Measuring Higgs Couplings

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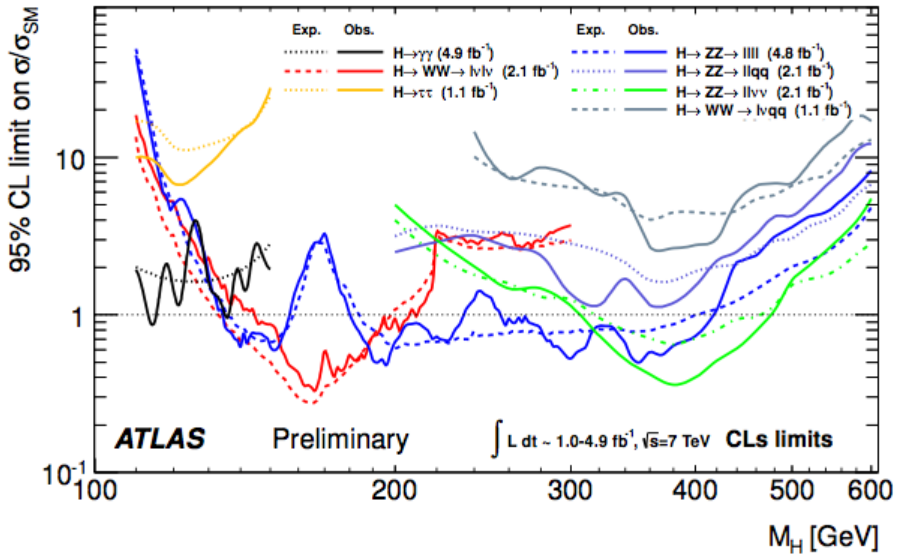
Pheno 2012, Pittsburgh

Data!

Around Moriond 2012

- ATLAS and CMS results published
- official line: ‘exclusion gone wrong’ [slowly changing]



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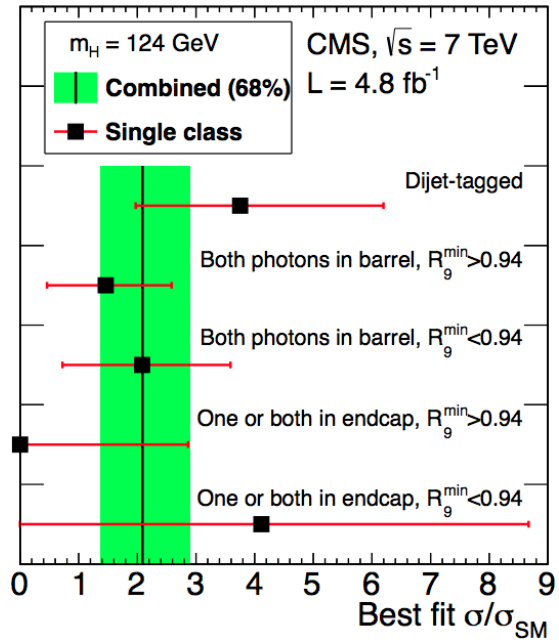

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Why 125 GeV is just perfect [Zeppenfeld et al; Dührssen et al; SFitter 2009; SFitter-Higgs soon]

- many parameters: Higgs couplings to $W, Z, t, b, \tau + (g, \gamma)$ [SM-like operators]

$$g_{Hxx} \equiv g_x = g_x^{\text{SM}} \; (1 + \Delta_x)$$

- many measurements: $GF : H \to ZZ, WW, \gamma\gamma$ [already 2011]
  $WBF : H \to ZZ, WW, \gamma\gamma, \tau\tau$ [mostly 2012]
  $VH : H \to b\bar{b}$ [2014]
  $t\bar{t}H : H \to \gamma\gamma, b\bar{b}$ [2014]

$\Rightarrow$ perfect application for SFitter

Global: likelihood maps

Markov chain probability map [SFitter]

- LHC parameters: weak-scale Lagrangean [Higgs, MSSM, dark matter,...]
- errors: correlated Poisson-Gaussian-RFit
- likelihood map: data given a model $p(d|m) \sim |\mathcal{M}|^2(m)$

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- is there a SM-like solution?
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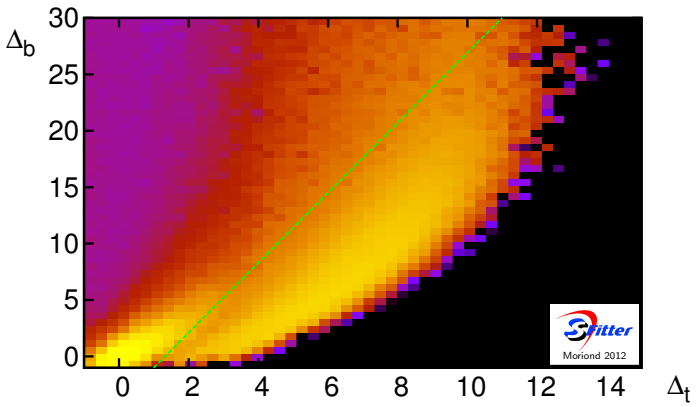
- large-coupling solution separable



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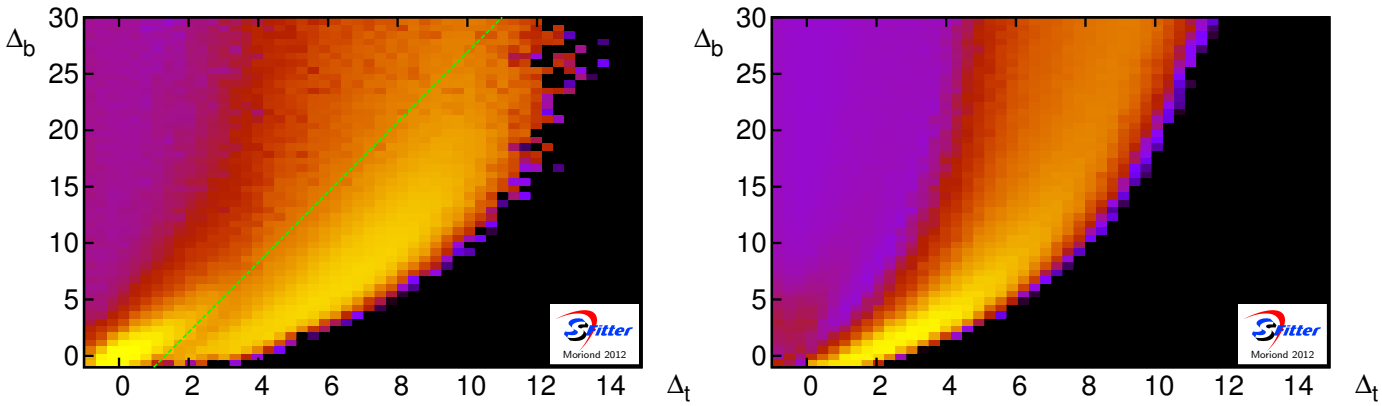
(2) measured 2011 results: measured central values and error bars

- both solutions overlapping



Local: parameter extraction

Parameters with error bars [SFitter]

- starting with best MC point
- best fit point from Minuit
- error bars from toy measurements
- 1D distibutions from profile likelihood

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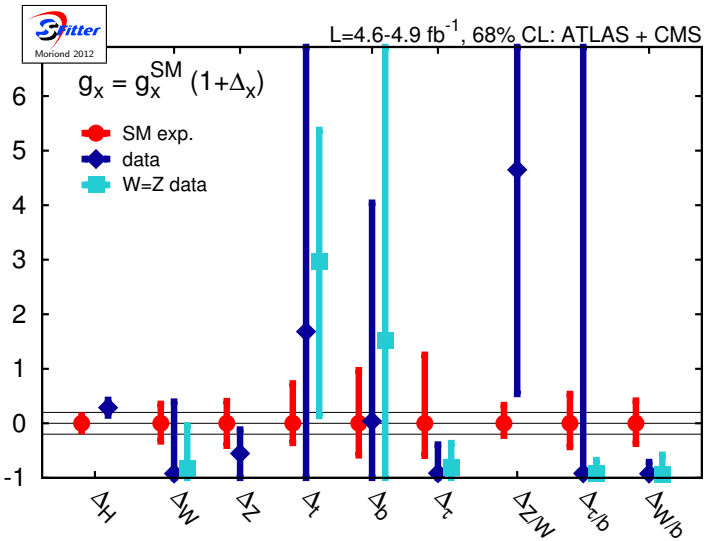
Local view of 2011 data [Klute, Lafaye, TP, Rauch, Zerwas, Dührssen]

- focus on SM solution where possible
- five couplings from data

  $g_W \sim 0$ while g_Z okay
  g_b and g_t hurt by secondary solution
  g_τ inconclusive in data
  g_g and g_γ requiring $t\bar{t}H$ analysis
- poor man's analysis great: $\Delta_j \equiv \Delta_H$

$\Rightarrow$ SFitter at work



Future

2012, 2014, etc

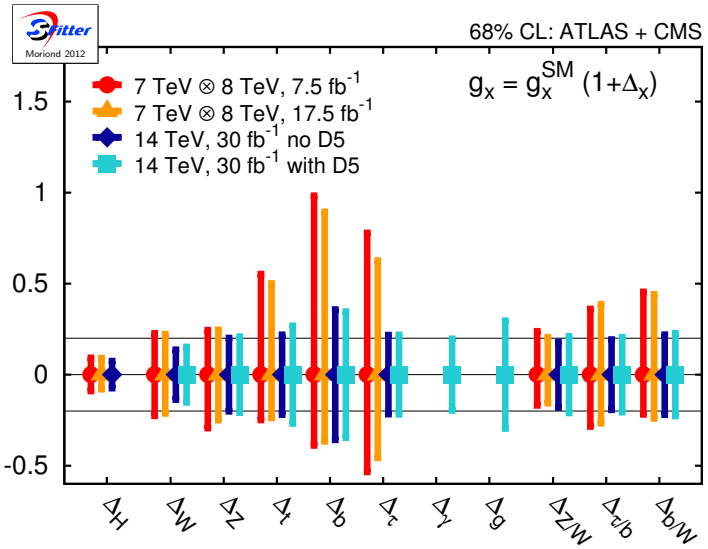
- specifically Higgs:

  dark side of the Higgs portal?
  new states in effective couplings?

- 2012: meaningful WBF measurements
  g_W and g_τ accessible

- 2014: $t\bar{t}H$ and $H \to b\bar{b}$ measurements
  g_g and g_γ accessible

$\Rightarrow$ exciting prospects!



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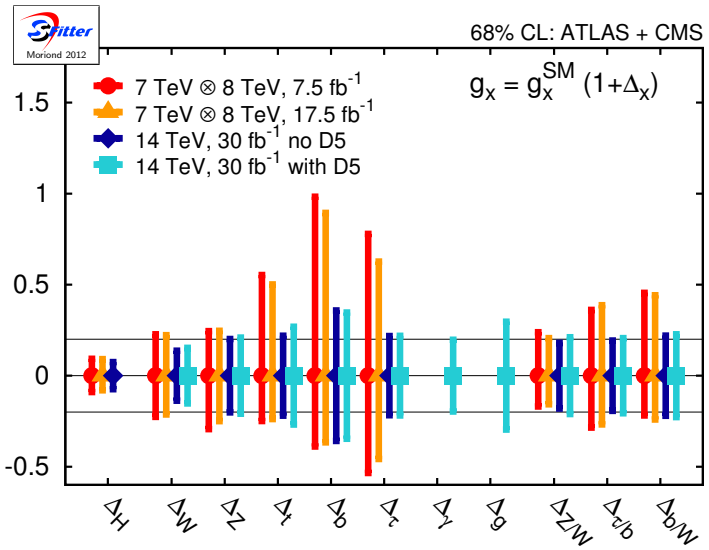

Missing information

- exclusive recoil jet counting [Erik's talk]
- currently unavailable efficiencies [Azatov etal]

N_{ev}/fb	1ℓ	jj	$p_T(\gamma\gamma) < 40$ GeV				$p_T(\gamma\gamma) > 40$ GeV			
			$R_9^>$ BAR	$R_9^<$ BAR	$R_9^>$ END	$R_9^<$ END	$R_9^>$ BAR	$R_9^<$ BAR	$R_9^>$ END	$R_9^<$ END
GF	0	0.14	3.23	3.40	1.20	1.44	1.55	1.64	0.58	0.69
WBF	0	0.44	0.067	0.071	0.026	0.031	0.17	0.18	0.066	0.079
VH	0.089	0.0035	0.059	0.063	0.028	0.033	0.17	0.18	0.081	0.097
GF/sum	0	0.24	0.96	0.96	0.96	0.96	0.82	0.82	0.80	0.80
WBF/sum	0	0.70	0.02	0.02	0.02	0.02	0.09	0.09	0.09	0.09
VH/sum	1	0.06	0.02	0.02	0.02	0.02	0.09	0.09	0.11	0.11

$\Rightarrow$ a lot published, but pieces missing

Outlook

Higgs analyses in the present and in the future

- Higgs couplings accessible
- model hypotheses flexible [HDecay]
- technically not trivial [SFitter]
- much more fun than Z@LEP
- 'Why don't you leave this to experimentalists?'

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- 'Why don't you leave this to experimentalists?'
  We mostly are LHC experimentalists!
- a case for a linear collider!?

Some of this work was funded by the BMBF Theorie-Verbund which is ideal for LHC phenomenology

Bundesministerium
für Bildung
und Forschung

SFitter: Error analysis

Sources of uncertainty

- statistical error: Poisson
  systematic error: Gaussian, if measured
  theory error: not Gaussian
- simple argument
  LHC rate 10% off: no problem
  LHC rate 30% off: no problem
  LHC rate 300% off: Standard Model wrong
- theory likelihood flat centrally and zero far away
- profile likelihood construction: RFit [CKMFitter]

$$-2 \log \mathcal{L} = \chi^2 = \vec{\chi}_d^T \; C^{-1} \; \vec{\chi}_d$$

$$\chi_{d,i} = \begin{cases} 0 & |d_i - \bar{d}_i| < \sigma_i^{(\text{theo})} \\ \dfrac{|d_i - \bar{d}_i| - \sigma_i^{(\text{theo})}}{\sigma_i^{(\text{exp})}} & |d_i - \bar{d}_i| > \sigma_i^{(\text{theo})} \end{cases}$$

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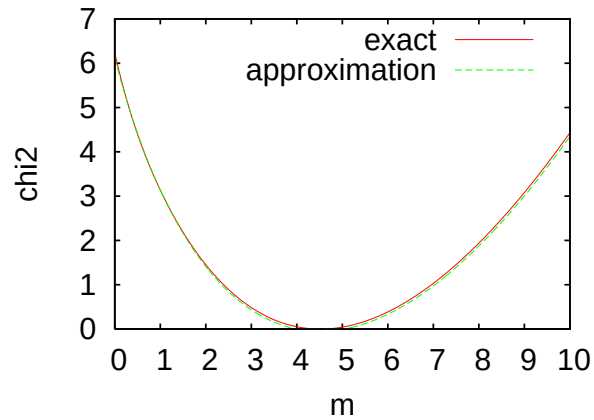
Combination of errors

- Gaussian $\otimes$ Gaussian: half width added in quadrature
  Gaussian/Poisson $\otimes$ flat: RFit scheme
  Gaussian $\otimes$ Poisson: ??
- approximate formula

$$\frac{1}{\log \mathcal{L}_{\text{comb}}} = \frac{1}{\log \mathcal{L}_{\text{Gauss}}} + \frac{1}{\log \mathcal{L}_{\text{Poisson}}}$$

- modified Minuit gradient fit last step



SFitter: Markov chains

Cooling Markov chains [Lafaye, TP, Rauch, Zerwas]

- zoom in on peak structures [inspired by simulated annealing]
- modified condition
  Markov chain in 100 partitions, numbered by j

$$\frac{p(m')}{p(m)} > r^{\frac{100}{j\ c}} \qquad \text{with} \quad c \sim 10, \qquad r \epsilon [0,1] \quad \text{random number}$$

- check for parameter coverage with many Markov chains

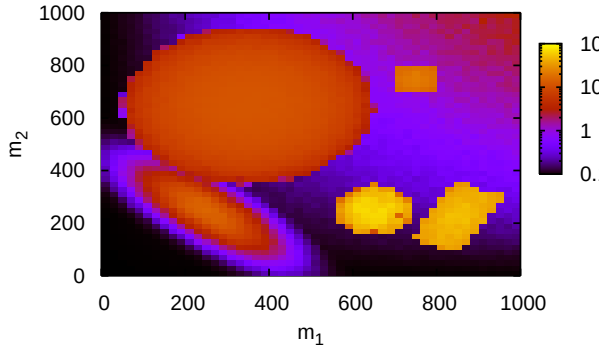
$\Rightarrow$ exclusive likelihood map first result

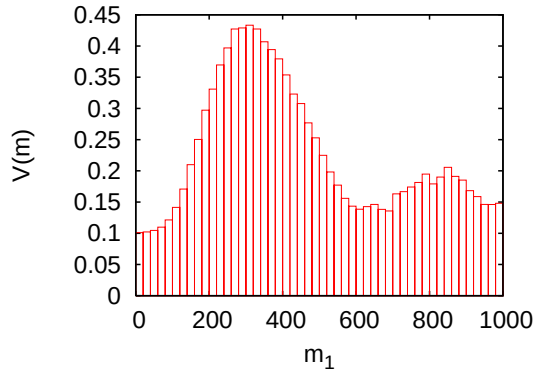
SFitter: Frequentist vs Bayesian

Getting rid of model parameters

- poorly constrained parameters
  uninteresting parameters
  unphysical parameters [JES part of m_t extraction]
- two ways to marginalize likelihood map

1– integrate over probabilities
normalization etc mathematically correct
integration measure unclear
noise accumulation from irrelevant regions
classical example: convolution of two Gaussians





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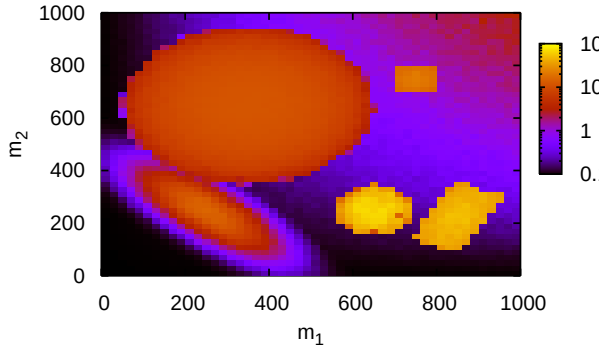

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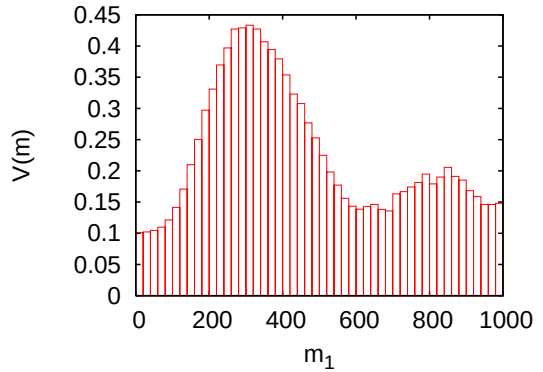
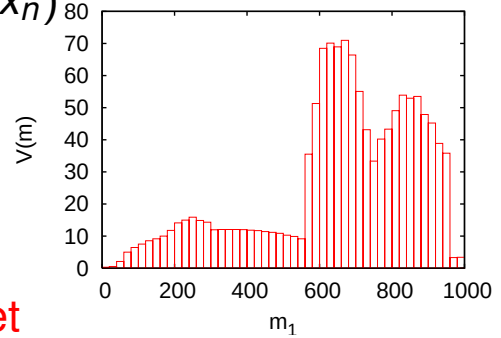


2– profile likelihood $\mathcal{L}(.., x_{j-1}, x_{j+1}....) \equiv \max_{x_j} \mathcal{L}(x_1, ..., x_n)$
no integration needed
no noise accumulation
not normalized, no comparison of structures
classical example: best-fit point



- one-dimensional parameter distributions second target