Tau Reconstruction in the MAIA Detector

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MAIA Detector and 10 TeV Studies

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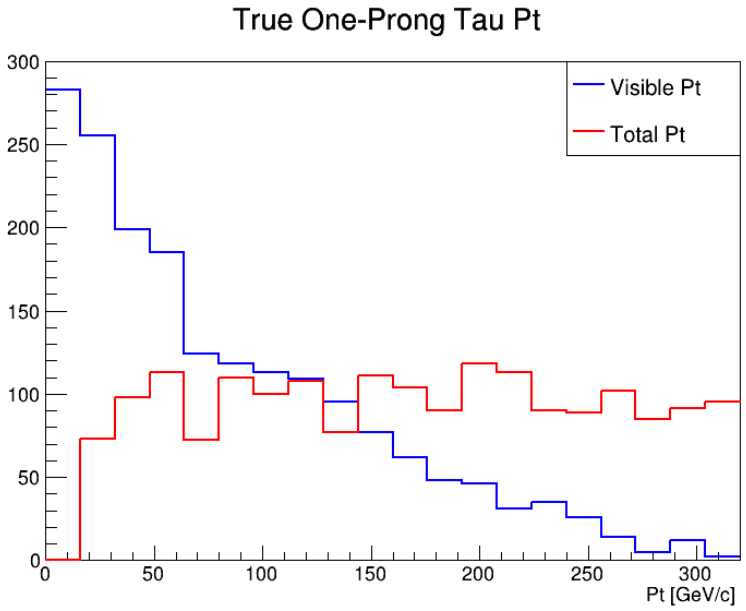
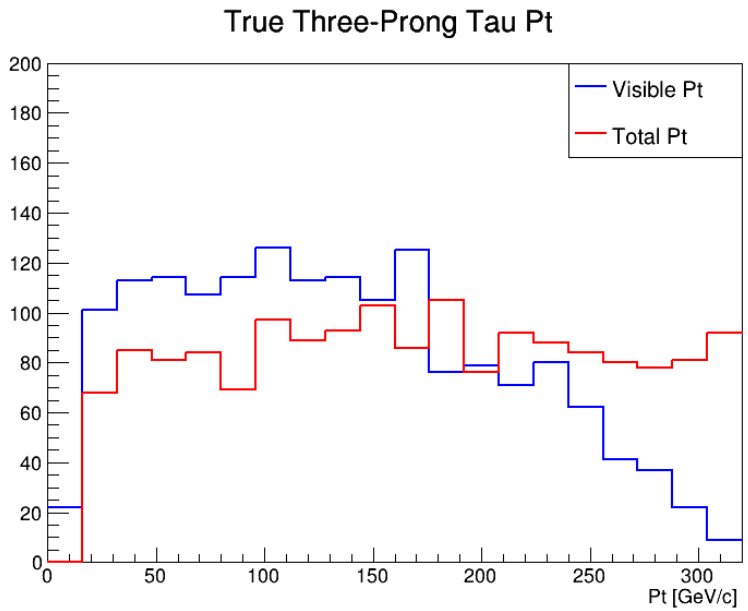
Generated Tau Events

- Generated $15{,}000\ \tau^-$ events in LCIO file with Python script
  - 1 τ^- per event
- $0 \leq \phi \leq 2\pi$ rad
- $10^\circ \leq \theta \leq 170^\circ$
- $20 \leq pT \leq 320$ GeV/c

Simulated Tau Events

- Taus simulated in MAIA detector with ddsim from Fermilab 2024 tutorial
- 1-prong (0 neutrals) decays make up ~12.29% of simulated decay modes
- 3-prong (0 neutrals) decays make up ~10.89% of simulated decay modes
- Neutrinos appear to be taking away larger fraction of energy from 1-prong taus





Simulated Branching Ratios

Decay Mode	Branching Ratio (%)
$\pi^- \nu_\tau$	12.29
$\pi^- \pi^0 \nu_\tau$	28.40
$\pi^- \pi^0 \pi^0 \nu_\tau$	9.86
$\pi^- \pi^+ \pi^- \nu_\tau$	10.89
$\overline{\nu_e} e^- \nu_\tau$	19.39
$\overline{\nu_\mu} \mu^- \nu_\tau$	19.17

Reconstructing Tau Events

1. Tau decay products reconstructed with ACTS and Pandora
   - Marlin workflow from Fermilab 2024 tutorial
   - Outputs PandoraPFOs collection (reconstructed tau decay products)
2. TauFinder (MarlinReco algorithm) runs on PandoraPFOs
   i. Charged particle seeded as τ candidate based on pT
   ii. Search cone formed around seed
   iii. Charged particles within search cone added to τ candidate, adjusting direction of cone for new combined momentum
   iv. Neutral particles are added to τ candidate in same fashion
   v. Momenta and energies of particles associated to τ candidate are combined into reconstructed τ
   vi. Outputs collection of τ ReconstructedParticles
      - Think of these as τ PFOs that have links to associated τ decay product PFOs

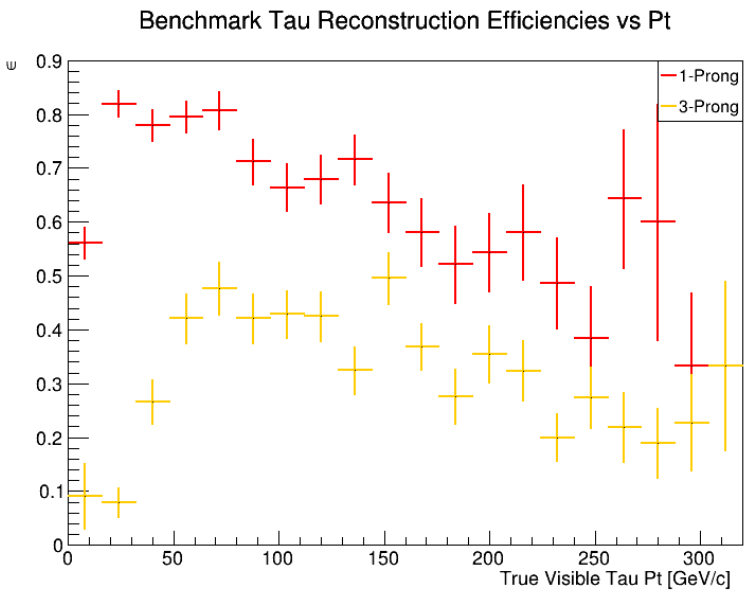
TauFinder Default Selection Cuts

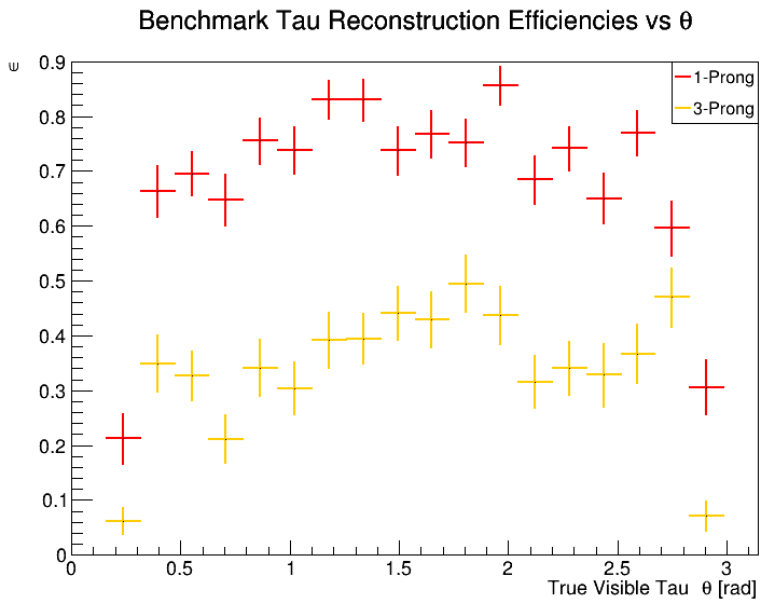
TauFinder Selection Cuts (Sequential)	
Each PandoraPFO (Input Collection) pT	≥ 0.1 GeV/c
Charged Particle Seed pT	≥ 5 GeV/c
Tau Invariant Mass	≤ 2 GeV/c^2
Number of Charged Tracks Associated to Tau	≤ 4 & > 0
Number of Particles Associated to Tau	≤ 10
Tau Isolation Energy	≤ 5 GeV
TauFinder Cone Angles	
Search Cone Angle	0.05 rad
Isolation Cone Angle	0.2 rad

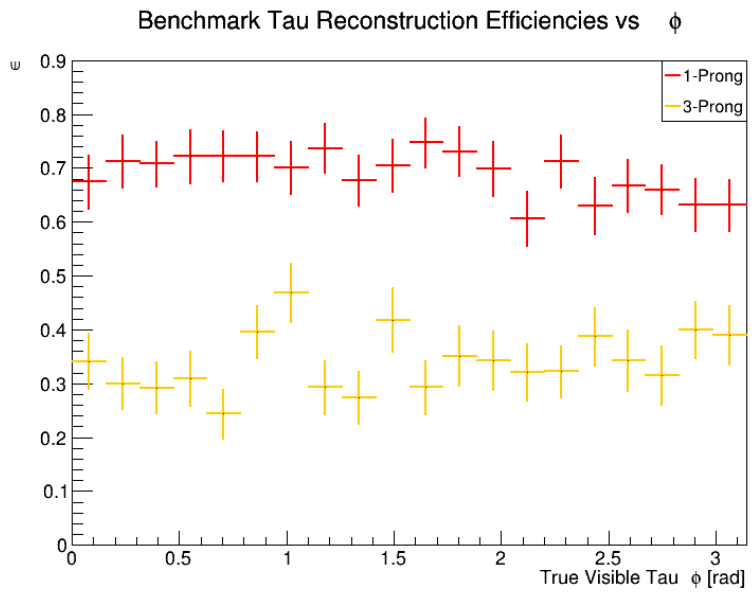
- Values obtained from Lorenzo Valla
  - Studied for 3 TeV MuCol_v1 geometry

Benchmark Reconstruction Performance

$$\epsilon = \frac{Number\ of\ 1P\ (3P) Reco\ \tau\ Matched\ with\ 1P\ (3P)\ MC\ \tau}{Total\ Number\ of\ 1P\ (3P)\ MC\ \tau}$$

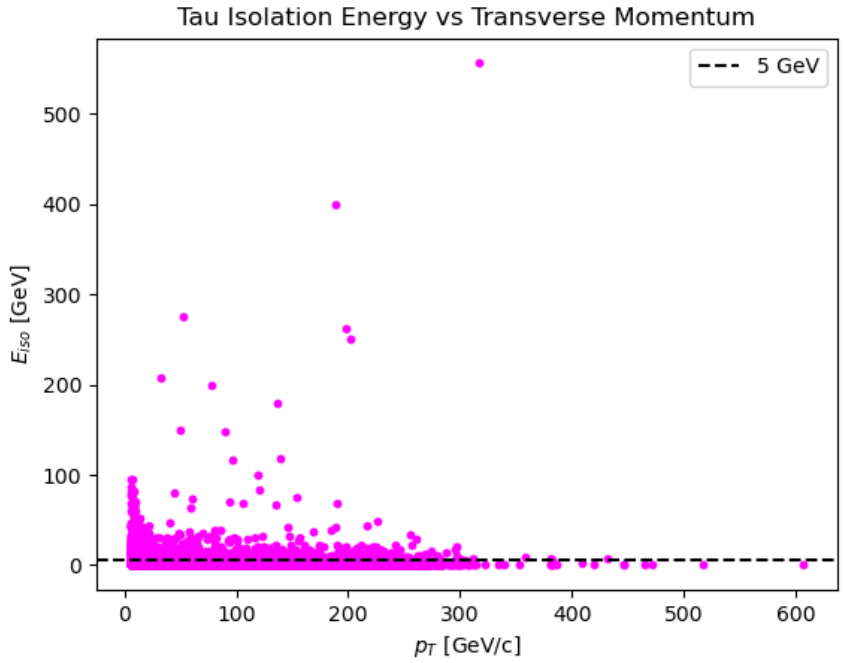


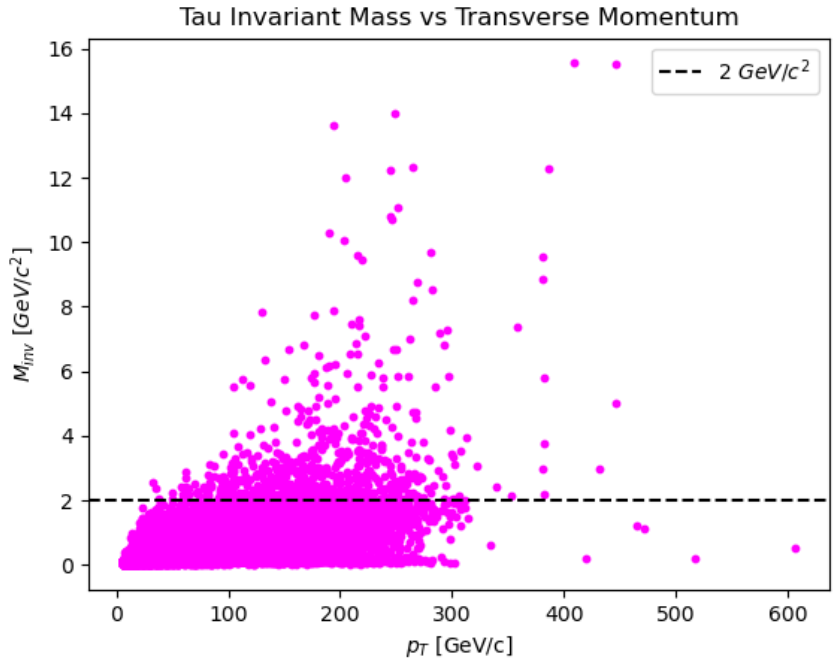




- Average 1-prong reconstruction efficiency appears to be at ~70%
- Losing efficiency at low (< 30 GeV/c) and high (> 100 GeV/c) Pts
- Average 3-prong reconstruction efficiency appears to be at ~35%
- Losing efficiency at low (< 50 GeV/c) and high (> 150 GeV/c) Pts

Investigation of TauFinder Selection Criteria



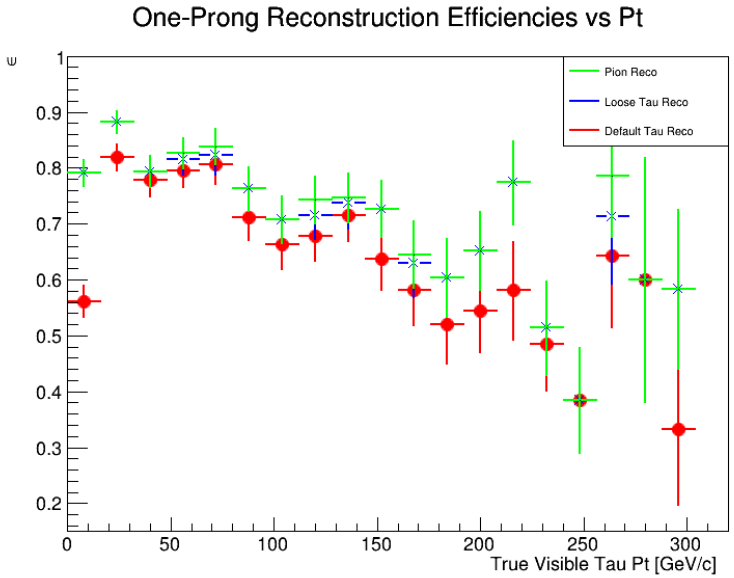


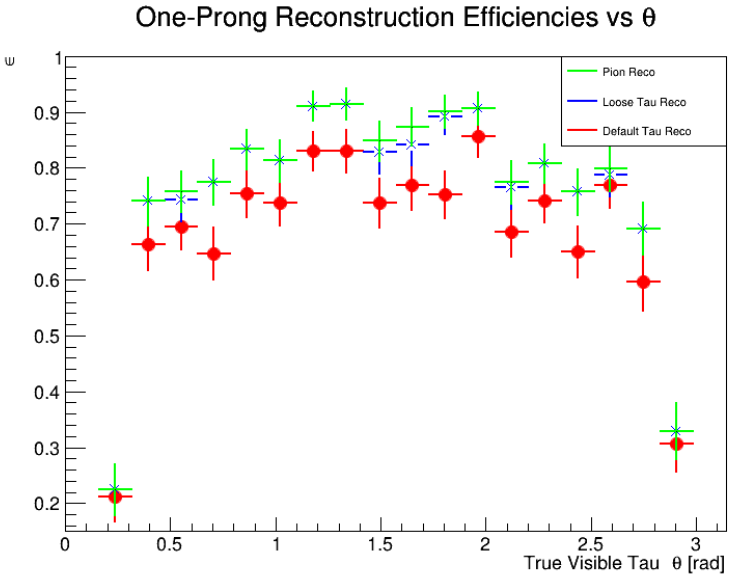
- Tau isolation energy threshold set at 5 GeV
  - Losing ~12% of taus (mostly those with low pT)
  - Planning to set a pT dependent isolation energy threshold
- Tau invariant mass threshold set at 2 GeV/c^2
  - Losing ~5% of taus (mostly those with high pT)
  - Planning to get rid of invariant mass selection cut all together

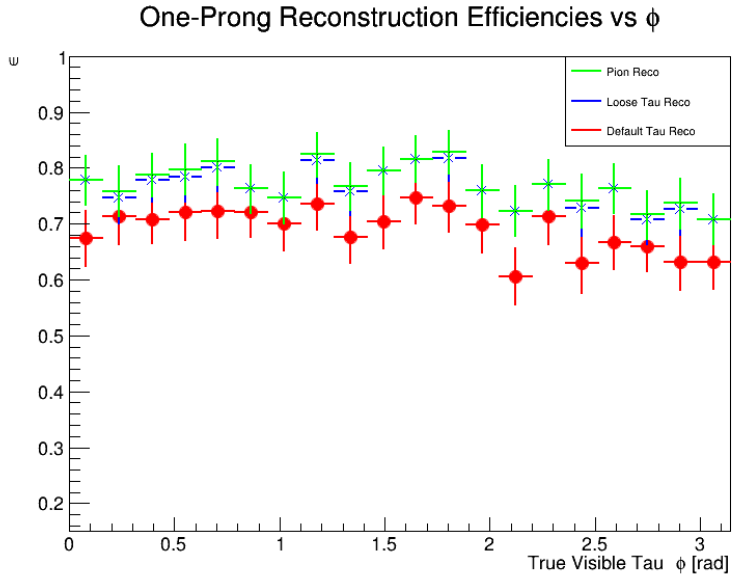
One-Prong Reconstruction Performance

$$\epsilon_\tau = \frac{Number\ of\ 1P\ Reco\ \tau\ Matched\ with\ 1P\ MC\ \tau}{Total\ Number\ of\ 1P\ MC\ \tau}$$

$$\epsilon_{\pi^\pm} = \frac{Number\ of\ Reco\ \pi^\pm\ Matched\ with\ MC\ \pi^\pm}{Total\ Number\ of\ MC\ \pi^\pm}$$





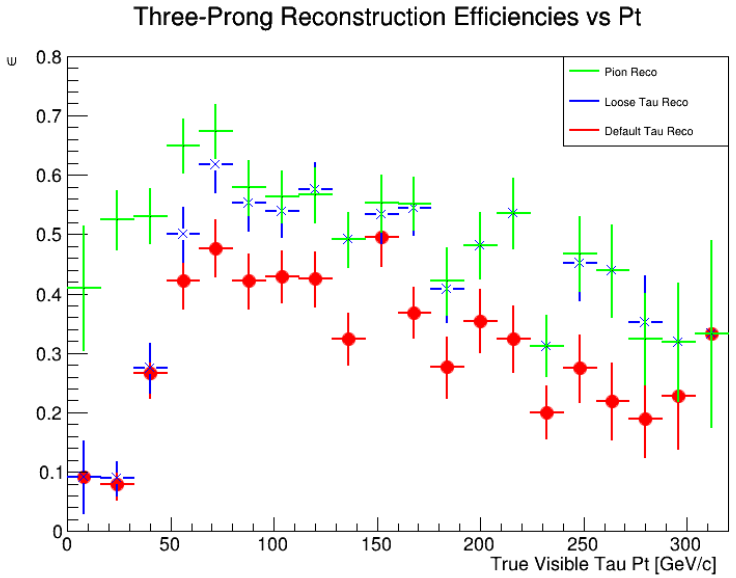


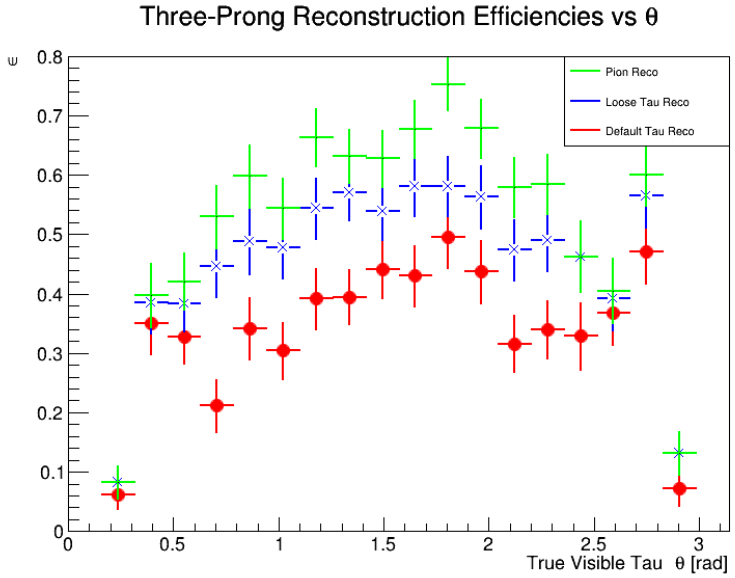
- Loosened tau isolation energy and invariant mass cuts such that they are negligible
  - Boosted 1-prong efficiency by ~5% on average
  - At the level of pion reconstruction efficiency
- Drop in 1-prong efficiency at large Pt due to pion reconstruction efficiency

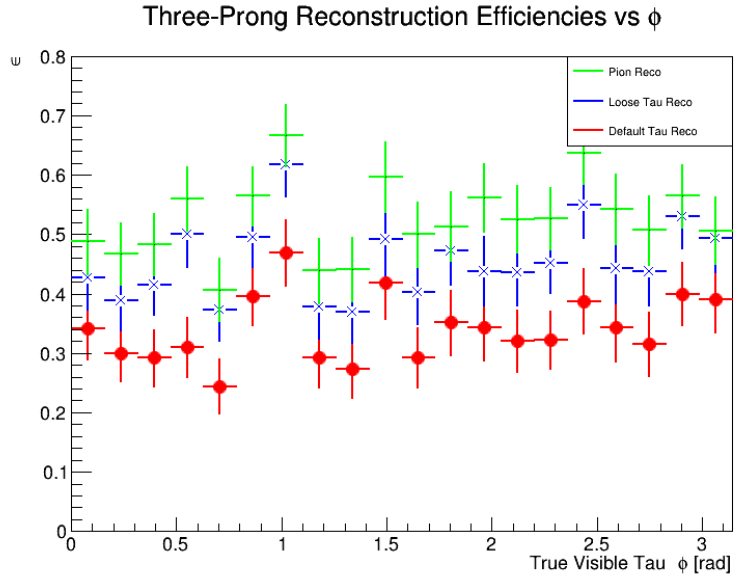
Three-Prong Reconstruction Performance

$$\epsilon_\tau = \frac{Number\ of\ 1P\ Reco\ \tau\ Matched\ with\ 1P\ MC\ \tau}{Total\ Number\ of\ 1P\ MC\ \tau}$$

$$\epsilon_{\pi^\pm} = \frac{Number\ of\ Reco\ \pi^\pm\ Matched\ with\ MC\ \pi^\pm}{Total\ Number\ of\ MC\ \pi^\pm}$$







- Loosened tau isolation energy and invariant mass cuts such that they are negligible
  - Boosted 3-prong efficiency by ~10% on average
  - At the level of pion reconstruction efficiency for high Pt
- Improvement of 3-prong efficiency to be made at low Pt
  - Need to study effect of widening search cone angle
  - Could be reconstructing three 1-prong taus instead of one 3-prong tau

Conclusions

- 1-prong tau reconstruction is at the level of pion reconstruction
  - Currently achieving ~75% reconstruction efficiency on average
  - Next step is to overlay BIB
- 3-prong tau reconstruction needs to be studied further
  - Currently achieving ~35% reconstruction efficiency on average
  - At the level of pion reconstruction for high Pt
  - Extremely low reconstruction efficiency at low Pt
    - Next steps are to study effect of widening search cone angle and to check if tau candidates are being split