# Study of the CLIC_ILD ECAL performance with tau decays

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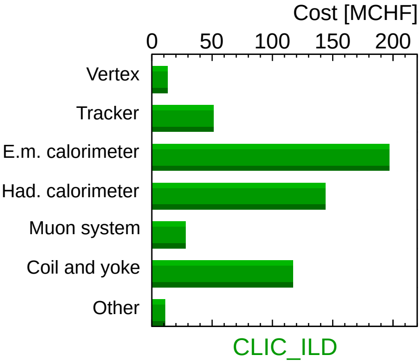
# CLIC ECAL studies

## ECAL in CLIC_ILD_CDR

- Sampling calorimeter: 30 layers of silicon-tungsten (23 $X_0$, 1 $\lambda_I$)
  - 30 tungsten absorber plates:
    2.1 mm $\times 20 \approx 0.6\ X_0$
    4.2 mm $\times 10 \approx 1.2\ X_0$
  - 0.5 mm thick silicon cells of $5.1 \times 5.1$ mm$^2$

- CLIC_ILD_CDR: ECAL is the cost driver (35%), mostly due to the price of the Si wafers
- Would like to decrease the price without loosing performance $\Rightarrow$ optimisation studies



# CLIC ECAL studies (continued)

- Optimisation studies: variation of layer numbers, hybrid ECAL (silicon plus scintillator), variation of absorber thicknesses, etc.
- Performance studied in terms of e.g. energy resolution: see **talk by John Marshall**
- Or look at how well close-by photons can be separated ⇒ tau decays

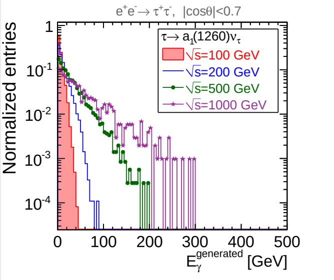
- Look at non-strange **hadronic tau decays**, with a single charged hadron (1-prong)

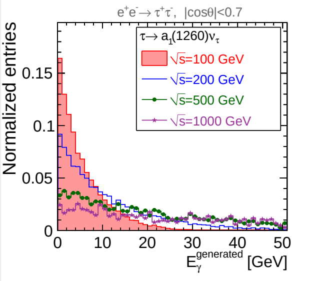
| $\tau$ decay mode | Branching ratio [PDG] | Resonance |
|---|---|---|
| $\tau^- \to \pi^- \nu_\tau$ | $(10.91 \pm 0.07)\%$ | |
| $\tau^- \to (\pi^- \pi^0) \nu_\tau$ | $(25.51 \pm 0.09)\%$ | $\rho(770)$ |
| $\tau^- \to (\pi^- \pi^0 \pi^0) \nu_\tau$ | $(9.51 \pm 0.11)\%$ | $a_1(1260)$ |

- Photons from $\pi^0$ decays are highly collimated ⇒ challenge for photon reconstruction in ECAL

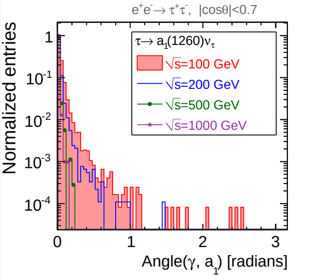
# Photons at Monte Carlo level

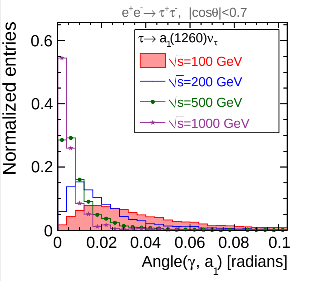
## Energy




## Angle



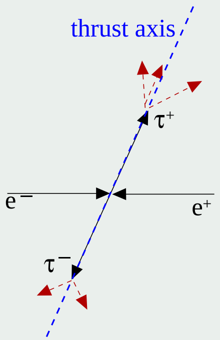



## Data samples

- $e^+e^- \to \tau^+\tau^-$ at $\sqrt{s} = 100$, 200, 500 and 1000 GeV
- Signal only (no beamstrahlung, no ISR, no background)

## Analysis method

- Neglecting radiative effect, $\tau^+$ and $\tau^-$ are produced back-to-back
- Find the **thrust axis** $\vec{n}_T$ which maximises the following quantity: $T = \max\left(\frac{\sum_i |\vec{p}_i \cdot \vec{n}_T|}{\sum_i |\vec{p}_i|}\right)$, where the sum extends over all particles in the event
- Split event into **2 hemispheres**, each associated to a candidate $\tau$ decay, by a plane perpendicular to the thrust axis and passing through the centre of the interaction region

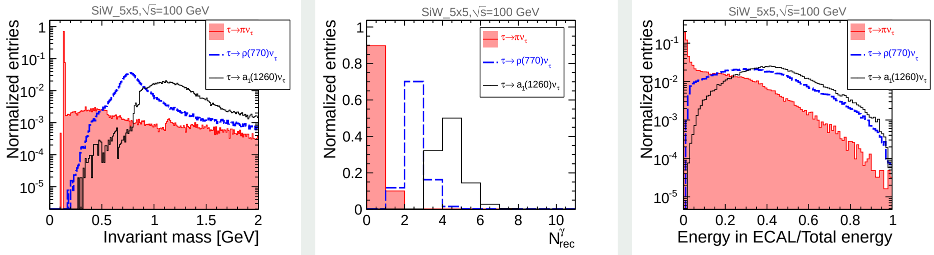


## Selection of events

- Only look at the barrel region in the moment: $|\cos\theta| < 0.7$
- Other requirements:
  - Invariant mass from sum of all 4-vectors in each hemisphere $< 2$ GeV
  - 1 charged pion in each hemisphere

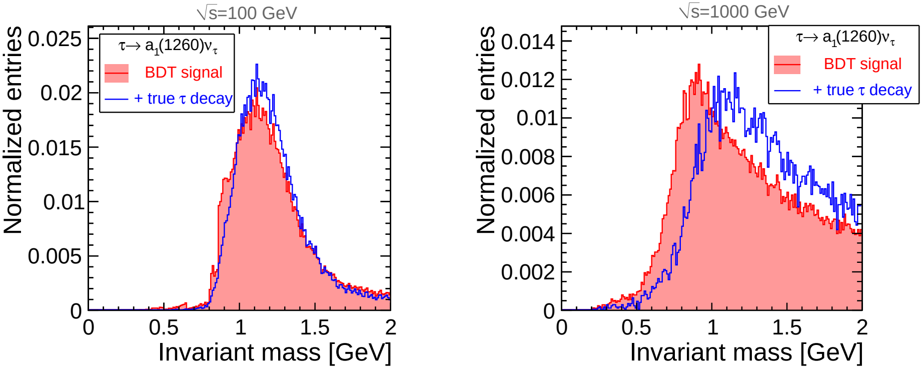
## Identify decay type based on TMVA with Boosted Decision Trees

- 3 input variables:




- BDT value chosen to maximise the statistical significance $S/\sqrt{S+B}$ ($S$ =signal, $B$ =background)

# $a_1$ invariant mass



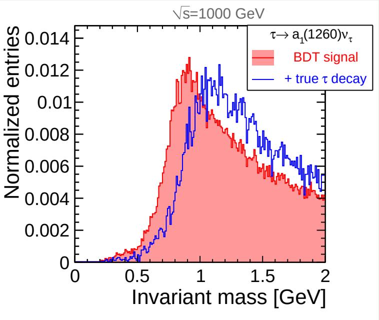

- $a_1$ invariant mass seems distorted at high energies: can we do better?

# Comparison of Pandora algorithms

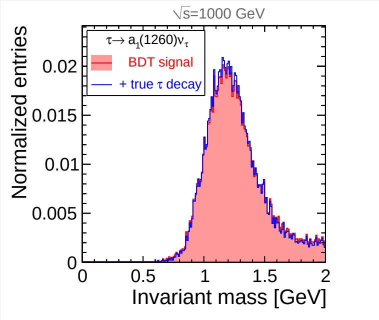
## Perfect photon

- Replaces the standalone photon algorithm with a **PerfectClustering** algorithm, which collects together calo hits associated with MC photons, forms clusters and guarantees they will form photon PFOs
- The cluster energies are not cheated.

## Default settings



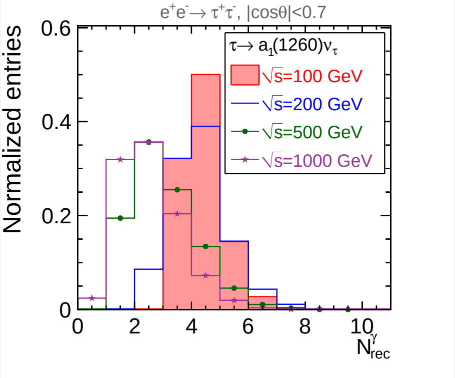

## Perfect photon



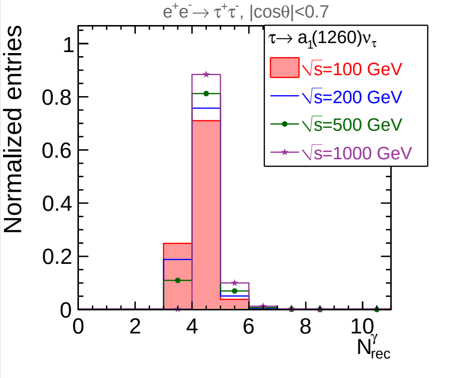
# Number of reconstructed photons for signal events

- With increasing energy, the photons are more and more collimated, hence more difficult to reconstruct
- E.g. in $a_1$ decay expect on average 4 reconstructed photons

## Default settings




## Perfect photon



# Comparisons of ECAL configurations

- **ECAL Si**: silicon, $5 \times 5 \times 0.5$ mm$^3$ cells
- **ECAL Sc**: scintillator, $5 \times 5 \times 2$ mm$^3$ cells

## $\sqrt{s} = 100$ GeV

| True $\tau$ decay mode | | BDT classification $\pi^-$ | $\rho$ | $a_1$ |
|---|---|---|---|---|
| $\pi^-$ | Si | **95%** | 2% | 0% |
| | Sc | 95% | 2% | 0% |
| $\rho$ | Si | 5% | **93%** | 24% |
| | Sc | 5% | 93% | 29% |
| $a_1$ | Si | 0% | 4% | **76%** |
| | Sc | 0% | 5% | 71% |

## $\sqrt{s} = 1000$ GeV

| True $\tau$ decay mode | | BDT classification $\pi^-$ | $\rho$ | $a_1$ |
|---|---|---|---|---|
| $\pi^-$ | Si | **84%** | 6% | 3% |
| | Sc | 85% | 6% | 3% |
| $\rho$ | Si | 15% | **73%** | 69% |
| | Sc | 14% | 75% | 72% |
| $a_1$ | Si | 1% | 21% | **27%** |
| | Sc | 1% | 19% | 25% |

- Define BDT classification efficiency as:

$$\text{Efficiency} = \frac{BDT_{signal} \text{ \&\& true MC decay}}{BDT_{signal}}$$

# Comparison of ECAL configurations

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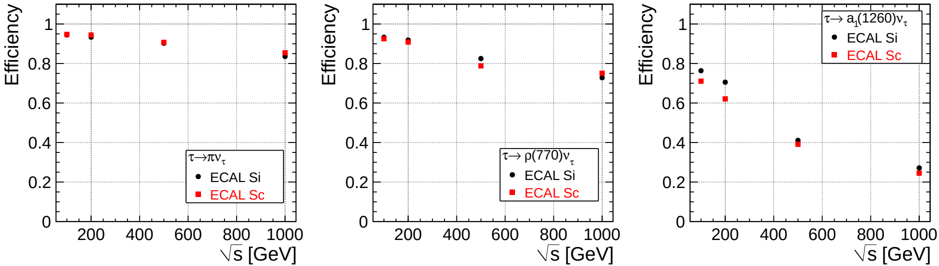
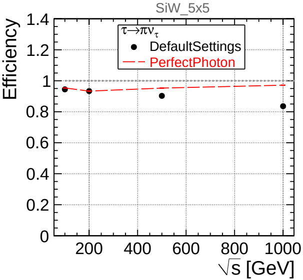
- **ECAL Sc**: scintillator, $5 \times 5 \times 2$ mm$^3$ cells

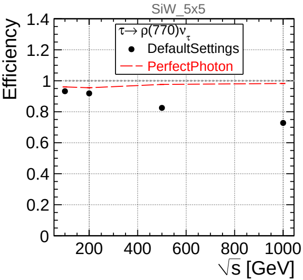


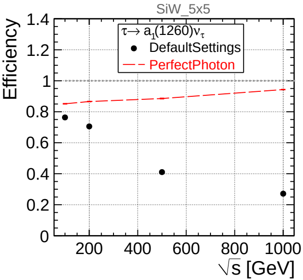

- BDT classification efficiencies similar for the two ECAL configurations (some differences in the case of $a_1$ decay)

# Comparison of Pandora algorithms

- **Default settings**: default PFA reconstruction
- **Perfect photon**: PerfectClustering algorithm for photons




- With increasing energy, photons are more difficult to reconstruct (unless PerfectClustering is used)

## Summary

- Use photons from 1 prong tau decays to test ECAL performance
- Decay products identified with the hemisphere method
- Decay type identified with TMVA based on boosted decision trees
- With increasing $\sqrt{s}$ the photons are closer to the leading meson, hence more difficult to reconstruct

## Next

- Apply analysis for different ECAL hybrid configurations

## Credits

- Mark Thomson: suggested the analysis method
- John Marshall: Mokka and Pandora reconstruction steering files
- Philipp Roloff: Whizard generator files

# BACKUP

## Data samples

- $e^+e^- \to \tau^+\tau^-$ at $\sqrt{s} = 100$, 200, 500 and 1000 GeV
- Signal only (no beamstrahlung, no ISR, no background)

## Mokka

- Model ILD_o1_v05 with ECAL from SEcal05 (silicon, cell size $5 \times 5$ mm$^2$)
- SVN revision 455

## ILC software

- Version v01-16-02, but with trunk of PandoraPFANew, MarlinPandora and Marlin Reco