Branon Phenomenology: Search for Extra Dimensions Dark Matter

José A. R. Cembranos

Department of Physics and Astronomy
University of California, Irvine
Irvine, CA 92697-4575

Work done in collaboration with
Antonio Dobado and Antonio L. Maroto

CONTENTS

1.- Brane Models Dark Matter

3.- Branons

3.a. Effective Action

3.b. Colliders

3.c. Cosmology and Astrophysics

3.d. Radiative Corrections

BRANE WORLDS (BWs)

The main idea is that our universe is restricted to a 3-brane embedded in a higher *D* dimensional space, with $D = 4+\delta$, being the δ extra dimensions compactified.

In this picture the Standard Model (SM) particles are confined to the 3-brane but gravitons can propagate along the whole bulk space.

Arkani-Hamed *et al.*, PLB 429, 263 (1998)
Arkani-Hamed *et al.*, PRD 59, 086004 (1999)

BRANE WORLD SIGNALS

1.- Metric effects ($f \gg M_D$) :

New particles:

Kaluza-Klein graviton tower

Newton law deviations

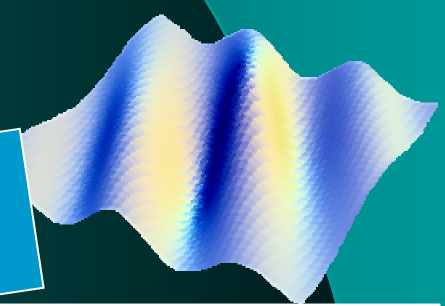
Black hole production

…

2.- Brane effects ($f \ll M_D$) :

New particles:

Branons = Brane fluctuati



Cosmological and Astrophysical Interest:
Dark Matter candidate

Cembranos *et al.*, PRL 90, 241301 (2003)

Sundrum, PRD 59, 085009 (1999)

Bando *et al.*, PRL 83, 3601 (1999)

Dobado and Maroto, NPB 592, 203 (2001)

BRANON EFFECTIVE ACTION

The interaction of the branons (π^α) with the SM particles is given by:

$$S_B = \int_{M_4} d^4x\sqrt{g}[-f^4 + \mathcal{L}_{SM}(\ldots$$

$$\ldots \frac{1}{2}M^2_{\alpha\beta}\pi^\alpha\pi^\beta$$

$$\ldots - M^2_{\alpha\beta}\pi^\alpha\pi^\beta\eta_{\mu\nu})T^{\mu\nu}_{SM}(\eta_{\mu\nu})\Big] + \mathcal{O}(\pi^3).$$

N: Number of branons.
M: Branon mass.
f: Brane tension scale.

As in the case of the gravitons, the branons couple to the SM through:

$$T^{\mu\nu}_{SM} = -\left(\tilde{g}^{\mu\nu}\mathcal{L}_{SM} + 2\frac{\delta\mathcal{L}_{SM}}{\delta\tilde{g}_{\mu\nu}}\right)\Bigg|_{\tilde{g}_{\mu\nu}=\eta_{\mu\nu}}$$

Dobado and Maroto, NPB 592, 203 (2001)	Cembranos *et al.*, PRD 65, 026005 (2002)
Creminelli and Strumia, NPB 596, 125 (2001)	Alcaraz *et al.*, PRD 67, 075010 (2003)

PARTICLE COLLIDERS

1.- Electroweak boson width modifications.

- 2.a. Invisible Z width.
- 2.b. W decay.

Alcaraz *et al.*, PRD 67, 075010 (2003)

2.- Direct searches in e^+e^- colliders.

- 2.a. Single photon channel.
- 2.b. Single Z channel.
- 2.c. Prospects for future LC.

L3, PLB 597, 145 (2004)

Alcaraz *et al.*, PRD 67, 075010 (2003)

3.- Direct searches in hadronic colliders.

- 3.a. Single photon channel.
- 3.b. Mono jet channel.
- 3.c. Prospects for future hadronic colliders.

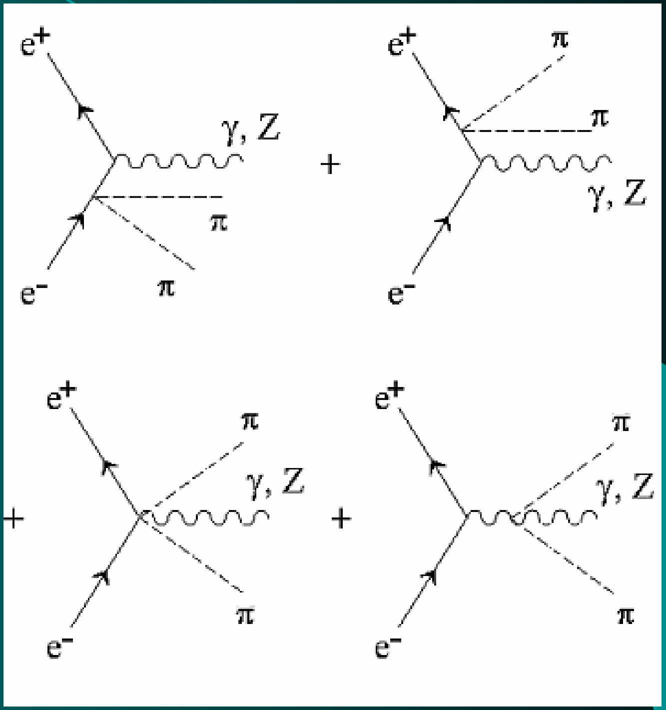
Cembranos *et al.*, PRD 70, 096001 (2004)

SINGLE γ AND Z CHANNELS

The most important signal in electron-positron colliders is associated with the single photon channel (or single Z channel) plus missing energy.

Alcaraz *et al.*, PRD 67, 075010 (2003)

γ or Z production



$$\frac{d\sigma_A}{dx\,d\cos\theta} = \frac{|h|^2}{4\pi}\frac{s(c_V^2+c_A^2)(s(1-x)-4\boxed{M^2})^2\boxed{N}}{61440\boxed{f^8}\pi^2}\sqrt{1-\frac{4\boxed{M^2}}{s(1-x)}}$$
$$\left[x(3-3x+2x^2)-x^3\sin^2\theta+\frac{2(1-x)(1+(1-x)^2)}{x\sin^2\theta}\right]$$

L3 DATA ANALYSIS

L3 is a collaboration with more than 50 institutions from all the world.

L3 was a detector working with the produced particles in the electron-positron collisions in the LEP ring (CERN).

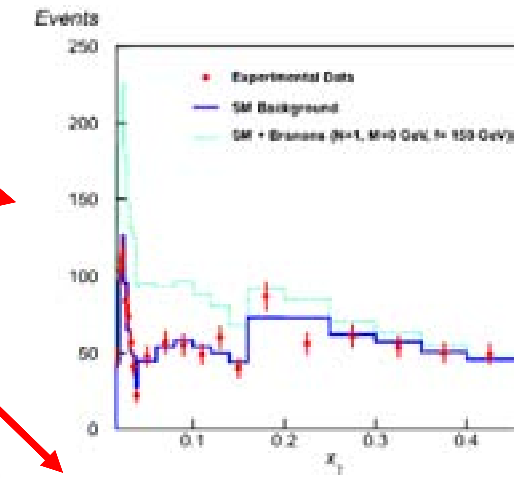
L3, PLB 597, 145 (2004)

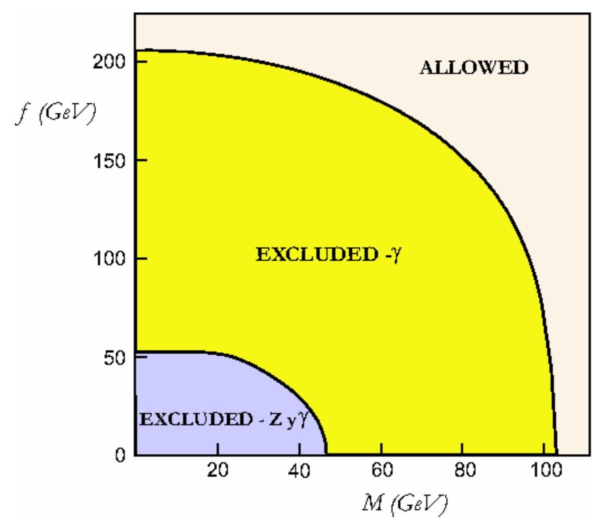
Analysis:

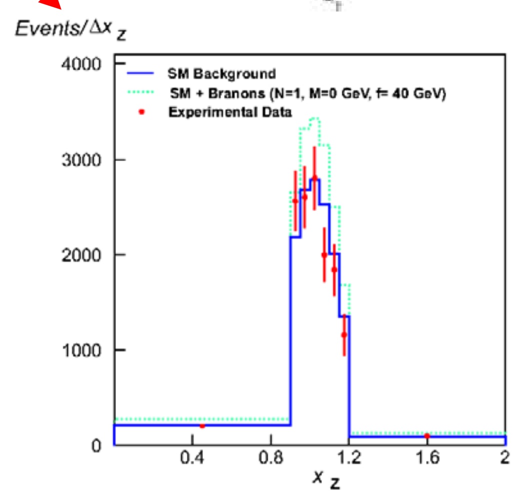
1.- Single photon

2.- Single Z

3.- Restrictions



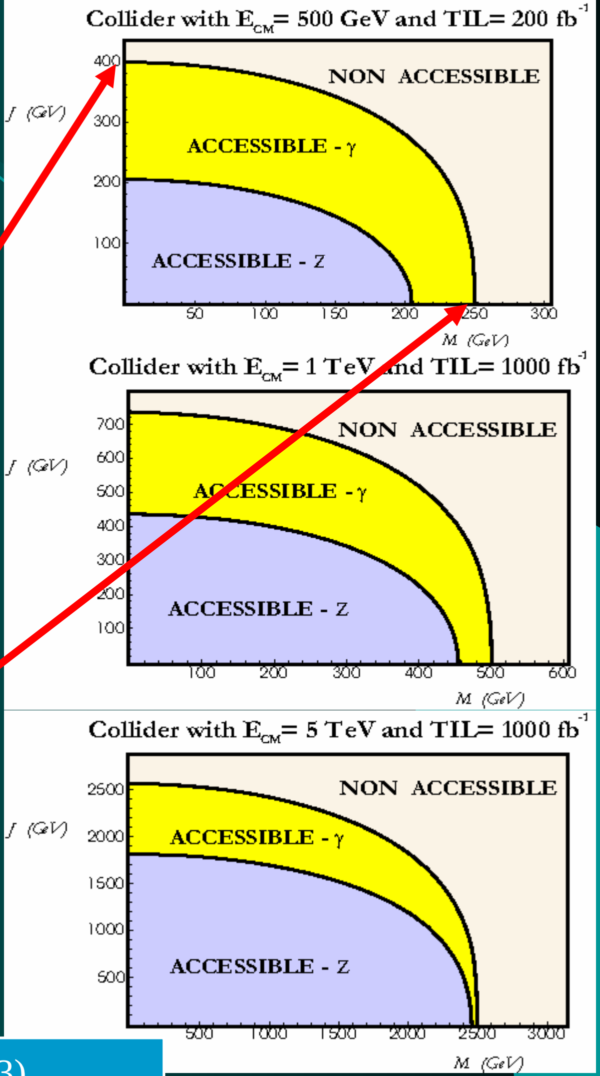




CONSTRAINTS AND PROSPECTS

Main analyses related to real branon production in collider experiments. All the results are performed at the 95% c.l. (N=1).

Experiment	$\sqrt{s}$(TeV)	$\mathcal{L}$(pb^{-1})	f_0(GeV)	M_0(GeV)
HERA [1]	0.3	110	16	152
Tevatron-I [1]	1.8	78	157	822
Tevatron-I [2]	1.8	87	148	872
LEP-II [2]	0.2	600	180	103
Tevatron-II [1]	2.0	10^3	256	902
Tevatron-II [2]	2.0	10^3	240	952
ILC [2]	0.5	2×10^5	400	250
LHC [1]	14	10^5	1075	6481
LHC [2]	14	10^5	797	6781
CLIC [2]	5	10^6	2640	2500



Alcaraz *et al.*, PRD 67, 075010 (2003)

BRANONS IN COSMOLOGY

Branons are generically stable, weakly interactive and massive.

Weakly-Interactive Massive Particles: WIMPs.

1.- Branons: Dark Matter (DM) candidates.

Cembranos *et al.*, PRL 90, 241301 (2003)

2.- Searches of branons as Dark Matter.

2.a.- Direct detection experiments.

Cembranos *et al.*, PRL 90, 241301 (2003)

2.b.- Indirect detection experiments.

AMS Note, 2003-08-02 (2003)

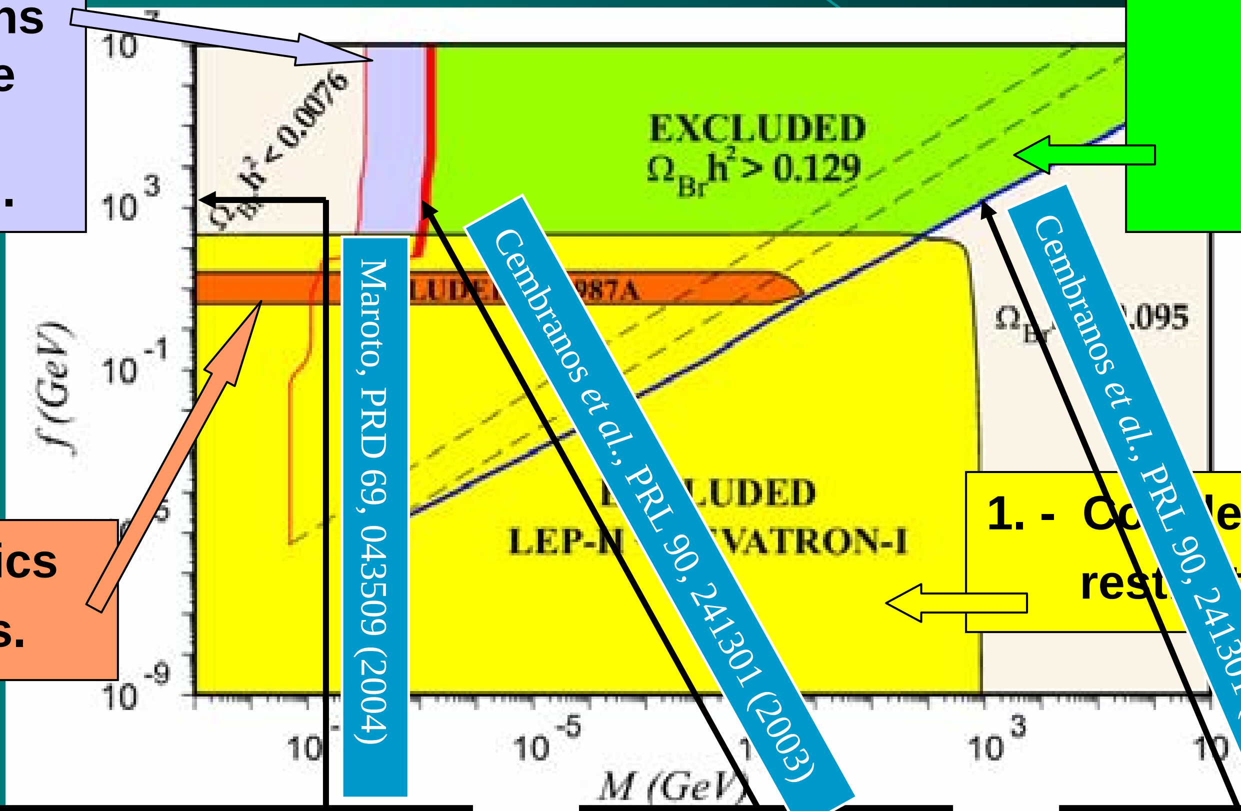
3.- Cosmological and astrophysical restrictions.

Kugo and Yoshioka, NPB 594, 301 (2001) | Cembranos *et al.*, PRD 68, 103505 (2003)

MAIN RESULTS

Cosmological and astrophysical constraints.

Cembranos *et al.*, PRD 68, 103505 (2003)



3. - Restrictions due to the power spectrum.

2.- Restrictions due to the total dark matter density.

4. - Astrophysics restrictions.

1. - Collider restrictions.

Maroto, PRD 69, 043509 (2004)

Cembranos *et al.*, PRL 90, 241301 (2003)

Cembranos *et al.*, PRL 90, 241301 (2003)

C.- Branons as a Non Thermal Relic

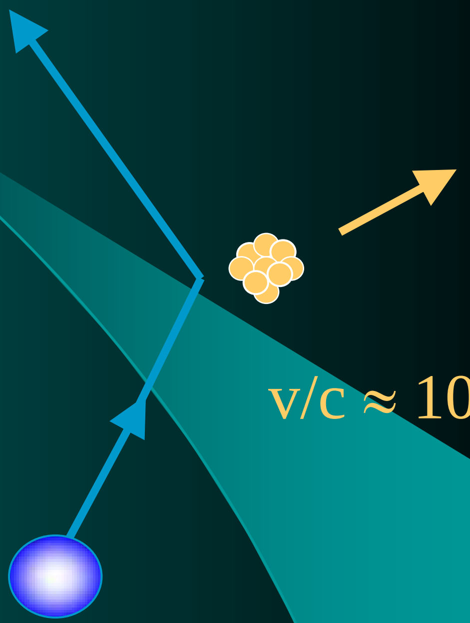
B.- Branons as Warm DM

A.- Branons as WIMPs

DIRECT SEARCHES

***WIMPs* elastically scatter off nuclei**

nuclear recoils
Measure recoil energy spectrum



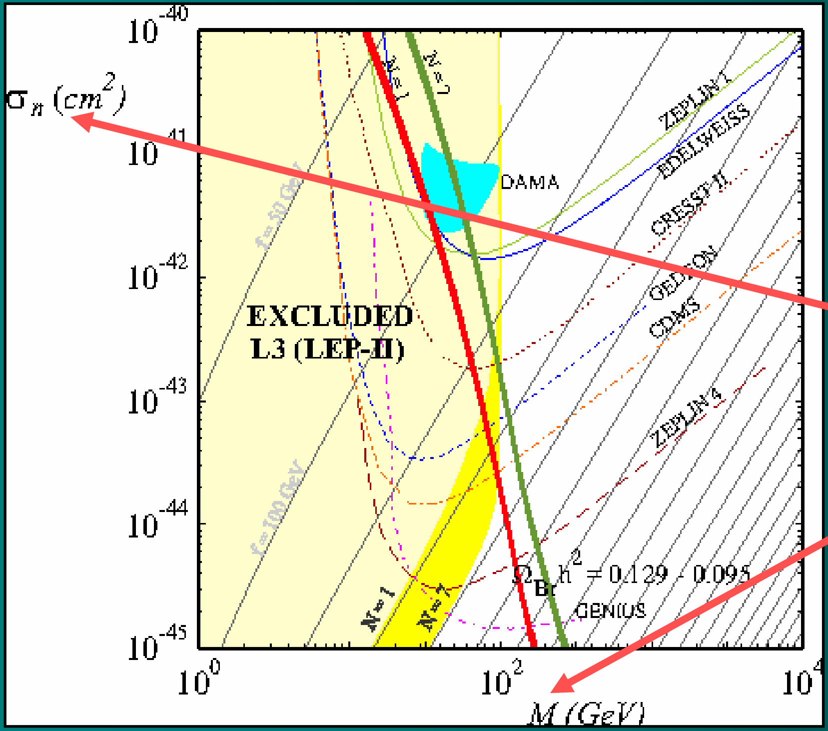
$v/c \approx 10^{-3}$

Direct interaction of the DM halo with the detector. Typical nucleus recoil energy: E_R~1-100 keV.

The rate of the *WIMP* interactions depends on the local DM density and relative *WIMP* velocity.

DIRECT RESULTS

The appropriate quantity to compare with the experimental results is not the elastic branon-nucleus cross section σ, but the differential cross section per nucleon at zero momentum transfer: σ_n.



For the branon case:

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

Cembranos *et al.*, PRL 90, 241301 (2003)

INDIRECT SEARCHES

***WIMPs* annihilate**

1.- In the center of the Sun, and the Earth core:
high energy neutrinos.

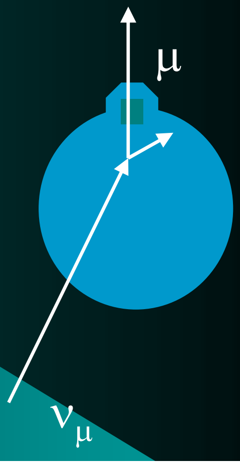
Antares, Amanda, IceCube, ...

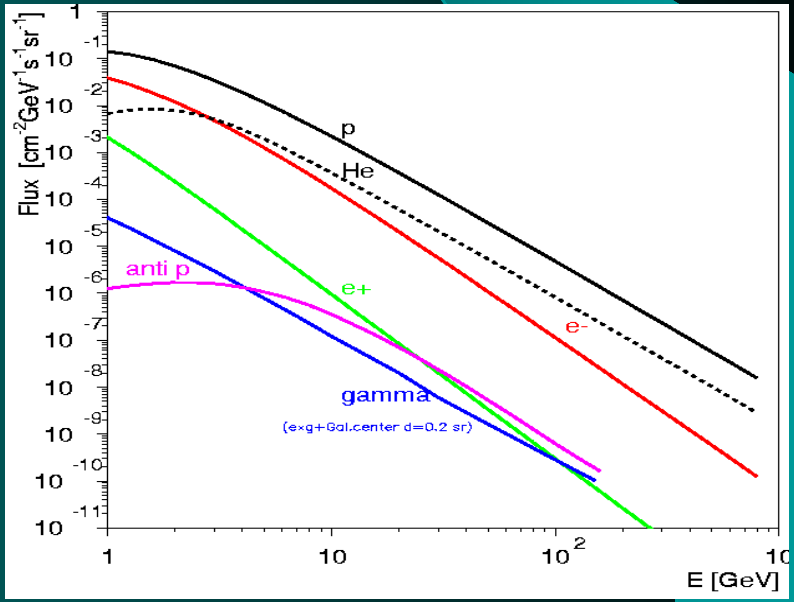
2.- In the halo: γ, e+, p-, D ...

2.a.- Halo profiles from simulations and rotation curves.

2.b.- Green´s functions from propagation model.

2.c.- Average cross section from the effective theory.



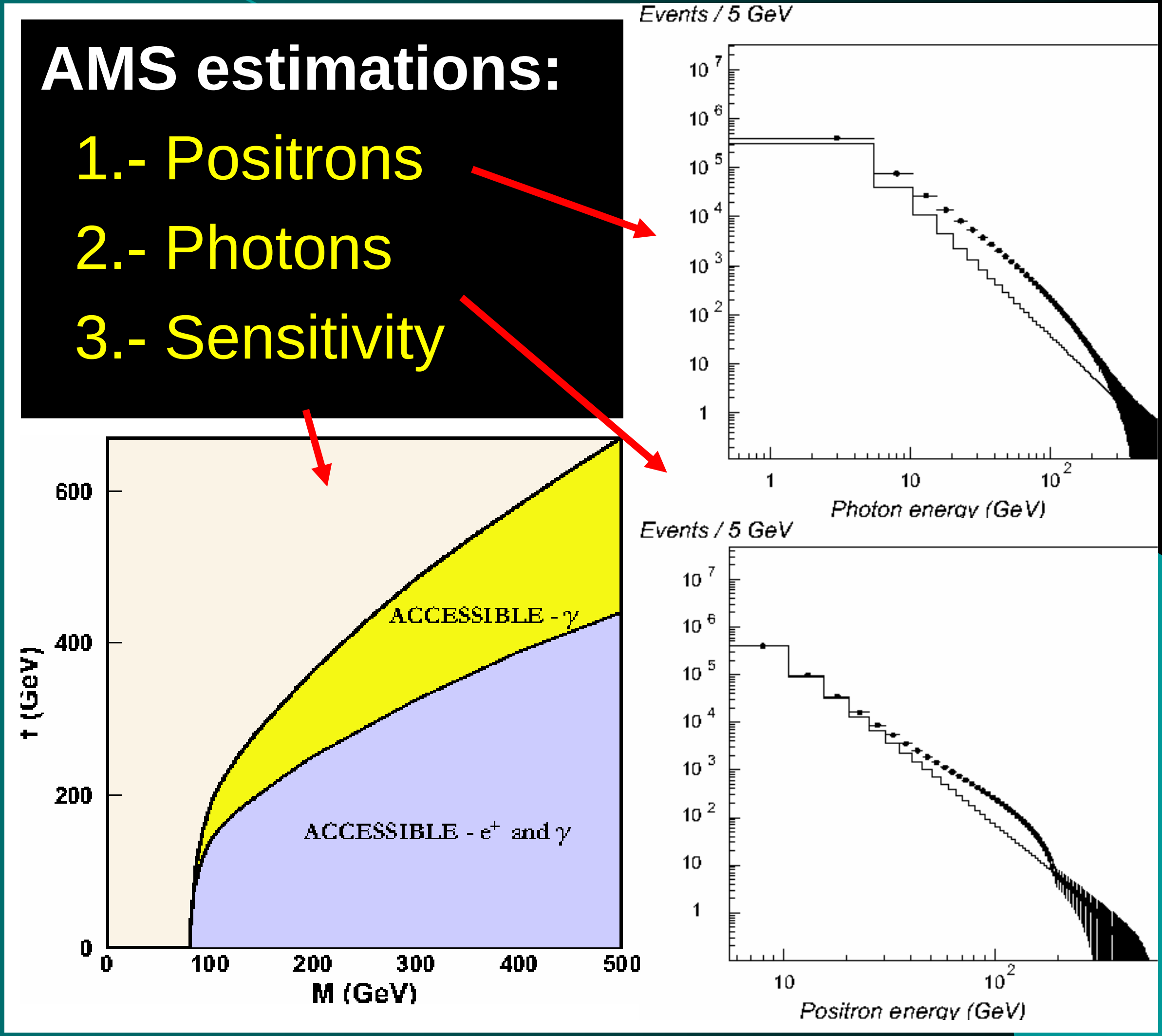


AMS PROSPECTS

Cosmic rays : p, D, He, C, …,e+, e-, γ, ...

It will collect ~10^{10} CRs in near-earth orbit from few GeV to few TeV.

AMS Note, 2003-08-02 (2003)

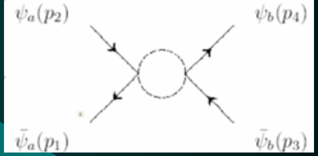


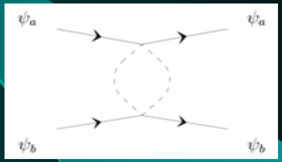
RADIATIVE CORRECTIONS

Modifications in the standard model phenomenology due to branon radiative corrections:

1.- One loop correction

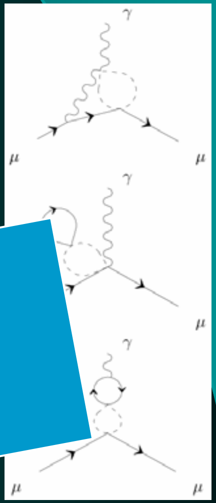
- 1.a. New effective interactions among four particles.
- 1.b. Force mediated by branons.





2.- Two loops corrections

- 2.a. Electroweak precision observables.
- 2.b. Muon anomalous magneti
  moment

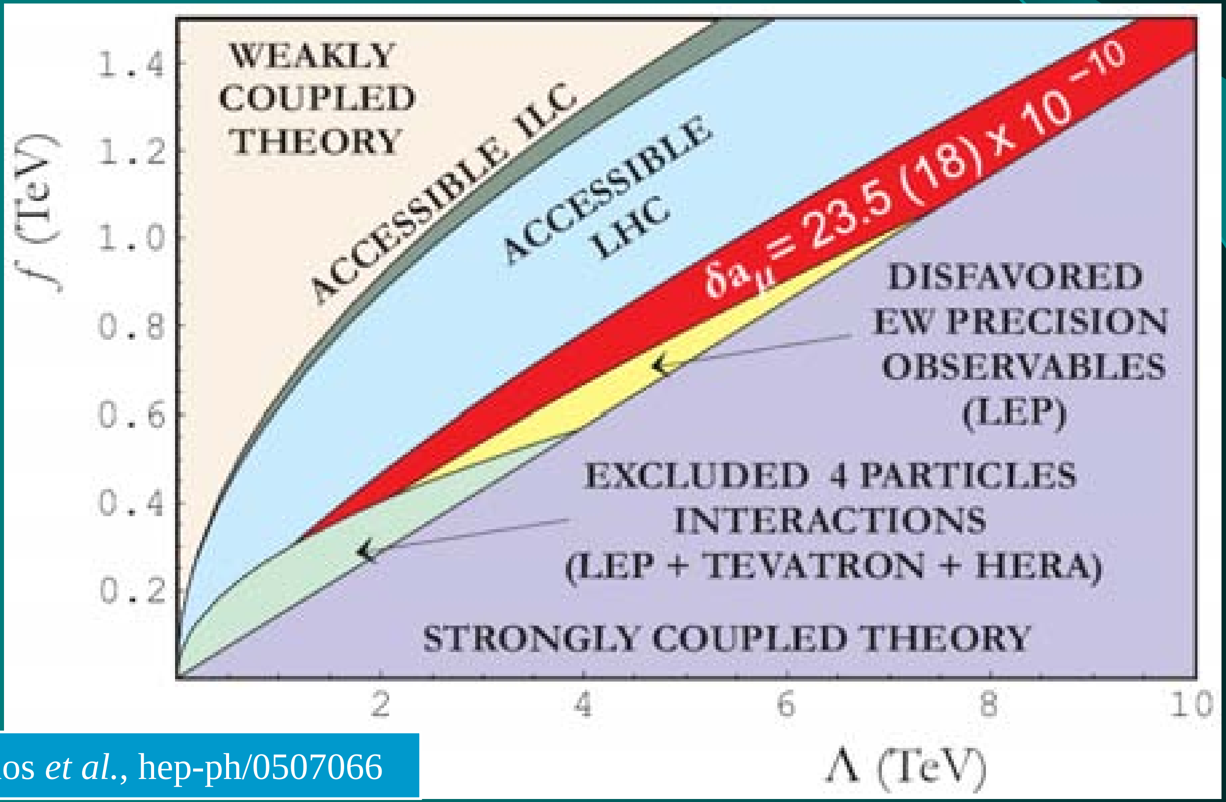


Cembranos *et al.*, hep-ph/0507066
Cembranos *et al.*, in preparation

Λ: Scale associated with new physics.

RADIATIVE RESULTS

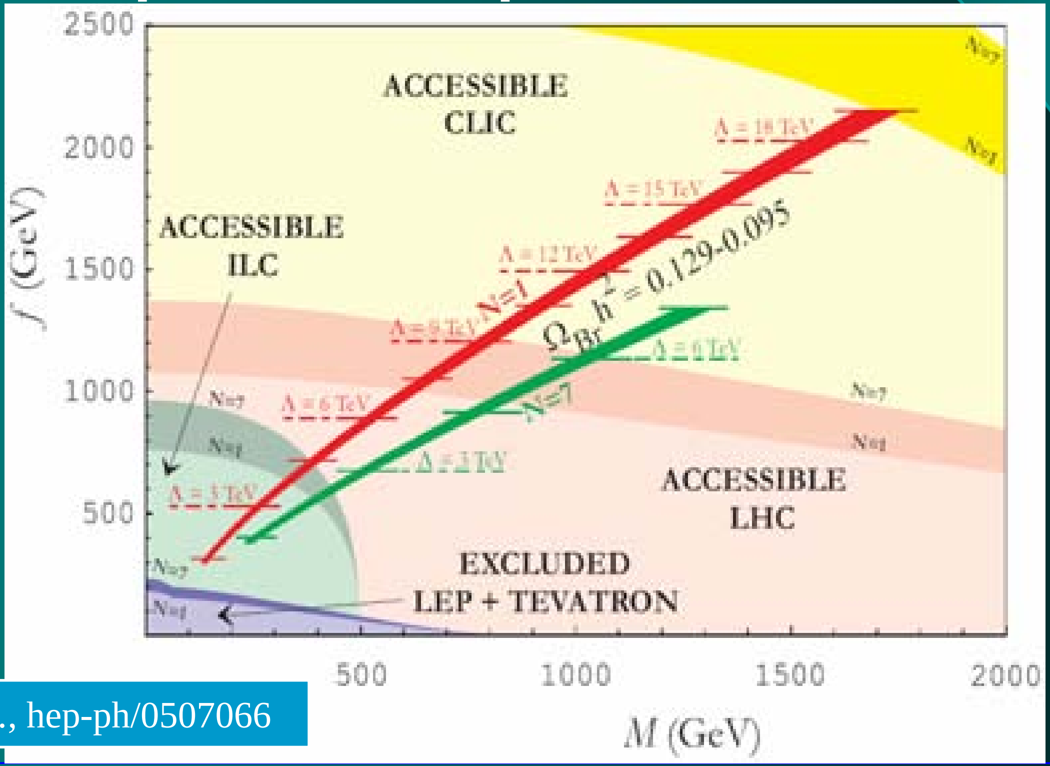
The branon radiative effects (at 95% C.L.) on the Standard Model phenomenology can be observed in the following general plot (*N* = 1):



Cembranos *et al.*, hep-ph/0507066

WMAP vs. BAGS

- **Flexible Brane Worlds can explain the non-baryonic dark matter abundance observed by WMAP and improve the present fits on the muon anomalous magnetic moment measured in the BAGS in a natural region of the parameter space.**



Cembranos *et al.*, hep-ph/0507066

CONCLUSIONS

1.- The branon signals constitute the first observational evidence for some extra dimensional models:

Flexible Brane Worlds ($f \ll M_D$).

2.- Their phenomenology can be determined in a model independent way in terms of the brane tension scale f , their number *N* and their masses *M*.

3.- This phenomenology is very rich and could be related to a great variety of experimental signals beyond the SM:

3.a. Scattering experiments: single γ , monoJet production, Bhabha scattering …

3.b. Cosmological observations: dark matter candidate …

3.c. Astrophysical Analysis: direct searches, indirect searches …

3.d. Electroweak precision observables.

3.e. Muon anomalous magnetic moment.