Hunting SUSY: Dark Matter at the LHC

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1. Introduction
   - Evidence for Dark Matter
   - Calculating the Density
   - Dark Matter and the LHC
2. SUSY Dark Matter
   - SUSY at the LHC
3. EW Scale MSSM Parameters
4. GUT Scale Parameters
5. Conclusions and open questions

Evidence for Dark Matter

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- The Cosmic Microwave Background

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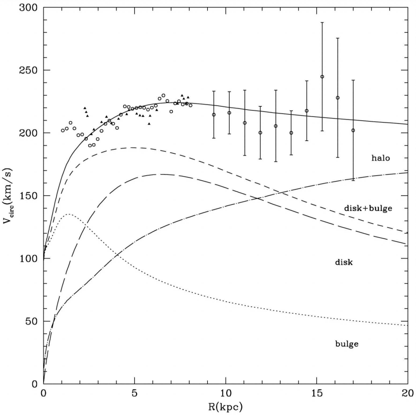
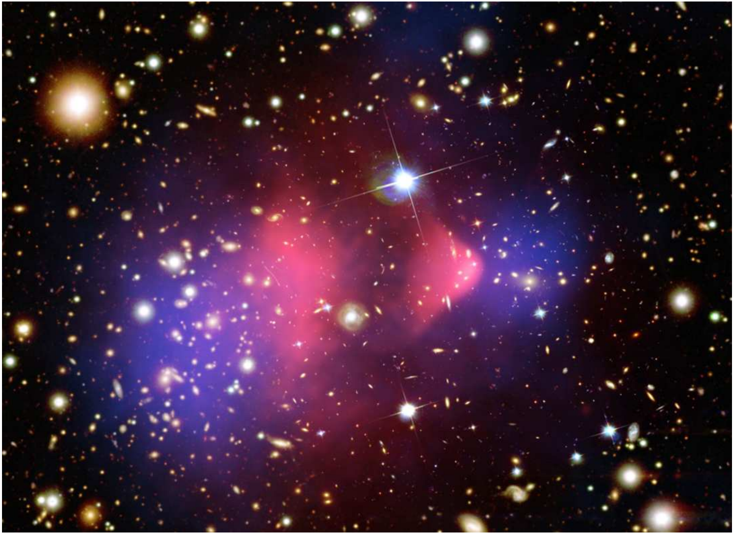


(From Klypin, Zhao and Somerville, 2002)

Lensing: Dark Matter in the Bullet Cluster



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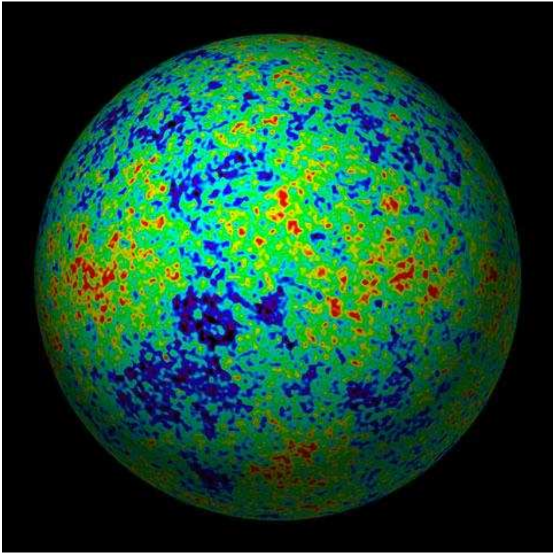

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In contrast, the density of baryonic matter is measured as:

$$\Omega_b h^2 = 0.0224$$

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- As the universe cools, the dark matter falls out of equilibrium.
- It's annihilation rate during this time determines the resulting relic abundance.
- The relic density can be approximated as:

$$\Omega_{CDM} h^2 \approx \frac{3 \times 10^{-27} \mathrm{cm}^3 \mathrm{s}^{-1}}{< \sigma v >}$$

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Therefore the LHC should be a dark matter factory.

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Dark matter allows us to differentiate theories with the same mass spectrum.

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3. What precision does this then give for the relic density calculation?

Candidates

- Neutralinos
- Kaluza-Klein excitations
- Massive neutrinos
- Axions
- Sneutrinos
- Axinos
- Gravitinos
- Q-balls
- Mirror particles
- WIMPZILLAS
- Shadow world matter
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- ... but here we stick to candidates from Supersymmetry.

The MSSM Particle Spectrum

Standard Model

quarks q

leptons l

gauge bosons $A_\mu^{(a)}$

Higgs boson H

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Standard Model		**Superpartners**
quarks q	$\longleftrightarrow$	squarks $\tilde{q}$
leptons l	$\longleftrightarrow$	sleptons $\tilde{l}$
gauge bosons $A_\mu^{(a)}$	$\longleftrightarrow$	gauginos $\lambda^{(a)}$
Higgs bosons H	$\longleftrightarrow$	higgsinos $\tilde{h}$

R-parity

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Under R-parity, Standard Model and supersymmetric matter have the following assignments:

Standard Model:	$P_R = 1$
SUSY:	$P_R = -1$

The Lightest Supersymmetric Particle

Due to R-parity, decays of the form:

$$\textbf{sparticle} \rightarrow \textbf{particle} + \textbf{particle}$$

are not allowed.

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R-parity conserving supersymmetry requires a relic density of sparticles.

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Providing a candidate is not enough. It must occur in the right abundance.

Bino annihilation

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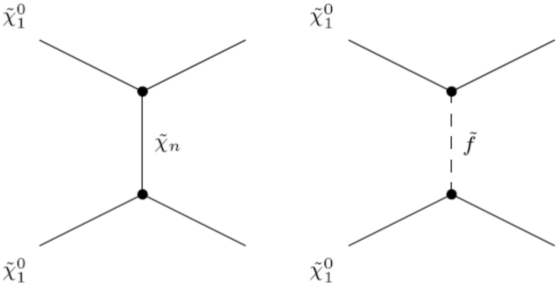

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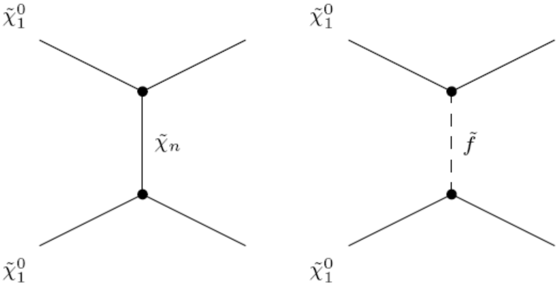

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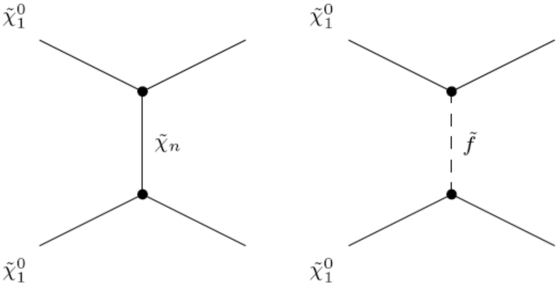

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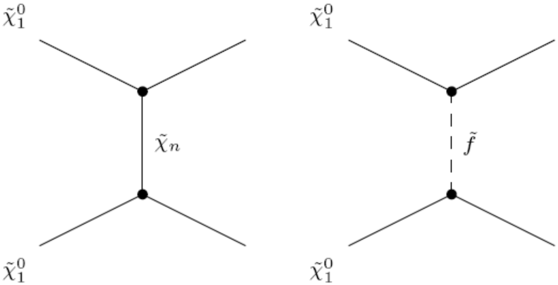

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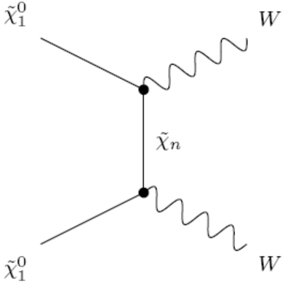

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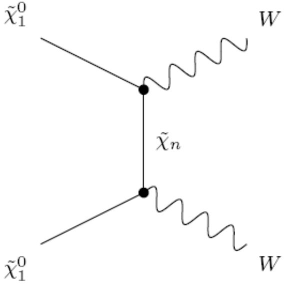

In general such processes are extremely efficient resulting in $\Omega_{CDM} h^2 \ll \Omega_{CDM}^{WMAP} h^2$.

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Therefore SUSY naturally gives the wrong dark matter density!

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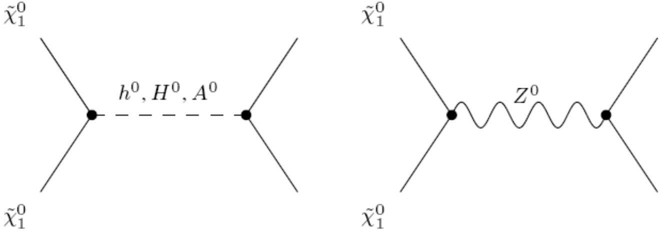

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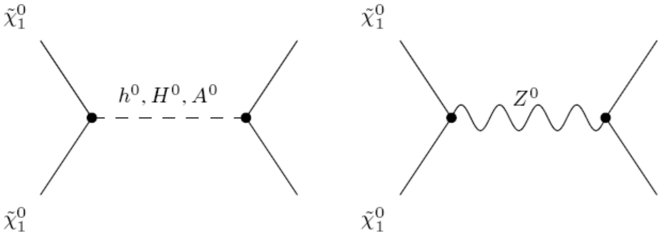

In this case, annihilation is usually **too efficient**: $\Omega_{CDM} h^2 \ll \Omega_{CDM}^{WMAP} h^2$ except on the edges of the resonance.

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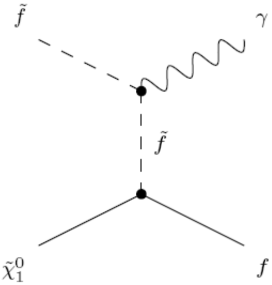
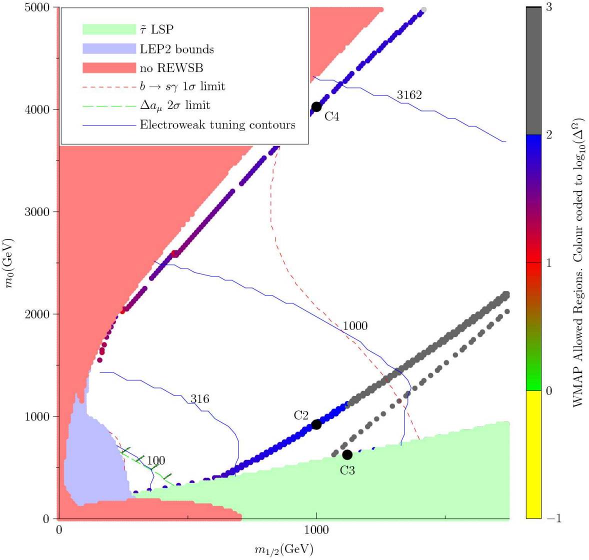


An example - the CMSSM parameter space



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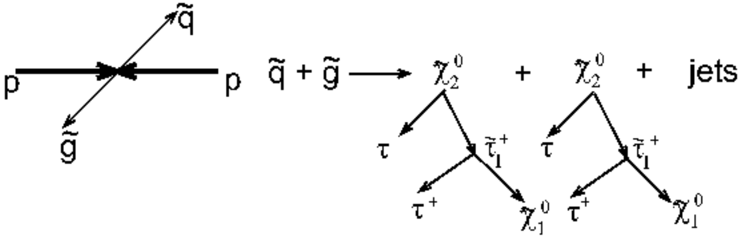

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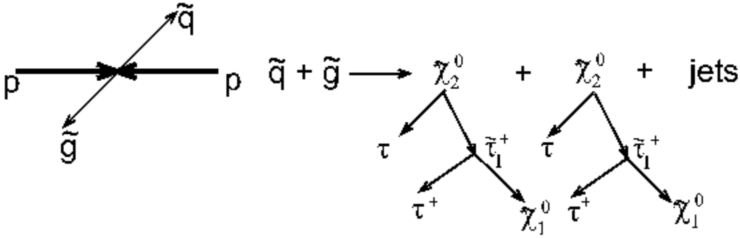

The neutralino will be seen as missing energy.

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The other parameters determine the rest of the spectrum and therefore, much of the LHC phenomenology.

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With these tools we can quantify the sensitivity of $\Omega_{CDM} h^2$ to SUSY inputs.

t-channel sfermion exchange

For a typical Bino dark matter region, the sensitivity to low energy masses is:

Parameter a	Δ_a^Ω
$m_{\tilde{\tau},\tilde{e}_R,\tilde{\mu}_R}$	0.6
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A caveat: here we only consider sensitivity to the masses, not the compositions. This decay channel cares about the composition of the lightest $\tilde{\tau}$, $\tilde{\mu}_R$ and $\tilde{e}_R$.

Resonant annihilation

Now consider a typical A^0 resonance.

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Therefore to calculate the relic density with a precision of $\mathcal{O}(1\%)$, we would need to know the mass of the A^0 and $\tilde{\chi}_1^0$ to $\mathcal{O}(0.02\%)$.

$\tilde{\chi}_1^0 - \tilde{\tau}$ Coannihilation

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Once again we need $\mathcal{O}(0.02\%)$ precision to achieve a $\mathcal{O}(1\%)$ precision in $\Omega_{CDM}h^2$.

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Can the LHC(ILC) achieve the precision required to compete with WMAP in these regions?

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In terms of the low energy MSSM:

- Study the LHC phenomenology in the WMAP regions to assess the LHC precision and understand the important signals.