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A NEW DARK MATTER CANDIDATE IN LOW-TENSION BRANE-WORLDS

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Brane world theories contain additional degrees of freedom related to the geometry of the extra dimension space which can be understood as brane oscillations (branons). In the case where the fundamental gravitational scale is much larger than the brane tension scale, these branons are the only extra degrees of freedom at low energies coming from the extra dimensions. Branons are generically stable, weakly interacting and massive. They could be produced in the next generation colliders and at the same time they are natural WIMP like candidates for dark matter.

1 The branon field

The Brane World (BW) models were proposed at the final of the past century, with the interesting possibility to have observable effects at the scale of present or near experiments [1]. The main idea that defines the BW scenario is that the Standard Model (SM) particles are restricted to a three-dimensional hypersurface or 3-brane, whereas the gravitons can propagate along the whole bulk space.

Since rigid objects do not exist in relativistic theories, it is clear that brane fluctuations must play an important role in this framework [2]. This fact turns out to be particularly true when the brane tension scale f ($\tau = f^4$ being the brane tension) is much smaller than the D dimensional or fundamental gravitational scale M_D, i.e. $f << M_D$. In this case the only relevant low-energy modes of the BW scenarios are the SM particles and branons which are the quantized brane oscillations. Indeed branons can be understood as the (pseudo-)Goldstone bosons corresponding to the spontaneous breaking of translational invariance in the bulk space produced by the presence of the brane.

The branon properties allow to solve some of the problems of the brane-world scenarios such as the divergent virtual contributions from the Kaluza-Klein tower at the tree level or

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non-unitarity of the graviton production cross-sections [3]. The SM-branon low-energy effective Lagrangian reads [2,4,5]:

$$\mathcal{L}_{Br} \;=\; \frac{1}{2}g^{\mu\nu}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha-\frac{1}{2}M^2\pi^\alpha\pi^\alpha+\frac{1}{8f^4}(4\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha-M^2\pi^\alpha\pi^\alpha g_{\mu\nu})T^{\mu\nu}_{SM} \qquad (1)$$

We see that branons interact by pairs with the SM energy-momentum tensor. This means that they are stable particles. On the other hand, their couplings are suppressed by the brane tension f^4, i.e. they are weakly interacting. These features make them natural dark matter [6,7] candidates (see [8] for updated reviews on cosmology and dark matter).

2 Brane World dark matter

When the branon annihilation rate, $\Gamma = n_{eq}\langle\sigma_A v\rangle$, equals the universe expansion rate H, the branon abundance freezes out relative to the entropy density. This happens at the so called freeze-out temperature $T_f = M/x_f$. We have computed this relic branon abundance in two cases: either relativistic branons at freeze-out (hot-warm) or non-relativistic (cold), and assuming that the evolution of the universe is standard for $T < f$ (see Fig. 1). On the other hand, if branons make up the galactic halo, they could be detected by direct search experiments from the energy transfer in elastic collisions with nuclei of a suitable target. For the allowed parameter region in Fig. 1, branons cannot be detected by present experiments such as DAMA, ZEPLIN 1 or EDELWEISS. However, they could be observed by future detectors such as CRESST II, CDMS or GENIUS.

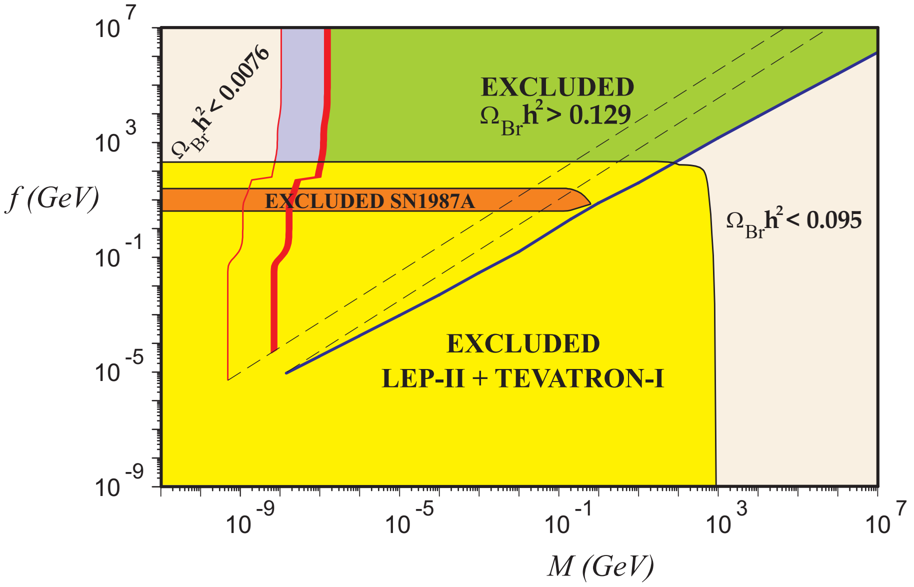

Figure 1: Relic abundance in the $f - M$ plane for a model with one branon of mass: M. The two lines on the left correspond to the $\Omega_{Br}h^2 = 0.0076$ and $\Omega_{Br}h^2 = 0.129 - 0.095$ curves for hot-warm relics, whereas the right line corresponds to the latter limits for cold relics. The lower area is excluded by single-photon processes at LEP-II together with monojet signal at Tevatron-I. The upper area is also excluded by cosmological branon overproduction. The astrophysical constraints are less restrictive and they mainly come from supernova cooling by branon emission.

Branons could also be detected indirectly: their annihilations in the galactic halo can give rise to pairs of photons or e^+e^- which could be detected by γ-ray telescopes such as MAGIC or GLAST or antimatter detectors (see [6] for an estimation of positron and photon fluxes from branon annihilation in AMS). Annihilation of branons trapped in the center of the sun or the earth can give rise to high-energy neutrinos which could be detectable by high-energy neutrino telescopes such as AMANDA, IceCube or ANTARES.

3 Branon signals in colliders

The dark matter searches complement those in high-energy particle colliders. The branon signals depend on their number N, the brane tension scale f, and their masses M. From the effective action given in the Equation (1), one can calculate the relevant cross-sections for different branon searches. The single photon channel and the monojet production are the more interesting ones. The main results in relation with these analysis are presented in Table 1, where one can find not only the present restrictions coming from HERA, Tevatron and LEP-II but also the prospects for future colliders like ILC, LHC or CLIC [5,9].

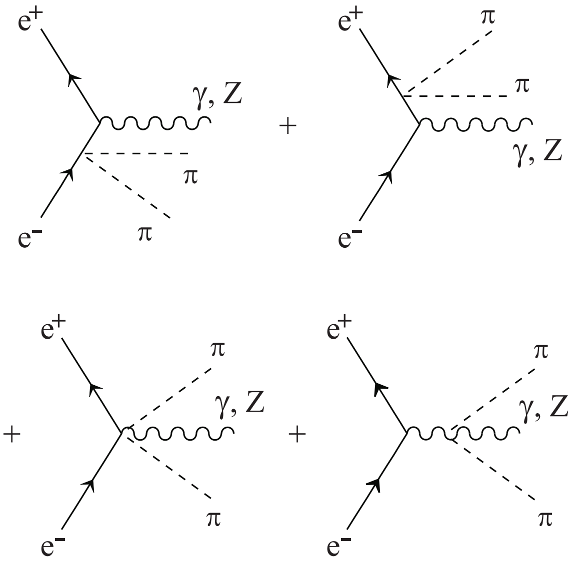

Figure 2: Relevant Feynman diagrams for the branon contribution to the single Z and the single photon channel.

Experiment	$\sqrt{s}$(TeV)	$\mathcal{L}$(pb^{-1})	σ_0(GeV^{-2})	f_0(GeV)	M_0(GeV)
HERA^{1}	0.3	110	$7.0\,10^{-7}$	16	152
Tevatron-I^{1}	1.8	78	$6.3\,10^{-10}$	157	822
Tevatron-I^{2}	1.8	87	$1.3\,10^{-10}$	148	872
LEP-II^{2}	0.2	600	$3.3\,10^{-11}$	180	103
Tevatron-II^{1}	2.0	10^3	$3.2\,10^{-10}$	256	902
Tevatron-II^{2}	2.0	10^3	$7.0\,10^{-11}$	240	952
ILC^{2}	0.5	$2\,10^5$	$1.5\,10^{-11}$	400	250
LHC^{1}	14	10^5	$1.8\,10^{-11}$	1075	6481
LHC^{2}	14	10^5	$3.8\,10^{-12}$	797	6781
CLIC^{2}	5	10^6	$6.6\,10^{-12}$	2640	2500

Table 1: Summary of the main analysis related to collider experiments. All the results are performed at the 95 % c.l. Two different channels have been studied: the one marked with an upper index ^{1} is related to monojet production, whereas the single photon is labelled with an upper index ^{2}. The table contains a total of seven experiments: HERA, LEP-II, the I and II Tevatron runs, ILC, LHC and CLIC. Obviously the data corresponding to the four last experiments are estimations, whereas the first three analysis have been performed with real data. $\sqrt{s}$ is the center of mass energy associated to the total process; $\mathcal{L}$ is the total integrated luminosity; σ_0 is the estimation for the cross section sensitivity limit; f_0, the bound in the brane tension scale for one massless branon ($N = 1$) and M_0 the limit on the branon mass for $f = 0$.

On the other hand, the branon radiative correction on the SM phenomenology could be important. The one loop calculation generates higher-dimensional operators involving SM fields, suppressed by powers of the brane tension scale [10,11]. One of the most relevant contributions of virtual branons to the phenomenology of the SM particles could be the effects on four-fermion interactions. For a generic four-fermion process, the branons induce a new effective vertex as the Figure 3 shows.

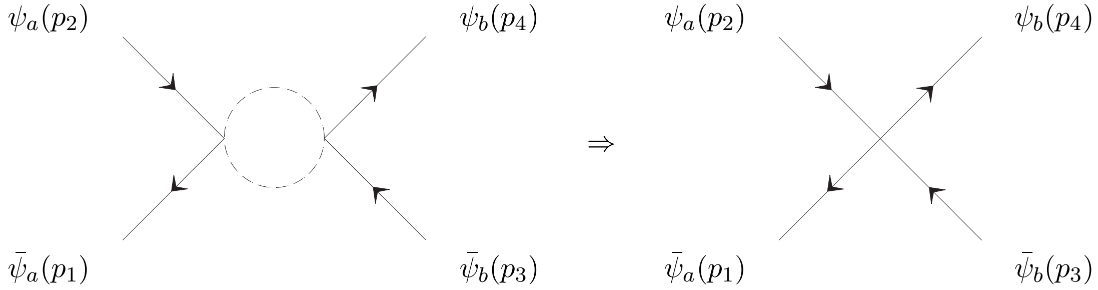

Figure 3: Four-fermion vertex induced by branon radiative corrections.

This kind of signals can be studied in the above mentioned colliders. The branons also can generate an anomalous magnetic moment for each charged fermion. However this effect and modifications on electroweak precision observables arise at higher orders. Work is in progress in these directions.

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