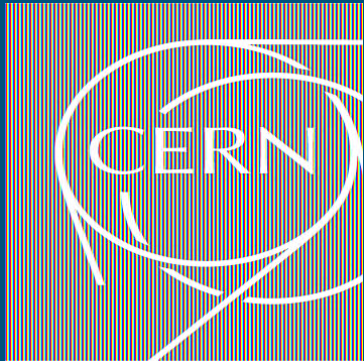




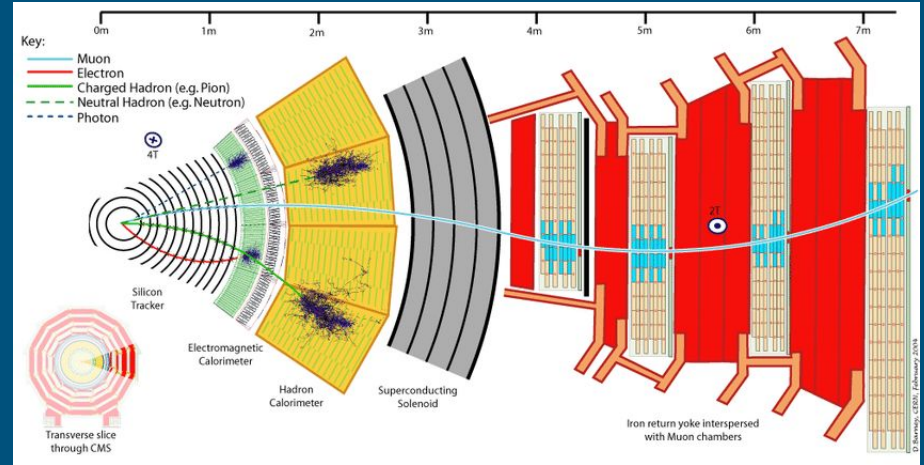
Evaluating Trigger Efficiencies for W-Boson to Three Charged Pion Decays



Logan Switzer
Supervisor: Riccardo Salvatico

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



<https://www.researchgate.net/>

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!!

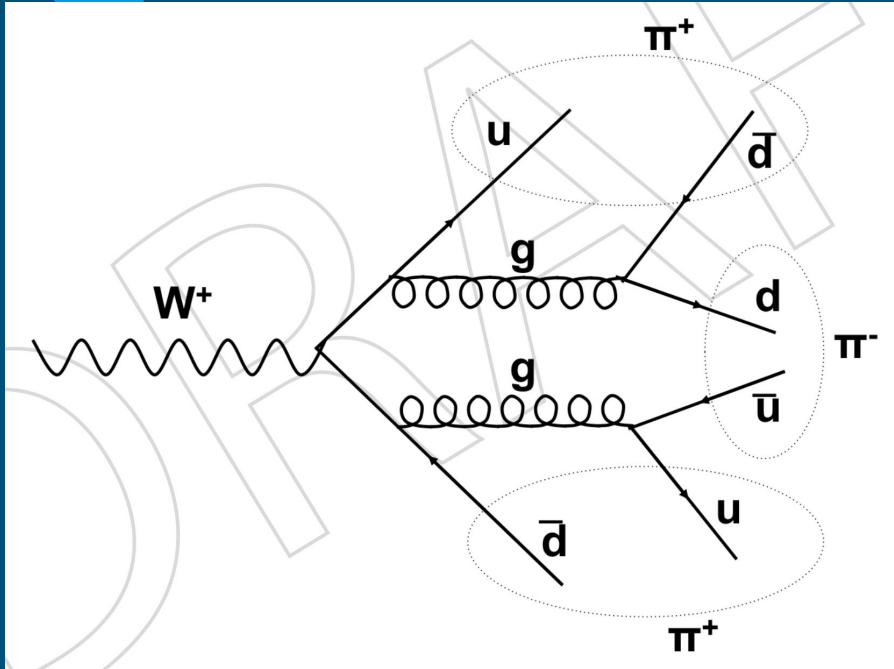
❖ Level 1 (L1) Trigger

- 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 Commission:
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.

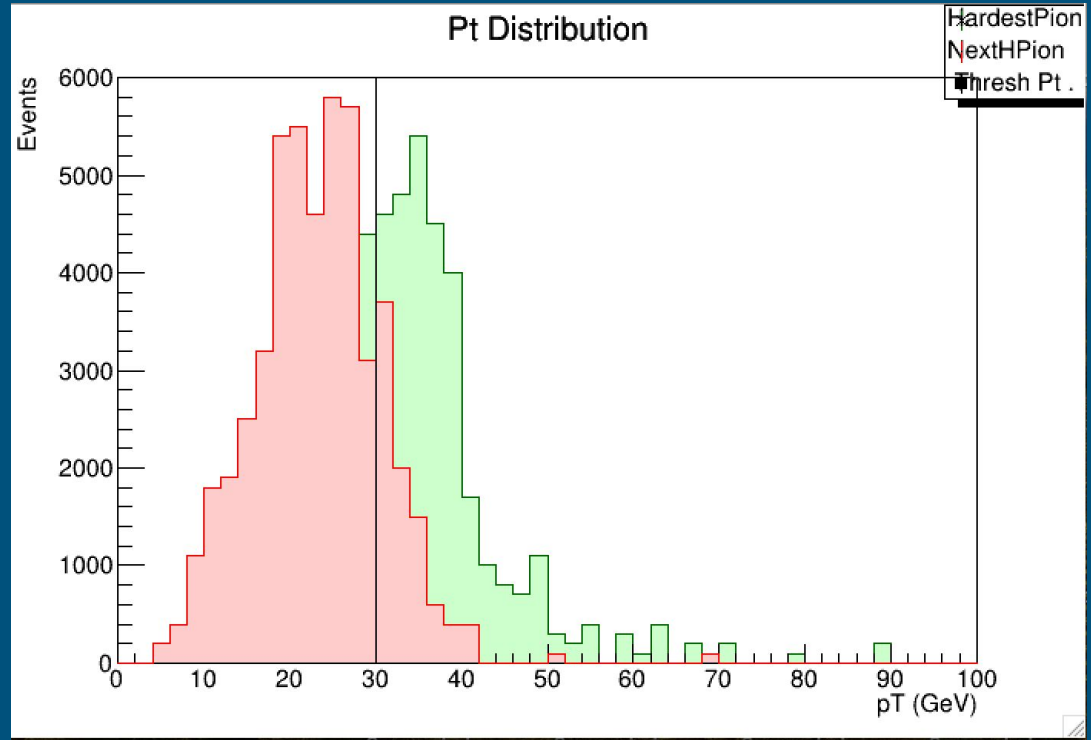
General Set-Up

❖ DeepTau Trigger:

➤ HLT_DoubleMediumDeepTauPFTauHPS30_L2N
N_eta2p1_OneProng_v*

❖ PNet Trigger:

HLT_DoublePNetTauhPFJet30_Medium_L2NN_e
ta2p3_v*

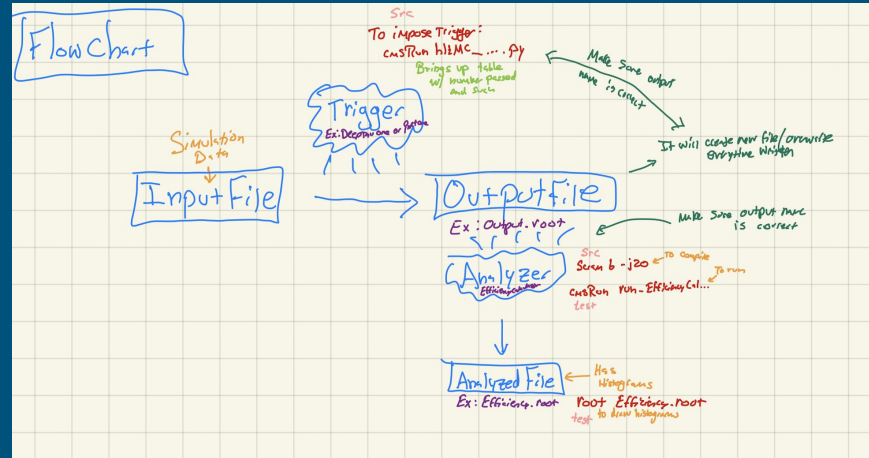


Why Taus?

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

```
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
```

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

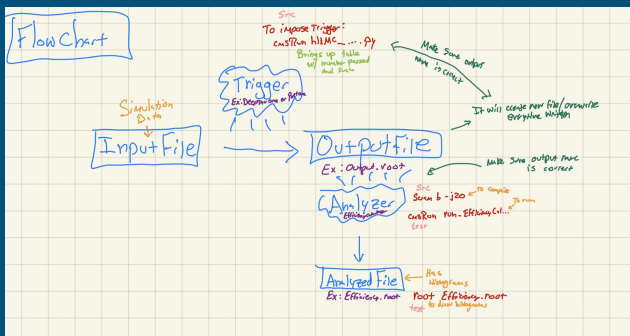
```
...
TrigReport 1 204 29 29 0 0 hltFixedGridRhoProducerFastjetAllTau
TrigReport 1 205 29 29 0 0 hltHpsPFTauBasicDiscriminatorsForDeepTau
TrigReport 1 206 29 29 0 0 hltHpsPFTauBasicDiscriminatorsdR03ForDeepTau
TrigReport 1 207 29 29 0 0 hltHpsPFTauDeepTauProducer
TrigReport 1 208 29 29 0 0 hltPFTau1ProngHPS
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?

Function Output

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



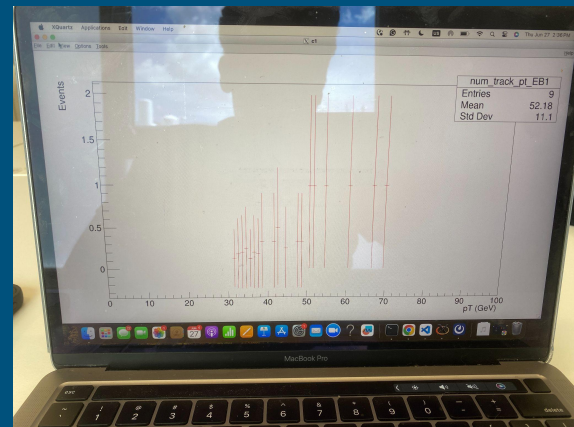
Visual file flow chart

Graphing function

```

CMS_SW_14_0_8 > src > Efficiency > TrigTools > test > Efficiency.py > ...
1  import ROOT
2  import glob
3  import os
4
5
6
7  outputFile = "Efficiency_DeepTau.root"
8  locationNum = "EfficiencyCalculator/num_track_pt_EB1"
9  locationDen = "EfficiencyCalculator/den_track_pt_EB1"
10
11
12
13
14  def graphEfficiencies (outputFolder1, locationNum1, locationDen1):
15
16
17      c = ROOT.TCanvas()
18
19      f = ROOT.TFile(outputFolder1)
20
21      histNum1 = f.Get(locationNum1)
22      histDen1 = f.Get(locationDen1)
23
24      histNum1.Divide(histNum1, histDen1, 1,1,"B")
25      histNum1.Sum2()
26
27      histNum1.SetName("eff1_track_pt_EB1")
28
29      histNum1.SetLineColor(ROOT.kRed)
30
31
32
33
34      c.cd()
35      histNum1.Draw("E1")
36
37      input("<Hit Return To Close>")
38
39  graphEfficiencies (outputFile,location1Num, location1Den)
40
41
42
43

```



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 (match_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());

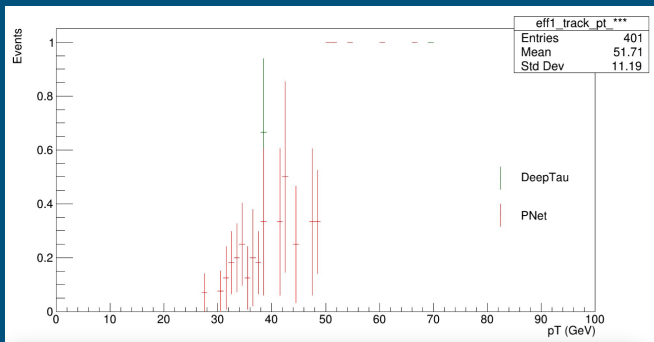
if (g.pt() > 10.) { //Choose appropriate pT cut value
    num_track_eta->Fill(g.eta());
    num_track_phi->Fill(g.phi());
}

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

```

Phase 3: How to compare two different trigger efficiencies?

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



```
outputFile1 = "Efficiency_DeepTau.root"  
locationNum = "EfficiencyCalculator/num_track_phi"  
locationDen = "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.Sum2()  
  
    histNum1.SetName("eff1_track_phi")  
  
    histNum2.Divide(histNum2, histDen2, 1,1,"B")  
    histNum2.Sum2()  
  
    histNum2.SetName("eff2_track_pt_***")
```

```
histNum1.SetName("eff1_track_phi")  
  
histNum2.Divide(histNum2, histDen2, 1,1,"B")  
histNum2.Sum2()  
  
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.SetFontSize(42)  
leg.SetTextSize(0.035)  
leg.AddEntry(histNum1, "DeepTau", "DeepTau")  
leg.AddEntry(histNum2, "PNet", "PNet")
```

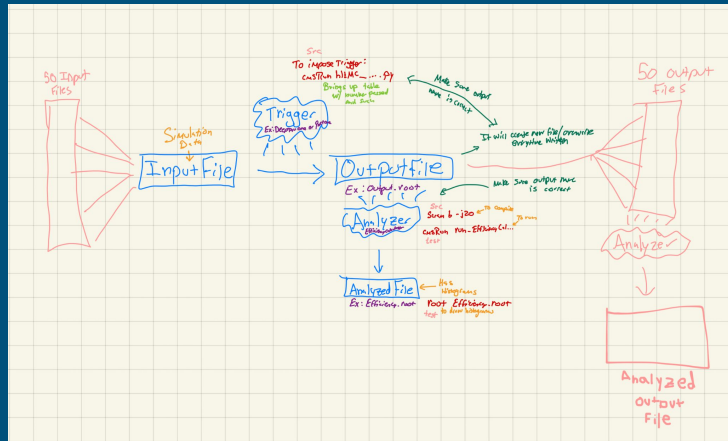
```
c.cd()  
histNum1.Draw("E1")  
histNum2.Draw("E1,same")  
leg.Draw()  
c.SaveAs("DeepTauPNet_ImprovedEfficienciesPhi.png")
```

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

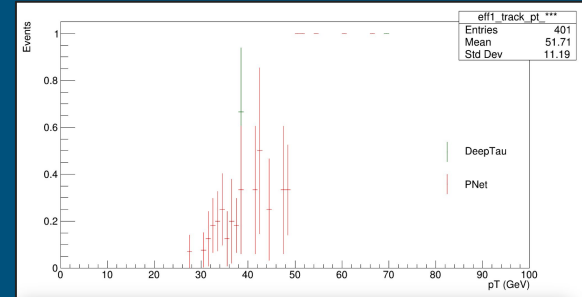
Phase 4: How to get more data?

❖ To shrink uncertainty bars, use CondorJobs to increase the computing power. We must:

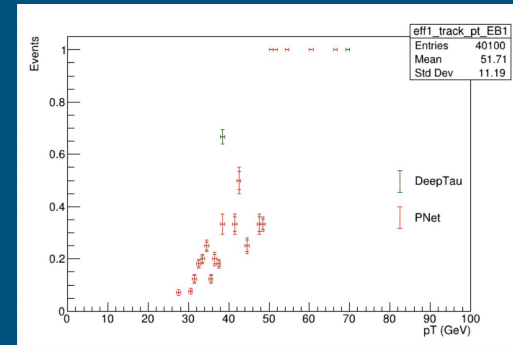
- Run trigger over 50 input files
- Run analyzer over 50 output files



Before:



After:



Results

DeepTau

❖ Overall Efficiency: 3.9%

```
Begin processing the 50000th record. Run 1, Event 469, LumiSection 1 on stream 0 at 07-Aug-2024 17:37:11 CEST
OverallDen: 1.086e+05
OverallDen: 1.086e+05
Numeta: 1.493
OverallNum: 4199
OverallDen: 1.086e+05
Numeta: 1.175
OverallNum: 4200
Overall Efficiency: 3.867
07-Aug-2024 17:37:11 CEST Closed file file:/eos/user/l/lswitzer/DeepTau/output_DeepTau_5472103_9.root
[lswitzer@lxplus9105 test]$
```

ParticleNet

❖ Overall Efficiency: 4.1%

```
Begin processing the 50000th record. Run 1, Event 469, LumiSection 1 on stream 0 at 07-Aug-2024 17:57:35 CEST
OverallDen: 1.086e+05
OverallDen: 1.086e+05
Numeta: 1.493
OverallNum: 4499
OverallDen: 1.086e+05
Numeta: 1.175
OverallNum: 4500
Overall Efficiency: 4.144
07-Aug-2024 17:57:35 CEST Closed file file:/eos/user/l/lswitzer/PNet/output_PNet_5607685_9.root
[lswitzer@lxplus9105 test]$
```

Continued

EB1: $\text{Eta} < 1.0$

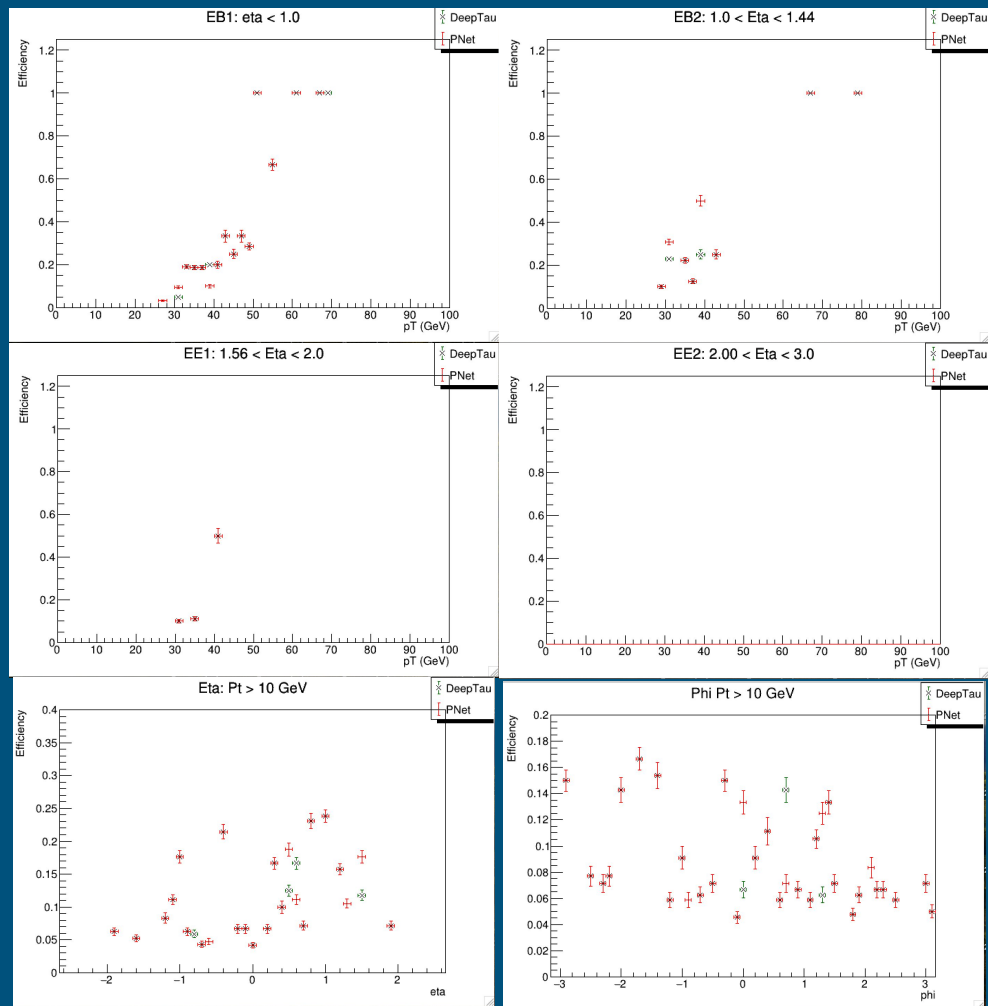
EB2: $1.0 < \text{Eta} < 1.44$

EE1: $1.56 < \text{Eta} < 2.0$

EE2: $2.00 < \text{Eta} < 3.0$

Eta: $\text{Pt} > 10 \text{ GeV}$

Phi Pt $> 10 \text{ GeV}$



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:

Riccardo Salvatico

Debabrata Bhowmik

CMS Collaboration

CERN

UM-CERN REU

National Science Foundation

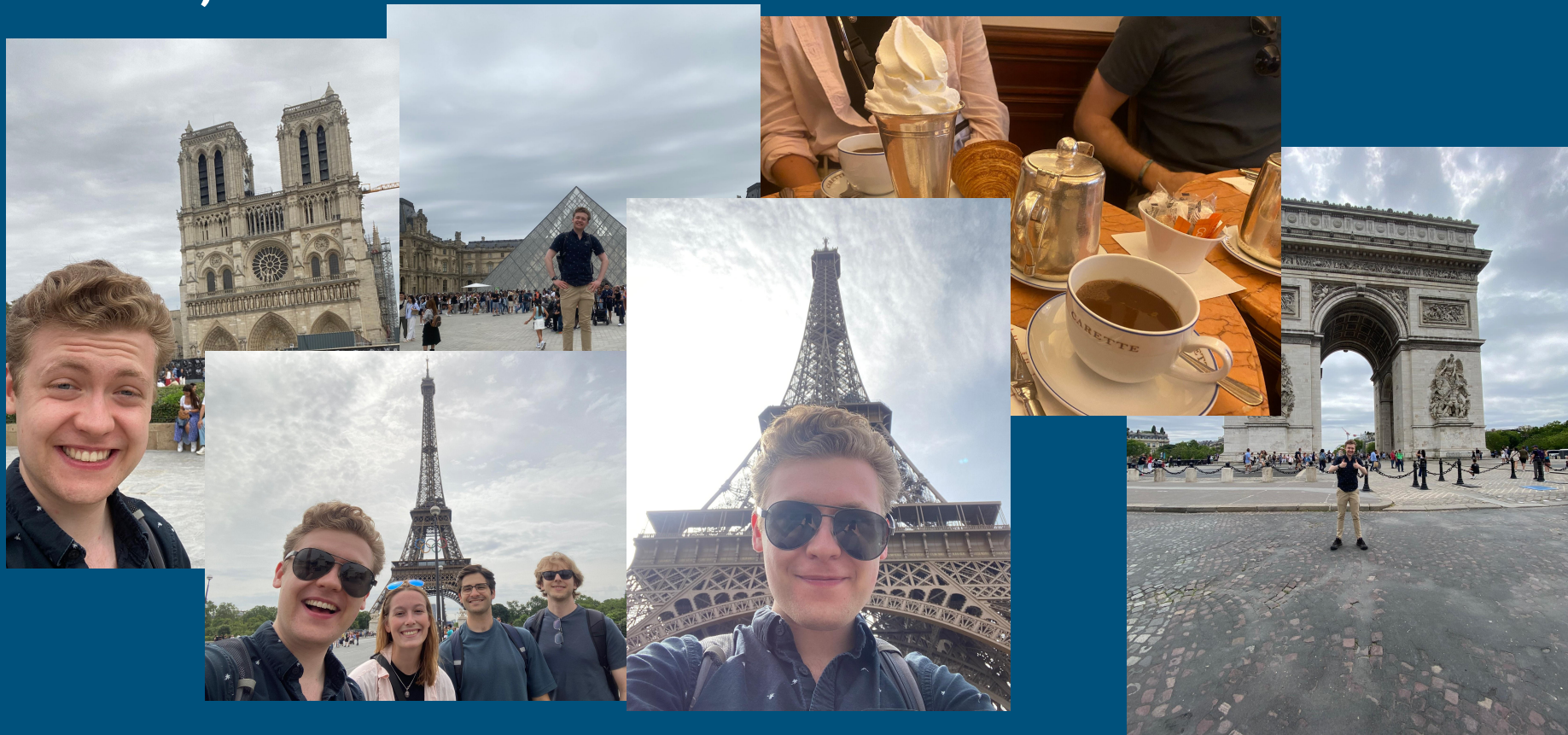
University of Michigan

Pacific University

My Adventures!!



Paris, France



Zürich, Switzerland



Milan, Italy



Interlaken/Schilthorn, Switzerland

