Timing and Synchronization of the DUNE Neutrino Detector

D.Cussans[1]
for the DUNE collaboration

[1] University of Bristol, UK

DEEP UNDERGROUND NEUTRINO EXPERIMENT

University of BRISTOL

15-Second Summary

Goal: The DUNE neutrino experiment far detector has a fiducial mass of 40kt. The O(1M) readout channels are distributed over the 4 x 10kt modules. They need to be synchronized to better than O(1ns) within a module and O(1µs) to TAI with a reliable, simple, and affordable system.

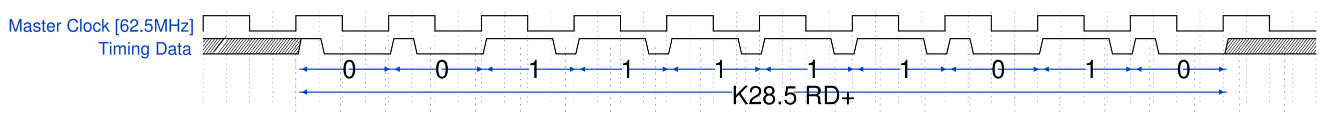
Summary: A 62.5MHz clock and 64-bit time-stamp are distributed by optical fibre.
The protocol is based on Duty Cycle Shift Keying(DCSK)
8b10b encoding is used to maintain a 50% duty cycle.

Laboratory Tests: Small scale tests show a timing jitter of O(10ps).

Beam Test: The DUNE timing system has been successfully prototyped at the ProtoDUNE detector at CERN.

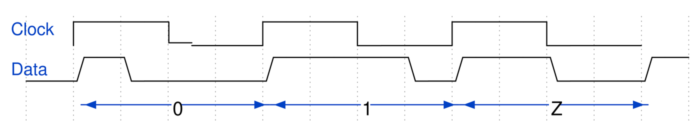
Protocol

- Duty Cycle Shift Keyed[b] serial data is transmitted over a 1000Base-Bx[c] optical link from the timing master to timing end-points. 8b/10b[d] encoding is used to enforce DC balance. Data are transmitted at 62.5Mbit/s with 25% duty cycle representing "0" and 75% representing "1".
- DCSK data has a rising edge at the beginning of every Unit Interval and can be directly used as the input to PLL-based clock generators. This removes the need for the CDR ASICs used in earlier prototypes of the DUNE Timing System[e]
- The data carries commands that are used to synchronize a 64-bit time-stamp counter in the end-point and propagate commands and synchronization messages.
- The link is bidirectional and data transmitted from the end-points are used to calculate the latency between master and end-point.



8b10 control character with Duty Cycle Shift Keying

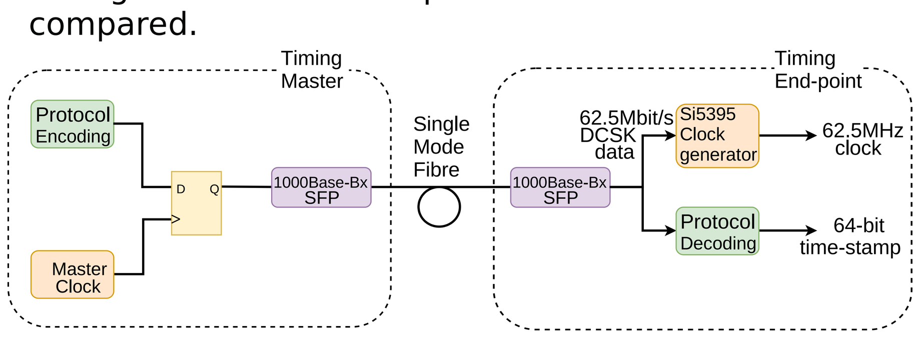

1000Base-BX
Small Form-factor Pluggable (SFP)
optical transceiver



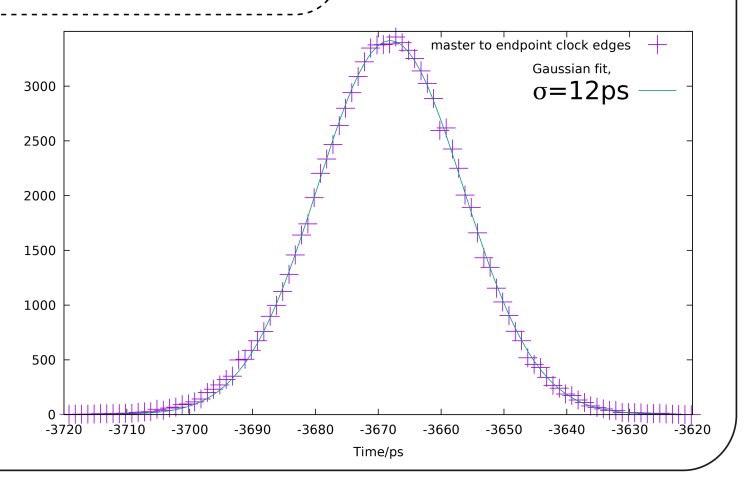
DCSK representation of '0' , '1' and 'Z'

Laboratory Tests

- Timing jitter performance was measured in the laboratory by connecting a timing master to an end-point. The clock in the master and endpoint were compared.

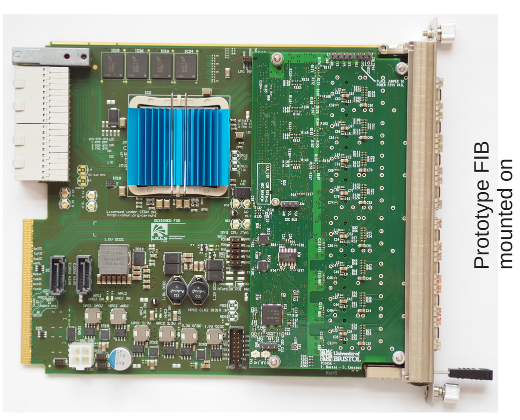


Block diagram of
jitter performance test set-up



"Beam Test" (ProtoDUNE)

- The DUNE timing system was used to synchronize the ProtoDUNE-SP experiment performed at the CERN Neutrino Platform. ProtoDUNE continues to be a test-bed for the timing system.


Prototype FIB mounted on COTS AMC (AFC)


FIB+AMC in uTCA crate

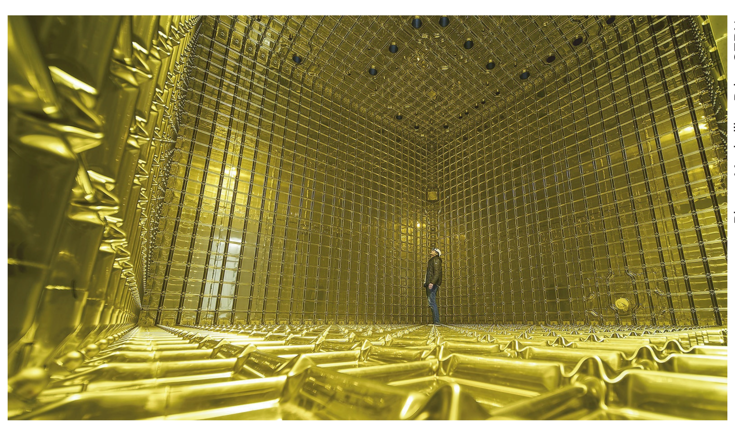
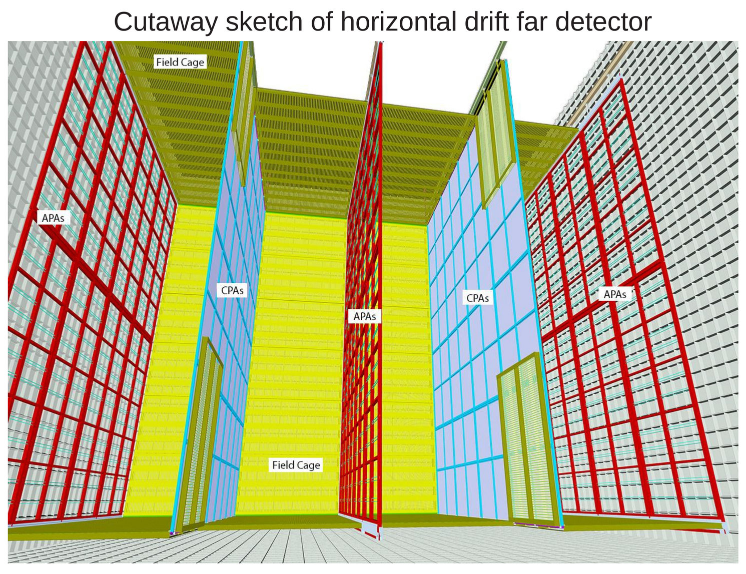


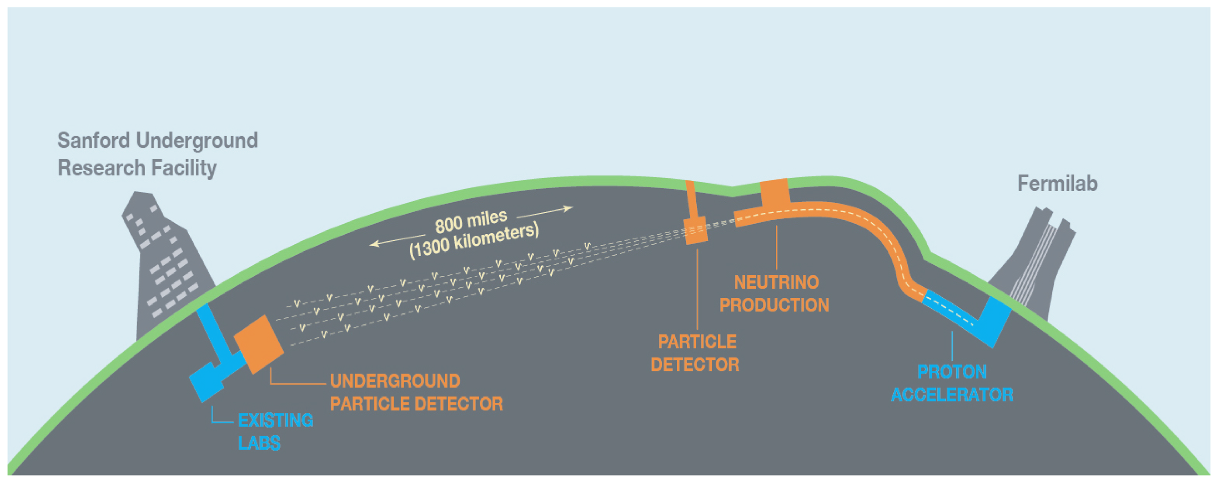
Photo: Maximilien Brice,CERN
Empty cryostat for ProtoDUNE-SP,HD

The DUNE Experiment

- The Deep Underground Neutrino Experiment (DUNE)[a] will detect neutrinos generated 1,300km away in Fermilab, near Chicago.
- The far detector will consist of four modules, each with 10kt fiducial mass of liquid argon. The energy deposited by the products of neutrino interactions will be detected in two ways: ionization drifted by an applied electric field to pick-up electrodes, forming a time projection chamber (TPC), and scintillation light.
- In order to reconstruct events with the photon detection system readout channels must be synchronized to each other with a precision of nanoseconds. To correlate events in the far detector with neutrino generation at Fermilab the entire detector must be synchronized to International Atomic Time (TAI) via GNSS to a precision of better than 1µs.

Cutaway sketch of horizontal drift far detector

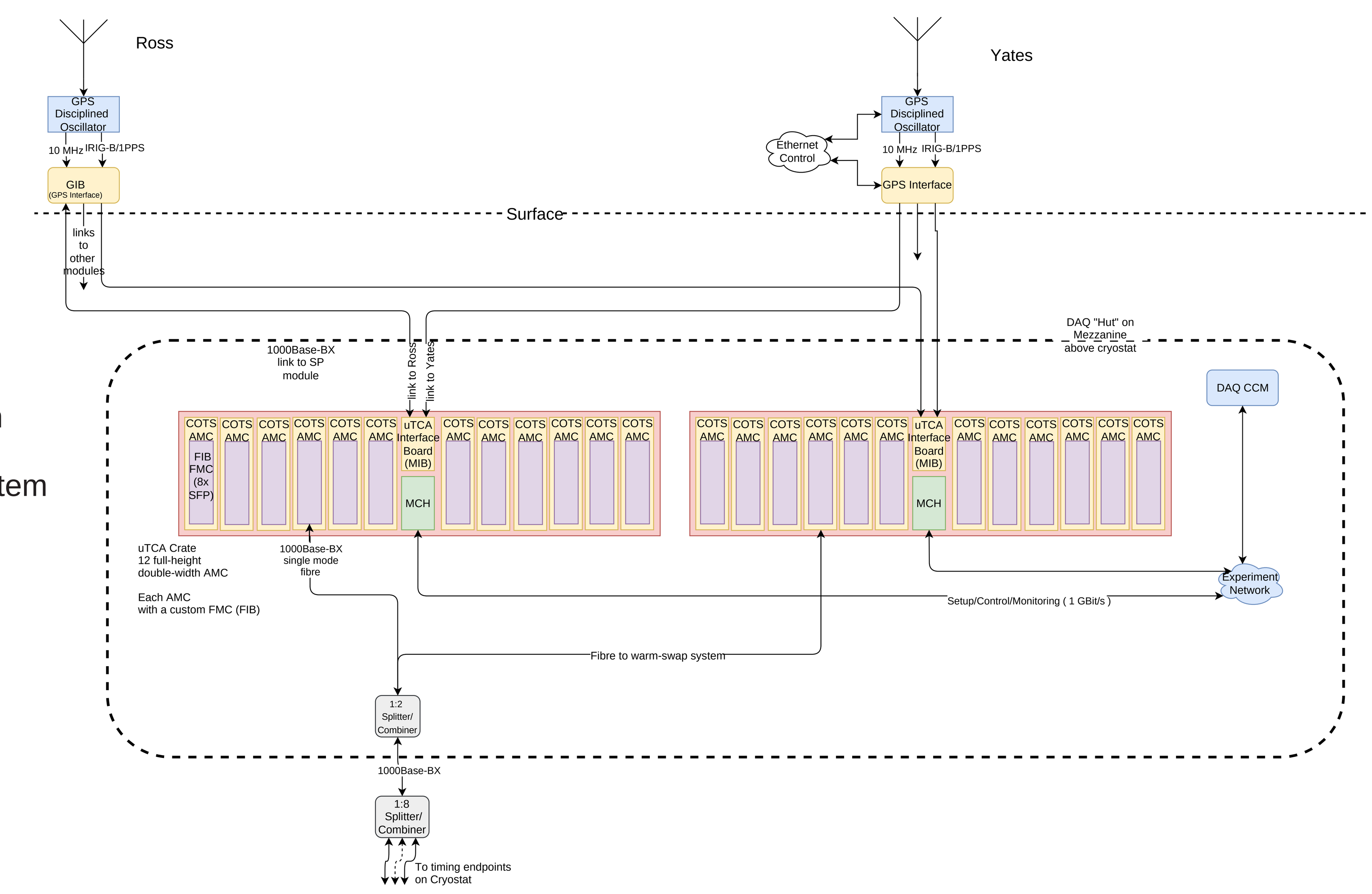




Implementation at DUNE

- The DUNE timing system is made of a mix of commercially available and custom components.
- At the top of each access shaft a GPS-disciplined oscillator provides timing information to a custom GPS Interface Module (GIB).
- Fibres from each GIB are connected to MicroTCA Interface Boards (MIBs), a custom AMC. They sit in one of the two crate controller slots of MicroTCA crates located on each detector module.
- Timing signals are distributed over the backplane to commercial AMC boards. Each AMC carries a fibre interface board (FIB). Each FIB has eight fibres, transmitting and receiving timing data to the detector readout electronics.
- The ability of the DUNE timing system protocol to be used with passive optical splitting and combining will be used to provide hot-swap redundancy to the system. The two completely independent master timing systems will allow firmware and software updates without interrupting system running.

Block diagram
of the
DUNE timing system



References

[a] DUNE Far Detector Technical Design Report (2020), Volumes I, III, and IV, JINST, DOI:10.1088/1748-0221/15/08/T08008

[b] S. A. Mirbozorgi, G. Nabovati and M. Maymandi-Nejad, "Duty Cycle Shift Keying data transfer technique for bio-implantable devices," 2011 IEEE International Symposium of Circuits and Systems (ISCAS), 2011, pp. 917-920, doi: 10.1109/ISCAS.2011.5937716.

[c] 802.3-2018 - IEEE Standard for Ethernet , DOI:10.1109/IEEE STD.2018.8457469

[d] A. X. Widmer, P. A. Franaszek (1983). "A DC-Balanced, Partitioned-Block, 8B/10B Transmission Code". IBM Journal of Research and Development. 27(5): 440–451. DOI:10.1147/rd.275.0440

[e] Cussans et. al. (2020) "Timing and synchronization of the DUNE neutrino detector", https://doi.org/10.1016/j.nima.2019.04.097