Initial Studies on TauFinder for the 10 TeV MAIA Detector Concept

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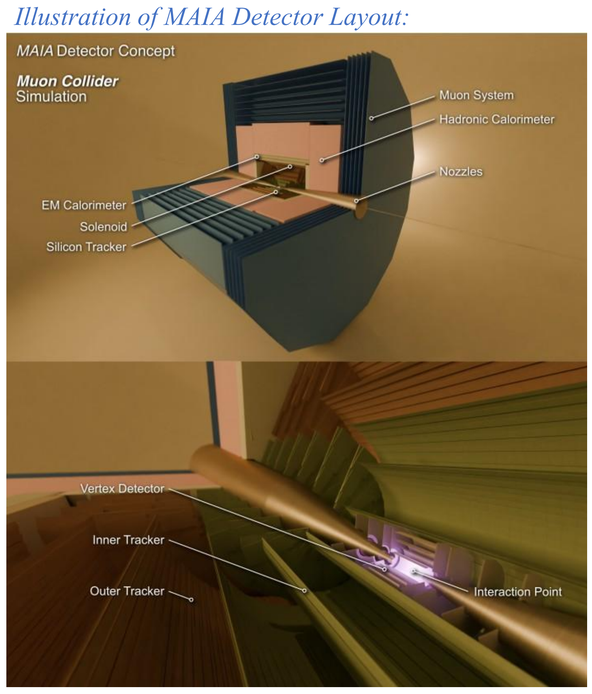
MAIA Detector Concept

- Designed for $\sqrt{s}$ = **10 TeV $\mu^+\mu^-$ collisions**
- **Shielding nozzles** (tungsten and borated polyethylene) to reduce flux of BIB in detector
  - Extends out to $\theta = 10°$ w.r.t. beam axis on both sides
- **Vertex, inner, and outer trackers** (silicon) to reconstruct charged particle trajectories
- **Solenoidal magnetic field**
  - 5 T
  - ~ 265 mm of aluminum layers in front of calorimeters
- **ECAL** (silicon and tungsten) to reconstruct energies of photons and electrons
- **HCAL** (steel-scintillator) to reconstruct energies of charged and neutral hadrons
- **Muon detector system** (air-RPC) to reconstruct straight track segments of muons

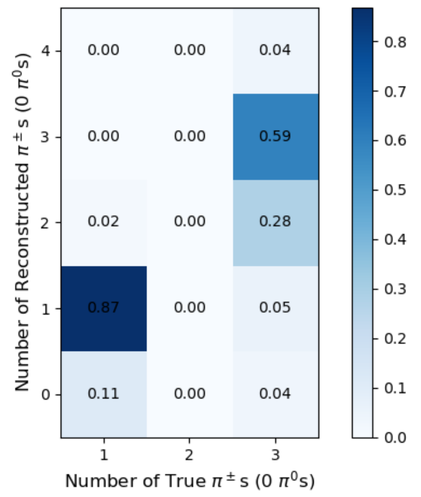
Illustration of MAIA Detector Layout:



Bell, C. et al., *MAIA: A new detector concept for a 10 TeV muon collider*, (2025)

Charged Pion Reconstruction

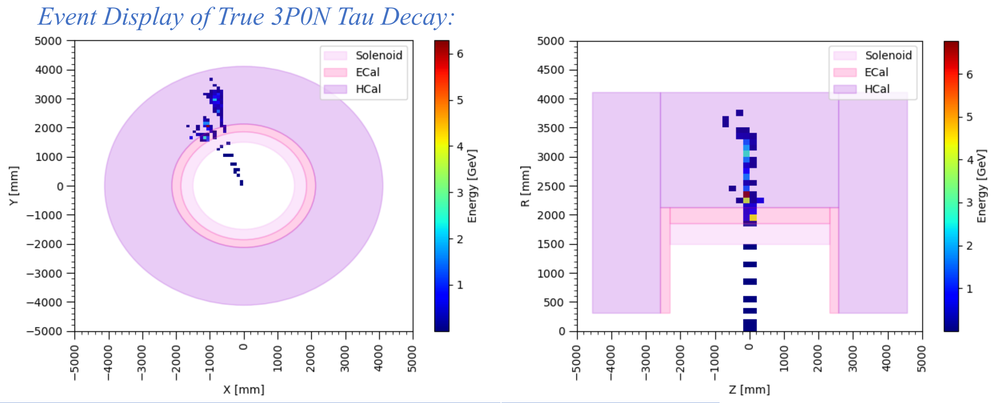
- Charged pions reconstructed as particle flow objects (**PFOs**) using the Pandora Particle Flow Algorithm (**PandoraPFA**)
- Charged pions are resulting charged PFOs which **fail built-in PandoraPFA electron-ID**
- PandoraPFA optimized for charged pion reconstruction by running the following:
  - Track and hit selection
  - Fast photon ID
  - Cone clustering
  - Topological cluster merging
  - Reclustering according to track-cluster consistency
  - PFO identification
- **Single charged pion reconstruction efficiency at 87%** with duplicate rate of 2%



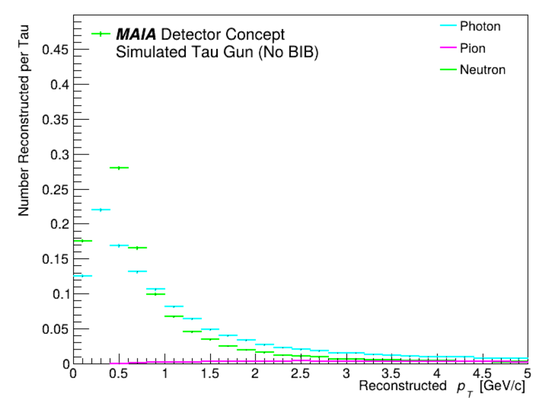
Tau Lepton Reconstruction

- A critical **tool for analyzing the production of Higgs and electroweak bosons**
- Taus reconstructed through decay products
  - **Decay before reaching detectors**
  - Mean lifetime of ~$2.9 \times 10^{-7} \mu$s
- Predominantly **decay hadronically** (~65%)
  - **Visible components** include mostly charged ($\pi^\pm$) and neutral (π^0) **pions**
  - Primarily **1-prong** (1 $\pi^\pm$) and **3-prong** (3 $\pi^\pm$) with between 0 and 2 π^0s
- Taus reconstructed with **TauFinder algorithm on decay product PFOs** by combining them inside shrinking signal cone
  - Current selection cuts designed to maximize acceptance of tau signal
  - Studies on background ongoing

Event Display of True 3P0N Tau Decay:

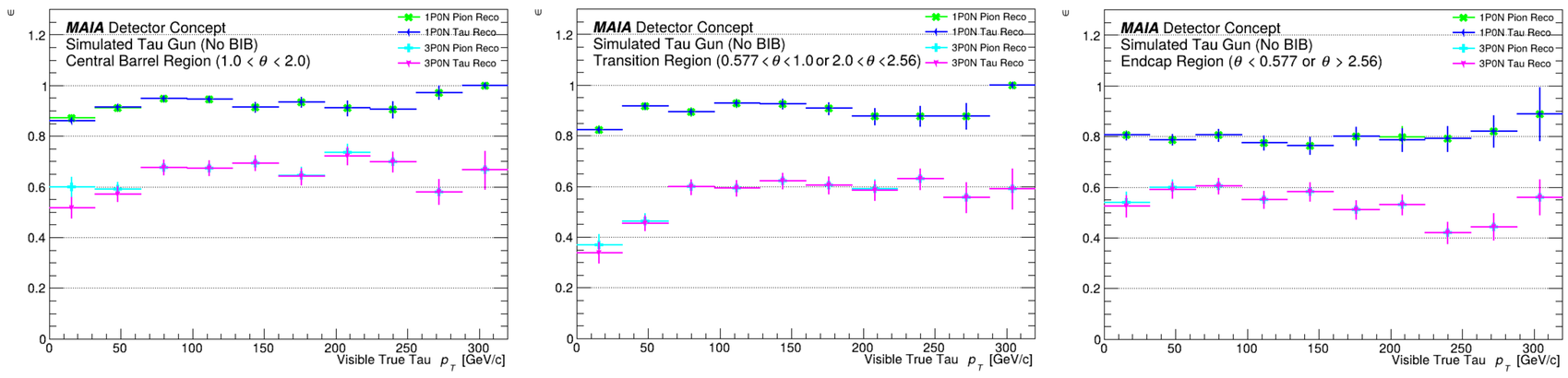


TauFinder Selection Cut	Threshold
p_T of PFOs Inside Signal Cone	> 1 GeV/c
Type of PFOs Inside Signal Cone	Reject Neutrons
Tau Invariant Mass (M_{inv})	< 10 GeV/c^2
# of Charged Tracks Inside Signal Cone	1 or 3
# of Particles Inside Signal Cone	< 10



- Majority of **low p_T PFOs** inside signal cone are **photons and neutrons**
  - Cutting at 1 GeV/c removes a large fraction of these objects
  - Lose a negligible fraction of charged pions
- **Neutrons are not a product of tau decays** and can be ignored
  - Greatly reduces number of PFOs inside signal cone
- Only save reconstructed taus with 1 or 3 tracks for analysis

1P0N and 3P0N Reconstruction Efficiencies

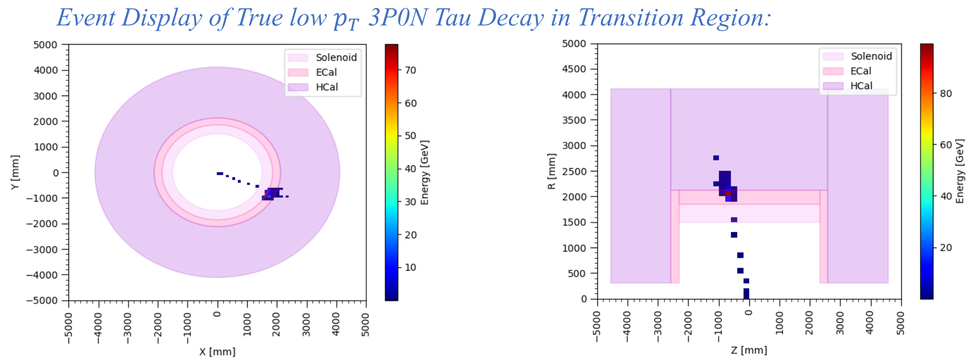


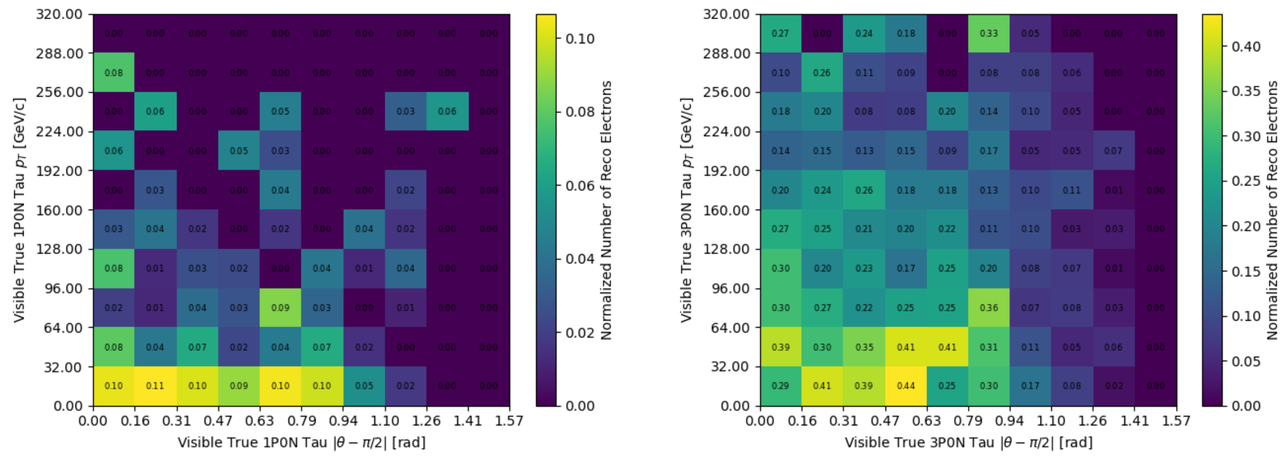
$$\epsilon_{xP0N\ \tau^\pm} = \frac{\#\ of\ Events\ with\ Matched\ Reco\ xP0N\ \tau^\pm}{Total\ \#\ of\ Events\ with\ True\ xP0N\ \tau^\pm}$$

$$\epsilon_{xP0N\ \pi^\pm} = \frac{\#\ of\ Events\ with\ x\ Matched\ Reco\ \pi^\pm s}{Total\ \#\ of\ Events\ with\ x\ True\ \pi^\pm s}$$

- **$\pi^\pm$ reconstruction efficiency gives upper limit** for $\tau^\pm$ reconstruction
- $\tau^\pm$ reconstruction optimized (without BIB) for **1P0N and 3P0N at ~87% and ~59%**
- Drop in 3P0N efficiencies at high p_T due to **overlapping tracks**
- Drop in 3P0N efficiencies at low p_T in transition region due to **mis-ID of $\pi^\pm$s as $e^\pm$s**

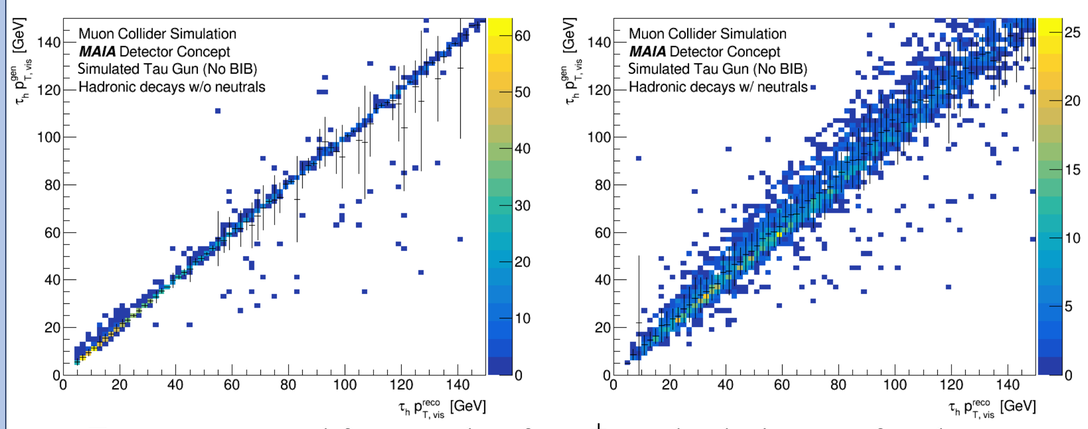
Event Display of True low p_T 3P0N Tau Decay in Transition Region:





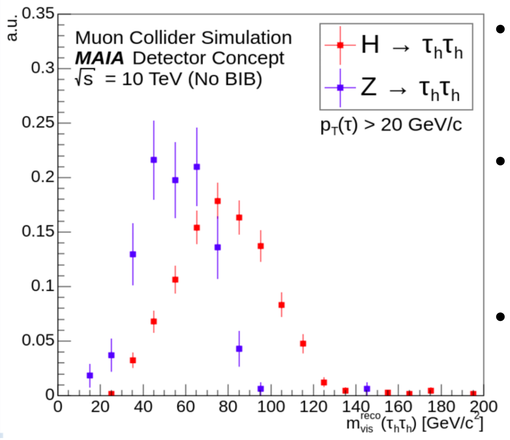
- Higher rate of $\pi^\pm$s reconstructed as $e^\pm$s for both 1P0N and 3P0N in the low p_T transition region ($0 < p_T < 64$ GeV/c, $0.57 < \left|\theta - \frac{\pi}{2}\right| < 0.99$ rad)
  - Particularly affects 3P0N decays due to higher rate of low p_T $\pi^\pm$s
- **Pandora's $e^\pm$ ID algorithm not designed for MAIA detector**
  - $e^\pm$ shower profile depends on θ in MAIA detector due to presence of solenoid
  - Pandora does not account for a solenoid upstream of calorimeters
- Expected to improve with better particle flow algorithm

Tau Energy Resolution



- Energy measured from tracker for $\pi^\pm$s and calorimeters for photons originating from π^0s

Reconstructed Higgs and Z Mass



- 10k $\mu^+\mu^- \rightarrow Z/H\nu_\mu\bar{\nu}_\mu \rightarrow \tau^+\tau^-\nu_\mu\bar{\nu}_\mu$ events generated with MadGraph5 at $\sqrt{s} = 10$ TeV
- Invariant mass reconstructed with visible components of τ_h decays
  - All hadronic decay modes considered
- Shows promise for Higgs/Z discrimination with further optimization

Next Steps

- Evaluate and optimize TauFinder performance with BIB overlay
- Evaluate and minimize fake rate of TauFinder with BIB and jets
- Improve particle flow algorithm, adapting to MAIA detector geometry