$H \rightarrow \tau^+\tau^-$ CP Violation Analysis for SiD

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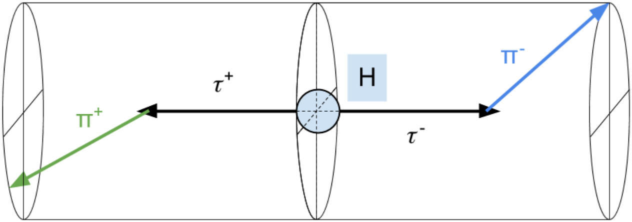
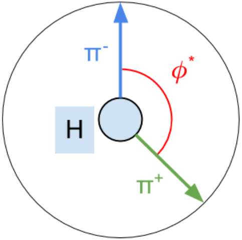
Tau-Based Analysis of Higgs CP Violation - Methodology

- General methodology: extract **polarimeter vector** from analyzing tau decay; find **azimuthal angle** between τ^+ and τ^- polarimeter vectors
- Polarimeter vectors vary with tau decay; $\tau^\pm \to \pi^\pm \nu_\tau$ (below) and $\tau^\pm \to \pi^\pm \pi^0 \nu_\tau$ are the simplest to analyze, but using **higher-multiplicity decays** would allow for **more events** to be used





$$\vec{n}_- \equiv \frac{\vec{q}_{\pi^-} \times \vec{q}_{\tau^-}}{|\vec{q}_{\pi^-} \times \vec{q}_{\tau^-}|} \qquad \vec{n}_+ \equiv \frac{\vec{q}_{\pi^+} \times \vec{q}_{\tau^-}}{|\vec{q}_{\pi^+} \times \vec{q}_{\tau^-}|}$$

$$\cos(\phi^*) \equiv \vec{n}_- \cdot \vec{n}_+$$

Input Distributions for Higher-Multiplicity Decay Tagging

- Group all **charged particles** closest to each seed inside and outside of 10° cone around seed
- Pair all photons to reconstruct **neutral pions** (requiring $0.12 < m_{\gamma\gamma} < 0.15$); assign to closest seed
- **Tau-vs-background NN:** 32 inputs
  - Z invariant mass, recoil mass, total event energy, invariant mass of remaining particles after Z daughters removed, Z invariant mass (total 5 inputs)
  - **Angle** between charged seeds
  - Energy and multiplicity of **charged particles** inside and outside of 10° cone for each τ (total 8 inputs)
  - Energy and multiplicity of π^0 and unpaired **photons** for each τ (total 8 inputs)
  - Total **visible invariant mass** of charged particles within 10° cone and all assigned π^0 and photons, as well as for just the charged particles, for each τ (total 4 inputs)
  - For **3-charged-prong decays**, invariant mass of product pair closest to **rho mass**, neutral pion multiplicity, and unpaired photon multiplicity, for each tau (6 inputs)
- **Tau decay separation NN:** 14 inputs
  - Energy and multiplicity of charged particles inside and outside of 10° cone (4 inputs)
  - Energy and multiplicity of π^0 and unpaired photons (total 4 inputs)
  - Total visible invariant mass of charged particles within 10° cone and all assigned π^0 and photons,as well as for just the charged particles (2 inputs)
  - For **3-charged-prong decays**, invariant mass of product pair closest to **rho mass**, neutral pion multiplicity, and unpaired photon multiplicity (3 inputs)
  - Seed is lepton (0) or hadron (1)?
- Preliminary testing using **1 hidden layer** for each NN

Higher-Multiplicity Decay Tagging with Delphes

- Now using signal and 4f background produced with **Delphes** fast simulation
- Strong tagging performance of most usable tau decays, though $\pi^{\pm}\pi^{0}$ and $\pi^{\pm}2\pi^{0}$ are still sometimes confused due to π^{0} reconstruction imperfections
- Note: Percent efficiencies are calculated after minimum multiplicity cuts, which remove **13.82% of signal events and 99.88% of 4f background events**

Tau tagging efficiency

NN tag	Truth event type	
	τ	bkg
τ	99.99	2.87
bkg	0.01	97.13

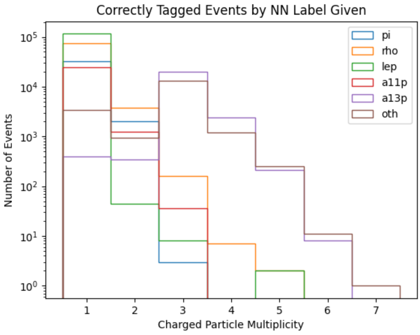
Migration among τ decay paths (%)

NN tag	Truth decay path						
	$\pi^{\pm}$	$\pi^{\pm}\pi^{0}$	ℓ	$\pi^{\pm}2\pi^{0}$	$\pi^{\mp}2\pi^{\pm}$	other	bkg
$\pi^{\pm}$	**94.80**	2.75	0.06	0.22	2.08	4.02	4.27
$\pi^{\pm}\pi^{0}$	3.38	**92.88**	0.12	12.65	2.31	7.07	13.03
ℓ	0.92	0.83	**99.02**	0.58	2.48	6.46	44.44
$\pi^{\pm}2\pi^{0}$	0.02	2.05	0.01	**82.71**	0.15	8.83	4.70
$\pi^{\mp}2\pi^{\pm}$	0.42	0.47	0.25	0.32	**85.49**	10.42	8.76
other	0.47	1.03	0.53	3.53	7.48	**63.20**	24.79

Signal vs 4f Background

Post-Tagging Multiplicity Analysis

- A key next step is to use tagged taus to perform CP violation analysis; this requires **post-tagging analysis of tau decay products** identified by tagging algorithm
- Preliminary analysis of charged and neutral particle multiplicities suggests that **charged decay products** are identified efficiently, but photons may decay to e^+e^-, and extra **low-momentum particles** may end up in tau cone; this is expected, but does require more thorough **post-tagging algorithms**



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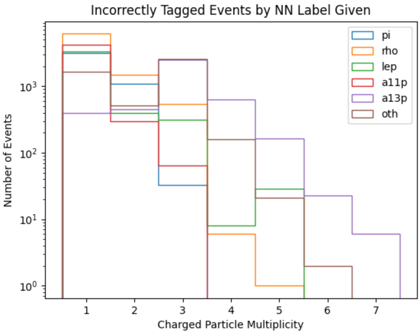

Incorrect Label

Next Steps

- Implement post-tagging **CP violation analysis**: reconstruct polarimeter vectors for each decay path, analyzing **post-tagging multiplicity distributions**
- **Full SiD reconstruction**: will allow for more accurate algorithm performance evaluation and detector studies
- **Full tau reconstruction**: once have basic post-tagging polarimeter reconstruction, can do full tau reconstruction to improve performance