Gamma-rays from the Inert Doublet Model at the TeV scale.

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Based on JCAP 1309 (2013) 025 and some work under preparation.
In collaboration with Michael Gustafsson and Alejandro Ibarra.

Outline

- Inert Doublet Model
- Gamma-ray spectral features : Internal bremsstrahlung and annihilation into photons
- The Sommerfeld enhancement
- Benchmarks
- Direct detection vs. Indirect detection
- 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 $\eta \to -\eta \qquad \Phi \to \Phi$

$(Z_2\ symmetry)$

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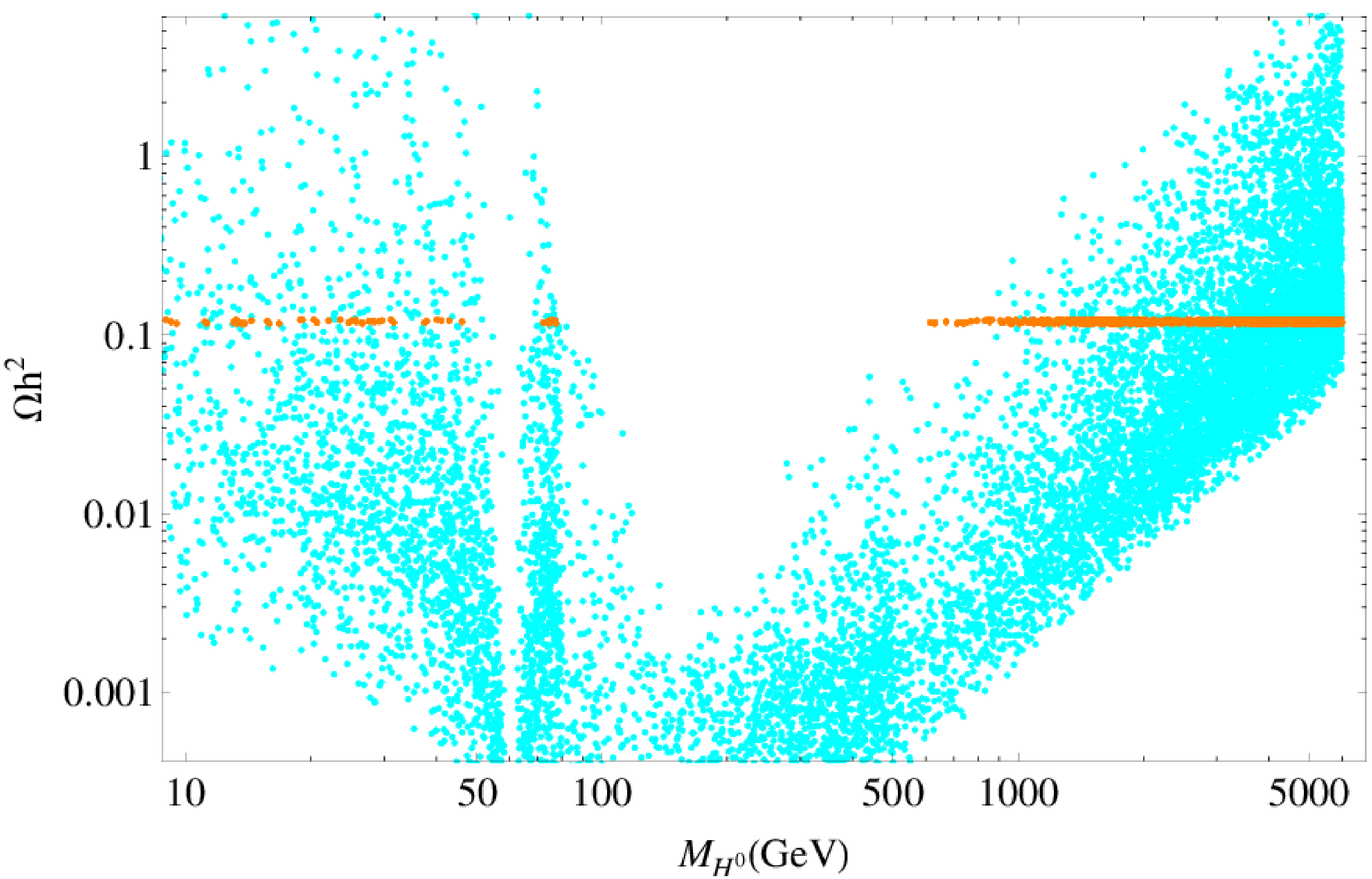
If the lightest particle that is charged under Z_2 is neutral : we have a **dark matter** candidate!!!

Dark Matter Abundance



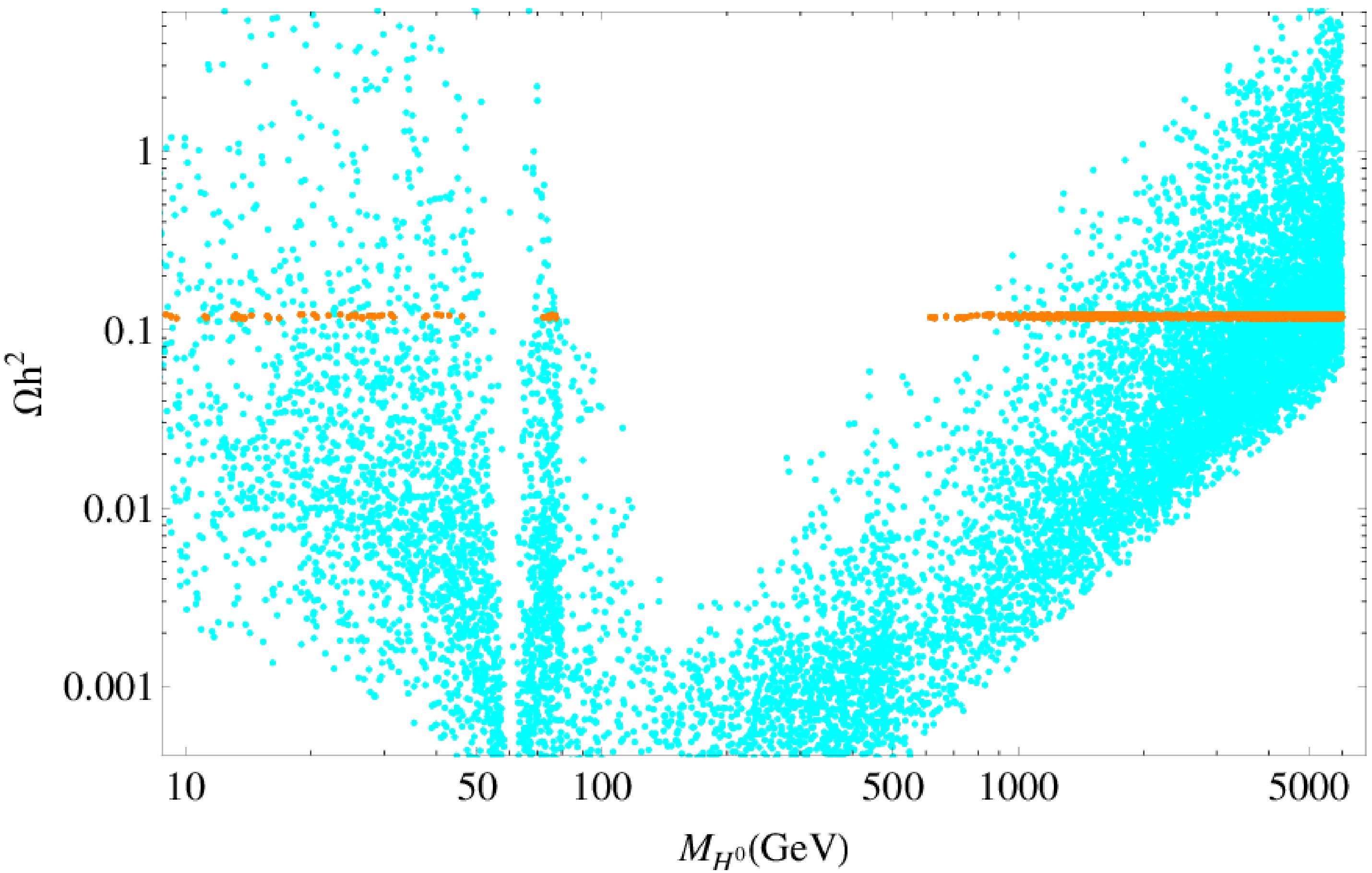
using micrOMEGAs G. Bélanger, F. Boudjema, A. Pukhov, A. Semenov,...

Dark Matter Abundance

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

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

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



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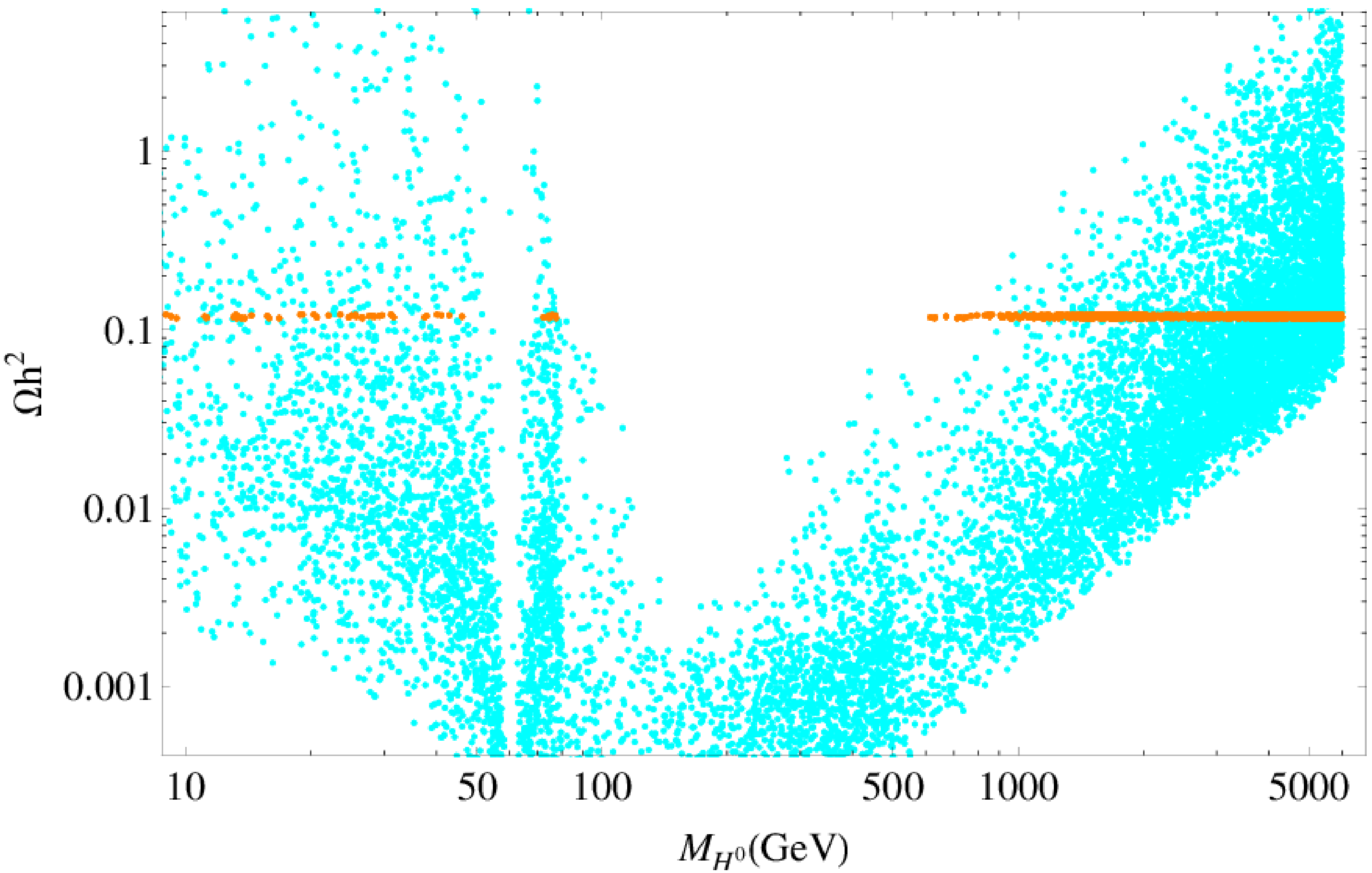
Cirelli NPB06, Hambye JHEP09



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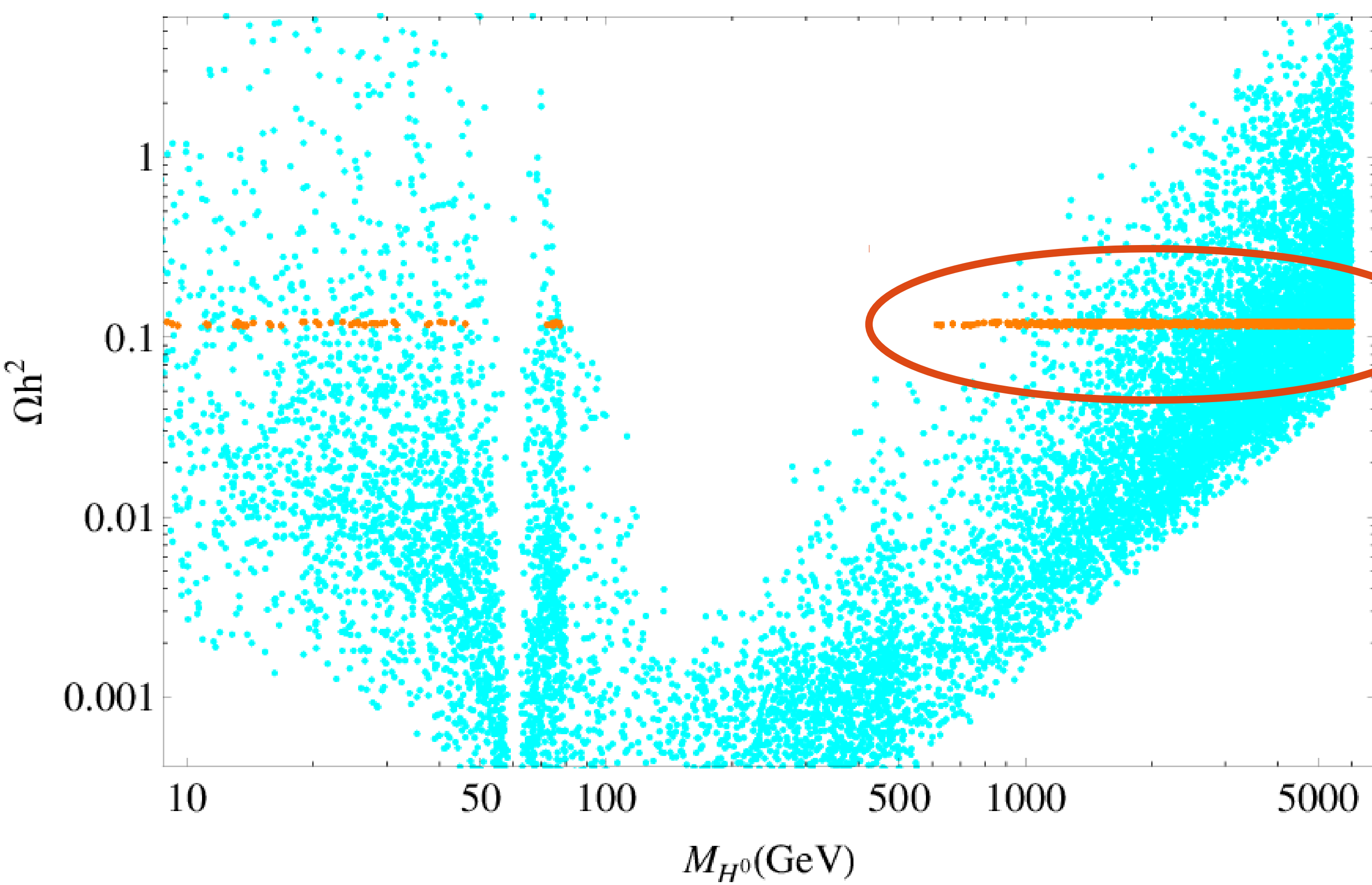

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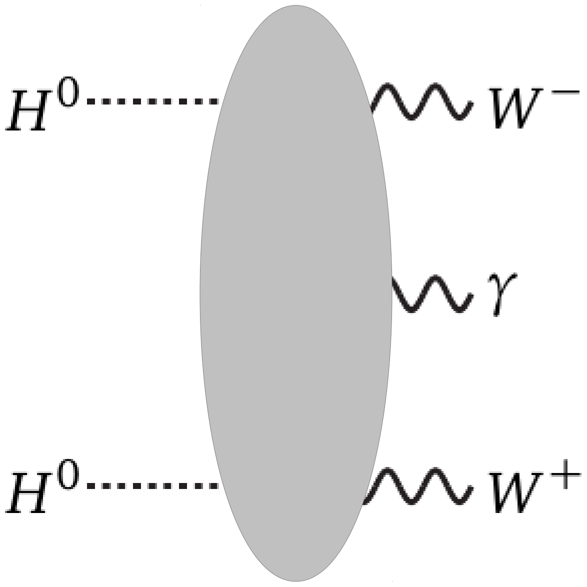
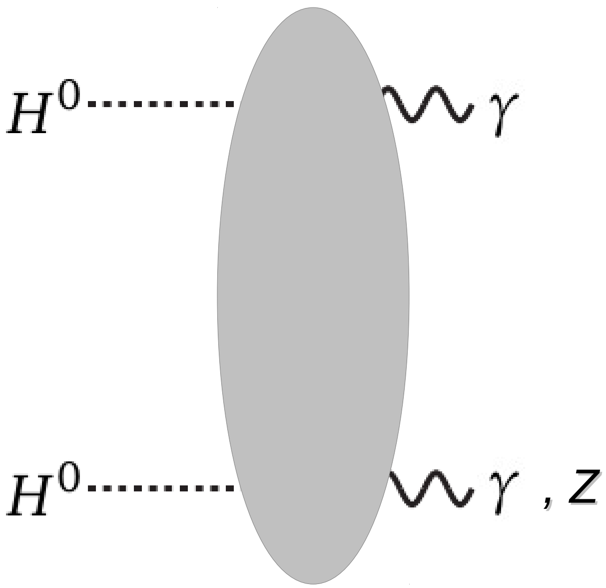
Gamma-ray spectral features

Smoking gun signature for dark matter : no astrophysical process is known to produce a sharp feature in the gamma-ray spectrum

Internal Bremsstrahlung



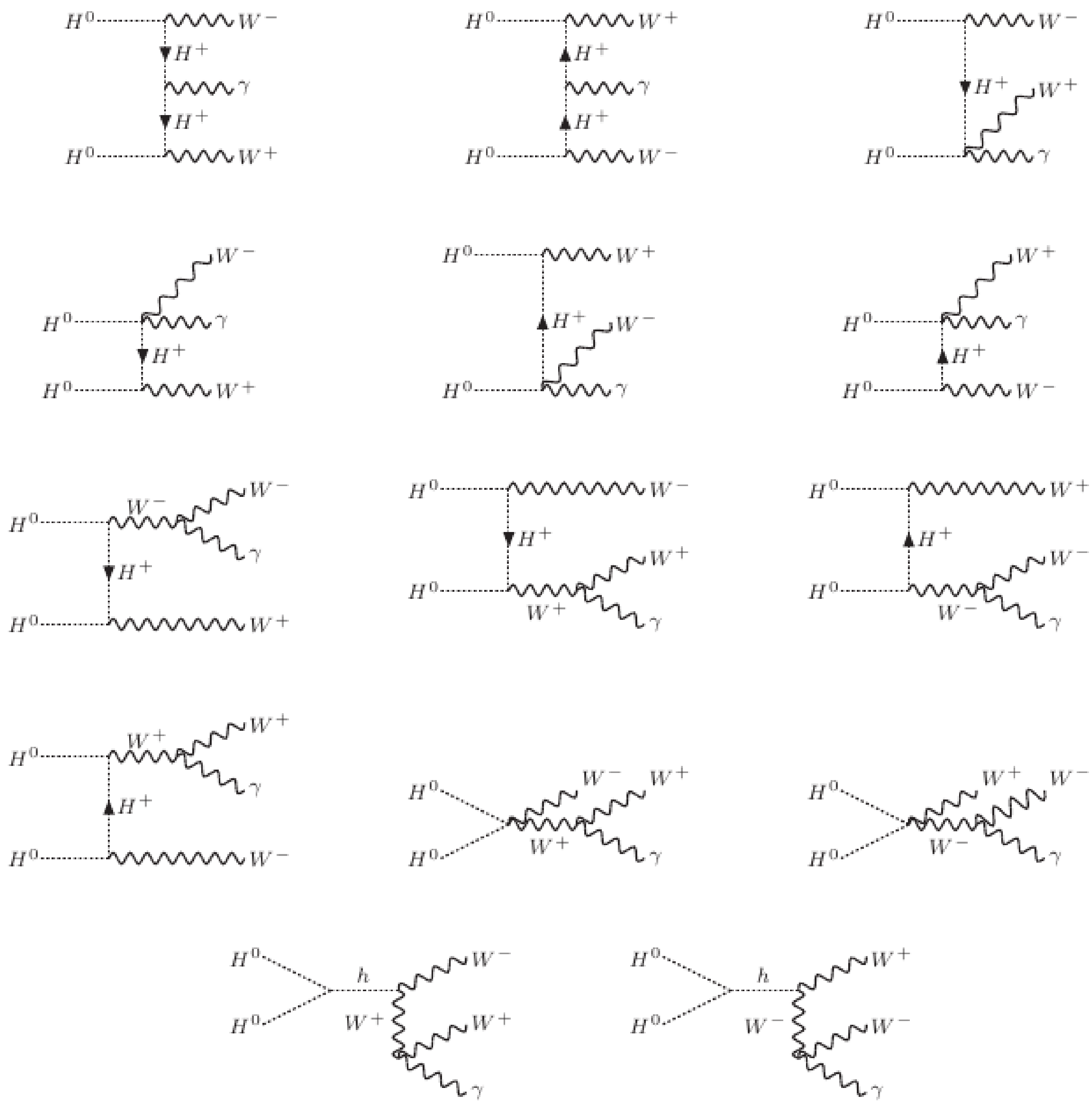
Gamma-ray Line



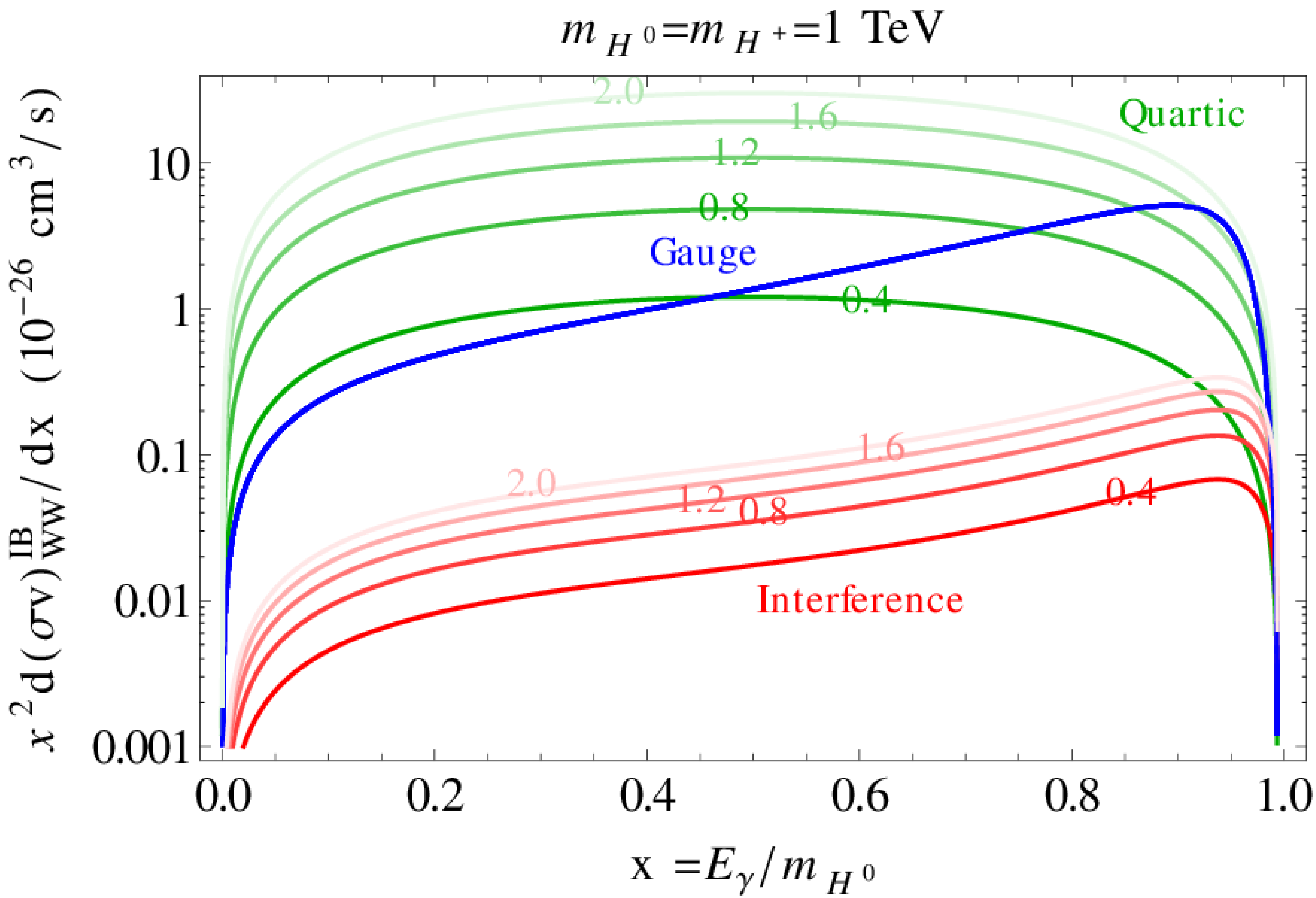
For the low mass-regime
Gustafsson et al. 2007

Internal Bremsstrahlung process

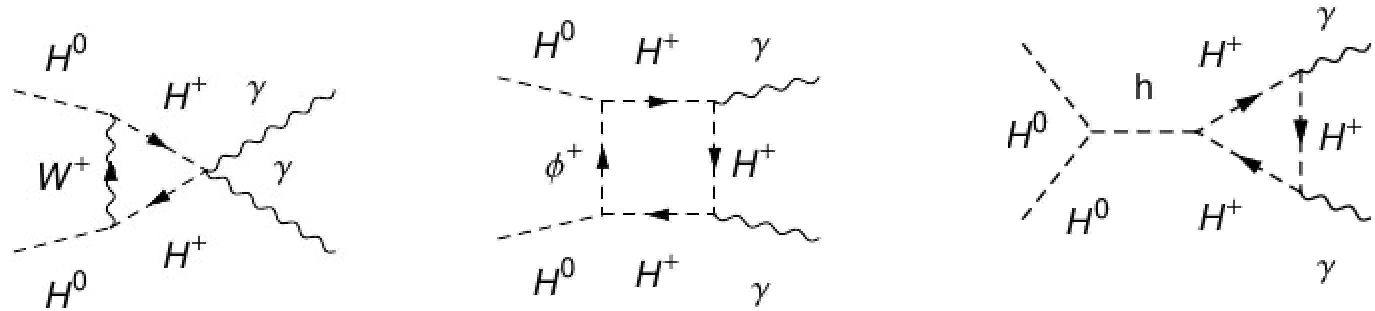
Garcia-Cely, Ibarra JCAP13



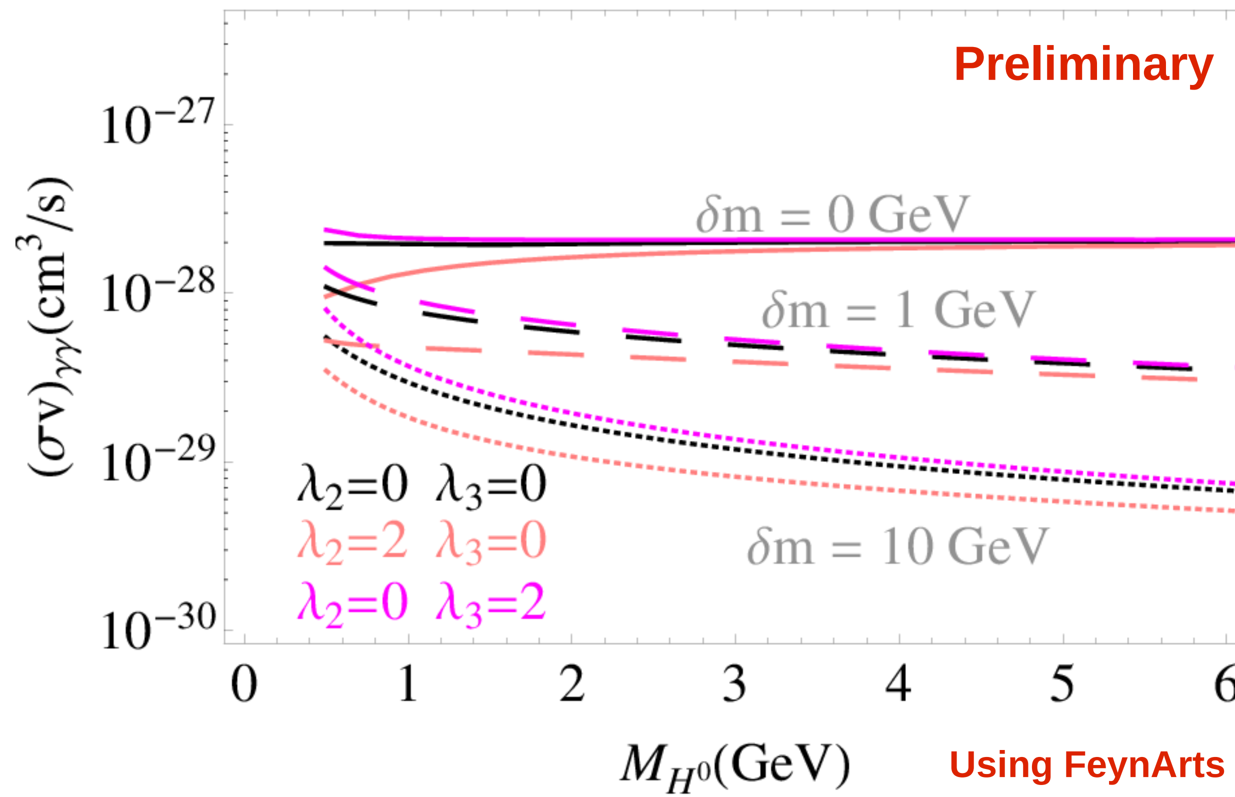
$$\frac{d(\sigma v)_{W^+W^-\gamma}}{dx} = \left.\frac{d(\sigma v)}{dx}\right|_{\text{Gauge}} + \left.\frac{d(\sigma v)}{dx}\right|_{\text{Quartic}} + \left.\frac{d(\sigma v)}{dx}\right|_{\text{Interference}},$$



One-loop annihilation into two photons



……..and many more



Using FeynArts **Hahn '00**

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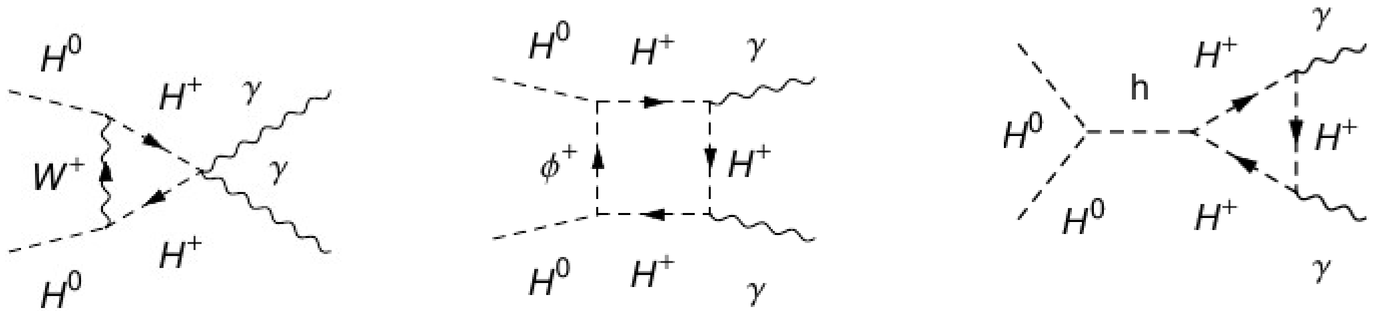

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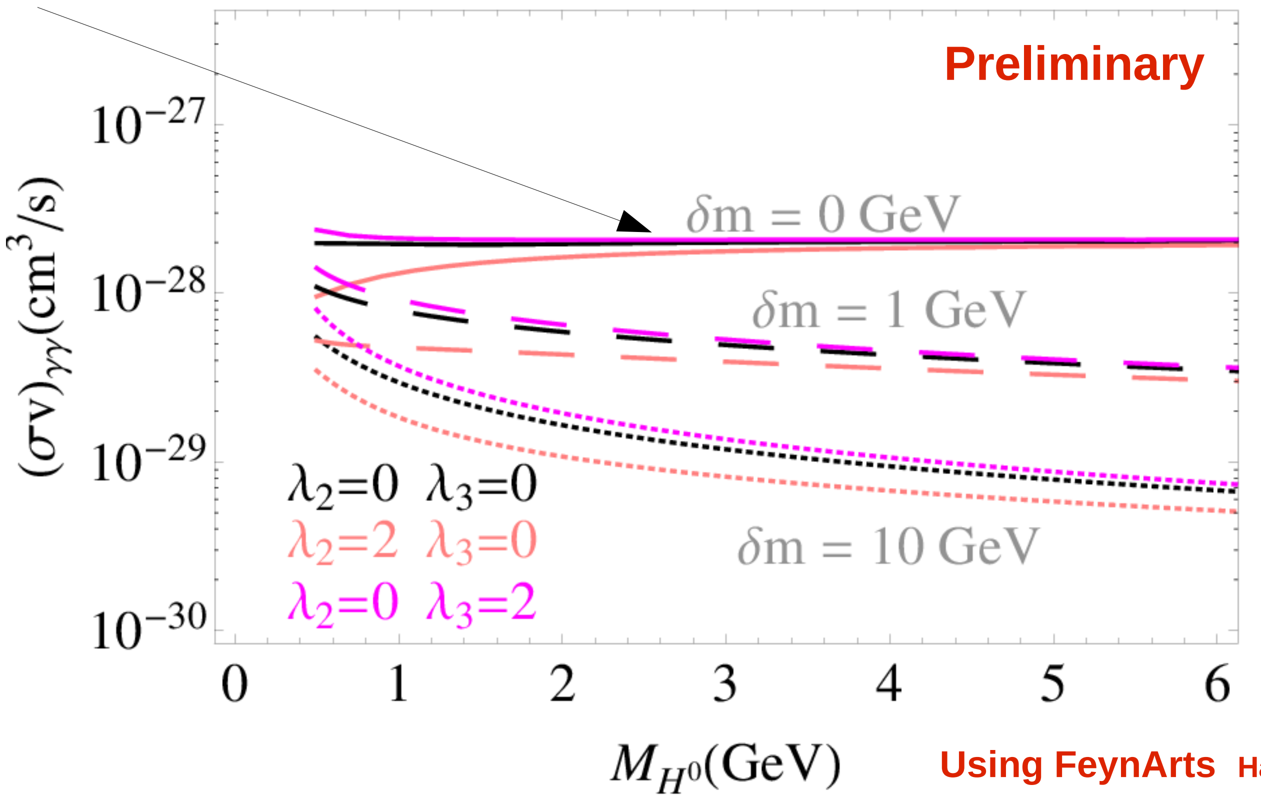
Something is wrong



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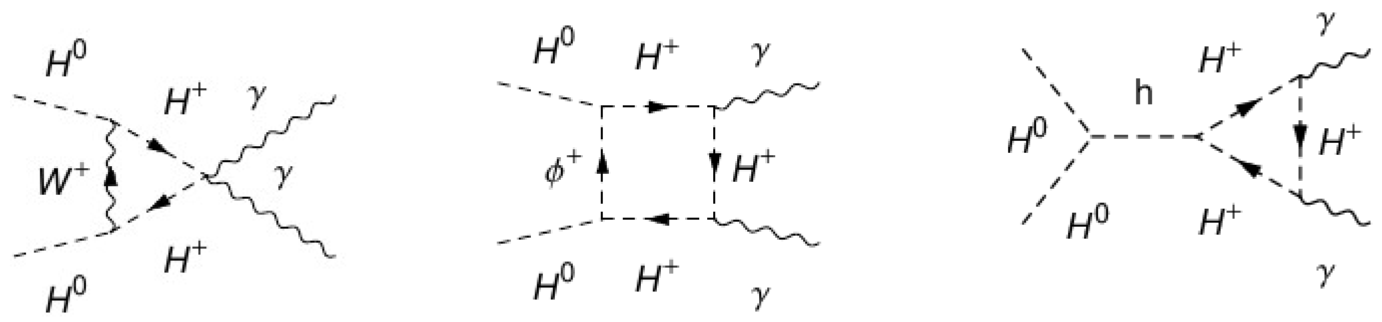

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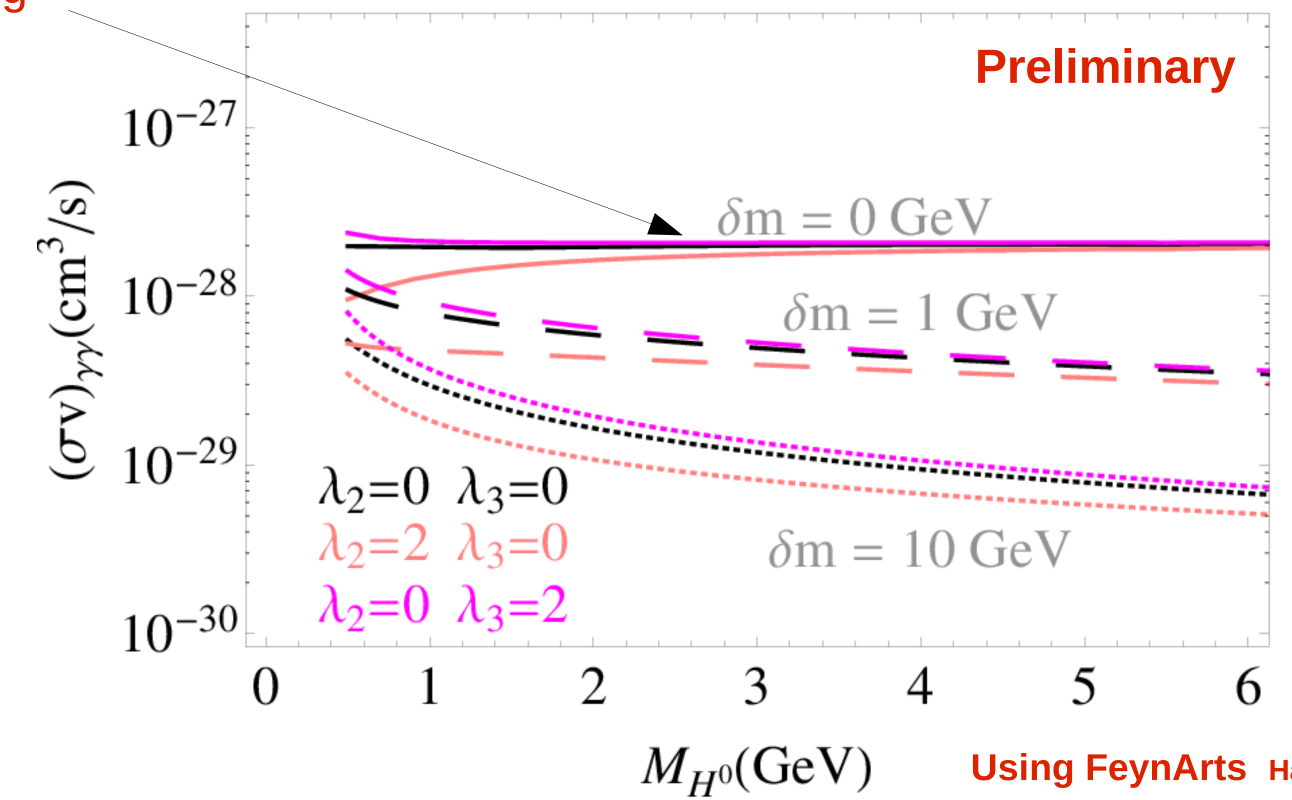
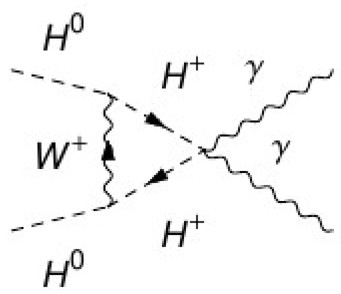


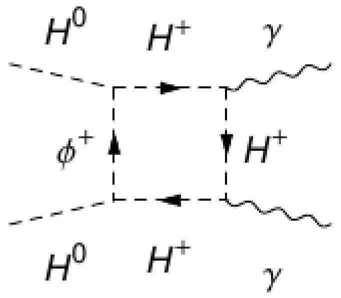
Using FeynArts **Hahn '00**

Including the Sommerfeld Enhancement solves the problem with unitarity!!!

Hisano, Matsumoto, Nojiri,Saito PRD05

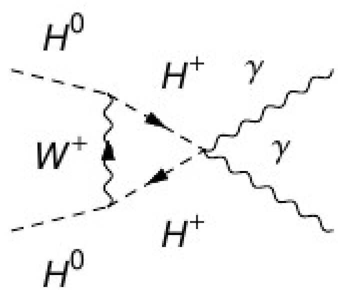
Sommerfeld Enhancement

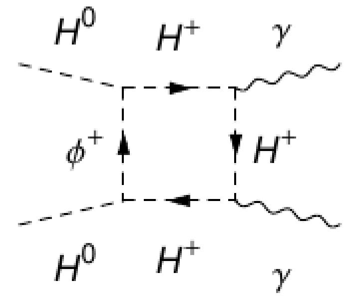




The exchange of W bosons - and in general of any boson- leads to a long range interaction that distorts the wave function of the annihilating particles

Sommerfeld Enhancement





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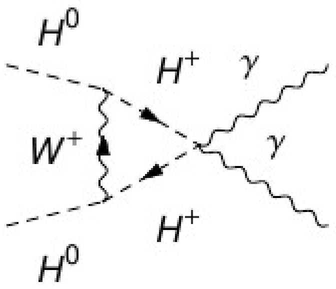
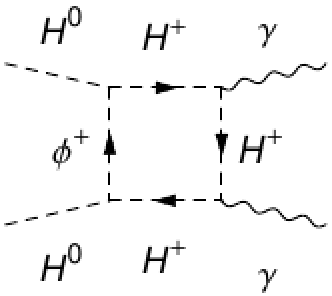
DM annihilation into any final state

$$\sigma v \left(H^0 H^0 \to f\right)\Big|_{s-wave} = \frac{1}{4M_{H^0}^2} \int \left(\prod_{a\in f} \frac{d^3 q_a}{(2\pi)^3 2E_a} \right) (2\pi)^4 \delta^4 \left(p_{H^0} + p'_{H^0} - \Sigma_{a\in f} q_a\right) \cdot \left| \mathcal{M}\left(H^0 H^0 \to f\right) \right|^2$$

No enhancement factors

Sommerfeld Enhancement





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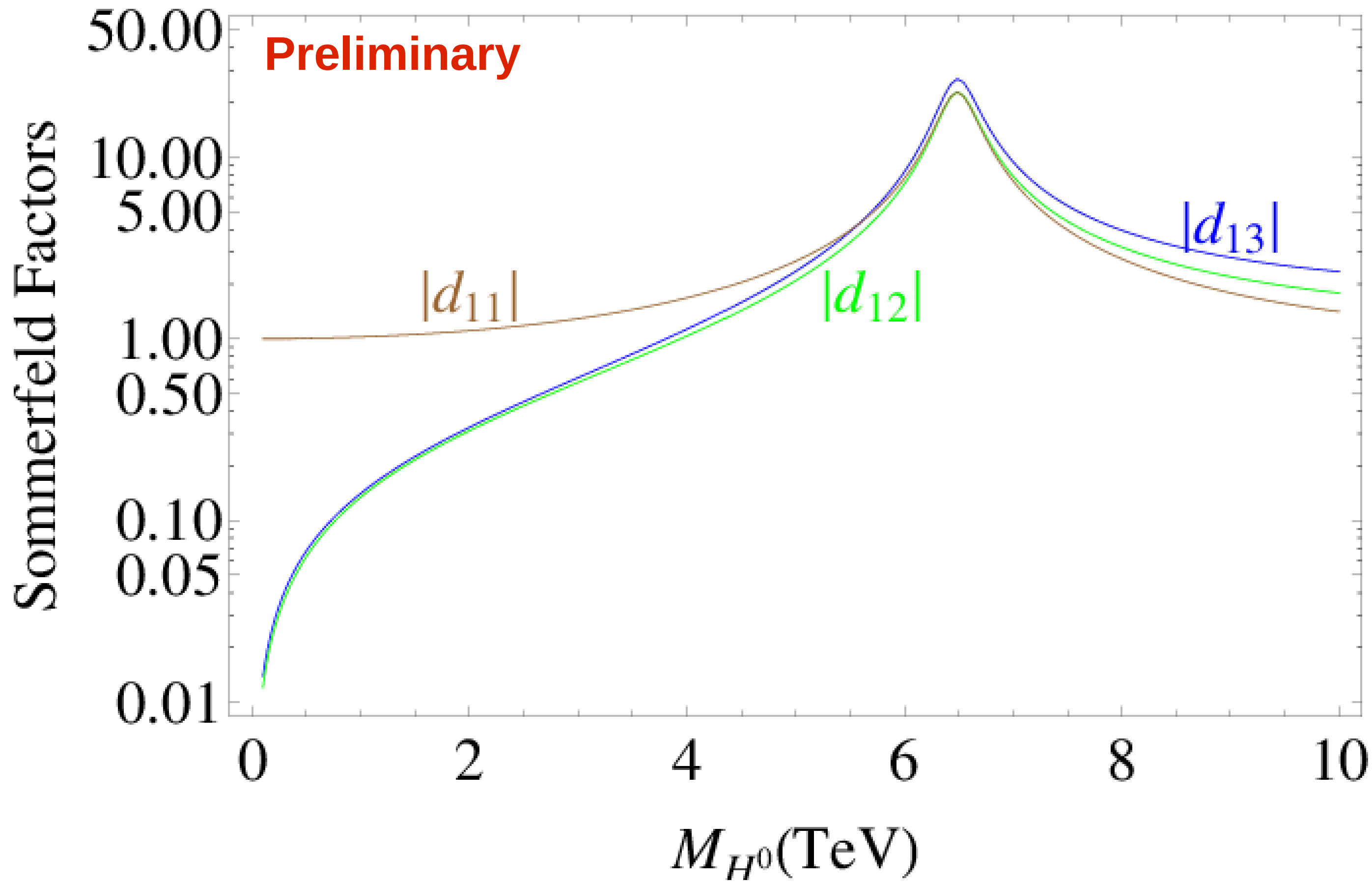
Enhancement factors

Example: when all the quartic couplings vanish



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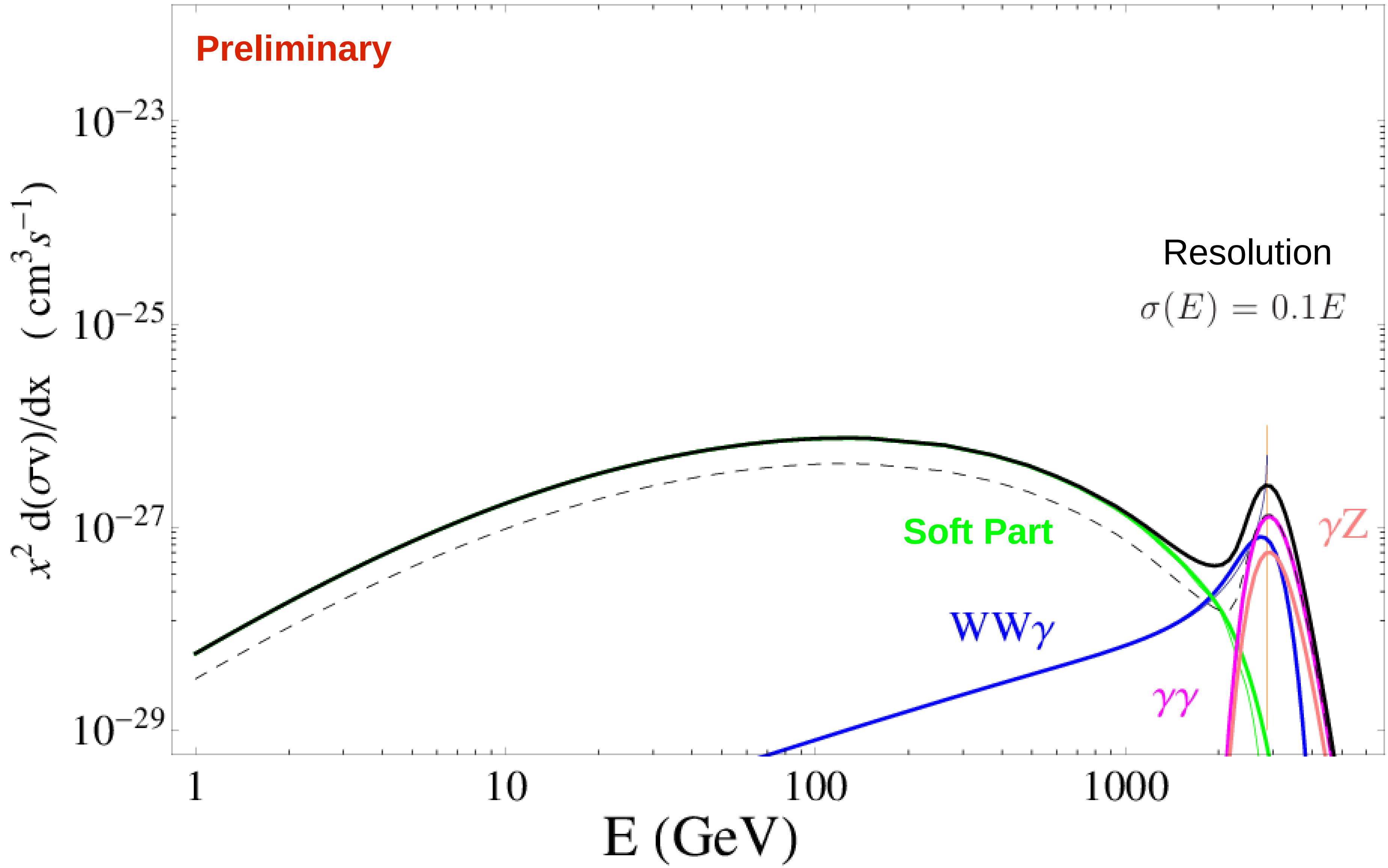
One Benchmark

The lines dominate over IB

m_{DM} = 2.88 TeV $\quad \Omega h^2 = 0.1199 \pm 0.0027$



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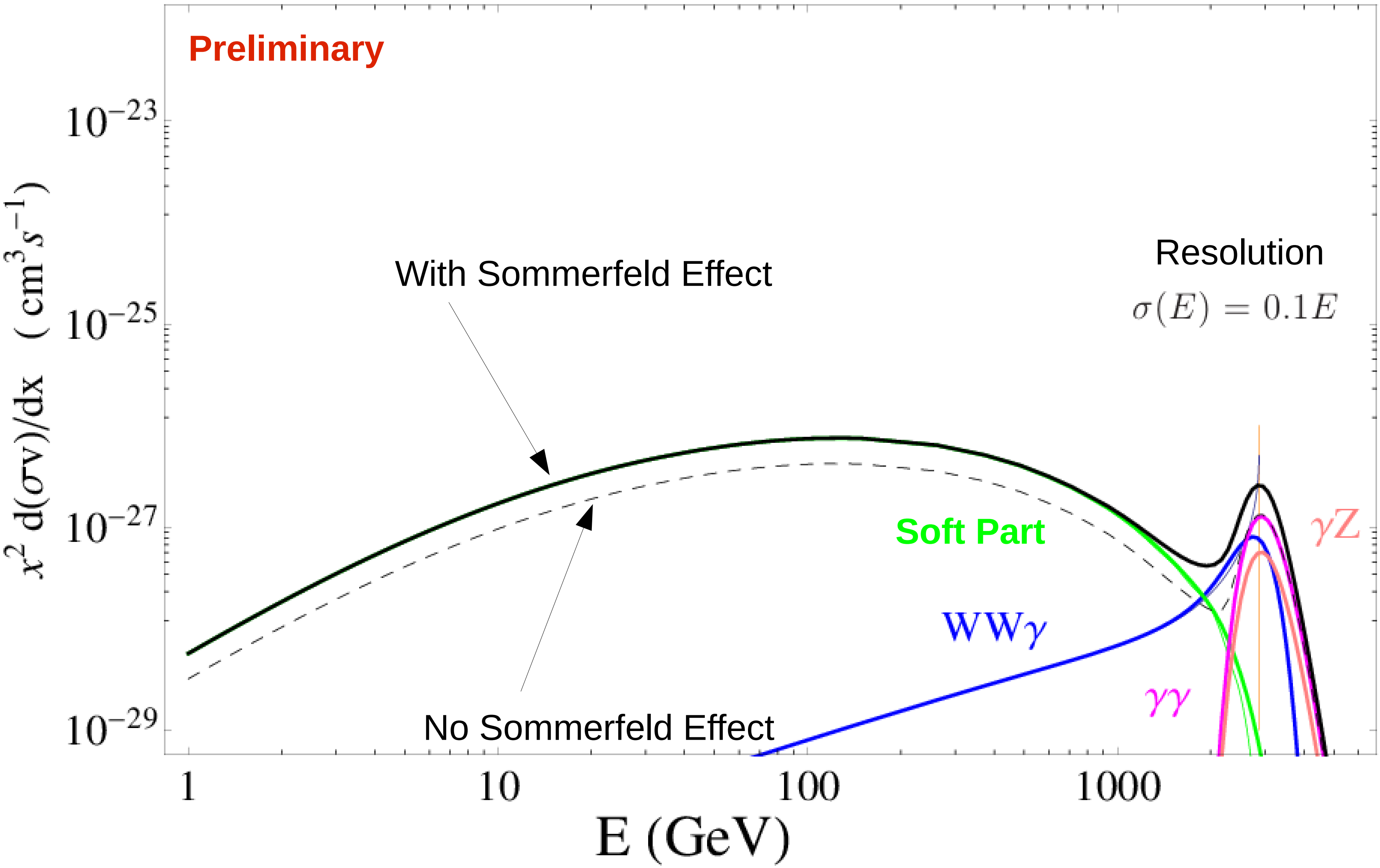

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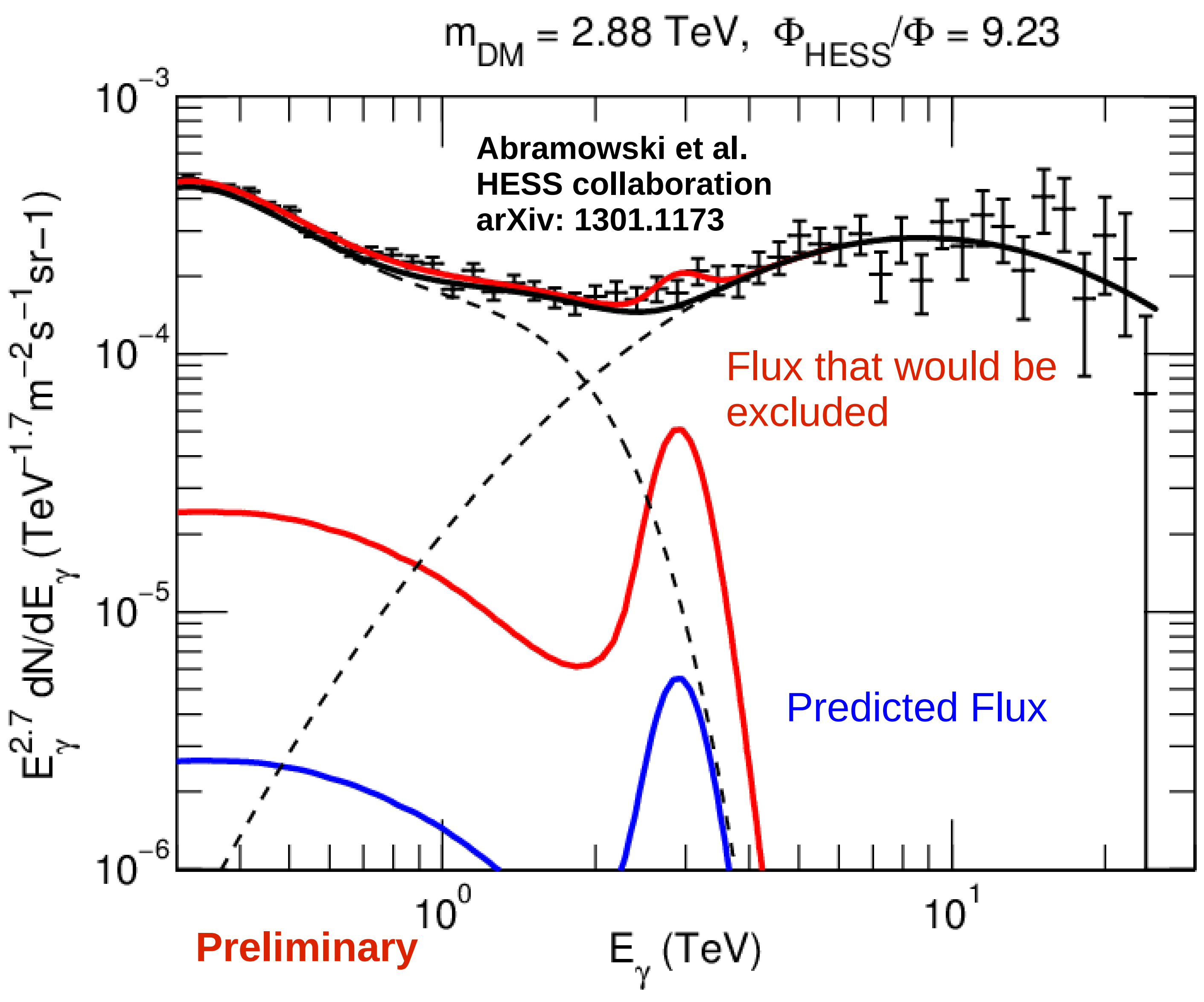

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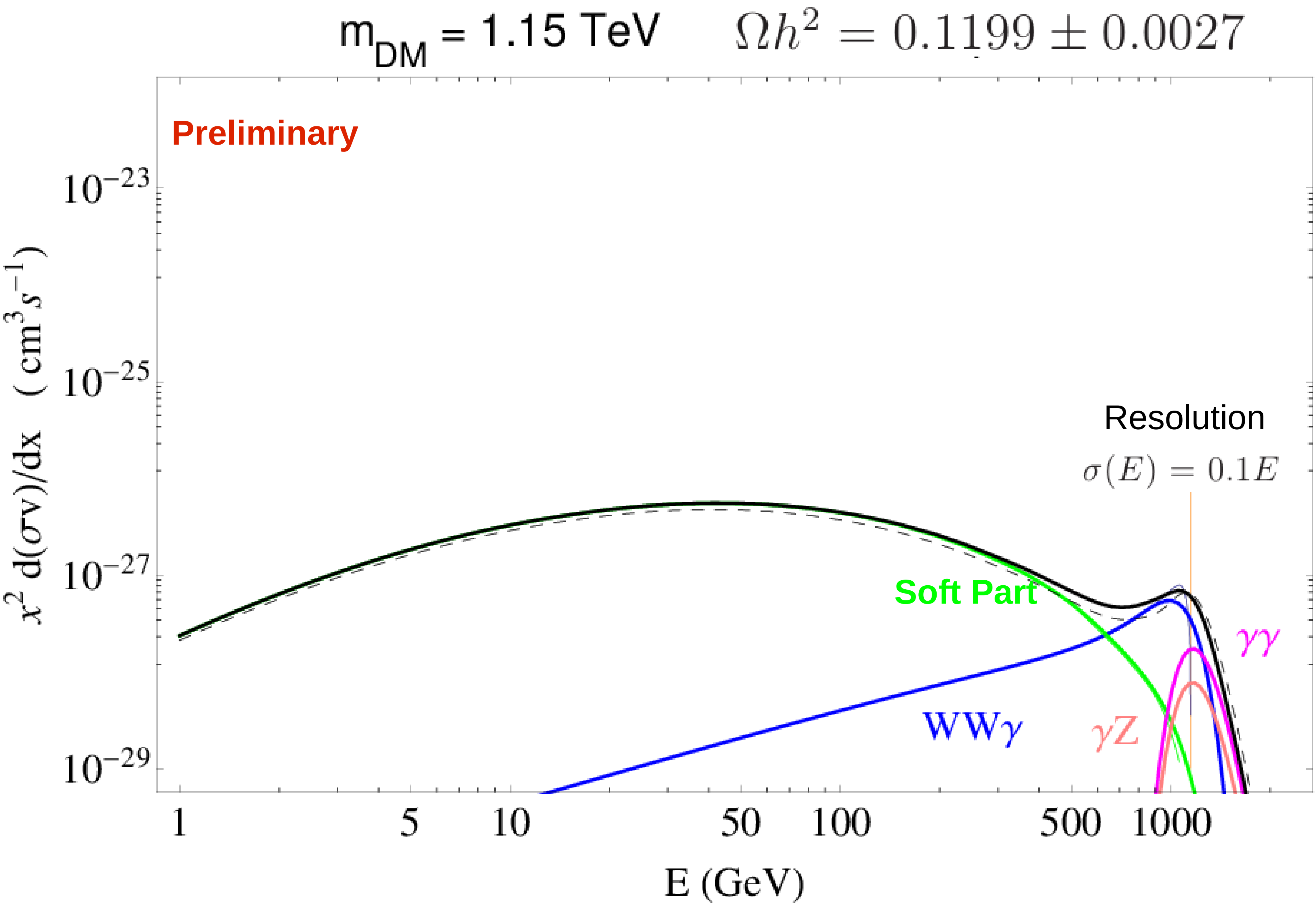

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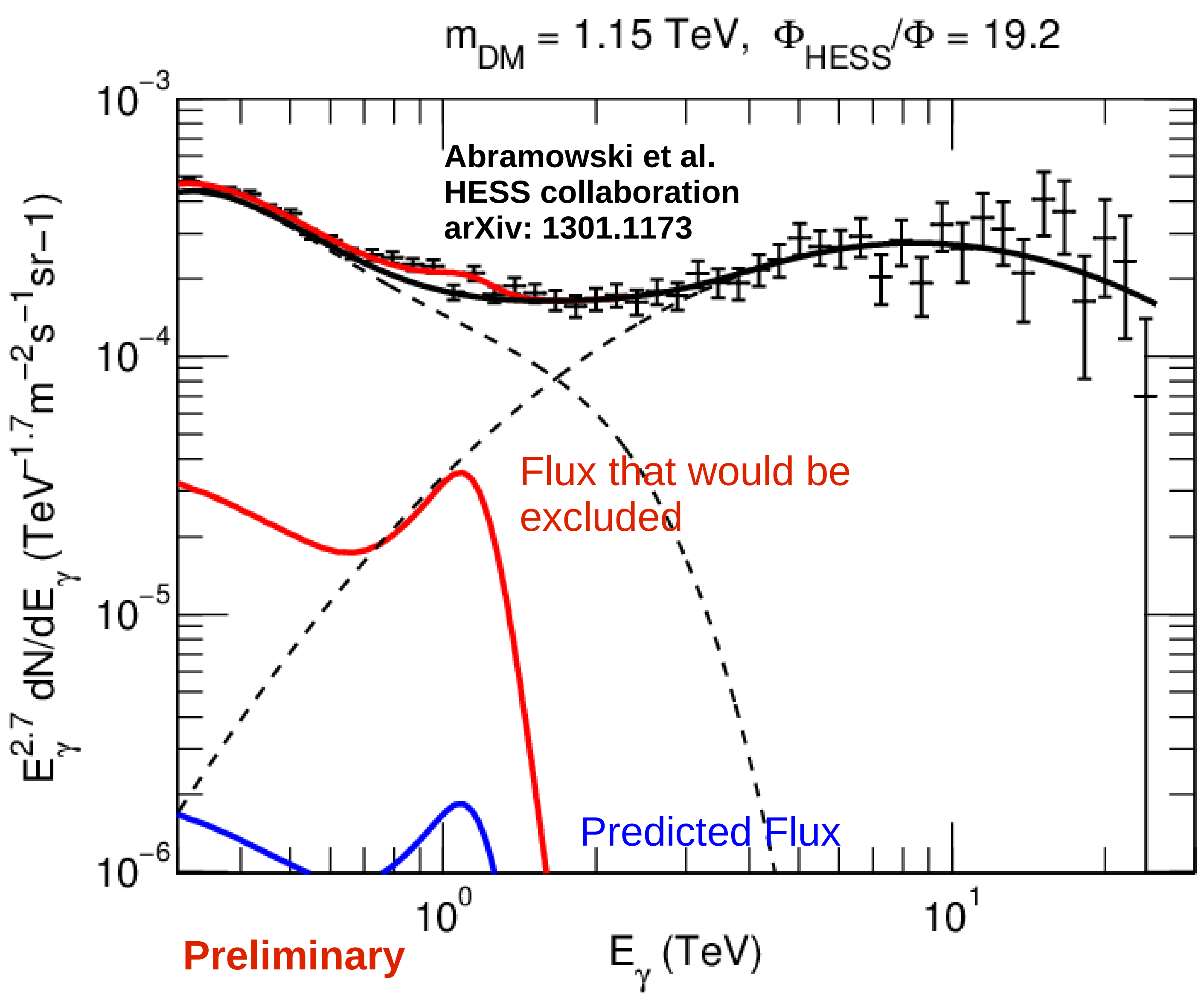
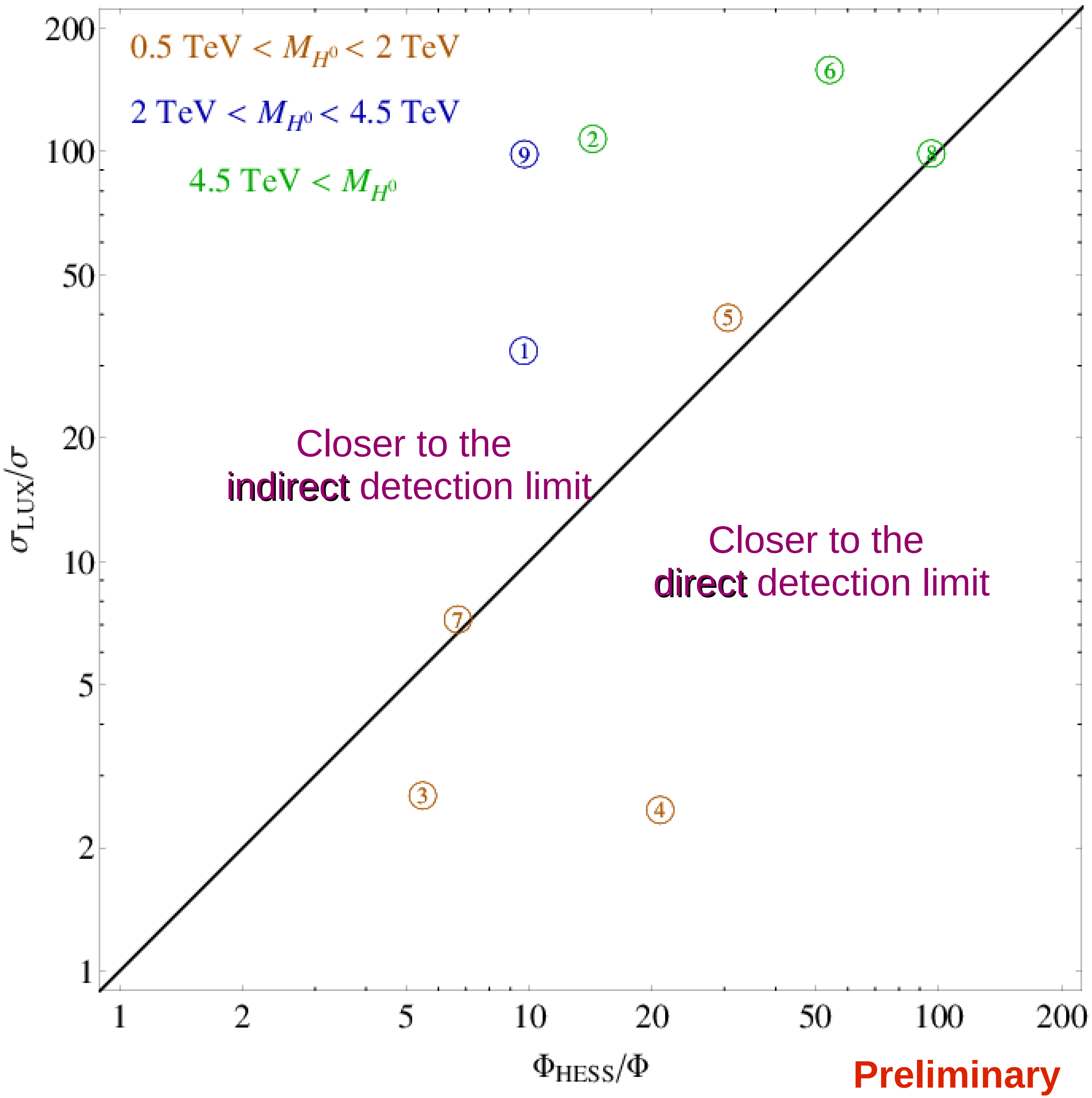
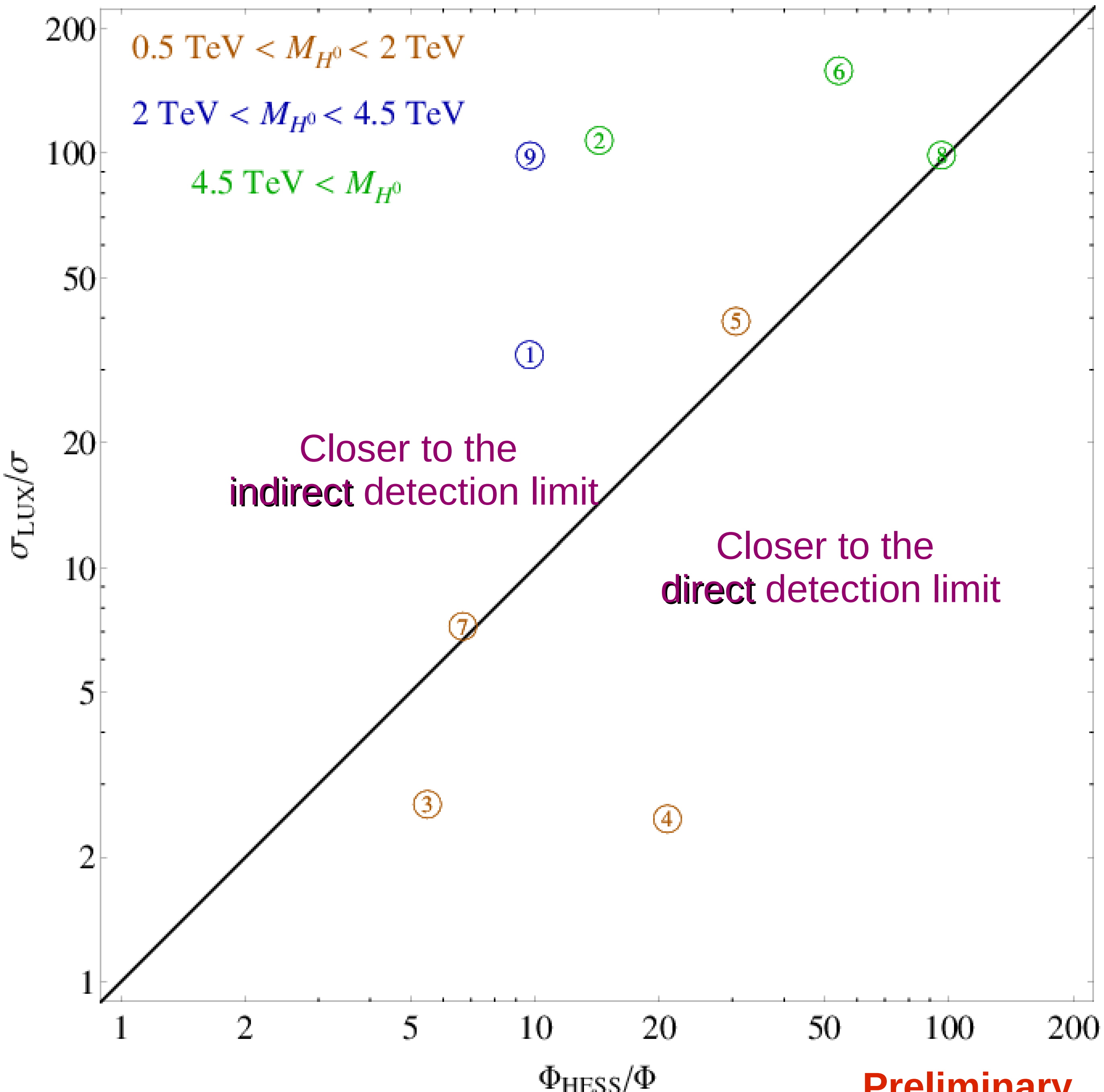


Direct Detection vs. Indirect Detection



Preliminary

Direct Detection vs. Indirect Detection



This includes one-loop effects

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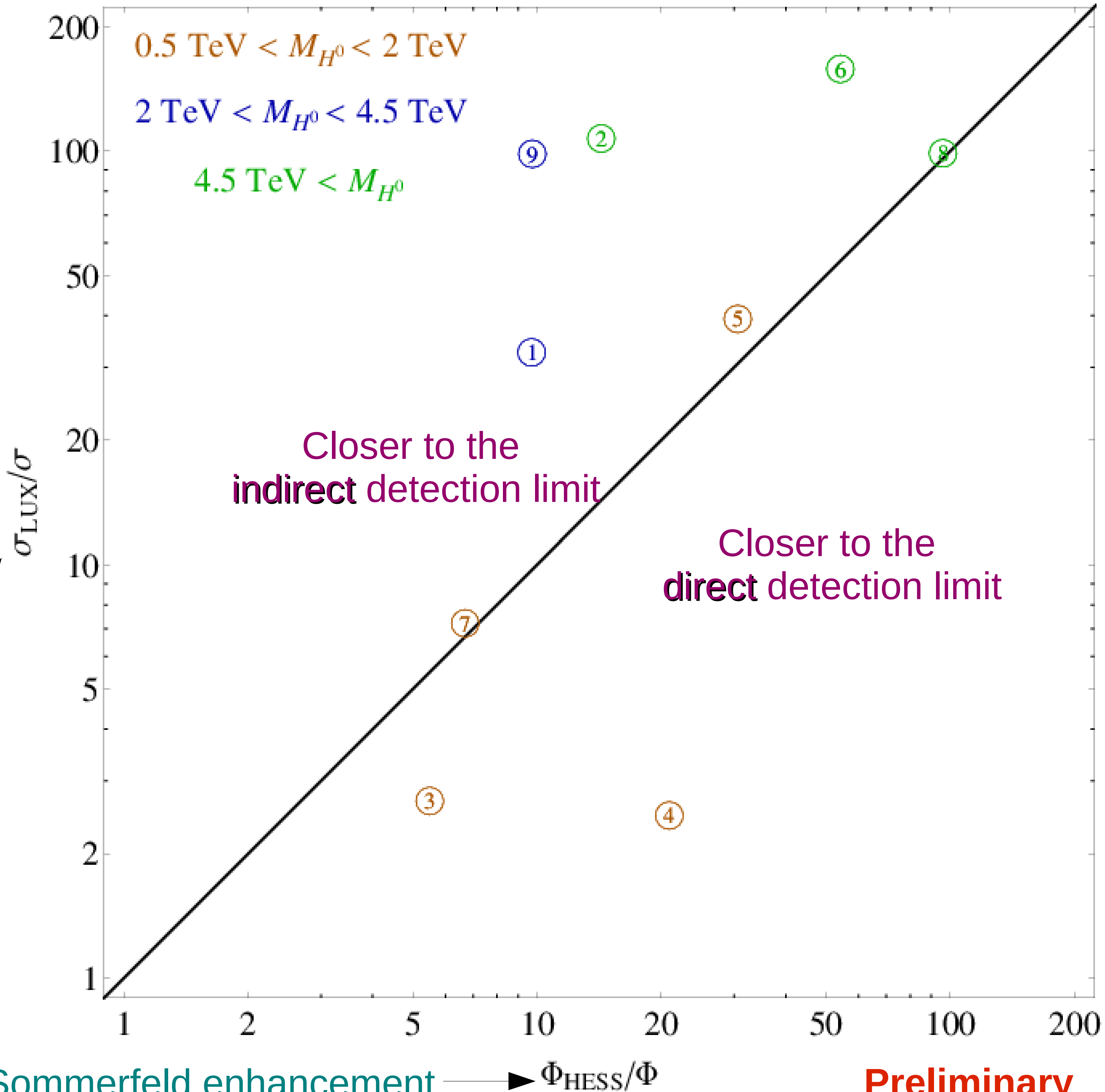

This includes one-loop effects

This includes Sommerfeld enhancement

Preliminary

Conclusions

- In the high mass regime of the inert doublet model, the internal bremsstrahlung process and annihilation into photons generate sharp gamma-ray spectral features.
- The Sommerfeld enhancement has to be taken into account.
- These spectral features can be searched for with gamma-ray telescopes, and eventally found or excluded in the near future.

Thank you for
your attention!!