UNIVERSITY OF BIRMINGHAM

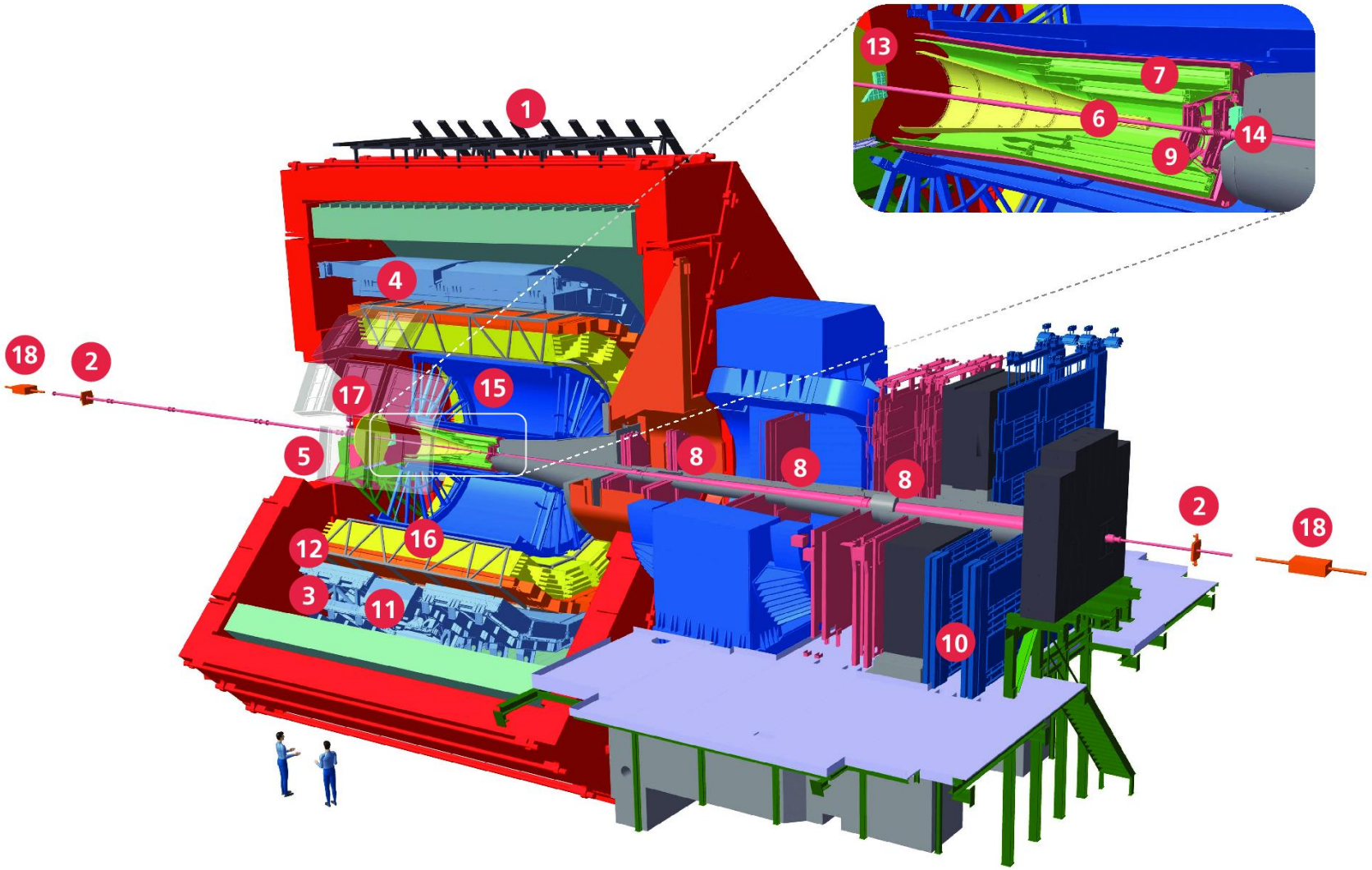
ALICE Central Trigger System for LHC Run 3

Jakub Kvapil for the ALICE CTP team

University of Birmingham, UK

25th International Conference on Computing in High-Energy and Nuclear Physics

The ALICE experiment for LHC Run 3



1. **ACORDE** | ALICE Cosmic Rays Detector
2. **AD** | ALICE Diffractive Detector
3. **DCal** | Di-jet Calorimeter
4. **EMCal** | Electromagnetic Calorimeter
5. **HMPID** | High Momentum Particle Identification Detector
6. **ITS-IB** | Inner Tracking System - Inner Barrel
7. **ITS-OB** | Inner Tracking System - Outer Barrel
8. **MCH** | Muon Tracking Chambers
9. **MFT** | Muon Forward Tracker
10. **MID** | Muon Identifier
11. **PHOS / CPV** | Photon Spectrometer
12. **TOF** | Time Of Flight
13. **T0+A** | Tzero + A
14. **T0+C** | Tzero + C
15. **TPC** | Time Projection Chamber
16. **TRD** | Transition Radiation Detector
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18. **ZDC** | Zero Degree Calorimeter

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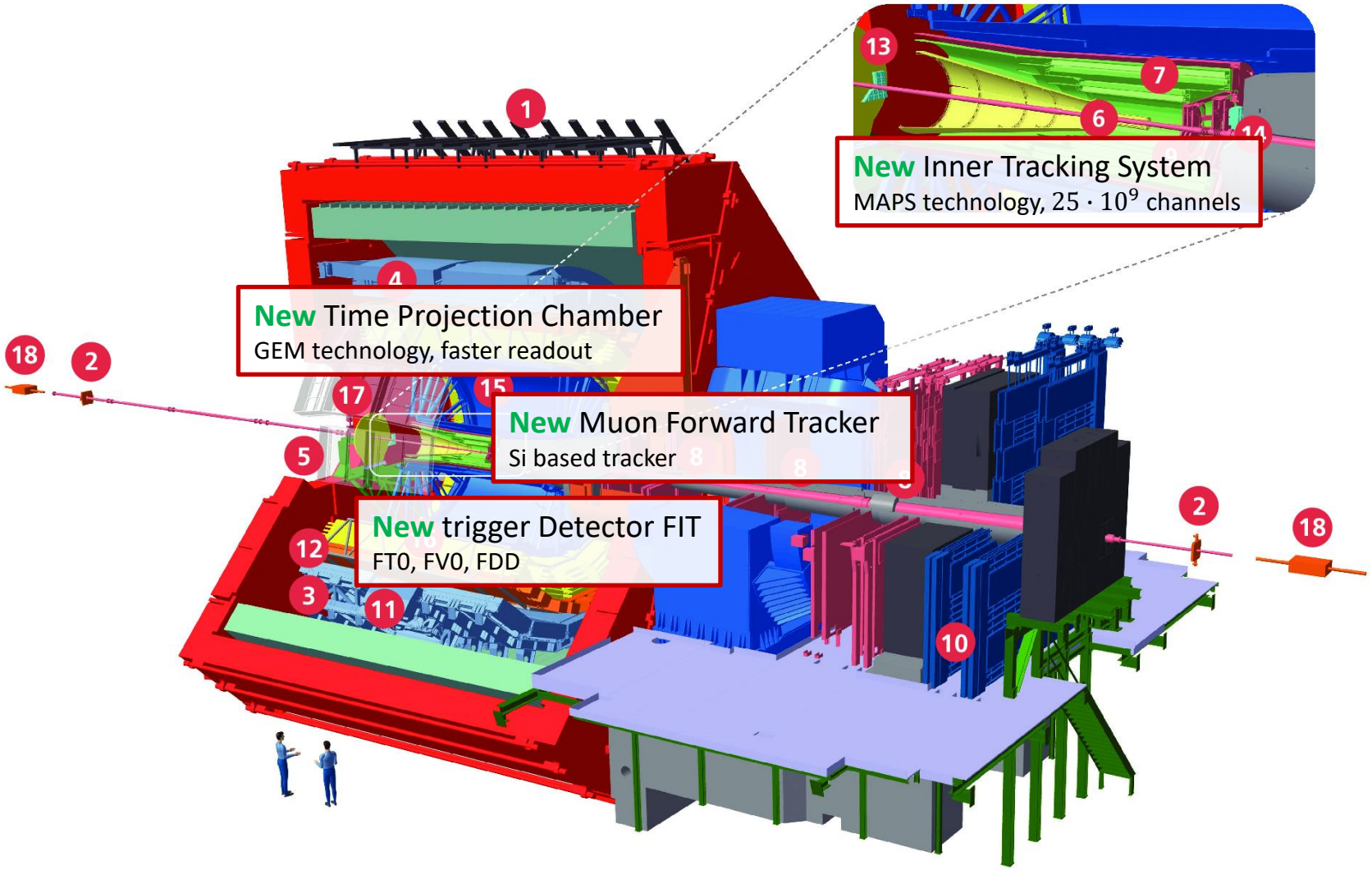

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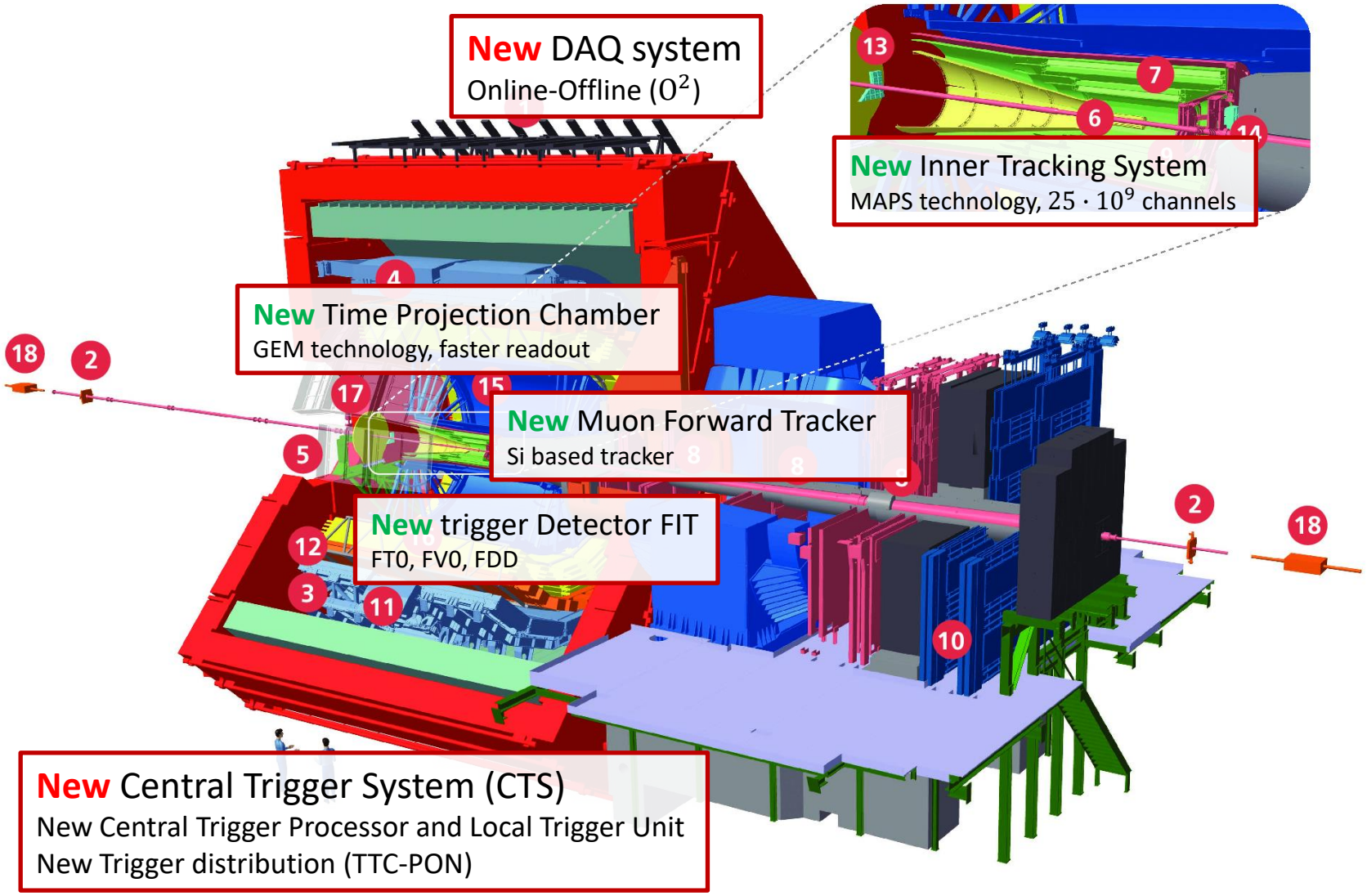

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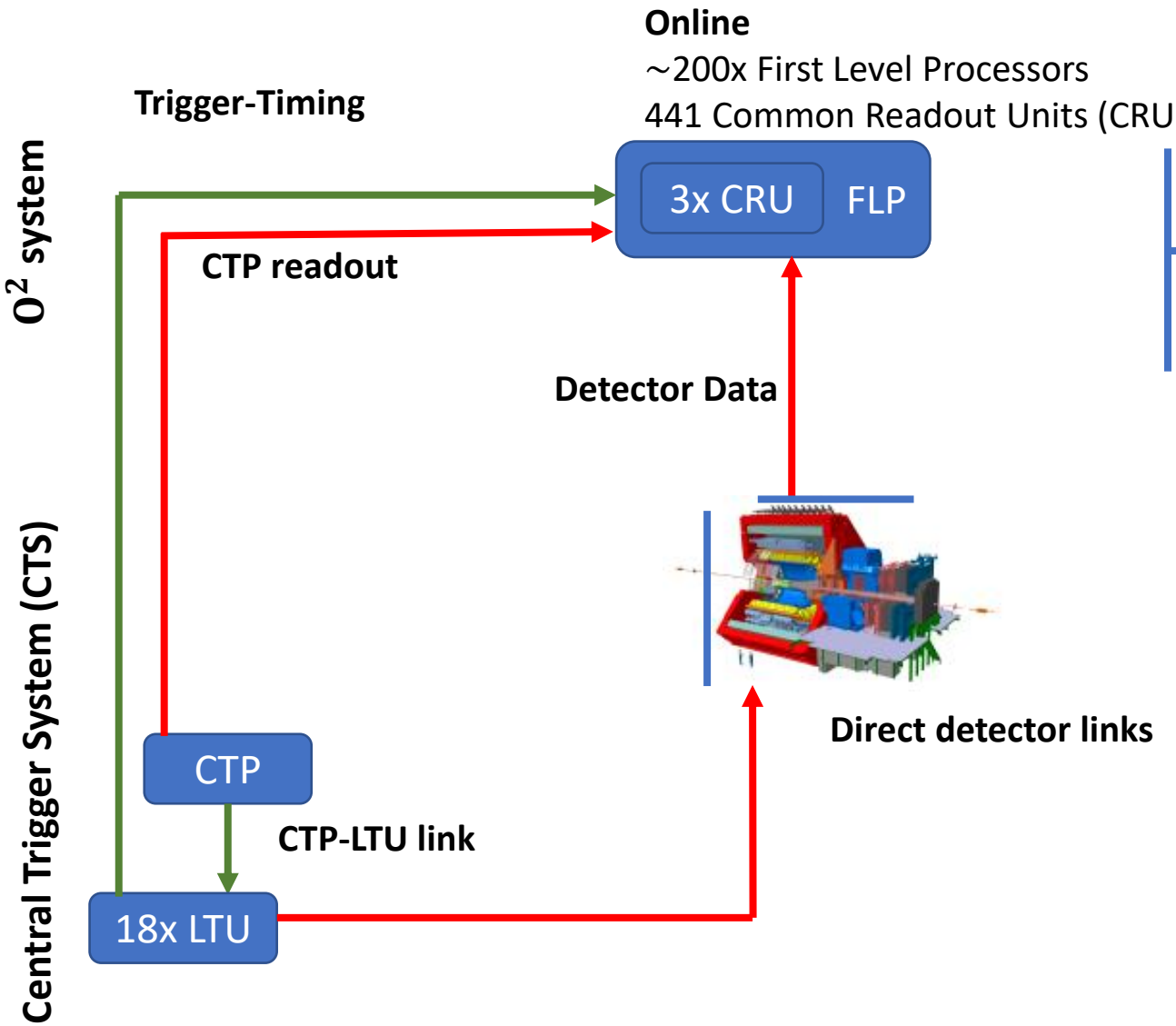
The CTS-CRU(FEE) dataflow

Check D. Rohr talk, 18th 16:05
Usage of GPUs in ALICE



Run 2: → **Run 3:**

Pb-Pb

- Interaction rate: 7-10 kHz → 50 kHz
- Readout rate: < **1 kHz** → **50 kHz**

pp

- Interaction rate: 100 kHz → 1 MHz
- Readout rate: ~ **5 kHz** → **1 MHz**

The CTS-CRU(FEE) dataflow

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Usage of GPUs in ALICE

Online
~200x First Level Processors
441 Common Readout Units (CRU)

Offline
Event Processing Nodes
~2000 CPU and GPU

Trigger-Timing
25x1.2 GB/s = **30 GB/s** (PON)

CTP readout
3x0.575 GB/s = **1.725 GB/s** (GBT)

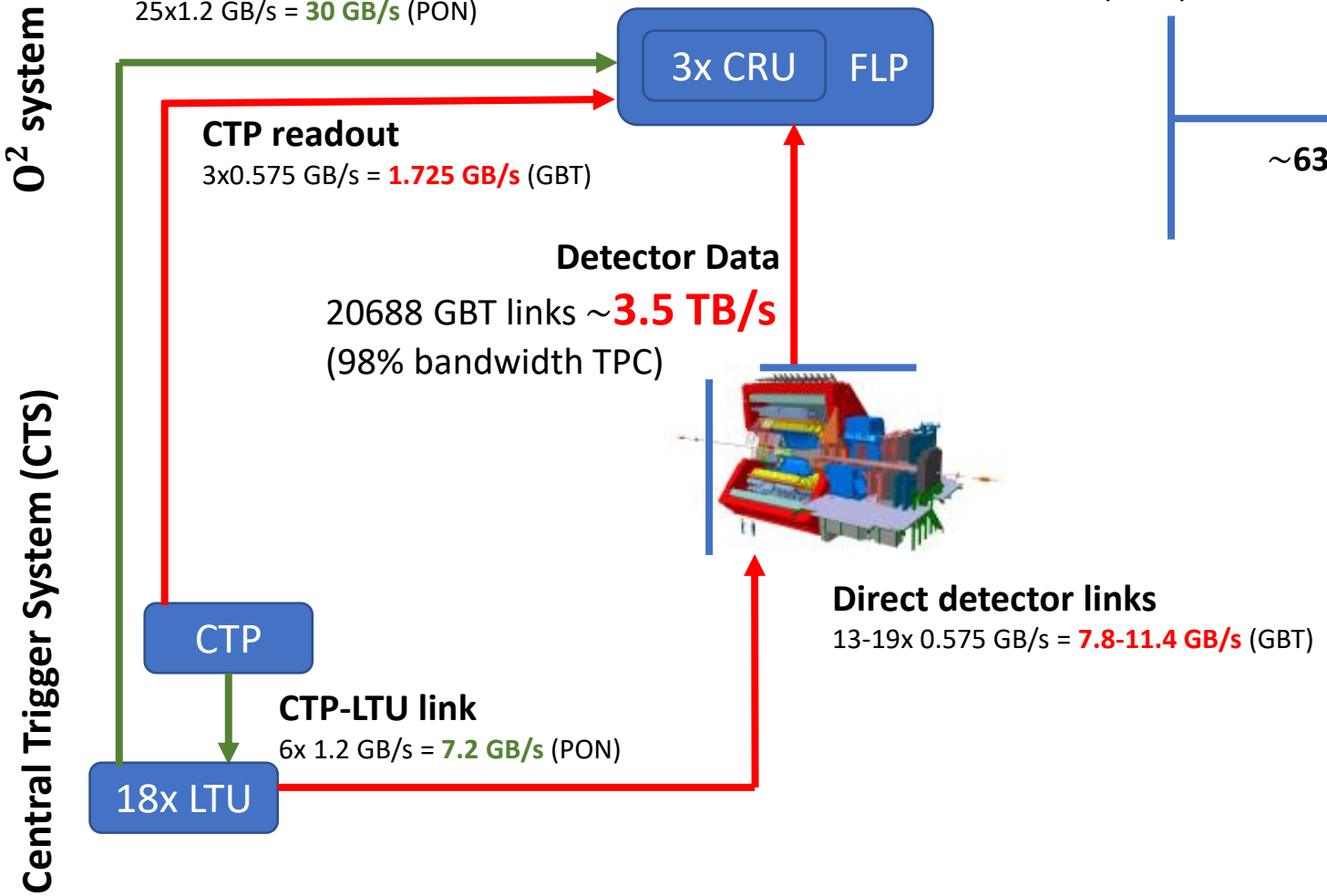
Detector Data
20688 GBT links ~**3.5 TB/s**
(98% bandwidth TPC)

Direct detector links
13-19x 0.575 GB/s = **7.8-11.4 GB/s** (GBT)

CTP-LTU link
6x 1.2 GB/s = **7.2 GB/s** (PON)

O^2 system

Central Trigger System (CTS)



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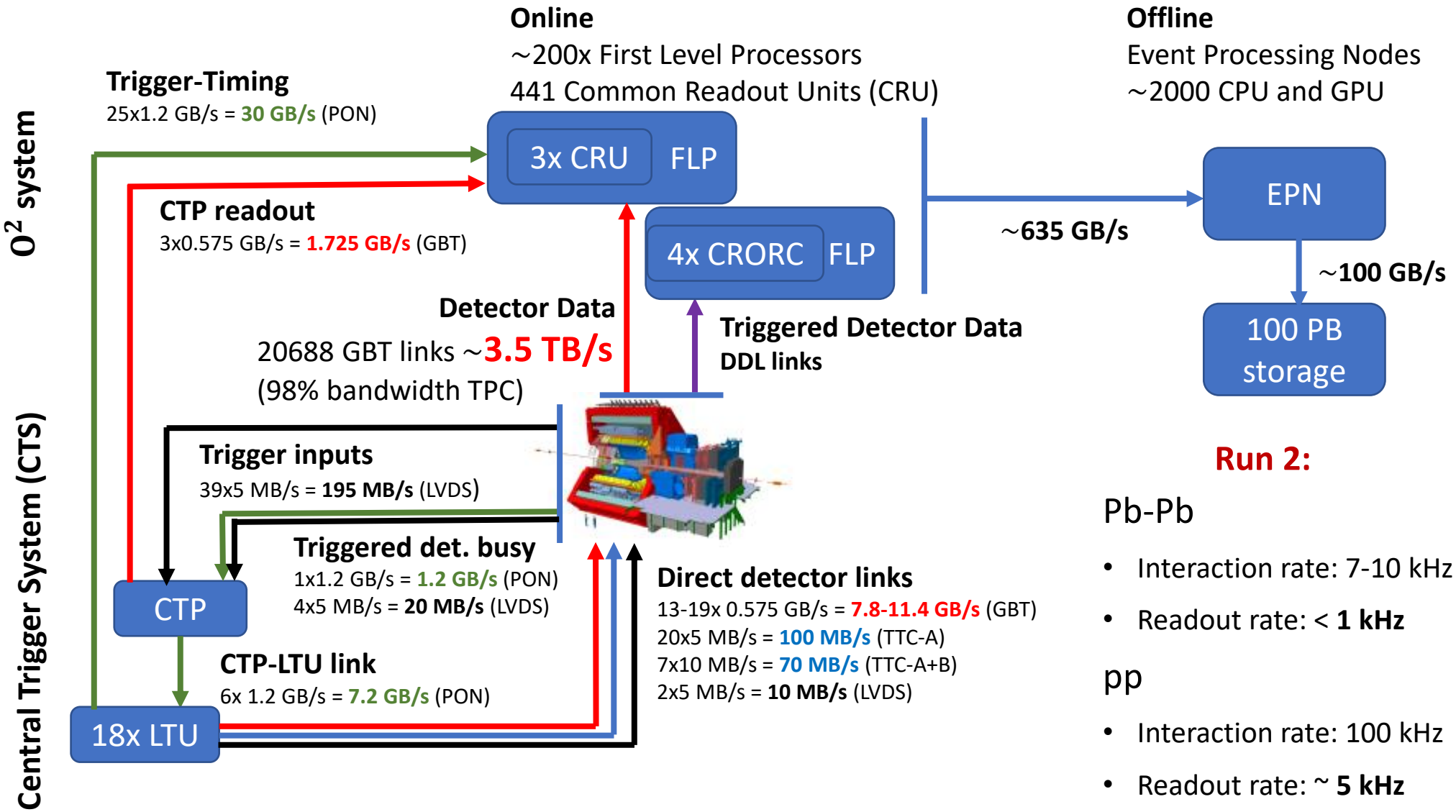

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Requirements of the new Central Trigger System

Central Trigger System = Central Trigger Processor (CTP) + 18 Local Trigger Units (LTU)

- Distribute clock and triggers to all ALICE detectors
- Local Trigger Unit for each detector
  - Allow a single detector decoupling from Central Trigger Processor to run independent tests

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Requirements:

- Concurrent processing - **no deadtime** (< 25 ns)
- **Low processing latency** – 100 ns (CTP) + 25 ns (LTU)
- Continuously monitor status of 441 CRU and **control data flow**
- Random jitter on clock <10 ps at FEE
- **Backward compatible** with Run 2 trigger distribution
- **Trigger protection** for triggered detectors while they are busy

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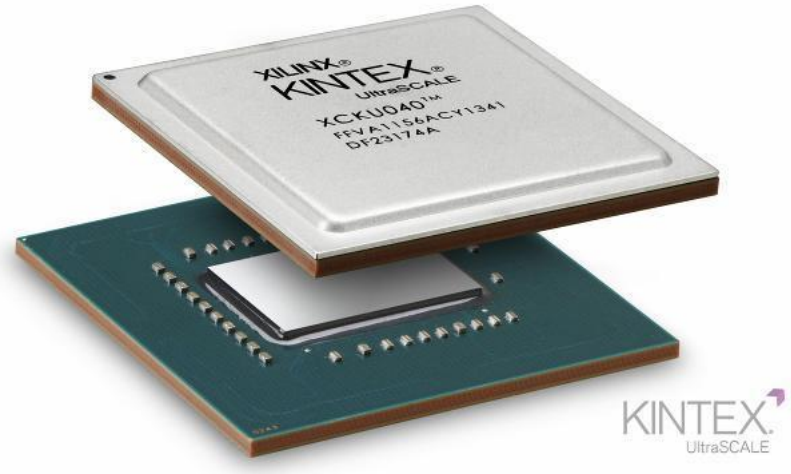


Solution: off-the-shelf FPGA on custom made board

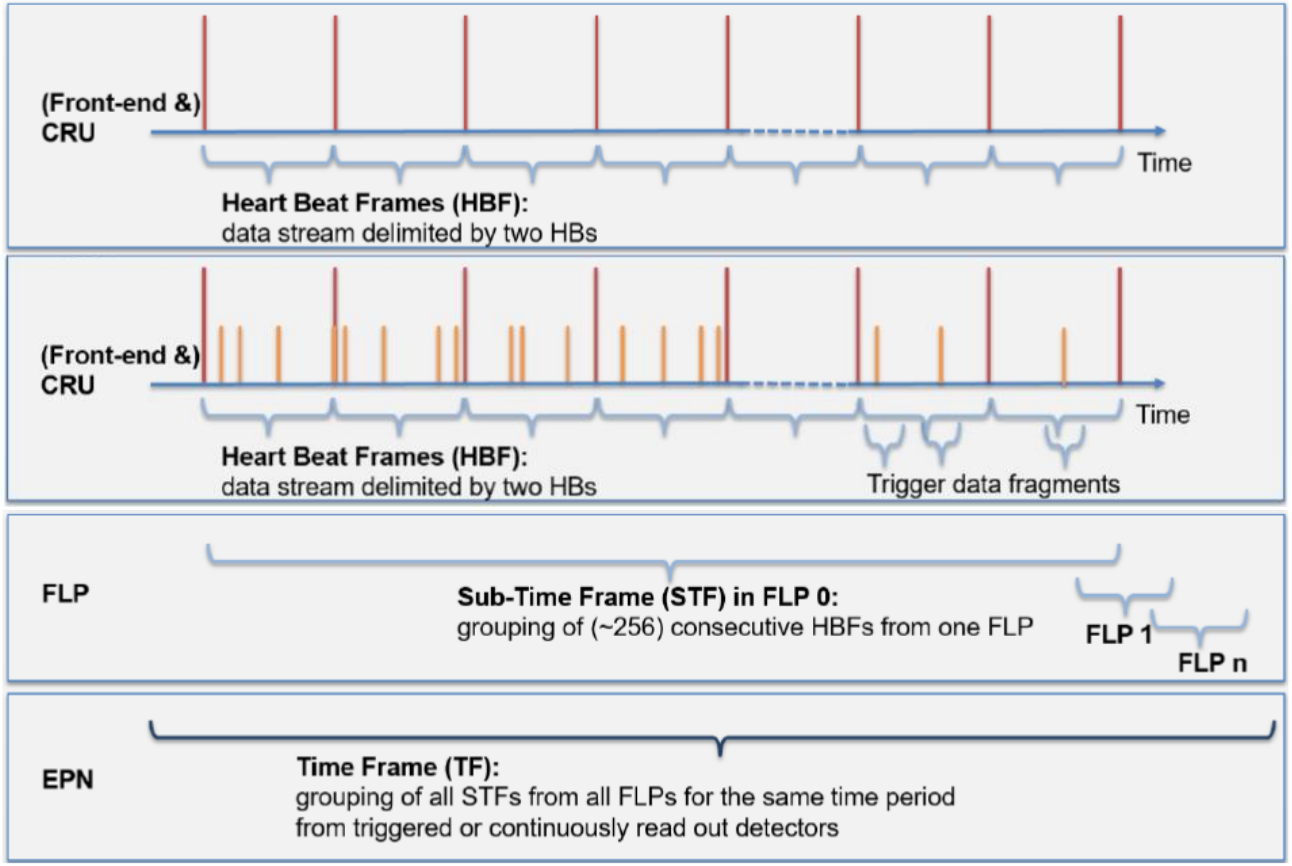
Challenges of the new Central Trigger System

- Magnetic field of 11 mT (rack below dipole magnet) and radiation environment
- **2 running** modes
  - Triggerless (continuous) and triggered mode – TPC, ITS, TOF, FIT, MCH, MID etc.
  - Some detectors able to run only in triggered mode – TRD, CPV, EMC, HMP, PHS
- **3 trigger** latencies
  - LM (650 ns), L0 (900 ns), L1 (6.5 μs)
  - Detectors can choose a latency and/or combinations
- **Single-level** or **two-level** trigger
- **3 types of trigger distribution**
  - Via Common Readout Unit (CRU) using **TTC-PON**
    - successor of RD12 TTC based on Passive Optical Network (PON)
  - **RD12 TTC**
    - Trigger-Timing-Control distribution used in Run 1+2 developed by RD12 collaboration
  - Directly to detector FEE via **GBT**
    - GigaBit Transceiver (GBT) designed to work in hard radiation environment

Continuous vs. triggered readout

- **Continuous readout is the main mode of operation**
- Detectors push **continuous stream of data** which are delimited by CTP HeartBeat (HB) triggers
- They must be capable of running in **triggered mode** as well

- ALICE data is divided into **HeartBeat frames** (HBf)
  - Each HBf is 88.92 μs - Time to fully read out TPC
  - 128 (programable) HBf compose a **Time-Frame** (TF)



Continuous readout

| HeartBeat Triggers
| Physics Triggers

Triggered readout

First Level Processor (FLP)

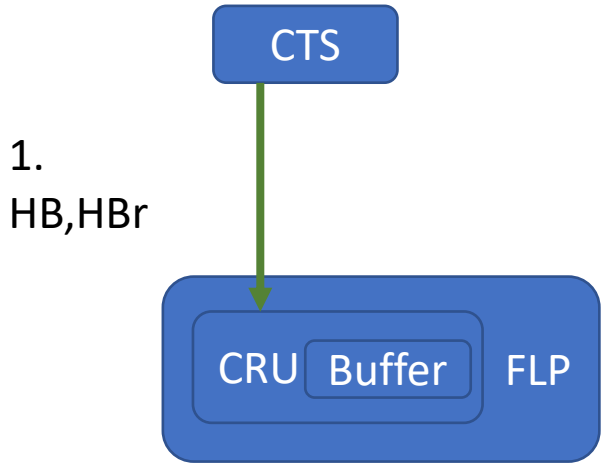
FLPs see only 3 CRU

Event Processing Node (EPN)

EPNs see all CRU

HeartBeat and CRU-FLP throttling via HB reject

1. CTP will send **HeartBeat (HB) signal with HB reject (HBr) flag** at the beginning of each HBf
   - **CRU will either accept or reject data** in the upcoming frame according to HB reject flag



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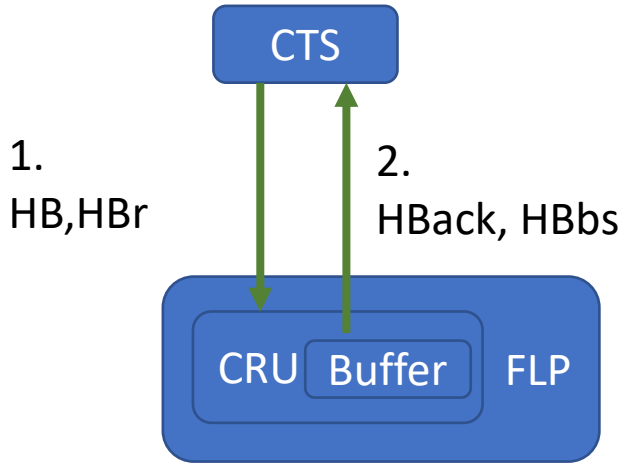
   - **HB buffer status (BS)** – buffer between CRU and FLP
   - **HB acknowledge** – HBf was successfully transferred to FLP



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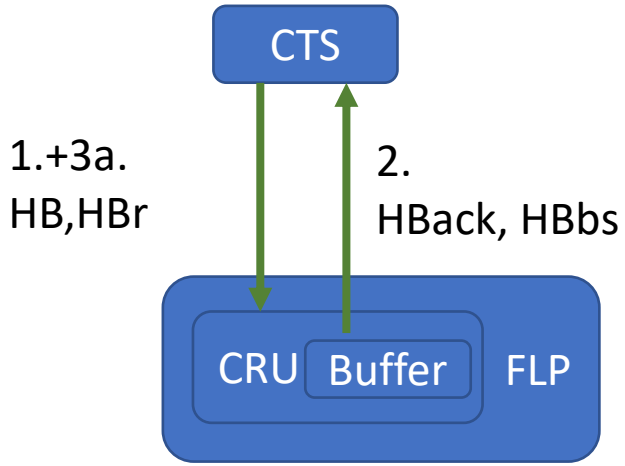
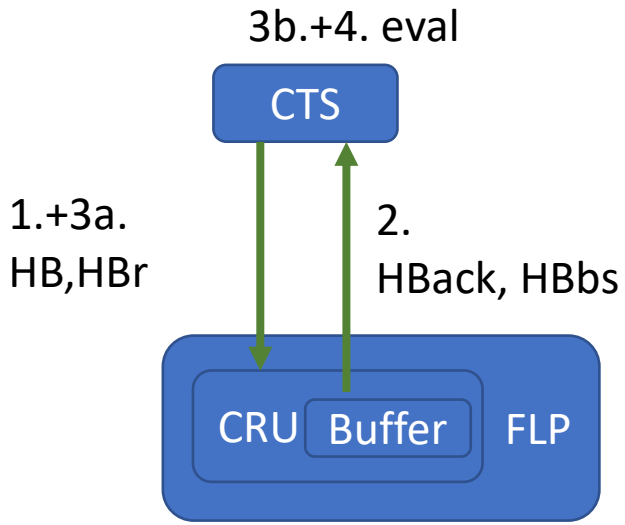
3a. CTP processes the buffer statuses to **control the CRU-FLP throttling**
   - **Autonomous mode** – no HBr, everything accepted (default)
   - **Downscaling** – fraction of HBr in TF to lower the data rate
   - **Collective mode** – CTP processes BS and evaluates HBr for the upcoming frame



HeartBeat decision from Acknowledges

3b. CTP collects HB acknowledge from all 441 CRU and forms a **Global HeartBeat Map (GHBmap)**

4. **A HB decision (HBd) will be evaluated** to decide whenever a HBf is good enough for data reconstruction



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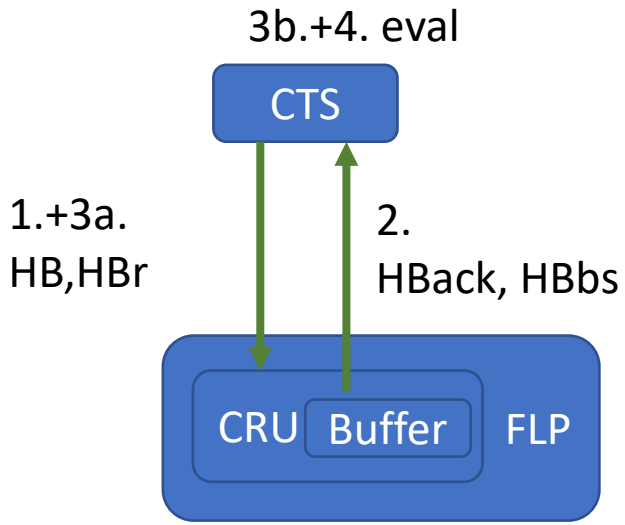

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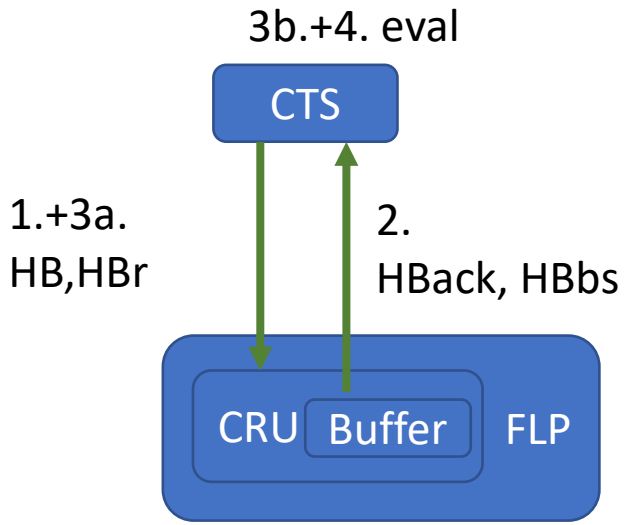
  - A **HB mask** is introduced to lower the dimension of the function
  - E.g. HB mask to require only TPC and ITS CRU with a function requirement of at least 80% successfully transferred data to FLP
  - As many HB functions as detectors to be universal in cluster creation
  - E.g. if the HB function is the same for all detectors, ALICE will behave as one detector, while when functions are different each detector runs independently of others



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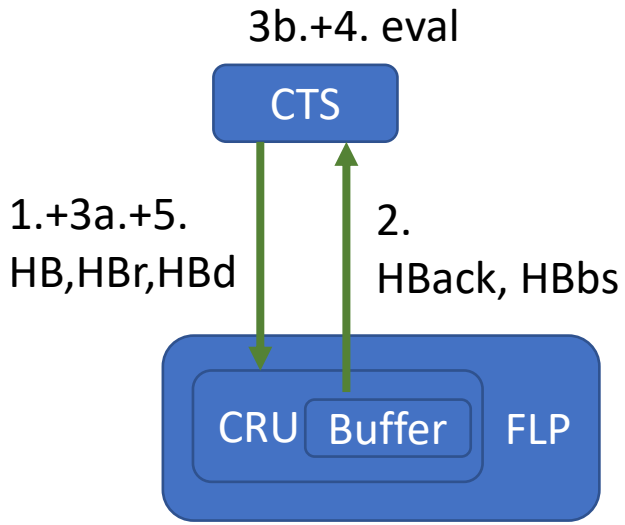
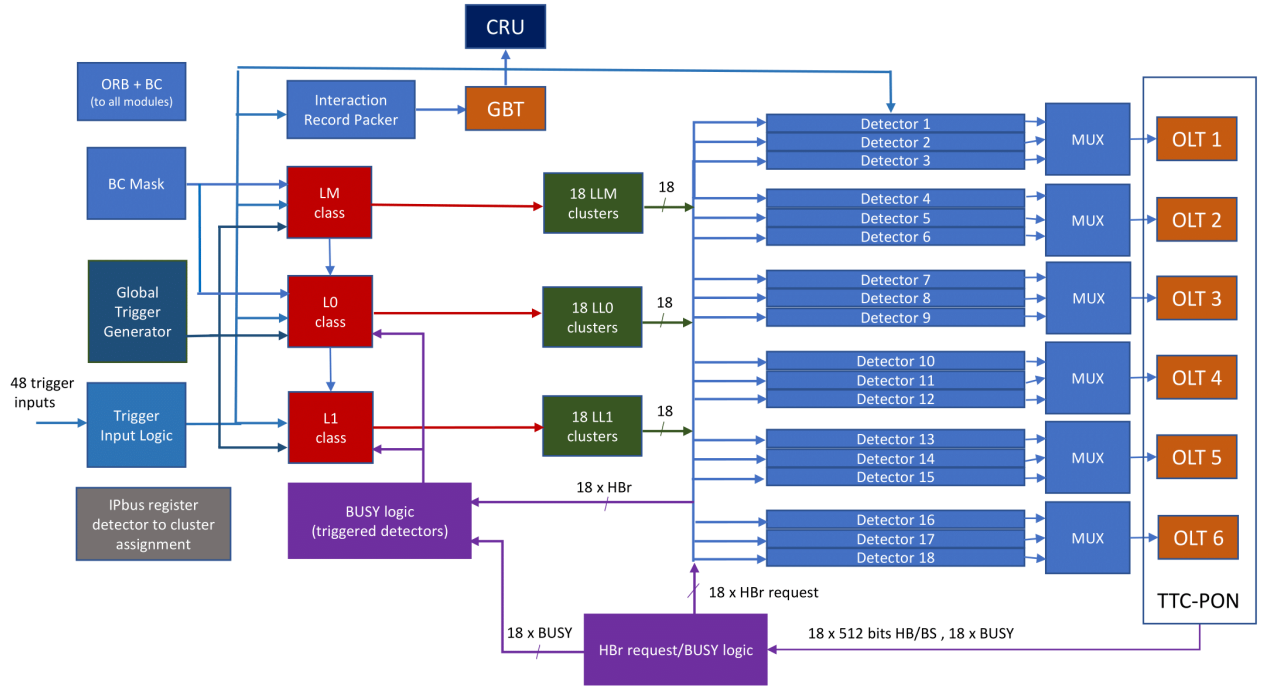
5. **Decision is transmitted to FLP via CRU** to either discard or process the frame



CTP logic - Trigger classes

Trigger class = Trigger Condition + Trigger Cluster + Trigger Vetoes

- **Trigger class** combines physics interest and readout
  - 64 classes
  - Important only to triggered detectors



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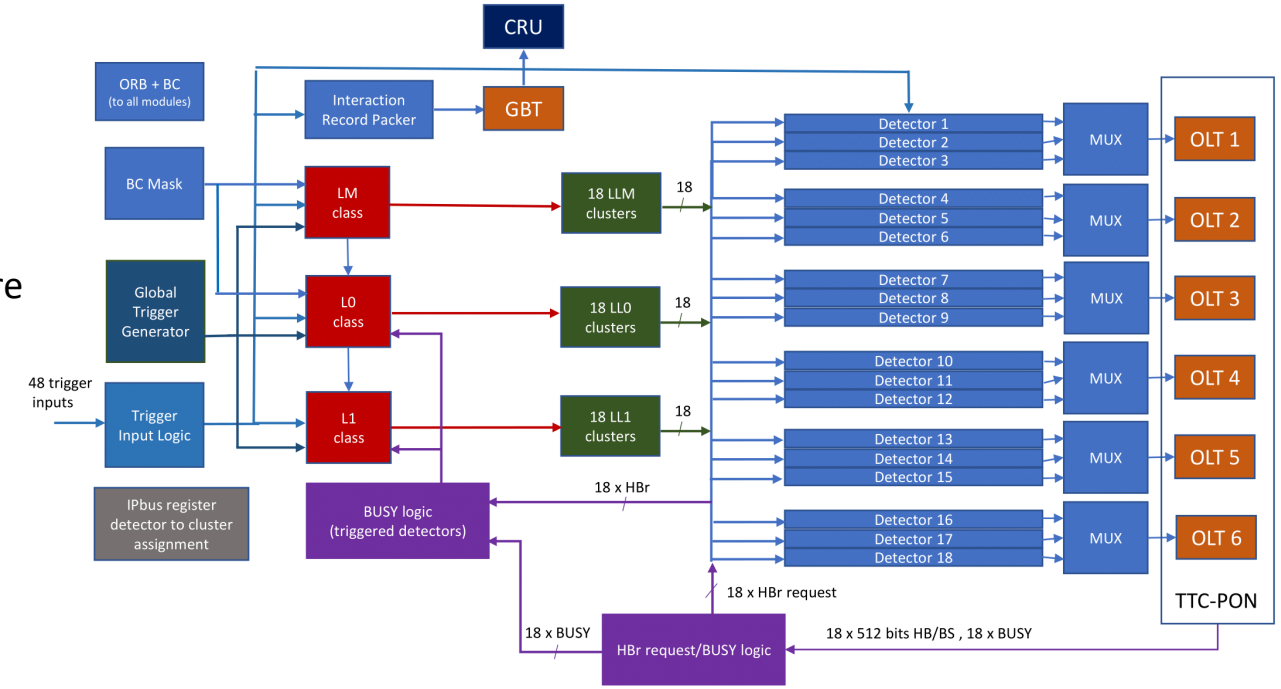
    - usually corresponds to LHC filling scheme - which BC are considered for interaction
    - used for luminosity estimation in Run 2



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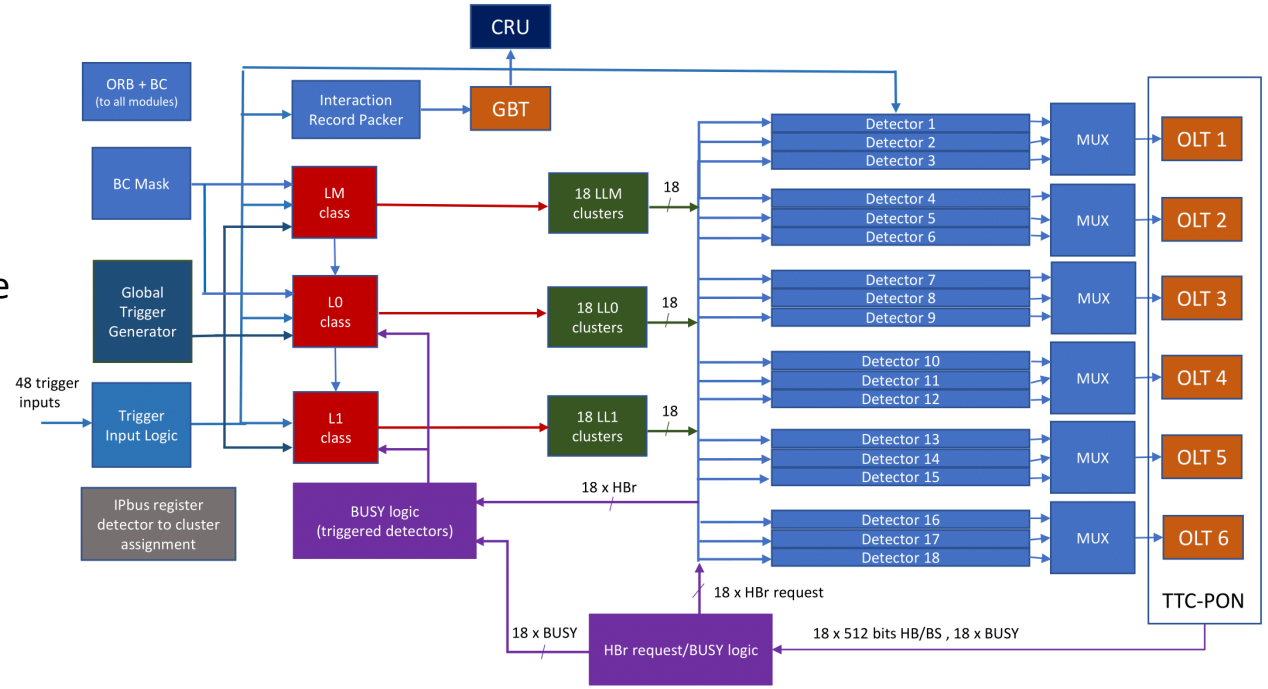

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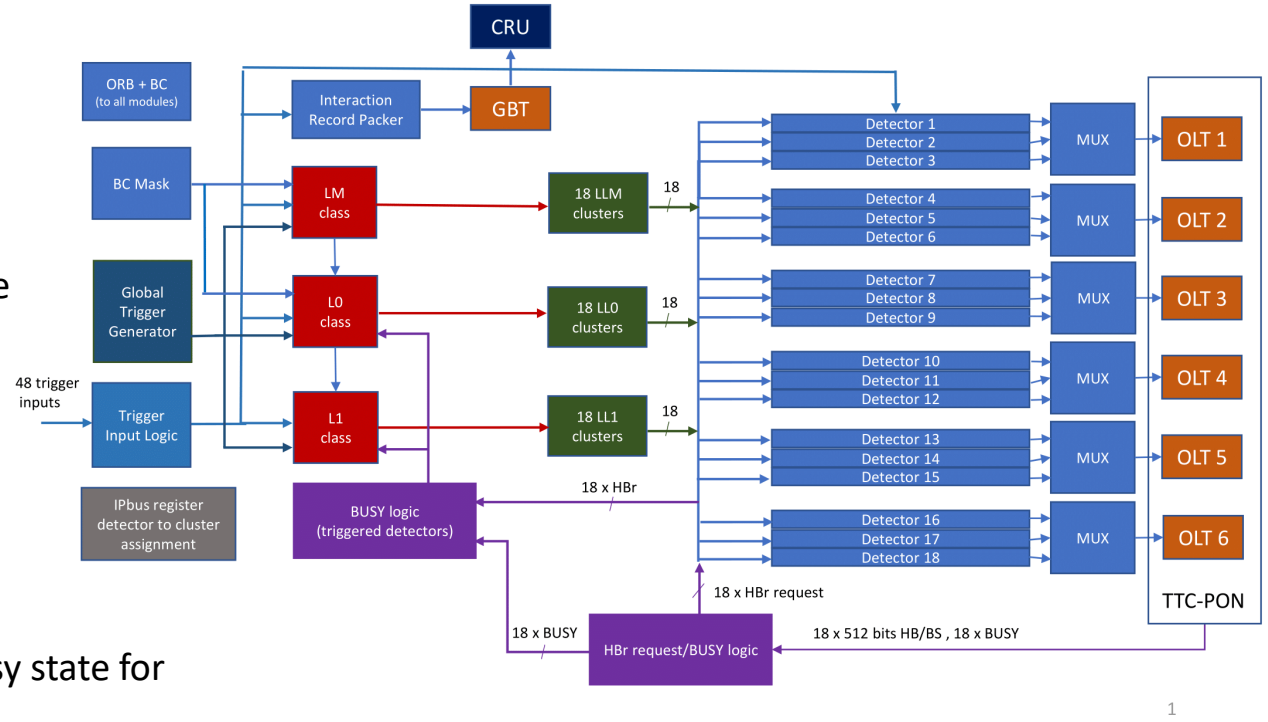
- **Trigger Vetoes**
  - Cluster busy = detectors in cluster either in HBr state or in Busy state for triggered detectors
    - Allows a correlation between triggered and continuous detectors
      - i.e no triggers in HBr frames



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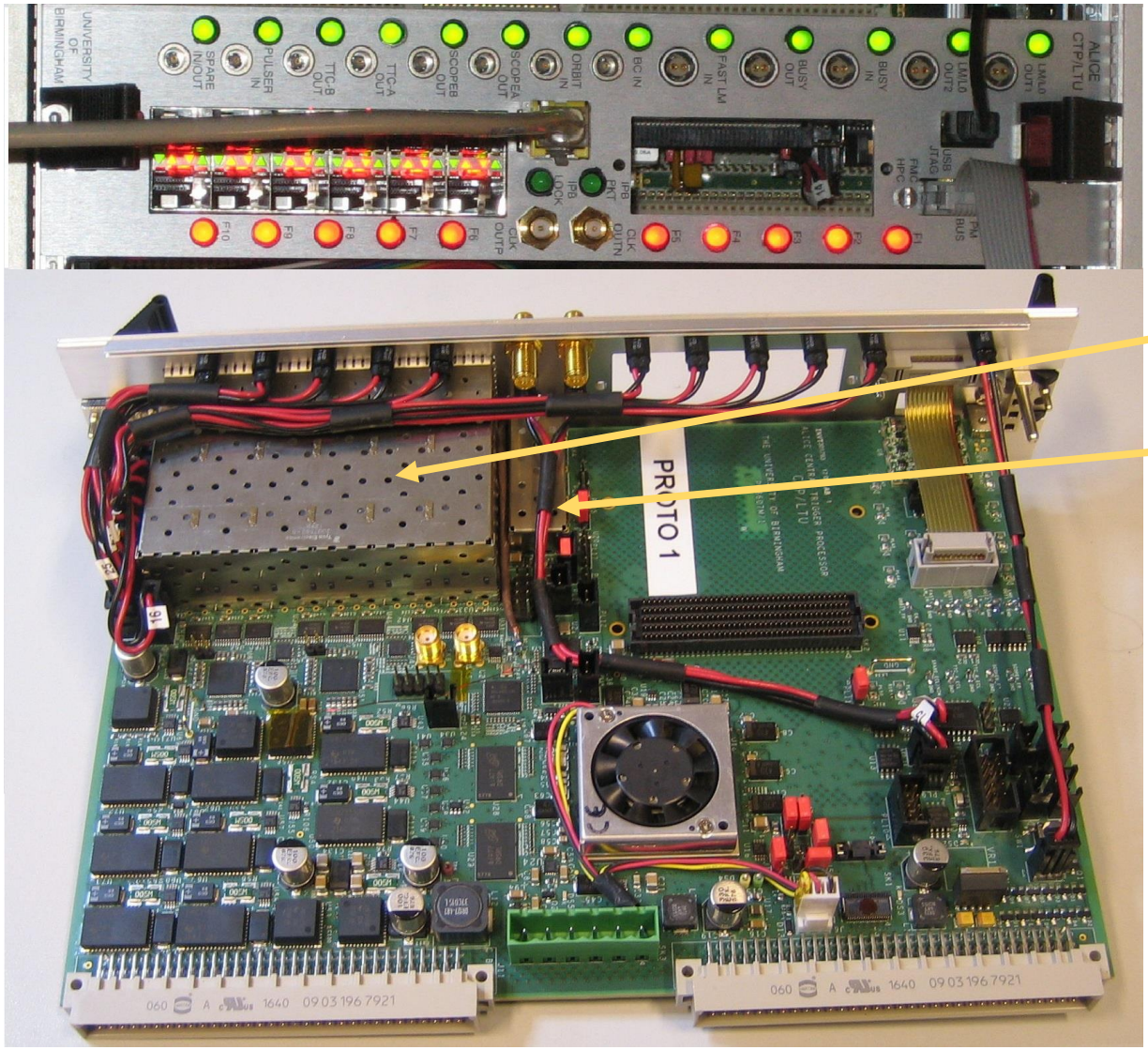

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- **Two six-fold SFP+**
  - Optical links – TTC-PON, GBT
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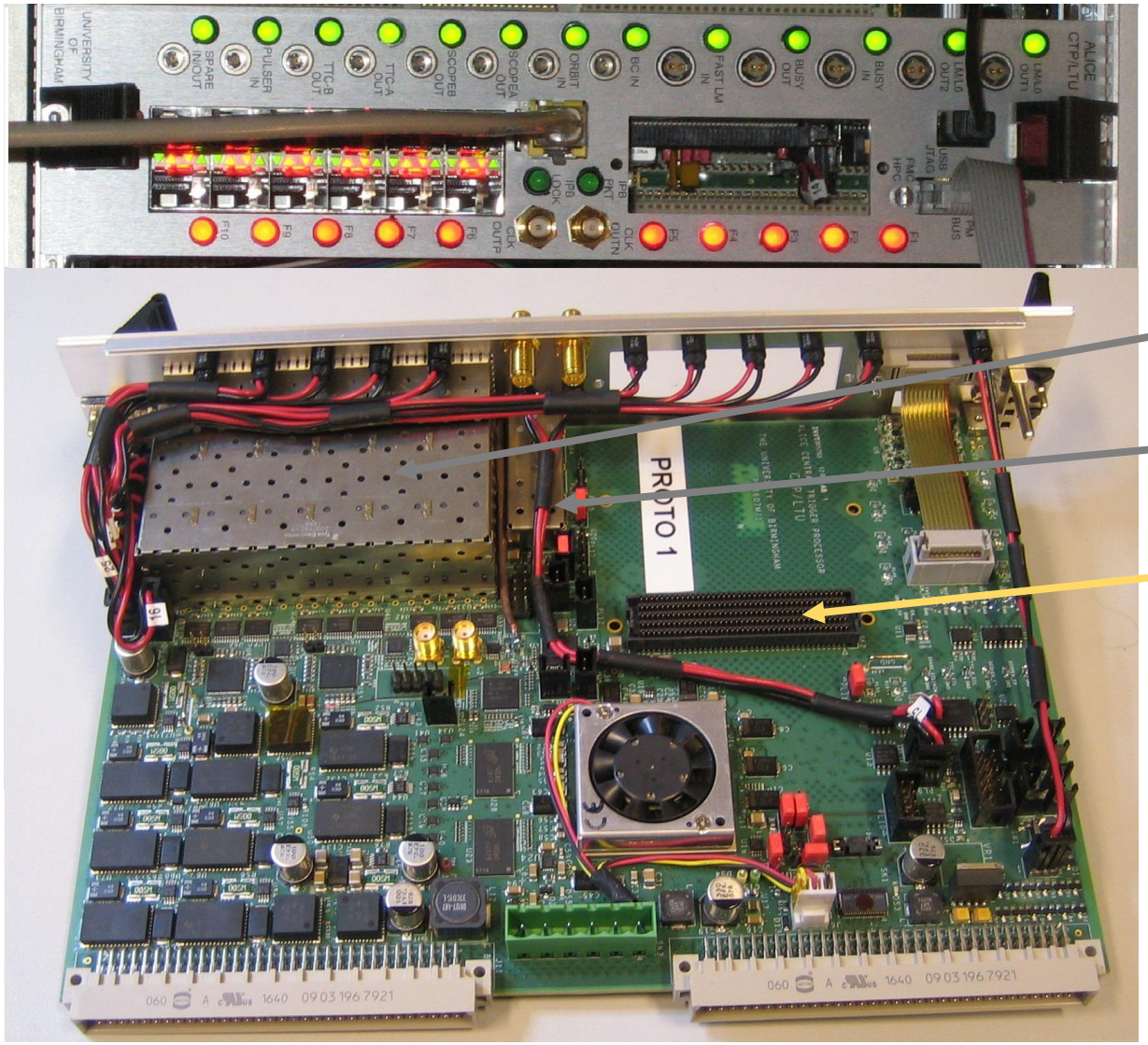

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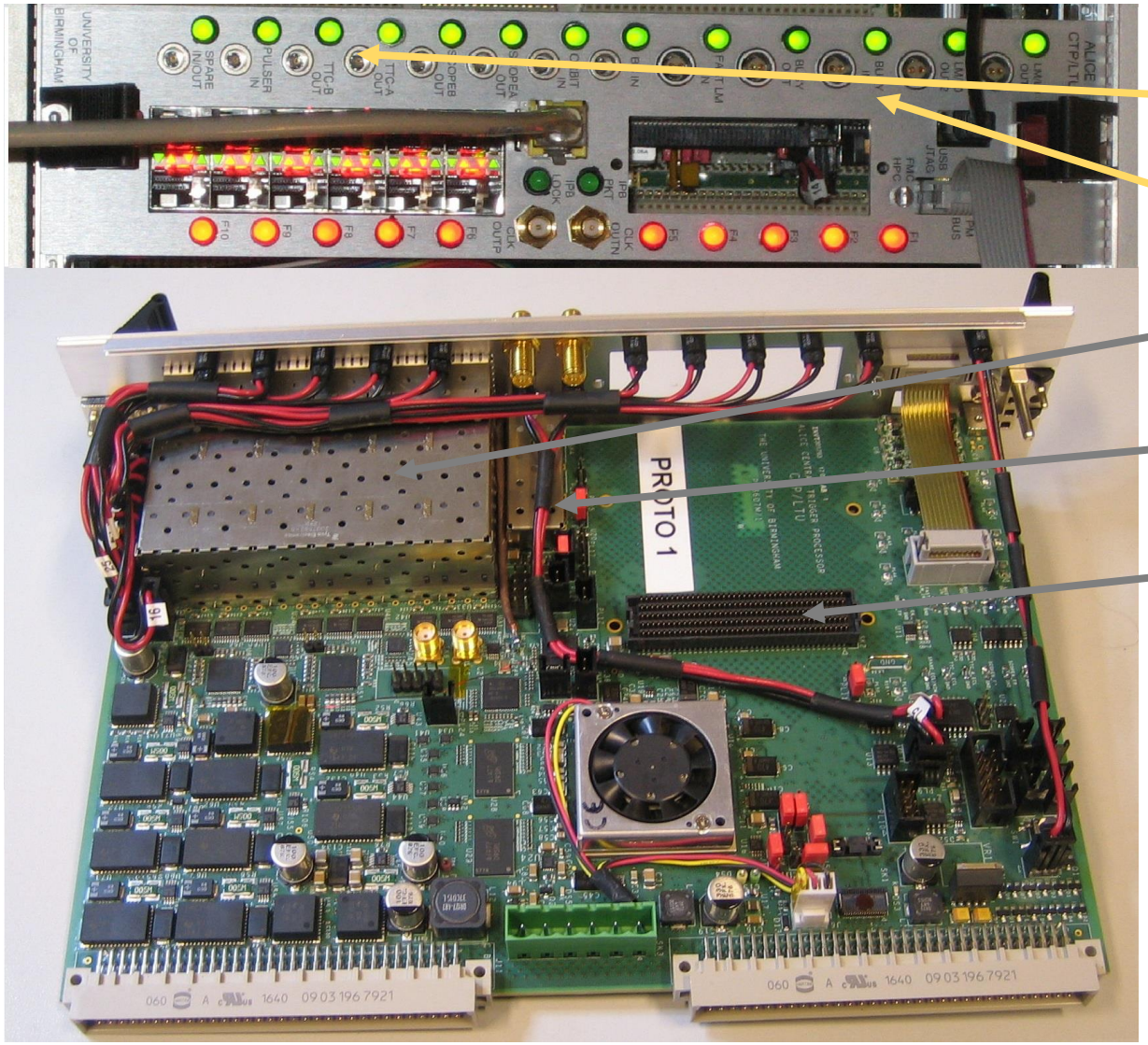

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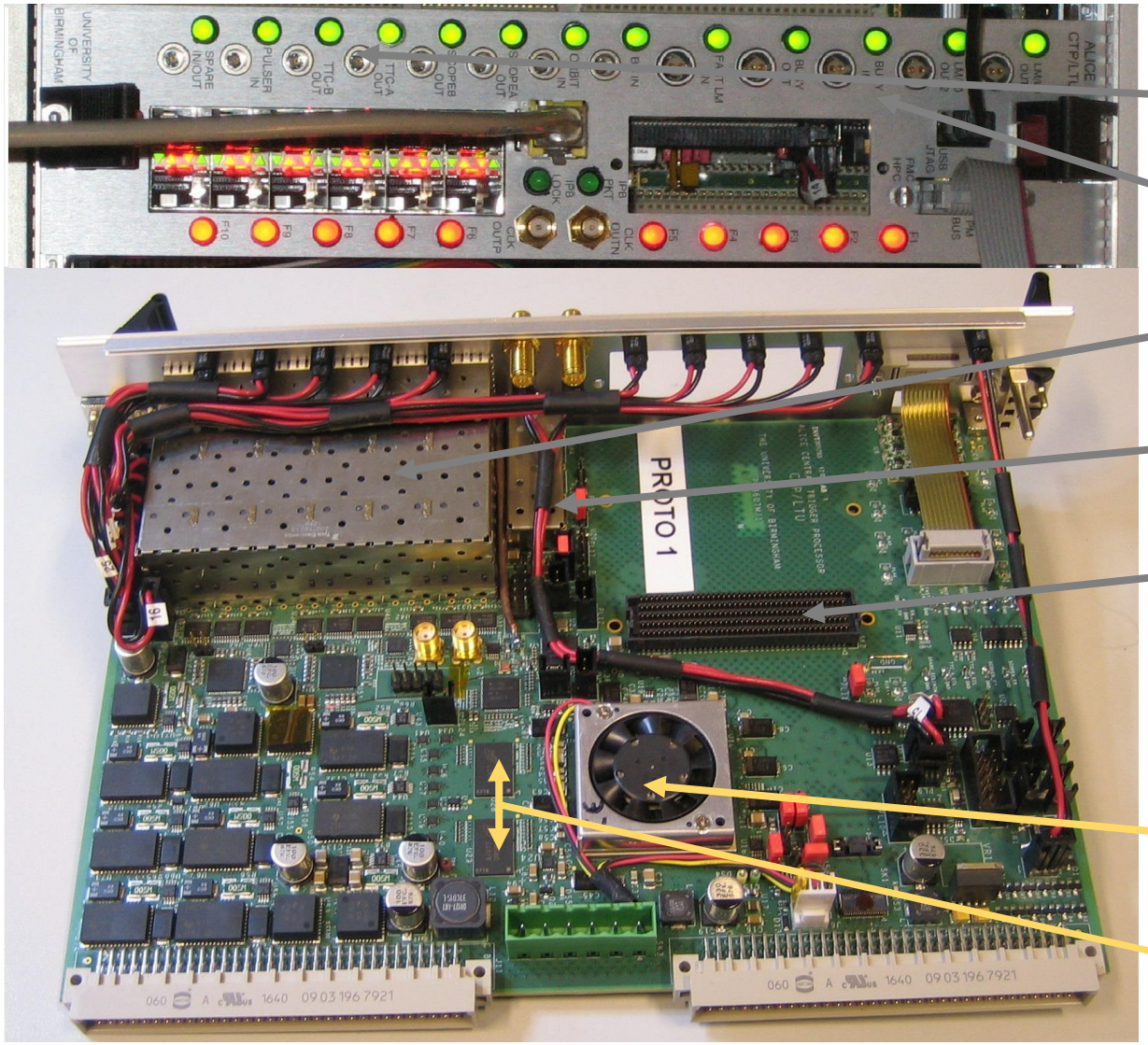

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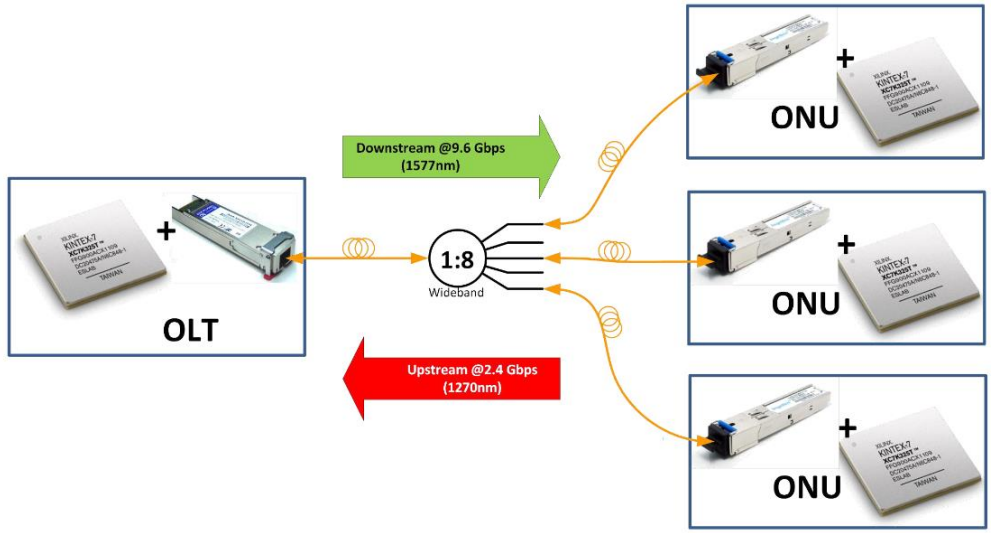
- **FPGA**
  - Xilinx Kintex Ultrascale
- **DDR4 SDRAM**
  - 2x 1 GB

Transceivers

- **TTC-PON**
  - Off-the-shelf Passive Optical Network (PON) technology
    - Optical Line Terminal (OLT) and Optical Network Unit (ONU)
  - Bidirectional, up to 9.6 Gbps downstream
    - 200 user bits per bunch crossing
  - Communication between **CTP-LTU** and **LTU-CRU**



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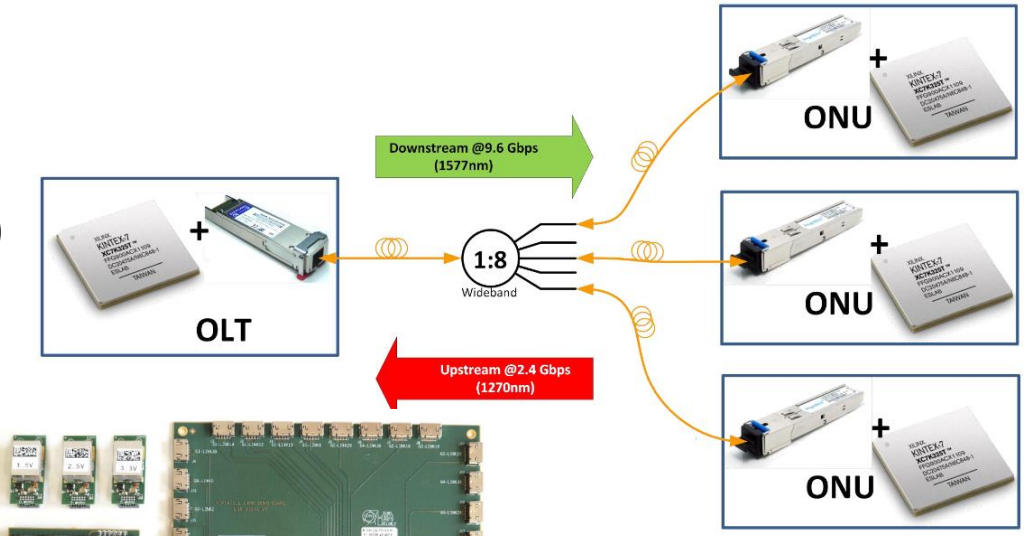
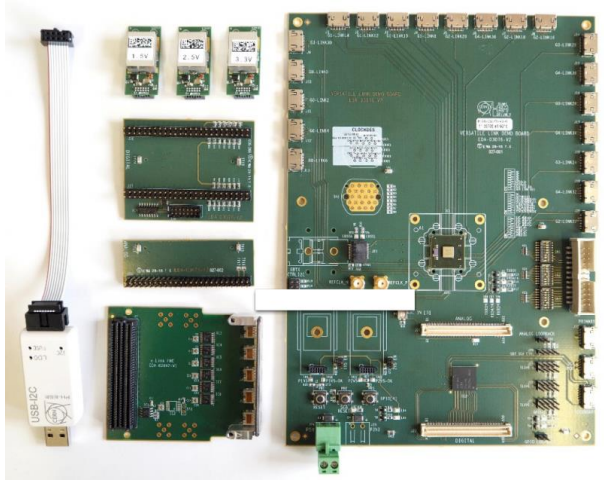
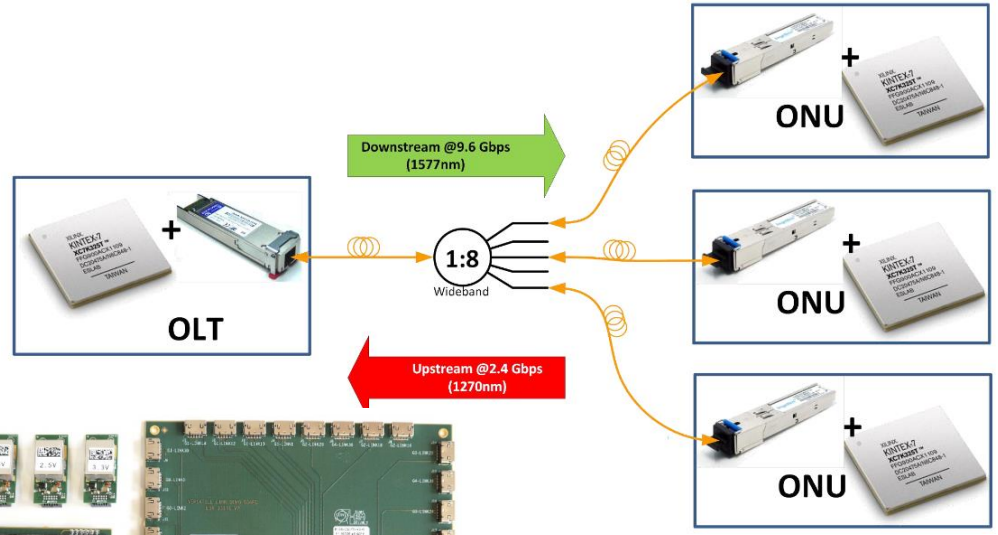
- **GBT**
  - Gigabit Transceiver
  - Radiation harnessed links
  - Bidirectional, up to 4.8 Gbps
    - 80 user bits per bunch crossing
  - Communication between **LTU-FEE** and **FEE-CRU**

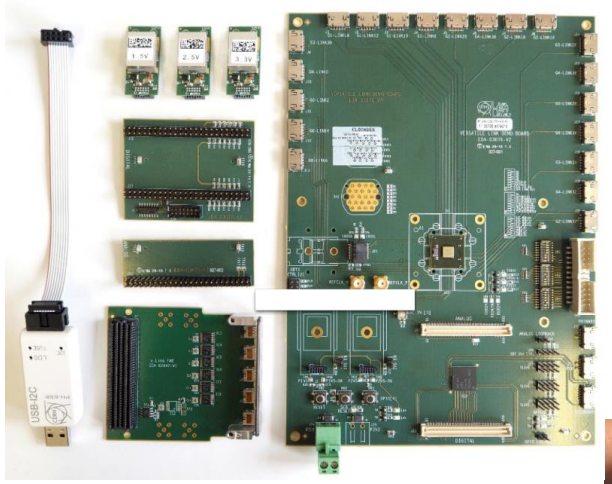


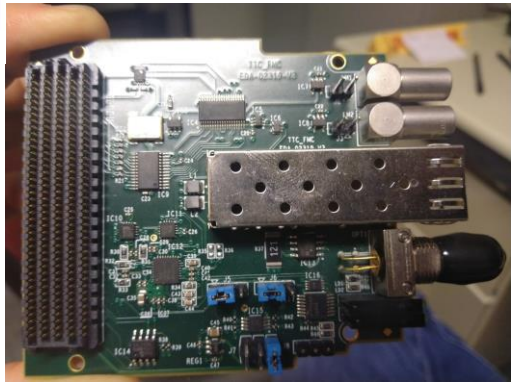


Transceivers

- **TTC-PON**
  - Off-the-shelf Passive Optical Network (PON) technology
    - Optical Line Terminal (OLT) and Optical Network Unit (ONU)
  - Bidirectional, up to 9.6 Gbps downstream
    - 200 user bits per bunch crossing
  - Communication between **CTP-LTU** and **LTU-CRU**
- **GBT**
  - Gigabit Transceiver
  - Radiation harnessed links
  - Bidirectional, up to 4.8 Gbps
    - 80 user bits per bunch crossing
  - Communication between **LTU-FEE** and **FEE-CRU**
- **RD12 TTC**
  - Trigger-Timing-Control developed by RD12 collaboration used till end of Run 2
  - Kept for backward compatibility for non-CRU detectors
  - 80 Mbps total downstream split in 2 channels (A and B)
    - synchronous trigger bit (in A) and asynchronous payload (in B)
  - Communication between **LTU-FEE** (legacy)







Trigger protocol

- **Trigger message** contains a time identification and a control/state (trigger type)
  - **Event Identification** – 44 bits
    - 32 bits LHC Orbit
    - 12 bits Bunch Crossing in a given Orbit
  - **Trigger Type** – 32 bits
    - Specify what happened in a given ID
    - Physics Trigger, Calibration, LHC Orbit, HeartBeat, HeartBeat reject, Start of Run, End of Run etc.

Trigger Types

Bit	Name	Comment
0	ORBIT	ORBIT
1	HB	Heart Beat flag
2	HBr	Heart Beat reject flag
3	HC	Health Check
4	PhT	Physics Trigger
5	PP	Pre Pulse for calibration
6	Cal	Calibration trigger
7	SOT	Start of Triggered Data
8	EOT	End of Triggered Data
9	SOC	Start of Continuous Data
10	EOC	End of Continuous Data
11	TF	Time Frame delimiter
12	FErst	Front End reset
13	RT	Run Type; 1=Cont, 0=Trig
14	RS	Running State; 1=Running
...	...	Spare
27	LHCgap1	LHC abort gap 1
28	LHCgap2	LHC abort gap 2
29	TPCsync	TPC synchronisation/ITSrst
30	TPCrst	On request reset
31	TOF	TOF special trigger

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- **TTC-PON + GBT**
  - These 76 bits are sent each BC over PON and GBT
  - In addition PON also contains HB decision record
    - List of HB decisions in a given Time Frame

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PON data format Trigger Message

PON bit	PON byte	Payload	Content
<31:0>	0-3	<31:0>	Trigger Type
<43:32>	4-5	<11:0>	BCID
<47:44>	5	<3:0>	Trigger Level/Spare
<79:48>	6-9	<31:0>	ORBIT
<118:80>	10-14	<38:0>	spare
<119:119>	14	<0:0>	TTValid
<120:120>	15	<0:0>	Header Flag
<127:121>	15	<6:0>	Word Count
<143:128>	16-17	<15:0>	HBDR payload
<144:144>	18	<0:0>	HBDRValid
<198:145>	18-24	<54:0>	Spare

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- **RD12 TTC**
  - 76 bits are asynchronously send over B channel by chopping into 7 TTC words (full transmission takes 308 BC)
    - Due to limited bandwidth only relevant control/states for particular detector are transmitted
      - Physics Trigger, Calibration, Start of Run, End of Run
      - Orbit and Calibration request require channel B resynchronisation with LHC and are broadcasted as short message of 16 bits

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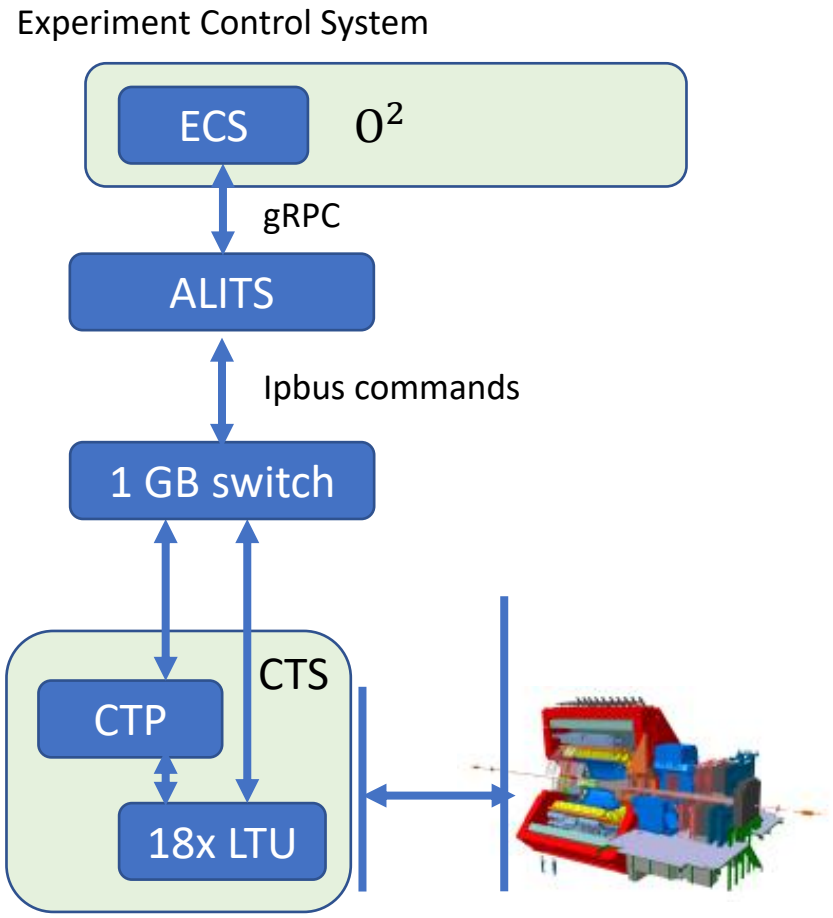
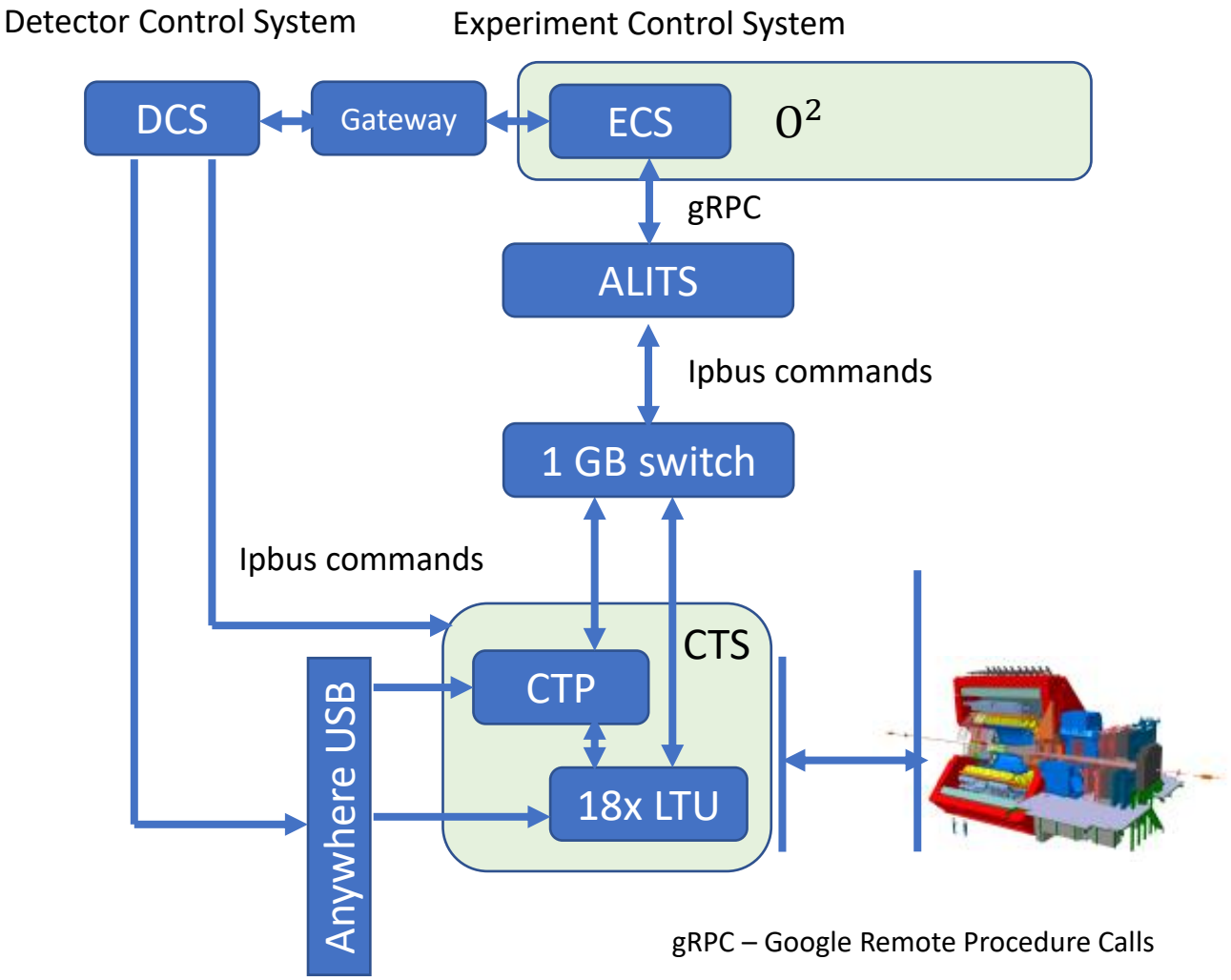
Infrastructure in Point 2 – ECD/DCS (preliminary)



gRPC – Google Remote Procedure Calls

- **Experiment Control System (ECS)** will communicate with trigger servers (**ALITS**) using **gRPC**
  - **ECS communicates with CTSproxy** from where commands are distributed as needed to CTPproxy and LTUproxies
  - Proxy between gRPC and ipbus calls

Infrastructure in Point 2 – ECD/DCS (preliminary)



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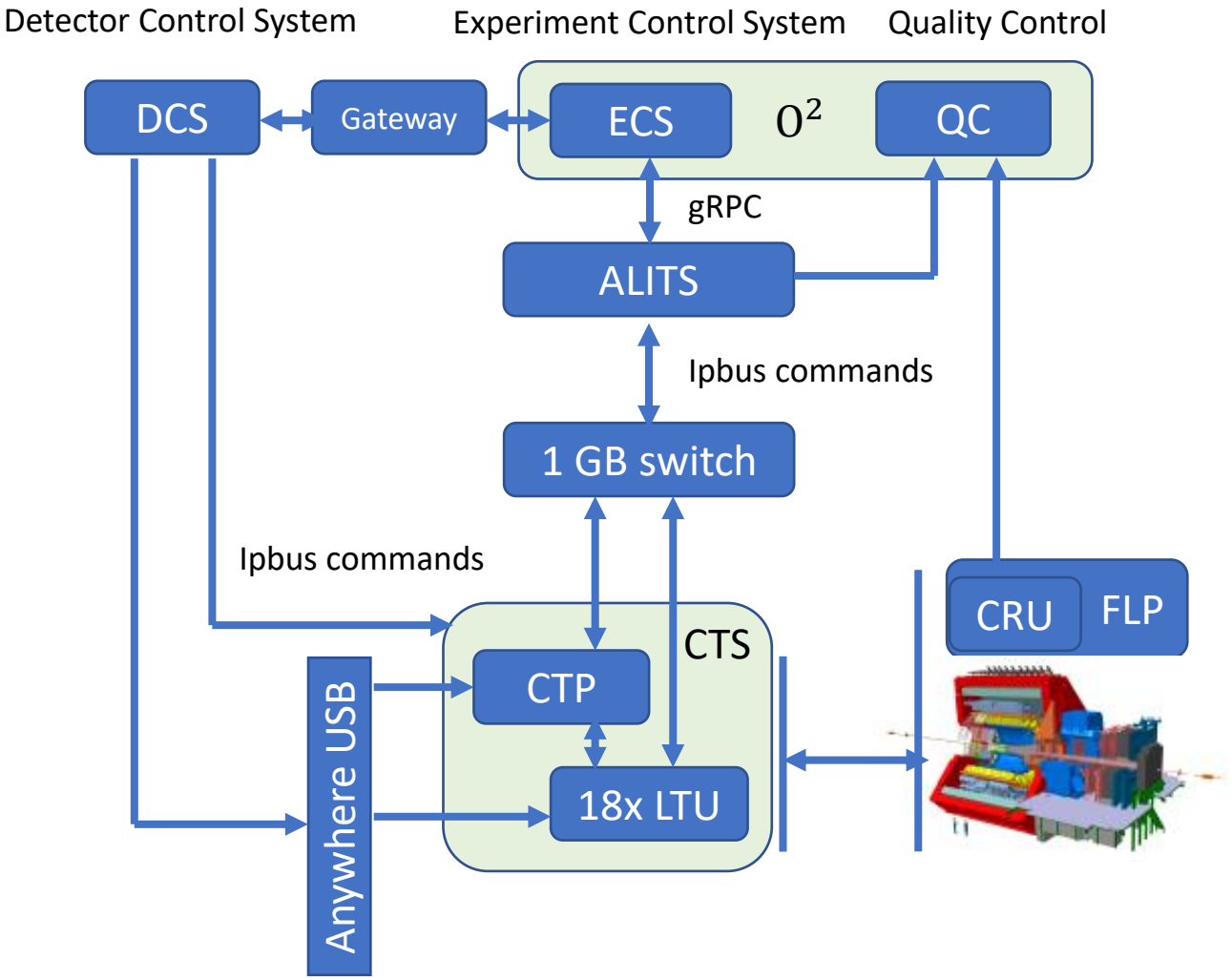
  - Proxy between gRPC and ipbus calls
- **Detector Control System (DCS)**
  - Crate control
  - WinCC – power monitoring
  - Backup FPGA reload via AnywhereUSB-JTAG connection
  - CTS alarms/warnings connected to our monitoring
- Mutex to prevent race conditions in ECS/DCS control system

Infrastructure in Point 2 - Monitoring (preliminary)

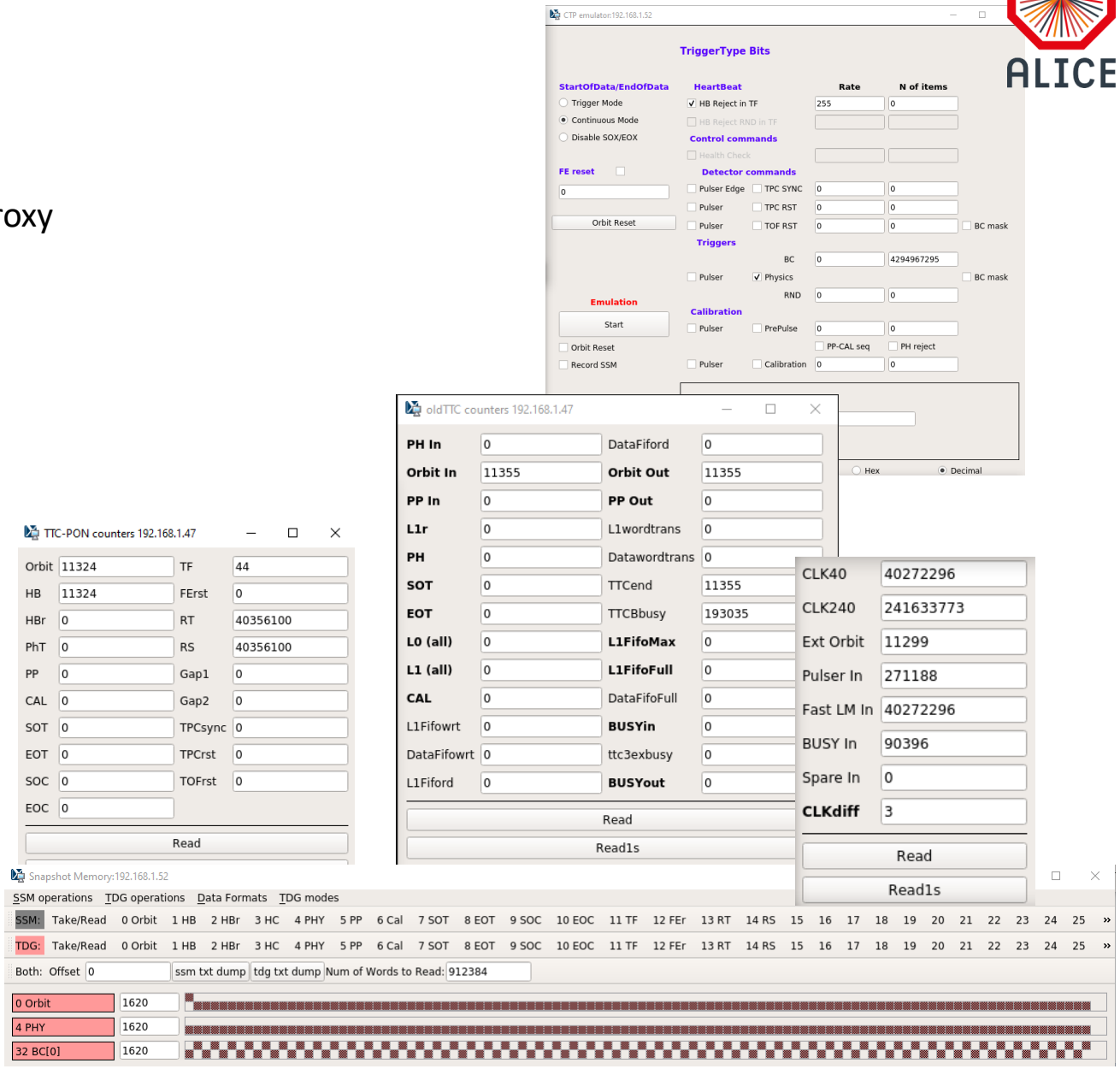


- **Quality Control (QC)**
  - Complete system managed by O^2 group
  - focusing on physics in retrieved data
  - run counters
  - samples from CTP readout streams
- **Each proxy sends** the content of relevant counters to a daemon taking care about passing it to
  1. time series database + visualisation through GUI WEB interface
  2. external online services (ECS, QC)
  3. offline database (run2: sent over DCS Shuttle service)

CTS Software

User

- **qtltu**
  - GUI control of Alice Trigger Board focused for users
  - Not full access to HW, gRPC communication with IPbus proxy
    - CTP emulator control, counters, Snap-Shot memory
  - C++ and Qt based



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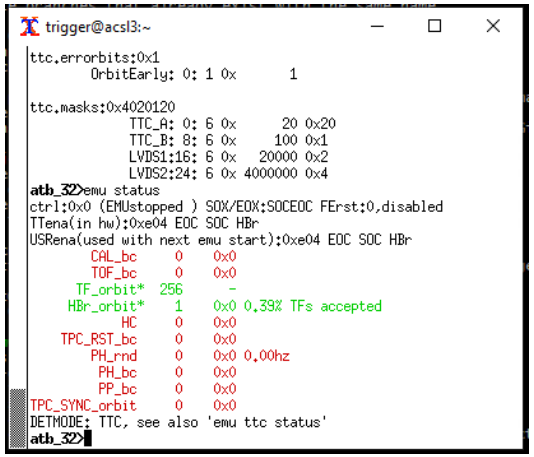
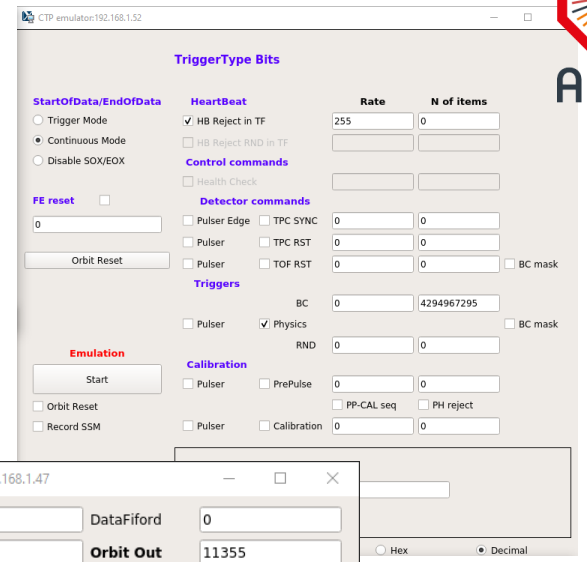
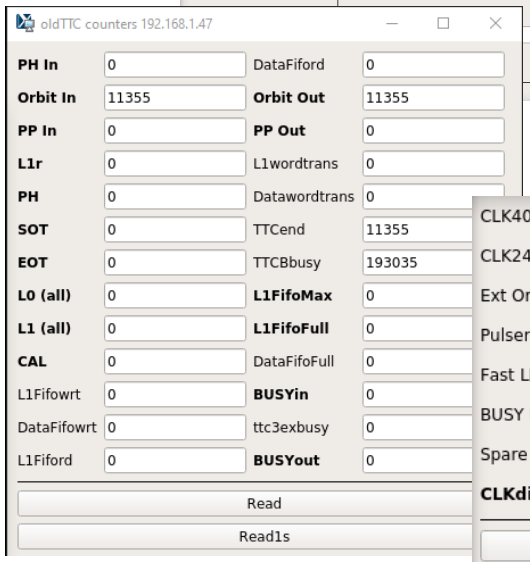
  - C++ and Qt based

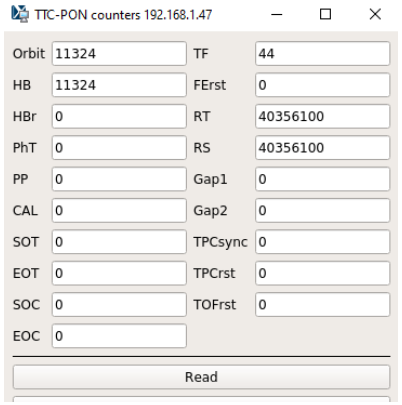
Expert

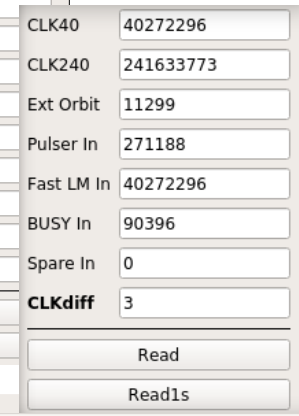
- **atb**
  - General access to a single Alice Trigger Board
  - For experts - development, control, status
  - Full and direct access to HW registers - IPbus
  - Python 2 (3 in the future)
- **ttcpon**
  - Set up and check the status of a ttcpon network
  - Network calibration
  - Python 2 (3 in the future)
- **ctp3-load**
  - Update/check the FW in the board flash memory
  - C++ based

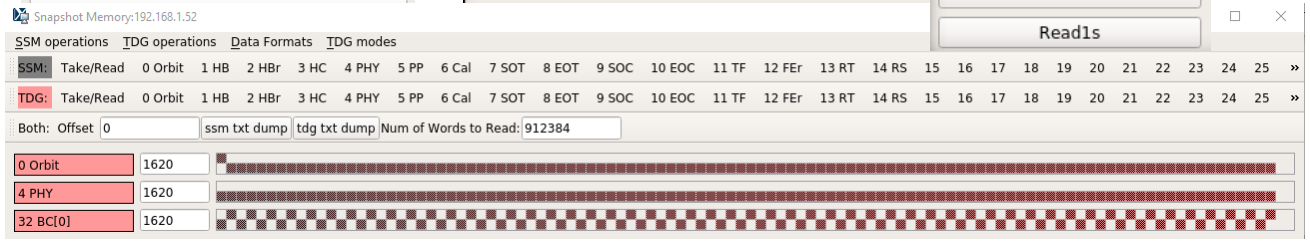








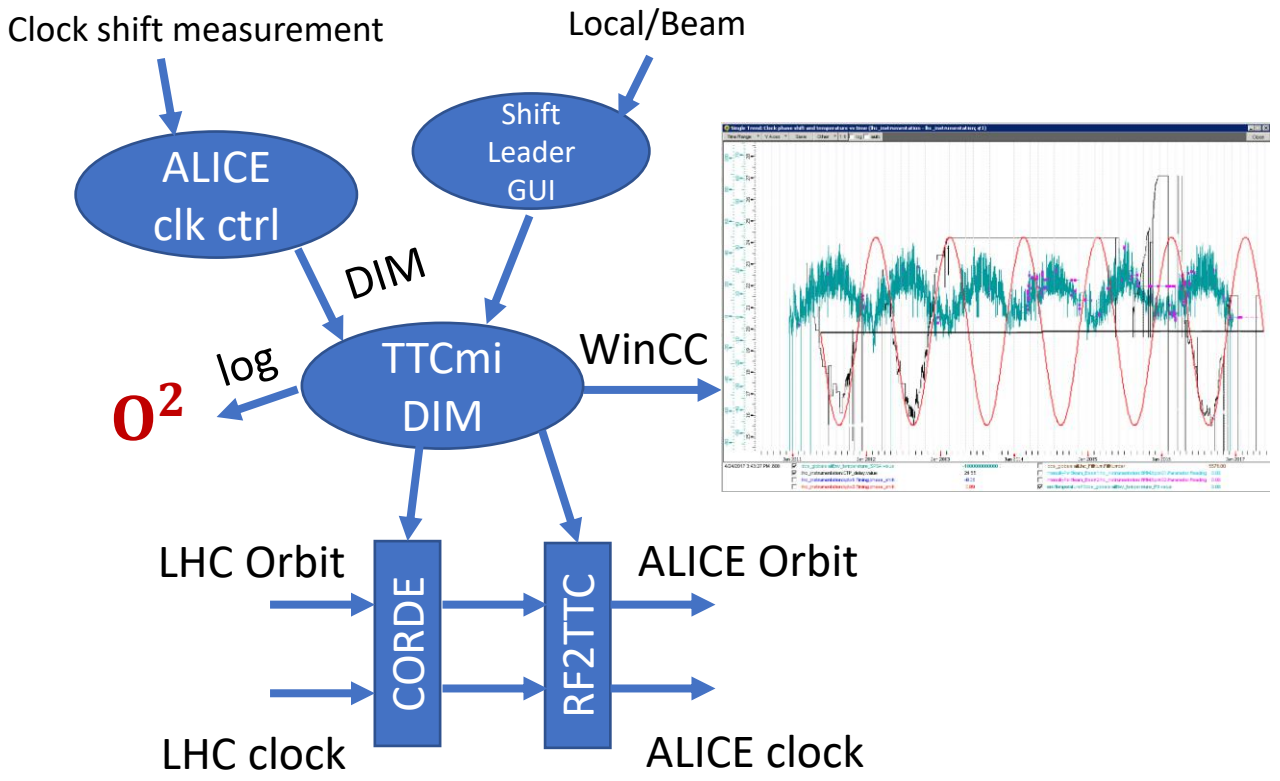




CTS Software

Expert

- **ALICE clock control**
  - switching between LHC and local clock
  - Clock shift adjustment w.r.t. beam
    - **seasonal (8 ns) + day/night (0.5 ns) corrections**
    - Coarse tuning (0.5 ns) using RF2TTC board
    - Fine tuning (10 ps) using CORDE board



DIM – Distributed Information Management System

CTS Software

Expert

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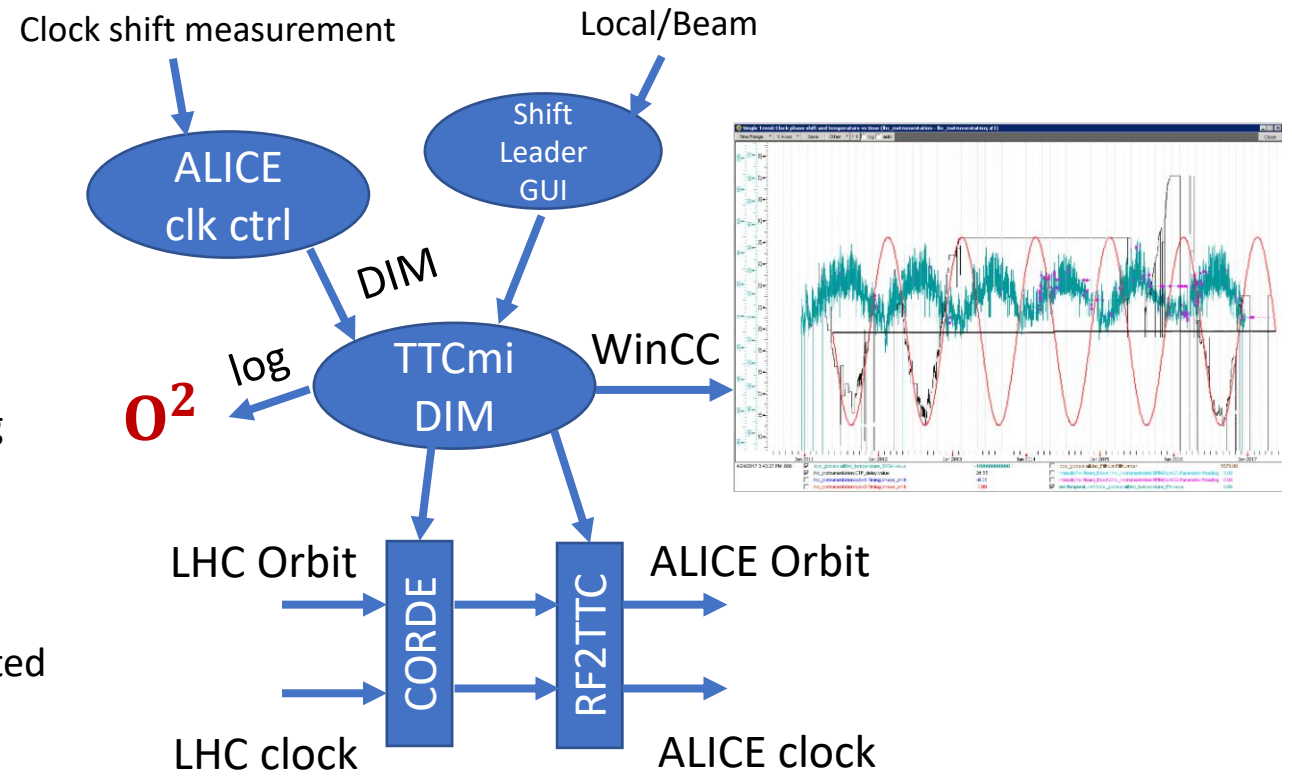
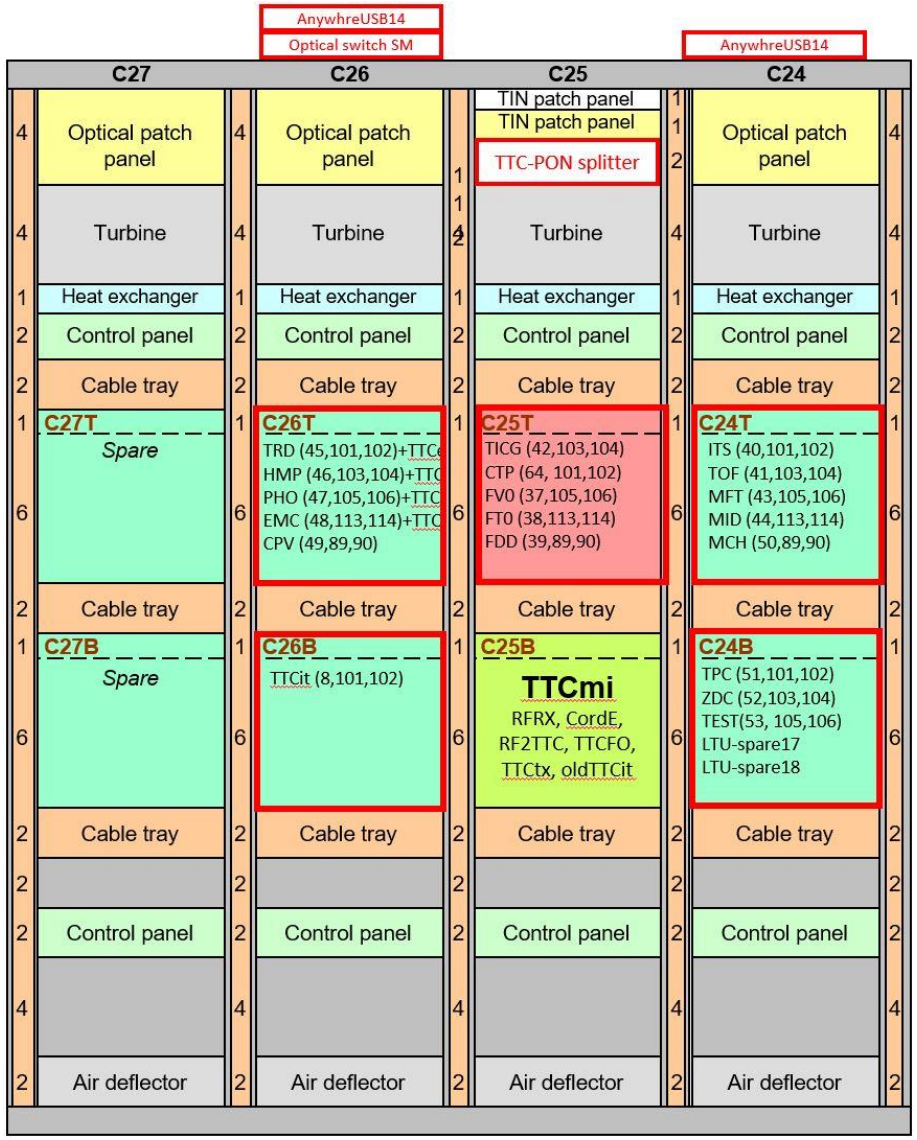
  - switching between LHC and local clock
  - Clock shift adjustment w.r.t. beam
    - **seasonal (8 ns) + day/night (0.5 ns) corrections**
    - Coarse tuning (0.5 ns) using RF2TTC board
    - Fine tuning (10 ps) using CORDE board
- **Filling scheme**
  - List of filled bunches in both beams
  - Calculates new ALICE BC masks with each new LHC filling scheme
  - Can be independently provided by BPTX detector
- **Luminosity calculation**
  - Instantaneous and bunch-by-bunch luminosity is calculated from Orbit and BC ID when CTP inputs were active
  - Sent back to LHC as a feedback



DIM – Distributed Information Management System

Installation in Point 2



Summary

- A **new Central Trigger System** was designed to allow **continuous readout** of detectors
- CTP and LTU **boards** have been **manufactured**, tested and **installed** in Point 2
- LTU Firmware is fully ready, CTP Firmware is under development
  - **First successful global run**
    - TPC and TOF measuring cosmic
- **Control and Monitoring** software
  - Detector Control system almost finalized
  - Quality Control integration with O^2 ongoing
  - ECS-CTP interface to be done

Don’t miss ALICE talks

- **A. Alkin**, 18th 11:29: ALICE Run3 Analysis Framework
- **V. Kučera**, 18th 11:42: Analysis of heavy-flavour particles in ALICE with the O2 analysis framework
- **D. Rohr**, 18th 16:05: Usage of GPUs in ALICE Online and Offline processing during LHC Run 3
- **E. Hellbar**, 19th 11:16: Deep neural network techniques in the calibration of space-charge distortion fluctuations for the ALICE TPC
- **A. Negru**, 20th 15:52: Analysis of data integrity and storage quality of a distributed storage system

One Board to rule them all, One Board to find them,
One Board to bring them all and in the darkness bind them.

Thank you for your attention

Technology

- Common Readout Unit (CRU)
  - PCIe40, Arria10 FPGA
- First Level Processor (FLP)
  - 2-socket Dell R740
- Alice Trigger Board
  - Xilinx Kintex Ultrascale FPGA
    - XCKU040-2FFVA1156E (LTU)
    - XCKU060-2FFVA1156E (CTP)
  - Flash memory
    - MT25QU128ABA1EW7 (LTU)
    - MT25QU256ABA1EW7 (CTP)
  - DDR4 SDRAM
    - 1 GB MT40A512M16HA-083E
  - FMC
    - Commercial FMC S-18 card with 7 x SFP+ (GBT)
    - FMC CTP
      - FIN1101K8X repeater
      - M24C02-WDW6TP Serial EEPROM FMC configuration
      - Samtec SEAC with 72 pair cable
  - SFP+
    - ONL, OLT - Gofoton
    - GBT AFBR-709DMZ
    - ABCU-5740ARZ for 1G copper Ethernet
    - AFBR-709DMZ for 1G optical Ethernet
- Software
  - G++, Qt, Python 3
- Ethernet communication
  - Ipbus suite, Rarpd
- ECS communication
  - GRPC, ZeroMQ
- Databases
  - RRDtool, Redis
- VMERCC driver
- Fusion Digital Power Designer – Pmbus
  - SIMATIC WinCC via DIM service

CTP Trigger Inputs

Detector	Lat./Level	N of inputs	Latency [ns]
FT0	LM	5	425
FV0	LM	5	425
FDD	L0	5	NK
TOF	L0	4	862
EMC	L0	2	843
	L1	8	6100
PHS	L0	2	843
	L1	5	6100
BPTX	L0	2	NK
TPC	L0	1	900
Total	LM/L0+L1	39	

- **Triggering detectors must be:**
  - Fast signal (time resolution)
  - high efficiency
  - high rate capability
  - high performance of FEE (segmented, small data output etc.)
- A New dedicated minimum Bias detector
  - **Fast Interaction Trigger (FIT)**
    - FV0, FDD - Scintillators
    - FT0 - Cherenkov
- **Delivered via LVDS towards CTP**
  - CTP FMC card allows up to 64 LVDS connections
- Evaluated for **trigger decision at L0 and L1 latency** (triggered detectors), and **included in Interaction Record**