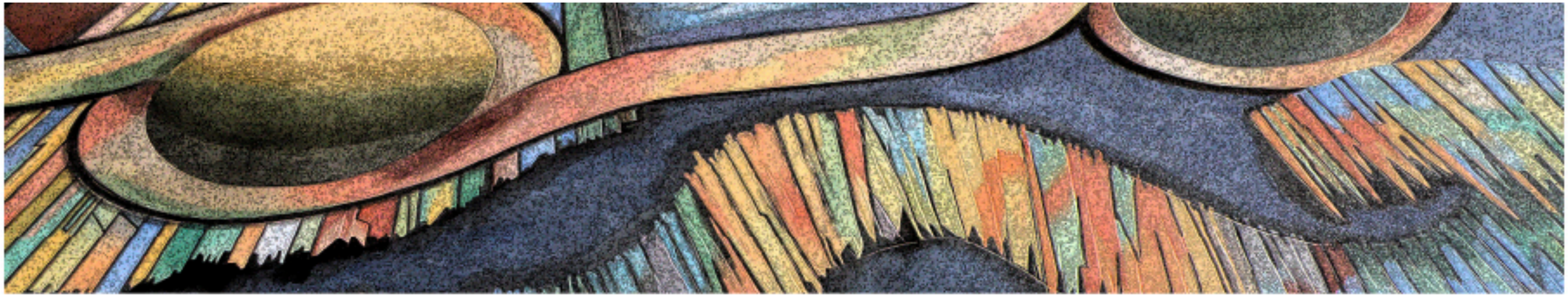


UiO : Department of Physics
University of Oslo

Statistical methods in Higgs to gamma gamma signal extraction and mass measurement

Alex Read

From Higgs to Dark Matter

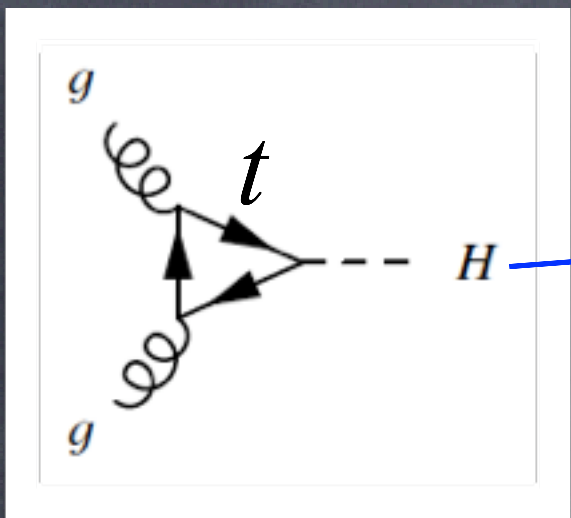
Geilo 2012, Dr Holms Hotel

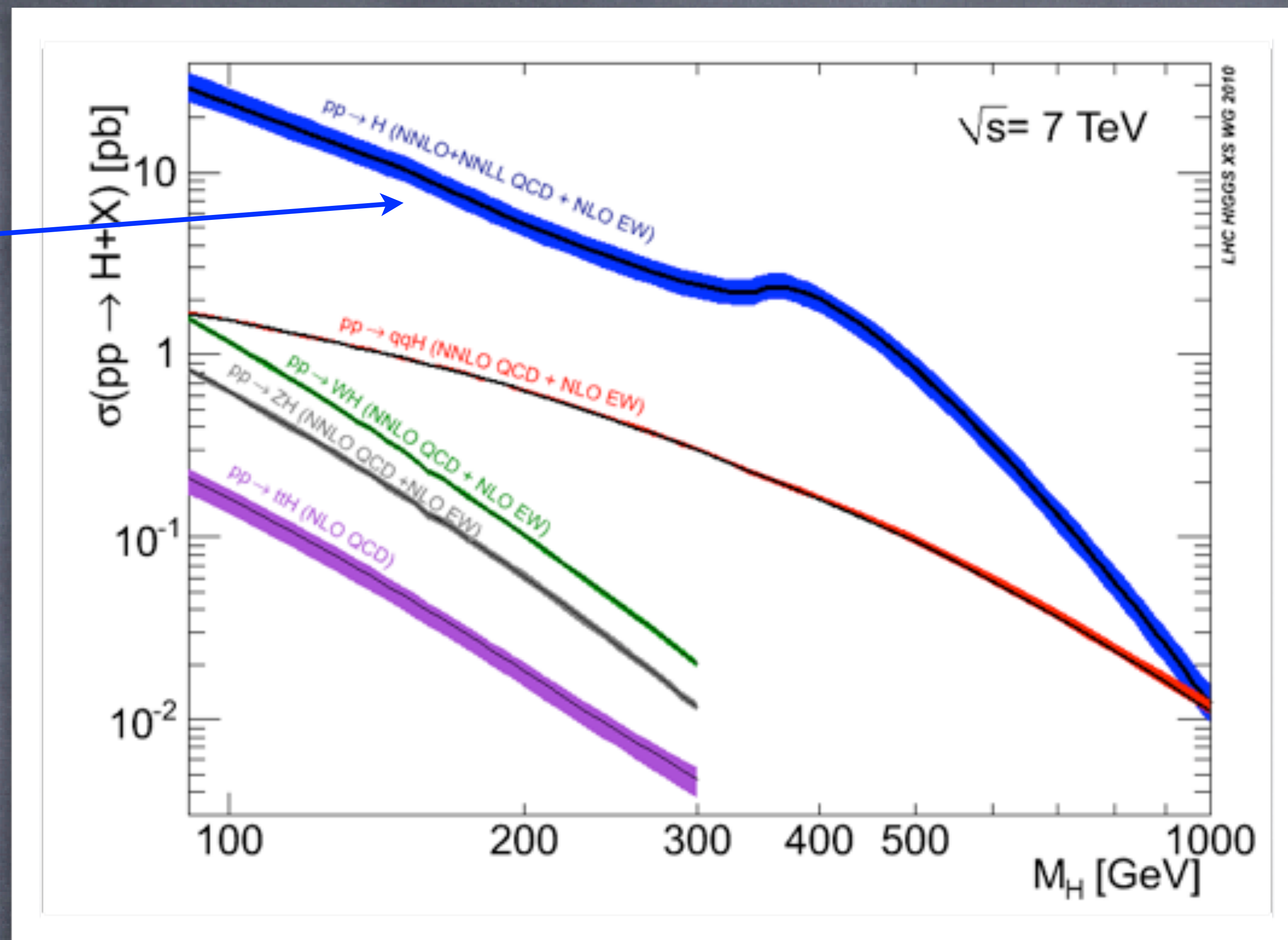
The Research Council of Norway

Introduction

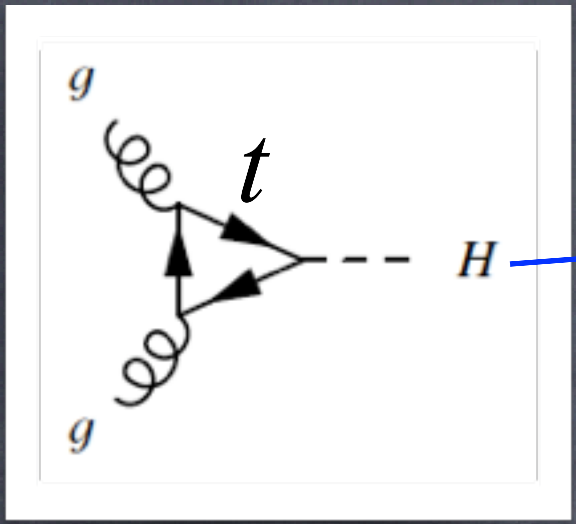
- Focus on ATLAS (latest $H \rightarrow \gamma\gamma$ results)
- Main features of Higgs properties
- Diphoton event selection
- Extracting signal strength(s) and mass
- P.S. First look at J^P

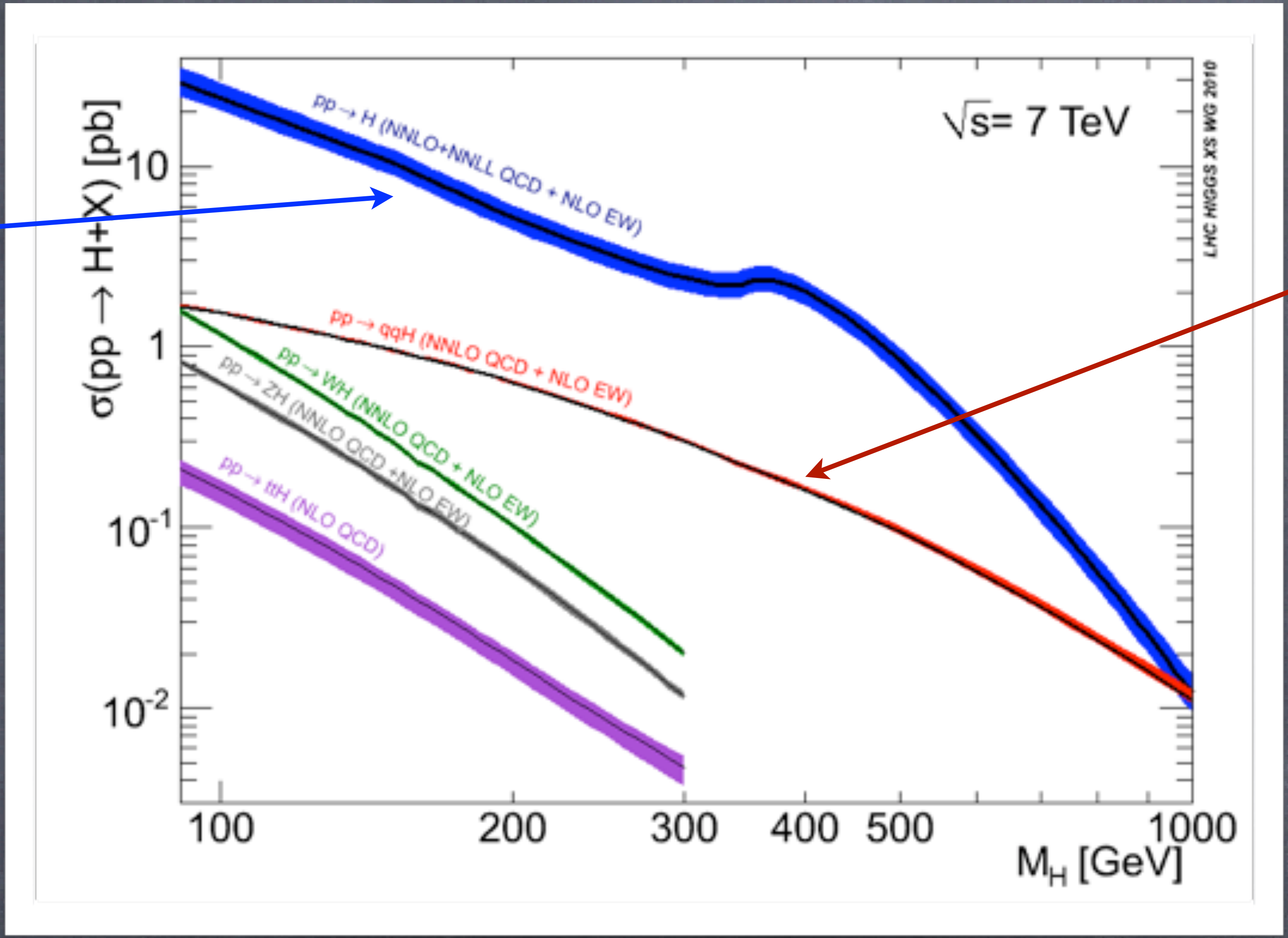
Higgs boson production

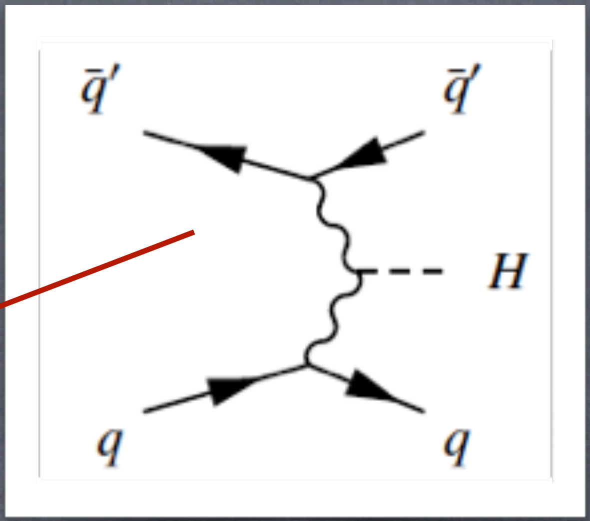




Higgs boson production

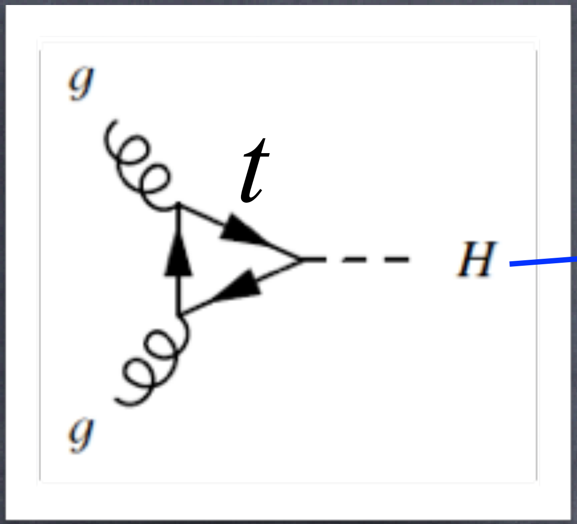


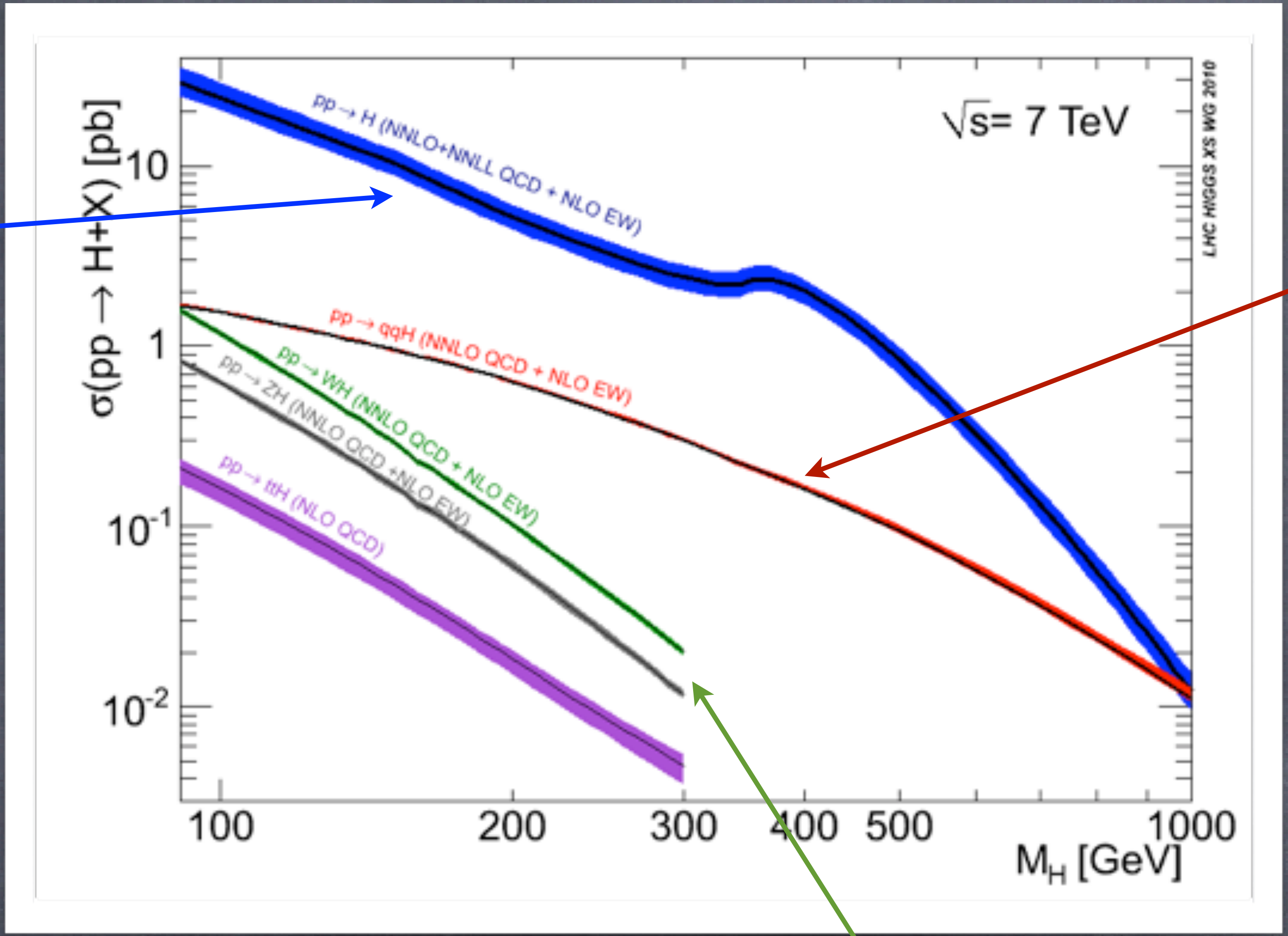


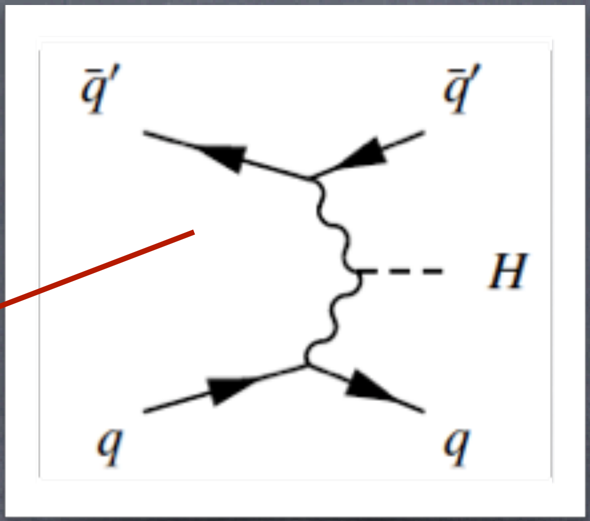


x0.1 but helps

Higgs boson production







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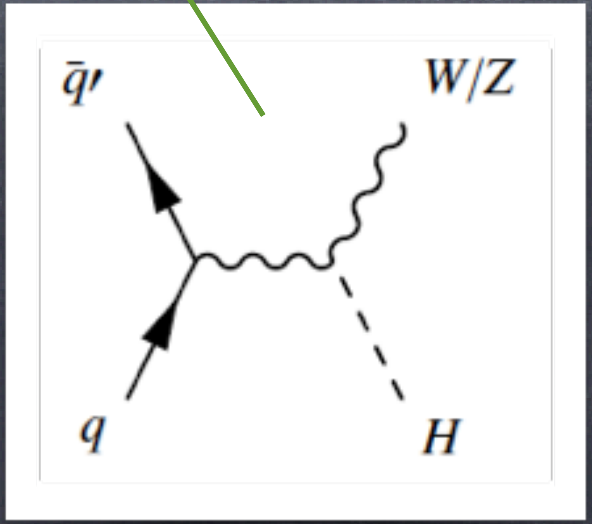
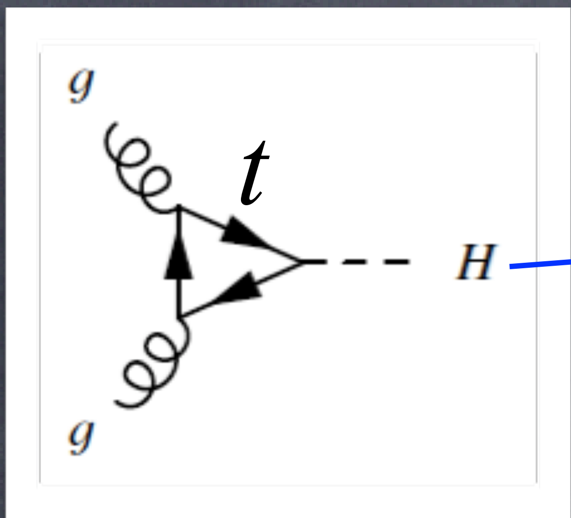
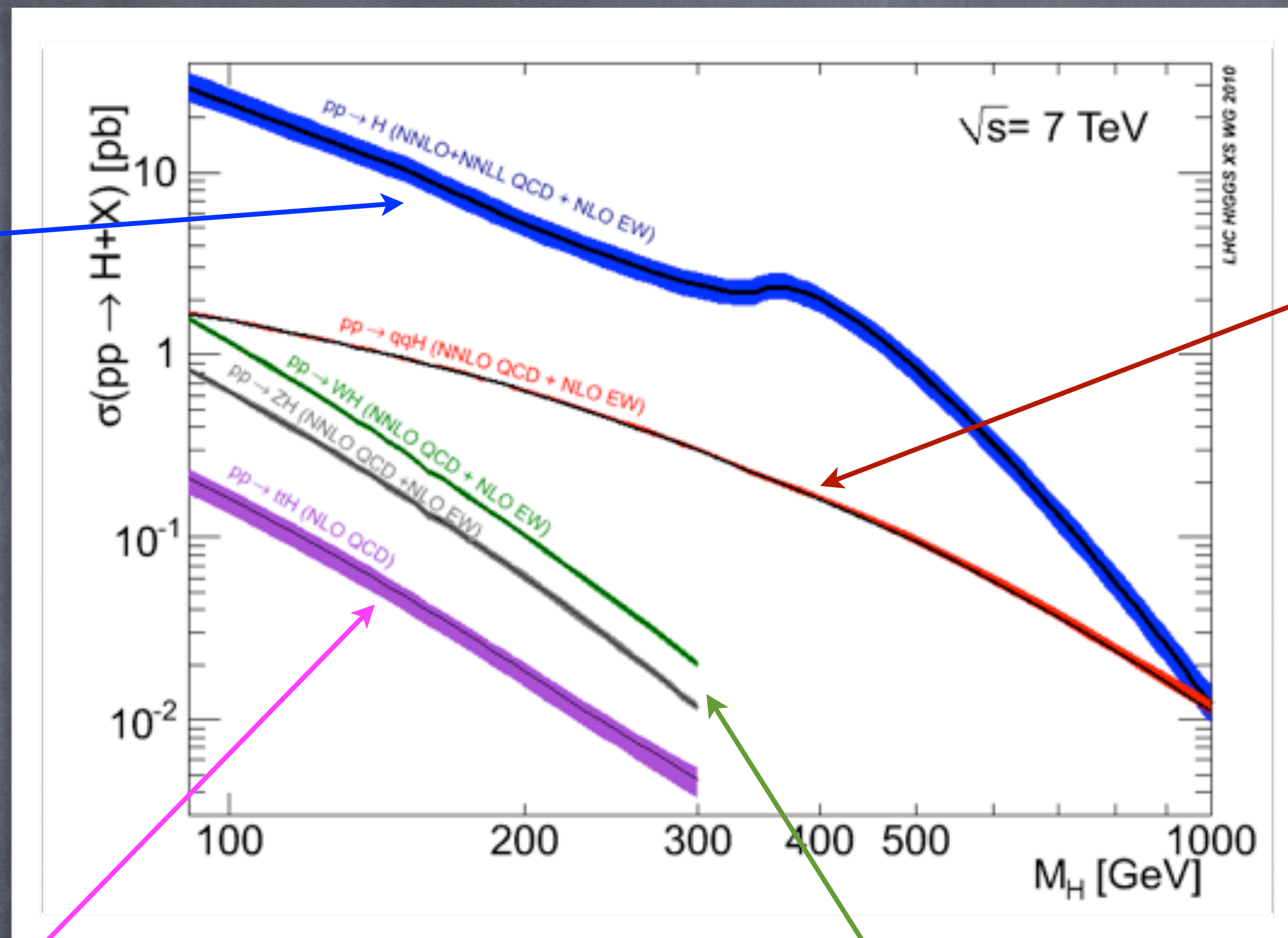
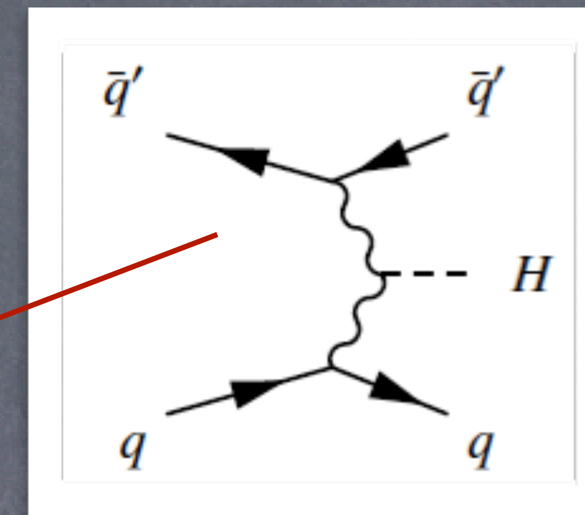


Even smaller, but very clean!

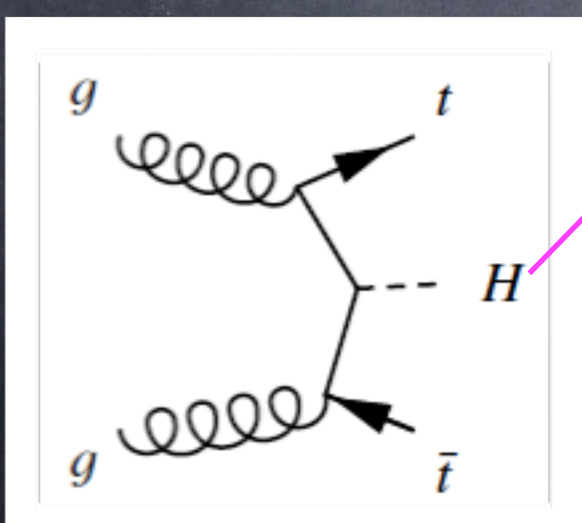
Higgs boson production



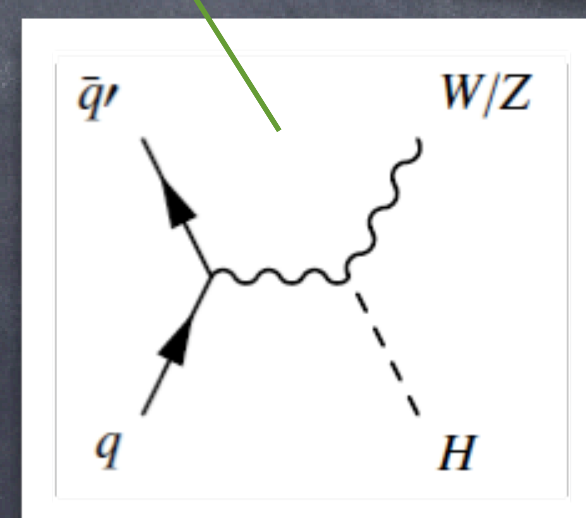




x0.1 but helps

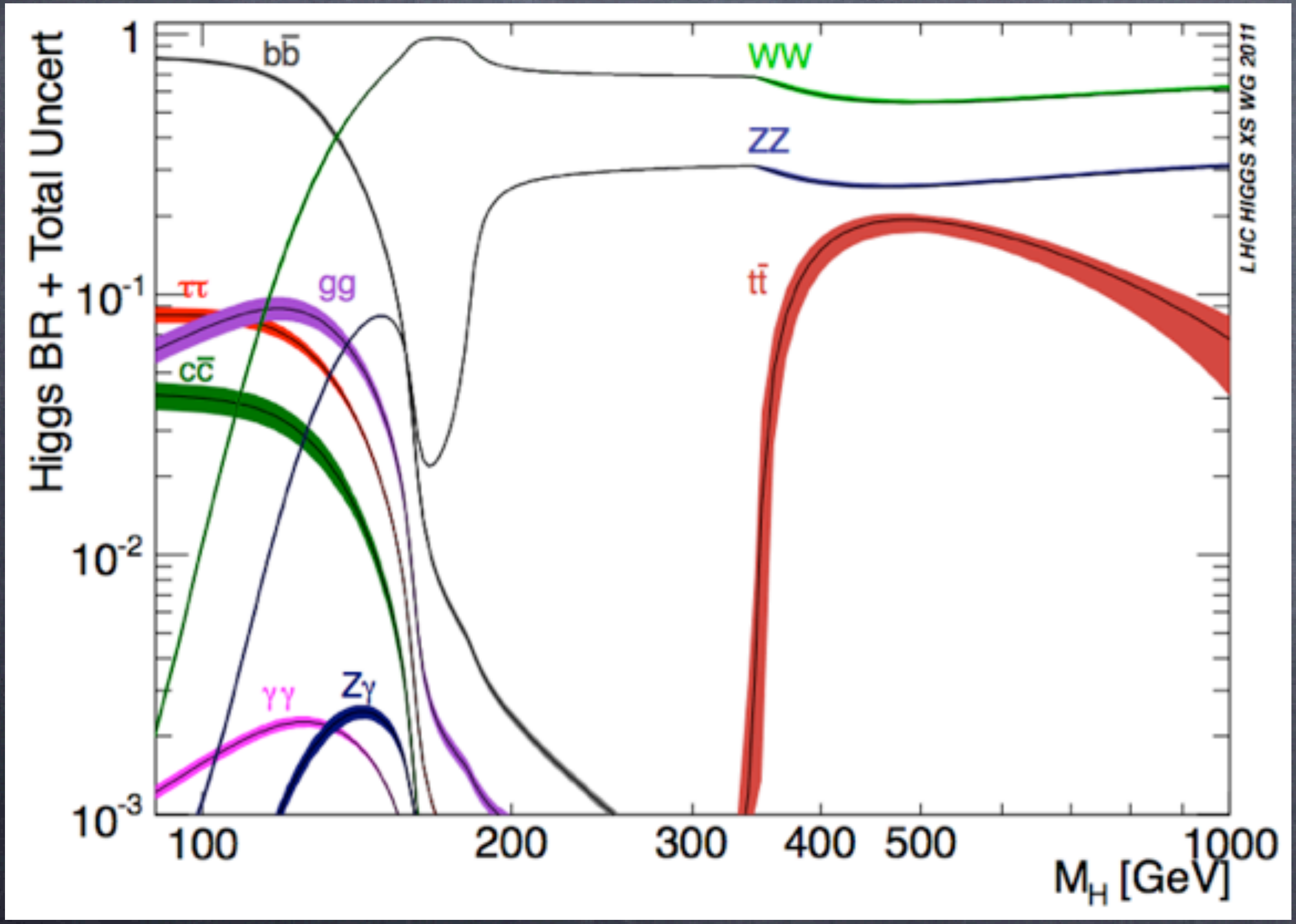


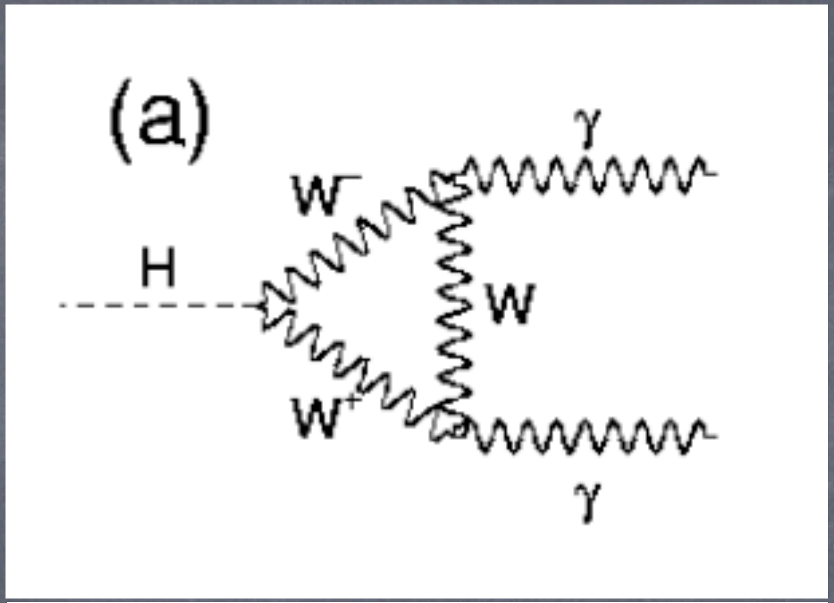
Difficult, but included

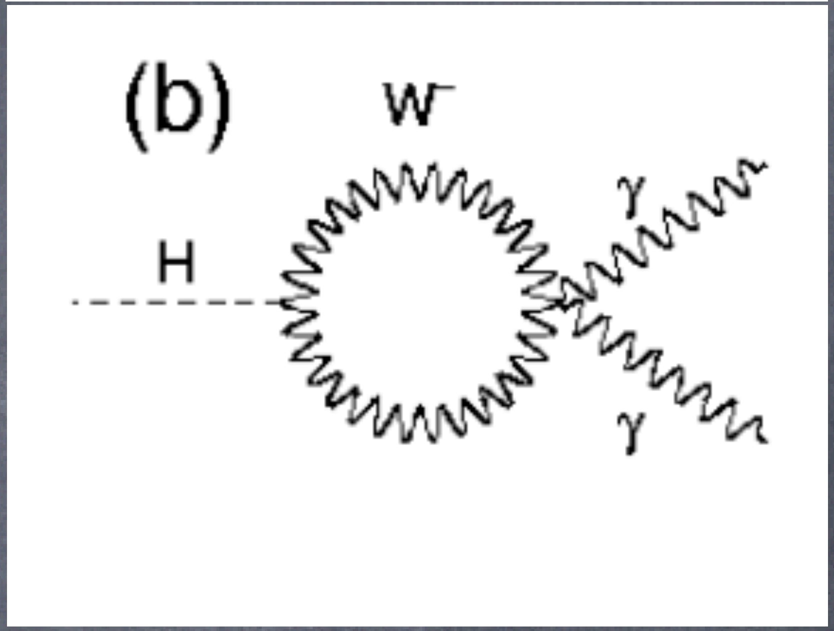


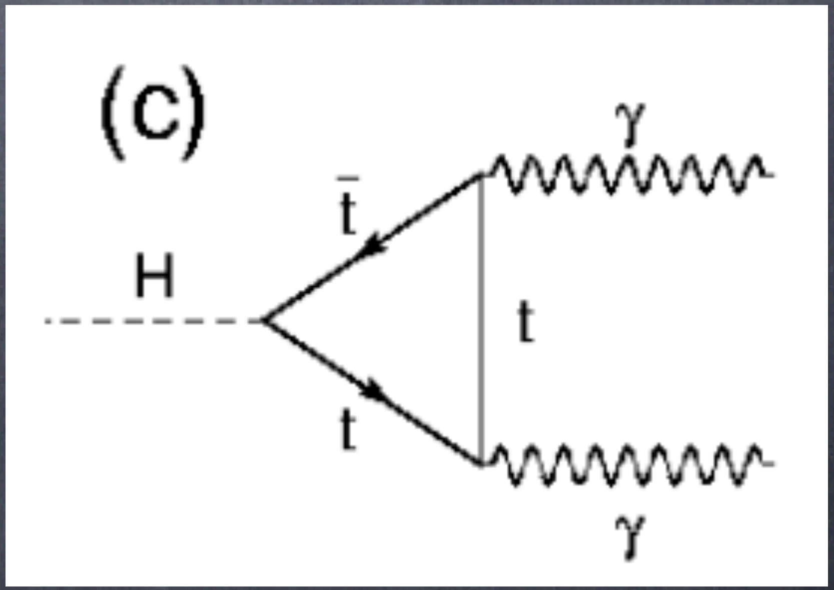
Even smaller, but very clean!

$H \to \gamma\gamma$

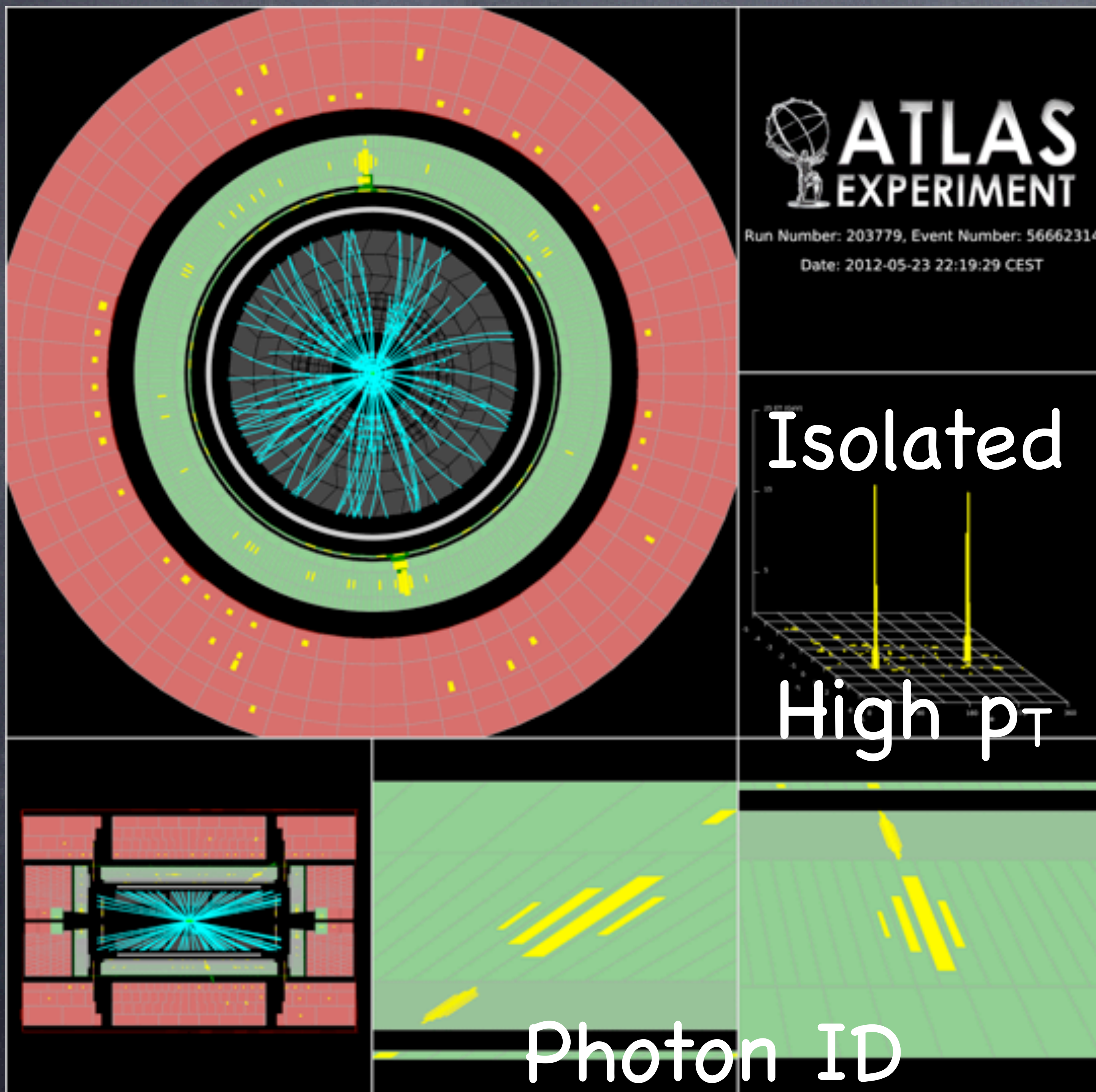








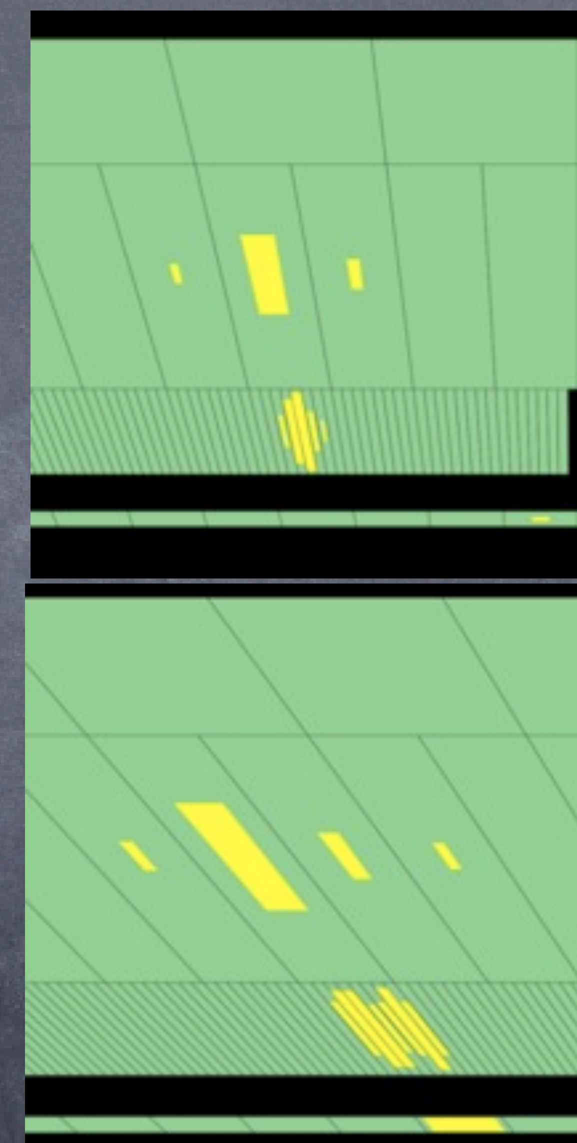
Diphoton candidates



Isolated

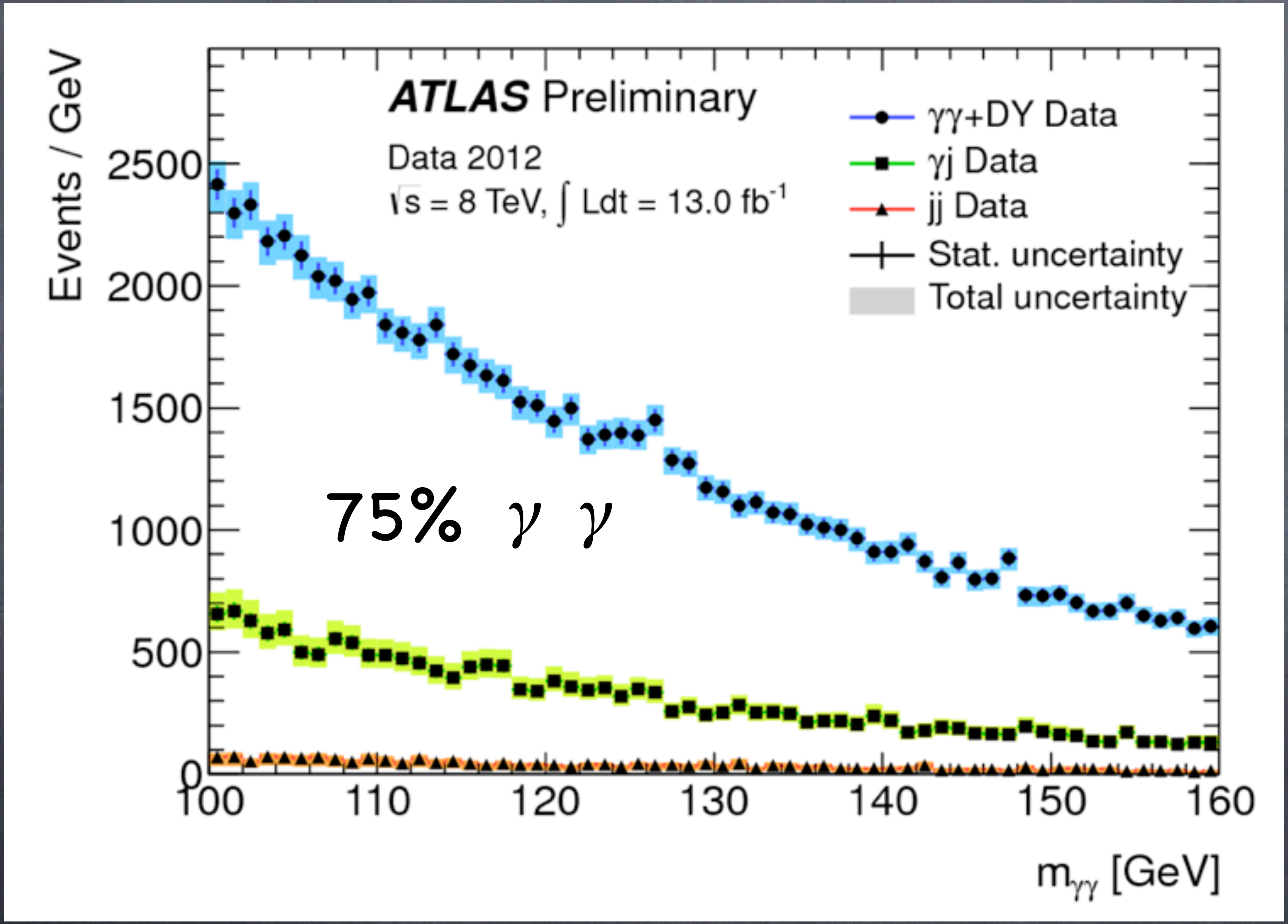
High p_T

Photon ID



Jet (~leading π^0) rejection

Sample composition



Categories?

Likelihood ratio for binned counts

$$Q_i = \frac{\dfrac{e^{-(s_i+b_i)}(s_i+b_i)^{n_i^{cand}}}{n_i^{cand}!}}{e^{-b_i}\dfrac{b_i^{n_i^{cand}}}{n_i^{cand}!}}$$

- Likelihood ratio for bin i
  - Poisson statistics

$$-2\,lnQ_i = 2\ s_i - 2\ n_i \ln\left(1+\frac{s_i}{b_i}\right)$$

- ...in useful form

$$Q = \prod Q_i$$

$$-2\ln Q = \sum -2\ln Q_i$$

- Likelihood ratio for entire distribution (or combination of channels, experiments, etc)
- ...in useful form

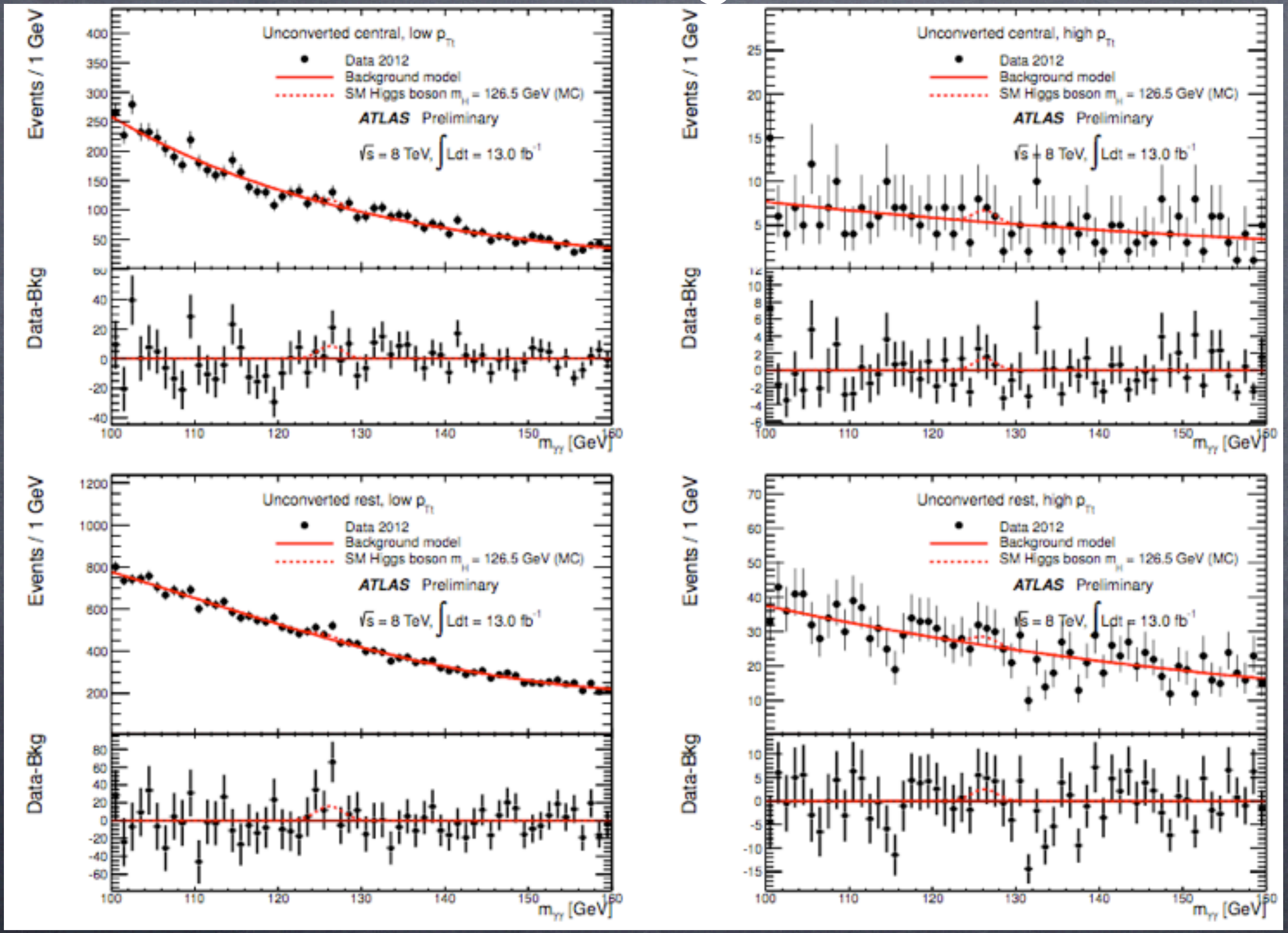
Categories

$\sqrt{s}$	8 TeV							
Category	N_D	N_S	$gg \to H$ [%]	VBF [%]	WH [%]	ZH [%]	ttH [%]	FWHM [GeV]
Unconv. central, low p_{Tt}	6797	32	93	4.2	1.4	0.9	0.2	3.45
Unconv. central, high p_{Tt}	319	4.7	76	15.2	3.9	2.9	1.7	3.22
Unconv. rest, low p_{Tt}	26802	69	93	4.2	1.7	1.1	0.2	3.75
Unconv. rest, high p_{Tt}	1538	9.7	76	15.1	4.5	3.3	1.2	3.59
Conv. central, low p_{Tt}	4480	21	93	4.2	1.4	0.9	0.2	3.86
Conv. central, high p_{Tt}	199	3.1	77	14.5	4.1	2.8	1.7	3.51
Conv. rest, low p_{Tt}	24107	60	93	4.1	1.7	1.1	0.2	4.32
Conv. rest, high p_{Tt}	1324	8.3	75	15.1	4.9	3.4	1.3	4.00
Conv. transition	10891	28	90	5.6	2.3	1.5	0.3	5.57
High Mass two-jet	345	7.6	31	68.2	0.3	0.2	0.1	3.65
Low Mass two-jet	477	4.7	60	5.1	20.7	12.1	1.6	3.45
One-lepton	151	2.0	3.2	0.4	62.5	15.8	18.0	3.85
All categories (inclusive)	77430	249	88	7.4	2.8	1.6	0.5	3.87

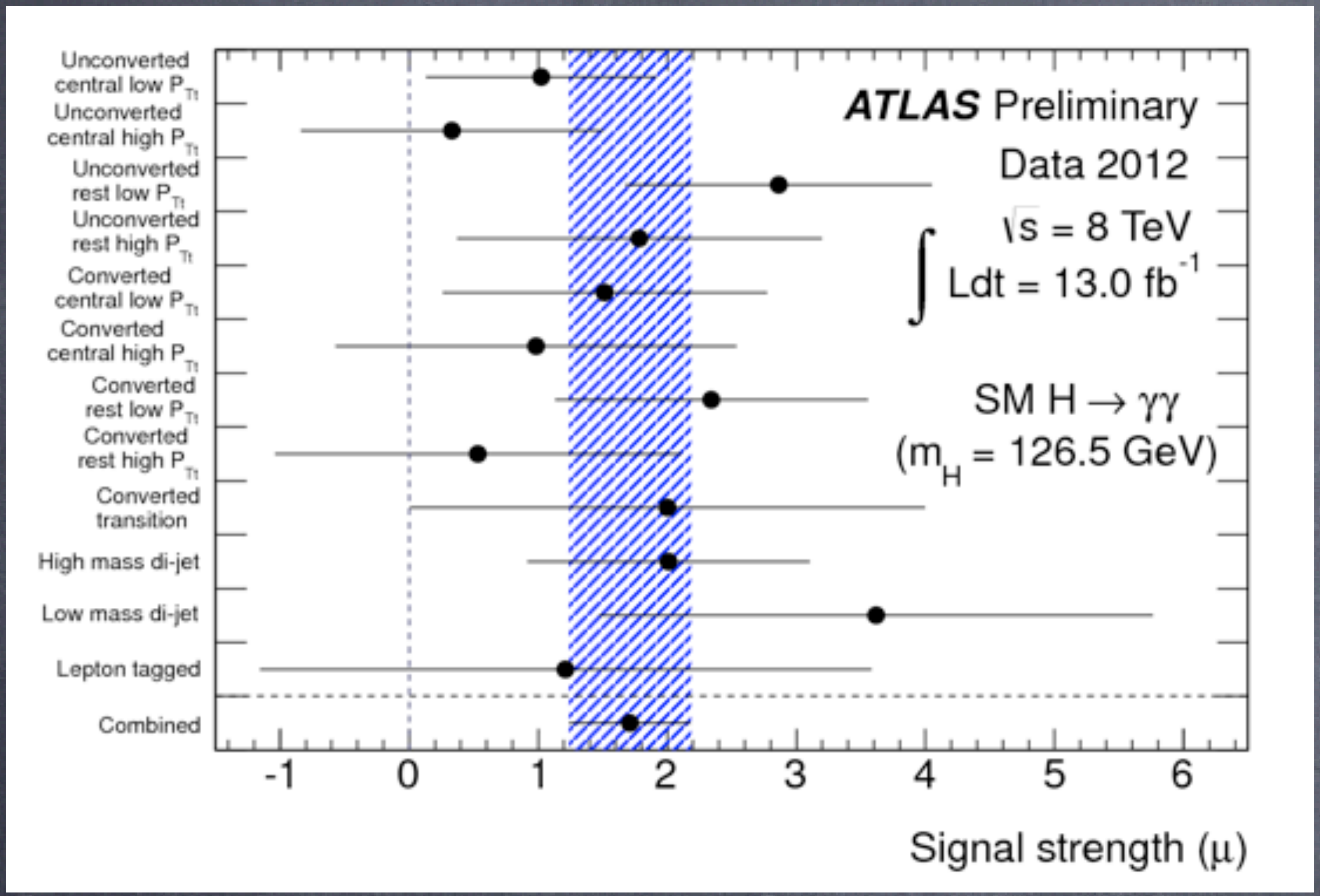
- Search: Optimal separation of signal and background assuming the production mechanisms (then unbinned mass fit in each category)
- Measure: Distinguish production mechanisms

Coherent signal fit

4/12 categories



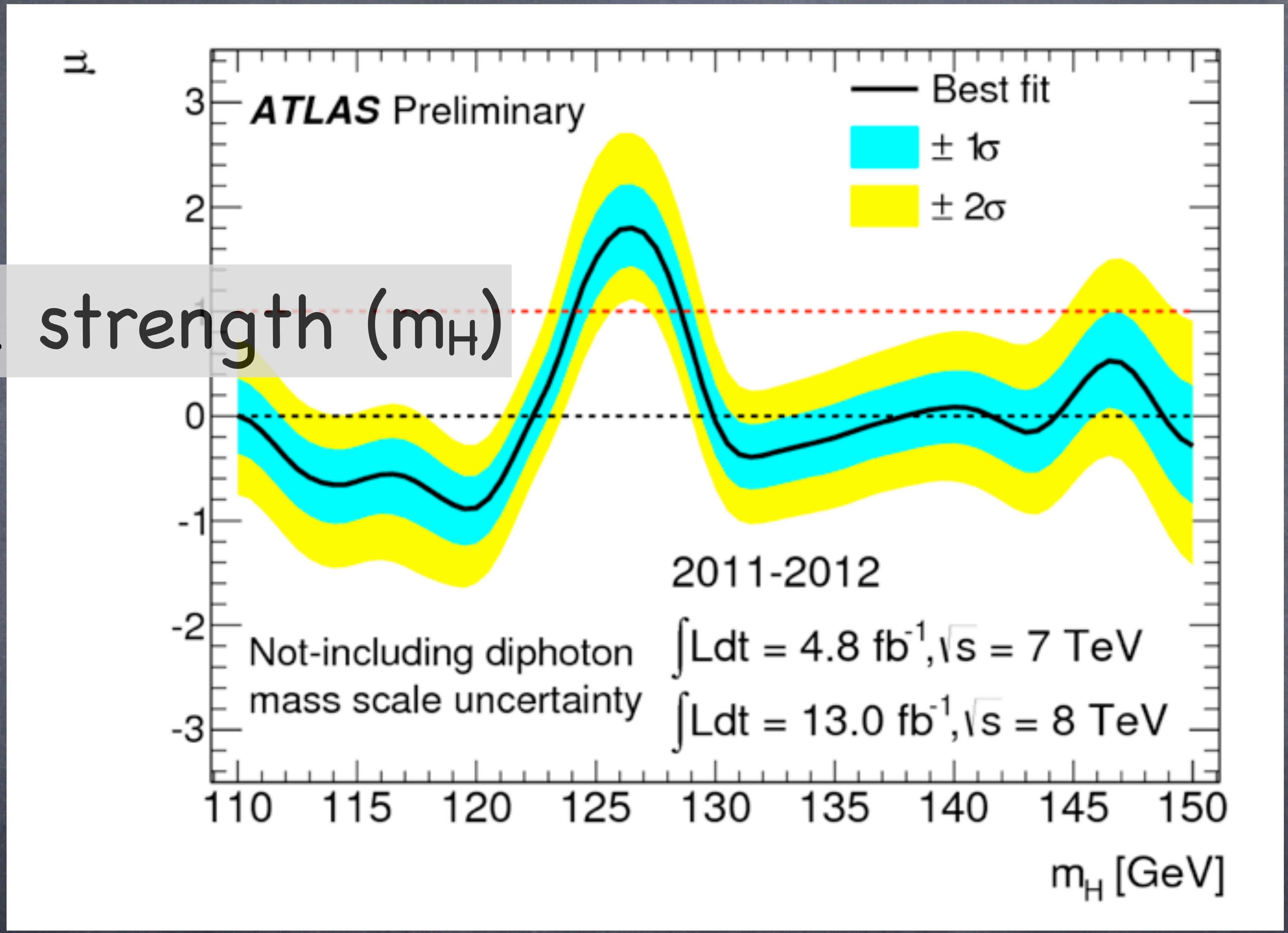
Signal strength breakdown



- Apart from some small/moderate correlations (lumi, γ -ID, theory, etc)

$$\frac{\mu}{\sigma^2} = \sum_i \frac{\mu_i}{\sigma_i^2}$$

Signal strength



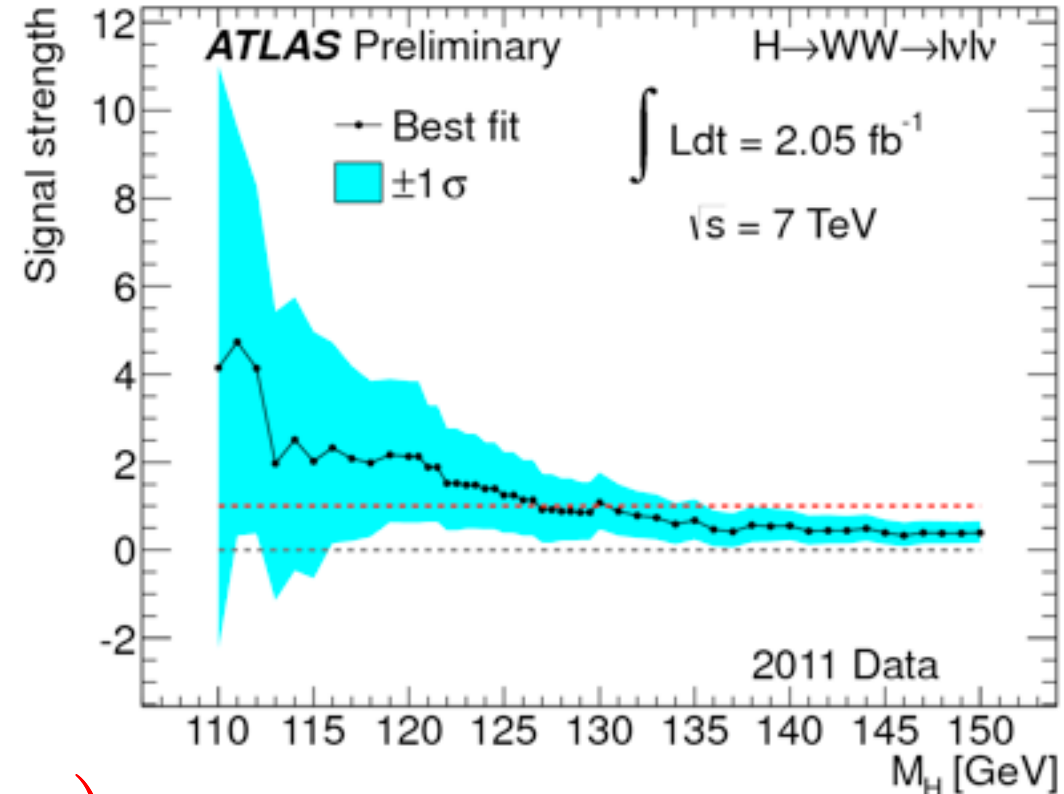
Fit signal strength (m_H)

$$\hat{\mu}(m_H = 126.6\,\mathrm{GeV}) = 1.80 \pm 0.30(stat) \pm^{0.21}_{0.15} (syst) \pm^{0.20}_{0.14} (theory)$$

Profile likelihood ratio: p_0 and $\hat{\mu}$

LHCHCG Combination Procedures

$$= -2\ln\left\{\frac{\mathcal{L}(\mu,\hat{\theta}_\mu)}{\mathcal{L}(\hat{\mu},\hat{\theta})}\right\}$$

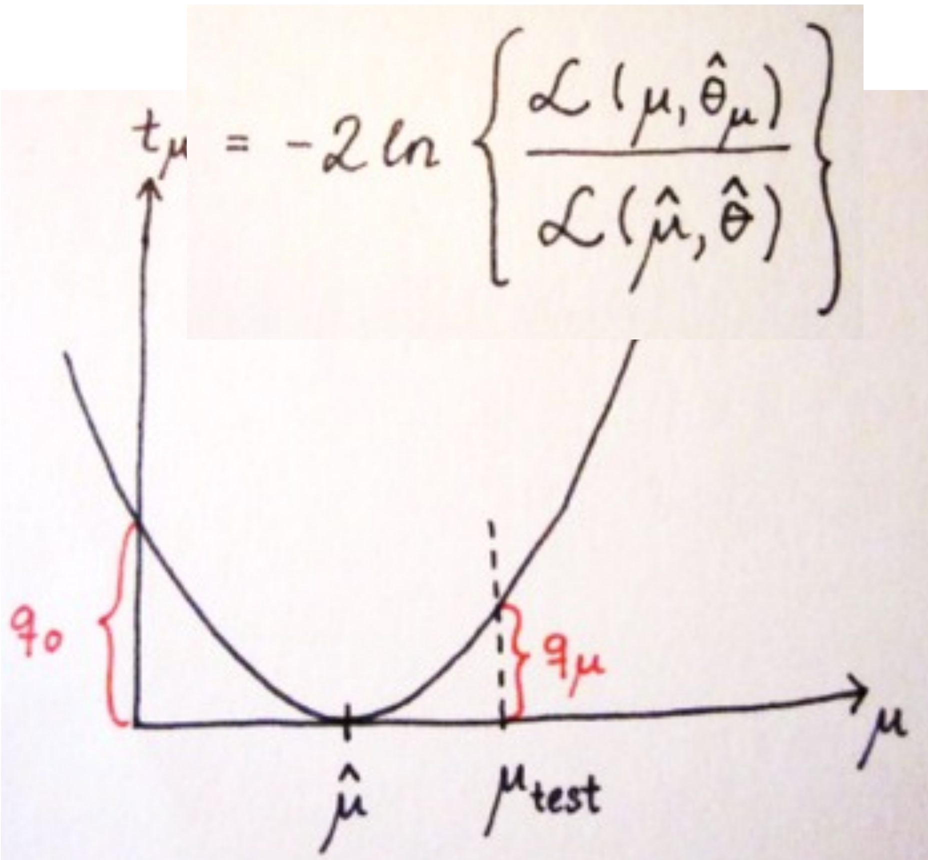


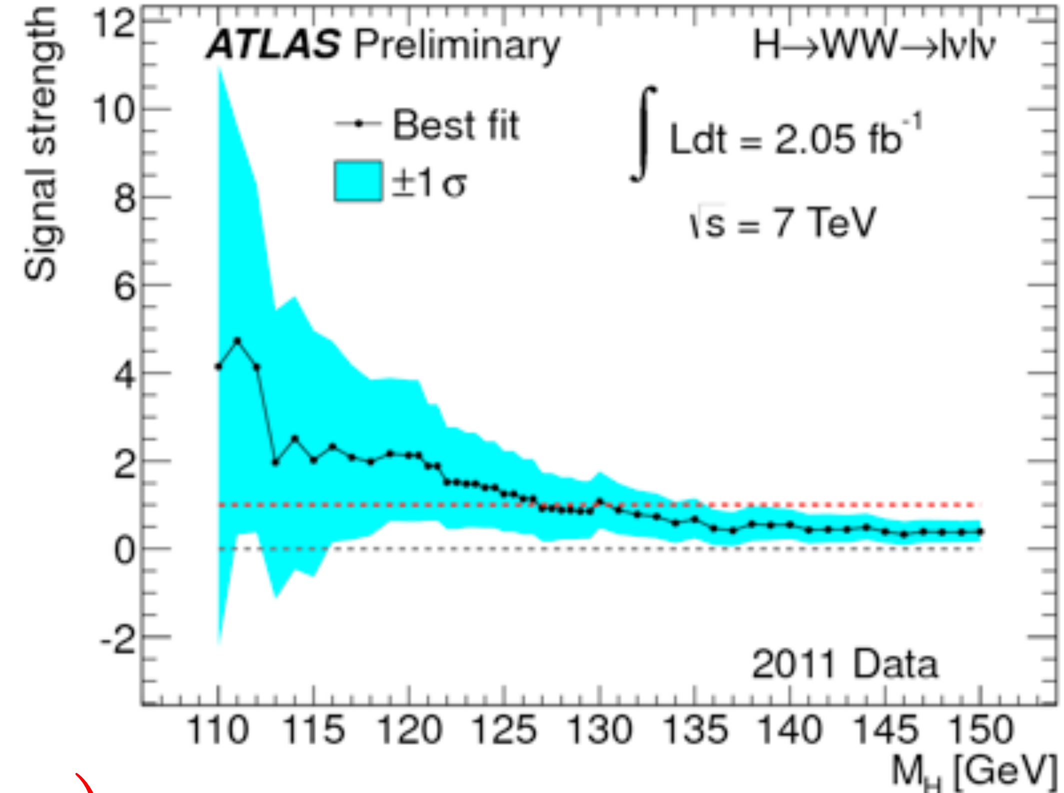
P.S. $q_{LEP}(\mu) = q_\mu - q_0$

χ^2

Profile likelihood ratio: p_0 and $\hat{\mu}$

[LHCHCG Combination Procedures]





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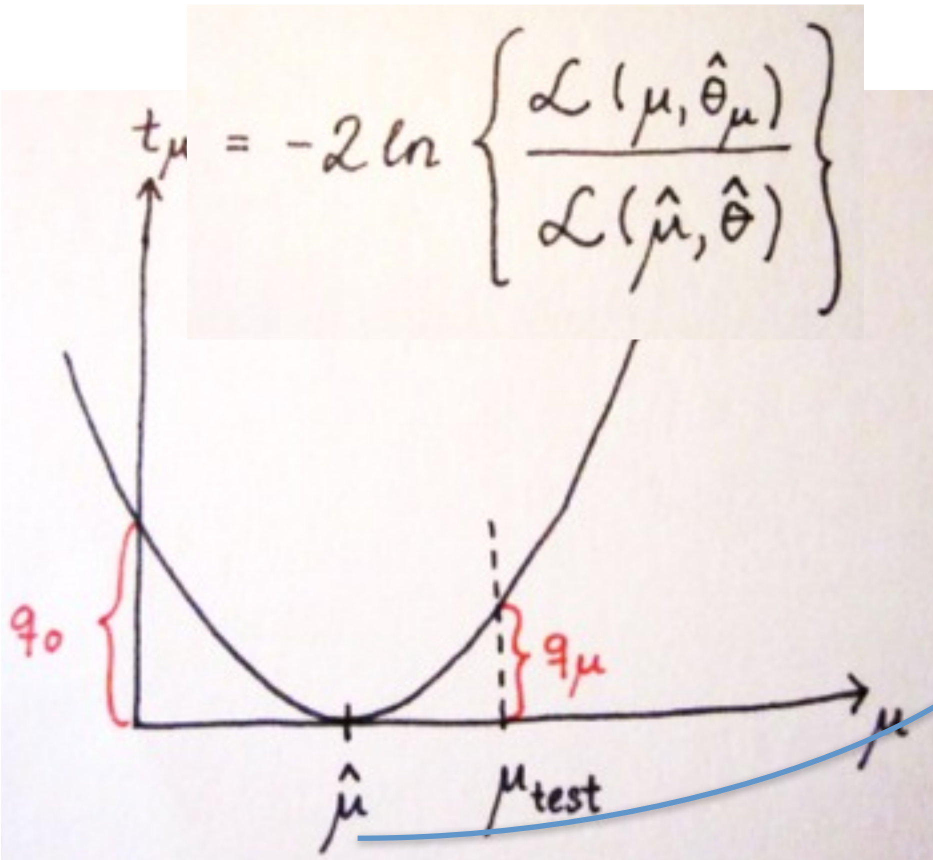
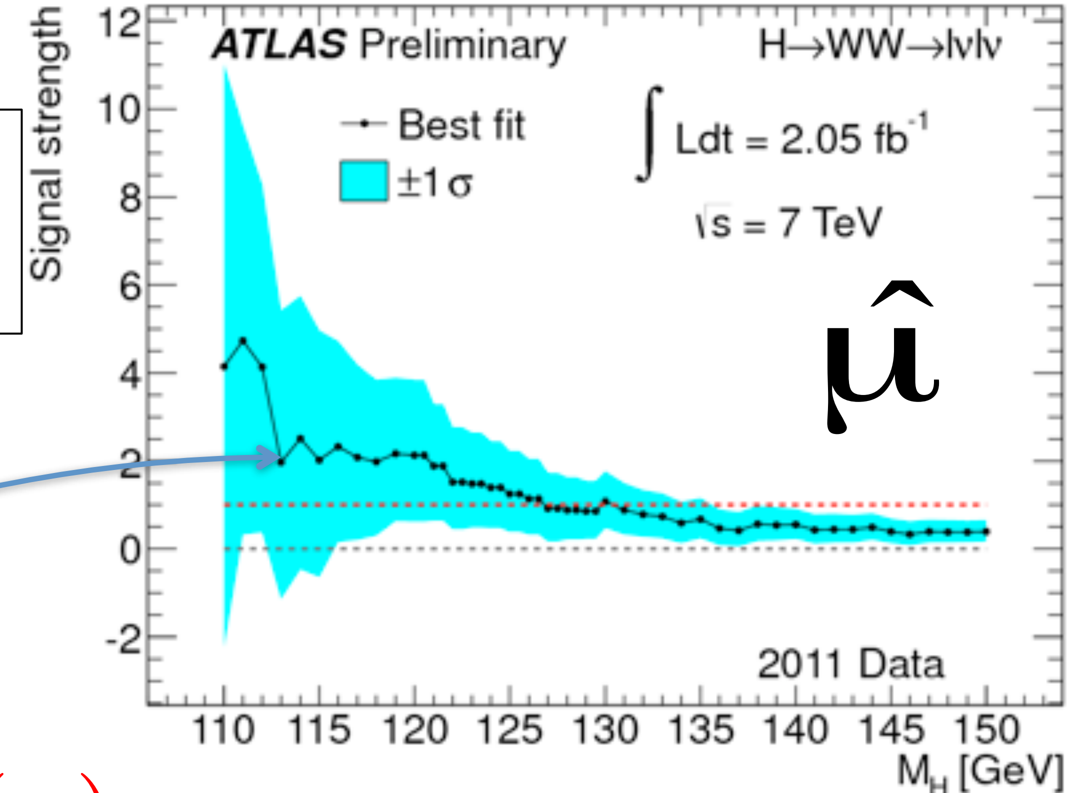
LHCHCG Combination Procedures



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



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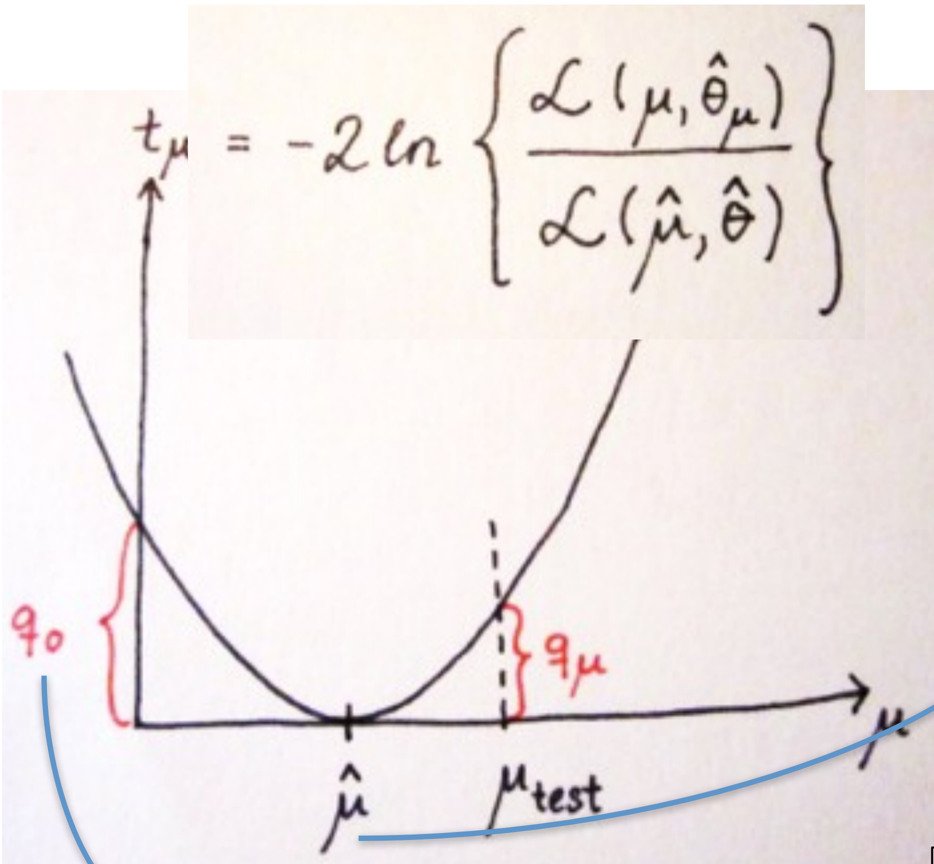
LHCHCG Combination Procedures



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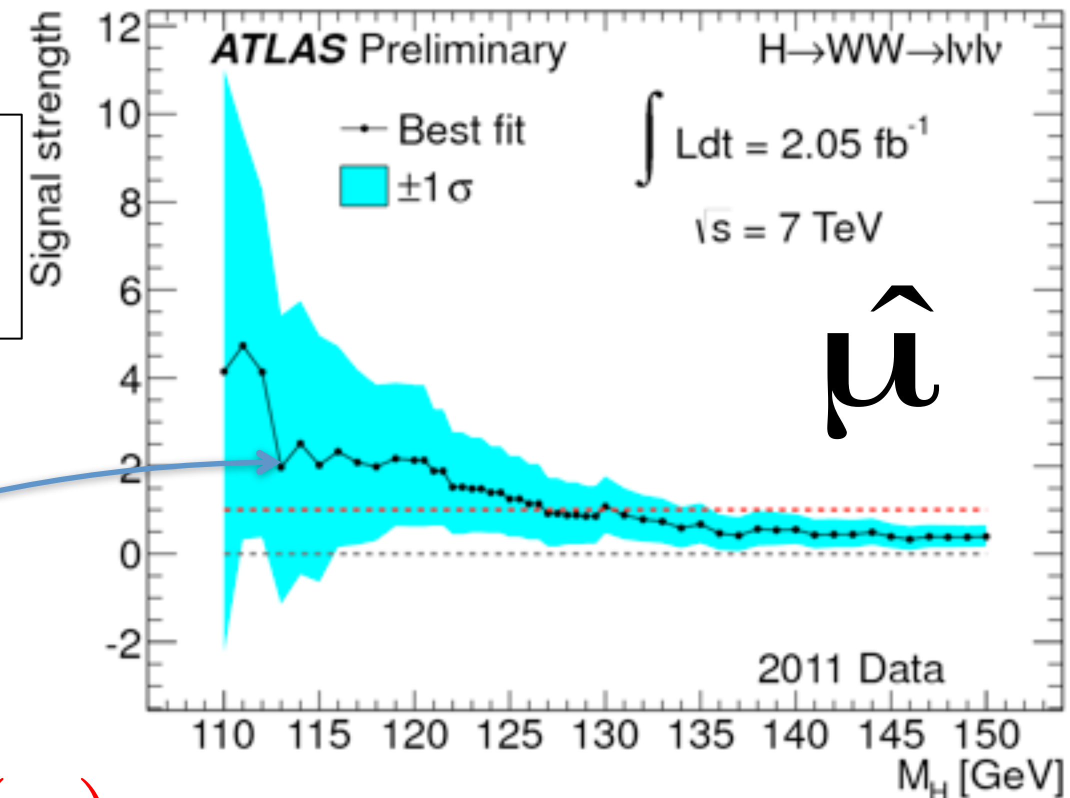
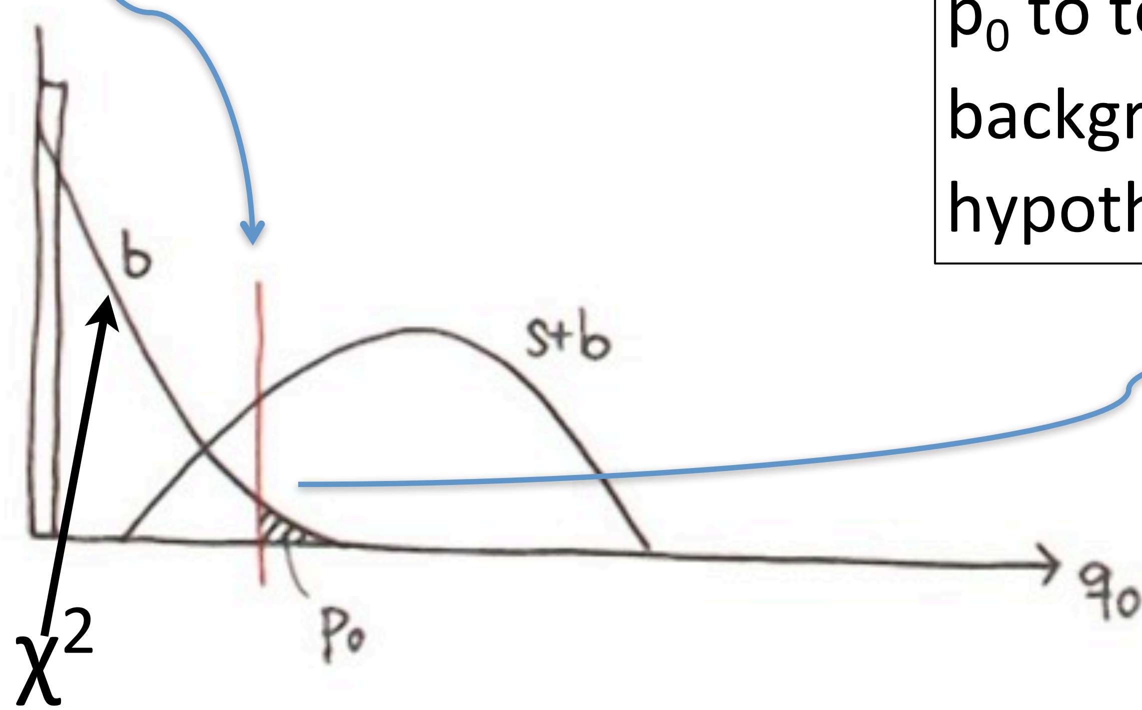
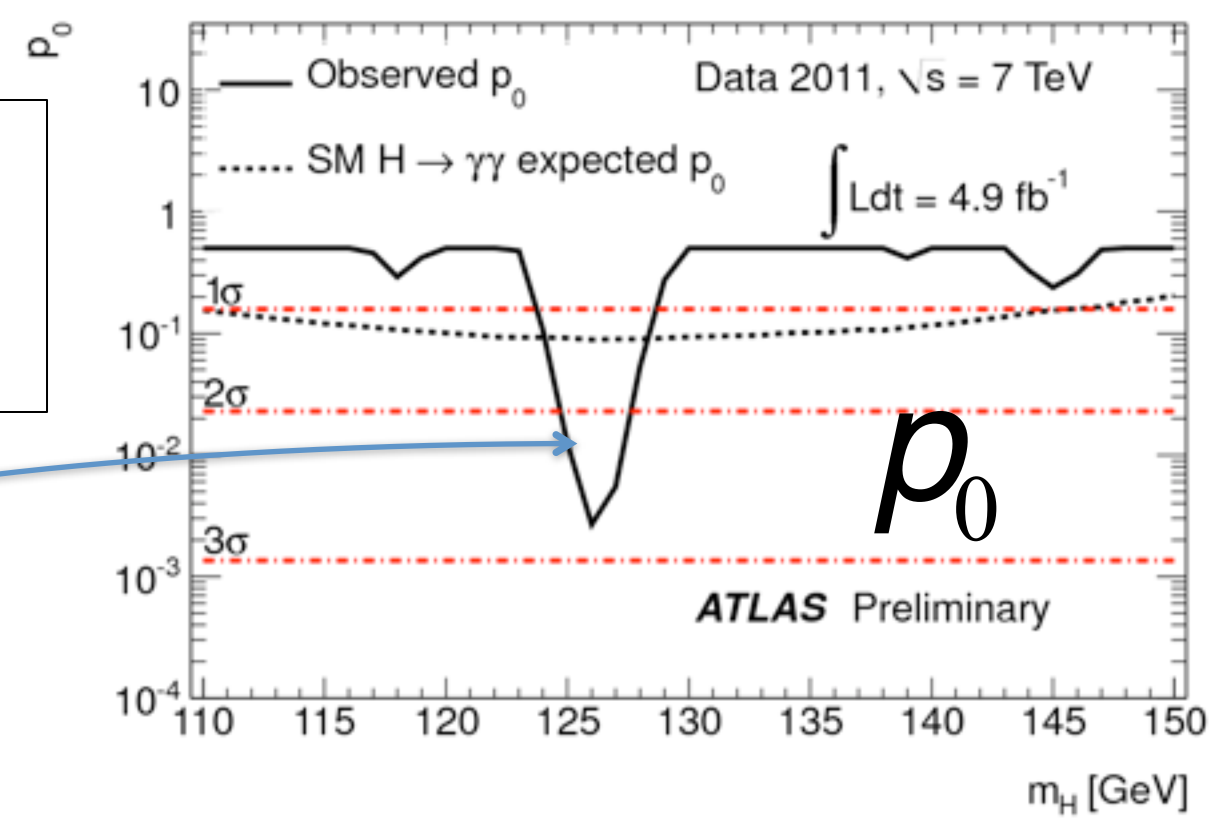


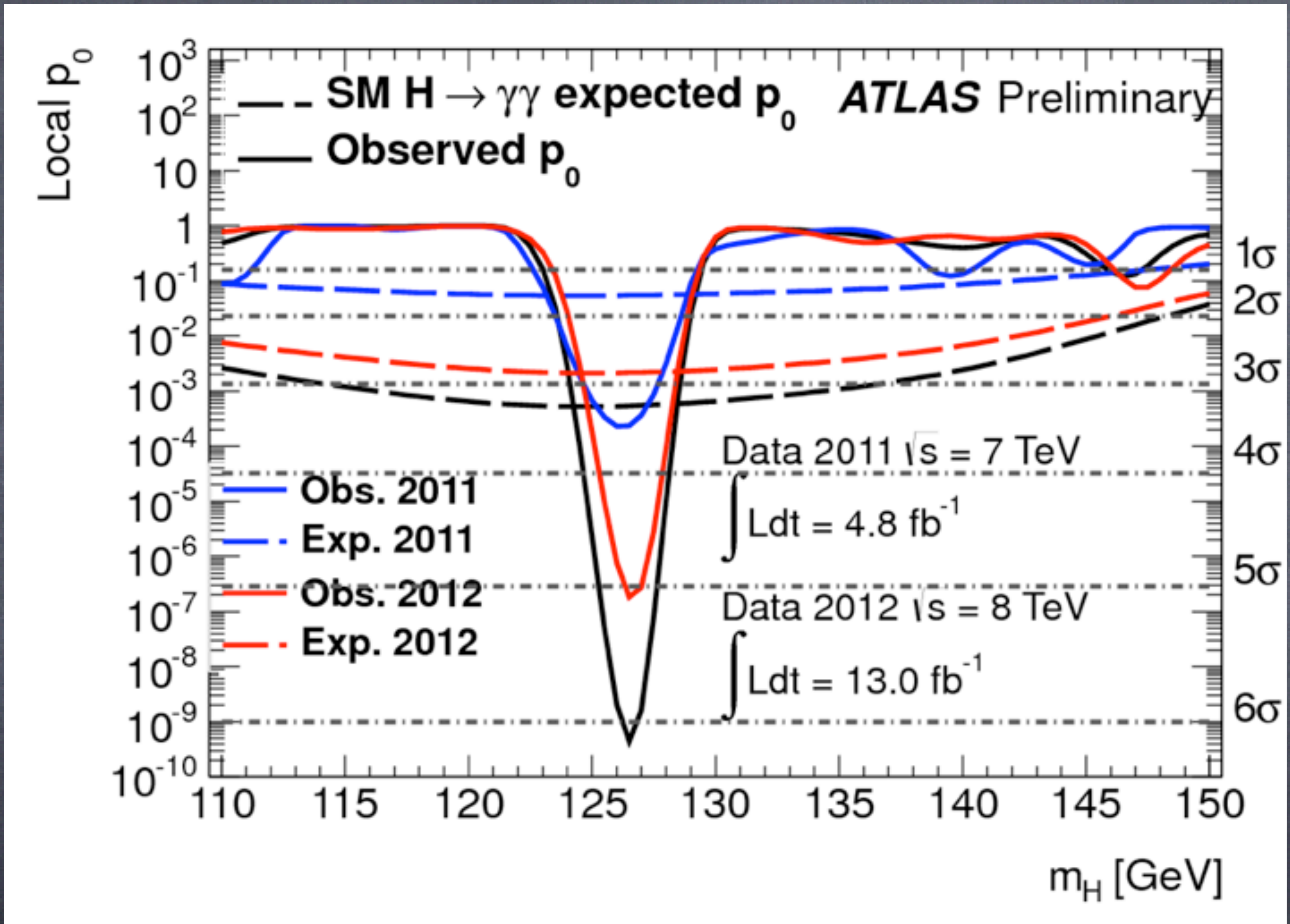
P.S. $q_{LEP}(\mu) = q_\mu - q_0$

p_0 to test background hypothesis

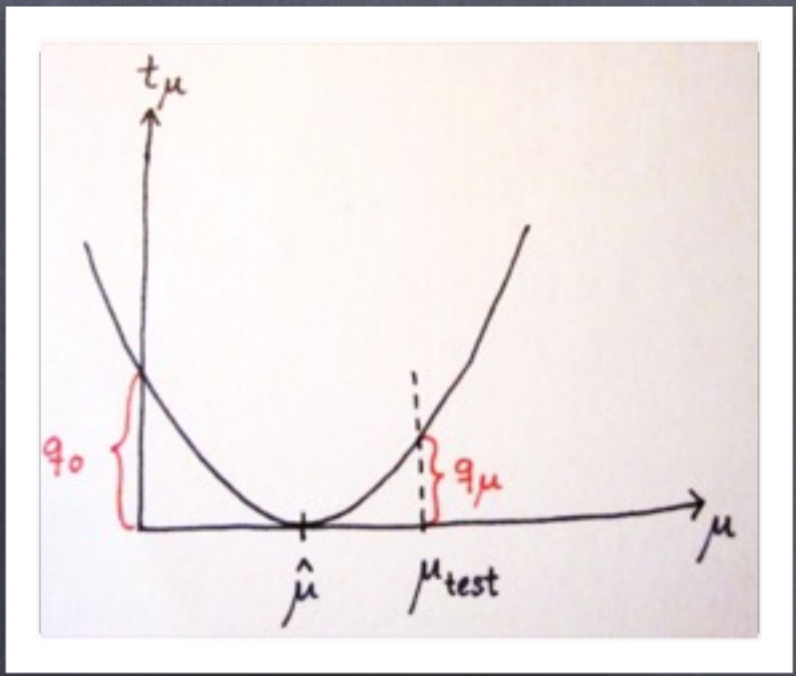




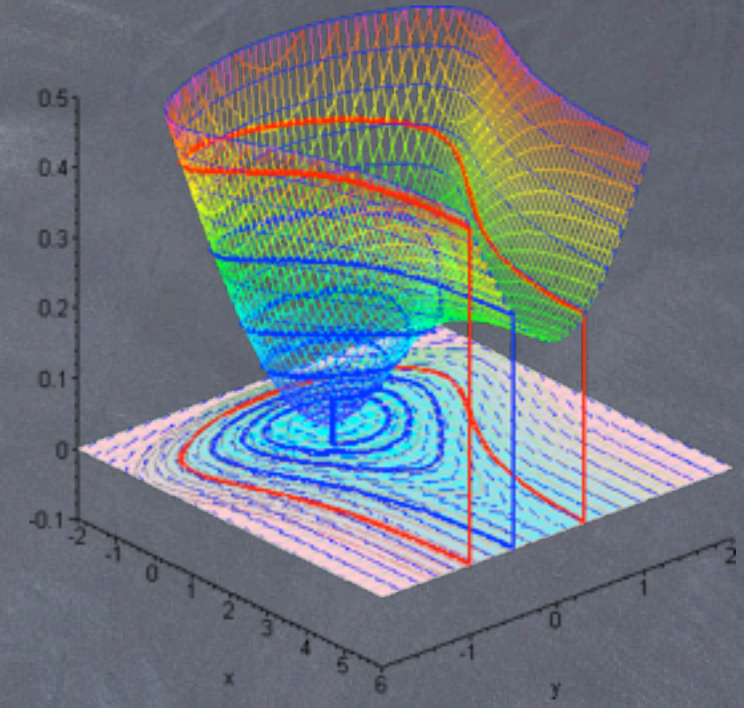
Significance



- 5.4 σ with look-elsewhere-correction

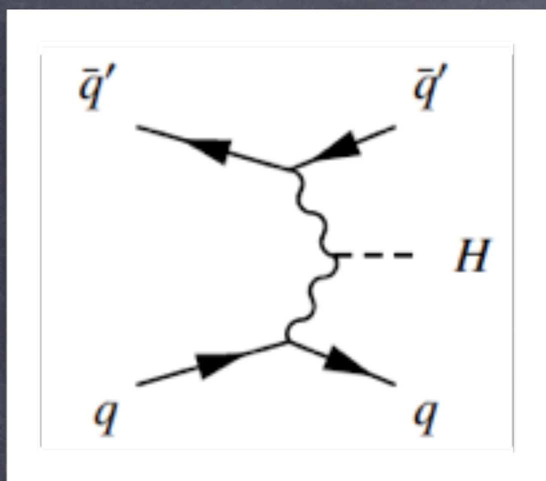


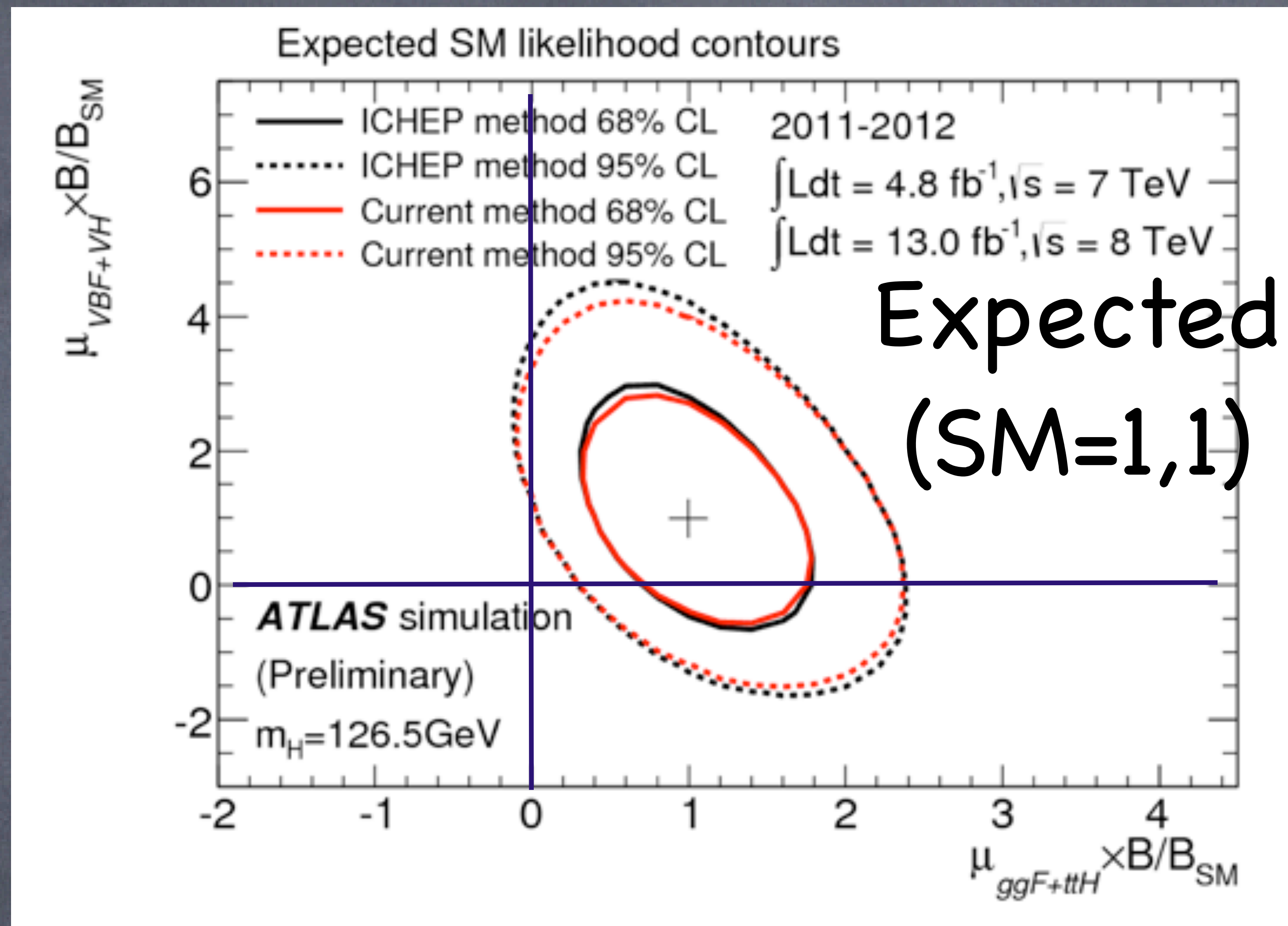
Various Hypothesis Tests

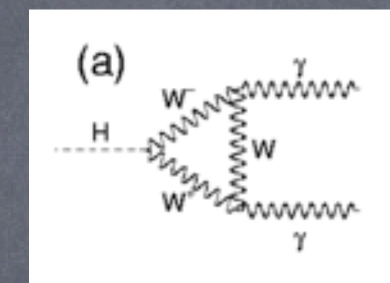


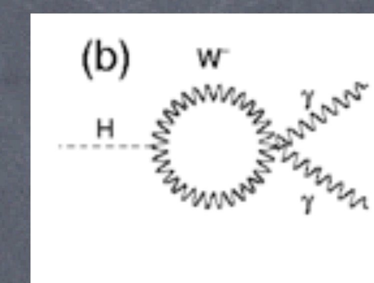
Background (scan m_H)	$\lambda(\mu=0,m_H)=\frac{L(\mu=0,m_H,\hat{\hat{\theta}})}{L(\hat{\mu},m_H,\hat{\theta})}$
Signal (scan m_H)	$\lambda(\mu,m_H)=\frac{L(\mu,m_H,\hat{\hat{\theta}})}{L(\hat{\mu},m_H,\hat{\theta})}$
Mass consistency	$\lambda(m_H)=\frac{L(m_H,\hat{\hat{\mu}}_1,\hat{\hat{\mu}}_2,\hat{\hat{\theta}})}{L(\hat{m}_{1H},\hat{m}_{2H},\hat{\mu}_1,\hat{\mu}_2,\hat{\theta})}$
Mass	$\lambda(m_H)=\frac{L(m_H,\hat{\hat{\mu}}_1,\hat{\hat{\mu}}_2,\hat{\hat{\theta}})}{L(\hat{m}_H,\hat{\mu}_1,\hat{\mu}_2,\hat{\theta})}$
Signal and mass	$\lambda(\mu,m_H)=\frac{L(\mu,m_H,\hat{\hat{\theta}}_\mu)}{L(\hat{\mu},\hat{m}_H,\hat{\theta}_\mu)}$

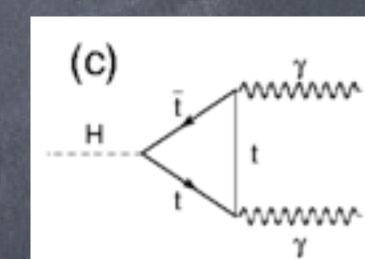
(partially) Untangle couplings

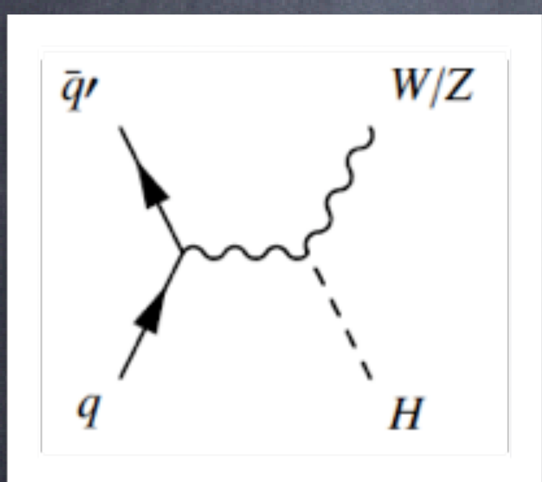




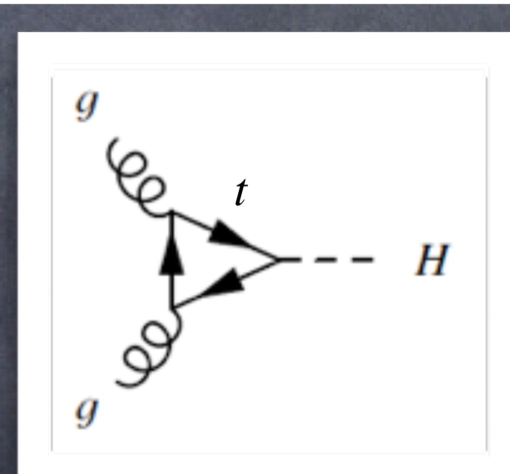


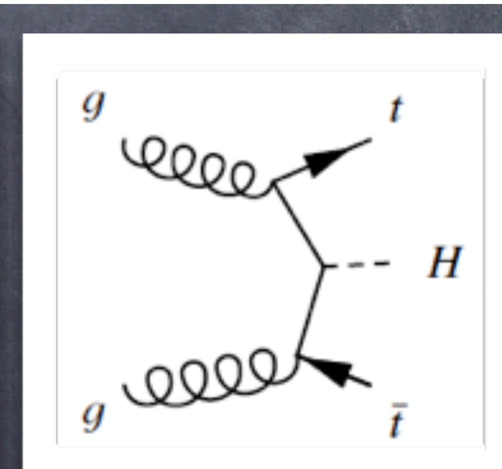




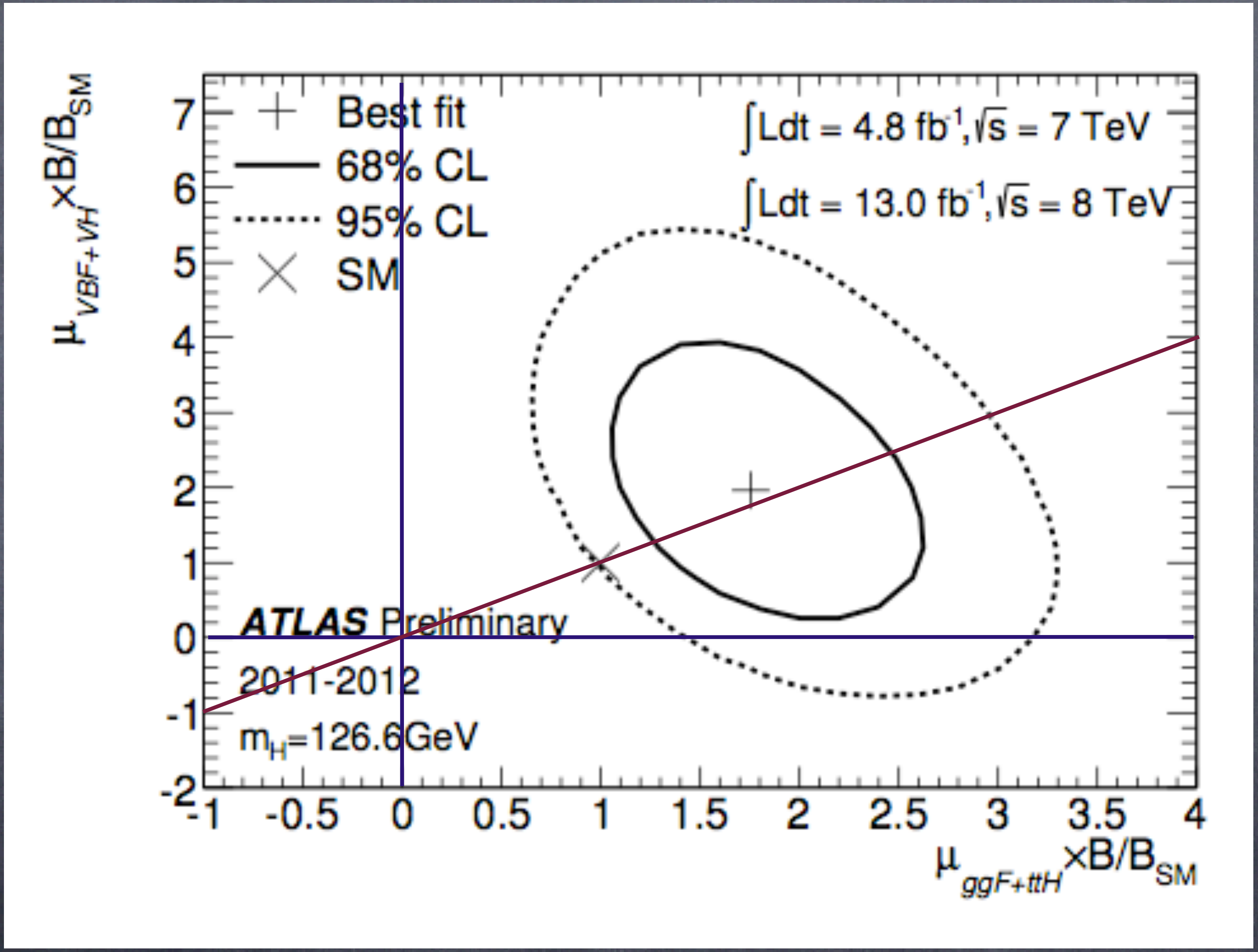


$$\frac{L(\mu_1, \mu_2, m_H, \hat{\hat{\theta}})}{L(\hat{\mu}_1, \hat{\mu}_2, m_H, \hat{\theta})}$$

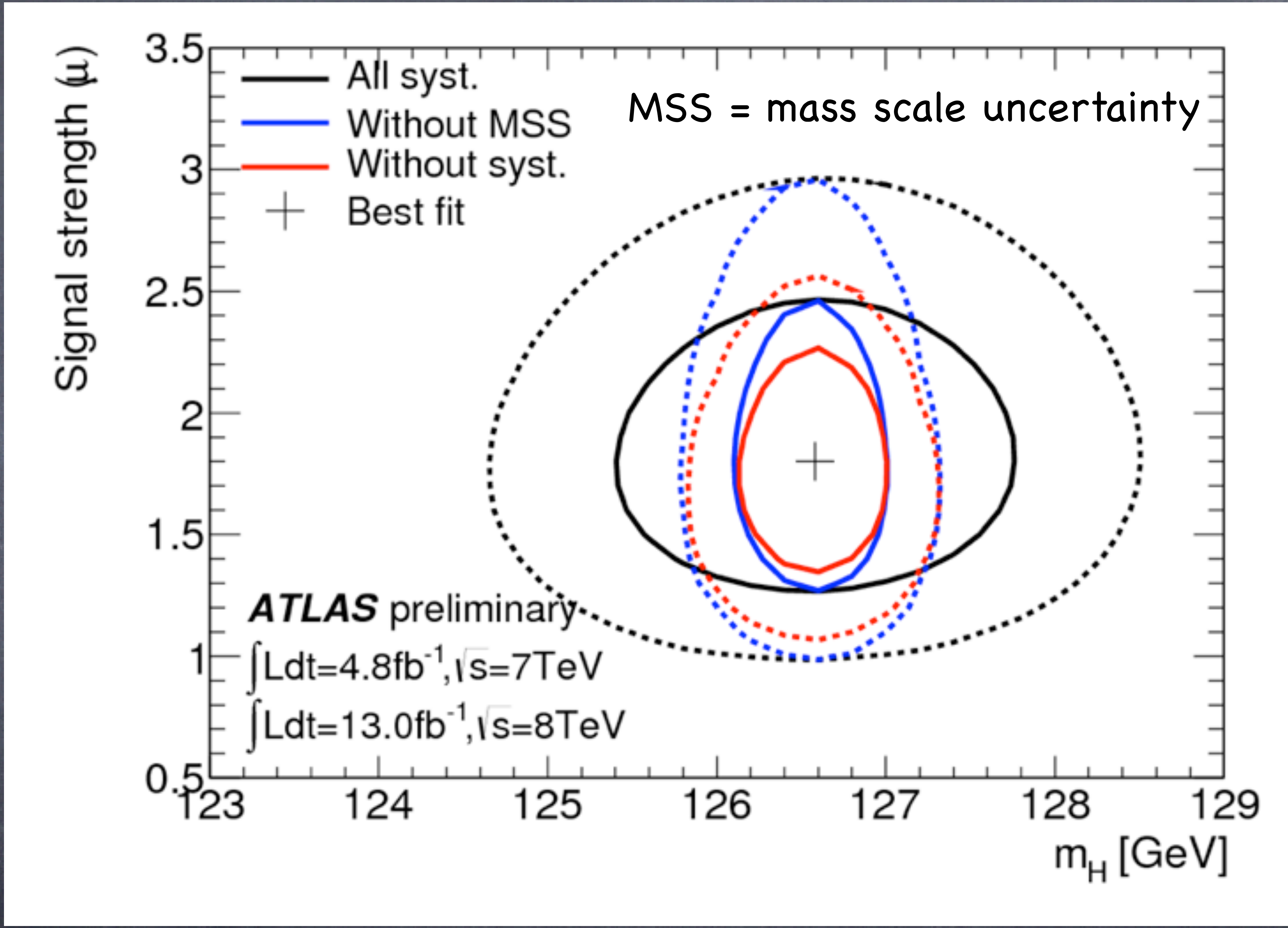




(partially) Untangle couplings

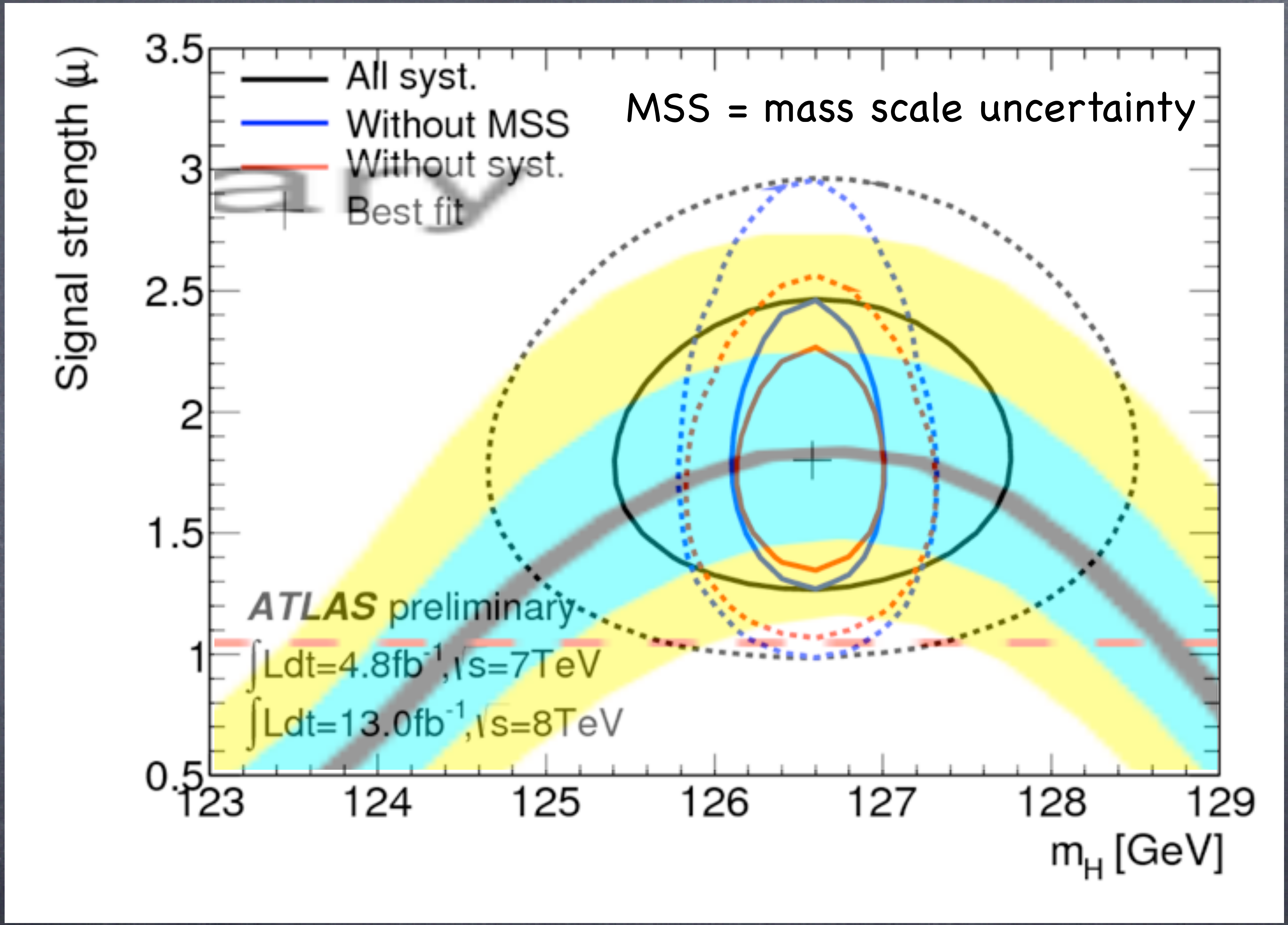


Mass measurement



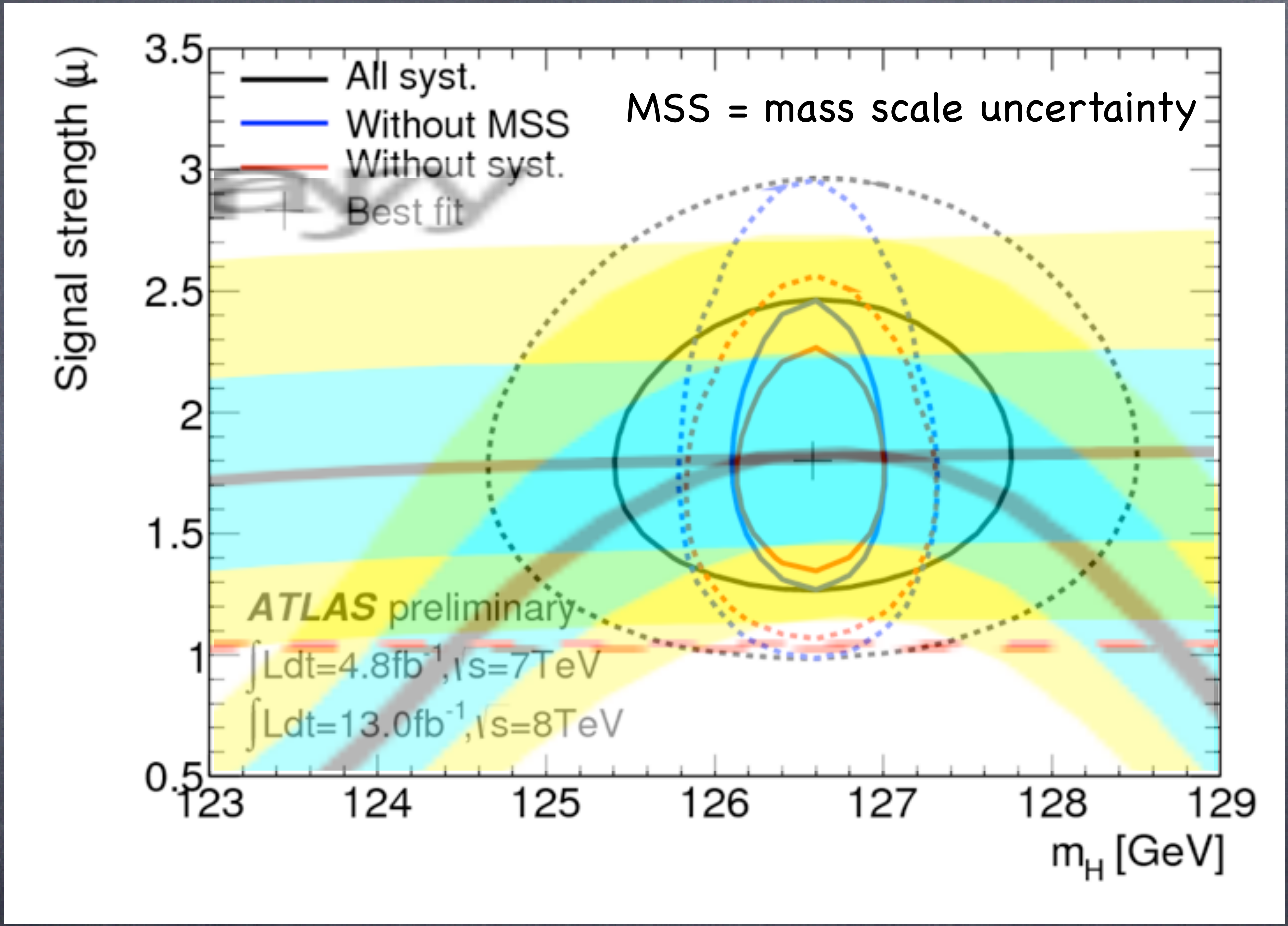
$$m_H = 126.6 \pm 0.3(stat) \pm 0.7(syst)\,\mathrm{GeV}$$

Mass measurement



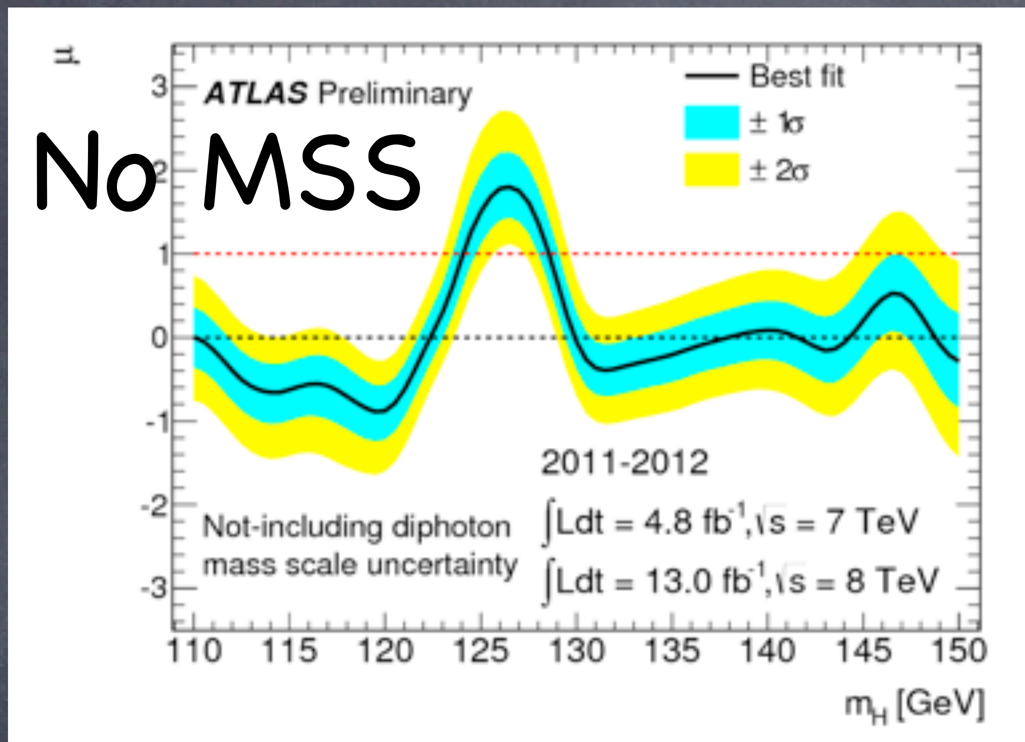
$$m_H = 126.6 \pm 0.3(stat) \pm 0.7(syst)\,\mathrm{GeV}$$

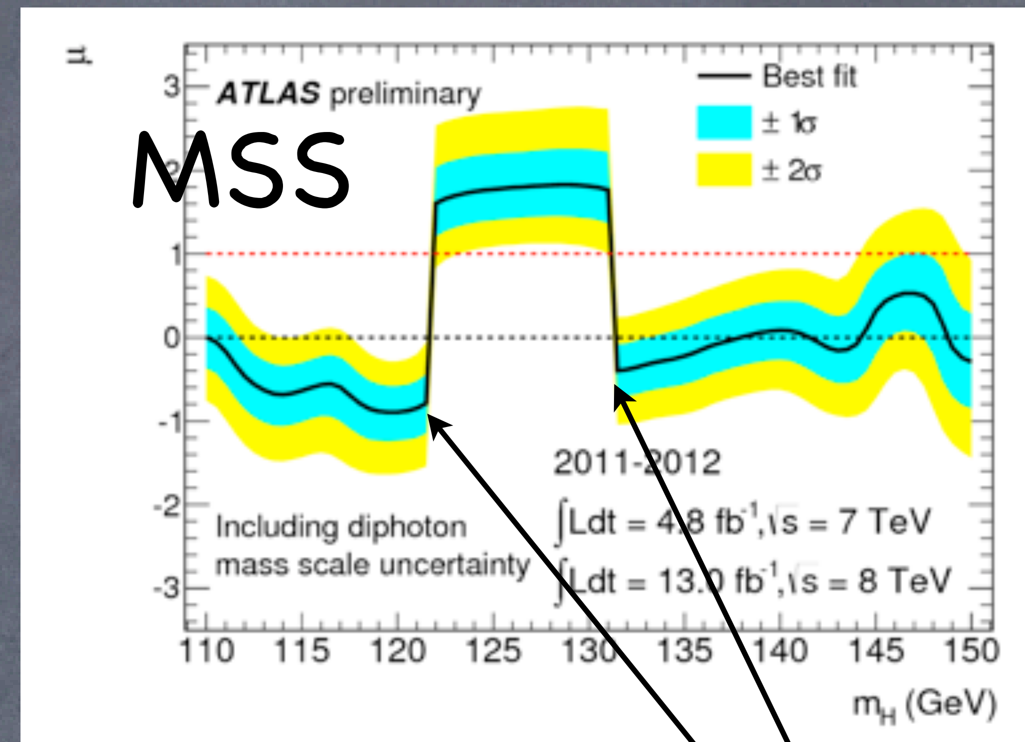
Mass measurement

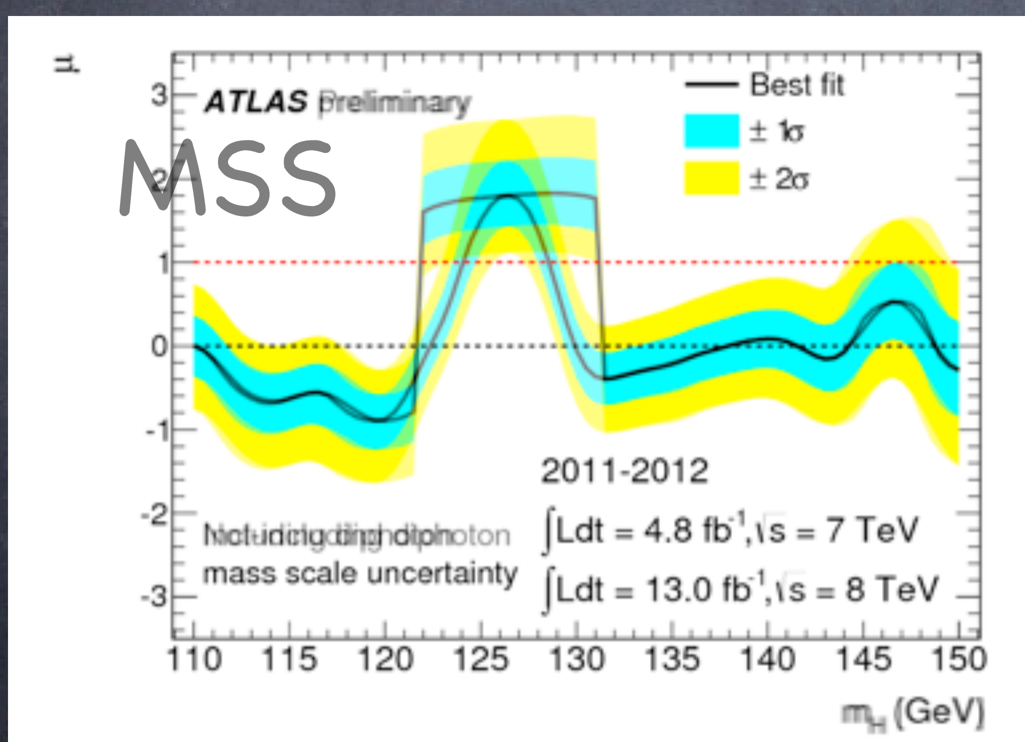


$$m_H = 126.6 \pm 0.3(stat) \pm 0.7(syst)\,\mathrm{GeV}$$

Effect of MSS on $\hat{\mu}$







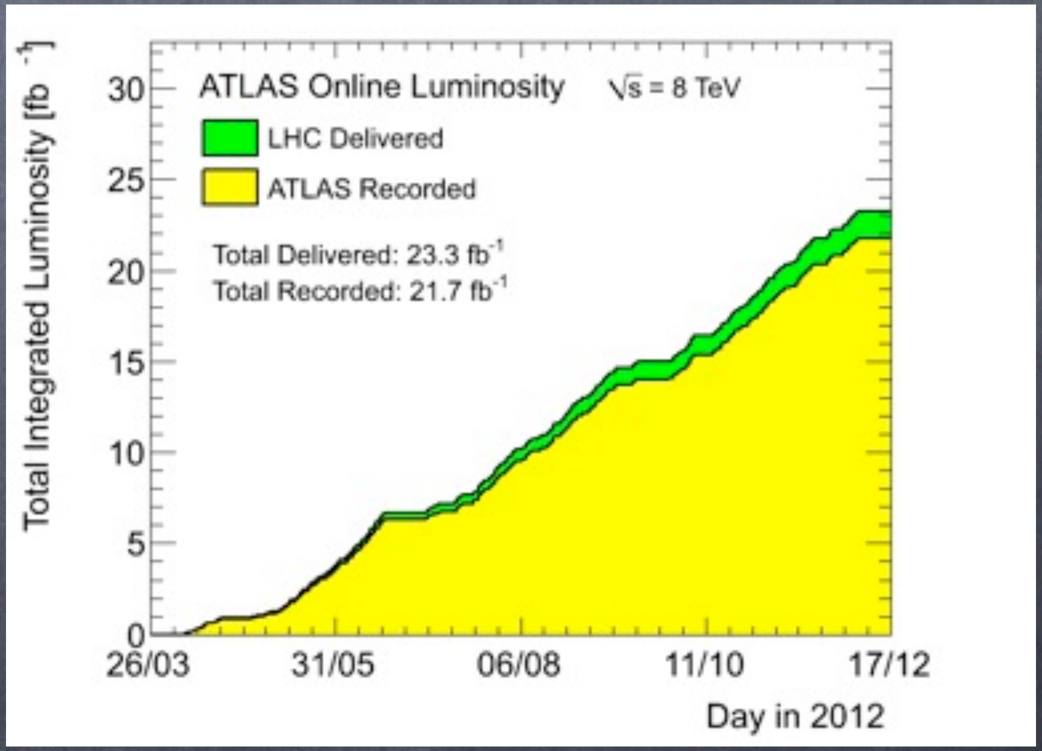
$$m_H(1+\delta_{MSS})$$

- Break-even points between MSS and ~zero amplitude

$$\Delta\chi^2 \sim (\frac{\delta_{MSS}}{\sigma_{MSS}})^2 + (\frac{(\hat{\mu}-\mu)(m_H(1+\delta_{MSS}))}{\sigma\mu})^2$$

Conclusions

- Search for H->$\gamma\ \gamma$ is no longer the frontier (5.4σ)
- Measurements of mass, signal strength (2.4σ sigma high), couplings (signal strength per production*decay mechanism)
- Several interesting trends but need more data (13->21/fb 2012 will not make a revolution)
- P.S. Spin 0 slightly preferred over spin 2



Backup

Diphoton spin state