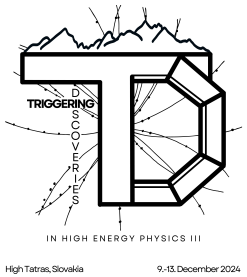
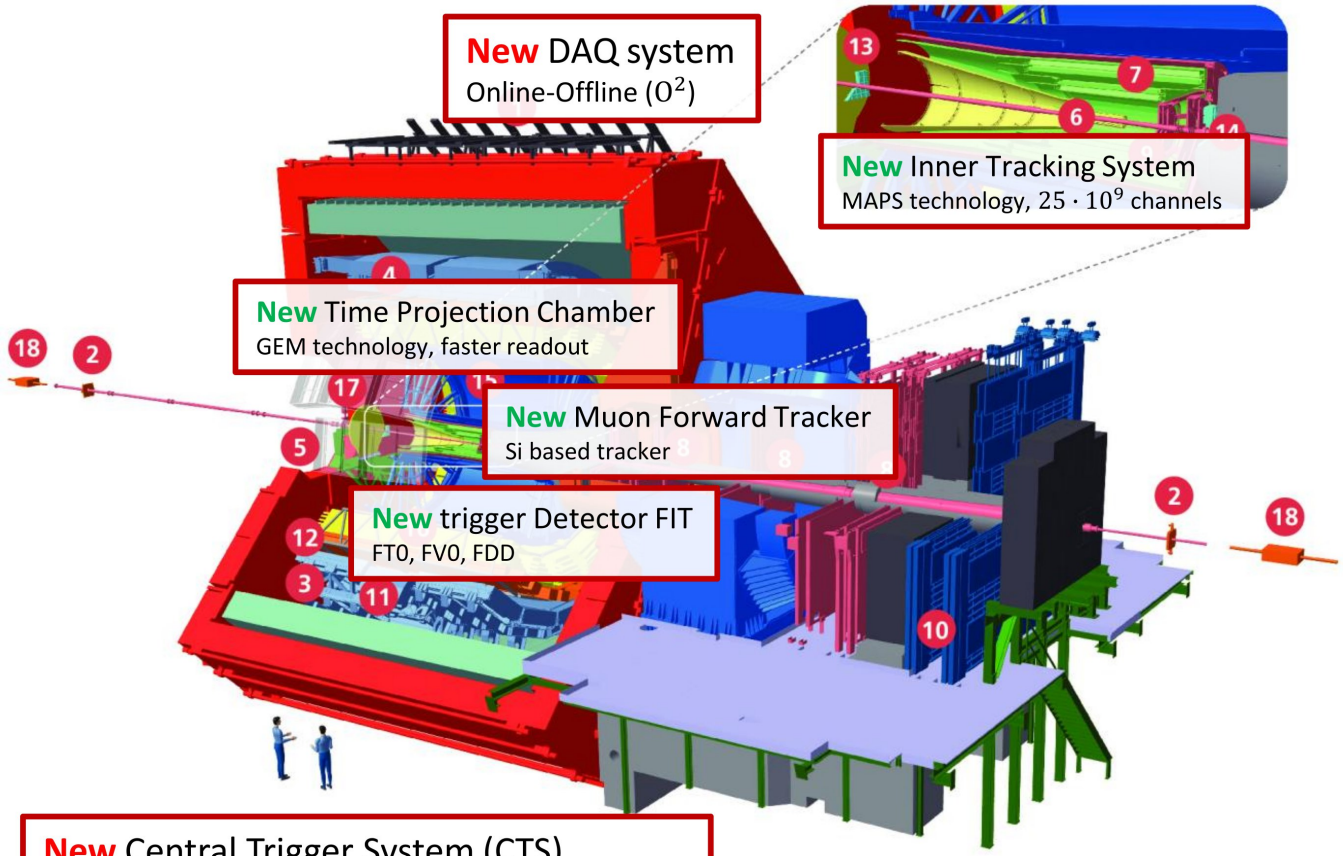


ALICE Central Trigger Processor in LHC Run 3

Ishaan Ahuja on behalf of the ALICE experiment
Pavol Jozef Šafárik University in Košice, Slovakia

Triggering Discoveries in High Energy Physics III
9–13 Dec 2024

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
17. **V0+** | Vzero + Detector
18. **ZDC** | Zero Degree Calorimeter

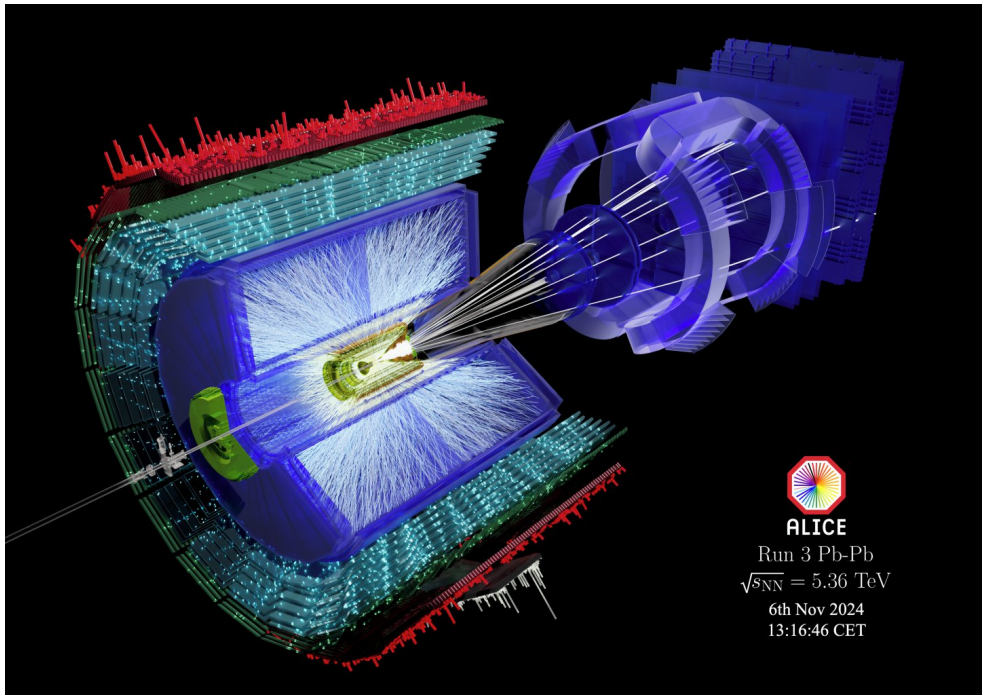
ALICE Run 3: Key Physics Objectives

Improved capabilities to probe QGP with heavy-flavour quarks

New measurements of the thermal emission of dielectron pairs

Distinctive high-precision ALICE measurements:

- Heavy-flavour transport parameters
  - study of QGP properties via transport coefficients (η/s, q)
- Charmonium states in low p_T and wide rapidity range
  - statistical hadronisation vs dissociation/recombination
- Low p_T di-leptons and low-mass vector mesons
  - chiral symmetry restoration, initial temperature and Equation of State
- High-precision measurement of light and hyper (anti-)nuclei
  - production mechanism and degree of collectivity



ALICE in Run 3

		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

- Improve triggering (selection) techniques
- Decrease background, increase SNR (improve pointing resolution)
- Larger statistics

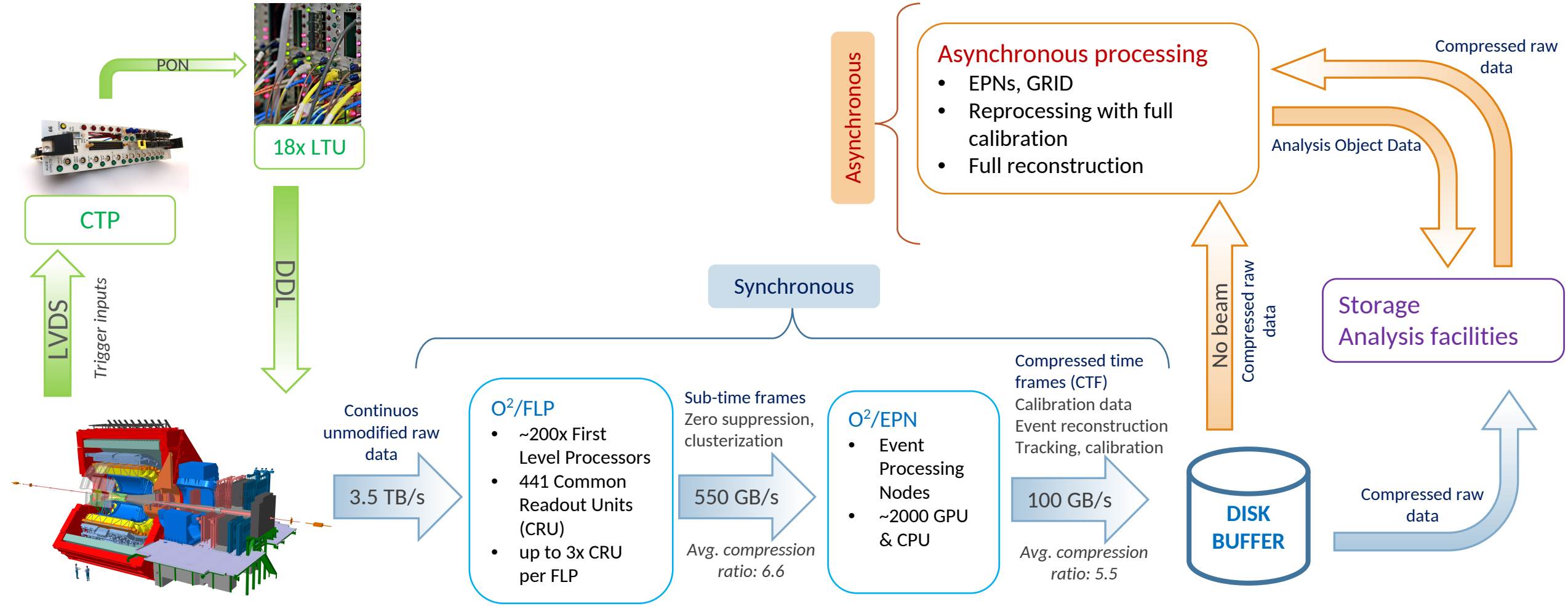
⇒ **Trigger-less continuous readout**: read and store all interactions

Challenges:

- Continuous readout → data in drift detectors overlap
- Recording time frames of continuous data, instead of events
- Min. bias Pb-Pb collisions at 50 kHz → ~100x more data than Run 2
- Cannot store all raw data → online compression (ALICE O^2 Project)

Visualisation of a 2 ms time frame of Pb-Pb collisions at a 50 kHz interaction rate in the ALICE TPC. Tracks from different primary collisions are shown in different colours.

ALICE Run 3 Dataflow



ALICE Run 3 Dataflow

Synchronous Reconstruction in the EPN Farm:

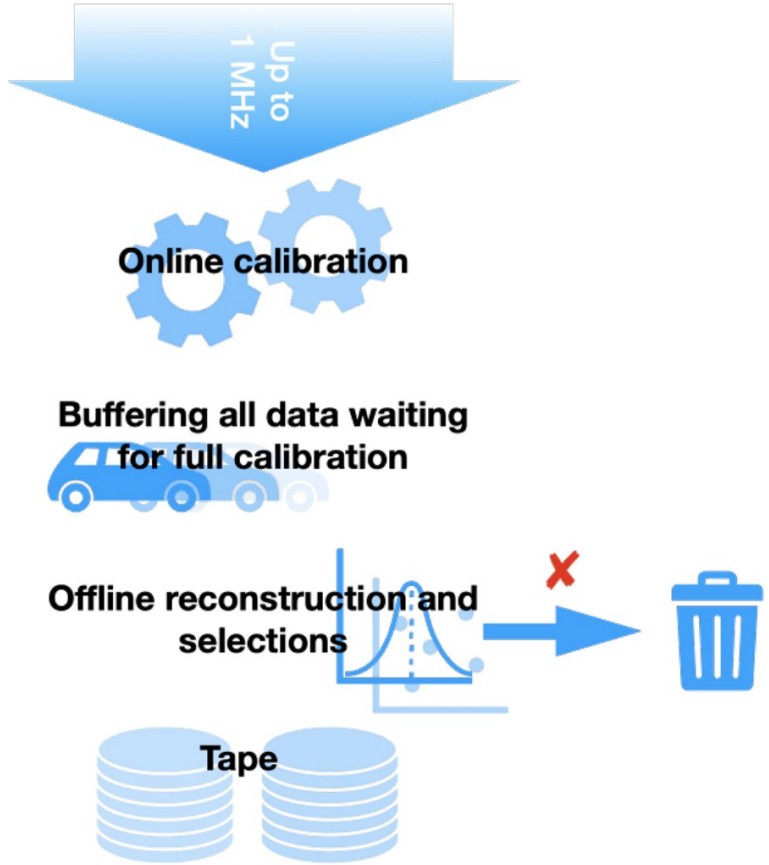
- Online calibration and data compression: TPC tracking, space point distortion calibration
- Needs ~10% (20%) of EPN resources at 500kHz (1MHz)

Buffering and Calibration:

- Calibrate all detectors ~2 weeks (+2 weeks contingency)

Asynchronous reconstruction and event selection:

- Data reconstruction with physics grade calibrations
- Event selection (time windows), final data compression, generate AOD



Central Trigger System

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

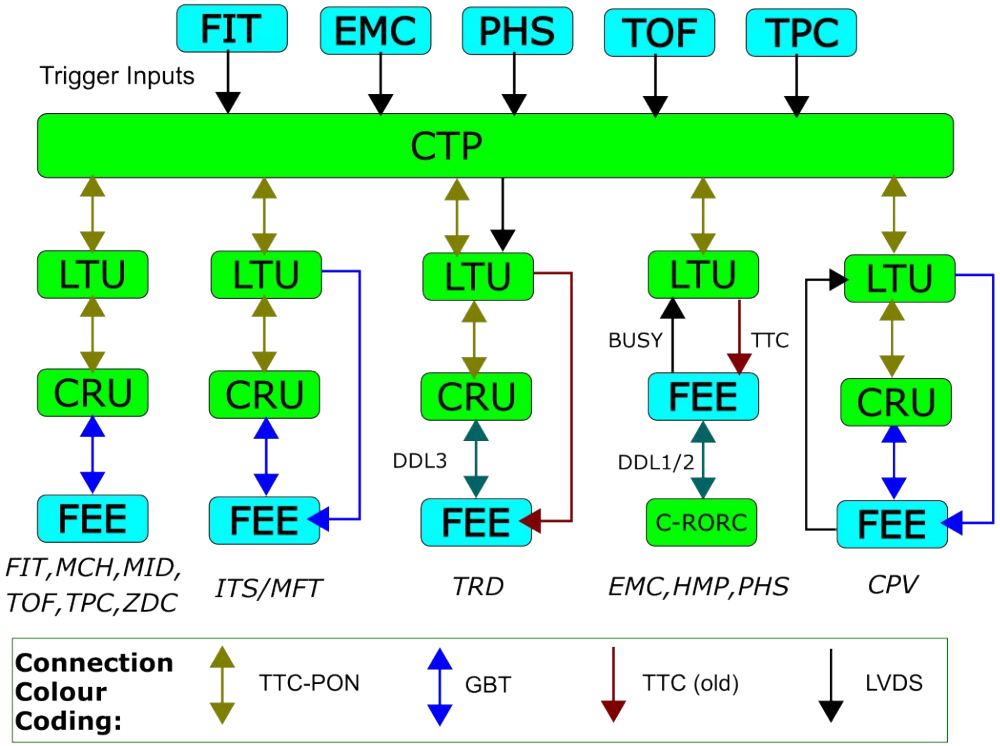
- Distribute clock and triggers to all ALICE detectors
- Generate HeartBeat (HB) markers
- Local Trigger Unit for each detector
- Allow a single detector decoupling from Central Trigger Processor to run independent tests (Standalone mode)

Technical Requirements:

- Concurrent processing - no dead time (< 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

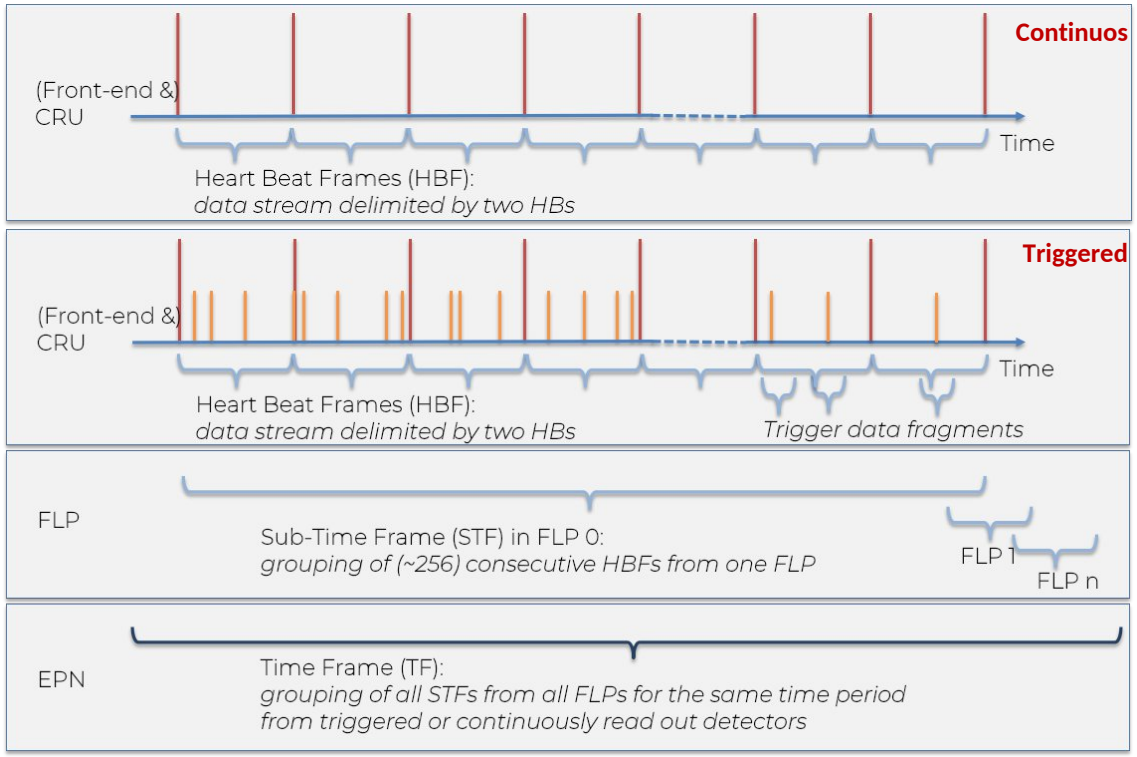
Central Trigger System

- 2 operating regimes:
  - 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



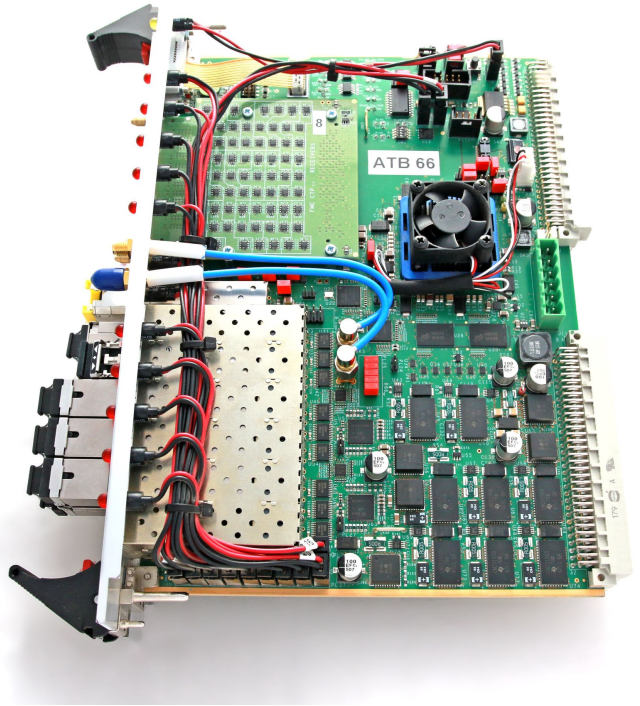
CTS Readout

- Continuous readout is the main mode of operation.
  - Detectors push continuous stream of data which are delimited by CTP Heart Beat triggers.
  - They must be capable of running in triggered mode as well
- ALICE data is divided into HeartBeat frames (HBf):
  - HB: 1 per orbit, 89.4 μs: ~10 kHz
  - 128 (programmable) HBf compose a Time-Frame (TF)
  - TF: 1 every ~10 ms: ~100 Hz
- Heart Beat (HB): issued in continuous & triggered modes to all detectors.
- Physics trigger mandatory for non-upgraded detectors, can be sent to upgraded detectors

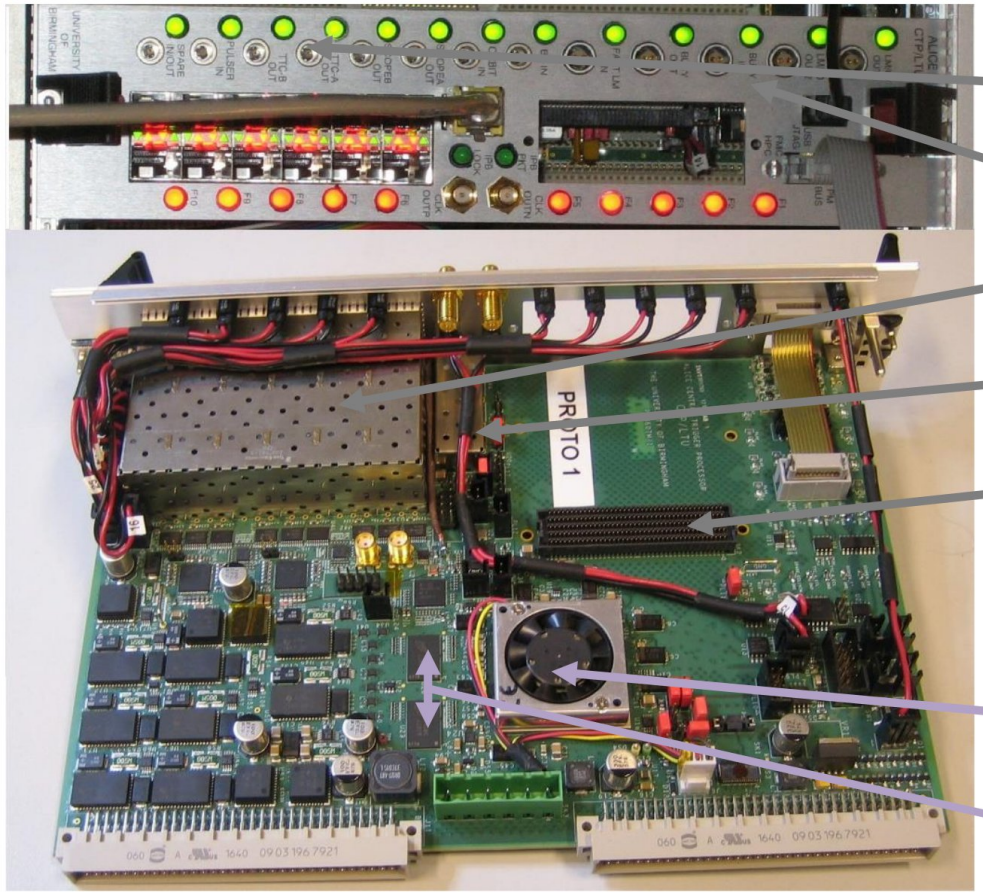


Trigger Board Design

- Single universal trigger board (CTP/LTU board)
  - FW configures board either in CTP or LTU configuration
- Kintex-Ultrascale FPGA (XCKU040-2FFVA1156E) for LTU board
- Kintex-Ultrascale FPGA (XCKU060-2FFVA1156E) for CTP board
- Interface between CTP and LTUs is via TTC-PON system
  - allows two-way data traffic between CTP and LTUs
- IPbus “basex” version of firmware, electrical SFP or optical SFP
- Plug in module for 1Gb Ethernet for control
- CTP/LTU board has FMC mezzanine card and triple-width front panel
  - VME-type 6U board (VME for power only)



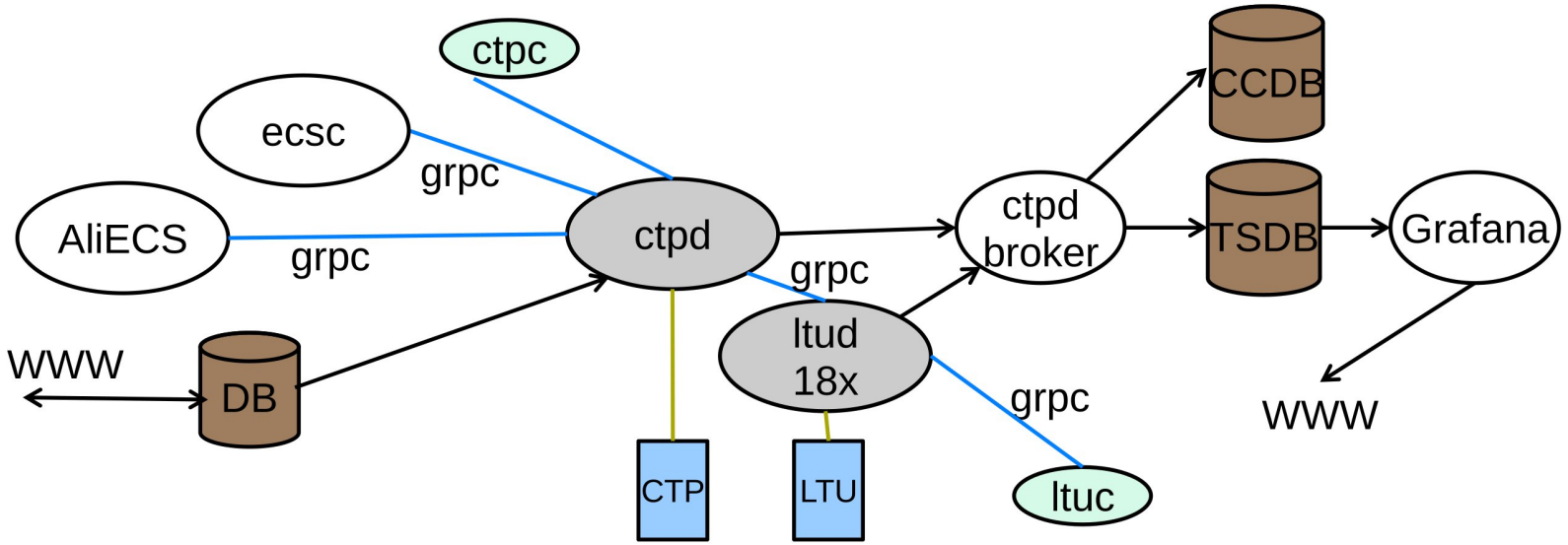
Trigger Board Design



- A universal VME-type 6U trigger board
- **8 ECL LEMO 00B**
  - RD12 TTC trigger distribution, LHC clock, orbit
- **6 LVDS LEMO B**
  - External trigger input, busy
- **Two six-fold SFP+**
  - Optical links – TTC-PON, GBT
- **Single-fold SFP+**
  - Ethernet communication via IPbus
- **FMC**
  - **CTP FMC** – 64 LVDS trigger inputs
  - **FMC FM-S18 rev. E** – additional 10 SFP+
  - **FMC GBTx** – interface for GBT links and LHC clock
  - **FMC TTCrx** – interface for RD12 TTC links
- **FPGA**
  - Xilinx Kintex Ultrascale
- **DDR4 SDRAM**
  - 2x 1 GB

CTP/LTU control

- **ctpd**
  - interface to AliECS
  - orchestration (stdalone/global for all LTUs)
  - monitor CTP, ctp.net, ttcpon fullcal
  - load CTP, start/stop triggers in global runs
- **ltud**
  - monitor LTU, det.net, ttcpon fullcal
  - CTPemu control in stdalone
- **ltuc,ctpc**
  - grpc expert clients
- **ecsc**
  - grpc client for ECS and detector crews



- TSDB database: Monitoring boards and infrastructure
- CCDB: Conditional and Calibration DB (Objects required for physics analysis)

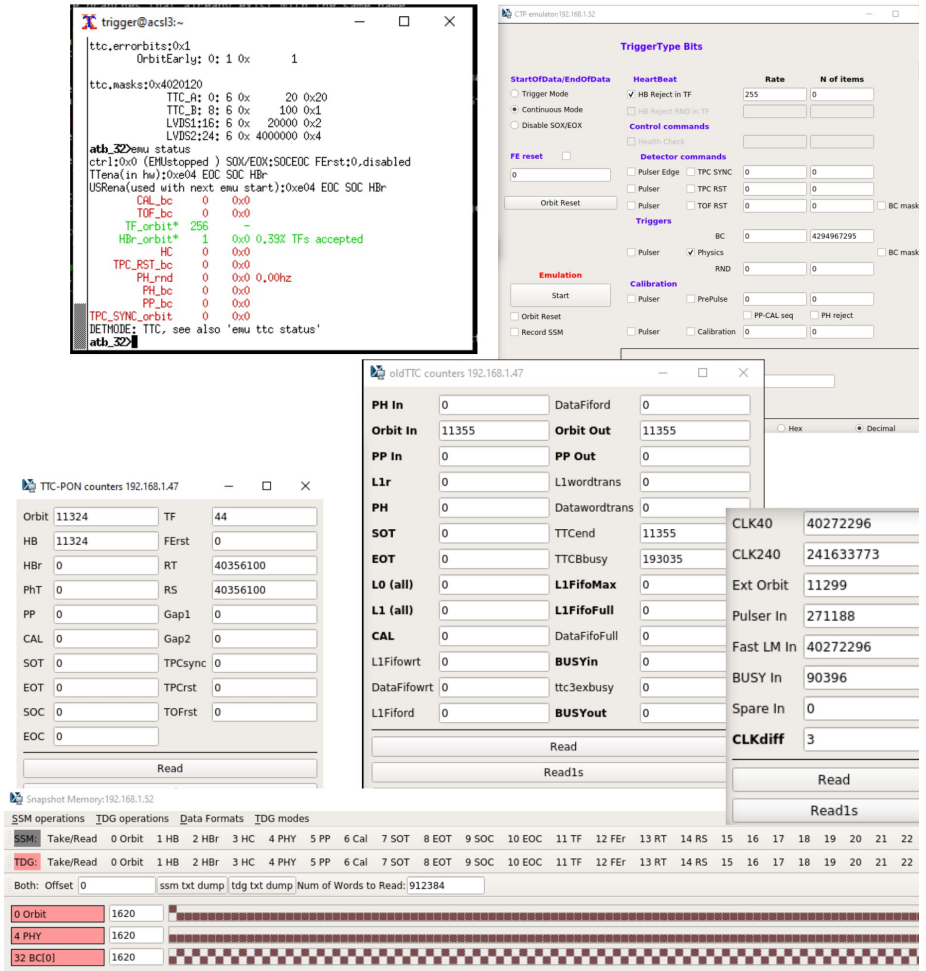
CTS Software

Users

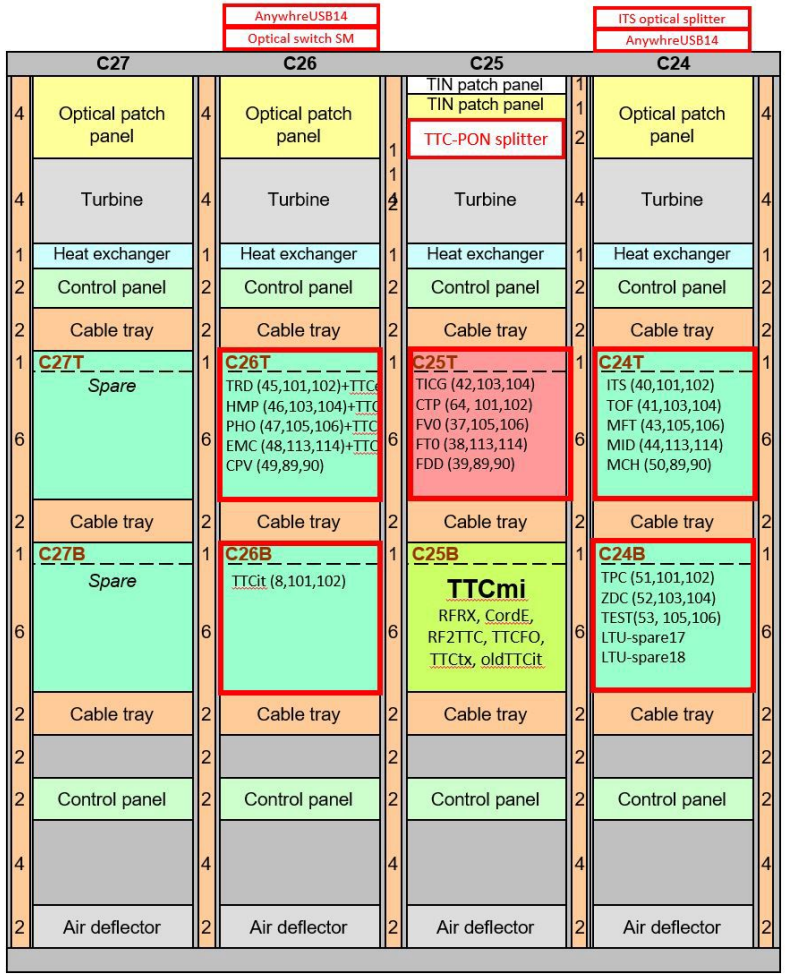
- qtltu
  - GUI control of Alice Trigger Board focused for users
  - Not full access to HW, gRPC communication with IPbus proxy
    - CTP emulator control, counters, Snap-Shot memory
  - C++ and Qt based
- atb
  - General access to a single ALICE Trigger Board
  - For experts - development, control, status
  - Full and direct access to HW registers - IPbus
  - Python 3 based

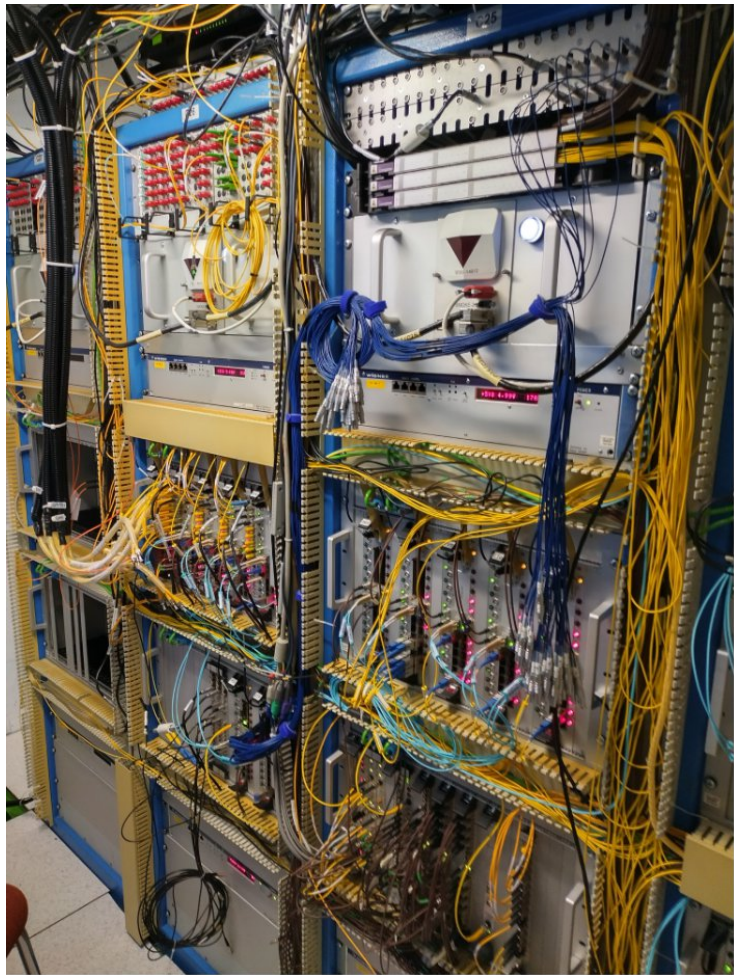
Experts

- ttcpon
  - Set up and check the status of a ttcpon network
  - Network calibration
  - Python 3
- ctp3-load
  - Update/check the FW in the board flash memory
  - C++ based



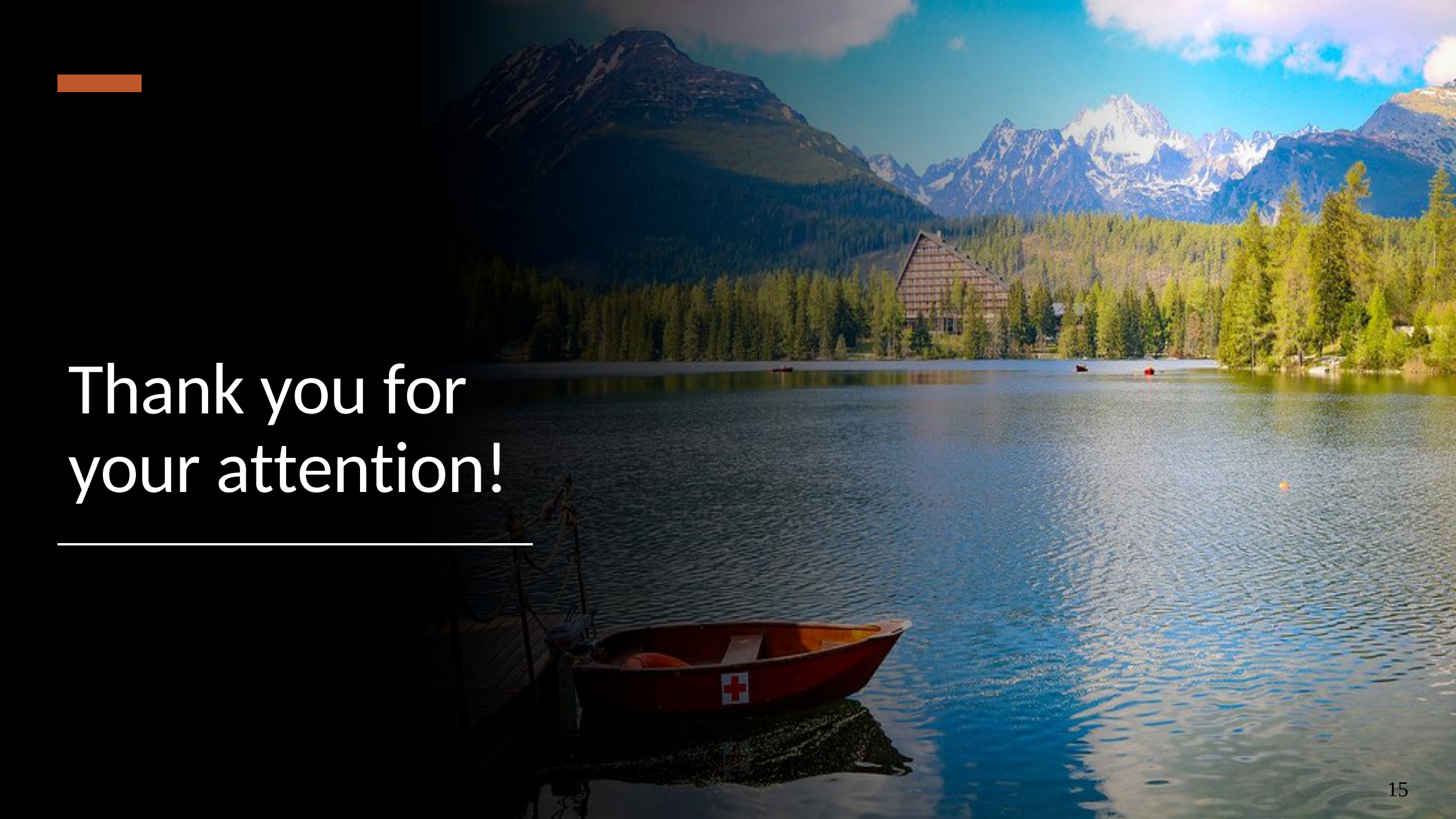
Installation in Point 2





Summary

- CTP and LTU boards manufactured, tested and installed in Point 2
- New Central Trigger System: continuous readout of detectors, backward compatible
- Distributes clock and HB frame delimiter
- Provides Minimum Bias trigger when needed
- Provides Continuous/Triggered Mode as required
- Most of the detectors take data in continous mode: read out data of all interactions (50kHz Pb-Pb and >500kHz pp)
- Compress data by online reconstruction
- One common online-offline system (The ALICE O^2 Project)
- New CTS providing clock, HB and triggers since October 2021

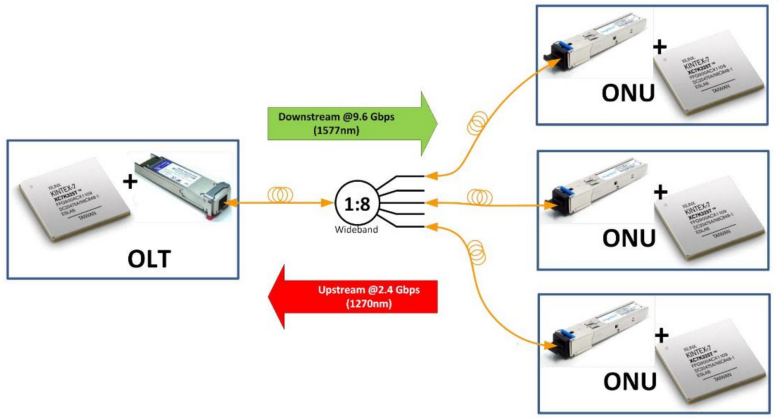


Thank you for your attention!

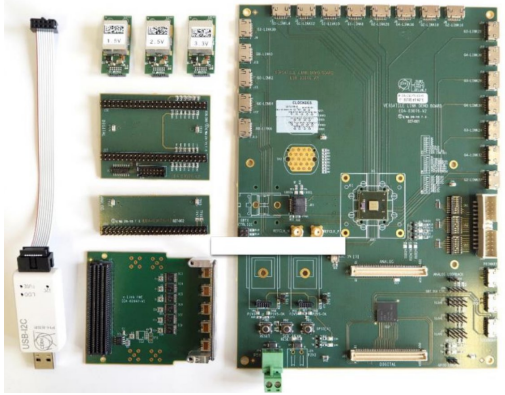
BACKUP SLIDES

Transceivers

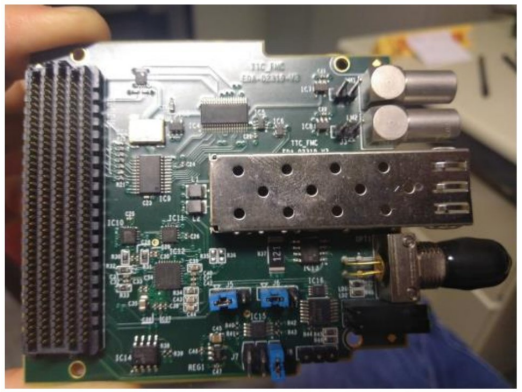
- TTC-PON
  - Off-the-shelf Passive Optical Network (PON) technology
    - Optical Line Terminal (OLT) and Optical Network Unit (ONU)
  - Bidirectional, up to 9.6 Gbps downstream
    - 200 user bits per bunch crossing
  - Communication between CTP-LTU and LTU-CRU
- GBT
  - Gigabit Transceiver
  - Radiation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



TTC-PON



GBT



RD12 TTC

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.
- 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
- 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

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

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