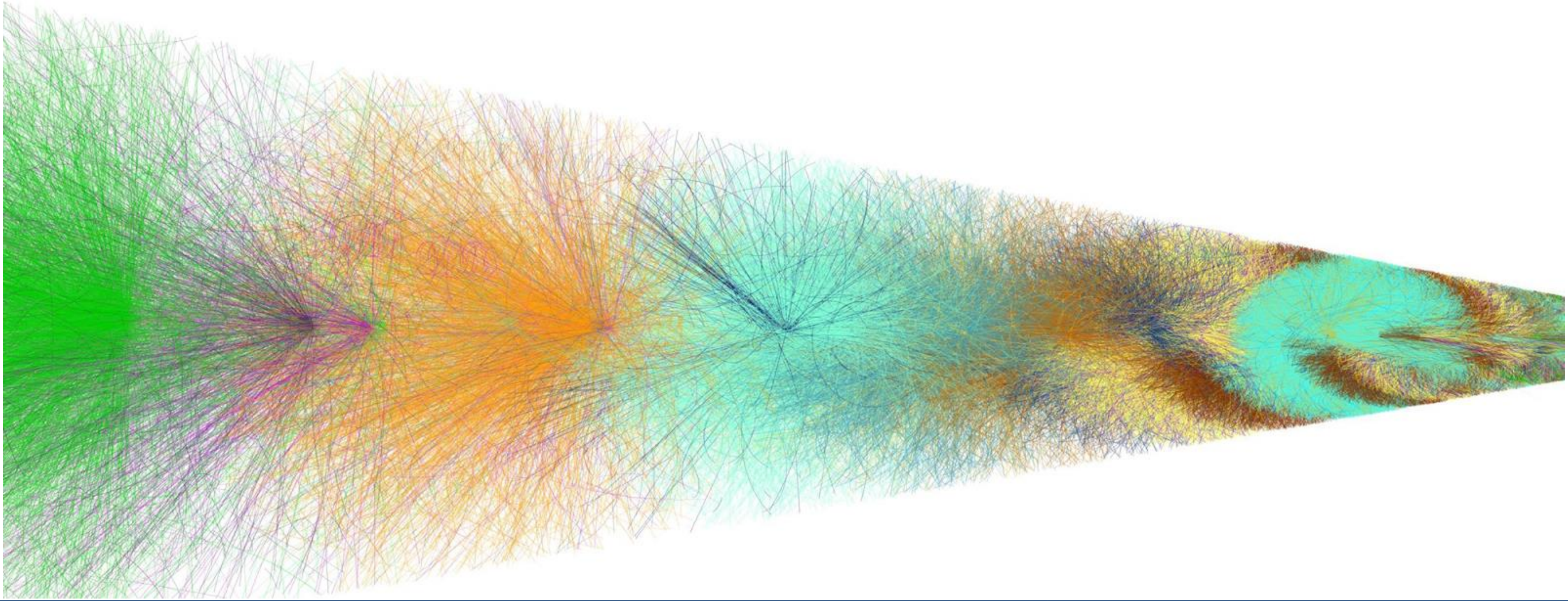


# ALICE Trigger System Run3


**R. Lietava**

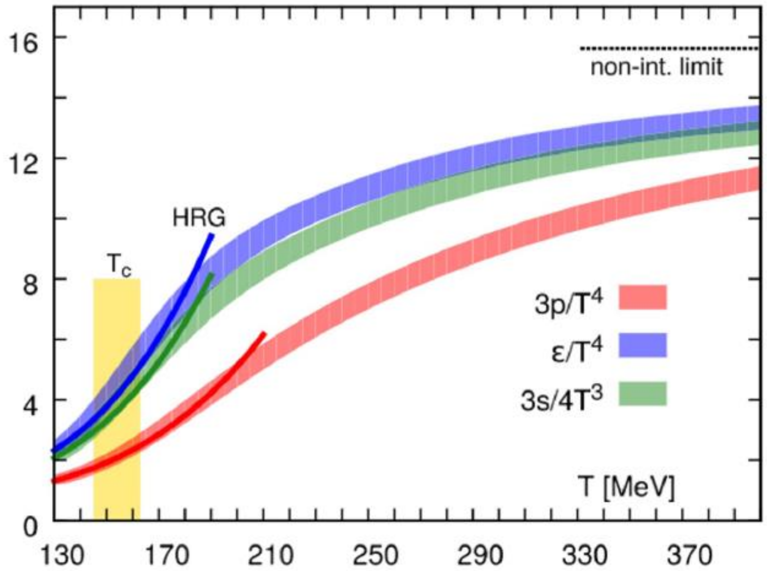
**The University of Birmingham**

# Content

- ALICE physics goals
- ALICE upgrade
- Trigger requirements
- Data
  - Flow and data processing
  - Format
- Trigger System :
  - Trigger board requirements
  - Trigger board design
  - Control and monitoring
  - Clock distribution
- Installation, integration and operation

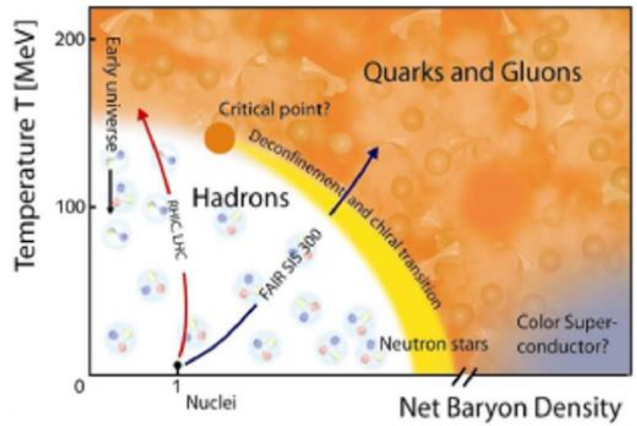
# Lattice QCD

- the rigorous way of performing calculations in the non-perturbative regime of QCD
- discretisation on a space-time lattice
  - → ultraviolet (i.e. large-momentum scale) divergencies can be avoided



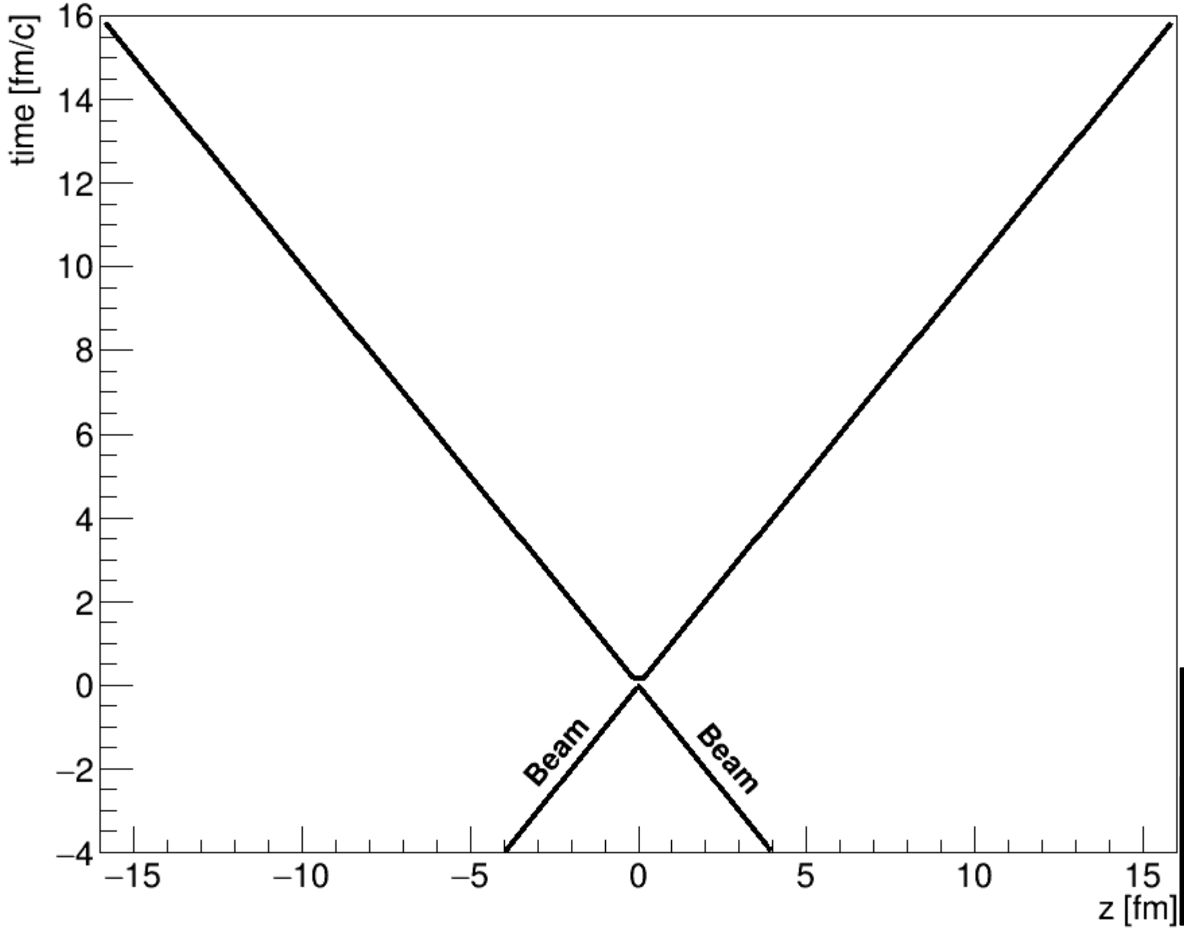

A Bazavov et al. PRD 90 094503 (2014)

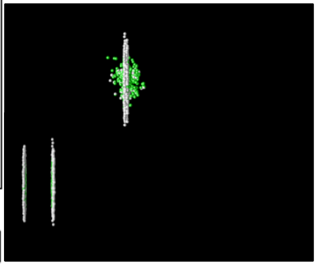
- around critical temperature ($T_C$): rapid change of
  - energy density $\varepsilon$
  - entropy density s
  - pressure p
- due to activation of partonic degrees of freedom
- at zero baryon density → smooth crossover
- $T_C = (156.5 \pm 1.5)$ MeV [A Bazavov et al. Phys.Lett.B 795 (2019) 15]
- $\varepsilon \sim O(\text{GeV/fm}^3)$



# Heavy ion collision

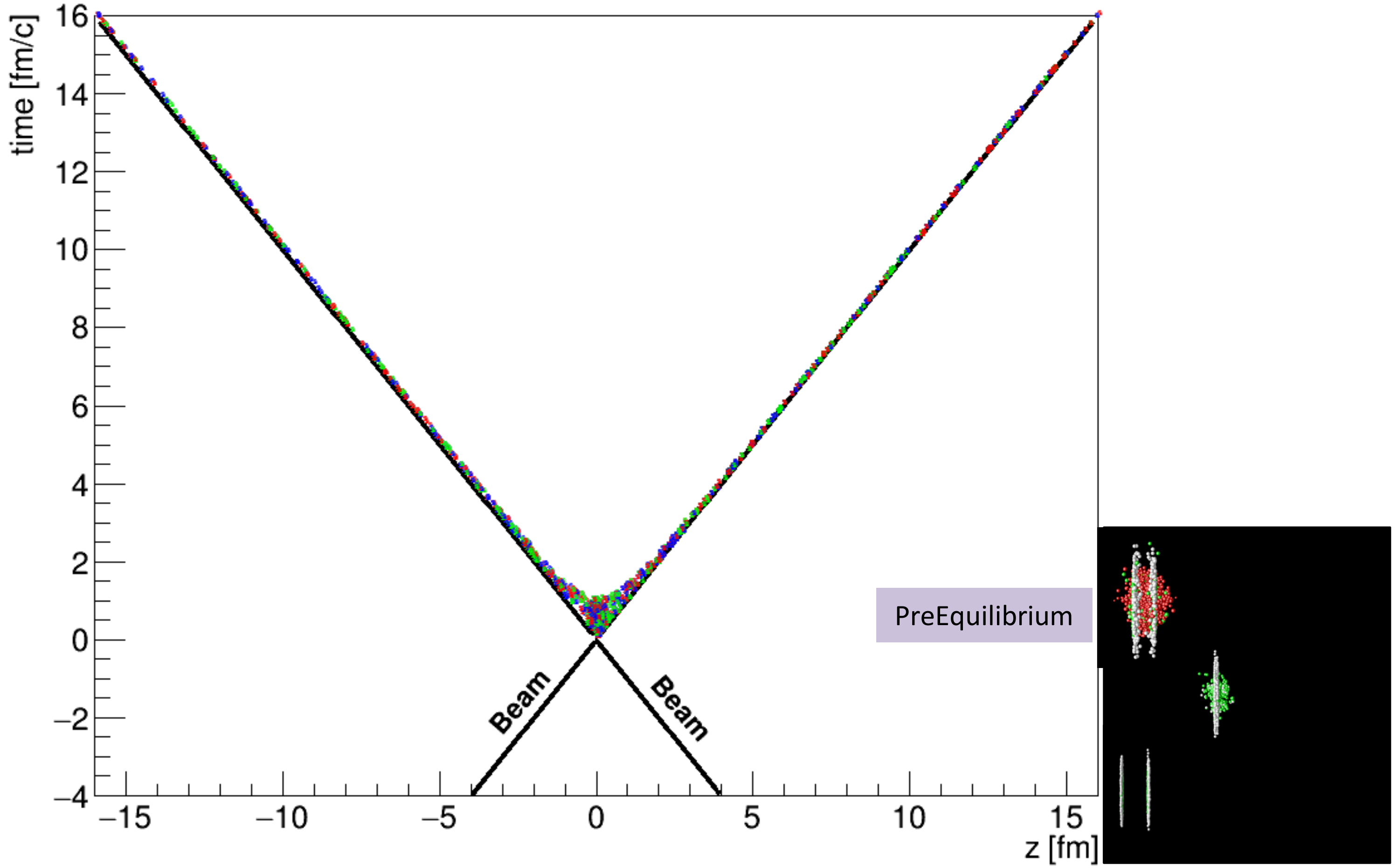
## Colliding nuclei



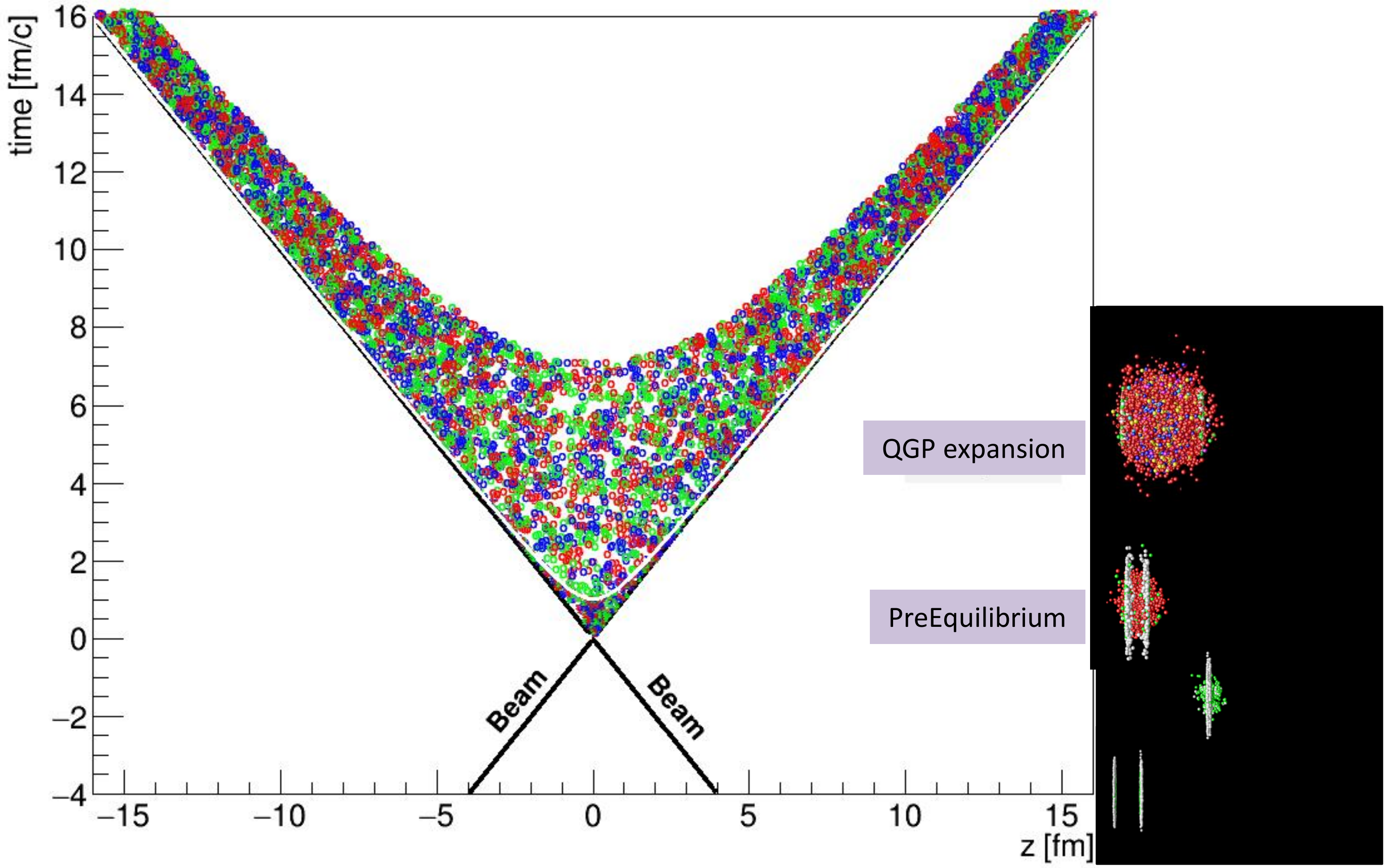
# Heavy ion collision

## Production of colour medium and equilibration



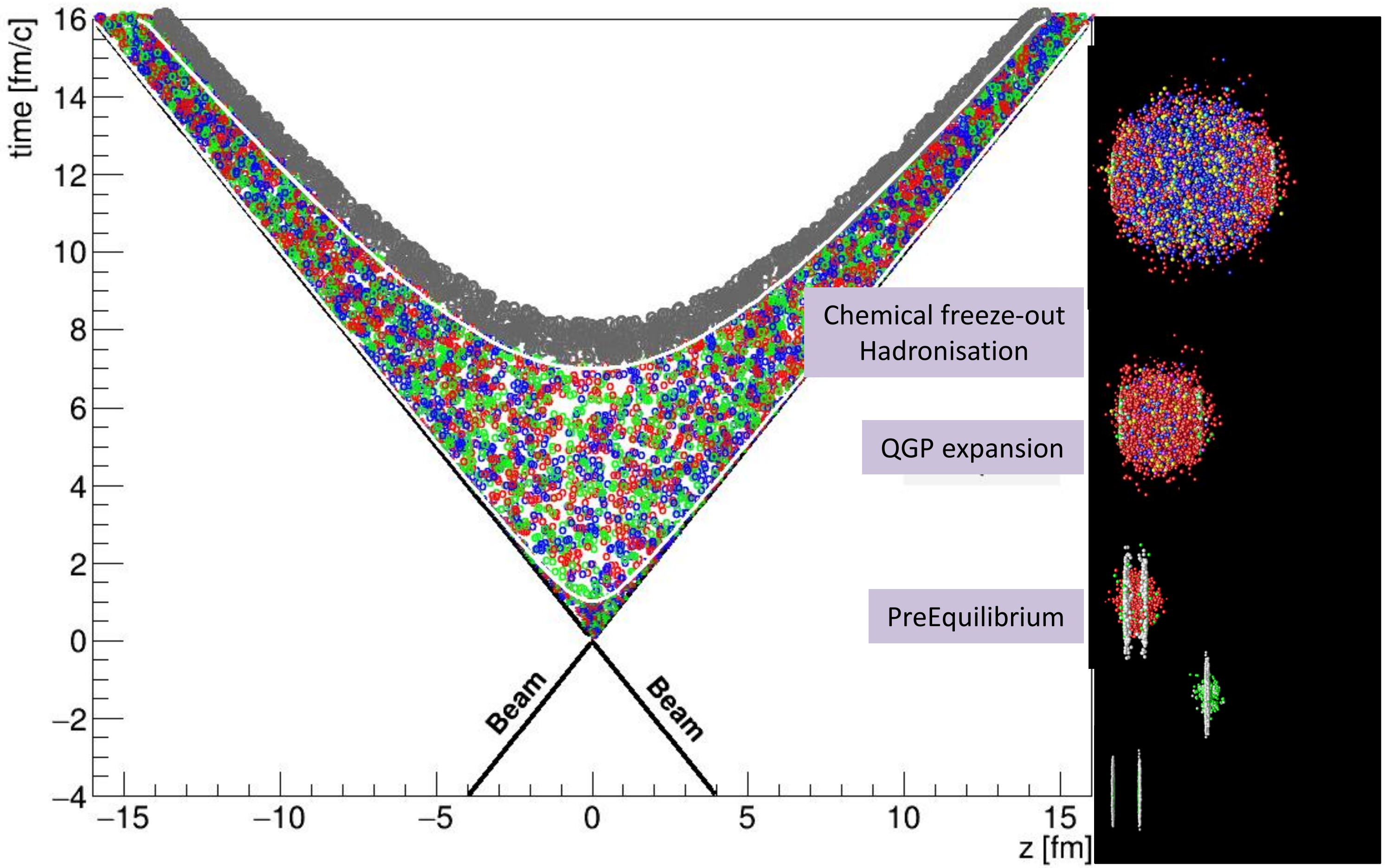
# Heavy ion collision

## QGP and expansion



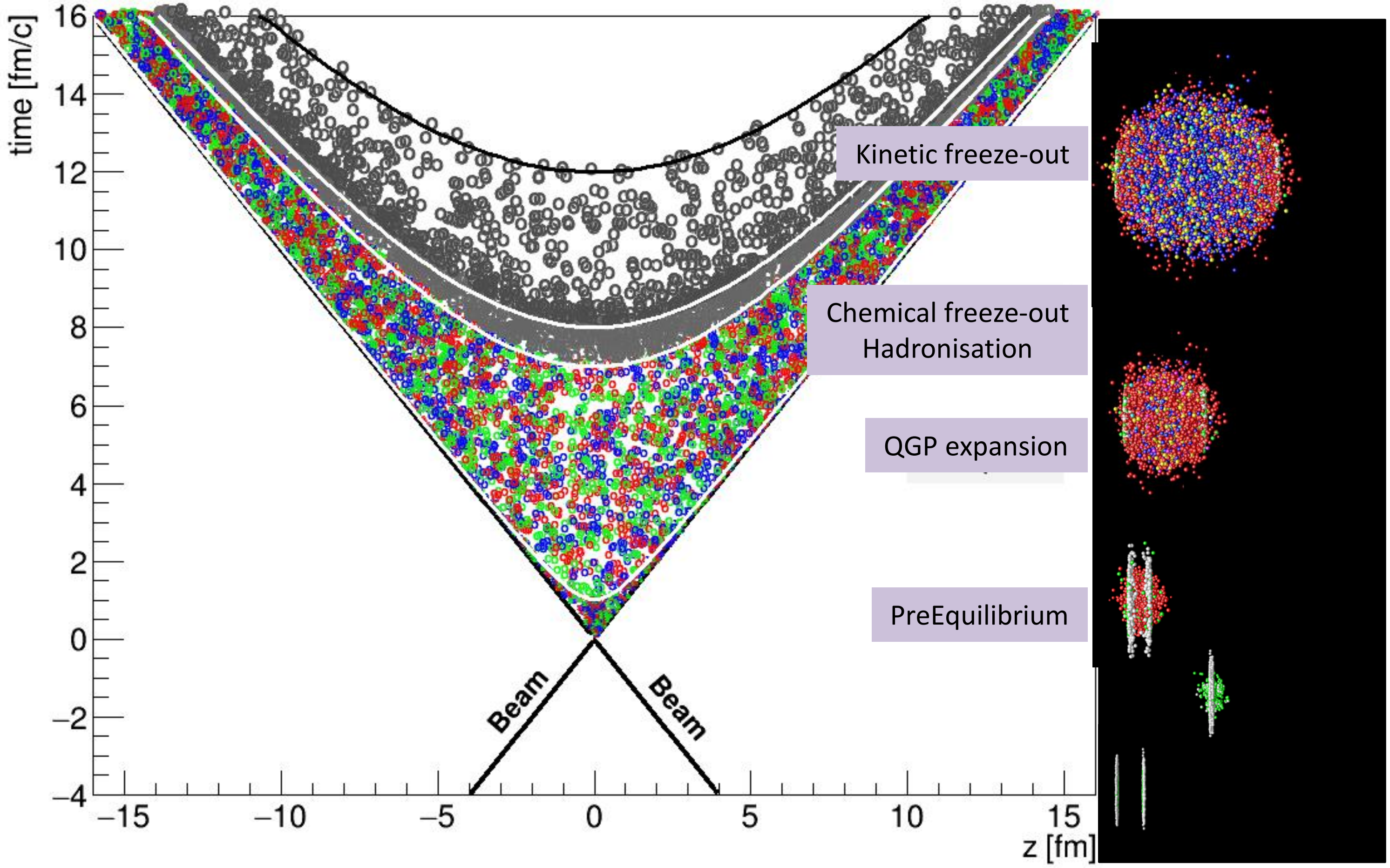
# Heavy ion collision

## Hadronisation and Chemical freeze-out



# Heavy ion collision

## Kinetic freeze-out



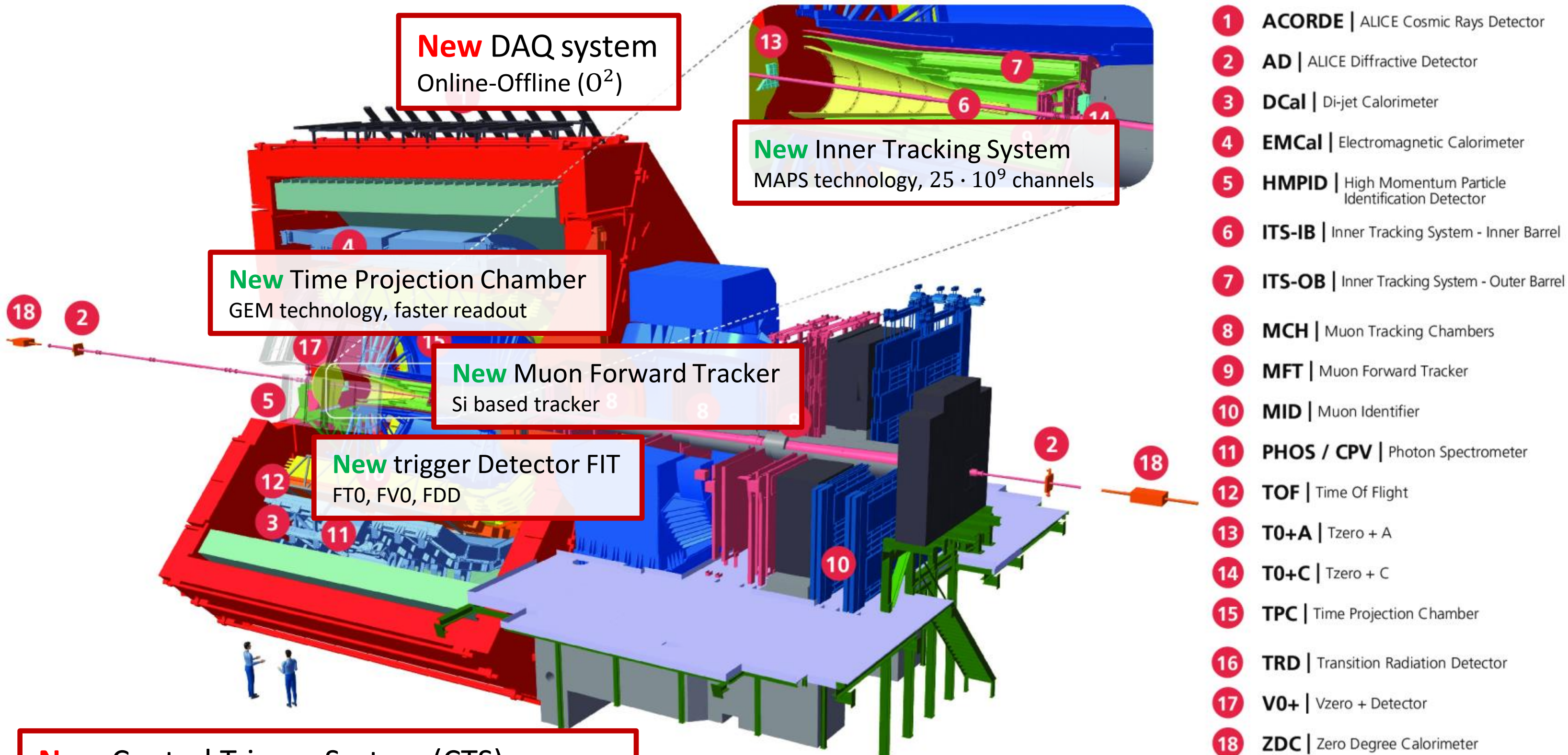
# Alice physics goals Run3

Precision measurement of the Quark Gluon Plasma (QGP) parameters to exploit scientific potential of the LHC fully – unique in:

- large cross sections for hard probes
- high initial temperature

- **Main physics topics, uniquely accessible with the ALICE detector:**
  - measurement of heavy-flavour transport parameters:
    - study of QGP properties via transport coefficients ( η/s, q)
  - measurement of low-mass and low-$p_T$ di-leptons
    - study of chiral symmetry restoration
    - space-time evolution and equation of state of the QGP
  - charmonium states down to zero $p_T$ in wide rapidity range
    - statistical hadronisation versus dissociation/recombination

# ALICE detector in Run3



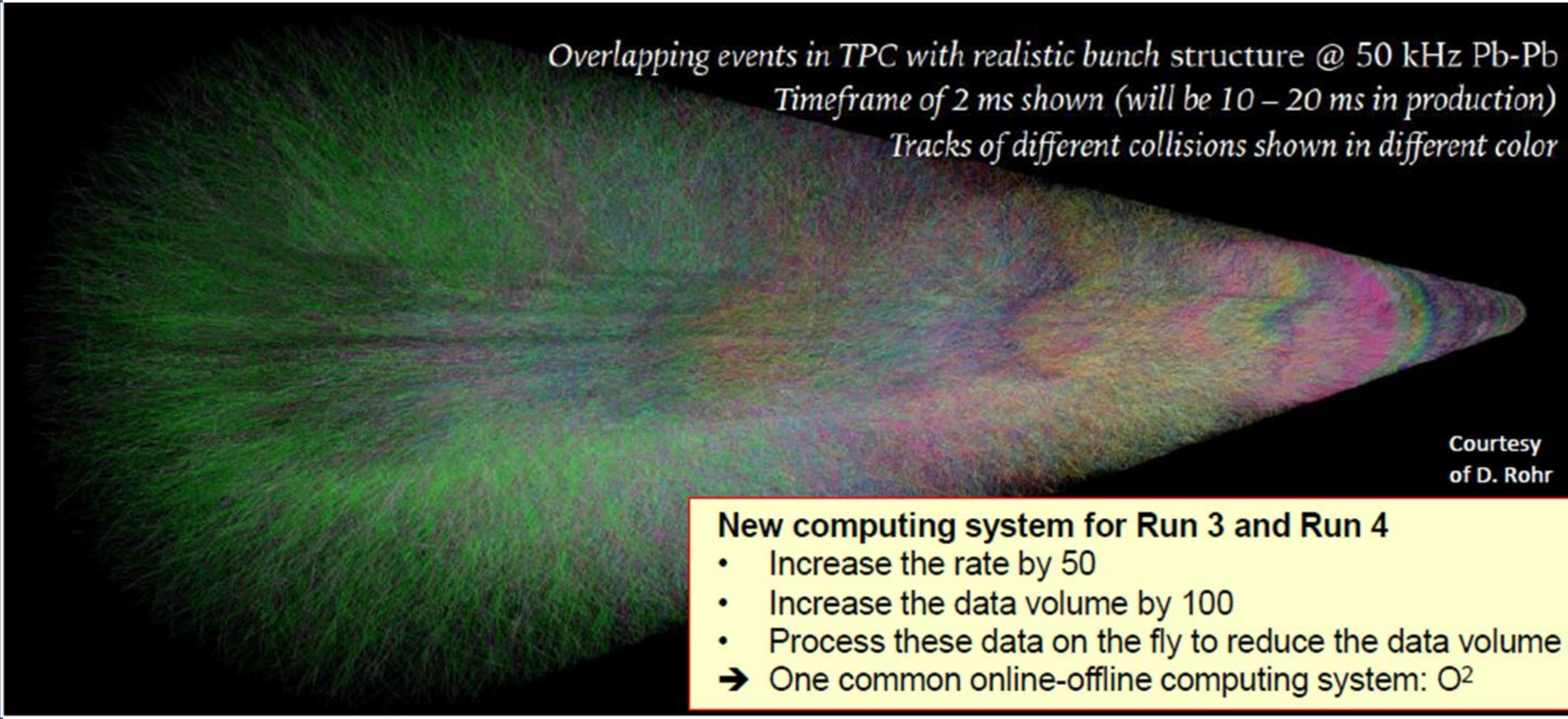

**New** Central Trigger System (CTS)
New Central Trigger Processor and Local Trigger Unit
New Trigger distribution (TTC-PON)

# ALICE challenges in Run3

- Physics topics addressed by ALICE upgrade
  - Very small signal-to-noise ratio and large background
  - Triggering (selection) techniques very inefficient if not impossible
  - Needs large statistics
- => **Read the data resulting from all interactions**
- LHC will deliver min bias Pb-Pb collisions at 50 kHz
  - ~100 x more data than Run2
  - => New concept needed to reduce the data volume
  - **=> Continuous detector read-out** (collision rate faster than TPC drift time (100 μs )

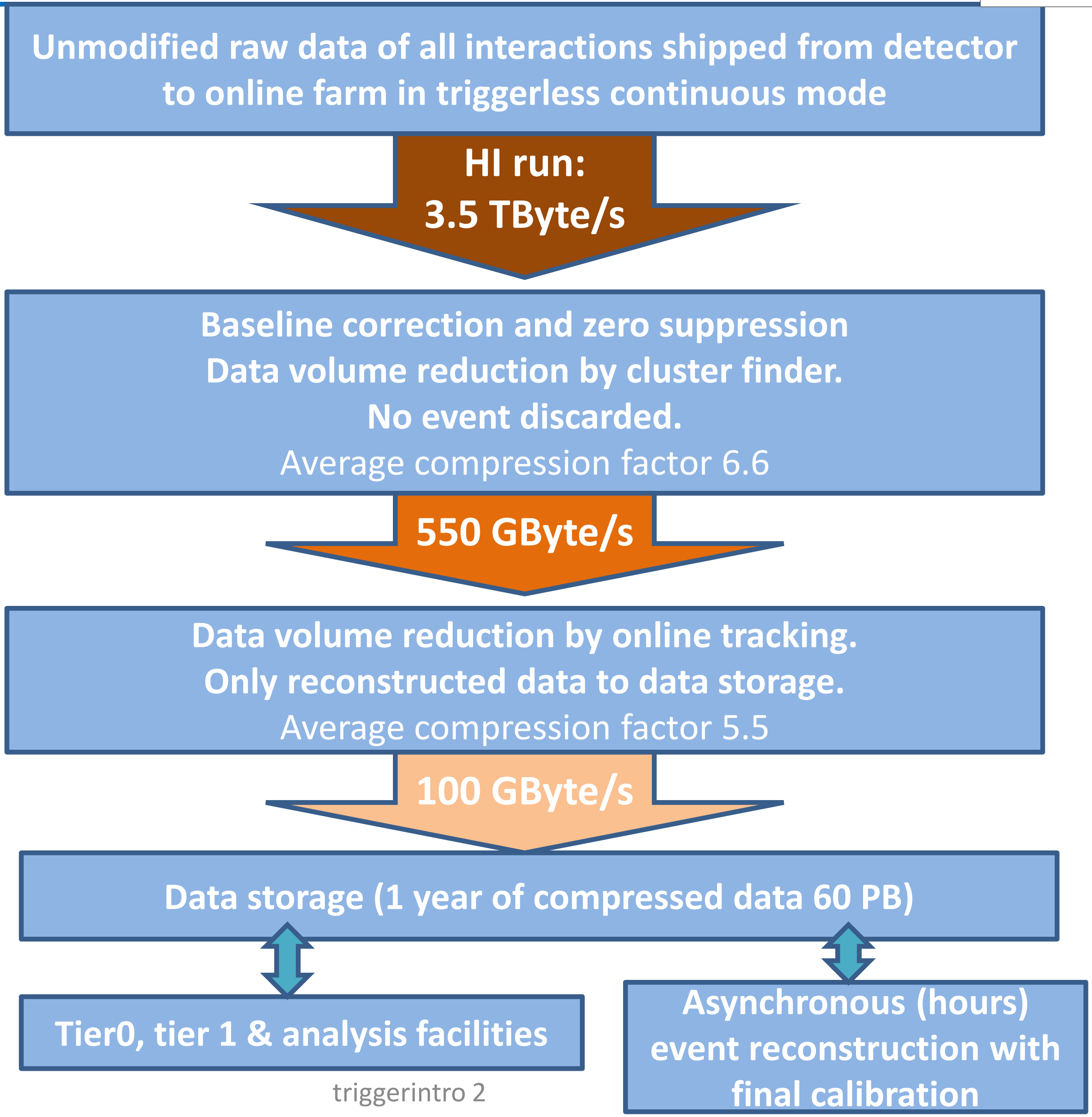
# Selecting interesting collisions

## 50 kHz Pb-Pb interaction rate

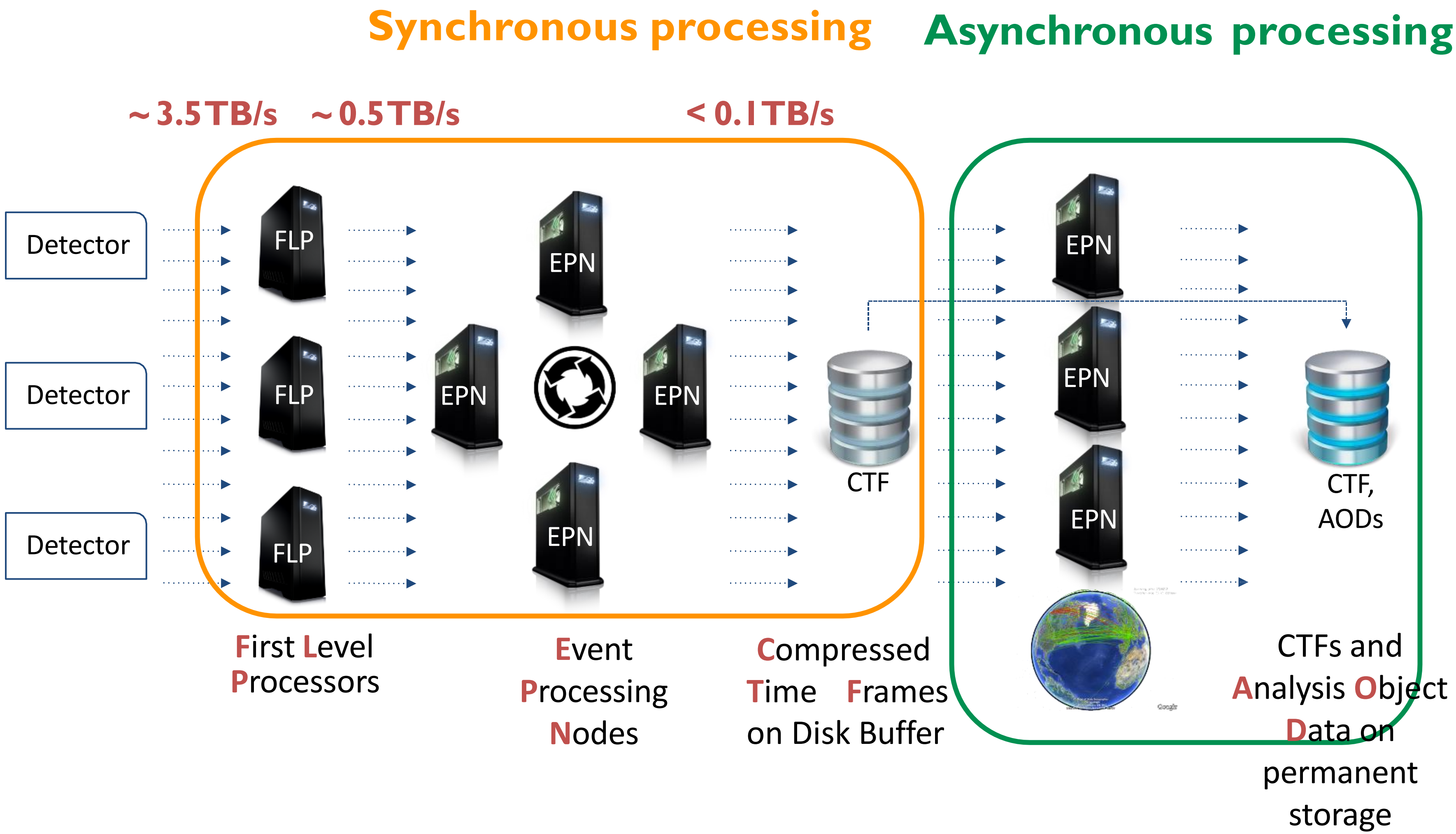


# New ALICE $O^2$ system

- Read out data of all interactions
- Compress these data by online reconstruction
- One common online-offline system

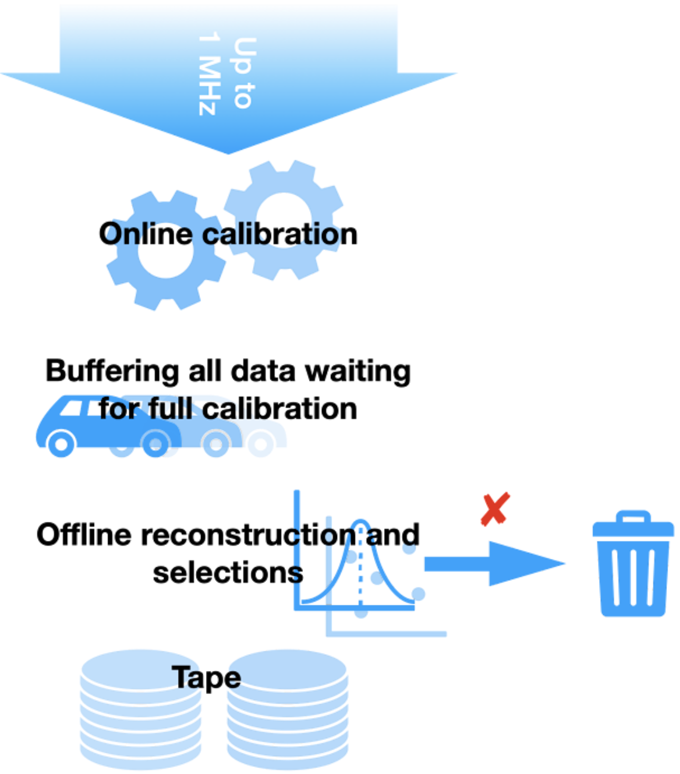


# ALICE online-offline system



# Data flow summary

- PbPb : store full sample
- pp : selection of interesting events to  store




Synchronous reconstruction in the EPN farm

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

Buffering and calibration:

- 2 weeks (+2 weeks of contingency) for calibrating all detectors

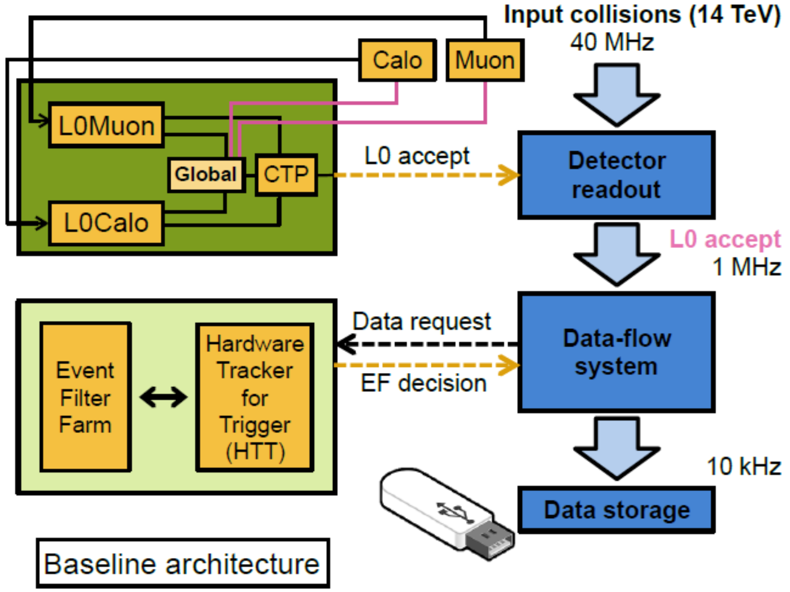
Asynchronous reconstruction and event selection

- Reconstruction of the data with physics grade calibrations
- Selection of the interesting events (time windows), final data compression and AOD creation

From data taking to analysis in ~1 month or less

# ATLAS and CMS HighLumi LHC (LS3)

ATLAS




ALICE/ATLAS/
CMS/LHCb
L1 ~ 1 MHz
HLT ~ 10 kHz

CMS

| CMS detector | LHC Run 2 | HL-LHC Phase-2 | |
|---|---|---|---|
| Peak ⟨PU⟩ | 60 | 140 | 200 |
| L1 accept rate (maximum) | 100 kHz | 500 kHz | 750 kHz |
| Event Size | 2.0 MB | 5.7 MB | 7.4 MB |
| Event Network throughput | 1.6 Tb/s | 23 Tb/s | 44 Tb/s |
| Event Network buffer (60 s) | 12 TB | 171 TB | 333 TB |
| HLT accept rate | 1 kHz | 5 kHz | 7.5 kHz |
| HLT computing power | 0.5 MHS06 | 4.5 MHS06 | 9.2 MHS06 |
| Storage throughput | 2.5 GB/s | 31 GB/s | 61 GB/s |
| Storage capacity needed (1 day) | 0.2 PB | 2.7 PB | 5.3 PB |

# ALICE pp physics in Run3

- Quite complete programme already put forward in the public note

| Measurement | ALICE uniqueness | Other experiments |
|---|---|---|
| $\Omega/\pi$ ratio vs. multiplicity | $\pi$, K, p PID $p_T > 0.15$ GeV/$c$ mid-$y$ | — * |
| Flow of $\pi$, K, p at high multiplicity | $\pi$, K, p PID $p_T > 0.15$ GeV/$c$ mid-$y$<br>$p_T < 0.5$ GeV/$c$ crucial for mass ordering | CMS in Run 4 (with proposed timing layer)<br>limited to $p_T > 0.4$ GeV/$c$ at $\lvert\eta\rvert \approx 1.4$ |
| h–jet recoil at high multiplicity | Charged jets $p_T^{jet} > 15$ GeV/$c$<br>maximum sensitivity to jet $\Delta E$ at low $p_T^{jet}$ | ATLAS and CMS ($\gamma$/Z–jet with $p_T^{jet} > 30$ GeV/$c$) |
| Nuclei and hypernuclei | $Z = 2$ nuclei PID $p_T > 0.8$ GeV/$c$ | — * |
| p–hyperon(Y) and Y–Y interaction | $\pi$, K, p PID $p_T > 0.15$ GeV/$c$ mid-$y$ | — |
| B mesons | PID, B mesons $p_T > 0$ mid-$y$<br>Reference for $p_T < 5$ GeV/$c$ B $R_{AA}$ | ATLAS and CMS ($p_T > 5$ GeV/$c$),<br>LHCb (forward rapidity) |
| Jets and HF jets | Charged jets $p_T^{jet} > 10$ GeV/$c$<br>Larger dead cone aperture at low radiator $E$ | ATLAS and CMS ($p_T > 30$ GeV/$c$) |
| Charmonia | J/$\psi$, $\psi$(2S) $p_T > 0$ mid- and fwd-$y$,<br>central-forward correlations | ATLAS and CMS ($p_T > 3$ GeV/$c$),<br>LHCb (forward rapidity) |
| Low-mass central diffraction | $\pi$, K, p PID $p_T > 0.15$ GeV/$c$ mid-$y$ | LHCb (forward rapidity) |
| Low-mass dielectrons | e ID $p_T > 75$ MeV/$c$ | — |

* possible in CMS only in Run 4 and with extended running (several months per year) at low rate (min-bias readout rate CMS Run 4: $< 250$ kHz i.e. 2–4 times lower than ALICE).

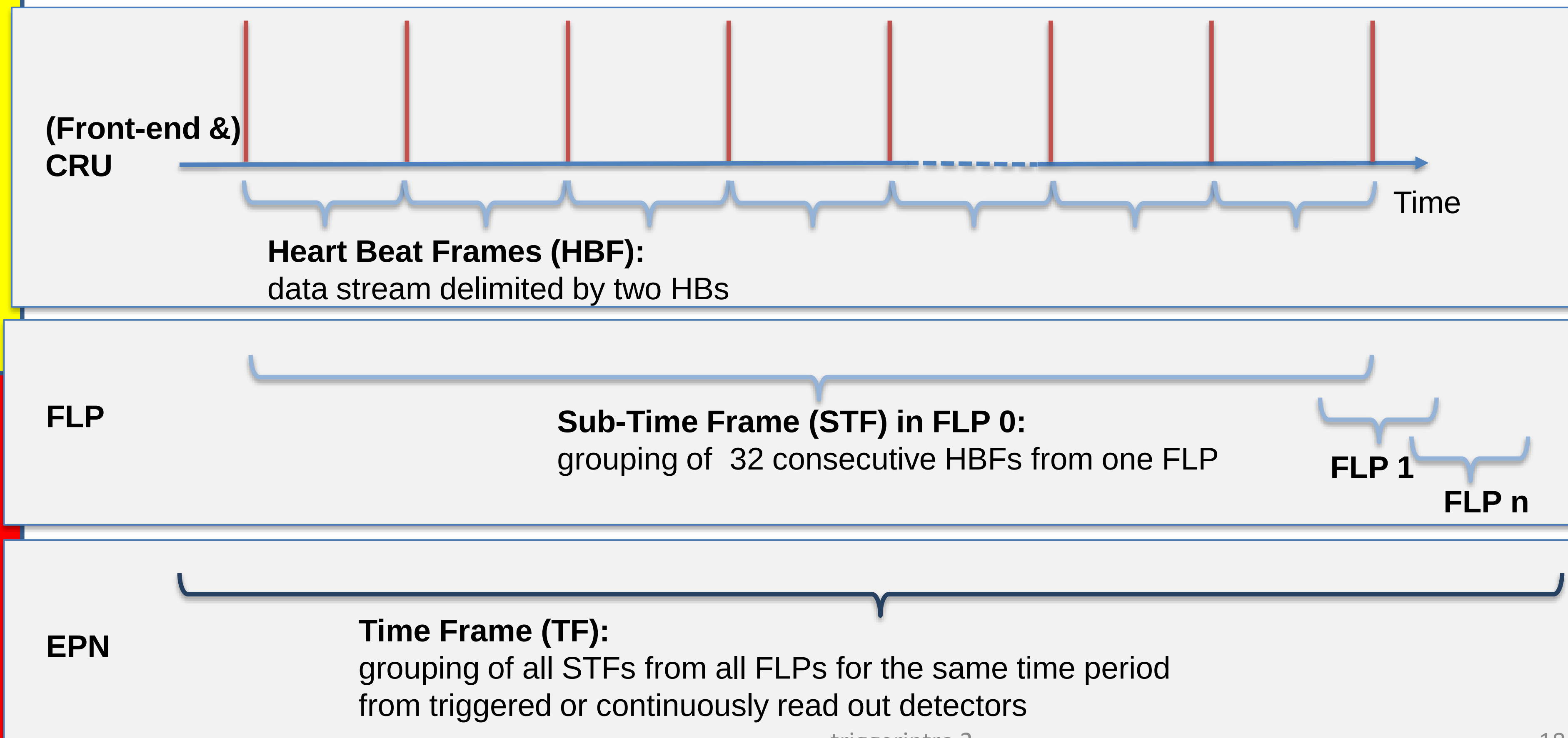
# Heart Beat Frames

## Heart Beat (HB)

issued in continuous &
triggered modes
to all detectors

HBF and TF rates programmable
Typical values:
- HB: 1 per orbit, 89.4 µs: ~10 kHz
- TF: 32 HBFs ~ 2.8 ms

## Continuous readout



# Heart Beat Frame

## Heart Beat (HB)

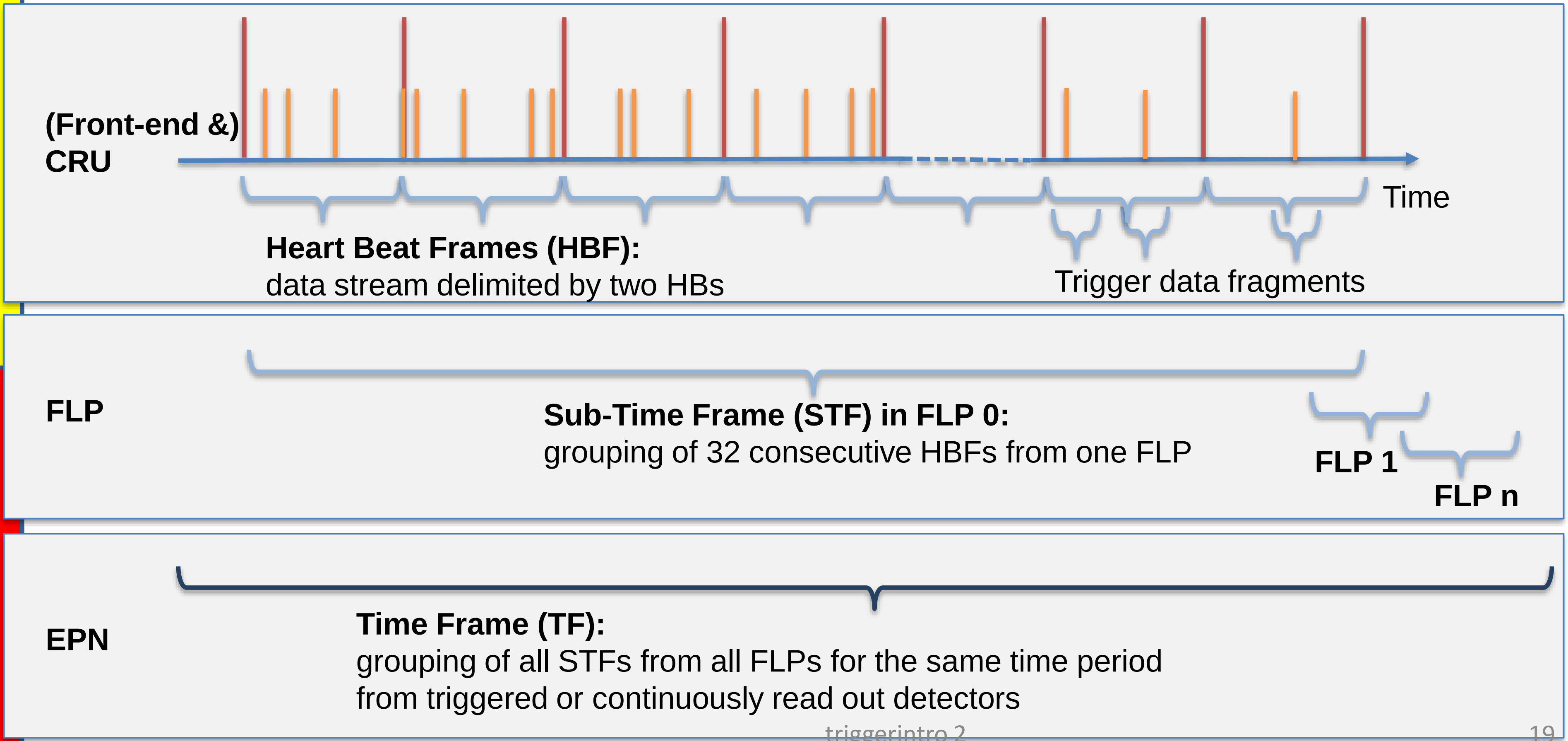
issued in continuous & triggered modes to all detectors

## Physics trigger

can be sent to upgraded detectors will be sent to non-upgraded detectors

HBF and TF rates programmable
Typical values:
- HB: 1 per orbit, 89.4 µs: ~10 kHz
- TF: 32 HBFs ~ 2.8 ms

## Triggered readout



# Requirements of Trigger system

- Distribute clock and triggers to all ALICE detectors
- Generate HB markers
- Central Trigger System = Central Trigger Processor (CTP) + 18 Local Trigger Units (LTU)
  - CTP – global running with all detectors
  - LTU for each detector – standalone running
- Concurrent processing - no deadtime (< 25 ns)
- Low processing latency – ~100 ns (CTP) + ~50 ns (LTU)
  - total latency FIT-CTP-LTU: ~550 ns
- Continuously monitor status of 441 Common Readout Units (CRU) and control data flow
- Random jitter on clock <10 ps at FEE
- Backward compatible with Run 2 trigger distribution
  - 3 running modes

# Design of CTP/LTU

- 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)

# FPGA

- Field Programmable Gate Arrays (FPGAs) are semiconductor devices that are based around a matrix of configurable logic blocks (CLBs) connected via programmable interconnects.
- FPGAs can be reprogrammed to desired application or functionality requirements after manufacturing. This feature distinguishes FPGAs from Application Specific Integrated Circuits (ASICs), which are custom manufactured for specific design tasks.

By Stephen M. (Steve) Trimberger, *Fellow IEEE*

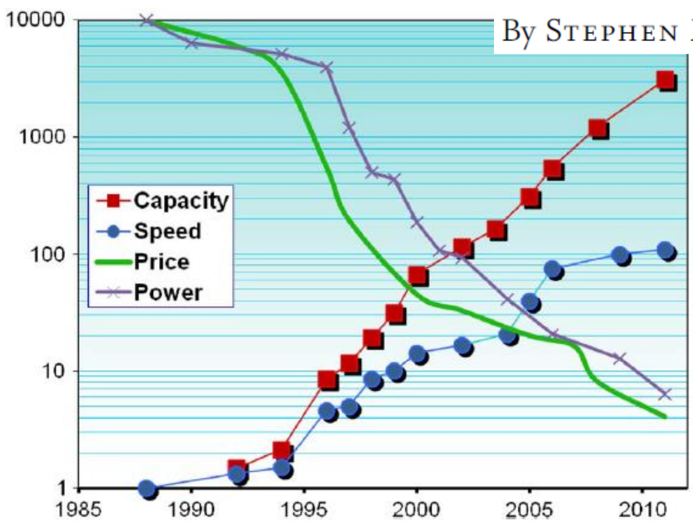
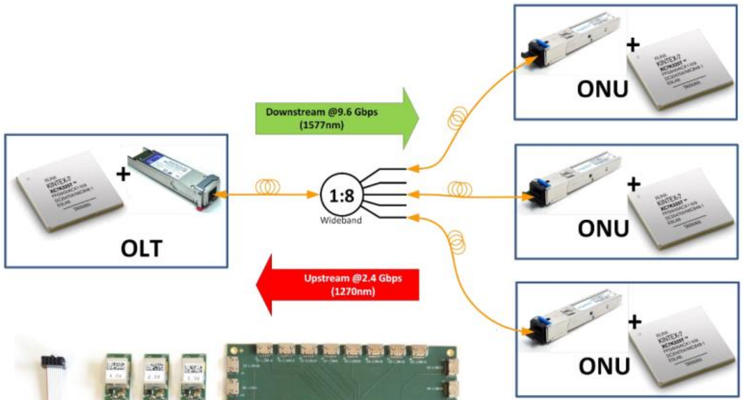


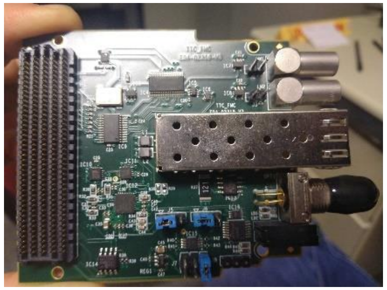

**Fig. 1.** ***Xilinx FPGA attributes relative to 1988. Capacity is logic cell count. Speed is same-function performance in programmable fabric. Price is per logic cell. Power is per logic cell. Price and power are scaled up by 10 000×. Data: Xilinx published data.***


By Stephen M. (Steve) Trimberger, *Fellow IEEE*

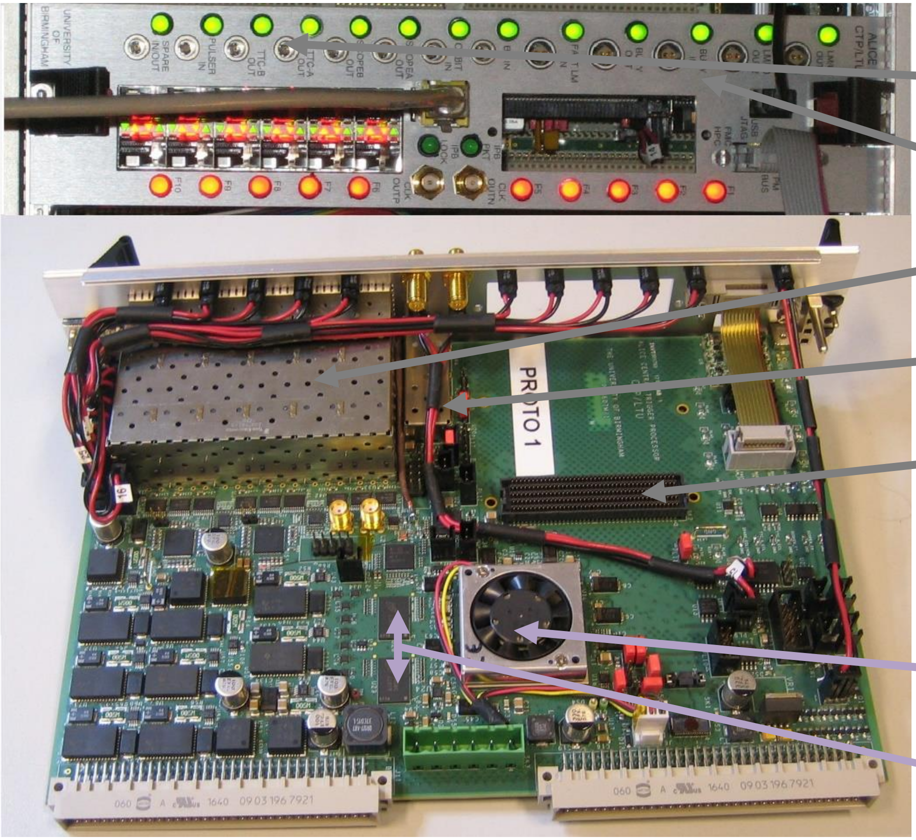
# Transceivers

- **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)



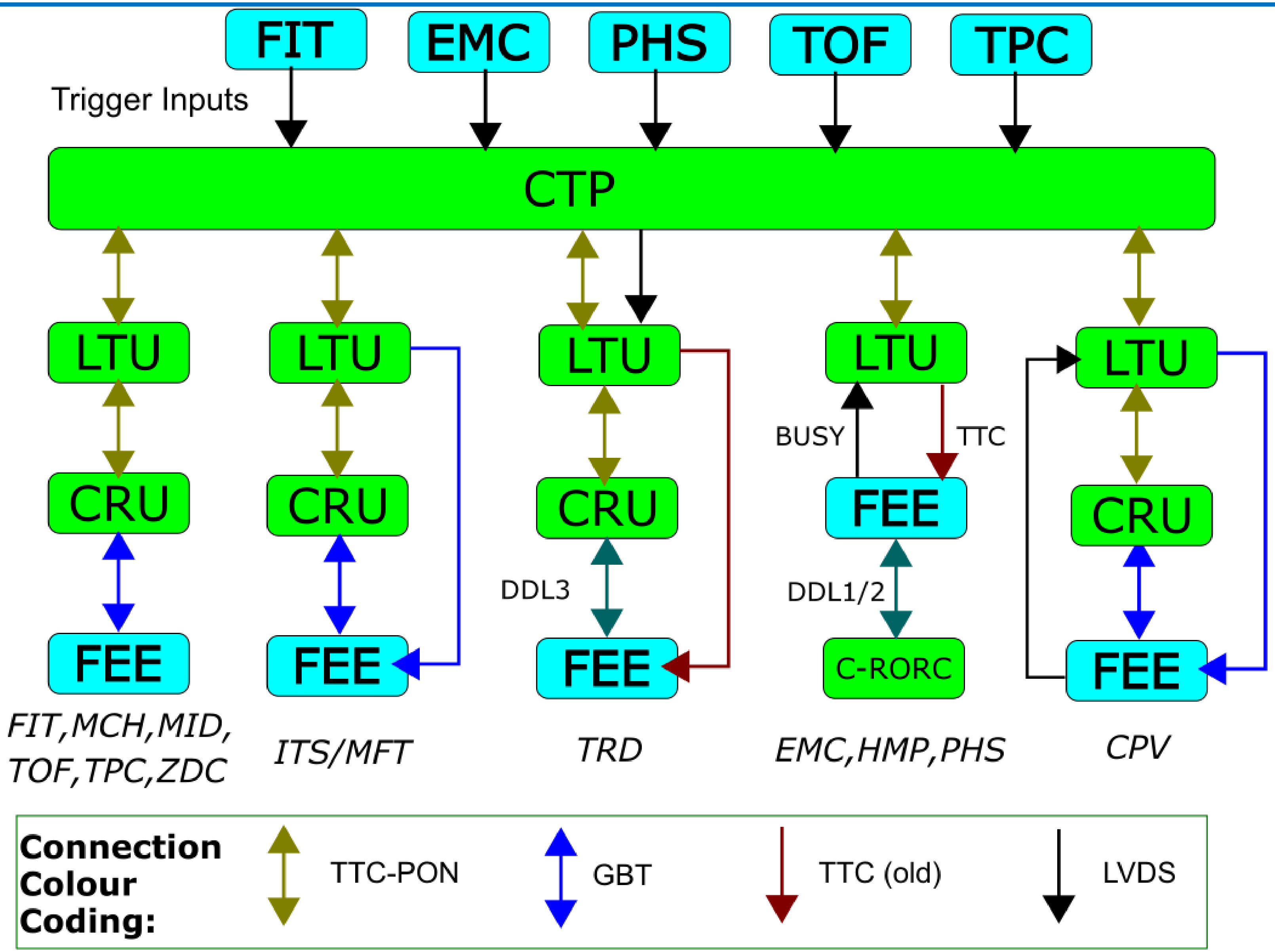



# Trigger board

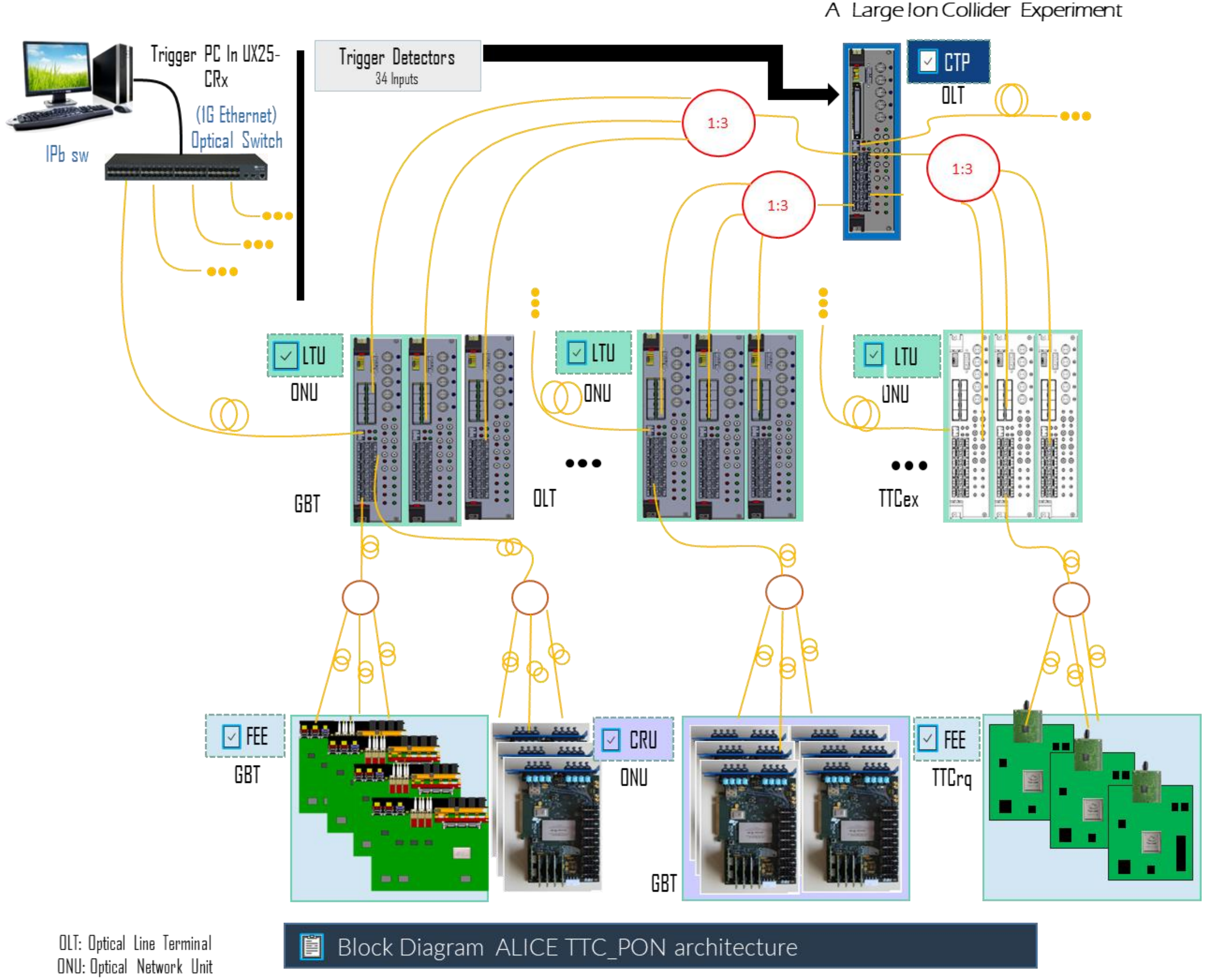


- A universal VME-type 6U trigger board
- **8 ECL LEMO 00B**
  - RD12 TTC trigger distribution, LHC clock, orbit
- **6 LVDS LEMO B**
  - External trigger input, busy
- **Two six-fold SFP+**
  - Optical links – TTC-PON, GBT
- **Single-fold SFP+**
  - Ethernet communication via IPbus
- **FMC**
  - **CTP 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

# Trigger/Clock distribution



# CTP trigger system



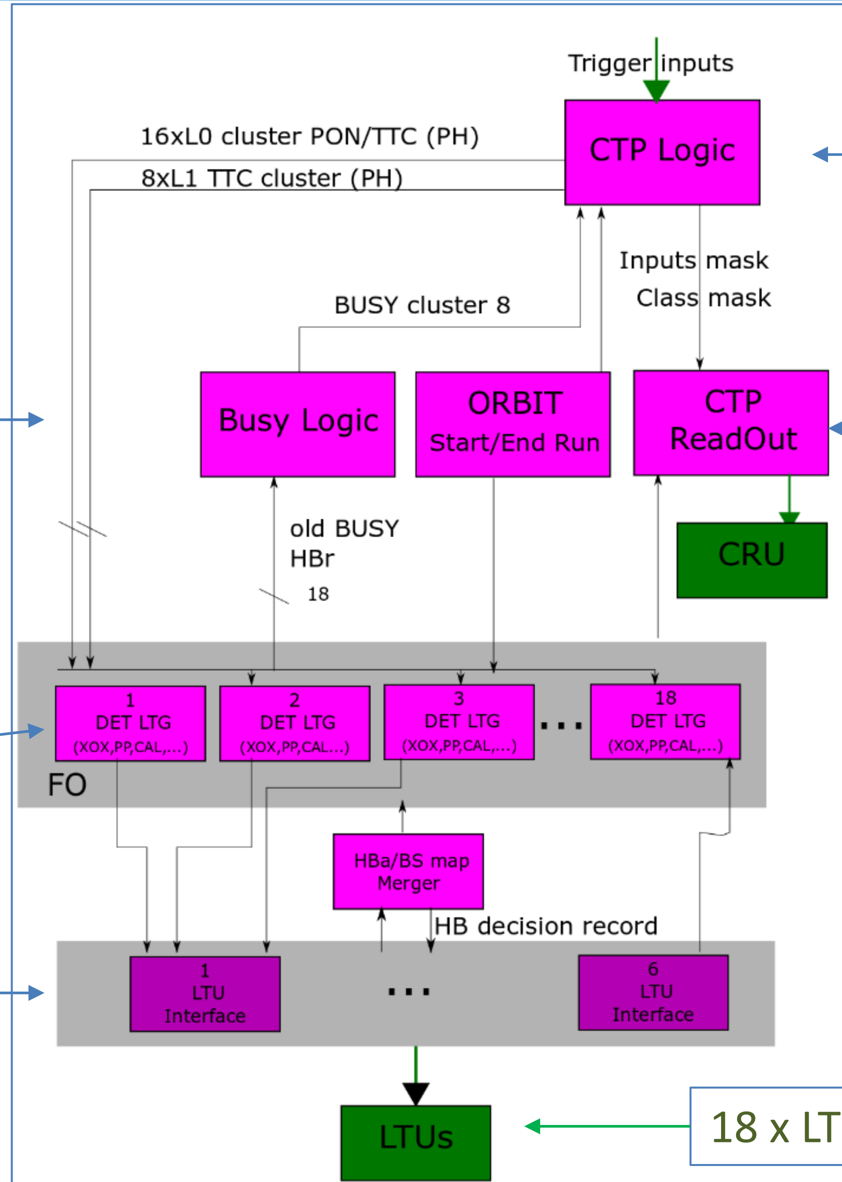

1 CTP

18 LTUs

441 CRUs

# CTP schematic diagram

## CTP firmware components




CTP Logic

Busy Logic

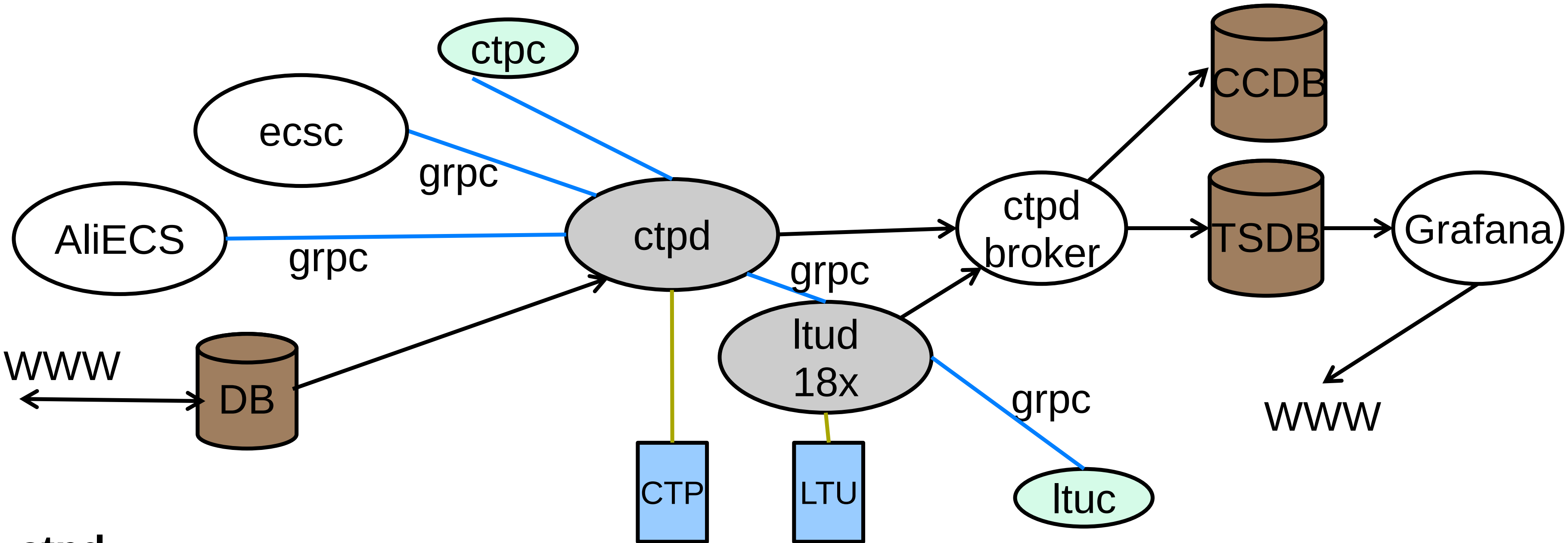
CTP readout: Interaction record

Basic CTP structure for 18 detectors (HB/TF/SOR)

LTU interface
(3 LTUs/TTC-PON link)

18 x LTU: 3/TTC-PON link

# 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

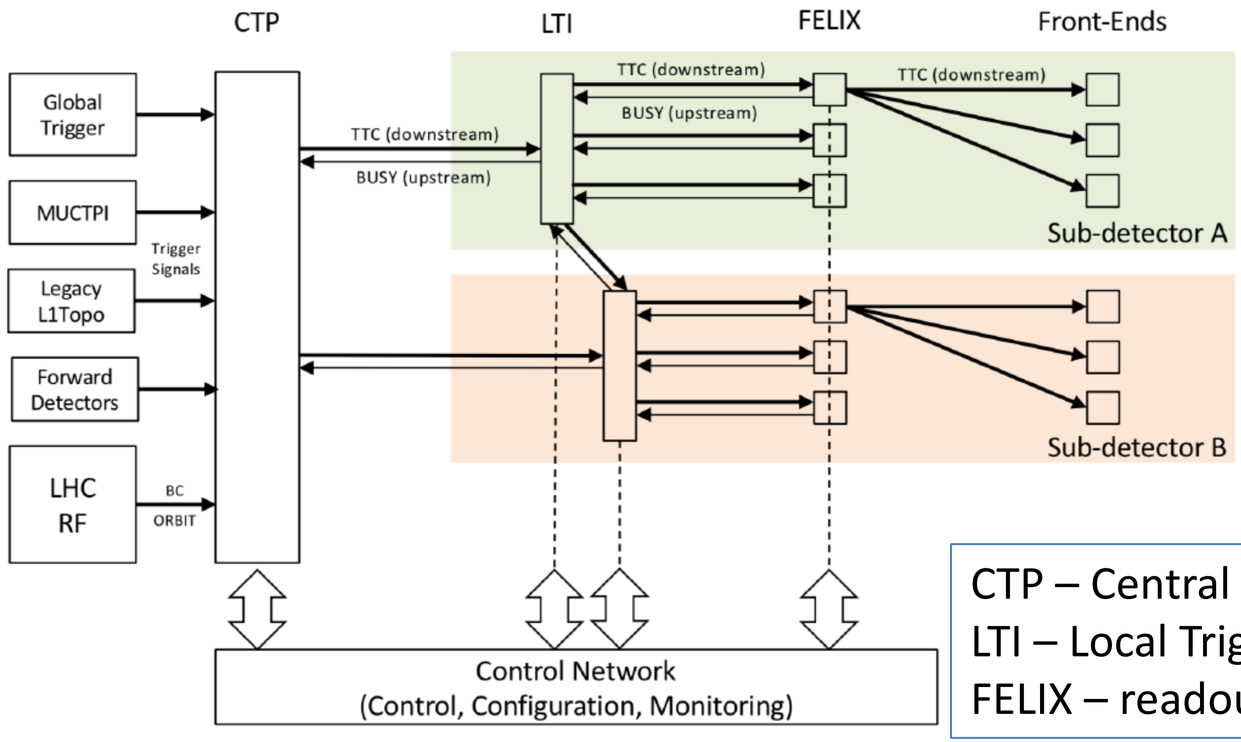
**ltuc,ctpc**
- grpc expert clients

**ecsc**
- grpc client for ECS and detector crews

**TimeSeriesDB database**
- Monitoring boards and infrastructure

**CCDB - Conditional and Calibration DB**
- Objects required for physics analysis

# ATLAS Trigger for HL-LHC




CTP – Central Trigger Processor
LTI – Local Trigger Interface
FELIX – readout card

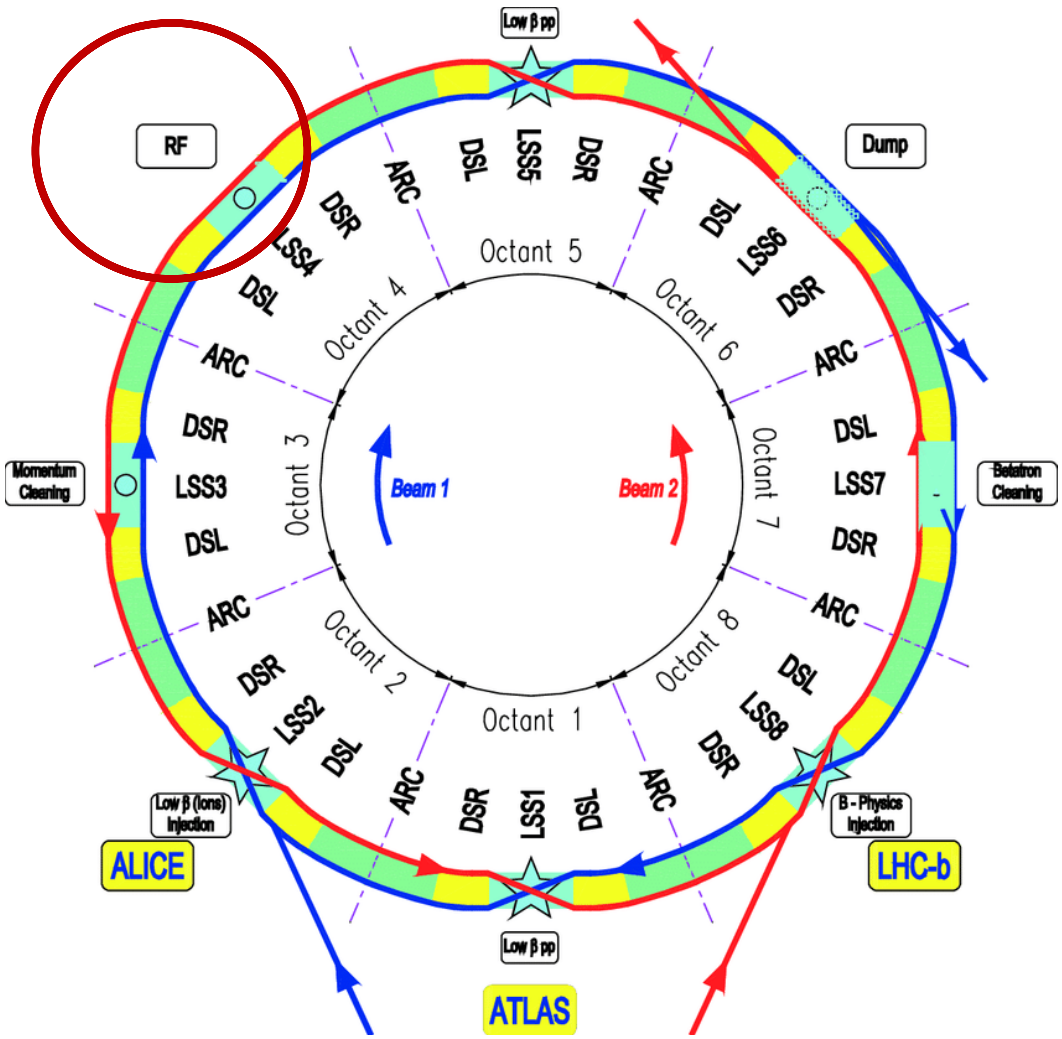
**Figure 1.1:** Context diagram of the TTC distribution system. In standard physics data-taking mode, the LTIs are connected directly to the CTP. As described later in this document, the LTI can also be used in more complicated alternative configurations to support concurrent, independent operation of multiple sub-detectors, e.g. during calibration or commissioning periods.

# LHC clock

In detectors everything is happening synchronously to the LHC closk

- Collisions
- Signal sampling for Analogue to Digital Conversion (ADC)
- Time measurement for event id
- Trigger transmission
- Data reduction
- Data transmisiion

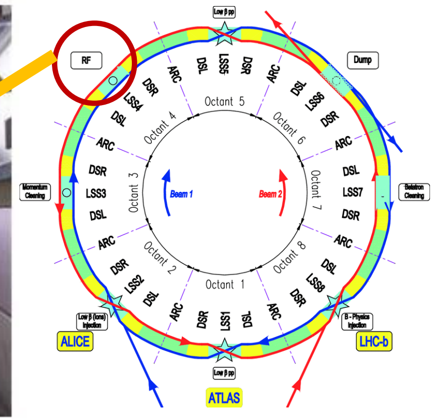
# Clock origin

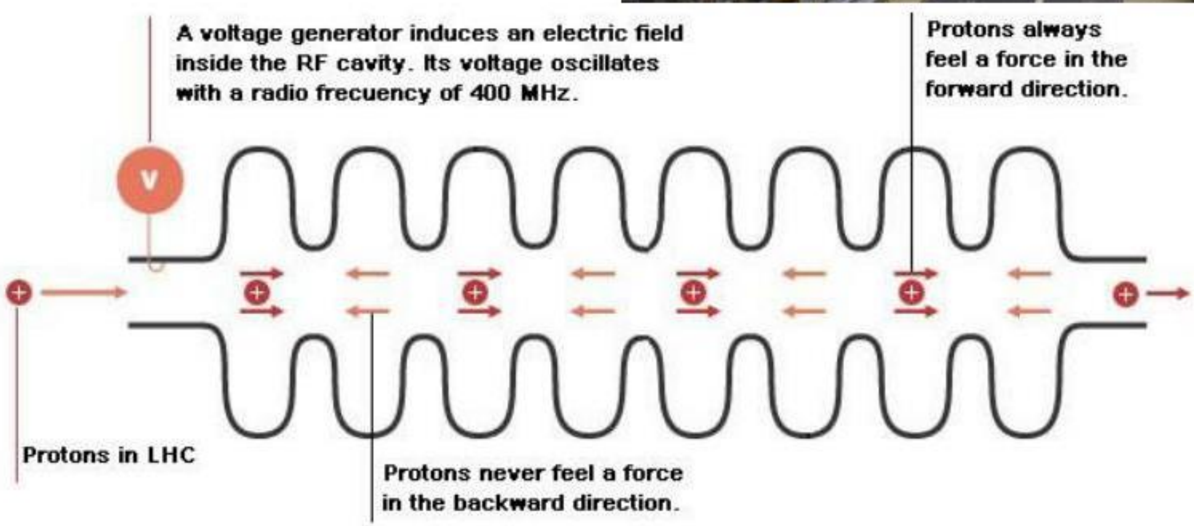


# Clock origin RF

RF cavities in LHC

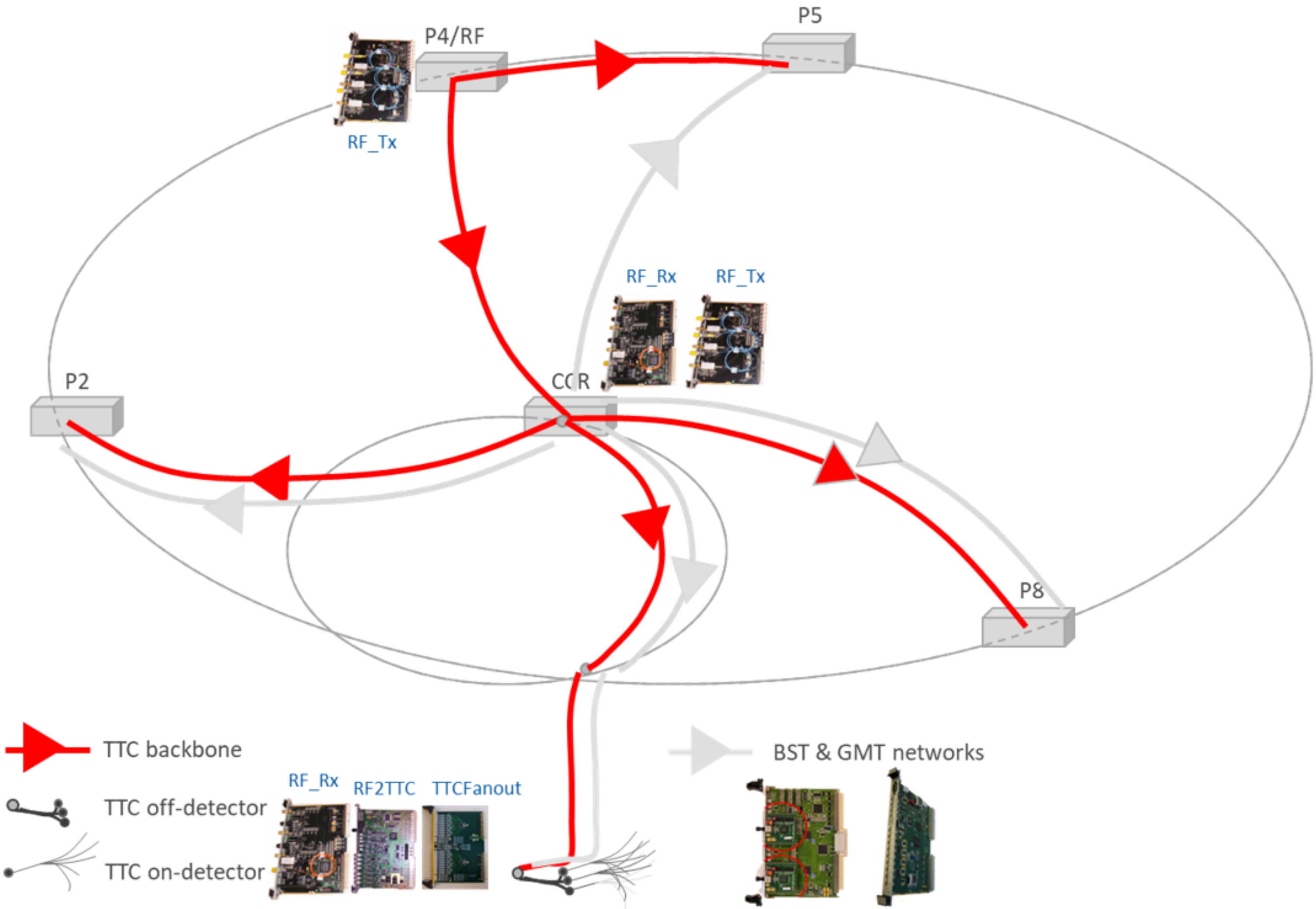
(4 modules@point4, Echenevex)



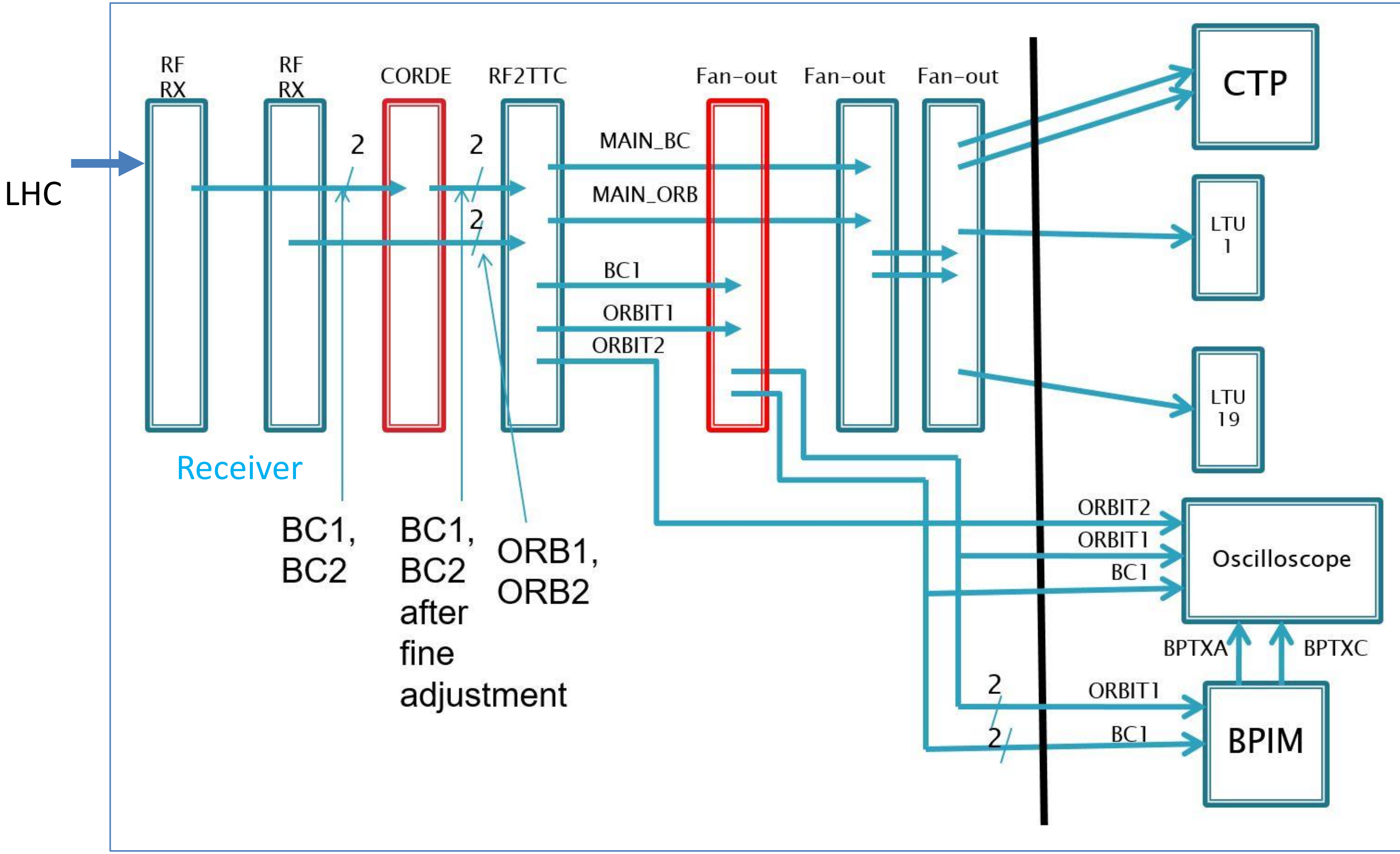




PH-ESE
ELECTRONIC SYSTEMS FOR EXPERIMENTS

# Clock distribution



# ALICE clock distribution



# White Rabbit Project

- The project was started within an effort to renovate the current CERN control and timing system.
- The **main features** of the White Rabbit Network are:
  - sub-nanosecond accuracy and picoseconds precision of synchronization
  - connecting thousands of nodes
  - typical distances of 10 km between network elements
  - Gigabit rate of data transfer
  - fully open hardware, firmware and software
  - commercial availability from many vendors

# White Rabbit in LS3 (2026)

## LHC low level RF consolidation Phase 0

**White-Rabbit based architecture**

- New Frequency program (WR RF frame master)
- WR2RF module upgrade (400MHz)

**Two phases for LHC Beam-Control upgrade**

- **Phase 0 (LS3)**
  - Partial upgrade
  - Programmed RF frequency distributed over WR
- **Phase 1 (LS4):**
  - full upgrade
  - beam synchronous RF over WR

**LHC Beam-Control Consolidation request**

- Phase 0 upgrade (LS3)
- EDMS 2956941 [1], Approval pending

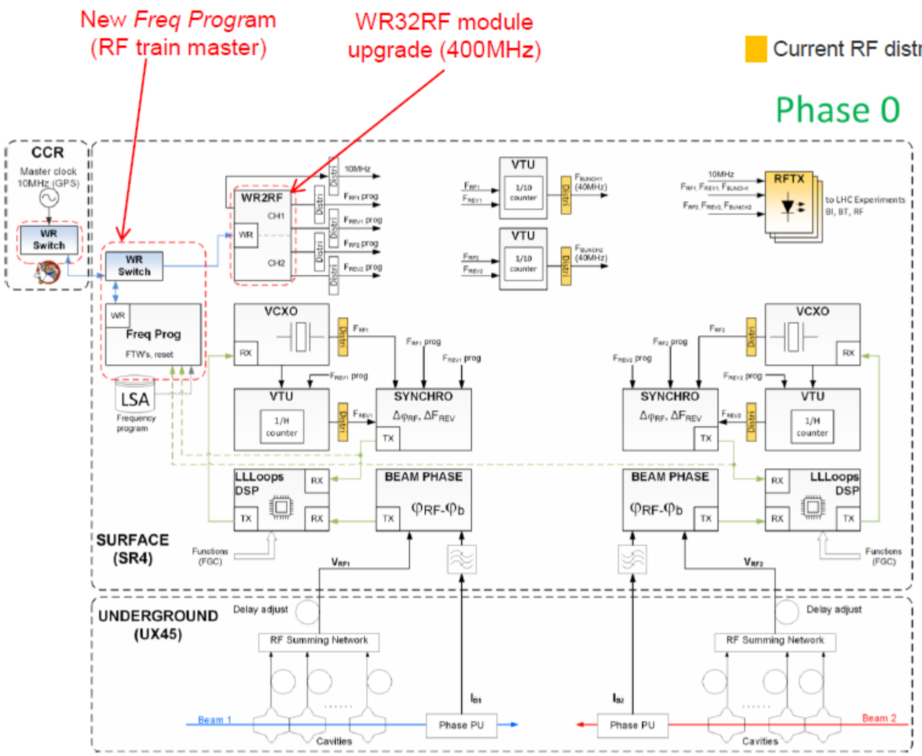



Fig – LHC SR4 upgrade, phase 0

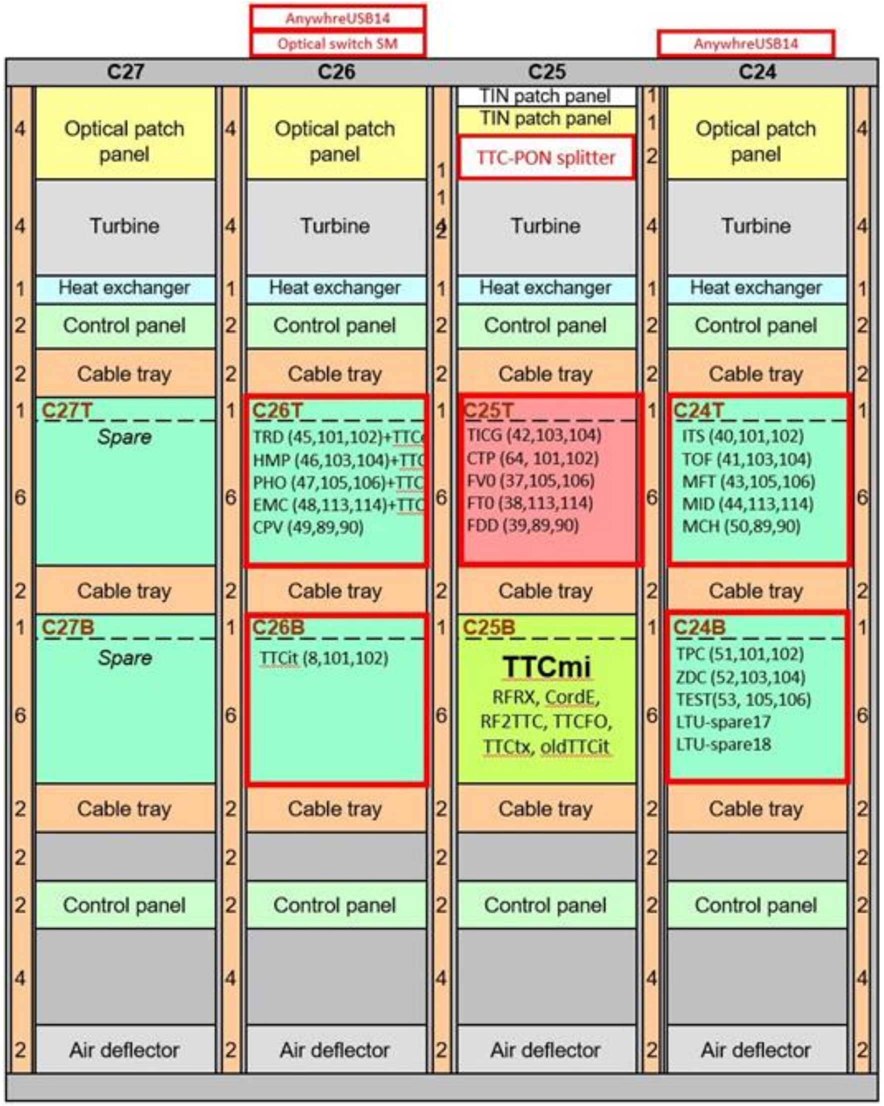
LHC RF Signal Distribution, HPTD meeting #15

3

# Installation, integration and operation

- Trigger distribution installed and integrated with detectors:
  - TTC-PON
  - GBT
  - TRD + BUSY via TTC-PON upstream
  - Legacy TTC
    - BUSY over LVDS
- CTP inputs alignment
- CTP readout fw/sw
- Clock distribution:
  - Hitless switching
- LHC interfaces and services sw

# Final installation at LHC Point 2




# LHC filling scheme – inputs allignment

{spacing}_{bunches}_{IP1/5}_{IP2}_{IP8}_{trainlength}_{injections}_{special info}

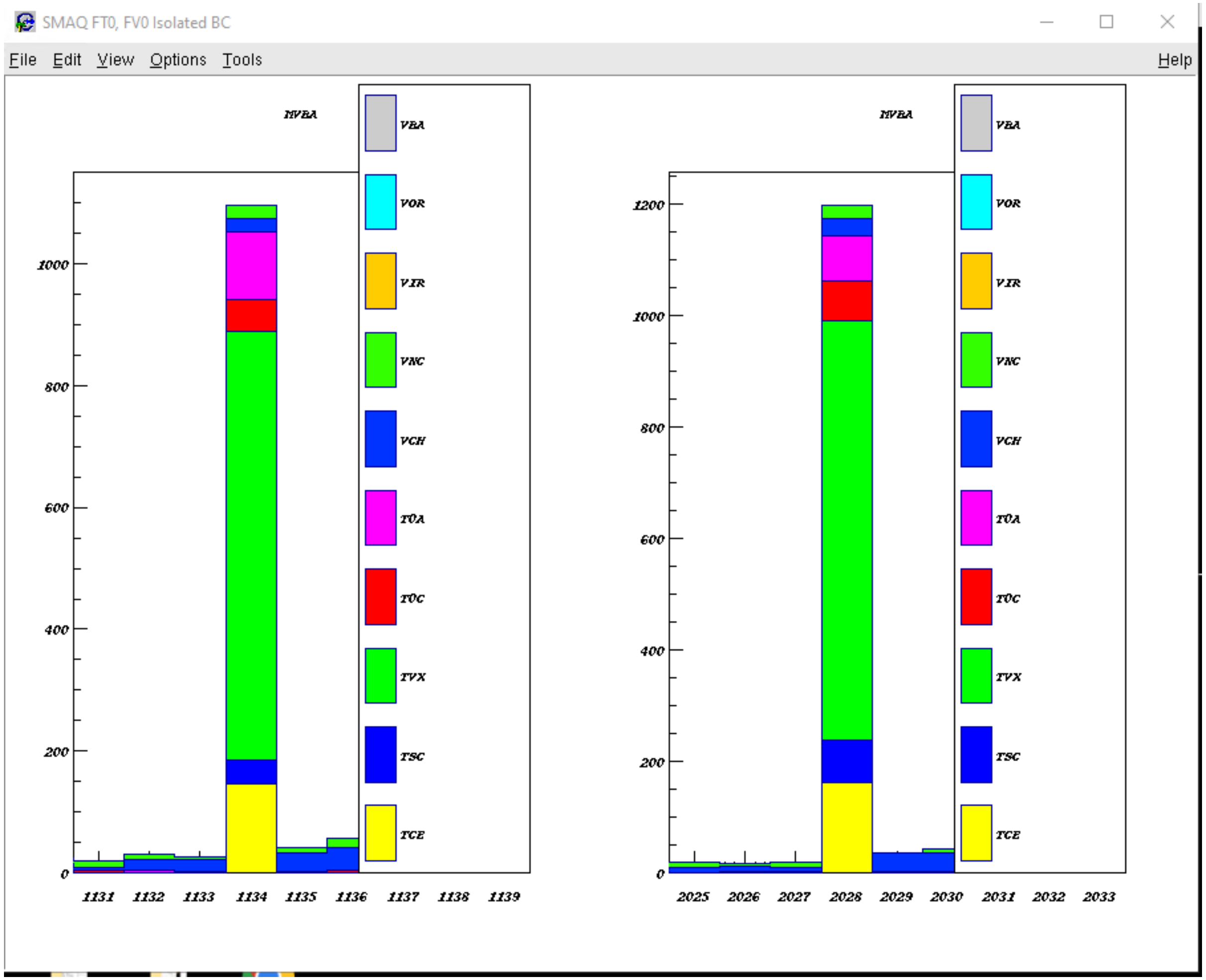
with

| | | |
|---|---|---|
| spacing | : | bunch spacing |
| bunches | : | number of bunches per beam |
| IP1/5 | : | number of collisions in IP1 and IP5 (ATLAS/CMS) |
| IP2 | : | number of collisions in IP 2 (ALICE) |
| IP8 | : | number of collisions in IP 8 (LHCb) |
| trainlength | : | the maximal length of a train |
| injections | : | number of injections per beam |
| special info | : | any other useful information |

NC denotes the number of non-colliding bunches.

25ns_1935b_1922_1758_1842_240bpi_12inj_3INDIVs
Isolated bunches: 1134, 2028

# LHC filling scheme



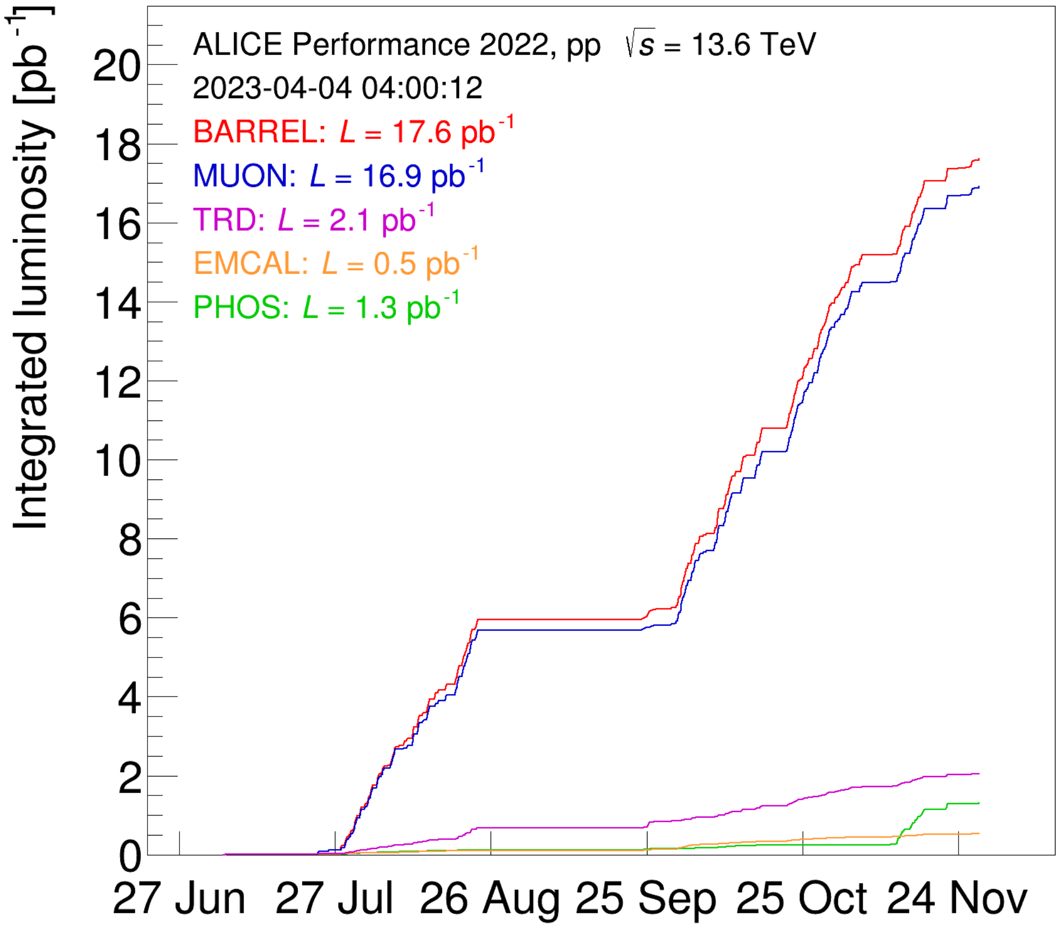

25ns_1935b_1922_1758_1842_240bpi_12inj_3INDIVs

Isolated bunches: 1134, 2028

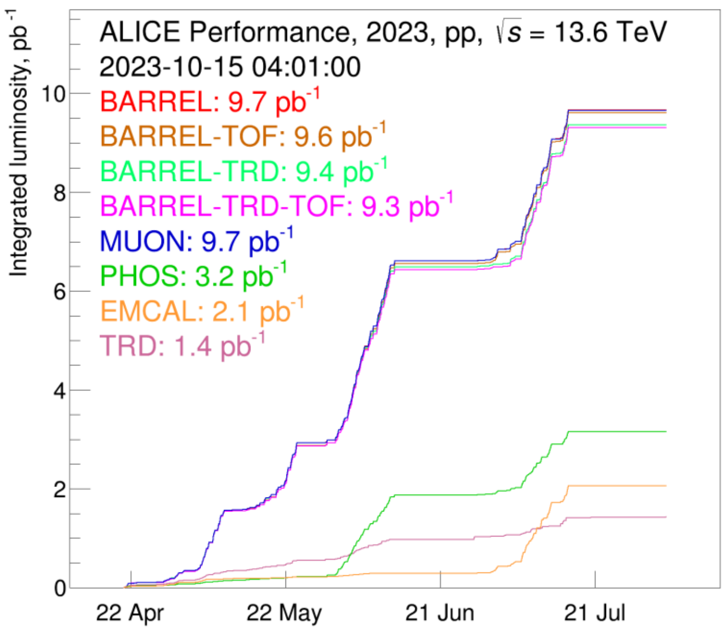
# Stable beams 5/7/22 ALICE CR


ALICE Control Room

# Integrated luminosity pp 22/23




(17.6+9.3)/pb > Run1+Run2

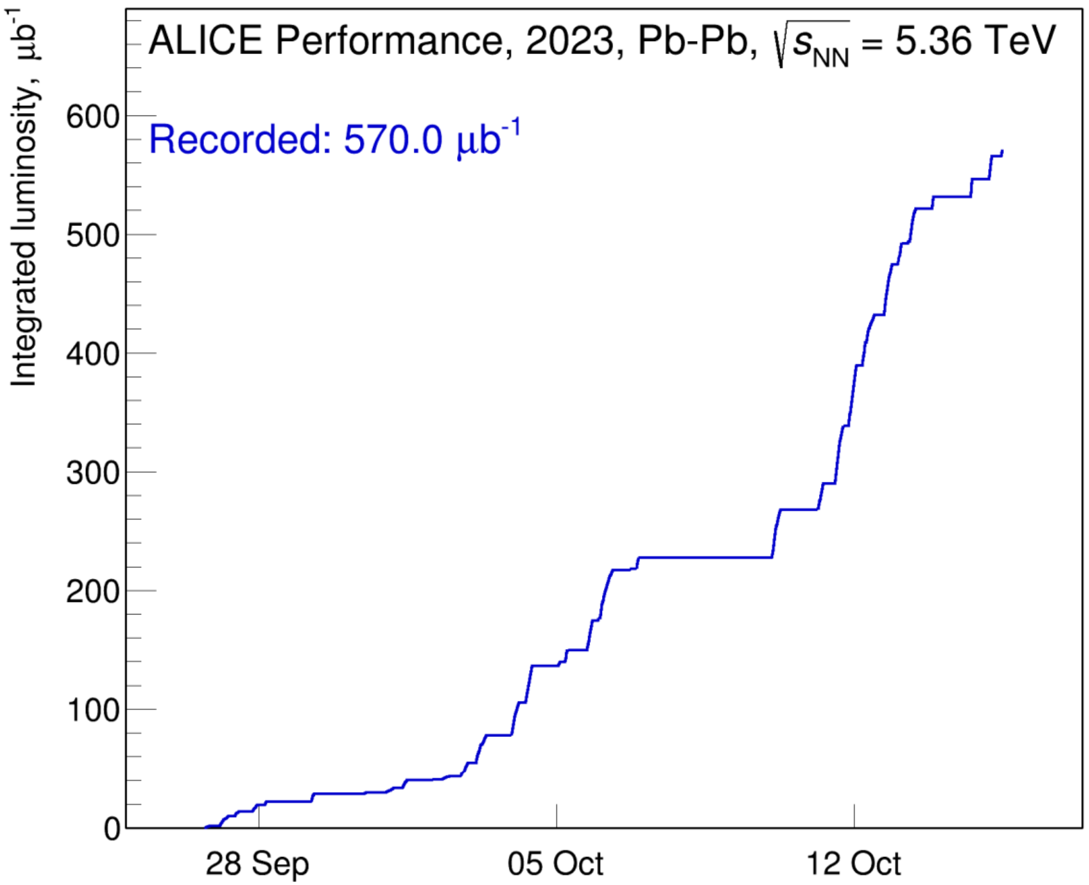


# Heavy Ions 26/09/23


ALICE Control Room

# Luninosity PbPb

- •PbPb after LHC background elimination and ramp up in full speed now
  - 20-45 kHz
- •Lumi including LHC background period
- •Run1+Run2 comparison:
  - ~0.5 for muons
  - ~ 7 x for barrel



# Summary

- Most of the detectors take data in triggerless mode: read out data of all interactions (50kHz Pb-Pb and > 500kHz pp)
  - Compress these data by online reconstruction
  - One common online-offline system
- Central trigger system:
  - Distributes clock and HB frame delimiter
  - Provides Minimum Bias trigger when needed
  - Provides Continuous/Triggered Mode as required
- All LHC experiments summary for HL LHC:
  - L1 output ~ 1 MHz
    - For ALICE = interaction rate
  - On tape: ~ 10 kHz

# Extra Slides

# Trigger messages and System Throttling

- Trigger messages
  - HB accept/HB reject
  - HB acknowledge
  - HB decision
  - HB map
- System scaling and throttling
  - CRU buffers never or rarely overflow: system works ok
  - CRU buffers overflow rate is high: TF mostly incomplete => need some throttling mechanism

# 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 |

# Trigger Class

## Trigger Conditions:

- Logical combination of trigger inputs
- BC mask: Usually corresponds to LHC filling scheme
- Internal trigger

## Trigger Cluster: Group of detectors to be read out

## Trigger Vetoes:

- Cluster BUSY
- Downscaling
- Past-Future Protection

**Trigger Class = Trigger Condition + Trigger Cluster**
**+ Trigger Vetoes**

# HB decision message