

$$\begin{aligned}
 \mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
 & + i \bar{\psi} \not{D} \psi + \text{h.c.} \\
 & + X_i Y_{ij} X_j \phi + \text{h.c.} \\
 & + |D_\mu \phi|^2 - V(\phi)
 \end{aligned}$$

# LHC to Terascale Physics Workshop

LAL-Orsay, November 22-23, 2011

## Implications of LHC results for TeV-scale physics:

### Discussion II of data interpretation

A. Read (U. Oslo/LAL)

# Topics

- Presentation of (Higgs) search results, a quick review
- Treatment of theory uncertainties, especially n-point on acceptance, shape
- LEE (had some interesting input from John Ellis and Sven H.)
- Making similar interpretations from different plots
- Confidence intervals for  $m_H$  ?
- Narrow signal systematics
- Combining indirect and direct (non)evidence





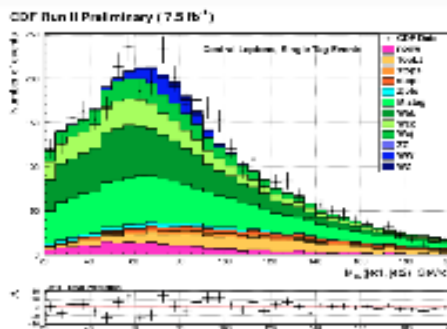
# Dibosons searches as proxy for $VH \rightarrow Vbb$

For  $M_H=115$  GeV,  $VH \rightarrow Vbb$  is 46 fb, while  $VZ \rightarrow Vbb$  is 202 fb.

talk by Grivaz  
Jean-Francois

The cross section for diboson production is 4.5 times larger than for  $VH$ . But the background situation at lower mass is more difficult.

## WW+WZ in $lv+HF$



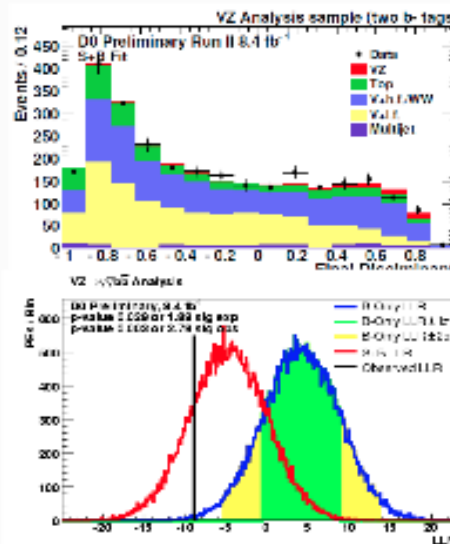
WW/WZ ratio fixed as in the SM  
Large contribution from  $WW \rightarrow lvcs$   
**3.0  $\sigma$  from the B-only hypothesis**  
(3.0 expected)

Good agreement with S+B:  
 $\sigma(WW+WZ) = (1.1 \pm 0.3 \pm 0.4) \sigma_{SM}$



CDF

## WZ/ZZ in MET + HF



**2.8  $\sigma$  from the B-only**  
(1.9 expected)  
 $\sigma(WZ+ZZ) = (1.5 \pm 0.5) \sigma_{SM}$   
Sensitivity shared by ZZ and WZ



The combination of these searches has been done using the same technique as for the Higgs.

**3.3  $\sigma$  evidence**  
**for WZ+ZZ combined**  
(2.9 expected)

$$-2 \ln \frac{L(\mu, \hat{\theta})}{L(0, \hat{\theta})}$$

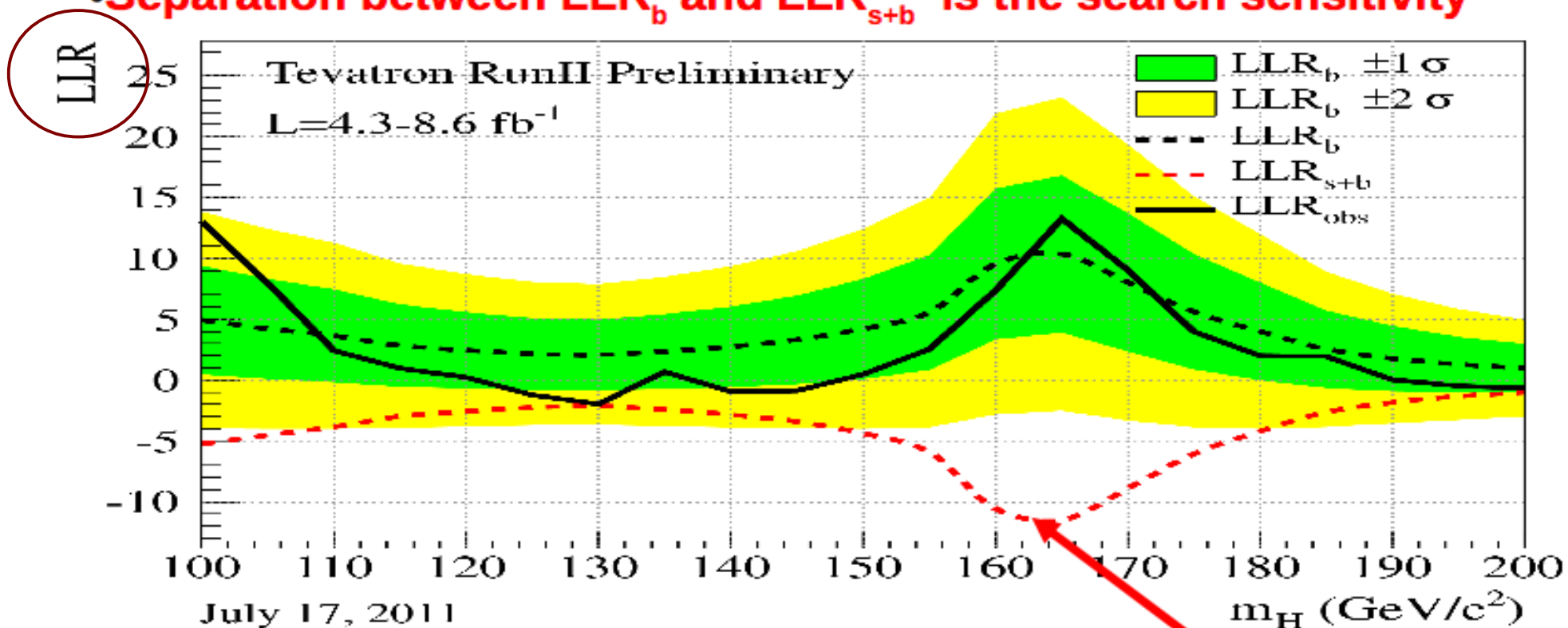
**Good agreement with S+B:**  
 $\sigma(WZ+ZZ) = (1.13 \pm 0.36) \sigma_{SM}$

D0

# Tevatron Sensitivity

- Log-likelihood Ratios (LLR):  $LLR_b$ ,  $LLR_{s+b}$ ,  $LLR_{obs}$

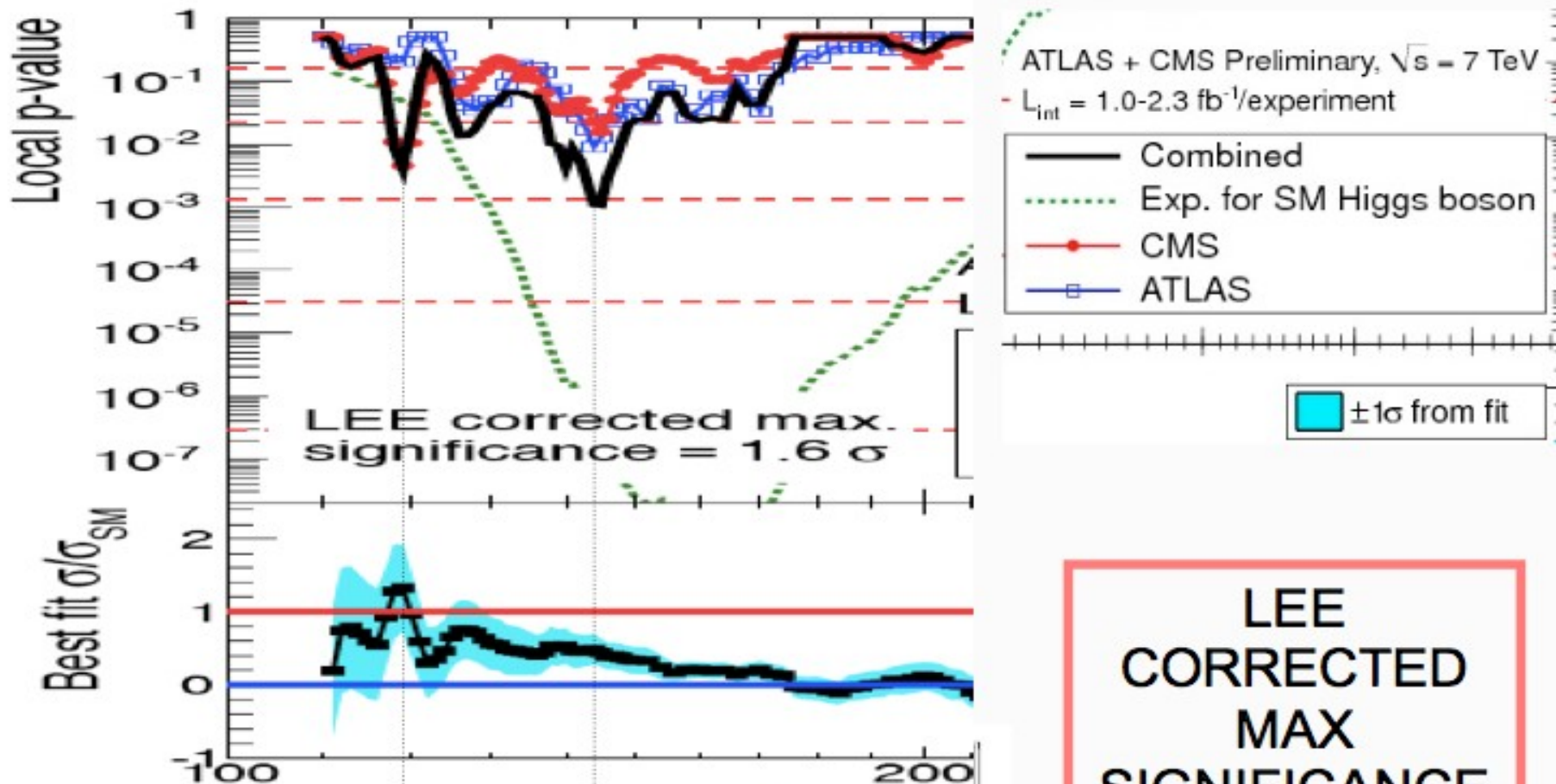
- Separation between  $LLR_b$  and  $LLR_{s+b}$  is the search sensitivity



We could be seeing a  $\sim 3 \sigma$  excess if Higgs was at 165 GeV!

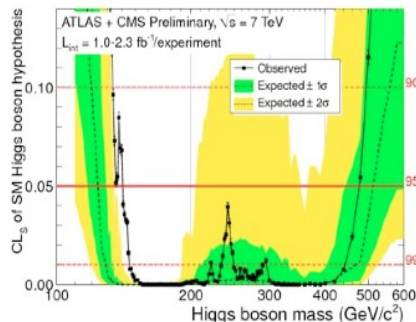


# Combination: p-values and $\sigma/\sigma_{\text{SM}}$

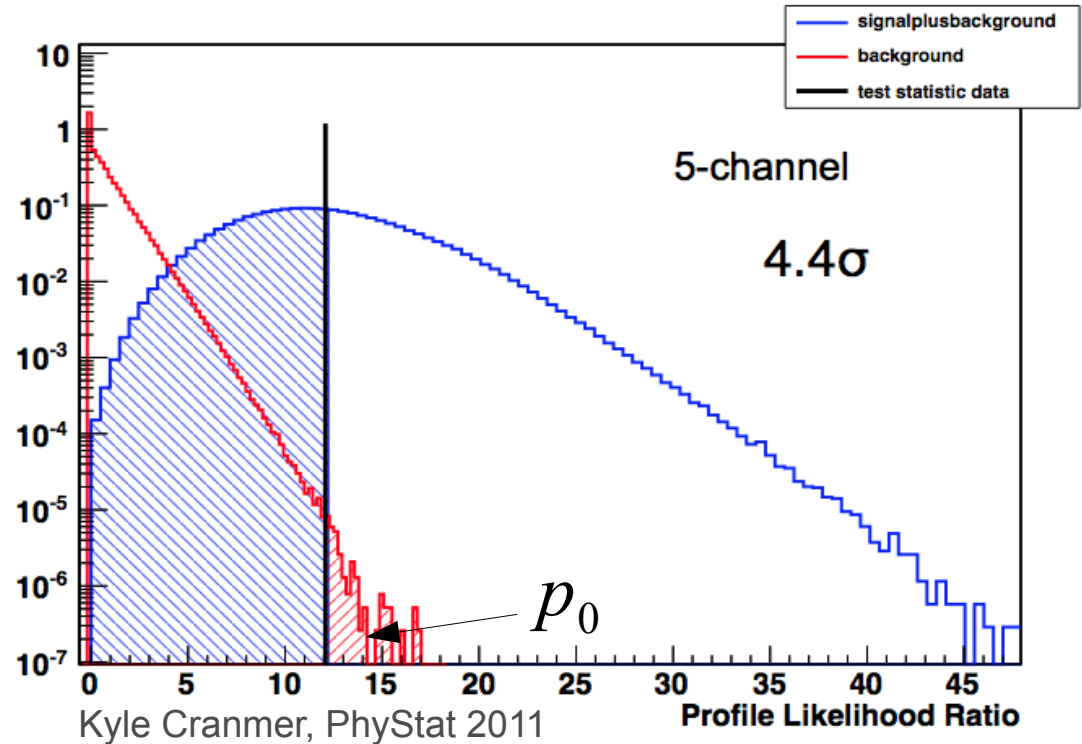
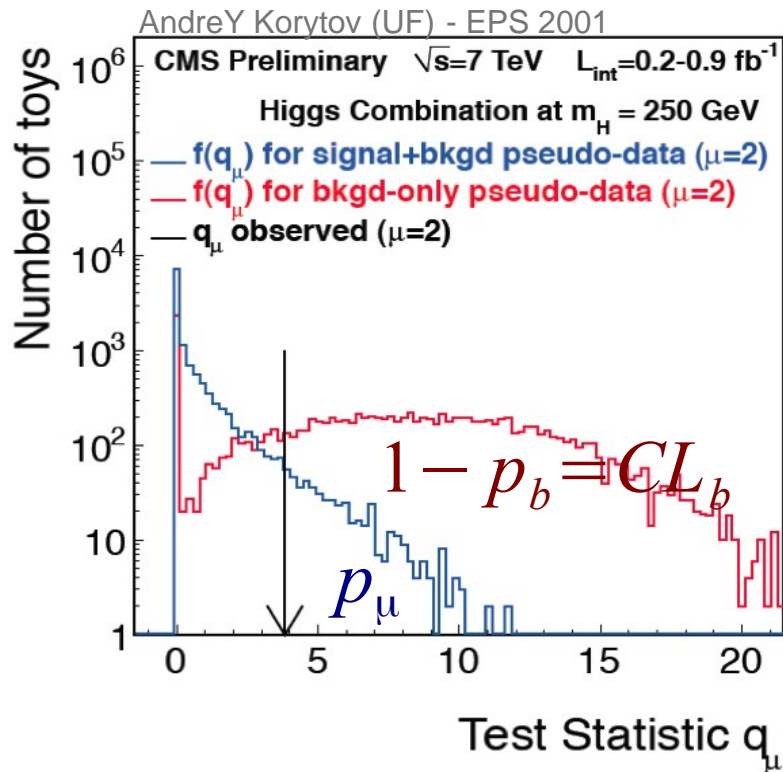


LEE  
CORRECTED  
MAX  
SIGNIFICANCE  
 $1.6\sigma$

LEE for not SM?  
Interpretations?



# “LHC” test statistics (2)



- Wonderful asymptotic properties
  - Signal+b is chi-squared for signal+b test
  - Background is chi-squared for b-test
- At cost of more information to digest
- Small cost of sensitivity
- Complicated. *Show them for POI?*



# Old thought about exclusion->measurement

## Presentation of search results: the $CL_s$ technique

A L Read

[Show affiliations](#)

 Tag this article  Full text PDF (382 KB)

**Abstract**

**References**

**Cited By**

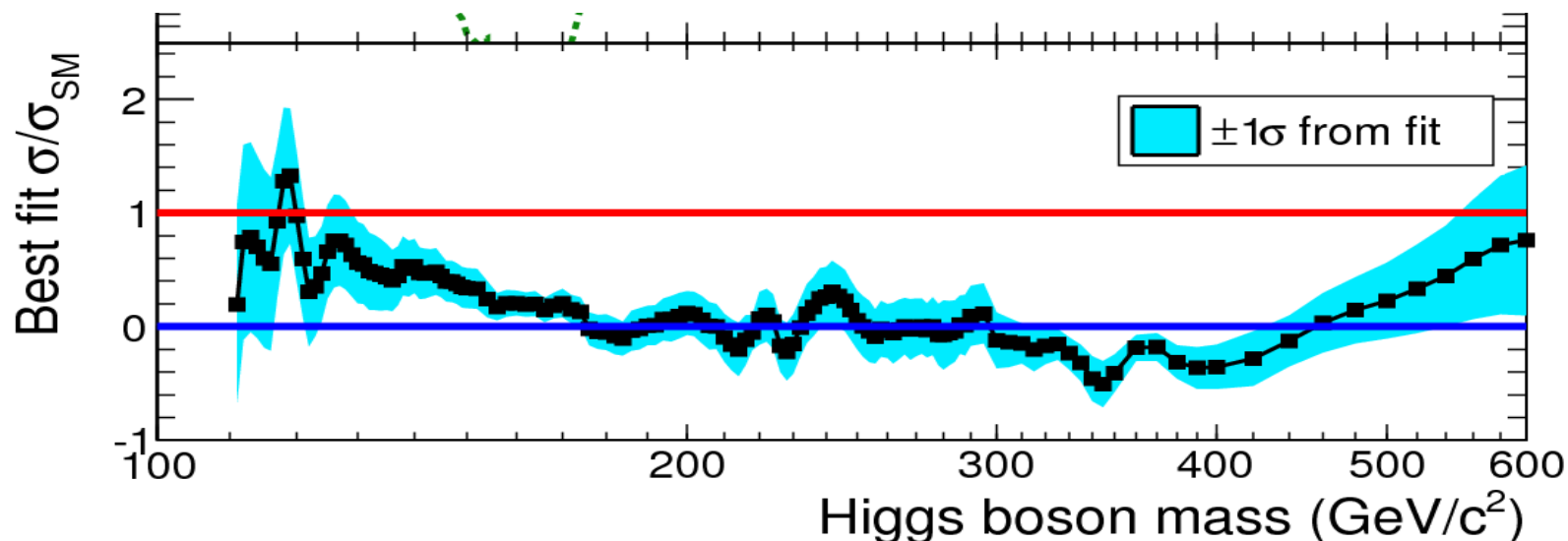
### DURHAM IPPP WORKSHOP PAPER

I describe a framework for the presentation of search results which is motivated by frequentist statistics. The most well-known use of this framework is for the combined search for the Higgs boson at LEP. A toy neutrino oscillations experiment is used to illustrate the rich information available in the framework for exclusion and discovery. I argue that the so-called  $CL_s$  technique for setting limits is appropriate for determining exclusion intervals while the determination of confidence intervals advocated by Feldman and Cousins' method is more appropriate for treating established signals, i.e. going beyond discovery to measurement.

(From the workshop 'Advanced Statistical Techniques in Particle Physics', 18–22 March 2002)

# Questions

- Is point of maximum  $\hat{\mu}(m_H)$  equivalent to  $\hat{m}_H$ ?
- Is point of maximum significance equivalent to  $\hat{m}_H$ ?
- How/when can we profile  $\hat{m}_H$ ?
- Can we turn  $\hat{\mu}(m_H)$  and confidence interval into effective likelihood function for third-party combinations/global fits?





# Combining measurements and searches

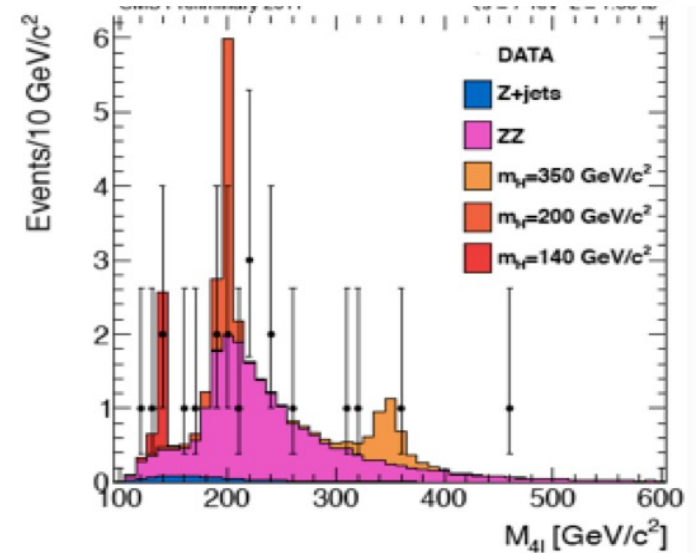
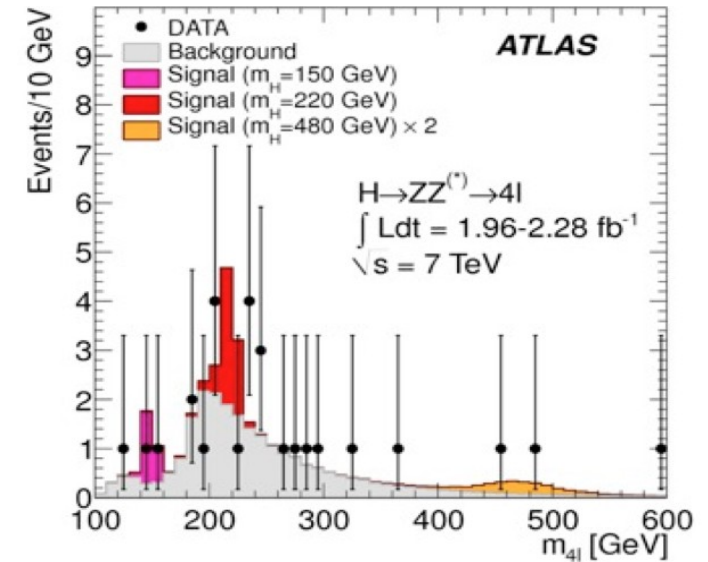
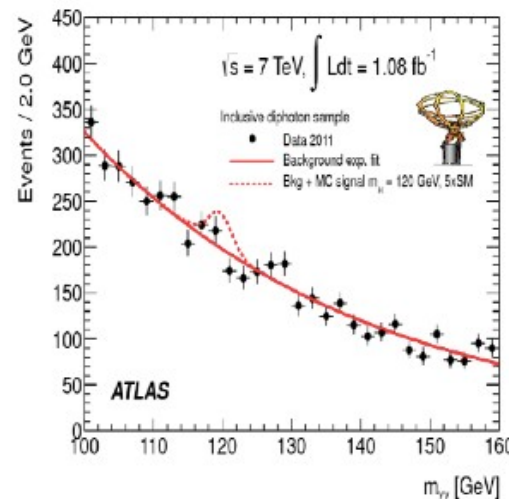
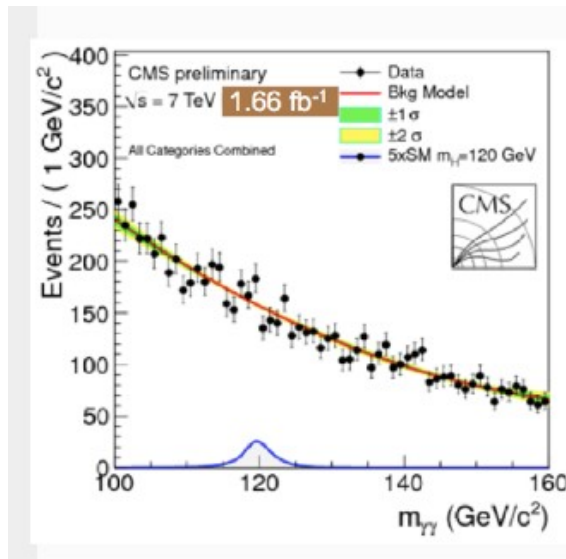
- Deriving likelihood function or posterior probability for signal from 1-sided limits is questionable, *except in asymptotic limit*.
- $\hat{\mu}$  is automatically either a limit or measurement, and *can* make sense to combine with other measurements.
- Difference is likelihood ratio with respect to most probable signal versus w.r.t. background hypothesis.

# 2(or n)-point uncertainties

- How to take into account systematic uncertainty when sampling e.g. 2 event generators?
  - Fit difference to continuously varying nuisance parameter which describes shape and/or acceptance difference?
  - Pseudo-prior 50-50?
  - Report 2 results? Take most conservative as main?
  - Report 1 result, take difference as uncertainty and ignore that there is a conceptual problem?

# Narrow signals

- Careful attention to
  - Inter-channel calibration
  - Inter-experiment calibration
  - Theory-experiment



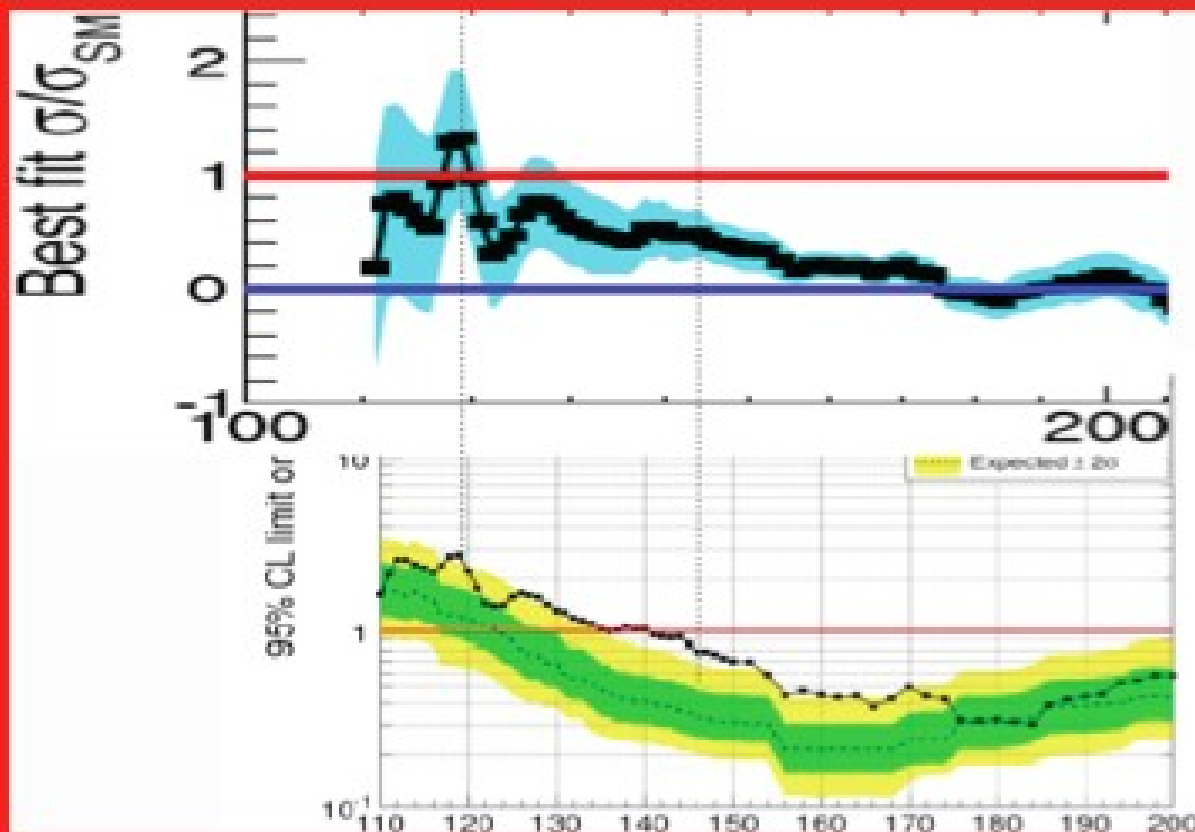


# Post-LHC, Post-XENON100



2011 ATLAS + CMS with  $1 \text{ fb}^{-1}$  of LHC Data

Higgs mass



LEE  
CORRECTED  
MAX  
SIGNIFICANCE  
 $1.6\sigma$

J. Ellis HCP 2011

27/32

Favoured values of  $M_h \sim 119 \text{ GeV}$ :  
Coincides with value consistent with LHC !

# Conclusions

- Rising demand for likelihood function or posterior probability distribution.
- LEE *may* be model dependent
  - Collaborators in same third-party client of combination results with precisely opposite opinions!
- $\hat{\mu}(m_H)$  very versatile in asymptotic limit!
  - Need to study the limitations, I still suggest  $\hat{m}_H$  as estimator of Higgs mass.
- Should pay careful attention to narrow signal challenges.
- Did we progress on treatment of theory syst?

# Backup



# LLR test statistics

	Test statistic	Test statistic	Nuisance parameters	Pseudo-experiments
LEP	$-2 \ln \frac{L(\mu, \tilde{\theta})}{L(0, \tilde{\theta})}$	Simple LR	Fixed by MC	Nuisance parameters randomized about MC
Tevatron	$-2 \ln \frac{L(\mu, \hat{\hat{\theta}})}{L(0, \hat{\hat{\theta}})}$	Ratio of profiled likelihoods	Best estimates	Nuisance parameters randomized about profiled, MC also fitted
LHC	$-2 \ln \frac{L(\mu, \hat{\hat{\theta}})}{L(\hat{\mu}, \hat{\hat{\theta}})}$	Profile likelihood ratio	Profiled (fit to data)	New nuisance parameters fitted for each pseudo-exp.

LHC sampling of test statistic is frequentist, LEP and Tevatron Bayes-frequentist hybrid.  $CL_s$  can be used together with any of these – must be specified! No longer sufficient to write e.g. “the  $CL_s$  method was used”.