Charge Readout and DAQ interface

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Dual Phase electronics Consortium Session
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Outline:

- Reminder of system components
- DAQ interface document
- Data flow
- Events sizes
- Possible back-end architecture

ProtoDUNE-DP accessible cold front-end electronics and uTCA DAQ system 7680 ch

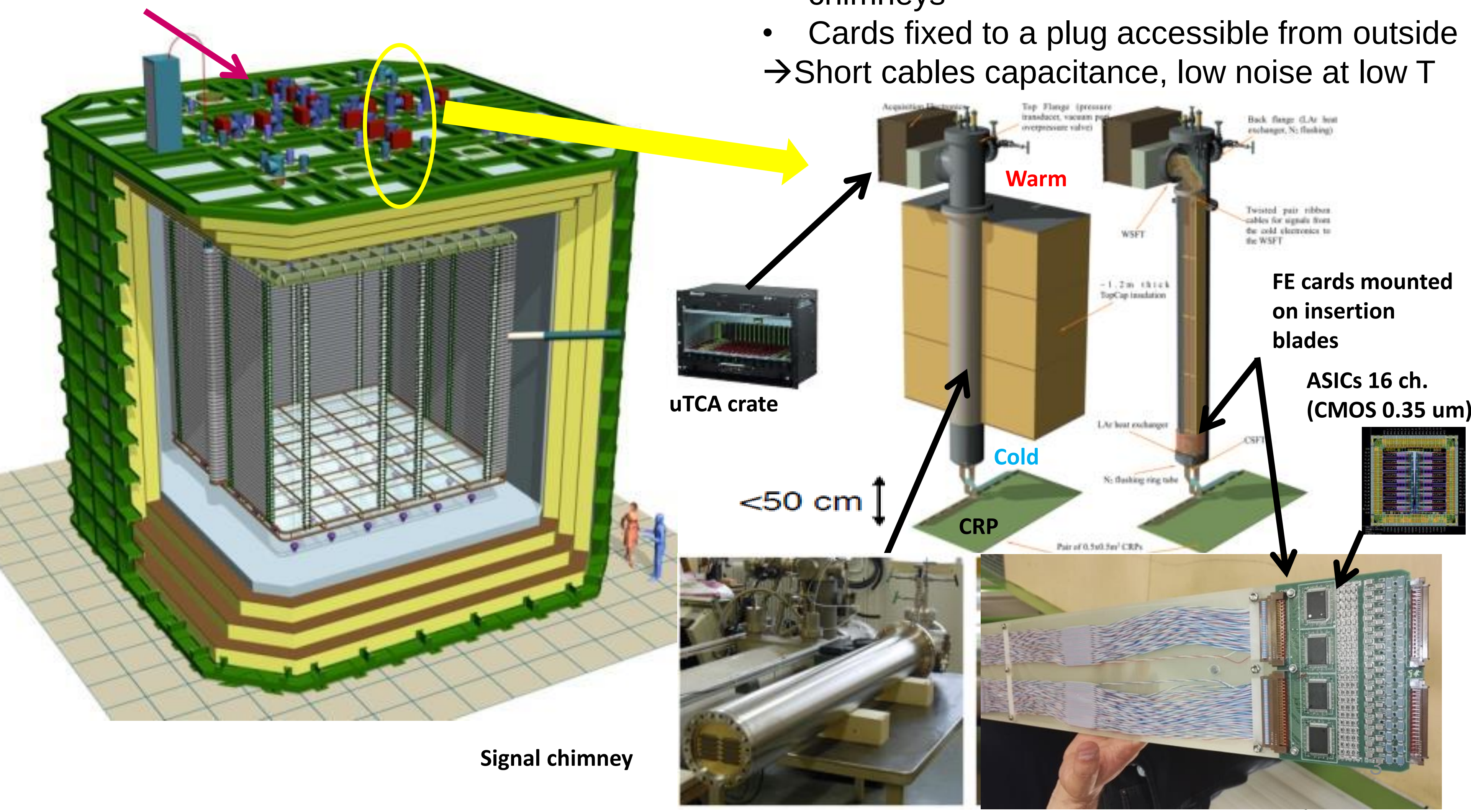
Full accessibility provided by the double-phase charge readout at the top of the detector

➢ **Digital electronics at warm on the tank deck:**
- Architecture based on uTCA standard
- 1 crate/signal chimney, 640 channels/crate

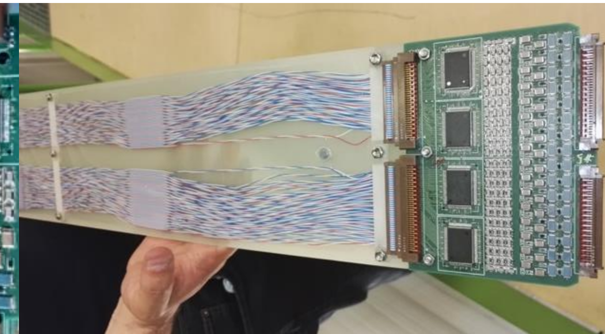
→ 12 uTCA crates, 10 AMC cards/crate, 64 ch/card

➢ **Cryogenic ASIC amplifiers (CMOS 0.35um) 16ch externally accessible:**
- Working at 110K at the bottom of the signal chimneys
- Cards fixed to a plug accessible from outside

→Short cables capacitance, low noise at low T



Electronics components (R&D since 2006):



Analog cryogenic FE:

- Cryogenic ASIC amplifiers DP-V3 production at the beginning of 2016
- 64 channels FE cards with 4 cryogenic ASIC amplifiers
- First batch of 20 cards (1280 channels) operational on the 3x1x1 since the fall 2016
- Production of remaining 100 cards for 6x6x6 completed on 2017 budget

Digitization cards:

uTCA 64 channels AMC digitization cards (2.5 MHz, 12 bits output, 10 GbE connectivity)

- 20 cards operational on the 3x1x1 since the fall 2016
- Production of remaining 100 cards for the 6x6x6 completed on 2017 budget

White Rabbit timing/trigger distribution system:

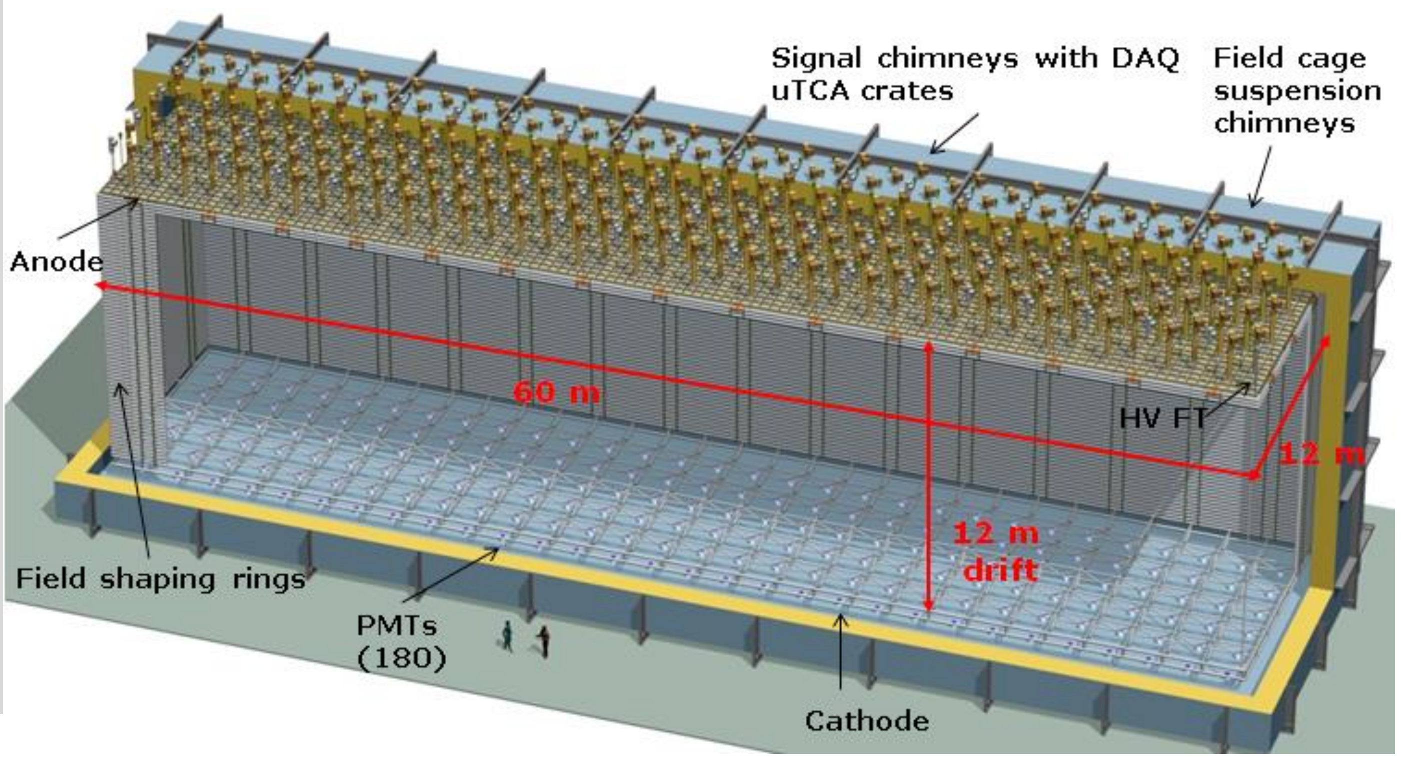
- Components produced in 2016 for the entire 6x6x6, full system operational on the 3x1x1 since the fall 2016

Dual-phase 10 kton FD module

- 80 CRP units
- 60 field shaping rings
- 240 signal FT chimneys
- 240 suspension chimneys
- 180 PMTs
- 153600 readout channels

Dual-Phase DUNE FD: 20 times replication of Dual-Phase ProtoDUNE (drift 6m → 12m) DUNE Conceptual Design Report, July 2015

Active LAr mass:12.096 kton, fid mass:10.643 kton, N. of channels: 153600



Advantages of double-phase design:

- Anode with 2 collection (X, Y) views (no induction views), no ambiguities
- Strips pitch 3.125 mm, 3 m length
- Tunable gain in gas phase (20-100), high S/N ratio for m.i.p. > 100, <100 KeV threshold, min. purity requirement 3ms → operative margins vs purity, noise
- Long drift projective geometry: reduced number of readout channels
- No materials in the active volume
- Accessible and replaceable cryogenic FE electronics, high bandwidth low cost external uTCA digital electronics

Components for a 10 kton dual-phase module, DUNE baseline: two DP modules

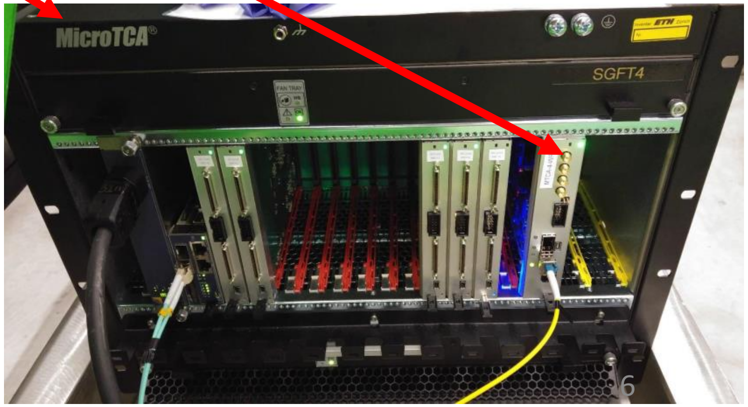
(list based on current 6x6x6 design prior to further optimization and channels density increase)

Total number of charge readout channels: 153600

- **Cryogenic ASICs (16 ch): 9600**
- **Cryogenic FE cards (64 ch): 2400**

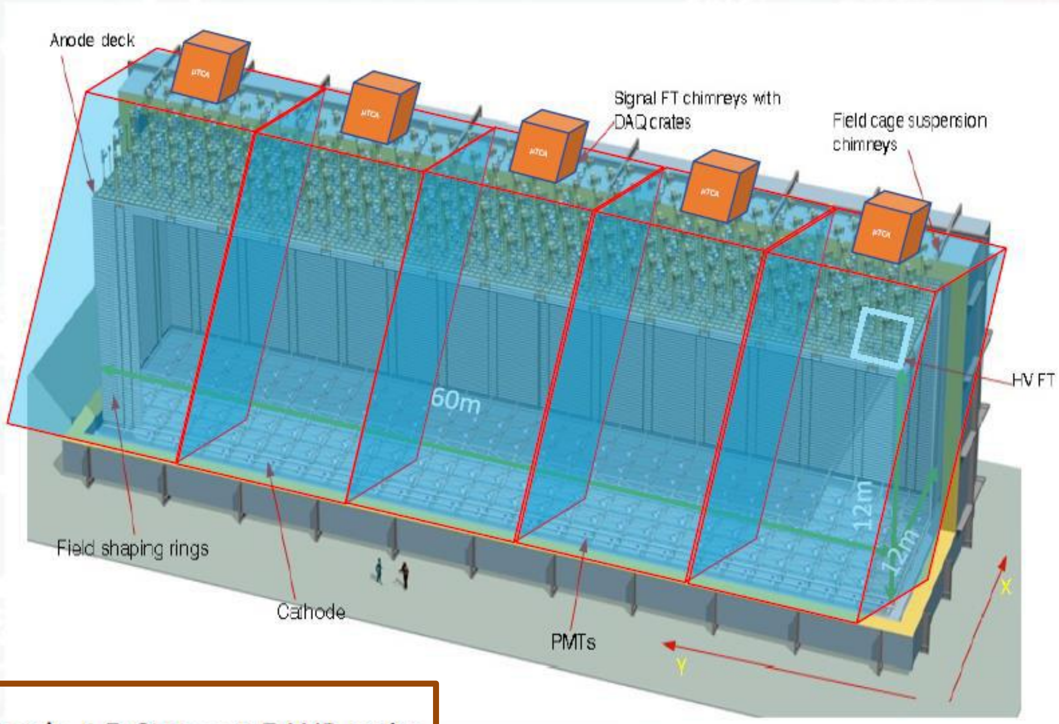
- **AMC cards (64 ch): 2400**
- **uTCA White-Rabbit cards: 240**
- **uTCA crates (including MCH,PU,FU): 240**
- **10 Gbe optical links to backend: 240**
- **VHDCI cables (32 ch) 4800**

White-Rabbit switches (18 ports): 16



Optimized version 1: 720 PMTs (1 PMT/ m^2)

Item	Details	Quantity
PMTs		720
FE-Cards	16 channels	45
	Components	
	printed cirquid	45
	PCB masques	1
	Mounting of components	
	Cabels SMA	720
	Catyroc	45
	ADC	45
micro-TCA crate		5
	MCH	5
	Power Module	5
	XAUI (x4)	5
	Uplink SFP+	5
	Uplink SFP+850	5
White Rabbit		5
	SPEC Card	5
	FMC DIO	5
	SFP (x2)	5



45 FE Cards + 5 Crates + 5 WR units

The distribution of the cards and number of crates to be optimized wrt to cable length and signal attenuation

First idea: cut detector in 5 12 m long segments
(5 x 12 m) long x 12 m wide -> 5 crates on top of the detector

Light Readout system (example assuming similar photodetectors coverage as in ProtoDUNE-DP)

DUNE Interface Document: Dual-phase Electronics/DAQ

Definition: This document describes the interface between the DUNE dual-phase far detector Electronics and DAQ. This document describes the necessary interfaces for both DP-Electronics and DAQ to complete the design, fabrication and installation of their subsystems. This document describes the elements of the scope of each subsystem at the interface between them.

Hardware: The hardware interface between DP-Electronics and DAQ has two components:

The first interface are the 10 Gbit/s optical fibers for data transfer between the uTCA crates hosting the digitizer AMC boards of the dual-phase electronics and the network interfaces of the DAQ system. In the baseline design for a DP far detector module it is foreseen to have **x240 10Gbit/s optical fiber links for the charge readout uTCA crates and x5 10Gbit/s optical links for the light readout uTCA crates**. The current fibers specifications is based on multimode OM3 fibers with LC-LC connectors, which are suitable for transmissions up to 300 m distance. On the side of the uTCA crate this optical fiber link will be connected to the optical transceiver in the MCH (providing two SFP+ (XAUI) links). On the DAQ side all these fibers will go to the network interfaces of the LV1 machines of the trigger farm, or to switches, depending on the network topology eventually implemented. The DAQ consortium will purchase the fibers while the DP-Electronics consortium will take care of their installation on the cryostat roof down to the locations of the uTCA crates, which will be located at close distance with respect to the signal feedthrough chimneys. The DP-Electronics consortium will also take care of all the digital electronics in the uTCA crates for both charge and light readout.

The second interface is a single optical fiber link 1Gbit/s syncE, which will go from the White Rabbit Grand Master switch of DUNE to a Master switch of the DP-electronics timing system. The White Rabbit Grand Master will be possibly installed on surface with the GPSDO clock unit which as to be on surface in order to receive the GPS signals. The White Rabbit fiber from the Grand Master allows distributing timing underground for tens of km with sub-ns accuracy, also automatically compensating for the propagation delays. The DP-Electronics consortium will take care of all the other steps concerning the purchase and installation of the White Rabbit switches and slave nodes needed by DP-Electronics system, including the related optical fibers cabling. The common Grand Master provided by the DAQ consortium has the purpose of making sure that the common time base is distributed to all DUNE 10kton Modules. In case it will be needed, the DP-Electronics consortium can also provide this common Grand Master unit and the GPSDO unit. The installation of the fibers going from the common WR Gran Master located on surface to the caverns is supposed to be taken care by LBNF.

It is assumed that the 10 Gbit/s data links will distribute a continuous data streaming to a set of network elements and event building machines which will then define triggers on the basis of the charge and/or light readout information. These triggers will be issued by processing the data over a sliding window, contained in a memory buffer on the trigger farm machines. The depth of this sliding window may tipically go up to 10s, as needed by the Supernova events trigger definition. These triggers will determine if the data contained in the event building buffers are eventually written on disk. Several LV1 event building units will be looking at the raw data in parallel and we able to exchange trigger information among them and also with similar units looking at the SP modules.

Any cables associated with DP photon system are described in the DP-Electronics/Photon interface document. Any cable trays or conduits to hold the DAQ/DP-Electronics cables are described in the LBNF/Technical Coordination interface documents and currently assumed to belong to Technical Coordination

Signals:

The DP-electronics is supposed to provide data in continuous streaming (12 bits at 2.5 MHz sampling) of all the charge readout channels over the 10 Gbit/s links. Each 10 Gbit/s link will be used to stream the data of 640 charge readout channels. The links will be operated as standard Ethernet links. The data streaming will be performed at constant rate without zero suppression and by applying lossless compression, derived from an optimized version of the Huffman algorithm. Given the noise characteristics and S/N ratio of DP electronics (RMS noise around 1 ADC count) a compression factor of 10 is expected. Blocks of data will be formatted in UDP packets which will also contain time stamps in the common WR time-base. The typical occupancy of a 10 Gbit/s link is expected to be 1.8 Gbit/s for each one of the 240 charge readout links and 4.7 Gbit/s for the 5 light readout links (sampling in normal conditions also at 2.5 MHz with 14 bits dynamics). Light readout may also operate with a sampling finer than 2.5 MHz in special runs devoted to measure the slow component of the scintillation light for purity measurements. Data transmission latency over the 10 Gbit/s network is expected to be at the level of few us, negligible with respect to the size of the memory buffers on the triggering farm.

More details are described in the document "DP-FE Electronics and DAQ interface aspects". The Data flow will be checked with the exchange of control UDP packets among the DAQ and the DP-Electonics AMC FE-units. This check will be periodically performed for fixed periods in order to make sure that the data streaming is proceeding smoothly and all FE units are aligned. The format and the frequency of exchange of control packets has to be defined.

Software: The software interface between DAQ and DP-electronics includes the software dealing with the data formatting in UDP packets, compression/decompression and exchange of control packets. The basic libraries will be provided by the institutions of the DP-Electronics consortium, which are also committed to the DAQ consortium.

Installation: The DP-electronics consortium will take care of the installation down to the optical fibers included.

Commissioning: DAQ and DP-electronics will provide staffing for common commissioning of the system including the DP-electronics and DAQ.

DP electronics-DAQ Interface document

https://indico.fnal.gov/event/16001/contribution/0/material/0/5.pdf

+ more detailed document on interface aspects:

https://indico.fnal.gov/event/15366/session/2/contribution/26/material/slides/0.pdf

Interfaces:

- 10 Gbit/s data links, fibers, data volume and protocols
- White Rabbit network, fibers
- Software
- Installation

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Interface from uTCA to DAQ:

- DP charge readout (baseline configuration with 240 uTCA crates):

240 ethernet optical links at 10 Gbit/s (or less links, 120, at 40 Gbit/s)
1 link/crate, 640 readout channels/crate, 12 bits, 2.5 MHz sampling, loss-less compression with factor 10 compression, continuous streaming
Compressed data rate per link 1.79 Gbit/s
Data rate per LV1 EVTB (8 links): 14.32 Gbit/s
Total data rate: 430 Gbit/s

- DP light readout (example corresponding to the same photocoverage as in PD-DP):

5 ethernet optical links at 10 Gbit/s
1 link/crate, 9 cards per crate (16 channels/card) → 144 channels/crate
14 bits, 2.5 MHz sampling continuous streaming → **4.7 Gbit/s per link**
Total data rate: 23.5 Gbit/s
Some special runs with 40 MHz sampling to study the time profile (purity) in self triggering mode (for instance selecting 20 us windows after the trigger)

- Integrated in common SP/DP White Rabbit network → common Grand Master switch + GPS on surface, 1 Gbit/s optical fiber links

Expectations from the DAQ system:

The DAQ system, common to both single and dual phase, is expected to be a network based DAQ system capable of:

a) Collecting this high bandwidth data volume coming from the data links of the FE crates
b) Putting together the data streams from different crates in Regions Of Interest (ROIs) or over the entire detector volume
c) Processing this data flow by an online trigger farm in order to select relevant events to be recorded on disk: neutrino beam, and off-beam events.
d) Producing charge readout triggers independently on the light readout triggers and beam spill information. In particular, triggers over a sliding timing window of about 10 seconds may be issued by the trigger farm for the search of SN neutrinos based on the presence of low energy depositions, in order to dump on disk the entire content of the SN trigger sliding time window.

It is assumed that the DAQ system will be constituted by a set of event building/trigger machines, high performance network elements, an online computing farm and a high bandwidth distributed storage system based on an array of storage servers operating in parallel.

PD-DP back-end vs 10 kton DAQ

protoDUNE-DP DAQ/back-end:

a) **external triggers** not generated by the charge readout itself (triggers from: beam counters, large area cosmic ray counters or light readout system) defining events corresponding to a drift window

b) **very large data volume to be written continuously on disk** (all drift windows at 100 Hz rate during the spills without zero suppression and using lossless compression)

c) **data quality online-analysis** (aimed at measuring the LAr purity and the detector gain) performed with batch jobs on the processing farm on cosmics overlapping beam events, each job corresponding to a multi-event file written on disk.

DAQ for 10 kton DP module: several similarities in the architecture and some differences related to new aspects related to the specific operation mode of the 10 kton detector (proton decay an SN neutrino searches):

a) **Continuous trigger-less, non zero-suppressed, loss-less compressed data streaming** from the AMC cards to the event builders situated in the DAQ system. The AMC cards operating in ProtoDUNE-DP function by dumping from their internal dual-port memories the drift windows corresponding to the time-stamps of the external triggers but they are already capable of working in a continuous sampling mode, as foreseen for the 10 kton operation.

b) **Charge triggers to be generated by the data analysis on the events builders**, this is a main difference with respect to the ProtoDUNE-DP working mode and it will require to implement the proper algorithms at the level of the event building farm.

c) **Smaller data volume to be written on disk**, just for the selected events (beam events, cosmic rays and proton decay candidates, SN burst candidates)

d) **Necessity of keeping a sliding 10s window on the event builders for SN events searches**

e) **Different requirements on the online analysis:** smaller rate of events, mainly cosmics

Events sizes

→ Event Size for 10kt Dual phase module 4.2GB
due to a good S/N ratio (the RMS noise at the level of 1-2 ADC counts)
loss-less compression is applied at the front-end allowing compressing the readout data flow by a factor 10 → event size = 0.42 GB

To write on disk the entire detector drift window can be considered as a pessimistic figure: events are normally contained in smaller detector regions. The 10kton detector can be seen as 20 ProtoDUNE-DP detectors running in parallel, each one defining a Region Of Interest (ROI). For beam or cosmic events, it is possible to dump on disk only the interested ROI(s).

→ Size of a single ROI: 22MB (compressed)

Source	Event Rate	Event size	Annual data volume
Neutrino beam	2000 $year^{-1}$	44MB (2ROIs)	86 GB (860 GB all ROIs)
Cosmic-muon	$6.5*10^{-2}$ Hz	44MB (2ROIs)	86 TB (860 TB all ROIs)
Atmospheric neutrino	1000 $year^{-1}$	44MB(2ROIs)	44 GB
SNB	12 $year^{-1}$	563 GB	6.6 TB

Conservative total annual data volume assuming some contingencies ~ 100 TB

Possible architecture:

10 kton DP readout architecture organized in 20 ROI, each similar to the PD-DP back-end architecture

- Triggers searched on EVTB L1 on sliding windows of 10 s
- Combination with beam data and with light data to define the window T0 and select streams
- Decompression + keeping compressed data in memory for further writing on disk from LV2

→ Definition of streams output streams: beam, cosmics/proton decay, SB burst

For beam/cosmics → dump in the event format one drift window

Charge readout data:

a) 0.43 Gbytes compressed per event if all ROIs dumped

b) 22 Mbytes compressed per event for one ROI (reasonable choice for beam and cosmic events)

→ Writing of multi-events files organized on EOS by LV2 EVBs, size ~6 GB/file

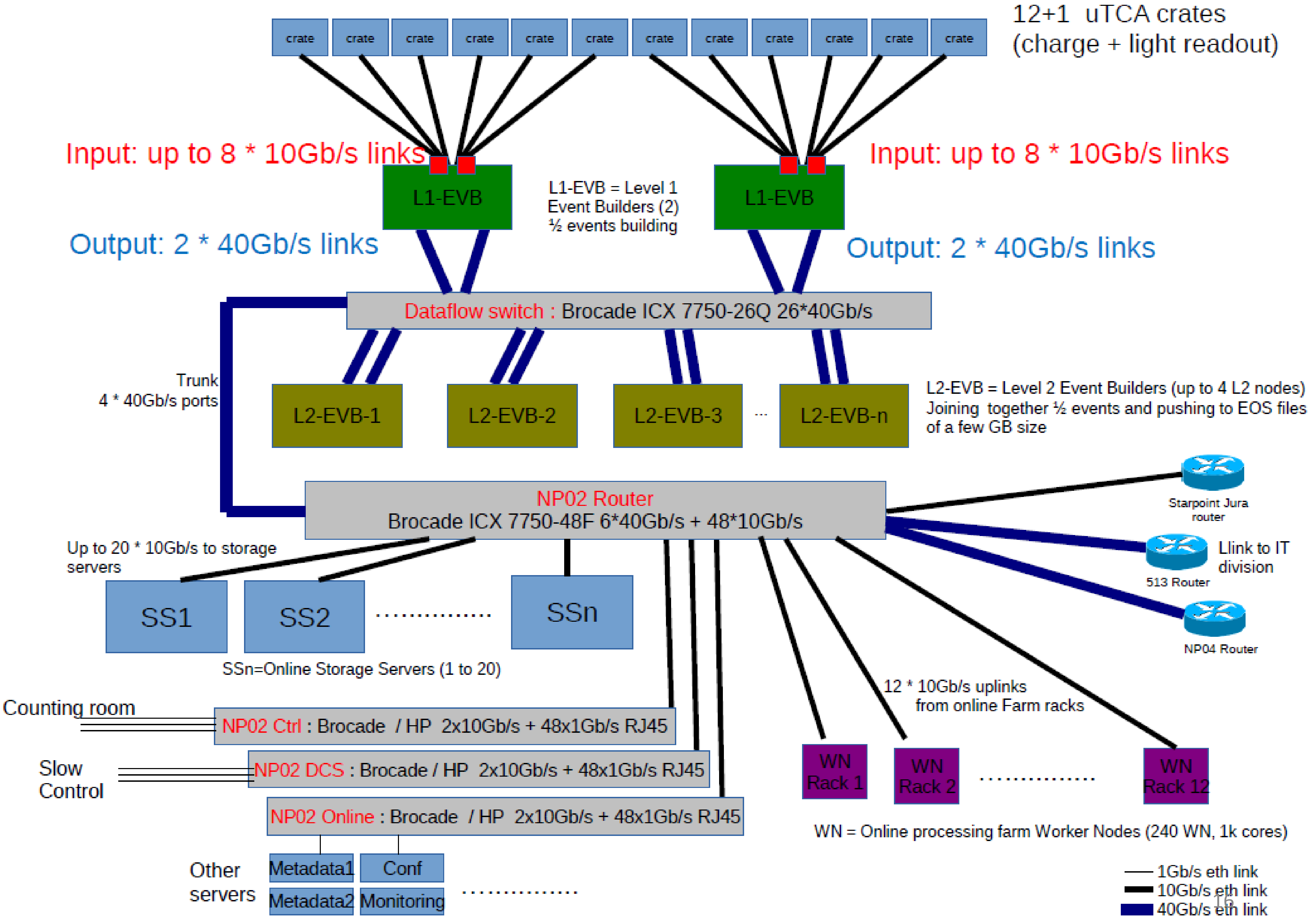
SN burst searches:

- Each L1 EVTB can look continuously at the 10s sliding window, can send trigger signals over the network to a general supervisor
- Criteria applied: compactness of the energy deposition, threshold, some channels excluded in order to define a fiducial volume to shield from environmental radioactivity also by detector elements.

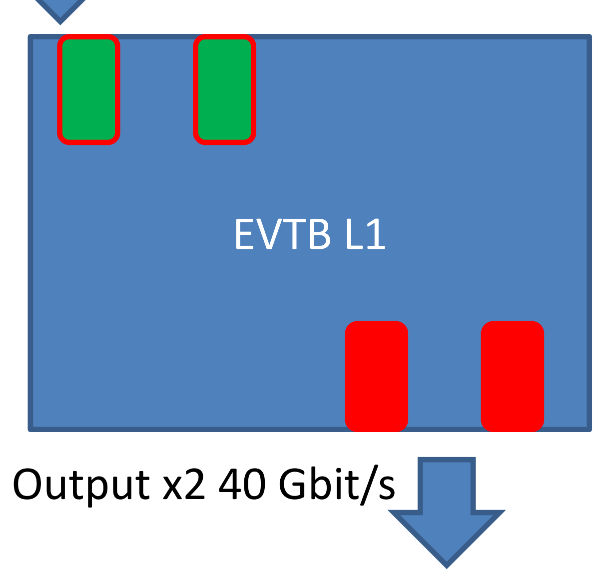
→ Supervisor can order the dump on disk of the EVTBs windows if a certain number of candidate energy depositions is found from the EVTBs. It is possible to put in communication in this scheme also parts of different 10 kton modules

→ Decide to dump on disk compressed data for selected ROIs or the entire 10 kton detector if it is the entire DP 10 kton module this corresponds to 536 GB compressed data (about 100 files from LV2)

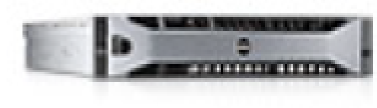
Details of WA105 DAQ back-end network structure



Input x8 10 Gbit/s from uTCA crates in two network cards with 4 inputs/card (total occupancy 6 Gb/s for the 8 links)



x2 L1 event building PCs:

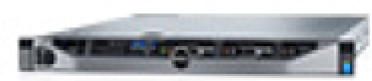


DELL R730, 256 GB RAM
x2 Intel X710 Quad Port 10Gbit/s
x1 Ethernet Mellanox Connect X3, Double port, 40Gbit/s, DA/QSFP

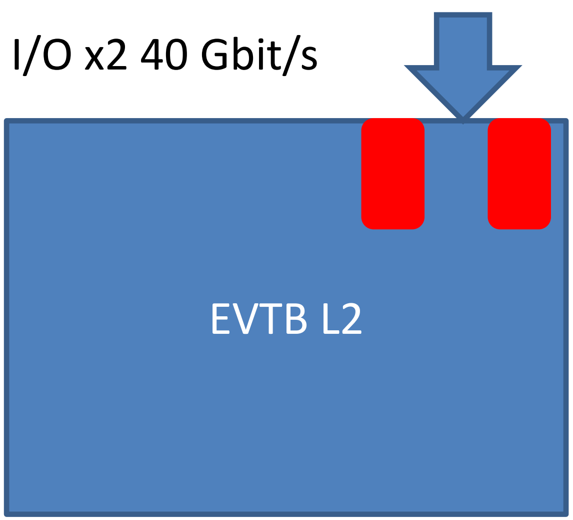
Task in ProtoDUNE-DP DAQ: put together data from the uTCA crates for the same drift widow corresponding to half of the detector → Two L1 EVTBs

Figure 3: The Brocade ICX 7750-26Q features 26 40 GbE QSFP+ ports that can be split into as many as 96 10 GbE SFP+ ports.

x4 L2 event building PCs:



DELL R630, 128 GB RAM RDIMM
x1 Ethernet Mellanox Connect X3, Double port, 40Gb, DA/QSFP



Task in ProtoDUNE-DP DAQ: put together events halves in single events and assemble multi-events files to be written on EOS → 4 LV2 units working in parallel

Interconnectivity via Brocade ITX7750-26Q switch, 26 ports at 40 Gbit/s

Scalability considerations

- The PD-DP back-end architecture is perfectly scalable (in terms of number of channels and performance). The technology is completely based on commercial components which will become cheaper and more performant in 3-4 years. This architecture of the EVB layers can be modified by including also the online charge analysis and can support the 10 s sliding window for SN bust searches. There is flexibility with respect to the software implementation. Present machines could already fit the needs for the 10kton.

- DP has high signal to noise (>100) which makes it very suitable to look for de-excitation photons in SN events

- The whole system was thought since the beginning to perform software triggers at the level of the EVTB building farm and to handle the 10s sliding window buffering and analysis for SN burst searches

- The system can provide high quality data without zero suppression. This is an essential feature for rare events. The final data flow on disk is not a problem.

- The present EVTB hardware/network scaled by a factor 20 to the 10 kton module, we know well its costs, even scaling by x 20 with no price reduction for larger quantity it is quite an affordable system

- The DAQ can be organized in ROI corresponding to PD-DP like architectures (20 ROI), each L1 EVTB can be used to define a smaller ROI (8 crates)