Introducing New Decay Modes & Electron Rejection in TauFinder

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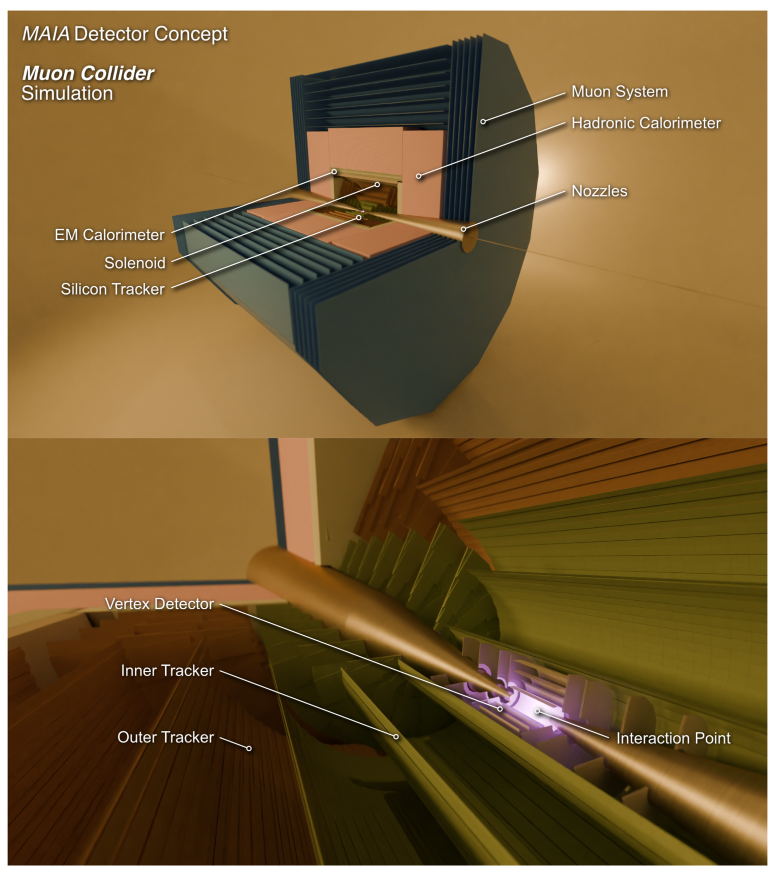
The MAIA Detector Concept

- **Designed for 10 TeV muon collider environment**
- Mitigates intense beam-induced backgrounds (BIB)
- **95% reconstruction efficiency with full BIB overlay** (central region)
- High-resolution, all-silicon tracking system
- **Supports precision Higgs and new physics searches**



Maia Detector Illustration [1]

τ^- Generation & Simulation

Generation:

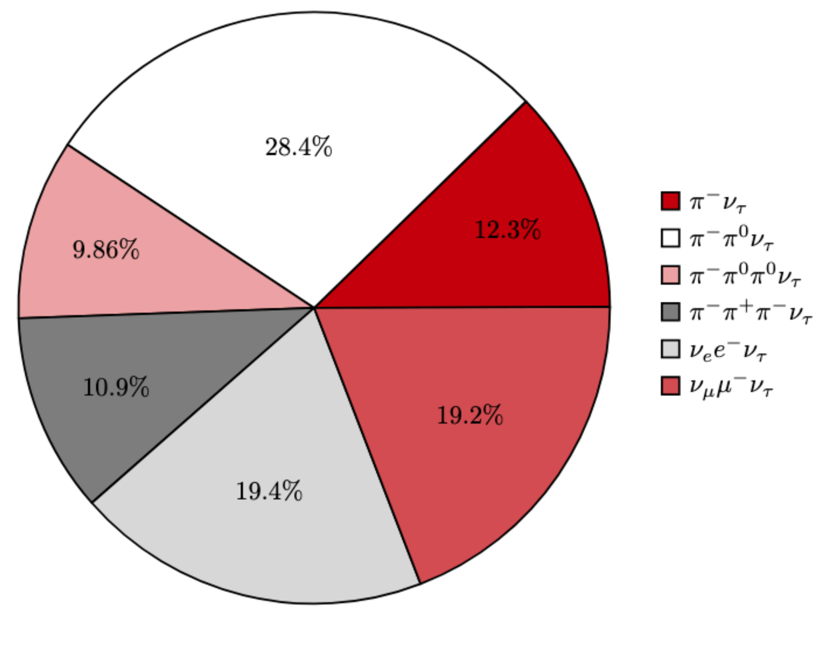
- 15,000 single τ^- MCParticle Events written to LCIO file

Simulation:

- Simulated τ^- MCParticle decays and interactions with MAIA detector in GEANT4

MC τ^- Parameters
$0 \leq \phi \leq 2\pi$ [rad]
$10^\circ \leq \theta \leq 170^\circ$
$20 \leq p_T \leq 320$ [GeV/c]

MC τ^- parameters set in LCIO event generation randomly and uniformly



Simulated branching ratios for the τ^-, note that two rarer decay modes are not simulated

τ^- Hadronic Decay Reconstruction

- τ^-s decay hadronically ~65% of the time
  - $\langle\tau\rangle \approx 10^{-13}$ s, doesn't reach the detector
  - Visible components are primarily charged ($\pi^\pm$) and neutral (π^0s) pions
  - **~60% of these τ^-s have π^0s**
- **TauFinder reconstructs τ^-s via decay products:**
  - Decay products are reconstructed by ACTS and PandoraPFA as particle flow objects (PFOs)
    - Doesn't reconstruct π^0, reconstructed γ-rays act as pseudo-π^0
  - TauFinder associates PFOs to a τ^- candidate
  - Selection cuts retain only high quality τ^-s

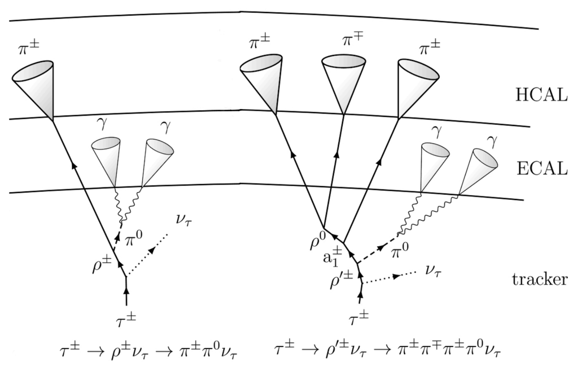


Illustration of 1-Prong and 3-Prong Hadronic τ^- Decays With π^0s [2]

Default TauFinder Selection Cuts
τ^- $M_{inv} < 2$ GeV/c2
0 < Charged Tracks Associated to τ^- < 4
Particles Associated to τ^- < 10
τ^- E_{iso} < 5 GeV

Default TauFinder selection criteria. All accepted reconstructed τ^- Pass these thresholds.

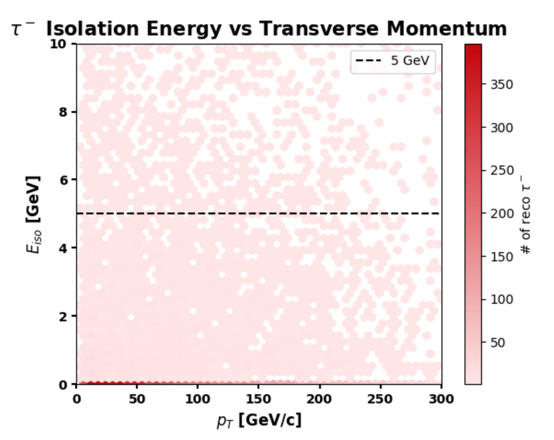
Default τ^- Reconstruction

Losing large portion of reconstructed τ^- with default selection criteria:

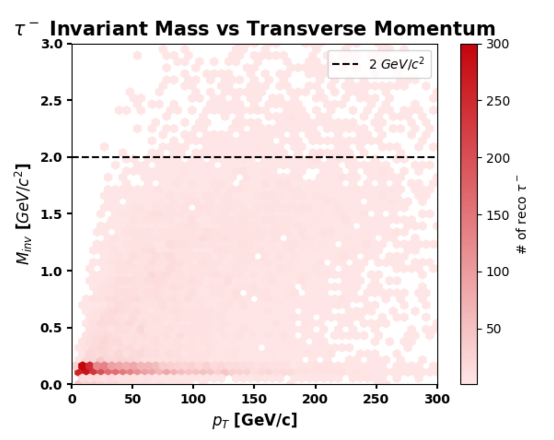
- Maximum isolation energy (E_{iso}) criteria on the τ^- candidates cuts ~14%
- Maximum invariant mass (M_{inv}) criteria on the τ^- candidates cuts ~ 10%

At low p_T the default cone size (0.05 rad) has high fake rate and cuts too many $\pi^\pm$

- **Suggests the need for a shrinking p_T dependent cone**



Reconstructed τ^- E_{iso} vs. reconstructed τ^- p_T, the dotted line represents default cuts.



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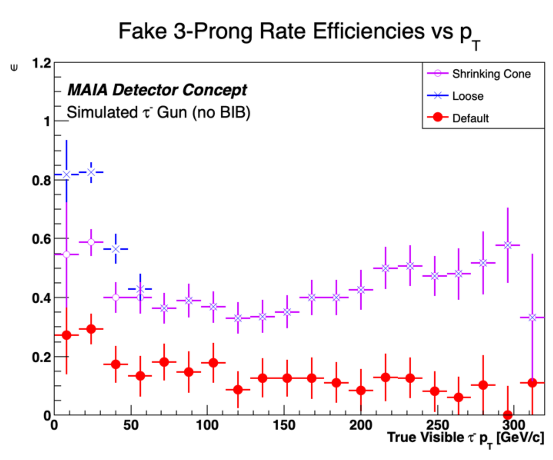


Fake rate of reconstructed 3-Prong τ^- vs. true 3-Prong τ^- p_T.

τ^- Reconstruction Efficiencies

$$\text{Signal Cone Angle} = \begin{cases} 0.3 & p_T \leq 10 \\ \frac{3}{p_T} & 10 < p_T < 60 \\ 0.05 & p_T \geq 60 \end{cases}$$

$$\epsilon_\tau = \frac{\text{\# of Reco 1P + Ns } \tau \text{ Matched to MC 1P + Ns } \tau}{\text{\# of 1P + Ns MC } \tau}$$

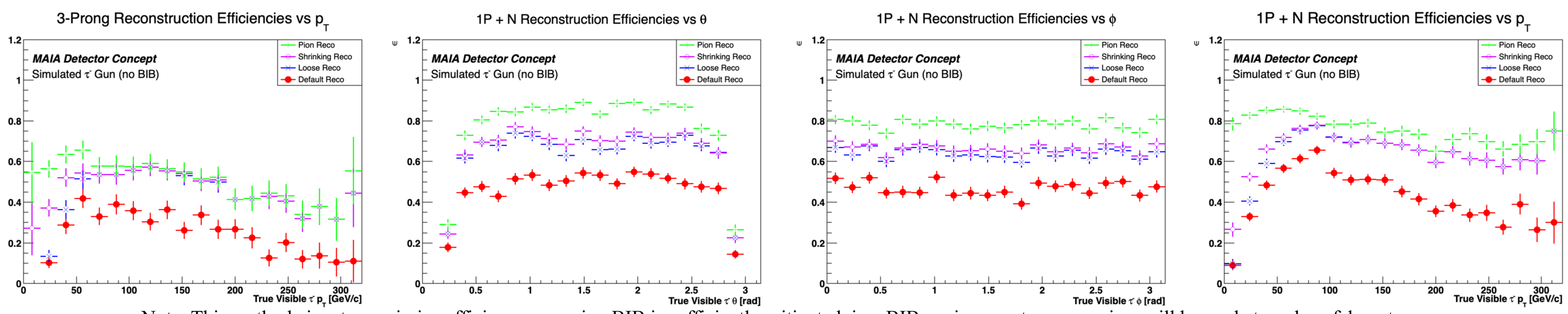
$$\epsilon_{\pi^\pm} = \frac{\text{\# of Events With 1 Reco } \pi^\pm \text{ Matched to Unique MC } \pi^\pm}{\text{\# of Events With 1 MC } \pi^\pm}$$

Loose cuts on E_{iso} and M_{inv}:

- **Boosts 1-Prong + π^0s efficiency by ~15%**

Shrinking cone:

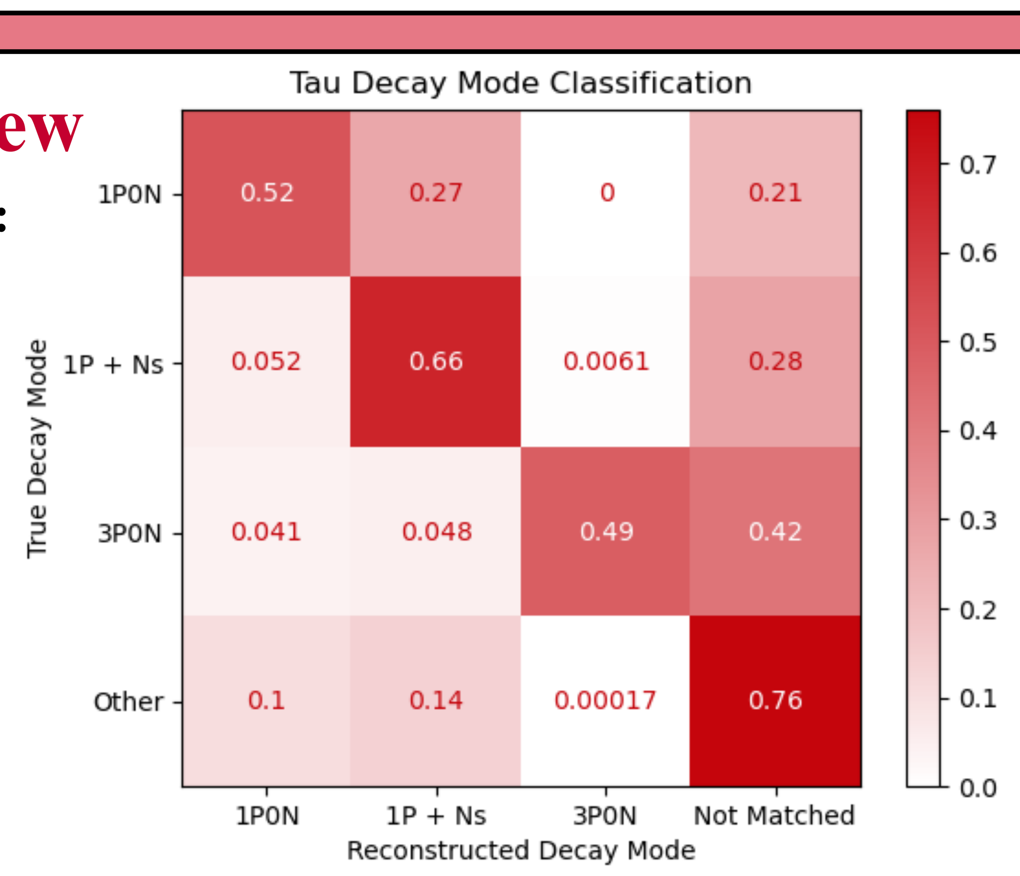
- Added to the loose cuts
- **Boosts low p_T (< 50) efficiencies by ~20%**
- **Creates ~1000 new τ^- candidates**
- **Reduces low p_T fake rate by ~20%**



Note: This method aims to maximize efficiency assuming BIB is sufficiently mitigated, in a BIB environment compromises will be made to reduce fake rate.

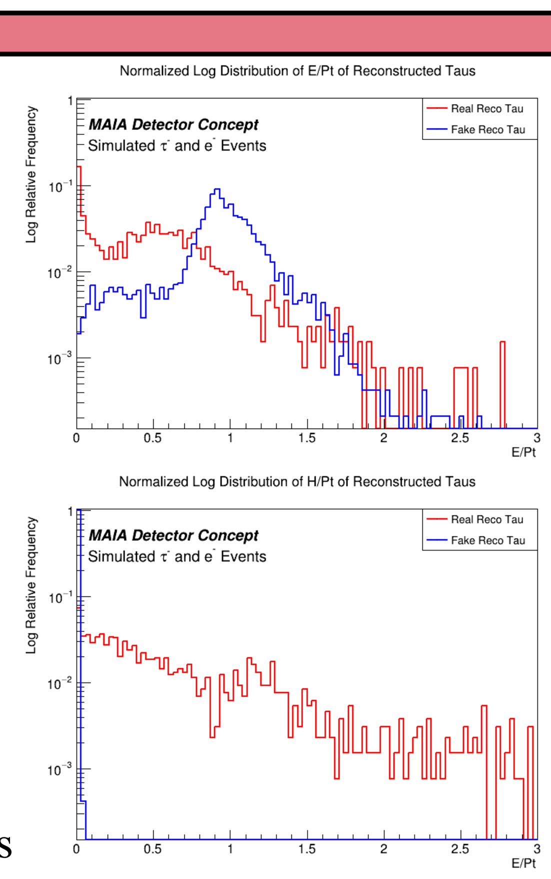
Confusion Matrix View

- **1-Prongs are confused often:**
  - $\pi^\pm$ and e⁻ confusion is a significant factor
  - Low p_T γ-rays lead to 1-Prong + π^0s confusion
- **1-Prong + π^0s have the best classification rate**
- $\pi^\pm$ reconstruction acts as an upper limit



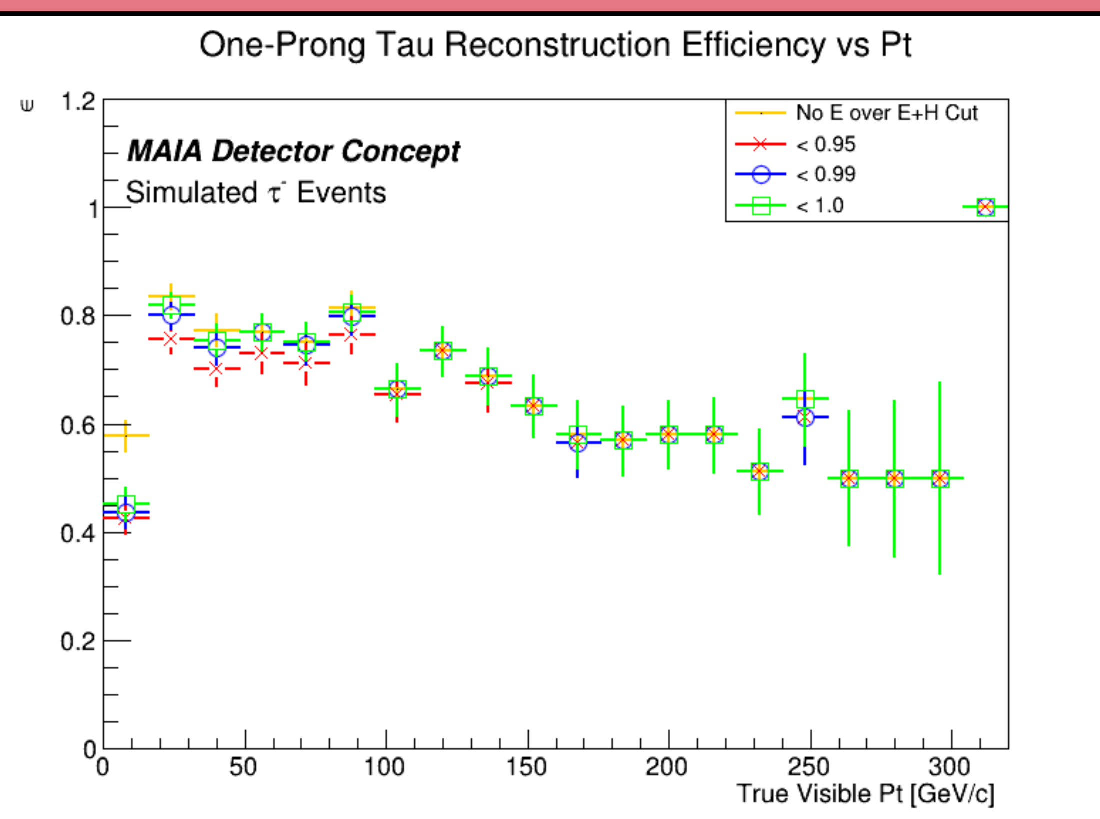
e^- Faking τ^-

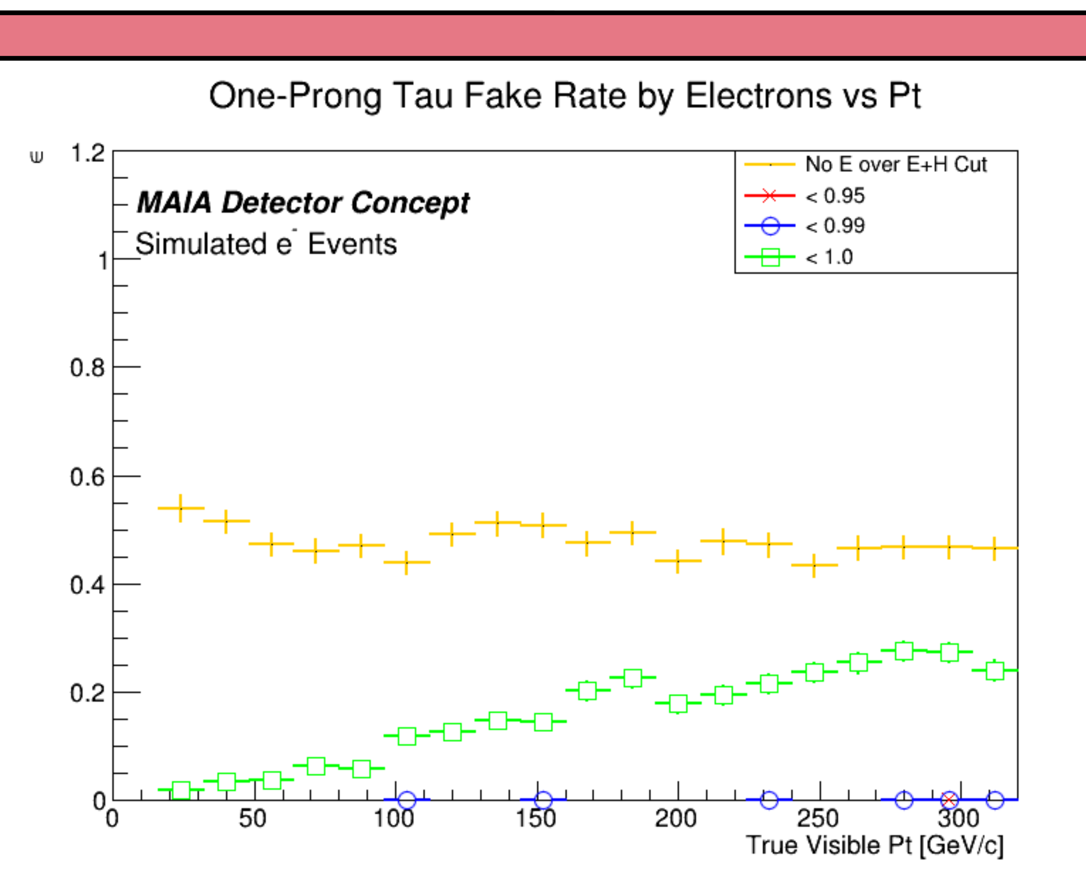
- **Generation, Simulation, and Reconstruction:**
  - 10,000 single e^- MCParticle Events with same parameters as generated τ^-
  - Simulated and reconstructed in same fashion as τ^- utilizing default TauFinder
- **Propose a cut on ECal and HCal energy:**
  - e^-s deposit almost no energy in HCal
  - Use the difference in τ^- vs e^- ECal (E) and HCal (H) energies to catch e^-s
  - Used E/(E+H) ratio as cut
  - Benchmarks derived from E/Pt and H/Pt distributions



e^- Rejection Results

- **e^-s fake $\pi^\pm$s ~50% of time:**
  - Fake $\pi^\pm$s get reconstructed as τ^-
  - Majority fake 1-Prong decay
- E/(E+H) cut decreases τ^- reconstruction efficiency but is highly effective at catching e^-s
  - The < 0.99 cut catches nearly all e^-s





Sources

[1] Bell, Charles, et al. "*MAIA: A new detector concept for a 10 TeV muon collider.*" (2025)
[2] Neutelings, Izaak. *"Hadronic tau decay."* TikZ.net, (2017)

Next Steps

- Simulate rare π^0 decay modes
- **Improve $\pi^\pm$ reconstruction efficiency**
- Introduce BIB
  - Fine-tune on the fake rate
- Integrate work with Yale and LIP Groups
- **Optimize e^- rejection for τ^- efficiency and prevent e^- faking**