Kaluza-Klein Dark Matter

Hsin-Chia Cheng
UC Davis

Pre-SUSY06 Workshop
Complementary between Dark Matter Searches and Collider Experiments

Introduction

- Dark matter is the best evidence for physics beyond the standard model.
- The most appealing candidate for the dark matter is WIMP (weakly interacting massive particle).
- The right amount of dark matter density can be obtained from the thermal relic of a weakly interacting stable neutral particle of ~TeV mass.
- Such a scenario will be probed at colliders in addition to other dark matter detection experiments. It may related to the electroweak symmetry breaking and the hierarchy problem.

Introduction

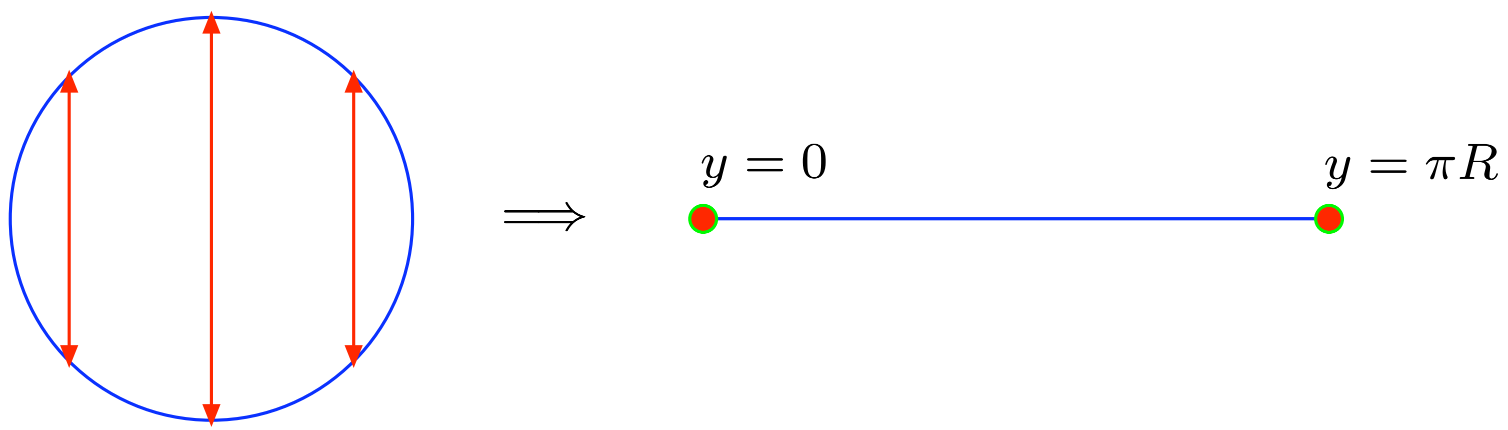
- A stable new particle at the TeV scale implies that there is a new symmetry under which all SM particles are not charged. The simplest possibility is a Z_2 parity.
- Such a new symmetry also helps the little hierarchy problem: the new particles charged under the new symmetry do not contribute to the electroweak observables at the tree level.
- The most popular and studied candidate is the lightest supersymmetric particle (LSP) which is odd under R-parity. However, there have been many new candidates proposed recently.

Universal Extra Dimensions

- Extra dimensions compacted on an orbifold often have some geometric symmetry which is a subgroup of the higher dimensional Poincare group.
- As a result, momentum (KK-number) conservation in extra dimensions is broken down to some discrete symmetry (KK-parity), which can play the role of the dark matter symmetry.
- The lightest Kaluza-Klein excitation charged under the KK-parity can be the dark matter particle if it is electrically neutral.

Universal Extra Dimensions

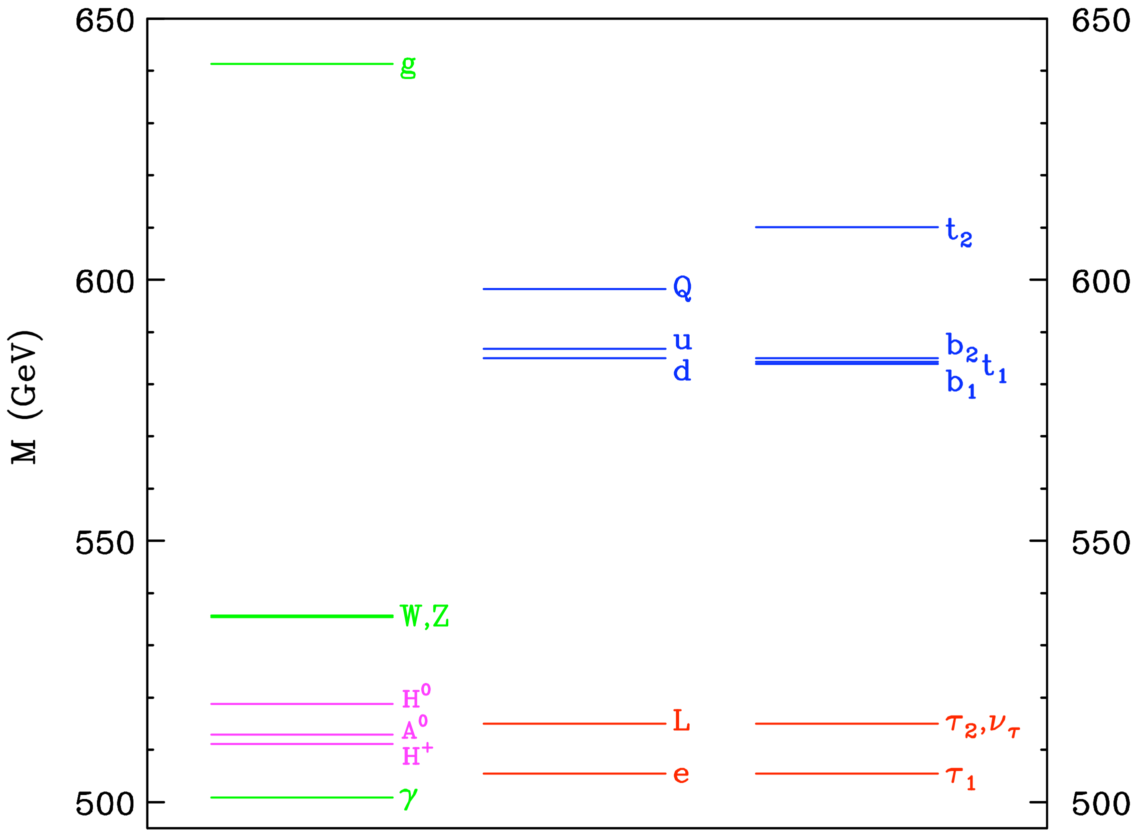
The simplest example is S^1/Z_2



The KK-number is broken down to a Z_2 KK-parity,
Even KK levels are even (including all SM fields).
Odd KK levels are odd. The lightest 1st KK state is stable.

Universal Extra Dimensions

The degeneracy in each KK level is lifted by radiative corrections and boundary terms.



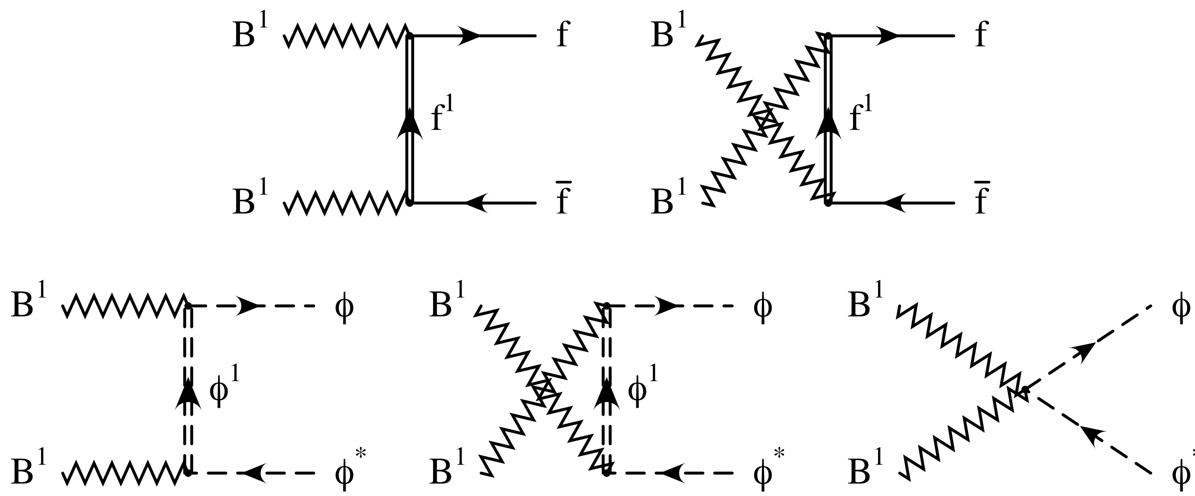
Cheng, Matchev, Schmaltz, hep-ph/0204342

Universal Extra Dimensions

- The spectrum of the 1st KK level looks like supersymmetry. The collider signals are similar.
- The lightest 1st level KK particle (LKP) is likely to be $\gamma^1 \approx B^1$ which can be a good dark matter candidate. (Another possibility is the KK graviton, a candidate for SuperWIMPs.)

Relic Density of B^1 LKP

Annihilation channels for

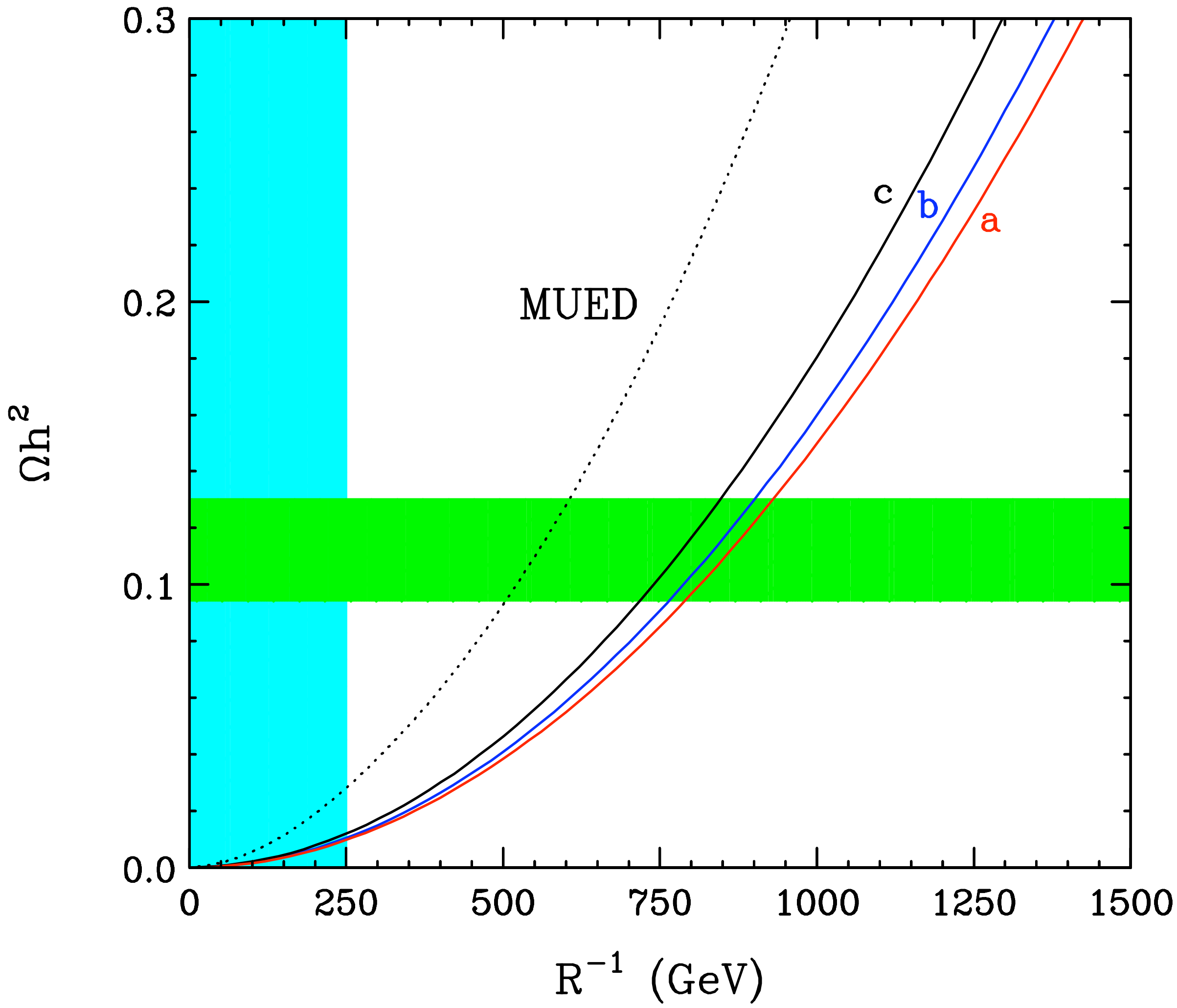


Servant, Tait, hep-ph/0206071

The B^1 has spin-1, its annihilations to SM fermions are not helicity-suppressed, unlike the neutralino LSP. The annihilation cross section is larger. To account for the dark matter, the mass of B^1 generally needs to be larger than the LSP mass in SUSY.

Relic Density of B^1 LKP

(Kong, Matchev, hep-ph/0509119)

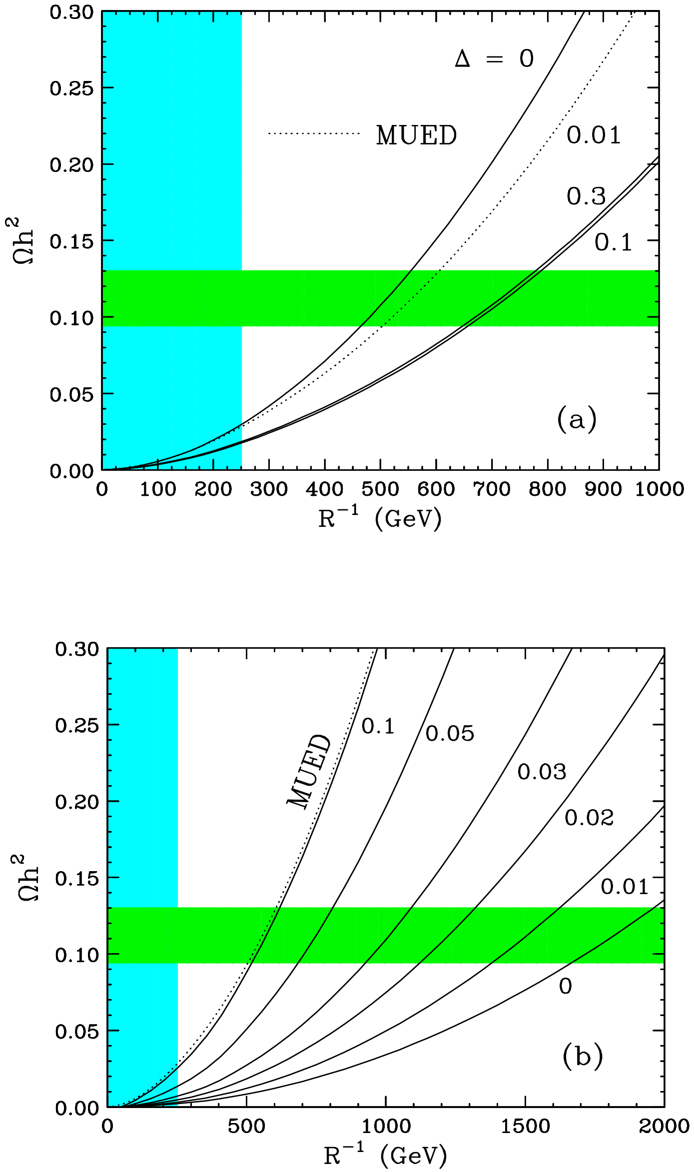


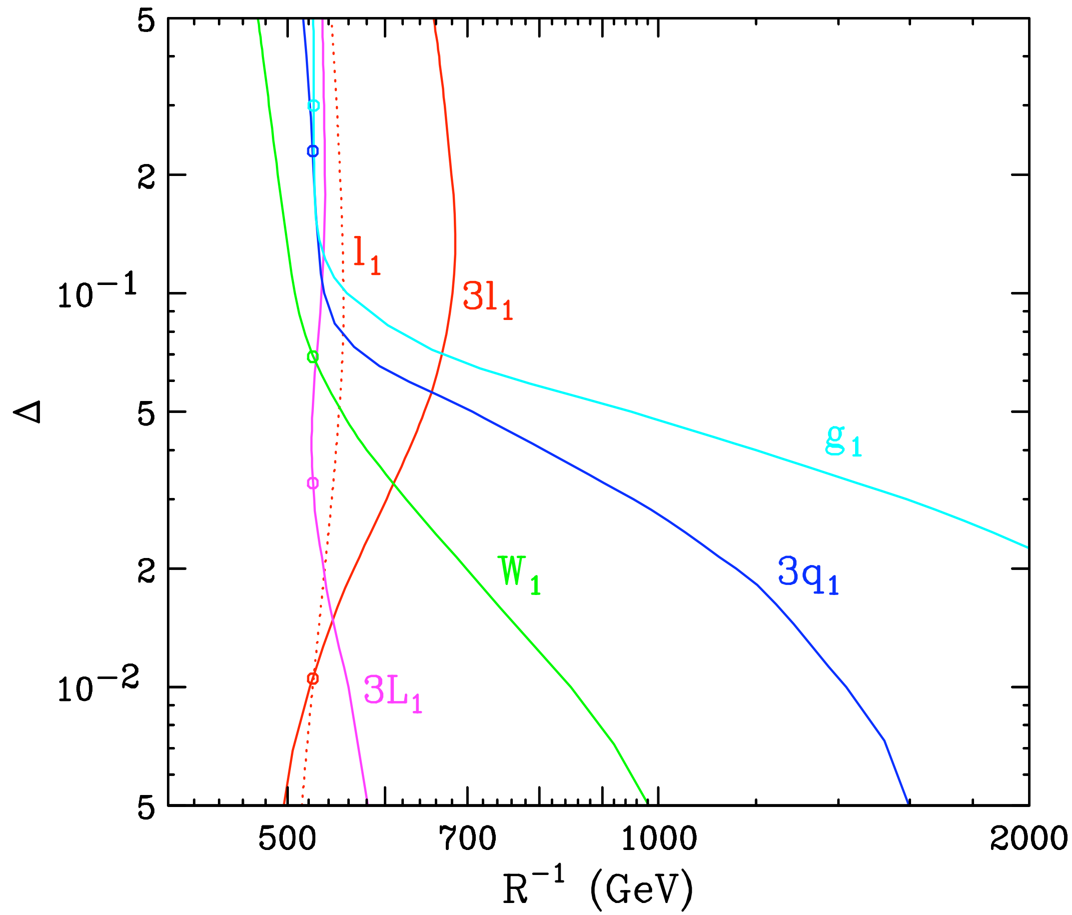
The Effects of Coannihilations

- Due to the degeneracy of the spectrum, coannihilation effects are important.
- Coannihilations with the SU(2) singlet KK leptons reduces the effective cross section and hence reduces the predicted LKP mass, in contrast to SUSY.
- Coannihilation with doublet KK leptons and KK quarks increases the effective cross section and the predicted LKP mass, due to larger SU(2) and SU(3) gauge couplings.
- Annihilation through the 2nd KK level Higgs resonance can also increase the cross section and the predicted LKP mass. (Kakizaki et al, hep-ph/0502059, 0508283)

The Effects of Coannihilations

Kong, Matchev, hep-ph/0509119

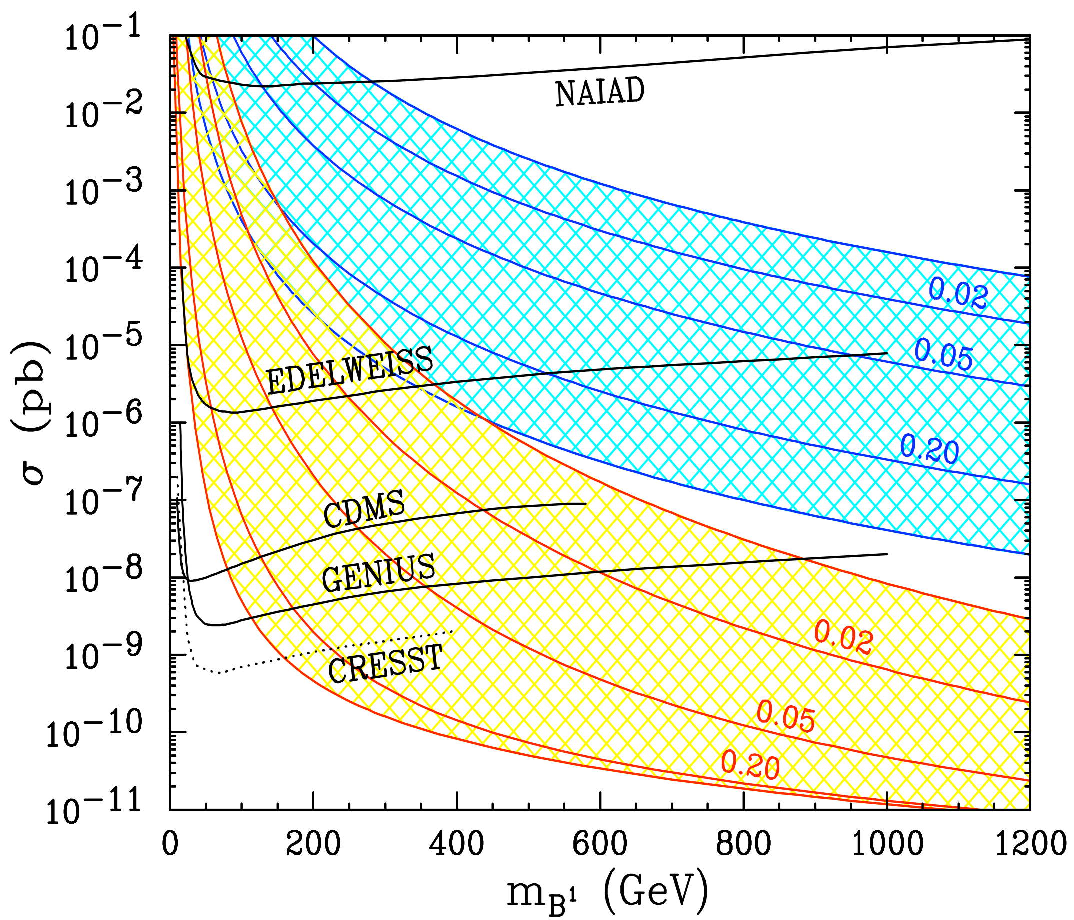


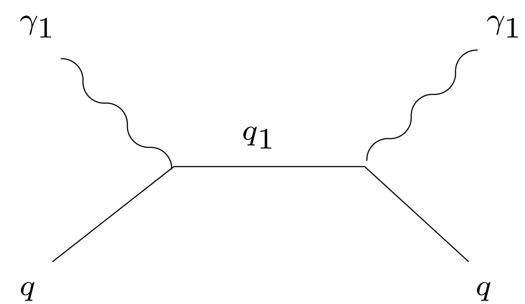


Direct Detection

- Predicted production cross sections for different $\Delta = \frac{m - m_{\gamma_1}}{m_{\gamma_1}}$

(Cheng, Feng, Matchev, hep-ph/0207125)





Blue:
Spin-dependent

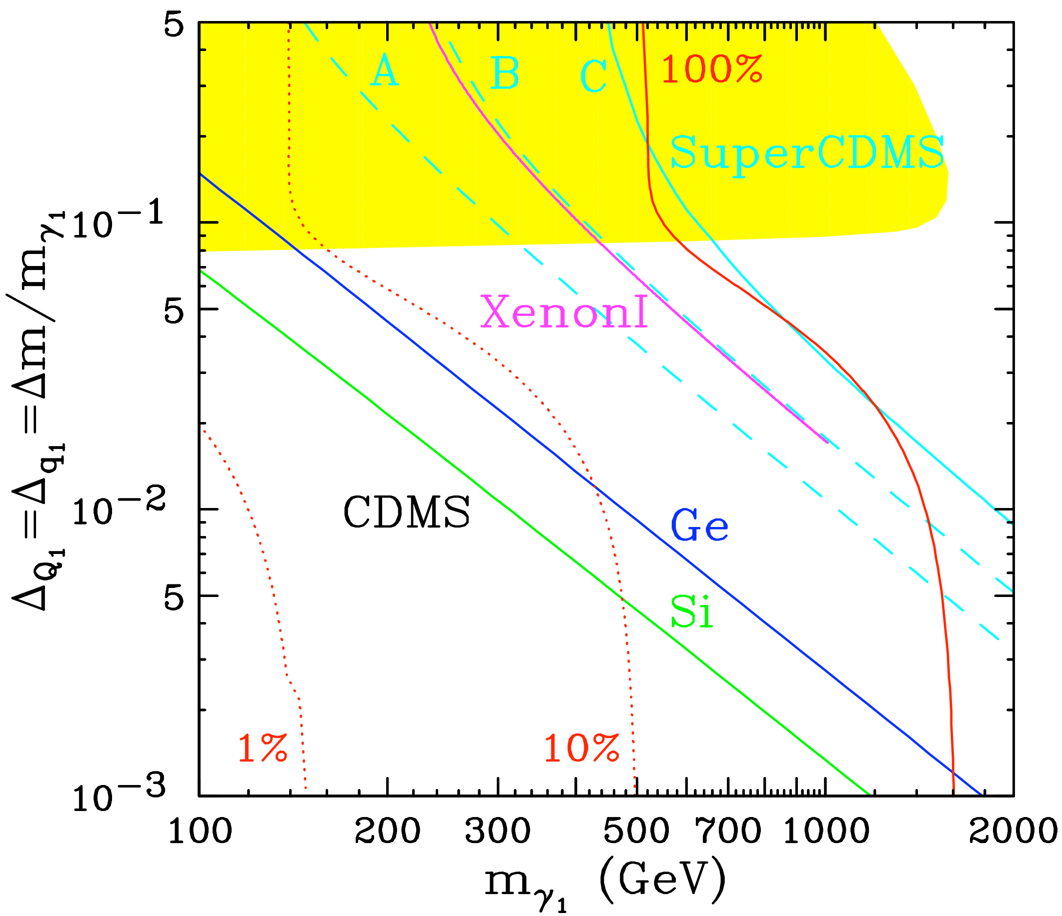
Yellow:
Spin-independent

The cross section is enhanced by the s-channel pole due to the degeneracy of the spectrum.

Direct Detection

- Spin independent:

(Baudis, Kong, Matchev, Preliminary)



- SuperCDMS (projected)
  - A (25 kg), B (150 kg), C (1 ton)
- $\Delta_{q_1} = \frac{m_{q_1} - m_{\gamma_1}}{m_{\gamma_1}}$

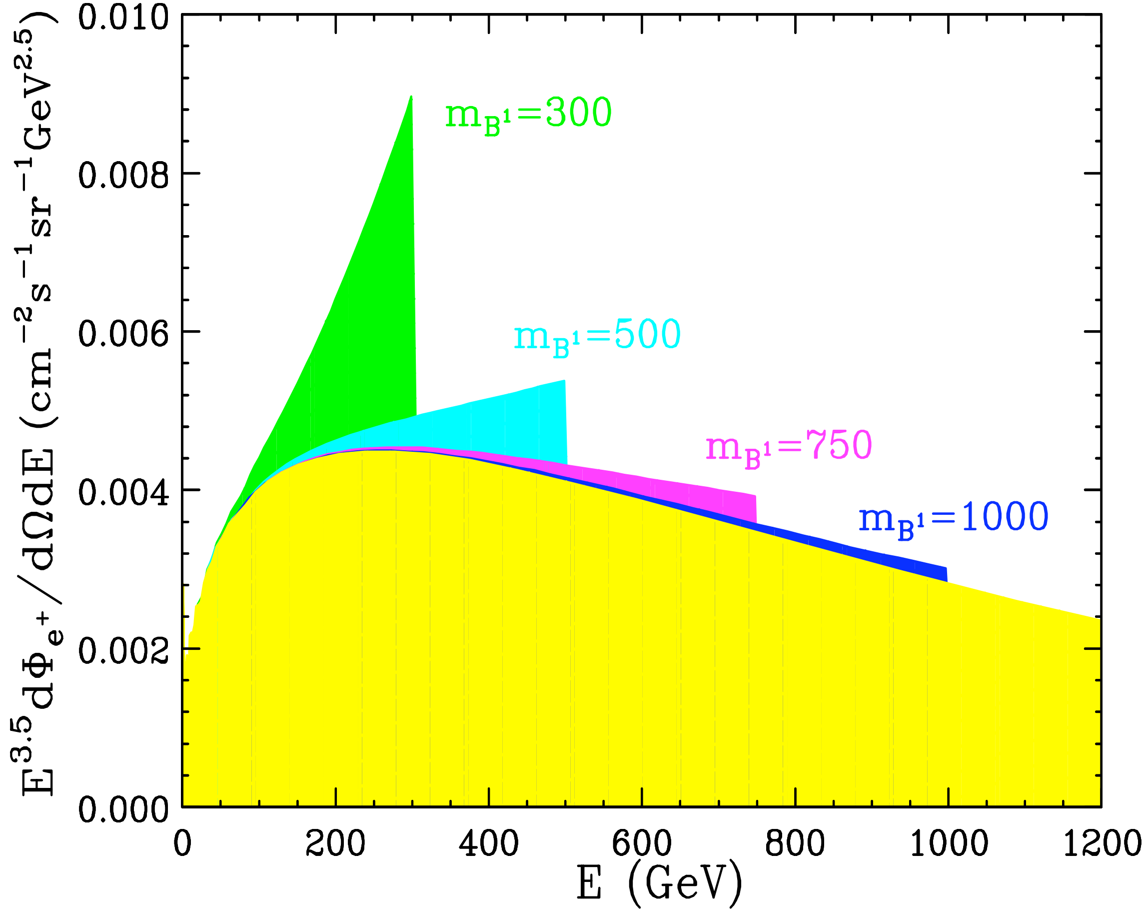
Indirect Detection

- Neutrinos from the centers of Sun and Earth
- Positrons and anti-protons from the galactic halo
- Photons from the galactic center
- B^1, B^1 can annihilate to light fermions directly, producing high energy neutrinos and positions with large rates, in contrast to the neutralino LSP in SUSY.

Indirect Detection

- Predicted positron signals

(Cheng, Feng, Matchev, hep-ph/0207125)



- SUSY: helicity-suppressed annihilation amplitudes
- A peak in the e^+ spectrum:
  - A smoking gun for γ_1 dark matter
  - can rule out neutralinos as the source

DM from Other Models

- Z_3 symmetry in a warped extra dimensional GUT model (Agashe, Servant, hep-ph/0403143, 0411254): Z_3 protects proton stability and gives a DM candidate (A neutral fermion in the same GUT multiplet as the top quark.
- Little Higgs models with T-parity (Cheng, Low, hep-ph/0308199, 0405243): T-parity solves the problem with the electroweak precision constraints. The lightest T-odd particle is a good DM candidate. It can be a heavy U(1) gauge boson as B^1 in UED, or a scalar pseudo-Nambu-Goldstone boson.

Conclusions

- There are many new WIMP (and superWIMP) dark matter candidates proposed recently related in one way or another to extra dimensions.
- The dark matter particle can have spin-0, 1/2, 1, (3/2, 2). They have different interactions and different reaches in various dark matter detection experiments.
- Most of the models beyond SM with dark matter candidates have some similar collider signals (jets/leptons + missing energy). Direct or indirect detections of dark matter provides complementary tests of the new models.