Kaluza-Klein Dark Matter: a review

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Based on work with

-Tim Tait: hep-ph/0206071 (NPB)
hep-ph/0209262 (New J.Phys.)

-Bertone & Sigl: hep-ph/0211342 (PRD)

-Kaustubh Agashe: hep-ph/0403143 (PRL)
hep-ph/0411254 (JCAP)

-Dan Hooper: to appear

ADD models

$R \sim meV^{-1}$ (flat)

only gravity in bulk

- radion dark matter m~meV; (fine-tuned)
- branon dark matter (fine-tuned)

TeV^{-1} X-dims

$R \sim TeV^{-1}$ (flat)

gauge bosons in bulk

all SM fields in bulk

"Universal" X-dims

- radion dark matter m~meV; (fine-tuned)
- KK dark matter

WIMP!

Hierarchy pb solved

Warped geometries (Randall-Sundrum)

$R \sim M_{Pl}^{-1}$ but $M_{KK} \sim TeV$

(AdS)

- radion unstable

if GUT in bulk → - KK dark matter

WIMP!

WIMP KK dark matter

So far, two working models :

✔ Universal Extra Dimensions (UED)

WIMP = Lightest KK particle (LKP)
stability symmetry = KK parity

✔ Warped GUTs

WIMP = Lightest Z_3 charged particle (LZP)
stability symmetry = Z_3 symmetry

+ a potential link between the LZP and baryogenesis...

Literature on KK dark matter: the complete list

Kolb & Slansky '84	Thought about it, but in 1984 R^{-1}~TeV was inconceivable...
Dienes, Dudas & Gherghetta '99 Mohapatra& Perez-Lorenzana '02	mentionned the idea in passing
Servant & Tait '02	Detailed relic density calculation
Cheng, Feng & Matchev '02	Direct and indirect detection
Servant & Tait '02	Direct detection
Majumdar '02	Direct detection
Hooper & Kribs '02	Prospects for neutrino telescopes
Bertone, Servant & Sigl '02	Indirect detection
Hooper & Kribs '04	Positron excess
Bergstrom, Bringmann, Eriksson & Gustafsson '04 Baltz & Hooper '04 Bergstrom, Bringmann, Eriksson & Gustafsson II '04	Indirect detection
Kakizaki, Matsumoto, Sato & Senami '05	A 2nd look at the relic density calculation
+ superWimp KK graviton papers	

} KK dark matter in UED

Agashe & Servant '04 Agashe & Servant II '04	Model building, relic density, direct detection, collider signatures ...
Hooper & Servant , upcoming	Indirect detection

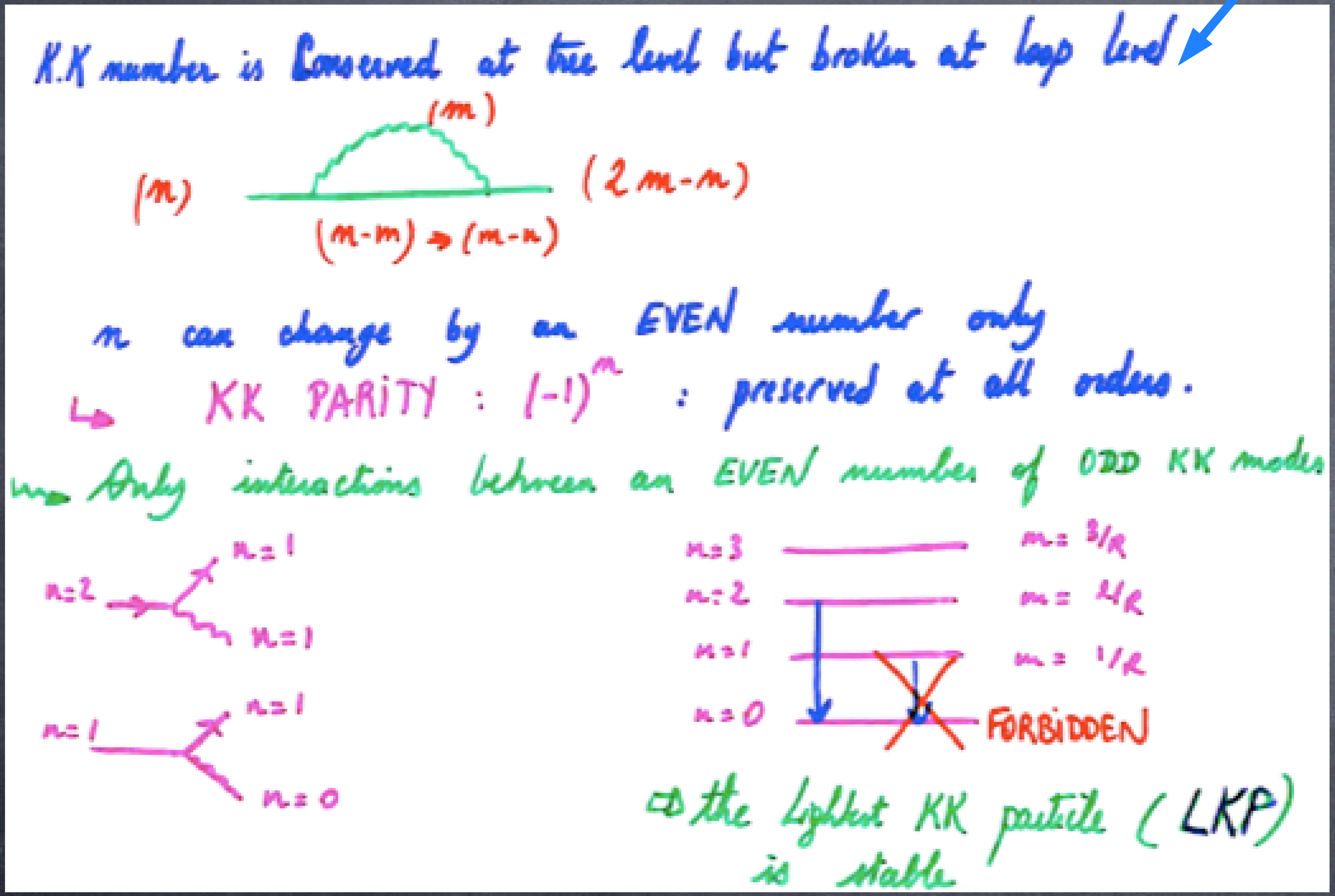
} Warped KK dark matter

LKP dark matter in Universal Extra Dimensions

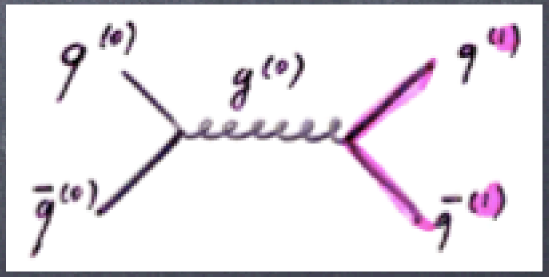
UED : ALL SM particles propagate into flat dimensions   Appelquist, Cheng & Dobrescu '01

Conservation of momentum along extra dimension translates in 4D into conservation of KK number

by the orbifold we impose to recover a chiral theory



Other consequence of KK parity:
Production of 1rst KK modes
only by pairs:

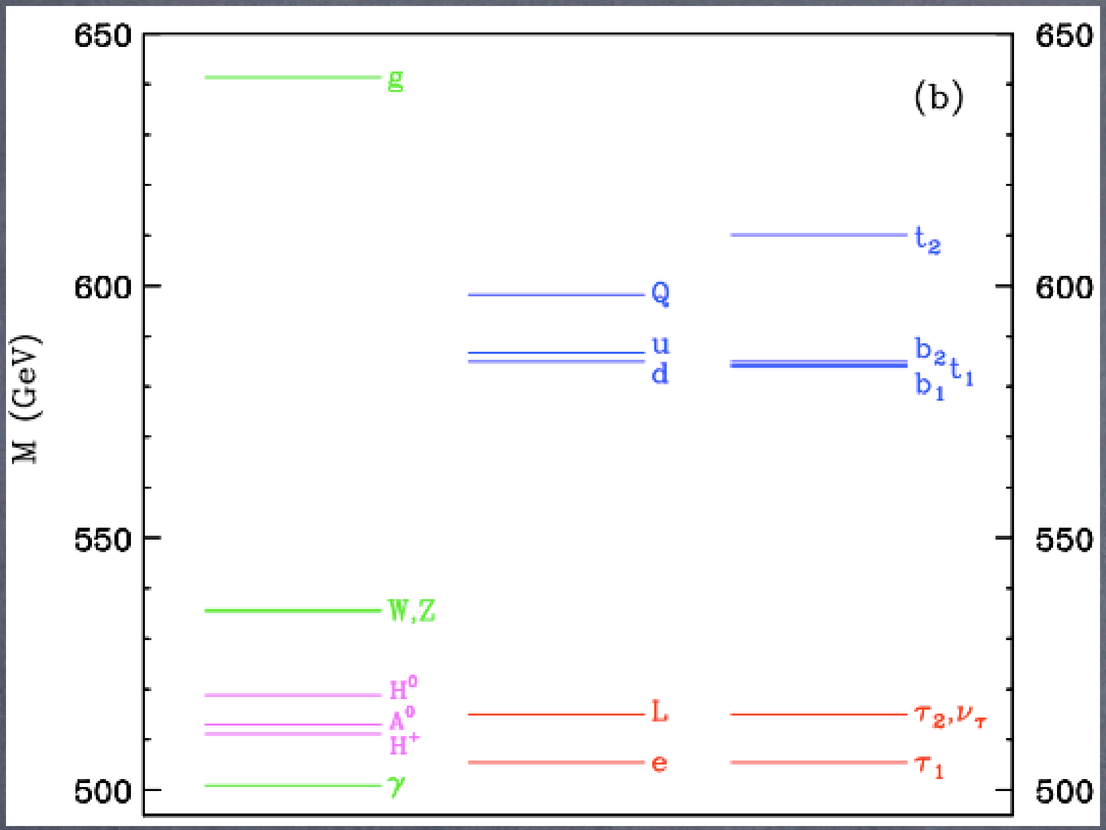


⇛Weak bound on 1/R

$R^{-1} \gtrsim 300$ GeV for $\delta = 1$
$R^{-1} \gtrsim 500$ GeV for $\delta = 2$

1-loop spectrum of 1rst KK modes

Cheng, Matchev & Schmaltz'02



assuming:1/R=500 GeV, $\Lambda R = 20, m_h = 120$ GeV
and vanishing boundary terms at the cutoff Λ

→ LKP: most likely a γ^1 (actually a B^1)

Another intriguing possibility: LKP=KK graviton (see S. Su's talk)

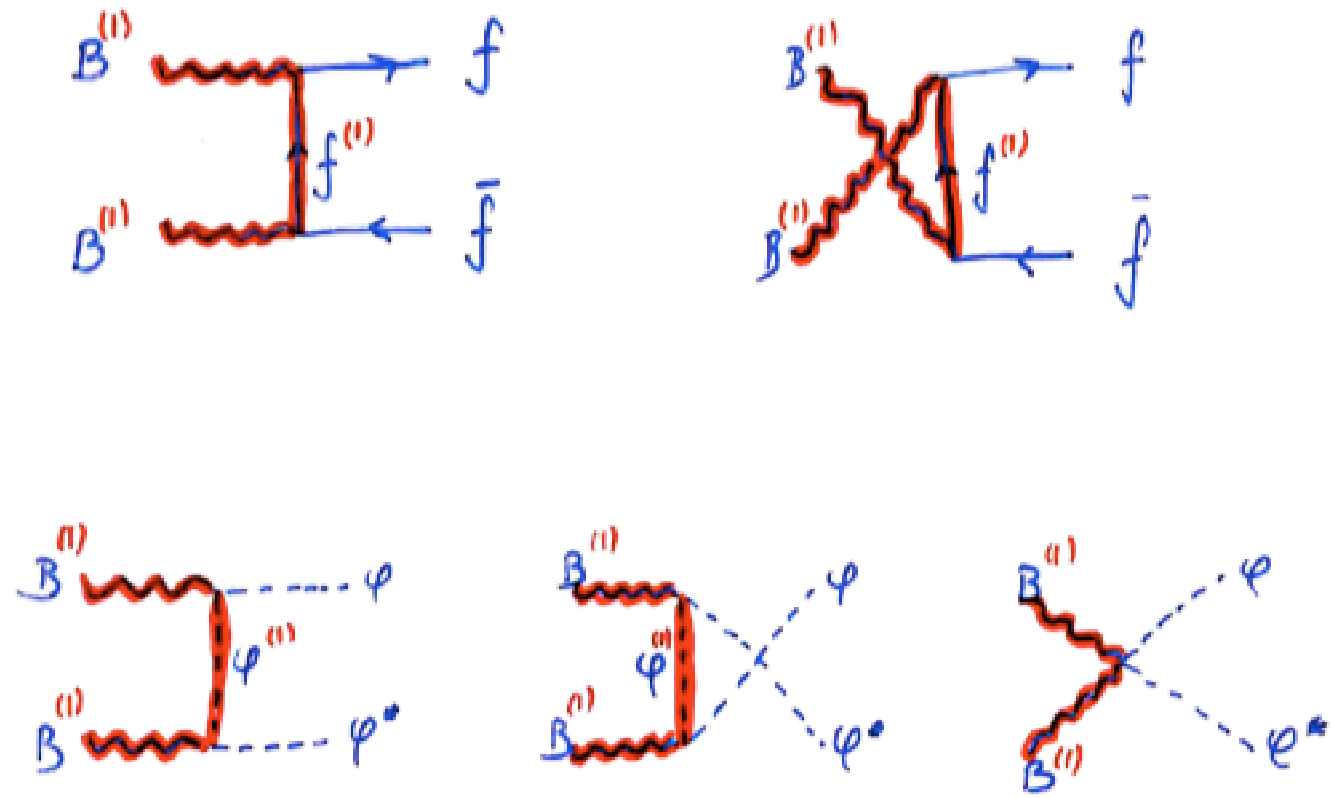
Relic density predictions

REMINDER :

$$\Omega h^2 \approx \frac{10^9}{m_{Pl}} \frac{x_F}{\sqrt{g_*}} \frac{\text{GeV}^{-1}}{\langle \sigma_{eff} v \rangle}$$

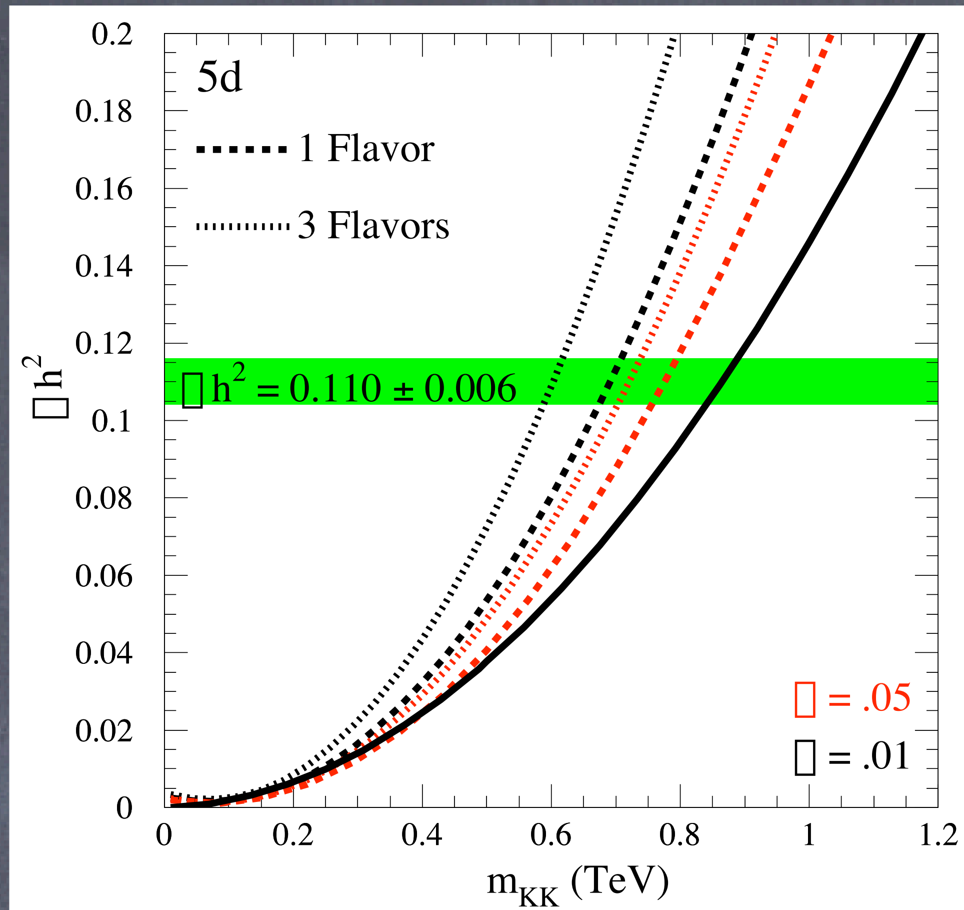
$\Omega h^2 \approx 0.11 \rightsquigarrow \langle \sigma_{eff} \rangle \sim 1\ \text{pb}$ $\quad (x_F \approx 25\text{-}35)$

Annihilation cross sections

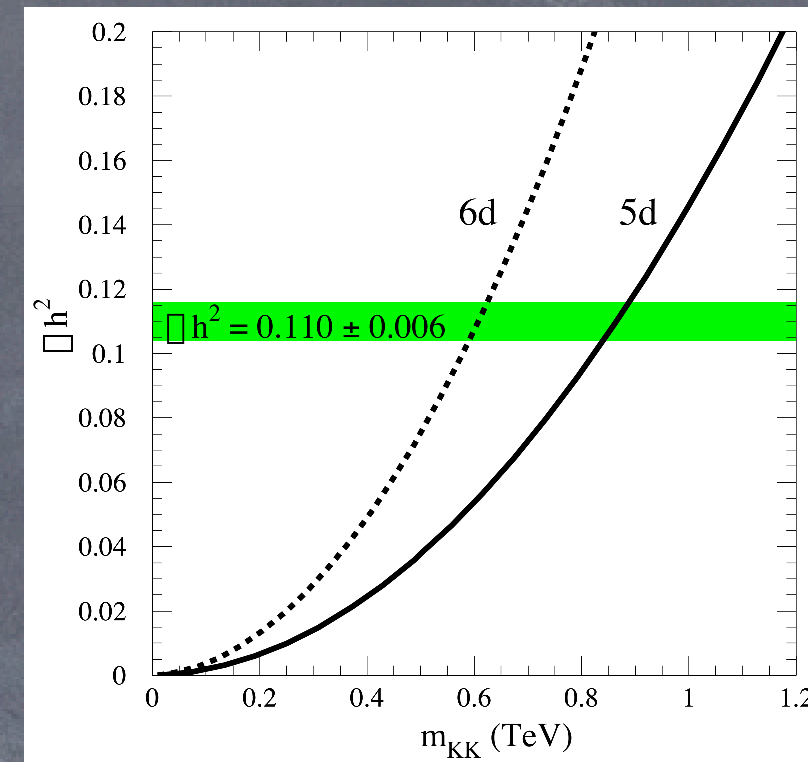


✔ Coannihilation effects

Servant-Tait



✔ Possible effect of additional dimension

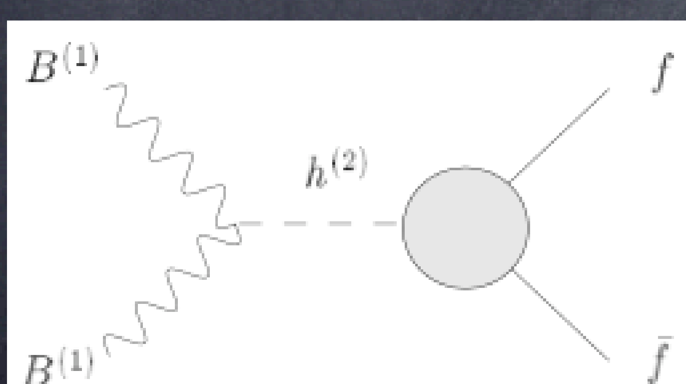


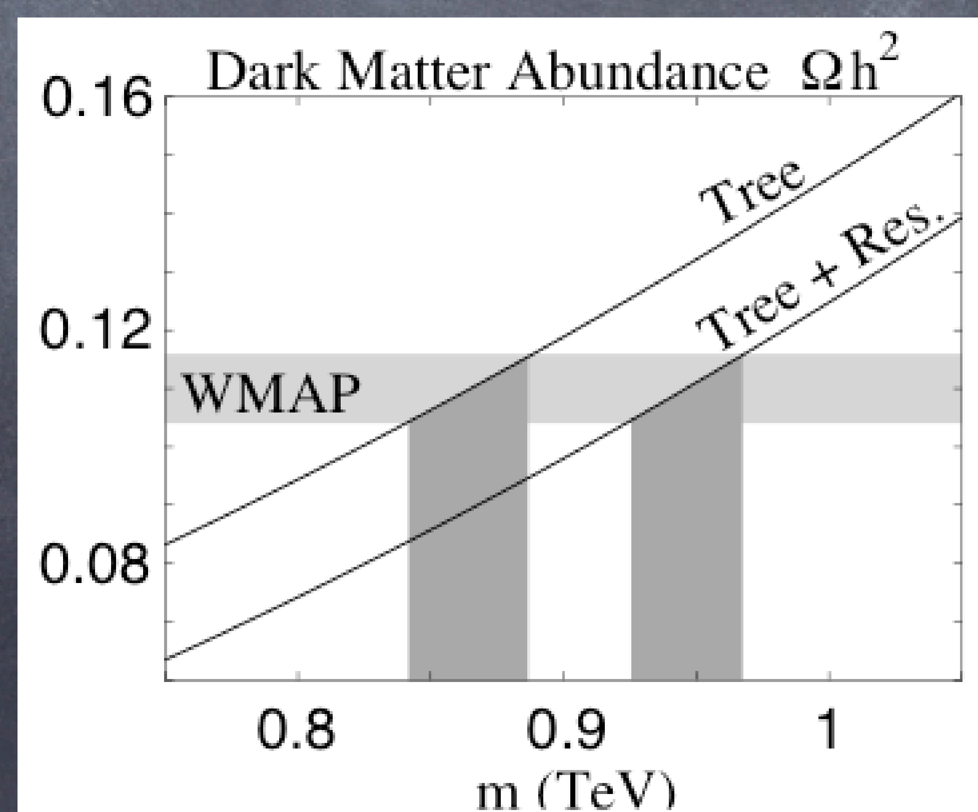
Servant-Tait

✔ Effect of 2nd KK modes

"natural KK resonance"

Kakizaki & al , hep-ph/0502059



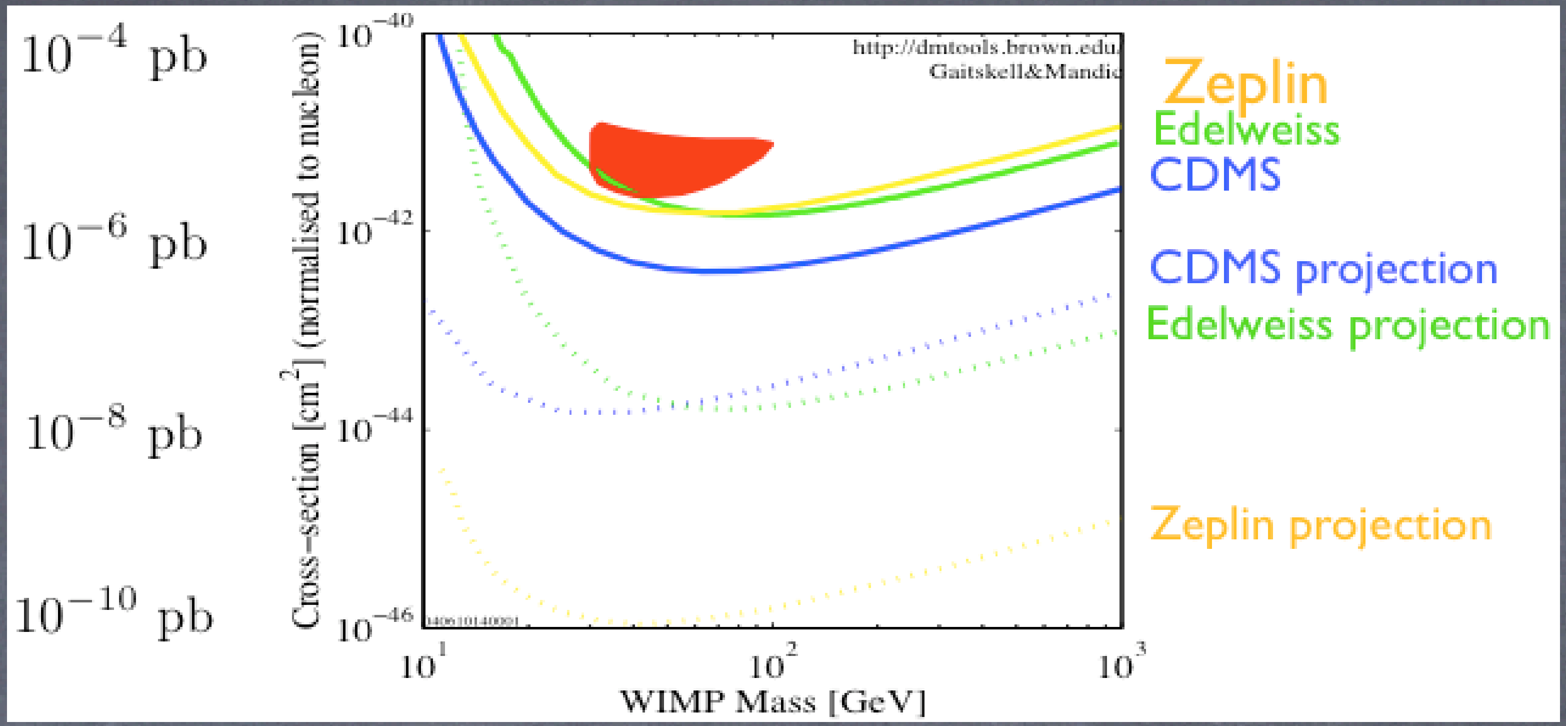


$\delta \equiv (m_{h^{(2)}} - 2m)/2m$

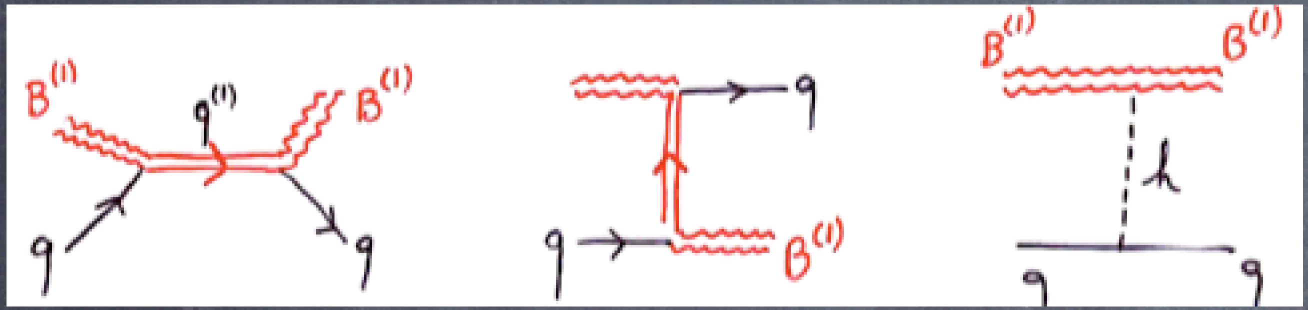
$\delta \sim 0.01$

Direct detection

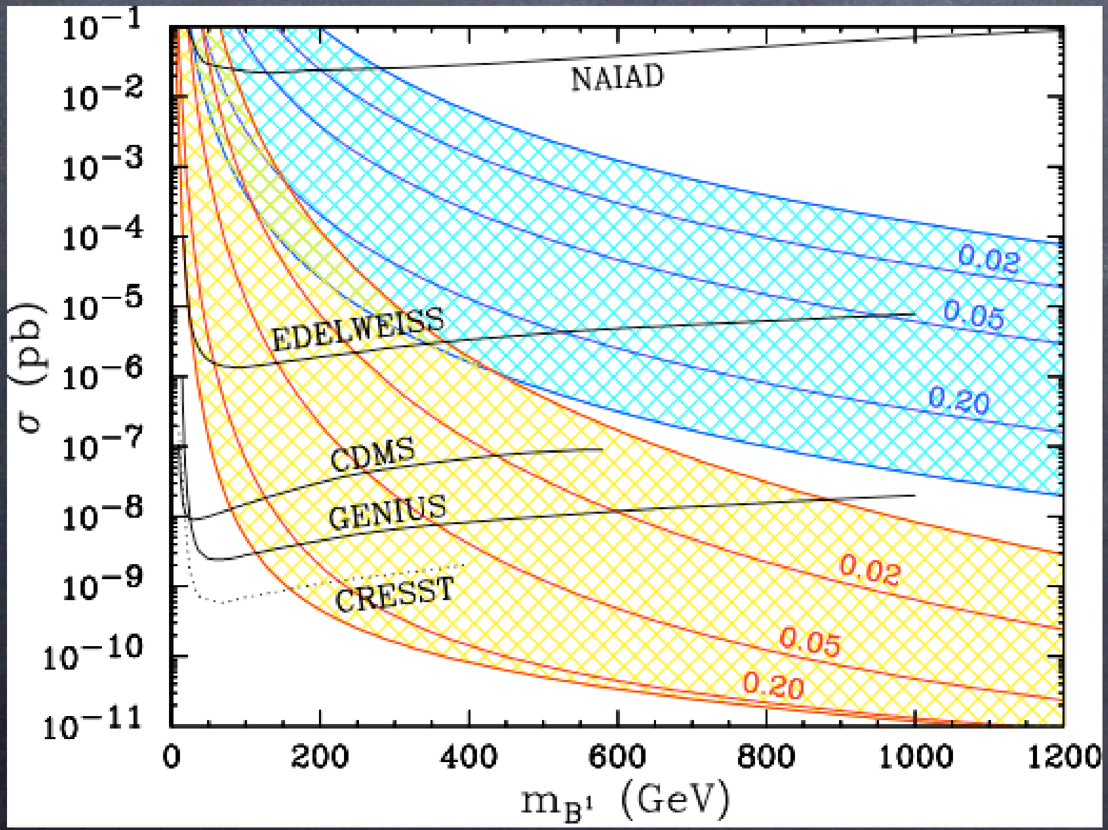
Experimental limits :

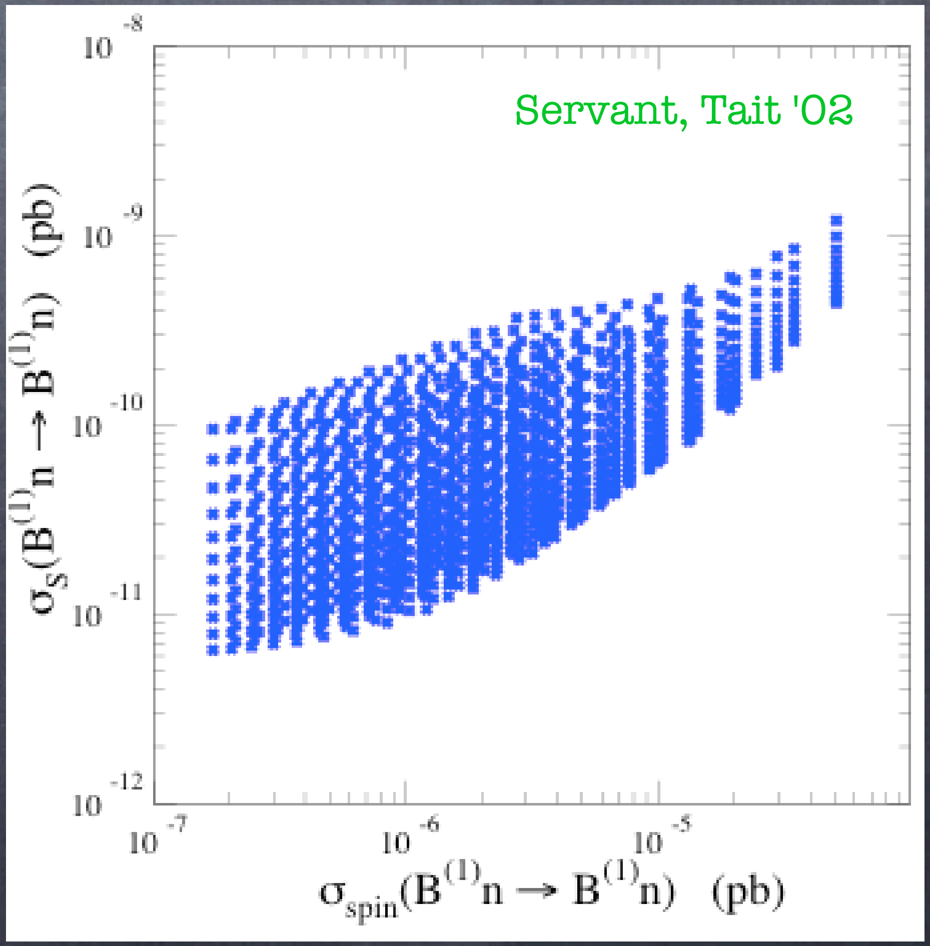


LKP signal :



Cheng, Feng, Matchev '02

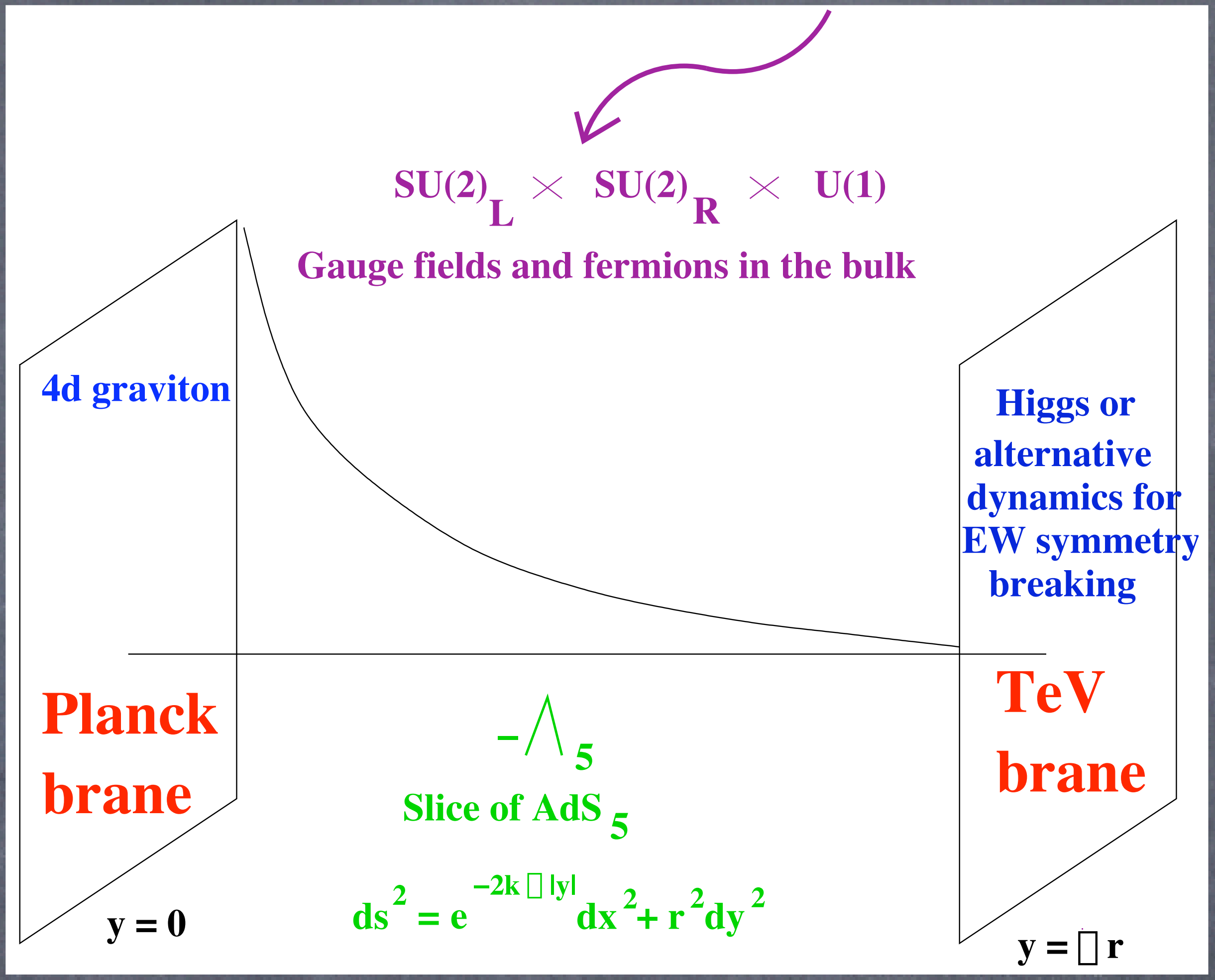




Particle physics model building in warped space

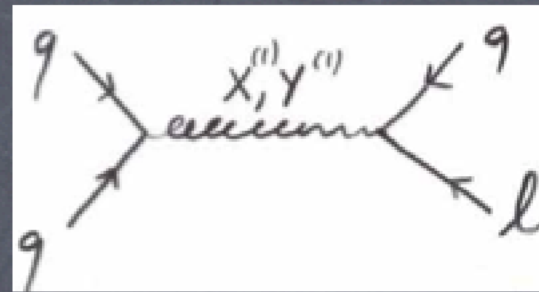
2005 favourite set-up:

- ✔ hierarchy pb
- ✔ fermion masses
- ✔ High scale unification
- ✔ FRW cosmology



Now embed this into a GUT + solve proton stability

- ✔ Dark matter

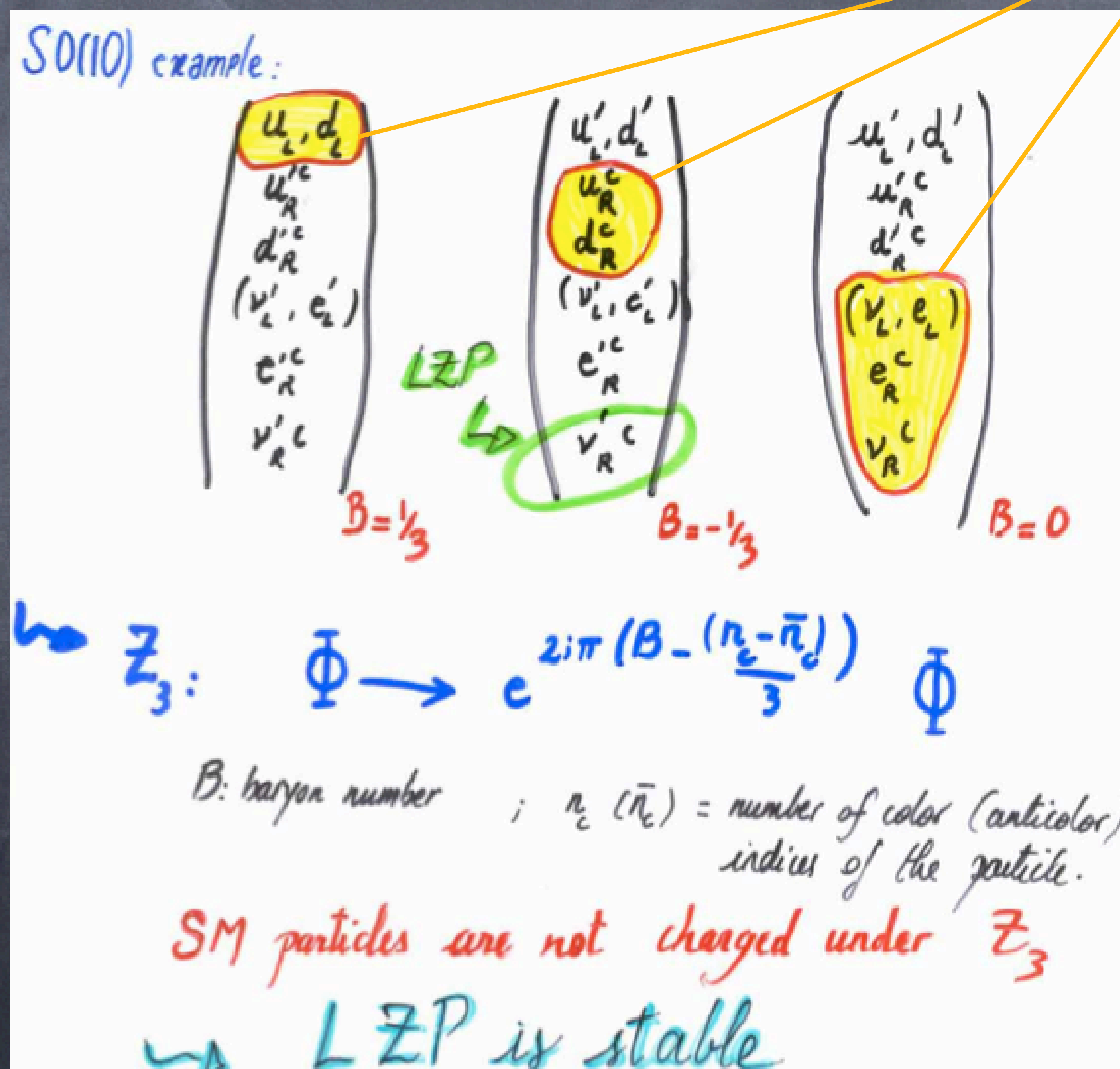
In GUTs ⇛ 

where $M_{X,Y}$ ~ few TeV

⇛ very fast proton decay

Solution: Break GUT by boundary conditions which split GUT multiplets

zero modes= SM fermions



Mass spectrum of KK fermions

Depends on:

✔ type of boundary conditions on TeV and Planck branes

✔ c-parameter (=5D bulk mass)
(=localization of zero-mode wave function)

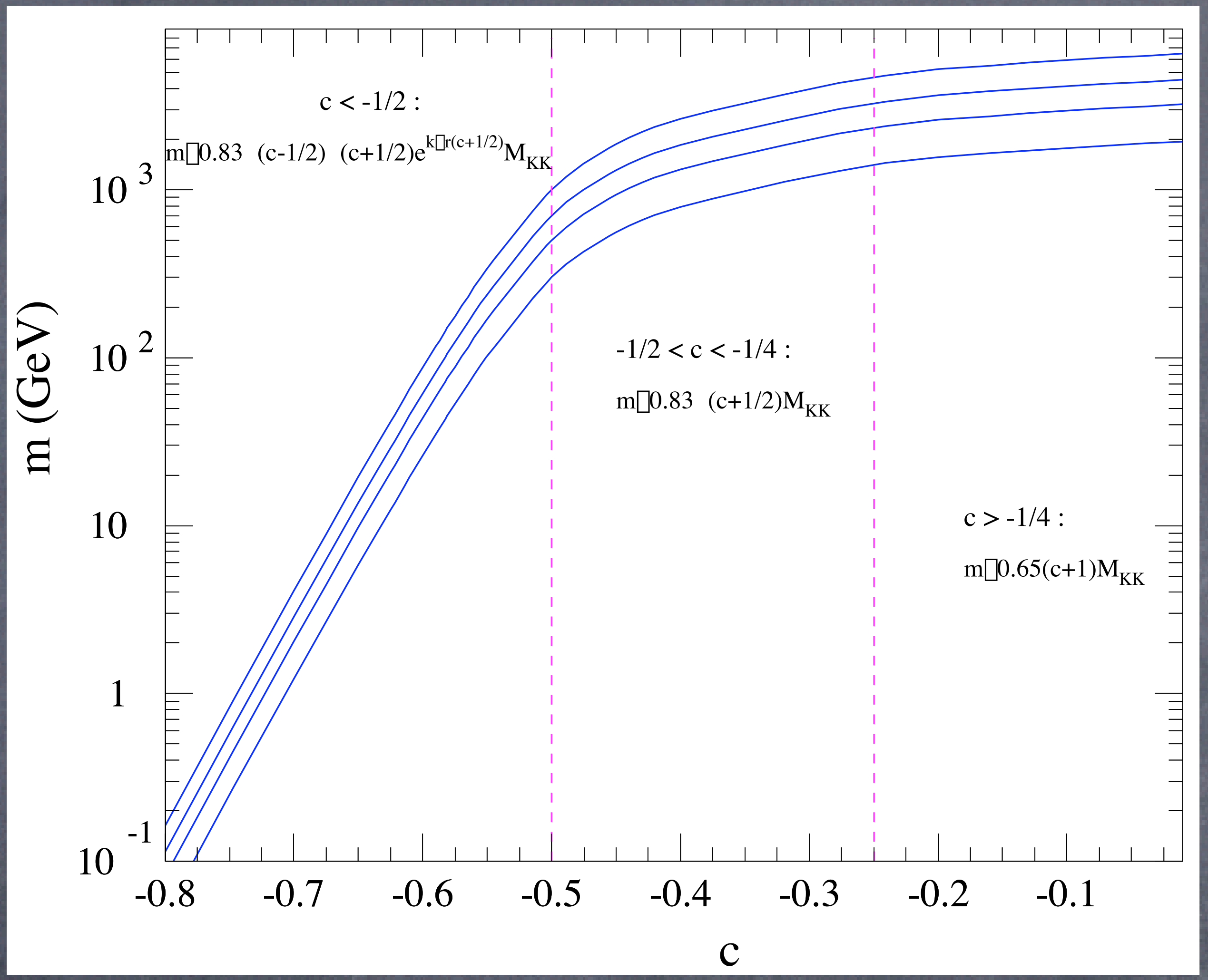
For certain type of boundary conditions on fermions, there can be a hierarchy between the mass of KK fermion and the mass of KK gauge bosons

$\Rrightarrow$ Not a single KK scale

Mass spectrum of lightest KK fermion

M_{KK} value

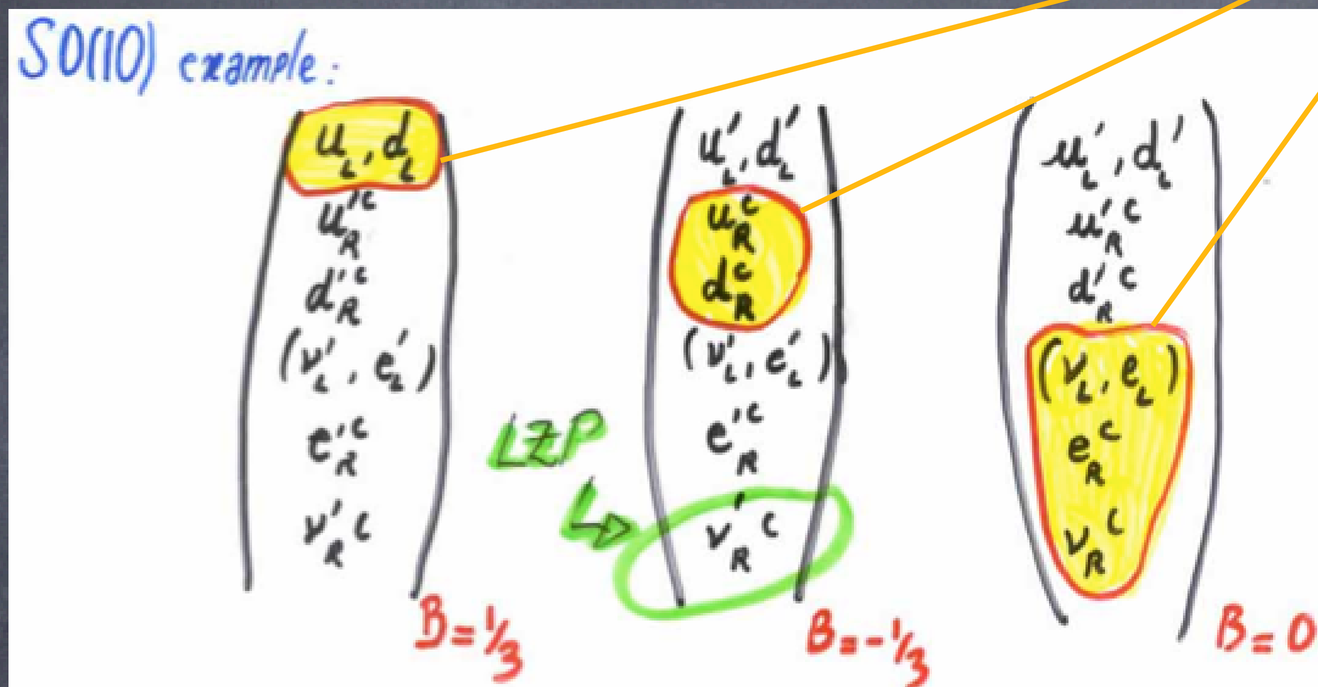
10 TeV
7 TeV
5 TeV
3 TeV



and smallest c: c of the top quark

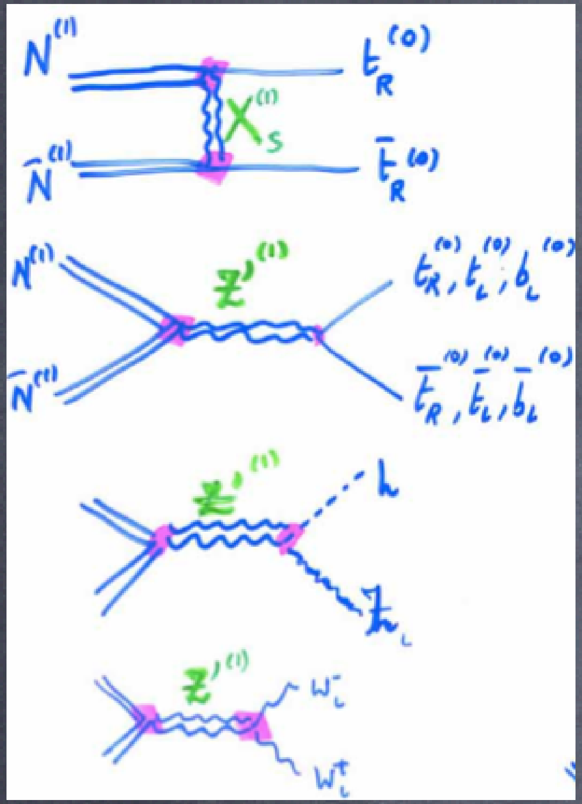
⇛ LZP belongs to the multiplet containing SM top quark

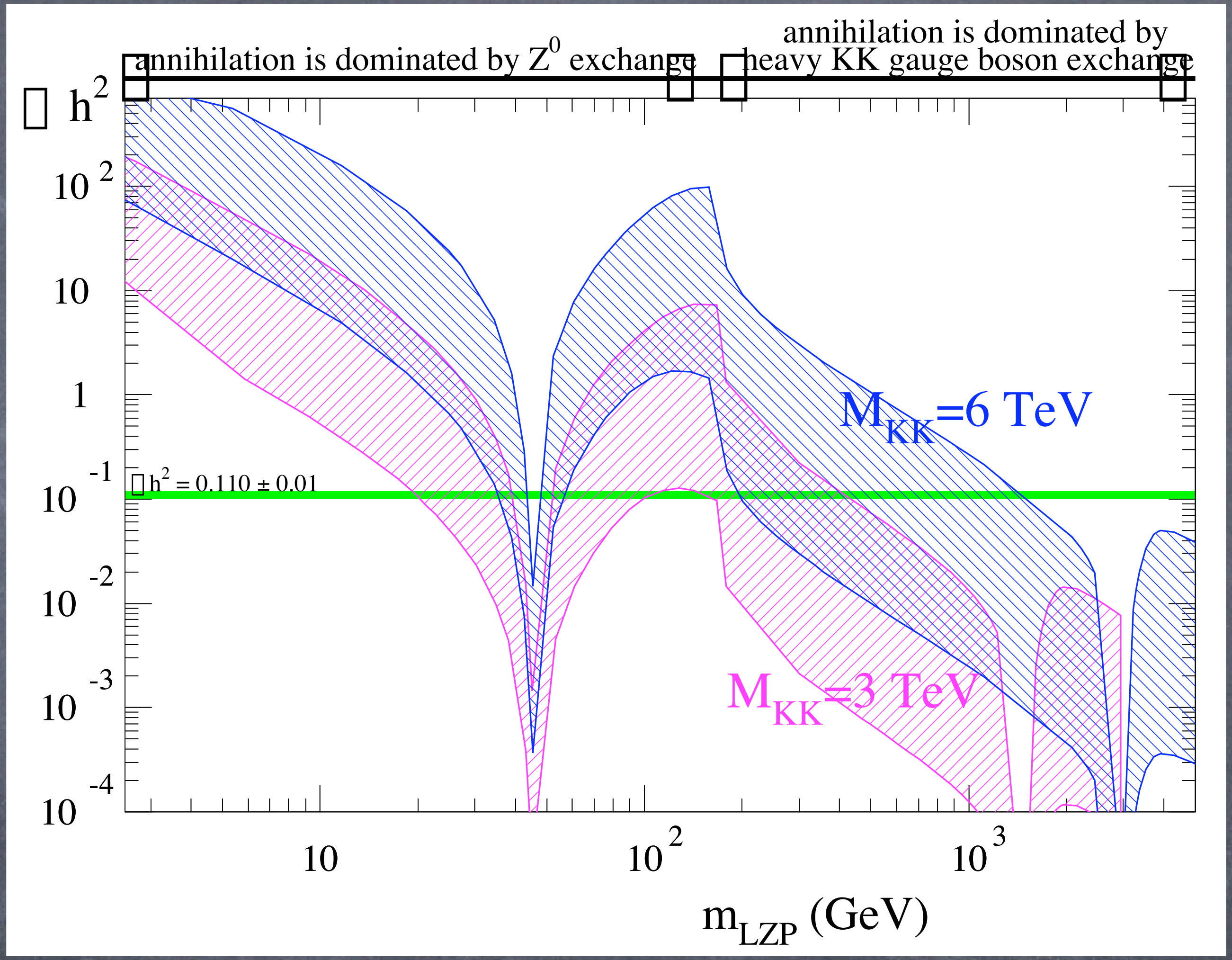
There exists a very light KK fermion as a consequence of the heaviness of the top quark



zero modes=
SM fermions

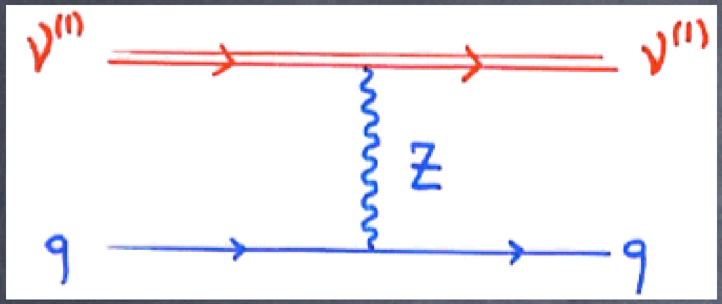
Relic density predictions





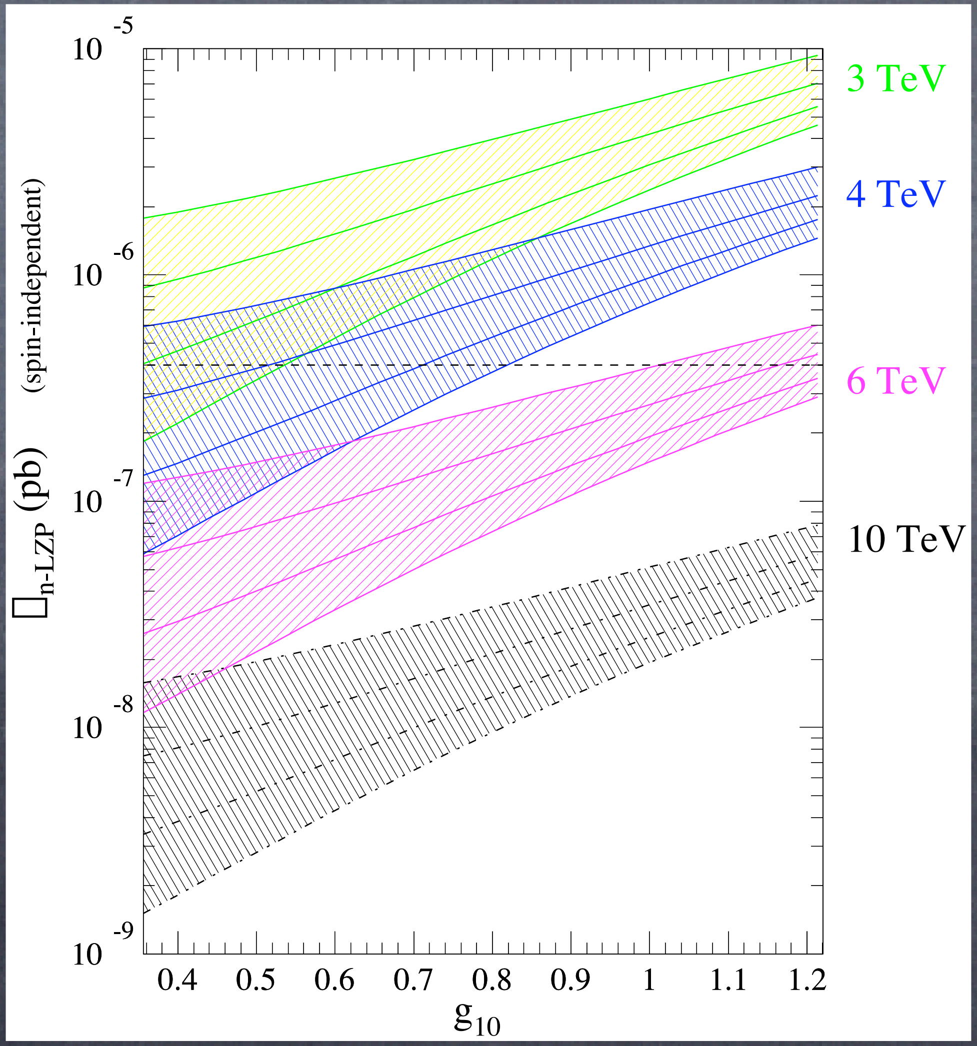
Agashe-Servant '04

Direct detection



Wimp-nucleon elastic scattering cross section (spin-independent)

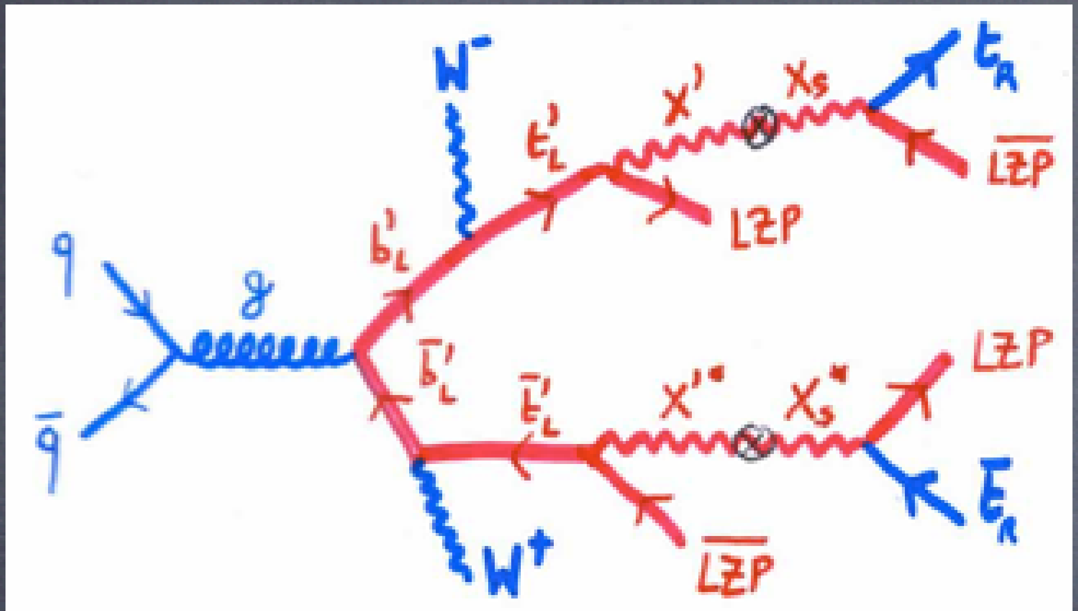
masses of KK gauge bosons



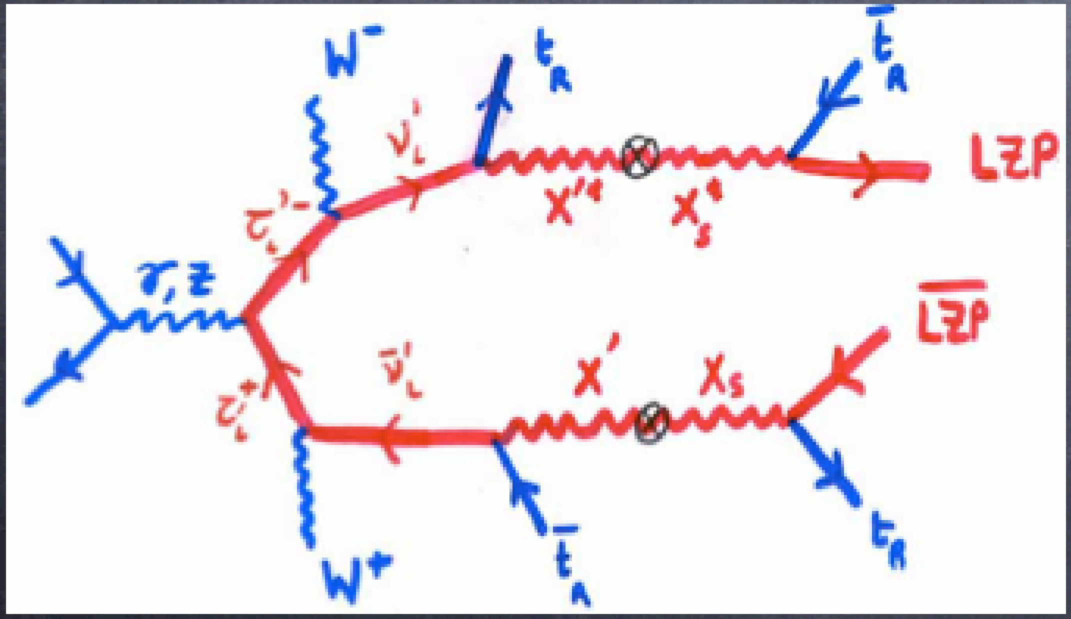
CDMS limit (only applies for some range of wimp masses)

Agashe-Servant '04

Collider Signatures: examples



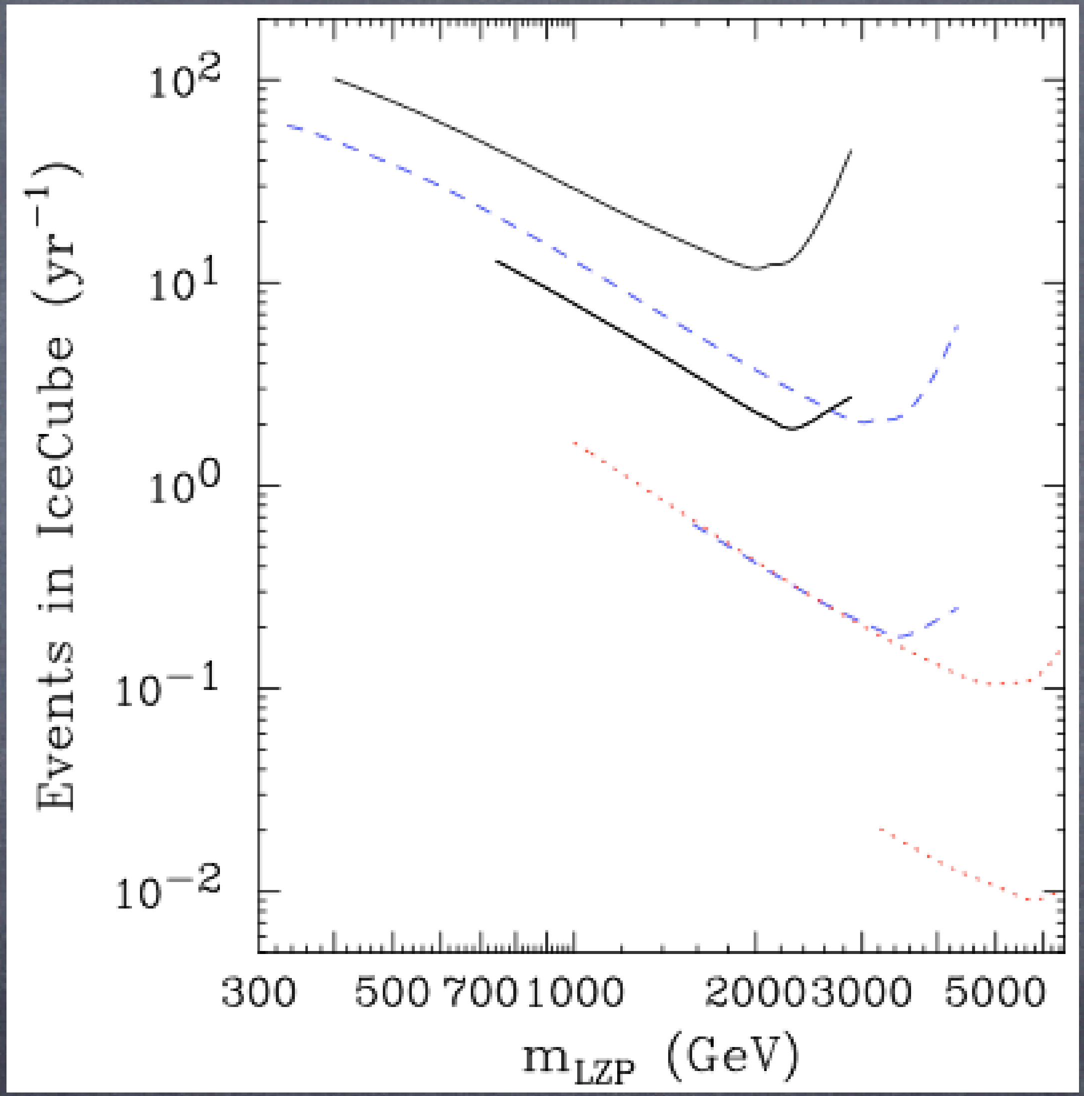
→ 4 W + 2 b+ $\not{E}_T$



→ 6 W + 4 b+ $\not{E}_T$

Indirect detection in neutrino telescopes

Large elastic scattering cross section: large capture rate in the Sun
Efficient production of neutrinos in annihilations



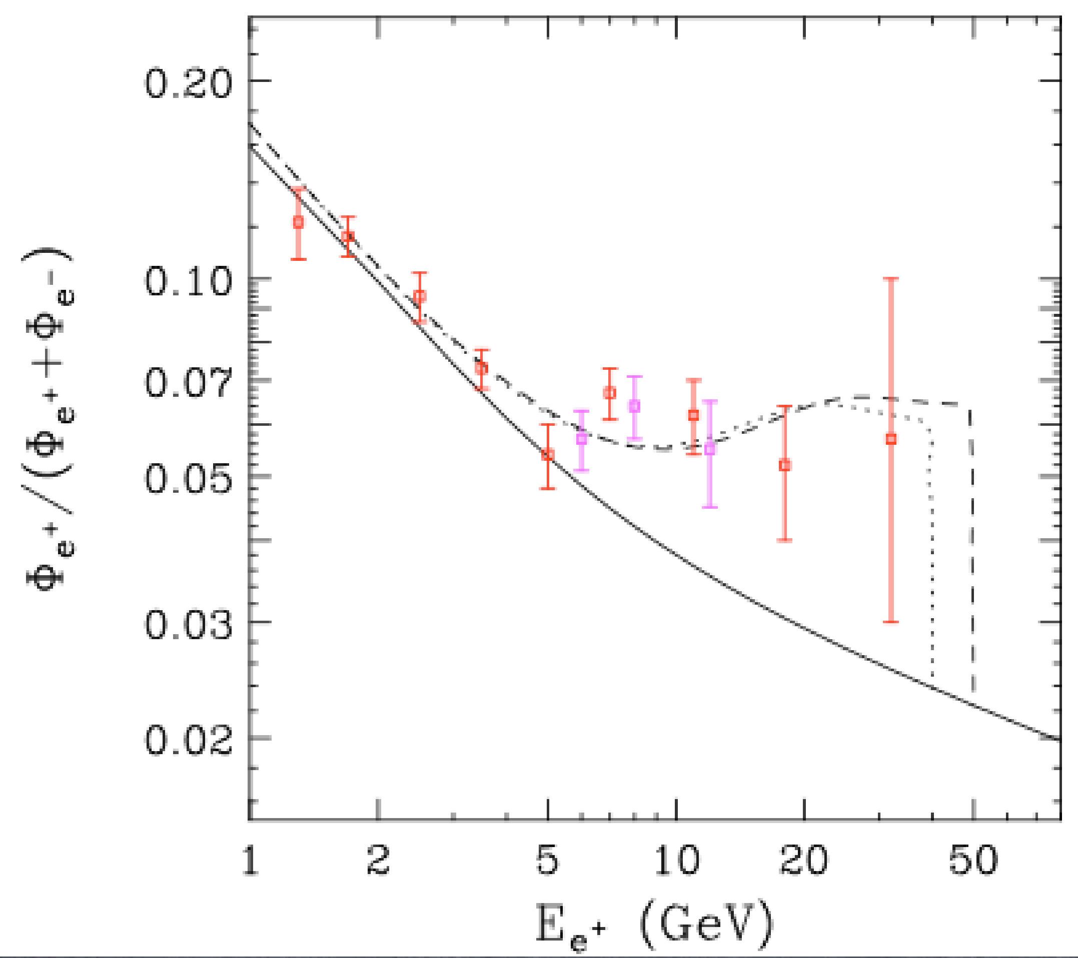
M_{KK}=4 TeV

M_{KK}=6 TeV

M_{KK}=10 TeV

Hooper & Servant, in prep.

Cosmic positrons from LZP annihilations



Hooper & Servant, in prep.

Fit of the HEAT data from LZP annihilations

.... 40 GeV LZP

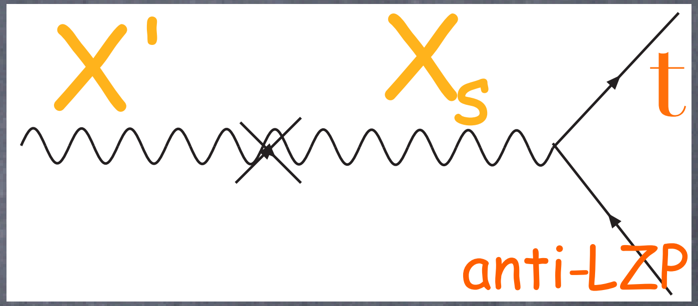
- - - - 50 GeV LZP

A natural framework to relate baryons *and* dark matter

Our dark matter candidate carries baryon number! (B=1/3)

$$B_{UNIVERSE} = 0 = \underbrace{B}_{\text{carried by baryons}} + (\underbrace{-B}_{\text{carried by anti-LZP}})$$

Assume an asymmetry between t and $\bar{t}$ is created via the out-of-equilibrium and CP-violating decay :



Baryon number conservation leads to:

$$3\,(n_{\overline{LZP}} - n_{LZP}) = n_b - n_{\bar{b}}$$

Assuming efficient annihilation between LZP and $\overline{LZP}$, and b and $\bar{b}$:

$$\rho_{DM} = m_{LZP}\, n_{LZP} \approx 6\rho_b \longrightarrow m_{LZP} \approx 18 \text{ GeV}$$

	LKP	LZP	LSP
nature	gauge boson	Dirac fermion	Majorana fermion
symmetry	KK parity $(-1)^n$	Z_3 $B - \frac{(n_c - \bar{n}_c)}{3}$	R-parity $(-1)^{3(B-L)+2S}$
		related to proton stability	related to proton stability
mass range	~600-1000 GeV	20 GeV-few TeV	~50 GeV-1 TeV
annihilation cross section	s-wave	s-wave	helicity suppressed (p-wave)
favourite detection	✔ LHC ✔ Indirect detection	✔ Direct detection! ✔ LHC! ✔ Indirect detection ! entire parameter space is testable	✔ LHC

To conclude

Abundance of experimental activity related to dark matter detection:

- Colliders
- Direct detection: CDMS, Edelweiss, Dama, Cresst, Zeplin, Xenon, Naiad ...
- Indirect detection:
  - Gamma-ray telescopes: Hess, Veritas, Glast, Magic
  - Neutrino telescopes: Amanda, IceCube, Antares
  - Cosmic positron experiments: HEAT, Pamela, AMS-2

⇛It is timely to study the distinctive signatures expected in different dark matter scenarios.

LKPs, LZPs: viable alternatives to LSPs