11th September 2017

Strategy for DUNE TPC Electronics (DRAFT)

This document outlines the strategy for the development, validation and testing of the Cold Electronics for the DUNE Far Detector. It follows on from the recommendations of the Cold Electronics Task force (dune-doc-2374). This report was discussed at the DUNE Executive Committee meeting on 5th June and three main points were agreed:

- the existing cold ADC ASIC design would no longer be pursued and a new cold ADC solution would be developed;
- the development of the new ADC should be a collaborative effort between more than one institution, to avoid a possible single point of failure;
- if resources were available, an alternative solution should be investigated. This could be a single-chip solution or an alternative to the new baseline cold ADC (once chosen).

Timeline

There are number of assumed dates that frame the programme of work:

- mid-2018: Technical Proposal;
- mid-2019: Technical Design Report;
- late 2021/early 2022: start of mass production of the chips;
- end 2024: first detector commissioned.

Overall Strategy for Options

There are four potential solutions that are being considered:

- Option 1: **a new custom ADC ASIC**, with the cold electronics system comprising: a final iteration of the existing frontend chip + a new custom ADC ASIC + the COLDATA ASIC:
    - within this option there are three ADC architectures currently being considered.
- Option 2: an integrated single-chip solution based on the **NEXO chip** being developed by SLAC.
- Option 3: **a commercial ADC**, replacing the custom ASIC;
- Option 4: other custom ADCs, such as **ATLAS ECAL ADC**, replacing the custom ASIC in Option 1;

The collaboration strategy is to focus on two solutions. The **baseline** is the new custom ADC ASIC (Option 1), as recommended by the Cold Electronics Task Force. The **alternative** solution is the SLAC NEXO single-chip solution (Option 2). The baseline will be used for the cost estimates in the Technical Proposal, but the final choice for the far detector will be based on the relative performance of the two solutions. Until the new custom ADC solution is proven, the commercial ADC and ATLAS ECAL ADC will be retained as fallback options for the 3-chip solution.

Option 1: Custom ADC ASIC (baseline)

- The choice of the custom ADC over, for example, a commercial option is motivated by a number of considerations, including the potential advantages of a solution using design rules for cold operation and the layout is understood by the consortium.

- The Cold Electronics consortium will not assume that the existing FE chip meets the requirements for DUNE and will define a programme of testing the FE chip to understand its contributions to the system noise, both in isolation and when coupled to the overall system.
- The design study for the architecture of the new custom ADC is already underway and the choice for the new ADC architecture will be made by the end of October 2017.

Option 2: SLAC NEXO chip (alternative)

- The SLAC NEXO chip has a similar FE architecture to that developed by BNL for the existing FE chip. It combines frontend, ADC and data handling functionality on a single device, which has potential advantages. However, modifications will be required to optimize the noise performance for much larger capacitive load of the DUNE APAs.
- DUNE supports the deployment of resources to modify the SLAC NEXO chip to account for the different capacitive load.
- It is not *a priori* clear that the SLAC NEXO solution will deliver the required performance; it is not self-calibrating and was not designed specifically for liquid argon temperatures. However, from the systems-engineering perspective, a single device may minimize other risks.
- If the SLAC NEXO chip were adopted, there would need to be a clear plan for how multiple institutions would be involved in the final design and evaluation to mitigate the risks of relying on a single institution.

Option 3: Commercial ADC (risk mitigation)

- The commercial ADC option is being studied by SBND and DUNE will monitor these studies. This is not a preferred solution, but it is considered as a risk mitigation strategy until the custom ADC has been developed and validated.
- There are concerns about the practicalities of the commercial ADC option for DUNE. It would require the purchase of a very large number of chips prior to long-term testing and evaluation in order to avoid potential changes in the production process and/or packaging. The commercial ADC option is therefore only considered as a risk mitigation strategy and will be discarded when a custom ADC has been validated.

Option 4: ATLAS upgrade ECAL ADC chip (risk mitigation)

- The ATLAS ADC for the ECAL upgrade is not a preferred solution, but it is considered as a risk mitigation measure until the custom ADC has been developed and validated.
- The ATLAS ADC is being developed for warm operation using ATLAS resources. Columbia will be provided with some limited project resources to evaluate its operation in the cold.

Testing Options

There are five (currently planned) options for testing the cold electronics chain:

- **CERN Cold Box:** this provides a systems test in the cold (gas) with a full-scale APA. DUNE plans to produce seven APA planes, six for protoDUNE-SP and one for the Cold Box, to provide a long-term test facility.
- **ProtoDUNE:** the existing implementation of the cold electronics (FE + ADC) will be tested in the first year(s) of protoDUNE operation. It provides a full systems test in the TPC environment, but not with the final version of the electronics. The comparison of the noise in protoDUNE-SP with that seen in the Cold Box will establish the level of equivalency of testing in the Cold Box with the full TPC.
- **LArIAT:** is an easy to use system that would allow DUNE to test future versions of the cold electronics systems in a small liquid argon TPC. The shorter wires mean that the capacitive load is different from a full scale APA.

- **ProtoDUNE (Phase 2):** in principal it is possible to replace the cold electronics boxes in ProtoDUNE-SP. This is not a trivial operation, but access through the manhole is possible. One installation option for the new cold electronics to be installed from outside the field cage. This appears to be possible from the Jura side of the detector. DUNE wishes to retain the option of second phase of protoDUNE operation as a possible test of the final system in 2020 or 2021, but this may not be possible due to lack of resources.
- **SBND:** could provide an option for a long-term test of DUNE cold electronics. However, it is not an ideal proxy because the SBND APAs are somewhat smaller and do not use wrapped wires. The current plan is for SBND to be operational in late-2019/early-2020. SBND intends to make a decision on electronics in 2018. SBND could provide risk mitigation in the event of the unavailability of protoDUNE-SP, but timing is an issue. A second phase of SBND operations (with replaced electronics) after the physics run would come too late for DUNE. If the start of SBND operations were delayed to 2021 for external reasons, it could provide a test bed for the DUNE Far Detector electronics. This is not the preferred option for DUNE and would require the DUNE final design to be ready relatively early.

Testing Strategy and Decision Tree

Prior to the TDR, DUNE will plan for systems tests of the baseline and alternative options in both the CERN Cold Box and in the LArIAT cryostat with a small liquid argon TPC. The Cold Box tests establish performance of the electronics coupled to a full-scale APA in a correctly grounded environment, but in a gaseous environment, without TPC drift. LArIAT would provide tests in an operational LAr-TPC, but at a much smaller scale. The technical feasibility of this plan still needs to be established and will be investigated before the end of 2017. The testing strategy and outline decision process is summarised below:

- **End of 2017**: the Cold Electronics Consortium will establish the criteria for deciding whether to adopt the baseline solution (2 or 3 chips) or the alternative single-chip solution.
- **End of 2017:** the current ProtoDUNE-SP electronics tested on an APA in the CERN cold box. This will establish the noise level in the existing system in this environment.
- **Early 2018:** standalone tests of SLAC NEXO chip. This will establish whether this chip might provide a route to the required low noise operation for the DUNE far detector.
- **Technical Proposal (Q2 2018):** unless initial testing of the SLAC NEXO chip excludes a viable path to the DUNE requirements, the technical proposal will include the baseline and alternative options,
- **Q3 2018:** operation of current ProtoDUNE-SP electronics in the full detector. This will provide a systems-level test of the existing solution and will establish the degree to which testing in the Cold Box can be used to predict the full performance.
- **Q3 2018:** standalone tests of new custom ADC ASIC.
- **Late 2018:** test the current electronics in LArIAT to establish a reference point that can: a) be compared to Cold Box and ProtoDUNE-SP performance; and b) to allow for subsequent comparisons with the designs for the final systems in LArIAT.
- **Early 2019:** tests of baseline *and* alternative options in both the CERN Cold Box (full size APA in cold gas) and in LArIAT (small TPC in liquid argon), prior to the TDR.
- **Technical Design Report (Q2 2019):** at this time, we will have results from protoDUNE-SP and the tests of the baseline and alternative options. If the performance of the baseline and alternative options are similar, e.g. within 20% in terms of Equivalent Noise Charge, both will be presented in the TDR. In this case, the DUNE collaboration will initiate a technical review (based on the previously agreed criteria) to decide which option is presented as the baseline for the DOE CD-2/3b

review. If there is a clear difference in performance in the testing environments, e.g. one option has 50% higher ENC, only one option will be presented in the TDR.

- **2020**: DUNE will plan for a full system test of the final cold electronics options presented in the TDR to take place during 2020. ProtoDUNE is the favoured choice, at this stage.
- **2020-2023:** A long-term, large-scale stability test of the final cold electronics, in order to test reliability and longevity, will take place in the period 2020-2023. The testing plan will be developed by Cold Electronics consortium during 2018.

Detailed Milestones

To be established by the Cold Electronics consortium.