DØ Higgs/Supersymmetry in Run IIa?

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- Signatures of supersymmetry
- What can we do in Run IIa (500 pb^{-1})
- Thoughts & Outlook

DØ Workshop, Seattle, Washington
June 28, 1999

Supersymmetry ?

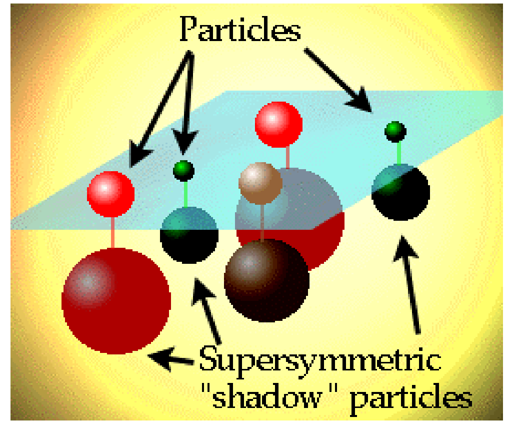
Standard Model Particles

$W^{\pm} H^{\pm}$ γ Z h H A u d e ν ......

$\Downarrow$ $\Downarrow$ $\Downarrow$

$\tilde{\chi}_2^{\pm}\ \tilde{\chi}_1^{\pm}$ $\tilde{\chi}_4^{0}\ \tilde{\chi}_3^{0}\ \tilde{\chi}_2^{0}\ \tilde{\chi}_1^{0}$ $\tilde{u}_L\ \tilde{d}_L\ \tilde{e}_L\ \tilde{\nu}_L$ $\tilde{u}_R\ \tilde{d}_R\ \tilde{e}_R\ \tilde{\nu}_R$ $\tilde{\ldots}$

Supersymmetric Particles

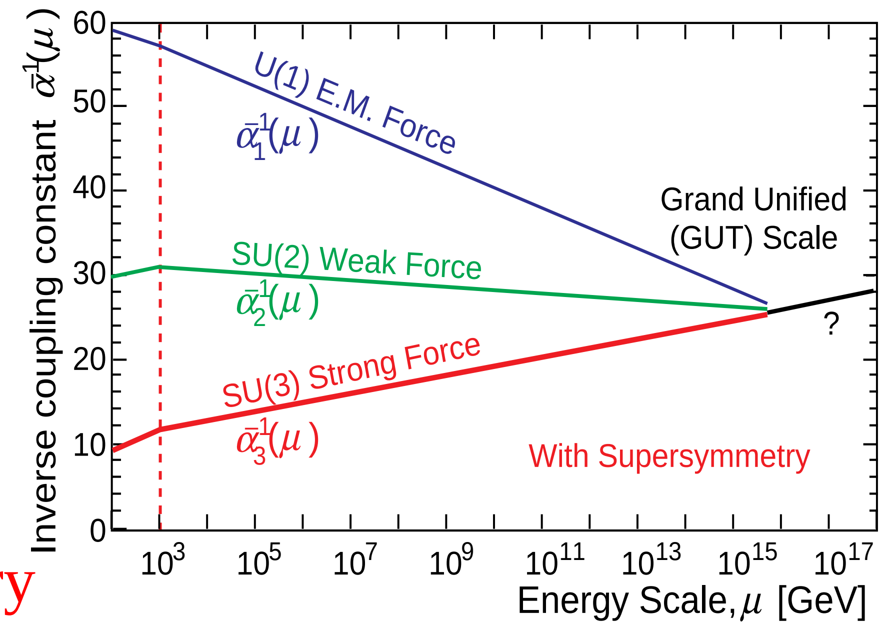


Supersymmetry must be broken

~~SUSY~~ is assumed to occur in a hidden sector

Phenomenology depends on

- the way ~~SUSY~~ is transmitted
- whether R-parity is conserved
- the lightest supersymmetric particle

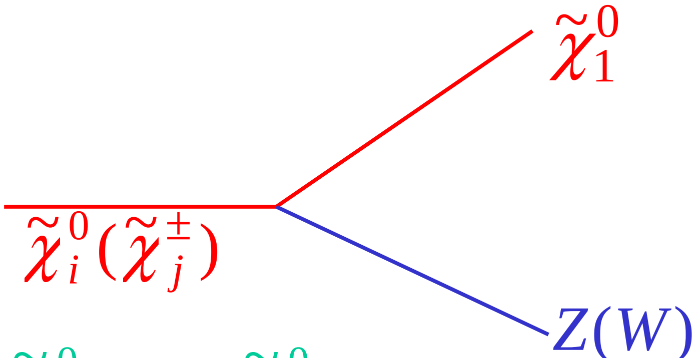


No evidence against supersymmetry

Gravity-Inspired Models

Supersymmetry breaking is transmitted by gravity-like interactions
breaking scale $\Rightarrow \Lambda \sim 10^9$ TeV

Lightest neutralino ($\tilde{\chi}_1^0$) is often assumed to be the LSP



$$\tilde{\chi}_i^0 \rightarrow Z\,\tilde{\chi}_1^0$$
$$\tilde{\chi}_j^\pm \rightarrow W\,\tilde{\chi}_1^0$$
$$\tilde{q} \rightarrow q\,\tilde{\chi}_1^0$$
$$\tilde{g} \rightarrow q\,\tilde{q}$$

$$p\bar{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow WZ + \not{E}_T \Rightarrow \ell^{1,2,3} + \not{E}_T + X$$
$$\tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \rightarrow WW + \not{E}_T \Rightarrow \ell^{1,2} + \not{E}_T + X$$

$$p\bar{p} \rightarrow \tilde{q}\tilde{\bar{q}} \rightarrow X + \tilde{\chi}_1^0 \tilde{\chi}_1^0 \Rightarrow jets + \not{E}_T$$
$$+ \tilde{\chi}_1^\pm \tilde{\chi}_1^0 \Rightarrow jets + \not{E}_T + \ell$$
$$+ \tilde{\chi}_1^\pm \tilde{\chi}_1^\mp \Rightarrow jets + \not{E}_T + \ell^\pm \ell^\mp$$
$$+ \tilde{\chi}_2^0 \tilde{\chi}_1^0 \Rightarrow jets + \not{E}_T + \ell^\pm \ell^\mp$$
$$+ \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \Rightarrow jets + \not{E}_T + \ell\ell\ell$$
$$+ \;\ldots\ldots$$
$$p\bar{p} \rightarrow \tilde{g}\tilde{g} \rightarrow X + \tilde{\chi}_1^\pm \tilde{\chi}_1^\pm \Rightarrow jets + \not{E}_T + \ell^\pm \ell^\pm$$

Signatures:

$$p\bar{p} \rightarrow SUSY \Rightarrow \not{E}_T + \ell^n + j^m$$

Gauge-Mediated Models

Supersymmetry breaking is transmitted through gauge-like interactions $\Rightarrow \Lambda \sim 100$ TeV

$$\Rightarrow \; m_{\tilde{G}} \sim 6 \times 10^{-5} \left(\frac{\Lambda}{500 \text{ GeV}} \right)^2 \text{ eV}$$

$\tilde{G}$ is naturally the LSP (GMSB models)

Signatures depend on the next-lightest supersymmetric particle (NLSP)

$$\tilde{\chi}_1^0 \to \gamma \tilde{G}, \;\; Z\tilde{G}, \;\; h\tilde{G}$$
$$\tilde{\ell} \to \ell \tilde{G}$$

$$p\bar{p} \to SUSY \to 2NLSP + \ell^n + j^m$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \gamma\gamma$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \ell\ell$$
$$\Rightarrow (\not{E}_T + \ell^n + j^m) + \gamma h$$
$$\ldots\ldots$$

Signatures:

$\gamma\gamma\not{E}_T, \;\; \ell\ell\not{E}_T, \;\; \gamma b\bar{b}\not{E}_T, \; \ldots$

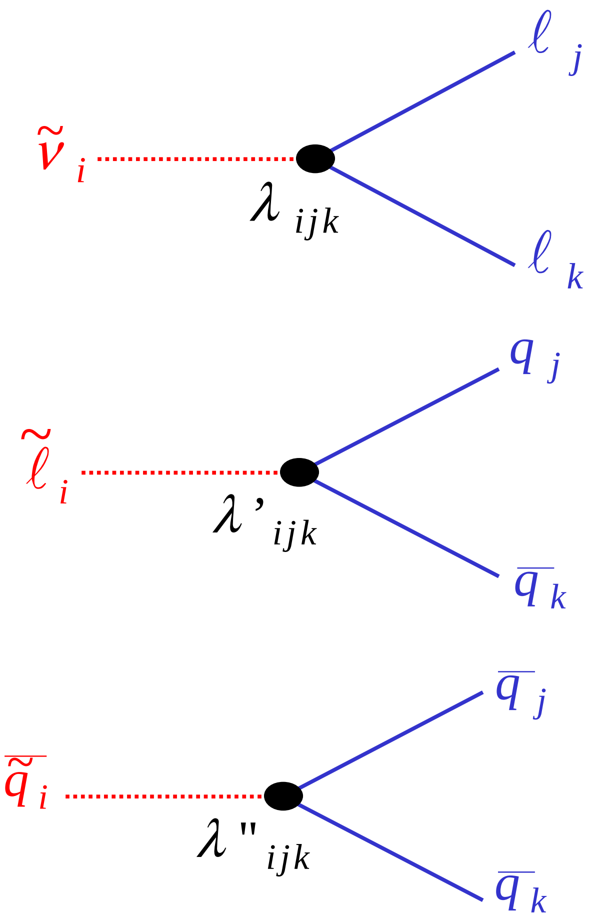
Depending on their lifetimes, NLSPs can decay at the production vertex, inside and outside detector

$\Downarrow$

displaced photons
hot cells
slow moving particles
kinked tracks

R-parity Violating Supersymmetry

In addition to the SM interactions, following interactions are allowed



Resulting lepton and baryon number violations
as well as the R-parity violation

B-violating λ''_{ijk} couplings will lead to
multijet events without $\not{E}_T$

The L-violating λ_{ijk} and λ'_{ijk} couplings
will give rise to multilepton events

$$\tilde{\chi}^0_1 \to \nu\tilde{\nu}^* \Rightarrow \nu\ell\ell \ \ (\lambda_{ijk})$$
$$\tilde{\chi}^0_1 \to \ell\tilde{\ell}^* \Rightarrow \ell qq \ \ (\lambda'_{ijk})$$

Frequent assumptions:

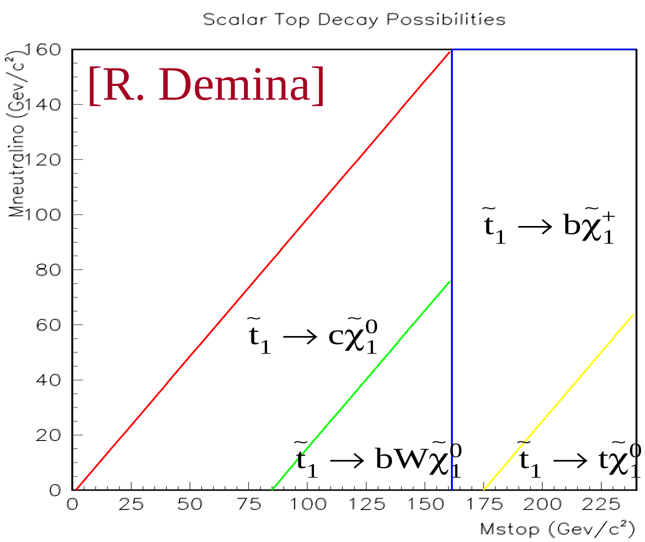
1) R-parity violating LSP decay
2) couplings are not too week or too strong
3) terms with similar event topology dominate

Signatures:

$$p\overline{p} \to SUSY \Rightarrow \ell^n + j^m (+\not{E}_T)$$

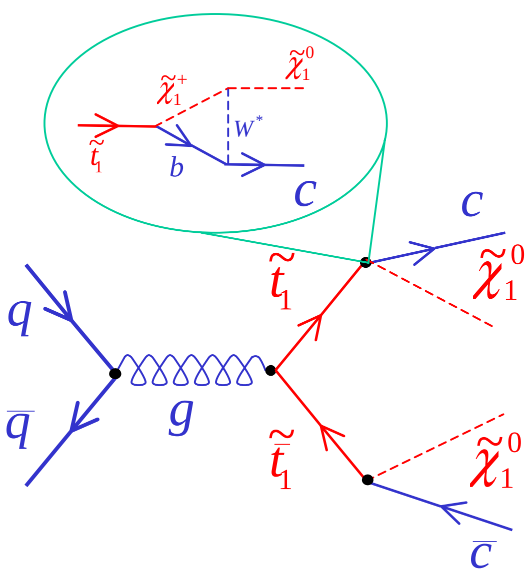
Heavy Flavor Super-Partners

In many supersymmetry models, stop (and sbottom) can be significantly lighter than other squarks

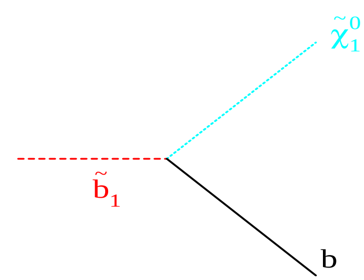


$$\tilde{t}_1 \to \tilde{\chi}_1^{\pm} + b \to \tilde{\chi}_1^0 + Wb$$
$$\tilde{t}_1 \to \tilde{\chi}_1^0 + c$$

Signatures:
1) two acoplanar c-jets with $\not{E}_T$
2) excess of SM top events



Assuming $Br(\tilde{b}_1 \to b\tilde{\chi}_1^0) = 100\%$
pair production of $\tilde{b}_1$ will yield
two acoplanar b - jets



Signatures:
two acoplanar b-jets with $\not{E}_T$

Minimal Models

The minimal supersymmetric extension of
the standard model has more than 100 additional parameters

Minimal SuperGravity Model (mSUGRA)

m_0	common scalar mass parameter
$m_{1/2}$	common gaugino mass parameter
A_0	common trilinear coupling
$\tan\beta$	ratio of the v.e.v of the two higgs doublets
sign(μ)	sign of the higgs mass parameter

Minimal Gauge Mediation Model (MGM)

Λ	supersymmetry breaking scale
M_m	messenger sector scale
N	number of messagers
$\tan\beta$	ratio of the v.e.v. of the two higgs doublets
sign(μ)	sign of the higgs mass parameter

Experimental Signatures

Most supersymmetry signatures can be grouped into three broad categories

Leptonic Signatures

- Single-lepton ✓
- Di-lepton
  - opposite-sign di-lepton ✓
  - like-sign di-lepton
  - massive stable charged particles
- Tri-lepton
  - chargino-neutralino ✓
  - R-parity violating ✓
- τ events

Run I Analyses:

1) mSUGRA motivated searches
   $\ell\ell jj\not{E}_T$ $\quad jets + \not{E}_T$
2) GMSB motivated searches
   $\gamma\gamma\not{E}_T$
3) $\not{R}_p$ searches
   $eejjjj$ $\quad \ell\ell\ell\not{E}_T$
4) Others
   $\ell\ell\ell\not{E}_T$ $\quad \gamma jj\not{E}_T$ $\quad jj\not{E}_T$

Photonic Signatures

- Single-photon ✓
- Di-photon ✓

Jet Signatures

- b-quark jets ✓
- c-quark jets
- jets ✓

New opportunities in Run II

1) like-sign di-leptons
2) massive stable charged particles
3) heavy-flavor jets
4) more efficient τ identification

Run II Higgs/SUSY Workshop

The year long workshop was organized to improve our understanding on what future Tevatron runs can do in the areas of Higgs and Supersymmetry

Five Working Groups:

Higgs physics
Supergravity models
Gauge mediated models
Beyond the MSSM
Event generators

Workshop Product:

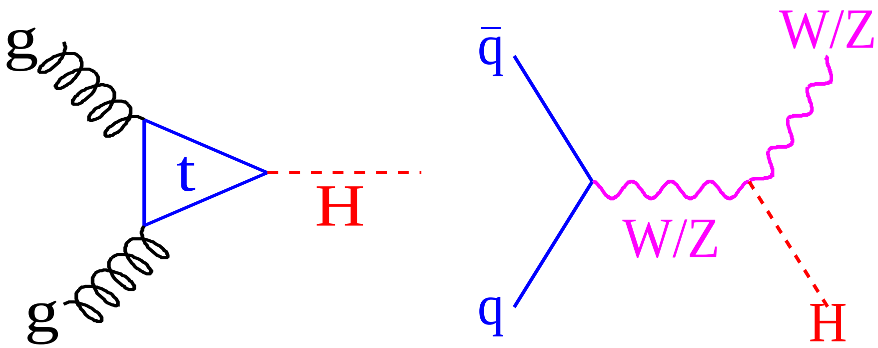
A published report summarizing the workshop results

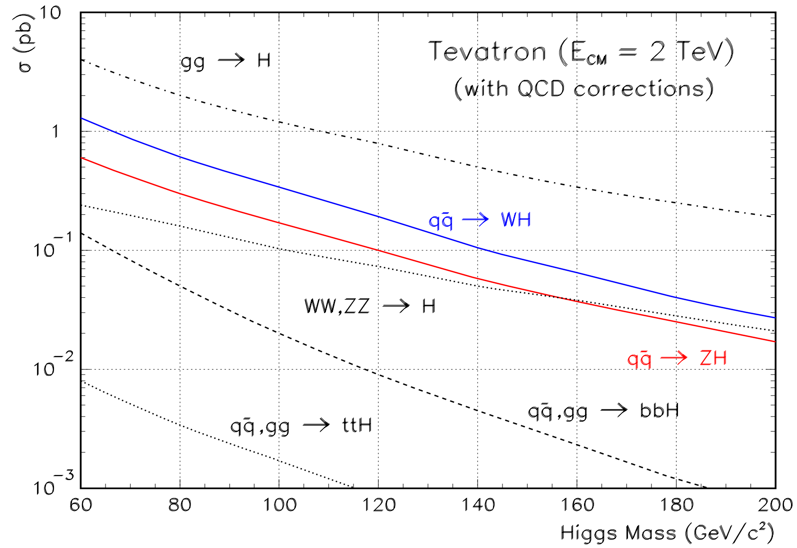
When?

First deadline: December 1998, final deadline: April 15, 1999
and we still don’t have the report...

Standard Model Higgs Boson

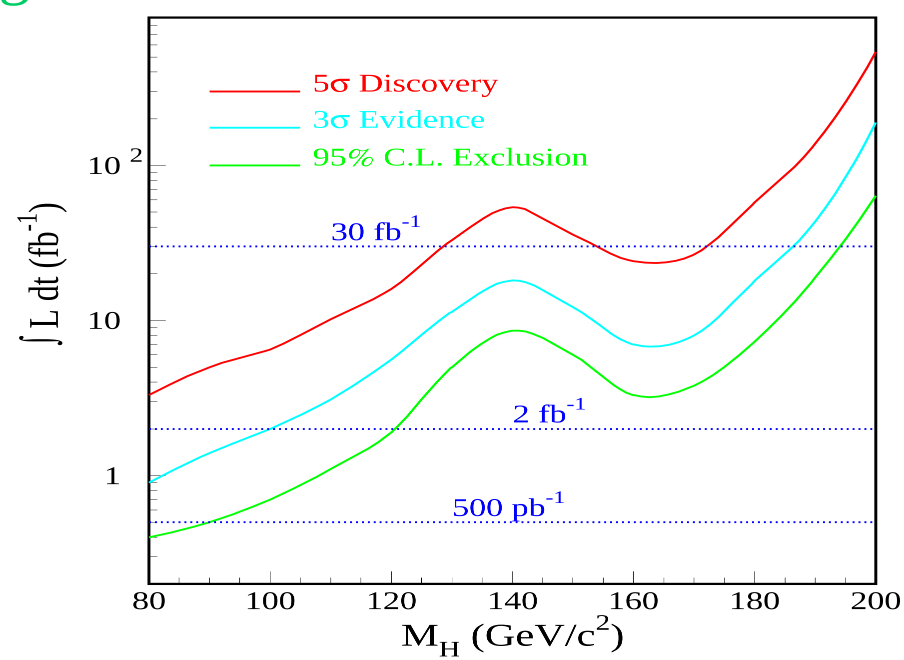
Production Processes





For $M_H = 120$ GeV, about 500 Higgs events are expected for in Run IIa

Most of those are $b\bar{b}$ events, buried by QCD $b\bar{b}$ events



There is no sensitivity for $\int Ldt = 0.5\ \text{fb}^{-1}$

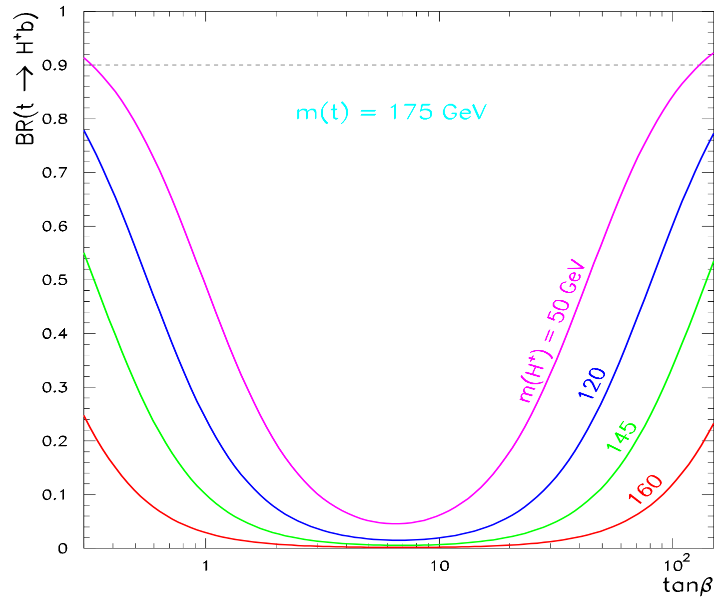
[Run II Higgs Working Group]

Charged Higgs Boson

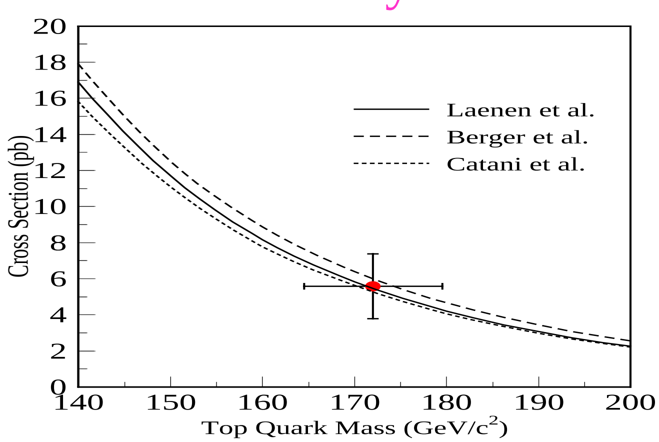
If $H^{\pm}$ are sufficiently light, they can be produced in top quark decays $t \rightarrow Hb$

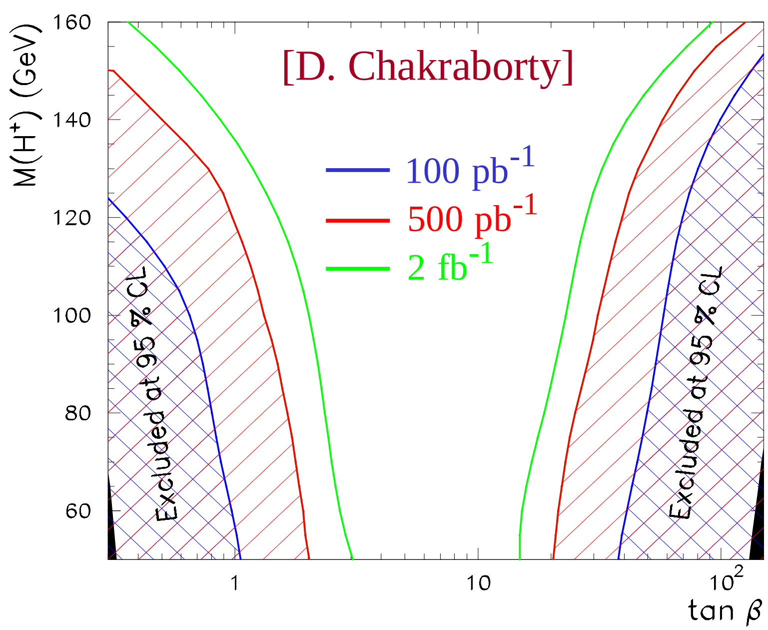
Therefore $t \rightarrow Hb$ will compete with the standard model $t \rightarrow Wb$ decay

Since $H^+ \rightarrow c\bar{s}, \tau\nu, Wb\bar{b}$
signature for H production in $t\bar{t}$ events
- disappearance of standard $WWbb$ signature
- anomalous τ lepton production



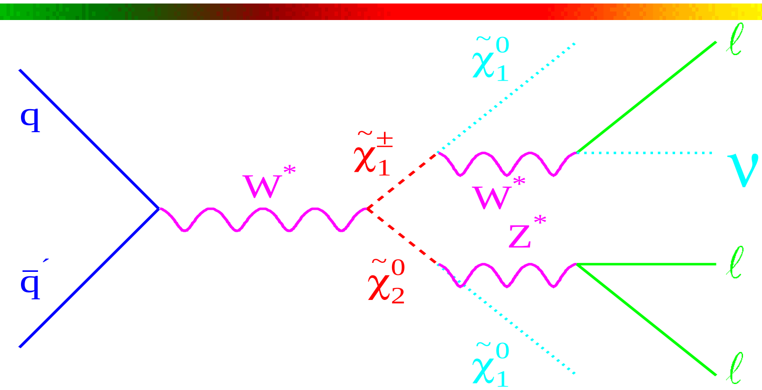
Sensitive only to the parameter regions with large Br($t \rightarrow Hb$)
Disappearance search is only sensitive to $H \rightarrow c\bar{s}$ and $\tau\nu$ decays





Charginos and Neutralinos

Production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ will lead to trilepton events with $\not{E}_T$, one of the cleanest signature for supersymmetry

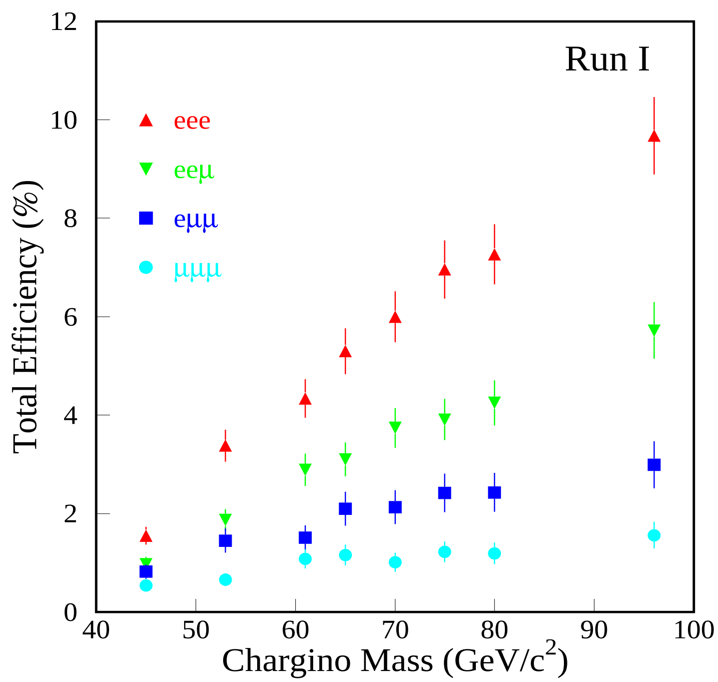


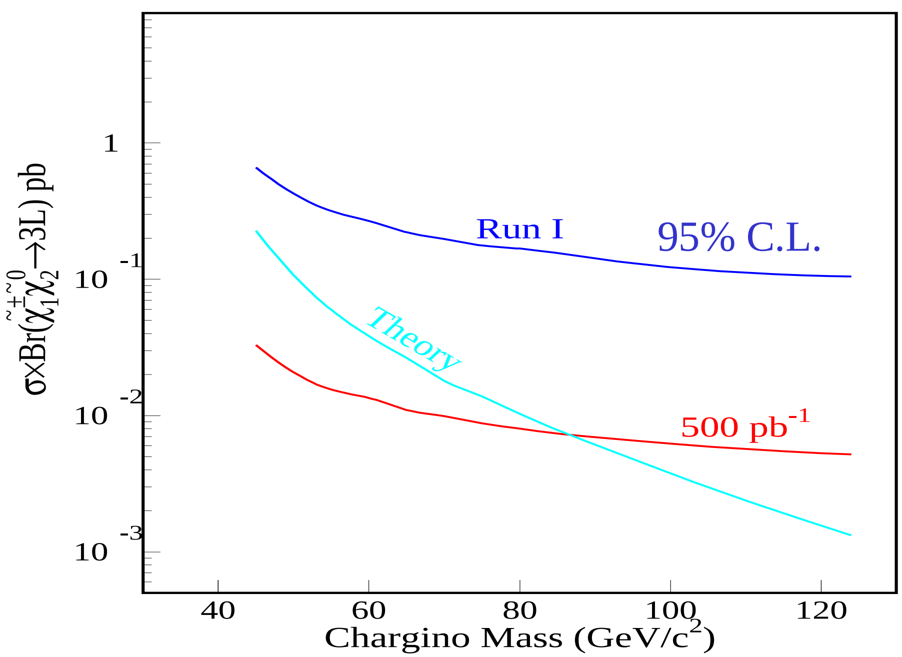
Backgrounds:

$WZ, ZZ, Zb, Wb\bar{b}, t\bar{t}, \ldots$

Run II improvements:

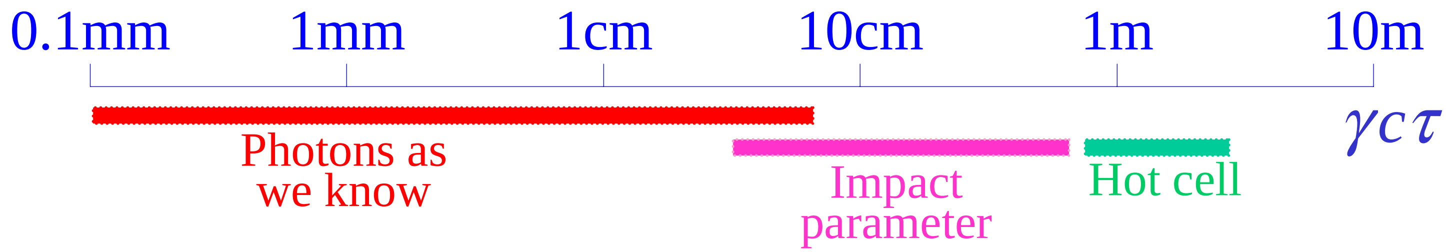
1) identification of soft-leptons (efficiency)
2) lepton charge measurement (background)

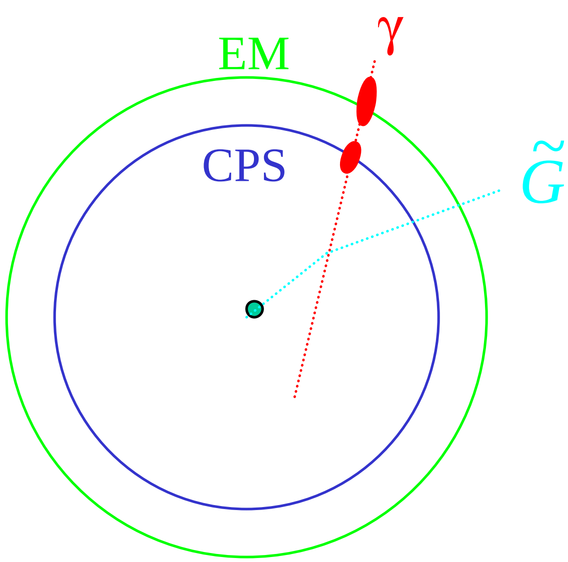




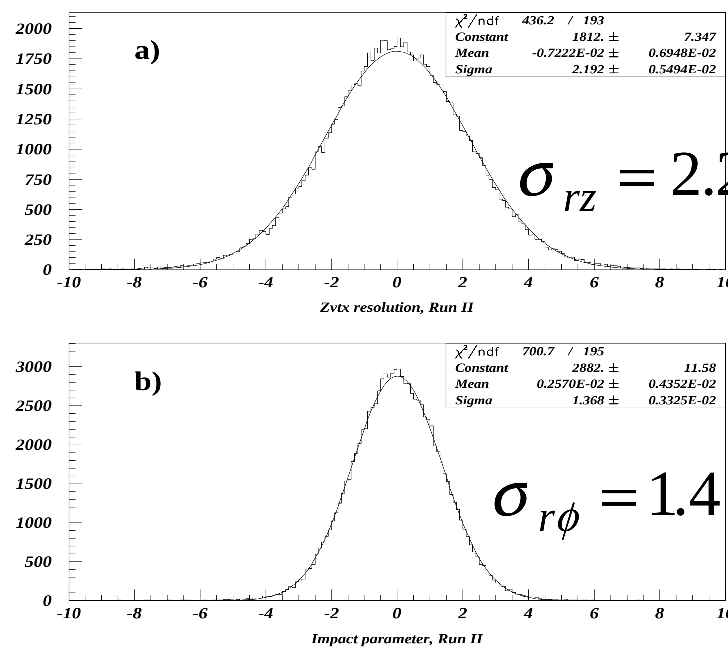
Long-lived Neutralino

$\tilde{\chi}_1^0 \to \gamma \tilde{G}$





Central Region



$\sigma_{rz} = 2.2$ cm

$\sigma_{r\phi} = 1.4$ cm

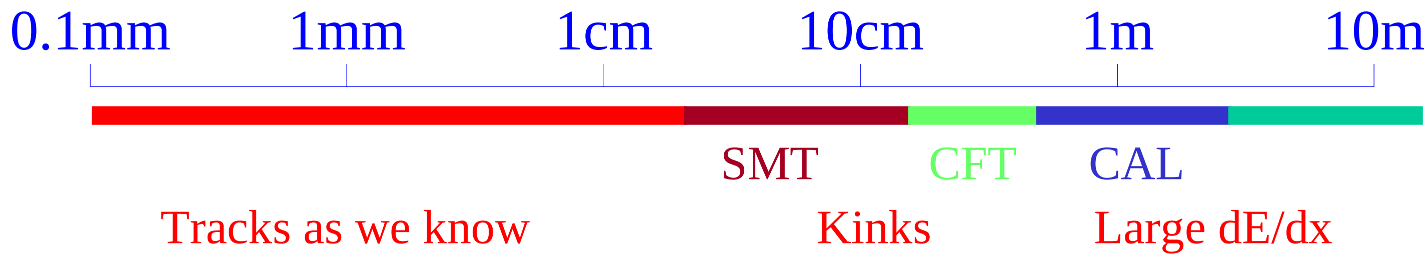
Similar resolutions in forward region

$\sigma_{r\phi} = 1.2$ cm $\quad \sigma_{rz} = 2.8$ cm

[D. Cutts & G. Landsberg hep-ph/9904396]

Long-lived Slepton

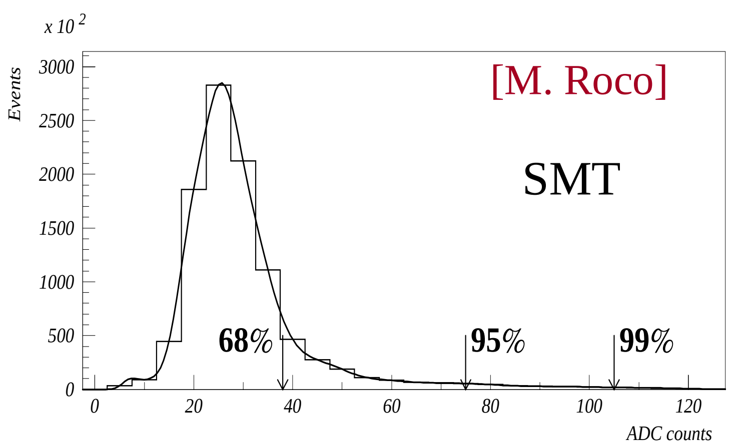
$\tilde{\ell} \to \ell \tilde{G}$

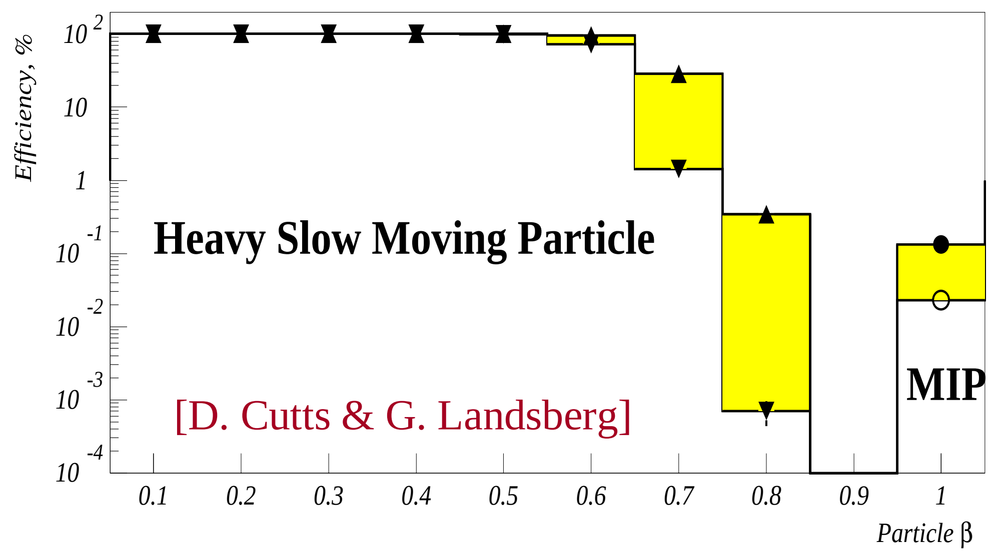


Tools for massive stable charged particles (MSP)

dE/dx information from

1) Silicon
2) Fiber tracker
3) Preshowers
4) Calorimeter

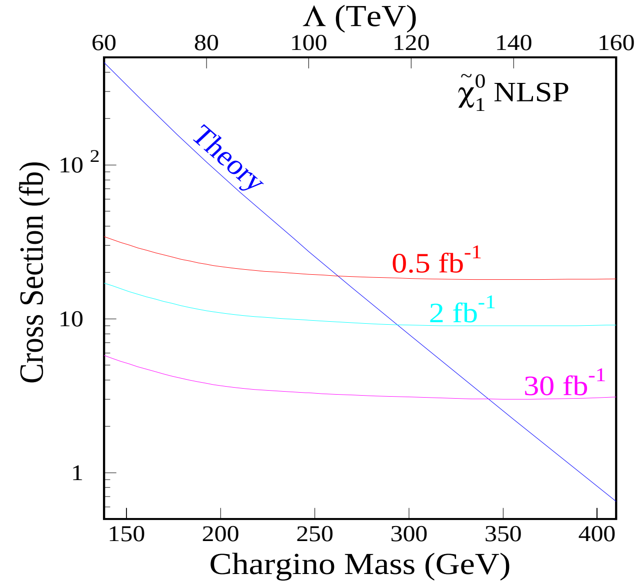




An efficiency of 68% for MSP and
a rejection factor of 10 for MIP are assumed

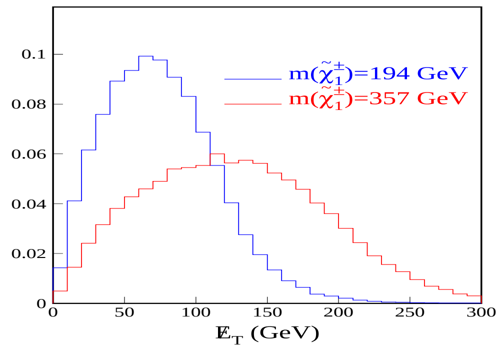
MGM with a Neutralino NLSP

$$p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\mp}, \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} \to \tilde{\chi}_1^{0}\tilde{\chi}_1^{0} + X$$
$$\Rightarrow \gamma\gamma \not{E}_T + X \text{ (prompt } \tilde{\chi}_1^0 \to \gamma\tilde{G})$$
$$\Rightarrow \gamma jj \not{E}_T + X \text{ (delayed } \tilde{\chi}_1^0 \to \gamma\tilde{G})$$



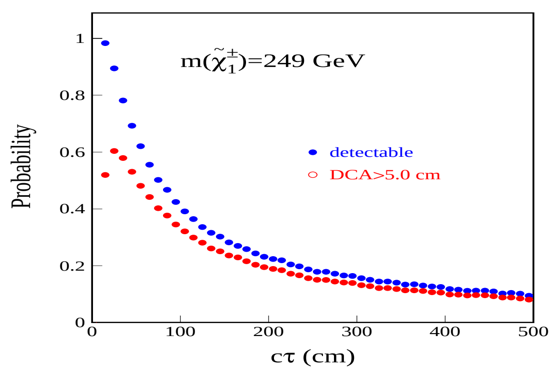
$\gamma\gamma\not{E}_T + X$

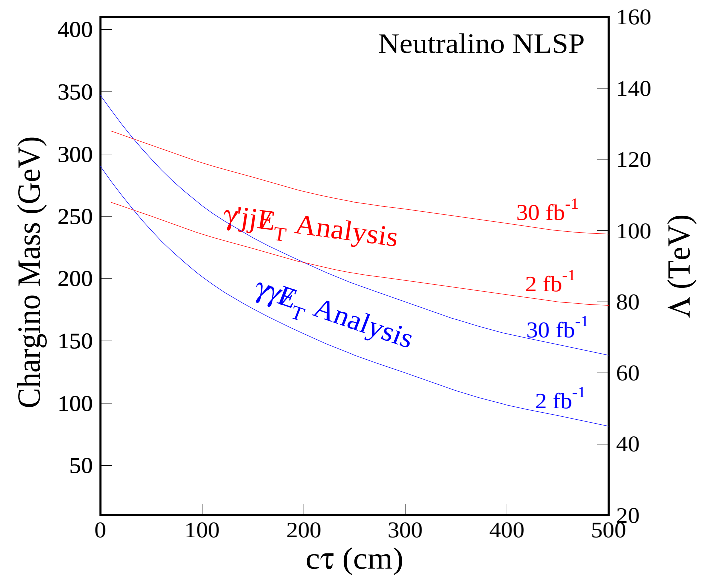
- Cuts: ≥2γ, E_T>20 GeV, $\not{E}_T$>50 GeV
- Backgrounds
  - 0.4 fb (QCD)
  - 0.2 fb (Fakes)
- Efficiency: 15–30%
- 5σ reach: $M_{\tilde{\chi}_1^{\pm}} < 260$ GeV



$\gamma jj\not{E}_T + X$

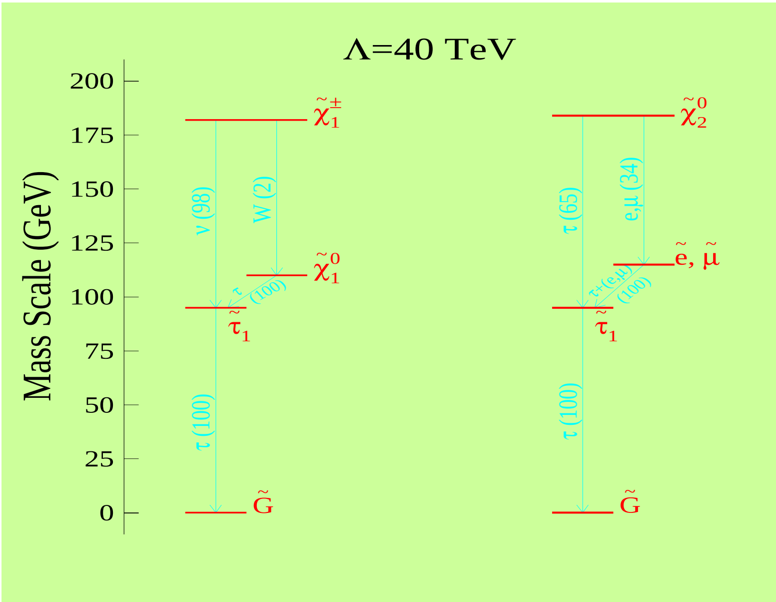
- Cuts: ≥1γ', E_T>20 GeV, $\not{E}_T$>50 GeV
- Backgrounds: 0.3 fb
- Efficiencies: varies





[JQ: hep-ph/9903548]

MGM with a Stau NLSP



Prompt $\tilde{\tau}_1 \to \tau\tilde{G}$

$\ell\ell\ell j\not{E}_T$

Cuts: $p_T^\ell > 15{,}5{,}5$ GeV, $E_T^j > 20$ GeV, $\not{E}_T > 20$ GeV

$\ell^\pm\ell^\pm jj\not{E}_T$

Cuts: $p_T^\ell > 15$ GeV, $E_T^j > 20$ GeV, $\not{E}_T > 25$ GeV

Background: 0.7 fb

Efficiency: 0.5–3.5%

Quasi-stable $\tilde{\tau}_1$

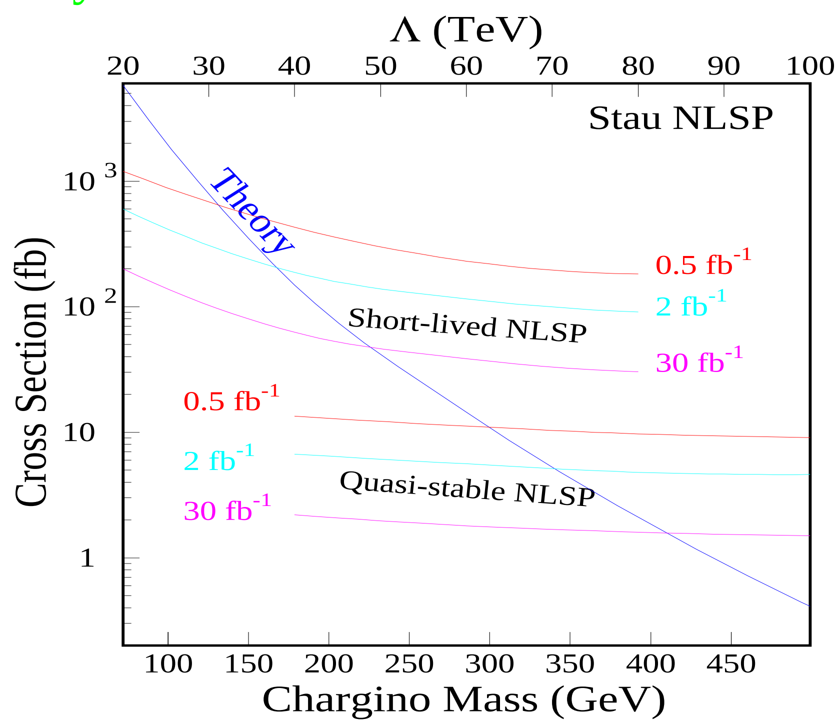
$\ell\ell + dE/dx$

Cuts: $p_T^\ell > 50$ GeV, $M_{\ell\ell} > 150$ GeV, dE/dx

Background: 0.5 fb

Efficiency: 35–55%

[JQ: hep-ph/9903548]



Slepton and Higgsino NLSPs

$\tilde{\ell} \to \ell \tilde{G}$

Prompt: $\ell\ell\ell j \not{E}_T + X$

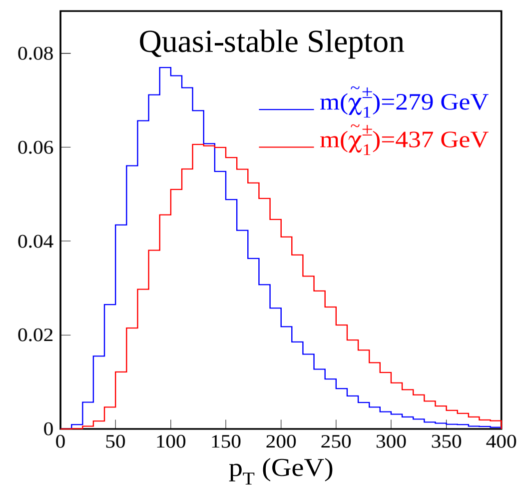
Efficiency: 1-15%

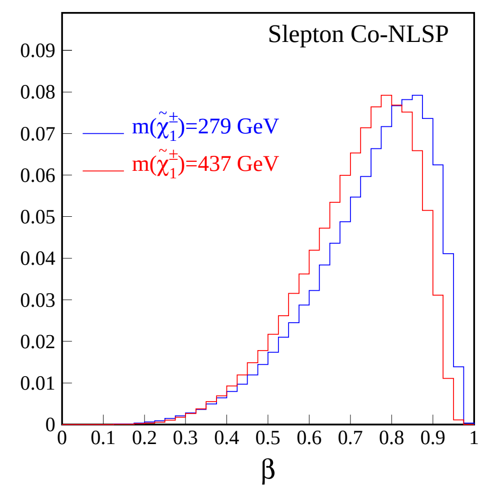
5σ reach: $M_{\tilde{\chi}_1^\pm} < 250$ GeV

Quasi-stable: $\ell\ell$ + dE / dx

Efficiency: 30-50%

5σ reach: $M_{\tilde{\chi}_1^\pm} < 330$ GeV





$\tilde{\chi}_1^0 \to \gamma \tilde{G}$

$\tilde{\chi}_1^0 \to h \tilde{G}$

Prompt decay

$\Rightarrow \gamma b j \not{E}_T + X$ events

$\geq 1\gamma$ with $E_T > 20$ GeV

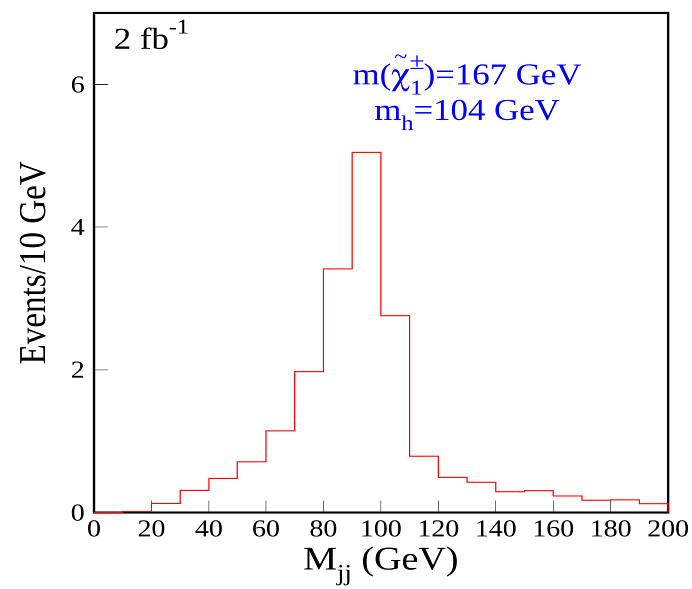
≥ 2j with $E_T > 20$ GeV

≥ 1 tagged b-jet

$\not{E}_T > 50$ GeV

Backgrounds: 0.4 fb

using P(j→b)=10^{-3}



For $\int Ldt = 0.5$ fb^{-1} and $m_h = 105$ GeV
Expect 5 signal events with
less than 1 background events

R-parity Violation

$$p\bar{p} \to SUSY \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 + X$$
$$\Rightarrow (\ell\tilde{\ell})(\ell\tilde{\ell}) + X \Rightarrow (\ell q\bar{q}')(\ell q\bar{q}') + X$$

$$p\bar{p} \Rightarrow \ell\ell + \geq 4\,\text{jets} \quad (\ell = e, \mu)$$

Sensitive to couplings λ'_{1jk} and λ'_{2jk}

Extrapolating from Run I *eejjjj* analysis:

Selection:

- $\geq 2\ell$ with $E_T > 15{,}10$ GeV
- ≥ 4jets with $E_T > 15$ GeV
- $Z \to \ell\ell$ veto

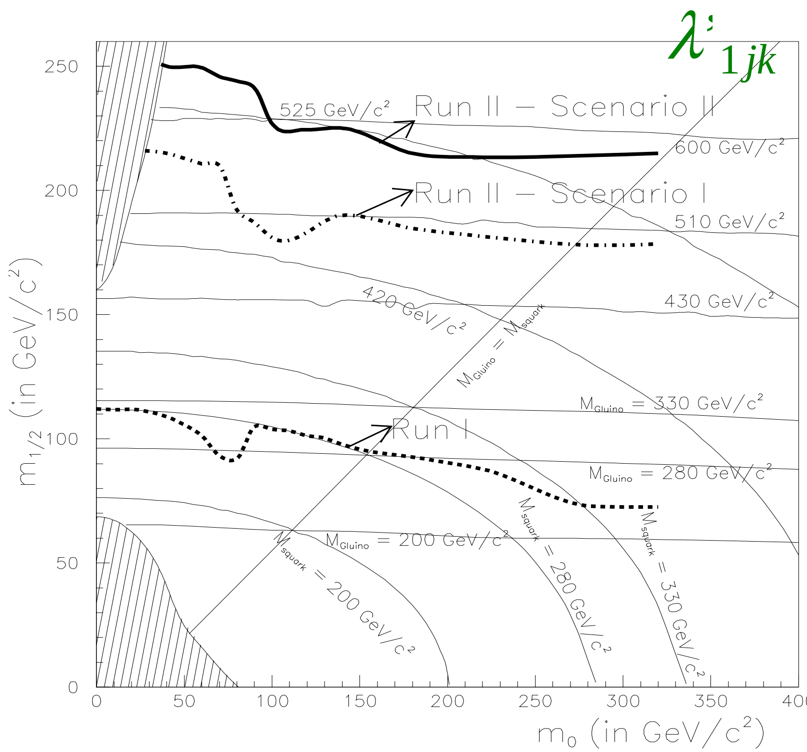
Backgrounds:

- DY + 4 jets
- $t\bar{t} \to \ell\ell +$ jets
- Fakes

[N. Parua et al.: hep-ph/9904397]

Using mSUGRA framework as a measure of sensitivity

tanβ=2, A_0=0, μ<0



Obviously we have much to gain from like-sign di-lepton events

Thoughts for Drink

- Focus on data, less on limits – keep our hope alive

- Orient analyses towards event topologies, not models
  - models are mostly wrong
  - models confuse people
  - better use resources, minimize duplication
  - fast response to theoretical fashions

- Uniform particle identifications – EB for particle IDs?
  - better documentation
  - reduce duplication
  - coherent publications

- Establish working groups with CDF

Outlook

We cannot exclude supersymmetry

then

Can we make discovery ?

Yes, we can

with an effective effort

and a little help from God