SUSY searches at the Tevatron

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For the CDF and D0 collaborations

Supersymmetry

- Theory that predicts a boson for any SM fermion and vice-versa
  - The superpartners differ only in their spin
- Removes fine tuning and offers ultra-violet completeness
  - Large radiative corrections of superpartners cancel each-other
- Possibility of force unification
  - Not exactly possible with SM
- Cold dark matter candidate
  - If the lightest supersymmetric particle (LSP) is stable
- Connections to superstrings
  - Incorporation of gravity
- Possibility of radiative Electroweak symmetry breaking
  - As an alternative to spontaneous breaking

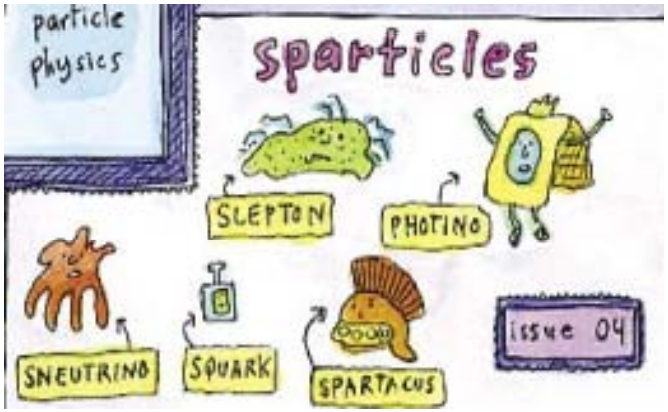
Supersymmetry breaking and spectrum

- "Minor detail": We haven't discovered new particles with same masses as our known SM particles and only a spin difference
- So if SUSY is a symmetry of nature, it has to be broken at a higher energy-scale and the effects are mediated to the electroweak scale.
- In Minimal SUSY (MSSM), supersymmetry is broken by introduction of extra Lagrangian terms
  - Soft SUSY Breaking
- Minimal Supergravity (mSUGRA) is MSSM with some extra boundary conditions and assumptions
  - SUSY breaking is mediated by gravity
  - LSP is the Neutralino
  - Only 4 parameters and a sign (m_0 , $m_{1/2,}$ tanβ, A, μ)
- Alternatively, in Gauge Mediated SUSY Breaking (GMSB), SUSY breaking is mediated by gauge fields
  - LSP is the Gravitino

Particles we (think we) look for

- There are scalar leptons (sleptons) and quarks (squarks)

$$l, \nu, q \rightarrow \tilde{l}, \tilde{\nu}, \tilde{q}$$

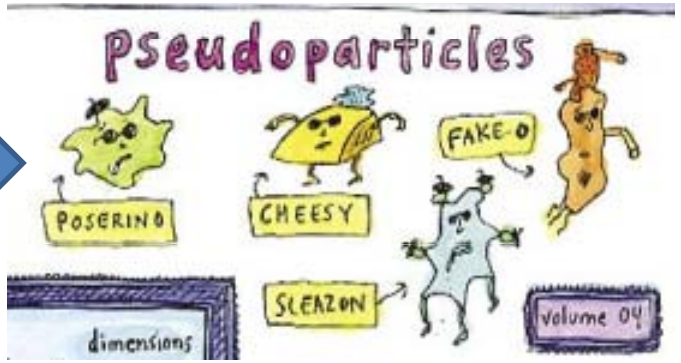


- There are fermionic gluons (gluinos) and fermionic gauge bosons and Higgses that mix to give charginos and neutralinos

$$g \rightarrow \tilde{g} \qquad W, Z, \gamma, \text{higgs sector} \rightarrow \chi^0_{1-4}, \chi^{\pm}_{1,2}$$

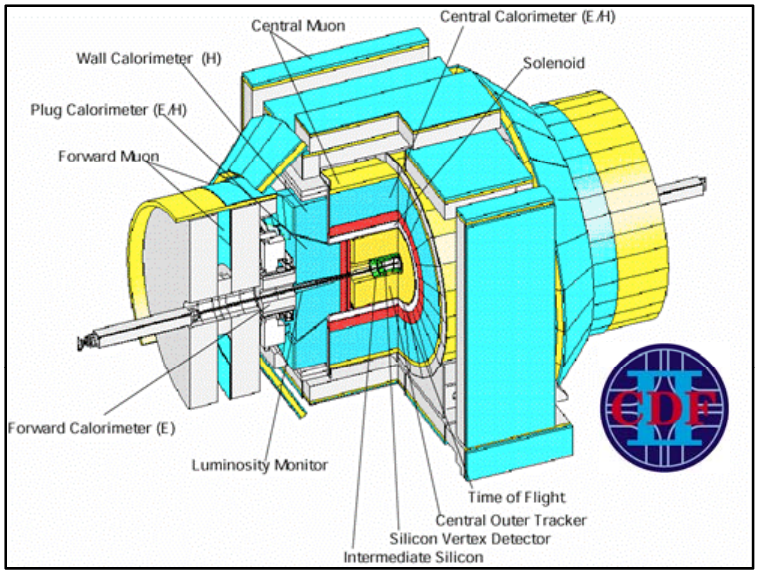
- We present today direct searches for chargino-neutralino, squark, gluino, stop/sbottom production

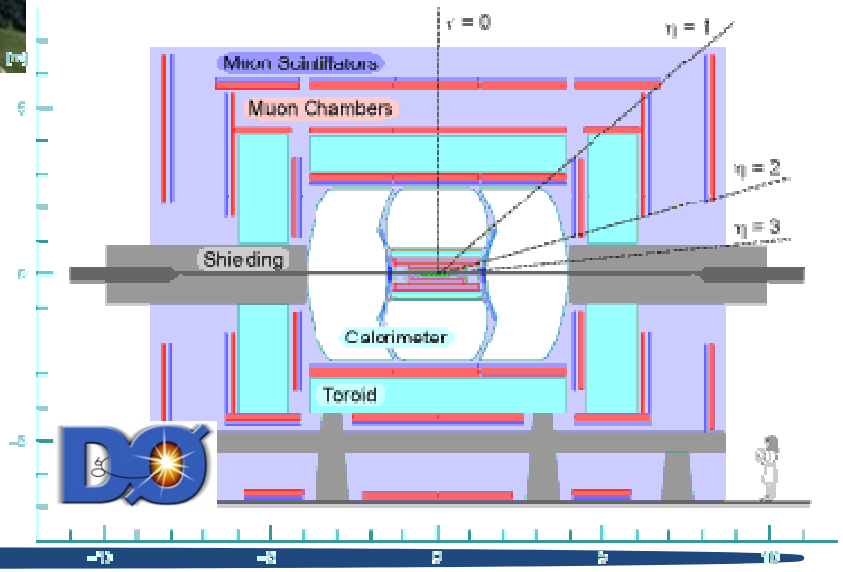
- Of course, we may discover something completely unanticipated in the process !



Cartoons by Roz Chast

The Tevatron and its collider experiments

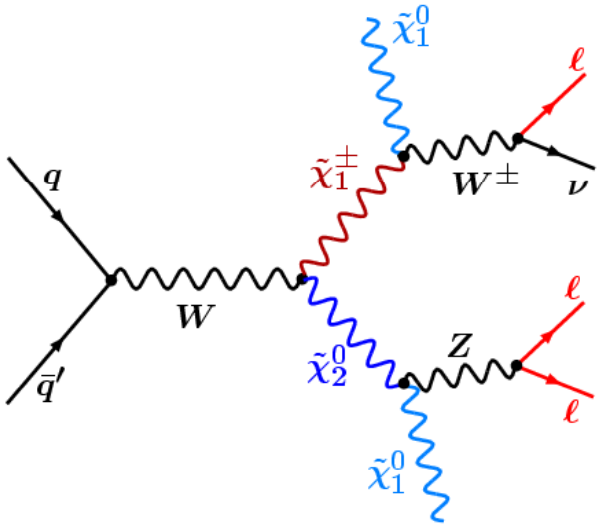




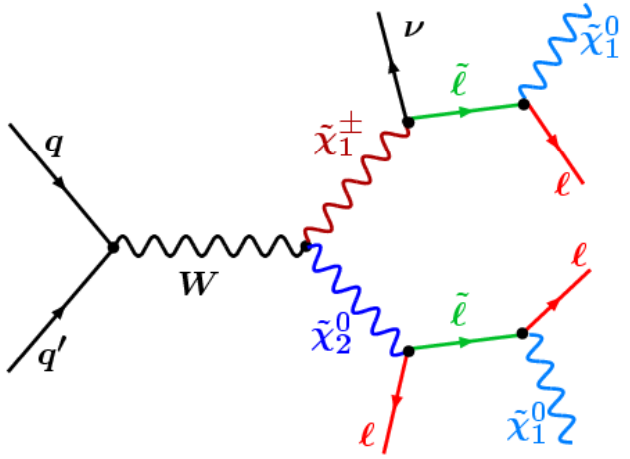
- **Recorded luminosity /experiment ~ 3 fb^{-1}**
- **Presented in this talk: up to 2 fb^{-1}**

Chargino – Neutralino to Trileptons

- Chargino-Neutralino production and decay to trileptons is a golden SUSY signature
  - Very low SM backgrounds, cross sections of the order of 0.1-1 pb have not been excluded yet



Decays through W/Z favorable for heavy sleptons, but BR to leptons low

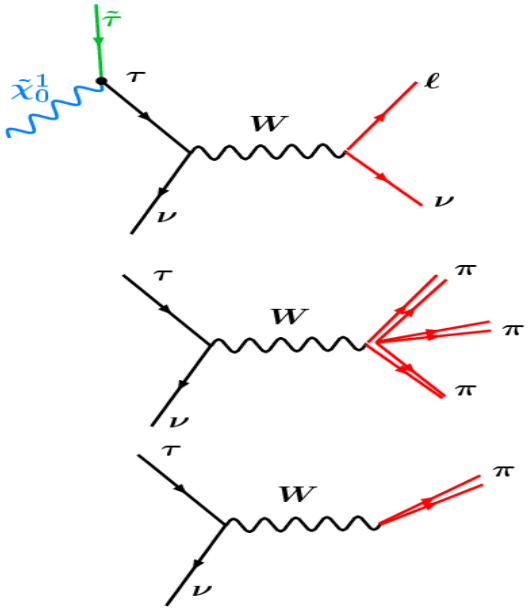


Decays through sleptons guarantee final leptons, but also preference to $\tilde{\tau} \rightarrow \tau$

- Signature of interest: Three leptons and Missing Transverse Energy (MET) due undetected neutralinos and neutrinos

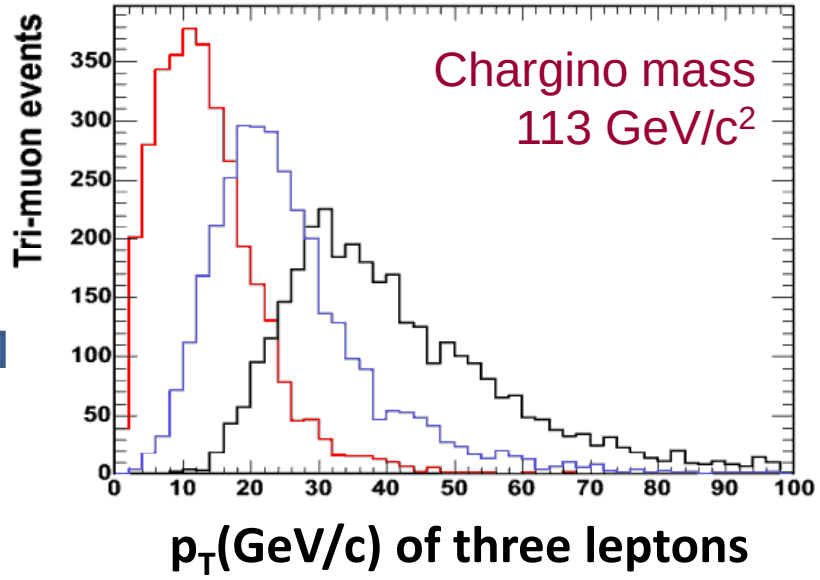
Soft leptons and isolated tracks

- Staus are expected to be the lightest sleptons
  - They will decay to one or three charged hadrons resulting to one or three tracks
  - Or, they will decay to soft leptons



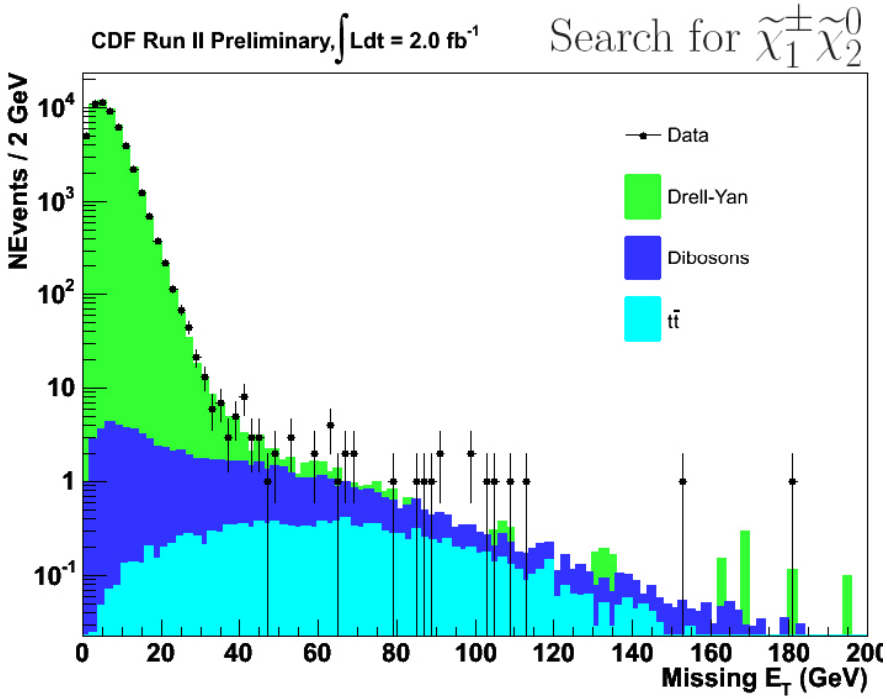
- For this reason, we include isolated tracks to reconstruct some of the "hadronic" taus

p_T of leptons can be really low
(we consider momenta > 5 GeV/c)



Chargino-Neutralino

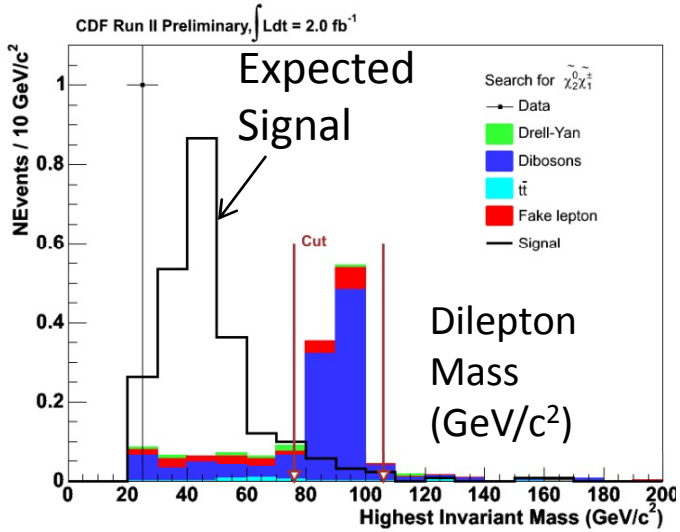
- $\mathcal{L} = 2.0\ fb^{-1}$
- Signature: (3 leptons or 2 leptons+track) +MET
- Selection (signal region):
  - p_T (15,10/5,5) GeV/c
  - MET>20 GeV (DY and QCD rejection)
  - $N_{jets} \leq 1$ and $H_T < 80$ (top rejection)
  - Z-mass veto (DY rejection)
  - Dilepton Mass above 20 GeV/c^2 (QCD and resonance rejection)
- Trilepton backgrounds:
  - DY+fake, Z+γ, diboson



- Control regions in MET vs $M_{\ell\ell}$ phase-space
  - Both dilepton and trilepton control regions show excellent agreement between SM backgrounds and observation

Chargino-Neutralino

- Signal region is investigated only after validating backgrounds in control regions (a blind analysis)
- Good agreement with SM background
- Benchmark SUSY: m_0 =60, $m_{1/2}$ =190, tanβ =3

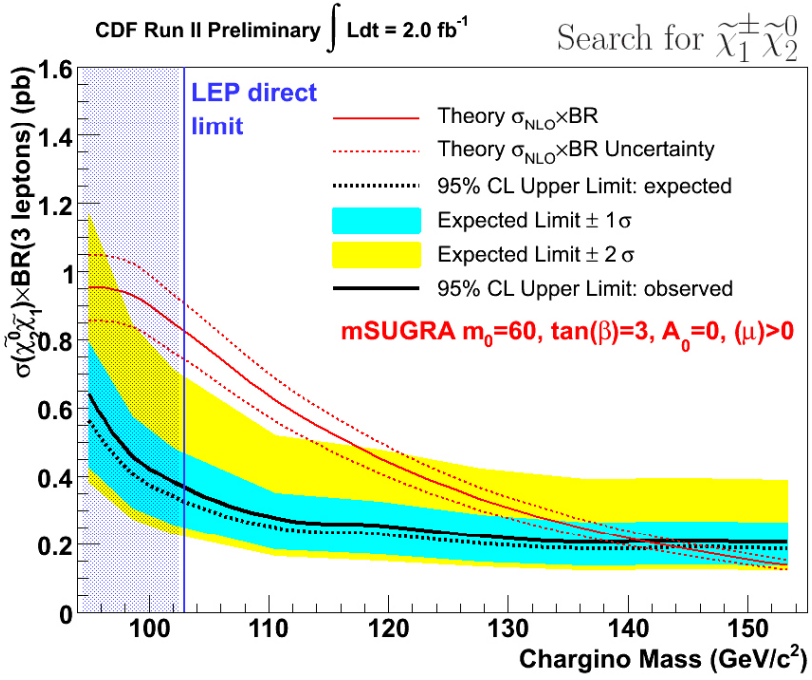


CDF Run II Preliminary, $\mathcal{L} = 2.0$ fb^{-1}

Analysis	Backg.	Signal	DATA
Trilepton	**0.9 ± 0.1**	4.5 ± 0.6	**1**
Dilepton+Track	**6.9 ± 0.9**	5.5 ± 1.1	**6**

First mSUGRA chargino-neutralino mass limit at the Tevatron

$M(\chi_1^\pm) > 140$ GeV/c^2 at 95% CL



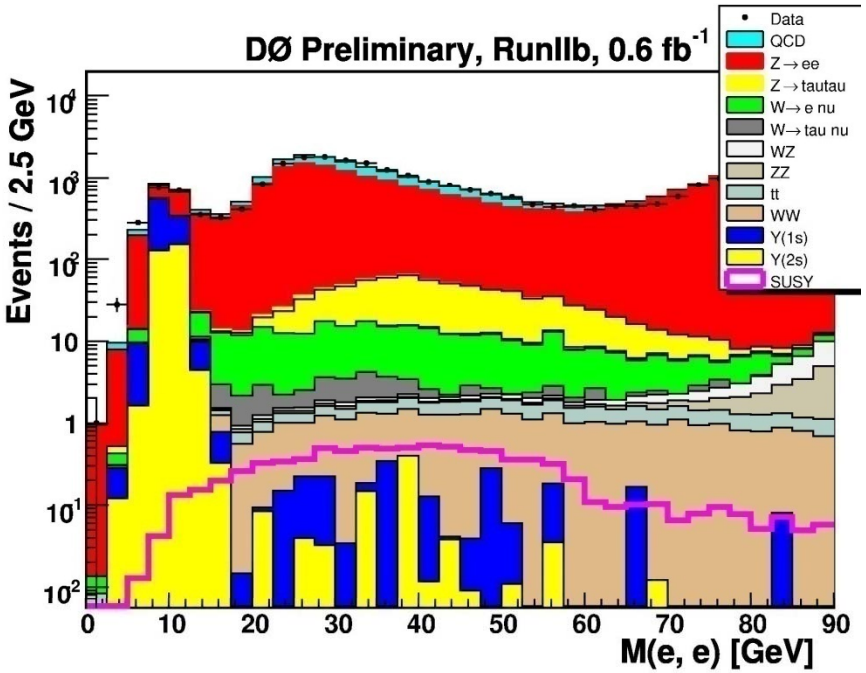
Chargino-Neutralino to eeX

- $\mathcal{L} = 0.6$ fb^{-1}
- Signature: (ee+track) +MET
- Selection (signal region):
  - 2 electrons with p_T >8,12 GeV/c
  - Third lepton or Isolated track with p_T > 4 GeV/c
  - MET>22 GeV (DY and QCD rejection)
  - H_T < 80 GeV (top rejection)
  - Z-mass veto (DY rejection)
  - Dilepton Mass above 18 GeV/c^2 (QCD and resonance rejection)
- Backgrounds:
  - DY+fake, diboson, QCD-multijet

DØ Run II Preliminary, $\mathcal{L} = 0.6$ fb^{-1}

Analysis	Backg.	Signal	DATA
ee+ℓ	**1.0 ± 0.3**	0.5 – 0.2	**0**

This result is combined with the other DØ analyses

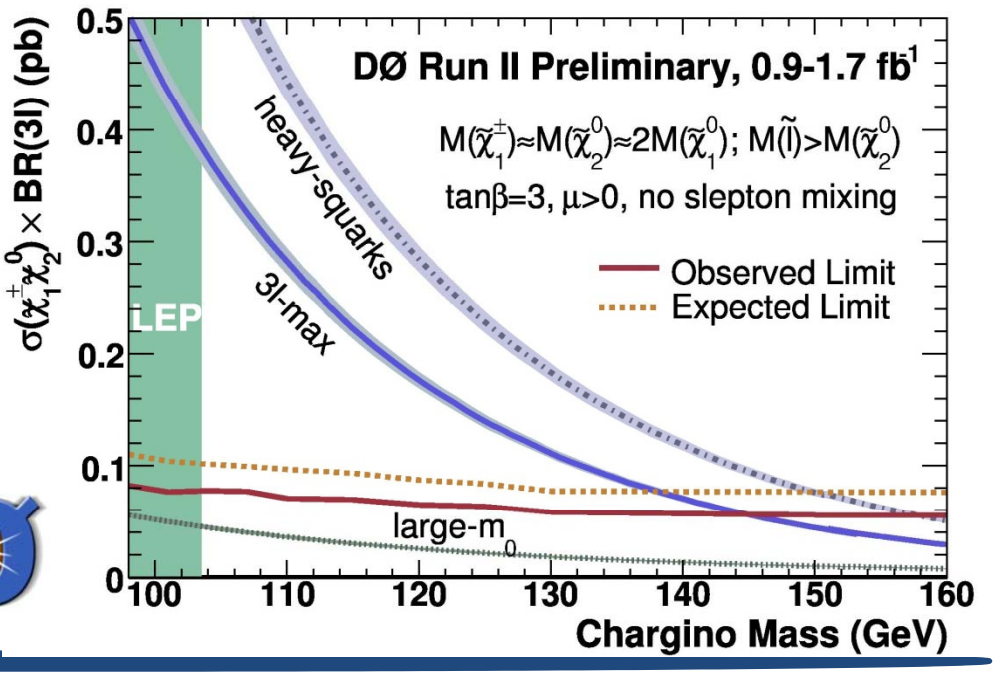


Chargino-Neutralino DØ combination

- The ee+track results are combined with other tri-object analyses of DØ

- Results are interpreted in several models
  - an mSUGRA inspired model with no-slepton mixing
    $M(\chi_1^{\pm}) > 145$ GeV/c^2 at 95% CL
  - A large-m_0 model (suppressed decays to sleptons)
  - A heavy-squarks model (suppressed t-channel production)

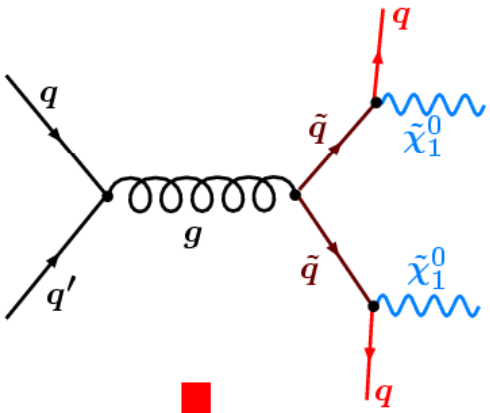
Analysis	$\mathcal{L}$ (fb)	Backg.	Signal	DATA
ee+ℓ	0.6	**1.0 ± 0.3**	0.5 – 0.2	**0**
μμ+ℓ	1	**$0.3^{+0.7}_{-0.03}$**	0.5 – 2.5	**2**
eμ+ℓ	1	**$0.9^{+0.4}_{-0.1}$**	1 – 4	**0**
ee+ℓ	1.1	**0.8 ± 0.7**	1.7 – 4.7	**0**
$\mu^{\pm}\mu^{\pm}$	0.9	**1.1 ± 0.4**	0.6 – 3.7	**1**



Squark-Gluino production and decay

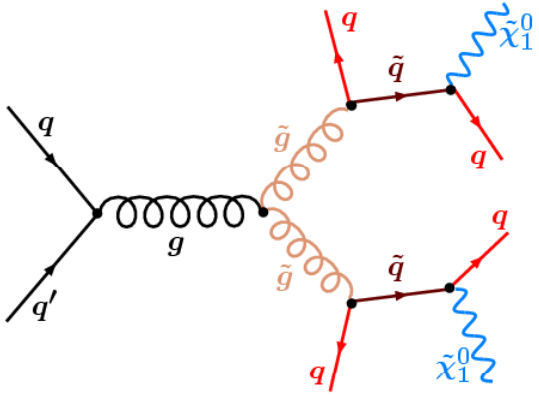
- The dominant squark-gluino production process depends on their mass (σ~0.1-0.2 pb for our sensitivity region)

If $M_{\tilde{q}} < M_{\tilde{g}}$



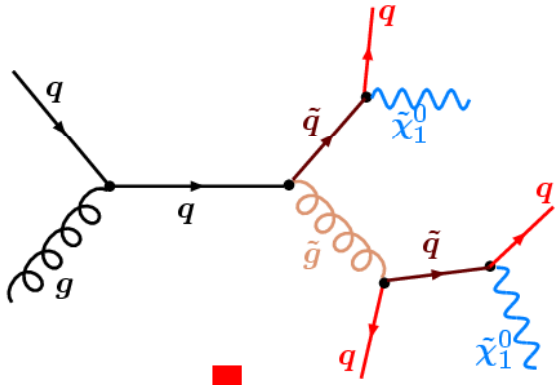
Result: 2 jets and MET

If $M_{\tilde{q}} > M_{\tilde{g}}$



Result: 4 jets and MET

If $M_{\tilde{q}} \approx M_{\tilde{g}}$ then additional contribution:

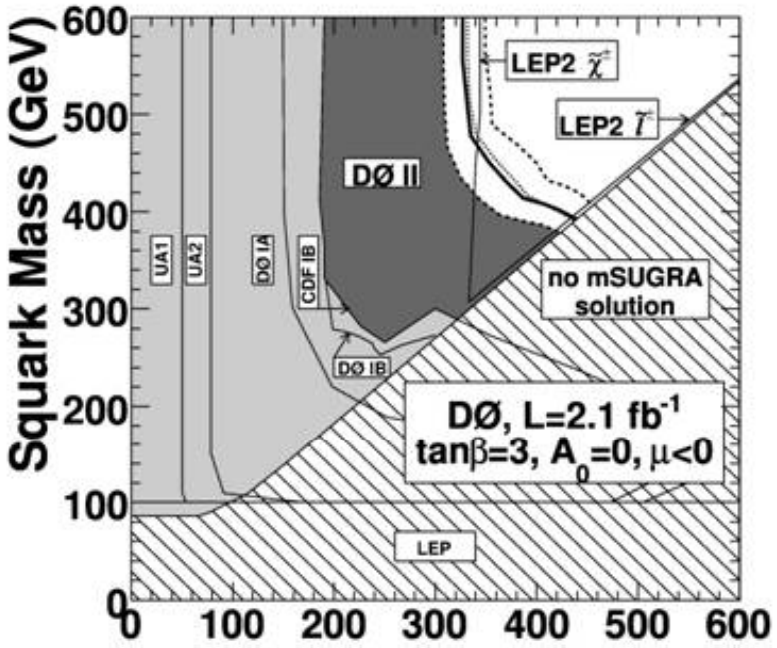


Result: 3 jets and MET

- Although the production is strong, the analyses are challenging due to QCD-multijet and W/Z+jet backgrounds
  - Solution: break-down analyses in jet-multiplicity bins and optimize separately (using MET and HT ← Sum of jet E_T)

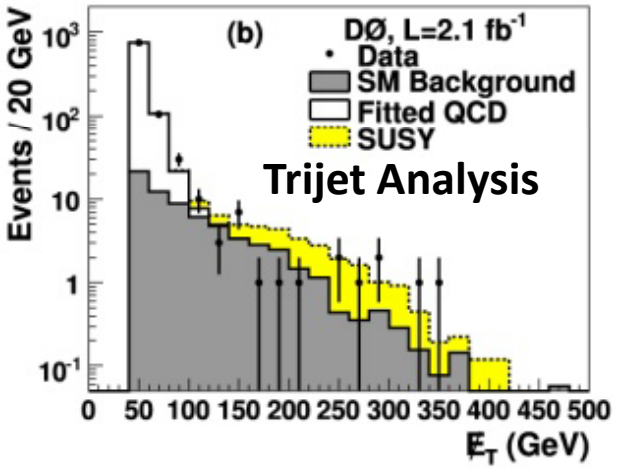
Gluino-Squark

- $\mathcal{L} = 2.1$ fb^{-1}
- Signature: Jets + MET
- QCD multijet background
  - estimated from data extrapolating the low-met distribution
  - Reduced with low Δϕ(MET-jet) and high MET cuts
- W/Z + jets, ttbar, diboson backgrounds (MC)
  - Reduced with lepton-vetos
- Backgrounds after selection: (Z-> νν)+jets, (W-> ℓν)+jets, tt -> ℓ+jets



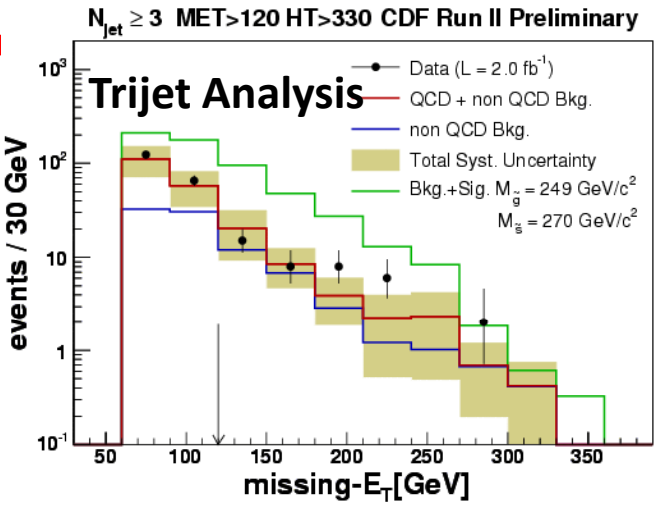
(hep-ex/0712.3805, *PLB 660, 449 (2008)*)

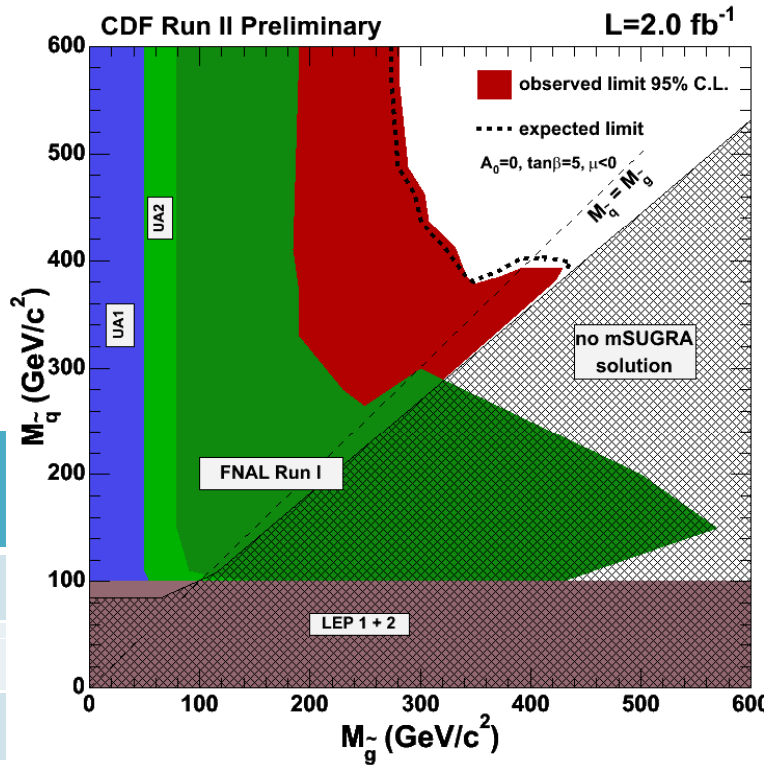
Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA
Dijet	325	225	**35,35**	**11** ± 1 +3/-2	**11**
Trijet	375	175	**35,35,35**	**11** ± 1 +3/-2	**9**
4-jet	400	100	**35,35,35,20**	**18**± 1 +6/-3	**20**



Gluino-Squark

- $\mathcal{L} = 2$ fb^{-1}
- Signature: Jets + MET
- Selection:
  - MET>70 GeV (for QCD reduction)
  - lepton-veto (for top and boson reduction)
  - small jet-met angle (for QCD reduction)
  - separate optimized cuts for 3 analyses
- Backgrounds: QCD multijets, Z+jets, W+jets, top, diboson
  - (all MC, for QCD it is normalized to data at low-met)



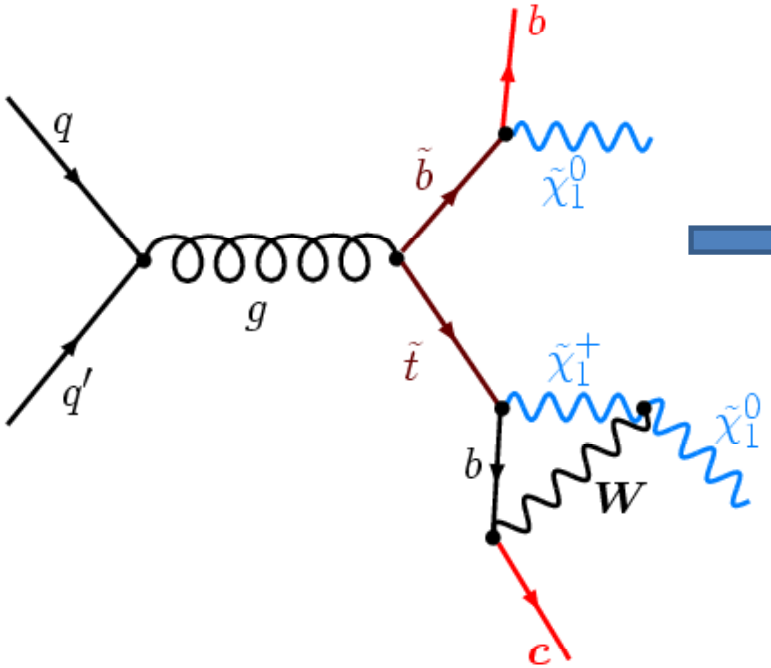


CDF Run II Preliminary, $\mathcal{L} = 2.0$ fb^{-1}

Analysis	HT cut (GeV)	MET cut (GeV)	Jet Et (GeV)	Bckg.	DATA
Dijet	330	180	**165,100**	**16 ± 5**	**18**
Trijet	330	120	**140,100,25**	**37± 12**	**38**
4-jet	280	90	**95,55,55,25**	**48 ± 17**	**45**

Search for stop and sbottom

- We expect one of the stops and sbottoms to be light
- If $m_c + m_{LSP} < m_t < m_b + m_W + m_{LSP}$ then the stop will decay to charm through flavor-changing loop processes



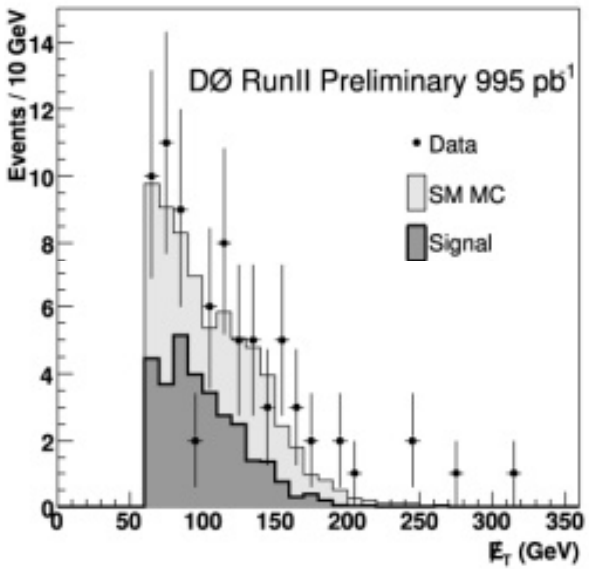
Light stop and sbottom production and decay

Other option is that stop does not decay in the detector (CHAMP)

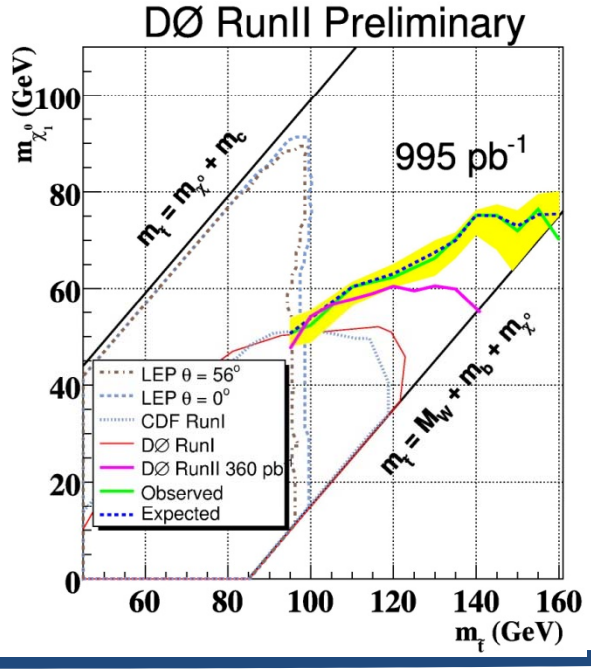
Stops to charm

- $\mathcal{L} = 995\ pb^{-1}$
- Expected cross sections are 1-15 pb
- Selection
  - Exactly 2 jets (reduction of QCD)
  - Jet pt cuts (20,40 GeV/c) and angular separation of jets (reduces QCD and W+jets)
  - Angle between jets and met (reduction of QCD)
  - Flavor tagging using Neural Network (impact parameter, secondary vertex information)
- Final optimization: H_T and MET

Exclusion: stop mass <149 GeV/c^2 for neutralino mass of 63 GeV/c^2



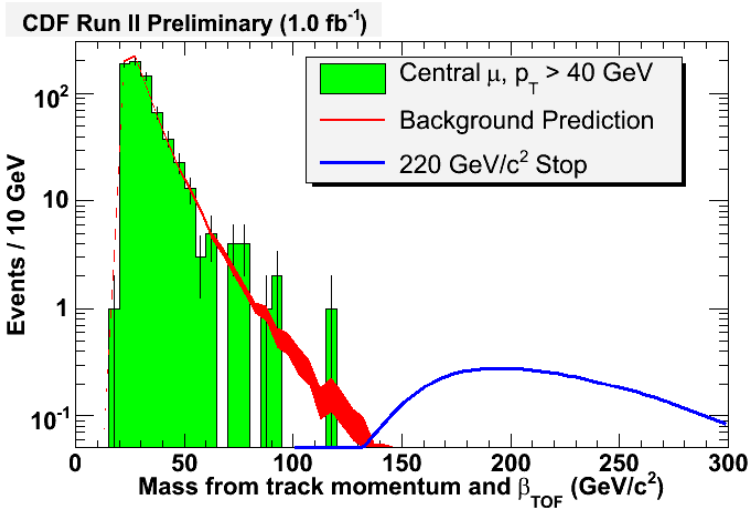
Process	N
W→ℓν + LF jets	21 ± 2
Z→νν + LF jets	13 ± 2
W→ℓν + HF jets	12 ± 1
Z→νν + HF jets	12 ± 1
Diboson	2.7 ± 0.3
t t	2.3 ± 0.1
Total Background	64 ± 3
DATA	66

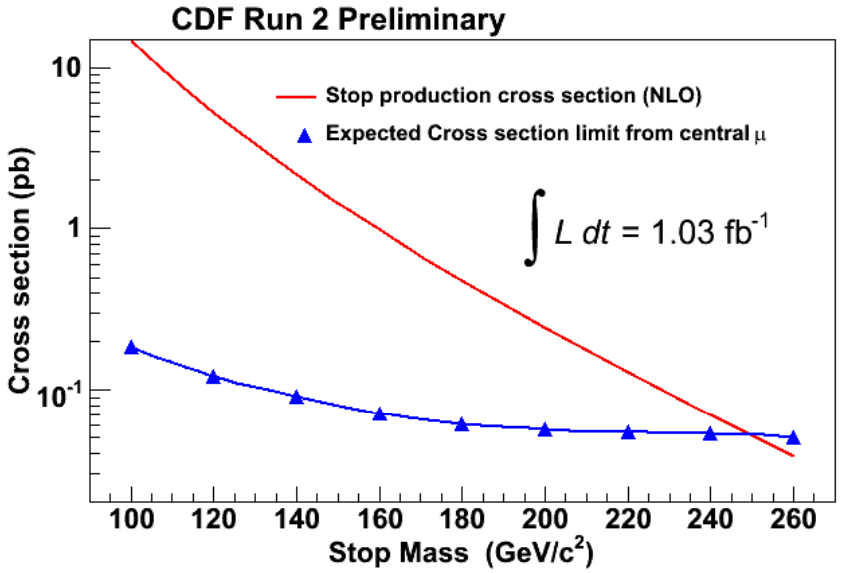


Long-lived top as CHAMP

- $\mathcal{L} = 1.0\ \text{fb}^{-1}$
- Slow particle signature : slowly-moving highly-ionizing highly-penetrating particle
  - Will look like muon with possible calorimetry energy deposition
- Goal: Measure Time of Flight mass of tracks
- Shape of TOF mass determined by beta-resolution, measured with W→ev
- Backgrounds: Cosmics, multiple interactions

Stop Mass (GeV/c²)	Bckg.	DATA	$\sigma_{95\%}$ (fb)
100	**4.7**± 0.3	**4**	160
120	**1.9**± 0.2	**1**	90
260	**(2.6** ± 0.5)10^{-2}	**0**	50





Stable stop mass > 250 GeV/c² at 95% CL

R-parity violation

- R-parity violating part of Lagrangian

Investigated at the Tevatron

$$L_{RPV} = \frac{1}{2}\varepsilon_{\alpha\beta}\lambda_{ijk}L_i^\alpha L_j^b E_k + \varepsilon_{\alpha\beta}\lambda'_{ijk}L_i^\alpha Q_j^b D_k + \frac{1}{2}\varepsilon_{\alpha\beta\gamma}\lambda''_{ijk}U_i^\alpha D_j^b D_k^\gamma + \varepsilon_{\alpha\beta}\mu_i L_i^\alpha H_u^b$$

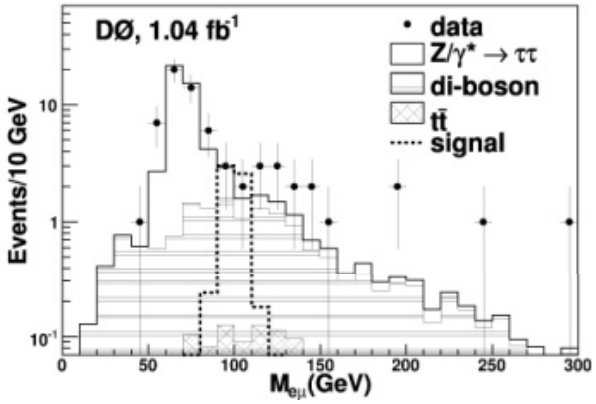
- μLH → neutrino masses
- LLE and LQD → lepton number violation
- UDD → baryon number violation

- We set limits on the couplings λ,λ’

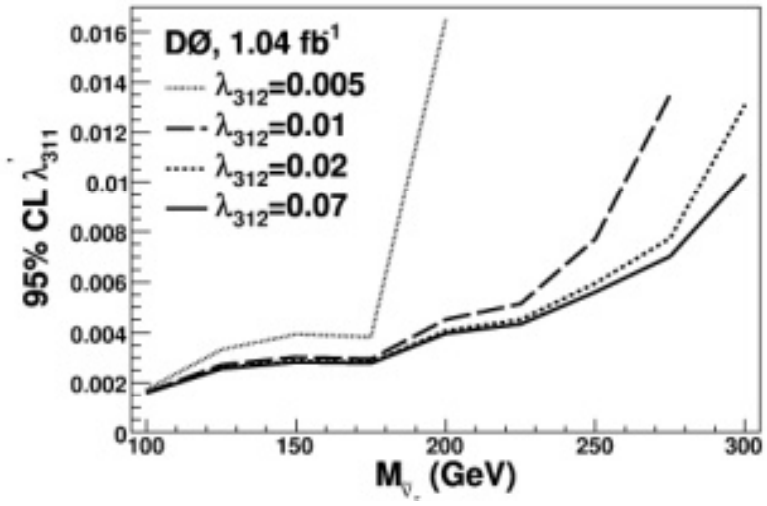
R-parity violating sneutrinos

- $\mathcal{L} = 1\ fb^{-1}$
- Assumption: sneutrino is the LSP
- Signature: e+μ (resonance at the $M_{e\mu}$)
- Backgrounds: $Z/\gamma \rightarrow \tau\,\tau$, diboson, t t
  - (W+γ, W+jets, QCD negligible)
- Selection :
  - E_T (ele) > 30, p_T (muon)> 25
  - MET < 15 (top rejection)
  - No extra leptons (diboson rejection)

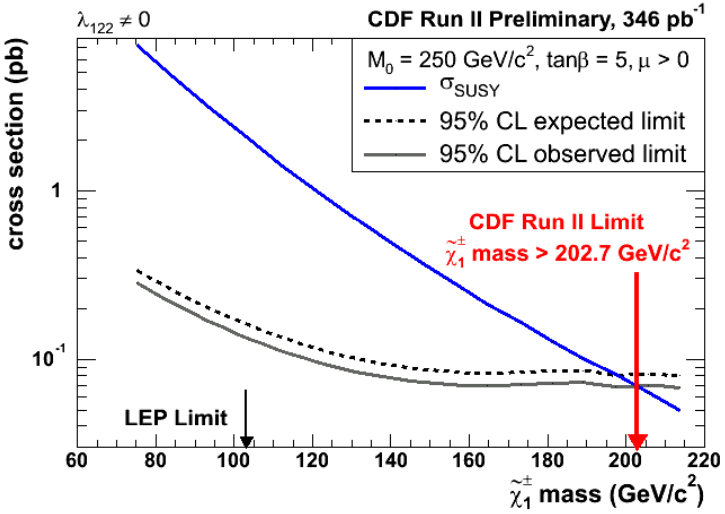
Process	Number of events
$Z/\gamma \rightarrow \tau\,\tau$	43 ± 4
WW	14 ± 2
t t	1.4 ± 0.3
WZ	1.2 ± 0.2
Total SM	**59 ± 5**
DATA	**68**

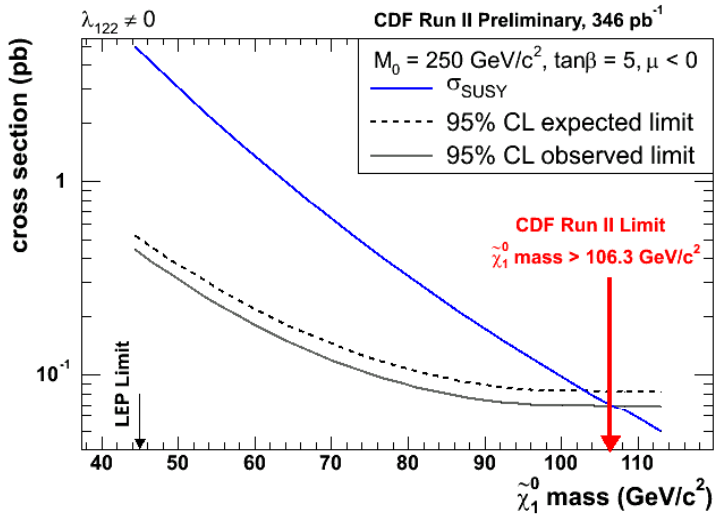


hep-ex/0711.3207 (submitted to PRL)



R parity violation with multileptons





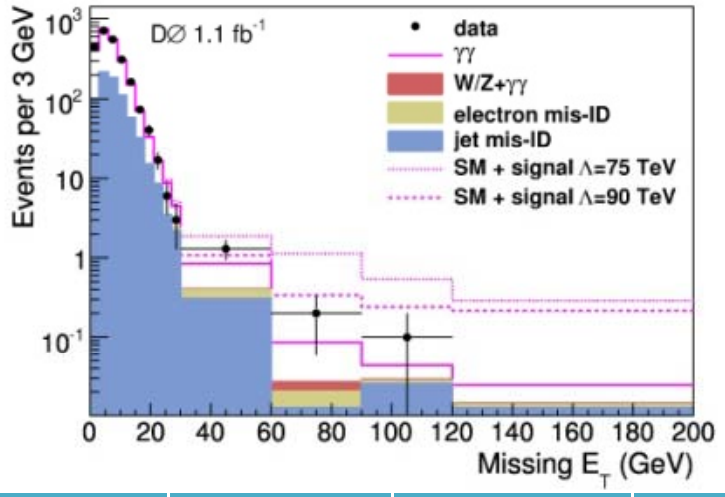
PRL 98, 131804 (2007)

- $\mathcal{L} = 346$ pb^{-1}
- Search for anomalous production of 3 or ≥ 4 leptons
- Both electrons and muons are used

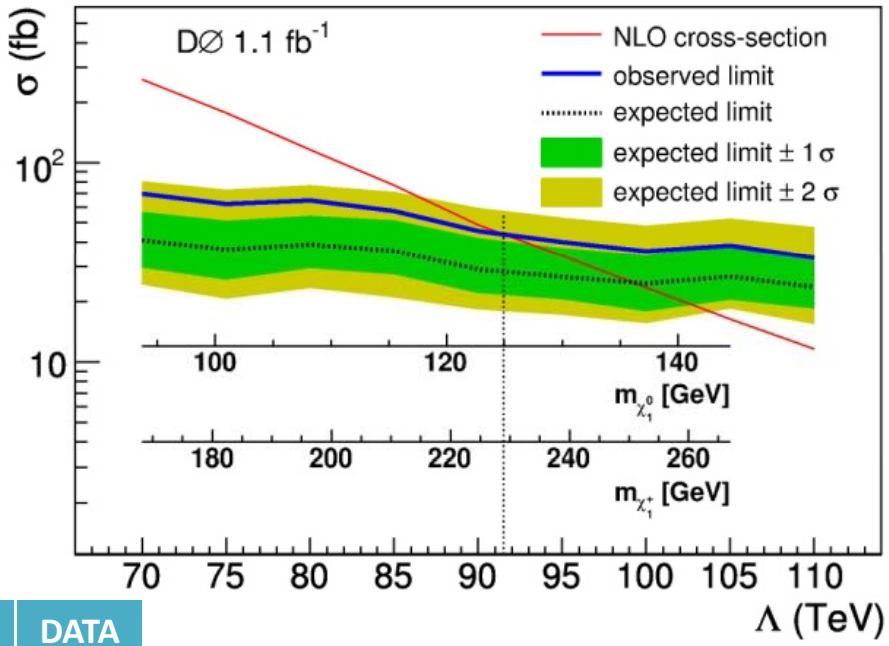
Mass Limits				
	$M_{\tilde{\chi}^0_1}$ (GeV/c^2)		$M_{\tilde{\chi}^{\pm}_1}$ (GeV/c^2)	
SUSY Scenario	**Expected**	**Observed**	**Expected**	**Observed**
λ_{121} and μ > 0	105.0	101.5	191.9	185.3
λ_{121} and μ < 0	101.1	97.7	192.2	185.6
λ_{122} and μ > 0	107.7	110.4	197.5	202.7
λ_{122} and μ < 0	102.7	106.3	195.3	201.9

Neutralinos to diphotons

- $\mathcal{L} = 1.1\ fb^{-1}$
- Signature: 2 photons plus MET (GMSB)
- Selection:
  - Photons: ET>25 GeV, eta<1.1
  - EM cluster pointing algorithm to the vertex within 2 cm
  - Jet-met separation



- Instrumental Backgrounds (fake photons)
  - Wγ, W+jet, ttbar, QCD multijet, Z → ee
  - **eγ sample used for normalizations**
- Physics backgrounds
  - Wγγ-> lγγν and Zγγ → νγγ (MC)



Analysis	Bckg.	Λ = 75 TeV	Λ = 90 TeV	DATA
MET > 30 GeV	**11 ± 1**	28 ± 4	9 ± 1	**16**
MET > 60 GeV	**1.6 ± 0.4**	18 ± 3	6 ± 1	**3**

(hep-ex/0710.3946, *PLB 659, 856 (2008)*)

Summary

- SUSY has not been observed yet
- At Tevatron we work hard trying to either discover it or set stringent limits
- Current state of the art :

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

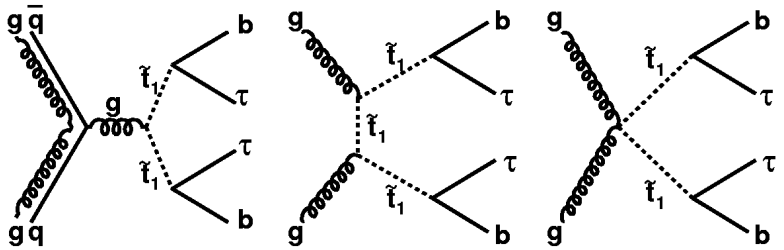
http://www-cdf.fnal.gov/physics/exotic/exotic.html

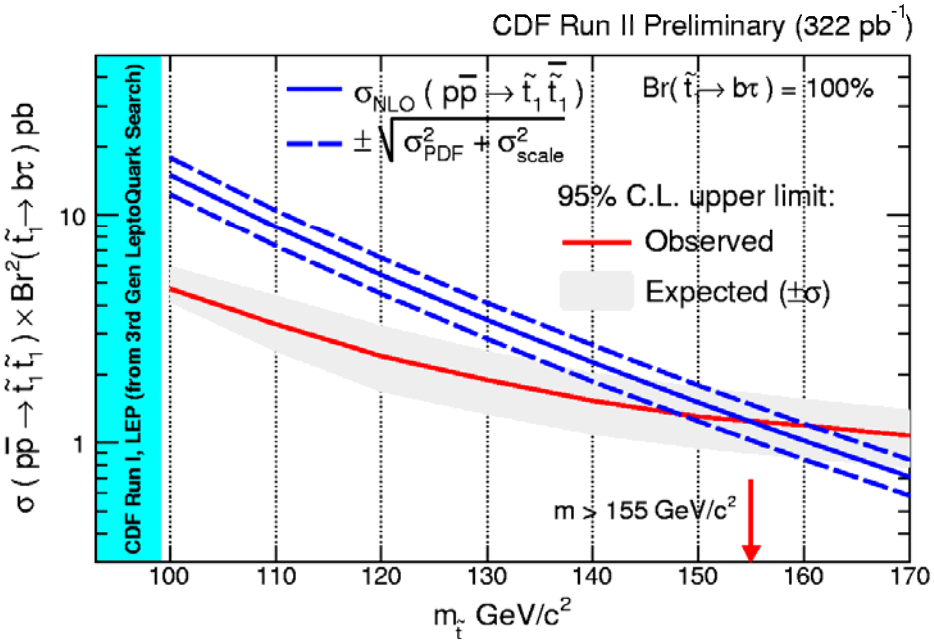
Sparticle	Low mass limit (GeV/c^2)
Chargino (mSUGRA)	~140-150
NL Neutralino (mSUGRA)	~140-150
Chargino (GMSB)	~230
LSP Neutralino (GMSB)	~125
Chargino mSUGRA, RPV	~200
Neutralino mSUGRA, RPV	~100
Squark	~400
Gluino	~300
Light stop or RPV stop	~150
Stop as CHAMP	~250

Additional analyses

RPV stop to tau + b

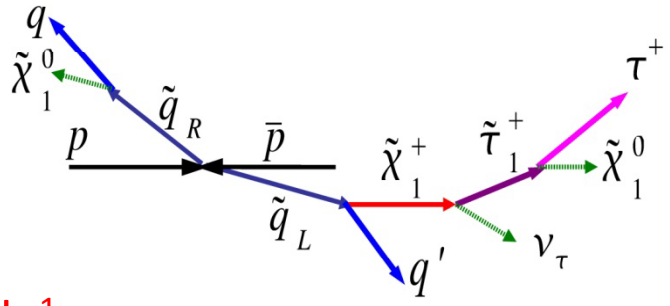
- $\mathcal{L} = 322\ pb^{-1}$
- Process: two stops produced, each of which decay to tau + b with a BR~β
  - Selection for one hadronic and one leptonic tau
- Signature: lepton + narrow jet + 2 jets
- SM Backgrounds: QCD (bb, γ+jet) and W/Z+jets
- Selection:
  - Electron or muon with p_T > 10 GeV/c
  - Hadronic tau with p_T > 15 GeV/c
  - Conversion, cosmic removal and Z → τ τ vetos
  - Signal region (blind) N_{jets} >2 and $M_T(\ell,MET)$<35
- Expected ~2±0.5 e+τ_h and observed 1
- Expected ~1±0.5 μ+τ_h and observed 1
- For β=1, m_{stop} >151 GeV/c^2 at 95% CL

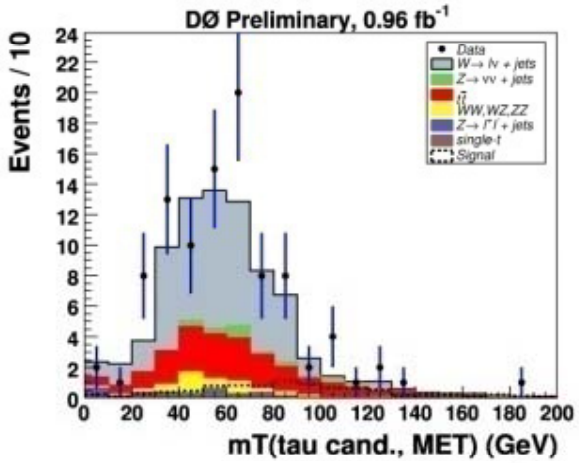




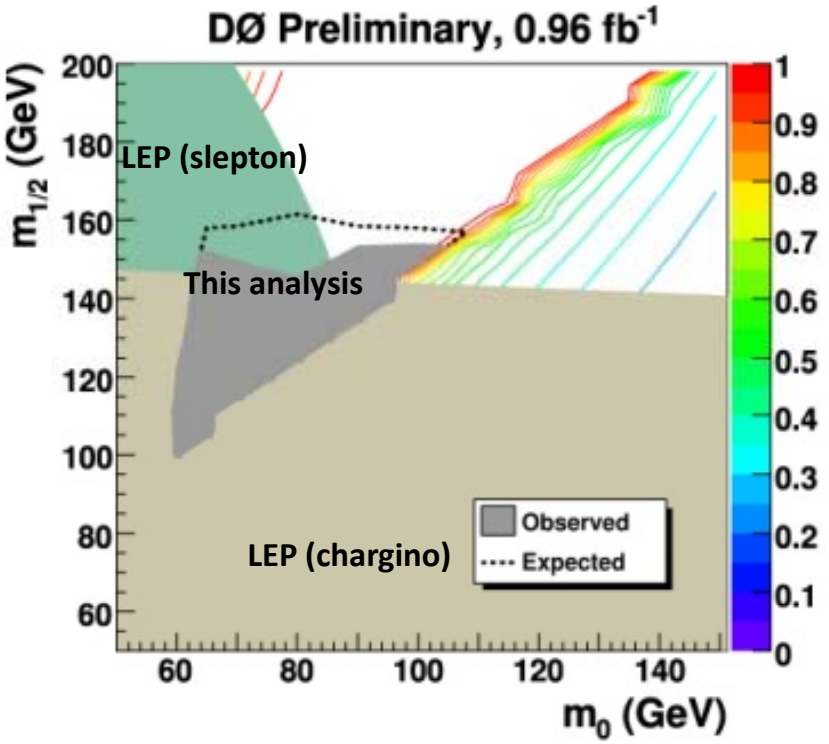
arXiv:0711.3161 (submitted to PRL)

Squark to taus





- $\mathcal{L}$ = 960 pb^{-1}
- Objects: Jets + MET + hadronic taus
  - Hadronic tau → narrow isolated jet with low track multiplicity
  - Three kinds of taus (with or without π^0)
- Require at least one tau, separated from jets, with pT(tau)>15 GeV
  - Neural Networks for tau-jet separation
- Main backgrounds after optimization: ttbar, W+jet
- Expect 1.7 +0.6/-0.4 and we observe 2 events (expected σ ~ 0.3 pb)



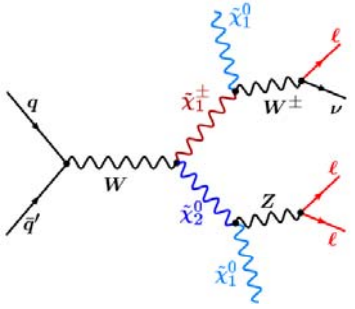
Stop dileptons

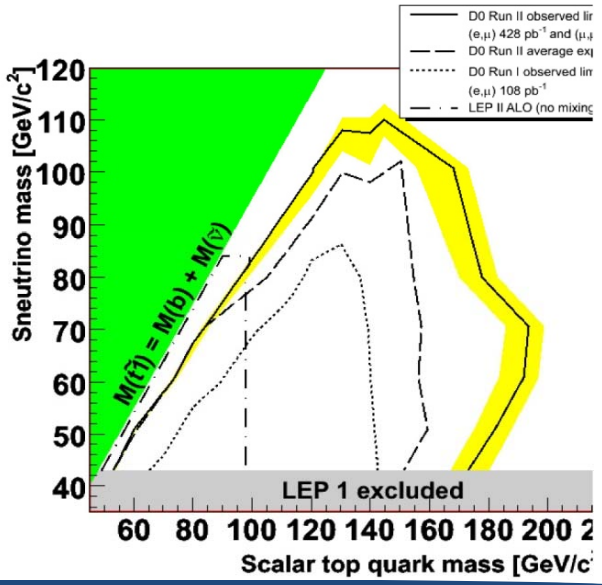
- $\mathcal{L} = 400$ pb^{-1}
- Signature: Two isolated leptons, met and jets
- QCD multijet background is estimated from data
  - by reversing the μ-isolation or e-likelihood function for eμ
  - by investigating SS dimuons for μμ
- Main backgrounds: QCD, Z/γ→ τ τ, WW
- μμ Selection
  - 2 track-isolated muons
  - p_T (muons) > 6, 8 GeV/c2 , MET>20 GeV+
  - $N_{jets} \geq 1$ (to reduce Z/γ → μμ + ISR)
  - High jet-probability
  - Z-veto
  - top dominates after the above selection

Channel	Z →ℓℓ	tt	Total Bckg.	DATA
μμ	0.1	2.3	**2.9 ± 0.4± 0.1**	1

- eμ Selection
  - 2 isolated leptons with pT (leptons) > 8, 10 GeV/c2
  - MET>15 GeV
  - Lepton-MET and lepton-jet separation
  - MT(μ+MET)>15 GeV/c2, for Z→ τ τ reduction
  - After the above selection, main background is WW and ttbar

Channel	QCD	Z →ℓℓ	tt	Diboson	Total Bckg.	DATA
eμ	5.9	3.6	7.4	20.2	37 ± 2.7 ± 0.9	34

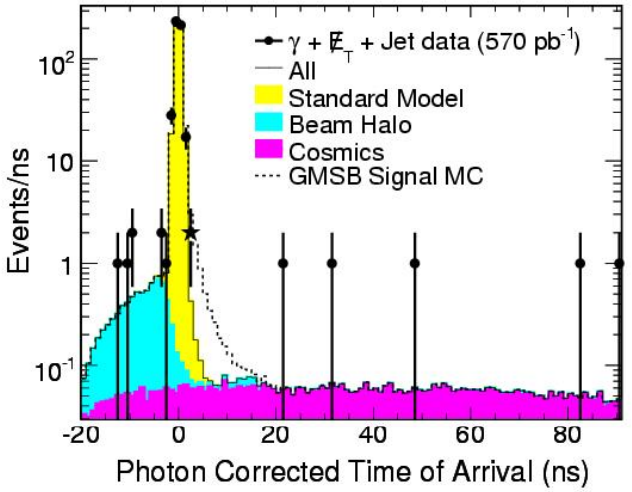


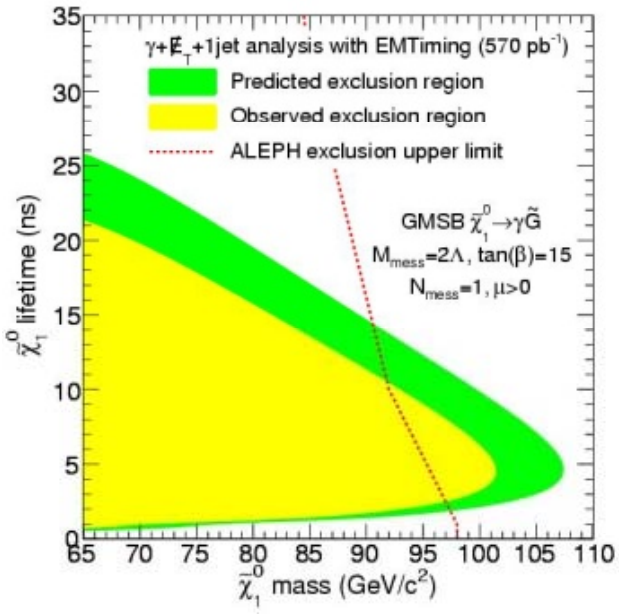


hep-ex/0707.2864, *PLB 659, 500 (2008)*

Long-lived neutralinos

- $\mathcal{L} = 570$ pb^{-1}
- Looking fro neutralino to gamma+gravitino
- The photon is "delayed" since it is originated from the decay of the neutralino
- Signature: photon + jet + MET
- Investigated GMSB signal
  - M_mess = 2 Lambda, tanbeta=15, mu>0 N_mess = 1
- Backgrounds:
  - Collision: γ+jet+fake-MET, di-jet + fake-MET, W → e ν
  - Non-collision: cosmic rays and beam effects
- Preselection:
  - photon ET> 30 , met ET> 30, jet ET>30 GeV
  - Geometric separation of muon hits and gamma (cosmic reduction)
  - Delayed signal 2 ns – 10 ns
  - Selection optimized for neutralino mass of 100 GeV/c^2 and lifetime of 5 ns
- Optimization of final cuts
  - MET>40, JET_ET>35, Δϕ(Jet-met)>1 rad, 2 ns <t<10 ns.
- m(neutralino)>101 GeV for lifetime of 5 ns.





PRL 99, 121801 (2007)

Stop-sbottom

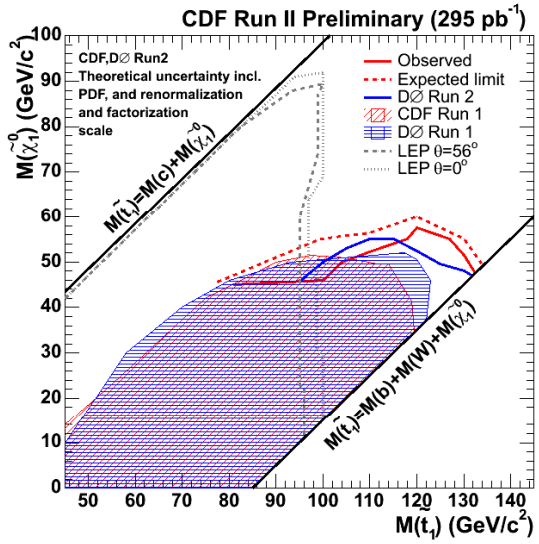
- $\mathcal{L} = 295$ pb^{-1}
- Expected σ of 50 pb to 0.25 pb for stop and sbottom masses from 80 to 200 GeV/c^2
- Signature: c+cbar+MET and b+bbar+MET
- Three mass ranges for each of the sbottom and stop analyses
- Backgrounds:
  - QCD multijet (from data, normalized to low-MET and MET//jet regions)
  - W/Z+jet, single top, ttbar, diboson.

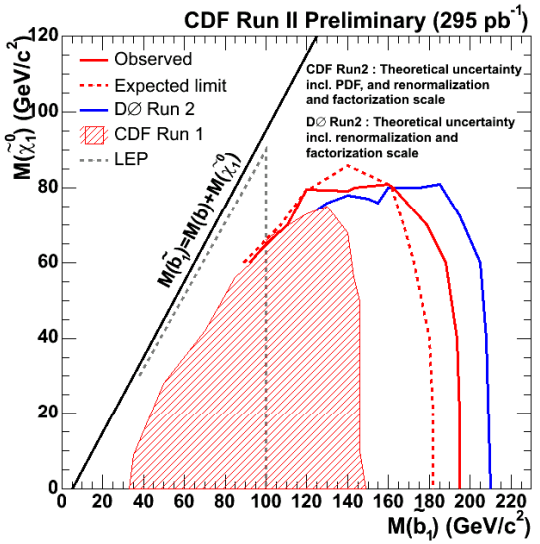
	M_{stop} <100	M_{stop} 100-120	M_{stop} >120
SM	137±16	95 ± 11	43 ± 5
DATA	151	108	43

	$M_{sbottom}$ <140	$M_{sbottom}$ 140-180	$M_{sbottom}$ >180
SM	55 ± 7	18 ± 2	4.7 +2.2/-0.7
DATA	60	18	3

PRD 76, 072010 (2007)

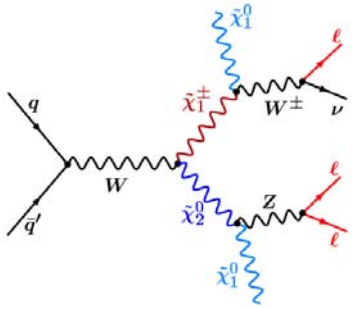
- Selection:
  - Charged particle and EM fraction cut (reduces cosmics beam-hallo, fake jets, wrong PV selection)
  - MET>50 GeV, no additional jets, no collinear jet and met and jets not collinear or back-to-back (for QCD reduction)
  - Lepton veto and high jet track multiplicity (for W/Z+jets reduction)
  - HF tagger (efficiency 40% and 17% for b and c – 1% and 5% mistag)
- After cuts the highest source of background is Mistag and HF multi-jet
  - the latter goes to zero for the high mass region of search)





Sbottom

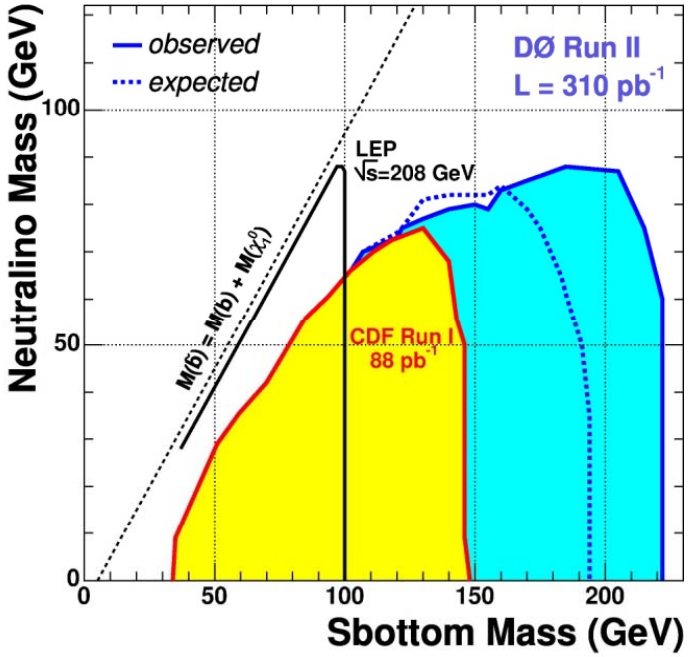
- $\mathcal{L} = 310\ pb^{-1}$
- Backgrounds:
  - QCD multijet (estimated by fitting data with MET<60 GeV and extrapolating
  - W/Z+jets,diboson, top



- Selection:
  - Charged particle mulitplicity (reject fake jets)
  - Azimuthal-angle jet-jet and jet-MET cuts (to reduce QCD)
  - MET>60 and jet ET>60,20 GeV (to reduce QCD)
  - Isolated lepton veto and jet-met not back-to-back (to reduce W/Z)
  - No more than 3 jets (to reduce top)
  - One heavy-flavor tagged jet (30% efficient for b, 5% for c)
- After selection, QCD and diboson are negligible.
- Further optimize the MET and jet ET values.
- sbottom mass>222 GeV at 95% CL.

PRL 97, 171806 (2006)

Process	Number of events
W→e/μ ν + jets	2.7 ± 0.2
W→τ ν + LF jets	4.1 ± 0.6
Z→νν + jets	8.8 ± 0.3
Diboson	0.9 ± 0.2
t t	3.8 ± 0.2
Total Background	**22 ± 1**
DATA	**22**



$B_s \rightarrow \mu\mu$ (CDF and D0)

CDF Run 2	(1.9 fb^{-1}):	BR($B_s \rightarrow \mu\mu$) < 5.8×10^{-8} @95% CL	Recent CDF result
Comb CDF/D0		BR($B_s \rightarrow \mu\mu$) < 1.5×10^{-7} @95% CL	hep-ex/0508058
CDF Run 2	(364 pb^{-1})	BR($B_s \rightarrow \mu\mu$) < 2.0×10^{-7} @95% CL	Phys. Rev. Letters 95, 221805 2005
D0 Run 2	(300 pb^{-1})	BR($B_s \rightarrow \mu\mu$) < 3.7×10^{-7} @95% CL	D0-Note 4733-Conf, Preliminary
D0 Run 2	(240 pb^{-1})	BR($B_s \rightarrow \mu\mu$) < 5.0×10^{-7} @95% CL	Phys. Rev. Letters 94, 071802 2005
CDF Run 2	(171 pb^{-1})	BR($B_s \rightarrow \mu\mu$) < 7.5×10^{-7} @95% CL	Phys. Rev. Letters 93, 032001 2004

http://www-cdf.fnal.gov/physics/new/bottom/070809.blessed-Bsd2mumu/

$B_d \rightarrow \mu\mu$ (CDF and D0)

CDF Run 2	(1.9 fb^{-1}):	BR($B_d \rightarrow \mu\mu$) < 1.5×10^{-8} @90% CL	Recent CDF result
CDF Run 2	(364 pb^{-1}):	BR($B_d \rightarrow \mu\mu$) < 3.9×10^{-8} @90% CL	Phys. Rev. Letters 95, 221805 2005
BaBar	(111 fb^{-1}):	BR($B_d \rightarrow \mu\mu$) < 8.3×10^{-8} @90% CL	Phys. Rev. Letters 94, 221803 2005
CDF Run 2	(171 pb^{-1}):	BR($B_d \rightarrow \mu\mu$) < 1.5×10^{-7} @90% CL	Phys. Rev. Letters 93, 032001 2004
Belle	(78 fb^{-1}):	BR($B_s \rightarrow \mu\mu$) < 1.6×10^{-7} @90% CL	Phys. Rev. D RC 68, 111101 2003

http://www-cdf.fnal.gov/physics/new/bottom/070809.blessed-Bsd2mumu/

How to get SUSY MC signal

- Assuming on shell produced SUSY particles, use only 2→ 2 decays:
  - Select a SUSY point (e.g., mSUGRA)
  - Get the spectrum (e.g., using SOFTSUSY)
  - Get Branching Ratios (e.g., using SDECAY)
  - Feed spectrum and BR to generator with fragmentation (e.g., PYTHIA)
  - Feed PYTHIA generated events to detector simulator (e.g., GEANT)
  - Correct using the NLO cross-section (e.g., from PROSPINO)

- Assuming the whole 2→ 6 decays of most processes (e.g., chargino-neutralino), which is more accurate:
  - Use the complete 2→6 matrix element (e.g., from MADGRAPH)
  - Get the spectrum (e.g., using SOFTSUSY)
  - Integrate using proper phase-space to generate events (e.g., using MADEVENT)
  - Feed the generated events to program with fragmentation (e.g., PYTHIA)
  - Feed PYTHIA generated events to detector simulator (e.g., GEANT)
  - Correct using the NLO cross-section (e.g., from PROSPINO)