Study of the Internal Bremsstrahlung in the Inert Doublet Model

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Based on work in progress done in collaboration with Pr. Alejandro Ibarra

Outline

- Inert doublet model and dark matter
- Indirect searches and spectral features
- Benchmark points and effect of the model parameters on the internal Bremsstrahlung
- H.E.S.S. Upper limits
- Conclusions

The inert doublet model

Let $\eta = \begin{pmatrix} H^+ \\ \frac{1}{\sqrt{2}}(H + iA) \end{pmatrix}$ be an extra doublet, and Φ the SM doublet

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}_\eta \qquad \mathcal{L}_{\rm SM} \supset -\mu_1^2 \Phi^\dagger \Phi - \lambda_1 (\Phi^\dagger \Phi)^2$$

$$\mathcal{L}_\eta = (D_\mu \eta)^\dagger (D^\mu \eta) - \mu_2^2 \eta^\dagger \eta - \lambda_2 (\eta^\dagger \eta)^2 - \lambda_3 (\Phi^\dagger \Phi)(\eta^\dagger \eta)$$
$$-\lambda_4 (\Phi^\dagger \eta)(\eta^\dagger \Phi) - \frac{1}{2}\left(\lambda_5 (\Phi^\dagger \eta)(\Phi^\dagger \eta) + \text{h.c.}\right) .$$

← Invariant under $\eta \to -\eta \quad \Phi \to \Phi$

$(Z_2\ symmetry)$

Electroweak symmetry breaking

$$\langle \Phi \rangle = \begin{pmatrix} 0 \\ \frac{v}{\sqrt{2}} \end{pmatrix} , \qquad \langle \eta \rangle = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

← Z_2 is not spontaneously broken

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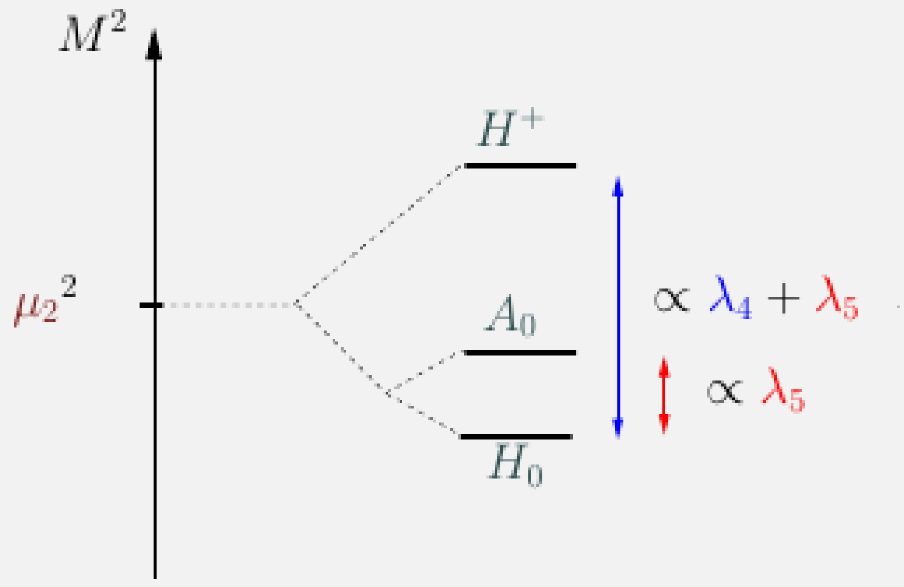
If the lightest particle that is charged under Z_2 is neutral : we have a **dark matter** candidate!!!

$$m_\chi{}^2 = \mu_2^2 + \lambda_\chi v^2$$



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$$\lambda_{H_0,A_0} \equiv (\lambda_3 + \lambda_4 \pm \lambda_5)/2$$

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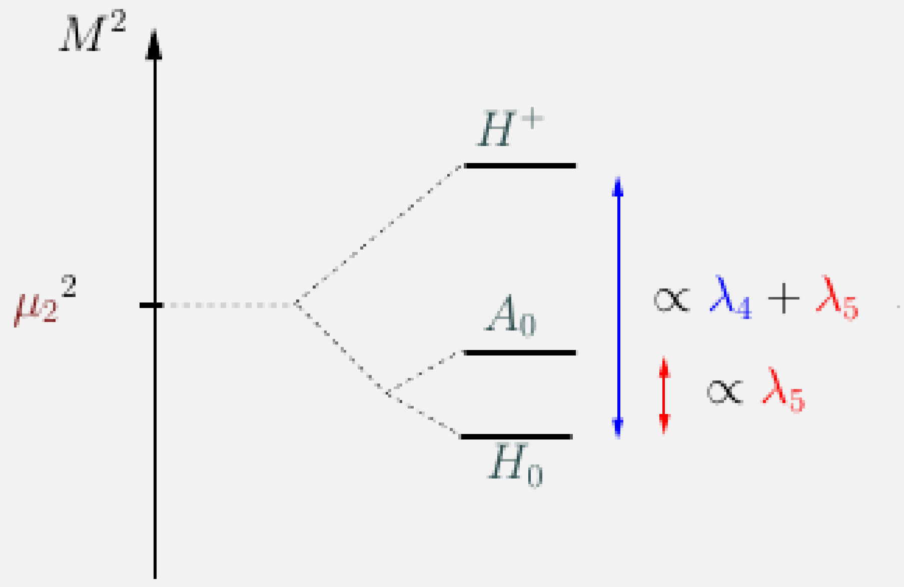

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For a heavy dark matter candidate $(M_{H^0} \gg M_W)$ the splitting is relatively small and we expect the particles belonging to the extra doublet to have nearly degenerate masses .

Dark Matter Abundance

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$m_{H_0} \lesssim m_W$: GeV range

$H_0 H_0 \to h^* \to \bar{f}f$ and $H_0 A_0 \to Z^* \to \bar{f}f$

Barbieri PRD06, LLH JCAP06,Gustafsson PRL07, Cao PRD07, Andreas JCAP08,...

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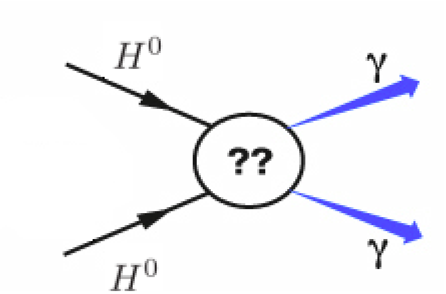
Indirect Searches



No astrophysical uncertainties

"Smoking gun"

Potentially low statistics.

Gustaffson et al. 2007

Indirect Searches

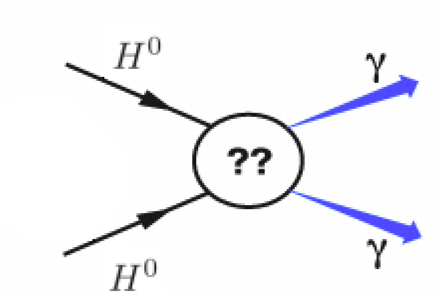


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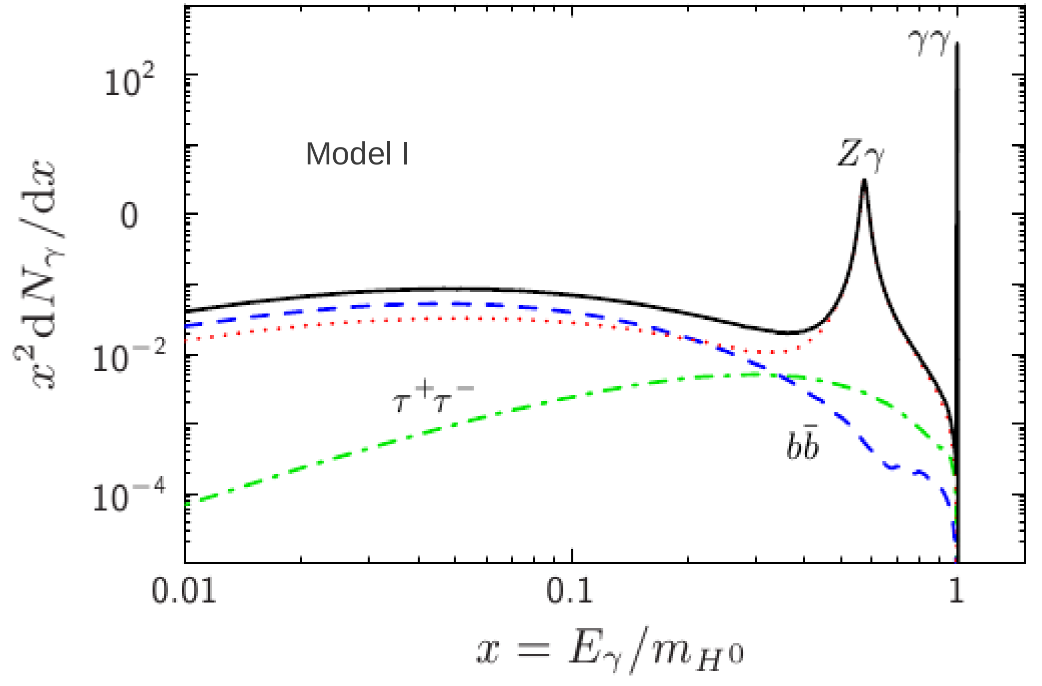
TABLE I: *IDM benchmark models. (In units of GeV.)*

Model	m_h	m_{H^0}	m_{A^0}	$m_{H^\pm}$	μ_2	$\lambda_2 \times 1$ GeV
I	500	70	76	190	120	0.1
II	500	50	58.5	170	120	0.1
III	200	70	80	120	125	0.1
IV	120	70	80	120	95	0.1

TABLE II: *IDM benchmark model results.*

Model	$v\sigma_{tot}^{v\to 0}$	Branching ratios [%]:					$\Omega_{\rm CDM}h^2$
	[cm^{3}s^{-1}]	$\gamma\gamma$	$Z\gamma$	$b\bar{b}$	$c\bar{c}$	$\tau^+\tau^-$	
I	1.6×10^{-28}	36	33	26	2	3	0.10
II	8.2×10^{-29}	29	0.6	60	4	7	0.10
III	8.7×10^{-27}	2	2	81	5	9	0.12
IV	1.9×10^{-26}	0.04	0.1	85	5	10	0.11



Gustaffson et al. 2007

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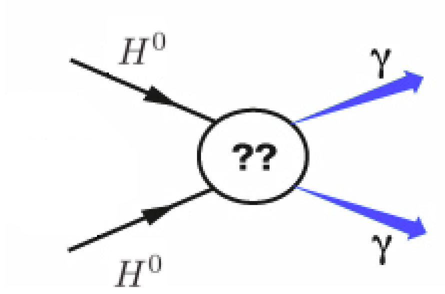

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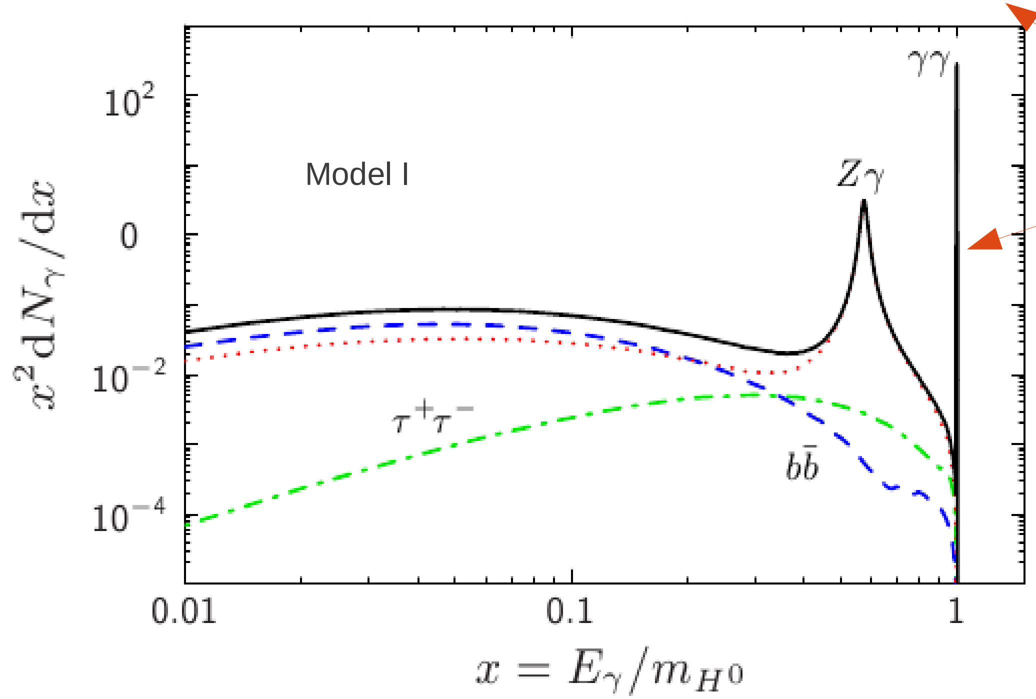

Very prominent spectral features, but very small cross sections (loop suppressed)

Gustaffson et al. 2007

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In general, one can single out two situations where photons emitted from virtual charged particles may give an even more important contribution to the total IB spectrum than FSR: i) the three-body final state $X\bar{X}\gamma$ satisfies a symmetry of the initial state that cannot be satisfied by the two-body final state $X\bar{X}$ or ii) X is a boson and the annihilation into $X\bar{X}$ is dominated by t-channel diagrams.

T. Bringmann et al. 2008

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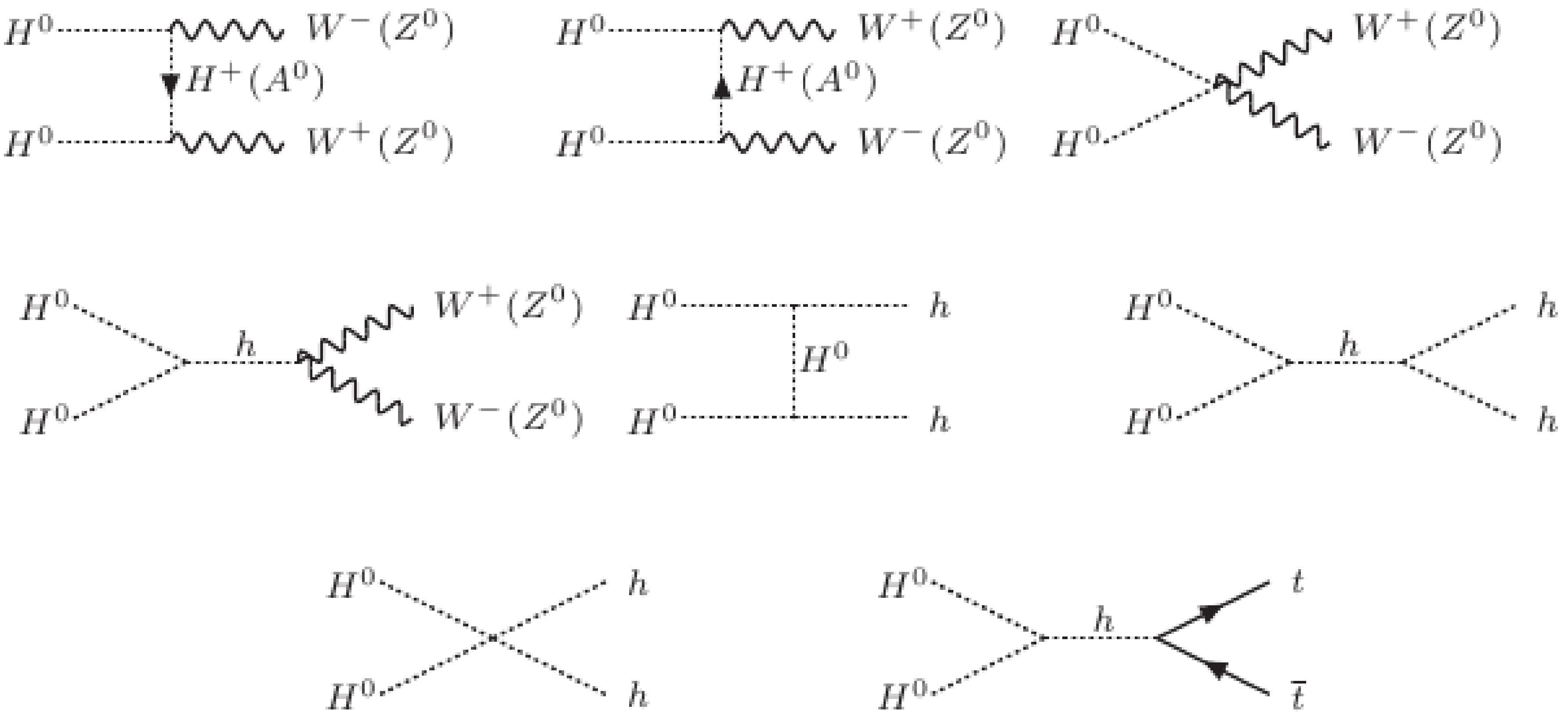
That is the case for the inert doublet model in the high mass regime if X is a W boson!

Annihilation diagrams



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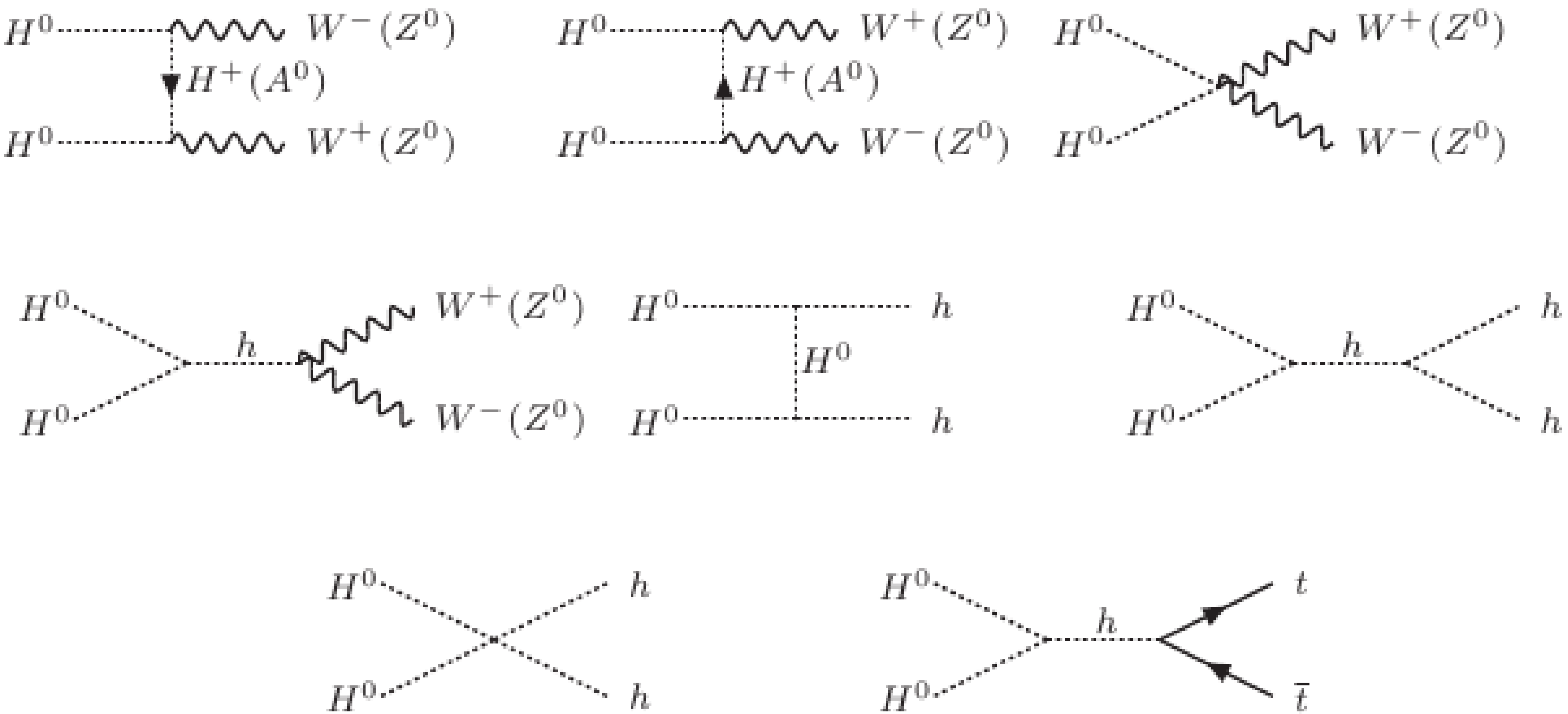
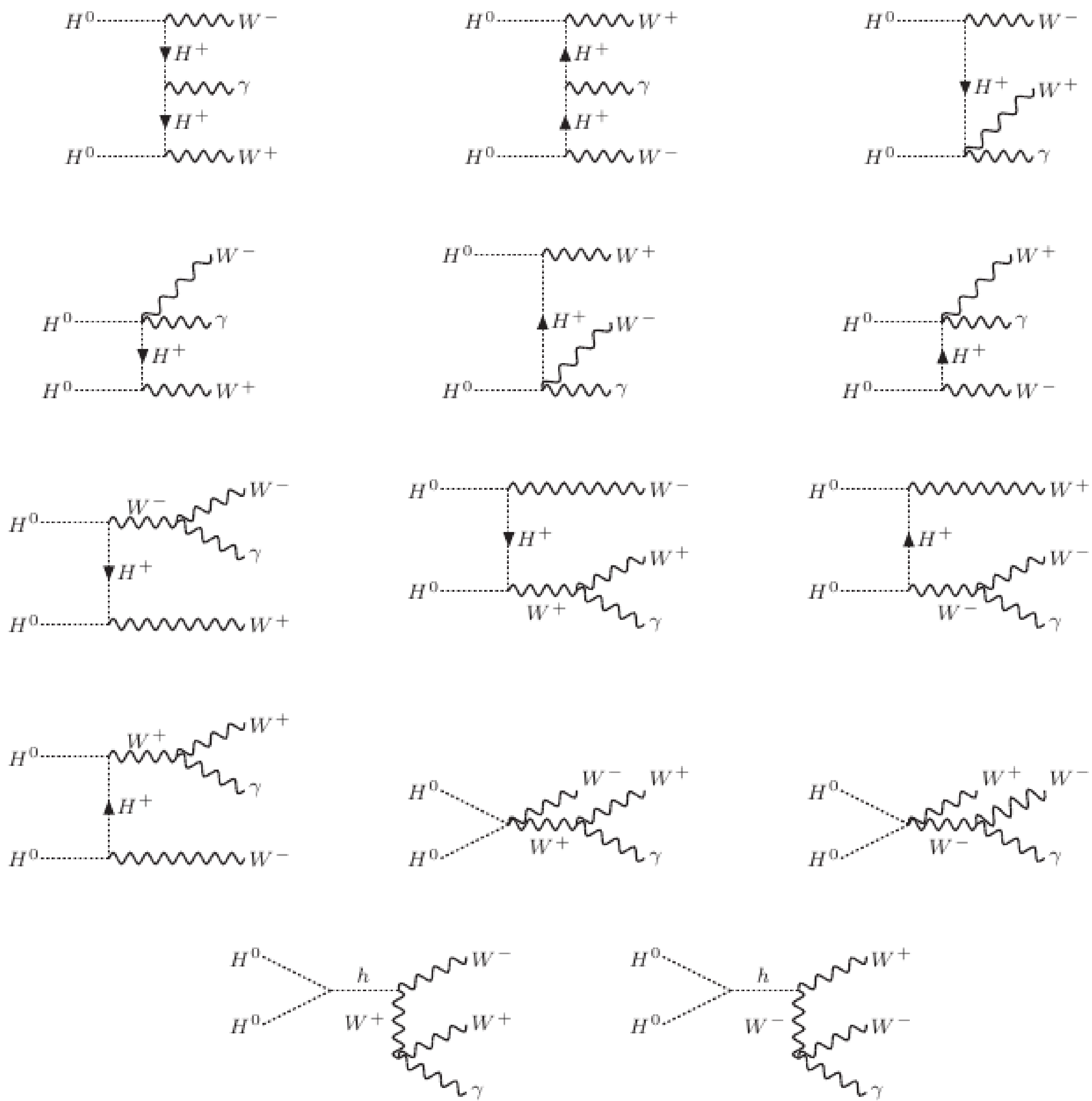


Why the t-channel?

$$D_t(p_W) \propto \left((p_{H^0} - p_W)^2 - M_{H^+}^2\right)^{-1}$$
$$\approx \left(M_{H^0}^2 + M_W^2 - M_{H^+}^2 - 2M_{H^0}E_W\right)^{-1}$$

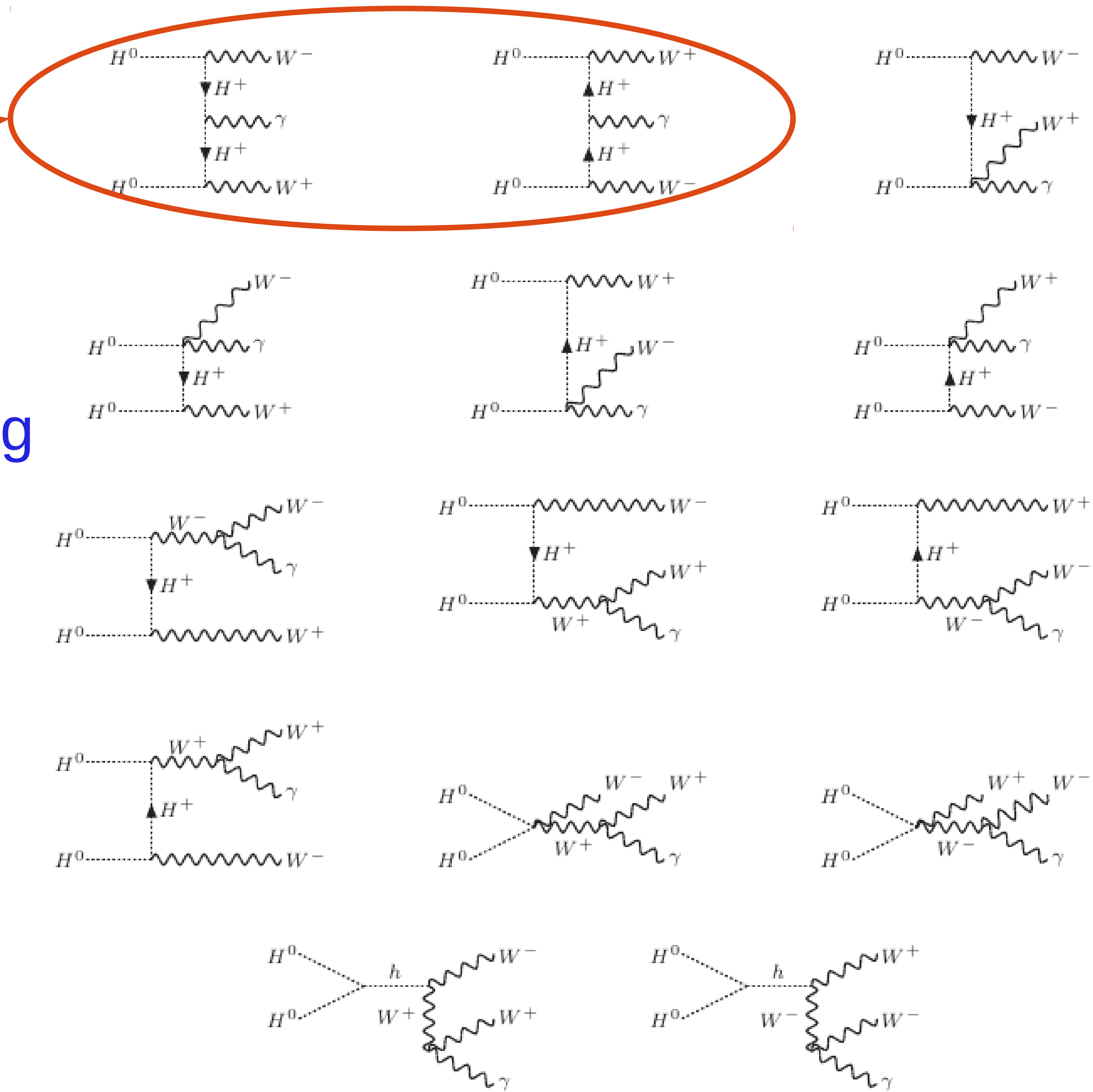
If H^0 and H^+ are almost degenerate in mass, one thus finds an enhancement for small E_W.

Bremsstrahlung diagrams



Photons emitted from internal lines

Bremsstrahlung diagrams



Photons emitted from internal lines

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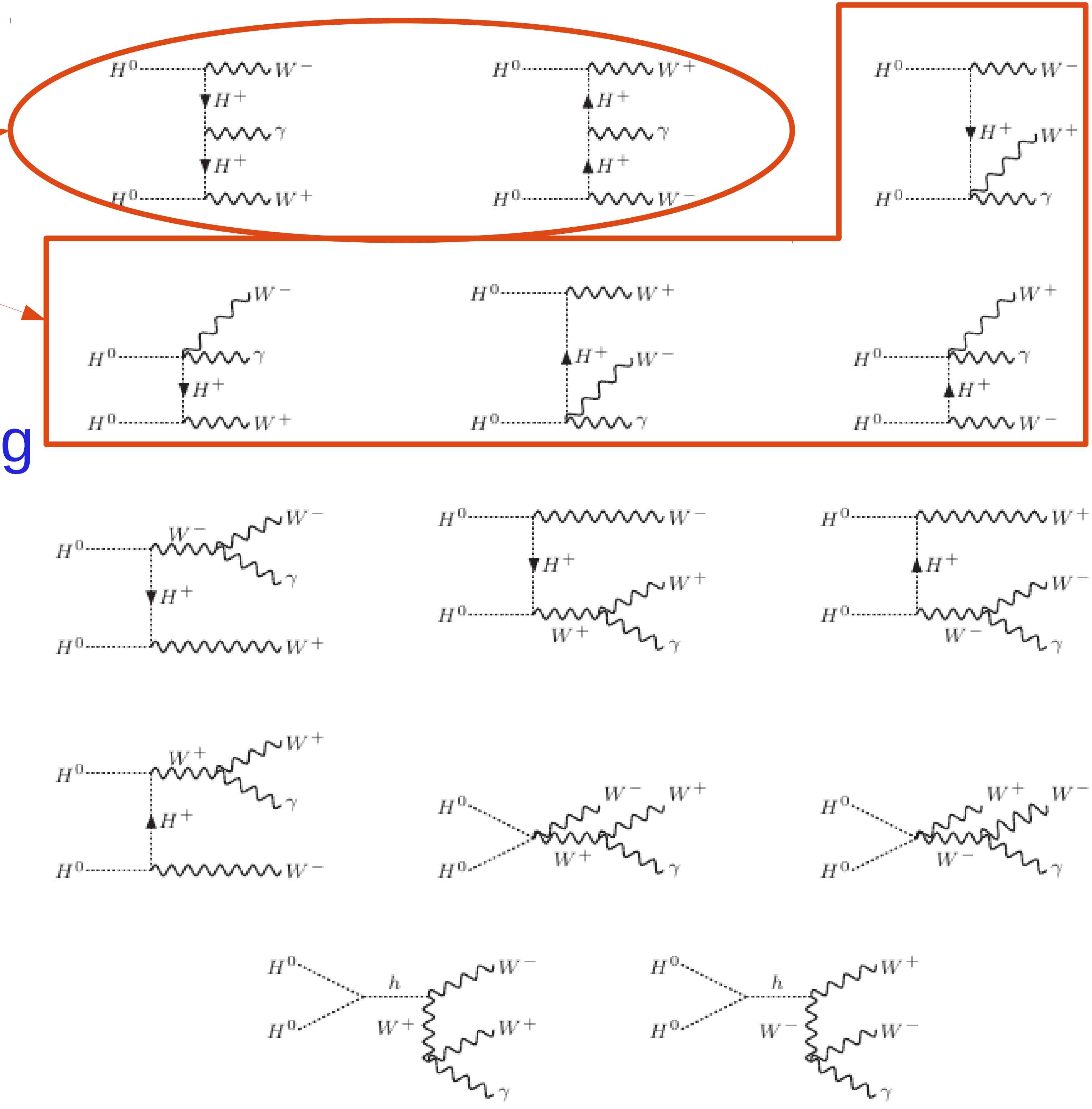
Bremsstrahlung diagrams



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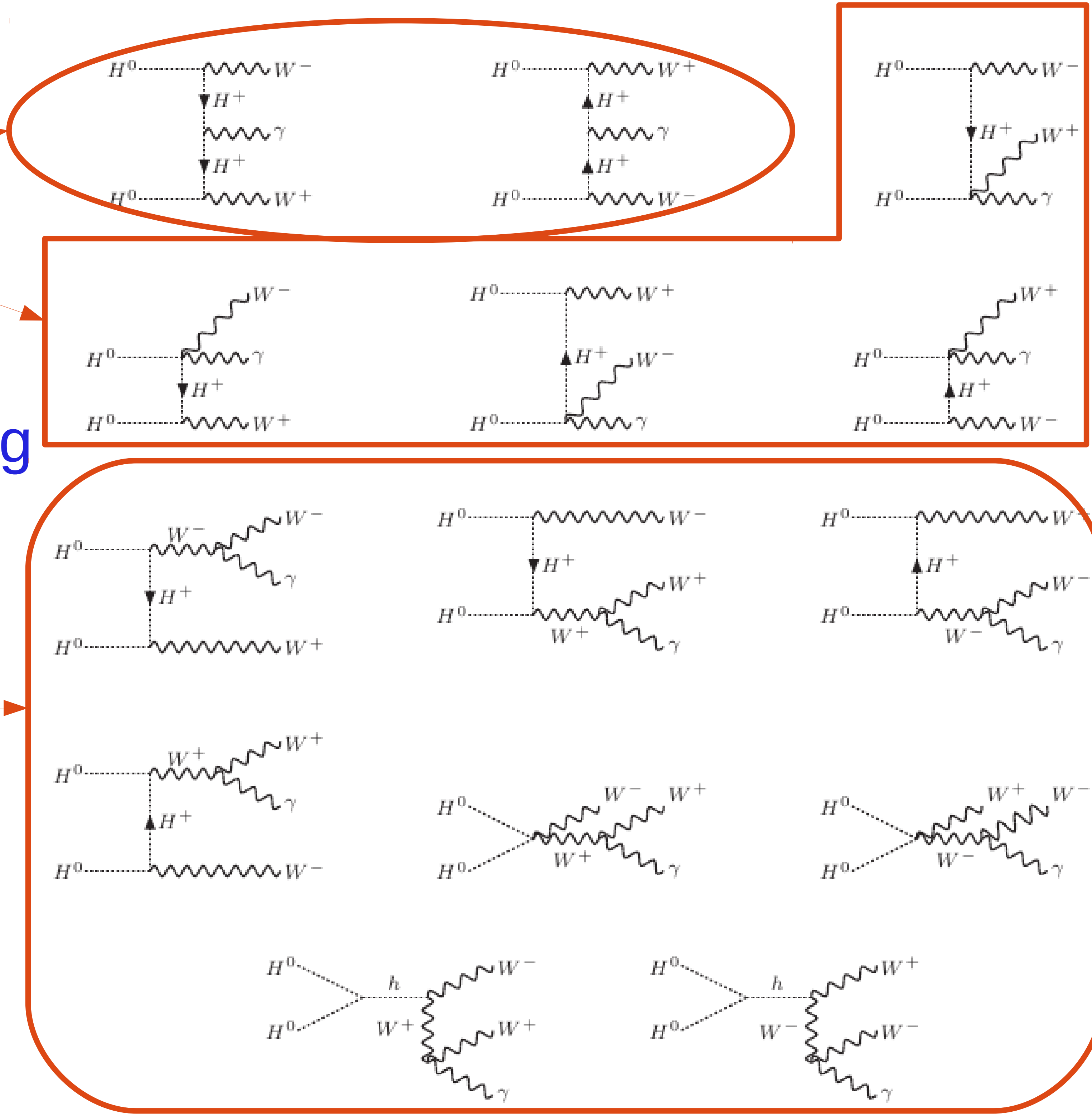
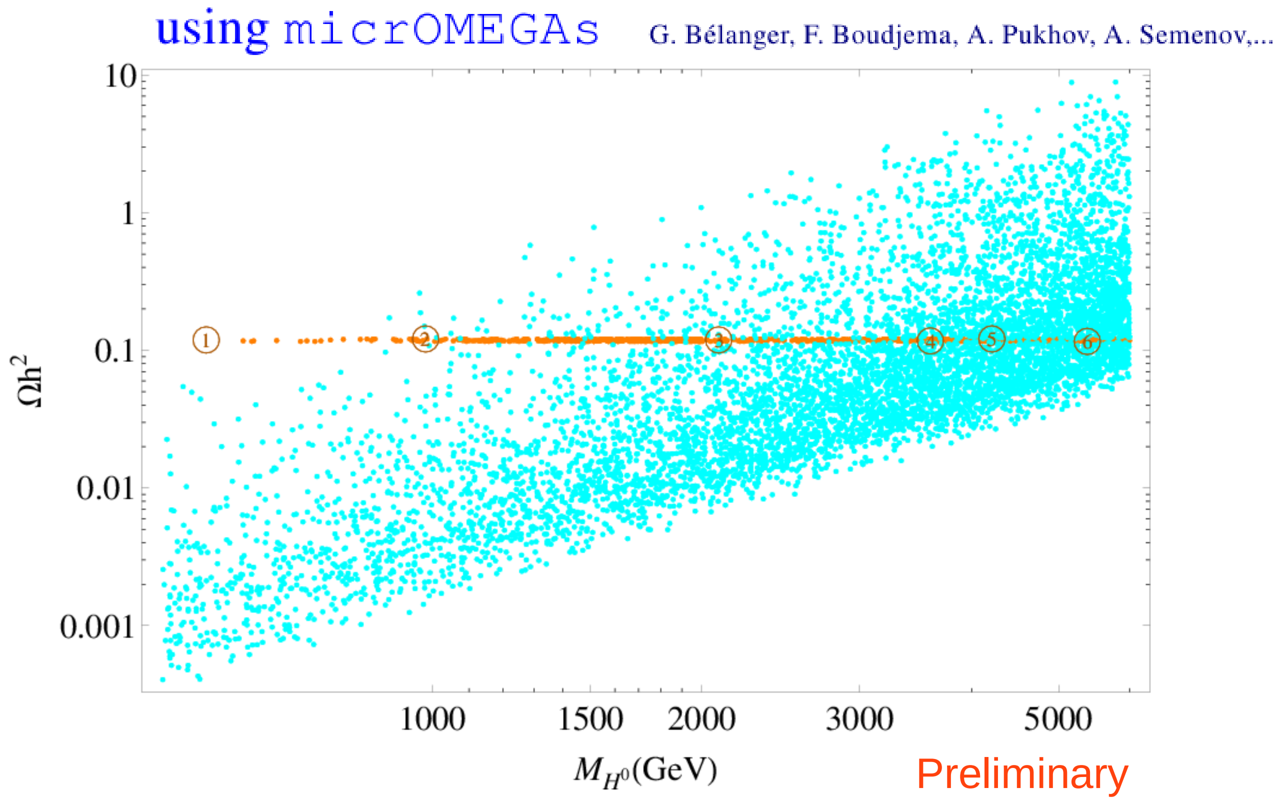
Photons emitted from vertices

Photons emitted from external lines

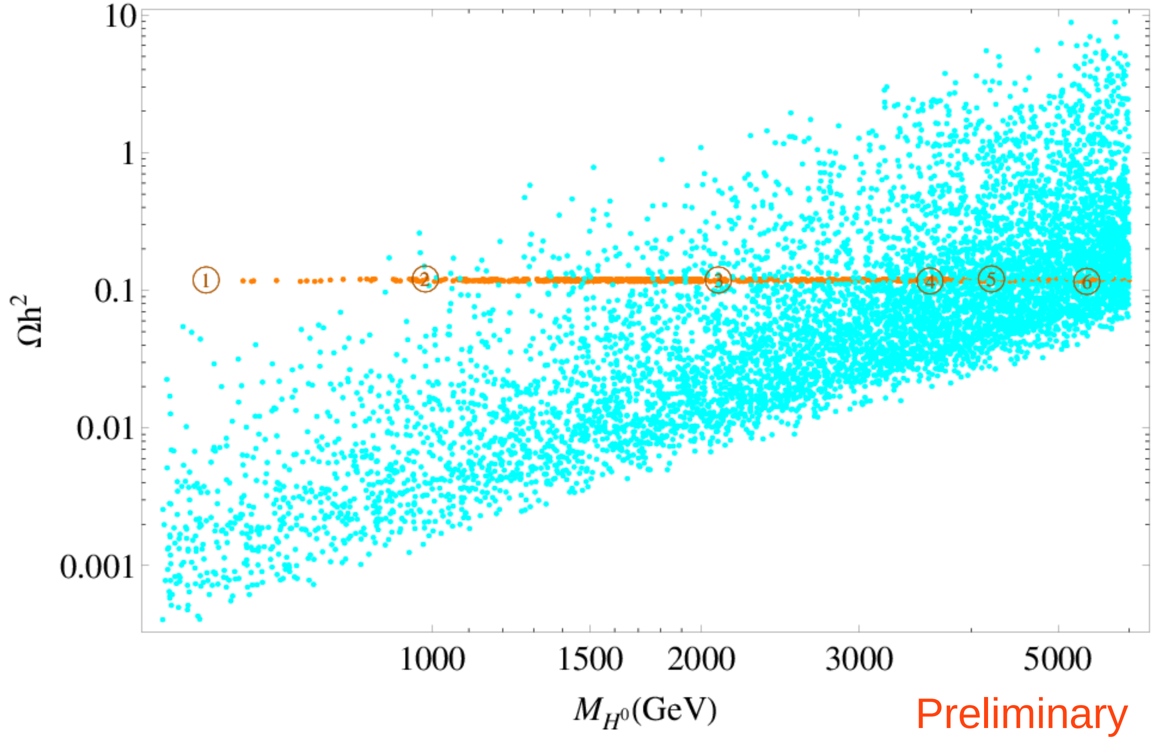


Benchmark points



BMP	M_{H^0}(GeV)	M_{H^+}(GeV)	M_{A^0}(GeV)	λ_3	λ_4	λ_5	λ_{H^0}	λ_{A^0}
1	559.99	561.85	560.67	-0.02	-0.06	-0.01	-0.05	-0.03
2	983.75	993.60	991.79	0.17	-0.38	-0.26	-0.23	0.03
3	2088.3	2090.99	2100.26	0.39	0.46	-0.83	0.01	0.83
4	3596.67	3597.99	3609.7	-0.07	1.24	-1.55	-0.19	1.36
5	4212.49	4213.09	4225.29	-0.58	1.61	-1.78	-0.37	1.41
6	5382.08	5382.21	5392.59	1.08	1.82	-1.87	0.51	2.38

using micrOMEGAs G. Bélanger, F. Boudjema, A. Pukhov, A. Semenov,...



Preliminary

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		W^+W^-	ZZ	hh	$t\bar{t}$	$W^+W^-\gamma$	
1	6.42	50.25	43.54	2.57	0.60	3.03	0.119
2	3.95	34.91	22.87	36.02	3.03	3.17	0.121
3	4.58	13.80	84.35	0.01	0.00	1.84	0.119
4	3.52	2.36	95.29	1.83	0.01	0.51	0.117
5	3.14	8.75	83.82	5.80	0.03	1.60	0.121
6	5.38	9.29	84.92	3.92	0.01	1.86	0.116

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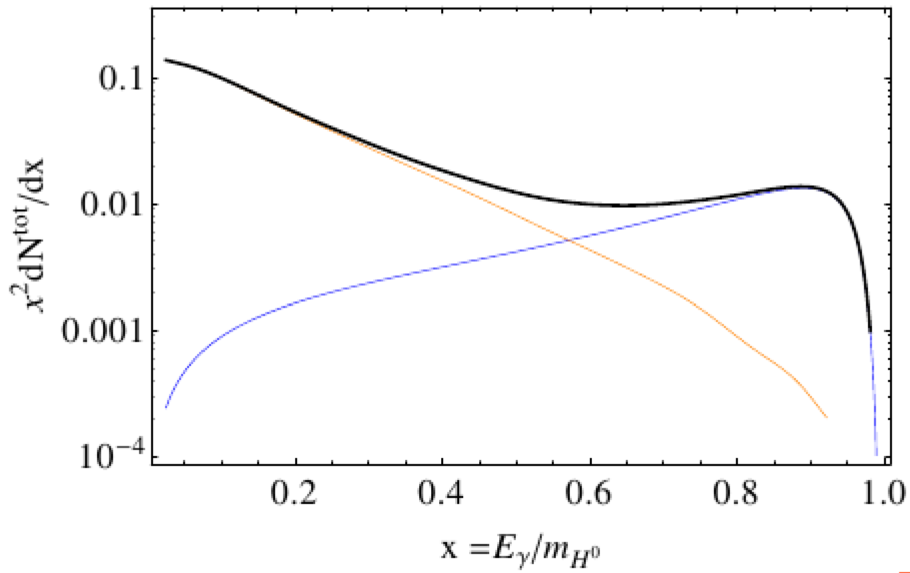
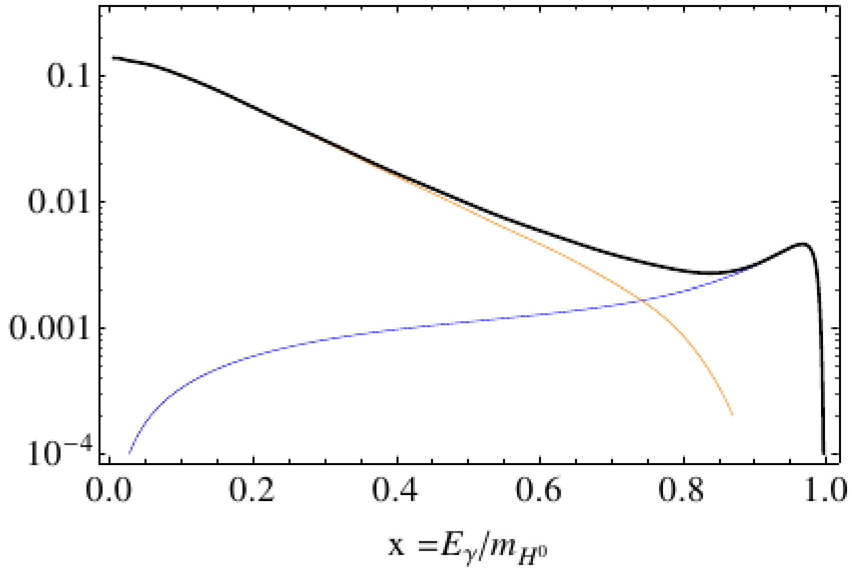
BMP 2



BMP 5



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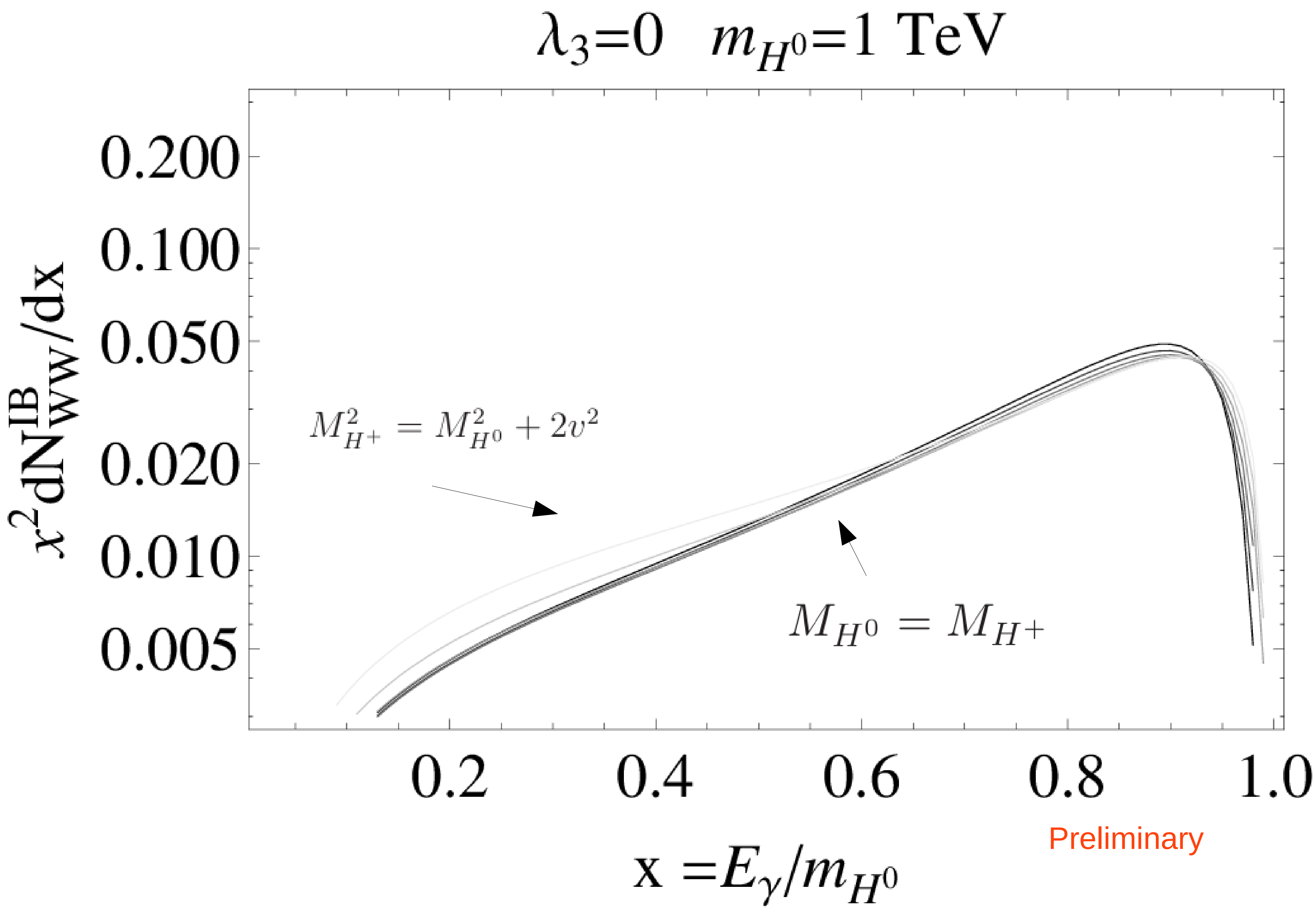
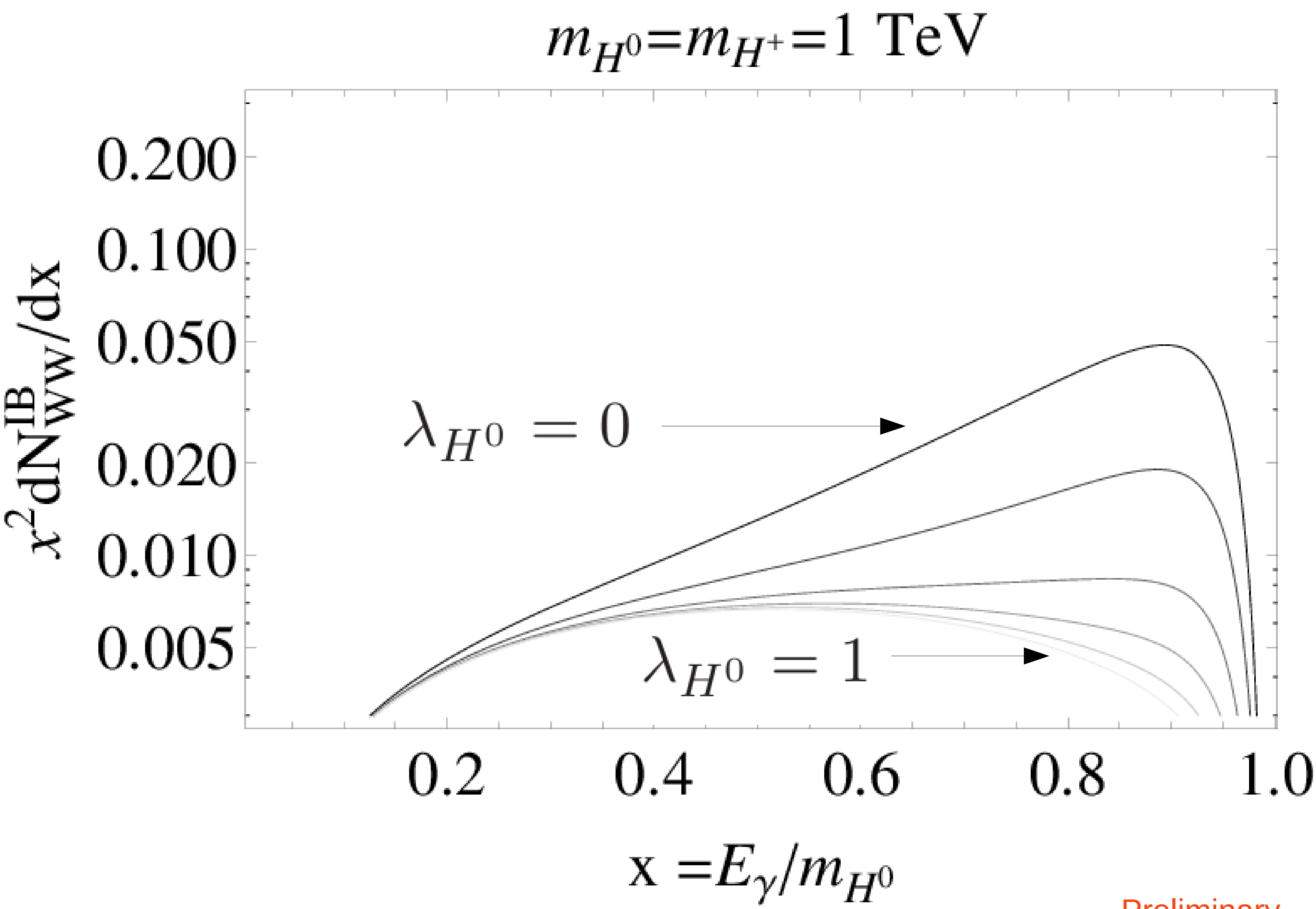
Effect of the mass splitting ($\lambda_4 + \lambda_5$)



Effect of λ_{H^0}



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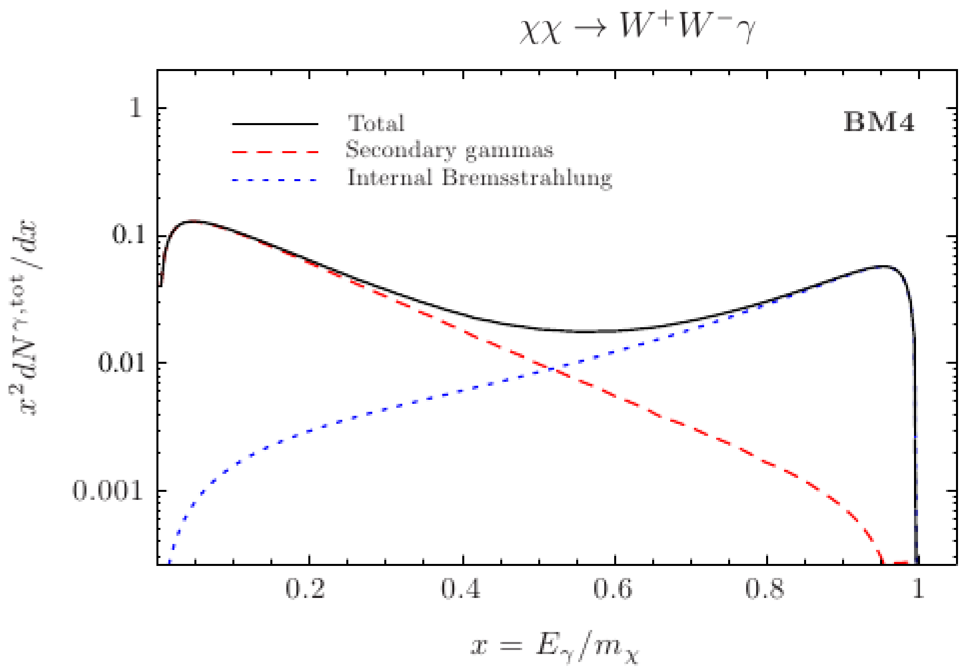
H.E.S.S. searches for photon-like signatures



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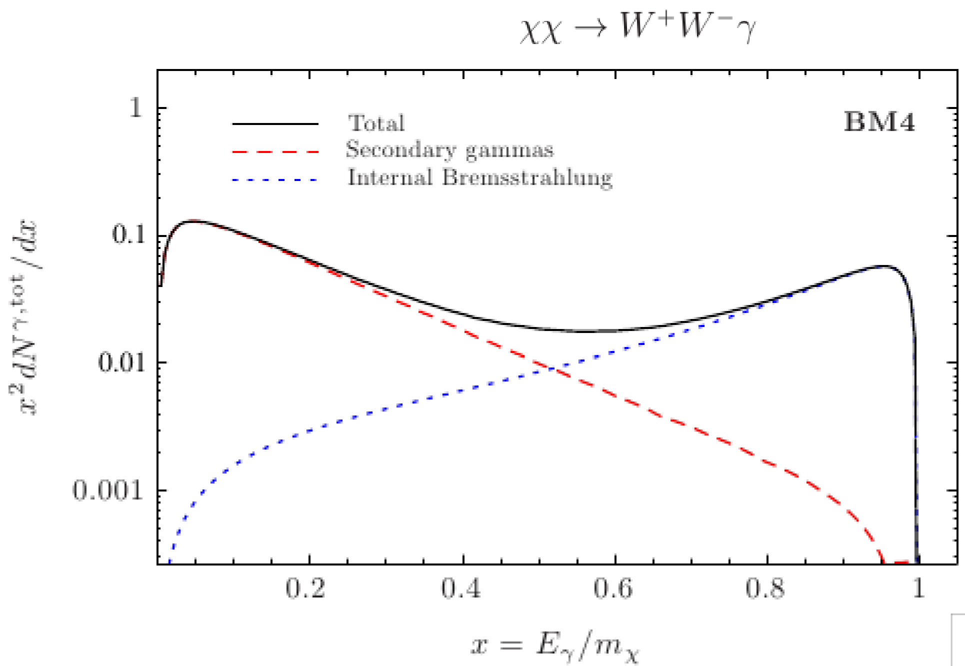

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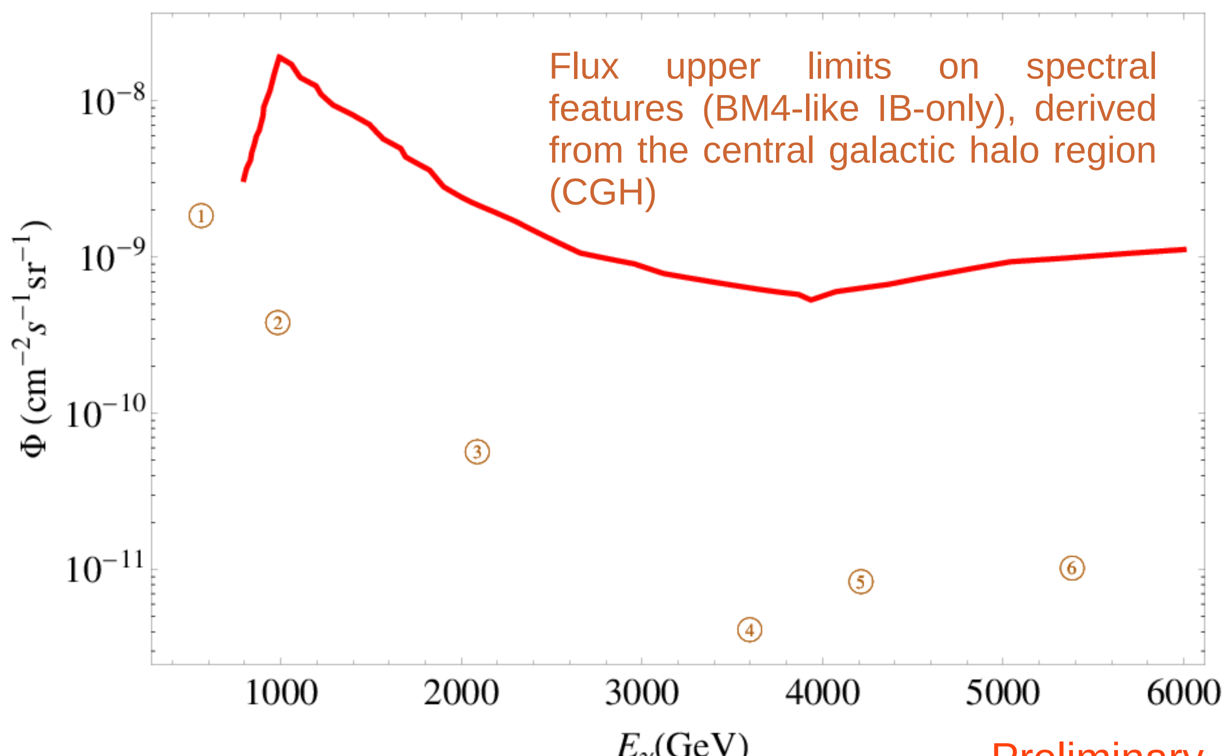
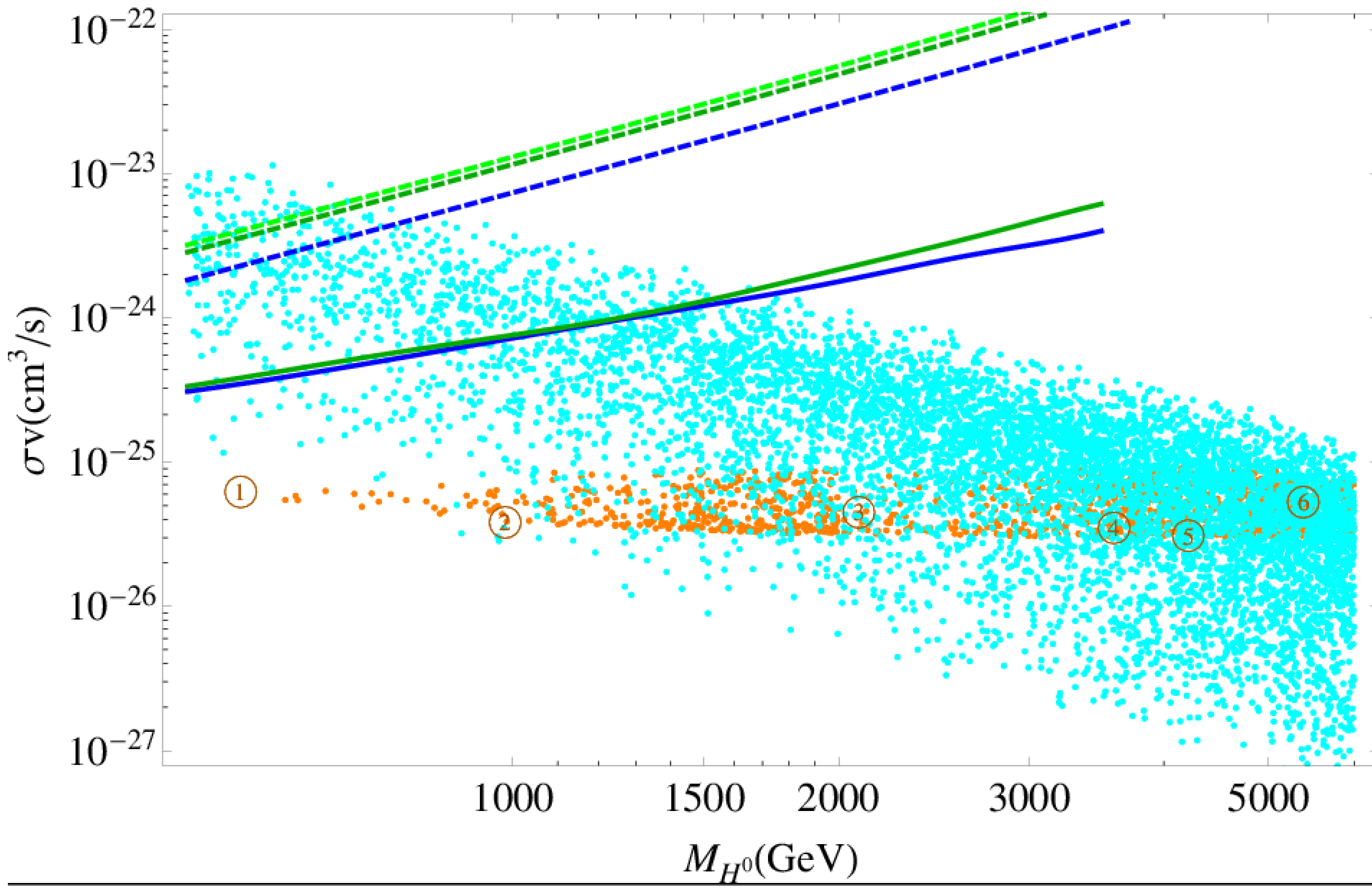


Conclusions

- Internal Bremsstrahlung signatures are present in the high-mass regime of the inert doublet model.
- In the case of small quartic couplings the feature is more prominent.
- In the high mass regime of the inert doublet model, the internal bremsstrahlung can lead to observable signatures in gamma-ray telescopes



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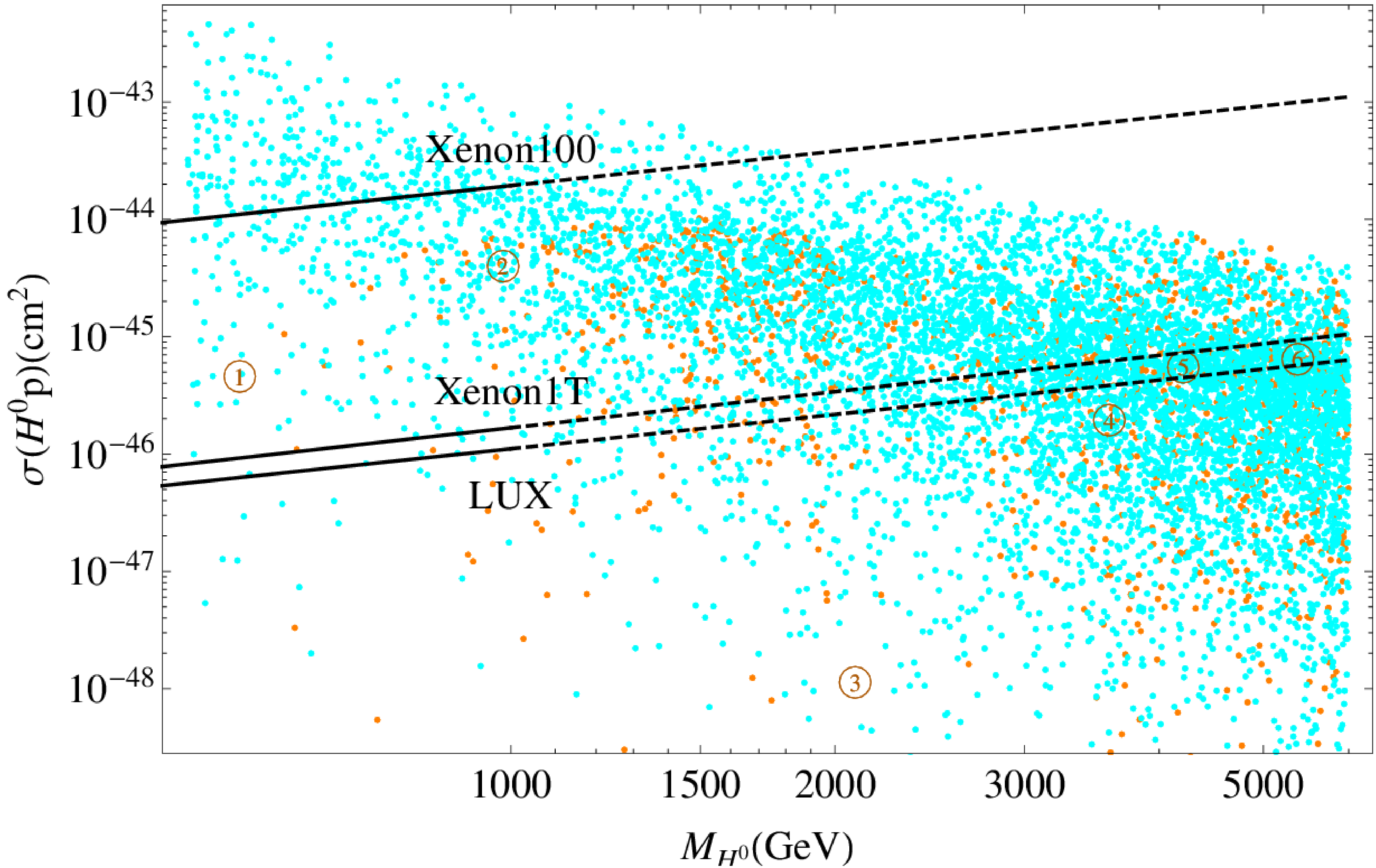

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