Study of the Internal Bremsstrahlung in the Inert Doublet Model

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Based on work in progress done under the advice of 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

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

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

Invariant under

$\eta \to -\eta \qquad \Phi \to \Phi$

$(Z_2\ symmetry)$

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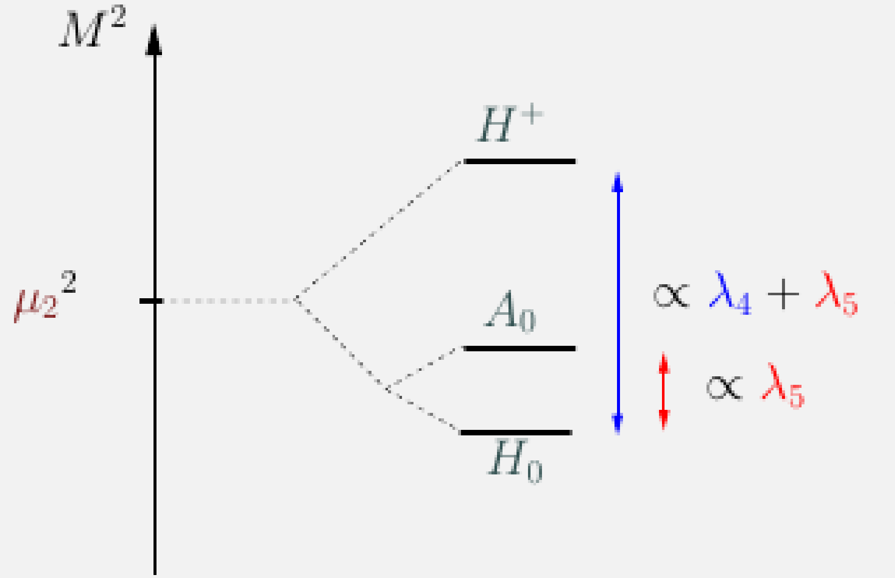
If the lightest particle that is charged under Z_2 is neutral : we have a **dark matter** candidate!!!

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



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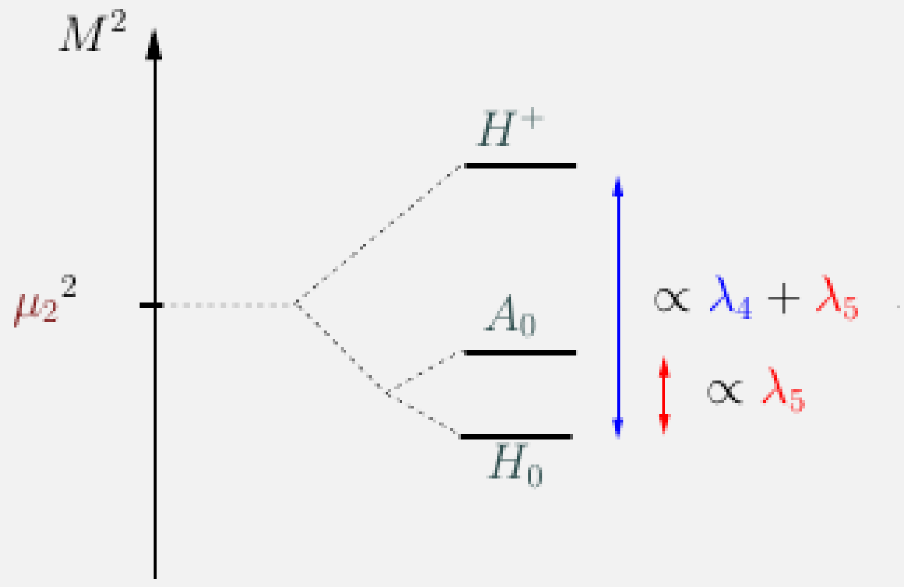

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For a heavy dark matter candidate $(M_{H^0} \gg M_W)$ the splitting is relatively small and we expect the particles belonging to the extra doublet to have nearly degenerate masses .

Dark Matter Abundance

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

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

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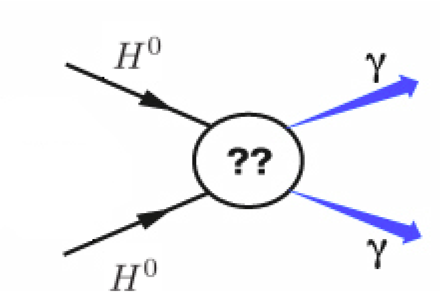
Indirect Searches



No astrophysical uncertainties

"Smoking gun"

Potentially low statistics.

Gustaffson et al. 2007

Indirect Searches

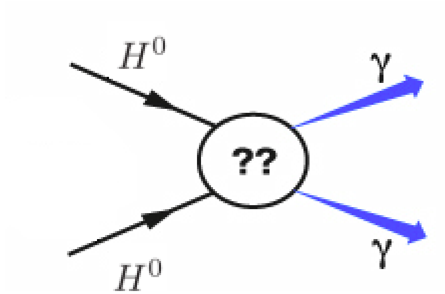


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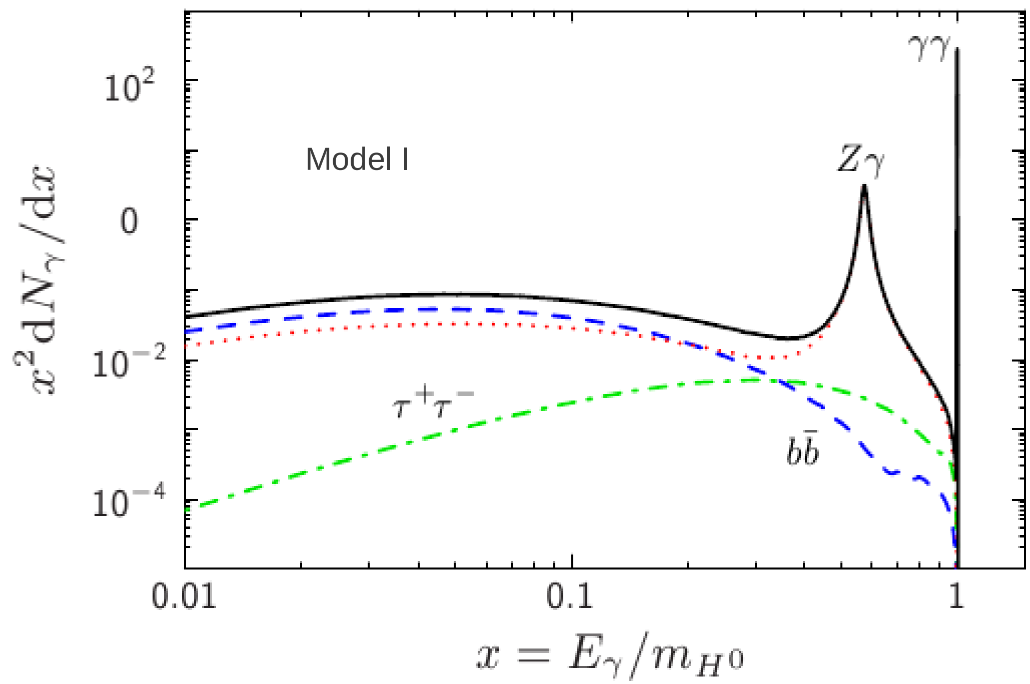
TABLE I: *IDM benchmark models. (In units of GeV.)*

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



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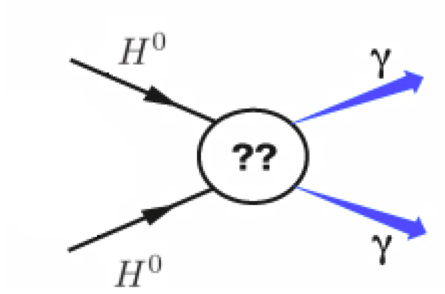

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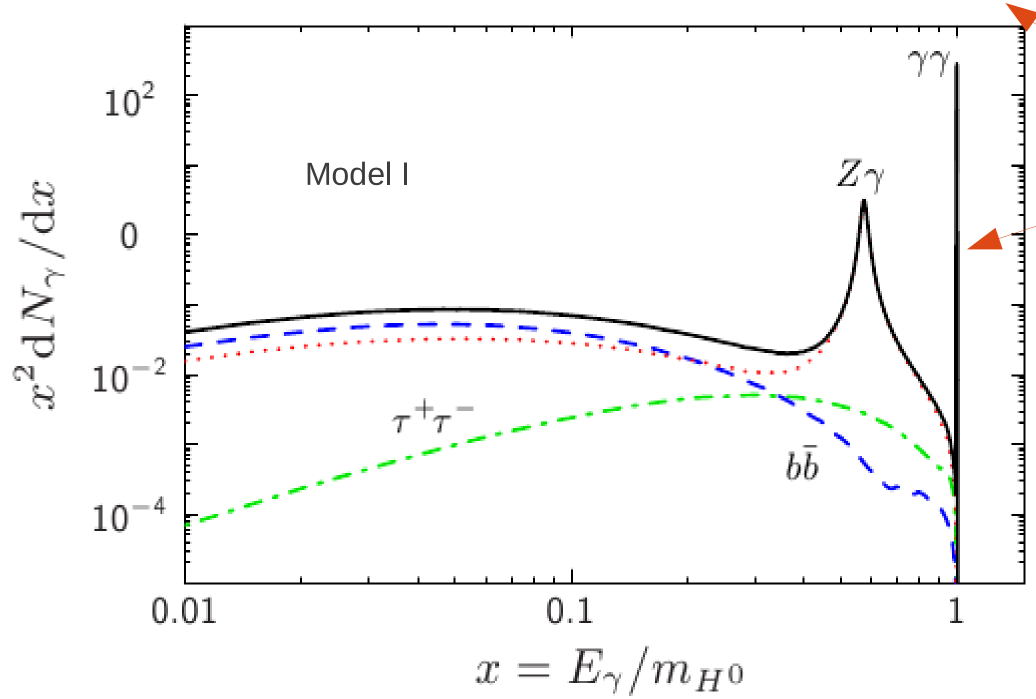

Very prominent spectral features, but very small cross sections (loop suppressed)

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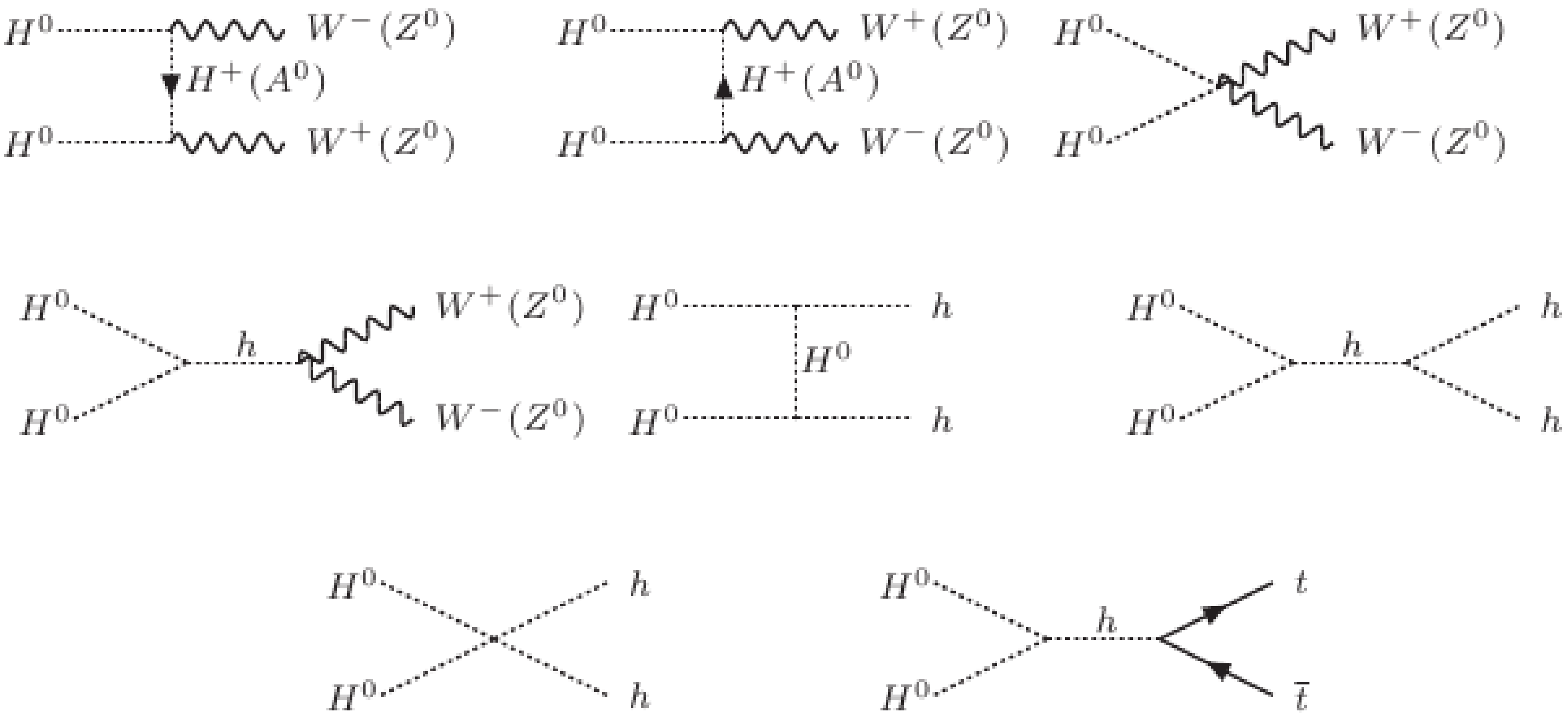
That is the case for the inert doublet model in the high mass regime if X is a W boson!

Annihilation diagrams



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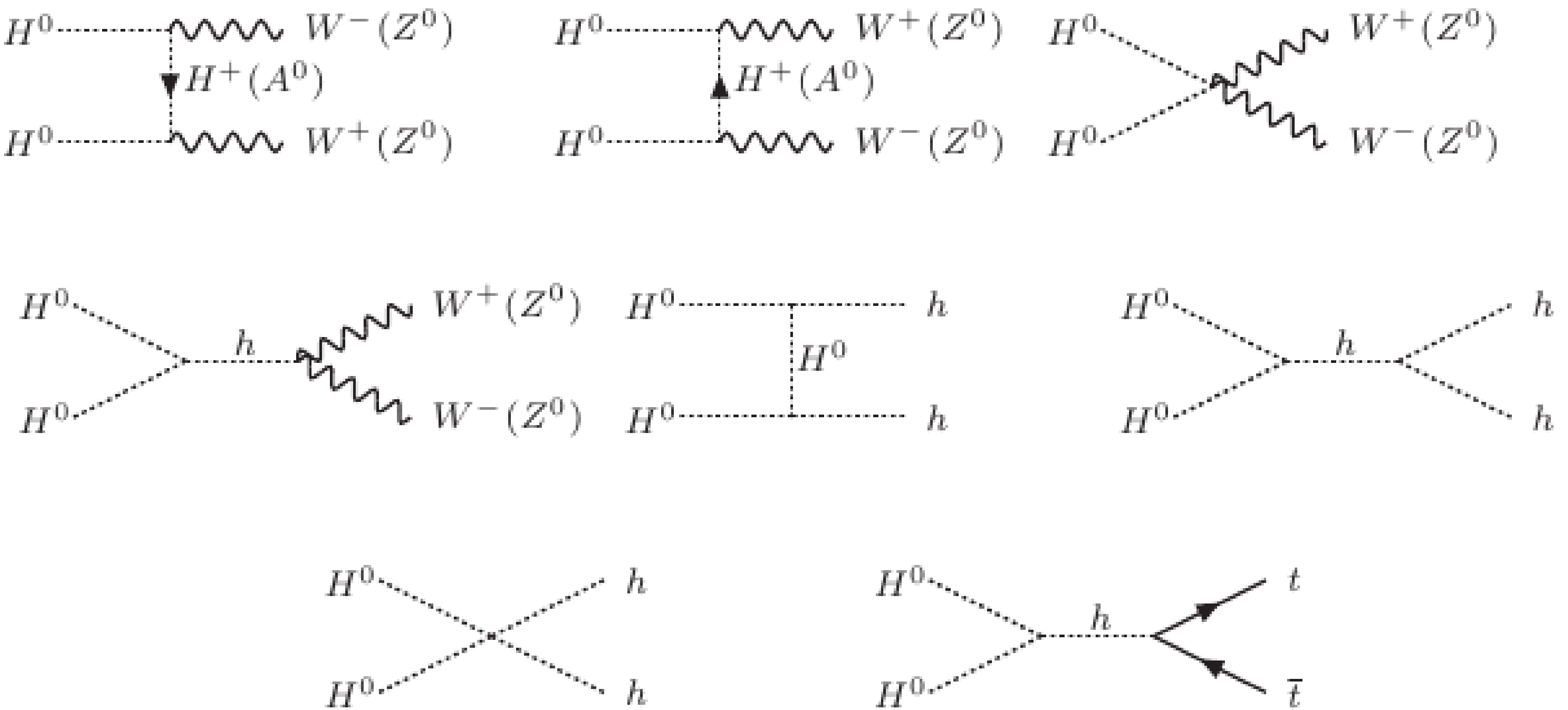
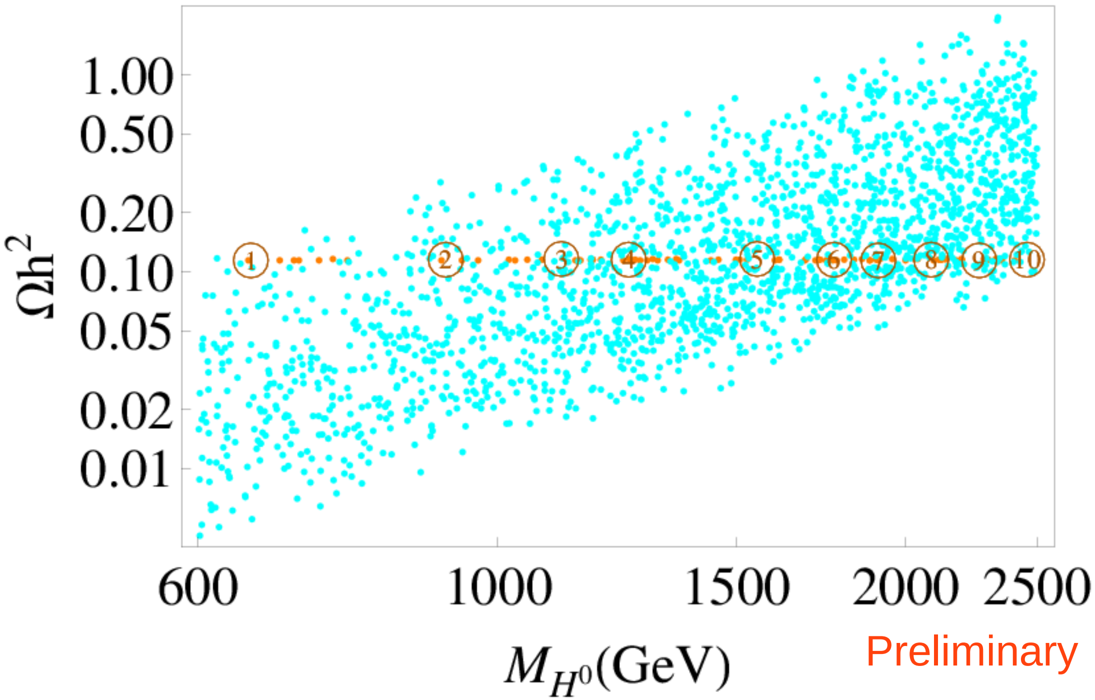


Why the t-channel?

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

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

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



Preliminary

Benchmark points

BMP	λ_2	λ_3	λ_4	λ_5	M_{H^0}(GeV)	M_{H^+}(GeV)	M_{A^0}(GeV)	Br(WW)	Br(ZZ)	Br(hh)	Br($t\bar{t}$)
1	0.32	0.02	-0.21	-0.04	657.	663.	659.	42.	41.	14.	2.
2	0.47	-0.48	0.08	-0.09	915.	915.	918.	55.	21.	23.	2.
3	0.23	0.14	0.06	-0.46	1114.	1119.	1126.	25.	67.	8.	0.
4	0.85	-0.44	0.26	-0.46	1249.	1251.	1260.	45.	18.	35.	2.
5	0.52	0.03	0.21	-0.71	1554.	1559.	1568.	12.	71.	16.	0.
6	0.93	0.91	-1.20	-0.13	1771.	1782.	1773.	85.	8.	7.	0.
7	0.68	0.84	-0.53	-0.68	1909.	1919.	1920.	55.	40.	5.	0.
8	0.19	0.18	0.49	-0.90	2089.	2092.	2102.	8.	90.	2.	0.
9	0.90	0.78	0.39	-0.74	2267.	2269.	2277.	26.	71.	3.	0.
10	0.93	0.61	0.43	-0.97	2459.	2462.	2471.	18.	82.	0.	0.

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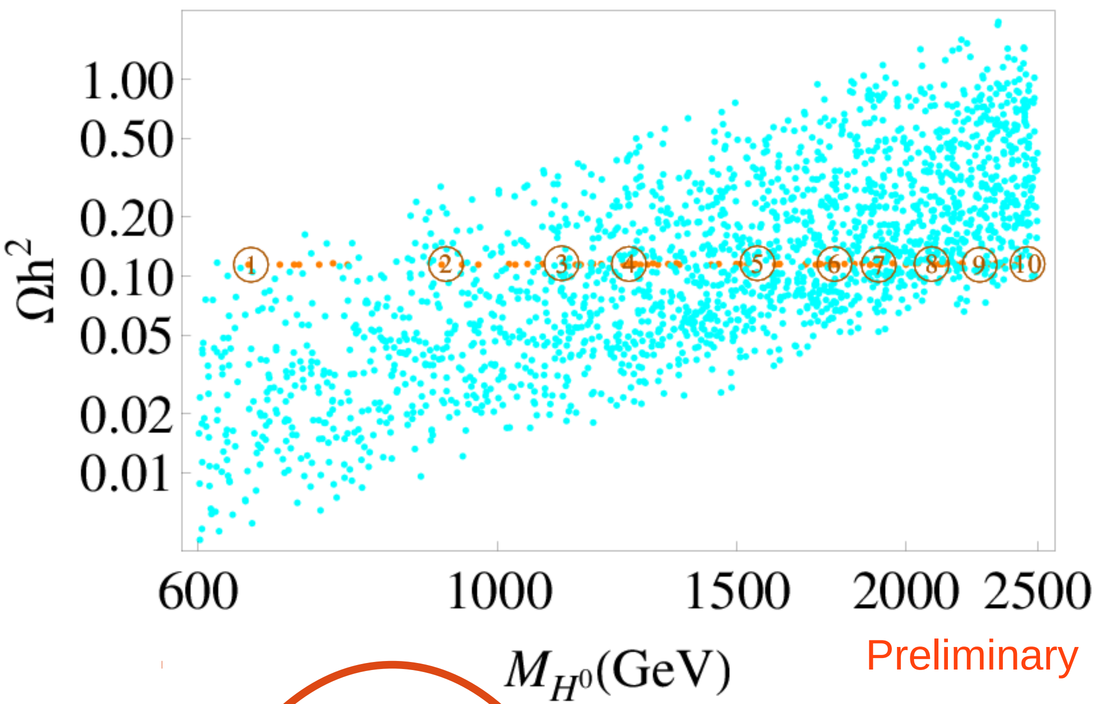

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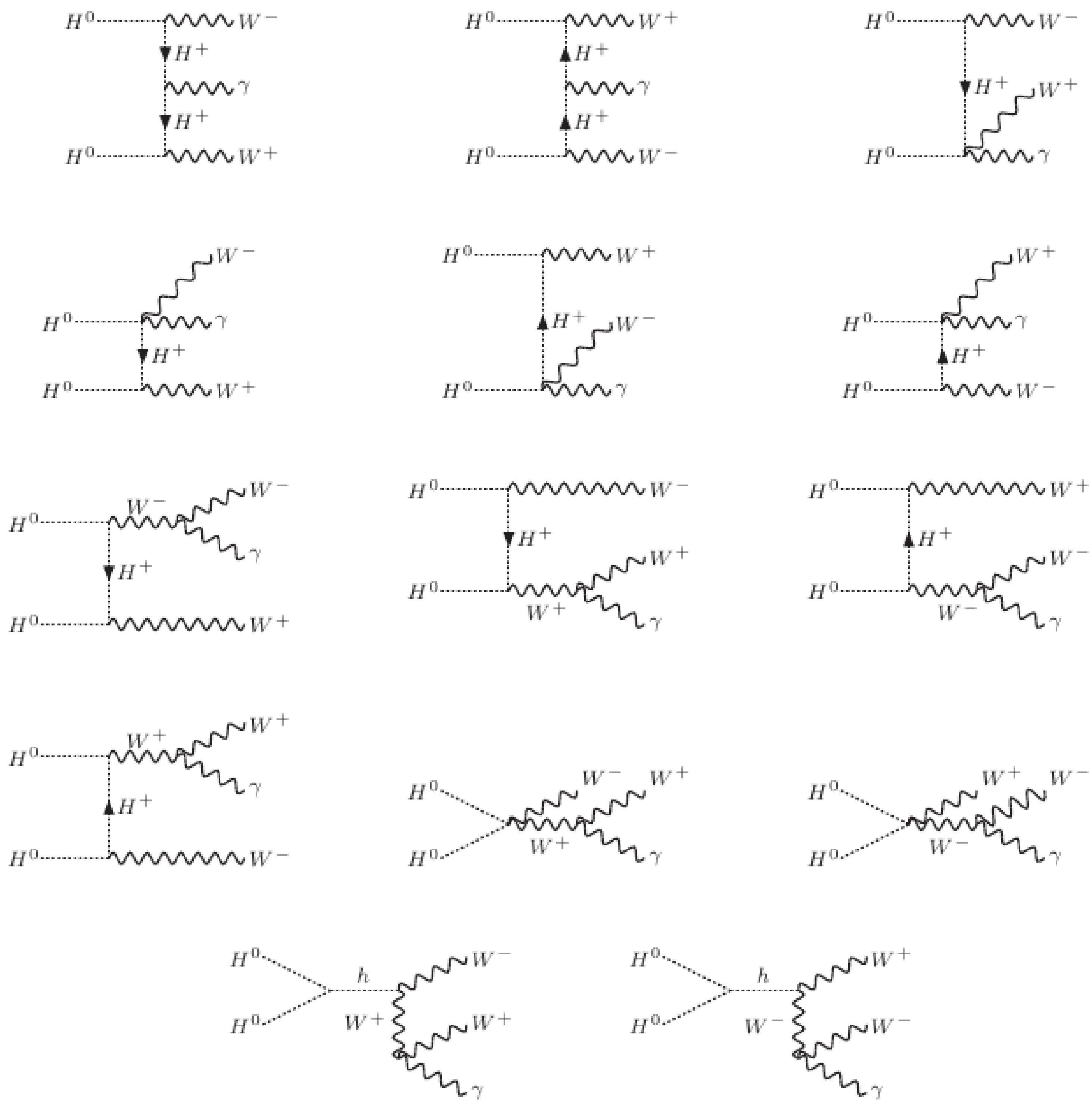
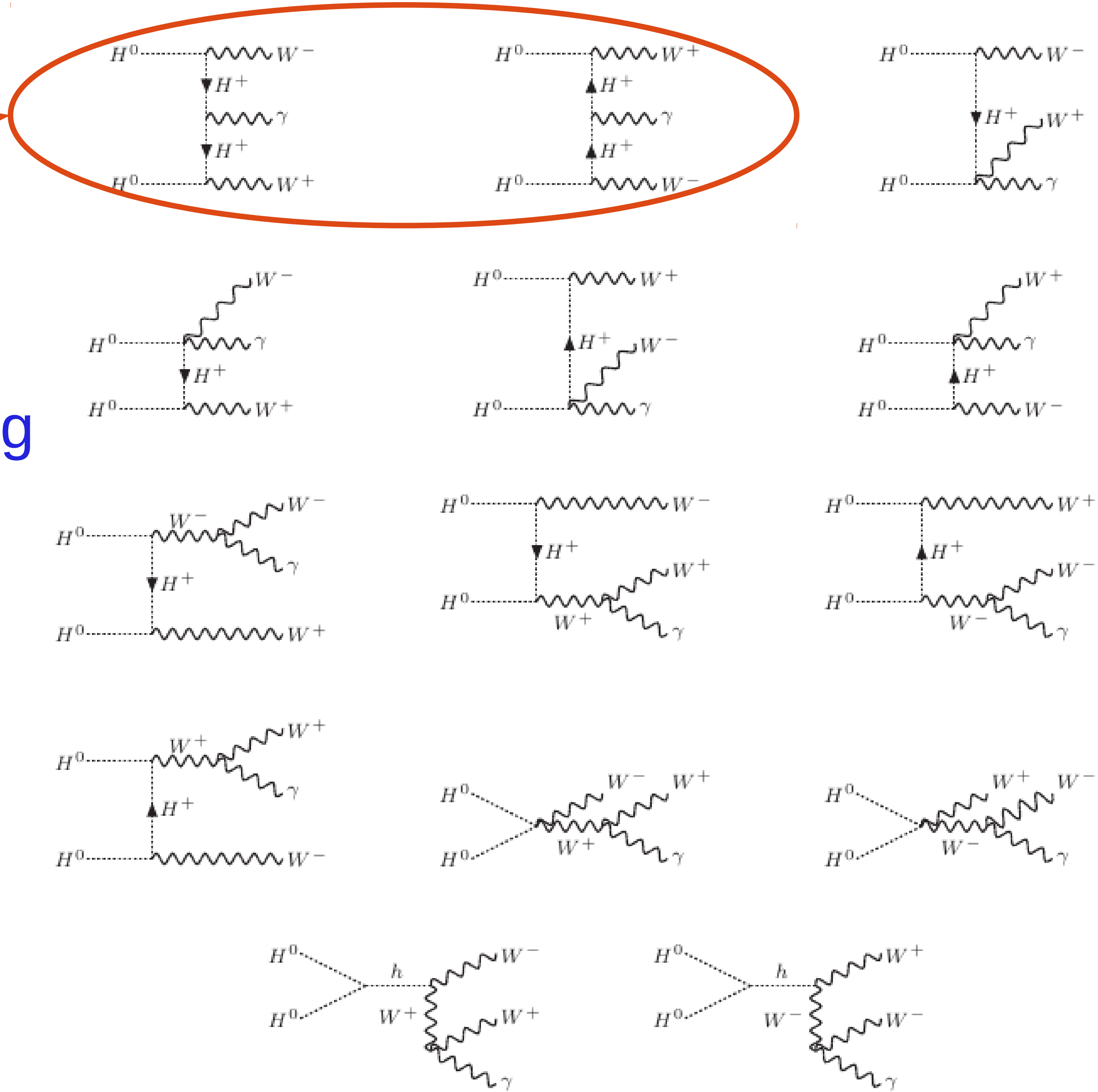
Bremsstrahlung diagrams



Photons emitted from internal lines



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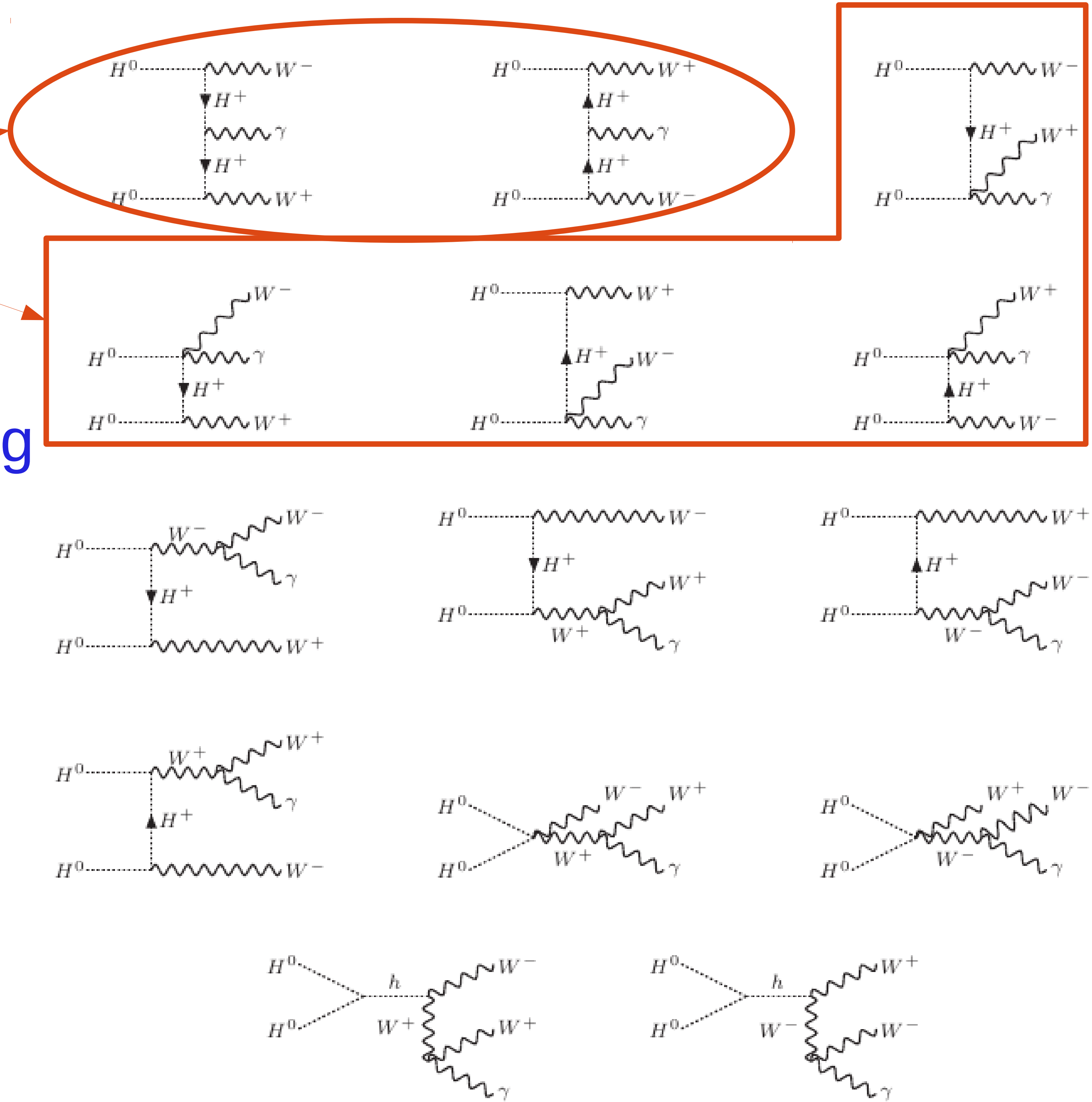
Photons emitted from vertices



Bremsstrahlung diagrams

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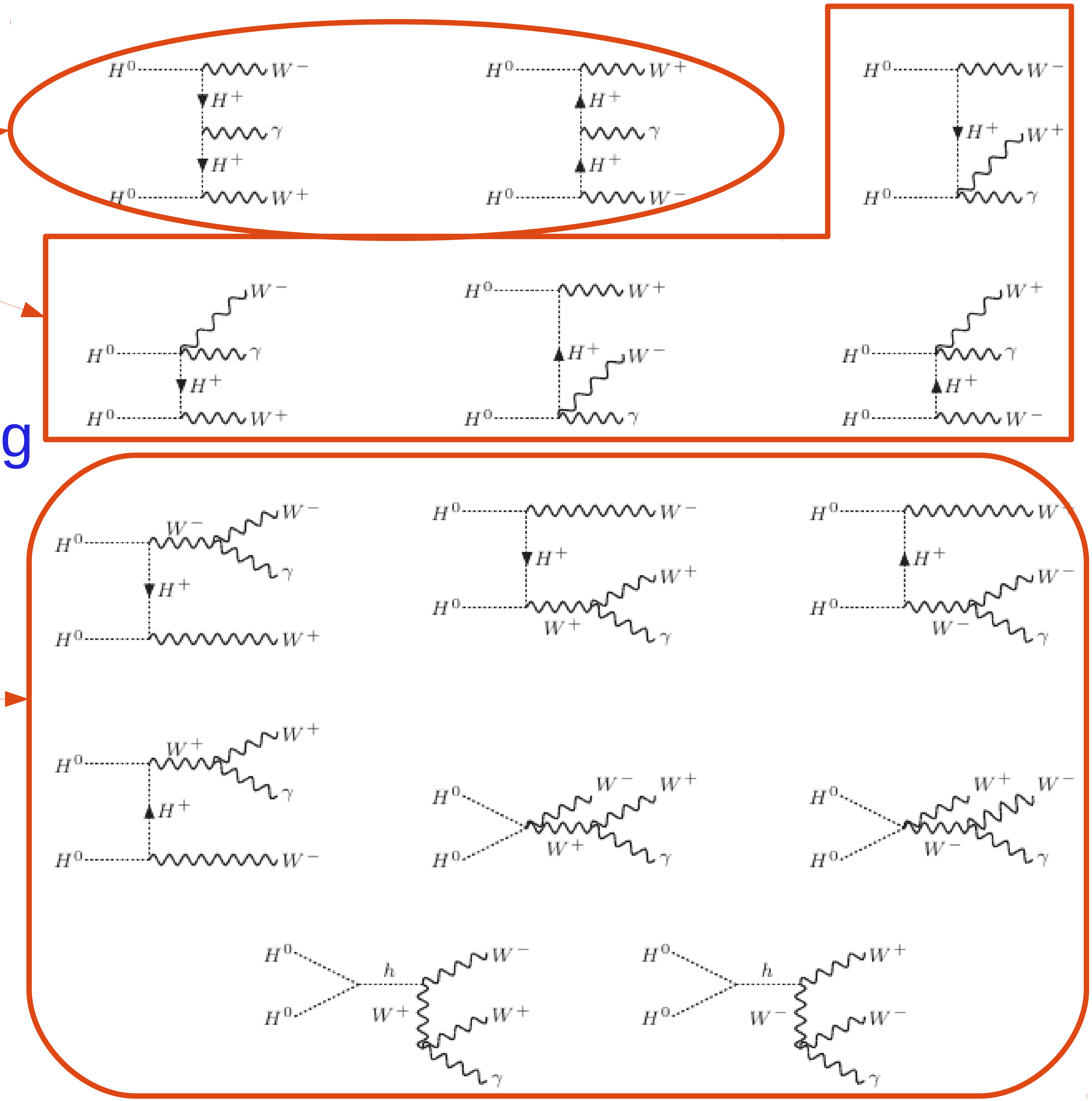

Cross Sections and Spectra

BMP	$\sigma v(10^{-27} cm^3/s)$
1	1.62
2	3.20
3	1.01
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7	2.86
8	0.47
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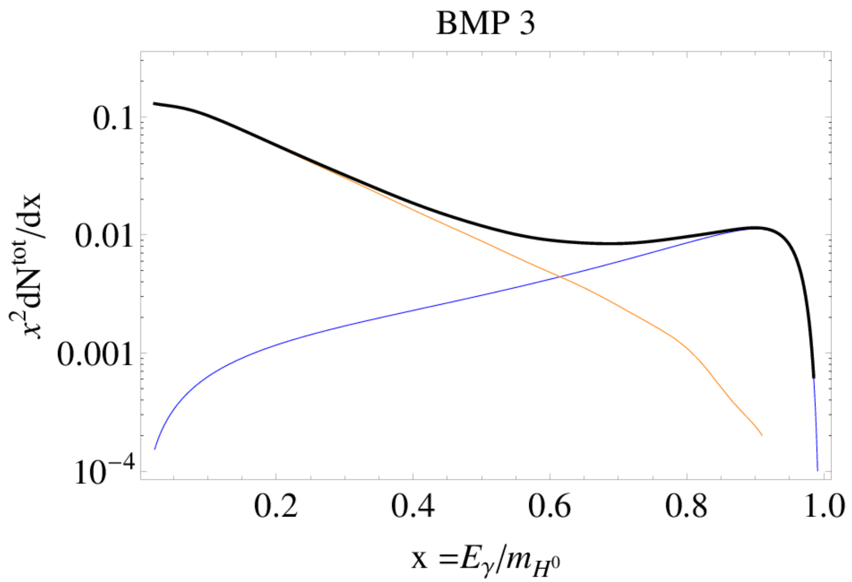
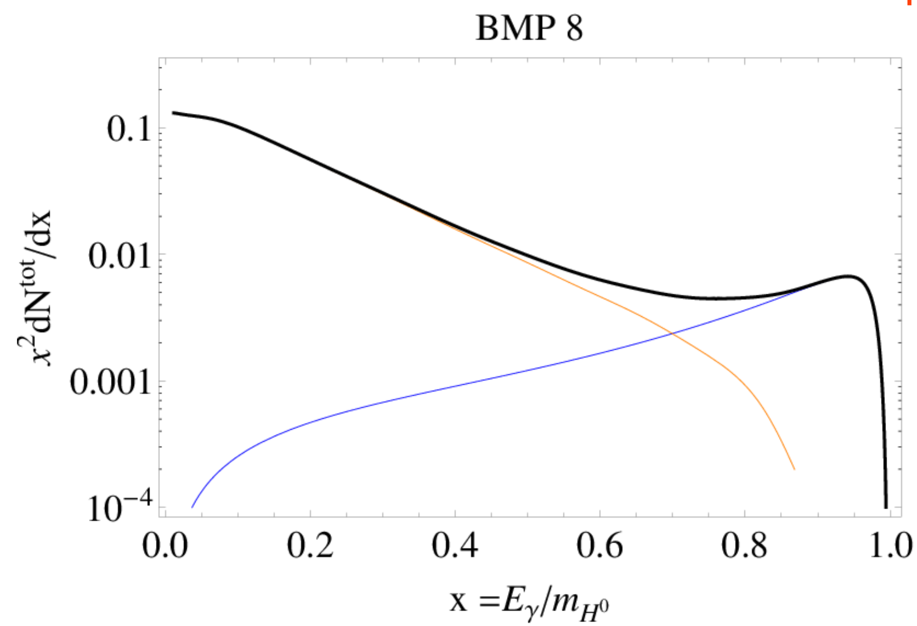
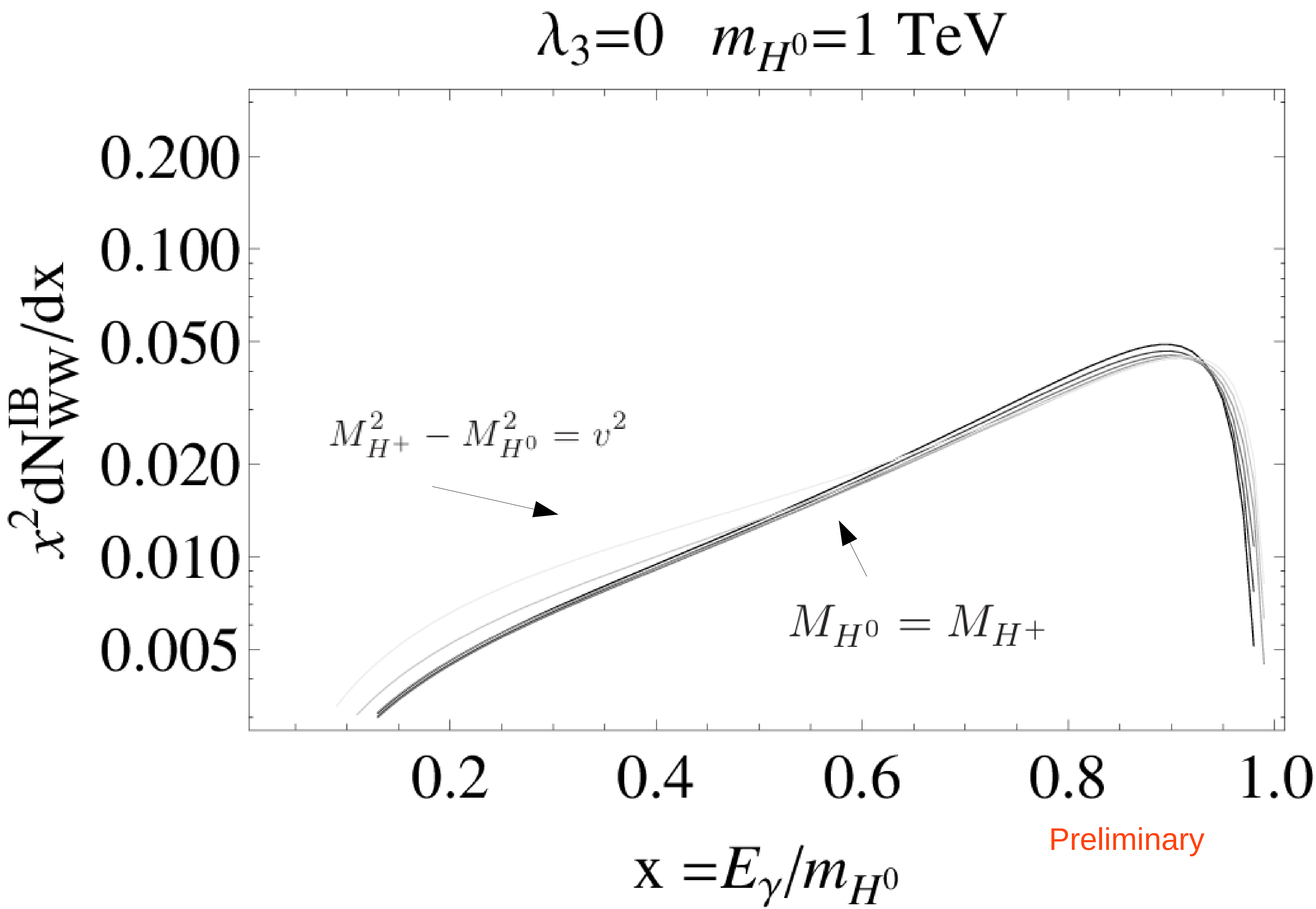


Preliminary



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



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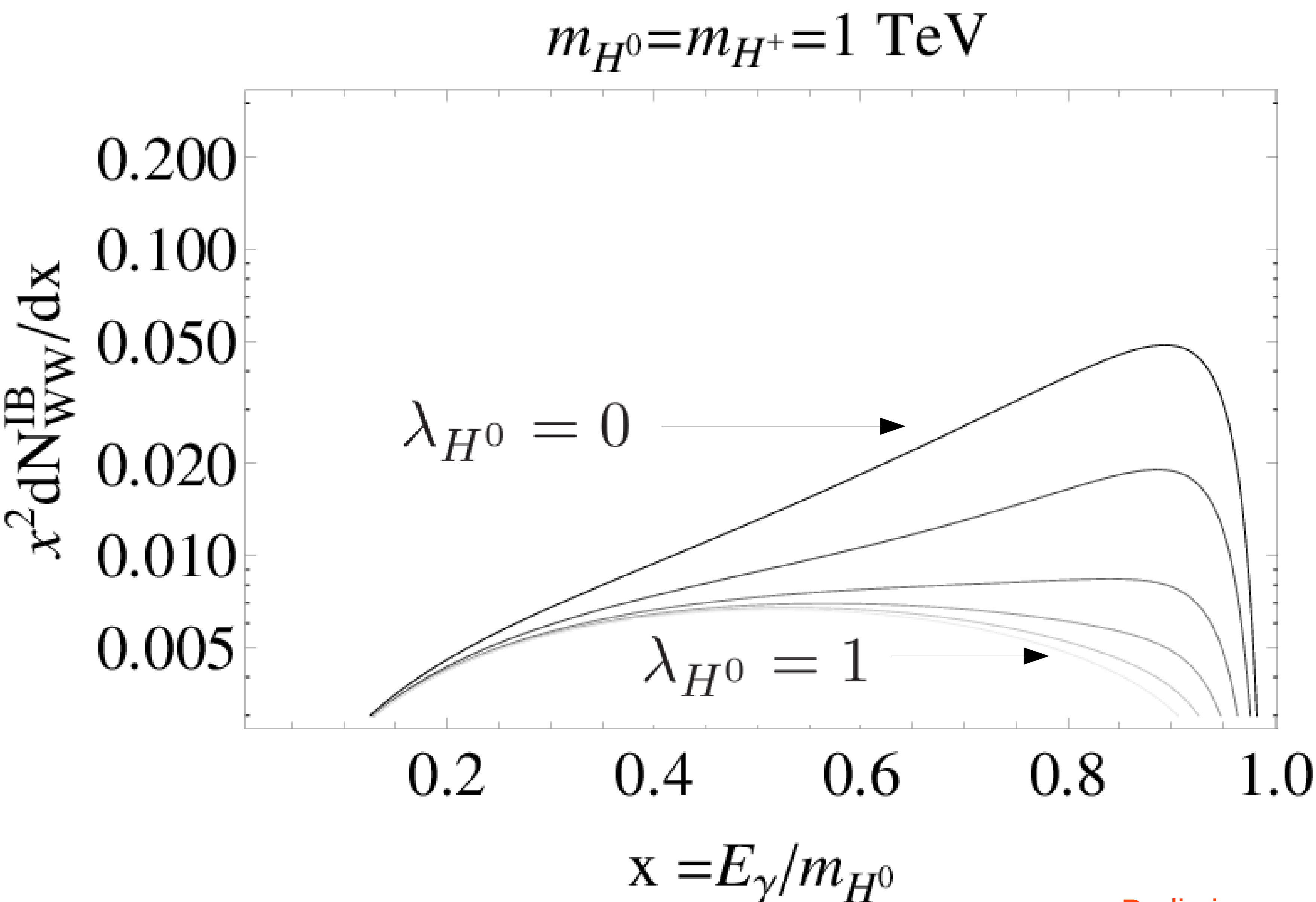
Effect of λ_{H^0}



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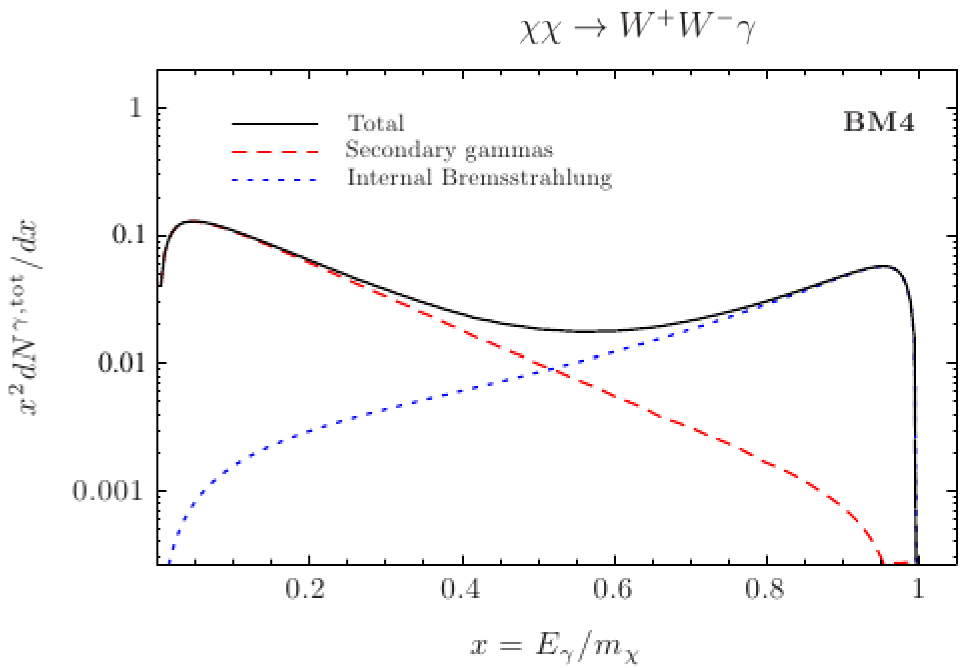
H.E.S.S. searches for photon-like signatures



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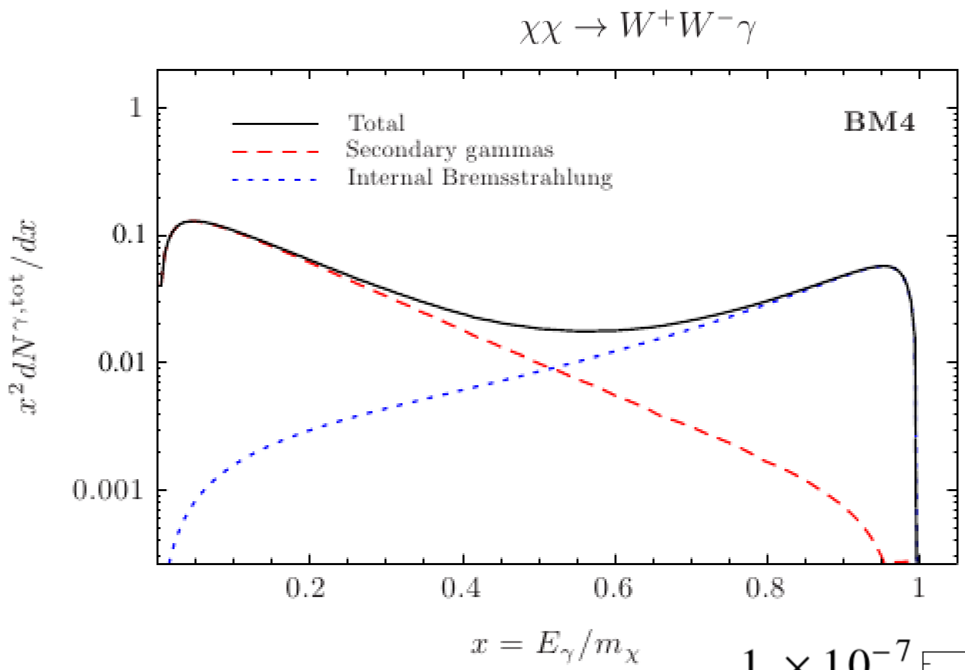

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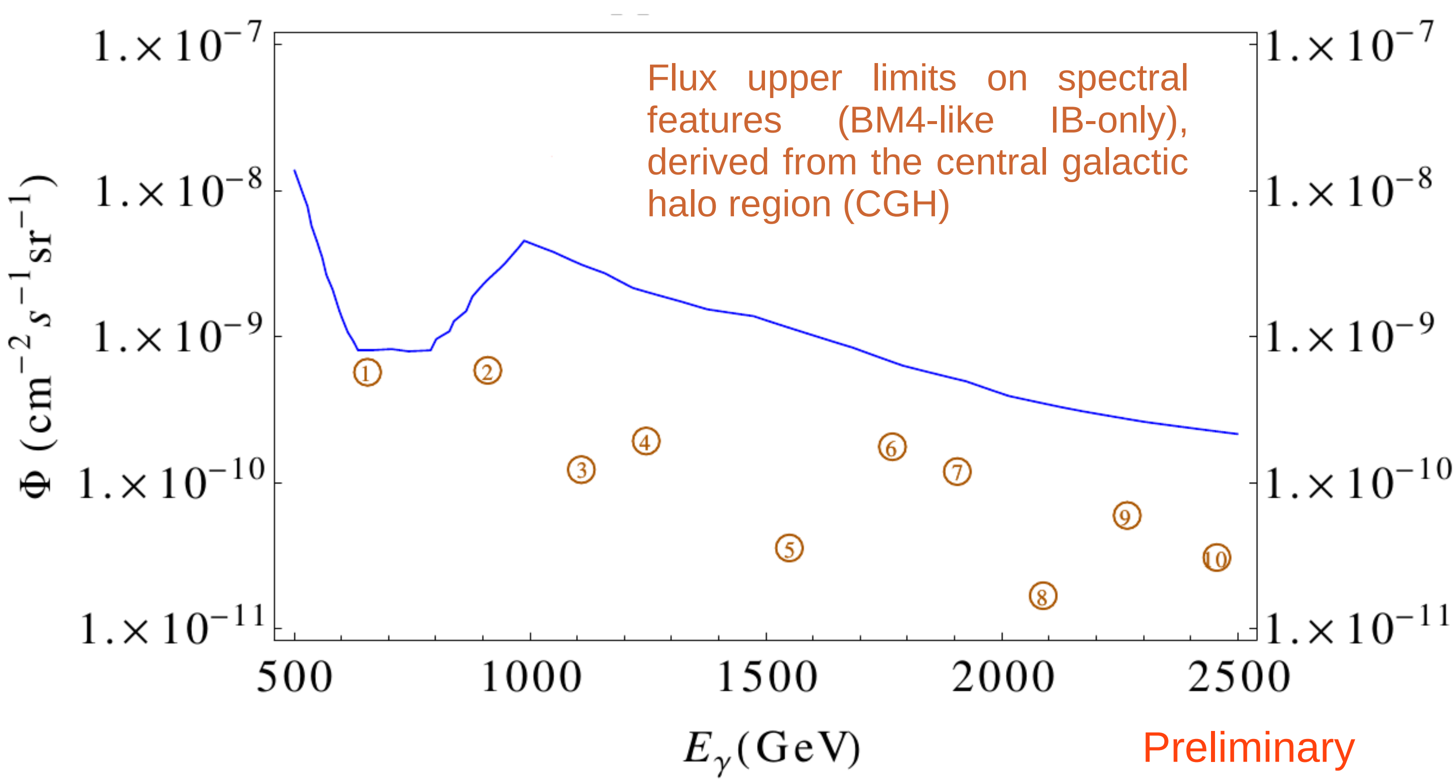
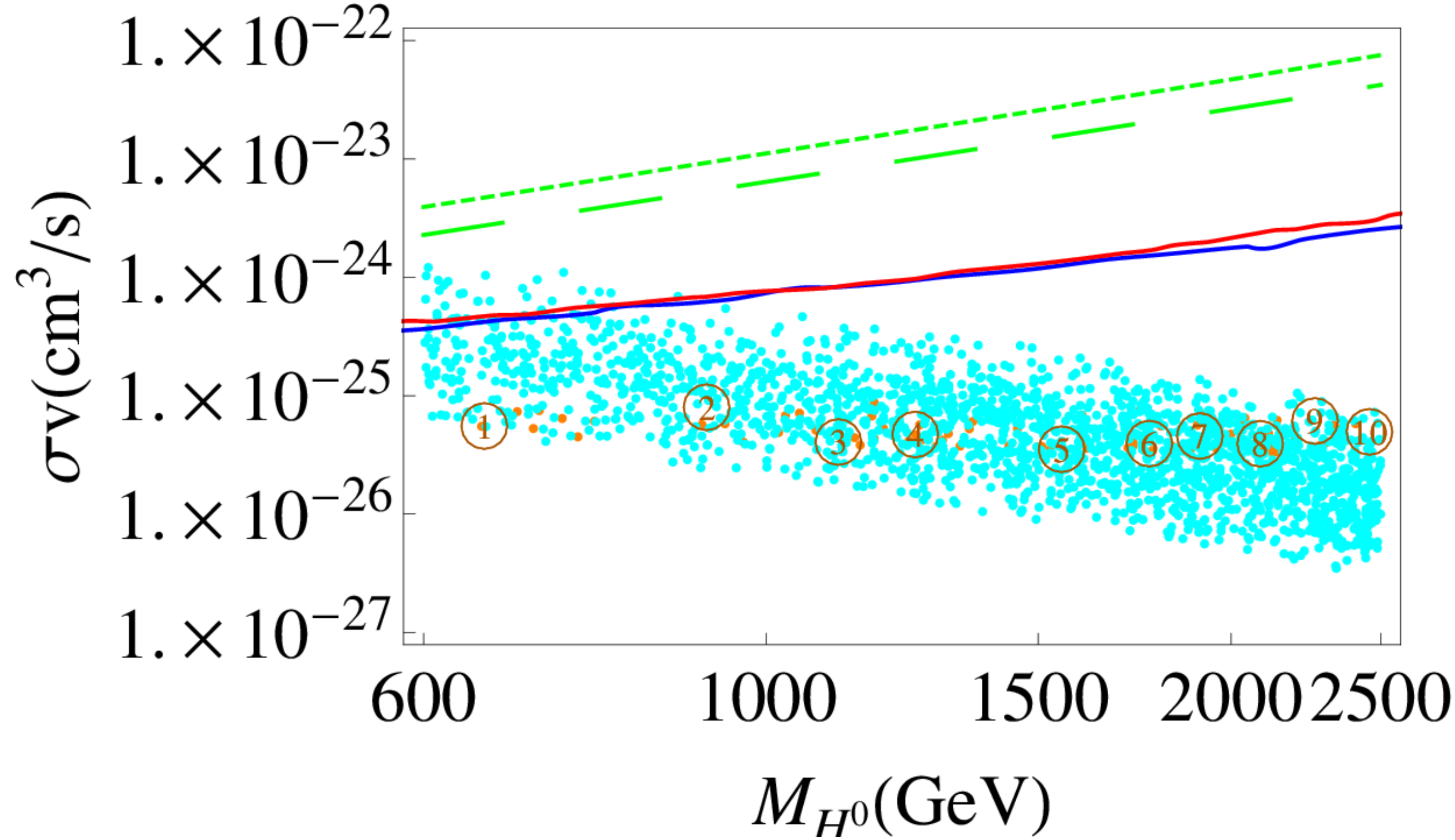


Preliminary

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.
- For heavy inert dark matter, internal bremsstrahlung signatures might be more relevant than mono-energetic photons in indirect searches.



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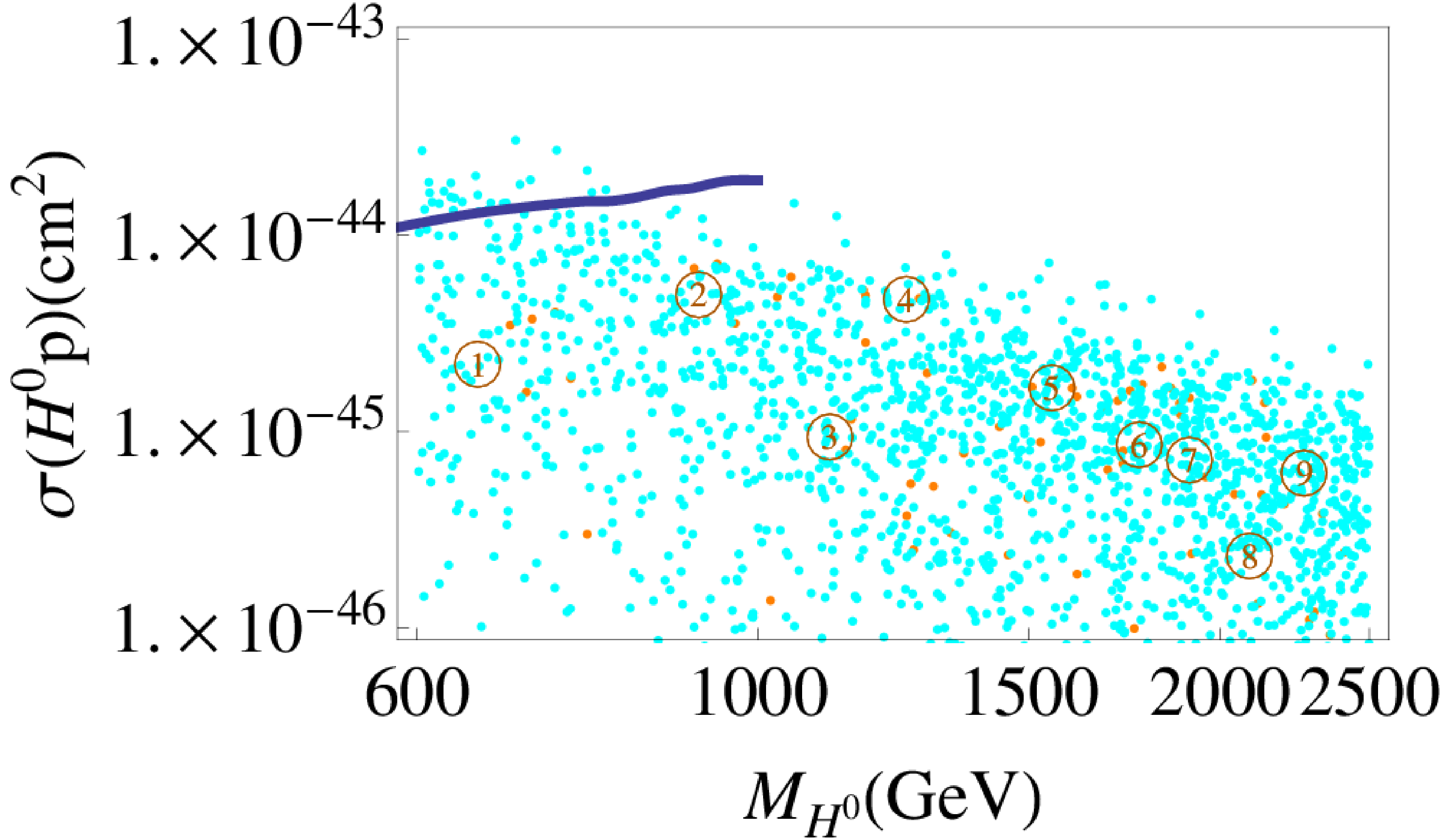

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