Title: Studying Supersymmetry With Dark Matter Experiments

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Abstract: If low-scale supersymmetry exists in nature, then it it will be very likely that a number of superpartners will be discovered at the LHC. It is also very likely, however, that much of the supersymmetric spectrum will go unobserved, leaving many important holes in our understanding of the TeV scale. Direct and indirect astrophysical probes of neutralino dark matter can enable for some of these holes to be filled. By studying the interactions of the lightest neutralino, in many models, a much more complete understanding of supersymmetry can be achieved than is possible by using hadron colliders alone.

Studying Supersymmetry With Dark Matter

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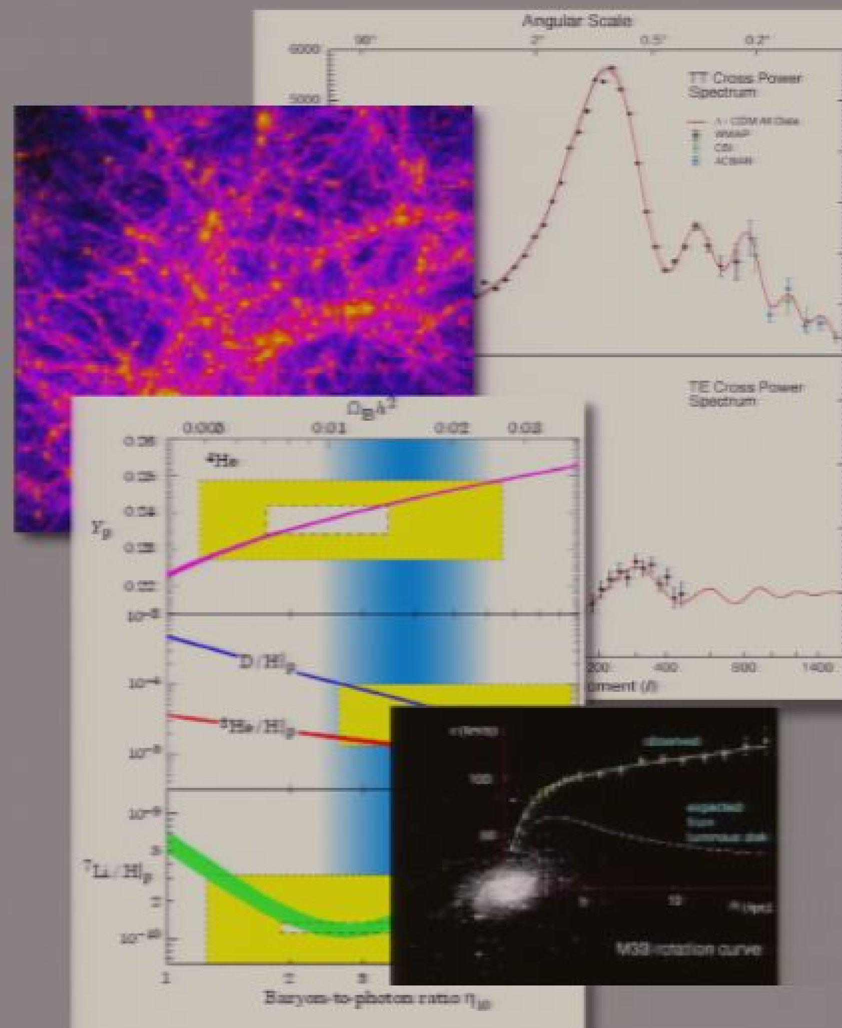
October 31, 2006

Dark Matter

•Evidence from a wide range of astrophysical observations including rotation curves, CMB, lensing, clusters, BBN, SN1a, large scale structure

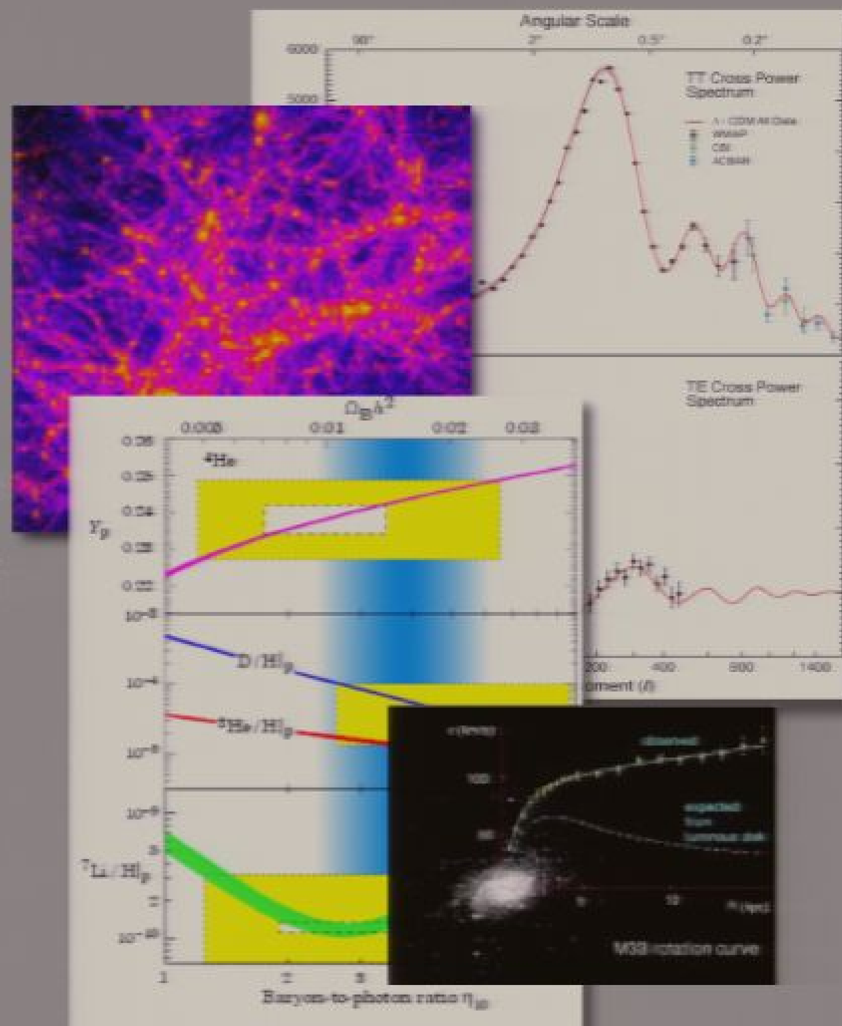


NASA/Chandra Press Release,
August 21, 2006

NASA/Chandra Press Release,
August 21, 2006

Dark Matter

- Evidence from a wide range of astrophysical observations including rotation curves, CMB, lensing, clusters, BBN, SN1a, large scale structure
- Each observes dark matter through its gravitational influence
- Still no (reliable) observations of dark matter's electroweak interactions (or other non-gravitational interactions)
- Still no (reliable) indications of dark matter's particle nature



The Dark Matter Candidate Zoo

Axions, Neutralinos, Gravitinos, Axinos, Kaluza-Klein Photons, Kaluza-Klein Neutrinos, Heavy Fourth Generation Neutrinos, Mirror Photons, Mirror Nuclei, Stable States in Little Higgs Theories, WIMPzillas, Cryptons, Sterile Neutrinos, Sneutrinos, Light Scalars, Q-Balls, D-Matter, Brane World Dark Matter, Primordial Black Holes, …

Weakly Interacting Massive Particles (WIMPs)

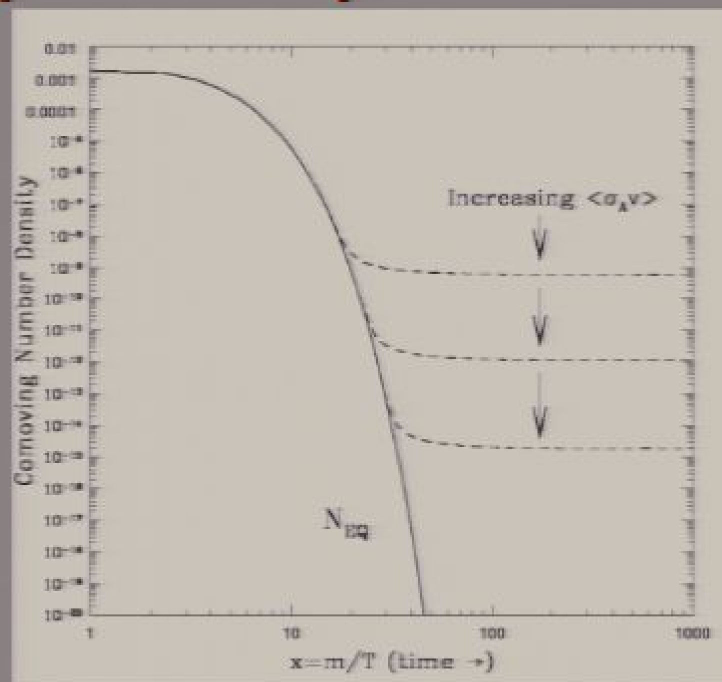
- As a result of the thermal freeze-out process, a relic density of WIMPs is left behind:

$$\Omega h^2 \sim x_F / \langle \sigma v \rangle$$

- For a particle with a GeV-TeV mass, to obtain a thermal abundance equal to the observed dark matter density, we need an annihilation cross section of $\langle \sigma v \rangle \sim$ pb

- Generic weak interaction yields:

$\langle \sigma v \rangle \sim \alpha^2 \,(100 \text{ GeV})^{-2} \sim$ pb



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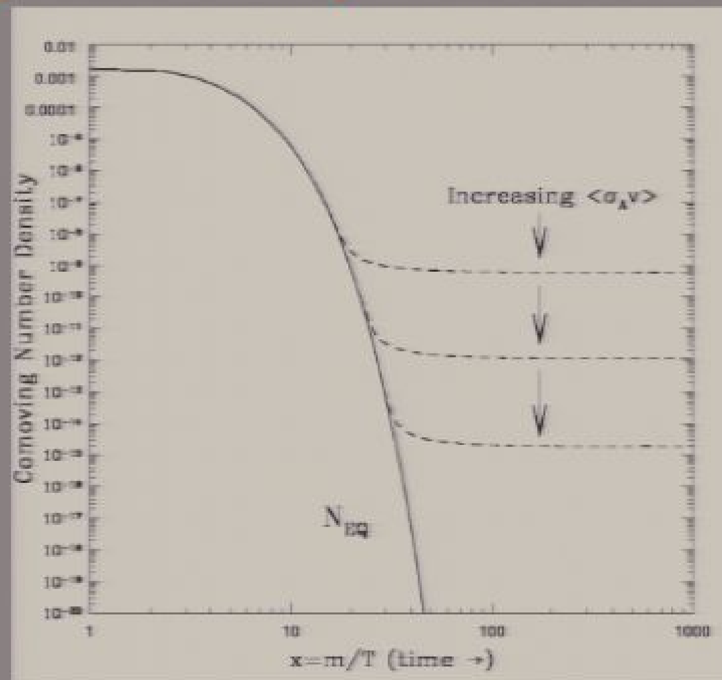
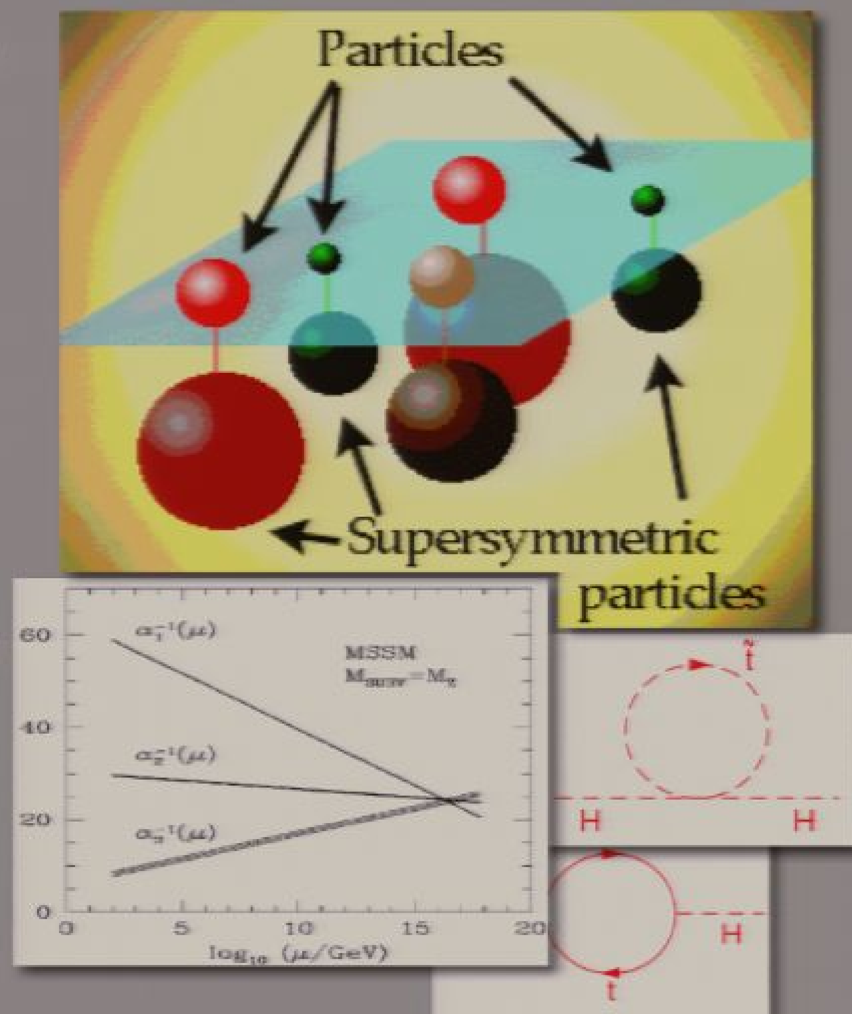


Numerical coincidence? Or an indication that dark matter originates from EW physics?

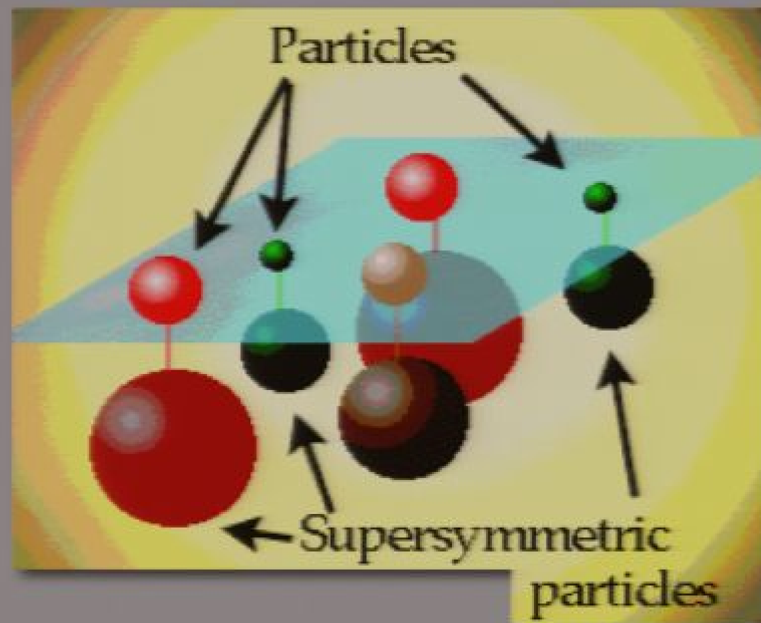
Supersymmetry

- Perhaps the most theoretically appealing (certainly the most well studied) extension of the Standard Model
- Natural solution to hierarchy problem (stabilizes quadradic divergences to Higgs mass)
- Restores unification of couplings
- Vital ingredient of string theory
- Naturally provides a compelling candidate for dark matter



Supersymmetric Dark Matter

- R-parity must be introduced in supersymmetry to prevent rapid proton decay
- Another consequence of R-parity is that superpartners can only be created and destroyed in pairs, making the lightest supersymmetric particle (LSP) stable



- Possible WIMP candidates from supersymmetry include: $\tilde{\gamma}, \tilde{Z}, \tilde{h}, \tilde{H}$ ⟵ 4 Neutralinos

$\tilde{\nu}$ ⟵ 3 Sneutrinos

Supersymmetric Dark Matter

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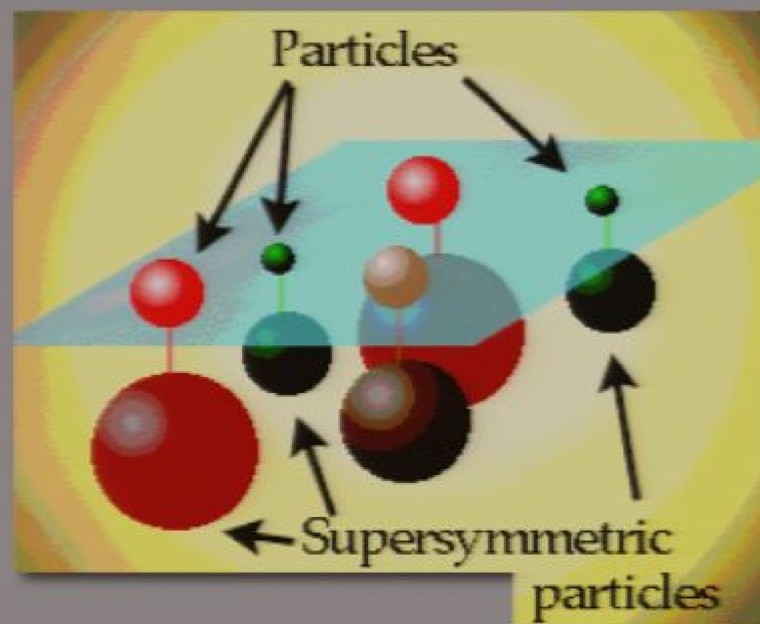


- Possible WIMP candidates from supersymmetry include:

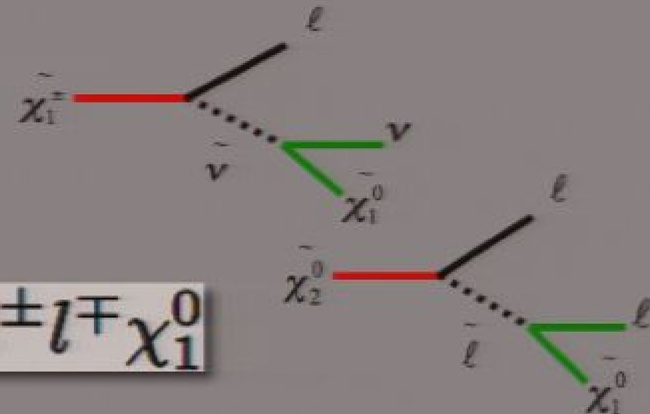
$\tilde{\gamma}, \tilde{Z}, \tilde{h}, \tilde{H}$ ← 4 Neutralinos

$\tilde{\nu}$ ← ~~3 Sneutrinos~~

Excluded by direct detection

Supersymmetry at the Tevatron

•Most promising channel is through neutralino-chargino production



For example:

$$\chi^\pm\chi_2^0 \rightarrow \tilde{\nu} l^\pm l^\pm \tilde{l}^\mp \rightarrow \nu \chi_1^0 l^\pm l^\pm l^\mp \chi_1^0$$

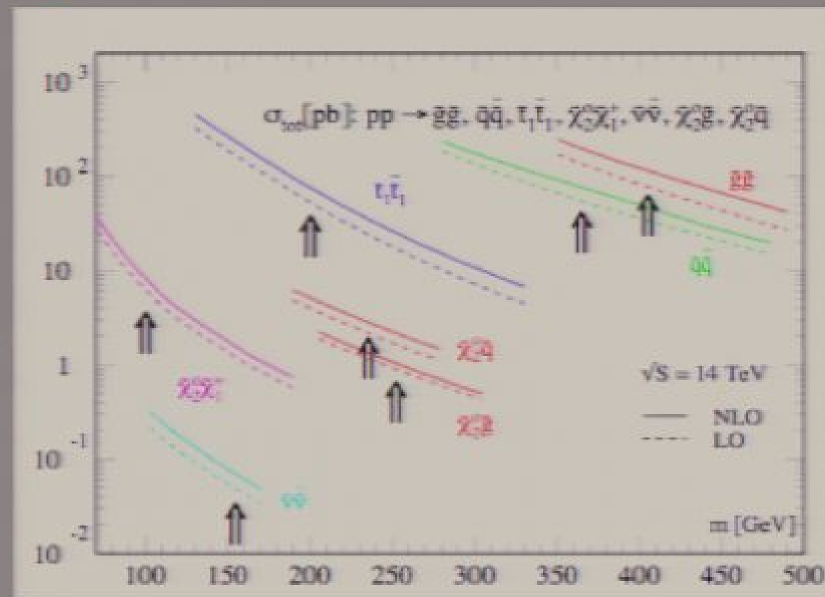
•Currently sensitive to charginos as heavy as ~140 GeV

•Tevatron searches for light squarks and gluinos are also very interesting

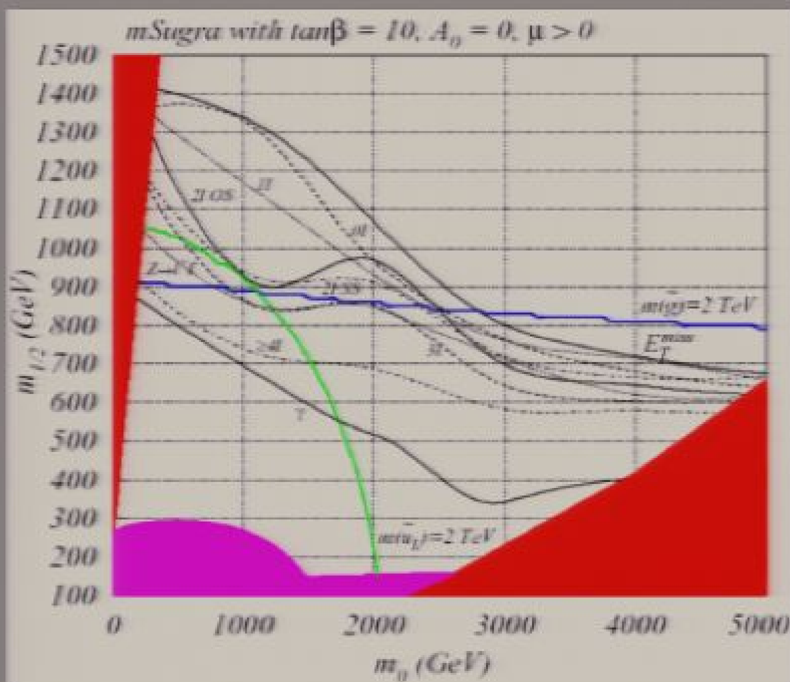
•For the case of light m_A and large tanβ, heavy MSSM higgs bosons (A/H) may be observable

Supersymmetry at the LHC

- Squarks and gluinos produced prolifically at the LHC
- Subsequent decays result in distinctive combinations of leptons, jets and missing energy



T. Plehn, Prospino 2.0



- Squarks and gluinos up to 1 TeV can be discovered with 1% of the first year design luminosity
- Ultimately, LHC can probe squarks and gluinos up to ~3 TeV

Supersymmetry at the LHC

What Can We Learn About Supersymmetry At The LHC?

- Kinematics of squark/gluino decays can reveal masses of squarks, gluinos, sleptons and neutralinos involved
- If many superpartners are light (bulk region), much of the sparticle spectrum could be reconstructed at the LHC

mass/mass splitting	LCC1 Value		LHC
$m(\tilde\chi^0_1)$	95.5	$\pm$	4.8
$m(\tilde\chi^0_2) - m(\tilde\chi^0_1)$	86.1	$\pm$	1.2
$m(\tilde\chi^0_3) - m(\tilde\chi^0_1)$	261.2	$\pm$	[illegible]
$m(\tilde\chi^0_4) - m(\tilde\chi^0_1)$	280.1	$\pm$	2.2*
$m(\tilde\chi^+_1)$	181.7	$\pm$	-
$m(\tilde\chi^+_2)$	374.7	$\pm$	-
$m(\tilde e_R)$	143.1	$\pm$	-
$m(\tilde e_R) - m(\tilde\chi^0_1)$	47.6	$\pm$	1.0
$m(\tilde\mu_R) - m(\tilde\chi^0_1)$	47.5	$\pm$	1.0
$m(\tilde\tau_1) - m(\tilde\chi^0_1)$	38.6	$\pm$	5.0
$BR(\tilde\chi^0_2 \to \tilde e e)/BR(\tilde\chi^0_2 \to \tilde\tau\tau)$	0.077	$\pm$	0.008
$m(\tilde e_L) - m(\tilde\chi^0_1)$	109.1	$\pm$	1.2
$m(\tilde\mu_L) - m(\tilde\chi^0_1)$	109.1	$\pm$	1.2
$m(\tilde\tau_2) - m(\tilde\chi^0_1)$	112.3	$\pm$	-
$m(\tilde\nu_e)$	186.2	$\pm$	-
$m(h)$	113.68	$\pm$	0.25
$m(A)$	394.4	$\pm$	*
$m(\tilde u_R)$, $m(\tilde d_R)$	548.	$\pm$	19.0
$m(\tilde s_R)$, $m(\tilde c_R)$	548.	$\pm$	19.0
$m(\tilde u_L)$, $m(\tilde d_L)$	564., 570.	$\pm$	17.4
$m(\tilde s_L)$, $m(\tilde c_L)$	570., 564.	$\pm$	17.4
$m(\tilde b_1)$	514.	$\pm$	7.5
$m(\tilde b_2)$	539.	$\pm$	7.9
$m(\tilde t_1)$	401.	$\pm$	(> 270)
$m(\tilde g)$	611.	$\pm$	8.0

E. Baltz, et al, hep-ph/0602187

Supersymmetry at the LHC

What Can We Learn About Supersymmetry At The LHC?

- Kinematics of squark/gluino decays can reveal masses of squarks, gluinos, sleptons and neutralinos involved
- If many superpartners are light (bulk region), most/much of the sparticle spectrum could be reconstructed at the LHC

But we might not be so lucky!

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$m(\tilde g)$	611.	$\pm$	8.0

E. Baltz, et al, hep-ph/0602187

Supersymmetry at the LHC

What Can We Learn About Supersymmetry At The LHC?

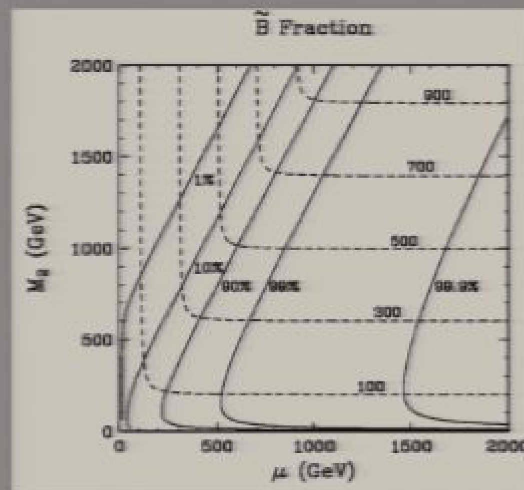
- For moderate and heavy SUSY models, the LHC will reveal far fewer superpartners
- It is not at all unlikely that the LHC could uncover a spectrum of squarks, gluinos and one neutralino
- Other than one mass, this would tell us next to nothing about the neutralino sector

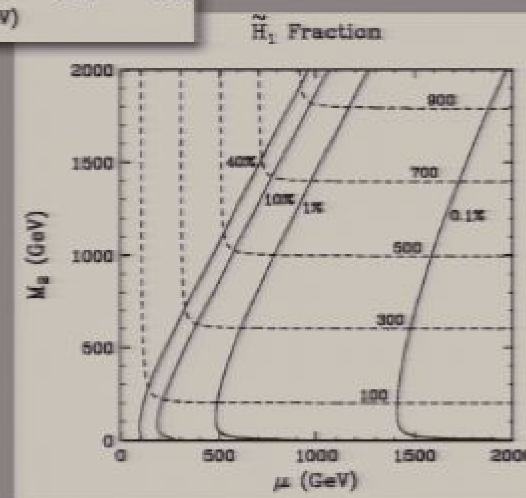
mass/mass splitting	LCC4 value		LHC
$m(\tilde{\chi}_1^0)$	169.1	$\pm$	17.0
$m(\tilde{\chi}_2^0)$	327.1	$\pm$	49.
$m(\tilde{\chi}_2^0) - m(\tilde{\chi}_1^0)$	158.0	$\pm$	-
$m(\tilde{\chi}_3^0) - m(\tilde{\chi}_1^0)$	370.6	$\pm$	-
$m(\tilde{\chi}_1^+)$	327.5	$\pm$	-
$m(\tilde{\chi}_1^+) - m(\tilde{\chi}_1^0)$	158.4	$\pm$	-
$m(\tilde{\chi}_2^+) - m(\tilde{\chi}_1^+)$	225.8	$\pm$	-
$m(\tilde{e}_R) - m(\tilde{\chi}_1^0)$	243.2	$\pm$	-
$m(\tilde{\mu}_R) - m(\tilde{\chi}_1^0)$	243.0	$\pm$	-
$m(\tilde{\tau}_1)$	194.8	$\pm$	-
$m(\tilde{\tau}_1) - m(\tilde{\chi}_1^0)$	25.7	$\pm$	-
$m(h)$	117.31	$\pm$	0.25
$m(A)$	419.3	$\pm$	1.5 *
$\Gamma(A)$	14.8	$\pm$	-
$m(\tilde{u}_R), m(\tilde{d}_R)$	944.,941.	$\pm$	94.
$m(\tilde{s}_R), m(\tilde{c}_R)$	941., 944.	$\pm$	97.
$m(\tilde{u}_L), m(\tilde{d}_L)$	971., 975.	$\pm$	141.
$m(\tilde{s}_L), m(\tilde{c}_L)$	975., 971.	$\pm$	146.
$m(\tilde{b}_1)$	795.	$\pm$	40.
$m(\tilde{b}_2)$	862.	$\pm$	86.
$m(\tilde{t}_1)$	716.	$\pm$	(> 345)
$m(\tilde{g})$	993.	$\pm$	199.

E. Baltz, et al, hep-ph/0602187

Studying Supersymmetry With Neutralino Dark Matter

- Unless several of the neutralinos are light enough to be discovered at the LHC, we will learn very little about the composition and couplings of the lightest neutralino
- Astrophysical dark matter experiments provide another way to probe these couplings
- Potentially enable us to constrain/measure parameters appearing in the neutralino mass matrix: μ, M_1, M_2, $\tan\beta$

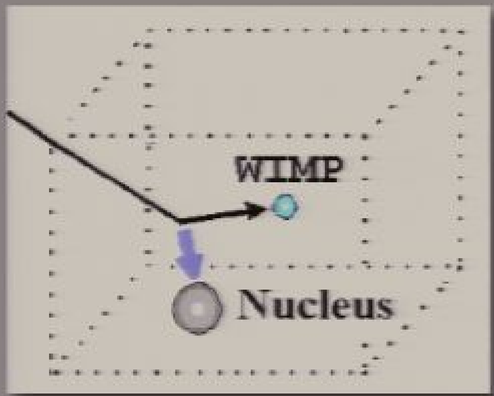




Astrophysical Probes of Particle Dark Matter

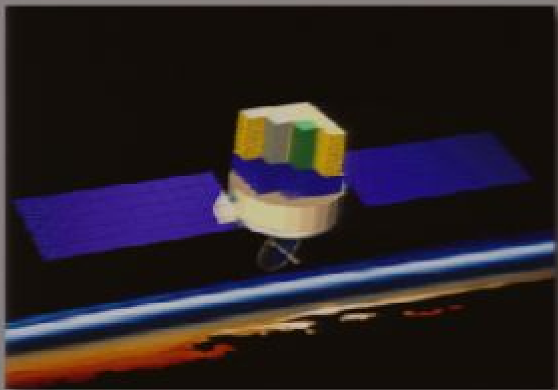
Direct Detection

-Momentum transfer to detector through elastic scattering



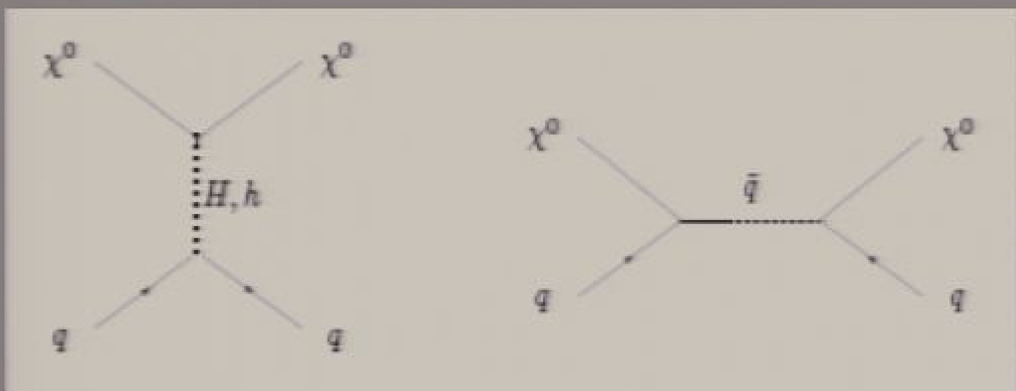
Indirect Detection

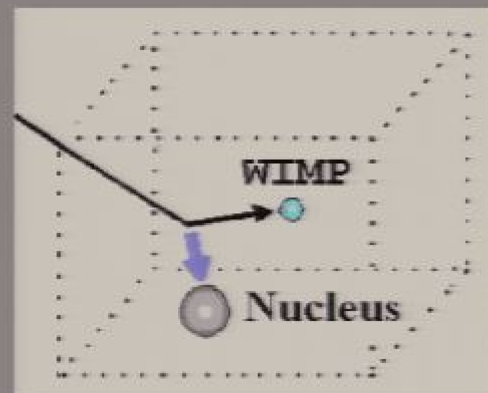
-Observation of annihilation products (γ, ν, e+, $\bar{p}$, etc.)



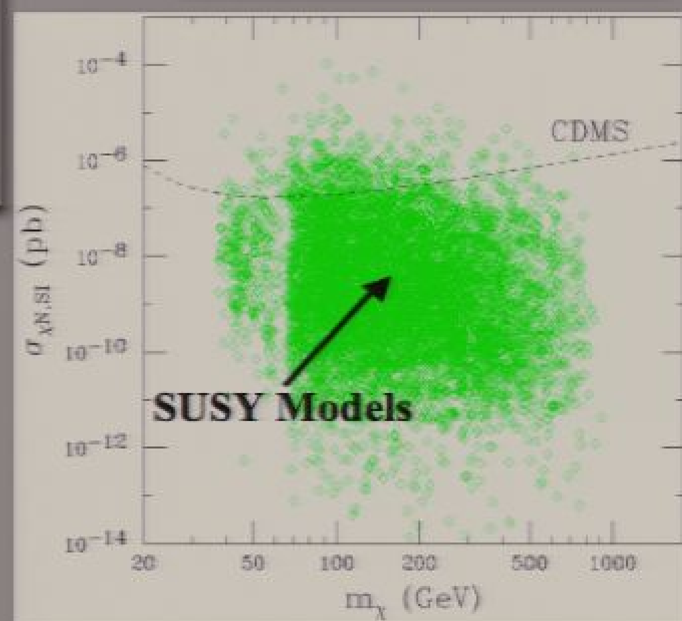
Direct Detection

•Neutralino-nuclei elastic scattering can occur through Higgs and squark exchange diagrams:

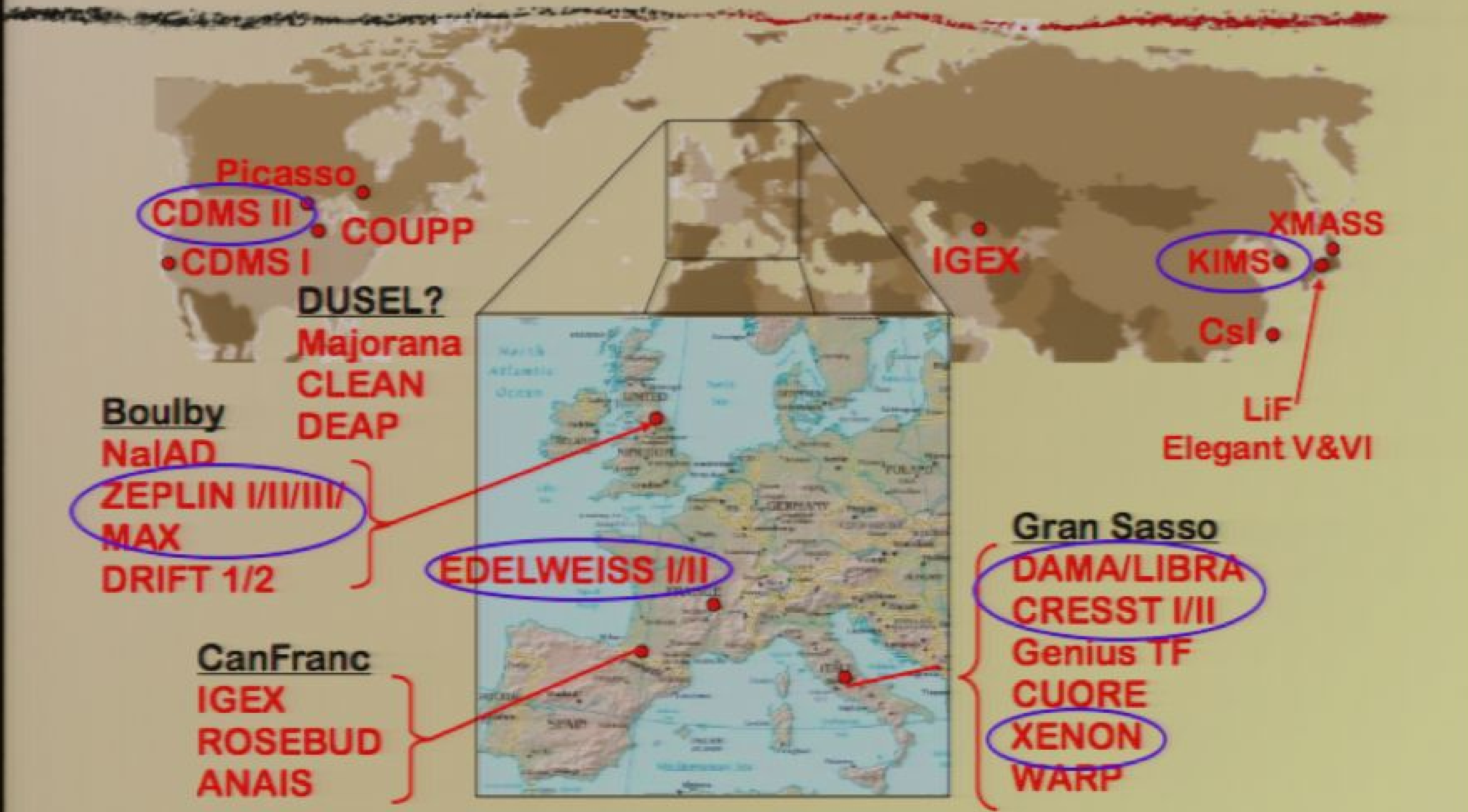




•Cross section depends on numerous SUSY parameters: neutralino mass and composition, tanβ, squark masses and mixings, Higgs masses and mixings

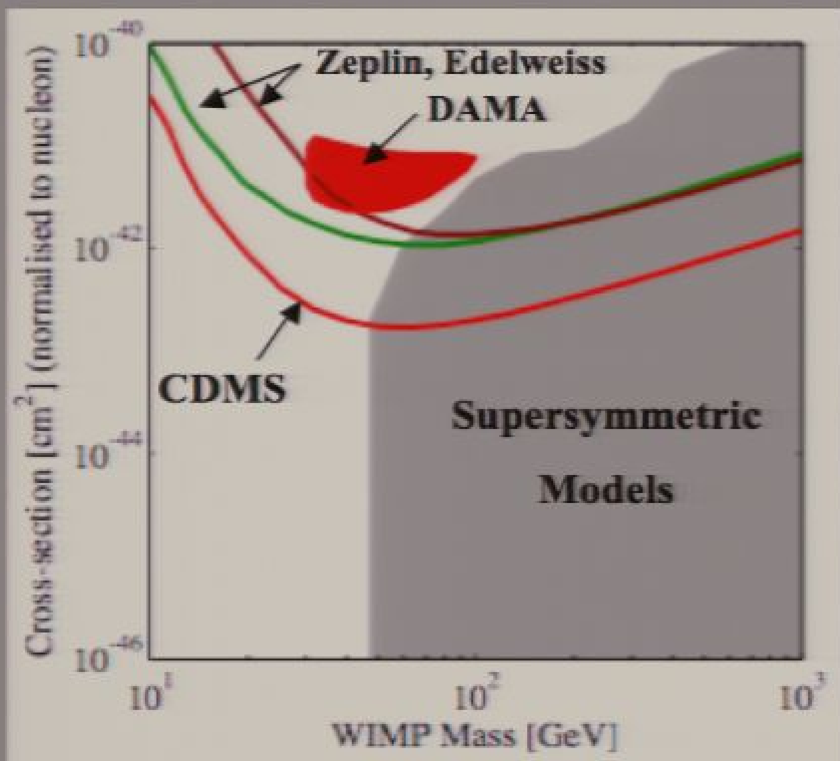


Direct Detection WIMP Experiments Worldwide



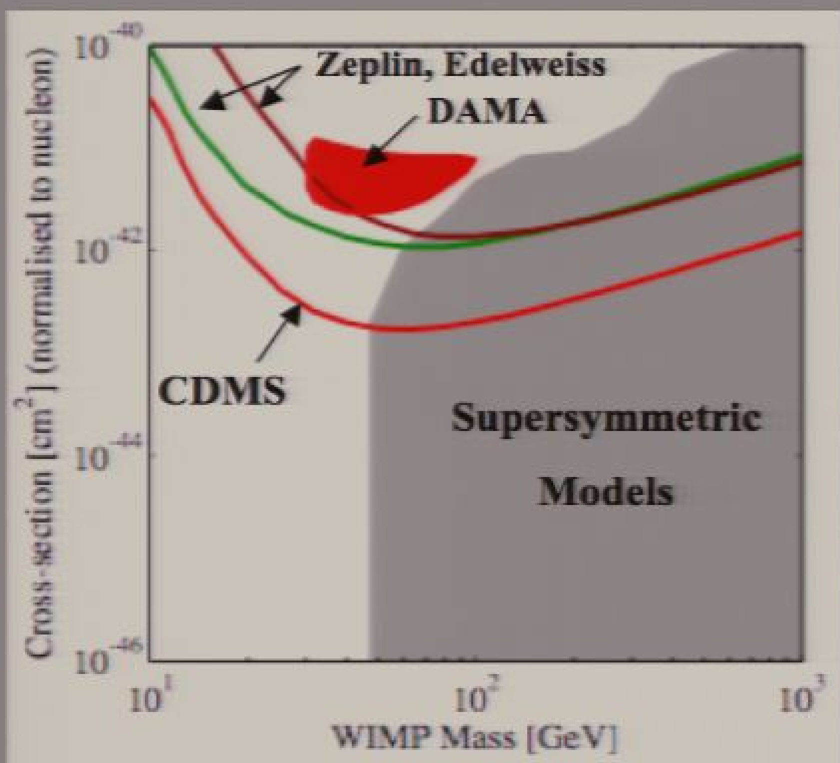
Direct Detection

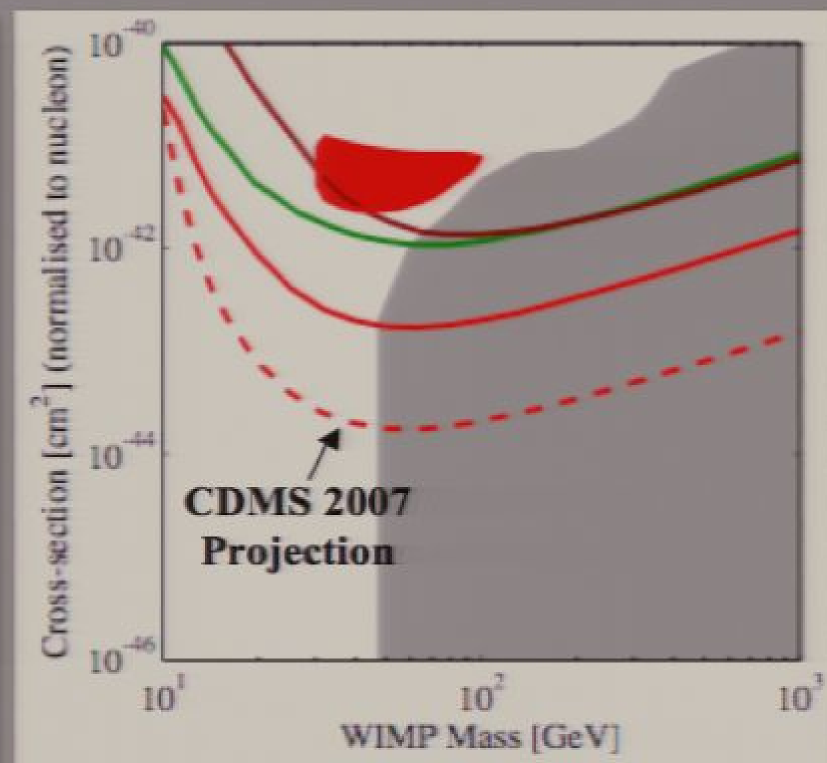
•Current Status:



Direct Detection

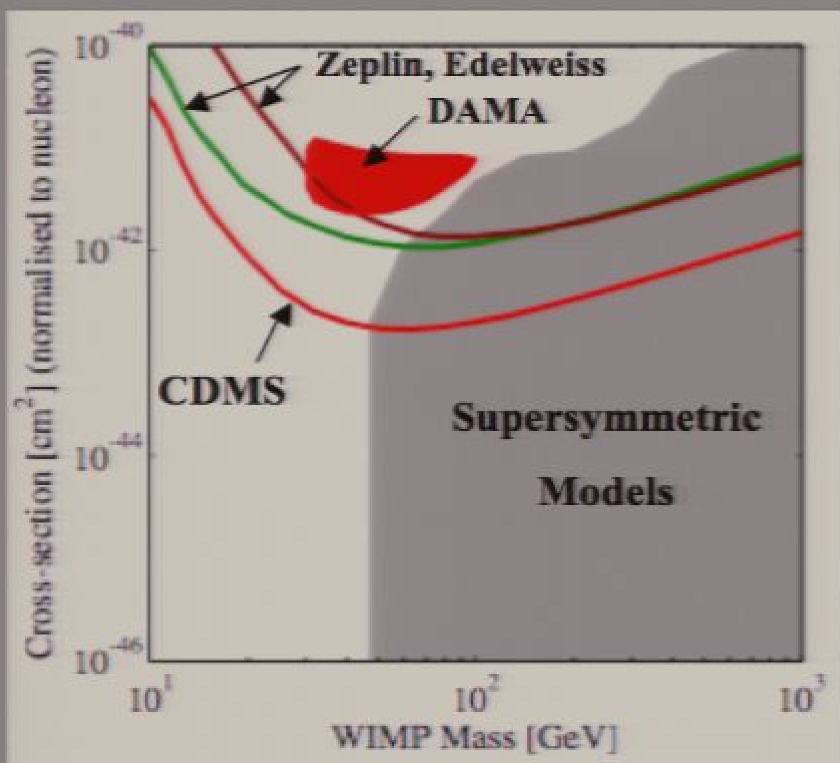
•Near-Future Prospects:

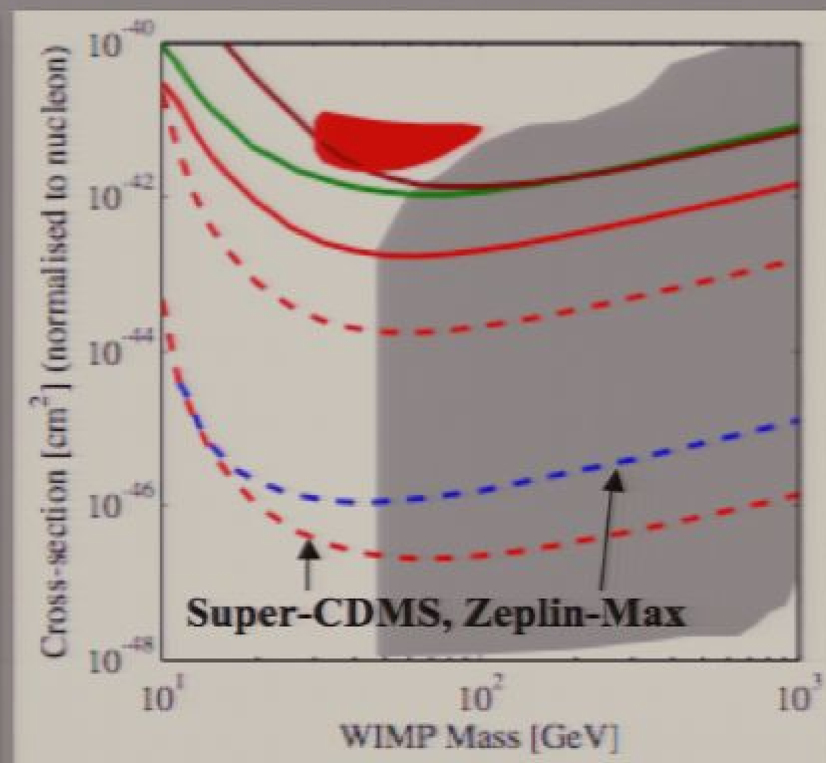




Direct Detection

- Long-Term Prospects:





Direct Detection

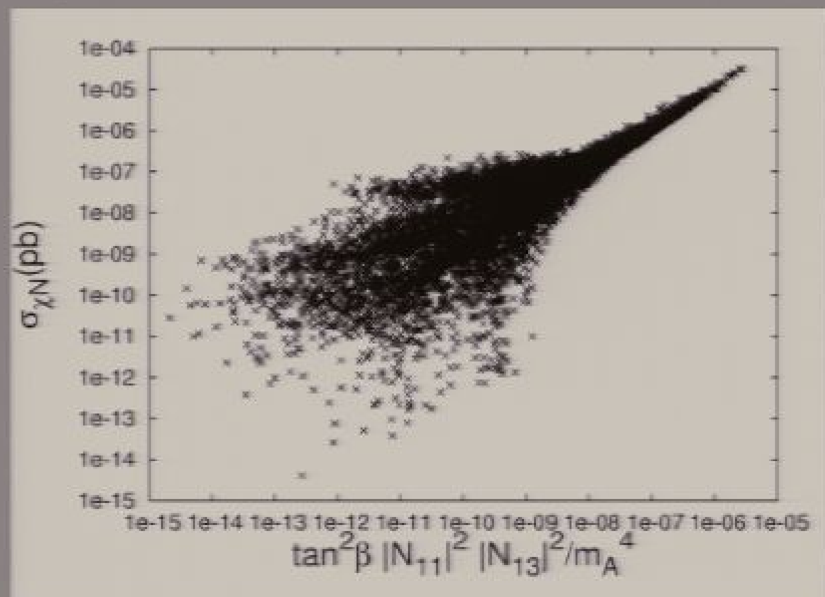
But what does direct detection tell us?

•Neutralino *is* dark matter
(μsec vs. cosmological time scales)

•Models with large cross sections are dominated by Higgs exchange, couplings to b, s quarks

•Squark exchange contribution substantial only below ~10^{-8} pb

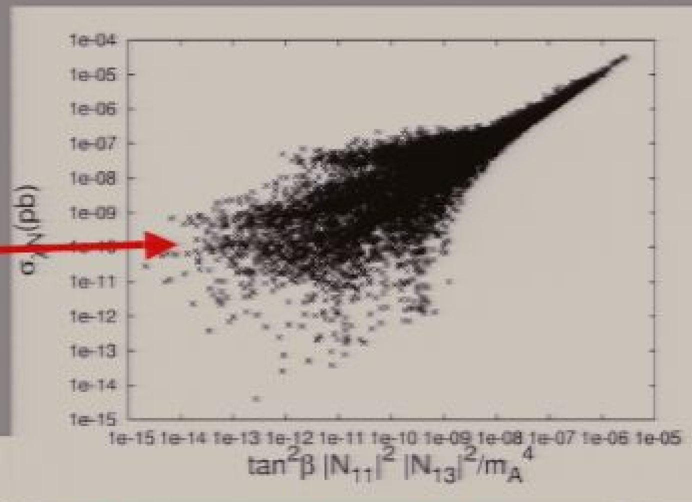
•Leads to correlation between neutralino composition, $\tan\beta$, m_A and the elastic scattering rate

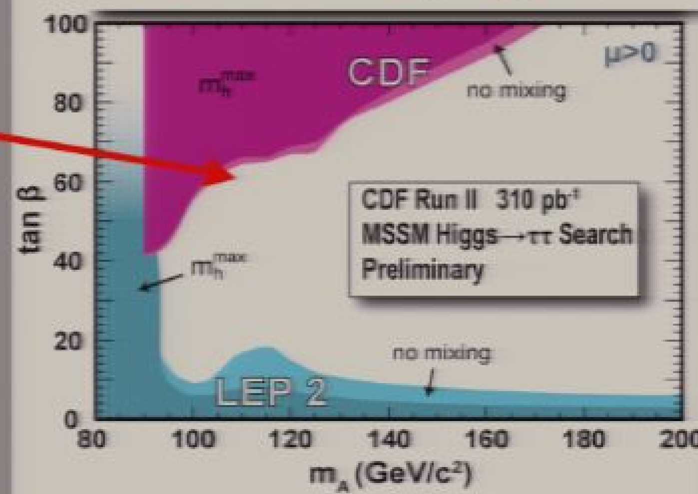


Hooper and A. Taylor, hep-ph/0607086

Direct Detection And The Tevatron

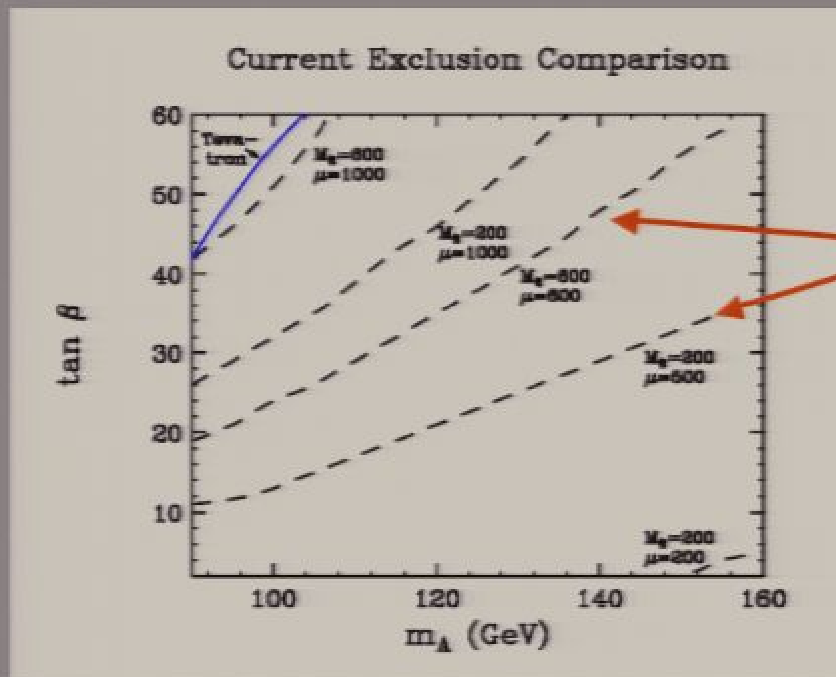
- Correlation between neutralino composition, tan β, m_A and the elastic scattering rate (large tanβ, small m_A leads to a large elastic scattering rate)
- MSSM Higgs searches at the Tevatron are also most sensitive to large tanβ, small m_A





M. Carena, Hooper and P. Skands, PRL, hep-ph/0603180

Direct Detection And The Tevatron

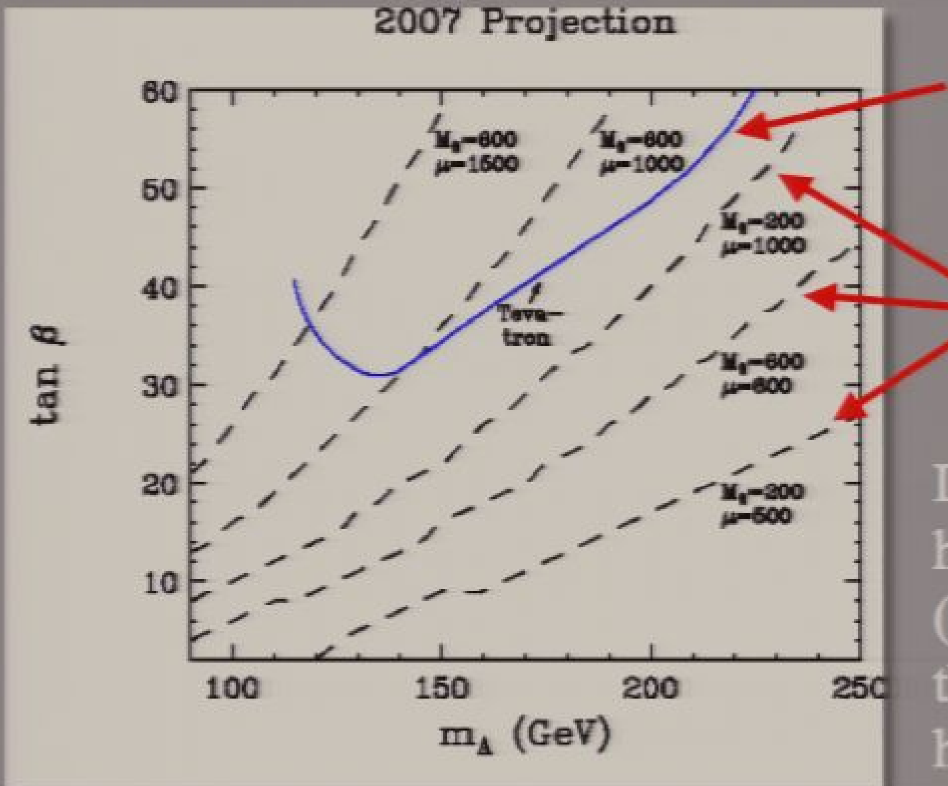


Current CDMS Limit

For a wide range of M_2 and μ, much stronger current limits on tanβ, m_A from CDMS than from the Tevatron

M. Carena, Hooper and P. Skands, PRL, hep-ph/0603180

Direct Detection And The Tevatron



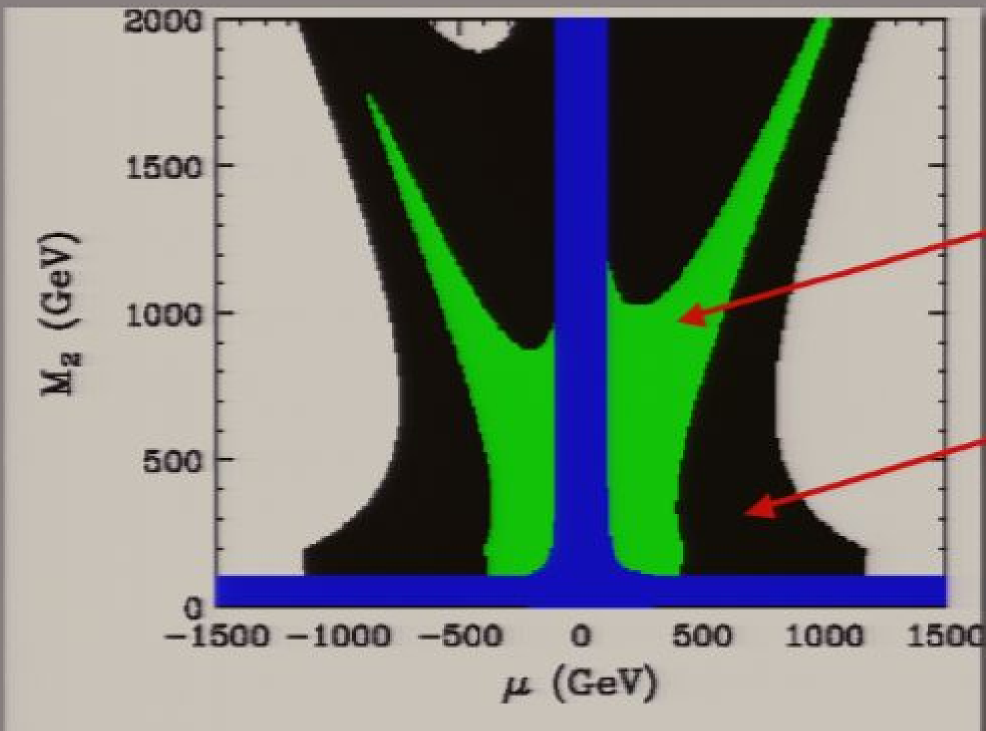
3σ discovery reach, 4 fb^{-1}

Projected 2007 CDMS Limit (assuming no detection)

Limits from CDMS imply heavy, neutral MSSM Higgs (H/A) are beyond the reach of the Tevatron, unless the LSP has a very small higgsino fraction ($\mu >> M_2$)

M. Carena, Hooper and P. Skands, PRL, hep-ph/0603180

Direct Detection And The Tevatron



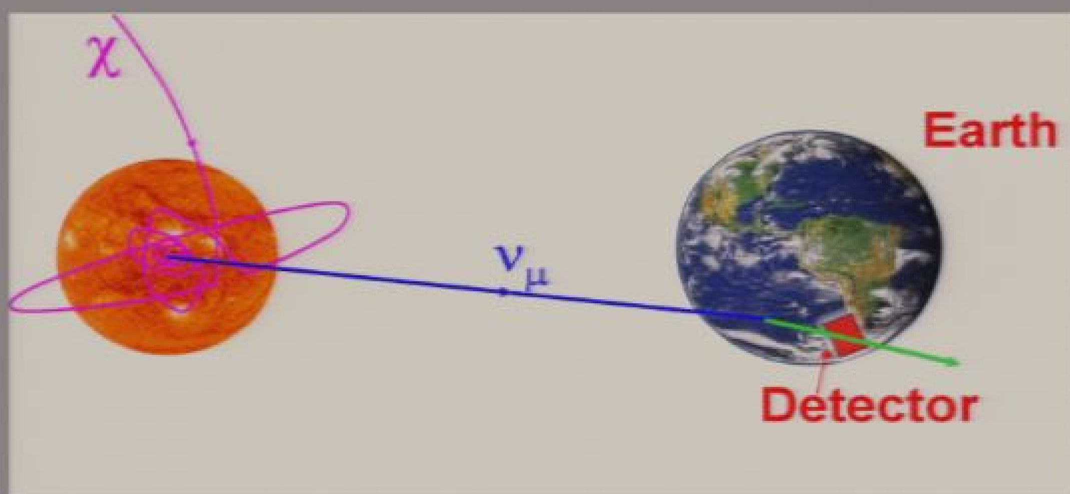
H/A discovery (3σ, 4 fb^{-1}) not expected given current CDMS limit

H/A discovery (3σ, 4 fb^{-1}) not expected given projected 2007 CDMS limits (assuming no detection)

M. Carena, Hooper and P. Skands, PRL, hep-ph/0603180

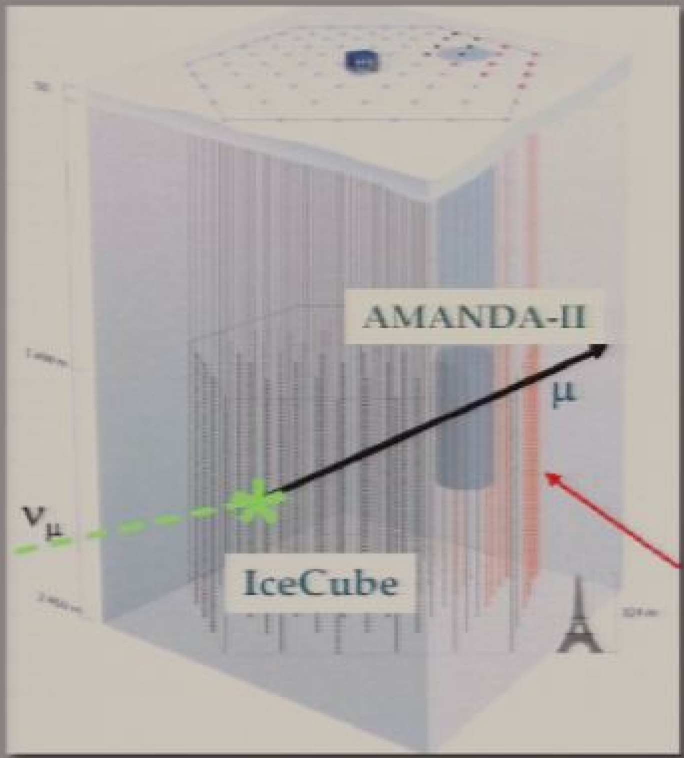
Indirect Detection With Neutrinos

- Neutralinos elastically scatter with nuclei in the Sun, becoming gravitationally bound
- As neutralinos accumulate in the Sun's core, they annihilate at an increasing rate
- After ~Gyr, annihilation rate typically reaches equilibrium with capture rate, generating a potentially observable flux of high-energy neutrinos



Indirect Detection With Neutrinos

- Muon neutrinos from the Sun interacting via charged current produce energetic muons
- Kilometer-scale neutrino telescope IceCube currently under construction at South Pole



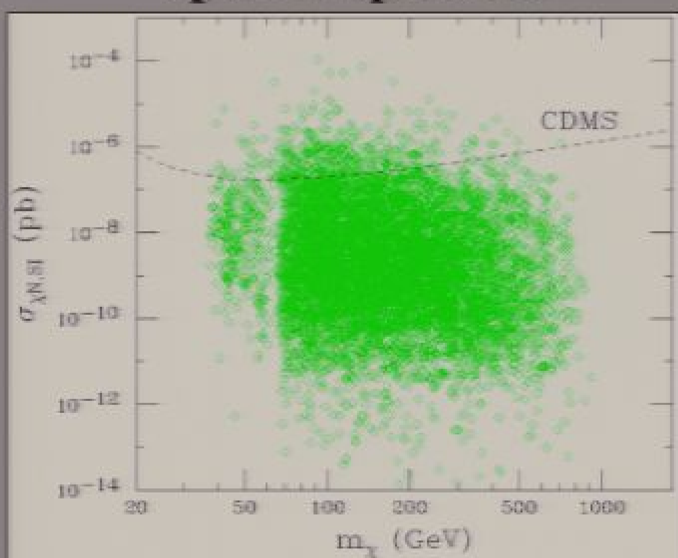
Indirect Detection With Neutrinos

- Rate observed at IceCube depends primarily on the neutralino capture rate in the Sun (the elastic scattering cross section)
- The reach of neutrino telescopes is, therefore, expected to be tied to that of direct detection experiments

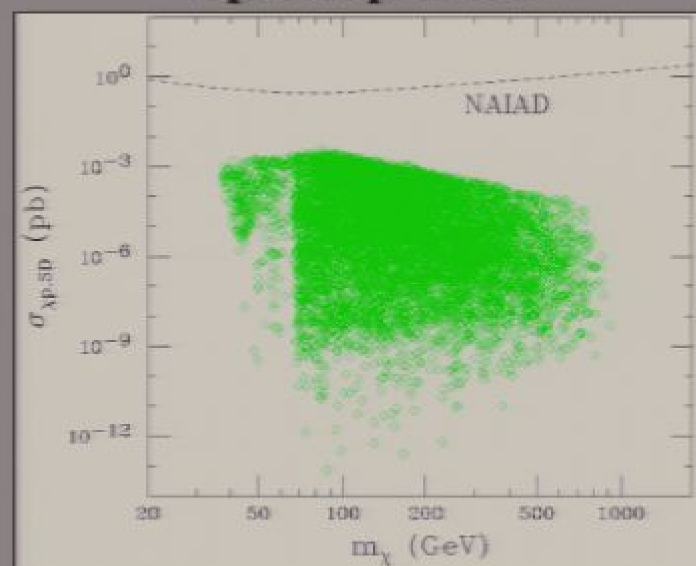
Indirect Detection With Neutrinos

- Important Caveat: WIMPs scatter with nuclei in the Sun through *both* spin-independent and spin-dependent scattering
- Sensitivity of direct detection to spin-dependent scattering is currently very weak

Spin-Independent



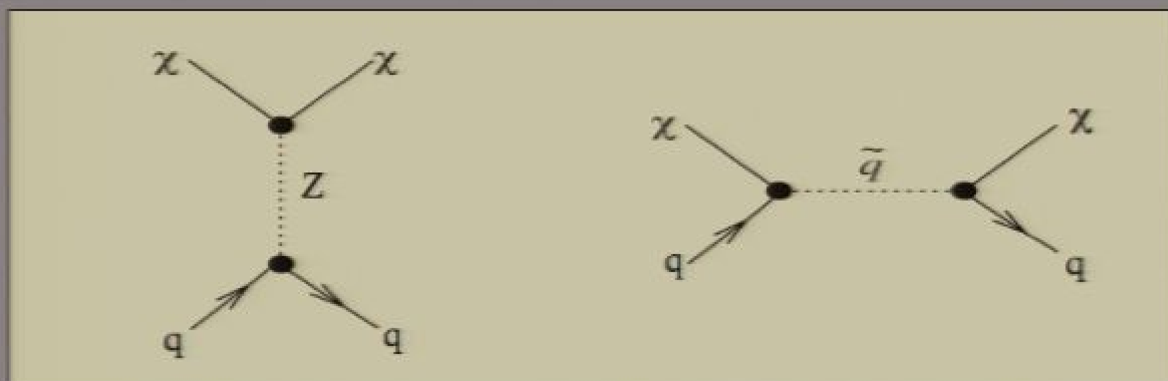
Spin-Dependent



F. Halzen and Hooper, PRD, hep-ph/0510048

Indirect Detection With Neutrinos

What kind of neutralino has large spin-dependent couplings?



$\propto \; [\, |f_{H1}|^2 - |f_{H2}|^2 \,]^2$ → **Substantial Higgsino Component Needed**

Always Small

Indirect Detection With Neutrinos

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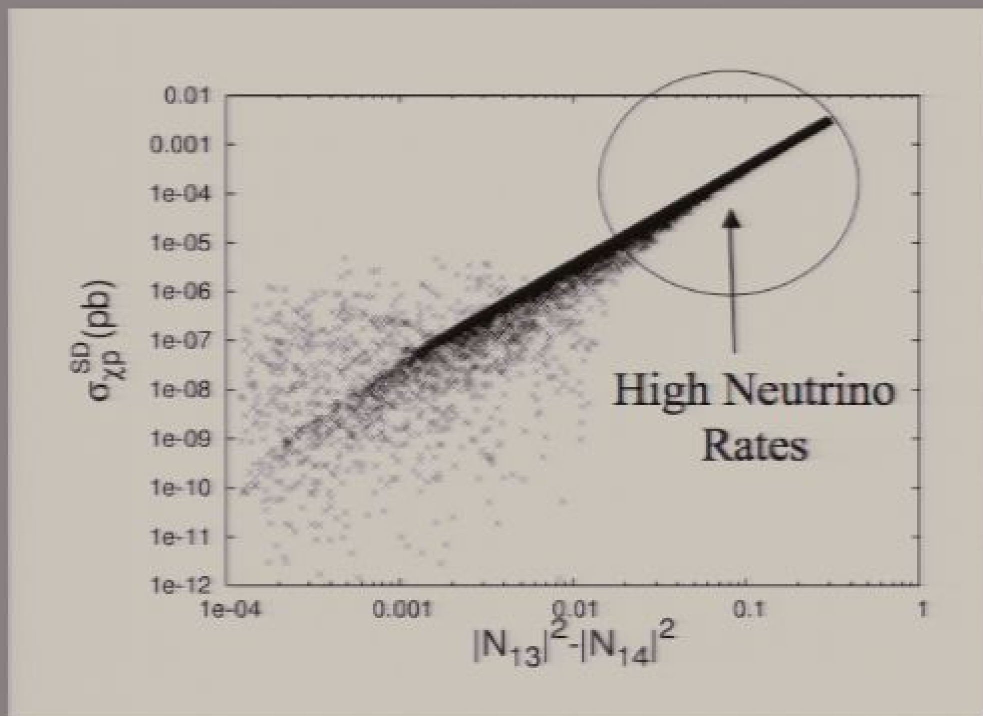
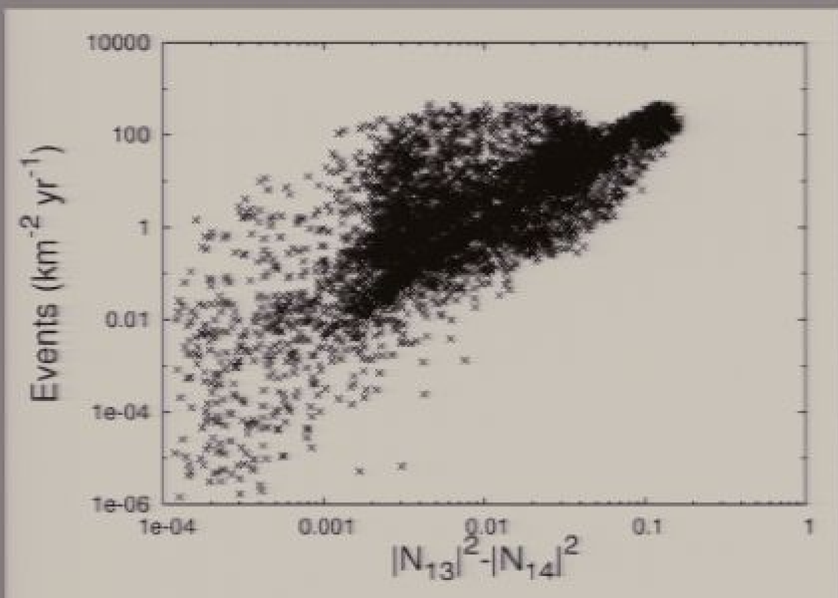


Hooper and A. Taylor, hep-ph/0607086;
F. Halzen and Hooper, PRD, hep-ph/0510048

Indirect Detection With Neutrinos

Rates complicated by competing scalar and axial-vector scattering processes

Current CDMS Constraint



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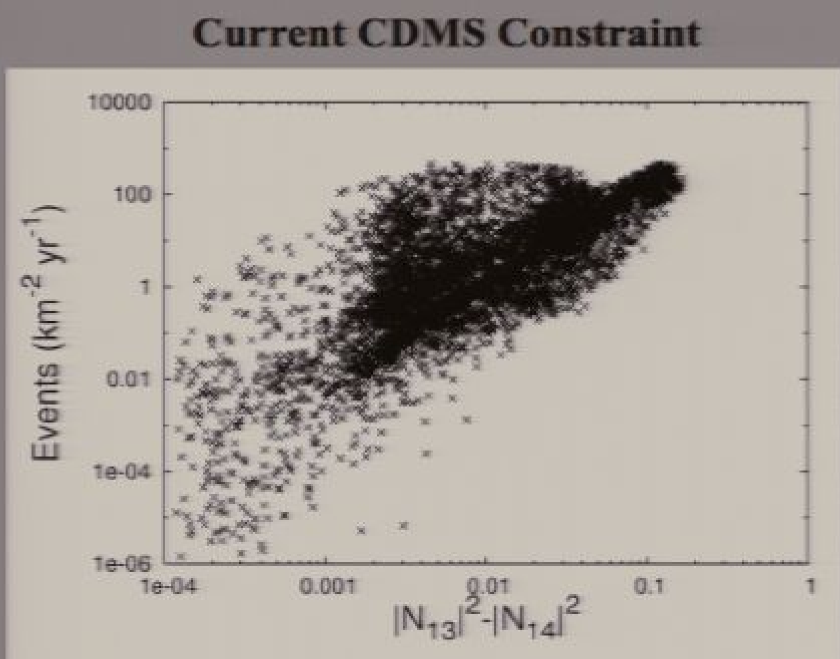
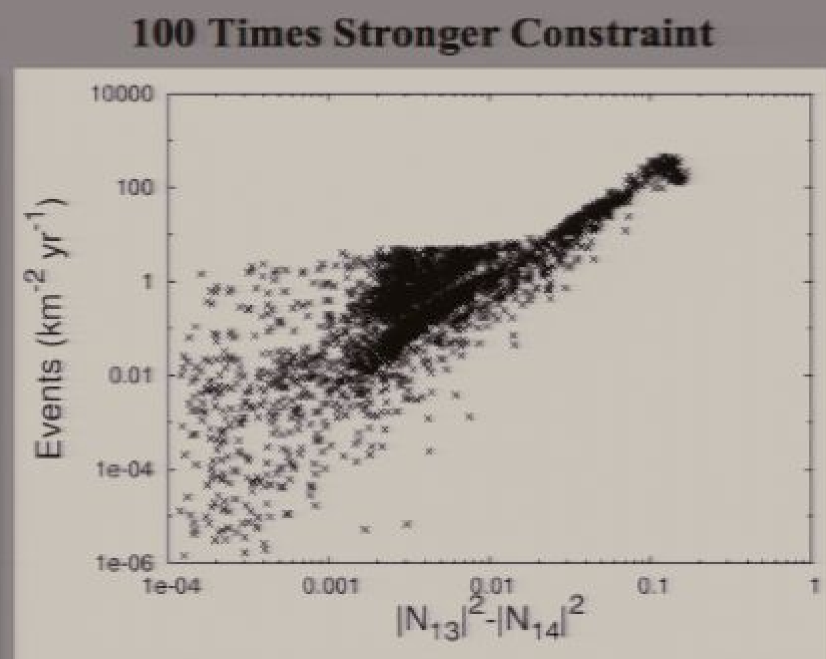
Indirect Detection With Neutrinos

Rates complicated by competing scalar and axial-vector scattering processes; but becomes simple with future bounds





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Indirect Detection With Gamma-Rays

Advantages of Gamma-Rays:

•Propagate undeflected (point sources possible)

•Propagate without energy loss (spectral information)

•Distinctive spectral features (lines), provide potential "smoking gun"

•Wide range of experimental technology (ACTs, satellite-based)

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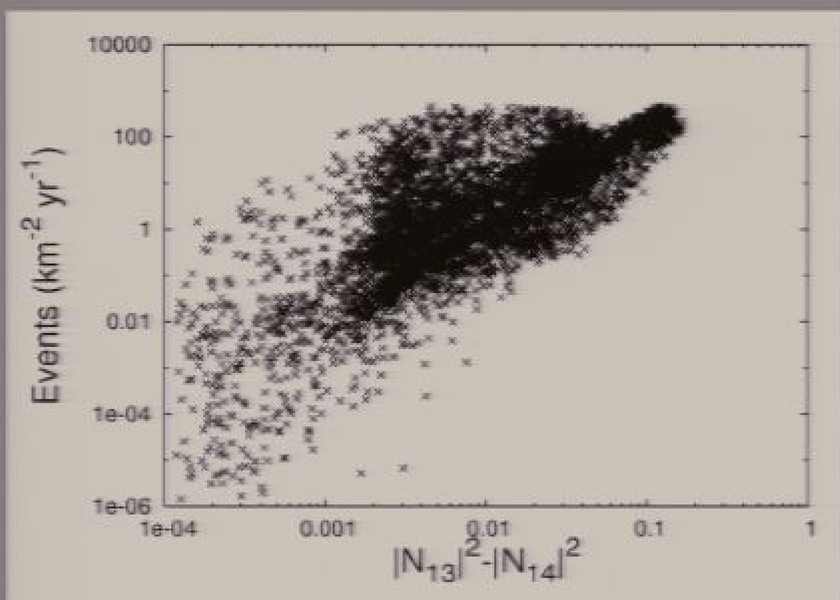
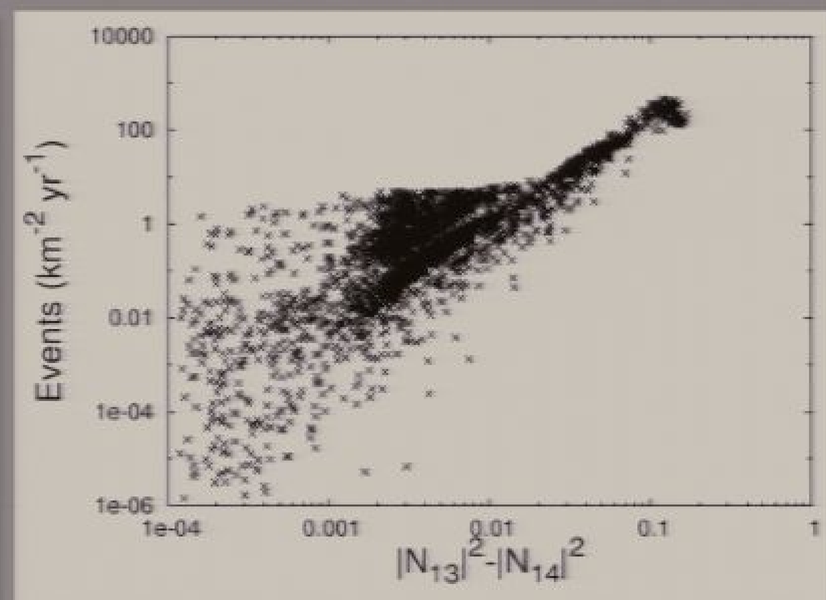


100 Times Stronger Constraint



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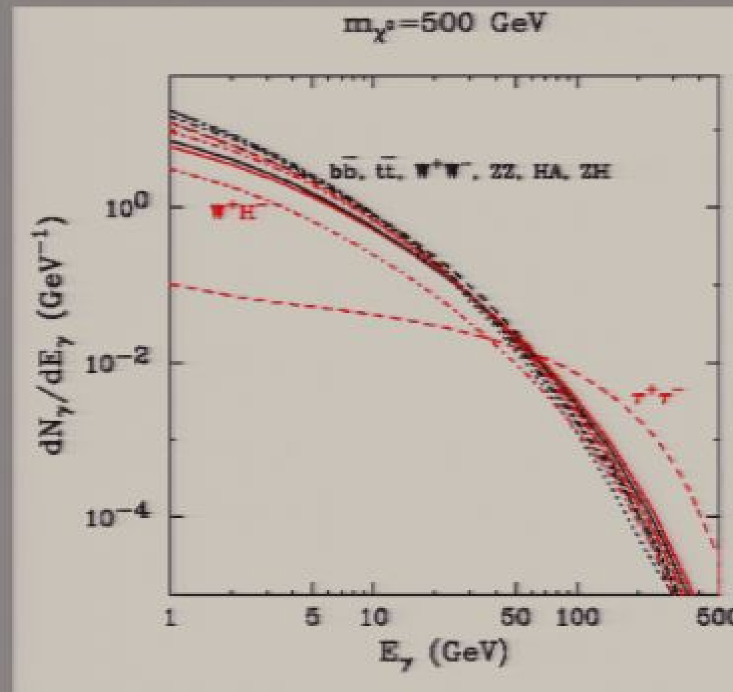
Indirect Detection With Gamma-Rays

What does the gamma-ray spectrum tell us?

•Most annihilation modes generate very similar spectra

•$\tau^+\tau^-$ mode is the most distinctive, although still not identifiable with planned experiments (GLAST, etc.)

•Neutralino mass and annihilation rate may be roughly extracted

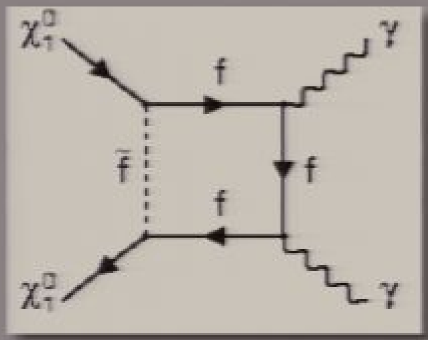


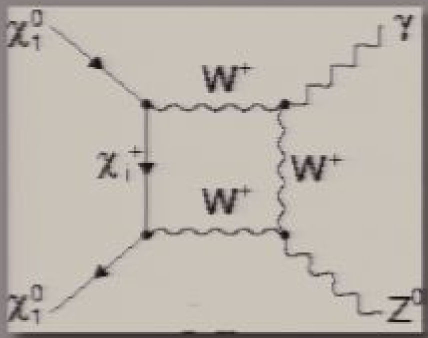
Hooper and A. Taylor, hep-ph/0607086

Indirect Detection With Gamma-Rays

What does the gamma-ray spectrum tell us?

- At loop level, neutralinos annihilate to $\gamma\gamma$ and γZ final states
- Distinctive spectral line features
- If bright enough, fraction of neutralino annihilations to lines can be measured





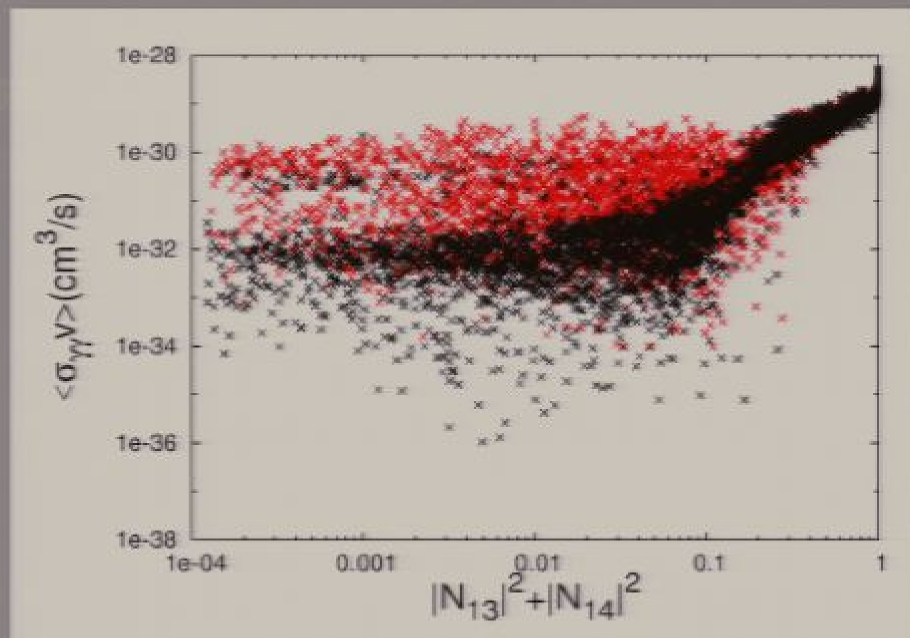
Indirect Detection With Gamma-Rays

What does the gamma-ray spectrum tell us?

- Chargino-$W^{+/-}$ loop diagrams provide largest contributions in most models

- Cross sections largest for higgsino-like (or wino-like) neutralinos

- Knowledge of squark masses makes this correlation more powerful



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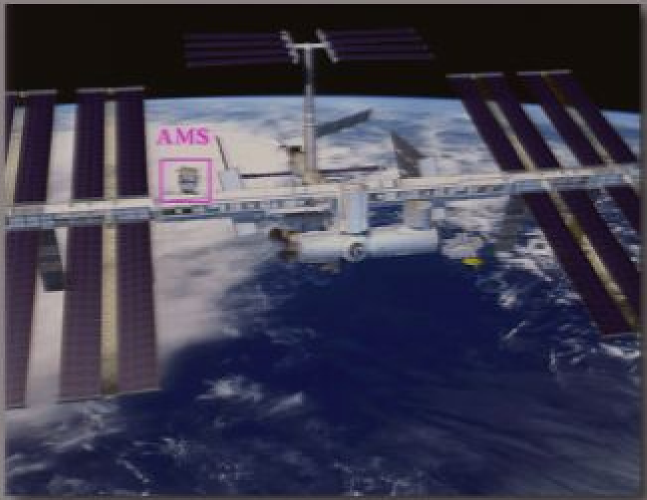
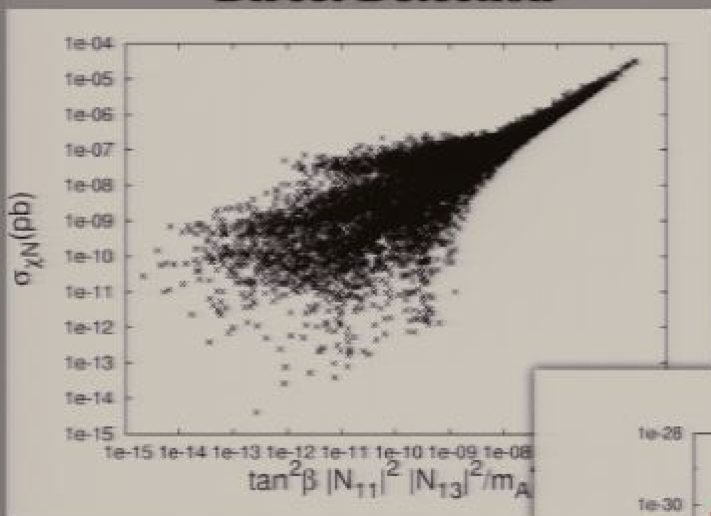
Information From Anti-Matter

- Gamma-ray observations can tell us the fraction of neutralino annihilation to various modes ($\gamma\gamma$, γZ), but cannot measure the total cross section
- Positron spectrum generated in neutralino annihilations is dominated by local dark matter distribution (within a few kpc)
- Considerably less uncertainty in the local density than the density of inner halo
- Cosmic positron measurements can roughly measure the neutralino's total annihilation cross section

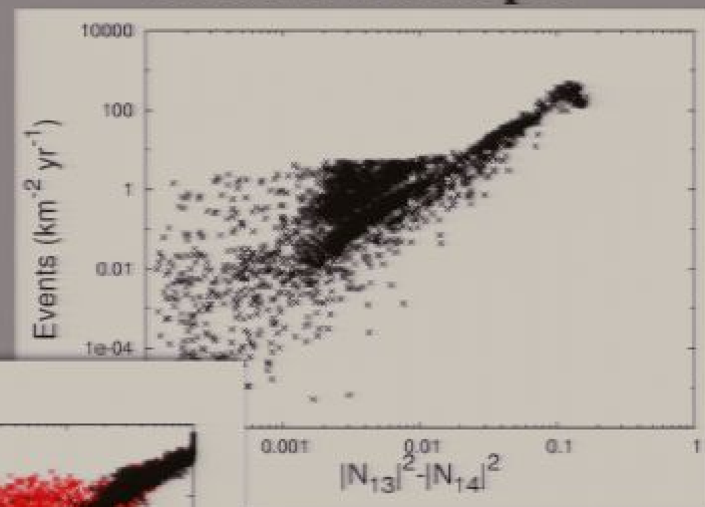


Putting It All Together

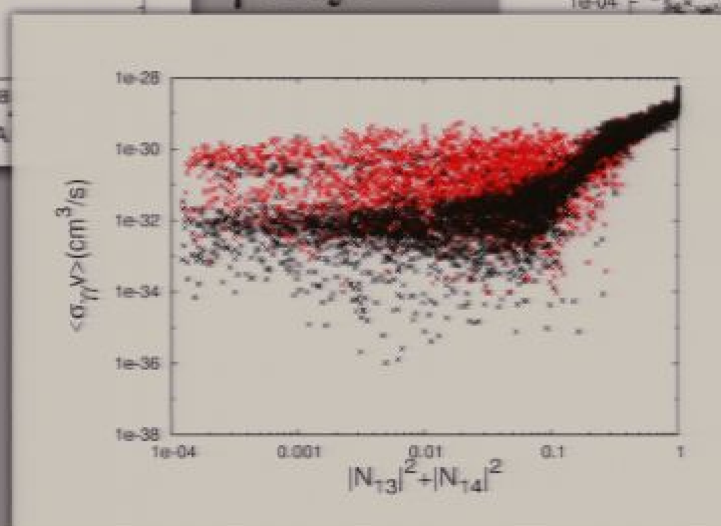
Direct Detection



Neutrino Telescopes



γ-Rays + e+



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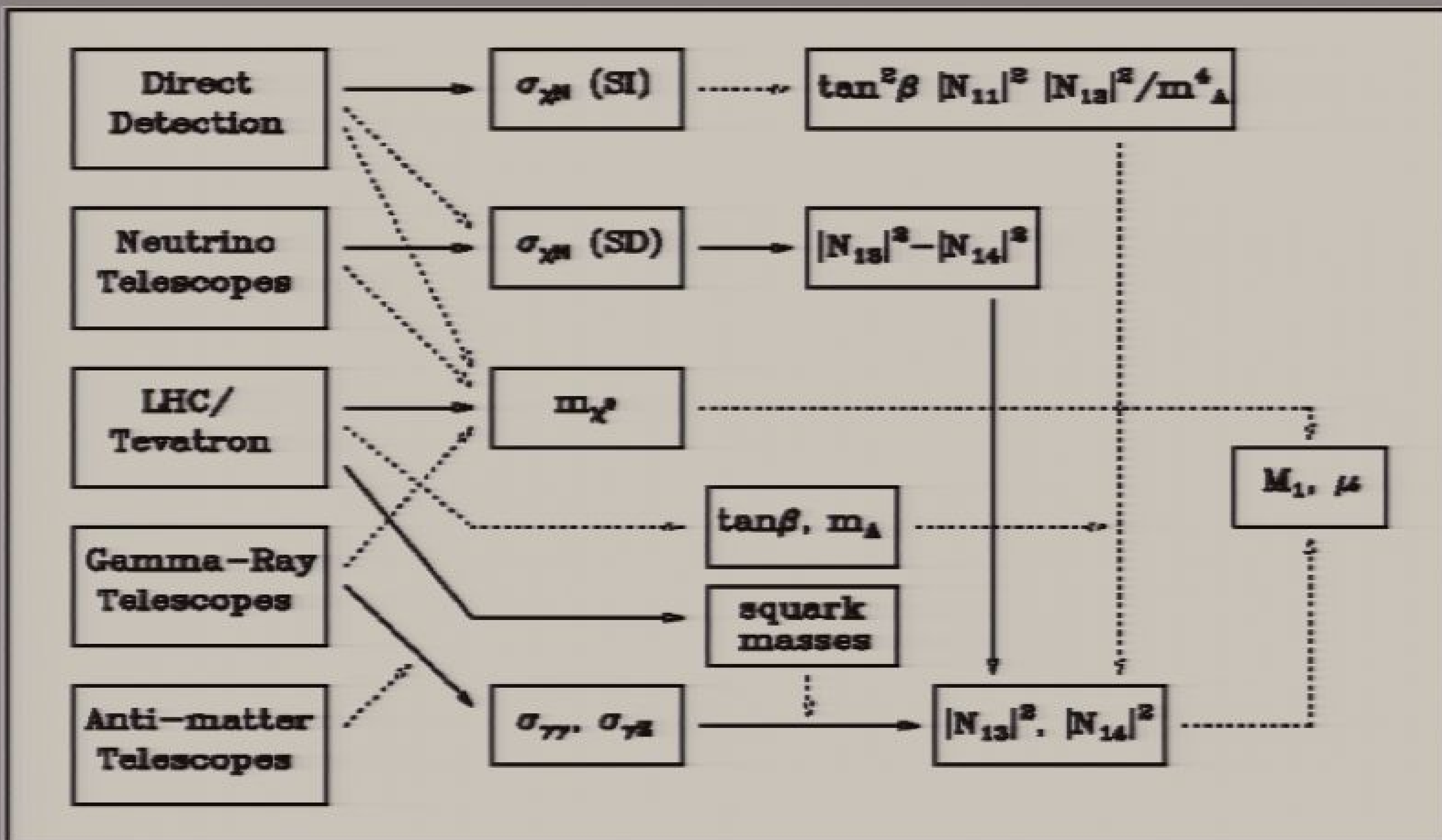

Studying SUSY with the LHC and Astrophysics

Benchmark model IM3:

SUSY Inputs: M_2=673 GeV, μ=619 GeV, m_A=397 GeV, $\tan\beta$=51,
2130 GeV squarks

Measured by the LHC: m_χ= 236 ± 10%, m_{squark}=2130 ± 30%,
$\tan\beta$=51 ± 15%, m_A=397 ± 1%
(no sleptons, charginos, or heavy neutralinos)

Measured by astrophysical experiments: $\sigma_{\chi N}$=9.6 10^{-9} pb x/÷ 2,
$R_\nu < 10\ yr^{-1}$, $\sigma_{\gamma\gamma+\gamma Z} / \sigma_{tot} < 10^{-5}$

Studying SUSY with the LHC and Astrophysics

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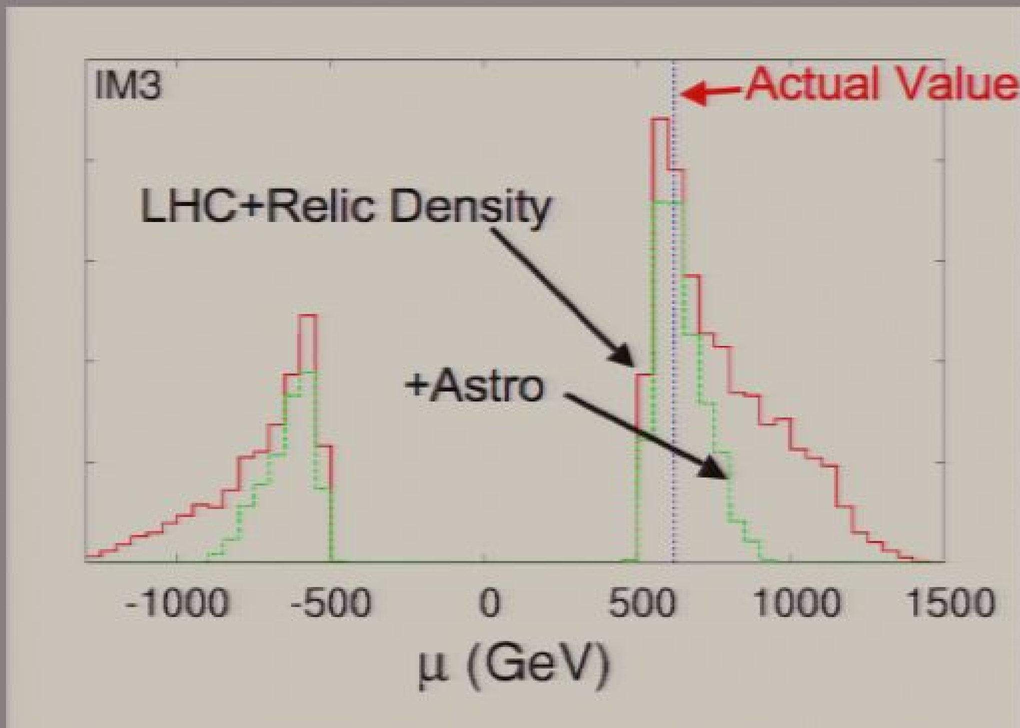

Hooper and A. Taylor, hep-ph/0607086

Studying SUSY with the LHC and Astrophysics

Benchmark model IM1:

SUSY Inputs: M_2=551 GeV, μ=1318 GeV, m_A=580 GeV, $\tan\beta$=6.8, 2240 GeV squarks

Measured by the LHC: $m_\chi = 276 \pm 10\%$, $m_{squark} = 2240 \pm 30\%$, (no sleptons, charginos, heavy neutralinos, heavy Higgs bosons or $\tan\beta$)

Measured by astrophysical experiments: $\sigma_{\chi N} < 10^{-10}$ pb, $R_\nu < 10\ \mathrm{yr}^{-1}$, $\sigma_{\gamma\gamma+\gamma Z} / \sigma_{tot} < 10^{-4}$ to 10^{-6}

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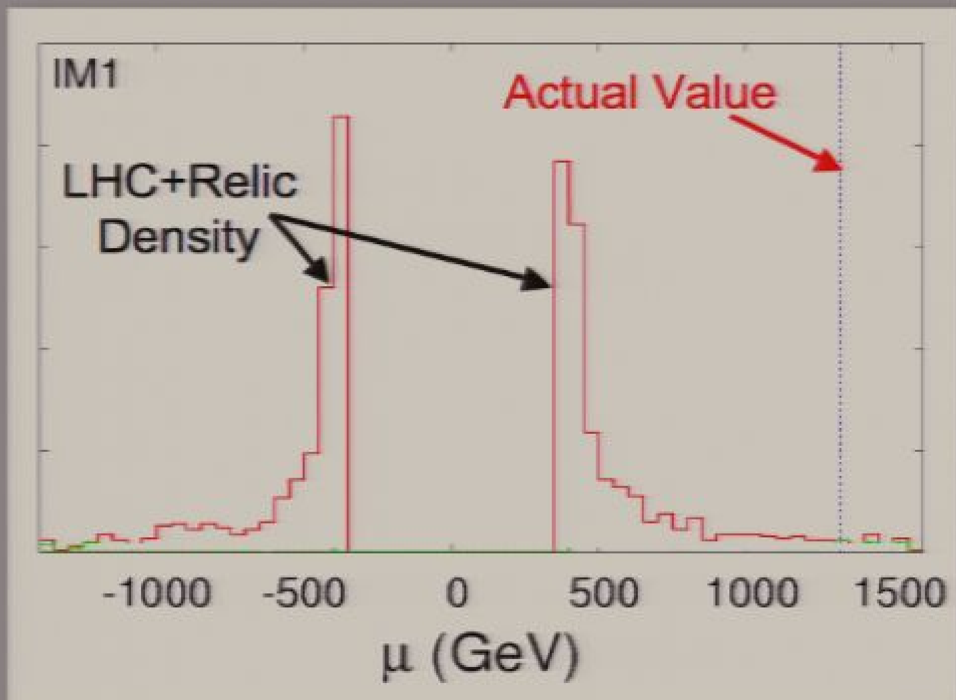

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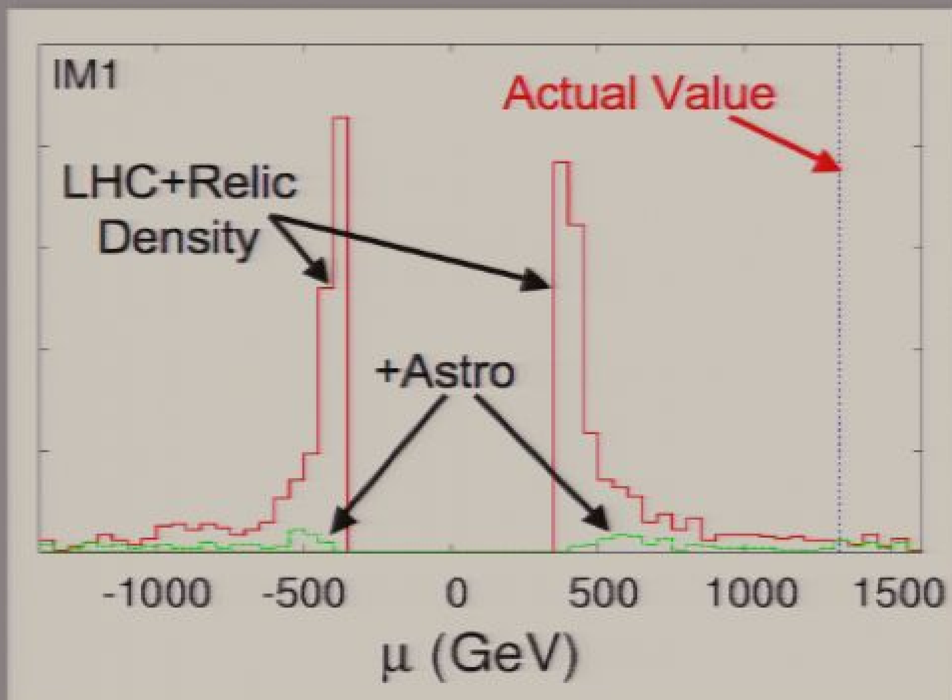

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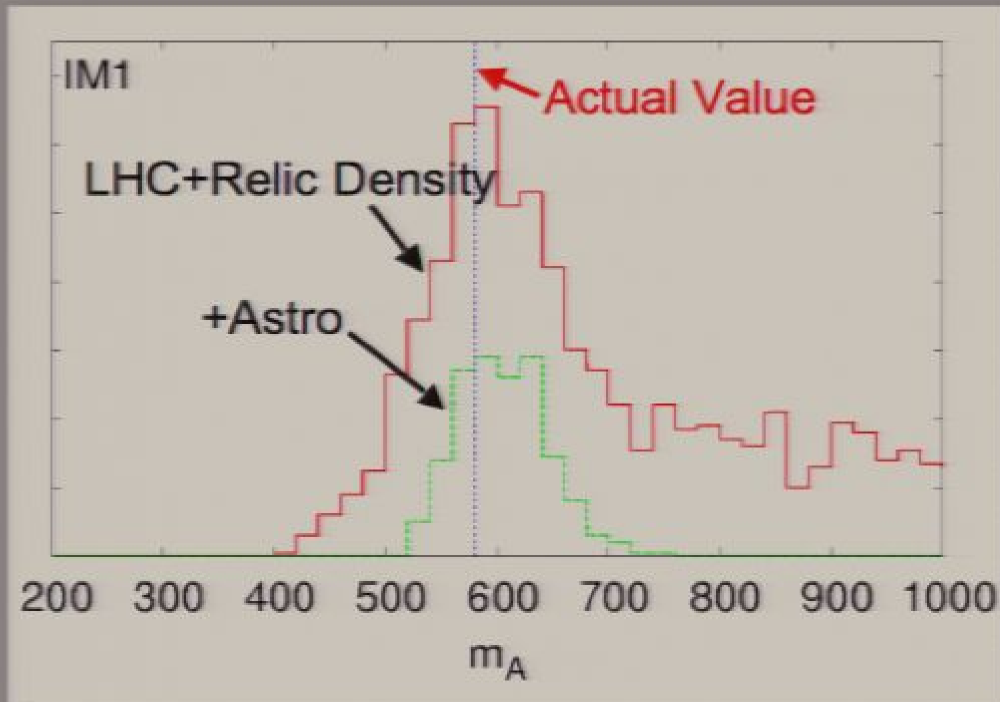


Hooper and A. Taylor, hep-ph/0607086

Is It SUSY?

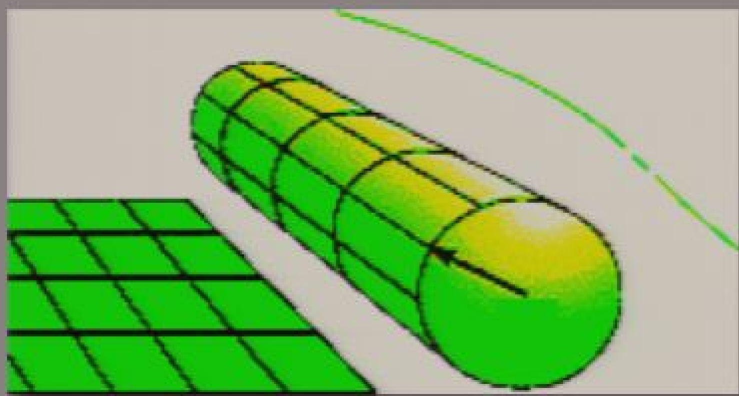
- Thus far, we have assumed that the new particles seen at the Tevatron/LHC and in dark matter experiments are superpartners of SM particles

- Several alternatives to supersymmetry have been proposed which may effectively mimic the signatures of supersymmetry at the LHC

Is It SUSY?

Universal Extra Dimensions (UED)

- All SM particles allowed to travel around extra dimension(s) with size ~TeV^{-1}
- Particles moving around extra dimensions appear as heavy versions of SM particles (Kaluza-Klein modes)
- The lightest Kaluza-Klein particle can be stable, weakly interacting and a suitable candidate for dark matter
- Can we distinguish Kaluza-Klein modes from superpartners?

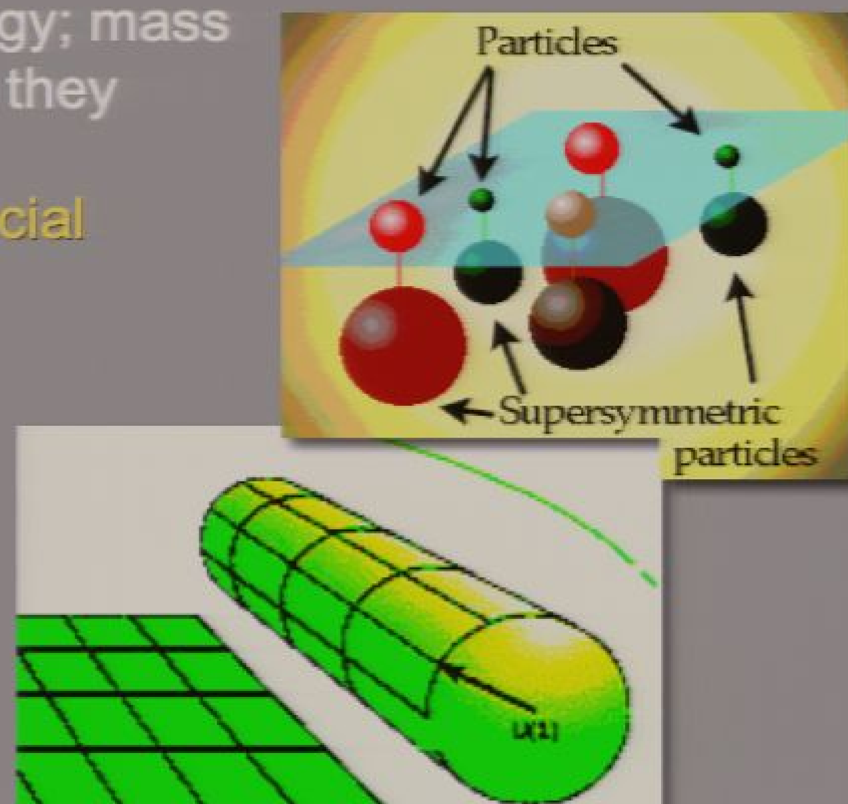


Is It SUSY?

Discriminating Supersymmetry and UED at the LHC

•Squarks and gluinos or KK quarks and KK gluons cascade to combinations of jets, leptons and missing energy; mass measurements possible, but are they sparticles or KK states?

⇒ Spin-determination crucial

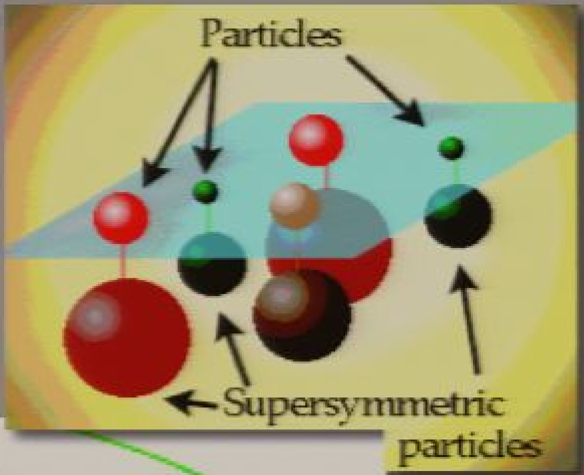


Is It SUSY?

Discriminating Supersymmetry and UED at the LHC

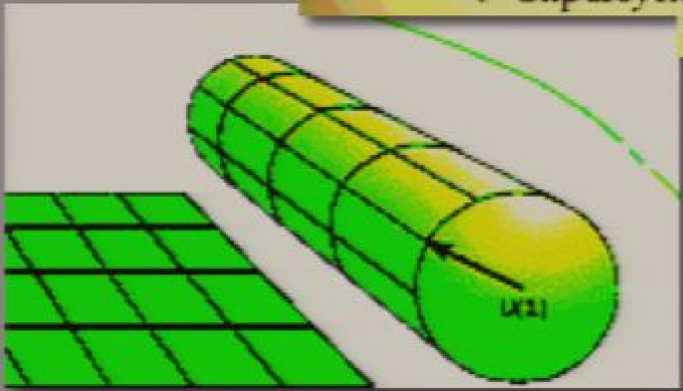
- Recent literature on SUSY/UED discrimination:

  (see Cheng, Matchev, Schmaltz; Datta, Kong, Matchev; Datta, Kane, Toharia; Alves, Eboli, Plehn; Athanasiou, Lester, Smilie, Webber)



- In the case of somewhat heavy masses or quasi-degenerate spectra, spin determination becomes very challenging/impossible

- The observation of 2nd level KK modes would bolster case for UED, but could be confused with a Z prime, for example



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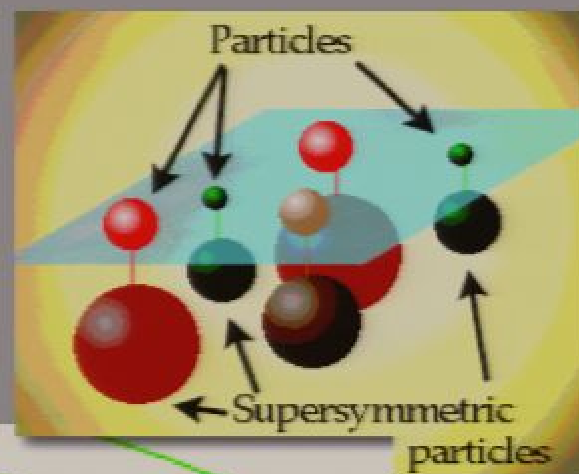
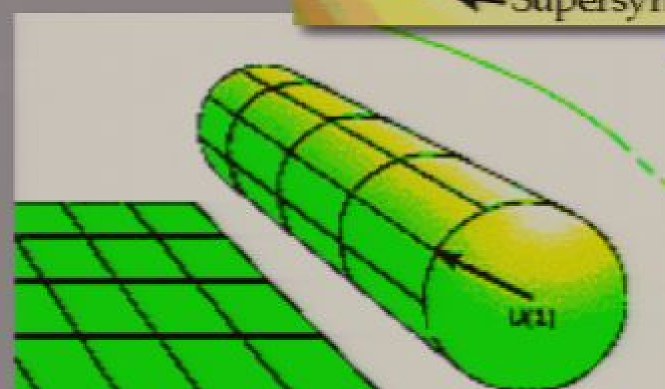
Discriminating Supersymmetry and UED with Dark Matter

- Kalzua-Klein dark matter (KK 'photon', $B^{(1)}$) annihilates primarily to charged leptons pairs (20-25% to each of e^+e^-, $\mu^+\mu^-$ and $\tau^+\tau^-$)

- Neutarlino annihilations to light fermions, in contrast, are chirality suppressed
  ($\sigma v \; \alpha \; [m_f/m_\chi]^2$)

- This difference can lead to very distinctive signatures in indirect dark matter experiments





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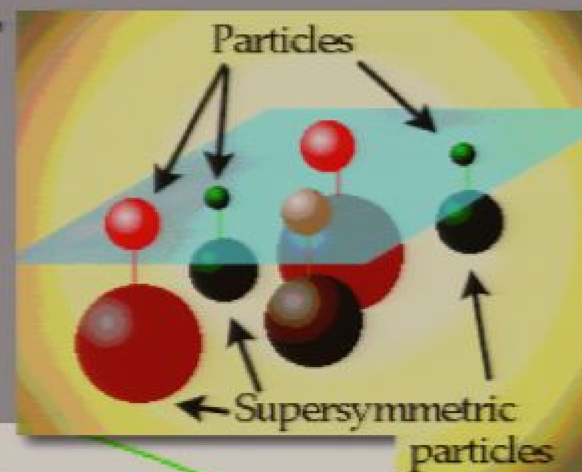

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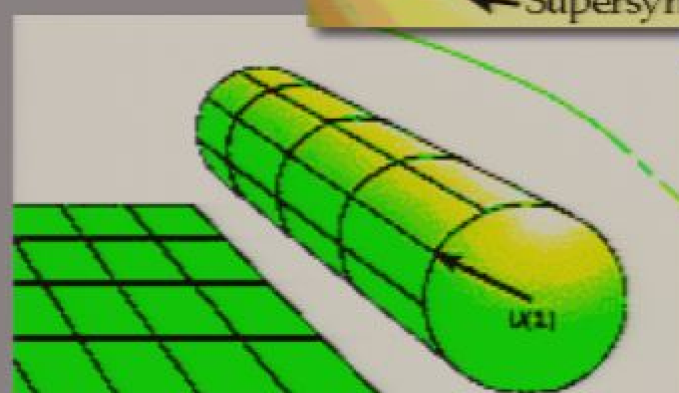

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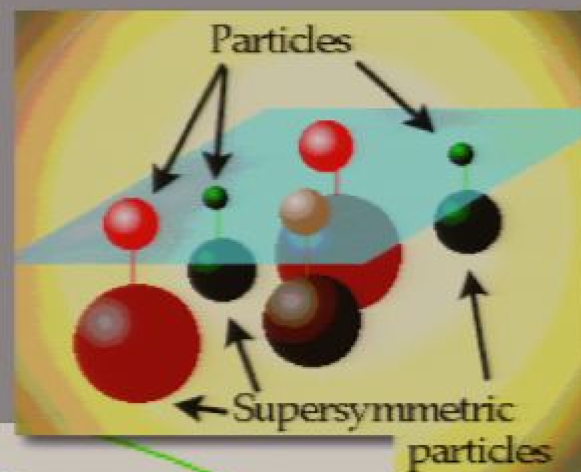
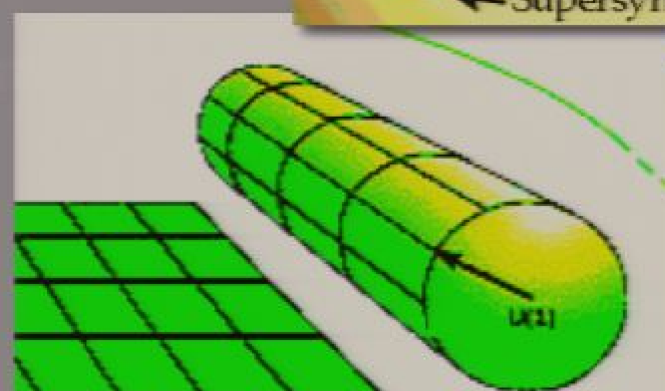
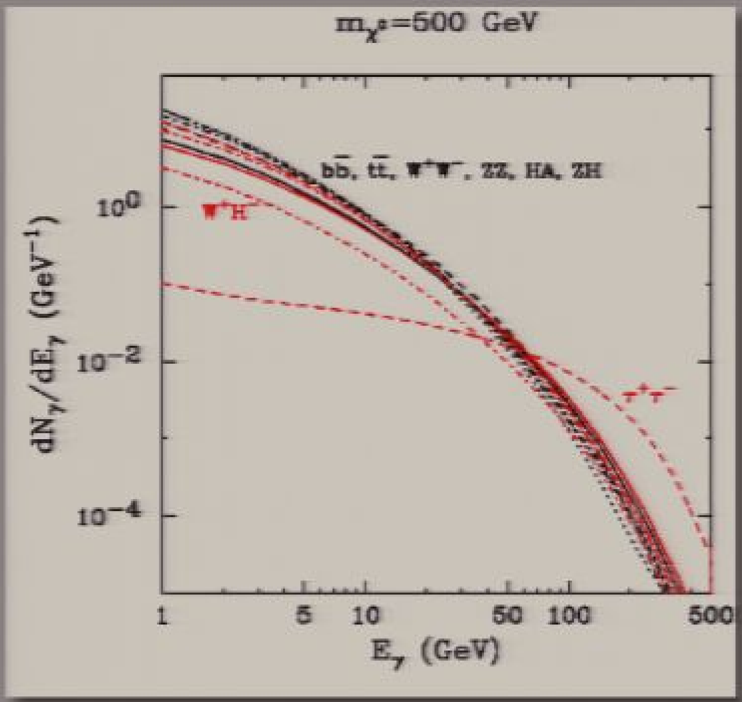




Is It SUSY?

The Gamma-Ray Annihilation Spectrum

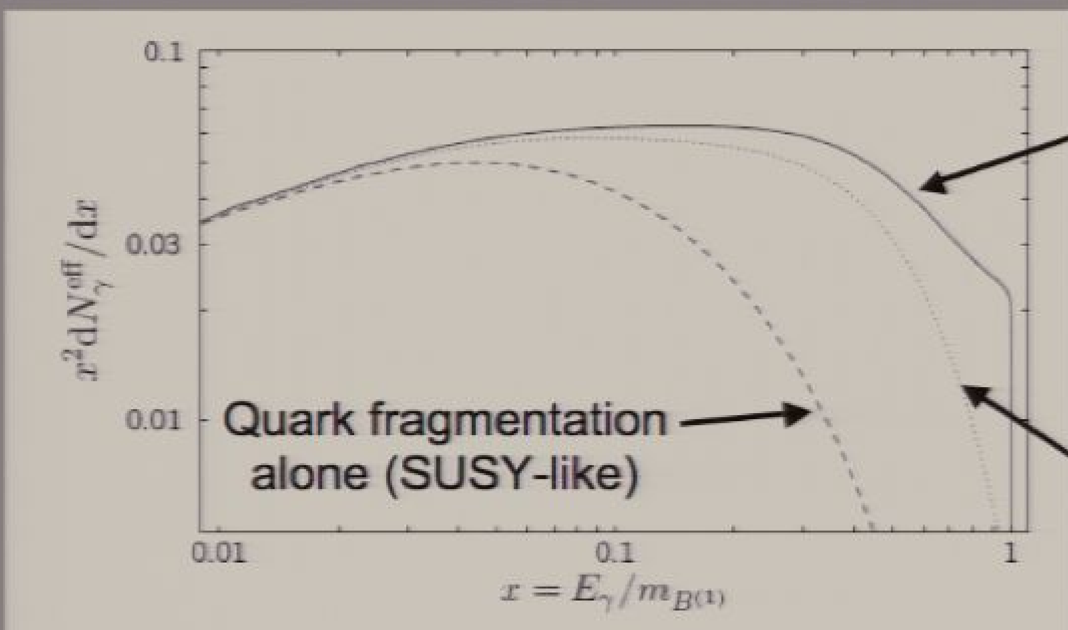
Neutralino annihilations to gauge/Higgs bosons and heavy quarks produce rather soft gamma-ray spectrum



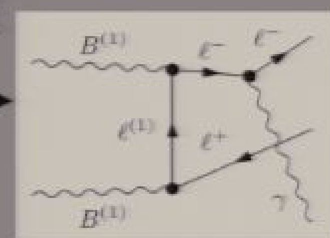
Is It SUSY?

The Gamma-Ray Annihilation Spectrum

Kaluza-Klein dark matter particles produce harder spectrum due to 20-25% annihilation to tau pairs, and final state radiation



Total, including τ's and FSR

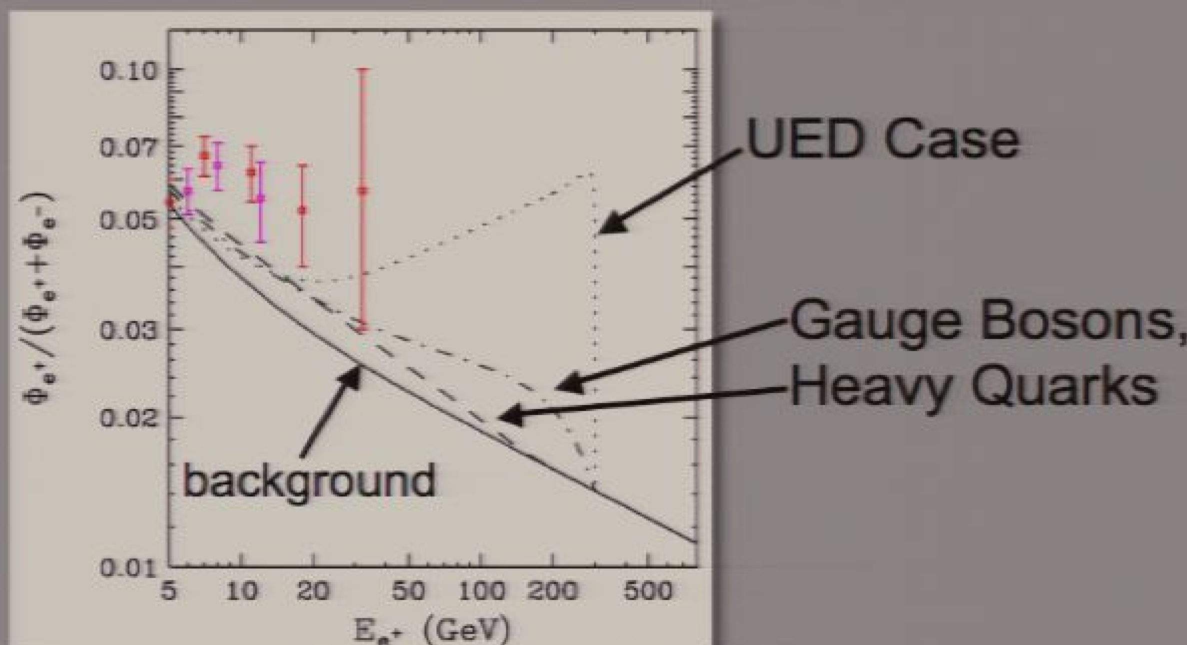


Including τ's

Is It SUSY?

The Cosmic Positron Spectrum

Annihilations to e^+e^- (and $\mu^+\mu^-$, $\tau^+\tau^-$) generate distinctive hard spectrum with edge



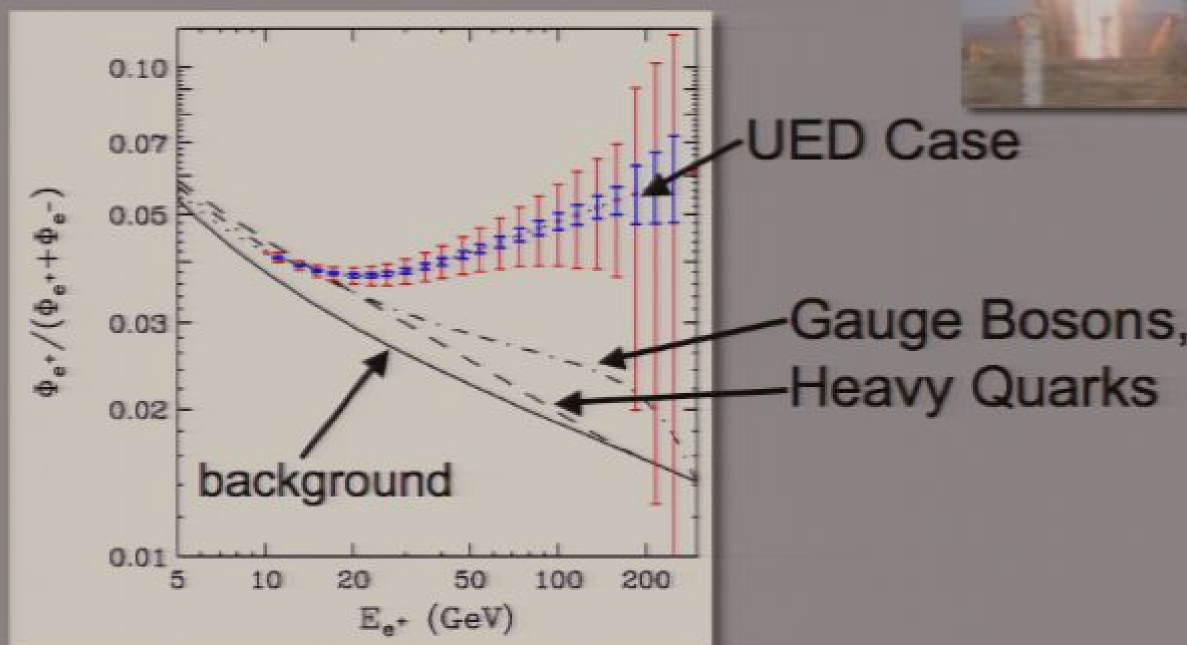
(m_{DM}=300 GeV, BF=5, moderate propagation)

Is It SUSY?

Pamela

The Cosmic Positron Spectrum

Clearly identifiable by future experiments (Pamela, AMS-02) for light/moderate masses



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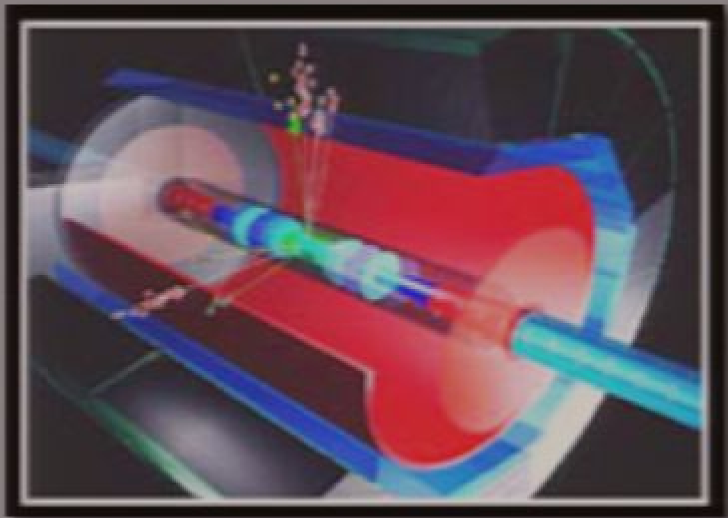
Supersymmetry in the ILC Era

- Combined with LHC data, likely able to measure much/most/all of the sparticle and Higgs masses

- With such knowledge of the particle spectrum, it may become possible to accurately calculate the expected relic abundance of neutralinos, and compare this to the observed dark matter density



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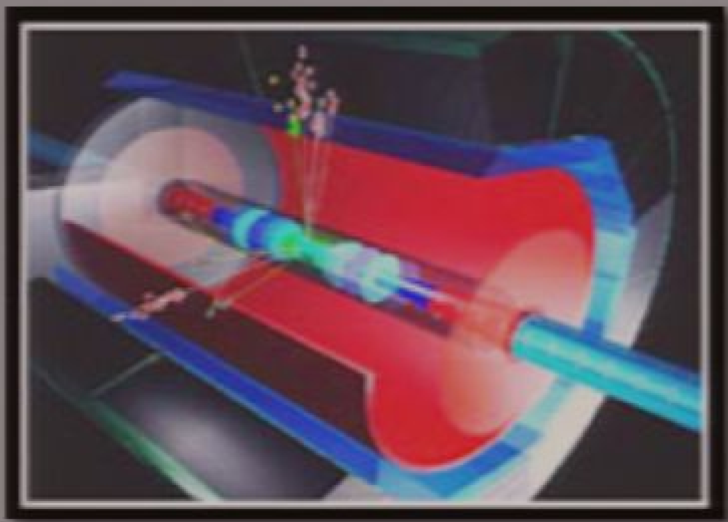
⇒ Confirmation that neutralinos make up the dark matter of our universe!

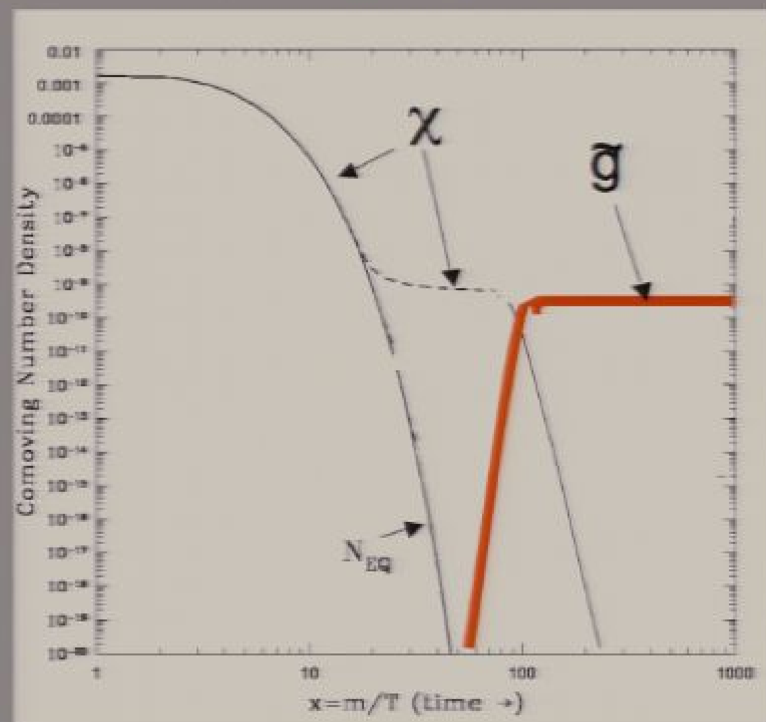


But what if they don't match?

Supersymmetry in the ILC Era

What if the calculated abundance doesn't match astrophysical observations?

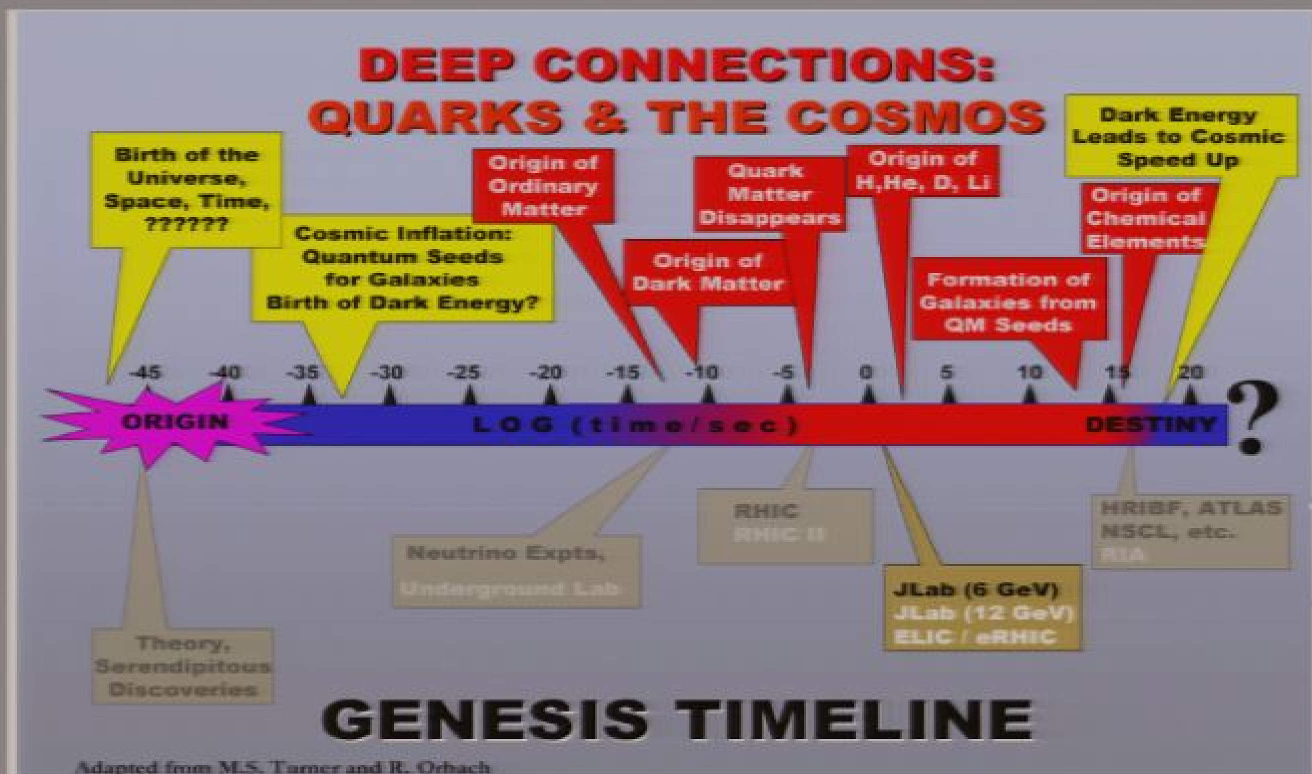
- SuperWIMP Scenario: neutralinos freeze-out, and later decay to gravitinos
- Non-WIMP dark matter generated through WIMP-like freeze-out process
- No signal for direct or indirect detection

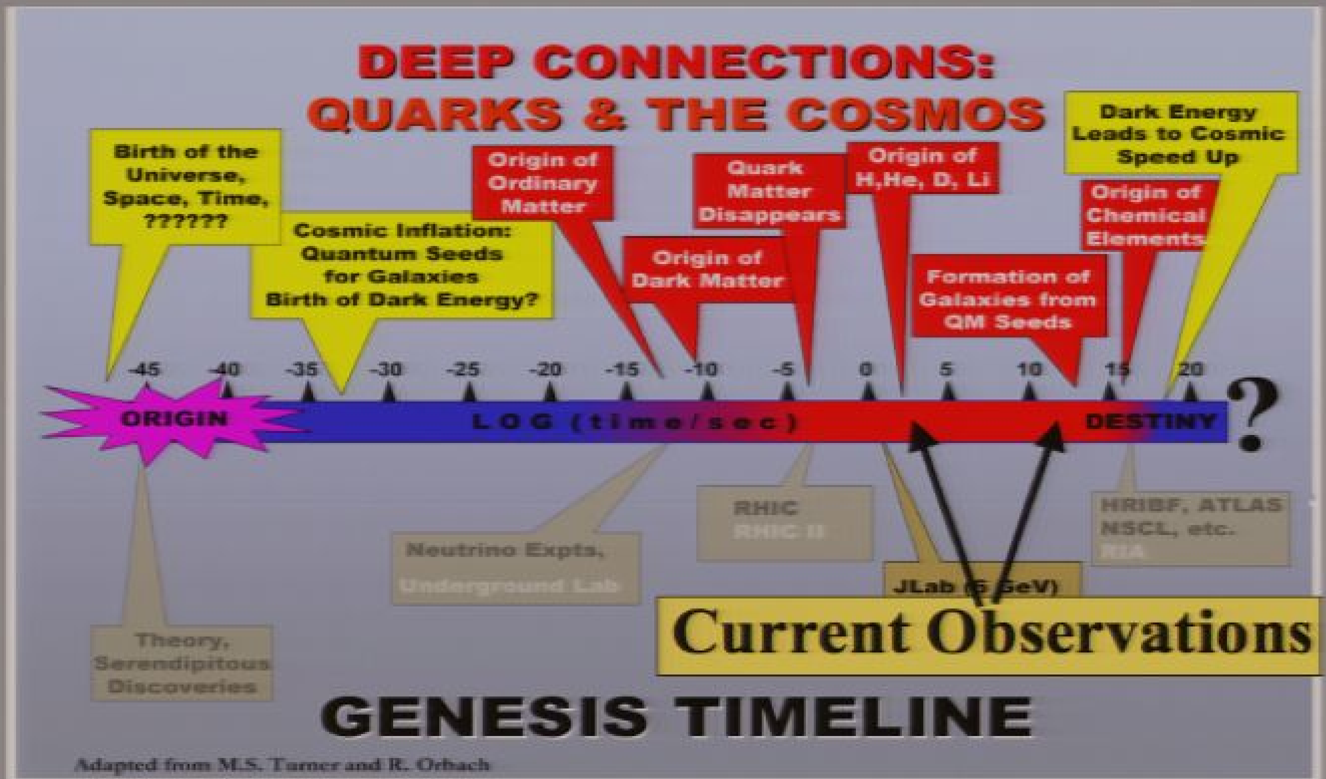


Supersymmetry in the ILC Era

What if the calculated abundance doesn't match astrophysical observations?

- Relic abundance calculation assumes standard cosmological picture
- Non-standard cosmology/expansion history can lead to very different relic abundance


DEEP CONNECTIONS:
QUARKS & THE COSMOS
Birth of the Universe, Space, Time, ??????
Cosmic Inflation: Quantum Seeds for Galaxies Birth of Dark Energy?
Origin of Ordinary Matter
Origin of Dark Matter
Quark Matter Disappears
Origin of H,He, D, Li
Formation of Galaxies from QM Seeds
Dark Energy Leads to Cosmic Speed Up
Origin of Chemical Elements
-45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20
ORIGIN
LOG (time/sec)
DESTINY
?
Theory, Serendipitous Discoveries
Neutrino Expts, Underground Lab
RHIC
RHIC II
JLab (6 GeV)
JLab (12 GeV)
ELIC / eRHIC
HRIBF, ATLAS
NSCL, etc.
RIA
GENESIS TIMELINE
Adapted from M.S. Turner and R. Orbach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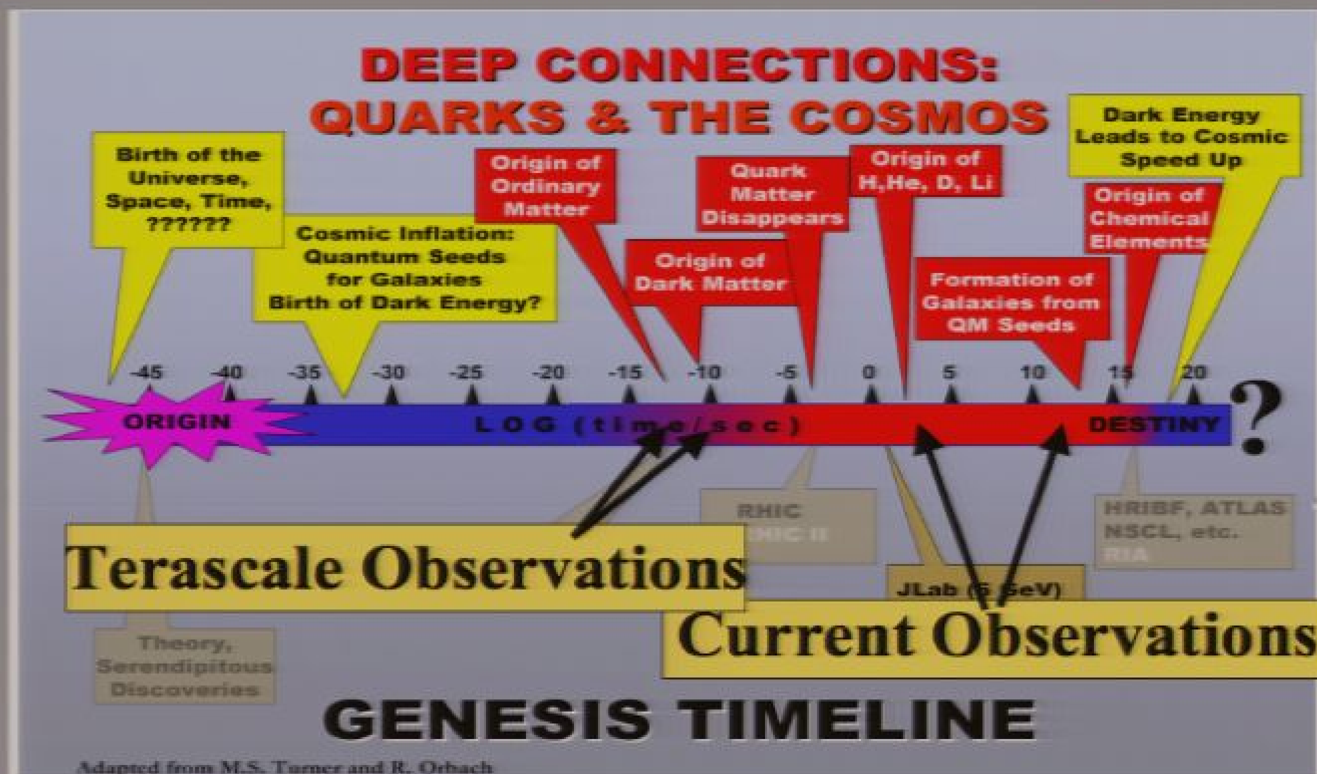
The ILC Is A Window Into The Early Universe!

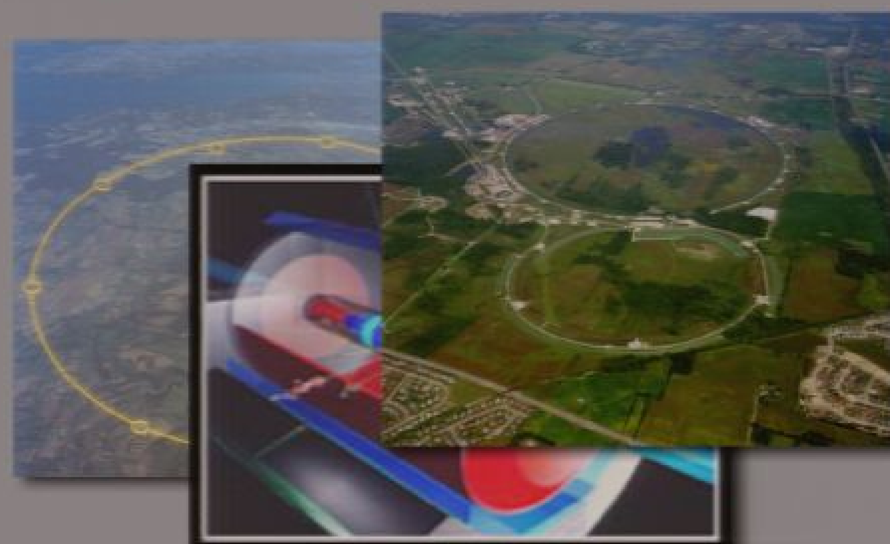


Summary

•If (low-scale) supersymmetry exists in nature, then the LHC is exceedingly likely to discover superpartners

•The sparticle spectrum measured by the LHC will be very incomplete unless most of the sparticles are very light

•To learn more about the SUSY spectrum with colliders, we may have to wait for the ILC

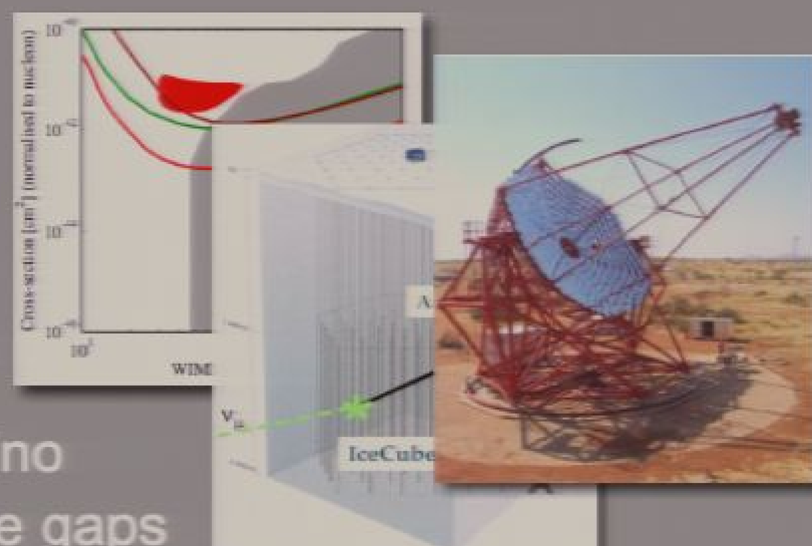


Summary

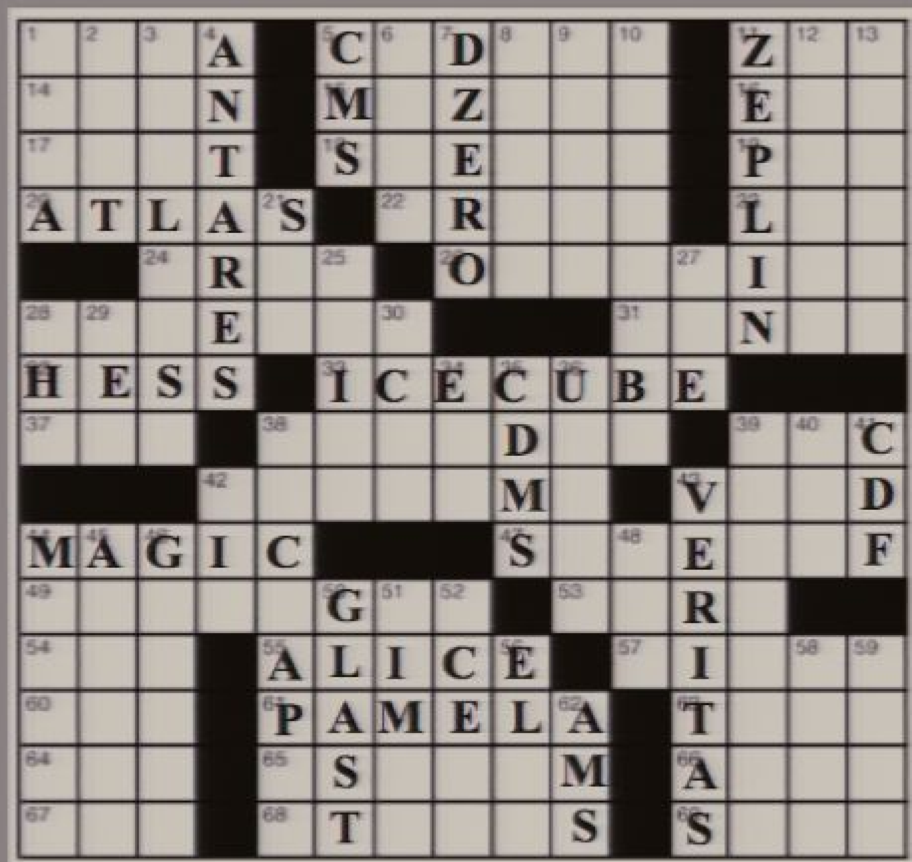
•Direct and indirect detection of dark matter can provide additional information on the couplings/composition of the lightest neutralino and masses of exchanged particles

•In many cases, dark matter measurements can break degeneracies between bulk/funnel/coannihilation regions of parameter space

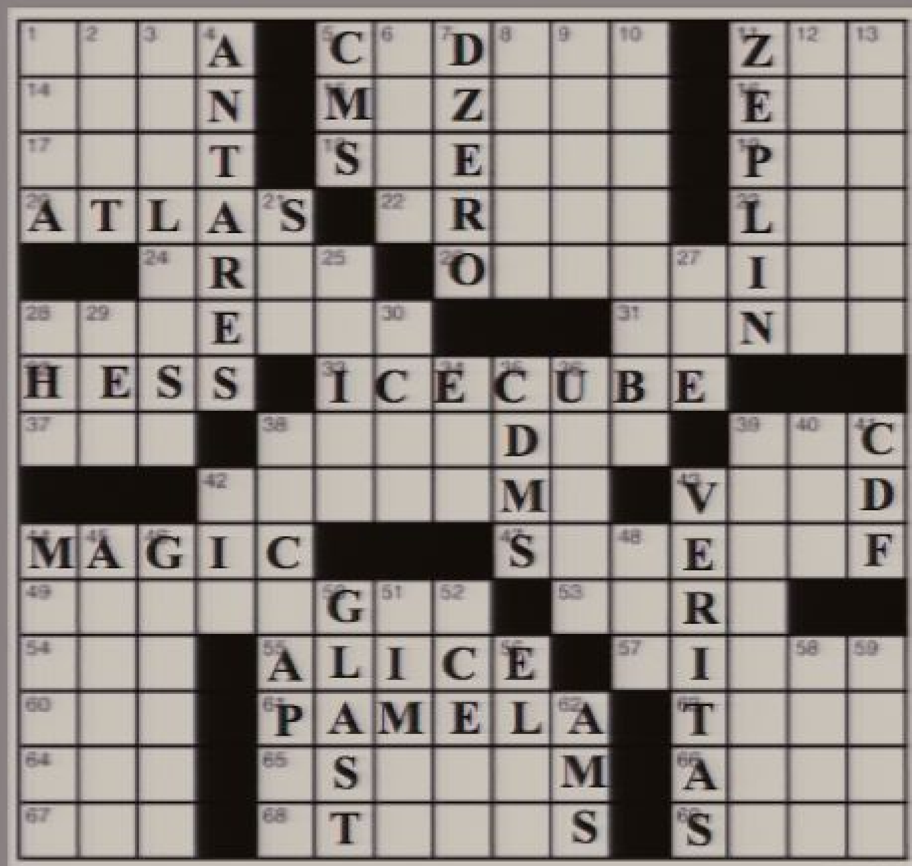
•For models in the A-funnel region of parameter space, m_A can often be determined by astrophysical measurements



•Astrophysical probes of neutralino dark matter can fill in some of the gaps in our post-LHC/pre-ILC understanding of supersymmetry



Let's use all of the tools we have to solve the puzzles of the terascale!



Let's use all of the tools we have to solve the puzzles of the terascale!