Composite Higgs revealed in HH photo-production at future e+e- colliders

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Zoom, 21/01/2021

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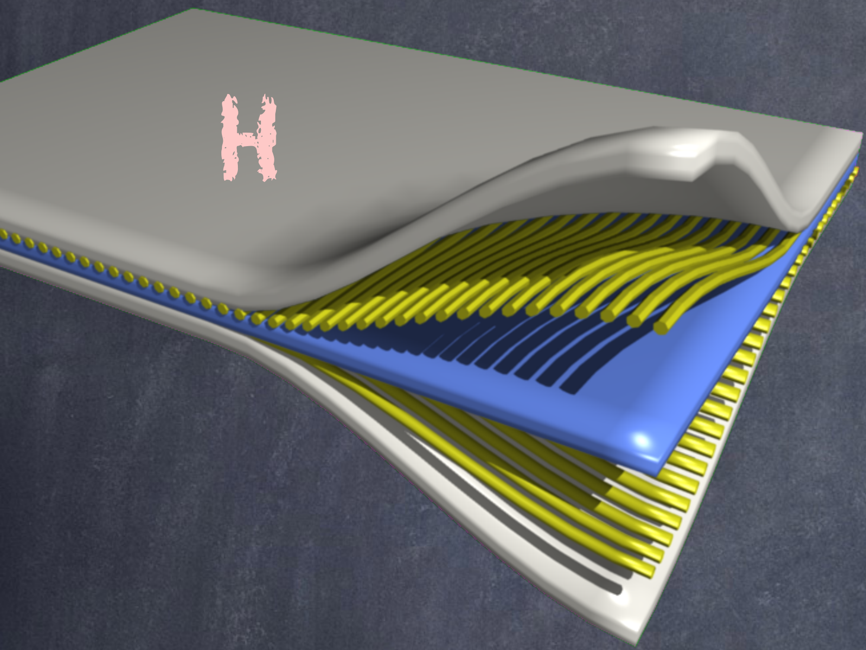
Why compositeness?



- The Higgs field may be made of more fundamental fields

- We have seen this in Nature: low-energy QCD!

- Symmetries can be broken dynamically without generating hierarchies of scales!

- Very simple models can be built. (With caveats...)

Why photon collisions?

- Electrons and positrons radiate photons, so why not using them in collisions?
- Photon couplings to the Higgs involve loops of all (charged) particles in the models...

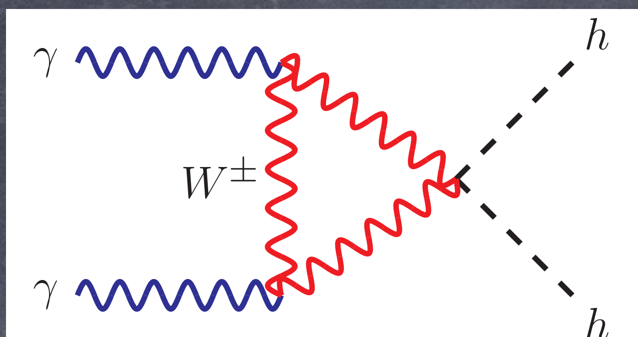
Why photon collisions?

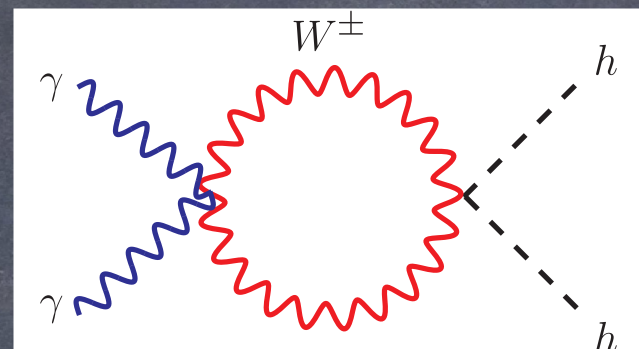
In the SM, production due to loops of W's and tops.

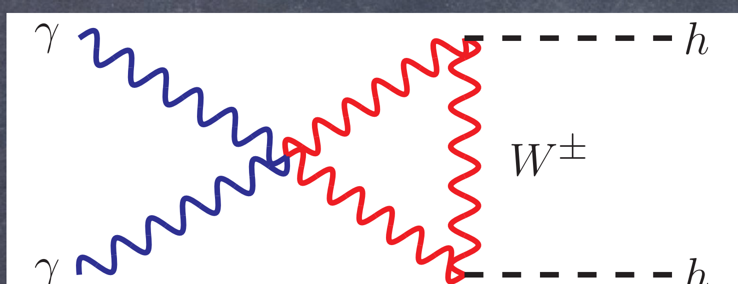
Gauge boson loops feature cancellation.

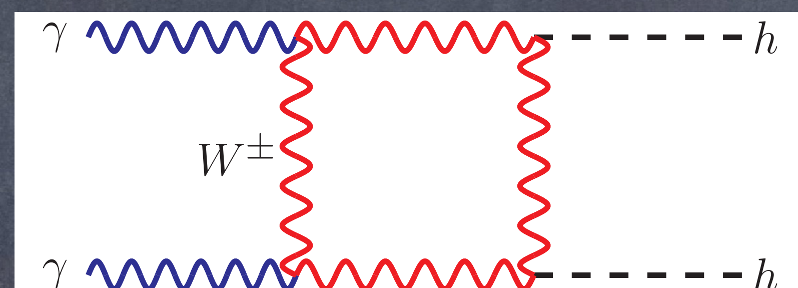
Sensitive to modifications of the Higgs couplings...

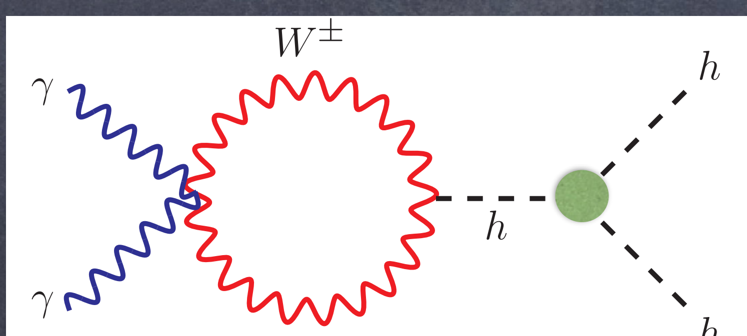
...and to Higgs self-coupling.

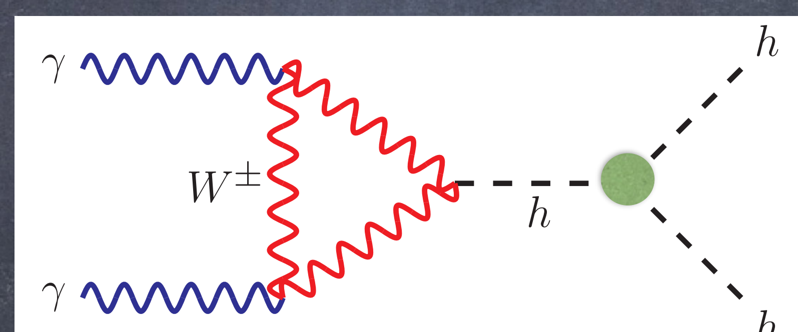


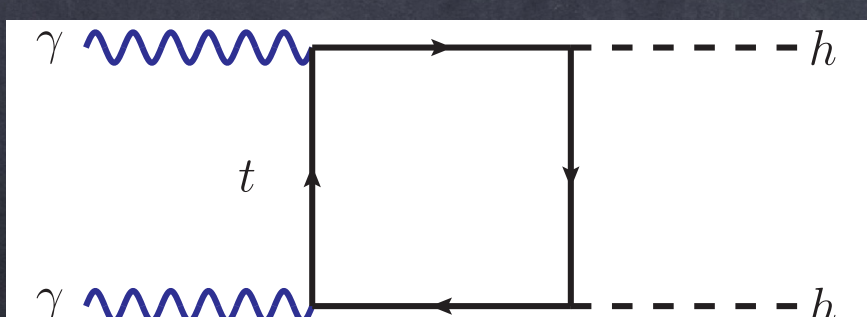


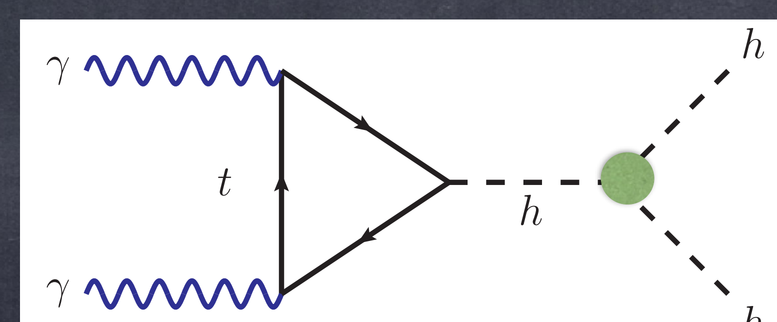




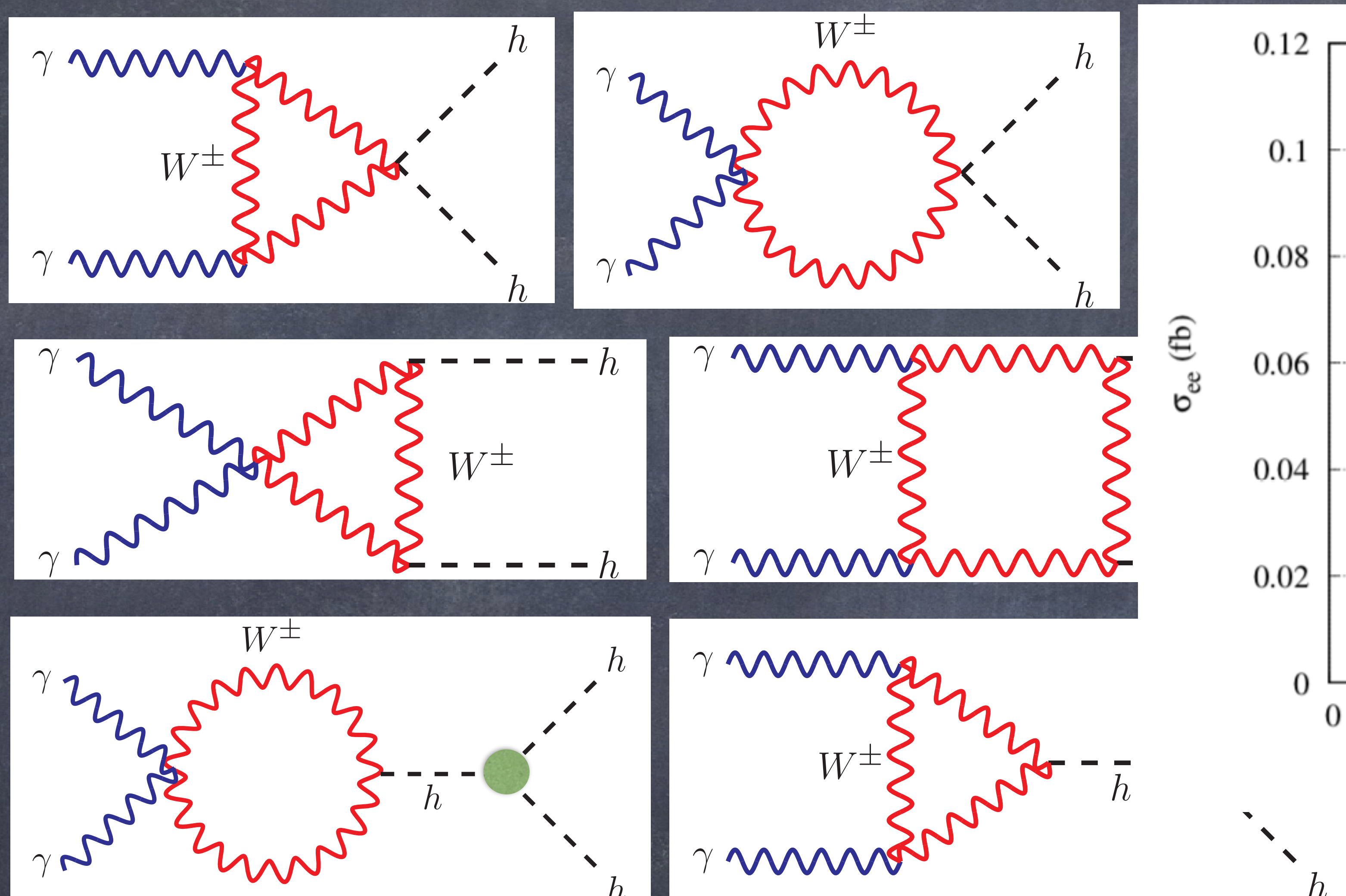


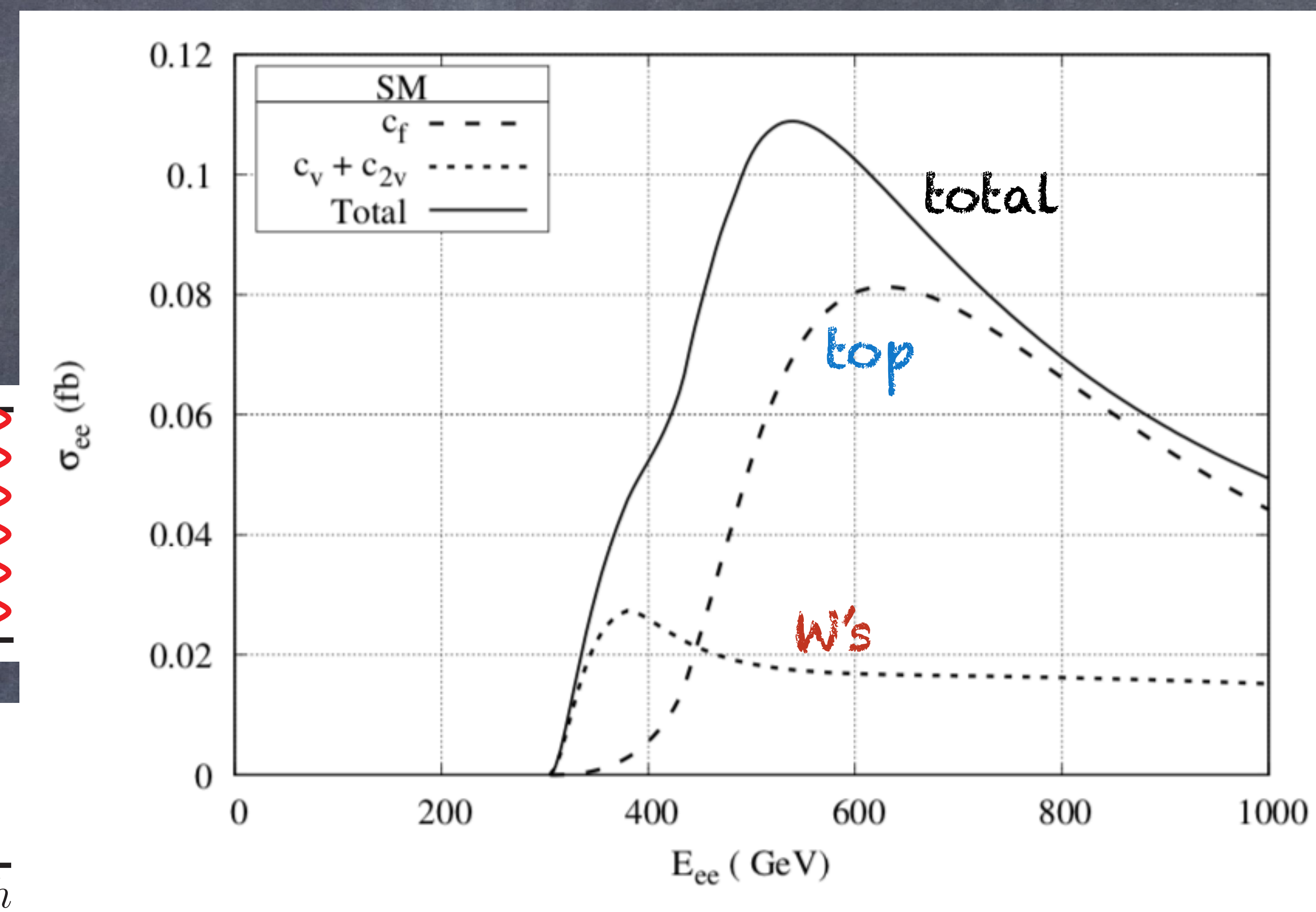




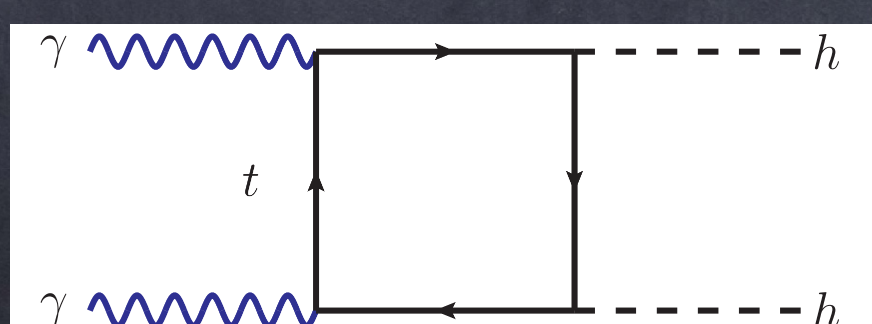


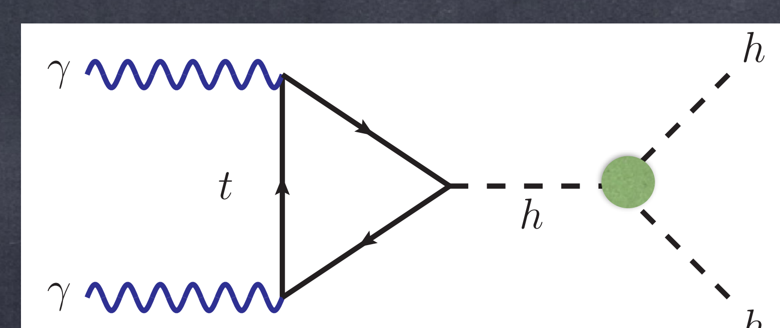
Why photon collisions?





self-coupling.





Minimal composite Higgs models

- Only modifications of the Higgs couplings

$$\mathcal{L} = m_W^2 W_\mu^+ W^{-,\mu} \left(1 + c_v \frac{h}{v} + \frac{c_{2v}}{2} \frac{h^2}{v^2} + \dots \right),$$

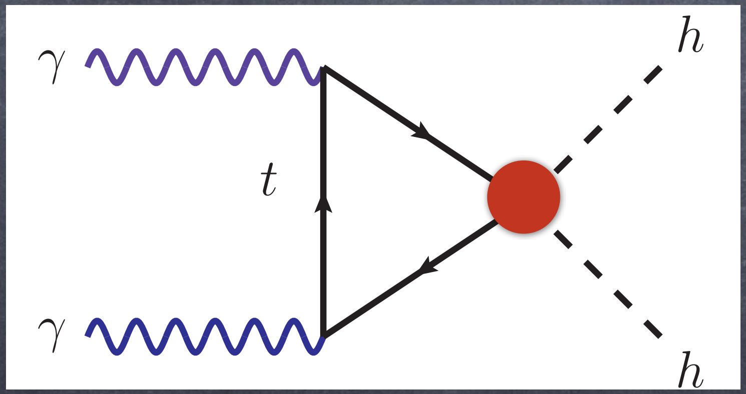
$$c_v = \cos\theta = \sqrt{1-\xi}\,, \qquad c_{2v} = \cos 2\theta = 1 - 2\xi\,;$$

Those are universal!

$$\mathcal{L} = m_t \left(\bar{t}_L t_R\right) \left(1 + c_f \frac{h}{v} + \frac{c_{2f}}{2} \frac{h^2}{v^2} + \dots \right) + h.c.$$

Those are model-dependent!

$$\xi \equiv \frac{v^2}{f^2}$$



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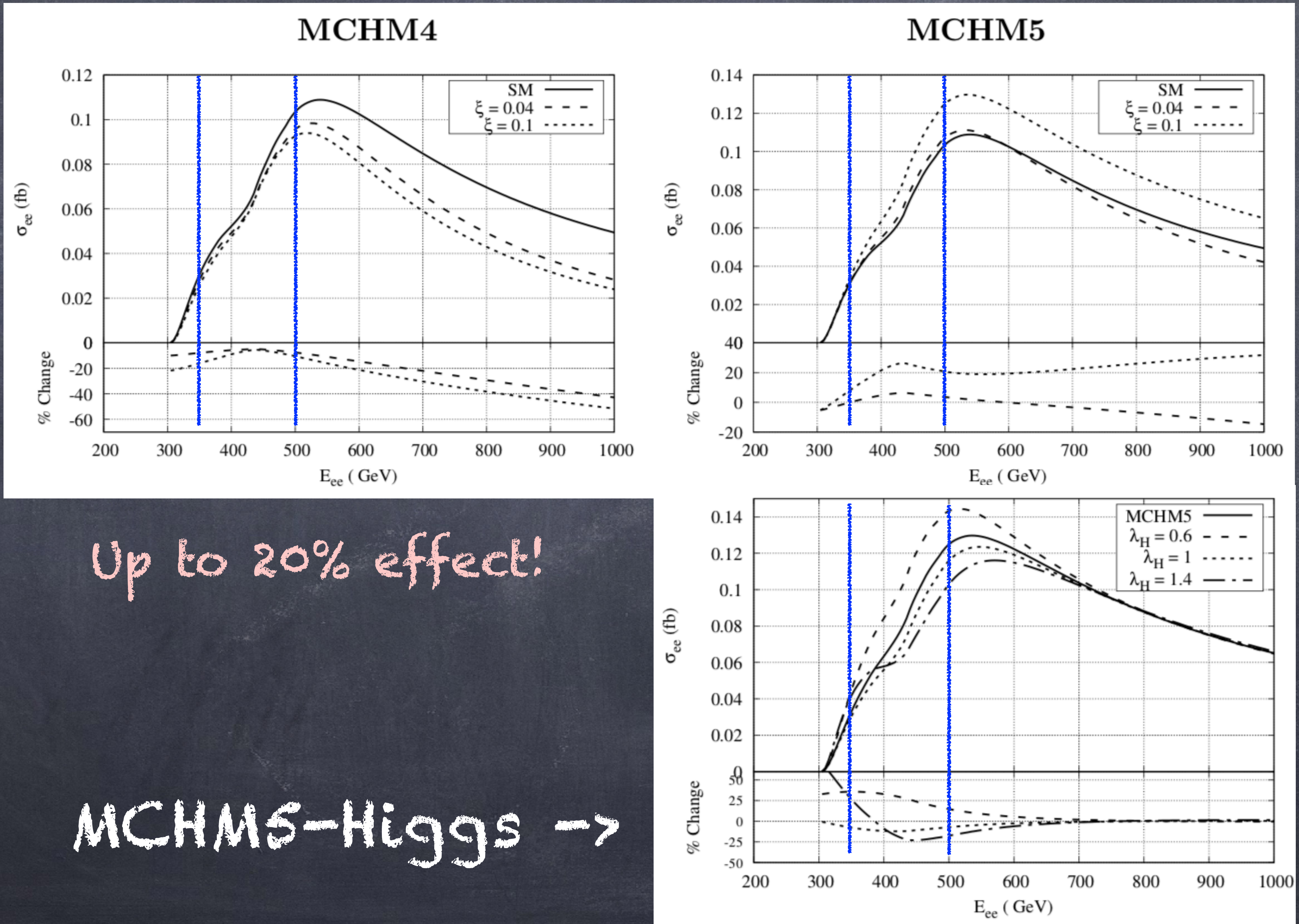
Model	$hf\bar{f}(c_f)$	$hhf\bar{f}(c_{2f})$	$hW^+W^-(c_v)$	$hhW^+W^-(c_{2v})$	c_{3h}
MCHM4 [9]	$\sqrt{1-\xi}$	$-\xi$	$\sqrt{1-\xi}$	$1-2\xi$	$\sqrt{1-\xi}$
MCHM5 [11]	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	$\sqrt{1-\xi}$	$1-2\xi$	$\frac{1-2\xi}{\sqrt{1-\xi}}$
MCHM5-Higgs	$\frac{1-2\xi}{\sqrt{1-\xi}}$	-4ξ	$\sqrt{1-\xi}$	$1-2\xi$	λ_H

Results apply to general class of models!

Minimal composite Higgs models



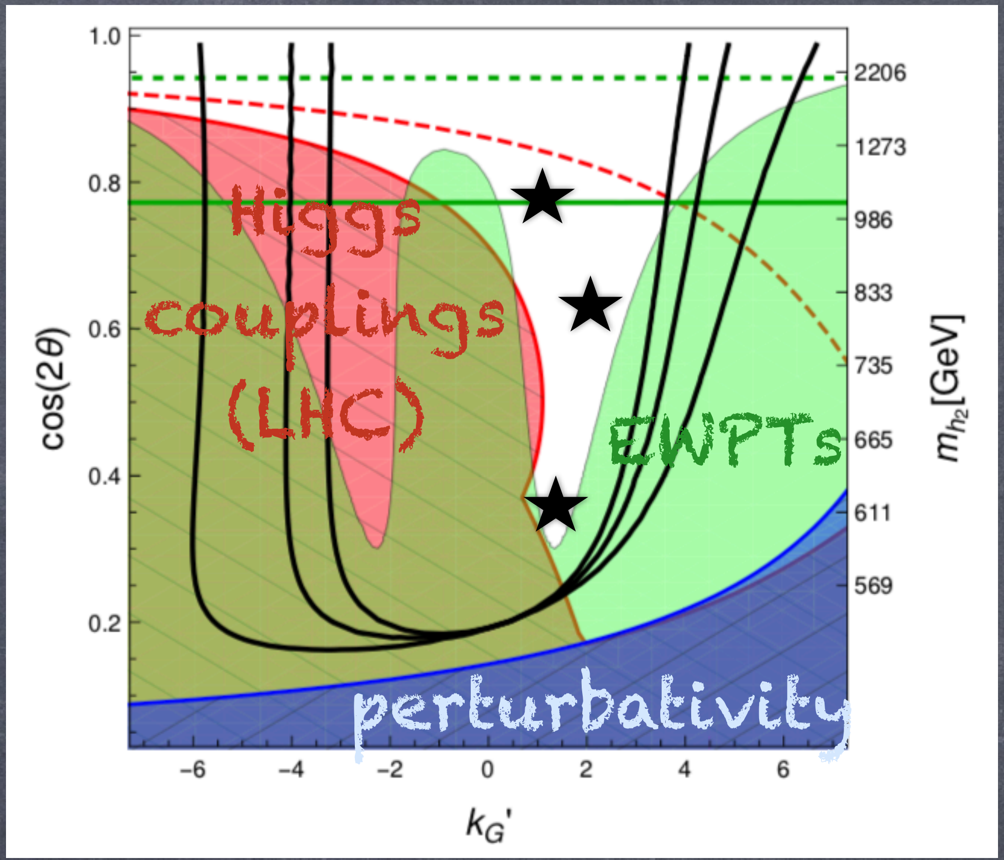
Up to 20% effect!

MCHM5-Higgs ->

Sigma-assisted models

1809.09146 w. D.Buarque Franzosi and A.Deandrea

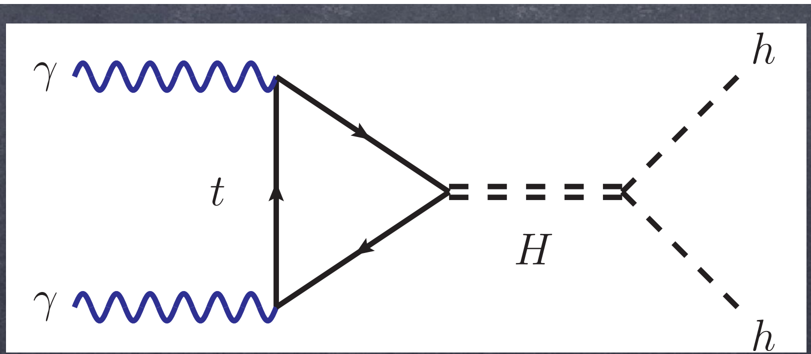
- A light-ish scalar can help with bounds
- Typically present in Lattice template models!
- We consider 3 benchmark points
- Note the large width of H

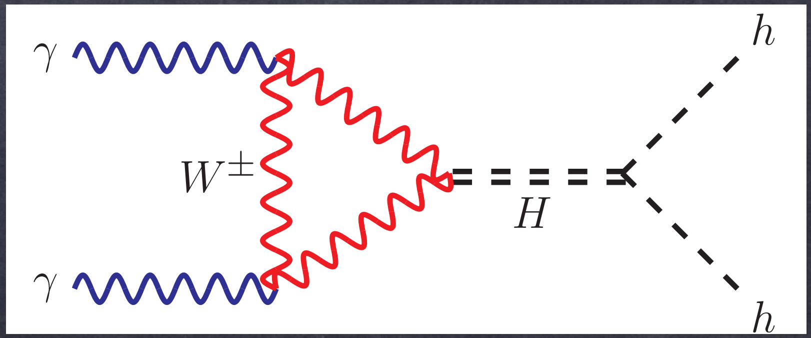


Benchmark 1	$m_H = 610$ GeV, $\xi = 0.306$, $\Gamma_H = 498$ GeV, $k'_G = 1.5$					
	c_f/c_f^H	c_{2f}	c_v/c_v^H	c_{2v}	c_{3h}	c_{Hhh}
h	0.9199	-0.7814	0.8791	0.5562	λ_h	$-$
H	3.507	...	0.3054	...	$-$	0.4149

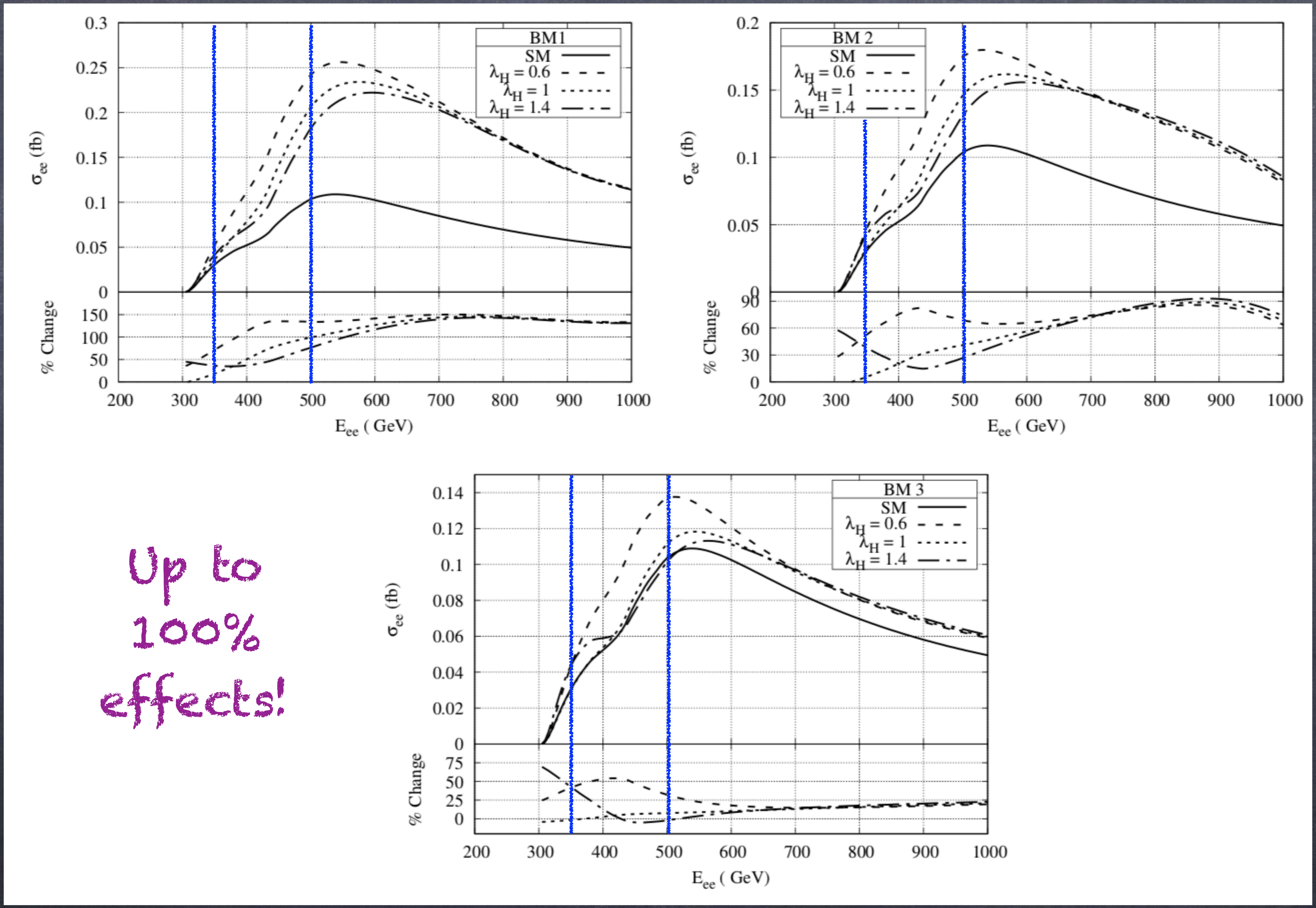
Benchmark 2	$m_H = 800$ GeV, $\xi = 0.197$, $\Gamma_H = 350$ GeV, $k'_G = 1.8$					
	c_f/c_f^H	c_{2f}	c_v/c_v^H	c_{2v}	c_{3h}	c_{Hhh}
h	0.9102	-0.4627	0.9305	0.7381	λ_h	$-$
H	2.368	...	0.3109	...	$-$	0.4001

Benchmark 3	$m_H = 1000$ GeV, $\xi = 0.0646$, $\Gamma_H = 47.6$ GeV, $k'_G = 1.$					
	c_f/c_f^H	c_{2f}	c_v/c_v^H	c_{2v}	c_{3h}	c_{Hhh}
h	0.9572	-0.1498	0.9741	0.9038	λ_h	$-$
H	0.6896	...	0.0511	...	$-$	0.1270



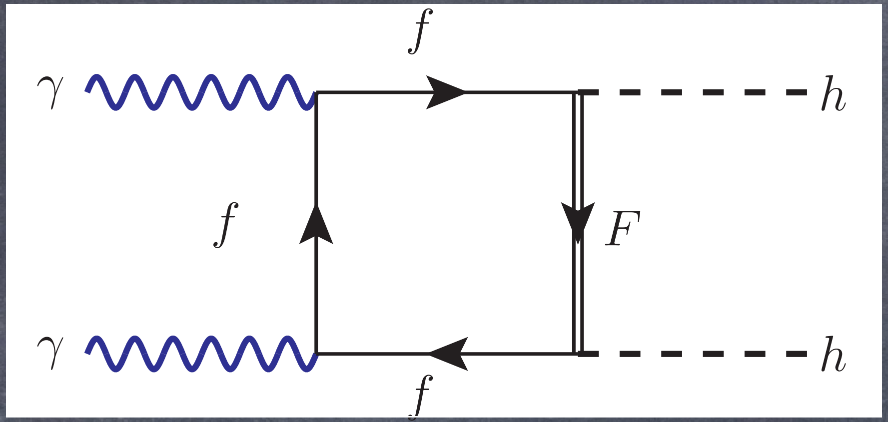


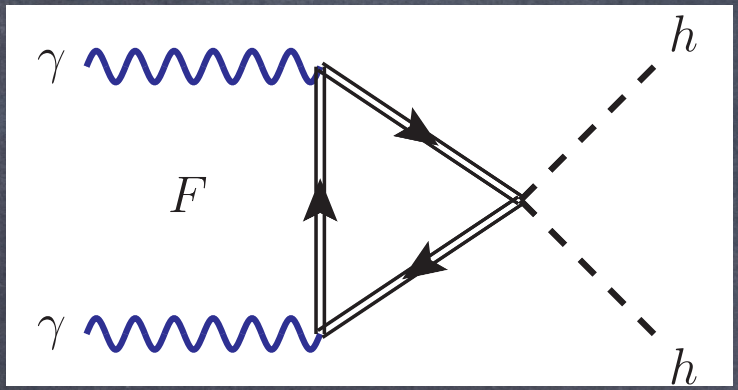
Sigma-assisted models

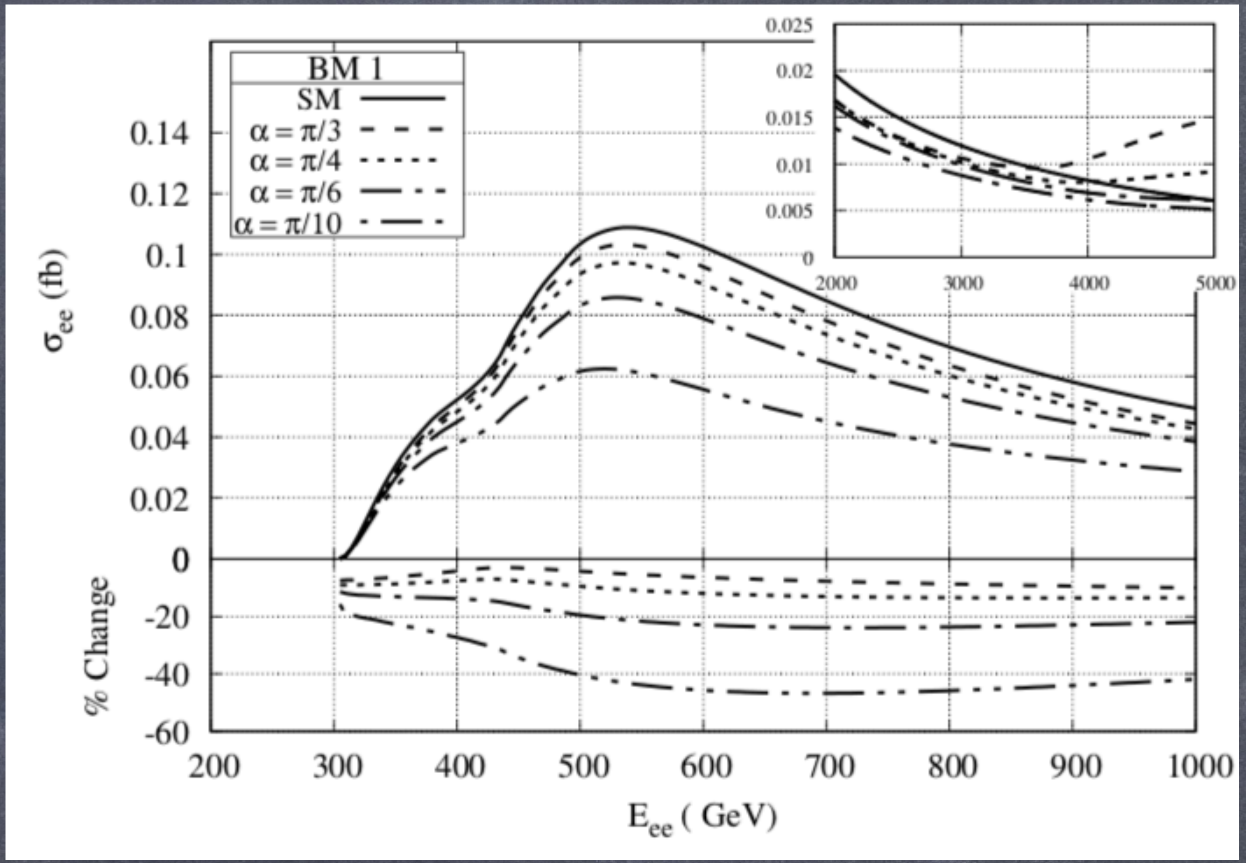


Up to 100% effects!

Top partners







- Large effects at high invariant mass (above threshold).
- Enhancement of the Higgs coupling modifications emerges at low energies.

Conclusions

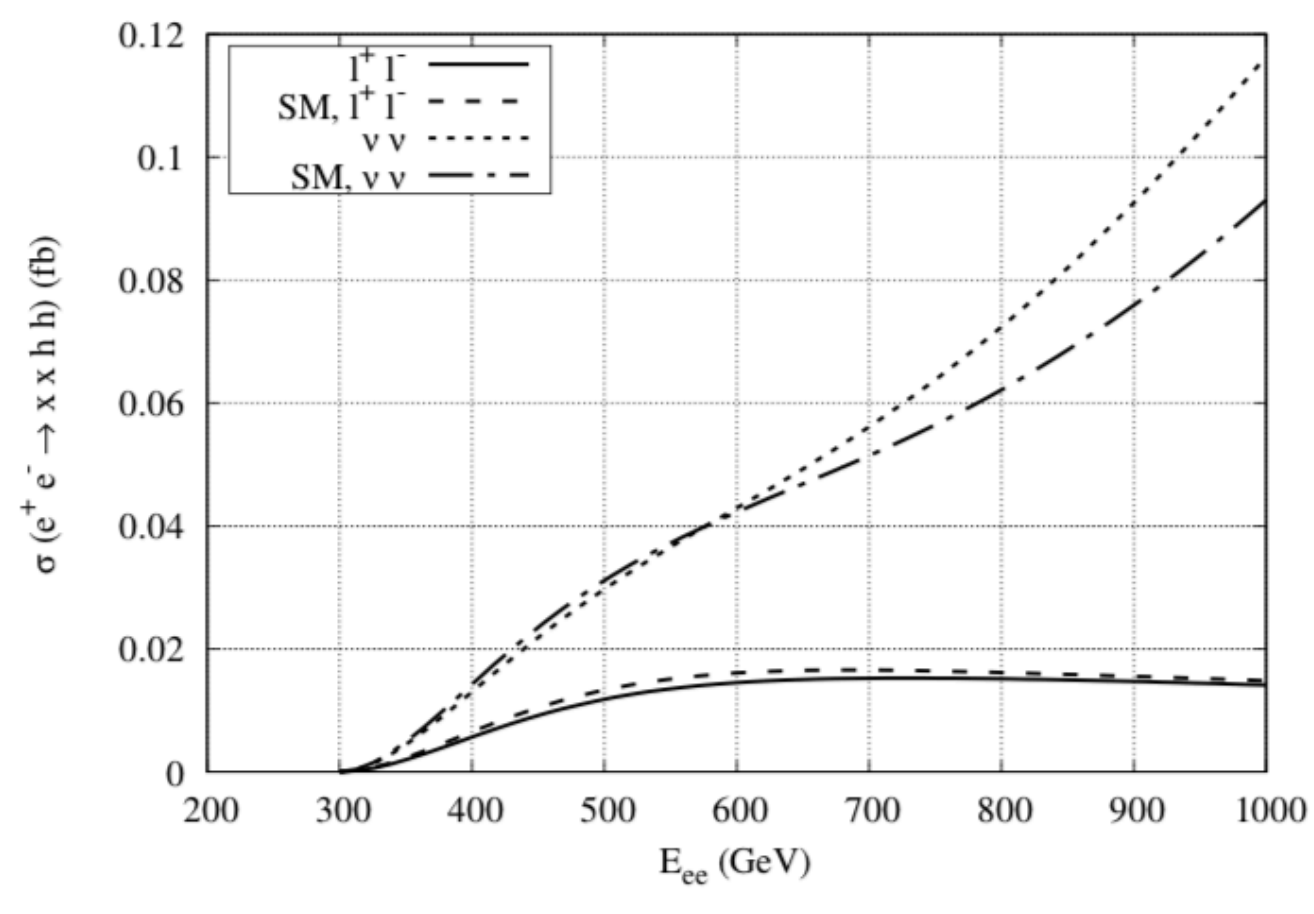
- Photon-fusion production of two Higgses probes most coupling modifications and new states in composite Higgs models.

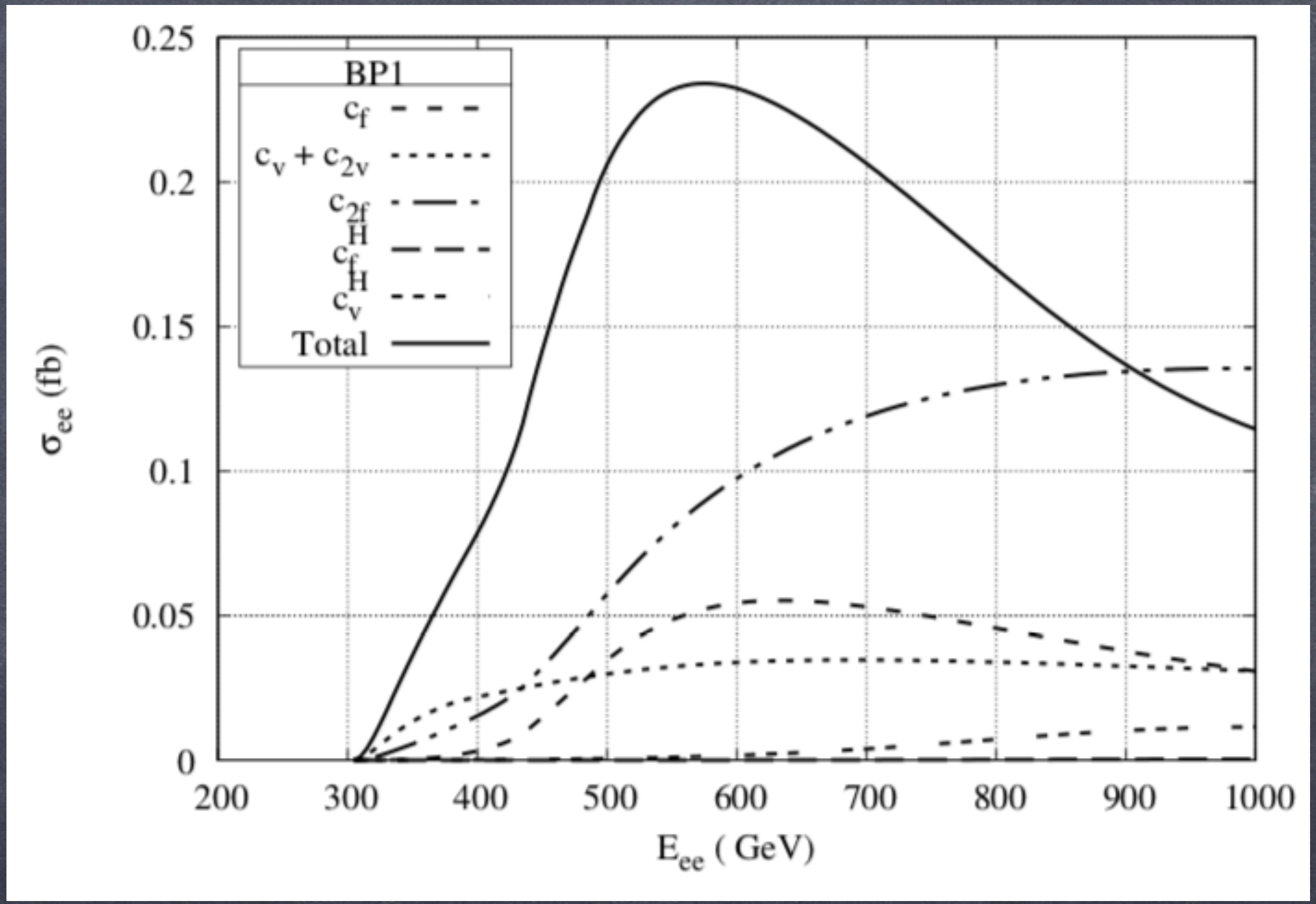
- e+e- colliders have a chance to probe these effects, complementary to other measurements (Higgs couplings, new resonances).

- Large effects are found for models with an additional light-ish composite scalar.

- To do: a detailed study of the signal (and its kinematics).

Bonus tracks





Bonus tracks

Benchmark 1	$M = 1500$ GeV, $\theta = 0.2$, $m_{\text{top}} = 173$ GeV							c_f^{eff}	
	M_T	c_f	c_{2f}	c_T	c_{2T}	c_{tT}	c_{Tt}	$c_f^{\text{eff},gg}$	$c_f^{\text{eff},\gamma\gamma}$
$\alpha_R = \pi/3$	1480	0.965	-0.0497	-0.212	-0.250	-0.603	-0.220	0.940	
$\alpha_R = \pi/4$	1496	0.945	-0.0596	-0.0427	-0.167	-1.034	-0.291	0.940	
$\alpha_R = \pi/6$	1525	0.906	-0.0685	0.293	-0.0923	-1.77	-0.347	0.939	
$\alpha_R = \pi/10$	1608	0.810	-0.0709	1.204	-0.0749	-3.123	-0.430	0.939	
Benchmark 2	$M = 1500$ GeV, $\theta = 0.2$, $m_{\text{top}} = 173$ GeV							c_f^{eff}	
	M_F	c_f	c_{2f}	c_F	c_{2F}	c_{fF}	c_{Ff}	$c_f^{\text{eff},gg}$	$c_f^{\text{eff},\gamma\gamma}$
$\alpha_L = \pi/3$	T: 1481	0.965	-0.0497	-0.212	-0.250	-0.220	-0.603	0.910	0.933
	B: 1478	0	0	-0.255	-0.250	-0.150	0		
$\alpha_L = \pi/4$	T: 1496	0.945	-0.0596	-0.0427	-0.167	-0.291	-1.034	0.920	0.935
	B: 1485	0	0	-0.169	-0.166	-0.173	0		
$\alpha_L = \pi/6$	T: 1525	0.906	-0.0685	0.293	-0.0923	-0.347	-1.77	0.929	0.937
	B: 1493	0	0	-0.0843	-0.0826	-0.149	0		
$\alpha_L = \pi/10$	T: 1608	0.810	-0.0709	1.204	-0.0749	-0.430	-3.123	0.936	0.939
	B: 1497	0	0	-0.0321	-0.0314	-0.101	0		
Control	MCHM5 with $\theta = 0.2$							c_f^{eff}	
	-	0.940	-0.158	-	-	-	-	0.940	