**LBNC Questions from May 10 Review Meeting**

May 27, 2021

**General / Performance Metrics**

1. Please list the differences between the FD2-VD and FD1-HD TPCs that affect physics performance and discuss the implication of each. Examples include:

a. 450v/cm vs 500

*and*

b. Drift distance (requirements on purity)

*The minimal purity requirement for FD1-HD in TDR (SP-FD-5) is <100ppt or >3ms. For the maximum drift distance of 3.5ms and nominal 500V/cm field the maximum signal attenuation for this lifetime is 0.48. For FD2-VD, the minimal requirement is >6ms or <50ppt O2 equivalent (Q1. from LBNC Dec 03 2020* [*https://edms.cern.ch/file/2447910/1/20-12-03-LBNC-breakout\_v5.pptx*](https://edms.cern.ch/file/2447910/1/20-12-03-LBNC-breakout_v5.pptx) *on p.6). This gives the maximum attenuation factor of 0.51 (0.50) for 500V/cm (460V/cm for 300kV PS), which is an equivalent figure to the one of FD1-HD. However, as discussed below for Q.2, the S/N expected for FD2-VD is higher at the same intrinsic noise level due to well-defined paths electrons follow through the anode holes leading to less signal induction on nearby electrodes. So, this is a conservative estimate.*

*Transverse diffusion in FD1-HD leads to a signal spread of ~2.4mm for the full drift distance. For FD2-VD this becomes ~3.3mm, similar to that in FD1-HD and still comfortably below the readout pitch. Longitudinal diffusion is smaller still.*

*We do not expect a significant difference in physics performance between 450V/cm and 500V/cm drift electric fields and the longer drift length.*

c. Readout strip length and pitch

*Taking the improved 3-view design (-30,30,90) degree as an example.*

*i) the strip pitch along the beam direction is 4.89mm, which is very close to the 4.79mm in the FD1-HD APA case. In comparison, the 3-view CDR reference gives 5.17mm strip pitch.*

*ii) the position resolution inside the anode plane (perpendicular to the beam direction) can be estimated as 7.335/cos(30°)~8.47mm, which is quite close to the 4.669/sin(35.7°)~8.00mm in the FD1-HD APA case. In comparison, the 3-view CDR reference gives 5.25mm.*

*Therefore, we do not expect a large difference in the hit-by-hit position resolution for the FD2-VD TPC 3-view design.*

*One advantage of FD2-VD compared to FD1-HD is the relative angle (~6°) between the anode plane and beam direction. This angle reduces the phase space of isochronous beam events (tracks or EM showers traveling parallel to the anode plane leading to ambiguities with the projection readout), which in principle can lead to better event reconstruction.*

*Compared to wire readout, the position accuracy for the PCB holes is better. This leads to improved uniformity in the reconstructed ionization charge (or deconvolved) charge.*

2. What are the criteria/metrics with which DUNE will determine whether the “image” quality of the events in VD is the equivalent to the one in HD? These criteria might also be different depending on the physics topic being addressed: nue appearance, numu disappearance, proton decay, supernova and solar neutrinos, BSM.

*At the same level of intrinsic electronics noise, the 3-view FD2-VD TPC performance is expected to be better than that of FD1-HD. This comes from the following:*

*i) the TPC signal in FD2-VD is expected to be larger than that of FD1-HD, which is a natural consequence of Ramo’s theorem, since the ionization electrons have to move through the PCB holes. The minimal distance between the ionization electrons and the sensitive electrodes is smaller than that of FD1-HD with wires. In this case, the TPC S/N is expected to be equivalent or higher in FD2-VD.*

*ii) Since the intrinsic electronics noise level of PCB strips is higher than that of wires at the equal length, we have to use shorter PCB strips (than wires). This means the total number of channels are larger in the FD2-VD than that of FD1-HD. More channels essentially mean more (geometry) information will be recorded, which is useful in reducing ambiguity.*

*Because of these, we expect the FD2-VD performance is equivalent or better FD1-HD in all physics subjects. A caveat mentioned during the meeting is that, for completeness, we intend to study particle tracking efficiencies for the lowest energy particles of interest for the baseline design, since the third view has a slightly larger pitch.*

*For the TPC broadly, the principal metrics that define the quality of the readout are minimal, largely defined at a low level (e.g., noise, pitch), and are comparable between the designs, by design.*

3. Regarding the above (metrics and the HV-VD comparisons), what will be provided/included in the CDR? Will there be a direct comparison of signal and S/N between HD and VD for the CDR?

*A more detailed articulation of the above will be included in the CDR, including comparing and contrasting the FD1-HD and FD2-VD designs. Available validation of noise and signal levels from the 50-L tests will be included. Cold box tests will come after the CDR but will provide a fresh round of validation in the fall/winter. Projected noise and signal characteristics from simulation, benchmarked against test stand or other data where possible, for the FD2-VD will be discussed quantitatively in the CDR.*

4. Please discuss the role of the calibration system and the requirements/specs for the system. When will these requirements be quantified?

*Calibration requirements for the FD1-HD design have been developed over a number of years and were further streamlined last summer during an extension internal review of the calibration and cryogenic instrumentation systems. Given the newness of the FD2-VD design, a first approximation is that the FD2-VD design would require comparable calibration systems. However, the implementations may ultimately differ.*

*The FD1-HD design includes an ionization laser system with eight upper field cage penetrations and the possibility of two additional penetrations to improve crossing-track coverage. This system would allow for monitoring of the detector, diagnosing of mechanical or electrical issues, and calibrating the uniformity or the drift field and readout plane alignment at the 1% level. An important step is the validation of this strategy in ProtoDUNE-II.*

*The FD1-HD design also includes at least one calibration system that can be used to study low-energy detector response. A pulsed neutron source is the favored approach for the FD1-HD, although a radioactive source system was also explored. The neutron source has the advantage of providing a high-statistics sample of low-energy neutron capture events throughout the active volume, thanks to the long mean-free path of neutrons in argon.*

**Simulation**

5. Results from ProtoDUNE HD showed that the TPC was very well modeled. However, for VD the simulation of the anode strips, holes, etc. may have different issues than the wires in the APAs. Simulation of induction strips needs to be benchmarked against upcoming coldbox data. Please discuss.

*The validation of TPC signal simulation and signal processing in MicroBooNE (*[*arxiv:1804.02583*](https://arxiv.org/abs/1804.02583)*) and ProtoDUNE-SP (*[*arxiv:2007.06722*](https://arxiv.org/abs/2007.06722)*) was completed. We plan to continue data/MC validation for FD2-VD TPC. We have initial studies based on data from the 50-L test stand. We will continue once coldbox data is available. The key metrics include:*

1. *Electronics noise level as a function of capacitance.*
2. *Raw waveform comparison between data and MC simulation for tracks with different incident angles.*
3. *Deconvoluted charge comparison between data and MC simulation.*
4. *Demonstration of consistency between deconvolved charge from different planes.*

 6. What are the plans for benchmarking the simulation against actual data (for example the coldbox) – for the TPC and PDS?

*TPC: please see the previous answer.*

*PDS: MC simulation for scintillation photons (from Ar) - propagation across large LAr volumes and collection by ARAPUCA and x-ARAPUCA detectors - has been extensively benchmarked with ProtoDUNE-SP data. The same light transport processes and input parameters in the simulation for ProtoDUNE-SP PDS are implemented and utilized for current Vertical Drift PDS simulations, with differences introduced for the propagation of Xe light in LAr. Results from the recent Xe doping tests with ProtoDUNE-SP are used as input parameters of the FD2-VD PDS simulation.*

*There are no plans for testing simulations with Cold Box data. Goals of the Cold Box tests are more technically oriented on individual detector components validation, rather than overall PDS characterization (that would require extended periods of data taking, dedicated external trigger system, accurate control and monitoring of operation conditions, etc.).*

*Opportunity for PDS simulation benchmarking will be provided by FD2-VD Module-0 data.*

7. Please describe/reference the light transmission in Xe doped LAr, justifying the choice of 15% Xe doping, and discuss the parameterization used in the simulation.

*The baseline assumption for FD2-VD is Ar doped with Xe at 10 –15ppm as scintillation medium. According to the Xe doping test in ProtoDUNE-SP [paper in preparation, main results presented at LBNC Review] this should allow for all Ar slow component light to be transferred and emitted as Xe light. A GEANT4 standalone simulation was performed to evaluate the impact of this amount of Xe doping on the overall light signal detected and uniformity of the light yield map. As in the DUNE TDR (vol IV), it was assumed that argon produces approximately 24,000 scintillation photons per MeV of energy deposited at the nominal DUNE electric field, with a distribution of 30% early plus 70% late scintillation light. The Rayleigh scattering length in argon for photons of 128nm (Ar scintillation) and 175nm (Xe scintillation) were taken to be 1m and 8.5m, respectively, taken from reference* [*arxiv:2002.09346*](https://arxiv.org/abs/2002.09346)*. The overall anode reflectivity was taken as 20% for Xe light only, accounting for the metallized area of the perforated anode PCB that could reflect light (about ~40% of the total area) and assuming a ~40–50% reflectivity of common metals to Xe light (reflectivity for Ar light is currently set to 0). Given the large FD2-VD volume, the impact of Xe doping with the aforementioned assumptions was an increase in the average light yield when compared to no doping of ~22% and a large increase in the minimum light yield of almost 3.5 times higher than with Ar alone, thus largely improving the uniformity of the light response across the active volume. This is due to the effect of the longer Rayleigh scattering length at the Xe emission wavelength, enhancing the collection probability for light emitted at longer distances from the detectors. This supports the choice of Xe-doped Ar as scintillation medium.*

**Trigger**

8. Does the choice of strip layout (for example the readout angles) impact the trigger?

*All trigger development to date for the FD1-HD module has used collection-wire information only. The orientation of the collection strips in the FD2-VD detector is only a 90 rotation around the z-axis compared to the FD1-HD, and thus has no impact on trigger activity-finding.*

*It is possible that induction-plane trigger primitives could help with fiducialization (see below) if we choose to do that in the Module-Level Trigger (before event building), and in that case there may be small differences depending on orientation. A finer pitch than that used by the FD2-VD (e.g., 3mm) could improve low-energy triggering simply because more collection channels may be hit for such events, but that will have to be balanced against the reduced signal per channel (and possible decreased signal-to-noise) for the finer pitch, and the increased rate of 39Ar for the longer drift volume imaged by each FD2-VD TPC compared to the FD1-HD. We expect the impact to be modest in any case, as triggering on trigger activity clusters of 3 wires in FD1-HD (which we have shown we can do if we would like to have ~50% efficiency or better at 5MeV) would become the equivalent of 5 hit wires for a 3mm pitch helpful for rejection pileup of 39Ar, but balanced against the higher intrinsic 39Ar rate because of the larger volume.*

 9. Quoting the talk by Josh Klein P20: "Can reduce background rates via fiducialization – maybe in high level filter". What is the time required for such an algorithm to run online? Will there be constraints from trigger point of view?

*Fiducialization is only helpful for low-energy events, in the solar neutrino regime (below about 15MeV, which means roughly 15–20 collection strips hit for “tracks” parallel to the plane). It is intended to remove neutrons that enter and capture near the edges of the active volume, or gamma rays that come from the anode planes or field-cage. These low-energy interactions thus do not require sophisticated reconstruction algorithms to determine their location in a way good enough to reject the external backgrounds. Fiducialization does, however, require good light yield for the PDS so that a well-defined t0 can be determined.*

*Along the drift direction, low-energy events can be fiducialized extremely quickly by comparing the timestamps of the PDS hits and the TPC hits (the system is fully synchronous). The PDS is so much faster than the TPC, that even an average of all PDS trigger primitive times is good enough to serve as a t0 for this purpose. Thus, this fiducialization could be done in the Module Level Trigger, upstream of the High-Level Filter, but it may be more natural to do it in the HLF simply because it may be interesting to also do simple PDS-based reconstruction there as well. Fiducialization along the z-axis is less critical for the FD2-VD, because the EndWalls have a smaller area than the top and sides, but with the planned orientation of the collection strips this is done simply by checking the closest strip to the EndWalls in a trigger activity cluster. Fiducialization along the x-axis is also very fast for these low-energy events because we only need to match hits between the induction and collection planes. This can be done using trigger primitive information, rather than full waveforms and associated deconvolution. In the FD2-VD case, the orientation of the induction strips parallel to the beam direction make this particularly easy as this becomes a strip-checking exercise like the z-axis, but for more angled views the matching of collection and induction hits will also be very fast.*

**PDS**

10. Please provide references / describe the justification for the assumed Arapuca efficiencies: 3% (reference layout) and 3.5% (fallback) (Laura Paulucci talk).

*A complete characterization of the ARAPUCA device (sensitivity to single PE, calibration, correlated noise and Signal-to-Noise evaluation, stability in time of the response, detection efficiency, energy resolution) can be found in the ProtoDUNE-SP performance paper (https://arxiv.org/pdf/2007.06722.pdf or https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004).*

*The most recent X-ARAPUCA performance paper, https://arxiv.org/abs/2104.07548, describes the full characterization of an X-ARAPUCA prototype with two dichroic filters (1/3 of a supercell). A second paper detailing a similar test, performed on a smaller prototype with just one dichroic filter and Eljen lightguide (1/6 of a supercell) will appear on arXiv shortly. A preprint can be downloaded https://drive.google.com/file/d/1sG8ypVv7QmG6zE1-rVe547WGq0yT2m4m/view?usp=sharing (we will update this link as soon as the paper appears on arXiv). In the former a measurement of 2.9(1)% was obtained. Similar numbers were obtained in the latter.*

*ARAPUCA represented the base of the development for the x-ARAPUCA design and in particular the ARAPUCA detection efficiency, cleanly measured in ProtoDUNE-SP, combined with detailed MC simulation of both ARAPUCA and x-ARAPUCA (see, for example,* [*https://iopscience.iop.org/article/10.1088/1748-0221/15/01/C01047/meta*](https://iopscience.iop.org/article/10.1088/1748-0221/15/01/C01047/meta) *or* [*arxiv:1912.09191)*](https://arxiv.org/pdf/1912.09191.pdf%29) *allows for the optimization of the number and geometrical distribution of SiPMs in the x-ARAPUCA final design. This together with improvements already prepared for the coupling of SiPM and the WLS bar, for example, should accommodate the efficiencies used in the simulation (3–3.5%).*

*It was an important step to have two independent simulations developed (Geant4 and Fluka) for internal cross-check and validation of the results in the system’s expected performance. The aforementioned difference in the efficiency parameter should alter the average light yield obtained by about 15%. Exactly the same set of input parameters’ values will be used in both simulations for the next round of event generation and calculations.*

11. The 1/sqrt(E) fits on p9 don’t look like they describe the shape of the resolution very well. Do you have more significant tails than expected?

*The 1/sqrt(E) term is a good approximation for the range of energy deposits up to about 40MeV. Above this value, the resolution reaches a plateau. The appropriate fit is “1/sqrt(E) + constant term”, as a consequence of the granularity (number of tiles per unit of surface and distance between tiles) of the photon detector coverage. This describes well the resolution for X and Z directions. In the Y direction (with less granularity), the resolution is coarse and poorly described by this fit. Improvements though are expected to come from the standard procedure (in large volume scintillation 4π experiments) of combining the simple barycenter determination with timing information on the arrival of the light signal by detectors at different positions (as indicated, for example, in the LENA proposal,* [*arXiv:1104.5620*](https://arxiv.org/abs/1104.5620)*). Information provided by the distribution of light detected by cathode photon detectors can also be used for improving Y-position resolution (see answer to question 16 below).*

 12. We understand that the specification for the light yield is >20PE/MeV (average) and 0.5 (minimum). Both the reference and fallback layouts satisfy these requirements, although only just for the fallback average.

a. How important to the physics reach is the improvement of the photon coverage from the Reference compared to the fallback layout, does the improved uniformity impact the physics?

*The backup design – as for the FD1-HD PDS - aims at being an ancillary system to the TPC, providing t0 determination and possibly some improvement on calorimetry when combined with charge information. On the other hand, the FD2-VD PDS reference design is envisioned as an enhanced PDS that will provide not only t0 but also independently energy and spatial location of an event, together with full trigger capability above ~10MeV (see answer below). Non-uniformity for light detection will likely limit energy resolution for the reconstruction of events across the FD2-VD volume. The relatively good light yield uniformity provided by the reference design would also likely reduce/simplify the requirements for calibration. Although it is not possible to provide a quantitative answer at this moment [see Q13,14], there are some existing studies of SN parameter biases as a function of uncertainty on detector parameters that may be relevant, and we are studying this.*

b. Please clarify the impact of the improved photon detection on the low energy triggering. Does it open up the window on new physics, or is that offset by backgrounds?

*With atmospheric argon, and no water shielding of the detector, it is expected that low-energy backgrounds will dominate over any (known) low-energy single-interaction physics signal, such as solar or diffuse supernova neutrinos, below about 7MeV. These backgrounds in the FD active volume include 6.2MeV neutron captures (1–10 Hz), 3.5MeV-endpoint 42Ar/42K betas (~1 kHz decay rate), and radon-chain decays. Above that energy, we expect that the PDS system will improve trigger efficiency, in part because of redundancy, but also because the “turn-on” curve for the PDS appears steeper in our studies to date. The PDS will also allow fiducialization of signal events, and thus can reduce the overall data rate and volume, thus potentially allowing a lower-energy threshold for triggering, which also improves efficiency above 7MeV. Nevertheless, significant work remains to determine quantitatively how much better we can do in the 7–10MeV regime by leveraging both the PDS trigger and the TPC trigger. Should underground argon become available or shielding with water (or another neutron attenuator) become possible, triggering at lower energies could leverage additional low-energy physics, perhaps including low-energy 8B solar neutrinos and the vacuum turn-on of the neutrino survival probability. Below about 2.5MeV, however, 2-neutrino double beta decay from 136Xe, which will be added with the Xe doping, would become a significant background.*

*For supernova triggering, the rate of backgrounds from neutron captures is not as significant an effect, because the “trigger” is on a burst of events, and background rates in the 10Hz regime can be mitigated if they are not also high in energy (thus, the rate from giant dipole resonances from alphas on argon is something that does need to be assessed further; it is expected now to be orders of magnitude smaller than anything that would matter for supernova bursts, but intrinsic Rn backgrounds will need to be measured). The PDS adds to the supernova burst triggering in two ways: first, it provides a way of removing “fake” bursts from neutrons caused by cosmic spallation, whose timing will look like the 200µs neutron capture time rather than the many seconds expected from a real supernova burst. Second, the increase in efficiency from the additional trigger path and the steeper turn-on curve allows a lower burst threshold, but this will have to be balanced against the natural inclusivity of the PDS trigger and whether the consequent increase in background rate will reduce the impact of the additional efficiency. Work to determine the improvement from using the PDS is still in progress.*

13. The physics case, as presented for the PDS (Kate Scholberg talk) and what it can offer to low energy neutrino physics, needs strengthening. Studies are ongoing, and slide 5 lists all that needs to be studied in order to see

a. what improvements the PDS system brings to those quantities (energy and position resolution, timing, etc.) and

*Traditional existing (and also more recently proposed) Scintillator based detectors implement 4π active coverage for underground low-energy neutrino physics. Along this line, by positioning large area detectors over multiple sides of the active LArTPC volume, the FD2-VD PDS reference design aims to reach uniform light yield throughout the volume and high on average, so as to be able to perform calorimetry and spatial reconstruction (and therefore also trigger with high efficiency) for neutrino events down to a very low threshold. Under this perspective, the FD2-VD PDS could perform those measurements on its own, completely independent and redundant to the charge TPC. At one hand, this represents a notable risk mitigation for physics, guaranteeing the highest possible live time (PDS active when LArTPC may be off for purity drop/maintenance, HV issues/maintenance, …) very relevant for long duration underground operation. On the other hand, given the complementarity of charge and light collected signals, the overall reconstruction capabilities of the FD2-VD detector can be improved when combining the information from the TPC with the PDS. Enhanced energy resolution is expected (as demonstrated by previous analysis from the LArIAT experiment), as well as in position resolution particularly helpful for rejection of radiological background near detector boundaries by volume fiducialization. PDS distinctive features, like time resolution and pulse-shape PID, and TPC specific features, like event directionality reconstruction, are expected to provide unprecedented means of overall physics reconstruction when combined information from high performance PDS and TPC is utilized.*

b. how these improvements affect the final physics output.

*The quantitative evaluation of the PDS background rejection capability and time resolution are the goals of the ongoing simulation studies. The combination with TPC response for full low energy underground physics reconstruction is next in pipeline.*

What is the timescale for providing more quantitative information on these?

*We can likely provide some improved answers to the questions on a relatively short timescale (in time for the CDR) by creating updated toy smearing matrices and using SNOwGLoBES to redo some of the TDR physics sensitivity studies. It’s also possible that we can do some preliminary low-energy directionality studies (using TPC simulation information) on a medium timescale. However comprehensive sim/reco studies will take somewhat longer, on the scale of 0.5–1yr.*

14. Many of the studies shown were rather schematic and clearly it will be some time before samples for physics studies are available yet those are vital for the decisions. Are there other ways in which the case could be fleshed out, e.g. using simplified simulation, etc.?

*See above answer. Some of the figure-of-merit studies for low-energy physics, such as SN parameter fitting, can be done using smearing matrices with approximate improved resolution in SNOwGLoBES. However, decisions, such as deviating from the PDS system reference design are not reliant on simulations, but instead on progress on the R&D. The choice from a physics perspective is clear and it becomes a matter of extracting as much benefit as possible as our analyses develop with time.*

15. What is the timescale for a more complete PDS simulation, including the “hybrid model” to include the volume outside the FC, the light that escapes from Arapucas, and benchmarking the fast simulation to full simulation.

*The full Geant4 simulation needed to obtain the parameters for the fast simulation in the vertical drift, using the semi-analytic model, are running at the moment and should be available in the next couple of weeks. The implementation of the hybrid model in LArSoft is in an advanced state, with tests performed for the SBND experiment, and should become available in the next month (it will be presented at the next LArSoft Coordination Meeting). In this way, we believe that a more complete PDS simulation should be available in July. A few weeks should be dedicated to testing and tuning of the parameters, including digitization of the signal and generation of backgrounds before samples for physics studies can be produced.*

*Regarding the light that escapes from Arapucas, the extra light emitted at the Arapuca optical window could contribute to the light yield budget in two ways: 1. being reflected on the semi-transparent surfaces closer to the photon detectors (cathode mesh or field cage) and return to an Arapuca; 2. passing the semi-transparent surfaces and reaching another plane of detectors. A simple estimate for situation 1 indicates that up to a 10% increase on the direct signal for cathode PDS could come from these reflections assuming: the mesh is close enough such that all photons return to the sensor's windows; its frontal transmission is ~80%; and a reflectivity of the order of 50%. This effect could be included as an overall increase in the detection efficiency instead of in the simulation itself. This estimate is expected to be lower for Arapucas over the membrane walls given the 60cm distance to the field cage. For situation 2, considering that the scattering length in liquid argon for photons at the PTP emission wavelength range (~350nm) is of order ~14m their trajectories can be taken as straight lines inside the FD2-VD volume for an estimation of the fraction of light that arrives on the other sensor planes. For instance, a calculation for back emitted light by an Arapuca placed over the cathode, accounting for the angular lambertian emission of PTP, transmission through the cathode mesh and through the field cage as function of incoming angles and surface detector coverage over the cryostat membrane walls indicates a fraction of 0.1% with respect to the total escaping light would be expected to be detected by the membrane sensors. Therefore, this should be negligible.*

*The currently used modes for fast simulation of light in DUNE simulation, the semi-analytic model and the use of an optical library, have been compared to the full light simulation in Geant4 for the SBND experiment. This used a highly segmented and large photon count optical library, created with ~1.6M voxels, with 0.5M photons being generated in each voxel (total of 7.9x1011 photons), resulting in a file of size 1.2GB. A similar optical library for the DUNE 1x2x6 geometry (volume of 7x12x13.9m3) would be prohibitively large. All DUNE optical libraries produced so far have significantly larger voxels and less photons per voxel being simulated in comparison with SBND which was used as reference for the comparison of the two modes. It has been reported that the optical library has problems to properly describe light signals generated closer to the detectors and more on-axis (up to ~50º). This is a known issue caused by the intrinsic discontinuity of the voxelization schemes. The semi-analytic model, on the other hand, presents a reduced resolution when going off-axis due to shadowing effects. The influence of shadowing should be minimal for the case of DUNE as there are no PMTs in the geometry (in SBND, the PMT windows reach out ~10cm beyond the x-Arapuca windows), so in the DUNE case we expect a good performance of the semi-analytic model also in the far-off-axis cases. Specifically for the x-Arapucas in SBND, a better performance of the semi-analytic model was identified: better resolution close-on axis (3.6% vs 5.6%), with no bias (less than 1%) in any case, while the optical library is systematically biased (2.5–4.9%), in particular for the larger/closer signals. This together with the very high memory consumption (of several extra GB) during simulations when using an optical library justifies the choice of the semi-analytic model as the default for fast simulations in the DUNE FD.*

 16. Can you use the PDS on the cathode to reduce the position error in the Y-axis?

*Yes, it should be possible to use the light detected by the cathode PDS to reduce the position error in the Y-axis. Two paths in order to achieve this are currently being considered: 1. To look at the total light detected by the cathode photon detectors. Since the light yield from the cathode plane alone (backup slide from L. Paulucci’s talk, number 20) shows a stronger dependence on the y position of the energy deposition, the total number of PEs detected at this plane could be used for an estimate on the y position; 2. To look at the geometric light pattern detected by the cathode photon detectors. Events happening closer to the cathode should provide a sharper peak when creating the histograms in the X and Z directions. A gaussian like fit directly in a 2D histogram of the number of PEs for that plane as a function of the X and Z position of the detectors might show a correlation between the y position and the sigma obtained.*

**2D/3D and Optimization**

17. Regarding the differences between HD and VD and on using the HD to study/optimize those (Dominic Brailsford talk): It is not straightforward to assume that the HD->VD transfer is applicable, please explain/make the case better. For example, why should HD studies on the 2-view vs 3-view HD will be applicable for the VD detector? The same question will hold for the rest of the VD optimization studies that need to be carried out.

*Both the horizontal and vertical drift detectors work under the same general principle, where each readout plane observes a 2D projection of a neutrino interaction. This is true despite any of the proposed differences in the readout systems and drift orientation.*

*The reconstruction’s task is to create clusters of hits in each 2D projection and then match those clusters between the readout planes, correlating timing or charge information, to create 3D particles. This procedure is also the same for both detector types.*

*Because of this equivalence, observed changes in reconstruction performance when varying common features (2-views vs 3-views, readout orientation and pitch, etc.) in one detector should reflect the performance changes in the other detector. This detector equivalence has been previously exploited for ProtoDUNE-DP (a 2-view/strip based LArTPC) where the Pandora reconstruction, designed in the scope of a wire-based/3-view LArTPC, successfully reconstructed ProtoDUNE-DP Monte Carlo without modification.*

*We plan on migrating the optimization studies to the full vertical drift geometry as soon as the reconstruction interface is configured. Studies performed so far have been done on the FD1-HD geometry only because that was available immediately.*

18. Initial studies suggest that 2-view readout will underperform compared to 3-view. What is the reason to continue studying 2-view as an option?

*The reconstruction for a 3-view detector is very well-established and validated in detectors such as MicroBooNE and ProtoDUNE-SP. The reconstruction algorithms that enhance the performance in a 2-view LArTPC were only recently released in the context of ProtoDUNE-DP, exploiting calorimetric information in 2D→3D matching for the first time, and thus making use of a limited suite of tools. It may very well be that, given sufficient development time, the performance of a 2-view detector approaches that of a 3-view detector, or it may be that it performs significantly more poorly.*

*So, while initial studies do indicate potential underperformance, given the potential cost savings of a 2-view readout, DUNE is continuing to develop the 2-view techniques in parallel to other reconstruction development. The 2-view option is a backup/alternative design, however, so 3-view studies are being prioritized.*