The CMS Level-1Trigger Barrel Track Finder

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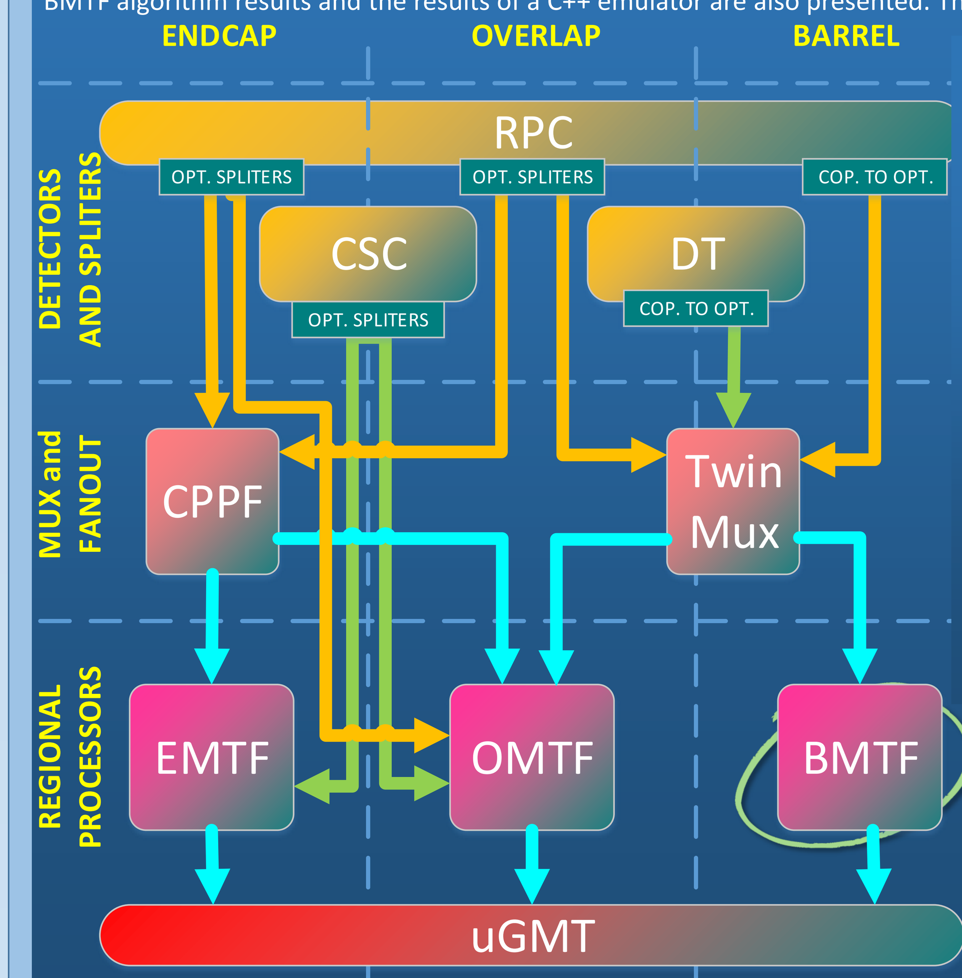
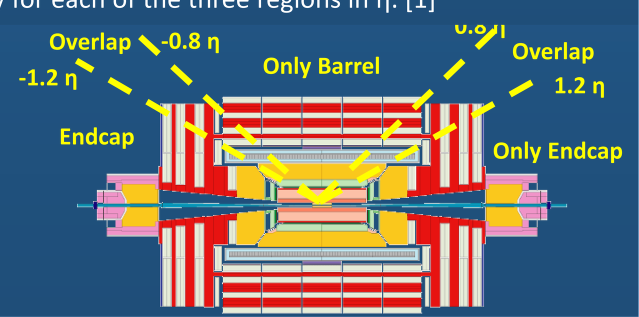
Overview

The design and performance of the upgraded CMS Level-1 Trigger Barrel Muon Track Finder (BMTF) is presented. Monte Carlo simulation data as well as cosmic ray and pp data from a CMS muon detector slice test have been used to study in detail the performance of the new track finder. The design architecture is based on twelve MP7 cards which use a Xilinx Virtex-7 FPGA and can receive and transmit data at 10 Gbps from 72 input and 72 output fibers. According to the CMS Trigger Upgrade TDR the BMTF receives trigger primitive data which are computed using both RPC and DT data and transmits data from a number of muon candidates to the upgraded Global Muon Trigger. Results from detailed studies of comparisons between the BMTF algorithm results and the results of a C++ emulator are also presented. The new BMTF will be commissioned for data taking in 2016.



Muon Trigger Strategy

The present muon trigger preserves the complementarity and redundancy of the three separate muon detection systems until they are combined at the input to the Global Trigger. In contrast, the upgrade to the muon trigger will utilize the redundancy of the three muon detection systems earlier in the trigger processing chain so as to obtain a more performant trigger with higher efficiency and better rate reduction. Recognizing that every additional hit along a muon trajectory further improves the fake rejection and muon momentum measurement, the upgraded system seeks to combine muon hits at the input stage to the Muon Track-Finder layer rather than at its output. The segmentation of the track processing will still be done regionally in sectors of ϕ and η. For the upgrade it is expected a separate treatment of transition region between barrel and endcap (|η|~1) in the algorithms and in the deployment of hardware processors as well. Therefore the processing will be subdivided in azimuth as well as in barrel, overlap, and endcap regions. The final sorting and ghost cancellation of muon candidates is also expected to be handled separately for each of the three regions in η. [1]



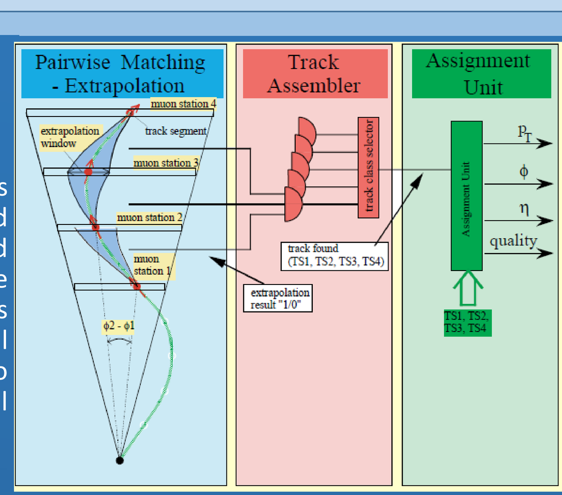
BMTF algorithm

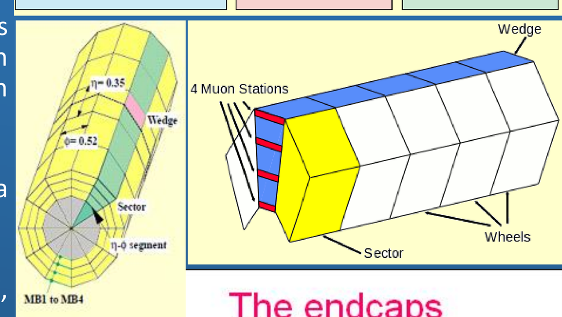
The muon barrel architecture groups the muon detectors in 12 wedges. Each wedge has five sectors and each sector, 4 DT detectors and 3 RPC. The front-end electronics record muon primitives and send them to the TwinMux which concentrate data from different sectors. The TwinMux combines DT and RPC to create more reliable primitives which are called superprimitives. Then it fanout the data to the barrel and the overlap track finders. The BMTF receive muon primitives from the DT and RPC detectors from the Barrel area of CMS (|η|<1). The data primitives give muon coordinates, bending angle as well as quality bits that are used to evaluate the inputs. The BMTF algorithm use the information to represent muon tracks and calculate physical parameters like the transverse momentum (pT), the total bending angle the quality of the track and the track addresses. The algorithm has three stages [2] :

1. In the first named Extrapolator Unit, the track primitives, the bending angle and the quality bits from different stations of the own sector or neighbor sectors are combined by using LUTs. Each combination extrapolates the muon candidate to the next station and checks whether it is within an acceptable window.

2. In the second stage the Track Assembler Unit receive the acceptable extrapolations and creates a track with a corresponding quality. The quality bits gives the candidate track class.

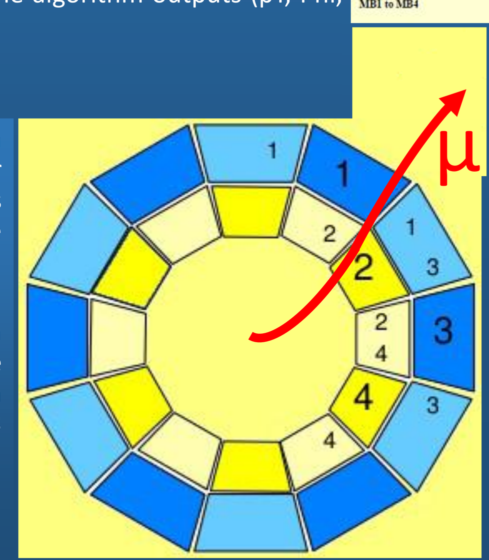
3. The Assignment Unit use LUTs to assign the physical parameters to the algorithm outputs (pT, Phi, Eta, track addresses and quality bits).

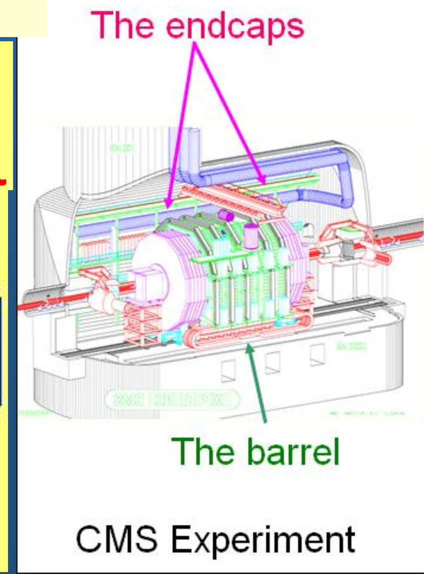




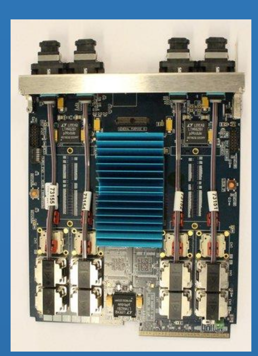
Each BMTF processor search for muon tracks in one wedge (own wedge) which may go also to the neighbor wedge (left and right). For example in the picture in the right side, the BMTF is searching for tracks in the wedge 2. To do that, it compares the own sector primitives with the primitives from the sectors 1, 2 and 3.

The algorithm runs in parallel for 2 muons in 6 sectors which correspond to 1 wedge (the sectors are 5 but the logic splits the middle to two). In the barrel there are 12 wedges. So it can find 2 x 6 = 12 muon tracks. Every BMTF processor has a sorting logic which give the best 3 muons of the 12 possible tracks.

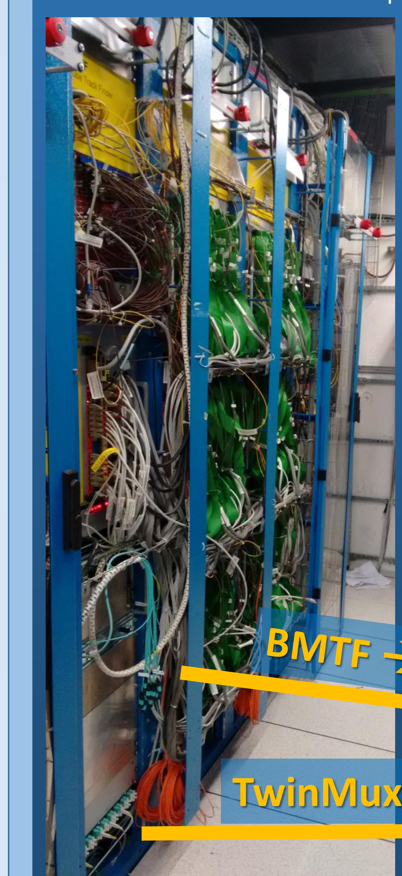




BMTF - Hardware



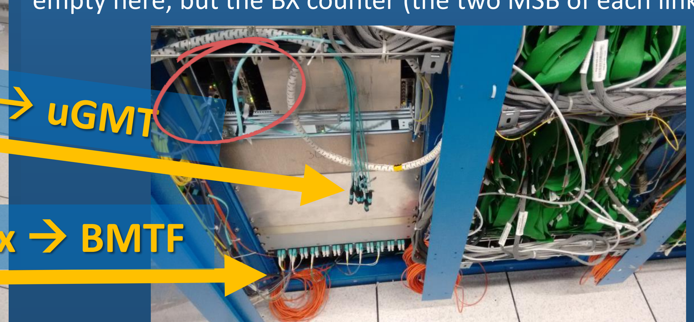
The BMTF is implemented in 690 series Virtex-7 FPGA which cover the needs of the needed resources (logic slices) as well as the total I/O bandwidth. The BMTF use 12 Master Processor - Virtex-7 card (MP7) which is design by the Imperial College. [1] The MP7 is a uTCA standard AMC card for the trigger system of the CMS. The MP7's optical interface is provided by up to six Avago MiniPOD transmitters and six Avago MiniPOD receivers. Each MiniPOD device provides 12 optical links running at up to 10.3 Gb/s, giving the MP7 a total optical bandwidth of up to 740 Gb/s in each direction. The optical outputs from the MiniPOD devices are transmitted on Corning unruggedized, non-peelable optical ribbons to 48-way MTP connectors (of which only 36 channels are used) mounted on the front-panel. Each MP7 card cover the needs of one wedge of the BMTF trigger system which receives 30 links from the TwinMux and send the algorithm results with one link to the uGMT. The Virtex 690 chip of the MP7 provides plenty of resources in case of adding extra logic in the algorithms and larger LUTs. [3]

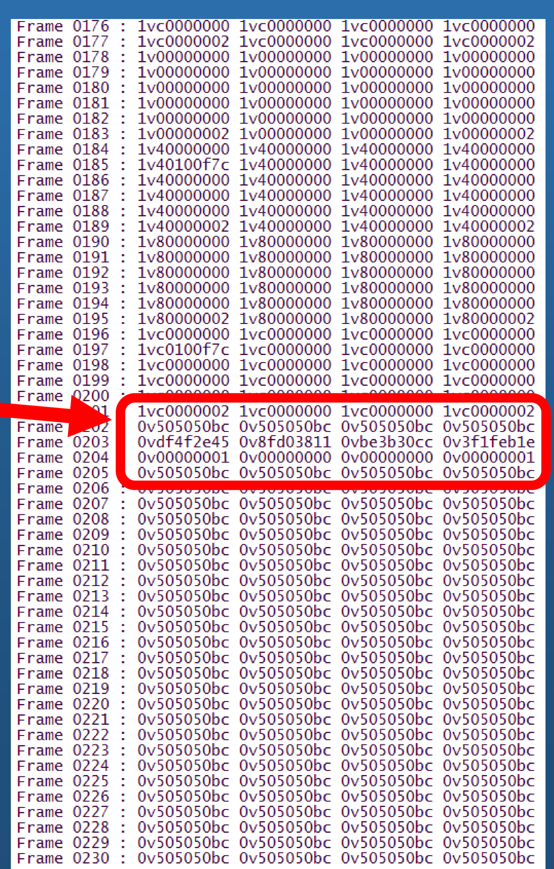


Starting the slice test

The BMTF crate is installed at the CMS – USC, at the rack S1D03. At the right side of the picture is the legacy muon track finder system (known as the green salad) and in the left side at the bottom, the upgraded system. Under the BMTF crate there is the patch panel from which the BMTF gets the inputs. In front of the crate there are MTP cables for connecting the BMTF the outputs to the uGMT patch panel.

The setup is ready to run. Muon data have been received from two the muon chambers. As it can be seen in the snapshot the input links have been captured and they are align. Those four inputs have been send from the TwinMux. The data have been taken from cosmic muons and since there are not frequent no muon observed. The primitives are empty here, but the BX counter (the two MSB of each link) works.

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Frame 0177 : 1vc0000002 1vc0000000 1vc0000000 1vc0000002
Frame 0178 : 1v00000000 1v00000000 1v00000000 1v00000000
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Frame 0182 : 1v00000000 1v00000000 1v00000000 1v00000000
Frame 0183 : 1v00000002 1v00000000 1v00000000 1v00000002
Frame 0184 : 1v40000000 1v40000000 1v40000000 1v40000000
Frame 0185 : 1v40100f7c 1v40000000 1v40000000 1v40000000
Frame 0186 : 1v40000000 1v40000000 1v40000000 1v40000000
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Frame 0195 : 1v80000002 1v80000000 1v80000000 1v80000002
Frame 0196 : 1vc0000000 1vc0000000 1vc0000000 1vc0000000
Frame 0197 : 1vc0100f7c 1vc0000000 1vc0000000 1vc0000000
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Frame 0199 : 1vc0000000 1vc0000000 1vc0000000 1vc0000000
Frame 0200
             1vc0000002 1vc0000000 1vc0000000 1vc0000002
Frame        0v505050bc 0v505050bc 0v505050bc 0v505050bc
Frame 0203   0vdf4f2e45 0v8fd03811 0vbe3b30cc 0v3f1feb1e
Frame 0204   0v00000001 0v00000000 0v00000000 0v00000001
Frame 0205   0v505050bc 0v505050bc 0v505050bc 0v505050bc
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Frame 0207 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
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Frame 0213 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
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Frame 0215 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
Frame 0216 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
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Frame 0219 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
Frame 0220 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
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Frame 0230 : 0v505050bc 0v505050bc 0v505050bc 0v505050bc
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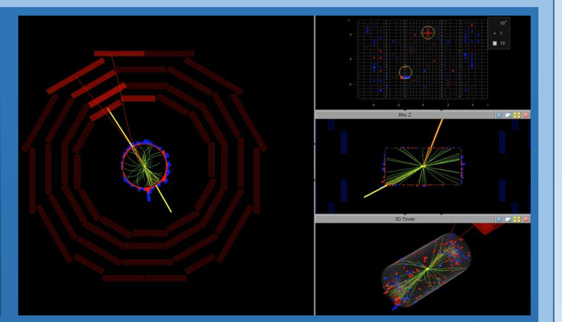
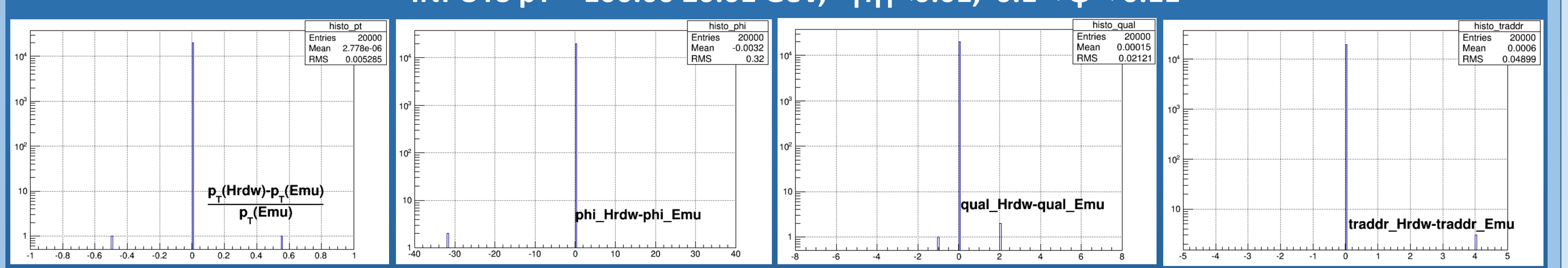
Algorithm Validation

To validate it, the implemented BMTF firmware is tested with emulated and real data. By using a particle gun and CMSSW we generate muon candidates which are use as inputs to the BMTF emulator and the hardware. As it is shown below the outputs are comparing with histograms. The statistics help to analyze the results and if any problem observed we search dipper in the VHDL. Python scripts are used for converting the muon inputs from root files to xml files and also to run the test by using the IPbus.

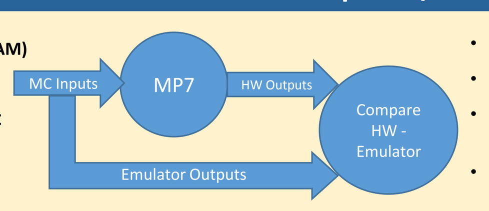


INPUTS pT = 100.00 ±0.01 GeV, |η|<0.01, 0.1 < ϕ < 0.11



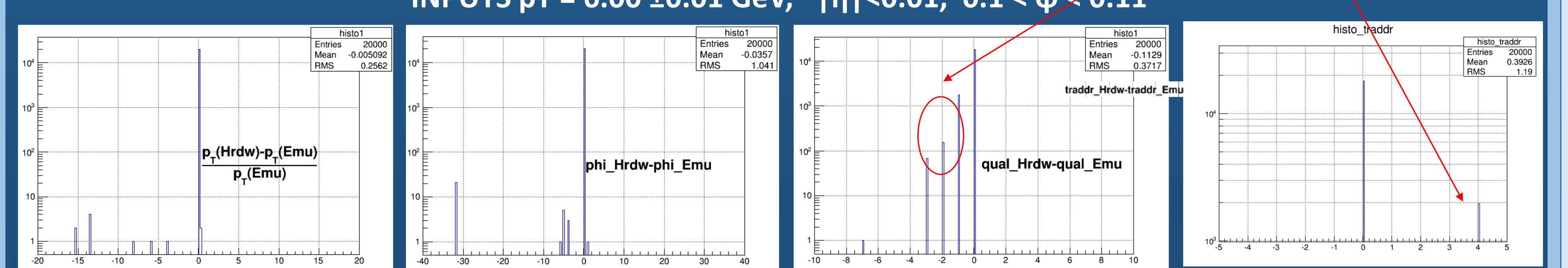
pT: 2/20.000 events | **phi: 2/20.000 events** | **qual: 3/20.000 events** | **TrAddr: 3/20.000 events**

- MC generated using CMSSW_7_2_0 (new lookup tables- Jorge Troconiz - UAM)
- Using Configuration/Generator/python/SingleMuPt100_cfi.py
- With p_T = 100.00±0.01 GeV, |η|<0.01, 0.01<ϕ<0.11, No antiparticle in MC
- With p_T = 6.00±0.01 GeV, |η|<0.01, 0.01<ϕ<0.11, No antiparticle in MC
- Global Tag: MCRUN2_72_V3



- Differences shown by red arrows are events where muons go to neighbor sector.
- Problem solved by Janos → update firmware
- The updated firmware uses the latest LUTs with 9-bit pT (provided by Jorge Troconiz - UAM)
- Quality and track addresses discrepancies concern the same events. Most of them happened when the muon goes to the neighbor sector

INPUTS pT = 6.00 ±0.01 GeV, |η|<0.01, 0.1 < ϕ < 0.11

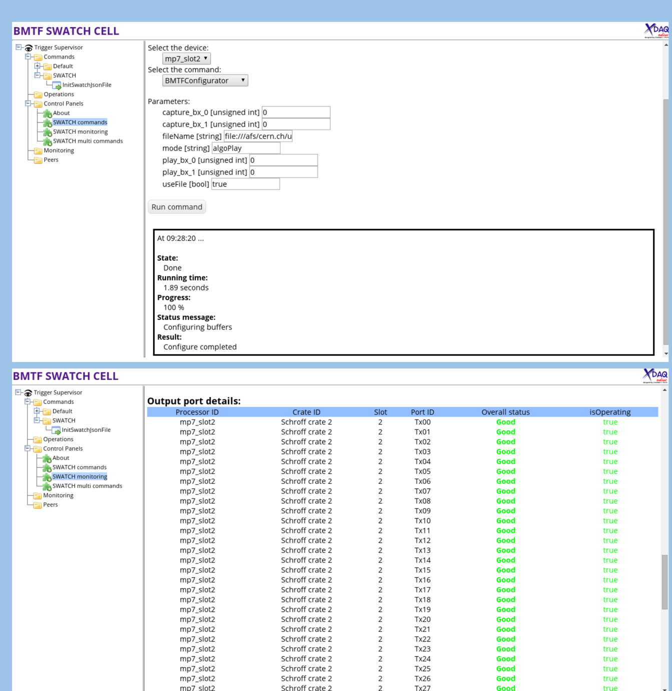


pT: 12/20.000 events | **phi: 31/20.000 events** | **qual: 1962/20.000 events** | **TrAddr: 1963/20.000 events**

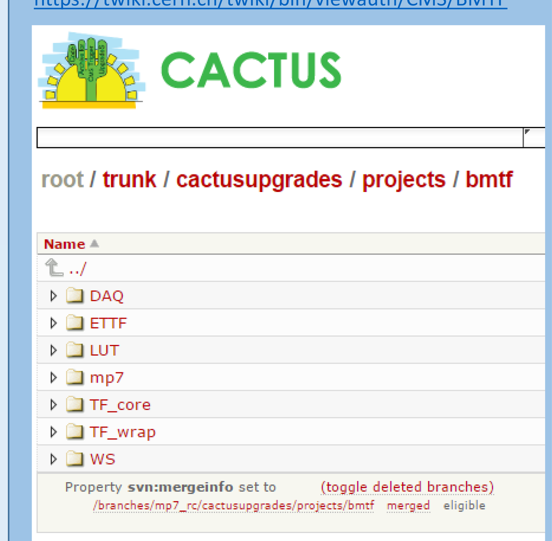
BMTF Online Software

The online software controls the BMTF system by using state machines implemented in the swatch environment. The main tasks of the BMTF online software are:

- SWTCH Cell which take care of all the basic functions reset, align links etc) (right hand top image)
- The SWATCH Cell is going to take care of the pattern tests as well
- Command sequences (inside SWATCH) have been developed
- Monitoring, which is already implemented in SWATCH Cell (right hand image)
- Standalone C++ scripts have been built especially for testing in case of emergency
- Development of the UnPacker code has been started



➢ Find and checkout the BMTF from cactus svn:
https://twiki.cern.ch/twiki/bin/viewauth/CMS/BMTF



Conclusions

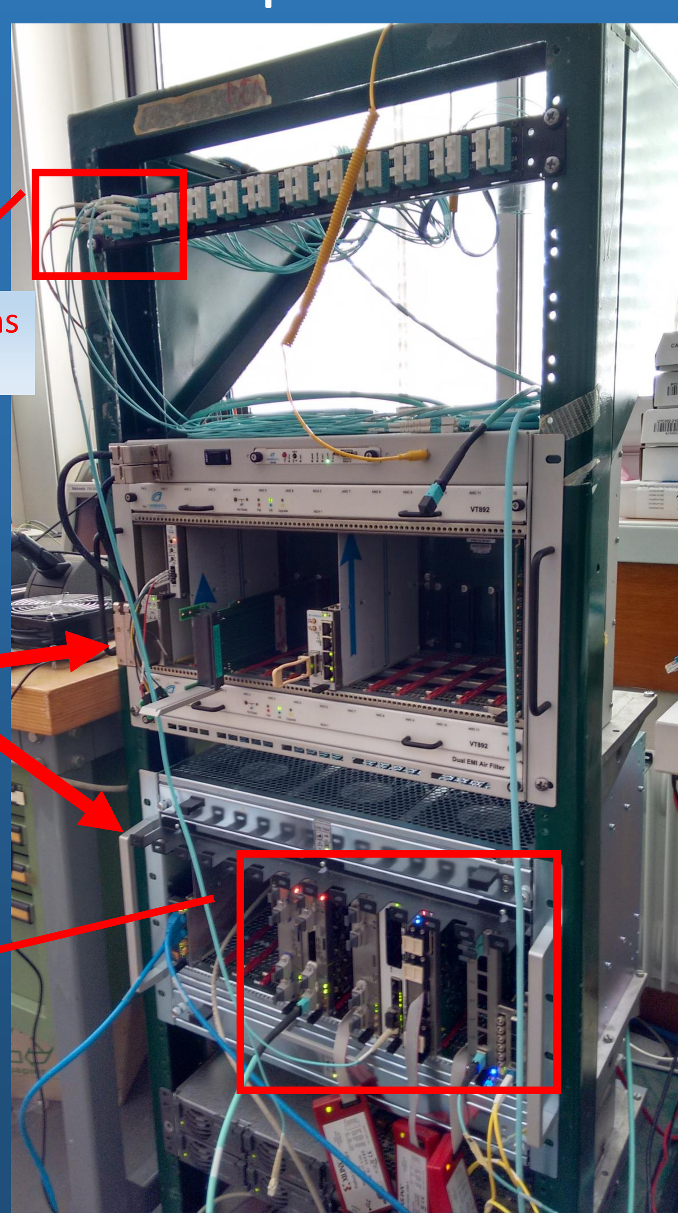
✓ The BMTF collaboration is working on the final version of the BMTF firmware. To validate we run the trigger emulator and the MP7 card with the same input data. The results are comparing and the implemented algorithm is improving.

✓ The hardware is installed at P5 in the underground of CMS. The data taking from the muon chambers has started and the triggered events are send to the global muon of the muon trigger chain, the uGMT. Also the triggers are sent via the DAQ system to the TCDS.

✓ The BMTF online software is been deployed in order to control the MP7 card following the philosophy of other L1 trigger systems in CMS.

✓ The BMTF has better resolution than the DTTF (Drift Tube Track Finder) what is the current system. That happens because the new hardware increase the processing power of the track finder algorithm. The resolution of the pT increase, because the new system use 9-bit assignment LUTs with linear scale instead of the current DTTF what use 5-bits non linear scale. [4]

Setup at CERN

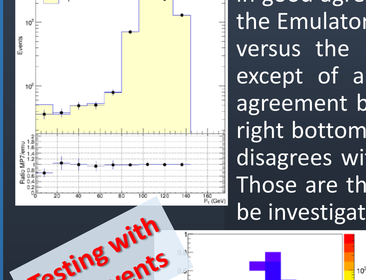


LC fiber connections over a patch panel

μTCA crates of Ioannina and Padova group

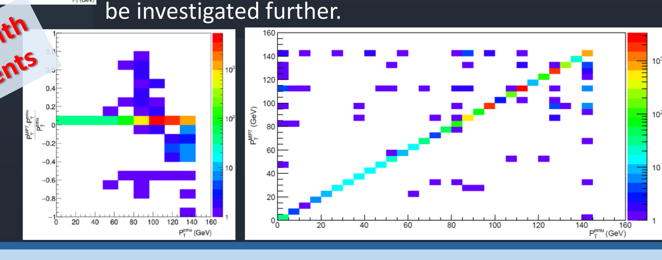
AMC cards:
- ➢ MP7s (MBTF),
- ➢ TwinMux
- ➢ AMC502
- ➢ CPPF
- ➢ AMC13

MP7 – emulator outputs comparisons with 9-bits pT



In the left plot the Pt distribution from the MP7 is in good agreement with the distribution coming from the Emulator. In the left bottom plot the Pt resolution versus the Pt coming from the emulator is zero, except of a few points, resulting to a very good agreement between the emulator and the MP7. The right bottom plot shows the points that the emulator disagrees with the implement algorithm in the MP7. Those are the ~1% of the all events and are going to be investigated further.

Testing with 10k events



References

[1] http://cds.cern.ch/record/1556311/files/CMS-TDR-012.pdf?version=3
[2] http://cds.cern.ch/record/1027486/files/p279.pdf
[3] http://www.hep.ph.ic.ac.uk/mp7/documents/UserGuideForTheMP7.latest.pdf
[4] http://cms.cern.ch/iCMS/jsp/openfile.jsp?tp=draft&files=DN2015_017_v1.pdf

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