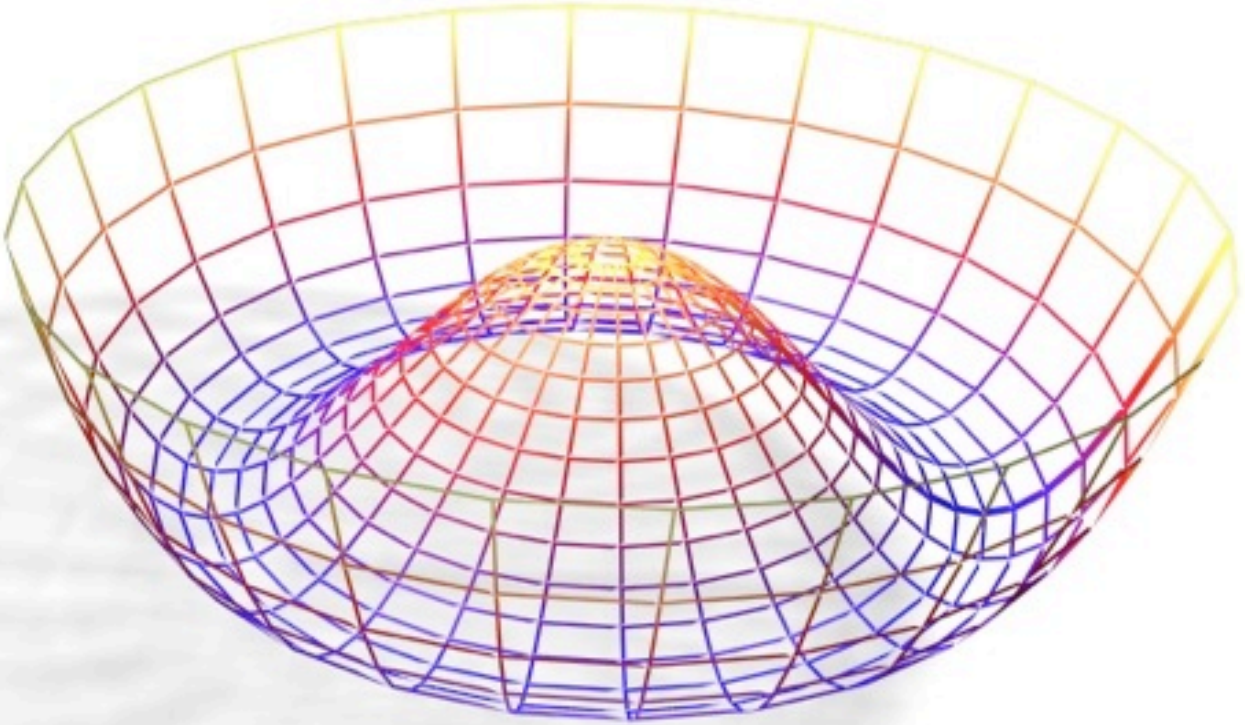
Center for
Cosmology and
Particle Physics

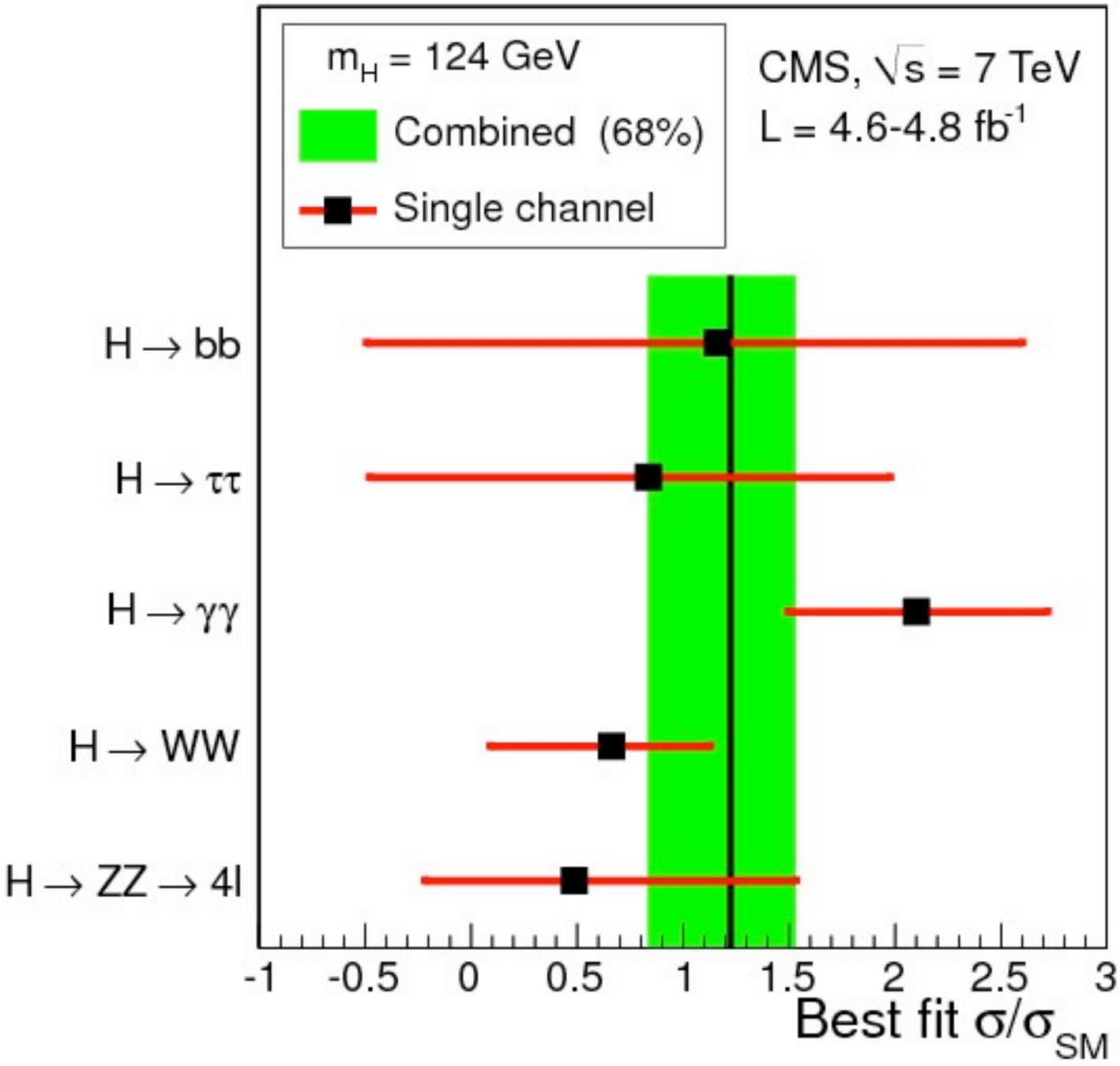
Combined Higgs searches: steps towards intepretation



Kyle Cranmer,
New York University

Northwest Terascale Research Projects: ***Interpreting emerging Higgs data***

Psychology / Sociology



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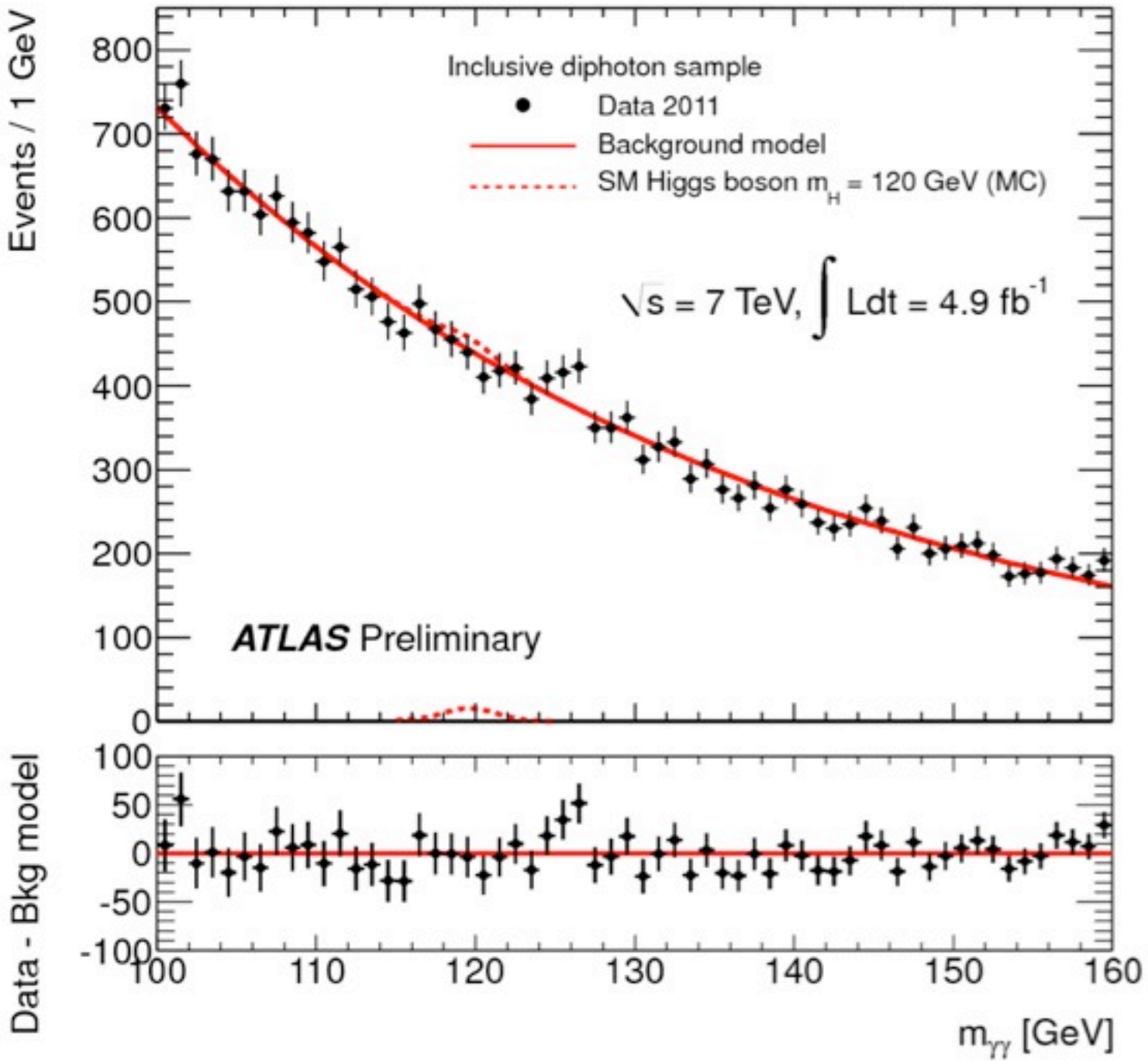

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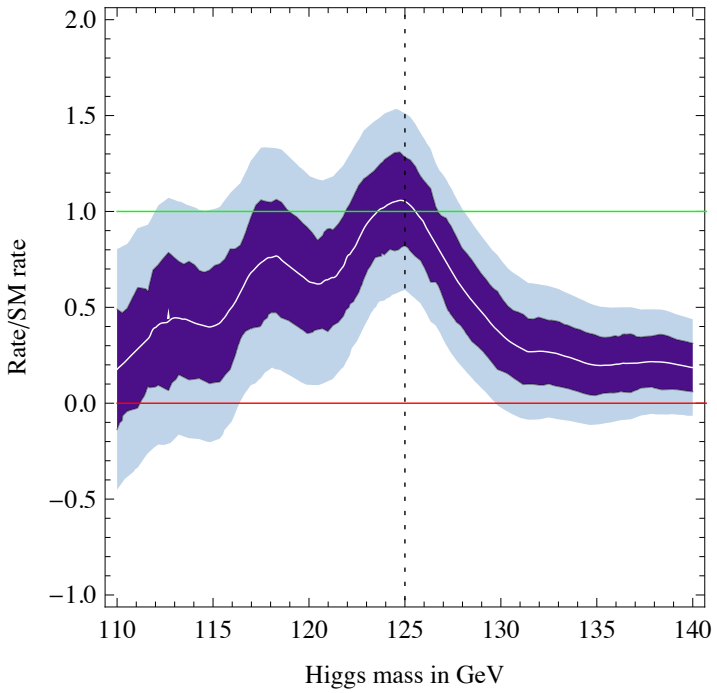
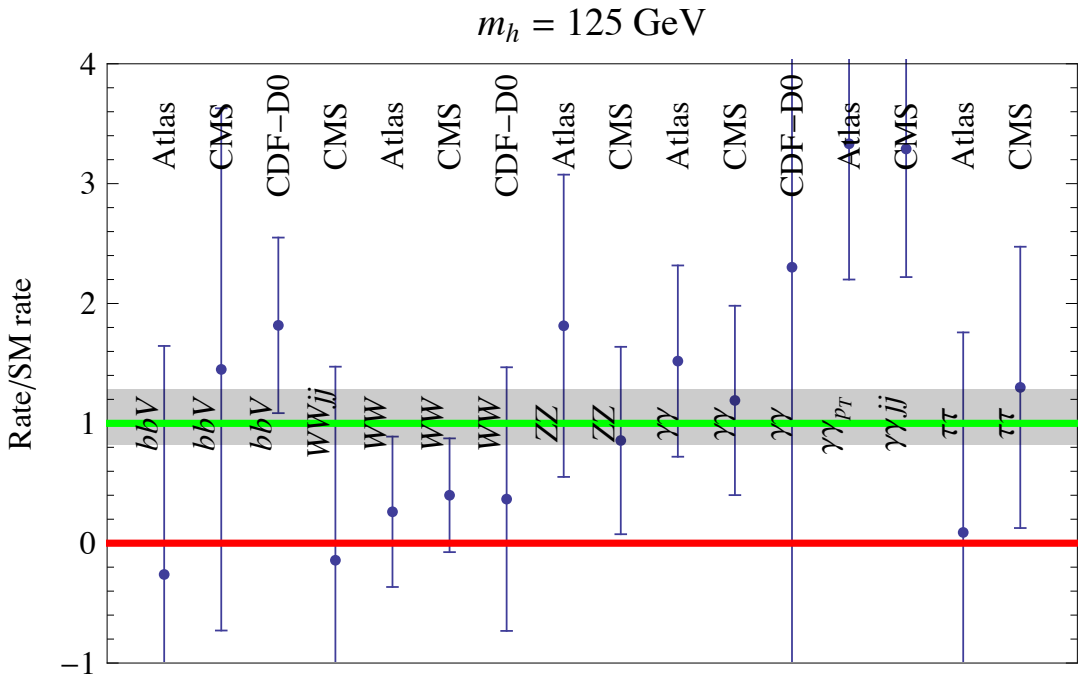
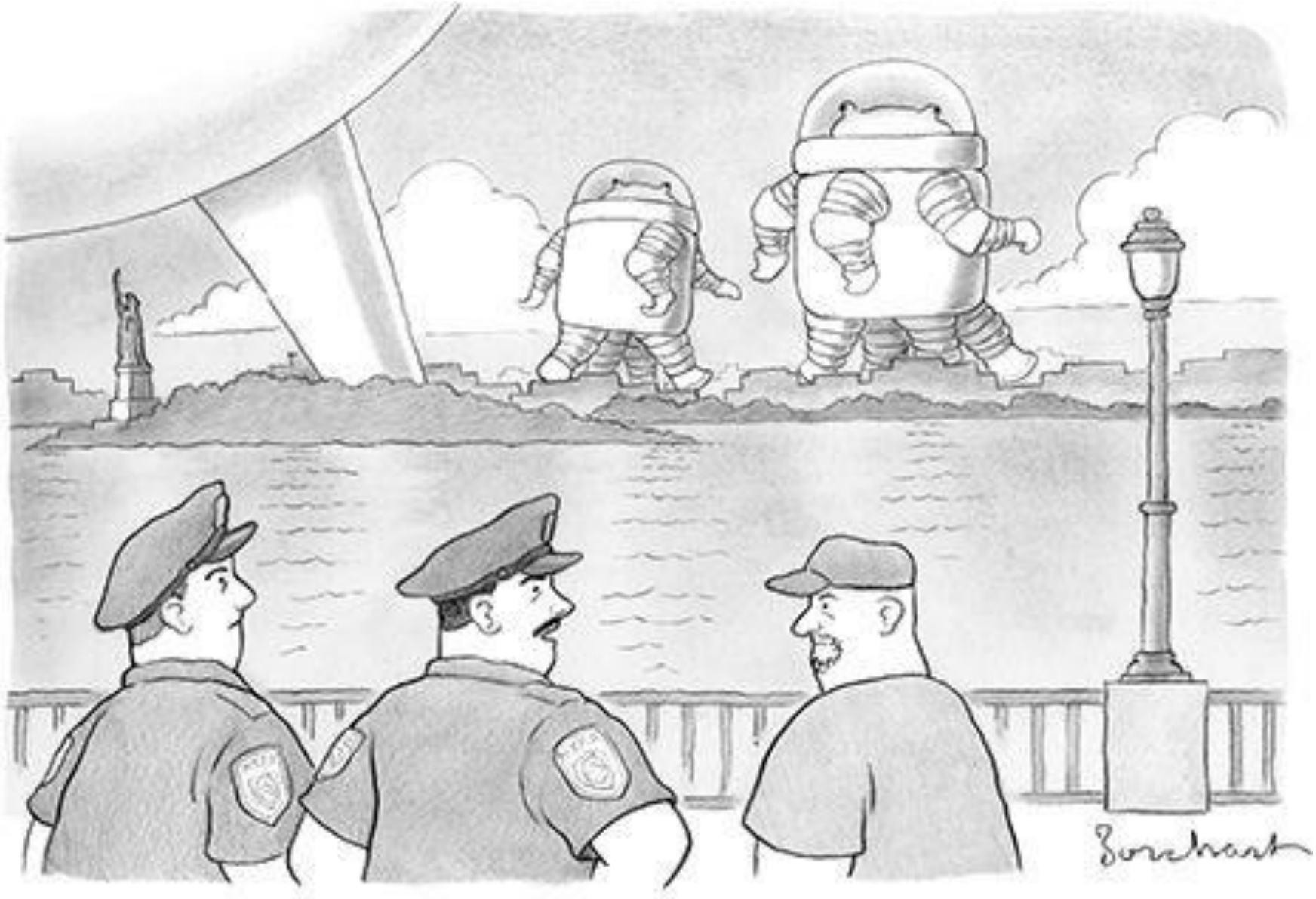




P. P. Giardino, K. Kannike, M., A. Strumia. arXiv:1203.4254

We are in this together



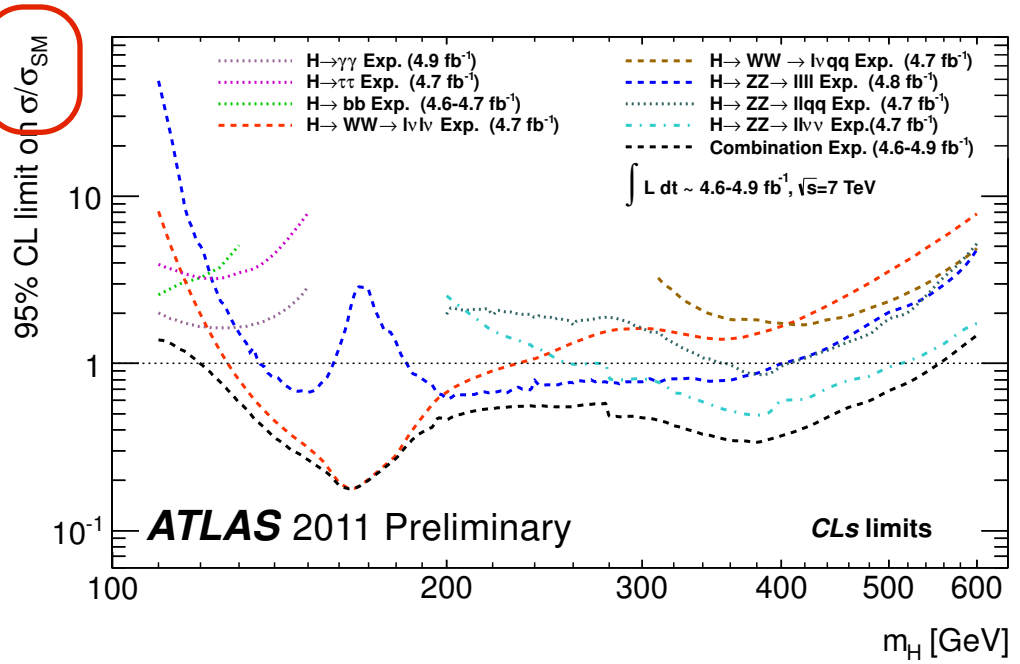
"Until we hear different, it's Jersey's problem."

Inputs to the combination

Table 1: Summary of the individual channels contributing to the combination. The central number in the three-part mass ranges indicates the transition from a low-m_H to high-m_H optimised event selections.

Higgs Decay	Subsequent Decay	Additional Sub-Channels	m_H Range	L [fb^{-1}]
$H \to \gamma\gamma$	–	9 sub-channels ($p_{T_t} \otimes \eta_\gamma \otimes$ conversion)	110-150	4.9
$H \to ZZ$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu2e, 4\mu\}$	110-600	4.8
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low pile-up, high pile-up}	200-280-600	4.7
	$\ell\ell q\bar{q}$	$\{b$-tagged, untagged$\}$	200-300-600	4.7
$H \to WW$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jet, 1-jet, VBF}	110-300-600	4.7
	$\ell\nu q\bar{q}'$	$\{e, \mu\} \otimes$ {0-jet, 1-jet}	300-600	4.7
$H \to \tau^+\tau^-$	$\ell\ell 4\nu$	$\{e\mu\} \otimes$ {0-jet} $\oplus$ {1-jet, VBF, VH}	110-150	4.7
	$\ell\tau_{\text{had}}3\nu$	$\{e, \mu\} \otimes$ {0-jet} $\otimes \{E_T^{\text{miss}} \gtrless 20$ GeV$\}$ $\oplus \{e, \mu\} \otimes$ {1-jet, VBF}	110-150	4.7
	$\tau_{\text{had}}\tau_{\text{had}}2\nu$	{1-jet}	110-150	4.7
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\text{miss}} \in \{[120,160), [160,200), \geq 200$ GeV$\}$	110-130	4.6
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7

$\mu = \sigma/\sigma_{SM}$



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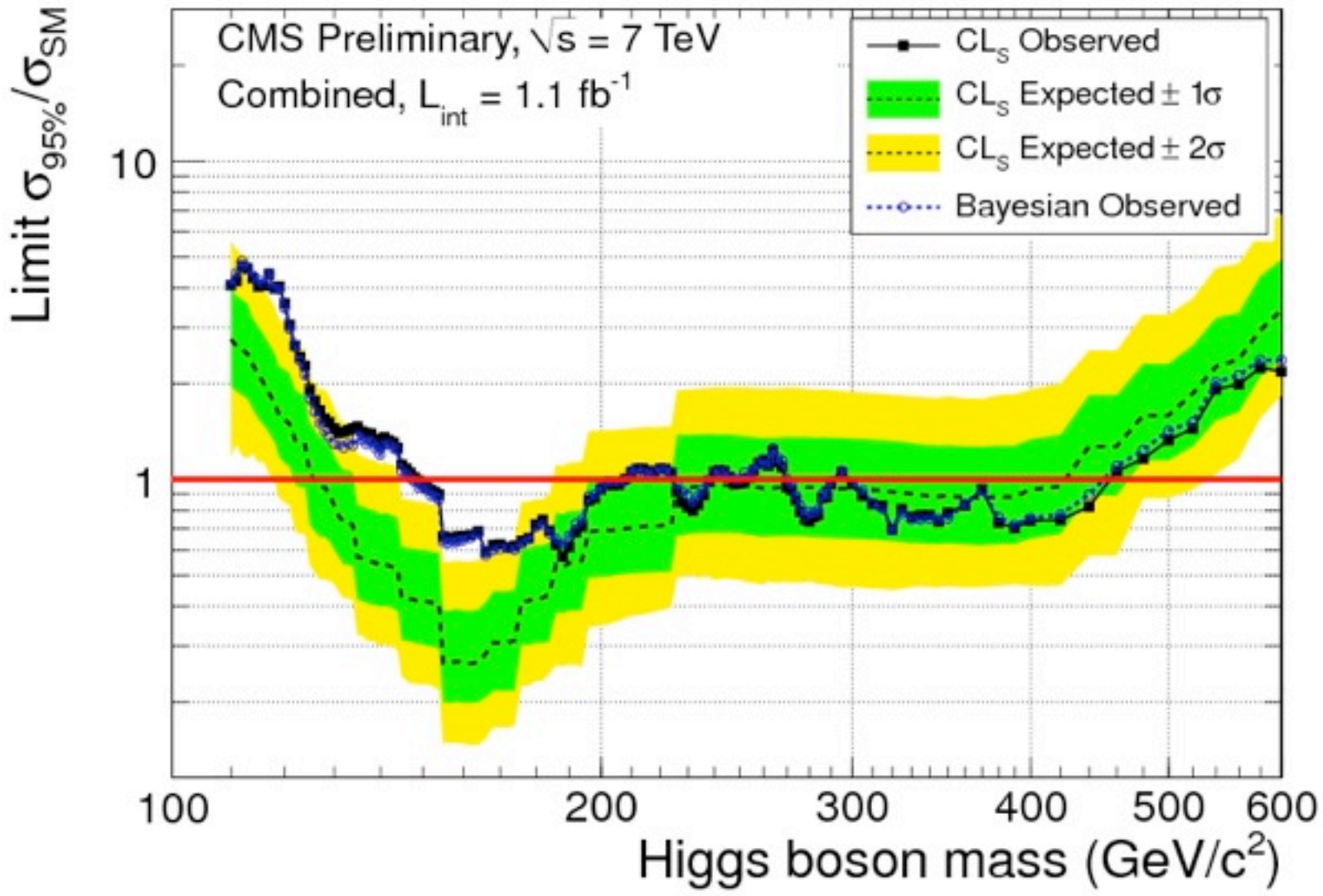
"VBF" and "VH" confusing contaminated by other processes

Cuts change and channels come in / drop out

Mass-dependent cuts

Since the cuts change with the m_H hypothesis, there is not just one likelihood function. Different selections have different minima associated to them, stitching them together this way is dubious.



Careful....

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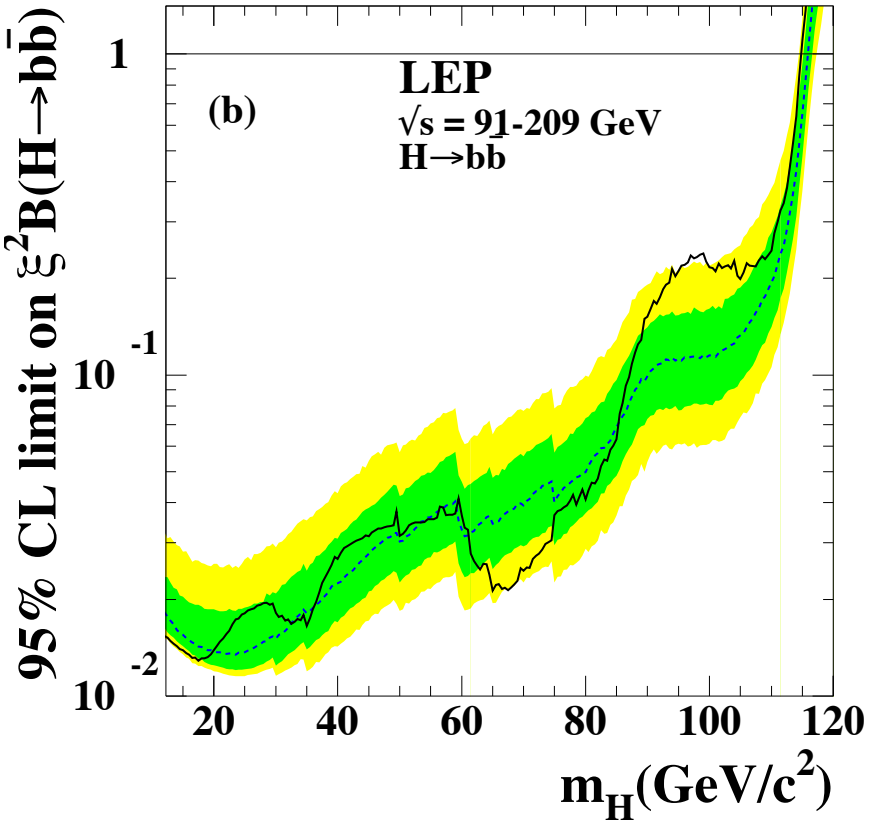
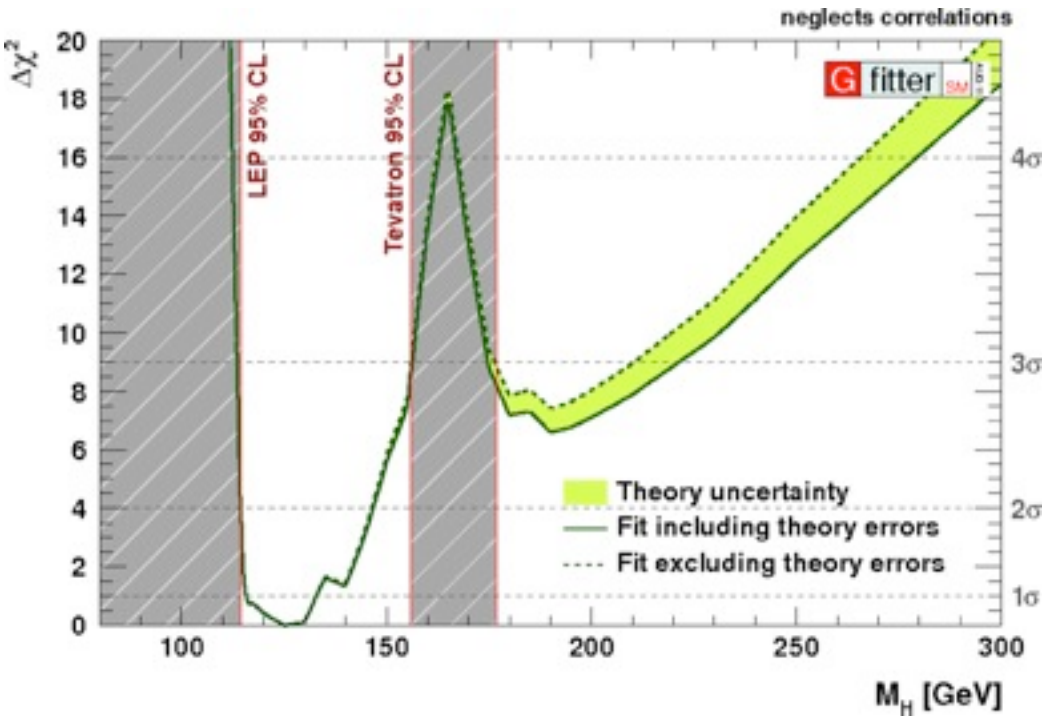
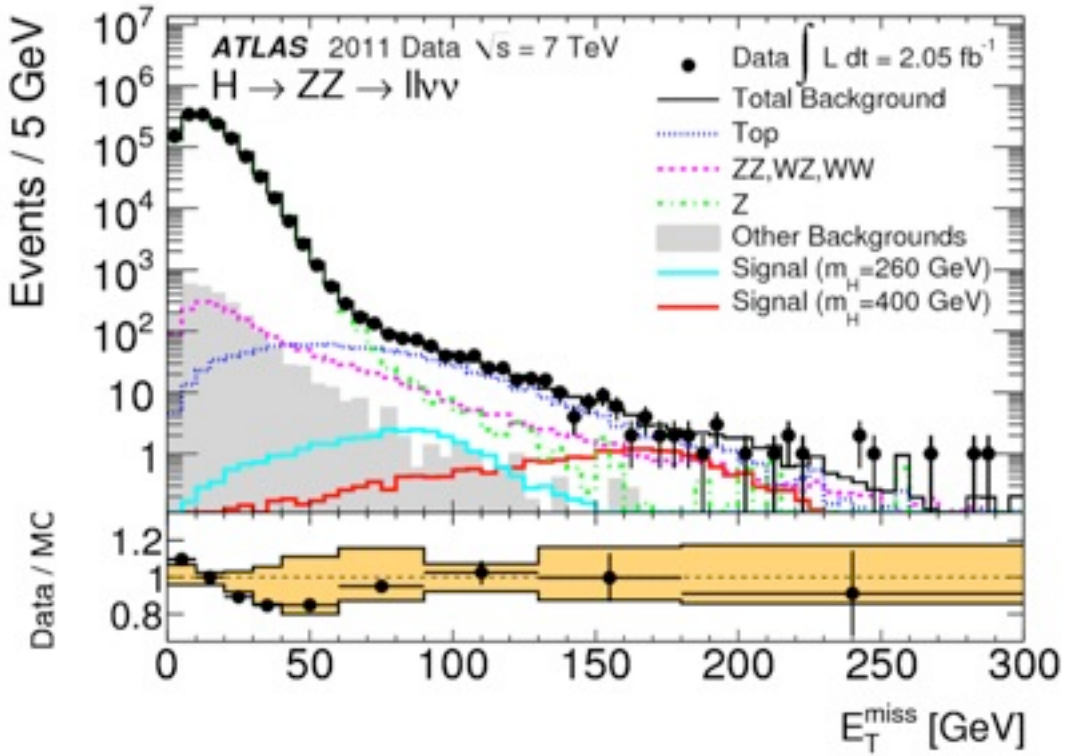




Single channel model

$$\mathbf{f}(\mathcal{D}|\nu,\alpha) = \mathrm{Pois}(n|\nu)\prod_{e=1}^{n} f(x_e|\alpha)\ ,$$

$$\nu_{\mathrm{tot}} = \sum_{s\in\mathrm{samples}} \nu_s \qquad f(x) = \frac{1}{\nu_{\mathrm{tot}}}\sum_{s\in\mathrm{samples}} \nu_s f_s(x)\ ,$$



Explicit parametrization of systematics

Important to distinguish between the **source** of the systematic uncertainty (eg. jet energy scale) and its **effect.**

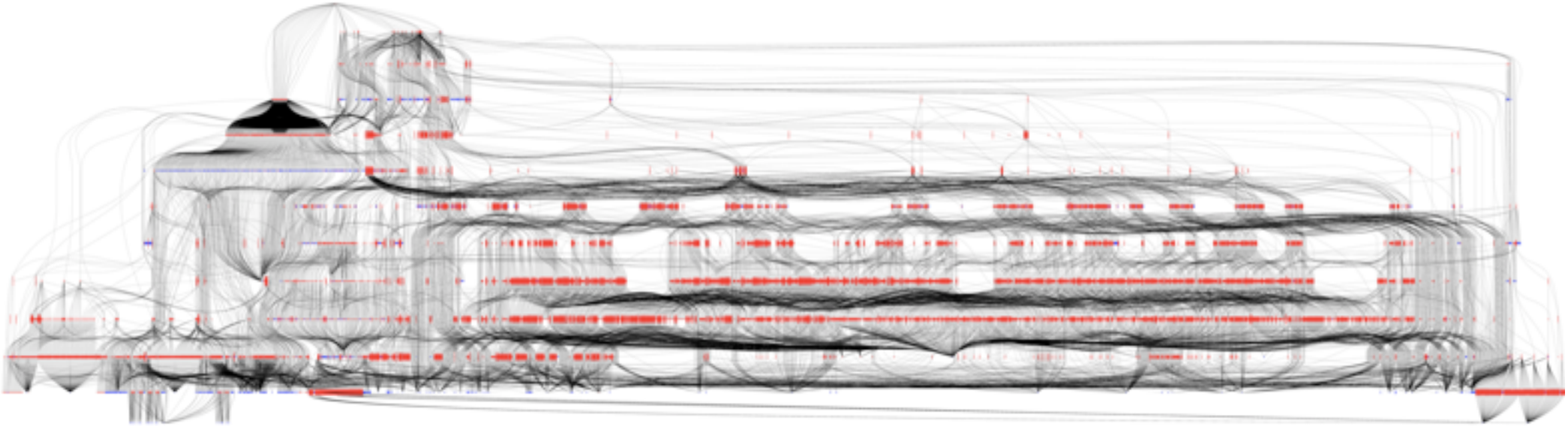
- The same 5% jet energy scale uncertainty will have different effect on different signal and background processes
  - not necessarily with any obvious functional form
- Usually possible to decompose to independent "uncorrelated" sources

Imagine a table that **explicitly quantifies** the effect of each source of systematic.

- Entries are either normalization factors or variational histograms

	sig	bkg 1	bkg 2	...
syst 1				
syst 2				
...				

Higgs Sausage



Combined Model:

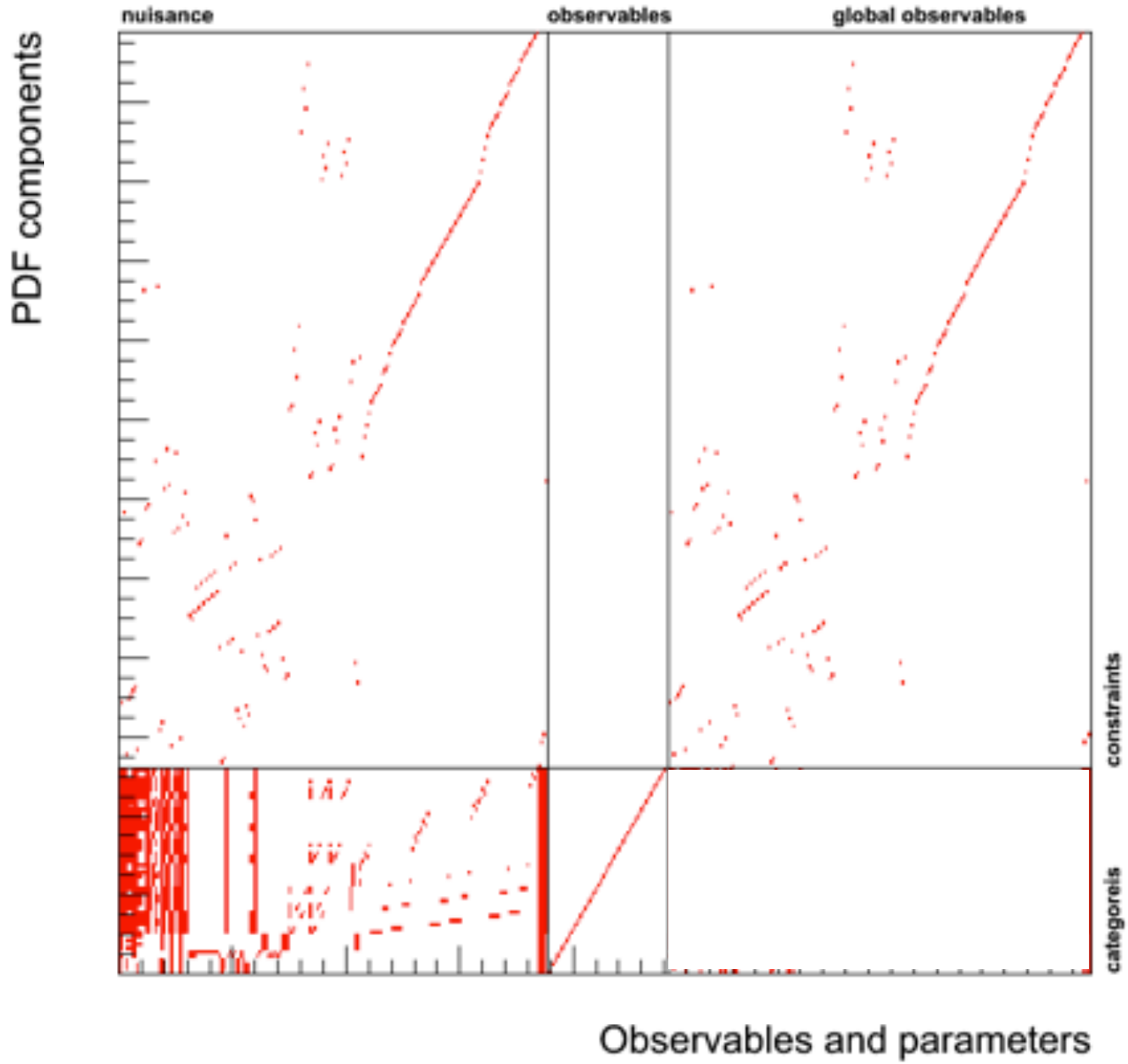
$$\mathbf{f}_{\text{tot}}(\mathcal{D}_{\text{sim}}, \mathcal{G}|\alpha) = \prod_{c\in\text{channels}} \left[\text{Pois}(n_c|\nu(\alpha)) \prod_{e=1}^{n_c} f(x_{ce}|\alpha)\right] \cdot \prod_{p\in\mathbb{S}} f_p(a_p|\alpha_p) \ .$$

Combined dataset:

$$\mathcal{D}_{\text{sim}} = \{\mathcal{D}_1, \ldots, \mathcal{D}_{c_{\max}}\} = \{\{x_{c=1,e=1} \ldots x_{c=1,e=n_c}\}, \ldots \{x_{c=c_{\max},e=1} \ldots x_{c=c_{\max},e=n_{c_{\max}}}\}\}$$

`global observables' from auxiliary measurements: $\mathcal{G}$

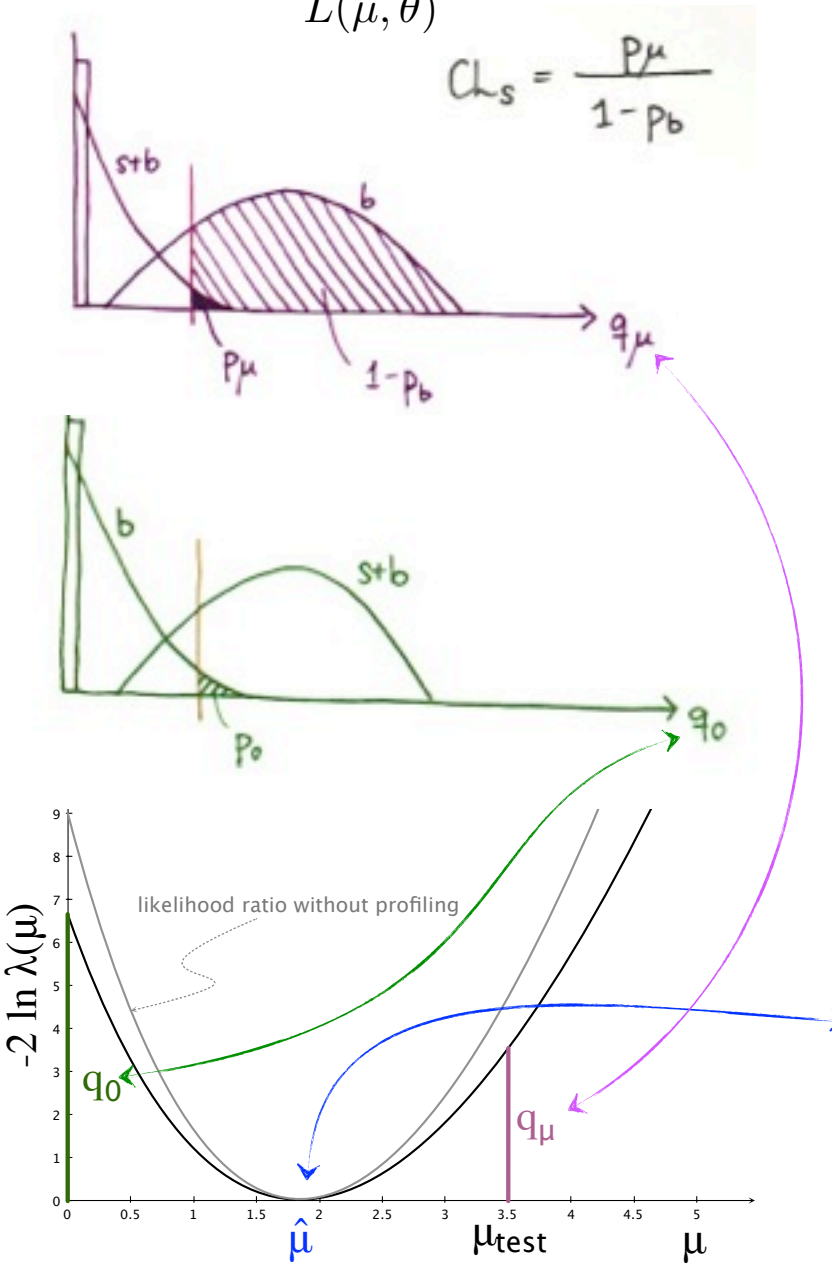
Representing the PDF



Thumbnail of the statistical procedure

$$\lambda(\mu) = \frac{L(\mu, \hat{\hat{\theta}}(\mu))}{L(\hat{\mu}, \hat{\theta})}$$

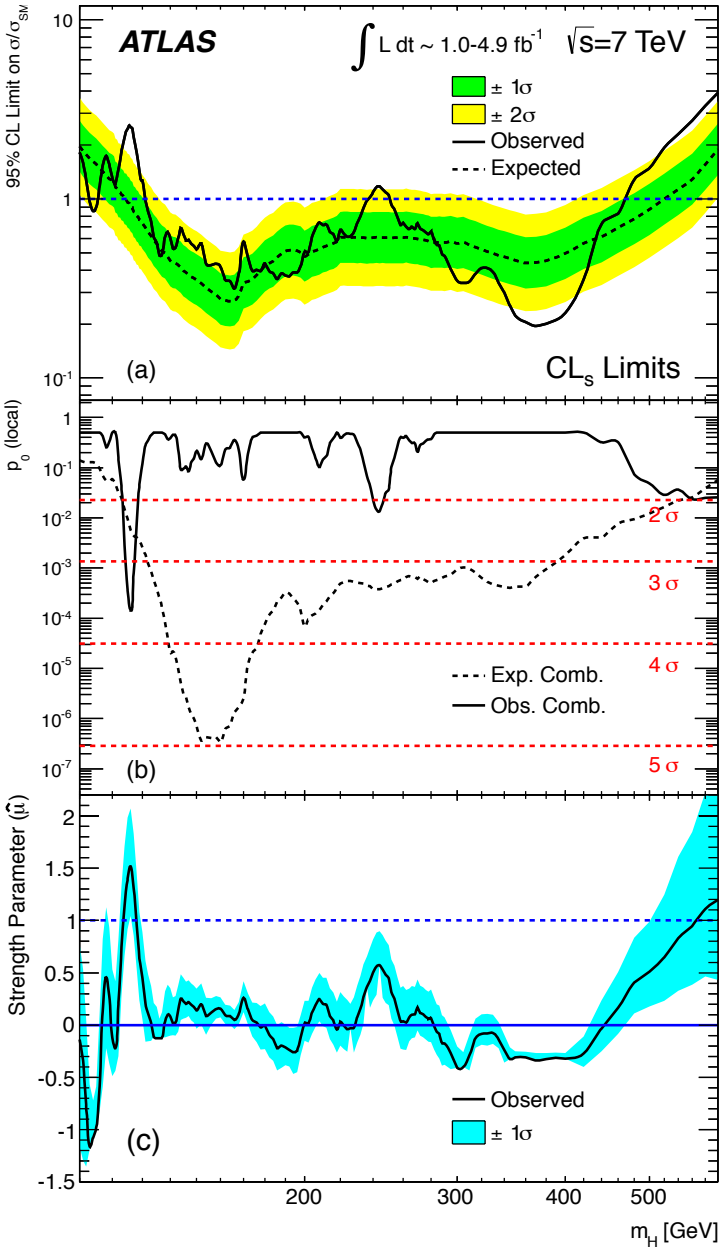
Follow LHC-HCG Combination Procedures



CL_s to test signal hypothesis

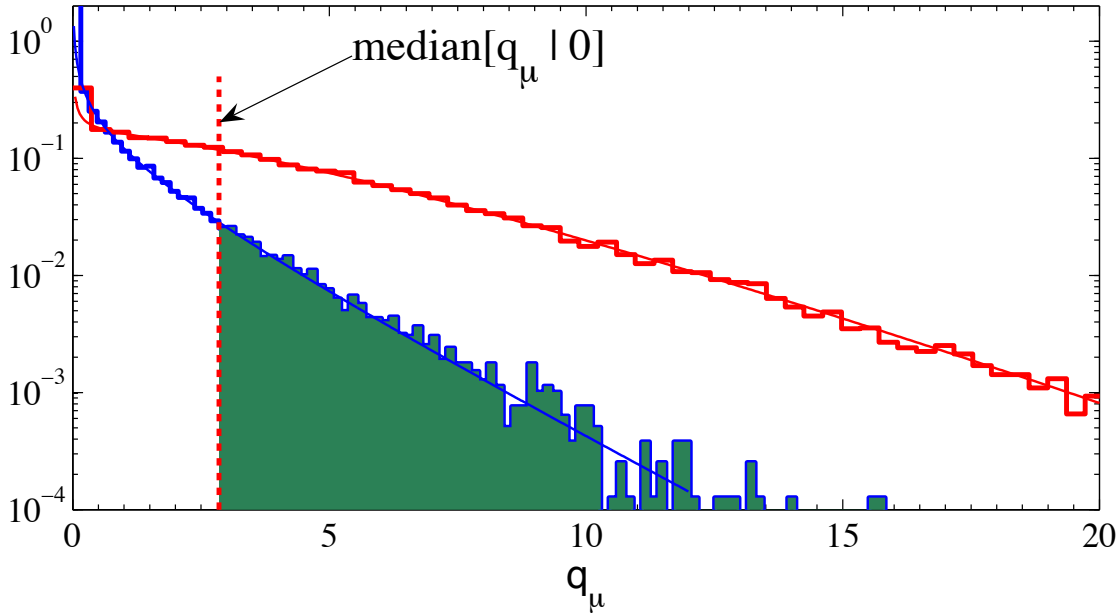
p_0 to test background hypothesis

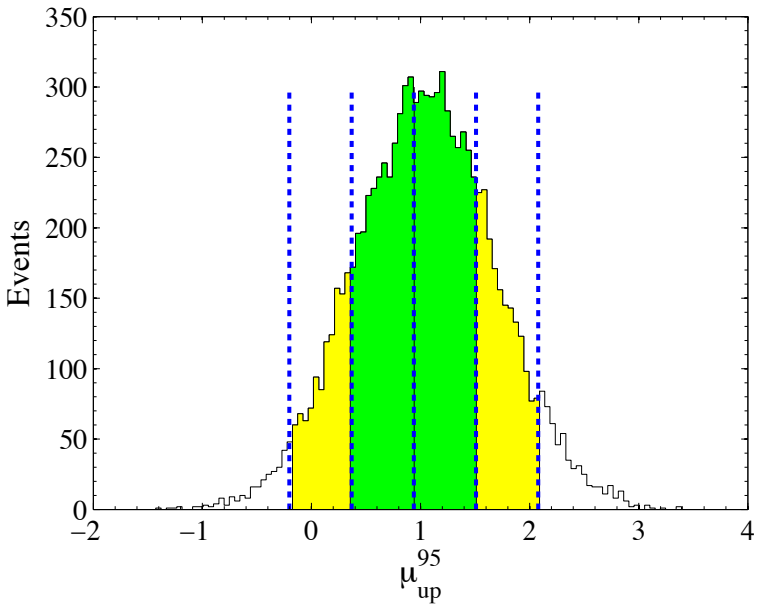
$\hat{\mu}$ to estimate signal strength



Median & bands from asymptotics

Get Median and bands in seconds, not days!

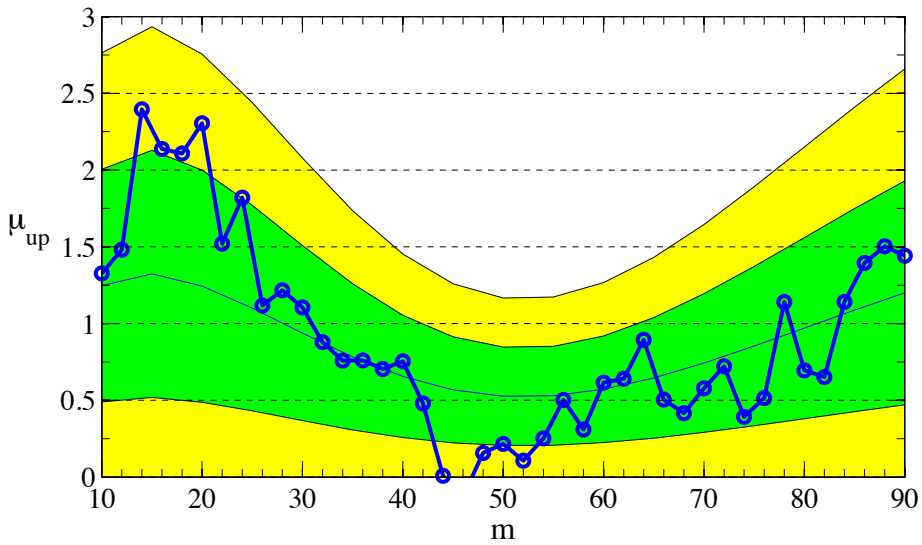




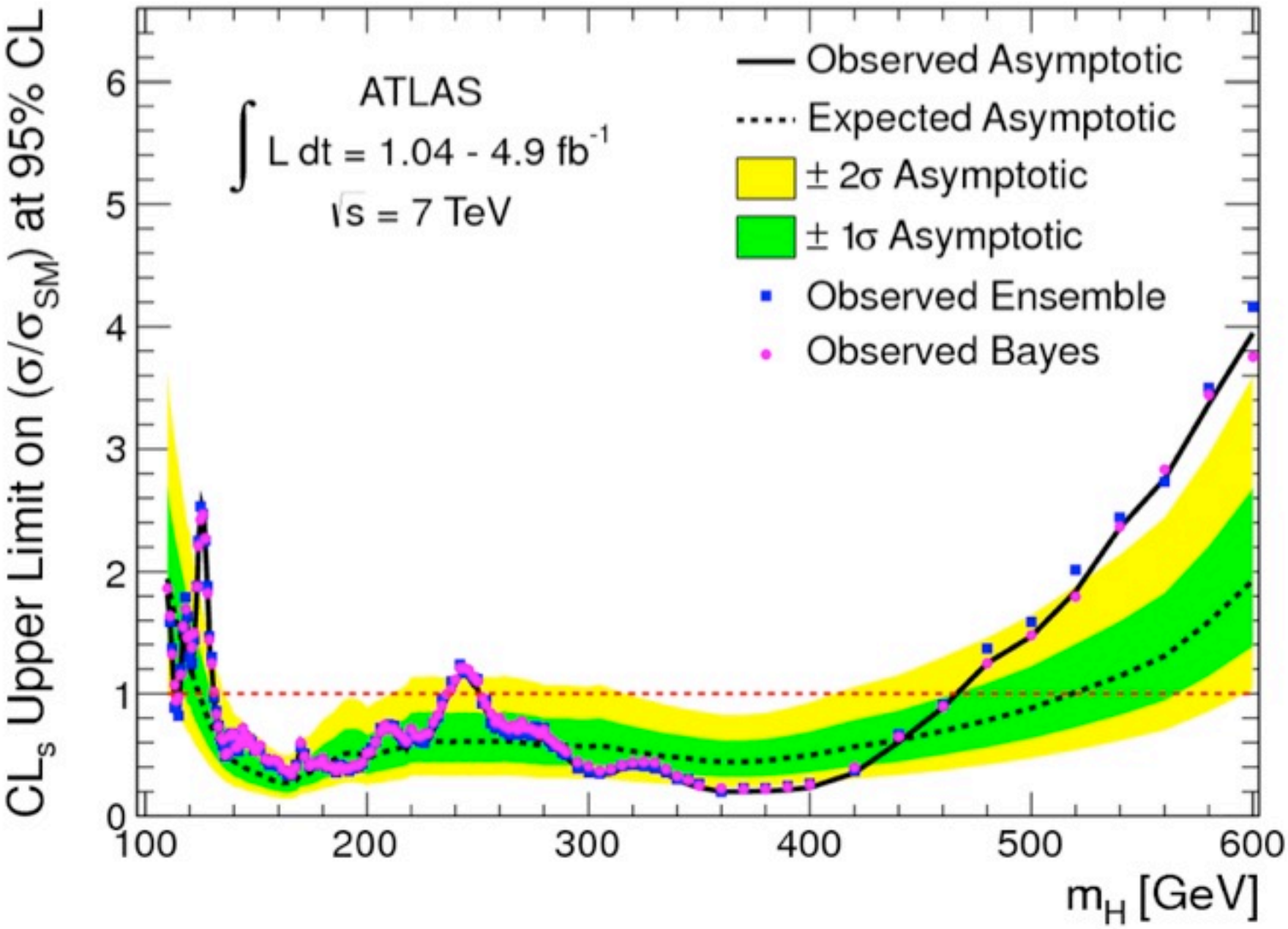
$$f(\tilde{q}_\mu|\mu') = \Phi\left(\frac{\mu'-\mu}{\sigma}\right)\delta(\tilde{q}_\mu)$$

$$+ \begin{cases} \frac{1}{2}\frac{1}{\sqrt{2\pi}}\frac{1}{\sqrt{\tilde{q}_\mu}}\exp\left[-\frac{1}{2}\left(\sqrt{\tilde{q}_\mu}-\frac{\mu-\mu'}{\sigma}\right)^2\right] & 0 < \tilde{q}_\mu \le \mu^2/\sigma^2 \\ \frac{1}{\sqrt{2\pi}\sigma}\exp\left[-\frac{1}{2}\frac{(\tilde{q}_\mu-(\mu^2-2\mu\mu')/\sigma^2)^2}{(2\mu/\sigma)^2}\right] & \tilde{q}_\mu > \mu^2/\sigma^2 \end{cases}$$

G. Cowan, KC, E. Gross, O. Vitells
Eur.Phys.J. C71 (2011) 1554
[arXiv:1007.1727]

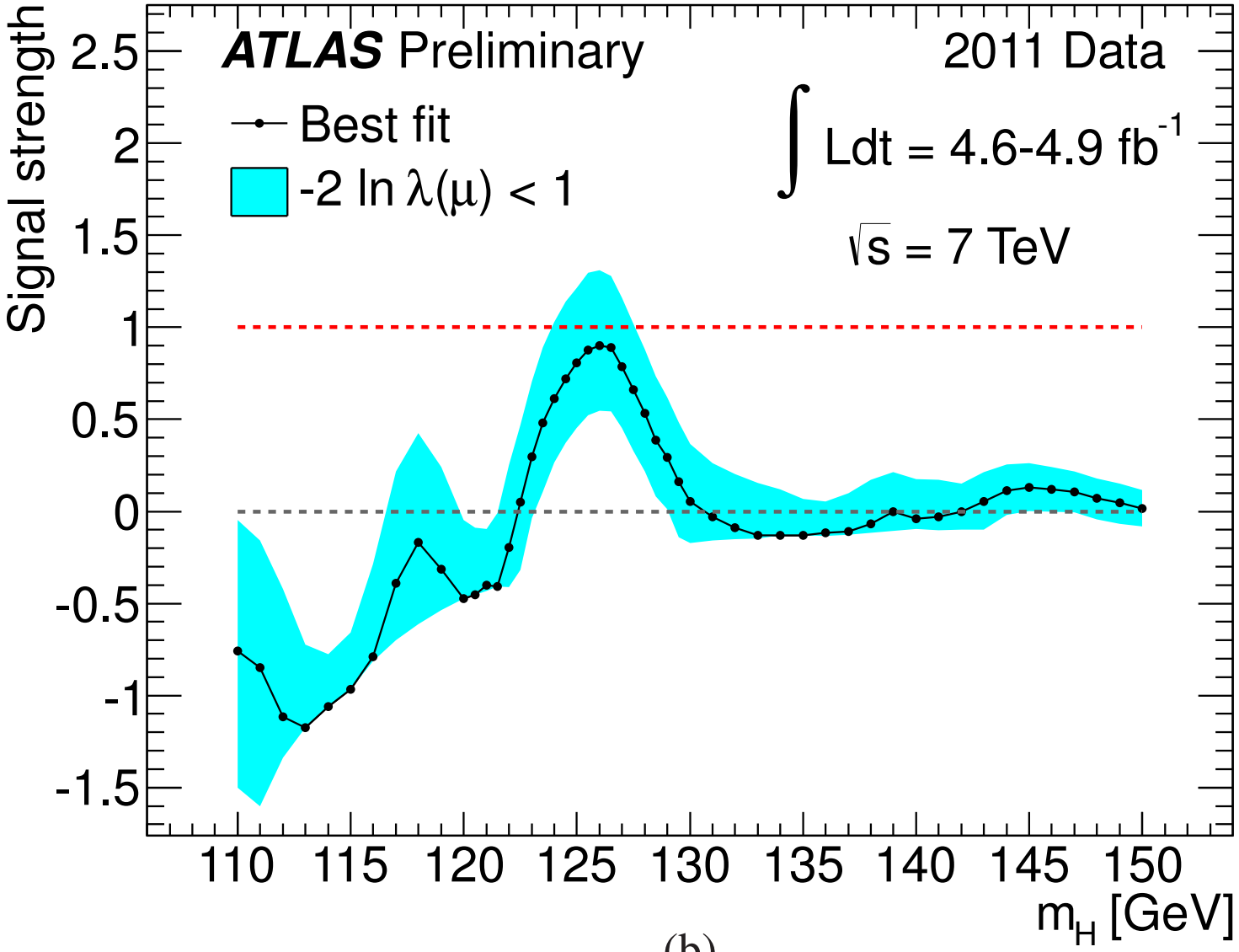


CLs w/ toys & asymptotics, Bayesian



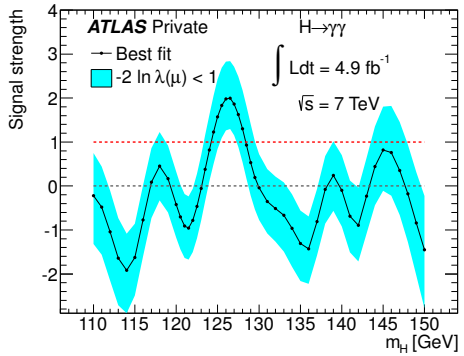
μ plot

This is a global scaling of σ BR for all production and decay modes.

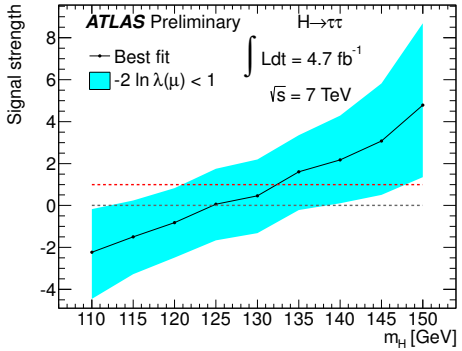


(b)

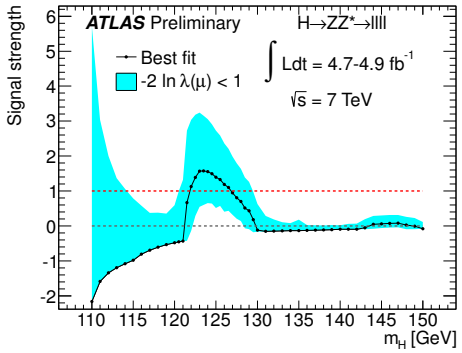
Individual μ plots



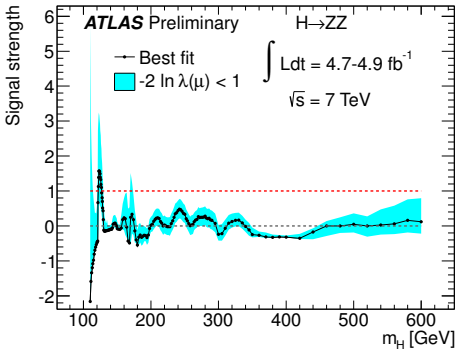
(a)



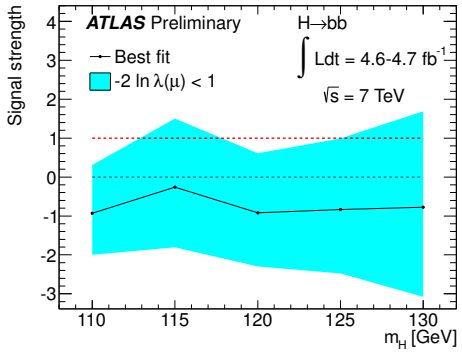
(b)

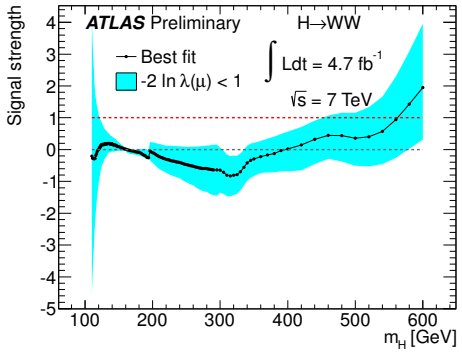


(c)



(d)





Moving beyond a single μ

In practical terms, we need a parameter for each branching ratio and a parameter for each production cross-section.

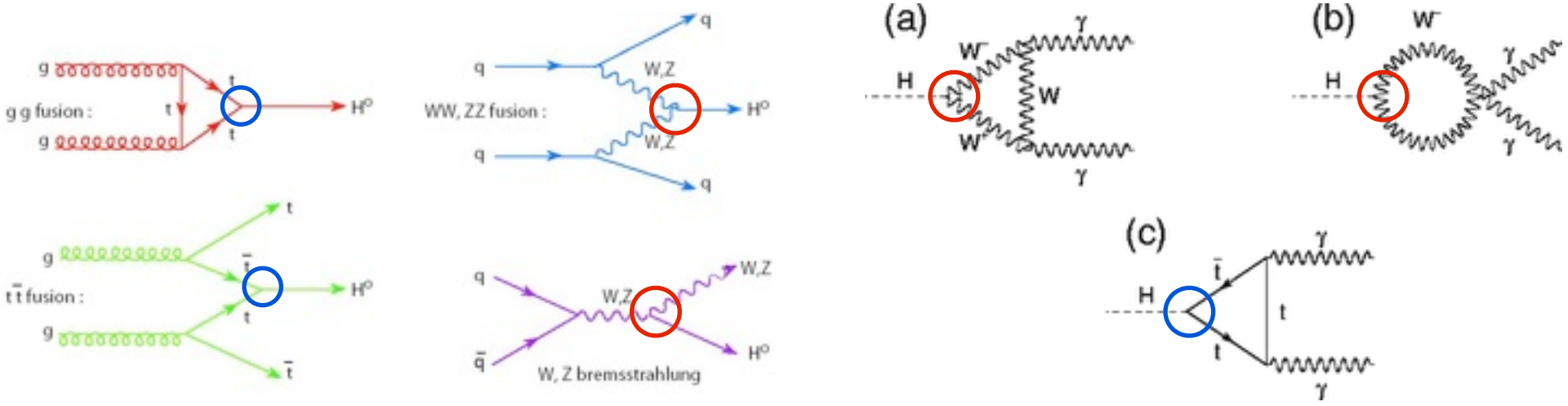
- We need signal contributions for different production mode separately
  - some work, need efficiencies and signal shapes for each
- Call them μ_i and μ_j where i is production index and j is decay index

Only consider SM-like interactions at first

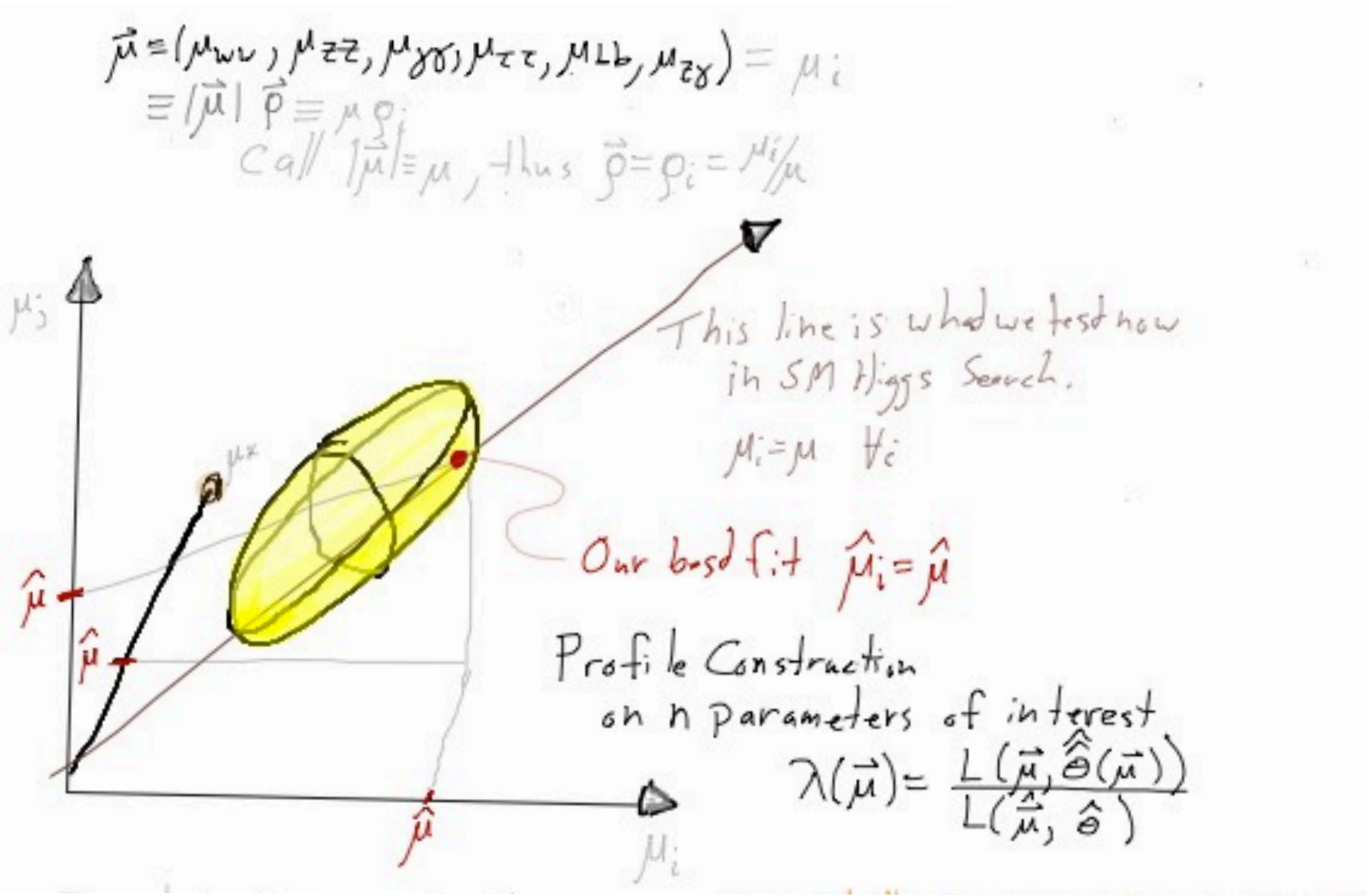
- if distributions change, much more work needed

However, the production and decay really are not independent

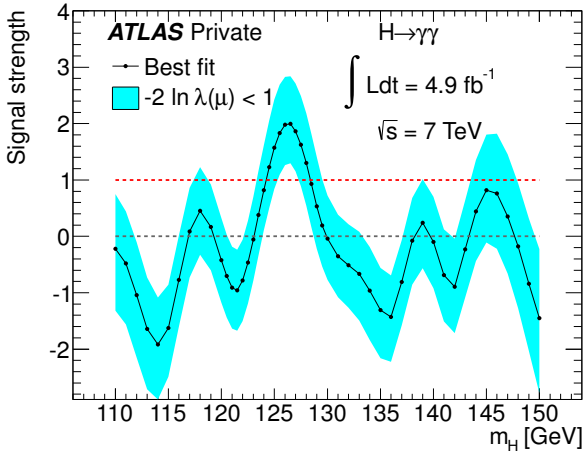
- better to re-parametrize in terms of couplings

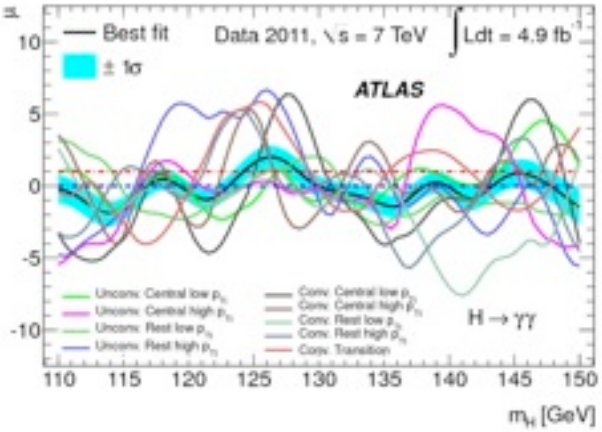


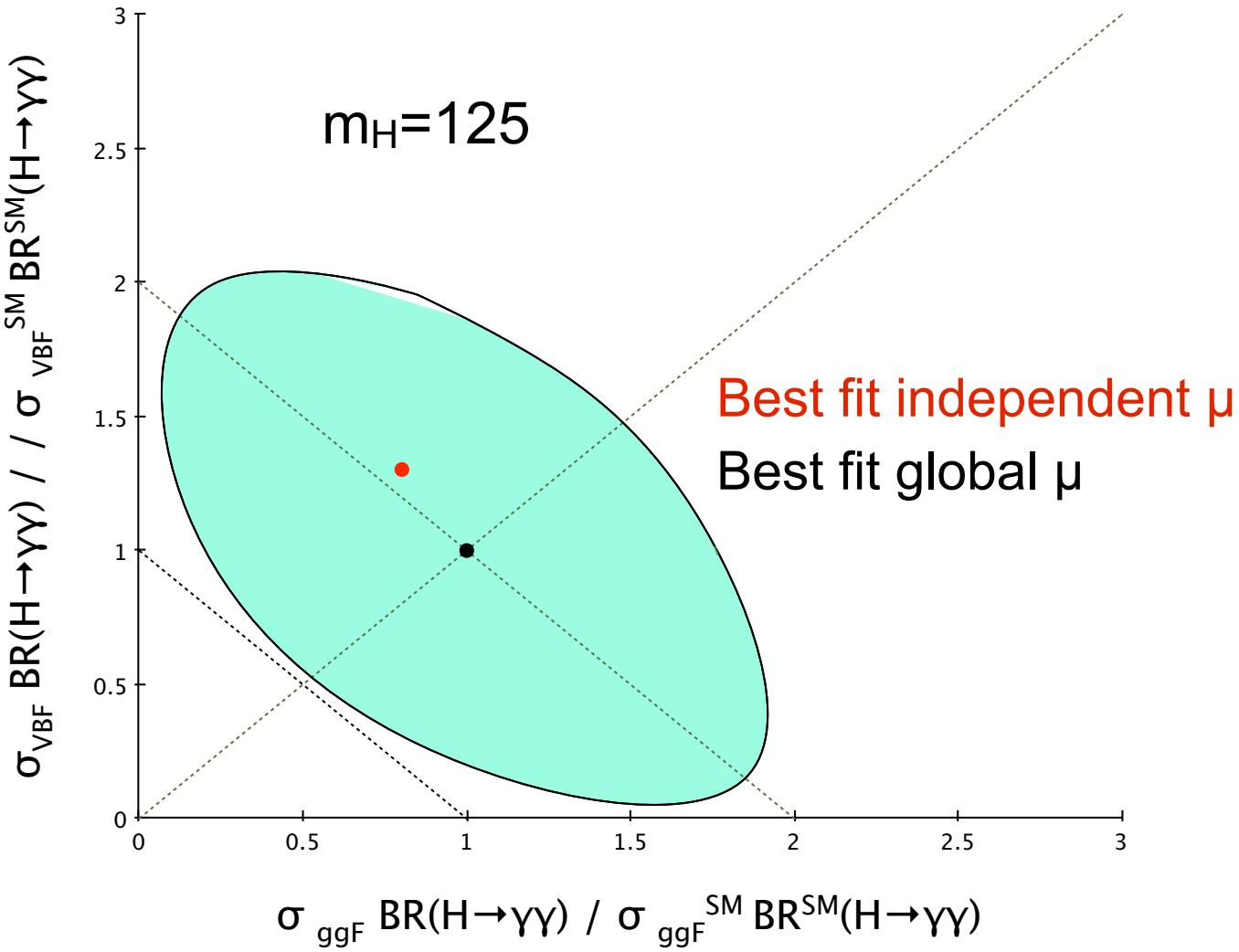
Moving beyond a single μ



μ_i contours for individual channels







Above drawn with equal efficiencies, different efficiencies will lead to a tilted contour.

Need significant differences in shape or relative efficiency across sub-channels to break degeneracy among production modes

If we introduce additional σ_X 2-d profile will fill plane

SFitter approach

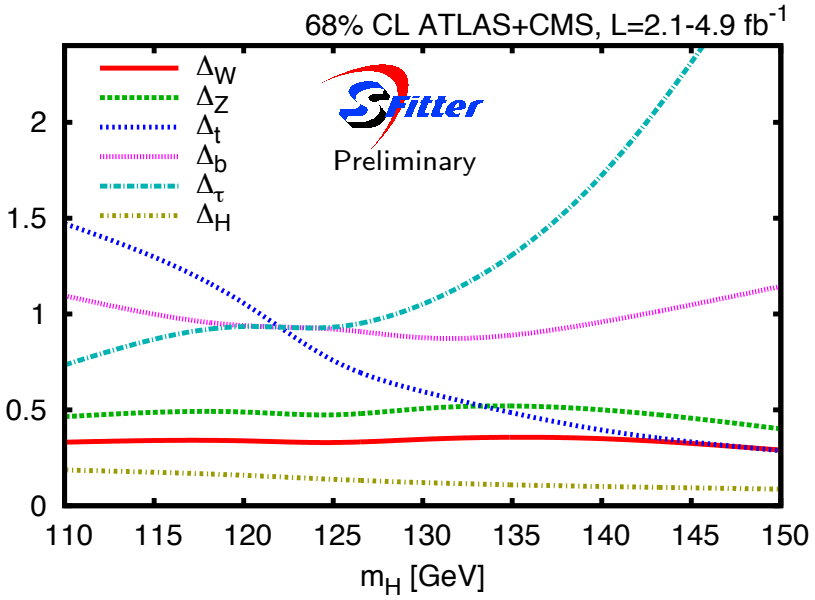
Implemented by hacking HDecay? I'm a little confused why that's necessary.

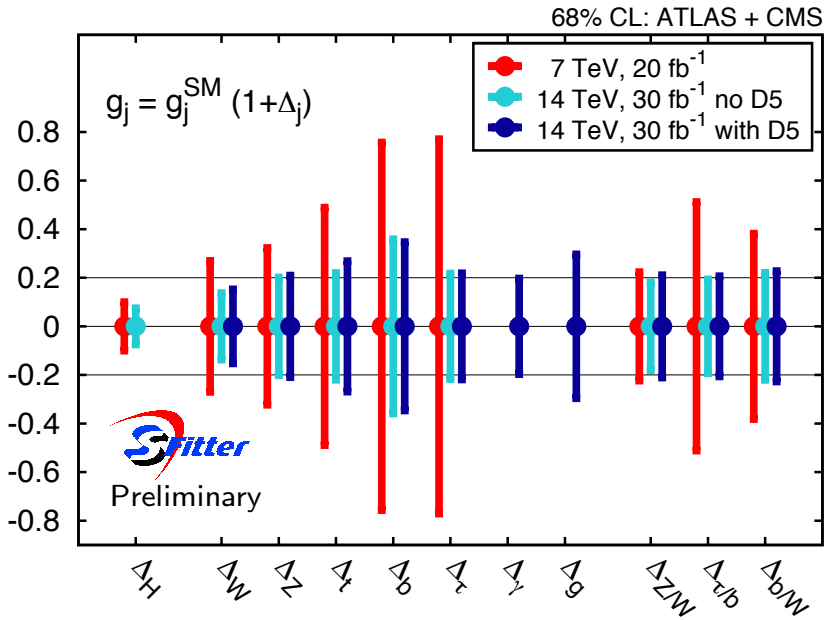
$$g_{iiH} \to g^{\rm SM}_{iiH}(1+\Delta_{iiH})$$

$$g_{iiH} \to g^{\rm SM}_{iiH}(1+\Delta^{\rm SM}_{iiH}+\Delta_{iiH})$$

The total width of the Higgs boson is too small to be measured directly at the LHC. Therefore we have to make one single model assumption about how to treat the total width, which we take as

$$\Gamma_{\rm tot} = \sum_{\rm obs} \Gamma_i(g_{iiH}) + \text{generation universality} \ .$$





One proposal for parametrization

The re-parametrization can be done as a post-processing step on the combined model if the inputs are broken down by production mode and decay.

- Recent paper with a convenient parametrization in terms of couplings

Interpreting LHC Higgs Results from Natural New Physics Perspective

arXiv:1202.3144

Dean Carmi[a], Adam Falkowski[b], Eric Kuflik[a], and Tomer Volansky[a]

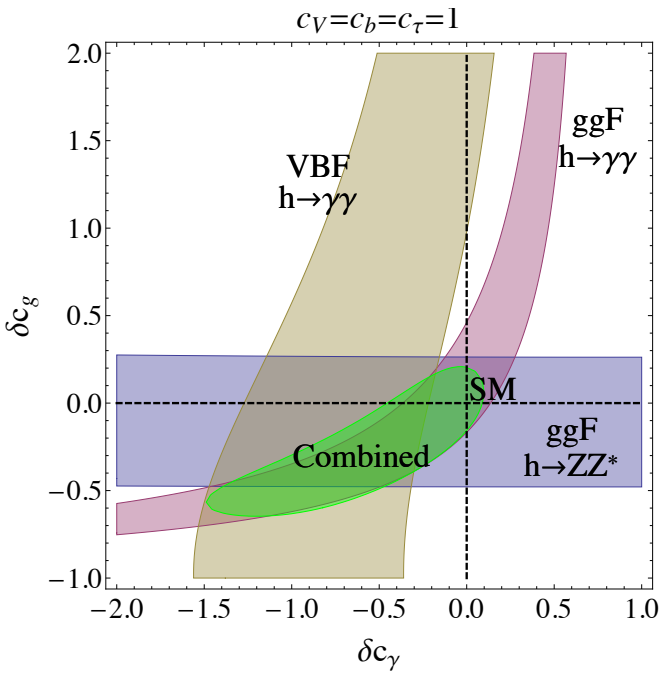
The decay widths of the Higgs relative to the SM predictions are modified approximately as,

$$\frac{\Gamma(h\to b\bar{b})}{\Gamma_{SM}(h\to b\bar{b})}=|c_b|^2\,,\qquad \frac{\Gamma(h\to WW^*)}{\Gamma_{SM}(h\to WW^*)}=\frac{\Gamma(h\to ZZ^*)}{\Gamma_{SM}(h\to ZZ^*)}=|c_V|^2\,,$$
$$\frac{\Gamma(h\to gg)}{\Gamma_{SM}(h\to gg)}\simeq|c_g|^2\,,\qquad \frac{\Gamma(h\to\gamma\gamma)}{\Gamma_{SM}(h\to\gamma\gamma)}=\left|\frac{\hat{c}_\gamma}{\hat{c}_{\gamma,SM}}\right|^2\,, \tag{2.5}$$

where $\hat{c}_\gamma$ includes also the one-loop contribution due to the triangle diagram with the W boson[1],

$$\hat{c}_\gamma(\tau_t,\tau_W)=c_\gamma(\tau_t)-\frac{c_V}{8\tau_W^2}\left[3(2\tau_W-1)f(\tau_W)+3\tau_W+2\tau_W^2\right]\,, \tag{2.6}$$

where $\tau_W=m_h^2/4m_W^2$. For $m_h=125$ GeV one finds $\hat{c}_\gamma\simeq c_\gamma-1.04c_V$, and thus $\hat{c}_{\gamma,SM}\simeq-0.81$.



To-do list

Efficiency and acceptance for each production mode vs. M_H for each channel

- not really enough b/c shapes etc.

μ_i contours per channel (next slide)

Form combined likelihood with $L(\mu_i, \mu_j; m_H)$

- no relationship between production and branching ratio
  - punt on other coupling structures, higher dim operators etc.

Reparametrize w/ D5 (Δ_g and Δ_γ) no constraint on total width

- ie. no generational universality and include unobserved Γ_{hidden}
- no sensitivity, could make plots with limited range on Δ_g, Δ_γ, Γ_{hidden} assuming generational universality
- make plots on ratios with respect to HWW coupling

Reparameterize w/ $\Delta_g = \Delta_\gamma = \Gamma_{hidden} = 0$ + generational universality

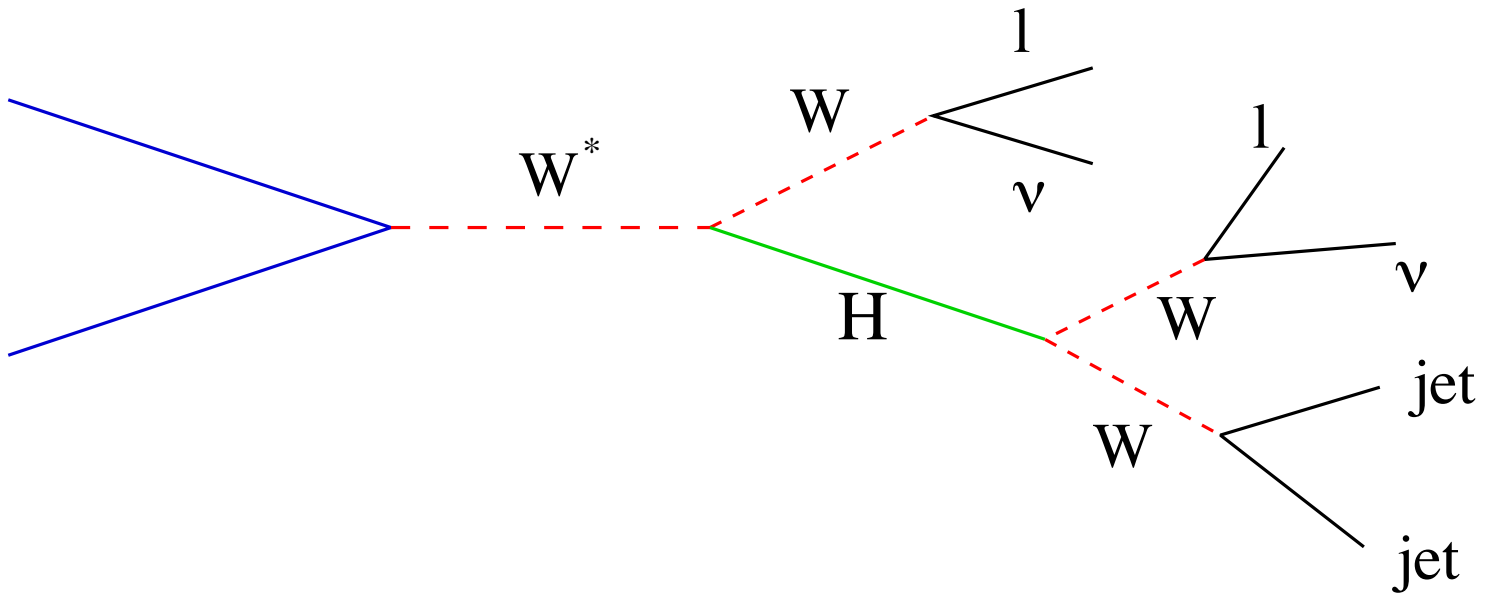
Add additional assumptions, ie. W/Z fixed or THDM relationships?

All couplings fixed to SM, but add Δ_g, Δ_γ, Γ_{hidden}

- would give sensitivity to counterfeit like scenarios?

$pp \to WH \to WWW \to l^{\pm} l^{\pm} jj$

Daniele Alves pointed out a potentially clean way to measure WW coupling: $pp \to WH \to WWW \to l^{\pm} l^{\pm} jj$



Curious that I never see separately cross-section for $pp \to W^{+}H$ and $pp \to W^{-}H$ in LHC Higgs Cross section working group.

- new physics and backgrounds can break the charge symmetry