Status of SUSY searches

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What this talk will not be:

- an introduction to SUSY (you are all experts)
- a discussion of cosmological implications (my own inability)
- a comprehensive review (half-an-hour)

What it will address:

- the LEP legacy (no experimental details)
- recent results from the Tevatron

In which framework ?

- mostly “standard” SUSY, i.e.(C)MSSM / mSUGRA
- some GMSB (clean and simple)
- no RPV (too many equally acceptable scenarios, no DM)

[Apologies to our HERA colleagues]

Standard SUSY:

- The MSSM with some unification conditions
- R-parity conservation
- Neutralino LSP

At LEP:

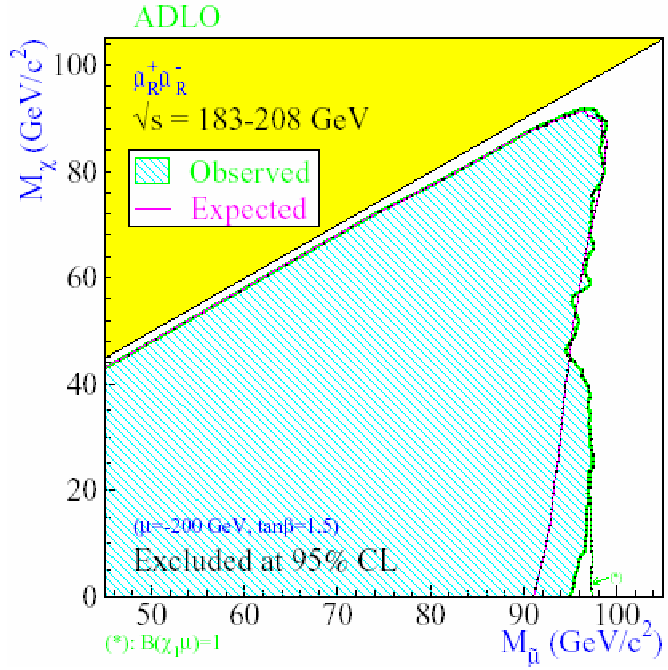
- All sparticles democratically produced (not the gluino…)
- Search for the next-to-lightest one(s) and express the results in a model-independent (or moderately dependent) way
- Combine the results within some constrained framework

At the Tevatron:

- Colored sparticles (squarks and gluinos) have the largest production cross sections, but backgrounds are also large
- Electroweak gauginos have small cross sections, but benefit from clean signatures (will win in the end…)
- Hard to get away from highly constrained models

A simple case at LEP: smuons

- Pair production only via s-channel γ/Z exchange
  $\Rightarrow m_{s\mu}$ = 1st parameter
- Assume $s\mu_R$ is NLSP
  ($s\mu_L$ is heavier in typical unified models,
  and would have larger cross section)
  Only decay mode: $s\mu_R \rightarrow \mu\chi$
  $\Rightarrow m_\chi$ = 2nd parameter



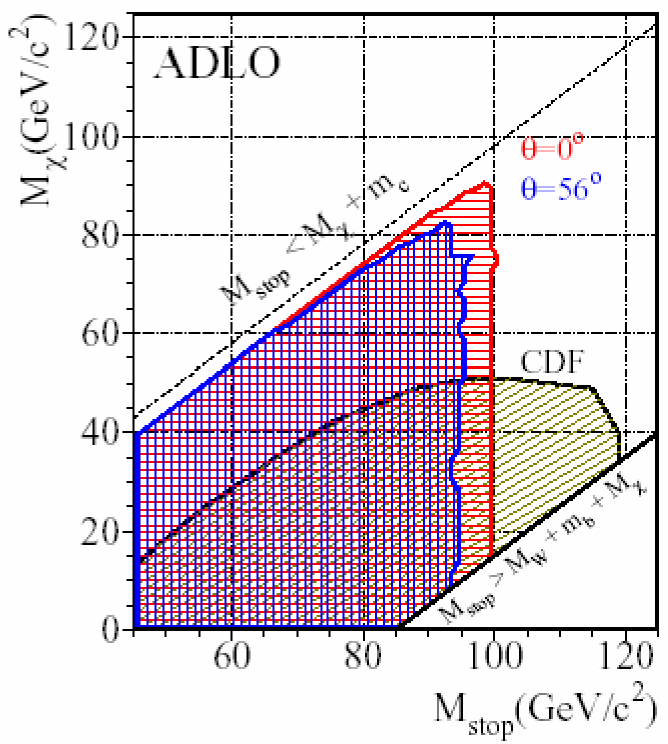
- Signature = acoplanar pair of muons
  Well controlled background: $WW \rightarrow \mu\nu\mu\nu$
- With gaugino mass unification,
  cascade decays ($s\mu_R \rightarrow \mu\chi'$ with $\chi' \rightarrow \chi\gamma$) can be taken into account

Other sleptons are more model dependent:

- Staus because of L-R mixing (Z-$s\tau_1$-$s\tau_1$ coupling may vanish)
- Selectrons because of t-channel neutralino exchange

Another simple case at LEP: stops

- Squarks are more efficiently searched at the Tevatron but…
- st_1 could be (very) light because of renormalization and mixing effects (both due to large topYukawa)
- For st_1 NLSP, $st_1 \rightarrow c\chi$ (loop decay)
  Window for LEP at small/moderate
  $st_1 - \chi$ mass difference
  Search in acoplanar jet topology
  Needed dedicated generator because of competing decay and hadronization times



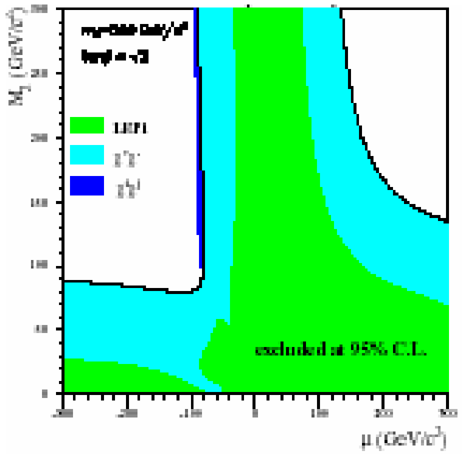
- For very small mass differences, specific searches have been performed for stop-hadrons with macroscopic decay lengths, and for (quasi) stable stops

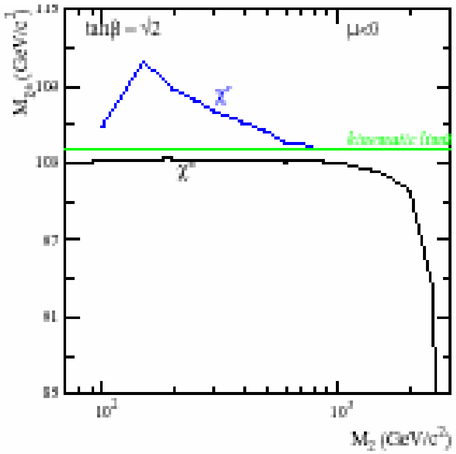
Charginos and neutralinos at LEP (I)

Chargino pair production (neutralino pair or associated production) involves s-channel γ/Z exchange, which depends on the field content, as well as t-channel sneutrino (selectron) exchange.

- First assume heavy sleptons $\Rightarrow$ s-channel only + decays to χW^* (χZ^*)
- Charginos are then fully described in terms of M_2, μ and $\tan\beta$
- Neutralinos need M_1 in addition: Assume unification ($M_1 \sim M_2/2$)

$\Rightarrow$Direct and indirect mass limits





Search extended to very small $\chi^+ – \chi$ mass differences

(ISR tagging, stable charged particles)

Applies to the deep higgsino region, or in AMSB models (M1~M2)

Charginos and neutralinos at LEP (II)

The impact of light sleptons:

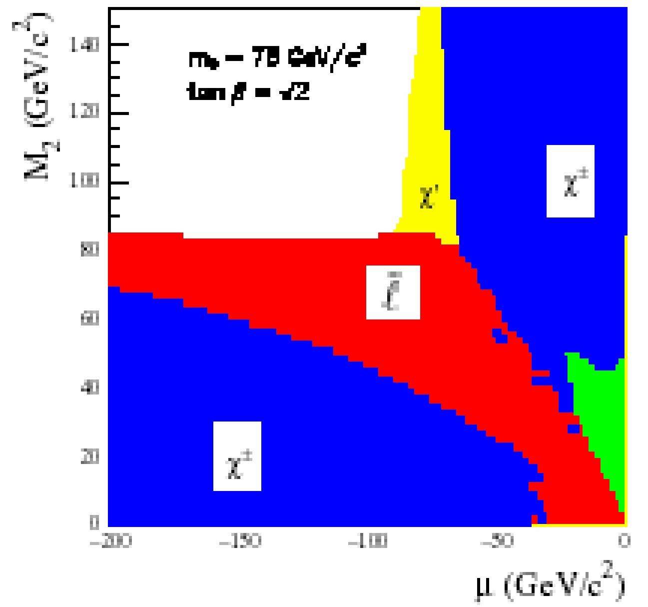
- Reduced chargino cross section (negative interference)
- Enhanced neutralino production (positive interference)
- Invisible decay modes: $\chi' \to \nu\, s\nu_L$
  or $\chi^+ \to l\, s\nu_L$ with small $\chi^+ - s\nu_L$ mass difference (the "corridor")

$\Rightarrow$ Use slepton searches and
assume scalar mass unification

$$m^2_{\tilde{\ell}_R} = m_0^2 + 0.22 M_2^2 - \sin^2\theta_W m_Z^2 \cos 2\beta$$

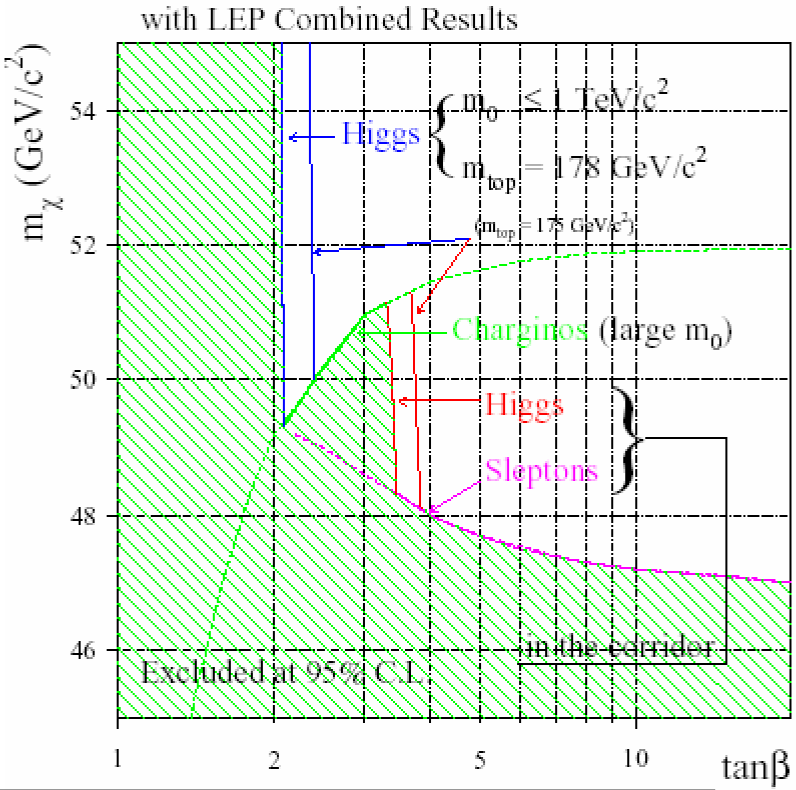
For m_0 and $\tan\beta$ given, a slepton mass limit gives a constraint on M_2

$\Rightarrow$ Robust chargino mass limit



The LSP mass limit at LEP

- There is no absolute neutralino-LSP mass limit from LEP
  ($e^+e^- \to \chi\chi$ vanishes for a pure photino and heavy selectrons)
- Indirect limits have been obtained under the assumption of gaugino mass universality
- For large slepton masses:
  ~ $m_{\chi+}/2$ (52 GeV) at large tanβ, somewhat lower otherwise
- For low slepton masses, scalar mass universality is also needed
  (The limit is set in the "corridor")
- And finally Higgs searches are used at low tan β…



The impact of stau mixing has recently been investigated: no loophole

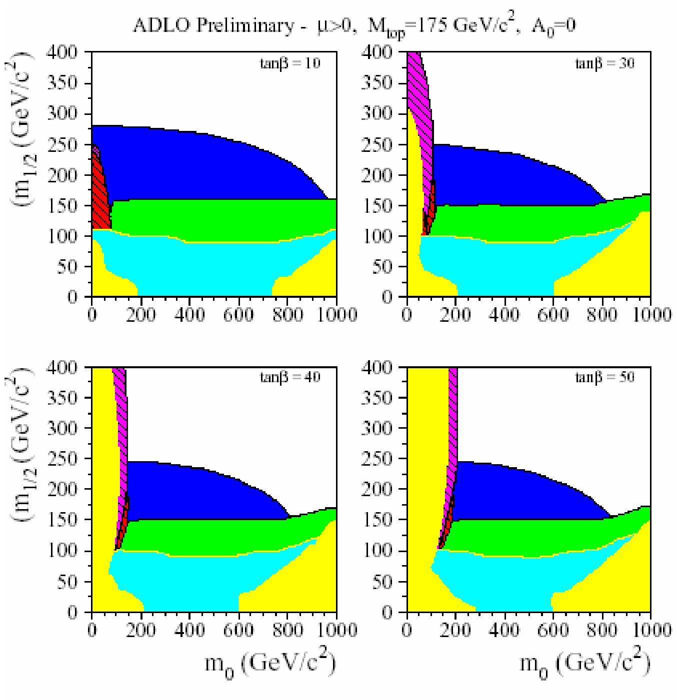
On the LEP Higgs constraints

- Assume scalar (sfermions only) and gaugino mass unifications
  (${m_A}$ and μ remain free parameters, compared to mSUGRA)
- m_0, $\tan\beta$ and $M_2 \Rightarrow$ masses of st_L and st_R
- maximal impact of stop mixing + large $m_A \Rightarrow m_{h\text{-max}}$
- for large m_A, h is SM-like $\Rightarrow$ compare to SM-Higgs limit
- This provides an upper limit on M_2, given m_0 and $\tan\beta$, which is most constraining at low m_0 and low $\tan\beta$

- However, configurations exist for m_h < SM-Higgs limit, which are not excluded by SM-Higgs searches (e.g. $h \rightarrow bb$ vanishes)
- Need to supplement SM-Higgs searches by other ones: hA, H^+H^-, invisible, flavor independent + SUSY particles
- Perform a parameter scan (with dichotomies as appropriate)
- Result: the SM-Higgs limit is robust, and hence was adequately used to set the LSP mass limit

mSUGRA at LEP

- Compared to the previous LSP-mass analysis, m_A and μ are no longer free parameters, A_0 controls all sfermion mixings



Excluded by…

theory

the Z width

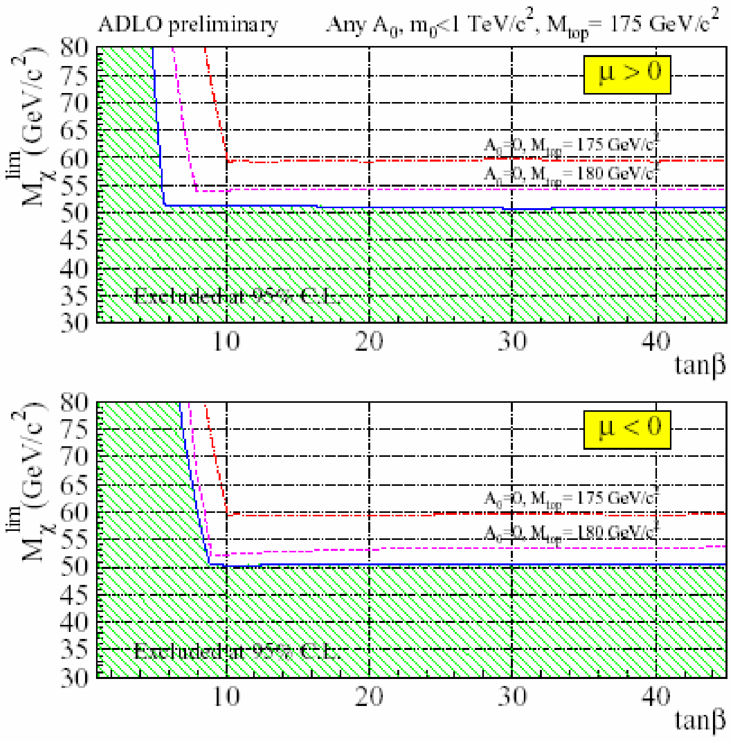
chargino

Higgs

slepton

stable particle

… searches

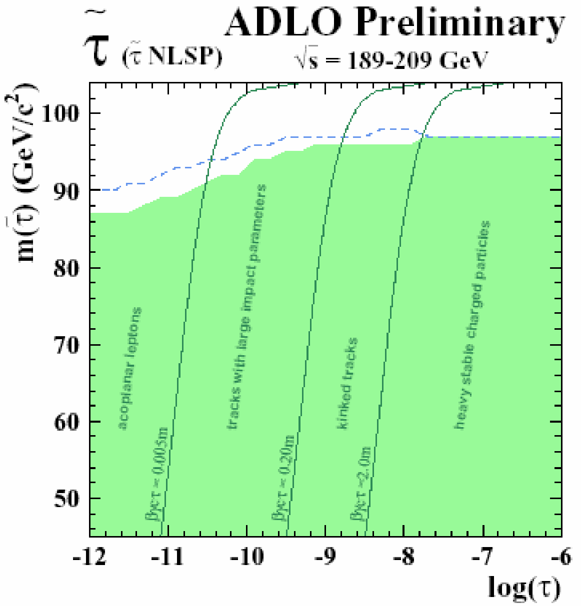


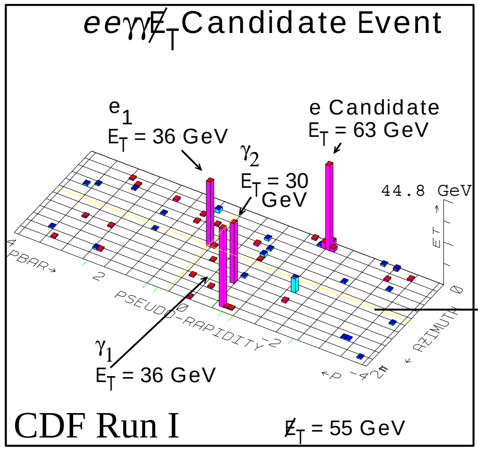
A bit of GMSB at LEP

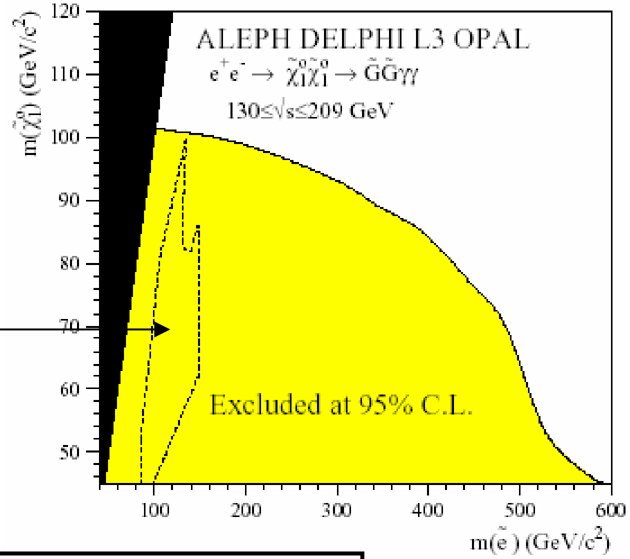
- In GMSB, the LSP is a (very light) gravitino G
- The phenomenology depends mostly on the nature (and lifetime) of the NLSP:

A slepton, preferably a stau: $s\tau_1 \rightarrow \tau$ G

A neutralino: $\chi \rightarrow \gamma$ G







Interpretations within mGMSB are available

GMSB at the Tevatron (I)

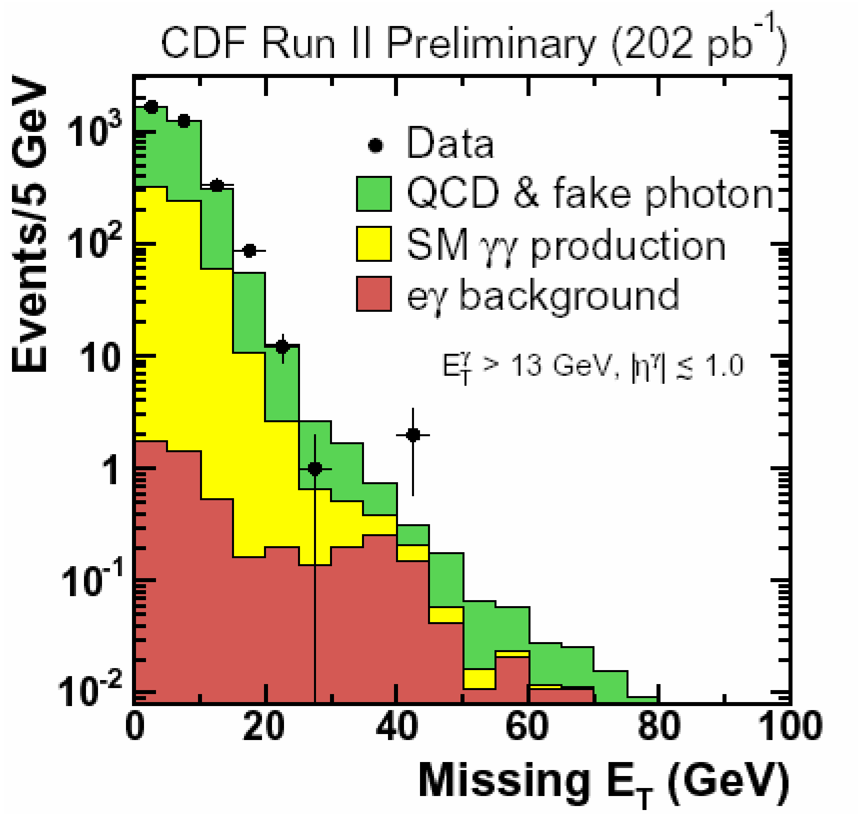
Inclusive searches for $\gamma\gamma$ + Missing E_T by both CDF / DØ

Photon = electron without track

- Photon ET > 13 / 20 GeV
- Missing ET > 45 / 40 GeV
- Mild topological cuts

Main backgrounds:
- EM-jets (or real QCD photons) + fake Missing ET
- electron + photon + real Missing ET

All determined from the data



CDF : 0 vs 0.6 expected
DØ : 1 vs 2.5 expected

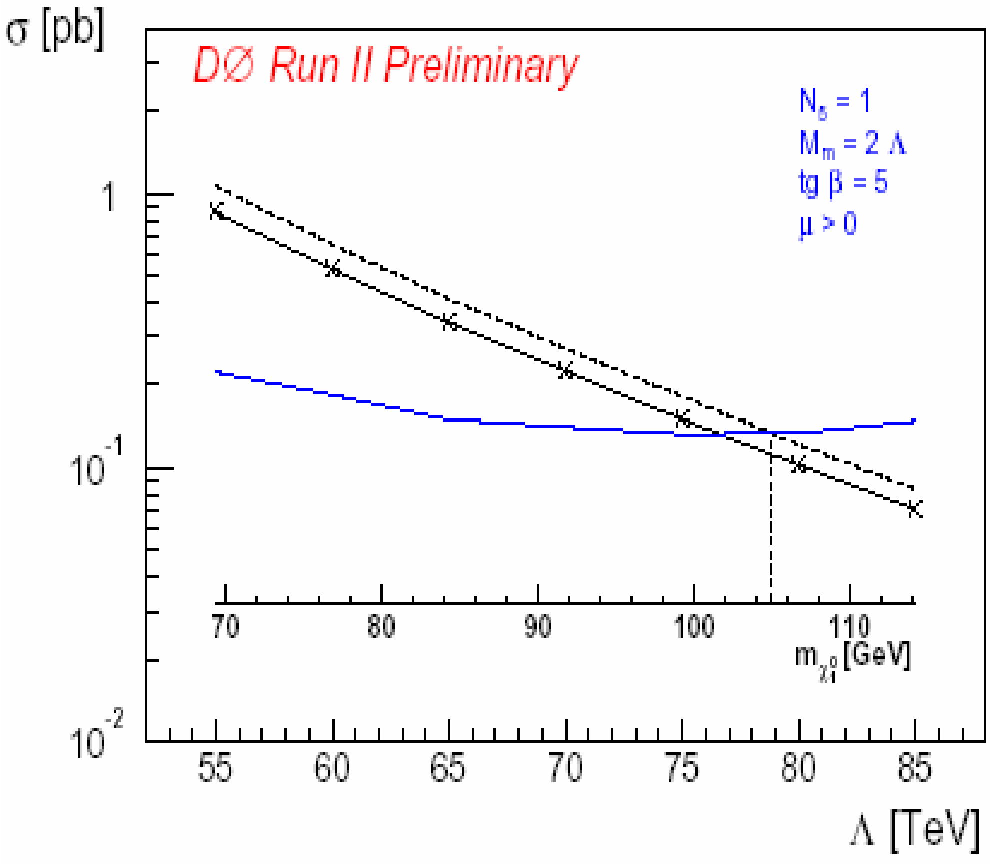
GMSB at the Tevatron (II)

Interpretation within mGMSB with:

- $N = 1$
- $M_{messenger} = 2\Lambda$,
- $\mu > 0$,
- $\tan\beta = 15$ (CDF) or 5 (DØ, aka "Snowmass slope")

Signal dominated by chargino-neutralino production

World best limit:
$m_\chi > 105$ GeV

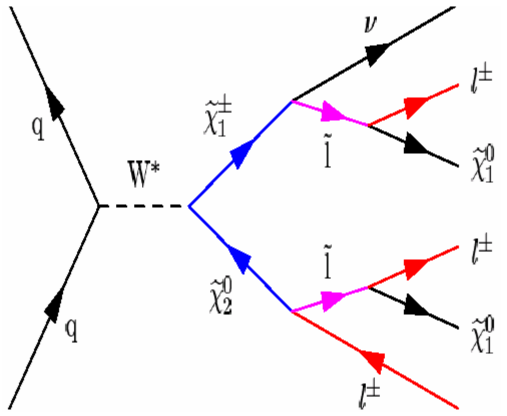


Trileptons at the Tevatron (I)

- Arise from chargino-neutralino associated production
- Clean signature but:
  - low cross sections ($\times$ BR)
  - soft leptons
  - taus (at large tanβ)

$\Rightarrow$ Needs large integrated luminosity

$\Rightarrow$ Combine various final states



(Also decays via W/Z exchange)

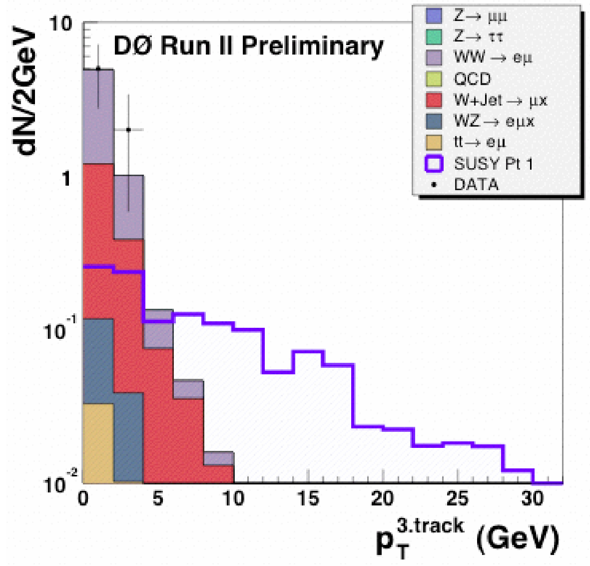
DØ analysis based on 145 – 175 pb^{-1}

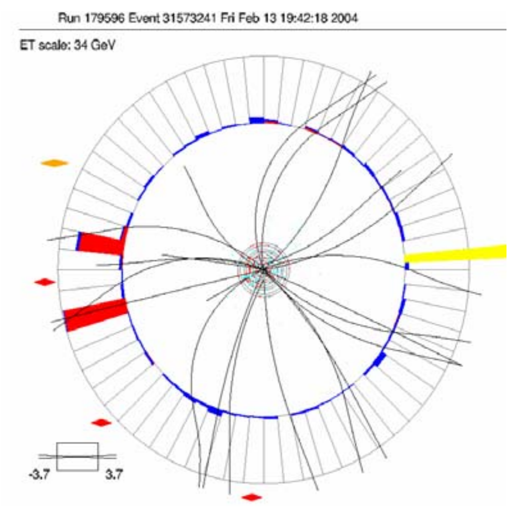
Combines eel, eμl and same sign dimuon final states

Addresses "just beyond LEP" mSUGRA

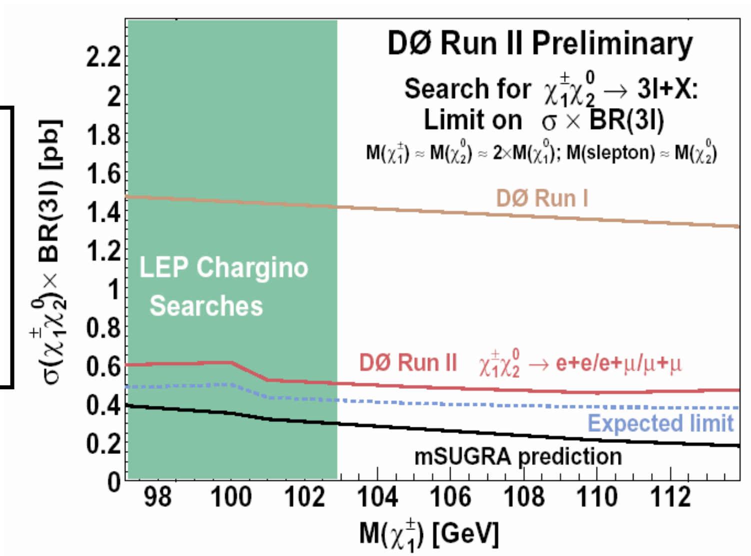
Trileptons at the Tevatron (II)

Two isolated (rather soft) e or μ
Require some Missing E_T
+ channel-dependent cuts (e.g. anti Z)
- Two same sign muons, or
- An isolated third track (no e or μ ID)
Main backgrounds: WW, WZ, Wγ, a bit of bb
Altogether: 2 events observed vs 0.9 ± 0.5 expected





Substantial improvement wrt Run I
Should soon probe virgin mSUGRA territory



Stop and sbottom at the Tevatron

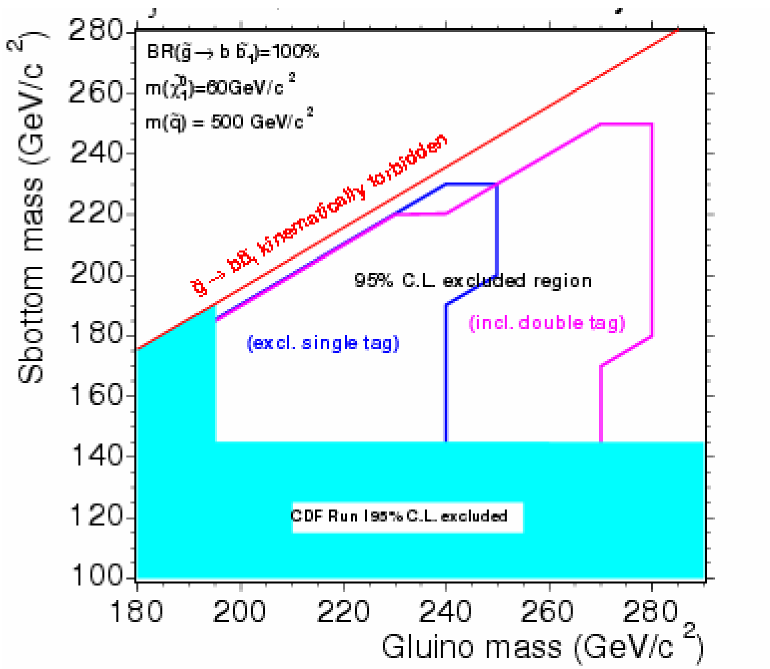
CDF has searched for charged massive particles in 53 pb^{-1}

- appear as slow moving (TOF) high p_T muons
- result interpreted for (meta)stable stop

$\Rightarrow$ m_{stop}>108 GeV (isolated) or 95 GeV (non-isolated)

CDF has searched for sbottoms in gluino decays (156 pb^{-1})

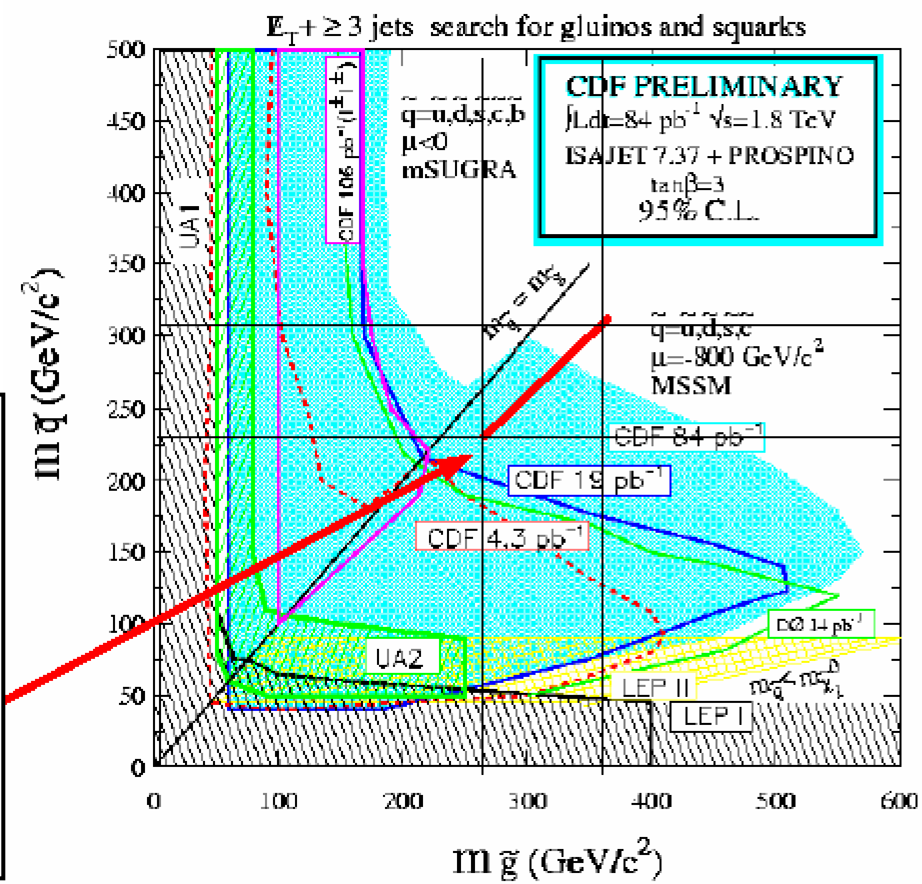
- assumes sb_1 much lighter than all other squarks (large tanβ)
- gluino $\rightarrow$ sb_1 b
  $\Rightarrow$ 4 b-jets + Missing E_T for gluino pairs
- the selection requires at least one b-tag, no isolated lepton



Generic squarks at the Tevatron (I)

Strong production of:
- sq-sqbar
- sq-sq
- sq-gl
- gl-gl

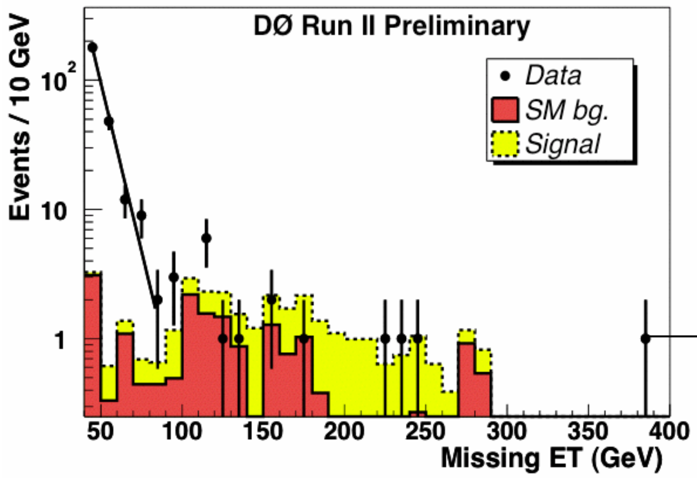
In $85pb^{-1}$, DØ has searched along the "minimum sq-mass line" of mSUGRA:
very low m_0 (25 GeV),
($\tan\beta = 3$, $A_0 = 0$, $\mu < 0$),
scan over $m_{1/2}$

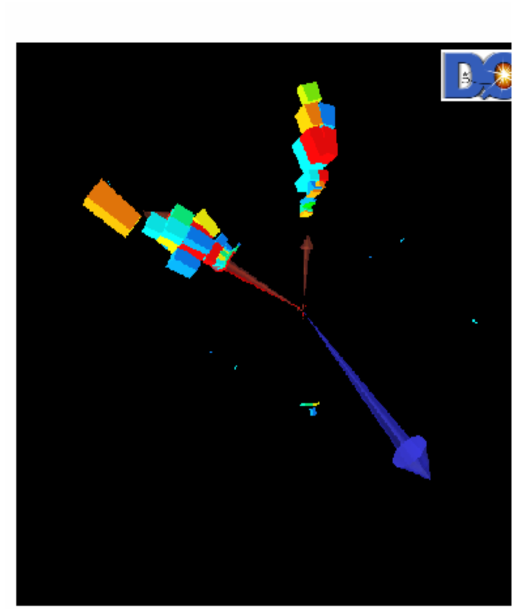


$\Rightarrow$ Mostly sq-sqbar with sq $\rightarrow$ q χ $\Rightarrow$ Acoplanar jets + Missing E_T

Generic squarks at the Tevatron (II)

Main selection cuts:
- at least two high pT jets
- isolated lepton veto
- Missing ET should not be along or opposite to a jet
- Sum of jet $p_T > 275$ GeV
- Missing $E_T > 175$ GeV





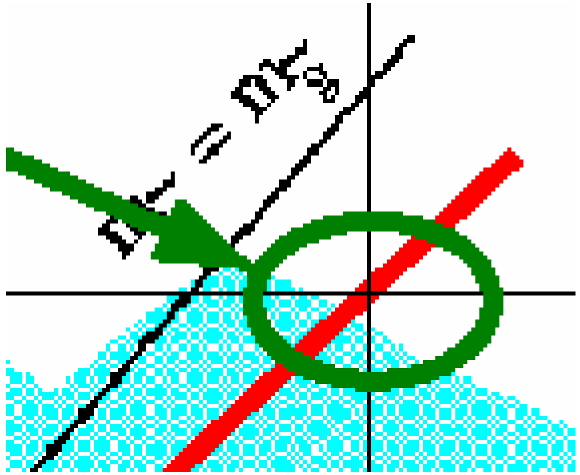
Main backgrounds left:
- $(Z \to \nu\nu)$ + jets
- $(W \to \tau\nu)$ + jets

QCD negligible

4 events selected
vs
$2.7 + 2.3 - 1.5$
expected

Generic squarks at the Tevatron (III)

Slight improvement over CDF-Run I along that "minimum sq-mass line": (m_{sq} > 292 GeV and m_{gl} > 333 GeV)



How relevant are the Tevatron results on squarks and gluinos ?

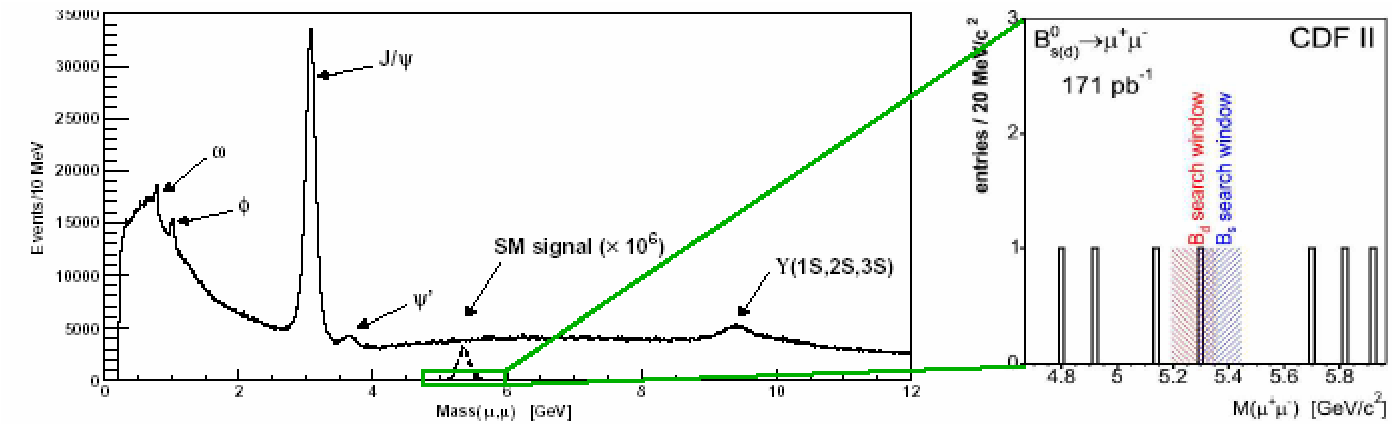
LEP slepton and chargino limits ⇒ much tighter constraints on m_0 and $m_{1/2}$ within mSUGRA (or even MSSM with unification)

The Tevatron should consider models with smaller M3/M2 ratios: not unnatural in GUTs (e.g. M3/M2 ~ 1 if SUSY breaking by a **75**) or in string inspired models

$B_s \to \mu\mu$ at the Tevatron

In SM, tiny BR ~ 3.5 10^{-9} (and 25 times smaller for B_d)
But in SUSY, a $(\tan\beta)^6$ factor could lead to an enhancement by as much as three orders of magnitude

Select dimuons originating from displaced vertices, and look inside a mass window:



CDF BR limit (95% CL): 7.5 10^{-7} (Previous best: CDF Run I < 2.6 10^{-6})
DØ: sensitivity study, but the box hasn't yet been opened…
Close to getting relevant

Conclusions

As of today, the main constraints on (RPC-) SUSY
from accelerator searches remain those established by LEP:
Slepton and chargino masses > 100 GeV

But…

The Tevatron already entered new GMSB territory:
NLSP neutralino mass > 105 GeV

Trilepton searches should provide relevant results very soon

Squark and gluino searches are well underway
(awaiting adequate interpretation)

$B_s \rightarrow \mu\mu$ is about to probe large $\tan\beta$ SUSY

…and the Tevatron luminosity is steadily increasing…