Split Supersymmetry

at the ILC (and the LHC)

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WK, T. Plehn, P. Richardson, and E. Schmidt, EPJ C 39 (2005) 229 [hep-ph/0408088]

A Short Reminder

N. Arkani-Hamed and S. Dimopoulos, hep-ph/0405159; G. Giudice and A. Romanino, hep-ph/0406088

SUSY is a nice idea — but phenomenologically, the scalar sector is just a mess . . .

. . . let's imagine, all sfermions (and extra Higgses) are superheavy — say, more than $1000\ \mathrm{TeV}$.

$\Rightarrow$ many problems of SUSY models would go away.

No FCNC, no dangerous dipole moments, very few new low-energy parameters, and the renormalization group drives the Higgs more heavy. But we may still have dark matter, gauge unification, and Planck-scale SUSY.

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- there may be good reasons for that from beyond field theory
- as phenomenologists, we should consider such a setup as an interesting SM extension

So, let's simply adopt this model as a possible alternative to the ordinary MSSM and look how much we then can learn at colliders.

Split Supersymmetry

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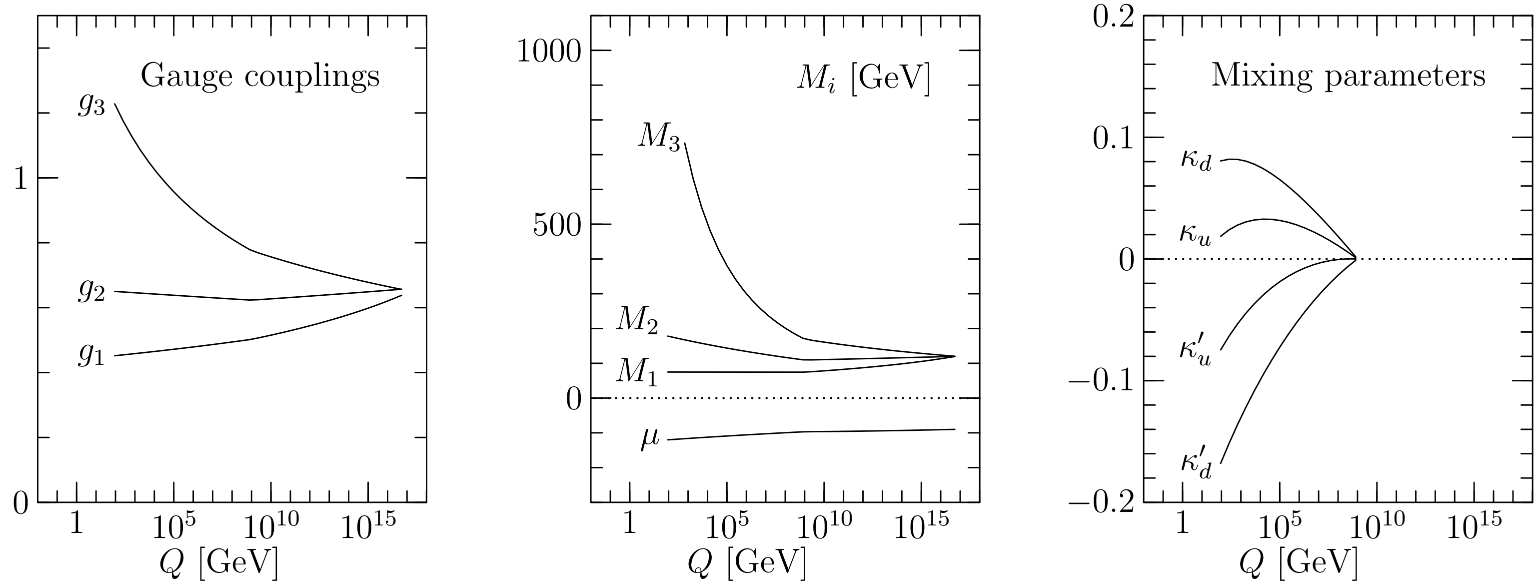
The fermion masses (higgsino, gaugino, gluino) are light. This is possible due to a combination of R parity and PQ symmetry, no accident. We get:

- A gluino which is metastable, because it can only decay via virtual sfermions.
- Charginos and neutralinos, mixed in the usual way. $\tilde{\chi}_1^0$ is a DM candidate, as usual.

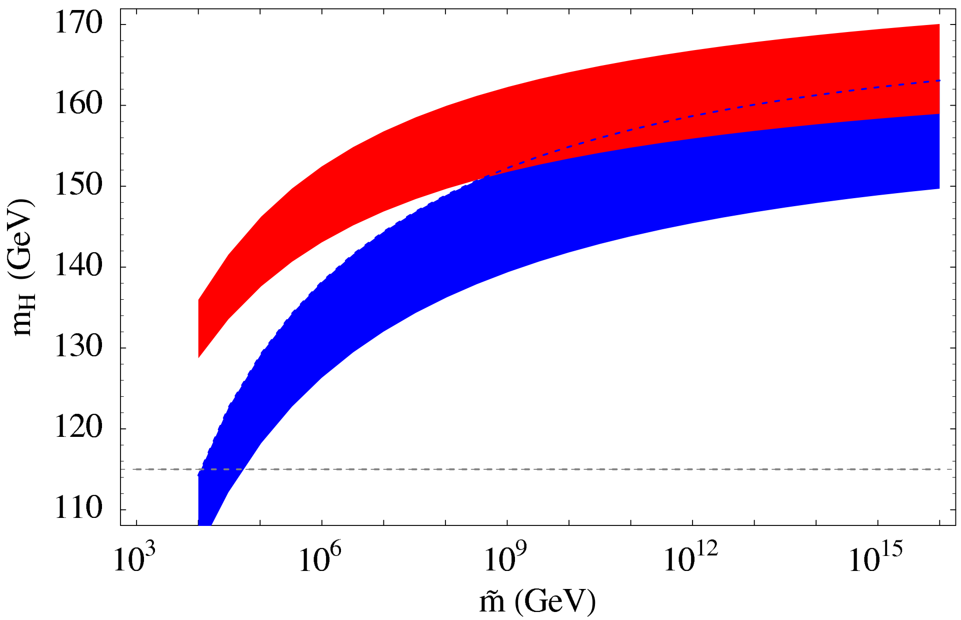
At some high scale $\tilde{m}$, the scalars come in. Here's the RG flow:



The Higgs boson

And this is very welcome:

Giudice, Romanino



⇒ The Higgs boson of Split SUSY is a SM Higgs

⇒ Distinguished from plain MSSM: $m_H > 130\,\mathrm{GeV}$ preferred

⇒ Therefore, sizable WW^* branching fraction, but WW on-shell probably still closed.

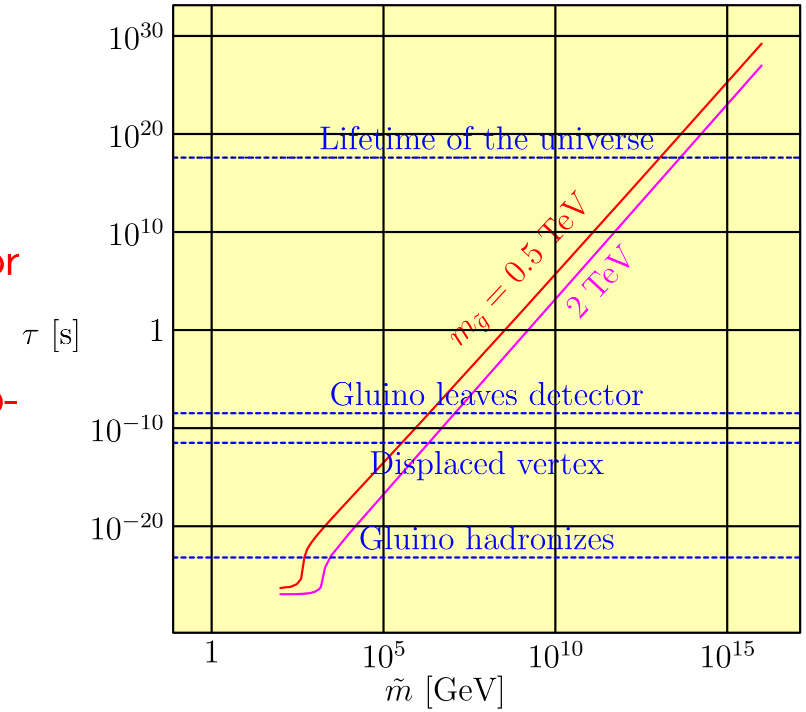
This is an ideal situation for LHC+ILC. Precision measurements should reveal the *absence* of any further scalar states.

The Gluino

Thus, Higgs physics is interesting (albeit not exciting).

Let's turn to the gluino: (This is LHC stuff)

- ∗ Gluino is long-lived
  - ⇒ Heavy hadron in LHC-Detektor (neutral or charged)
  - ⇒ Displaced vertex, or late decay, or no decay observed
- ∗ No cascades



The Gluino

- $\tilde{m} \lesssim 10^6 \ldots 10^7$ GeV: Standard LHC signatures (maybe anomalous flavor decomposition)
- $\tilde{m} \gtrsim 10^6 \ldots 10^7$ GeV: Displaced vertices
- $\tilde{m} \gtrsim 10^8 \ldots 10^9$ GeV: Gluino metastable, decays become rare

In the latter case, the gluino signature is the one of a heavy stable hadron.

We consider the latter case:

(meta)stable gluino

Gluino production

Production of gluinos: Need model for the fragmentation into R hadrons

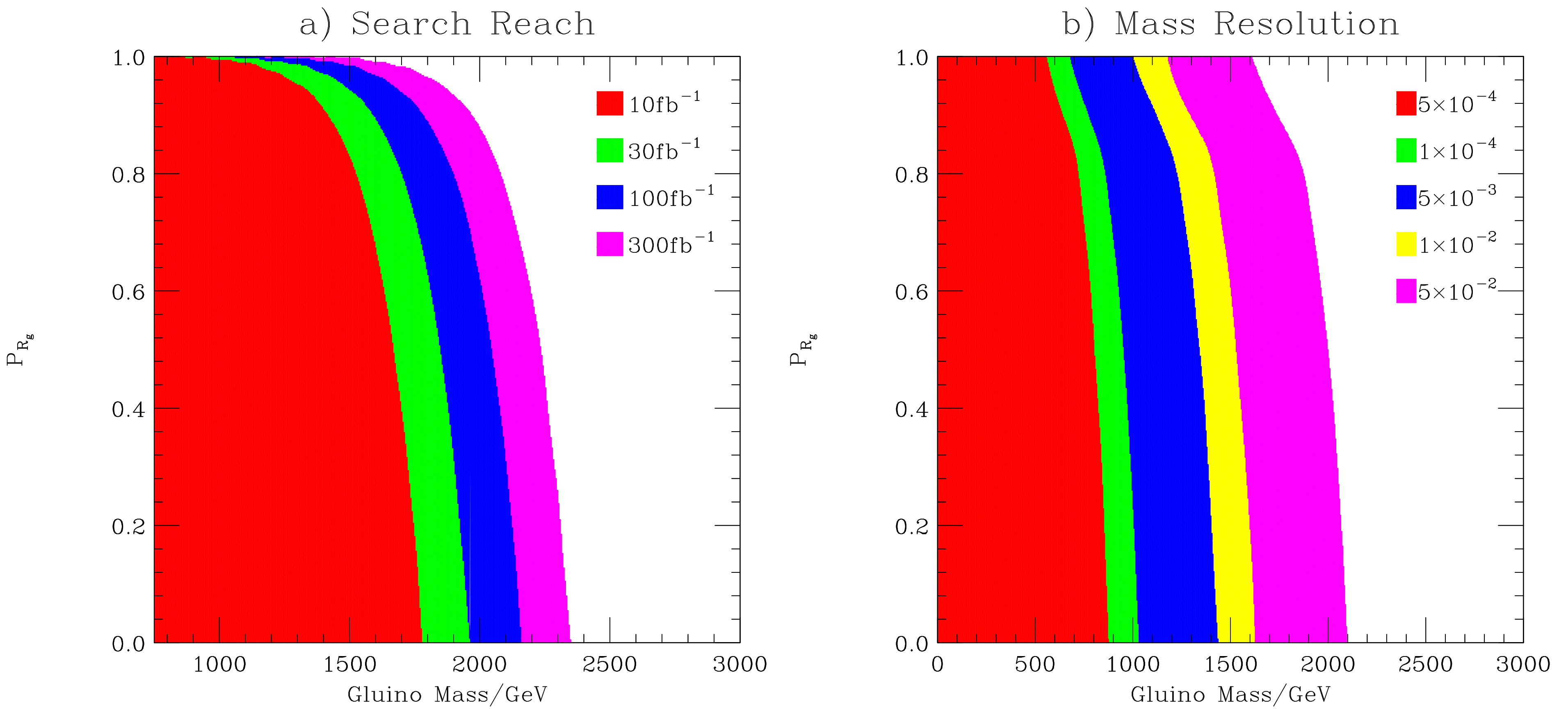
⇒ HERWIG cluster fragmentation (R baryons neglected)

- shower jets and cluster into color-singlet combinations (including gluino)
- fragment cluster into R-hadrons according to kinematics; spectrum taken from lattice
- free parameter: probability of producing R_g

R-hadron	$M_{\tilde{g}} = 50\text{GeV}$		$M_{\tilde{g}} = 2000\text{GeV}$	
	Number per fb^{-1}	Percentage	Number per fb^{-1}	Percentage
R_{ρ^0}	$(4.152 \pm 0.006) \times 10^8$	28.10 ± 0.04	0.5576 ± 0.0007	28.22 ± 0.04
R_{ρ^-}	$(2.067 \pm 0.004) \times 10^8$	14.00 ± 0.03	0.2788 ± 0.0005	14.11 ± 0.07
R_{ρ^+}	$(2.076 \pm 0.004) \times 10^8$	14.05 ± 0.03	0.2788 ± 0.0005	14.11 ± 0.07
R_{K^0}	$(1.302 \pm 0.003) \times 10^8$	8.81 ± 0.02	0.1730 ± 0.0004	8.76 ± 0.02
$R_{\bar{K}^0}$	$(1.291 \pm 0.003) \times 10^8$	8.74 ± 0.02	0.1730 ± 0.0004	8.76 ± 0.02
R_{K^+}	$(1.300 \pm 0.003) \times 10^8$	8.80 ± 0.02	0.1728 ± 0.0004	8.75 ± 0.02
R_{K^-}	$(1.299 \pm 0.003) \times 10^8$	8.79 ± 0.02	0.1725 ± 0.0004	8.73 ± 0.02
R_η	$(1.286 \pm 0.003) \times 10^8$	8.71 ± 0.02	0.1687 ± 0.0004	8.54 ± 0.02
R_D	$(2.1 \pm 0.7) \times 10^4$	$(14.5 \pm 2.6) \times 10^{-4}$	$(6.5 \pm 0.8) \times 10^{-5}$	$(3.2 \pm 0.4) \times 10^{-3}$
R_B	$(7 \pm 7) \times 10^3$	$(0.5 \pm 0.5) \times 10^{-4}$	$8.0 \pm 2.8 \times 10^{-6}$	$(0.4 \pm 0.2) \times 10^{-3}$

Charged R Hadrons

Resulting sensitivity:



⇒ sensitivity up to 2 TeV, but reduced if R_g fraction large

⇒ beyond detection? Unclear . . . certainly, this doesn't prove SUSY.

Charginos and Neutralinos

What else can we do?

LHC and ILC: Charginos and neutralinos produced by $q\bar{q}$ (e^+e^-) annihilation.

SUSY: At the matching scale, the Yukawa couplings $\tilde{\chi}h\tilde{\chi}$ are all given by gauge couplings and $\tan\beta$.

⇒ measure at least two of them (better more) to establish SUSY and determine $\tan\beta$

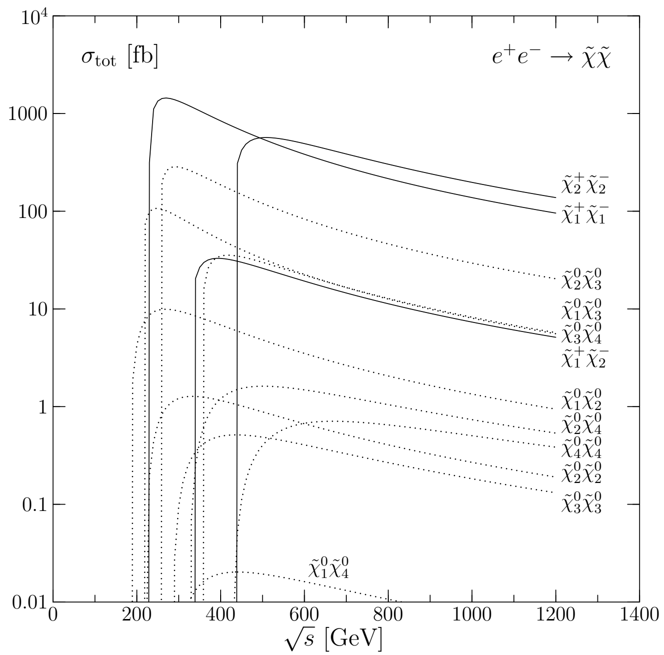
⇒ precise measurement will establish the running between $\tilde{m}$ and v (anomalous contributions between 0 and $20\,\%$)

Higgs VEV: Yukawa couplings generate neutralino/chargino mixing matrix

⇒ measurement of masses, production and decay channels

⇒ need ILC for precision

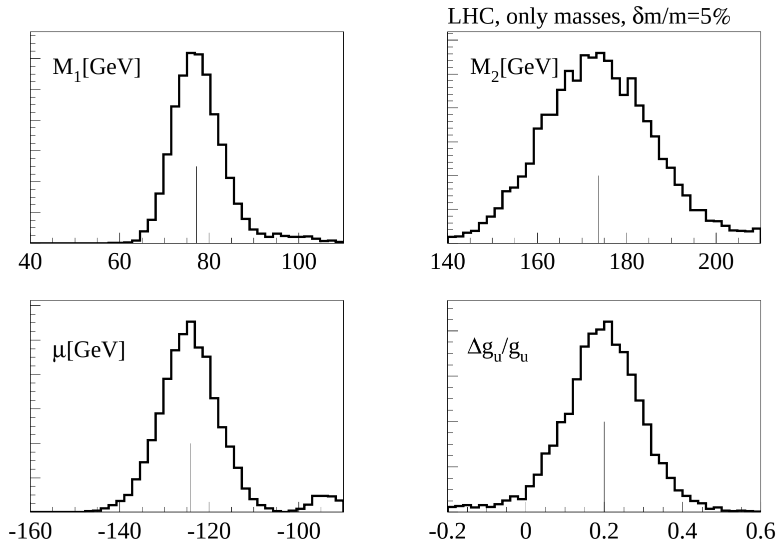
⇒ establish dark matter (higgsino content of $\tilde{\chi}^0_1$)

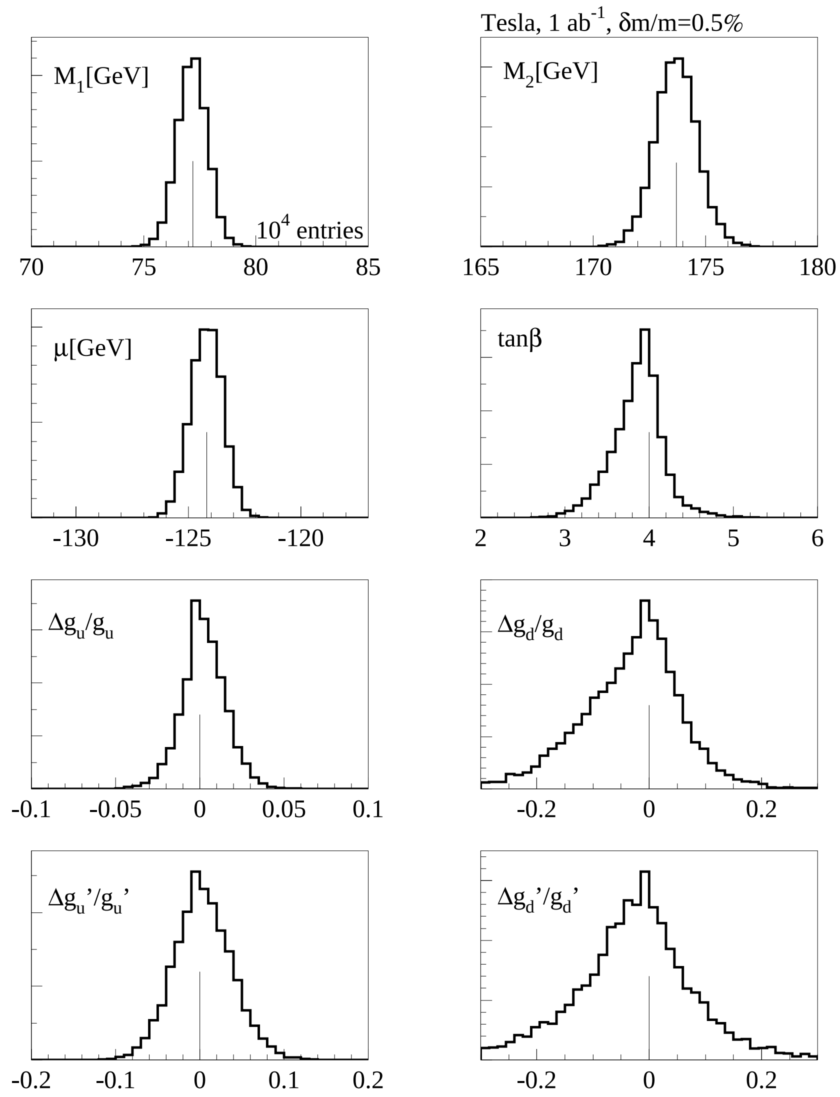


Charginos and Neutralinos

Can we establish (Split) SUSY experimentally?

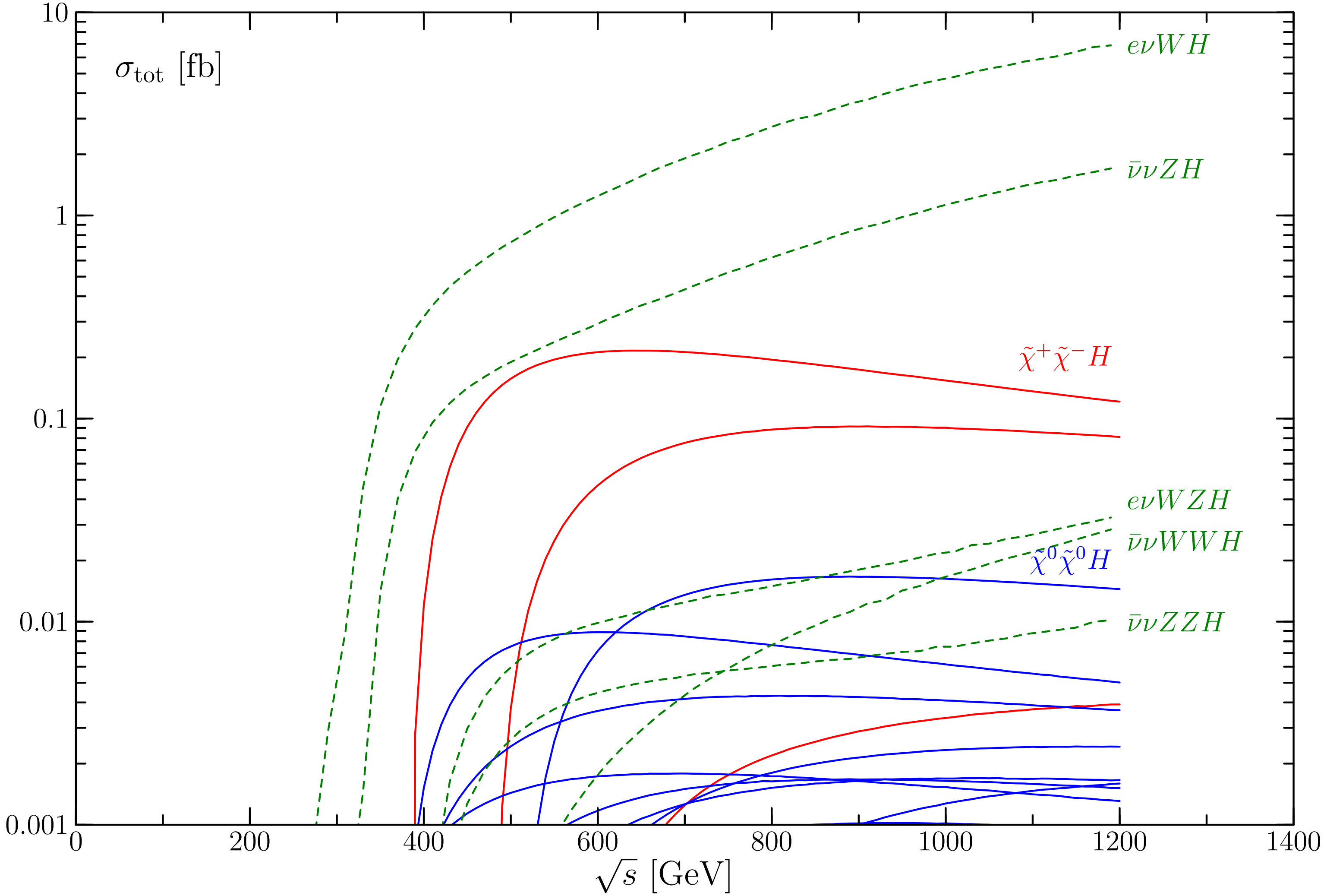
Simultaneous fit of all mass parameters
and Yukawa couplings to (assumed)
LHC and ILC data





Charginos and Neutralinos

Direct measurement of Yukawa couplings: $e^+e^- \to \tilde{\chi}\tilde{\chi}H$



Summary

- MSSM has problems that are usually eliminated by assumptions on SUSY breaking mechanism
- Split Supersymmetry implements a different assumption: MSSM does not solve the naturalness problem – all scalars are heavy

  $\Rightarrow$ ...and flavor problems go away
- Colliders: LHC can see the long-lived gluino; analysis of hadronization and decay is interesting new physics

  The Higgs boson is a SM Higgs boson, somewhat above the usual (c)MSSM limit. No other scalar bosons are expected at accessible energies.

  Establishing the model as a SUSY model requires precision measurement of gaugino mixing $\Rightarrow$ ILC can do this.