Feasibility Study of Light Additional Psuedo-Scalar Higgs Boson Decay in the Cool Copper Collider

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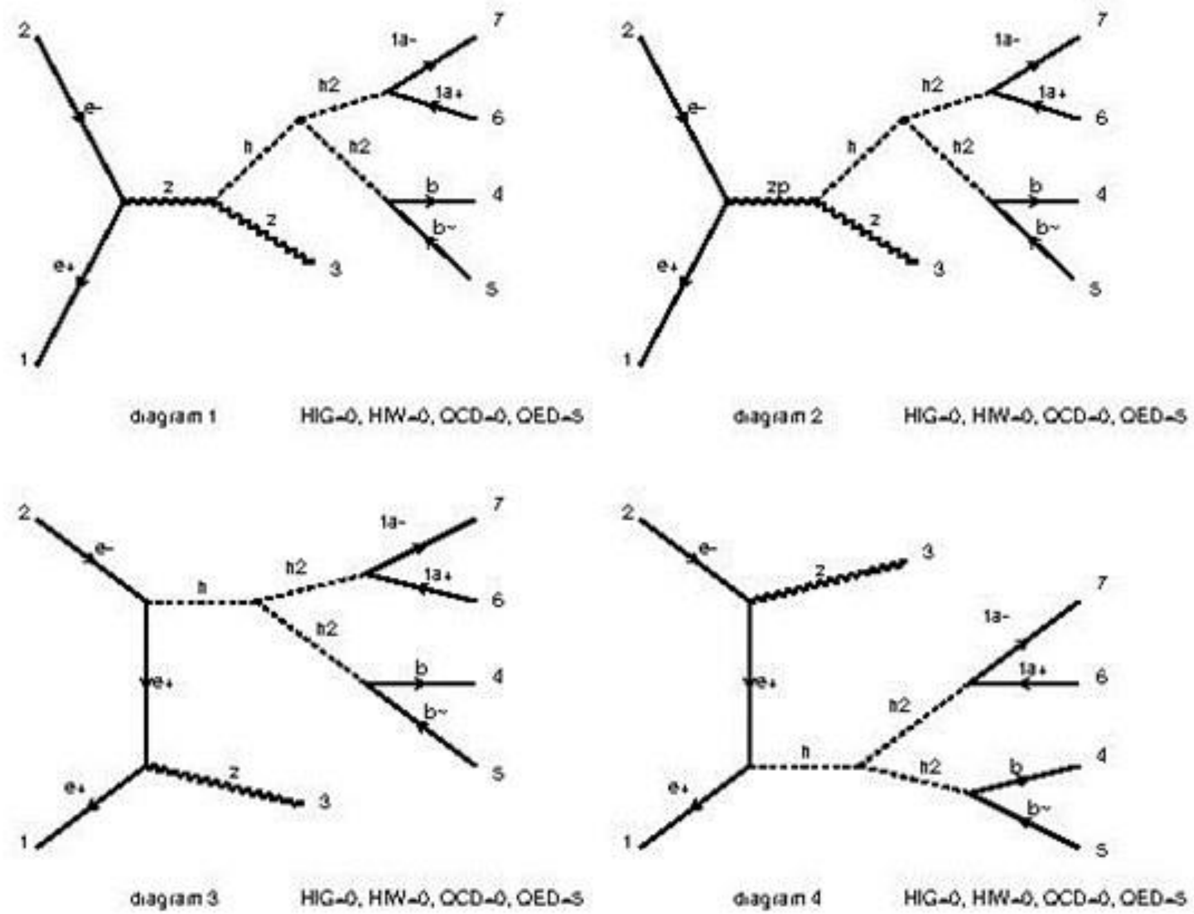
e+e- -> ZH -> aa -> bbtautau (Z -> mu+mu-)



Madgraph-Pythia-Delphes

Producing Madgragh5 based signals

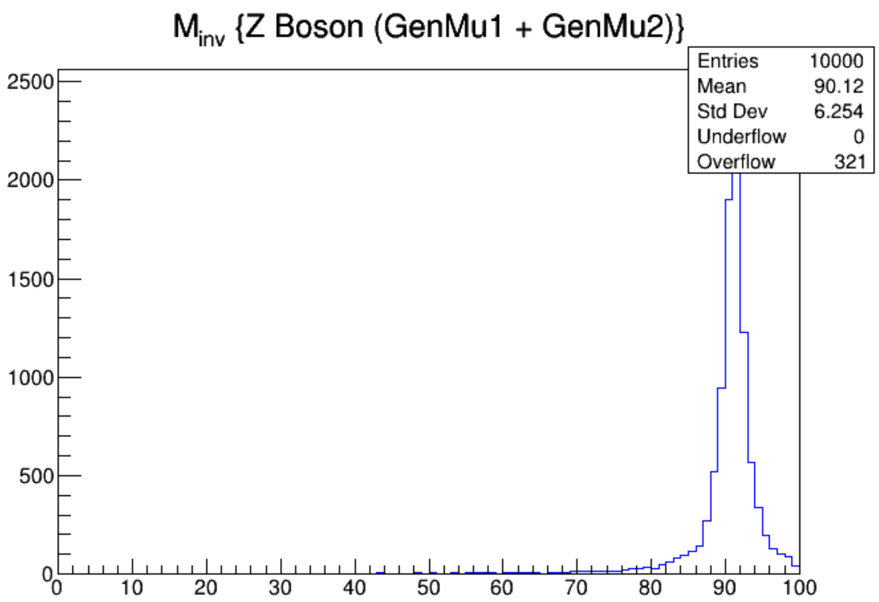
Hadronized the signals with Pythia8

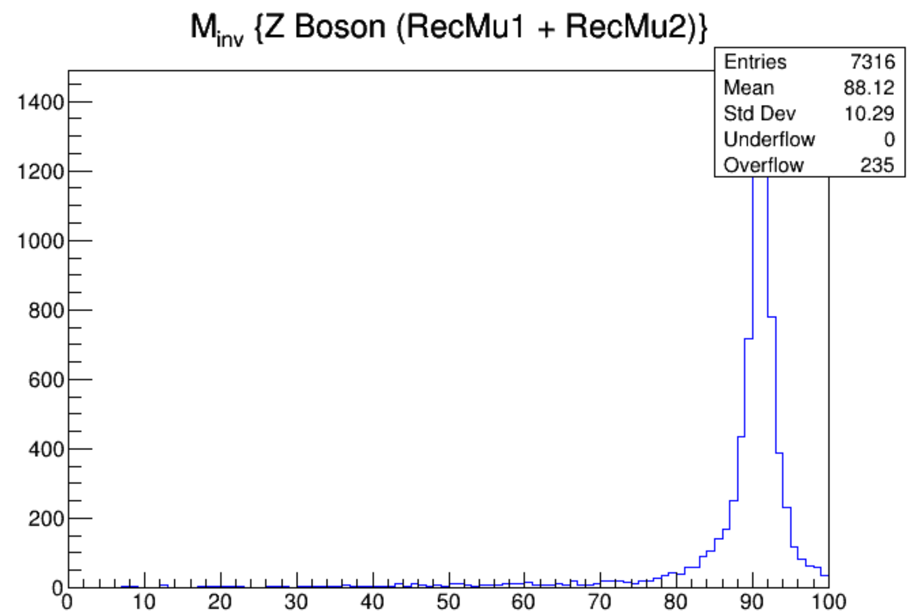
Simulate for detector’s response with Delphes

Muons (Z -> mu+mu-)

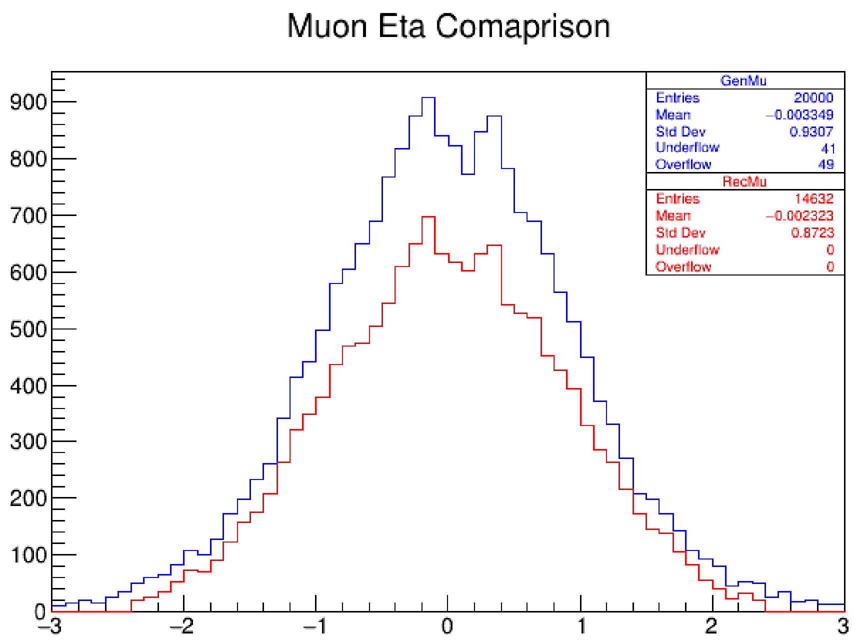
Comparison of Z Boson Mass with GenMuon and RecMuon

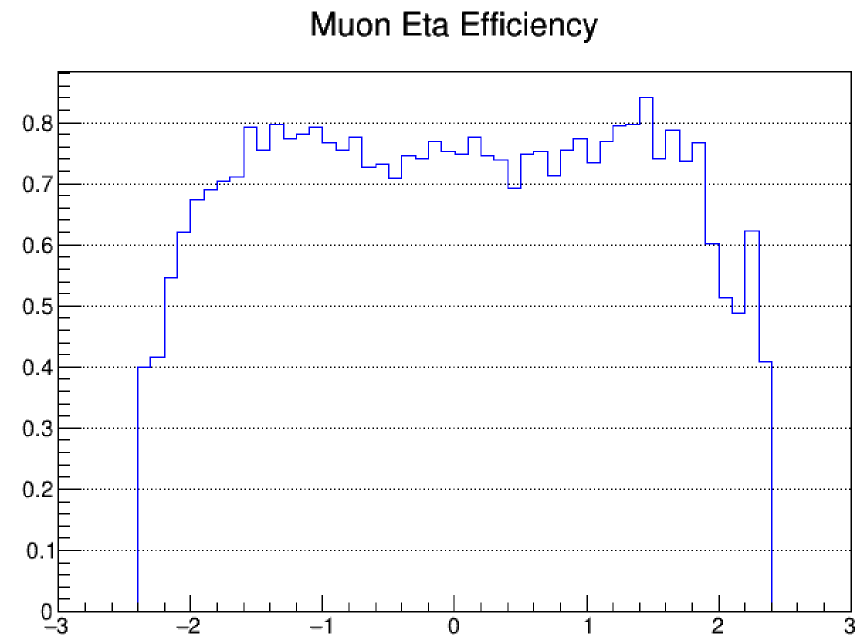
Selection Efficiency: 73%





Muon Eta Efficiency





Taus

Generator level Tau

1. Loop through each particle in branchParticles:
   - Check if the particle is a tau neutrino (abs(particle->PID) == 16).
   - Trace the ancestry of the tau neutrino to find the parent tau particle.
   - Handle special cases:
     - Z or W boson decay neutrinos: Skip.
     - D or B meson decay products: Skip.
2. Extract decay products of the parent tau:
   - Identify charged prongs with the highest PT (e.g. pi+ or K+).
   - Count photons and neutral hadrons in the decay.
3. Create `genTaus` and `visTaus` objects:
   - `genTaus`: Information about the parent tau particle and its decay products.
   - `visTaus`: Information about visible tau decay (parent tau momentum - tau neutrino momentum).

Tau Reconstruction

Reconstructing tau particles using energy flow (EFlow) data from tracks, photons, and neutral hadrons.

Reconstruction Process:

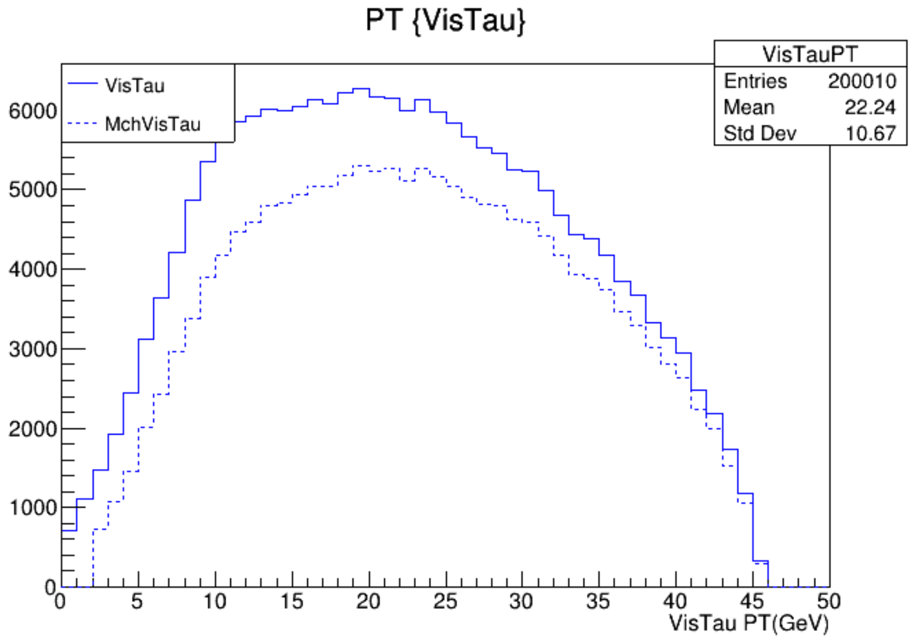
1. Loop through each track in branchEFTracks:
   - Consider tracks with PT > 2.0 GeV as potential tau remnants.
   - Create a tau candidate with the track's PT, eta, phi, and mass.
   - Compute isolation and sum charge of the tracks in the tau candidate.
2. Add in tracks and clusters within a 0.2 DeltaR cone around the tau candidate:
   - Calculate isolation as the sum of PT for tracks and clusters in the 0.3-0.5 DeltaR range.

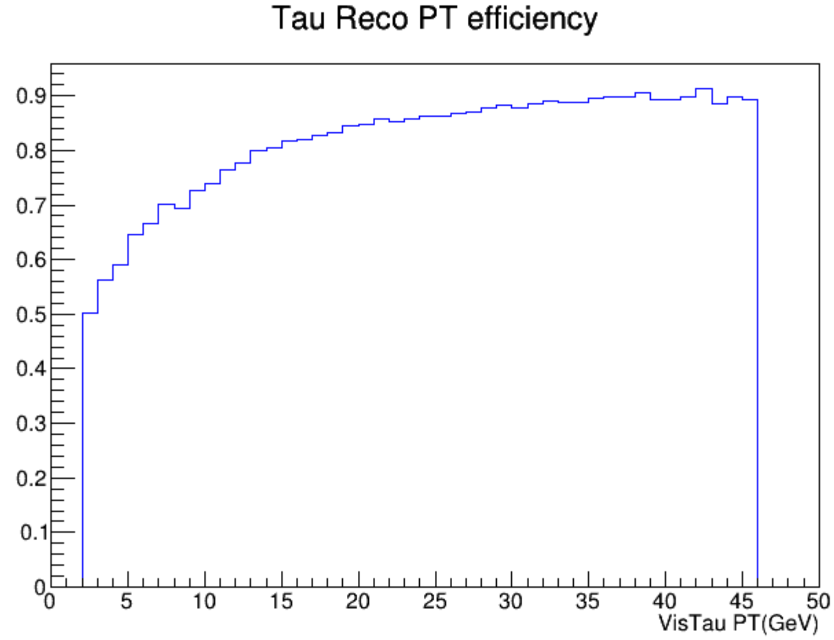
4. Repeat the process for photons and neutral hadrons from branchEFPhotons and branchEFNHadrons

5. Apply selection criteria to the tau candidates:
   - Only consider tau candidates with a maximum of 5 charged prongs.

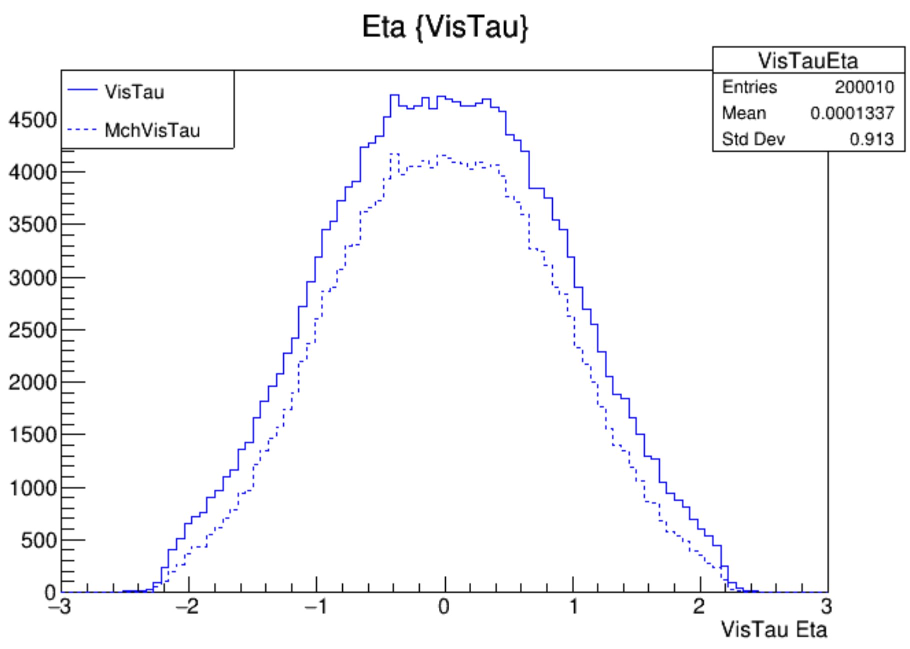
e+e- -> Z(91) -> tautau

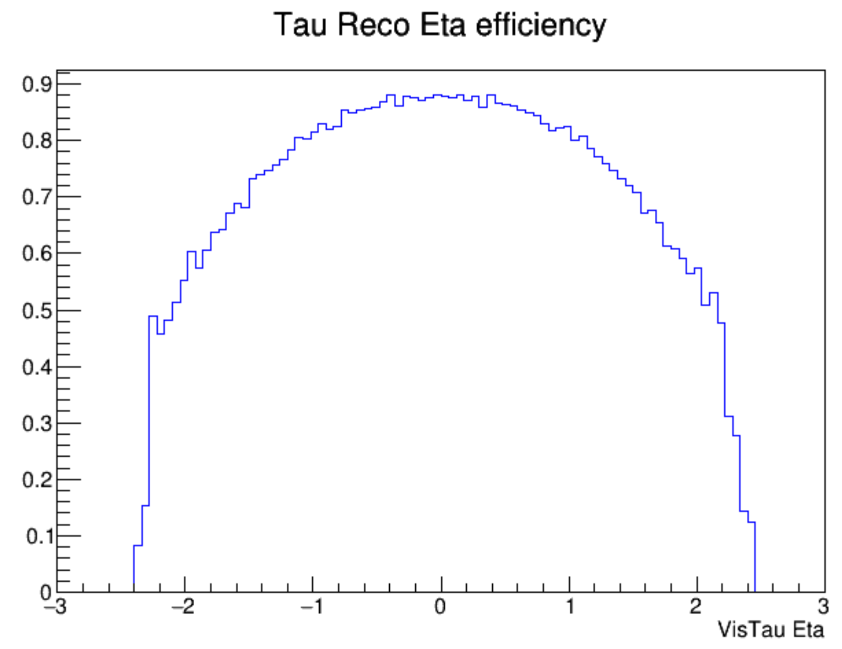
Reconstruction Efficiency (e+e- -> Z(91) -> tautau)





Reconstruction Efficiency (e+e- -> Z(91) -> tautau)



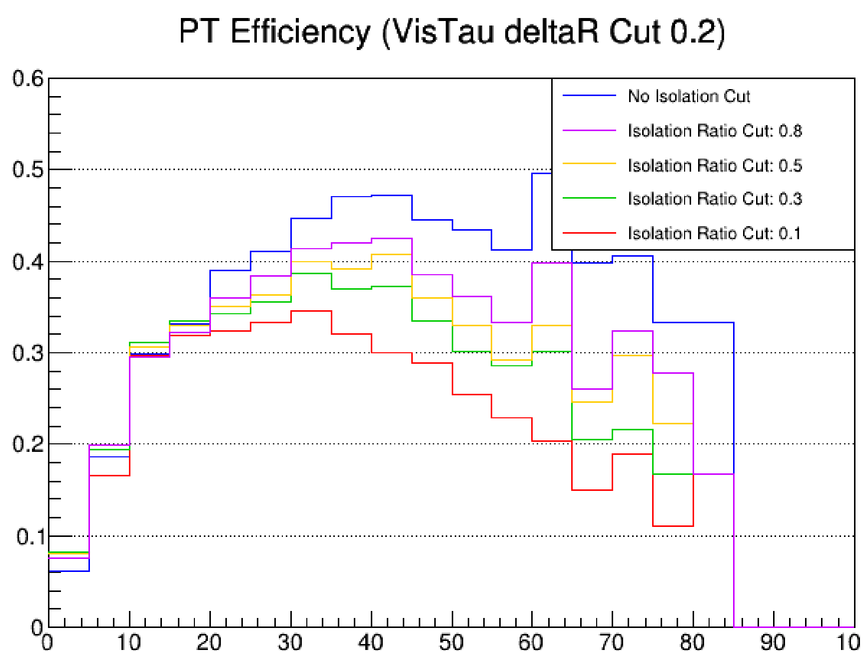


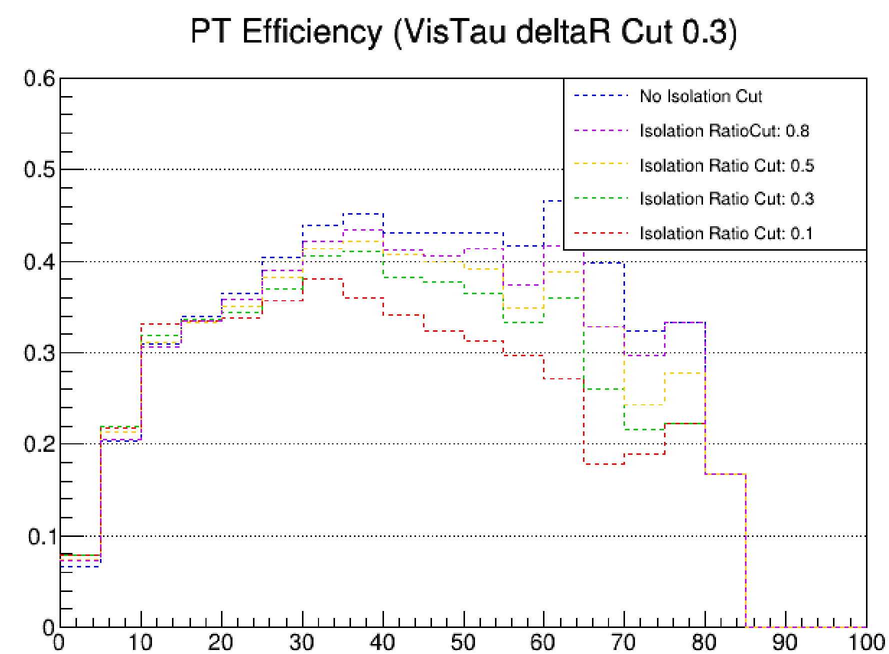
e+e- -> ZH -> aa -> bbtautau

Applying Inner Cone DeltaR and Isolation Ratio Cut on RecTau

Table for different Inner Cone deltaR & Isolation Ratio Cut

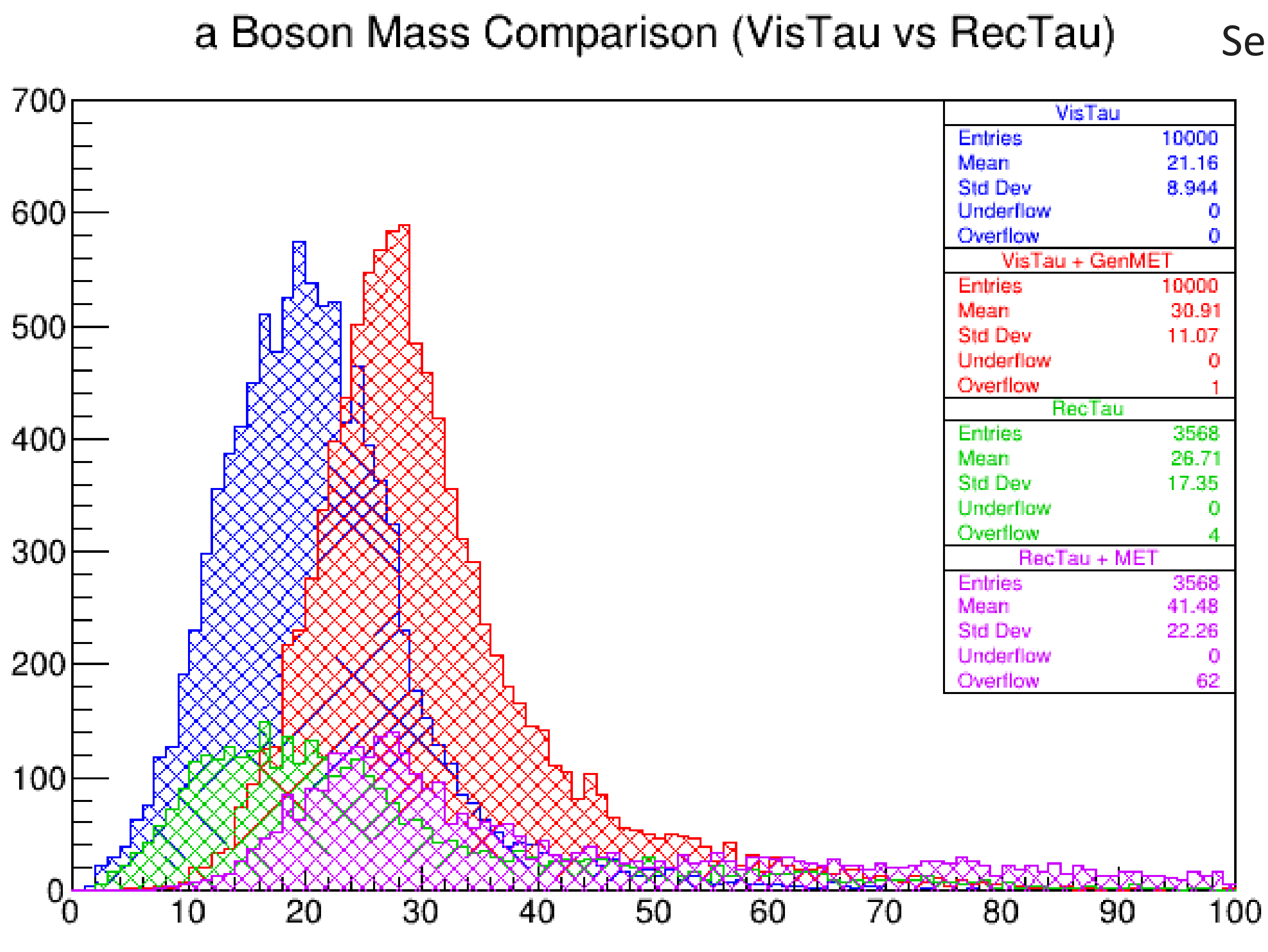
deltaR & Isolation Ratio Cut / a Boson Mass (RecTau)Stats	deltaR: 0.2 Isolation: 0	deltaR: 0.2 Isolation: 0.8	deltaR: 0.2 Isolation: 0.5	deltaR: 0.2 Isolation: 0.3	deltaR: 0.2 Isolation: 0.1	deltaR: 0.3 Isolation: 0	deltaR: 0.3 Isolation: 0.8	deltaR: 0.3 Isolation: 0.5	deltaR: 0.3 Isolation: 0.3	deltaR: 0.3 Isolation: 0.1
Entries	4886	4252	3925	3568	2928	4662	4441	4676	4054	3547
Mean	29.75	29.73	28.67	26.71	22.03	30.36	30.56	30.41	29.45	25.99
Std DEV	17.28	17.67	17.7	17.35	13.97	17.93	18.14	18.24	18.32	17.05





Reconstruction Tau (deltaR Cut: 0.2, Isolation Ratio Cut: 0.3) (e+e- -> ZH -> aa -> bbtautau)

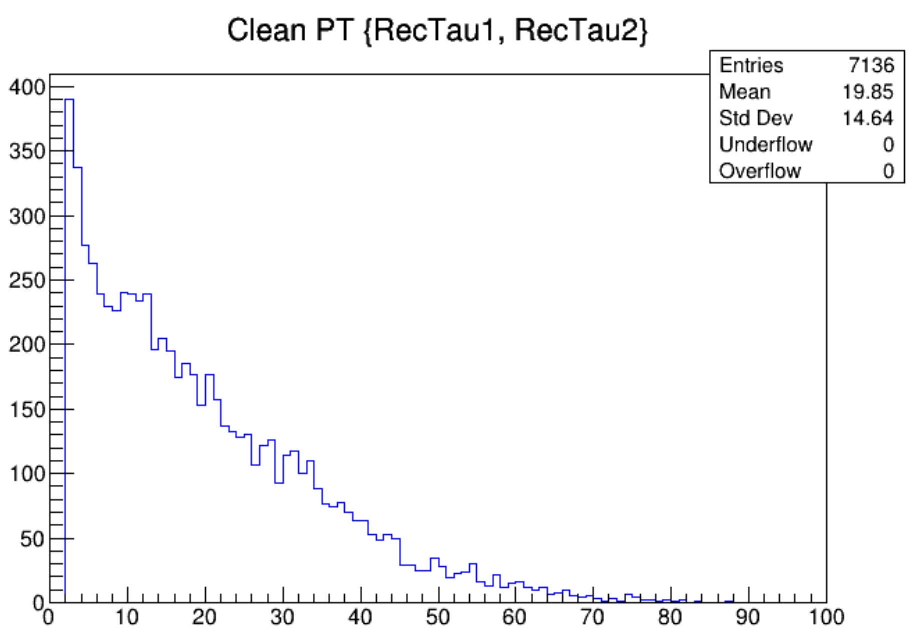
Selection Efficiency: 35%



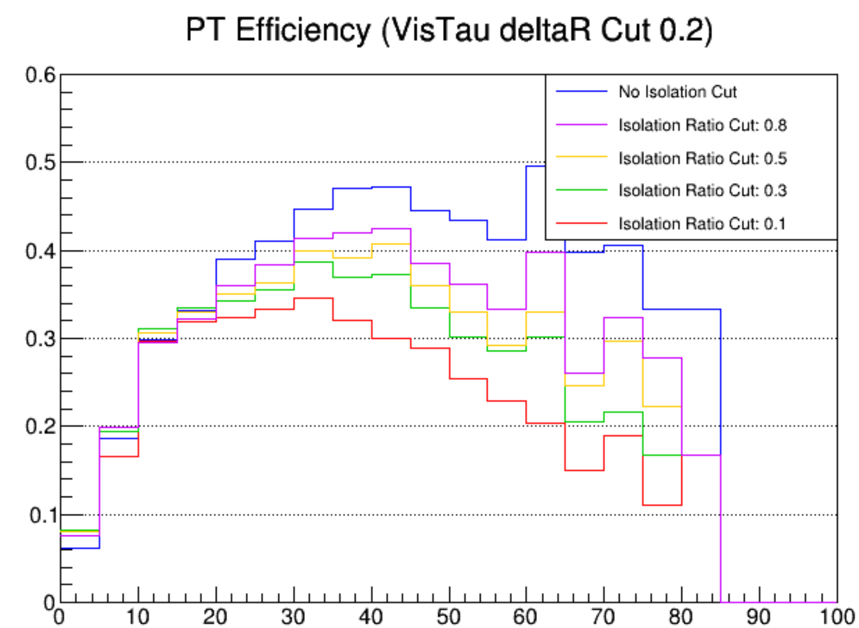
Comparison of RecTau vs VisTau

Stats \ Type	VisTau	RecTau
Entries	10000	3568
Mean	21.16	26.71
std Dev	8.944	17.35

Selection Efficiency: 35%



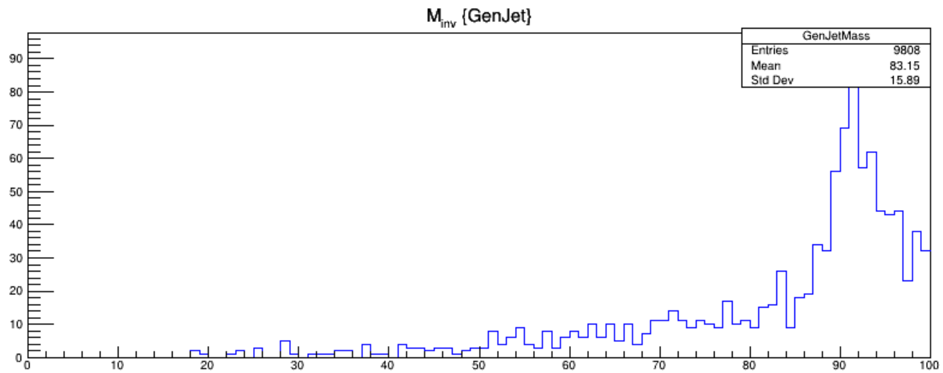
PT for the diRecTau with deltaR cut 0.2 and isolation ratio cut 0.3

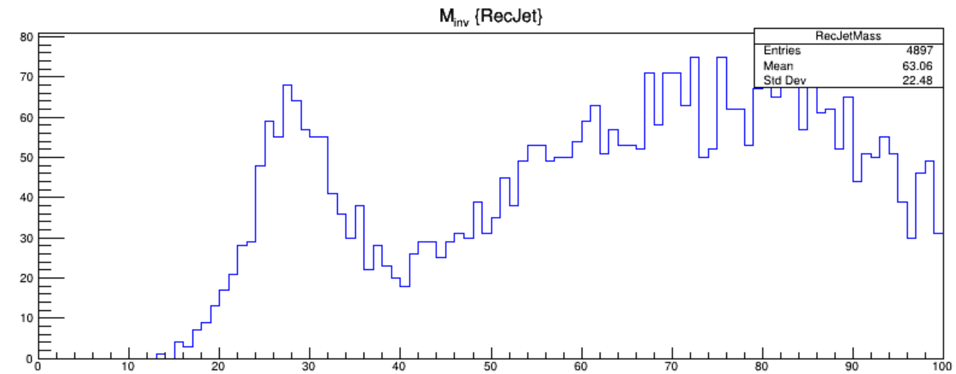


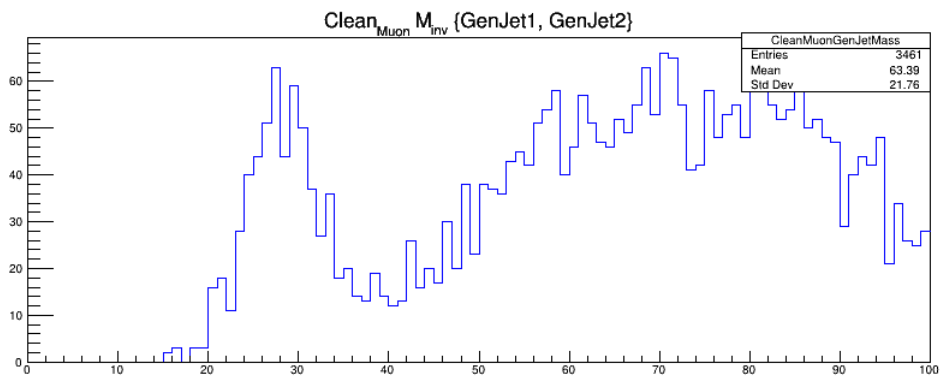
Using Delphes Definition of GenJet and RecoJet

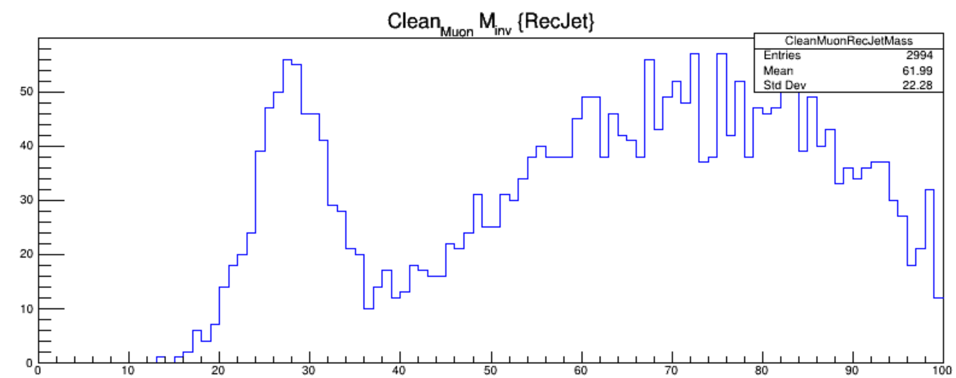
JetCleaning

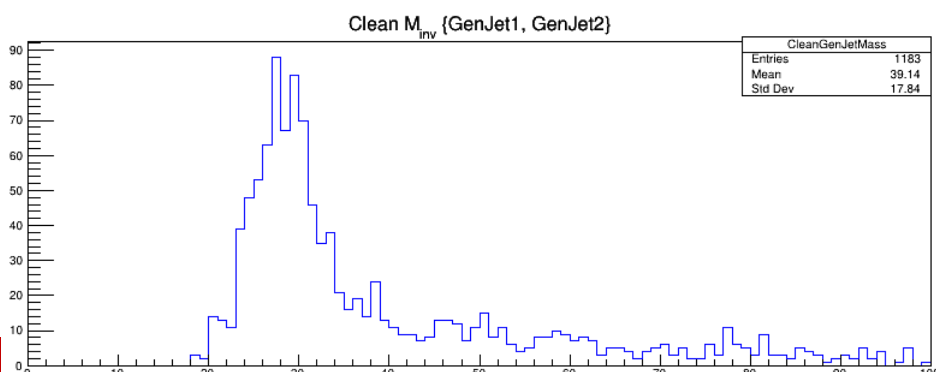
Gen Type	Entries	Rec Type	Entries
GenJet	9808	RecJet	4897
GenJet (Clean: Muon)	3461	RecJet (Clean: Muon)	2994
GenJet (Clean: Muon + Tau)	1183	RecJet (Clean: Muon + Tau)	1176

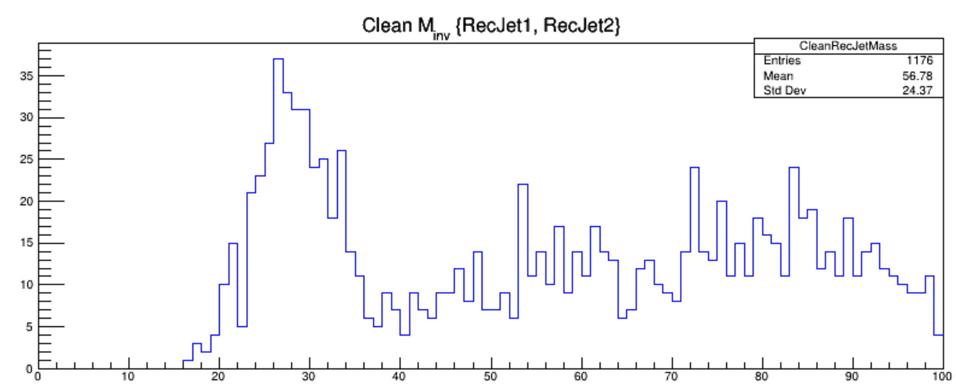












Using Stable Particles for approximate GenJet (GenROE) and Eflow for RecJet (RecROE)

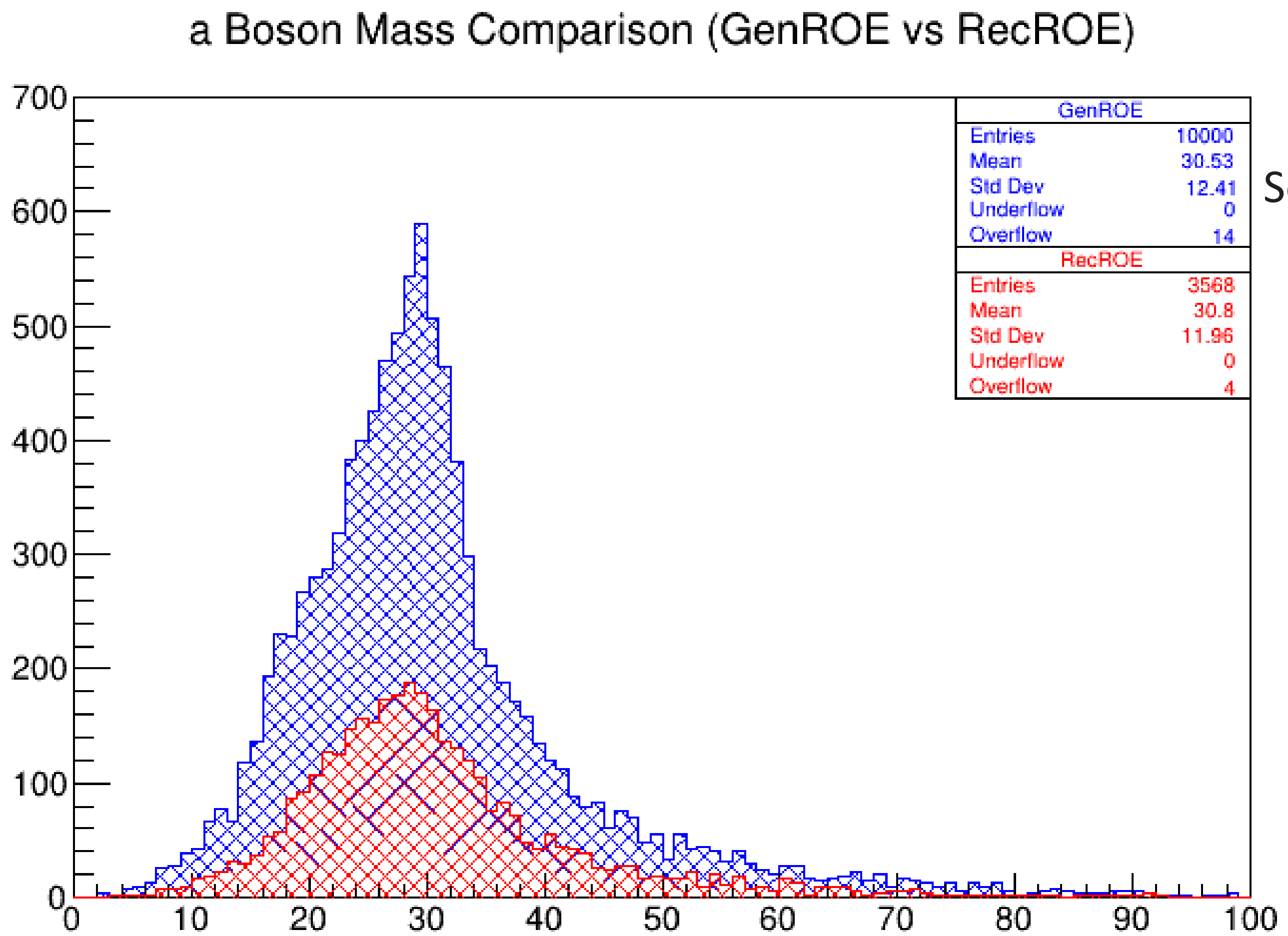
GenROE Analysis:

- If there are particles in the branchParticles, two clean_genTaus, and two clean_genMuons:
  - Loop over the particles from branchParticles.
  - Select stable particles (status 1).
  - Exclude electrons based on their PID values.
- Calculate deltaR between the current stable particle and genTaus as well as muons GenROE Cleaning:
  - Update the particles as GenROE

RecROE Analysis

- If there are entries in branchEFTracks and more than one entry in branchMuon and the size of clean_recTaus is 2:
  - The track's proximity to other particles like clean_recTaus and muons is checked using Delta R.
  - If the track is sufficiently separated from these particles (DeltaR >= 0.2), classified it as RecROE.
- If there are entries in branchEFPhotons and a track has been selected:
  - The code loops over all photon entries and checks their proximity to clean_recTaus and muons.
  - If they are separated, they are added to the invariant mass and momentum sums, and histograms are updated.
- Same for branchNHadrons

The Comparison for GenROE and RecROE



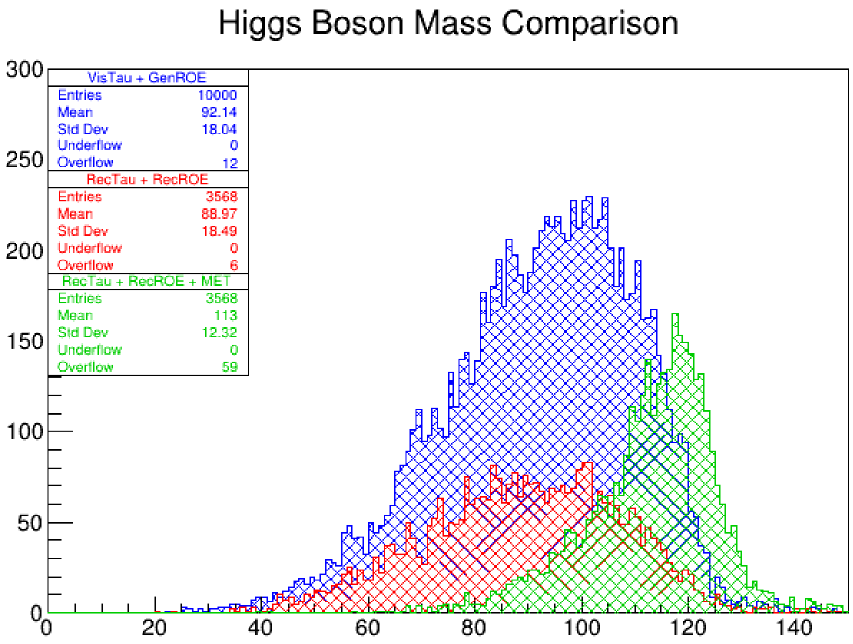
Selection Efficiency: 35%

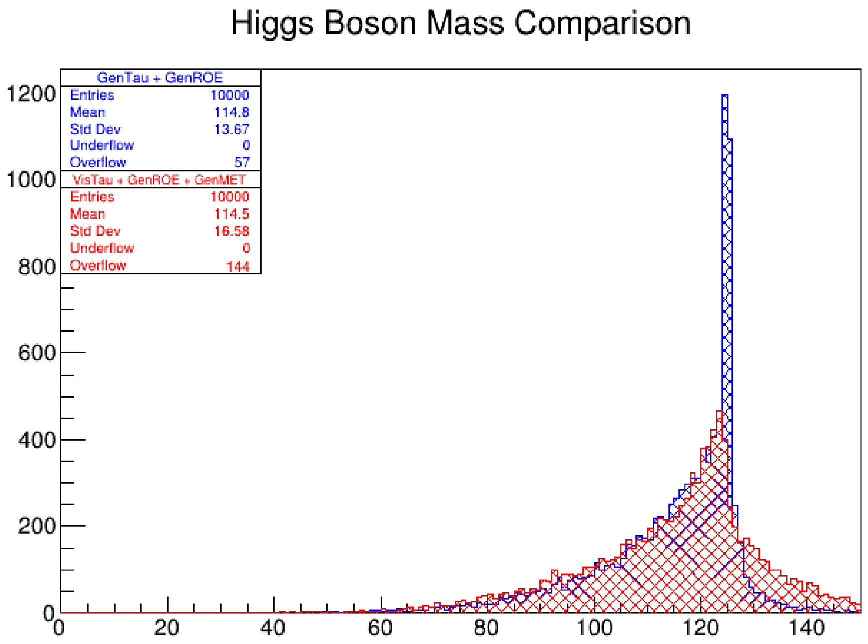
Table for Comparison of Delphes Jet and ROE

Stats \ Type	GenJet	GenROE	RecJet	RecROE
Entries	1183	10000	1176	3568
Mean	39.14	30.53	54.76	30.8
std Dev	17.84	12.14	29.37	11.96

Higgs Boson

Higgs Boson Mass Comparison





Future Plan

- Working on improving the reconstruction process for the Tau.
- Improving the selection efficiency for the Muons.
- Improved the clarity of the ROE and Higgs peaks.
- Moving forward to other Z decay options.

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