130GeV gamma-ray line and DM model-building constraints from continuum gamma rays, radio and antiproton data

M. Vollmann M. Asano T. Bringmann G. Sigl

II. Institut für Theoretische Physik
Universität Hamburg

MITP Workshop "Cosmic-Rays and Photons from Dark Matter Annihilation: Theoretical Issues"

Outline

The 130 GeV line

- Monochromatic γ-ray lines from the GC $\Rightarrow$ Smoking-gun signature for indirect searches of DM

The claim (arXiv: hep-ph/1203.1312; hep-ph/1204.2797)

- 43 month of *Fermi* data
- Optimized target regions analysis method

$\Rightarrow$ 3.2σ γ-ray line at $E_\gamma \sim 130\,\text{GeV}$

- If interpreted as $\chi\chi \to \gamma\gamma$, γZ or γH, $\Rightarrow \sigma v \sim 10^{-27}\,\text{cm}^3/\text{s}$ $M_\chi = \{130\,\text{GeV}, 145\,\text{GeV}, 155\,\text{GeV}\}$ respectively.
- DM interpretation in debate

Model-building constraints

- $\chi\chi \to \gamma\gamma$, γZ and $\gamma H \Longrightarrow$ 1-loop processes (χ's are electrically neutral)

Immediate questions

★ What kind of particles run on the loops?

★ If these are dominated by SM particles, how are associated tree-level processes related to the 1-loop one describing the line signal?

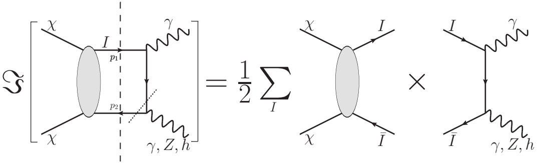
★ Can we relate them in a model-independent fashion?

$$\Downarrow$$

- "Generalized" Optical Theorem (see Abazajian et al (arXiv: hep-ph/1111.2835))
- ID (continuum γ's, $\bar{p}$'s, radio) searches put limits on those tree-level processes $\Rightarrow$ We use these limits to constraint the models

Optical Theorem

- We make use of the generalized Optical Theorem:



Conditions

- Interaction must respect CP and Lorentz invariance
- Initial $|i\rangle$ and final $|f\rangle$ $\Rightarrow$ eigenstates of the total angular momentum @ the CoM

Remark: Setting $|i\rangle = |f\rangle$ yields to the familar optical theorem

Optical Theorem (Cont.)

- Master formula

$$r_{i\to f} \equiv \frac{\Im[\mathcal{M}_{i\to f}]^2}{|\mathcal{M}_{i\to f}|^2} \propto \frac{\sum_I \sigma_{i\to I} \sum_I \langle \sigma v \rangle_{f\to I}}{\langle \sigma v \rangle_{i\to f}}$$

allows the user to set constraints on the observable quantity $\Im[\sigma v]_{i\to f} \equiv r_{i\to f} \langle \sigma v \rangle_{i\to f}$, if he follows the following

Procedure

- Compute SM prediction of $\sum \sigma_{i\to I}$
- $\sum \langle \sigma v \rangle_{f\to I}$ → Constraints from continuum γ's, $\bar{p}$'s and radio
- $\langle \sigma v \rangle_{i\to f}$ → Claimed value ($\sim 10^{-27}\,\mathrm{cm}^3/\mathrm{s}$)

Computation of tree-level amplitudes in the SM

1. Initial state $|i\rangle = |\chi\chi\rangle \Rightarrow$ s-wave ($L = 0$)
   ↖ Squared amplitudes of partial waves of superior order ($L > 0$) go like β^{2L} when $\beta \to 0$ (typically $\langle\beta^2_{DM}\rangle \sim 10^{-6}$)
2. Use CP & Lorentz symmetry to determine $|i\rangle$, $|I\rangle$ and $|f\rangle \Rightarrow$ you are left with just a handful of possible states!!
3. Decompose amplitudes in terms of helicity eigenstates
4. Use Feynmann rules
5. Integrate over phase space

Limits from indirect detection

- $\chi\chi$ annihilation products undergo several interesting physical processes
  - Fragment into stable particles such γ's, $\bar{p}$'s and $e^{\pm}$'s
  - $e^{\pm}$ diffuse and may
    - Scatter with a CMB photon and produce high-energy γ's
    - Interact with the galactic magnetic field and emit synchrotron radiation

$$\Downarrow$$

Fairly well understood expected Continuum gamma-ray, antriproton and synchrotron radiation fluxes.

These suffer from several astrophysical uncertainties, though.

Continuum gamma-rays

Gamma-ray emission by DM-annihillation is well described by

$$\gamma\text{ -diff. flux} = \frac{1}{8\pi m_\chi^2} \sum_{\text{ann. chann.}} \sigma v \frac{\mathrm{d}N}{\mathrm{d}E_\gamma} \underbrace{\int_{\Delta\Omega} \mathrm{d}\Omega \int_{\text{l.o.s.}} \mathrm{d}s \rho_\chi(r)^2}_{J_{\text{astro}}} .$$

Likelihood fits to observations enable to constraint several annihilation channels. We use the following

Observations analyses

- Dwarf spheroidal galaxies by Fermi collaboration (arXiv:astro-ph/1108.3546)
- Galactic Centre (Cholis et al. arXiv:hep-ph/1207.1468)
  - Slightly different DM profile than the one in Weniger's hep-ph/1204.2797

$\Rightarrow$ Rescale J_{astro}

Antiprotrons

Diffusive propagation of antiprotons in the galaxy is described by a diffusion eq. where

- The antiproton yield (→ source function Q) was computed by using DarkSUSY
- We use two different propagation prescriptions (see Evoli et al. astro-ph.HE/1108.0664)
    - "KRA" ($L = 4\,\mathrm{kpc}$)
    - "CON" ($L = 10\,\mathrm{kpc}$)

Data analysis

- PAMELA data (arXiv:1007.0821)
    - Prescription: Minimally expected astrophysical background+signal $<$ Data+3σ

Synchrotron radiation

Synchrotron radiation produced by high-energy $e^{\pm}$ is given by

$$\nu \frac{\mathrm{d}W_{\text{synch.}}}{\mathrm{d}\nu} \approx \frac{1}{2m_\chi^2} \sum_{\text{ann. chann.}} \sigma v \int_{\text{cone}} \mathrm{d}V E_c \rho_\chi^2(r) N_e(E_c)$$

$$E_c(r) = 0.46\,\mathrm{GeV} \left(\frac{\nu}{\mathrm{GHz}}\right)^{1/2} \left(\frac{\mathrm{mG}}{B(r)}\right)^{1/2}$$

- Galactic magnetic field

$$B(r) = 7.2\,\mathrm{mG} \times \begin{cases} (R_{\text{acc}}/r)^{5/4} & r < R_{\text{acc}} \\ (R_{\text{acc}}/r)^2 & R_{\text{acc}} < r \lesssim 100 R_{\text{acc}} \\ 10^{-4} & r \gtrsim 100 R_{\text{acc}} \end{cases}$$

- Prescription: $\nu \frac{\mathrm{d}W_{\text{synch.}}}{\mathrm{d}\nu}\Big|_{\nu = 408\,\mathrm{MHz}} < 50\,\mathrm{mJy}$

Constraints on the model-building

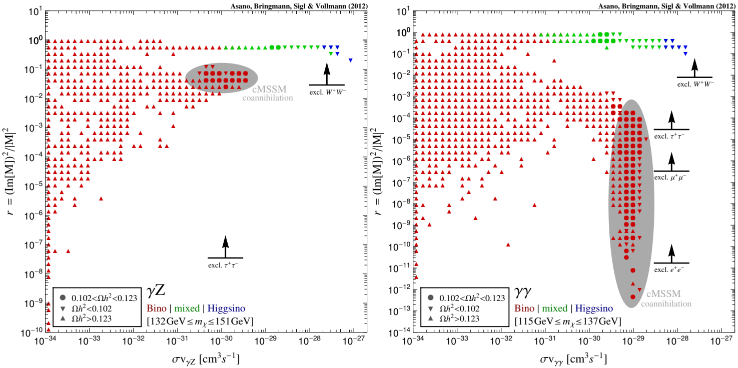
Constraints on $r_{i\to f}$

Majorana WIMP	cont. gamma *limit* (GC)	antiproton *limit* ('KRA', $L = 4\,\mathrm{kpc}$)	synchrotron *limit* (full cone)
$b\bar{b}$	6.0×10^{-6} (5.3×10^{-6})	3.0×10^{-6} (2.8×10^{-6})	7.8×10^{-6} (7.2×10^{-6})
$\tau^+\tau^-$	2.9×10^{-5} (3.5×10^{-8})	—	5.3×10^{-5} (6.8×10^{-8})
$\mu^+\mu^-$	5.1×10^{-7} (5.6×10^{-10})	—	3.3×10^{-7} (4.4×10^{-10})
e^+e^-	1.7×10^{-11} (1.4×10^{-14})	—	1.9×10^{-11} (2.6×10^{-14})
W^+W^-	0.021 (0.074)	7.9×10^{-3} (0.029)	0.025 (0.10)

Scalar WIMP	cont. gamma *limit* (GC)	antiproton *limit* ('KRA', $L = 4\,\mathrm{kpc}$)	synchrotron *limit* (full cone)
$b\bar{b}$	6.0×10^{-6} (5.7×10^{-6})	3.0×10^{-6} (3.0×10^{-6})	7.8×10^{-6} (7.7×10^{-6})
$\tau^+\tau^-$	2.9×10^{-5} (3.7×10^{-8})	—	5.3×10^{-5} (7.2×10^{-8})
$\mu^+\mu^-$	5.1×10^{-7} (5.8×10^{-10})	—	3.3×10^{-7} (4.5×10^{-10})
e^+e^-	1.7×10^{-11} (1.5×10^{-14})	—	1.9×10^{-11} (2.6×10^{-14})
W^+W^- (t)	0.023 (0.076)	8.8×10^{-3} (0.030)	0.028 (0.10)
W^+W^- (l)	1.2×10^{-3} (5.3×10^{-4})	4.5×10^{-4} (2.1×10^{-4})	1.4×10^{-3} (7.1×10^{-4})

Applications

Scan (DarkSUSY) over a selection of MSSM and cMSSM's with $m_\chi \approx 145\,\text{GeV}$



Conclusions

- Interesting debate on the 130 GeV line over the last several months
- Developed a general method constraining model-building, which only assumes Lorentz and CP symmetry
- Applied this formalism to DM particle physics models accounting for the 130 GeV line
  - The method can be adapted to several situations where model-independence is needed (e.g. arXiv: hep-ph/1111.2835)
- Revised the commonly used methodology used in deriving (radio) constraints
- Demonstrated usefulness of the method by considering a large set of models