Search for top and bottom squarks

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International Europhysics Conference on High Energy Physics, Aachen, 2003

SUSY Motivation

- SUSY is a possible extension of the Standard Model to achieve unification

Third generation sparticles could be light, due to large mixing

$$\tilde{q} = \tilde{q}_L \cos\Theta_{\tilde{q}} + \tilde{q}_R \sin\Theta_{\tilde{q}}$$

- Mass matrix mixing term

$$m_q(A_q - mk)$$

$k = \tan b$ down type quarks

$k = 1/\tan b$ up type quarks

SUSY parameters:
- Ratio of vac. exp. values of two Higgs doublets: $\tan b$
- gaugino mass parameter: m_0
- common mass for scalar fermions at GUT scale: $m_{1/2}$
- Higgsino mixing parameter: m
- Trilinear coupling in the Higgs sector: A_0

Light **Stop**
Large mass splitting

Light **Sbottom**
Large tanb

ΔM = mass diff. of squark under investigation to LSP

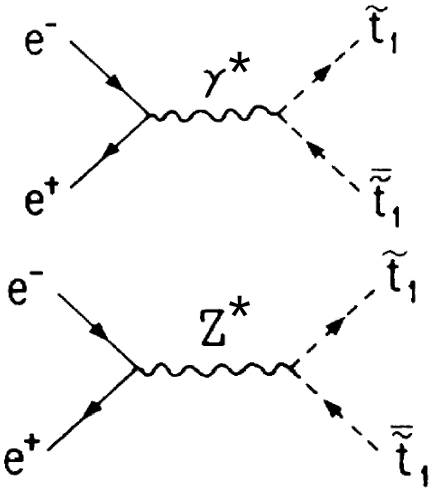
Stop and Sbottom Searches

- **Stop and Sbottom Searches at LEP II**
  - Sbottom
  - Stop (three-body decay)
  - Stop (two-body decay)
  - Stop summary (two & three-body decays)
  - Stop (four-body decay)
  - Stop nearly mass degenerated
- **Stop and Sbottom searches at the Tevatron**
  - Run I
    - Stop Search with OS dileptons
    - R_P-violating stop
  - Run II
    - Search for long lived stop
    - Sbottom from gluino decays

Stop and Sbottom Production at LEP II

LEP

EWK produced SUSY

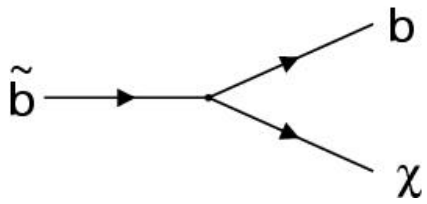


Production x-section depends on mass and mixing angle

$\Theta_{\tilde{t}} = 0^o$	max $\tilde{t}\,\tilde{t}\,Z$ coupling
$\Theta_{\tilde{t}} = 56^o$	min $\tilde{t}\,\tilde{t}\,Z$ coupling
$\Theta_{\tilde{b}} = 0^o$	max $\tilde{b}\,\tilde{b}\,Z$ coupling
$\Theta_{\tilde{b}} = 68^o$	min $\tilde{b}\,\tilde{b}\,Z$ coupling

Year	E_{cm} [GeV]	<L/Exp> [pb^{-1}]
1996	161-172	~ 20
1997	183	~ 55
1998	189	~170
1999	192-202	~230
2000	204-209	~227

Sbottom searches at LEP II



Signature:
- Two acoplanar jets (B-Tagging possible)
- Missing Energy

Backgrounds: $gg, W^+W^-, W^\pm e^\mp n, ZZ, Ze^-e^+, q\bar{q}(g)$

L3

Select two high multiplicity acoplanar jets

Preselection based on:

E_{vis} P_T^{miss} E_{30} $\sin\Theta_{miss}$

Optimize for 4 ΔM regions

$E_{vis}/\sqrt{s}$ $P_T^{miss}/\sqrt{s}$ cuts

Event B-tagging used

L3 Note 2804

OPAL

Selection based on:

2jets $y_{cut} = 0.005(E_{vis}/\sqrt{s})^{-1}$

$P_T^{miss} > 4.5\text{GeV}$

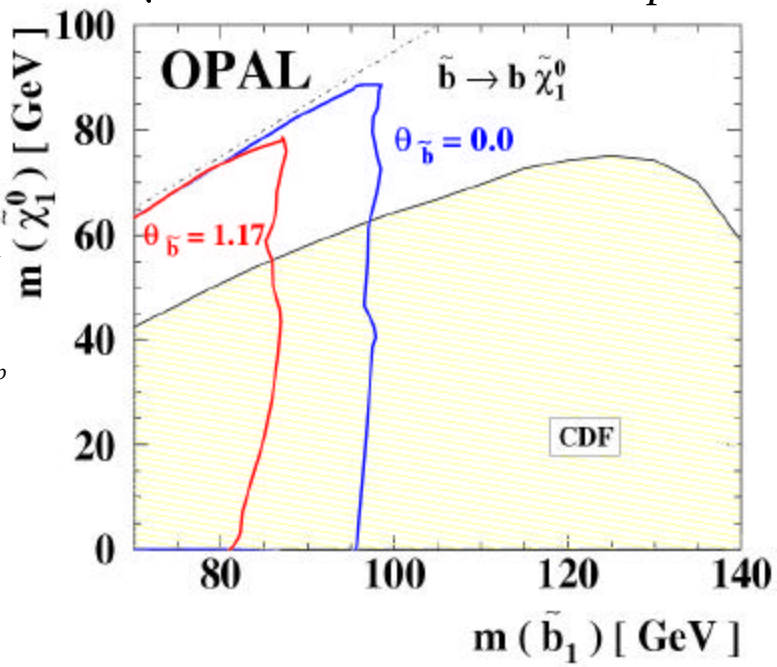
Acoplanarity angle f_{acop}

Softness (based on the inv. masses of the jets) $\left[\frac{M_1}{E_1} + \frac{M_2}{E_2}\right]$

Arithm. mean of inv. masses $\overline{M}_{jet}$

CERN EP/2002-050

$\sqrt{s} = 192 - 209\,GeV$ $437.6\,pb^{-1}$

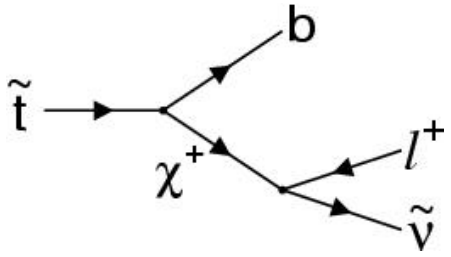


CERN-EP/2003-007 Delphi

CERN EP/2002-026 Aleph

Stop Searches (three body-decay)

Dominant decay mode if kinematically allowed



Signature:
- Two acoplanar jets
- Acoplanar leptons
- Missing Energy

OPAL

$\Delta M < 10$GeV

Selection based on:

$P_T^{miss} > 5\text{GeV}$ $N_{trk} \geq 6$

$N_{jets} \geq 4$

Acoplanarity

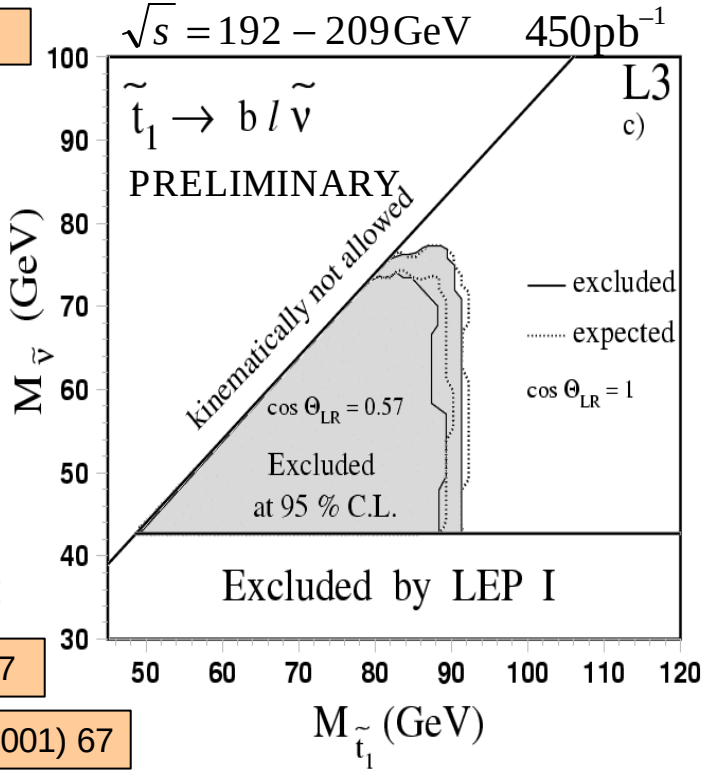
$\Delta M > 10$GeV was considered as a second case

CERN EP/2002-050

L3

L3 Note 2804

Selection of acoplanar jets with one or more isolated leptons.
Min. energy cut on most energetic lepton



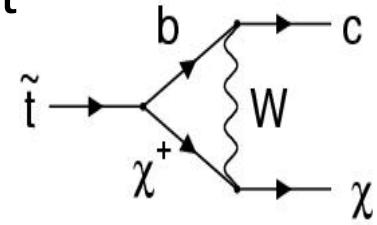
Similar searches done by:

Delphi CERN-EP/2003-007

Aleph Phys. Lett **B 499** (2001) 67

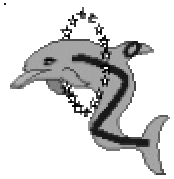
Stop Searches (two-body decay)

- If $\tilde{t}_1 \to bl\tilde{n}$ kinematically not allowed and $m_{\tilde{t}_1} - m_{\tilde{c}_1^0} > m_{W^\pm} + m_b$
- Flavor changing decay
- Loop suppressed



Signature:
- Two acoplanar jets
- Missing Energy

Similar to $\tilde{b}_1 \to b\tilde{c}_1^0$



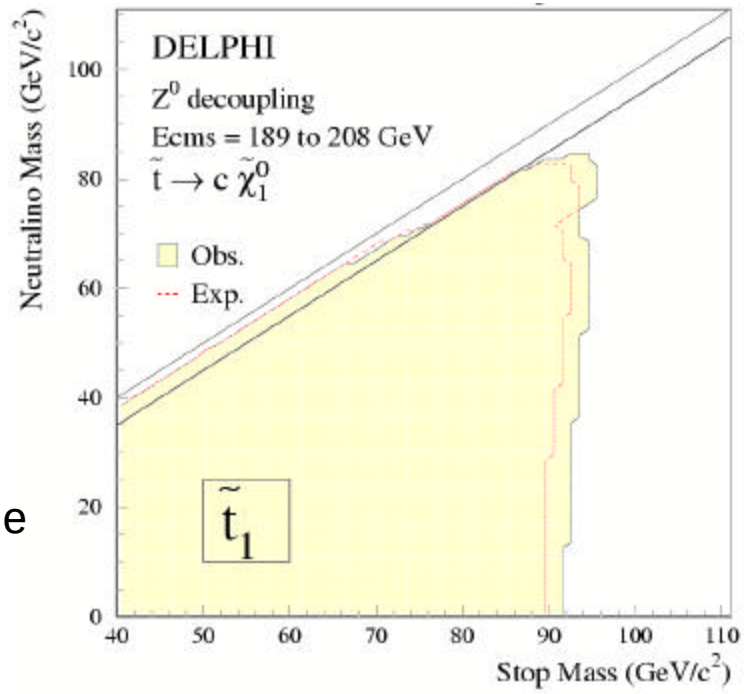
Sequential cut approach to search for nearly degenerated $\tilde{t}_1$ and LSP
Events forced into 2 jets
Preselection based on:
$N_{trks}, P_T^{miss}, E_{40^o}$
ΔM ranges considered:
5-20GeV and ΔM>20GeV

CERN-EP/2003-007

Final selection NN:
- 10x10x3
- Input:

$\frac{P_T^{miss}/E^{vis}}{\sqrt{(P_t^{jet1})^2 + (P_t^{jet2})}}$ E_T M^{vis}

Softness, acopl., acolin., b-tag prob. Sum Fox-Wolfram moments, polar angle of miss momentum



$\tilde{t}_1 \to c\tilde{c}_1^0$ analysis also performed by:

OPAL CERN-EP/2002-050 L3 L3 Note 2804 Aleph Phys. Lett **B 499** (2001) 67

Summary of (two/three-body decays)

Following mass limits have been obtained

	ΔM	$\tilde{t}_1 \to c\tilde{c}_1^0$	$\tilde{t}_1 \to bl\tilde{n}$	$\tilde{t}_1 \to bt\tilde{n}_t$
OPAL	>10GeV	97.6 95.7	96.0 92.6	95.5 91.5
	>5GeV	95.2 91.4		
DELPHI	>10GeV	96 92		
	>2GeV	75 71		
L3	15-25GeV	95 90	96 93	93/95
ALEPH	>8GeV	92	97	

Branching Ratio can be 100%, if chargino is purely wino state

Z decoupled
Max coupling

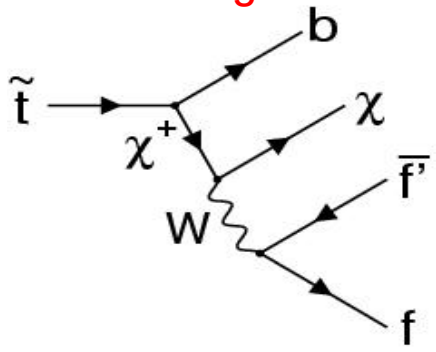
Numbers given in this table are as submitted to this conference

Stop Searches (four body decay) [I]

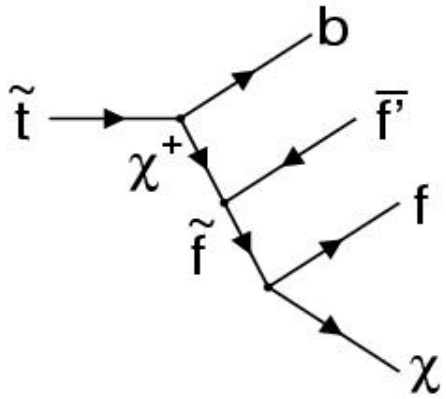
$\tilde{t}_1 \to b\tilde{c}_1^0 f\bar{f}'$

mediated by:

Virtual chargino + W



Virtual chargino + sfermion



Can be substantially enhanced for chargino masses not much larger than current limits

Four-body decay topologies

- b jets
- jets
- leptons
- missing mass
- missing energy

Use new multi-jet analysis

CERN EP/2002-026
Submitted Phys. Letters B

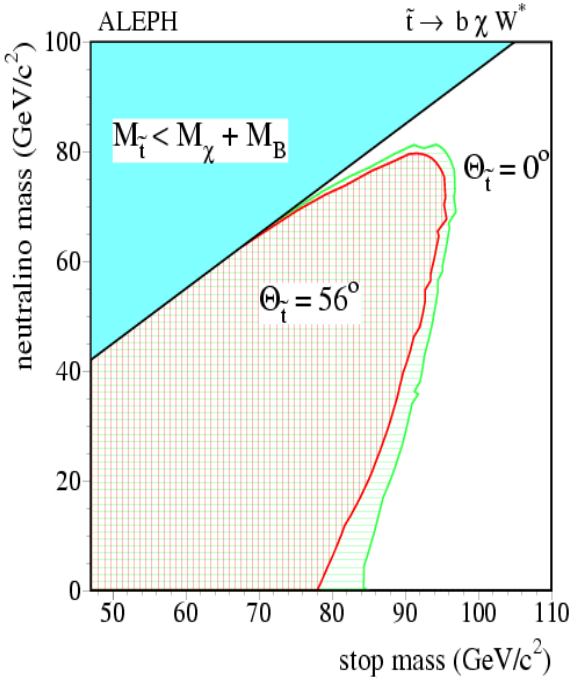
Stop Searches (four body decay) [II]

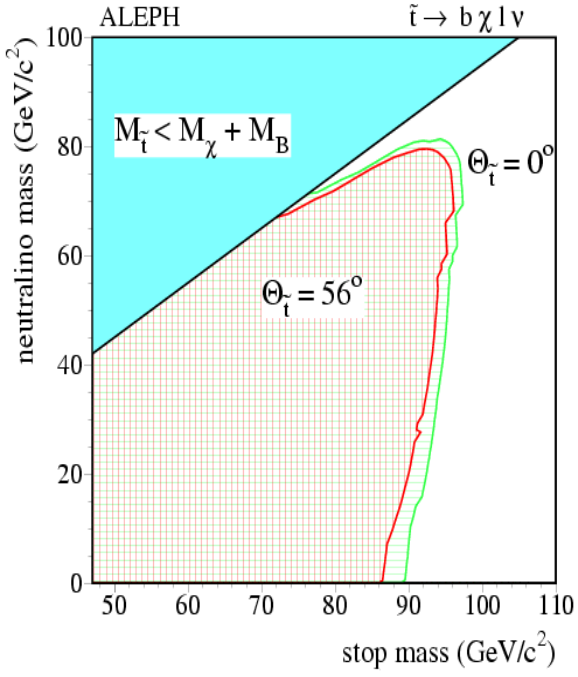
Multi-jet analysis with 207.3pb^{-1} taken in 2000
later extended to 675pb^{-1}

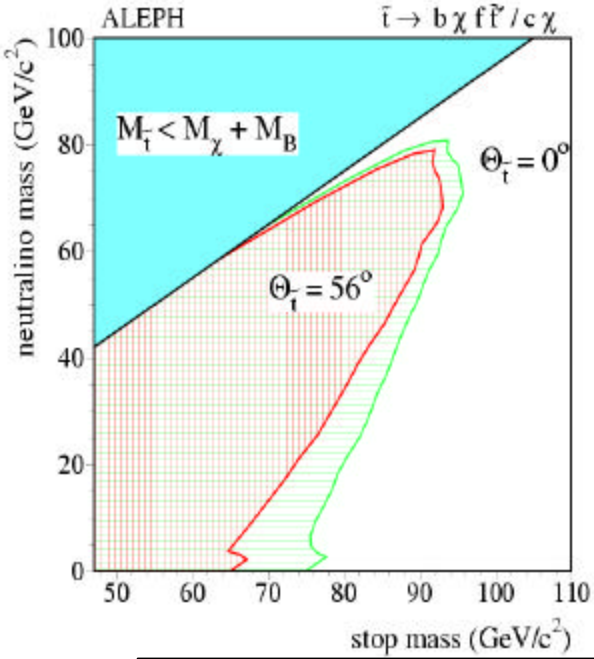
Combined multi-jet and acoplanar jets analysis

Branching ratio independent exclusion

Hypothesis dominant decay $\tilde{t}_1 \to b\tilde{c}_1^0 f\bar{f}'$







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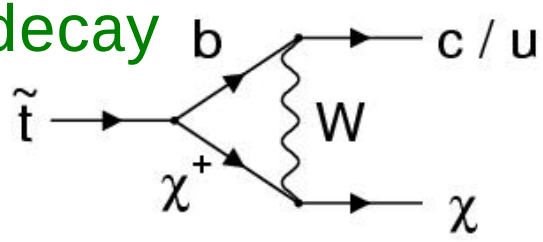
Stop Search (small ΔM Region)

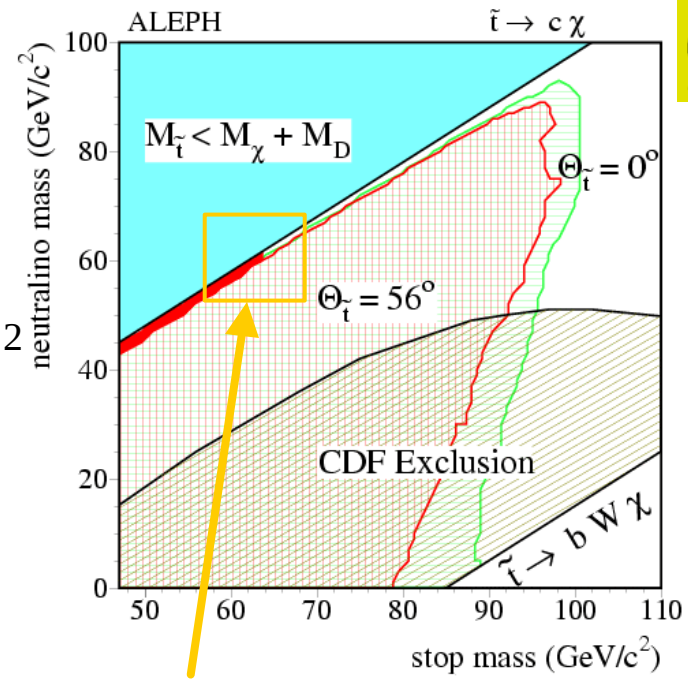
2-body decay



Width of decay $\tilde{t} \rightarrow c\tilde{c}_1^0$ proportional to $m_{\tilde{t}}(1-m_{\tilde{c}_1^0}{}^2/m_{\tilde{t}}{}^2)^2$

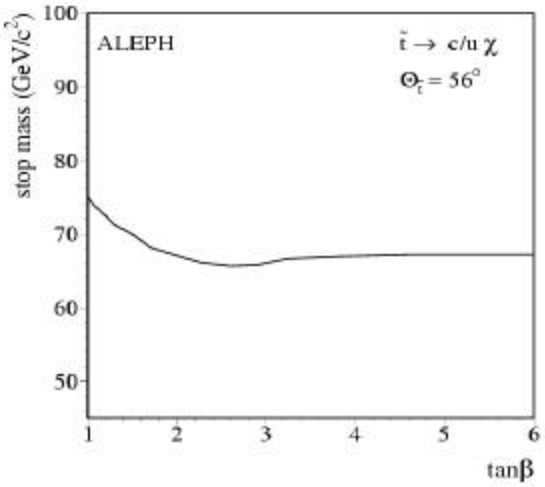
Stop lifetime becomes sizeable for ΔM small enough

Phys. Lett B 488(2000) 234



Long lived hadron analysis

$\Delta M \leq 6\mathrm{GeV}/c^2$



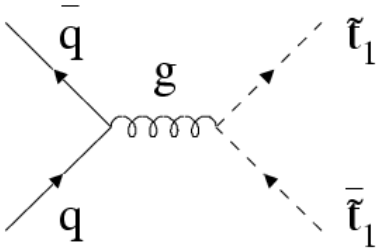
95%C.L. on stop mass for any tanβ

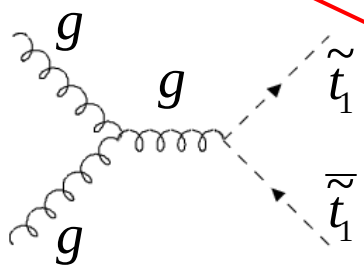
$m_{\tilde{t}} > 65\mathrm{GeV}$

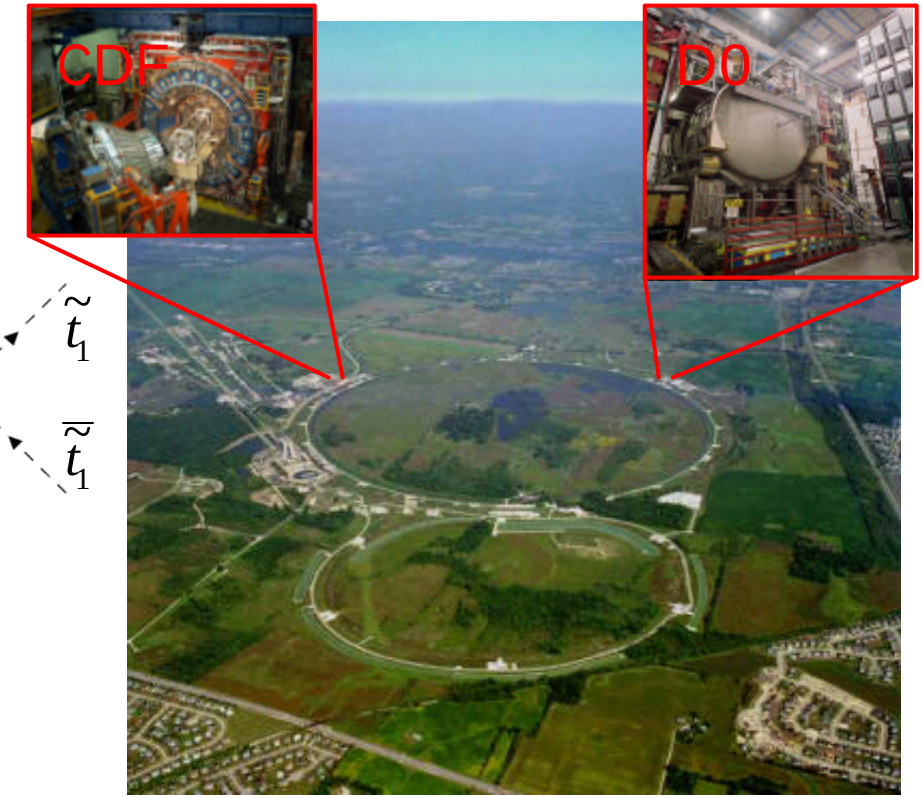
Stop and Sbottom at the Tevatron

Tevatron

Strong produced SUSY







Centre-of-mass energies

Run I	$\sqrt{s} = 1.8\,\mathrm{TeV}$	1992-1995	~110 pb^{-1} used for analysis
Run II	$\sqrt{s} = 1.96\,\mathrm{TeV}$	2001-2005	~200 pb^{-1} currently recorded

Search for Stop with OS Dileptons [I]

$p\bar{p} \to \tilde{t}\bar{\tilde{t}} \to (bl\tilde{n})(\bar{b}\bar{l}\bar{\tilde{n}})$ $(l = e, m, t$ with Br = 33% for each)

Run I, 107 pb^{-1} PRL **90**, 25180 (2003)

Signature:

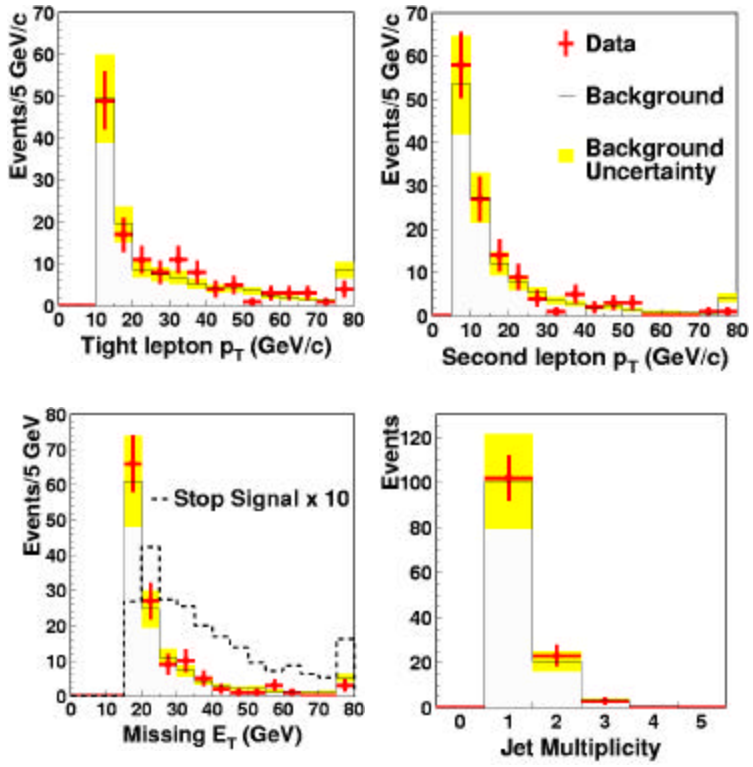
=2 OS leptons, =1 jet, $\not\!\!E_T$

Background:

Drell-Yan + Jets
Heavy Flavor Production
$t\bar{t}$, Dibosons, Fake Leptons

Preselection stage:

2 isolated leptons (e,μ)
$p_T(l_1)$=10 GeV, $p_T(l_2)$=6 GeV
$\not\!\!E_T$= 15 GeV
Jet E_T = 15 GeV



- Data agree w/SM expectations
- Sensitivity too low at this stage

Search for Stop with OS Dileptons [II]

Performed two "blind" analyses:

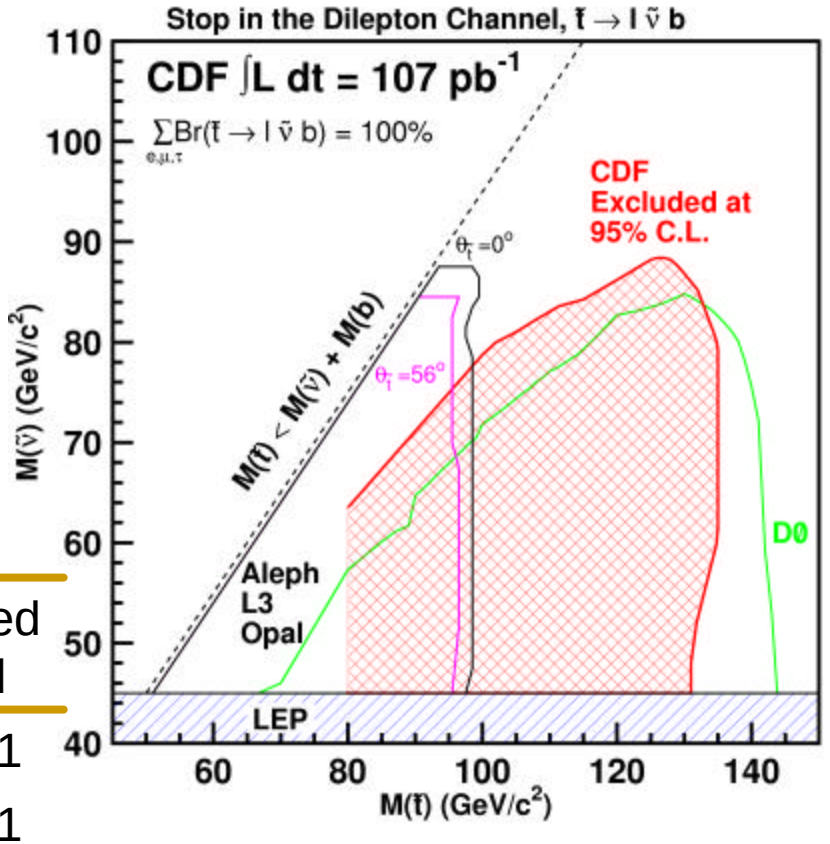
$\not\!\!E_T$ > 35 GeV & Angle Cuts

& for small ΔM, $pT(l_2) = 6$ GeV

& for large ΔM, $pT(l_2) = 10$ GeV

Results

? M	Observed	Expected Background	Expected Signal
small	0	1.5±0.5	5.7±2.1
large	0	2.1±0.5	8.2±3.1



PRL **90**, 25180 (2003)

Excluded new regions of phase space

Increased stop sensitivity 4x

Stop in R-parity violating Decay

- R_P conservation is not required by SUSY but often build in

Run I, 106 pb^{-1}

$$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow (bt)(\bar{b}\bar{t}) \rightarrow b(ln_l\bar{n}_t)\bar{b}(t_h) \quad (l = e, m)$$

Signature:

=1 lepton (e, μ)
hadronic t
=2 b-jets (no tag)

Background:

$Z/g^*(\rightarrow t^+t^-) + \text{jets}$

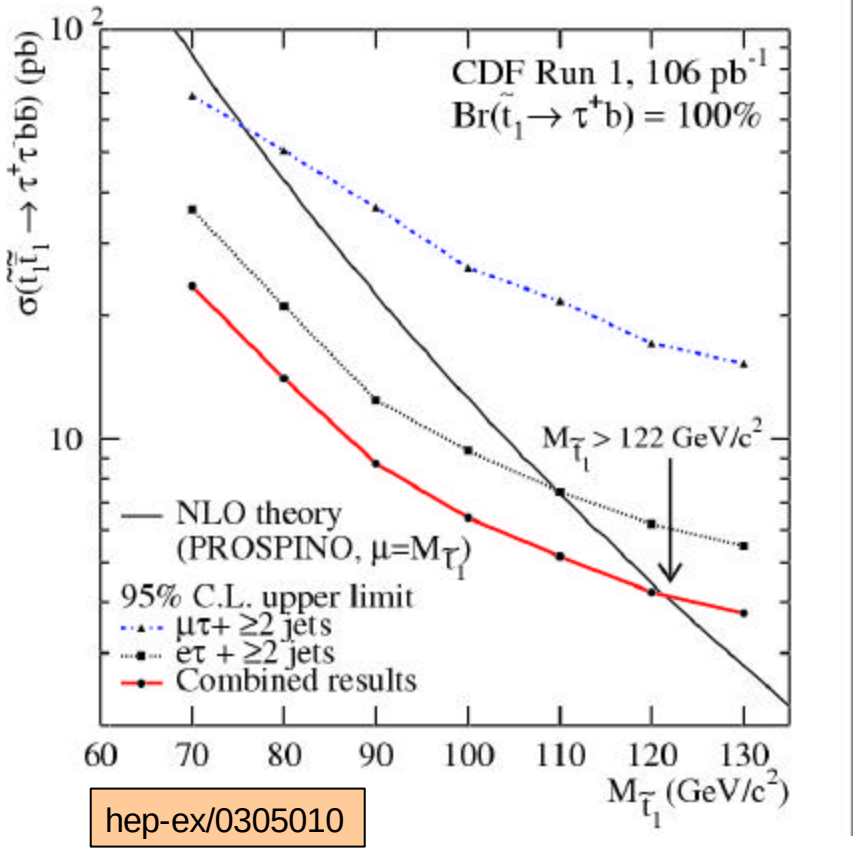
$t\bar{t}$, diboson

Event selection:

hadronic t

$M_T(l, E_T^{miss}) < 35\,\text{GeV}/c^2$

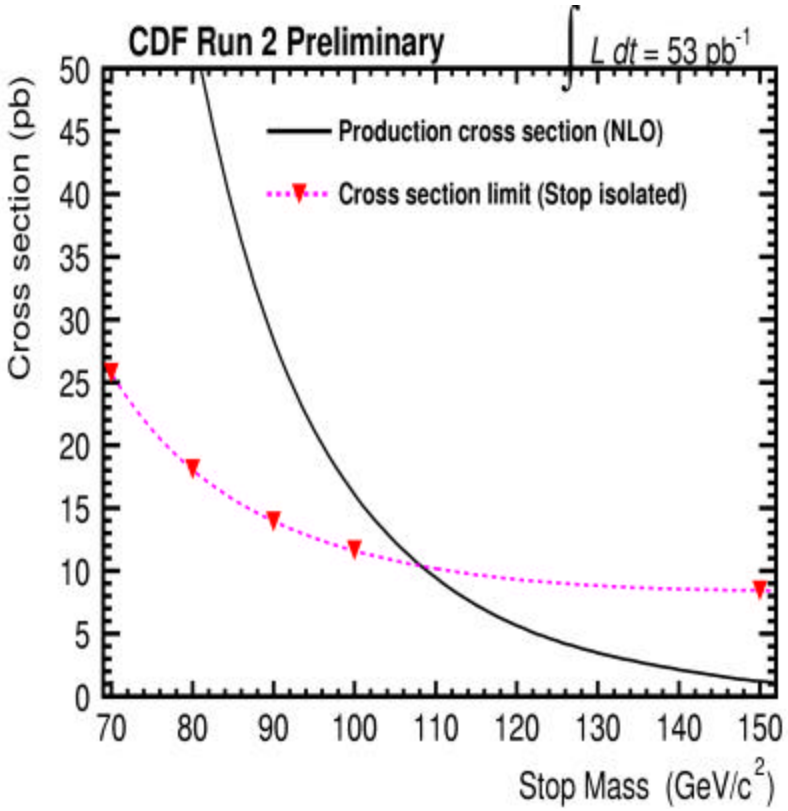
$\Sigma_{P_T}(l, t_h, E_T^{miss}) > 75\,\text{GeV}/c^2$



hep-ex/0305010

Search for long lived Stop

- Previously searched for:
  - Stop decaying within detector
- If Stop long lived:
  - acts as Min. Ion. Particle
  - has a large Time Of Flight
- Heavy Stop:
  - high p_T tracks
  - would reach muon system
- Selection:
  - tracks with $p_T = 40$ GeV/c^2
    $|TOF - t_0| = 2.5$ ns



Observed 7 events
Expected 2.9±0.7(stat) ±3.1(syst)
Excluded m(stop)<107 GeV

Sbottoms from Gluino decays [I]

- Gluino pair production cross section large
- Very distinctive signature

Run II, 38.4 pb^{-1}

$m_{\tilde{g}} > m_{\tilde{b}} > m_{\tilde{c}_1^0}$

Signature:

4 bjets, $\not\!\!E_T$

$\tilde{g}\tilde{g} \rightarrow (b\tilde{b}_1)(b\tilde{b}_1) \rightarrow (bb\tilde{c}_1^0)(bb\tilde{c}_1^0)$

Background:

$b\bar{b}$ QCD

$t\bar{t}$, W/Z+jets

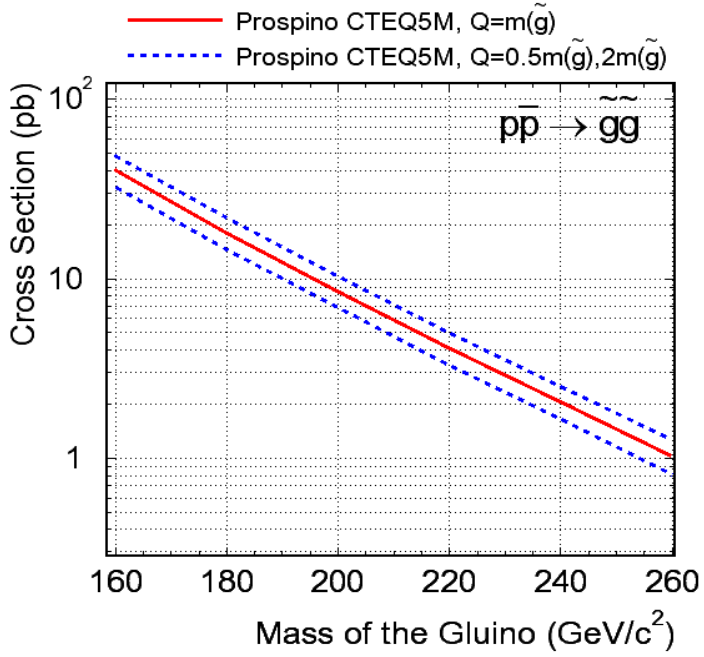
Preselection cuts:

= 3 jets, (10GeV,|η|<2)

$\not\!\!E_T$ > 35 GeV

Lepton veto

$\Delta\phi(\not\!\!E_T, \text{jets})$ cuts



Sbottoms from Gluino decays [II]

Secondary vertex tagging algorithm used to reduce backgrounds

Signal Region:

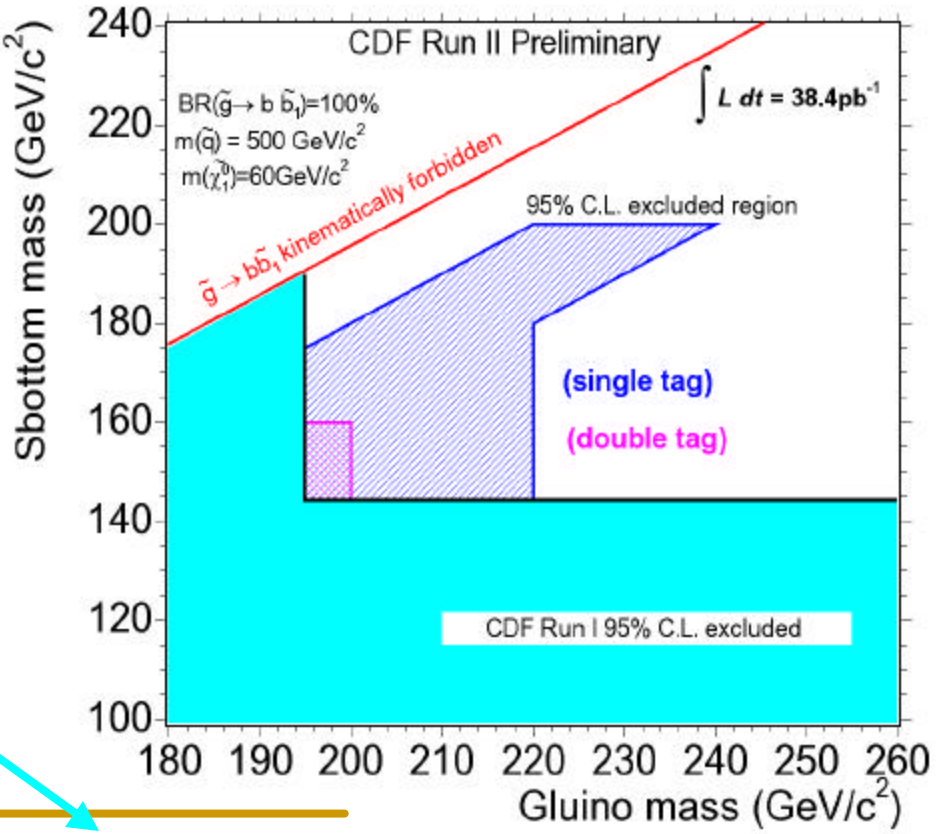
$\not\!\!E_T > 50$ GeV

1 b-tag

2 b-tags

Assuming $m_{\tilde{c}_1^0} = 60 GeV$

$m_{\tilde{g}} = 220 GeV$ $m_{\tilde{b}_1} = 160 GeV$



b-*tag*	Observed	Expected Background	Expected Signal
Single	4	5.6±1.4	10.6±1.7
Double	1	0.5±0.1	4.4±0.9

Conclusions

- Interesting results from LEP still come out
- DØ and CDF are coming up to speed
- Tevatron has the best SUSY discovery potential before LHC