# Evaluating Trigger Efficiencies for W-Boson to Three Charged Pion Decays



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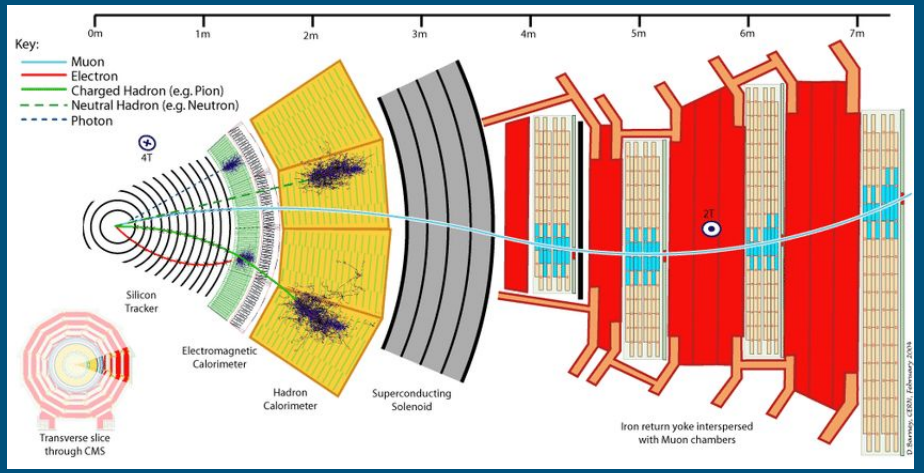
# CMS Background

- Compact Muon Solenoid (CMS)
  - Goal: General detector that aims to test the Standard Model of Particle Physics.
- Tracker
  - Pixel
  - Silicon
- Calorimeters
  - Electromagnetic Colorimeter
  - Hadronic Calorimeter
- Muon Chambers

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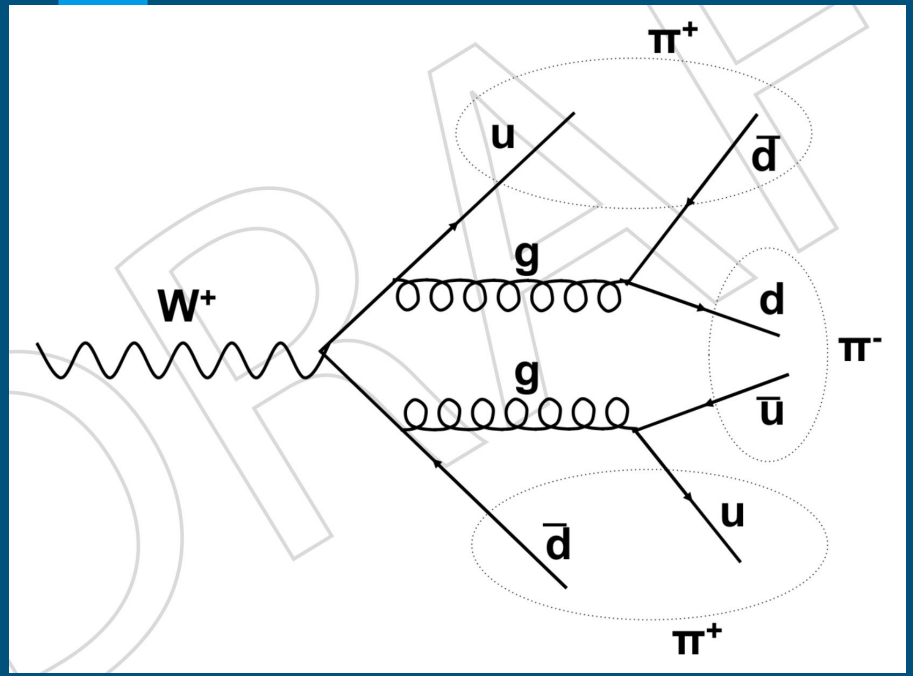
# CMS Trigger Systems

- Trigger
  - Detector component that sifts through data looking for events to save and events to discard.
    - 32 million bunch crossings per second and each event is  more than one MB!!

- Level 1 (L1) Trigger
  - First level of triggers that data goes through
  - Hardware-Based (FPGAs)
  - Makes the most simplest of decisions (most inclusive)
  - From 32 MHz to 100 kHz
  - Only Calorimeters and Muon Chamber Data

- High Level Trigger (HLT)
  - Next Phase after L1 Trigger
  - Software-Based (Commercial CPUs and GPUs)
  - Makes more Complicated Decisions
  - From 100 kHz to 1kHz
  - Processing each event is about 400 ms
  - All detector areas are covered

# My Specific Project




CMS Collaboration

- Description: Evaluating HLT efficiencies for W-boson decays into three charged pions.
  - If found:
    - Potential alternative measurement of W mass
    - Prove its branching fraction
    - Help theorists make rare decay calculations
- Context: The current Trigger Algorithm, Deep Tau, is going out of commission.
- Goal: Evaluate Trigger efficiencies to find either a more efficient or equally efficient trigger algorithm to replace DeepTau

# DeepTau and ParticleNet

DeepTau (HLT Algorithm)

- Looks for and reconstructs Hadronic Tau decays.
- Current Trigger algorithm used for W to 3 Pions.

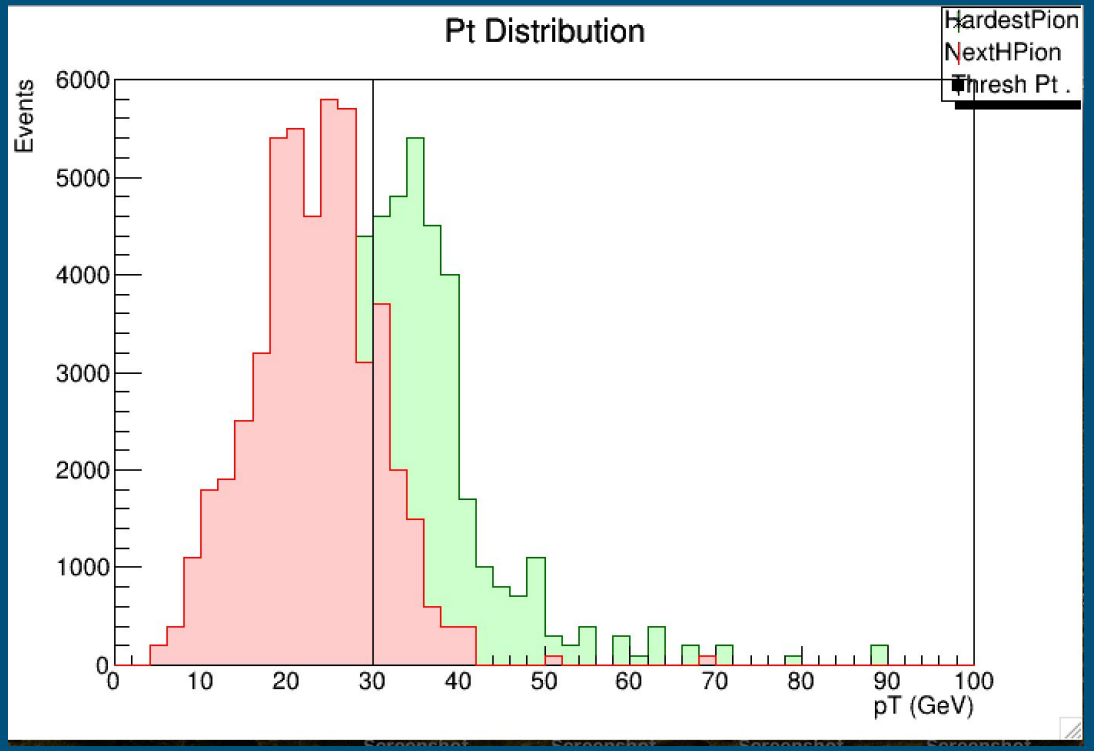
*DeepTau Out of Commision: Everyone is using ParticleNet except this group. Having DeepTau is hindrance.

ParticleNet (HLT Algorithm)

- Looks for and reconstructs jets.
- A lot more people use ParticleNet instead of DeepTau.

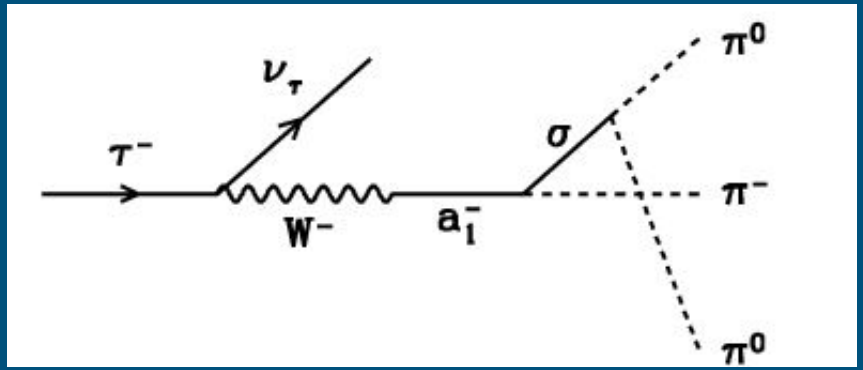
# General Set-Up

- DeepTau Trigger:
  - HLT_DoubleMediumDeepTauPFTauHPS30_L2NN_eta2p1_OneProng_v*
- PNet Trigger:
  - HLT_DoublePNetTauhPFJet30_Medium_L2NN_eta2p3_v*



# Why Taus?

- Hadronically decaying Taus and Pions have very similar detector signatures.



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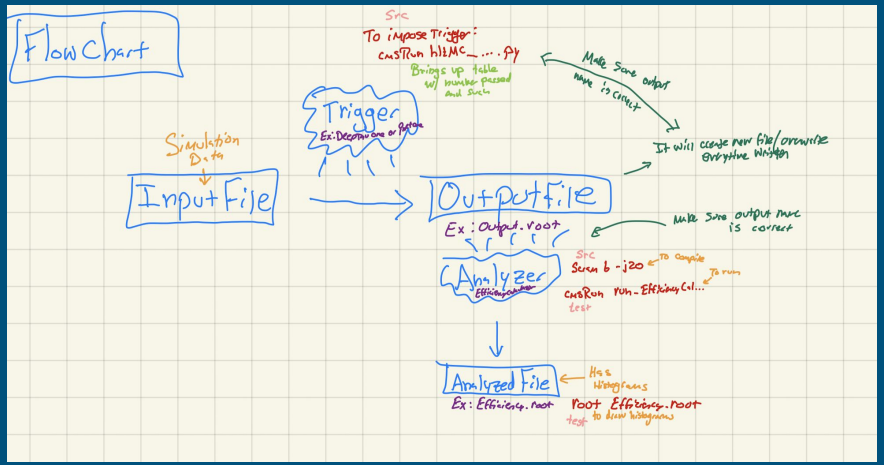
- The requirements triggers are looking for are very similar.
  - ➢ Hence DeepTau!!

# My Project Phases



# Phase 1: How to impose triggers on simulations?

- Run trigger over Monte Carlo (MC) simulation input files and calculate efficiencies.

$$Efficiency = \frac{\#\ of\ Passed\ Events}{Total\ Events}$$

```
TrigReport ---------- Modules in Path: HLT_DoubleMediumDeepTauPFTauHPS30_L2NN_eta2p1_OneProng_v6 ------------
TrigReport  Trig Bit#    Visited     Passed     Failed      Error Name
TrigReport     1    0        500        500          0          0 hltTriggerType
TrigReport     1    1        500        500          0          0 hltGtStage2Digis
TrigReport     1    2        500        500          0          0 hltGtStage2ObjectMap
TrigReport     1    3        500        500          0          0 hltOnlineMetaDataDigis
TrigReport     1    4        500        500          0          0 hltOnlineBeamSpot
TrigReport     1    5        500         33        467          0 hltL1sDoubleTauBigORWithLowMass
TrigReport     1    6         33         33          0          0 hltPreDoubleMediumDeepTauPFTauHPS30L2NNeta2p1OneProng
TrigReport     1    7         33         33          0          0 hltOnlineBeamSpotDevice
TrigReport     1    8         33         33          0          0 hltSiPixelClustersSoA
TrigReport     1    9         33         33          0          0 hltSiPixelClusters
```

...

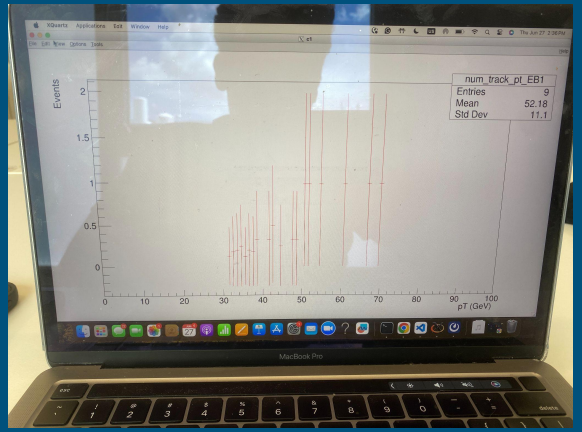
```
TrigReport     1  204         29         29          0          0 hltFixedGridRhoProducerFastjetAllTau
TrigReport     1  205         29         29          0          0 hltHpsPFTauBasicDiscriminatorsForDeepTau
TrigReport     1  206         29         29          0          0 hltHpsPFTauBasicDiscriminatorsdR03ForDeepTau
TrigReport     1  207         29         29          0          0 hltHpsPFTauDeepTauProducer
TrigReport     1  208         29         29          0          0 hltPFTau1ProngHPS
TrigReport     1  209         29         29          0          0 hltHpsSelectedPFTausMediumDitauWPDeepTau30
TrigReport     1  210         29         29          0          0 hltHpsL1JetsHLTDoublePFTauMediumDitauWPDeepTauMatch30
TrigReport     1  211         29         13         16          0 hltHpsDoublePFTau30MediumDitauWPDeepTauL1HLTMatched
TrigReport     1  212         13         13          0          0 hltBoolEnd
```

DeepTau trigger run over MC simulation input files.

# Phase 2: How to analyze results and graph efficiencies?

- Run analyzer over output file and create python function to graph analyzed output file's efficiency data.

Function Output

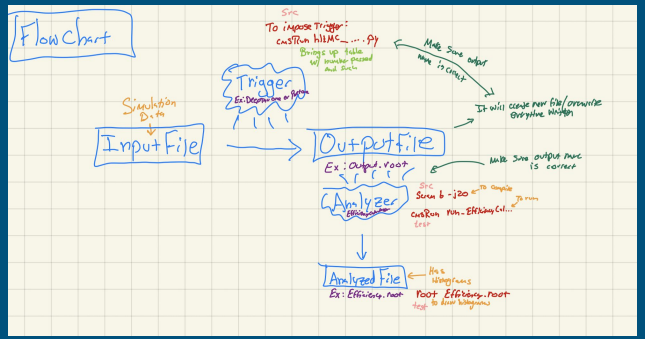



Graphing function

```
CMSSW_14_0_8 > src > Efficiency > TrigTools > test > Efficiency.py > ...
import ROOT
import glob
import os


outputFile1 = "Efficiency_DeepTau.root"
location1Num = "EfficiencyCalculator/num_track_pt_EB1"
location1Den = "EfficiencyCalculator/den_track_pt_EB1"


def graphEfficiencies (outputFolder1, locationNum1, locationDen1):

    c = ROOT.TCanvas()

    f = ROOT.TFile(outputFolder1)

    histNum1 = f.Get(locationNum1)
    histDen1 = f.Get(locationDen1)

    histNum1.Divide(histNum1, histDen1, 1,1,"B")
    histNum1.Sumw2()

    histNum1.SetName("eff1_track_pt_EB1")

    histNum1.SetLineColor(ROOT.kRed)



    c.cd()
    histNum1.Draw("E1")

    input("<Hit Return To Close>")

graphEfficiencies (outputFile1,location1Num, location1Den)
```

Analyzer function efficiency calculation

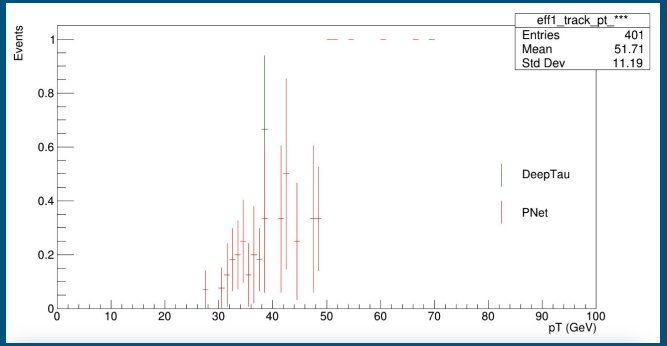
```
//Fill denominators
  if (fabs(g.eta()) < 1.0 ) den_track_pt_EB1->Fill(g.pt());
  if (fabs(g.eta()) > 1.0 && fabs(g.eta()) < 1.44 ) den_track_pt_EB2->Fill(g.pt(

  if (fabs(g.eta()) > 1.56 && fabs(g.eta()) < 2.0) den_track_pt_EE1->Fill(g.pt())
  if (fabs(g.eta()) > 2.00 && fabs(g.eta()) < 3.0) den_track_pt_EE2->Fill(g.pt())

  if (g.pt() > 10.) {
  den_track_eta->Fill(g.eta());
  den_track_phi->Fill(g.phi());
  }


//Fill numerators
if(nmatch_filter>0){

  pion_counter++;

  if (pion_counter ==2) {

    pair_pion_counter++;

  }

  if (fabs(g.eta()) < 1.0 ) num_track_pt_EB1->Fill(g.pt());
  if (fabs(g.eta()) > 1.0 && fabs(g.eta()) < 1.44) num_track_pt_EB2->Fill(g.pt()

  if (fabs(g.eta()) > 1.56 && fabs(g.eta()) < 2.0) num_track_pt_EE1->Fill(g.pt())
  if (fabs(g.eta()) > 2.00 && fabs(g.eta()) < 3.0) num_track_pt_EE2->Fill(g.pt())

  if (g.pt() > 10.) { //Choose appropriate pT cut value
  num_track_eta->Fill(g.eta());
  num_track_phi->Fill(g.phi());

occupancy_phi_eta_all->Fill(g.eta(),g.phi());
```




Visual file flow chart

# Phase 3: How to compare two different trigger efficiencies?

- Create new function that plots two trigger efficiencies on one graph.

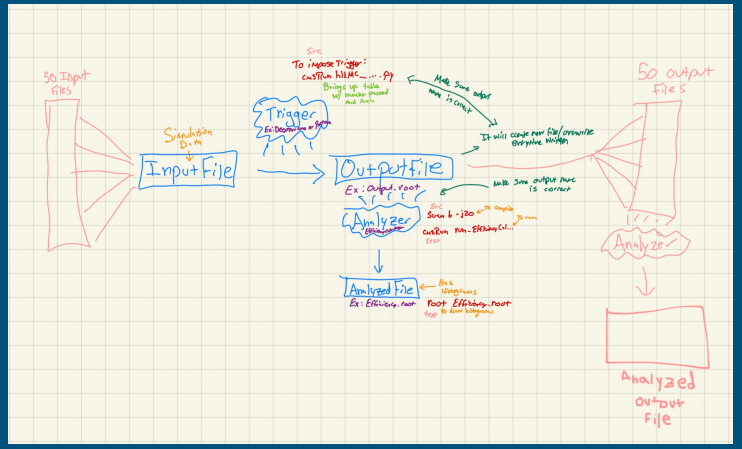



```
outputFile1 = "Efficiency_DeepTau.root"
location1Num = "EfficiencyCalculator/num_track_phi"
location1Den = "EfficiencyCalculator/den_track_phi"

outputFile2 = "Efficiency_PNet.root"
location2Num = "EfficiencyCalculator/num_track_phi"
location2Den = "EfficiencyCalculator/den_track_phi"


def graphEfficiencies (outputFolder1, outputFolder2, locationNum1, locationDen1, locationNum2, locationDen2):


    c = ROOT.TCanvas()

    f = ROOT.TFile(outputFolder1)

    histNum1 = f.Get(locationNum1)
    histDen1 = f.Get(locationDen1)

    print(histNum1)


    d = ROOT.TFile(outputFolder2)

    histNum2 = d.Get(locationNum2)
    histDen2 = d.Get(locationDen2)

    print(histNum2)

    # eff1 = ROOT.TEfficiency(locationNum1,locationDen1)


    histNum1.Divide(histNum1, histDen1, 1,1,"B")
    histNum1.Sumw2()

    histNum1.SetName("eff1_track_phi")


    histNum2.Divide(histNum2, histDen2, 1,1,"B")
    histNum2.Sumw2()

    histNum2.SetName("eff2_track_pt_***")
```

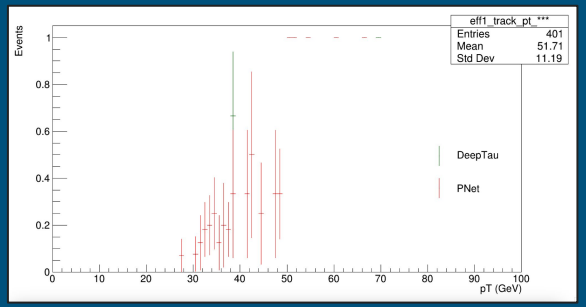
```
    histNum1.SetName("eff1_track_phi")


    histNum2.Divide(histNum2, histDen2, 1,1,"B")
    histNum2.Sumw2()

    histNum2.SetName("eff2_track_pt_***")


    histNum1.SetLineColor(ROOT.kGreen+3)
    histNum2.SetLineColor(ROOT.kRed)

    # overall = ROOT.THStack()


    # overall.Add(histNum1)
    # overall.Add(histNum2)

    leg = ROOT.TLegend(.73,.32,.97,.53)
    leg.SetBorderSize(0)
    leg.SetFillColor(0)
    leg.SetFillStyle(0)
    leg.SetTextFont(42)
    leg.SetTextSize(0.035)
    leg.AddEntry(histNum1,"DeepTau","DeepTau")
    leg.AddEntry(histNum2,"PNet","PNet")



    c.cd()
    histNum1.Draw("E1")
    histNum2.Draw("E1,same")
    leg.Draw()
    c.SaveAs("DeepTauPNet_ImprovedEfficienciesPhi.png")

    input("<Hit Return To Close>")

graphEfficiencies (outputFile1, outputFile2, location1Num, location1Den, location2Num, location2Den)
```

# Phase 4: How to get more data?

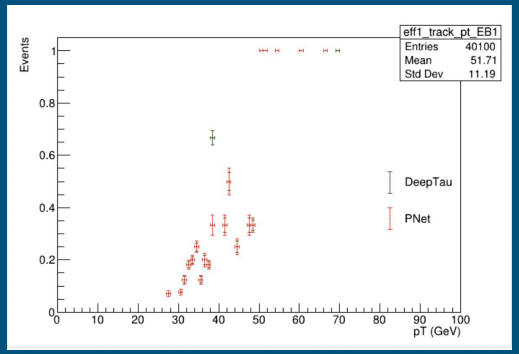
- To shrink uncertainty bars, use CondorJobs to increase the computing power. We must:
  - Run trigger over 50 input files
  - Run analyzer over 50 output files




Before:




After:



# Results

DeepTau

- Overall Efficiency: 3.9%
- PT Distribution:

ParticleNet

- Overall Efficiency: 4.1%
- PT Distribution:

# Continued

EB1: Eta < 1.0

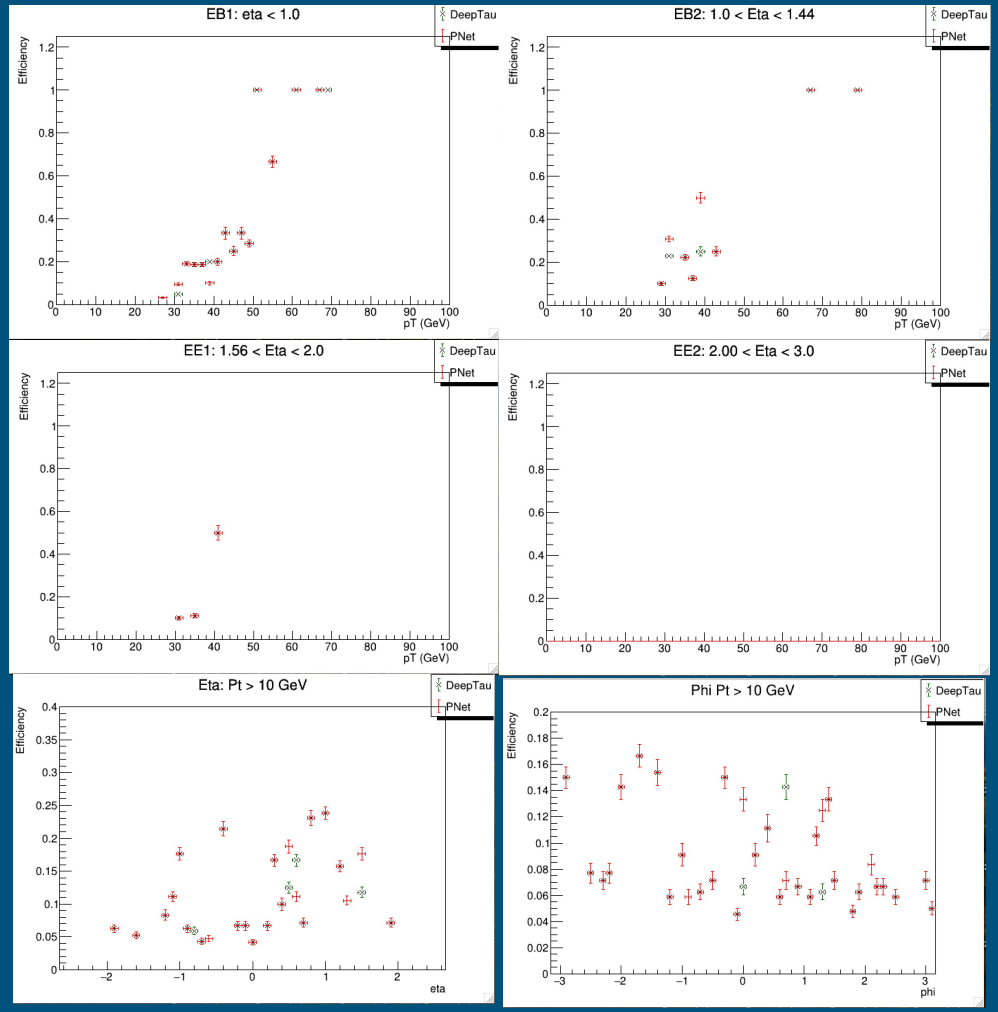
EB2: 1.0 < Eta < 1.44

EE1: 1.56 < Eta < 2.0

EE2: 2.00 < Eta < 3.0

Eta: Pt > 10 GeV

Phi Pt > 10 GeV



# Phase 5: Next Steps

- Developing a New Trigger Algorithm?
- Combining ParticleNet and Hadron Plus Strips (HPS) to create a worthy DeepTau replacement.
- Would another next step be using offline reconstruction.

# Acknowledgements

Special Thanks to:

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CMS Collaboration

CERN

UM-CERN REU

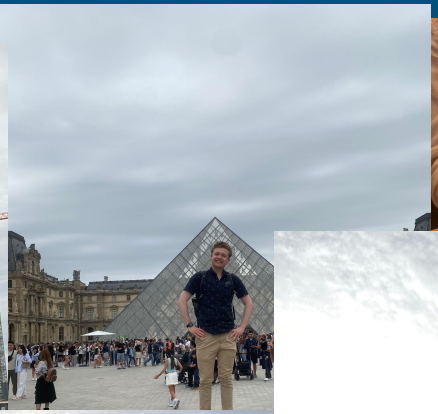
National Science Foundation

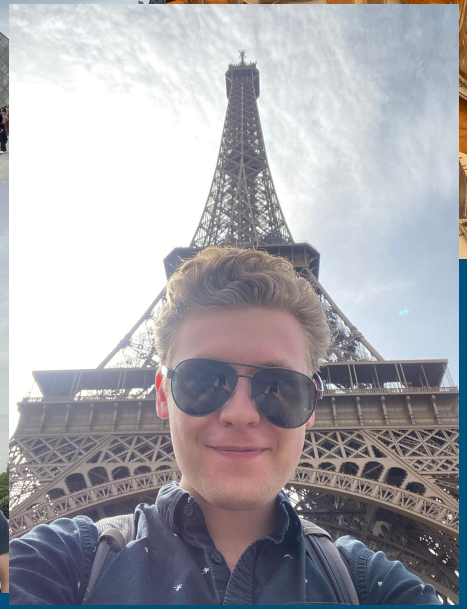
University of Michigan

Pacific University

# My Adventures!!

# Paris, France

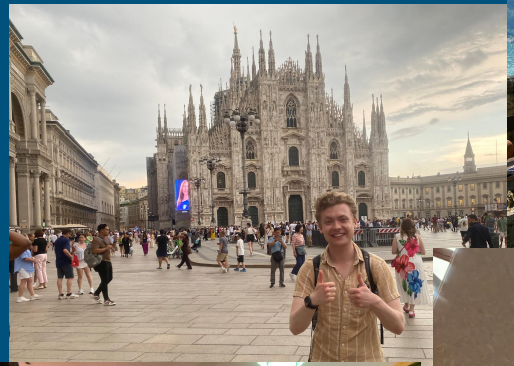


# Zürich, Switzerland



# Milan, Italy



# Interlaken/Schilthorn, Switzerland