begin LBNC comments in italic

Calibration: We consider this part to be generally in good shape. Also, the talk clarified well the roles of the various calibration signals (those that come for free and those that are planned to be installed. The questions below in part go beyond the physics TDR itself.

(i) What are the exact inputs expected from CAPTAIN? How important are these inputs, and how much impact is there if CAPTAIN can't deliver these inputs?

Our uncertainties do not currently rely on CAPTAIN inputs. Generous uncertainties are assigned in the detector response. (Mini) CAPTAIN has released new results which will be used to improve the detector model.

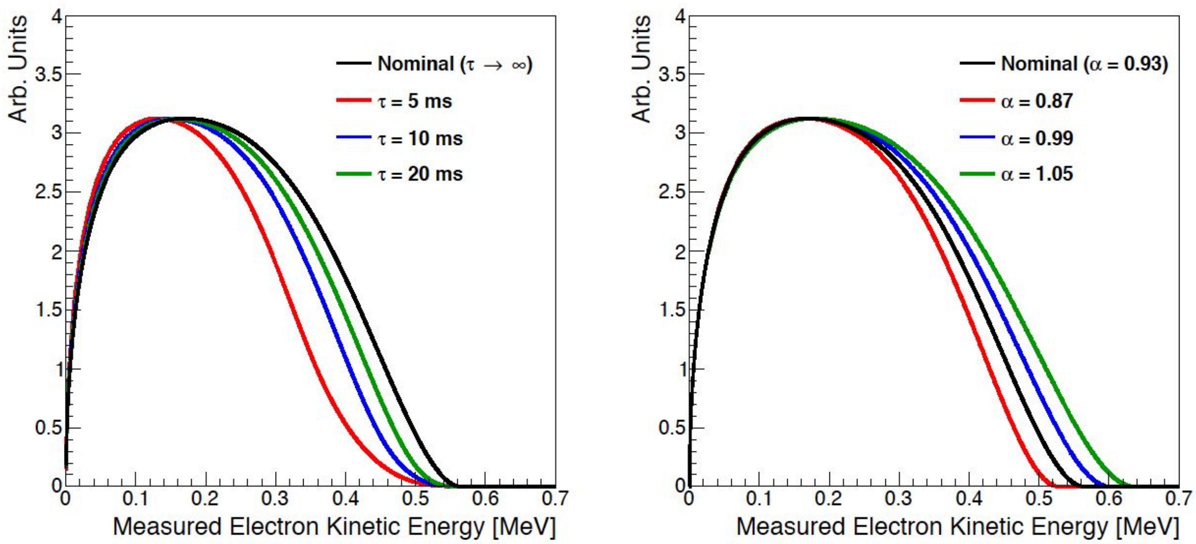
The uncertainties in the LBL analysis include uncertainties on both the neutron detector response model and also on the neutrino interaction model. Calibration informs the first category. At the time of the TDR writing, CAPTAIN had not released results. The neutron response uncertainties were determined based on previous single-detector/calorimetry analyses (MINERvA) and corresponded to 20% on neutron energy scale. This assumes that the disagreements between existing models and data are: 1) similar between C and Ar and therefore comparably sized for Ar, and 2) the entire source of the discrepancy is attributed to the detector model.

We expect that there are significant uncertainties on the interaction model with energy into neutrons, and these are separately treated. These are (currently) outlined in the appendix of the physics TDR. The major sources of missing energy from neutrons are the FSI uncertainties, "E_availible/q0" uncertainty (intended to inflate FSI uncertainties as Ar has larger FSI effects).

(Mini)CAPTAIN recently released first results on the total neutron cross section as a function of kinetic energy [https://arxiv.org/abs/1903.05276]. The neutron total cross section is flat with energy except for the lowest energies and around 600 MeV. These results (and any others) will be valuable for DUNE in refining the detector model, but our current uncertainties attempt to reflect the limited information available now.

(ii) Ar-39 decay- How are you going to measure the end point energy accurately?

The technique is being developed and we will reply with more details soon. The Ar(39) samples serve as one of the tests of the detector model and calibration program, i.e. it compares a "known" source to our detector simulation. The method is as follows. MC templates with data-driven noise model will be used to measure the end point of the reconstructed beta decay electron energy spectrum. A number of factors can impact accurately measuring the end point energy: noise, wire response, electron lifetime, recombination (and electric field). In addition to the mentioned detector response effects, cosmogenic activity and other radiological backgrounds can contribute to the high energy tail of the observed. Many of the detector effects may be determined in-situ. For instance, measuring the electronics response can be done in situ with pulser data (charge injection on the front-end ASICs); measuring the wire field response can be done with cosmic tracks and other dedicated measurements ex situ (e.g. at BNL). There are plans to measure recombination parameters ex-situ (e.g ProtoDUNE, MicroBooNE). The MC templates will change due to lifetime and recombination. As lifetime and recombination impact the energy spectrum in different ways (see the plots below), even if we didn't know them very well, one should in principle be able to extract both simultaneously given the different impact to the shape.



This technique is currently being demonstrated using MicroBooNE and ProtoDUNE-SP data. A preliminary result from MicroBooNE on Ar39 can be found at this public note: http://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1050-PUB.pdf. A public presentation at a recent LArTPC Calibration/reconstruction workshop would also be useful to understand the method: https://indico.fnal.gov/event/18523/session/17/contribution/27.

(iii) *What kind of LASER system will be used? What will be the configuration?*

We propose to use a 266nm Nd:Yag laser as has been done in previous experiments (ArgonTube, MicroBooNE and soon SBND, helpful reference: New J.Phys.12:113024,2010, https://arxiv.org/abs/1011.6001). An example vendor is here: https://amplitude-laser.com/ The details of the entire laser system will be found in the SP detector volume for calibration.

(iv) *What is the plan for calibration of the Near Detector? Whose responsibility it is? Is there a connection between the FD calibration effort and the ND calibration plan?*

The current calibration effort is to develop a plan for the FD calibration program only, as the ND concept design is evolving. Each individual component of the ND will need suitable calibration systems and this will likely be the responsibility of the ND consortium (or suitable structure) when it is formed, with advice from the existing FD effort.

Some of the calibration systems may be applicable from the FD LAr detector (such as the laser system or pulsed neutron source) for the ND LAr detector, however, the different detection method (pixel readout) will require modifications to design or deployment. While the FD lacks copious cosmic rays, the ND will have those as a source as well as neutrino+rock interactions producing muons in a horizontal direction as well. These provide straight tracks for which a variety of measurements can be made. However, we also note that space charge will be an issue for the ND, so dedicated calibration systems (e.g. the laser) may be needed; this is to be assessed. The pulsed neutron system may be very valuable for characterizing neutron capture in the detector 'on demand', however copious neutron captures (though without timing) will be available in the ND hall.

(v) How accurately do you know the neutron cross section for use with the pulsed neutron source?

The exact anti-resonance cross section "depth" and energy point are not a major factors in design, as we moderate the neutrons to 70 keV, and the Ar between the entry point and FV down-moderates the neutrons until they hit the anti-resonance. Furthermore, the anti-resonance is slightly different for the different Ar isotopes, so the scattering length is so the scattering length is a weighted average of the different isotopes. The entire (pulsed neutron source) system will also be demonstrated in ProtoDUNE with existing feedthroughs.

There are plans to measure the anti-resonance cross section in detail, with a transmission experiment with a liquid argon target at LANSCE. A proposal has been submitted to LANL this spring; it is not expensive or time-consuming as LANL has the appropriate instrumented beam, details below. LANL has already indicated a willingness to host such an experiment, as they recently did for our neutron capture on argon experiment (ACED). The only additional items are to make a target of ~1m; it does not have to be pure argon since it is just an absorber.

The LANSCE beam is pulsed into a moderator so that there is a good energy separation via Time of Flight (TOF) below about 1 MeV, so it works quite well to do this experiment. Only certain times (corresponding to certain energies) will make it through. Flight Path 14 (FP14) has a 20 meter TOF baseline. So the difference between a 65 keV and 50 keV neutron is almost 0.8 microseconds.

(vi) Slide 23- Neutron absorption is not uniform. What is the reason for this?

We didn't completely understand what the question was exactly referring to, but here is a more general description of what is shown in the figure.

The neutrons are collimated and moderated to enter the detector. The entry points are above the fiducial volume, so one should imagine an isotropic source placed above the top of the figure, which is providing a slight forward (== downward, decreasing z) bias to the event rate. There are two sources, producing the two lobes at the extreme edges of the detector as the sources are placed at the manholes. Finally, note the difference in the y-axis (z in detector dimension) scale (neutrons travelling down can reflect back up, but neutrons travelling in x-axis (== x detector dimension) go 30m on average before an interaction. We are happy to answer any further questions you may have on this.

(vii) *Is there a plan to put Rn in the Ar?*

We understand that this is a common system for dark matter experiments and can have significant value. We have had some discussion about this and it could be a useful idea, but we have to mitigate the following concerns for this technique as applied to DUNE:

- Concern: photon detection systems are not as efficient/complete coverage as they are in Dark Matter experiments. This will affect our ability to tag t0. Then, we don't know the spatial distribution to do lifetime corrections since we don't know t0 -- may be able to do something in y and z (not drift direction). The lack of t0 also impacts the ability of using these sources to track the fluid flow.
- Concern: Need to consider radio-purity requirements (and if there are consequences for daughter particles produced). Example: Currently protoDUNE screens for radon parents and radon daughters (which can plate out) so would not choose Rn222, would consider Rn220 (aka thoron) as an injection candidate.
- Concern: visibility of signal and triggering relative to the massive amount of 39Ar-- may need quite an intense source to see it over the 39Ar.

The concerns above were viewed as a major limitation for this method. However, we understand that the photon detection system has recently improved capabilities, so we can revisit discussing how t0 tagging of point like activity in the detector // conceptual idea of how the analysis would proceed.

On a practical level, we have prioritized our effort on ensuring suitable feedthrough options and the designs of the externally deployed systems, which are more urgent in DUNE's timeline. We plan to revisit Rn injection at a later date. But, given the list of concerns/limitations discussed above, we will consider this as an alternative in the future. In terms of cryostat accommodations, the multi-purpose calibration penetrations can be used for injection sources if we decide to use this calibration method in the future.

(viii) *No mention of timing calibration which may be extremely useful for SN events.*

This is under study and more details will be provided in the future. The value of one of the baseline systems (the pulsed neutron source), is that it has a timing signal associated to it, though the system also has to rely on neutron capture. This will provide a timing calibration for the DAQ for neutron response for SN signals. The laser system also is timed.

JM: If you mean calibration of the PDS, that is outside the scope of the Calibration Consortium, and in the scope of the PDS.

(ix) Is there going to be a calibration section in the detector TDRs?

Yes! There will be dedicated chapters for SP and DP.

(x) This section focuses on dedicated calibration systems. Should calibration via cosmics or other more or less well-known backgrounds be mentioned? BH: I disagree with this comment. There is a discussion of cosmics and other "free"sources, see table 4.1.

Thank you, Beate! Yes, this was a part of the calibration chapter under ‘tools and methods’ in the physics TDR material provided. If further details are desired for our existing sources (cosmics, beam pi0s, Ar(39)) we will add appendices, please let us know.