Physics potential for the measurement of the Higgs boson decay to tau leptons at CLIC

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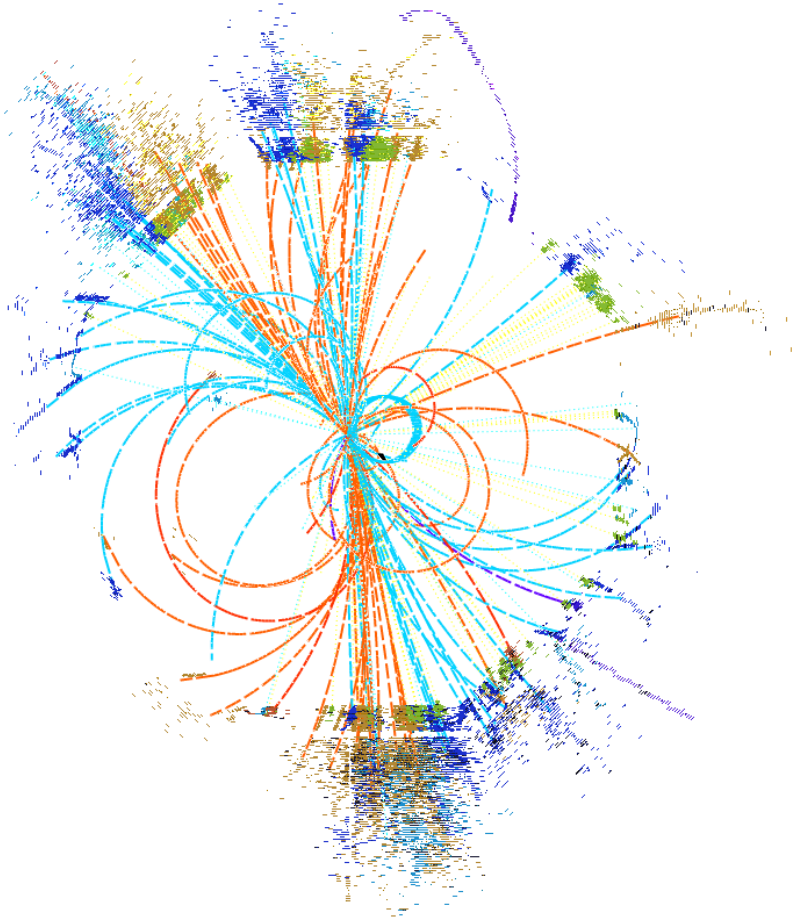
on behalf of the CLICdp collaboration



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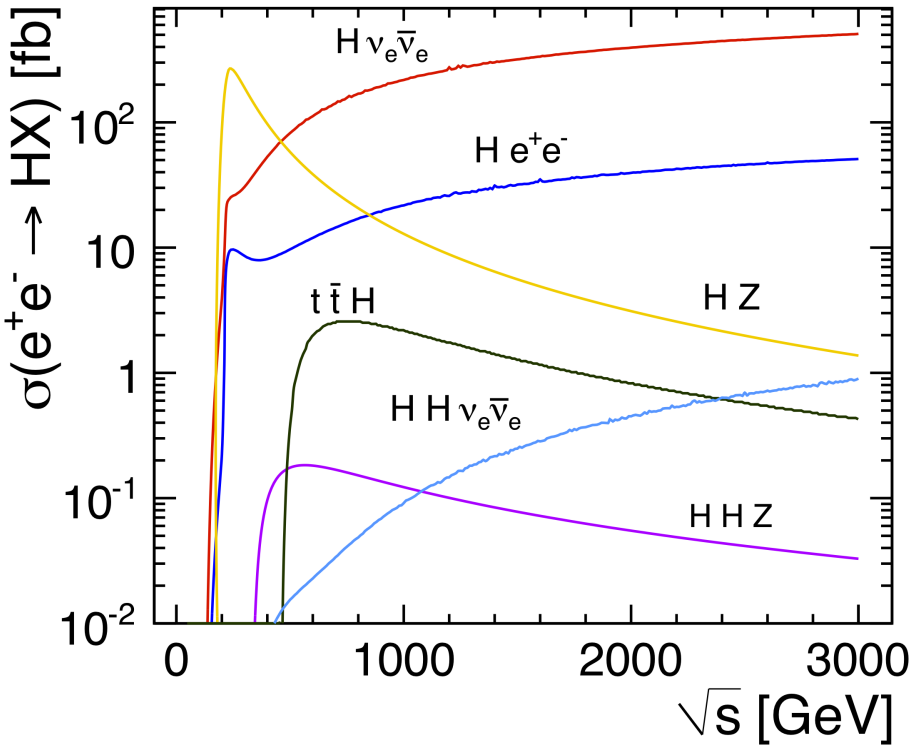
Introduction

Aim: Measure $\sigma \times BR(H \to \tau^+\tau^-)$ at various CLIC energies using hadronic tau lepton decays



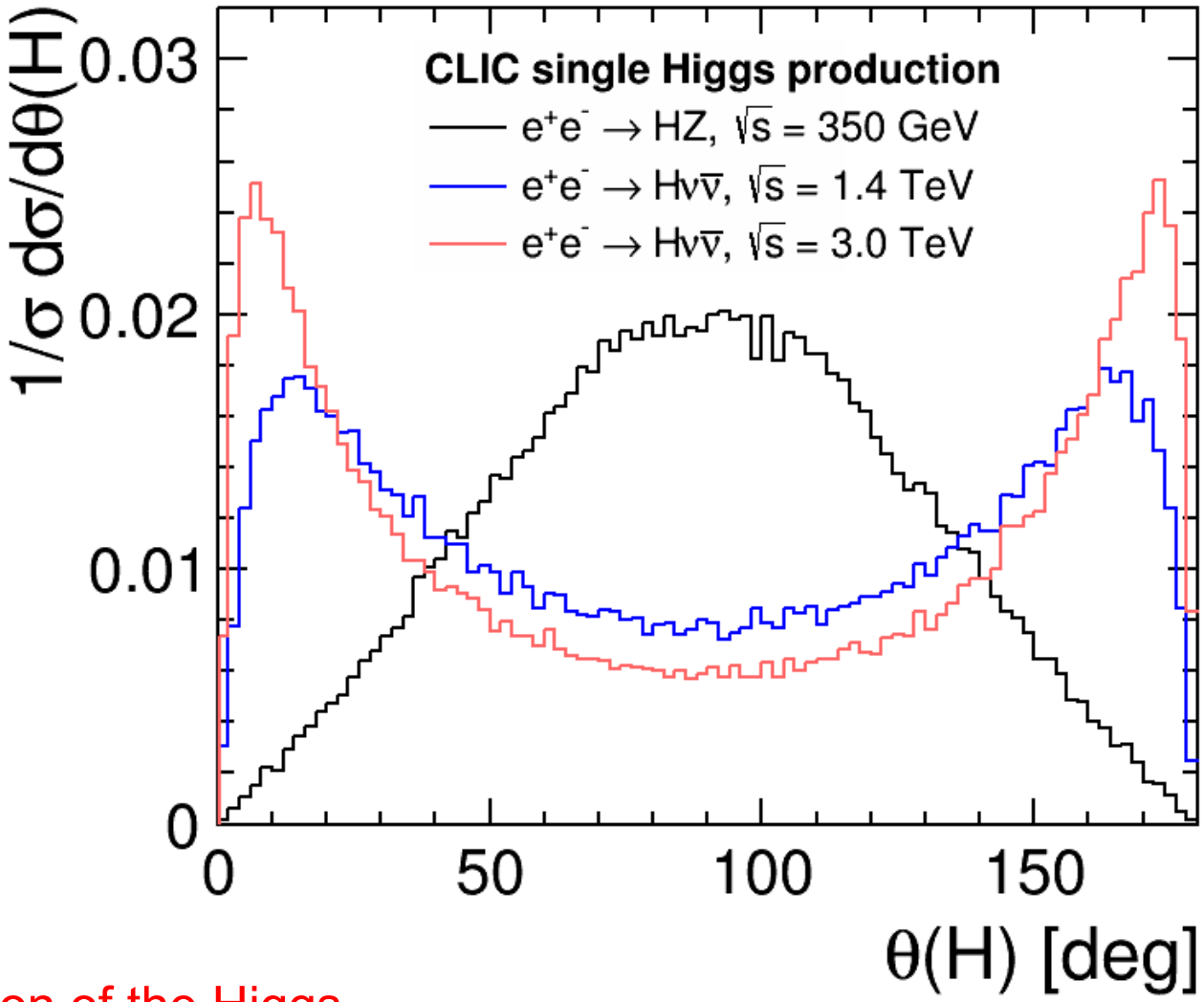
M(H) = 126 GeV
$BR(H \to \tau^+\tau^-)$ = 6.15%
BR(τ→hadrons) = 64.8%

350 GeV, L=500 fb^{-1}:
$e^+e^- \to HZ \to \tau^+\tau^- q\bar{q}$
σ(HZ) = 137 fb
→ N ≈ 1200

1.4 TeV, L=1.5 ab^{-1}:
$e^+e^- \to H\nu_e\bar{\nu}_e \to \tau^+\tau^-\nu_e\bar{\nu}_e$
σ(HZ) = 244 fb
→ N ≈ 9500

3 TeV, L=2 ab^{-1}:
$e^+e^- \to H\nu_e\bar{\nu}_e \to \tau^+\tau^-\nu_e\bar{\nu}_e$
σ(HZ) = 415 fb
→ N ≈ 21000

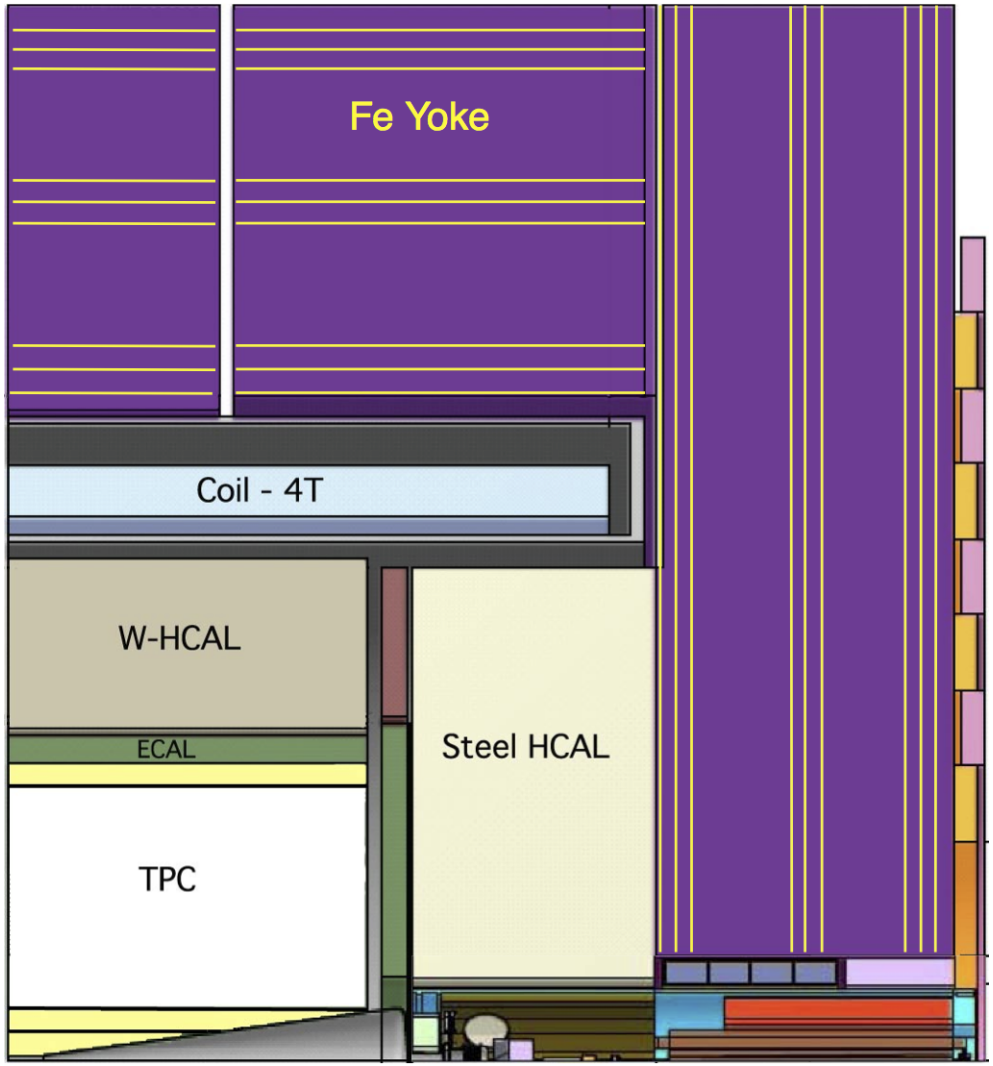
Event kinematics



→ The polar angle distribution of the Higgs bosons peaks in the forward direction at high energy!

Event simulation

- Pile-up from $\gamma\gamma \rightarrow$ hadrons interactions overlaid (60 BX)
- Simulation of the CLIC_ILD detector based on Geant4
- Reconstruction of particles using the Particle Flow technique (Pandora)
- Suppression of beam-induced backgrounds using combined timing and momentum cuts



Tau lepton reconstruction

Similar to cone jet algorithm with some specific requirements for tau lepton identification:

1.) Use charged particle with highest energy and test as seed

2.) Loop over charged particles and add those inside the search cone to seed adjusting cone to new combined momentum

3.) Associate neutral particles in same manner

4.) Repeat the steps 1 – 3 till no further tau candidate is found

5.) Combine all particles inside in the tau candidates

6.) Check for split tau candidates

7.) Apply cuts on invariant mass, number of charged tracks and isolation criteria

A. Münnich, LCD-Note-2010-009

Event samples at 350 GeV

Process	Cross section [fb]	avail. Lumi [ab^{-1}]
$ee \to HZ \quad (H \to \tau\tau, Z \to qq)$	5.7	6.6
$ee \to HZ \quad (H \to X, Z \to \tau\tau)$	4.6	2.4
$ee \to qq\tau\tau$ (m_H=12TeV)	70.0	1.2
$ee \to qq\tau\tau\nu\nu$	1.6	5.0
$ee \to qqqq$	5900	0.1
$\gamma\gamma \to qq\tau\tau$	4.5	0.55
$\gamma\gamma \to qqqq$	84.0	0.64
$\gamma e \to qq\tau\tau e$	1.1	2.7
$\gamma e \to qqqq e$	52.6	0.46

Event reconstruction at 350 GeV

1.) tau lepton identification:

Minimum p_T for tau seed: 5 GeV

Maximum for invariant mass of tau candidate: 2.5 GeV
Opening angle of search cone: 0.1 rad
Opening angle of isolation cone: 0.3 rad
Maximum energy allowed in isolation cone: 2.0 GeV

Single tau efficiency: 73%
Fake rate for quarks: 4.7%

2.) Jet reconstruction for other particles, forced into 2 jets

3.) Preslection cuts:

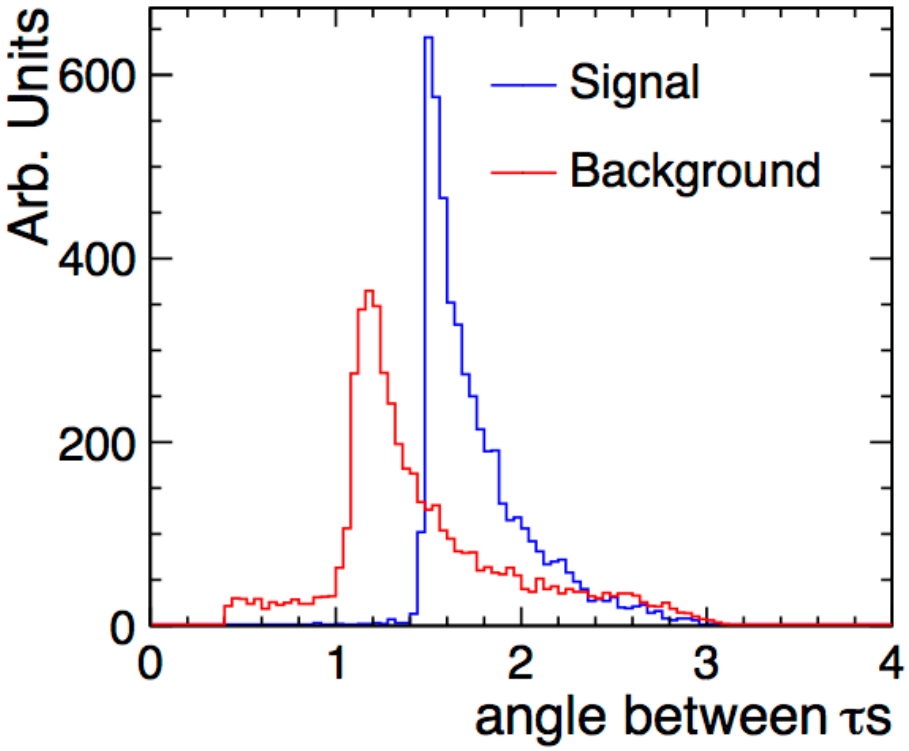
Cut-based preselection for events with 2 hadronic tau decays (1 and 3 prong)

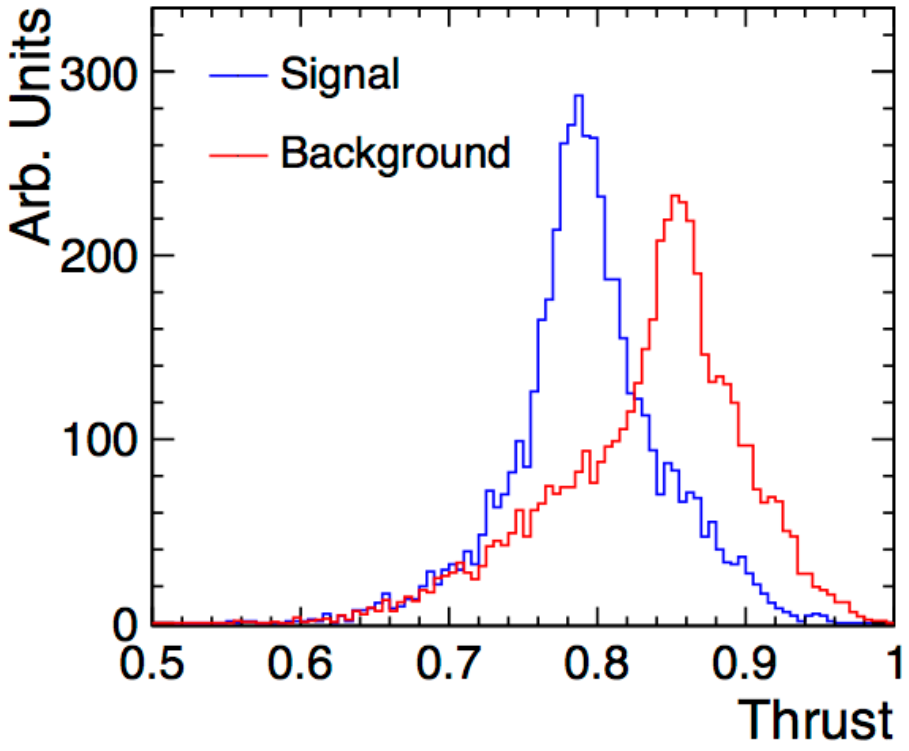
4.) Event selection using BDTs → see next slide

Event selection at 350 GeV

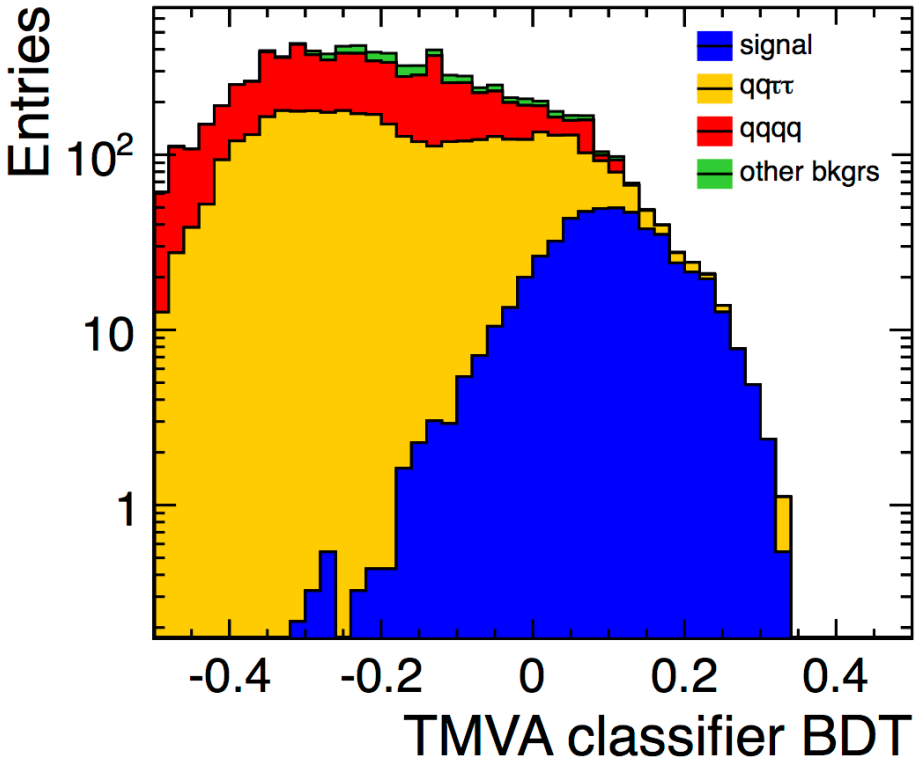
Events are selected using Boosted Decision Trees (BDTs) using event variables and properties of the tau lepton system

Example selection variables at 350 GeV:





Results at 350 GeV



Dominant backgrounds:

- $e^+e^- \rightarrow \tau^+\tau^- q\bar{q}$
- $e^+e^- \rightarrow qqqq$

Cut on BDT output:

BDT > 0.08 maximises $S / \sqrt{S+B}$

$\Delta(\sigma(HZ) \times BR(H \rightarrow \tau^+\tau^-) = 6.9\%$

Template fit to BDT output distributions:

$\Delta(\sigma(HZ) \times BR(H \rightarrow \tau^+\tau^-) = 6.2\%$

(result stable against variations of the binning)

Cuts on generator level at 1.4 TeV

Reusing some background samples produced for CDR SUSY studies.

Selection on generator level:

- $10 < \Theta(\text{tau}) < 170$ deg, where Θ is the polar angle of the tau candidate
- $p_T(\text{tau}) > 20$ GeV
- $\Delta\Phi(\text{tau,tau}) < 178$ deg
- Angle between both tau candidates > 0.4 rad (23 deg)
- $40 < M(\text{tau,tau}) < 650$ GeV

→ Tigher preselection cuts applied on reconstructed tau candidates

→ Cut on p_T(tau) very useful against $\gamma\gamma$ and $e\gamma$ backgrounds

Processes at 1.4 TeV

Process:	Cross section [fb]:
$e^+e^- \to H\nu_e\bar{\nu}_e \to \tau^+\tau^-\nu_e\bar{\nu}_e$	15.0
$e^+e^- \to \tau^+\tau^-$	5.3(*)
$e^+e^- \to \tau^+\tau^-\nu\bar{\nu}$	38.5(*)
$e^+e^- \to e^+e^-\tau^+\tau^-$	67.6(*)
$e^+e^- \to \tau^+\tau^-\mu^+\mu^-$	2.0(*)
$e^+e^- \to q\bar{q}\nu\bar{\nu}$	648.2(*)
$e^+e^- \to qqe^+e^-$	225.9(*)
$\gamma\gamma \to \tau^+\tau^-(\nu\bar{\nu}/l^+l^-)$	128.1(*)
$e\gamma \to eq\bar{q}$	4715(*)
$e\gamma \to e\nu\nu q\bar{q}$	22.3(*)
$\gamma\gamma \to \tau^+\tau^-$	5003(*)
$\gamma\gamma \to qq\nu\bar{\nu}$	0.93(*)
$\gamma\gamma \to qqee$	18.4(*)
$e\gamma \to e\tau^+\tau^-$	2580(*)

(*) = includes effect of the stdhep cuts

Event reconstruction at 1.4 TeV

1.) tau lepton identification:

Minimum p_T to enter reconstruction: 1 GeV ←

Minimum p_T for tau seed: 5 GeV

Maximum for invariant mass of tau candidate: 2.5 GeV

Opening angle of search cone: 0.07 rad ←

Opening angle of isolation cone: 0.3 rad

Maximum energy allowed in isolation cone: 5.0 GeV ←

Single tau efficiency: 70%
Fake rate for quarks: 7%

2.) Preselection cuts:

Cut-based preselection for events with 2 hadronic tau decays

→ see next slide

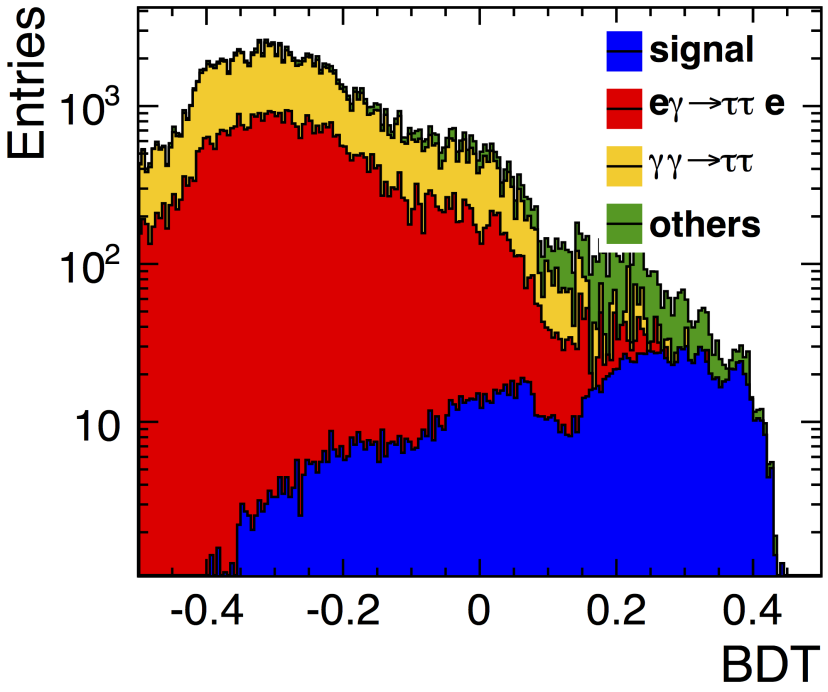
3.) Event selection using BDTs (as for 350 GeV)

Preselection cuts

Cuts on analysis level have to be stronger than generator level cuts:

- No leptons in tau candidates
- $15 < \Theta(\text{tau}) < 165$ deg
- $p_T(\text{tau}) > 25$ GeV
- $\Delta\Phi(\text{tau,tau}) < 177$ deg
- Angle between both tau candidates > 0.5 rad
- $45 < M(\text{tau,tau}) < 130$ GeV
- Thrust < 0.99
- $20 < M_T(\text{tau,tau}) < 400$ GeV
- Number of tracks in each tau candidate either 1 or 3

Results at 1.4 TeV



Dominant backgrounds:

- $e^+\gamma \to \tau^+\tau^- e$
- $\gamma\gamma \to \tau^+\tau^-$

Cut on BDT output:

BDT > 0.24 maximises $S / \sqrt{S+B}$

$\Delta(\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-) = 4.9\%$

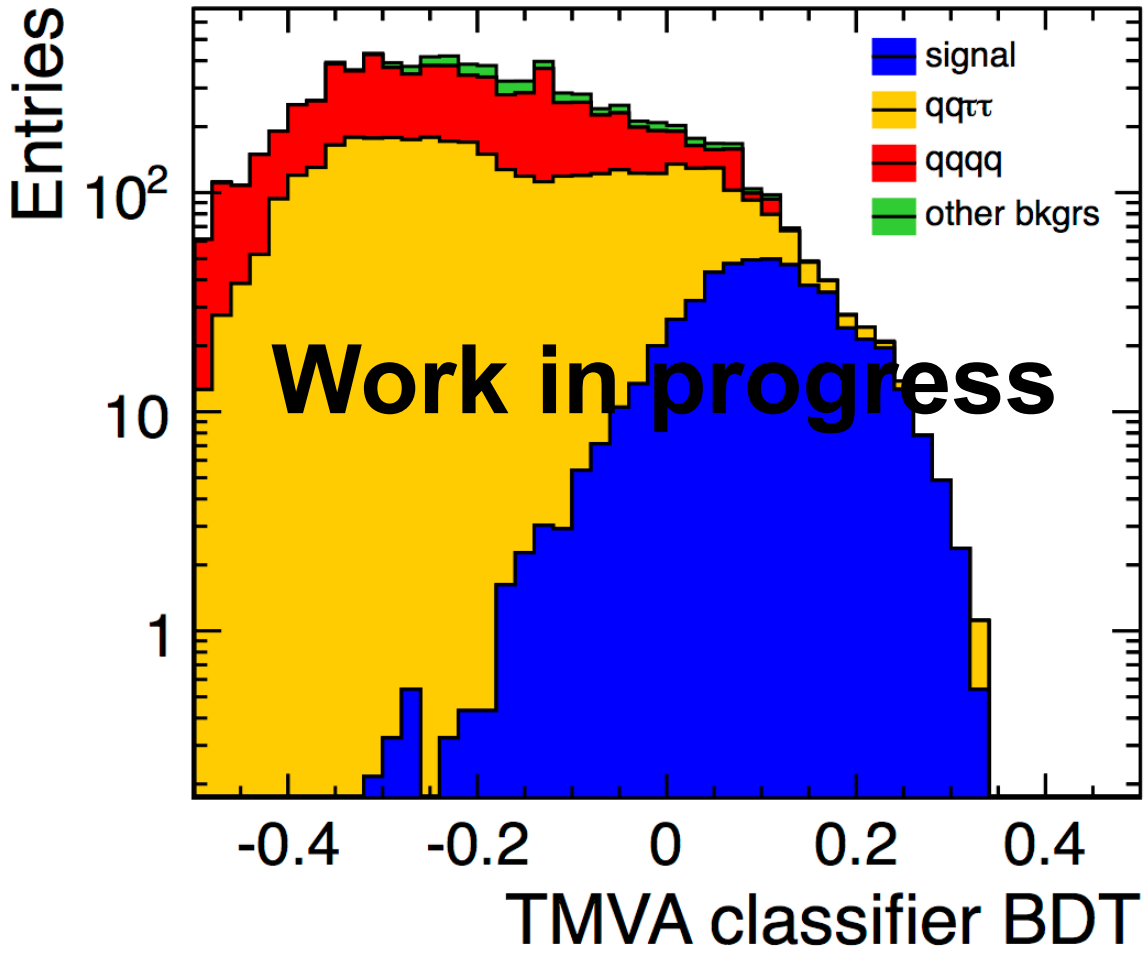
Template fit to BDT output distributions:

$\Delta(\sigma(H\nu_e\bar{\nu}_e) \times BR(H \to \tau^+\tau^-) = 4.2\%$

(result stable againt vaiations of the binning)

Analysis at 3 TeV

Analysis strategy very similar to study at 1.4 TeV



Expect results very soon!

Summary and conclusions

- The physics potential for measurements of SM Higgs boson decays to tau leptons at CLIC is investigated using a full detector simulation and including pile-up from $\gamma\gamma \rightarrow$ hadrons interations

- **350 GeV:** 6.2% precision on $\sigma \times BR(H \rightarrow \tau^+\tau^-)$ from Higgs bosons produced in Higgsstrahlung events

- **1.4 TeV:** 4.2% precision $\sigma \times BR(H \rightarrow \tau^+\tau^-)$ from Higgs bosons produced in WW fusion

- **3 TeV:** analysis to be finished soon