Notes on Higgs searches plots

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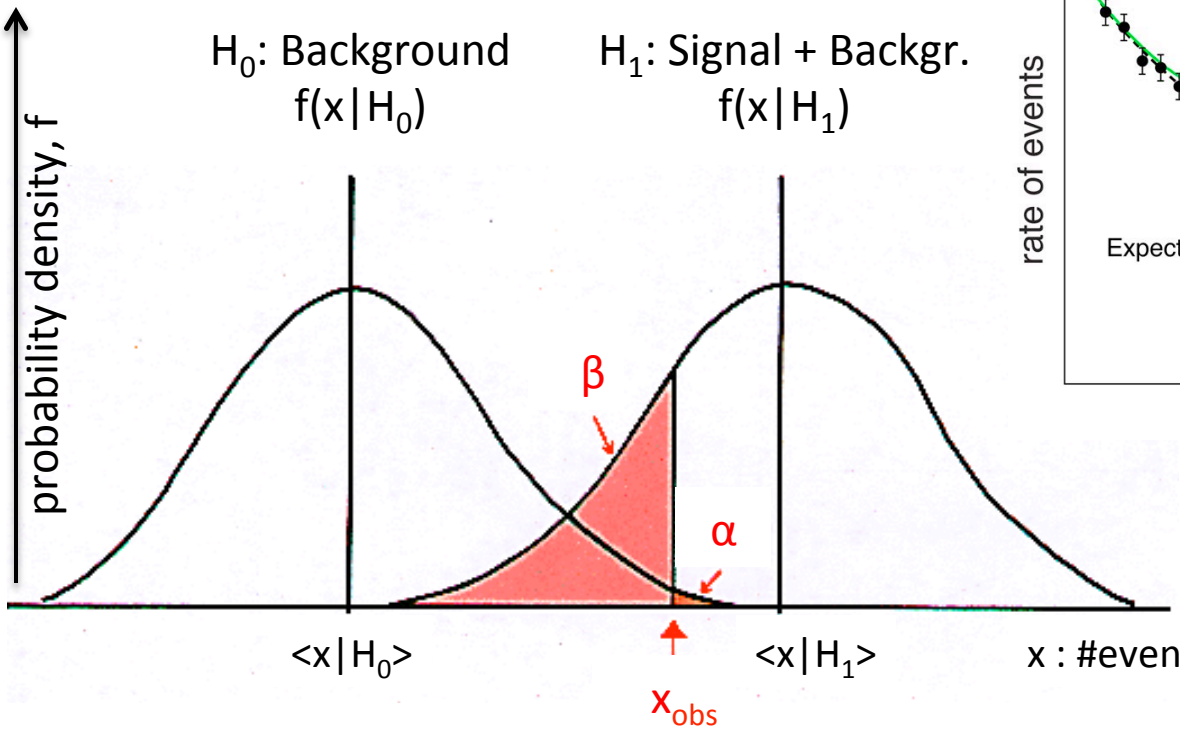
Recommended reading

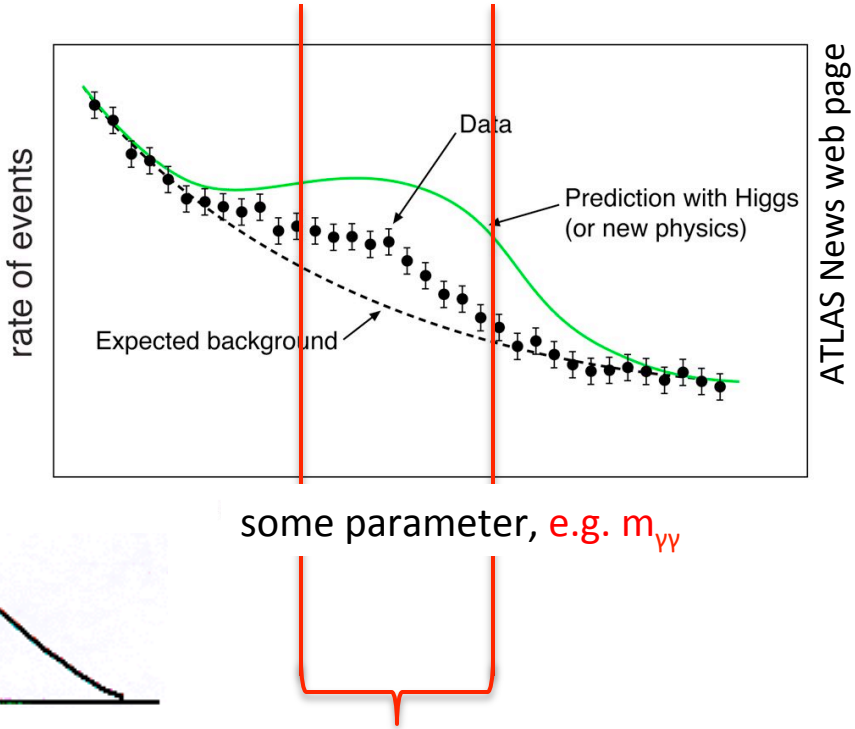
- ATLAS Explanatory Figures for the Higgs Boson Exclusion Plots
  - http://www.atlas.ch/news/2011/simplified-plots.html
  - fast introduction on exclusion only; nothing on p-values
- Deeper into statistics for HEP
  - Glen Cowan's Home Page
    http://www.pp.rhul.ac.uk/~cowan/
  - many useful links and pedagogical, lengthy lectures

- → these notes: somewhere in between

Hypothesis test

- Searches for Higgs or New Physics → hypothesis testing
  - H_0: null hypotheses → SM background (b)
  - H_1: alternative one → SM + Higgs, New Physics (s+b)





Hypothesis testing results

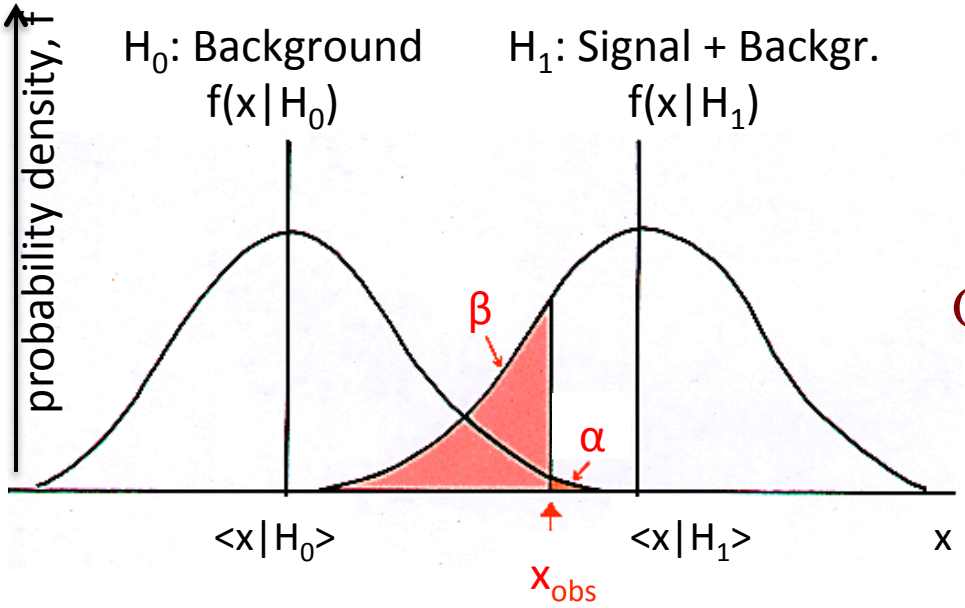
- We do not quote our confidence of being right…
- …instead talk about probability of being wrong
  - Type-I error: probability to reject H_0, when in reality it is true (claim false discovery)
    - estimated when Higgs evidence or discovery is studied
  - Type-II error: probability to accept H_0, when in fact it is wrong (wrongly exclude Higgs & miss a discovery)
    - useful when Higgs exclusion is claimed

Exclusion of H_1 (Higgs boson)

- Quantified in terms of power (1-β); usually set to **95%**
  - i.e. 5% probability of being wrong if we exclude Higgs

$$\mathrm{CL}_{s+b} = \beta = \int_{-\infty}^{x_{\mathrm{obs}}} \mathrm{d}x f(x|H_1)$$

- x (#events) directly related to σ, independently of assumed (Higgs) model



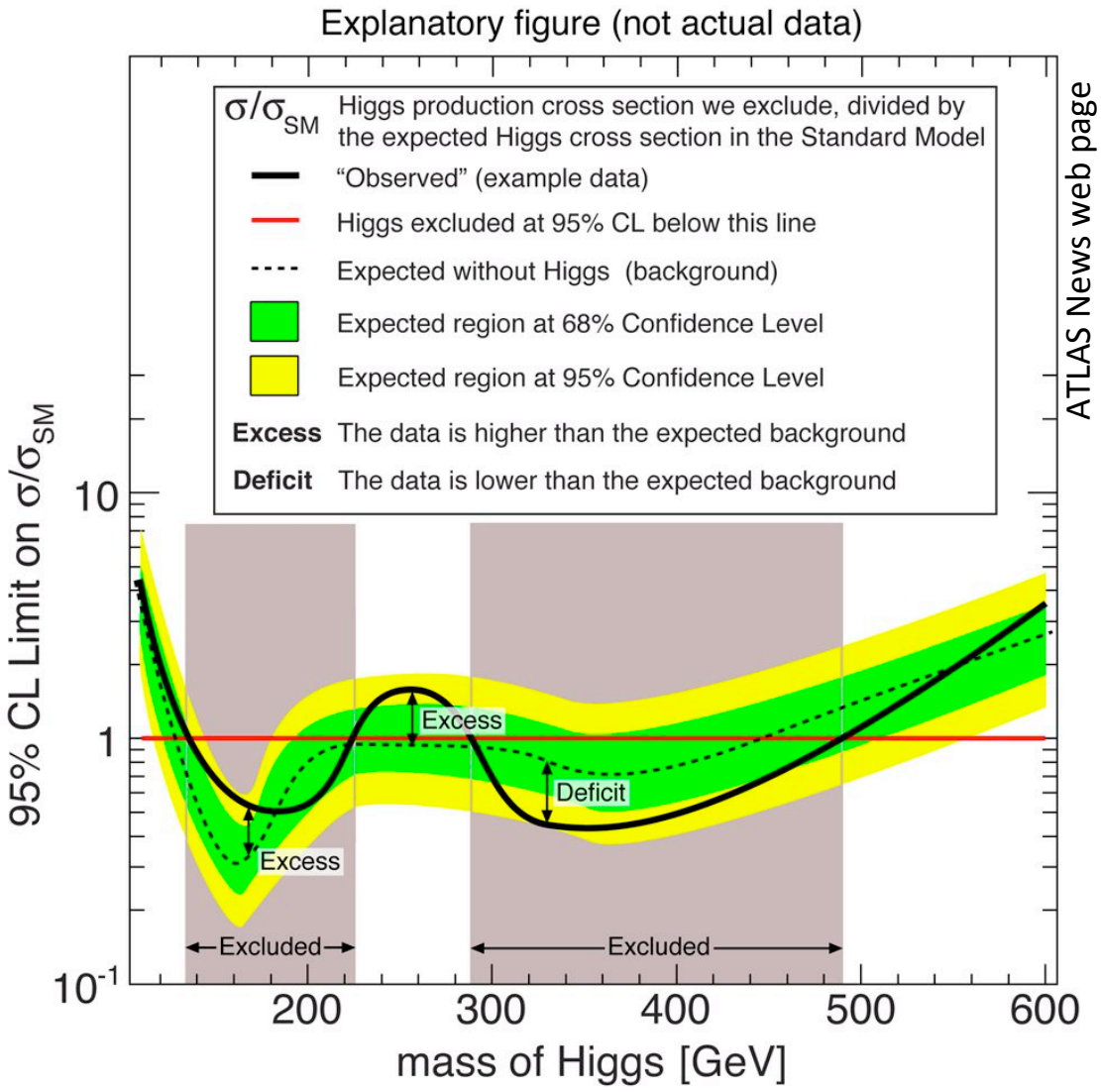
- $\sigma_{95\%}$: 95% confidence limit on σ×BR, i.e. $\langle x|H_1\rangle$ such that

$$\mathrm{CL}_{s+b} = \int_{-\infty}^{x_{\mathrm{obs}}} \mathrm{d}x f(x|H_1) = 0.05$$

  - depends on observable (e.g. $m_{\gamma\gamma}$) range

"Exclusion(?) plot"

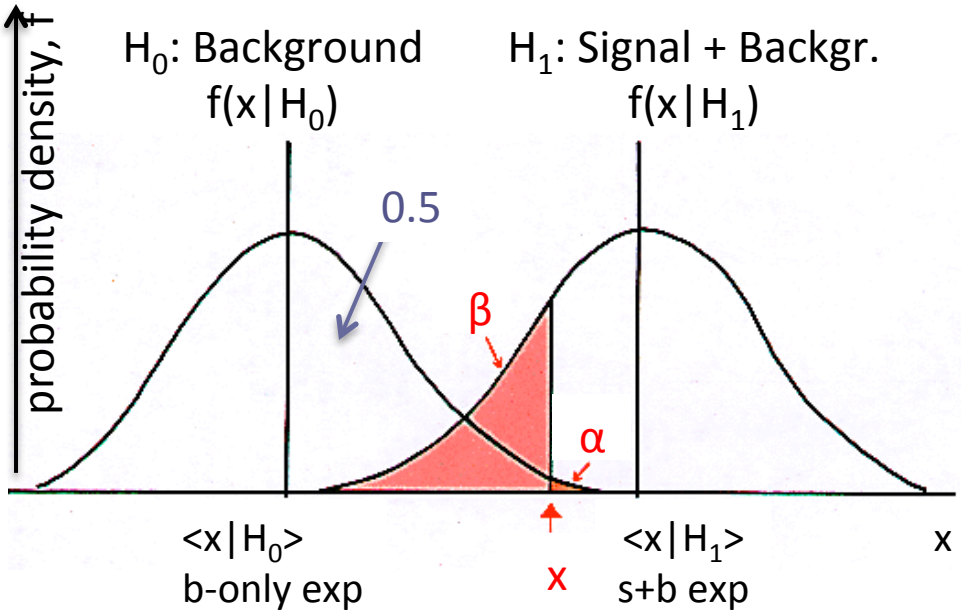
- $\sigma_{95\%}$ only gives our excluded σ×BR
- If $\sigma_{95\%} > \sigma_{SM\ Higgs}$, not sensitive enough to exclude it
- If $\sigma_{95\%} < \sigma_{SM\ Higgs}$ YES!
- $\sigma_{95\%}$ fluctuates with experimental uncertainties
  - → 1σ and 2σ bands



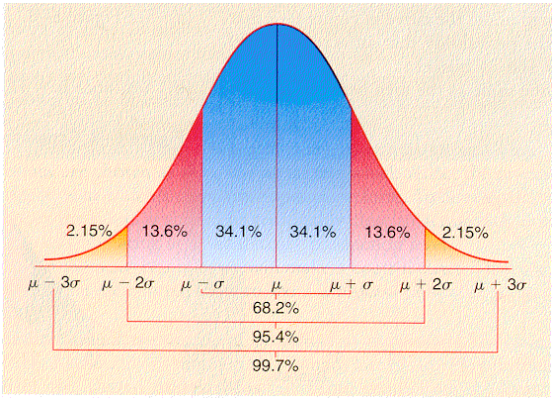
Discovery → exclusion of H_0

- Quantified as significance (*p*-value), i.e. probability to be a background fluctuation $P(p_0 \leq \alpha | H_0) = \alpha$
  - 5σ discovery: when $\alpha < 2.9 \times 10^{-7}$ (from one-sided Gaussian)

$$p\text{-value of } H_0 = p_0(x) = \int_x^{+\infty} \mathrm{d}x' f(x'|H_0)$$



$$p_0(b\text{-only exp}) = 0.5$$
$$p_0(s+b \text{ exp}) \leq 0.5$$

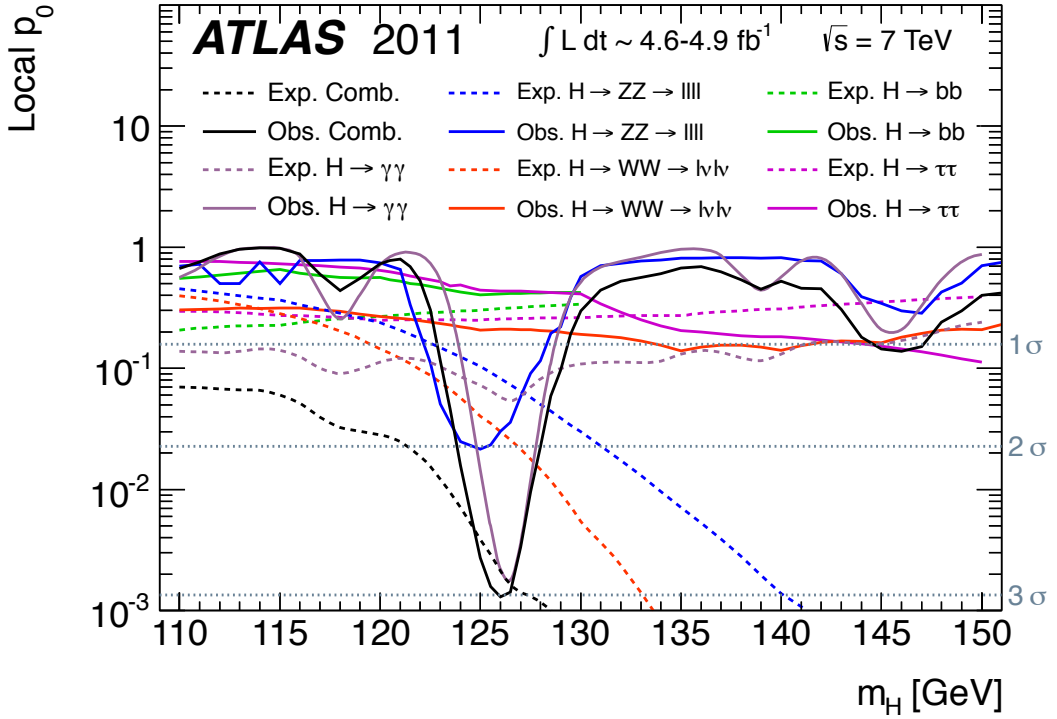


p_0 value: "Discovery(?) plot"

- Tells us how far from background-only expectation (p_0=0.5) are:
  - s+b expectation
  - observation

$$p_0(b\text{-only exp}) = 0.5$$

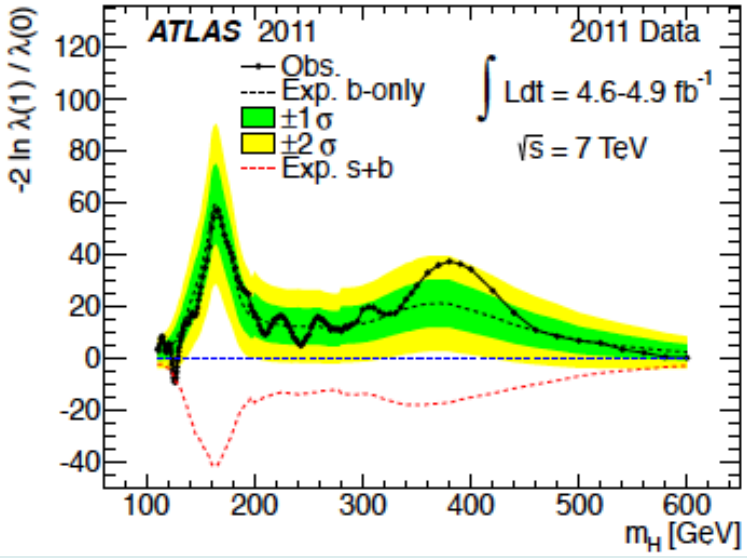
$$p_0(s+b \text{ exp}) \leq 0.5$$



- Look-elsewhere-effect: local p_0 measures significance for specific mass window. Probability to find an excess of events increases with considered mass windows ("look elsewhere")
  - significance lower if correction for LEE taken into account

Signal strength factor μ

- μ defined such that
  - μ = 0 corresponds to background-only model
  - μ = 1 corresponds to the SM Higgs boson signal
- Assuming there is a signal, μ expresses measured cross section normalised to SM Higgs



Likelihood ratio for μ=1 (signal) over μ=0 (background)