Anti proton constraints from electroweak bremsstrahlung

arXiv:1105.5367 [hep-ph]

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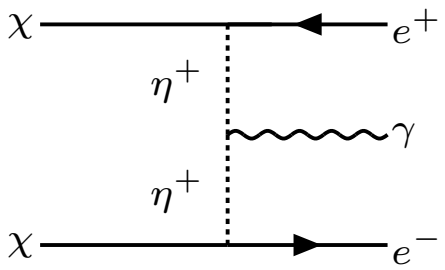
A minimal anti proton signal from bremsstrahlung

- 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]



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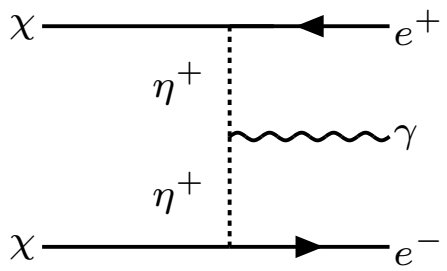
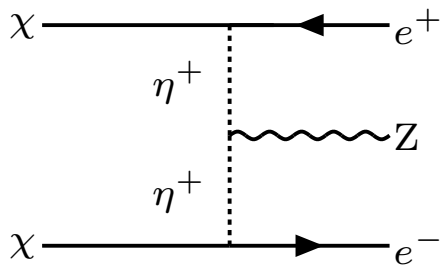


- the suppression can be lifted as well by the emission of electroweak gauge-bosons $W^{\pm}$ and Z



- 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

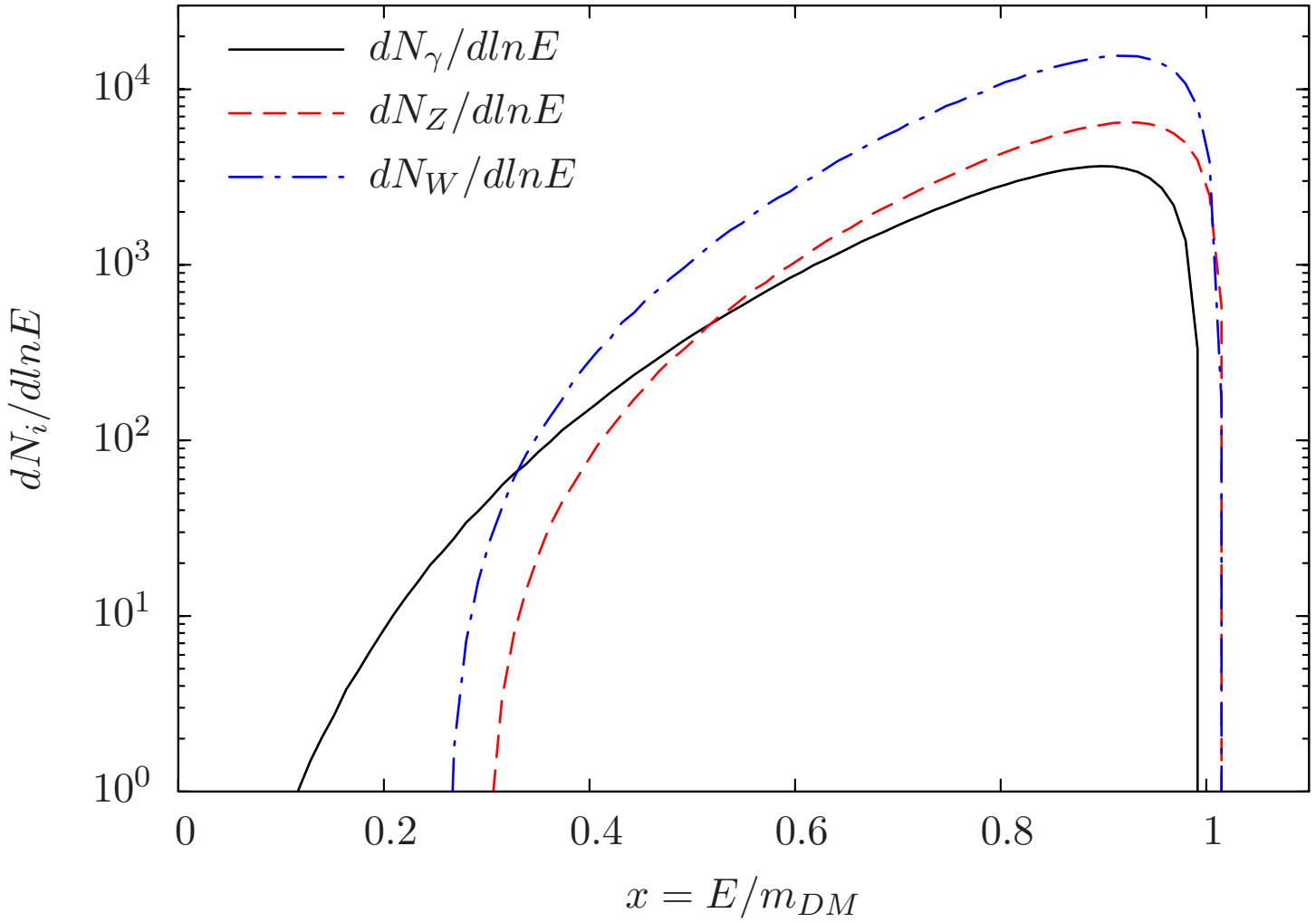
$$\chi \equiv (1,1,0), \quad \eta = \begin{pmatrix} \eta^+ \\ \eta^0 \end{pmatrix} \equiv (1,2,1/2)$$

  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]

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

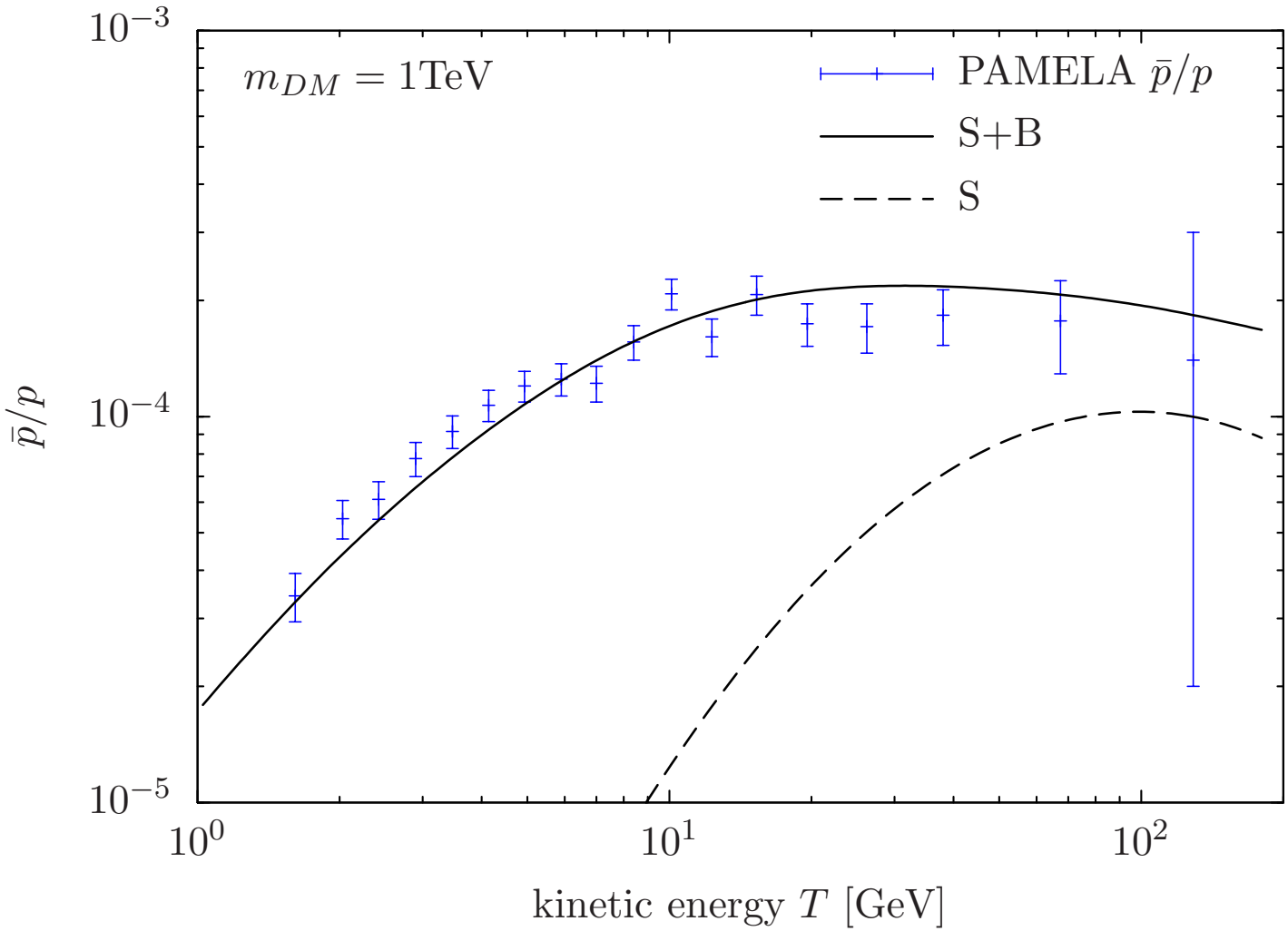
- In this setup the production of the heavy gauge bosons $W^\pm$ and Z in a three body final state is the only mechanism for sizable $\bar{p}$ production.
- the toy model allows an easy access to the phenomenology of this process and offers the possibility to calculate constraints on the total allowed cross section

gauge boson spectra



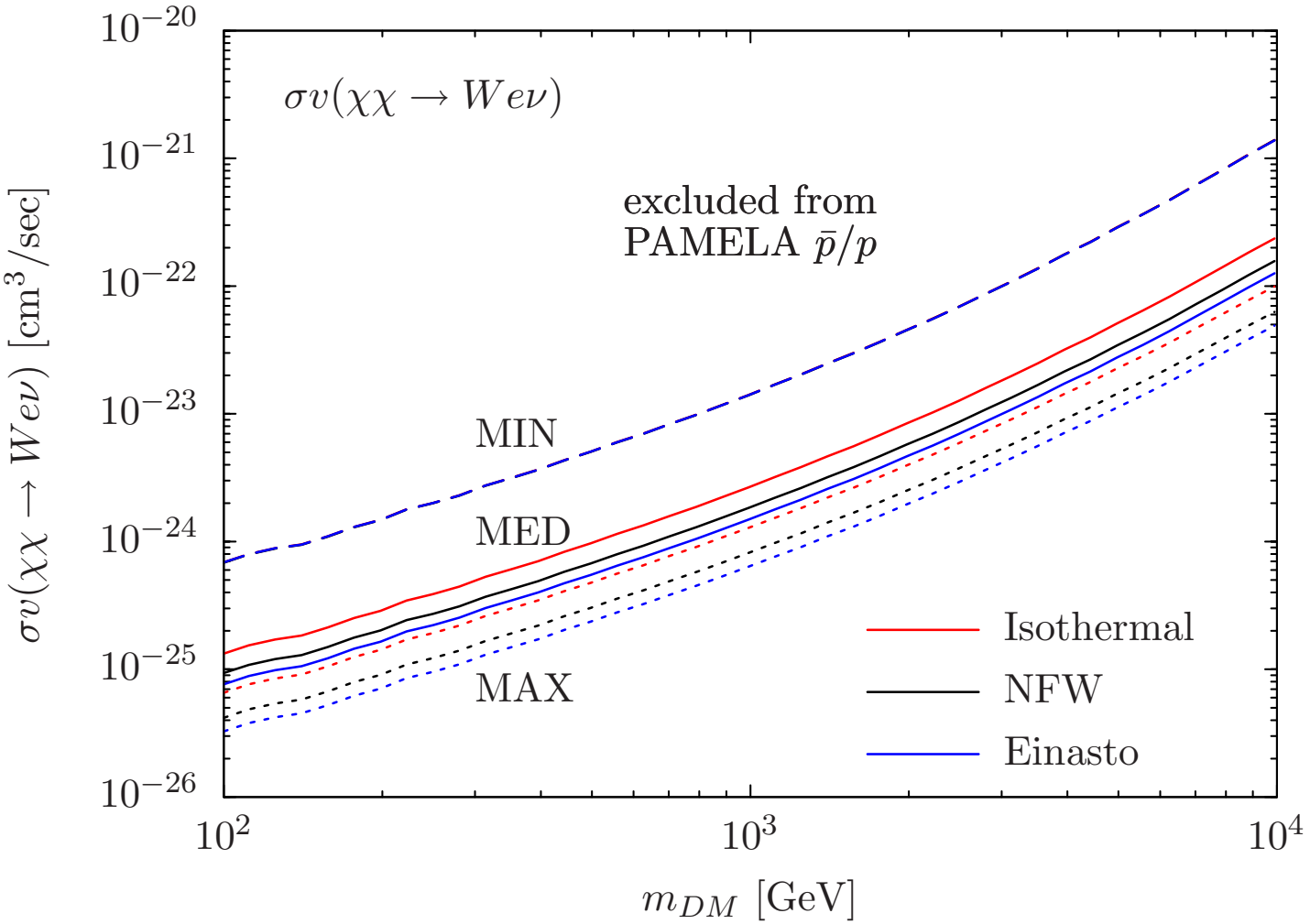
Spectrum of photons, $W^{\pm}$, and Z produced by internal bremsstrahlung for $m_\chi = 300\text{GeV}$ and $m_{\eta^0} = m_{\eta^\pm} = 330\text{GeV}$

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

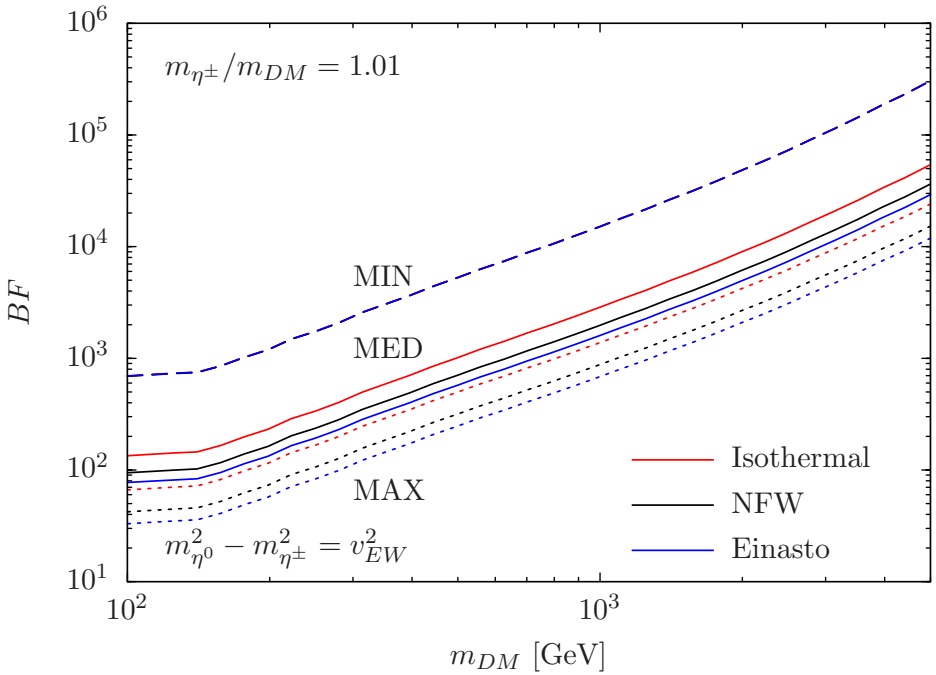
Bounds on the cross section

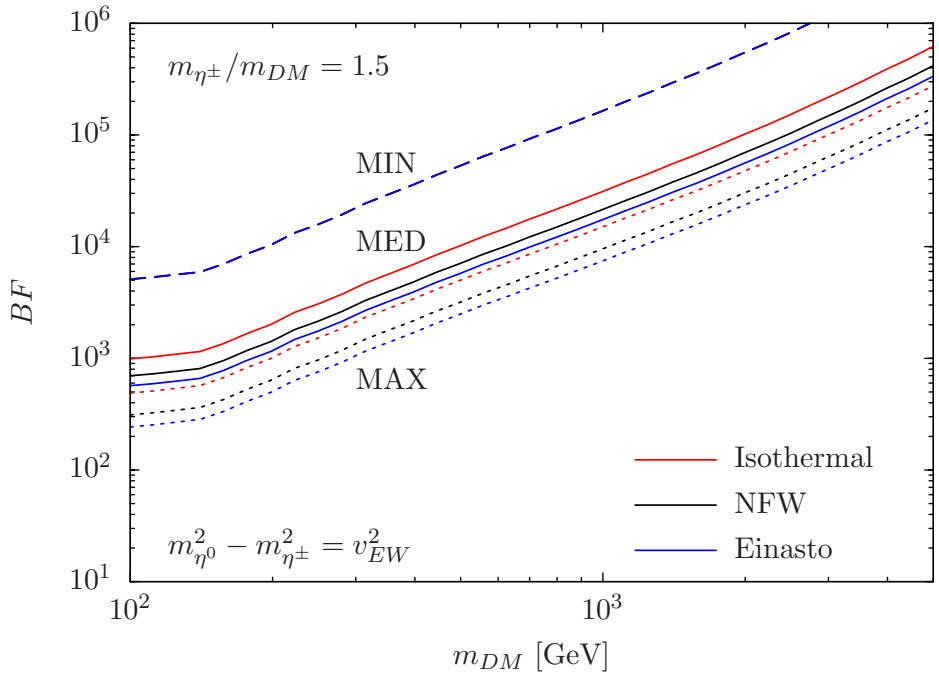


Upper bound on the cross section $\langle \sigma v(2 \to 3) \rangle$ calculated from the PAMELA data on the cosmic anti proton to proton ratio.

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