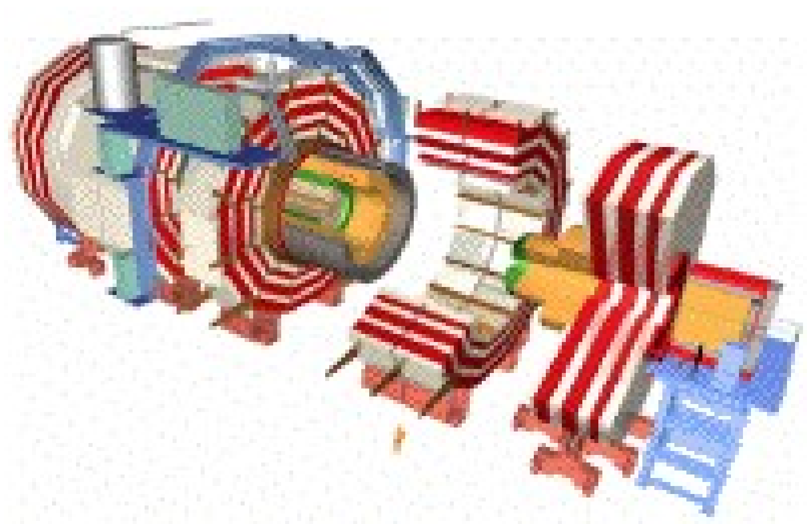
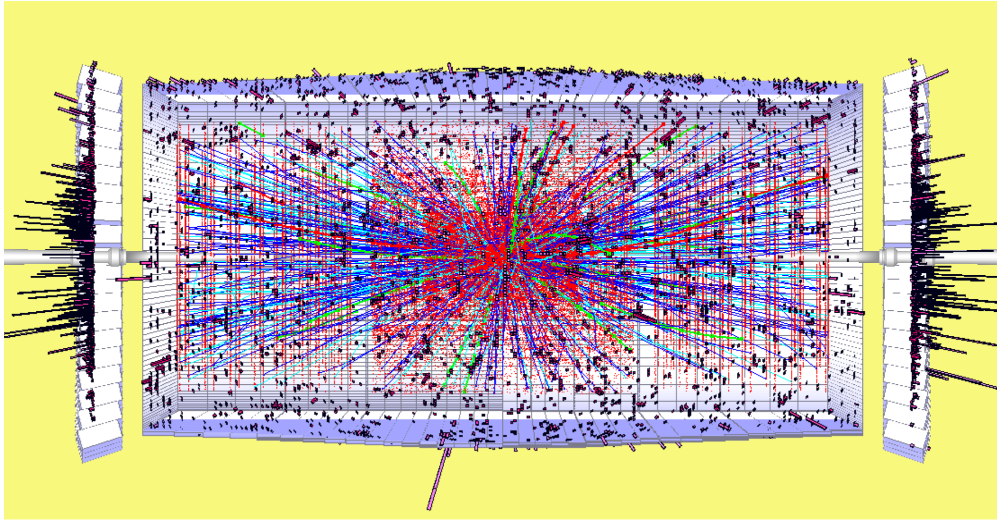
CMS Phase 2 Track Trigger



Anders Ryd
(Cornell University)

on behalf of the
CMS Collaboration

Outline:
- CMS Phase 2 Tracker
- L1 Track Finding
- L1 Track Trigger Objects



Introduction

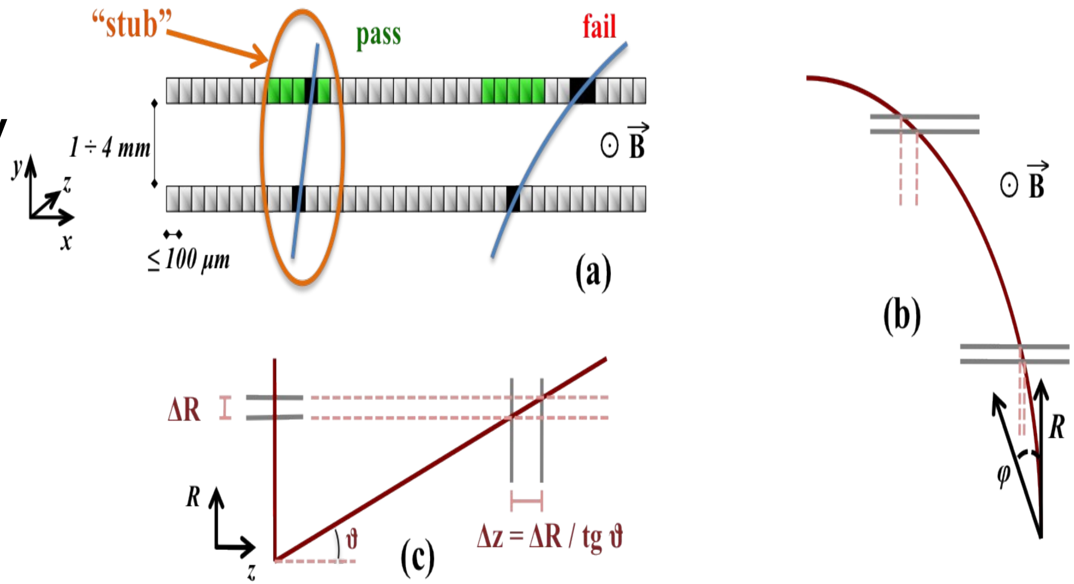
- The proposed CMS track trigger is self seeded:
  - We make use of 'pT modules' that apply a momentum selection to reduce the data volume needed for the trigger.
  - Our baseline is to reconstruct tracks with pT>2 GeV in the $|\eta|<2.5$ region
- Having this capability in the L1 trigger provides a completely new tool
  - Currently this level of tracking information is only available in the HLT.
- CMS has carried out a detailed simulation of the proposed phase 2 detector
  - Full G4 simulation
    - Minbias with <PU>=140 for rate studies
    - Signal overlayed on <PU>=140 for efficiencies
- Results from these studies are presented in this talk

Outline

- CMS Phase 2 Tracker
  - pT modules
  - Detector layout
  - Stub finding performance
- L1 Track Finding
  - AM and Tracklets
  - Simulation performance
- L1 Track Trigger Objects
  - Muons
  - Electrons
  - Track based isolation
  - Photons
  - Primary vertex finding
  - Jet vertexing and HT
  - tkMHT and tkMET
  - Taus

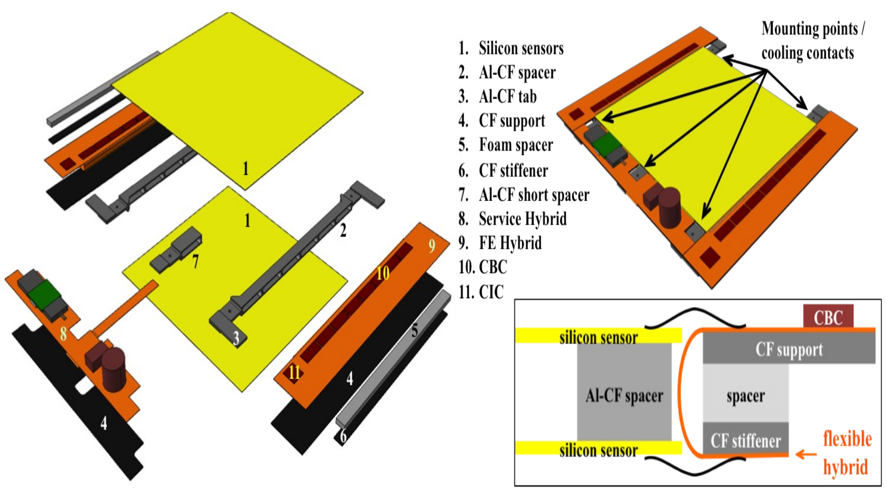
pT Modules

- Correlating hits in closely spaced sensors give pT discrimination
- Correlations formed on module – data reduction for trigger readout



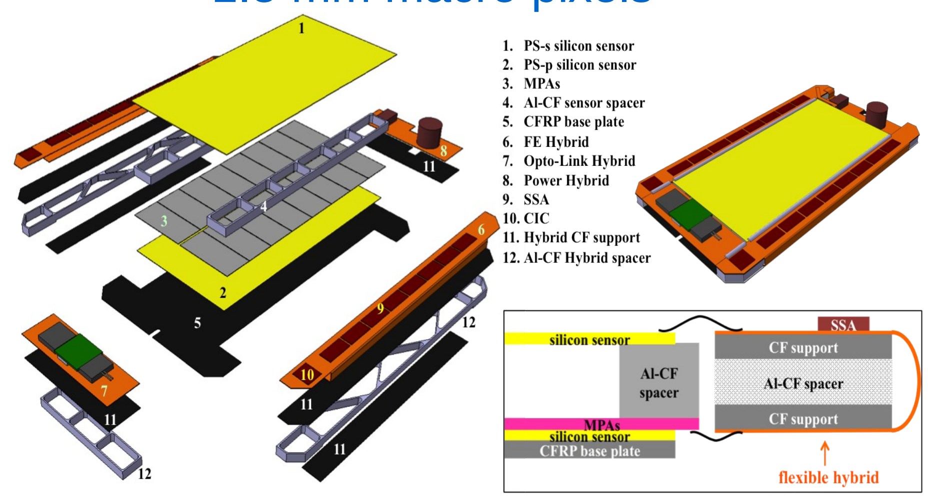
Strip-strip (2S) Modules

2x5 cm strips 90 um pitch



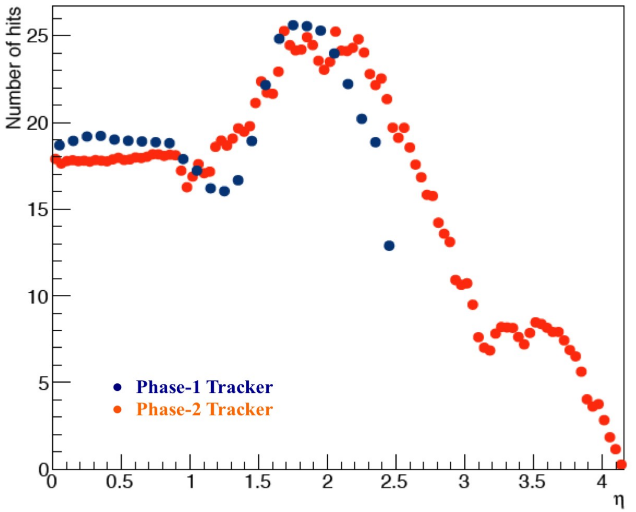
Pixel-strip (PS) Modules

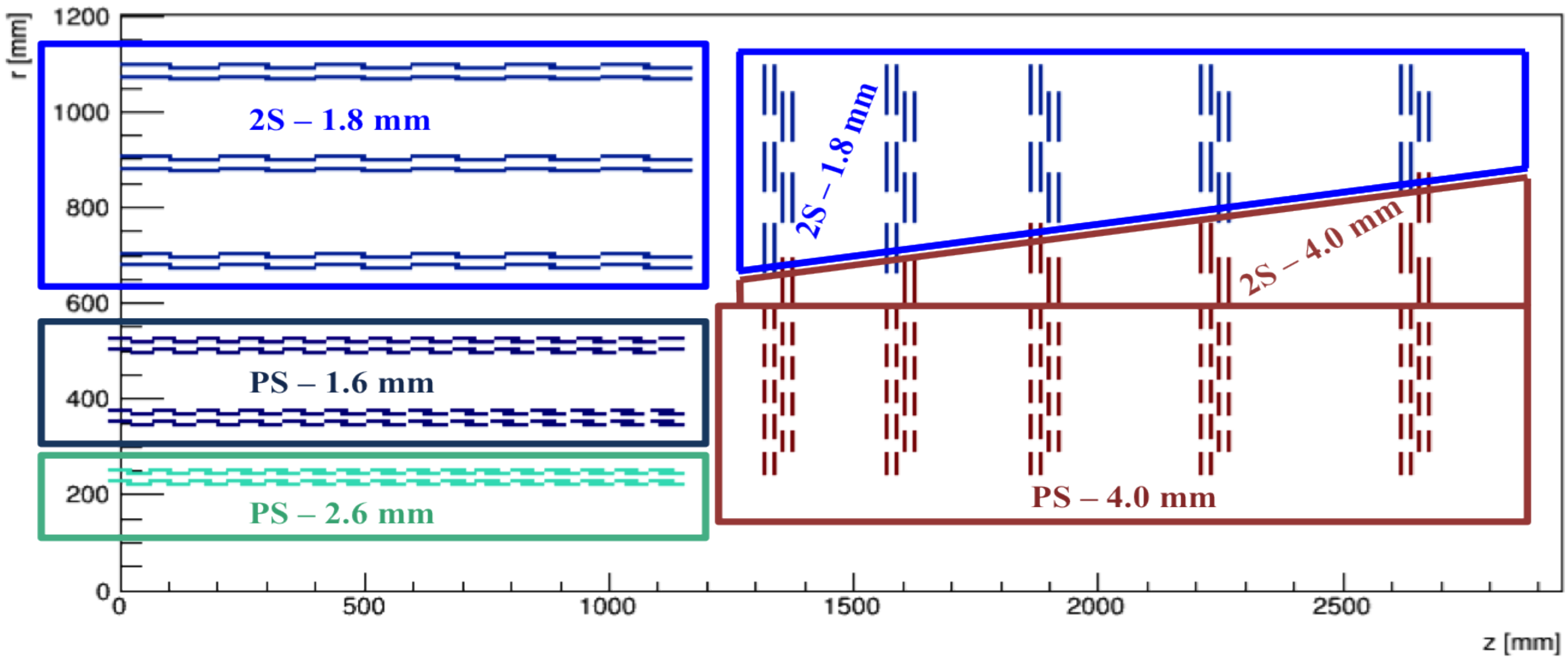
2x2.5 cm strips 100 um pitch
1.5 mm macro pixels



CMS Tracker for Phase 2

- Six barrel layers with two-sensor layers each
- Five disks also with two-sensor layers each

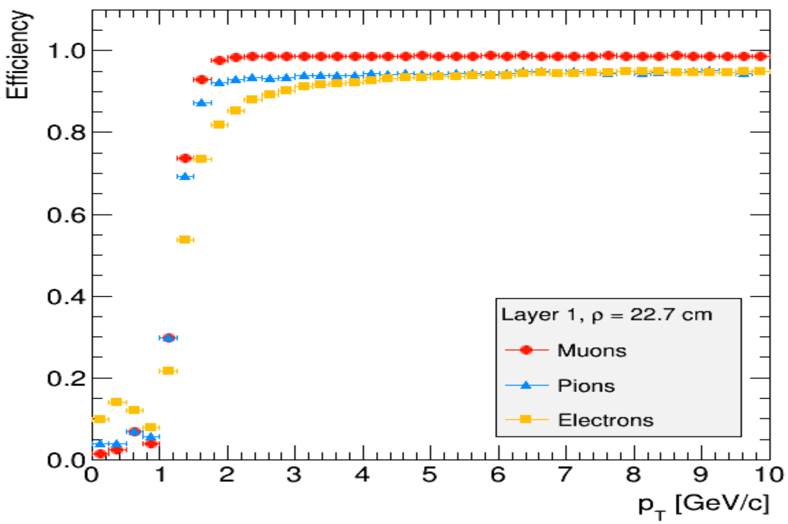




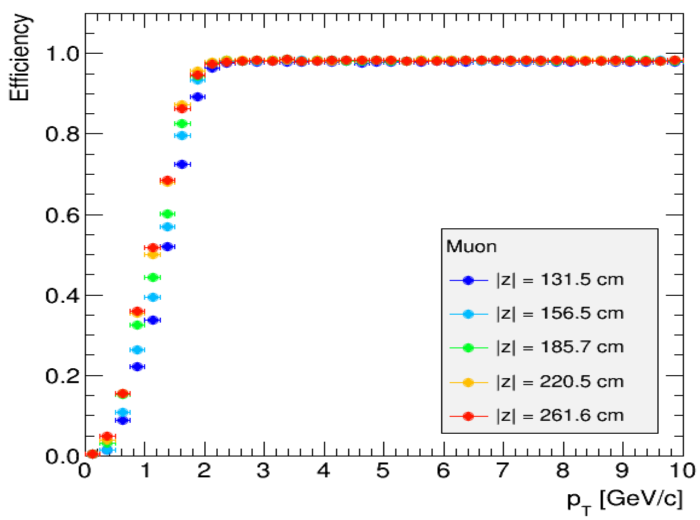
Stub Finding

- Baseline is a threshold of 2 GeV
- Sharper turn-on curve in outer layers where track bending is larger. (3.8 T magnetic field useful)

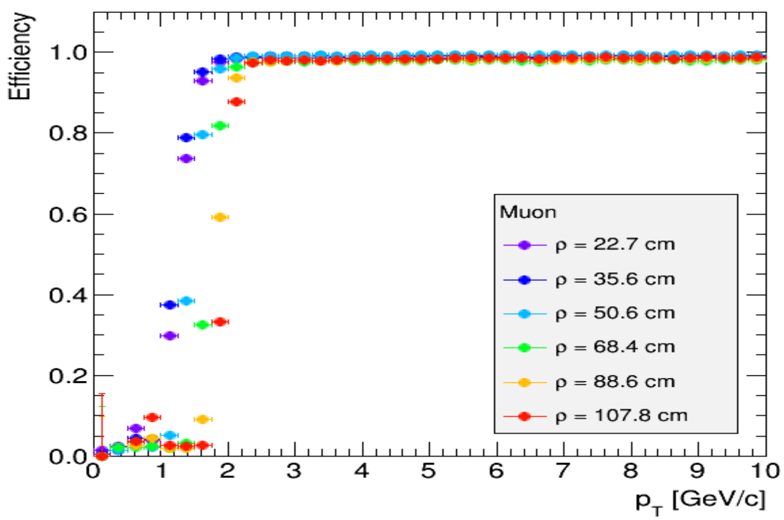
Layer 1 Stub Finding Efficiency



Stub Finding Efficiency per Disk

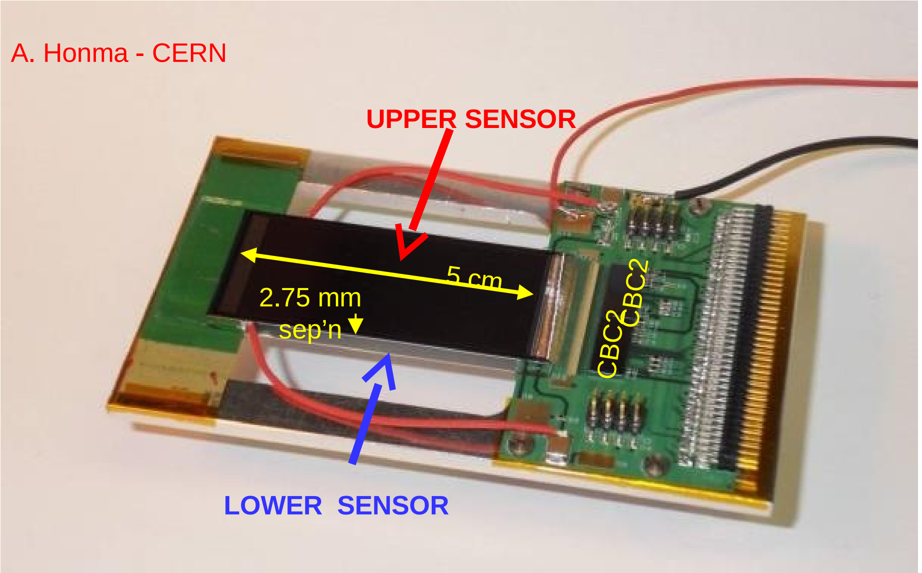


Stub Finding Efficiency per Layer

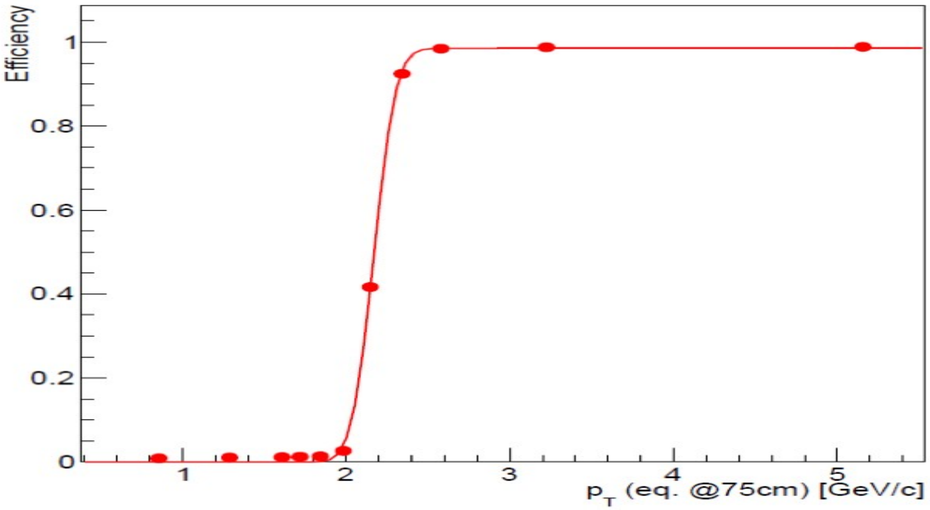


2S Module Test Beam Performance

- Prototype 2S modules have been tested in test beams
- The pT discrimination performance is as expected from simulations

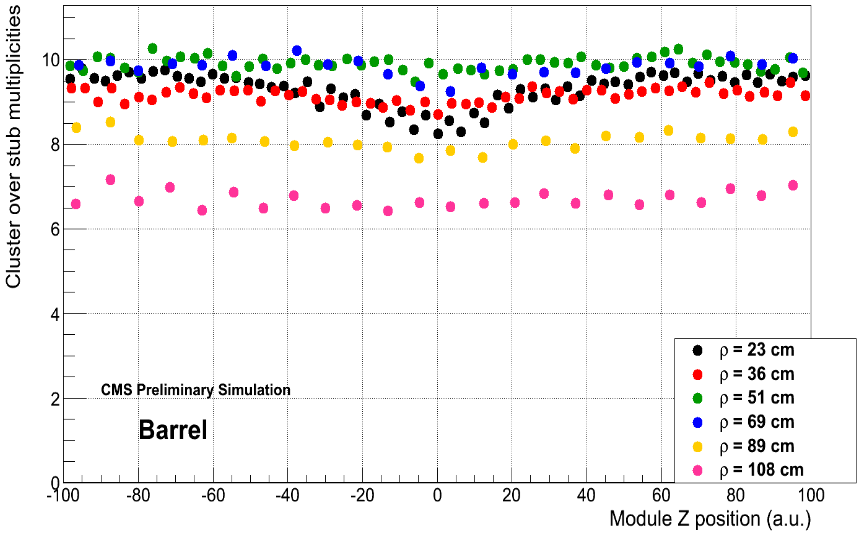


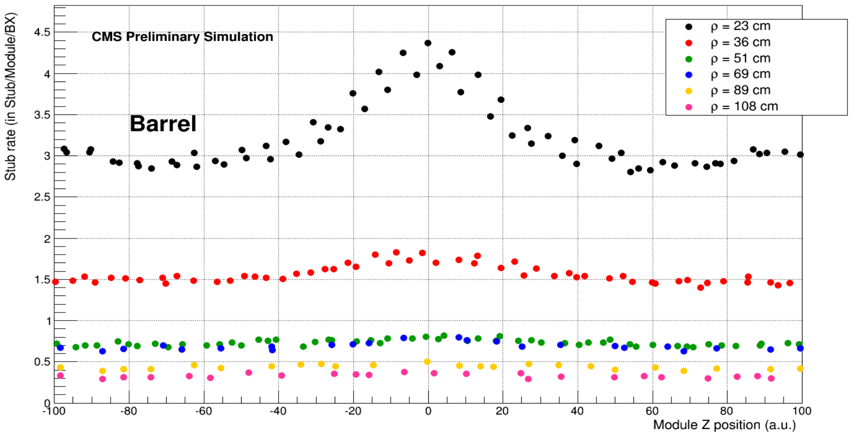
each CBC2 chip takes 127 inputs from upper sensor and 127 inputs from bottom sensor



Stub Rates and Data Reduction

- By forming stubs we reduce the data volume, compared to clusters, by a factor of 8 to 10.
- This reduction in data volume makes it possible to read out the data for use in the L1 trigger





- In the innermost layer we have on average 3 to 4 stubs per module per bunch crossing at <PU>=140.
- This pushes the limits of what we can read out with 5 Gbits/s links.

L1 Track Finding Requirements

- To implement the proposed track trigger the L1 track finding/fitting needs to:
  - Highest possible efficiency for isolated tracks (e,μ,τ)
  - Good pT resolution (muon threshold)
  - Good z-resolution (for PU mitigation)
  - Good efficiency for tracks in jets (e.g. for tkMET)
  - Low fake rate (tkMET)
  - Reasonable efficiency for low pT (2 to 5 GeV) tracks (track based isolation)
  - Low latency: track finding has to be completed in ~5 us

- Challenges are:
  - ~10,000 stubs per bunch crossing, 40 MHz bunch crossing rate – find about 125 tracks with pT>2 GeV

L1 Tracking R&D

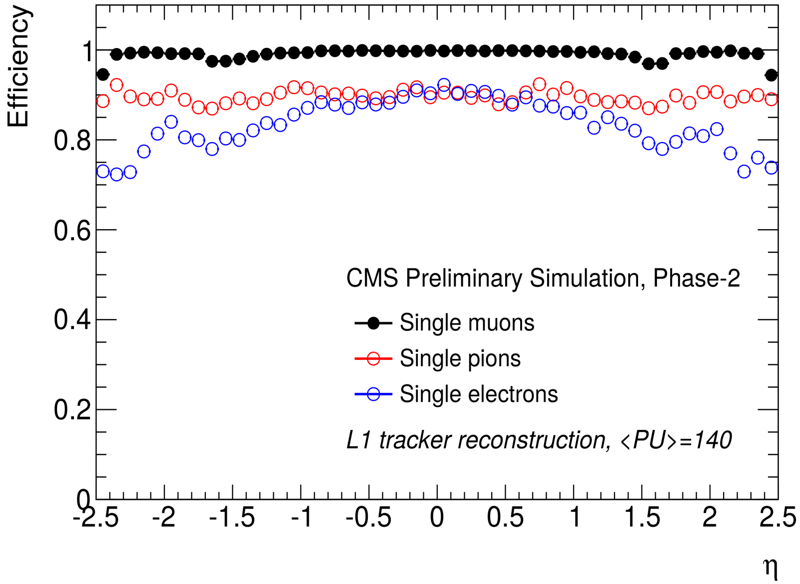
Two approaches considered for the L1Tracking
- tracklet-based approach (seeding with pairs of stubs
- pattern recognition via associative-memories (AM)

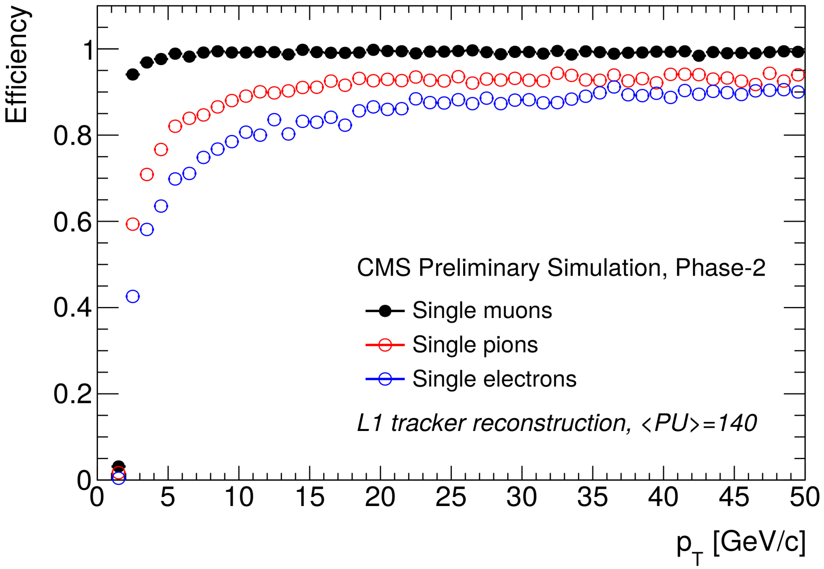
- Tracklet-based L1Tracking
  - Traditional road search with seeding in pairs of layers + linear χ2-fit
  - Implemented using FPGAs (no custom ASICs)
  - Easy to simulate – all studies presented in this talk are based on the tracklets

- AM approach :
  - Pattern recognition performed in custom ASICs (CAMs)
  - Hits in matched patters fit (Hough transform, principal, component, or linear χ2-fit)

We are now developing demonstrators for these tracking approaches
The goal is to have demonstrating the L1 track finding by 2016 for our TDR

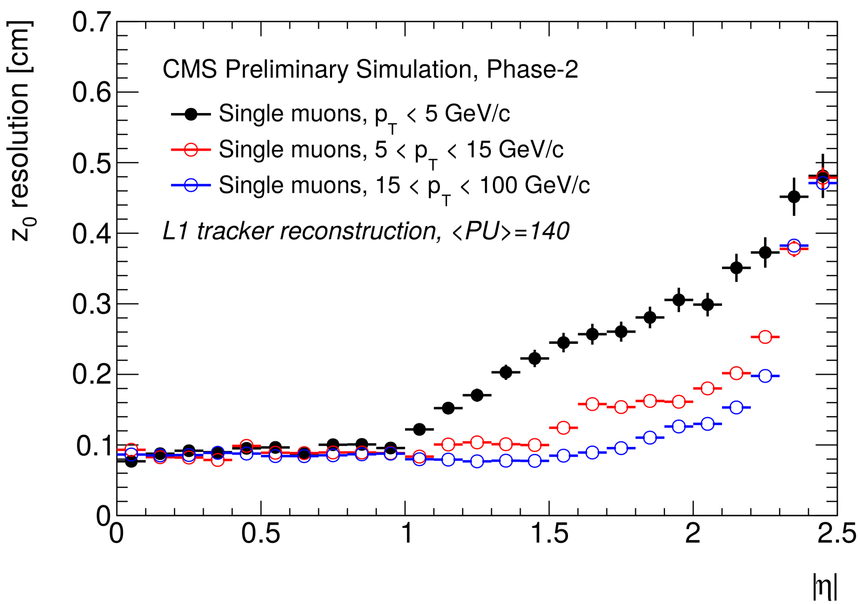
L1 Tracking Performance: Efficiency

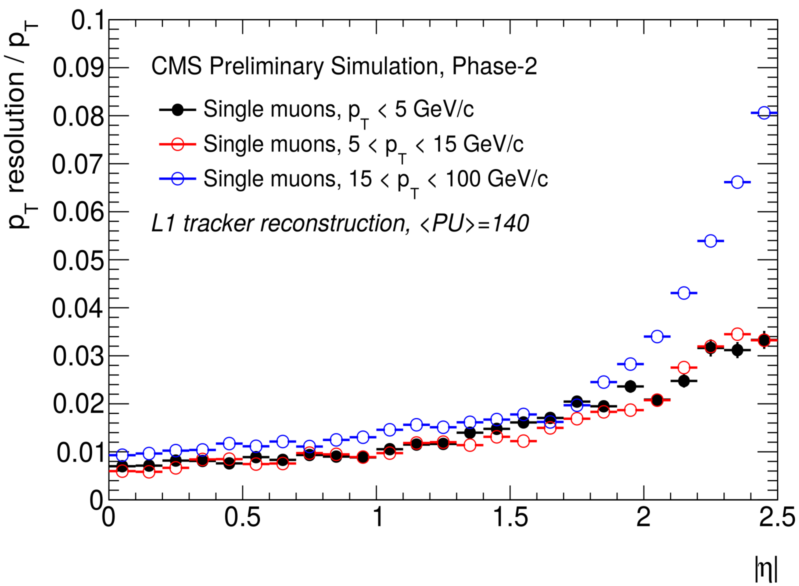




- Good efficiency of full eta range |η|<2.5
- High efficiency for tracks with pT down to 2 GeV
- Muon efficiency ~99%
- Pion efficiency 90 to 95% (worse for low pT)
- Electron efficiency 80 to 90% (harder due to bremsstrahlung)

L1 Tracking Performance: Resolution





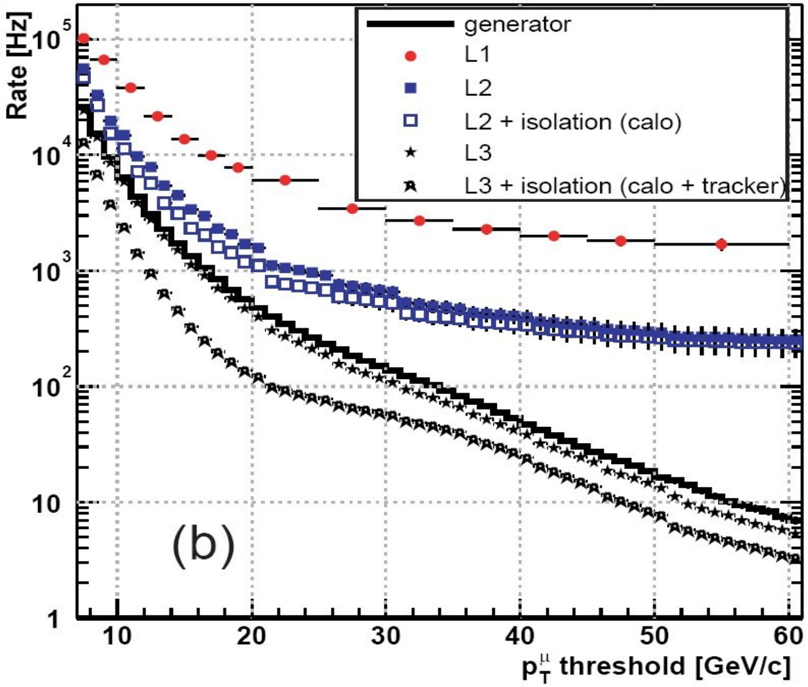
- z_0 resolution around 1 mm – worse for $|\eta|>2$ and soft tracks
- pT resolution around 1 to 2% out to eta of ~2

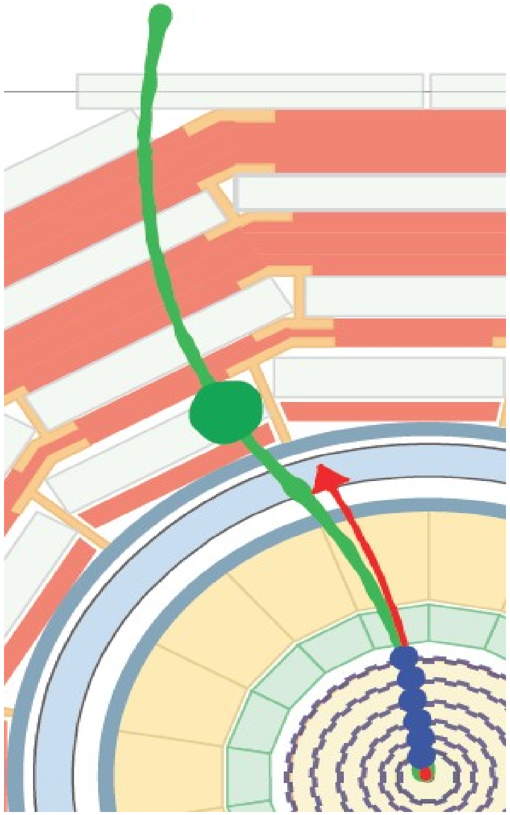
L1 Track Trigger Objects

- The L1 Tracks are combined with other L1 objects to form track trigger primitives:
  - L1Muon+L1Track : Improve muon pT determination
  - L1EG+L1Track : For election selection
  - L1EG or L1CaloTau + L1Track : Hadronic tau selection
  - L1Jet+L1Track : Jet vertex determination
  - L1Tracks : Primary vertex finding + tkMET
  - L1Tracks + other L1 object : Track based isolation

Muon Triggers

- Match muons to L1 tracks
  - Improves pT determination
  - Gives vertex position
  - Can also apply track based isolation
- Should have high efficiency since muon tracking is simple

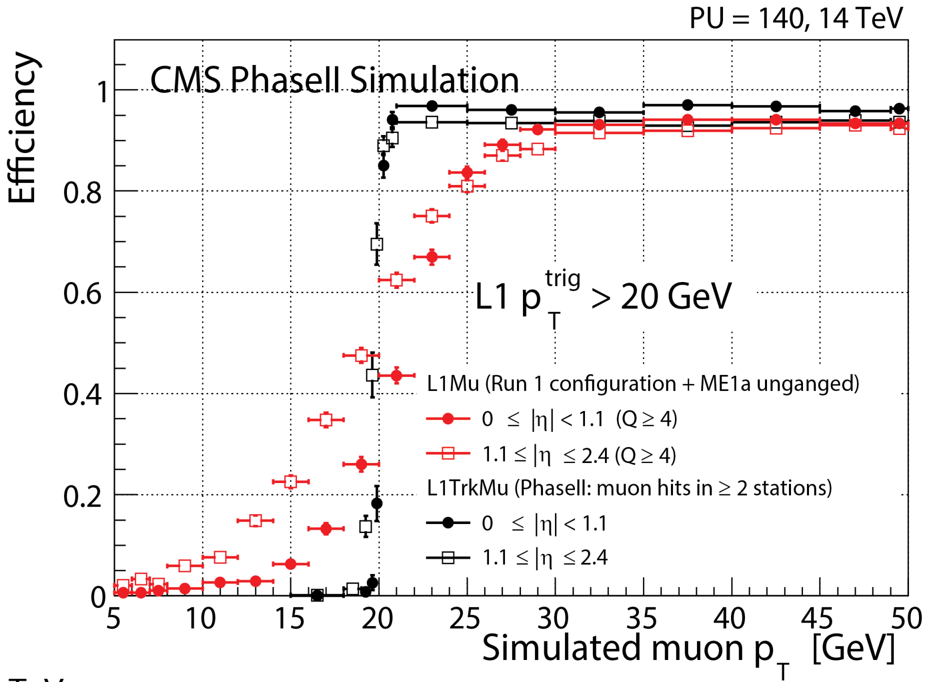


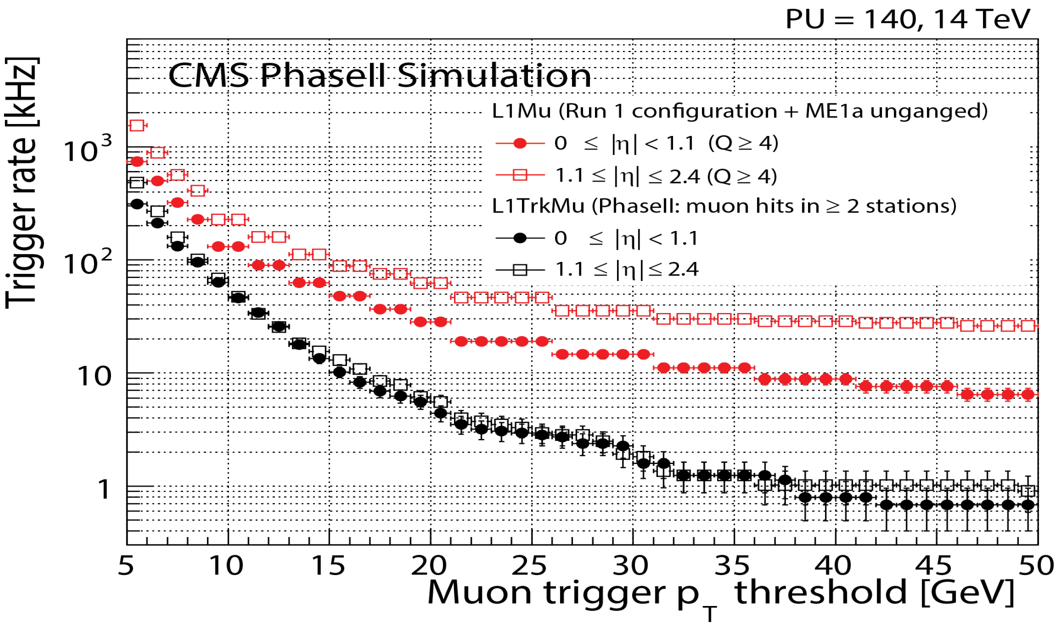


Without tracking information the rate curve flattens out due to mismeasured muon pT

Muon Triggers

- Track matching to muon candidates has high efficiency
- Muons+L1Tracks provide much sharper threshold





- Sharp threshold allows a significant rate reduction:
  - At 20 GeV we have a factor of ~10.

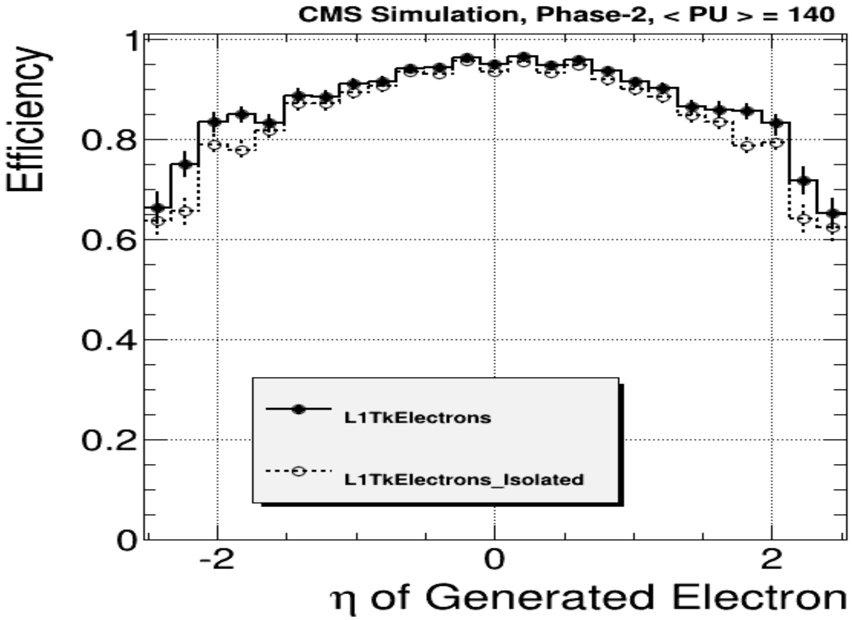
Electron Triggers

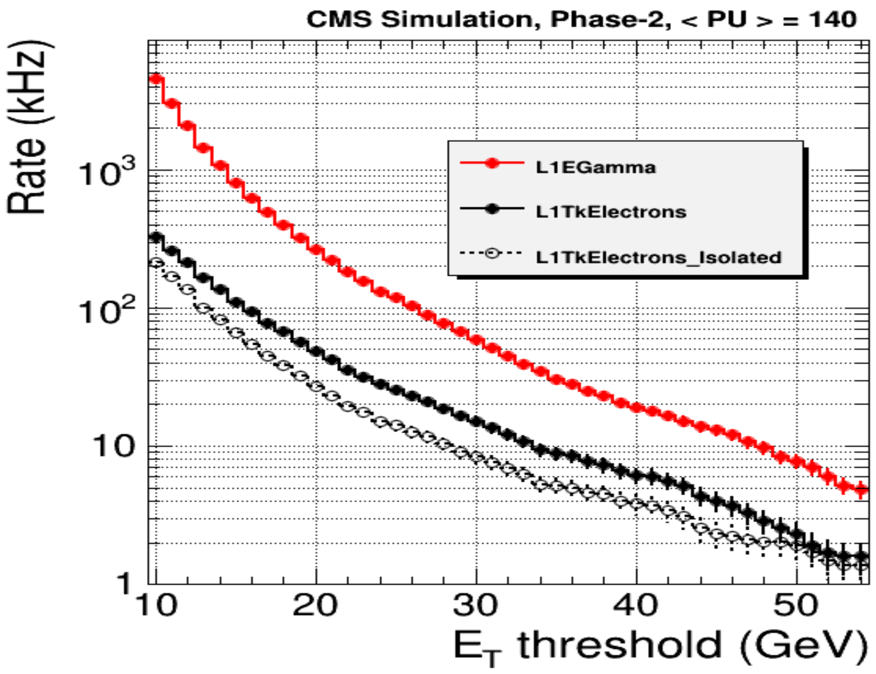
- Match L1EG objects with tracks to reject π^0 background.
- More challenging than muons as electron tracks are harder to reconstruct.
  - Hard to obtain very high efficiency

Electron Triggers

- We obtain efficiencies for matching L1 tracks to L1EG objects above 90% in the central region and falling to 70% for large eta.

20<Et<50 GeV



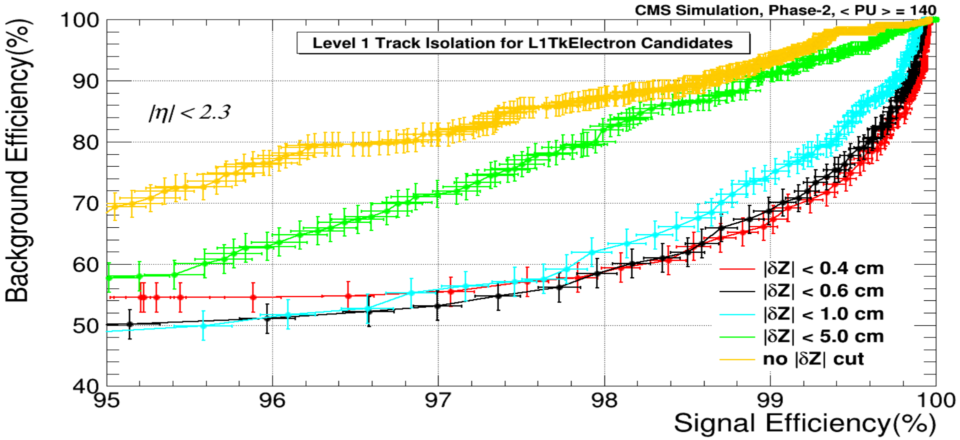


- With this efficiency we have a rate reduction of ~6 for a 20 GeV threshold
  - Using track based isolation we obtain a factor of 10 rate reduction with a very small loss of efficiency

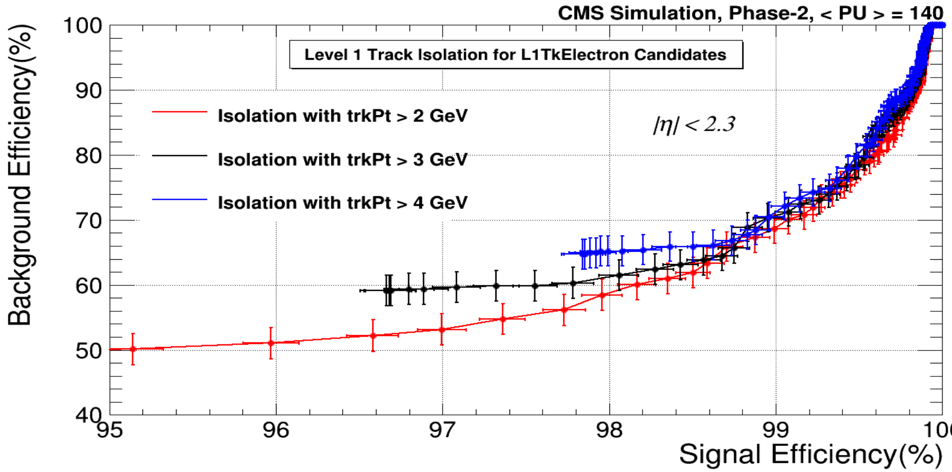
Isolation of Leptons w.r.t. L1Tracks

- Relative isolation
  - Use track in cone around lepton track
  - Isolation track z vertex consistent with lepton vertex
  - 97% efficiency for 50% background rejection
- Isolation performance not strongly dependent on track min pT
- Similar performance for taus and muons

Isolation for electrons, |η|<2.5 (W→eν)

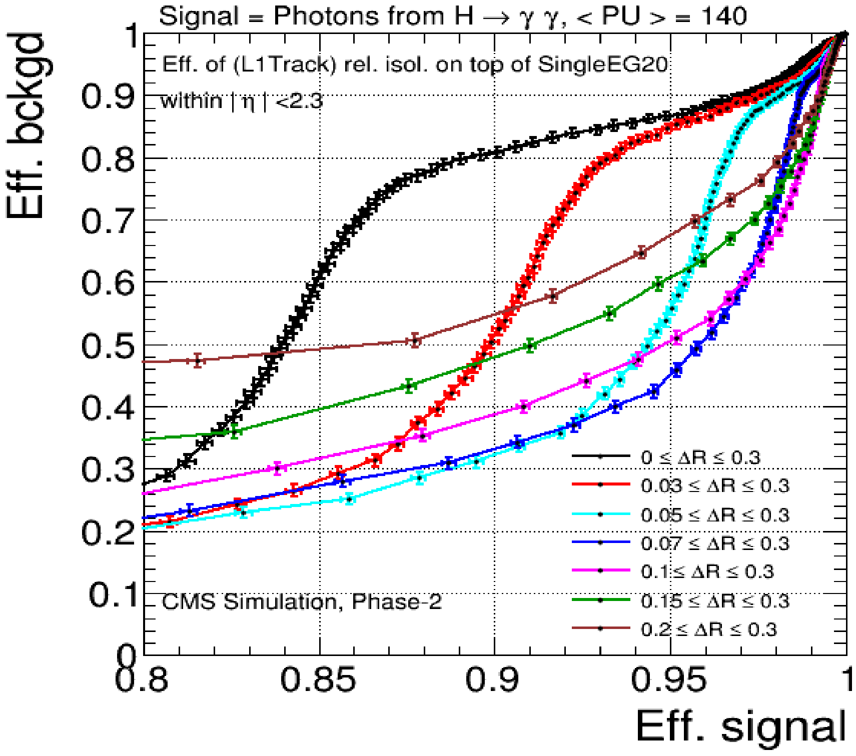


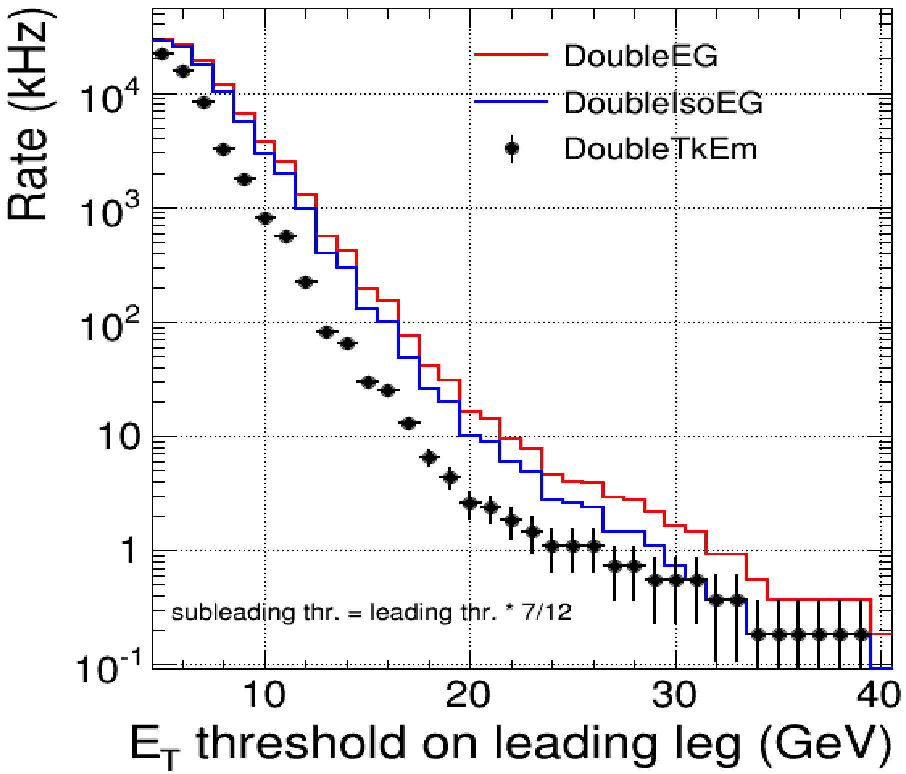
Shows the limited degradation in the performance when p_{Tmin} is increased to 3 GeV.



Photons: Higgs to $\gamma\gamma$

- Even though we don't have a z-vertex position for photons we can apply track based isolation

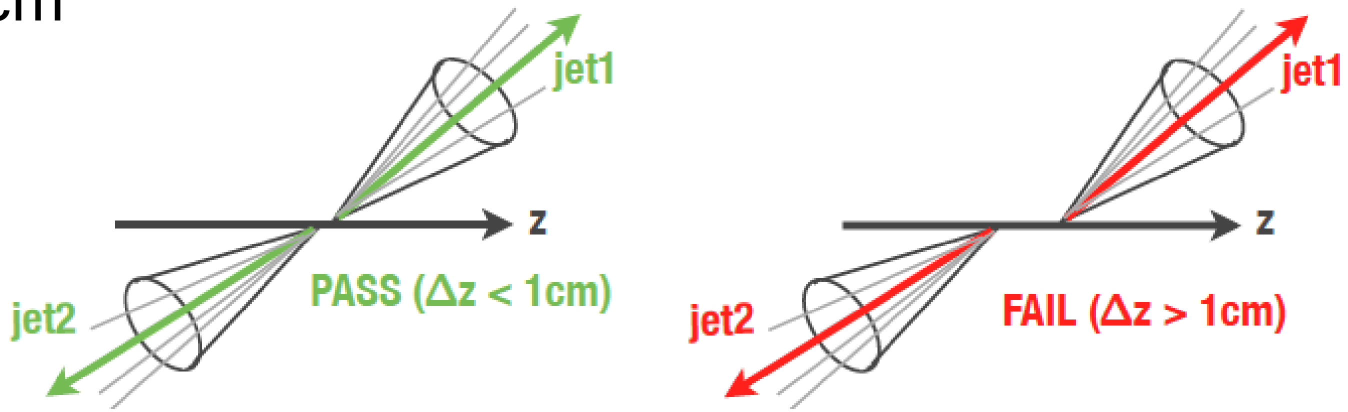




- Can obtain factor of 3 background rejection while keeping >90% efficiency

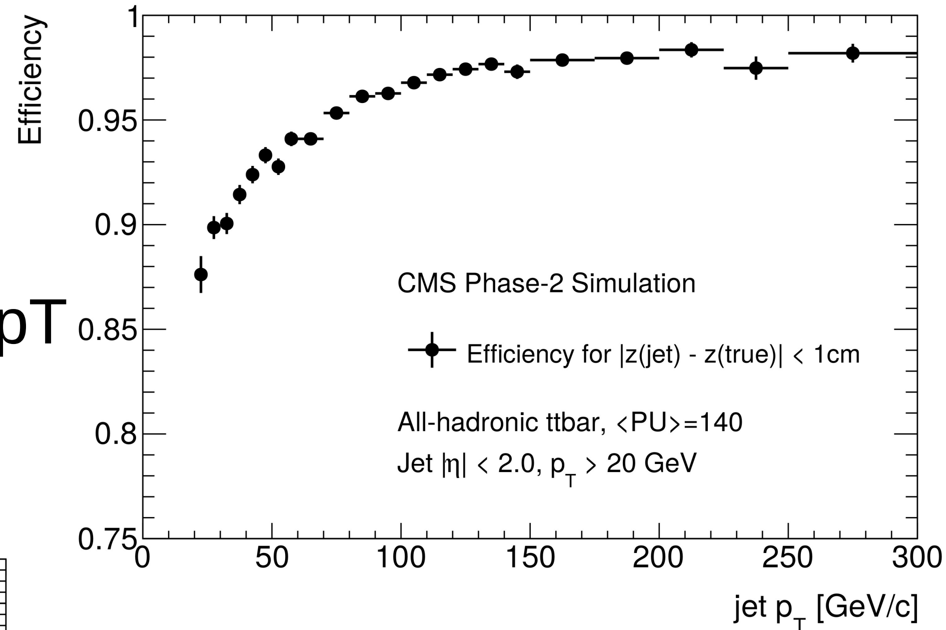
Jets, HT and MHT

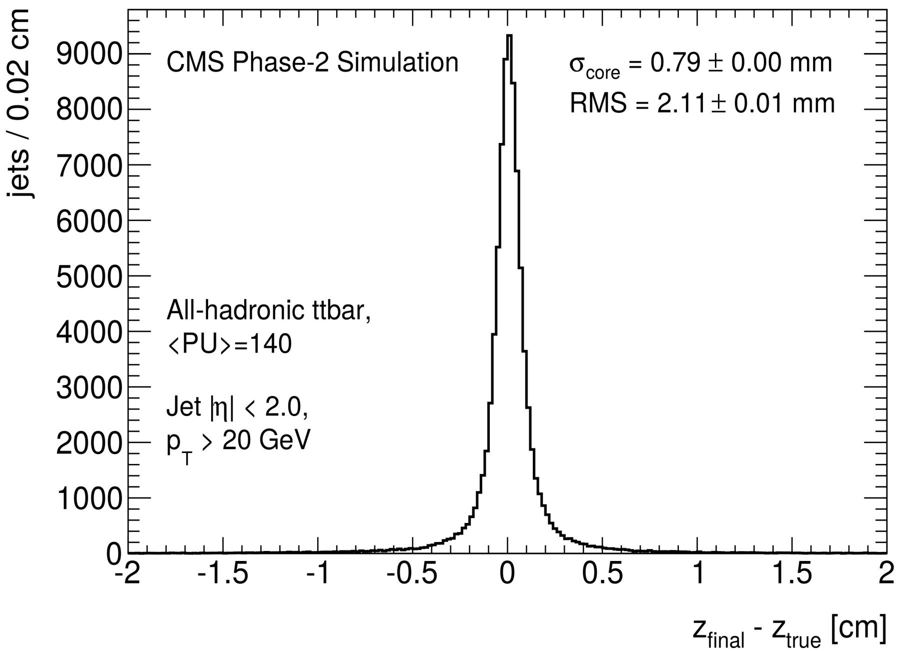
- Triggers with multiple jets, HT, or MHT are very sensitive to PU
  - To mitigate the PU dependence we require vertex consistency of the object we use in these triggers
- We use a cone around the L1Jet to find matching tracks. From these tracks we determine a z-vertex position for each jet
- Typically we require vertex consistency at the level of 1 cm



Jets, HT and MHT : Jet Vertex Reconstruction

- Efficiency for correctly reconstructing the vertex is >90% for pT>50 GeV and increases to 97% for higher pT



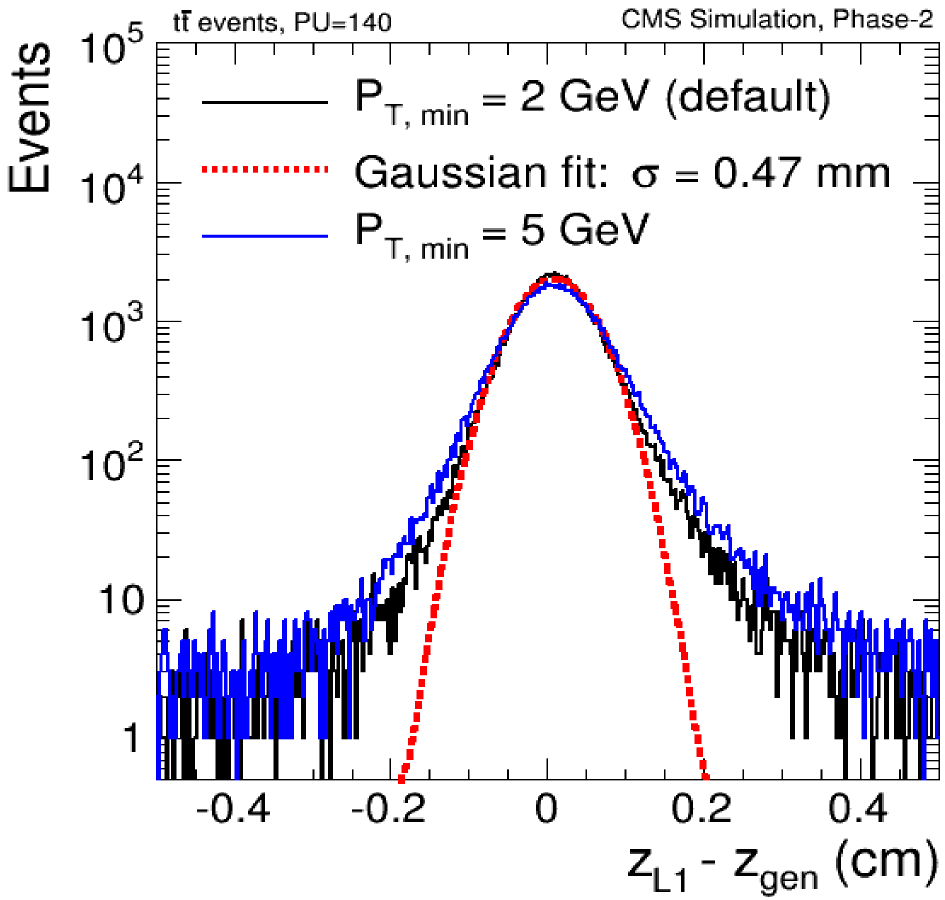


- Vertex position determined to about 1 mm
  - Longer tails give larger RMS

- Vertex consistency of ~1 cm is a fairly loose cut which rejects ~90% of PU.

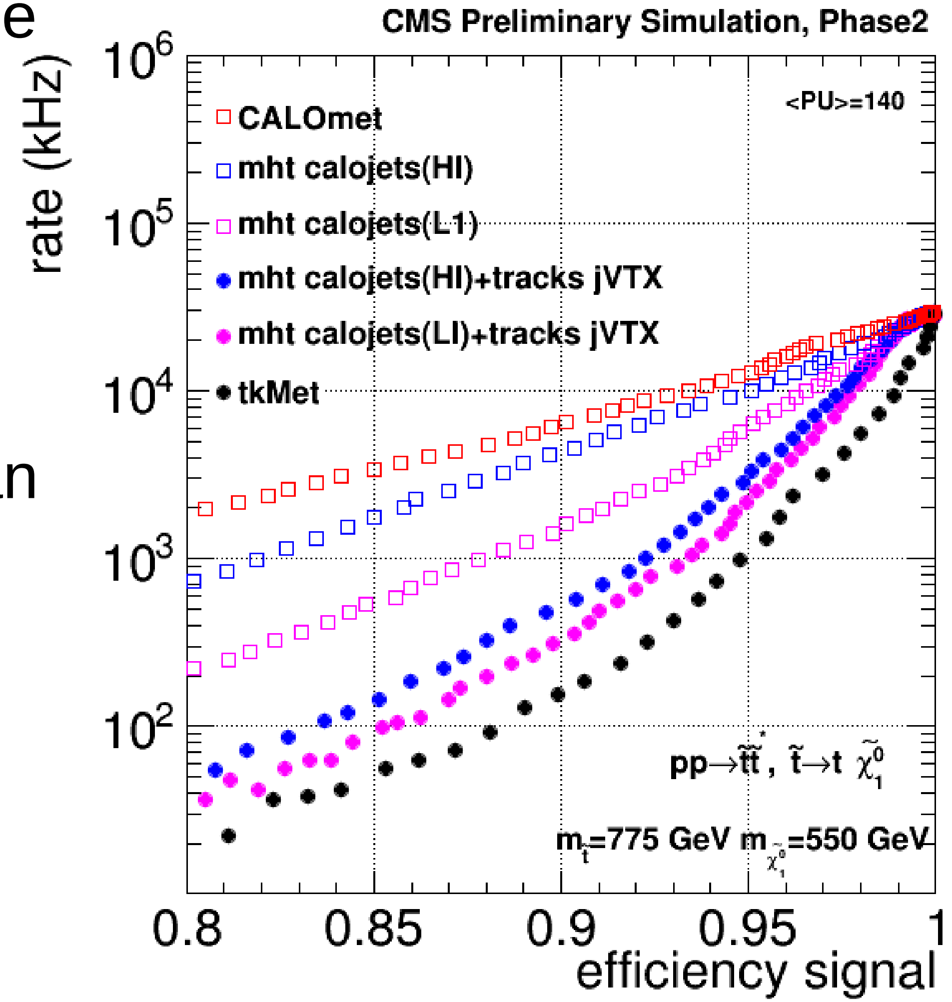
Primary Vertex and tkMET

- We can determine the primary vertex by looking in bins of z for the highest sum of pT
  - In tt events we find vertex position with 0.5 mm resolution
- High efficiency for selecting the correct vertex in tt events.



L1Track Based tkMET and MHT

- For these hadronic triggers the L1Track based selectors perform significantly better than the calo only algorithms
  - For the relatively low MET SUSY sample at 90% efficiency we have more than a factor 10 lower rate.



Hadronic Tau Selection

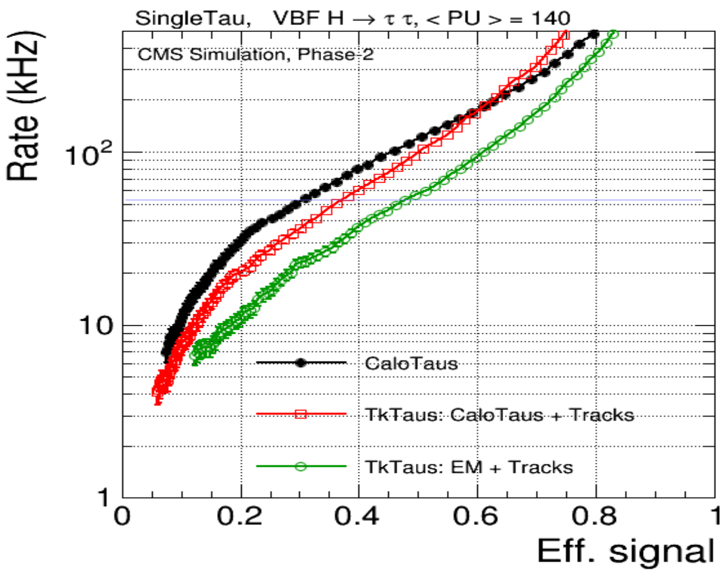
We have considered two different algorithms for selecting hadronic taus:

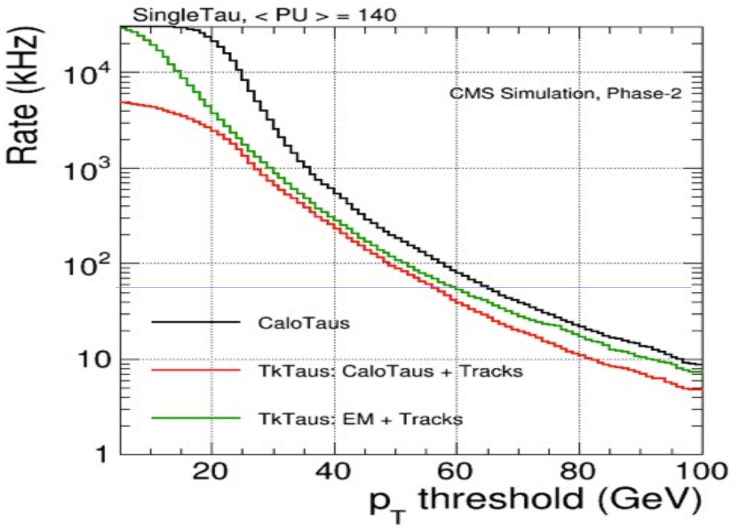
- L1CaloTau + L1Track
  - Seed algorithm with L1CaloTaus
  - Require a matching lead track plus possible additional tracks
  - Apply track based isolation
- L1Track + L1EM
  - Seed with L1Track (pT>5 Gev)
  - Add additional L1Tracks and L1EM objects to the tau candidate such that the invariant mass of the L1Tracks and L1EM objects are below the tau mass
  - Apply track based isolation

We consider both a single tau and double tau selection for the $H \to \tau\tau$ final state

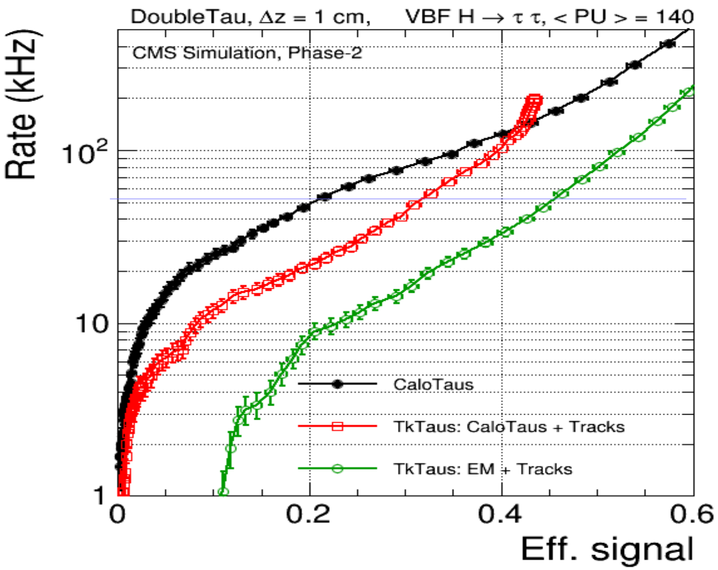
Tau Trigger Objects

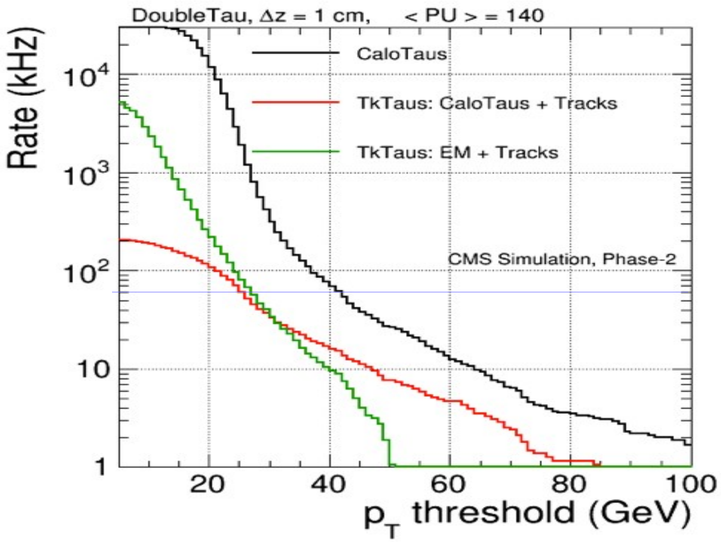
Single Tau





Double Tau

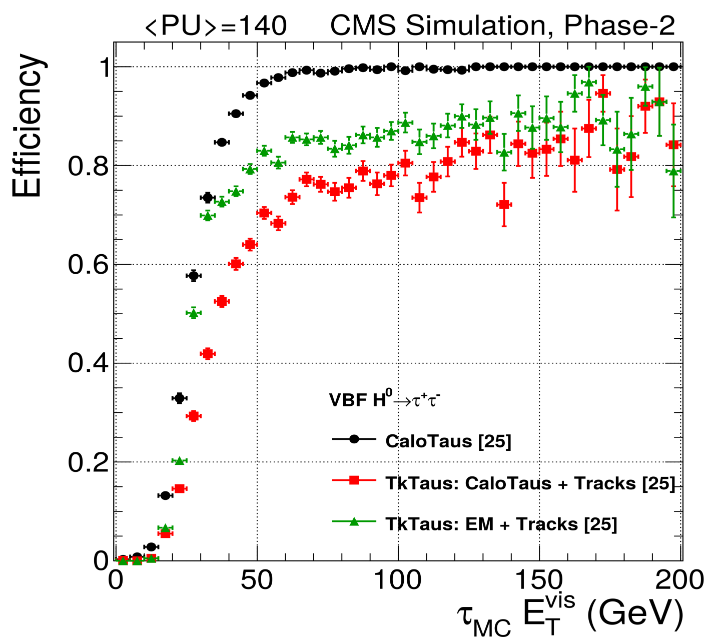




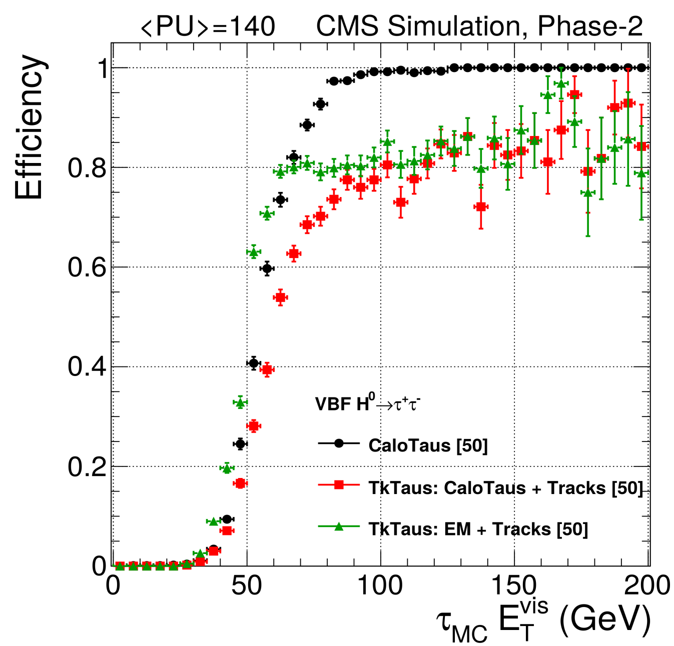
Tau Trigger Turn-on Curves

- Requirement to find lead track gives plateau efficiency for tracking algorithms around 85%
- Turn-on curve for L1Track+L1Em algorithm reasonably sharp.

25 GeV Threshold



50 GeV Threshold



Use of Pixels in L1 Trigger

- We are considering the use of pixel information in the L1 trigger
- Could be useful for
  - Electrons
  - Impact parameter triggers (b-jets)
- Considering a 'region-of-interest' approach where we seed using L1Calo or L1Track objects
  - L1Tracks could allow reading out a very small region of the pixels and reducing the data volume for the pixel trigger
  - We are developing the tools to study these triggers, e.g. H$\rightarrow$bb, where we match L1 tracks to L1Jets and then refit the L1 tracks with pixel information

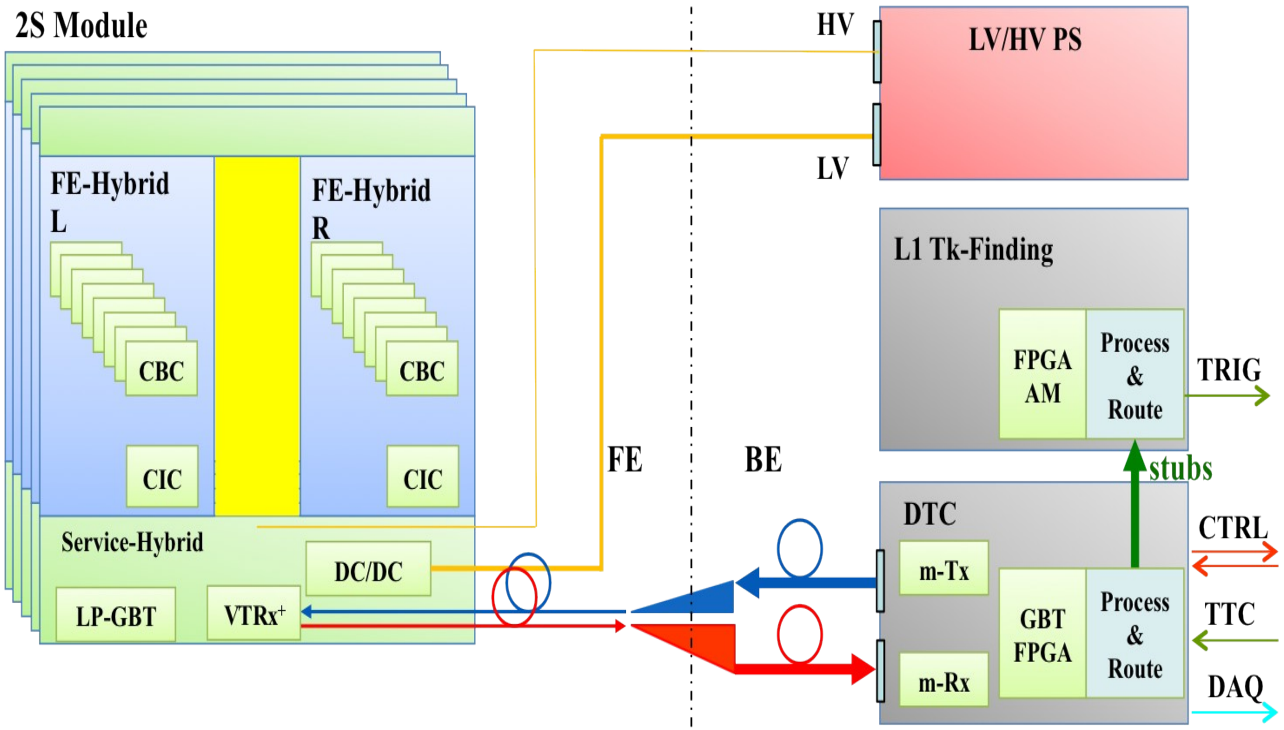
- For now the pixels are considered an option that is under study

Summary

- We have performed detailed simulations of the proposed CMS tracker and track trigger
- The pT modules are shown to proved trigger primitives, stubs, that can be used for an efficient L1Track finding
- Combining the L1Tracks with other L1 objects from the calorimeters and muons we have shown a significant improvement on most trigger objects:
  - Larger rate reductions for lepton triggers: e, μ, and τ
  - Use of track based isolation – including for photons
  - Primary vertex determination
  - Powerful PU mitigation in hadronc triggers (tkMET, MHT)
- R&D underway to demonstrate the feasibility of the L1 tracking
- The track trigger at L1 will provide many powerful handles to control the trigger rates at the HL-LHC
  - We will likely come up with new ideas as we get more familiar with this new tool

Back up

FE Electronics



Stub Rate and Data Reduction in Disks