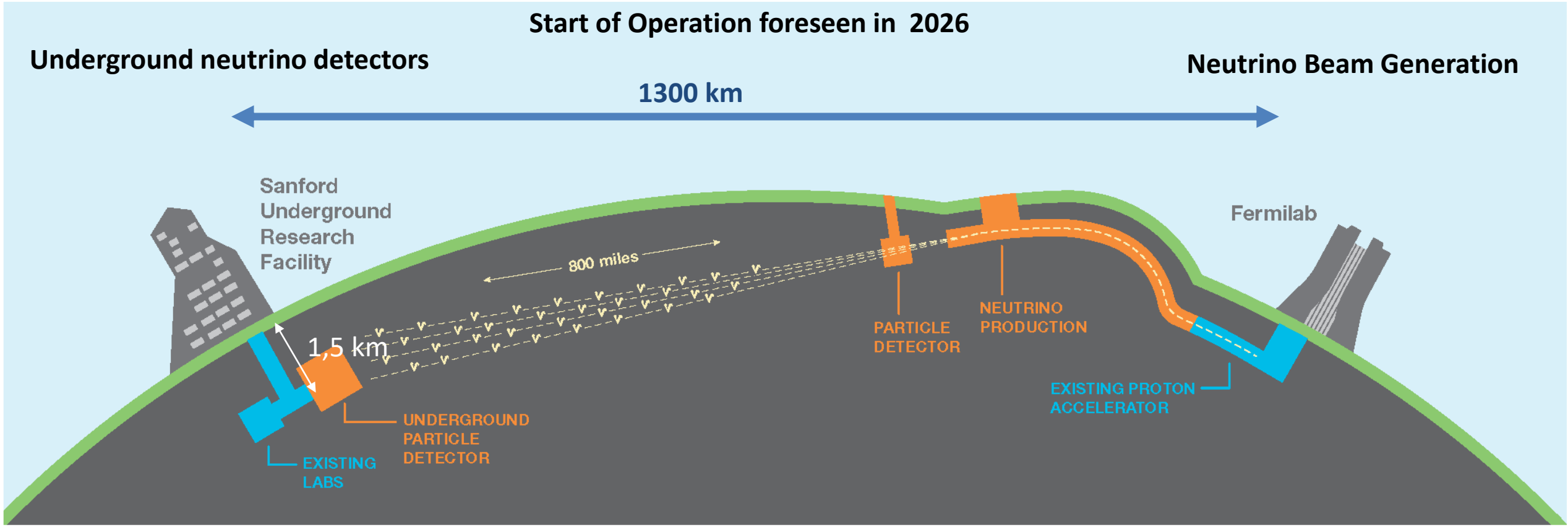
22nd Virtual IEEE Real Time Conference

The Data Acquisition System of protoDUNE dual-phase

2020

DUNE : The Deep Underground Neutrino Experiment

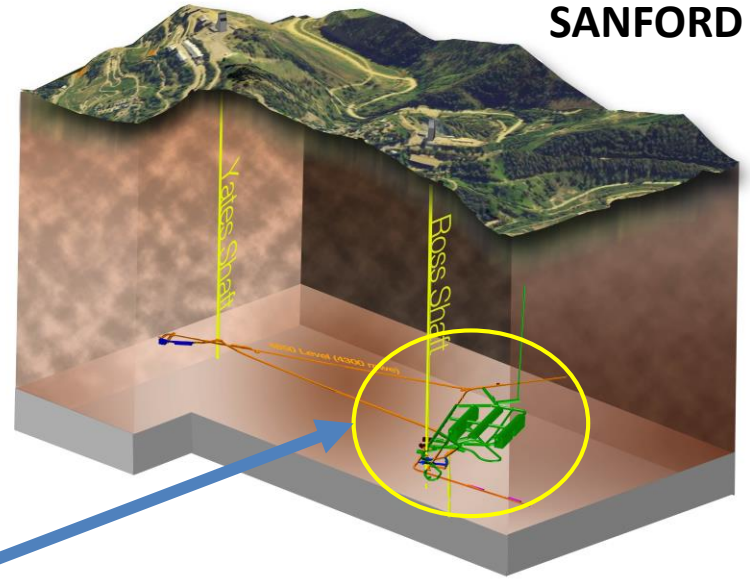
A next generation experiment for neutrino science, supernova physics, and physics beyond the Standard Model

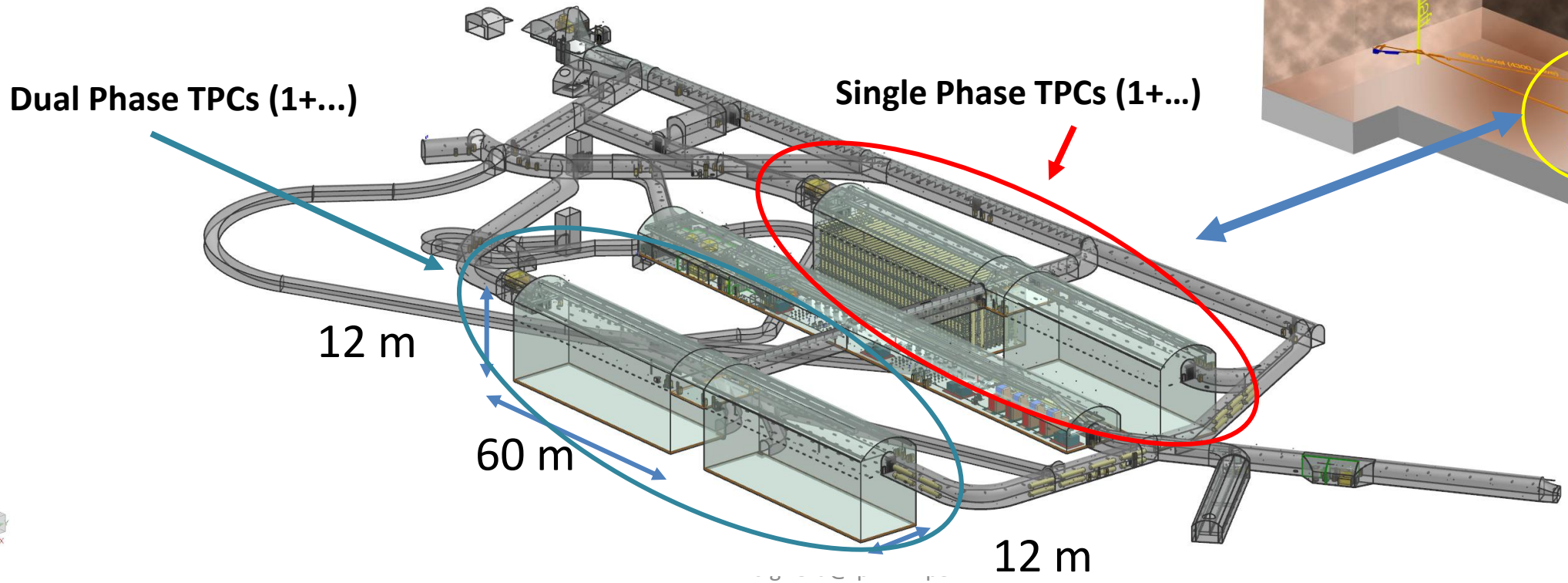


Dune Neutrino Detectors

- x4 Modules of **Liquid Argon Time Projection Chambers** of 60m x 12m x 12m
- Each hosting 10 kton of Liquid Argon
- Total Detector Mass of 40 kton of liquid Argon
- Big technical challenges in all domains (cryogenic, electronic, data rate and processing)

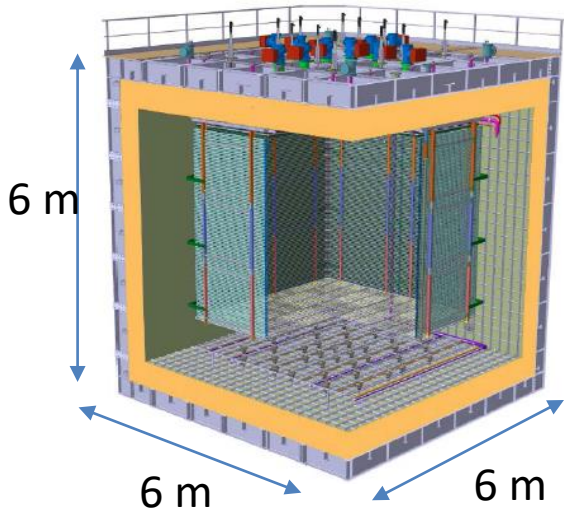
Underground laboratory at SANFORD





ProtoDUNE demonstrator at CERN 1:20 scale of DUNE

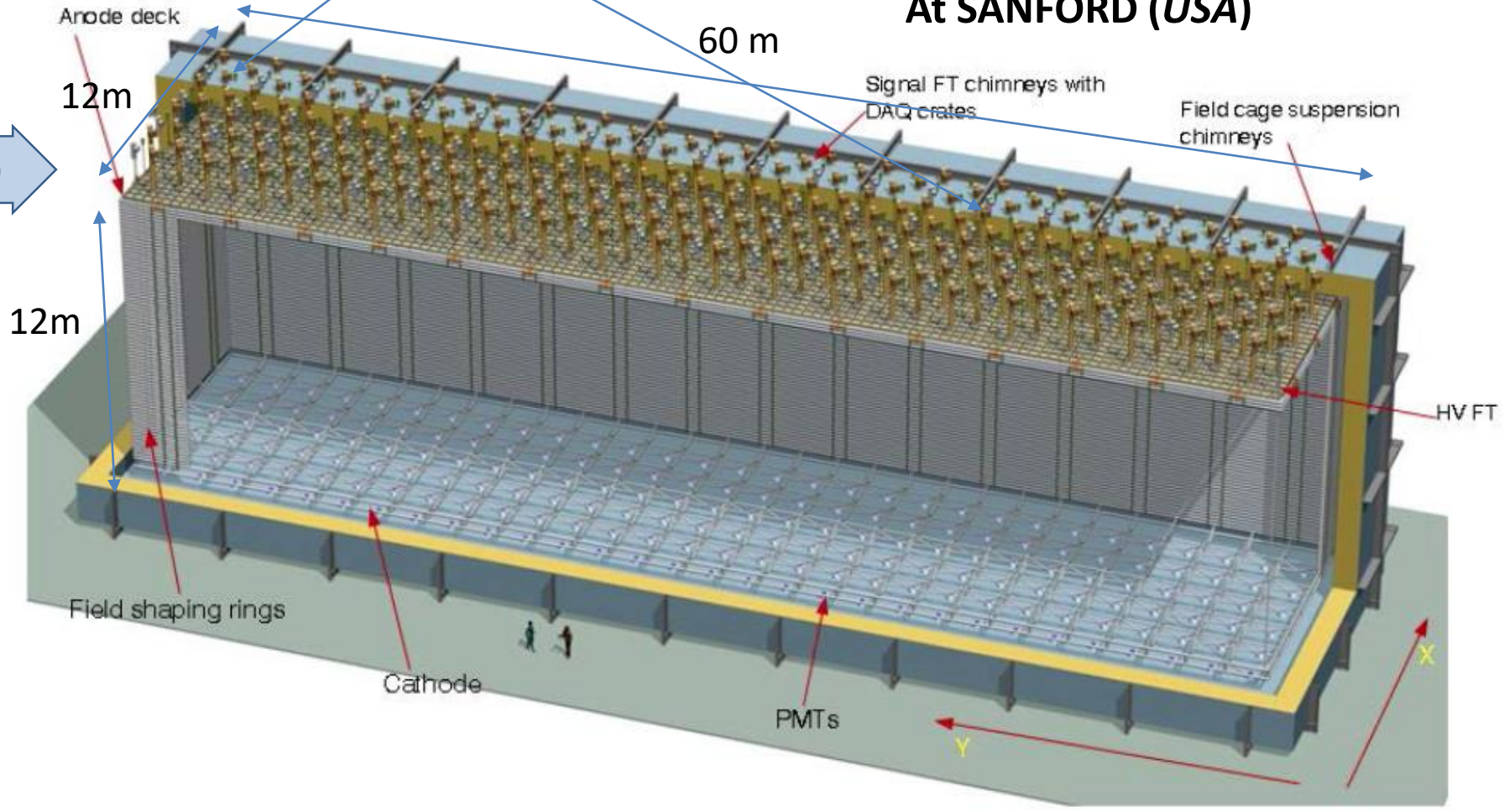
protoDUNE TPC
At CERN (*Switzerland)*



x20

Output signals of detectors distributed on all the surface of the top

DUNE TPC
At SANFORD (*USA*)

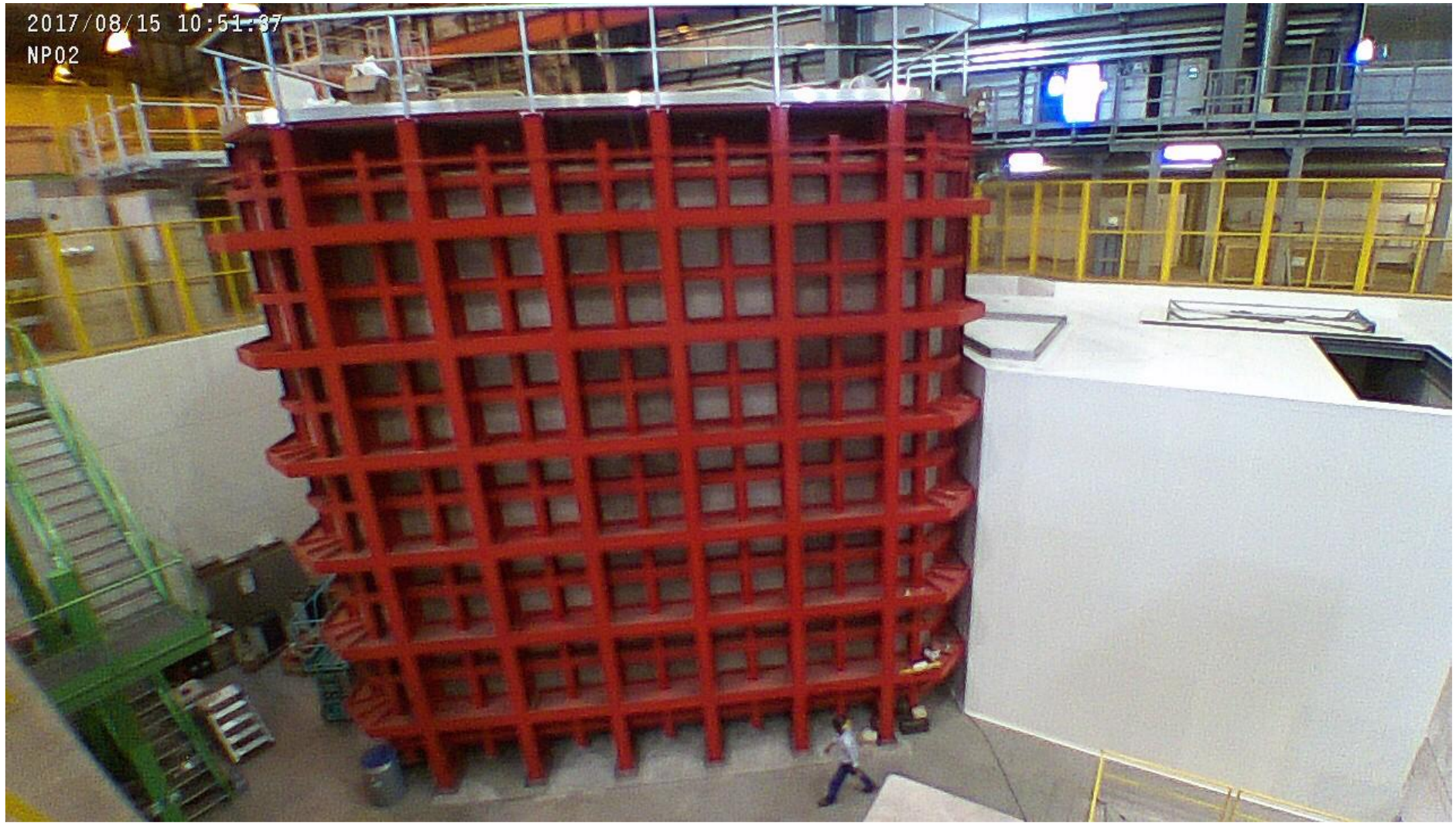


GOAL : defining modular and scalable technical solutions for large detectors

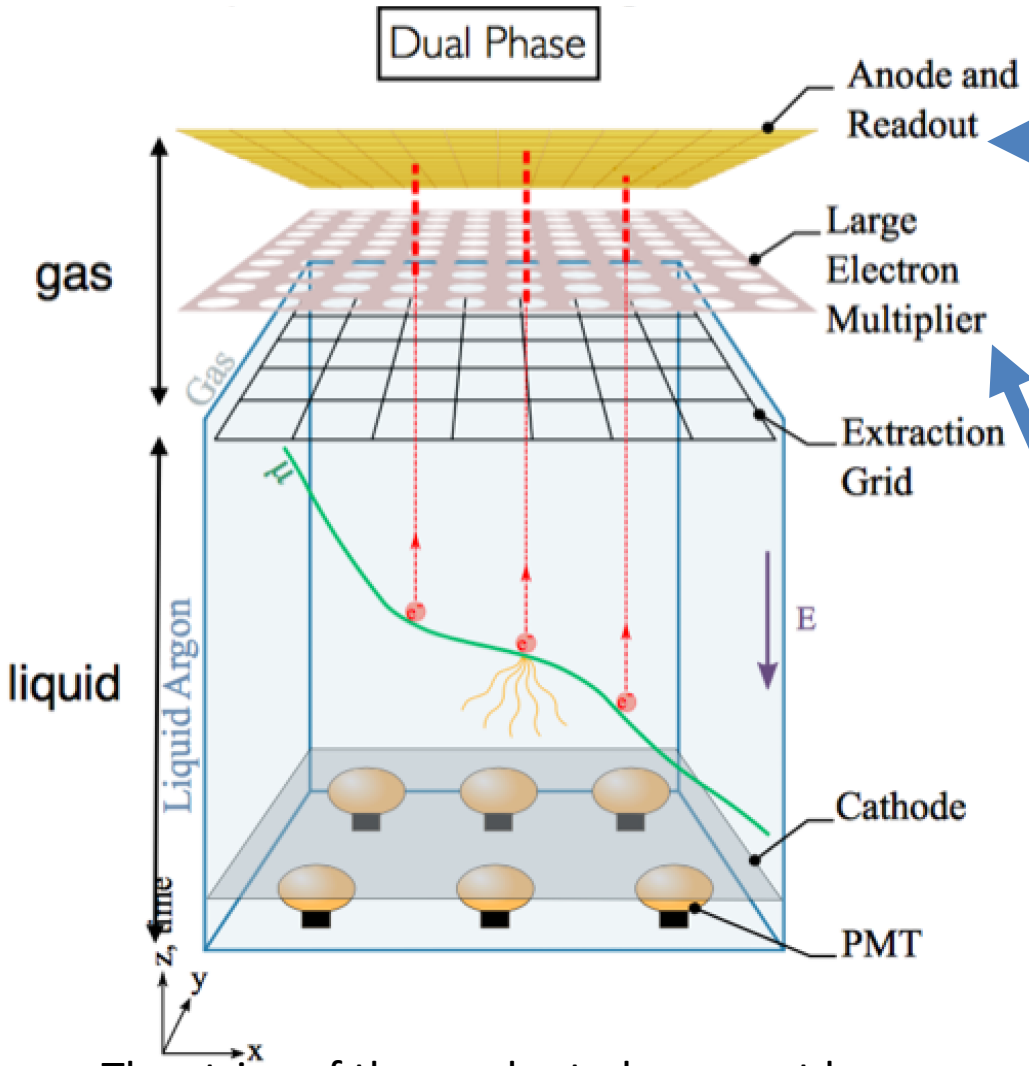
Present ProtoDUNE experiment at CERN (Switzerland)

ProtoDUNE dual phase detector installation has started in 2017.

It is operational at CERN (since august 2019)

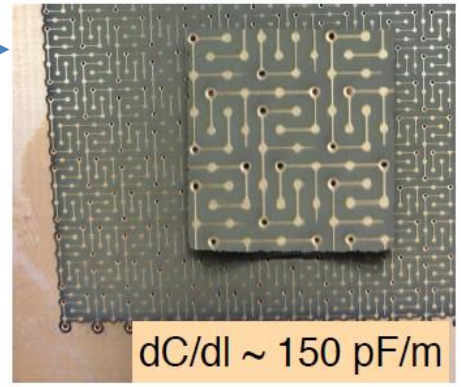


Dual Phase Liquid Argon Time projection chambers technologies

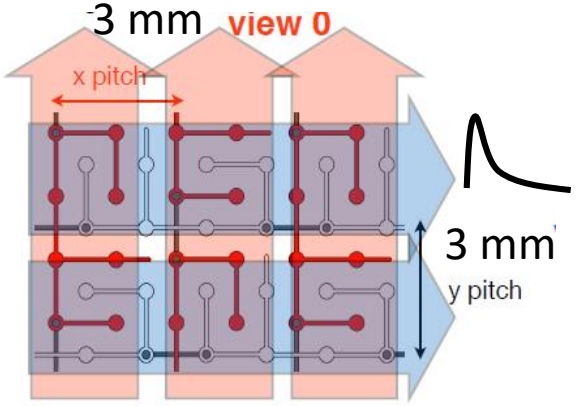


The strips of the readout plane must be digitized continuously

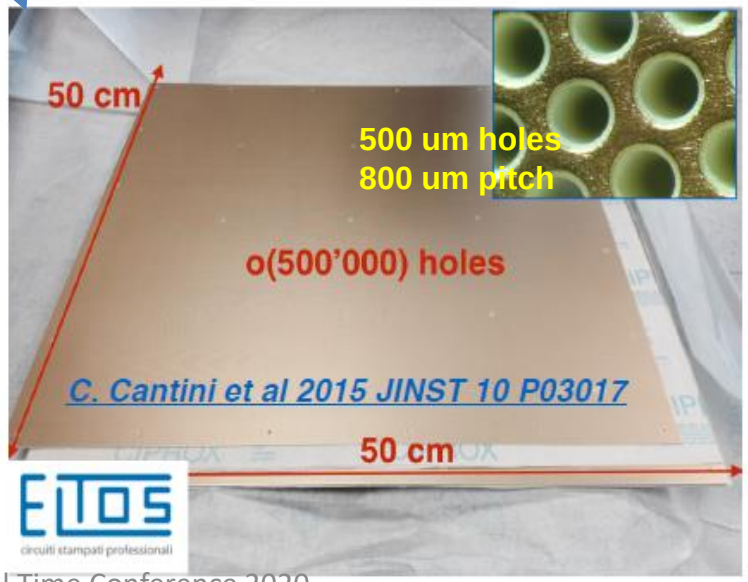
ANODE PCB



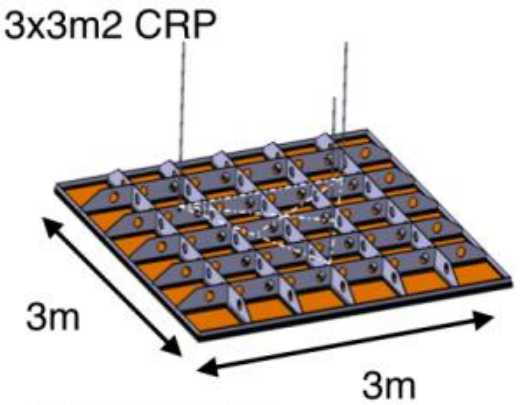
Output analog signals



LEM



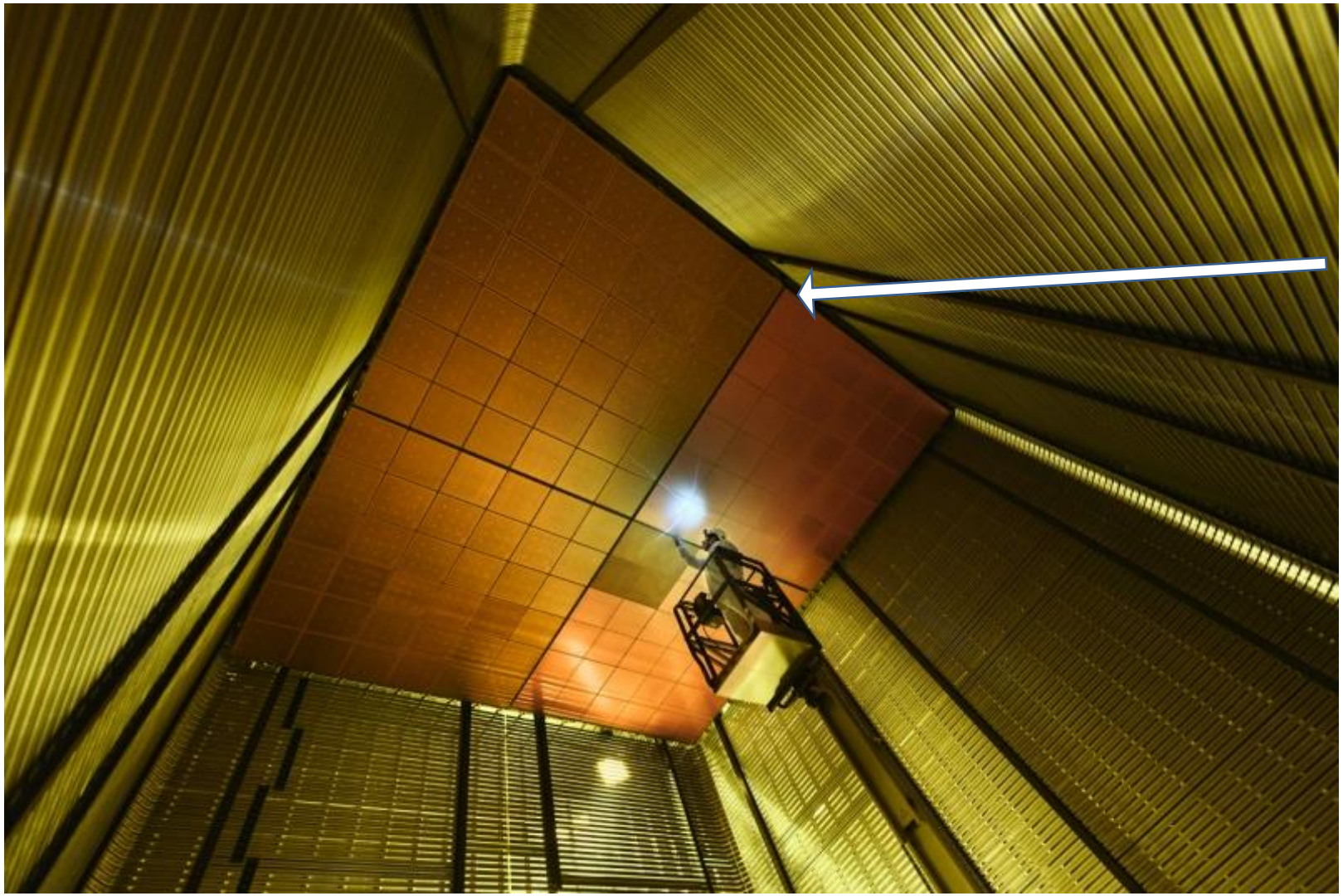
Charge Readout Plane



1920 channels/CRP
Accessible cold electronics in chimney

1920 channels

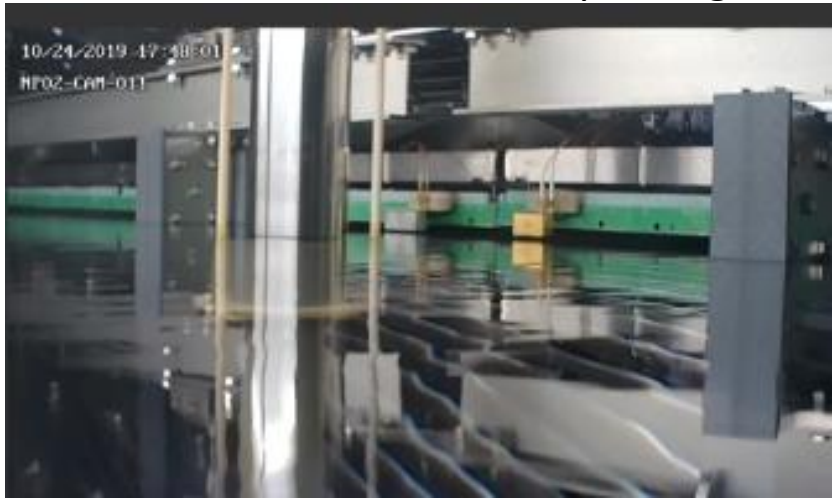
Internal view of protoDUNE with the charge readout plane



Bottom view of the Charge Readout plane with LEMs. (4 CRP of 3mx3m)

A total of 7680 analog signals to digitize and sent to event builders.

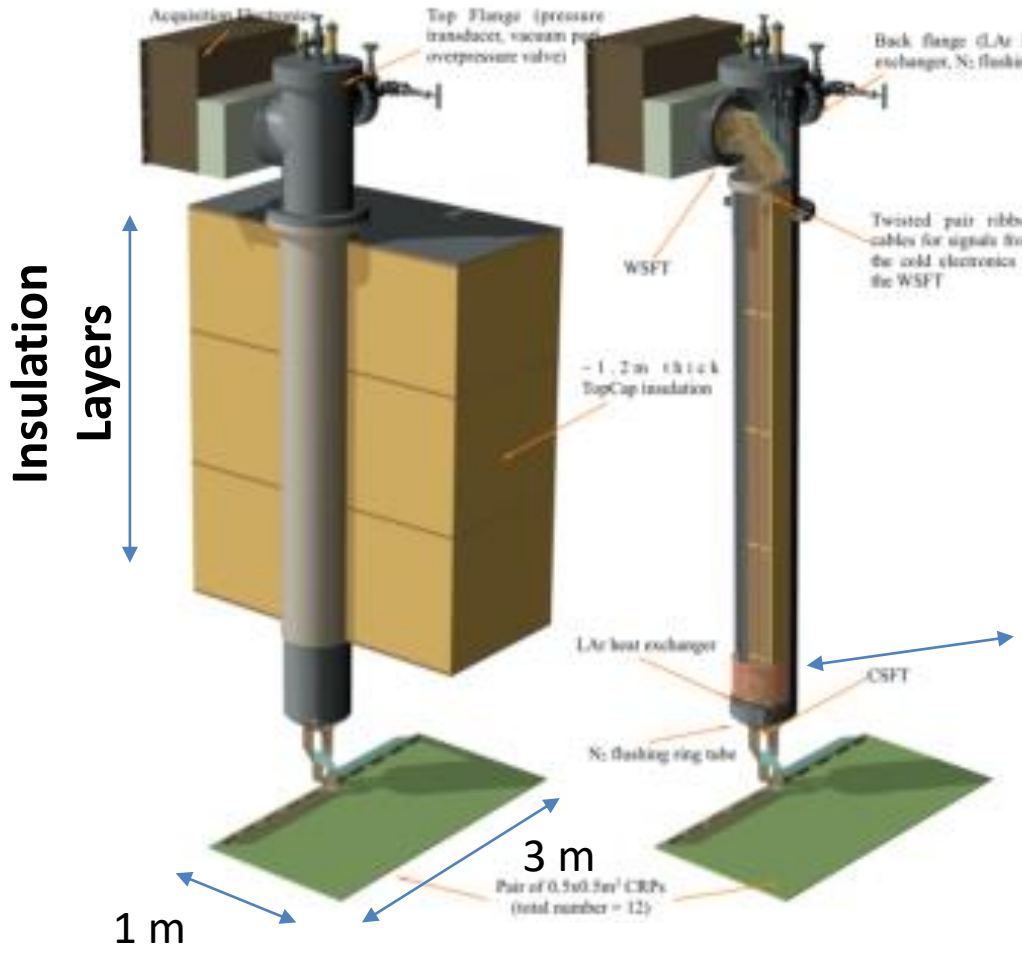
Camera view of surface of liquid Argon



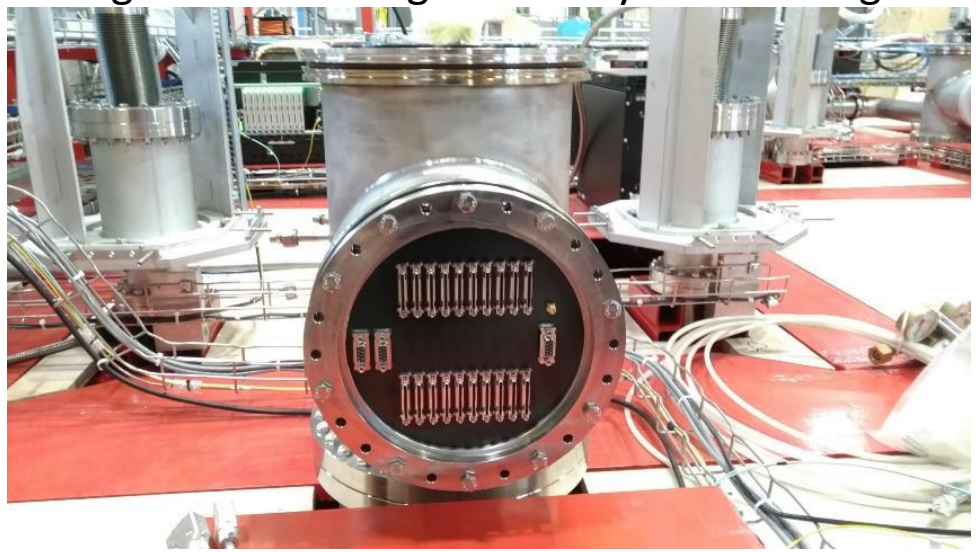
Cold electronic (in the gaseous phase) and signals output trhough chimneys

Front-end Readout

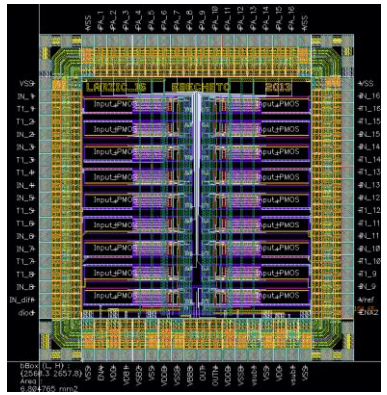
10 baldes / chimney



Signal Feedthrough Chimney Warm Flange



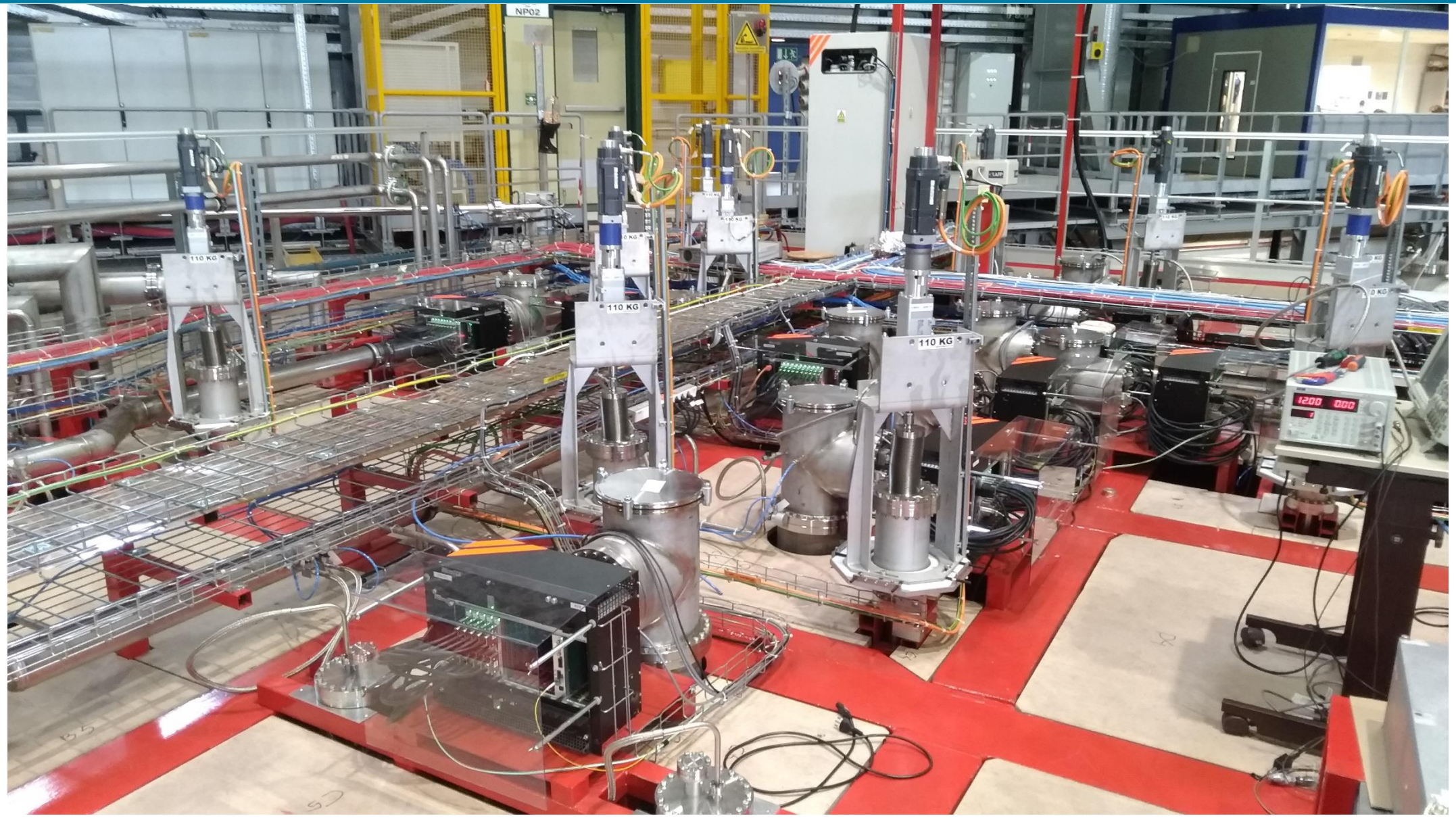
16 channels amplifiers ASIC
CMS 0.35 um (x40)



- Charge to voltage conversion (up to 1200 fC)
- Operating at 110°K
- Low noise (1300e-)
- Low power (18mW)

Possibility of cold electronic replacement

Top View of protoDUNE at CERN



Readout Requirements summary

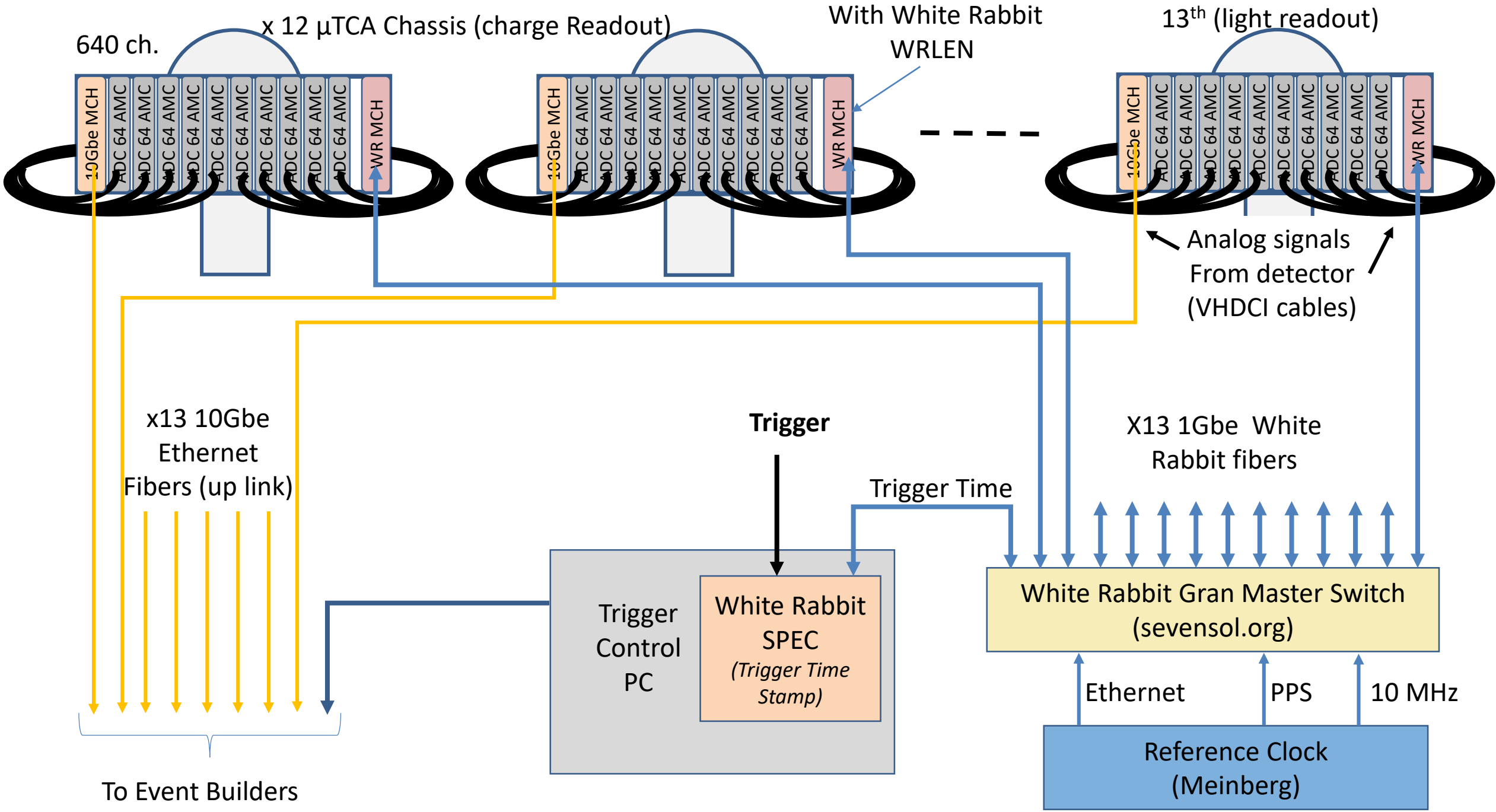
For protoDUNE

- **6m x 6m x 6m**
- **7680** channels
- Sample Rate 2.5 Msps/s and 12 bits resolution
- Synchronization system for synchronous sampling.
- 6 m of drift corresponds to 4 ms
- 10000 samples / channel / full drift
- **Readout of the full detector on trigger Event (100 Hz)**
- 961 Mbits of data / trigger.
- Huffman lossless compression
- **Low cost**

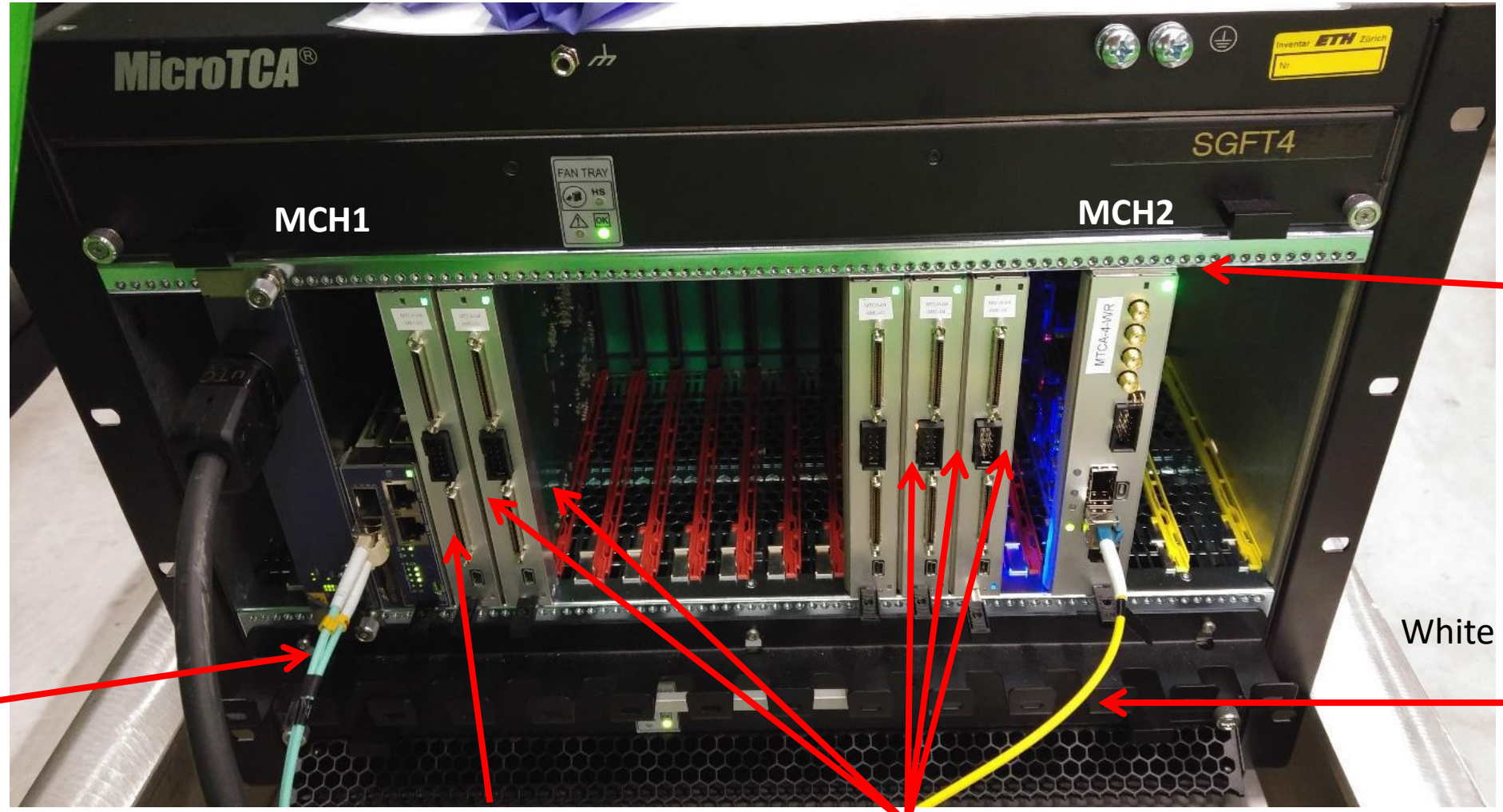
X20

For DUNE

- **60m x 12 m x 12m**
- **153600** channels
- Sample Rate 2.5 Msps/s and 12 bits resolution
- Synchronization system for synchronous sampling.
- 12 m of drift corresponds to 8 ms
- 20000 samples / channel for the full volume
- **Continuous streaming**. (4,6 Terabit / sec)
- **Online primitive search for zero rejection.**
- 46 Terabit to analyze in 10 sec.
- **Low cost**


640 ch.
x 12 µTCA Chassis (charge Readout)
With White Rabbit
WRLEN
13th (light readout)
10Gbe MCH
ADC 64 AMC
WR MCH
Analog signals
From detector
(VHDCI cables)
x13 10Gbe
Ethernet
Fibers (up link)
Trigger
Trigger Time
X13 1Gbe White
Rabbit fibers
Trigger
Control
PC
White Rabbit
SPEC
(Trigger Time
Stamp)
White Rabbit Gran Master Switch
(sevensol.org)
Ethernet
PPS
10 MHz
Reference Clock
(Meinberg)
To Event Builders

Micro TCA Chassis on protoDUNE



WR uTCA slave card node with WRLEN mezzanine

10 Gbit/s data link

White Rabbit optical link

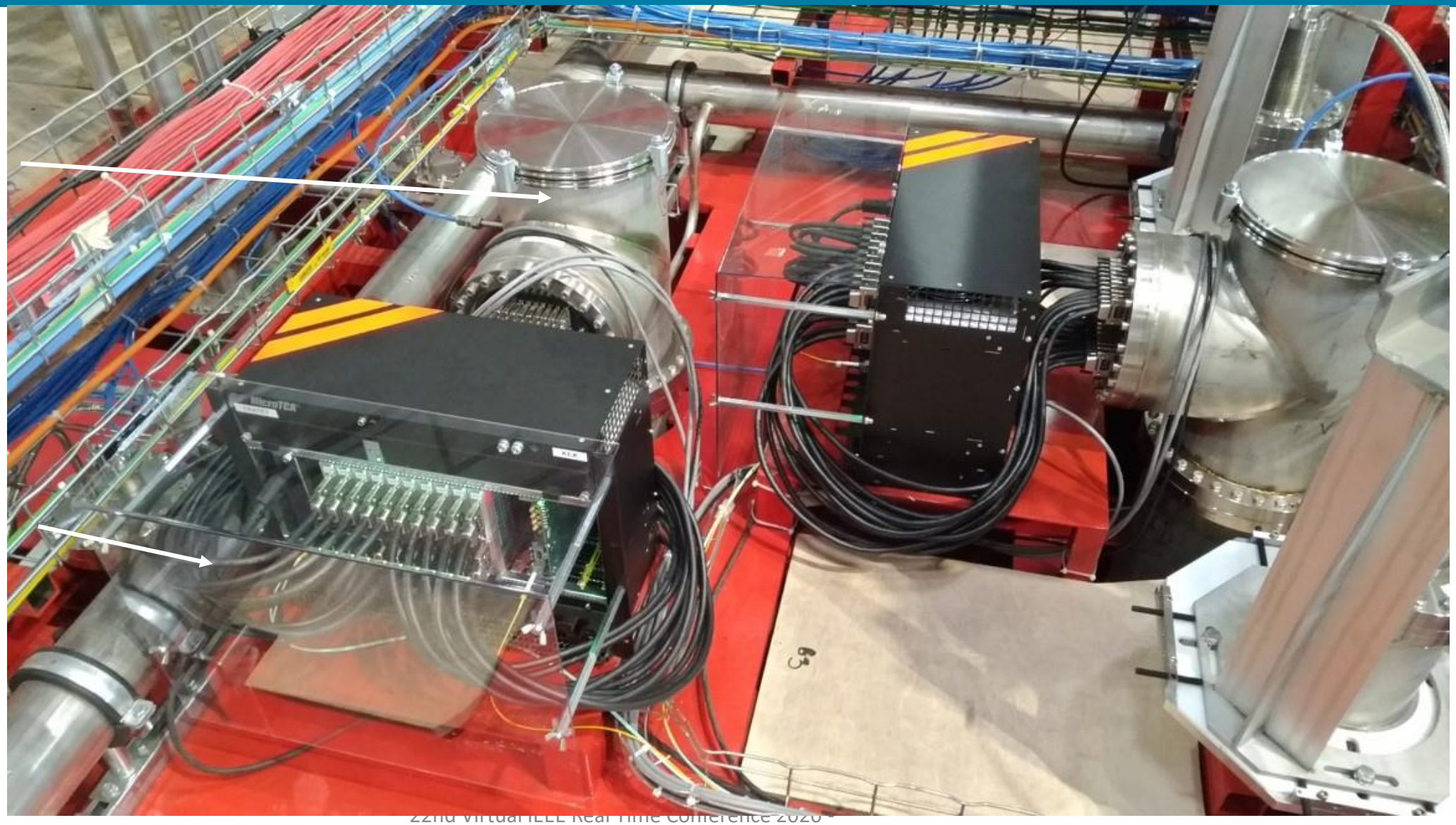
NAT MCH (10Gbe)

AMC 64 channels digitization cards

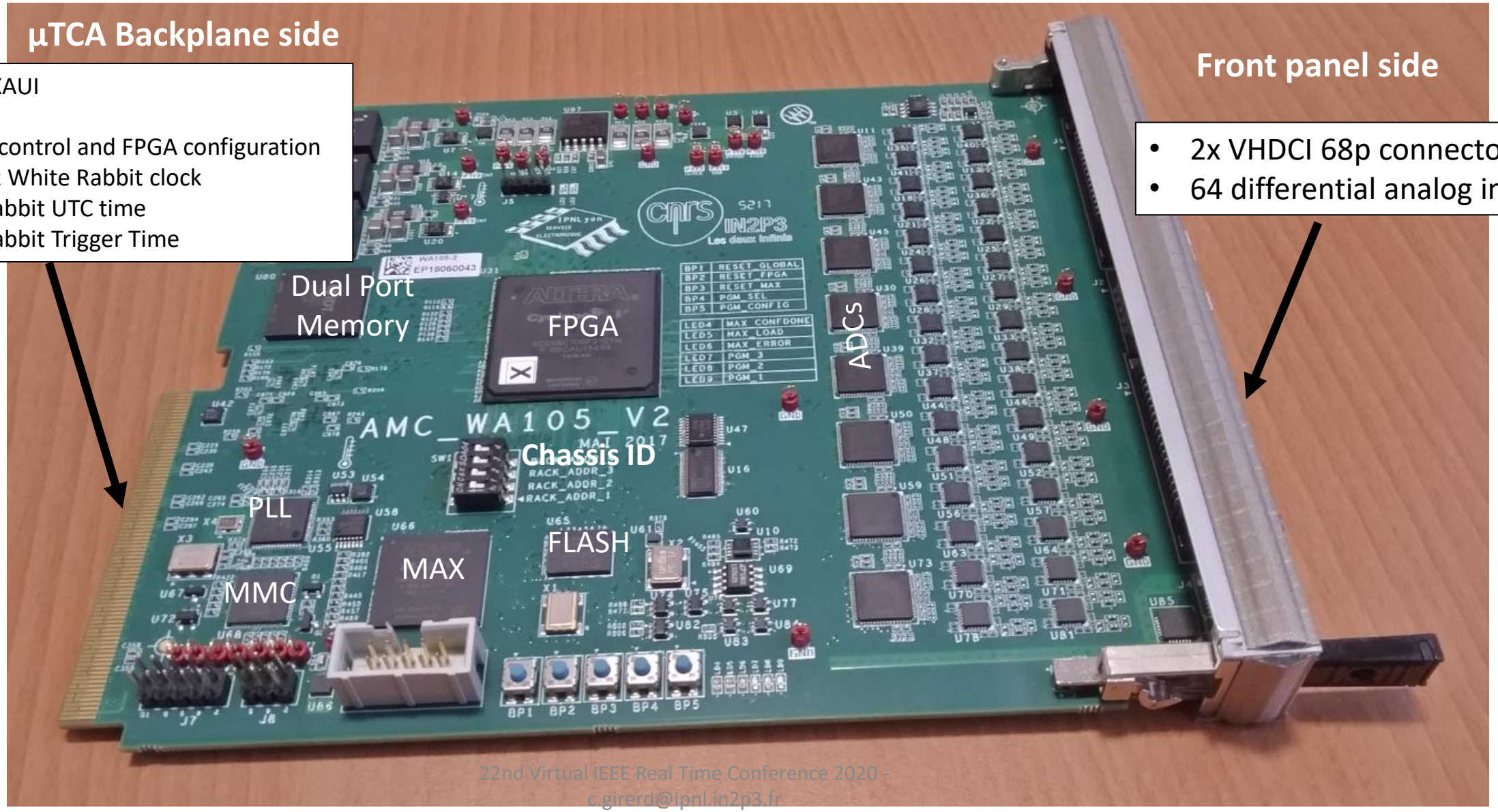
MicroTCA chassis installed on the top of protoDUNE

chimneys

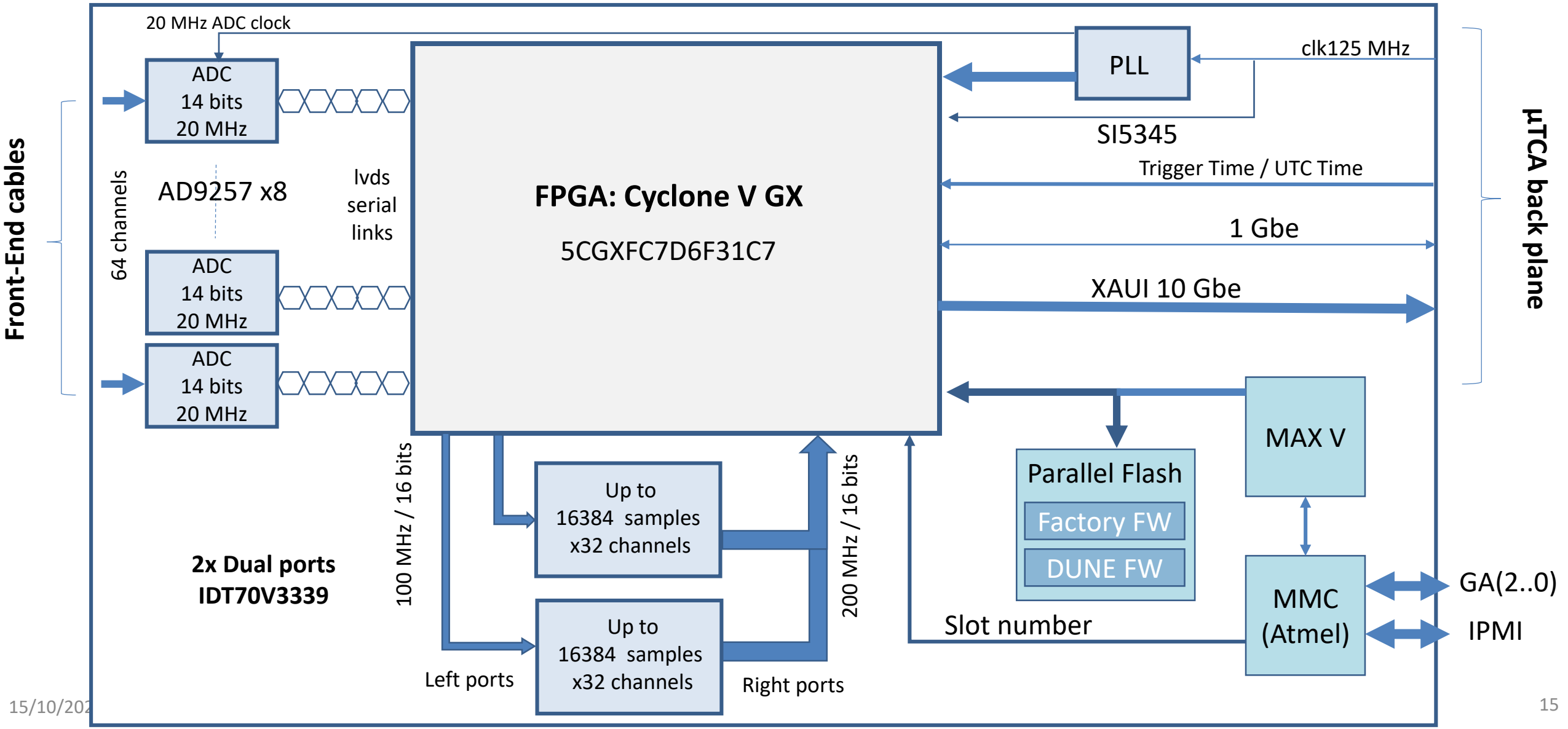
VHDCI cables to AMC readout card

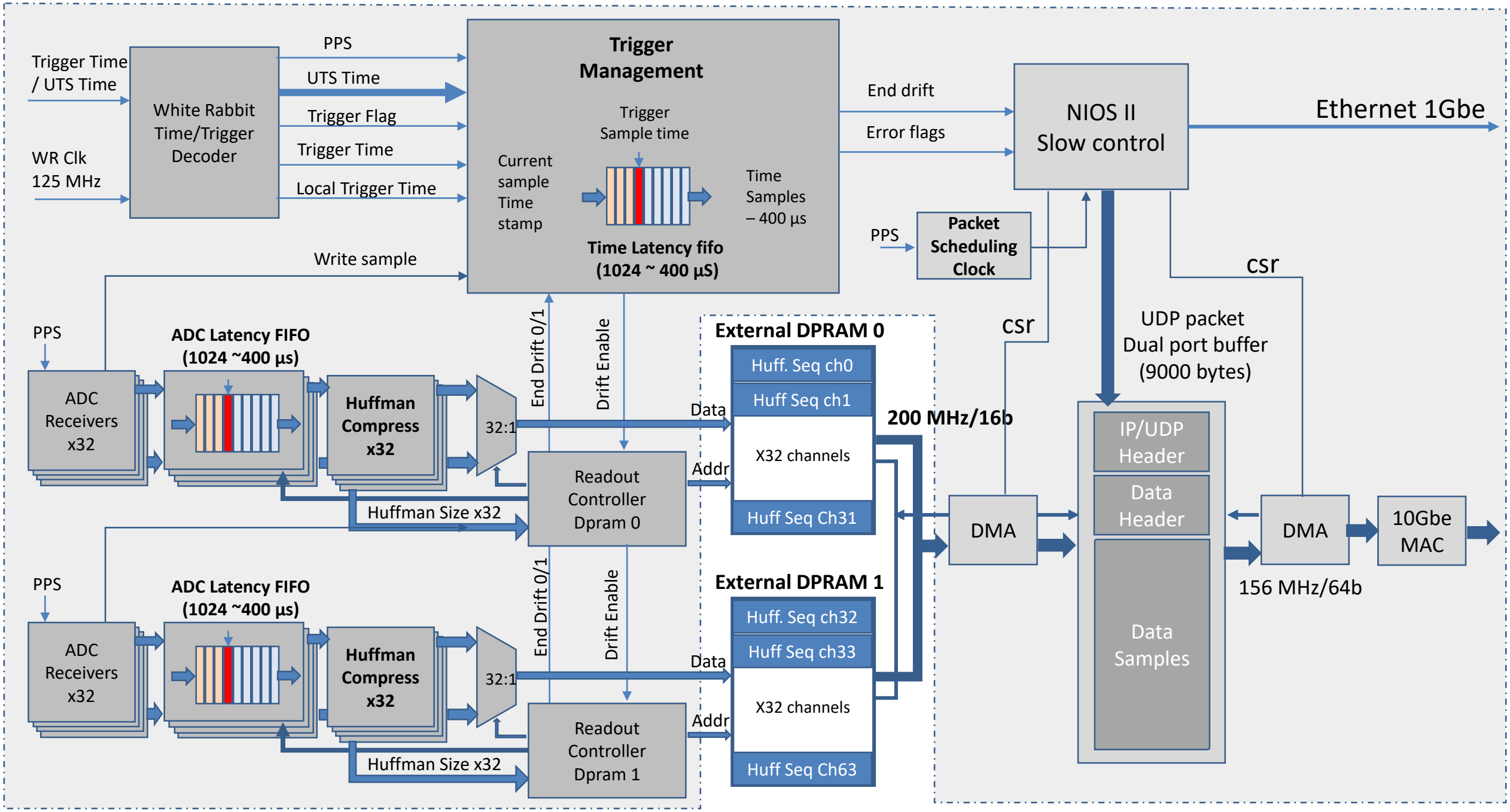


ProtoDUNE charge readout AMC (120 units for protoDUNE)



Front-end AMC: 64 ADC channels / 10 Gbe readout

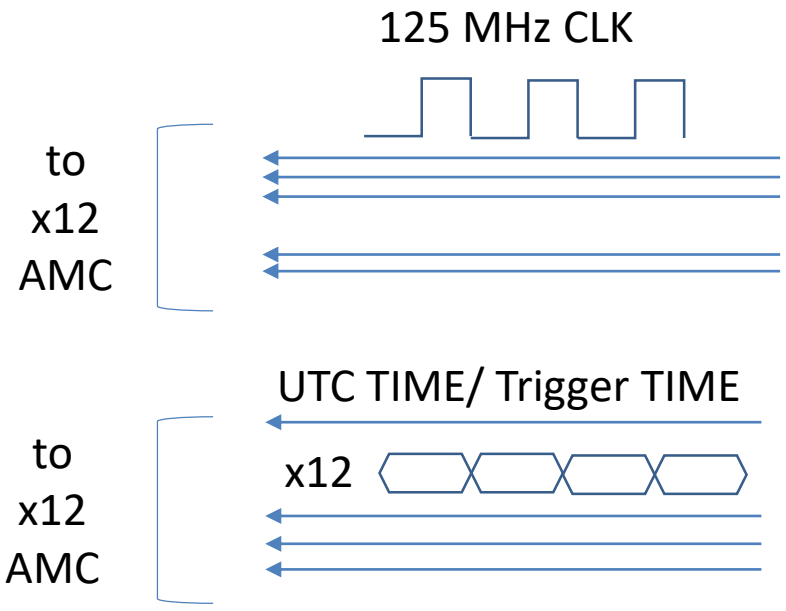


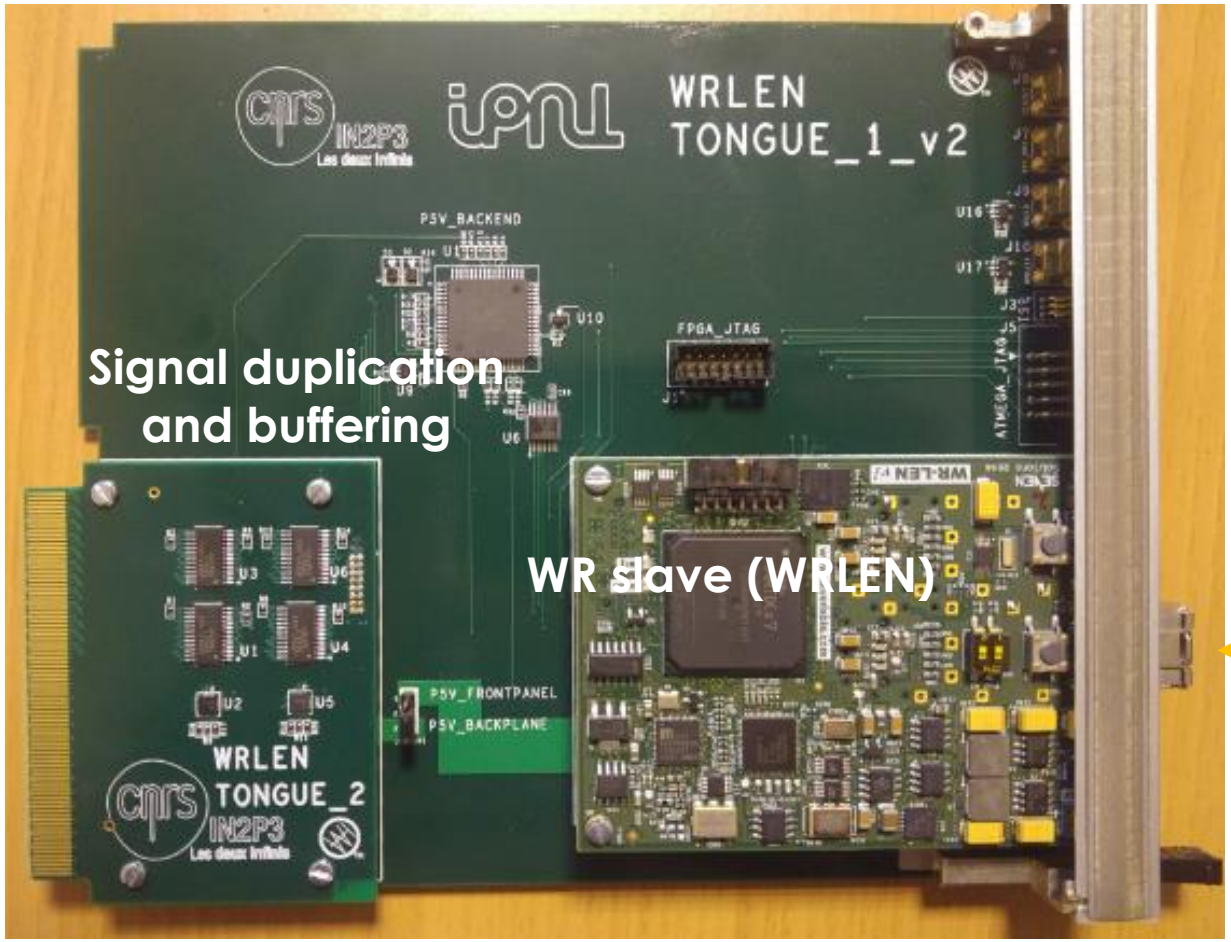

Trigger Time / UTS Time
WR Clk 125 MHz
White Rabbit Time/Trigger Decoder
PPS
UTS Time
Trigger Flag
Trigger Time
Local Trigger Time
Trigger Management
Trigger Sample time
Current sample Time stamp
Time Samples – 400 µs
Time Latency fifo (1024 ~ 400 µS)
Write sample
End drift
Error flags
NIOS II Slow control
Ethernet 1Gbe
PPS
Packet Scheduling Clock
csr
csr
UDP packet Dual port buffer (9000 bytes)
PPS
ADC Latency FIFO (1024 ~400 µs)
ADC Receivers x32
Huffman Compress x32
32:1
End Drift 0/1
Drift Enable
Huffman Size x32
Readout Controller Dpram 0
External DPRAM 0
Huff. Seq ch0
Huff Seq ch1
X32 channels
Huff Seq Ch31
Data
Addr
200 MHz/16b
PPS
ADC Latency FIFO (1024 ~400 µs)
ADC Receivers x32
Huffman Compress x32
32:1
End Drift 0/1
Drift Enable
Huffman Size x32
Readout Controller Dpram 1
External DPRAM 1
Huff. Seq ch32
Huff Seq ch33
X32 channels
Huff Seq Ch63
Data
Addr
DMA
IP/UDP Header
Data Header
Data Samples
DMA
156 MHz/64b
10Gbe MAC

The WRLEN mounted on the WRLEN adaptboard (WRLEN TONGUE_1 + TONGUE_2)

Distribution on Backplane from MCH 2 tongue 2

Allows Chassis Synchronization



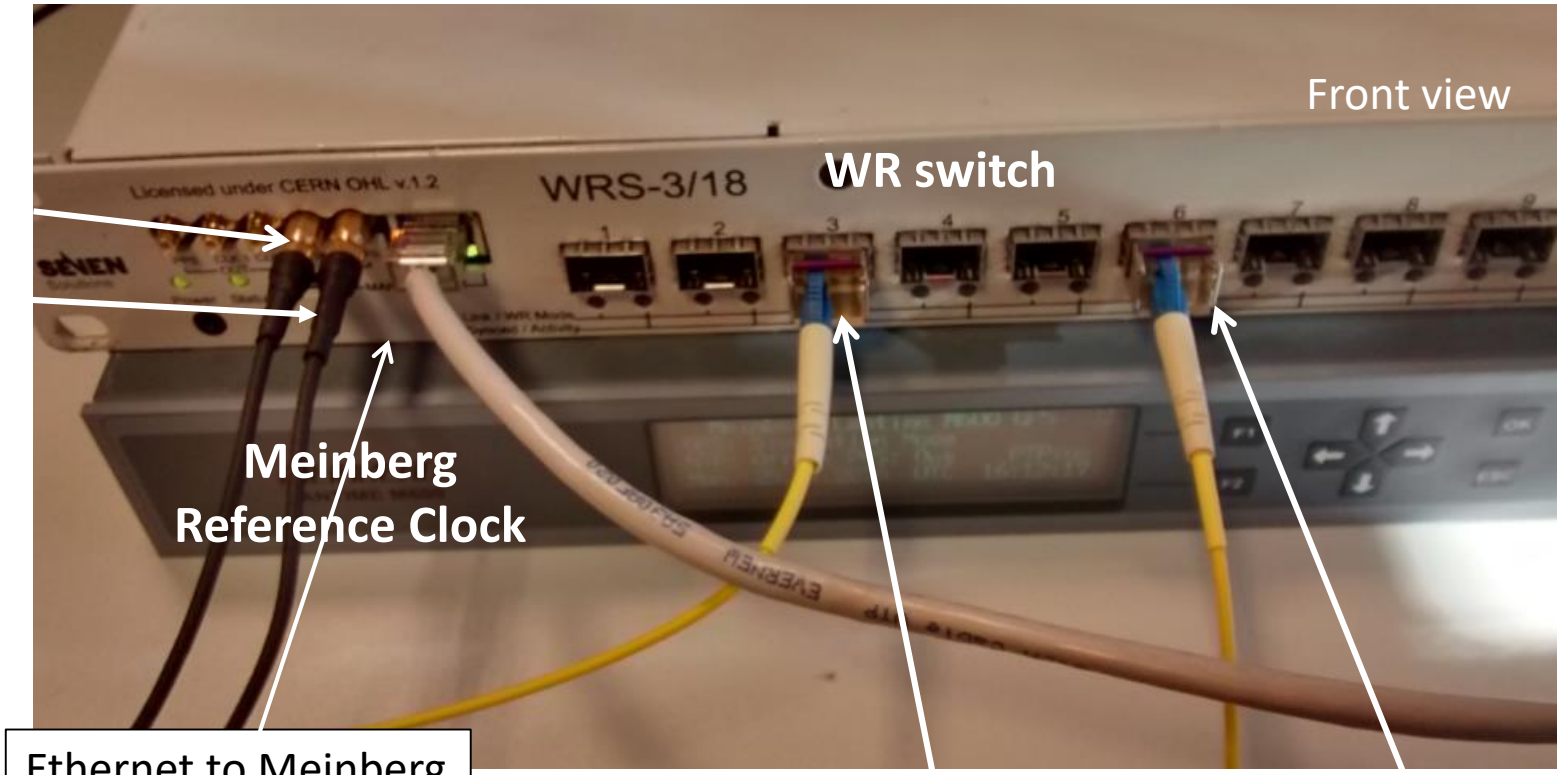


Optical Fiber
from WR switch

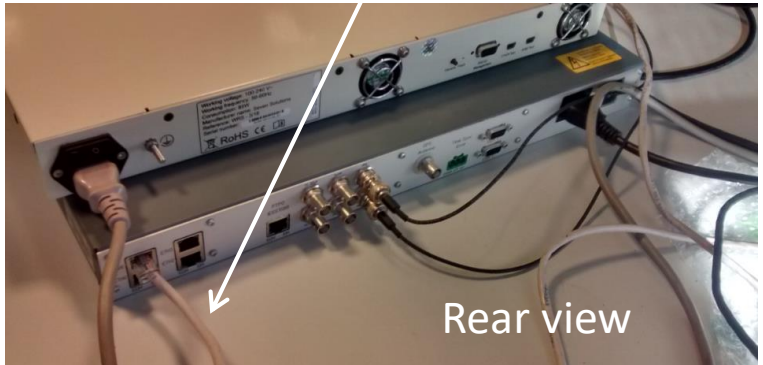
- Simple board on which the WRLEN is plugged on
- Provides power to the WRLEN via the standard uTCA facilities
- Delivers a pair of WR_CLOCK (125 MHz) and WR_DATA to each AMC slot (12)

WR switch and reference clock

10 MHz
and PPS
From reference
Clock (Meinberg)



Ethernet to Meinberg



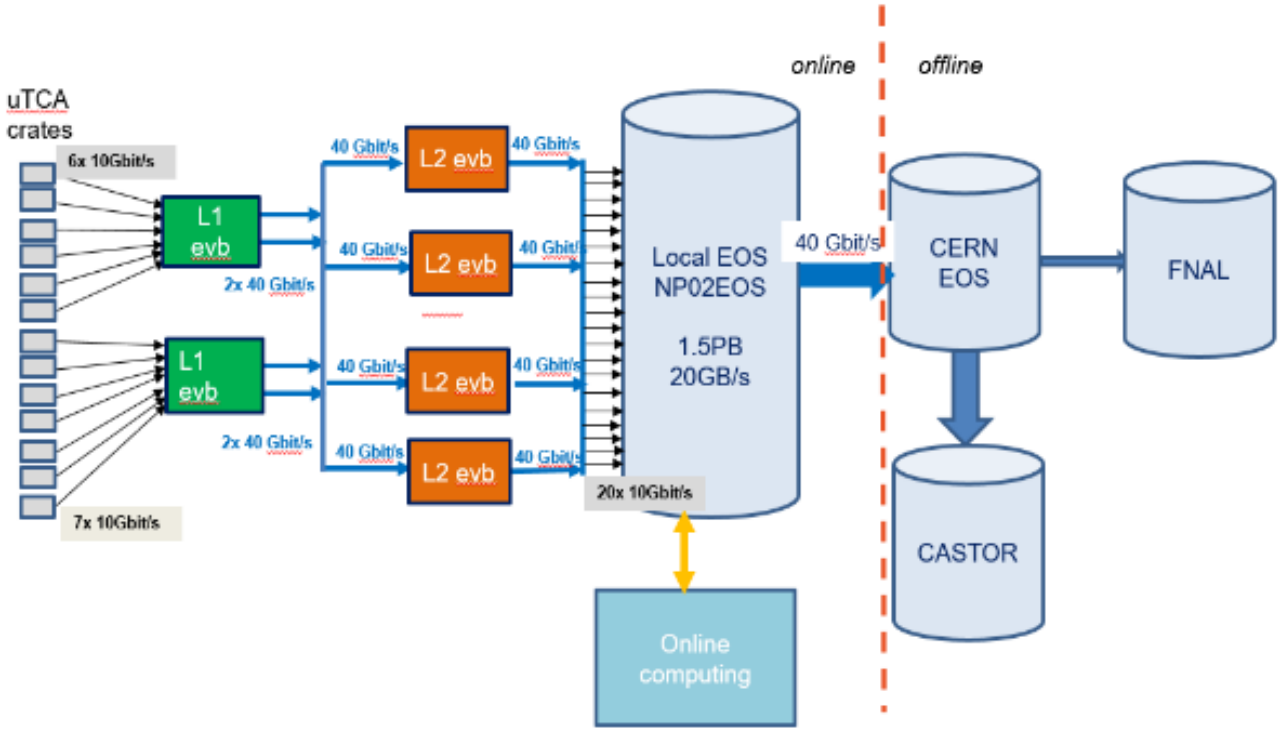
Fiber trigger from to
PC + FMC_DIO
Transports reference
time and triggers

Fiber to WRLEN
(to MCH 2 adapter)
and then to AMCs
for time and triggers

The big-data/DAQ challenge

ProtoDUNE dual-phase DAQ/online storage facility /online processing system/offline data handling

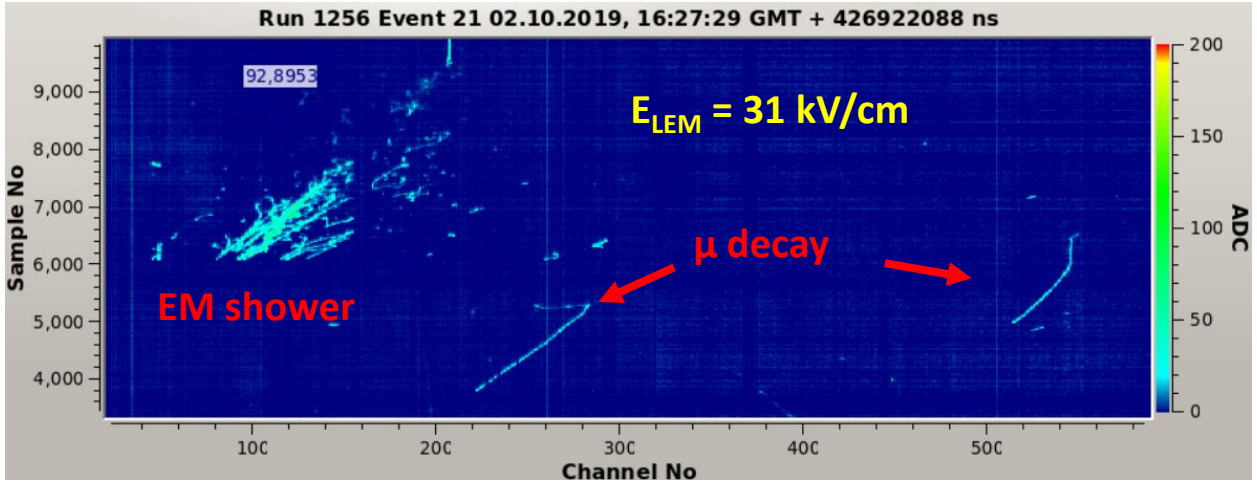
NP02 DAQ/network infrastructure



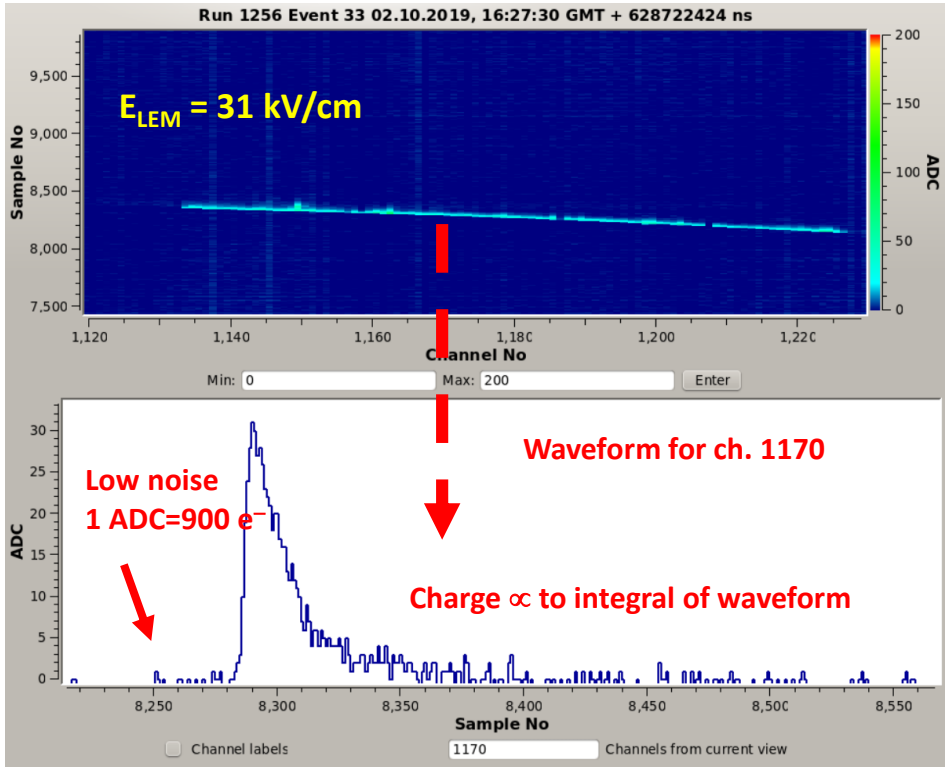
- ✓ Excellent performance of DAQ back-end system (20 GB/s data storage bandwidth)
- ✓ 2 M events (4ms drift) acquired corresponding to 200 TB, data transferred to CERN EOS and FNAL
- ✓ Fast reconstruction (15s/event) performed on real time on the online computing farm (450 cores)
- ✓ Offline reconstruction of data performed with LarSoft by the DUNE computing group

Cosmic Ray events in protoDUNE dual-phase

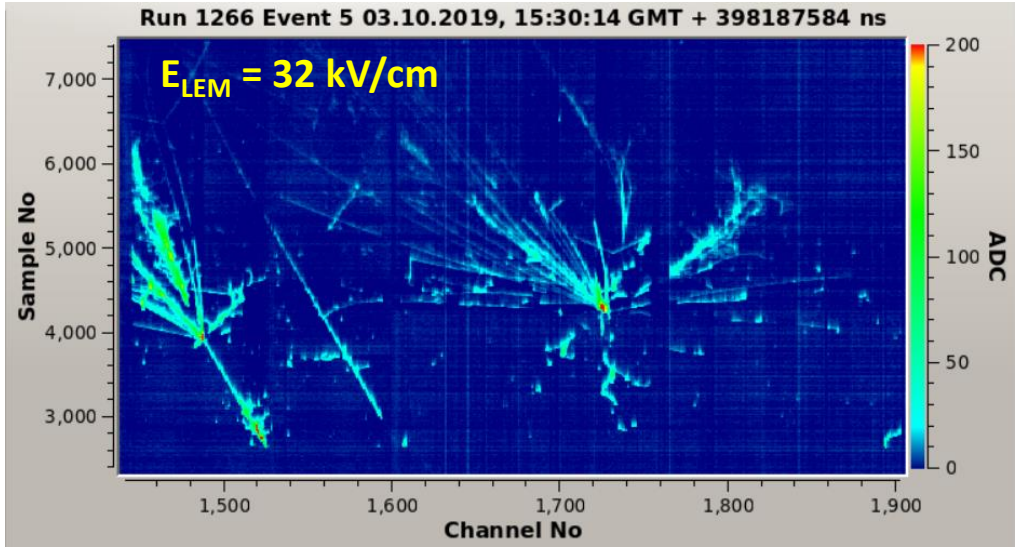
Electromagnetic shower + two muon decays



Horizontal muon track



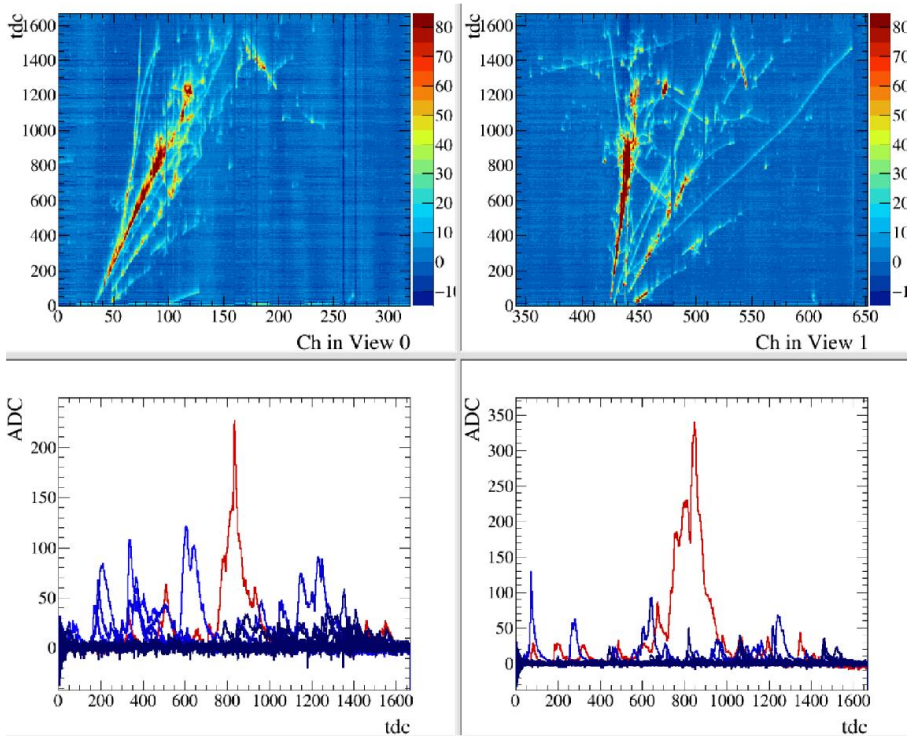
Multiple hadronic interactions in a shower

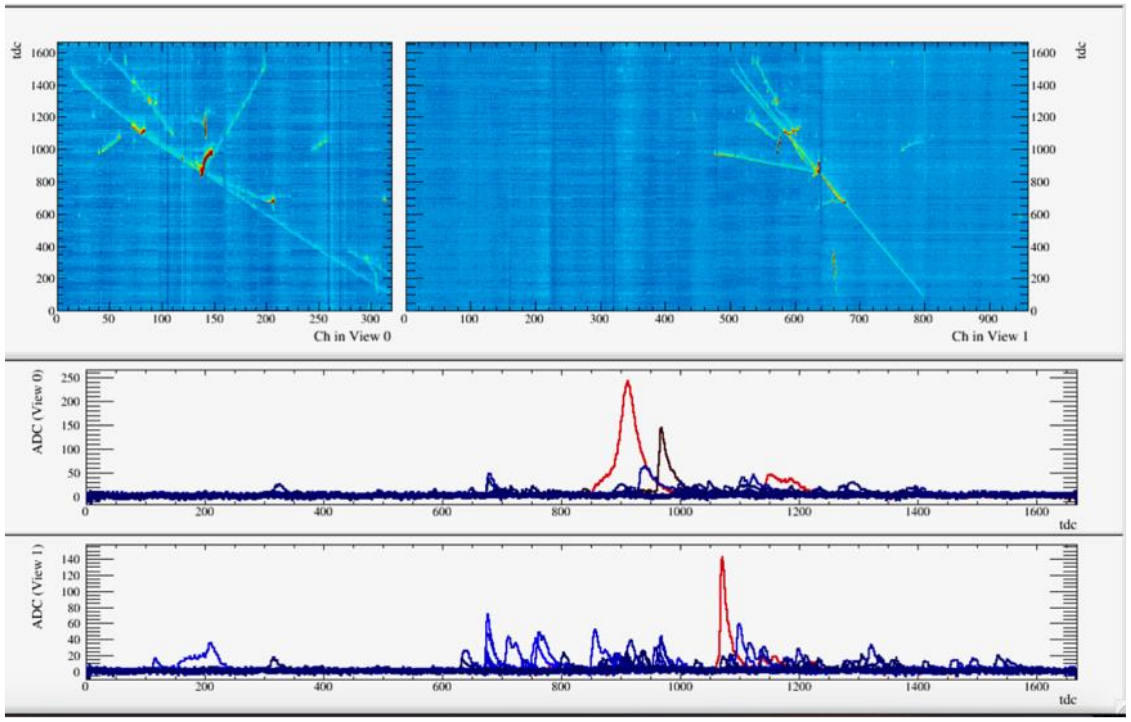


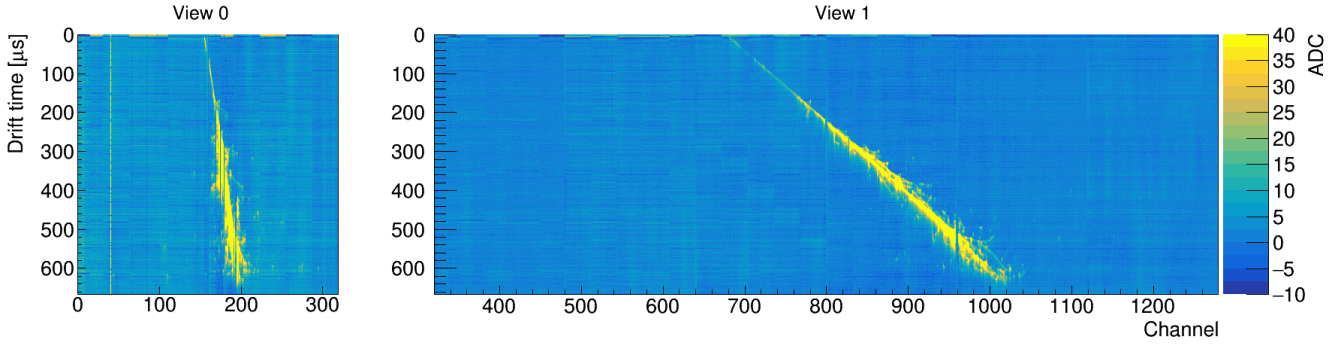
Thank you for your attention !

See also the presentation of Quentin David for Huffman Compression/decompression implementation and performances

Cosmic events examples

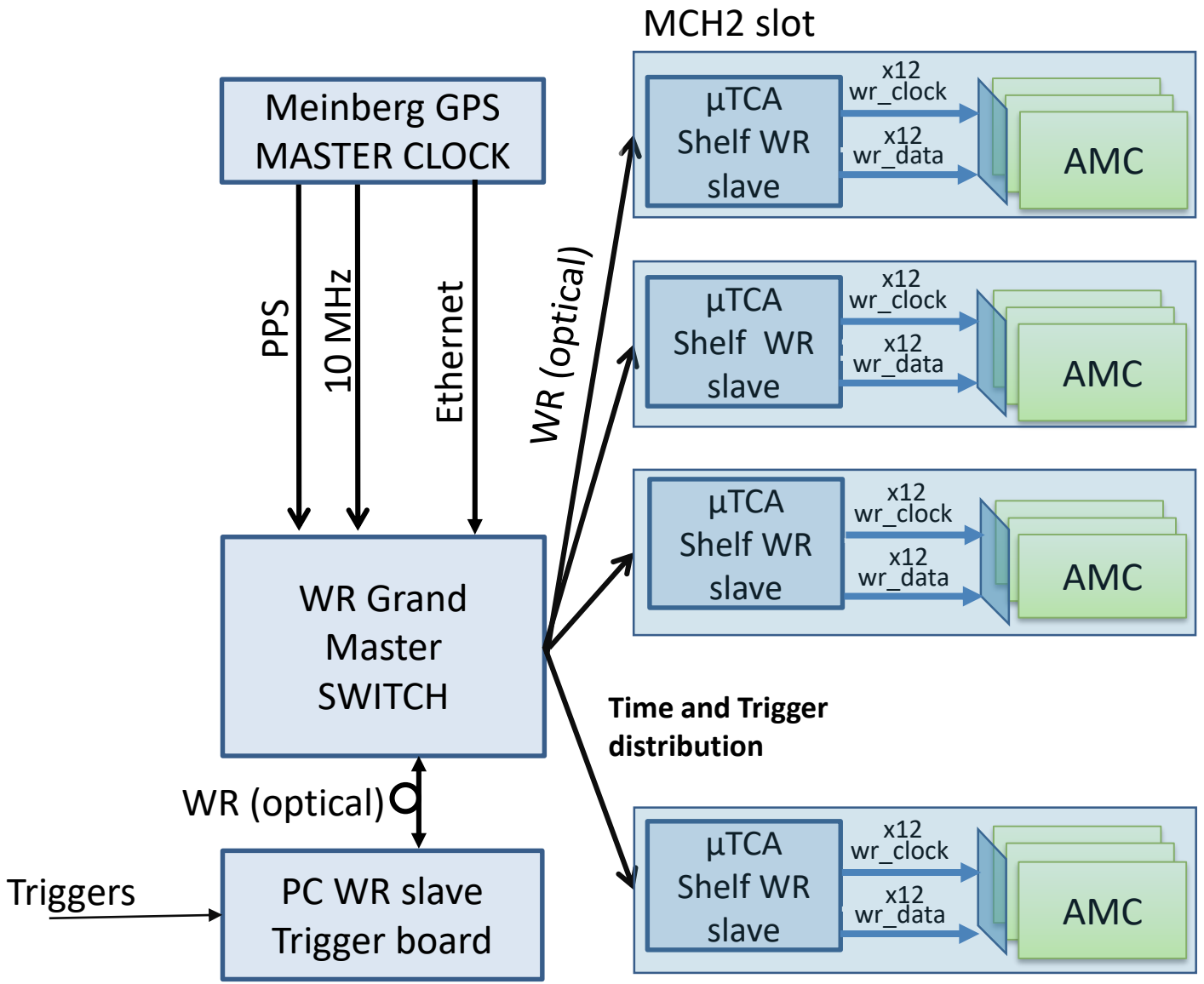




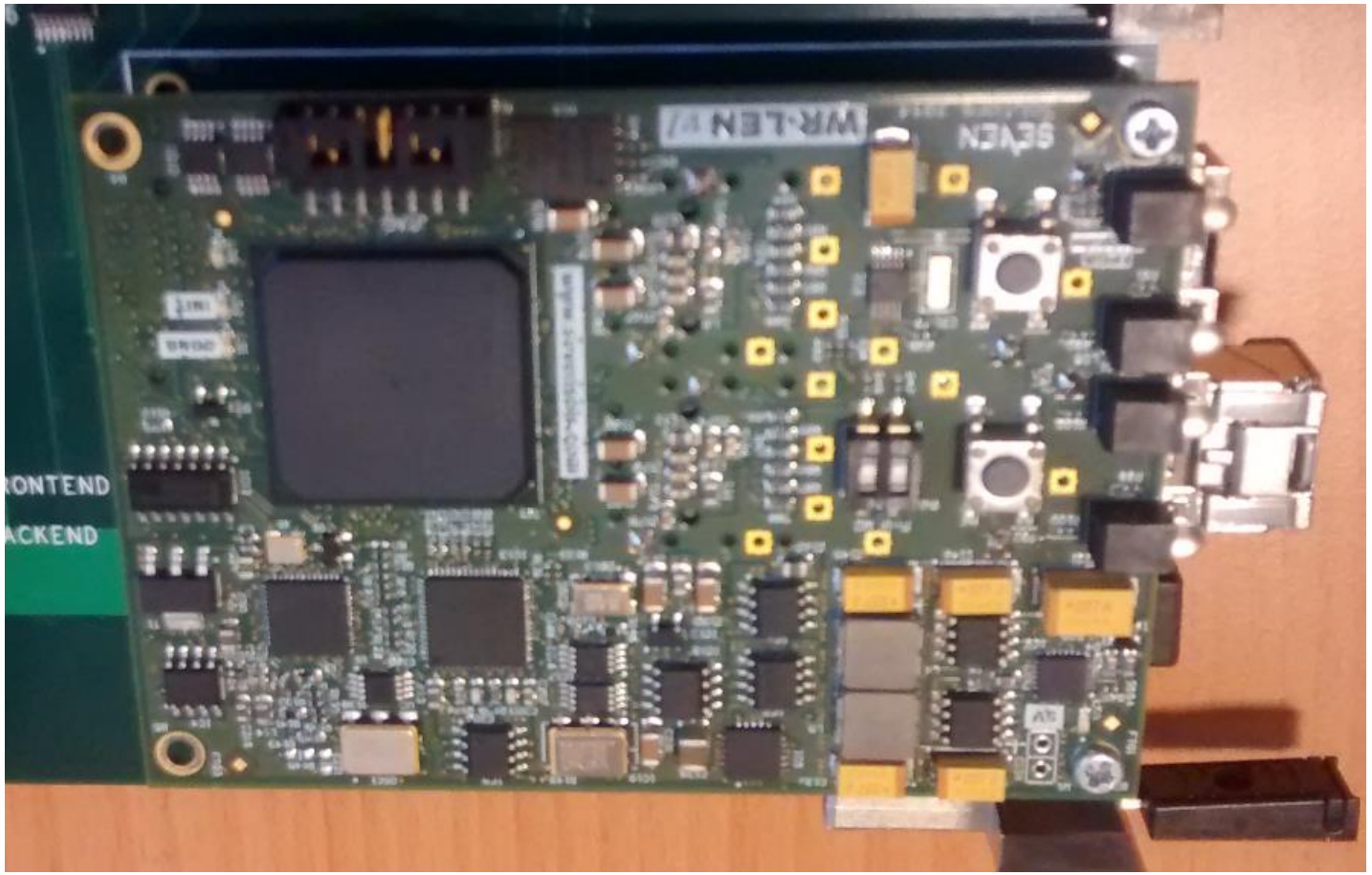


White Rabbit based time and trigger distribution

- **No need to develop analog clock distribution system and microTCA receiver cards**
- **Beam counters/large area cosmic counters trigger board also in WR standard → generates trigger timestamps transmitted on WR network**
- **Development of the WR slave as MCH mezzanine from a commercial WR node**
- **Tongue 2 of MCH2 is used to distribute clock and time on the backplane to all AMCs**
- **Sub-ns sync accuracy**



WRLEN CARD (SEVEN)



Optical Fiber to WR switch

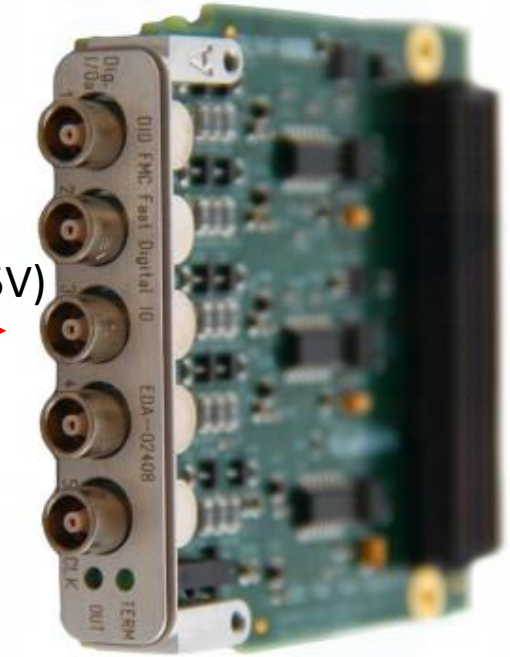
- Clock recovery 125 MHz phase control within 1 ns.
- Time keeping relative to Master.
- Modified firmware for backplane time/trigger distribution
- Bytes sent on WR_DATA are 8b/10b encoded (K28.1 is used as the no data word)

SPEC and FMC DIO cards (from Sevensol firm)

Analog trigger to WR frames conversion

- A FMC DIO card generates time stamps when a trigger arrives
- The timestamp is send to every WRLEN node via the WhiteRabbit network
- The trigger frame is then forwarded to the AMC boards

FMC DIO card:



Trigger Signal (5V)

WR Network

SPEC card:

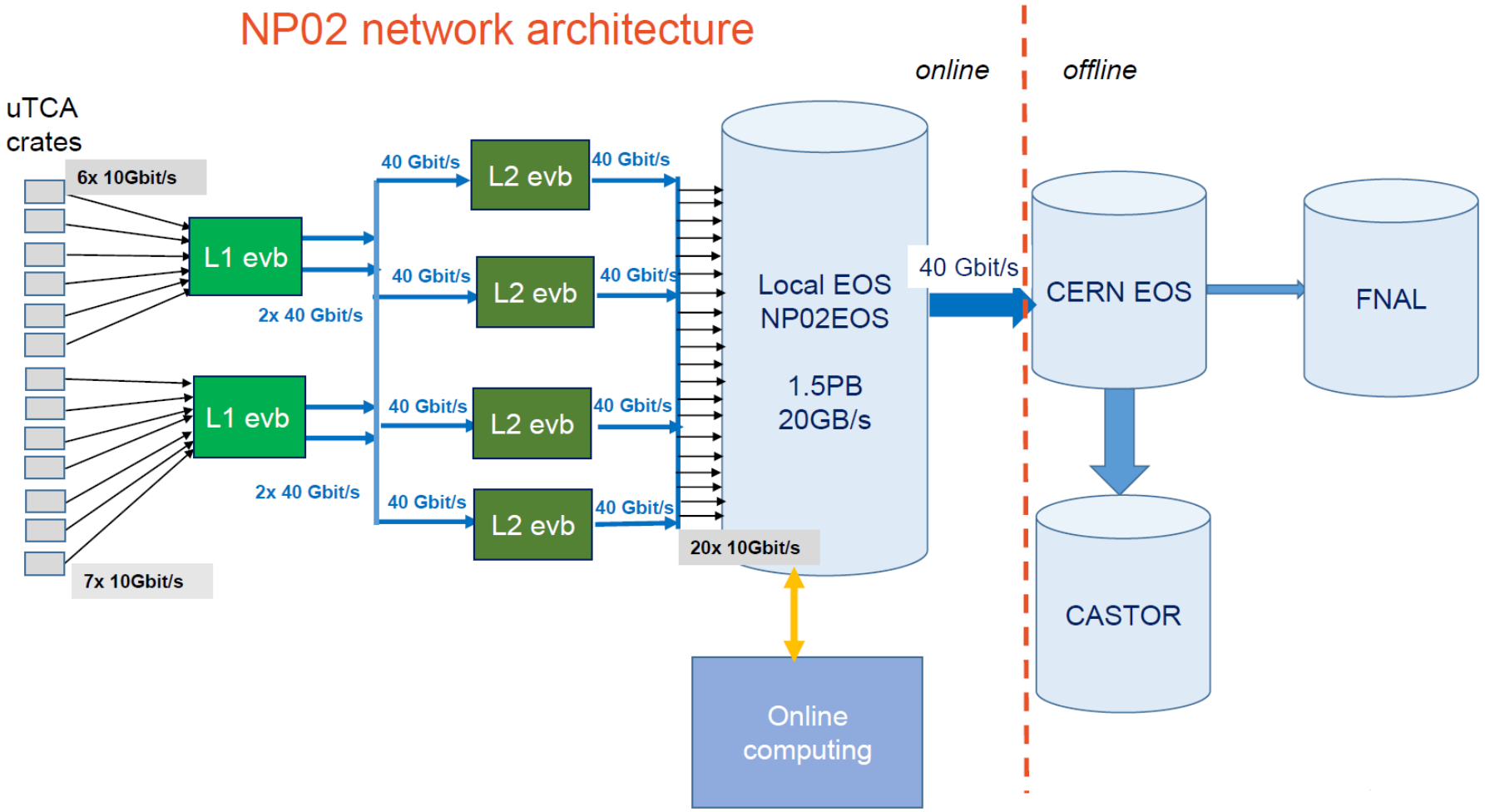
Data Acquisition Main Features.

- **Front-end** :
  - 10Gbe Ethernet for data transmission and control (well adapted for large distributed system
  - microTCA standard (12 chassis double width, dual star)
  - Advanced Mezzanine Board: 64 channels ADC 40 Msps (120 cards)
  - MCH with 10Gbe switch XAUI on backplane.

- **Synchronization and trigger management**
  - Grand Master White Rabbit switch (Distributed by SevenSol)
  - Custom AMC 13 for White Rabbit Slave and clock/trigger distribution on backplane
  - SPEC board from Sevensol for trigger distribution through the White Rabbit network

- **Backend** :
  - High performance Ethernet cards, servers

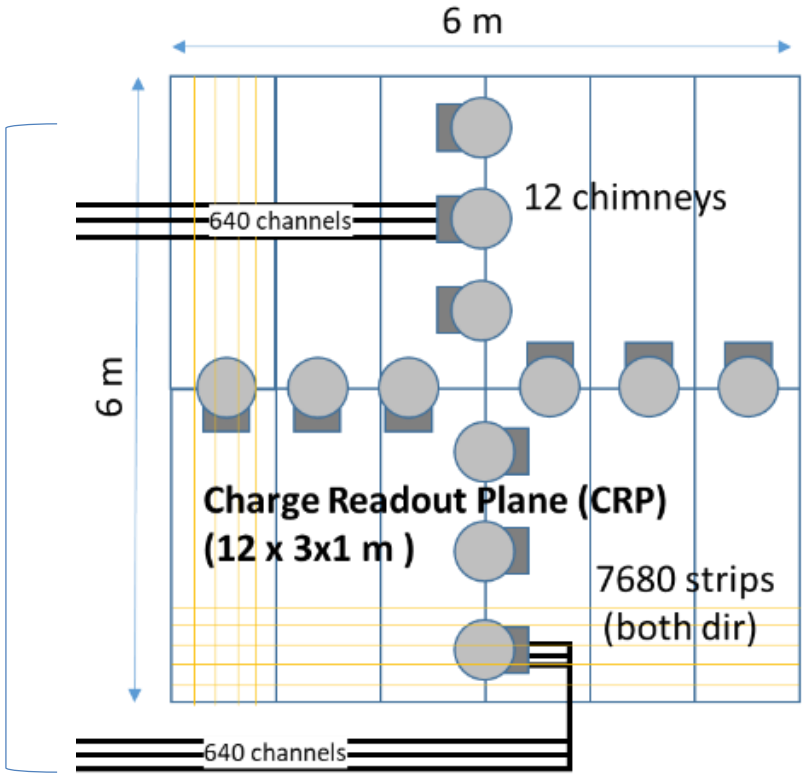
BACKEND for protoDUNE

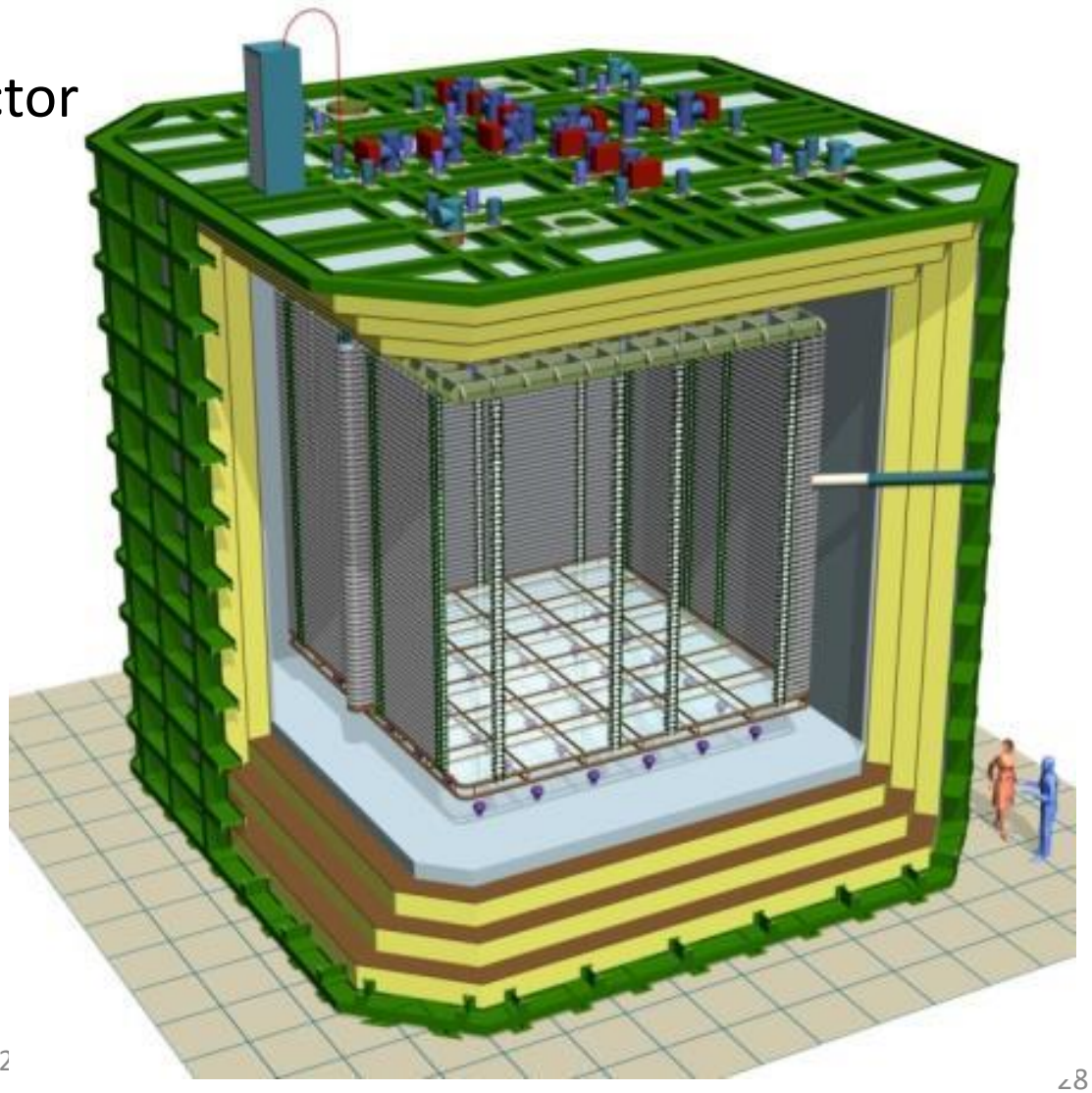


ProtoDUNE: 1:20 scale Demonstrator of DUNE at CERN

- 7680 output signals from detector readout plane
- 12 Chimneys allow the signal output from the detector
- This structure should be duplicated for DUNE

7680
Channels
off analog signals





DAQ back-end equipment in the DAQ room (IP2I) (support for 4 active CRPs readout):

- **High bandwidth (20GByte/s) distributed EOS file system for the online storage facility**

→ Storage servers: 20 machines + 5 spares (DELL R510, 72 TB per machine): up to 1.44 PB total disk space for 20 machines, 10 Gbit/s connectivity for each storage server.

- **Online storage and processing facility network architecture:**

→ Backend network infrastructure 40 Gbit/s DAQ switch (Brocade ICX7750-26Q) + 40/10 Gbit/s router (Brocade ICX 7750-48F)
→ Dedicated 10 Gbit multi-fibers network to uTCa crates
→ Dedicated trigger network (x2 LV1 event builders + trigger server)
→ x2 40 Gbit/s link to IT division

- **DAQ cluster and event builders:**

→ DAQ back-end: 2 LV1 event builders (DELL R730 384 GB RAM) + 4 LV2 event builders (DELL R730 192 GB RAM)
→ DAQ cluster service machines: 9 Poweredge R610 service units: 2 EOS metadata servers, configuration server, online processing server, batch management server, control server, …

- **Online computing farm (room above the DAQ room):**

→ 40 servers Poweredge C6200 (450 cores)