New developments in MadDM - lines and loops

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MadDM v3.2

MadDM [1] is a numerical tool, plugin of MadGraph_aMC@NLO, able to compute dark matter observables for generic models. Version 3.2 updates the indirect detection module, extending it with the possibility to compute loop-induced processes in an automatised way. The feature relies on the use of an UFO dark matter model, obtained by using the Mathematica packages FeynRules and NLOCT [2]. The computation is addressed by the MadLoop [3] tool, already embedded in MadGraph_aMC@NLO.

Gamma-ray line indirect detection

Indirect detection looks for annihilation or decay products of dark matter in over-dense regions of galactic halos. We consider the annihilation of dark matter into two photons: in most models, dark matter does not couple directly to photons, so the process is loop-induced. It gives rise to a sharp line in the energy spectrum, considered as a smoking gun signature, hardly mimicked by any astrophysical background. In particular, every process of the kind DM DM $\to \gamma X$, gives rise to a peak in the energy spectrum at energy:

$$E_\gamma = m_{\mathrm{DM}}\left(1 - \frac{m_X^2}{4m_{\mathrm{DM}}^2}\right).$$

The flux of photons from a direction ψ in the sky, averaged over an angle $\Delta\psi$ is given by:

$$\frac{\mathrm{d}\Phi}{\mathrm{d}E}(E,\psi) = \frac{\langle\sigma v\rangle}{2m_{\mathrm{DM}}^2}\sum_i \mathcal{B}_i \frac{\mathrm{d}N_\gamma^i}{\mathrm{d}E}\frac{1}{4\pi}\int_\psi \frac{\mathrm{d}\Omega}{\Delta\psi}\int_{\mathrm{l.o.s.}}\rho^2(\psi,l)\,\mathrm{d}l\,.$$

- Spectrum weighted over branching ratio, $\frac{\mathrm{d}N_\gamma}{\mathrm{d}E} = k\cdot\delta(E-E_\gamma)$, with $k=2$, for $\gamma\gamma$ and $k=1$ otherwise.
- J-factor depending only on astrophysical quantities; $\rho(\psi,l)$ is the density profile (NFW, Einasto, Burkert, ...).

Line phenomenology with MadDM

The new command implemented in MadDM:

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MadDM> generate indirect_spectral_features
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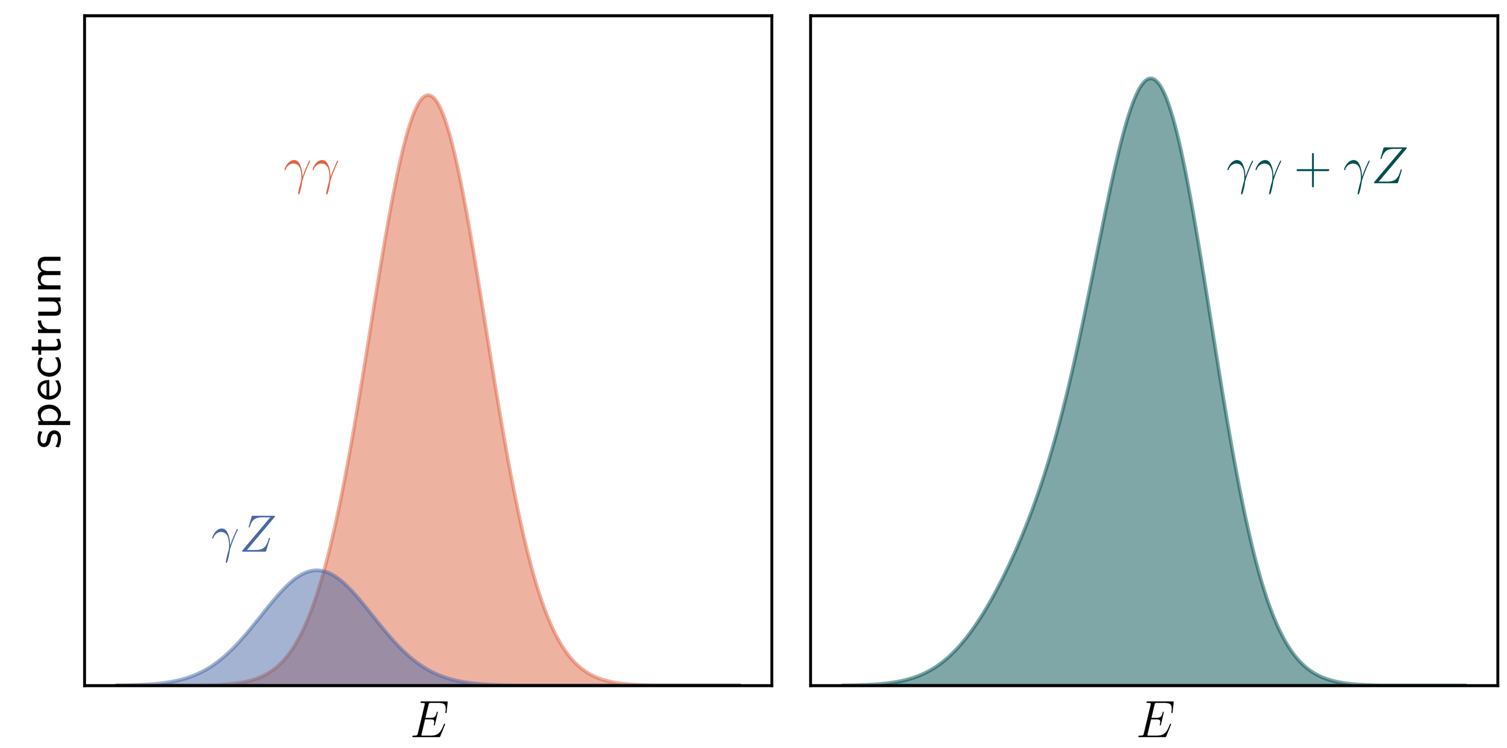
allows one to generate the diagrams for indirect detection final states γX, where X includes γ, Z, h and any additional BSM particle which transforms evenly under a Z_2 dark symmetry. MadDM will then compute the $\langle\sigma v\rangle$ for each process and will perform an analysis of the line spectrum, comparing the γ-ray flux with the upper limits from Fermi-LAT [4] and HESS [5] experiments. The line spectrum is smeared according to the energy resolution of the experiment. Multiple line signatures could overlap and appear as a single line, if sufficiently close in energy. We implemented an algorithm which takes care of this, eventually merging the lines which are too close and combining the fluxes.



The user is able to choose the main astrophysical parameters choosing the dark matter density profile and the Region Of Interest (ROI) relevant for the analysis:

- profile: NFW, Einasto, Burkert, Isothermal;
- Fermi-LAT: ROI 3°, 16°, 41°, 90°;
- HESS: ROI 1°.

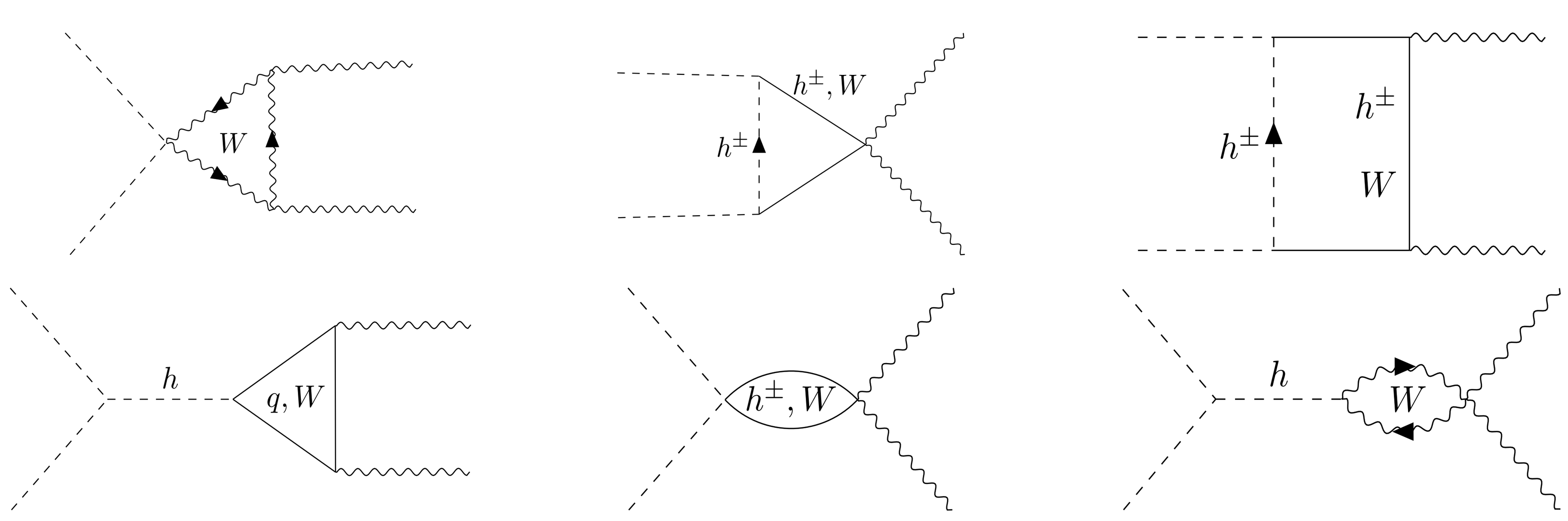
MadDM will take this into account by computing a new J-factor, and rescaling the upper limits on the basis of it. Moreover, for Fermi-LAT ROI 3° and 16° we implemented the likelihoods coming from the collaboration.

Physical applications: Inert Doublet Model (IDM)

The model is built on top of the Standard Model and contains an additional (*inert*) Higgs doublet Φ, odd under an exact Z_2 symmetry [6]. The potential reads:

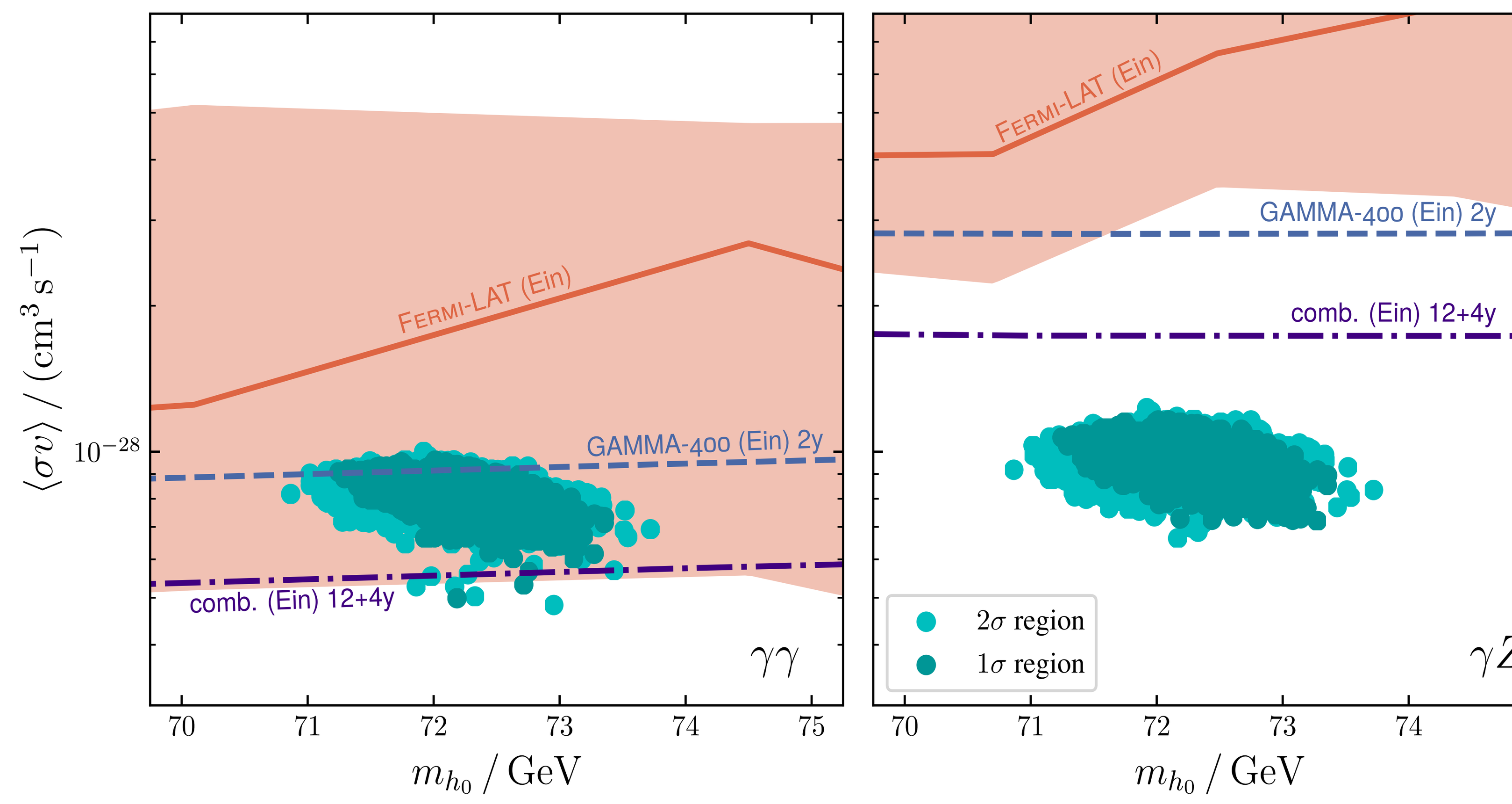
$$V = \mu_1^2|H|^2 + \mu_2^2|\Phi|^2 + \lambda_1|H|^4 + \lambda_2|\Phi|^4 + \lambda_3|H|^2|\Phi|^2 + \lambda_4|H^\dagger\Phi|^2 + \frac{\lambda_5}{2}\left[(H^\dagger\Phi)^2 + \mathrm{h.c.}\right].$$

After electroweak symmetry breaking $\Phi = \left(h^\pm, \frac{1}{\sqrt{2}}(h_0 + ia_0)\right)^{\mathrm{T}}$, the model contains five physical scalar states h, h_0, a_0, $h^\pm$. We also define $\lambda_{\mathrm{L,S}} = \frac{1}{2}(\lambda_3+\lambda_4\pm\lambda_5)$. We have five free parameters: m_{h_0}, m_{a_0}, $m_{h^\pm}$, λ_{L} and λ_2. We assume h_0 to be the dark-matter candidate (the choice of a_0 is equivalent). We exploited the capabilities of MadDM of computing loop-induced annihilations in $\gamma\gamma$ and γZ to constrain the parameter space of the model. Some examples of the loop-induced annihilation diagrams are:



We focus on a region around $m_{h_0} \simeq 72$ GeV, where the measured relic density can be explained by annihilation into WW^*, ZZ^* via the gauge kinetic interaction alone. This part of the parameter space is still uncontrained by current limits from LHC and direct detection. We employ the parameter scan performed in [6].

We only considered points allowed within the 2σ region taking into account constraints from the relic density, electroweak precision observables, new physics searches at LEP-II, indirect detection searches for continuous γ-ray spectra from dwarf spheroidal galaxies and theoretical requirements of unitarity, perturbativity and vacuum stability.



We show the following upper limits on the $\langle\sigma v\rangle$:

- Fermi-LAT, considering different density profiles (contracted NFW, Einasto, canonical NFW, Isothermal) using the ROI that have been optimised for these, so that the shaded area represents the uncertainty on the basis of the J-factor: the upper bound is given by the isothermal profile, while the lower bound is related to a contracted NFW profile;
- GAMMA-400 predictions, considering the sensitivity after 2 years of observations of the Galactic Centre in the case of the Einasto profile;
- combined limits from 12y Fermi-LAT and 4y GAMMA-400 (projected sensitivity), considering the case of the Einasto profile.

Discussion and conclusions

From the plot of the IDM parameter space, we can see that the loop-induced annihilation in $\gamma\gamma$ is constrained by Fermi-LAT searches. The parameter space is almost entirely excluded for the choice of the cuspy (contracted) NFW profile. On the other hand, future searches by the GAMMA-400 experiment has the potential to rule-out the parameter space also for the Einasto profile. Nevertheless, the limits are weaker for γZ final states. In summary, MadDM v3.2 allows the automatic computation of loop-induced annihilation of dark matter for generic models, relevant for γ-ray line searches. Those are strongly constrained by present and future experiments, given their clean astrophysical signature. *The code is in beta version now, a stable version will be released soon.*

References

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