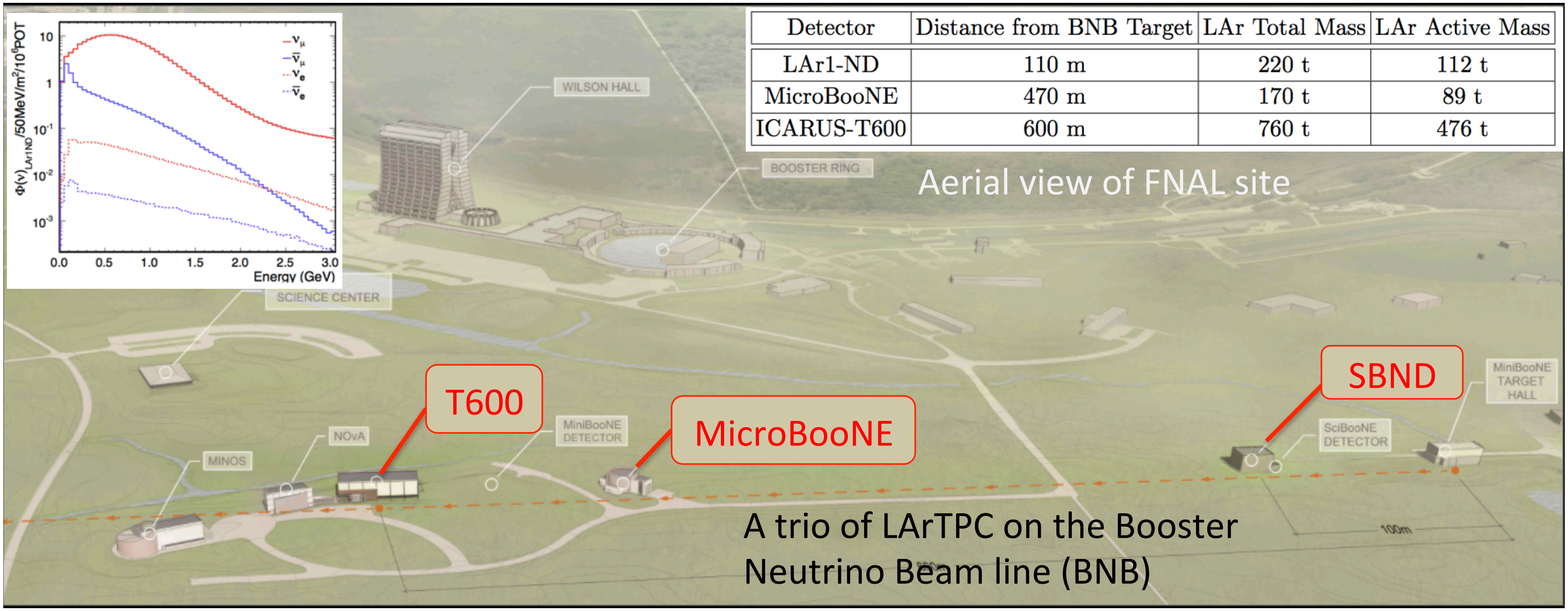
Short Baseline Near Detector (SBND) Photon Detection System (PDS)

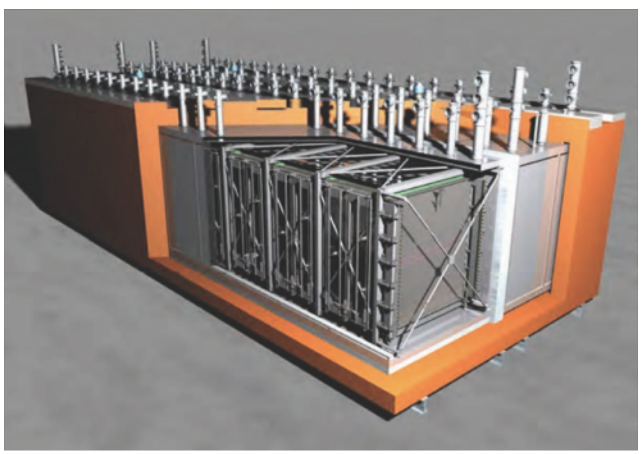
DUNE PD Working Group Meeting
10/8/15

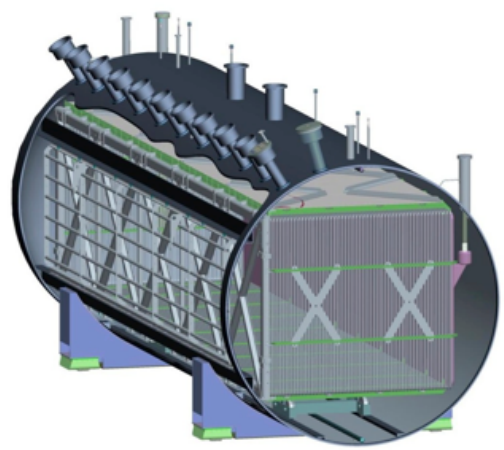
M. Toups, FNAL

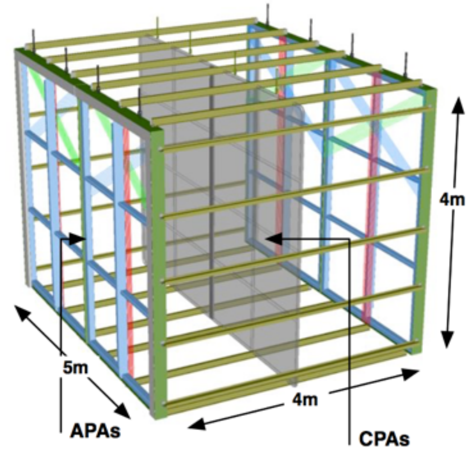
Short Baseline Neutrino (SBN) Program starts in 2018

Detector	Distance from BNB Target	LAr Total Mass	LAr Active Mass
LAr1-ND	110 m	220 t	112 t
MicroBooNE	470 m	170 t	89 t
ICARUS-T600	600 m	760 t	476 t









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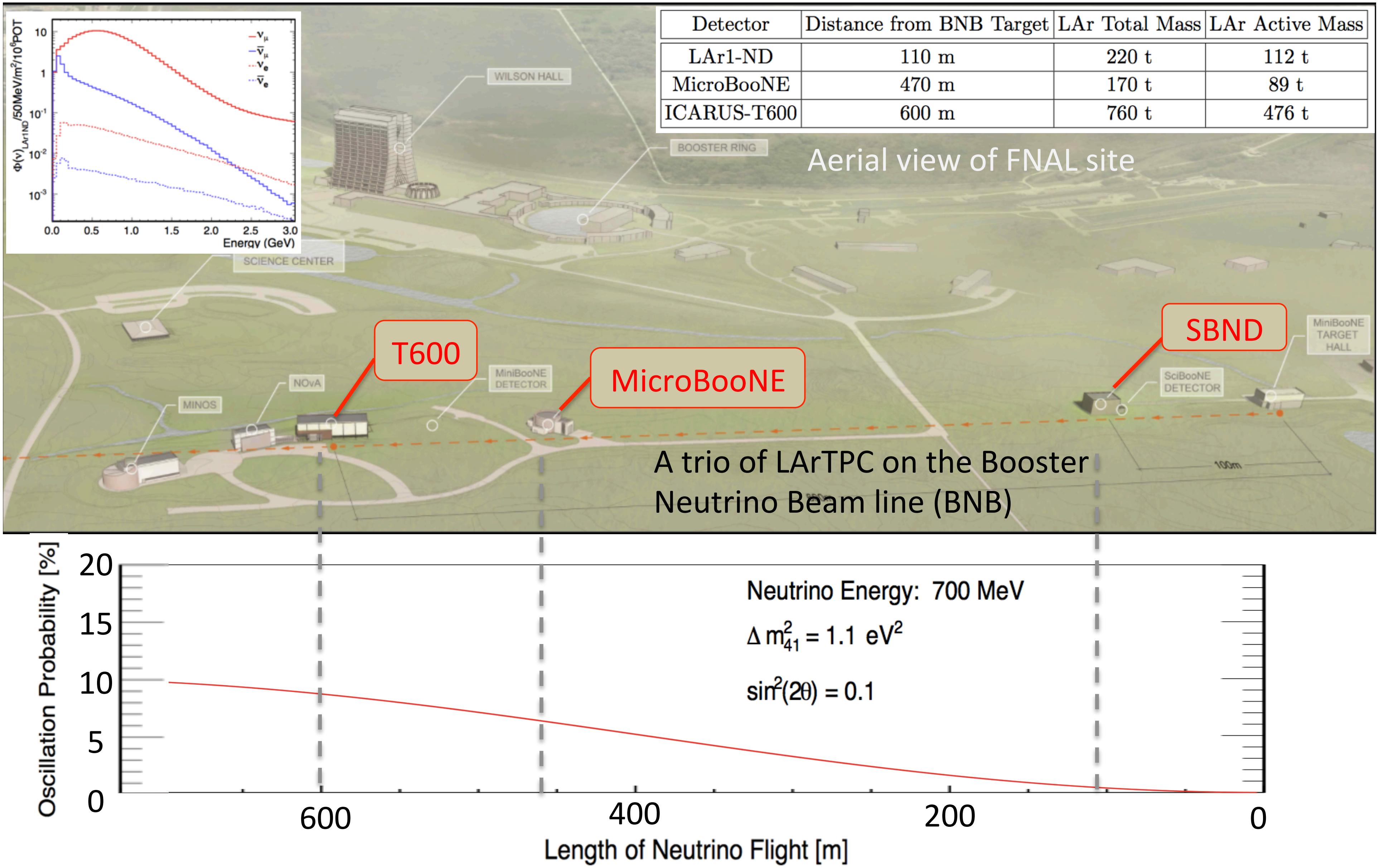


SBND is a Near Detector on the Surface

- Large LArTPC detectors operating on the surface have unique challenges
  - copious external backgrounds from cosmic ray muons, showers, and neutrons need to be identified and rejected
- Large LArTPC detectors operating as near detectors have unique physics opportunities
  - searches for rare and beyond standard model processes with high efficiency and mm-scale position resolution

SBND Photon Detection System Plan

- SBND needs to achieve its main oscillation physics goals but should also, if possible, pursue a broad physics program

- SBND is a "test experiment" with an important part of the mission being R&D for future LAr neutrino experiments, such as DUNE.

Possible Enhanced SBND Physics Leveraging Scintillation Light

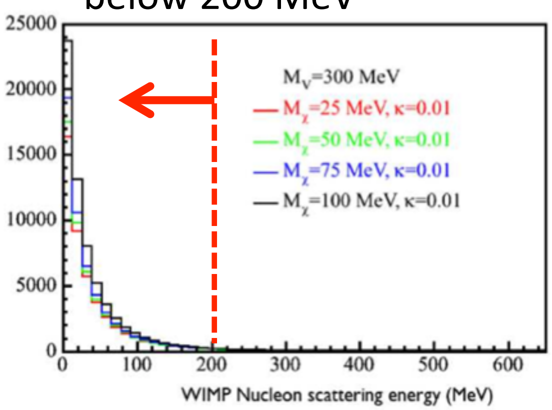
- Good timing/position resolution will improve dirt/cosmic background rejection
  - decrease oscillation and cross section physics systematics, especially at low energy 100-200 MeV, which significantly improves sensitivity.
- Good timing/position resolution will allow analysis of low energy physics that 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

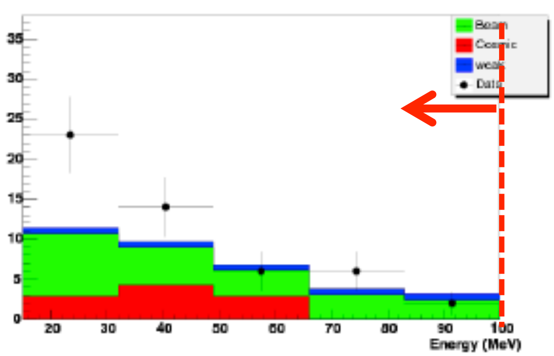
- The photon detection systems significantly reduces cosmogenic and external neutrino backgrounds which dominate below an energy threshold of 200 MeV.
- This opens up new physics searches, especially for the SBND detector which is four times smaller than MiniBooNE, but twice the reconstruction efficiency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

Overall about ~order magnitude better sensitivity for…

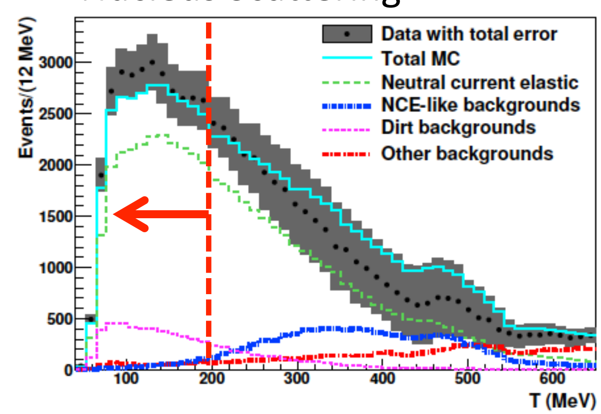
Sub-GeV Dark Matter:
scatter signal energies below 200 MeV



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



Performance Parameters Requirements

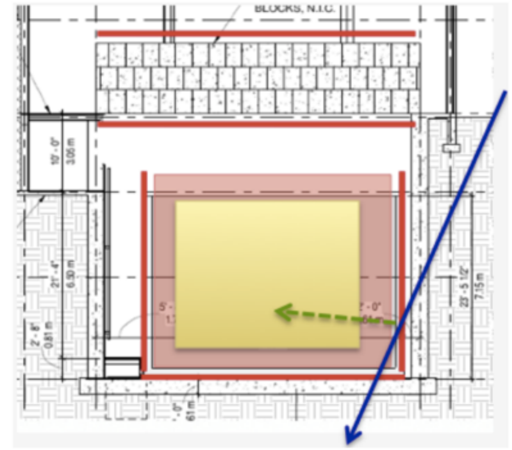
- **<u>Time resolution performance requirement</u> for the light collection system depends on the physics you want to use it for:**

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?
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

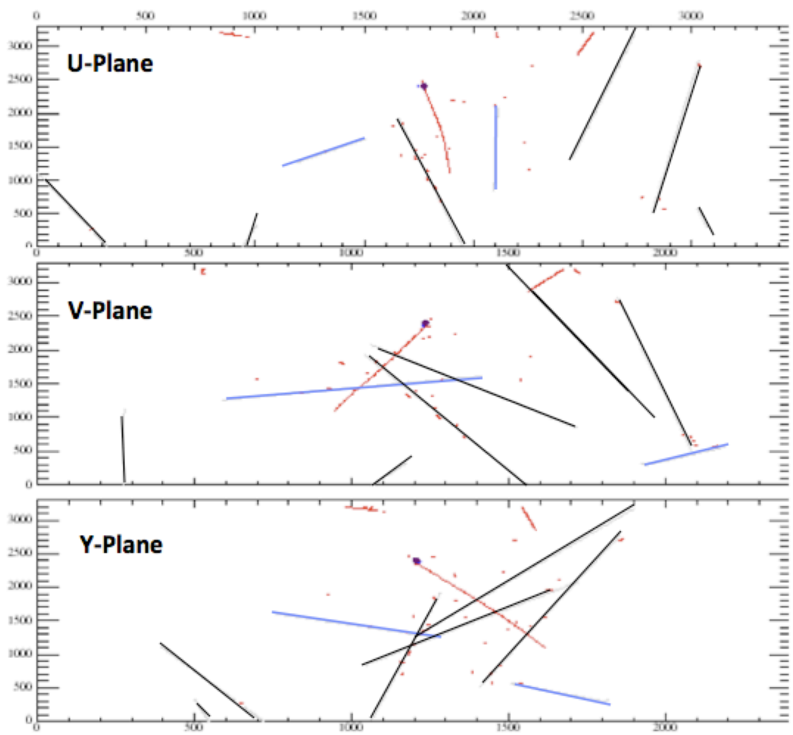
SBND External Background Strategy



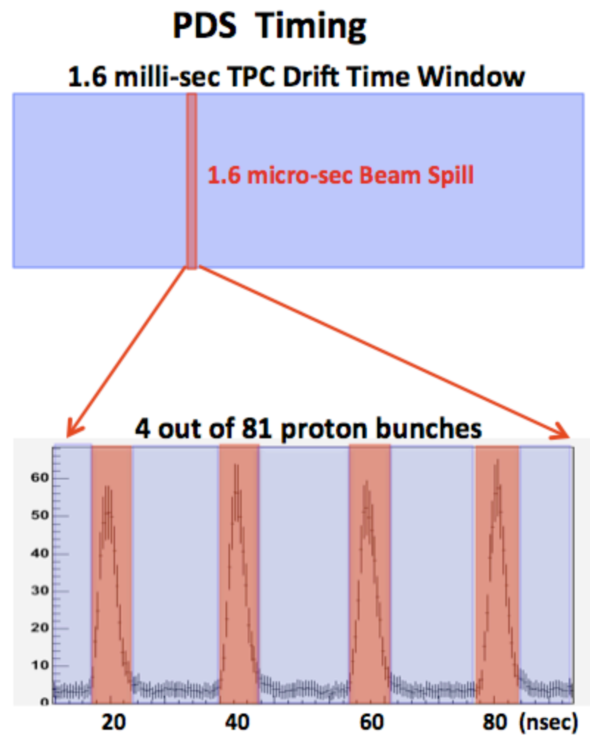
- 3m overburden will shield against EM showers and neutrons
- Constructing a cosmic ray tracker (CRT) with ~98% coverage and ~nsec timing.
  - Excellent job identifying incoming charged particles.
- A PDS system with ~nsec timing will provide further external background rejection
  - Especially for problematic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

Time Structure of the Booster Neutrino Beam

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.



TPC Track Position 2-D Planes (mm)

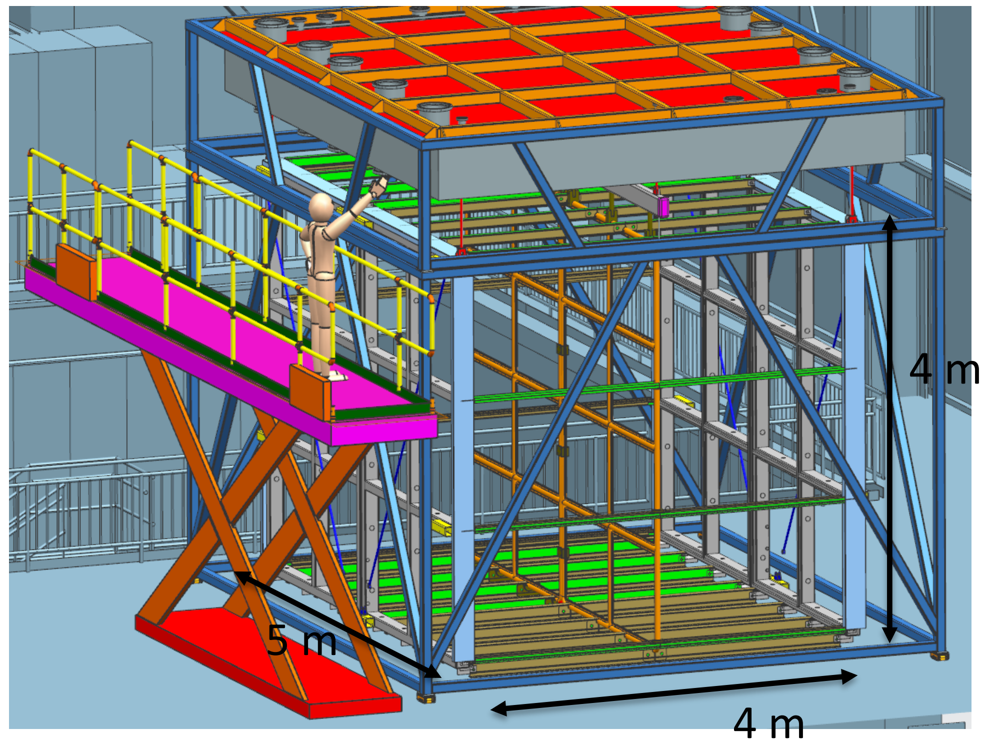


53 MHz Beam Spill Fine Timing: (nsec)

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

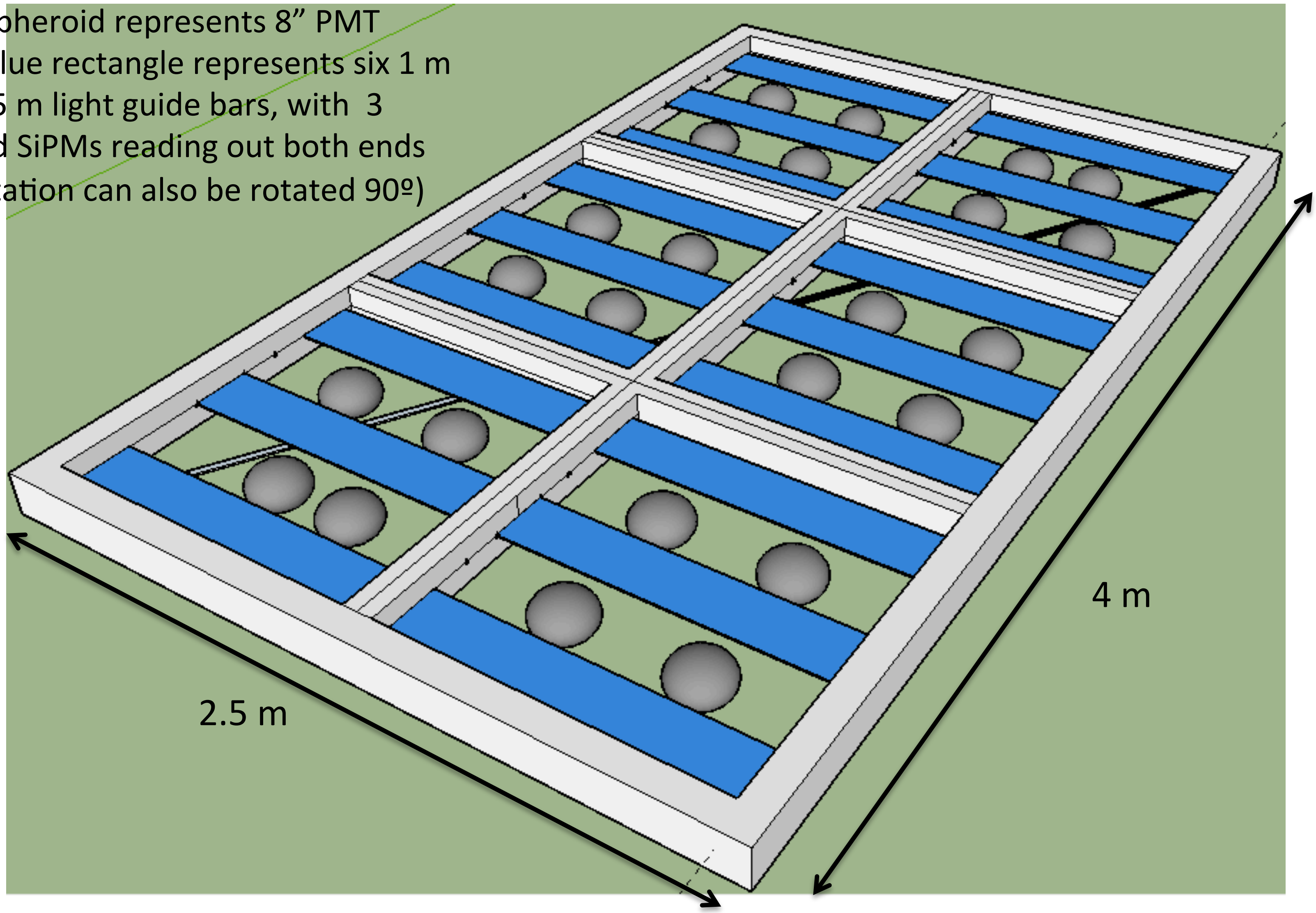
SBND Detector Design in a Nutshell

- Central CPA, 4 APAs on sides
  - No wrapped wires
  - Access to APA frame from outside TPC
- TPC constructed in separate building and moved to BNB
  - TPC suspended from cryostat top plate
  - Field cage similar to 35 ton
- Light detection system installed just before lowering TPC into cryostat
- Cold feed-throughs (<100K)



SBND Hybrid Photon Detection 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, with 3 ganged SiPMs reading out both ends (orientation can also be rotated 90º)



SBND Hybrid Photon Detection System: PMTs

- 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" R5912 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.

SBND Hybrid 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.
- Proves an opportunity to operate a full-scale light guide-based system as foreseen in the initial single phase 10 kt 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.**

Reference Design For Light Guide Bars in SBND

- MIT dip-coated "Wunderbars"
  - protoDUNE reference design: WLS radiator + green light guide from Eljen
- Bars are 1" wide x 1 m long and read out on each end by 3 ganged SensL 6x6 mm^2 SiPMs
  - protoDUNE bars are 0.1 m wide x 2.1 m long and read out on one end by 12 SiPMs ganged in groups of 3
- Fractional APA coverage is 27%
  - protoDUNE fractional APA coverage is 15%

Reference Design For Light Guide Bars in SBND

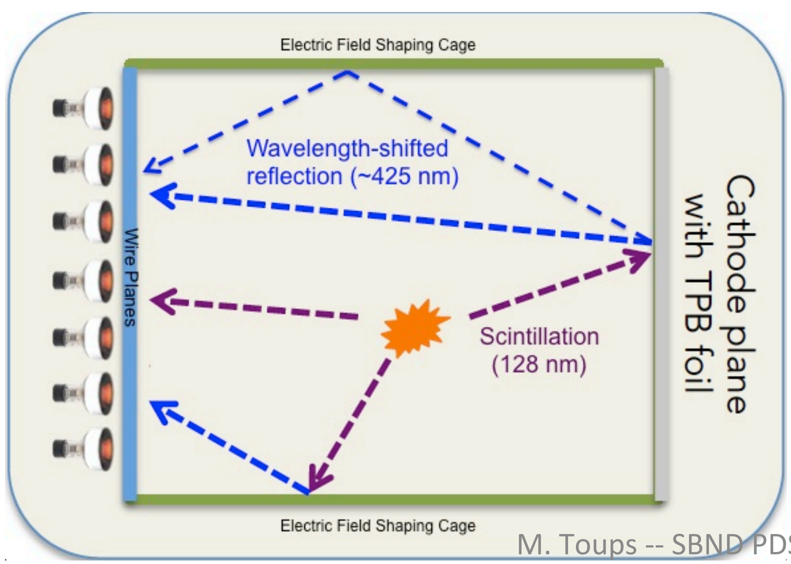
- MIT dip-coated "Wunderbars" — Factor of ~2 greater
  - protoDUNE reference design: WLS radiator + green light guide from Eljen
- Bars are 1" wide x 1 m long and read out on each end by 3 ganged SensL 6x6 mm^2 SiPMs — Factor of ~2 greater
  - protoDUNE bars are 0.1 m wide x 2.1 m long and read out on one end by 12 SiPMs ganged in groups of 3
- Fractional APA coverage is 27% — Factor of ~2 greater
  - protoDUNE fractional APA coverage is 15%
- Net result of these (and shorter drift), is roughly an order of magnitude greater light collection efficiency than in DUNE

SBND/protoDUNE Light Detection System Synergies

- Joint SBND/DUNE meeting on SSP readout electronics design optimization (9/15/15)
- Initial discussions with Peter Wilson and Eric James about looking for possible overlaps/synergies with system design and engineering
- Much of the DUNE light detection system development work (and many of the specific work packages outlined by Norm) apply also to SBND. A partial list of possible overlaps is:
  - PD module mounting
  - SiPM mounting board
  - Cables/connectors
  - Light guide testing and Q&A
  - Cryogenic qualification of light guides and wavelength shifter
  - Long-term SiPM cryogenic qualification
  - Passive/active SiPM ganging verification
  - Readout electronics design optimization
- Also, some clear overlaps on simulation/reconstruction needs
- Next step is a systematic assessment of SBND/protoDUNE synergies

Potential Performance Enhancements

- 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?

Summary

- SBND has unique challenges and opportunities as a "near" neutrino LArTPC detector on the surface
- To achieve its dual purpose of doing physics and R&D as a "test" experiment, it will employ a hybrid photon detection system
  - PMTs and light guide bars
  - Over an order of magnitude greater photon detection efficiency than in DUNE
- Close communication between SBND and DUNE will be important to maximize synergy and minimize any duplication of work

End.