BSM Higgs

benchmarks scenarios after the discovery of a (SM)like) 126 GeV particle

HXSWG

LHC Higgs XS WG

CERN, December 6, 2012

On behalf of the Heavy Higgs/BSM conveners

Christophe Grojean

ICREA@IFAE/Barcelona

(christophe.grojean@cern.ch)

iCrea
INSTITUCIÓ CATALANA DE RECERCA I ESTUDIS AVANÇATS

2 Higgs(es) or not 2 Higgs(es)

"We have found a new particle"

The next stage is to determine whether this Higgs-like particle is fully responsible for the generation of the masses of the other SM particles, or in other words, whether it fully unitarizes the high-energy scattering amplitudes

This question is intimately connected to the determination of the Higgs couplings

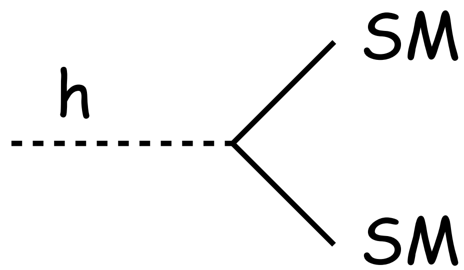
what kind of information can we extract on possible new states from the measurements of the Higgs couplings at 126 GeV?

Two concrete proposals

include the interference and lineshape effects with the same prescription for handling higher-order corrections as in the existing Heavy Higgs search

1 parameter BSM Higgs @ LHC$_{2011\text{-}2012}$

universal rescaling of Higgs couplings



$$\sqrt{\mu}\, g_{hXX}^{SM}$$

$$c_V = c_F = \sqrt{\mu}$$

Explicit and calculable models

SM Higgs mixed with an EW singlet

if assuming that this singlet unitarize the longitudinal amplitudes (in the isospin 0 channel)

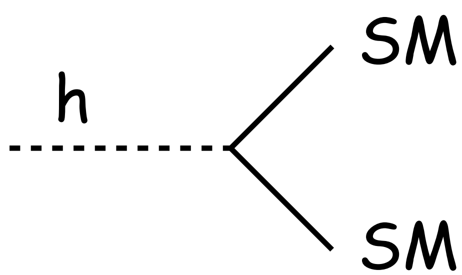
$$V_L V_L \to V_L V_L \qquad\qquad V_L V_L \to f \bar{f}$$

then the couplings of the singlet are fixed by the one of the Higgs (up to a possible additional invisible decay width)

$$c_V^2 + c_V'^2 = 1 \qquad\qquad c_V c_F + c_V' c_F' = 1$$

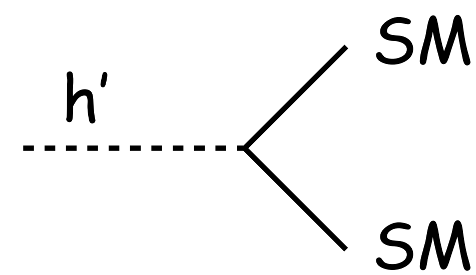
1 parameter BSM Higgs @ LHC$_{2011\text{-}2012}$

Higgs @ 125 GeV

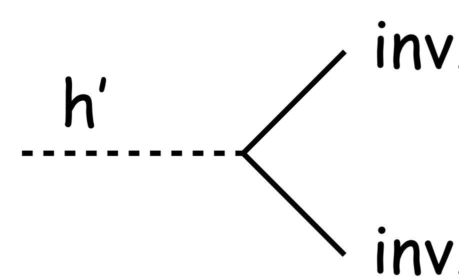


$$\sqrt{\mu}\, g_{hXX}^{SM}$$

heavier Higgs



$$c'\, g_{hXX}^{SM}$$



$$\mathrm{BR}'_{inv.}$$

$$\mu' = \frac{\sigma \times \Gamma(H \to XX)}{\sigma \times \Gamma(h@m_H \to XX)|_{\mathrm{SM}}}$$

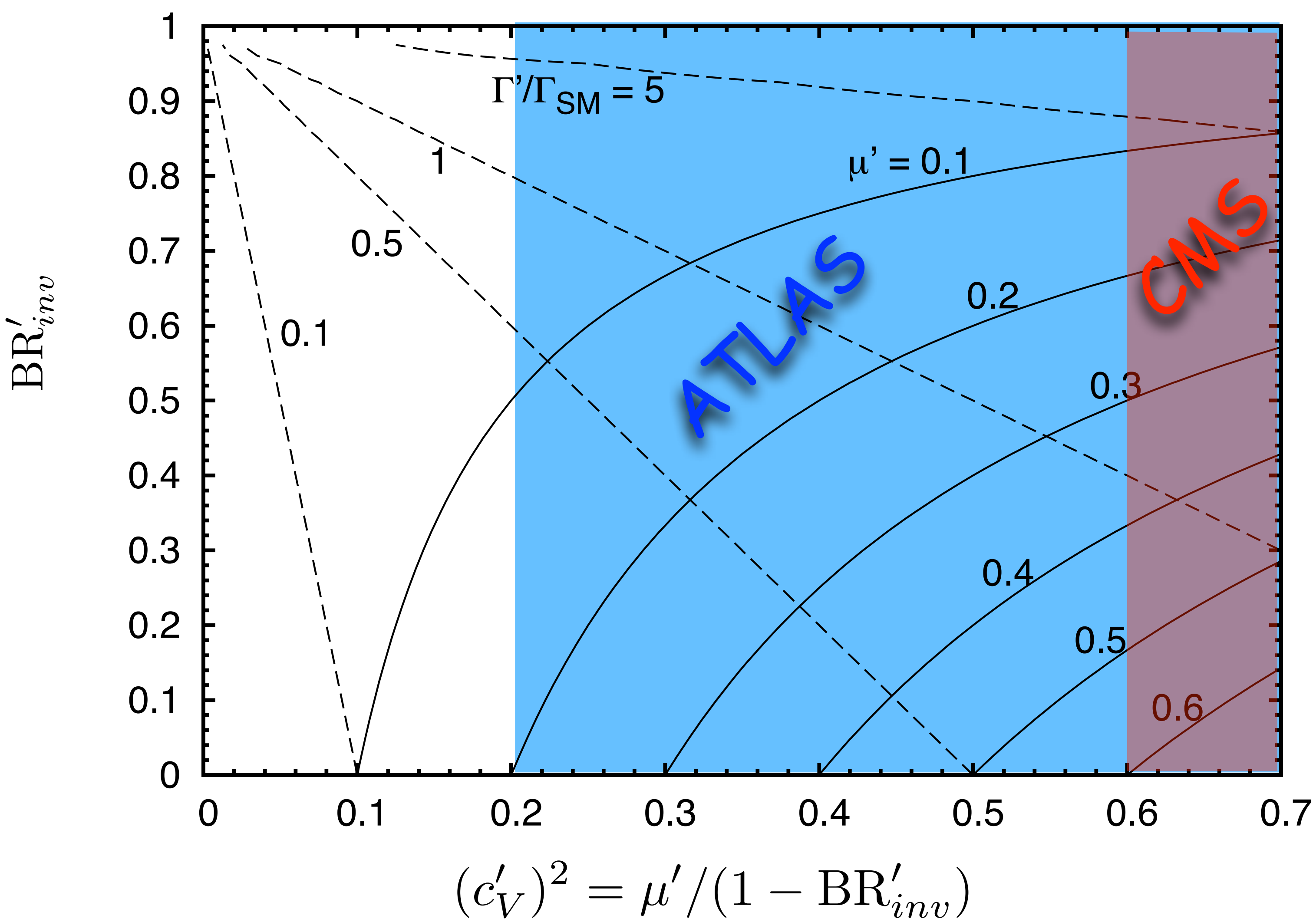
$$\mu' = c'^2 \times (1 - \mathrm{BR}'_{inv.})$$

Unitarity sum rules

$$\mu' = (1-\mu) \times (1 - \mathrm{BR}'_{inv}) \qquad \Gamma'_{tot} = \frac{1-\mu}{1-\mathrm{BR}'_{inv}}\, \Gamma_{\mathrm{SM}}$$

1 parameter BSM Higgs @ LHC$_{2011\text{-}2012}$

$$\mu' = (1-\mu) \times (1 - \mathrm{BR}'_{inv}) \qquad \Gamma'_{tot} = \frac{1-\mu}{1-\mathrm{BR}'_{inv}}\,\Gamma_{\mathrm{SM}}$$



ATLAS : $\mu = 1.4 \pm 0.3$

CMS : $\mu = 0.87 \pm 0.23.$

$\Downarrow$ $\Downarrow$ $\Downarrow$

uppper bounds on μ'

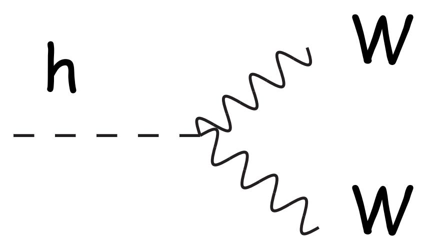
using the SM Higgs searches can put some bounds on the mass of the singlet

2 parameter Higgs physics @ LHC$_{2011\text{-}2012}$

$$\frac{c_H}{2f^2}\left(\partial^\mu |H|^2\right)^2$$

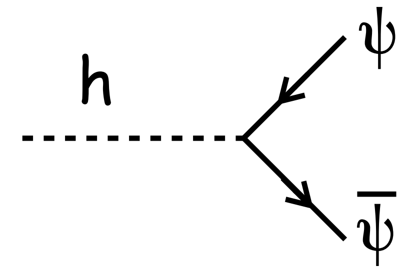
$$\frac{c_y y_\psi}{f^2}|H|^2 \bar\psi_L H \psi_R$$

Controls the hWW, hZZ couplings



$$a\, g^{SM}_{hVV}$$

Controls the hψψ couplings



$$c\, g^{SM}_{h\psi\psi}$$

Explicit and calculable models

Composite Higgs models

MCHM5

$$a = \sqrt{1-\xi} \qquad c = \frac{1-2\xi}{\sqrt{1-\xi}}$$

MCHM4

$$a = \sqrt{1-\xi} \qquad c = \sqrt{1-\xi}$$

disfavored by EW data (Zbb)

SM is recovered
as particular limits

Two Higgs Doublet models Type I

	2HDM I
u	Φ_2
d	Φ_2
e	Φ_2

	2HDM I
hVV	$\sin(\beta-\alpha)$
hQu	$\cos\alpha/\sin\beta$
hQd	$\cos\alpha/\sin\beta$
hLe	$\cos\alpha/\sin\beta$

e.g, Craig, Thomas '12

BSM interpretation

New interactions
composite Higgs

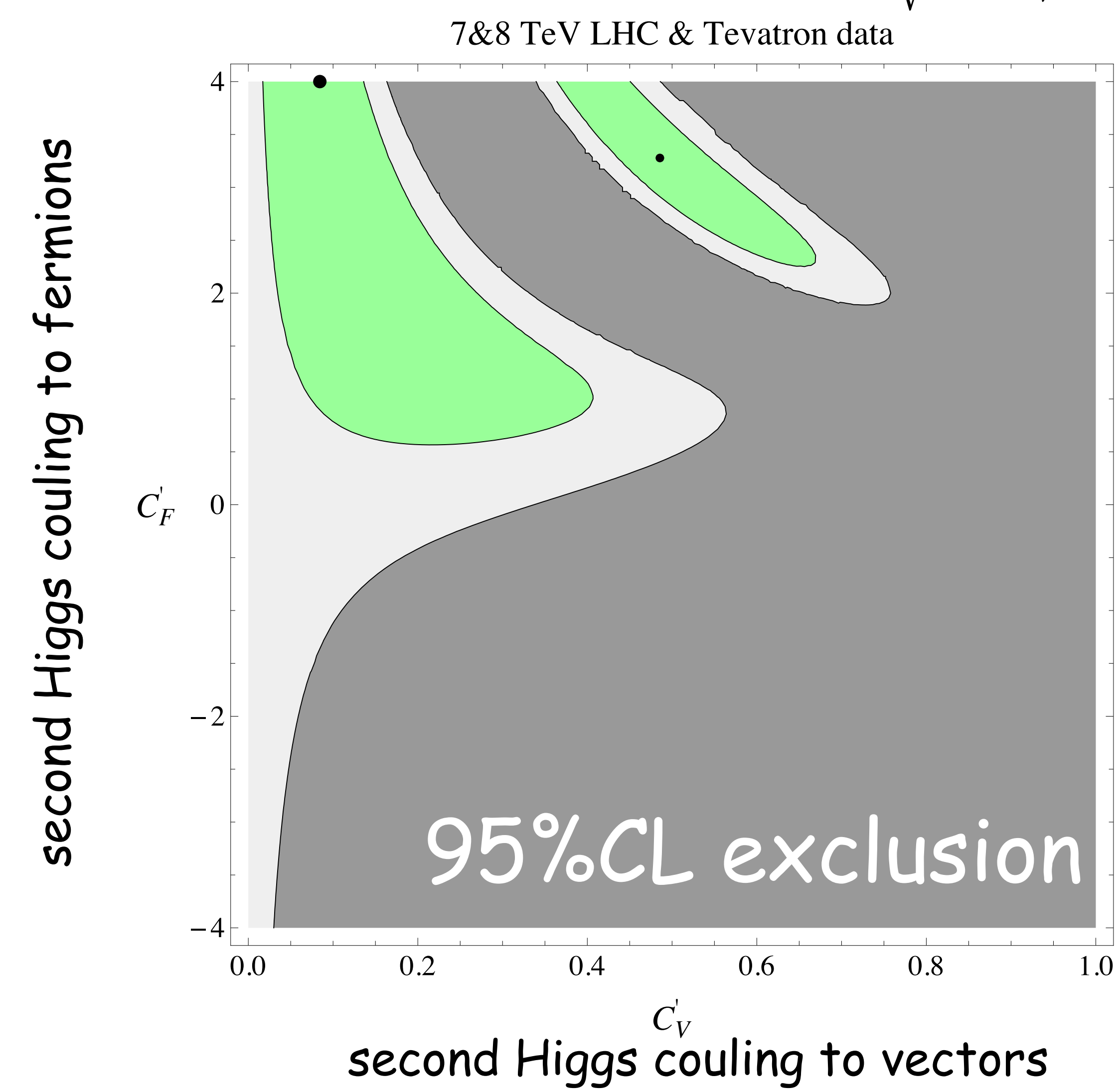
New particles
e.g. a second Higgs

$$C'_V = \sqrt{1 - C_V^2} \qquad C'_F = \frac{1 - C_V C_F}{\sqrt{1 - C_V^2}}$$

- deviation δ_h
- no new state up to M

$$g_\rho > \sqrt{\delta_h}(M/v)$$

(similar, but indirect, to an
enhancement δ_h of in WW scattering)



Non Standard SUSY=Higgsinoless MSSM

The Higgs could actually be the first supersymmetric particle discovered!

$$\tilde{H} = \begin{pmatrix} h^0 \\ h^- \end{pmatrix} = (1,2)_{1/2}$$

$$L = \begin{pmatrix} \nu \\ e^- \end{pmatrix} = (1,2)_{1/2}$$

"the superpartner of the Higgs is a neutrino"

Fayet '76

Biggio, Pomarol, Riva '12

	$SU(3)_c \times SU(2)_L \times U(1)_Y$	$U(1)_R$
Q	$(3,2)_{\frac{1}{6}}$	$1+B$
U	$(\bar{3},1)_{-\frac{2}{3}}$	$1-B$
D	$(\bar{3},1)_{\frac{1}{3}}$	$1-B$
$L_{1,2}$	$(1,2)_{-\frac{1}{2}}$	$1-L$
$E_{1,2}$	$(1,1)_1$	$1+L$
$H \equiv L_3$	$(1,2)_{-\frac{1}{2}}$	0
E_3	$(1,1)_1$	2
W_a^α	$(8,1)_0+(1,3)_0+(1,1)_0$	1
Φ_a	$(8,1)_0+(1,3)_0+(1,1)_0$	0
$X \equiv \theta^2 F$	$(1,1)_0$	2

X: spurion superfield to give mass to up quarks

Φ_a adjoint chiral superfields to marry to gauginos and generate Dirac masses

- no second higgs doublet so no μ-problem
- lepton # = R-symmetry
  - ☑ B≠L, no proton decay
  - ☑ L≠1, LLE and QLD are not allowed in superpot.
  - ☑ L≠0, neutrino masses are protected and naturally of the order of the gravitino mass
- up quark masses generated by susy breaking

$\Downarrow \quad \Downarrow$

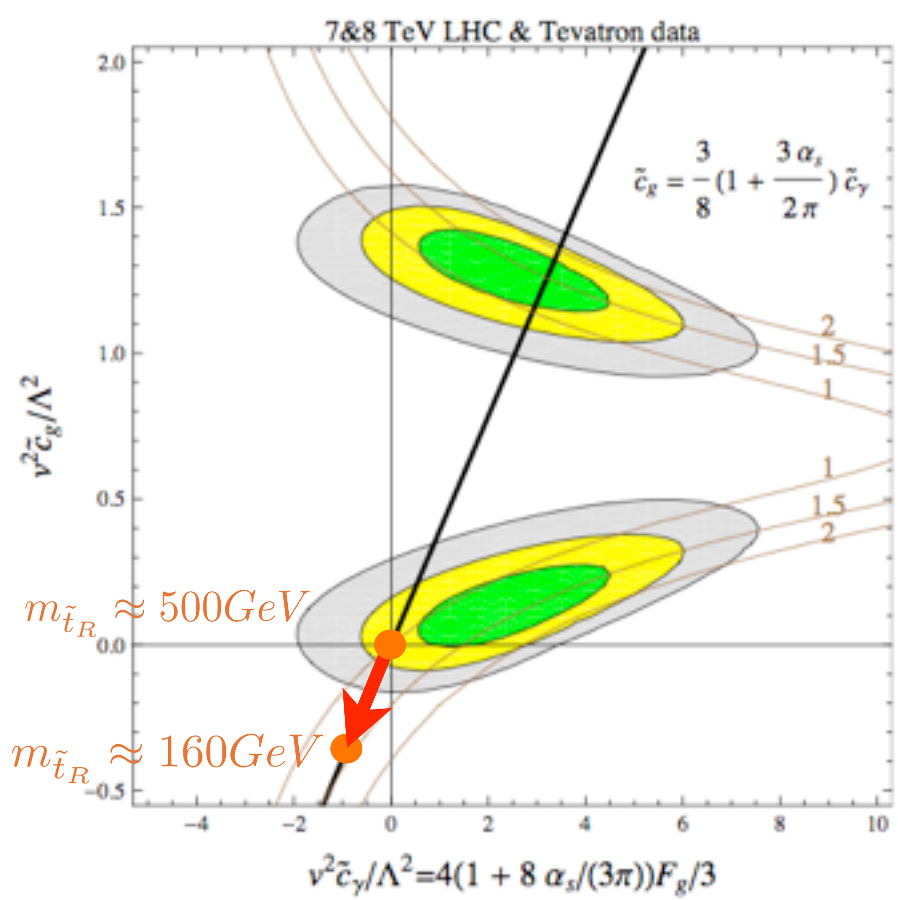
the model is not UV complete as is

so nice features of MSSM like unification have to be readdressed

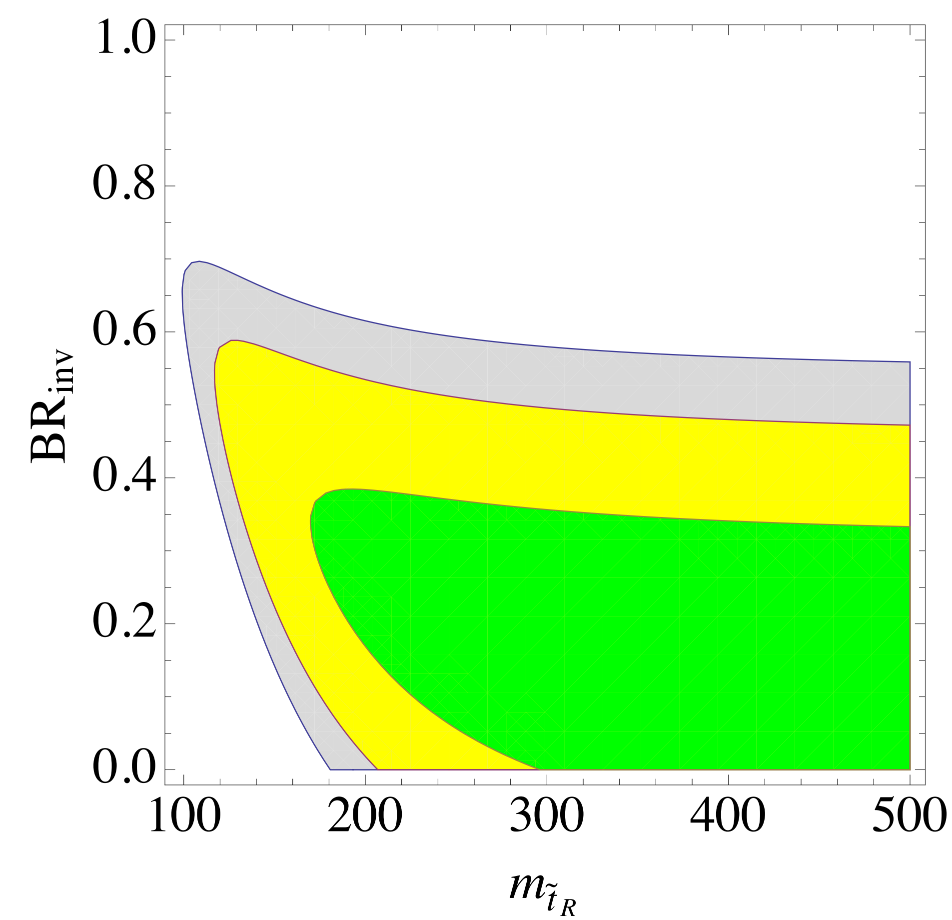
Higgsinoless MSSM: exotic pheno

Biggio, Pomarol, Riva '12

1. Higgs physics
   - loop mediated by light and unmixed stops: $h\gamma\gamma \Uparrow$ and $hgg \Downarrow$
   - invisible decay: $h \to \nu_L \tilde{G}$
   - higher dimensional operator effects



Espinosa, Grojean, Sanz, Trott '12



Biggio, Pomarol, Riva '12

Higgsinoless MSSM: exotic pheno

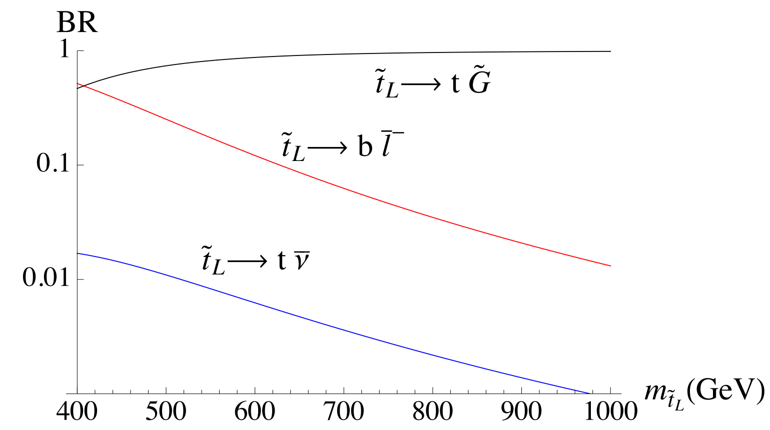
Biggio, Pomarol, Riva '12

2 stops and sbottoms physics

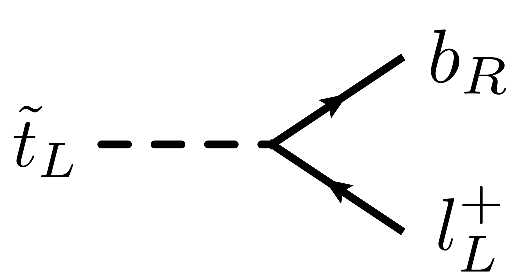
- soft trilinear A terms forbidden by R-symmetry: no L-R mixing
- $\tilde{b}_L$ always lighter than $\tilde{t}_L$: $m^2_{\tilde{b}_L} = m^2_{\tilde{t}_L} - m_t^2 + m_b^2$
- interesting decay channels

Decay	Interaction
$\tilde{t}_L \to b_R \bar{l}^-_L$	$Y_d\, HQD\|_{\theta^2}$
$\tilde{t}_L \to t_R \bar{\nu}_L$	$\frac{1}{\Lambda^2}\|H\|^2\|Q\|^2\|_{\theta^4}$
$\tilde{t}_L \to t_L \tilde{G}$	$\frac{m_t^2 - m^2_{\tilde{t}_L}}{F}\, \tilde{t}^*_L \tilde{G}\, t_L$
$\tilde{b}_L \to b_R \bar{\nu}_L$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_L \to b_L \tilde{G}$	$\frac{m_b^2 - m^2_{\tilde{b}_L}}{F}\, \tilde{b}^*_L \tilde{G}\, b_L$

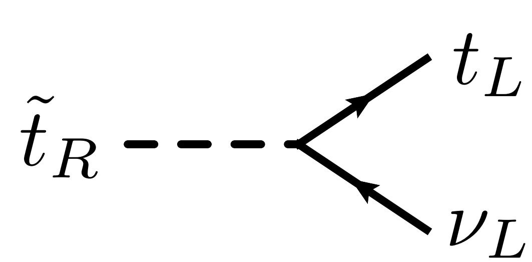
Decay	Interaction
$\tilde{t}_R \to t_L \nu_L$	$\frac{1}{\Lambda^2}\|H\|^2\|U\|^2\|_{\theta^4}$
$\tilde{t}_R \to t_R \bar{\tilde{G}}$	$\frac{m_t^2 - m^2_{\tilde{t}_R}}{F}\, \tilde{t}^*_R \bar{\tilde{G}}\, \bar{t}_L$
$\tilde{b}_R \to b_L \nu_L$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_R \to t_L\, l^-_L$	$Y_d\, QHD\|_{\theta^2}$
$\tilde{b}_R \to b_R \bar{\tilde{G}}$	$\frac{m_b^2 - m^2_{\tilde{b}_R}}{F}\, \tilde{b}^*_R \bar{\tilde{G}}\, \bar{b}_L$



Branching ratios for $\tilde{t}_L$ decays as a function of its mass, for $\Lambda = \sqrt{F} = 2$ TeV



Leptoquark signal



SUSY signal

(but different helicity structure)

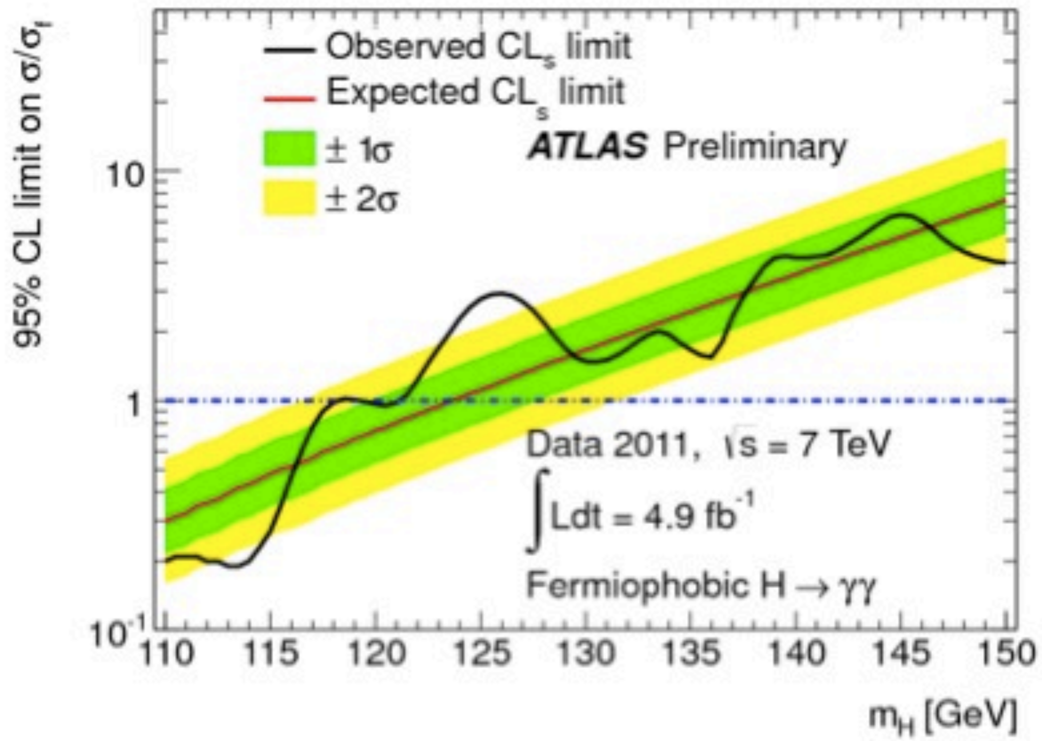
Beyond these simple benchmarks

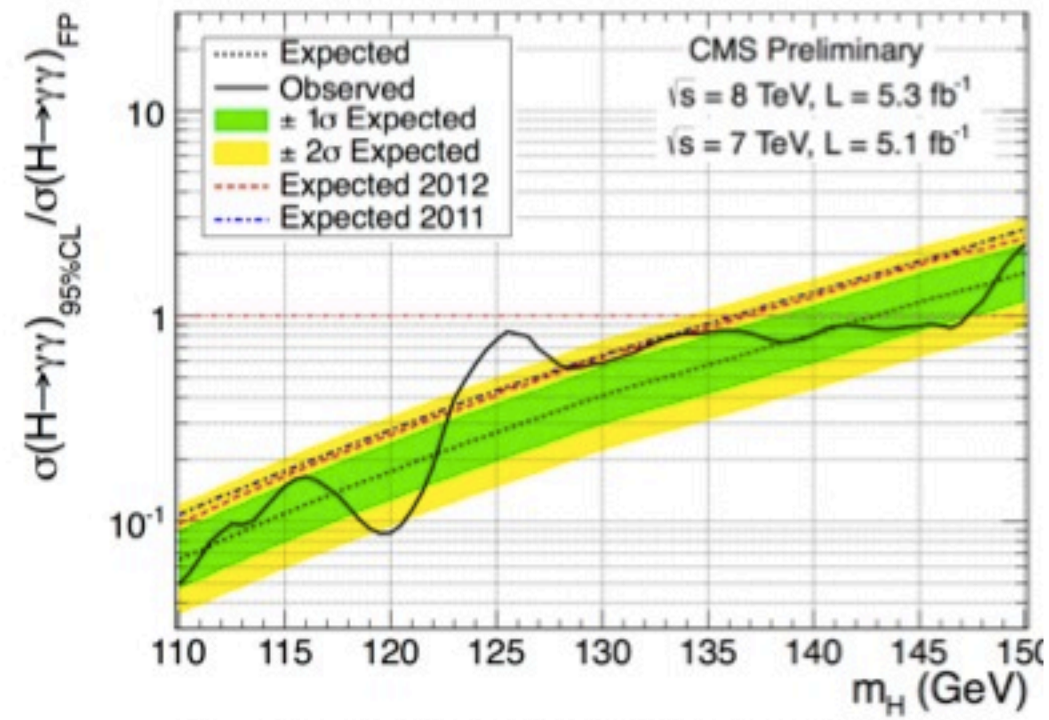
- general scan (mass vs. width) - bump hunt (in *gg* or ZZ channels)
- strongly interacting Higgs: search for additional resonances
- composite Higgs: WW scattering, WW->hh, *gg*->hh
- charged Higgs
- rare decays
- beyond MSSM

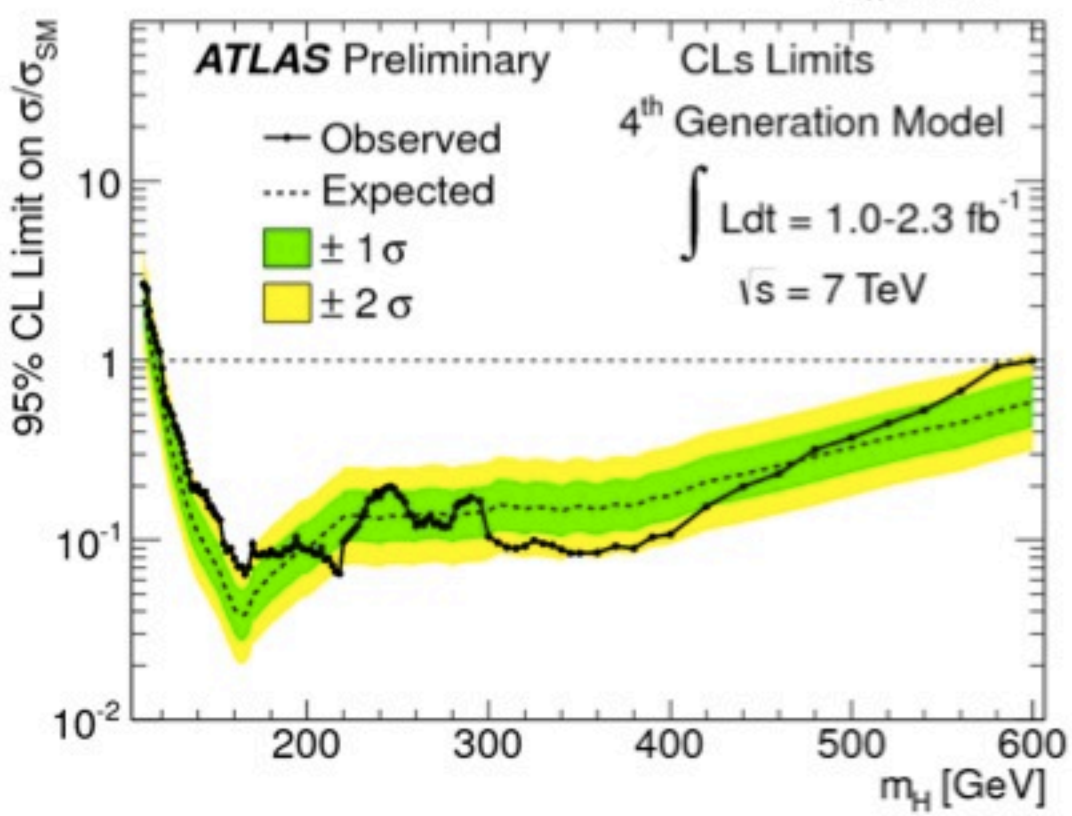
• detector resolution (in bb, tautau, WW): impossible to distinguish anything when too close to the peak.

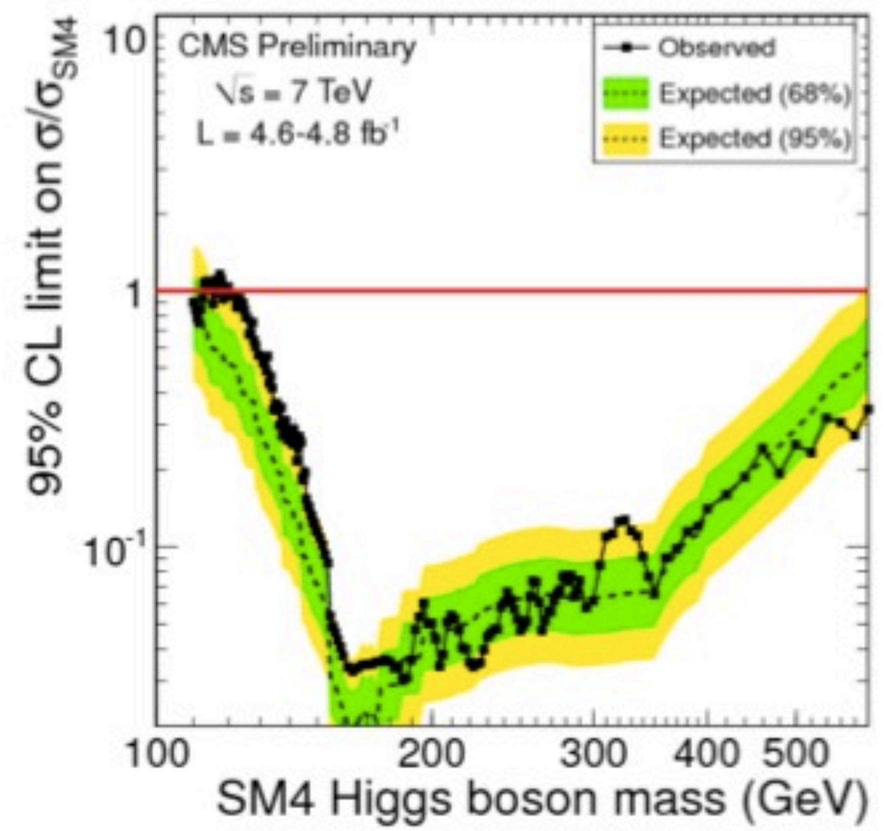
Experimental Searches

4th generation and fermiophobic



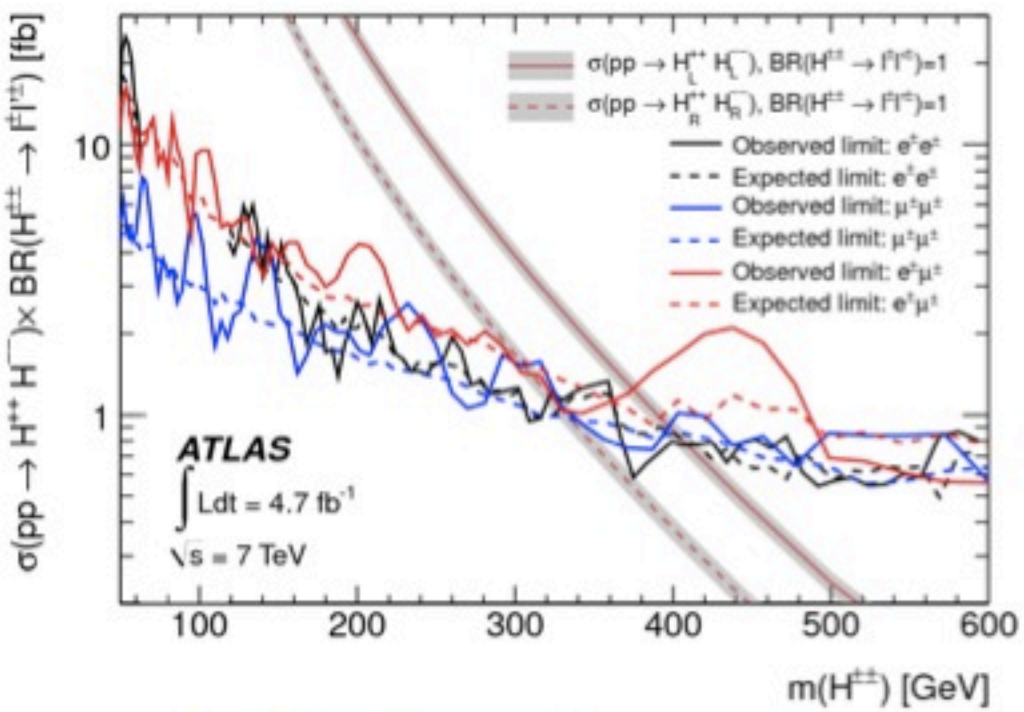


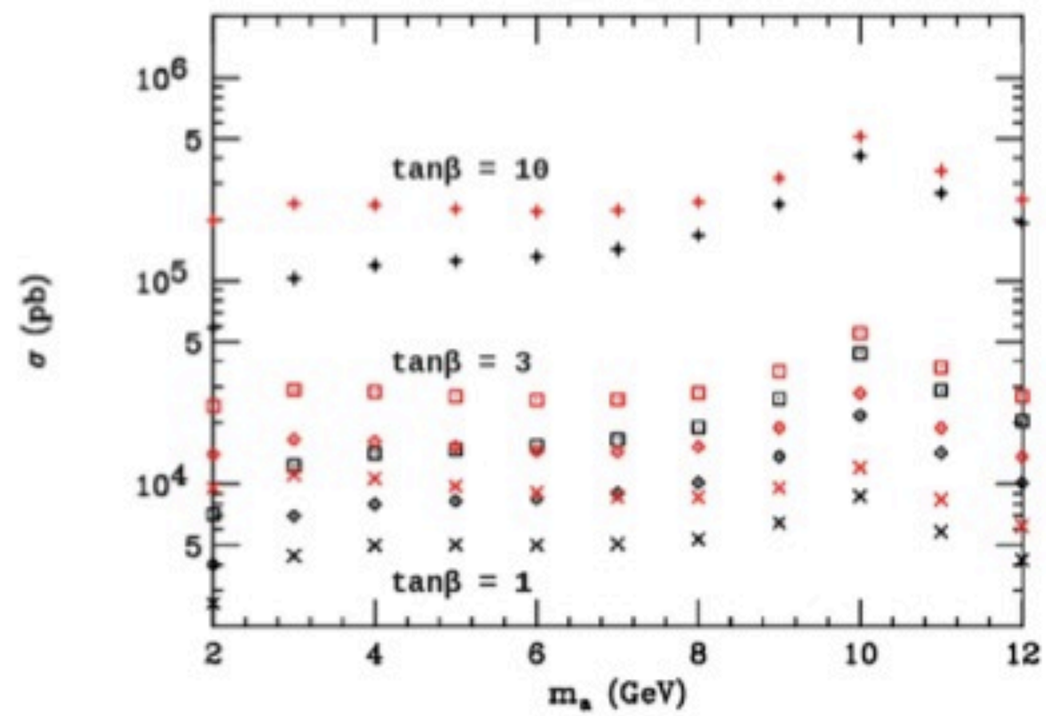


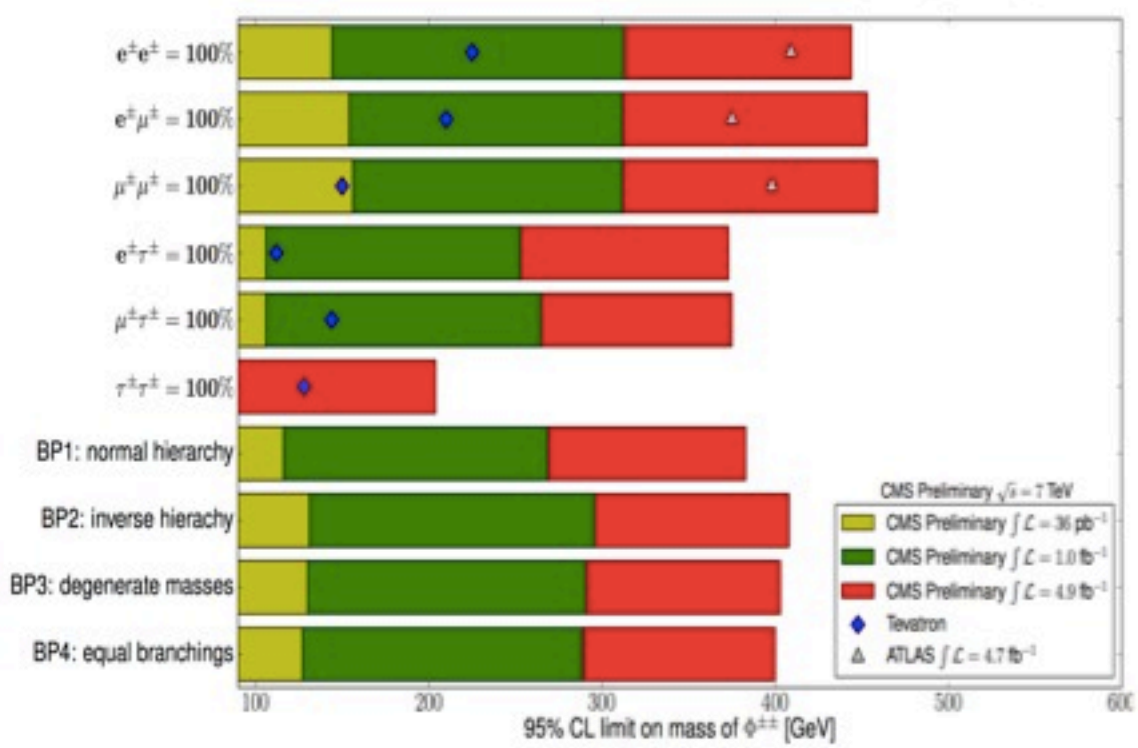


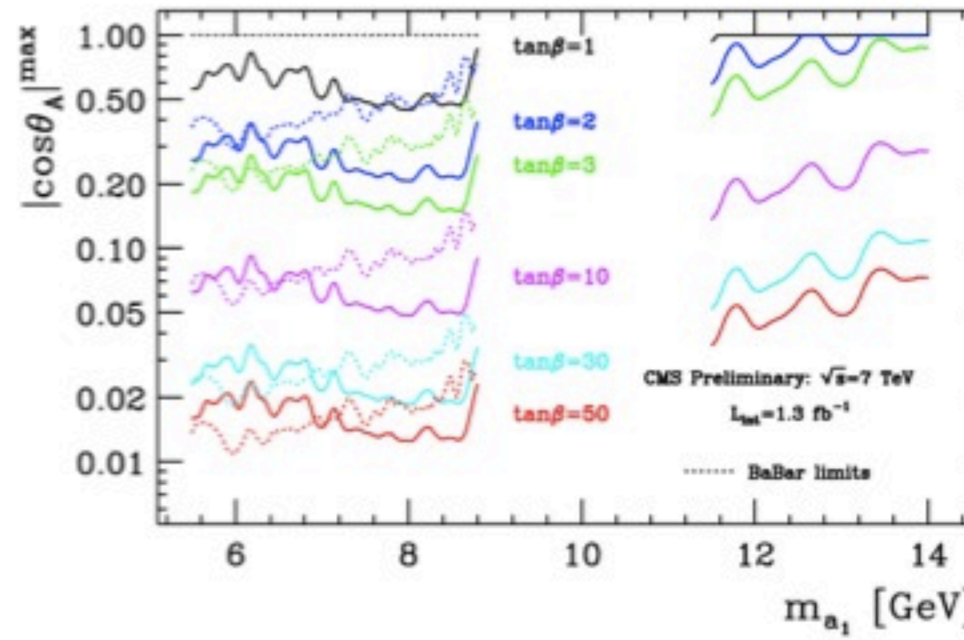
Experimental Searches

Doubly charged Higgs, a0→μμ





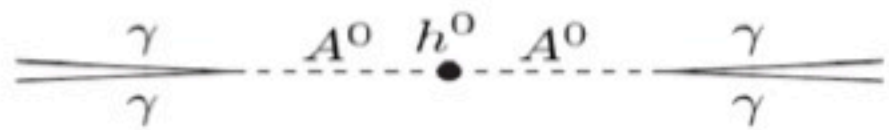




Experimental Searches

Search for H → aa → 4γ

- Various models with extended Higgs sector (MCHM, NMSSM) predict light CP-odd scalar a with H → aa
- If ma <3mπ0 then a→γγ with large BF



- Assume decay length < 0.5 m
- Reconstructed as events with two photon candidates since photons from a decay overlap in calorimeter
- Dedicated a → γγ "photon" selection to account for wider shower shapes with substructure ("isolated (heavy) π0")