Inside ATLAS search: ~~an analysis example~~
A short guide to read results

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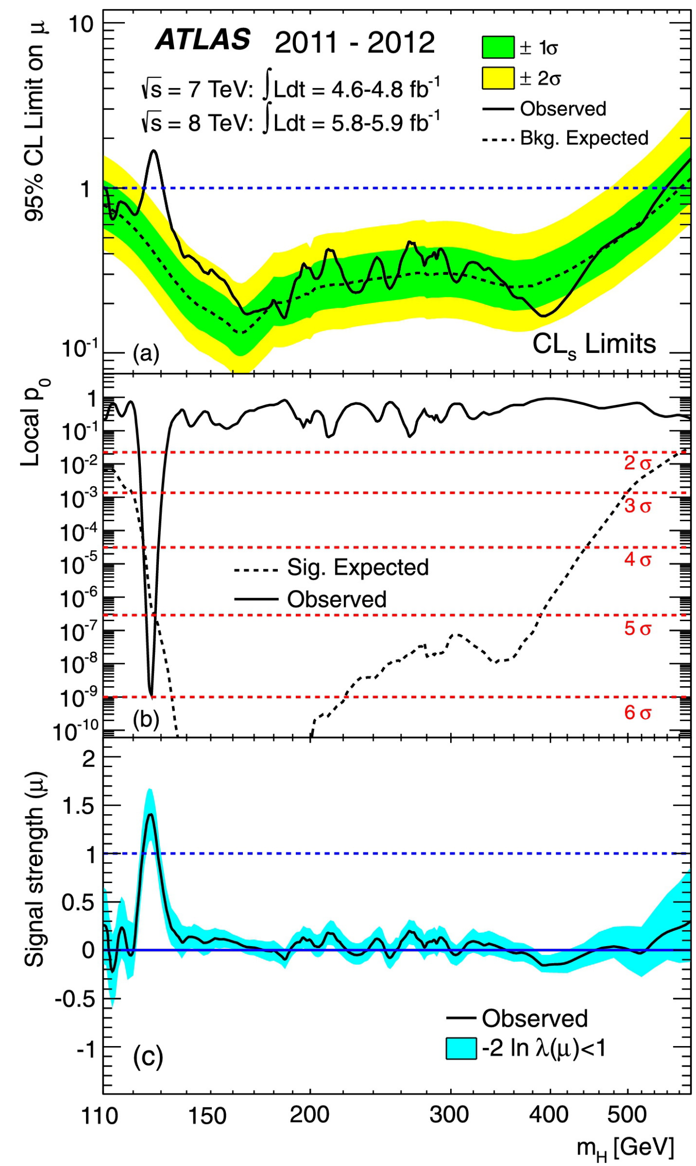
What does it mean?

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC



"[...] Hypothesised values of μ are tested with a statistic λ(μ) based on the profile likelihood ratio. This test statistic extracts the information on the signal strength from a full likelihood fit to the data. The likelihood function includes all the parameters that describe the systematic uncertainties and their correlations.

Exclusion limits are based on the CLs prescription. […] The significance of an excess in the data is first quantified with the local p0..."

Overview

- Small review of statistic tools
- Limits settings and significance test
- Result interpretation

Some definitions

- Given an observable X distributed with p.d.f, f (x,θ)
- Suppose a counting experiment: the p.d.f of N measure of X → D$\{x_1, \ldots x_n\}$ is a marked Poisson.

- DEF: Likelihood is the p.d.f calculated for the observations

$$L(D, \upsilon, \theta) = \text{Pois}(n|\upsilon) \prod^{N}_{i} f(\theta \mid x_i)$$

- One can determine the most likely θ or υ by maximizing

  $L(D, \upsilon, \theta)$ → maximum likelihood estimator → profiling

Some definitions

- Signal strength for Higgs search $\mu = \sigma/\sigma_{SM}$
- In case of signal one would expect to see:

$$\nu = \mu s + b$$

- s = expectation for SM signal
- b = expectation for background
- $\mu = 1 \rightarrow$ SM signal ; $\mu = 0 \rightarrow$ background only

$$L(D, \upsilon(\mu), \theta) = \text{Pois}(n|\upsilon) \prod^{N}_{i} f(\theta \mid x_i)$$

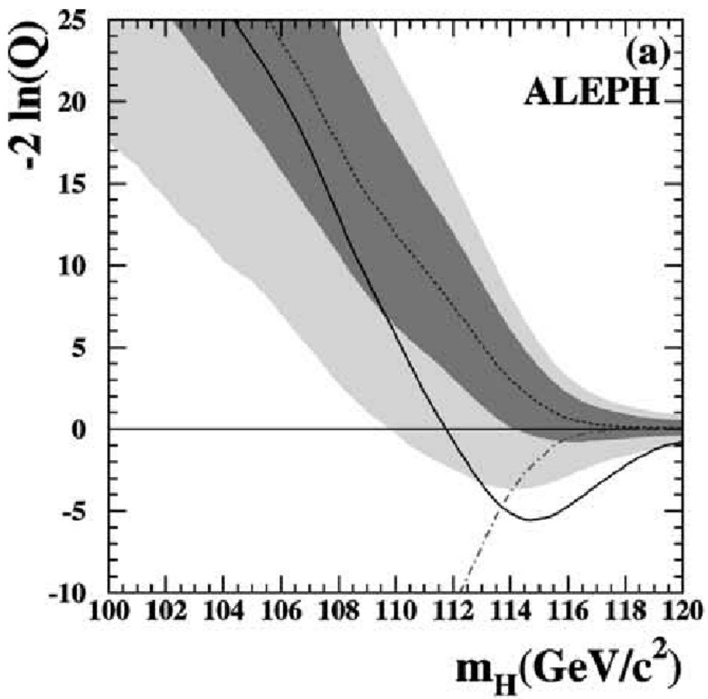
Hypothesis testing: modern approach

- H_0 = null Hypo. → describes known process
- H_1 = alternative Hypo. → includes s+b
- Neuman and Person defined some rules to test H_1 against H_0:
  - Define Test statistic T(D) → R
  - if $T(D) < t_\alpha$ the null Hypo. is accepted and vice versa
  - Define size α: $P(T(D) > t_\alpha | H_0)$ → Type I error
  - Define $\beta = P(T(D) < t_\alpha | H_1)$ → Type II error

Hypo. test: best test statistic

- Lemma: best test statistic for counting experiment is the likelihood ratio → $Q = L(s+b, \theta) \ / \ L(b, \theta)$

- Remember: L is the pdf fixed with the dataset D

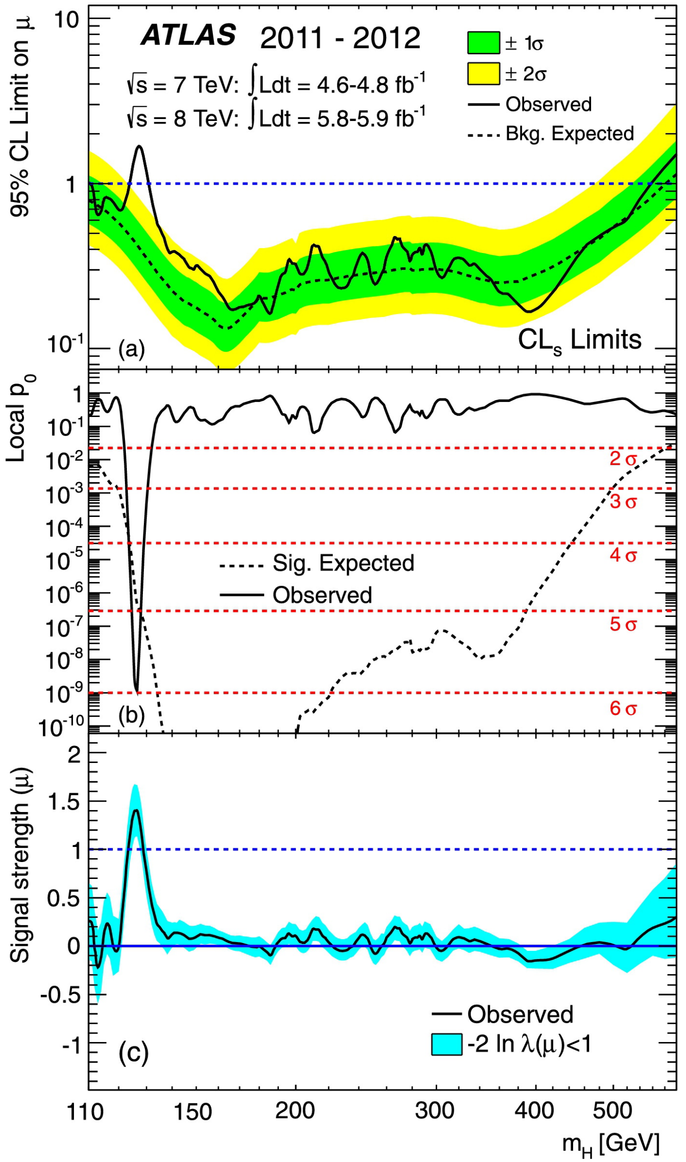


Do you remember?

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC

“[...] Hypothesised values of μ are tested with a statistic λ(μ) based on the profile likelihood ratio. This test statistic extracts the information on the signal strength from a full likelihood fit to the data. The likelihood function includes all the parameters that describe the systematic uncertainties and their correlations.

Exclusion limits are based on the CLs prescription. […] The significance of an excess in the data is first quantified with the local p0, the probability that the background can produce a fluctuation greater than or equal to the excess observed in data. “



Test statistic for LHC:

$$\tilde{q}_\mu = -2\ln\frac{\mathcal{L}(\text{data}|\mu,\hat{\hat{\theta}}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\theta})}, \quad \text{with a constraint } 0 \leq \hat{\mu} \leq \mu \tag{5}$$

where $\hat{\hat{\theta}}_\mu$ refers to the conditional maximum likelihood estimators of θ, given the signal strength parameter μ and "data" that, as before, may refer to the actual experimental observation or pseudo-data (toys). The pair of parameter estimators $\hat{\mu}$ and $\hat{\theta}$ correspond to the global maximum of the likelihood.

$$\lambda(\mu) \equiv \frac{\mathcal{L}(\text{data}|\mu,\hat{\hat{\theta}}_\mu)}{\mathcal{L}(\text{data}|\hat{\mu},\hat{\theta})},$$

- $0 < q_\mu < \infty$
- To asses limits you should know the distro of q_μ
- This allow to make asymptotic extrapolations

P-value: significance

- Given an observable X distributed with pdf f(x) you can evaluate the significance of outcome of an experiment for hypo. H
- p-value = Prob. of obtaining the value observed plus all more extreme outcome under H.

$$p_\mu = P(\,\tilde{q}_\mu \geq \tilde{q}_\mu^{obs}\,|\,\mathrm{signal{+}background}) = \int_{\tilde{q}_\mu^{\mathrm{obs}}}^{\infty} f(\tilde{q}_\mu|\mu, \hat{\theta}_\mu^{\mathrm{obs}})\, d\tilde{q}_\mu$$

Limits

- The confidence in the S+B Hypo. is given by the probability that the test statistic is > of Observed.

$$\mathbf{CL_{S+B}} \equiv p_\mu = P(\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} \,|\, \text{signal+background}) = \int_{\tilde{q}_\mu^{\text{obs}}}^{\infty} f(\tilde{q}_\mu | \mu, \hat{\theta}_\mu^{\text{obs}}) \, d\tilde{q}_\mu$$

- If $CL_{S+B} < 5\%$ the signal is excluded at 95% Confidence Level
- Problem: if down-fluctuation you can exclude an arbitrarily small signal → not desired!

Limits: the CL_s method

$$\mathbf{CL_{S+B}} \equiv p_\mu = P(\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} \,|\, \text{signal+background}) = \int_{\tilde{q}_\mu^{\rm obs}}^{\infty} f(\tilde{q}_\mu|\mu, \hat{\theta}_\mu^{\rm obs})\, d\tilde{q}_\mu$$

$$\mathbf{CL_{B}} \equiv 1 - p_b = P(\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} \,|\, \text{background-only}) = \int_{q_0^{\rm obs}}^{\infty} f(\tilde{q}_\mu|0, \hat{\theta}_0^{\rm obs})\, d\tilde{q}_\mu$$

$$\mathbf{CL_S} \equiv \mathbf{CL_{S+B}} \,/\, \mathbf{CL_B}$$

You can't exclude a signal if you are not sensitive to it → $CL = 1 - CL_S$

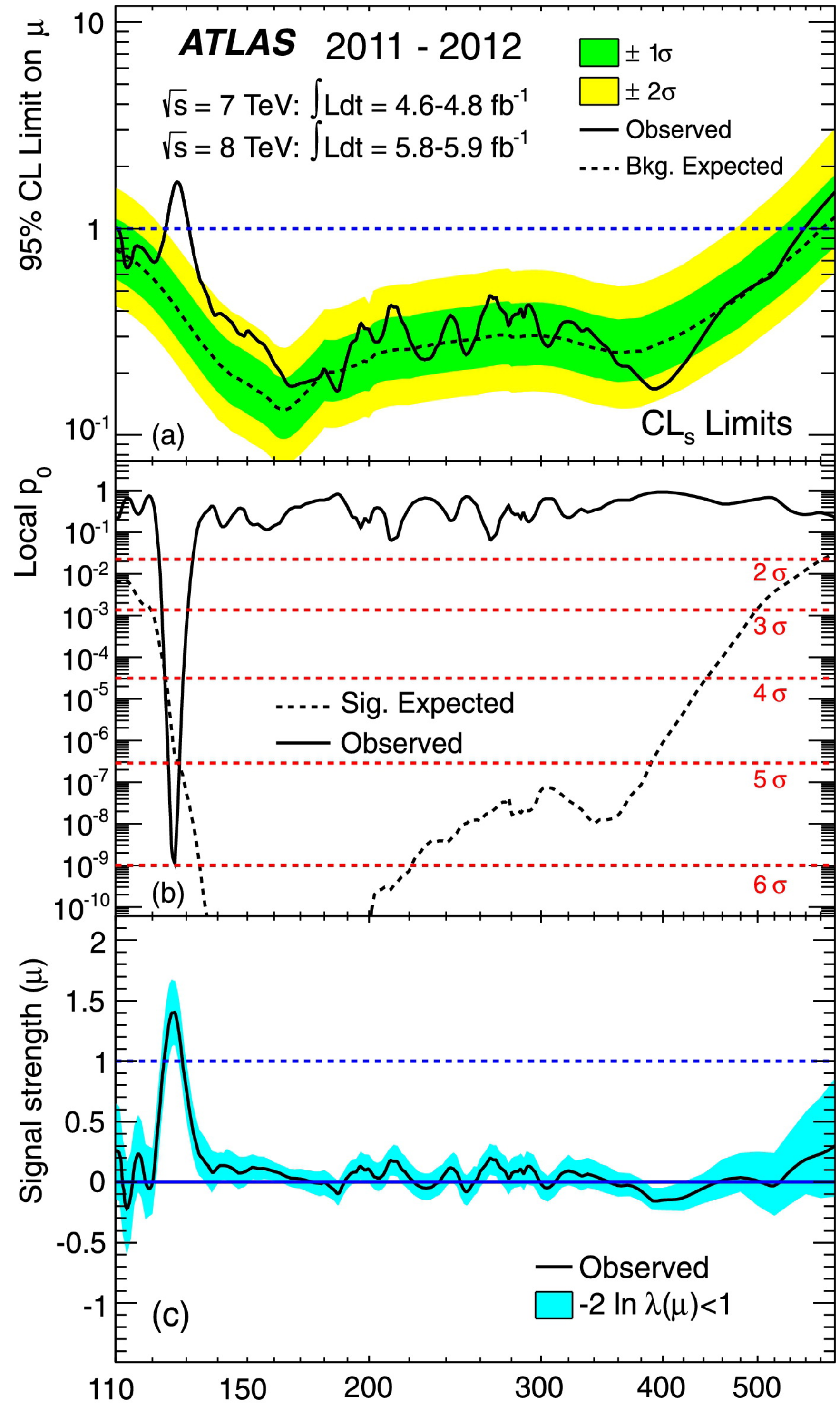


Fig. Combined search results:

(a) The observed (solid) 95% CL limits on the signal strength as a function of mH and the expectation (dashed) under the background-only hypothesis. The dark and light shaded bands show the ±1σ and ±2σ uncertainties on the background-only expectation.

(b) The observed (solid) local p0 as a function of mH and the expectation (dashed) for a SM Higgs boson signal hypothesis (μ = 1) at the given mass.

(c) The best-fit signal strength View the MathML source as a function of mH. The band indicates the approximate 68% CL interval around the fitted value.

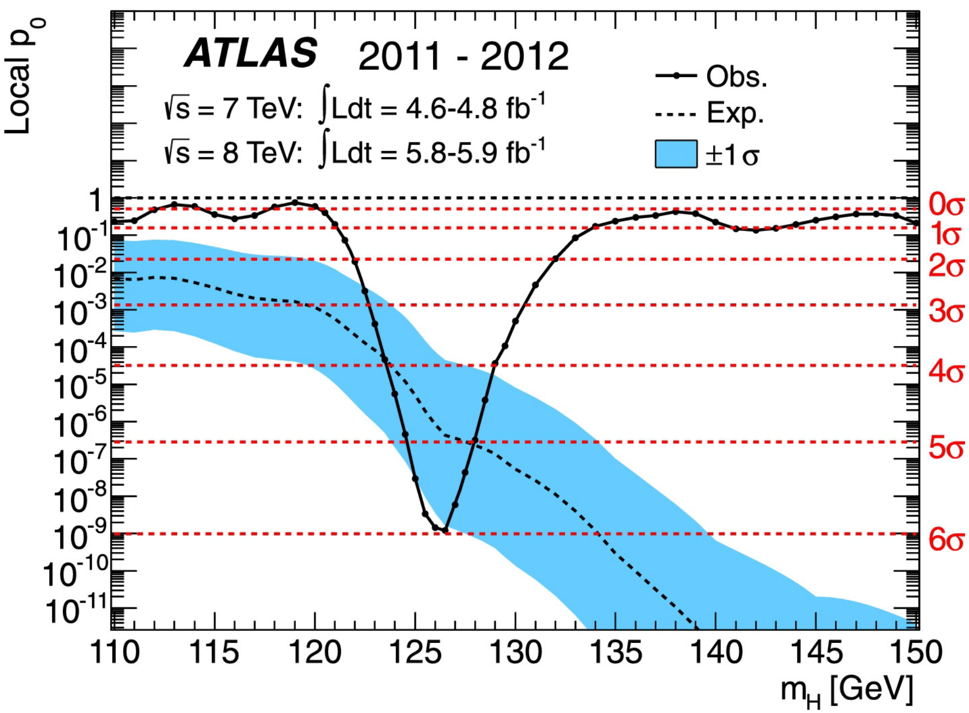
Definition of P_0

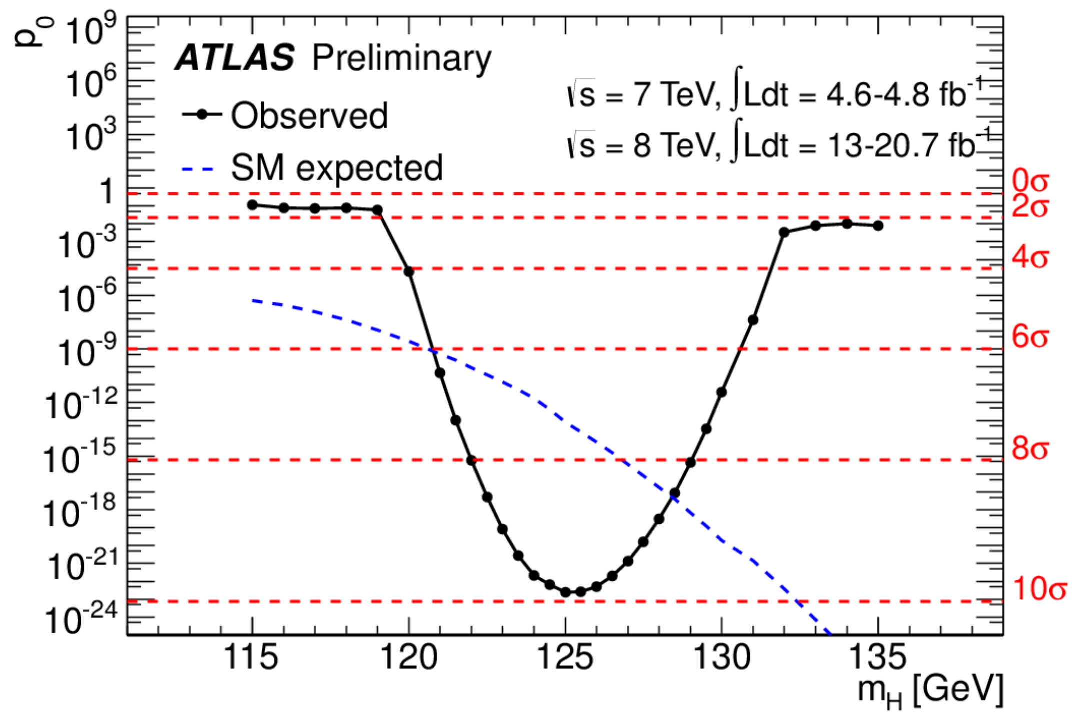
- In case of discovery important parameter is Significance of H_0

$$\mathbf{p_0 \approx CL_B \equiv} \; P(\,\tilde{q}_\mu \geq \tilde{q}_\mu^{obs} \,|\, \text{background-only}) \;=\; \int_{q_0^{\rm obs}}^{\infty} f(\tilde{q}_\mu|0, \hat{\theta}_0^{\rm obs})\, d\tilde{q}_\mu$$

- For a significance against H_0 of 5σ you need $p_0 = 2.87\ 10^{-7}$

p-value of discovery





The observed (solid) local p0 as a function of mH in the low mass range. The (dashed) curve shows the expected local p0 under the hypothesis of a SM Higgs boson signal at that mass with its ±1σ band. The horizontal dashed lines indicate the p-values corresponding to significances of 1 to 6 σ.

Let's wait for new exciting p-values then!!

THANKS!