

Analysis of Higgs bosons decaying to two photons at CMS

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PG Initial Report Talks, 2014

1 Introduction

- The SM Higgs Boson
- LHC, CMS and ECAL

2 $H \rightarrow \gamma\gamma$

- Photon and Vertex Identification
- Event Categorisation and Analysis

3 Outlook and future work

The Standard Model Higgs boson

History



The authors of the “1964 PRL symmetry breaking papers” won the Sakurai Prize in 2010. Higgs and

Englert won the Nobel prize in 2013. Left: Kibble, Guralnik, Hagen, Englert,

Brout. Right: Higgs

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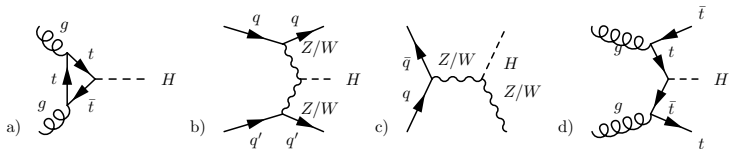
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- Massive and observable. Now known to be ~ 125 GeV.
- Couples to particles proportional to their mass.
- Only one Higgs boson in SM, while other BSM theories predict more.

The Standard Model Higgs boson

Production and decay at LHC

- H couples to particles $\propto m$, so main production modes at LHC are:

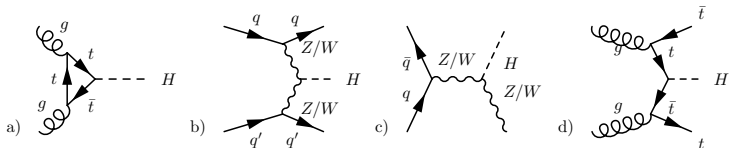


- a) gg fusion via t loop, b) Vector Boson Fusion (VBF), c) Assoc. Z, W production, d) Assoc. $t\bar{t}$ production.

The Standard Model Higgs boson

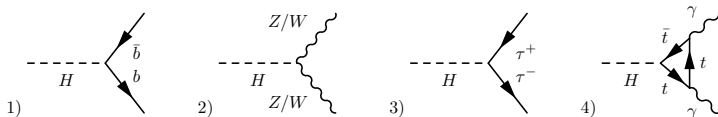
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- By the same token, it decays mostly to heavy particles:

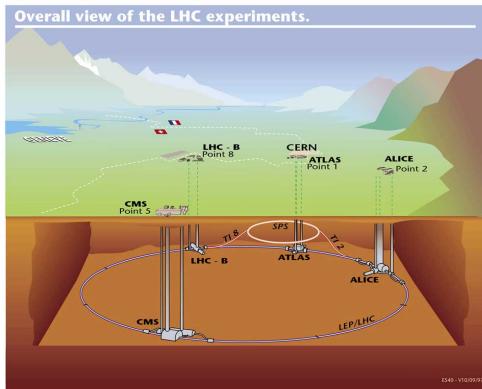


Decay to 1) $b\bar{b}$ pair, 2) vector boson pair, 3) τ^+, τ^- , 4) two photons via t loop (can also be W).

- t, \bar{t} pair kinematically forbidden. $H \rightarrow \gamma\gamma$ is rare, but one of the most sensitive channels at the LHC.

LHC, CMS and the ECAL

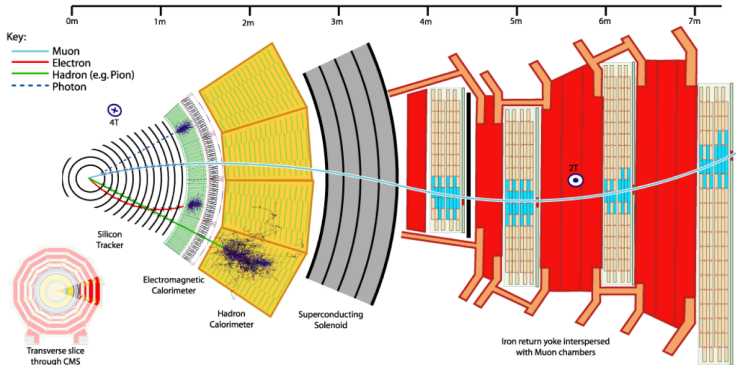
The Large Hadron Collider



- The LHC is a 27km circumference synchrotron at CERN, as explained by my colleagues.

LHC, CMS and the ECAL

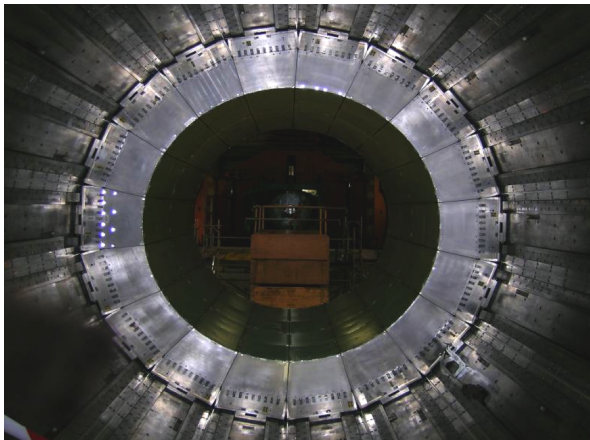
The Compact Muon Solenoid



- Explained already by previous talks - I will focus on ECAL layer.

LHC, CMS and the ECAL

The Electromagnetic Calorimeter



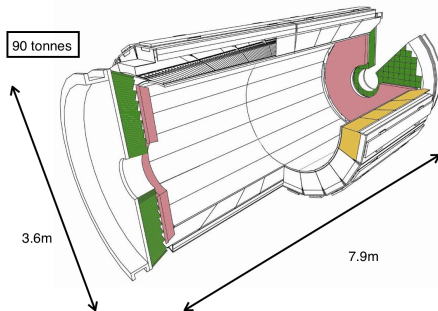
A view of the inside of the ECAL Barrel.

LHC, CMS and the ECAL

The Electromagnetic Calorimeter

The CMS ECAL is composed of an array of PbWO_4 crystals.

The Crystals are offset by an angle of 3° from the vertex to avoid particles going through the gaps in between.



- 62,100 crystals in 36 supermodules
- Supermodule containing 4 modules
- Endcaps containing 14,648 crystals
- Preshower for π^0 ID.

Photon and Vertex Identification

Initial event selection and mass reconstruction

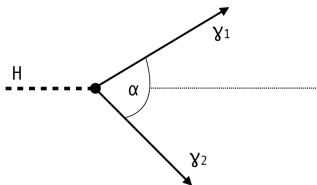
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$$m_H = m_{\gamma\gamma} = \sqrt{2E_{\gamma 1}E_{\gamma 2}(1 - \cos \alpha)}$$

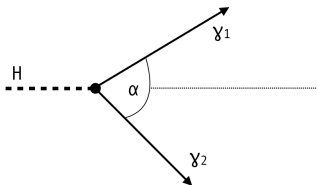


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- $E_{\gamma 1}, E_{\gamma 2}$ dominate mass resolution if primary interaction vertex is identified. Thankfully ECAL has excellent E resolution.
- However, diphoton interaction vertex must be correctly identified to measure α .

Photon and Vertex Identification

Vertex ID and Pair Conversion

- If the diphoton vertex is reconstructed with 10mm of true position then the mass resolution is dominated by the E_γ resolution.

Photon and Vertex Identification

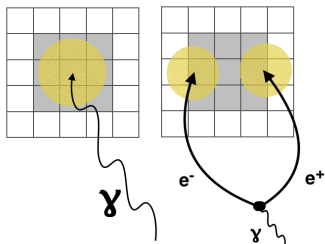
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- A BDT is used to identify vertex using kinematic properties as inputs. Also makes use of extra information from tracker if γ has converted to e^+e^- .
- We can tell if γ has converted using $R_9 \equiv \frac{E_{3 \times 3}}{E_{SuperCluster}} < 0.94$.



- If γ hits, most of the energy is deposited within 3×3 array, so $E_{3 \times 3} \simeq E_{5 \times 5}$ so $R_9 \simeq 1$
- If γ has converted, less energy will be focused within 3×3 , so $R_9 < 1$

Photon and Vertex Identification

Higgs decay candidates

- Not all diphoton events are of interest! We only want those which are Higgs decay candidates.
- Higgs decay photons should be highly energetic, so impose:

$$E_{\gamma 1}^T > \frac{m_{\gamma\gamma}}{3} \text{ and } E_{\gamma 2}^T > \frac{m_{\gamma\gamma}}{4}$$

- A further BDT is used to remove “non-prompt” photons and particles misidentified as photons, as they are of no interest.

Event Categorisation and Analysis

- Events are segmented into categories based on expected signal to background ratio and mass resolution using a BDT.
- This increases the overall sensitivity of the analysis.
- The background is modelled using data rather than Monte Carlo.

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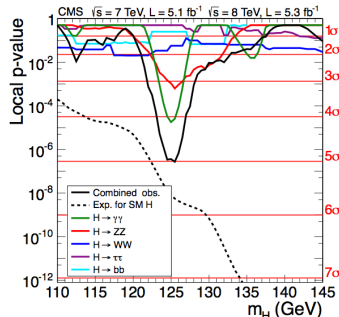
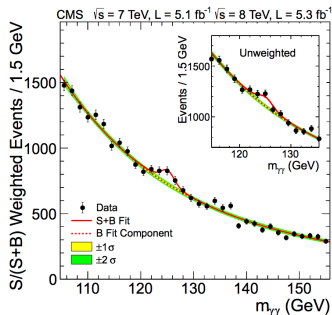
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 - Fitting function chosen based on bias minimisation. Bias is negligible for all categories when Bersteins of order 3-5 (depending on category) are used.

Analysis

- The mass distribution is plotted for each category and compared to the background prediction. The categories are then combined to form the global analysis.
- In 2012, this method yielded an observed local significance of 4σ at ~ 125 GeV. Combined with other analyses, the total local significance was 5σ , allowing a discovery to be claimed by CMS (and ATLAS).



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- Although we have found the H , further studies are not only desirable but imperative.

Questions

Thanks for listening!
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