Phase2 L1T EndCap Track-Muon Correlator with Stubs

Report to Joint Muon-Trigger Workshop

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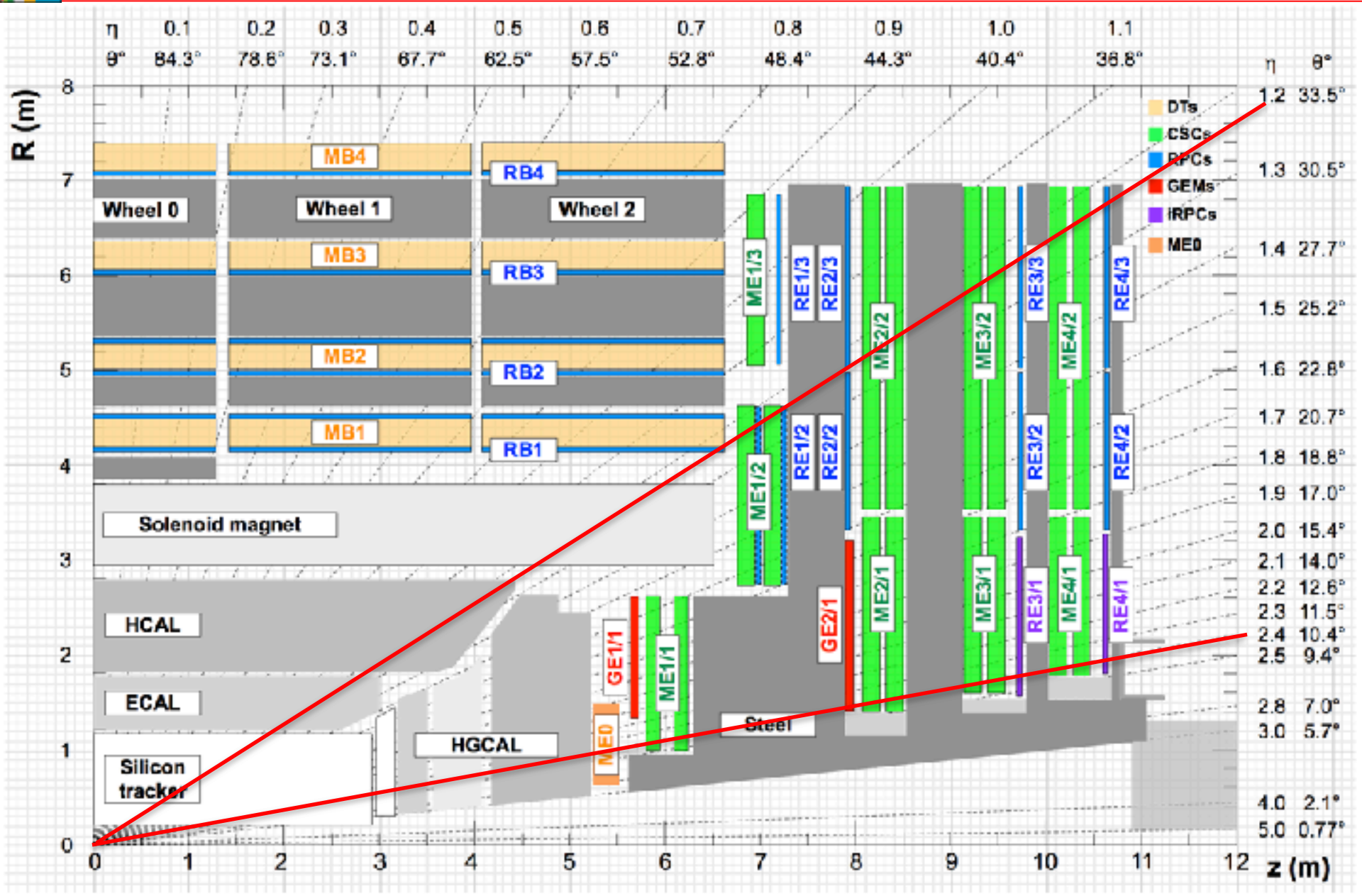
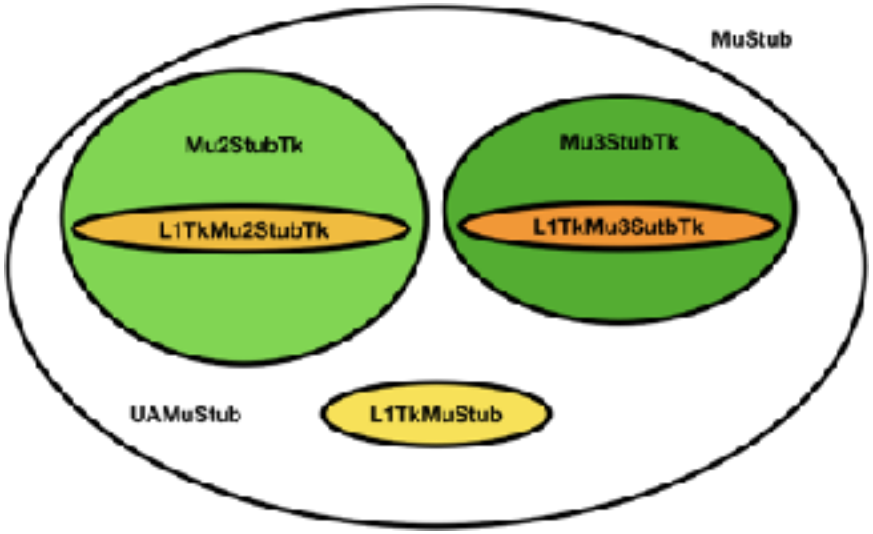
Muon Phase-2 Detector - Today considering region w/in red lines



Setting the stage ….

Current status of TkMu correlator in EndCap

For the EndCap we have implemented a L1TkMu correlator which matches L1TTTracks with EMTF muons (tracks) in pt-dependent matching eta & phi windows.



EMTF tracks are made of 2 or more muon stubs, which are either CSC TPs or RPC TPs in the currently available EMTF emulator in CMSSW (Phase-1).

Immediate plans

Apart from understanding the nature of these matched L1TkMu objects, we are interested in understanding the nature of the unassociated stubs, and explore their use in a correlation with L1TTTracks.

In the analysis we will exploit the L1TT Truth and Reco information and address the performance metrics of (a) currently available L1TkMu correlator and (b) newly developed L1TkMuStub correlator:

1. Efficiency
2. Rate
3. Purity
4. Understand cause of fakes

Use GEN-SIM-DIGI-RAW data-tier with PU 0 and 200:
- Single Neutrino (MinMias).
- Single Muon

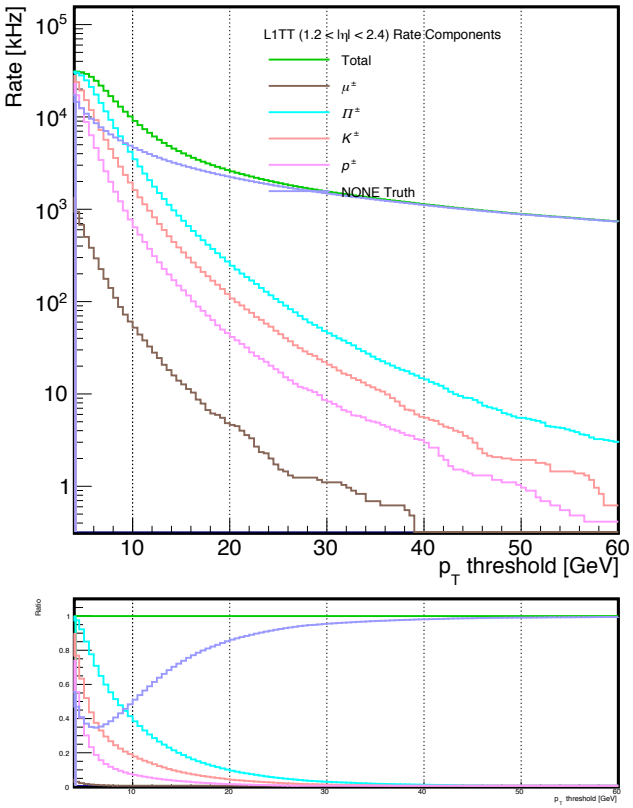
L1TT Tracks in forward (1.2 <|η| < 2.4) : Rate - Truth

- Dataset: centrally produced, NuGun PU 200

- **L1TT Tracks (Tracklets) Rate**

  - Top plot shows the rate of L1TT Tracks as obtained from Tracklet algorithm used Phase2-l1t-integration, with nstub >=4, chi² <100, and 1.2 <|η| < 2.4
    - Over-all (Total) rate is shown in green.
    - L1TTTracks matched with Truth (*mu*, *Pi*, *K*, *p*) are shown in different colors and L1TTT matched to NONE Truth are fakes.
  - Bottom plot shows the ratio of individual rates to total rate.

L1TTTs in EndCap



- **L1TT Tracks (Tracklets) Rate Composition**
  - Most of the rate comes from PU pions and fakes.
    - True (PU) muons fraction is virtually zero.
      - Few % to below 0.1%, above 20 GeV
    - π and K are high for low pT
      - 100-50%, below 20 GeV.
    - Fakes are high and overwhelming for higher pT
      - ~50-80%, between 10 and 20 GeV
      - ~80-100%, above 20 GeV.

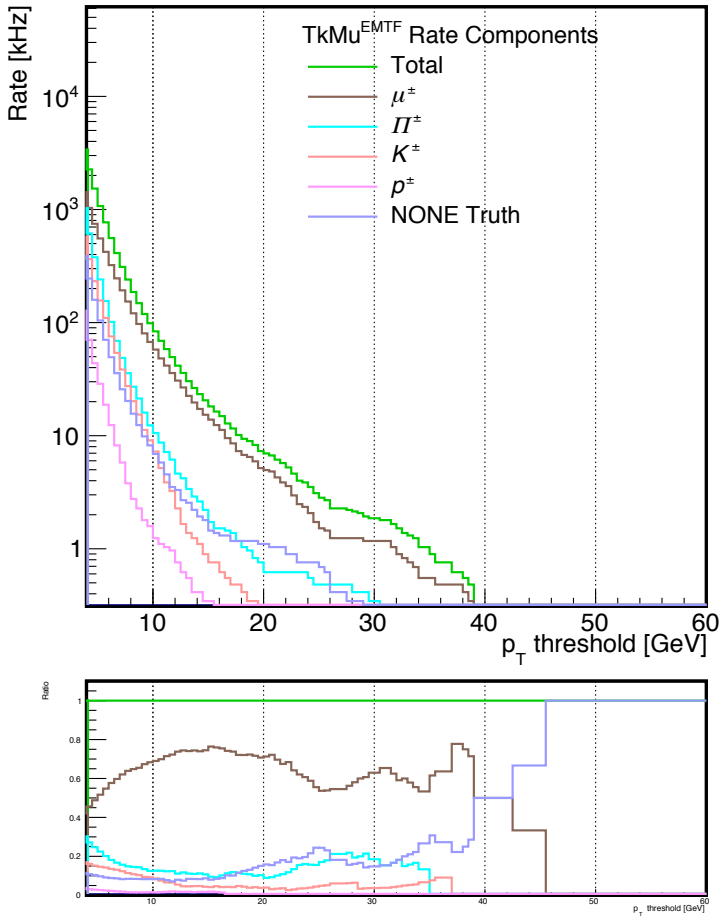
L1TkMu**EMTF** Correlator: Rate - Truth - Purity

- Dataset: centrally produced, NuGun PU 200

- **L1TkMu correlator (L1TTTrack with EMTF track, integrated in CMSSW)**

  - Top plot shows the rate of L1TkMu(EMTF) correlator which is already integrated in CMSSW, now with relaxed MWs.
    - Over-all (Total) L1TkMu rate is shown in green.
    - L1TkMu(EMTF) matched with Truth (*mu*, *Pi*, *K*, *p*) are shown in different colors and L1TkMu(EMTF) matched to NONE Truth are fakes.

  - Bottom plot shows the fraction of different individual rates to Total rate of L1TkMu(EMTF).



pT range with sufficient stats

- **L1TkMu Correlator Purity**
  Most of the rate comes from PU muons.
  (There are no muons from Physics Collision in this sample)
  - Purity (true muons fraction) is high in range of sufficient stats.
    - up to 70~80% in range pt (10-20 GeV)
    - Up to 50-70% in range pt (20-40 GeV),
  - Punch-throughs (Pi +/-) relatively low
    - Dropping 20-10% in range (4-20 GeV), then goes up to 20 % @ pt 26 GeV
  - Fakes are low
    - at 10% constant in range (4-15 GeV), then goes up to 25% @ pt 25 GeV

- Remark: these muons do not come from the PVtx (Nu Gun) !
  so we should be able to remove good fraction of them with a cut on Delta (Ztrk,Zvtx) once the PVtx calculated down stream in L1T flow.

Implement Correlator L1TTTk + MuStub = TkMu**Stub**

- *To discuss further, this is the first implementation, and not the final proposal.*

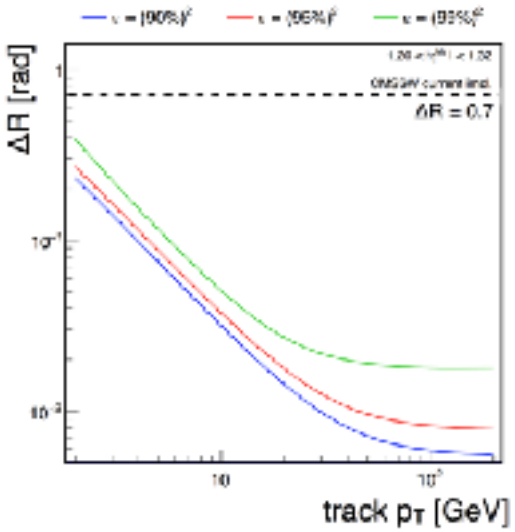
1. L1TTks in feudicial region and quality cuts
   (pt > 3.5 GeV, nStubs >=4, Chi2<100)

2. Project L1TTk to EndCap Muon station (S2).

3. Match L1TTk with EndCap Stub found in station S2 (S1).
   - use pT dependent matching windows in eta and phi
     - For L1TTk find best matched Stub in the window

4. Arbitrate stub matched to more than one L1TTk by choosing the one with higher pT L1TTk.

From Luca C.

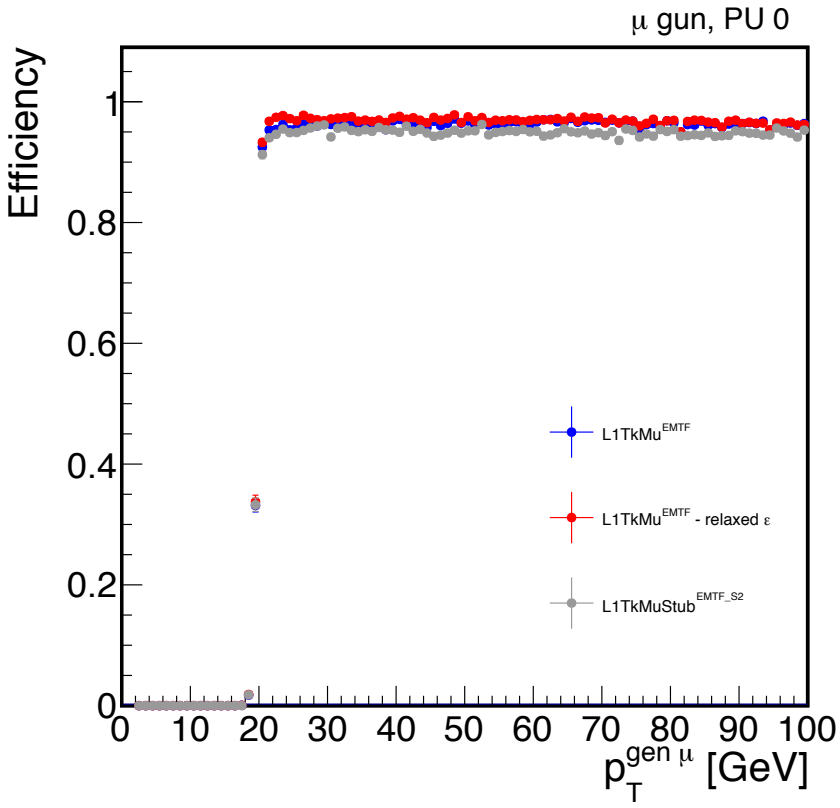


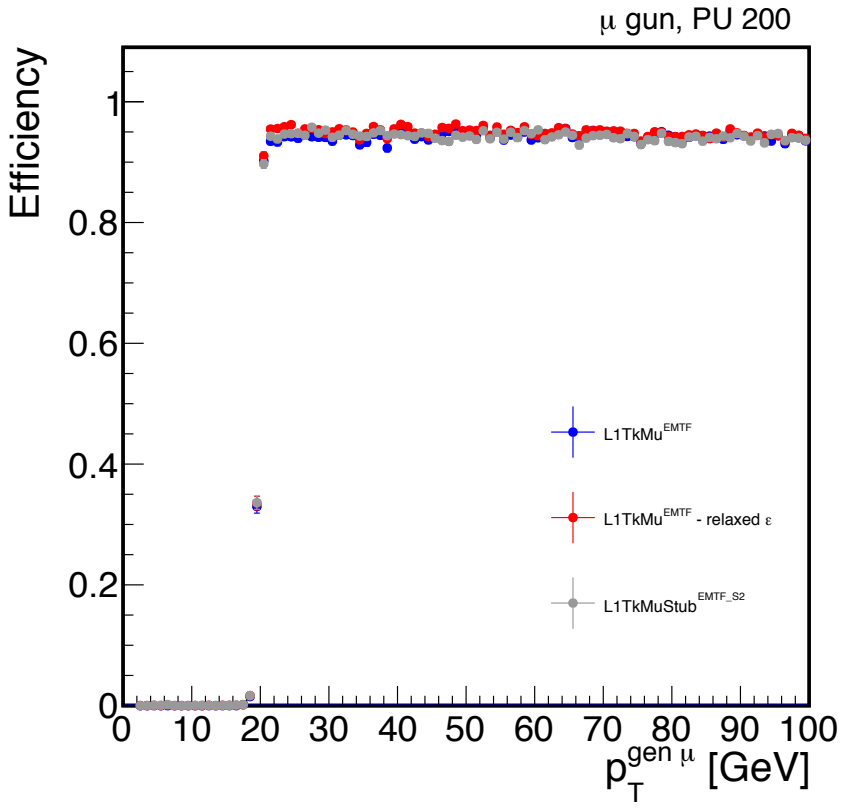
5. For time being, two separate instances of TkMuStub correlators, (not exclusive)
   - Tk + Stub_EMTF_Station 2 (main)
   - Tk + Stub_EMTF_Station 1 (for reference)

Note: In future, will make the TkMuStub correlator smarter: if Stub in one station not present, try to match to a Stub from the other station, or some combination.

Performance: Turn-on for TkMu**Stub** > 20 GeV

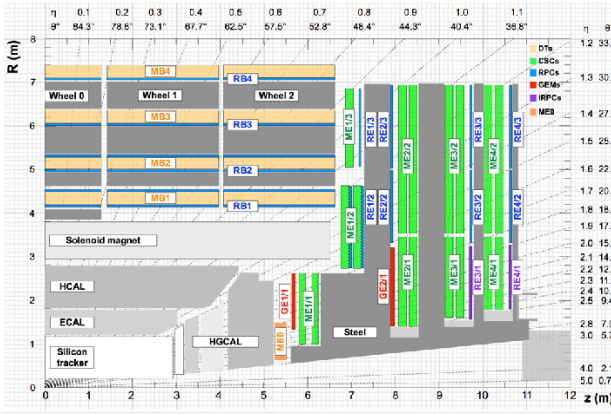
- Only showing TkMuStub(S2).
- TkMuStub efficiency is equally as sharp as TkMuEMTF.
- For higher PU, the efficiency of TkMuStub is lower than in PU0, but closer to efficiency TkMuEMTF.
  - (To be looked at vs Eta and with the study of Truth— Next Slides)

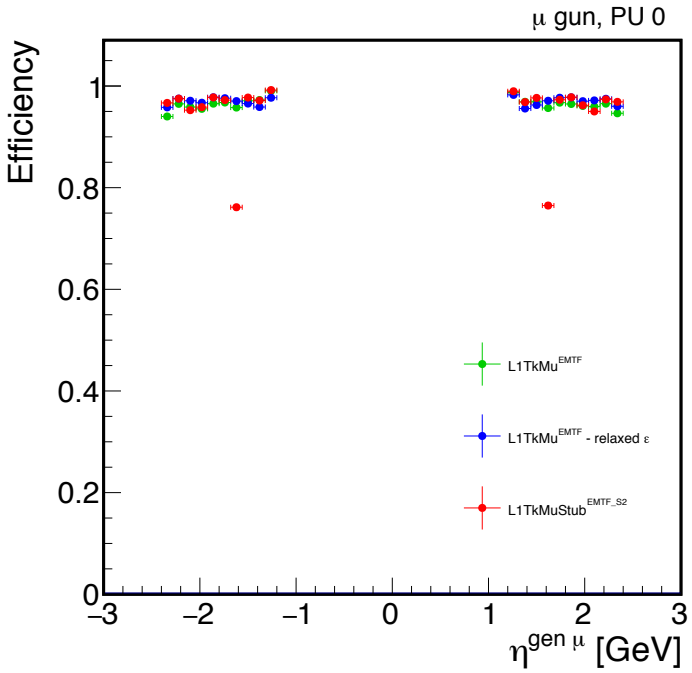


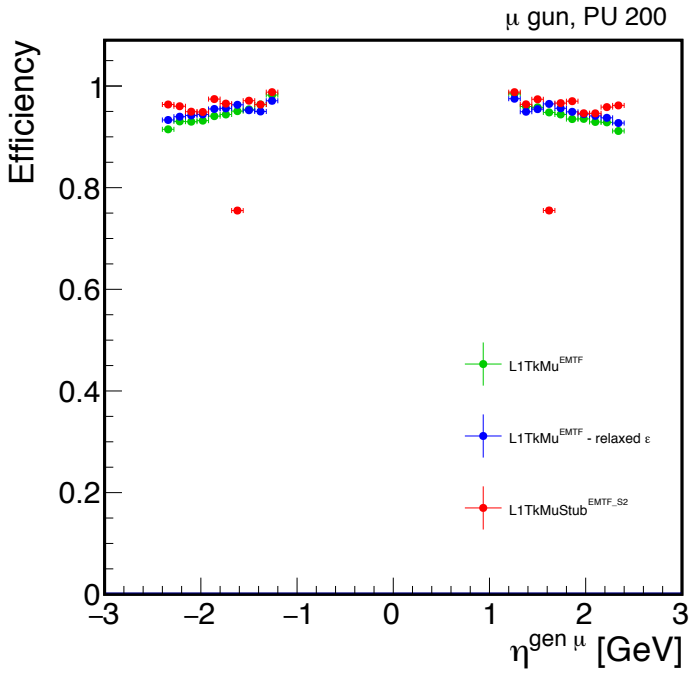


Performance: Efficiency vs eta (in the plateau of turn-on)

- At PU0 (left):
  Eff(TkMuStub) >= *Eff*(TkMu), for low |eta|
  Eff(TkMuStub) < *Eff*(TkMu),
  - for|eta|= ~1.7 due to gap b/w ME2/1 & ME2/2 no CSC
  - for|eta|= ~2 due to no RPC ?
  - At PU200 (right):
    Eff(TkMu) drops, especially @ high |eta|, (ineff P1 EMTF)
    Eff(TkMuStub) > *Eff*(TkMu), almost for all|eta|
    Eff(TkMuStub) < *Eff*(TkMu),
    - for|eta|= ~1.7 due to gap b/w ME2/1 & ME2/2 no CSC

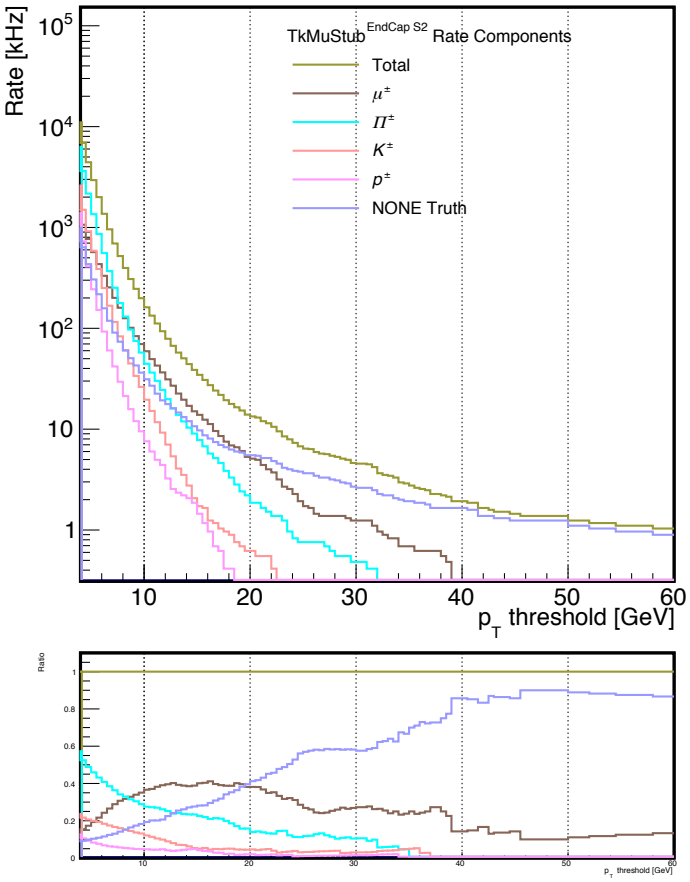




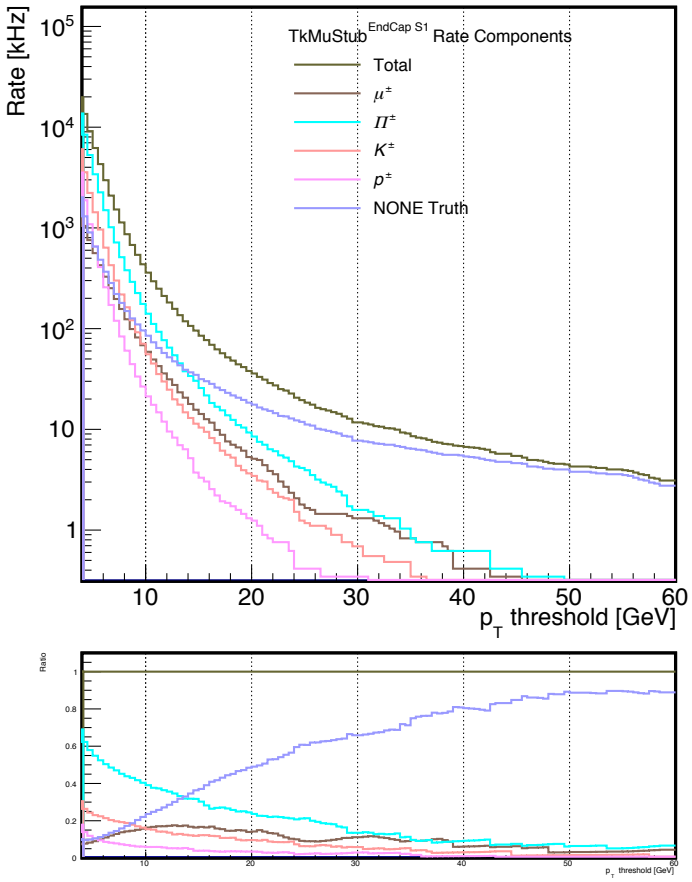


Purity of L1TkMuStub

TkMuStub S2 (main)



TkMuStub S1 (for reference)



- **TkMuStub S2** (left) is 20-40% pure in range pt <20 GeV, and then goes down to ~20% pure in range 20-40 GeV. The fakes take over for pt above 30 GeV. Punch-throughs are low, staying at about half the fraction of the purity.
- TkMuStub S1 (right) has low purity, ~20% pure in lower pt range (< 20 GeV), and then goes down to about 10% in range. The rate is dominated (60-40%) by punch-troughs for very low pt (4-15 GeV), and then it is quickly taken over by fakes.

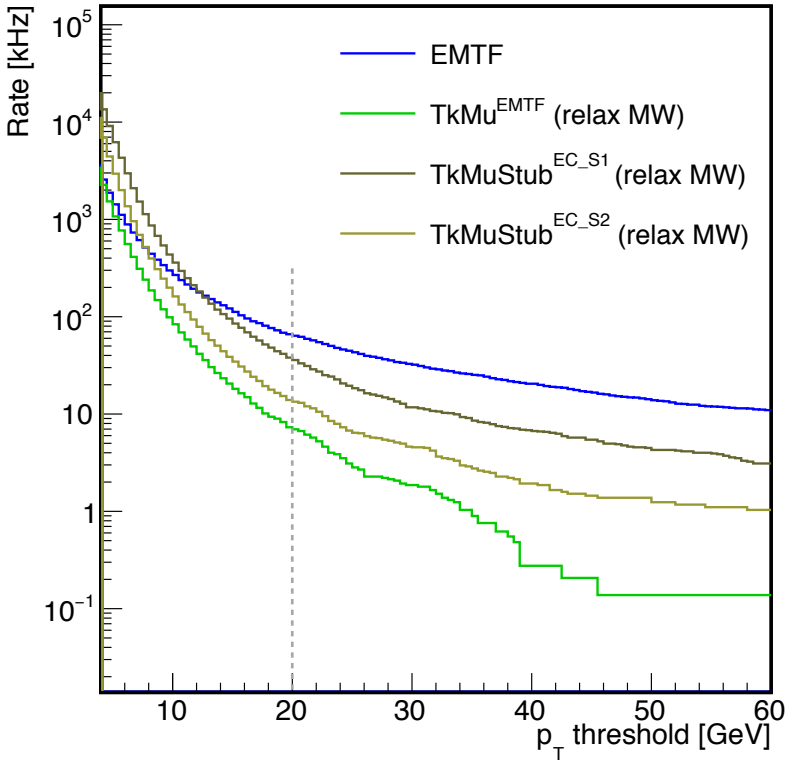
Performance - Rates

- Rate of TkMuStub S2 significantly lower than TkMuStub S1
  -S2: ~15 kHz @20 GeV
  -S1: ~50 kHz @20 GeV

- This is probably due to multiple reasons:
  1. Higher CSC/RPC hit occupancy in S1 vs S2 (closer to IP)
  2. Matching windows used were derived for S2, so matching S1 Stubs more likely to pick up PU Stubs.

- However, 15 kHZ @20 GeV for TkMuStub S2 is encouraging!

- Need to further optimize the algorithm.



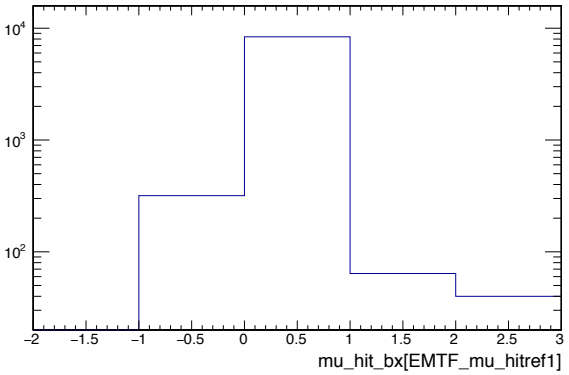
Timing (BX) in Muon Detector Trigger Primitives

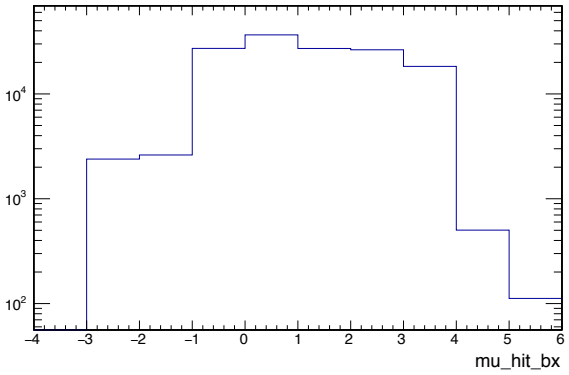
- MuGun PU 200

BX of Phase-1 EMTF Stubs

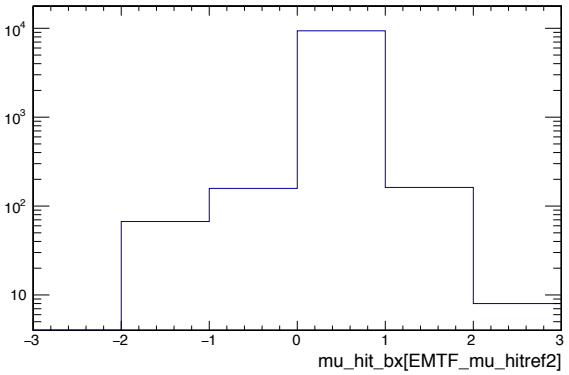
BX of Phase-1 EndCap Stubs (CSC,RPC)

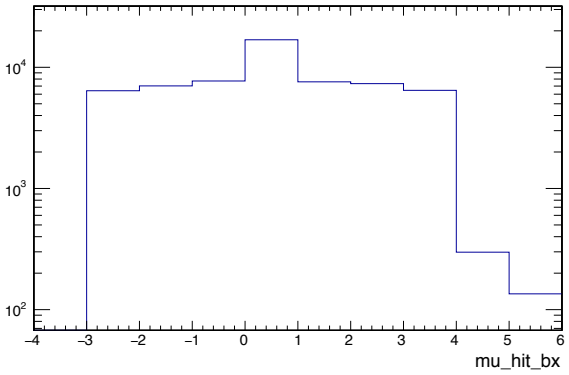
Station 1





Station 2



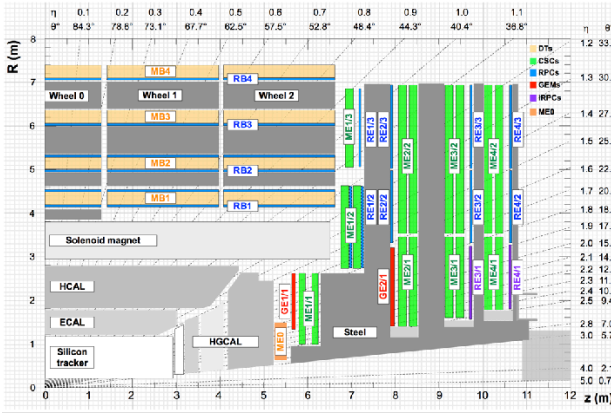


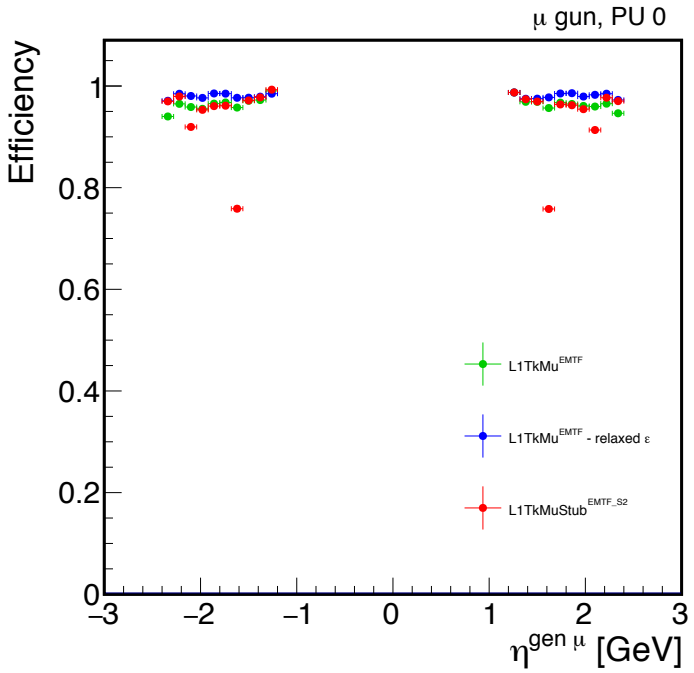
EMTF inputs are CSCs & RPCs with BX (-3,+3), but the reconstructed EMTFs have mostly stubs from BX=0: 97% @ Station1, 98% @ Station2.

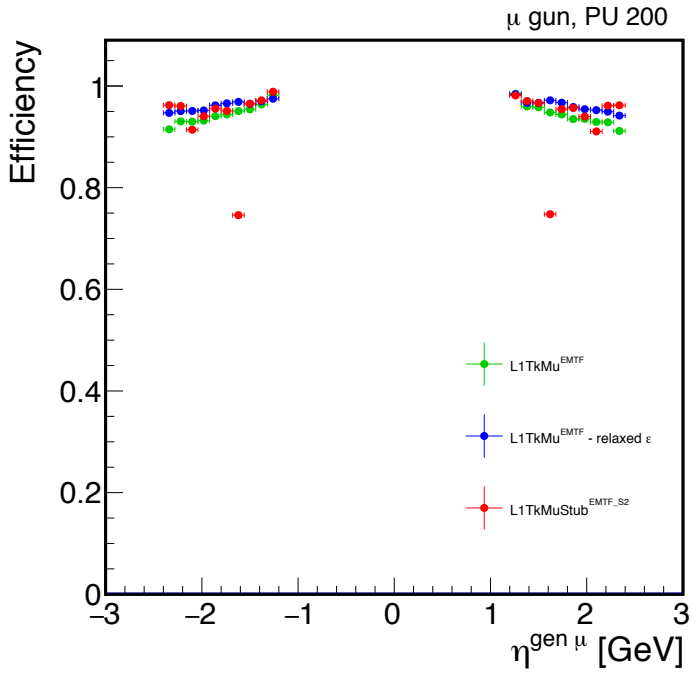
EndCap Muon TPs (Stubs) have lots of stubs in BX !=0……..**Let's restrict Stubs to BX=0 when building TkMuStub**

Performance: Efficiency vs eta (in the plateau of turn-on) with **BX=0**

- At PU0 (left):
  Eff(TkMuStub) ~ *Eff*(TkMu), for low |eta|
  Eff(TkMuStub) < *Eff*(TkMu),
  - for|eta|= ~1.7 due to gap b/w ME2/1 & ME2/2 no CSC
  - for|eta|= 1.7 to 2 due to no RPC ? Will have GE2/1
- At PU200 (right):
  Eff(TkMuEMTF) drops, especially @ high |eta|, (ineff P1 EMTF)
  Eff(TkMuStub) >= *Eff*(TkMu), almost for high and low eta|
  Eff(TkMuStub) < *Eff*(TkMu),
  - for|eta|= ~1.7 due to gap b/w ME2/1 & ME2/2 no CSC

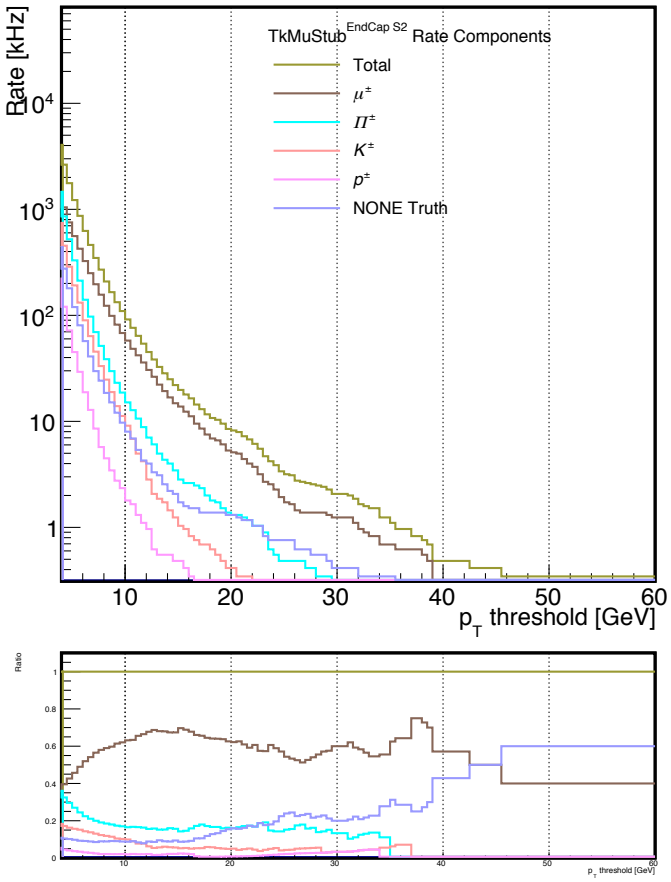




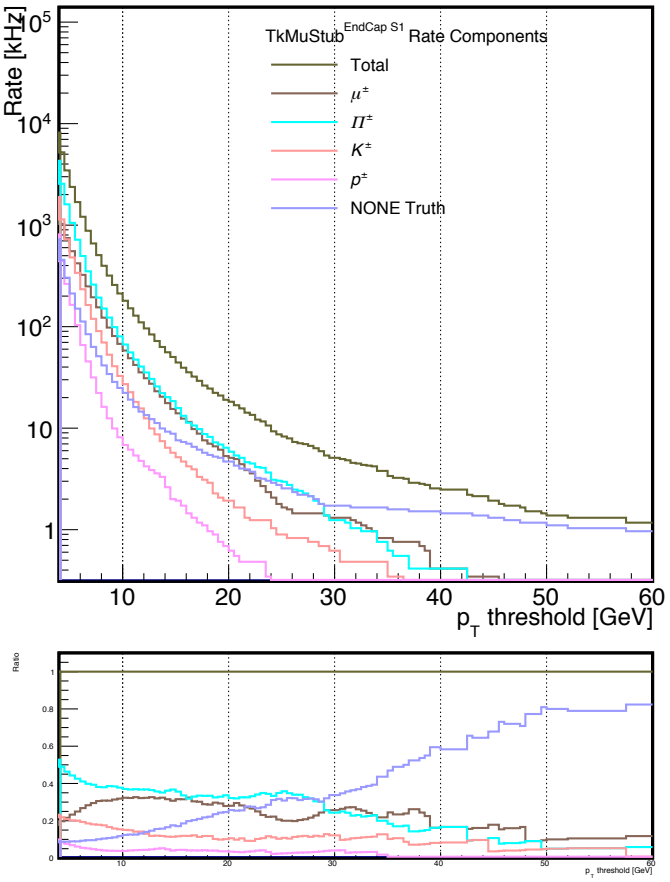


Purity of L1TkMuStub with **BX=0**

TkMuStub S2 (main)



TkMuStub S1 (for reference)



- **TkMuStub S2** (left) has 60-80% purity in range pt >10 GeV. The fakes remain 10~20%. Punch-throughs are low, staying at about 20% purity.
- TkMuStub S1 (right) has 20-40% purity. The rate is dominated (40%) by punch-troughs for pt < 30, and then it is quickly taken over by fakes.

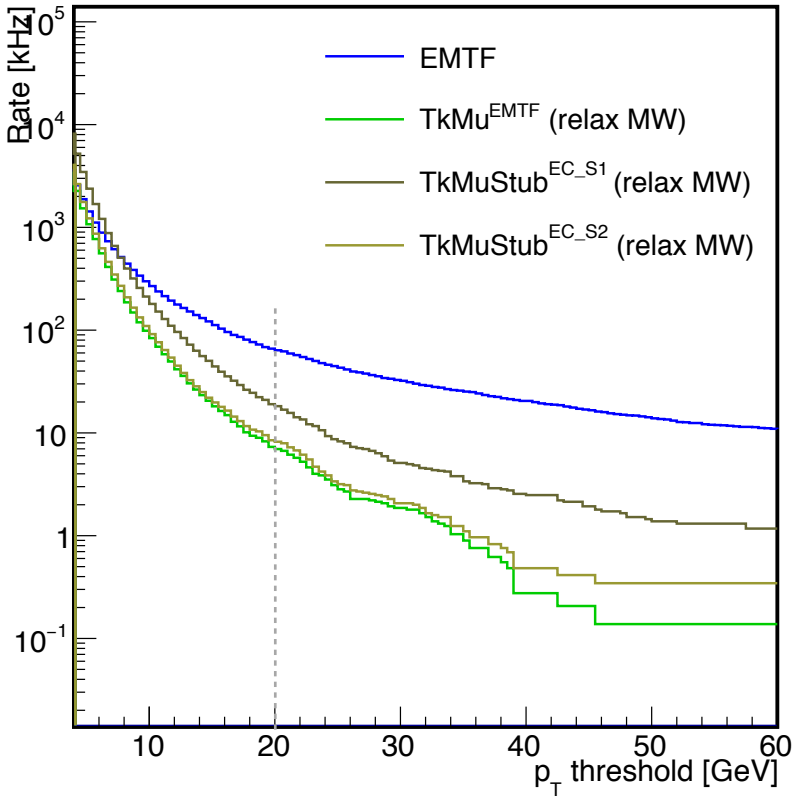
Performance - Rates with **BX=0**

- Rate of TkMuStub S2 significantly lower than TkMuStub S1
  -S2: ~8 kHz @20 GeV
  -S1: ~20 kHz @20 GeV

- This is probably due to multiple reasons:
  1. Higher CSC/RPC hit occupancy in S1 vs S2 (closer to IP)
  2. Matching windows used were derived for S2, so matching S1 Stubs more likely to pick up PU Stubs.

- However, 8 kHZ @20 GeV for **TkMuStubS2** is encouraging as very close to **TkMuEMTF**

- Need to further optimize the algorithm.



Conclusions

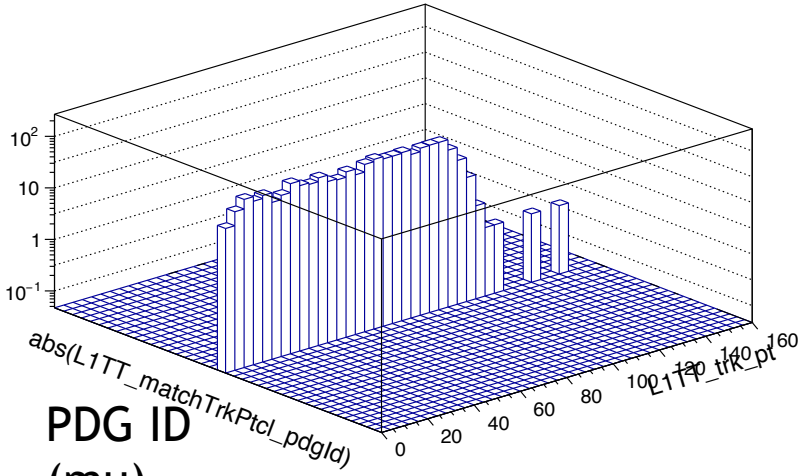
- Done
  - Designed Correlator L1Tk + Stubs in EndCap from individual Stations and understood purity
  - Obtained reasonable rates, even below 10 kHz @ 20 GeV
  - High efficiencies, with understood drops due to non-included chambers/detectors.
- To do:
  - Obvious improvements:
    - Combine TkMuStub(S1/3/4) and TkMuStub(S2), solve the efficiency drops at |eta| ~1.7
  - Use new Phase2 detector TPs (GEMs, ME0), fit for CSC Correlated TP(JiaFu is using)
  - Develop TkMuStub correlator smarter to Match to Stub from other station if Stub in one station not present. This will solve the gap at |eta| ~1.7 but might add rate.
  - Study rate and efficiencies with extreme PU 250 and 300.
  - Study rate and efficiencies with aging of muon detectors.

Backup

Truth in Physics Collision

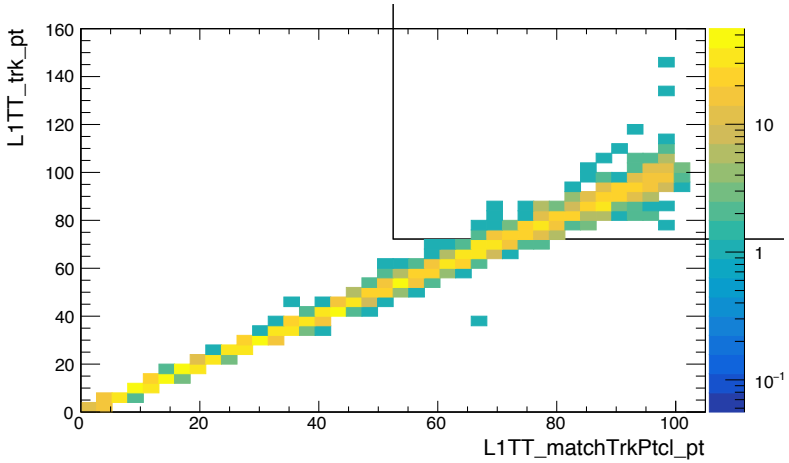
- Dataset: SingleMu_PU200 (flat pT 2-100 GeV)… 1kEvts
- In physics-collisions, all Truth are muons.

Truth PDG ID vs matched-L1TT pT

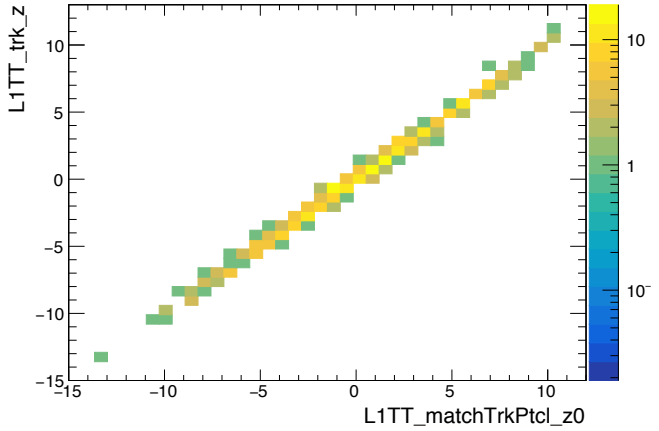


PDG ID (mu)

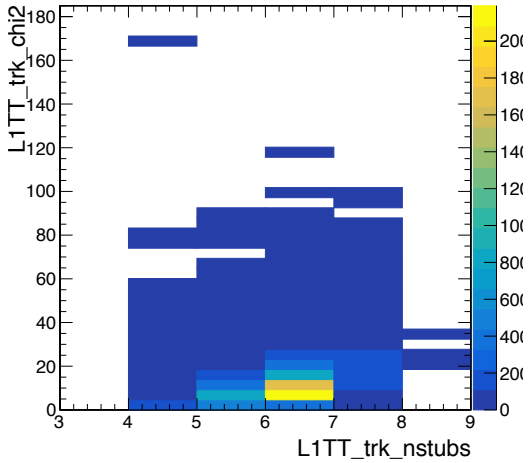
Truth vs matched-L1TT pT



Truth vs matched-L1TT *z*



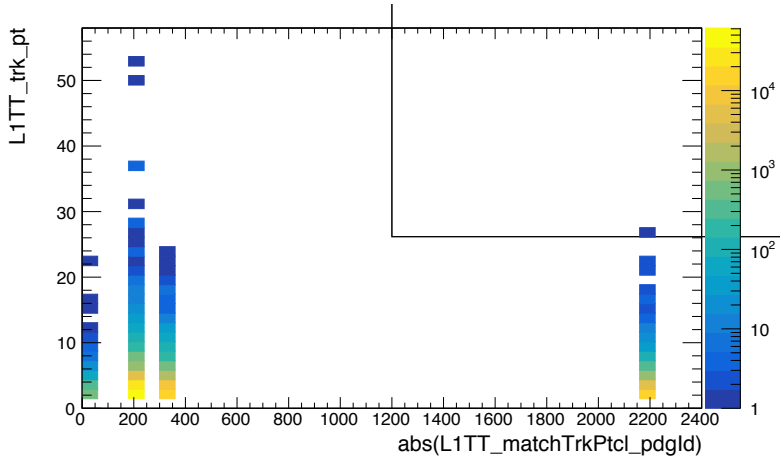
chi2 vs nStubs in L1TT Truth matched

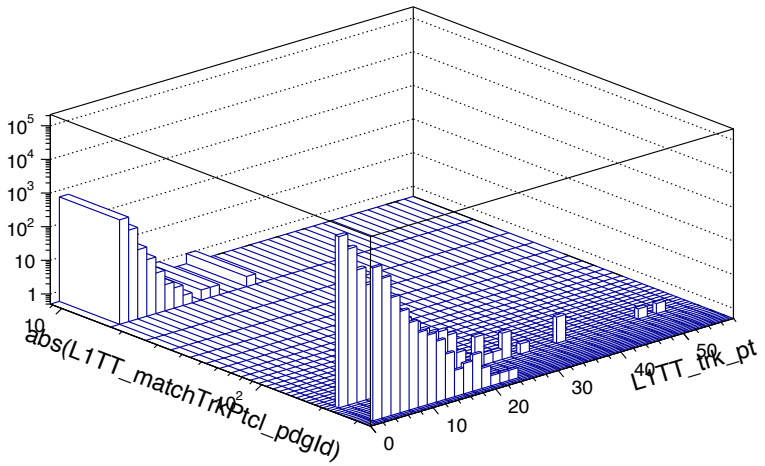


PU

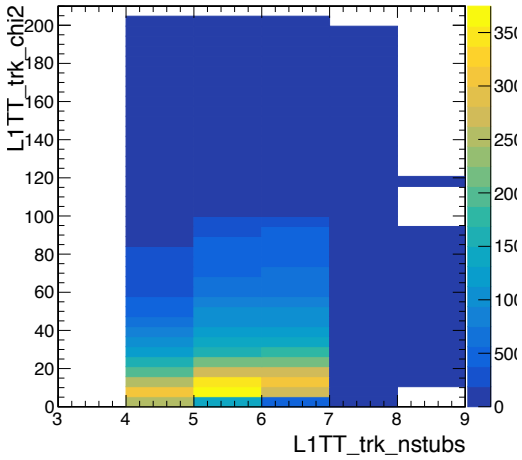
- Dataset: SingleMu_PU200 (flat pT 2-100 GeV)… 1kEvts (left) and 5kEvs (right)
- In PU, Truth are from *mu, Pi, K, p.*

Matched-L1TT Pt vs Truth PDG ID (mu, Pi, K, p)

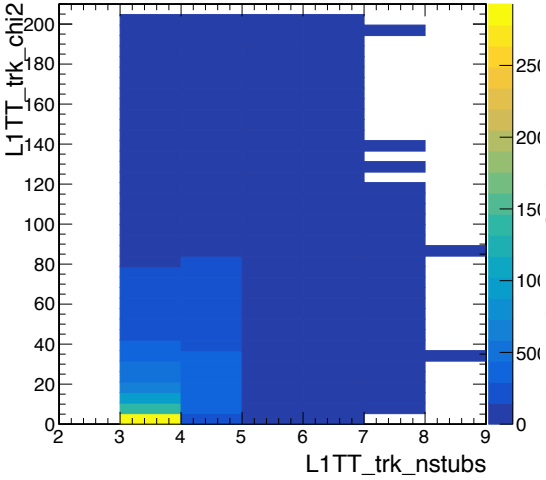




chi2 vs nStubs in L1TT Truth **matched**



chi2 vs nStubs in L1TT Truth **nonmatched**



Large number of tracks with nStub=4 & chi2<100

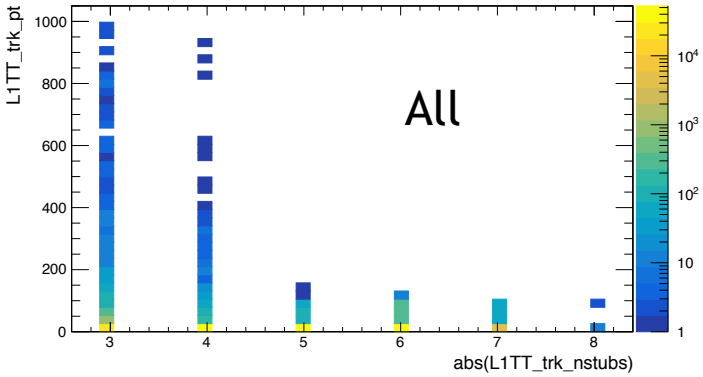
- Look at Truth (TrackingParticles)
  - For the moment only looking at truth from *e*, *mu*, *Pi*, *K*, *p*, produced close to center of CMS (since for now we are looking at prompt *mu* samples).

  - Truth TrckPtcl
    - Gen MinPt = 3.0
    - Gen MaxAbsEta= 2.4
    - Gen MaxVertR = 1.0 // Max distance of ptcl production vertex from centre of CMS
    - Gen MaxVertZ = 30.0
    - Gen PdgIds = 11, 13, 211, 321, 2212 (*e*,*mu*, *Pi*,*K*,*p*)

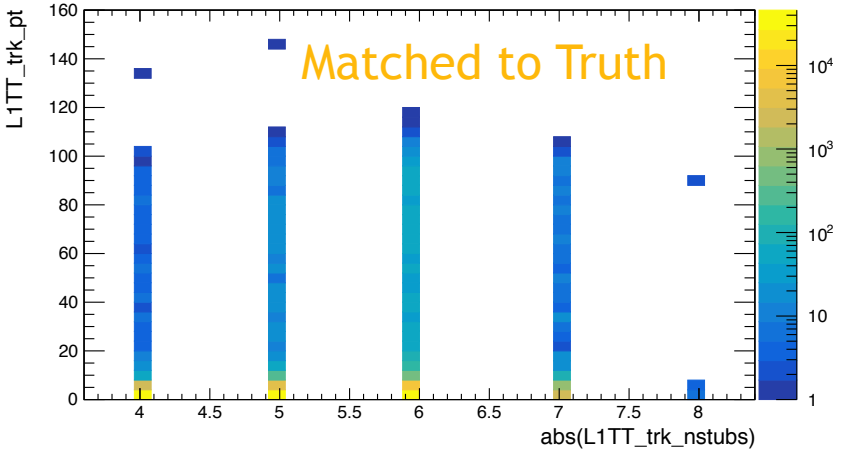
-

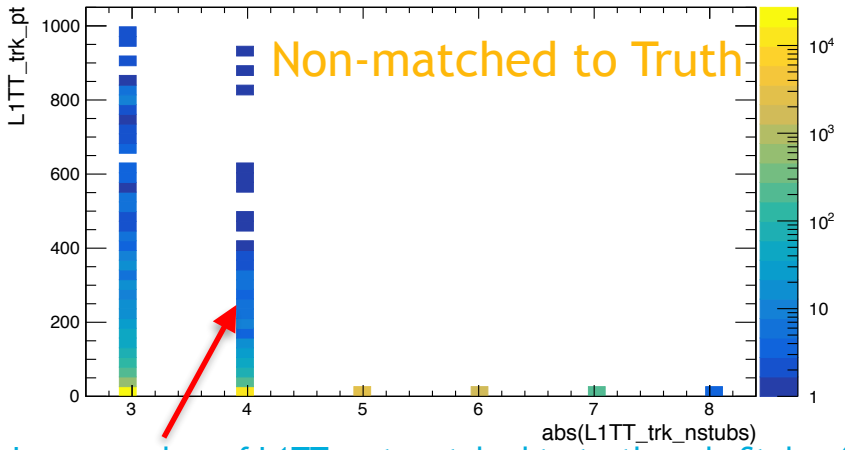
Match to Truth

- Dataset: centrally produced SingleMu_PU200 (flat pT 2-100 GeV)… 1kEvts
- L1TTTracks: Tracklets



- Match to Truth: Test for common L1TT Stub with TrckPtcl Stub
  - If (# matched stubs >= 4) : L1TT matched to Truth
  - Else : L1TT non-matched

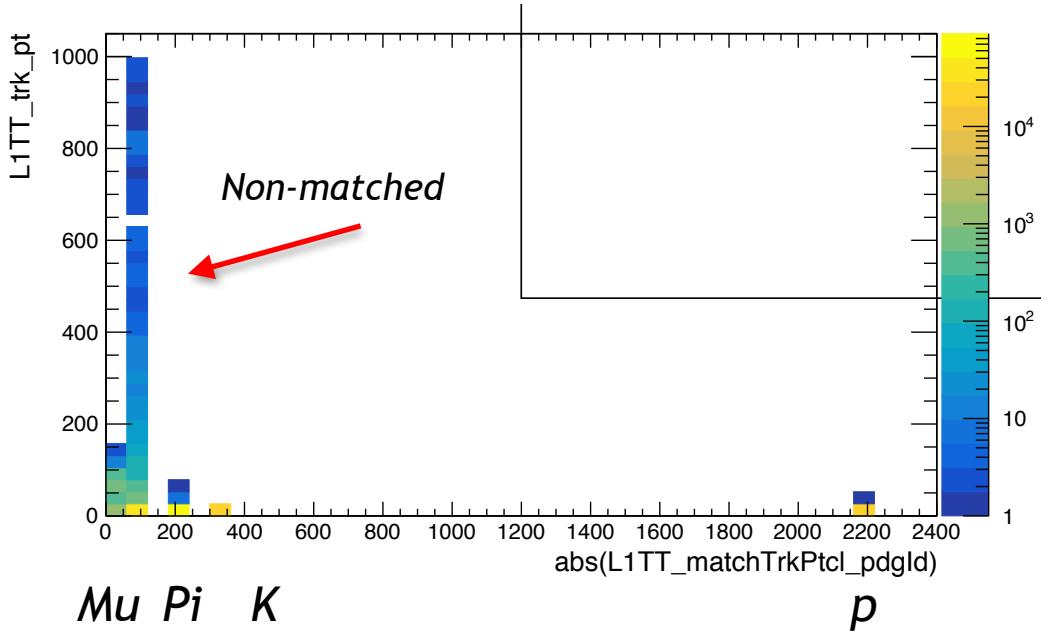




Large number of L1TTs not matched to truth and nStubs=4 and considerable pt

- Dataset: SingleMu_PU200 (flat pT 2-100 GeV)… 1kEvts

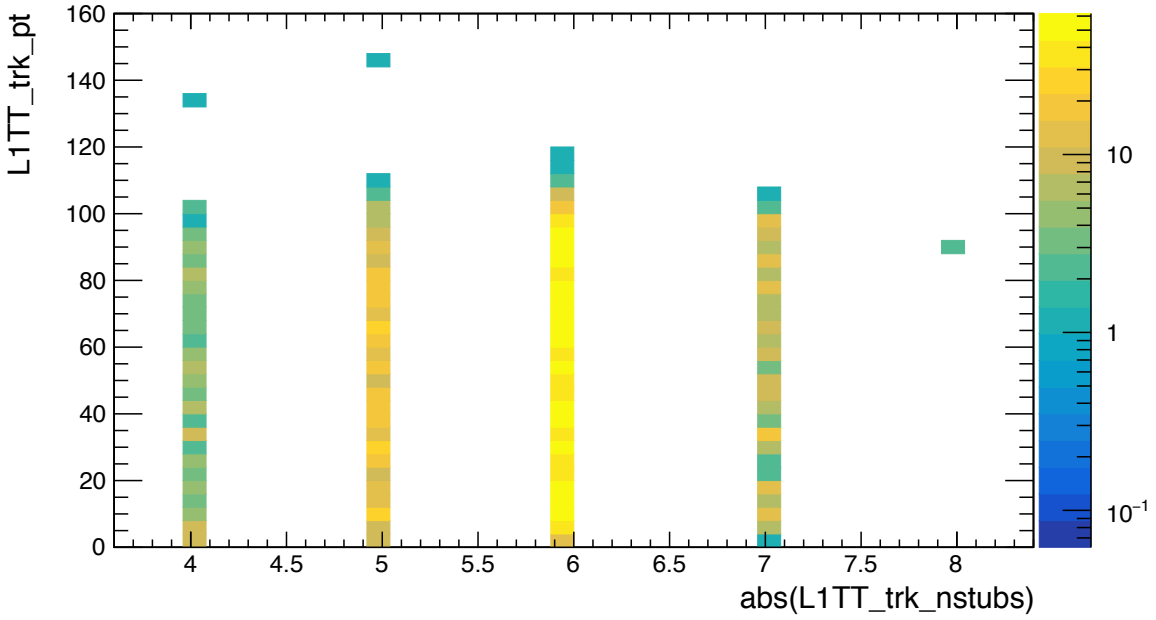
Matched L1TT pT vs Truth PDG ID (matched and non-matched)



L1TT match to Truth-mu (Physics Collision and PU)

- Dataset: SingleMu_PU200 (flat pT 2-100 GeV)… 1kEvts

pT vs nSubs in L1TT matched to Truth-Mu



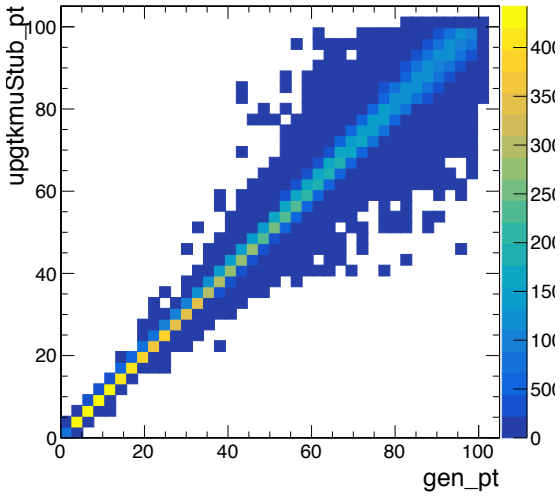
TkMuStub vs GEN

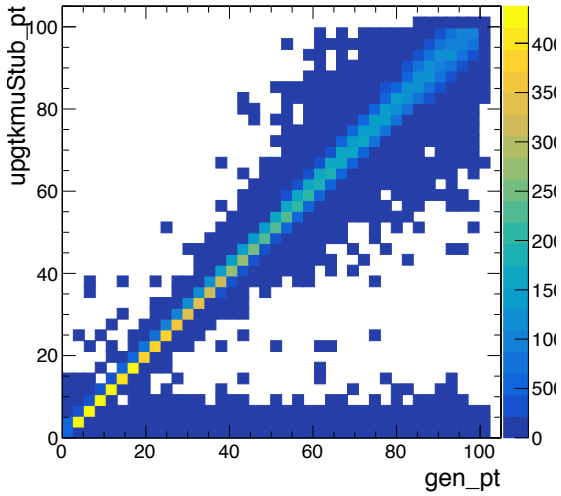
- MuGun (PU0 and PU200)

PU 0

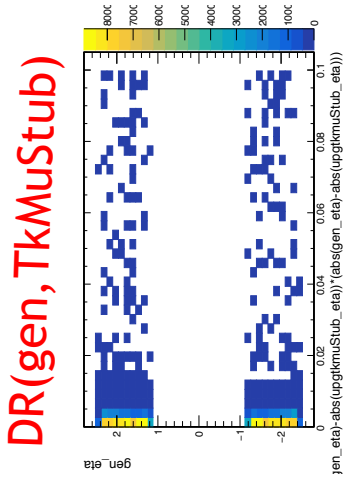
PU 200

TkMuStub Pt

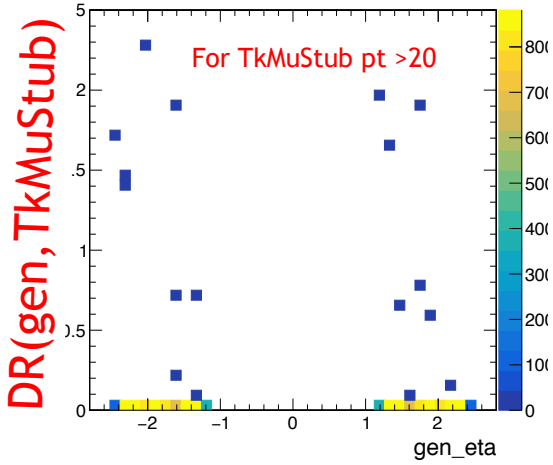




For all pt

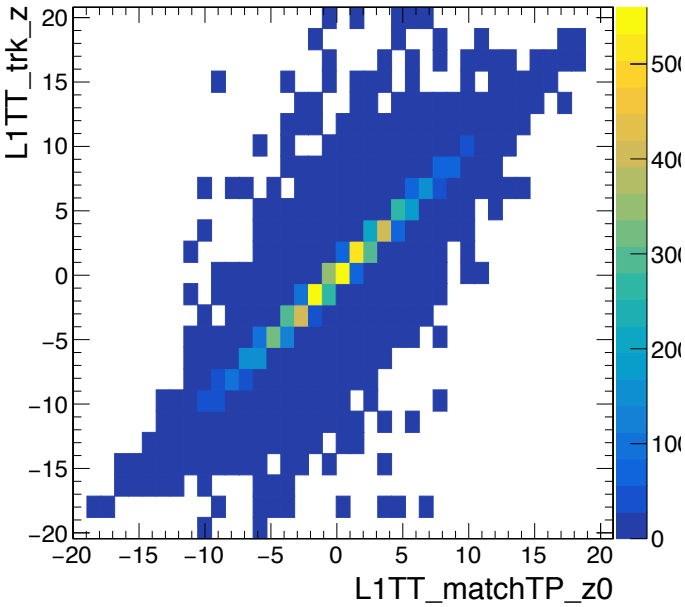


Good match in DR



TkMu Rate of Truth - z0

- Dataset: centrally produced, NuGun PU 200
- Most of the rate of L1TkMu comes from PU muons.
  - These muons do not come from the PVtx of Physics Collision (Neutrino Gun)
- Compare PU particles Truth z0 with L1TTT z.



- Seams that PU muons could be greatly removed with cut |L1TTrk_Z,PVtx_Z| < ~2 cms , once the PVtx calculated somewhere down stream in L1T.
  - This should bring the rate down significantly!

Performance: Turn-on for TkMuStub > 20 GeV with **BX=0**

- Only showing TkMuStub(S2).
- TkMuStub efficiency is equally as sharp as TkMuEMTF.
- For higher PU, the efficiency of TkMuStub is lower than in PU0, but closer to efficiency TkMuEMTF.
  - (To be looked at vs Eta and with the study of Truth.)