Dark matter search from space

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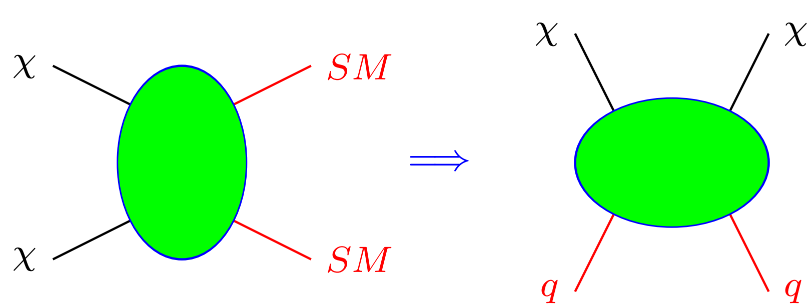
Dark matter and new physics BSM

- Many motivations for new physics, but... dark matter is our best evidence for new physics BSM: $\Omega_{DM} = 0.23 \pm 0.04$.
- How do we find it experimentally?
  - We can make it at high energy colliders $\surd$
  - Direct detection: underground.
  - Indirect detection:
    - underground/underwater/underice: ν_μ
    - in space: e^+, $\bar{p}$, γ ... $\surd$
- WIMPs: motivated by both particle and astrophysics.
  - Predicted in many particle physics scenarios BSM.
  - Give the right order of magnitude Ω_{DM}.

$$\Omega_{DM} h^2 \sim 0.1 \left(\frac{\sigma_{EW}}{\sigma_{ann}} \right)$$

  - Potentially observable signals in DM detection expts.



New physics models with DM WIMPs

- Recipe for BSM dark matter
  - invent a model with new particles
  - invent a symmetry which guarantees a stable new particle
  - fudge parameters until the lightest new stable particle is neutral and has the correct relic density
- Three generic examples of new physics with a DM WIMP
  - supersymmetry: DM = lightest superpartner.
  - extra dimensions: DM = lightest Kaluza-Klein mode.
  - Little Higgs: DM = LPOP, LZOP?
- How can we distinguish the different DM scenarios?
  - at high energy colliders
  - in astroparticle physics experiments in space
- A model-independent framework for discussing collider and indirect dark matter signals after WMAP

Supersymmetry

- Supersymmetry is an extra dimension theory with new anticommuting coordinates θ_α:

$$\Phi(x^\mu,\theta) = \phi(x^\mu) + \psi^\alpha(x^\mu)\theta_\alpha + F(x^\mu)\theta^\alpha\theta_\alpha$$

- SUSY relates SM particles and their superpartners ($\phi \leftrightarrow \psi$)
  - quarks, leptons $\Leftrightarrow$ squarks, sleptons
  - gauge bosons: g, $W^\pm$, W_3^0, B^0 $\Leftrightarrow$ gauginos: $\tilde{g}$, $\tilde{w}^\pm$, $\tilde{w}^0$, $\tilde{b}^0$
  - Higgs bosons: h^0, H^0, A^0, $H^\pm$ $\Leftrightarrow$ higgsinos: $\tilde{h}^\pm$, $\tilde{h}_u^0$, $\tilde{h}_d^0$
- The superpartners have
  - spins differing by 1/2
  - identical couplings
  - unknown masses (model-dependent)
- Discovering new particles with those properties IS discovering supersymmetry
- The superpartners are charged under a conserved R-parity
  - SM particles: $R = +1$
  - superpartners: $R = -1 \Longrightarrow$ stable LSP (DM?).
- No tree-level contributions to EW data, proton decay...

SUSY WIMPs

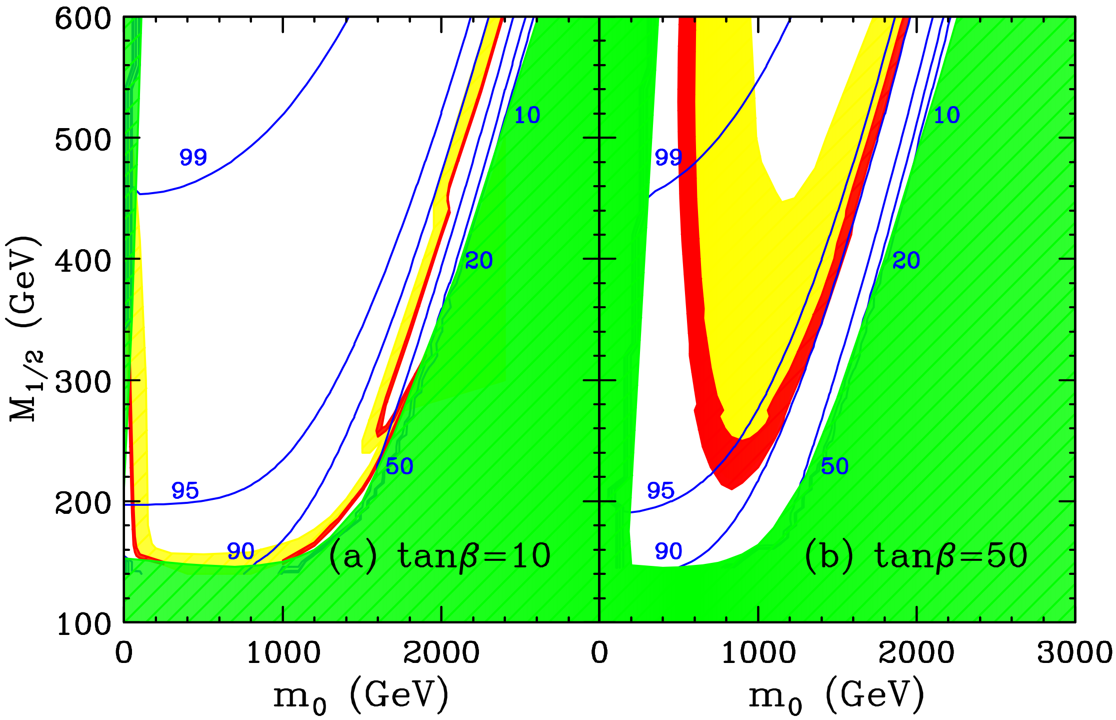
- The lightest neutralino $\tilde{\chi}_1^0$ is a mixture of $\tilde{b}^0$, $\tilde{w}^0$, $\tilde{h}_u^0$, $\tilde{h}_d^0$:

$$\tilde{\chi}_1^0 = a_1\,\tilde{b}^0 + a_2\,\tilde{w}^0 + a_3\,\tilde{h}_u^0 + a_4\,\tilde{h}_d^0$$

- Gaugino fraction R_χ of the LSP:

$$R_\chi \equiv |a_1|^2 + |a_2|^2 \approx |a_1|^2.$$

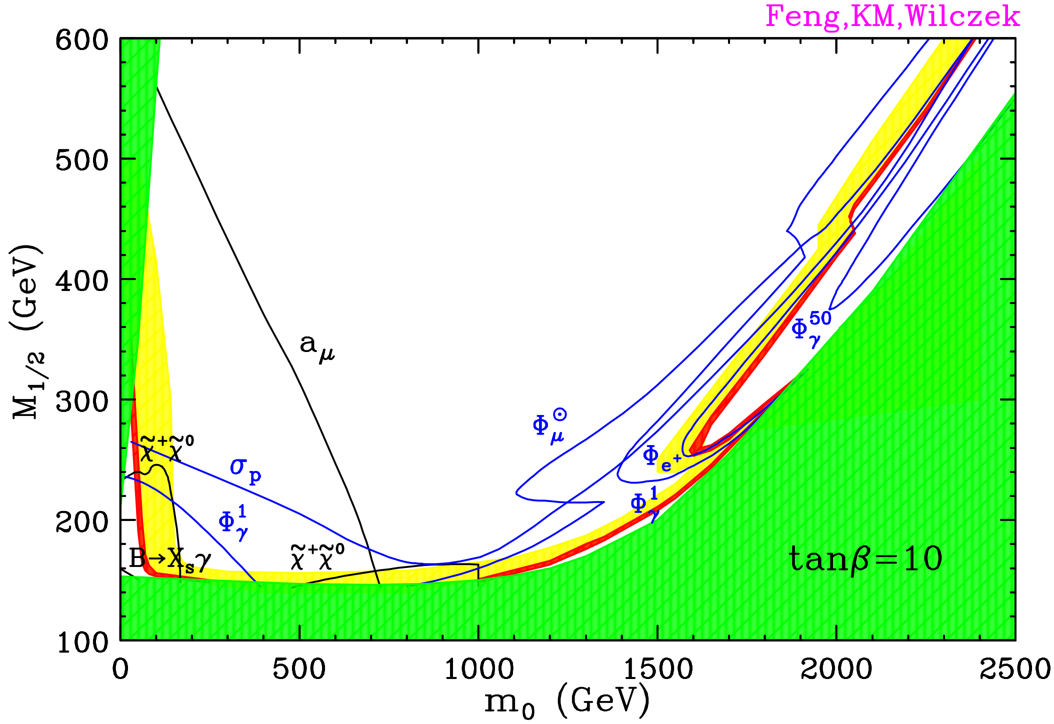
Feng,KM,Wilczek (2000)



- Focus point region: large m_0, mixed LSP.
- Coannihilation region: small m_0, $\tilde{\tau} - \tilde{\chi}_1^0$ degeneracy.

SUSY WIMP detection

- Combination of "all" pre-LHC experiments
  - Direct SUSY searches: Tevatron
  - Indirect SUSY searches: E827, B-factories
  - Direct WIMP searches: CDMS, CRESST, GENIUS
  - Indirect WIMP searches: Amanda, AMS, GLAST



- Many possible DM signals before 2007-08.
- Particle physics and astrophysics probes are highly complementary.

Universal Extra Dimensions

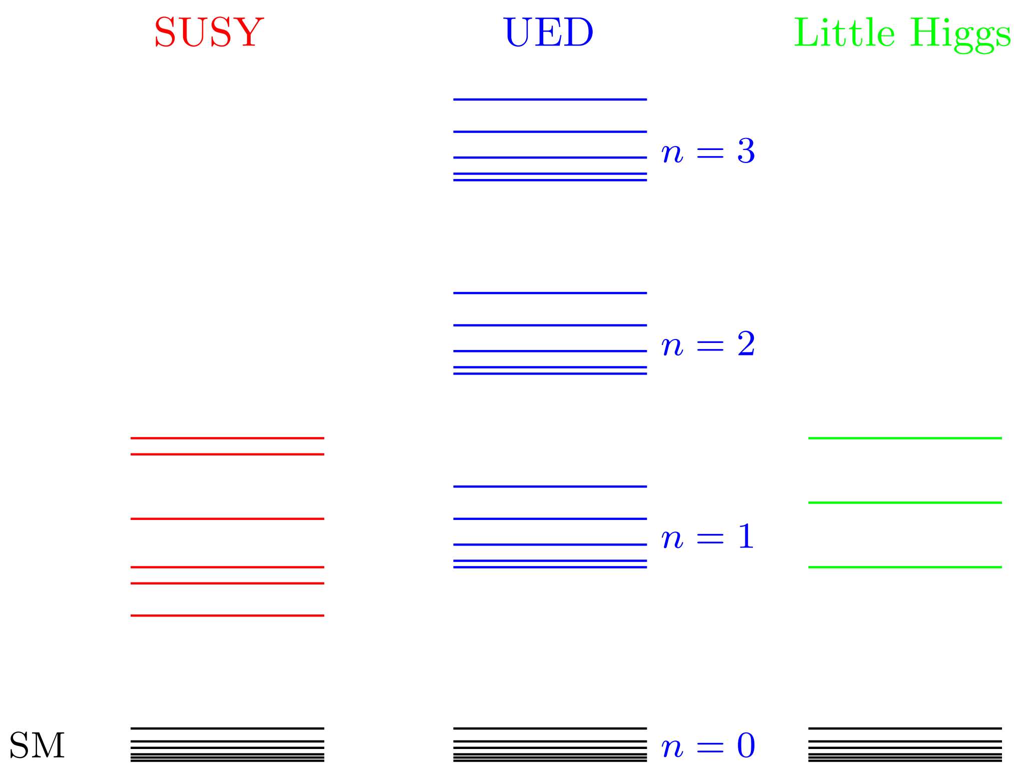
Appelquist, Cheng, Dobrescu, hep-ph/0012100

- Universal Extra Dimensions is an extra dimension theory with new bosonic coordinates y (spanning a circle of radius R):

$$\Phi(x^\mu, y) = \phi(x^\mu) + \sum_{i=1}^{\infty} \phi^n(x^\mu)\cos(ny/R) + \chi^n(x^\mu)\sin(ny/R)$$

- Each SM field ϕ ($n = 0$) has an infinite tower of Kaluza-Klein (KK) partners ϕ^n and χ^n with
  - identical spins
  - identical couplings
  - unknown masses of order n/R
- Remnant of p_5 conservation: KK-parity $(-1)^n$
  - $KK = +1$ for even n and $KK = -1$ for odd n.
  - lightest KK partner at level 1 (LKP) is stable.
    $P_3 \to P_3' P_0, P_2 P_1, P_1 P_0$;
    $P_2 \to P_2' P_0, P_1 P_1, P_0 P_0$;
    $P_1 \to P_1' P_0$.
- No tree-level contributions to precision EW observables

Model summary

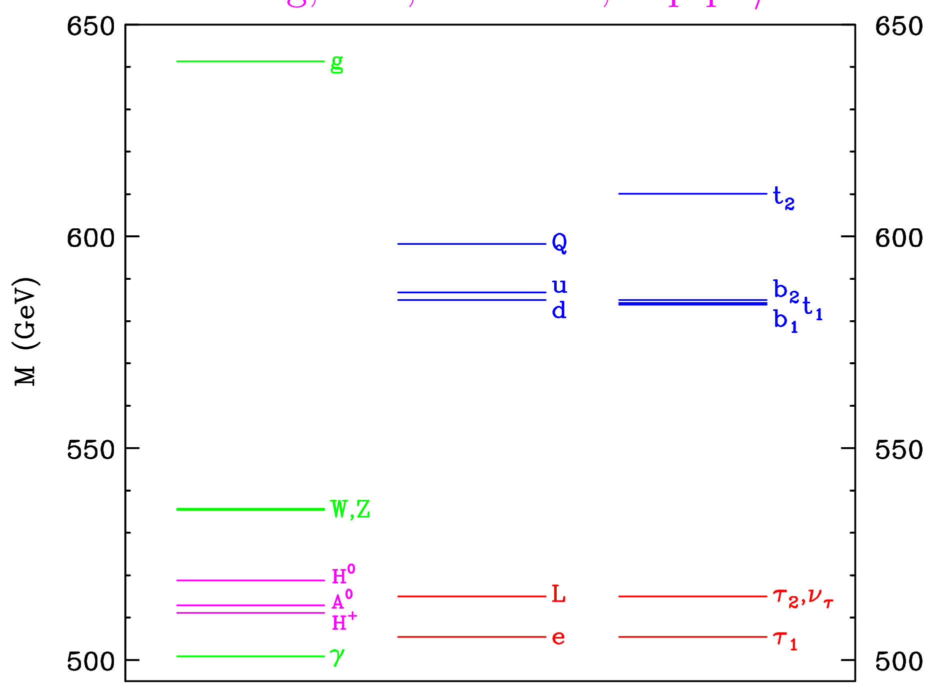


	SUSY	UED	Little Higgs
DM particle	LSP	LKP	LTP
Spin	1/2	1	0
Symmetry	R-parity	KK-parity	T-parity
Mass range	50-200 GeV	600-800 GeV	400-800 GeV

UED spectrum at level 1

- Including radiative corrections, the mass spectrum of level 1 KK modes looks something like this:

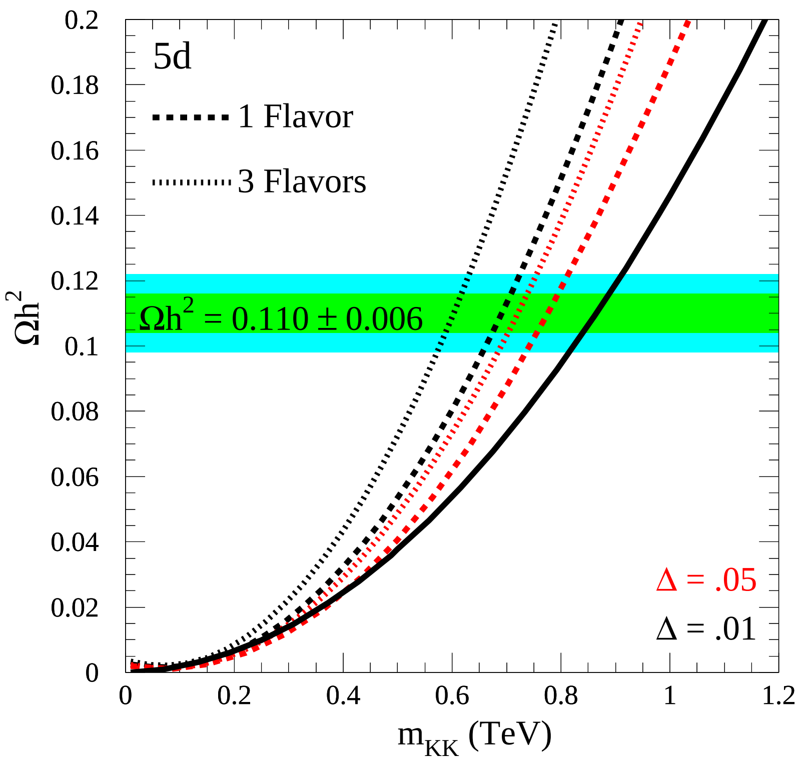
Cheng, KM, Schmaltz, hep-ph/0204342



- Mimics (fermionic) supersymmetry!
- Seems difficult to discover at the LHC, but...
- $W_1^\pm$, Z_1 have pure leptonic branchings!
- $\sin^2\theta_W^1 \approx 0 \Longrightarrow \gamma^1 \approx B^1$, similar to $\tilde{B}$ in SUSY.

KK dark matter relic density

- Relic density: G.Servant, T.Tait, hep-ph/0206071



- Unlike supersymmetry: no helicity suppression

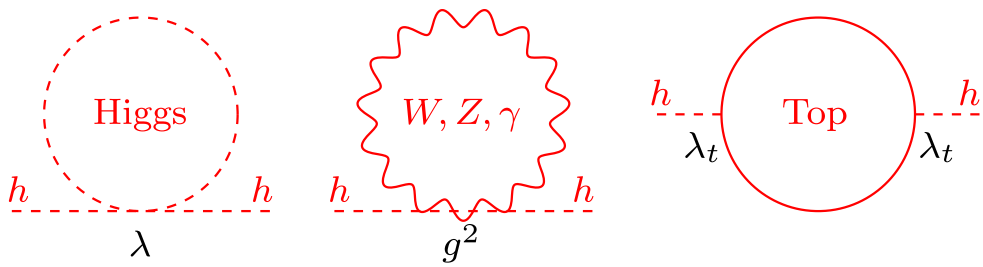
$$\Omega h^2 = \frac{1.04\ 10^9\ \mathrm{GeV}^{-1}}{M_P \sqrt{g_*}} \frac{x_F}{a + 3b/x_F}; \qquad x_F = \frac{M_{KK}}{T_F}$$

$$a = \frac{\alpha_1^2}{M_{KK}^2} \frac{380\pi}{81}; \qquad b = -\frac{\alpha_1^2}{M_{KK}^2} \frac{95\pi}{162}.$$

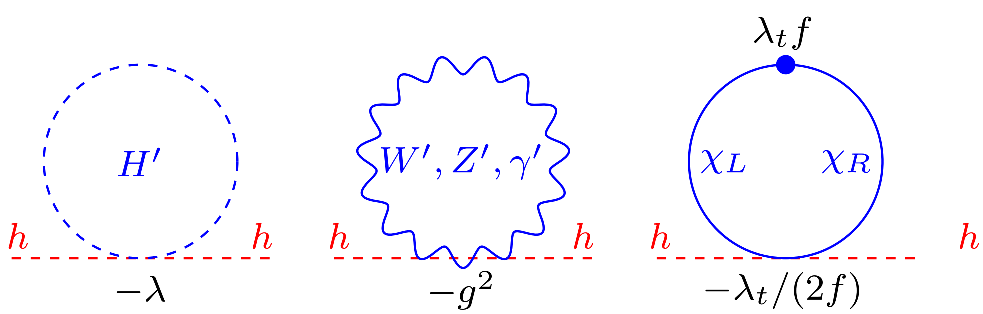
- Unlike supersymmetry: coannihilation lowers the bound

Little Higgs models

- The hierarchy problem in the SM



- Introduce new particles at TeV scale to cancel the one-loop quadratic divergences



- Conserved T-parity (Cheng, Low hep-ph/0308199)
  - $T = +1$ for SM particles, $T = -1$ for new particles.
  - the lightest T-odd particle is stable.
- No tree-level contributions to precision EW observables

SUSY versus UED at a LC

- The spin information is encoded in the angular distributions!

SUSY

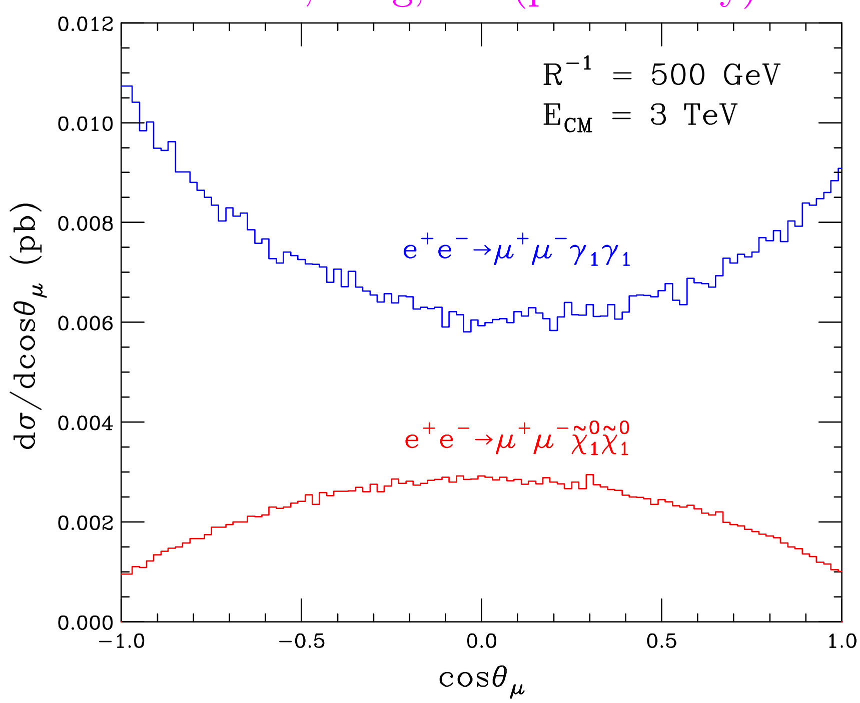
$$e^+e^- \to \tilde{\mu}^+\tilde{\mu}^- \to \mu^+\mu^-\tilde{\chi}_1^0\tilde{\chi}_1^0$$

UED

$$e^+e^- \to \mu_1^+\mu_1^- \to \mu^+\mu^-\gamma_1\gamma_1$$

$$\frac{d\sigma}{d\cos\theta} \sim 1 - \cos\theta^2 \qquad \frac{d\sigma}{d\cos\theta} \sim 1 + \cos\theta^2$$

Datta,Kong,KM (preliminary)

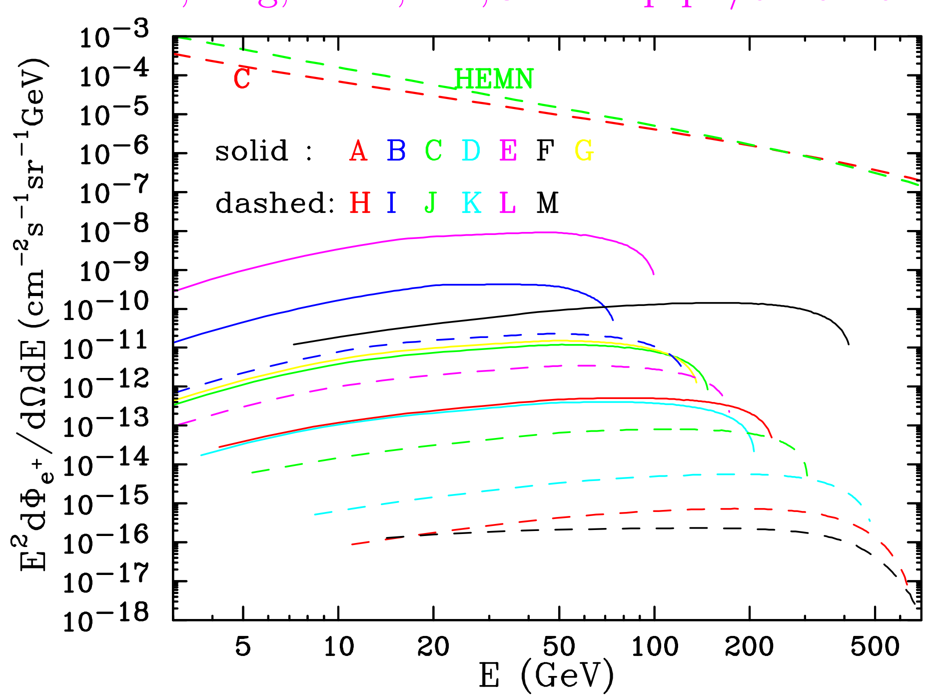


- Threshold scan would confirm the spins.
- It will be very difficult to do this at the LHC

Indirect DM detection from space: Positron signal in SUSY

- Both the shape and the normalization of the background are uncertain.
- $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to e^+e^-$ is helicity suppressed by m_e
- Hard positrons come from $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to WW$ and $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to ZZ$.
- The signal is typically a small fraction of the background, and the shape is not very characteristic.
- MSUGRA predictions for the 13 (“CERN”) benchmarks points

Ellis,Feng,Ferstl,KM,Olive hep-ph/0110225



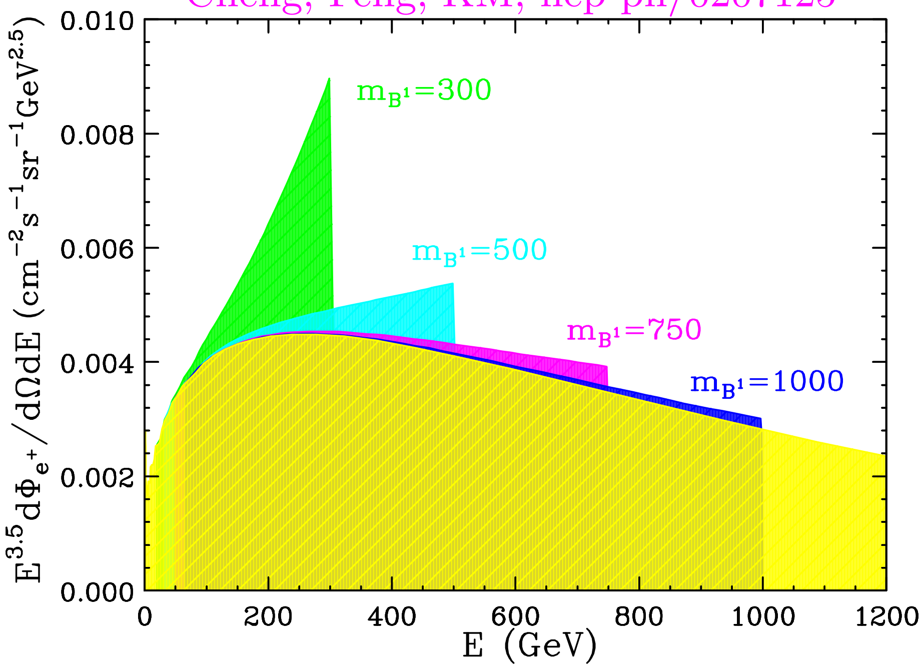
Indirect DM detection from space: Positron signal in UED

- Annihilation into fermion pairs is not helicity suppressed.

$$B(B^1 B^1 \to e^+ e^-) = 20\%$$

- There is a bump! The positrons are monoenergetic at birth. Some smearing from propagation through the galaxy.

Cheng, Feng, KM, hep-ph/0207125

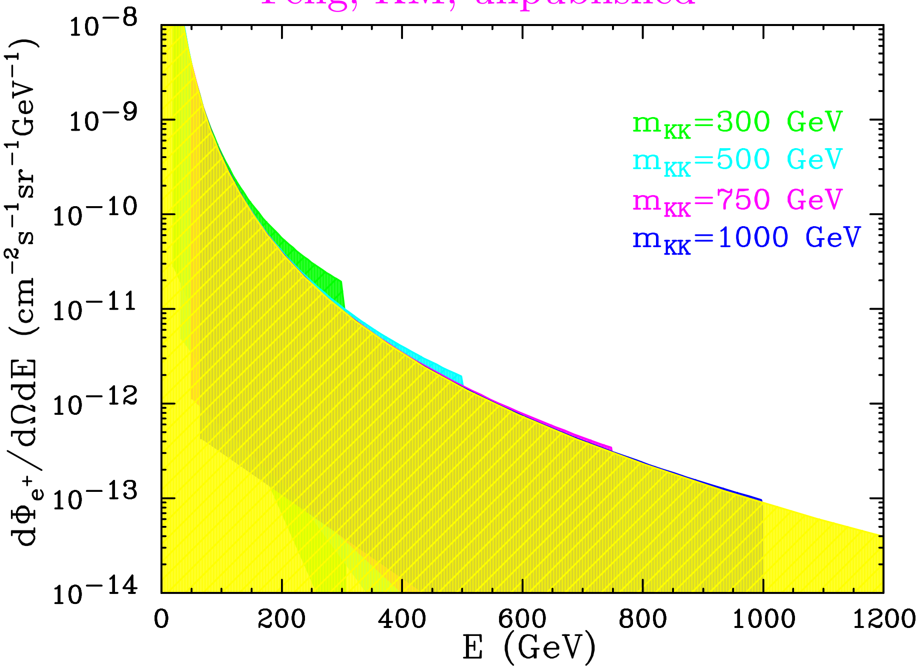


- AMS-II will be able to measure high-p_T positrons!

Positron fluxes in UED: signal versus background

- The positron flux without the E^2 scaling:

Feng, KM, unpublished



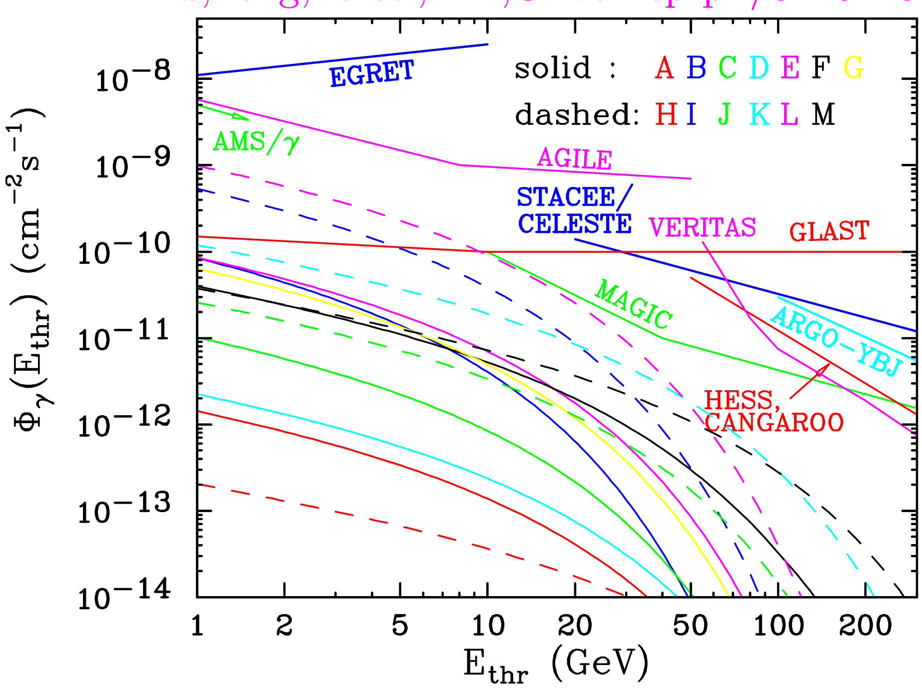
Indirect DM detection from space: Photon signal in SUSY

- Hard photons from DM annihilation in the galactic centre.

$$\Phi_\gamma(E_{th}) = 5.6 \times 10^{-12}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1} \bar{J}(\Delta\Omega)\,\Delta\Omega$$
$$\times \left[\frac{1\ \mathrm{TeV}}{m_\chi}\right]^2 \sum_q \frac{\langle\sigma_{qq} v\rangle}{\mathrm{pb}} \int_{E_{th}}^{m_\chi} dE \frac{dN_\gamma^q}{dE} .$$

- Expectations in supersymmetry

Ellis,Feng,Ferstl,KM,Olive hep-ph/0110225

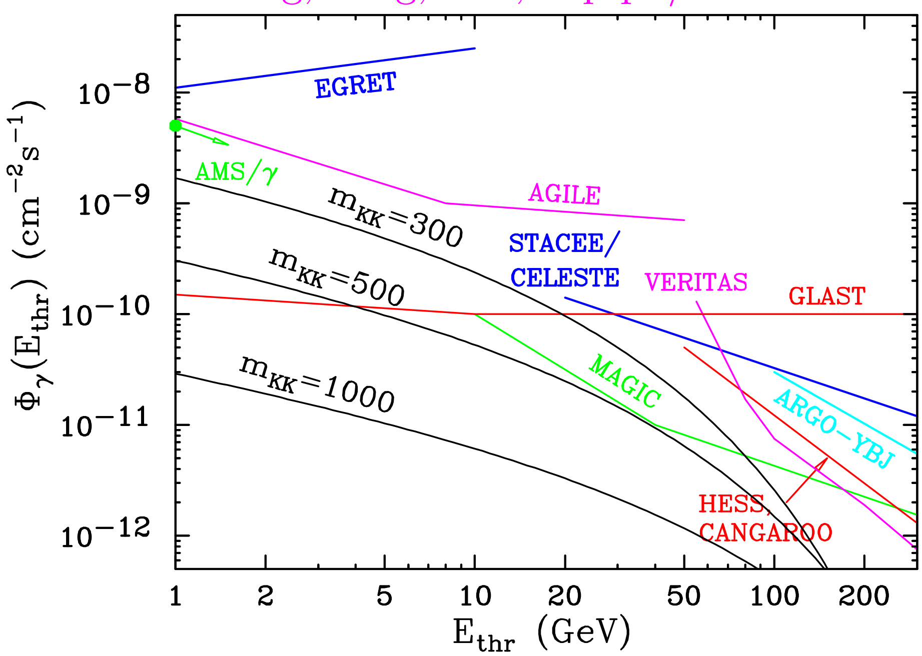


- $\bar{J}$ encodes the halo model dependence. ($\bar{J} = 500$)

Indirect DM detection from space: Photon signal in UED

- Expectations in UED

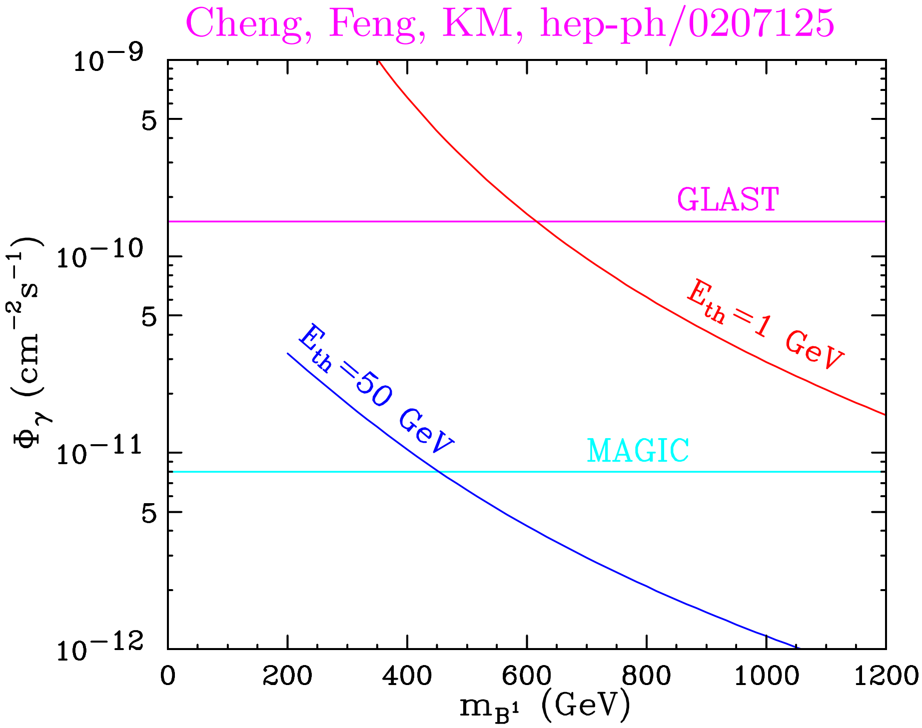
Cheng, Feng, KM, hep-ph/0207125



- Advantages over supersymmetry:
  - The preferred m_{KK} is larger $\Rightarrow$ harder spectrum.
  - The hardest fragmentation functions are for light quarks. Absent in supersymmetry, dominant here.

Indirect detection reach for UED: photons

- Reach of two representative experiments: low and high threshold.



- The signals may be further enhanced by halo clumpiness.

The Message

- Recent new ideas in particle physics lead to novel alternatives for dark matter candidates. SUSY DM? Not so fast...
- Elucidating the nature of the dark matter can be challenging in either direct detection experiments or at hadron colliders; and expensive at lepton colliders.
- Dark matter detection experiments should be prepared for surprises, avoid theory bias.
- Astroparticle physics experiments in space may discover and/or provide important clues to the identity of the dark matter particle.

A teaser

- Indirect DM searches from space: positrons

$$\kappa_e = \frac{\sigma^{(0)}(\chi\chi \to e^+e^-)}{\sigma^{(0)}(\chi\chi \to X\bar{X})}$$

- Implications of WMAP for the indirect DM positron search

KM, Perelstein, preliminary