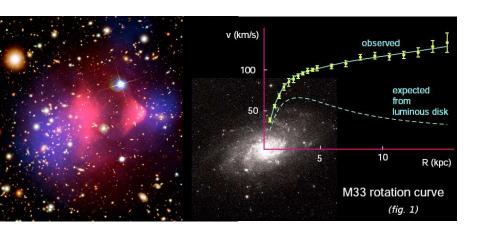# Anti proton constraints from electroweak bremsstrahlung in dark matter annihilations

arXiv:1105.5367 [hep-ph]
JCAP07(2011)028
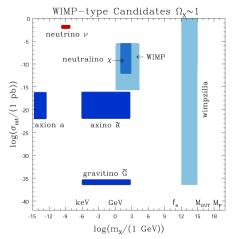Alejandro Ibarra, Mathias Garny, Stefan Vogl

Stefan Vogl

ΠΙΠ

Technische Universität München

Why do we need Dark Matter?

M33 rotation curve
(fig. 1)

- there is a compelling list of cosmological and astrophysical indications for the existence of dark matter
- rotation curves, weak gravitational lensing, bullet cluster and so on

What is Dark Matter?

- we don't know any properties like mass, spin, interaction strength
- there are a number of candidates that are motivated by particle physics

WIMP-type Candidates $\Omega_\chi \sim 1$

A Majorana Fermion as Dark Matter

- a possible choice for Dark Matter is a Majorana Fermion
- most popular example of Majorana dark matter: the neutralino
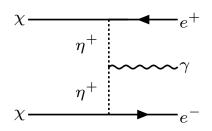- thermally averaged cross section $\langle \sigma_{ann} v \rangle$ can be expanded as

$$\langle \sigma_{ann} v \rangle = a + b v^2 + \mathcal{O}(v^4)$$

- today $v \approx 10^{-3}$, this means that the p-wave is strongly suppressed
- for Majorana fermions annihilation in two light fermions in s-wave is suppressed by chirality

$$\langle \sigma_{ann} v \rangle \approx a \approx \frac{m_f^2}{m_{DM}^2}$$
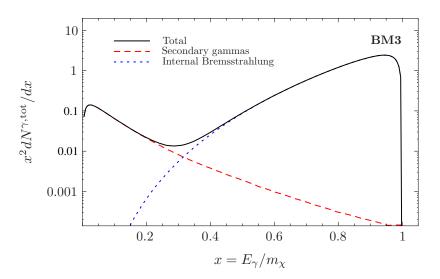
A Gamma feature from bremsstrahlung

- the annihilation of Majorana Dark Matter χ into a pair of light fermions $f\bar{f}$ is suppressed in the non relativistic limit
- $\chi\chi \to f\bar{f}\gamma$ lifts this suppression and can lead to a hard feature in the γ spectrum [Bergström, Bringmann, Edsjö 08]
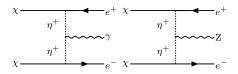
Gamma feature

A minimal anti proton signal from bremsstrahlung

- the suppression can be lifted as well by the emission of electroweak gauge-bosons $W^{\pm}$ and Z

- the fragmentation of $Z, W^{\pm}$ leads to the minimal production of anti protons that is associated with a gamma-ray feature

Toy Model

- Making room for Dark Matter: add a Majorana fermion χ as dark matter and a scalar η to the Standard Model, with $m_\chi < m_\eta$

- The charges under $SU(3)_C \times SU(2)_L \times U(1)_Y$ are

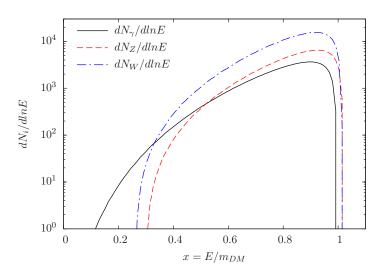$$\chi \equiv (1, 1, 0), \quad \eta = \begin{pmatrix} \eta^+ \\ \eta^0 \end{pmatrix} \equiv (1, 2, 1/2)$$

and η carries electron lepton number $L_e = -1$, which prevents coupling to quarks, or μ and τ

- The Lagrangian for the interaction of χ with fermions reads [motivated by Ma 01]

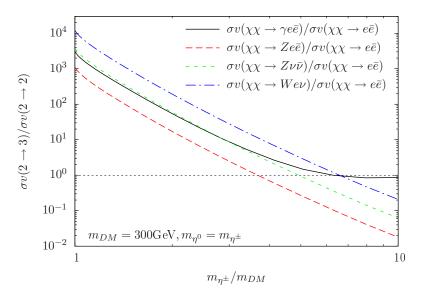$$\mathcal{L}_{\text{int}}^{\text{fermion}} = f\bar{\chi}(\nu_{eL}\eta^0 - e_L\eta^+) + \text{h.c.}$$

- In this setup the production of the heavy gauge bosons $W^\pm$ and Z in a three body final state is the only mechanism for sizable $\bar{p}$ production.

- the toy model allows an easy access to the phenomenology of this process and offers the possibility to calculate constraints on the total allowed cross section

gauge boson spectra

Spectrum of photons, $W^{\pm}$, and Z produced by internal bremsstrahlung for $m_{\chi} = 300$GeV and $m_{\eta^0} = m_{\eta^{\pm}} = 330$GeV
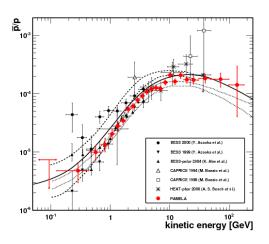
How important can the three body final state be?

$m_{DM} = 300\,\text{GeV}, m_{\eta^0} = m_{\eta^\pm}$

Legend:
- $\sigma v(\chi\chi \to \gamma e\bar{e})/\sigma v(\chi\chi \to e\bar{e})$
- $\sigma v(\chi\chi \to Z e\bar{e})/\sigma v(\chi\chi \to e\bar{e})$
- $\sigma v(\chi\chi \to Z \nu\bar{\nu})/\sigma v(\chi\chi \to e\bar{e})$
- $\sigma v(\chi\chi \to W e\nu)/\sigma v(\chi\chi \to e\bar{e})$

y-axis: $\sigma v(2 \to 3)/\sigma v(2 \to 2)$

x-axis: $m_{\eta^\pm}/m_{DM}$

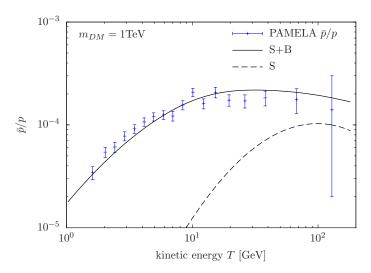- IB dominates over the two body process for doublet masses $m_{\bar{\eta}} < 5 m_\chi$

Pamela anti proton to proton flux ratio

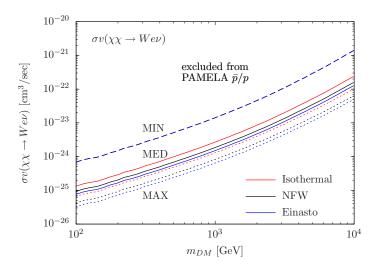- the anti proton to proton flux ratio measured by Pamela is described well by astrophysical sources

PAMELA anti proton to proton flux ratio

The anti proton to proton ratio for a dark matter mass of 1 TeV and with a cross section of $1.87 \times 10^{-24}\,cm^3 s^{-1}$ against the PAMELA data
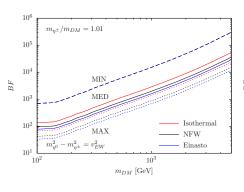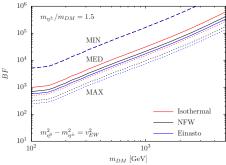
Bounds on the cross section

Upper bound on the cross section $\langle \sigma v(2 \to 3) \rangle$ calculated from the PAMELA data on the cosmic anti proton to proton ratio.

Boost factors for thermal production

- there are a few arbitrary constants in the model, notably the coupling f and the masses of the scalar m_η.
- demanding thermal production determines the coupling for a given set of masses and allows the calculation of the maximal boost factors consistent with observations

Application to the MSSM

- electroweak bremsstrahlung appears also in the MSSM
- we analyze a number of mSUGRA benchmark points that are known to exhibit a pronounced gamma ray feature [Bringmann, Doro, Fornasa 09]

Model	m_{DM} [GeV]	BF $(\bar{p}/p)$ Med total	BF $(\bar{p}/p)$ Med $2 \to 3$
BM2	453	< 5900	$< 1.3 \cdot 10^5$
BM3	234	< 1500	$< 1.3 \cdot 10^4$
BMJ$'$	316	< 330	$< 3.5 \cdot 10^4$
BMI$'$	141	< 11	< 6900

Table: Upper limits on the boost factor BF in the Milky Way obtained from the PAMELA $\bar{p}/p$ data for several MSSM benchmark points at 95%C.L. The number in brackets correspond to the boost factors from $2 \to 3$, while those without include channels with quark production

- for more realistic models the constraints on the boost factor get stronger by a factor of at least 10 when other anti proton sources are taken into account

Conclusion

- the chirality suppression of $\chi\chi \to e^+ e^-$ is efficiently lifted by the emission of W$^\pm$ or Z for m_η comparable to m_χ
- for $m_{\text{dark matter}} \geq \frac{m_W}{2}$ gamma rays from electromagnetic bremsstrahlung are always accompanied by electroweak bremsstrahlung and thus anti protons
- the maximal allowed thermally averaged cross section $\sigma v(2 \to 3)$ can be of order $10^{-24} \frac{cm^3}{s}$ for reasonable choice of halo and propagation model
- in models that are not strictly leptophilic constraints from anti protons are even more stringent