



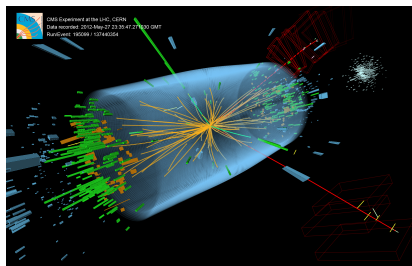
# Higgs Boson Searches at CMS

## What Have We Found So Far?

Patrick Dunne

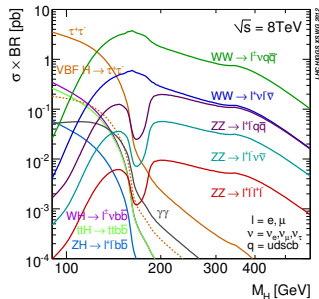
## Outline

- ▶ A Higgs-like boson was discovered in 2012 at the LHC.
- ▶ How did we decide we'd discovered something?
- ▶ How do we answer the question: "Is it the Higgs?"



## The Standard Model and the Higgs Boson

- ▶ Higgs boson is a consequence of the Higgs mechanism which gives mass to the weak vector bosons
- ▶ Higgs mechanism also gives rise to the fermion masses
- ▶ Standard Model couplings are well predicted



## Combinations

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- ▶ The combination has three aims:
  - ▶ Setting exclusion limits on the SM Higgs Boson
  - ▶ Characterising excesses over the background
  - ▶ Extracting signal model parameters from the data

## Setting Exclusion Limits

- ▶ The  $CL_s$  statistic is used, which is the number of times more likely the signal hypothesis is than the background hypothesis.
- ▶ It is defined as:

$$CL_s = \frac{P(q_\mu \geq q_\mu^{obs} | \mu \cdot s + b)}{P(q_\mu \geq q_\mu^{obs} | b)}$$

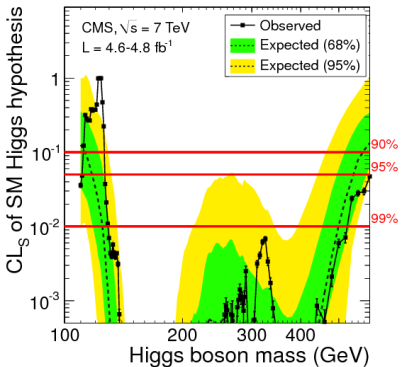
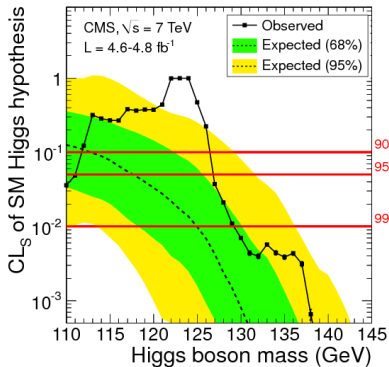
- ▶  $\mu$  is a signal strength modifier
- ▶  $q_\mu$  is a profile likelihood ratio defined as:

$$q_\mu = -2 \ln \frac{\mathcal{L}(obs | \mu \cdot s + b, \hat{\theta}_\mu)}{\mathcal{L}(obs | \hat{\mu} \cdot s + b, \hat{\theta})}$$



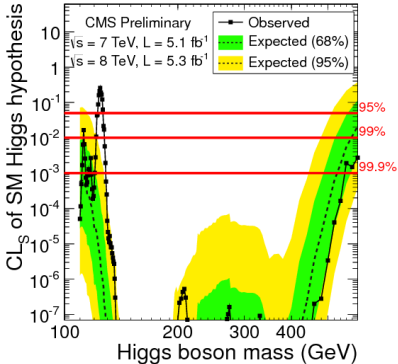
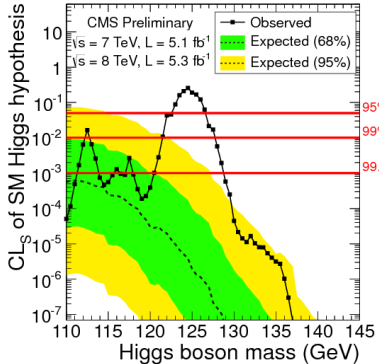


## 2011 Exclusion



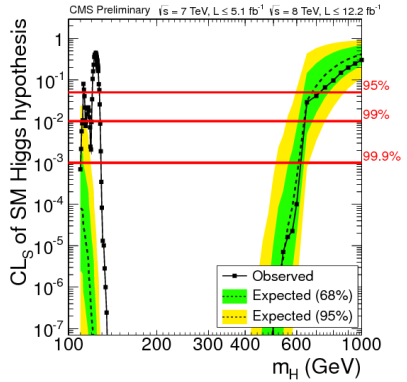
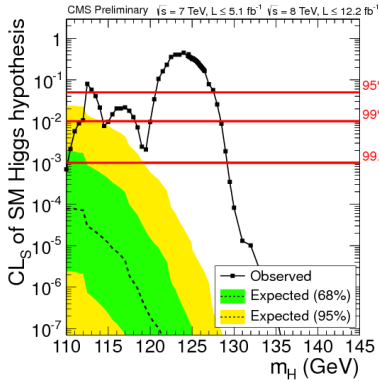


## Discovery Exclusion





## HCP Exclusion



## Characterising Excesses

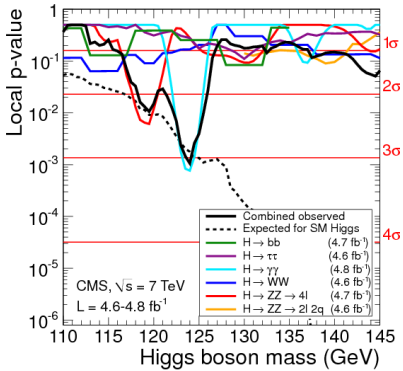
- ▶ Higgs analyses use the p value, defined as:

$$p_0 = P(q_0 \leq q_0^{obs} | b),$$

- ▶  $q_0$  is the profile likelihood from above with  $\mu$  set to zero
- ▶ i.e. the p value is the probability of observing a background fluctuation as likely or less likely than that observed in the absence of signal.
- ▶ 1-p does not tell you P(signal)!

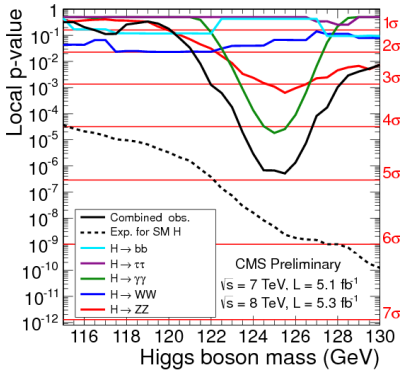


# 2011 Significance



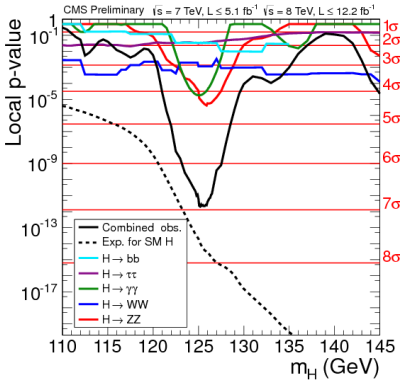


# Discovery Significance





## HCP Significance



## Signal Parameter Determination

- ▶ Most channels give their results in terms of  $\sigma \times BR$
- ▶ We want model parameters so another, slightly different, profile likelihood ratio is used

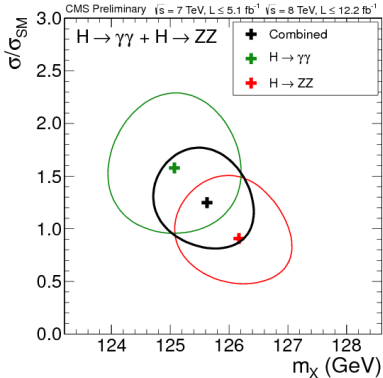
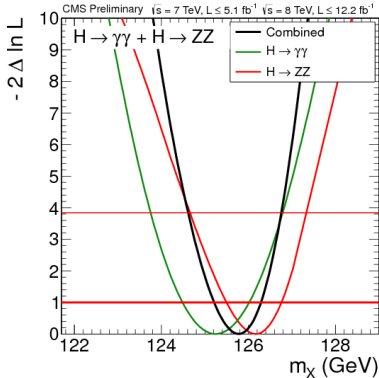
$$q(a) = -2 \ln \frac{\mathcal{L}(obs|s(a) + b, \hat{\theta}_a)}{\mathcal{L}(obs|s(\hat{a}) + b, \hat{\theta})}$$

- ▶  $a$  is the parameter of interest and hatted values are the values which maximise  $\mathcal{L}$
- ▶ Basically a  $\Delta$  log likelihood method so  $1 \sigma$  etc. contours can be plotted.

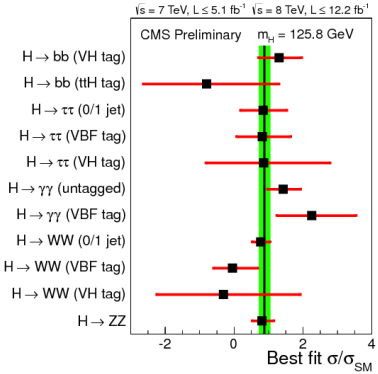
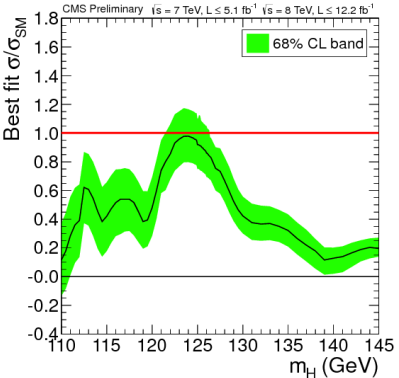




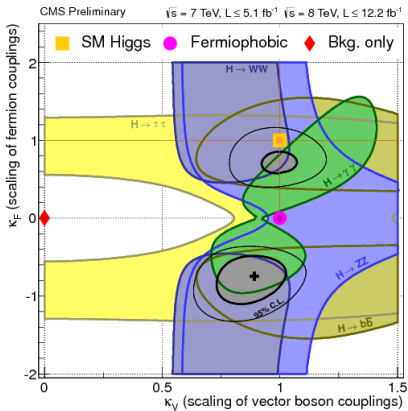
## Mass



# Signal Strength



## Couplings



## What Next?

- ▶ Finish analysing the 2012 dataset
- ▶ Analyse parked data
- ▶ Determine spin and parity
- ▶ Better coupling determination

