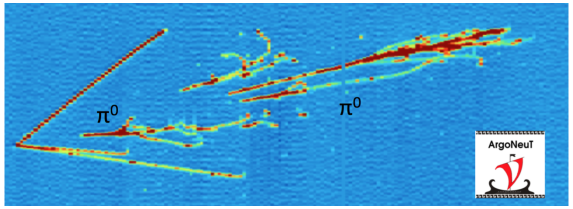
- 120 8" Hamamatsu R5912 Cryogenic PMTs
  - 10-stage 10^7 gain, 16% QE (LAr temp), 1 nsec resolution for single p.e.
  - Coated with TPB wavelength shifter
- 24 extra PMTs with no TPB coating
  - Sensitive to prompt Ckv light
- $\sim$15 p.e. per MeV deposited 2 m from PMT plane.



High event rate with excellent imaging capabilities

$\nu_\mu CC$, 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 π	3,814,198	3,744,108
0 π + 0p	27,269	34,696
0 π + 1p (> 20 MeV)	1,629,252	2,235,338
0 π + 2p (> 20 MeV)	1,150,368	637,535
0 π + 3p (> 20 MeV)	413,956	229,239
0 π + >3p (> 20 MeV)	396,212	263,727
1 π^+ + X	942,555	1,021,212
1 π^- + X	38,012	21,242
1 π^0 + X	406,555	370,666
2 π + 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





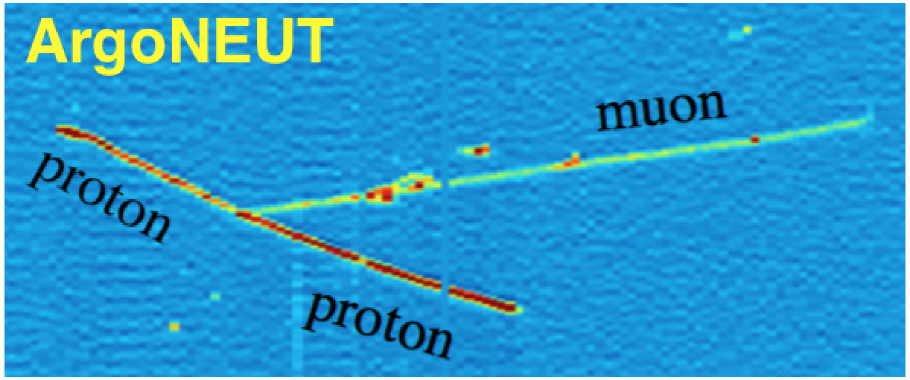
Also:
- ≈ 350k NCπ^0 events
- ≈ 12k ν_eCC events
- ≈ 1k charm (QE) events
- ≈ 400 $\nu + e^-$ events

A generational advance in neutrino-nucleus interaction studies.

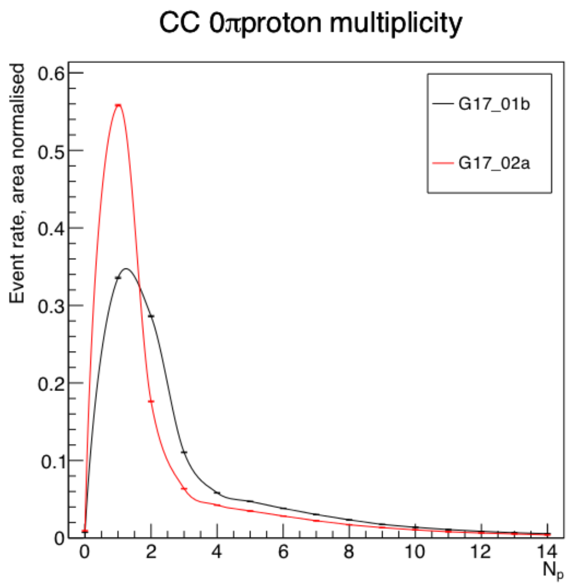
G17_01b: Updated empirical model / **G17_02a**: Theory-driven model (See J.Wolcott's GENIE talk)

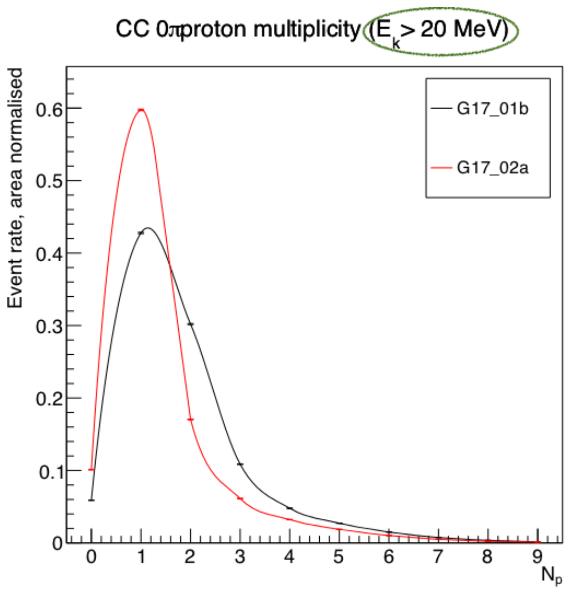
Illustration of cross-section measurement capabilities

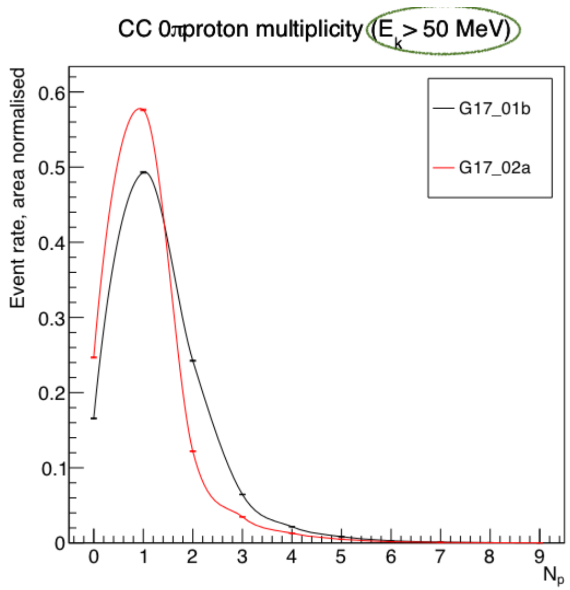
- One of the most pertinent SBND features is the low threshold for proton detection.
- Different predictions (2p2h, FSI and other aspects of nuclear modelling play a role)



Proton kinetic energy (MeV)	Proton track length (cm)
20	≈ 0.4
50	≈ 2
100	≈ 8
200	≈ 26



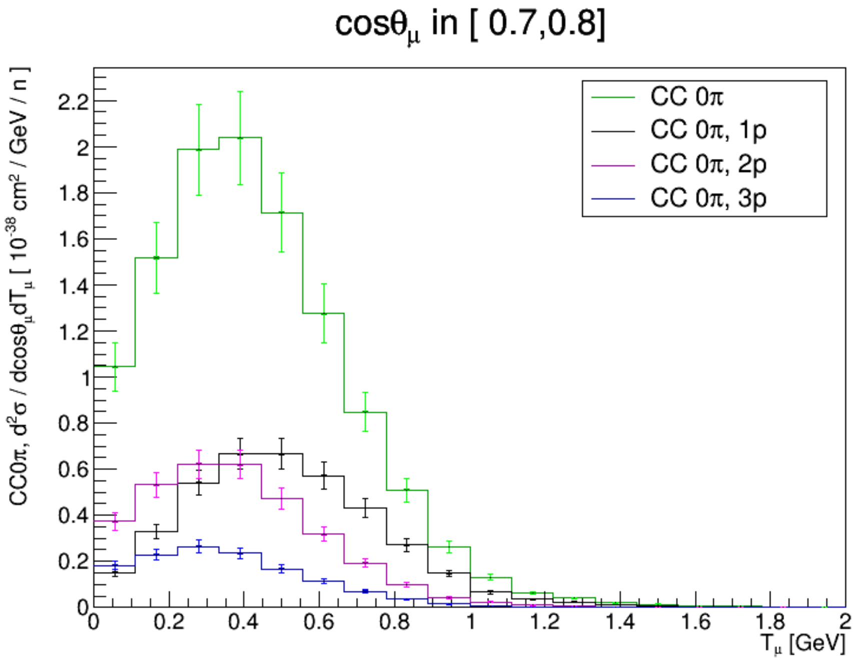


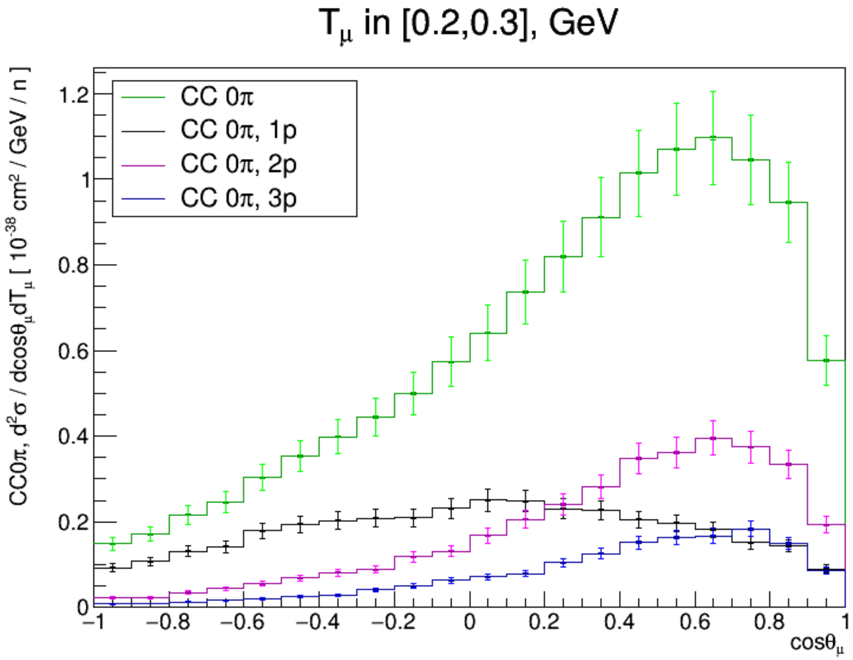


G17_01b: Updated empirical model / **G17_02a**: Theory-driven model (See J.Wolcott's GENIE talk)

Illustration of cross-section measurement capabilities

High statistics and excellent granularity will allow SBND to study more exclusive final states and provide results in kinematic spaces of higher dimensionality.



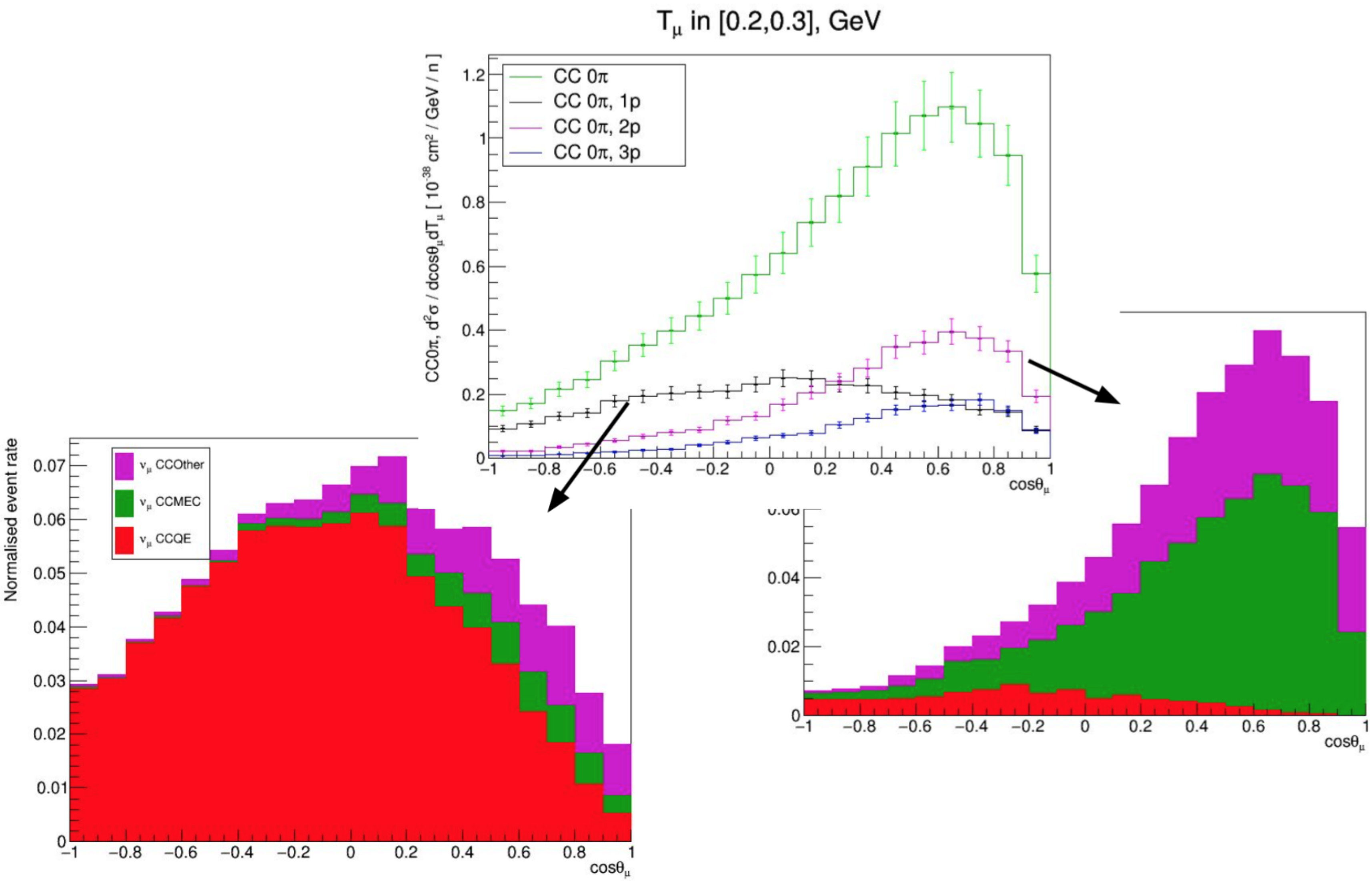


Example of an SBND sensitivity study of ν_μCC 0π flux-integrated cross-sections (FHC, 6.6×10^{20} POT) and corresponding results for 0π+1p, 0π+2p, 0π+3p exclusive final states.
Sensitivity study results are shown for a single T_μ and a single cosθ_μ bin.

Flux error assumed above is 10%.

Illustration of cross-section measurement capabilities

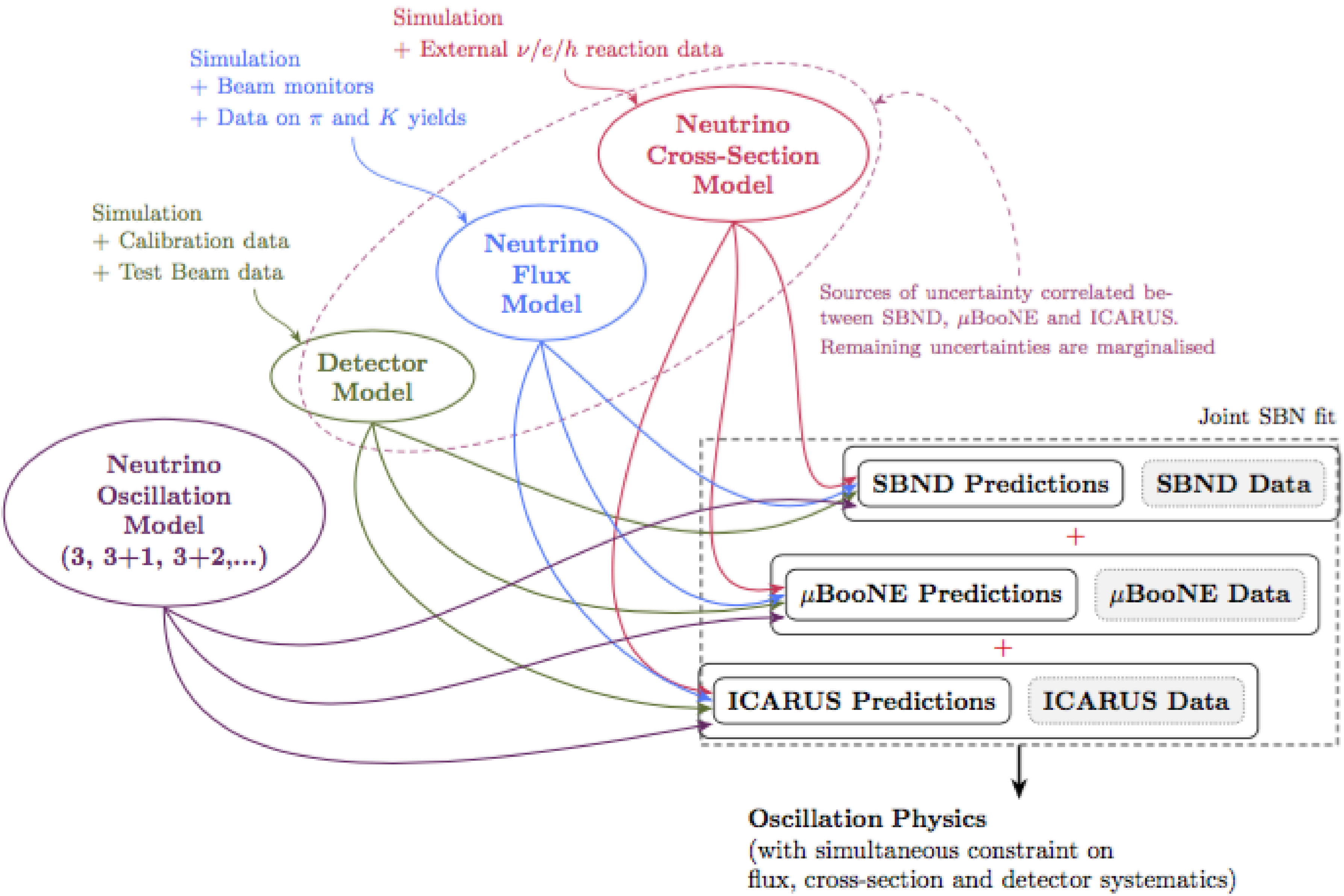
Study of several exclusive states would allow to disentangle different aspects of neutrino-nucleus interaction phenomenology.



Preparations for SBND data analysis

- Development of several prototype analyses based on full simulation and reconstruction: **Aiming at prompt physics exploitation.**
- Aiming to underpin a **quantitative** analysis and tuning of $\nu/\bar{\nu}$+Ar modelling in the energy range of the 1st and 2nd DUNE osc. max.:
  - **Joint analysis** of several exclusive samples.
  - Provide full correlation matrix (incl amongst exclusive samples).
- Design/development of suitable cross-section analysis tools underway.
- Additionally, SBND is making preparations to play its role in the **joint SBN oscillation analysis**, providing systematic error constraints and extrapolated unoscillated spectra for MicroBooNE and ICARUS.
  - Currently implementing the SBND data-driven physics systematic constraint using the VALOR neutrino fit (also used in T2K, DUNE)

Towards a joint SBN oscillation analysis



SBND analysis samples and physics systematics

Samples:

- ν_μ CC inclusive
- ν_μ CC 0π 1-track
- ν_μ CC 0π 2-tracks
- ν_μ CC 0π >2-tracks
- ν_μ CC $1\pi^\pm$
- ν_μ CC $1\pi^0$
- ν_μ CC coherent
- ν_e CC inclusive
- ν_e CC 0π
- ν_e CC $1\pi^\pm$
- NC inclusive
- NC 1γ
- NC 0π
- NC $1\pi^0$
- NC coherent
- νe^-

[Included][Working to include]

Systematics floating in fit: Flux, Cross-Sections, FSI, Detector

- 0-18: $\nu_\mu/\bar{\nu}_\mu$ flux in E_ν bins[a]
- 19-29: $\nu_e/\bar{\nu}_e$ flux in E_ν bins[b]
- 30-35: ν and $\bar{\nu}$ CC QE cross-section in Q^2 bins
- 36-37: ν and $\bar{\nu}$ CC MEC cross-section
- 38-43: ν and $\bar{\nu}$ CC $1\pi^\pm$ cross-section in Q^2 bins
- 44-49: ν and $\bar{\nu}$ CC $1\pi^0$ cross-section in Q^2 bins
- 50-51: ν and $\bar{\nu}$ CC 2π cross-section
- 52-57: ν and $\bar{\nu}$ CC DIS ($> 2\pi$) cross-section in E_ν bins
- 58-59: ν and $\bar{\nu}$ CC coherent cross-section
- 60-61: ν and $\bar{\nu}$ NC cross-section
- 62: ν_e/ν_μ cross-section ratio
- 63-64: re-interaction rates for pions and nucleons
- 65-72: relative strength of chg. exch., inelastic, absorption and pion production for rescattered pions and nucleons
- 73-135: thresholds, efficiencies, mid-ID rates, energy scales

[a] [0.2,0.3,0.4,0.45,0.5,0.55,0.6,0.65,0.7,0.75,0.8,0.85,0.9,0.95,1.,1.25,1.5,2.,2.5,3.] GeV
[b] [0.2,0.35,0.5,0.65,0.8,0.95,1.1,1.3,1.5,1.75,2.,3.] GeV

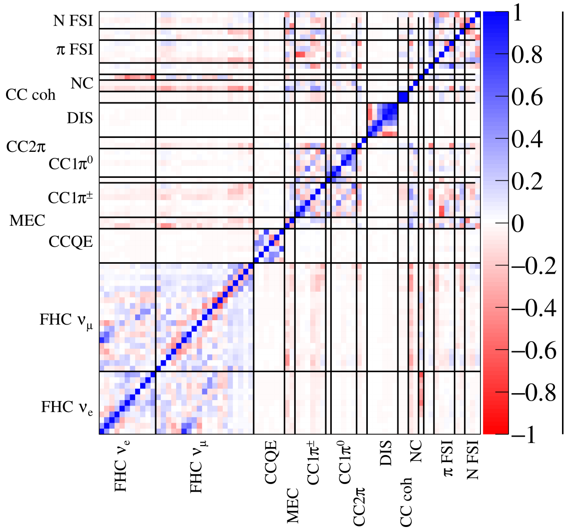
Proof-of-concept SBND systematics constraint fit

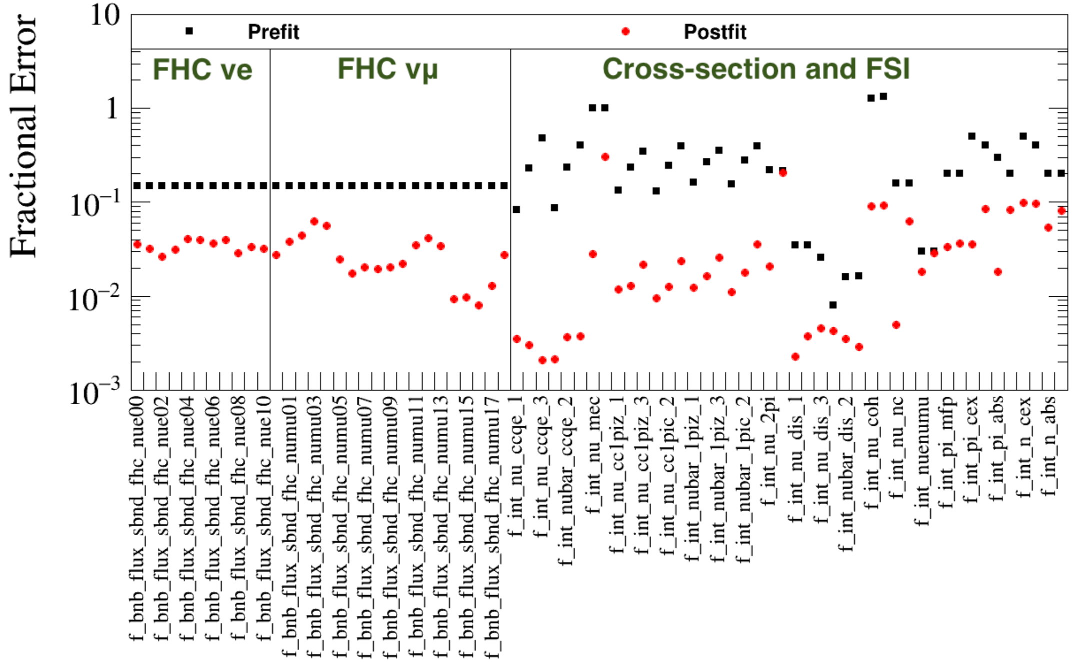
Preliminary results from proof-of-concept SBND fit: Joint multi-channel fit cuts systematic parameter correlations achieving a substantial systematic error reduction.

- e.g. ν_e flux: $\sim$15% $\rightarrow$ 3-4%

Work on reconstruction, event selection and detector systematics in progress.

Post-fit correlation matrix

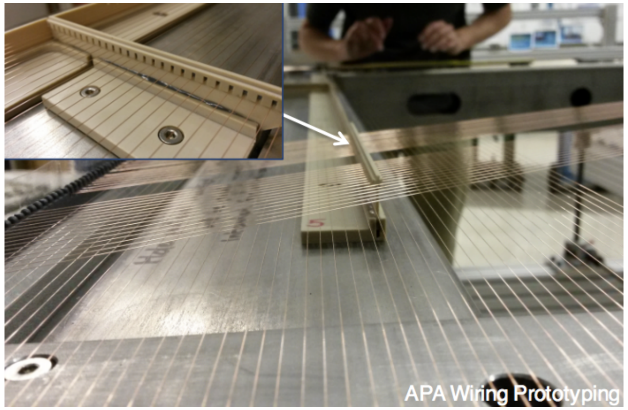




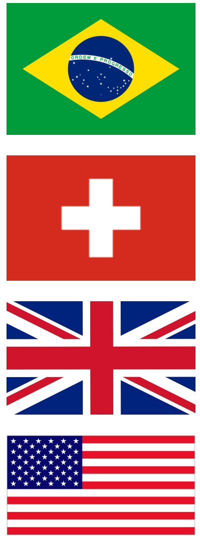
To combine the high-statistics SBND with MicroBooNE and ICARUS data, it is crucial to evaluate the detector response systematics and correlations between detectors.
See poster by Raquel Castillo Fernandez and Angela Fava.

Summary

- SBND is a new LArTPC detector at the Booster neutrino beam
- With very high event rates and oustanding imaging capabilities, SBND will
  - tranform our understanding of $\nu/\bar{\nu}$ interactions in the few-GeV energy range, and
  - carry the main burden of systematic error reduction for SBN sterile ν searches.
- SBND is currently under construction.
  - Neutrino data-taking expected to start in 2019!
  - Preparations for prompt and succesful physics exploitation already underway.



Thank you



- Argonne National Lab
- University of Bern
- Brookhaven National Lab
- University of Cambridge
- University of Campinas
- CERN
- University of Chicago
- Columbia University
- Federal University of ABC
- Federal University of Alfenas
- Federal University of Sao Carlos UFSCAR
- Fermilab
- Illinois Institute of Technology
- Indiana University
- Kansas State University
- Lancaster University
- University of Liverpool
- Los Alamos National Lab
- University of Manchester
- University of Michigan
- MIT
- New Mexico State University
- University of Oxford
- Pacific Northwest National Lab
- University of Pennsylvania
- University of Puerto Rico
- University of Sheffield
- Syracuse University
- University of Tennessee Knoxville
- University of Texas Arlington
- University College London
- Virginia Tech
- Yale University