Potential for future e^+e^- colliders to measure the decay process: $H \rightarrow \gamma\gamma$

Elliott Jones

Supervisors: Katharina Behr and Krisztian Peters

University of Birmingham

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Outline

1. Theory
   - Decay Processes Involved
   - Important Detector Components
2. Simulation and Analysis
   - Simulation
   - Analysis
3. Results
   - CMS detector
   - Detector Parameter Changes

Introduction

- Historically prominent process in 2012 Higgs boson discovery.
- Important input for global fit of Higgs couplings.
    - Cornerstone of FCC physics programme.
- Rare process requires large amount of data.
    - Understanding of important detector components.
- Feasibility studies added to the FCC Conceptual Design Report (CDR)

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Higgs Production: $e^+e^- \rightarrow HZ$

- Cross-section $\sigma = 200$ fb at leading order for s = 240 GeV.

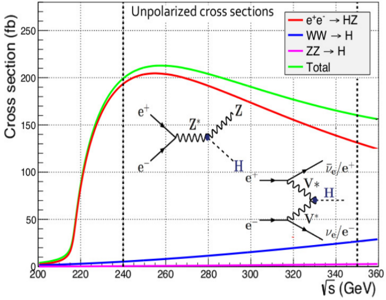
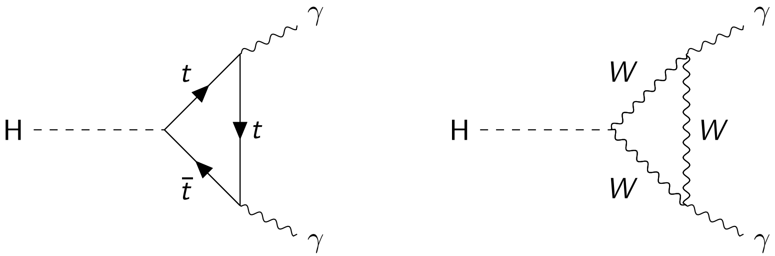
- 

Figure 1: Higgs production cross sections.

Higgs Decay: $H \rightarrow \gamma\gamma$

- $BR \approx 0.2\%$.
  - Only 2000 events in 5 ab^-1 at s = 240 GeV.



(a) Higgs decay to 2 photons via fermionic loop.

(b) Higgs decay to 2 photons via bosonic loop.

Figure 2: Decays of a Higgs boson to 2 photons.

Background Production: $e^+e^- \to Z\gamma$

- Cross-section $\sigma = 26.4$ pb at leading order at s $= 240$ GeV.

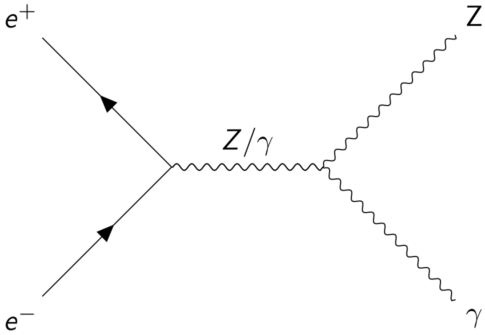


Figure 3: Production of Z and γ from e^+e^- collisions.

- Only events with ISR will pass event selection.

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Most important components

- The Higgs mass is given by: $M_H = \sqrt{2E_1E_2(1 - cos(\theta)}$.
  - Granularity improves θ measurement.
  - Resolution improves E_1 and E_2 measurements.
- $Resolution = \sqrt{(\frac{a}{E})^2 + (\frac{b}{\sqrt{E}})^2 + c^2}$ where a, b, c are noise, stochastic and constant terms respectively.
- Tracking detector important for Z reconstruction $\rightarrow$ important for choosing a Higgs candidate.

Outline

Events Created

- Using PYTHIA8 to simulate events.
- Starting with 1k events for testing purposes.
- 40k events for final measurements.
- 1M background events.
  - 10M events desirable.
- Particles produced in PYTHIA8 passed through a parametrised detector simulation (PAPAS).
  - Github repository: `https://github.com/cbernet/heppy/tree/master/papas`.

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Cuts and Efficiencies

Table 1: Cuts made to the events and their efficiencies.

Cut	Continuous	Individual	Marginal
> 2 photons	97%	97%	61%
Photon Energy	93%	96%	61%
Photon Isolation	86%	92%	64%
Photon Pseudo-rapidity	64%	71%	84%
Higgs angle	59%	97%	61%

- LEP3 study[1] achieved an efficiency of $\approx$ 85% at the photon isolation cut stage.
- LEP3 study[1] achieved an efficiency of $\approx$ 60% after all cuts.

Higgs Reconstruction

- First produce a Higgs from all possible combinations of photon candidates in the event.
- Produce Z from all leftover particles in the event.
- Choose combination to minimise:
  - $\chi^2 = |M_H - M_{H,nominal}| + |M_Z - M_{Z,nominal}|$

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Signal + Background Histogram

- A Gaussian plus linear fit is made to the data.

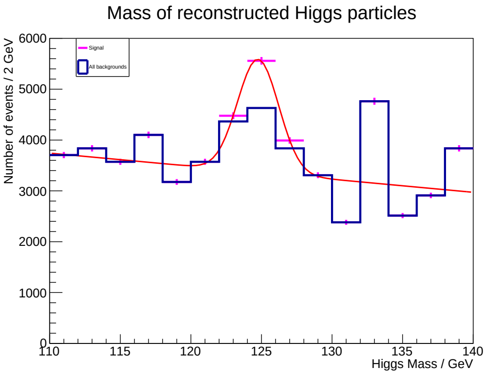


Figure 4: Distribution of the Higgs mass in the H$\rightarrow \gamma\gamma$ channel.

The width of the Gaussian in this plot is 1.4606 $\pm$ 0.0050 GeV.

Pure signal

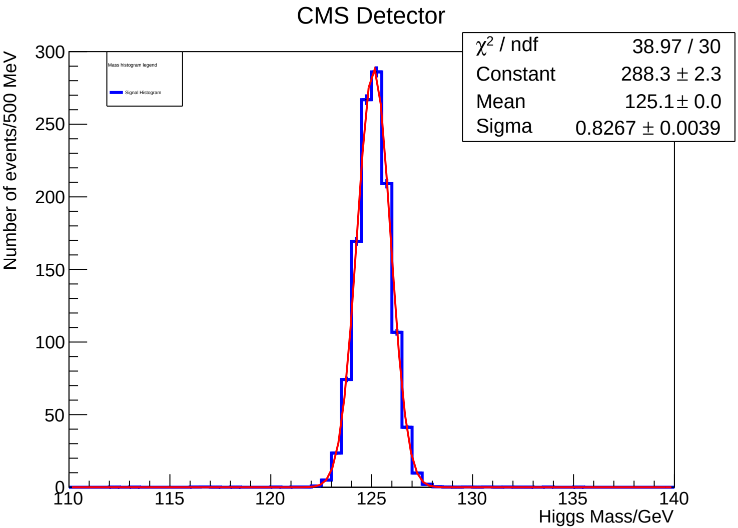


Figure 5: Higgs mass reconstruction from H$\rightarrow \gamma\gamma$ events.

Outline

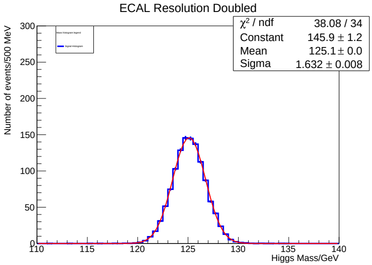
Effect on the width of the Gaussian

Table 2: Detector parameters and their effect on the width of the Gaussian.

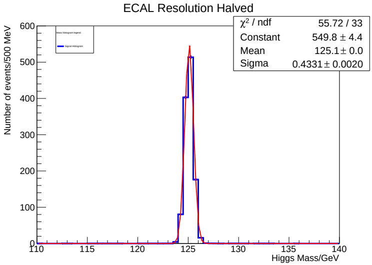
Width/GeV	Doubled	Halved
Cluster Size	0.8327±0.0040	0.8249±0.0039
All ECAL Resolution terms	1.632±0.008	0.4331±0.0020
All HCAL Resolution terms	0.8288±0.0040	0.8277±0.0039

Nominal value - 0.8267±0.0039 GeV

Effect of ECAL resolution



(a) Histogram with largest Gaussian width.



(b) Histogram with smallest Gaussian width.

Figure 6: Smallest and largest width measurements.

Summary

- With $5ab^{-1}$ of data, the width of the mass peak can be measured to be 1.4606 ± 0.0050 GeV.
- The main detector component that will improve measurements of the $H \to \gamma\gamma$ channel is the ECAL resolution.
- Outlook
    - Using a larger number of events for the background would improve the predictions significantly.
    - The tracking detector and magnet would be interesting detector components to investigate in the future.

References I

(Azzi et al., 2012)
Prospective Studies for LEP3 with the CMS Detector
Submitted to the European Stategy Preparatory Group
18/10/2012