ProtoDUNE-DP Electronics and DAQ

LBNC Meeting, 5 December 2019

Dario Autiero

- SFT chimneys, cryogenic FE electronics, Low Voltage distribution system
- uTCA and data network infrastructure
- Front-end digitization system
- Timing and trigger system
- Online back-end DAQ system + online storage and online processing

ProtoDUNE-DP accessible cryogenic front-end electronics and uTCA DAQ system

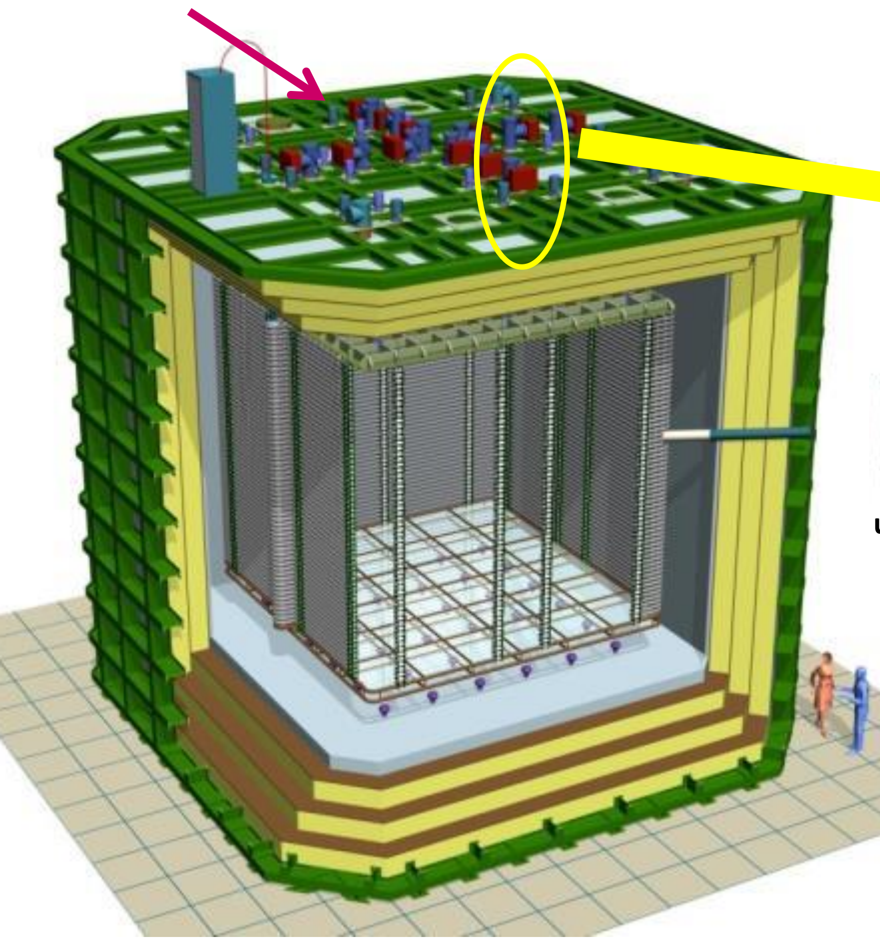
Full accessibility provided by the double-phase charge readout at the top of the detector

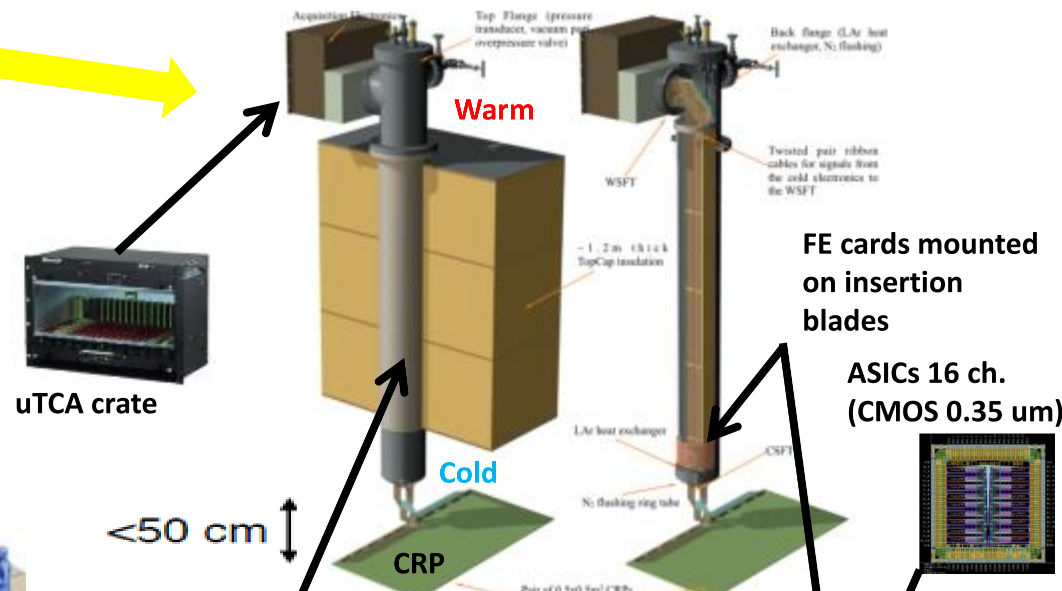
- **Digital electronics at warm on the tank deck:**
  - Architecture based on uTCA standard
  - 1 crate/signal chimney, 640 channels/crate

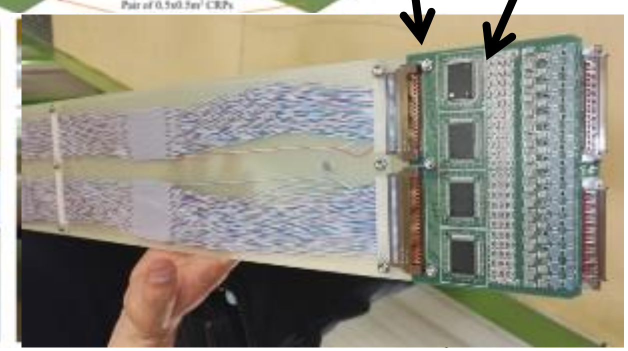
  → 12 uTCA crates, 10 AMC cards/crate, 64 ch/card

- **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







Signal chimney

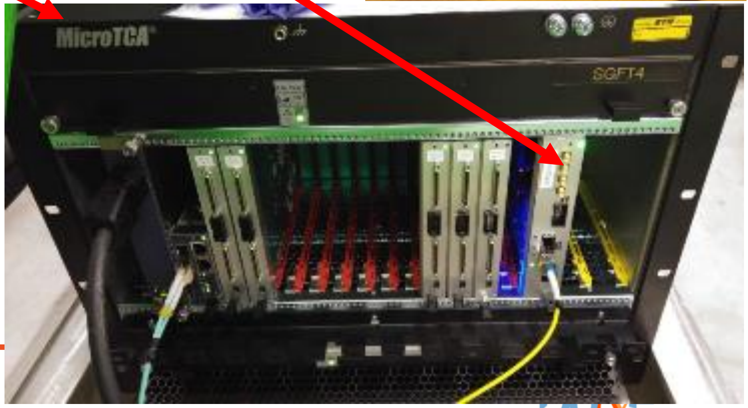
Readout system for a 10 kton dual-phase module (DUNE TDR DP Volume)

Total number of charge readout channels: 153600
(+light readout channels 720)

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

- AMC cards (64 ch): 2400 + 45 for LRO
- uTCA White Rabbit MCH: 240 + 5 for LRO
- uTCA crates (including MCH,PU,FU): 240 + 5 for LRO
- 10 Gbe optical links to backend: 240 + 5 for LRO
- VHDCI cables (32 ch) 4800

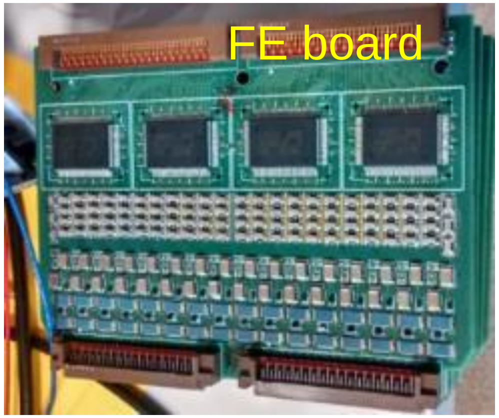
White Rabbit switches (18 ports): 16



Charge readout electronics components chain already massively implemented in ProtoDUNE-DP (1/20 of DUNE 10 kton). Final system also for DUNE 10 kton.

(R&D since 2006, long standing effort long standing effort aimed at producing low cost analog and digital electronics, tailored to DP configuration)

Main components ASIC amplifiers, ADCs, FPGAs, IDT memories already procured in 2015-2016. 3x1x1 pre-production batch in 2016.



Analog cryogenic FE:

- **Cryogenic ASIC amplifiers DP-V3, 0.35um CMOS → production performed 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 (fall 2016-spring 2018)**
- **Production or remaining FE cards for 6x6x6 launched in 2017: batch of 120 cards for 4 CRPs, extensive testing in 2018**

AMC digitization cards:

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

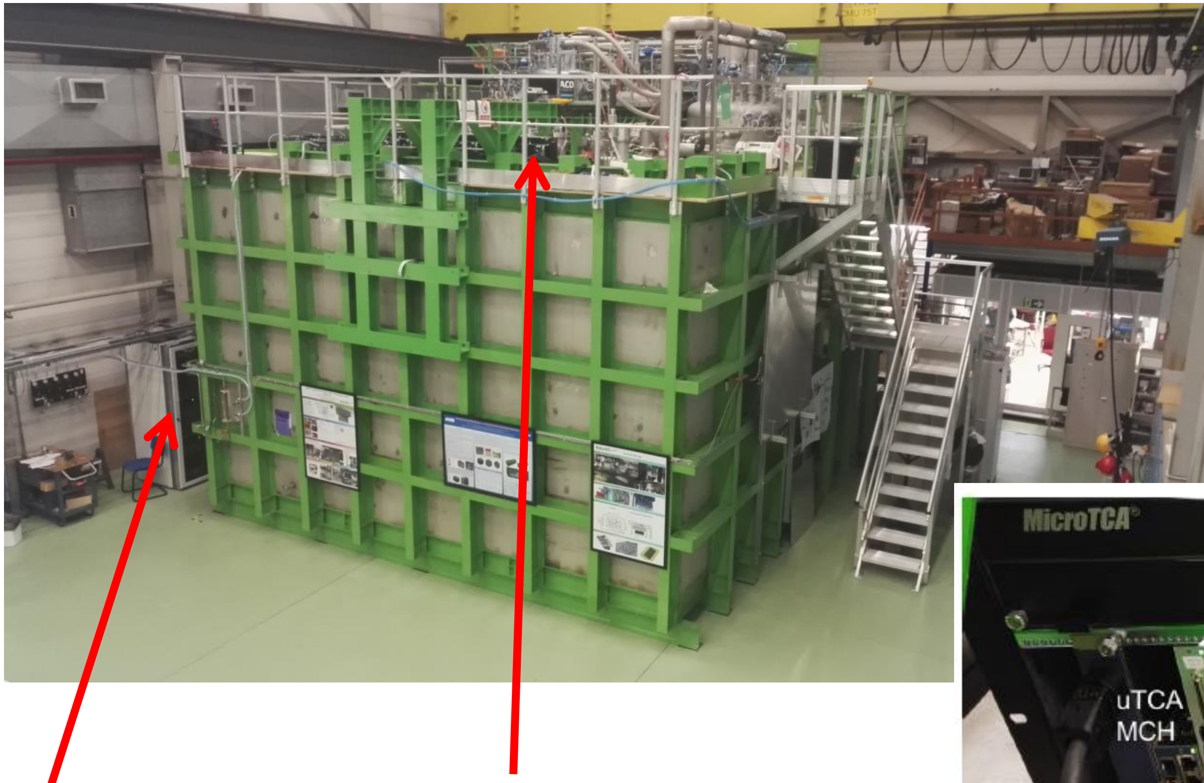
- **First batch of 20 cards operational on the 3x1x1 (fall 2016-spring 2018)**
- **Production or remaining AMC cards for 6x6x6 launched in 2017: batch of 120 cards for 4 CRPs, extensive testing in 2018**

White Rabbit timing/trigger distribution system:

- **Components produced in 2016 for the entire 6x6x6, Full system architecture operational on the 3x1x1 (fall 2016-spring 2018) including uTCA White Rabbit MCH**

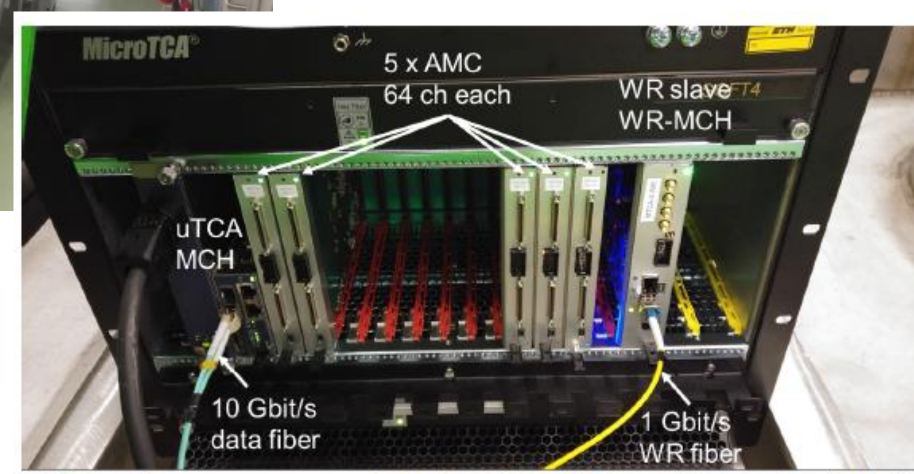
ProtoDUNE dual-phase: 12 chimneys/uTCA crates (120 AMCs, 7680 readout channels)

→ **3x1x1: 4 chimneys/uTCA crates (20 AMCs, 1280 readout channels), smaller chimneys 5 FE cards instead than 10 FE cards for protoDUNE-DP**



Electronics/DAQ system smoothly operational in the period November 2016-March 2018

3x1x1 published on JINST: https://arxiv.org/abs/1806.03317

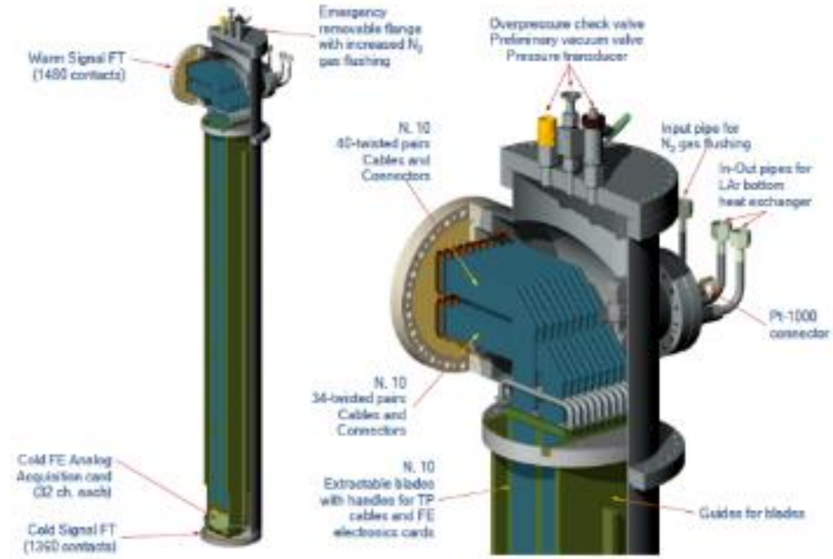


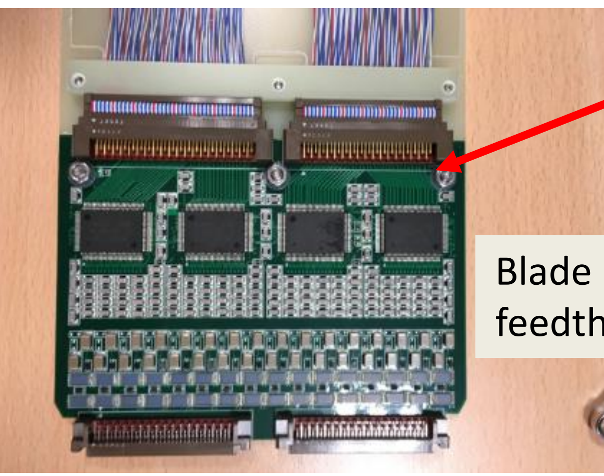
Signal Chimneys and uTCA crates

Event builder, network, GPS/White Rabbit GM, WR Trigger PC

Blades preparation and insertion in the chimneys (April 2019):

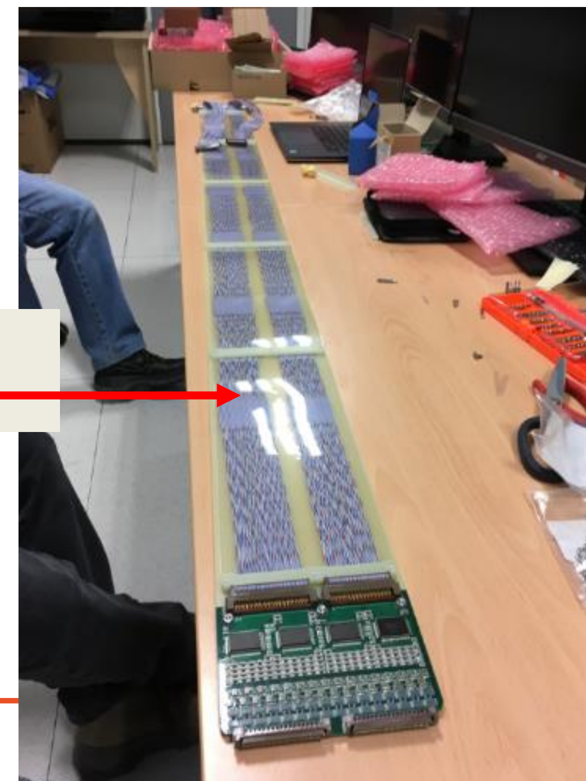
Insertion blades after assembly with flat cables, mylar protection foils and fixation mechanics → 70 + 10 (spares) blades produced





Assembly of the 64 channels cryogenic FE cards on the insertion blades and pre-insertion checks

Blade ready for its insertion in the signal feedthrough chimney



Signal Feedthrough Chimney Warm Flange

Controls

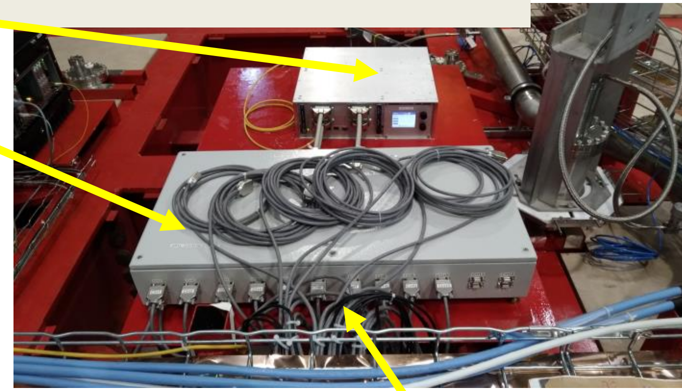
LV distribution, Sense

VHDCI signal cables to uTCA crates (shielded differential pairs)

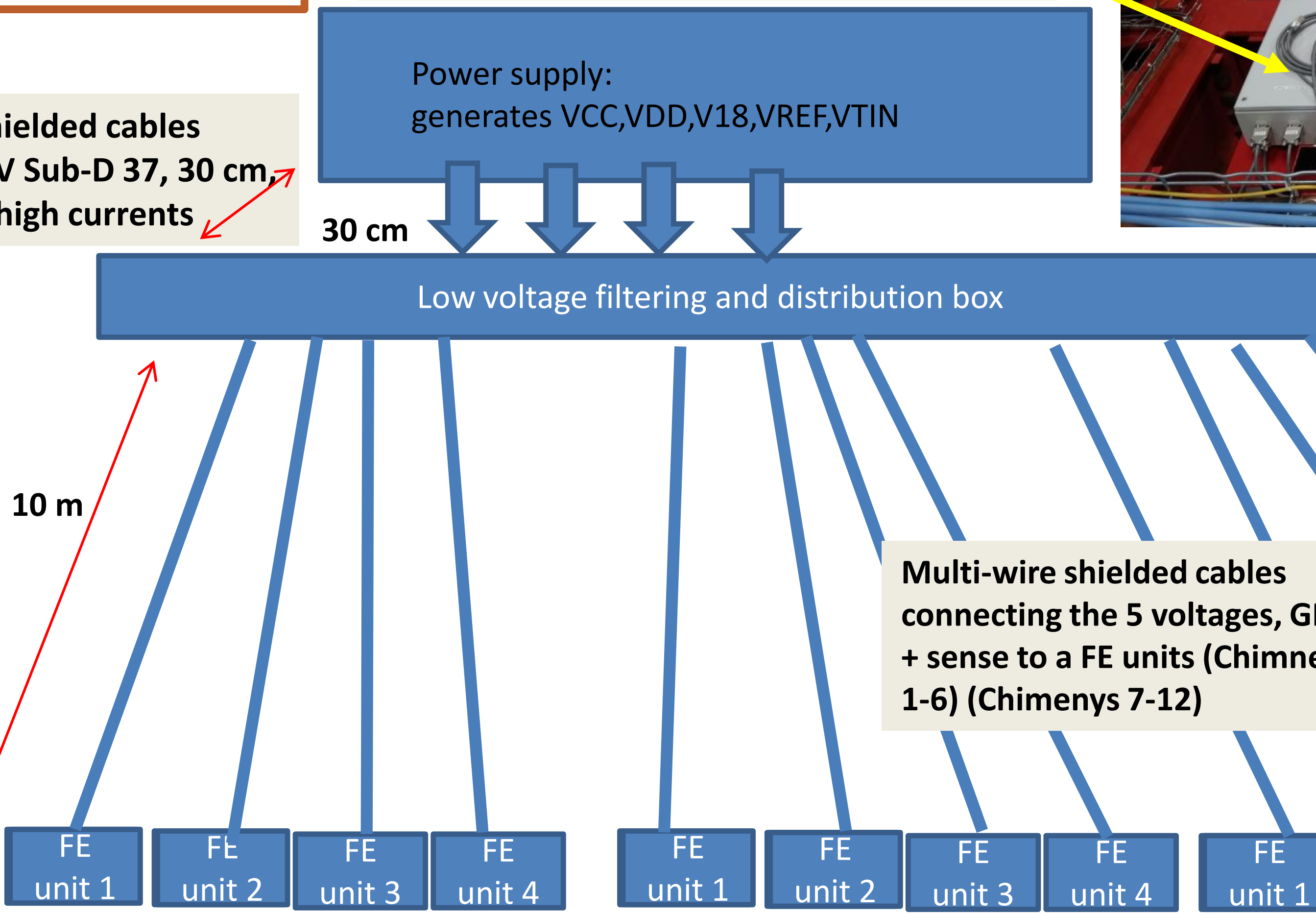
Low voltage generation and distribution system

Low voltage power supply: Wiener MPOD Micro-2 LX 800 W with 2 modules MPV 4008I (remote control by network)

LV filtering and distribution box (5 voltages distributed per chimney + sense system)



4 shielded cables MPV Sub-D 37, 30 cm, for high currents



Cabling to 10 chimneys

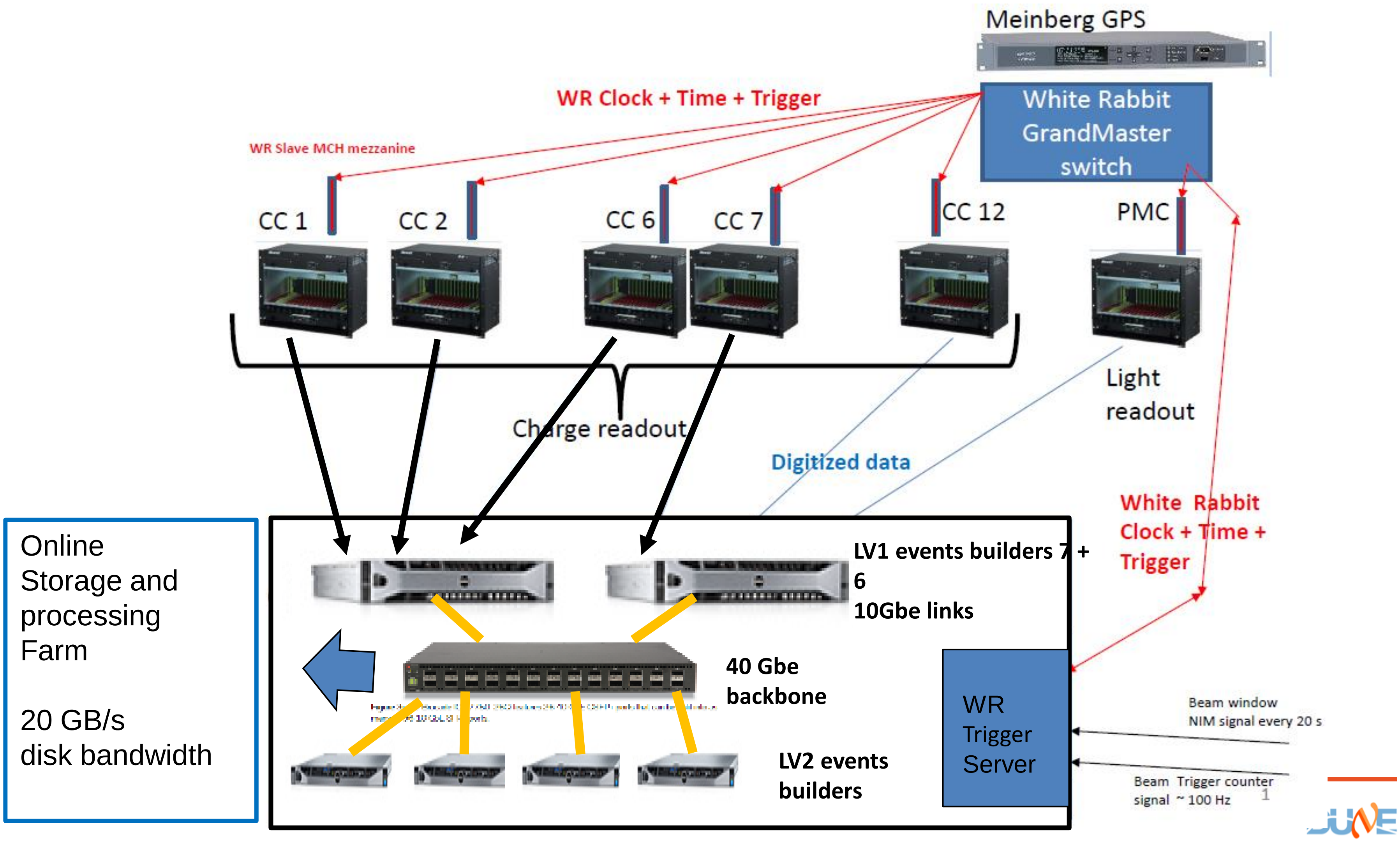
Multi-wire shielded cables connecting the 5 voltages, GND + sense to a FE units (Chimneys 1-6) (Chimenys 7-12)

Front-End Units (chimneys warm flanges)

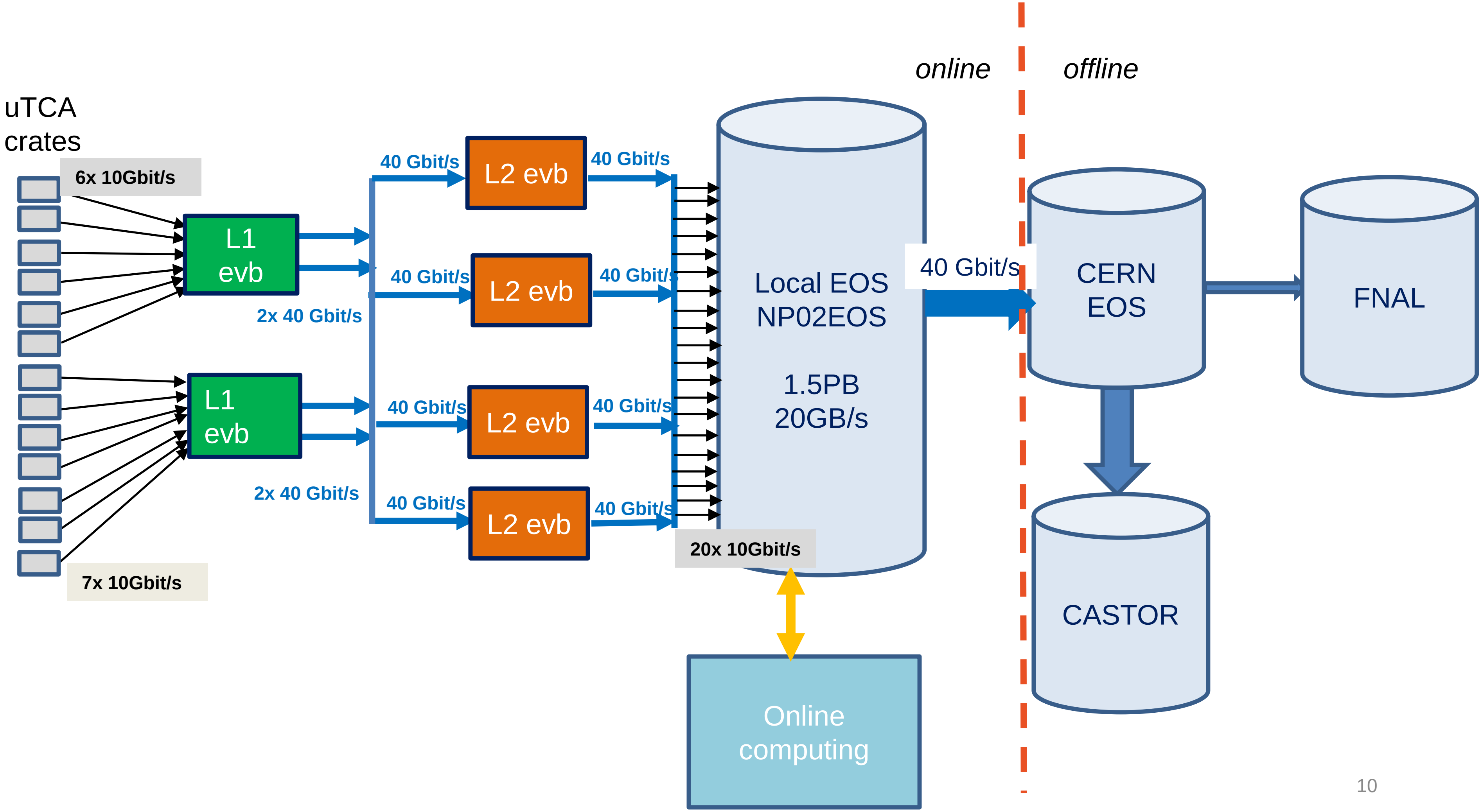
Chimneys+ LV distribution system + cabling to uTCA and uTCA infrastructure → very successful system for noise prevention

Global uTCA DAQ architecture for ProtoDUNE-DP

DAQ integrated with White Rabbit (WR) Time and Trigger distribution network:
White Rabbit slaves MCH nodes in uTCA crates + WR system (time source, Grand Master, trigger system)



NP02 DAQ/network infrastructure



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DAQ back-end equipments in the DAQ room (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:**

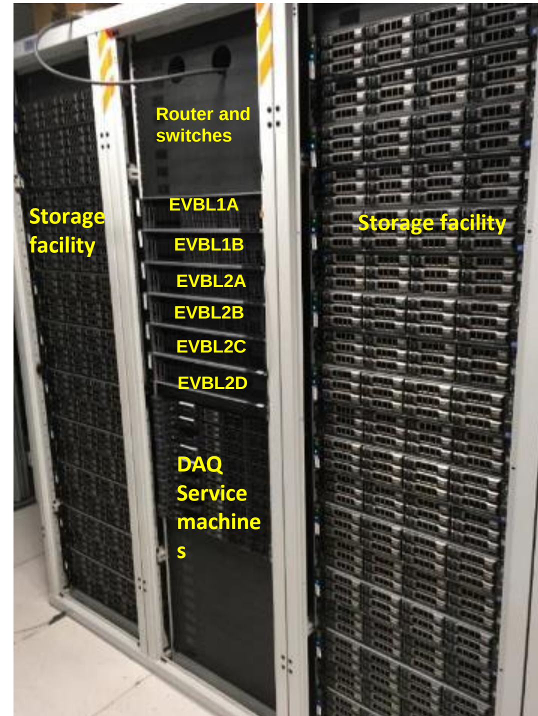
→ Backend network infrastructure 40 Gbit/s DAQ switch (Brocade ICX7750-26Q) + 40/10 Gbit/s router (Brocade ICX 7750-48F)
→ Dedicated 10 Gbit multi-fibers network to uTCa crates
→ Dedicated trigger network (x2 LV1 event builders + trigger server)
→ x2 40 Gbit/s link to IT division

- **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, …

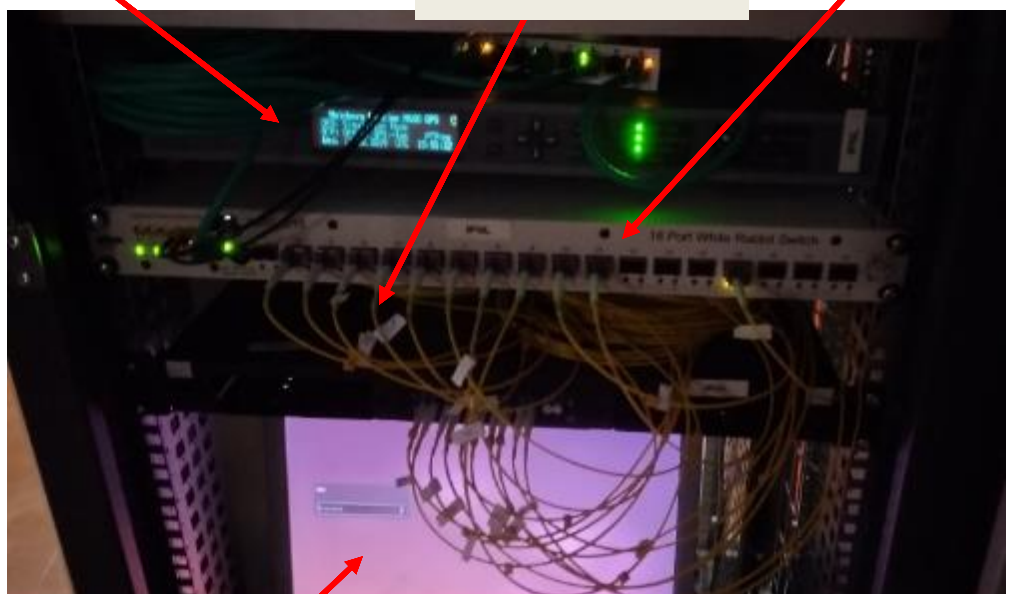
- **Online computing farm (room above the DAQ room):**

→ 40 servers Poweredge C6200 (450 cores)



ProtoDUNE-DP Timing System (similar to the system which was operating on the 3x1x1):

- **GPSDO GPS disciplined oscillator (generates 1PPS, 10 MHz, NTP timing)**
- **White Rabbit Grand Master (connects to slave node in the uTCA crates and to the timestamping card in the trigger server**
- **Trigger server with WR FMC-DIO for external triggers time-stamping (Light, Cosmic Counters, Beam, Calibration), new machine, new network interfaces and switches**
- **Private fast trigger network to the two LV1 event builders (dedicated fiber + switch)**
- **Service network for trigger server, GPSDO and WR Grand Master with local switch and cable to DAQ room**



White Rabbit Trigger server and private Trigger network to event builders

- **Charge readout electronics and DAQ FE production completed at the beginning of 2018 and extensively tested and calibrated during the entire 2018**
- **DAQ backend and online storage and processing facility completed and commissioned in the fall 2018**

→ Complete exercice for production-QA/QC-installation for the TDR

- **Installation activities at EHN1 in 2019:**

February 2019:

- Electrical power on the cryostat roof
- Optical fibers backbone infrastructure in between the cryostat roof and the DAQ room for data and white-rabbit
- Installation of uTCA crates, cabling and commissioning
- Installation and commissioning of White-rabbit slave nodes in uTCA crates
- Installation of commissioning of White Rabbit timing and trigger system (GPS, WR Grand Master, Trigger server)
- Installation and commissioning of dedicated trigger network among trigger server and event builders

March 2019:

- Installation and commissioning of uTCA digitization cards for all chimneys
- Full commissioning of digital front-end system and trigger timing system
- Installation and commissioning of low voltage power supply and control and of the low voltage distribution system for cryogenic electronics, and its cabling to chimneys
- Successful operation tests of the full DAQ chain from the uTCA crates to event builder to EOS storage system

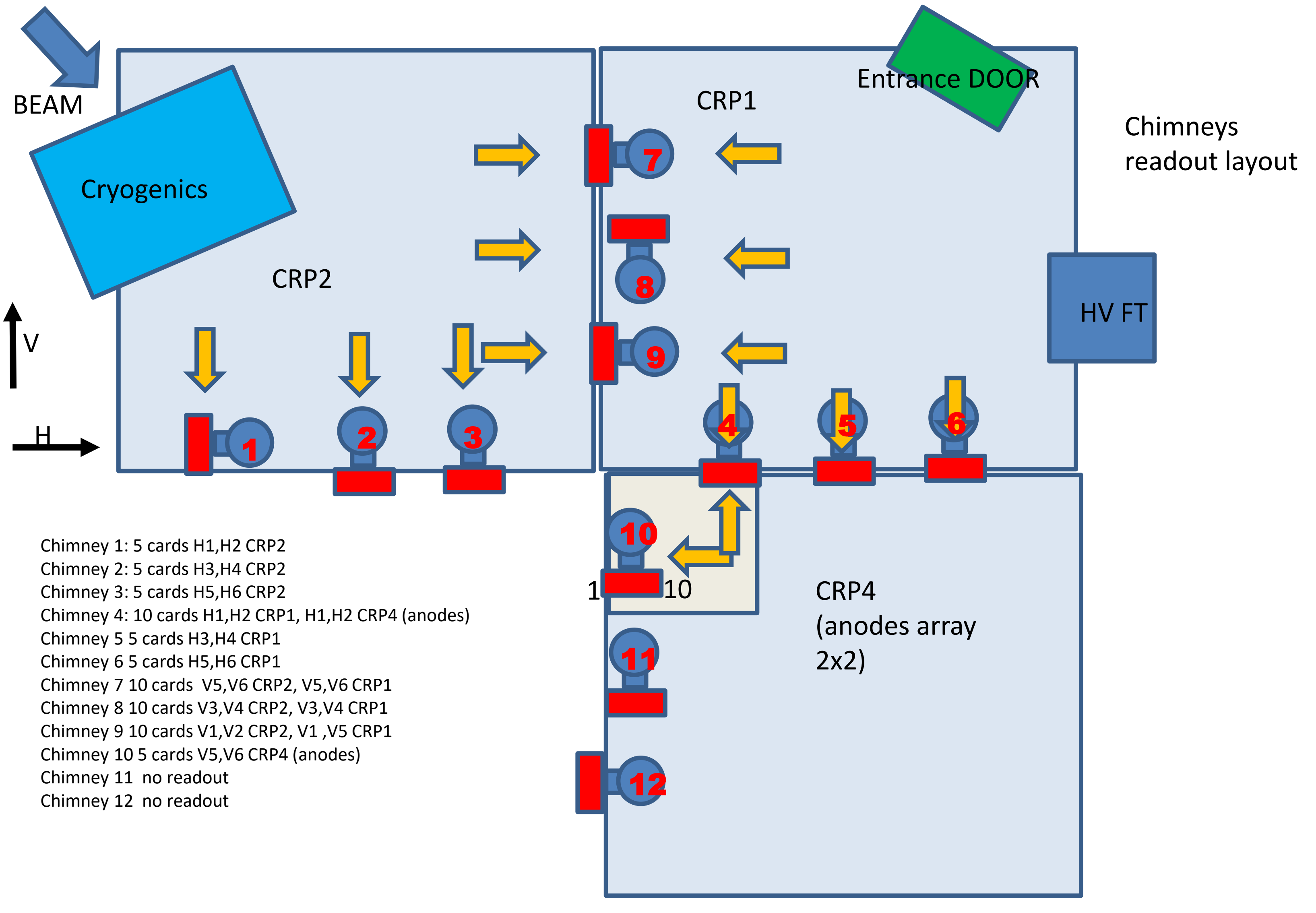
April 2019 :

- Assembly of the insertion blades with their mechanics, mylar foils and flat cables
- Cabling and test of the anode strips pulsing system
- Mounting of the cryogenic front-end cards on the blades
- Installation of the blades in the signal feed-through chimneys
- Systematic test of the charge readout signals by using the pulsing system injecting signals in the anode strips

June-July 2019 :

- Intensive running of Electronics and DAQ. Campaign of systematic checks of grounding of the slow control systems in order to mitigate external noise sources

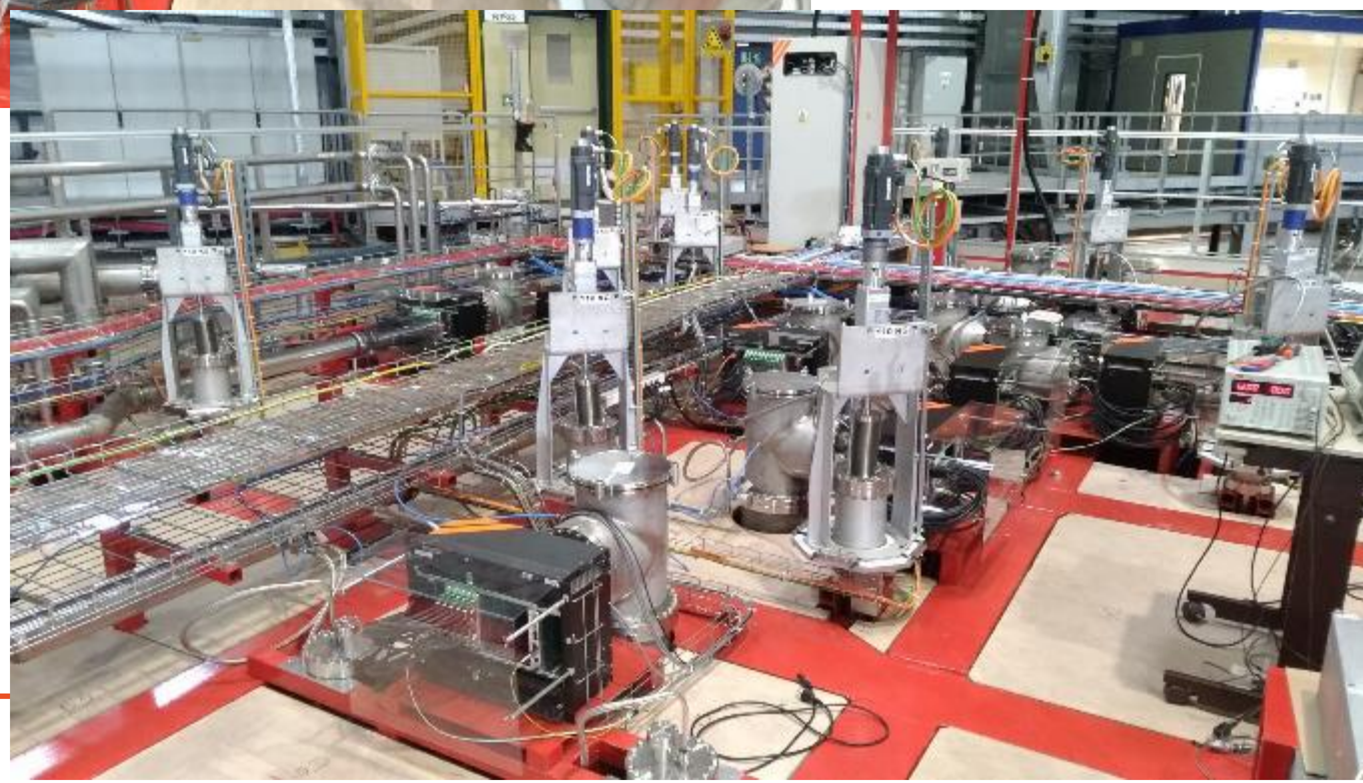
Current CRP readout in ProtoDUNE-DP: two active CRPs (CRP1+CRP2) + 2x2 anode array on CRP 4



Chimney 1: 5 cards H1,H2 CRP2
Chimney 2: 5 cards H3,H4 CRP2
Chimney 3: 5 cards H5,H6 CRP2
Chimney 4: 10 cards H1,H2 CRP1, H1,H2 CRP4 (anodes)
Chimney 5 5 cards H3,H4 CRP1
Chimney 6 5 cards H5,H6 CRP1
Chimney 7 10 cards V5,V6 CRP2, V5,V6 CRP1
Chimney 8 10 cards V3,V4 CRP2, V3,V4 CRP1
Chimney 9 10 cards V1,V2 CRP2, V1 ,V5 CRP1
Chimney 10 5 cards V5,V6 CRP4 (anodes)
Chimney 11 no readout
Chimney 12 no readout

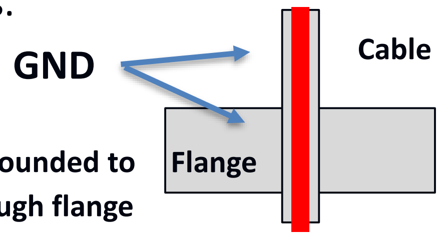
ProtoDUNE dual-phase view of the cryostat roof with:

- **FE digitization electronics in the uTCA crates**
- **Signal feedthrough chimneys with cold electronics**

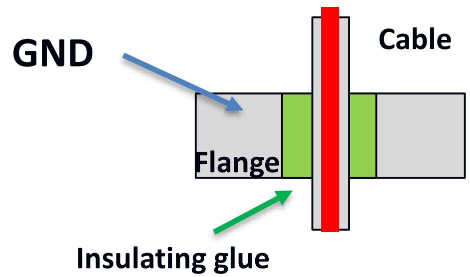


Noise

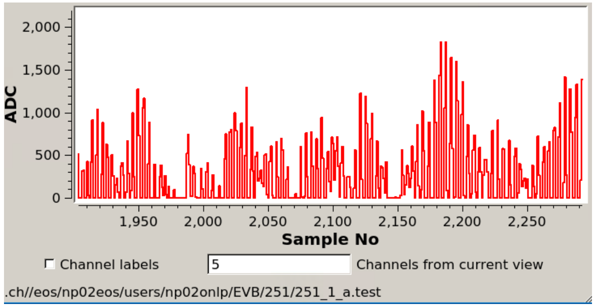
- In June/July were **realized grounding issues on the slow control cabling:** LEM HV, Grids HV, CRP level meters and distance meters, CRP temperature probes) + cameras.
- Cables are shielded but the shield was not grounded at the flanges (for the LEM and grid HV cables this was not possible) → cables acting as antennas injecting noise in the cryostat which is then picked up by the CRP anodes.



OK: Coax cable shield grounded to cryostat at the feedthrough flange



NOT OK: Coax cable shield disconnected from flange

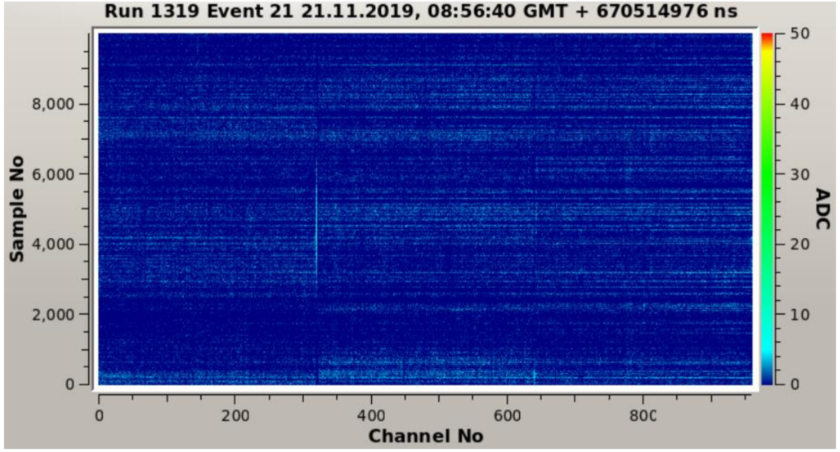


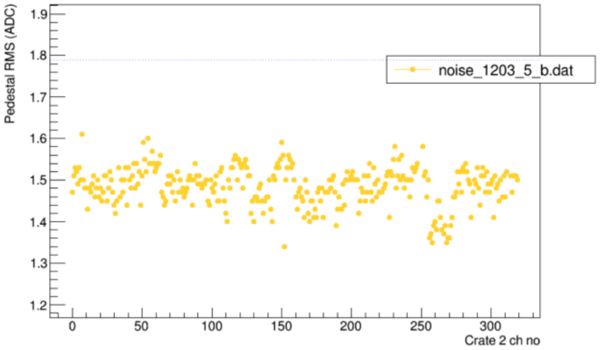
- Initial measurements in June: noise ~300 ADC counts RMS
  Characteristic frequencies of pickup signals 50 KHz and 625 KHz
- **Mitigation strategy implemented since July with some tails in August →**

1) Implement cables **grounding at the flanges with some patches** were possible
2) build **flange extensions** with deported grounded patch panels + Faraday cages for grounding of **LEM and grids HV**
3) Cameras, LEDs, CRP distance meters **kept off,** CRP temperature probes **disconnected**

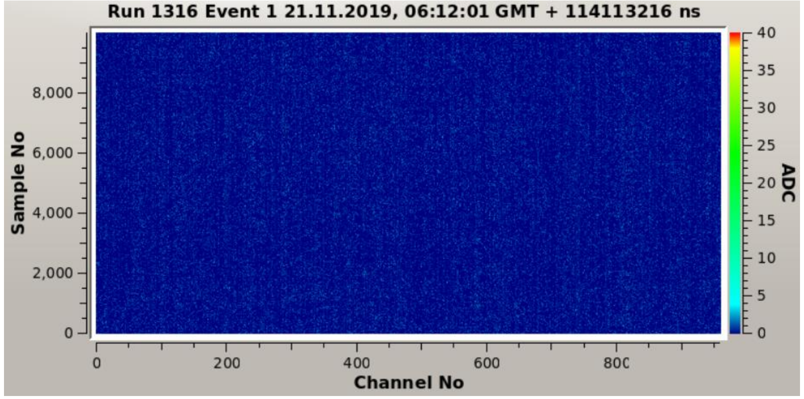
Noise

→ **After slow-control grounding improvements pickup noise brought to a good level: typically ~1.5 ADC counts RMS**





Intrinsic electronic noise measured with blades disconnected from cold flanges 0.7 ADC counts RMS

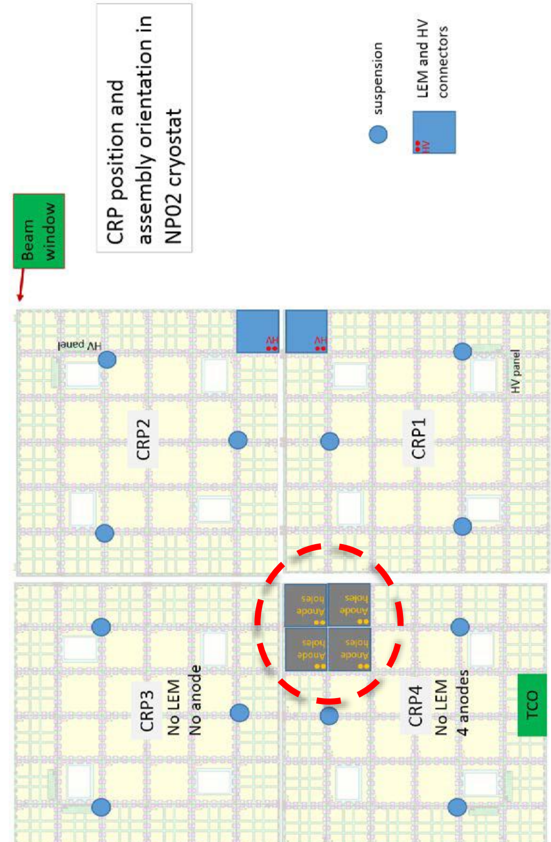


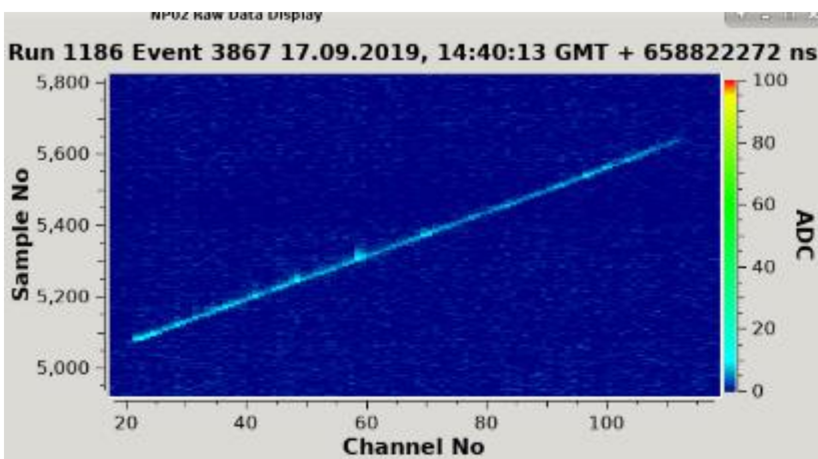
Noise still dominated by coherent noise due to external grounding of slow control cabling to be further improved (same frequencies as before mitigation actions)→ **goal: bring to intrinsic electronics noise ~<1 ADC RMS** (1 ADC count ~ 900 electrons). Noise filtering can reduce this coherent noise from grounding issues. In the events which will be shown **<u>noise filtering is not applied</u>**

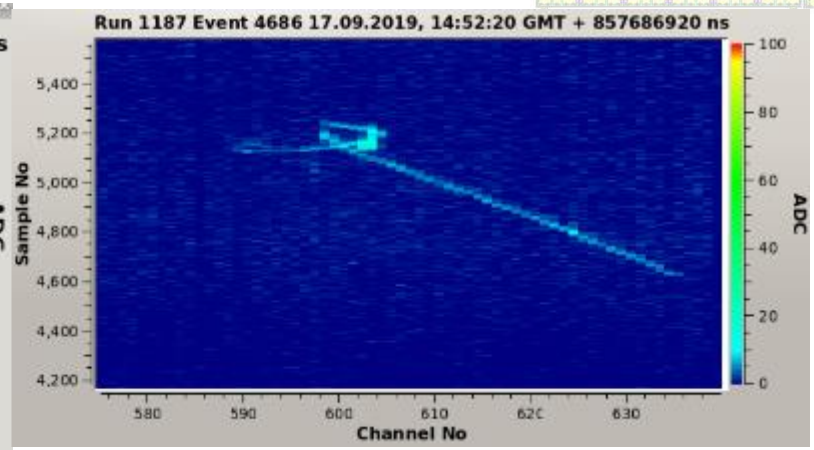
- **CRP level meters flanges and other connections could be still better grounded**
- **TBD: decoupling cryostat GND from building GND →**

CRP4

- CRP4 has no LEM. It is instrumented with 4 anodes connected to the charge readout the two anode views share evenly the charge extracted with the grid
- Grid operating at 4 kV. Half of SP signal due to charge sharing among the two views + some inefficiency factors from extraction/collection + 3.1 mm pitch and 2.5 MHz sampling → "~1/2 SP mode" with electrons extraction in gas
- → Nice tracks observed with current levels of noise
- dE/dx measurements used as consistency check of the gain assessment of the two CRPs instrumented with LEMs







CRP4 and access to FE electronics

A sparking incident happened on 20/8 during CRP4 commissioning activities :

- Given the absence of the LEMs on CRP4 the FE electronics connected to the anodes is directly exposed to the possibility of grid sparking
- The FE electronics has protection components which are designed to protect against LEMs sparking but cannot withstand direct grid sparking
- At the time of the incident CRP4 alignment was not fully established yet and also there was little experience conditions with the LAr surface and effects of waves.

→ The sparking incident damaged ~10 FE cards, mostly in chimney 4.

→ The cards have then been replaced by using the foreseen procedure of extraction/insertion of the blades. This was the occasion to fully test the procedure

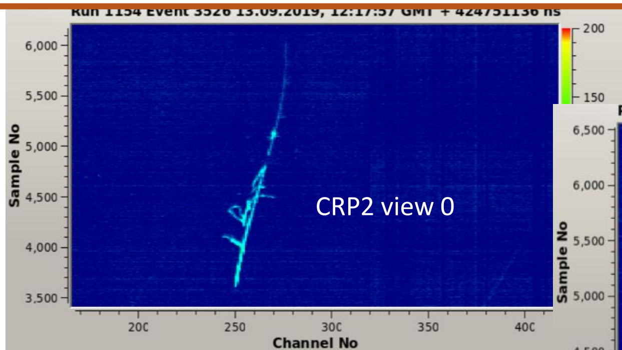
- The procedure requires 15 minutes access for a complete chimney and it is quite straightforward

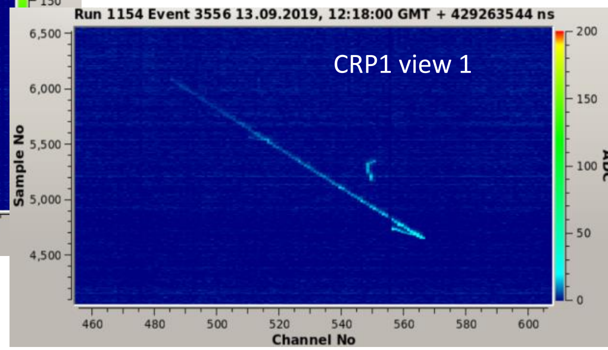
→ See movie here

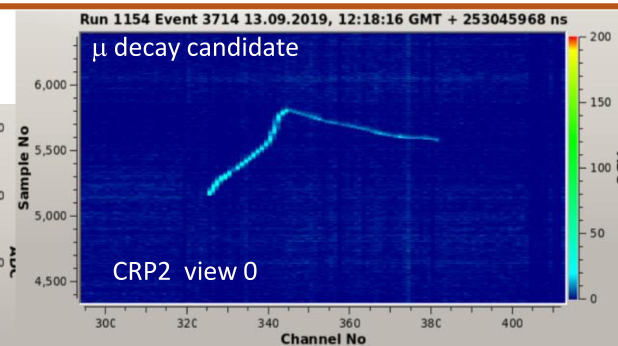
- CRP4 was then operated (see slide before) with electronics back working, correct grid immersion and no sparking anymore

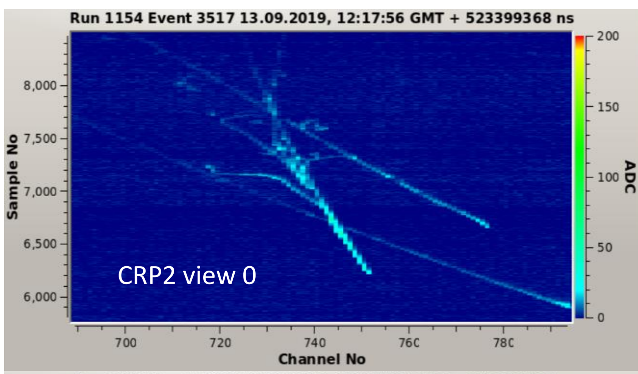
First events observed since 29/8

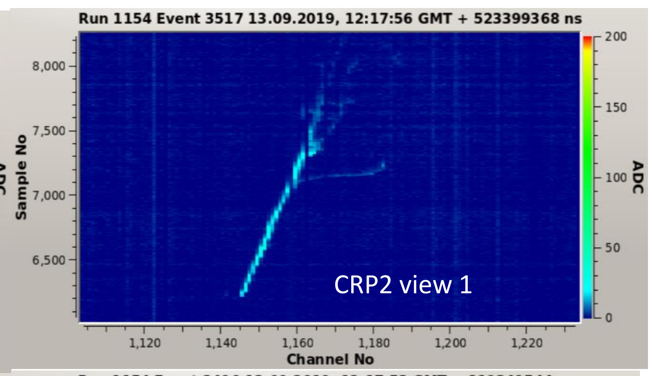
Gallery of tracks (LEMs at 2.9 kV, grids at 6 kV, cathode at 50 kV, random trigger, 400 us lifetime, raw data display, no noise filtering)

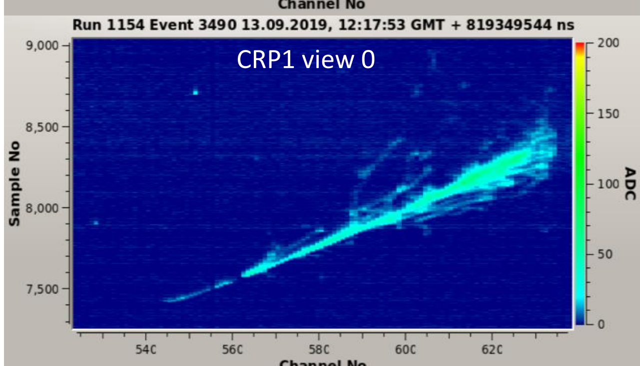


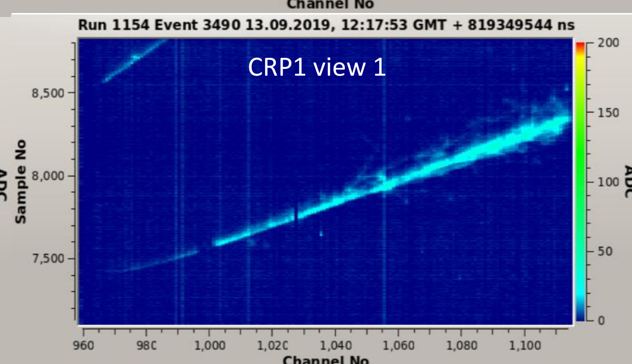








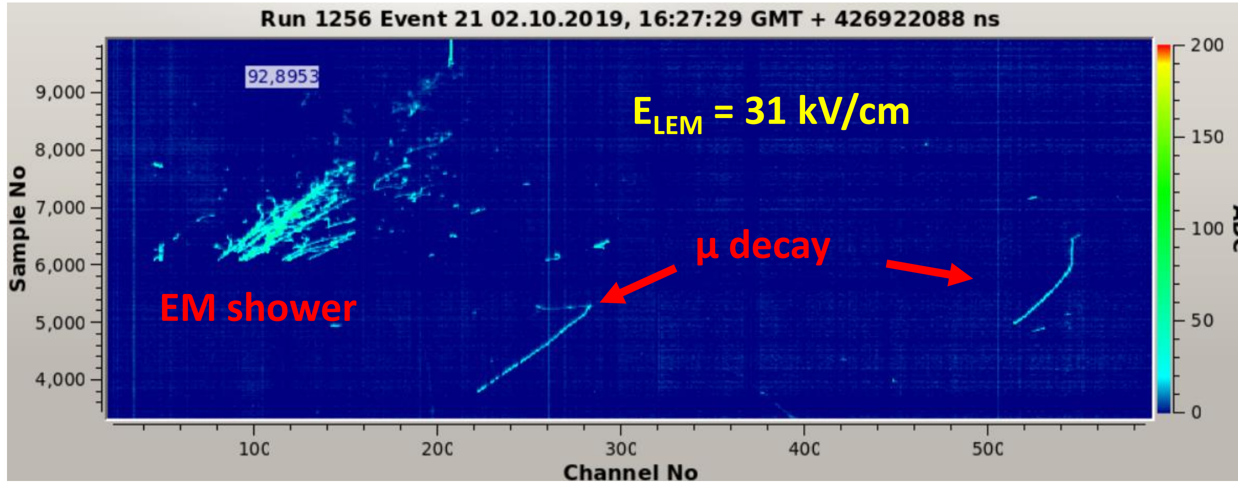




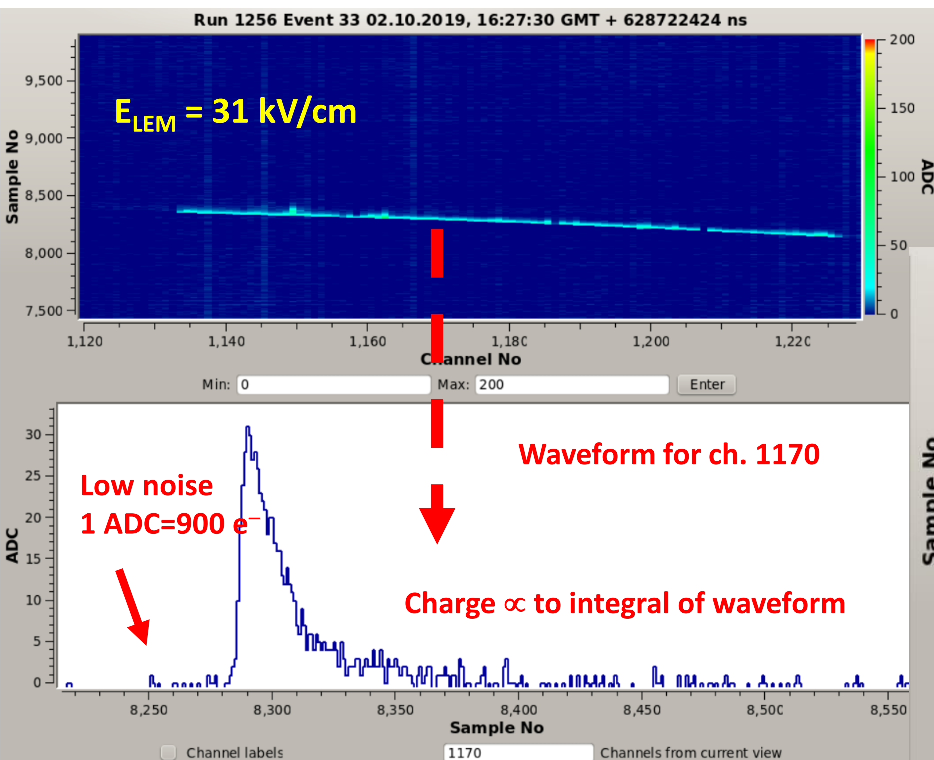
Zoom on same track details observed from the two perpendicular views

Cosmic ray events at higher gains in protoDUNE dual-phase

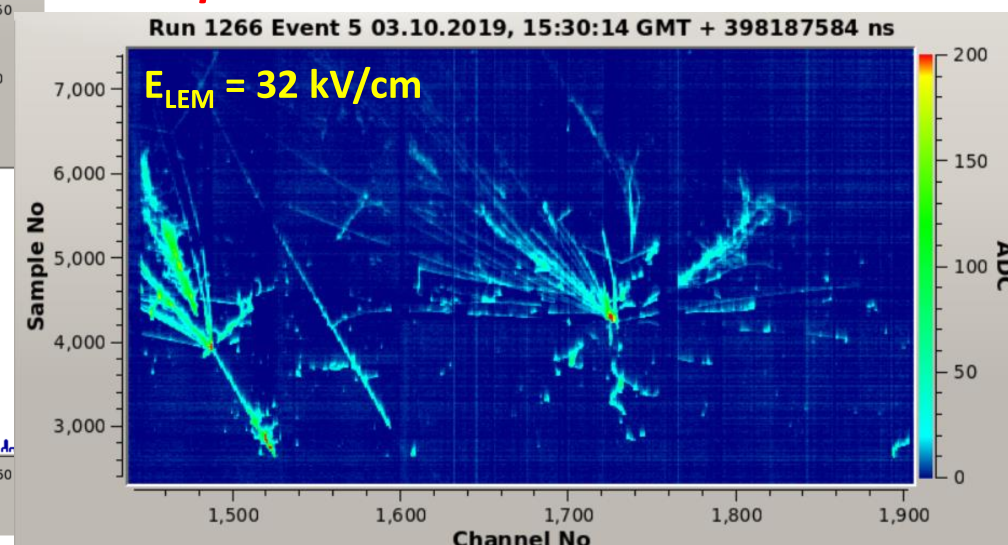
Electromagnetic shower + two muon decays



Horizontal muon track



Multiple hadronic interactions in a shower

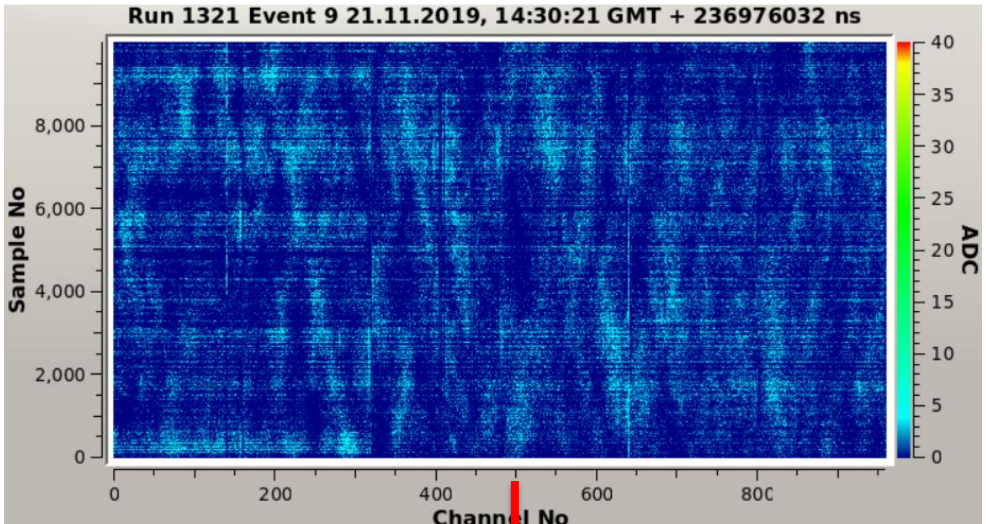


Induced signals from CRP capacitance variations: waves

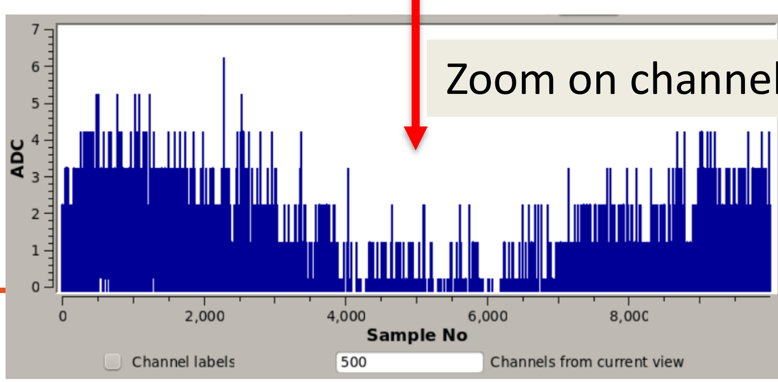
The CRP stack grid+ 2 LEM faces is electrically transparent to the anode due to the high impedance (0.5 GOhm) HV connections:

→ Any kind of perturbation happening in between the grid and the bottom face of the LEM (sparking, change in capacitance) or inside the LEM (sparking) induces visible signals on the anode

ΔV grid-LEM=2.4 kV



Zoom on channel 500



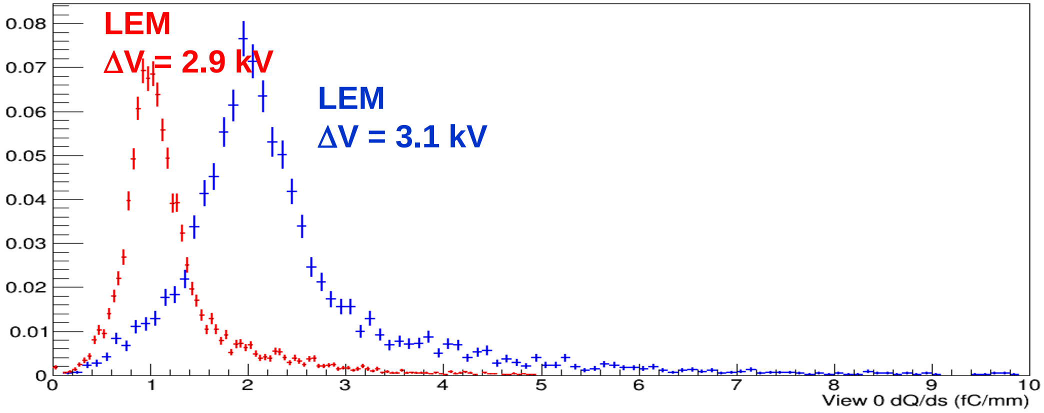
a) If the LEM bottom and the grid are HV polarized and with ΔV grid-LEM > 0

b) If the grid is immersed and if the liquid surface is wavy enough

→ Tiny signals ~2-3 ADC counts are induced on anodes by the LAr level variations happening in between the LEM and the grid changing the capacitance, it is a kind of microphonic effect

→ The pattern of waves changes continuously with the events

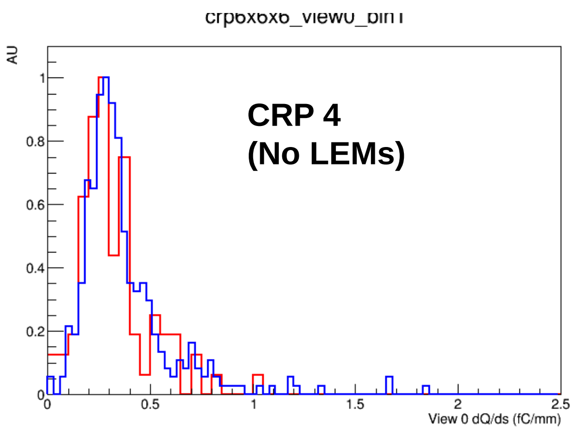
Measured dQ/dx in one of the collection views of a CRP



Assuming a drift field of 0.166 kV/cm a corresponding recombination factor of 0.55 and purity corrections completely effective and compensating for losses

→ expected dQ/dx = 0.8 fC/mm

(0.4 fC/mm per view after charge sharing in the anode)



Measured on CRP4 compatible value to 0.4 fC/mm per view

From measured dQ/dx per view → measured gain

G=2 @2.9 kV → S/N view (pitch 3.125 mm, 1 ADC RMS noise) = ~17
G=4 @3.1 kV → S/N view (pitch 3.125 mm, 1 ADC RMS noise) = ~35

DAQ and Back-end

- The DAQ and the back-end system (2 levels of event builders, the network infrastructure, and the online storage facility) working smoothly with no particular issues. Random triggers, mostly used, cosmic trigger counters being set up. DAQ typically running at 10-50 Hz with no compression. Typical file size of a run sequence ~3GB containing 30 events

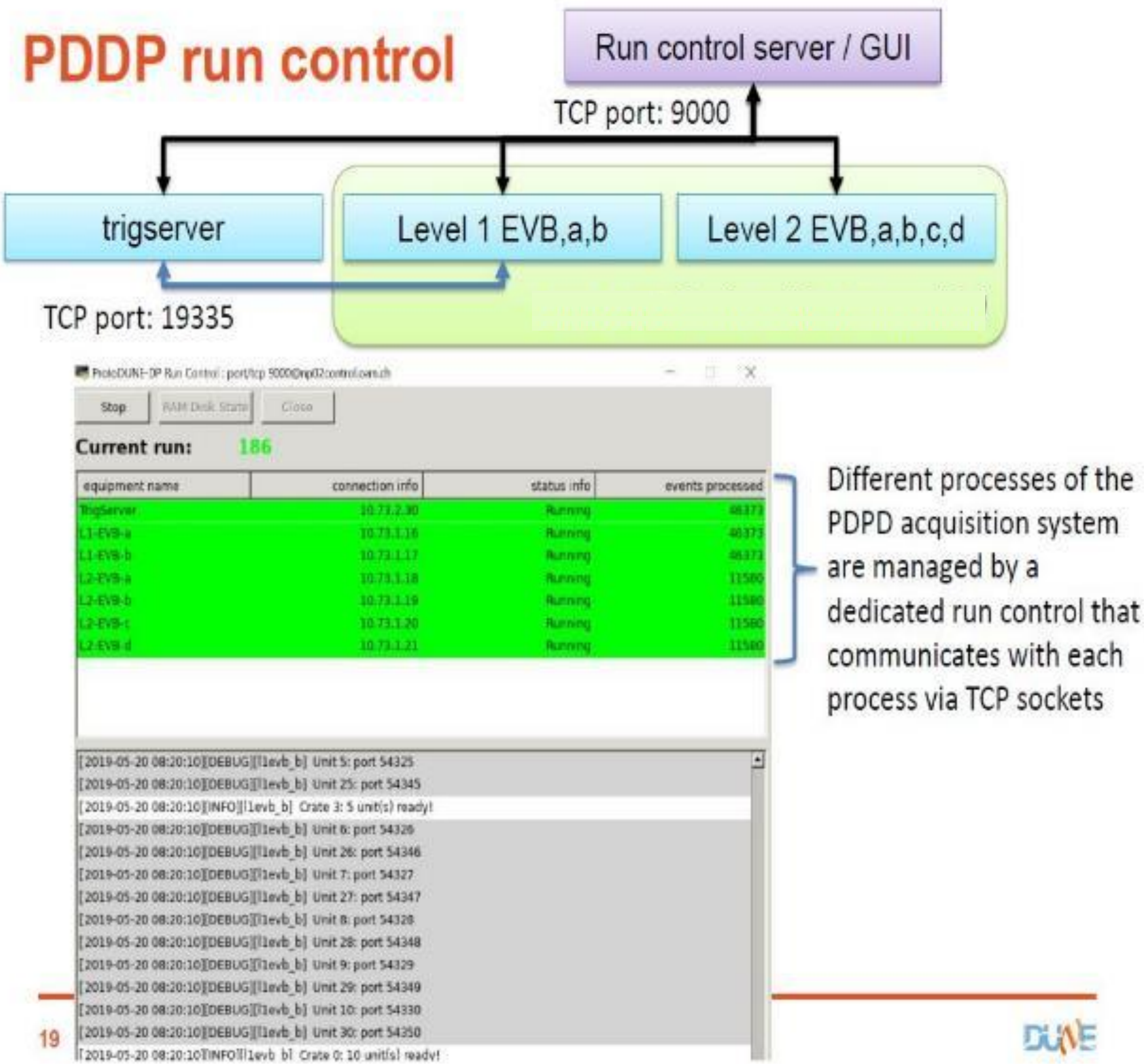
- From **August 28th ~1.5 M events, 4 ms drift, have been taken, corresponding to ~50k data files, for a data volume of ~ 150TB**

- Data files moved from the /ramdisk of the four L2 event builders first to the online storage facility *np02eos* (High bandwidth 20GBytes/s distributed EOS file system: 20 servers, 1.44 PB total disk space, 10Gb connectivity per server) and then to **EOSPUBLIC** (*/eos/experiment/neutplatform/protodune/rawdata/np02/rawdata*)

- JSON files generated and copied on EOSPUBLIC in order to transfer the files to **CASTOR and Fermilab**

- All steps of raw data online treatment stored in a dedicated **online database**.

- **Online processing facility (**30 servers Poweredge C6620 II → **450 cores, 9270 HES06 computing unit,** workload manager: SLURM) running tracks reconstruction on real time on all the acquired files (15s/event). Used for Data Quality Monitoring and first reconstruction



Developments of the online software:

1) Data acquisition processes (LARGUI) running on the LV1 even builders from the front-end DAQ AMC in the uTCA crates

2) Event building and EOS data writing software

3) Run control

4) Software for the management and synchronization of the different components of the back-end system and online computing

Performance

Excellent performance of front-end analog cryogenic electronics, digital uTCA front-end electronics, timing system and DAQ back-end system:

- **A sub-sample of the system had been already tested on the 3x1x1 for >1 year. The production, tests and installation for protoDUNE-DP were prepared well in advance for both the FE analog and digital electronics and the back-end system**
- **Complete exercise for the TDR with the production, QA/QC, installation and commissioning chains**

- **Expected performance of chimneys and FE cryogenic electronics, access and swapping of blades well demonstrated**
- **Cryogenics FE kept stably on without human interventions for long periods (~2 months).**
- **Intrinsic low noise levels of the charge readout system**
- **Overall low noise levels after a campaign of mitigation of grounding issues of the slow control cabling, residual coherent noise can be further improved**

- **Stable operation of DAQ hardware (AMC cards, Event builders) and associated software → no changes to the system since the beginning of the summer, smooth data taking of large data volumes**
- **Shifters documentation: https://twiki.cern.ch/twiki/pub/CENF/DUNEProtDPOps/DAQforshifter_v2r2.pdf**
- **White-Rabbit timing and trigger system also well operating as expected**
- **Main perturbations to the system due to CERN power cuts and cooling failures: 4 announced issues + 5 unforeseen brutal stops affecting the back-end system→ cooling should be now more stable, installation of continuity group for protoDUNE-DP back-end foreseen**

- **Back-end system equivalent to the one for DUNE (see DAQ DUNE TDR chapter) further tests in self-triggering mode foreseen in the next months**
- **Smooth performance of data storage and data handling, data transferred to FNAL (see Data and Analysis talk)**
- **Online reconstruction of tracks regularly performed on all acquired data (see Data and Analysis talk)**

Brief reminder of the DAQ system architecture:

The NP02 DAQ system has been presented in details numerous times in the four last years at the DUNE and ProtoDUNE-DP meetings. It is a Ethernet network based DAQ system which can acquire data at very high bandwidth (up to 20 Gbyte/s). **The front-end digitization units** (AMCs) are contained in uTCA crates. Each charge readout crate, located in front of the corresponding signal feedthrough chimney on the cryostat roof can include up to 10 AMC reading each 64 channels for a total of 640 channels per crate digitized at 2.5 MHz.

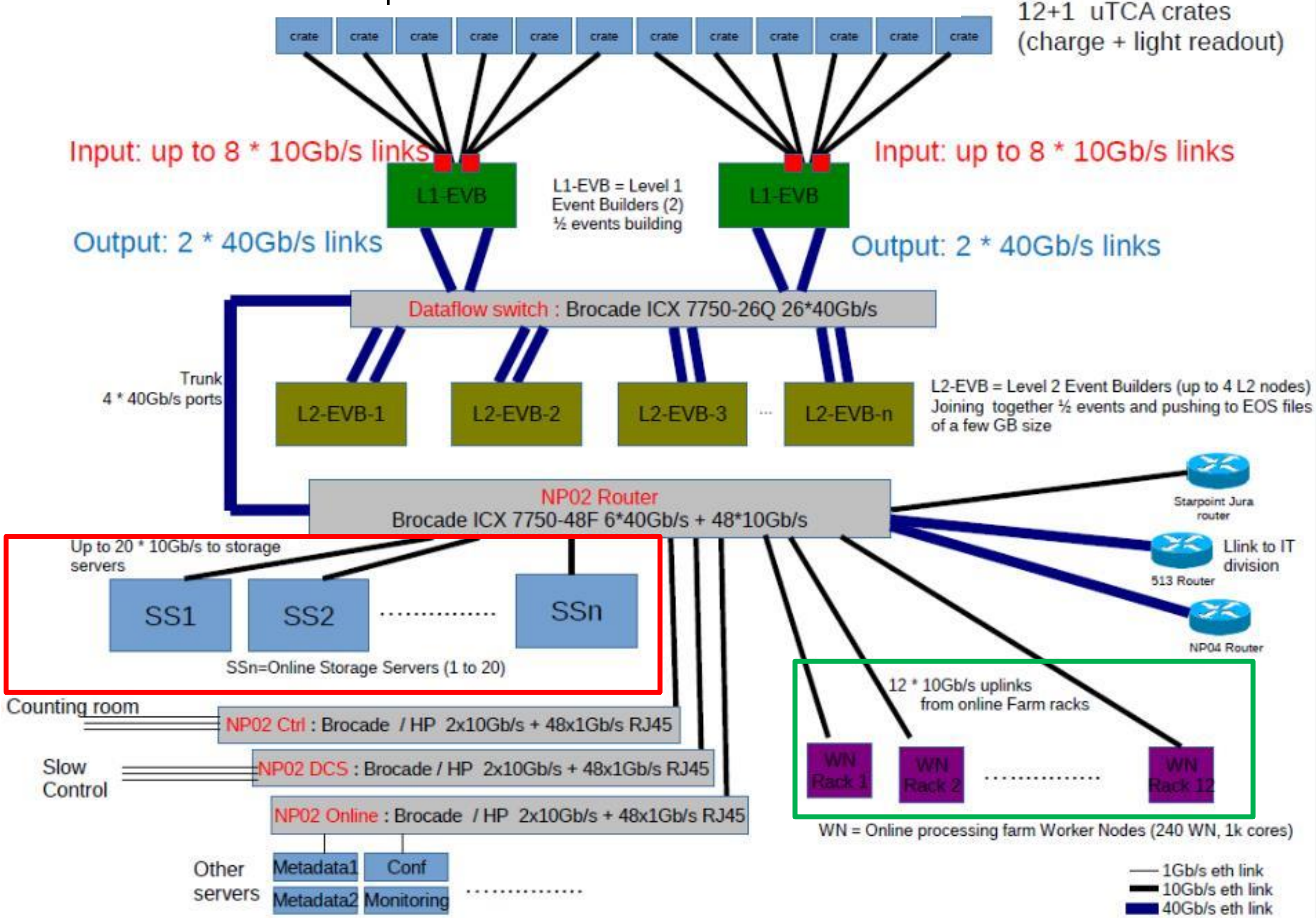
A uTCA crate is a 10 Gbit/s network system connecting the AMC with its own switch included in the crate controller (MCH). The MCH of each crate is connected with a dedicated 10 Gbit/s to a **Level 1 (L1) event builder**. Two L1 event builders are used to read several crates corresponding to a detector half. The L1 event builders are connected via several links on a high speed network at 40 Gbit/s to the Level 2 (L2) event builders and to a high bandwidth distributed storage system (EOS), the network infrastructure ensures total 20 Gbyte/s bandwidth. Each L1 event builder puts together the data, corresponding to the drift window starting with the trigger timestamp, acquired from the connected crates to build an event half on its ramdisk.

The L1 ramdisks are visible via the network to the **L2 event builders** who assemble together the two event halves in the final even format and assemble on their own ramdisks the events in 3 Gbyte files which are then pushed through the EOS high bandwidth storage system which can absorb up to 20 Gbyte/s data writing on disk. Four L2 event builders work in parallel by sharing evenly the events produced by the L1 event builders and producing the final 3 Gbyte data files to be written on disk. **Automatic file transfer systems** transfer the data from the local EOS system to the CERN IT division and Fermilab.

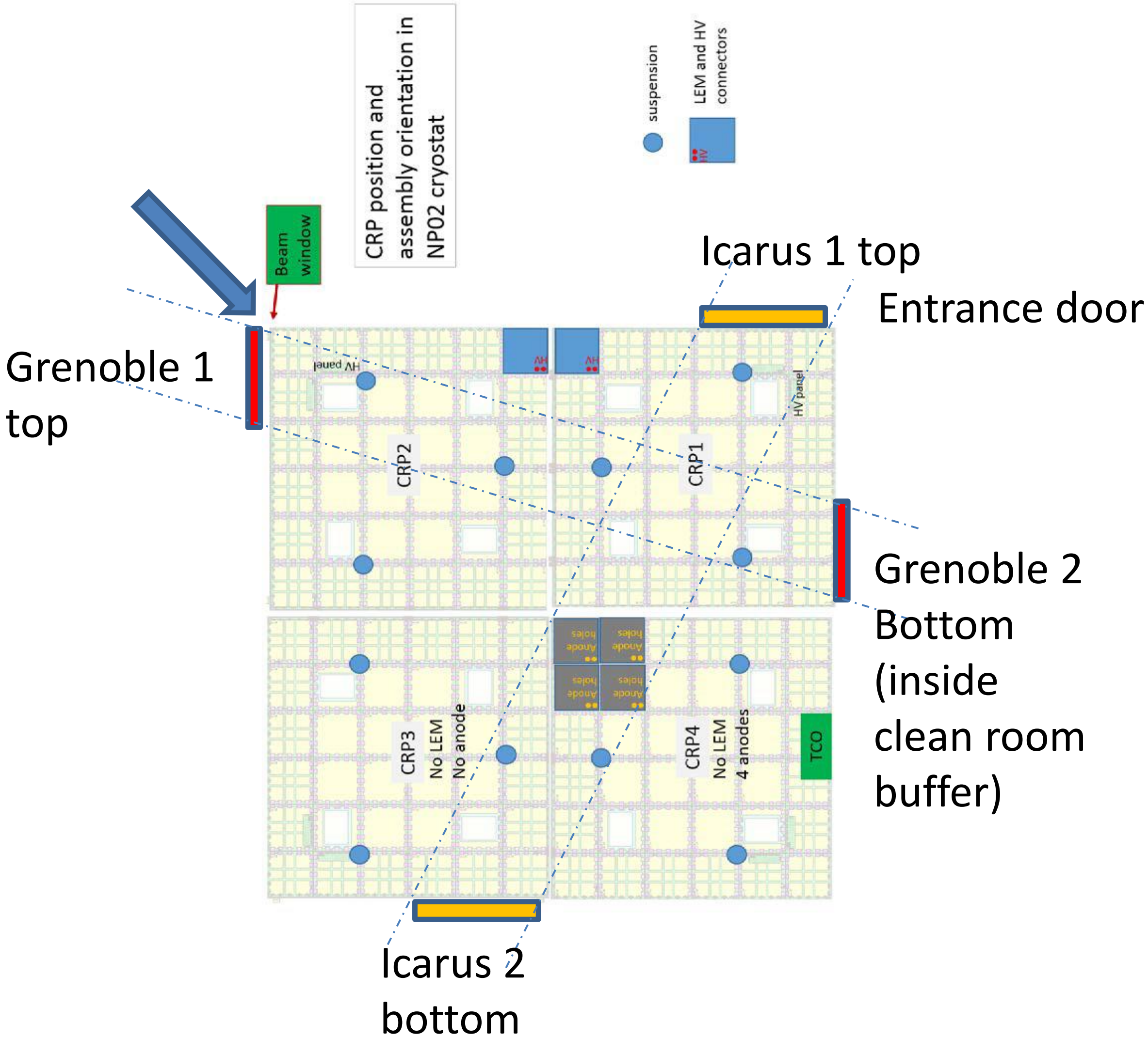
A trigger server handles the white-rabbit timestamping of external trigger signals (beam counters, cosmic counters, PMTs trigger, calibration triggers) and the transmission of these timestamps to the AMCs via the white-rabbit network and of the trigger information to the L1 event builders via a dedicated Ethernet network. **The white-rabbit network** ensures also the timing and synchronization of the AMC digitization units.

The run control interface ensures the control and monitoring of all the components of the system in order to start and stop runs, and check the data transfer to the local EOS. The transfer to the final storage for offline exploitation is run by DAQ experts.

Details of ProtoDUNE dual-phase back-end architecture



Cosmic trigger systems



Grenoble counters installed last week