Brane vector dark matter

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Introduction

We consider the effective theory describing the Standard Model on a brane in an embedding space.

The effective theory generically contains additional scalar fields (global case) or massive vector fields (local case) associated with the spontaneous breaking of the translation symmetries.

These degrees of freedom can be stable and they can have weak scale masses and interactions. Hence they are dark matter candidates.

In this talk I consider the bounds on the parameters of the effective theory based on the observed dark matter relic abundance (WMAP) and the results of direct dark matter detection experiments (CDMSII, Xenon10), with a particular focus on extrinsic curvature interactions.

Other talks concerning the same model at this conference:

"Higgs Decays and Brane Graviphotons," Sherwin Love, 3.15 pm, this afternoon, Extra Dimensions session.

"Brane Osciallation at the TeVatron and LHC," Thomas Clark, 3.30 pm, this afternoon, Extra Dimensions session.

The Model

Fields:

X_μ brane vector field

$F_{\mu\nu}$ field strength for brane vector field

$B_{\mu\nu}$, $\tilde{B}_{\mu\nu}$ field strength for hypercharge gauge field, and dual

$$L_{SMX} = L_{SM} - \frac{1}{4} F^{\mu\nu} F_{\mu\nu} + \frac{1}{2} M_X^2 X_\mu X^\nu + \frac{1}{2} \frac{M_X^2}{F_X^4} X^\mu T^{SM}_{\mu\nu} X^\nu$$

$$+ \frac{M_X^2}{F_X^4} \left(\kappa_1 B_{\mu\nu} + \kappa_2 \tilde{B}_{\mu\nu}\right) \partial^\mu X^\rho \partial_\rho X^\nu$$

← extrinsic curvature interaction

Parameters:

F_X^4 brane tension

M_X brane vector mass

κ_1, κ_2 dimensionless coupling constants

Additional comments

The displayed action is the leading part of an underlying action that is invariant under all Standard Model symmetries and the non-linearly realized symmetries corresponding to extra dimensions. That underlying invariant action was constructed using the coset method

An additional coupling of the brane vector to the Higgs bilinear invariant can also be included in the action but will not be consider it here.

A flavor index for the brane vector has been suppressed. There is one flavor of brane vectors for each additional dimension. In this talk I will focus on the case of a single flavor. Generalization of the results is trivial.

The link with the globally invariant action can be made with the identification

$$\frac{M_X^2}{F_X^4} X^\mu \longleftrightarrow \partial^\mu \varphi$$

← Goldstone boson

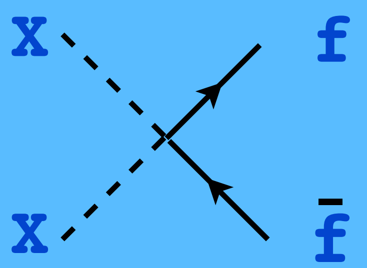
P. Creminelli, A. Strumia

J. A. R. Cembranos, A. Dobado, A. L. Maroto

Note that the extrinsic curvature interaction terms identically vanish in the global case.

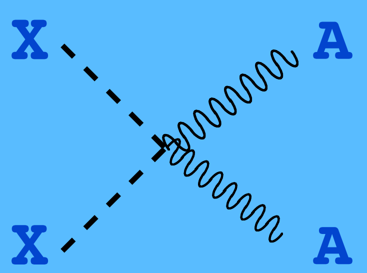
Relic Density Calculation

Brane vector annihilation cross-sections: (non-relativistic limits shown)



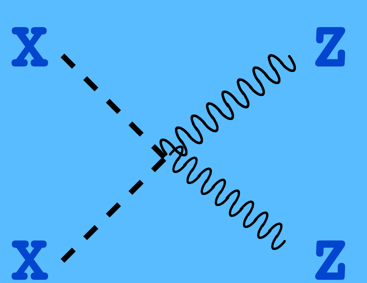
$$\frac{1}{72\,\pi}\;\frac{MX^2}{F_X^8}\;\frac{\sqrt{MX^2 - mf^2}\,\left(MX^4 - mf^4\right)}{\sqrt{s - 4\,MX^2}}$$

universal for all SM fermions

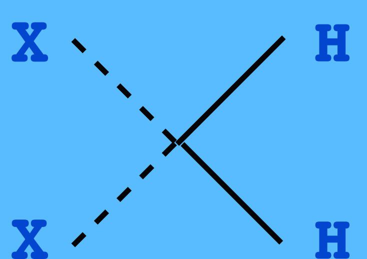


$$\frac{1}{144\,\pi}\;\frac{MX^2}{F_X^8}\;\frac{\sqrt{MX^2 - M_H^2}\,\left(2\,MX^4 + M_H^4\right)}{\sqrt{s - 4\,MX^2}}$$

$$\sqrt{s - 4\,MX^2} \longrightarrow 2\,MX\,v$$

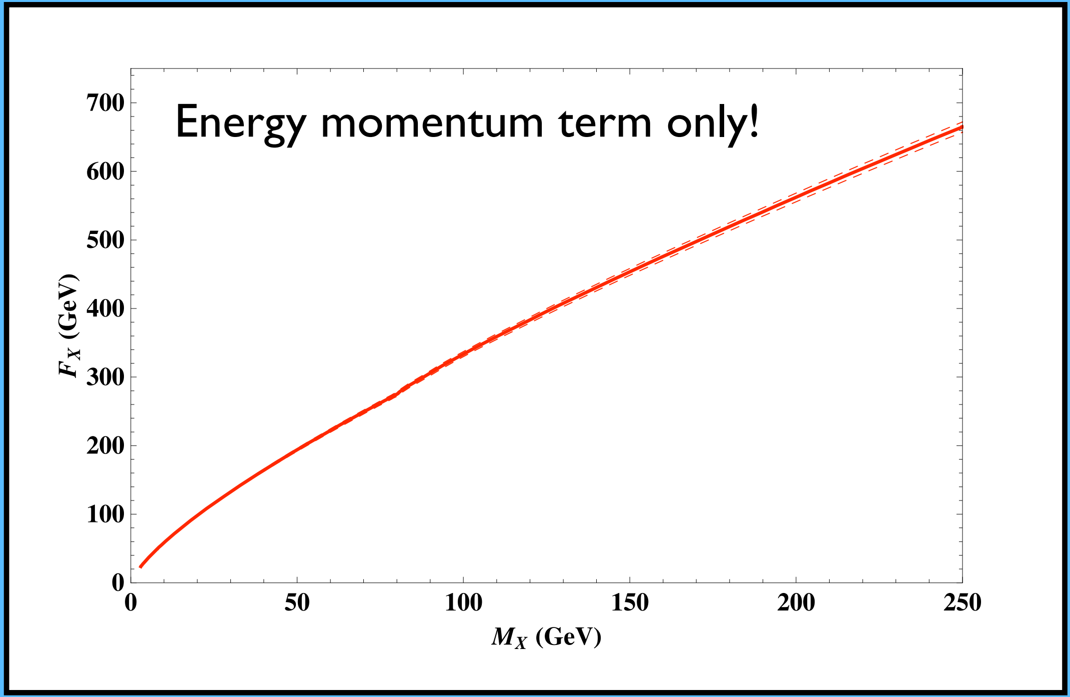


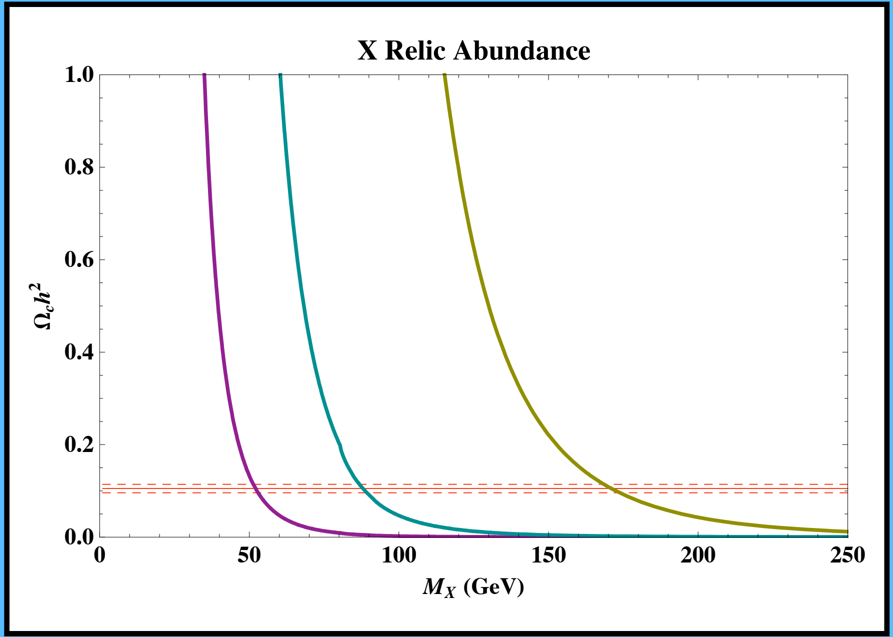
$$\frac{1}{18\,\pi}\;\frac{MX^7}{F_X^8}\;\frac{1}{\sqrt{s - 4\,MX^2}}$$

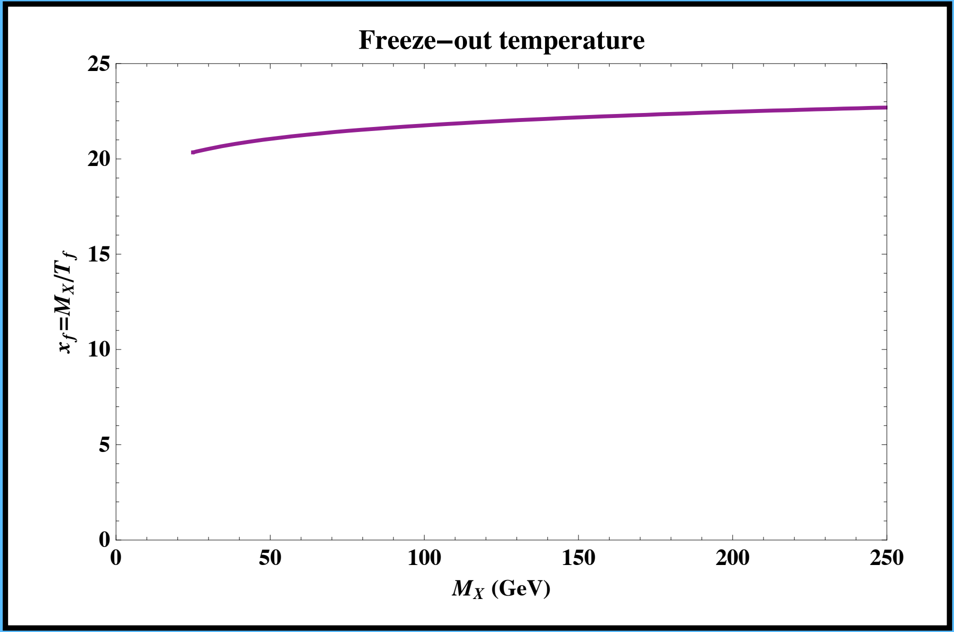


$$\frac{1}{144\,\pi}\;\frac{MX^2}{F_X^8}\;\frac{\sqrt{MX^2 - M_Z^2}\,\left(10\,MX^4 + 8\,MX^2\,M_Z^2 + 3\,M_Z^4\right)}{\sqrt{s - 4\,MX^2}}$$

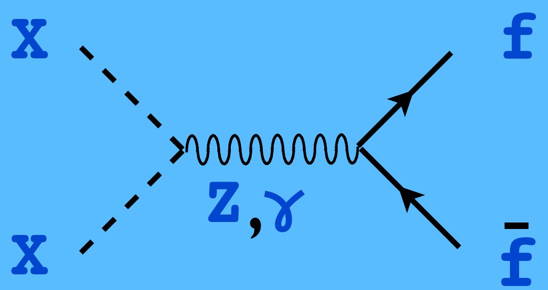
Relation between parameters so that WMAP result for the relic dark matter density is reproduced.



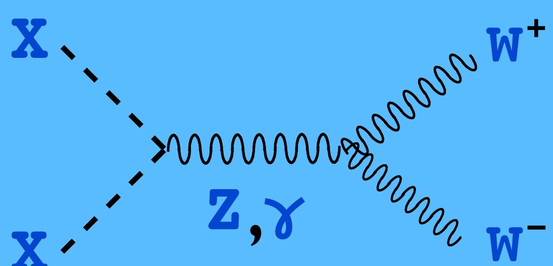




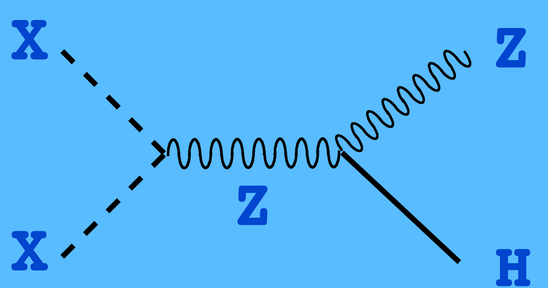
Additional contributions to the annihilation cross-sections



$$\frac{1}{3456\,\pi}\,\frac{MX^2\,s}{F_X^8}\,\sqrt{s-4\,mf^2}\,\sqrt{s-4\,MX^2}\,\left(A^2\,\left(2\,mf^2+s\right)+B^2\,\left(s-4\,mf^2\right)\right)\times\left(s\,\kappa1^2+\kappa2^2\,\left(s-4\,MX^2\right)\right)$$



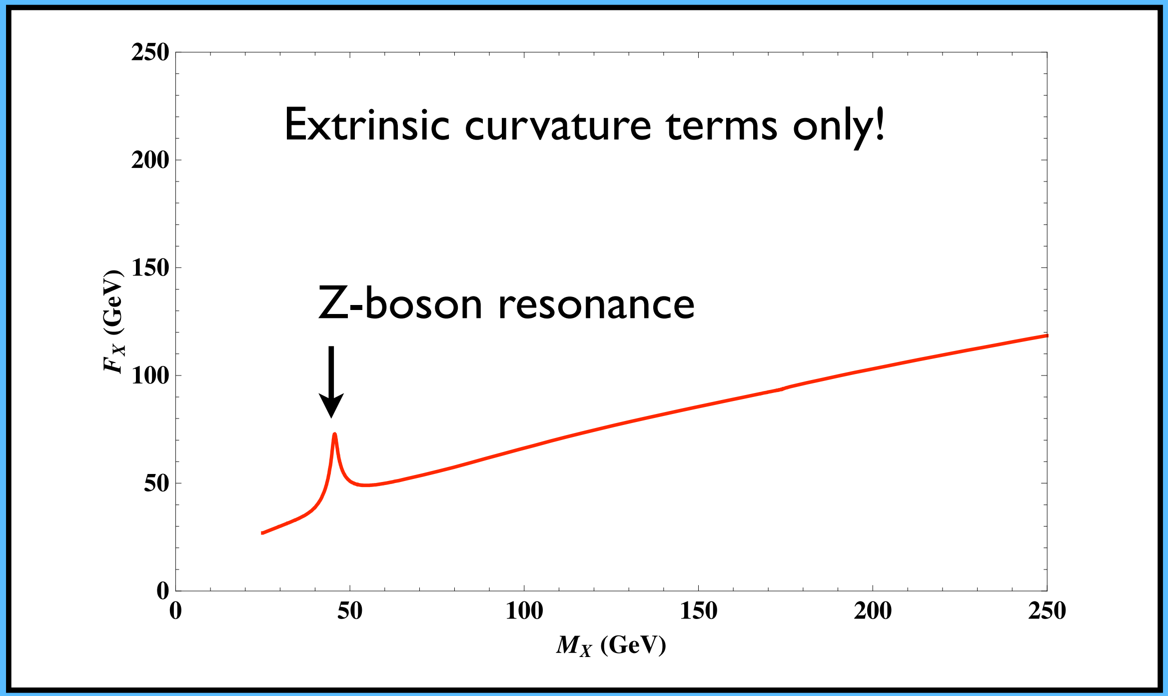
$$\frac{1}{27\,648\,\pi}\,\frac{A^2\,MX^2\,s^2}{F^8\,MW^4}\,\sqrt{s-4\,MW^2}\,\sqrt{s-4\,MX^2}\,\left(9\,s^2+4\,MW^2\,s-160\,MW^4\right)\times\left(s\,\kappa1^2+\kappa2^2\,\left(s-4\,MX^2\right)\right)$$

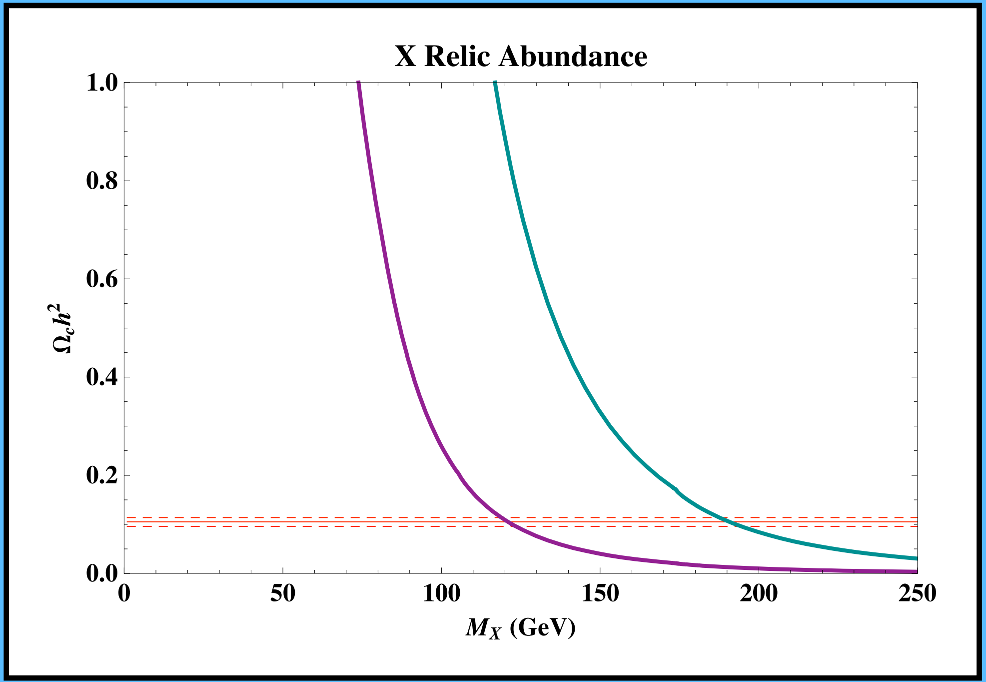


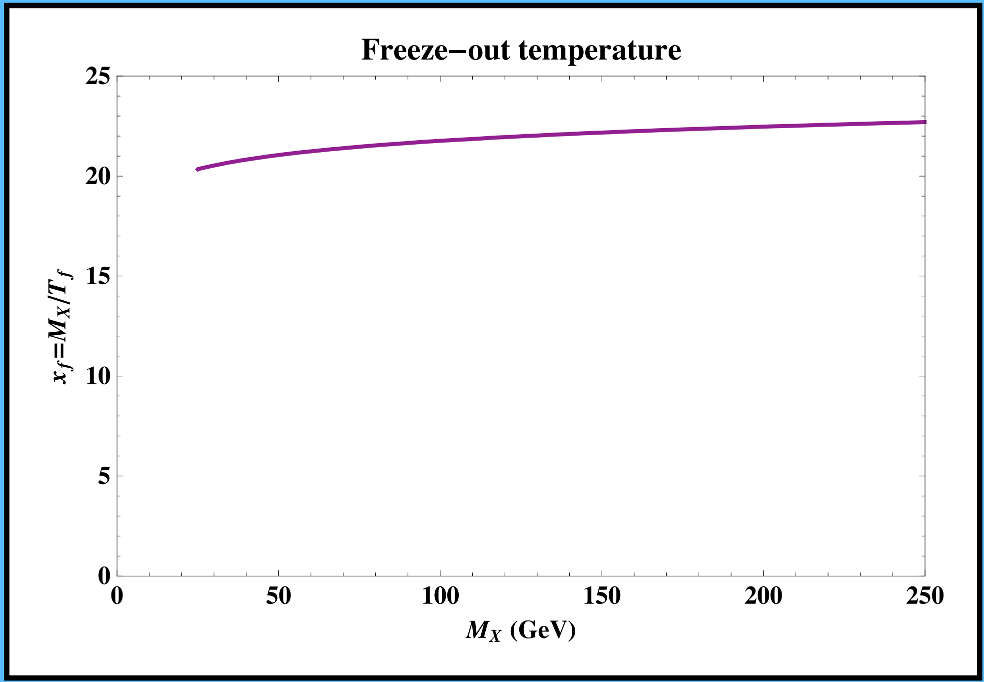
$$\frac{1}{13\,824\,\pi}\,\frac{1}{F_X^8}\,\frac{A^2\,MX^2}{MZ^2\,\sqrt{s}}\,\sqrt{s-4\,MX^2}\,\sqrt{s-(MH-MZ)^2}\,\sqrt{s-(MH+MZ)^2}\times\left(MH^4+MZ^4-26\,MZ^2\,s+s^2-2\,MH^2\,\left(MZ^2+s\right)\right)\,\left(s\,\kappa1^2+\kappa2^2\,\left(s-4\,MX^2\right)\right)$$

These contributions to the annihilation cross-sections are suppressed in the non-relativistic limit.

Relation between parameters so that WMAP result for the relic dark matter density is reproduced.

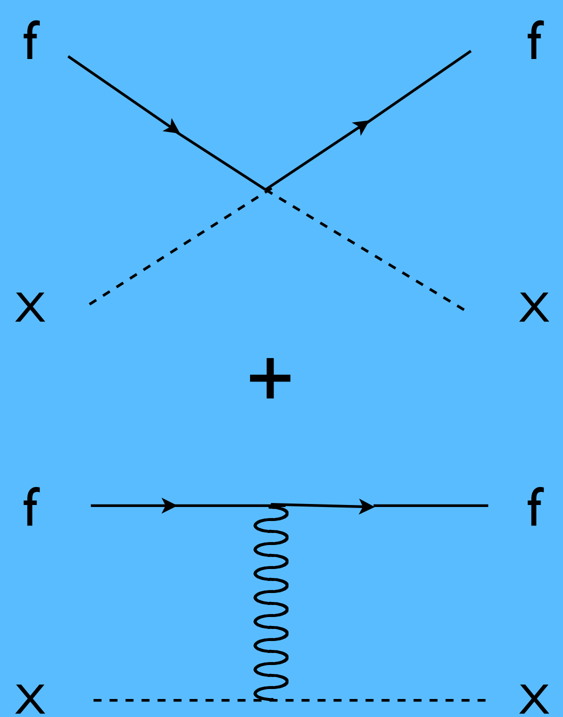






Direct Detection

Elastic scattering cross-section



Non-relativistic limit, $M_X >> m_f$

$$\sigma_{el} = \frac{7}{36\pi}\kappa_0^2 \frac{M_X^4}{F_X^8}\frac{(M_X\ m_f)^4}{(M_X + m_f)^6}\left(\frac{v_0}{c}\right)^4 + \frac{5}{9}\kappa_1^2\,\alpha\, q^2\, \mathrm{Cos}^2(\theta_W)\frac{M_X^4}{F_X^8}\frac{(M_X\ m_f)^4}{(M_X + m_f)^6}\left(\frac{v_0}{c}\right)^4 + \kappa_2^2\,\alpha\, q^2\, \mathrm{Cos}^2(\theta_W)\frac{M_X^4}{F_X^8}\frac{(M_X\ m_f)^2}{(M_X + m_f)^2}\left(\frac{v_0}{c}\right)^2$$

Suppression factor:

$$\frac{v_0}{c} = 0.001$$

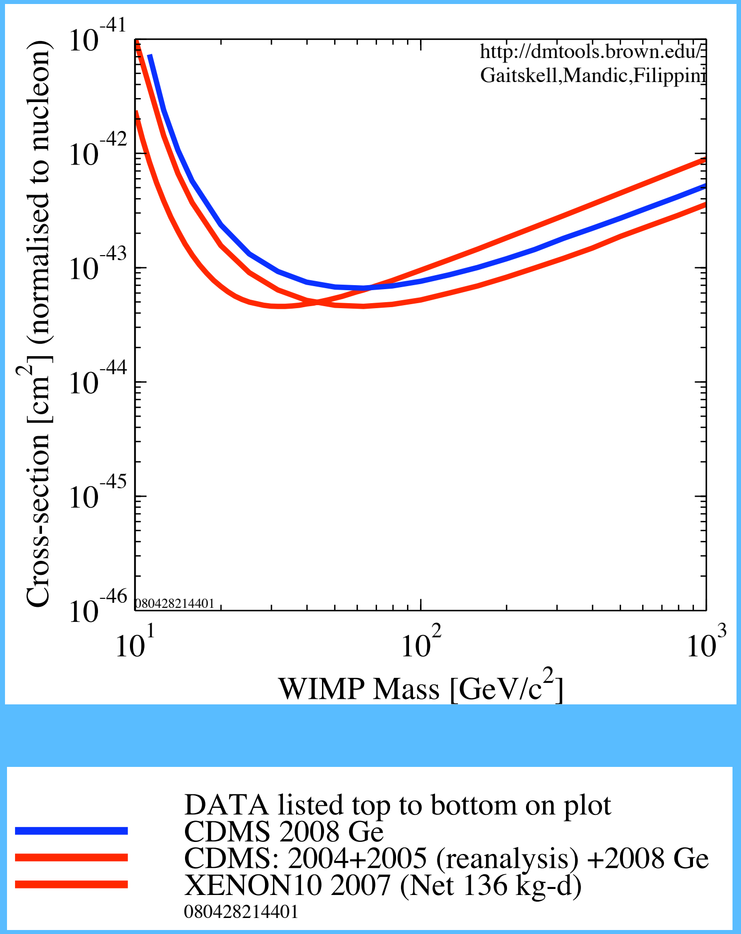
Estimate:

$M_X = 100$ GeV

$F_X = 250$ GeV

$\kappa_2 = 1$

$\sigma_{el} = 10^{-51}$ cm^2



The parameter space of the model is not constrained by the direct detection data.

Since the indirect detection signal from neutrinos due to annihilation of dark matter in the center of the Sun or the Earth is also determined by the same non-relativistic elastic scattering cross section, the neutrino data is not expected to constrain the model either.

Conclusions

The brane vector model provides an effective description of some scenarios where our world is embedded in a higher dimensional space.

The brane vector is a dark matter candidate as it can be stable.

The WMAP observed relic dark matter can be correctly reproduced without straining the parameter space.

The elastic scattering cross-section of the brane vector with fermions is suppressed in the non-relativistic limit. It seems therefore unlikely that the parameter space can be probed by using the data from the direct dark matter detection experiments.

For the same reason it is expected that the indirect detection results which yield bounds on potential neutrinos produced in dark matter annihilations in the center of the Sun or the Earth do not put constraints on the parameter space.

Additional constraints on the parameter space follow from collider experiments data See talk by Thomas Clark later this afternoon.