Search for SUSY at the Tevatron

no indirect limits

+

no Higgs

~ 30 papers or notes

ICHEP06 Moscow

2006-07-28/29

parallel session `Beyond the SM‘

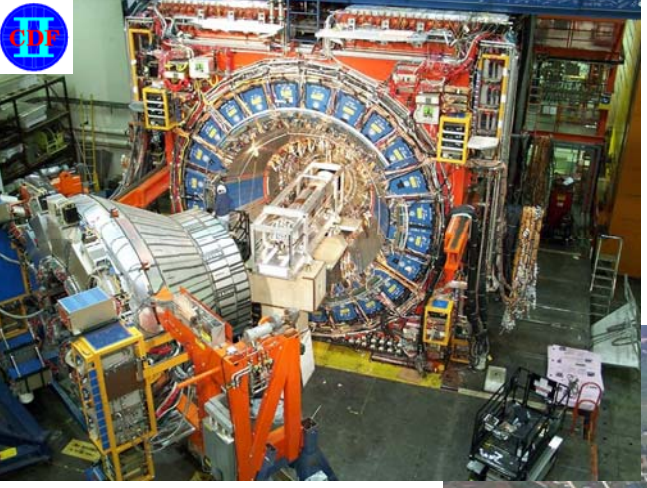
Thomas Hebbeker

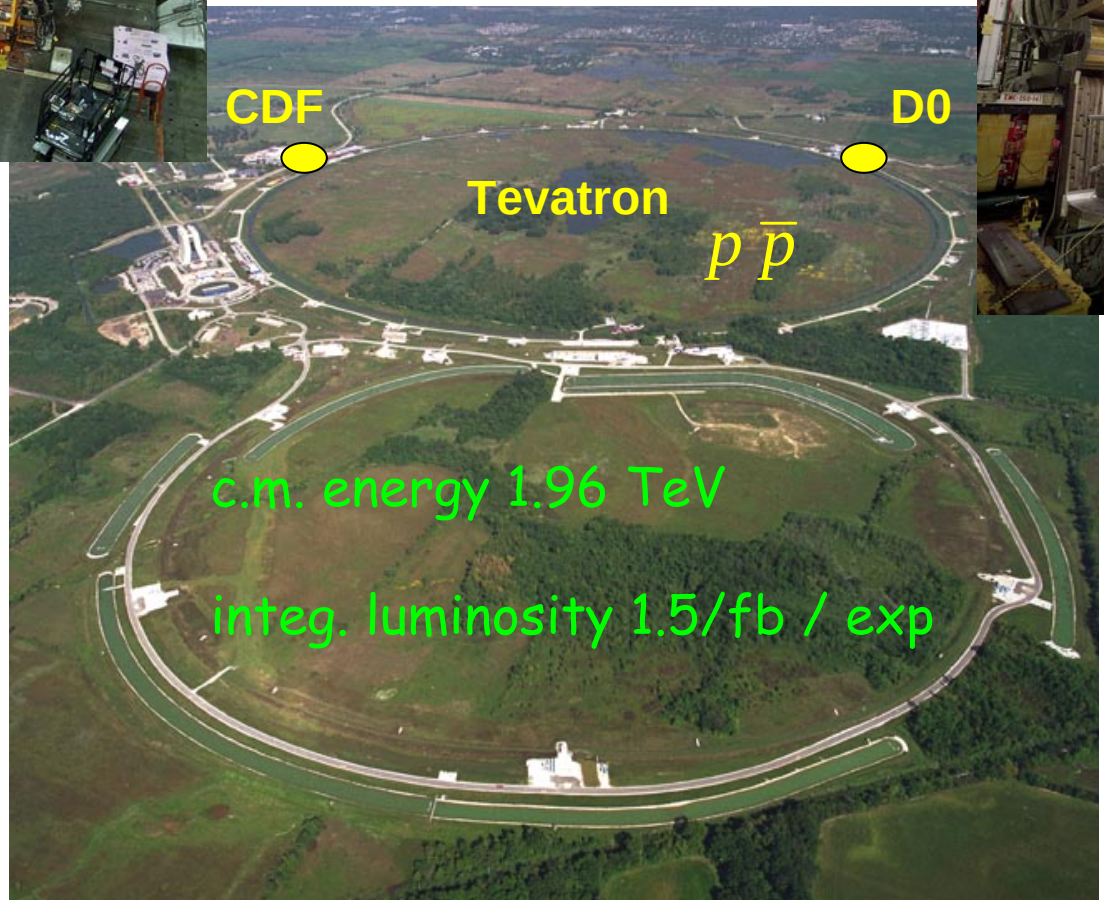
Aachen University

RWTH AACHEN
Phys. Inst. III A

bmb+f
Großgeräte der physikalischen Grundlagenforschung

Tevatron

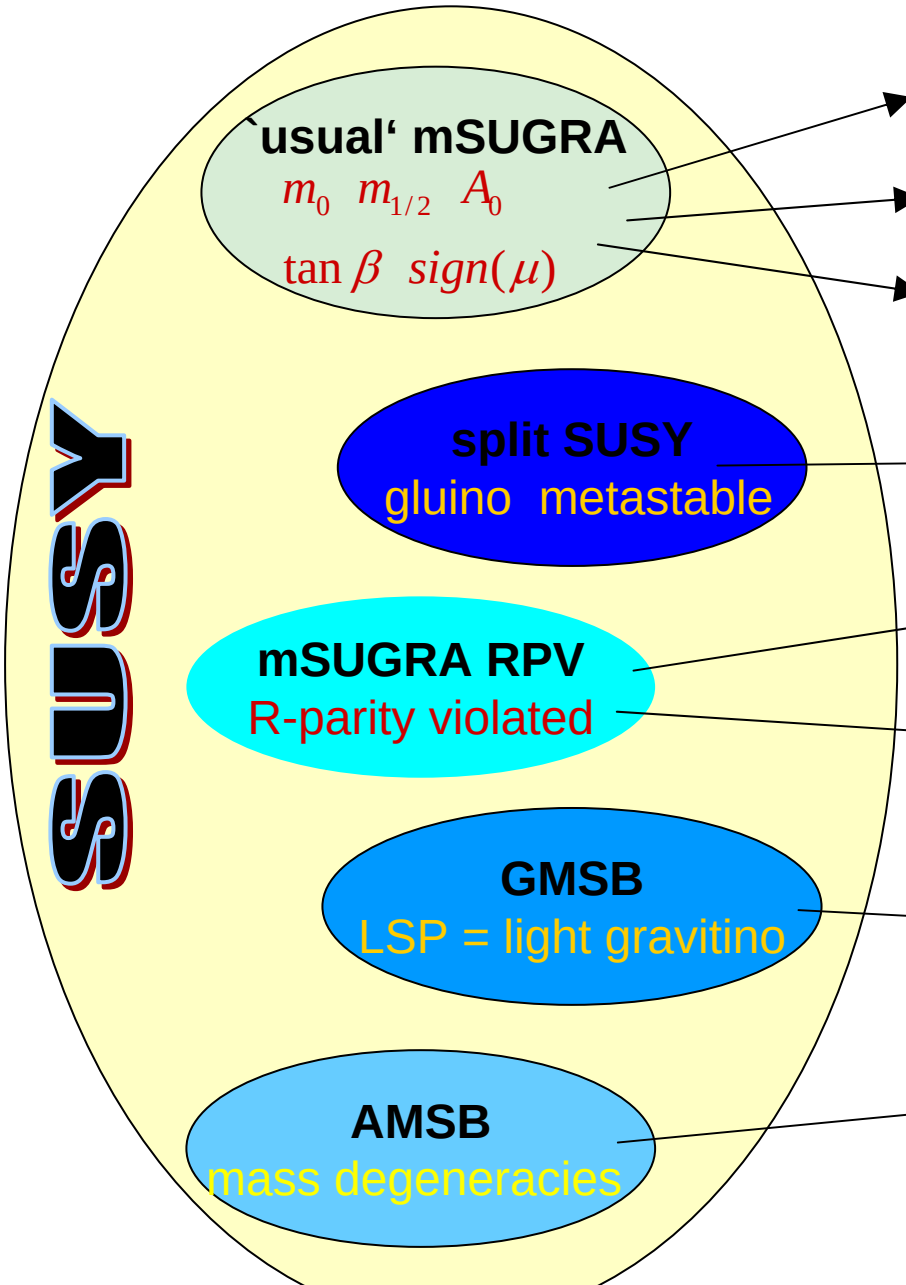




CDF: http://www-cdf.fnal.gov/physics/exotic/exotic.html

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

SUSY Models and Signatures



generic squarks and gluinos

sbottom and stop

gauginos → leptons

stopping gluinos

lepton-lepton couplings

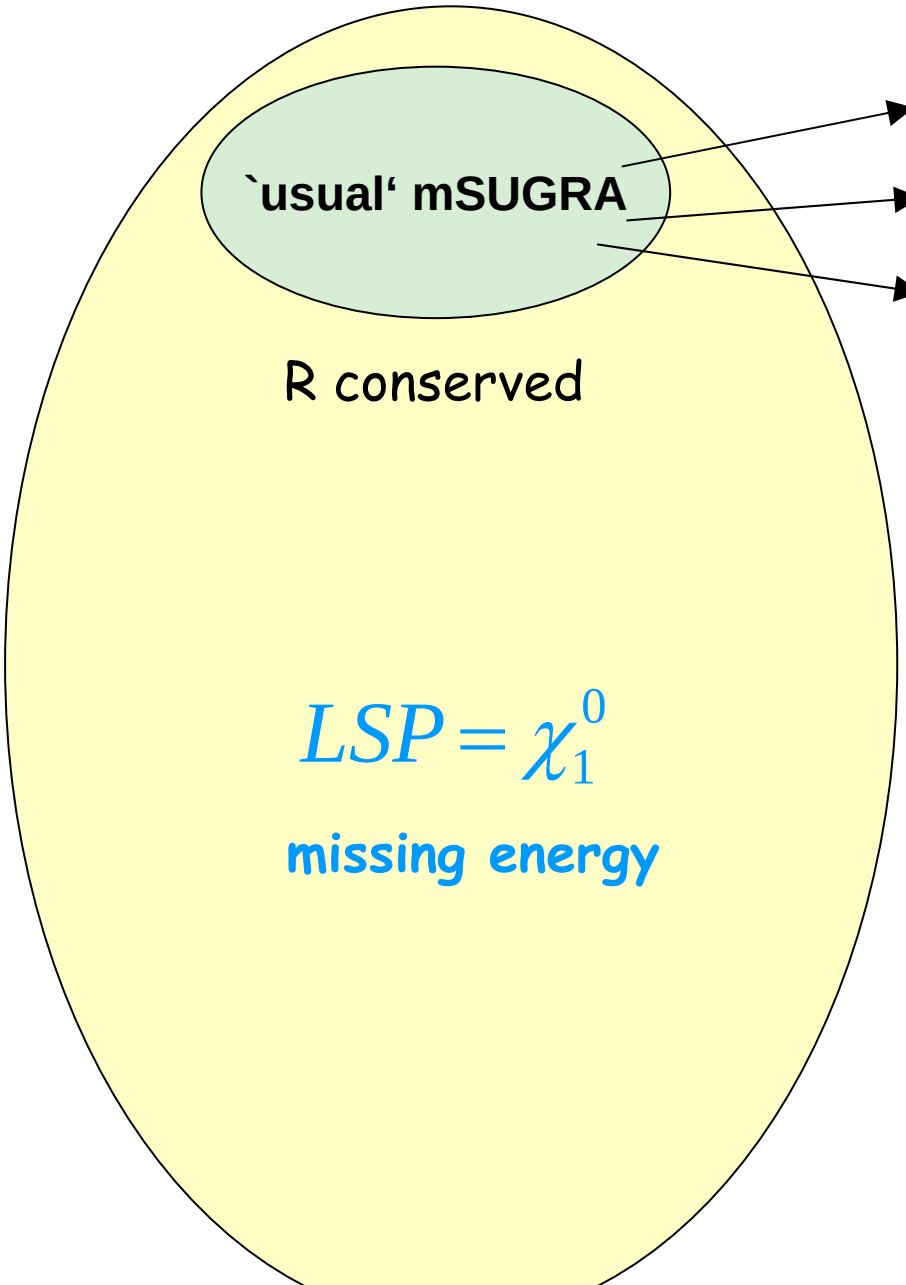
lepton-quark couplings

photons + missing energy

long lived heavy charged particles

LIMITS 95%

mSUGRA analyses



- generic squarks and gluinos
- sbottom and stop
- gauginos $\rightarrow$ leptons

m_0

$m_{1/2}$

A_0

$\tan\beta$

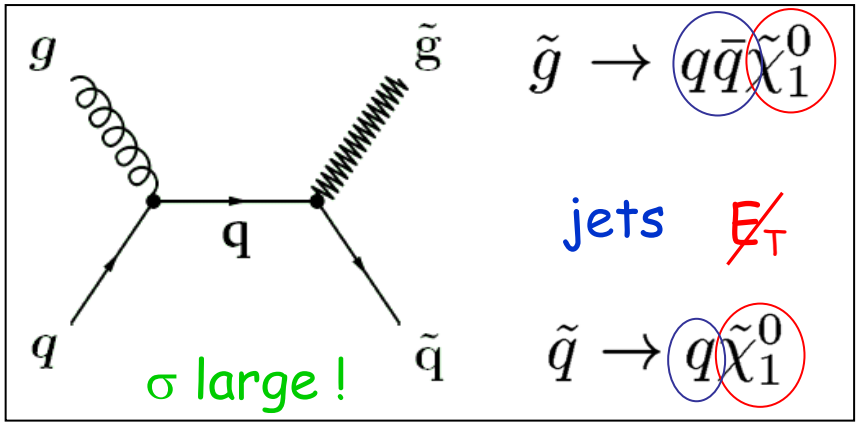
$sign(\mu)$

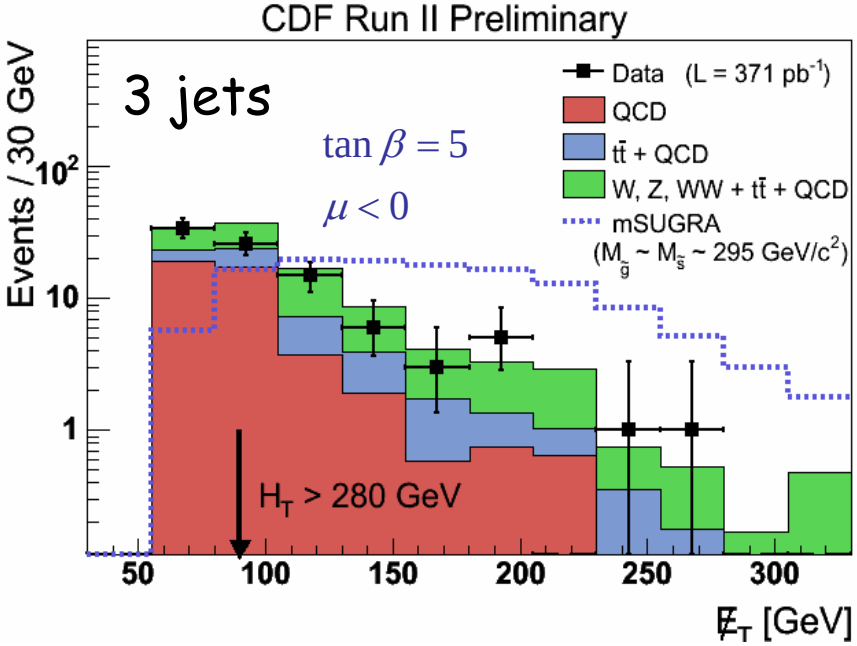
Note:

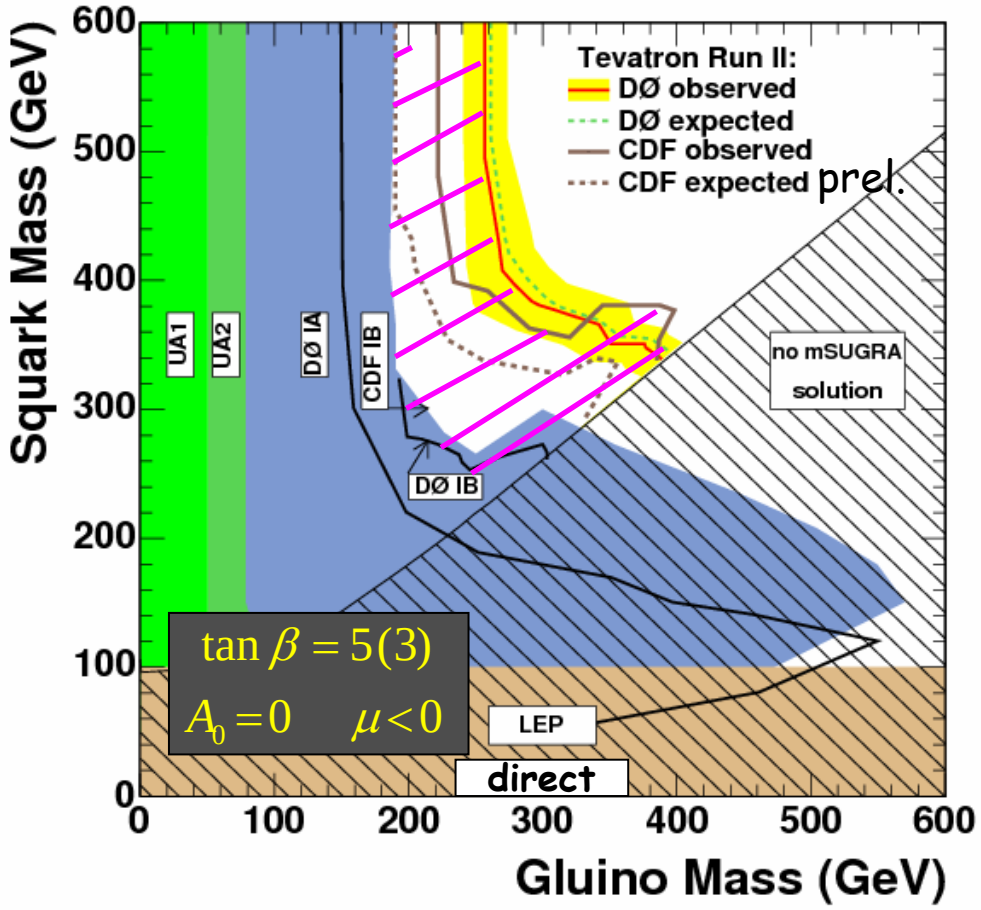
stop or sbottom might be light

Squarks and gluinos: jets and missing energy

e.g:







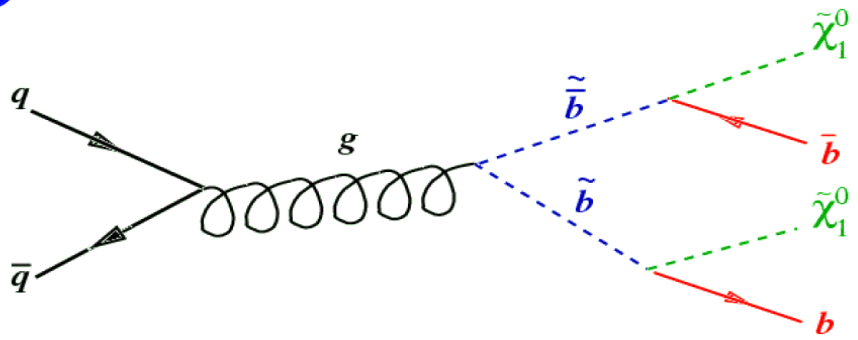
$\tilde{g} > 241 GeV$ absolute

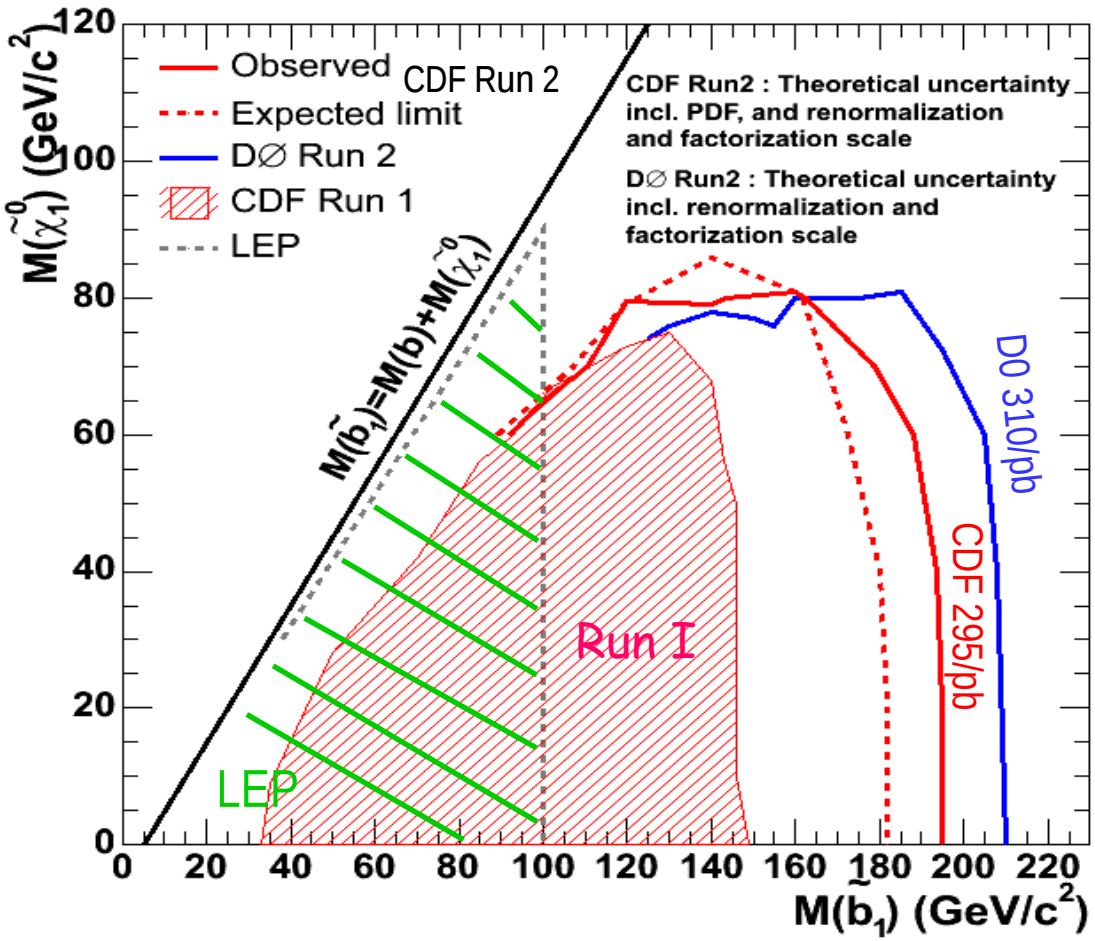
$\tilde{g}, \tilde{q} > 387 GeV$ for equal masses

310/pb

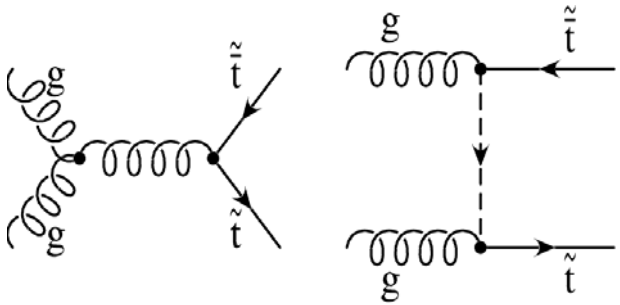
371/pb prel.

Sbottom

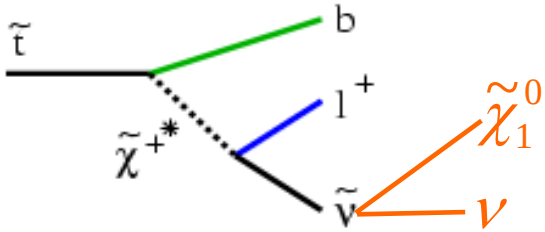

q
$\bar{q}$
g
$\tilde{b}$
$\bar{\tilde{b}}$
$\tilde{\chi}_1^0$
$\bar{b}$
b

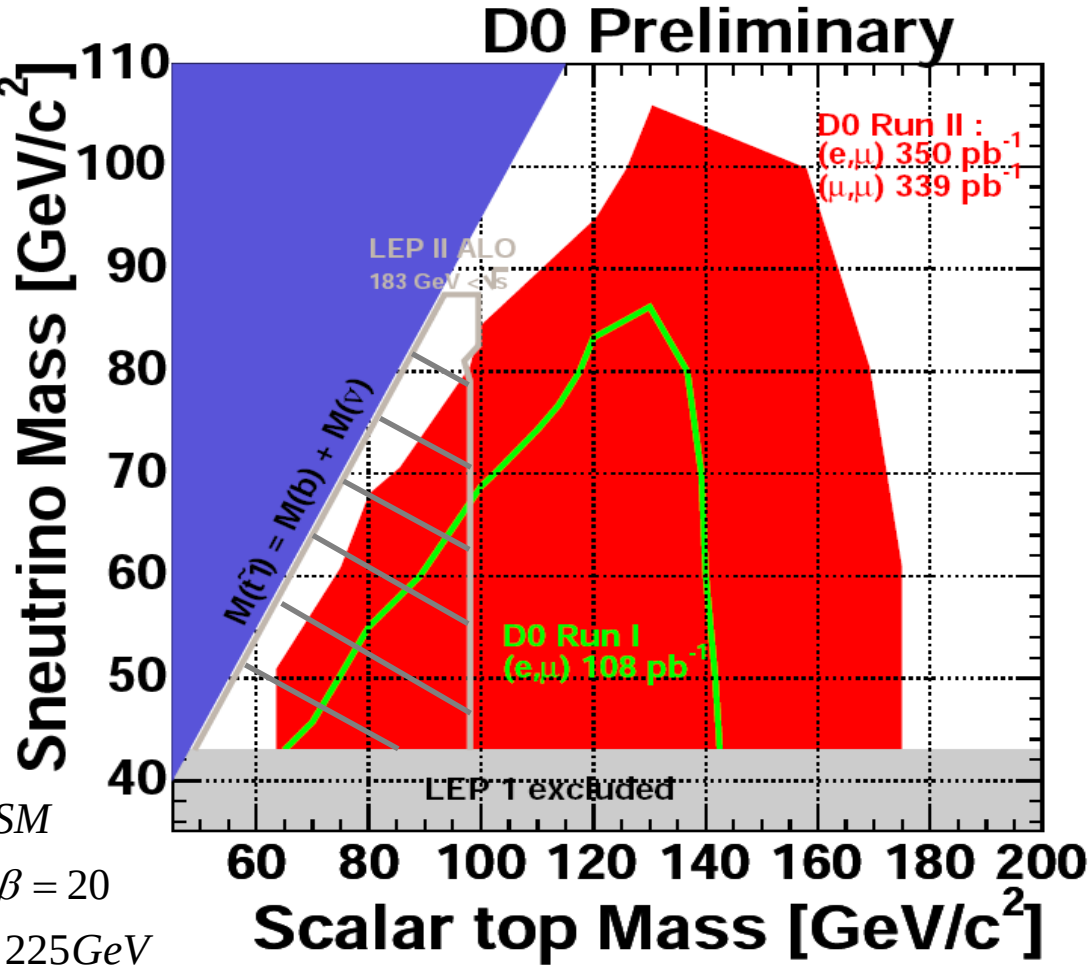

Observed
Expected limit
DØ Run 2
CDF Run 1
LEP
CDF Run 2
CDF Run2 : Theoretical uncertainty incl. PDF, and renormalization and factorization scale
DØ Run2 : Theoretical uncertainty incl. renormalization and factorization scale
$M(\tilde{b}_1)=M(b)+M(\tilde{\chi}_1^0)$
Run I
LEP
D0 310/pb
CDF 295/pb
$M(\tilde{\chi}_1^0)$ (GeV/c^2)
$M(\tilde{b}_1)$ (GeV/c^2)
0
20
40
60
80
100
120
140
160
180
200
220

Stop



$\tilde{t} \rightarrow b\, l\, \nu\, \tilde{\chi}_1^0 \qquad l = e, \mu$



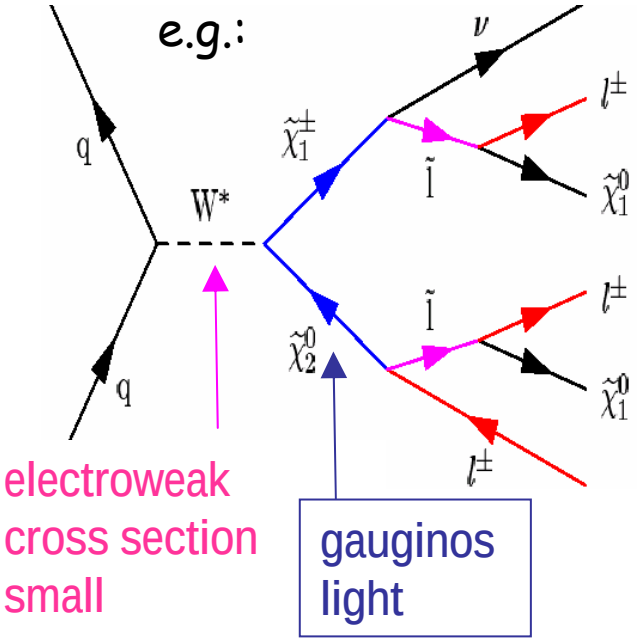


MSSM

$\tan\beta = 20$

$\mu = 225 GeV$

Charginos/Neutralinos → Leptons



electroweak cross section small

gauginos light

trilepton +missing energy

clean signature !

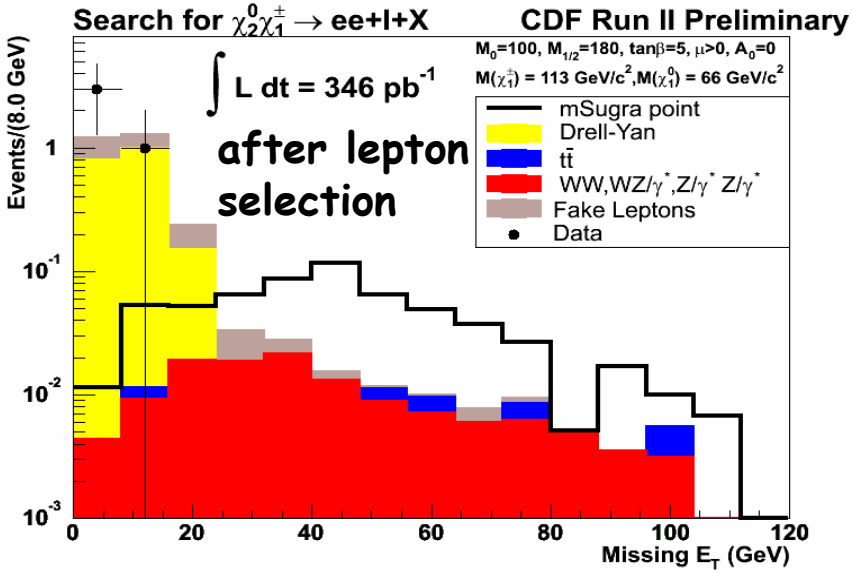
signatures:

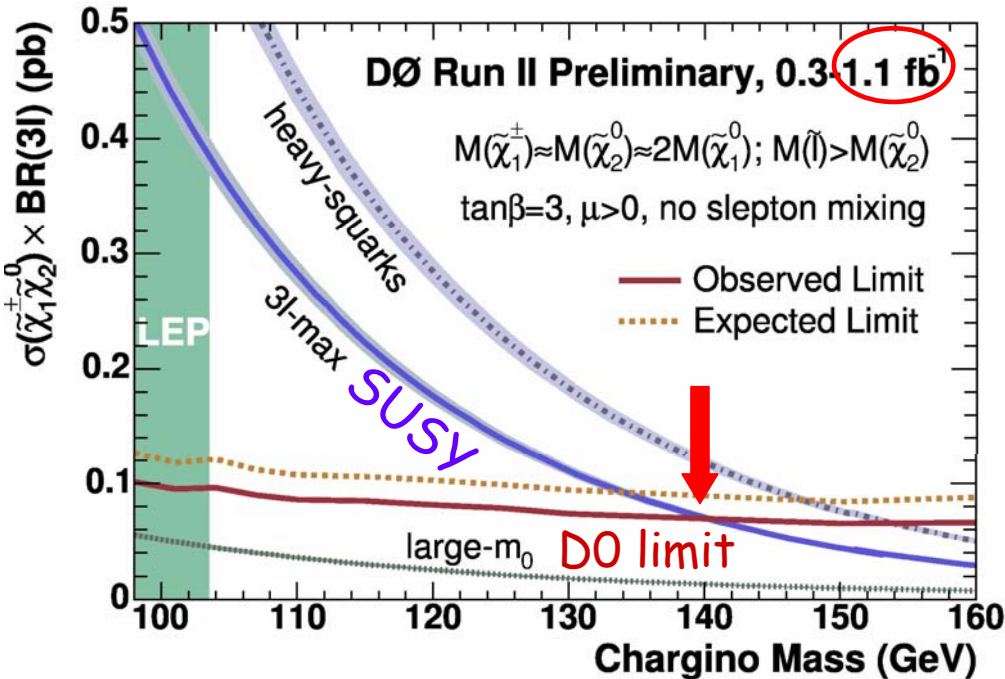
$ee+l$

$\mu^-\mu^- / \mu^+\mu^+$

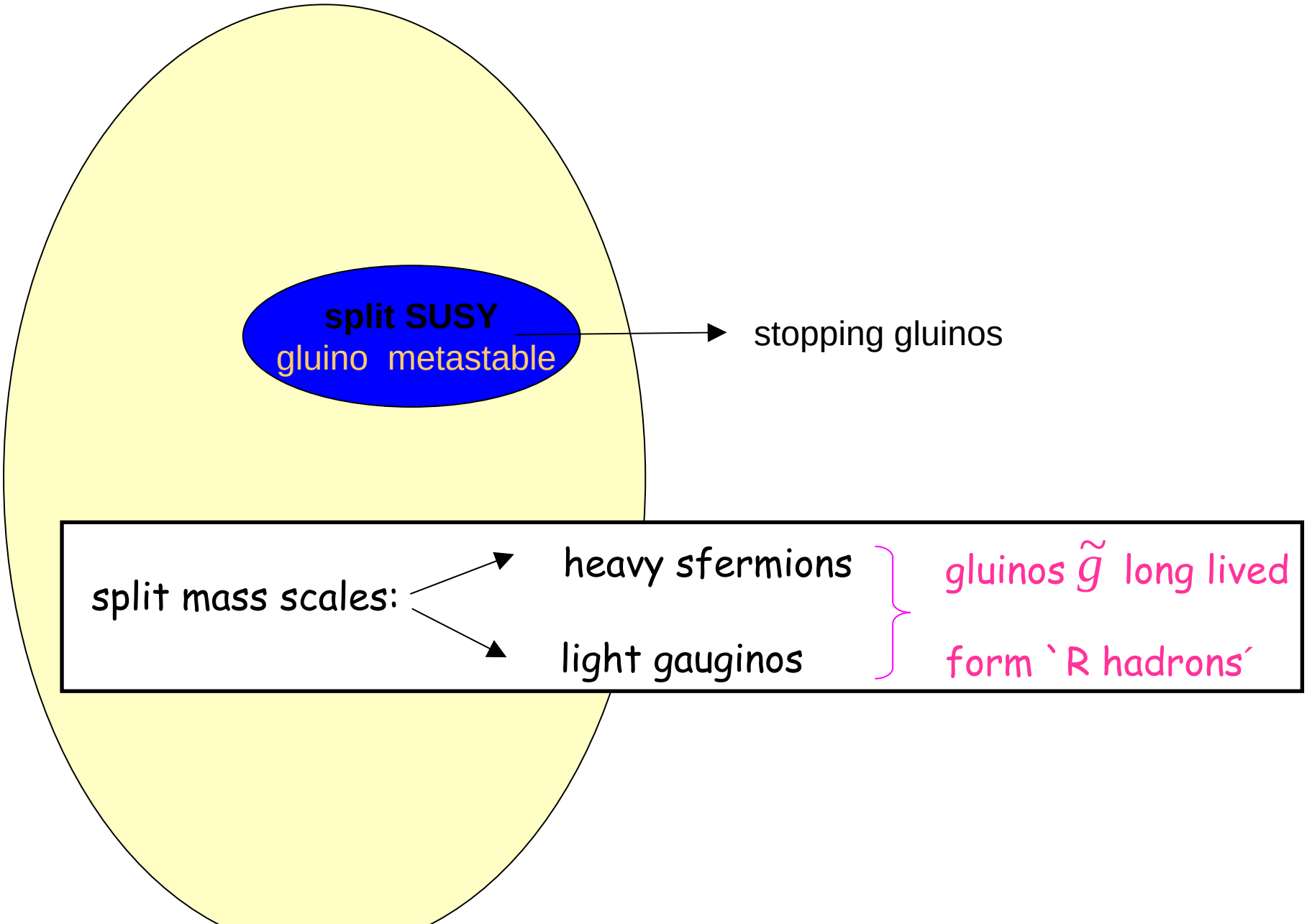
$e/\mu+\tau+l$

+ ...





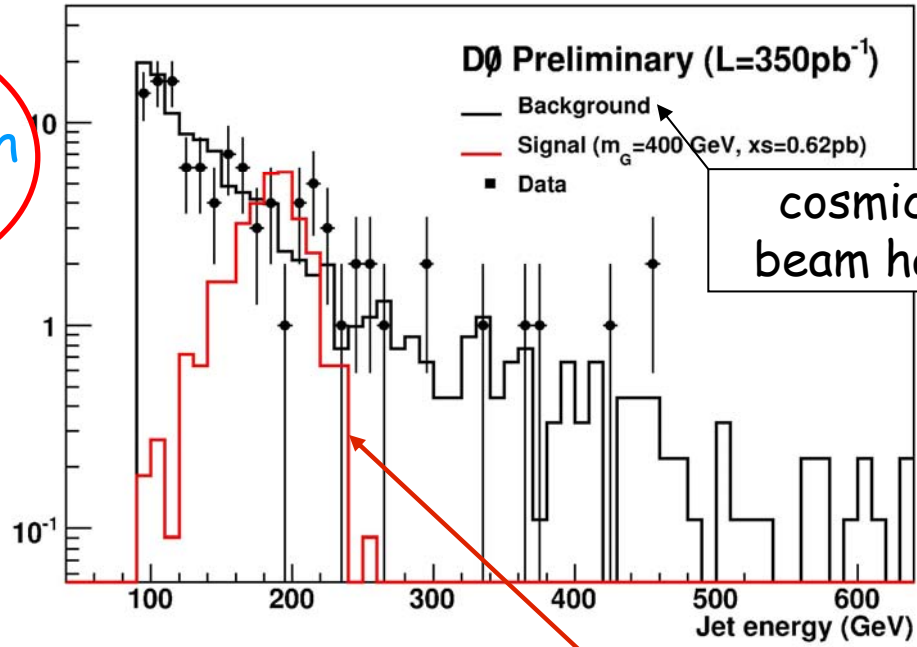
´Split SUSY´

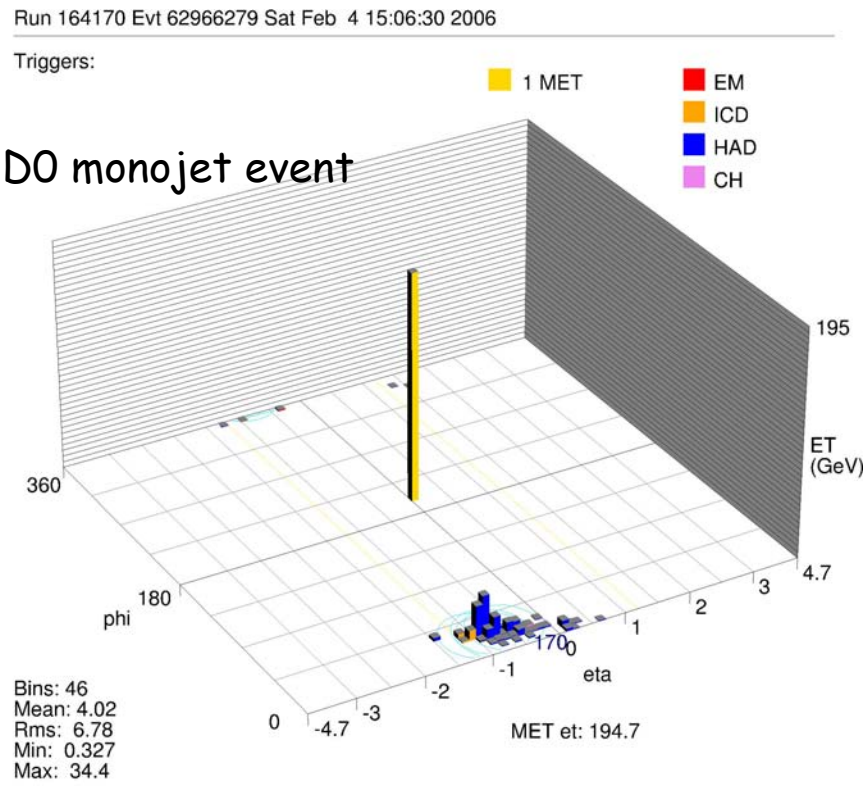

split SUSY
gluino metastable
stopping gluinos
split mass scales:
heavy sfermions
light gauginos
gluinos $\tilde{g}$ long lived
form `R hadrons´

Split SUSY: stopping gluinos

charged R
stops in detector
isotr. decay $\rightarrow jet + \chi^0$
! monojet !

$\tau > 10\,\mu s$
= many bunch crossings!





cross section limits
~ 0.5-1.5 pb
for gluinos 200-550 GeV

$\rightarrow \tilde{g} > 270\ GeV$

if LSP light

prel.

mSUGRA with R-parity violation

$$W_{\not R_P} = \frac{1}{2}\lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \frac{1}{2}\lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$

family indices

lepton number violation

difficult for hadron colliders

mSUGRA RPV
R-parity violated

- lepton-lepton couplings (LLE)
- lepton-quark couplings (LQD)

$$R = (-1)^{3(B-L)+2s}$$

LSP unstable !

? dark matter ?

assume: only **one** RPV coupling $\lambda \neq 0$

R-Parity Violation: LLE couplings λ_{ijk}

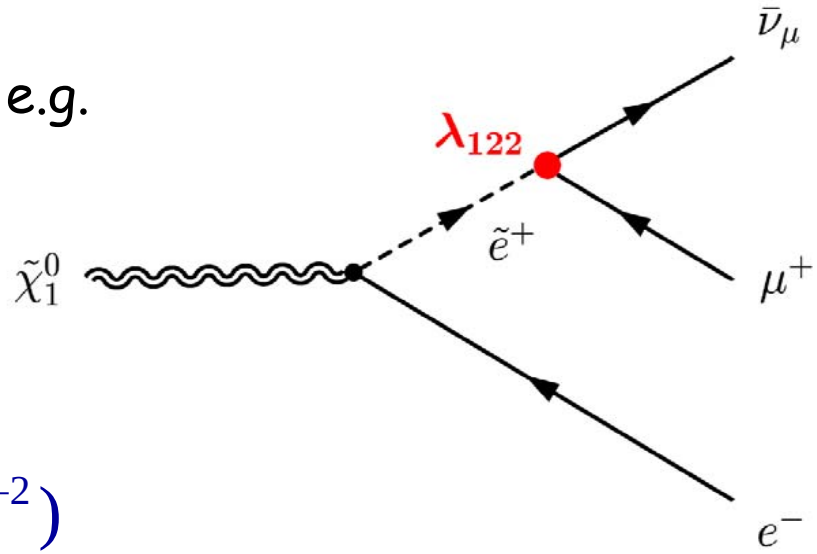
- **production** of SUSY particles in $p\,\bar{p}$:

  R conserving, two SUSY particles,

  e.g. $\chi_1^{\pm}\ \chi_2^0$

$\lambda_{ijk} L_i L_j \bar{E}_k$

- **decay**: R violating, e.g.



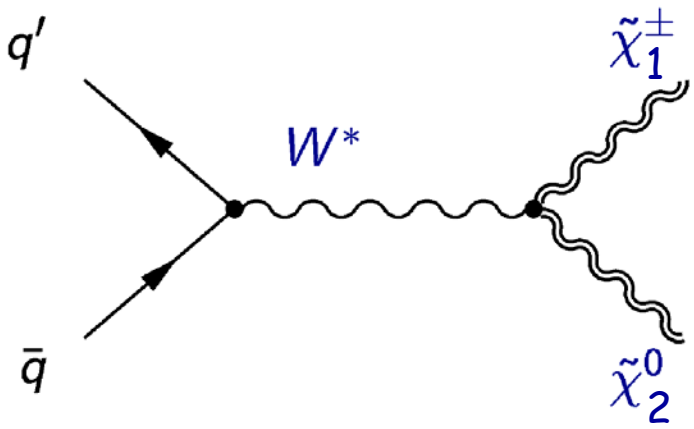
a) $\lambda_{ijk} > O(10^{-2})$

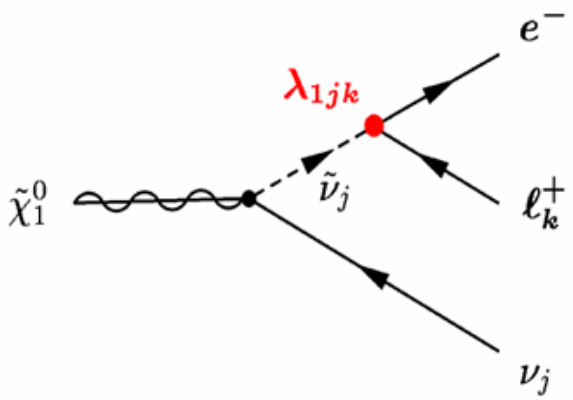
decay prompt, phenomenology independent of coupling

b) $\lambda_{ijk} < O(10^{-2})$

long lived particle, decay inside detector

Large LLE couplings: prompt decays





≥ 4 charged leptons

(require 3)

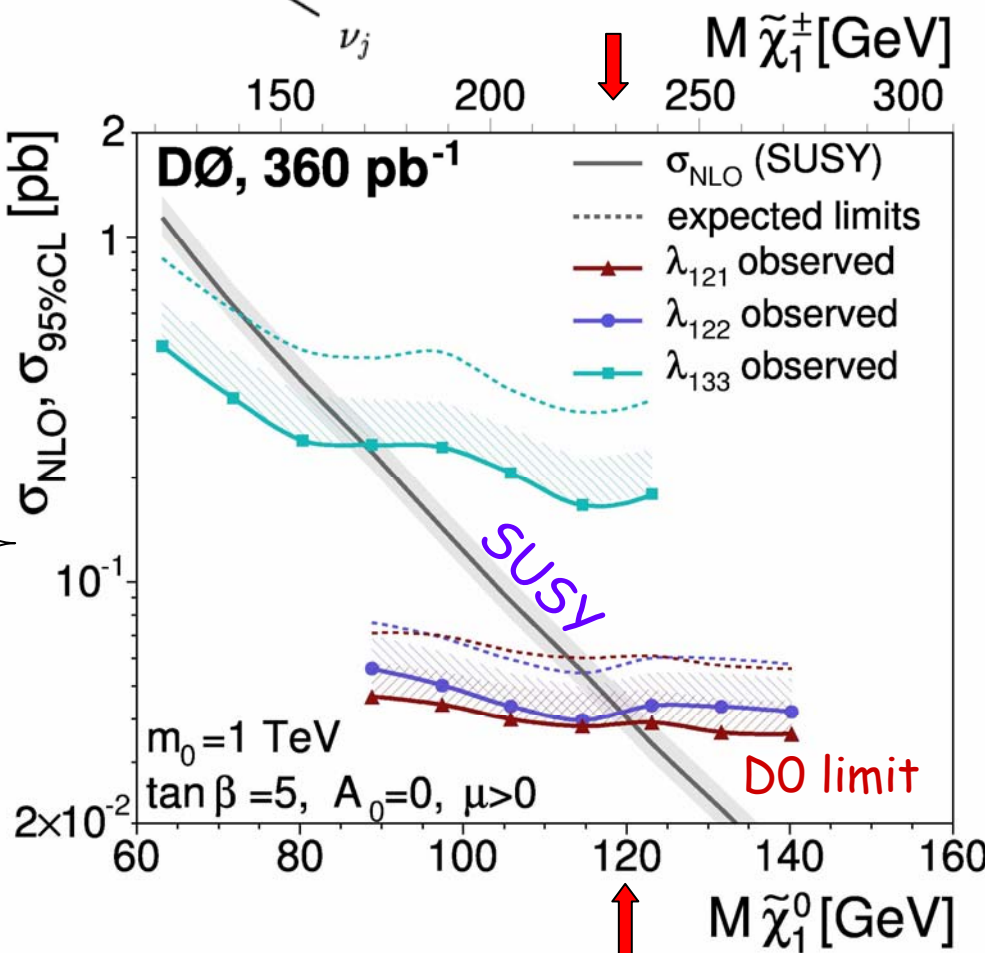
+ missing energy

$\lambda_{121} \rightarrow ee + (e,\mu)$

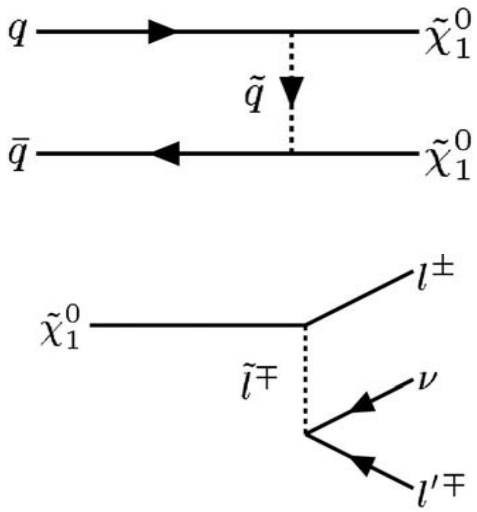
DØ : $\lambda_{122} \rightarrow \mu\mu + (\mu,e)$

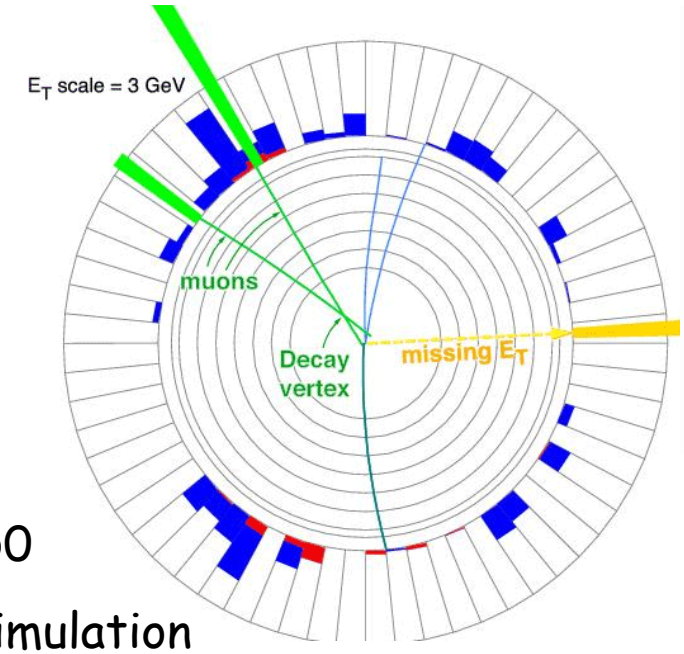
$\lambda_{133} \rightarrow \tau\tau + (\tau,e)$

	D0 data	SM backgr.
eel	0	0.9 ± 0.4
$\mu\mu l$	0	0.4 ± 0.1
τee	0	1.3 ± 1.8



Small LLE couplings: long lived (MSSM)





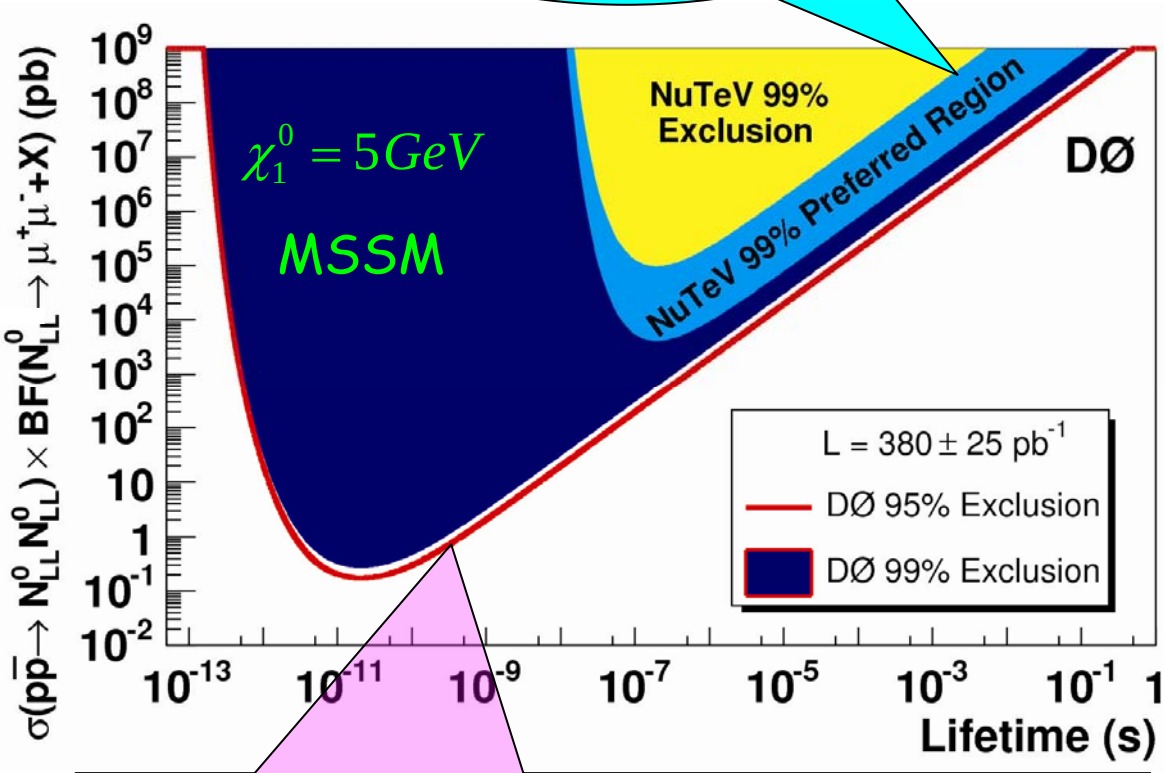
DO simulation

NuTeV: pp 38 GeV

3 dimuon events

(0.07 expected)

translated to 1.96 TeV

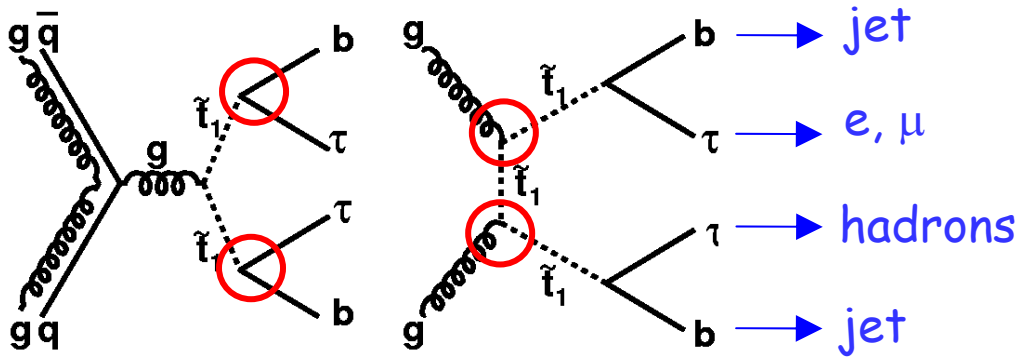


dimuons, displaced vertex (5-20 cm)

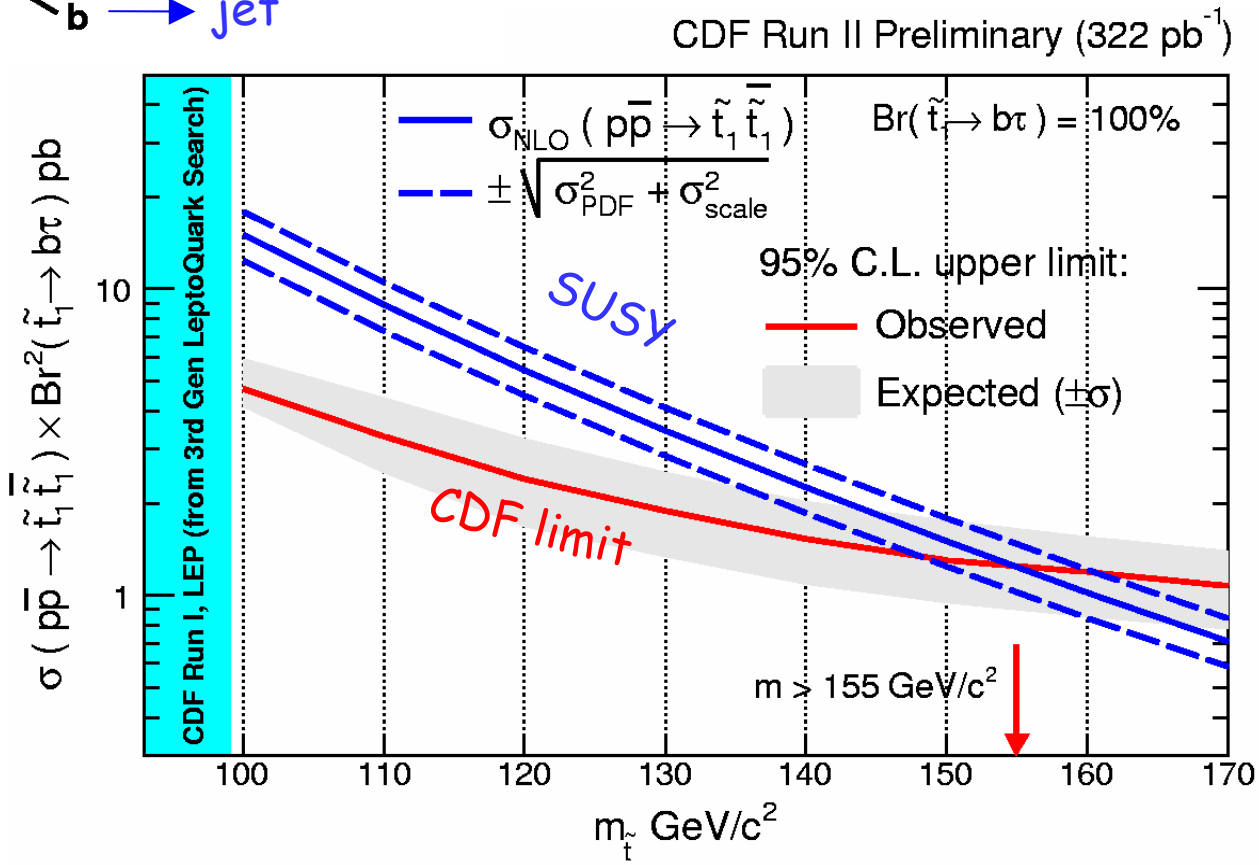
NO event

R-Parity Violation: LQD couplings λ'_{ijk} (prompt)

A) stop pairs

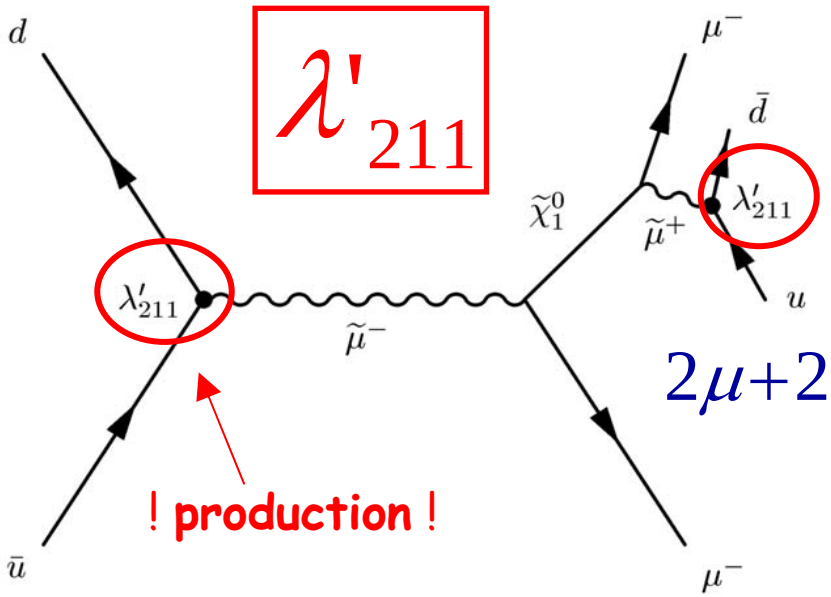


λ'_{333}

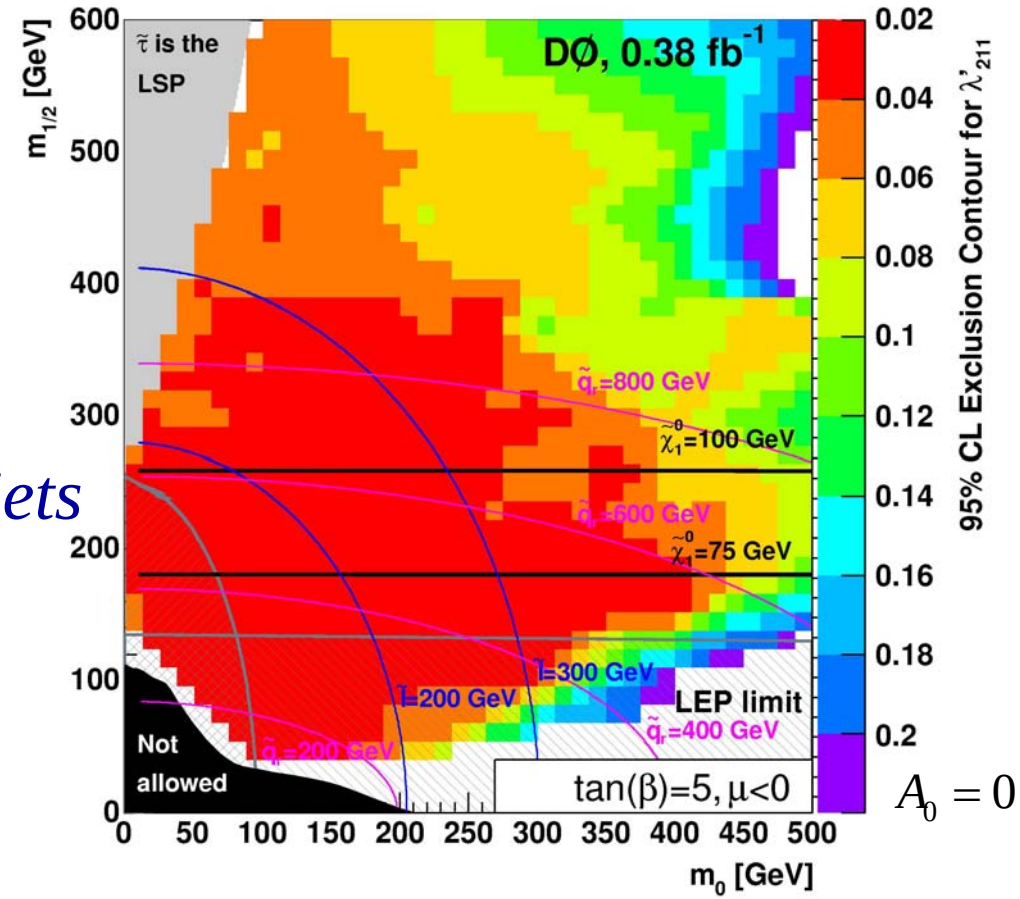


R-Parity Violation: LQD couplings λ'_{ijk} (prompt)

B) resonant slepton production



$2\mu+2$ *jets*



absolute slepton $(\tilde{\mu}, \tilde{\nu}_\mu)$ mass limits

Excluded slepton mass range	Coupling strength
$m(\tilde{l}) \leq 210$ GeV	for $\lambda'_{211} \geq 0.04$
$m(\tilde{l}) \leq 340$ GeV	for $\lambda'_{211} \geq 0.06$
$m(\tilde{l}) \leq 363$ GeV	for $\lambda'_{211} \geq 0.10$

Gauge Mediated SUSY Breaking

$LSP = \tilde{G}$

missing energy

here:

$NLSP = \tilde{\chi}_1^0 \rightarrow \gamma \tilde{G}$

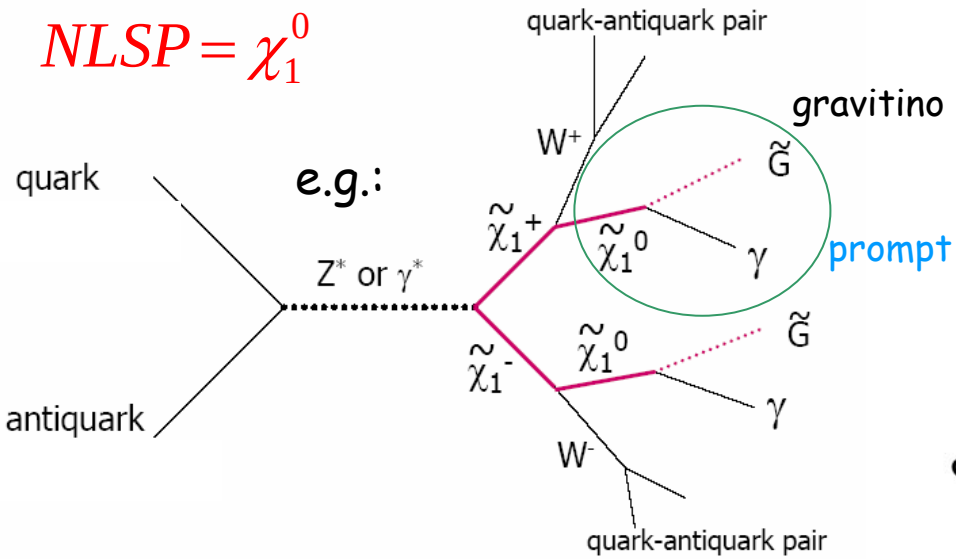
GMSB
LSP = light gravitino

→ photons + missing energy

M_m
Λ
N_m
$\tan\beta$
$sign(\mu)$
c_{grav}

GMSB: 2 photons + MET (prompt)

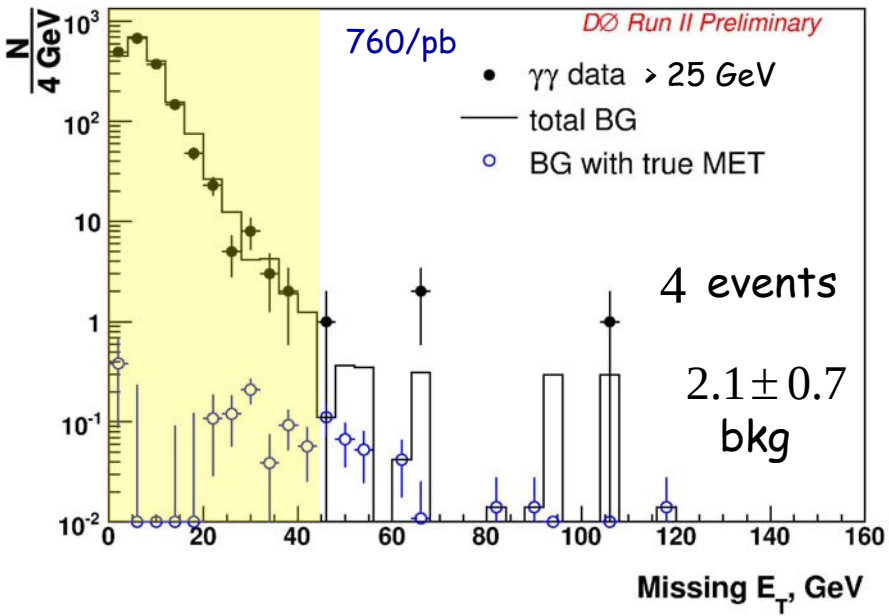
$NLSP = \chi_1^0$

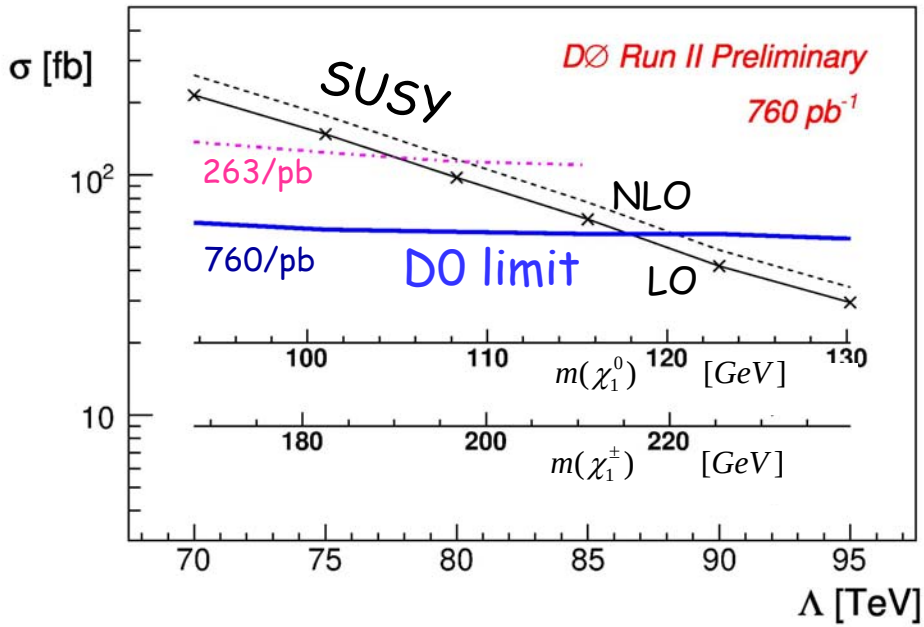


Snowmass **„Slope"** **SPS 8**

$$M_m = 2\Lambda \qquad N_m = 1$$

$$\tan\beta = 15 \qquad \mu > 0$$



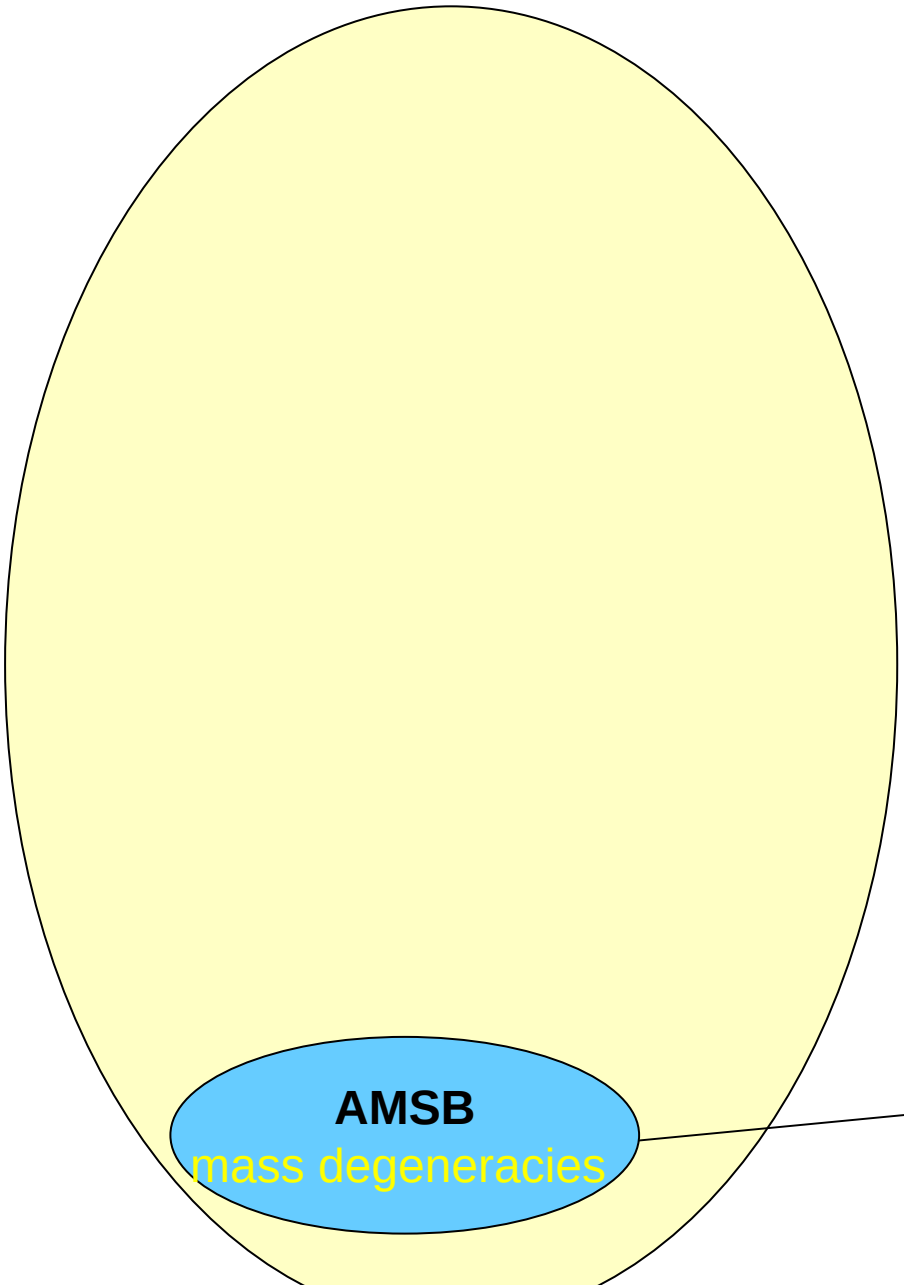


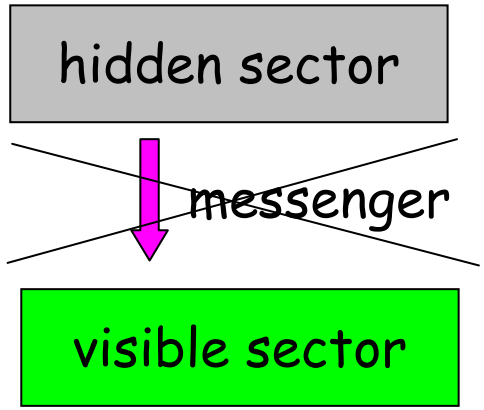
$$\chi_1^0 > 120\,GeV$$

$$\chi_1^\pm > 220\,GeV$$

prel.

Anomaly Mediated SUSY Breaking





susy masses through loops

AMSB
mass degeneracies

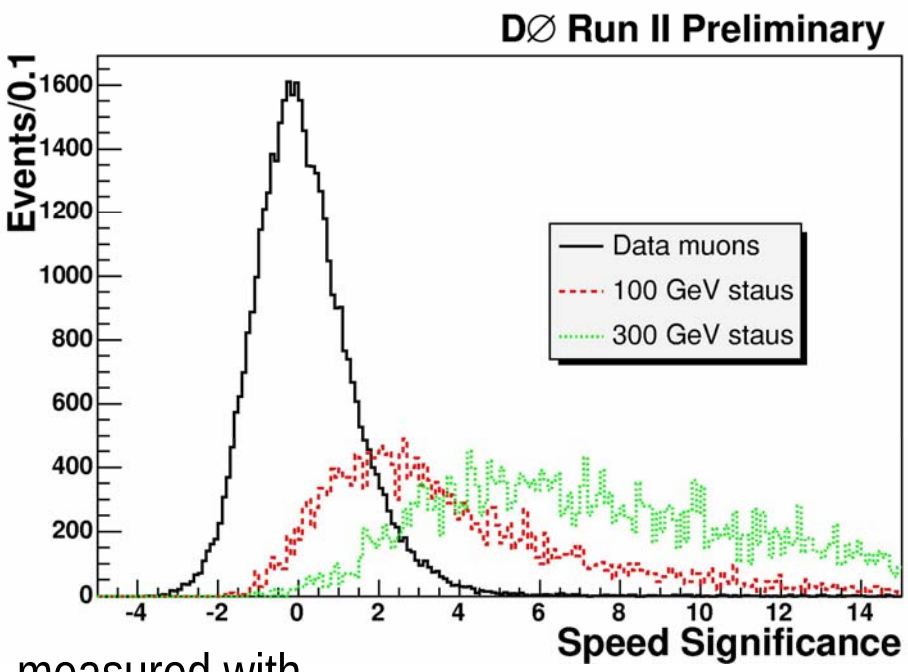
→ long lived heavy charged particles

Long lived staus or charginos

GMSB: decay $\tilde{\tau} \rightarrow \tau \tilde{G}$ suppressed

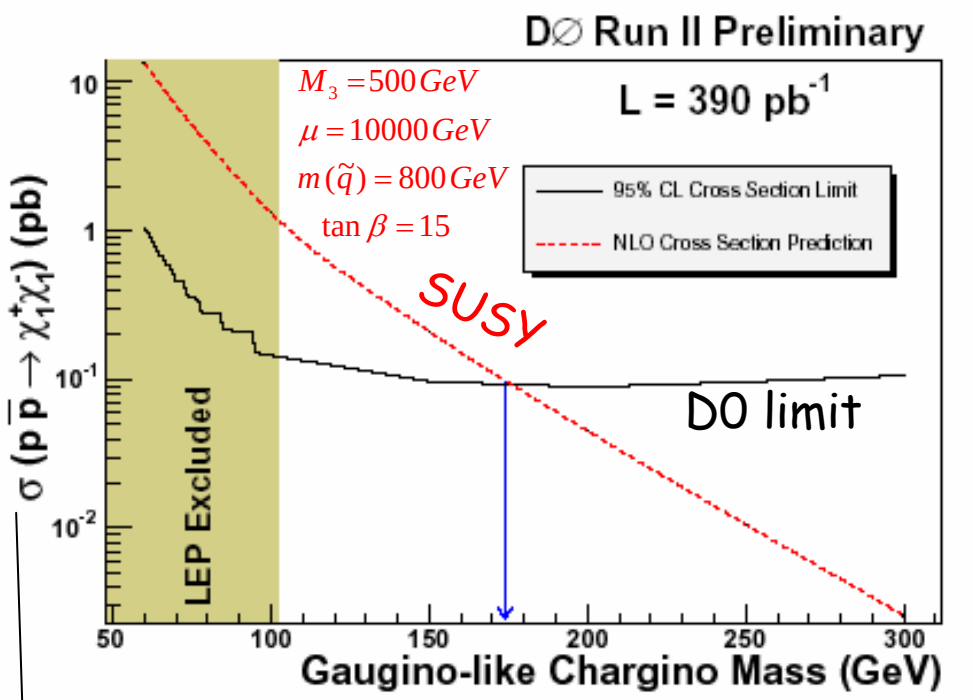
AMSB: mass difference $\chi_1^{\pm} - \chi_1^0$ small

⟹ heavy charged particle traversing **slowly** D0 detector



measured with scintillators in muon system

$$= \frac{1 - speed}{\sigma_{speed}}$$



chargino pair production

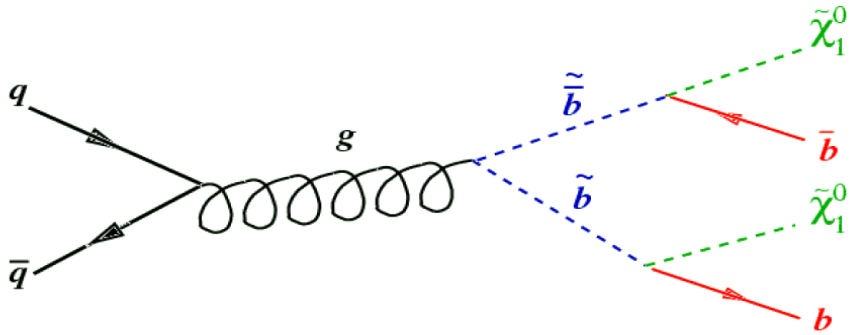
Summary and outlook

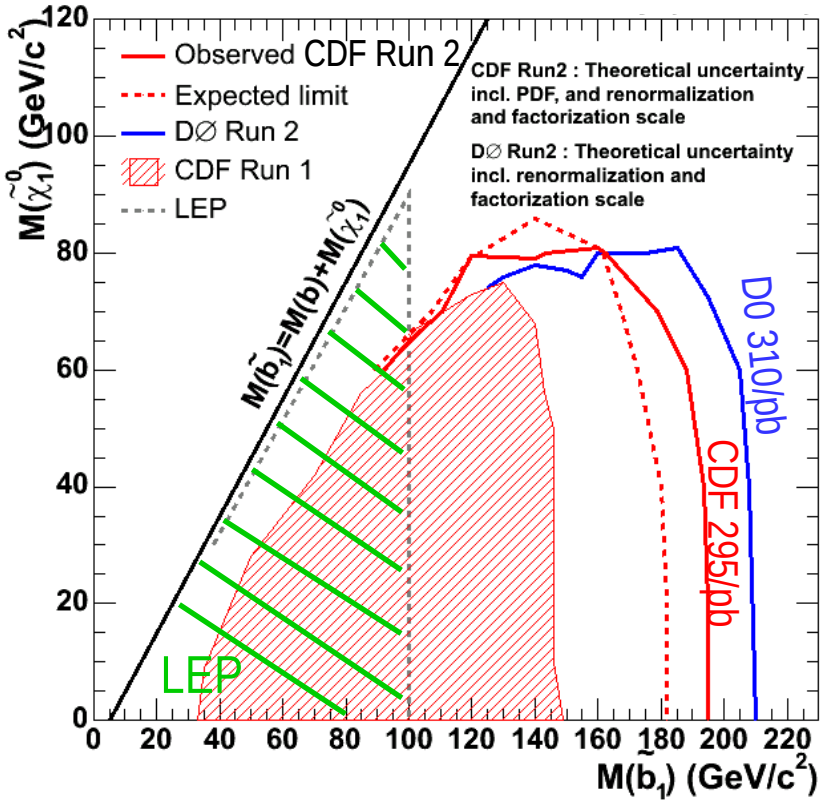
- Multitude of SUSY corners and signatures explored
- **Stringent limits were set**
- Significant improvements compared to Tevatron Run I (signal types analyzed and signal sensitivity)
- Tevatron limits often exceed LEP/Hera bounds or are complementary
- **0.2 - 1.1 /fb analyzed, much more to come!**

SPARE TRANSPARENCIES

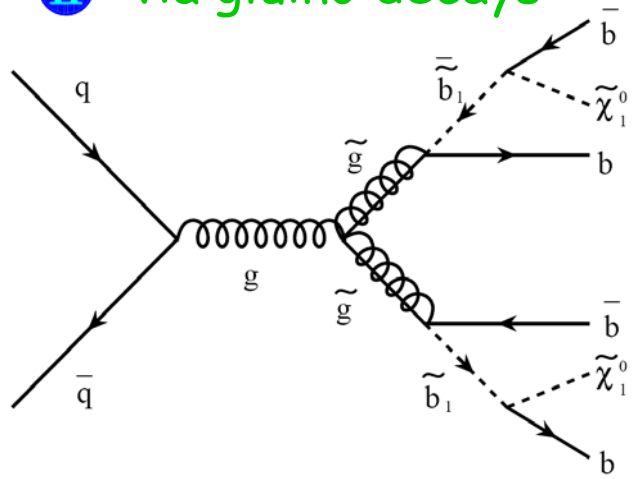
Sbottom

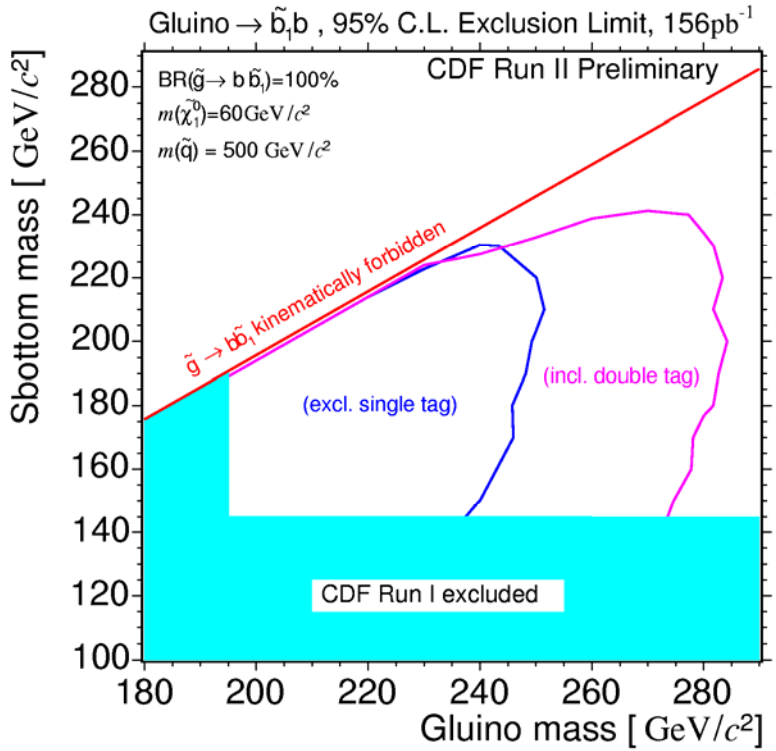
A) CDF DØ direct production



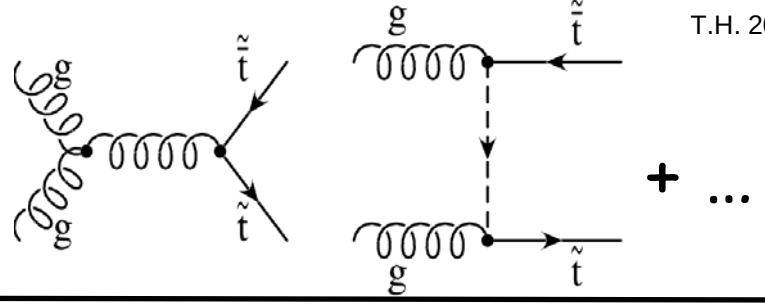


B) CDF via gluino decays

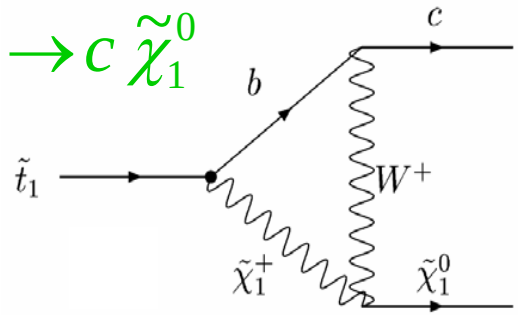


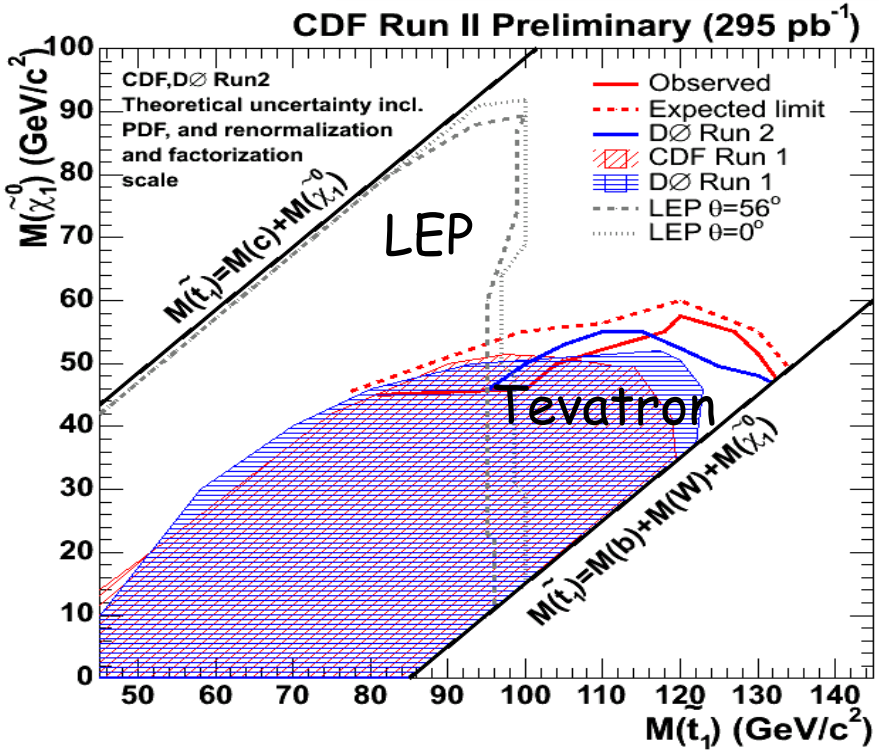


Stop pair production

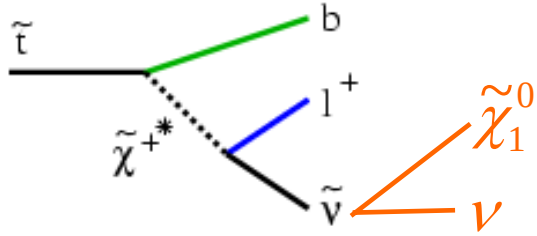


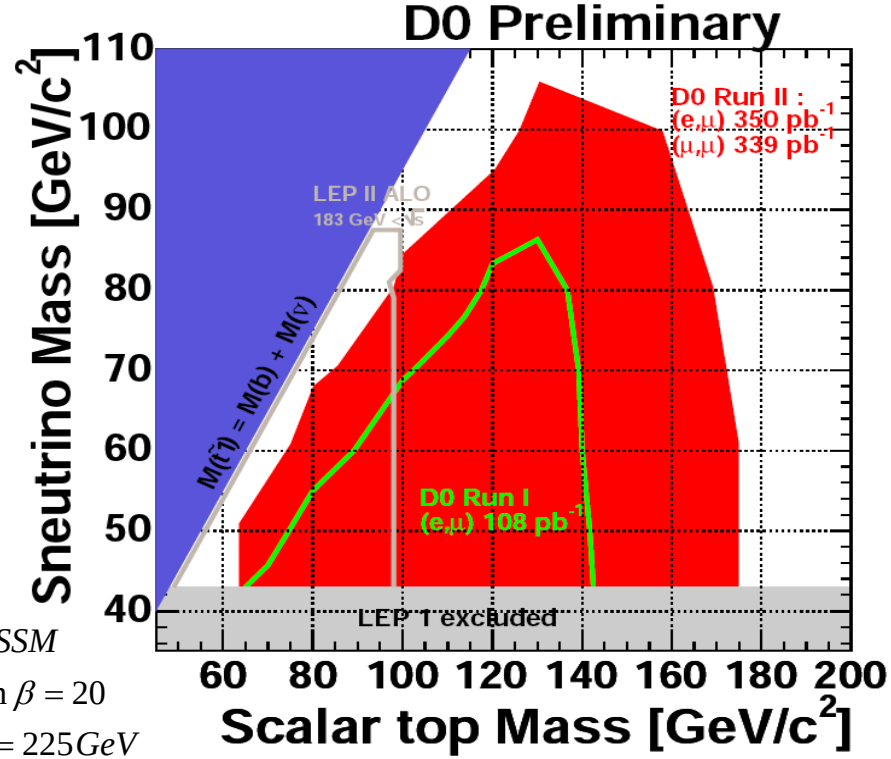
A) $\tilde{t} \to c\,\tilde{\chi}_1^0$ (FCNC)





B) $\tilde{t} \to b\,l\,\nu\,\tilde{\chi}_1^0$ $\quad l = e, \mu$

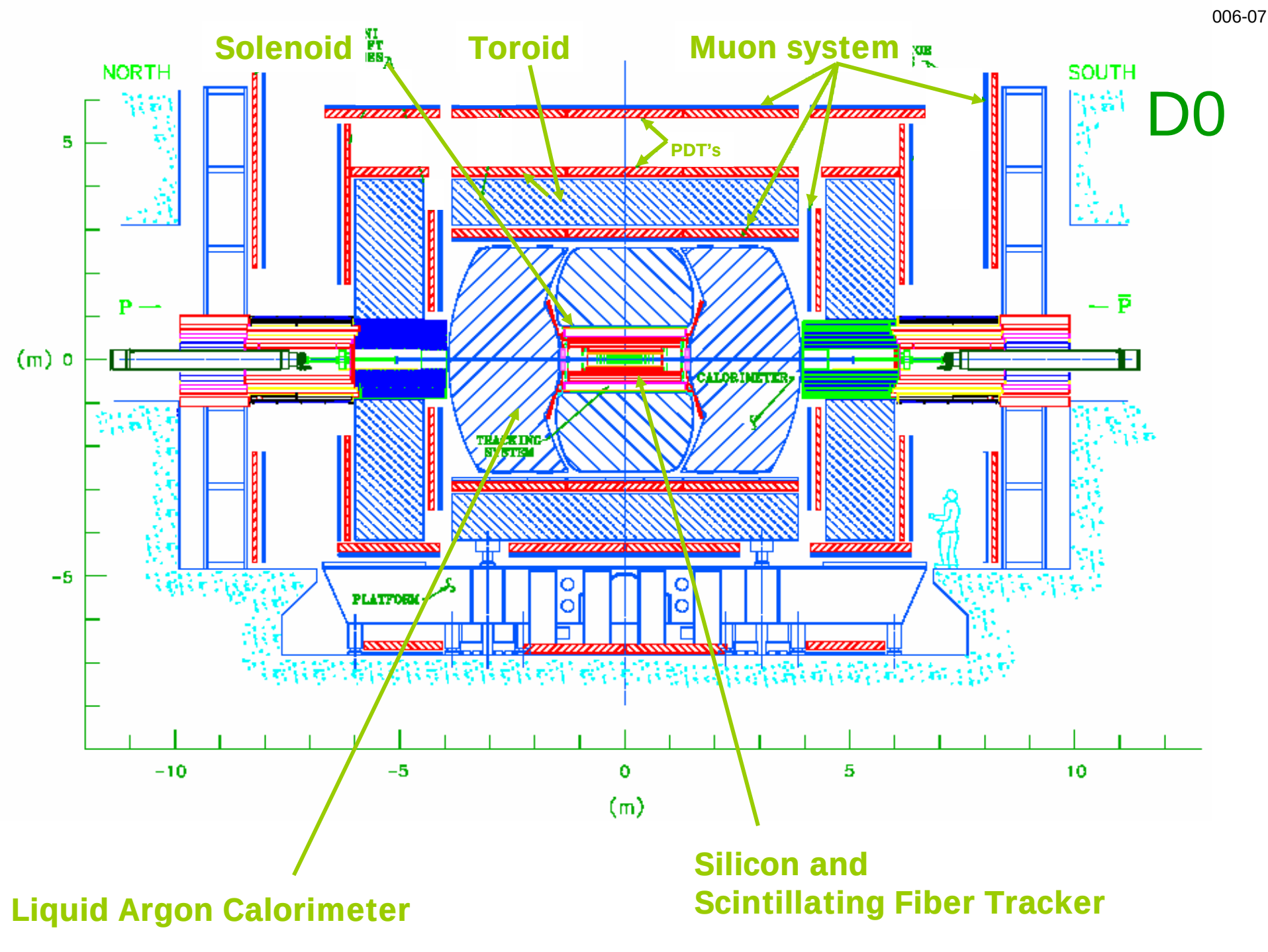


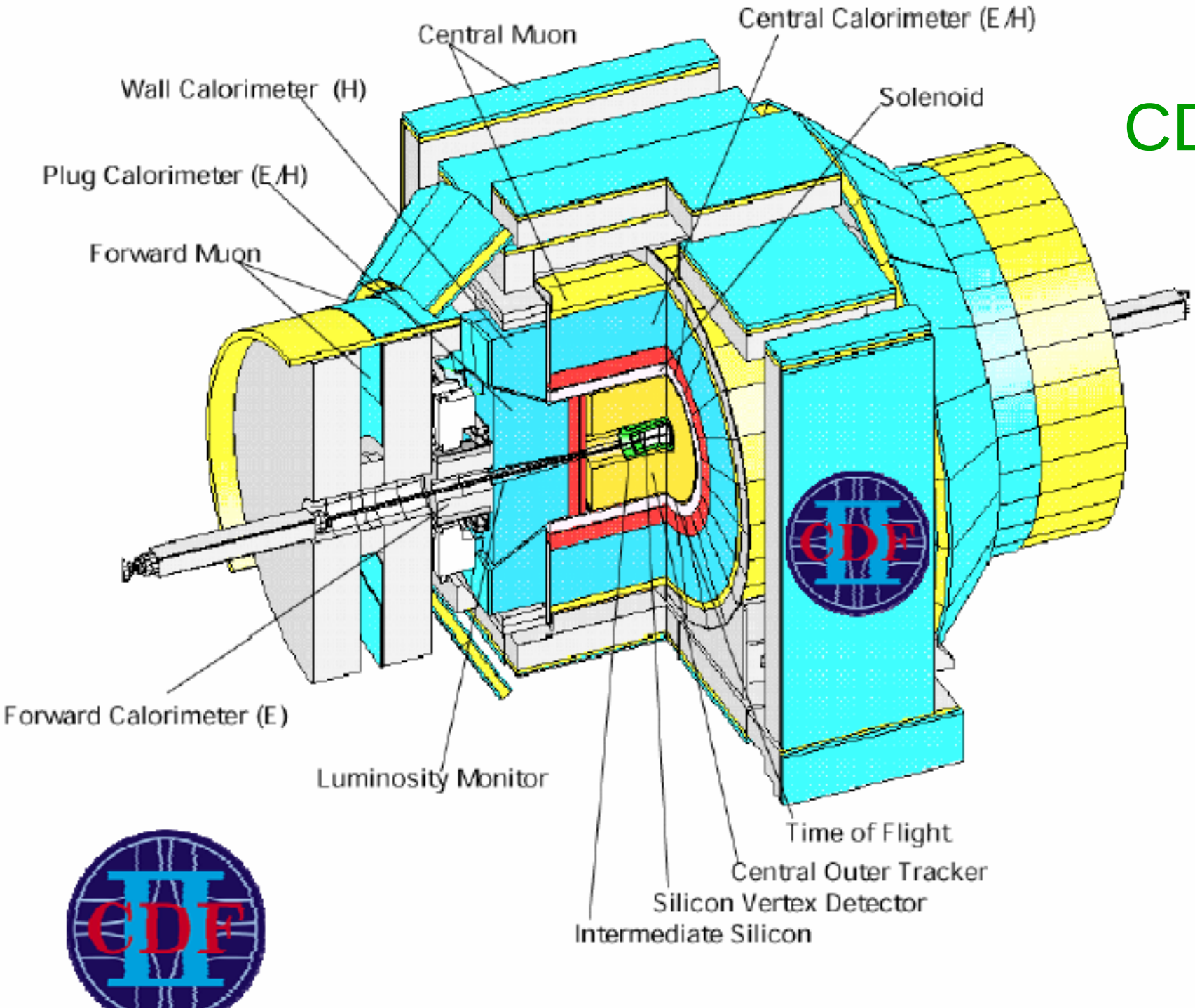


MSSM

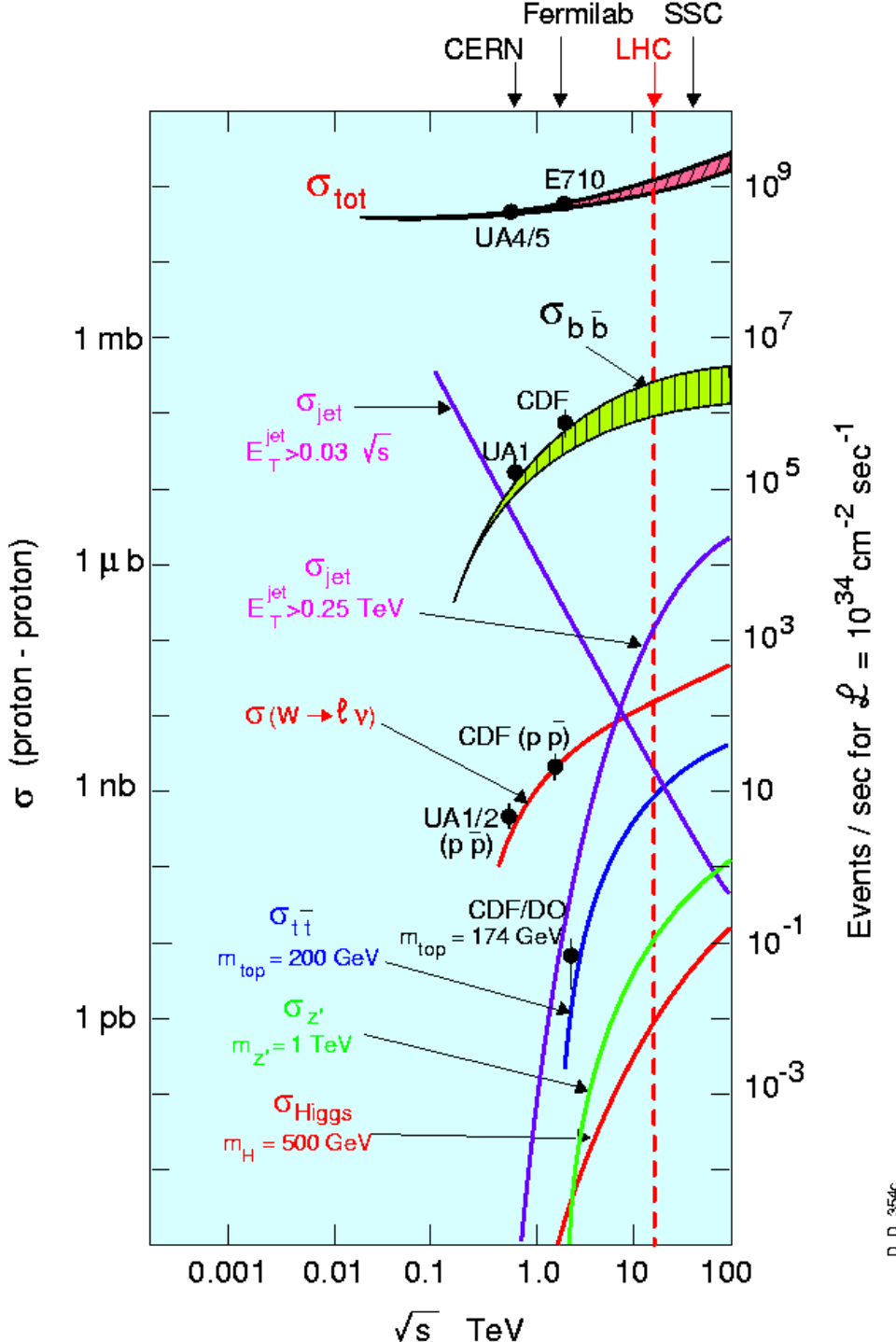
$\tan\beta = 20$

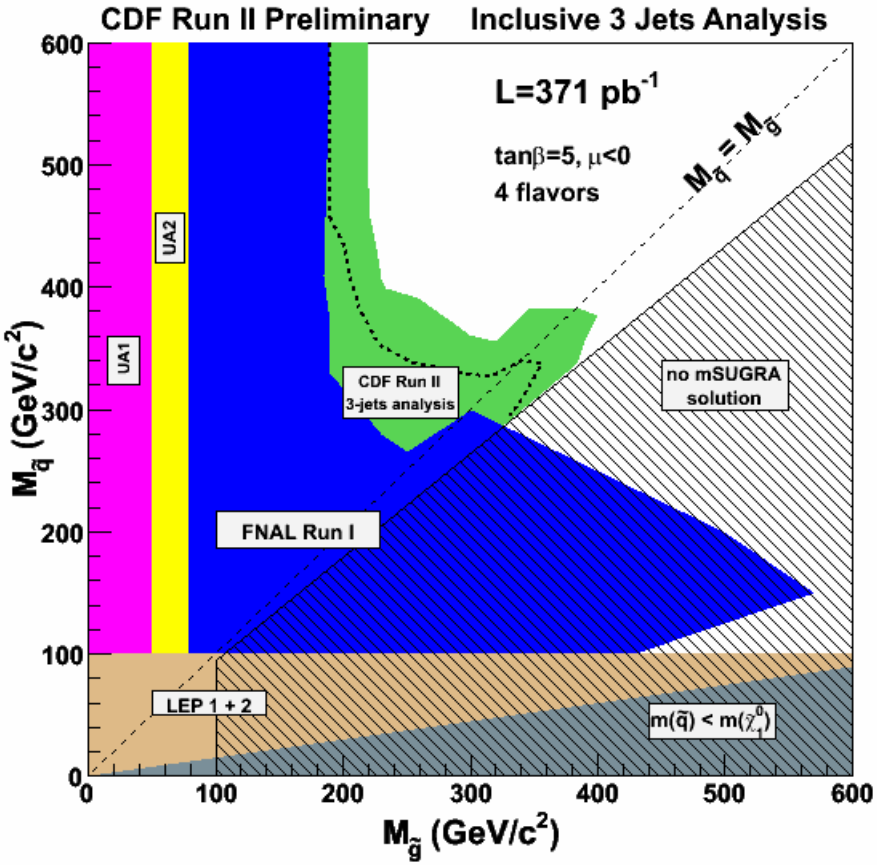
$\mu = 225 GeV$

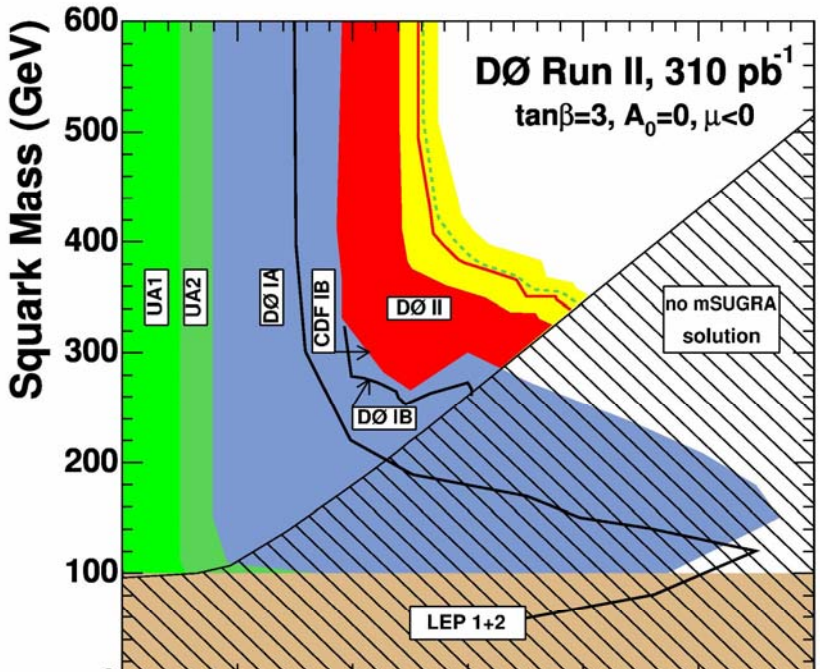

Solenoid
Toroid
Muon system
NORTH
SOUTH
D0
PDT's
P
$\bar{P}$
CALORIMETER
TRACKING SYSTEM
PLATFORM
5
0
-5
(m)
-10
-5
0
5
10
(m)
Liquid Argon Calorimeter
Silicon and
Scintillating Fiber Tracker

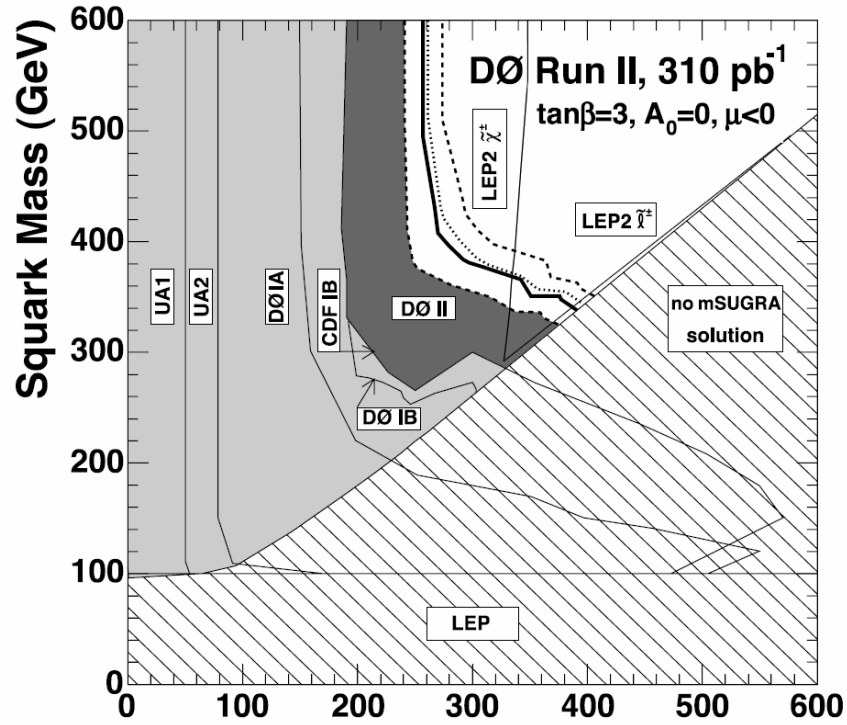

Central Muon
Central Calorimeter (E/H)
Wall Calorimeter (H)
Solenoid
CDF
Plug Calorimeter (E/H)
Forward Muon
Forward Calorimeter (E)
Luminosity Monitor
Time of Flight
Central Outer Tracker
Silicon Vertex Detector
Intermediate Silicon

Cross Sections at Hadron Colliders



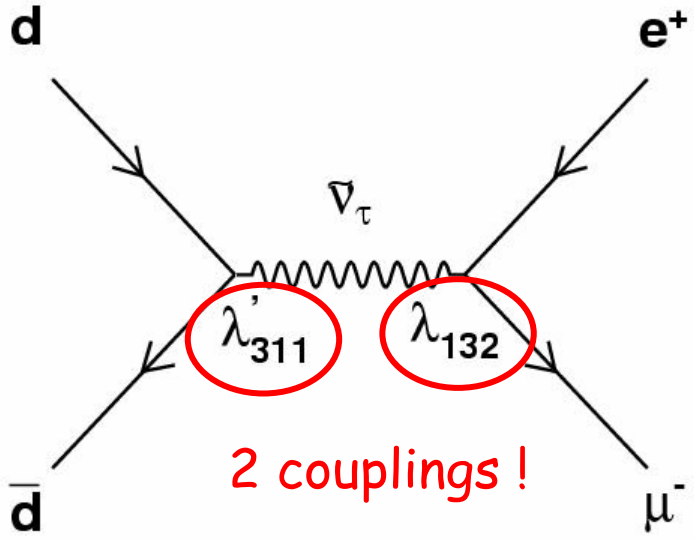


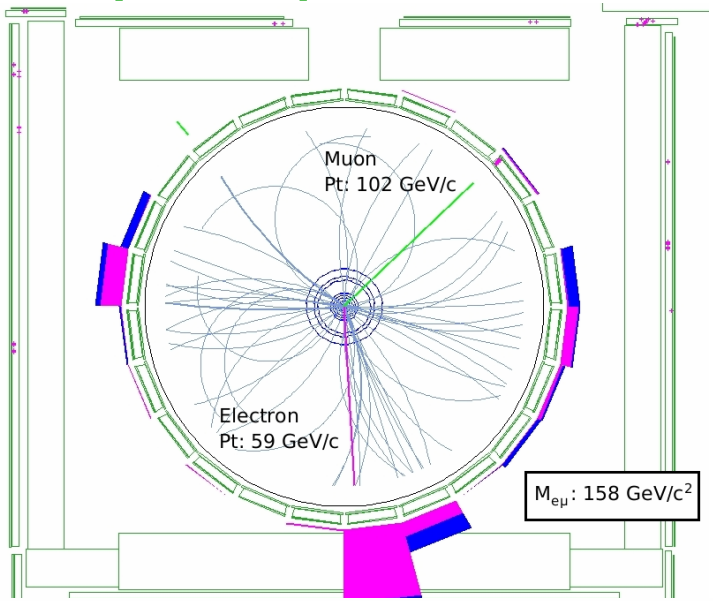


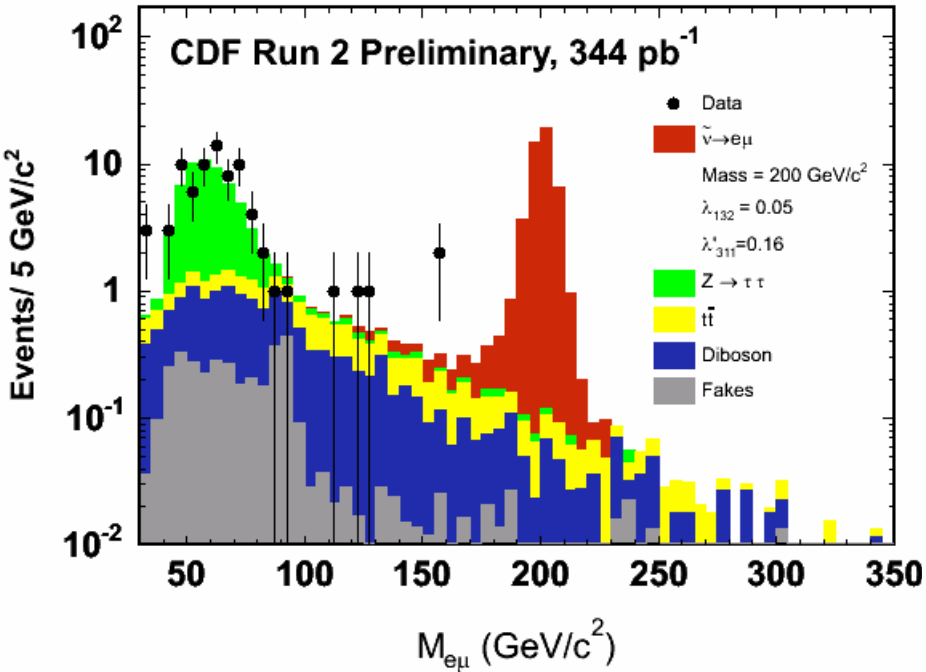


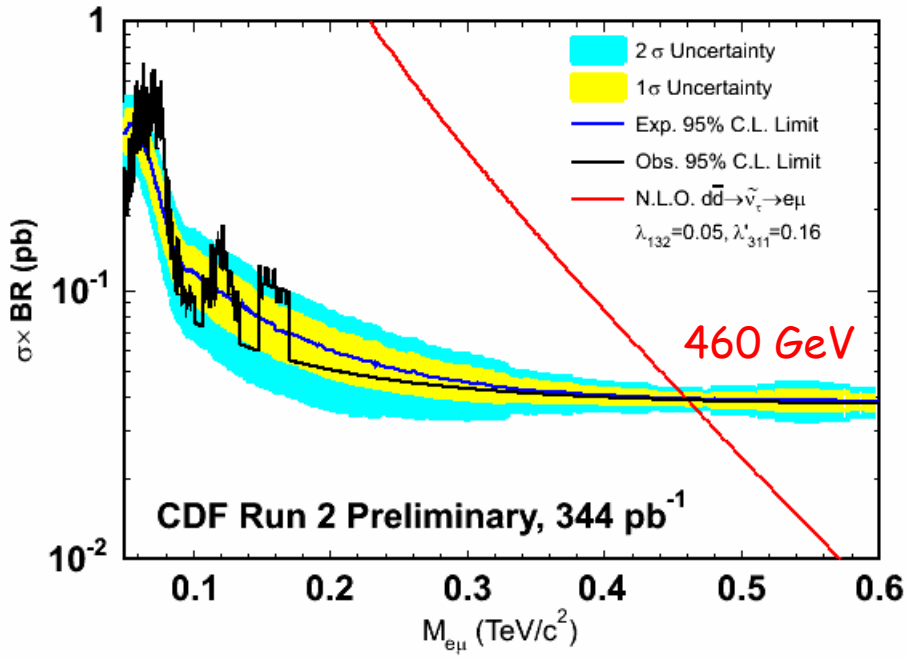
Squark gluino limits

CDF tau sneutrino (RPV)

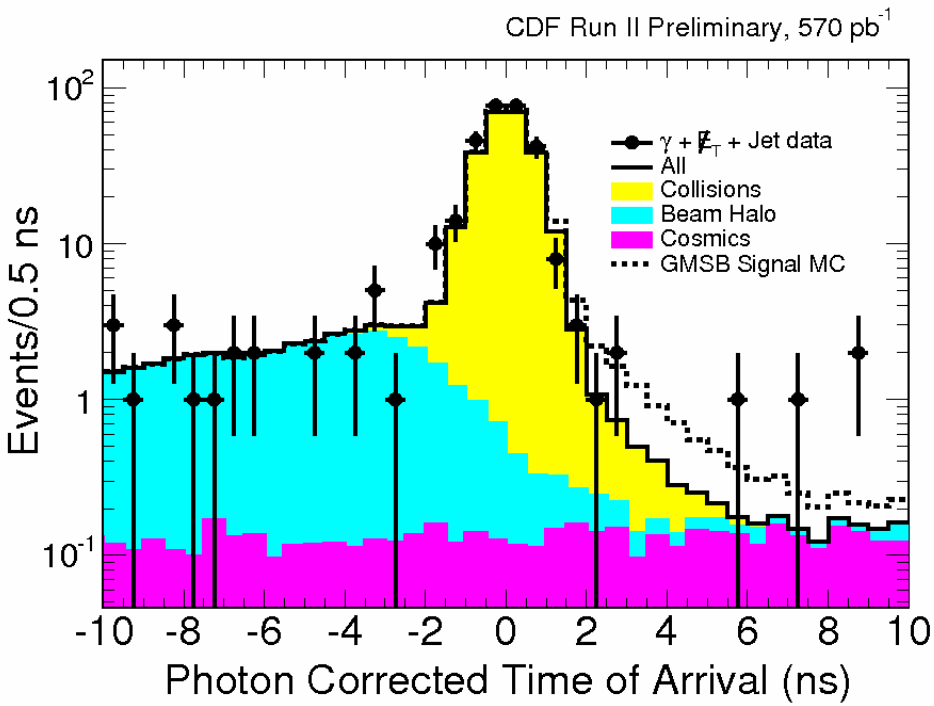


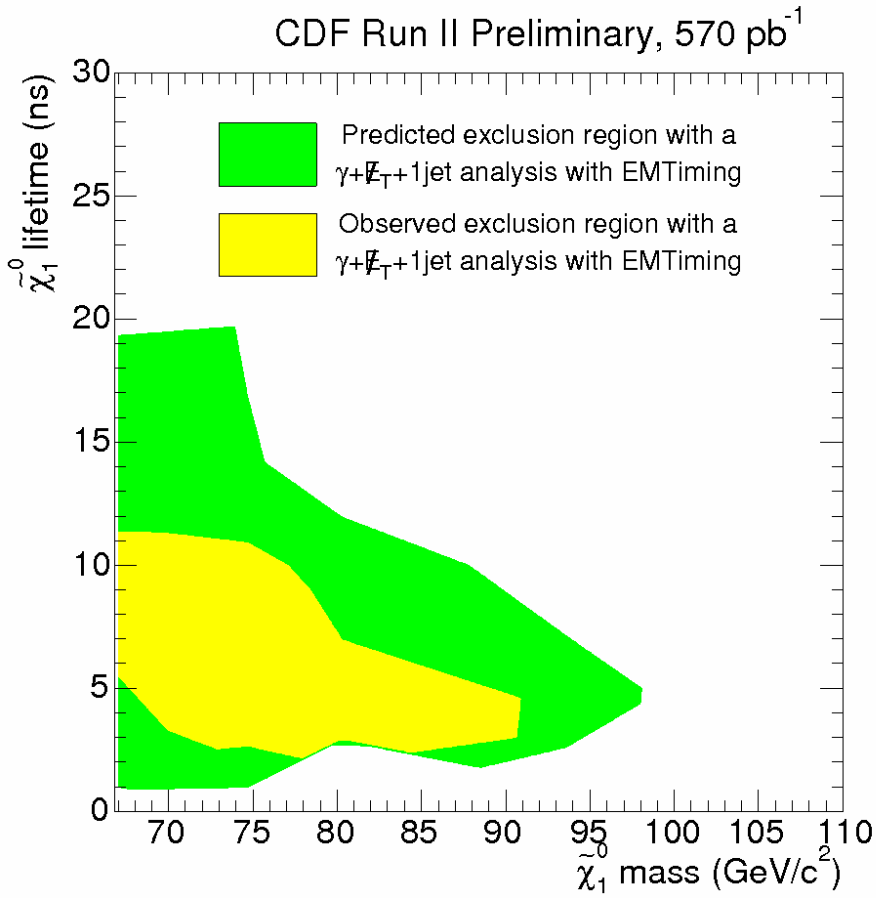




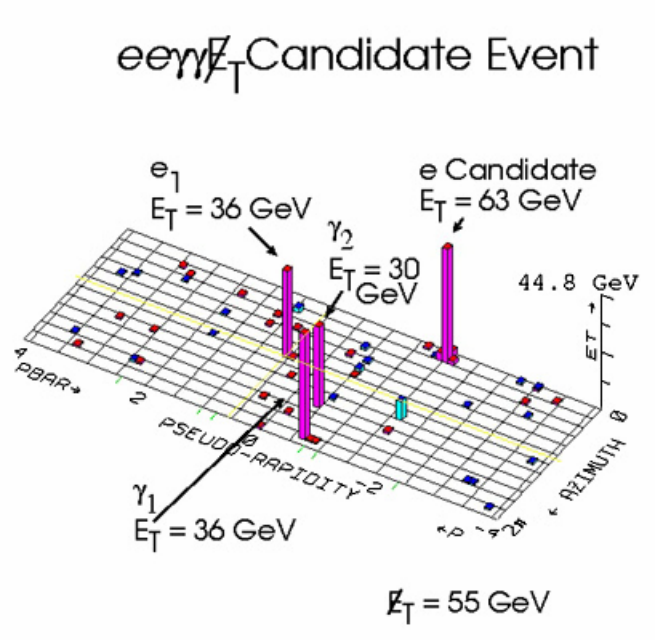


CDF long lived neutralino, GMSB decay

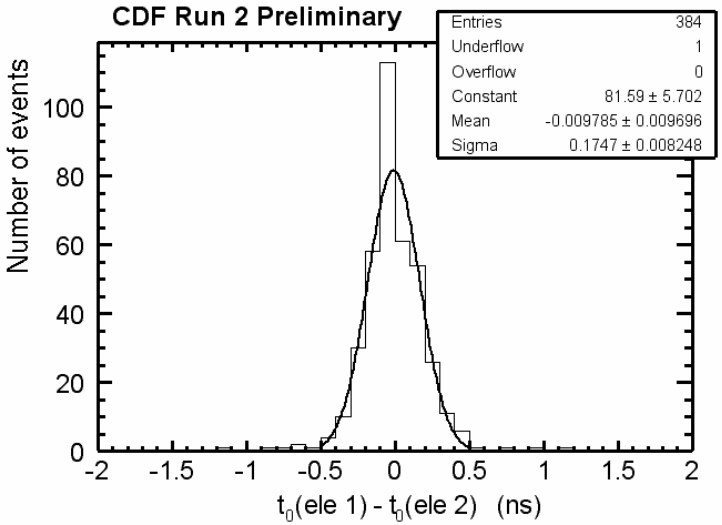


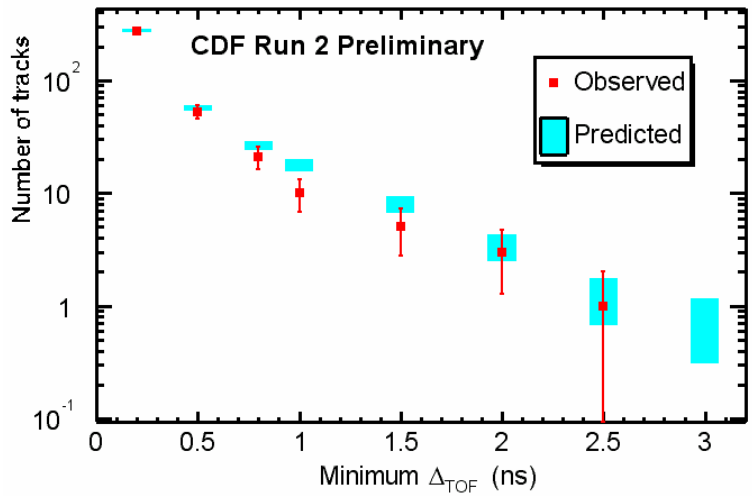


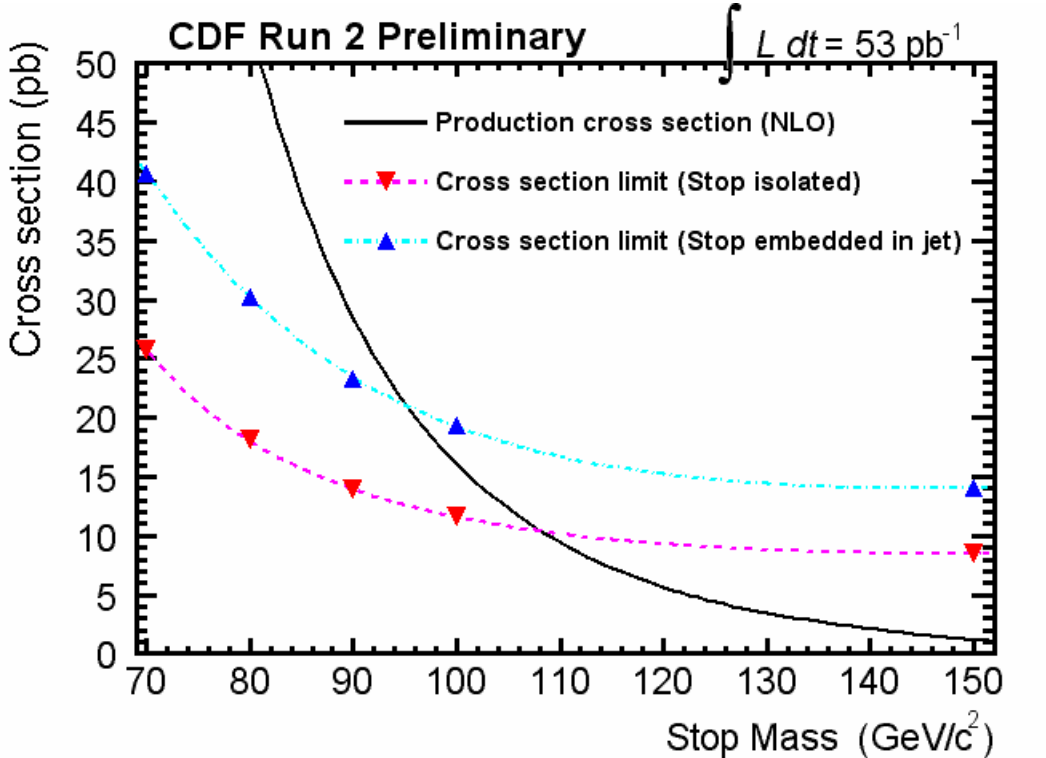
CDF di-photon event



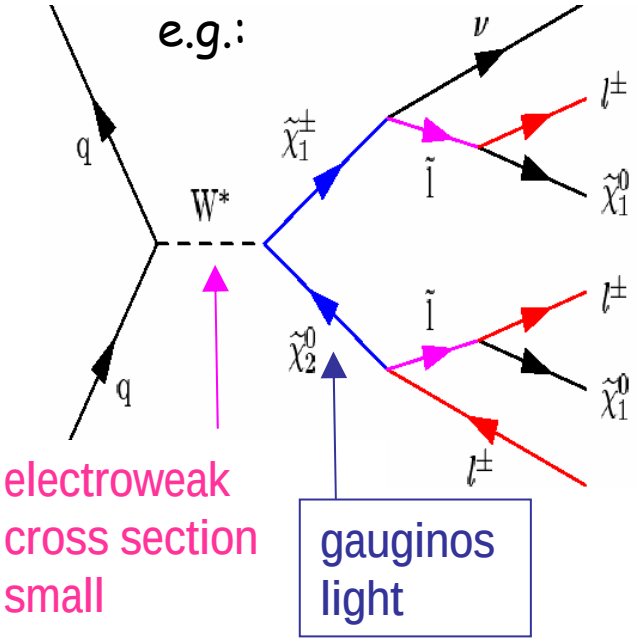
CDF champ (=stop) search (2003)







Charginos/Neutralinos → Leptons



electroweak cross section small

gauginos light

`golden' trilepton +missing energy signature

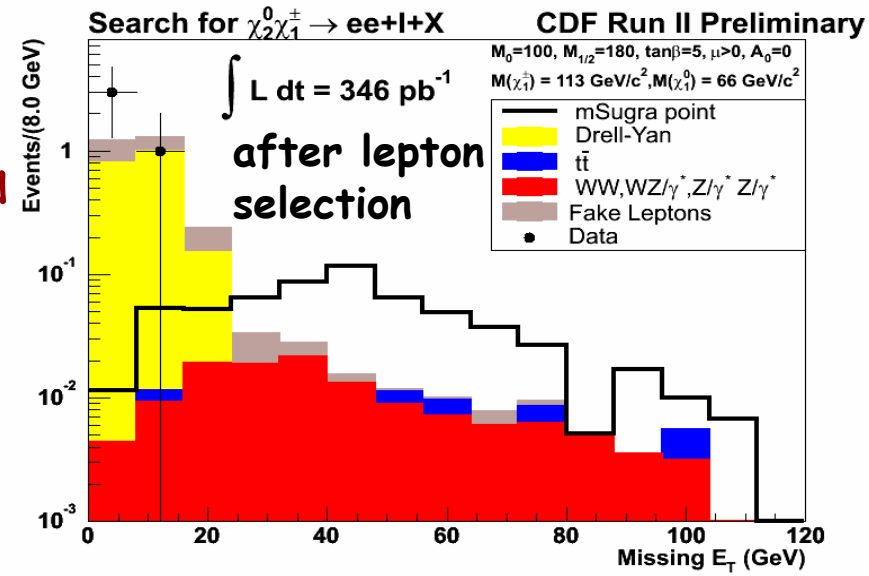
signatures:

$ee + e/\mu$

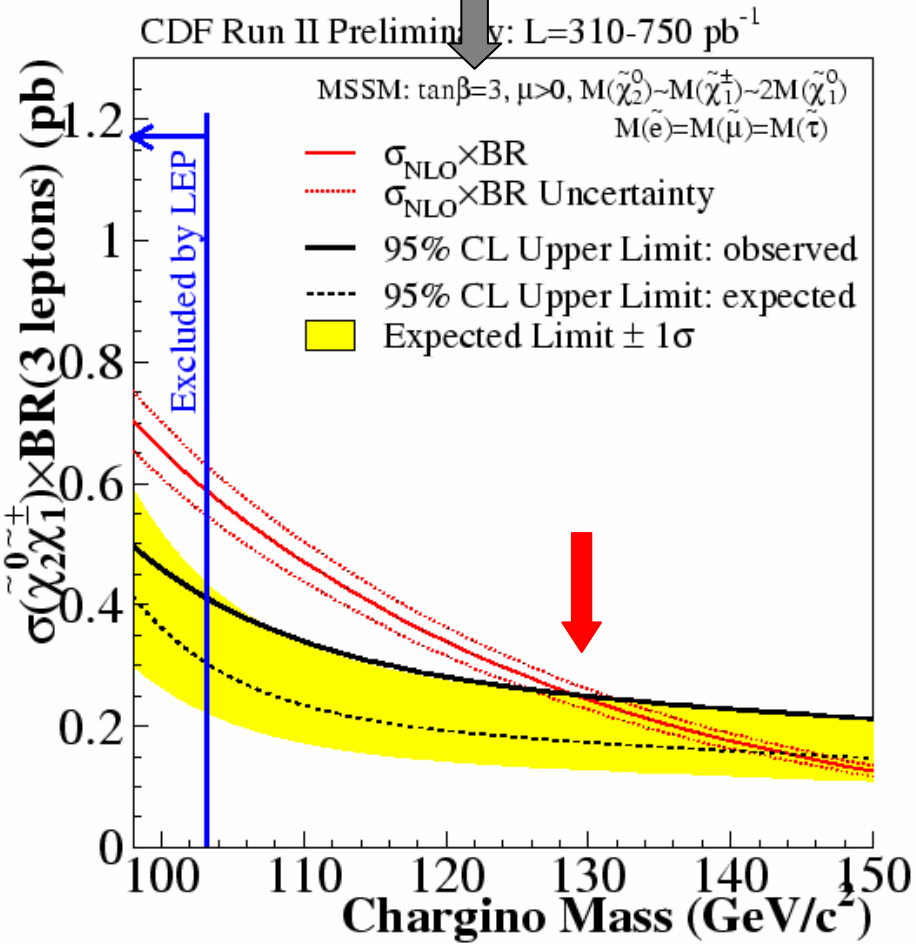
$\mu\,\mu + e/\mu$

e^+e^+ / e^-e^-

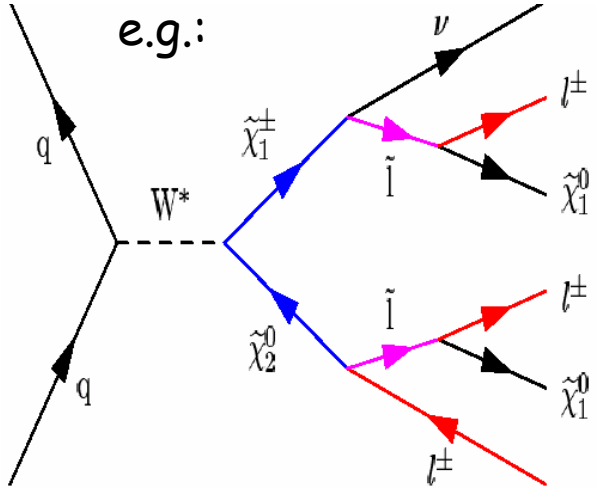
+ ...



example



Charginos/Neutralinos → Leptons



`golden' trilepton +missing energy signature

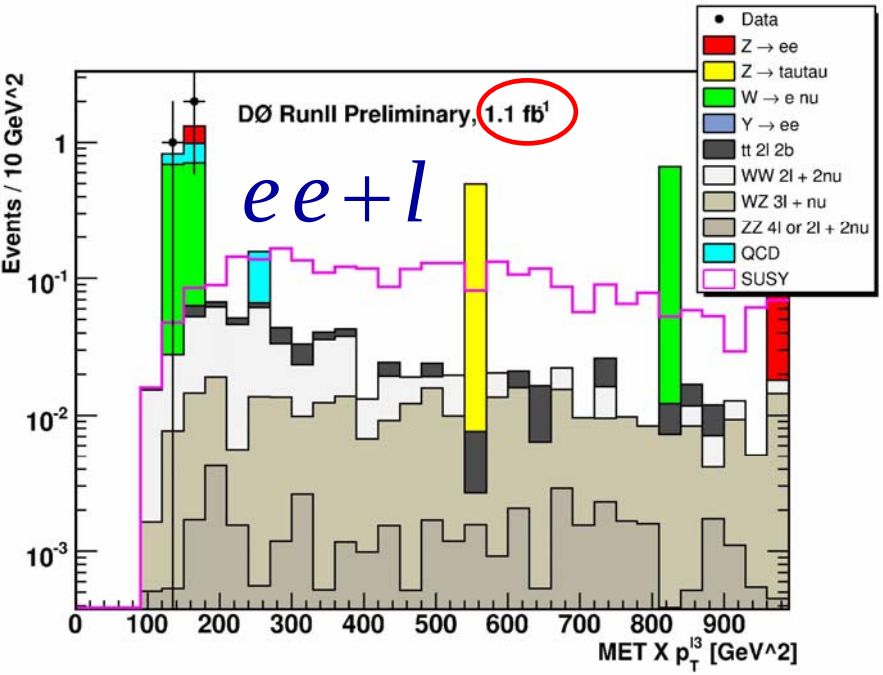
signatures:

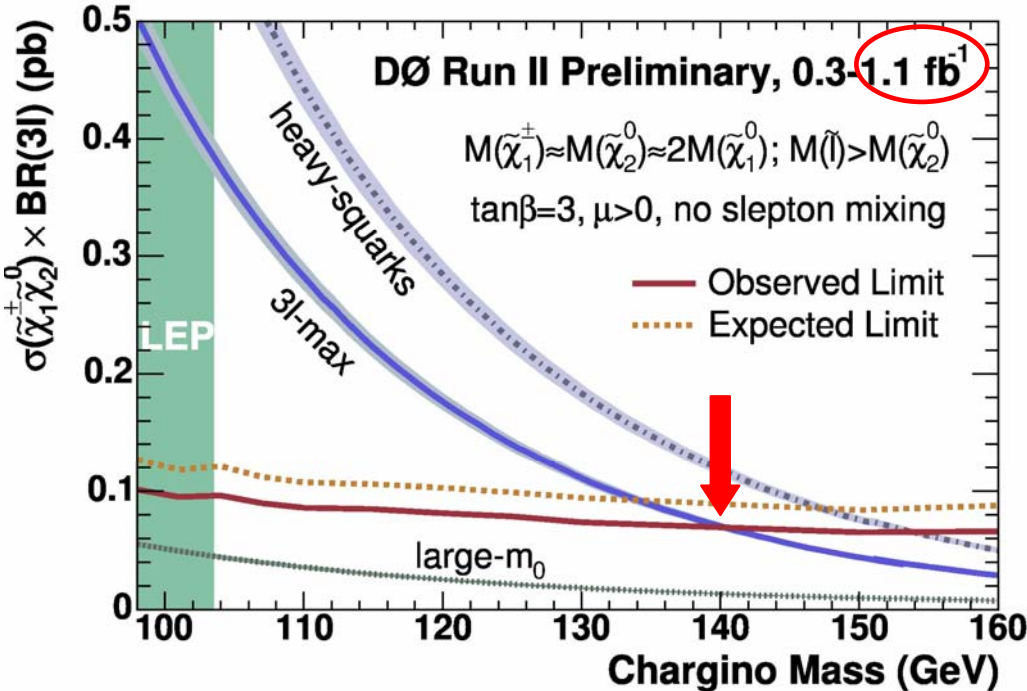
$ee+l$

$\mu^-\mu^- / \mu^+\mu^+$

$e/\mu+\tau+l$

+ ...





Chiral supermultiplets

Gauge multiplet		Chiral multiplet	
J = 1	J = 1/2	J = 1/2	J = 0
g	$\tilde{g}$	Q_L, U_L^C, D_L^C	$\tilde{Q}_L, \tilde{U}_L^C, \tilde{D}_L^C$
$W^{\pm}, W^0$	$\tilde{W}^{\pm}, \tilde{W}^0$	L_L, E_L^C	$\tilde{L}_L, \tilde{E}_L^C$
B^0	$\tilde{B}^0$	$\tilde{H}_d, \tilde{H}_u$	H_d, H_u

	Charge	Scalar
Q	**(3,2,+1/3)**	$Q = (\tilde{u}_L, \tilde{d}_L)$
U^c	**(3,1,-4/3)**	$U^c = \tilde{u}_L^c$
D^c	**(3,1,+2/3)**	$D^c = \tilde{d}_L^c$
L	**(1,2,-1)**	$L = (\tilde{\nu}_L, \tilde{e}_L)$
E^c	**(1,1,+2)**	$E^c = \tilde{e}_L^c$
H$_d$	**(1,2,-1)**	$H_d = (H_d^0, H_d^-)$
H$_u$	**(1,2,+1)**	$H_u = (H_u^+, H_u^0)$

from Luc Pape