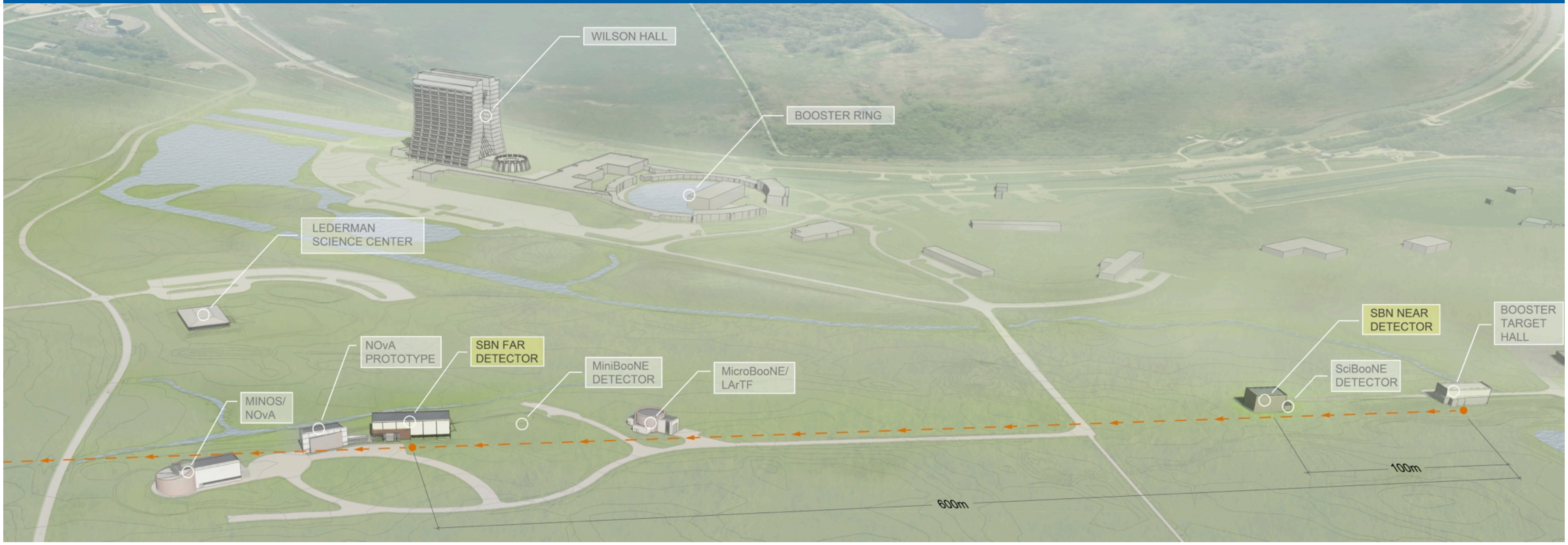


PMT System (SBND)

Richard Van de Water (LANL)

Director's Progress Review of SBN

15-17 December 2015

Outline

- System Overview
- Technical Design
- Resources
- Basis of Estimate (for DOE costs)
- Schedule and Cost Summary
- Status of design
- ES&H and QA
- Summary

SBND Photon Detection System (PDS) Goals

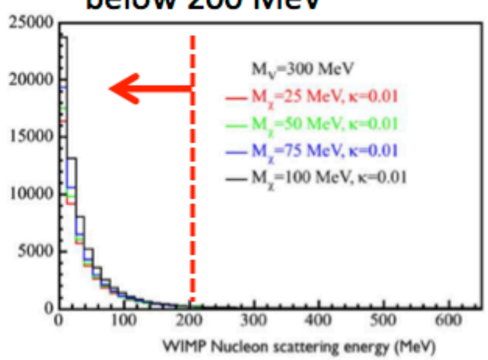
- SBND needs to achieve its main oscillation physics goals, and if possible, pursue other physics searches.
- An important part of the SBND mission is R&D for future LAr neutrino experiments.
- Large LAr detectors operating on the surface have unique challenges.
  - copious cosmic ray muons, showers, and neutrons.
  - MiniBooNE tackled this with an integrated cosmic ray veto and ~1 nsec event reconstruction.

Enhanced SBND Physics Leveraging Scintillation Light

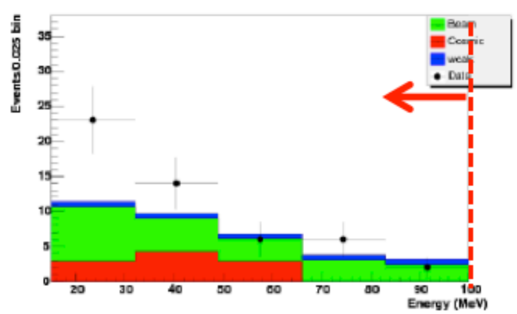
- Good PDS timing resolution will improve dirt/cosmic background rejection decreasing oscillation systematics
  - Enable lower analysis energy thresholds, i.e. E_{vis}(oscillations) > 100 MeV, which improves oscillation sensitivity.
- Good timing will improve analysis of low energy (< 200 MeV) physics that are dominated by dirt/cosmic backgrounds:
  - Low mass dark matter search
  - ν_μ magnetic moment
  - Neutral Current Elastic cross sections

Enhanced SBND physics due to its proximity to the source

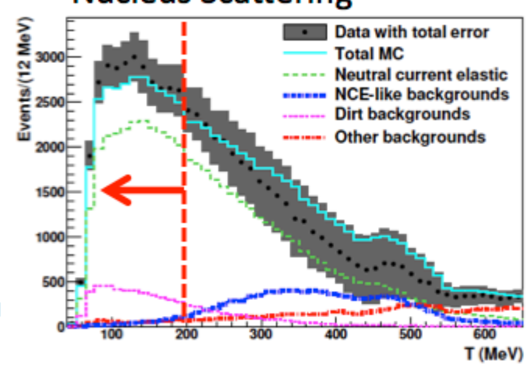
Sub-GeV Dark Matter: scatter signal energies below 200 MeV



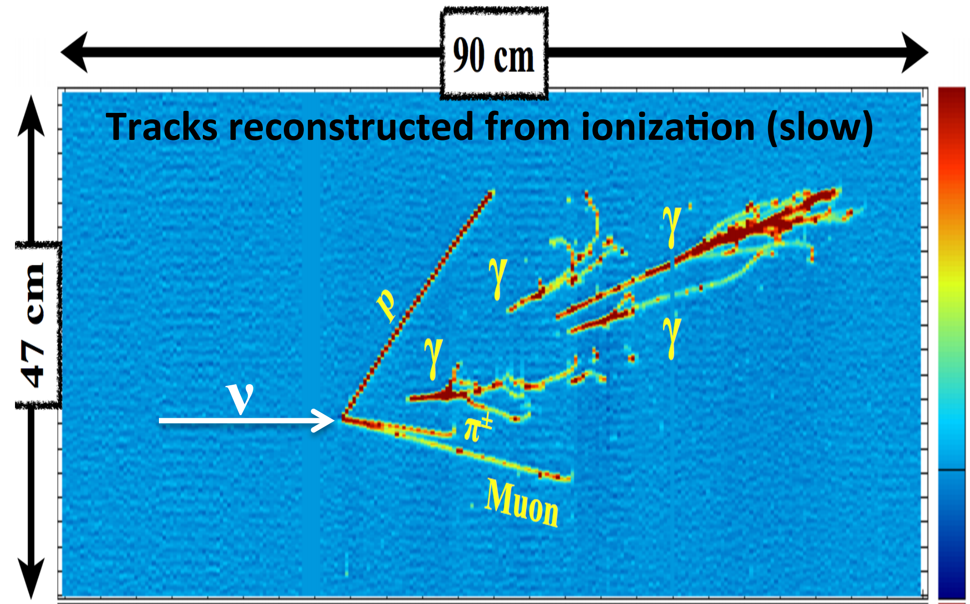
Muon ν Magnetic Moment:
MiniBooNE Limit < 12.7 x10^{-10} μ_B
LSND Limit < 6.8 x10^{-10} μ_B



Cross Sections:
MiniBooNE Neutral Current Nucleus Scattering

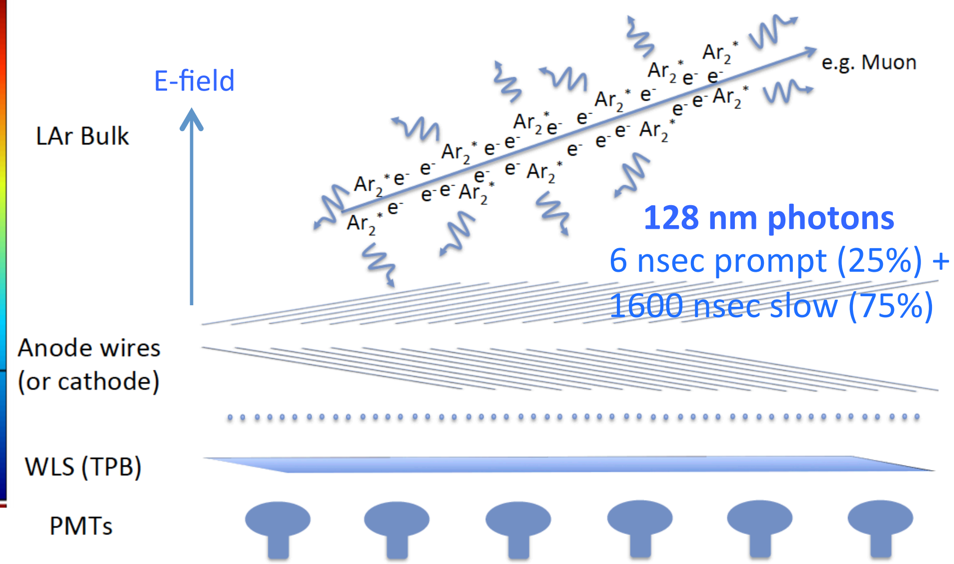


Liquid Argon Time Projection Chamber Capabilities



Example DIS event
(courtesy of ArgoNeuT collaboration)

Ionization electron drift is slow (10^{-3} sec)
Scintillation photon production/propagation is fast (10^{-9} sec)



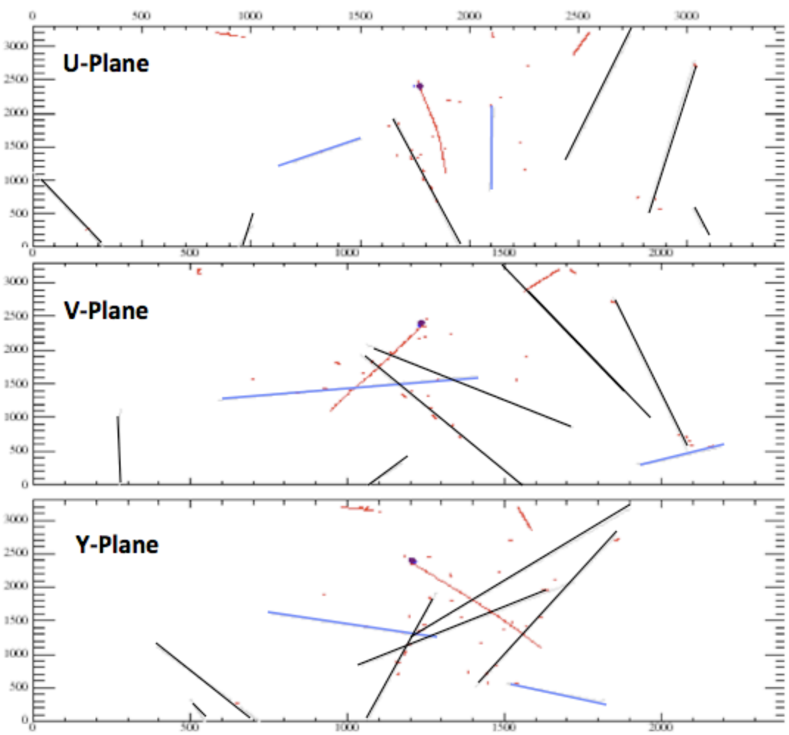
Beam timing ~10^{-9} sec

- Liquid Argon TPC detectors provide precision tracking, but are extremely **SLOW** with 10^{-3} second drift compared to 10^{-6} (10^{-9} RF) second beam time, allowing for copious external backgrounds, especially in surface LAr detectors.

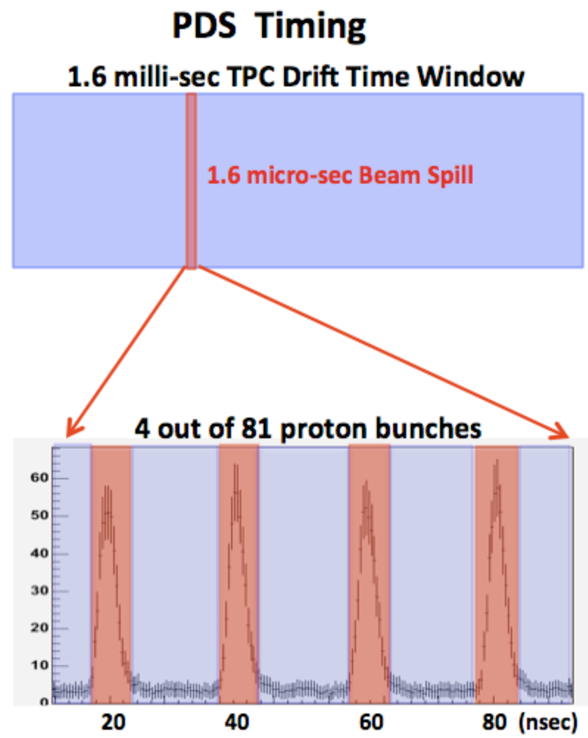
- Detection of photons from scintillation light is relatively **FAST** (~10^{-9} second) allowing potential efficient tagging/rejection of external backgrounds.

Reducing External backgrounds with a Photon Detection System (PDS)

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 2×10^{-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.
- **External neutron backgrounds rejection with PDS.**

Performance Parameters

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

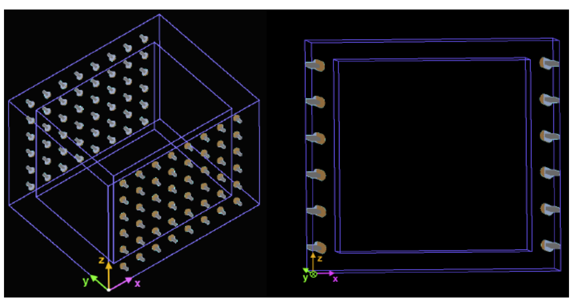
Required	tag events as being "in-spill" (energy threshold?)	few-100ns resolution
	tag Michel electron decays through timing	order 100ns resolution (also requirement on light yield)
	tag muons as 'entering' or 'exiting' (by measuring sign(t_{TPC} - t_{CRT}))	~5ns resolution (also requirement on CRT timing)
	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" for maximum external background rejection	1-2ns resolution
Goal	dark matter searches (additional science objective)	1-2ns resolution

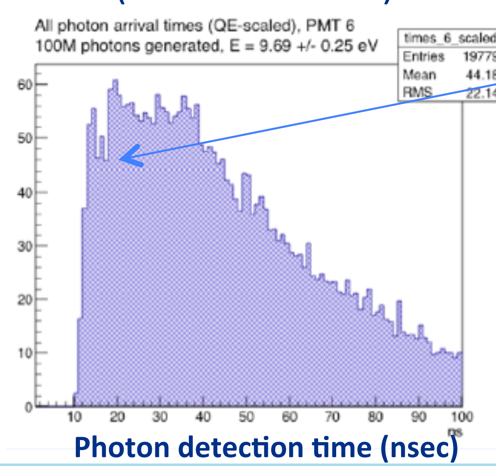
- Maximum external background rejection and enhanced physics requirements requires ~1-2 nsec timing performance.
- This also gives best spatial reconstruction resolution for TPC track matching.

The SBND Photon Detection System:

- A “**primary PDS**” based on 60 PMTs mounted behind each APA wire frame, for a total of 120 PMTs.
- **PMTs are a proven technology** for scintillation light detection in LAr giving a high level of confidence for reaching our physics goals.
  - Possibility to install DUNE style light guide bar system along side PMT system (backup slide). Allows for cross comparisons.
  - Wavelength shifting reflectors to increase amount of detected light are being considered.
- Simulation studies ongoing to determine TPC track matching efficiency, timing resolution, angular/position resolution, etc.

LAr Scintillation Light Simulations (SBND detector)

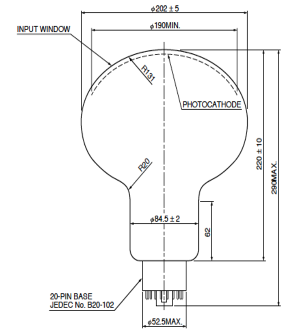




- Best event timing requires maximum photocathode coverage and PMT timing response to extract prompt light.
- More PMT’s improves triggering threshold stability and dynamic range.

PDS Technical Status

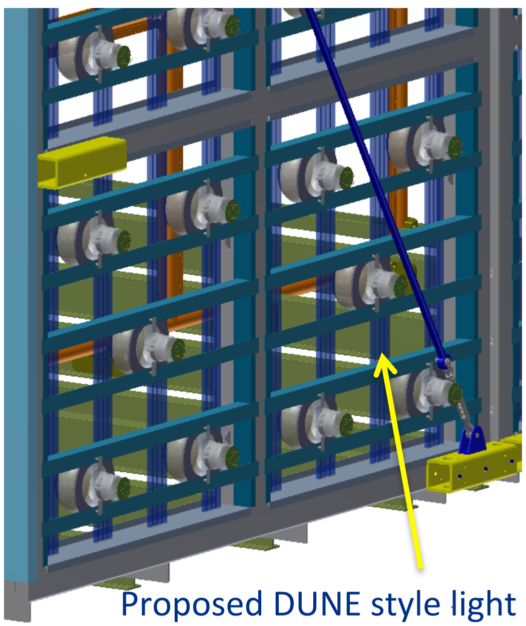
- **PMTs**
  - Decided on the Hamamatsu R5912 Cryogenic PMT.



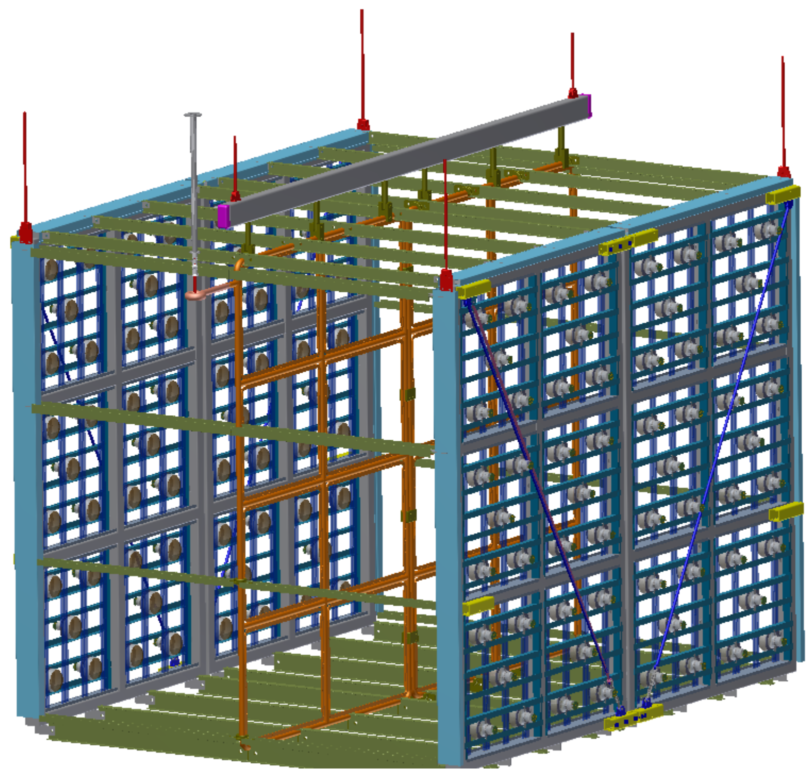
  - Robust and proven cryogenic PMT
    - Same choice as ICARUS uB, miniCLEAN.
    - 10 stage 10^7 gain.
    - 1.5 nsec Gaussian timing resolution for single photo-electron.
    - PMT base will be mini-CLEAN design (Photo-cathode at ground).
    - Tetraphenyl butadiene TPB wavelength shifting (128 nm -> 425 nm peak) film coated directly on PMT glass.
  - Total of 120 8” R5912 PMTs will achieve up to ~15 photo-electrons/MeV at 2m from PMT plane.
  - Negotiating with Hamamatsu with order to be placed in the new year.
  - Discussions with ICARUS to perform TPB evaporative coating and testing of PMTs at CERN.

PDS Technical Status

- **Support structure and PMT mounting**
  - Jan Boissevain (LANL engineer) has started work on support structure design, fully integrated with FNAL CAD/setp file models.
  - PMT support structure will bolt onto TPC frame. Integration into TPC needs to take account of TPB light sensitivity.
    - Dry weight per APA 124 kg; Buoyancy weight 50 kg.
  - Cable plant and cold feed thru needs to be designed.
  - PMT support structure will be designed to accept DUNE style light guide bars.



Proposed DUNE style light guide bars fill in space between PMTs.



Adding center PMT increases total to 120 PMT's

Technical Status

- **Electronics**
  - Options: CAEN, ANL, Nevis, others…
  - Desirable to use common system between SBND and ICARUS.
  - Fast digitization allows complete characterization of PMT pulse shape (~10-20 nsec width).
  - CAEN has two models available with large memory option (~5 Ms/channel => 0.01 sec):
    - 1725: 250 MHz and 14 bits, 16 channel/board, ~$700/channel
    - 1730: 500 MHz and 14 bits, 16 channel/board, ~$1000/channel
    - 14 bit ADC would provide 2^5 charge bits for single PE and a dynamic range of around 512 PE.
    - Fiber optic readout (80 Mbit/s per link), 64 MHz external clock input/sync, onboard triggering/filtering options, FPGA programming support.
  - ANL design has similar features, but requires some up front engineering development (different ADC than current SiPM design).
  - Begun work with DAQ group on interface/sync issues.

Resources

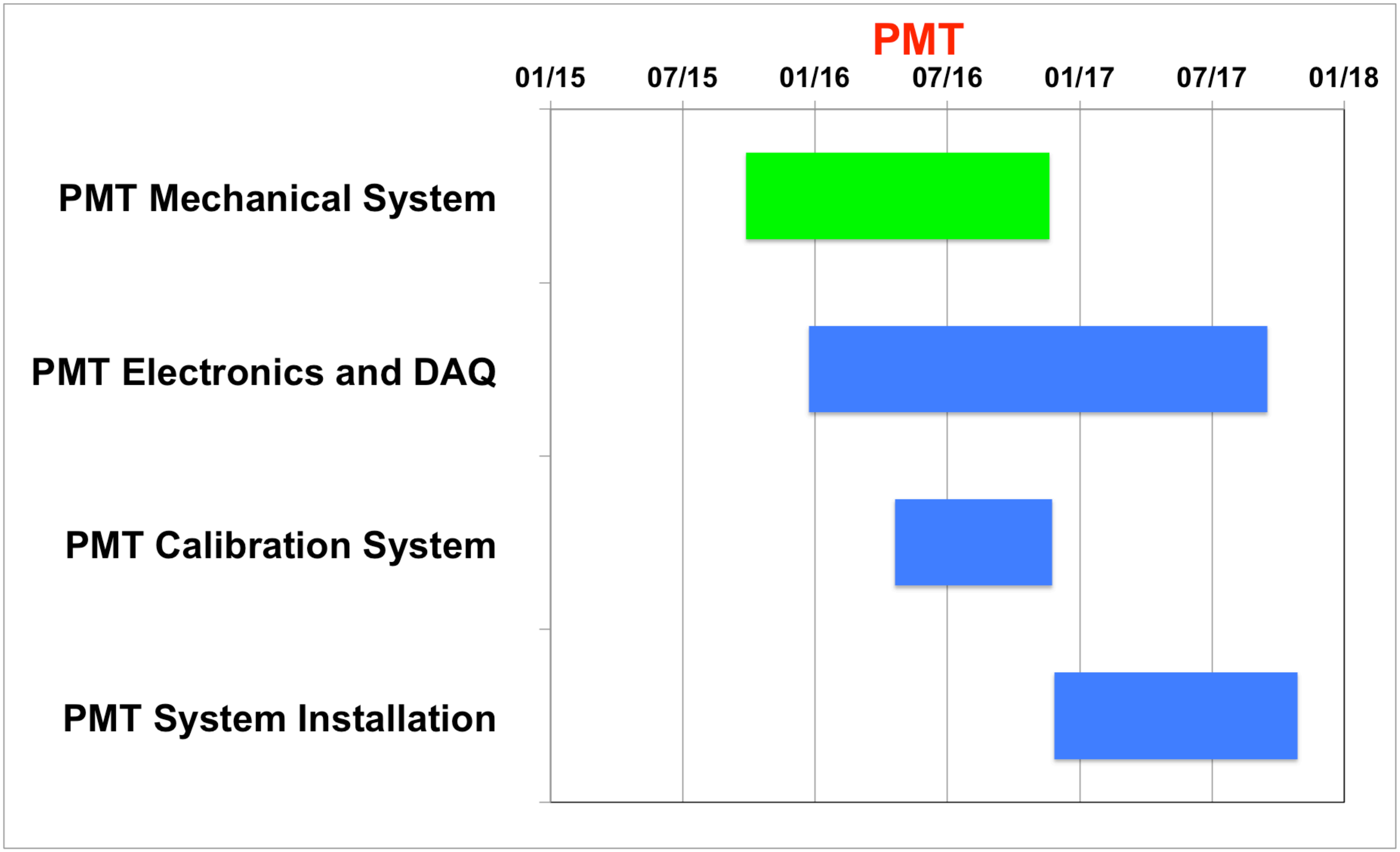
- PMT system fully funded by LANL LDRD.
  - $1.1 million for PMT system hardware, support structure, cabling, feed-thru, electronics and DAQ.
  - 1.8 FTE and 1 PD for experimental work to design and build PMT system, develop DAQ, and reconstruction.
  - 1.0 FTE and 1 PD for theoretical work on neutrino LAr cross sections and sterile neutrino theory.
- L2 project manager R.G. Van de Water (LANL) and deputy Keith Rielage (LANL)
  - L3 positions being filled
- SBND photon detection working group provides physics and technical input/ideas, critical thought, simulation support, and decision making forum.

Basis of Estimate

- Cryogenic PMTs systems are not new.
  - LANL group has had extensive experience building PMT systems (LSND, SNO, MiniBooNE, MiniCLEAN)
  - Manufacture quotes for about 40% of the total cost.
  - Project contingency is 20%, with $100k further reserve.
  - Biggest unknown is cold feed thru design and construction cost

WBS Title	Duration (days)	M&S ($)	M&S Contingency (% and rule)	Labor resource and % effort or total hours for each labor resource
PMT system design, layout and integration	120	$10,000	10%	0.1 FTE-E
PMT mounting design and modeling	90	$10,000	5%	0.2 FTE-E
PMT mounting fabrication	180	$100,000	30%	0.2 FTE-T
PMT cryostat feed through design and testing	180	$30,000	100%	0.2 FTE-E
PMT cryostat feed through flange fabrication	90	$100,000	30%	0.2 FTE-T
PMT base circuit and cable design, fabrication and testing	180	$20,000	5%	0.4 FTE-T
HV power supply specification, procurement and testing	180	$25,000	5%	0.1 FTE-T
PMT readout electronics design and fabrication	360	$120,000	5% (quote)	0.25 FTE-E 0.5 FTE-T
DAQ System	270	$50,000	20%	PostDoc
PMT specification and procurement	180	$230,000	5% (quote)	0.1 FTE-T
PMT QA test design and fabrication	30	$10,000	5%	Use ICARUS setup
TPB coating applicator design and fabrication	90	$30,000	20%	0.1 FTE-T
PMT QA testing	180	$20,000	30%	1.0 FTE-PD
PMT assembly and cabling	60	$5,000	20%	1.0 FTE-PD/T
PMT cryostat feed through and cable installation	60	$5,000	20%	1.0 FTE-PD/T
PMT installation test run at DAB	60	$5,000	20%	1.0 FTE-PD/T
PMT mounting holder instalaltion at DAB	60	$5,000	20%	1.0 FTE-PD/T
Readout electronics installation	60	$5,000	20%	1.0 FTE-PD/T
PMT installation at SBND building	60	$5,000	20%	1.0 FTE-PD/T
PMT QA test before cryostat closeup	60	$5,000	20%	1.0 FTE-PD/T
Calibration System	180	$30,000	30%	
Nearline Monitoring System	180	$20,000	20%	1.0 FTE-PD/T
Total		$830,000	$165,000	

PMT System Preliminary Schedule/Cost: L3 Tasks (details in full schedule)



- LANL LDRD funding began 10/15, three year duration.

Status of Design

- Done:
  - Secured LANL-LDRD funding for a PDS.
  - Collaboration decision made on type of PDS: PMTs
- ToDo's
  - Desire to install DUNE style light guide bars, reflectors are being considered (not part of this sub project).
  - Order 120 8” Hamamatsu R5912 PMTs (early 2016)
  - PMT base design (started)
  - Complete design of support structure, PMT fixtures, and interfacing (started).
  - Cold cable feed thru design (start early 2016).
  - PMT coating and testing at CERN (mid/late 2016)
  - Decision on which electronics to use (mid 2016)
  - Development of DAQ and calibration system (start late 2016)
  - PMT system simulations (ongoing).

ES&H, QA

- ES&H considerations for this subsystem:
  - Will work with FNAL safety on PMT base and readout electronics electrical standards.
  - Support structure design using FNAL standards.
- Quality Assurance Program for this subsystem:
  - PMT's will be tested at the CERN WA104 test facility. This is the same testing being done for the ICARUS PMT's.
  - PMT tests include gain, timing, and dark current rates.

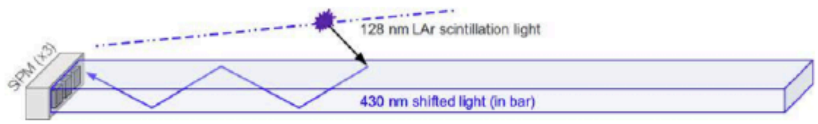
Summary

- Sufficient funding is available to design and build the primary photon detection system for SBND, which is 120 8” PMTs.
  - This is a proven and robust design.
  - Will easily achieve required goal of 100 nsec timing, and most likely get to 1-10 nsec timing needed for maximum background rejection. Studies ongoing to determine final timing resolution.
  - Large number of PMTs will produce stable triggering with large dynamic range required for online triggering.
- PMT subproject is ramping up (LDRD funding started Oct 2015).
  - Significant contingency and reserve funding.
  - Sufficient FTE for design, procurement, and construction.
  - Realistic schedule for installation in 2017.

BackUp Slides

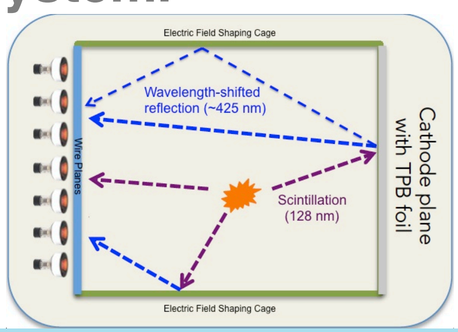
Backup Slide: Light guide bars and reflectors options

- **Light guide bars are new PDS design which can cover large surface area for relatively low cost, however, requires large number of electronics channels**



  - Scales up baseline DUNE design, builds off DUNE R&D efforts (TallBo, 35 ton)
  - TPB-coated light guide bars measuring 1 m x 1” x ¼” behind each APA
  - Both ends of each bar read out by 3 SensL SiPMs (6 mm x 6 mm)

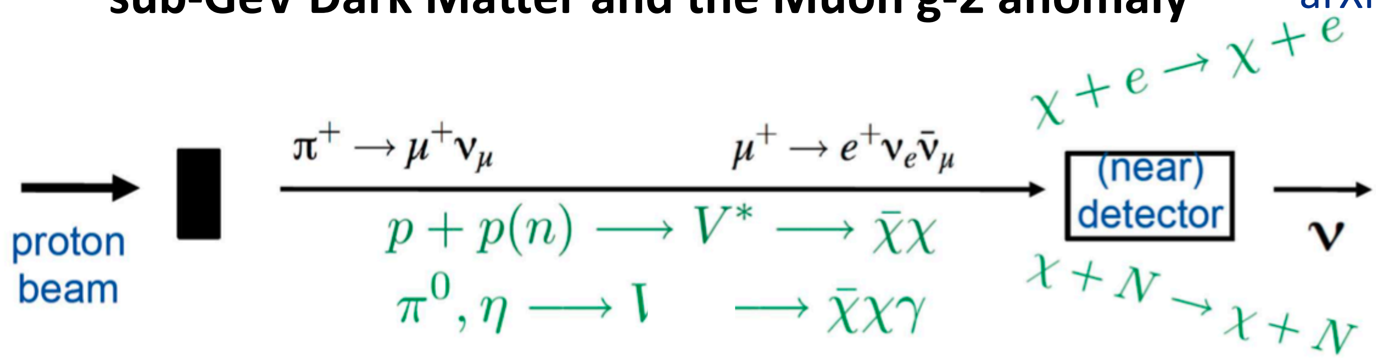
- **Add wavelength shifting reflectors on cathode and side surfaces to increase light output, low cost, but not clear if they dilute the time response of the PMT system.**



Sub-GeV Dark Matter Searches with SBND

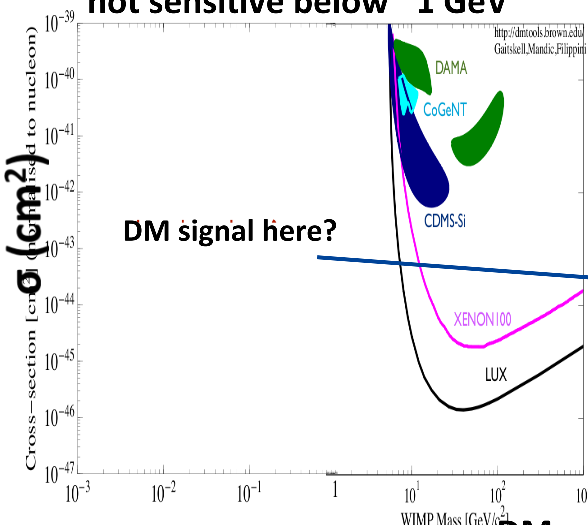
Test U(1) Dark Sector Models which are motivated by sub-GeV Dark Matter and the Muon g-2 anomaly

arXiv:0906.5614
arXiv:1211.2258

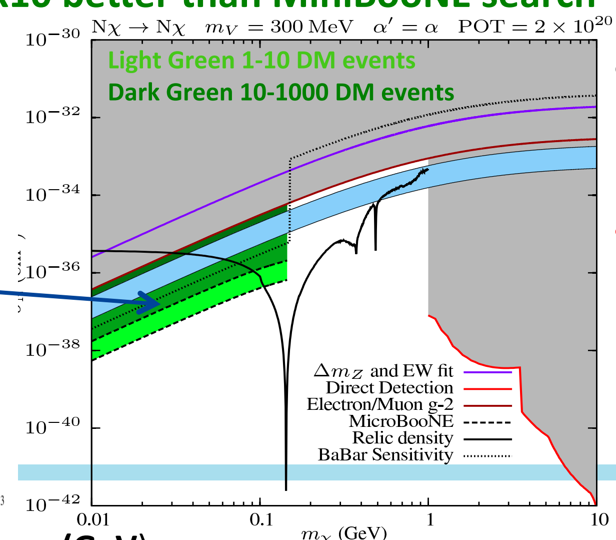


- Dark sector mediator **(V)** couples to photons from beam π^0 decay.
- Dark Matter **(χ)** scatters off detector nucleons or electrons.

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.