Recent SUSY results from DØ

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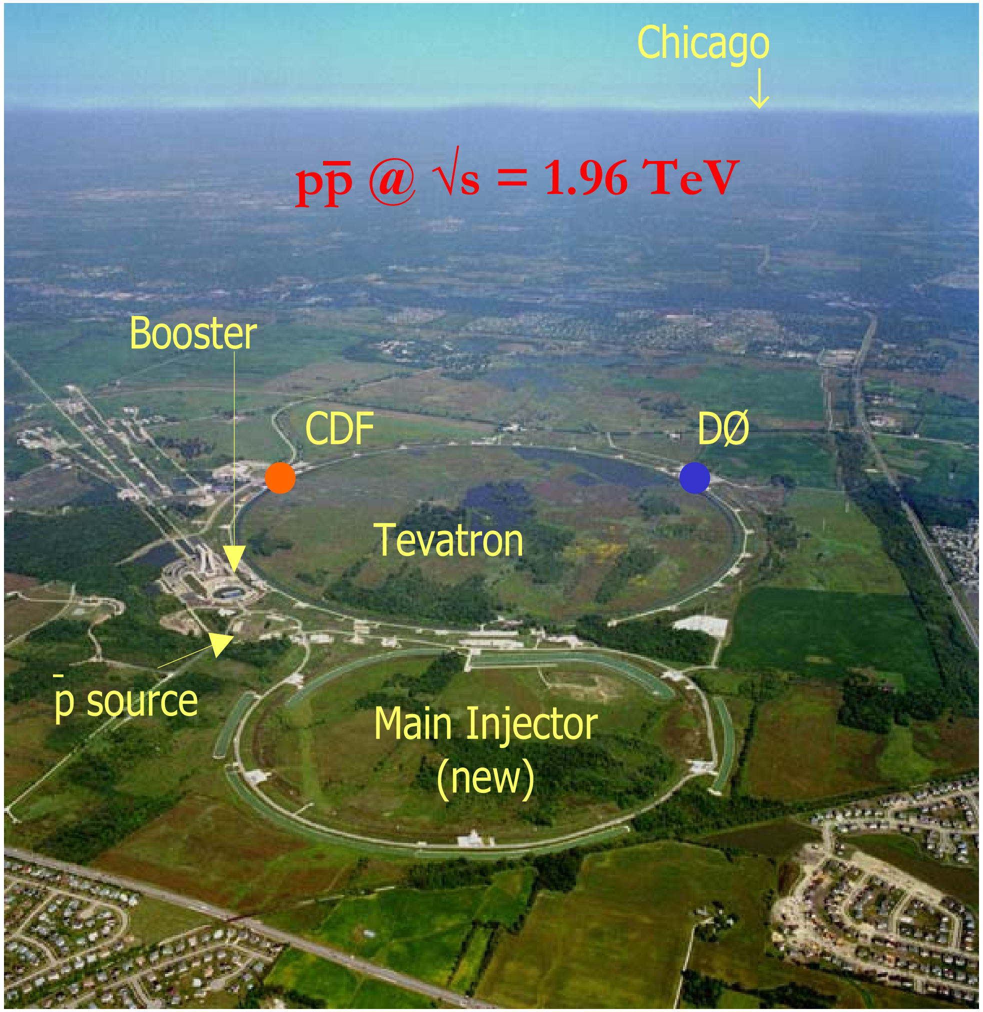
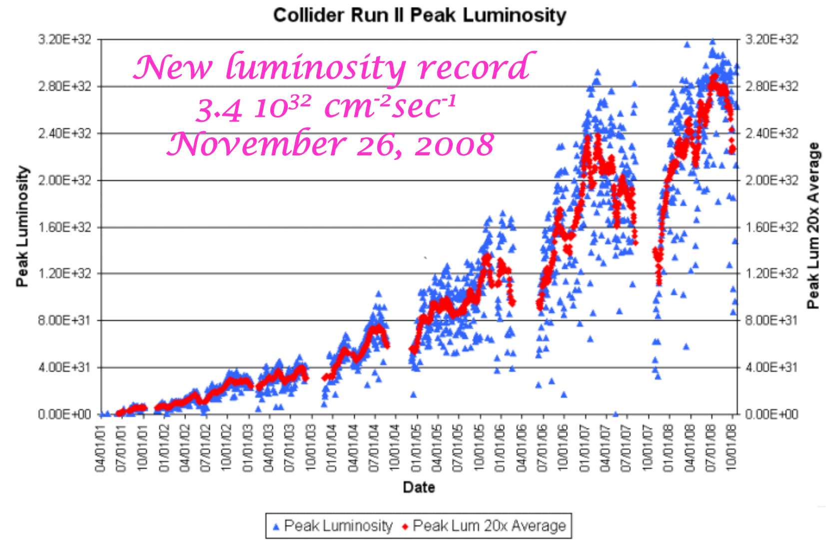
LPC Clermont-Ferrand

- The Tevatron and DØ
- Squarks and gluino searches
- Stop searches
- Charged Massive Stable Particles
- RPV search: Sneutrino
- Conclusion

The TeVatron

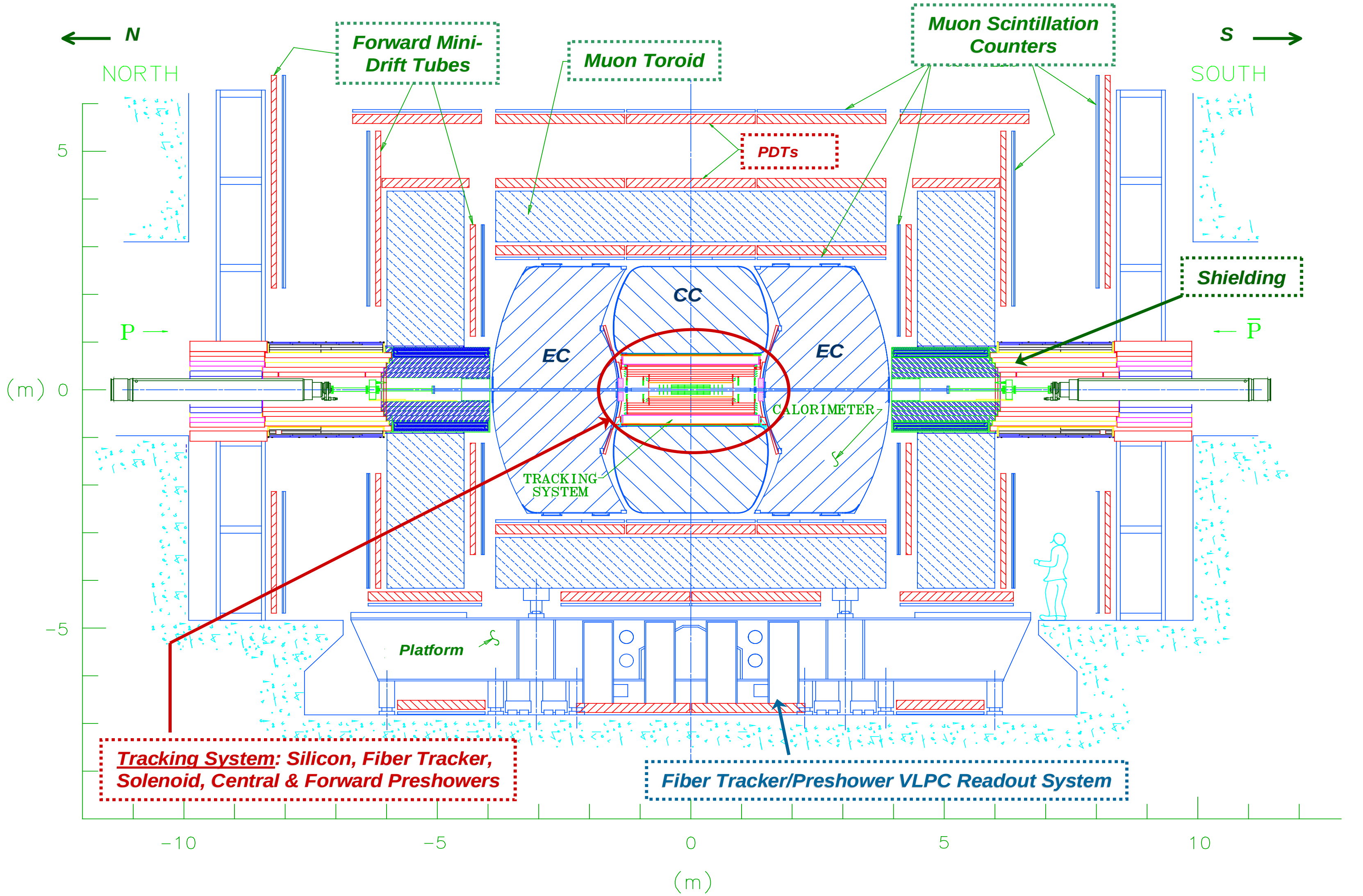




Typical «recorded» to «delivered» luminosity ratio: 90%
~4.7 fb^{-1} recorded per experiment.
7 to 9 fb^{-1} expected in 2009
(Reminder: RunI: 100 pb^{-1})

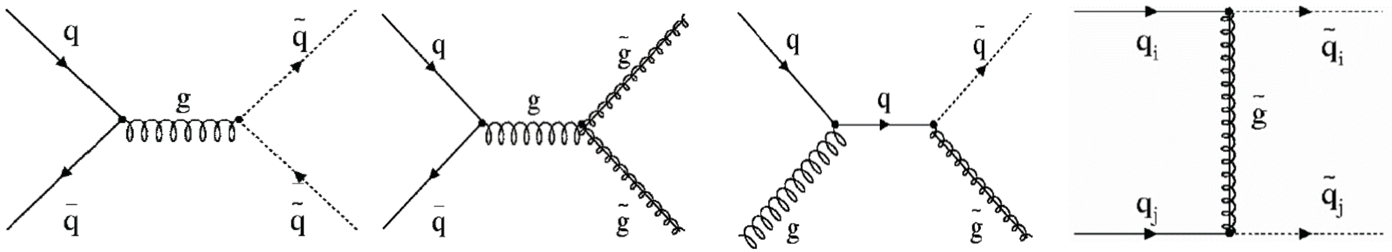
Results presented in this talk: 1 to 2 fb^{-1}

DØ detector



N
S
NORTH
SOUTH
Forward Mini-Drift Tubes
Muon Toroid
Muon Scintillation Counters
PDTs
Shielding
CC
EC
EC
CALORIMETER
TRACKING SYSTEM
P
P̄
Platform
(m) 0
5
-5
-10
-5
0
5
10
(m)
Tracking System: Silicon, Fiber Tracker, Solenoid, Central & Forward Preshowers
Fiber Tracker/Preshower VLPC Readout System

Squarks and gluinos searches



mSUGRA
LSP: $\tilde{\chi}_1^0$

$m_0 << m_{1/2} \rightarrow m_{\tilde{q}} << m_{\tilde{g}} \rightarrow \tilde{q}\tilde{q}$ with $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ — 2 jets + MET (« dijet »)

$m_0 \sim m_{1/2} \rightarrow m_{\tilde{g}} \approx m_{\tilde{q}} \rightarrow \tilde{q}\tilde{g}$ with $\tilde{q} \rightarrow q\tilde{\chi}_1^0, \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$ — ≥ 3 jets + MET (« 3 jets »)

$m_{1/2} << m_0 \rightarrow m_{\tilde{g}} << m_{\tilde{q}} \rightarrow \tilde{g}\tilde{g}$ with $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$ — ≥ 4 jets + MET (« gluino »)

All squark species except stop

Trigger: dijet+MET (« dijet »)
multijet+MET (« 3 jets » and « gluino »)

SM background:
- W/Z + jets
- WW,WZ,ZZ
- tt

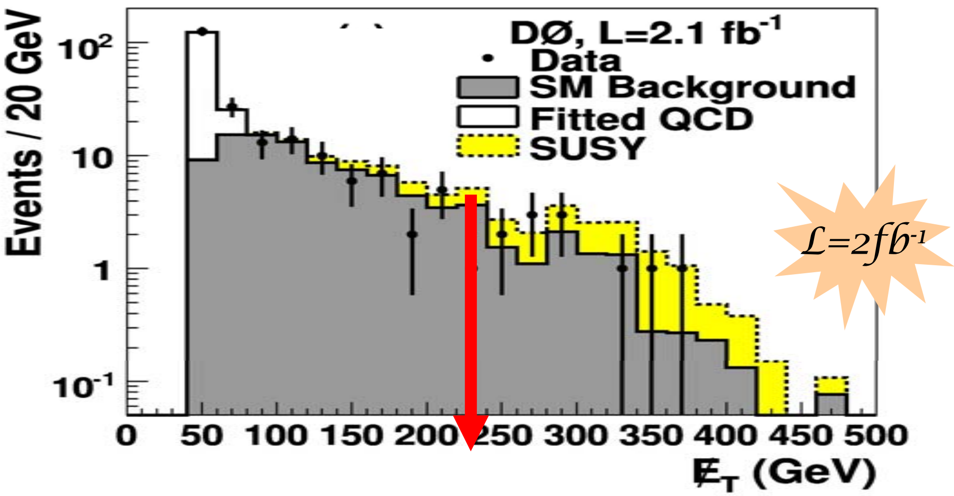
Instrumental background
- Multijets (mismeasured jets)

Selection Criteria:

- MET ≥ 40 GeV
- at least two acoplanar jets p_T ≥ 35 GeV
- Lepton vetoes
- ΔΦ(MET,jet)
- Analysis optimizations (CLs)

Squarks and gluinos searches

Dijet analysis



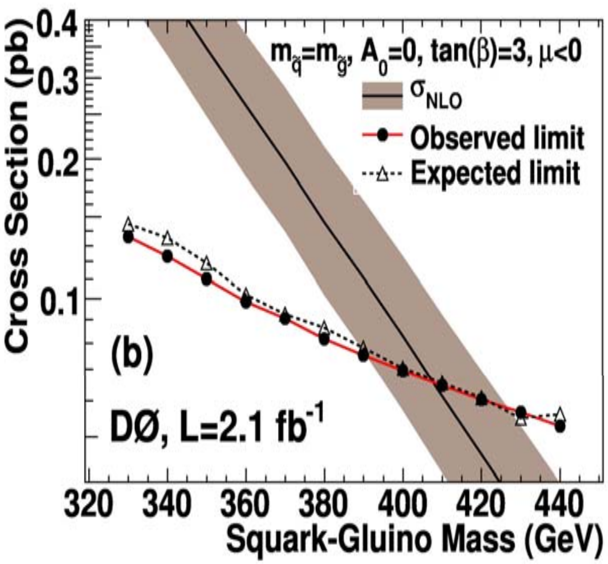
JES	6-15%
Jets	2-4%
Trigger	2%
Luminosity	6%
Back. Norm V+jets	15%
Back. Norm ttbar	15%
Back. Norm Di-boson	15%
PDFs	6%
ISR/FSR	6%

Systematic uncertainties

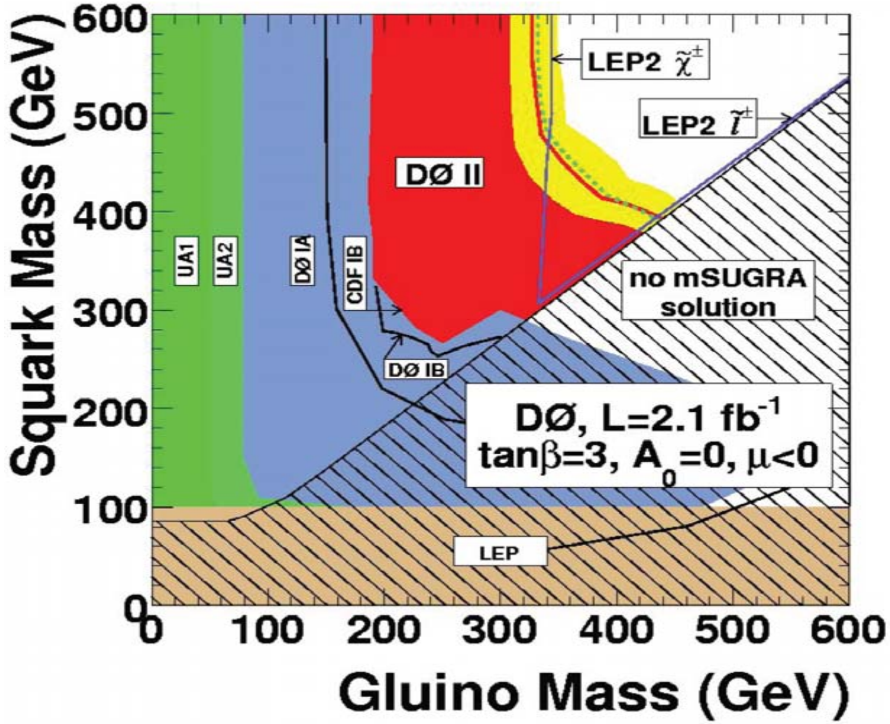
Final selection on MET and H_T (Σp_T^{jets})

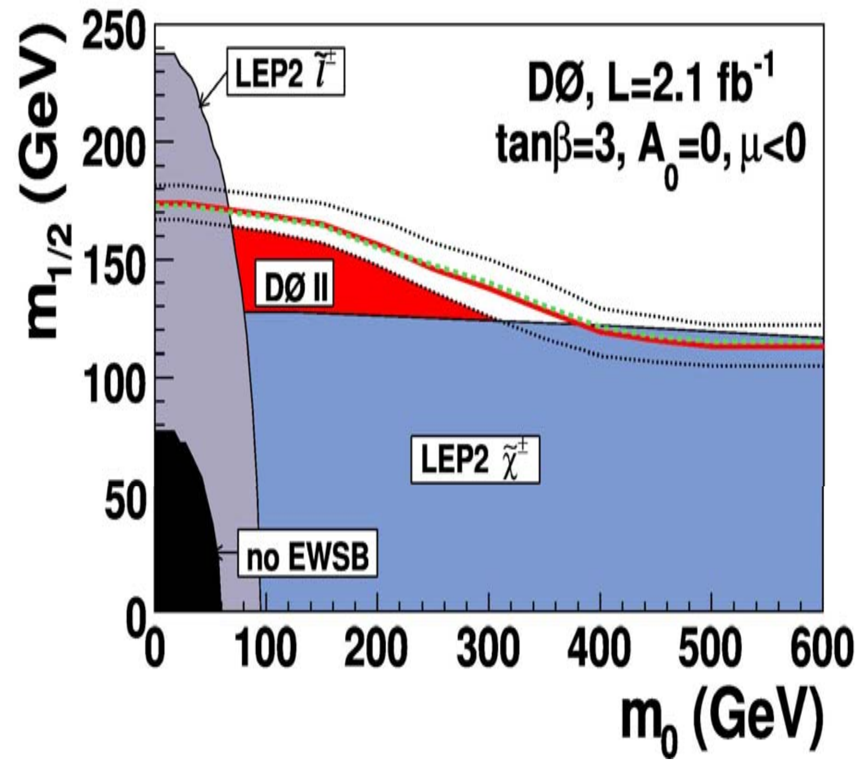
	dijet		3 jets		gluino	
DØ	H_T>335	MET>225	H_T>375	MET>175	H_T>400	MET > 100
	11	$11.1\pm1.2^{+2.9}_{-2.3}$	9	$10.7\pm0.9^{+3.1}_{-2.1}$	20	$17.7\pm1.2^{+3.3}_{-2.9}$

6 combinations: Data: 31 MC: 32.6±1.7



Squarks and gluinos searches





Phys. Lett. B 660, 449 (2008)

$$\tan\beta = 3,\ A_0 = 0,\ \mu < 0$$
$$m_{\tilde{q}} > 392\ (379)\ \ GeV$$
$$m_{\tilde{g}} > 327\ \ (308)\ GeV$$

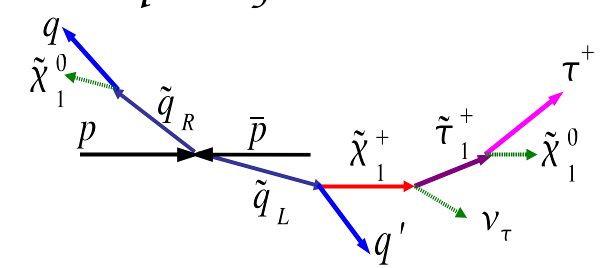
Limits @95%C.L

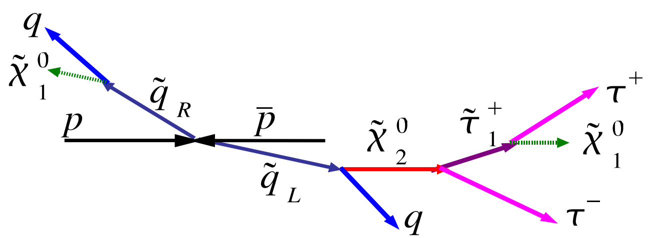
Best Limits

Cross section uncertainty

Squarks decaying to τ, jets and MET

- In some region of the SUSY space parameter: squarks may decay to $\tilde{\chi}^0_2, \tilde{\chi}^\pm_1$ -> final states with leptons
- At high tanβ: light stau $\tilde{\tau} \rightarrow \tau \tilde{\chi}^0_1$ (other leptonic decays suppressed)
- Squark production dominant in these regions (no stop considered)





Signature: τs+jets+MET

Background:

- W/Z+jets, WZ, WW, ZZ, tt
- instrumental: multijets

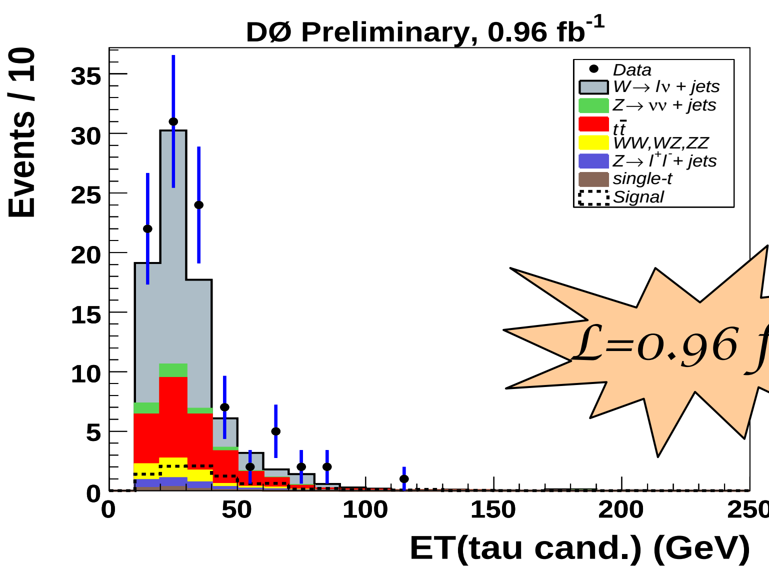
Complementarity with other SUSY searches

- Trigger: acoplanar dijet and multijets
- Selection:
  - MET> 75 GeV + at least 2 jets E_T>35 GeV
  - cuts on ΔΦ(MET,jets)
  - 2 analyses (triggers)
  - At least one hadronic isolated tau (NN)
    - $\tau^\pm \rightarrow \pi^\pm \nu_\tau$ single track, no EM cluster
    - $\tau^\pm \rightarrow \pi^\pm \pi^0 \nu_\tau$ single track+EM cluster(s)
    - $\tau^\pm \rightarrow \pi^\pm \pi^\pm \pi^\pm (\pi^0) \nu_\tau$ 2 - 3 tracks w/wo EM cluster
  - 2 final cuts (analyses ored optimisation)
    - $E_T^{jet1}+E_T^{jet2}+E_T^{\tau} \geq 325$ GeV
    - MET ≥ 175 GeV

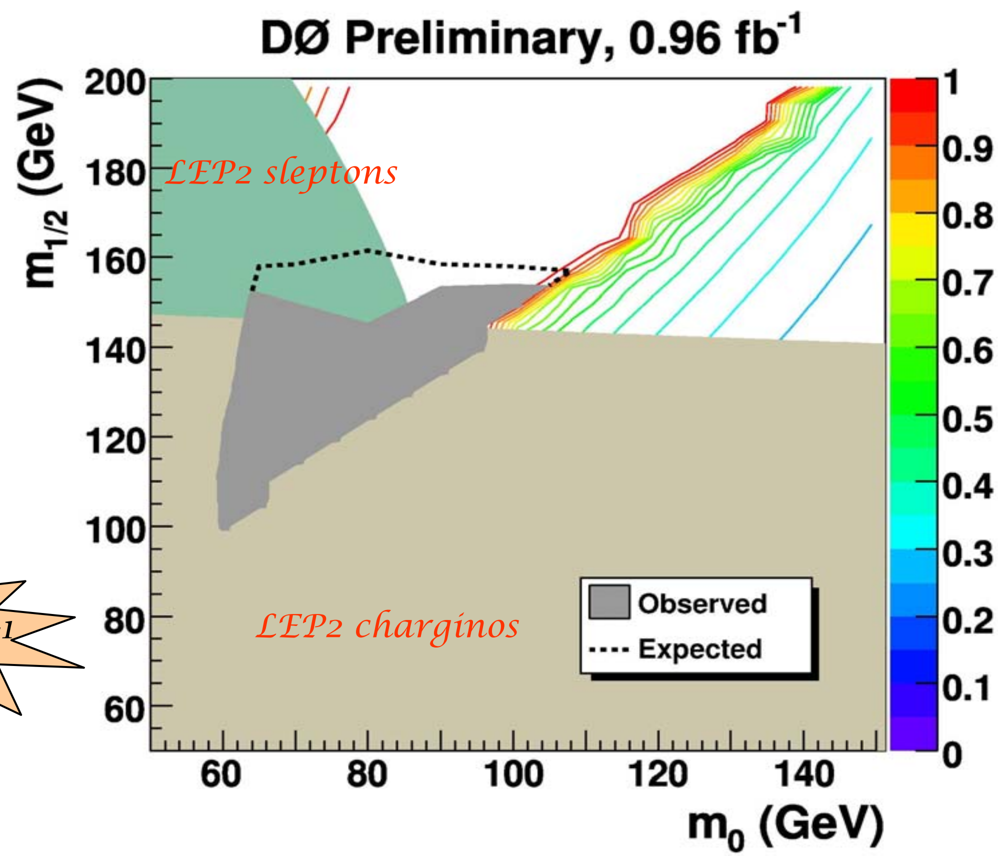
Squarks decaying to τ, jets and MET

Data	MC	(m_0=80 GeV,$m_{1/2}$=160 GeV)	(m_0=100 GeV, $m_{1/2}$=150 GeV)
2	$1.7 \pm 0.2(stat)\ _{-0.31}^{+0.55}(syst)$	4.73 ± 0.37	7.08 ± 0.57

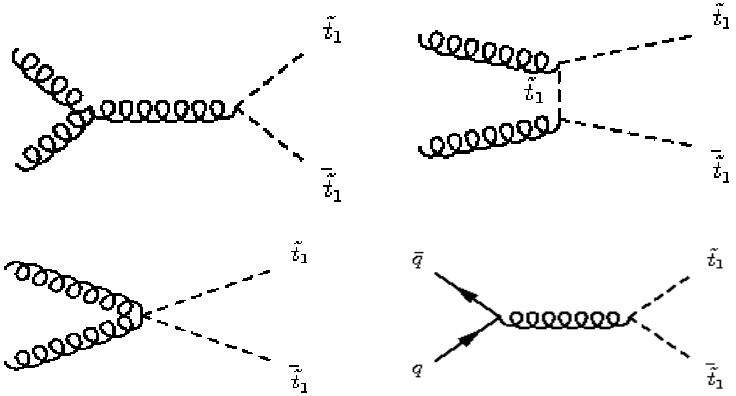
Systematic uncertainties:
- JES: 15% (MC), 10%(signal)
- Luminosity: 6%
- τ id: 2 - 4%
- PDFs: 6%
- ISR, FSR: 6-10%

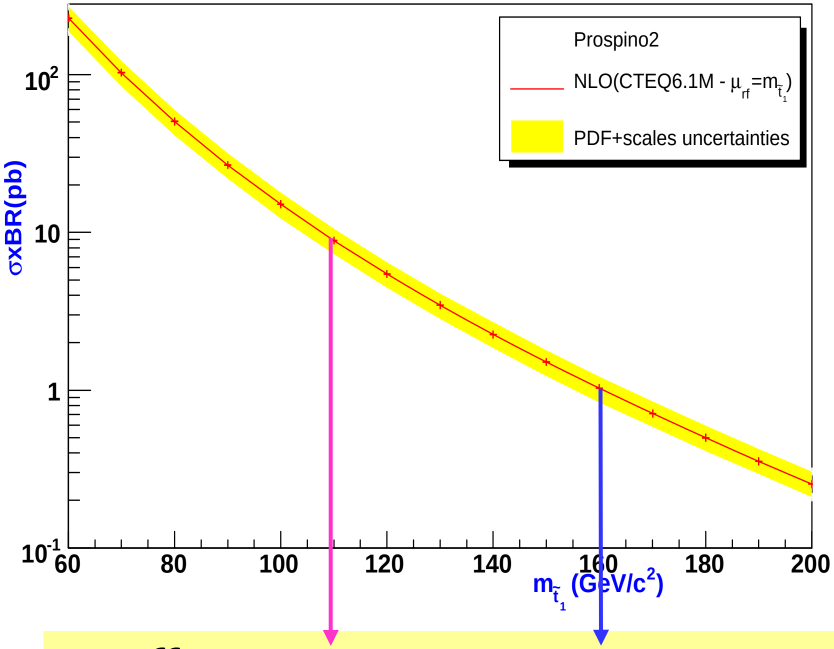


$\mathcal{L}$=0.96 fb^{-1}



Stop searches





$\mathcal{L}$=1 fb⁻¹ 9000 evts 1000 evts

Stop decays

$$2\text{-body}: \tilde{t}_1 \to t\tilde{\chi}_1^0, \tilde{t}_1 \to c\tilde{\chi}_1^0, \tilde{t}_1 \to b\tilde{\chi}_1^+, \ldots$$

$$3\text{-body}: \tilde{t}_1 \to bW\tilde{\chi}_1^0, \tilde{t}_1 \to bl\tilde{\nu}, \tilde{t}_1 \to b\tilde{l}\,\nu, \ldots$$

$$4\text{-body}: \tilde{t}_1 \to bf\bar{f}\tilde{\chi}_1^0$$

Assumptions for stop searches at the TeVatron:

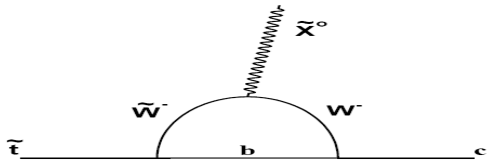
R_{parity} $\quad m_{\tilde{t}_1} < m_{top}$

$$2\text{-body}: \tilde{t}_1 \to c\tilde{\chi}_1^0, \tilde{t}_1 \to b\tilde{\chi}_1^+$$

$$3\text{-body}: \tilde{t}_1 \to bW\tilde{\chi}_1^0, \tilde{t}_1 \to bl\tilde{\nu}$$

$$4\text{-body}: \tilde{t}_1 \to bf\bar{f}\tilde{\chi}_1^0$$

Stop searches: $\tilde{t}_1 \to c\tilde{\chi}_1^0$



$m_{\tilde{t}_1} < m_b + m_{\tilde{\chi}_1^+}$ $m_{\tilde{t}_1} < m_W + m_b + m_{\tilde{\chi}_1^0}$

Signature: 2 acoplanar jets+MET

Trigger: jets+MET

Background:

- *W/Z+jets*
- *WW, ZZ, WZ*
- *tt*
- *multijets*

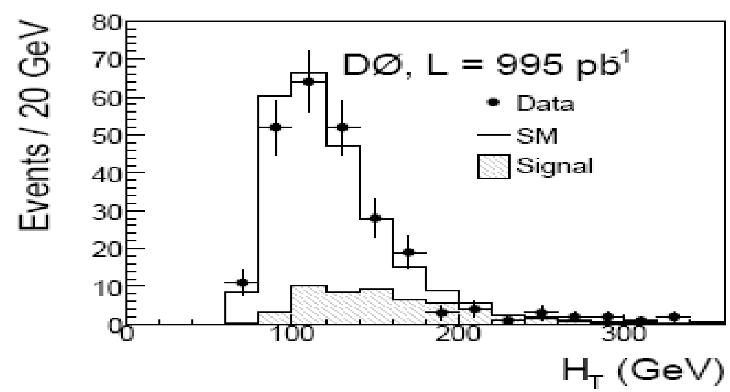
Selection criteria:

- *2 jets E_T>15 GeV*
- *MHT>40 GeV*
- *Leading jet p_T > 40 GeV*
- *Nleading jet p_T> 20 GeV*
- *isolated lepton, track veto*
- *ΔΦ(MET,jets)*
- *flavor tagging*
- *MET>60 GeV*

Final optimisation using:
-MET
- S= $\Delta\Phi_{min} + \Delta\Phi_{max}$ (azim jet-MET)
-H_T(p_T sum of the jets)

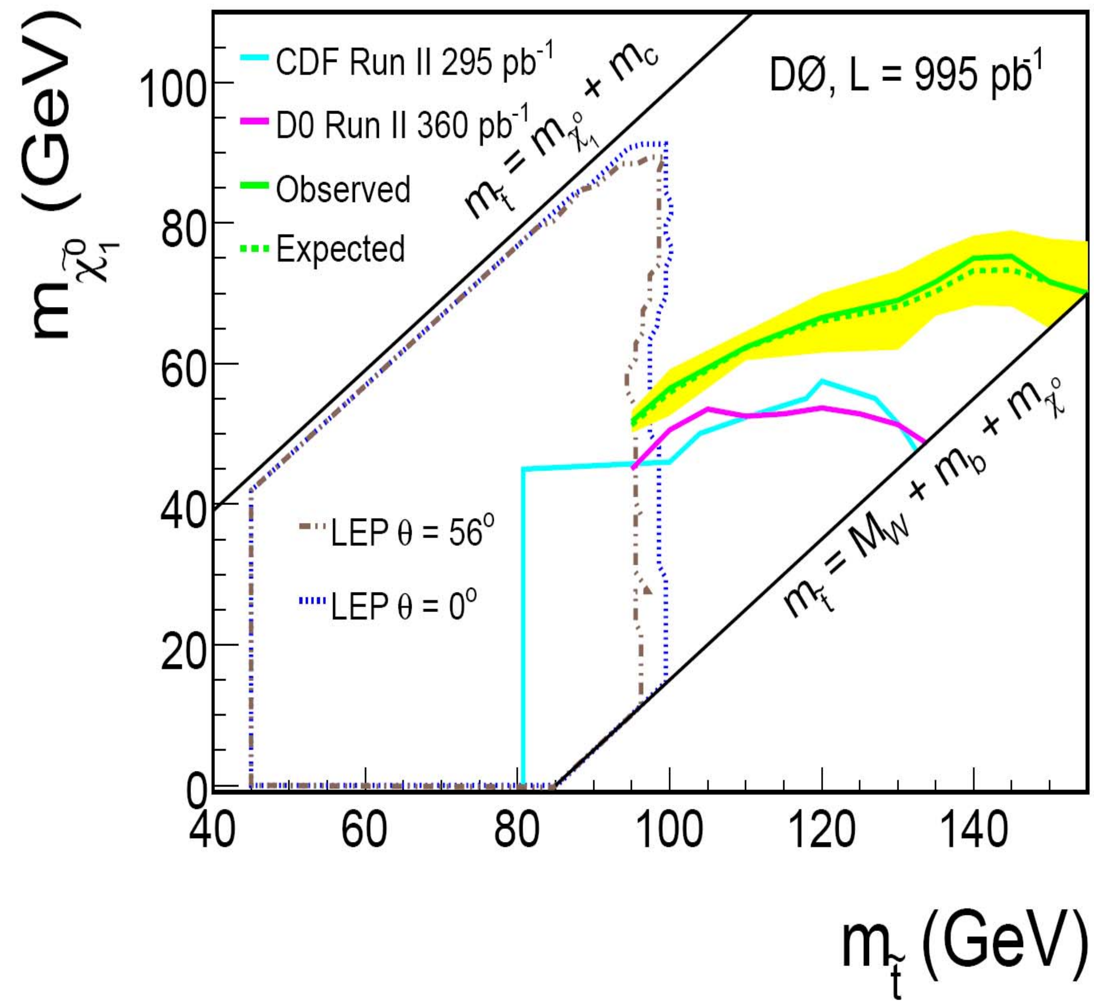
$\mathcal{L}$=995 pb^{-1}

$m_{\tilde{t}}$	H_T	S	Observed	Predicted
95 – 130	> 100	< 260	83	$85.3 \pm 1.8^{+12.8}_{-13.0}$
135 – 145	> 140	< 300	57	$59.0 \pm 1.6^{+8.5}_{-8.8}$
150 – 160	> 140	< 320	66	$66.6 \pm 1.1^{+9.6}_{-10.0}$



Stop searches: $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$

$(m_{\tilde{t}},\, m_{\tilde{\chi}_1^0})$ GeV	Efficiency (%)	Expected Signal Events
$(130, 55)$	1.5	$51.9 \pm 2.7^{+7.2}_{-7.1}$
$(140, 80)$	0.9	$19.6 \pm 0.8^{+2.8}_{-2.5}$
$(150, 70)$	2.1	$30.8 \pm 1.2^{+4.2}_{-3.7}$



Largest Stop mass excluded

$$m_{\tilde{t}_1} = 155\,(150)\ GeV$$

$$m_{\tilde{\chi}_1^0} = 70\ \ (65)\ GeV$$

Cross section uncertainty

Phys. Lett. B 665, 1 (2008)

Stop searches: $\tilde{t}_1 \to c\tilde{\chi}_1^0$

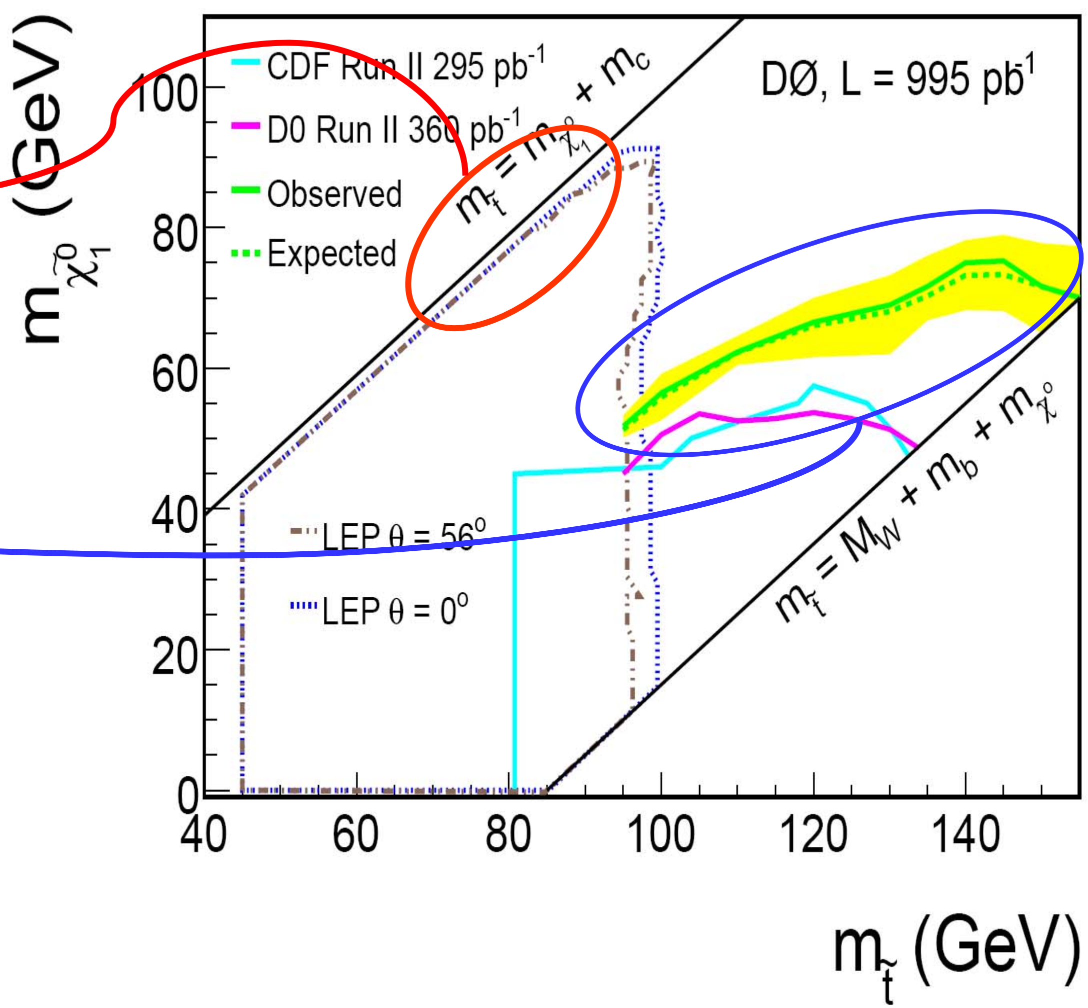
LEP: sensitivity up to

$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx 5\,GeV$$

TeVatron sensitivity

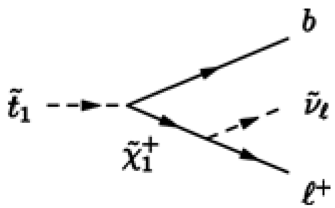
$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\chi}_1^0} \approx 60\,GeV$$

(MET cut (trigger+analysis))



Phys. Lett. B 665, 1 (2008)

Stop searches: $\tilde{t}_1 \rightarrow bl\tilde{\nu}$



$\tilde{\nu}$ LSP or invis. decay

$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow e^\pm \mu^\mp b\bar{b}\,\tilde{\nu}_e\tilde{\nu}_\mu$

$\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow e^\pm e^\mp b\bar{b}\,\tilde{\nu}_e\tilde{\nu}_\mu$

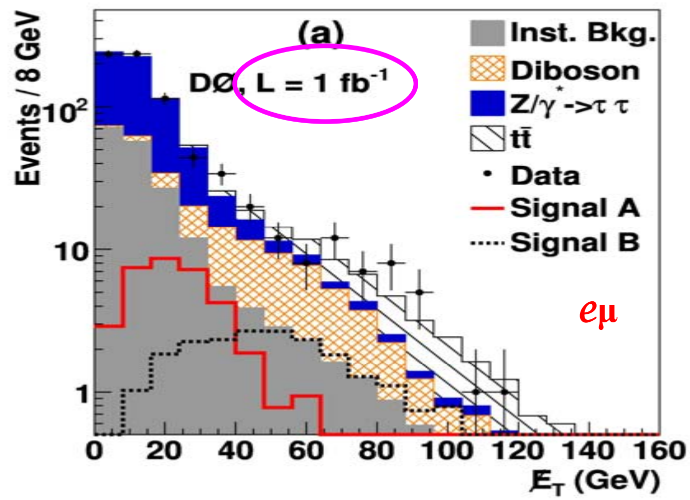
2 (OS) leptons
2(b) jets
MET

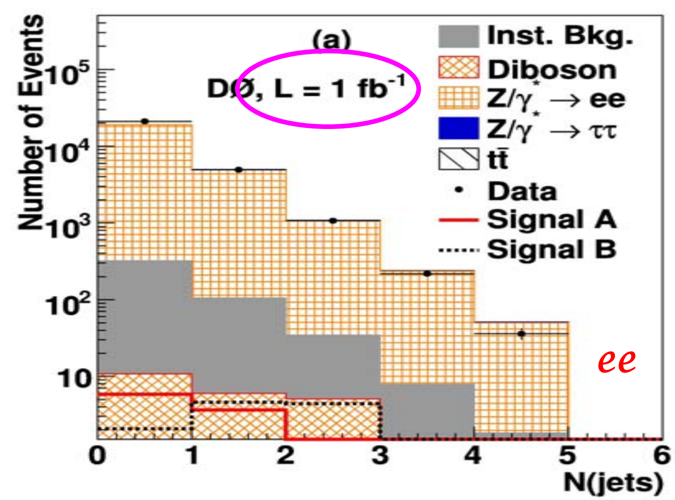
Signal topology depends on $\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}}$
- MET
- p_T(leptons, jets) ↘ with Δm

Trigger: electron+muon, single electron

Main background:
- Z→ee, Z→ττ
- Inst. background
- WW, ttbar

Selection criteria:
- 2 leptons p_T > 10,15 GeV (μ, e)
- MET > 15, 30 GeV
- cuts to remove Z→ee, Z→ττ and instrumental background





Stop searches: $\tilde{t}_1 \rightarrow bl\ \tilde{\nu}$

	Obsev	Expect	Stop (140,110)	Stop (170,90)
eμ	61	65±4	6.0±0.6	16.1±0.5
ee	12	12.2±0.4	0.6±0.1	4.6±0.2

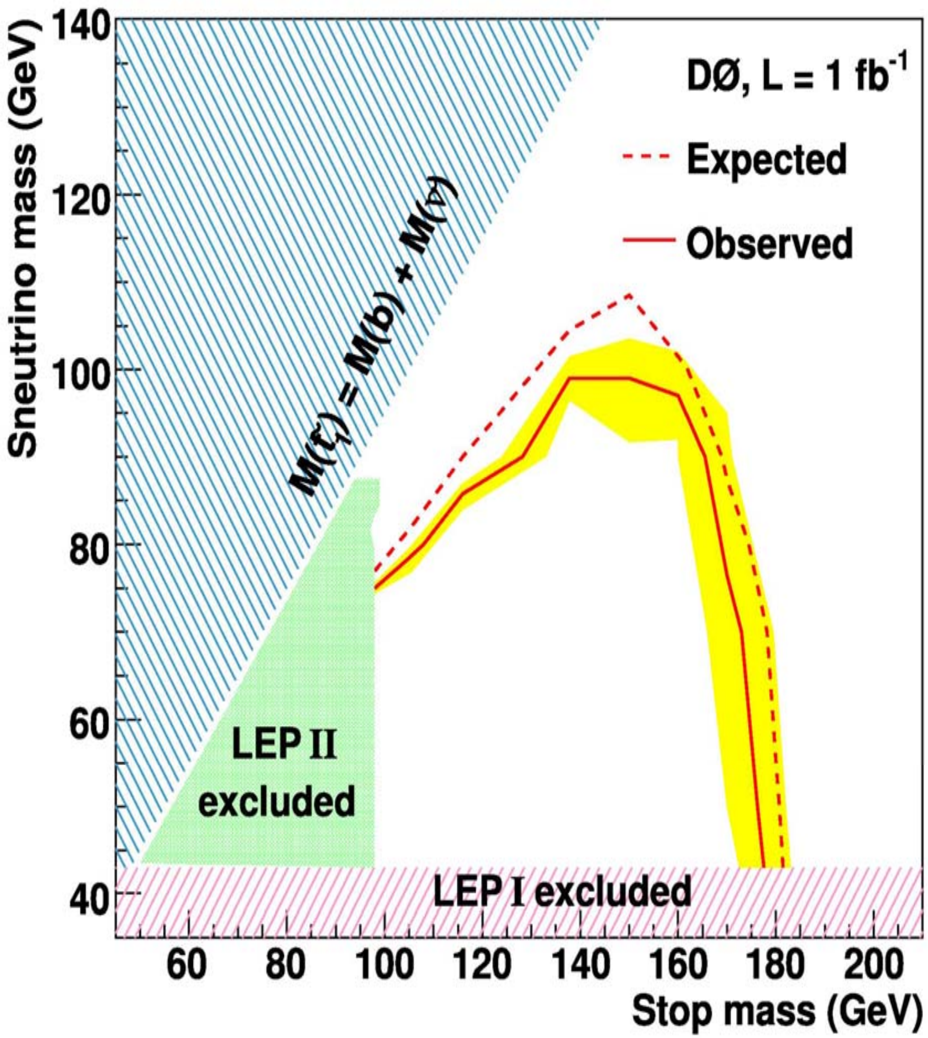
Systematic Uncertainties

Lept. ID	1-11%
Trigger	2%
Luminosity	6.1%
Instr. Back.	5-18%
JES	1-11%
Jet ID	1-17%
B-tag (ee)	2-5%
PDF	5-15%

$$m_{\tilde{t}_1} \geq 175\,GeV \ \ if\ \ m_{\tilde{\nu}} = 40\,GeV$$

$$m_{\tilde{t}_1} \geq 150\,GeV \ \ if\ \ m_{\tilde{\nu}} = 95\,GeV$$

@ 95% C.L.



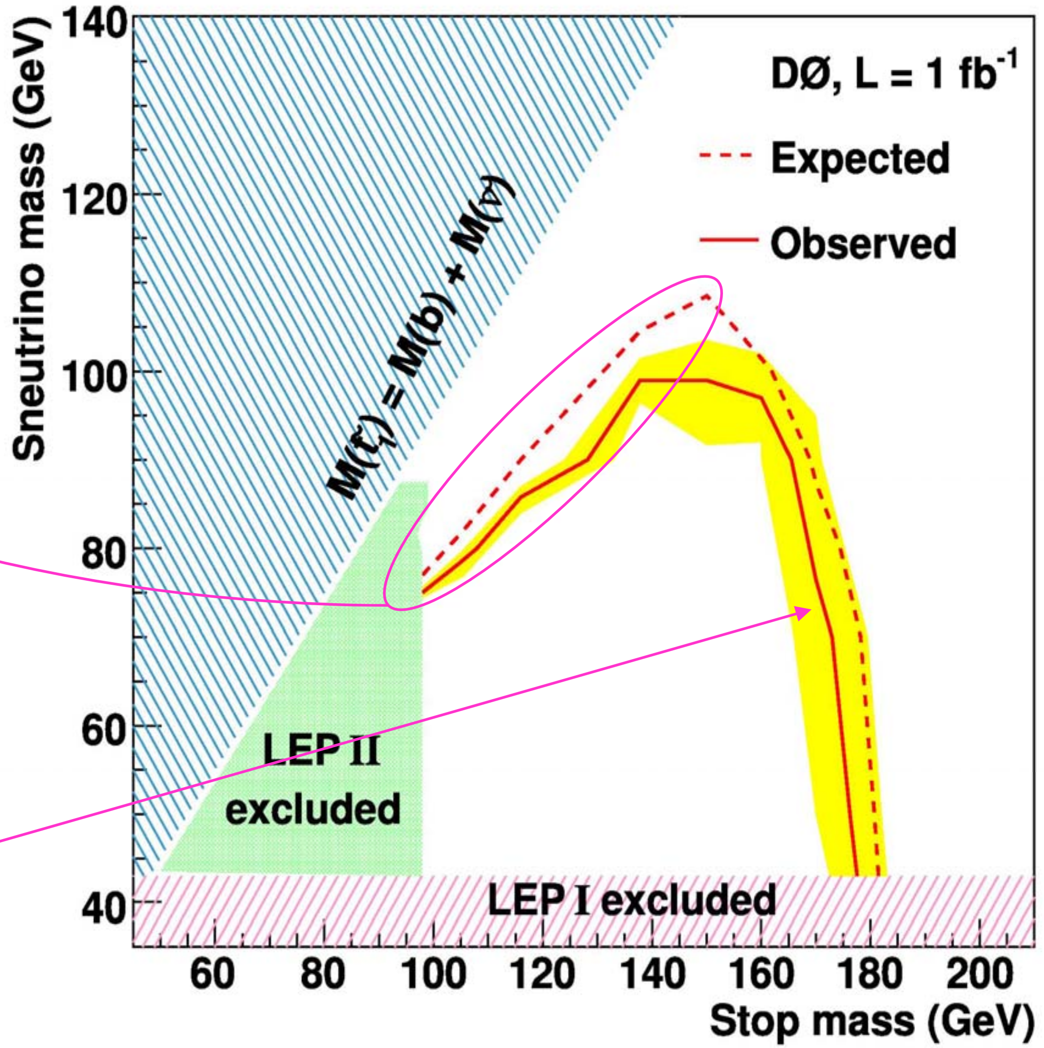
arXiv:0811.0459v1 Submitted to Phys. Lett. B

Stop searches: $\tilde{t}_1 \rightarrow bl\tilde{\nu}$

Sensitivity up to

$$\Delta m = m_{\tilde{t}_1} - m_{\tilde{\nu}} \approx 30\text{ - }40\ GeV$$

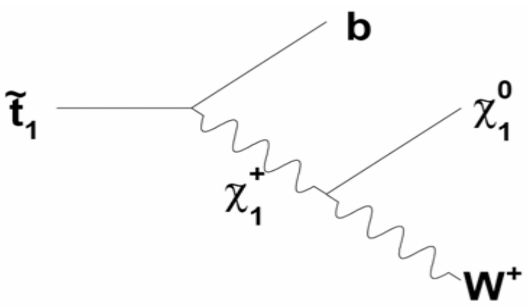
(Lepton p_T)



Cross section uncertainties (PDFs+renormalization and factorization scales): 17-20%

arXiv:0811.0459v1 Submitted to Phys. Lett. B

Stop searches: $\tilde{t}_1 \rightarrow b\,\tilde{\chi}_1^+$



Signature: 1 lepton (e or μ) + 4 jets (2 b) +MET

Main back: tt,W+jets, Instr. back.

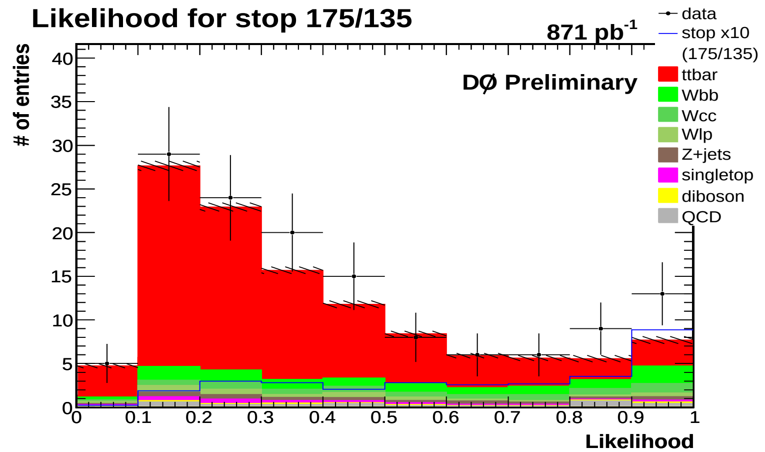
<u>e+jets</u>

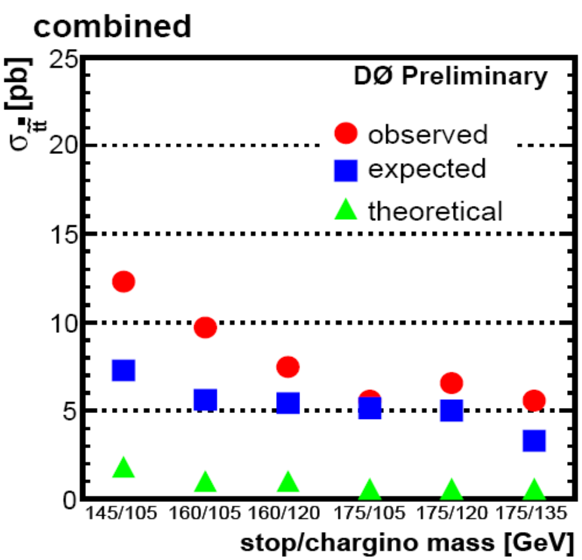
at least 4 jets p_T>15 GeV
leading jet p_T> 40 GeV
one isolated electron p_T > 20 GeV
primary vertex
MET>20 GeV
selections Instr. Back.

<u>μ+jets</u>

at least 4 jets p_T>15 GeV
leading jet p_T> 40 GeV
one isolated electron p_T > 20 GeV
primary vertex
MET > 25 GeV
selections against Z->μμ and Instr. Back.

Background rejection:
- btagging
- stop mass reconstruction
-likelihood discriminant





Cross section limits
7 to 12 times higher than theoretical.

DØ Note 5438 – CONF
Publication very soon

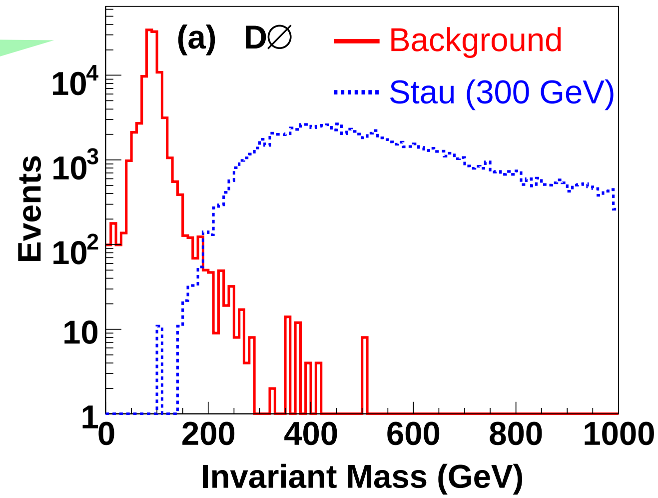
Charged Massive Stable Particles (CMSPs)

GMSB : $\tilde{\tau}_1$ lifetime may be large

AMSB : long lifetime possible for $\tilde{\chi}_1^{\pm}$

$(m_{\tilde{\chi}_1^+} - m_{\tilde{\chi}_1^0} \sim 150\ MeV)$

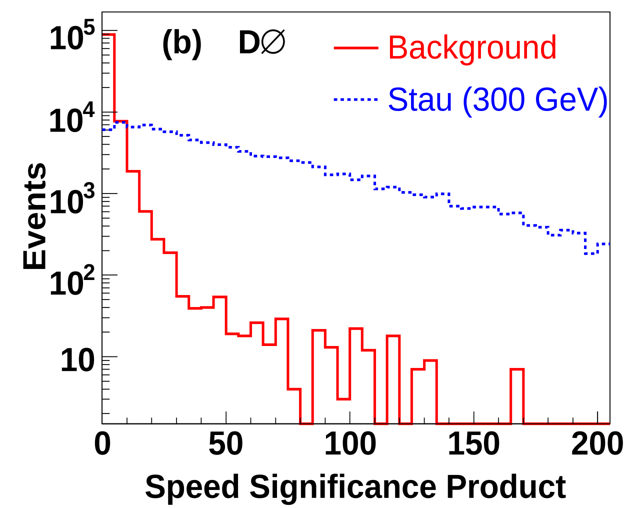
Decay outside the detector



Signature: similar to two muons, but with a slow speed energy loss by ionization

The analysis uses the timing information of the muon system

dimuons trigger: CMSPs may arrive outside a muon trigger timing gate (ε (Mstau=300 GeV) = 60%)



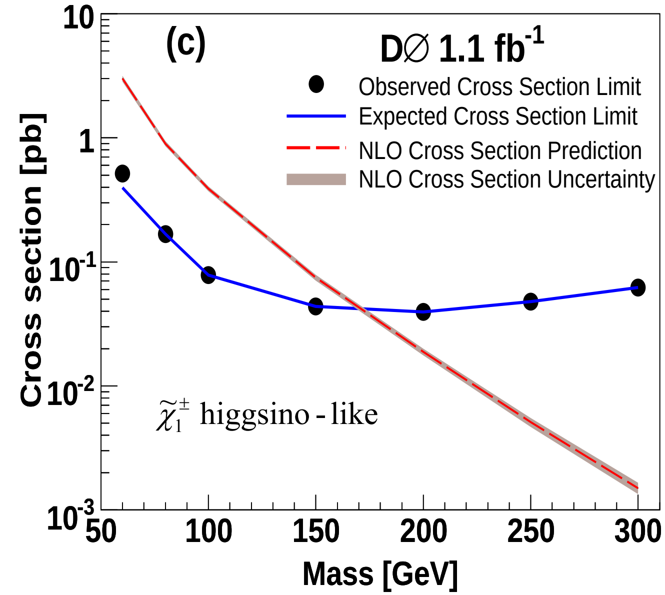
Selection:

- *two muons $p_T > 20$ GeV, at least one isolated*
- *cosmic ray veto*
- *primary vertex condition*
- *Time-of-flight and dimuon invariant mass*

Background: Time-of-flight and p_T mismeasurements → estimated from data

Charged Massive Stable Particles (CMSPs)

Mass (GeV)	Signal Acceptance	Predicted Background	Observed Events
(a) stau			
60	$0.064 \pm 0.001 \pm 0.005$	$30.9 \pm 2.2 \pm 1.9$	38
80	$0.038 \pm 0.001 \pm 0.005$	$2.6 \pm 0.6 \pm 0.4$	1
100	$0.056 \pm 0.001 \pm 0.004$	$1.6 \pm 0.5 \pm 0.3$	1
150	$0.123 \pm 0.002 \pm 0.013$	$1.7 \pm 0.5 \pm 0.2$	1
200	$0.139 \pm 0.002 \pm 0.011$	$1.7 \pm 0.5 \pm 0.5$	1
250	$0.133 \pm 0.002 \pm 0.013$	$1.7 \pm 0.5 \pm 0.3$	1
300	$0.117 \pm 0.002 \pm 0.013$	$1.9 \pm 0.5 \pm 0.2$	2
(b) gaugino-like charginos			
60	$0.032 \pm 0.001 \pm 0.003$	$23.6 \pm 1.9 \pm 1.4$	24
80	$0.024 \pm 0.001 \pm 0.003$	$1.9 \pm 0.5 \pm 0.3$	1
100	$0.046 \pm 0.001 \pm 0.004$	$1.6 \pm 0.5 \pm 0.3$	1
150	$0.085 \pm 0.001 \pm 0.009$	$1.2 \pm 0.4 \pm 0.1$	1
200	$0.089 \pm 0.001 \pm 0.007$	$1.9 \pm 0.5 \pm 0.0$	1
250	$0.074 \pm 0.001 \pm 0.007$	$1.7 \pm 0.5 \pm 0.3$	1
300	$0.059 \pm 0.001 \pm 0.007$	$1.7 \pm 0.5 \pm 0.1$	2
(c) higgsino-like charginos			
60	$0.029 \pm 0.001 \pm 0.002$	$17.9 \pm 1.7 \pm 1.1$	21
80	$0.024 \pm 0.001 \pm 0.003$	$1.6 \pm 0.5 \pm 0.3$	1
100	$0.049 \pm 0.001 \pm 0.004$	$1.6 \pm 0.5 \pm 0.3$	1
150	$0.089 \pm 0.001 \pm 0.009$	$1.4 \pm 0.5 \pm 0.1$	1
200	$0.096 \pm 0.001 \pm 0.008$	$1.9 \pm 0.5 \pm 0.0$	1
250	$0.081 \pm 0.001 \pm 0.008$	$1.7 \pm 0.5 \pm 0.3$	1
300	$0.064 \pm 0.001 \pm 0.007$	$1.7 \pm 0.5 \pm 0.1$	1



$m_{\tilde{\chi}_1^\pm} \geq 206$ GeV (gaugino - like)

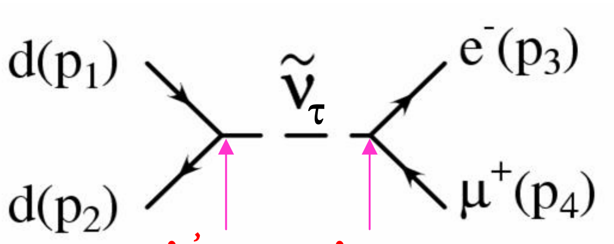
$m_{\tilde{\chi}_1^\pm} \geq 171$ GeV (higgsino - like)

No sensitivit y to $\tilde{\tau}_1$

arXiv:0809.4472v1 Submitted to Phys. Rev. Lett.

Best Limits

RPV search: sneutrino to e+μ



λ'_{311} λ_{321}

Signature: 1 electron, 1 muon

Main back: Z->ττ, WW,tt , WZ, ZZ

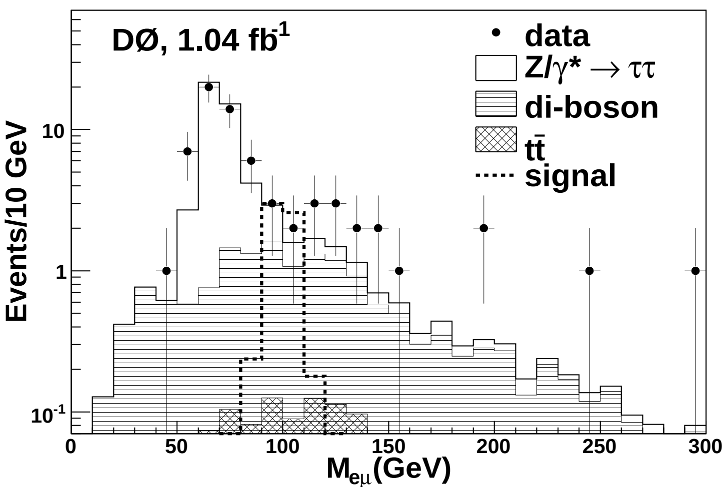
Selection:
- *one electron $p_T > 30$ GeV*
- *one muon $p_T > 25$ GeV*
- *veto: events with two electrons and/or two muons*
- *no jet with $p_T > 30$ GeV*

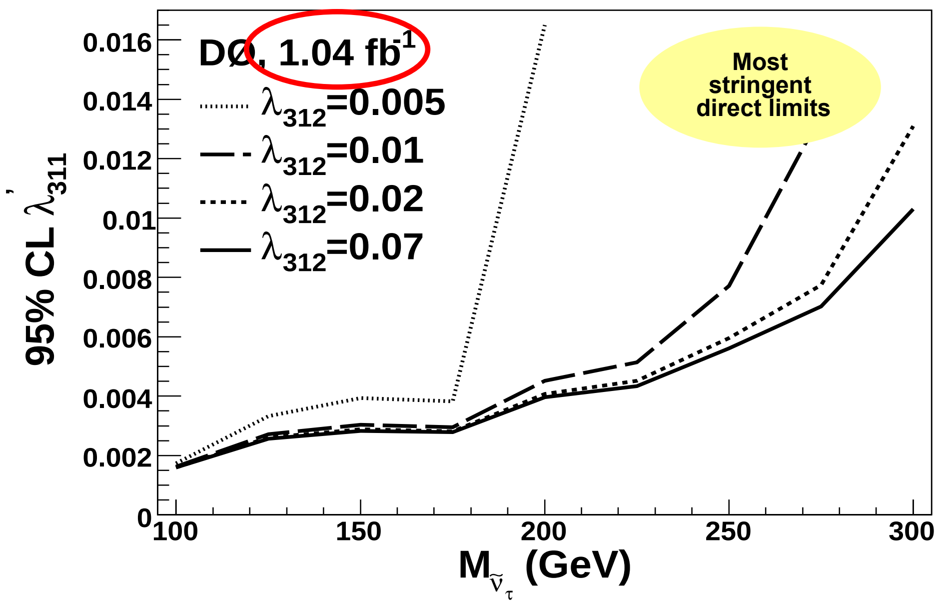
Indirect 2σ bound (M=100 GeV):

$\lambda'_{311}\ \lambda_{321} \leq 2.1\ 10^{-8}$

$\lambda'_{311} \leq 0.12 \quad \lambda_{321} \leq 0.07$

Observ: 68 Expect: 59.2±5.3 (stat. + syst.)





Phys. Rev. Lett. 100, 241803 (2008)

Conclusions and outlook

- *Extensive searches for squarks, gluinos, stops, sneutrino, and CMSPs have been performed at the TeVatron. No evidence found yet.*

$\tan\beta = 3,\ A_0 = 0,\ \mu < 0$

$m_{\tilde{q}} > 392 \quad GeV$

$m_{\tilde{g}} > 327 \quad GeV$

Most constraining direct limits on squark and gluino masses to date

- *Other searches not covered in this talk:*
  - *Chargino/neutralino to trilepton*
  - *sbottom to b+neutralino*
  - *...*

  http://www-d0.fnal.gov/Run2Physics/np/

- *The TeVatron is performing very well: 4.6 fb^{-1} recorded per exp.*

The search for SUSY at the TeVatron is not over.
Updates forseen for Winter'09 conferences (3.6 fb^{-1})
Stay tuned for new exciting results!

Backup

SUSY partners of quarks and gluons

gluon (spin 1) <-> gluino (spin ½)
Quark (spin ½) <-> squark (spin 0)

$$q_R \rightarrow \tilde{q}_R \quad q_L \rightarrow \tilde{q}_L \quad \tilde{q}_1 = \cos\theta_q \tilde{q}_L + \sin\theta_q \tilde{q}_R \quad \tilde{q}_2 = -\sin\theta_q \tilde{q}_L + \cos\theta_q \tilde{q}_R$$

$$\Delta m^2 = m^2_{\tilde{q}_2} - m^2_{\tilde{q}_1} = \sqrt{(M^2_{\tilde{q}_L} - M^2_{\tilde{q}_R})^2 + 4(A_q - \mu\cot\beta)^2 m_q^{\ 2}}$$

Soft SUSY breaking terms

Trilinear coupling

quark mass

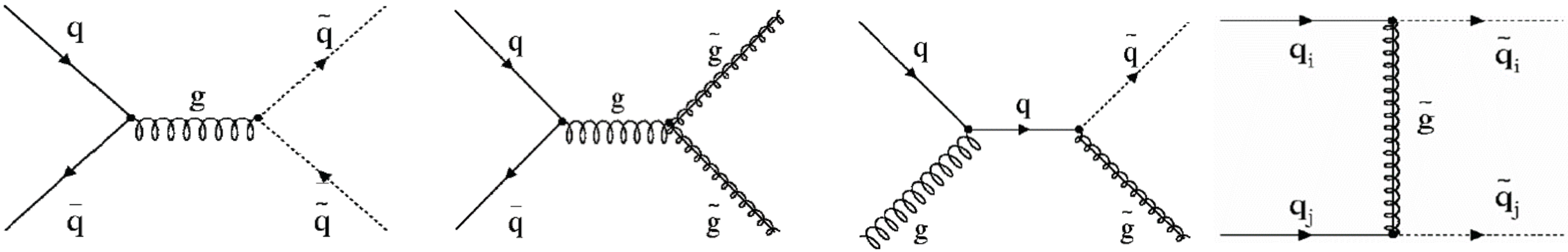
Negligible for the two first generations
-> Δm small
-> squarks are mass-degenerate

3rd generation: m_{top}, m_{bottom}
-> Δm non neglible (high tanβ for sbottom)
-> $\tilde{t}_1$ or $\tilde{b}_1$ light

Squarks and gluinos searches

Stop and sbottom searches

Squarks and gluinos production



Large cross section (few pb)

Studies performed in mSUGRA (R_{parity})

- m_0: universal scalar soft breaking mass at M_G
- $m_{1/2}$: universal gaugino soft breaking mass at M_G
- A_0: universal cubic soft breaking mass at M_G
- tanβ=<H2>/<H1> at the electroweak scale
- sign(μ)

Lightest Supersymmetric Particle(LSP):

$\tilde{\chi}_1^0$

3 regimes

low m_0 : $m_0 << m_{1/2}$ → $m_{\tilde{q}} << m_{\tilde{g}}$

intermediate m_0 : $m_0 \sim m_{1/2}$ → $m_{\tilde{q}} \sim m_{\tilde{g}}$

large m_0 : $m_0 >> m_{1/2}$ → $m_{\tilde{g}} << m_{\tilde{q}}$

Object definitions

Jets:

- from energy deposition in the calorimeter (cone algorithm $\Delta R=0.5$)
- Selection cuts to suppress background(noise,…)
  - Coarse hadronic fraction
  - Em fraction
  - tracks pt sum associated with the jet coming from the PV0
- non-linearities of the calorimeter response, non instrumental response, noise: corrected by JES -> relative uncertainty on the jet calibration: ≈7% for $20 < p_T > 250$ GeV
- jet momentum resolution: p_T =50 GeV
  - $\sigma(p_T)/p_T \approx$ 13% (CC)
  - $\sigma(p_T)/p_T \approx$ 12% (EC)

Electron/photon:

- Localized energy deposits in the EM calorimeter (clusters)
- large EM fraction
- Longitudinal and lateral shower profiles of EM cluster compatible with those of an electron (photon)
- Isolated cluster
- Electron: track match
- Electron: likelihood (7 variables)
- Energy resolution:
  - CC: $\sigma(E)/E \approx (15/\sqrt{E}+4)\%$
  - EC: $\sigma(E)/E \approx (21/\sqrt{E}+4)\%$

MET:

- Computed from the vector sum of the transverse energies of all calorimeter cells surviving noise suppression algorihtms -> raw MET
- After EM and JES correction: raw Met is adjusted through vector substraction (hadronic part from clustered jets)-> calorimeter MET
- muons are identified and subtracted -> MET

Muon:

- Identification based on a matches between charged particles found in the central tracking system and trajectories reconstructed in the muno systems.
- Consistency with the primary vertex
- Isolated object (track-based and calorimeter-based)
- 99% of muons originating in hadronic jet decays are rejected.
- 87% efficiency for a muon coming from a top quark decay

Jet Energy Scale in D0

- Jets are reconstructed from energy deposits in the calorimeter using a cone algorithm
- Jets are made of different kinds of particles (γ,π, K, p, n) for which calorimeter responses are different.
- Moreover: there are energy depositions in the calorimeter from spectator interactions, additionnal $p\bar{p}$ interactions, electronic noise, and noise due to radioactive decay of uranium.
- Furthermore: not always all particles in a jet deposit energy within algorithm cone.

-> all these effects produce a distortion in the jet energy and the particle level jet energy can be obtained from the measured jet energy through:

$$E_{jet}^{ptcl} = \frac{E_{jet}^{meas} - E_0(R,\eta,\mathcal{L})}{R_{jet}(E_{jet}^{meas},\eta) * R_{cone}(R, E_{jet}^{meas},\eta)}$$

Offset energy(multiple interaction, underlying event energy, electronic noise, uranium noise and pile-up)

Calorimeter response to the hadronic jet

Fraction of pqrticle jet energy contained within the algorithm cone

γ+jet events (p_T imbalance)

dijet events

Zero Bias (ZB) and Minimum Bias (MB) events