Branon Dark Matter

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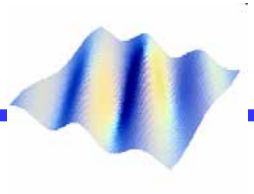
Introduction: brane fluctuations

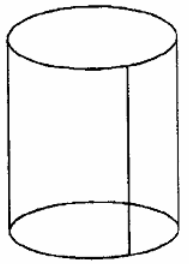


Brane-world scenario

(ADD, 98)

- **Rigid branes (f >> M_D)**

  KK modes

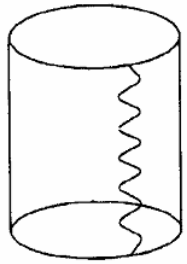


- **Flexible branes (f << M_D)**

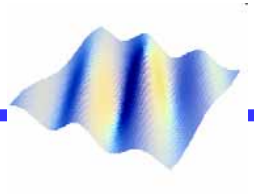
  Branon fields

  (KK modes decouple from SM)

  Bando et al. '99



Brane fluctuations

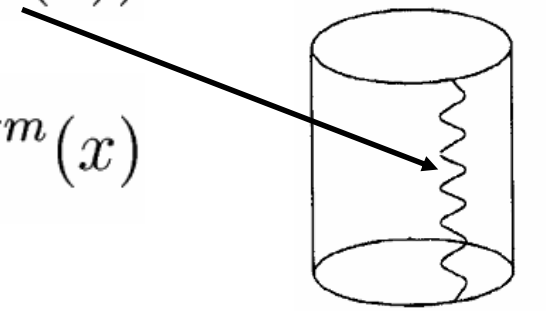


- **Bulk metric:**

$$ds^2 = \tilde{g}_{\mu\nu}(x) W(y) dx^\mu dx^\nu - g'_{mn}(y) dy^m dy^n$$

- **Brane position:** $Y^M = (x^\mu, Y^m(x))$

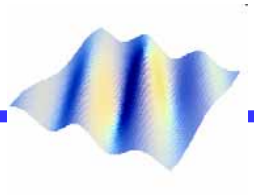
- **Branon fields:** $\pi^\alpha(x) = f^2 \delta^\alpha_m Y^m(x)$



- **Branon mass related to bulk curvature:**

$$M^2_{\alpha\beta} = \tilde{g}^{\mu\nu} R_{\mu\alpha\nu\beta}\big|_{y=0}$$

Branon dynamics



- **Induced metric on the brane:**

$$g_{\mu\nu}(x,\pi) = \tilde{g}_{\mu\nu}(x)\left(1+\frac{M^2_{\alpha\beta}\pi^\alpha\pi^\beta}{4f^4}\right) - \frac{1}{f^4}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha + \mathcal{O}(\pi^4)$$

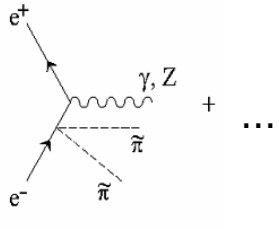
- **Dirac-Nambu-Goto action:** $S_B = -\int_{M_4} d^4x\sqrt{g}\ f^4$

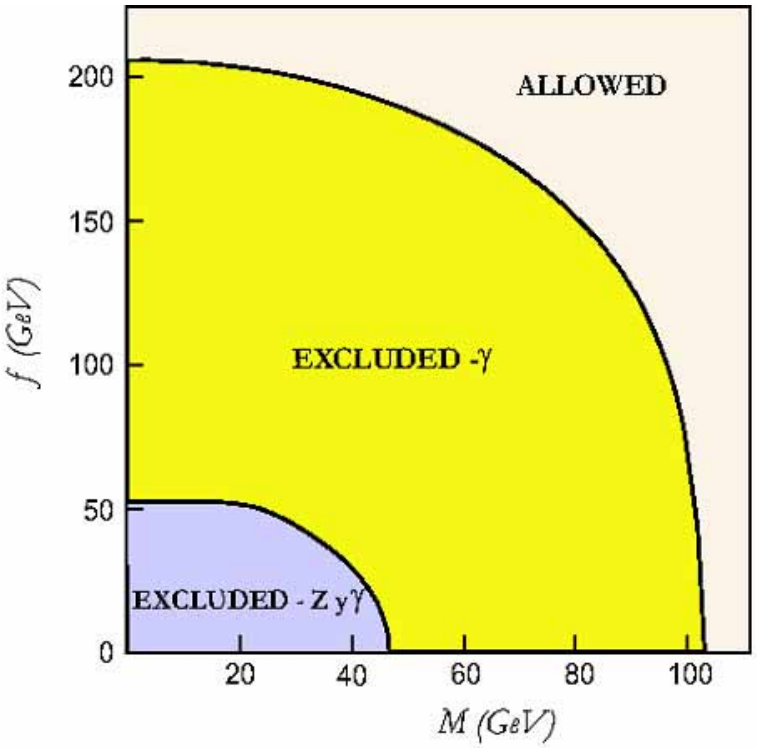
Branon effective action Sundrum' 99, Dobado & A.L.M '01

$$\begin{aligned} S_{Br} &= \int_{M_4} d^4x\sqrt{\tilde{g}}\left[\frac{1}{2}\left(\tilde{g}^{\mu\nu}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - M^2_{\alpha\beta}\pi^\alpha\pi^\beta\right)\right. \\ &+ \left.\frac{1}{8f^4}(4\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - M^2_{\alpha\beta}\pi^\alpha\pi^\beta\tilde{g}_{\mu\nu})T^{\mu\nu}_{SM}\right] \end{aligned}$$

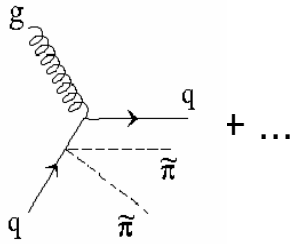
Limits from colliders

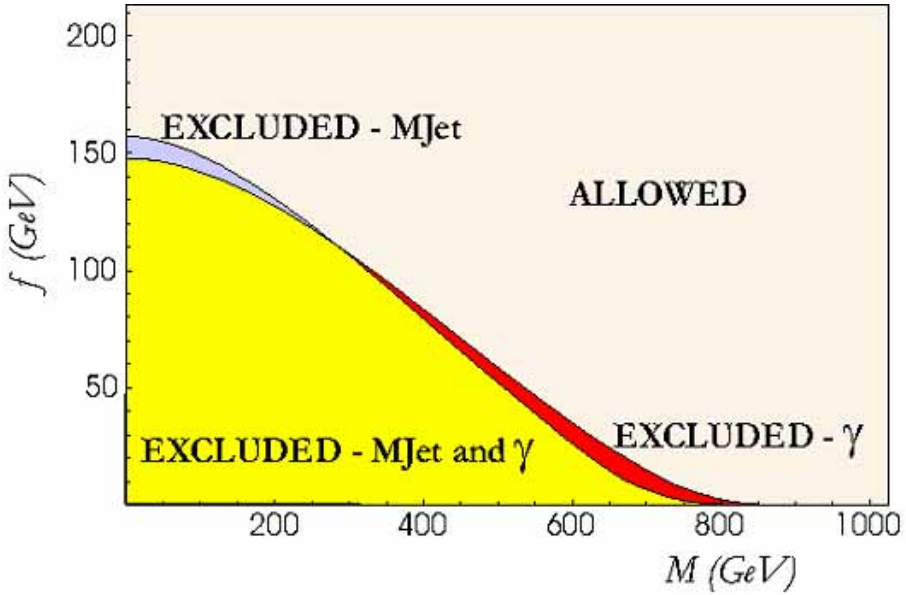
LEP-II



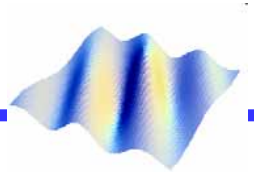


TEVATRON-I





A new dark matter candidate

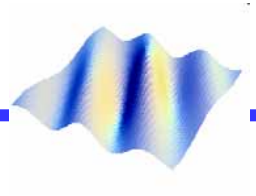


- **Brane orientation $\Longrightarrow$ branons are pseudoscalar particles**

- **Parity on the brane $\Longrightarrow$ branons couple by pairs to SM (stable particles)**

Branons are stable, massive and weakly interacting particles

Branon cosmic abundance



Freeze-out in an expanding universe:

$$\frac{dn_\alpha}{dt} = -3Hn_\alpha - \langle\sigma_A v\rangle(n_\alpha^2 - (n_\alpha^{eq})^2)$$

Annihilation into all SM pairs *X* : $\sigma_A = \sum_X \sigma(\pi^\alpha\pi^\alpha \to X)$

(Light hadrons below QCD phase transition or quarks and gluons above)

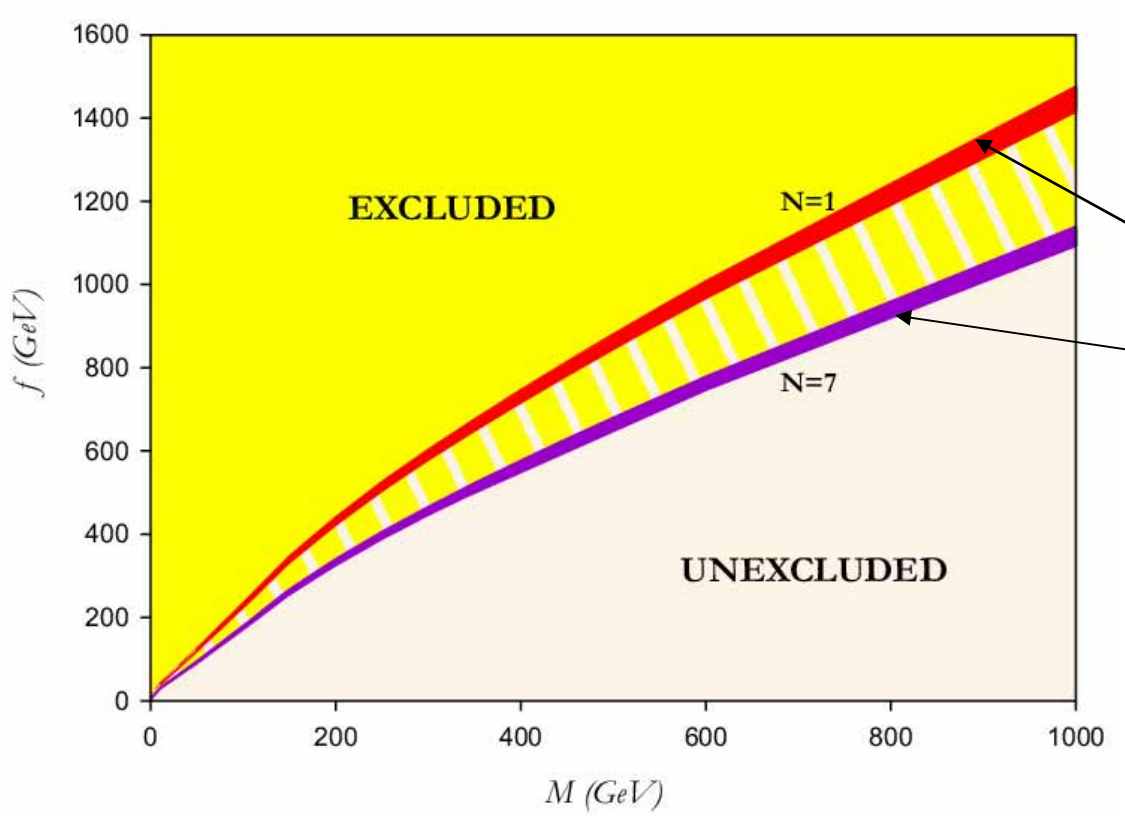
Cold branons (M >> T) $\boxed{\pi\ \pi \longrightarrow \gamma\ \gamma}$ **Hot branons (M << T)**

$$\langle\sigma_{\gamma\gamma} v\rangle \simeq \frac{68M^4T^2}{15\pi^2 f^8}$$

$$\langle\sigma_{\gamma\gamma} v\rangle \simeq \frac{16\pi^7T^6}{297675 f^8}$$

Branon cosmic abundance

Cold branons



WMAP limits

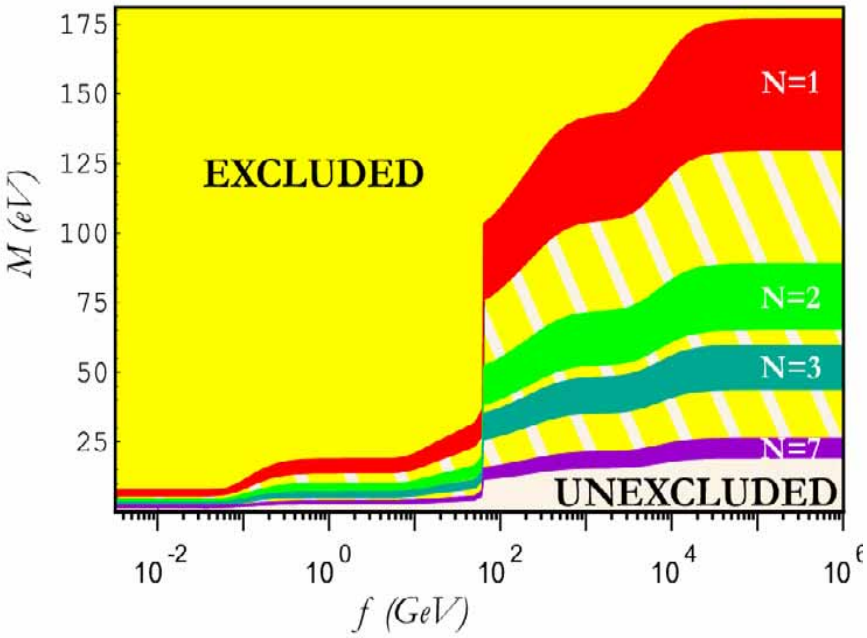
$$\Omega_{Br}h^2 = 0.129 - 0.095$$

Branon cosmic abundance

Hot branons

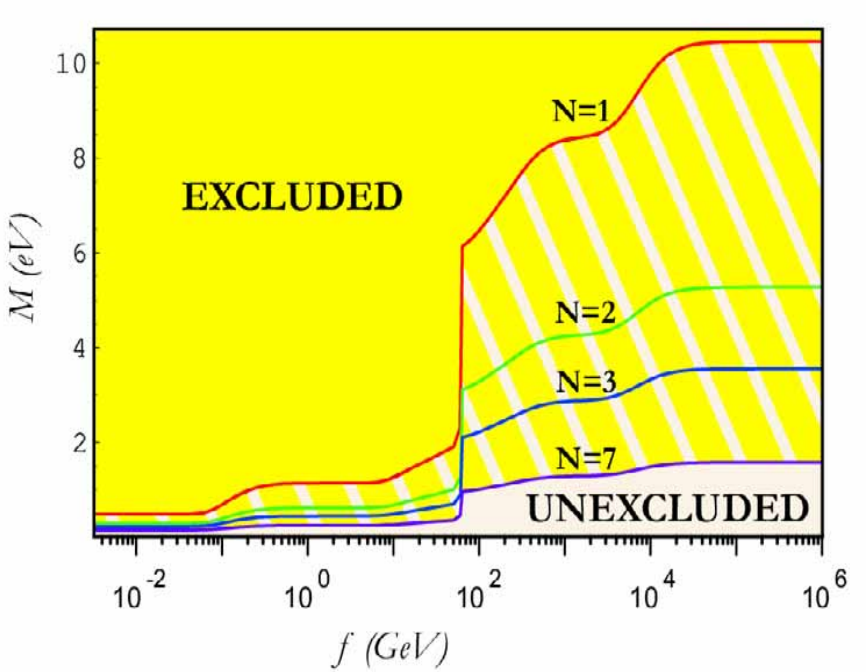
WMAP

$$\Omega_{Br} h^2 = 0.129 - 0.095$$



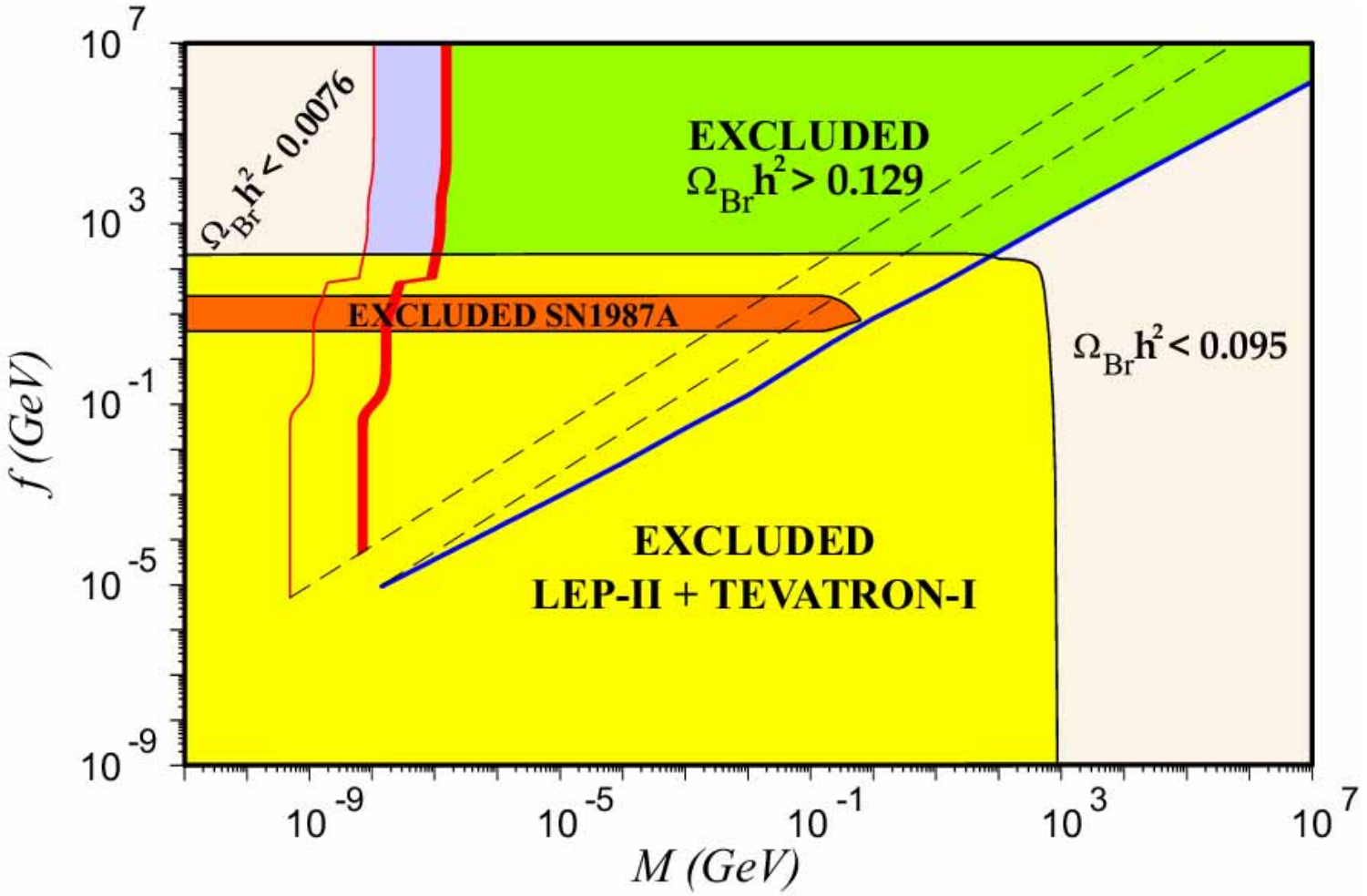
WMAP-CBI-ACBAR-2dF-Ly-α

$$\Omega_{Br} h^2 = 0.0076$$

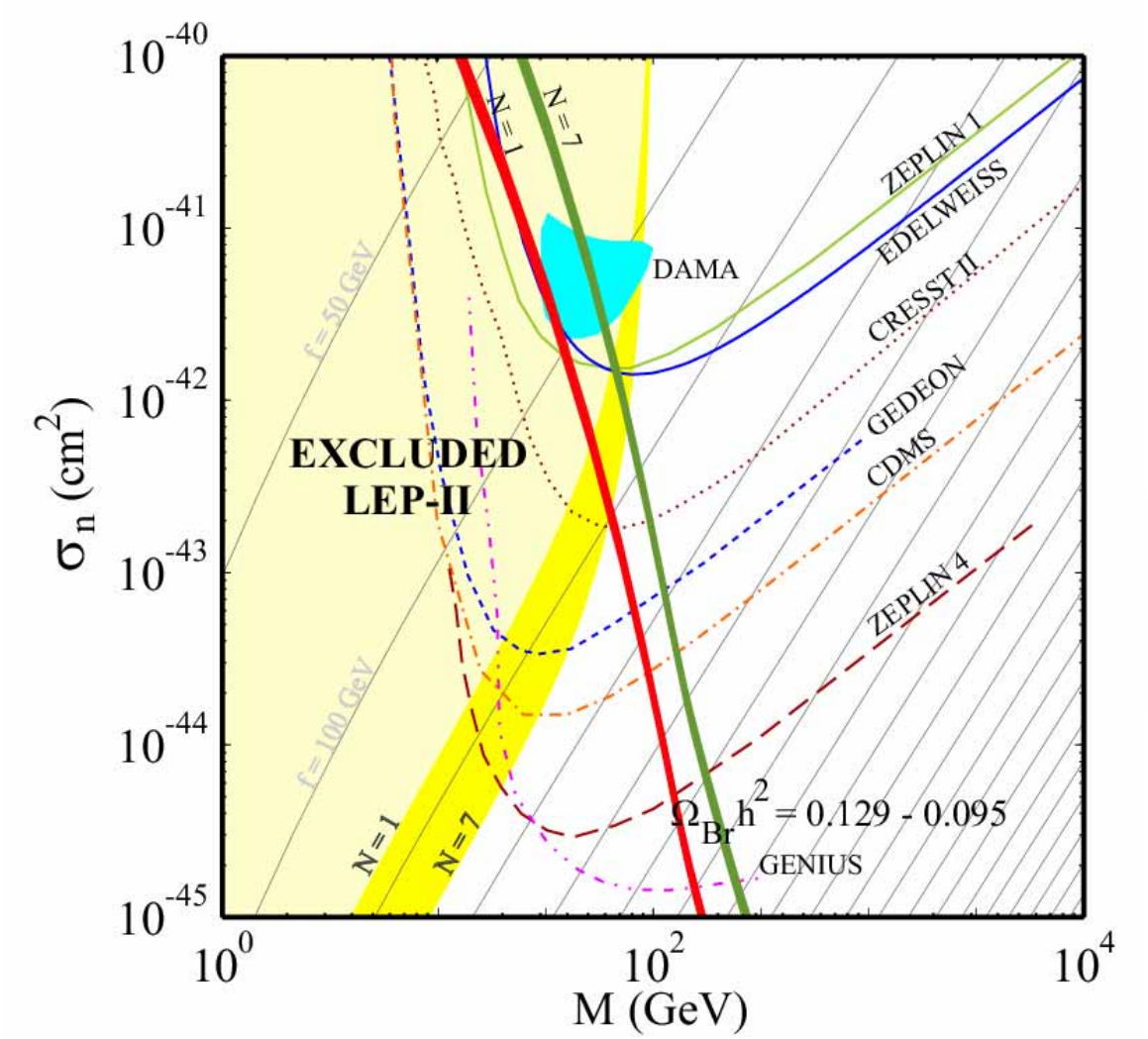


BBN limits: $N \lesssim 18$ **for** $f \gtrsim 60$ GeV

Combined limits



Direct detection

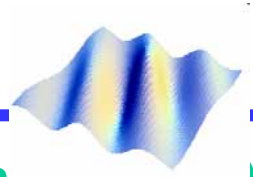


Elastic branon-nucleon cross section (spin independent)

$$\frac{d\sigma}{d|q|^2} = \frac{\sigma_n A^2 F^2(|q|)}{4v^2\mu^2}$$

$$\sigma_n = \frac{9M^2m^2\mu^2}{64\pi f^8}$$

Non-thermal branon production



If $T_{RH} << T_f$ and $T_{RH} >> \Lambda$ (Λ explicit symmetry brea).

Branons are essentially massless and decoupled from SM.

⇩

Brane initial position: $Y_0 = O(R_B)$ and $\pi_0 = f^2 R_B$

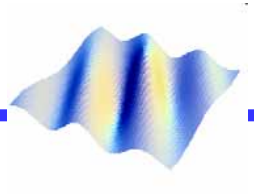
Dark matter as coherent brane oscillations (similar to axions)

If $H(T) > \Gamma(T)$ for $T < T_{RH}$ brane oscillations only diluted by Hubble expansion.

Non-thermal branon abundance:

$$\Omega_{Br} h^2 \simeq \frac{6.5 \cdot 10^{-20} N}{\mathrm{GeV}^{5/2}} f^4 R_B^2 M^{1/2}$$

Cosmic coincidence problem



AdS_6 soliton solution

$$ds^2 = M^2(\rho)\eta_{\mu\nu}dx^\mu dx^\nu - d\rho^2 - L^2(\rho)d\theta^2$$

$$M(\rho) = \cosh^{2/5}(k\rho); \quad L(\rho) = \frac{\sinh(k\rho)}{k\,\cosh^{3/5}(k\rho)} \qquad k = \sqrt{-\frac{5\Lambda_6}{8M_6^4}}.$$

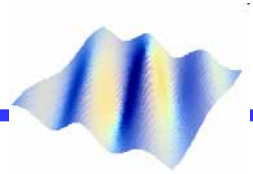
Branon mass: $M^2 = \dfrac{8k^2}{5} = -\dfrac{\Lambda_6}{M_6^4}$

Fundamental scale: $M_6 \sim f \sim \mathrm{TeV}$

Bulk C.C. (loop effects): $\Lambda_6 \sim R_B^{-6}$

$$\left.\begin{aligned} M &\sim 10^{-33}\ \mathrm{eV} \\ R_B^{-1} &= 10^{-3}\ \mathrm{eV} \end{aligned}\right\} \Longrightarrow \quad \boxed{\Omega_{Br}h^2 \simeq 0.1}$$

Conclusions and future perspectives



- Branons are natural dark matter candidates in brane-world models.
- Produced as thermal or non-thermal relics (cosmic coincidence)

  ... or strongly self-interacting dark matter.
- They could be detected in future direct search experiments (CDMS, CRESST II, ...).
- Indirect detection from halo annihilations into photons or e^+e^- by MAGIC, GLAST or AMS (coll.).
- Indirect detection by ANTARES, IceCube, ... from high-energy neutrino annihilation.
- L3 direct searches.
- Future searches at hadronic (LHC) or Linear Colliders.