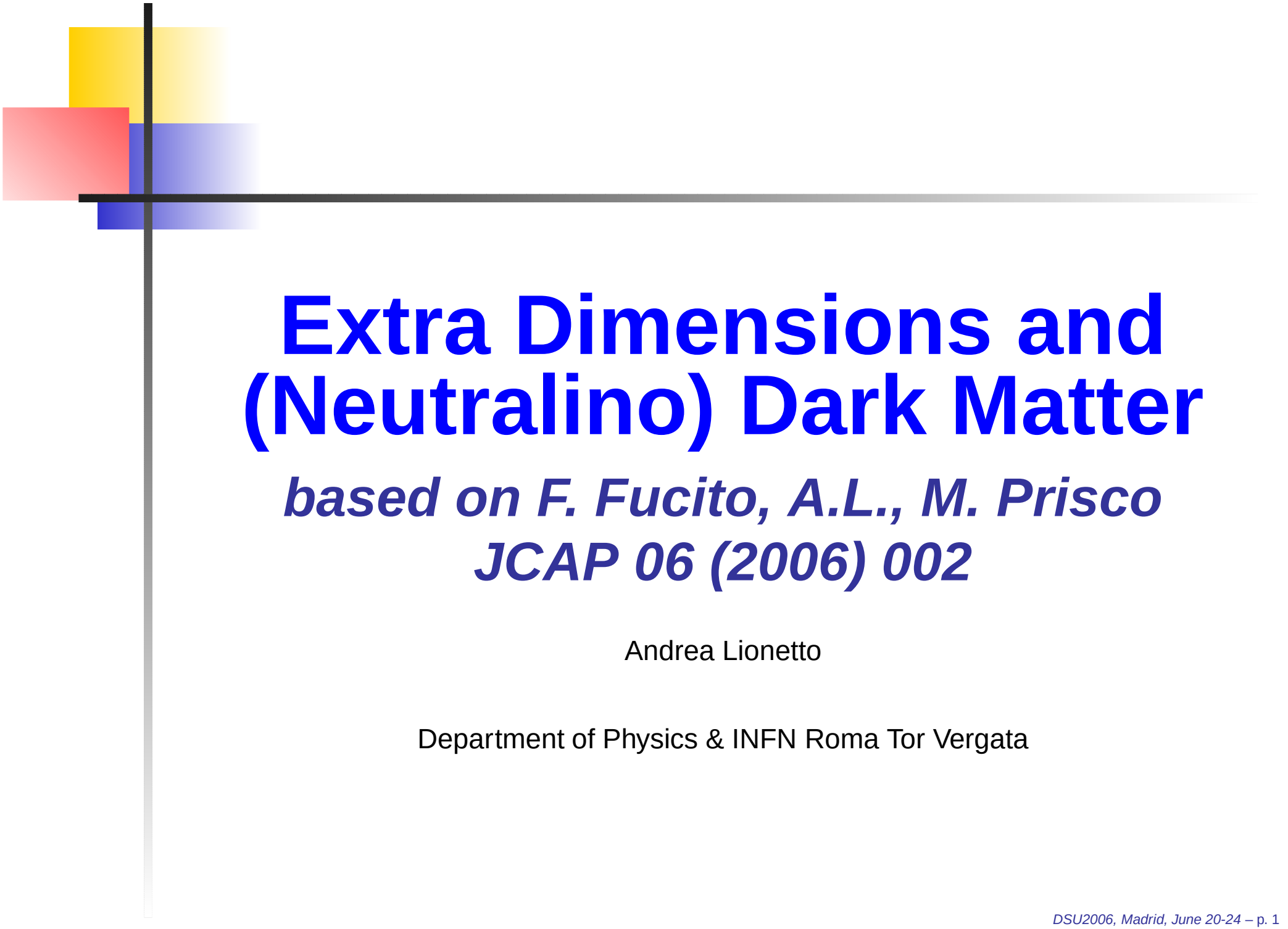

Extra Dimensions and (Neutralino) Dark Matter

based on F. Fucito, A.L., M. Prisco JCAP 06 (2006) 002

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Outline

- Models with Extra Dimensions
- Orbifold Compactifications
- Power-law Running
- Soft Terms
- Phenomenology

Extra Dimensions

- Extra dimensions are not new (Kaluza-Klein theories)
- String theories need extra dimensions for consistencies (anomaly cancellations)
- A new appealing application: lowering the unification scale
- A first example: the heterotic (closed strings) and type I (open+closed strings)

Extra Dimensions

We consider a model with $D = 4 + \delta$ space-time dimensions with δ compactified dimensions (over $S^1 \times S^1 \times \cdots$ of radius R)

$$\mu_0 \equiv R^{-1}$$

is the threshold beyond which the effects of extra dimensions can be felt.
The $D = 4$ effective theory contains massive excitations (KK-modes)

$$m_n^2 = m_0^2 + \vec{n} \cdot \vec{n}/R^2$$

where $\vec{n} = (n_1, n_2, \ldots, n_\delta)$, $n_i \in \mathbb{Z}$

Extra Dimensions and MSSM

How to incorporate extradim into the MSSM?

- Not all MSSM have KK states. For example chiral states, to form a KK mass must appear together with their chiral conjugate mirror.
- η number of generations can possess KK states
- $\eta = 0$ case: the KK $N = 1$ vector bosons $(A_\mu^{(n)}, \lambda^{(n)})$ + $N = 1$ chiral multiplet $(\phi^{(n)}, \psi^{(n)})$ get arranged into a massive $N = 2$ vector supermultiplet

Extra Dimensions and MSSM

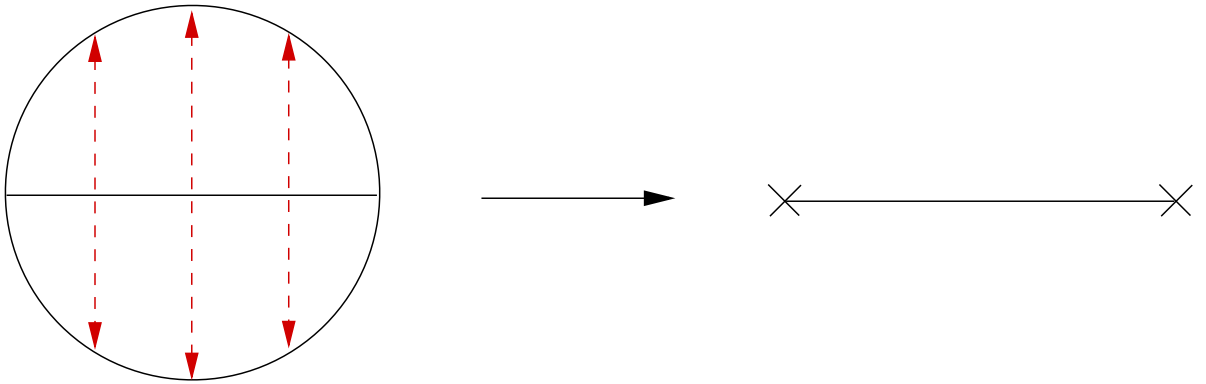
- The appearence of $N = 2$ multiplets is not surprising.
  Extra dimensions imply extended SUSY.
  $N = 2$ needed for á la Wilson renormalization (at least for gauge couplings)
- For $\eta > 0$ the KK excitations of the chiral fermions appear with their mirrors
- How is it possible to have $N = 2$ multiplets if the 0-mode are $N = 1$? Is it possible to decouple some particles from the others?

Orbifolds and MSSM

At the 0-mode level we want to reproduce the MSSM

$$\Downarrow$$

we must impose additional $\mathbb{Z}_2 : y \to -y$ symmetry



The quotient space $S^1/\mathbb{Z}_2$ is known as orbifold.
The compact dimensions are simply intervals.

Orbifolds and MSSM

Orbifold is a convenient mechanism to select which field have KK-excitations. General field decomposition $\Phi(x^\mu, y) = \Phi_+(x^\mu, y) + i\Phi_-(x^\mu, y)$

$$\Phi_+(x^\mu, y) = \sum_{n=0}^{\infty} \left[\phi^{(n)}(x^\mu) + \phi^{(-n)}(x^\mu)\right] \cos(ny/R)$$

$$\Phi_-(x^\mu, y) = \sum_{n=1}^{\infty} \left[\phi^{(n)}(x^\mu) - \phi^{(-n)}(x^\mu)\right] \sin(ny/R)$$

Under $y \to -y \quad \Rightarrow$

$$\boxed{\begin{aligned}\Phi_+(x^\mu, y) &= +\Phi_+(x^\mu, y)\\ \Phi_-(x^\mu, y) &= -\Phi_-(x^\mu, y)\end{aligned}}$$

Projected theory

- $\Phi_-(x)$ lacks a zero mode so (A, λ) can be even while the chiral multiplet odd
- Moreover the orbifold action has special points: the fixed points

$$y^{(A)} = 0, y^{(B)} = \pi R$$

- Fields sitting on the fixed points admit the following decomposition

$$\Phi(x, y) = \Phi^{(A)}(x)\delta(y) + \Phi^{(B)}(x)\delta(y - \pi R)$$

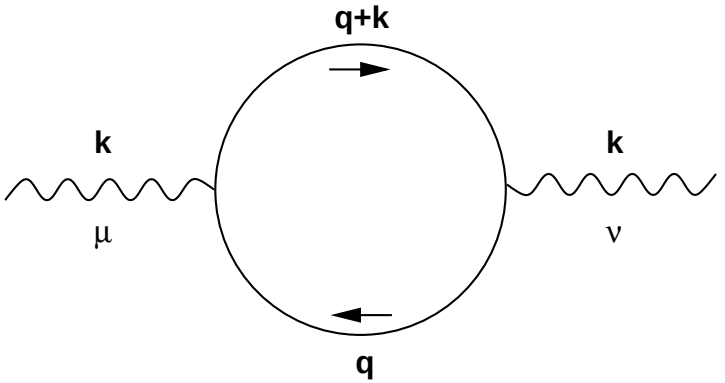
Projected theory

Field content

- Gauge bosons, always KK towers, $N = 2$ in the bulk
- Higgs bosons, always KK towers, $N = 1$ or $N = 2$ in the bulk to keep us as general as possible
- η fermion generations with KK towers

Extradim Loop Effects

In the $D = 4$ theory KK-states are now allowed to circulate into the loops



$$\Pi \approx \sum_{n_i=-\infty}^{\infty} \int_0^{\infty} \frac{d^4q}{(2\pi)^4} \left\{ \frac{-(k+q)\cdot q + 2m_n^2}{(q^2-m_n^2)[(k+q)^2-m_n^2]} \right\}$$

$$\approx \int_0^{\infty} \frac{dt}{t} \left[\vartheta_3 \left(\frac{it}{\pi R^2} \right) \right]^{\delta}$$

Power-law Running

Putting the infrared cut-off $\mu_0 = R^{-1}$ and an ultraviolet cut-off Λ we find

$$\alpha_i^{-1}(\Lambda) = \alpha_i^{-1}(\mu_0) - \frac{b_i - \tilde{b}_i}{2\pi} \ln \frac{\Lambda}{\mu_0} - \frac{\tilde{b}_i X_\delta}{2\pi\delta} \left[\left(\frac{\Lambda}{\mu_0} \right)^\delta - 1 \right]$$

where

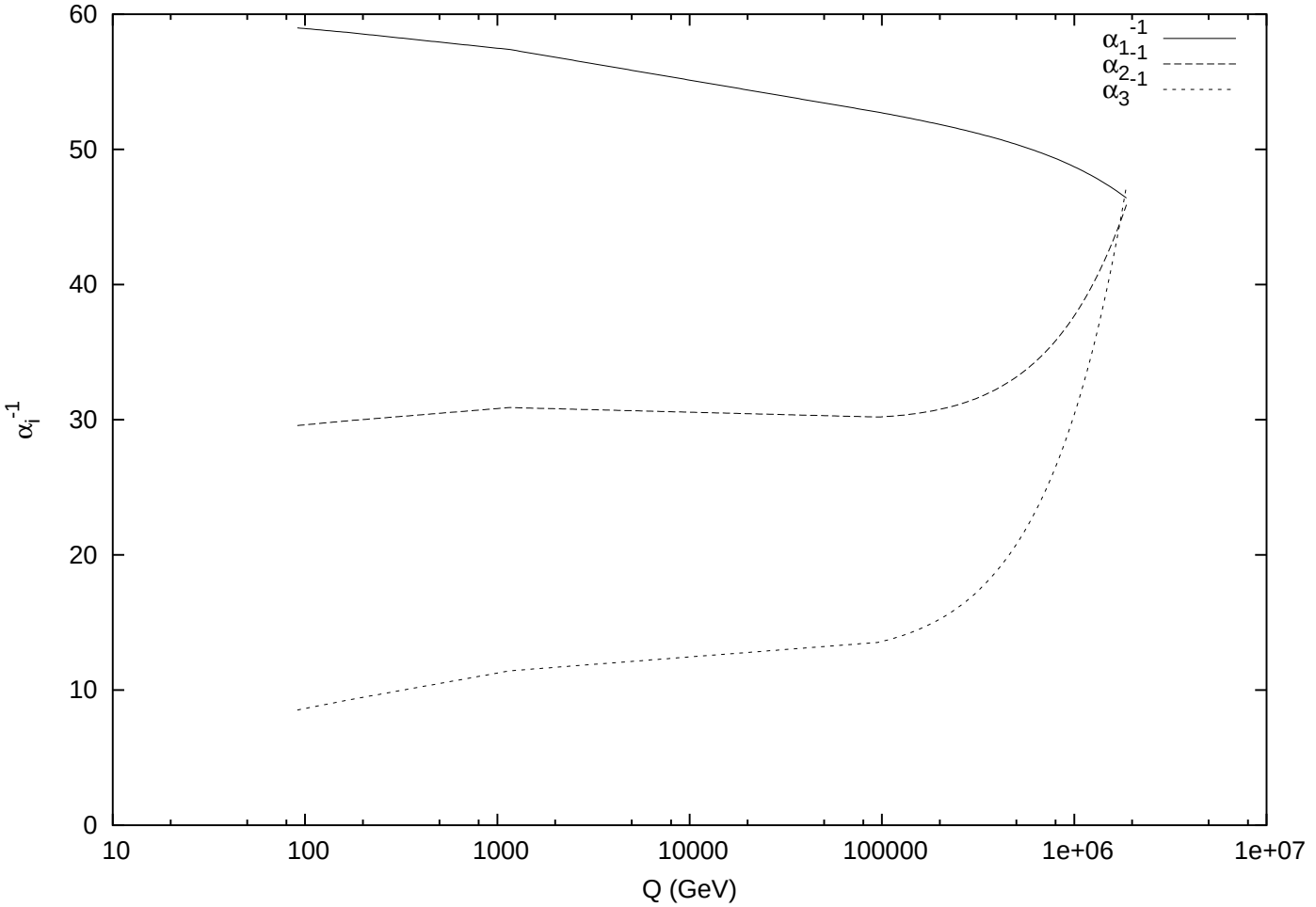
$$X_\delta = \frac{\pi^{\delta/2}}{\Gamma(1+\delta/2)}$$

and

$$b_i = (33/5, 1, -3) \qquad \tilde{b}_i = (3/5, -3, -6) + \eta(4, 4, 4)$$

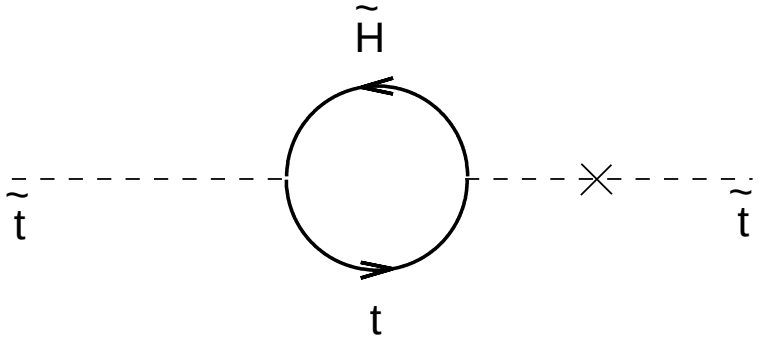
Early Unification

Power-law running $\Rightarrow M'_{GUT} \ll M_{GUT} = 10^{16}$ GeV

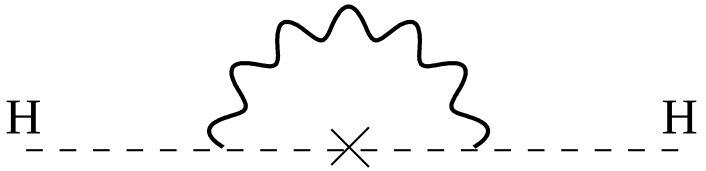


Soft Terms

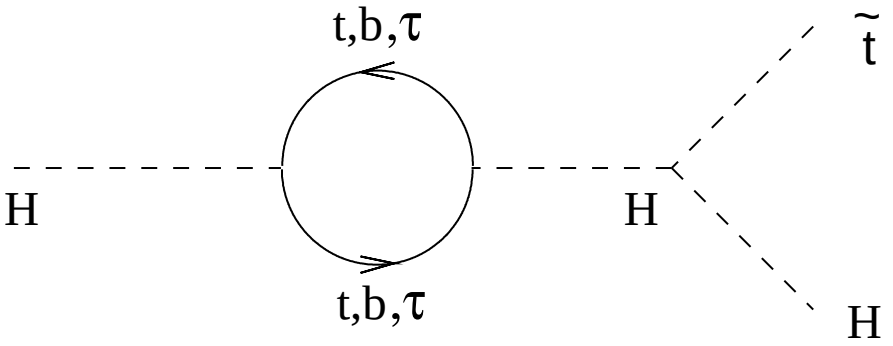
Which diagrams gives a power-law contribution?



$$\left(2y_t^2 + 2y_b^2\right) m_t^2$$



$$b\left(-3g_2^2 - 3/5g_1^2\right)$$



$$3a_t y_t^2$$

Phenomenology

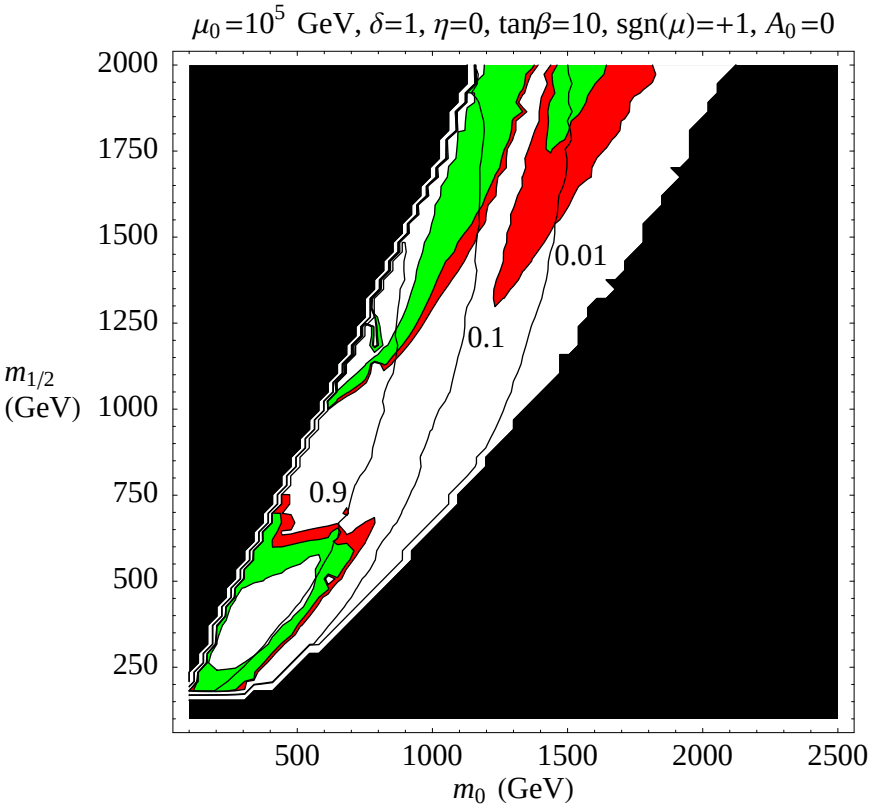
- mSUGRA inspired boundary conditions at M'_{GUT} , i.e. m_0 common scalar mass, $m_{1/2}$ common gaugino mass
- Low-energy observables ISASUGRA (modified) + DarkSUSY
- Standard thermal relic density computation (no moduli fields decaying)

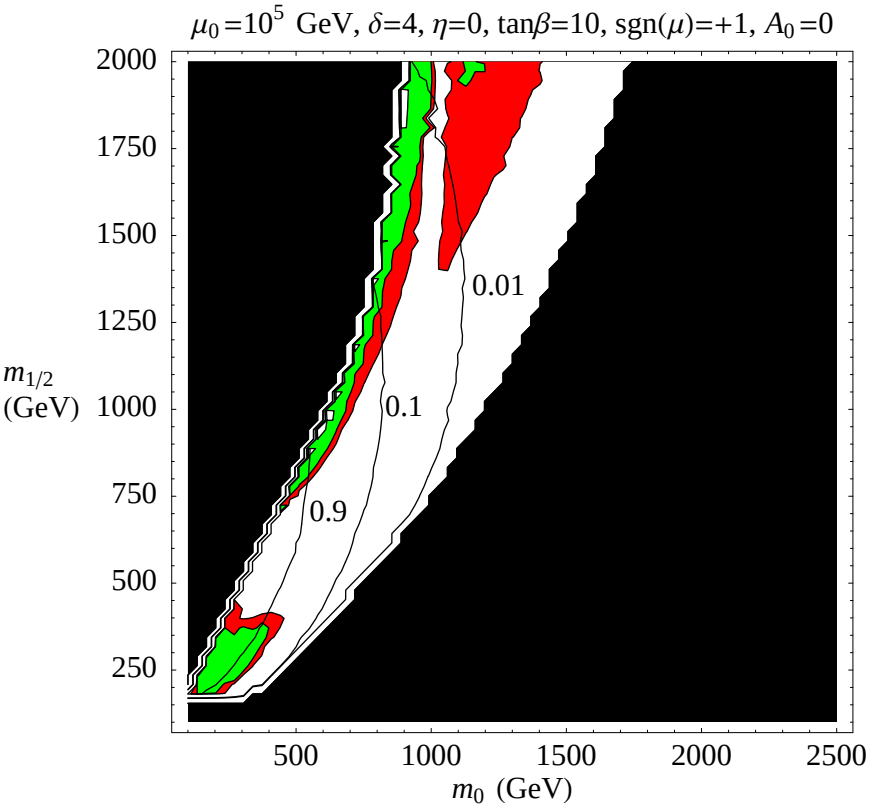
Phenomenology

Results

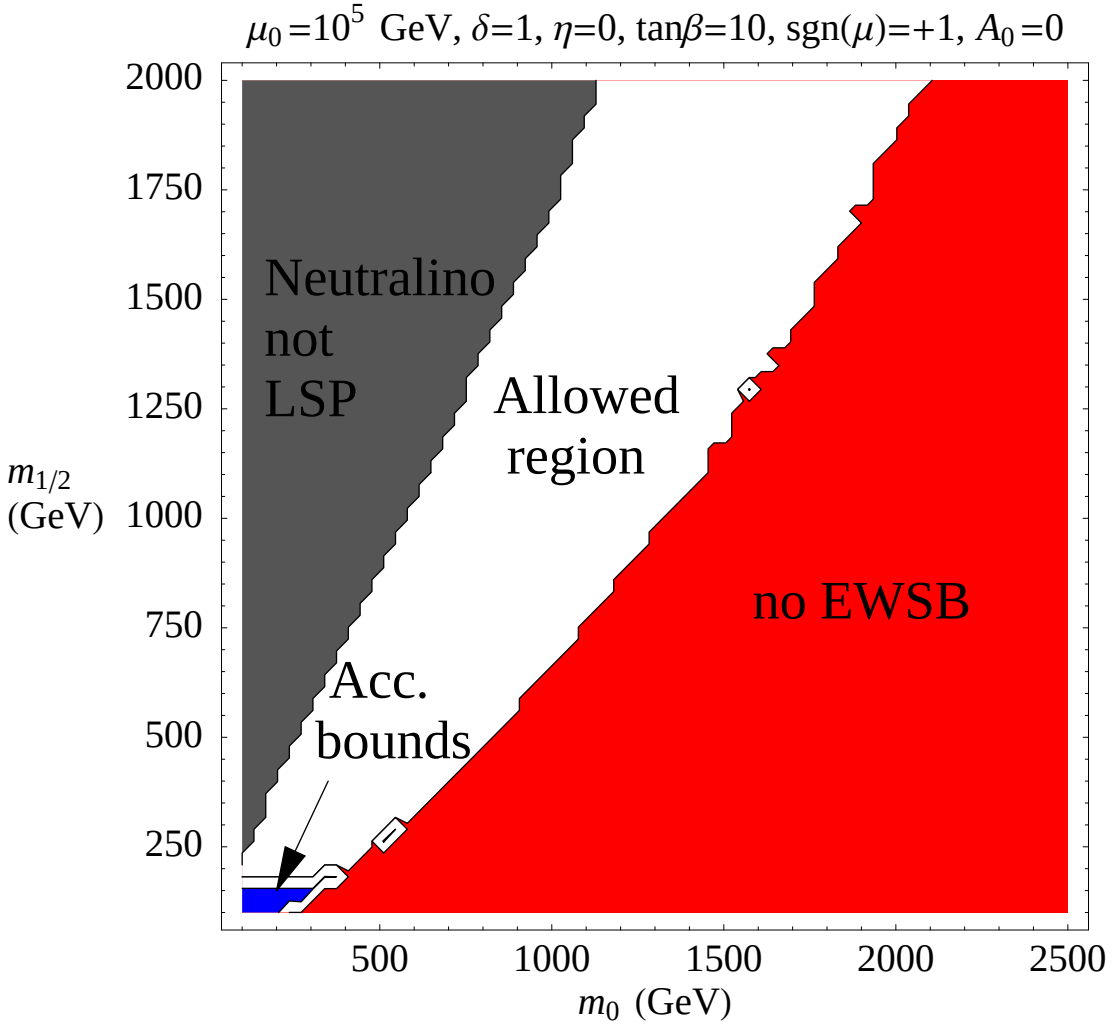
- Neutralino is the LSP (almost all the parameter space)
- Higgsino-like in the minimal scenario $\eta = 0$
- Quite insensitive to $N = 1$ or $N = 2$ Higgs

Neutralino and Extra Dimensions

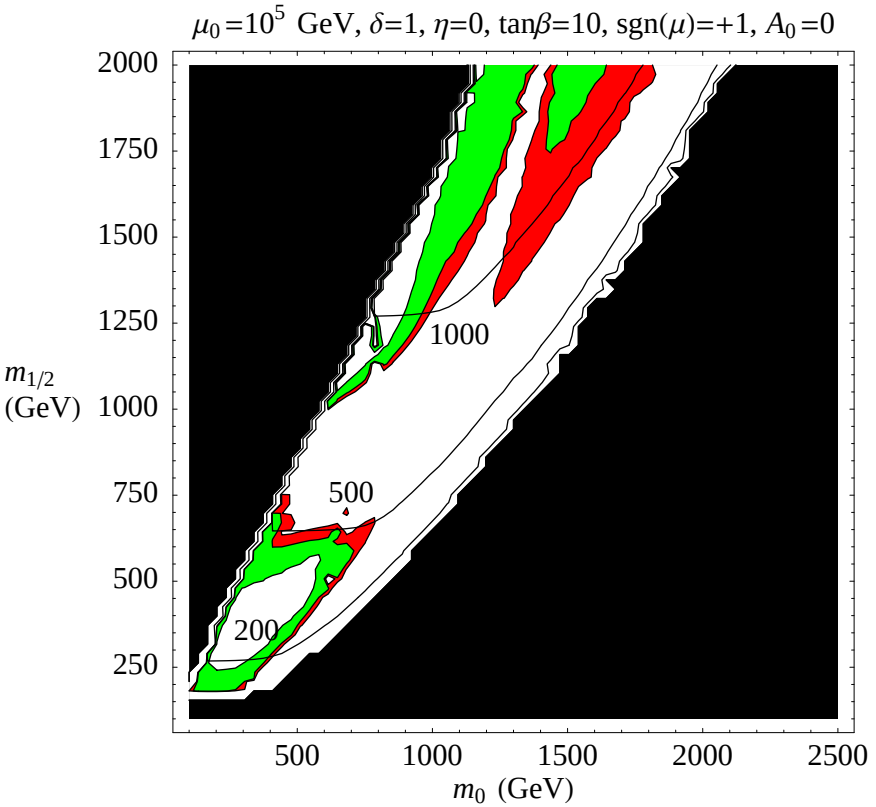


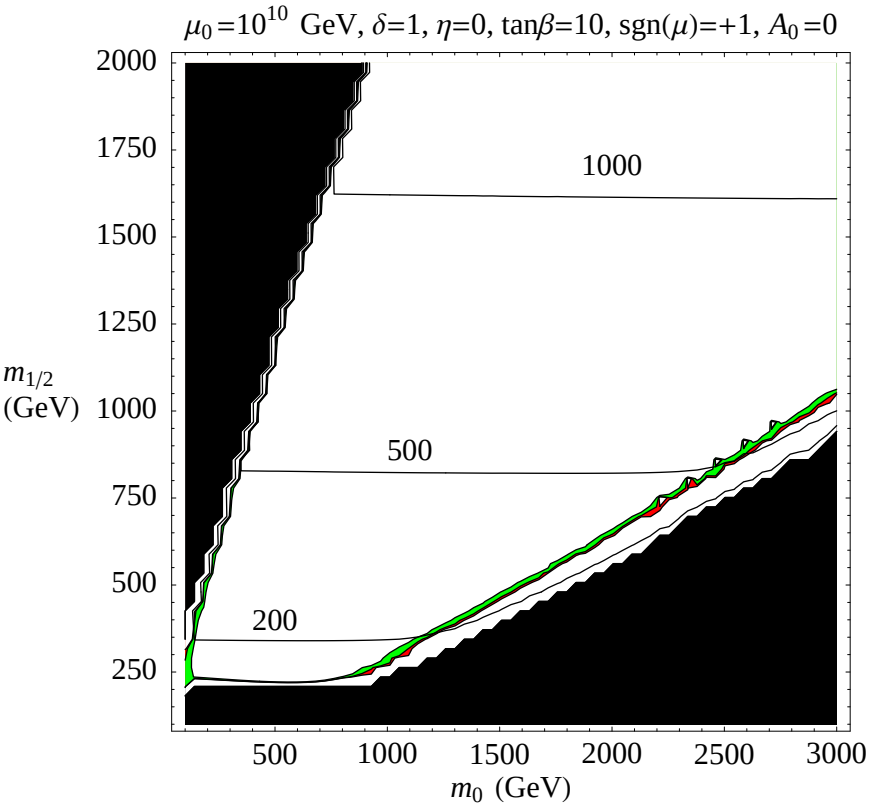


Excluded Region

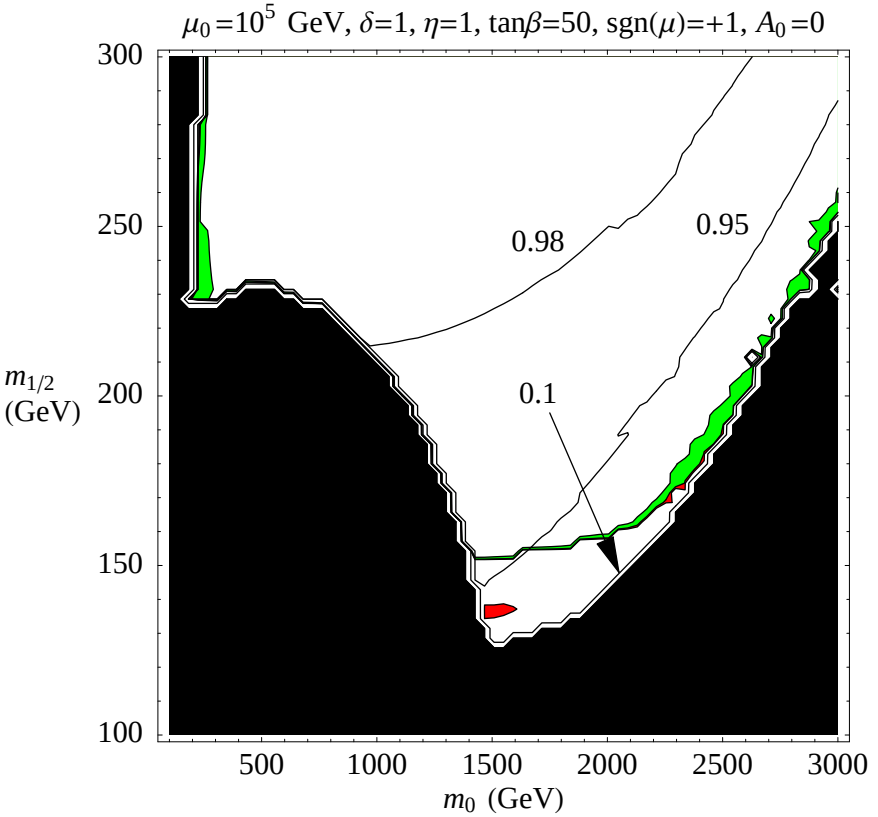


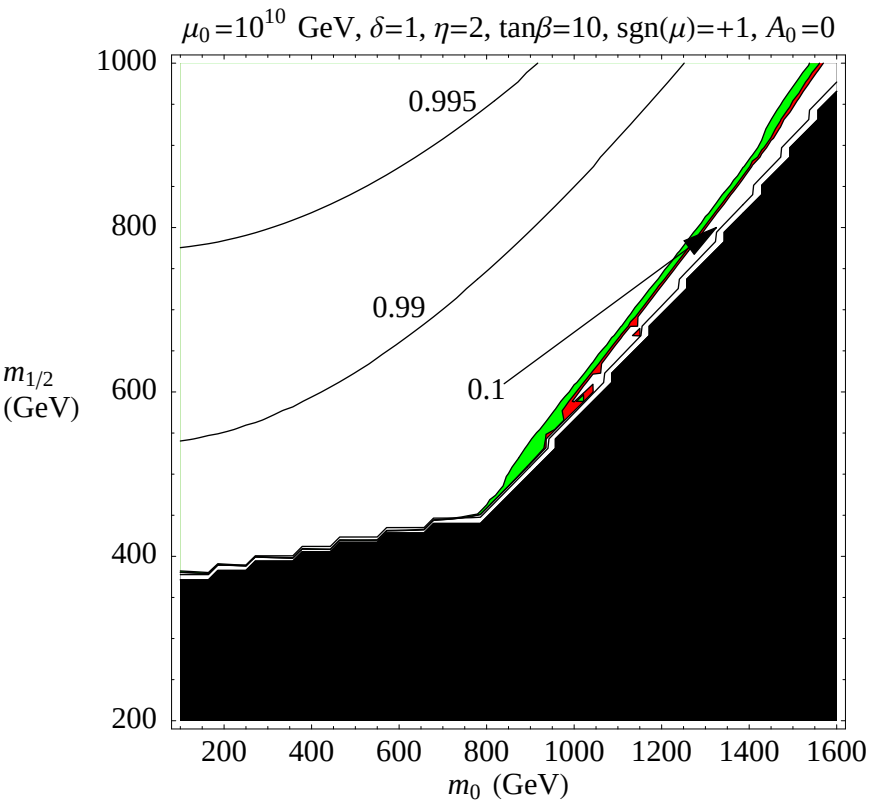
Neutralino and Extra Dimensions





Neutralino and Extra Dimensions





Work in Progress

- Direct, indirect DM searches and accellerator implications
- Non thermal production (moduli fields decaying)
- 1-loop annihilation processes (line enhancement?)
- Hints from top-down approaches