Search for squarks and gluinos and 3rd generation squarks with the D0 detector

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Outline

- Phenomenology
- generic squarks and gluinos
- Search for 3rd generation squarks
  - sbottom
  - stop :
    - c-neutralino decay
    - b lepton sneutrino decay

Same topology :

Acoplanar jet topologies

but :

- different kinematics
- different jet flavors

http://www-d0.fnal.gov/Run2Physics/WWW/results/np.htm

Supersymmetry

Idea : extend SM with new symmetry fermions ↔ bosons

Many attractive features:
- Low scale supersymmetry protects Higgs mass,
- provides dark matter candidate,
- unification @10^{16} GeV.

New quantum number : $R_P = (-1)^{3(B-L)+2s}$ **+1 SM** / **- 1 SUSY**

In this talk:

The R-parity is supposed to be conserved :
⇒ LSP stable
⇒ superpartners produced in pair
⇒ superpartner decays lead to SM particles and LSP

LSP is the lightest neutralino (models inspired by supergravity)

Squarks and gluinos

At the TeVatron, squarks and gluinos are produced via the strong interaction $\Rightarrow$ large cross section

$m_{\tilde{q}} << m_{\tilde{g}}$ $\quad \tilde{q}\tilde{\bar{q}} \rightarrow q\tilde{\chi}_1^0\bar{q}\tilde{\chi}_1^0$

$\Rightarrow$ at least 2 high pT jets and missing transverse energy

$m_{\tilde{q}} \approx m_{\tilde{g}}$ $\quad \tilde{q}\tilde{g} \rightarrow q\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$

$\Rightarrow$ at least 3 jets and missing transverse energy

$m_{\tilde{q}} >> m_{\tilde{g}}$ $\quad \tilde{g}\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0 q\bar{q}\tilde{\chi}_1^0$

$\Rightarrow$ higher jet multiplicity
softer jets
missing transverse energy smaller

Cascade decays complicate the picture
$\Rightarrow$ model needed (mSUGRA)

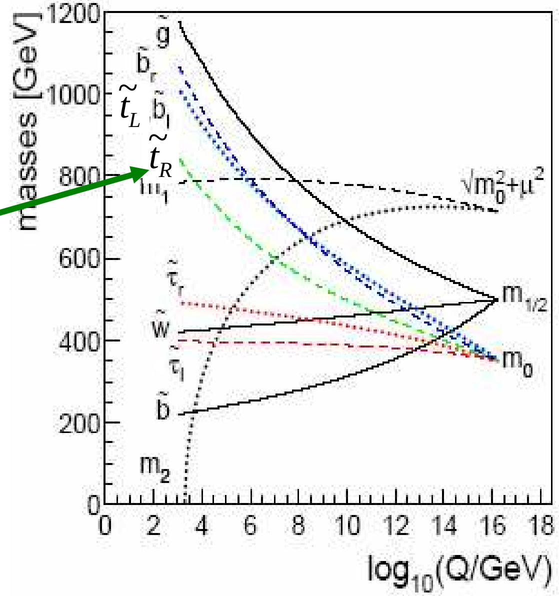
Different analyses for the three cases

Stop and sbottom : motivation

Left and right quark superpartners can strongly mix to form mass eigenstates :
- mixing proportional to quark masses
- mixing proportional to cotan(β) for stop and to tan(β) for sbottom

large top mass
⇒ the stop can be the lightest squark

stops can also be light due to the large
top-Yukawa impact in RGE
in Grand Unified Model



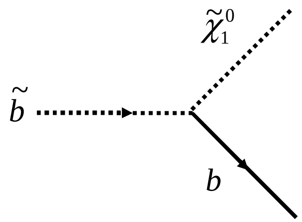
light stops are required for the realization of the
mechanism of electroweak baryogenesis in the MSSM

large tan(β) ⇒ the sbottom can be the lightest squark

Stop and sbottom : search channels

Scalar bottom

Dominant decay mode : $\tilde{b}_1 \to b\tilde{\chi}_1^0$



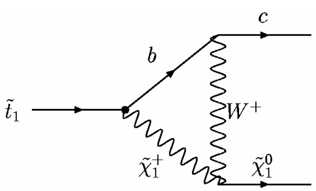
⇒ 2 b-jets and met

Scalar top

The decay $\tilde{t}_1 \to t\tilde{\chi}_1^0$ is kinematically forbidden if the stop is lighter than the top
⇒ rich phenomenology depending on the mass spectrum

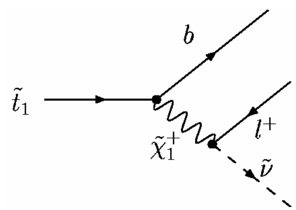
Two scenarios have been investigated :

Decay channel $\tilde{t}_1 \to c\tilde{\chi}_1^0$ (FCNC)
Main decay if the stop is the NLSP



⇒ 2 c-jets and met

Decay channel $\tilde{t}_1 \to bl\tilde{\nu}$ which dominates if the sneutrino mass is small



$\tilde{\nu} \to \nu\tilde{\chi}_1^0$

⇒ 2 b-jets, 2 leptons and met

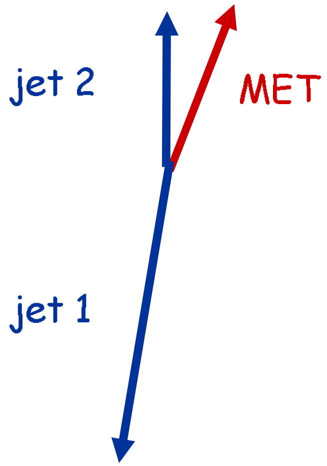
Background for acoplanar jet topologies : QCD

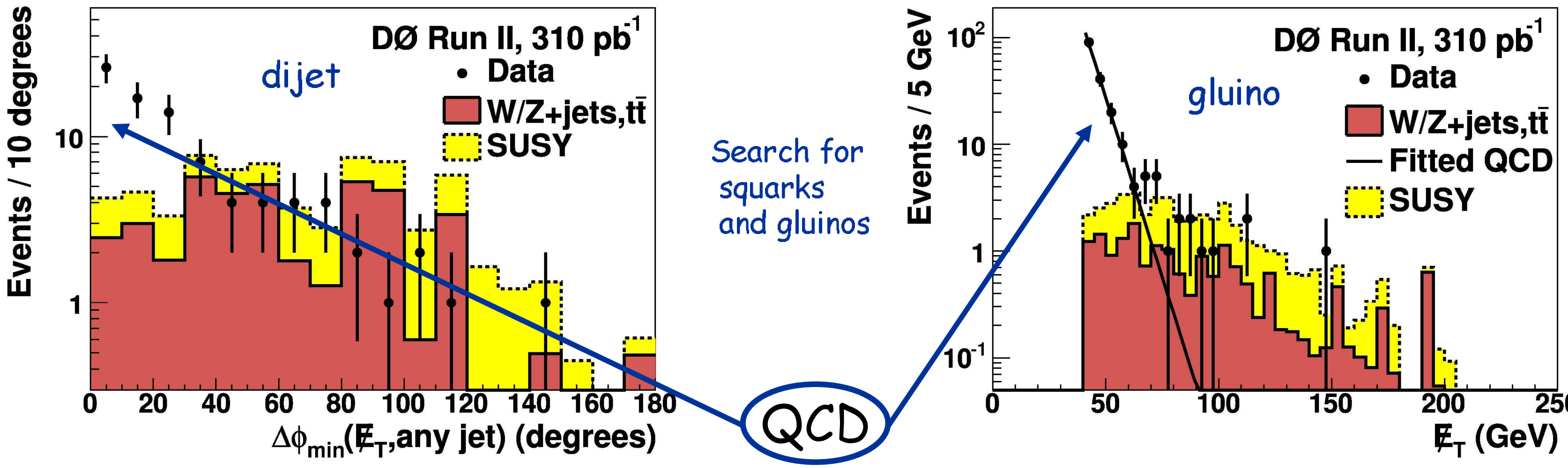
✓ Jet production via strong interaction

✓ MET due to jet energy mismeasurement

✓ MET aligned with a jet direction
⇒ cut on angle between jet and met

✓ low MET
⇒ cuts on MET remove qcd background contribution.
⇒ Otherwise, contribution extrapolated from data behavior at low missing ET region.

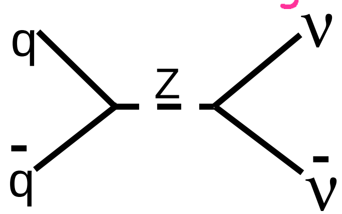




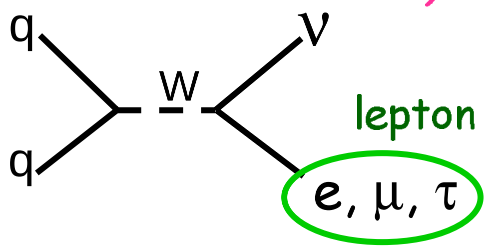
Background for acoplanar jet topologies : SM

Main background : W and Z production

- Z + jets → νν + jets
(irreducible background)



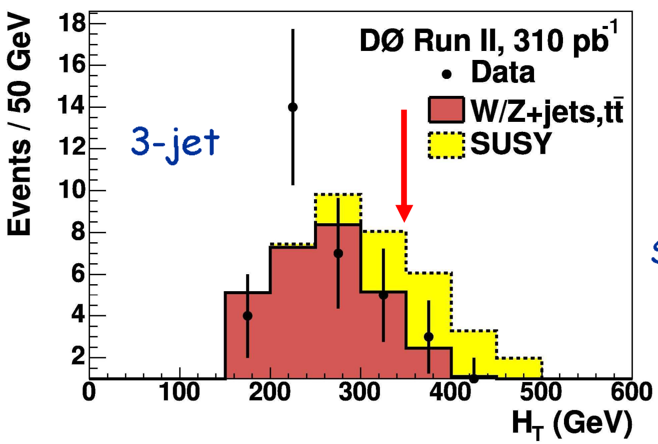
- W + jets → lν + jets (l = e, μ,τ)
(lepton not reconstructed)



lepton vetoes

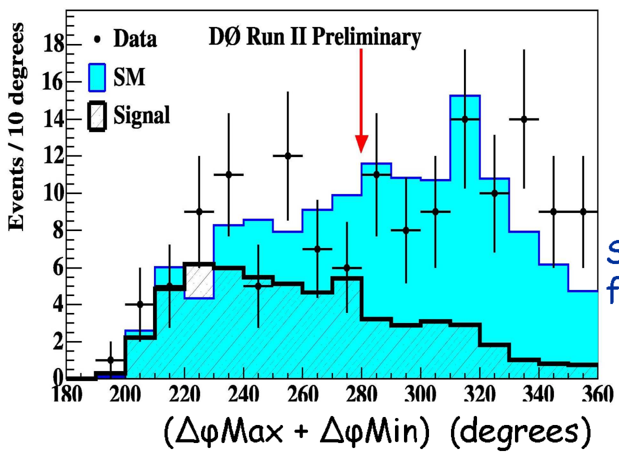
and also : WW, WZ, ZZ, top

Jets softer than for the signal
⇒ Cut on H_T = sum of jets p_T's



Search for squarks and gluinos

Different topology between signal and SM :
⇒ cut on angular variable

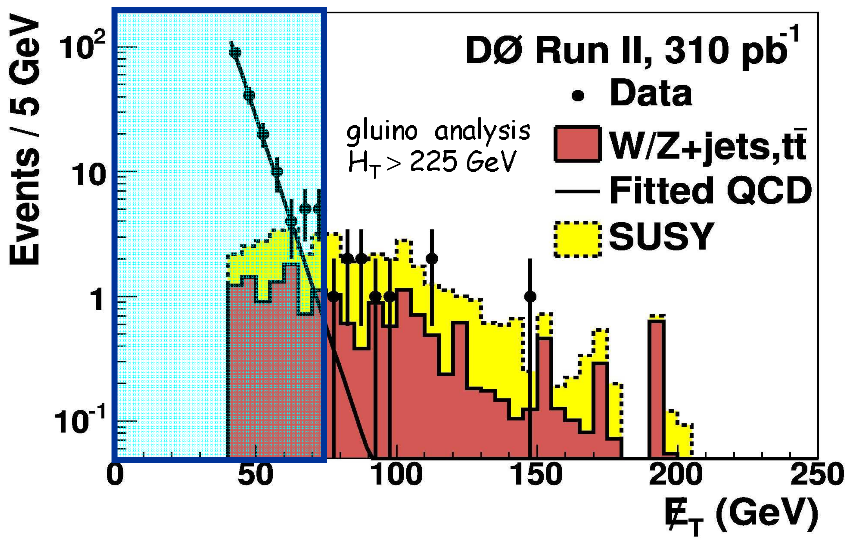


Search for stop

Search for squarks and gluinos

Analyses	Background expected	Events observed
m(squark) < m(gluino) ≥ 2 jets	4.8 ± 4.5	6
m(squark) = m(gluino) ≥ 3 jets	3.9 ± 1.5	4
m(squark) > m(gluino) ≥ 4 jets	10.3 ± 2.4	10

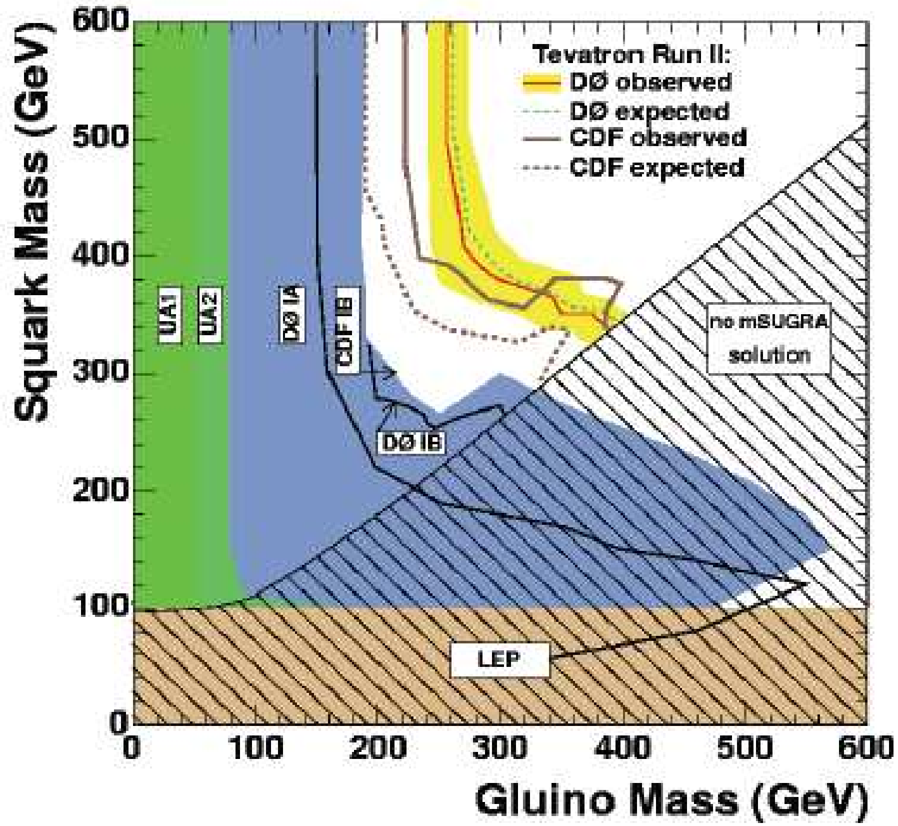
Main analysis cuts:
- Data cleaning
- Jet pT
- Missing ET
- HT = sum of jet pT's
- Lepton veto
- Angles (jet,missing ET)



Good agreement between data and MC
⇒ no obvious squark and gluino production

Search for squarks and gluinos

Combine the 3 analyses for the limit computation



red line : nominal result
yellow region : effect of the theoretical uncertainty on the production cross section (+/-1 sigma)

Phys. Lett. B 638, 119-127 (2006)

Theoretical uncertainties on the signal production cross-section due to :
- choice of the pdf
- choice of the renorm./factor. scale

DØ RunII convention :
Use the lower cross section to set a limit

The lower limits on the squarks and gluinos masses are :

$M_{gl} > 241$ GeV & $M_{sq} > 325$ GeV

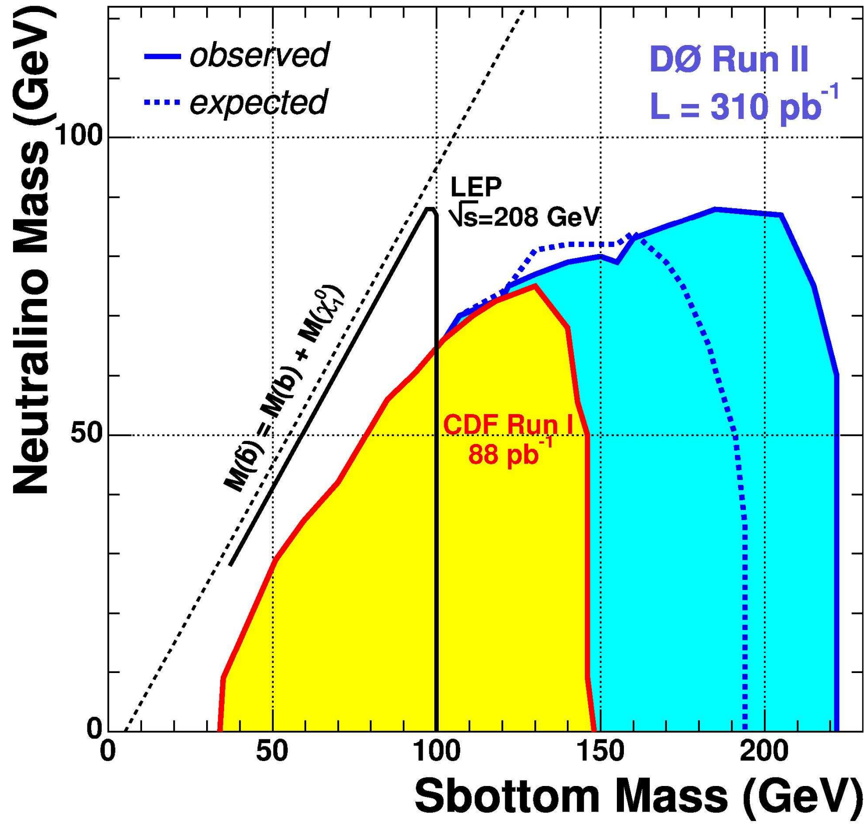
Search for sbottom

Final state : 2 b-jets and met

Softer jets and MET for low ΔM=mass(sb)-mass(χ)

Analysis strategy close to the squark and gluino analysis except :

- looser cut on jet pT and met
- at least one tagged jet (low mistag rate: 0.1%)
- optimized for various m(sb),m(χ))



No excess is observed

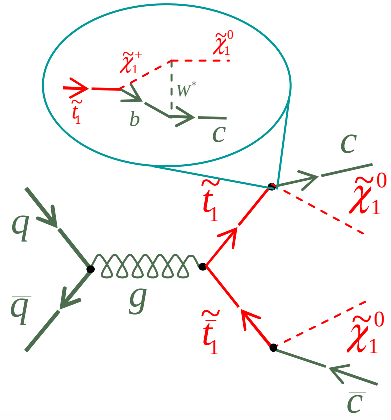
Previous limits are largely improved

Accepted by PRL

Search for stop : c-neutralino channel

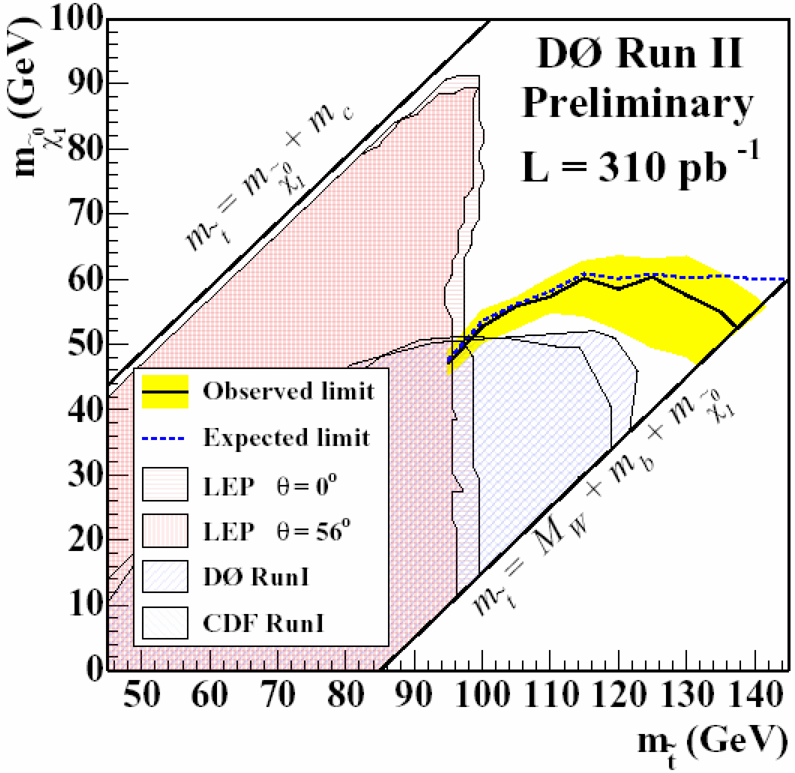
Final state : 2 c-jets and met

Softer jets and MET for low ΔM=mass(st)-mass(χ)



Analysis strategy close to the squark and gluino analysis except :

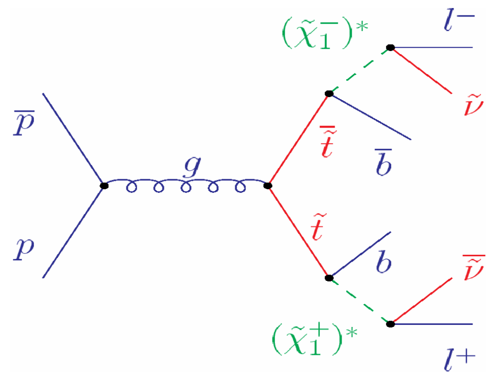
- looser cut on jet pT and met
- at least one tagged jet (higher mistag rate: 4%)
- optimized for various m(st),m(χ))



No excess is observed
Previous limits are improved

Stop : b l snu channel

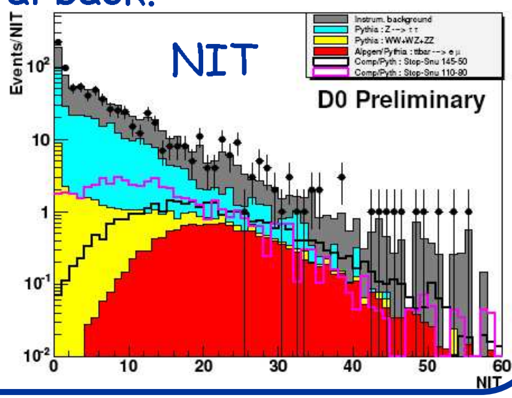
Final state : 2 b-jets, 2 leptons and met



e-mu channel : L=350 pb-1
(Most sensitive channel)

➔ 1 isolated muon with pT>8 GeV
➔ 1 isolated electron with pT > 12 GeV
➔ opposite sign
➔ MET
➔ $\Delta\Phi$ (e,MET) vs $\Delta\Phi$ (μ,MET)
➔ Number of non isolated tracks (NIT) instead of requiring reconstructed jets

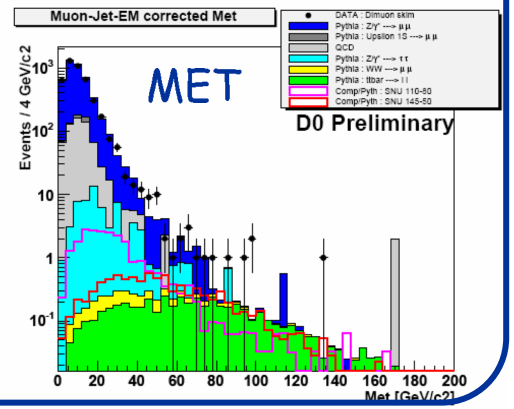
Main backgrounds:
➔ Instrumental back.
➔ di-boson
➔ top pair
➔ $Z\rightarrow\tau\tau$



Di-muon channel : L=339 pb-1

➔ 2 opposite sign muons pT > 8 and 6 GeV
➔ $\Delta\Phi$ (leading mu,MET) vs MET
➔ at least 1 jet with pT > 15 GeV and $|\eta|$<2.5
➔ 1 loosely b-tagged jet
➔ Anti-$Z\mu\mu\rightarrow$ cut

Main backgrounds:
➔ QCD
➔ $Z\rightarrow\tau\tau$
➔ top pair



Stop : b l snu channel

No excess is observed
Previous limits are largely improved

The two channels are combined.
Stop exclusion up to m(top)

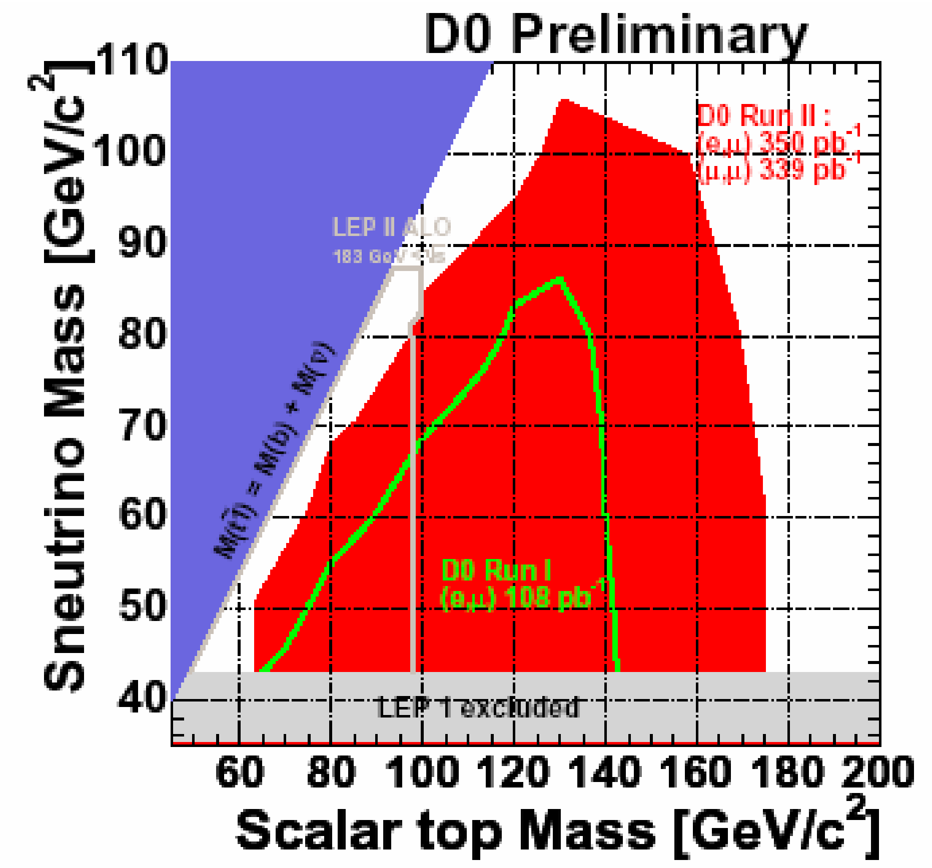
Framework : MSSM

χ^0_1 = LSP

$\tan\beta = 20,\ \mu = +225$ GeV

$M_{\tilde{g}} = 500$ GeV/c^2

$M_A = 800$ GeV/c^2



Conclusion

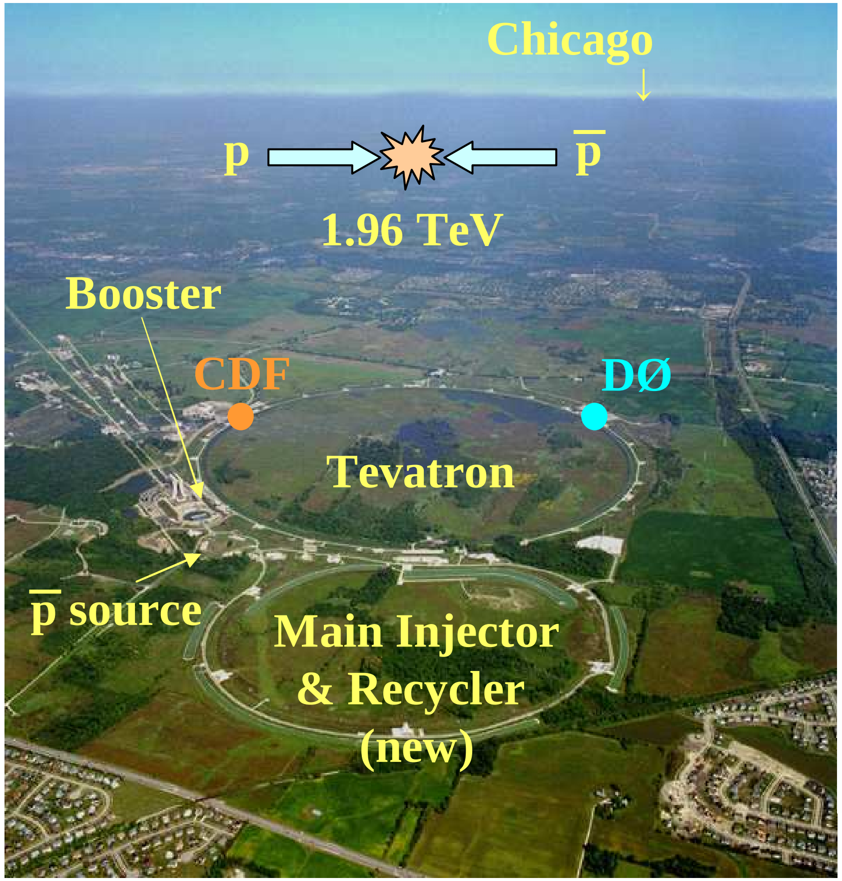
D0 has searched for generic squarks and gluinos and for third generation squarks with ~ 350 pb^{-1}

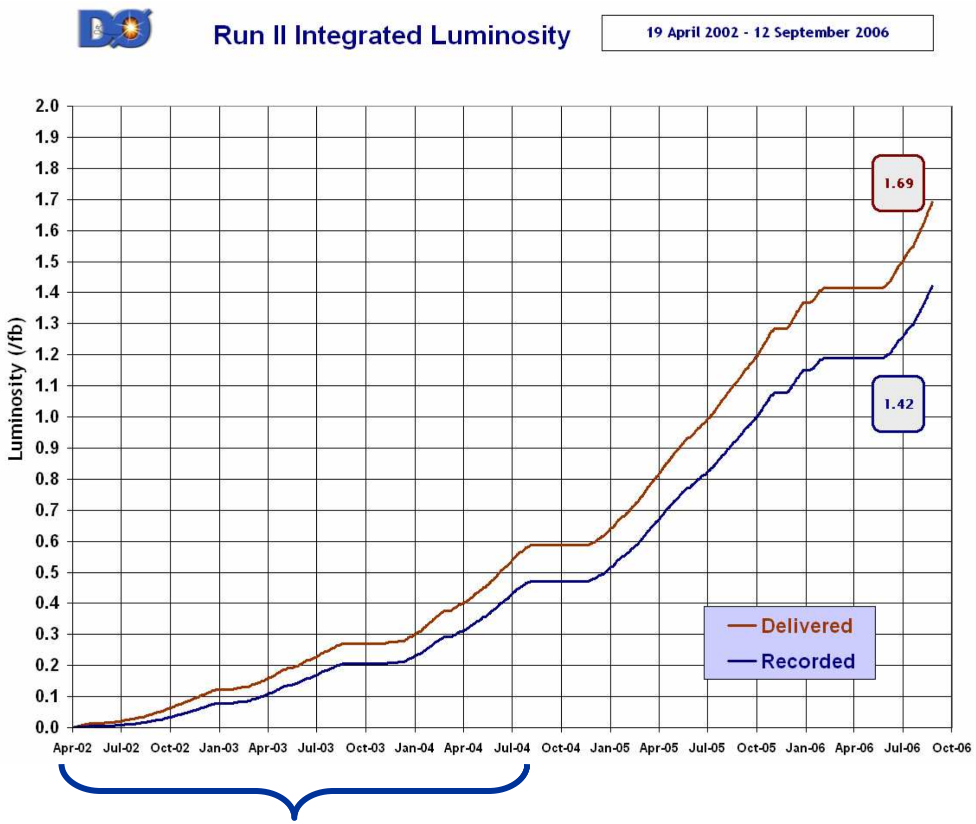
So far, nothing really interesting

but hopefully with more luminosity…
or at the LHC…

BACK UP

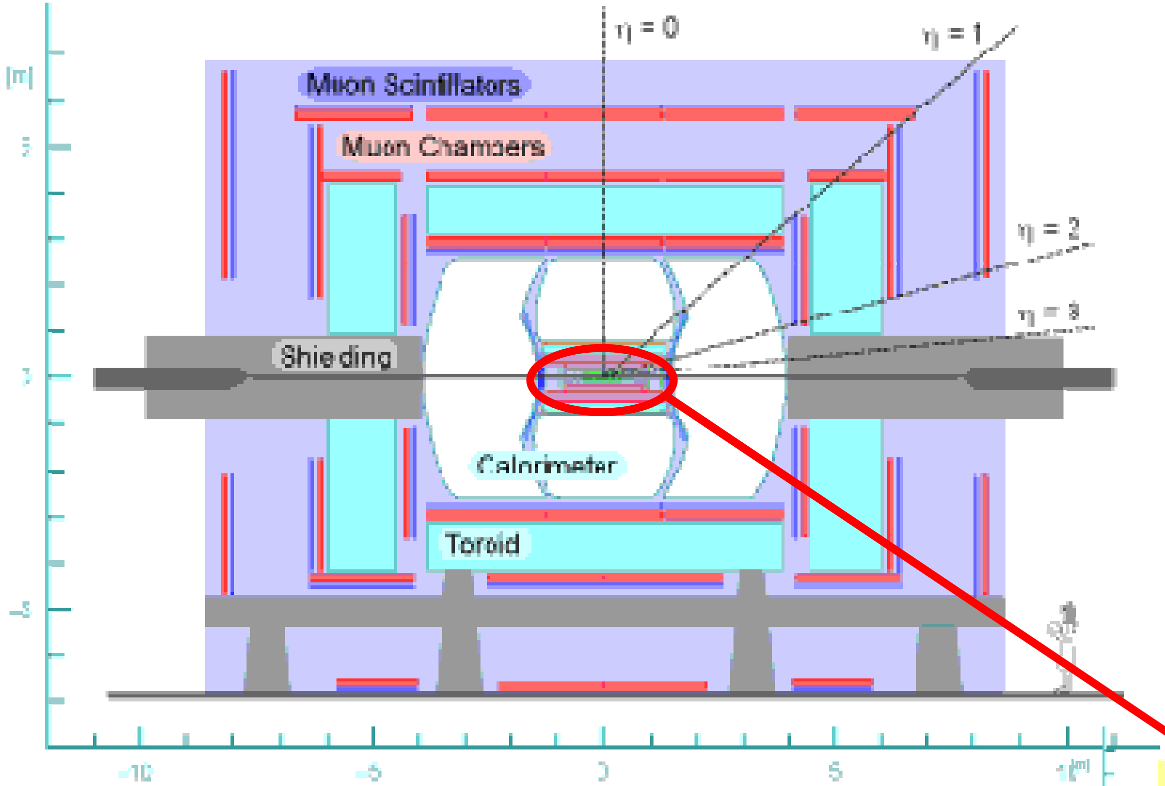
TeVatron





luminosity up to 350 pb^{-1}
for the analysis shown in this talk

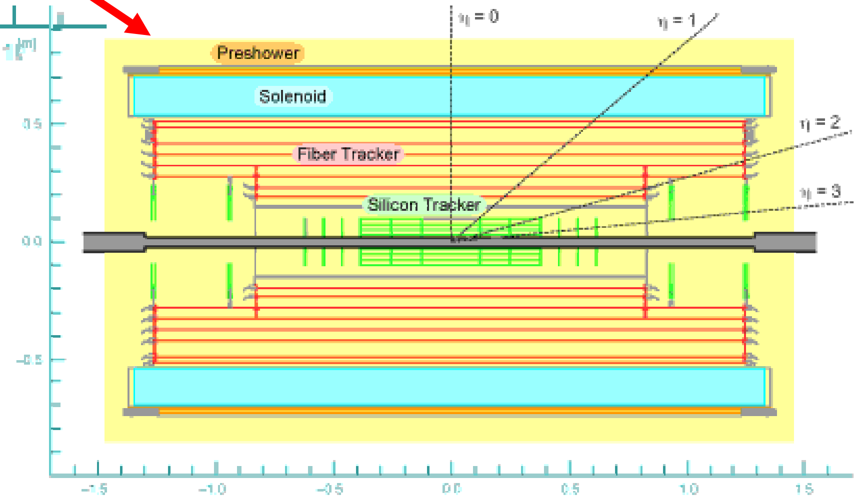
D0 detector



Multipurpose detector

- Calorimeter LAr/Uranium
- Muons detector
  → drift chamber
  → scintillators

- Silicon Microstrip Tracker
- Central Fiber Tracker
- superconducting magnet (2T)



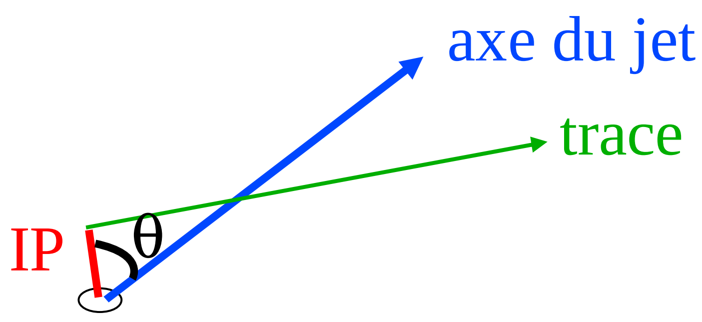
Supersymmetry

SUSY parameters:

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

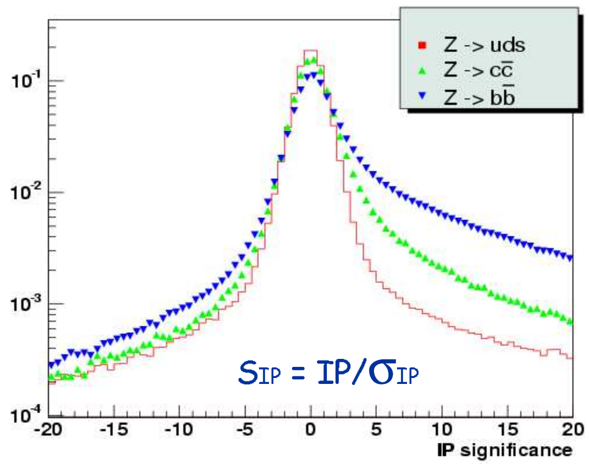
Heavy flavor tagging - Jet Lifetime Probability

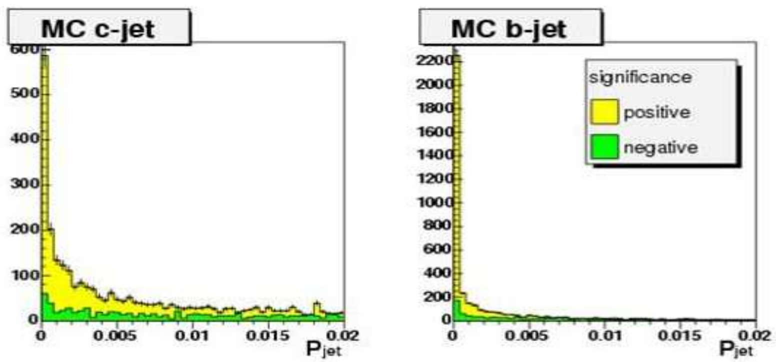
Use the signed impact parameter significance of tracks associated to a jet (ΔR<0.5 cone matching) to identify jets with long lived particles



Jet lifetime probability is computed using tracks associated to a jet.

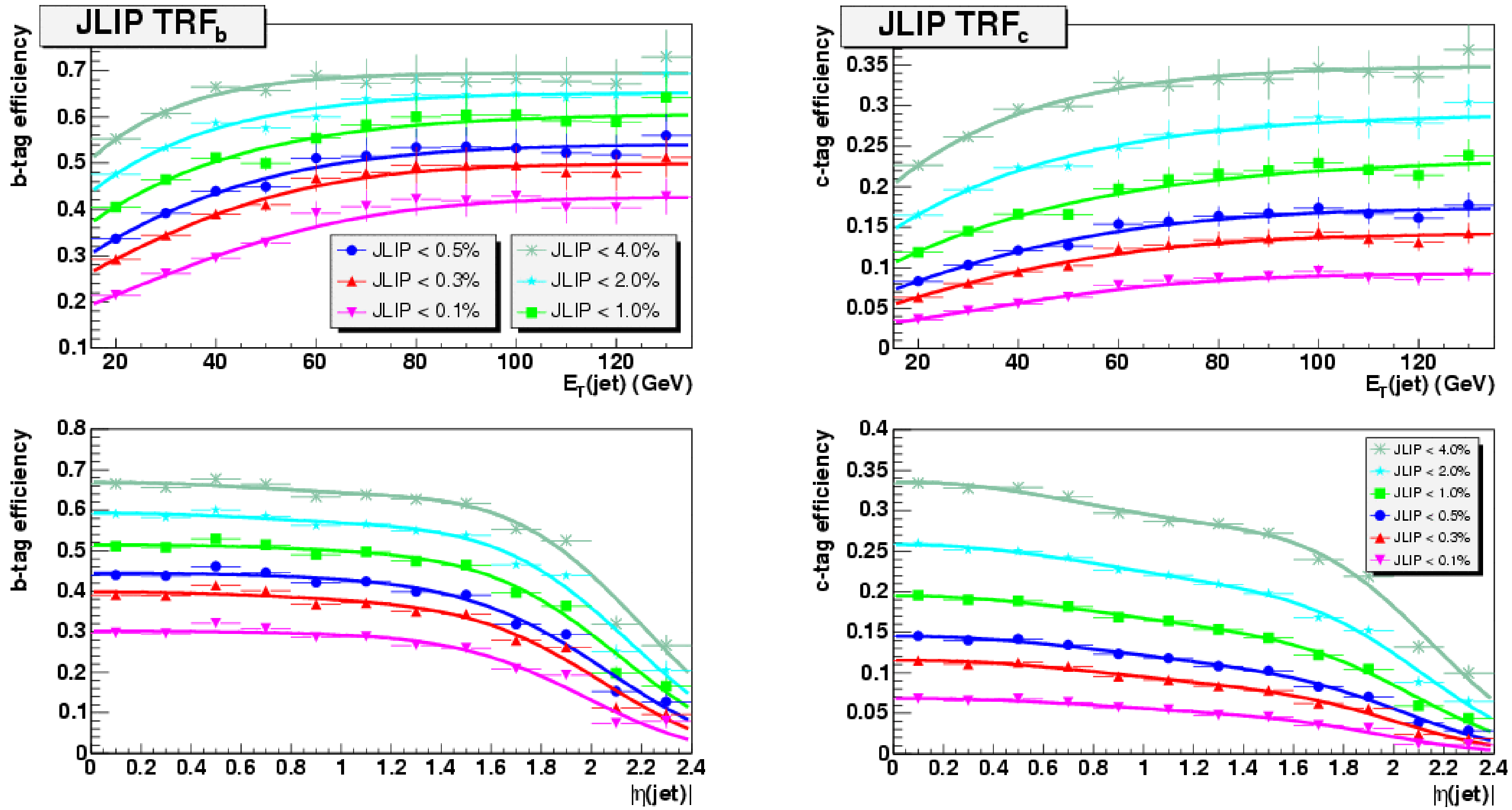
- Light quark jets have a flat probability distribution by construction
- Jets from c and b quarks have a probability peaked at zero





More difficult to tag a c-jet than a b-jet

Jet Lifetime Probability

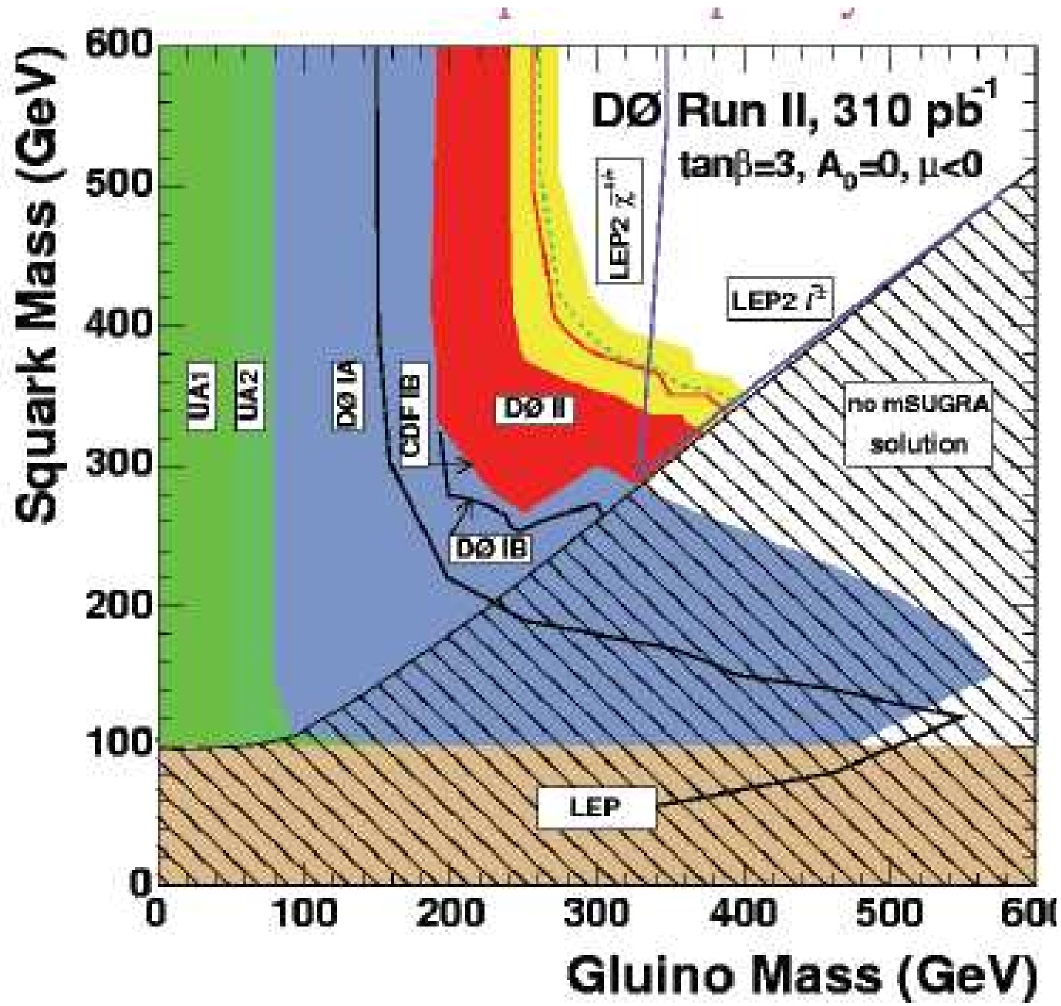


Squarks and gluinos

- Candidate with the largest MET:
  - → MET = 349 GeV
  - → HT = 389 GeV
  - → pT (jet1) = 266 GeV
  - → pT (jet2) = 100 GeV

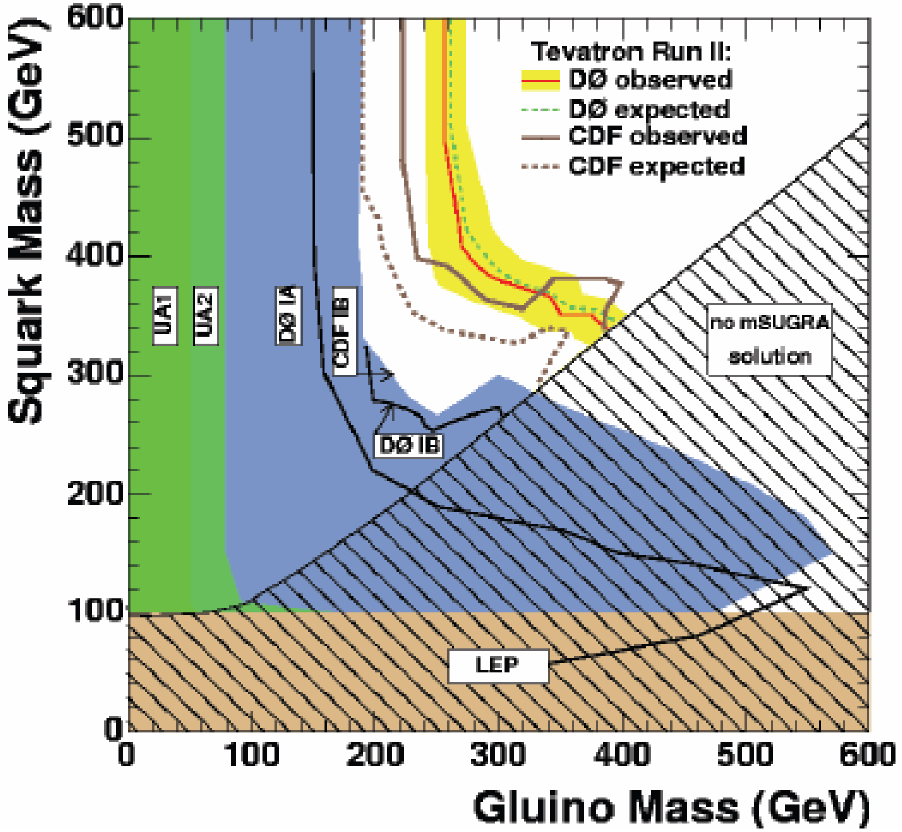
Squarks and gluinos

tan(β)=3, A=0, μ<0



Squarks and gluinos

CDF released a preliminary analysis with 378pb-1 optimized for M(squark)=M(gluino):
➔ tan(b)=5 (=3 for DØ) : small effect
➔ only 1st and 2nd gen. squarks (+sbottom for DØ) : small effect
➔ CDF treats the effect of the PDF/Scale on the signal cross section as a systematic uncertainty on the number of signal events expected, in the limit computation : DØ result for the minimal cross section is much more conservative



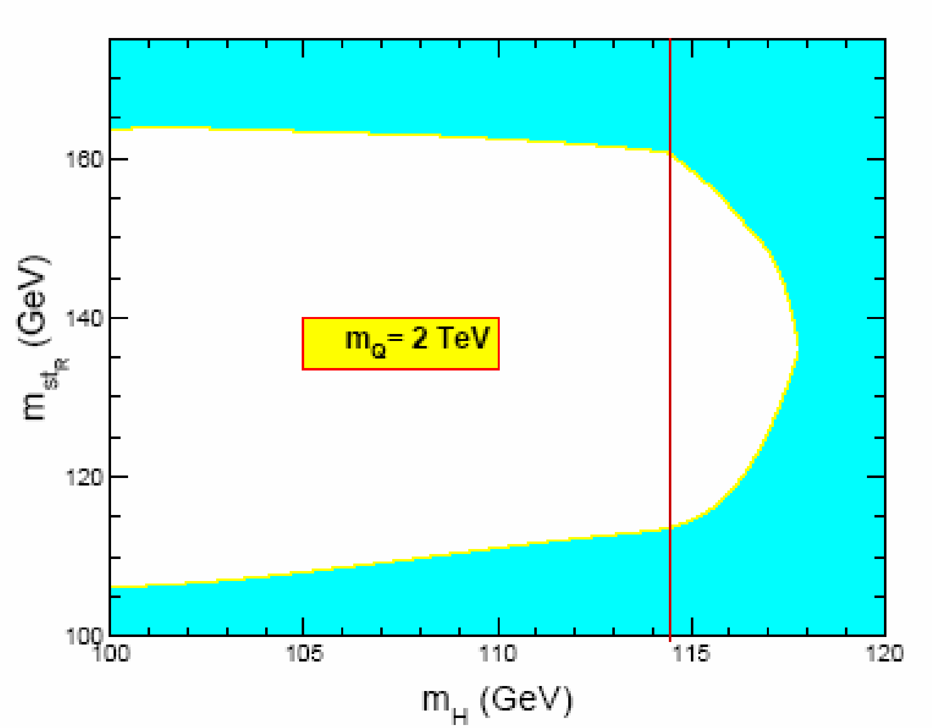
Squarks and gluinos

Systematic Uncertainties :

➔ JES (10-20%)
➔ luminosity (6.5%)
➔ PDF on the acceptance (6%)
➔ jet-ID (5%)
➔ 15% on back. cross sections (W/Z+jets, ttbar)
➔ Effect of renormalization/factorization scale on the signal cross section :

➔ correct treatment of error correlations between back. and signal

Electroweak Baryogenesis ⇒ a light stop



$m_h \lesssim 120$ GeV

$m_{\tilde{t}_1} \lesssim 180$ GeV

$\tan\beta \sim 2\text{–}8$

heavy $\tilde{t}_2 \simeq \tilde{t}_L$

[Carena, Quiros, Wagner, hep-ph/9710401]
[Balazs, Carena, Menon, Morrissey, Wagner, hep-ph/0412264]

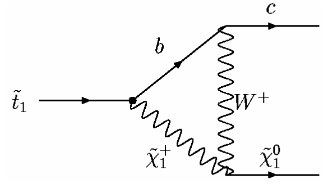
Stop decays

2-body decays via virtual chargino:

The decay channel $\tilde{t}_1 \to t\tilde{\chi}_1^0$ is cinematically forbidden if the the stop is lighter than the top

Decay channel $\tilde{t}_1 \to b\tilde{\chi}_1^\pm$ (on-shell chargino) is difficult to explore at the Tevatron due to the high chargino mass limit of LEP2

Decay channel $\tilde{t}_1 \to c\tilde{\chi}_1^0$ (FCNC)



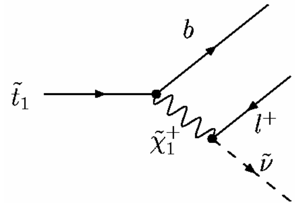
Main decay if the stop is the NLSP
(relevant as long as m(st) < m(b)+m(W)+m(χ))
(in SUGRA, needs M1 < M2 at GUT scale)

3-body decays via virtual chargino:

Decay channel $\tilde{t}_1 \to b\tilde{l}\,\nu$ is almost closed for most of the stop mass within the Tevatron reach, due to slepton mass limit of LEP2

Decay $\tilde{t}_1 \to bW\tilde{\chi}_1^0$ dominates if the sneutrino mass is much greater than the W mass, but it has very limited potential for the Tevatron

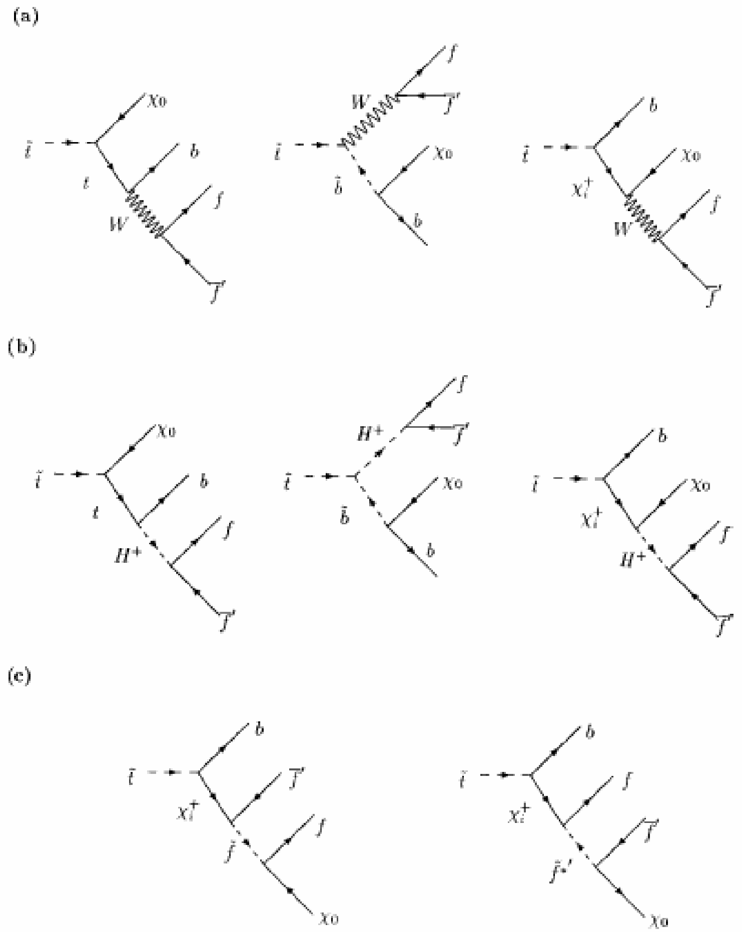
Decay channel $\tilde{t}_1 \to bl\tilde{\nu}$ dominates if the sneutrino mass is of the same order as the W mass.



Stop decays

4-body decay:

$$\tilde{t}_1 \rightarrow b\chi_1^0 f\overline{f'}\,.$$



Same order as the $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$ decay can compete with it if the exchange particles do no have an overly virtuality

Decays of the lightest top squarks
C. Boehm et al.
PRD 61 095006

CDF stop and sbottom results