Timing interface aspects

D. Autiero

IP2I Lyon

Top-Electronics CDR Review

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White Rabbit

The White Rabbit Project focuses on:

- **Sub-nanosecond accuracy**: synchronization of more than 1000 nodes via fiber or copper connections of up to 10 km of length.
- **Flexibility**: creates a scalable and modular platform with simple configuration and low maintenance requirements.
- **Predictability** and **Reliability**: allows the deterministic delivery of highest priority messages by using Class of service.
- **Robustness**: no losses of high priority system device control messages.
- **Open source hardware and software**: to avoid vendor lock-in.

https://en.wikipedia.org/wiki/White_Rabbit_Project
https://ohwr.org/projects/white-rabbit

Obtained by combining in a dedicated 1Gbit network synchronous ethernet (fed by an atomic oscillator clock class, as a GPSDO) + continuous exchange of PTP packets

Keep synchronized far end-nodes at better than 1 ns
Can generate high accuracy timestamps
Self- calibrating at better than 1 ns (you do not have to worry about connection lenghts)
Cheap, robust and standardized
Impressive: torture tests in 2011 heathing a few km roll of fibers with a high power heather → keeping sync accuracy
Use massively for critical missions as the accelerators chain synchronization at CERN
Large community and standard open-hardware industry products

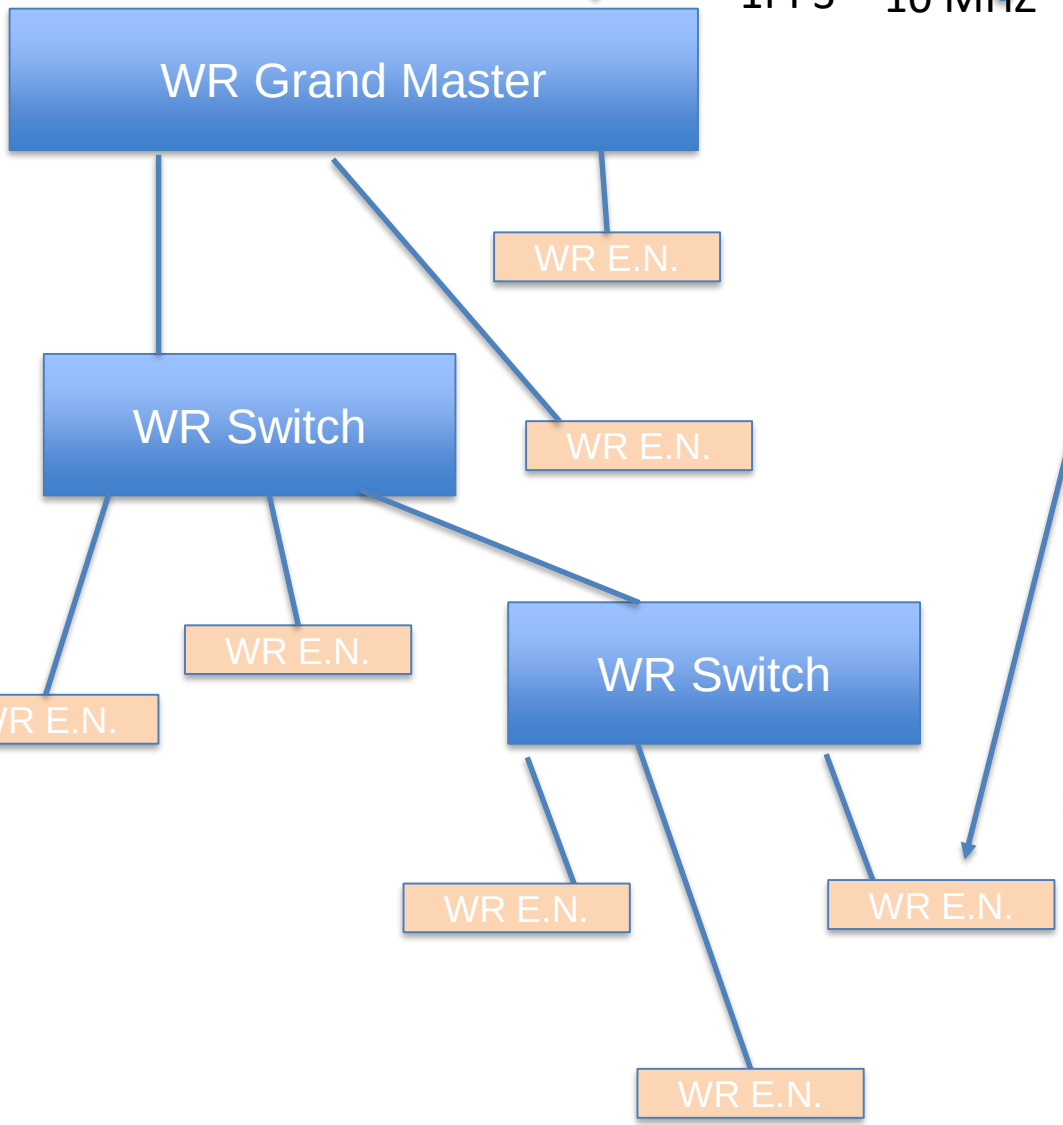
Concept developed and demonstrated in R&D for bottom electronics in 2008 and since then routinely deploied. Main difficulties design the WR switches to build a network → successfully done by CERN around 2010 in open-hardware and then becoming industry products

We use standardized WR components → sub-ns sync accuracy guaranteed by construction

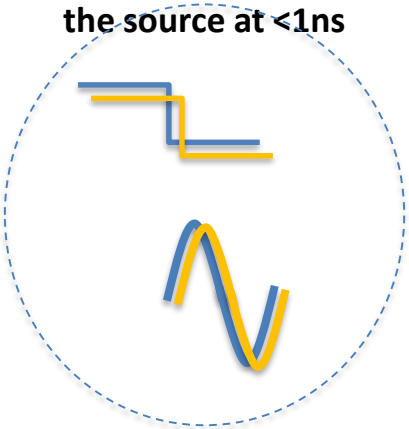
High accuracy signals 1 PPS, 10 MHz from GPSDO on other source

1PPS

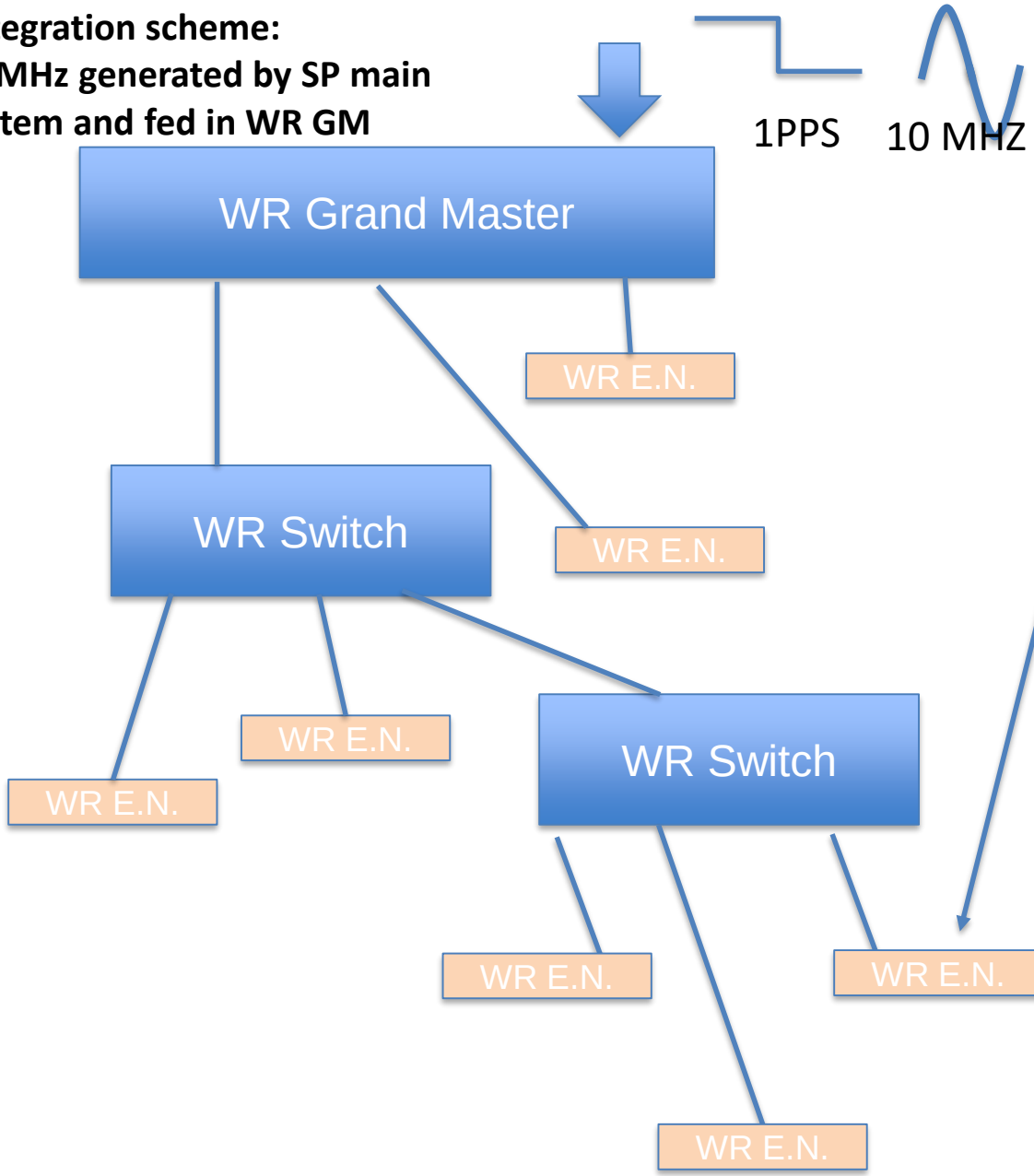
10 MHZ



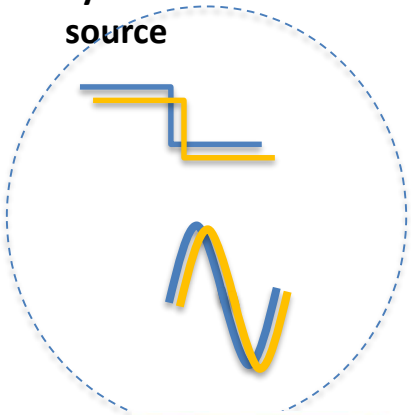
In any point of the chain one can produce the same signals to monitor the synchronization and measure at the scope that they are automatically synchronized/phased with the source at <1ns



Simple integration scheme:
1 PPS, 10 MHz generated by SP main timing system and fed in WR GM



It is guaranteed by the system design that the WR-end nodes used by the bottom electronics (which ar WR standard) will be synchronized with the source



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WR Grand Master

WR E.N.

WR Switch

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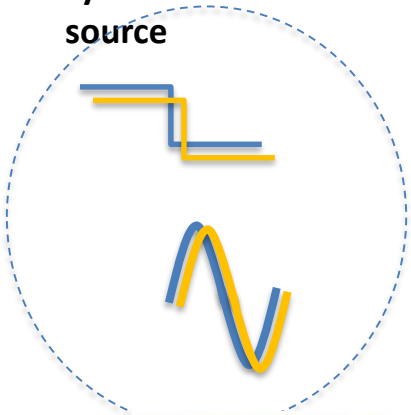


WR watchdog, use some time-tagging end-nodes connected to the distribution chain to time-tag bottom-electronics reference singnals in a few point of the cryostat (cheap to implement) and capable of calibrating the other system

WR E.N.

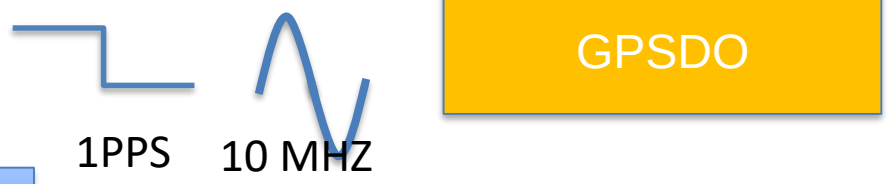
BE

Watchdog Timestamps data

WR E.N.

WR E.N.

More accurate scheme:
1 PPS, 10 MHz generated by GPSDO on surface



WR Grand Master

Provides GPSDO equivalent 1PPS 10 MHz signals Underground to SP Main timing system

WR Switch

SP Main timing system

WR E.N.

WR E.N.

WR Switch

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WR watchdog, use some time-tagging end-nodes connected to the distribution chain to time-tag bottom-electronics reference singnals in a few point of the cryostat (cheap to implement) and capable of calibrating the other system

BE

Watchdog Timestamps data

Advantage:

- Automatic correction of signals propagation undeground
- Entire DUNE system absolutely aligned to UTC at ns level

uTCA AMC digitizer cards (See Slavic's presentation)

- FPGA Cyclone V with NIOS virtual processor, ADC AD9257, **64 channels per card sampled at 2.5 MHz (DP), up to 10 Gbit/s Ethernet data flow per card, for vertical drift can reduce sampling to 2MHz (real sampling up to 40MHz)**

- **Time sync at ns level, external triggers handling via White Rabbit network (Dedicated WR slave node in uTCA crate and timing/clock dedicated lines on backplane). Transmission of external triggers timestamps on WR network.**

Working mode in protoDUNE-DP (based on external triggers):

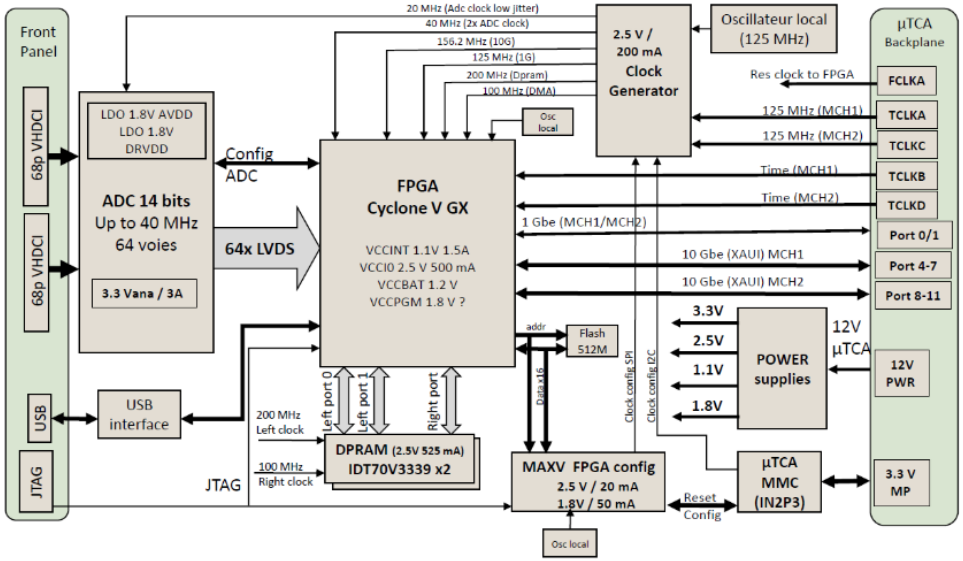
a) No compression mode saturating the 10 Gbit link, up to 50 Hz rate

b) Lossless compression (Optimized Huffman, up to factor 10 gain), developed, exploited in August 2020

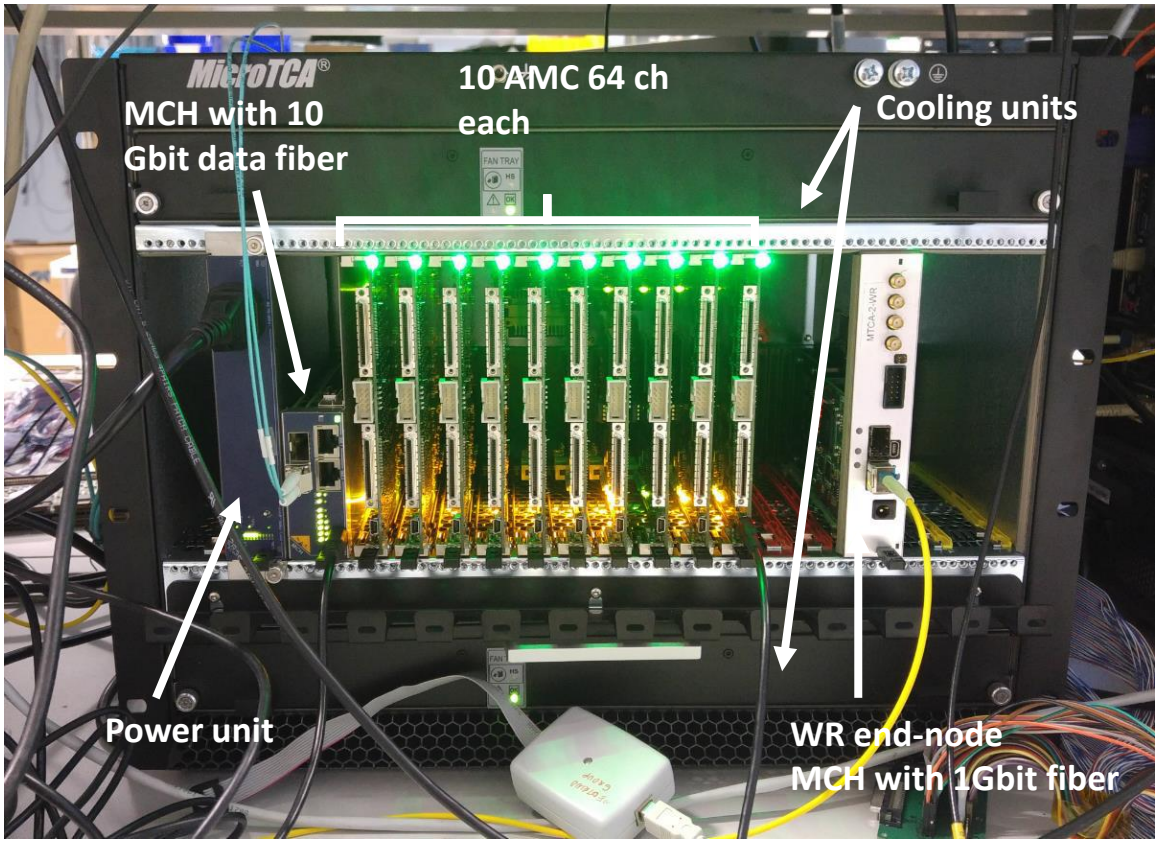
Working mode in DUNE:

Originally foreseen with 10 Gbit uTCA MCH: Continuous streaming + lossless compression (10 Gbit/s MCH)

New baseline (40 Gbit MCH): Continuous streaming, no compression (40 Gbit/s MCH), possibility for trigger primitives



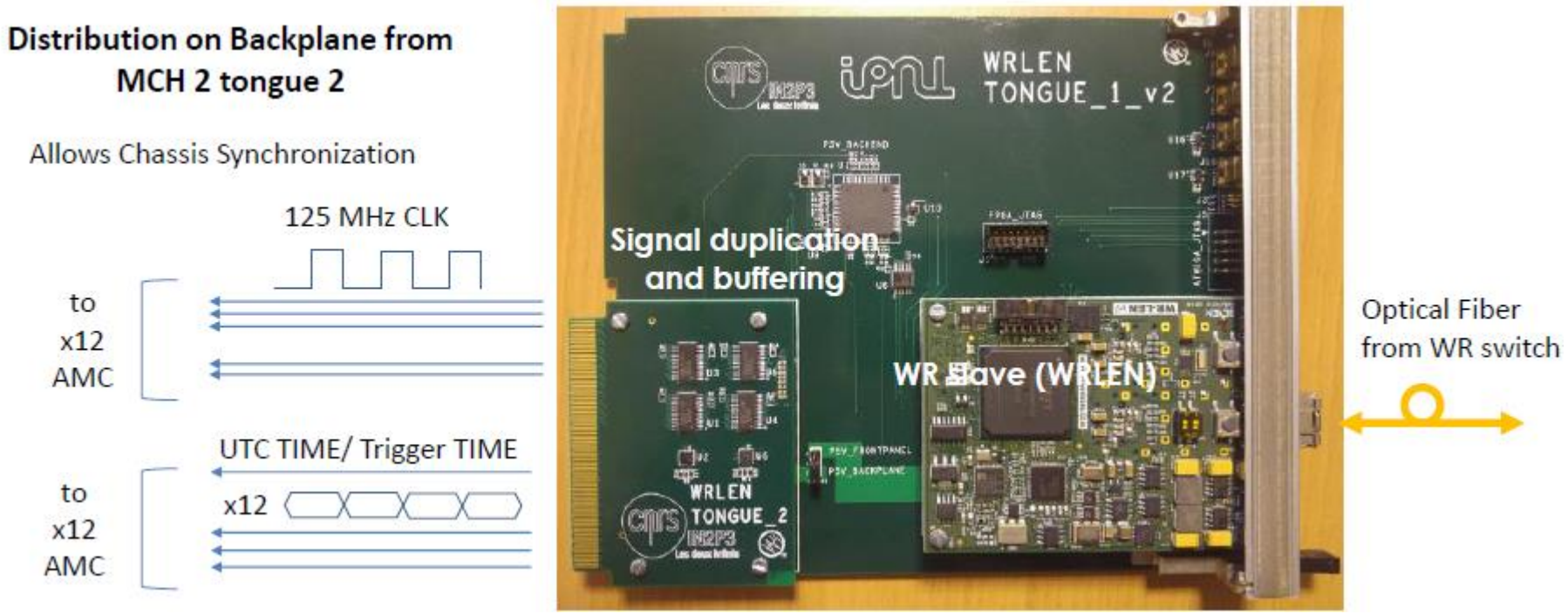
uTCA crates (See Slavic's presentation)



Readout system with 10 AMC cards (640 channels) and 10Gbit MCH (like in NP02)

Same system with 40Gbit MCH

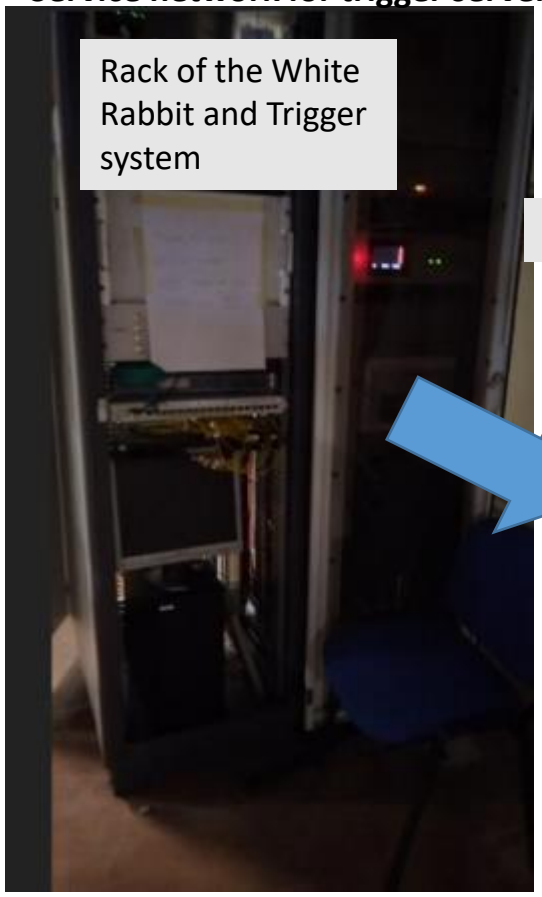
WR-MCH (See interface presentation)

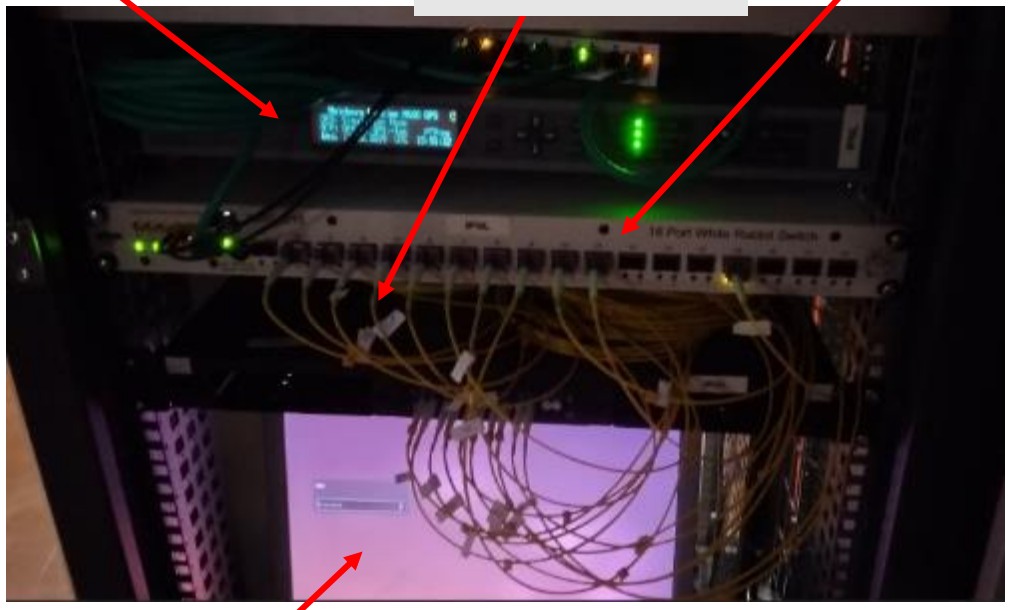


- Simple board on which the WLREN (commercial WR end-node) is plugged in
- Occupies the second MCH slot (12) and provides power to the WRLEN via standard uTCA facilities
- Delivers via the backplane a pair of WR_clock (125 MHz) and WR_DATA for sync to each AMC
- Control signals timing signals available on front-face connectors
- WR network can be used also to transmit the WR time-stamped trigger data to all digitizing units (trigger mode in NP02)

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**





Conclusions:

- **WR is a very convenient system for time distribution and it is integrated in the top-electronics uTCA infrastructure. The system was designed in early 2008 and depoied on 3x1x1 and NP02**

- **WR is self-compensating for the connections lenght/speed of propagation of the signals and guarantees synchronization accuracy at <1ns level**

- **There are several possible integration schemes, some would turn useful for calibration or to improve the overall DUNE alignment to UTC at ns level**

Proto DUNE UDP DATA packet Format

IP/ UDP Header + Data Header
48 bytes
(64 bits aligned)

Source IP[2] = 32+ChassisNum
Source IP[3]= AMC slot + 12
Source MAC[4] = chassisNum+1
Source MAC[5] = AMC slot + 12

UDP Lenght	UDP lenght	0xD (4 bits)	0xE (4 bits)	0xF (4 bits)	Total Packet Number (6 bits)	Current Packet Number (6 bits)	ADCchannel (6 bits)	Global Packet Counter (MSB)	Global Packet Counter(LSB)

ADCs or Encoded Huffman Sequence
(10000 samples for protoDUNE)

No compression => 2 packets of 8000 bytes (4000 samples)
+ 1 packet of 4000 bytes (2000 samples)

Compression => 1 packets of 8048 bytes max
Size of Huffman Sequence is the UDP lenght – 6 bytes