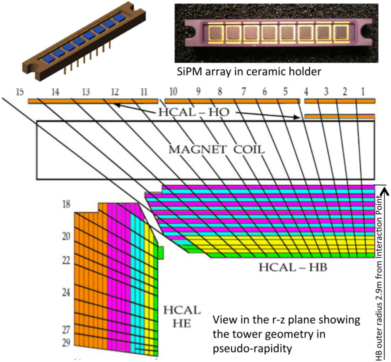
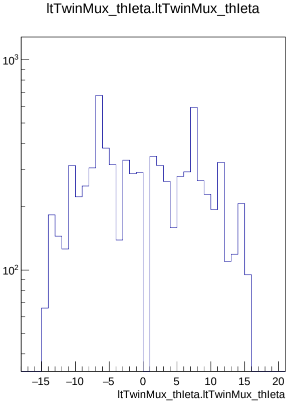
DTTP-HOTP matching in the TwinMux emulator

Soham Bhattacharya[1] Pooja Saxena[2]

[1]TIFR, Mumbai, India

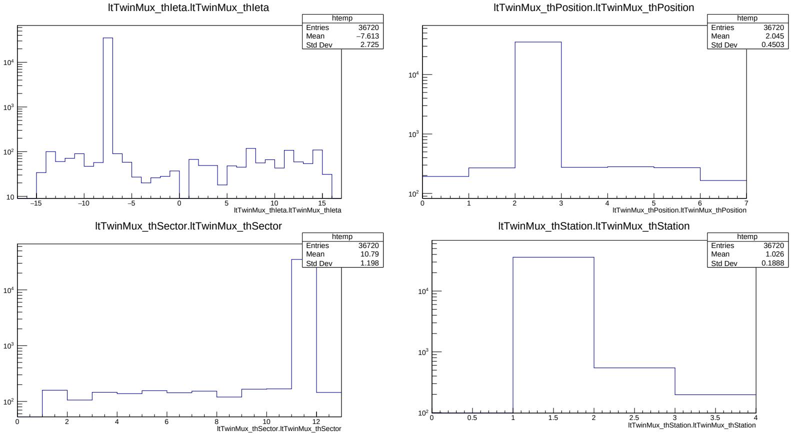
[2]DESY



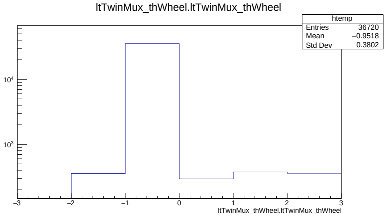


- DT +ve, -ve orientation taken care of according to this.
- Only with HQ th-DTTPs.
- Some excess can be seen at $i\eta = \pm 7, \pm 11, \pm 14$.
- HO wheels ± 1 have 6 $i\eta$ each $[\pm 5, \pm 10]$. But the DT has 7 bins in each wheel. Hence when converting DT bin value to HO $i\eta$, one $i\eta$ gets entries twice.
- Similarly for HO wheels ± 2, which have 5 $i\eta$ each $[\pm 11, \pm 15]$.

Getting DT $i\eta_{global}$ (HQ+LQ) [1]



Getting DT $i\eta_{global}$ (HQ+LQ) [2]



- Both LQ and HQ th-DTTPs.
- Global tag: `92X_dataRun2_Prompt_v4`.
- 5000 events from run number 297656 of `ZeroBias9/Run2017B-v1/RAW`.
- The same feature (spike at the same location) is also showing up in run 299380 of `ZeroBias10/Run2017C-v1/RAW`.

DT-HO matching

The HO will provide support to the isolated MB1TPs.

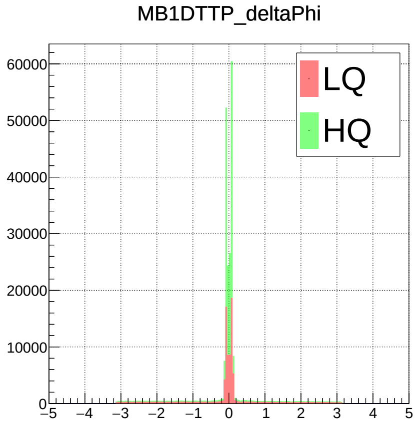
Isolated MB1s are obtained with:

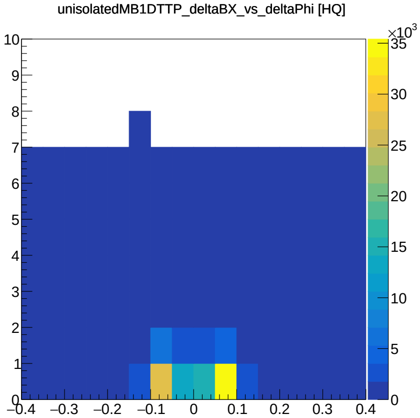
- Exclude MB1TPs in wheels ± 2.
- Use $\Delta\phi$ cut 0.4 for finding isolated MB1TPs.
- No cut on BX or deltaBX when obtaining isolated MB1TPs.

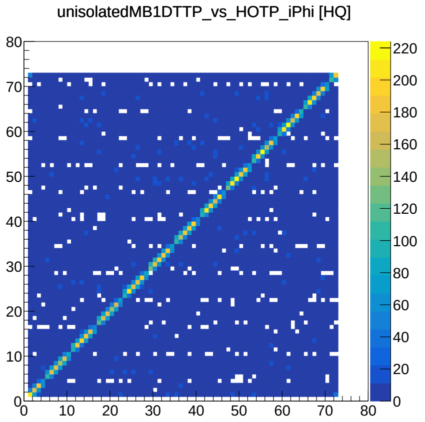
Nearest HO to an MB1 is selected such that:

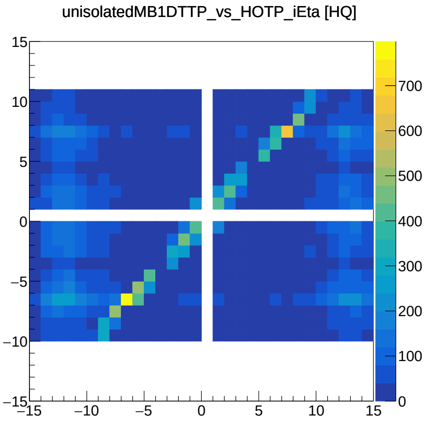
- Minimum $\Delta i\phi$.
- Minimum Δwheel.
- Minimum $\Delta i\eta$ if there is at least one th-Digi with a valid $i\eta$ ($[-15, +15]$) in the same wh/st/sc as the MB1TP in question.
- When counting which MB1TPs have HO support, count only those that satisfy all of the following:
  - $\Delta i\phi \leq 1$.
  - $\Delta\text{sector} = 0$.
  - $\Delta\text{wheel} = 0$.
  - If $i\eta$ is available for the MB1TP in question, then also impose $\Delta i\eta \leq 1$.

MB1-HO matching: Unisolated MB1 TPs [1]

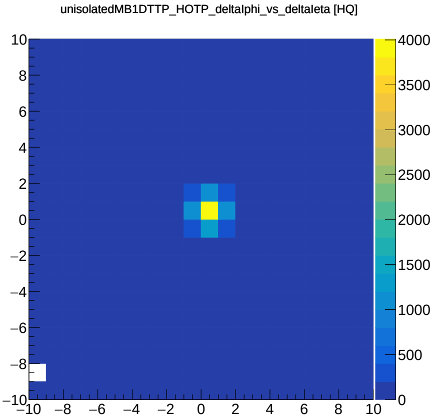





unisolatedMB1DTTP_vs_HOTP_iPhi [HQ]
0
10
20
30
40
50
60
70
80
220
200
180
160
140
120
100
80
60
40
20
0


unisolatedMB1DTTP_vs_HOTP_iEta [HQ]
−15
−10
−5
0
5
10
15
700
600
500
400
300
200
100
0

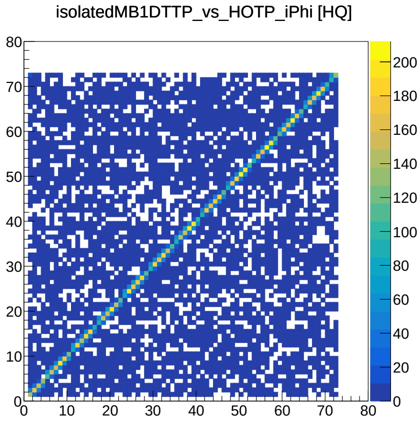
MB1-HO matching: Unisolated MB1 TPs [3]

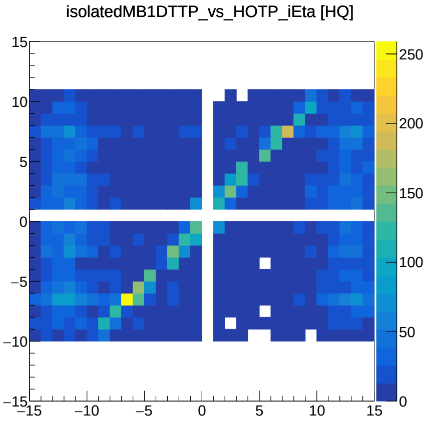


MB1-HO matching: Isolated MB1 TPs [1]

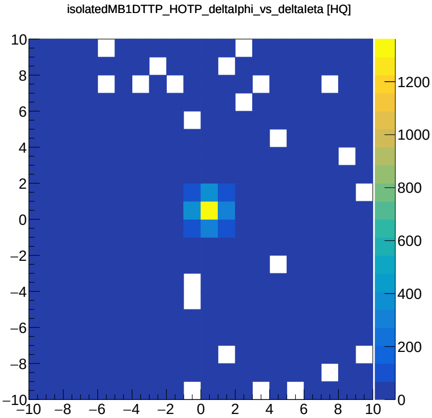
- Unisolated MB1TPs are mostly coming from genuine muons. They have a **strong linear correlation** in η, ϕ with the matched HOTP.
- The HO will provide support to the isolated MB1TPs.
- Hence have to **check the η, ϕ correlations for the isolated MB1TPs**.

MB1-HO matching: Isolated MB1 TPs [2]

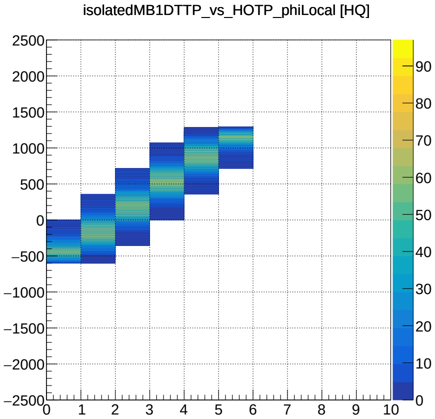




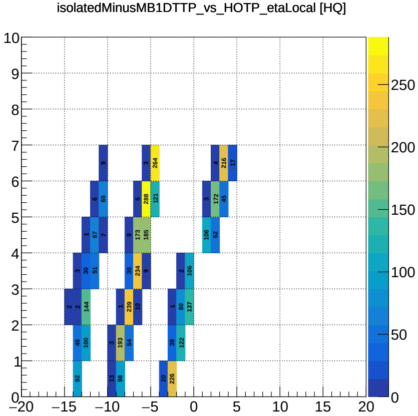
MB1-HO matching: Isolated MB1 TPs [3]

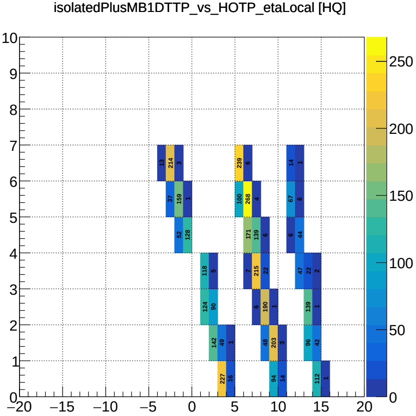


MB1-HO ϕ_{local} matching for LUTs [1]



MB1-HO η_{local} matching for LUTs

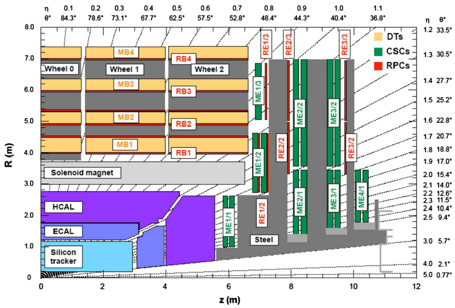




Summary

- The HO support potential looks promising.
- Thanks to **Georgios** for providing the LUTs for obtaining p_T of DTTPs.
- **Need help with reading the LUTs.**
- Will I proceed with implementing the current MB1-HO η, ϕ matching in the TwinMux emulator?

Backup



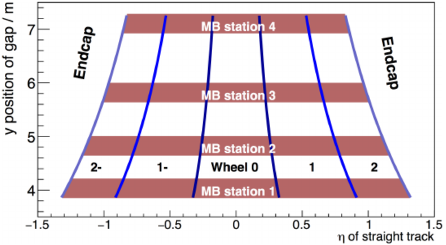
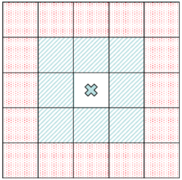


Figure 2.11: y projection of the muon chambers (MB station 1–4). A straight muon track has a fixed η value on the x-axis. This plot allows to easily see which MBs are hit by a muon with a straight track. The blue lines mark the wheel borders.

- Efficiency in muon barrel gap regions is much lower.
- Scenario where a DT station fails.
- Since the HO covers the muon barrel gap regions (along constant η), it can be used to aid the muon track finder.
- The HO-DT algorithm's effect on the efficiency improvement has been studied by Florian Scheuch (Aachen) using 2015 data. **I took the task of implementing the algorithm in the TwinMux emulator.**

The algorithm [1]



Loop over all the DTTPs in the following manner:

1. Take a DTTP in the first station/barrel (MB1).
2. Decide whether the DTTP is Low Quality ($0 < LQ < 4$) or High Quality ($3 < HQ < 7$).
3. For LQ, try to find a matching HOTP in the same wheel (that is, a looser $\Delta i\eta$) as the DTTP such that $\Delta i\phi < 1$.
4. For HQ, try to find a matching HOTP such that $\Delta i\eta \times \Delta i\phi < 1 \times 1$, i.e. within a 3×3 tile window.
5. If a matching HOTP is found, then the quality code of the DTTP is modified to indicate that this DTTP has support from the HO.
6. This modified DTTP, say DTTP' (primed) will be treated differently in the BMTF.

The modified DTTPs can be used by the BMTF to:

- recover muons in case of a muon barrel failure.
- recover muons in the barrel gap regions where the efficiency is low.

DTTP - HOTP matching (using reco info) [1]

- **Suggestions from the DT group (Stefano, Luigi, Carlo, etc.).**
- **Have used in my efficiency study.**
- Reco muon is the candle in the efficiency study - match all entities (BMTF tracks, TPs, etc.) against a reco muon to reduce chances of fakes. The reco muon must satisfy tight selection criteria with $p_T > 14$ GeV.
- ϕ of DTTP: From L1MuDTChambPhDigi

```
double globalPhi = digi_L1MuDTChambPh.phi() / 4096.0;
globalPhi += 2*M_PI / 12 * (digi_L1MuDTChambPh.scNum() - 1);
```

- η of DTTP: Get the **best DT reco segment** (DTRecSegment4DCollection) in the same wheel/station/sector as the DTTP. Use the η of this DT reco segment.
- Compare η, ϕ of the MB1 DTTP to that of the reco muon: $\Delta\phi < 0.2$, $\Delta\eta < 0.5$
- For the HOTP: Check $\Delta R < 0.2$ between the HOTP and the reco muon. Since the segmentation of the HO is $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$, the η (ϕ) for a given $i\eta$ ($i\phi$) is estimated by the average
  $\eta = \frac{(i\eta - 1) + i\eta}{2} \times \Delta\eta$
- Match the DTTP and HOTP to the **same** reco muon.

DTTP - HOTP matching (no reco info) [1]

- From Florian's setup.
- $i\phi$ of DTTP: From L1MuDTChambPhDigi:

```
double globalPhi = digi_L1MuDTChambPh.phi() / 4096.0;
globalPhi += 2*M_PI / 12 * (digi_L1MuDTChambPh.scNum() - 1);

int getIPhi(double phi)
{
// Segmentation is 0.087
double dPhi = 2.0*M_PI / 72.0;

if(phi < 0)
phi += 2*M_PI;

int iPhi = (int) (phi/dPhi + 1);

return iPhi;
}
```

- $i\eta$ of DTTP: Get a L1MuDTChambThDigi in the same wheel/station/sector as the L1MuDTChambPhDigi.

```
double getEtaFromSegment(L1MuDTChambThDigi digi_L1MuDTChambTh)
{
int pos = -1;

for(unsigned int i = 0; i < 7; i++)
if(digi_L1MuDTChambTh.code(i) == 2)
pos = i;

if(digi_L1MuDTChambTh.whNum() == -2 || digi_L1MuDTChambTh.whNum() == -1
|| (digi_L1MuDTChambTh.whNum() == 0
&& (digi_L1MuDTChambTh.scNum() == 0 || digi_L1MuDTChambTh.scNum() == 3
|| digi_L1MuDTChambTh.scNum() == 4 || digi_L1MuDTChambTh.scNum() == 7
|| digi_L1MuDTChambTh.scNum() == 8 || digi_L1MuDTChambTh.scNum() == 11)))
{
pos = 6 - pos;
}

if(digi_L1MuDTChambTh.whNum() == -2)
return ((int) (round((-5. / 7.) * (pos + 1) - 10)));
if(digi_L1MuDTChambTh.whNum() == -1)
return ((int) (round((-6. / 7.) * (pos + 1) - 4)));
if(digi_L1MuDTChambTh.whNum() == 0)
return ((int) (round((-8. / 7.) * (pos + 1) + 5)));
if(digi_L1MuDTChambTh.whNum() == 1)
return ((int) (round((-6. / 7.) * (pos + 1) + 11)));
if(digi_L1MuDTChambTh.whNum() == 2)
return ((int) (round((-5. / 7.) * (pos + 1) + 16)));
```

```
return -99;
}
```

- Compare the $i\eta, i\phi$ obtained above to that of the HOTP.

- Global ϕ calculation.
- What is the best way to estimate the global η of a given L1MuDTChambPhDigi.
- Since the DT η is not as well measured as the ϕ, should the DT-HO η matching be as strict as the ϕ matching?
- BMTF efficiency definition.

P.S. The HO timing problem has been resolved (**Pooja has tested with SingleMuon dataset of 24th June generation date, run 297505**). I will be using 2017 dataset for further studies.

Part 1: Efficiency study

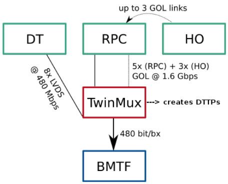
- Dataset (suggested by DT group):
  `/SingleMuon/Run2016H-ZMu-PromptReco-v2/RAW-RECO`
- `CMSSW_9_0_1` to produce ntuples from the dataset.
- `CMSSW_8_0_20` for analysing ntuples.
- HOTPs:
  - With 2016 dataset, we found that the HOTPs were not consistent and timing has a large offset. Hence, the plots shown here are preliminary.
  - We have notified HCAL; will check the timing using 2017 dataset. Necessary steps will then be taken, if needed, to fix the timing delay.

- A DT track segment is reconstructed from a single DT chamber.
- In-time means that the TP must have been recorded at the correct bunch-crossing.
- The efficiencies are computed separately for each muon station (barrel).
- The DTTP efficiency is defined as (thanks to **Stefano Marcellini**):

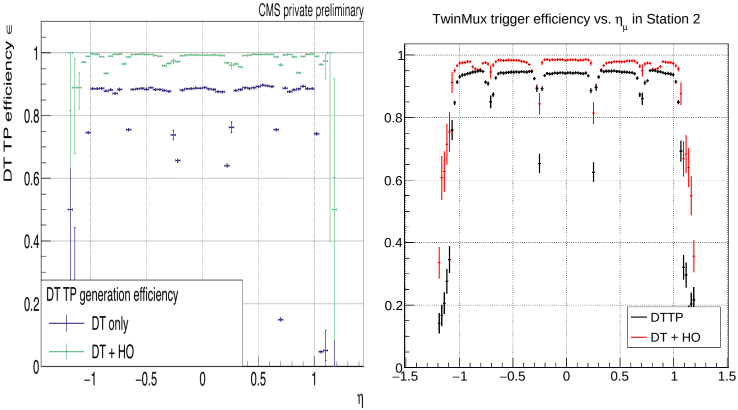
$$\epsilon_{DTTP}^{MBi} \text{ (in a bin)} = \frac{\text{\# of in-time DTTPs in the same wh/sec of MBi as the denominator}}{\text{\# of DT track segments in MBi matched to reconstructed muon tracks}}$$

- Say a DTTP is missing in MB2. Then the MB1 and HO information can be used. The efficiency with HO support is defined as:

$$\epsilon_{HOTP}^{MB2} \text{ (in a bin)} = \frac{\text{\# of HOTPs matched to in-time MB1 DTTPs matched to the denominator}}{\text{\# of DT track segments in MB2 matched to reconstructed muon tracks}}$$

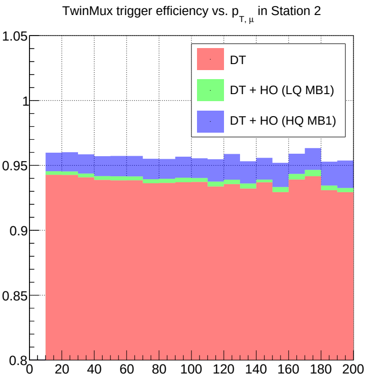


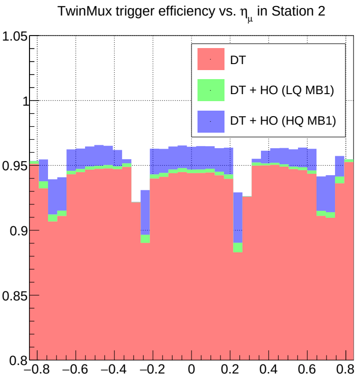
Algorithm performance: DTTP Efficiency [2]



- Trend similar to Florian's result.

Algorithm performance: DTTP Efficiency [3]

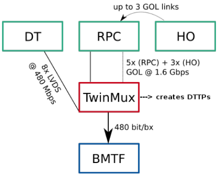


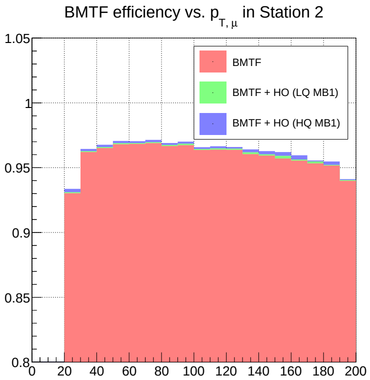


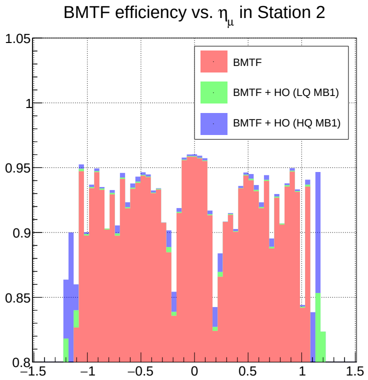
- The BMTF constructs tracks out of DTTPs.
- The efficiencies are computed separately for each muon station (barrel).
- The BMTF efficiency is defined as: given there is a genuine DTTP, what fraction of times was it used to create a track.

$$\epsilon_{BMTF}^{MBi} \text{ (in a bin)} = \frac{\text{\# of BMTF tracks matched to the denominator}}{\text{\# of genuine DTTPs in MBi}}$$

- A genuine DTTP is one that is matched to a DT track segment which was in turn matched to a reconstructed muon track.
- To support MB2: in case of a missing BMTF track coinciding with a missing DTTP in MB2, there is a potential for track recovery - look for a matching MB1 DTTP which as HO support (matching HOTP).




BMTF efficiency vs. $p_{T,\mu}$ in Station 2
BMTF
BMTF + HO (LQ MB1)
BMTF + HO (HQ MB1)
1.05
1
0.95
0.9
0.85
0.8
0
20
40
60
80
100
120
140
160
180
200


BMTF efficiency vs. η_{μ} in Station 2
BMTF
BMTF + HO (LQ MB1)
BMTF + HO (HQ MB1)
1.05
1
0.95
0.9
0.85
0.8
−1.5
−1
−0.5
0
0.5
1
1.5

Part 2: L1 rate study

- Dataset: /ZeroBiasBunchTrains[0-5]/Run2016H-v1/RAW
- CMSSW_8_0_20.

The L1 trigger

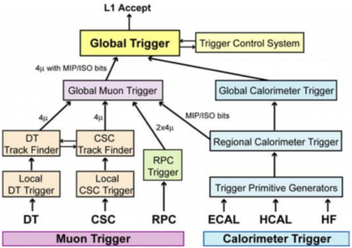


Figure 2.14: Schematic of the L1 legacy trigger chain till 2015 [23]. The information is processed from the bottom up. All steps are realized on dedicated hardware. The muon trigger has changed afterwards, combining DT, RPC, and HO information at the stage of the DT Track Finder (see figure 2.15).

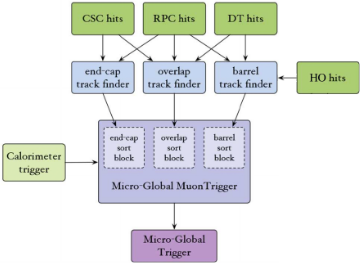


Figure 2.15: Schematic of the upgraded muon trigger [50]. Data is processed from the top down. The detector data is merged for the barrel, overlap, and endcap region. The μ-Global Muon Trigger includes calorimeter data for isolation assignment. The combination of muon candidates from every subsystem can be omitted, resulting in a shorter trigger latency. The μ prefix refers to the newly used μTCA technology. All steps are processed on dedicated hardware.

Algorithm performance: L1 trigger rate [1]

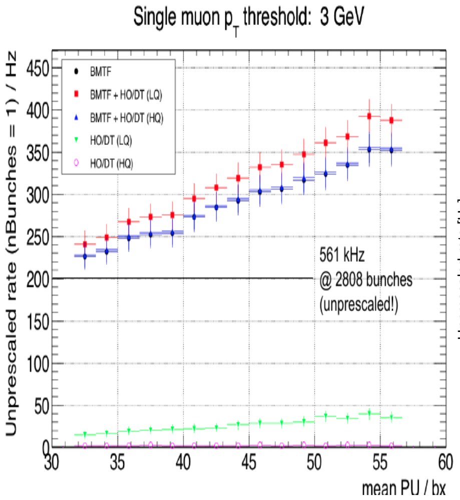
Have to check that the rate increase of the L1 trigger is not too high. The dataset is a **zero-bias** one: `/ZeroBiasBunchTrains[0-5]/Run2016H-v1/RAW`

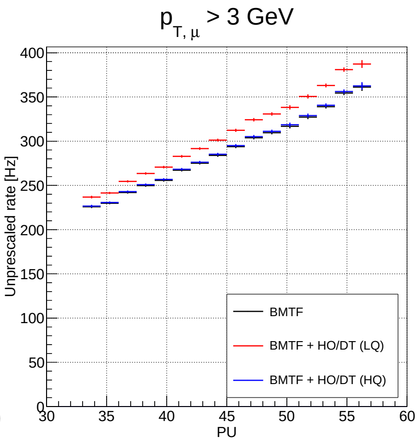
- **The L1 Trigger uses the output of the BMTF.**
- Hence the trigger rate (due to BMTF tracks) can be estimated as, **the number (fraction) of events with at least one valid BMTF track**. That of course needs to be scaled appropriately by the LHC revolution frequency ($f_{rev} = 11245.5$ Hz) for proton energy 6.5 TeV.

$$Rate \text{ (in a PU bin)} = \frac{\text{\# of events with at least one BMTF track in that PU bin}}{\text{Total \# of events in that PU bin}} \times f_{rev}$$

- **In case of a missing BMTF track, there is a potential for track recovery and hence a gain in rate.**
- Count the number events with at least one MB1 DTTP that has a matching HOTP, coinciding with a **missing BMTF track**. Let such a DTTP be called DTTP' (primed).
- In the best (or worst?) case scenario, each of those events with a DTTP', can potentially give rise to a new BMTF and hence increase the L1 rate. **So the rate increase can be estimated as the number of such events.**

Algorithm performance: L1 trigger rate [2]





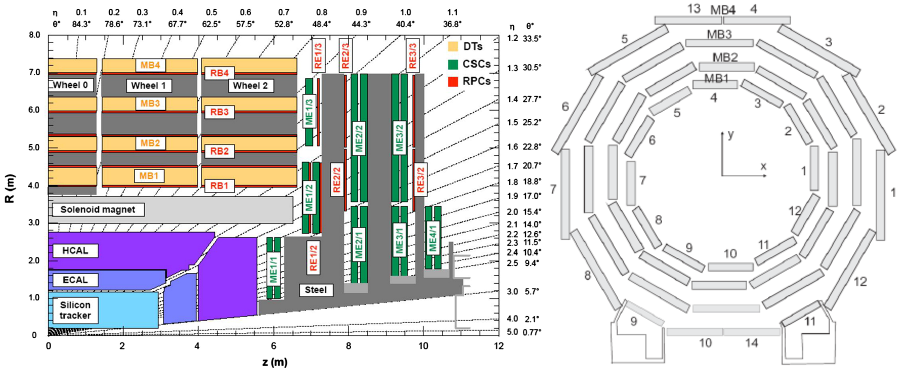
- The rate increase is tolerable.
- The rates are unprescaled, that is $nBunch = 1$; can be scaled to any arbitrary bunch filling.

Summary

- HO has been partially implemented in the TwinMUX emulator code setup; **preliminary studies seems promising**.
- Currently using the HOTPs from HCAL FEDs; **will switch to HOTPs from TwinMux, once the unpacker is ready**.
- Will perform the studies with 2017 data to check the timing delay issues with the HOTPs.

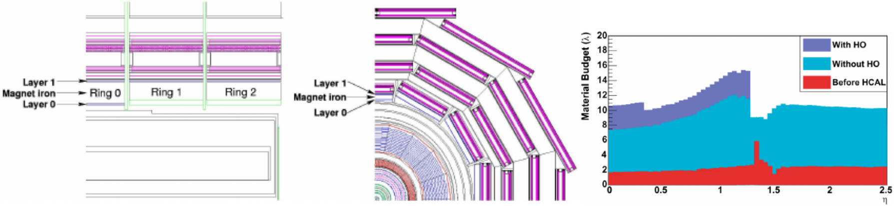
Work done over $\sim$ 3.5 months:

- Started with Florian's setup for L1 rate estimation; **have written independent setup to reproduce the result.**
- **Completely independent** setup to reproduce Florian's efficiency study using 2016 data.
- HO has been partially implemented in the TwinMux emulator code setup - however, cannot check actual performance unless the BMTF algorithm is changed to use the modified DTTPs.



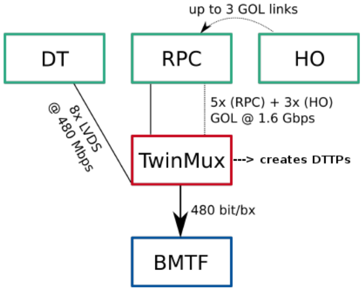
- The DT chambers provide Trigger Primitives (TPs) which store information about the location of the hit, number of aligned DT-hits, the bending angle ϕ_B etc. It also contains a quality code which indicates the number of Superlayer (SL) hits and the how well aligned they are.

The Outer Hadron (HO) calorimeter



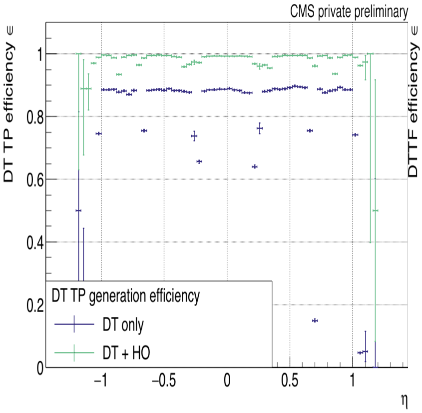
- $|\eta| < 1.4$.
- Central ring has 2 layers. The others have 1.
- Segmentation: $\Delta\eta \times \Delta\phi = 0.087 \times 0.087$.
- The HO provides Trigger Primitives (TPs) which among other things, store the η-ϕ location information, and also a mip-bit which stores whether the hit is mip-like (within certain thresholds) or not.

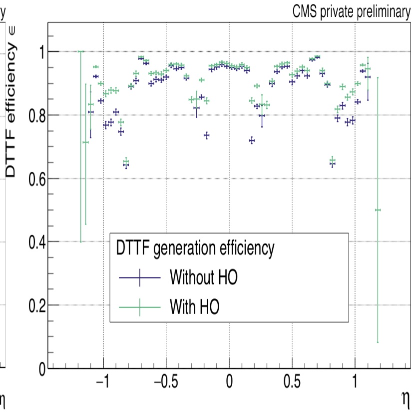
The TwinMux



- The DTTPs are created by the TwinMux (a μTCA board) using information from the DT and RPC (mainly for timing), and sent to the Barrel Muon Track Finder (BMTF).
- The TwinMux emulator is a piece of code that emulates this behaviour, and can be used for stuff like testing new algorithms.
- Currently, the HO information is not used by the TwinMux.

- Efficiency study performed earlier by **Florian Scheuch (Aachen)** with 2015 data.
- **I am studying the efficiency with 2016 data, using independent codes.**





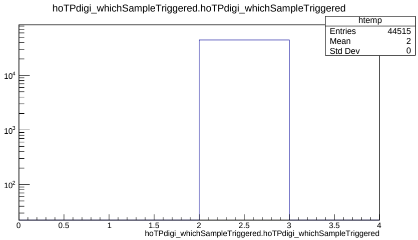
An insight into HOTPs [1]

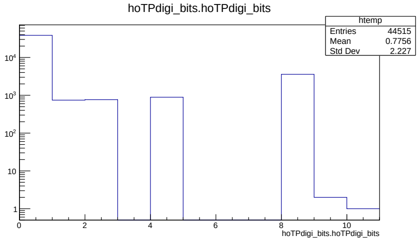
- Running producer hcalDigi from EventFilter.HcalRawToDigi.HcalRawToDigi_cfi to produce the HOTP collection.
- HOTP unpacker is HOTriggerPrimitiveDigi.h.
- Will use the TwinMux HO unpacker (HOTPDigiTwinMux.h) once it's ready.
- Accessing mip-bit (suggested by **Christopher West**):

```
(hoTP.bits()>>hoTP.whichSampleTriggered())&0x1
```

- ```
  /// get the number of the triggering sample
  int whichSampleTriggered() const { return (theHO_TP>>16)&0x000F; }
  /// get the single-bit data
  int bits() const { return (theHO_TP>>20)&0x03FF; }
  ```

- Issue with HOTP mip-bit - needs to be resolved.
  ```



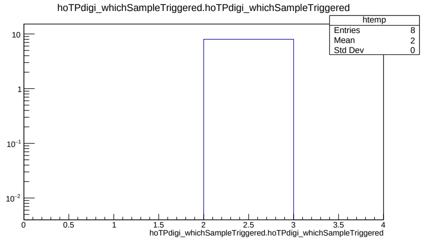


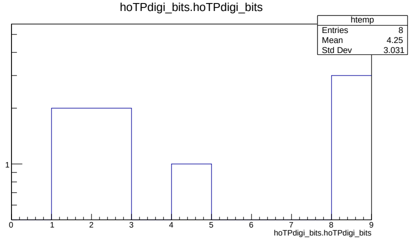
- hotp.bits() needs to peak at 4 to get the mib-bit as 1.
- Because hotp.bits() does not peak at 4, the mib-bit is mostly 0.

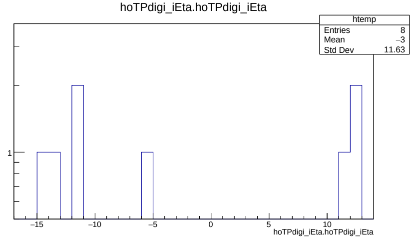
Tests with pedestal and LED runs:

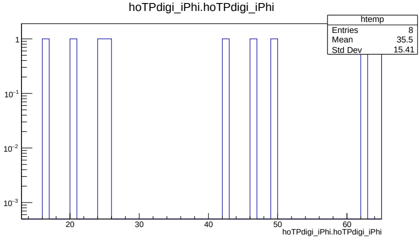
- Pedestal:
  `/store/group/dpg_hcal/comm_hcal/USC/run296181/USC_296181.root`
  (2000 events)
- LED:
  `/store/group/dpg_hcal/comm_hcal/USC/run295675/USC_295675.root`
  (2000 events)

Pedestal: $bits() > 0$



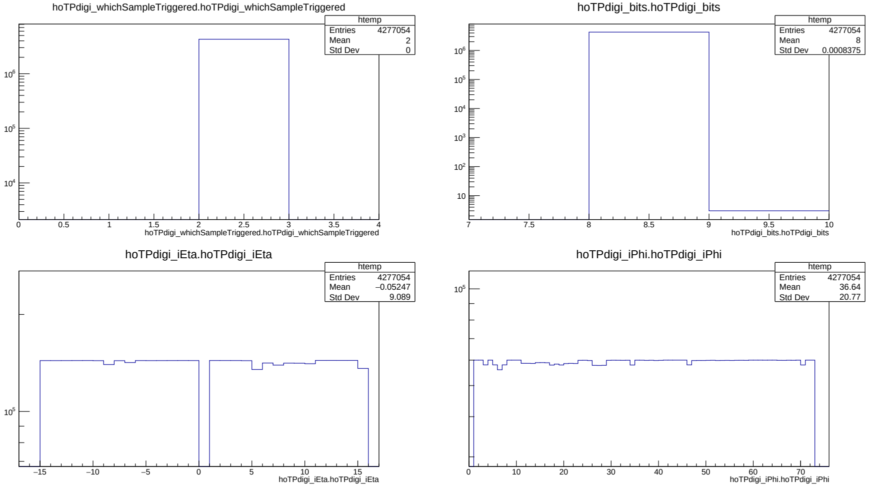




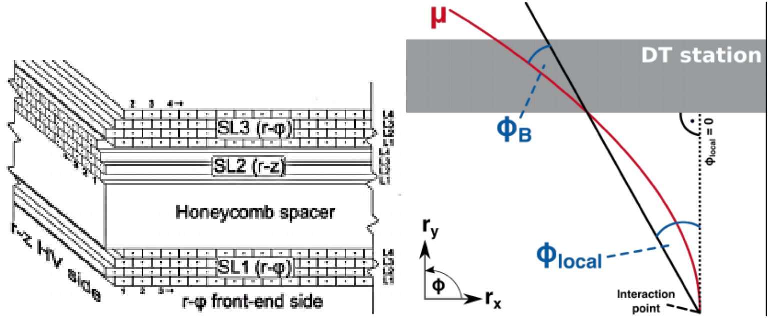


An insight into HOTPs [5]

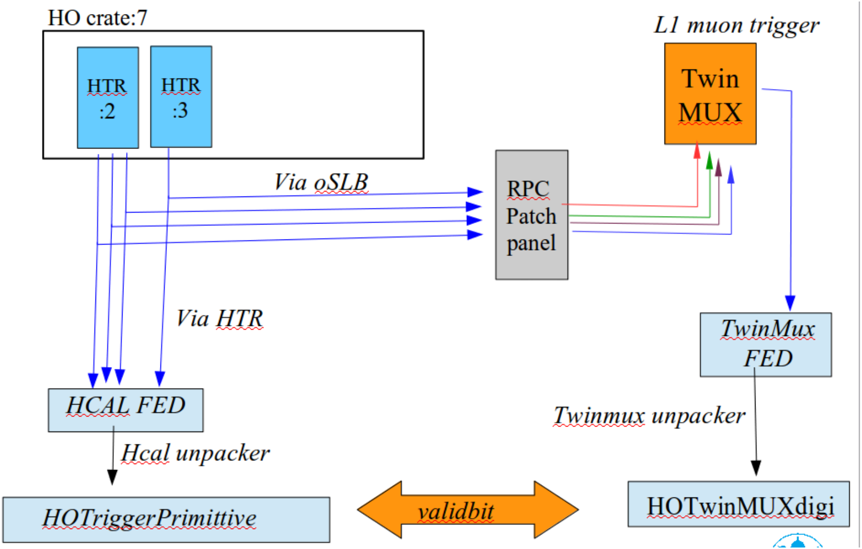
LED: $bits() > 0$



The Muon Drift Tube (DT) system [1]



- 4 staggered layers form 1 SuperLayer (SL).
- $SL_{r\text{-}\phi}$ have wires parallel to the beamline, and measure quantities in the r-ϕ plane.
- SL_z have wires perpendicular to the beamline, and measure quantities in the r-z plane.
- In MB1/2/3, one chamber is formed by 2 $SL_{r\text{-}\phi}$ and 1 SL_z.
- In MB4, one chamber is formed by only 1 $SL_{r\text{-}\phi}$.
- The DT chambers provide Trigger Primitives (TPs) which store information about the location of the hit, number of aligned DT-hits, the bending angle ϕ_B etc. It also contains a quality code which indicates the number of SL hits and the how well aligned they are.


HO crate:7
HTR :2
HTR :3
Via oSLB
RPC Patch panel
L1 muon trigger
Twin MUX
Via HTR
TwinMux FED
HCAL FED
Twinmux unpacker
Hcal unpacker
HOTriggerPrimittive
validbit
HOTwinMUXdigi

Level-1Single Objects Triggers