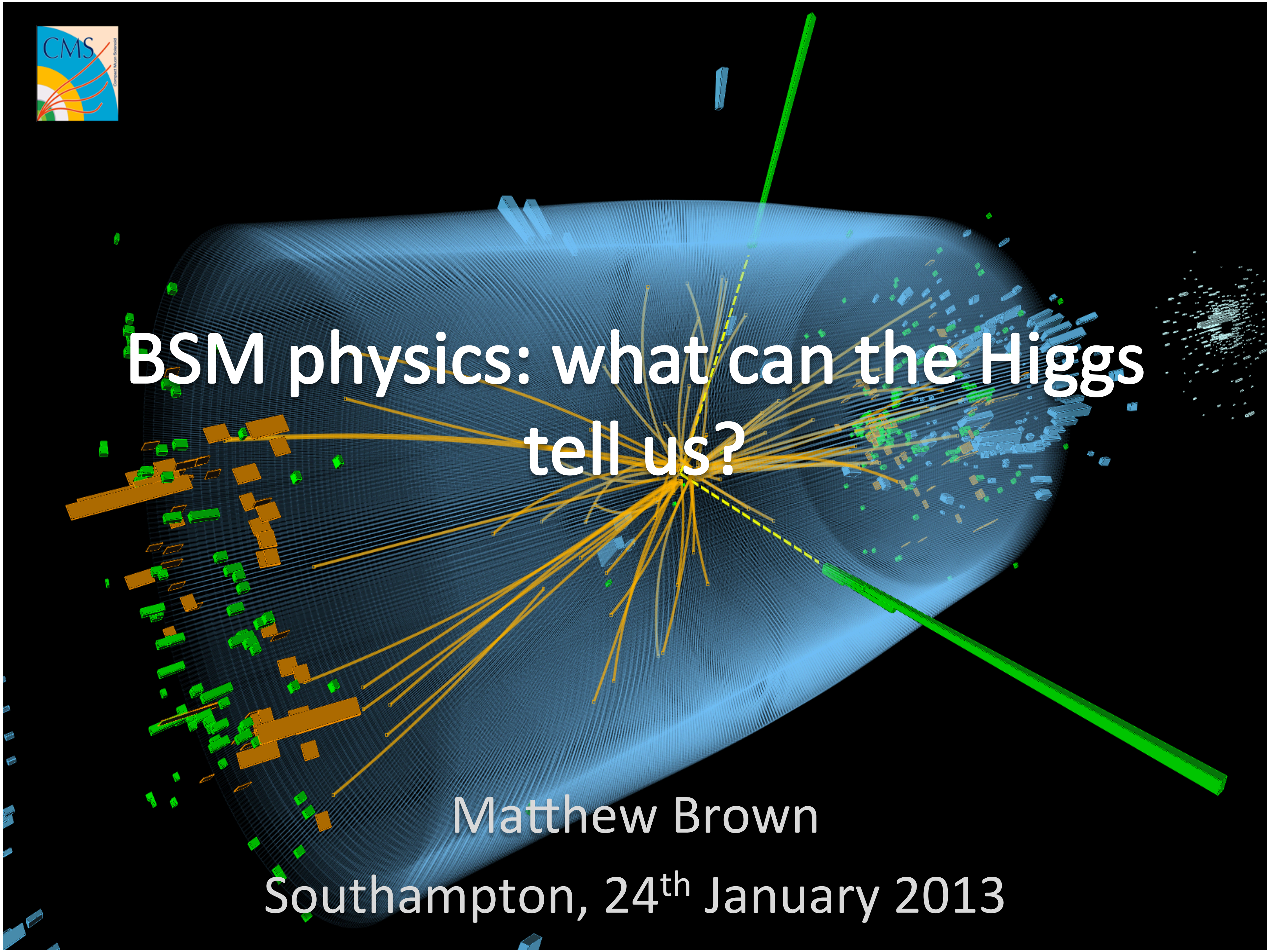


BSM physics: what can the Higgs tell us?

Matthew Brown

Southampton, 24th January 2013

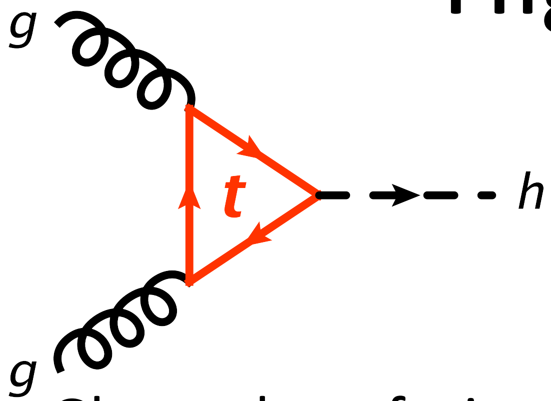
Outline

- Assumptions and framework for SM Higgs
- Exclusion limits (Brazil band plots)
- Higgs discovery
- Ruling out BSM theories
- Results for
  - MUED
  - 4DCHM
- Conclusions

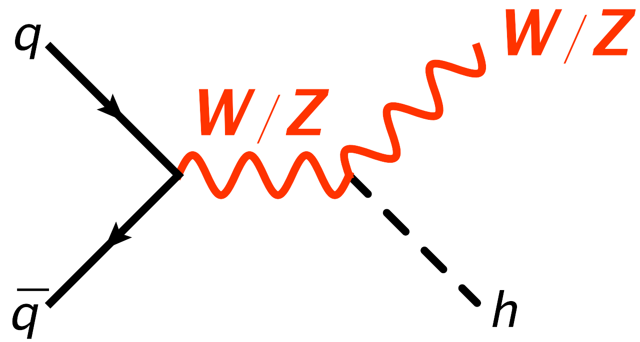
Higgs physics assumptions

- Negligible interference with background
  Kauer, arXiv:1201.1667
- Narrow-width approximation
  - Produce on-shell Higgs (PDFs become simple factors)
  - Multiply by decay branching ratio (BR) to find complete pp → h → XX cross-section
- NWA → 1% error. Must go beyond when statistical errors fall Kauer and Passarino, arXiv:1110.1613

Higgs production



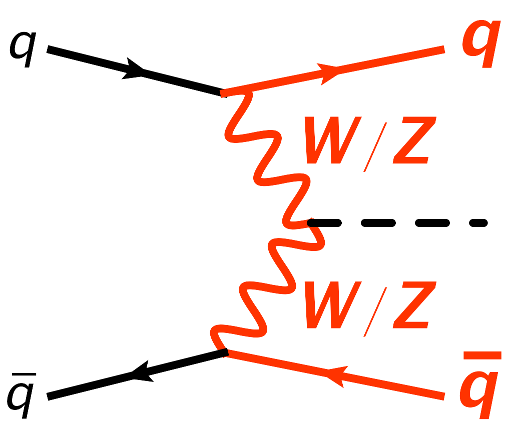
Gluon-gluon fusion
87%



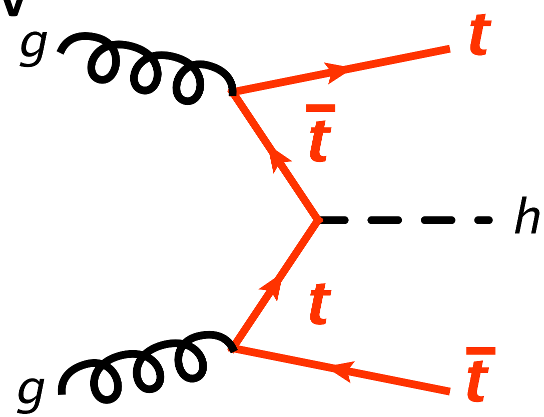
Higgs Strahlung
4.8%

$\sqrt{s}$ = 8 TeV

M_h = 125 GeV

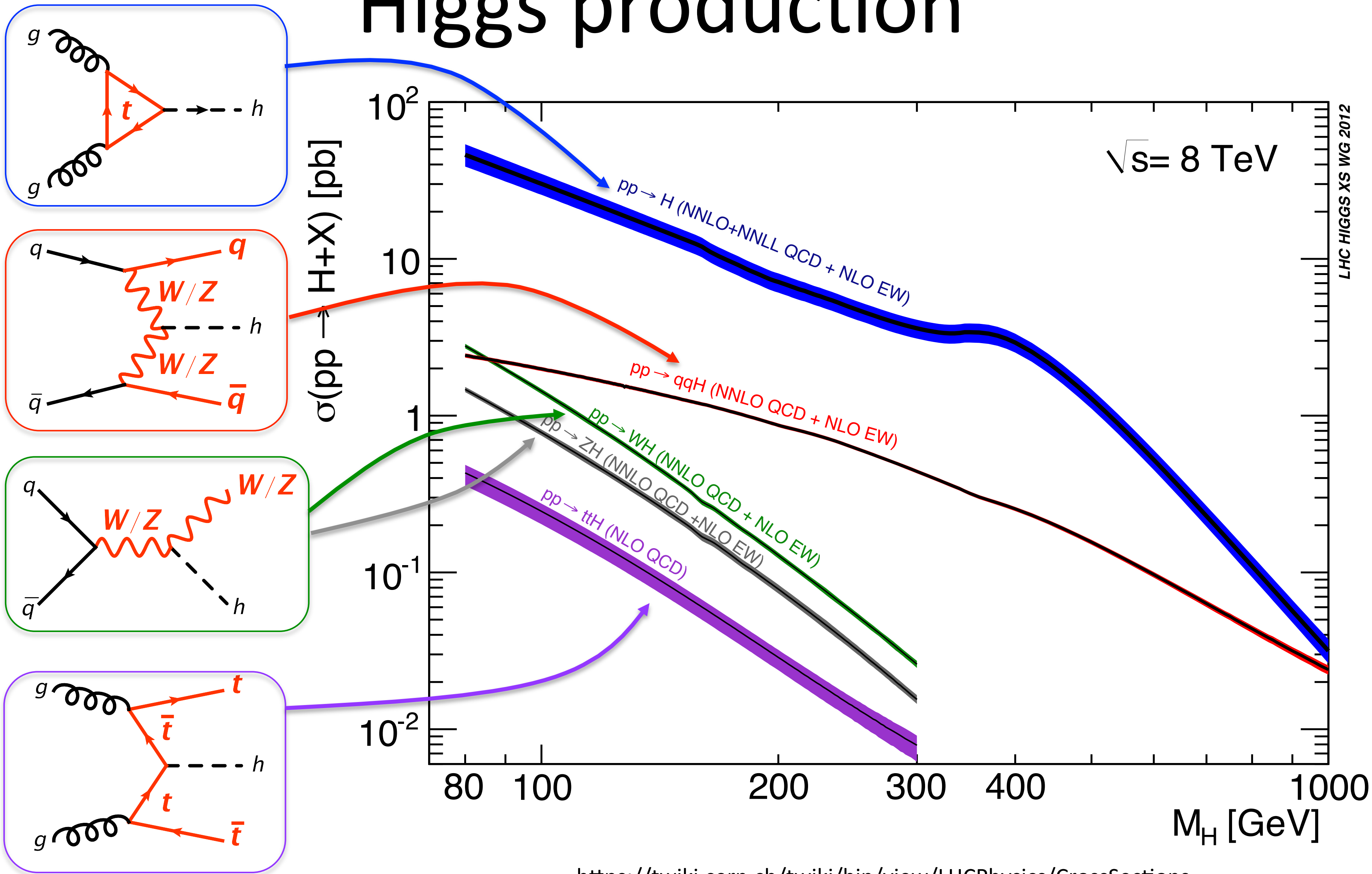


Vector boson fusion (VBF)
7%



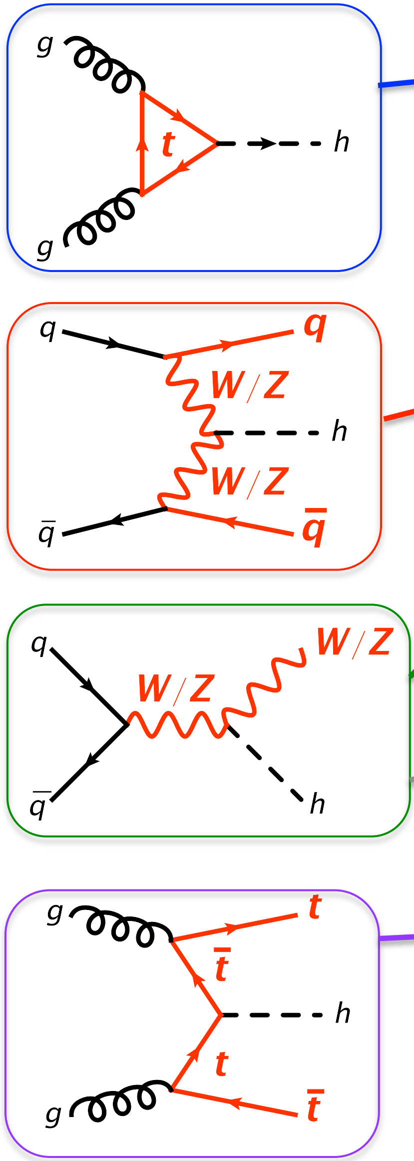
Associate top production
0.58%

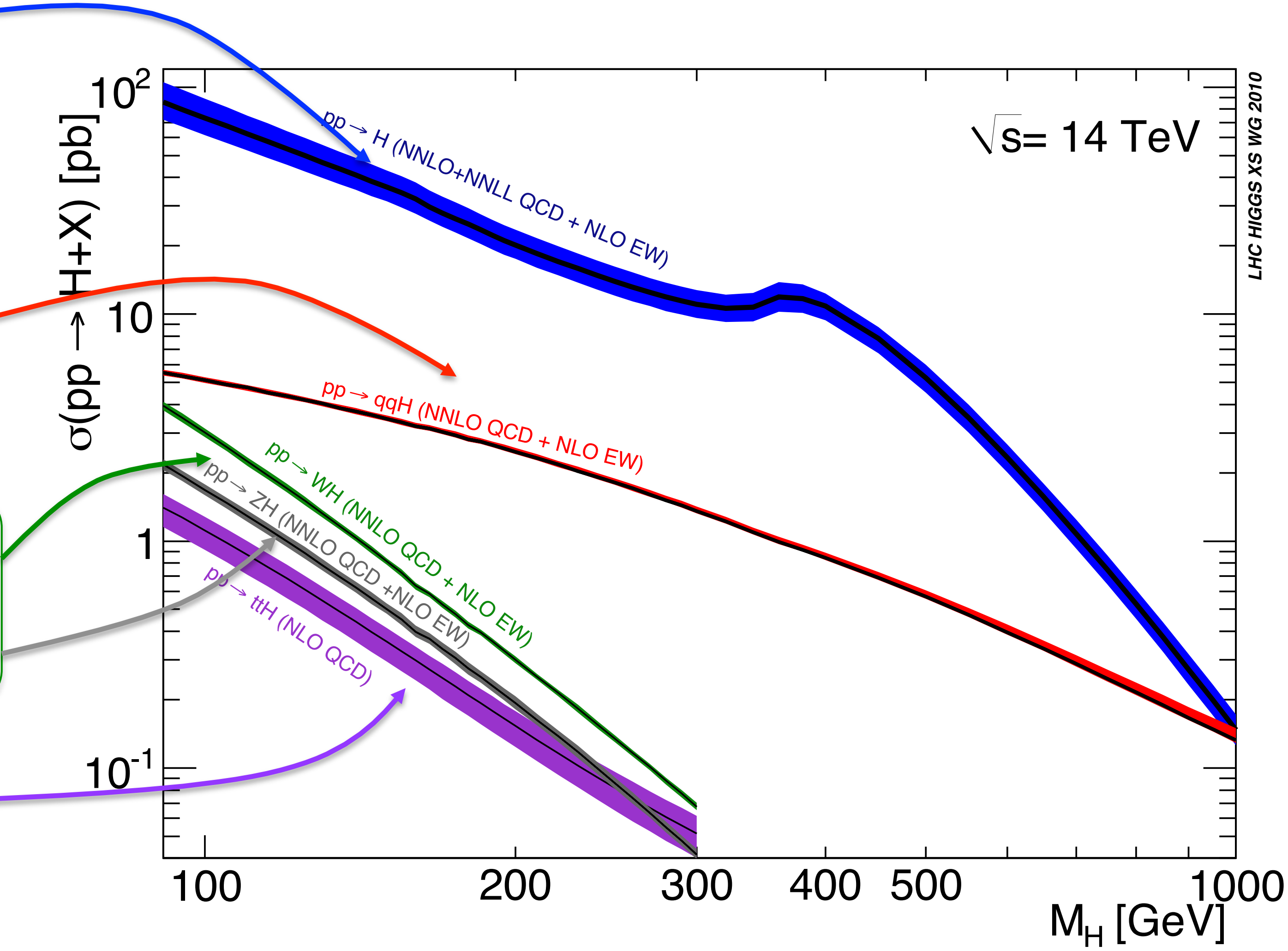
Higgs production



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Higgs production





https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

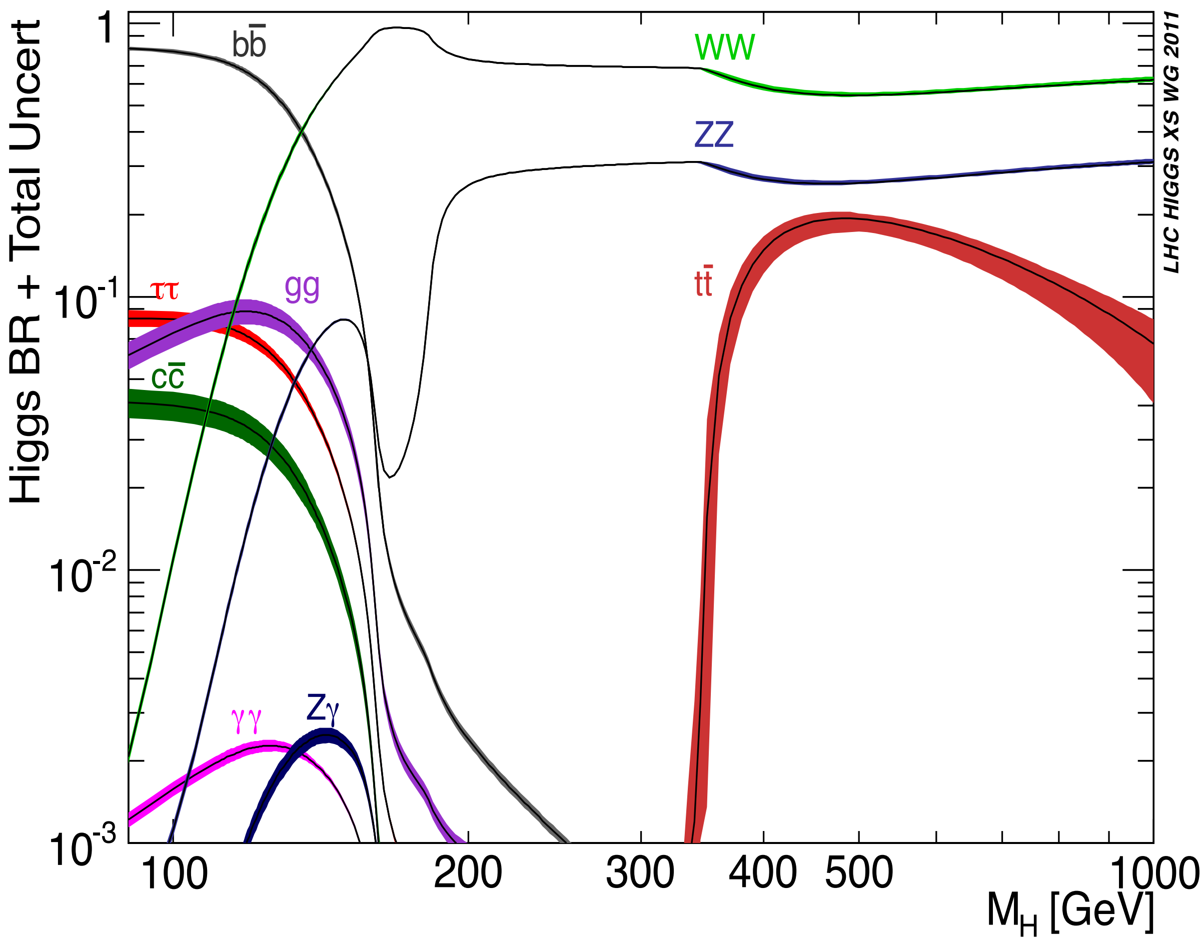
Higgs decay

Channel	Branching
bb	58 %
WW	22 %
~~gg~~	~~8.6~~
$\tau\tau$	6.3 %
~~cc~~	~~2.91 %~~
ZZ	2.6 %
$\gamma\gamma$	0.22 %

$h \rightarrow \gamma\gamma$

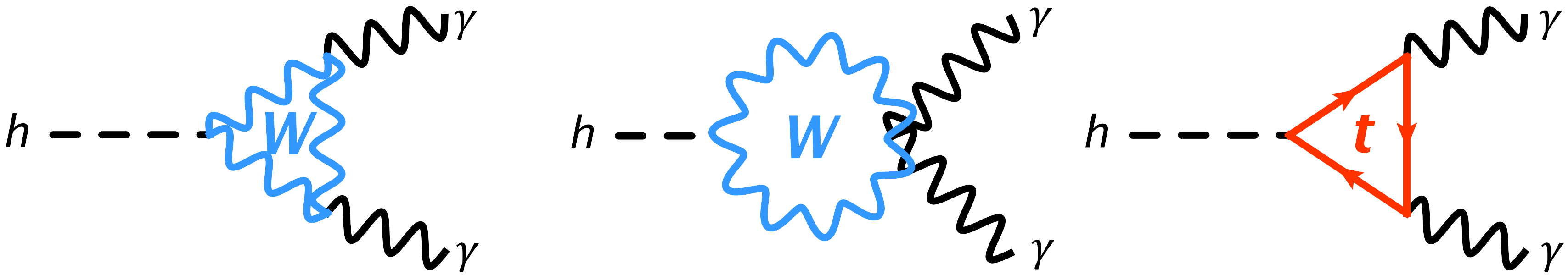
$h \rightarrow ZZ \rightarrow 4\ell$

($h \rightarrow WW \rightarrow 2\ell 2\nu$)



https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

Higgs to two photons



$$\mathcal{M}(h \to \gamma\gamma) \propto m_h^3 \left(\overset{-7}{A_W}(\tau_W) + \sum_f N_{C,f} Q_f^2 \overset{4/3}{A_f}(\tau_f) \right)$$

- SM-like particles *don't* decouple as m → ∞
- Particles which get mass from elsewhere *do* decouple

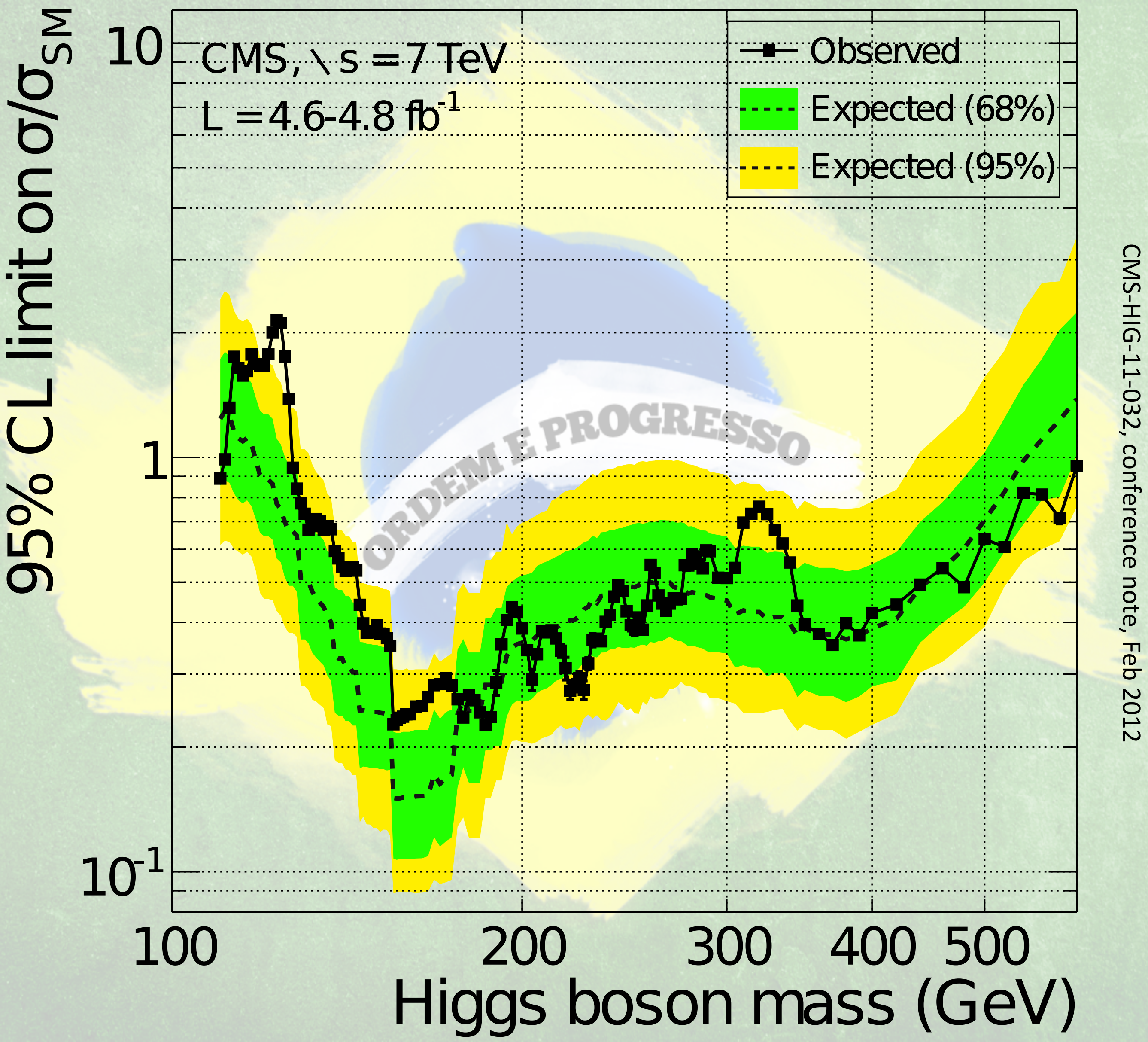
-7 : 3×(2/3)^2 × (4/3)

-3.9 : 1

(amplitude level)

$$\tau_i = \frac{m_h^2}{4m_i^2}$$


ORDEM E PROGRESSO
http://dangelo.deviantart.com/art/Grunge-Brazilian-flag-189016067


CMS, √s = 7 TeV
L = 4.6-4.8 fb-1
Observed
Expected (68%)
Expected (95%)
ORDEM E PROGRESSO
95% CL limit on σ/σSM
10
1
10-1
100
200
300
400
500
Higgs boson mass (GeV)
CMS-HIG-11-032, conference note, Feb 2012

Testing our hypothesis

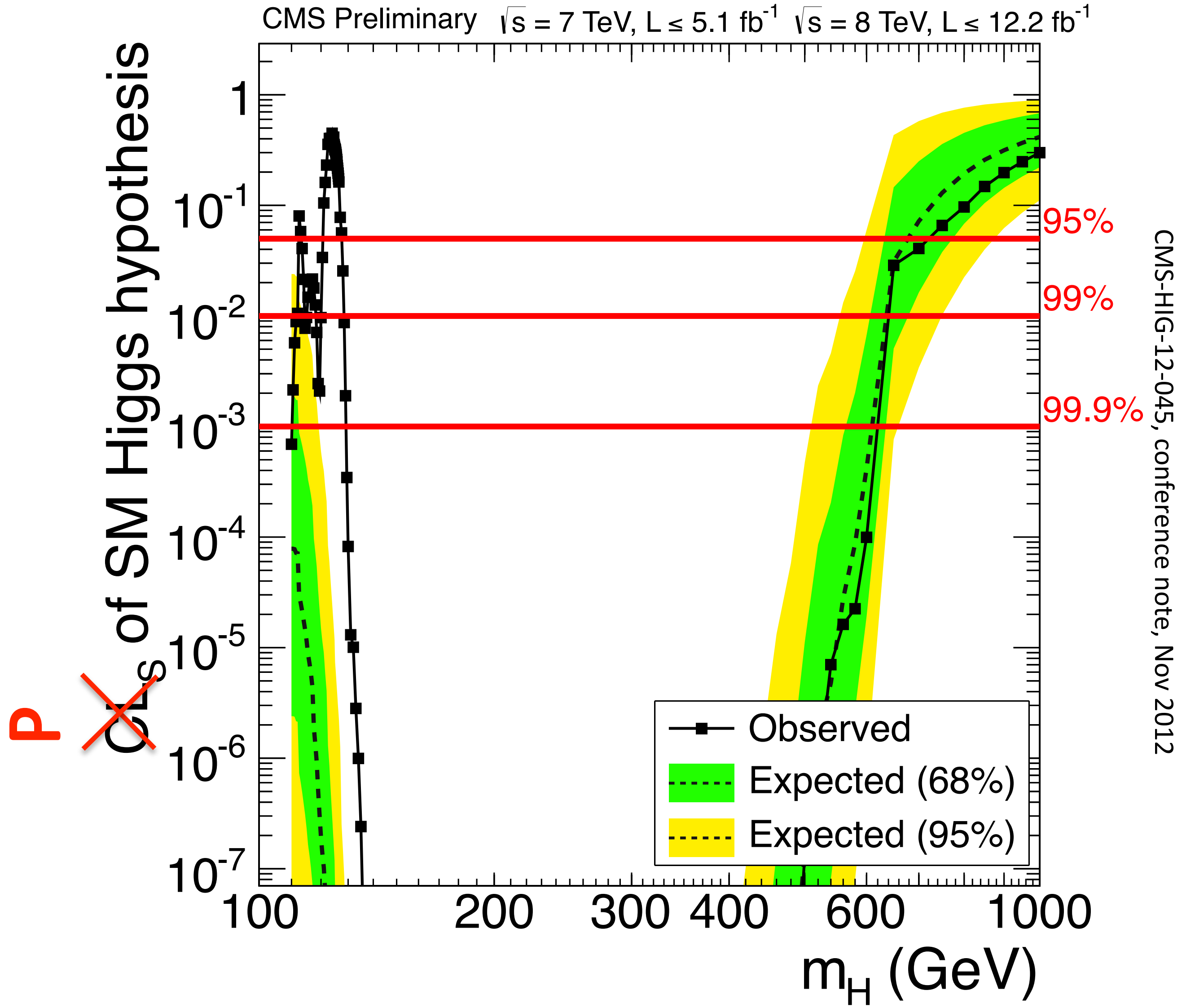
$\bar{s} = \varepsilon L \sigma$

- Measure *n* events
- Assume hypothesis predicting $\bar{s} + \bar{b}$

$$P(n|\bar{s}+\bar{b}) \sim \exp\left[-\frac{(n-\bar{s}-\bar{b})^2}{2(\bar{s}+\bar{b})}\right]$$

- $p = \int_0^n P(n|\bar{s}+\bar{b})\,\mathrm{d}n$
- CL = 1 - *p*

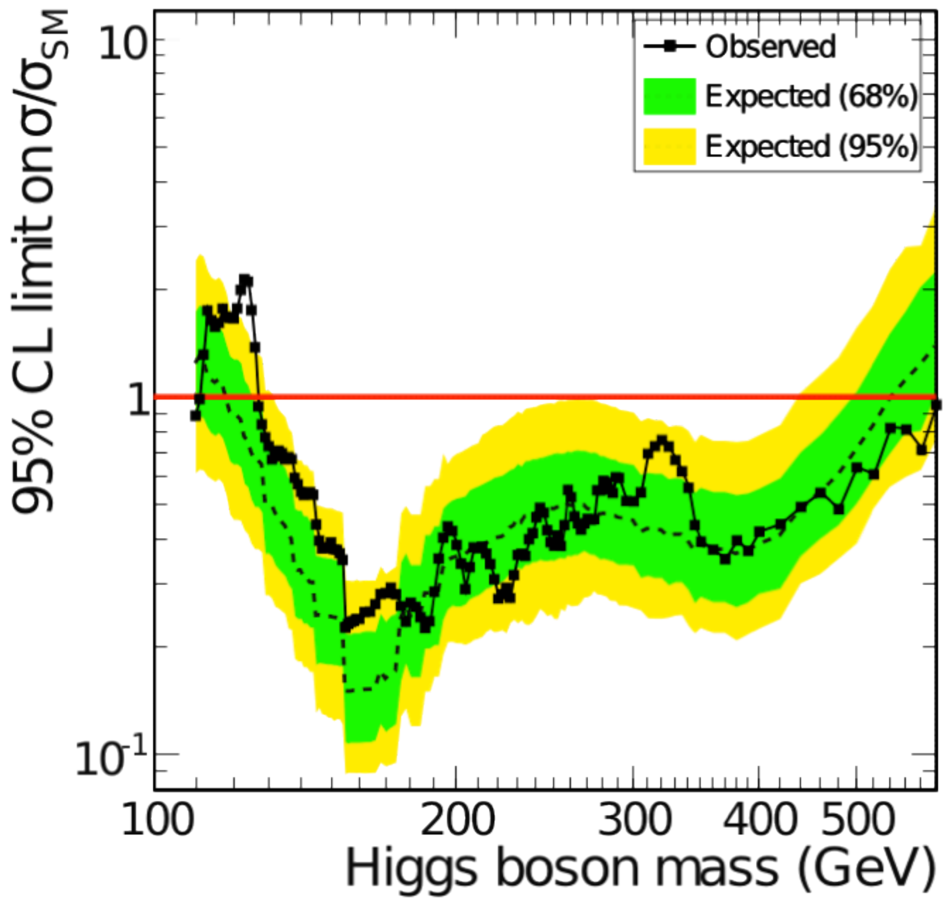
Testing our hypothesis



Testing our hypothesis

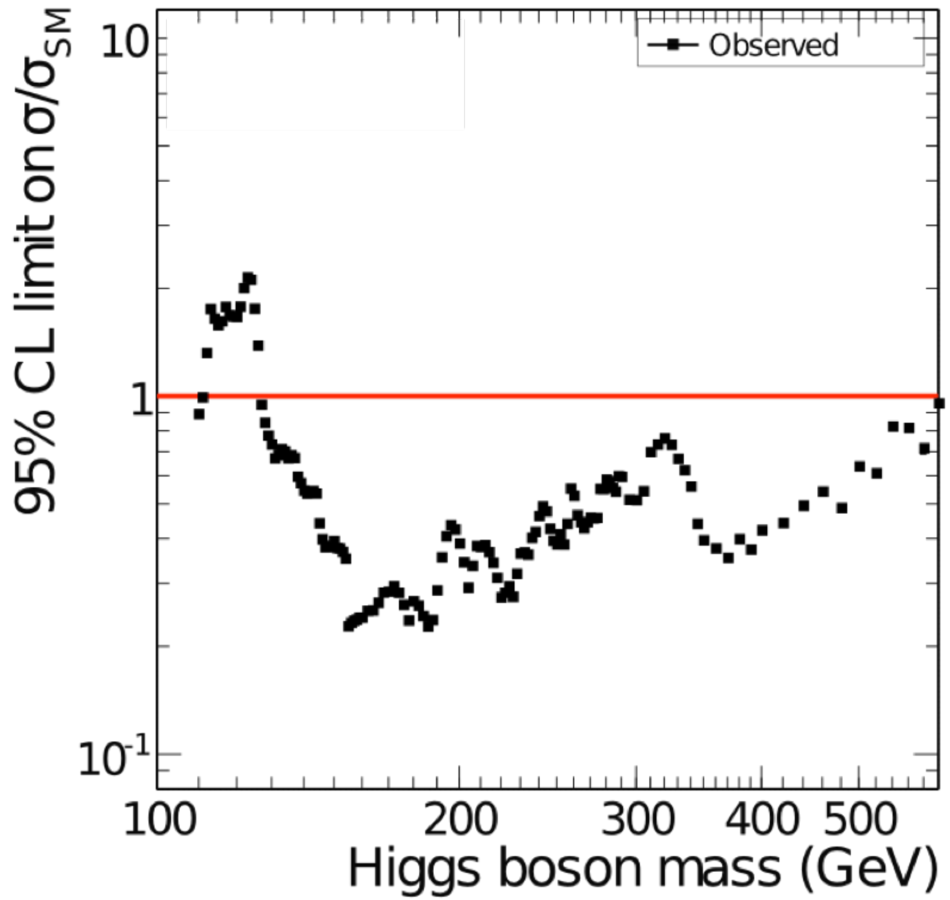
- Model: Higgs production cross-sections uniformly enhanced by factor $\mu = \sigma/\sigma_{SM}$
- $\bar{s} = \mu\, \varepsilon\, L\, \sigma$
- Given data *n* we can calculate exclusion CL for different hypotheses (m_h, μ)

Brazil band plots



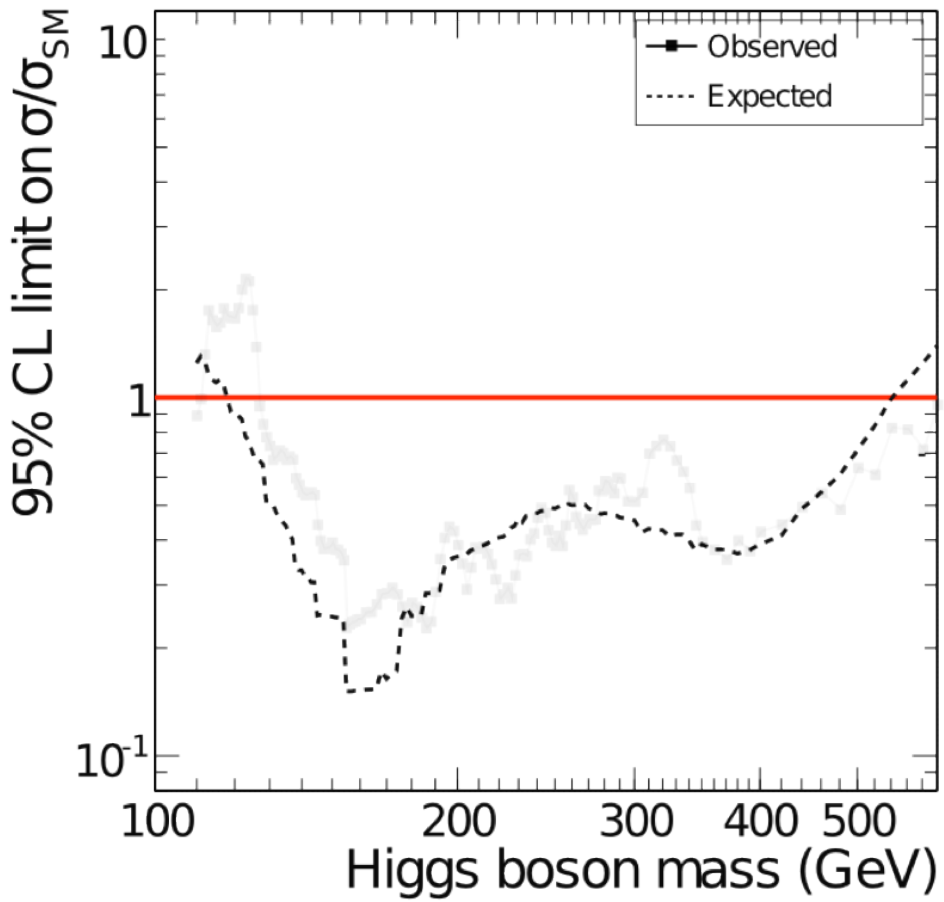
Observed limits

- Fix m_h
- Calculate p for various μ
- Plot μ for which CL ≡ 1 - p = 95%
- All μ above this $\mu_{95\%}$ are excluded at 95% CL



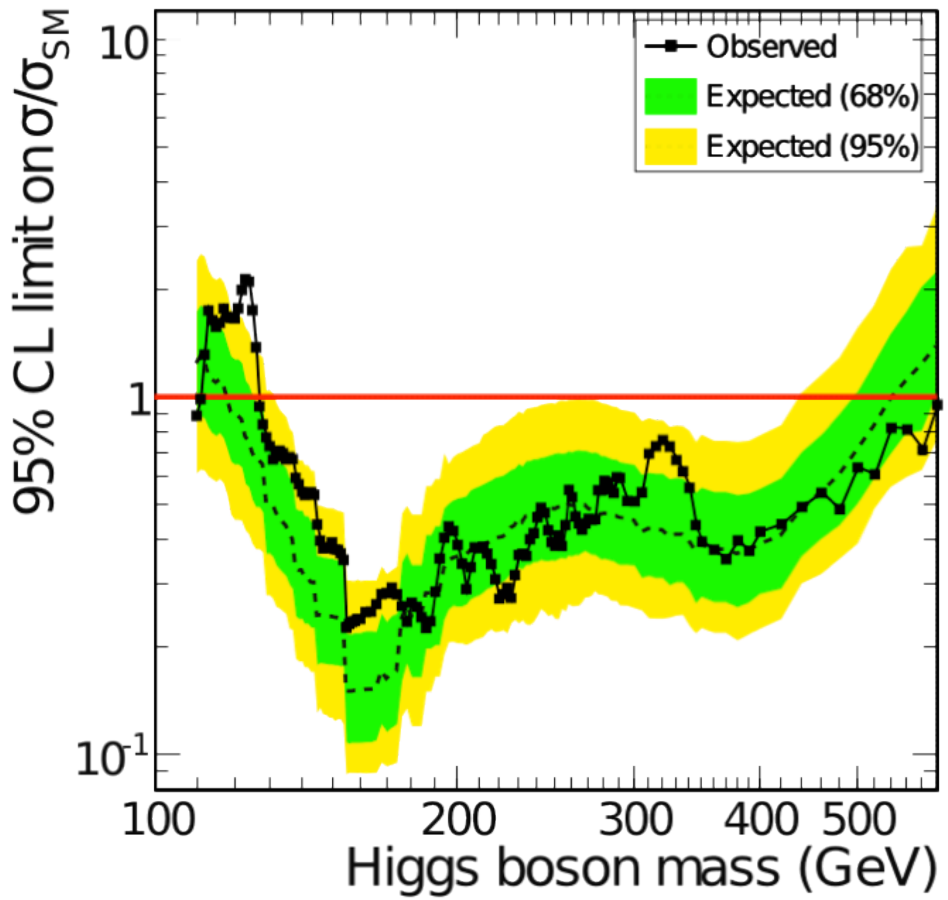
Expected limits

- Imagine that the observed $n = \bar{b}$
- Find $\mu_{95\%}$ in this case

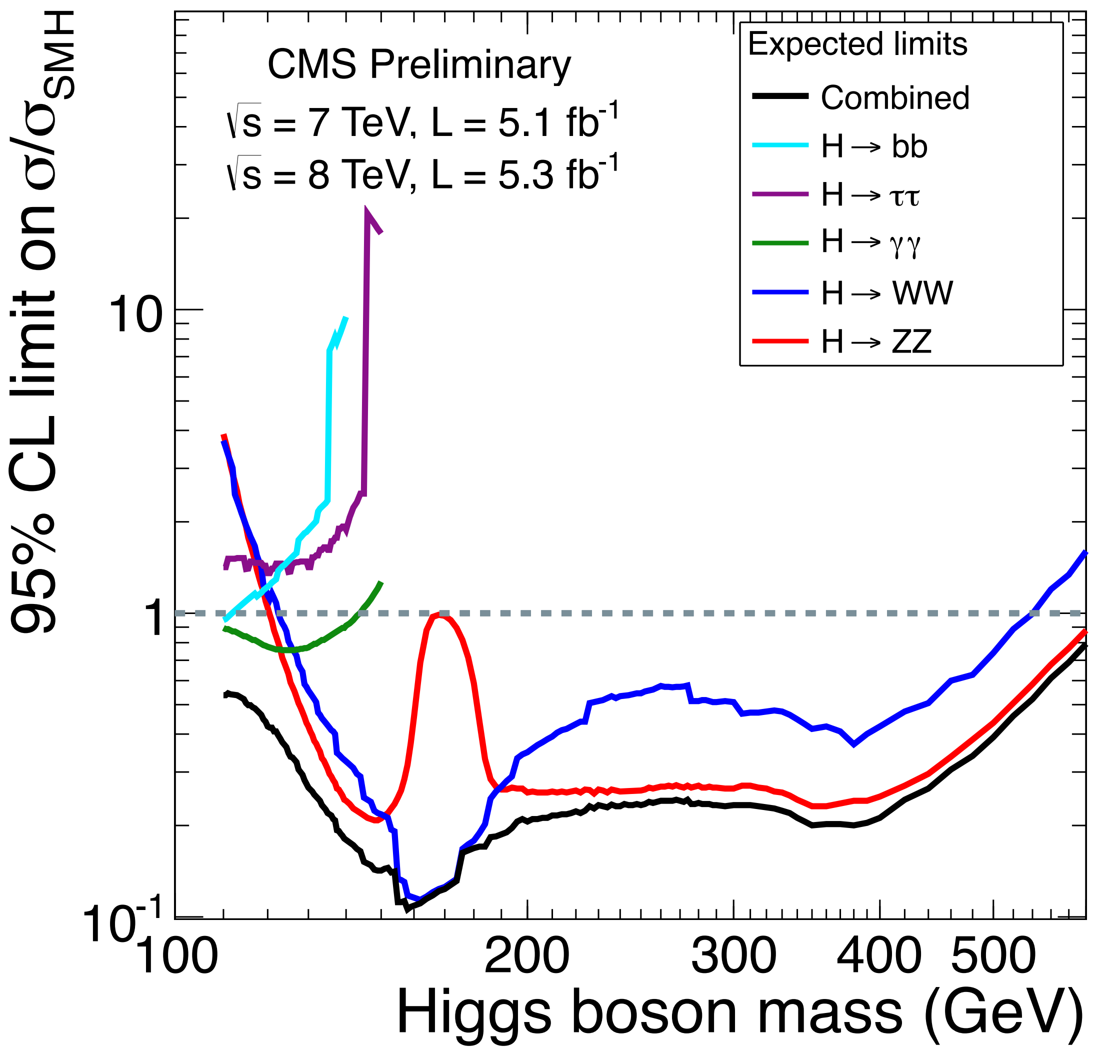


Expected limits

- Imagine that the observed $n = \bar{b}$
- Find $\mu_{95\%}$ in this case
- Then
  $n = \bar{b} \pm \sqrt{\bar{b}}$
  and
  $n = \bar{b} \pm 2\sqrt{\bar{b}}$



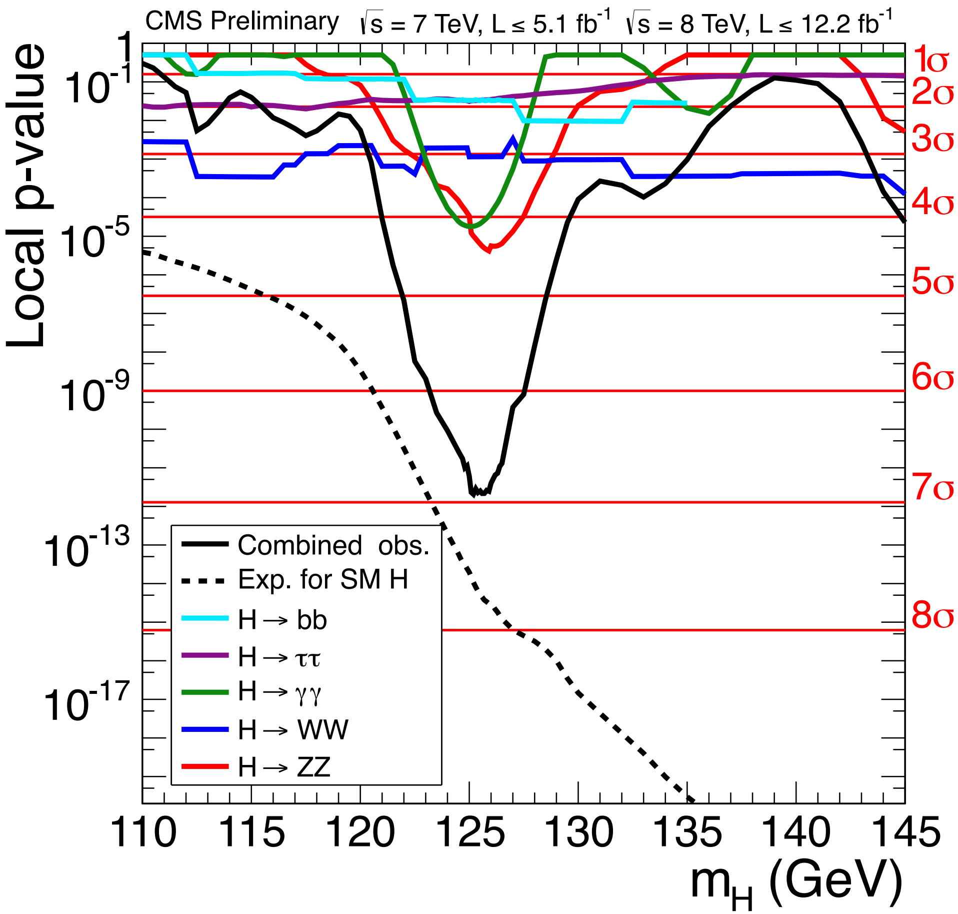
Separate channels



CMS-HIG-12-020, conference note, July 2012

Discovery significance

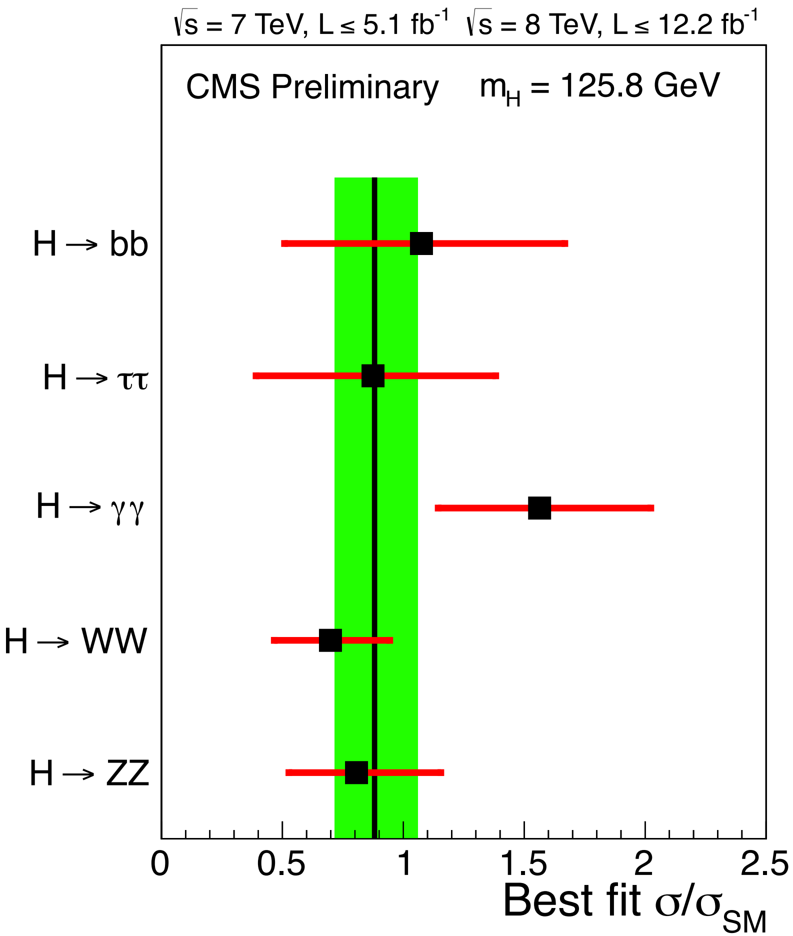
- $p_b = \int_n^\infty P(n|\bar{b})\,\mathrm{d}n$
- Why m_h dependence?!
- $\bar{b} = \varepsilon_b(m_h) \times L\,\sigma_b$
- *n* also depends on cuts

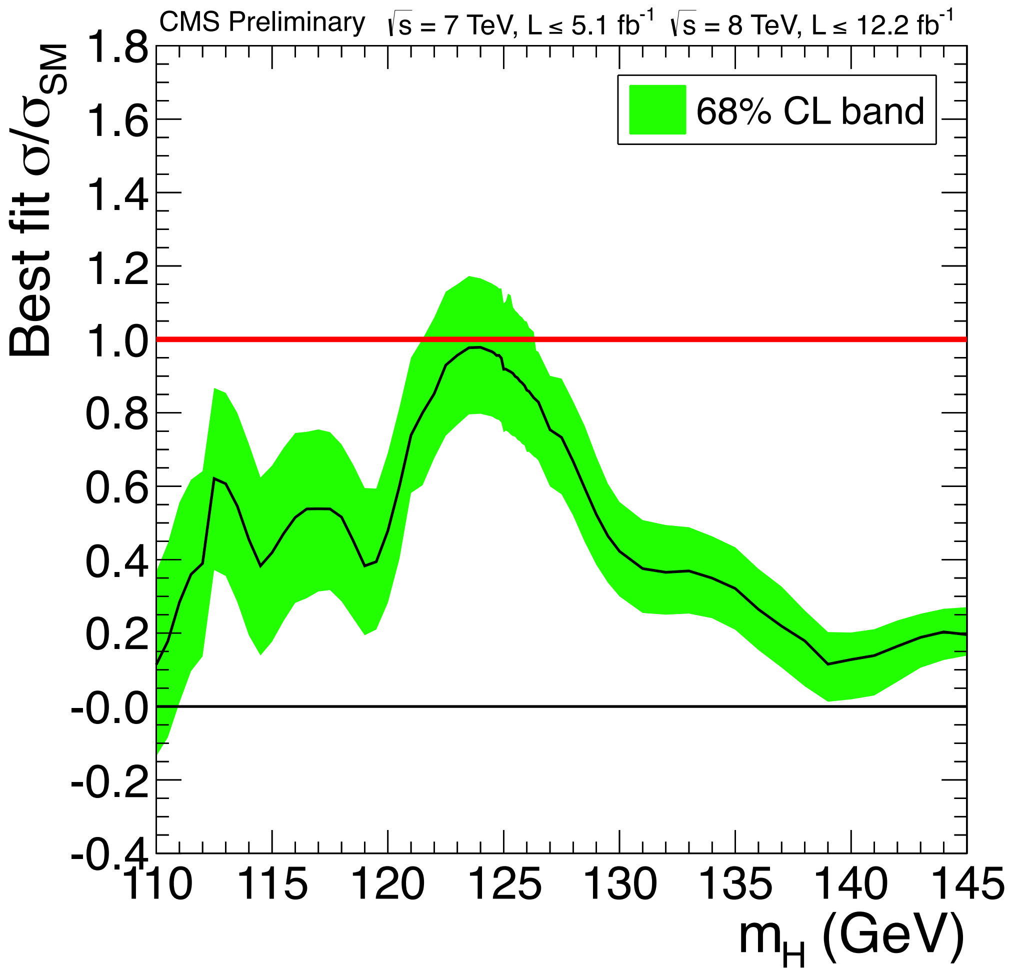


CMS-HIG-12-045, conference note, Nov 2012

*In the original talk, I showed the wrong graph here. I explain this on the penultimate slide.

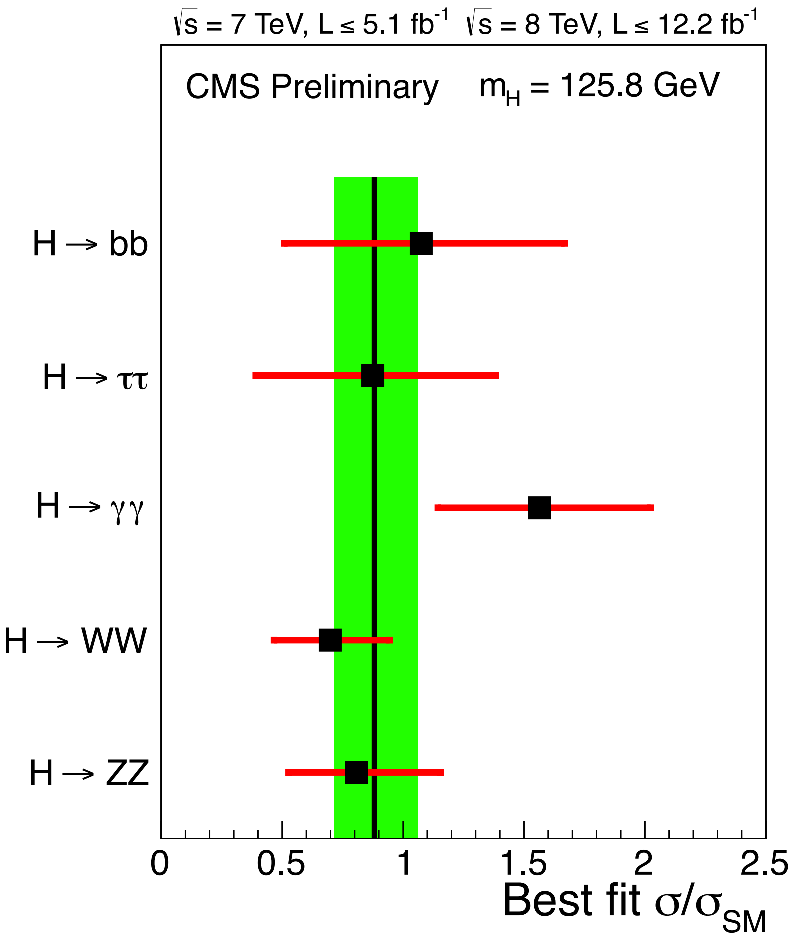
Characterising the excess

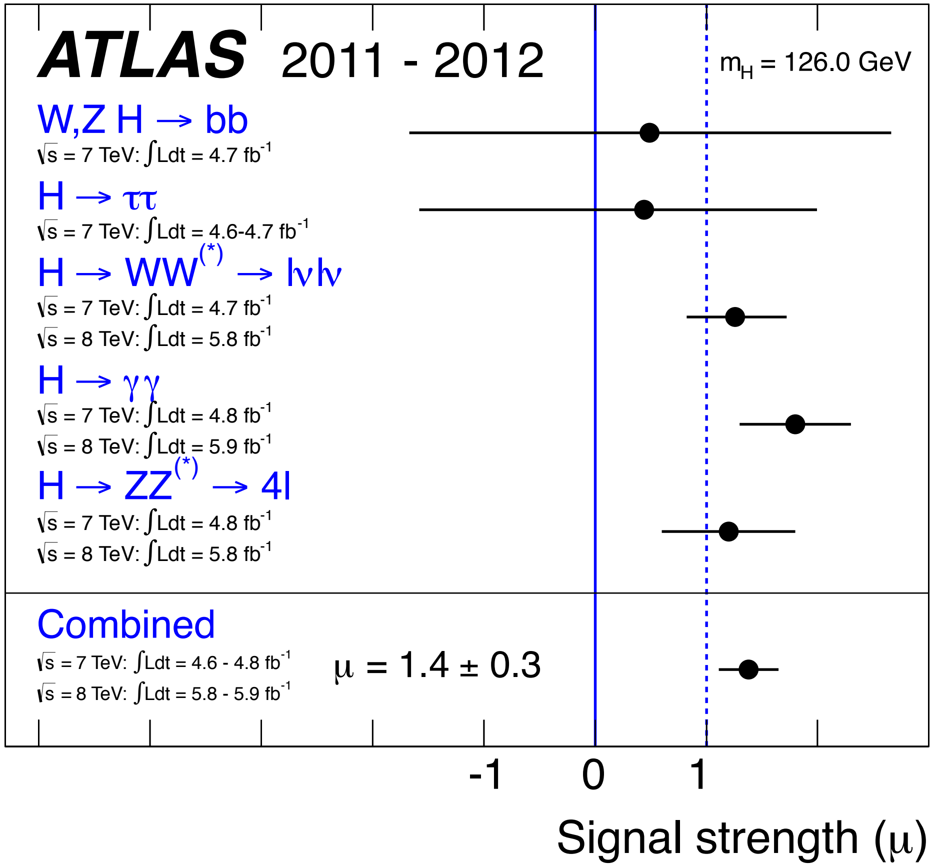




CMS-HIG-12-045, conference note, Nov 2012

Characterising the excess





CMS-HIG-12-045, conference note, Nov 2012

Calculating μ

- If one production process dominates…

$$\mu_{XX} = \frac{n_{XX}}{n^{\mathrm{SM}}_{XX}} = \frac{\sigma_{\mathrm{prod}} \times \mathrm{BR}\quad(h \to XX)}{\sigma^{\mathrm{SM}}_{\mathrm{prod}} \times \mathrm{BR}^{\mathrm{SM}}(h \to XX)}$$

$$= \frac{\kappa^2_{YY}\kappa^2_{XX}}{\kappa^2_h}$$

$$\boxed{\kappa^2_h = \frac{\Gamma_h}{\Gamma^{\mathrm{SM}}_h}}$$

- If several production processes are significant we *must* be told efficiencies!

Excluding BSM models

- For $n \gg 1$…

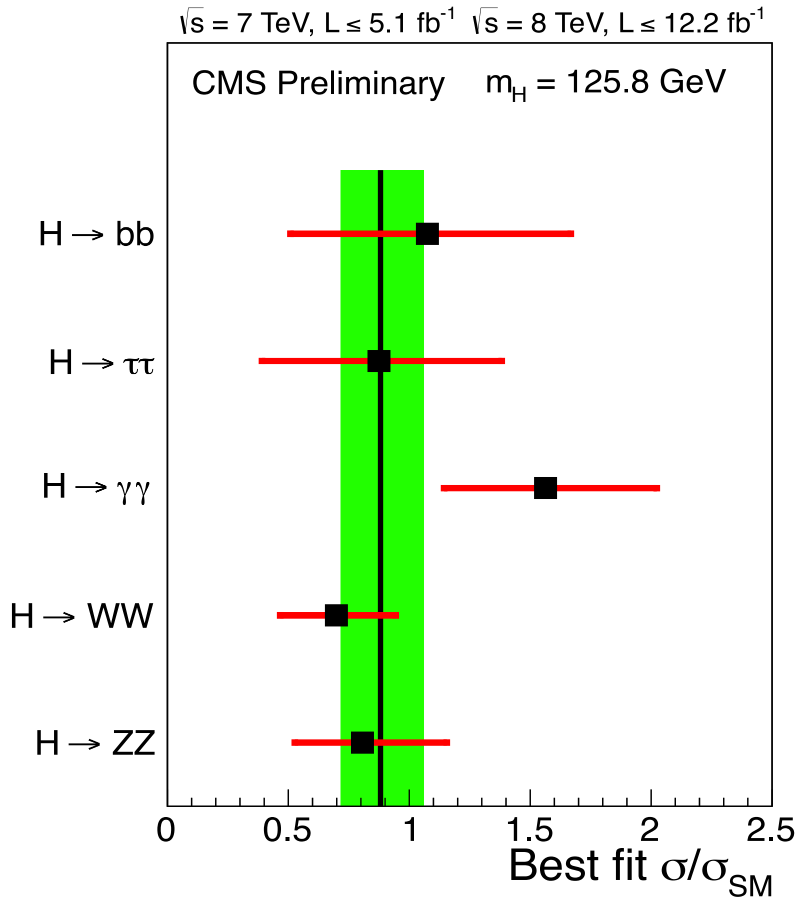
$$\boldsymbol{P(n|\mu\bar{s}^{\mathrm{SM}} + \bar{b}) \propto \exp\left[-\frac{(n - \mu\bar{s}^{\mathrm{SM}} - \bar{b})^2}{2(\mu\bar{s}^{\mathrm{SM}} + \bar{b})^2}\right]}$$

$$\boldsymbol{\sim \exp\left[-\frac{(\mu - \hat{\mu})^2}{2\Delta^2}\right]}$$

- Multiply likelihoods of different channels and experiments → sum exponents

$$\boldsymbol{\chi^2 = \sum_X \frac{(\mu_{XX} - \hat{\mu}_{XX})^2}{\Delta^2_{XX}}}$$

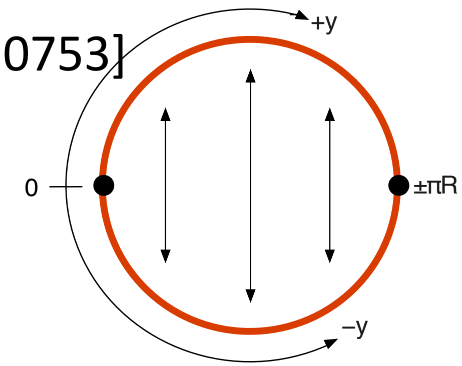
Excluding BSM models



$$\chi^2 = \sum_X \frac{(\mu_{XX} - \hat{\mu}_{XX})^2}{\Delta^2_{XX}}$$

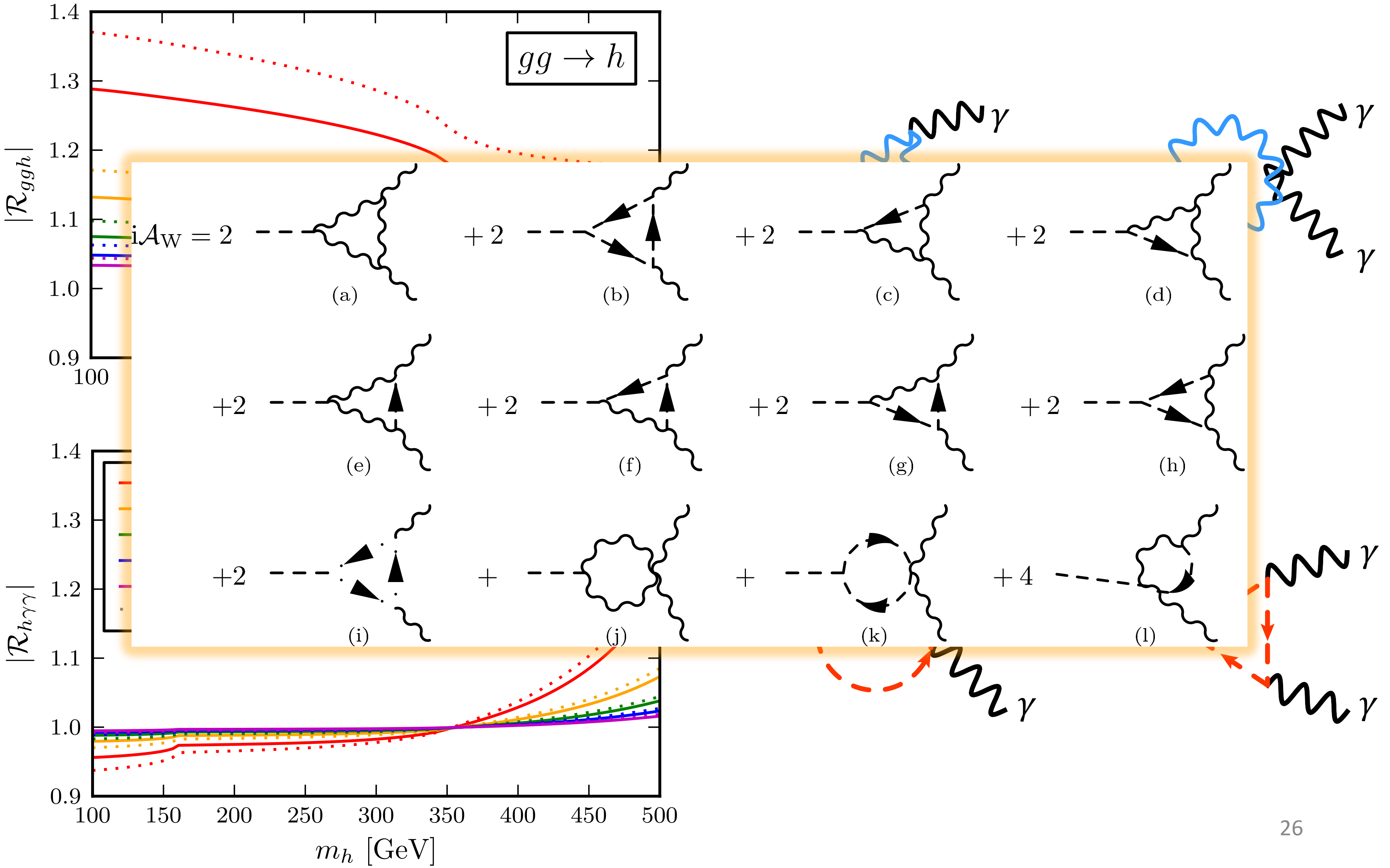
Minimal Universal Extra Dimensions

Bélanger, Belyaev, Brown, Kakizaki, Pukhov [arxiv:1209.0753]

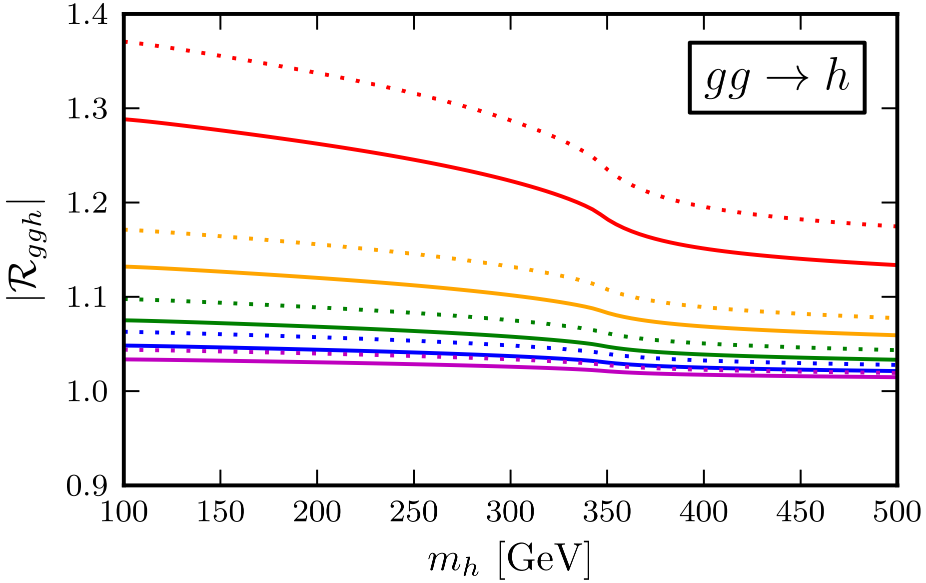


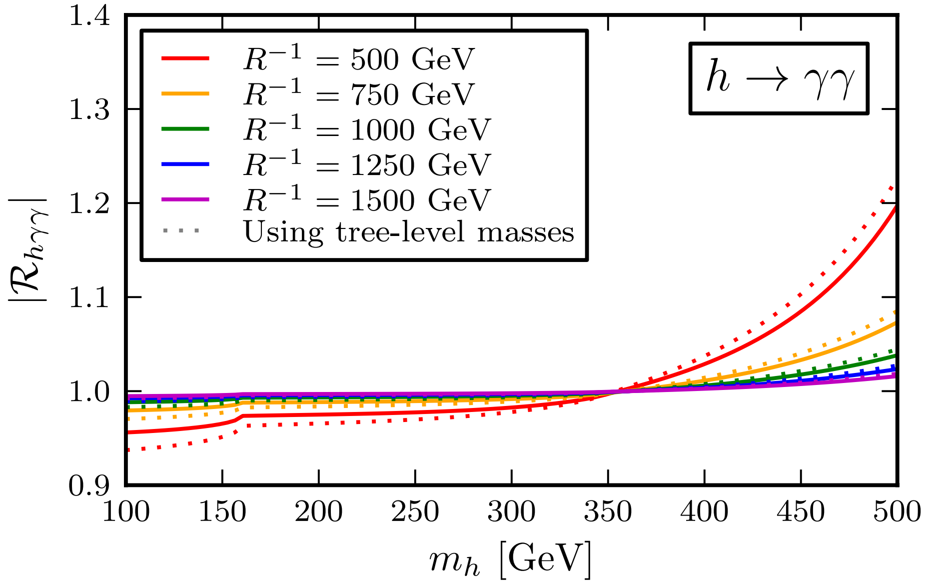
- 1 extra dimension on S^1/Z_2 orbifold (chiral interactions)
- Action 5D Lorentz invariant at cutoff scale
- KK photon is natural DM candidate
- KK partners of SM vectors and fermions contribute to loops
- gg → h enhanced; h → $\gamma\gamma$ suppressed
- R^{-1} is only new parameter

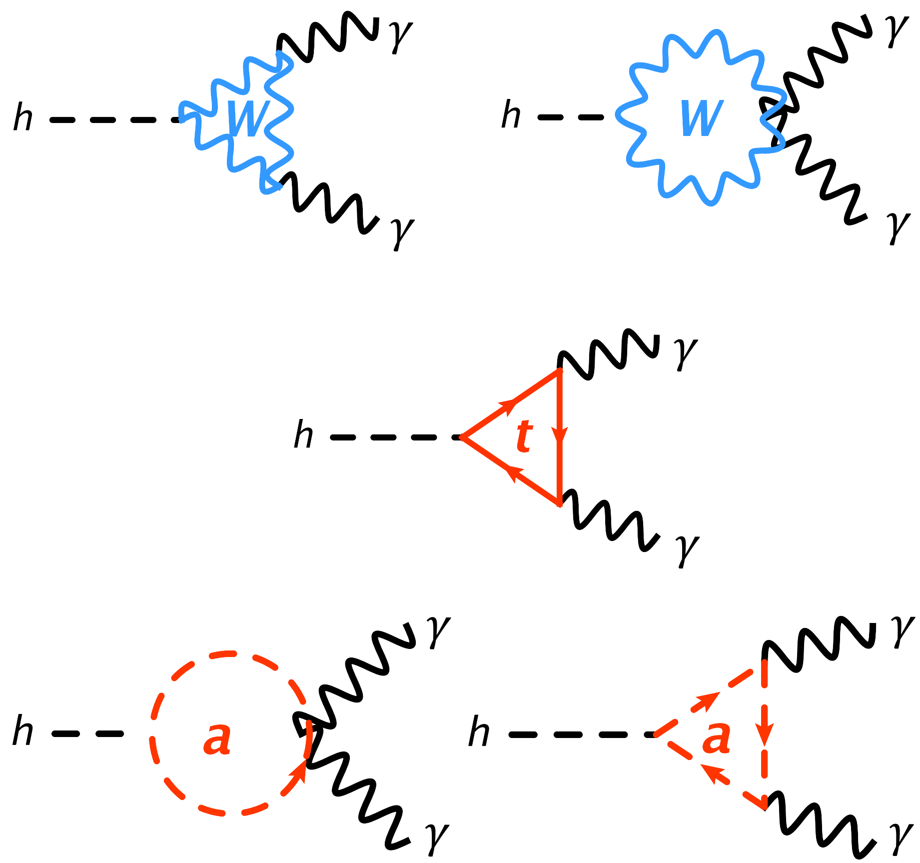
Minimal Universal Extra Dimensions



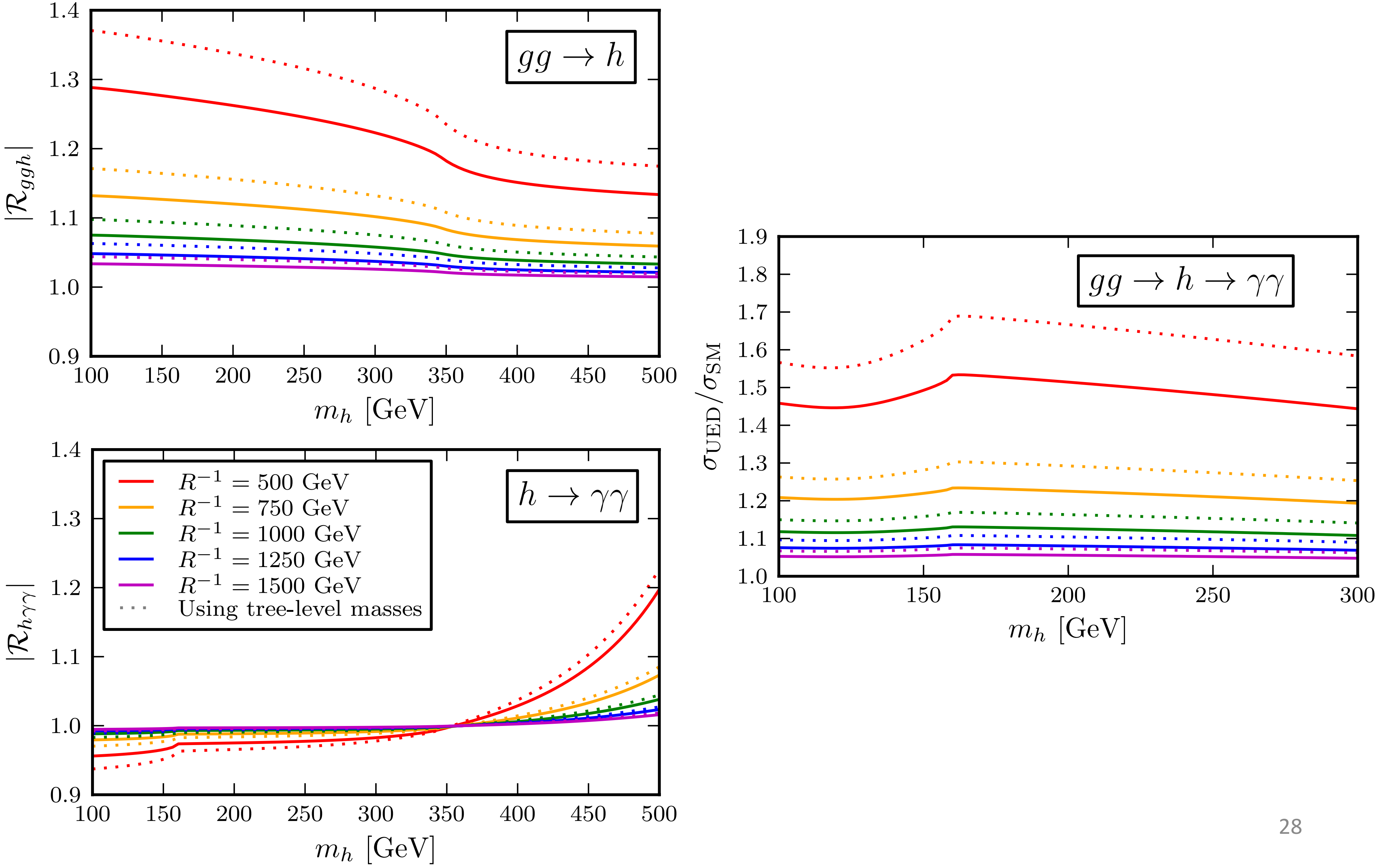
Minimal Universal Extra Dimensions





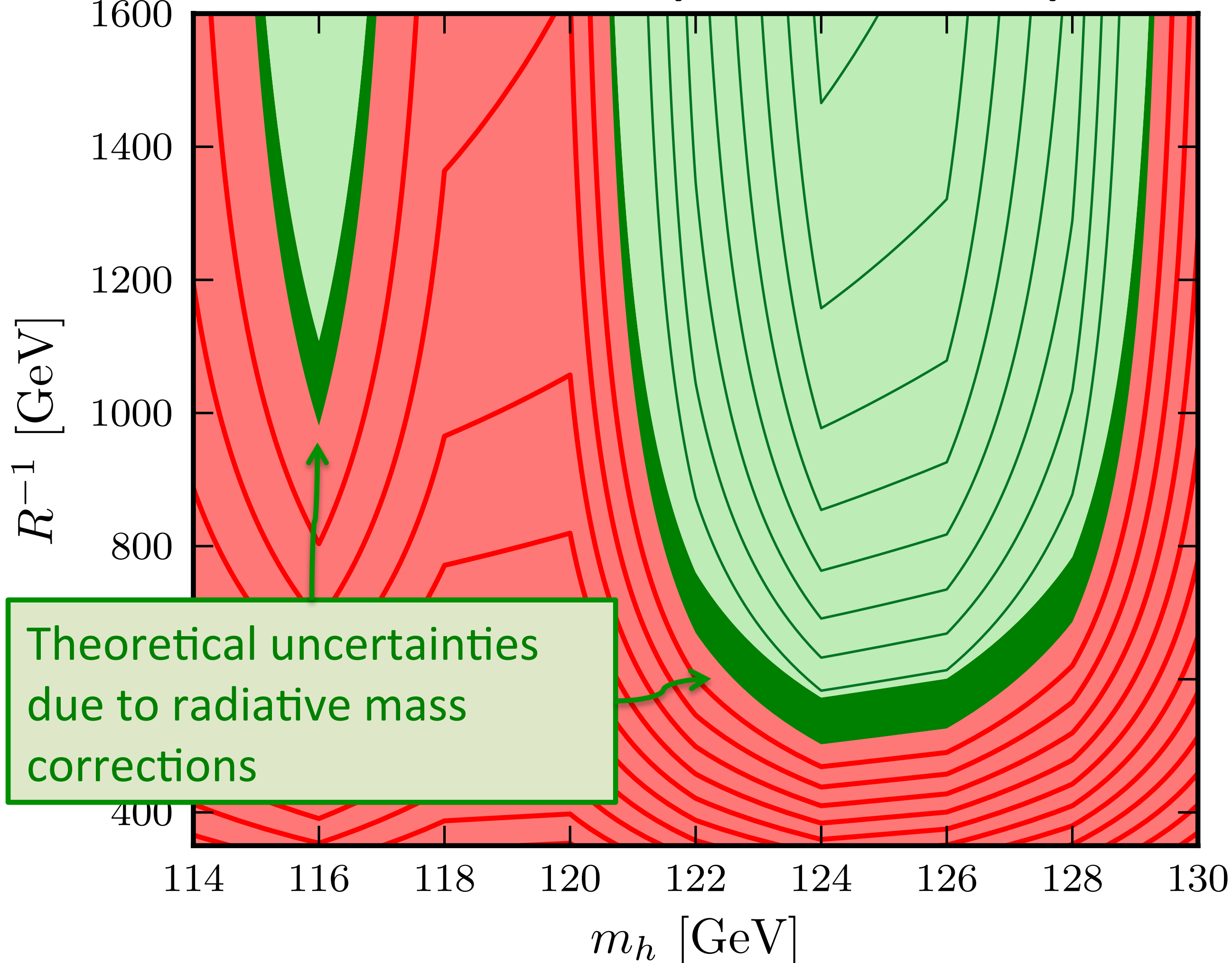


Minimal Universal Extra Dimensions



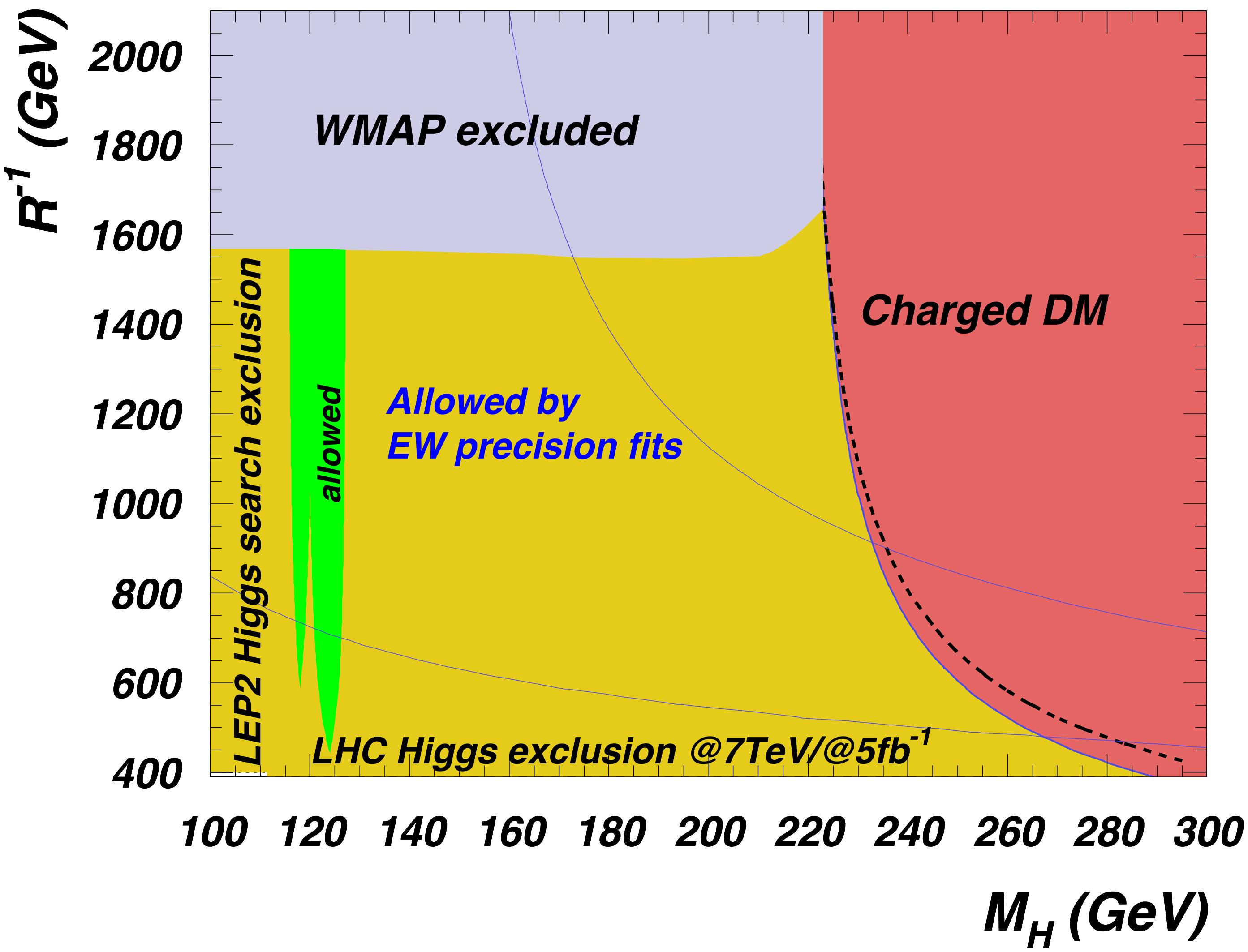
Constraining MUED

95% CL limits on parameter space



Bélanger, Belyaev, Brown, Kakizaki, Pukhov [arxiv:1209.0753]

Constraining MUED



Bélanger, Belyaev, Brown, Kakizaki, Pukhov (2013) [arxiv:1209.0753]

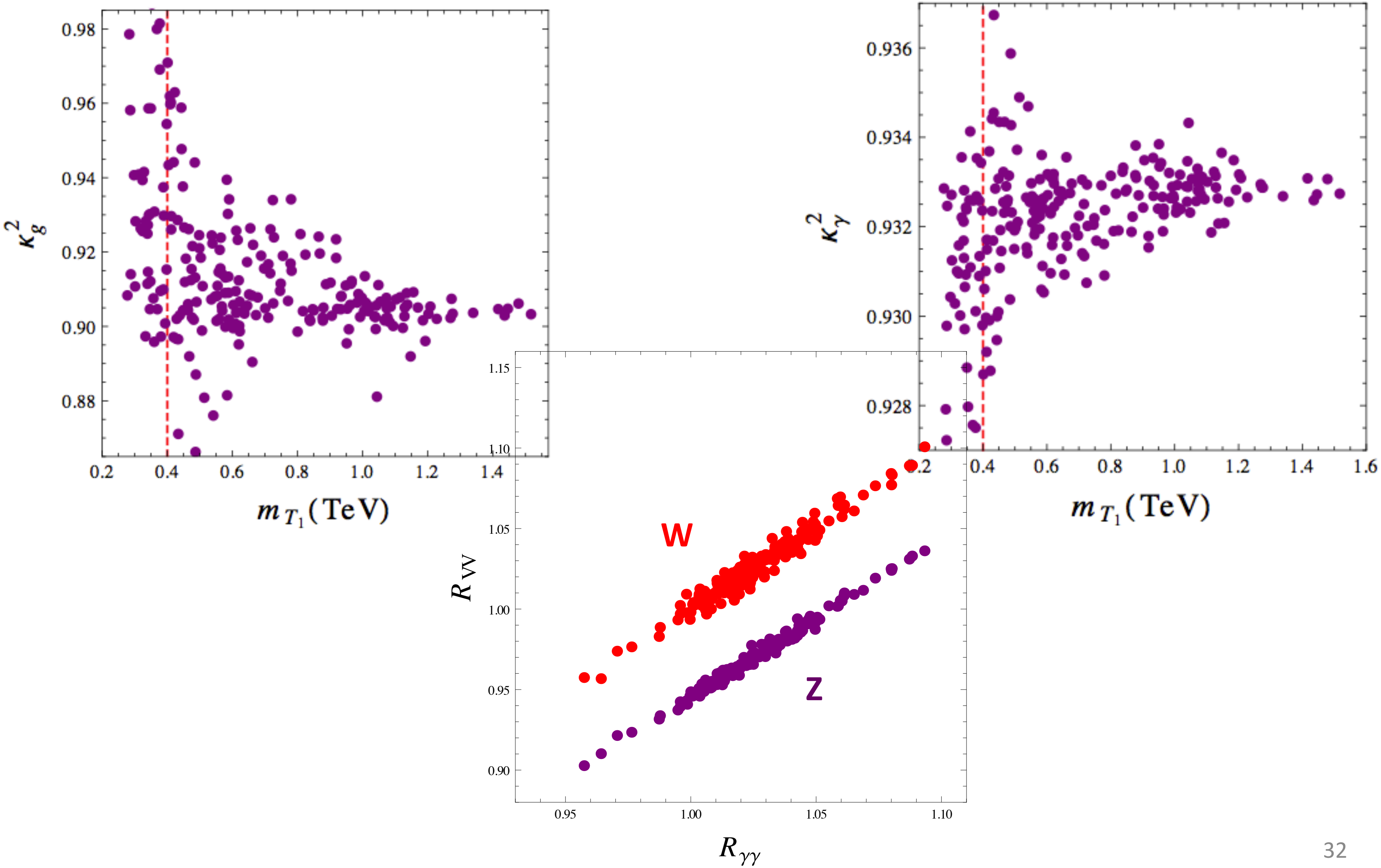
4D Composite Higgs Model

Barducci, Belyaev, Brown, De Curtis, Moretti, Pruna, *in perparation*

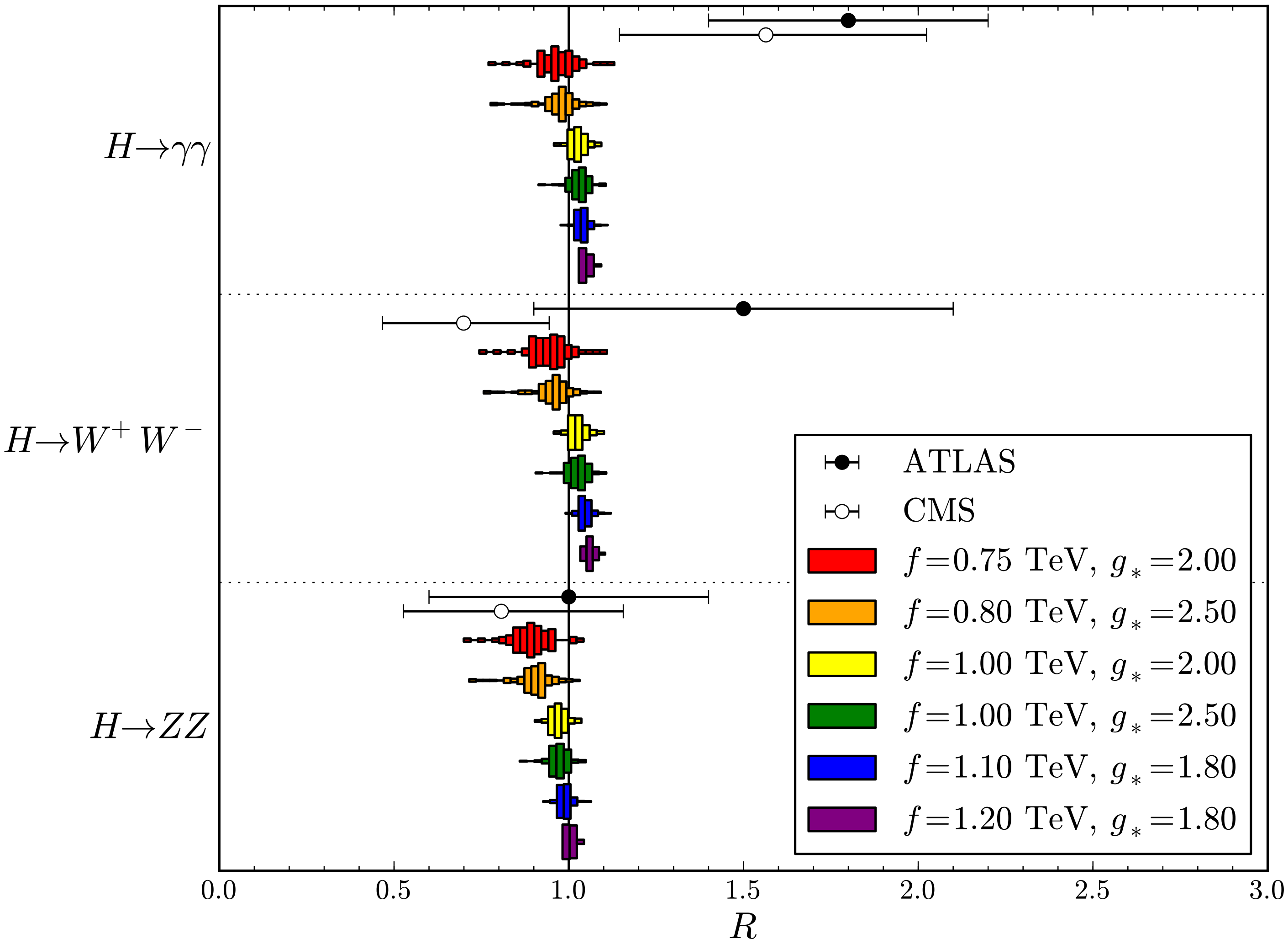
- New strongly interacting sector possessing global symmetry
- Symmetry is spontaneously broken
- Four of the (pseudo) Nambu-Goldstone bosons form the SM Higgs doublet
- Makes Higgs naturally light
- New top- and bottom-like quarks and W'/Z's. Also exotic

Neutral Gauge Bosons	$Z_{1,2,\ldots,5}$
Charged Gauge Bosons	$W^{\pm}_{1,2,3}$
Charge 2/3 quarks	$T_{1,2,\ldots,8}$
Charge $-1/3$ quarks	$B_{1,2,\ldots,8}$
Charge 5/3 quarks	$\tilde{T}_{1,2}$
Charge $-4/3$ quarks	$\tilde{B}_{1,2}$

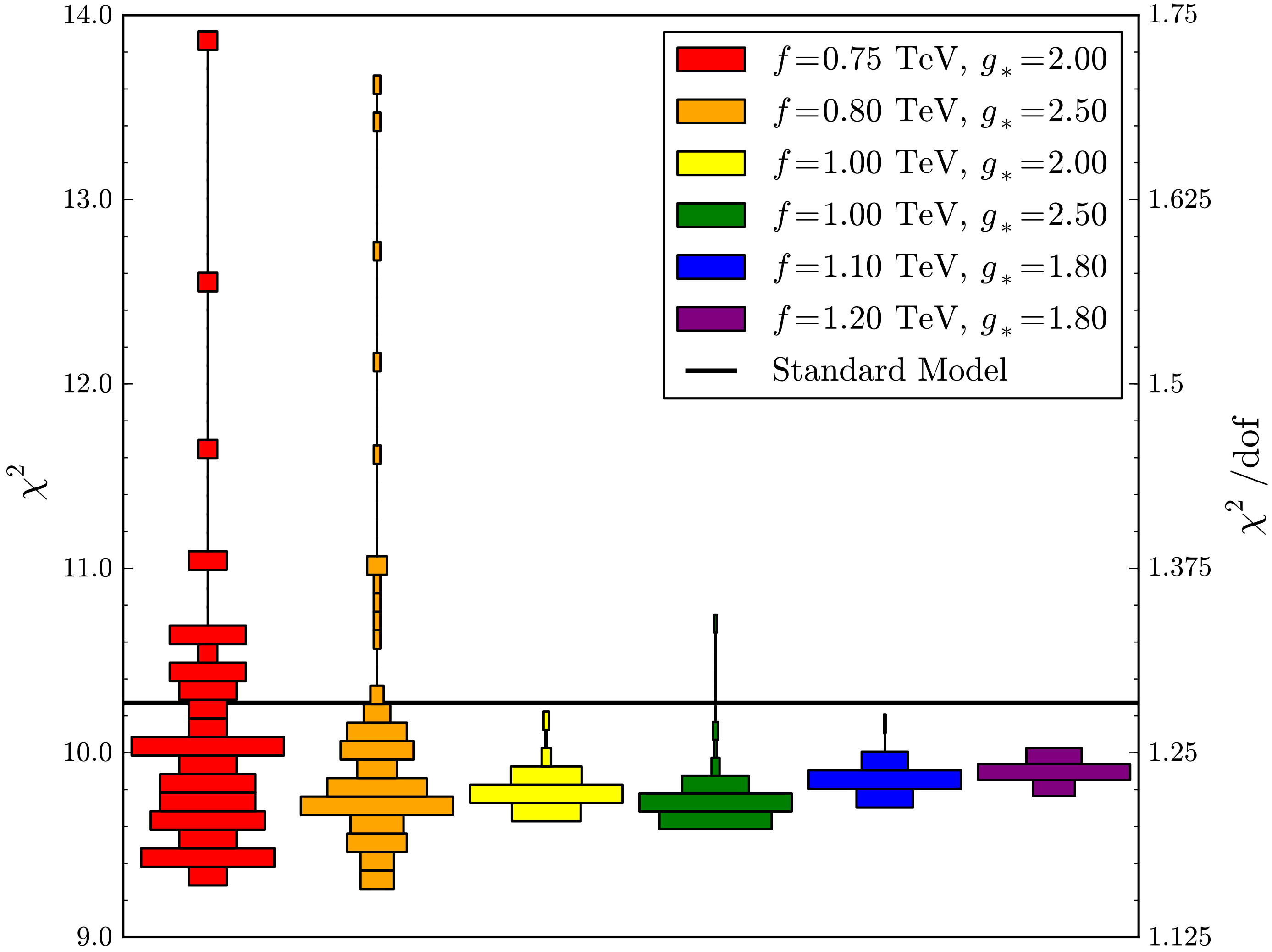
4D Composite Higgs Model



Constraining 4DCHM



Constraining 4DCHM



Conclusions

- Higgs physics can place powerful constraints on BSM models
- Model *dependent* tests must be performed to properly test plausible models of new physics
- I am investigating Higgs physics of
  - MUED [1209.0753]
  - 4DCHM [in preparation]
  - Technicolor models (Sasha, Mads Fandsen, Roshan Foadi, Tuomas Hapola)
  - E_6SSM (Sasha, Patrik, Marco Pruna)

Outlook

- Higgs couplings are poorly resolved at present, but will errors decrease with new data
- Experimentalists will need to release more information (Likelihoods? Efficiencies?) as precision becomes important
- Will need to move beyond NWA

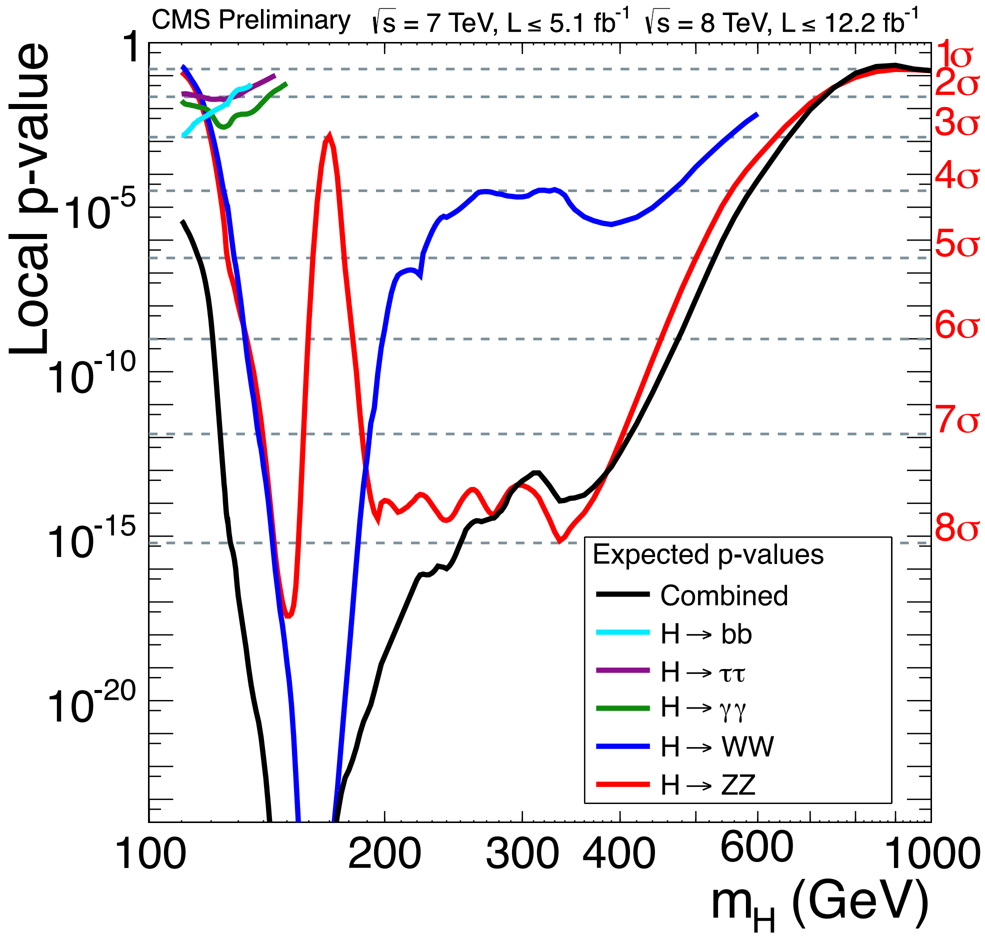
Expected/observed graph confusion

In the original talk, I showed the wrong graph on slide 19. I've fixed this now, but here I show and explain the incorrect graph…

This graph is made before taking any data. For each Higgs mass, we imagine that the number of observed events is exactly equal to the signal-plus-background expectation for that value of m_H. We then work out the probability that the background could fluctuate up to that hypothetical value and plot this p value.

The graph tells us which Higgs mass hypotheses we might expect to be able to exclude with the given integrated luminosity. For example, in the ZZ channel, even if the number of observed events exactly corresponded to the m_H ~ 160 GeV prediction, that number would not be different enough from the background-only prediction to exclude the background at 5 sigma. But when you combine all the channels, we would expect to be able to "discover" a Higgs of any mass up to ~500 GeV.

It shows that a SM Higgs with m_H ~ 160 GeV would be the easiest to discover by combining all the channels.



$\mathrm{CL_s}$ beginning of backup slides

$$\mathrm{CL}_{s+b} = \int_0^n P(n|\bar{s} + \bar{b})\,\mathrm{d}n$$
$$\mathrm{CL}_b = \int_0^n P(n|\bar{b})\,\mathrm{d}n$$
$$\mathrm{CL}_s = \mathrm{CL}_{s+b}/\mathrm{CL}_b$$
$$\mathrm{CL} = 1 - \mathrm{CL}_s$$