University of Glasgow | Experimental Particle Physics

Application of CLs Method to ATLAS Higgs Searches

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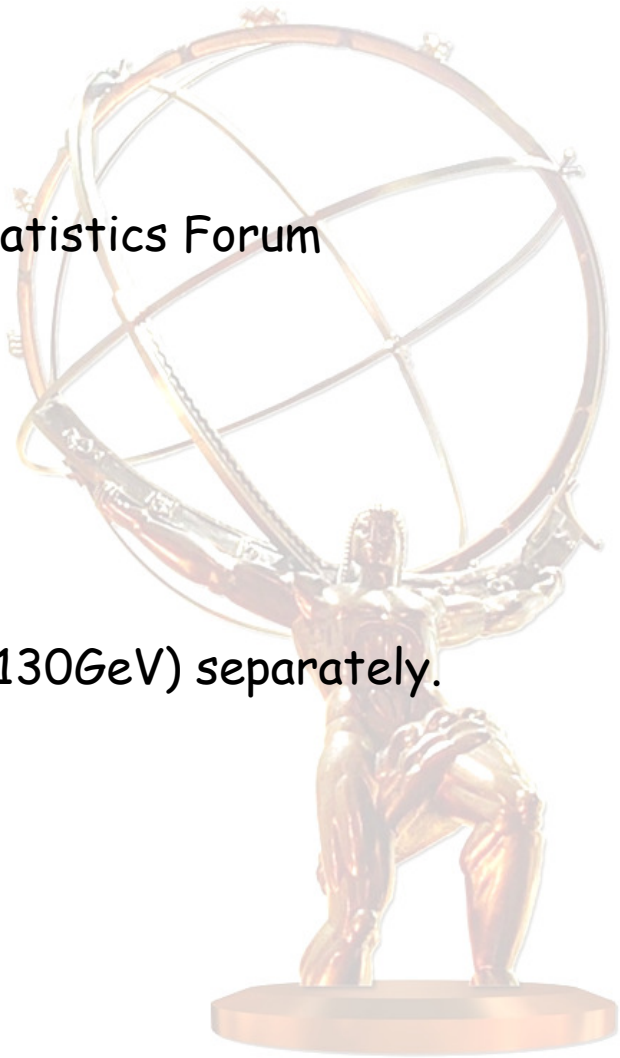
ATLAS UK Physics Meeting (11/01/08)

The 12 minute plan

- The road to discovery..
- The Help Along the Way – The ATLAS Statistics Forum
- Statistical Methods for Combination
- The 'CL_S Method'
  - Results for $H\rightarrow\gamma\gamma$ and $H\rightarrow\tau\tau$ (at 130GeV) separately.
- Toy Combination Exercise
- Conclusions/Outlook



Discovery Process

Quoting Alex Read:

'EXCLUSION → OBSERVATION → DISCOVERY → MEASURE'

↑

All we have so far, are exclusion limits.

→ LEP2 placed a 95% Confidence Level exclusion on the mass of the Higgs at lower than 114.4GeV.

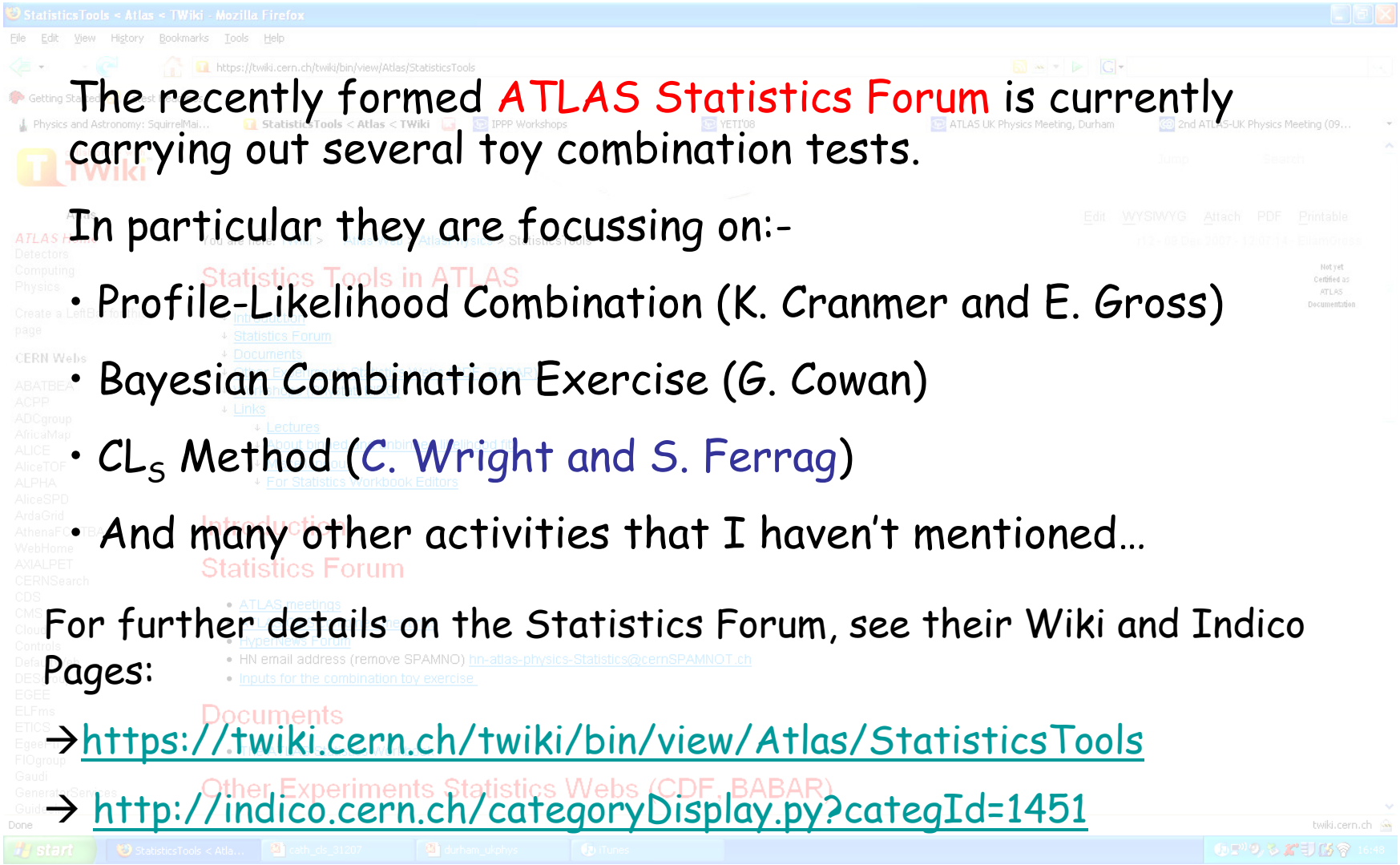
→ Tevatron are close to exclusion (or discovery) at ~160GeV.

→ Will ATLAS need to place limits? (Or are we just going to jump in at the deep end and find the Higgs?)

↓

If yes (to calculating limits), we should exploit the expertise of previous experiments at ATLAS.

The ATLAS Statistics Forum



The recently formed ATLAS Statistics Forum is currently carrying out several toy combination tests.

In particular they are focussing on:-

- Profile-Likelihood Combination (K. Cranmer and E. Gross)
- Bayesian Combination Exercise (G. Cowan)
- CL_S Method (C. Wright and S. Ferrag)
- And many other activities that I haven't mentioned…

For further details on the Statistics Forum, see their Wiki and Indico Pages:

→https://twiki.cern.ch/twiki/bin/view/Atlas/StatisticsTools

→ http://indico.cern.ch/categoryDisplay.py?categId=1451

'CL_S Method'

- Log-Likelihood Ratio (LLR)

Bin-by-bin Log-Likelihood Ratio analysis on the signal and background distributions of the channel in question.

The test statistic:-

$$LLR = -2\sum_{i=1}^{N}\left(s_i - n_i \ln\left(1+\frac{s_i}{b_i}\right)\right)$$

Produce two distributions of the test statistic.

- H_1 is the test hypothesis - signal plus background
- H_0 is the null hypothesis - background only.

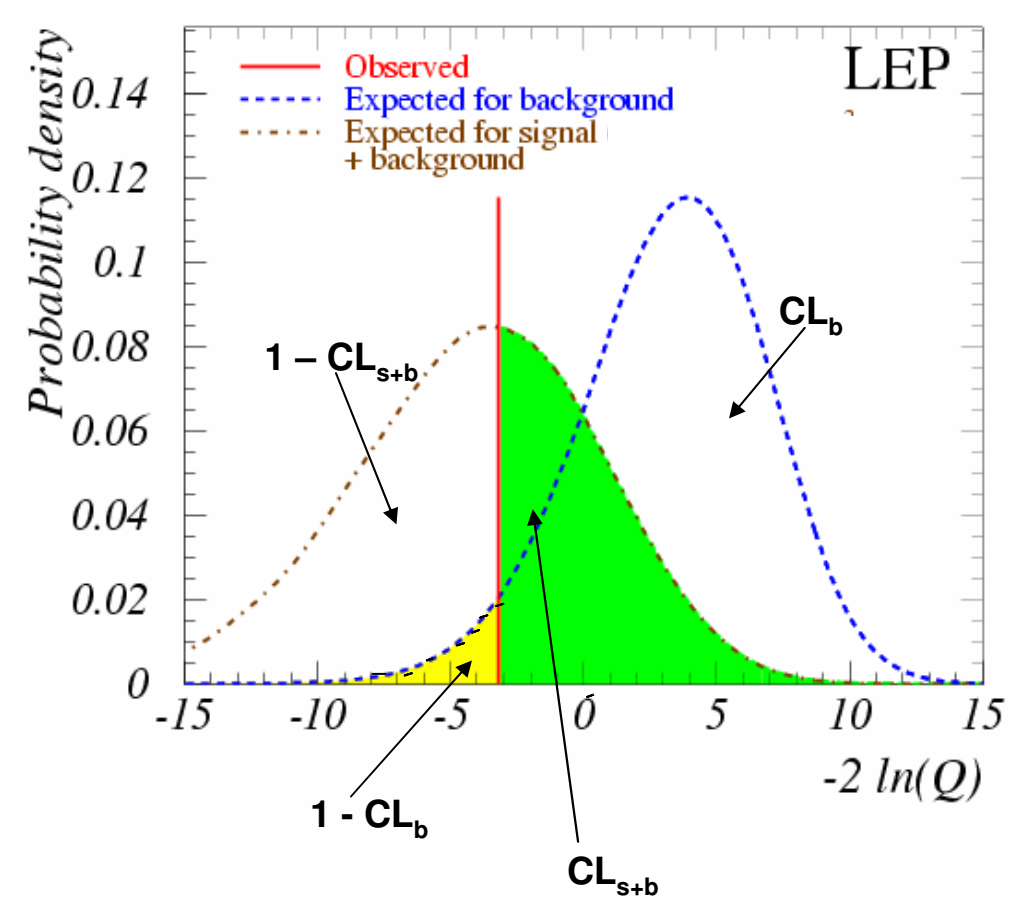
How to make the Distributions (PDFs):.

- 'Generate' fake data (pseudo-data) in ROOT - follows the reconstructed s+b template, within Poisson statistical fluctuations.
    - Calculate LLR value for H_0.
    - Calculate LLR value for H_1.
- Generate 'Data' 10,000 times (i.e. make 10,000 pseudo experiments)

→ Get distributions of test statistics for H_1 and H_0. (See over for example)

Interpreting Results

CL_s method is an inaccurate name for this method, it is a log-likelihood ratio test, which uses the CL_S value to imply EXCLUSION or $1\text{-}CL_b$ to estimate the significance of a possible discovery!



$1\text{-}CL_{s+b}$ = Discovery potential.

CL_{s+b} = False Exclusion Rate

CL_b = Exclusion potential

$1\text{-}CL_b$ = False Discovery Rate (Power)

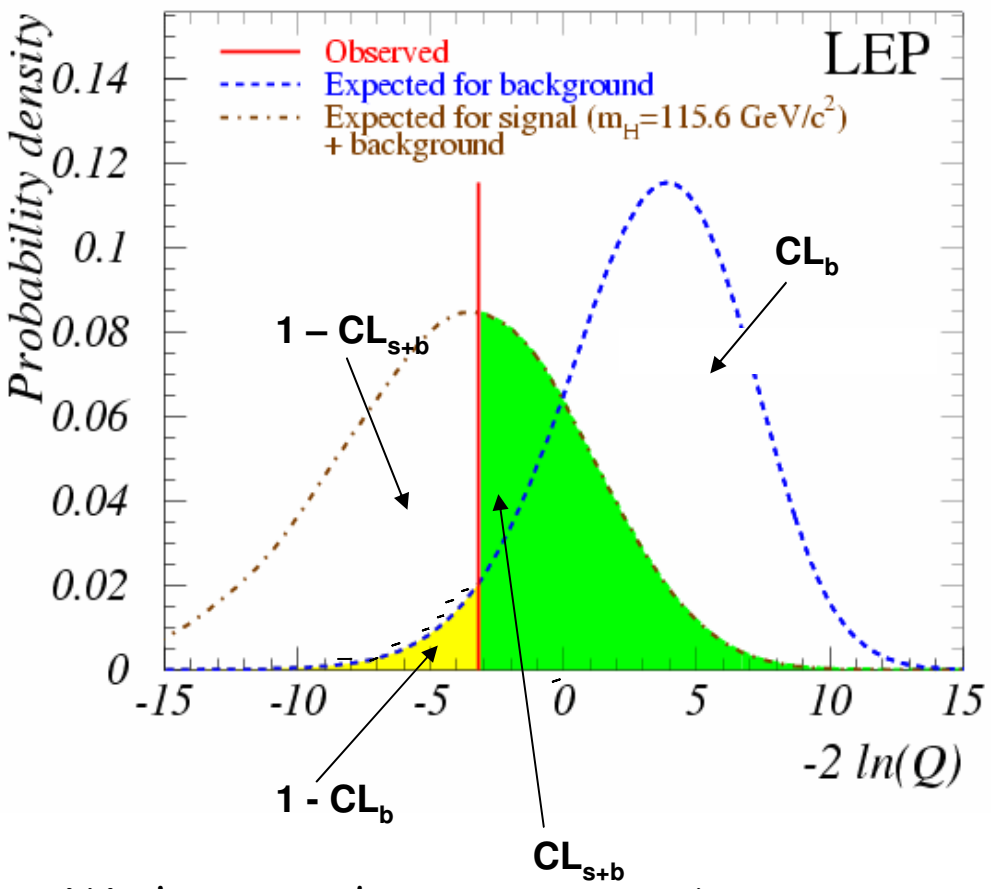
≡ Significance Level

Exclusion at LEP :

To exclude at given modified Confidence Level (CL), introduce CL_S:

$$CL_s = \frac{CL_{S+b}}{CL_b}$$

Interpreting Results (2)



To exclude at given Confidence Level (CL):

$$1-CL_s \geq CL$$

So, to Exclude at 95% CL:

$$1-CL_s \geq 0.95$$

i.e. the False Exclusion Rate (CL_{s+b}) cannot be any more than 5% of the Exclusion Potential (CL_b).

→ Protects against excluding when you are insensitive to the result.

We have no data… so we can't state an exclusion limit or definite significance. NOTE: Due to limited statistics, using same mc samples for mc (expected distn) and 'data'.

Instead, we estimate an expected significance or state a required luminosity to achieve a 95% CL Exclusion or 5sigma discovery.

Input Requirements

For the CL_s method, the input requirements are simple:-

- Un-normalised histograms of signal and background SEPARATELY (Required to correctly deal with MC statistical fluctuations in mclimits).
- Scale Factors for a given luminosity e.g. $10fb^{-1}$.

Alternatively, if the un-normalised histograms are provided, then we can estimate the scale factor, if provided with:-

- cross-sections (so far, have been taken from ATL-COM-2007-024)
- efficiency, ε_{EF}, of any generator level cuts placed on the channel.
- N_{gen}, number of generated events in sample.

So that we can use:

$$L_{gen} = \frac{N_{gen}}{\varepsilon_{EF} . \sigma_{channel}}$$

to get scale factors.

→ Results using T.Junk's mclimits.C code CDF/DOC/STATISTICS/PUBLIC/8128

The Toy Combination

- Channels and mass points provided by WGs to Stat Forum

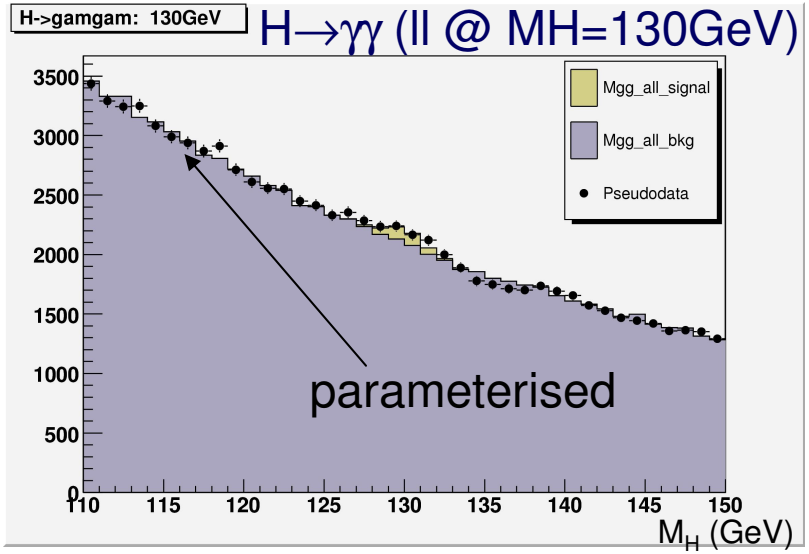
→https://twiki.cern.ch/twiki/bin/view/Atlas/CombinationInputs

- $H \to \gamma\gamma$ - Signal and background @ M_H=130GeV normalised to 10fb^{-1}
- $H \to \tau\tau$ - Signal and background @ M_H=105 - 135GeV normalised to 1fb^{-1}.
- $H \to 4l$ - Signal and background @ M_H=130GeV normalised to 1fb^{-1}.
- $H \to WW$ - weighted events… don't know yet how to handle this with mclimits.

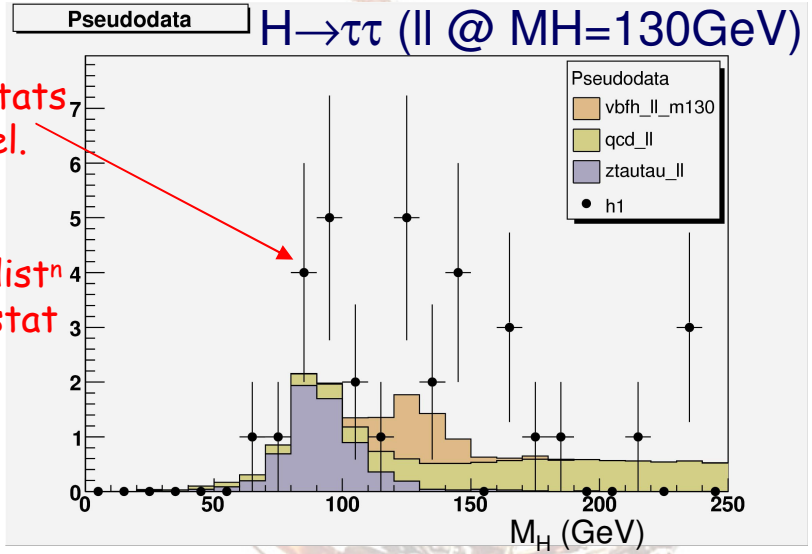
NB. The samples available on the Wiki for the combination are NORMALISED… ideally, we would have UN-NORMALISED distributions. (see previous)

Not looked at the $H \to 4l$ or $H \to WW$ data yet so results shown are for the $H \to \gamma\gamma$ and $H \to \tau\tau$ channels at M_H=130GeV.

$H\to\gamma\gamma$ and $H\to\tau\tau$ Distributions for $10fb^{-1}$...



Limited MC stats in this channel. Generated pseudo-data follows this distⁿ with LARGE stat fluctuations.



$H\to\gamma\gamma$

Background will be estimated from data i.e. no mc stat uncertainties.

- Scale up by 10000 to get 'infinite' statistics i.e. shape exactly correct. (asymptotic limit.)
- Give 0.0001 as scale factor for $10fb^{-1}$, to mclimits code.

$H\to\tau\tau$

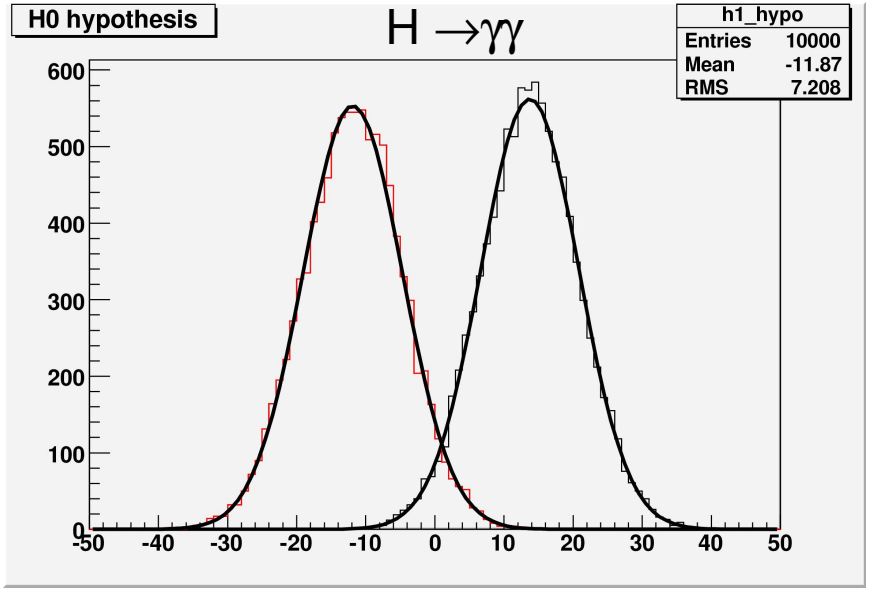
Background will be estimated from control samples. As yet, not been provided with these samples.

So, we make do with what we have.

Notice, s_i much lower for $H\to\tau\tau$ so either need more MC stats or fits or better method of generating pseudodata.

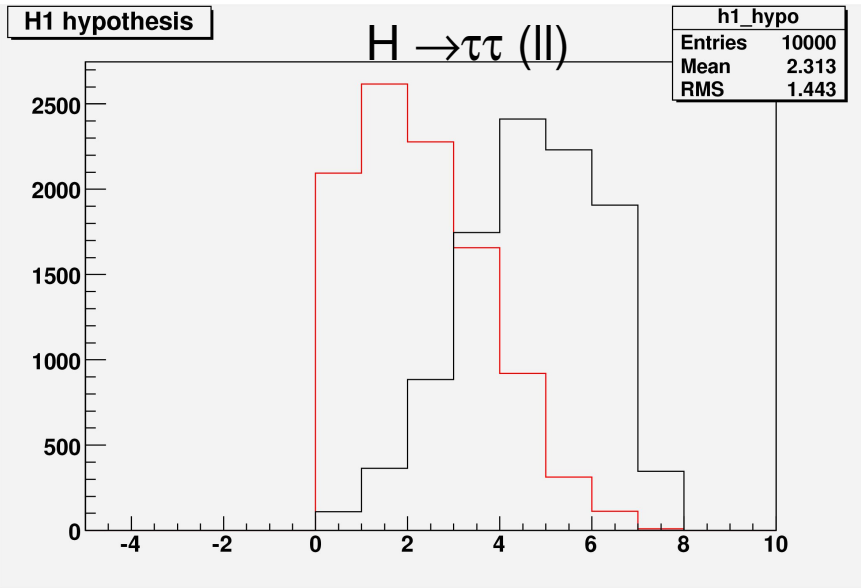
(→Work to improve on-going.)

Results - H→ττ and H→γγ



	Luminosity – Exclusion (95% CL)	Luminosity – Evidence (3 sigma)	Luminosity – Discovery (5 sigma)
H →γγ (@130GeV)	**3.1fb^{-1}**	**6.9fb^{-1}**	**19.4fb^{-1}**

Significance (for 10fb^{-1}) ~ 3.3σ



	Luminosity – Exclusion (95% CL)	Luminosity – Evidence (3 sigma)	Luminosity – Discovery (5 sigma) *
H →ττ (ll) (@130GeV)	**39.1fb^{-1}**	**83.4fb^{-1}**	**185.7fb^{-1}**

Significance (for 10fb^{-1}) ~ 2σ

* Results are affected by inaccurate pseudo-data.

A preliminary combination

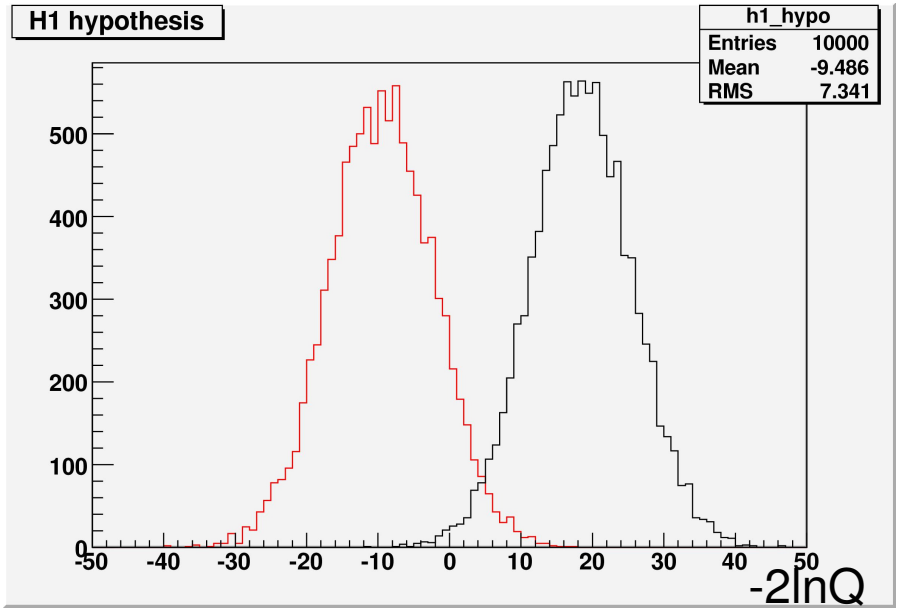
Easy to extend LLR method to more than one channel! Method used for Tevatron combination exercises. (See CDF Note 8384/ D0 5227.)

N is the total number of bins over all analyses

$$LLR = -2\sum_{i=1}^{N}\left(s_i - n_i \ln\left(1+\frac{s_i}{b_i}\right)\right)$$

i.e. the sum now runs over the total number of bins and/or analyses being considered.

Combination of $H\to\gamma\gamma$ and $H\to\tau\tau$(ll) at 130GeV with 10fb^{-1} of data…



	Luminosity – Exclusion (95% CL)	Luminosity – Evidence (3 sigma)	Luminosity – Discovery (5 sigma)
$H\to\gamma\gamma$ + $H\to\tau\tau$ (@130GeV)	**3.04fb^{-1}**	**6.62fb^{-1}**	**18.7fb^{-1}**

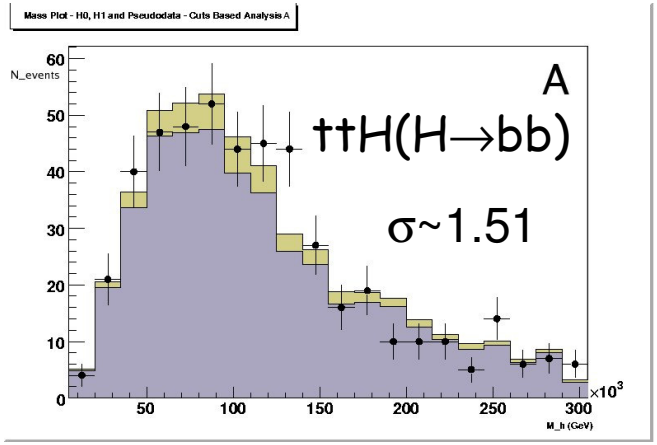
Significance (for 10fb-1) [quadrature] = 3.85σ

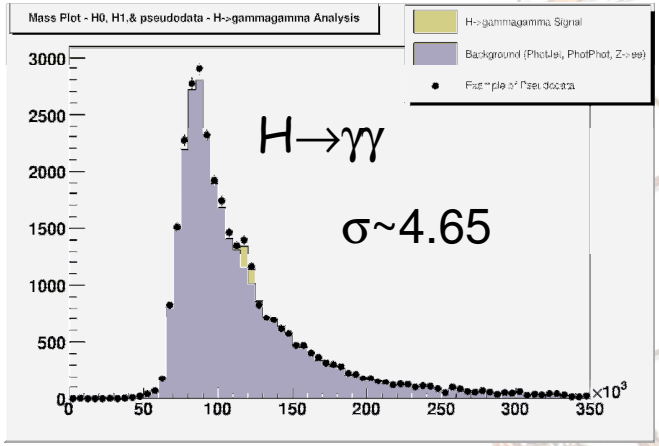
Significance (for 10fb-1) [Likelihood] = 3.5σ

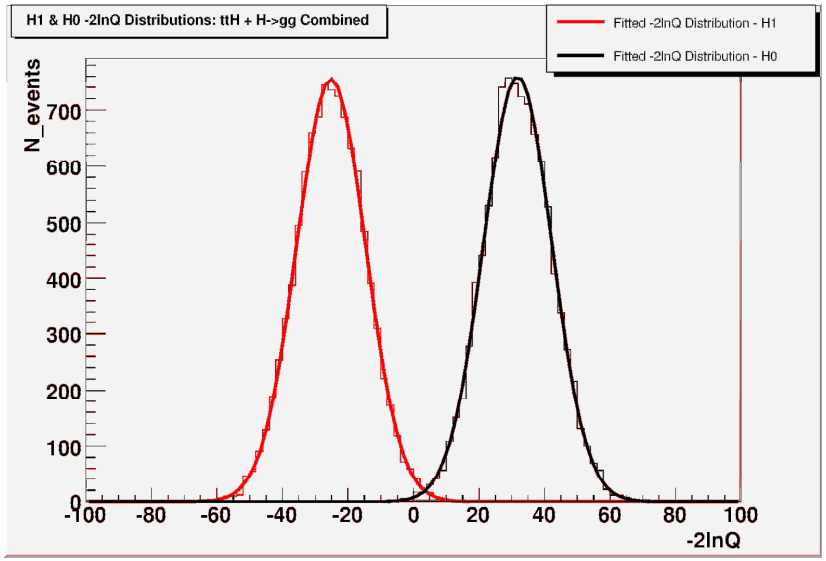
→Looks bad! But remember pseudodata stat fluctuations!

A better (but older!) example

Combine ttH(H→bb) and H→γγ @ M_H=120GeV for 30fb^{-1}.







Significance (for 10fb-1) [quadrature] = 4.8σ

Significance (for 10fb-1) [Likelihood] = 5.4σ

Small but important increase in the sensitivity when both channels are considered in the likelihood!

Conclusions/Outlook

- Introduced the Statistics Forum.
- Discussed the so-called CL_S method.
- Following the CDF/DØ approach for combining channels, produced a result for the combination of $H\rightarrow\gamma\gamma$ and $H\rightarrow\tau\tau$(ll) .

  → 'Official' toy data results – looks like adding in quadrature better than the likelihood.

  →Suspect this is due to the low mc stats in the $H\rightarrow\tau\tau$ sample, causing pseudo-data to fluctuate.

  →Look at other example (ttH + H $\rightarrow\gamma\gamma$) and see Likelihood is 'better'.

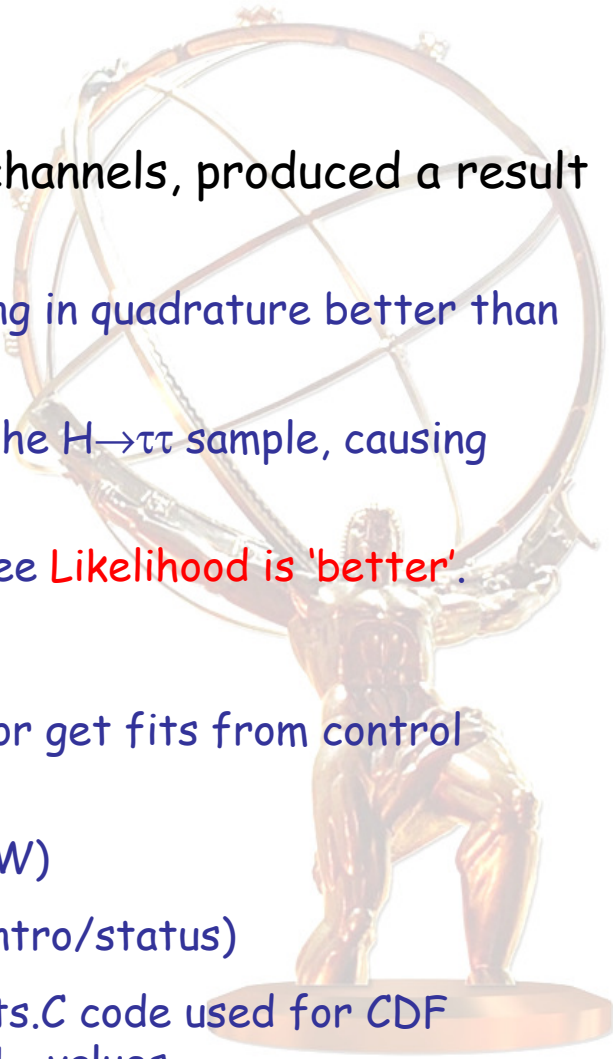
Outlook includes:

→Generate (maybe using FastSim) more MC or get fits from control samples for $H\rightarrow\tau\tau$.

→Including other channels ($H\rightarrow$4l and $H\rightarrow$WW)

→Inclusion of systematics (See backup for intro/status)

→Further understand and exploit the mclimits.C code used for CDF combinations to look at expected CL_s and 1-CL_b values.

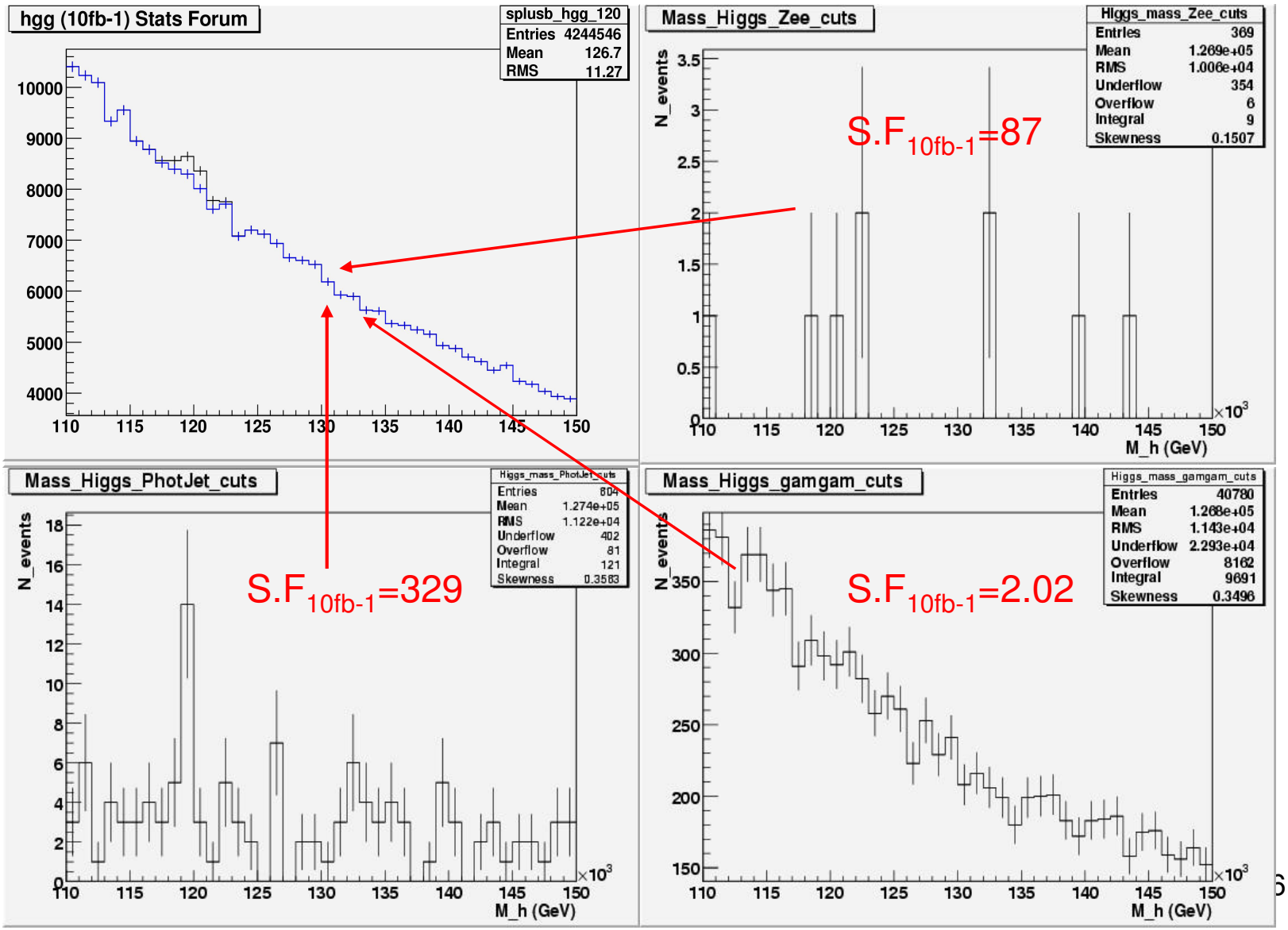


There is a LOT still to do!!!

Back-up

Scaled vs. Non-scaled

(Example is at 120GeV as samples provided in ntuple format were at that mass.)



Effect of Systematics

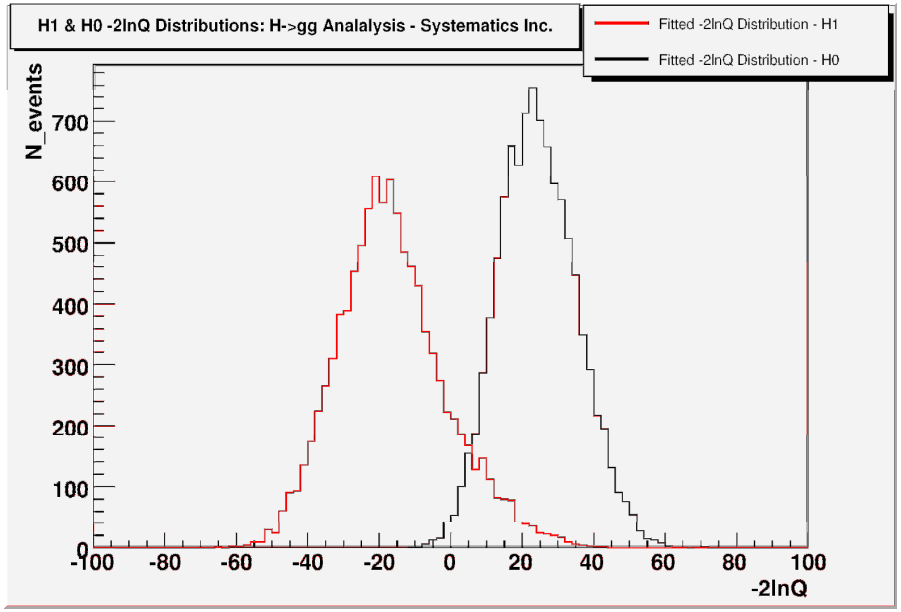
Some systematic uncertainties affect the expected rate of the signal and background, whilst others affect the expected shape of the distributions.

The systematics shown here are preliminary and are estimated from Performance Group results, theoretical uncertainties and the systematic uncertainties from the Tevatron (ref: FERMILAB-PUB-03/320-E).

In mclimits these two systematics are treated separately.

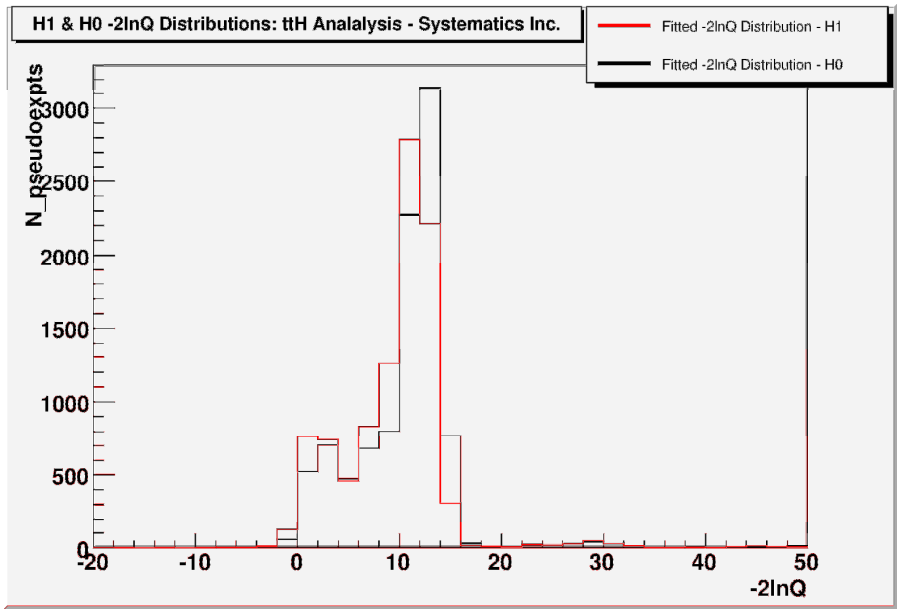
- A number is provided for the nuisance parameters that affect expected rate. E.g. 10%
- A histogram must be provided for those affecting expected shape.

Results – Including Systematics



Sensitivity Threshold (H->γγ)	2σ	3σ	5σ
$P(N_{\sigma\_H0})$ | H1 true (%)	89.0	72.4	19.6
$P(N_{\sigma\_H1})$ | H0 true (%)	2.27	0.13	2×10^{-7}

Probabilities are reduced as a result of including the systematics though not hugely… Discovery/Exclusion limits with $30fb^{-1}$ remains feasible in this channel.



Sensitivity Threshold (ttH)	2σ	3σ	5σ
$P(N_{\sigma\_H0})$ | H1 true (%)	10.8	1.79	0.01
$P(N_{\sigma\_H1})$ | H0 true (%)	2.27	0.13	2×10^{-7}

With $30fb^{-1}$, (and systematic uncertainties as suggested) would not be possible to place limits on the exclusion of the Higgs with the ttH channel.