The CMS Barrel Muon Trigger Upgrade

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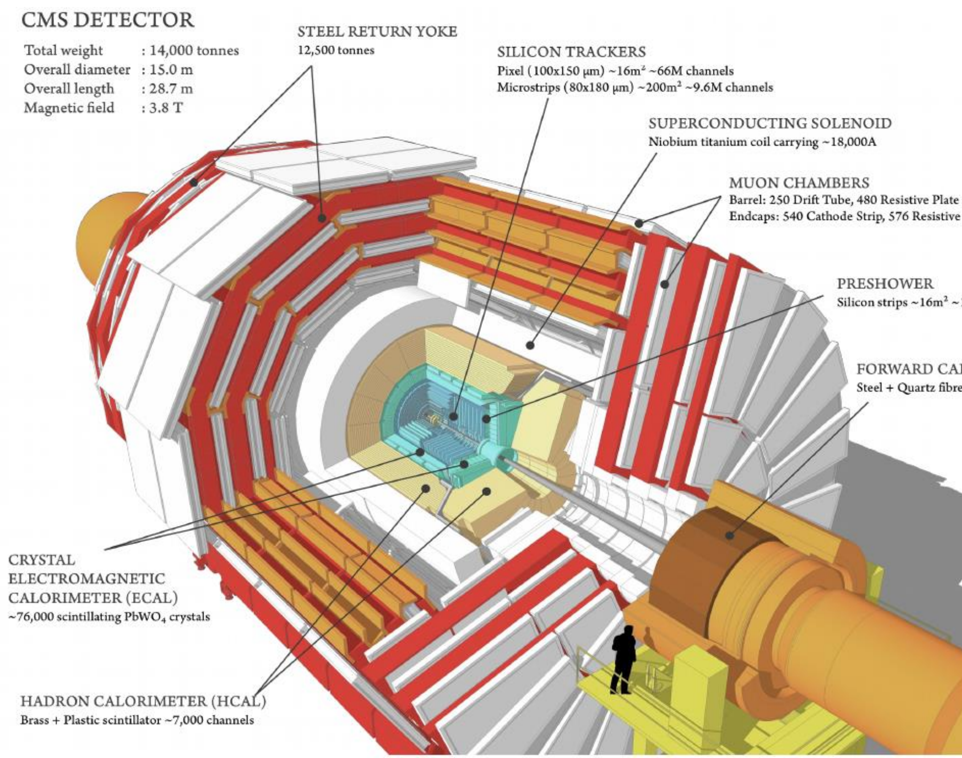
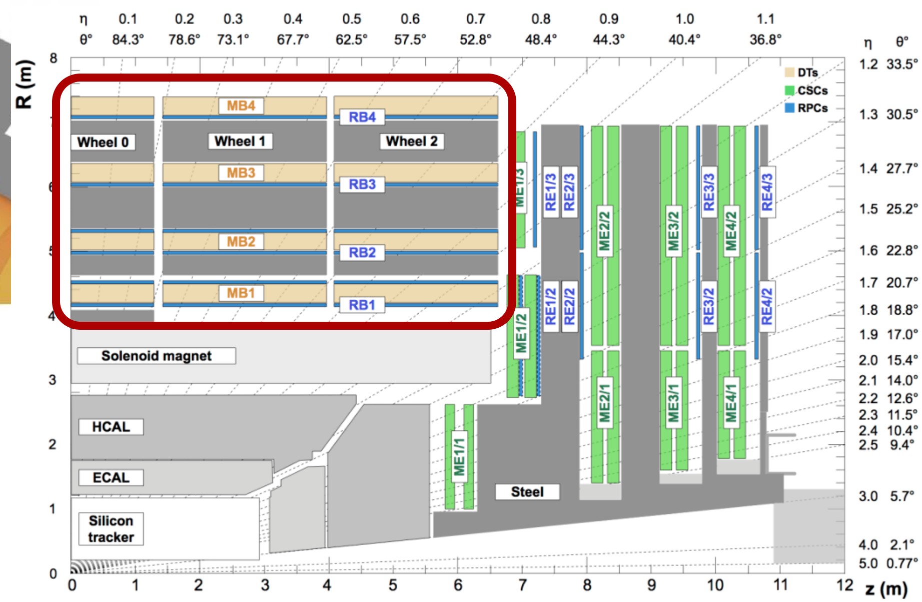
on behalf of CMS Collaboration

Contents



- Goals and motivations
- L1-Trigger Upgrade overview (beginning 2016)
- Barrel Muon Electronics upgrade from LS1 to LS2



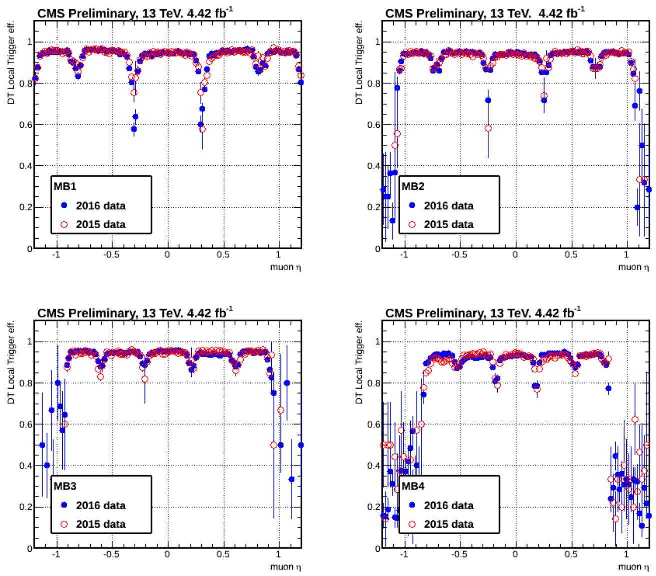
DT: Drift Tubes

RPC: Resistive Plate Chambers

- DT data concentrator (TwinMux) Hardware, Firmware and Software
- Barrel Muon Track Finder (BMTF) Hardware Firmware and Software
- DT-RPC combination

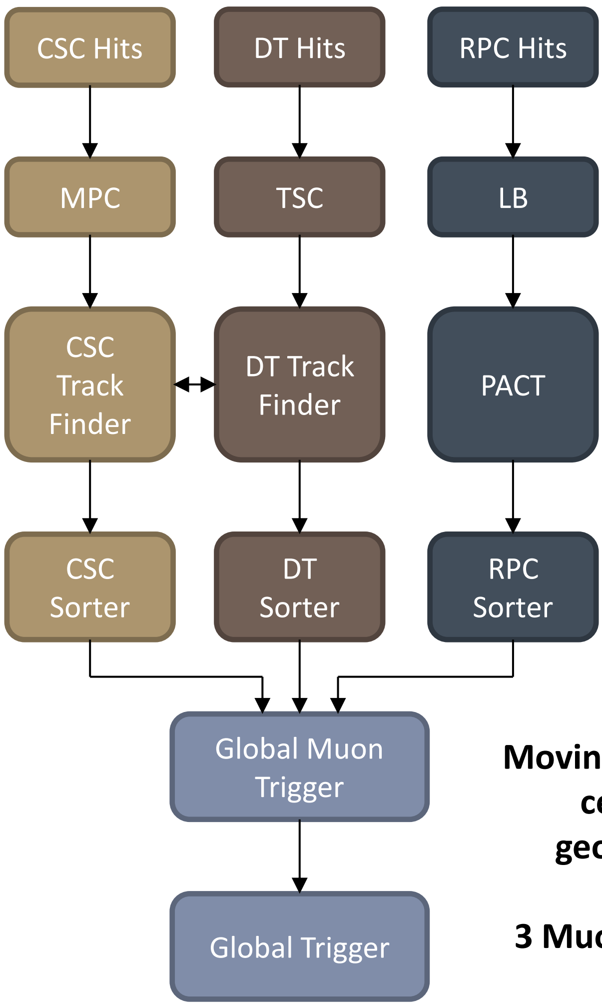
Goals and Motivations

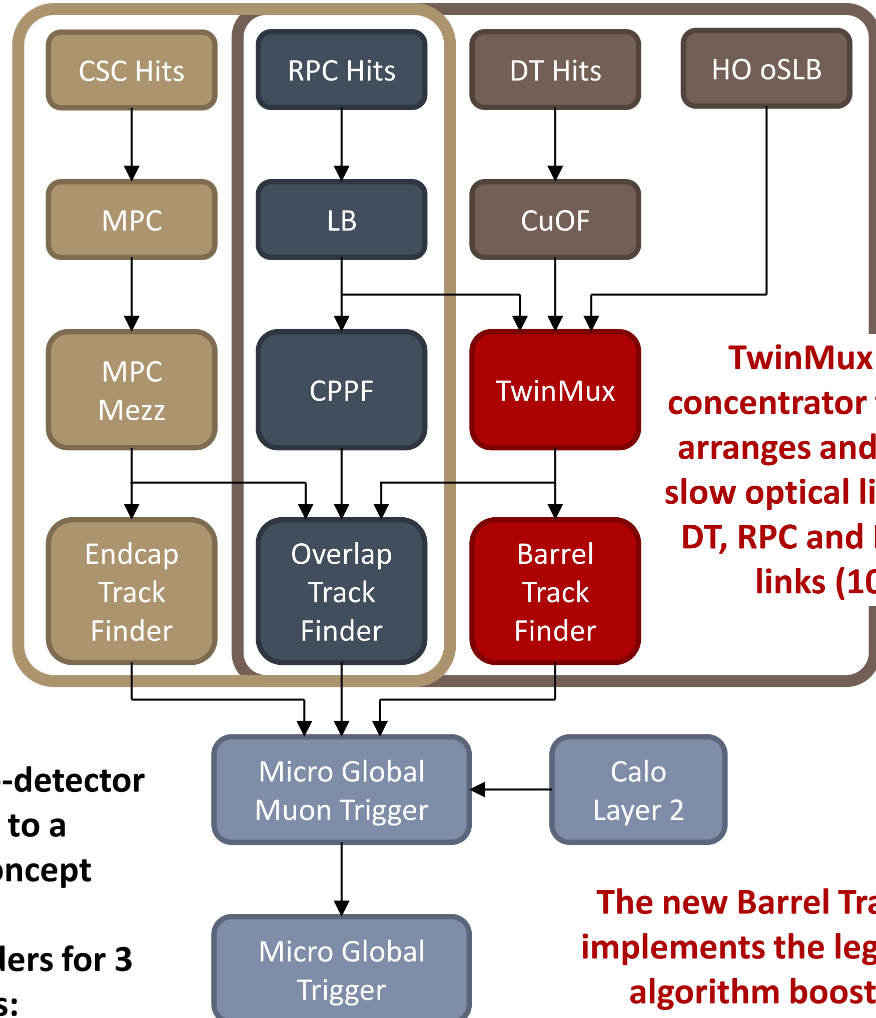
- Maintain about the same physics acceptance as in Run1 but at higher luminosity $\sim 2 \cdot 10^{34}\ cm^{-1}s^{-1}$
- Increase rate reduction improving the P_t assignment
- Improve flexibility to adapt to new conditions and to exploit new possible trigger path
- Reduce limitations in the data flow from on detector electronics to the back end electronics
- Exploring new trigger algorithm combining several sub-detectors or exploiting trigger primitives at a finer granularity
- Overcome present track finding efficiency limitations (crack regions)
- Improve robustness and longevity



Technical Design Report for the Level-1 Trigger Upgrade, CERN-LHCC-2013-011. CMS-TDR-12, Jun 2013

Where Are We in the L1 Upgrade?





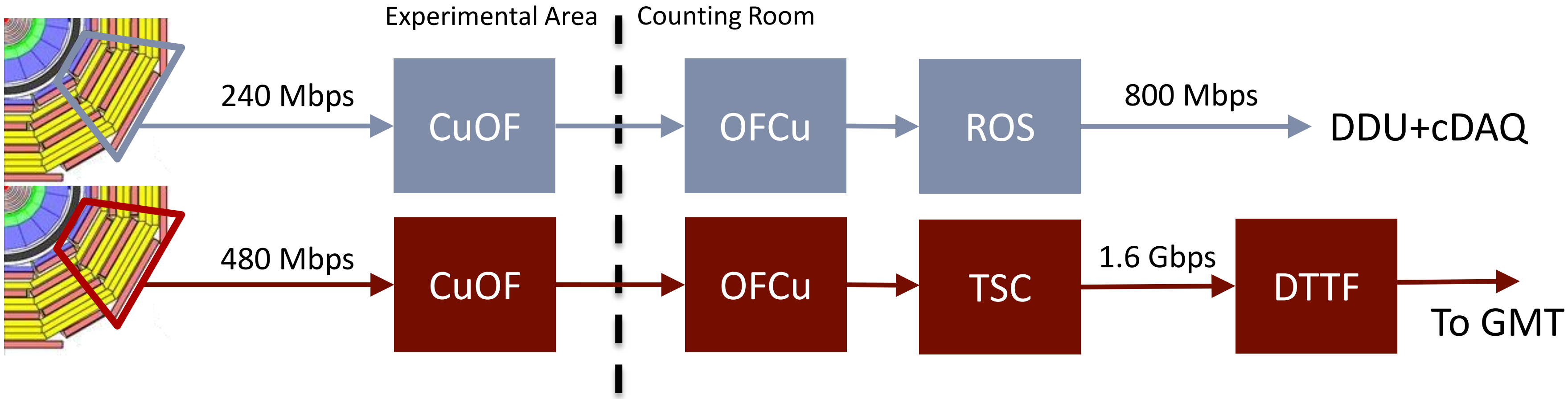
TwinMux is a data concentrator that merges, arranges and fan-out the slow optical links from the DT, RPC and HO in faster links (10 Gbps)

Moving from a sub-detector centric layout to a geographical concept

3 Muon Track Finders for 3 eta regions:
BarrelMTF OverlapMTF EndcapMTF

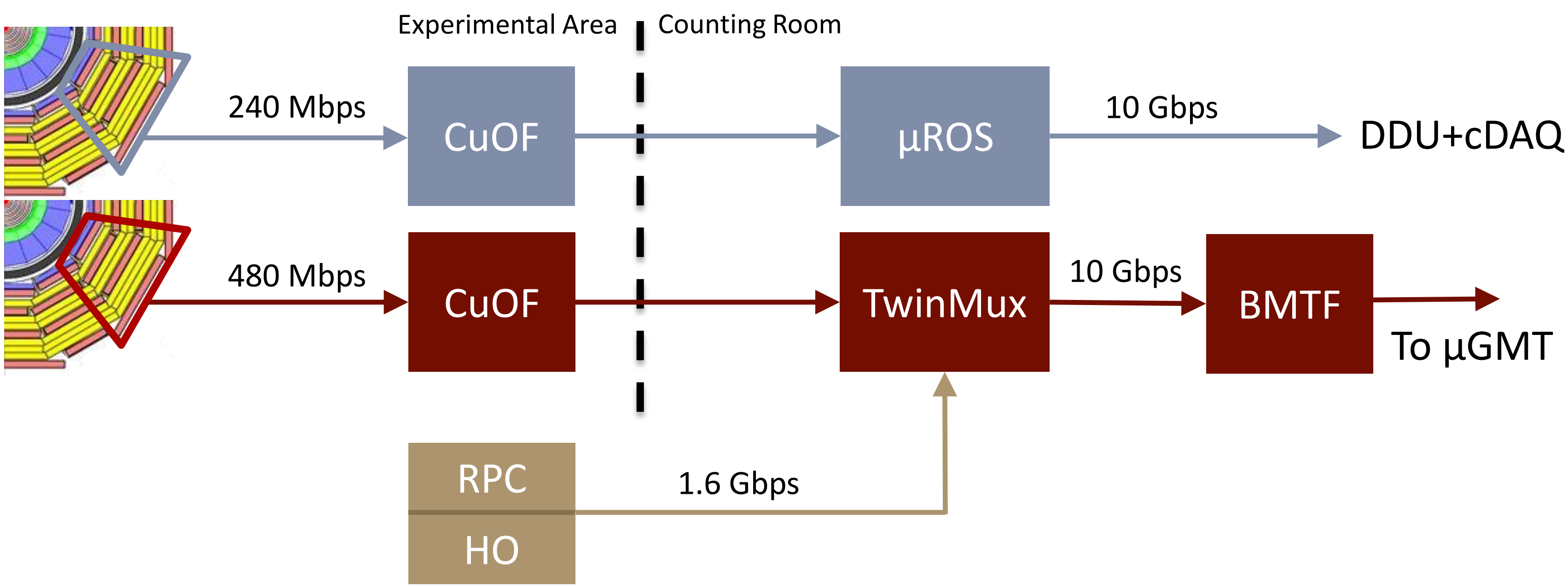
The new Barrel Track Finder implements the legacy trigger algorithm boosting rate reduction at higher efficiency

DT System After LS1



- During LS1 Trigger Sector Collector and Read Out Server crates have been relocated by simple electronics converting copper signal to optical. CuOF does a parallel conversion from copper to optical and OFCu reconverts the signal to copper
- «Intelligent» electronics removed from radioactive zone:
  - Data collection reliability improved
  - Decoupling between LHC stops and future improvements and installations

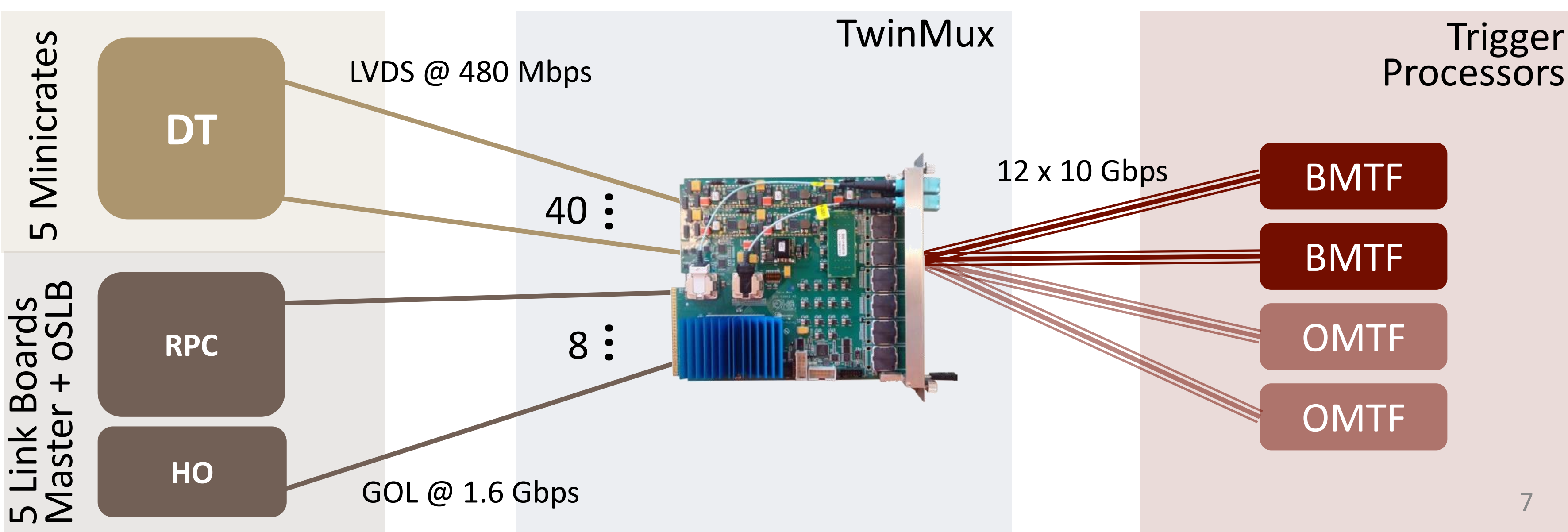
Complete Improvement: Run2



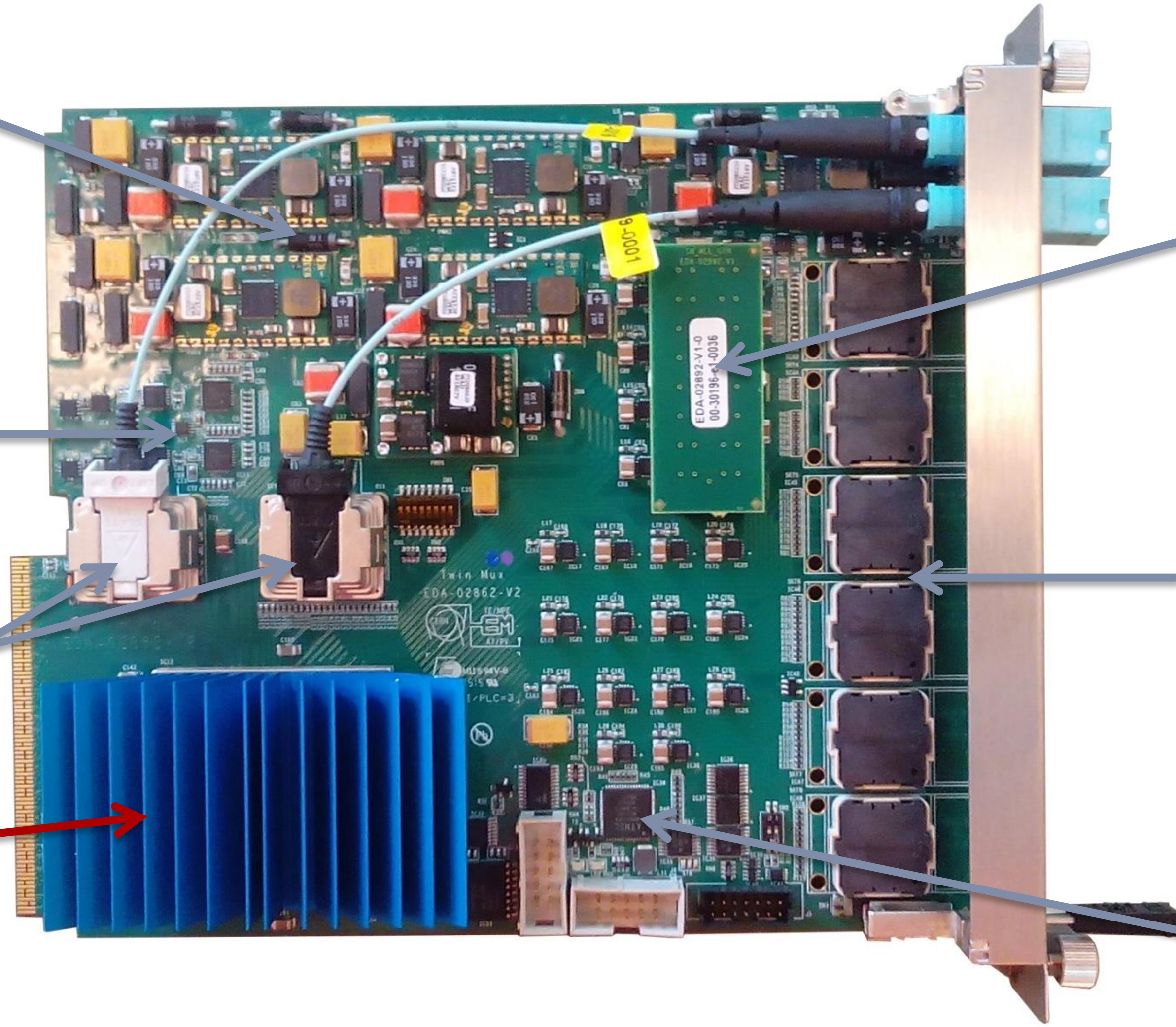
- More powerful electronics based on µTCA has replaced the Trigger Sector Collector and will replace the Read Out Server. Such electronics is needed to overcome the limitations from the increase of luminosity in terms of processing speed and trigger rates
- Optical decoupling facilitated the electronics improvement without interfering LHC schedule (optical splitting)

DT-RPC-HO to Track Finders

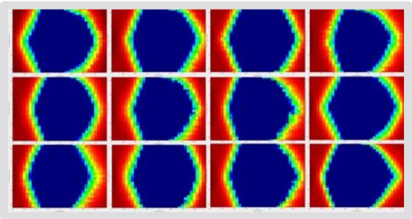
- Early combinations of DT+RPC+HO can be useful for improving the LV1 trigger efficiency in the gaps between wheel YB0 and YB±1
- DT+RPC joined information combines DT segment identification and position resolution with RPC temporal resolution
- Primitives replication to avoid data exchange among trigger processors
  - It minimizes latency and simplifies interconnections



TwinMux Hardware

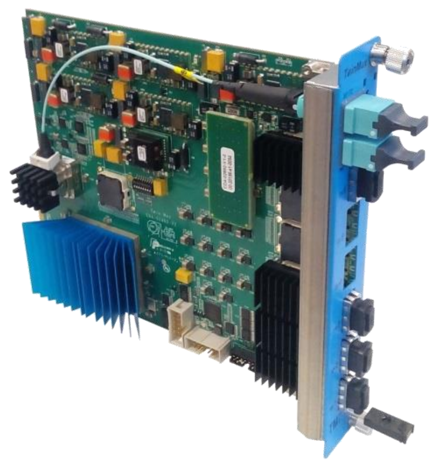


Hardware Validation and Installation

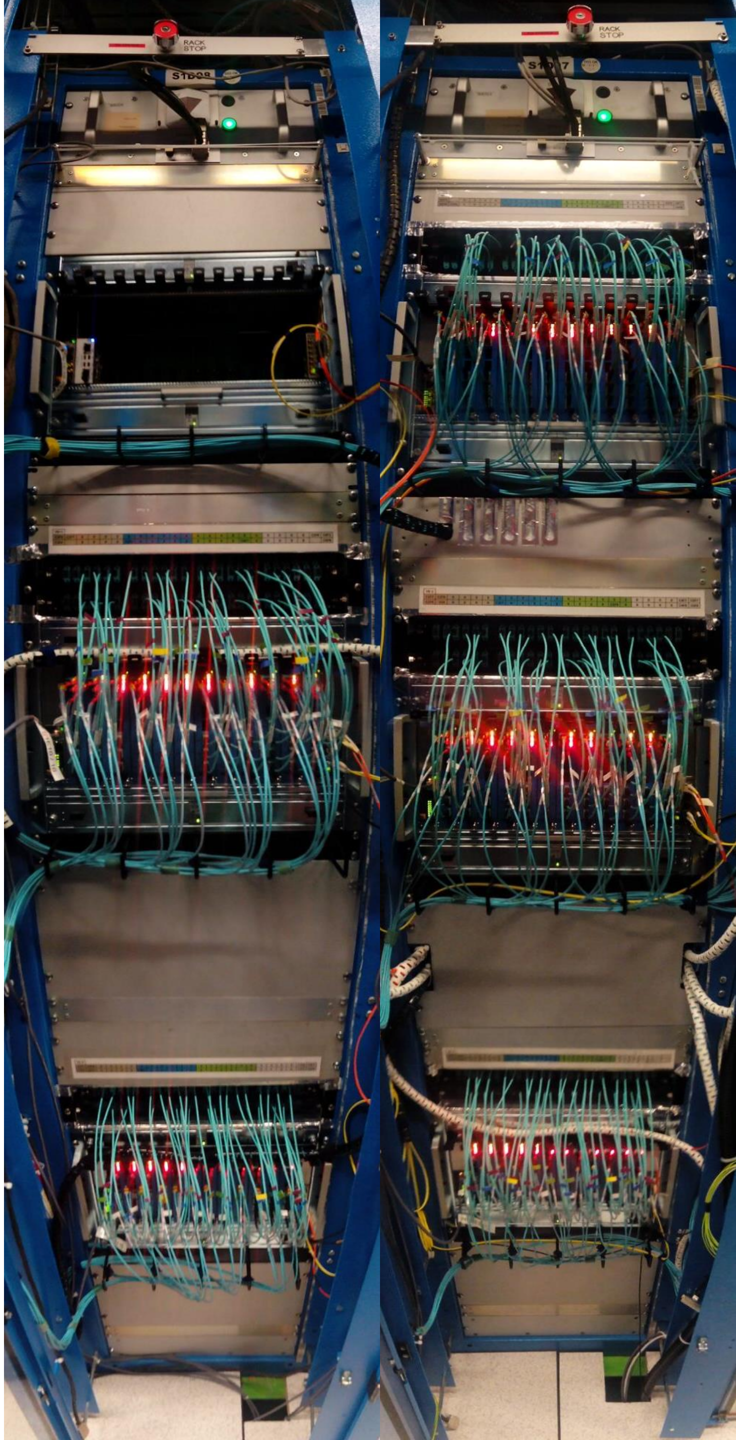


10Gbps Eye Diagrams

- Pre-series: 12 boards
  - No major issues found
  - 6 boards extensively tested in a slice test in parallel with Run1

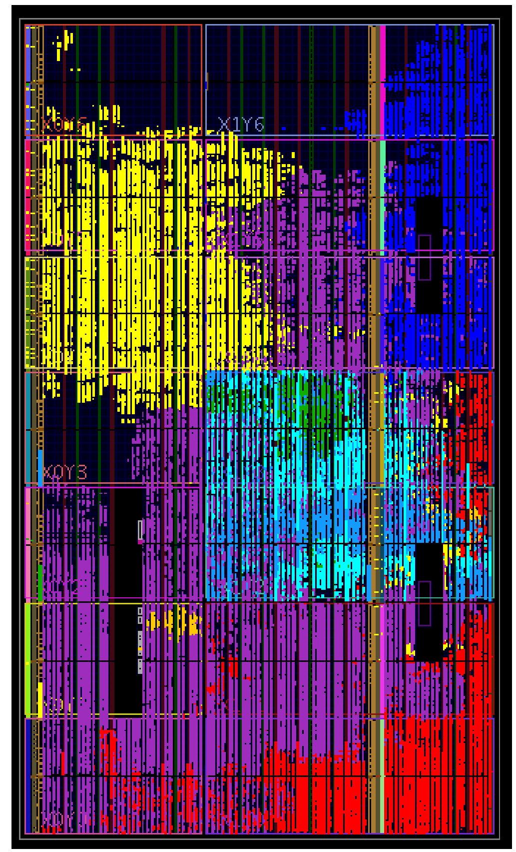


- Final production: 60 boards
  - Installed in 5 crates at the beginning of 2016
  - 2720+720 optical fibers
  - Fully operational during Run2

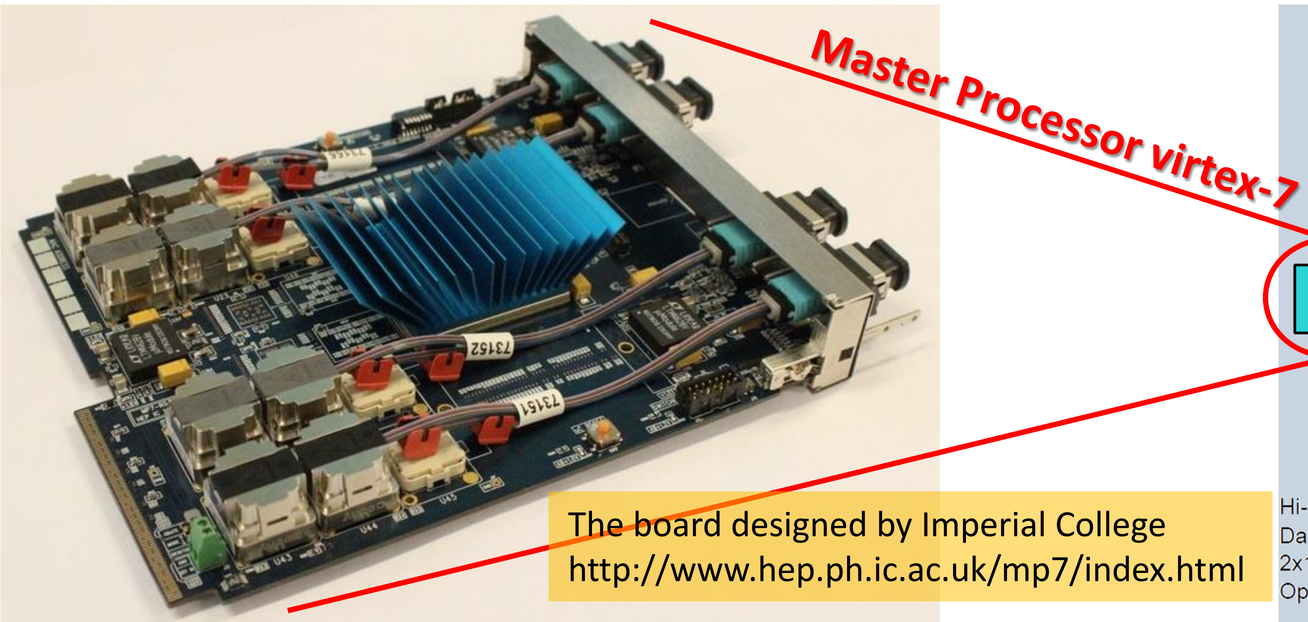


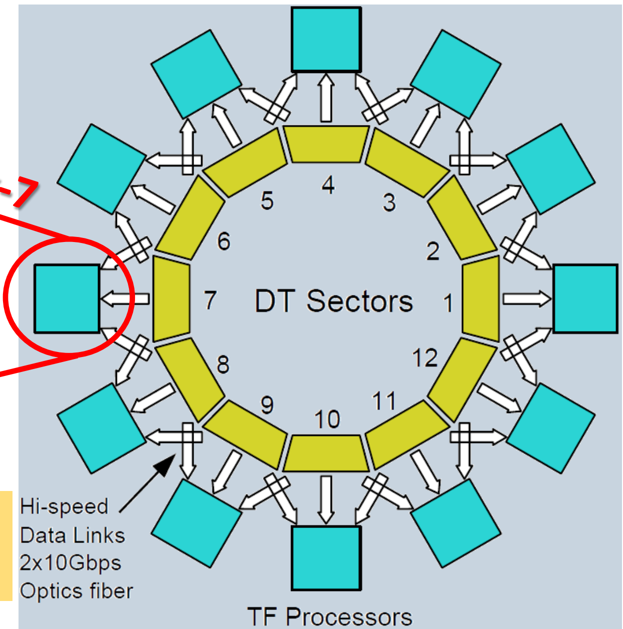
TwinMux Firmware

- DT receiving
  - 40 input channels (1 sector)
  - Oversampling x3   480Mbps ⟶ 1.44Gbps
  - Digital filter on oversampled data
  - Automatic procedure for link locking
- RPC+HO receiving
  - 5 input at 1.6 Gbps (GOL links)
  - Automatic links synchronization, alignment and monitoring
  - Clustering and coordinate conversion
- B/OMTF transmission
  - TwinMux adheres to the calorimeter 10Gbps protocol
- Superprimitive
  - Bx-assignment via phi-matching
  - Generation of RPC only primitive
- DAQ link
  - It sends to the cDAQ a window of BXs around a L1A
- Slow control: IPbus



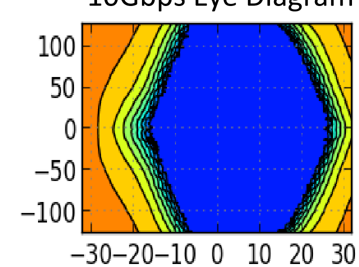
BMTF Processor - MP7





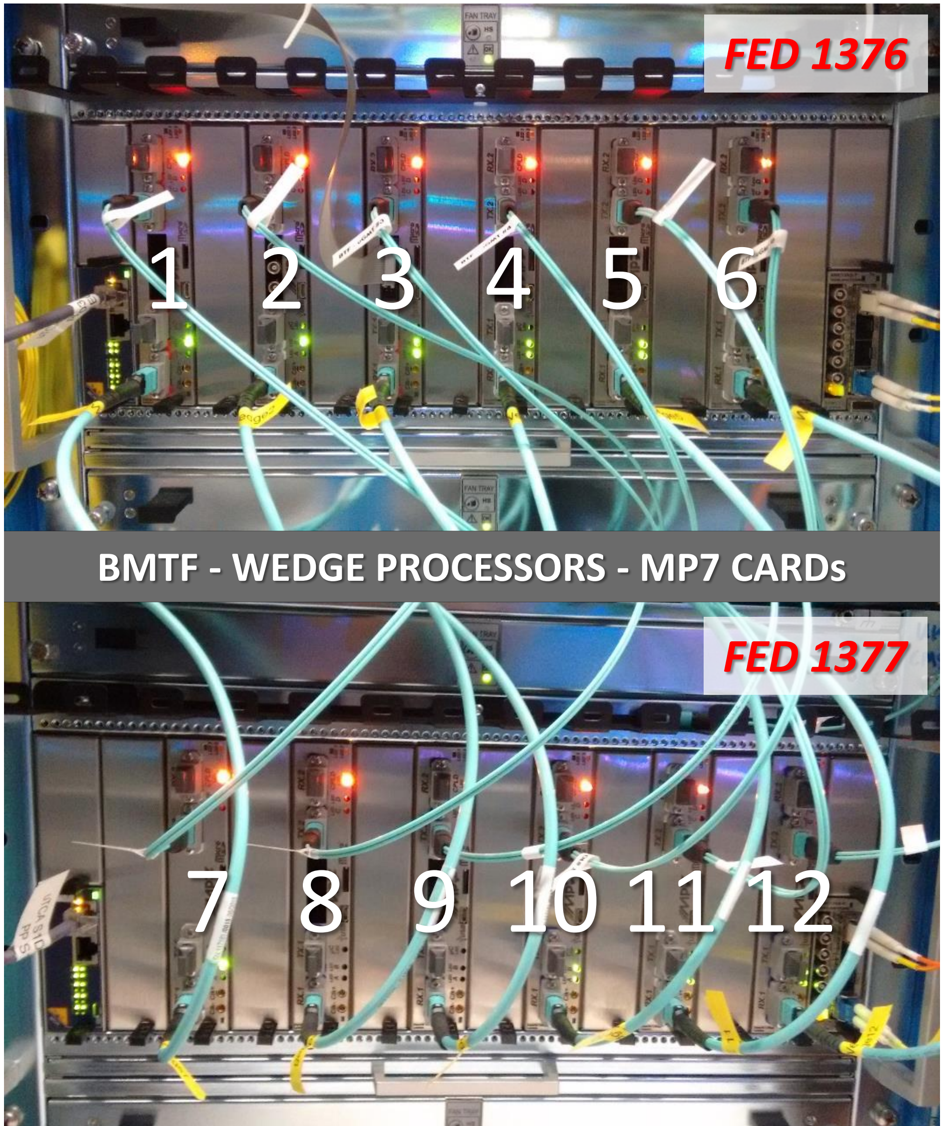
The board designed by Imperial College
http://www.hep.ph.ic.ac.uk/mp7/index.html

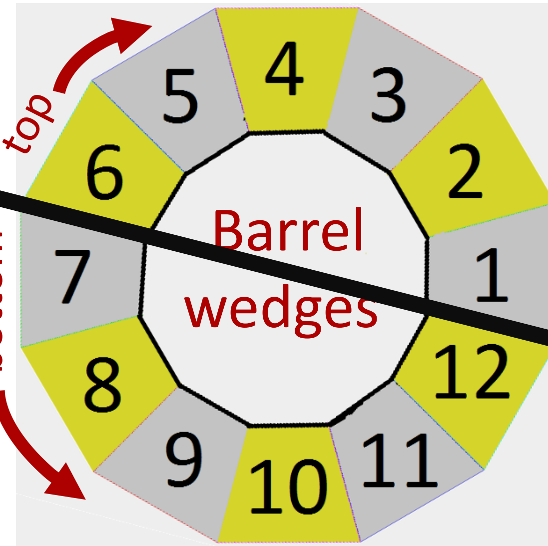
10Gbps Eye Diagram



- 72 inputs and 72 output optical links operating up to 11Gbps
- 12 minipod optics with MTP-48 connectors
- Large scale 690 Virtex7 Xilinx FPGA

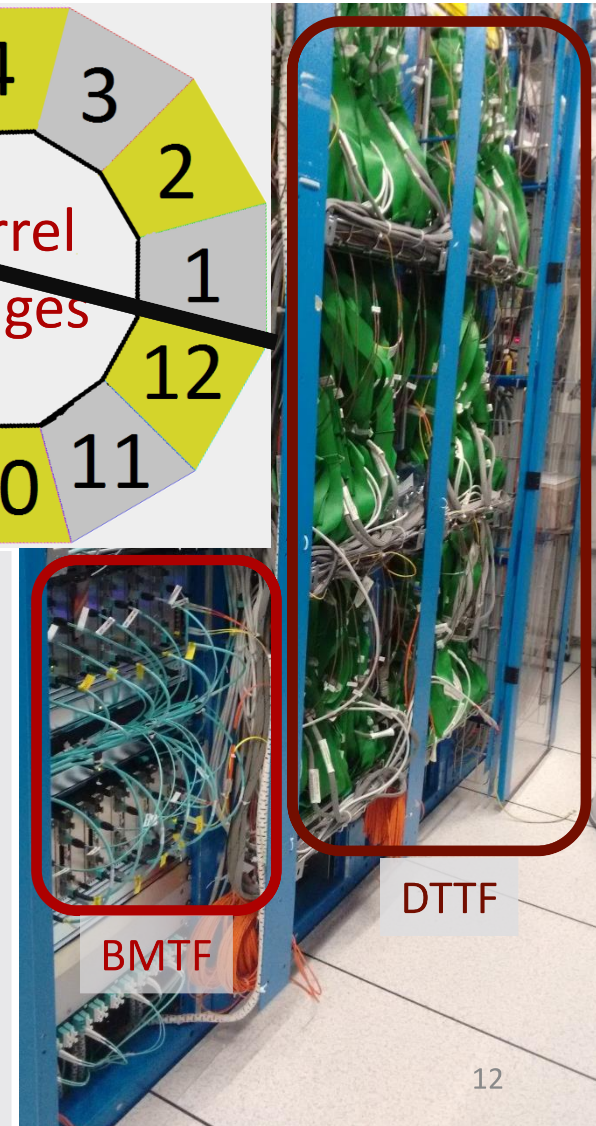
BMTF System @ P5





Top crate processes muon candidates from the top wedges 1,2,3,4,5,6.

Bottom crate processes muon candidates from the top wedges 7,8,9,10,11,12.



Firmware Performance

- MP7 framework. Stable mp7fw2.2.0 version is used
- The algorithm latency reduced after several changes. Initially the ported algorithm was running with 40MHz clock. The latest design is working at 120MHz
- Total latency reduced from 25BXs to 15BXs
- The unused quads are not instantiated to save power and resources consumption
- 1/3 of the FPGA resources are used

40MHz

3 BX	15 BX	2 BX	1	2 BX	2 BX
Rx	A L G O	W	X	Tx	C
Total 25 BXs					

80MHz

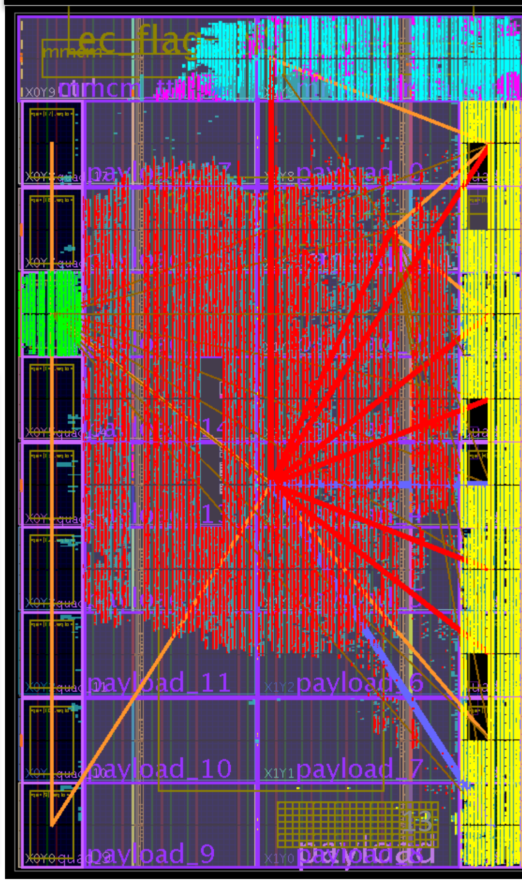
3 BX	9 BX	2 BX	1	2 BX	2 BX
Rx	A L G O	W	X	Tx	C
Total 19 BXs					

120MHz

2 BX	7 BX	1	1	2 BX	2 BX
Rx	A L G O	W	X	Tx	C
Total 15 BXs					

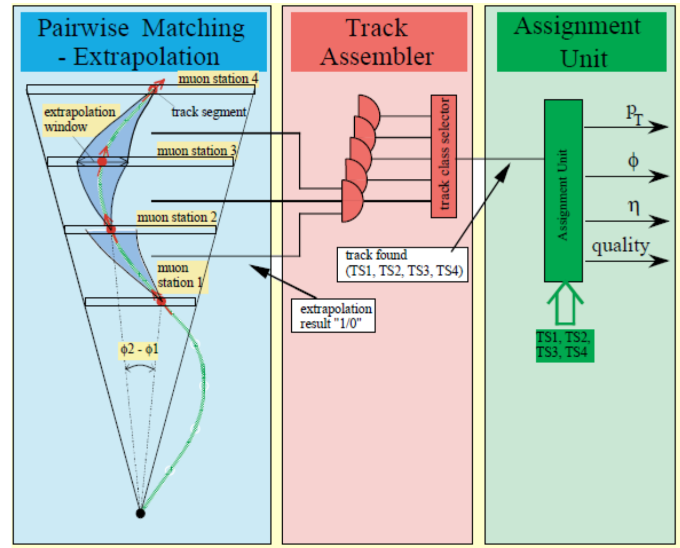
Rx: Input logic
ALGO: Track finders
W: Wedge Sorter
X: Pipe
Tx: Output Logic
C: Cable to µGMT

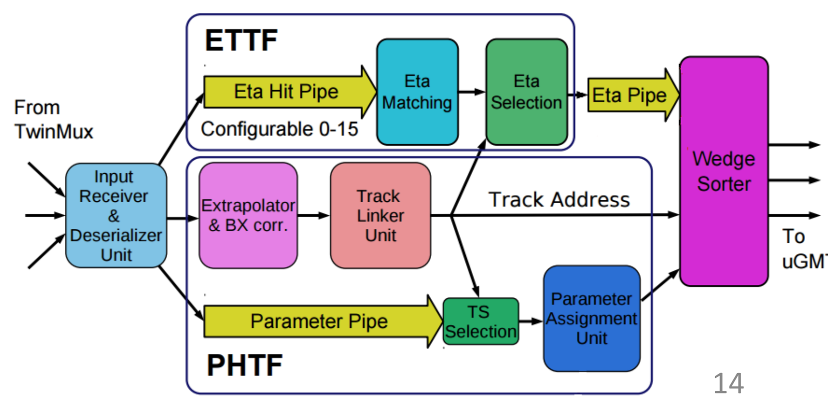
Yellow: Inputs
Green: Outputs
Red: Algorithm
Light bleu: Readout (DAQ)
Purple: General infrastructure



Barrel Muon Algorithm

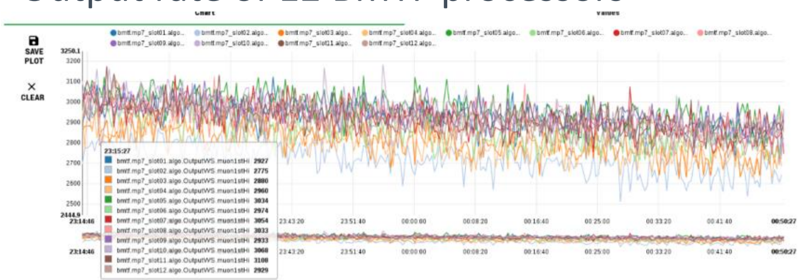
- Each BMTF processor (MP7 card) tracks muons within a given wedge and from its neighbors of the barrel area|η|<0.8
- pT and ϕ values from the one hand and η from the other hand are calculated using two parallel algorithms which are fed with (super)primitives sent by the TwinMux
- The BMTF algorithm has three main steps:
    - The extrapolator unit searches for track segments using information from the track stubs, the bending angle from different DT stations using LUTs. Each combination extrapolates the muon candidate to the next station and checks whether it is within an acceptable window
    - The track assembler receives the acceptable extrapolations and reconstructs a track with the corresponding quality bits.
    - The assignment unit computes the spatial coordinates, pT, quality values, and track addresses using look-up tables (LUT)





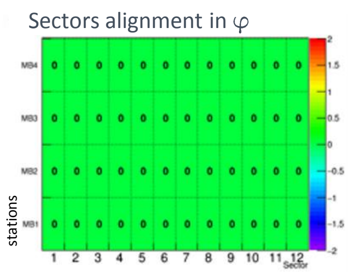
BMTF and TwinMux Software

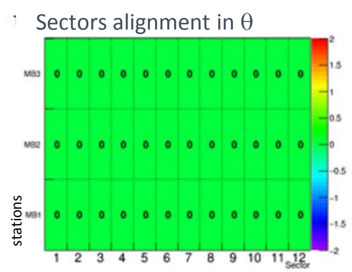
Output rate of 12 BMTF processors



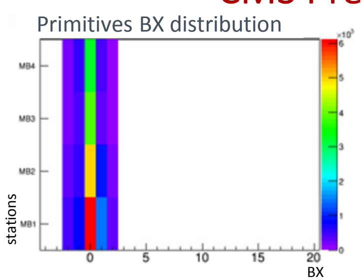
CMS Preliminary

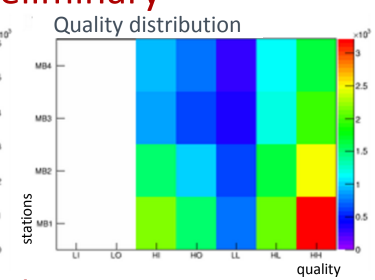
Example DQM plots





CMS Preliminary





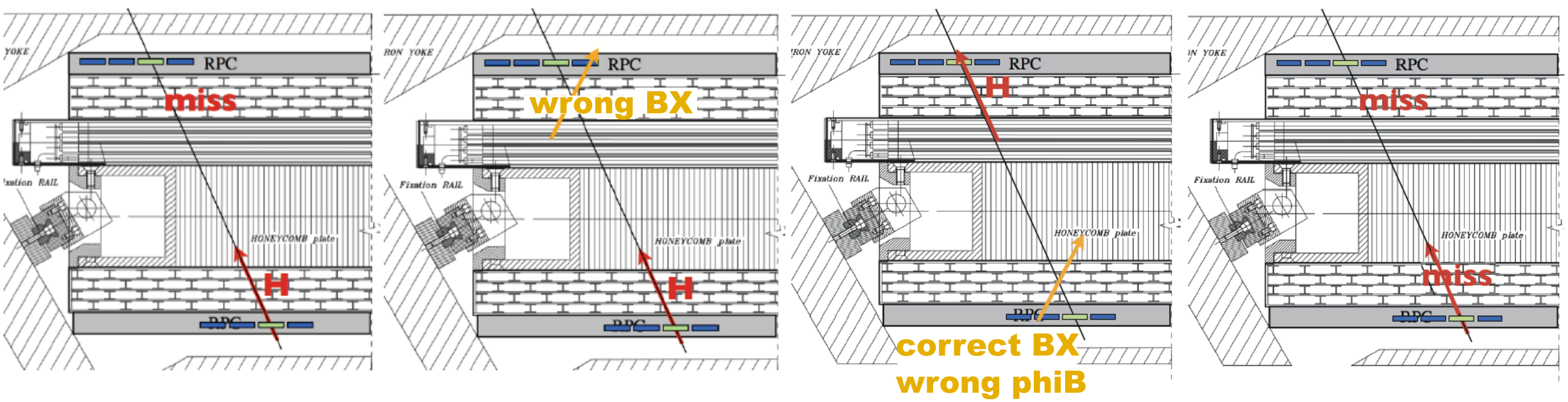
CMS Preliminary

- Online Software
  - Controlled by SWATCH (SoftWare for Automating conTrol Common Hardware) framework, as all the L1 Trigger Systems
  - Status monitor, I/Os rates, Upload firmware, Automatic masking of the input ports, etc
- DQM
  - Several plots available online and offline for input and output data monitoring
- Emulator
  - In general very good data to emulator agreement
  - TwinMux legacy behavior extended for RPC inclusion

DT-RPC Combination

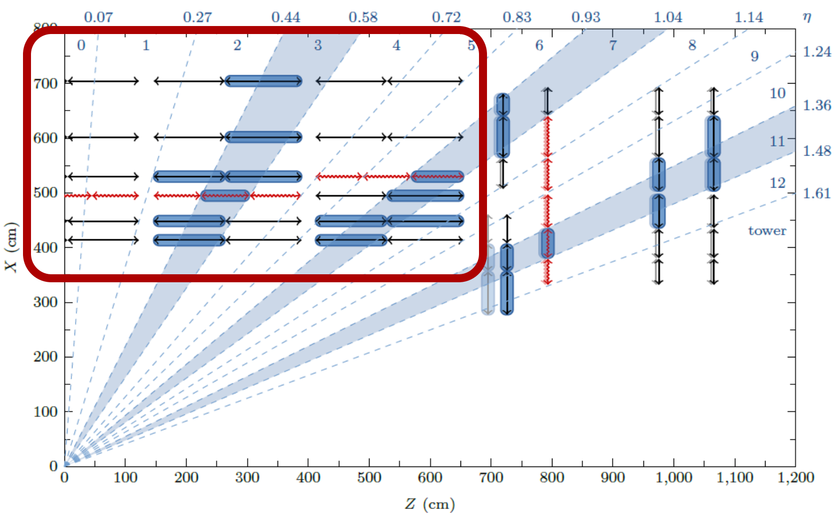
- Goals:
  - Improve BX identification using RPC hit
  - Improve segments with DT-RPC combined spatial information
  - More segment efficiency: improve Low quality DT or RPC only segments

- Create combined DT-RPC → expected higher efficiency (3-4%) @ TwinMux level
- New PT assignment algorithm → expected higher rate reduction @ BMTF level
- Use adapted legacy Track Finder algorithm



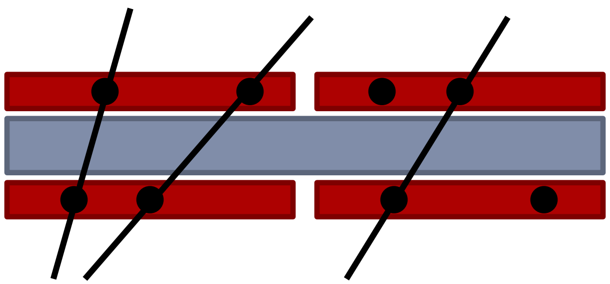
SuperPrimitive: Bx Assignment

- RPC sends 2 clusters per roll
  MB1 – 4 rolls – 8 clusters
  MB2 – 5 rolls – 10 clusters –> 8 after sorting
  MB3 – 2 rolls – 4 clusters
  MB4 – 2 rolls – 4 clusters
- $\Delta\varphi$ DT-RPC with each cluster in the range ±1BX
- Smallest $\Delta\varphi$ out of 24 for MB1 and MB2.
  Smallest $\Delta\varphi$ out of 12 for MB3 and MB4
- Change the BX of the DT primitive according to the smaller $\Delta\varphi$
- In case of conflict priority is given to φ in its own BX
- Quality cut on BX assignment and within an acceptance window
- Same algorithm applied on second track segment



RPC Only Algorithm

- Only for MB1 and MB2 because in MB3 and MB4 there is only one RPC layer
- RPC clusterization provides position and ϕ
- Arctan computed by a LUT loaded through IPbus
- Best (lower) ϕ_b chosen
- ϕ_b acceptance window applicable
- The quality assigned to the RPC only primitive is compared with the best uncorrelated DT
- Due to bandwidth issues RPC only primitive is suppressed when there are two DT primitive in the same Bx



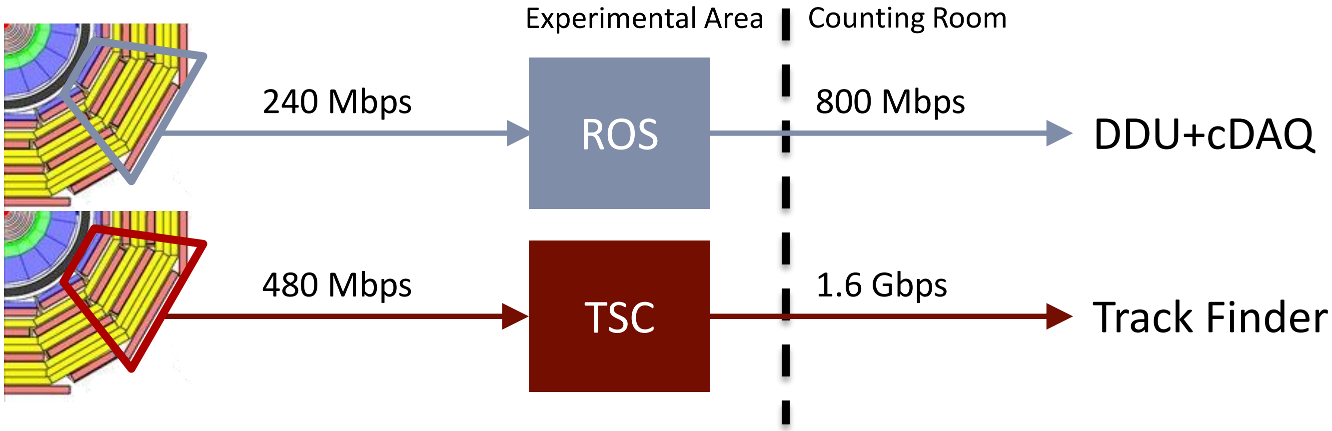
$$\phi_b = \arctan\left(\frac{x_2 - x_1}{d}\right) - \phi$$

Summary

- The increase of luminosity of LHC demanded considerable improvements in L1 Trigger
- TwinMux and BMTF are two trigger components that have been installed at the beginning of 2016
  - Both systems have been presented in terms of hardware, firmware and software
  - A smooth operation of these systems has been achieved during Run2
- Present activities focus on the validation of the DT-RPC primitive combination
  - Superprimitives combine RPC temporal resolution with DT spatial resolution
  - RPC only primitives aim to merge DT and RPC segments at the track finder level

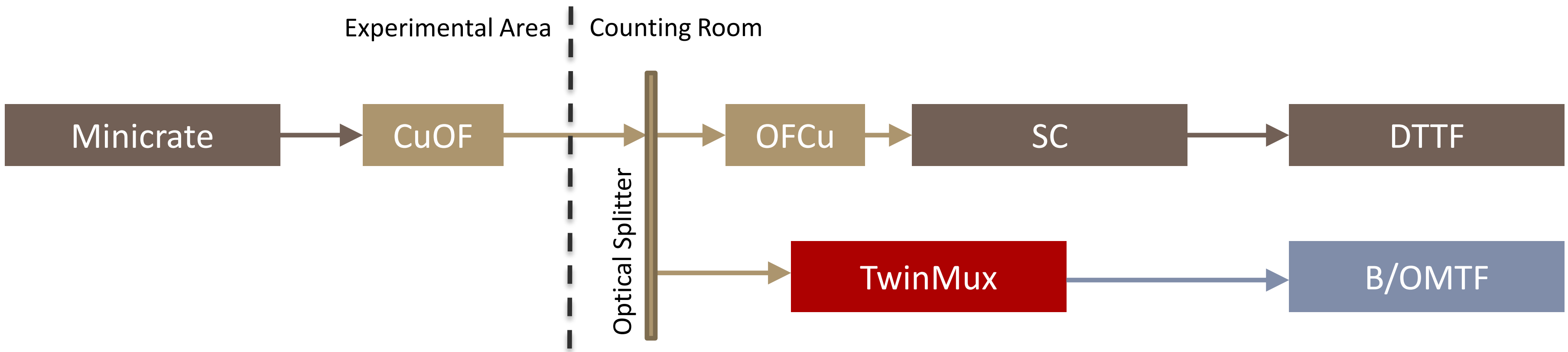
Backup

Before LS1



- DT electronics is divided into two different paths for the Readout and for the Trigger. This separation starts at the early on detector electronics, so called Minicrate
- Before LS1 the two data concentrators, called respectively Read Out Server (ROS) and Trigger Sector Collector (TSC), were placed in the experimental area

Optical Splitting: the Slice Test



- 15% of the links coming from the Minicrates have been equipped with passive optical splitters in order to deploy and validate the TwinMux (304 links split!)
- At least three sectors over two wheels had to be split in order to enclose all possible neighbor correlations that the track finding algorithm has to explore to correlate track segments
- A slice of the new DT trigger system has been commissioned in parallel with the operation of the legacy trigger
- Optical splitter can be reused also after full system replacement for testing new algorithms

BMTF Online Software

The BMTF, as all other L1 Trigger systems in CMS, is controlled by SWATCH (SoftWare for Automating conTrol Common Hardware) framework

- Through SWATCH the BMTF is fully accessible
  - Status monitor
  - I/Os rates
  - Upload firmware
  - Masking of the input ports is done automatically according to the TwinMux's masked FEDs
  - The State of the system is known by the FSM and can be changed either Centrally or by the commands
  - Configuration can be done manually or from DB (using XML files in both cases)