The **S**hort **B**aseline **N**ear **D**etector at Fermilab

Diego Garcia-Gamez for the SBND Collaboration
The University of Manchester

Outline

- SBND Physics Goals
  - Sterile neutrino searches in SBN
  - Neutrino interactions in LAr:
    cross sections, nuclear effects, …
- SBND Detector
  - Time Projection Chamber
  - Light Detection System
- Time schedule

SBND Physics Goals

Two primary physics goals:

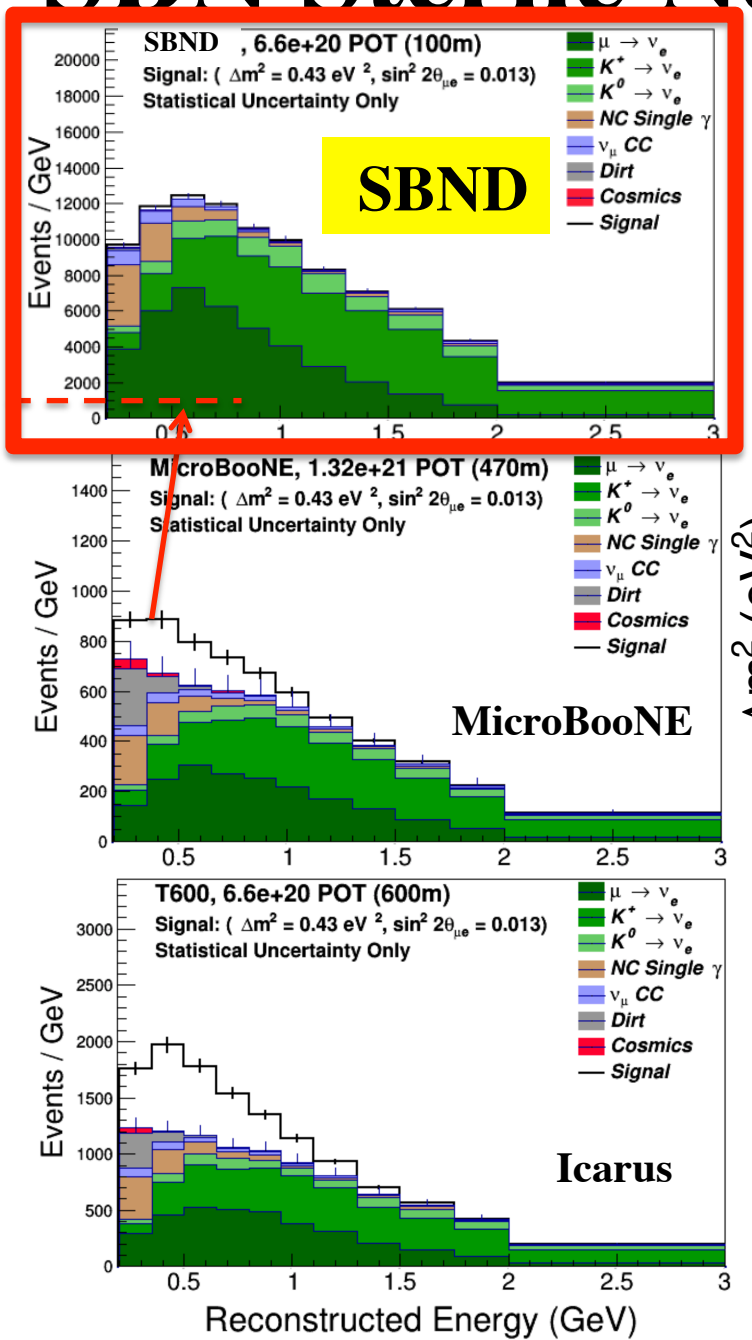
1. **Measure the unoscillated fluxes:** ν_μ-CC, ν_e-CC, and NC interactions to enable precise sterile neutrino oscillation searches in combination with the SBN Program far detectors, ICARUS and MicroBooNE

2. **Study neutrino-nucleus interactions on argon with unprecedented precision and detail:** inclusive and exclusive cross sections, observation of rare production channels, and careful study of nuclear effects in neutrino-nucleus scattering

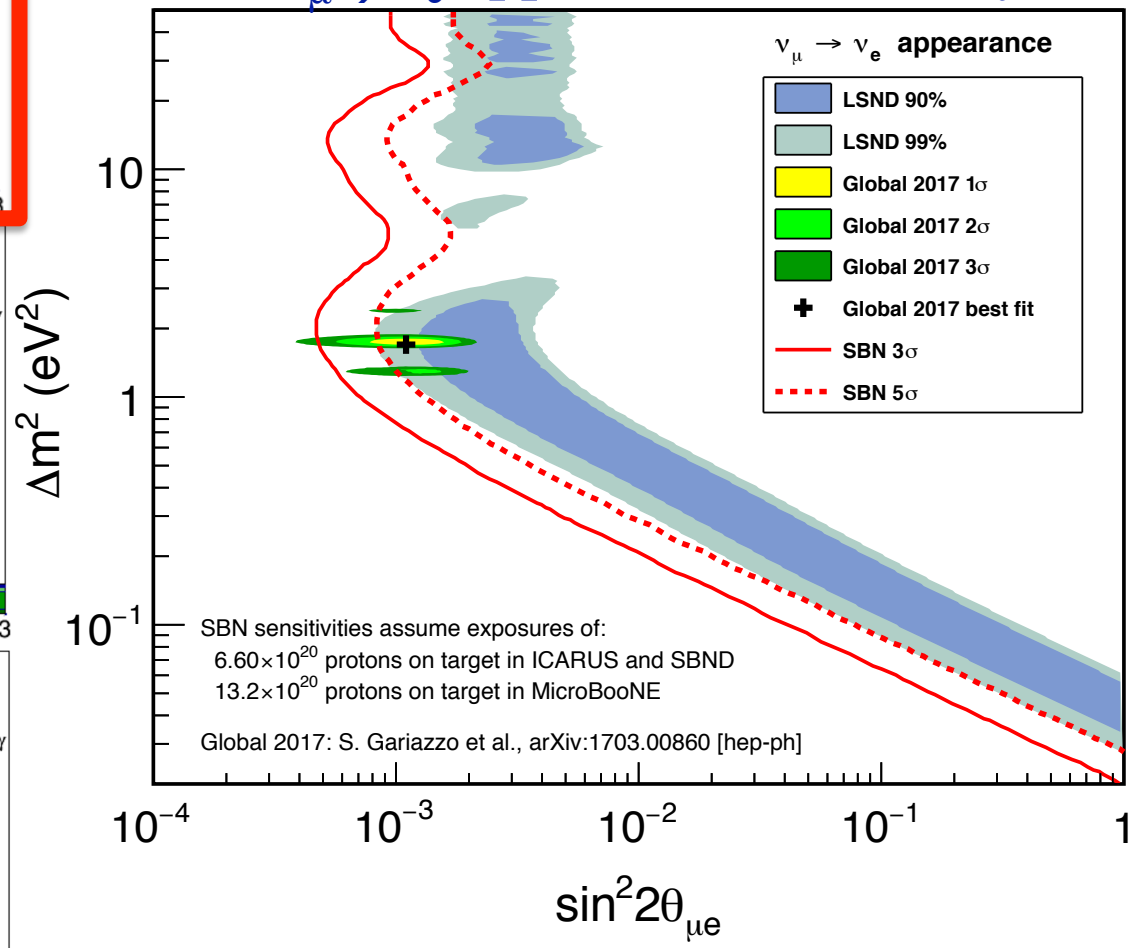
Additional searches include:

3. **Detection of supernova ν, dark matter searches (Sub-GeV) …**

SBN Sterile Neutrino Oscillation Searches



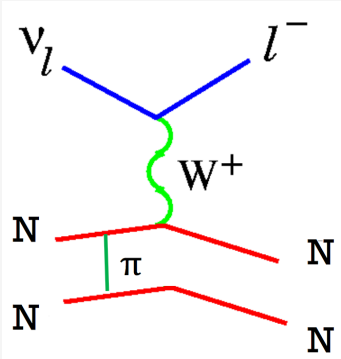
$\nu_\mu \to \nu_e$ appearance sensitivity



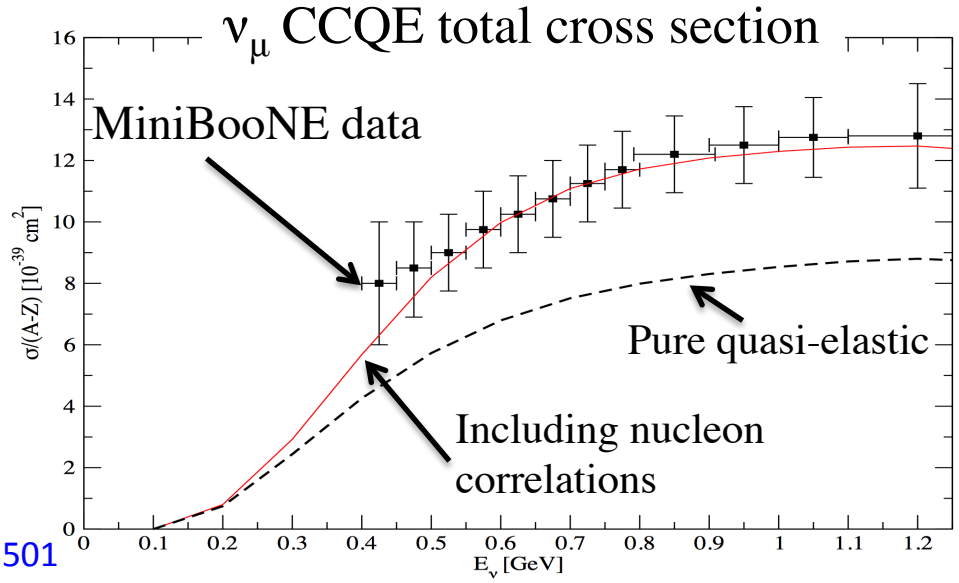
Definite test (> 5σ) of the currently allowed oscillation parameter regions

Neutrino Cross Section

- ✓ ν experiments use complex nuclei as neutrino target → nuclear effects
- ✓ Intra-nuclear re-scattering and effects of correlation between target nucleons: Significantly alter final state particle topology and kinematics.



High precision measurements of these processes are deemed necessary!
→ SBND is ideal for this purpose



Phys Rev C 80:065501

SBND & Neutrino Interactions

Due to its location near (110 m) the neutrino source and relatively large mass (112 ton active volume) SBND will have the world's highest statistics in ν_μ-Ar and ν_e-Ar interactions:

- ✓ Measurement of cross sections
- ✓ Nuclear effects and their impact on the predicted rates, final states, and kinematics in ν-Ar interactions
- ✓ Inform neutrino MC generators and can provide an important discriminator among models

SBND Neutrino Event Rates

$\nu_\mu CC$, 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
$0\ \pi + 1p$	1,629,252	2,235,338
$0\ \pi + 2p$	1,150,368	637,535
$0\ \pi + 3p$	413,956	229,239
$0\ \pi + >3p$	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

~ 3 years of exposure

✓ In enumerating proton multiplicity, we assume their kinetic energy ≥ 21 MeV

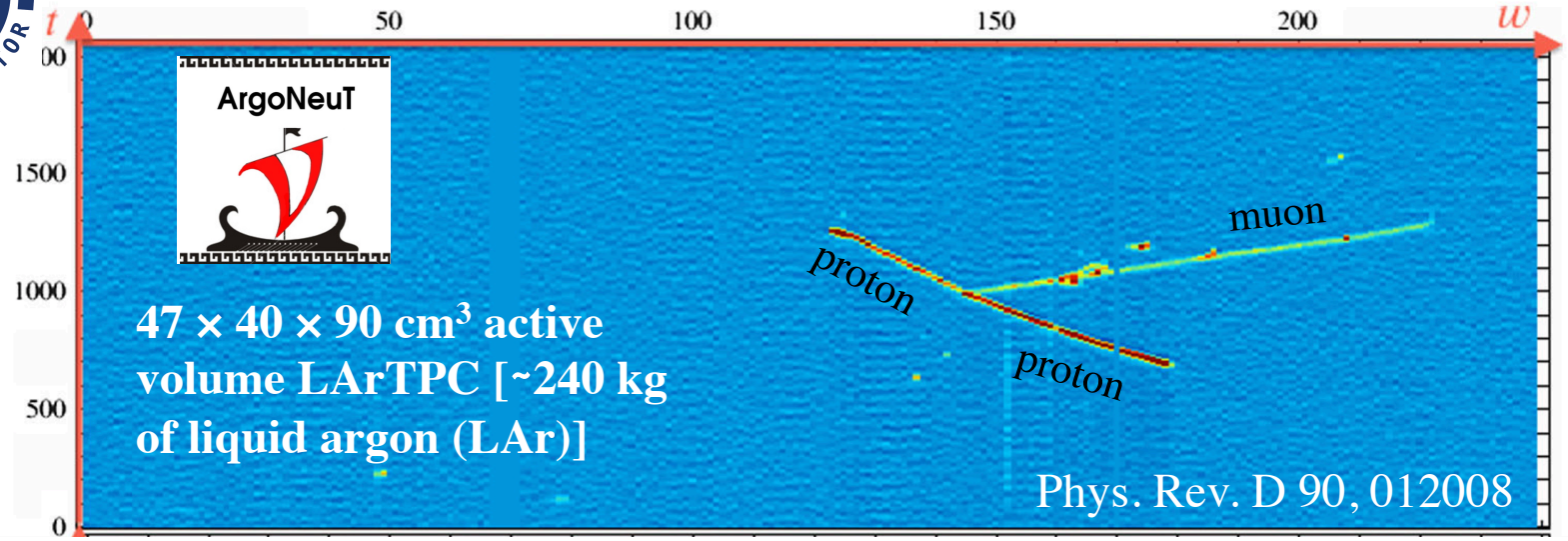
Proton kinetic energy (MeV)	Proton track length (cm)
20	≈ 0.4
50	≈ 2
100	≈ 8
200	≈ 26

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

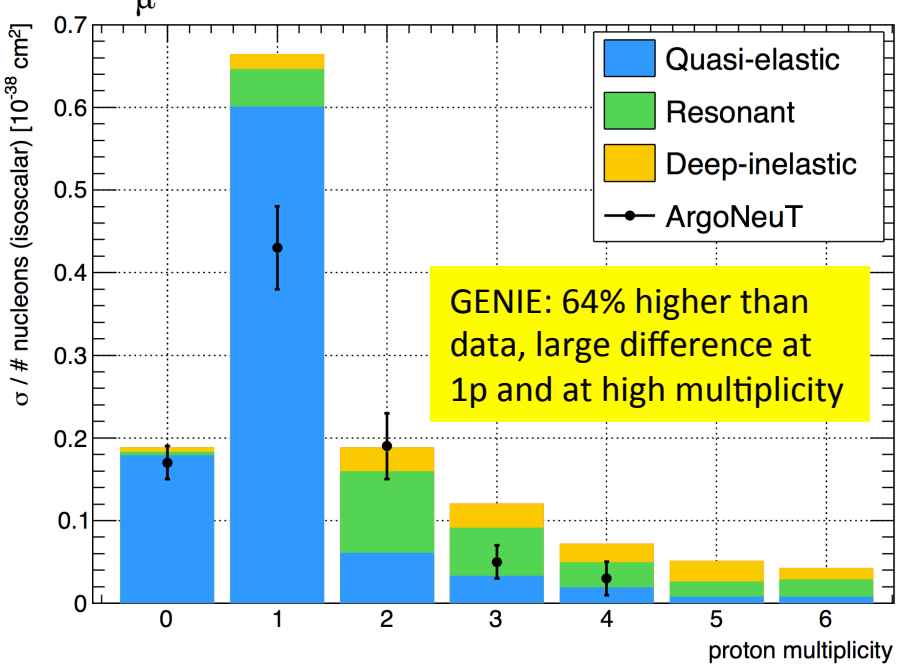
Courtesy of Costas Andreopoulos

G17_01b: Updated empirical model / **G17_02a**: Theory-driven model

Final State Interactions: 0π



ν_μ CC-0π cross section



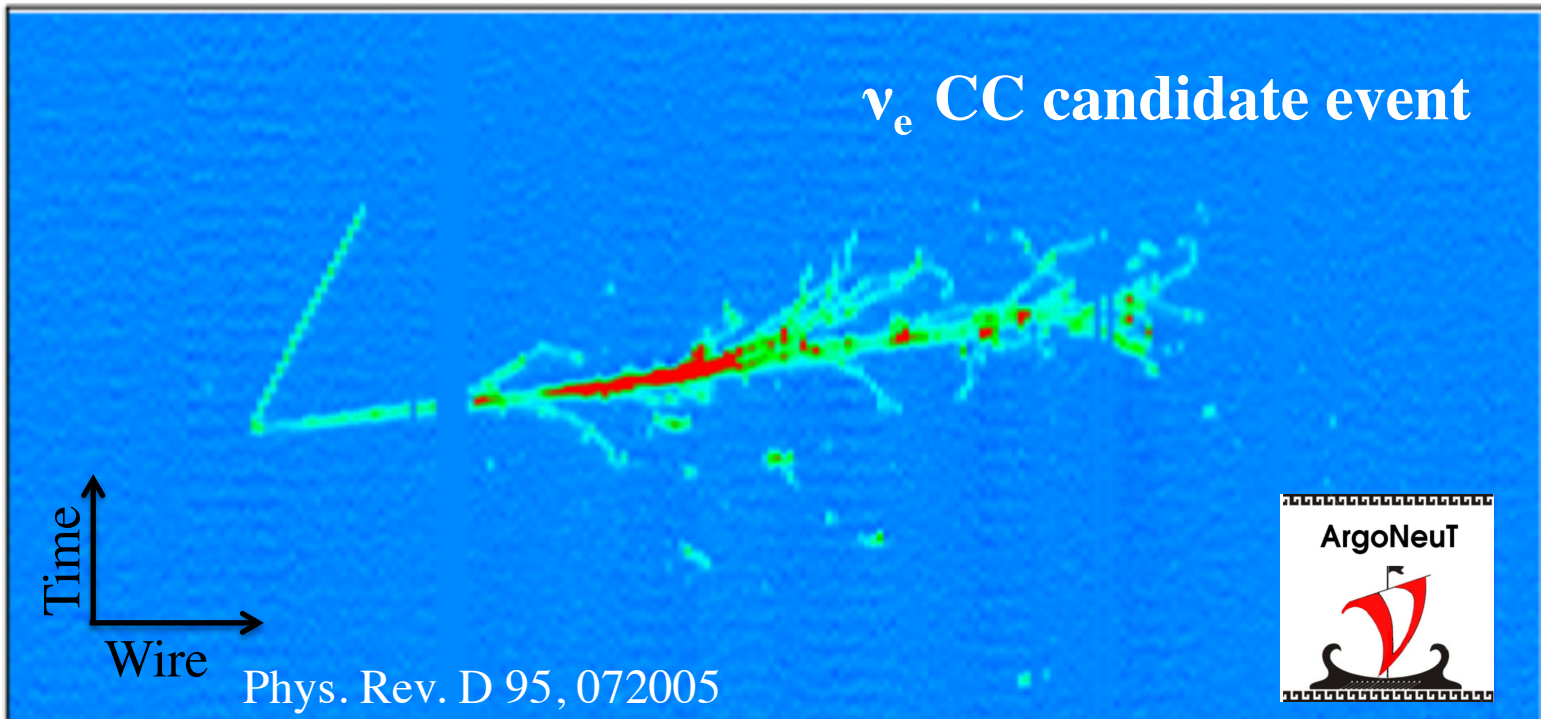
SBND Charge Current Zero Pion Expectations (GENIE estimate, rounded)

arXiv:1503.01520

	1 Month	*3 Years*
CC + Np	97 K	3.5 M
CC + 0p	22K	0.79 M
CC + 1p	56K	2M
CC + 2p	10K	0.36M
CC + ≥ 3p	10K	0.37M

SBND will have 30x higher rate than MicroBooNE → ArgoNeuT statistics in ~1 day of beam!!!

Electron Neutrinos



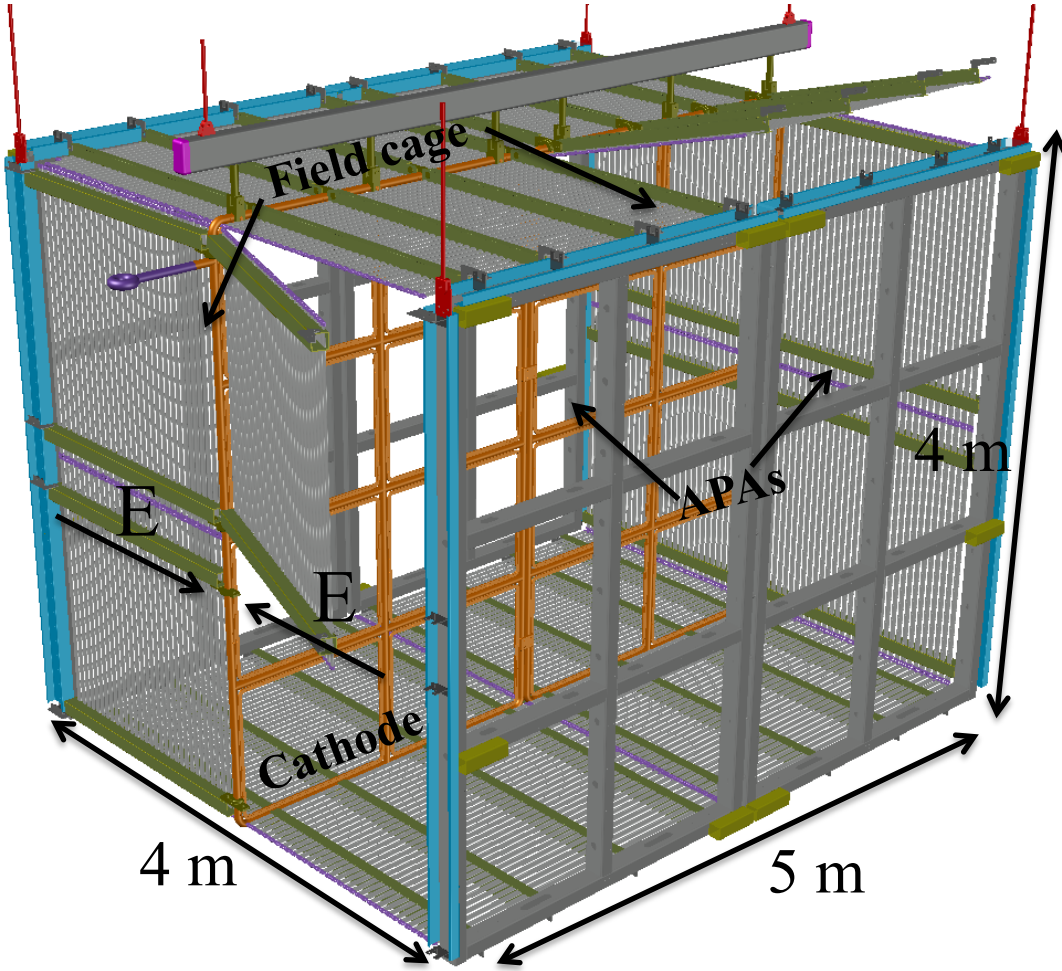
SBND Charge Current Electron Neutrino Expectations (GENIE estimate, rounded)

arXiv:1503.01520	*1 Month*	*3 Years*
CC ν_e	1 K	37 K

The high statistics electron neutrino sample will be hugely beneficial to both SBN and DUNE physics programs

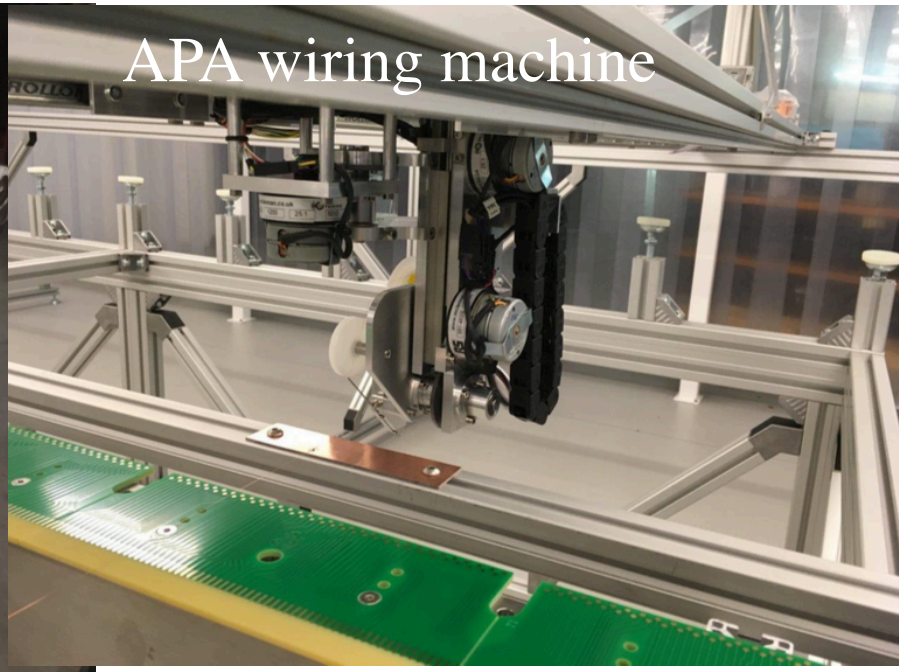
SBND TPC Layout

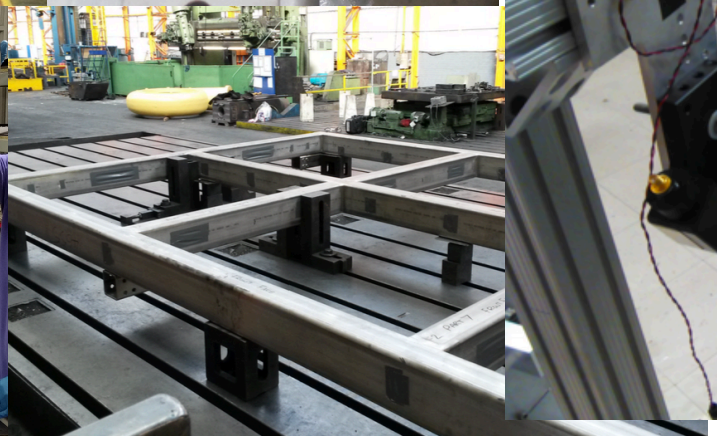
- ✓ Two drift volumes separated by a central cathode plane
- ✓ Each drift volume has a 2 m drift distance
- ✓ Facing the cathode plane in each drift volume are anode plane assemblies (APAs): 3 planes of sensing wires

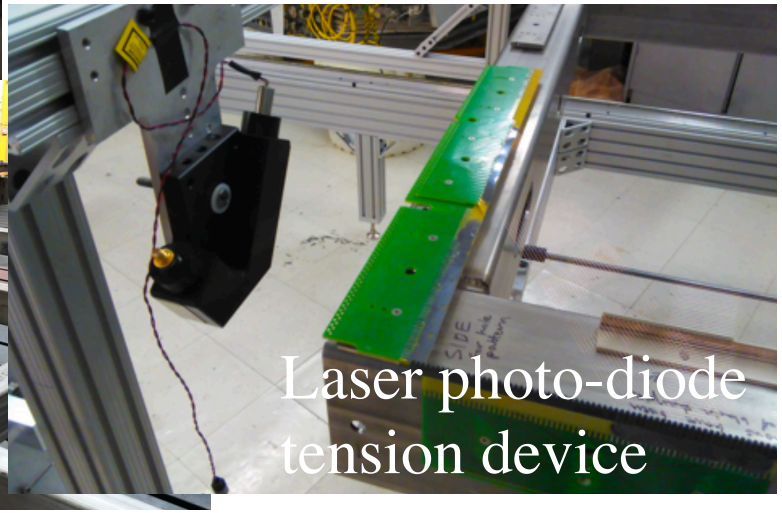


- ✓ Two sets of field cage modules surround the drift volumes to provide uniform drift field of 500V/cm

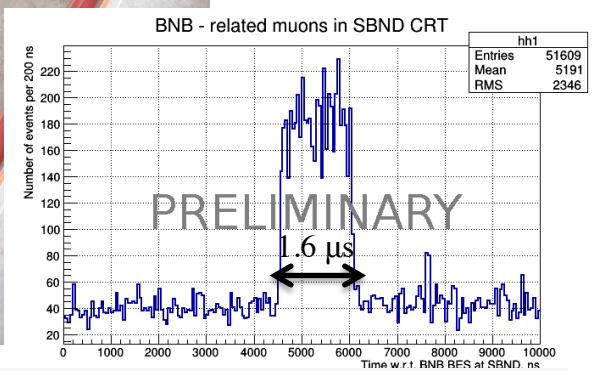
SBND is under construction







SBND construction has begun

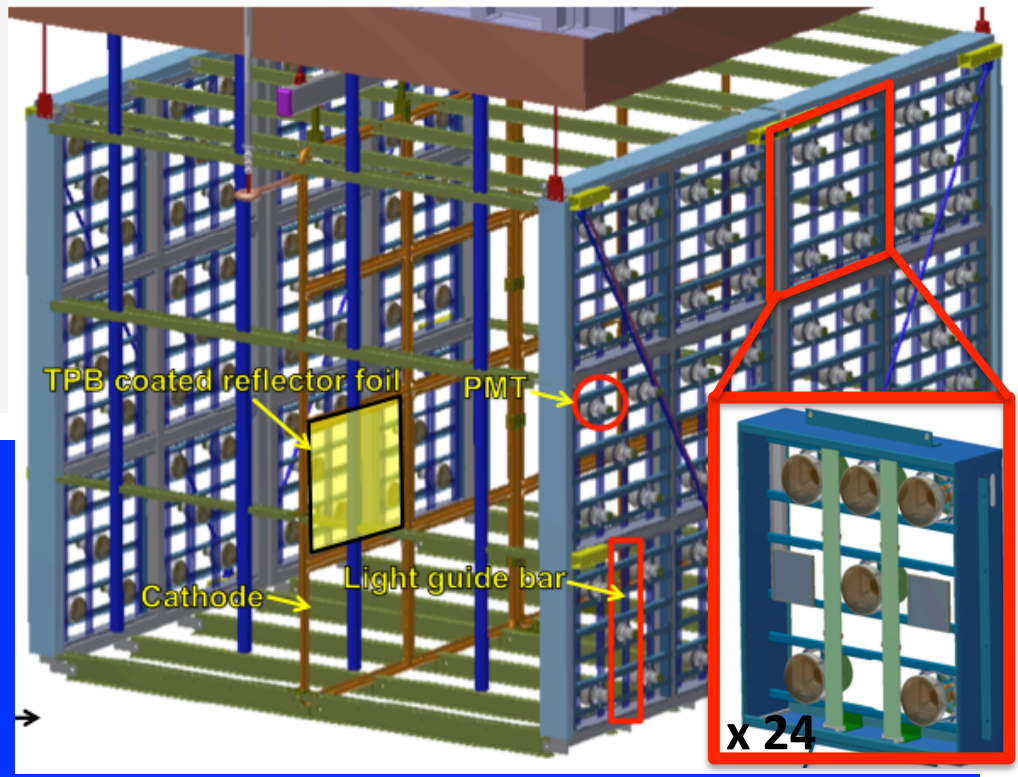


Timing distributions clearly show the increased activity during the 1.6 μs beam spill of the BNB

- TPC Design and Fabrication ready → 1Q 2018
- TPC Assembly → 4Q 2018
- Detector and Cryogenics Installation → 3Q 2019
- LAr Filling & Commissioning right after

SBND Light Detection System

- ✓ SBND is implementing a high LY Light Detection System scheme
- ✓ PMTs + Light Guide Bars as detectors
- ✓ Possibility of adding WLS covered reflector foils (generic R&D)



- ✓ Simulations show that it can help determine timing, calorimetry and position resolution →

Adding WLS-covered reflector foils improves the overall performance of the system

Summary

- The ND of the Short Baseline Neutrino program at Fermilab is being constructed successfully
- SBND will play a crucial role in SBN program providing huge data sets of ν-Ar interactions
- Further develop the LArTPC technology and help build expertise of the global neutrino physics community working toward DUNE

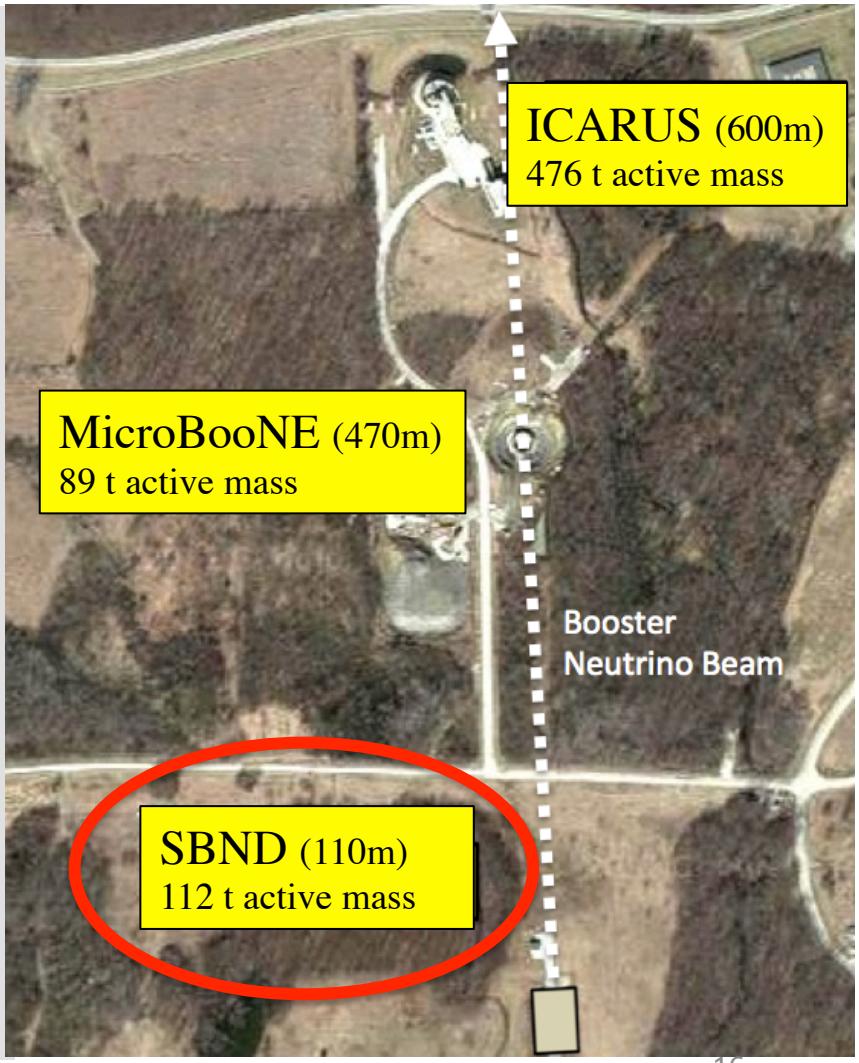
Back-Up

Short Baseline Neutrino Program at Fermilab

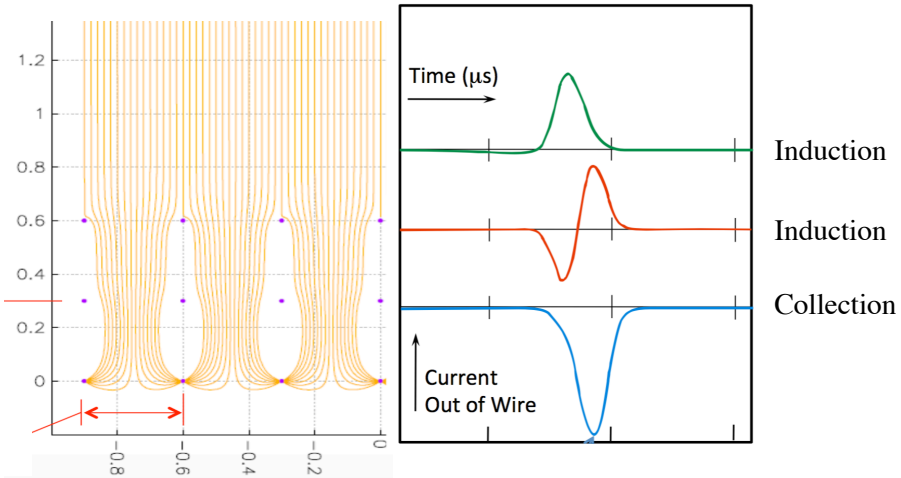
- ✓ An accelerator-based neutrino beam facility provides a rich oscillation program with a single experiment:
  - both neutrino and antineutrino modes
  - $\nu_\mu \rightarrow \nu_e$ appearance
  - ν_μ and ν_e disappearance
  - CC and NC interactions

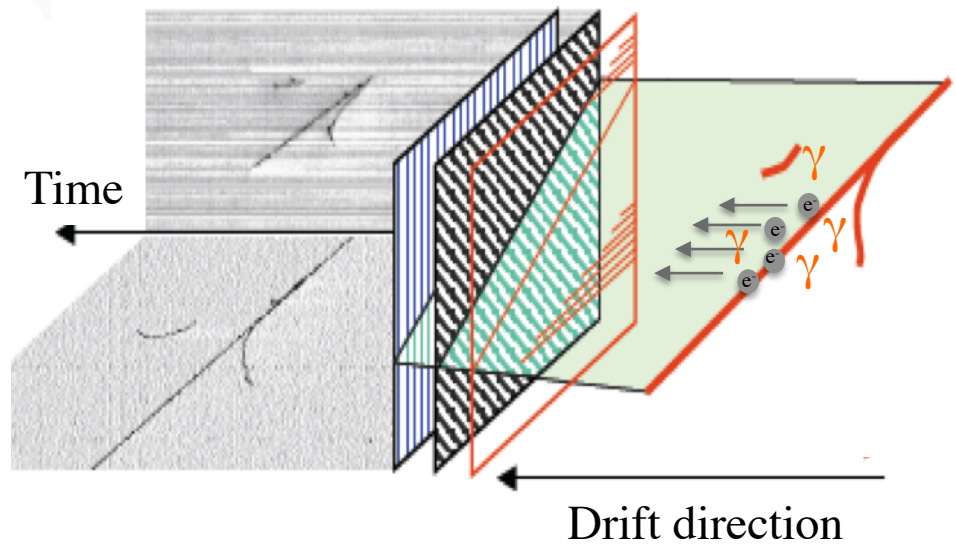
→ explore Sterile ν Oscillations

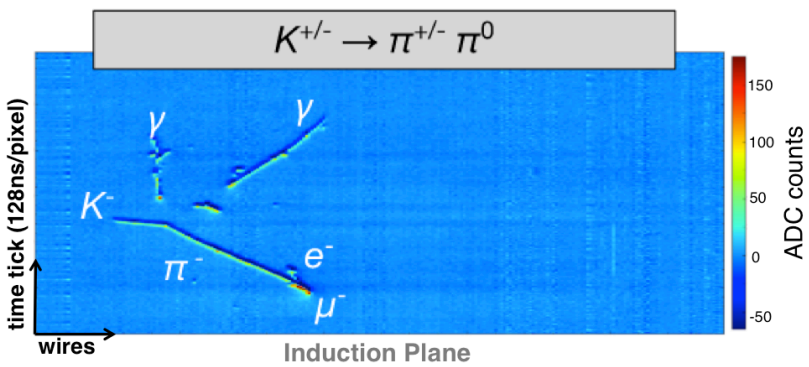
- ✓ Detectors that can **distinguish electrons from photons** to reduce key backgrounds
- ✓ **Multiple detectors at different baselines** are key for reducing systematic uncertainties

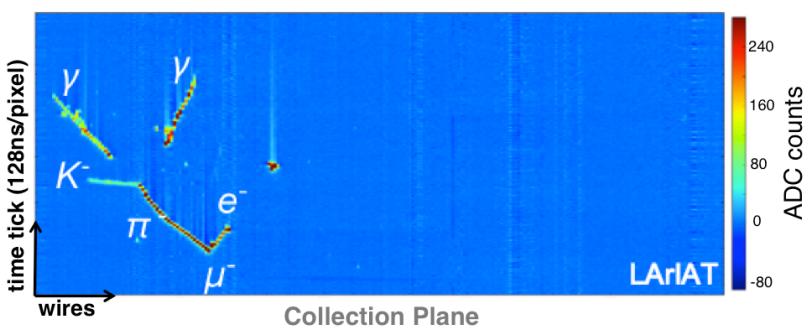


LArTPC Technology









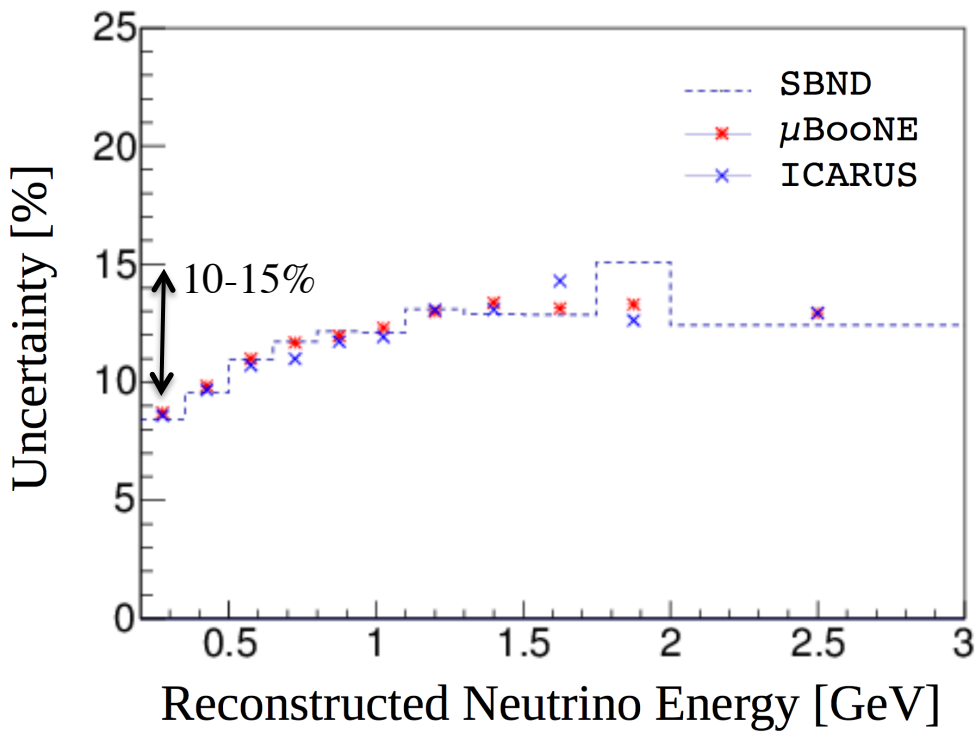
- ✓ Passing charged particles ionize argon
- ✓ Electric field drifts electrons meters to wire chamber planes
- ✓ Induction/Collection planes image charge, record dE/dx
- ✓ Scintillation light in LAr

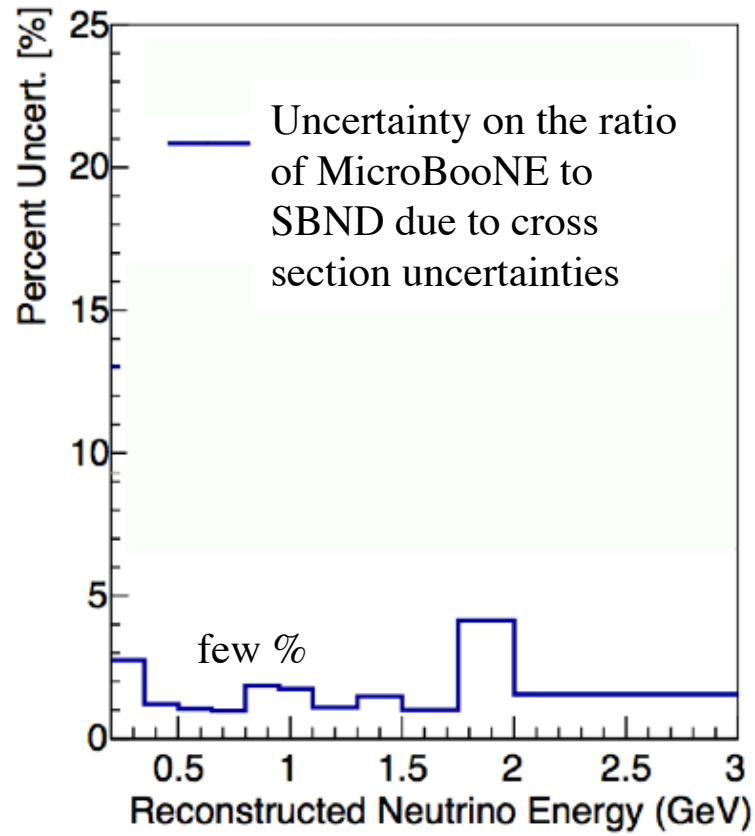
Multiple Detectors in SBN

$$N_{ND}^{data}(\nu_\mu) = \Phi_{ND}(\nu_\mu) \otimes \varepsilon_{ND}(\nu_\mu) \otimes \sigma_{ND}(\nu_\mu)$$

$$N_{FD}^{expected}(\nu_\mu) = N_{ND}^{data}(\nu_\mu) \otimes \frac{\Phi_{FD}(\nu_\mu)}{\Phi_{ND}(\nu_\mu)} \otimes P(\nu_\mu \rightarrow \nu_\mu) \otimes \frac{\varepsilon_{FD}(\nu_\mu)}{\varepsilon_{ND}(\nu_\mu)} \otimes \frac{\sigma_{FD}(\nu_\mu)}{\sigma_{ND}(\nu_\mu)}$$

ν_e Cross Section Fractional Uncertainties





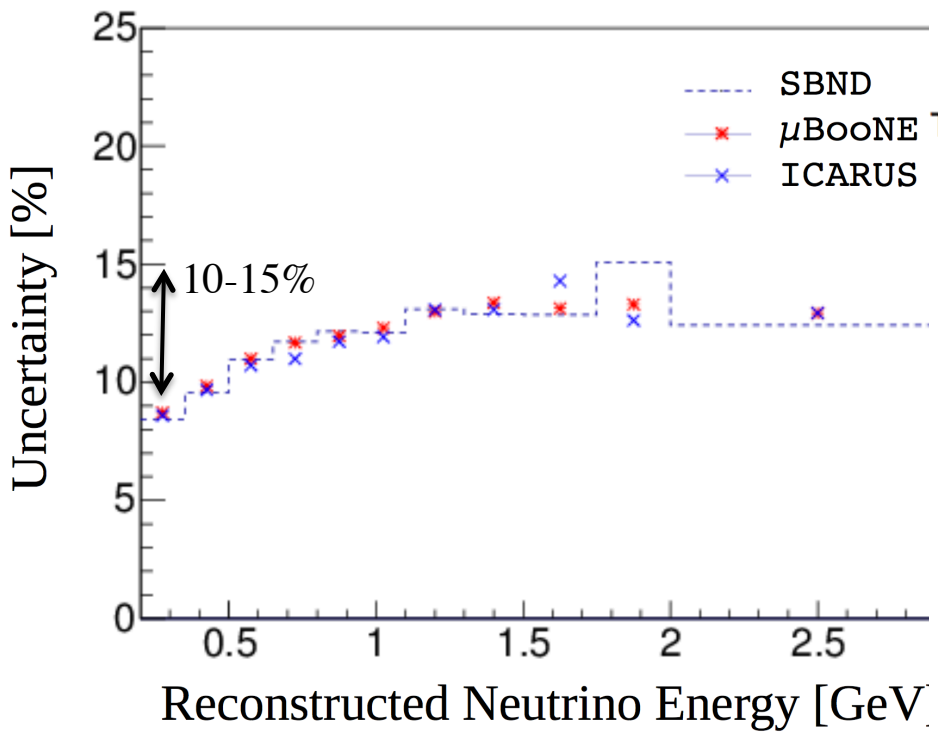
arXiv:1503.01520

Multiple Detectors in SBN

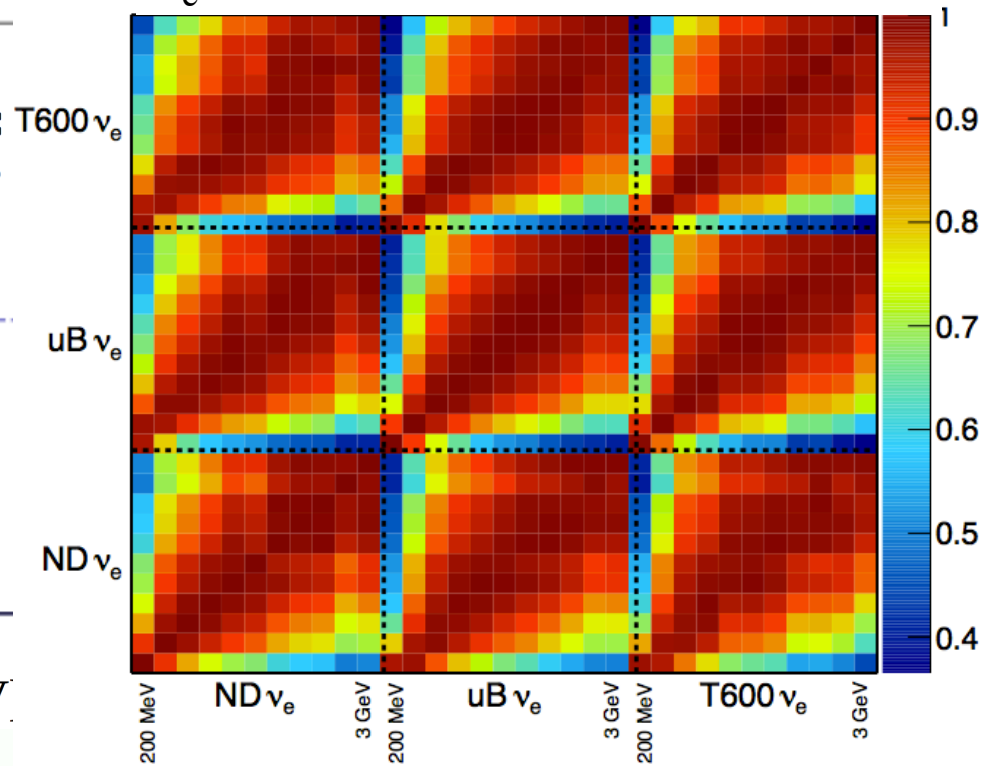
$$N_{ND}^{data}(\nu_\mu) = \Phi_{ND}(\nu_\mu) \otimes \varepsilon_{ND}(\nu_\mu) \otimes \sigma_{ND}(\nu_\mu)$$

$$N_{FD}^{expected}(\nu_\mu) = N_{ND}^{data}(\nu_\mu) \otimes \frac{\Phi_{FD}(\nu_\mu)}{\Phi_{ND}(\nu_\mu)} \otimes P(\nu_\mu \rightarrow \nu_\mu) \otimes \frac{\varepsilon_{FD}(\nu_\mu)}{\varepsilon_{ND}(\nu_\mu)} \otimes \frac{\sigma_{FD}(\nu_\mu)}{\sigma_{ND}(\nu_\mu)}$$

ν_e Cross Section Fractional Uncertainties

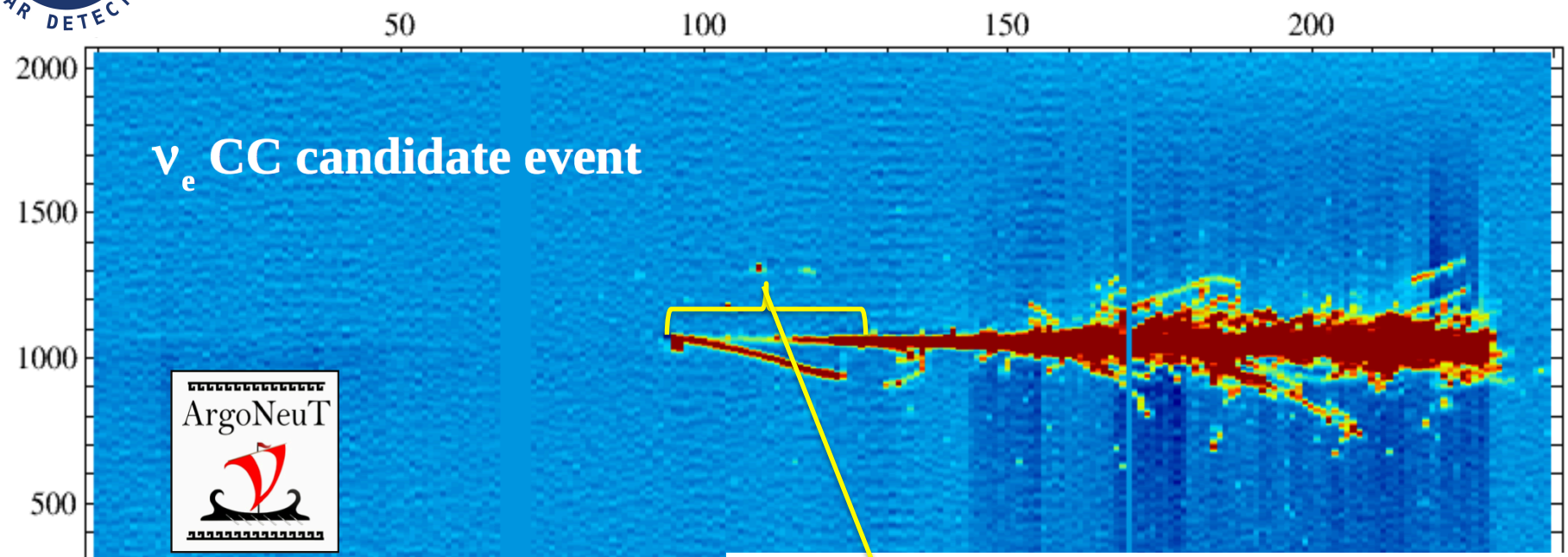


ν_e cross section correlation matrix



arXiv:1503.01520

Electron Neutrinos

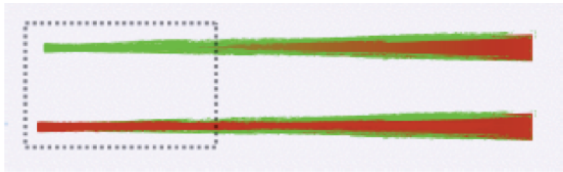


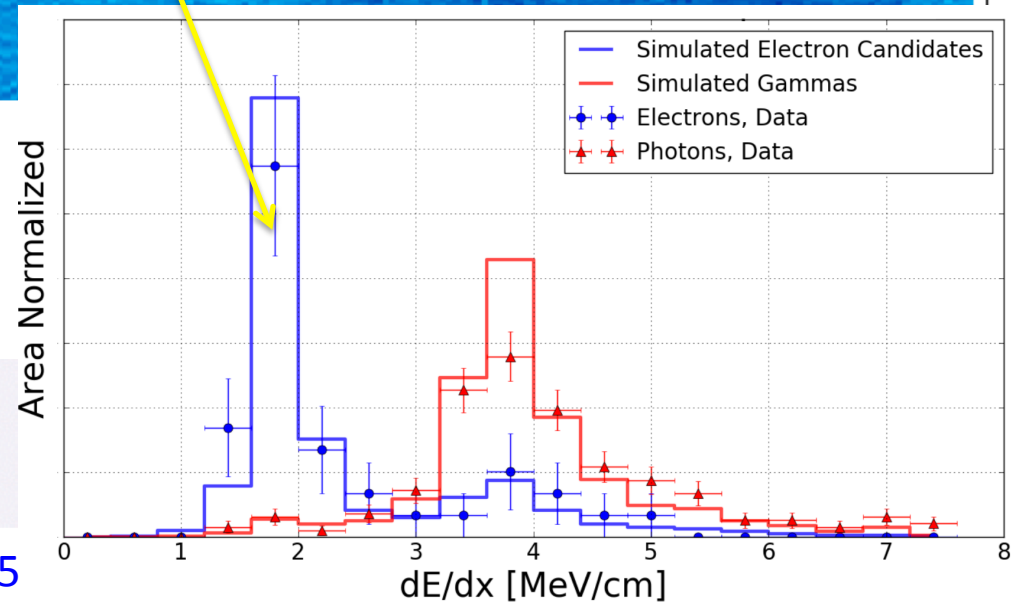
LAr TPC offers incredible fine tracking along with electron/photon separation

4 cm x 1 cm

Electron

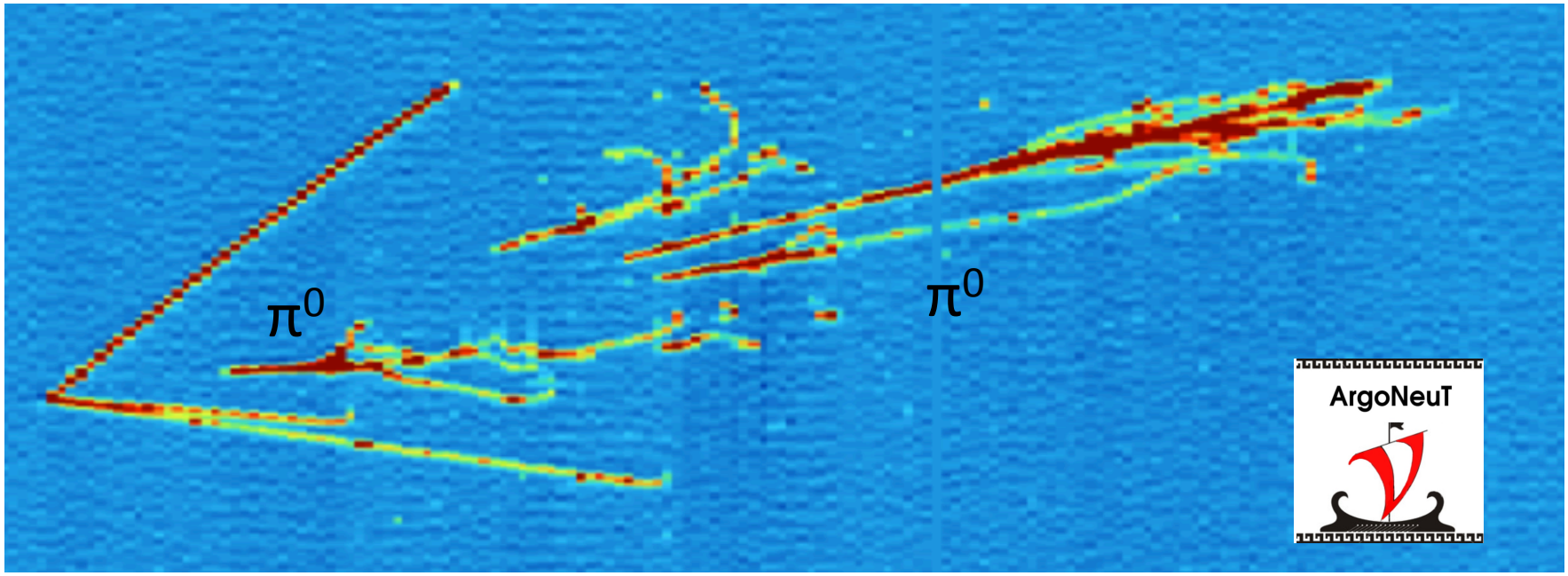
$\gamma \rightarrow e^+ + e^-$





Phys. Rev. D 95, 072005

Neutral Current Backgrounds



arXiv:1511.00941v2

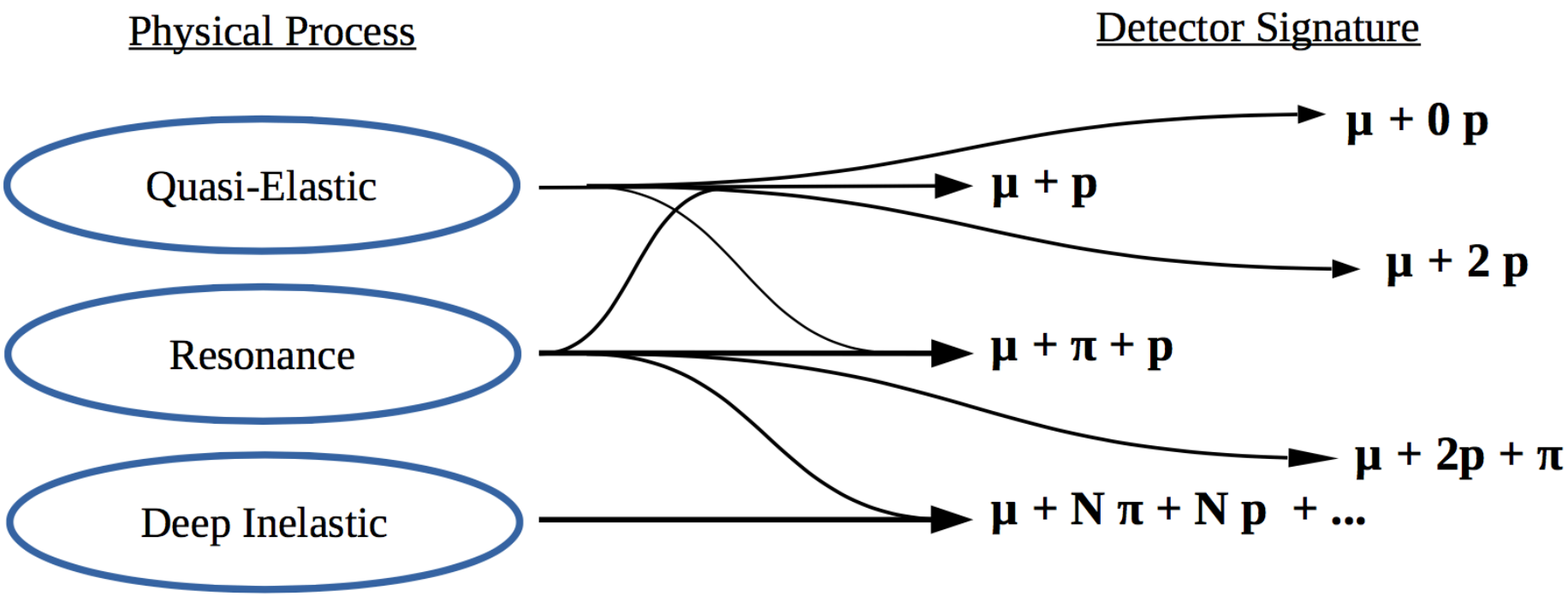
Particular importance to neutrino oscillation experiments → can be experimentally misidentified as ν_e CC production

SBND Charged Current Neutral Pion Expectations (GENIE estimate, rounded)

	1 Month	1 Year	3 Years
CC + 1 pi0	14,000	166,000	498,000
NC + 1 pi0	10,000	120,000	358,000

arXiv:1503.01520

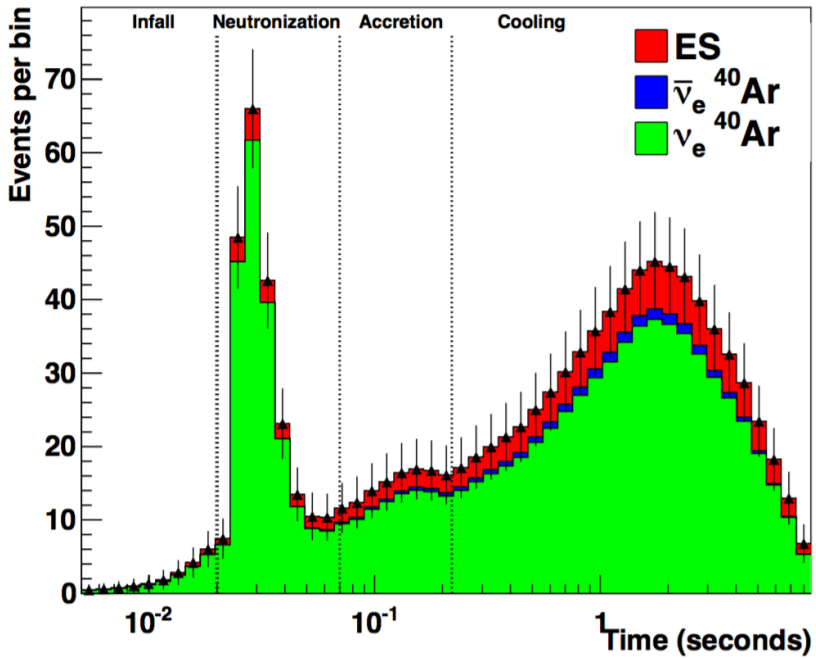
Final State Interactions



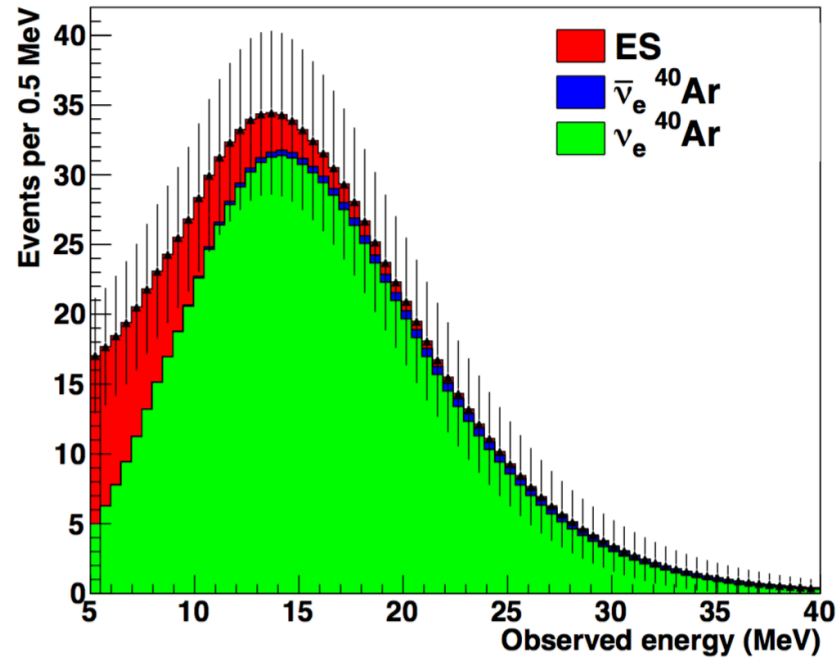
Courtesy of Corey Adams

Supernova neutrinos

Flavor composition as function of time



Energy spectra integrated over time



Expected signal in 40 kt of liquid argon for the electron-capture supernova at 10 kpc, calculated using SNoWGLoBES

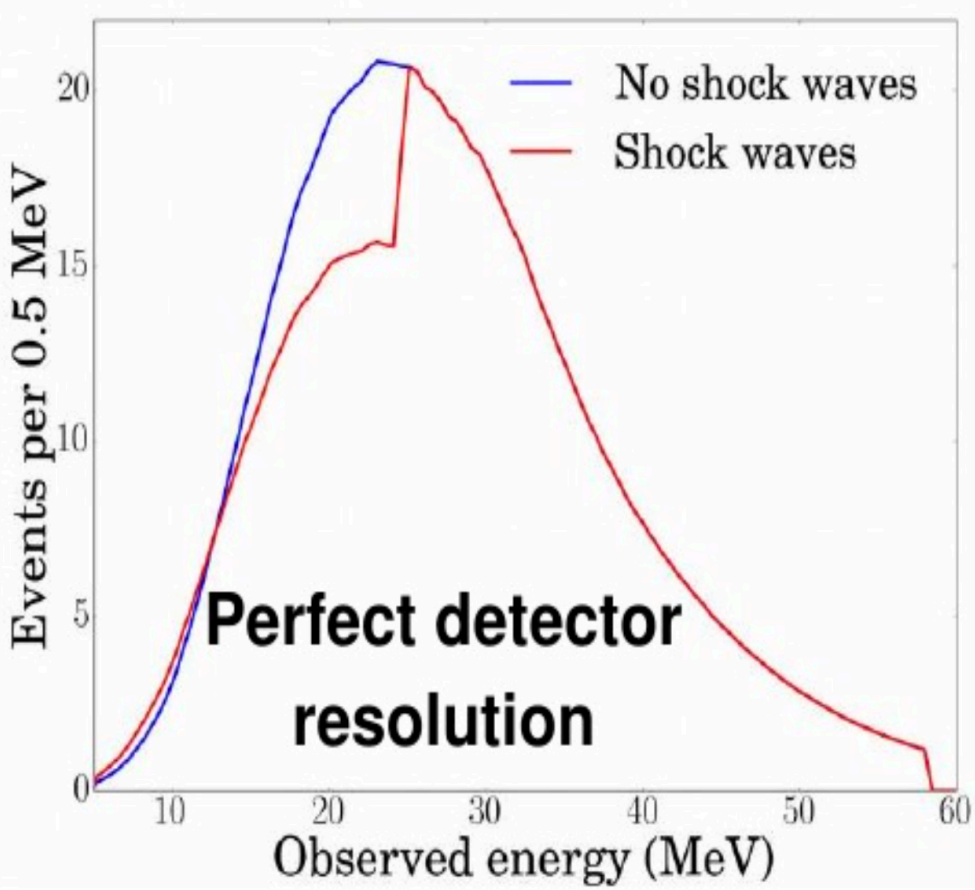
Most challenging/opportunities for scintillation light.

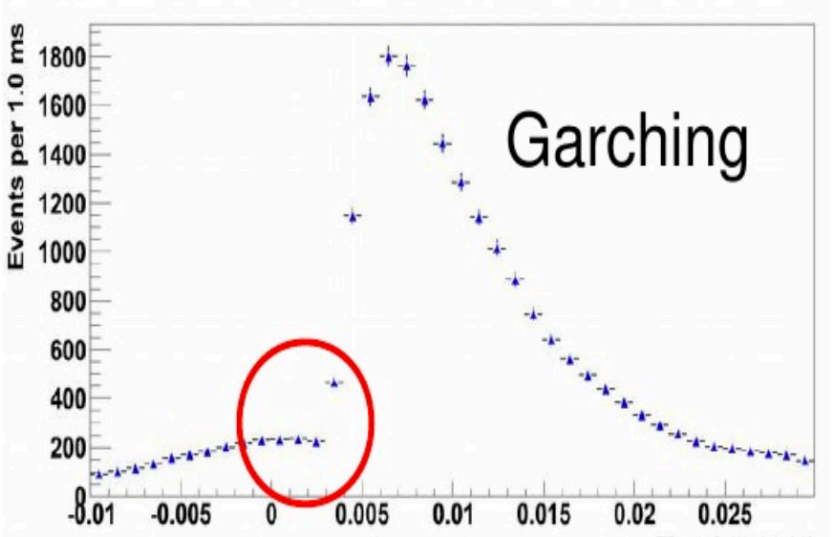
Energy resolution differentiates between models.

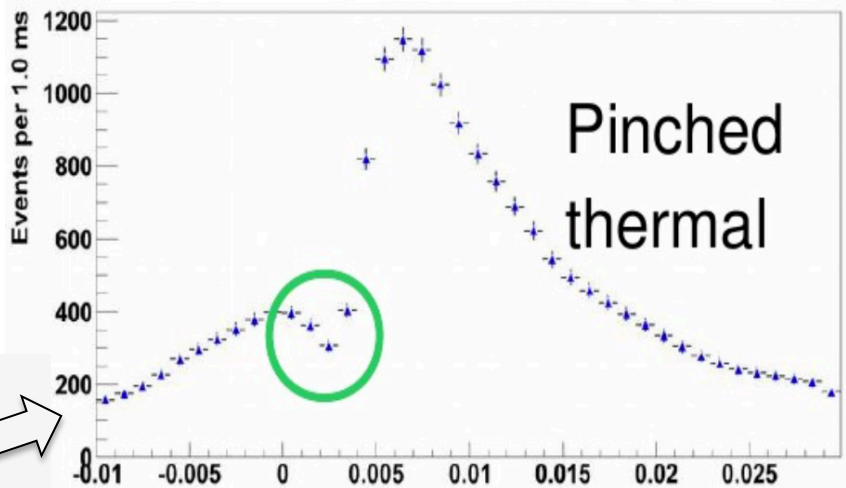
Timing differentiates between models.

Depending on how close the SN is, we may be swamped with events?

Supernova neutrinos





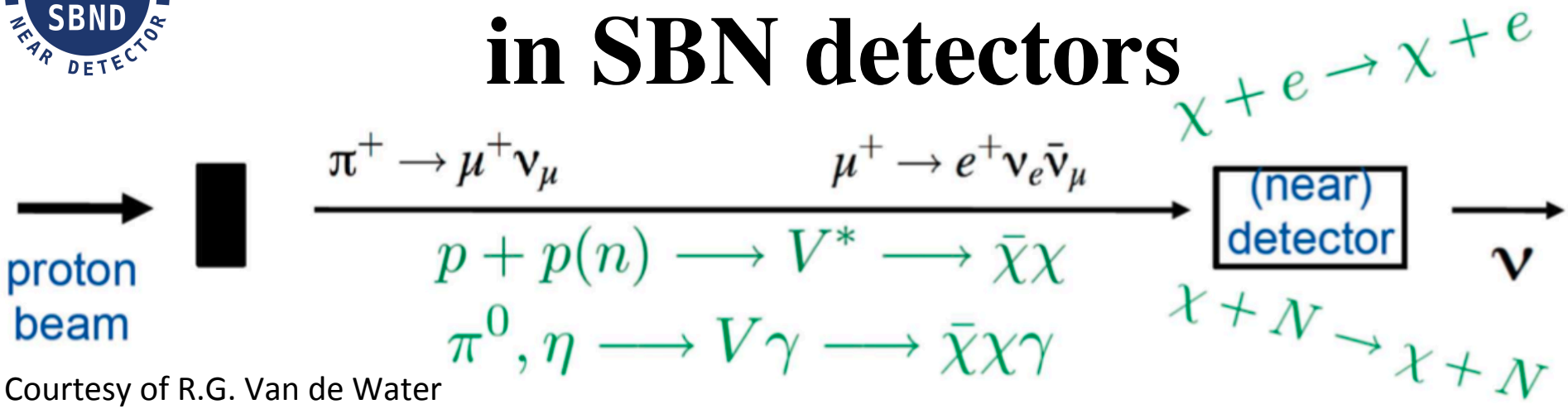


G. Sinev

Time (seconds)

- These feature happen on timescales of order of ms
- Most light systems under consideration should cope with this

Sub GeV dark matter searches in SBN detectors



Courtesy of R.G. Van de Water

Why are neutrino experiments (e.g. SBN detectors) useful for new particle searches?

- Require lots of protons on target: SBN has a total of ~2×10^{21} @ E_{proton}= 8GeV
- Detector needs to be close to source (for rate), but far enough away to minimize beam related backgrounds
- Big detector
- Good particle identification
- Good event reconstruction
- Good cosmogenic background rejection, especially below 200 MeV.

Comprehensive Model Configurations

CMC: "Status Quo"

Nuclear model	RFG (Bodek-Ritchie)
QE	Llewellyn Smith (CC) Ahrens (NC)
RES/COH π	Rein-Sehgal
DIS	Bodek-Yang
FSI	hA

CMC: "Status Quo ++"

"Status Quo", Plus:

MEC	Empirical MEC (Dytman)

CMC: "Best Empirical"

"Status Quo ++", With:

Diffractive π	Rein
QE hyperon	Pais
FSI	Updated hA

CMC: "Best theory* I"

Nuclear model	LFG (València)
QE	València (CC) Ahrens (NC)
QE hyperon	Pais
MEC	València (CC only)
RES/COH π	Berger-Sehgal
Diffractive π	Rein
DIS	Bodek-Yang
FSI	Updated hA

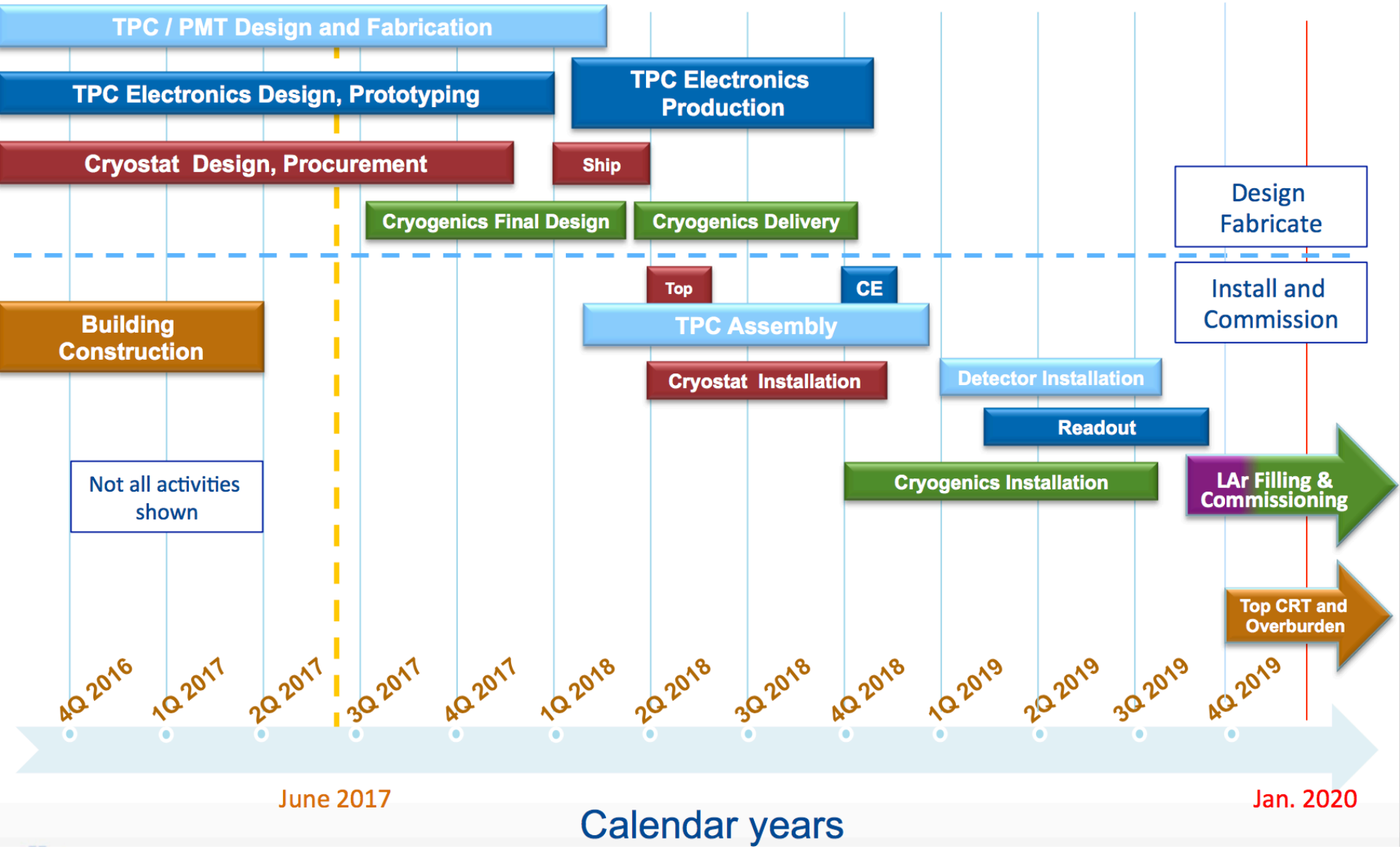
CMC: "Best Theory* II"

"Best Theory I", But:

FSI	hN

* where "best theory" means "best theory currently available in GENIE" :)

Technically Driven Schedule



Capabilities of a High LY LDS

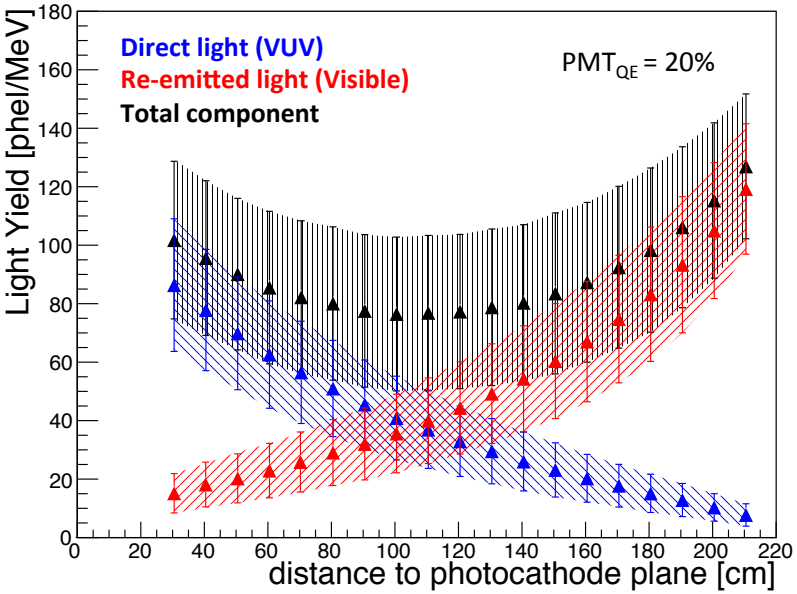
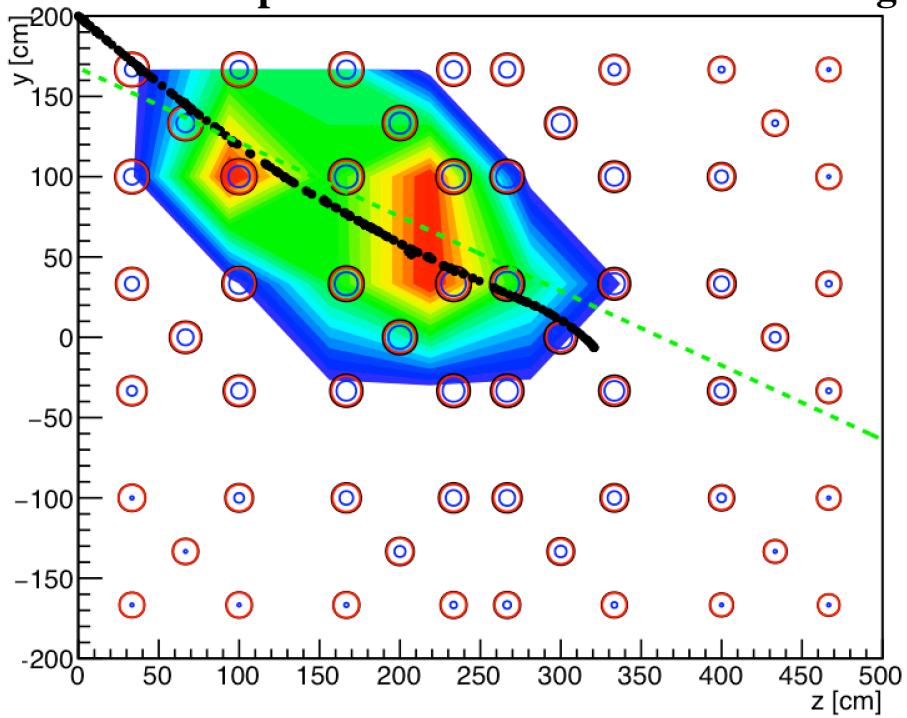
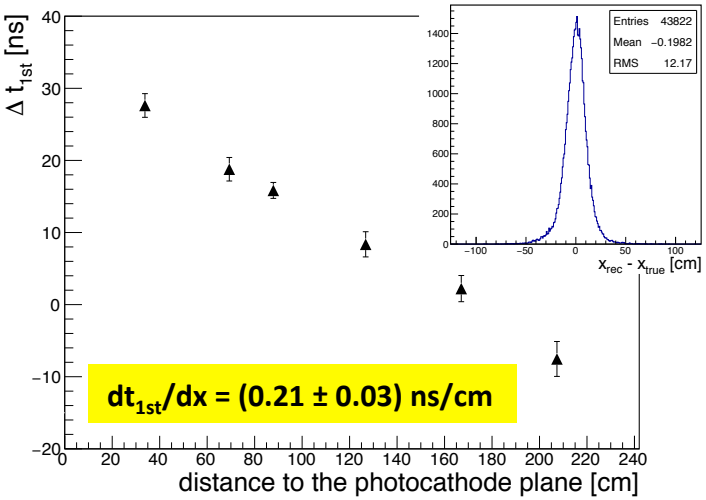


Photo-cathode plane location of the events with light



Drift coordinate location of the events with light



- ✓ Uniform and enhanced light collection efficiency help triggering and studying low energy events
- ✓ High density array of PMTs allows for the location of the events in the photocathode plane
- ✓ Separating the direct from reflected light can lead to position resolution in drift direction