SBND Photon Detection System (PDS) Plan

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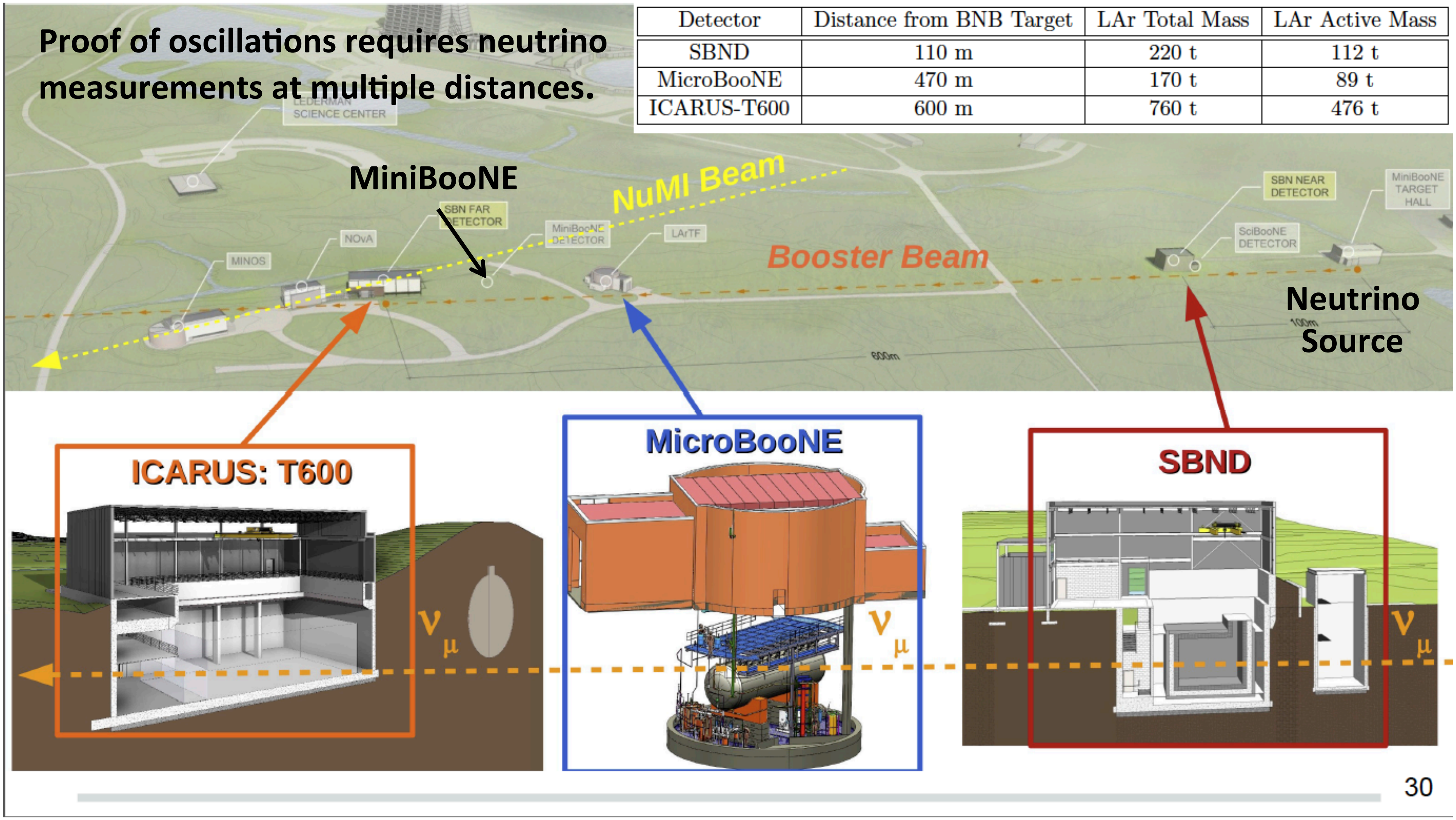
For the SBND Collaboration

Short Baseline Neutrino (SBN) Program which will begin operations in 2018

Detector	Distance from BNB Target	LAr Total Mass	LAr Active Mass
SBND	110 m	220 t	112 t
MicroBooNE	470 m	170 t	89 t
ICARUS-T600	600 m	760 t	476 t



SBND Photon Detection System Goals

- SBND needs to achieve its main oscillation physics goals, and if possible, pursue other physics searches.
- SBND is a "test experiment" with an important part of the mission being R&D for future LAr neutrino experiments.
- Large LAr detectors operating on the surface have unique challenges.
  - copious external backgrounds from cosmic ray muons, showers, and neutrons need to be identified and rejected

Possible Enhanced SBND Physics Leveraging Scintillation Light

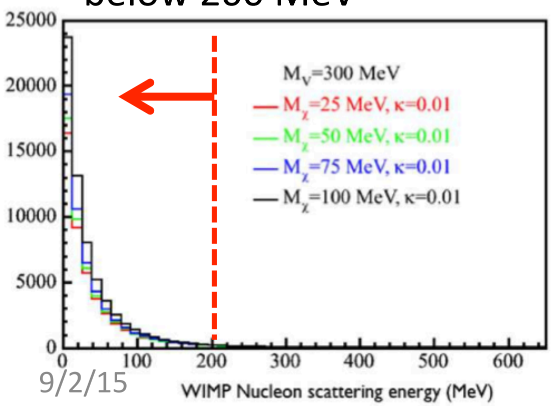
- Good timing/position resolution will improve external background rejection
  - decrease oscillation and cross section physics systematics, especially at low energy 100-200 MeV, which significantly improves sensitivity.
- Good timing/position resolution will allow analysis of low energy physics that are dominated by dirt/cosmic backgrounds below 200 MeV:
  - Low mass dark matter search
  - ν_μ magnetic moment
  - Neutral Current Elastic cross sections and low energy neutrons.
- Improved light collection efficiency and uniformity will allow low energy neutron, gamma, and Michel reconstruction
  - enable the study of low energy nuclear effects, supernova signals, and the wrong-sign component of an antineutrino beam.

SBND Stretch Physics goals: sub-GeV dark matter, muon neutrino magnetic moment, neutral current neutrino cross sections, etc

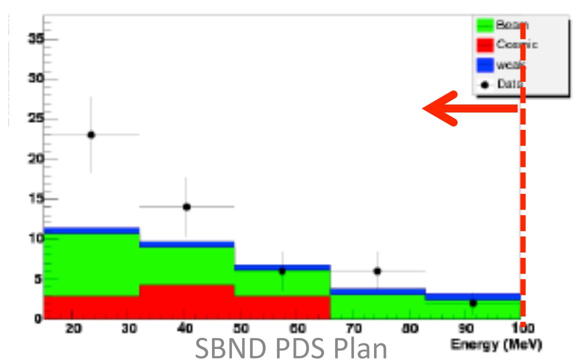
- The photon detection systems significantly reduces cosmogenic and external neutrino backgrounds which dominate below an energy threshold of 200 MeV.
- This opens up new physics searches, especially for the SBND detector which is four times smaller than MiniBooNE, but twice the reconstruction efficiency and five times closer to target (x25 flux increase).

Overall about ~order magnitude better sensitivity for…

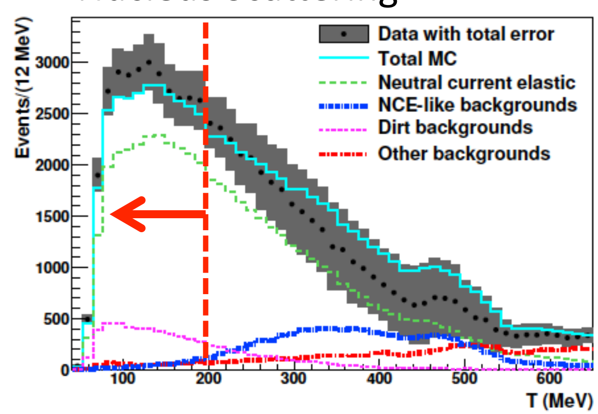
Sub-GeV Dark Matter: scatter signal energies below 200 MeV



Muon ν Magnetic Moment: MiniBooNE Limit < 12.7 $\times 10^{-10}\ \mu_B$ LSND Limit < 6.8 $\times 10^{-10}\ \mu_B$



Cross Sections: MiniBooNE Neutral Current Nucleus Scattering



PDS Performance Parameters Requirements

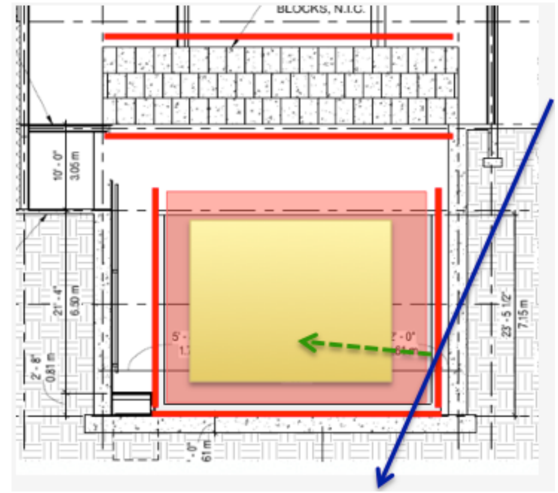
- **<u>Time resolution performance requirement</u> for the light collection system depends on the physics you want to use it for:**

Which of these levels do the global science requirements point us to?

tag events as being "in-spill" (energy threshold?)	few-100ns resolution
tag Michel electron decays through timing	order 100ns resolution (also requirement on light yield)
tag muons as 'entering' or 'exiting' (by measuring sign(t_{TPC} - t_{CRT}))	~5ns resolution (also requirement on CRT timing)
tag kaon production through timing? (t_{K+} = 12ns, t_{K0} = 51ns)	~3-5ns resolution? (impossible given scint. light structure?)
tag events as being "in-bucket" (low energy physics searches)	1-2ns resolution for further x5 backgrond reduction
Dark Matter searches (additional science objective)	1-2 ns DM time of flight

- Other requirements being considered: position resolution, charge/energy resolution, trigger thresholds, etc

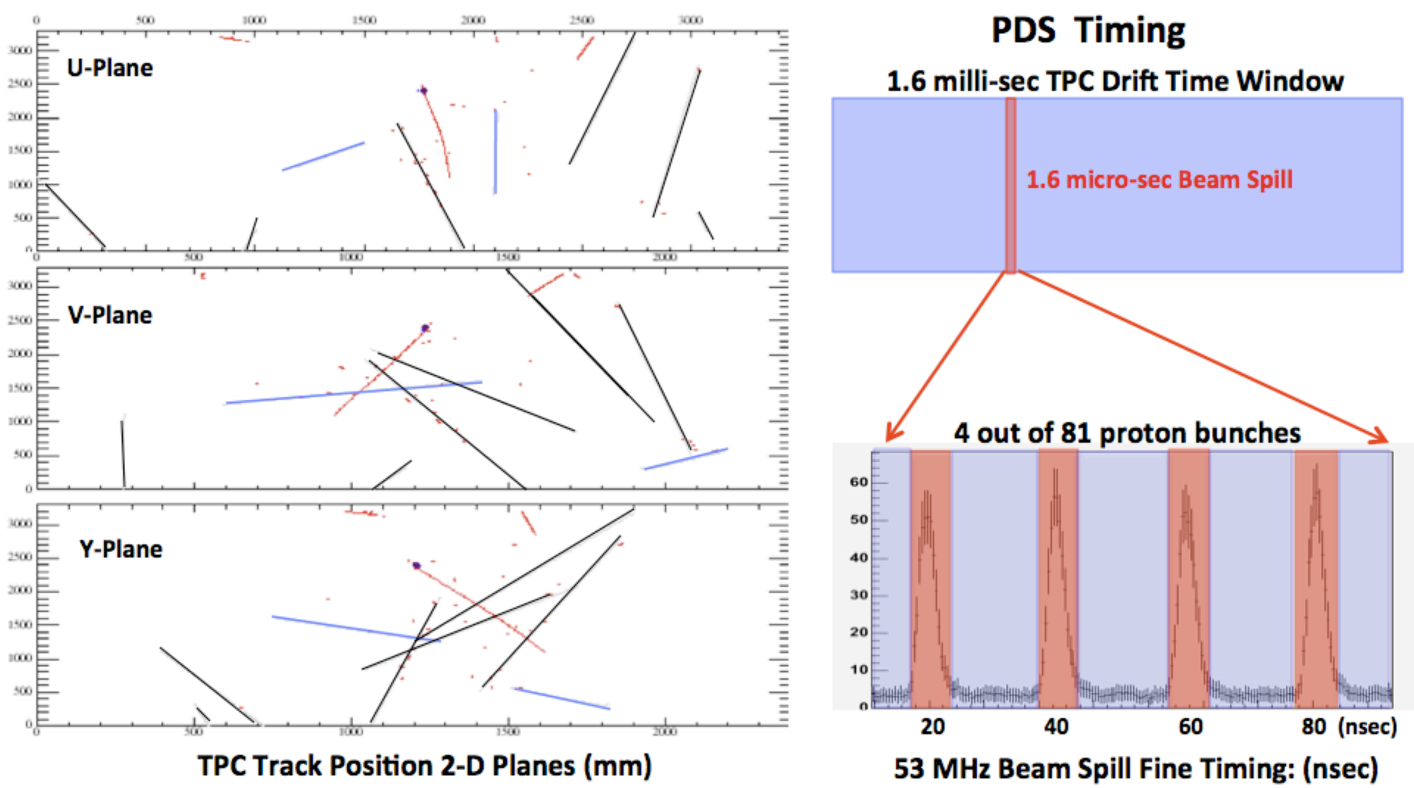
SBND External Background Strategy



- 3m overburden will shield against EM showers and neutrons.
- Constructing a cosmic ray tracker (CRT) with ~98% coverage and ~nsec timing.
  – Excellent job identifying incoming charged particles.
- A PDS system with ~nsec timing will provide further external background rejection
  – Especially for problematic neutrals from rock/dirt neutrinos which requires RF bucket timing resolution.

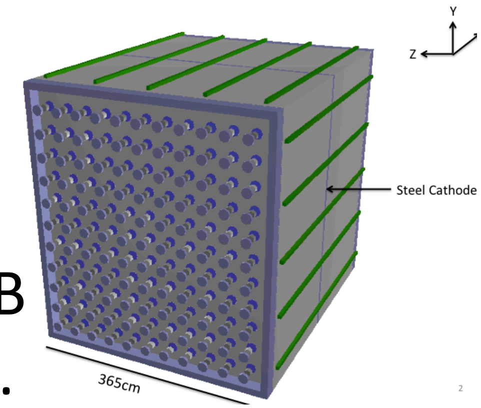
LAr generates significant amounts of scintillation light that can be detected and used to reconstruct time and match with TPC tracks

With good PDS/TCP track matching, and ~nanosecond timing resolution, reject of out of time backgrounds (black, blue) from neutrinos that are in-time with the beam (red) at the $2x10^{-4}$ level.



- Coupled with CRT, expected significant oscillation sensitivity improvement >100 MeV.
- Neutron backgrounds at low energy can be addressed by PDS.

Outline of the SBND Photon Detection System: PMT's



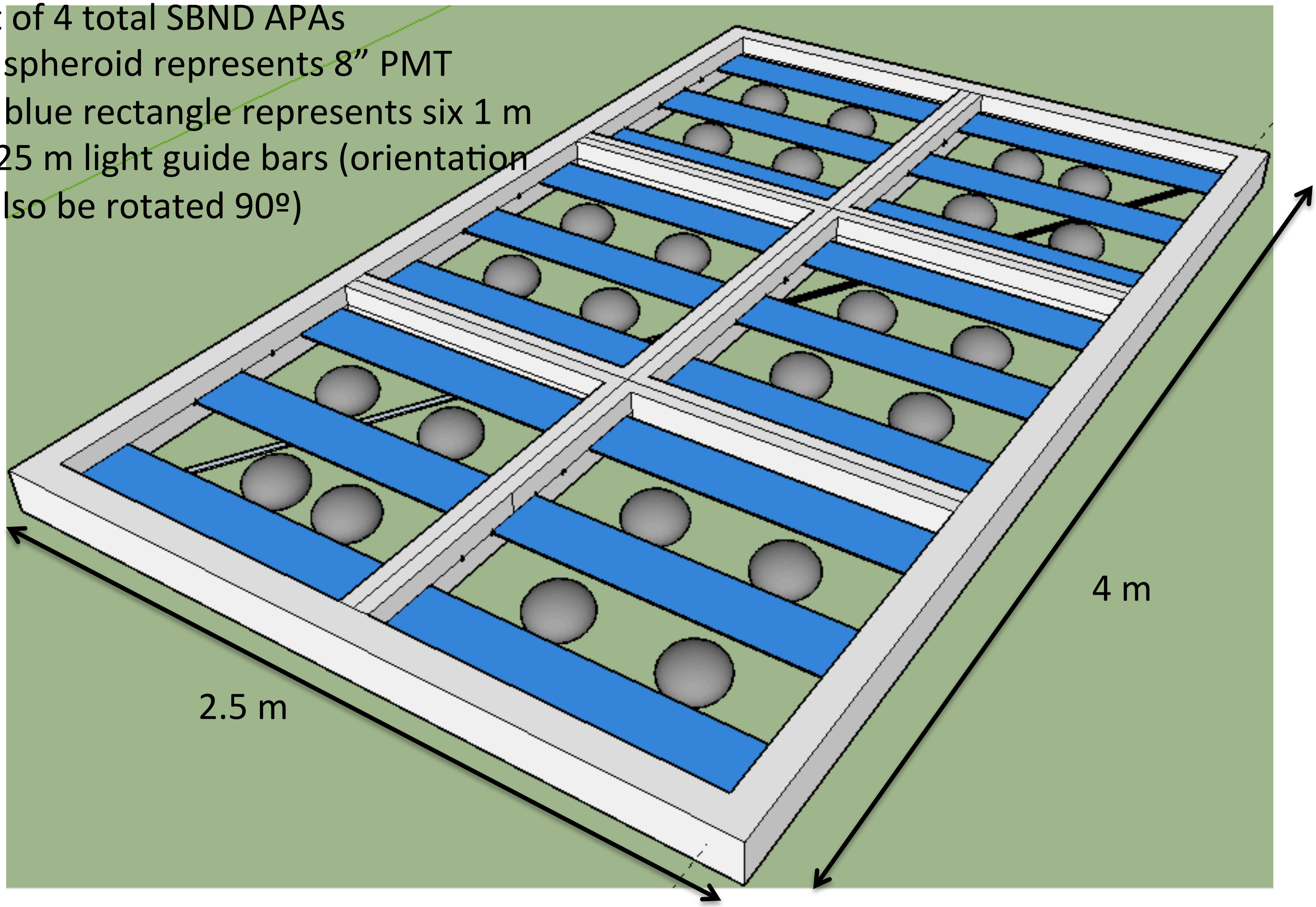
- We have a "**primary PDS**" based on 60-100 TPB coated PMTs mounted behind the wire planes.
- **PMTs are a proven technology** for scintillation light detection in LAr giving us a high level of confidence for reaching our physics goals
- The **minimum density** of tubes should be driven by the science requirements of the experiment
- The **maximum density** of tubes is likely to be limited by the funds available
  – Example: 96 8" PMTs will achieve up to 30 photo-electrons/MeV at 2m from PMT plane. Studies ongoing to determine track matching efficiency and timing reconstruction.
- **Primary system design uses R5912 8" PMTs** (though other models are still being considered) which allows the sharing with ICARUS of identical electronics, DAQ and PMT reconstruction software/analysis.

Outline of the SBND Photon Detection System: Light guide bars

- Given our role as an R&D experiment, we will implement a "**complementary PDS**" using light guides and SiPM readout.
- Provides an opportunity to operate a full-scale light guide-based system as foreseen in the first single phase DUNE module in a running neutrino experiment for the first time (and only time before DUNE)
- **This is substantial on its own.** This is important for showing how neutrino events can be reconstructed with such a system, rather than just that light guides see light.
  - For example, 432 dip-coated light guide bars and 2592 SiPMs total see an amount of light comparable to 96 8" R5912 PMTs
  - Light guide bars are double-sided providing veto coverage
- Operation side-by-side with a well-understood PMT system allows **valuable cross-calibration.**

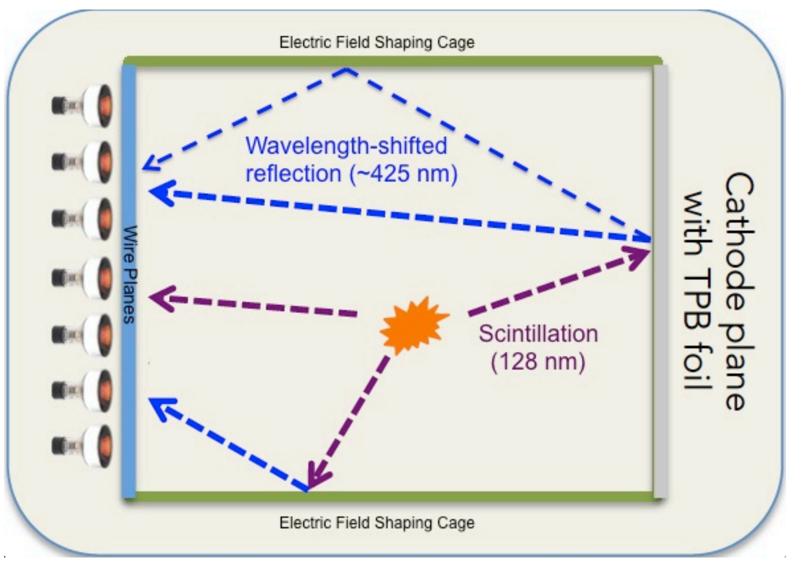
SBND Photon Collection System

- 1 out of 4 total SBND APAs
- Gray spheroid represents 8" PMT
- Each blue rectangle represents six 1 m x 0.025 m light guide bars (orientation can also be rotated 90º)



Outline of the SBND Photon Detection System: TPB coated wavelength shifting reflecting foils

- Given our role as an R&D experiment, we will continue to study the **potential performance enhancements** with the installation of reflective foils on some part of the cathode and/or field cage in SBND.
- **Foils increase the photon/MeV collected**, but also uniformity of light collection efficiency across the detector volume is a potential advantage.
- Simulations are important to show what signals will look like with and without foils installed before deciding how to proceed.

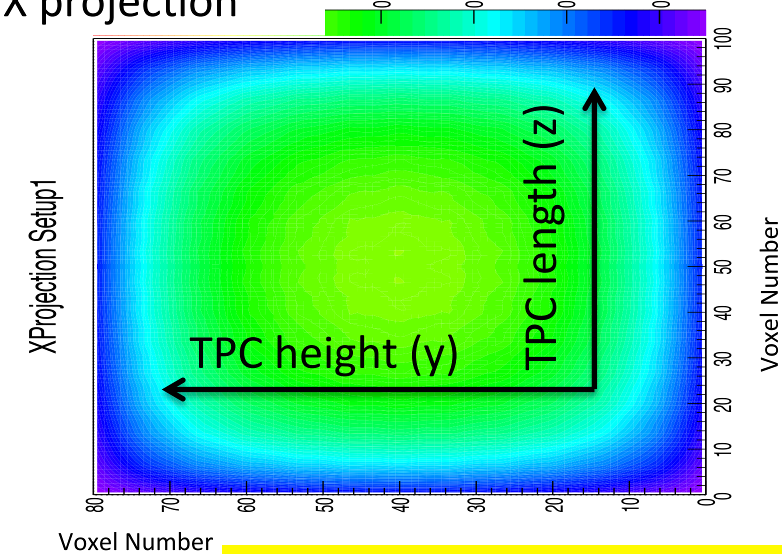


- Does the increased late light interfere with prompt photons needed for good timing and position resolution?

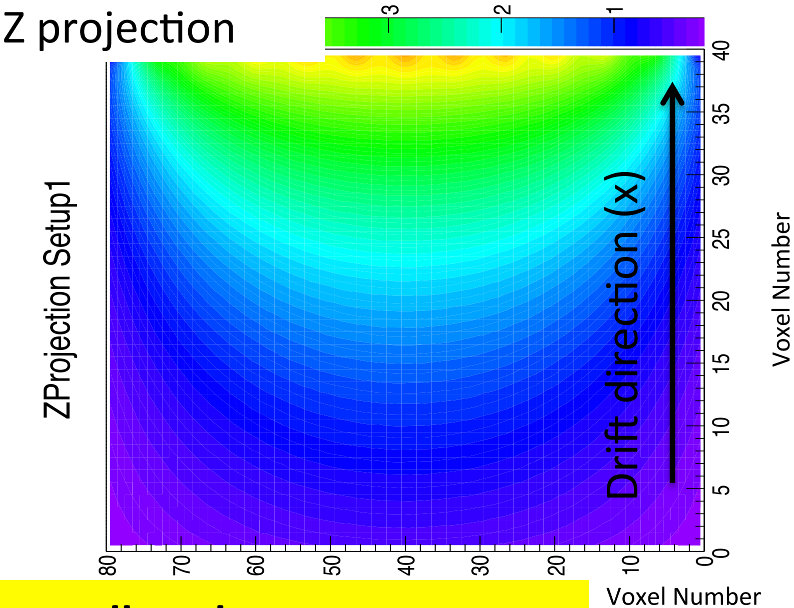
Visibility maps

High density PMT (no reflectors)

X projection

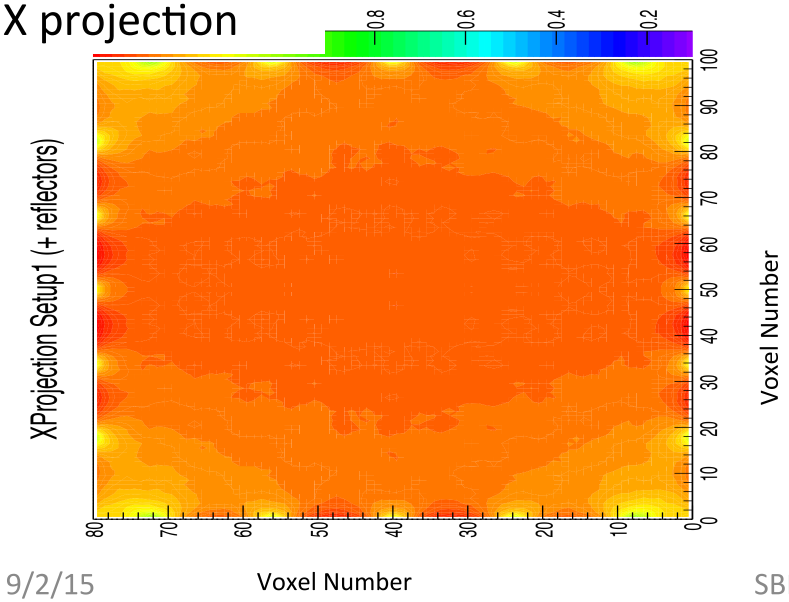


Z projection

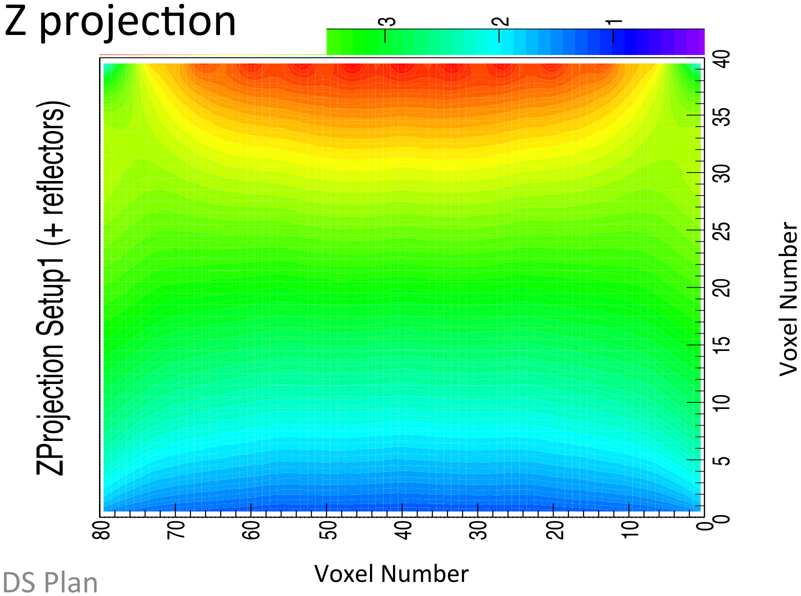


High density PMT + reflectors on walls only

X projection



Z projection



Summary

- SBND's primary goal is to ensure the desired oscillation physics sensitivity can be achieved.
  - PMT system
- Secondary goals include a test bed for new photon detection technologies which will also enhance physics goals
  - Light guide bar system
  - TPB coated wavelength shifting reflectors
- Will also test SiPM's, electronics, DAQ, reconstruction software, etc
- Close communication with DUNE will be important to maximize opportunities and synergy.

Key points, open questions, ongoing or needed development….

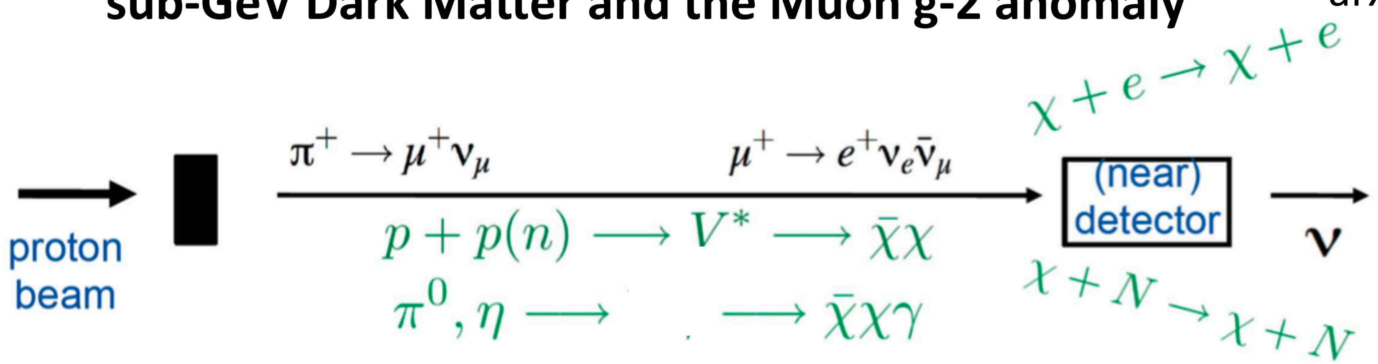
- PMTs to be TPB coated or plates in front (uB style)?
  - Light guide bars placed in front of PMTs?
- Fast PMT/SiPM electronics digitization (large data volumes), high/low gains for large charge dynamic range (doubling channels)?
- Cold cable feed thru development, need a cost effective but robust solution.
- With/without wavelength shifting reflectors?
- N2 filtration required for long term stability?
- A similar PDS in near and far detector allows sharing resources, but does it improve systematics?

Backup Slides

Improved Sub-GeV Dark Matter Searches with SBND

Test U(1) Dark Sector Models which are motivated by sub-GeV Dark Matter and the Muon g-2 anomaly

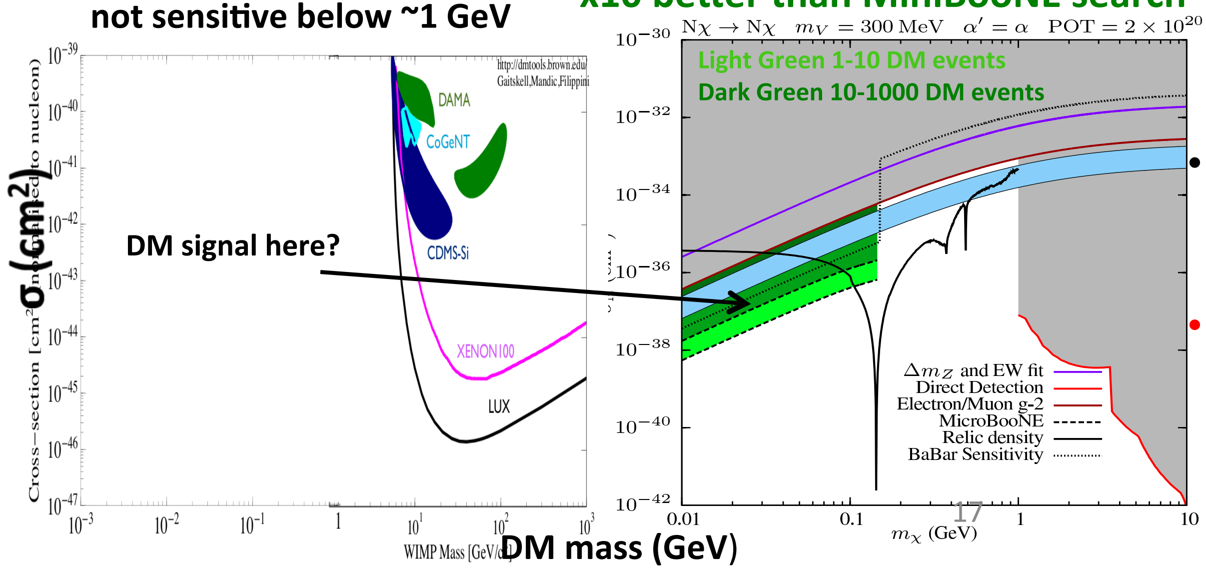
arXiv:0906.5614
arXiv:1211.2258



- Dark sector mediator **(V)** couples to photons from beam π^0 decay.
- Dark Matter **(χ)** scatters off detector nucleons or electrons.

Direct detection experiments not sensitive below ~1 GeV

SBND Dark Matter-Nucleon Sensitivity x10 better than MiniBooNE search



- Probes **Muon g-2 anomalous region** and relic density solution (solid black line).
- SBND will have excellent signal sensitivity, but requires improved low energy background rejection (<200 MeV) with PDS.