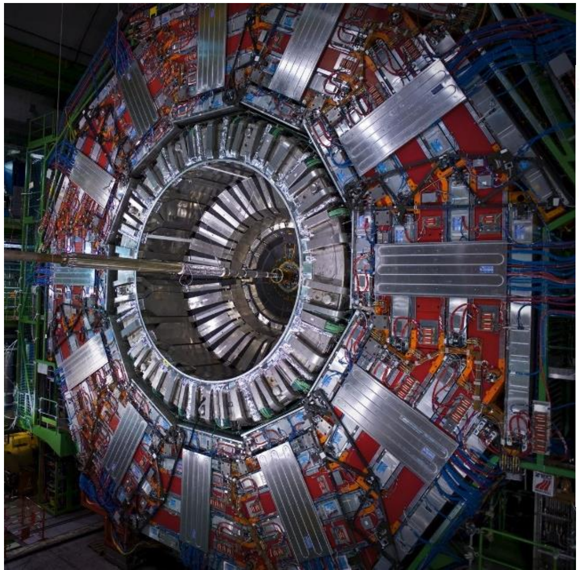
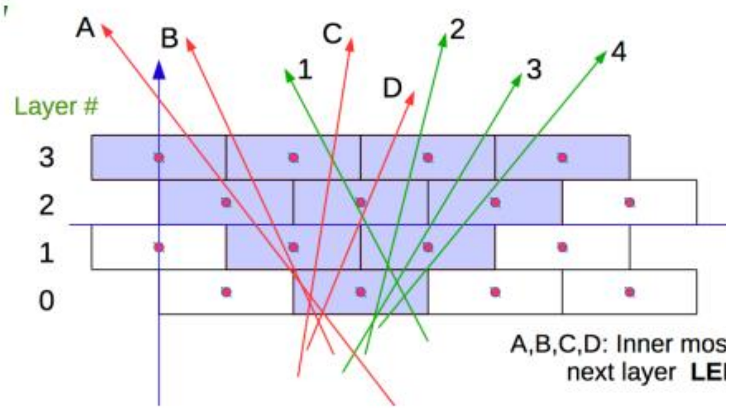
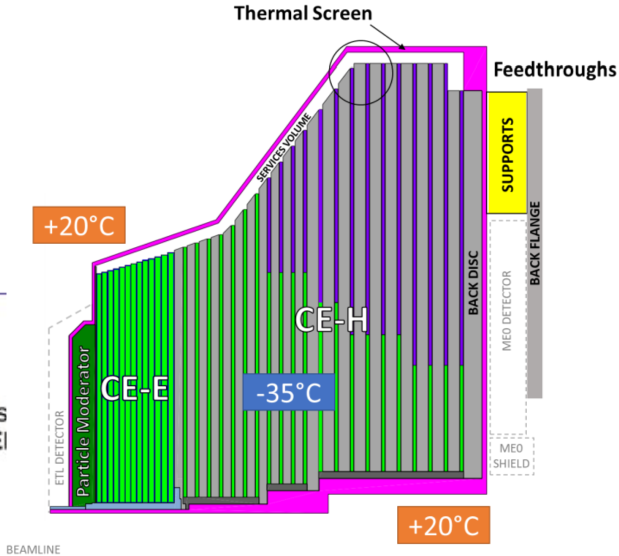
CIEMAT contributions to CMS HL-LHC Upgrade in Muon, L1T and HGCAL

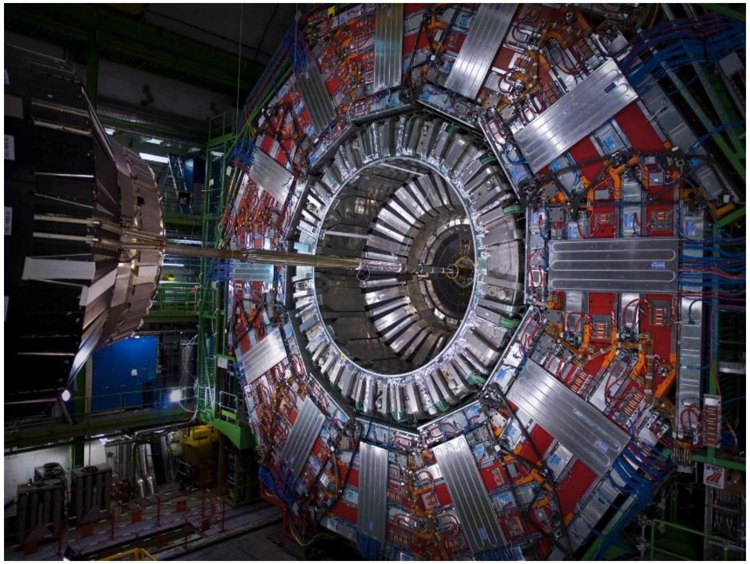
Ignacio Redondo -CIEMAT





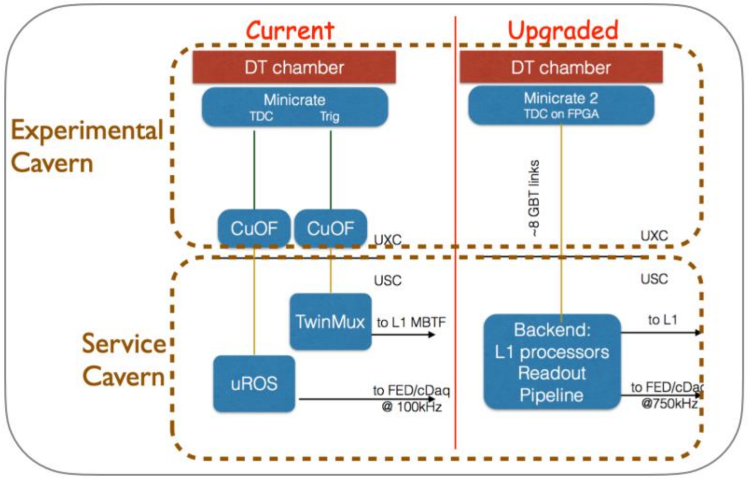


CMS Muon Drift Tube Upgrade for HL-LHC



- 250 CMS DT gas chambers instrument the barrel region of the return yoke providing superb Muon identification, reconstruction and triggering over > 40 % of CMS Volume. CIEMAT is significant collaborator of DT (~1/4) since CMS construction
- In HL-LHC: chambers remain, but full electronics system is replaced to match CMS operating conditions
- Electronics has been redesigned with a new architecture with the goal to bring offline reconstruction precision and methods to the L1 trigger (HW) trigger.

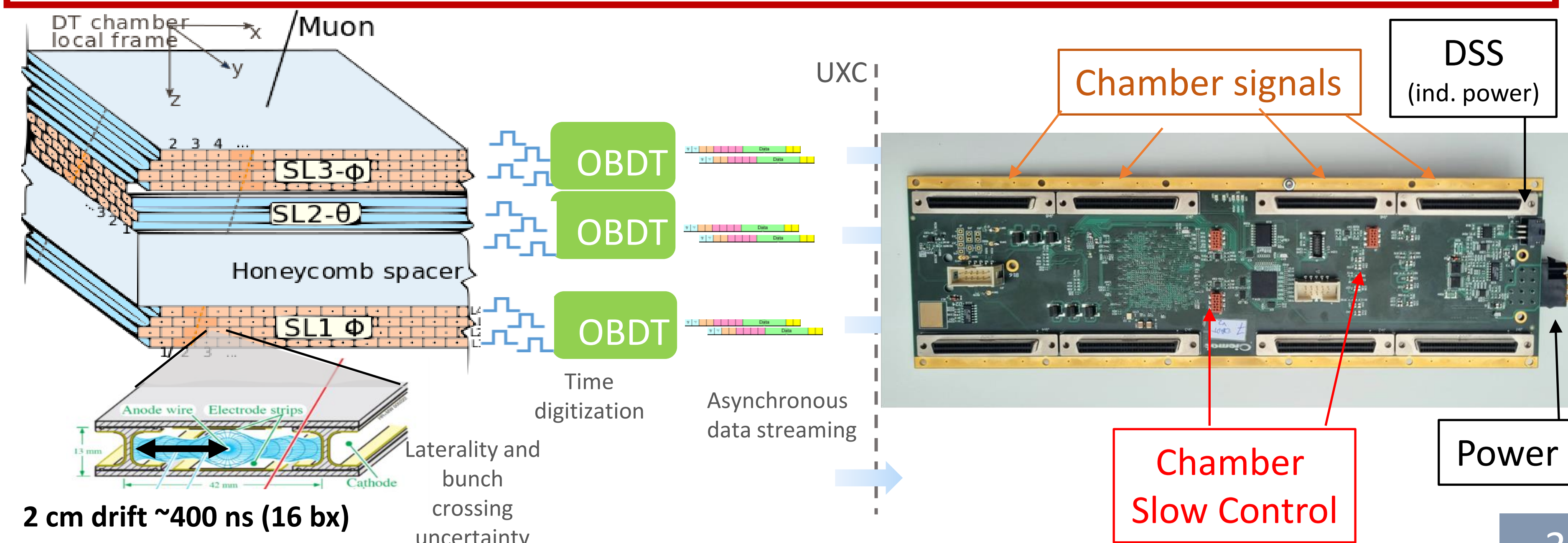
- Present system relies on filtered data through copper links to get the data out of the chambers.
- Leveraging from rad-hard optical links technologies ubiquitous at LHC, all hits are sent to the backend, where Trigger Primitives and Readout Event matching will be produced by powerful FPGAs without radiation constrains.
- System started in production status after internal review (ESR, May 22).



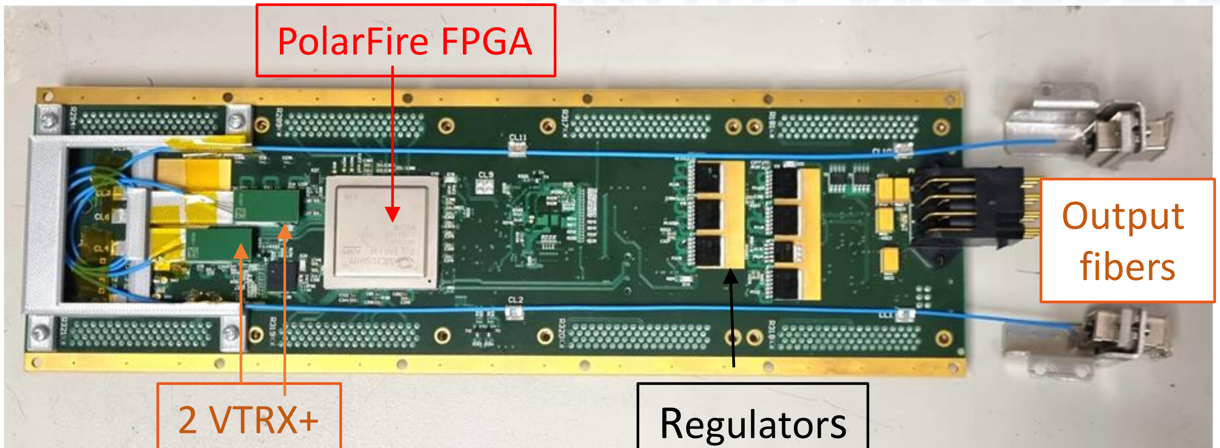
- CIEMAT have lead Phase 1 upgrade and Phase 2 since conception from different positions (Project Leader, Upgrade, TDR editor…). Presently C.F. Bedoya is DT Upgrade Coordinator.
- Spain committed to **26 % of the DT Upgrade Core Cost.**

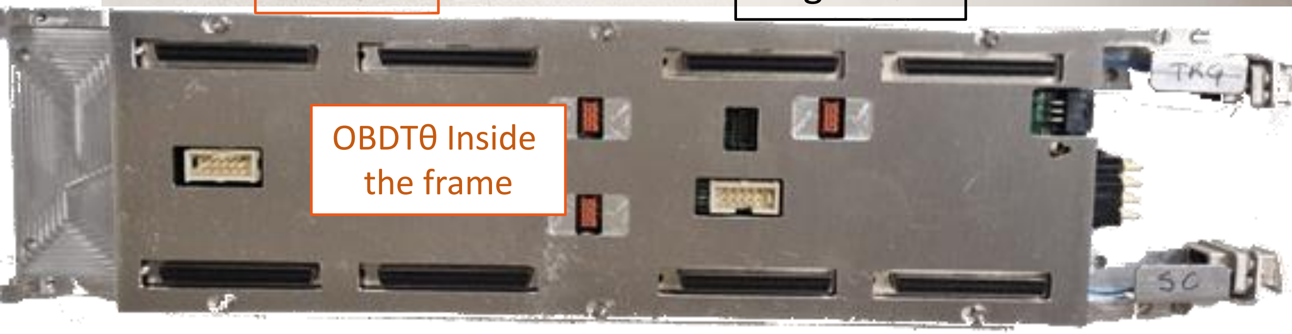
Frontend Electronics Design and Functionality

- The Frontend system digitize the LVDS hit times coming from the chambers in rad-hard PolarFire Microsemi FPGA, which can instrument > 200 channels with a precision of 0.8 ns, enough for the DT chamber precision.
- There will be ~1000 such boards of two kinds: ϕ and θ. As the θ SuperLayer chamber connectors are deep in the yoke and cables cannot be replaced without extracting the chamber, an specific board, **OBDTθ** has been designed by CIEMAT to serve the legacy cables.
- It also needs to provide slow control to legacy chamber systems as : i) inside-chamber analogue electronics ii) pressure sensing iii) alignment hw iv) a time calibration system (developed with RTWH Aachen). It is protected by an onboard safety system based on temperature and power sensing, complemented by a humidity sensor monitoring (cooling leaks in CMS happen regularly).
- After several prototype cycles, final revision ongoing before full production is launched (**220 boards**).

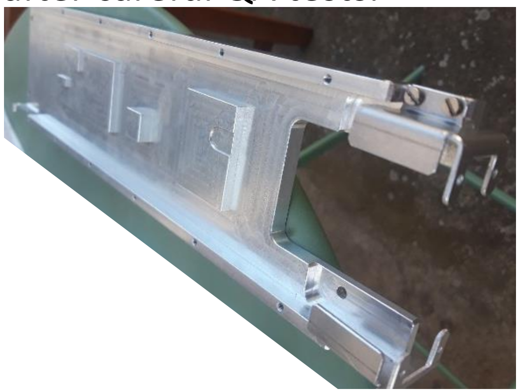


OBDTθ Mechanics

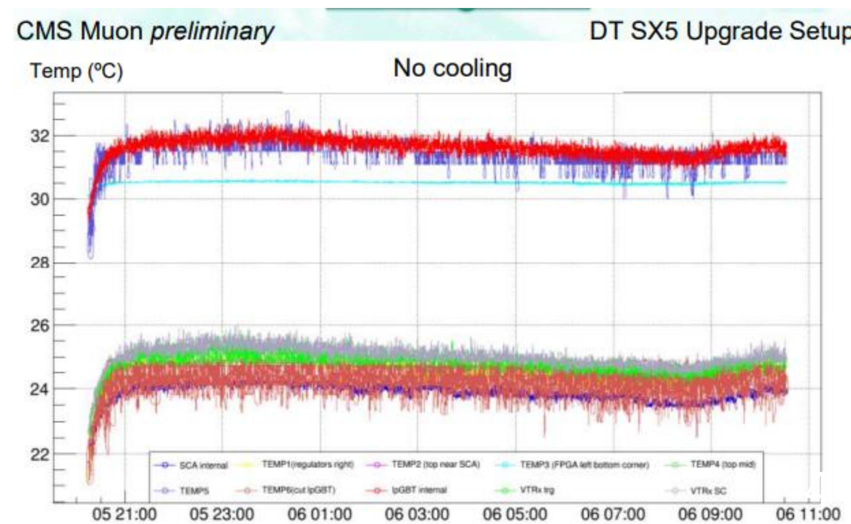




-Assembly in Aluminum frame which acts as thermal interface and as mechanical and electro-magnetic shield, being ready for field deployment after careful QA tests.

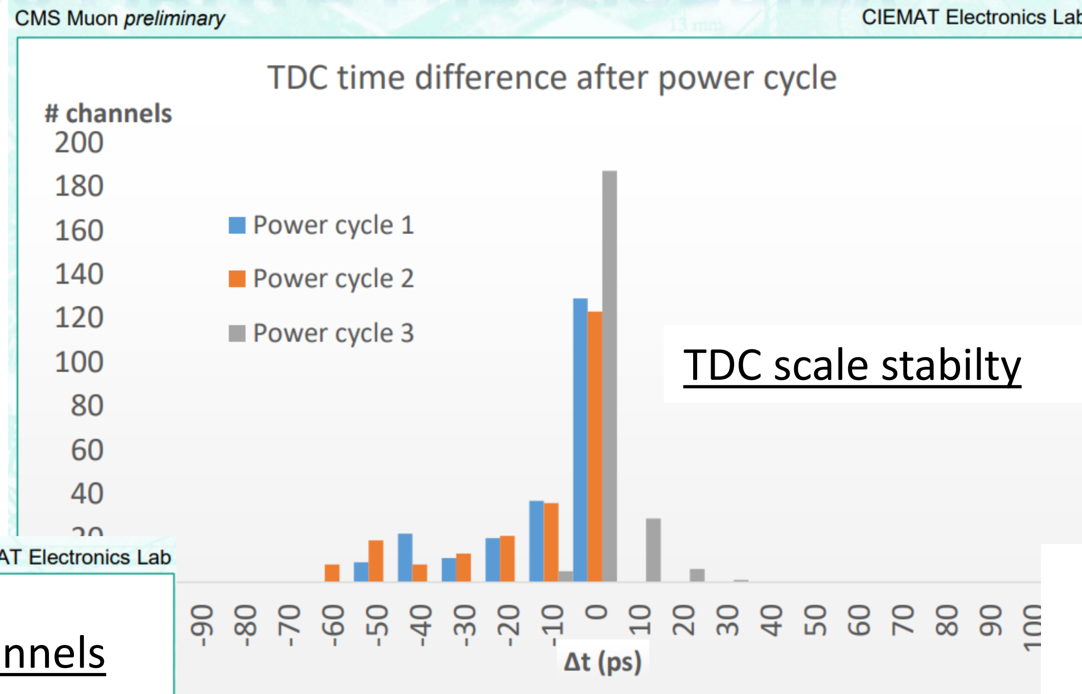


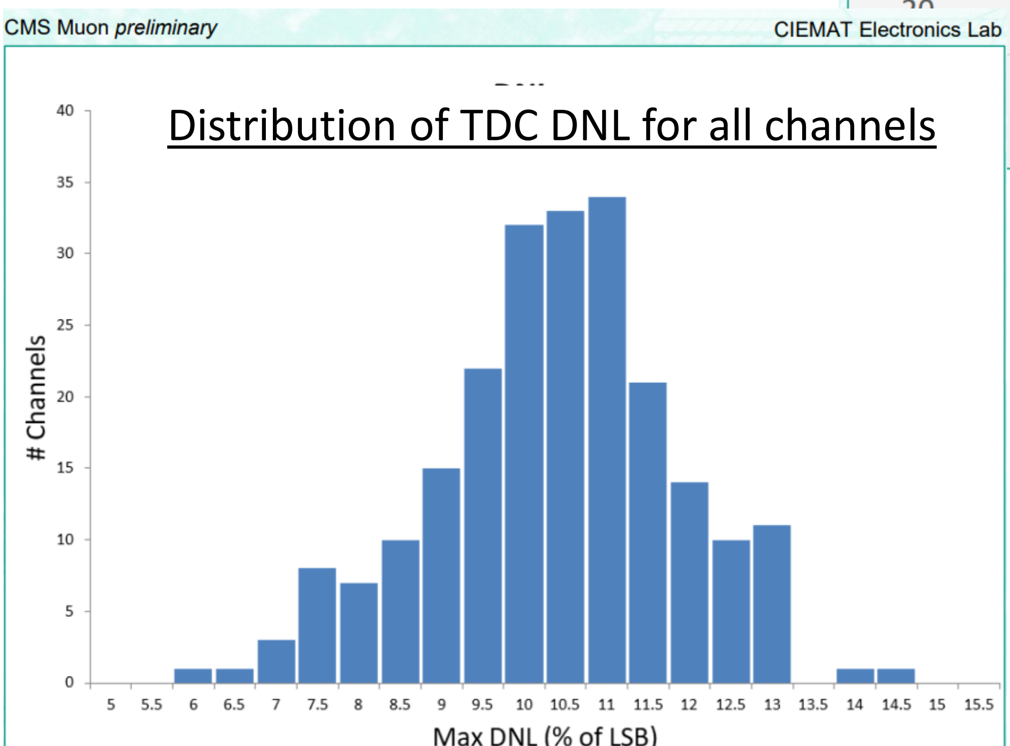
- Several thermal fillers tested for thermal behavior and for irradiation degradation at CIEMAT's Co^{60} "Nayade" facility .
- Optimal thermal interface and low power consumption allows operation <40 C when in normal operating conditions as in CMS (water -cooled). In the lab we have routinely operated stably without cooling inside the frame.



Validation of the OBDTθ Functionality

- TDC timescale stability, phase predictability problems was identified early in LS2 demonstration test.
- FW was refactored to guarantee time scale stability, providing excellent results.

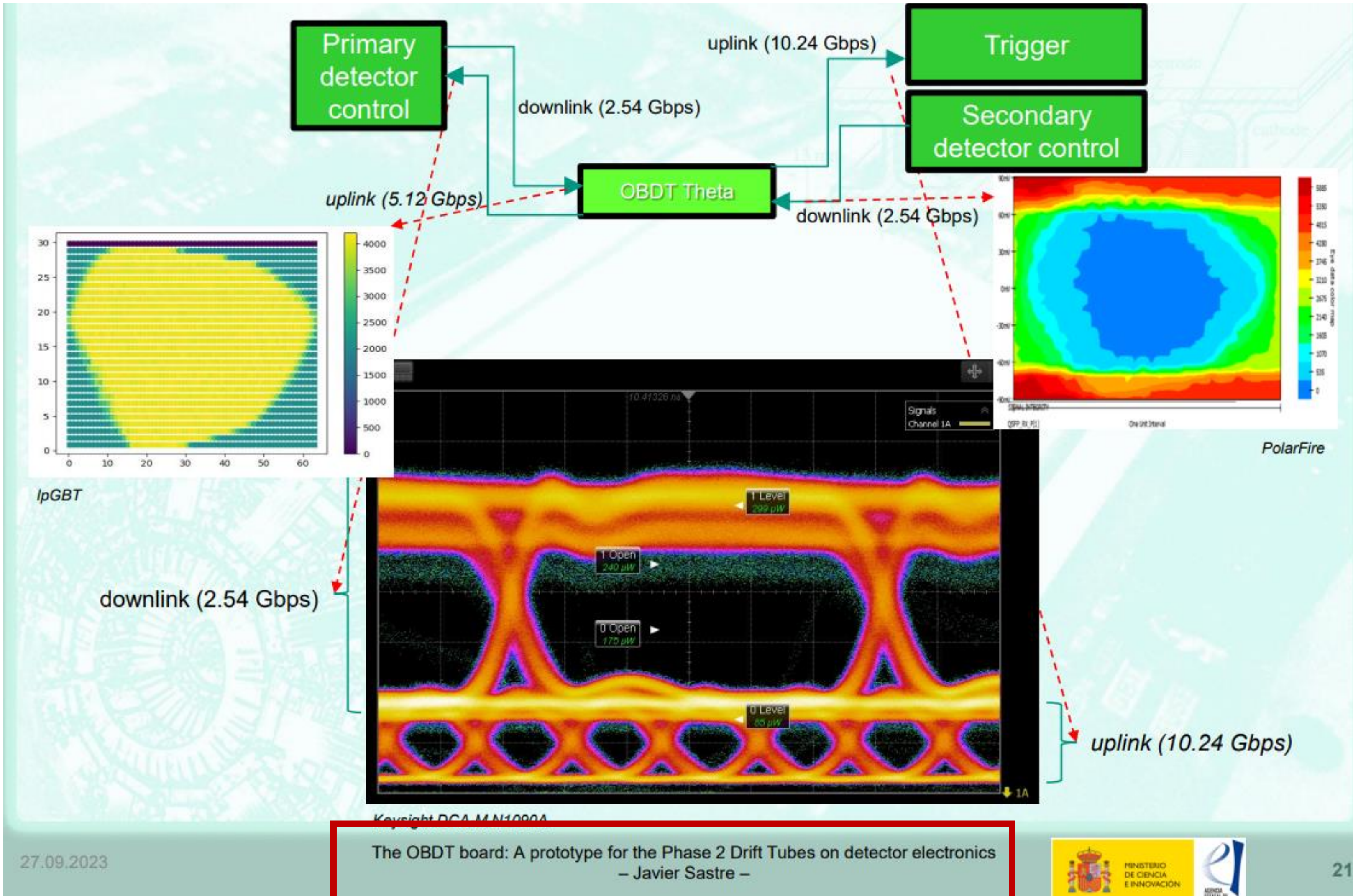




- Least Significant Bit = 800 ps
- Chamber precision is 1-2 ns
- **Excellent TDC Performance**, more than sufficient for our application.

Optical signal Integrity

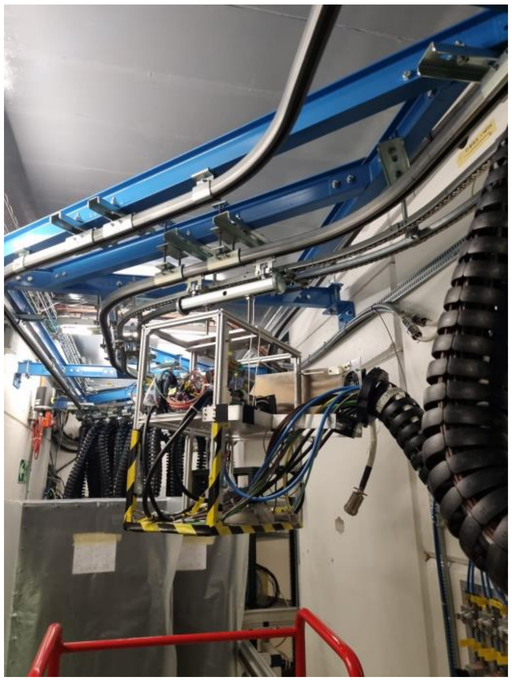
- Mechanics integration of the VTRX+ is crucial for optimal cooling without disturbing optical power

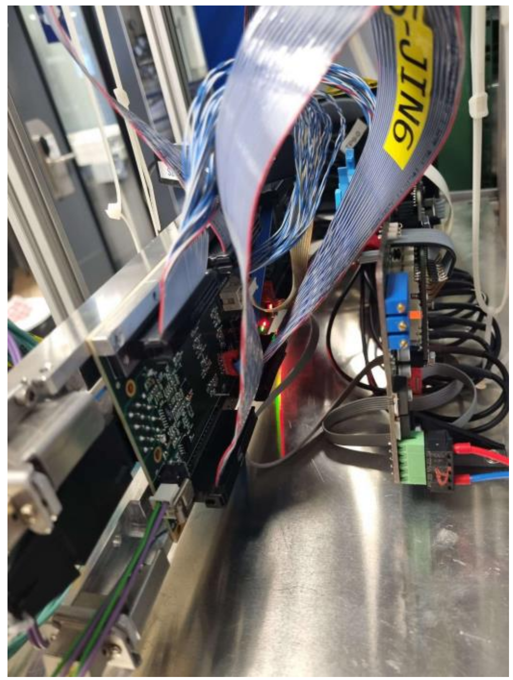


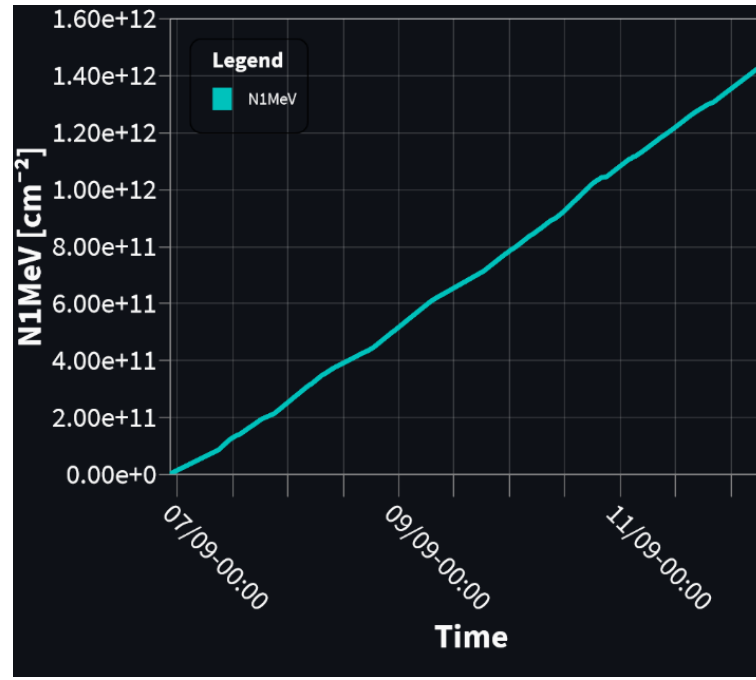
Much more on the OBDTθ in Twepp 23 presentation by J.Sastre this Thursday!

Radiation hardness verification of the OBDTθ

- Previous irradiation of OBDTv1 (GBTx) prototype at CERN CHARM facility reported last year in TWEPP22, also OBDTv2 phi in medical accelerator➔ MicroSemi PolarFire can be used with intended functionality for the required fluences.



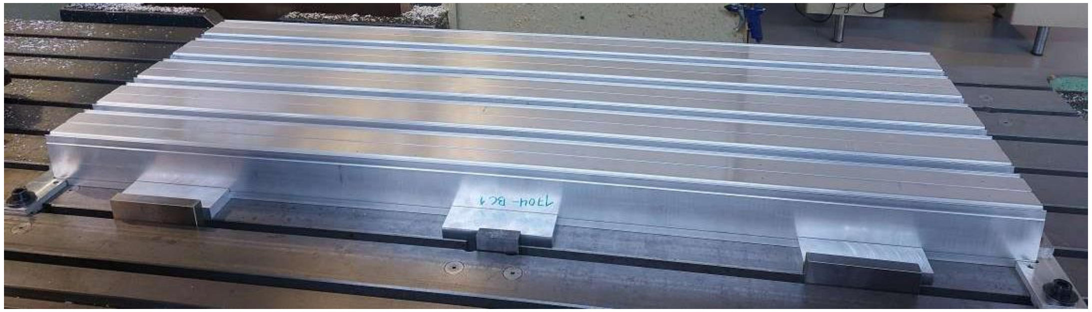




- This September we irradiated present OBDTθ (lpGBT) prototype. The board did not require periodic power cycles or configurations to operate correctly,.
- No intervention was required until reaching a dose equivalent to **20 x HL-LHC** for our application.
  - Optocoupler ACPL-247, part of the onboard DSS, degraded during irradiation until it was cutting power. The factor of 20 safety margin can be increased optimising this part of the design.
- Full OBDTθ production will suffer accelerated aging test "burnt-in" in an oven @ 70 C, setup being prepared @ CIEMAT

Production of the Phase 2 Minicrates

- Phase 2 Minicrate design inherits from legacy Minicrate, avoid integration problems in the chamber by keeping design modify only inside of the profile for optimal cooling.
- Instrumentation of the 250 chambers requires several (**11**) types of minicrates. CIEMAT produces and mechanizes all the Minicrates profiles and the OBDTθ frames.

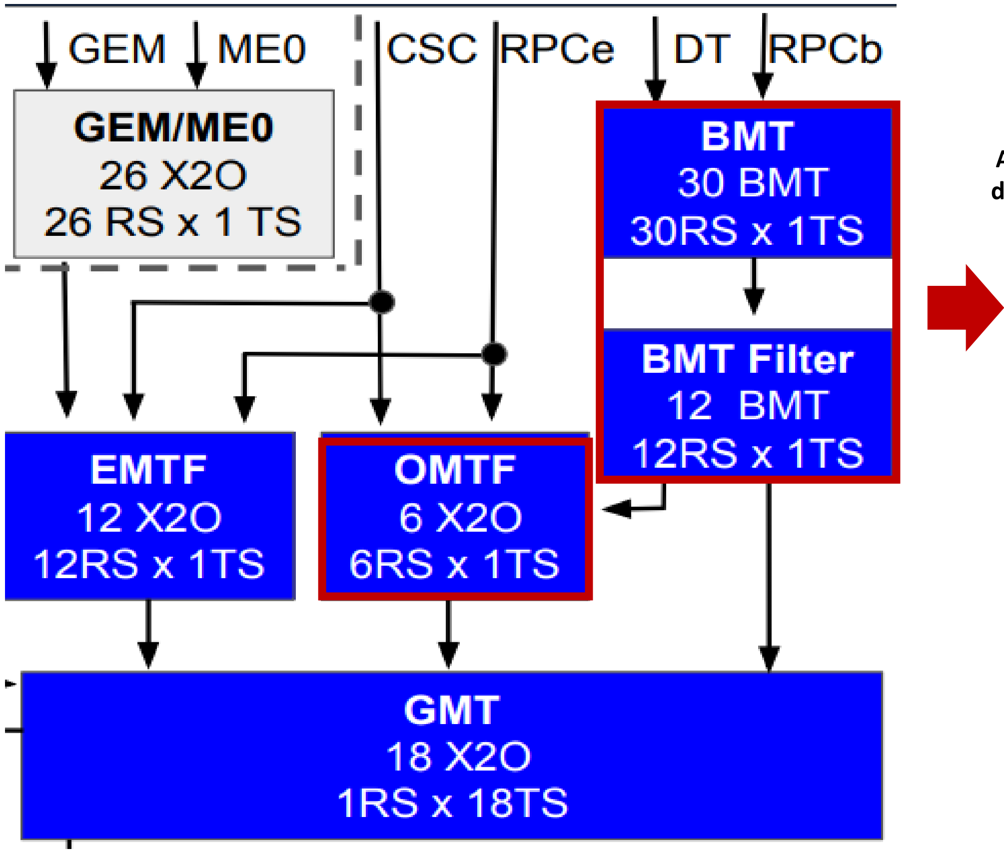


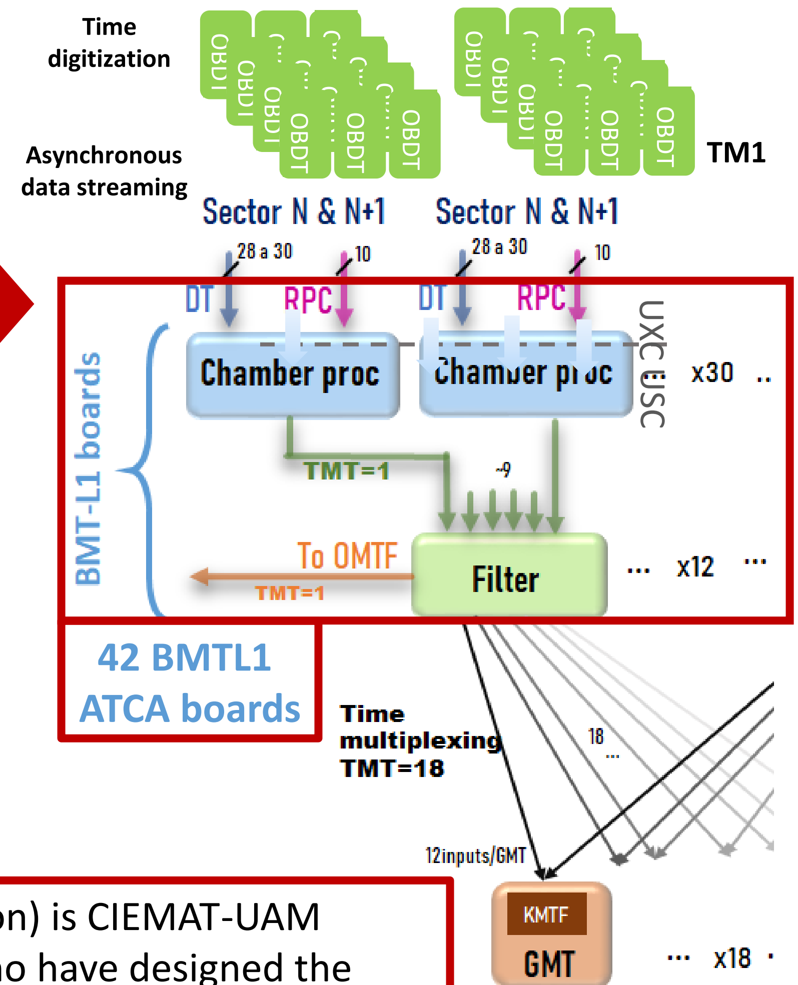
- Mechanical and cabling verification of the MB1 minicrate design in a MB1 chamber with realistic services and phase 2 cables at P5 surface

- CIEMAT getting ready to i) produce OBDTθ frames, ii) assembly   all OBDTθ boards into frames, iii) qualify them testing all functionality and iii) assembly MB2 minicrates (adding OBDTϕ produced by INFN).
- All minicrates should be at CERN before installation access is allowed by CMS, ½ year after LS3 start.

Spain in HL-LHC L1T Upgrade

UAM participated in L1T already during CMS construction CIEMAT and U. Oviedo joined later as a result of Phase1. C.F.Bedoya is L1T Resource Manager, S. Folgeras L1T DPG coordinator.

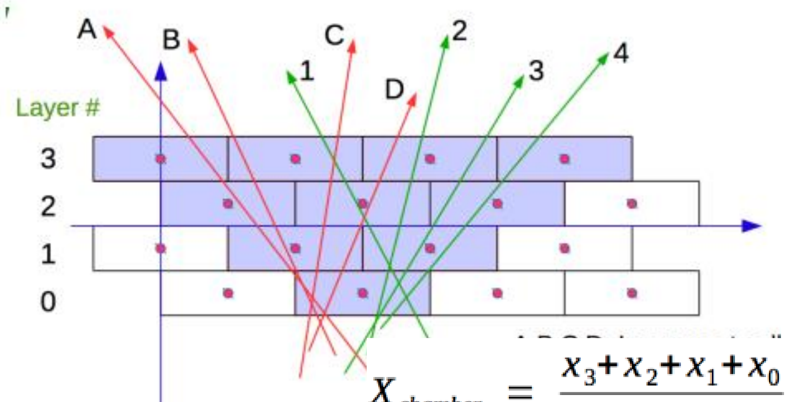




- **BMTL1** (OBDT data backend and trigger primitive generation) is CIEMAT-UAM responsibility in collaboration with U. Ioannina, Greece, who have designed the ATCA board.
- Uni. Oviedo is responsible of **OMTF** with Polish collaborators and based on X20 board (produced by UCLA) and has SW responsibilities in BMTL1.

L1T: AM (Analytical Method) algorithm

- The Analytical Method has been developed by CIEMAT-UAM to implement analytical solutions for reconstructing the DT trigger primitives for Phase 2. It exploits the maximum resolution achievable by the DT chambers, bringing the hardware system close to the offline performance capabilities.
- Recent publication product of **close collaboration between CIEMAT-UAM and Uni.Oviedo**: G. Abbiendi et al. 2023 “*The Analytical Method algorithm for trigger primitives generation at the LHC Drift Tubes detector*”. 10.1016/j.nima.2023.168103



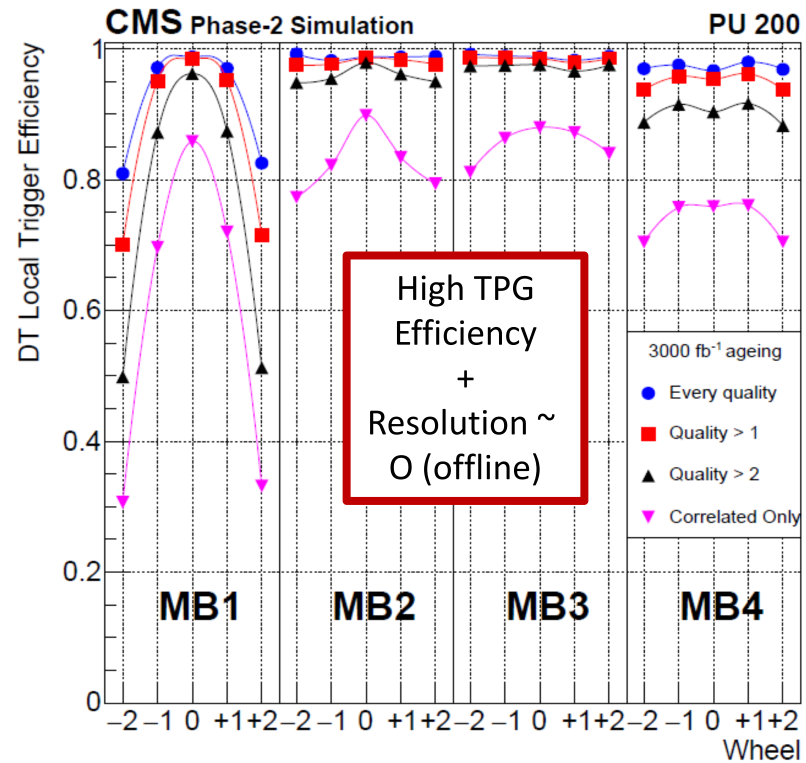
|X_in_cell| ~ v time
Analytical solution
For 4 layer stack
Implemented in FW

$$X_{chamber} = \frac{x_3 + x_2 + x_1 + x_0}{4}$$

$$\tan(\varphi) = \frac{3 \cdot x_3 + x_2 - x_1 - 3 \cdot x_0}{10 \cdot h}$$

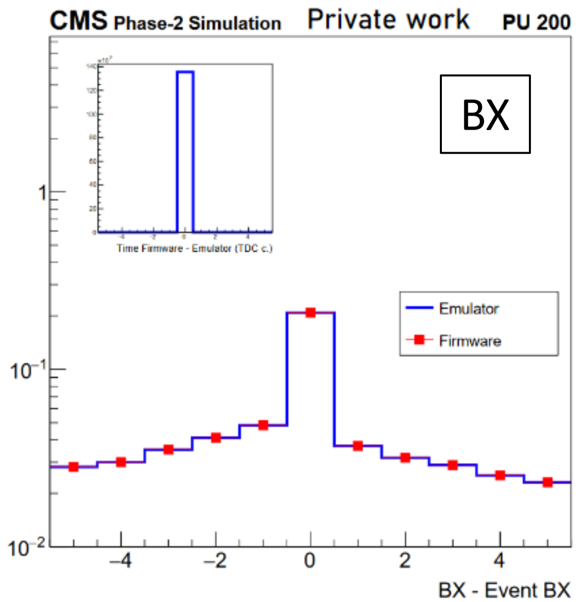
$$\chi^2 = \sum_{i=0}^{3} \left(x_i - \tan(\varphi) \cdot y_{wire_i} - b\right)$$

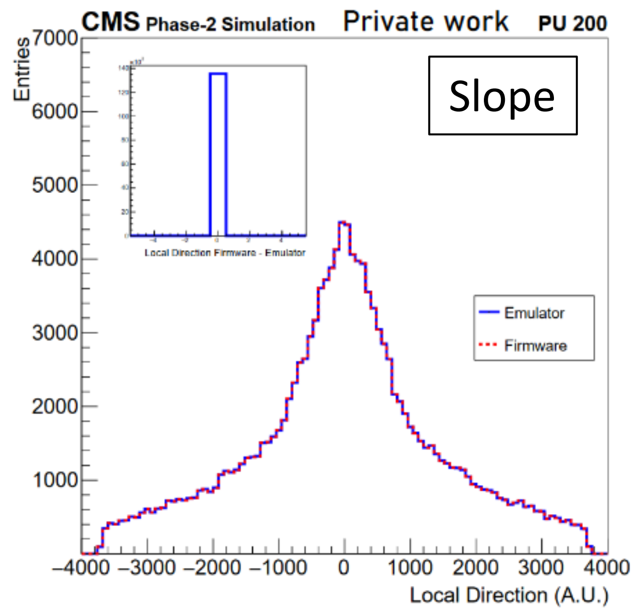
$$b = \frac{1}{4} \sum_{i=0}^{3} x_i$$



- To be complemented by BMTL1 Filter time coincidences across Muon Stations for rate control and confirmation … and possibly to deploy long lived particle triggers

AM performance: FW-Emulator comparison





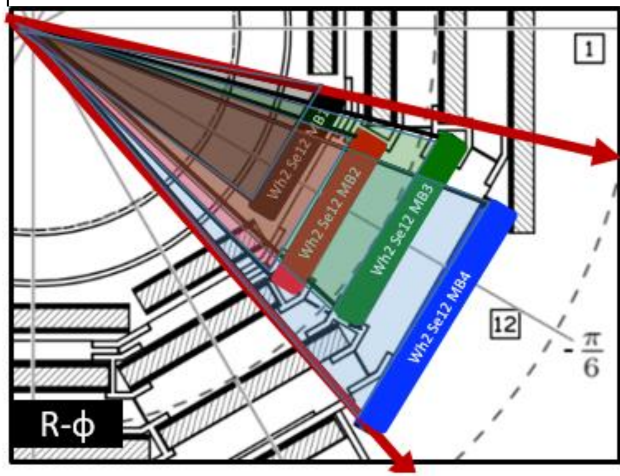
Agreement to the least significant bit achieved comparing the output parameters (time, slope, position) obtained by both firmware and emulator the trigger primitives fitting the same hits with the same laterality assumption.

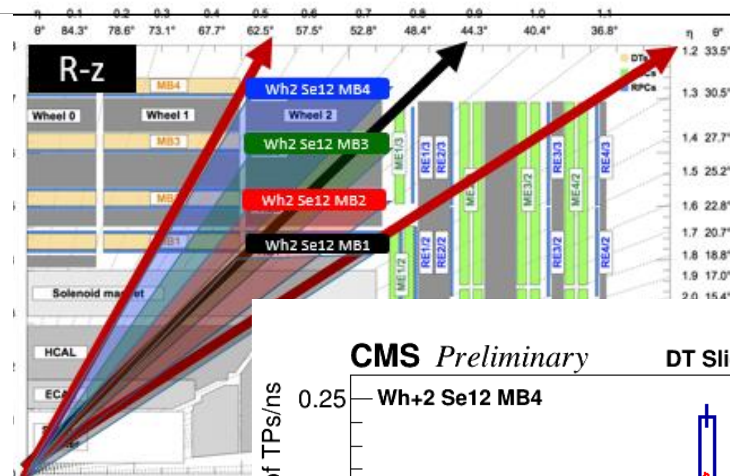
AM FW has been latency optimized **(~<20 bx for algo)**/ Low algo latency leaving room now a second layer (Filter) which allows optimal interface to next layer (TMT1➔TM18) and tunable fake rate control via multi-chamber time coincidences.

- Filter is part of L1T baseline for final CMS internal review of Phase 2L1T before production (ESR).

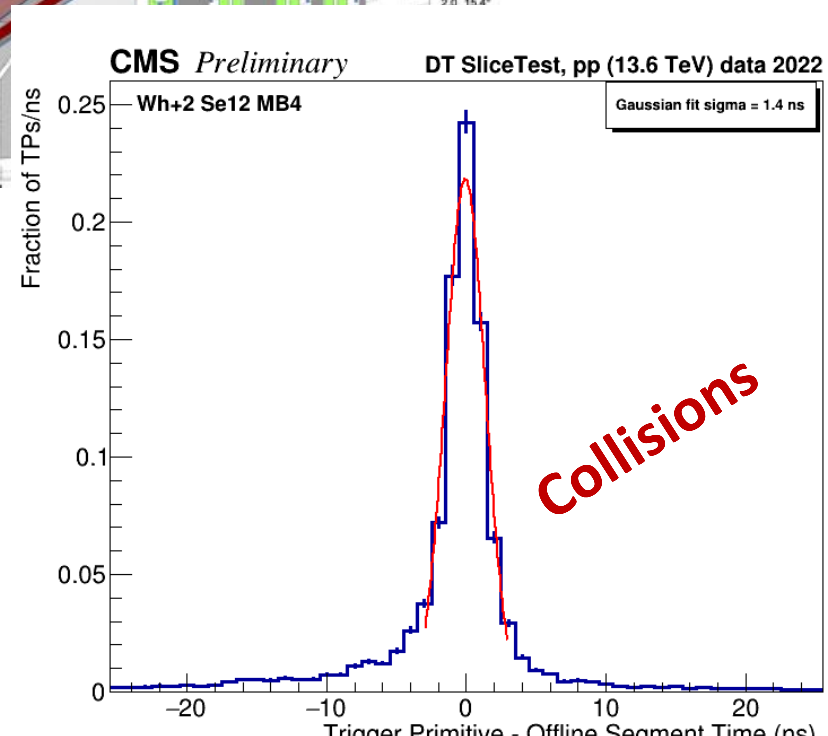
AM performance in CMS during LHC collisions

- FE: 13 **OBDTV1 (GBT) in YB+2 S12**
- Backend : Phase 1 HW TM7 for :
  - TPG generation (AM) &readout
  - Slow control&timing
- Integrated in CMS (power, TCDS, DAQ, CMSSW)
- Extensively operated in GR during LS2 and Run3 & calibrated, delivering **superb performance**





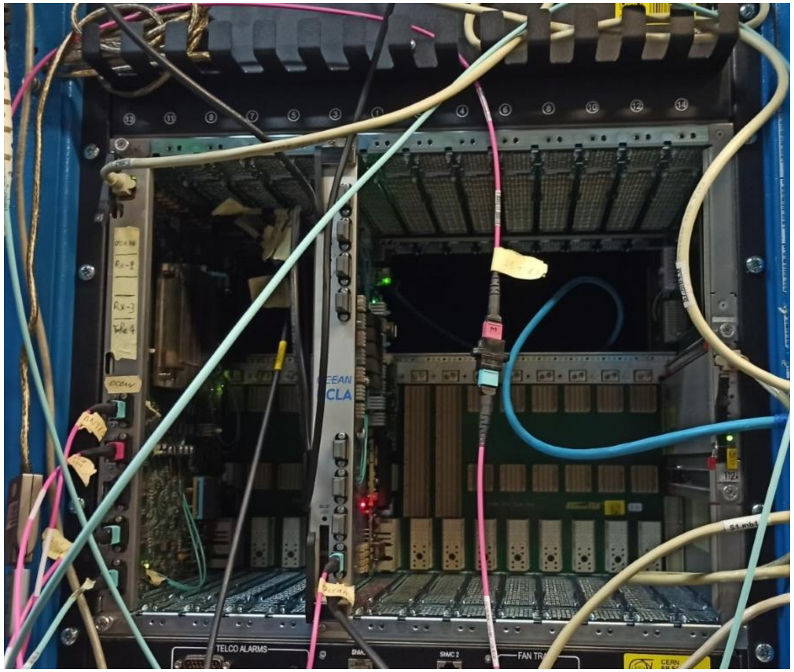
Presented in Twep22



Demonstrated new DT BMTL1 Phase 2 architecture achieving offline-like resolutions

AM performance in CMS during LHC collisions

- In 2023 demonstrator has been updated with **9 OBDTv2 (lpGBT) prototypes** in neighboring sector and backend prototypes (**BMTL1 ATCA board** &Slow Control).
- BMTL1 have already operated during collisions on OBDTv1 boards
- We will continue in 2024 updating the Slice Test@ P5 as it provides ideal field testing



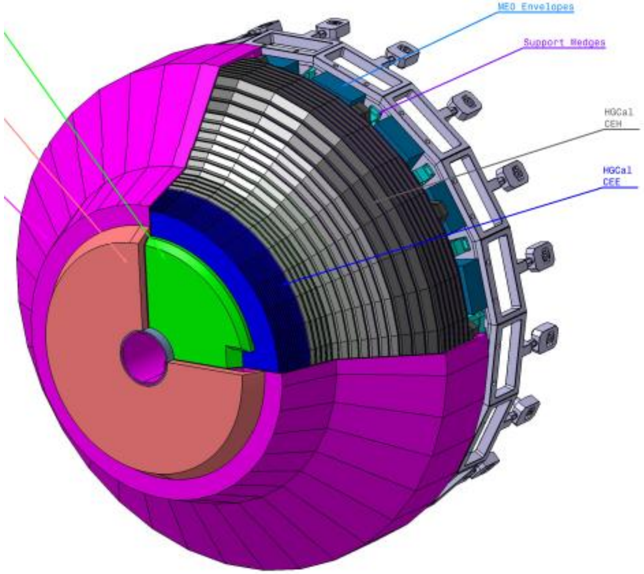
Next: BMTL1 & OMTF boards (X20) will be integrated in L1T 904 integration facilty in preparation for final CMS internal review, which is expected soon.

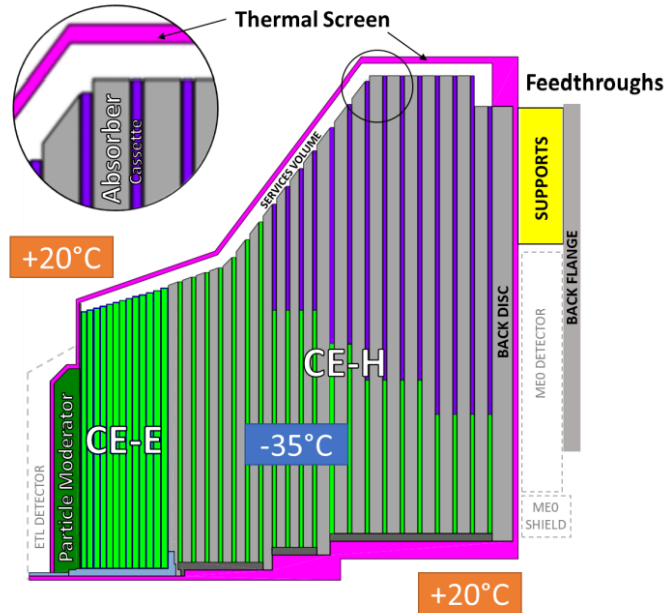
CMS High *Granularity* Calorimeter

Due to radiation degradation of the sampling scintillator in the forward calorimeter, and the physics potential of having good reconstruction in the forward rapidity region, CMS choose its replacement to leverage high granularity calorimetry techniques pioneered by CALICE for ILC.

- CE-E & inner CE-H use **Si sensors**, outer CE-H scintillator plastic as sampling material. HGCAL uses many silicon tracker technologies.

- $1.5 < |h| < 3.0$
- Maintained at -30ºC
- ~620m^2 Si area
- ~370m^2 of scint. tiles
- 6M Si channels, 0.5 or 1.1 cm^2 cell size



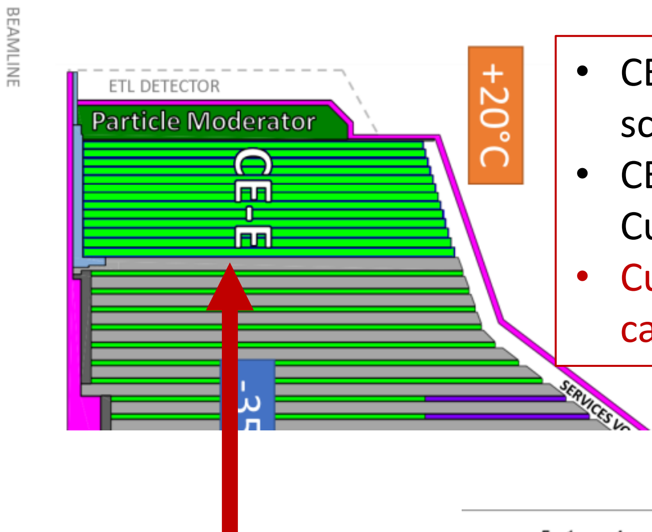


After Ukraine invasion, Russian institution collaboration with CERN and CMS in particular is at risk: ➔ CMS stablished a commonly shared fund (Detector Upgrade Fund) of 10 MCHF to cover shortfall in funding.

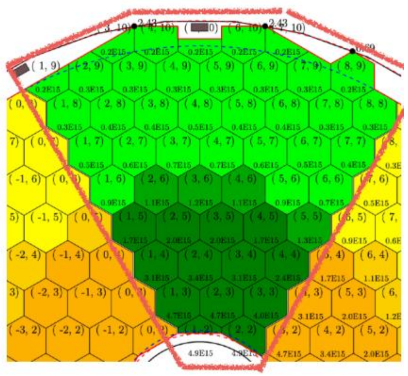
- Spain's fraction of the DUF is 3 %, which is set from the fraction of Spanish PhDs in CMS (fare-share).
    - Spanish fraction of CMS HL-LHC upgrade is roughly ½ of fare-share.
- Russian institutions were to provide in-kind CuW baseplates for Si modules.

HGC CuW Baseplates for CE-E Si modules

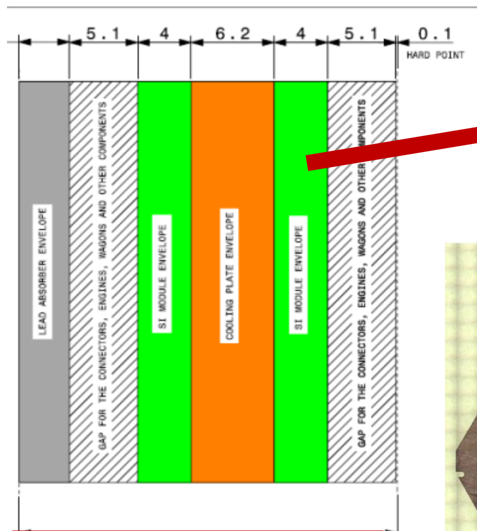
- CE-E & inner CE-H use **Si sensors**, outer CE-H scintillator plastic scintillators.
- CE-E uses CuW baseplates with Si modules attached to both sides of the Cu Cassette cooling plate
- CuW baseplates provide the module thermal and mechanical interface to cassettes as well as compact absorber material



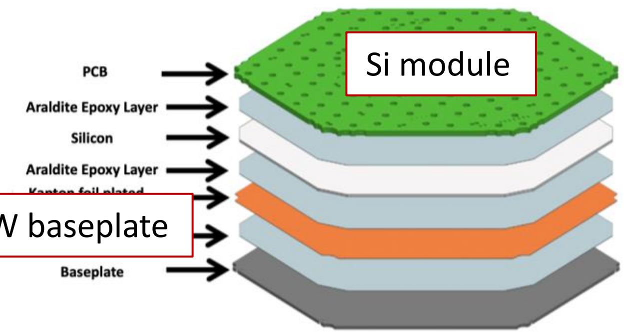
CE-E Cassettes

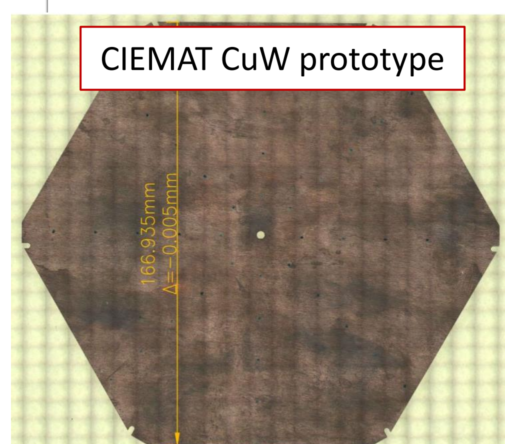


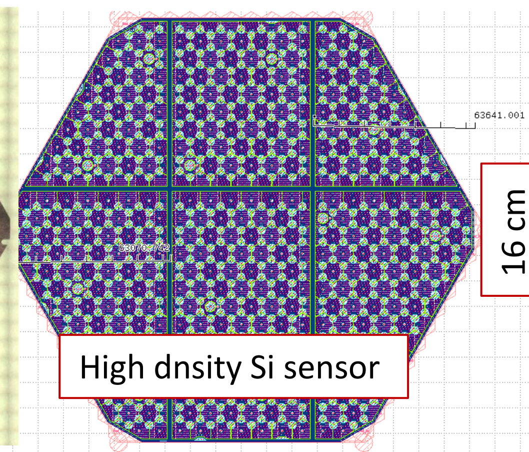
26 layers of modules in 13 double-sided cassettes covering 60 degree



Si modules cover both sides of the Cassette Cu cooling plate

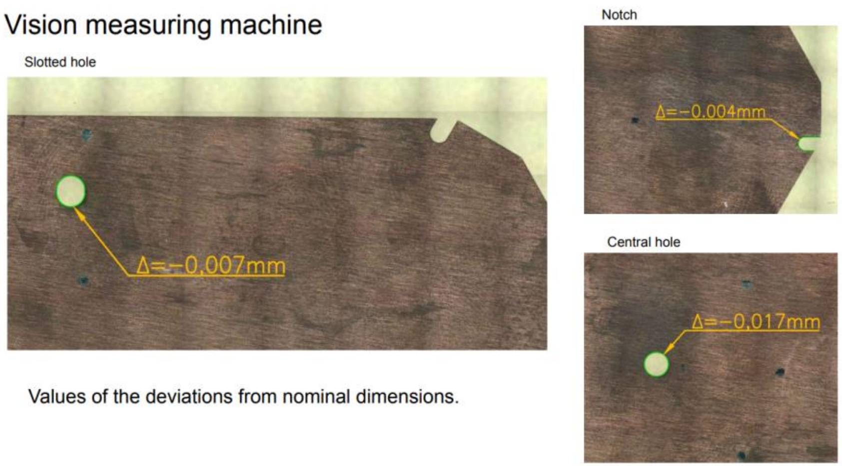


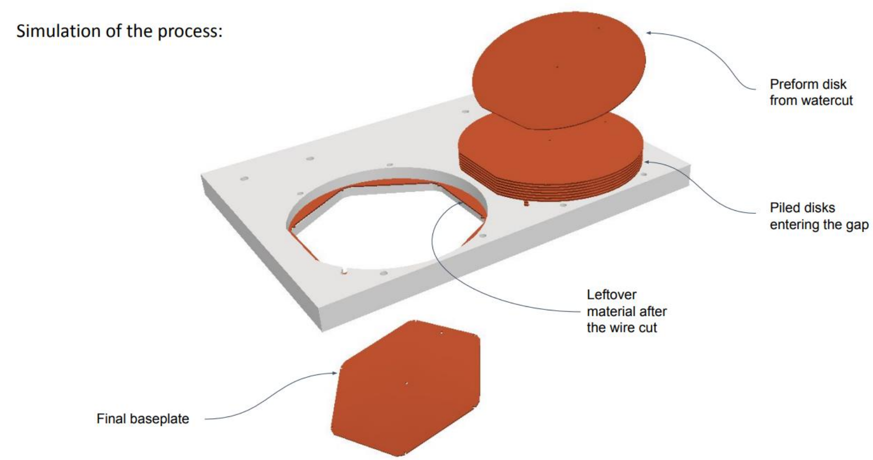




CIEMAT Contribution ot HGC CuW Baseplates

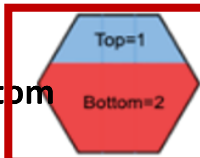
- So far: We have been doing several trials of cutting CuW baseplates (23 piece done) , building specific tools, **measuring the results** and **stablishing a process according to specs**.
- Also investigated its densitiy homogeneity using industrial radiography tools available at CIEMAT.





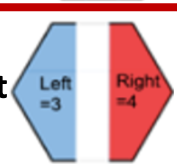
- Beyond Spain, China, Germany and India have also steppd up to cover Russian CuW contribution
- There are several types of baseplates.

804 LD top/bottom

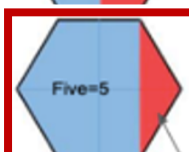


312 HD Botttom

360 LD Left/Right



312 HD Left/Right

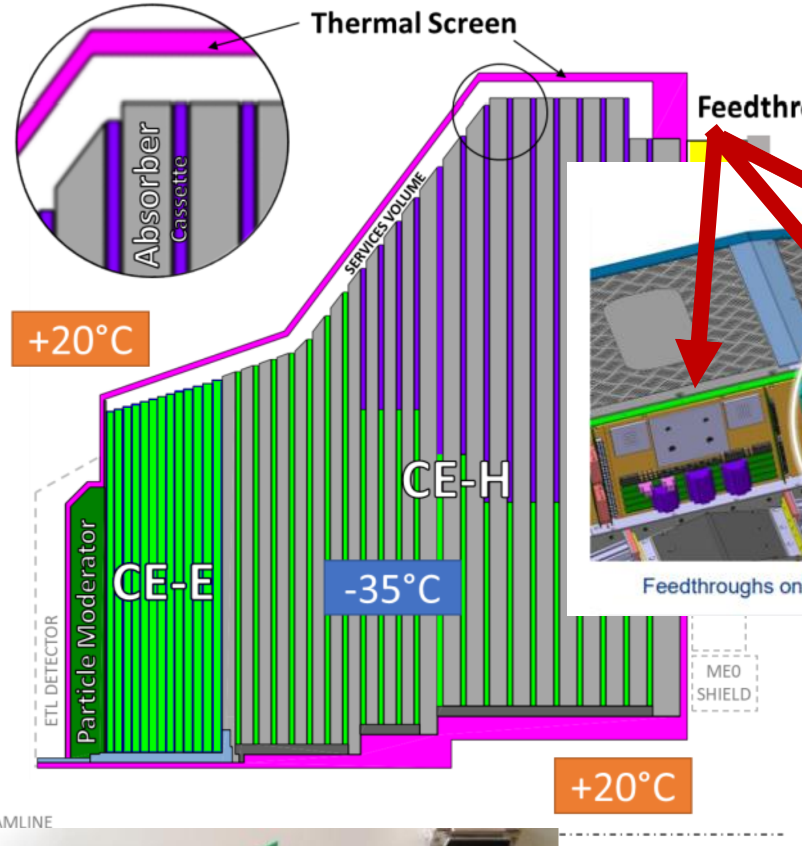


660 LD Five

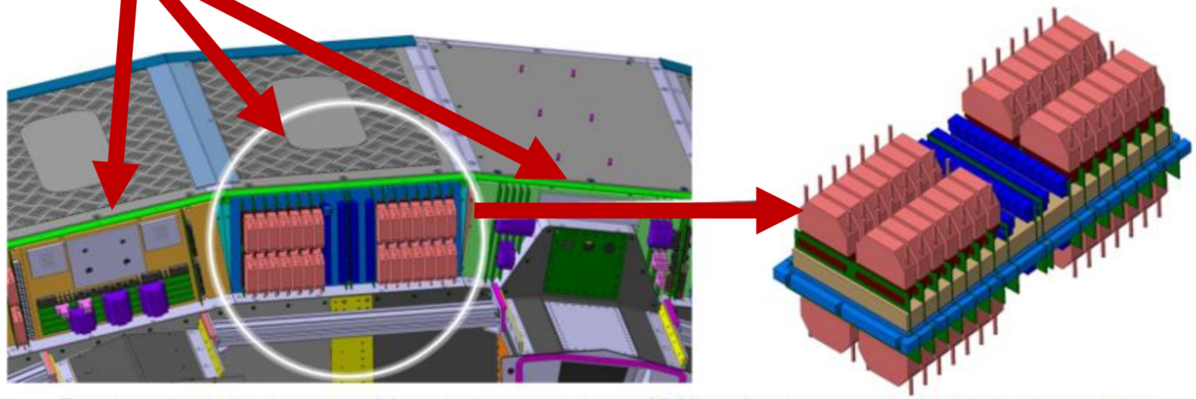
13164 Full hexagons

- CIEMAT targets producing a modest fraction of the CuW baseplates
- Being discussed as potential in-kind contribution to the DUF

HGC CuW Thermal Screen Feedthrough Ring

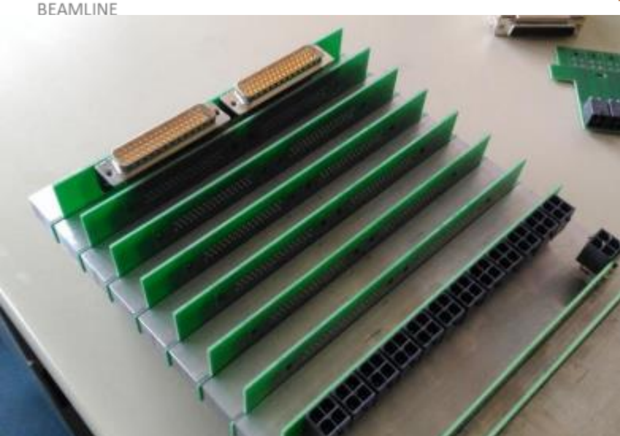


- CERN design, Thermal Screen will be likely become an in-kind UK contribution



Feedthroughs on thermal screen (L) and individual assembly of PCBs with connectors, Al-alloy blocks and insulation

- HGCAL attached to the bare disk in CMS without services (LV,HV, optical fibers)
- Ring of Service Feedthroughs allows passage of services for all layers, while keeping the sealing.
- Huge cabling density constraints technical choices.



- **CIEMAT** designed and produced the first **prototype**s of HV and LV thermal screen feedthroughs, used for Thermal Screenreview. Boards are simple but strict conditions due to harsh environmental conditions (radiation,+ magnetic field+cryo)
- **CIEMAT** preparing for the **pre-production**, due in January 24
- Total production consist **of 1200 PCBs of 19** types of simple PCBs
- Being discussed as a potential in-kind contribution

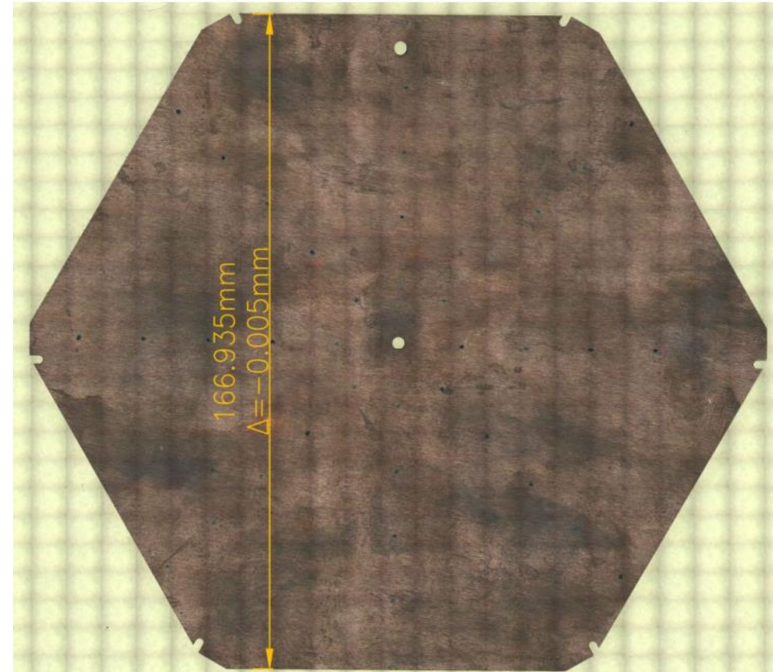
In Summary

- CIEMAT is responsable for **26 % of DT Upgrade**
  - Project is in production phase.
  - After several prototype cycles, final revision of **OBDTθ is** ongoing before full production is launched (**220 boards**).
  - Minicrate Mechanics hosting OBDT frames are validated and in production
  - Electronics architecture changes, with most of the intelligence moved to the backed, which is a common project between Muon-DT and L1T: **BMTL1**, a 42 ATCA board system.
- CIEMAT-UAM have developed the **AM** (Analytical Method) algorithm implementing analytical solutions for reconstructing the DT trigger primitives in FPGAs.
  - It exploits the maximum resolution achievable by the DT chambers, bringing the hardware system close to the offline performance capabilities.
  - Its performance have been demonstrated in CMS experiment during collisions
  - CIEMAT-UAM is responsible with University of Ioannia (Greece) for the BMTL1 HW&FW and collaborates closely with University of Oviedo on the BMTL1 **Filter** algorithm and BMTL1 online SW.
- Russian contribution shortfall endagers CMS upgrade, **HGCAL** in particular. CIEMAT have been helping in two areas ➔ Potential in-kind contributions:
  - HGCAL **CuW baseplates**
  - HGCAL **Thermal Screen Feedtrough** Ring

CIEMAT Contributions to HGCAL, so far

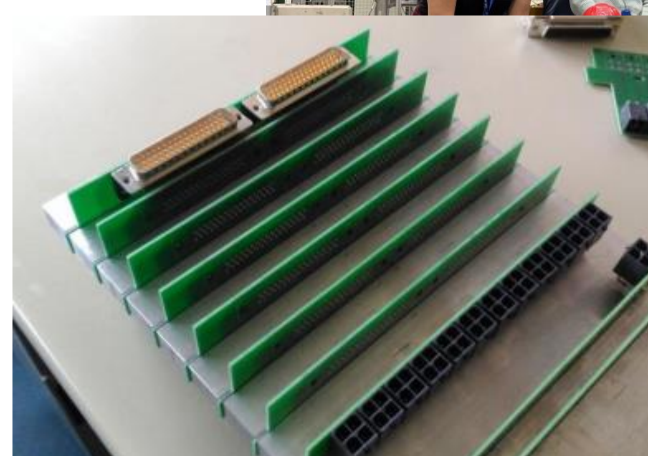
Since October 22 CIEMAT, among others, has answered the call to help HGCAL from CMS Upgrade management:

1-We have been doing several trials of cutting CuW baseplates (23 pieces will be done) heatsink &interface of the Si modules, building specific tools, measuring the results and stablishing a process according to specs. Also investigated its densitiy homogeneity using industrial radiography tools available at CIEMAT.



2- Some limited participation on commissioning activities at CERN like participating in a SPS testbeam of HGCAL modules.

3- Designed and produced the first prototypes of HV and LV thermal screen feedthroughs, used to pass the thermal screen PRR (CMS internal review). Boards are simple but strict conditions due to harsh environmental conditions (radiation,+ magnetic field+cryo)



CMS HL-LHC Upgrade