SUSY and the Cosmic Connection

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In collaboration with:

J. Feng and F. Wilczek   Phys. Lett. B482, 388 (2000)
Phys. Rev. D63, 045024 (2001)

Arlington Linear Collider Workshop,
University of Texas at Arlington,
January 9, 2003

Brief Outline

- The Large Hadron Collider at CERN will establish a new energy frontier (2006?).

  How do we probe the energy frontier prior to the LHC?

- The new energy frontier is set by physics beyond the SM
  - Low Energy Supersymmetry (SUSY)
    - grand unification
    - hierarchy problem
    - decoupling
    - light Higgs boson
    - dark matter
    - etc. etc.
- How far is the relevant scale of the new physics?
  - Naturalness $\Longrightarrow$ avoid fine-tuning
  - Cosmology $\Longrightarrow$ good dark matter candidate
  - Grand unification
- How do we find it experimentally?
  - Direct searches for superpartners (Tevatron)
  - Indirect hints from low-energy precision experiments
  - Dark matter searches

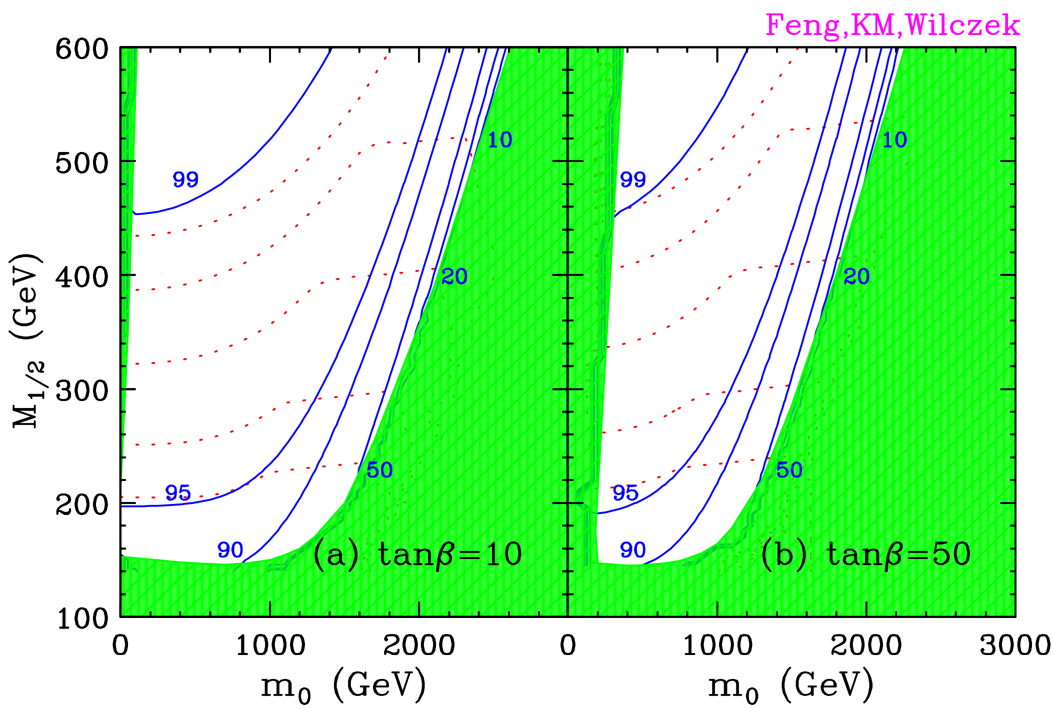
Gaugino fraction of the LSP WIMP

- 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:

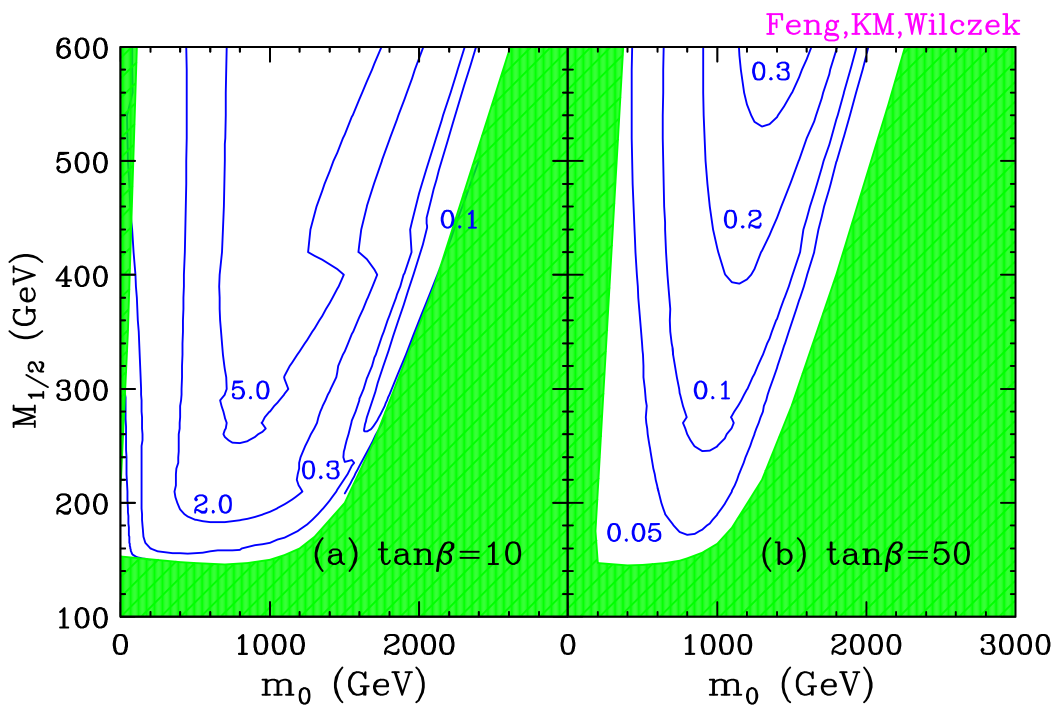
$$R_\chi \equiv |a_1|^2 + |a_2|^2.$$

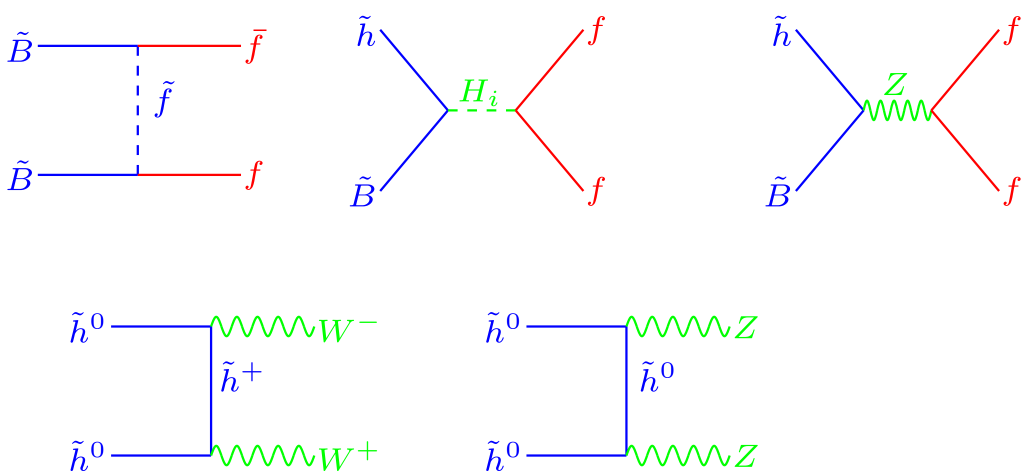


- The focus point region exhibits a mixed LSP.
- Pure higgsino LSP is already ruled out by LEP.

Relic abundance

- $\Omega_\chi h^2$ decreases again in the FP region!

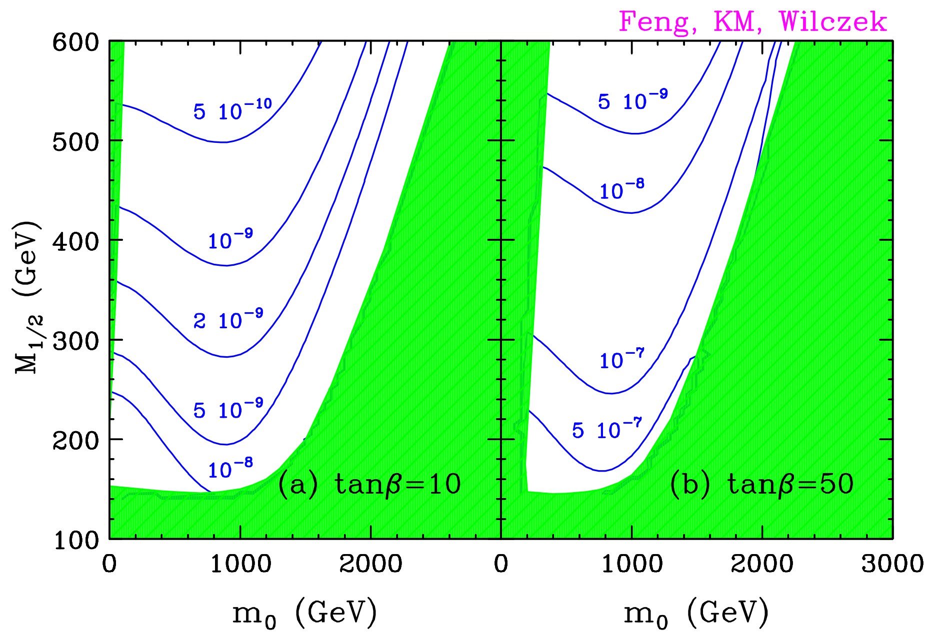


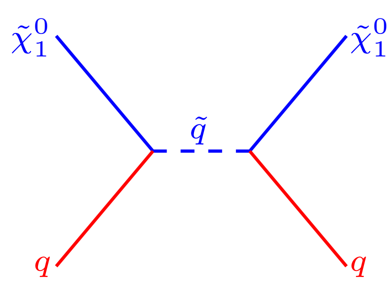


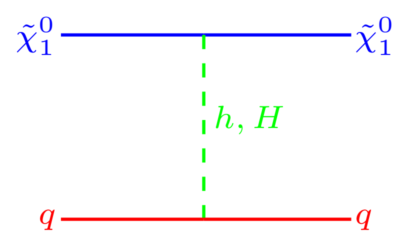
Direct detection

- Ongoing experiments test potentially interesting parts of parameter space:
  - DAMA: $\sigma_P \sim 10^{-6} - 10^{-5}$ pb, $30 < m_{\tilde{\chi}_1^0} < 200$ GeV.
  - CDMS, EDELWEISS: negative result.
- Major uncertainty from the nucleon matrix element

$$f_{T_s} \equiv \langle N | m_s \bar{s} s | N \rangle / m_N, \qquad 0.08 - 0.14 - 0.62.$$







Indirect Detection: Neutrinos

- Neutralinos accumulate at the center of the Earth/Sun $\Longrightarrow$ annihilate $\Longrightarrow$ secondary neutrinos escape $\Longrightarrow$ reach the surface of the Earth $\Longrightarrow$ interact in the rock/detector $\Longrightarrow$ convert into muons $\Longrightarrow$ detect Cherenkov light.
- Look in underground/underwater/under-ice neutrino telescopes for upward-going muon flux
- The Earth is closer, but the Sun is bigger...
- Neutralino density:

$$\dot{N} = C - AN^2$$

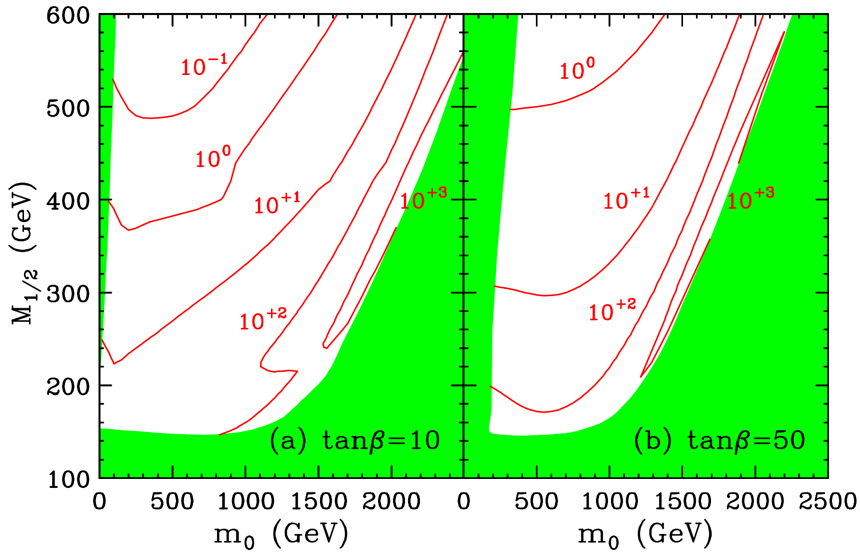
- Present neutralino annihilation rate:

$$\Gamma_A = \frac{1}{2}AN^2 = \frac{1}{2}C\tanh^2(\sqrt{CA}\,t_\odot).$$

Depends on the capture rate C and the "filling parameter" $\sqrt{CA}\,t_\odot$, the maximum being $\Gamma_A = C/2$.

- Typically $C_\odot/C_\oplus \sim 10^8 - 10^9$ $\Longrightarrow$ the Sun offers a more promising signal.

Muon Flux from the Sun



- The signal is enhanced in the focus point region

  Feng,KM,Wilczek (2000)

- Energy dependence
  - $\sigma(\nu_\mu \to \mu) \sim E_\nu$
  - Muon range $\sim E_\nu$
  - Rate $\sim E_\nu^2 \Longrightarrow$ determined by the hard component

of the neutrino energy spectrum

- $\chi\chi \to WW, ZZ$ followed by $W \to \ell\nu$ or $Z \to \nu\nu$ is

the best source of high-energy neutrinos.

- This requires a significant higgsino component.

Indirect Detection: Positrons

- Energetic positrons result from $\chi\chi \to WW, ZZ$. Again, this requires mixed gaugino-higgsino DM.
- Differential positron flux

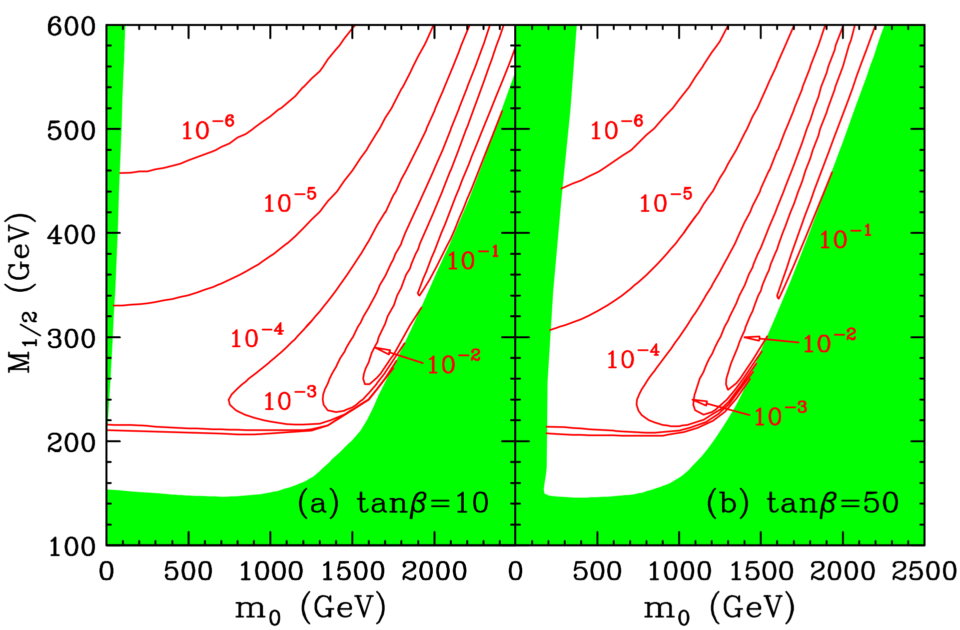
$$\frac{d\Phi_{e^+}}{d\Omega dE} = \frac{\rho_0^2}{m_\chi^2} \sum_i \sigma_i v B^i_{e^+} \int dE_0 \, f_i(E_0) \, G(E_0, E)$$

- Green function parameterization.

Moskalenko,Strong (1999)

- S/B at the optimal energy for positron signal.

Feng,KM,Wilczek (2000)

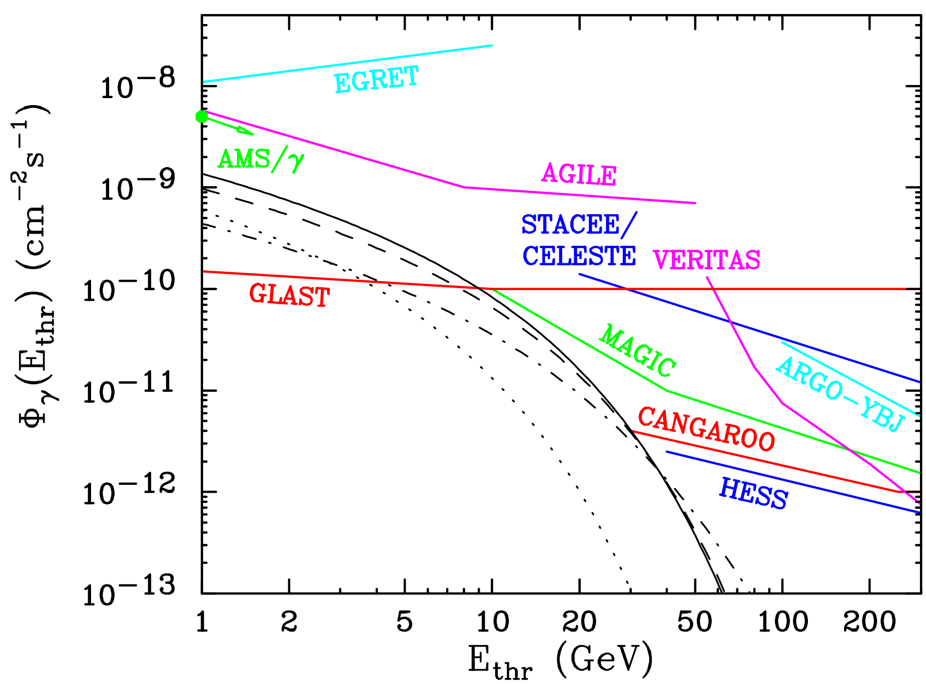


Indirect Detection: Photons

- Two possible signals
  - Line (primary γ's, monoenergetic, loop suppression)
  - Continuum (secondary γ's, spread out)
- Differential photon flux along a line of sight ψ

$$\frac{d\Phi_\gamma}{d\Omega dE} = \sum_i \frac{dN_\gamma^i}{dE} \sigma_i v \frac{1}{4\pi m_\chi^2} \int_\psi \rho^2 dl \ ,$$

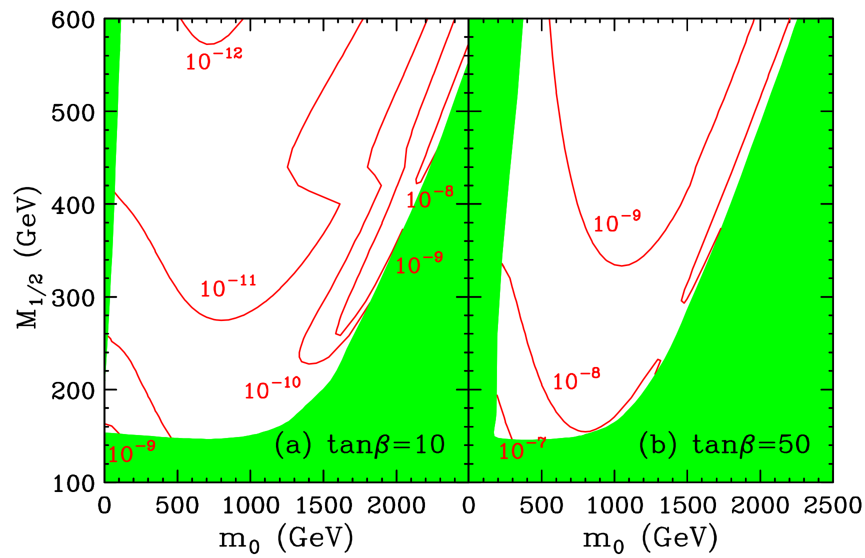
- Energy spectrum parameterized after Buckley et al. (1998)
- Photon flux sensitivities



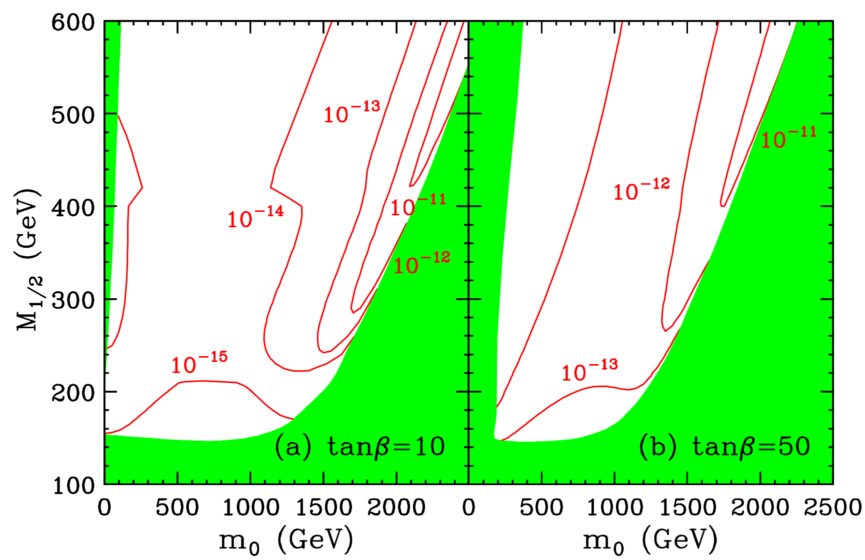
Signal Photon Flux ($\mathrm{cm}^{-1}\mathrm{s}^{-1}$)

Feng,KM,Wilczek (2000)

- $E_{thr} = 1$ GeV



- $E_{thr} = 50$ GeV



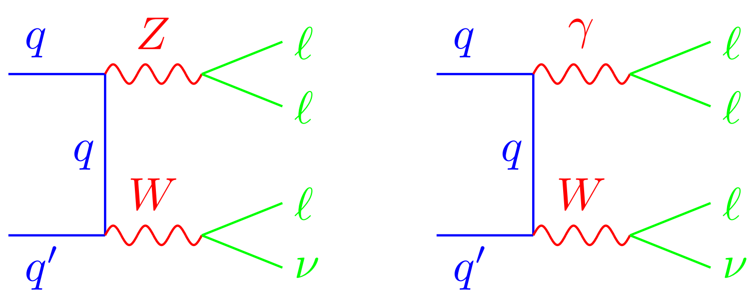
Trilepton Signal in Run II

KM,Pierce (1999)

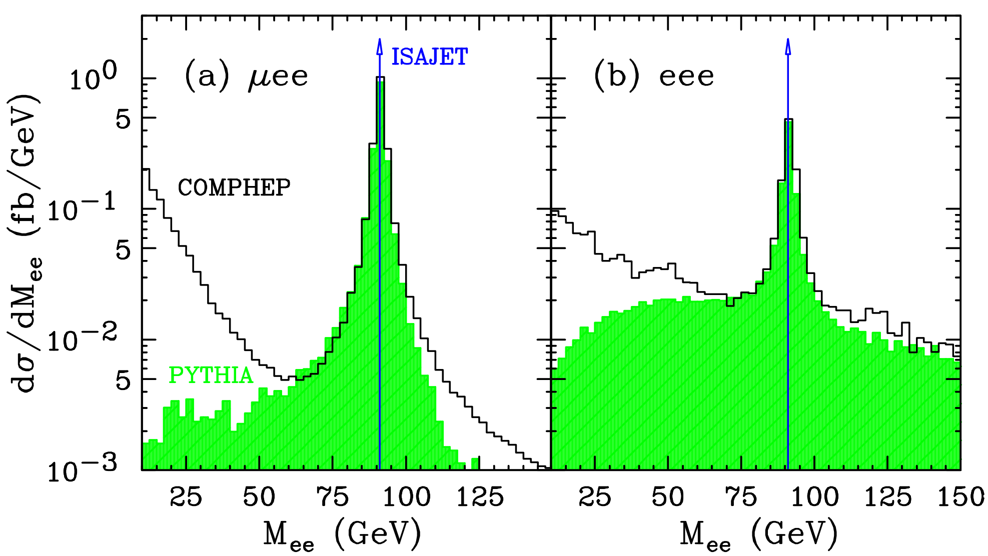
- "The gold-plated SUSY discovery mode" in Run II: $3\ell \not{E}_T$

$$p\bar{p} \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \to (\ell^+ \ell^- \tilde{\chi}_1^0)(\nu \ell' \tilde{\chi}_1^0)$$

- Main background: "WZ". It was underestimated by more than an order of magnitude.



- Dilepton invariant mass distribution



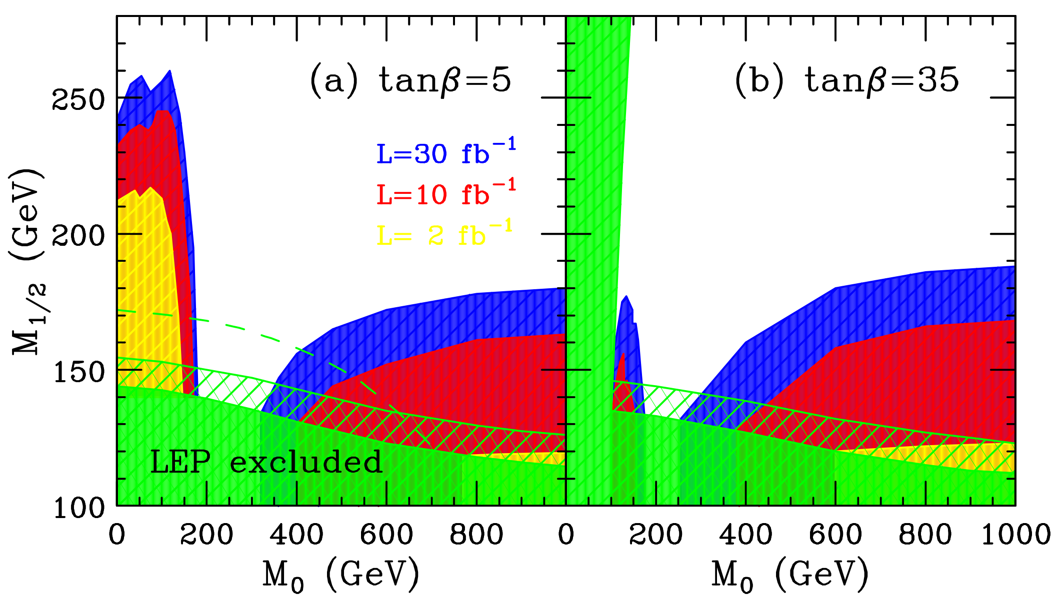
Tevatron Reach for Trileptons

- New cuts needed to be designed.

1. New low-dilepton mass cut (removes $W\gamma^*$).
2. New cut on the W transverse mass (removes $WZ, W\gamma^*$).

- New optimization scheme

1. Choose several values for each cut.
2. Form all possible combinations (thousands).
3. Select the one maximizing $S/\sqrt{B}$.
4. Repeat for every parameter space point.



Signatures with Tau Jets

Lykken,KM (1999)

- In generic models one often finds examples where

$$m_{\tilde{\chi}_1^0} < m_{\tilde{\tau}_1} < m_{\tilde{\chi}_1^+} \sim m_{\tilde{\chi}_2^0} < m_{\tilde{\mu}_R}.$$

and all three final state leptons are taus. Now what?

- Branching ratios:

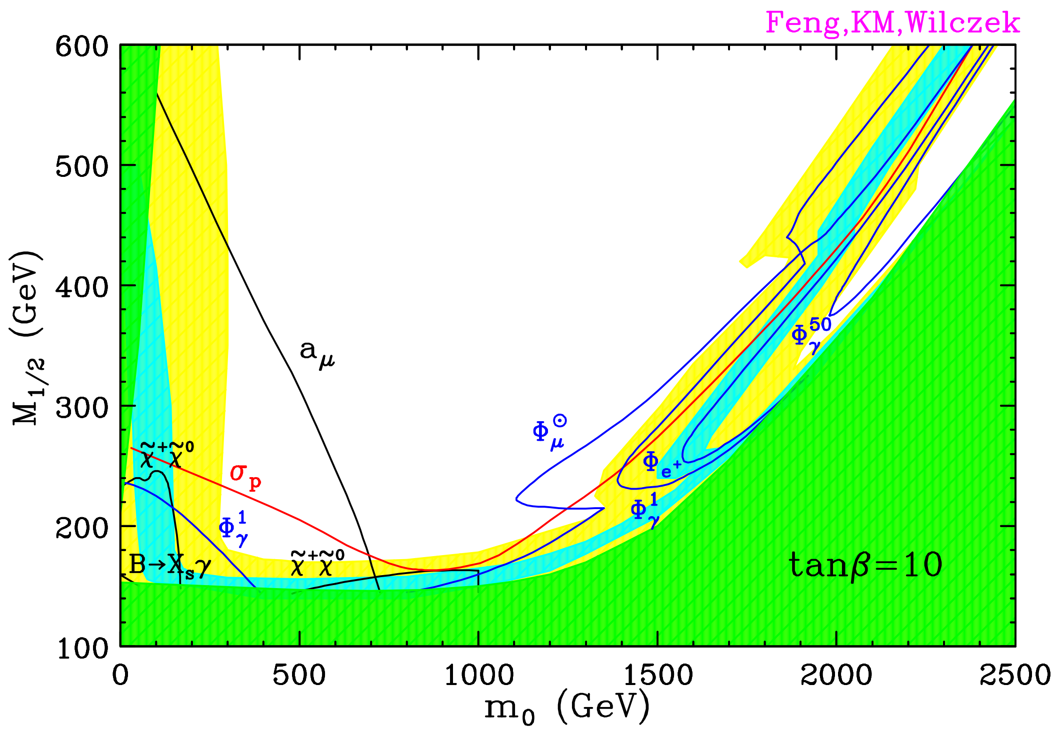
Experimental signature	Trilepton SUSY signal			
	$\tau\tau\tau$	$\tau\tau l$	$\tau l l$	lll
$\tau_h\tau_h\tau_h$	0.268	—	—	—
$l\tau_h\tau_h$	0.443	0.416	—	—
$ll\tau_h$	0.244	0.458	0.645	—
lll	0.045	0.126	0.355	1.00

- Other factors: tau ID efficiency, QCD fake rate for taus jets, lepton p_T spectrum, triggers $\Longrightarrow$ requires detailed modelling

- The tau channels win over the trilepton one. The best S/B is in $\ell^+\ell^+\tau$.

Putting It All Together: Small $\tan\beta$

- Combination of "all" pre-LHC experiments



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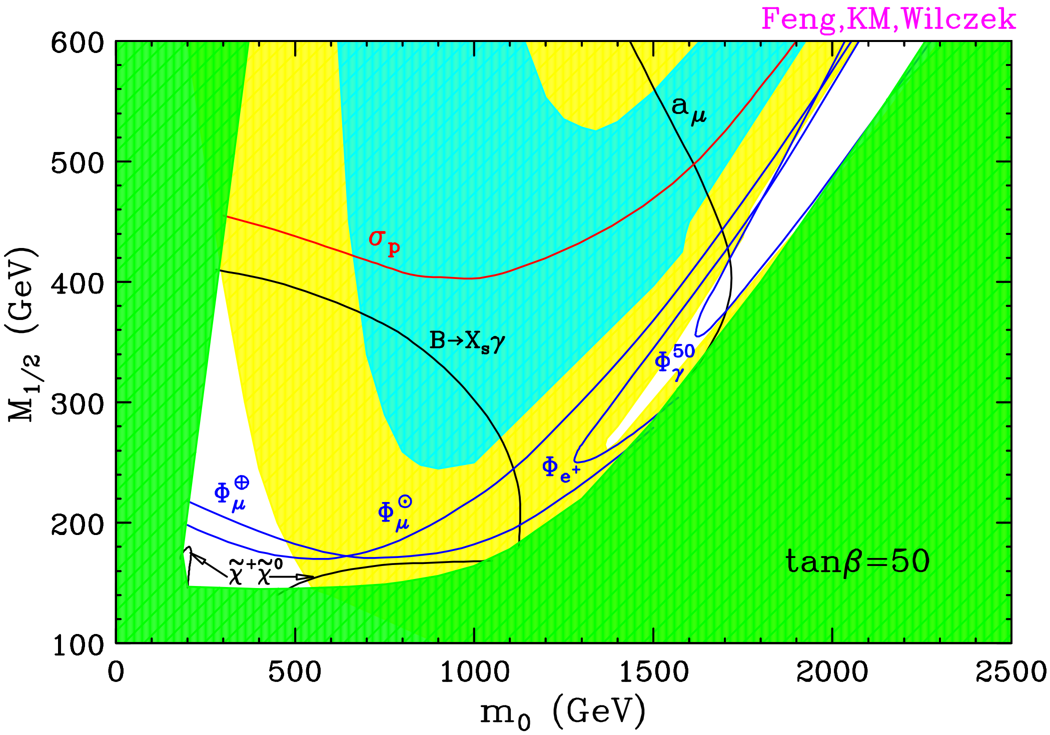
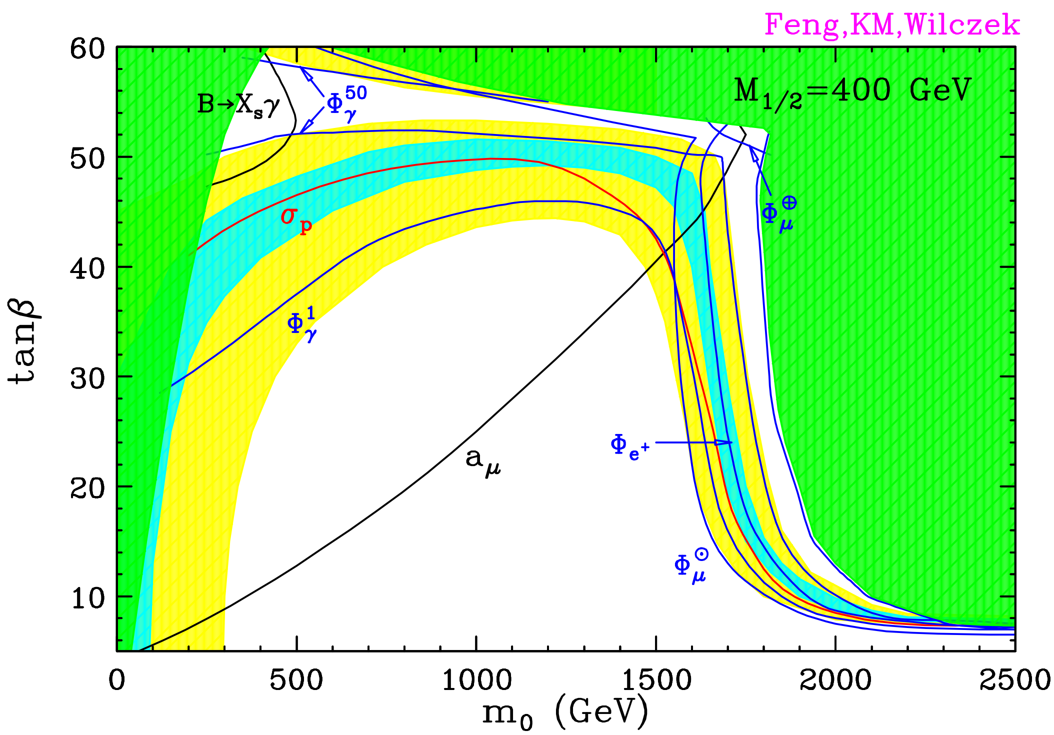


NLC-500 Reach

- $M_{1/2} = 400$ GeV, charginos barely within reach of NLC-500.



Conclusions

- LHC will establish the new energy frontier, but...
- Many pre-LHC experiments have the ability to probe the energy frontier. The theoretically preferred regions of the full SUSY parameter space are already being tested...
- If SUSY is light (accessible at NLC-500) and relevant for the dark matter problem, some signal will show up before the LHC. (MSUGRA?)