Searches for SuperSymmetry at the TeVatron (Recent Results*)

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*many approved during this week !

Les Rencontres de Physique de la Vallée d'Aoste

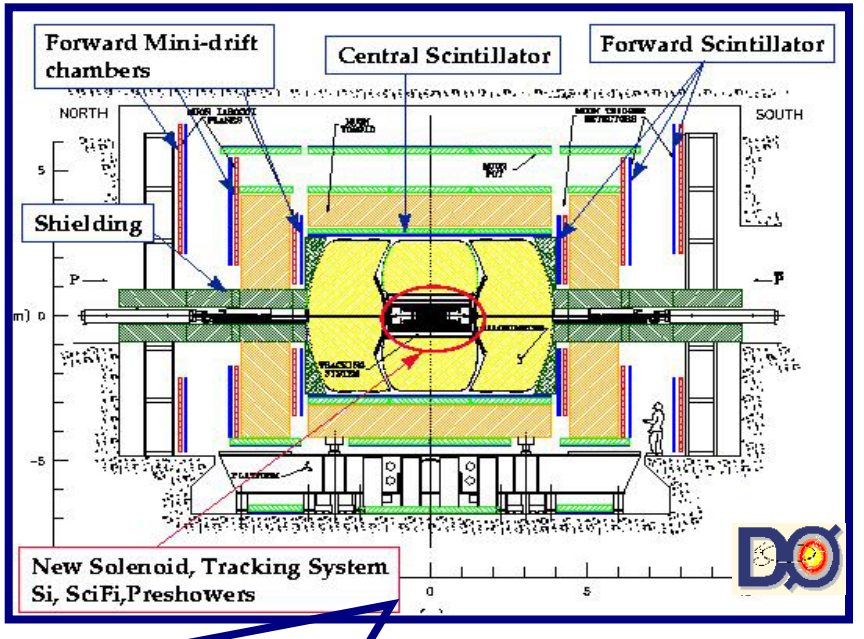
February 27-March 5, 2005

Tevatron at Run II

Run II started March 2001

- Higher energy
  (1.8 TeV → 1.96 TeV)
  => Higher cross sections
  (~ 20-30 % for $\chi^{\pm}\chi^{o}$)
- Higher antiproton intensity
  6×6 → 36 × 36 bunches
  (3.5 μs → 396 ns)
  antiproton "recycler"
  => Higher luminosity
- Powerful Trigger Systems
  (2.5 MHz → 50 Hz)

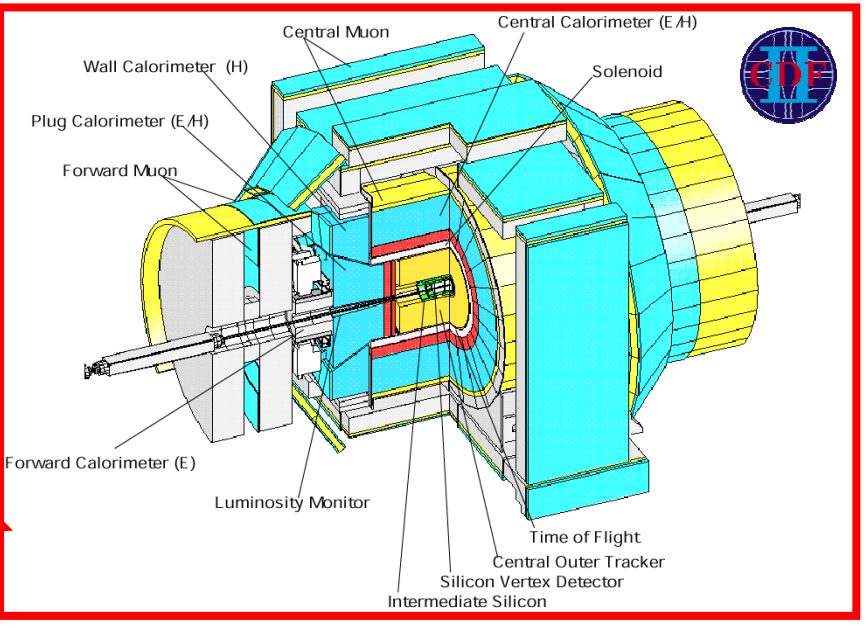
DO and CDF Upgrade



	DO	CDF	(Acceptance)
Electron	$\|\eta\|<3$	$\|\eta\|<3$	
Muon	$\|\eta\|<2$	$\|\eta\|<1.5$	
Tracking (Si)	$\|\eta\|<3$	$\|\eta\|<2$	

Tracking in 2T magnetic field (silicon and fibers), Hermetic Calorimeter (Argon), Wide Muon Coverage ...

Tracking in 1.4T magnetic field (silicon and drift chamber), up to 96 hits per tracks, Displaced track trigger...



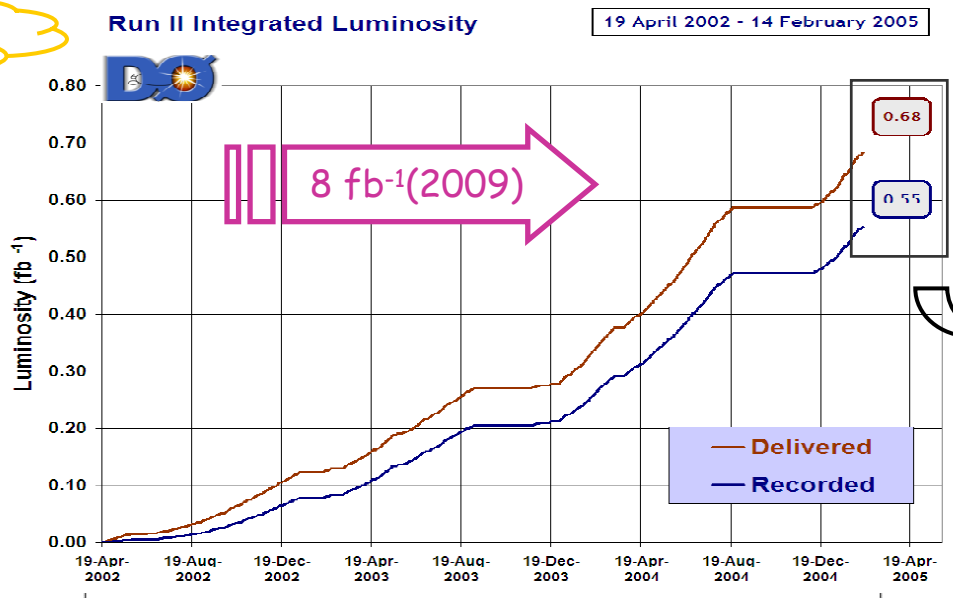
Luminosity Performance

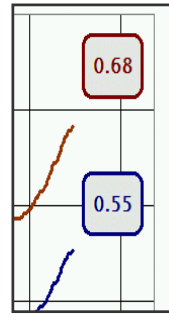
In 2005:

02/23/2005

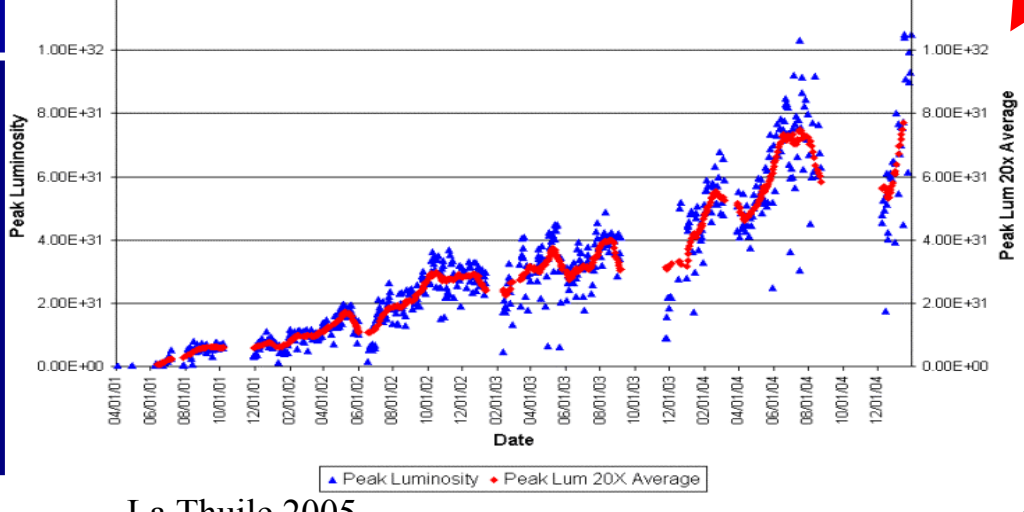
- Peak luminosity:
  $107.\ 10^{30}\ cm^{-2}\ s^{-1}$
- Weekly delivered:
  $8 - 16\ pb^{-1}$
- Data taking efficiency:
  80 - 90%

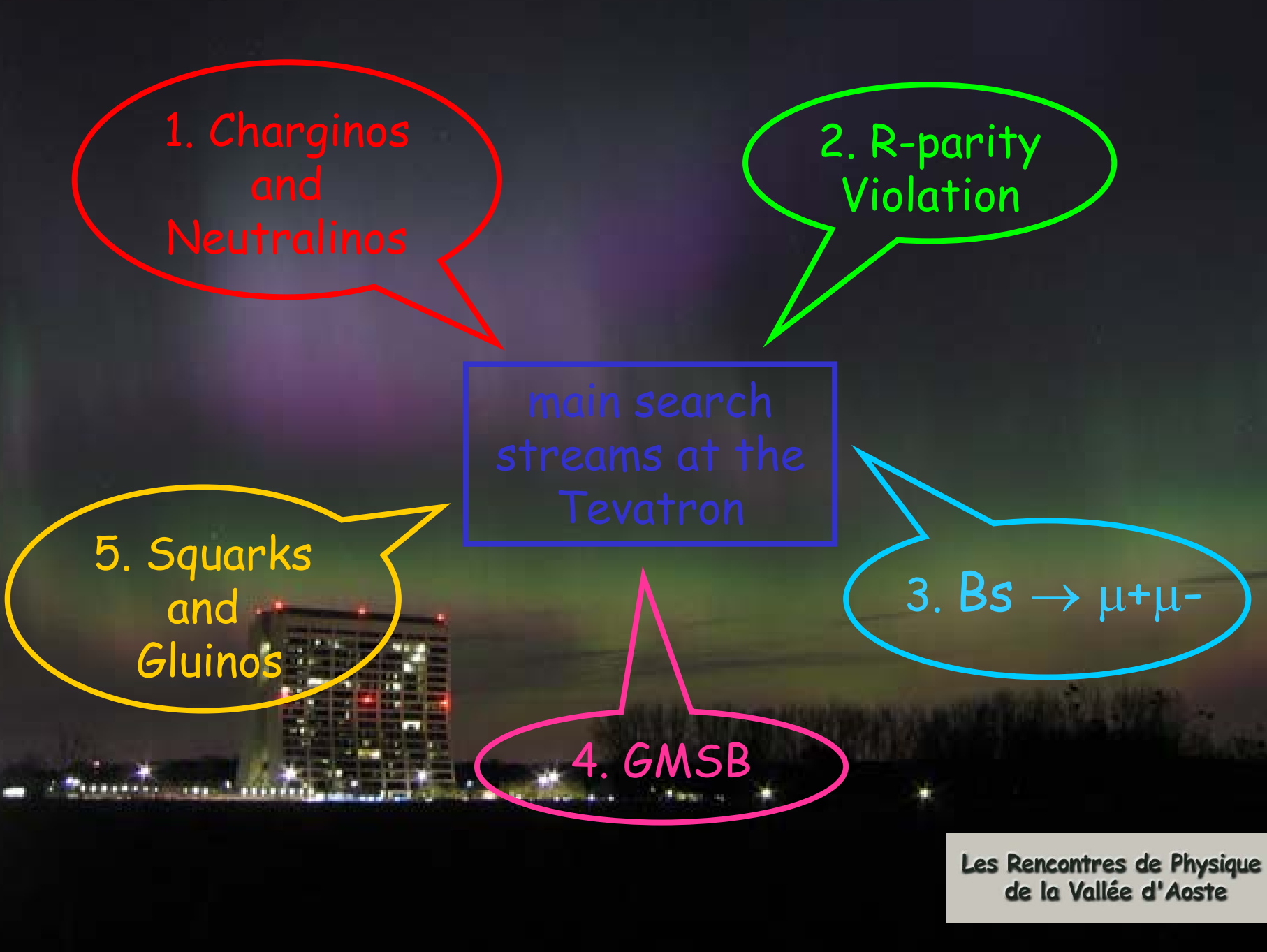
Physics quality data collected so far :
$> 550\ pb^{-1}$
Analysis shown :
up to $390\ pb^{-1}$





10^{32}




1. Charginos and Neutralinos
2. R-parity Violation
main search streams at the Tevatron
3. Bs → μ+μ-
4. GMSB
5. Squarks and Gluinos
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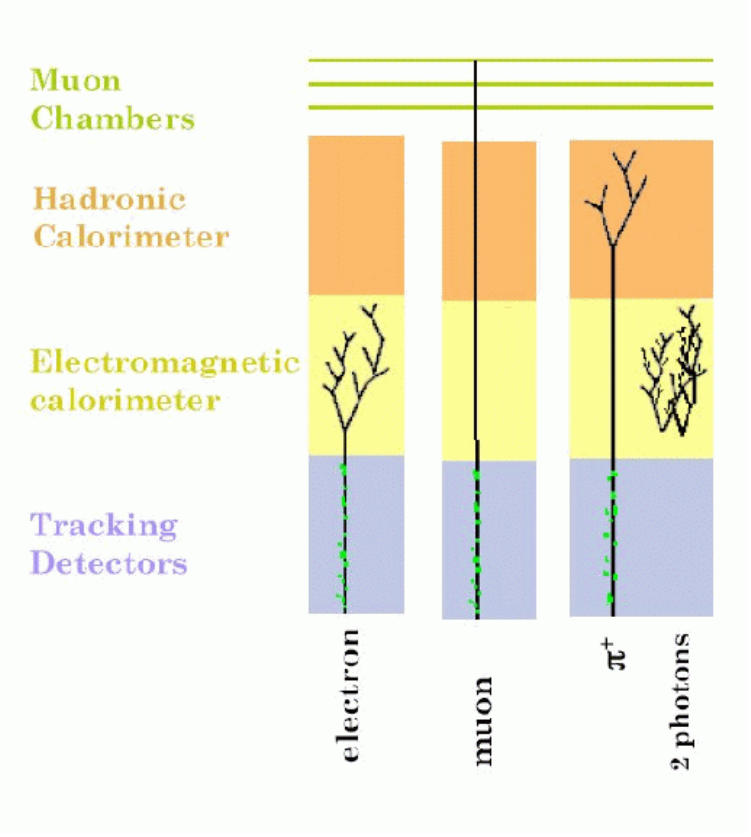


Multi-leptons

- Low production cross sections
- Typically low leptonic branching ratios
- Clean experimental signature

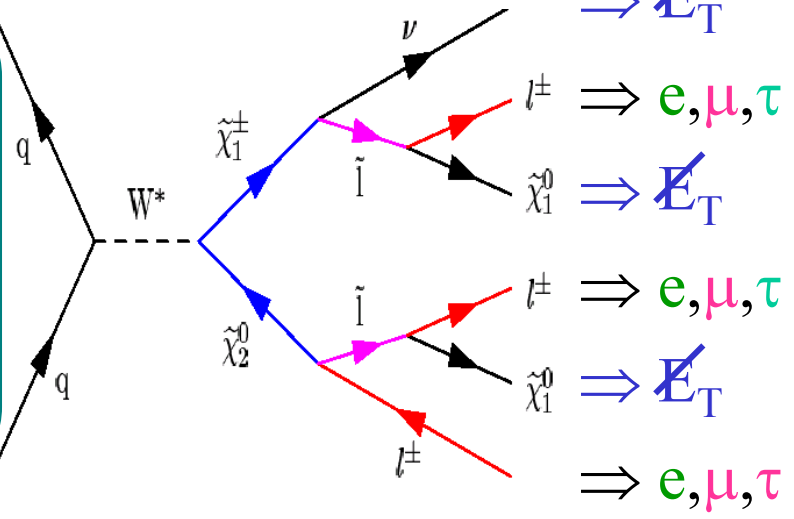
1. Trileptons

from Chargino-Neutralino production

Clean signature but:
- low cross sections ($\sigma \times BR < 0.5$ pb)
- soft leptons
- taus (at large tanβ)

⇒ Needs large integrated luminosity

⇒ Combine various final states



$\int L\,dt =$ new

DØ analysis combines 6 final states :
- eel (316 pb^{-1})
- eμl (318 pb^{-1})
- μμl (300 pb^{-1})
- same sign dimuon (313 pb^{-1})

Luminosity uncertainty : ± 6.5%

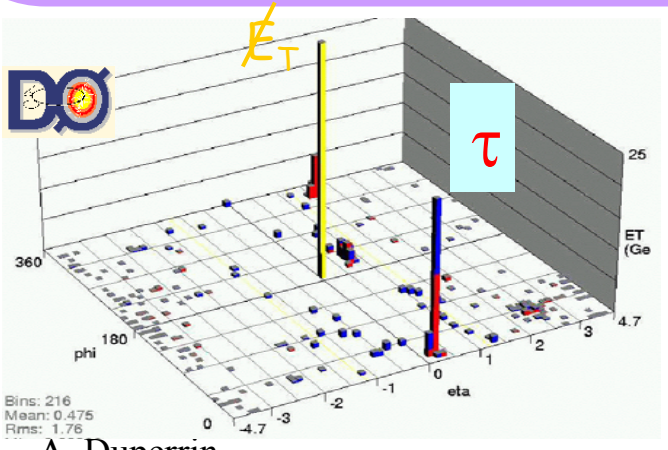
+ New Results :
- eτl (325 pb^{-1})
- μτl (326 pb^{-1})

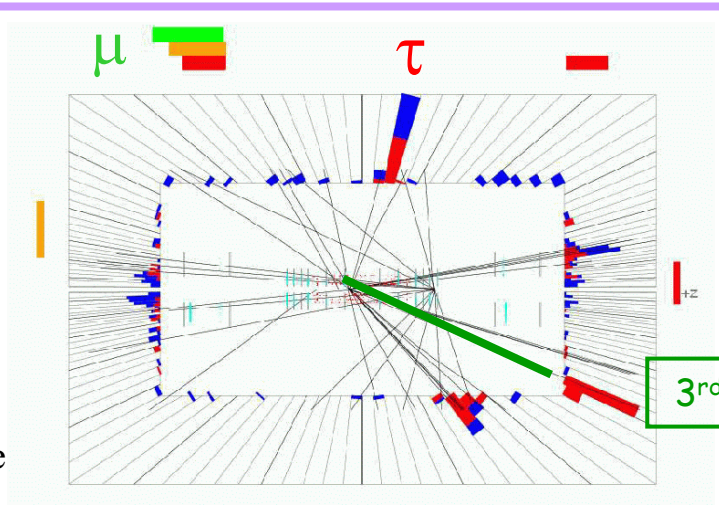
Trileptons (II)

- **Trigger :**

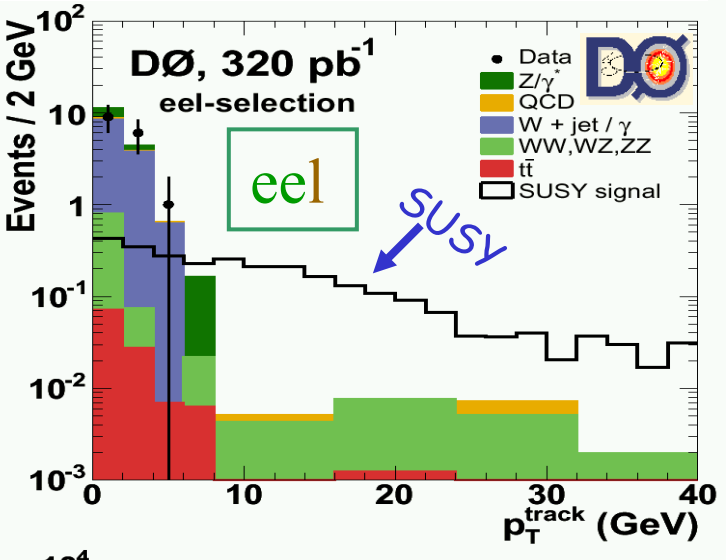
Inclusive combination of many different triggers with very tight cuts at low pt and many looser versions for higher and higher pt

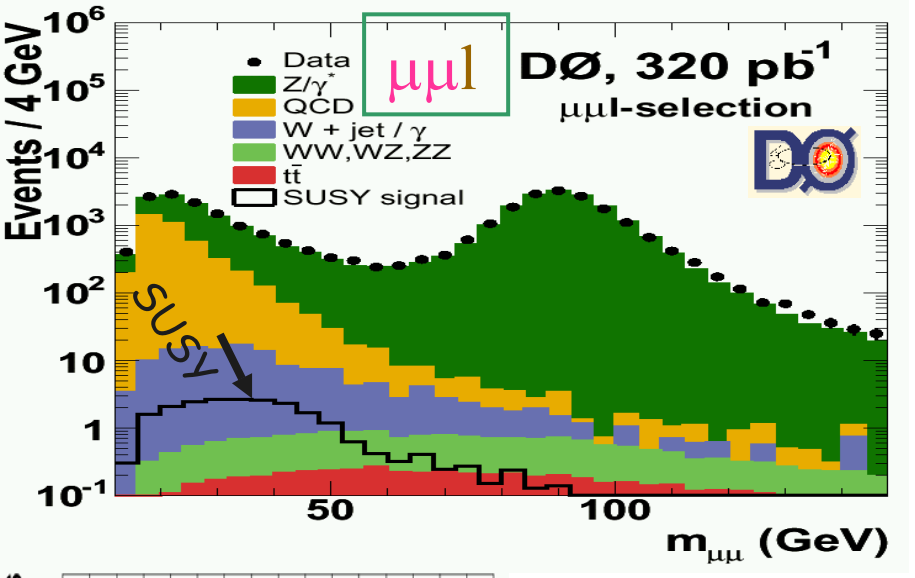
- **Offline :**
  - 2 well identified and isolated e or μ ($P_T \sim 10$ GeV) or τ
    - $\Rightarrow$ Increase acceptance by requiring 2 out of 3 leptons
  - + Isolated high quality track (= third lepton : e, μ, τ) with $P_T \sim 5$ GeV
  - + Transverse Missing energy (= neutrinos, neutralinos) with $\not{E}_T \sim 20$ GeV
  - + Anti Z cuts (15 GeV < inv. Mass < 60 GeV)
  - Or Like-Sign requirements (dimuons)

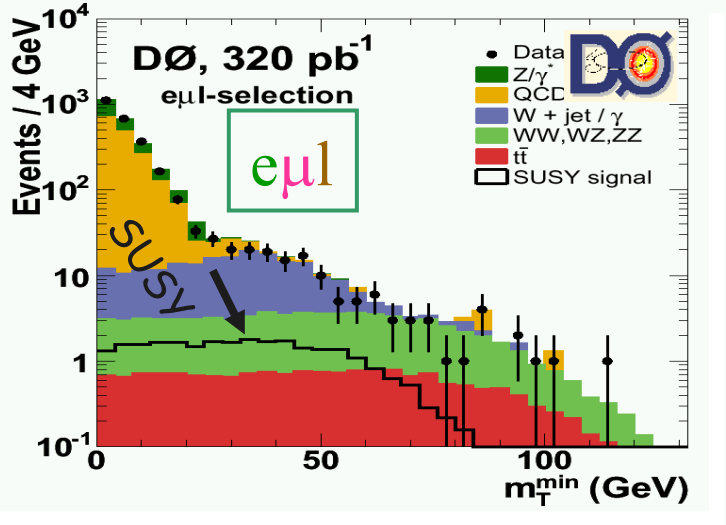


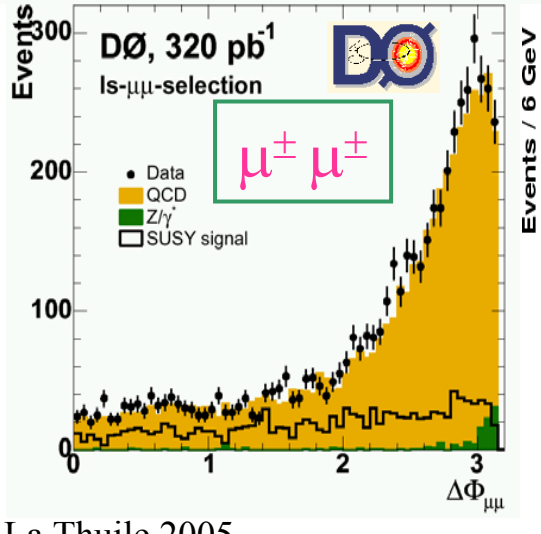


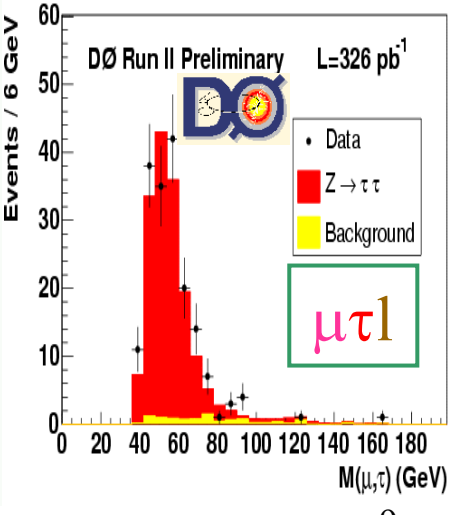
Trileptons (III)











Trileptons (IV)

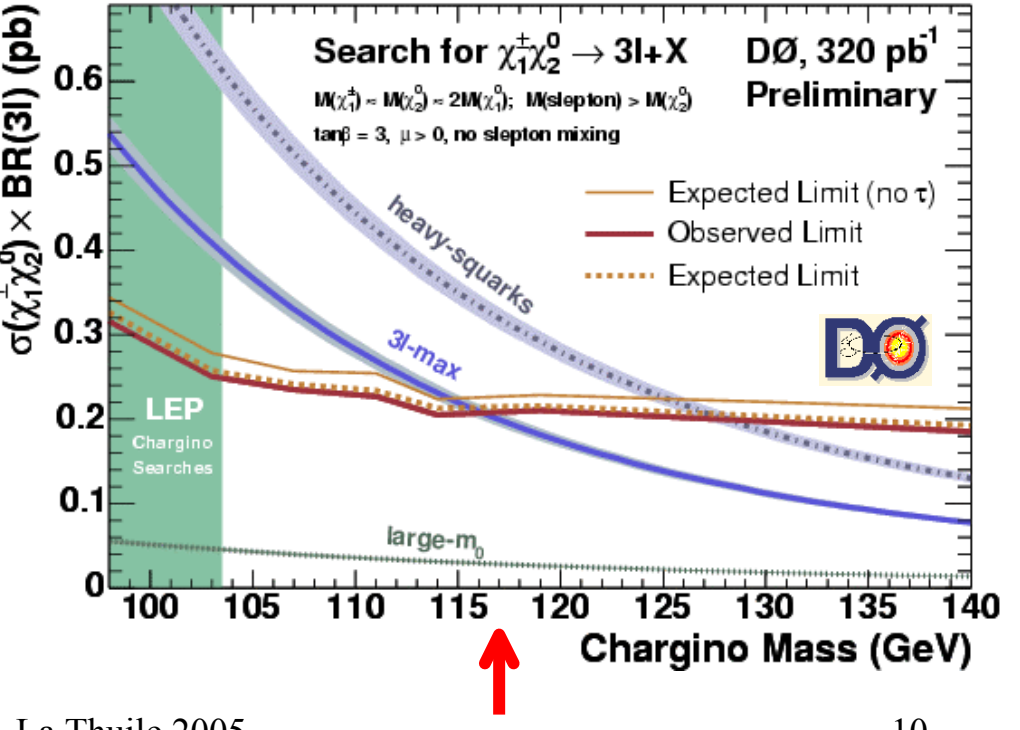
$\int L\,dt \approx 320\ pb^{-1}$

$\chi^{\pm}\chi^{o}$	Observed	Standard Model	Signal
eel	0 event	0.21 ± 0.12	1.94 ± 0.17
eμl	0 event	0.31 ± 0.15	1.50 ± 0.13
μμl	2 event	1.75 ± 0.57	1.01 ± 0.12
LS μμ	1 event	0.66 ± 0.37	0.80 ± 0.20
eτl	0 event	0.58 ± 0.14	0.36 ± 0.05
μτl	1 event	0.36 ± 0.13	0.67 ± 0.05

new

Data : 4
SM : 3.85 ± 0.57 (stat) ± 0.49 (sys)

Significant improvement versus LEP :
$m(\chi^{+}) > 117.7$ GeV
for $m(\text{slepton}) \approx m(\chi')$

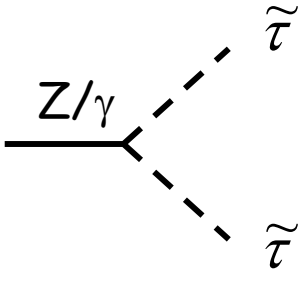


CMSP (stable stau and $\chi^{\pm}$)

$\int L\,dt \approx 390\ pb^{-1}$

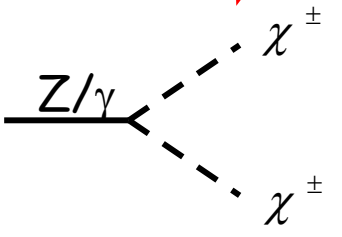
DØ has searched for
Charged Massive Stable Particles

new



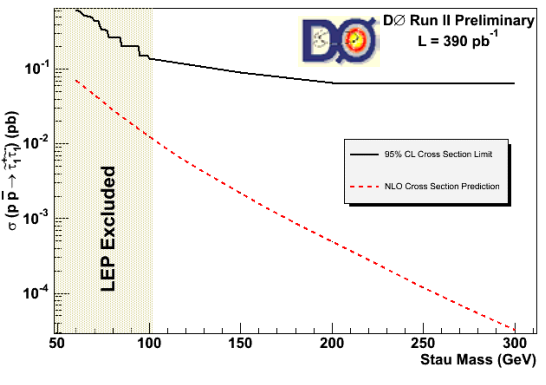
stau

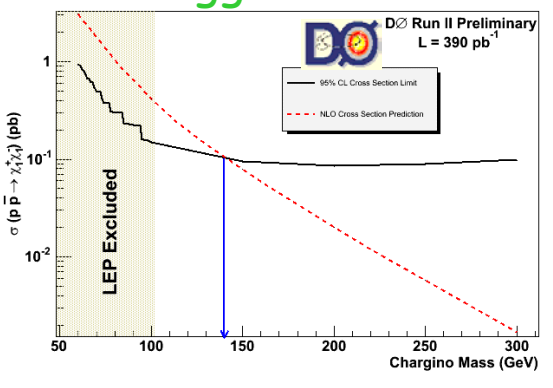
- appear as slow moving high P_T μ
- timing of the muon scintillators used

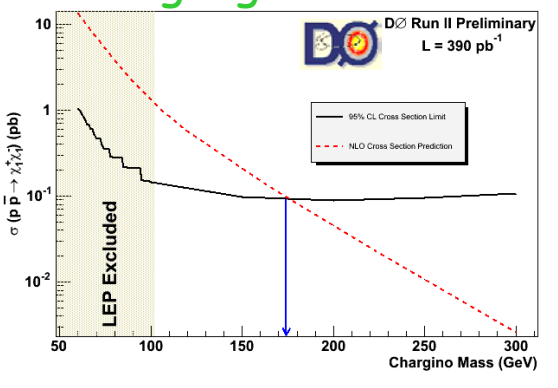


higgsino-like

gaugino-like







σ^{limit}=0.06-0.62 pb

$m_{\chi^+} > 140$ GeV

World best limit

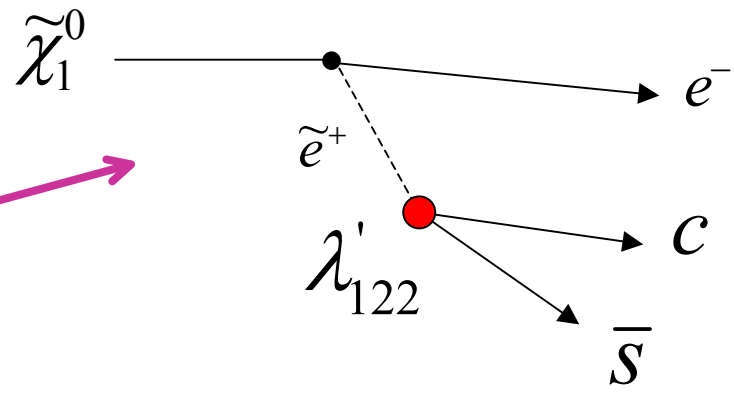
$m_{\chi^+} > 174$ GeV

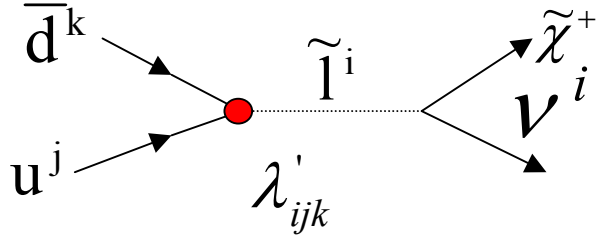
2. R-parity violation : RPV

$$W_{RPV} = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

Experimental signatures :

- **Pair production and RPV decays of LSP**
  - **λ and λ' couplings**
- **Resonant sparticle production**
  - **λ' and λ'' couplings**





RPV consequences :

- Susy signature can be very different
  - Less missing E_T
  - More leptons and jets
- sparticle may be produced by RPV couplings as single sparticles

LSP is not anymore a candidate for dark matter

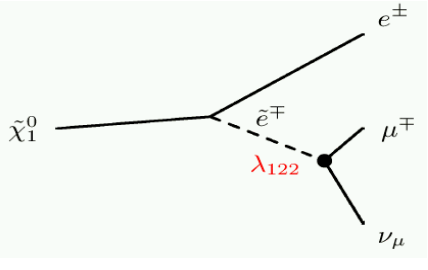
RPV with $\lambda_{ijk} L_i L_j E_k$ coupling

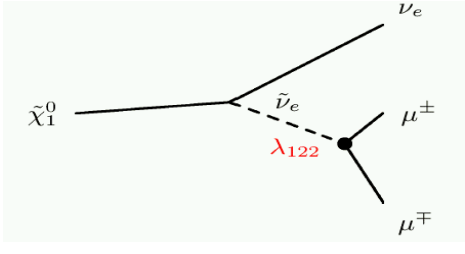
DØ has searched for multilepton final states arising from SUSY particle pair production with R-parity violating decays of two neutralino LSP's

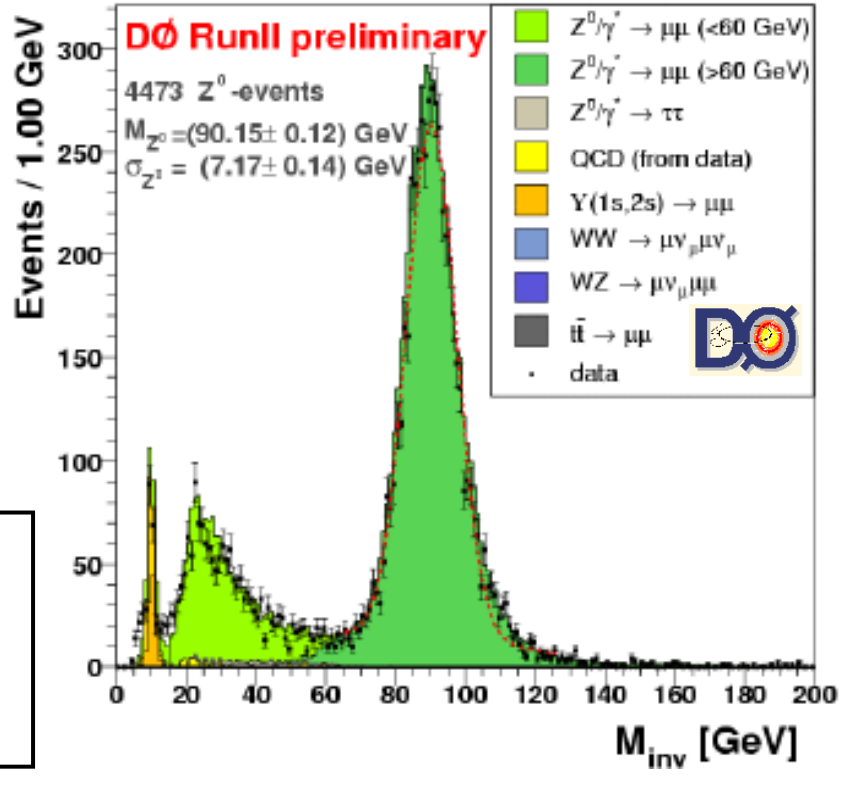
The couplings considered :

$\lambda_{121} \Rightarrow eeee,\ eee\mu$ or $ee\mu\mu + \nu\nu$

$\lambda_{122} \Rightarrow \mu\mu\mu\mu,\ \mu\mu\mu e$ or $\mu\mu ee + \nu\nu$





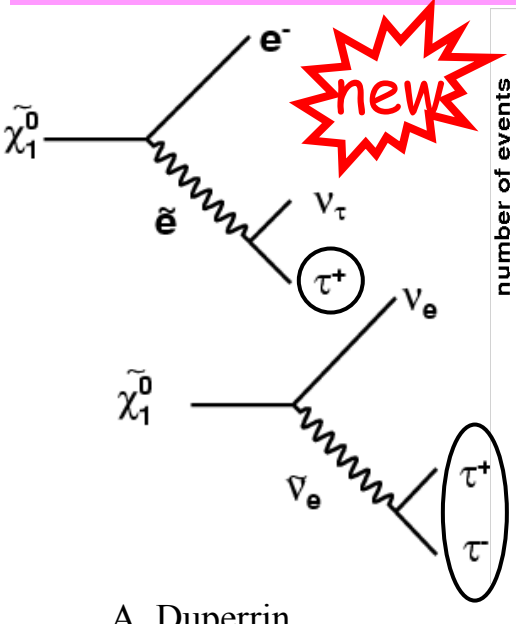


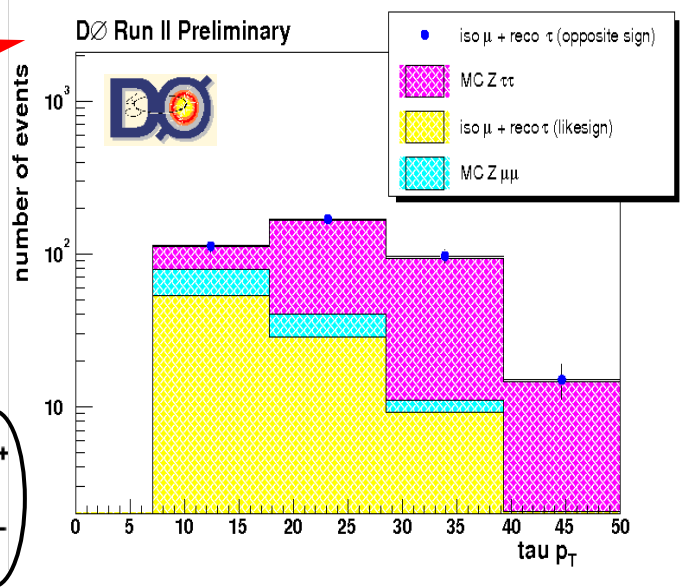
Three isolated rather soft (i.e neutralino mass expected small≈50-90 GeV) e or μ
+ Missing E_T
+ channel-dependent cuts (e.g. anti Z)

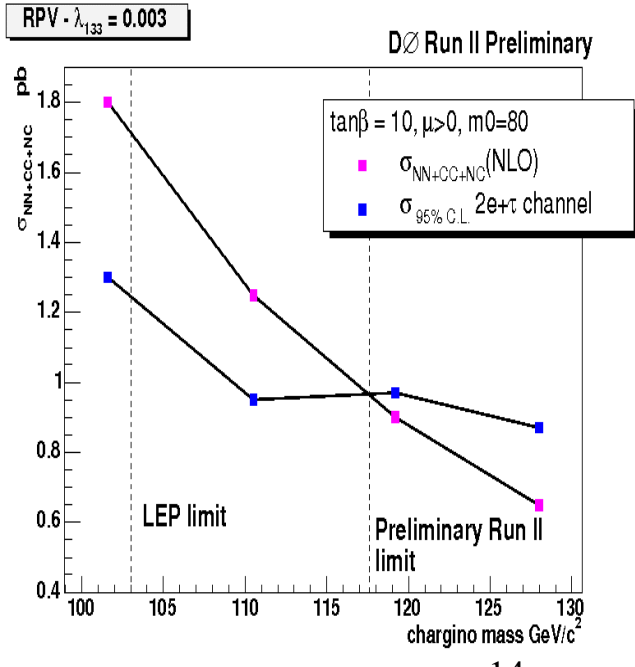
RPV with $\lambda_{ijk} L_i L_j E_k$ (II)

$\int L\,dt = 160\ pb^{-1}$	λ_{122}: 2 (data) / 0.6 ± 1.9 SM	⇒	$m_{\chi^+} > 165$ GeV
$\int L\,dt = 238\ pb^{-1}$	λ_{121}: 0 (data) / 0.5 ± 0.4 SM	⇒	$m_{\chi^+} > 181$ GeV
$\int L\,dt = 200\ pb^{-1}$	λ_{133}: 0 (data) / 1.0 ± 1.4 SM	⇒	$m_{\chi^+} > 118$ GeV

with $\tau \rightarrow$ hadrons + ν :

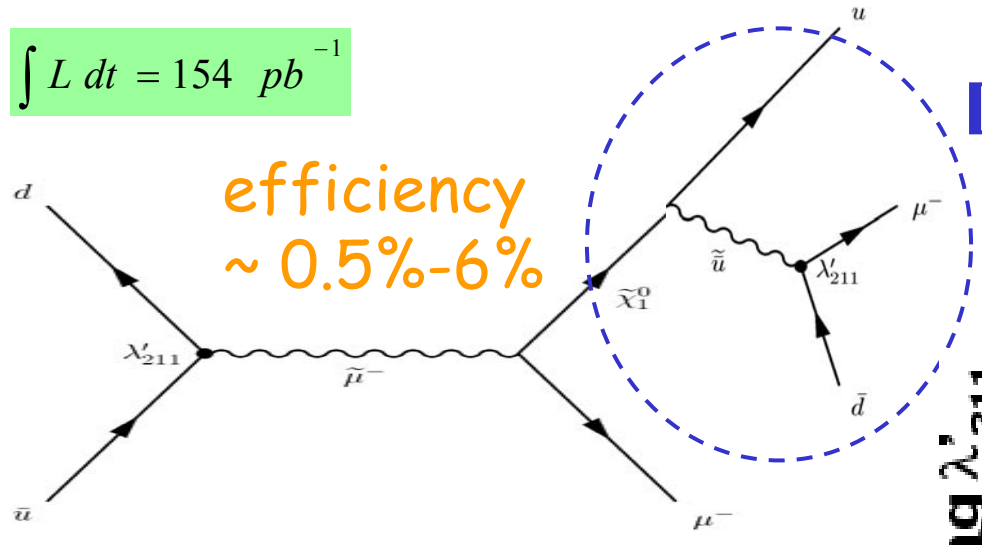






RPV with $\lambda'_{211} L_i Q_j D_k$

$\int L\,dt = 154\ pb^{-1}$

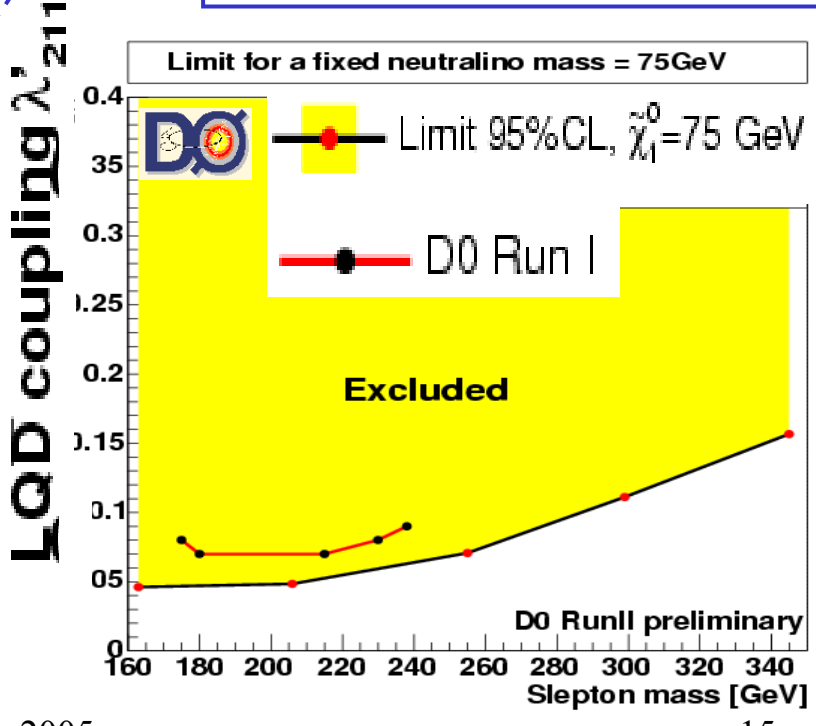


efficiency
~ 0.5%-6%

Neutralino and smuon invariant mass reconstruction possible

- 2 jets
- 2 isolated μ
- P_T(e,μ)~20 GeV

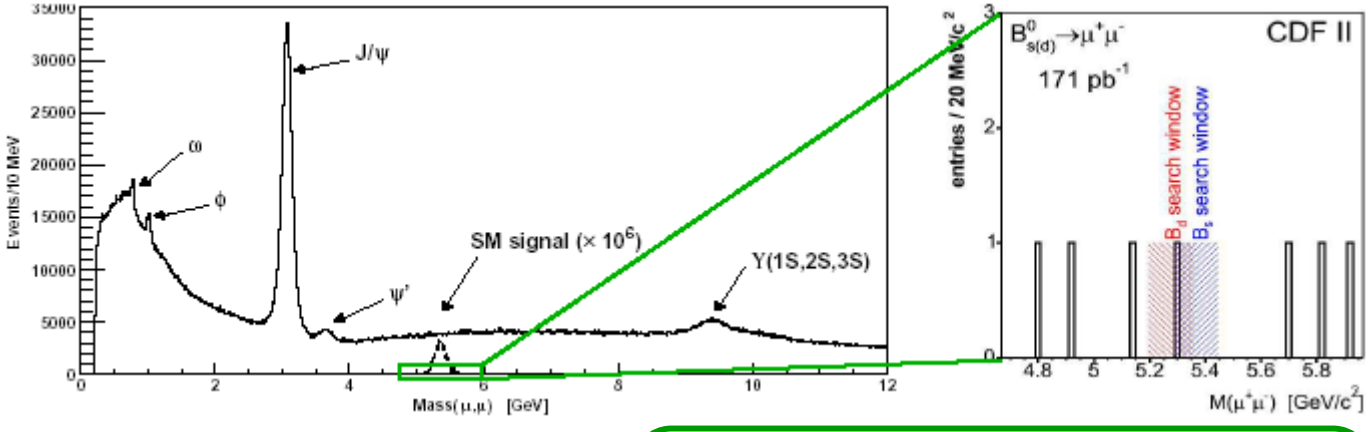
λ'_{211}: **2 (data) / 1.1 ± 0.4 SM**



3. $B_s \rightarrow \mu^+\mu^-$

- In SM, tiny BR ~ 3.5 10^{-9} (and 25 times smaller for Bd)
- But in SUSY, enhancement ~ $(\tan\beta)^6$ factor

Select μμ :
- from displaced vertices
- look inside a mass window:



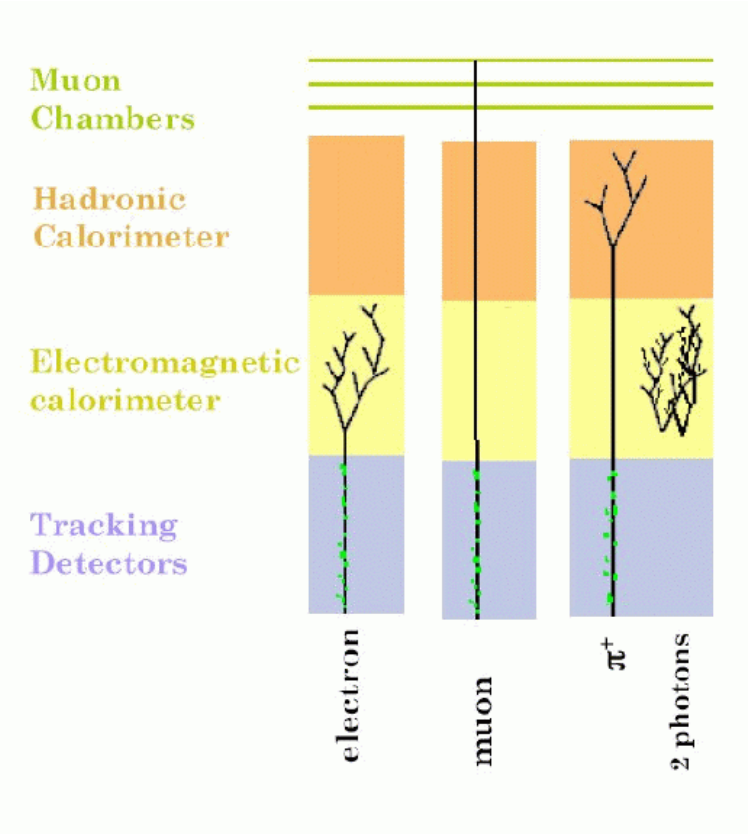
$\int L\,dt = 240\ pb^{-1}$

$\int L\,dt = 171\ pb^{-1}$

BR($B_s \rightarrow \mu+\mu-$) :
- DØ < 4.6 10^{-7}
- CDF < 7.5 10^{-7}

Combined @90% CL
BR($B_s \rightarrow \mu+\mu-$) < 2.7 10^{-7}

start to probe …

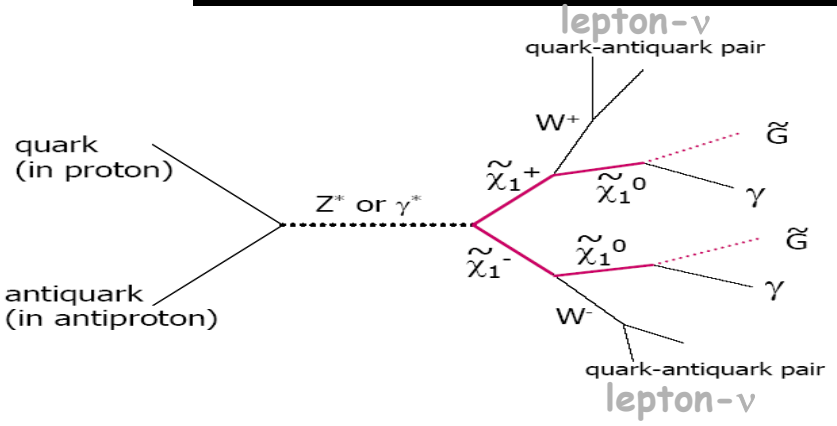


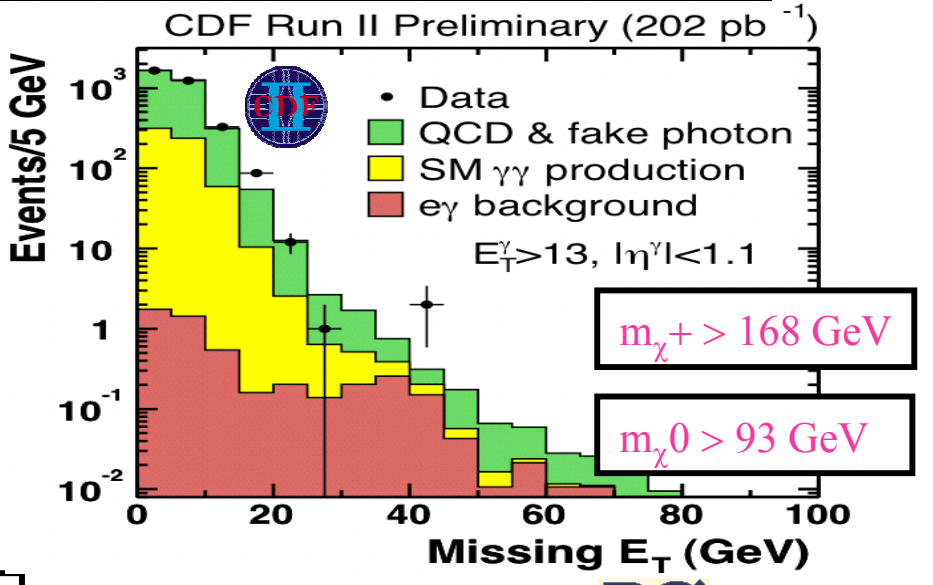
$\gamma\gamma$

+

missing E_T

4. GMSB with χ^0 NLSP



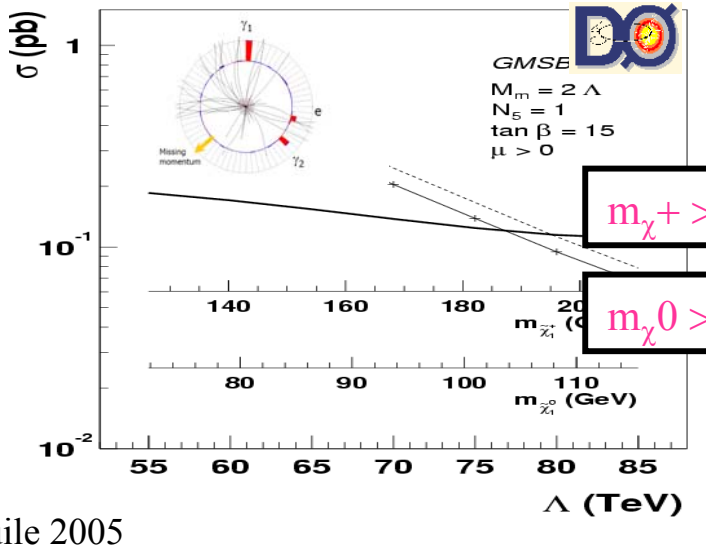


$\int L\,dt = 263\ pb^{-1}$ $\int L\,dt = 202\ pb^{-1}$

DØ and CDF searched for inclusive final state with 2 γγ + Missing ET

2 (data) / 3.7 ± 0.6 SM

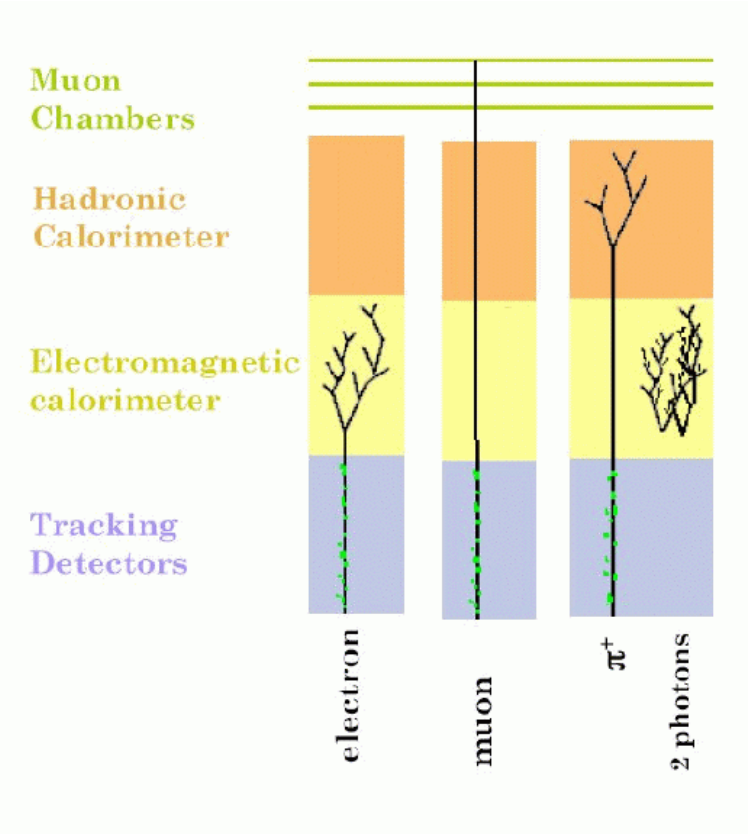
0 (data) / 0.3 ± 0.1 SM



World best limit:

$m_{\chi^+} > 195$ GeV

$m_{\chi^0} > 108$ GeV



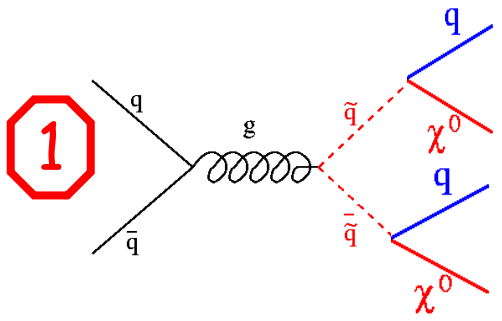
Multijet + missing E_T

- Large production cross sections
- Large experimental backgrounds

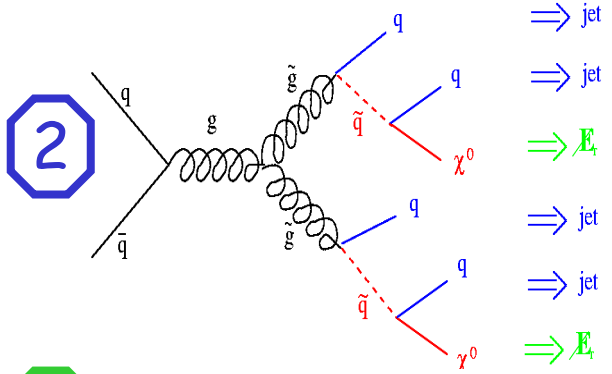
5. Generic squarks/gluinos

DØ has searched for generic squarks-gluinos

1 $m(\tilde{g}) > m(\tilde{q})$ 2 $m(\tilde{q}) > m(\tilde{g})$ 3 $m(\tilde{q}) \approx m(\tilde{g})$

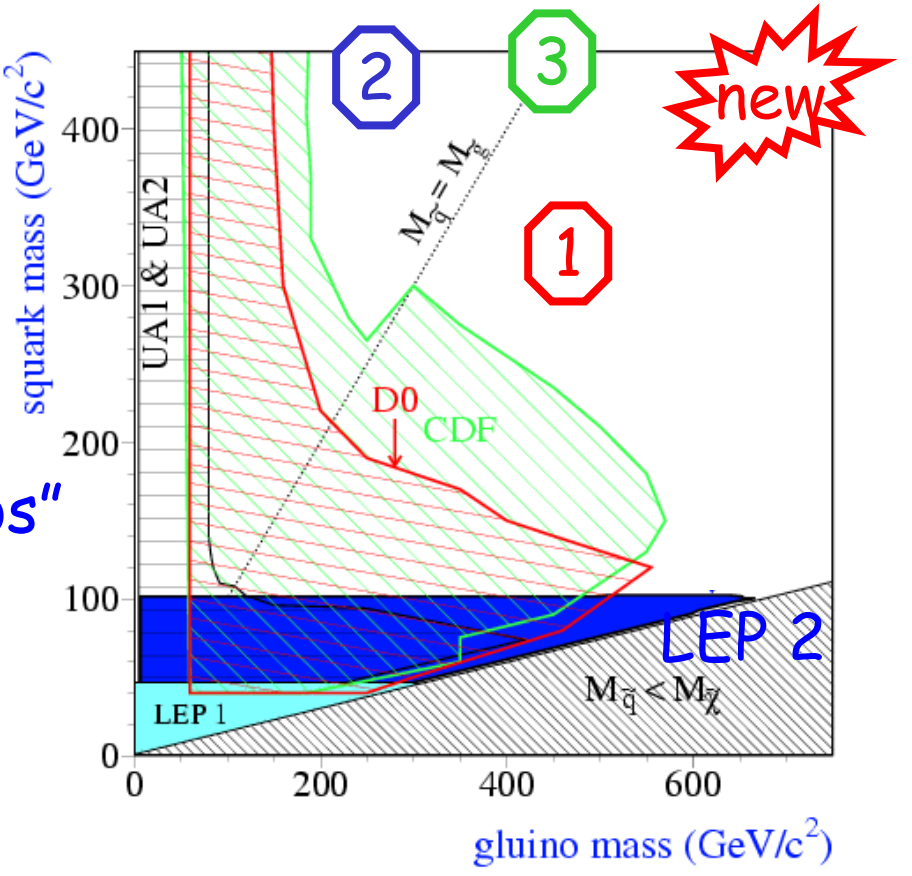


"dijet"



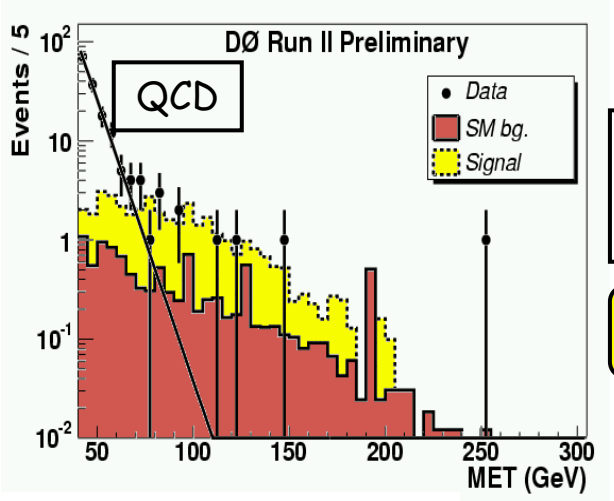
"gluinos"

3 $\tilde{q}\tilde{g} \Rightarrow \geq 3$ jets



Generic squarks/gluinos (II)

Example of the "gluinos" analysis (2)

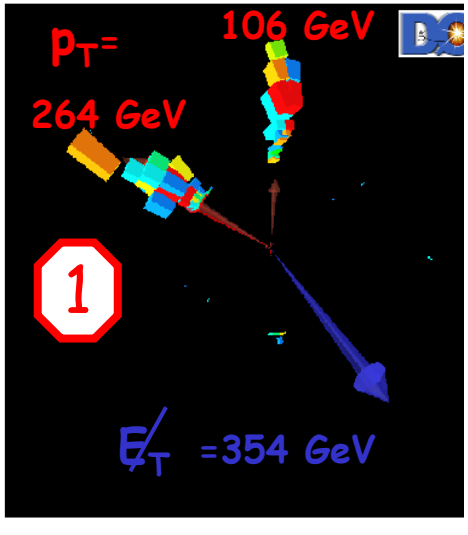


- Sum of jet p_T>250 GeV
- Missing E_T>75 GeV

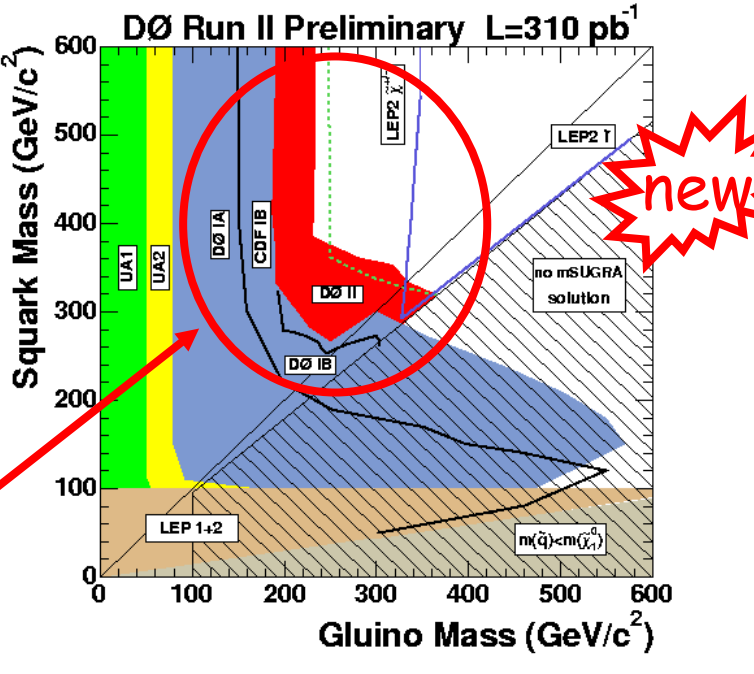
10 (data) / 7.1 ± 1.6 SM

Main backgrounds left:
- ($Z \rightarrow \nu\nu$) + jets
- Top

$\int L\,dt = 310\ pb^{-1}$

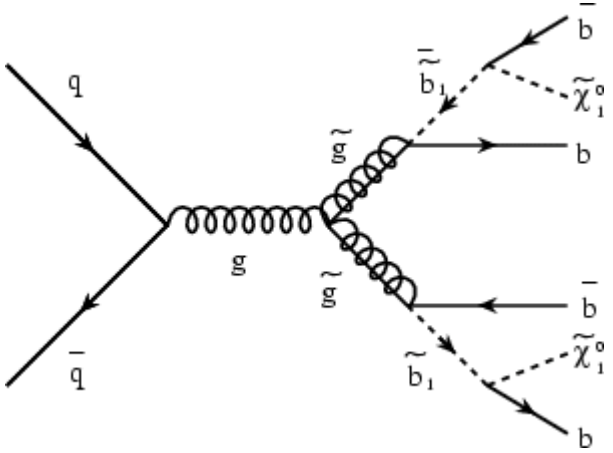


Significant improvement over CDF-Run I :
m(squark) > 318 GeV
(m_0= 25)
m(gluino) > 233 GeV
(m_0= 500)
m(gl)~m(sq) > 333 GeV



Sbottom

CDF has searched for sbottom in gluino decays (asumming $m_{sb1} \ll m_{squarks}$)



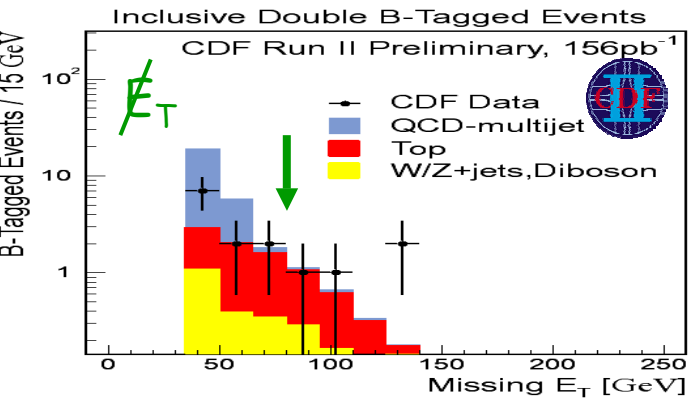
$\Rightarrow$ 4 b-jets + Missing E_T

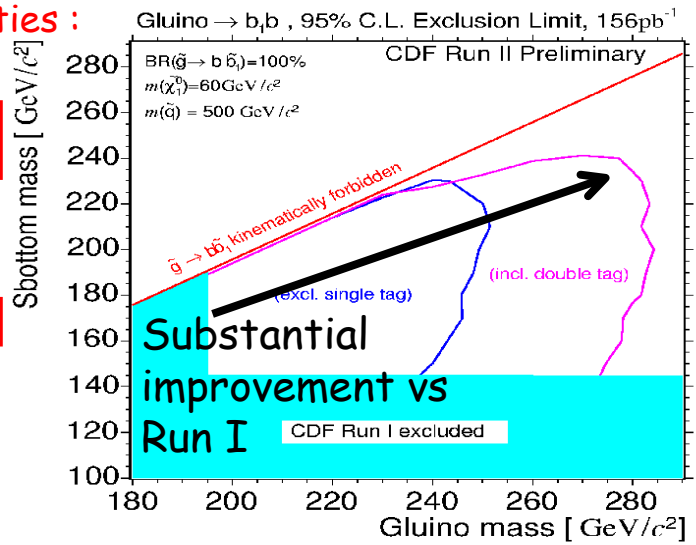
$\int L\,dt = 156\ pb^{-1}$

Process	Exclusive Single B-Tag	Inclusive Double B-Tag
EWK	$5.66 \pm 0.76(stat) \pm 1.72(sys)$	$0.61 \pm 0.21(stat) \pm 0.19(sys)$
TOP	$6.18 \pm 0.12(stat) \pm 1.42(sys)$	$1.84 \pm 0.06(stat) \pm 0.46(sys)$
QCD	$4.57 \pm 1.64(stat) \pm 0.57(sys)$	$0.18 \pm 0.08(stat) \pm 0.05(sys)$
Total Predicted	$16.41 \pm 1.81(stat) \pm 3.15(sys)$	$2.63 \pm 0.23(stat) \pm 0.66(sys)$
Observed	21	4

- Main systematic uncertainties :

Luminosity	6.0%
Tagging efficiency	14.0%
Energy scale	25.0%
Trigger efficiency	2.5%
PDF uncertainty	2.0%
Scale factor	-
Cross-section	11.5%
Lepton veto	2.0%
$\Delta\phi$ cuts	0.5%
Total	31.5%





Stop

CDF has searched for stop in various decays and models

new

$\int L\,dt = 53\ pb^{-1}$

CHAMPS (charged massive particles)

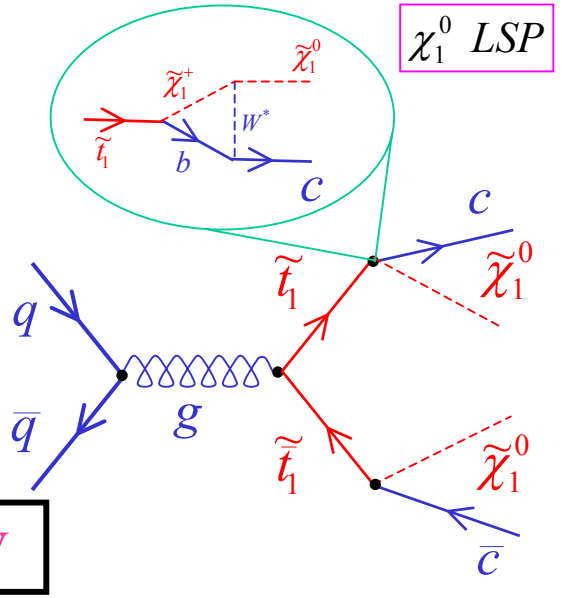
RPC $\tilde{t} \to c\,\chi_1^0$

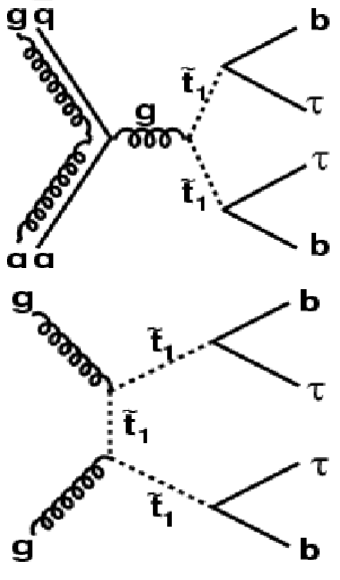
RPV $\tilde{t} \to b\,\tau$

- Search for long-lived charged particles using Time-of-Flight system
- Particles behave like slow, but high P_T muons

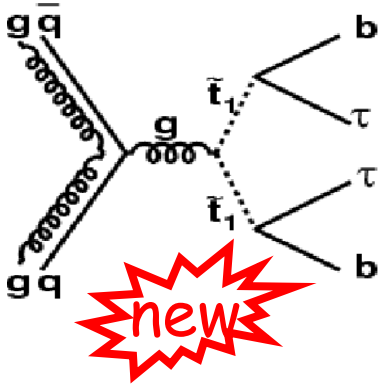
7 (data) / 2.9 ± 3.1 SM

- Result interpreted for isolated (meta) stable stop ⇒ $m_{stop} > 108$ GeV





Stop (RPV $\tilde{t} \to b\tau$)



$$BR(\tilde{t} \to b\tau) = 100\ \%$$

$\Rightarrow$ $\geq$ 2 jets + e/μ +

τ hadronic + Missing E_T

with :

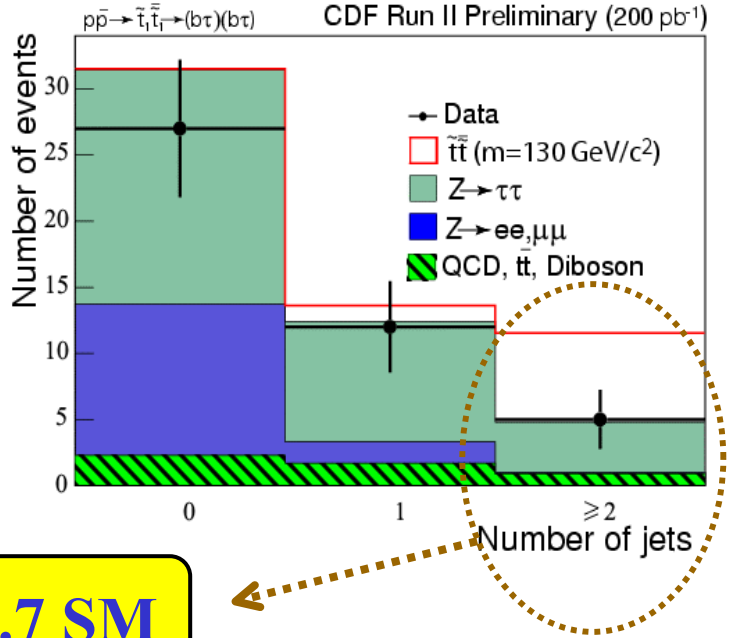
- $\tau_h \to$ *hadrons* + ν
- $\tau_l \to l\nu_l\nu_\tau$ (l=e,μ)

electron or muon $p_T^{e,\mu} \geq 10$ GeV

+ at least one τ_h candidate $p_T^{\tau} \geq 15$ GeV
+ jets (isolated from e,μ) $E_T \geq 15$ GeV
+ m(*lepton*,Missing E_T) ≤ 35 GeV
+ e.g. anti Z

Main backgrounds left:

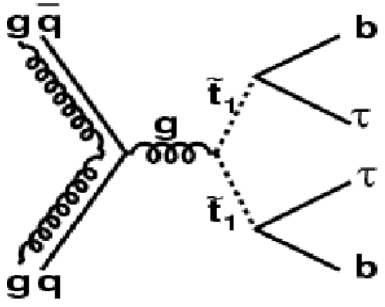
- QCD (bb,γ+jets)
- vector bosons + jets



$$\int L\,dt = 200\ pb^{-1}$$

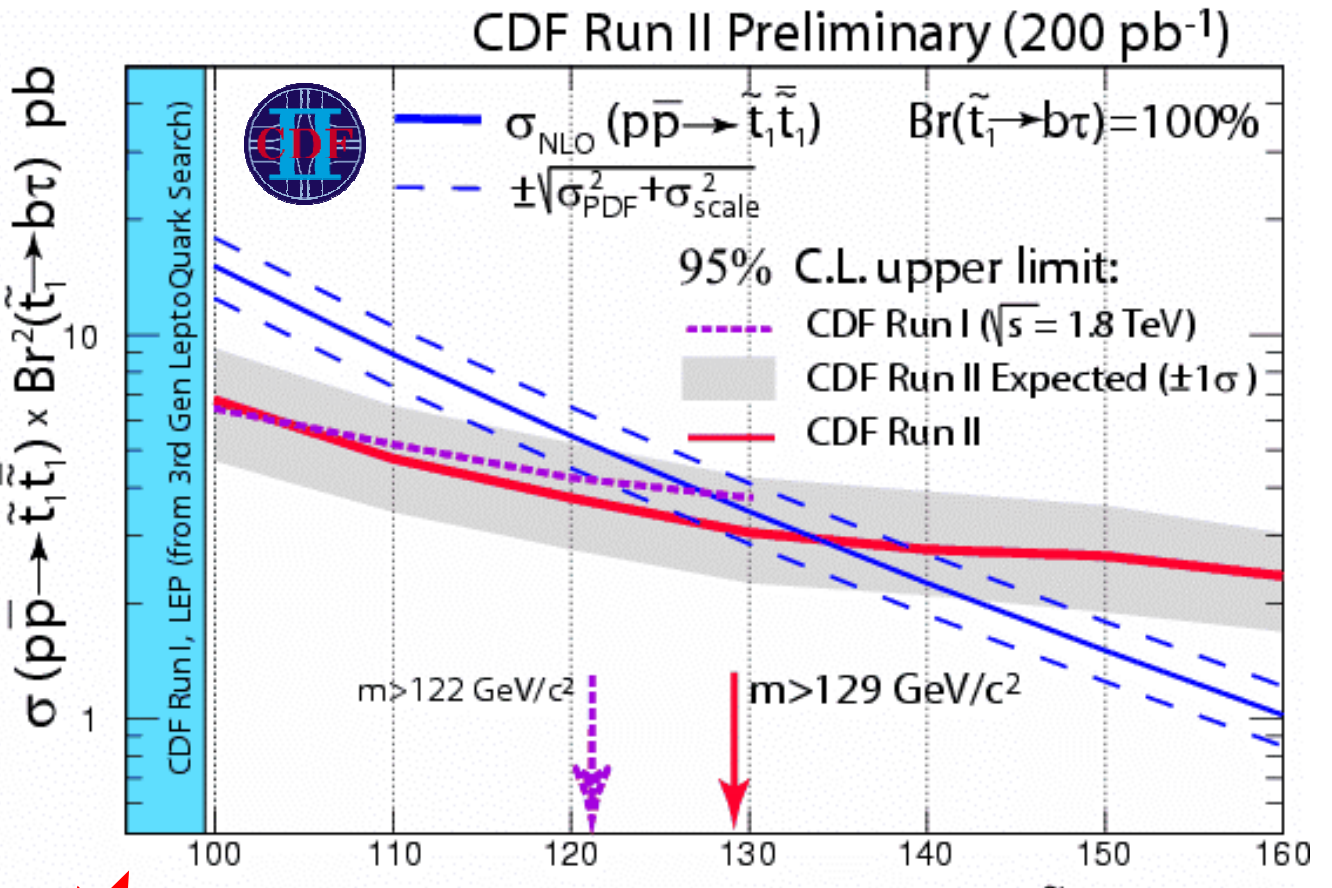
5 (data) / 4.8 ± 0.7 SM

Stop (RPV $\tilde{t} \to b\tau$) (II)



can also be interpreted as pair production of the 3rd generation of scalar leptoquark

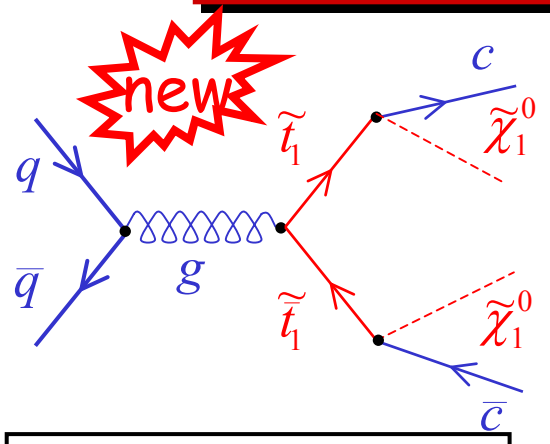
LQ→bτ



new

$m_{stop} > 129$ GeV

Stop (RPC $\tilde{t} \to c\,\chi_1^0$)



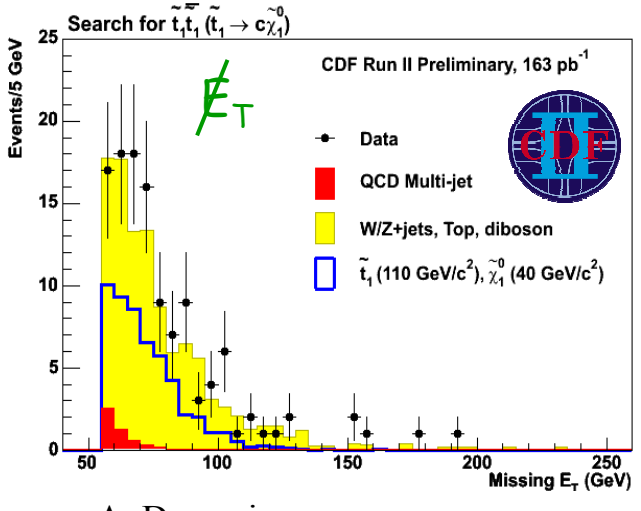
$\Rightarrow$ 2 acoplanar jets + Missing E_T

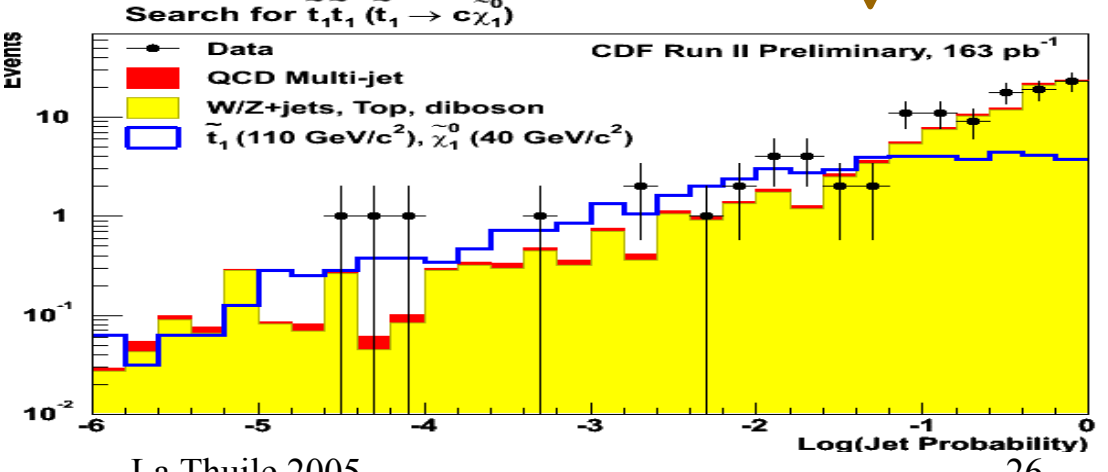
$$BR(\tilde{t} \to c\chi_1^0) = 100\ \%$$

χ_1^0 *LSP*

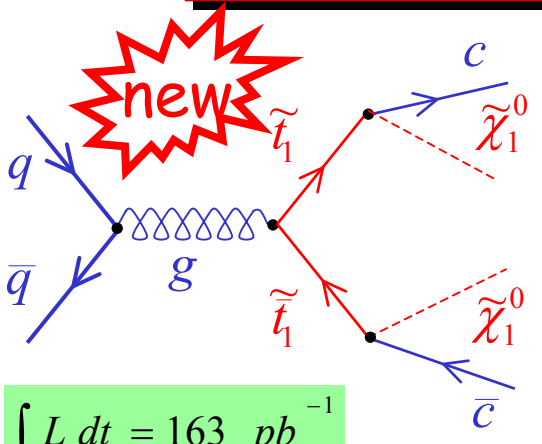
2 jets $E_T \geq$ 35,25 GeV (central $|\eta| \leq 1{,}1.5$)
+ Missing $E_T \geq$ 55 GeV
+ e.g anti QCD back to back jets
+ no isolated lepton $p_T^{e,\mu} \geq$ 10 GeV, anti τ
+ double heavy-flavor-tagging

Main backgrounds:
($Z \to \nu\nu$) + 2 jets





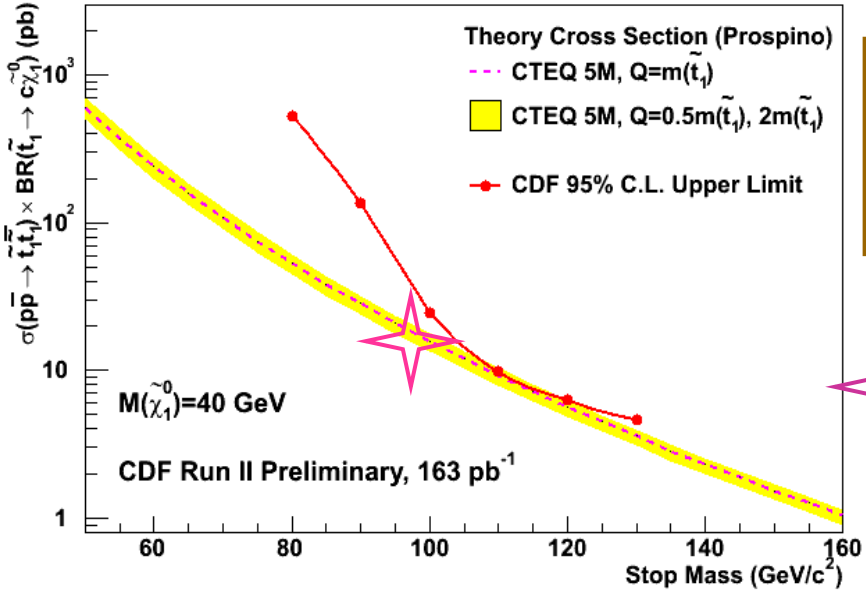
Stop (RPC $\tilde{t} \to c\,\chi_1^0$) (II)



$\int L\,dt = 163\ pb^{-1}$

Major sources of systematic uncertainties: background arises from Jet Energy Scale correction (6%-33%) + tagging heavy flavor jets (13%)

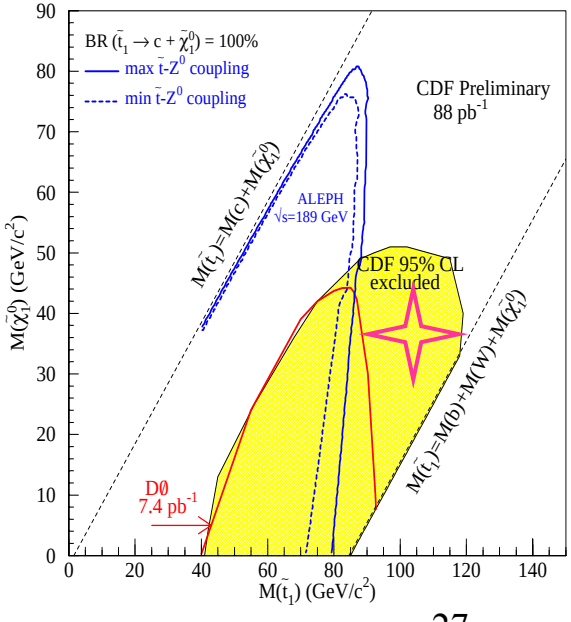
CDF 11 (data) / 8.3 ± 2.0 SM



does not exclude (yet) Run I

$m_\chi 0 = 40$ GeV

$m_{stop} = 100$GeV



Conclusions

- Tevatron collider, CDF and D0 are running well
- Analysis shown here based on up to 390 pb^{-1} (200 pb^{-1} more data are already being analyzed now!)
- Still only half of SUSY particles have been found …
- But already many new results are derived which significantly improve on existing limits (ex : $B^0_s \rightarrow \mu^+\mu^-$ results starting to constrain high tan β region)
- In La Thuile 2009, expect 8 fb^{-1} (reasonably optimistic)
- Still many years to expand the frontiers of discoveries of New Phenomena for CDF and D0 experiments