SBND Design Review of PMT Integration

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Executive Summary

There has been excellent progress made on the development of the PMT system for SBND. The 120 8" PMT layout will produce a high light yield and should easily meet the minimum timing resolution requirement of 100 ns. 135 sandblasted PMTs have been purchased from Hamamatsu, and readout electronics and HV supplies from CAEN are in hand. Design of the PMT base is ongoing with good progress being made. Designs of the mechanical support system and cable feedthroughs are advanced and ready for prototyping. A strong team is in place to complete the project and deliver the system on schedule for installation in 2018.

Below we list 41 comments for your consideration and 1 recommendation to work with the TPC design team in order to resolve an interface issue with the APA frames.

Specific Comments and Recommendations

Report Terminology

Findings are statements of fact that summarize noteworthy information presented during the review.
Comments are judgment statements about the facts presented during the review. The reviewers' comments are based on their experiences and expertise. The comments are to be evaluated by the project team and actions taken as deemed appropriate.
Recommendations are statements of actions that should be addressed by the project team. A response to the recommendation is expected and that the actions taken would be reported on during future reviews.

Findings:

1. Overview:
    a. The SBND PMT System will consist of 120 8" PMTs (Hamamatsu R5912-mod cryogenic PMT) mounted behind the TPC wire planes (60 per APA frame)
    b. Simulations show this configuration is capable of detecting 15 PEs/MeV for events at the cathode, 2m from the wire plane.
    c. A primary requirement for the PMT system is to match events to the 1.6 us long beam spill, therefore, the minimum timing resolution requirement is 100 ns for the system. A goal of 1-2 ns is set, however, in order to extend the physics program (dark matter searches) or reduce backgrounds further by timing to the individual 2 ns wide 53 MHz proton bunches within the beam spill. The system hardware are chosen to achieve 1-2 ns, but the ultimate resolution may be limited by the physics of light production in argon and wavelength shifting.
    d. Considering the addition of 24 non-TPB-coated PMTs to detect visible light. These could be used to detect Cherenkov light. Depends upon available funds.
2. PMT coatings:
    a. Tubes were sandblasted by Hamamatsu and are rated to 700 kPa. Expect deepest PMTs to experience 90 kPa => x8 safety factor.
    b. Plan to coat PMTs at INTLVAC in Ontario. Same company did evaporative coating for MiniCLEAN plates.
3. PMT base still being designed and tested to minimize overshoot response, two designs presented
    a. Splitter circuit described, using 4.7nF coupling capacitor, plan to change to .01uF
    b. Cables will be soldered to bases. Presented response of cables, RG-316 and LMR-195.
4. PMT readout done by 10 CAEN V1730 boards, 16 channels/board.
    a. 500 MHz digitization allows complete characterization of PMT pulse shape (~5 to 10 timing samples per PE pulse width).
    b. 14 bit ADC provide 25 charge bits for single PE and a dynamic range of around 512 PE.
5. Presented electronics rack requirements, AC Distribution chassis (SurgeX), HV Power supply, HV breakout chassis, CAEN VME crate, two grounding options, and safety 'handshake'.
    a. The HV DC Power supply requires 120V/30A service with a maximum power capability of 2340 W. The maximum power consumption in a given rack is limited to ~2.5kW due to cooling and the maximum continuous current allowed by the NEC code (80%). The fuse value on the unit is 25A which is a little above the continuous current max, 24A.

    b. The requirements call for an additional 120V/15A service within the same rack to power the AC Distribution chassis (SurgeX) to provide power to 'cooling fan inserts' and the VME crate (1200W).
    c. Grounding options were presented identifying options between building or detector ground and shield/return locations.
    d. DOE handbook hazard analysis was presented based on requirements of LANL safety review requirements, similar to our SEDR review requirements.
6. Presented plans to include a LED calibration based on system developed at ANL and deployed in the 35-ton detector. Small diffuser cells mount to the cathode plane and optical fibers must route to the feedthroughs in the cryostat roof.
7. PMT support frames mount to back of APA frames. 24 frames total, each holds 5 PMTs.
    a. The design is a deep-walled box frame that can be covered on front and back with removable panels. This design provides light protection and makes it possible to flush the volume with dry nitrogen gas if needed to protect the PMTs during construction phases.
    b. Uses threaded standoffs to make electrical/mechanical connection to APA frame. APA frames defined as detector ground.
8. Presented a design for cryostat feedthroughs needed for the PMT system.
    a. Construction includes the flange, a cable dressing ring, and heat shield. The flange includes HV SHV, sensor, and optical connectors.
    b. The SHV connectors are isolated with PEEK adapters which will be glued in place.
    c. Grounding tabs are provided on all SHV connectors.
9. Testing of components of the system is planned for spring 2017 using the mini-Captain detector at LANL.
10. Plan to cold test all tubes, 12 PMTs at a time, using cryostat setup at NMSU.

Comments:

PMTs:

1. Several months ago there was some concern regarding the safety of the sandblasting procedure. During this time, the warranty from Hamamatsu was reviewed to confirm that the company guarantees the product after the sandblasting procedure is completed.
2. Good idea to include non-TPB coated PMTs, if funds are available. Detection of Cherenkov light would demonstrate a new detection technique in LAr and provide a handle for testing the detector's optical model.

TPB coating:

1. Using a commercial company to do the evaporation of the TPB means they will need to be trained to handle PMTs, so this should be discussed soon to avoid delays later one.
2. A determination of the temperatures the PMTs will be exposed to in the evaporator should be made, and compared to Hamamatsu's maximum specifications.
3. Should specify acceptance thickness of TPB coating, if not already done.

Base design:

1. The overshoot in the PMT signal can become a problem when the overall detector rates are included. At MicroBooNE rates, the pileup of real signals with the overshoot tail will be a problem. A decision will have to be made on whether timing is more important than charge. You can remove overshoot by integrating the pulse shape, which loses timing information. Leaving things as they are is OK if the pileup probability is small enough to be tolerable.
2. Base design produces 0.72 W per tube. Should confirm with cry group that this is acceptable.
3. Solder flux needs to be well cleaned after soldering process. Suggest establishing a plan on exactly how to do this.

Calibration system:

1. Calibration of the absolute light scale will probably have to be done with cosmics (perhaps leveraging the tracker) and Michels. Some thought should be given to how important this will be for the various physics goals.
2. If SSP system is used, need to identify length limitation of quartz fiber. This will define the location of the chassis.

Mechanical support:

1. A measurement of the complexity of the assembly of the PMT support should be done, to ensure they can be assembled quickly and accurately.
2. Mounting design has numerous sharp edges. Typical designs have all edges rounded.
3. A suggestion was made to consider Teflon/peek bushings to slide frames on.
4. The PMT frame is directly attached to the APA frame. The APA frame is connected to detector ground (cryostat) via the CE LV returns on the warm electronics crate backplane. This means the PMT frame, and all metal components, will be on the preamp ground. We suggest insuring that all mechanical connections also be good electrical connections. Alternately, one could isolate the PMT frame from the APA frame and ground the PMT frame at the flange. The point is to make sure the PMT frame unit does not introduce noise onto the APA frame.
5. Need to work out how cables are routed outside of frame to the feedthroughs on cold side. Suggested a tray mounted off side of frame. Ensure local strain relief at bases.

Feedthroughs and cables:

1. Heat shield cable holes should be large enough to prevent cable jackets from being damaged.
2. Conduit routing forms a large inductive loop. Suggest routing one feedthrough conduit along top of I-beam structure to minimize loop area.
3. Feedthrough is very crowded, consider if a 14” flange is possible, given space.
4. Consider performing an FEA on peek feed-through connectors. Should do shear analysis.
5. There are different cables inside and out of cryostat. RG-316 is for cold with more loss. LMR-195 is for warm with less loss. But they have different capacitance, so need to confirm this is not an issue. Also, will be running these at voltages above their rating (1500V on the PMTs, cables rated at 1200V). Proper cables in full lengths should be used in testing.

Electrical, racks, grounding:

1. VME crate current requirements were not stated. 1200W, assuming ~10A.
2. System shown has 1 rack containing HV mainframe, break out chassis, and Digitizer VME crate.
3. Rack layouts do not take into account cable dressing.
4. Equipment power requirements exceeds maximum power limit per rack (3540W).
5. Rack layout requires two separate sources of AC power, 120V/30A and 120V/15A.
6. Crate sizes need to be compared with rack depths to insure adequate space for cable dressing and maintenance.
7. Suggest the rack layout be reconsidered to accommodate the multitude of cables.
8. Don't see any way of preventing two sources of power within one rack.
9. Due to the RPS requirements, an AC Switch Box 30 or similar device will need to be used to interface with the HV crate.
10. The current requirements of the equipment using the Surge-X should be evaluated to insure a 15A is actually big enough. Suggest using a 20A unit for commonality across the SBN program.
11. Suggest isolating cryostat from concrete floor and paying attention to all grounding connections.
12. There will not be room in one rack to contain the entire PMT system.
13. Suggest providing a threaded hole for securely connecting a ground braid from the SHV connectors to the flange top, if needed.
14. Grounding schematic should be revised to indicate that the system is powered from detector ground. Building ground is not an option. The option is where to ground the return of the HV cable going into and out of the 'splitter-breakout box', at the cryostat flange, power supply, or breakout box. Options could be tested at the cryo test stand.
15. Strongly suggest using the cryo test stand as a 'membrane' cryostat with 1 ground connection, continue to use full length cables that are NOT coiled up but actually routed in a serpentine manner, and the production electronics, cabled as though they were on the detector ground system -- one connection to the cryostat from the racks, isolated from the concrete floor. There will be no coiled cable in SBND, inside or out.

Testing:

1. Cold testing of all PMTs to measure tube gains, dark rate, linearity, and timing response is an important part of the team's plan.
2. Important that production cable types and lengths are being used during testing.
3. Suggest prototyping small version of flange with connectors to be used on experiment.
4. Pressure testing should include input from FNAL safety to insure the design meets lab safety requirements.
5. Cold testing of the calibration connections (fibers, etc.) should be considered, so there are no surprises when turning on.
6. Mini captain run should prove to be quite useful in gaining operational experience.

Recommendations:

The new PMT support frame box design interferes with a structural element that had been planned for the APA frames. Steel tie rods with turnbuckles connecting the upper corners to the bottom middle of the double APA assemblies are envisaged as a backup option to remove any vertical sag that may occur in the final TPC design since the deflection depends on the final weights of several systems (APA frames, field cage, PMTs, etc.). We recommend you work with the APA design group to update the engineering analysis with all the latest detector component weights to determine the necessity of the tie rods. If required, then a new design solution will need to be found to avoid interference with the PMT support boxes while providing the necessary support.

Answers to Charge Questions

1) Are the technical specifications adequately defined? Does the design meet the specifications?

Yes, the technical specifications are adequately defined and the design appears to meet them. The 100 ns timing resolution requirement will be easily met, and the goal of 1-2 ns may be possible - this is likely to be limited by the physics of scintillation production in LAr and will rely on sophisticated analysis and calibration techniques, will not be hardware limited with the present design. .

2) Is the design sufficiently complete to support the safe handling and installation of PMTs during assembly and transportation?

The support frame box design provides a possibility for minimizing light and humidity exposure when handling and storing PMTs during assembly. It is important to ensure proper handling during TPB coating at INTLVAC and should be discussed with the company (see comments).

3) Are there adequate engineering analyses performed to support the design?

Mechanical analysis of the mounting frames and feedthroughs have been performed. Engineering analysis and testing of PMT base designs are ongoing.

4) Are key interface and integration issues to TPC and cryostat identified and adequately addressed?

Interference with APA frame structural elements should be addressed (see recommendations). What is plan for routing cables in the cryostat, should explore if there are places on the APA frame to attach insulated cable runners.

5) Does the design of cabling and feed-through meet SBND electronics safety and grounding standard?

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6) Are the planned quality control measurements including PMT cold test sufficient to identify potential performance issues?

Yes, the cold testing of all PMTs in the system to measure tube gains, dark rate, linearity, and timing response is an important part of the team's plan.

7) Is the present design sufficient enough to support the start of PMT support and cabling component fabrication?

A prototype PMT holder bracket could be built to test the design. A prototype of the cryostat feedthrough should be built for pressure and electrical testing, working closely with FNAL safety personnel. Production of the PMT support box design should await decision on the APA support tie rod (see recommendations).

Appendix A: Charge to Reviewers

SBND Design Review of PMT Integration

Nov 18, 2016

Charge

SBND plans to deploy cryogenics PMTs from Hamamastu to detect scintillation lights from neutrino interaction in the liquid argon. The PMT tubes are to be mounted behind the TPC wire-planes to collect the vacuum ultraviolet (VUV) light produced in the TPC drift volume. The high voltage and signal cables are routed through cryostat feed-through ports before reaching the high voltage power supplies and CANE electronics in the detector building. The Committee is to conduct a technical design review of the subsystem including PMT surface coating treatment, PMT mounting support, HV divider circuit, signal calibration, cold cables and cryostat feed-through. Specially, the review team is asked to address the following questions:

- **Are the technical specifications adequately defined? Does the design meet the specifications?**
- **Is the design sufficiently complete to support the safe handling and installation of PMTs during assembly and transportation?**
- **Are there adequate engineering analyses performed to support the design?**
- **Are key interface and integration issues to TPC and cryostat identified and adequately addressed?**
- **Does the design of cabling and feed-through meet SBND electronics safety and grounding standard?**
- **Are the planned quality control measurements including PMT cold test sufficient to identify potential performance issues?**
- **Is the design present sufficient enough to support the start of PMT support and cabling component fabrication?**

The committee should present its findings, comments, and recommendations as well as answers to the above questions in a written report within 2 weeks of the actual review.