Search for Supersymmetry at DØ

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for the DØ Collaboration

Introduction

Search for Diphoton+$\not{E}_T$ Events

Search for Trilepton+$\not{E}_T$ Events

Search for Multijet+$\not{E}_T$ Events

Summary

12th Workshop on Hadron Collider Physics
Stony Brook, June 10, 1997

Minimal Supersymmetric Standard Model

Supersymmetry predicts a supersymmetric
particle for every Standard Model particle

Under R-parity conservation
supersymmetric particles are pair produced

The lightest supersymmetric particle (LSP)
is stable and weakly interacting
escaping detection $\Rightarrow \not{E}_T$

MSSM is the simplest supersymmetric model

(1) add an extra Higgs doublet of opposite hypercharge

(2) supersymmetrization of the gauge theory

In the framework of MSSM

The Gaugino-Higgsino sector is parameterized by
four parameters: M_1, M_2, μ, $\tan\beta$

Gauge/Higgs Bosons: γ, Z^0, $W^\pm$, h^0, H^0, A^0, $H^\pm$, g

Neutralinos/Charginos: $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$, $\tilde{\chi}^0_3$, $\tilde{\chi}^0_4$, $\tilde{\chi}^\pm_1$, $\tilde{\chi}^\pm_2$, $\tilde{g}$

The scalar sector is parameterized by many mass parameters

lepton/quark $(\nu,e)_L$ e_R $(u,d)_L$ u_R d_R

slepton/squark $(\tilde{\nu},\tilde{e})_L$ $\tilde{e}_R$ $(\tilde{u},\tilde{d})_L$ $\tilde{u}_R$ $\tilde{d}_R$

Different SUSY breaking leads to different models

Minimal SuperGravity Model

Motivated in part by its simplicity and
by the apparent unification of the measured gauge couplings
within the minimal supersymmetric standard models

The model assumes
The scalar and gaugino mass unifications
Supersymmetry breaking is transmitted
to the visible sector through gravitational interaction

The model has four continuous
and one discrete free parameters at GUT scale

m_0	common scalar mass parameter
$m_{1/2}$	common gaugino mass parameter
A_0	common trilinear coupling
$\tan\beta$	ratio of V.E.V.
sign(μ)	sign of higgsino mass parameter

The model predicts radiative breaking
of the electroweak gauge symmetry

Entire supersymmetric mass spectrum
is described by a small number of free parameters

Minimal Supersymmetric Standard Model

Chargino and Neutralino Mass

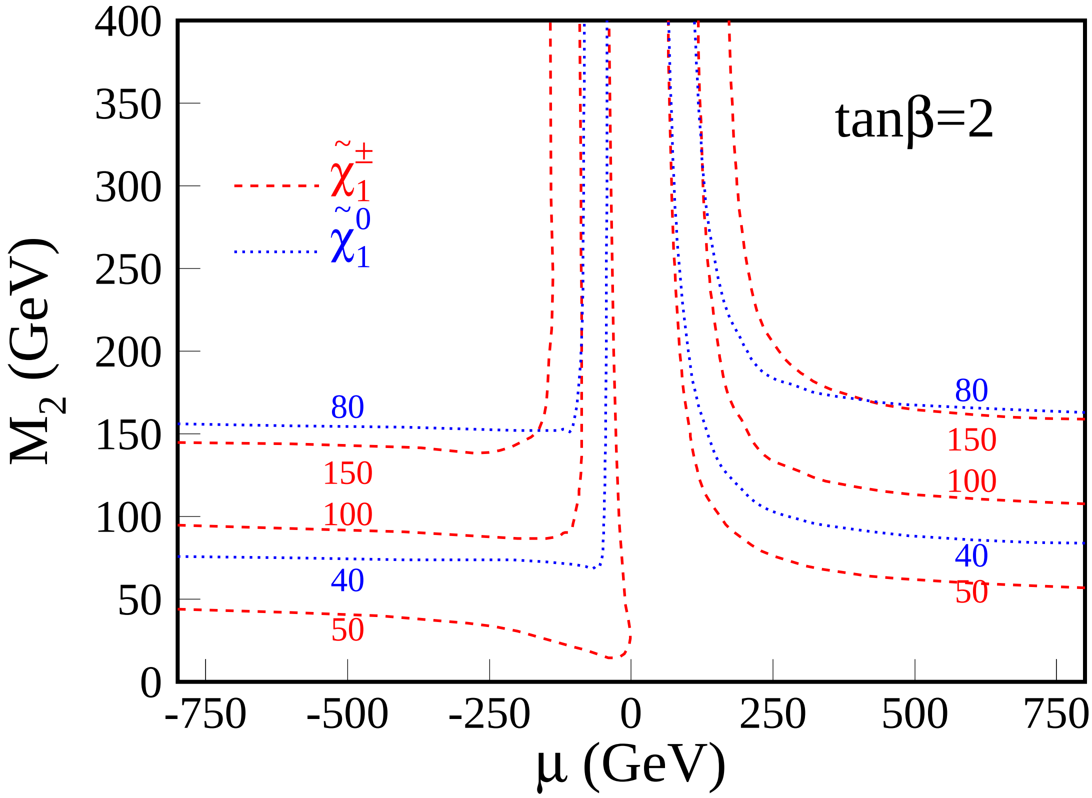
With the gaugino mass unification at the GUT scale

$$M_1 = \frac{5}{3} M_2 \tan^2\theta_W$$

The gaugino-higgsino sector is governed by
three parameters: M_2, μ, $\tan\beta$

We choose to explore (μ, M_2) space
while keeping $\tan\beta$ fixed

The chargino and neutralino masses are therefore
fixed by two parameters: μ and M_2



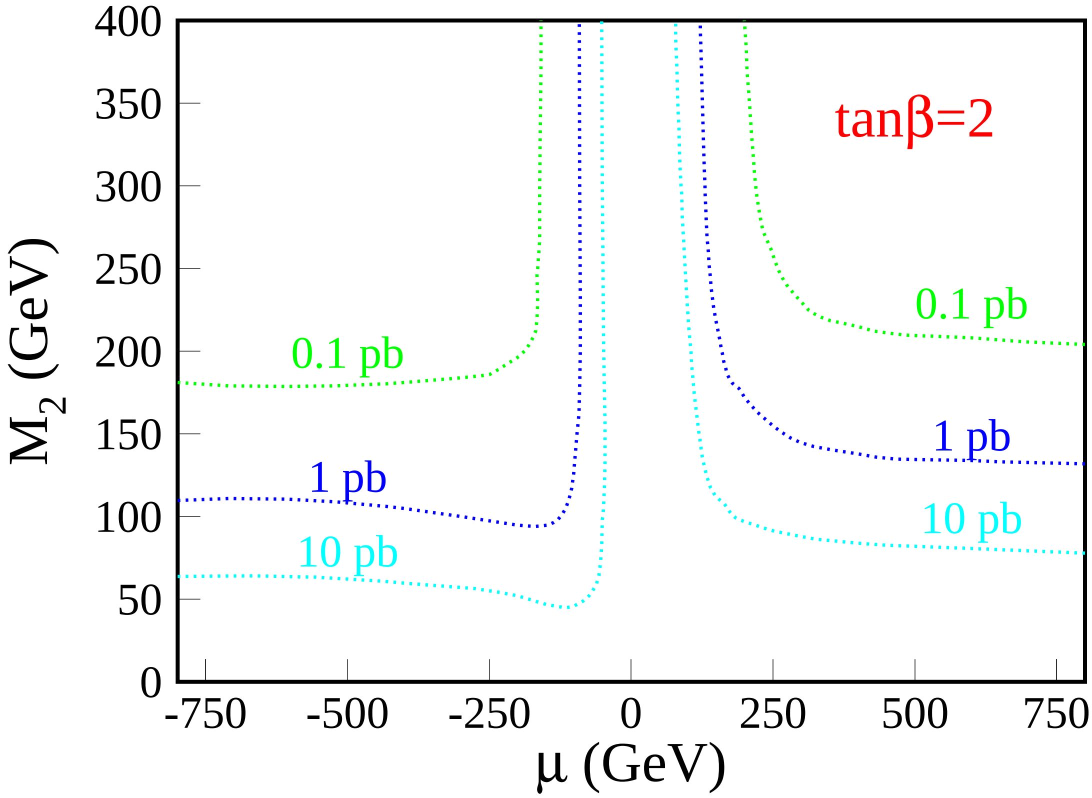
Minimal Supersymmetric Standard Model

$\tilde{\chi}_i\tilde{\chi}_j$ Production Cross Section

Pair production cross section of charginos and neutralinos
are also predicted within the model

For most part of the parameter space
the pair production is dominated by
$p\bar{p}\rightarrow\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm},\ \tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0} + X$

$p\bar{p}\rightarrow\tilde{\chi}_i^{\pm}\tilde{\chi}_j^{\pm},\ \tilde{\chi}_i^{\pm}\tilde{\chi}_j^{0},\ \tilde{\chi}_i^{0}\tilde{\chi}_j^{0} + X$



Search for Diphoton+$\not{E}_T$ Events

Why and How

$\gamma\gamma\not{E}_T$ events are expected from pair production of supersymmetric particles in models with either gauge- or gravity-mediated supersymmetry breaking

Gauge Mediated Models

Gravitino ($\tilde{G}$) is light and is the LSP

$Br(\tilde{\chi}_1^0 \rightarrow \gamma + \tilde{G}) = 100\%$

Any pair production of supersymmetric particles will result $\gamma\gamma\not{E}_T$ events

Gravity Mediated Models

Gravitino is heavy and $\tilde{\chi}_1^0$ is the LSP

$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + \gamma$

if $\tilde{\chi}_1^0$ is mostly higgsino and $\tilde{\chi}_2^0$ is mostly gaugino

Processes $p\bar{p} \rightarrow \tilde{e}\tilde{e}$, $\tilde{\nu}\tilde{\nu}$, $\tilde{\chi}_2^0\tilde{\chi}_2^0$ will result $\gamma\gamma\not{E}_T$ events

Events with two high E_T photons and large missing transverse energy with or without leptons/jets

Search for Diphoton+$\not\!\!E_T$ Events

Event Selection

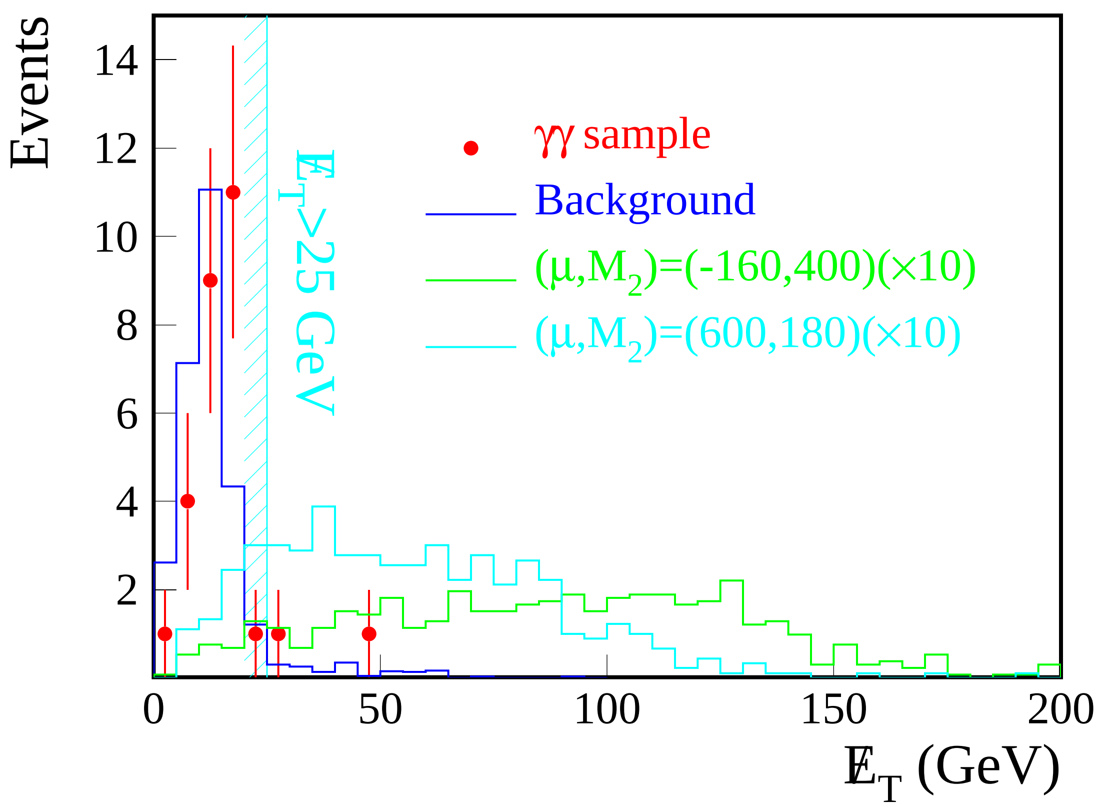
(1) $E_T^{\gamma 1}$>20 GeV $|\eta|$<1.2 or 1.5<$|\eta|$<2.0

(2) $E_T^{\gamma 2}$>12 GeV $|\eta|$<1.2 or 1.5<$|\eta|$<2.0

(3) $\not\!\!E_T$>25 GeV

No requirements on jets or other objects are made

Two events survived
from a data sample of 106 pb^{-1}



Search for Diphoton+$\not\!E_T$ Events

QCD Background

Multijet and direct photon events with
misidentified photons and/or mismeasured $\not\!E_T$
will fake $\gamma\gamma\not\!E_T$ events

This background is estimated
using events with two EM-like clusters

By normalizing the observed $\not\!E_T$ distributions
a background of 2.1±0.9 events is obtained

W-Like Background

Events with genuine $\not\!E_T$ such as those from
$W+\gamma$, $Z\rightarrow\tau\tau\rightarrow ee$, $t\bar{t}\rightarrow ee$+jets would fake $\gamma\gamma\not\!E_T$
events if the electrons were misidentified as photons

We estimate their contribution using a sample
of $e+\gamma$ events passing the kinematic requirements

Applying the electron rejection factor from the photon ID
a background of 0.2±0.1 events is obtained

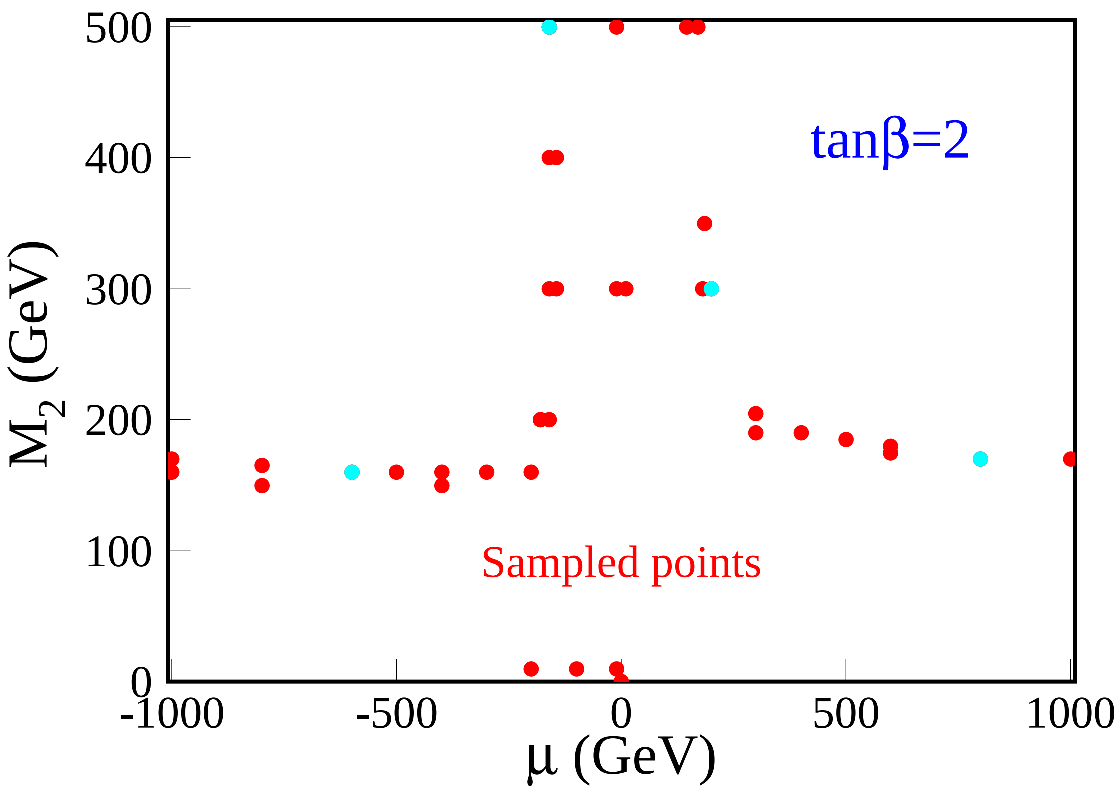
Total number of background events 2.3±0.9

Gauge Mediated Supersymmetry Models

Signal Efficiencies

Pair production of charginos and neutralinos
is modeled using SPYTHIA Monte Carlo program

μ (GeV)	M_2 (GeV)	$m(\tilde{\chi}^0_1)$ (GeV/c^2)	$m(\tilde{\chi}^{\pm}_1)$ (GeV/c^2)	ε_K(%)	ε (%)
-160	500	156	167	66.0	33.4
-600	160	83	166	58.0	18.4
200	300	118	160	66.8	27.9
800	170	83	162	58.7	25.4



Gauge Mediated Supersymmetry Models

Limits on the Total Cross Section

Based on 2 events observed, 2.3±0.9 events expected
we set a 95% CL cross section limit
for every parameter point sampled

The 95% CL cross section limits are

$\sigma < 140$ fb for $(\mu, M_2) = (-160, 500)$ GeV

$\sigma < 260$ fb for $(\mu, M_2) = (-600, 160)$ GeV

Limits on the Observable Cross Section

The detecting efficiency for events passing the kinematic
requirements at the parton level is typically ~40%

The 95% CL cross section limits are

$\sigma_D < 95$ fb for $m(\tilde{\chi}_1^0) = 156$ GeV, $m(\tilde{\chi}_1^\pm) = 167$ GeV

$\sigma_D < 151$ fb for $m(\tilde{\chi}_1^0) = 83$ GeV, $m(\tilde{\chi}_1^\pm) = 166$ GeV

These limits are less model-dependent

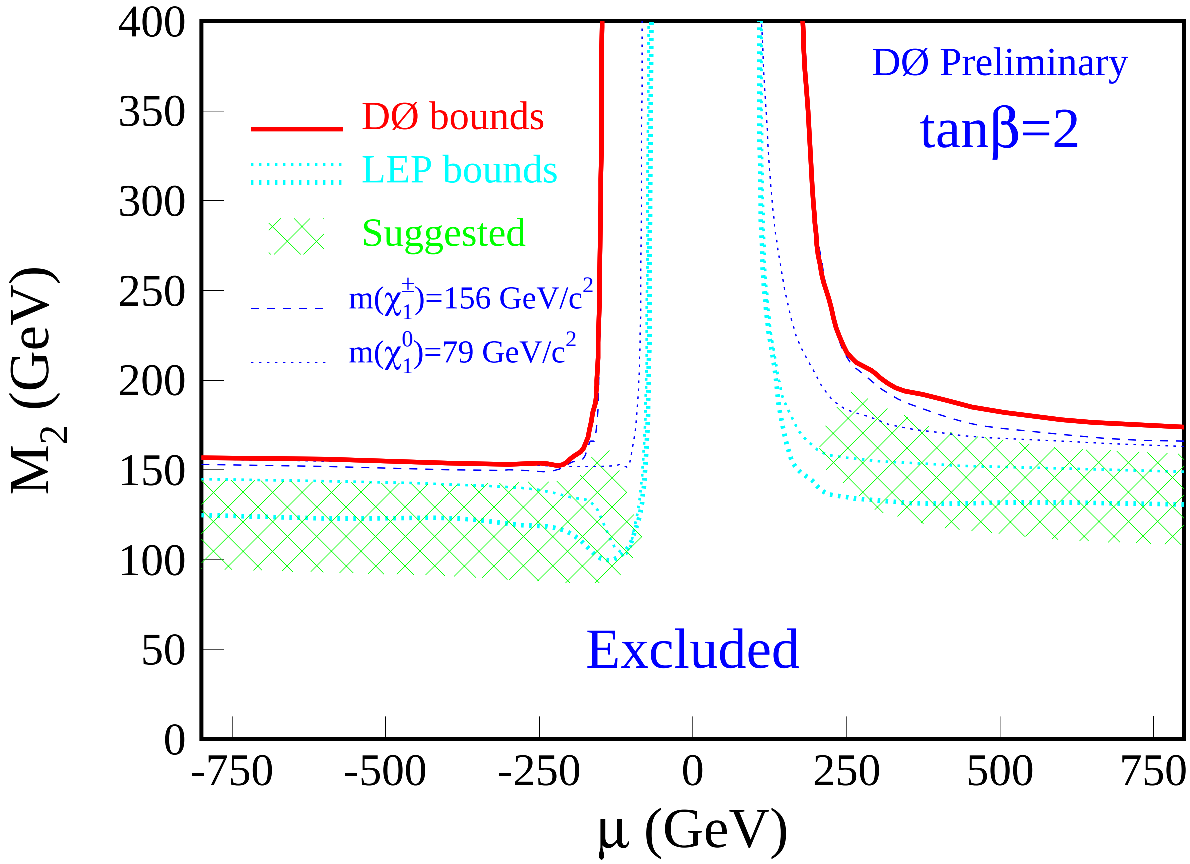
Gauge Mediated Supersymmetry Models

Bounds in (μ, M_2) Plane

The cross section limits constrain
the supersymmetry parameters μ and M_2

We set 95% lower mass limits
$m(\tilde{\chi}_1^{\pm}) > 156$ GeV/c^2
$m(\tilde{\chi}_1^{0}) > 79$ GeV/c^2

Suggested: $\tilde{\chi}^+\tilde{\chi}^- \rightarrow ee\gamma\gamma\,\nu\nu\tilde{G}\tilde{G}$

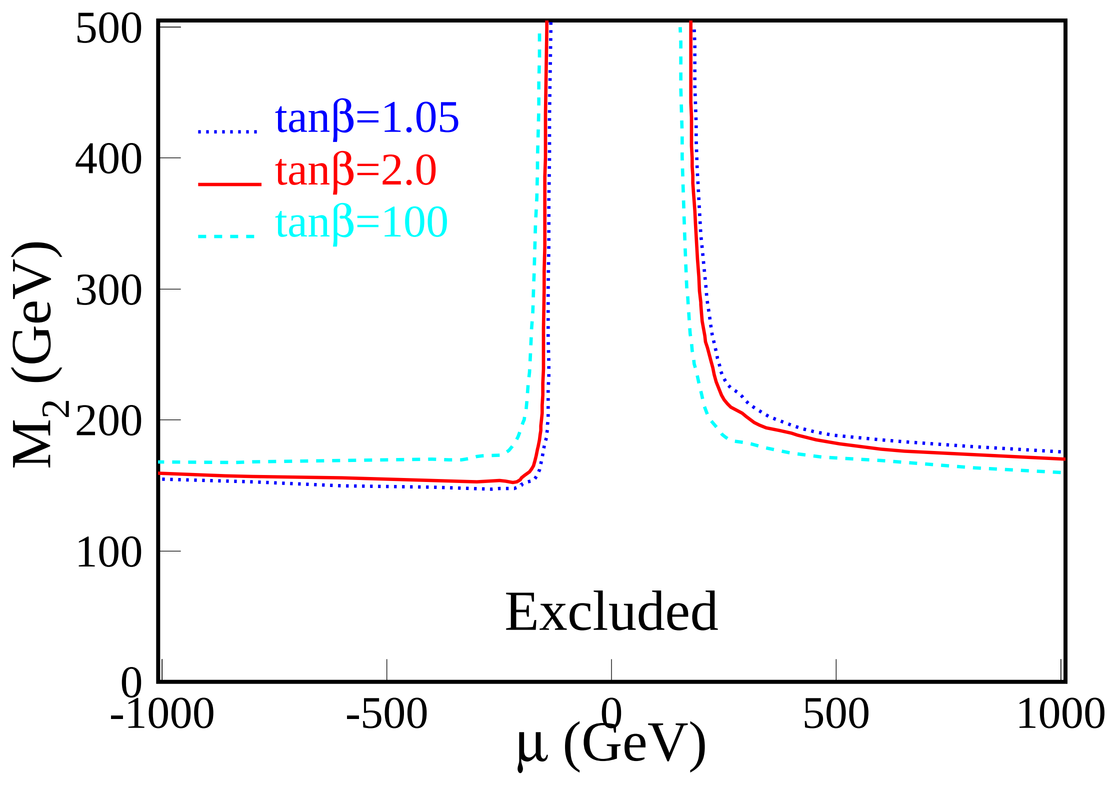


Gauge Mediated Supersymmetry Models

tanβ Dependence

The bounds depend on the value of
tanβ slightly, due to the tanβ dependence
of the expected cross section

As tanβ is increased, the limits become
stronger in the μ<0 half-plane
and weaker in the other half-plane



Gauge Mediated Supersymmetry Models

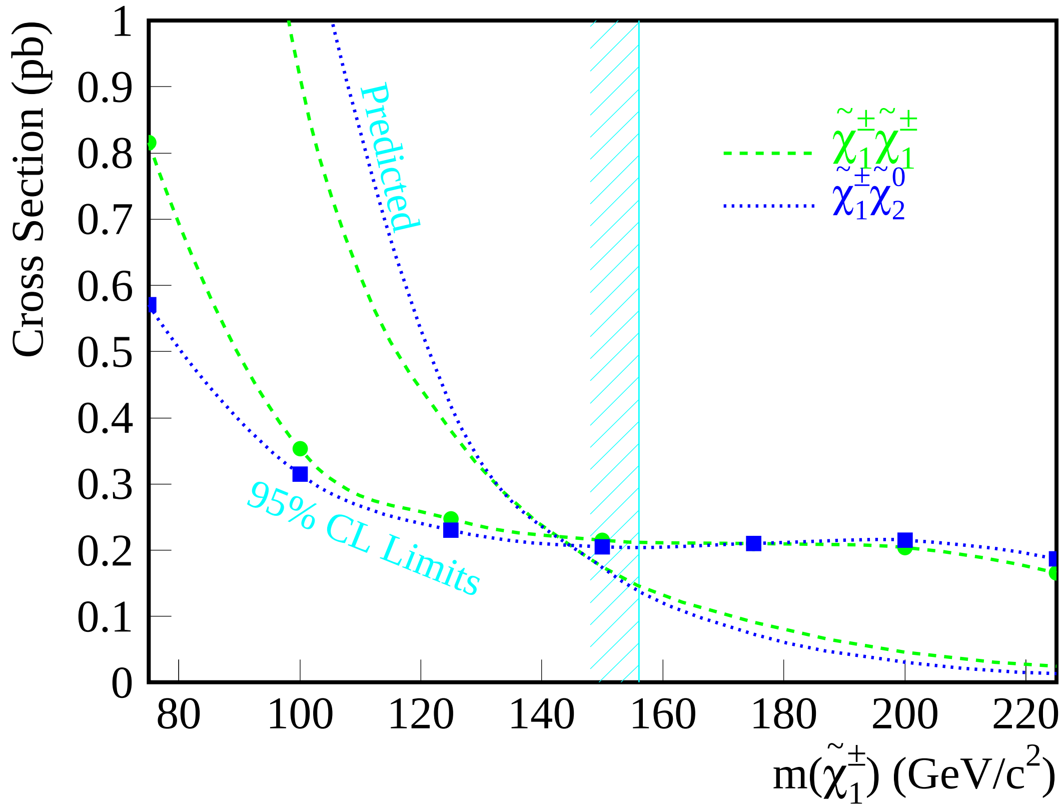
Limits for $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ Productions

$p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{0}$ dominates
pair production of charginos and neutralinos

For a large part of the parameter space

$$m(\tilde{\chi}_1^{\pm}) \approx m(\tilde{\chi}_2^{0}) \approx 2m(\tilde{\chi}_1^{0})$$

For a heavy $\tilde{\chi}_1^{\pm}$
the upper cross section limit is ~200 fb



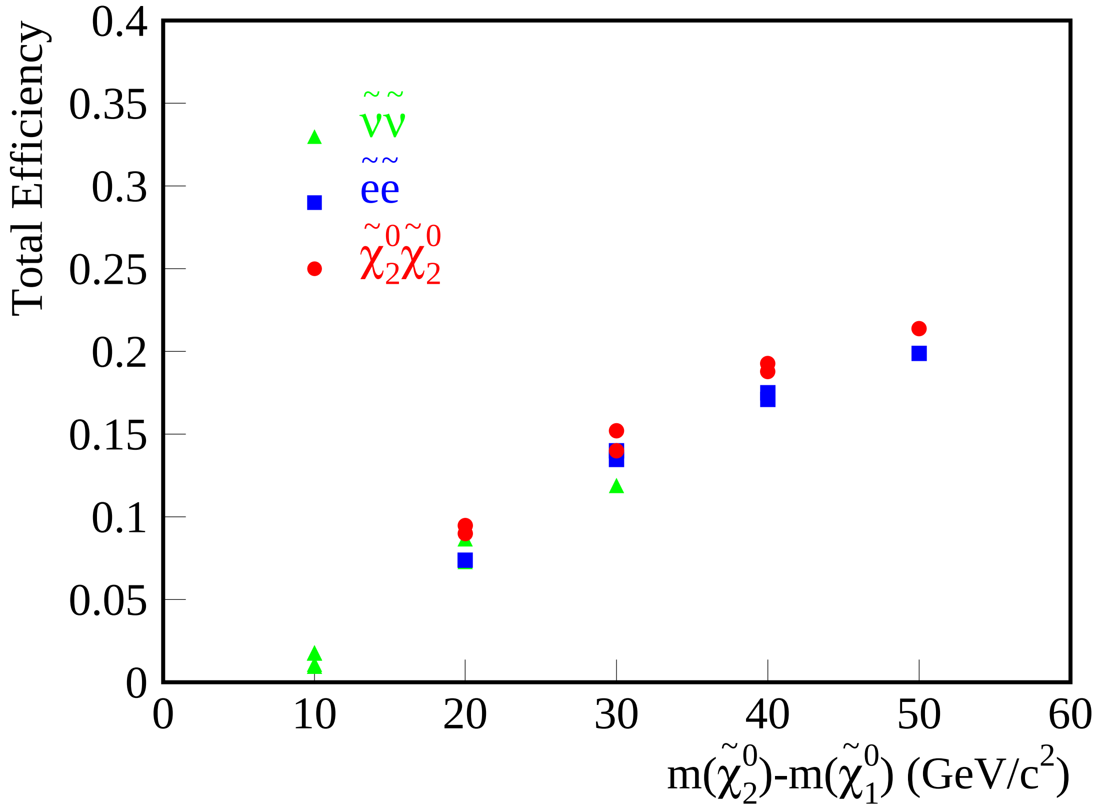
Gravity Mediated Supersymmetry Models

Signal Efficiencies

The productions and decays of $\tilde{e}\tilde{e}$, $\tilde{\nu}\tilde{\nu}$, $\tilde{\chi}^0_2\tilde{\chi}^0_2$
are modeled using ISAJET Monte Carlo program

Since $\tilde{\chi}^0_2 \rightarrow \tilde{\chi}^0_1 + \gamma$
The event topology is largely determined by
the mass difference between $\tilde{\chi}^0_2$ and $\tilde{\chi}^0_1$

For a given $m(\tilde{\chi}^0_2)$-$m(\tilde{\chi}^0_1)$
the efficiency is almost independent of the processes



Gravity Mediated Supersymmetry Models

Cross Section Limits

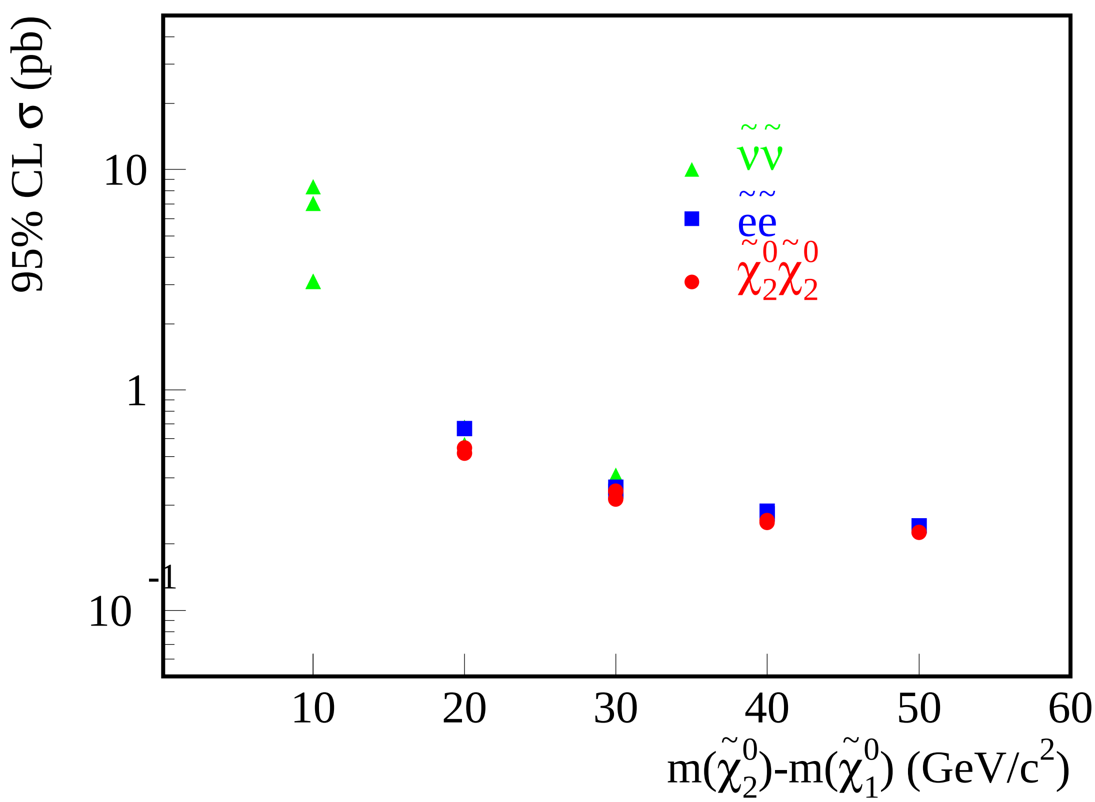
For $m(\tilde{\chi}_2^0)$-$m(\tilde{\chi}_1^0)$> 30 GeV/c^2

σ < 350 fb

σ_D< 150 fb

almost independent of the processes

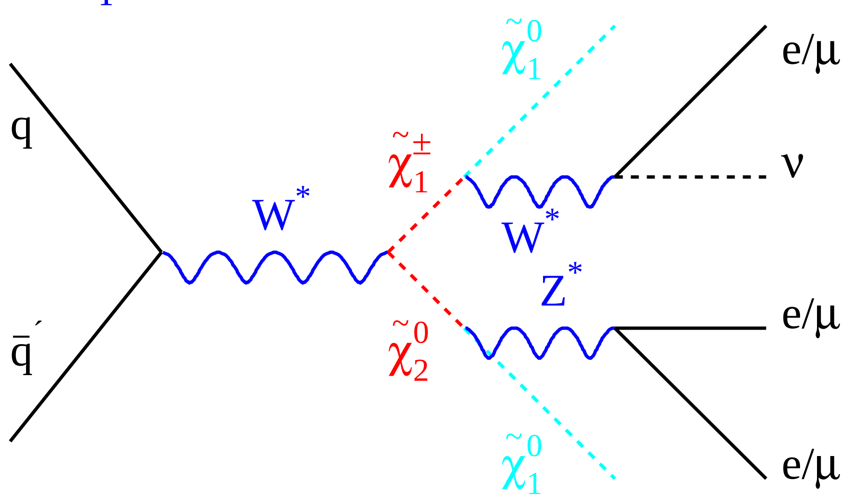
Generally, the limits are above the expected cross sections for the mass range studied



Search for Trilepton+$\not\!E_T$ Events

Why and How

The production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ will lead to trilepton events with $\not\!E_T$, one of the cleanest signature of supersymmetry



We search for eee, eeμ, eμμ and μμμ events with $\not\!E_T$ from a sample of ~100 pb^{-1} data

Event Selection

	eee	eeμ	eμμ	μμμ
Lepton E_T	Varies, but E_T>5 GeV for all leptons			
$\not\!E_T$ (GeV)	>15	>10	>10	>10
Mass (GeV/c^2)	$\|M_{ee}-M_Z\|>10$	-	$M_{\mu\mu}>5$	$M_{\mu\mu}>5$
Angle	$\|\pi-\Delta\phi_{ee}\|>0.2$	-	$\|\pi-\Delta\phi_{\mu\mu}\|>0.1$	$\|\pi-\Delta\phi_{\mu\mu}\|>0.1$

No events are selected

Search for Trilepton+$\not{E}_T$ Events

Background Estimation

Backgrounds are estimated from data whenever possible
supplemented with Monte Carlo simulations

Physics backgrounds from Standard Model processes
are expected to be very small

WZ, Zb, Wbb $\rightarrow$ eee, eeμ, e$\mu\mu$, $\mu\mu\mu$

Primary sources of background are single lepton
and dilepton events with one or more spurious leptons

eee: $Z/\gamma(\rightarrow ee)$+\`e´

eeμ: $Z/\gamma(\rightarrow ee)$+\`μ´

e$\mu\mu$: $Z/\gamma(\rightarrow \mu\mu)$+\`e´, $J/\psi(\rightarrow \mu\mu)$+\`e´

$\mu\mu\mu$: $Z/\gamma(\rightarrow \mu\mu)$+\`$\mu$´, $J/\psi(\rightarrow \mu\mu)$+\`$\mu$´

Total estimated background is 1.3±0.4

(0.34±0.07, 0.61±0.36, 0.11±0.04, 0.20±0.04)

Search for Trilepton+$\not{E}_T$ Events

Theoretical Interpretation

With no events observed
we have no evidence for the supersymmetry

ISAJET program is used to model $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ production
within the minimal SuperGravity Model

The model parameters are chosen to give
$m(\tilde{\chi}_1^{\pm}) \approx m(\tilde{\chi}_2^0) \approx 2m(\tilde{\chi}_1^0)$

We vary the mSUGRA parameters in the following ranges

$1 < m_0 < 100$ GeV/c^2

$60 < m_{1/2} < 155$ GeV/c^2

$1.5 < \tan\beta < 6$

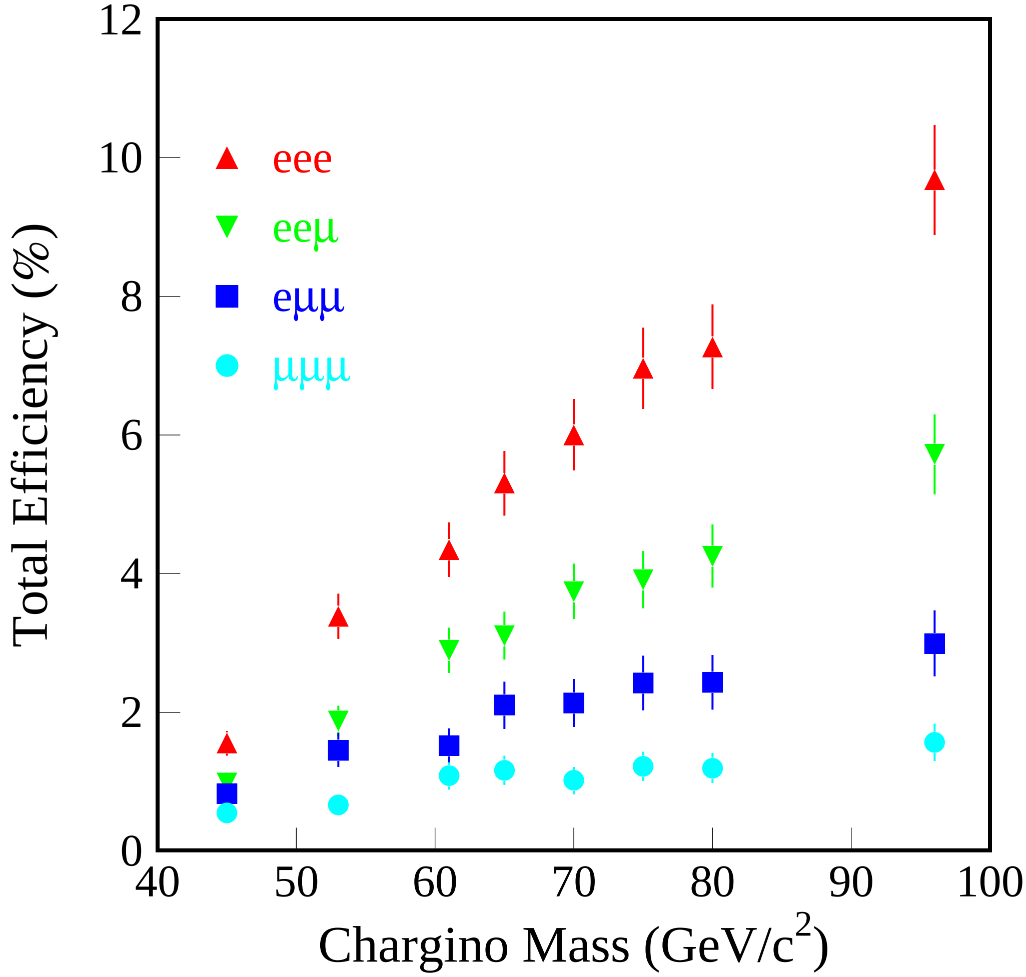
$-200 < A_0 < 200$

sign of the Higgsino mass parameter μ

Search for Trilepton+$\not{E}_T$ Events

Signal Efficiencies

The efficiency is a strong function of the chargino mass and is smaller for channels with muons due to reduced η-acceptance and lower identification efficiency

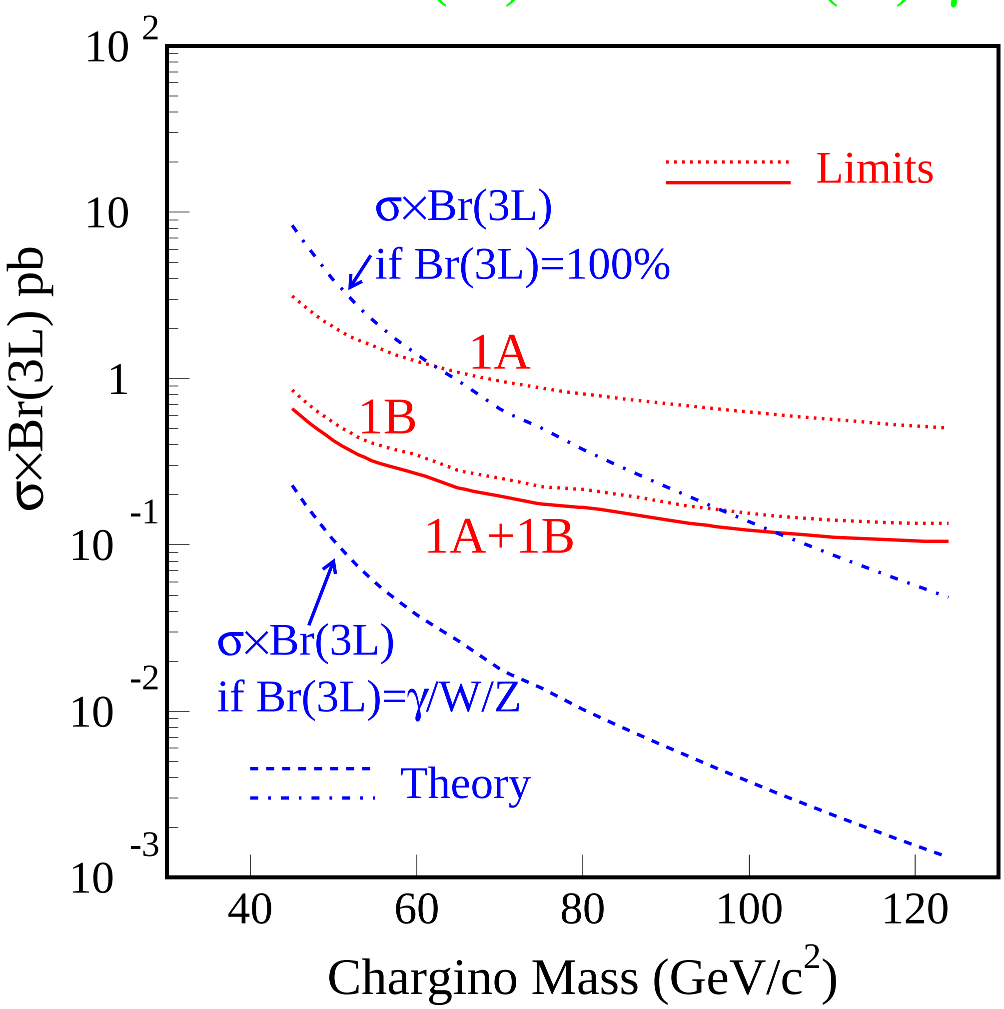


Search for Trilepton+$\not\!E_T$ Events

$\sigma\times$Br Limits

Combining all four channels and assuming that the branching fractions for the four channels are equal, we calculate the 95% CL upper limit on $\sigma\times$Br for any one channel

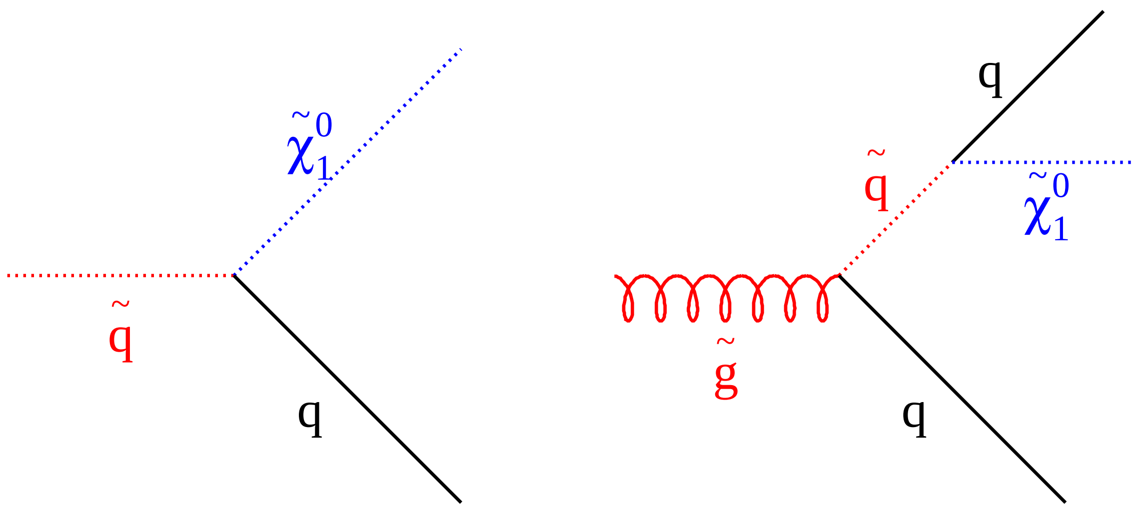
The theoretical $\sigma\times$Br(3L) is mostly between the two curves of Br(3L)=100% and Br(3L)=γ/W/Z



Search for Multijet+$\not{E}_T$ Events

Why and How

$p\bar{p} \rightarrow \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{q}\tilde{g}$+X processes
will result in multijet events with $\not{E}_T$
one of the toughest signature of supersymmetry



Direct squark and gluino decays

Cascade decay will increase jet multiplicity
and soften $\not{E}_T$ and jet E_T spectra

Event Signature

High jet activity, large missing transverse energy

We search for multijet events with large $\not{E}_T$
from a sample of 79 pb^{-1} data

Search for Multijet+$\not\!\!E_T$ Events

Event Selections

Basic Selection Criteria

At least 3 jets with E_T>25 GeV

Leading jet E_T>115 GeV

Miscellaneous cleanup requirements

Varied Selection Criteria

H_T^2 > 100, 120, 140, 150, 160 GeV

$\not\!\!E_T$ > 75, 90, 100 GeV

H_T^2=Scalar sum of jet E_T (excluding the leading jet)

Number of candidate events

3 events for H_T^2>150 GeV and E_T>100 GeV

15 events for H_T^2>100 GeV and E_T>75 GeV

Search for Multijet+$\not{E}_T$ Events

Background Estimation

Physics Backgrounds

those with genuine $\not{E}_T$ due to neutrinos in the events such as $t\bar{t}$, $W(\rightarrow e\nu,\mu\nu)$+jets and $Z(\rightarrow\tau\tau,\nu\nu)$+jets events

The number of background events from these sources is estimated using Monte Carlo events

Instrumental Backgrounds

multijet events with large $\not{E}_T$ due to mismeasurements

The number of instrumental background events is estimated by extrapolating the $\not{E}_T$ spectrum

For $H_T^2>100$ GeV and $\not{E}_T>75$ GeV
the estimated numbers of physics and instrumental background events are
5.8 ± 1.6 and 3.5 ± 2.6 respectively

Search for Multijet+$\not\!\!E_T$ Events

Theoretical Interpretation

The result is interpreted within
the minimal SuperGravity Model by fixing three parameters
to $\tan\beta=2$, $A_0=0$, μ=negative

Therefore, the production cross sections and
squark/gluino masses are determined by m_0 and $m_{1/2}$

Next-to-leading order cross sections
calculated by the PROSPINO program are used

ISAJET program is used to model
the productions and decays of squarks and gluinos

m_0(GeV)	$m_{1/2}$(GeV)	σ(pb)	$\not\!\!E_T$>(GeV)	H_T^2>(GeV)	ε(%)
50	70	25.6	75	100	2.7
100	60	36.1	75	100	2.2
250	110	0.2	75	160	10.7
400	60	4.4	75	120	2.5

The detection efficiency is typically a few percent

Summary

We have searched for diphoton+$\not{E}_T$, trilepton+$\not{E}_T$,
and multijet+$\not{E}_T$ events at DØ

Such events are expected from
productions of supersymmetric particles

No excess of events beyond those expected from
background processes are observed

The null results are interpreted
in various supersymmetric models

And the journey continues...