Optimizing TauFinder For The MAIA Detector Concept

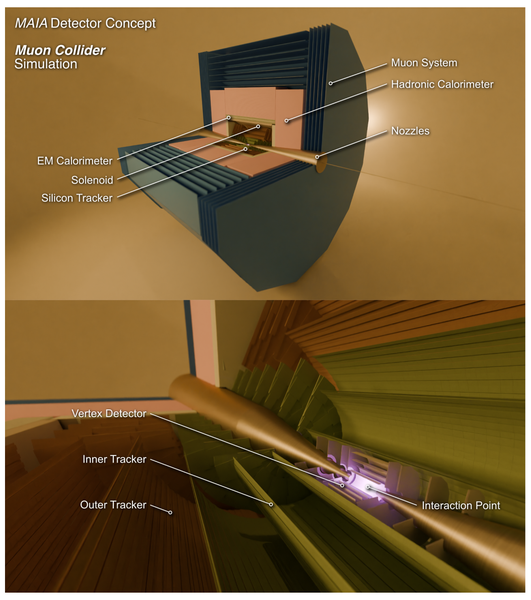
Cyrus Kianian, Moses Glassman, Abdollah Mohammadi, Sridhara Dasu

WISCONSIN UNIVERSITY OF WISCONSIN-MADISON

International MUON Collider Collaboration

The MAIA Detector Concept

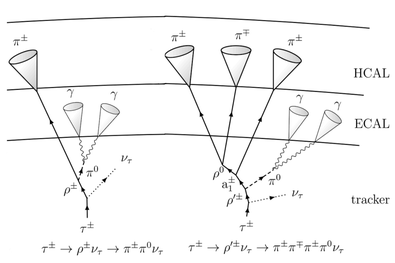
- **Designed for 10 TeV muon collider environment**
- Mitigates intense beam-induced backgrounds (BIB)
- **95% reconstruction efficiency with full BIB overlay** (central region)
- High-resolution, all-silicon tracking system
- **Supports precision Higgs and new physics searches**



Maia Detector Illustration [1]

τ^- 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 act as pseudo-π^0
  - TauFinder associates PFOs to a τ^- candidate
  - Selection cuts retain only high quality τ^-s



$\tau^{\pm} \to \rho^{\pm}\nu_\tau \to \pi^{\pm}\pi^0\nu_\tau$ $\quad$ $\tau^{\pm} \to \rho'^{\pm}\nu_\tau \to \pi^{\pm}\pi^{\mp}\pi^{\pm}\pi^0\nu_\tau$

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

Default TauFinder Selection Cuts
τ^- $M_{inv} < 2$ GeV/c_2
0 < Charged Tracks Associated to τ^- <
Particles Associated to τ^- < 10
τ^- E_{iso} < 5 GeV

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

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
$0 \le \phi \le 2\pi$ [rad]
$10^{\circ} \le \theta \le 170^{\circ}$
$20 \le p_T \le 320$ [GeV/c]

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

Decay Mode	Sim. Br. Ratios (%)	True Br. Ratios (%)
$\pi^- \nu_\tau$	12.3	10.8
$\pi^- \pi^0 \nu_\tau$	28.4	25.5
$\pi^- \pi^0 \pi^0 \nu^\tau$	9.86	9.26
$\pi^- \pi^0 \pi^0 \pi^0 \nu^\tau$	0.0	1.04
$\pi^- \pi^+ \pi^- \nu^\tau$	10.9	8.99
$\pi^- \pi^+ \pi^- \pi^0 \nu^\tau$	0.0	2.74
$\nu_e e^- \nu_\tau$	19.4	17.8
$\nu_\mu \mu^- \nu_\tau$	19.2	17.4

Simulated and true branching ratios for the τ^-

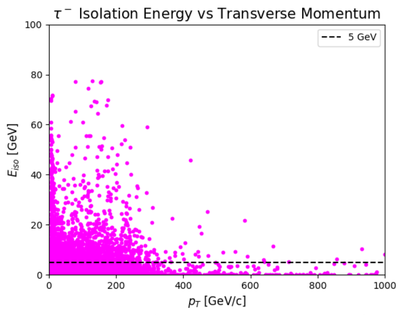
Default τ^- Reconstruction

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

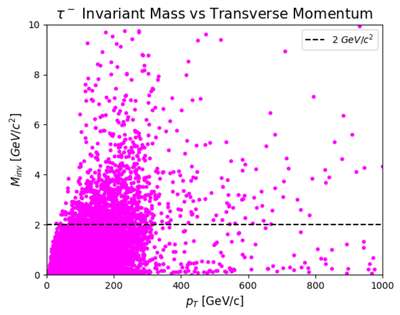
- Maximum isolation energy (E_{iso}) criteria on the τ^- candidates cuts ~14%
- Maximum invariant mass (M_{inv}) criteria on the τ^- candidates cuts ~ 10%

The default cone size (0.05 rad) cuts too many $\pi^{\pm}$ at low p_T

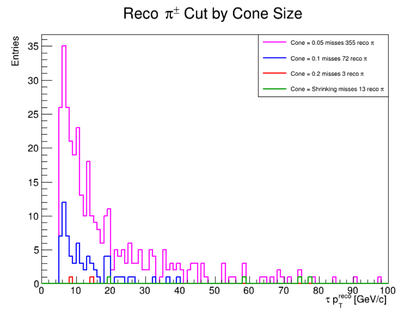
- **Suggests the need for a shrinking p_T dependent cone**



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



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



# of reconstructed $\pi^{\pm}$ cut by different search cone angles vs. reconstructed τ^- p_T.

τ^- Reconstruction Efficiencies

$$\text{Search Cone Angle} = \begin{cases} 0.6 & p_T \le 10 \\ \frac{6}{p_T} & 10 < p_T < 120 \\ 0.05 & p_T \ge 120 \end{cases}$$

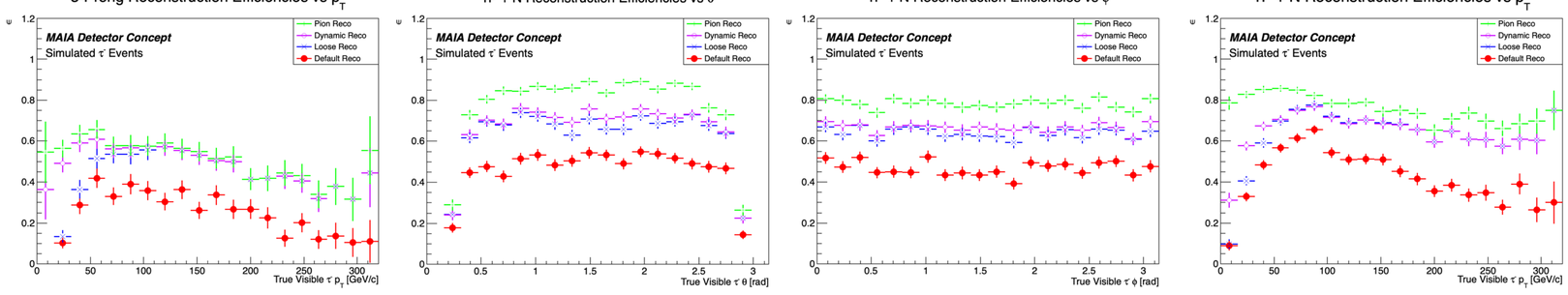
$$\epsilon_\tau = \frac{\#\text{ of Reco 1P + N } \tau \text{ Linked With MC 1P + N } \tau}{\text{MC 1P + N } \tau} \qquad \epsilon_{\pi^{\pm}} = \frac{\#\text{ of Events With 1 Reco } \pi^{\pm} \text{ Linked With Unique MC } \pi^{\pm}}{\#\text{ of Events With 1 MC } \pi^{\pm}}$$

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 ~40%**



Note: These plots aim to maximize efficiency assuming BIB is sufficiently mitigated, in a BIB environment compromises will be made to reduce fake rate.

Confusion Matrix View

Electron Intro (Moses)

Electron Results (Moses)

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**
- Moses next steps or other points