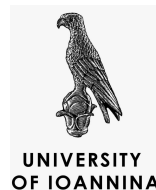


# Results using data from proton-proton collisions at the LHC collected using the CMS Barrel Muon Trigger electronics for Phase-2

*HEP2023 - 40th Conference on Recent Developments on High Energy Physics and Cosmology,  
Ioannina, Greece*

7 April 2023

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# Outline

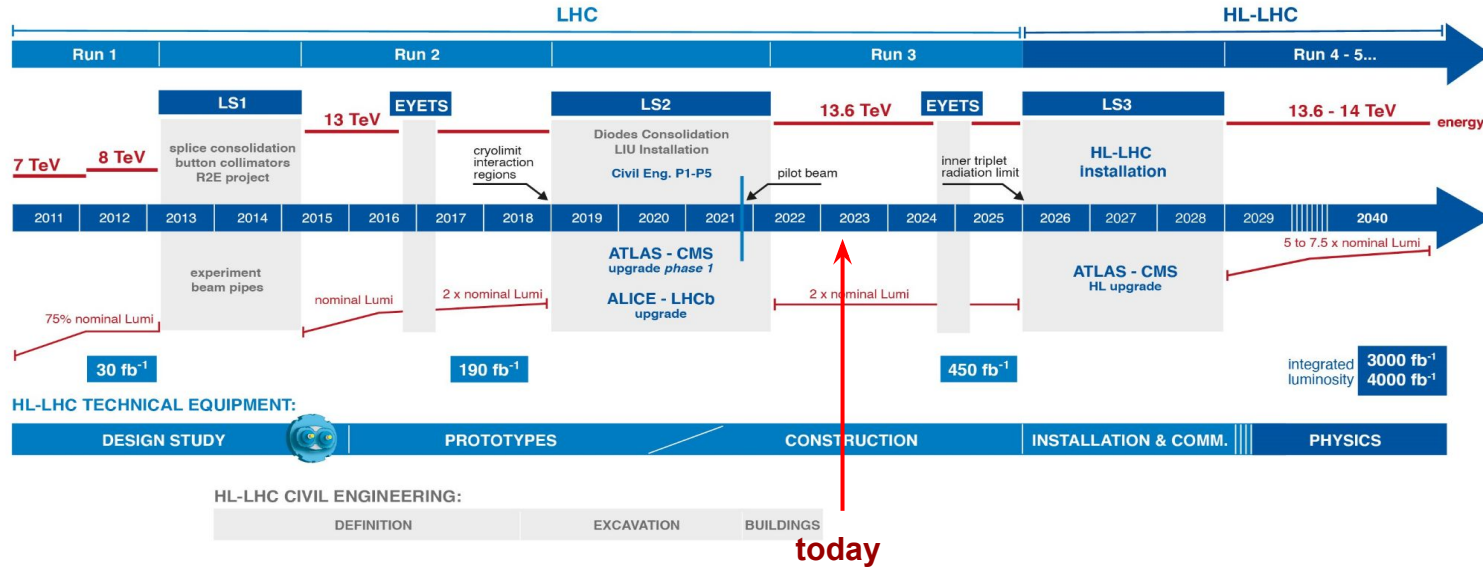
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- CMS & Level-1 Trigger for Phase-2
- Barrel Muon Trigger architecture
- Barrel Muon Trigger Layer-1
- Slice test at USC with proton-proton data
- Current status & Plans

# LHC/HL-LHC Plan



## LHC / HL-LHC Plan



# Compact Muon Solenoid at Phase-2

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T

STEEL RETURN YOKE  
12,500 tonnes

### SILICON TRACKERS

Pixel ( $100 \times 150 \mu\text{m}^2$ )  $\sim 1.9 \text{ m}^2 \sim 124\text{M}$  channels  
Microstrips ( $80\text{--}180 \mu\text{m}$ )  $\sim 200 \text{ m}^2 \sim 9.6\text{M}$  channels

### SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying  $\sim 18,000 \text{ A}$

### MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers  
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

### PRESHOWER

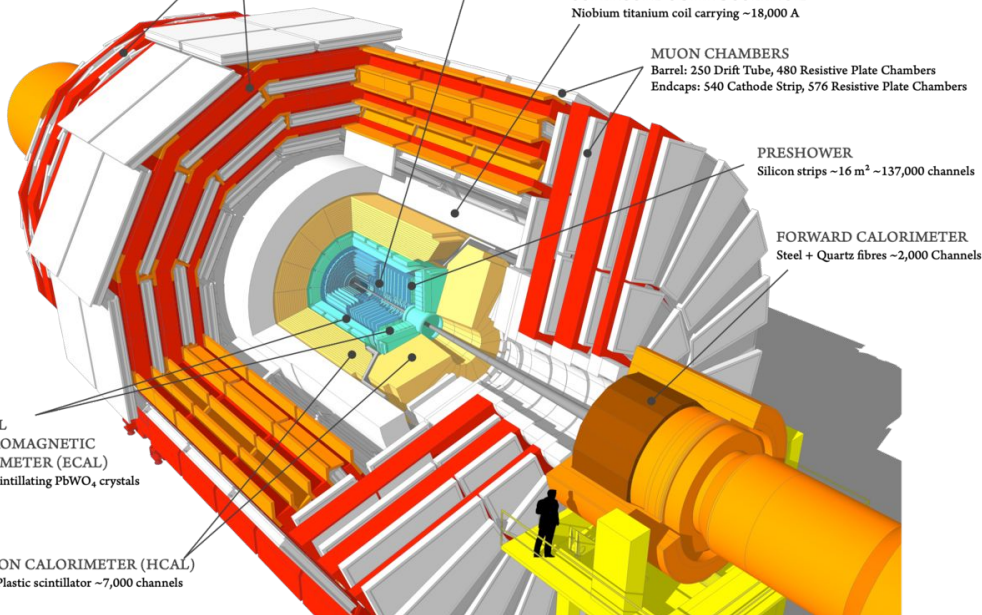
Silicon strips  $\sim 16 \text{ m}^2 \sim 137,000$  channels

### FORWARD CALORIMETER

Steel + Quartz fibres  $\sim 2,000$  Channels

CRYSTAL  
ELECTROMAGNETIC  
CALORIMETER (ECAL)  
 $\sim 76,000$  scintillating  $\text{PbWO}_4$  crystals

HADRON CALORIMETER (HCAL)  
Brass + Plastic scintillator  $\sim 7,000$  channels



## ➤ High-Luminosity LHC

- Peak instantaneous luminosity  
 $7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-2}$
- Pileup of 200

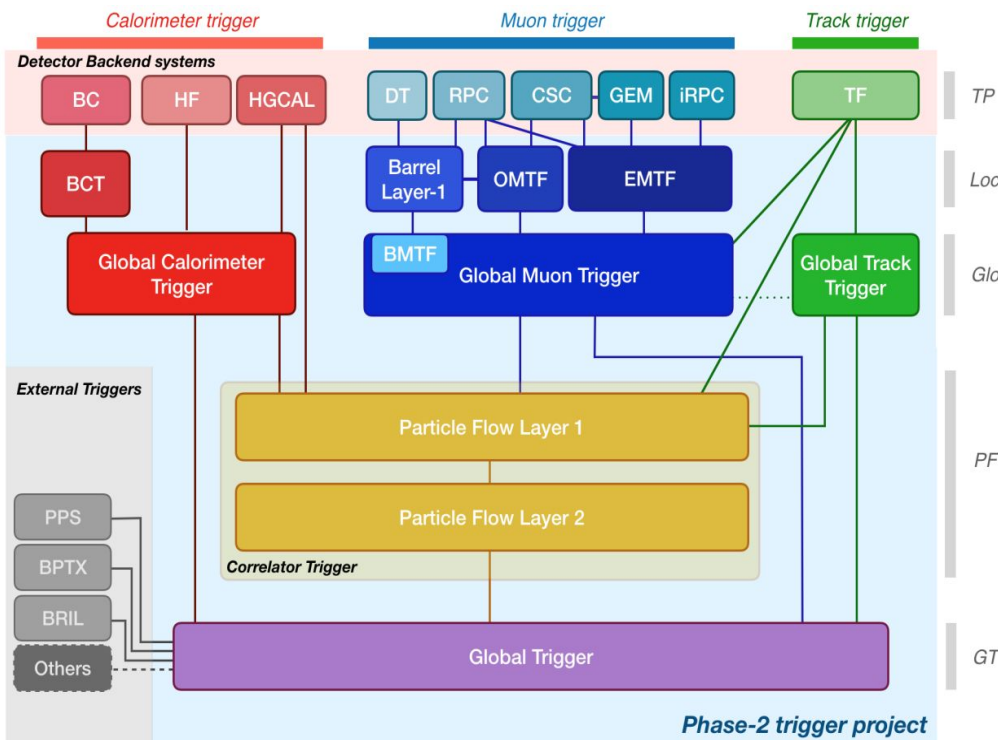
## ➤ CMS at Phase-2

- Major detector and on-detector electronics upgrades
- Complete replacement Trigger and DAQ systems

## ➤ Trigger System

- Level-1
  - Entirely **custom processors** running on powerful FPGAs
  - Output rate 750 kHz & latency 12.5  $\mu\text{s}$
- High Level Trigger
  - **CPUs and GPUs**
  - Output rate 7.5 kHz

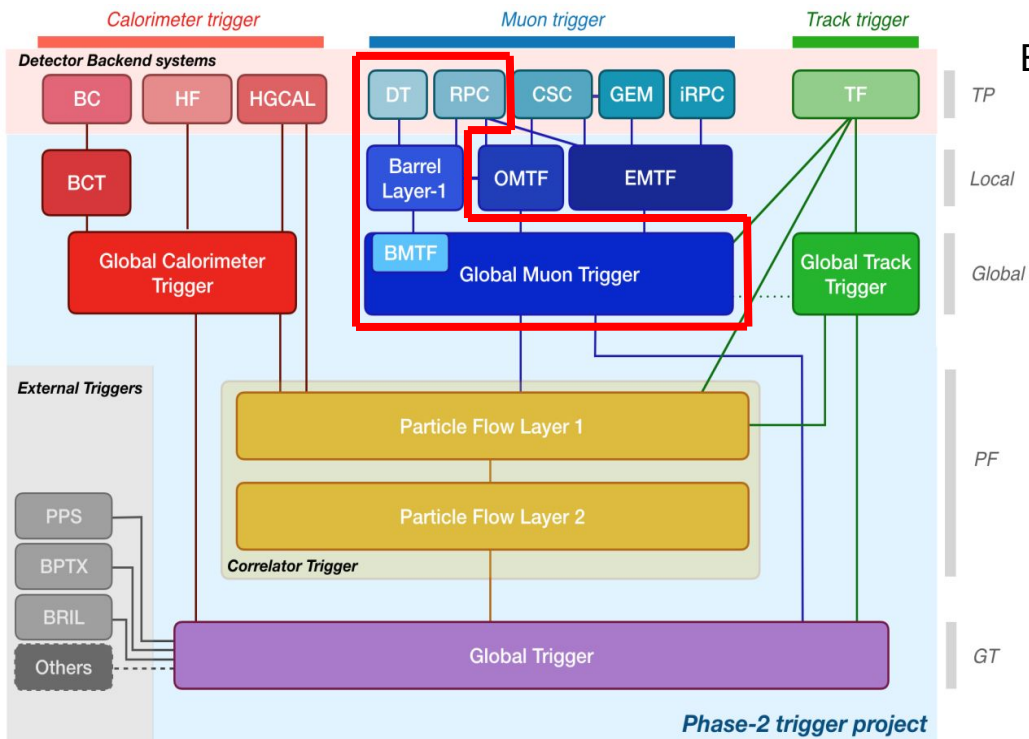
# CMS Level-1 Trigger for Phase-2



## Four independent data processing paths

- **Calorimeter Trigger**
  - Builds **calorimeter-only objects**
  - $e/\gamma$ , tau leptons, jets and energy sums
- **Muon Trigger**
  - Reconstructs **muons** and performs track matching
- **Track Trigger** (*not present in Phase-1*)
  - **Reconstructs tracks** of charged particles
- **Correlator Trigger** (*not present in Phase-1*)
  - Runs Particle-Flow reconstruction algorithms to **produce higher-level trigger objects**
  - Provides a sorted list of objects to the Global Trigger
- **Global Trigger**
  - Receives outputs of the four Trigger paths
  - **Runs physics menu** of algorithms
  - Calculates the **trigger decision** - **accept or ignore** an event

# Barrel Muon Trigger (BMT)



## BMT reconstructs Muons of the CMS Barrel

### ➤ On-Detector

- Drift Tubes (DT) and Resistive Plate Chambers (RPC) transmit Muon hits to BMT Layer-1

### ➤ BMT Layer-1 (BMTL1)

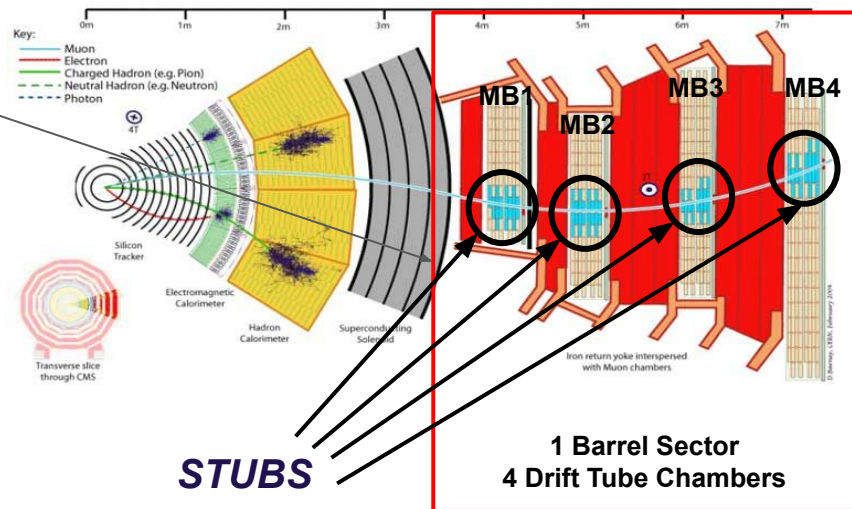
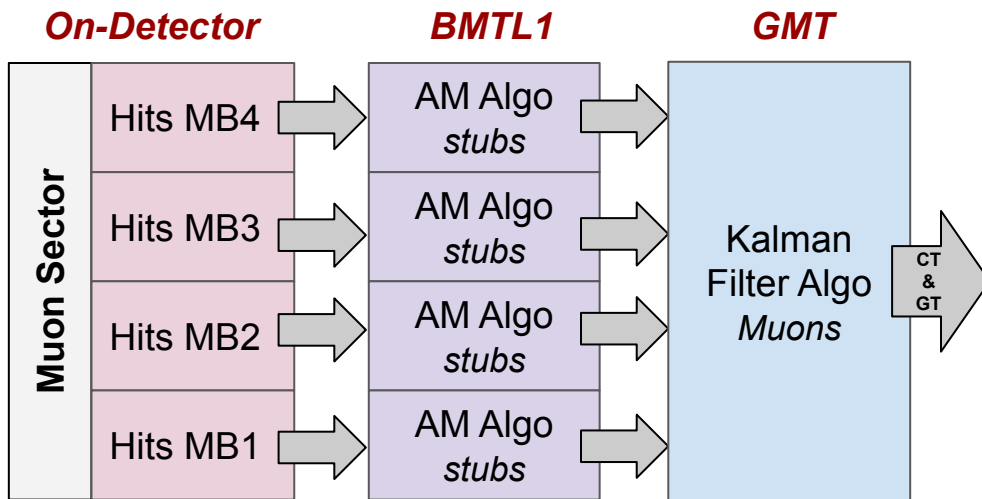
- Builds DT track segments and clusters RPC hits
- Merges both sub-system information to the combined “super-primitives”

### ➤ Global Muon Trigger (GMT)

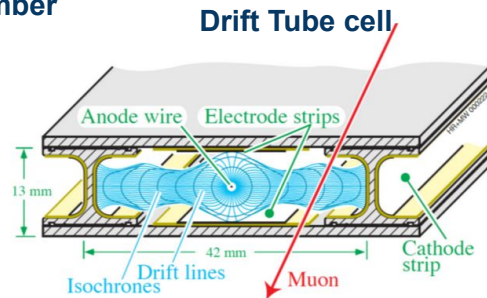
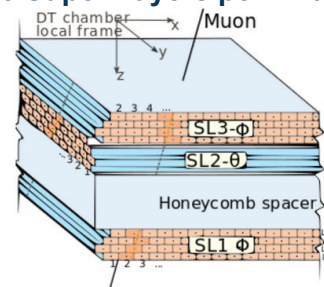
- Matches track segments to reconstruct standalone Muon candidates

# Barrel Muon Trigger

- CMS Barrel consists of **60 Muon Sectors**
- One Sector contains 4 Chambers
  - Chambers made of 3 Super Layers of DT cells
- DT cells produce charge pulse when particles pass through

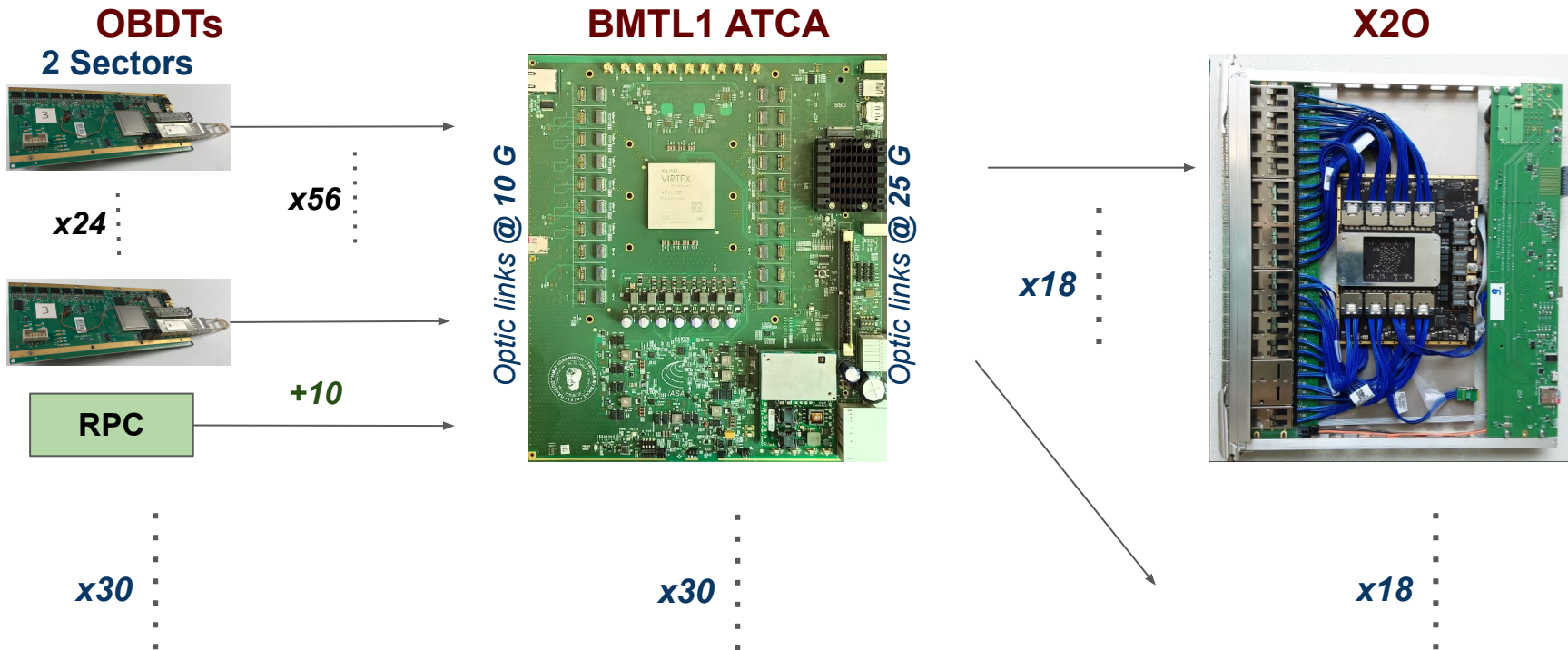


## 3 Super Layers per Chamber





# Barrel Muon Trigger Architecture



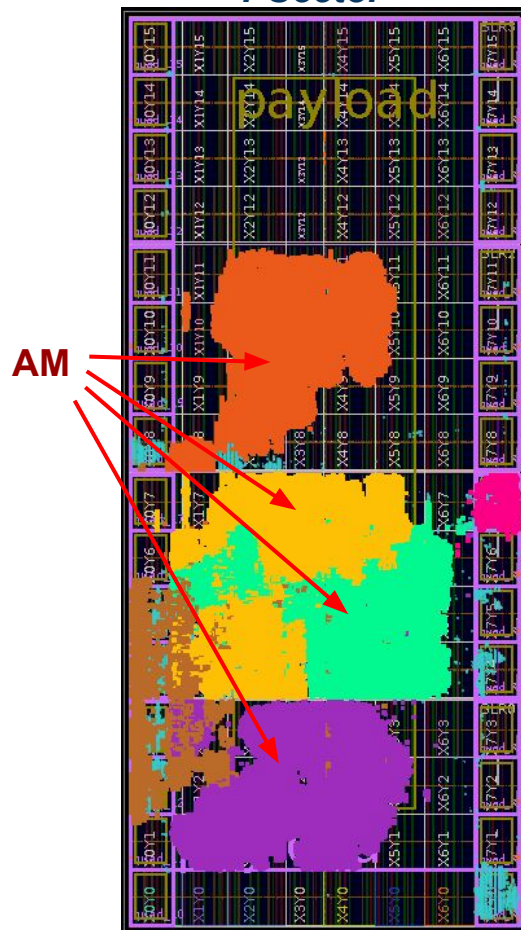
	Sectors	Input links	Output links
<b>1 BMTL1 Board</b>	2	66	18
<b>BMTL1 System</b>	60	1980	540



# BMTL1 Firmware

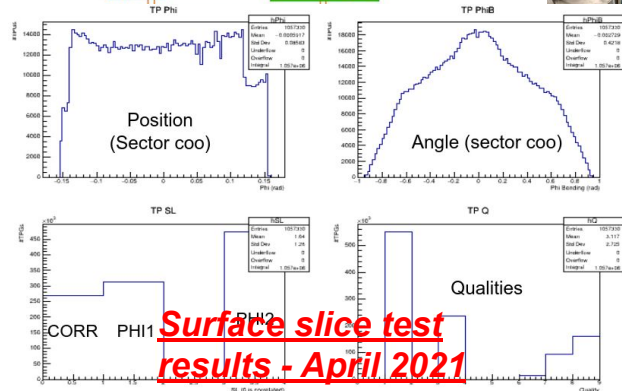
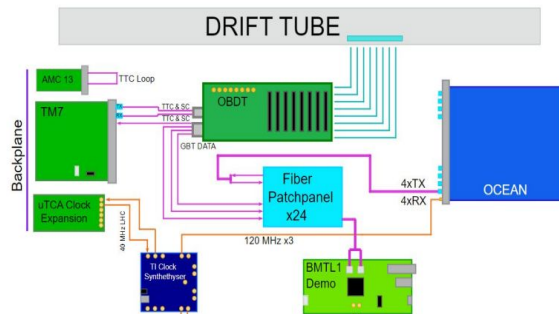
- Runs on BMTL1 ATCA processor
  - Hosts 1 powerful **VU13P FPGA**
  - Extended IO capability with optical links at **16 & 25 Gbps**
- Firmware of BMTL1
  - Uses EMP-FWK (*Serenity*) - provides basic functionalities
    - **Software interface** for firmware control
    - **TTC, TCDS2 & Readout** interface
    - Optical link protocols
      - **CMS Standard Protocol** (*co-developed by Ioannina*)
      - **GBT & IpGBT**
  - Hosts the Analytical Method (AM) algorithm (provided by CIEMAT)
    - Performs **per Chamber processing of DT hits**
    - Produces **track segments** - stubs - Trigger Primitives
      - Bunch Crossing, Stub Position & Bending Angle, etc

## Implementation of 1 Sector

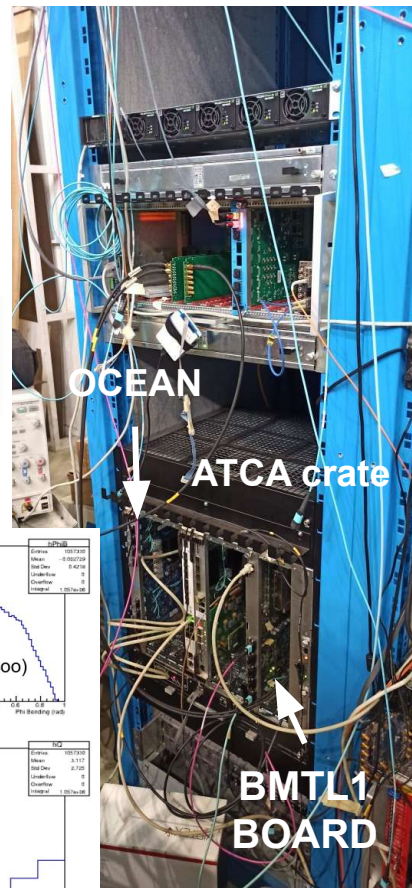


# DT test area at CMS surface

- DT area at p5 surface is used for **integration tests of the BMT system**
  - Tests started September 2021 with prototype hardware
- A real DT Chamber is installed
- Goal was to perform full chain slice test
  - **DT Chamber -> OBDT -> BMTL1 -> GMT**
- **Cosmic Muons** passing through DT Chamber
- OBDT transmits **TDC hits to BMTL1**
  - 1 optical link @5G
- **BMTL1 produces stubs & transmits to GMT**
  - 1 optical link @16G
- **GMT receives and writes stubs for analysis**
  - **On hard disk** using integrated scouting system
- On October 2022 **Slice Test successfully replicated** using BMTL1 pre-production ATCA board

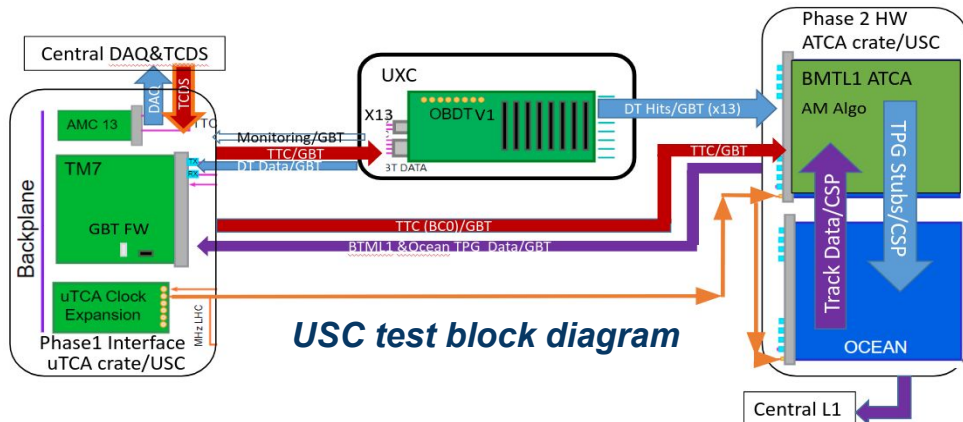


**Surface slice test results - April 2021**

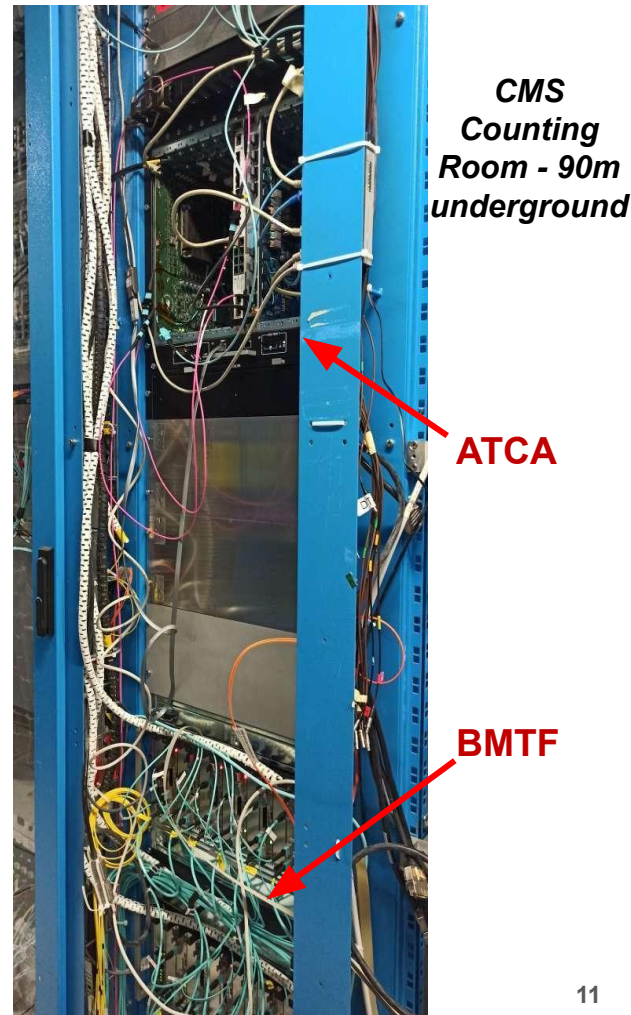


# Slice Test at USC

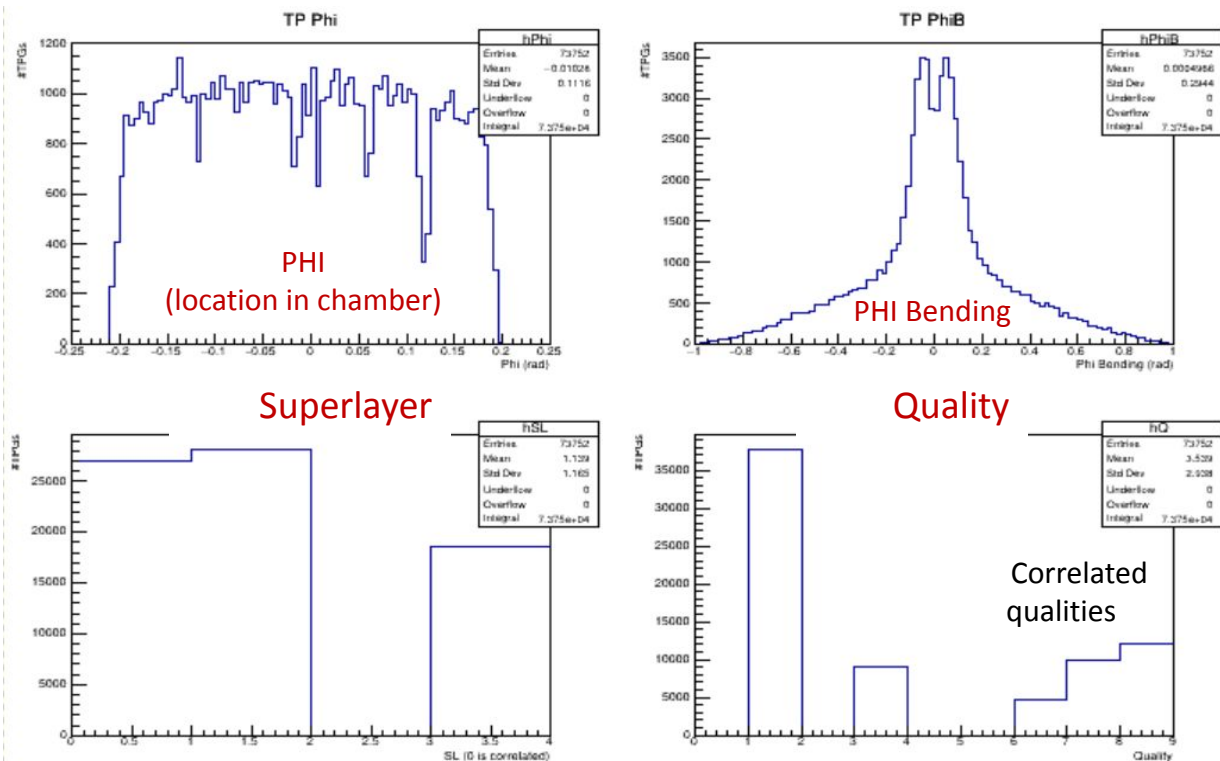
- An **ATCA crate** was installed at **USC** summer 2022
  - On the same rack as BMTF Phase-1 system
- **13 OBDTs** were already installed in 1 DT Sector
  - Transmitting hits from all 4 Chambers
- On November 2022 we installed the **surface system on the CMS Counting Room**
- Received **LHC clock** through **SMA**
- **BC0** received via **optical link** from a Phase-1 TM7 board
- Managed to **write TPs** last days of 2022 p-p run



*USC test block diagram*



# Results from proton-proton collisions data



- BMTL1 TPs (stubs) written at disk on GMT
- Most of the time took data with MB3 with 15 s samples separated by 5 minutes gaps
- ~4 KHz of TPGs from MB3 as legacy trigger.

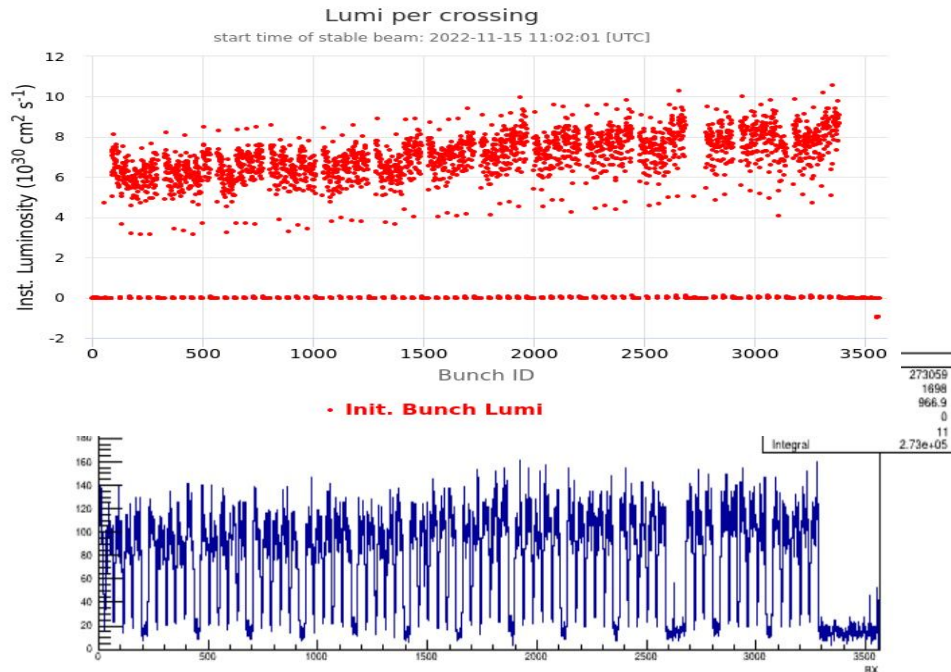
**DT TP  
Format**

Data field	Fine t0 (ns)	BX in-orbit	Position (Phi)	Bending angle (PhiB)	Chi2	RPC info	Quality	Spare	SuperLayer	Chamber
Bits	5	12	17	13	4	3	4	2	2	2



# Results from proton-proton collisions data

## Inst. Luminosity within the orbit from BRIL/OMS



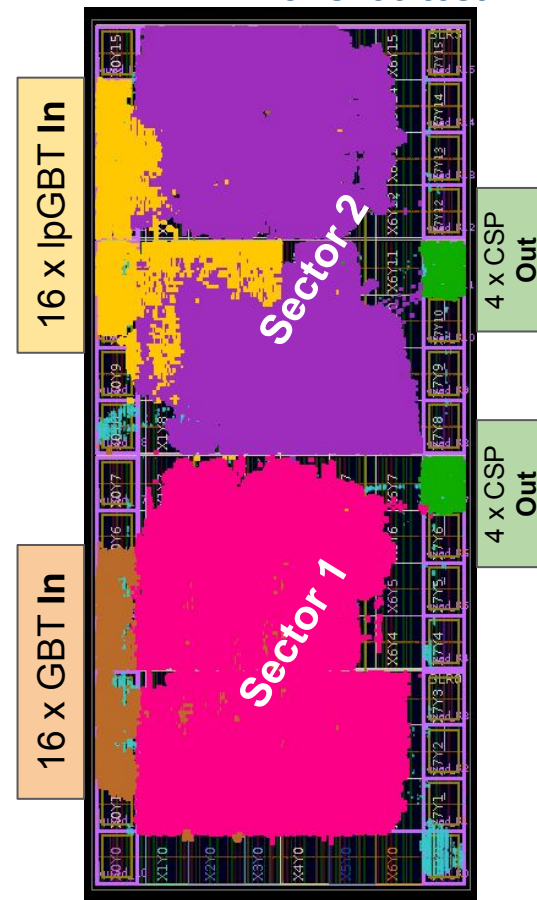
➤ Bunch Crossing  
number produced by  
BMTL1 TPs

## BMTL1 BX Number from MB3 @ Ocean

# Current Status and Plans

- Many blocks are **still not present**
  - Receive through IpGBT links
  - Transmit at 25G
  - Algorithm blocks
    - Theta SL processing
    - Phi and Theta matching
  - Perform Muon tracking at GMT
  - Advanced readout
- Board moved **back at surface** for further development and tests
- A second **Sector** is instrumented with OBDTv2 (Ipgbt)
- The setup will **move again underground** when ready
  - **Goal this time is to produce Muon tracks**

*BMTL1 FW for slice test*



# Summary

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- Vertical integration of the Barrel Muon Trigger has been successfully demonstrated
  - DT -> OBDT -> BMTL1 -> GMT
- Managed to run Phase-2 electronics in parallel with Phase-1 proton-proton collisions
  - And produce good results
- Many more to be done but slowly moving toward the final system

**Thank you!**

