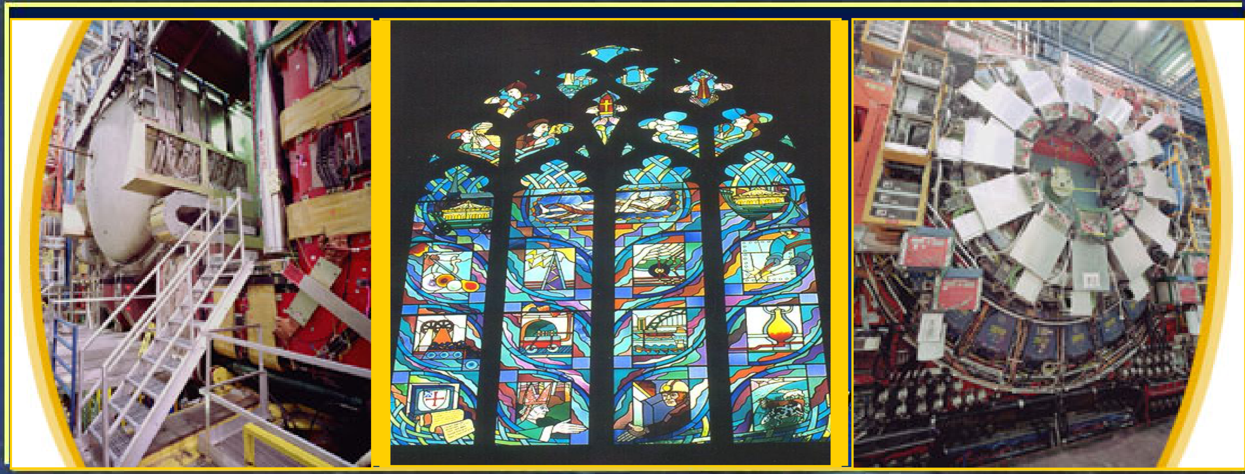


From サイエンス '82

Recent SUSY Searches at the Tevatron

Teruki Kamon

(Texas A&M University)

For CDF and DØ Collaborations

The 13th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2005)

July 18-23, 2005, IPPP Durham

Talk Outline

Introduction

Tevatron

CDF and DØ

R_p conserving SUSY
- Signatures with missing E_T

R_p violating (RPV) SUSY

CHAMPS

$B_s \to \mu\mu$

Summary

See plenary talk "Higgs Searches at the Tevatron" by C. Tully (DØ)

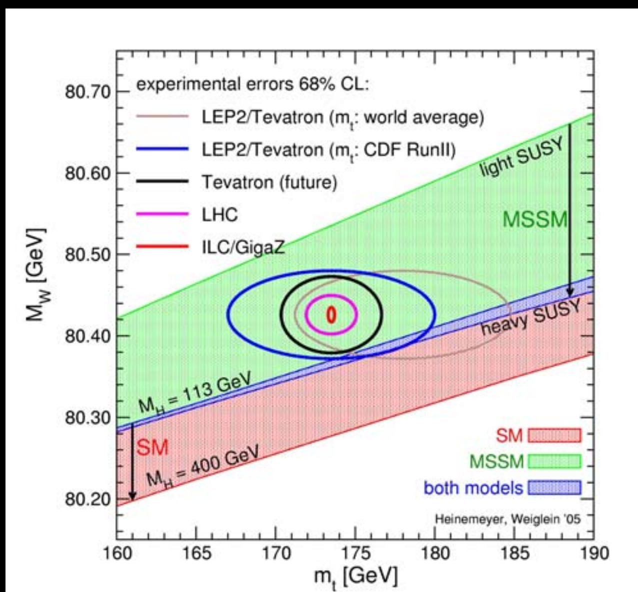
TEV → LHC → ILC

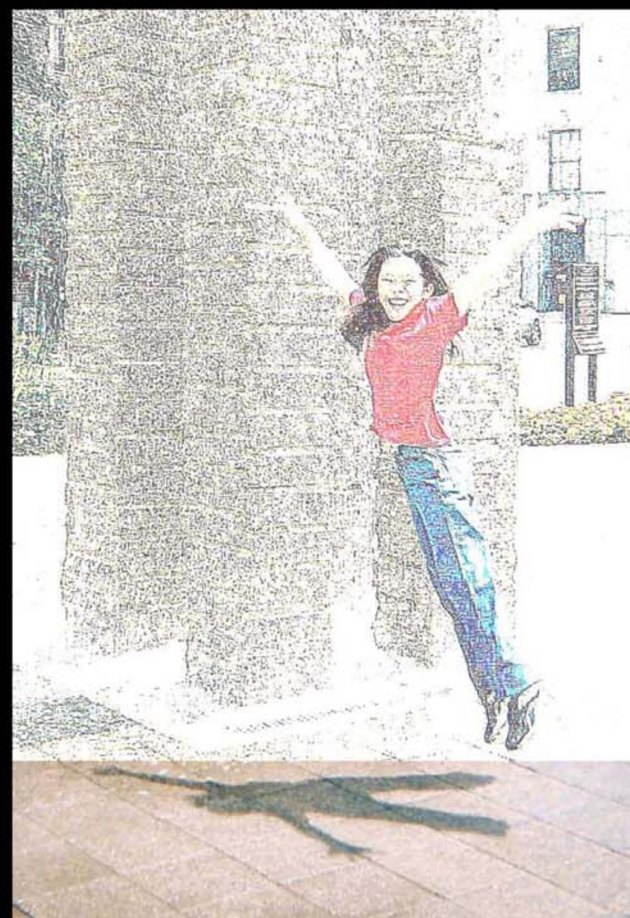
E

Tevatron
HERA
LEP2

LHC

ILC

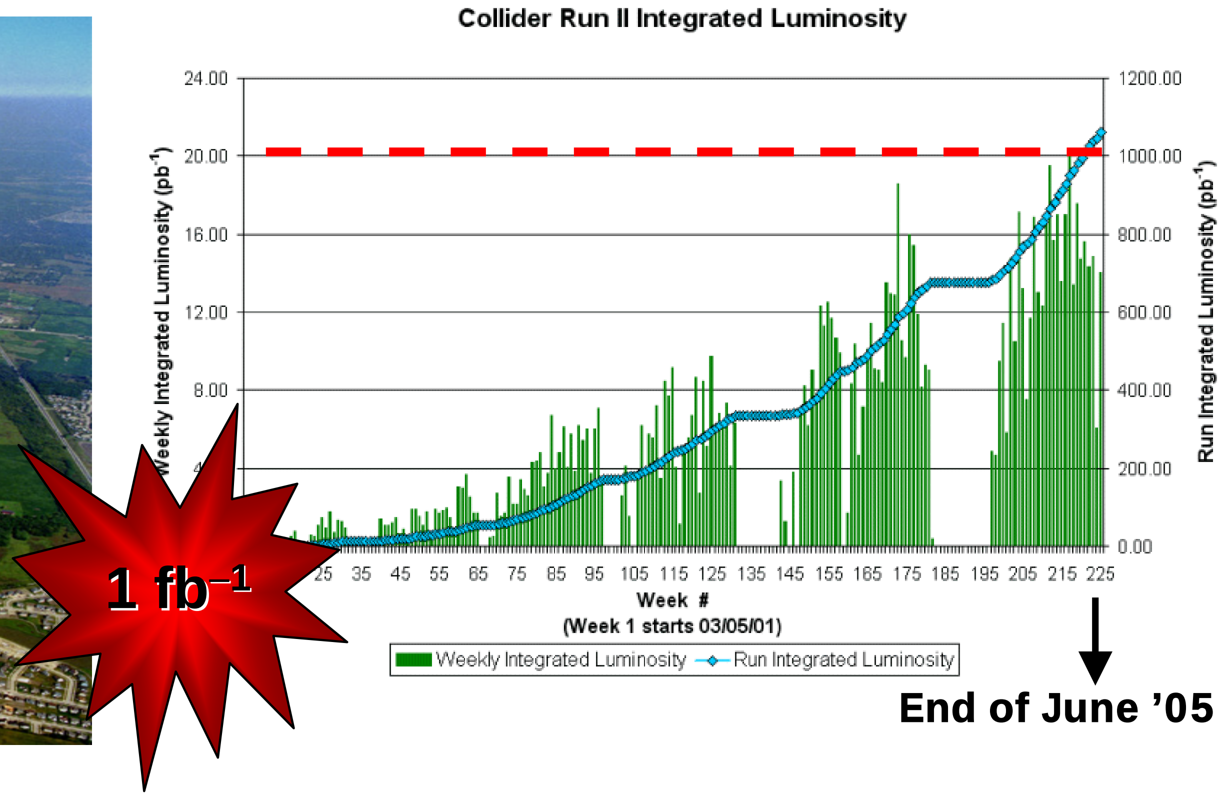




Precision

$\mathcal{L}$ =

Tevatron

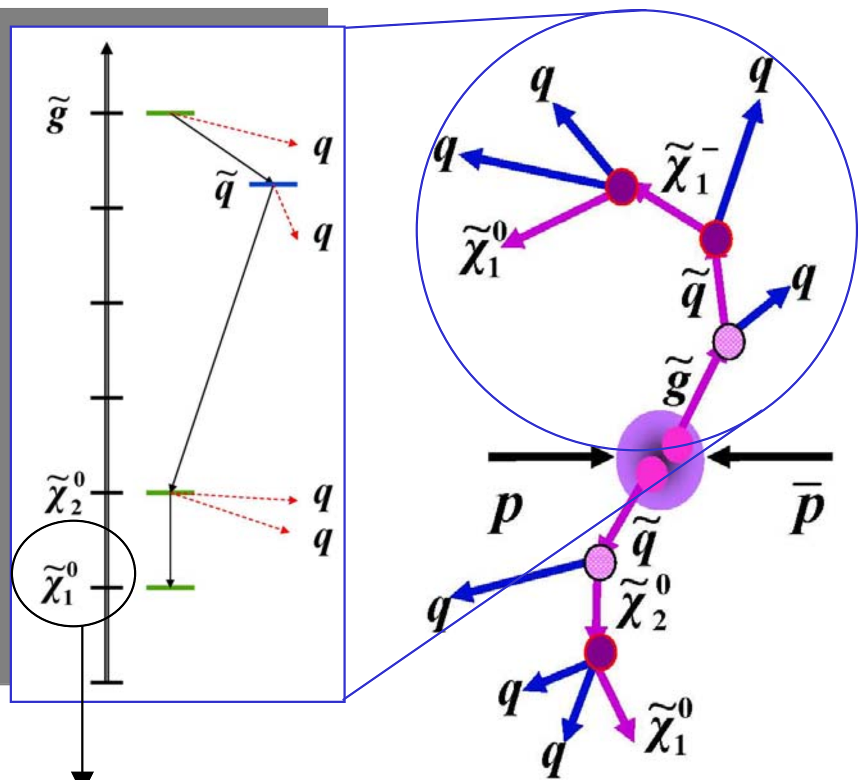


See the backup slide for details of the CDF and DØ detectors.

Gluinos/Squarks

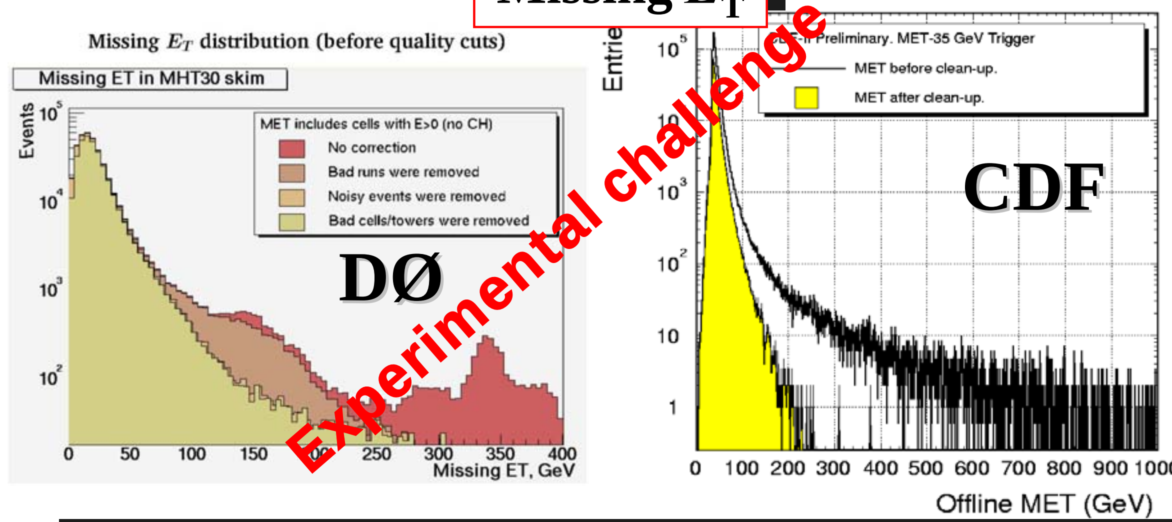
SUGRA   jets+$\not{E}_T$

$$\tilde{g} \rightarrow qq+(\tilde{\chi}_1^{\pm} \text{ or } \tilde{\chi}_2^0) \text{ or } qq+\tilde{\chi}_1^0$$
$$\tilde{q} \rightarrow q+(\tilde{\chi}_1^{\pm} \text{ or } \tilde{\chi}_2^0) \text{ or } q+\tilde{\chi}_1^0$$



Escaping the detector
→ Missing E_T

Missing E_T



Main SM Backgrounds after clean-ups:

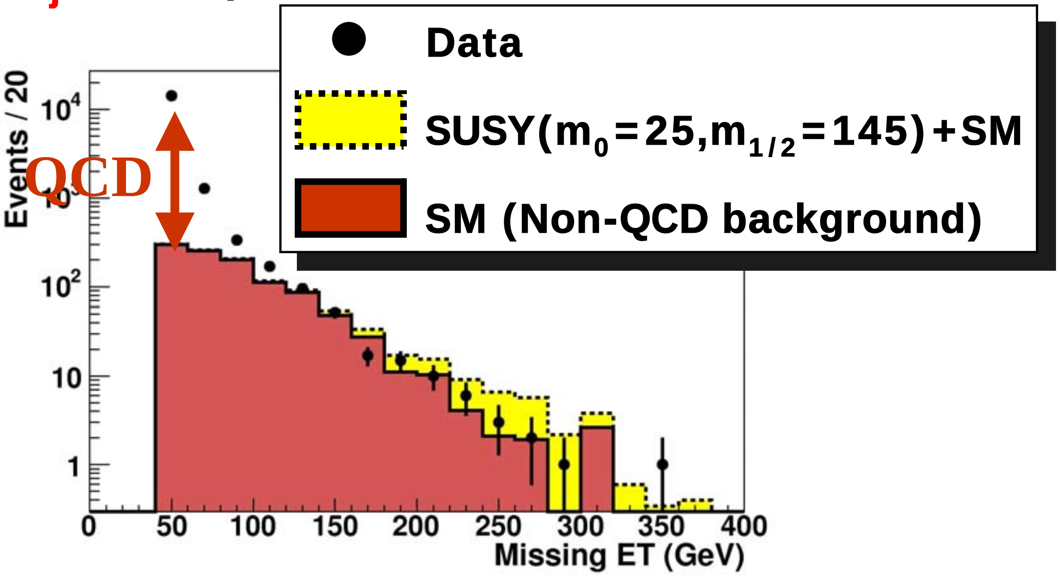
- QCD jets with fake missing E_T
- $W(\rightarrow e\nu, \mu\nu, \tau\nu)$+jets
- $Z(\rightarrow \nu\nu)$+jets

Main selection cuts

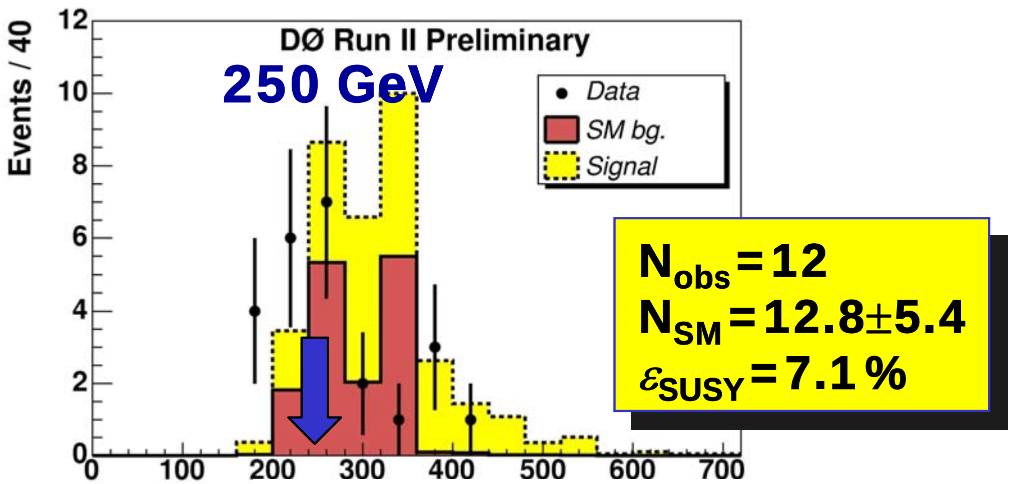
- ❑ Multi-jets + missing E_T
- ❑ Separation of missing E_T direction from jets
- ❑ Lepton veto
- ❑ Large H_T + large missing E_T

DØ (2 jet Analysis)

$N_j \geq 2$, $\not{E}_T > 40$ GeV (presection)



$N_{j(E_T>50)} \geq 2$, $\not{E}_T > 175$ GeV, and $\Delta\Phi(\not{E}_T, j)$ cuts,



$H_T = \Sigma p_{T(jet)}$ (GeV)

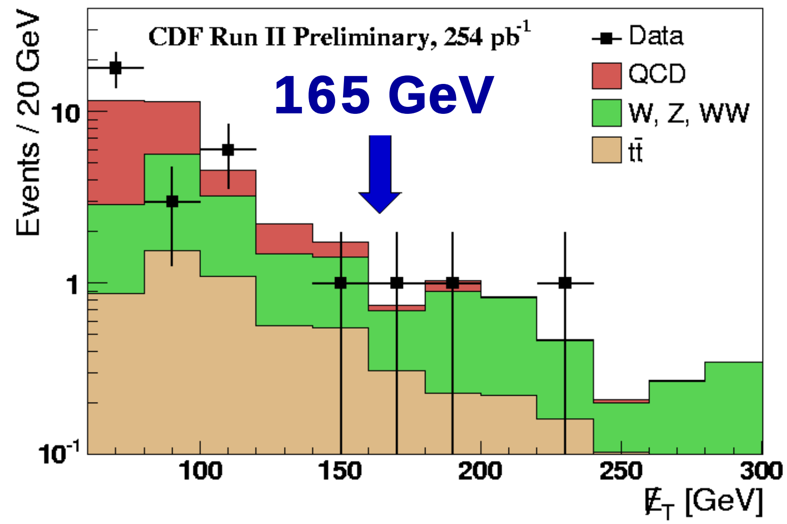
CDF (3 jet Analysis)

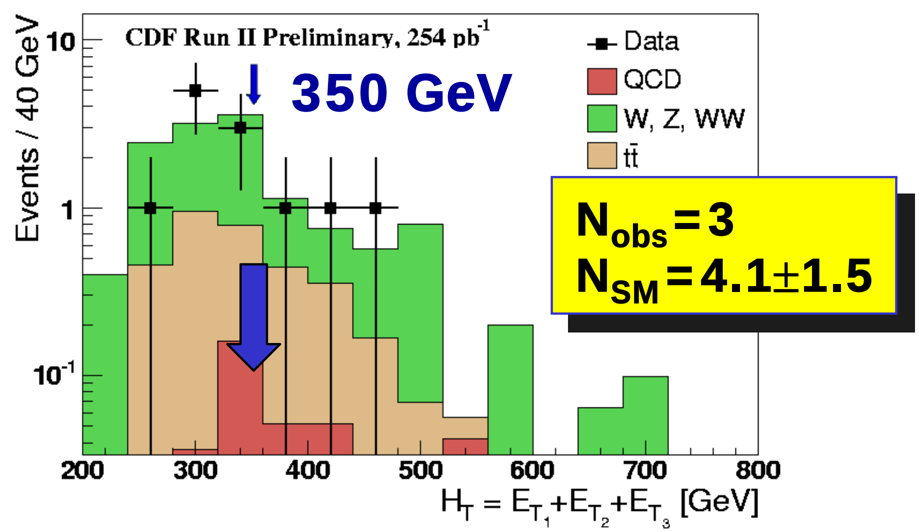
Similar analysis to DØ, but with

$N_j \geq 3$, $\not{E}_T > 60$ GeV

$E_T(j_1) > 125$ GeV, $E_T(j_2) > 75$ GeV

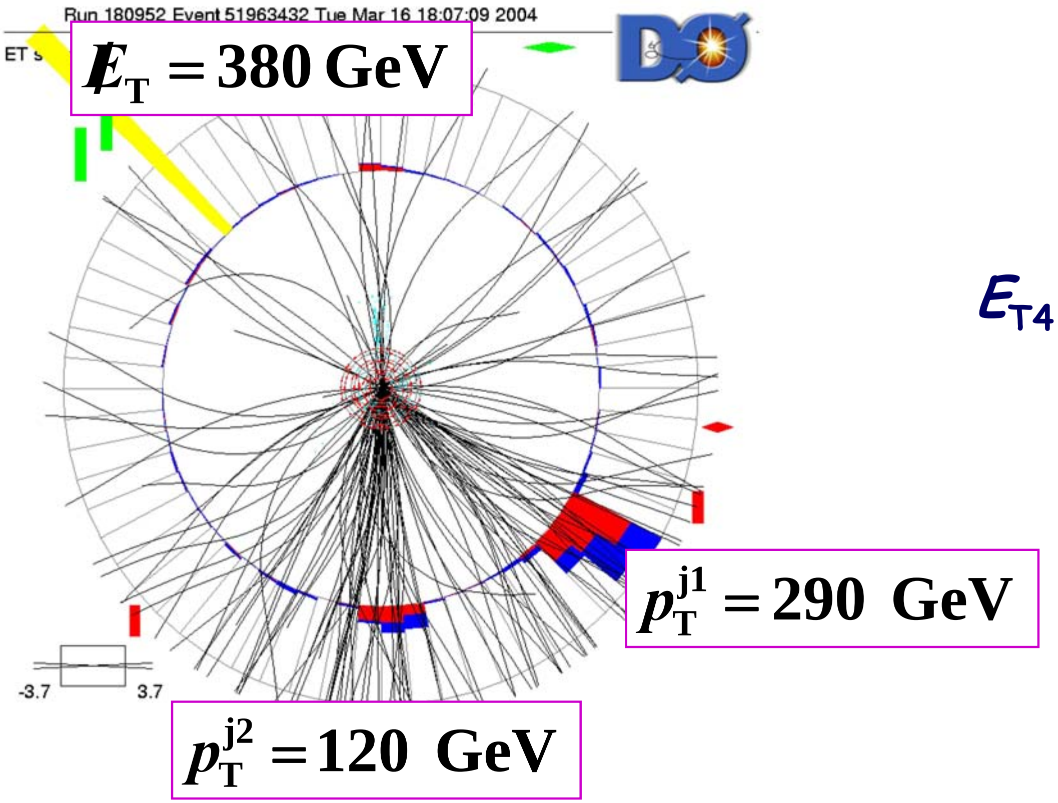
$E_T(j_3) > 25$ GeV and $\Delta\Phi(\not{E}_T, j)$ cuts





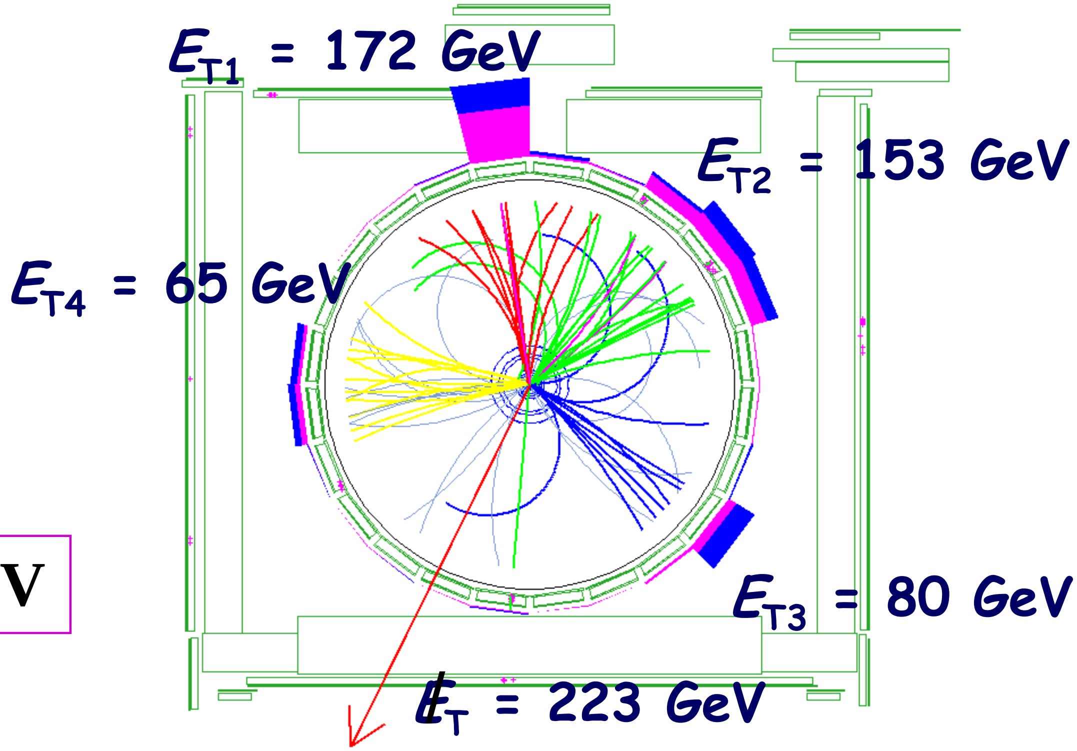
"Highest H_T Event" Display

DØ



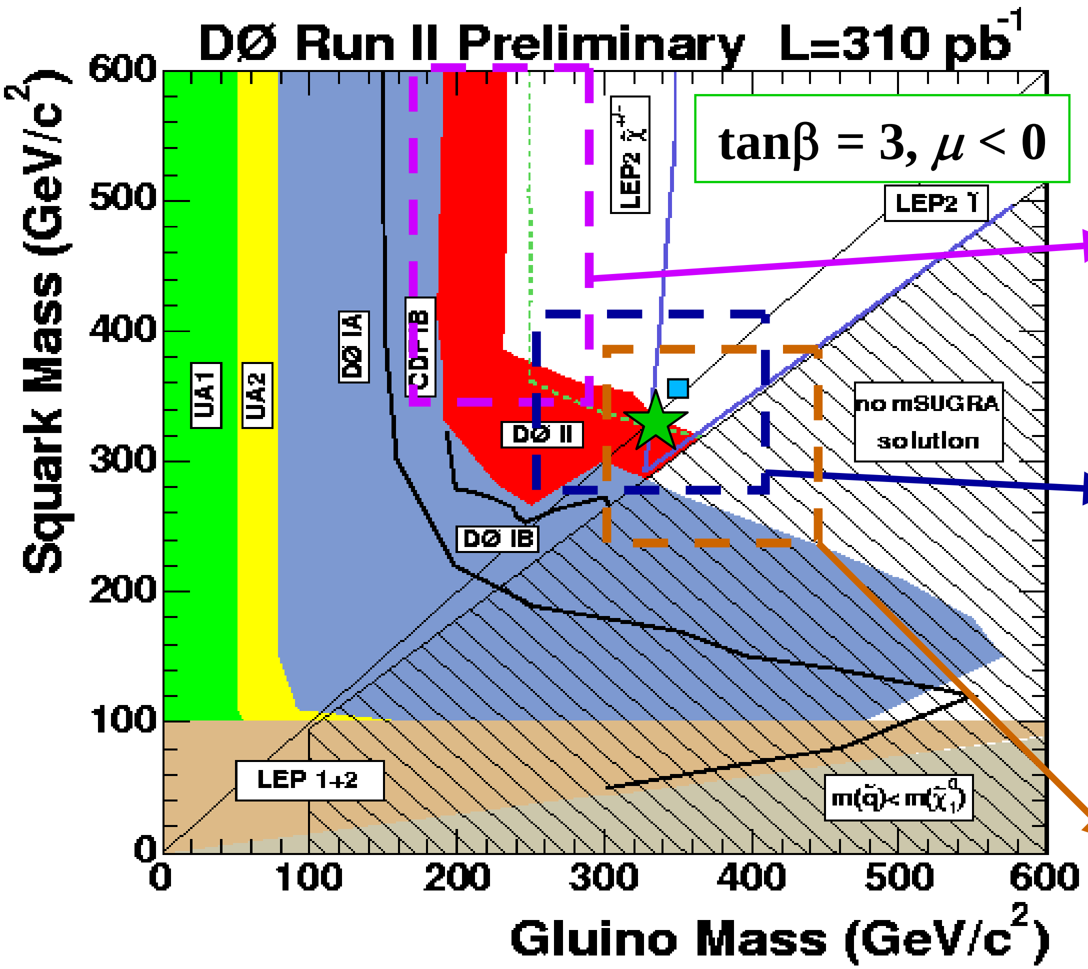
$H_T = p_{T1} + p_{T2} = 410$ GeV

CDF



$H_T = E_{T1} + E_{T2} + E_{T3} = 404$ GeV

$\tilde{g}/\tilde{q}$ Mass Limits



DØ : 4 jets
- $\not\!\!E_T$ > 75 GeV
- H_T > 250 GeV
- N_{SM} = 7.1 ± 0.9
- N_{obs} = 10

DØ : 3 jets
- $\not\!\!E_T$ > 100 GeV
- H_T > 325 GeV
- N_{SM} = 6.1 ± 3.1
- N_{obs} = 5

CDF : 3 jets
- $\not\!\!E_T$ > 165 GeV
- H_T > 350 GeV
- N_{SM} = 4.1 ± 1.6
- N_{obs} = 3

DØ : 2 jets
- $\not\!\!E_T$ > 175 GeV
- H_T > 250 GeV
- N_{SM} = 12.8 ± 5.4
- N_{obs} = 12

■ CDF sensitivity (3 jets)
- N_{SUSY} = 4.8 ± 0.7
- ε_{SUSY} = 7.2 %

★ 95% CL limit (DØ : 3 jets)

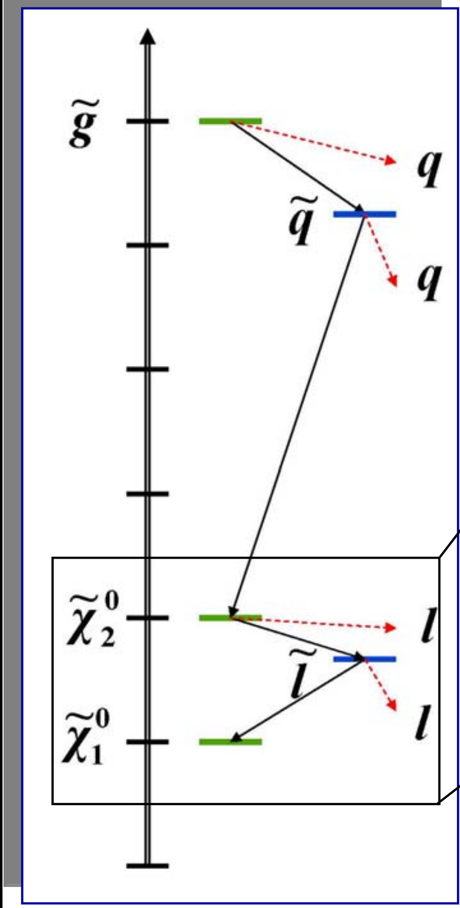
$$M_{\tilde{g}} > 333\,\mathrm{GeV}/c^2 \text{ for } M_{\tilde{q}} = M_{\tilde{g}}$$

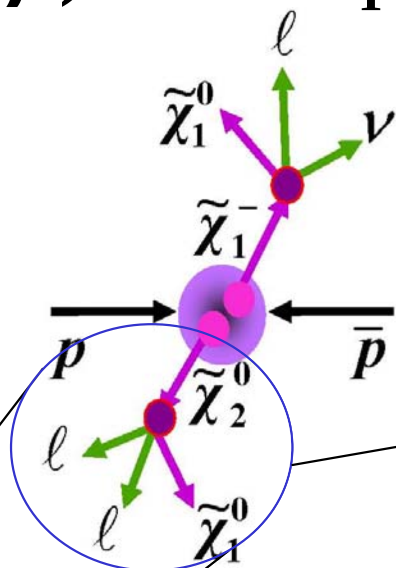
See talks by D. Sajot (DØ) and G. Manca (CDF)

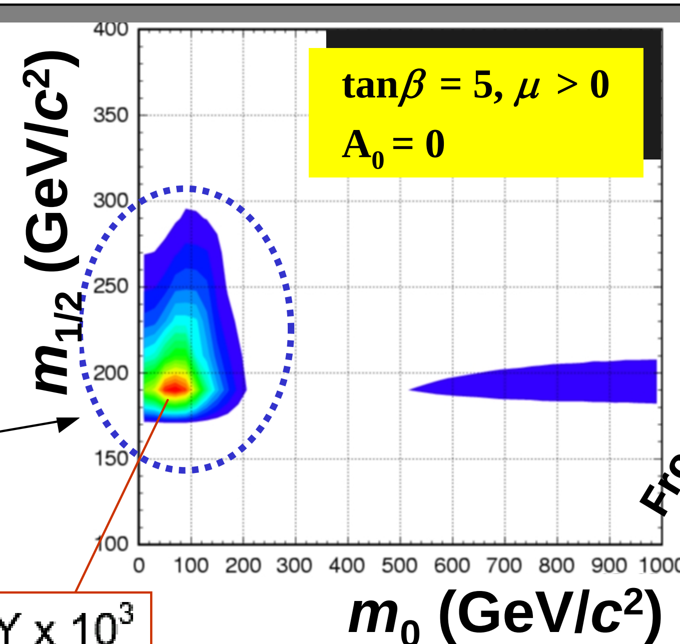
Chargino/Neutralino

SUGRA(lowβ) $\ell\ell\ell + \not{E}_T$

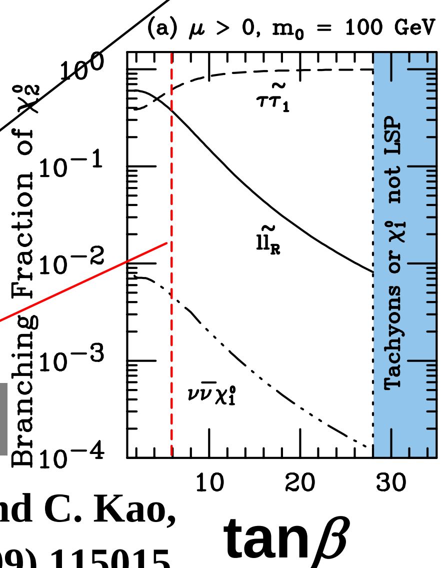
$\sigma(p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0) \cdot BR(\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \ell\ell\ell)$







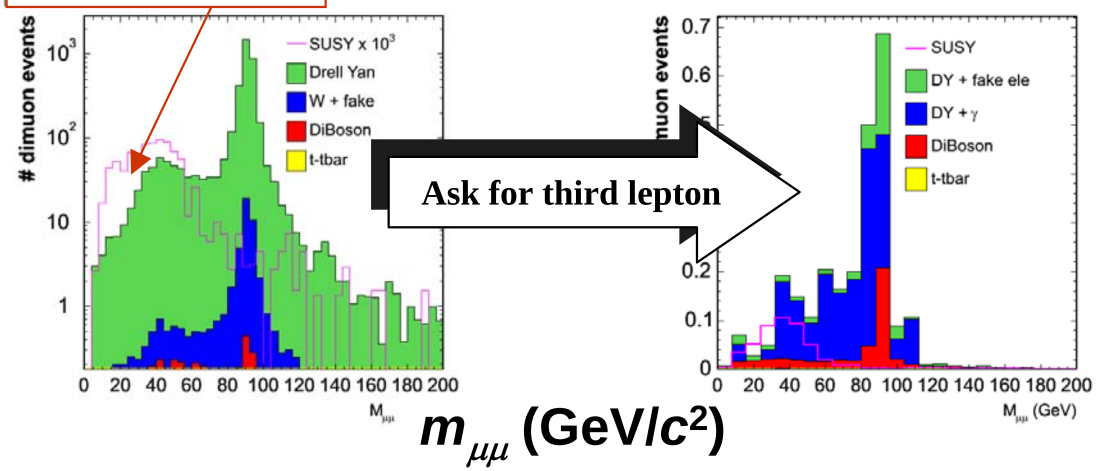
From A. Canepa (CDF)



tan$\beta \leq 8$

V. Barger and C. Kao, PRD 60 (1999) 115015

SUSY x 10^3



Strategy: 2 leptons+l_3+$\not{E}_T$

DØ and CDF Analyses

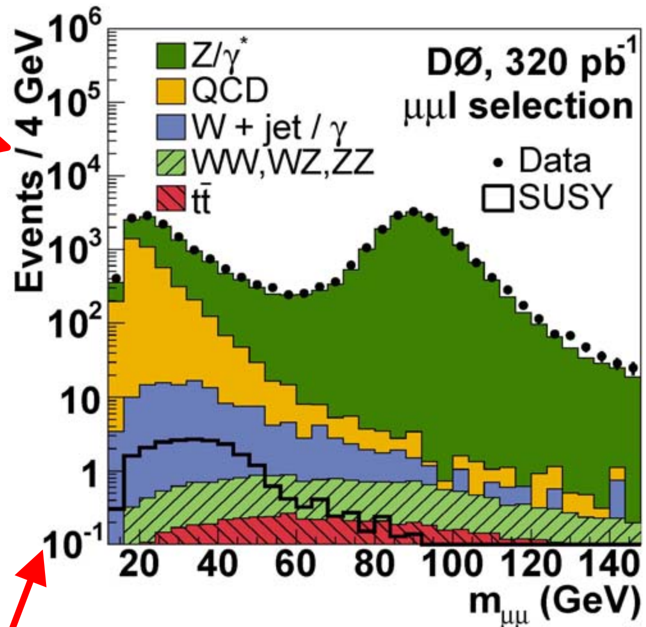
$2l$ ($l=e,\mu,\tau$) + isolated track or $\mu^{\pm}\mu^{\pm}$

-$\not{E}_T$ and topological cuts (M_{ll}, $\Delta\phi$, M_T)

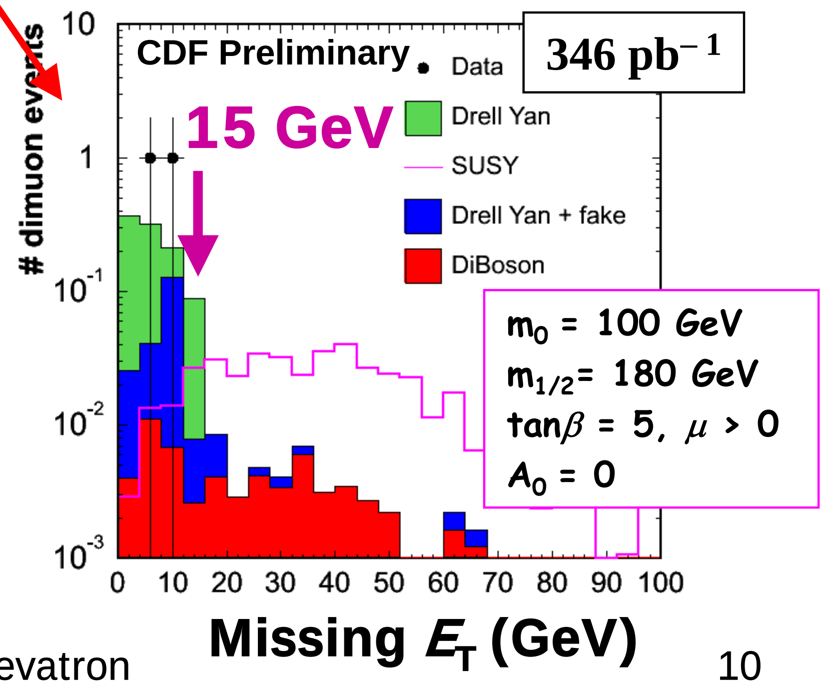
		DØ (320 pb^{-1})		CDF (346 pb^{-1})	
Selection		N_{SM}	N_{OBS}	N_{SM}	N_{OBS}
(1)	$ee+l$	0.21±0.12	0	0.22±0.06	0
	ee + track			0.34±0.26 (224 pb^{-1})	2
(2)	$\mu\mu+l$	1.75±0.57	2	0.09±0.05	0
(3)	$e\mu+l$	0.31±0.13	0	---	---
(4)	$\mu^{\pm}\mu^{\pm}$	0.66±0.37	1	---	---
Subtotal		2.93±0.79	3	0.65±0.27	2
(5)	$e\tau+l$	0.58±0.14	0	---	---
(6)	$\mu\tau+l$	0.36±0.13	1	---	---
Total		3.85±0.81	4		

Note: DØ analyses (1)~(4) is published in Fermilab-Pub-05/075-E or hep-ex/0504032

DØ : $\mu\mu$ + track



CDF : $\mu\mu+l$

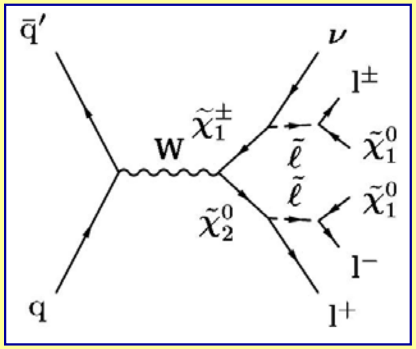


Chargino Mass Limits

mSUGRA "small m_0"

$M(\tilde{\ell}) > M(\tilde{\chi}_2^0)$

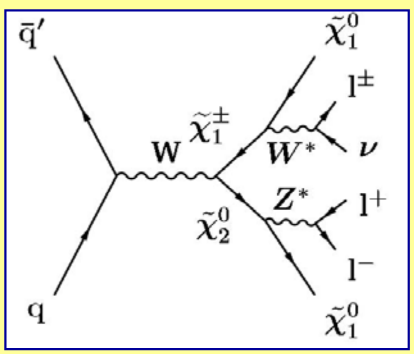
No slepton mixing



- $\sigma \times BR < 0.2$ pb

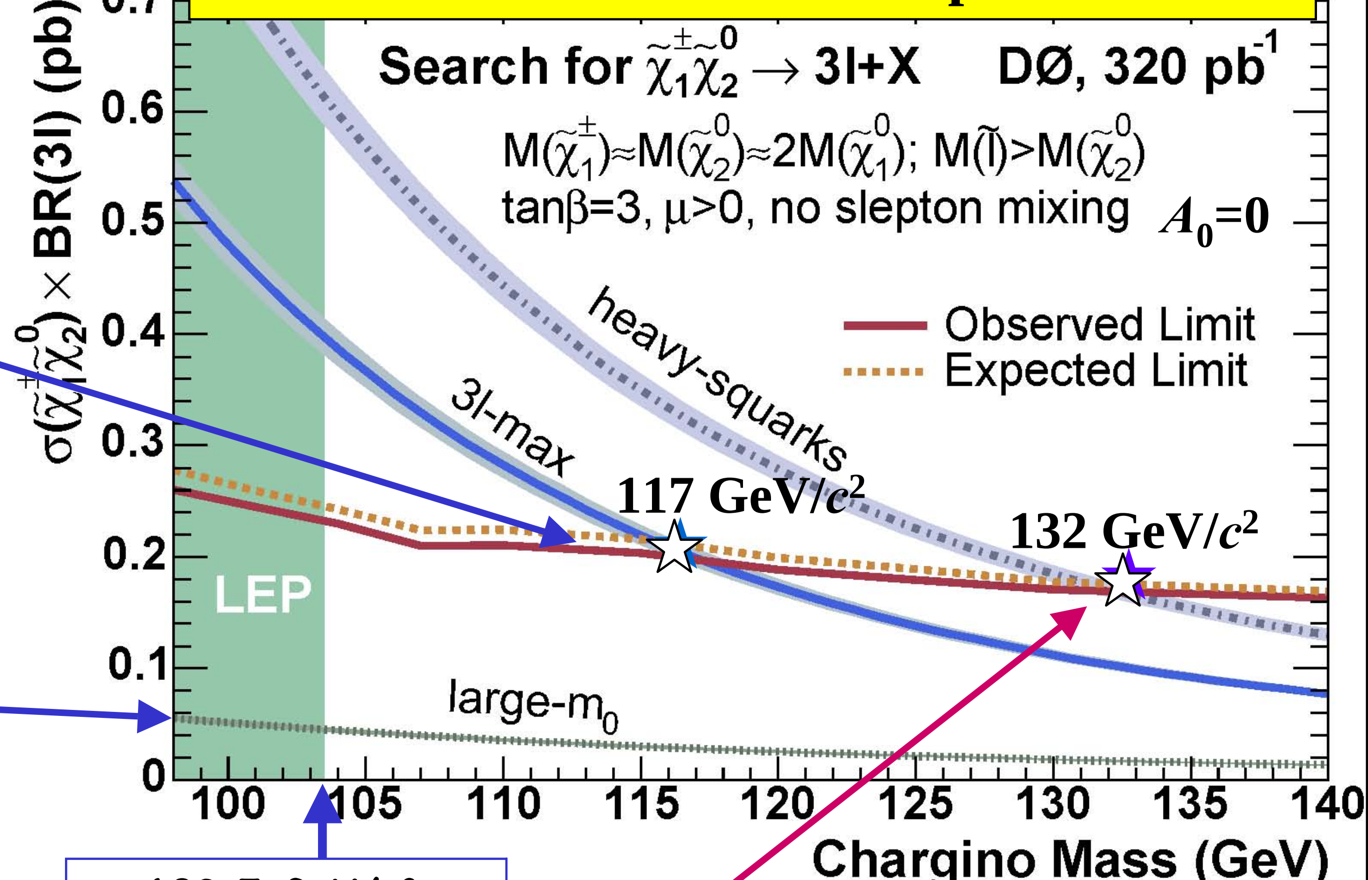
mSUGRA "large m_0"

$M(\tilde{\ell}) \gg M(\tilde{\chi}_2^0)$



- No sensitivity

Fermilab-Pub-05/075-E or hep-ex/0504032



103.5 GeV/c^2
(model independent)

Those limits are improved by ~10% if tau's are included.

Scenario

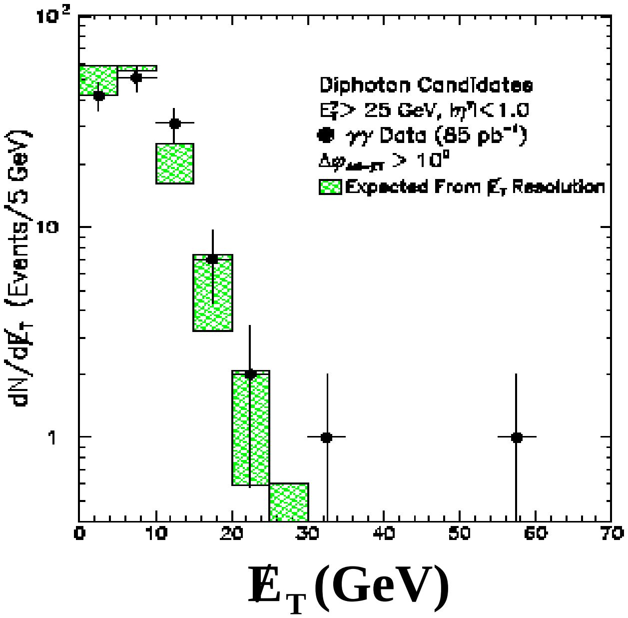
light sleptons but heavy squarks

$M(\tilde{\chi}_2^0) \approx 3M(\tilde{q})$

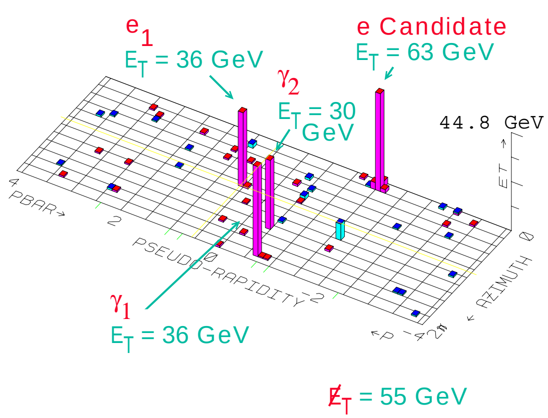
See talks by P. Gay (DØ) and A. Canepa (CDF)

Chargino/Neutralino (LSP = $\tilde{G}$)

Run 1 $\gamma\gamma$ (85 pb^{-1})



$ee\gamma\gamma\not{E}_T$ Candidate Event



$\Lambda = F/(C_G M_m)$

N_m (# of Messengers)

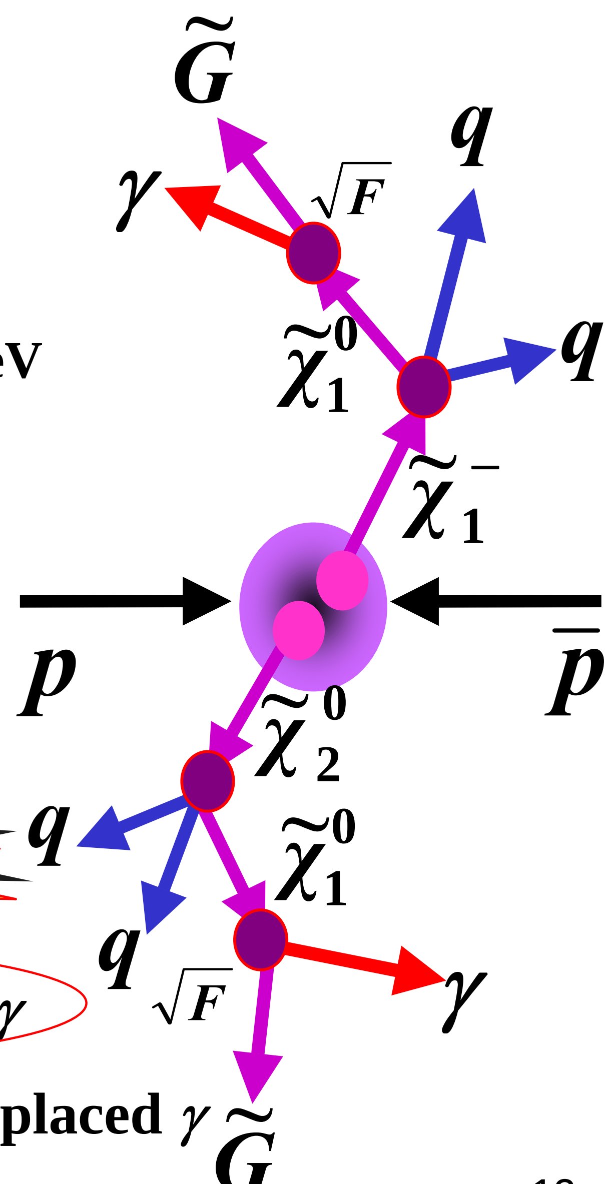
M_m (Messenger Mass)

$\tan\beta$, sign(μ), C_G

$$m_{\tilde{G}} = \frac{F}{\sqrt{3}M_{pl}} \approx 2.4\left(\frac{\sqrt{F}}{100\text{ TeV}}\right)^2 \text{eV}$$

$$\underbrace{M_i}_{\text{gaugino mass}} = k_i N_m \Lambda \left(\frac{\alpha_i}{4\pi}\right)$$

GMSB $\gamma\gamma + \not{E}_T$



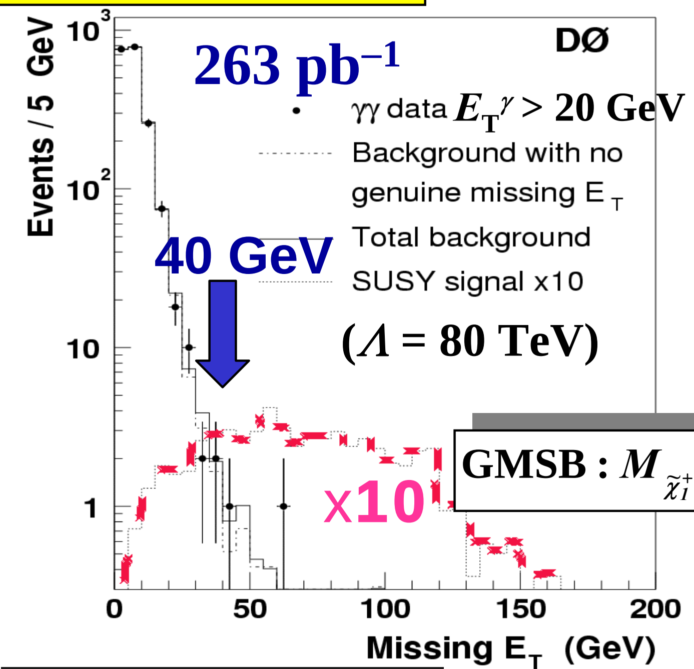
Today's talk

$F^{1/2}$ < a few TeV → Prompt γ

$F^{1/2}$ > a few 1000 TeV → Displaced γ

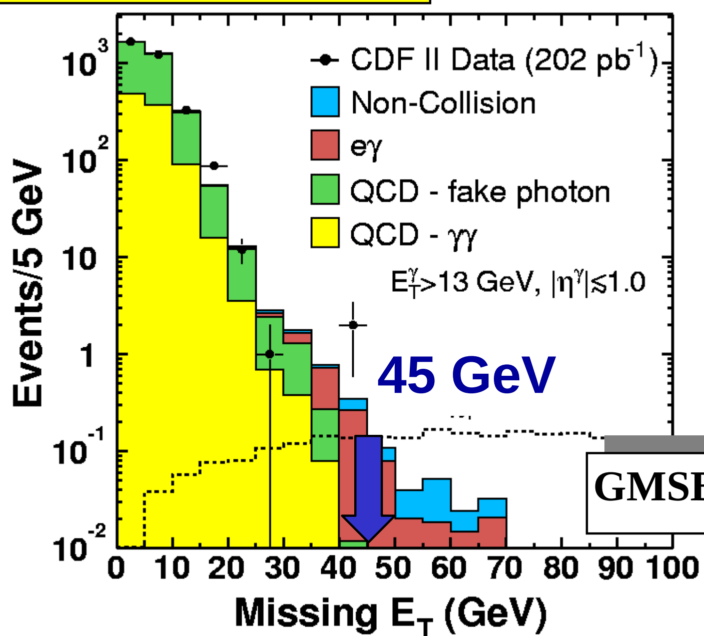
Chargino Mass Limits (LSP = $\tilde{G}$)

PRL (2005) 041801



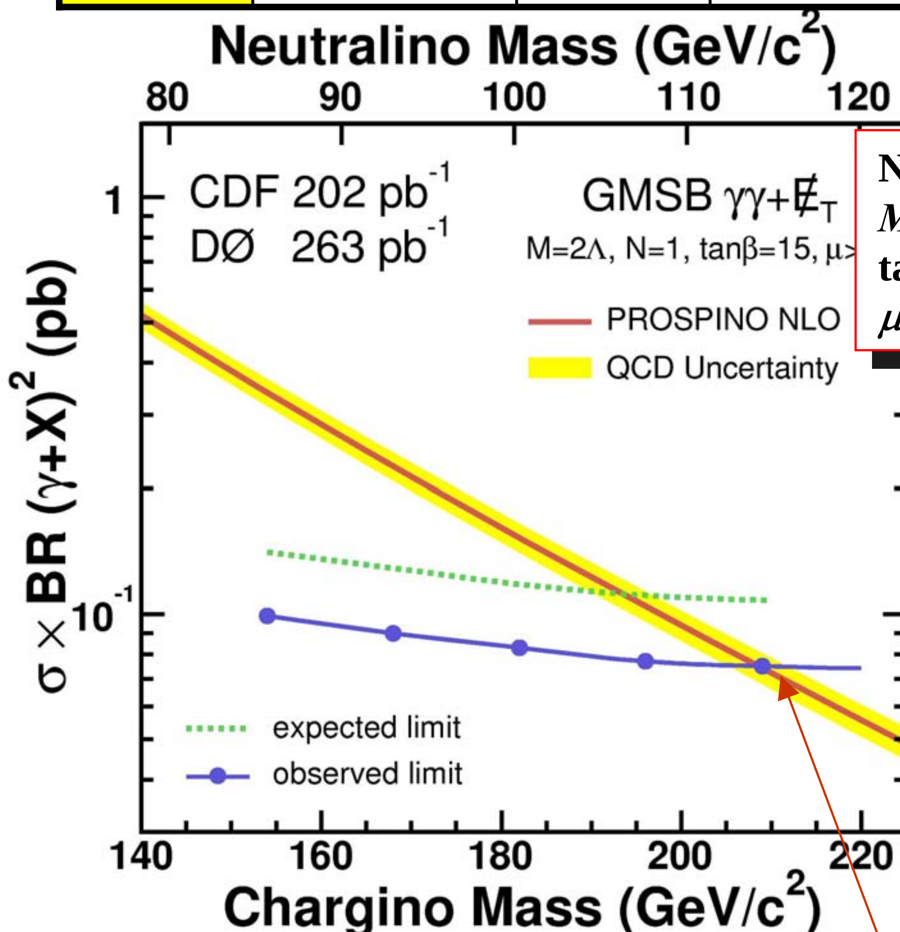
GMSB : $M_{\tilde{\chi}_1^+} = 195\ \text{GeV}/c^2$

PRD (2005) 031104



GMSB : $M_{\tilde{\chi}_1^+} = 175\ \text{GeV}/c^2$

	N_{BG}	N_{OBS}	$M_{\tilde{\chi}_1^+}$ Limit
DØ	3.7±0.6	2	195
CDF	0.3±0.1	0	167



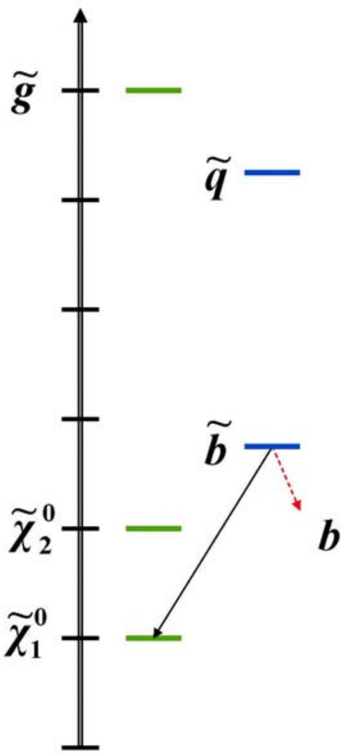
N_m=1
M_m/Λ=2
tanβ=15
μ>0

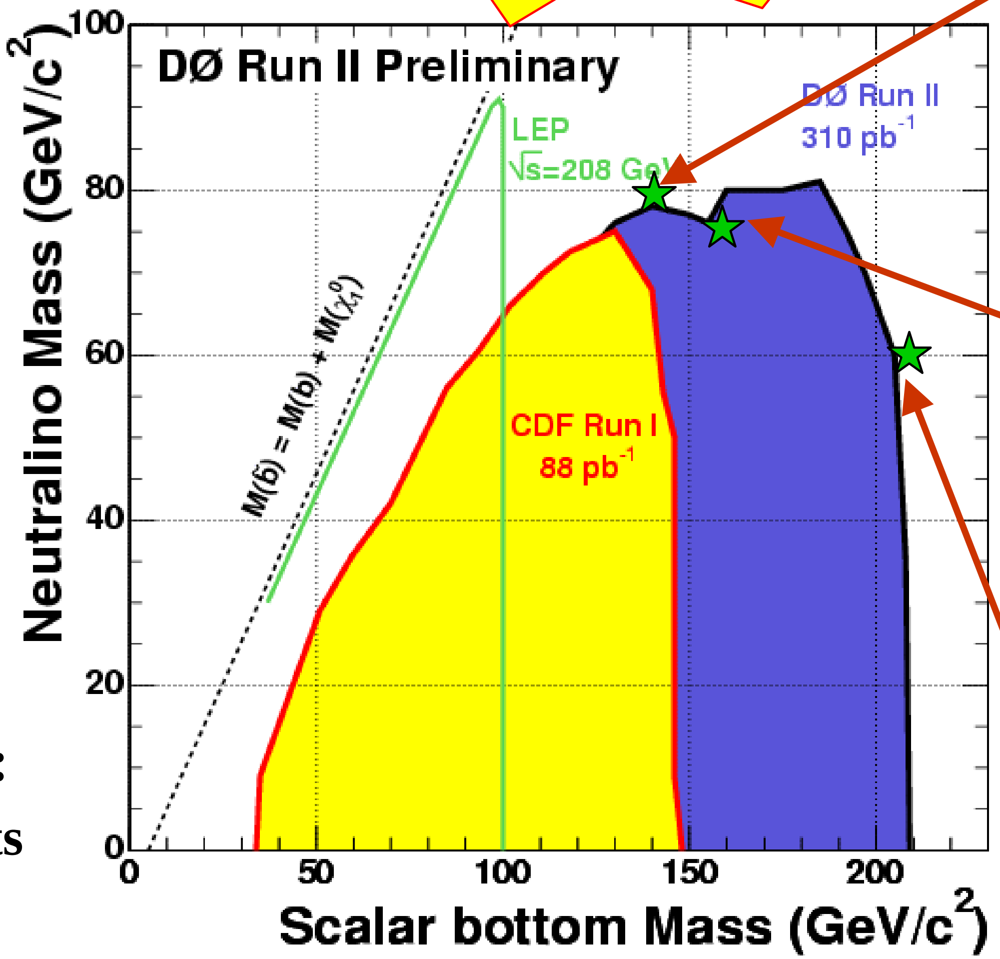
$$M_{\tilde{\chi}_1^+}\ (\text{Tevatron}) > 209\ \text{GeV}/c^2$$

Sbottom

B-tagging is working beautifully!

MSSM $bb + \not{E}_T$





SM Backgrounds:

$W(\rightarrow e\nu, \mu\nu, \tau\nu)$+jets

$Z(\rightarrow \tau\tau, \nu\nu)$+jets

QCD jets

Top, diboson

2,3 jets (E_T>40,15,15)
$\not{E}_T$ > 60 GeV
N_{SM}=38.6±2.8
N_{obs}=36
N_{SUSY}=35.0±1.2

2,3 jets (E_T>40,15,15)
$\not{E}_T$ > 80 GeV
N_{SM}=19.6±1.7
N_{obs}=15
N_{SUSY}=21.6±0.7

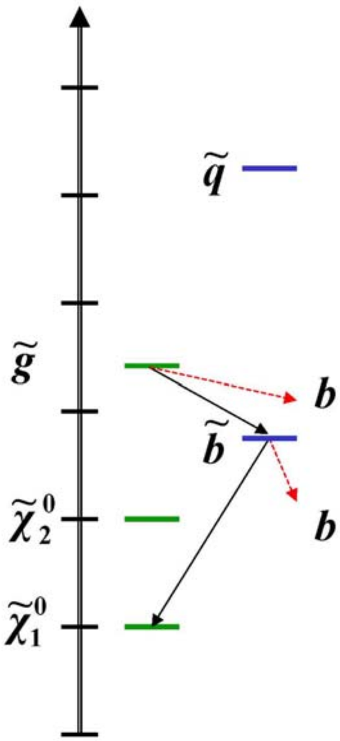
2,3 jets (E_T>70,40,15)
$\not{E}_T$ > 100 GeV
N_{SM}=4.40±0.44
N_{obs}=2
N_{SUSY}=6.10±0.17

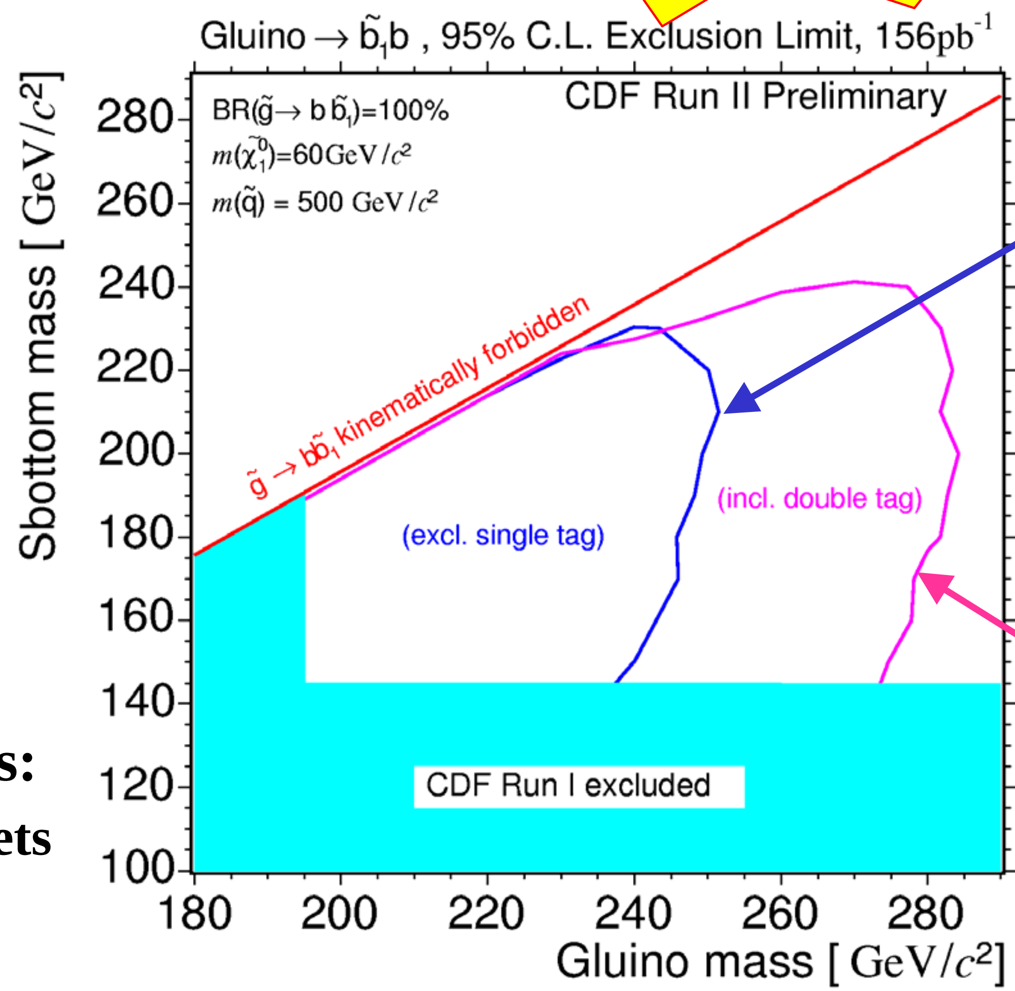
See talk by P. Ratoff (DØ) for sbottom and stop

Sbottom

MSSM $bbbb + \not{E}_T$

B-tagging is working beautifully!





≥3 jets (E_T>15)
$\not{E}_T$ > 80 GeV
$N_{b\text{-tag}}$ = 1
N_{SM}=16.4±3.7
N_{obs}=21

≥3 jets (E_T>15)
$\not{E}_T$ > 80 GeV
$N_{b\text{-tag}} \geq 2$
N_{SM}=2.6±0.7
N_{obs}=4

SM Backgrounds:

$W(\to e\nu, \mu\nu, \tau\nu)$+jets
$Z(\to \tau\tau, \nu\nu)$+jets
QCD jets
Top, diboson

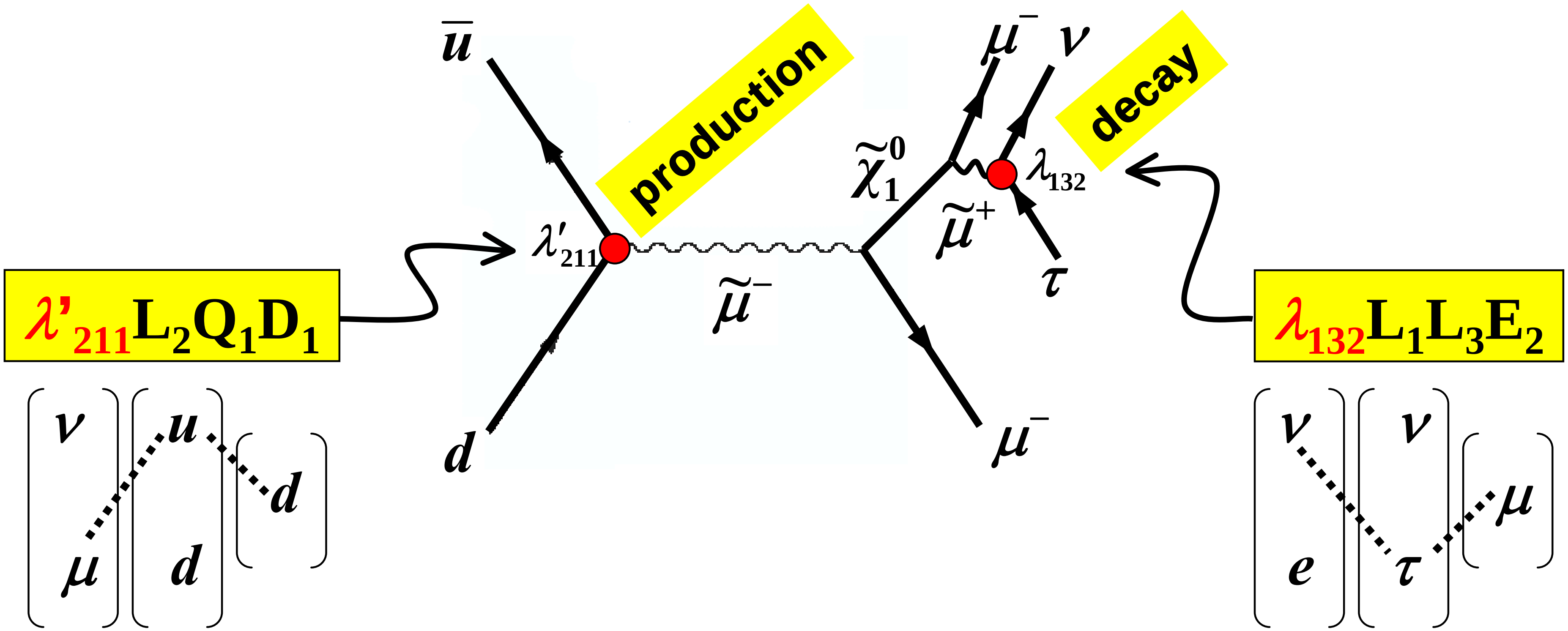
See talk by O. Gonzalez-Lopez (CDF) for sbottom and stop

R-parity Violating (RPV) SUSY

$$e.g.,\ W_{\mathrm{TRPV}} = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k$$

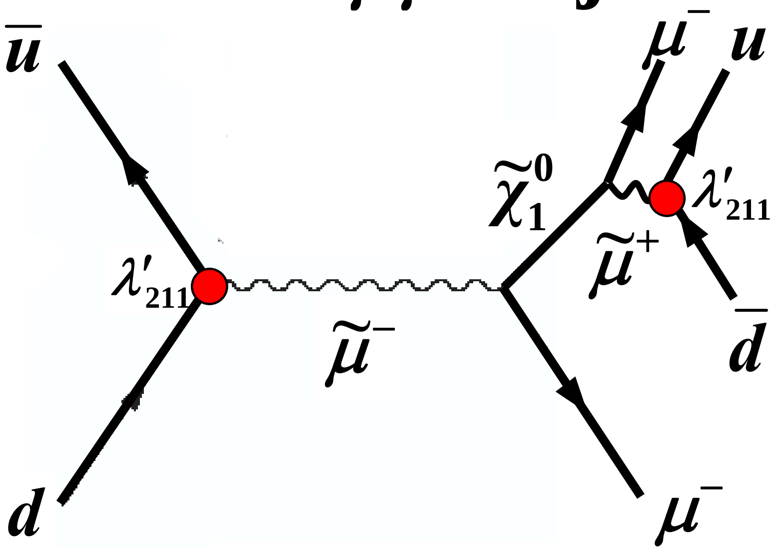
Accessible by hadron colliders

Example of RPV SUSY Process



RPV – Scalar Muon

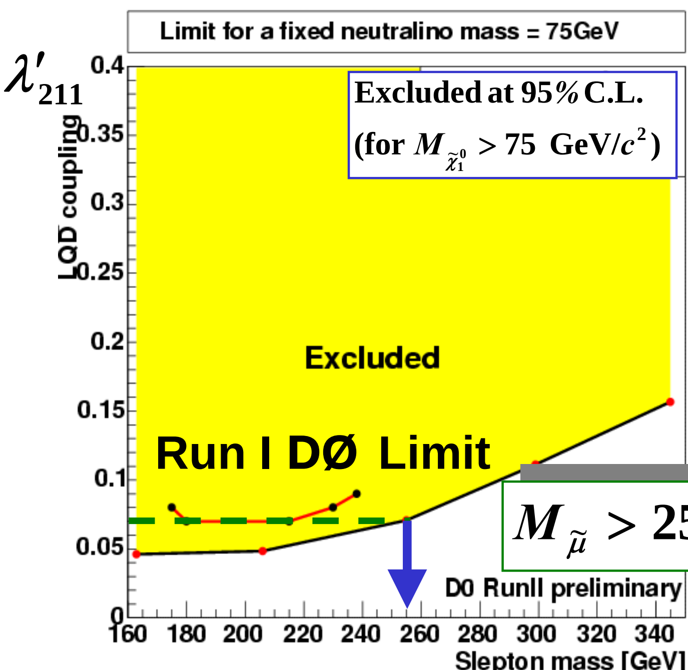
MSSM $\mu\mu + 2$ jets



Prompt $\tilde{\chi}_1^0$ decay
Soft leptons and jets:
$p_T^{\mu_2} \geq 10$ GeV/c
$p_T^{j_1} \geq 25$ GeV/c

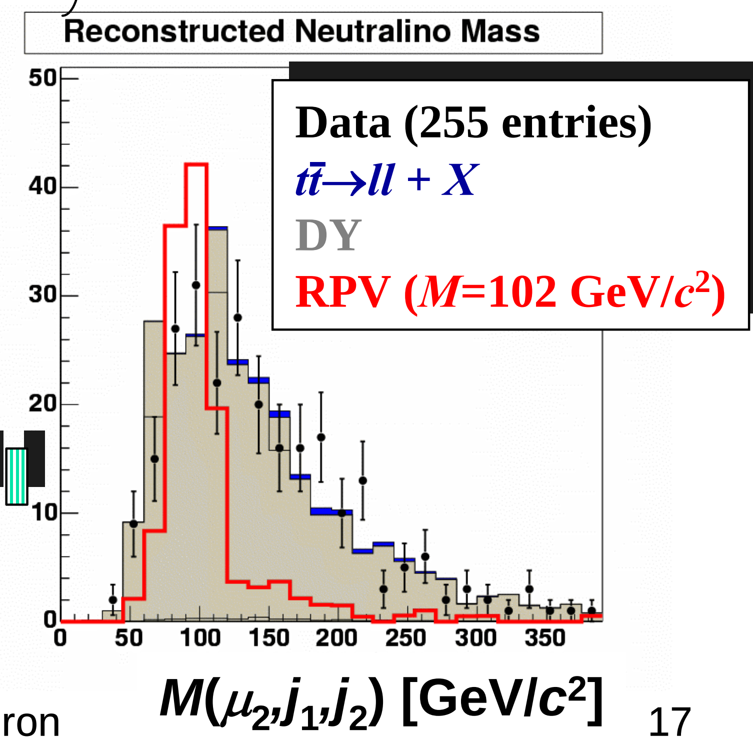
Can reconstruct $\tilde{\chi}_1^0$ and $\tilde{\mu}$ masses

Use the masses to suppress backgrounds



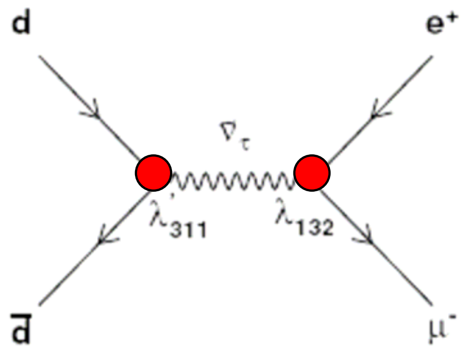
DØ (154 pb^{-1})	
N_{SM}	1.1±0.4
N_{obs}	2

$M_{\tilde{\mu}} > 255$ GeV/c^2 for $\lambda'_{211} = 0.07$



RPV – Scalar Neutrino

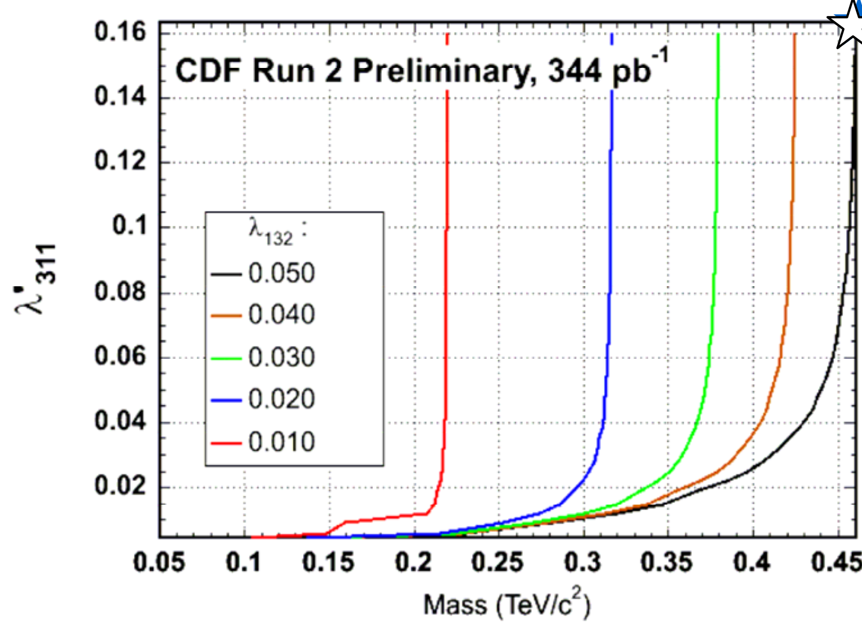
$X \rightarrow e\mu$ Search $(X = \tilde{\nu})$



$e + \mu\ (p_T > 20)$
$N_{SM} = 7.66 \pm 0.63$
$N_{obs} = 5$

$$\sigma \propto \lambda'^{\,2}_{311}\ \lambda^{2}_{132}$$

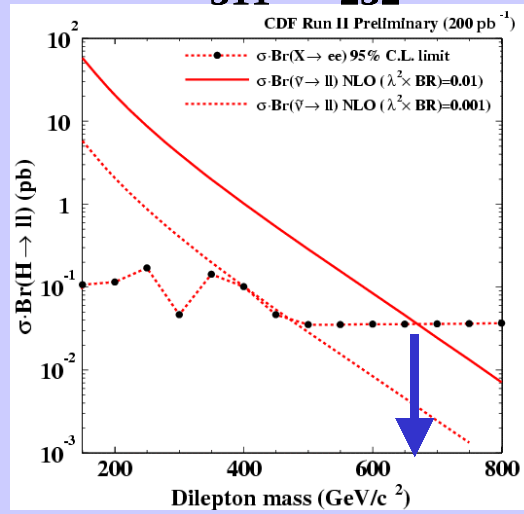
Allowed region
$\lambda'_{311} < 0.16$
$\lambda_{132} < 0.05$



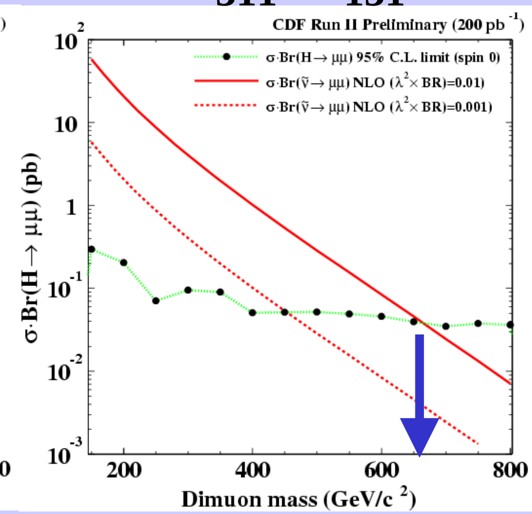
$$M > 450\ \text{GeV}/c^2 \text{ for } \lambda'^{\,2}_{311} \cdot B(\tilde{\nu} \rightarrow e\mu) = 0.01$$

$X \rightarrow ee, \mu\mu, \tau\tau$ Search $(X = \tilde{\nu})$

$\lambda'^{\,2}_{311}\ \lambda^{2}_{232}$



$\lambda'^{\,2}_{311}\ \lambda^{2}_{131}$



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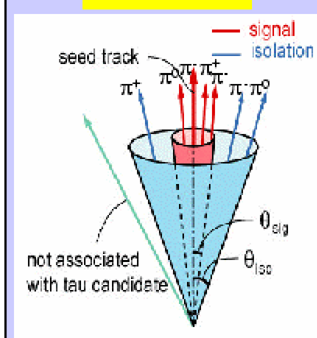
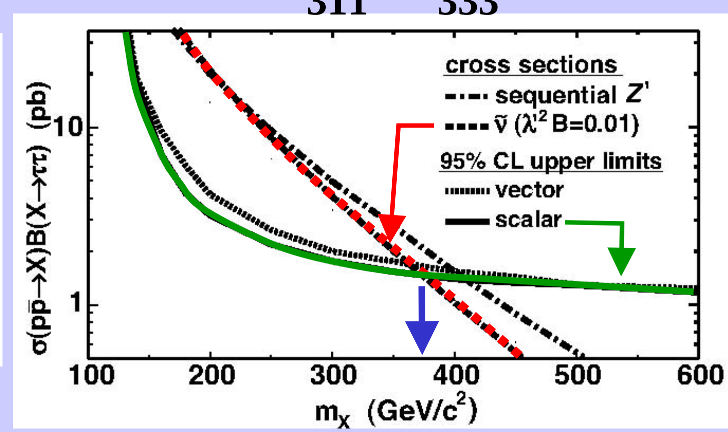


$\lambda'^{\,2}_{311}\ \lambda^{2}_{333}$

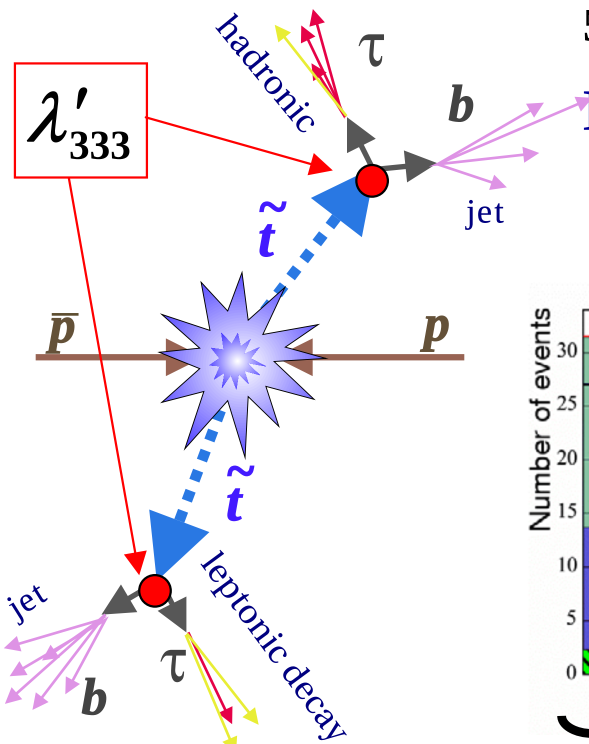


See talk by M. Karagoz-Unel (CDF)

RPV – Stop

MSSM $\ell + \tau_h + \geq 2$ jets

$p_T^{\tau} > 15$ GeV/c



$p_T^{l} > 10$ GeV/c

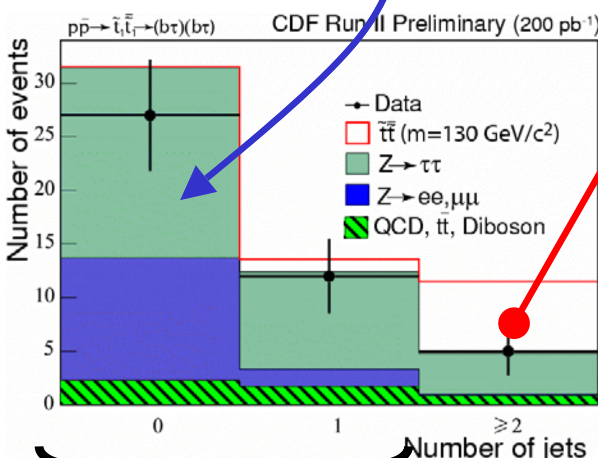
Lepton+Track Triggers

8 GeV lepton (*e* & *μ*) in $|\eta| < 1$

5 GeV/*c* isolated track

Main Background:

$Z \rightarrow \tau\tau$

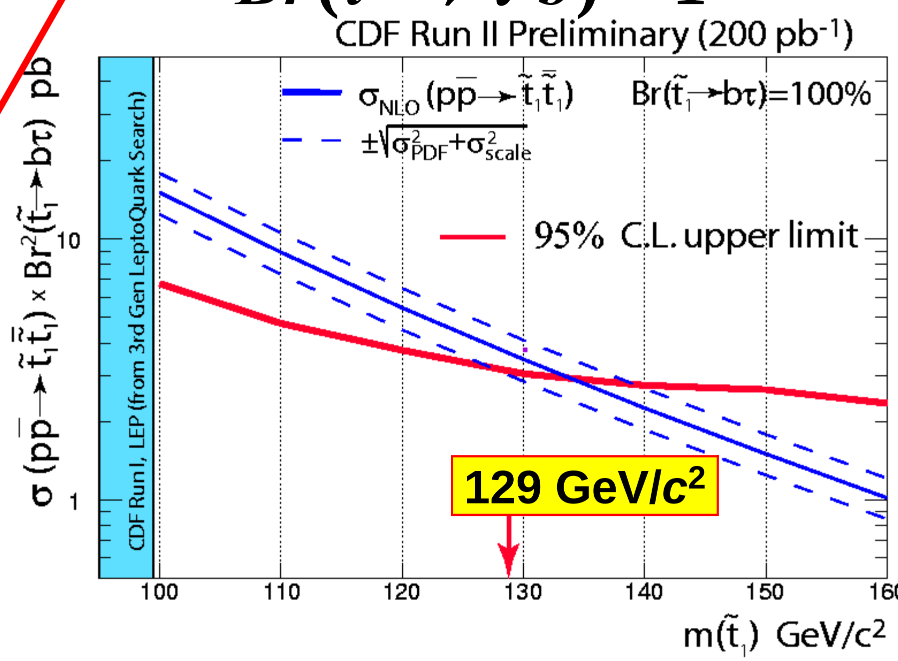


control region
(N_{jet} = 0 or 1)

signal region
($N_{jet} \geq 2$)

CDF (200 pb^{-1})	
N_{SM}	4.8±0.7
N_{obs}	5

$Br(\tilde{t} \rightarrow \tau b) = 1$



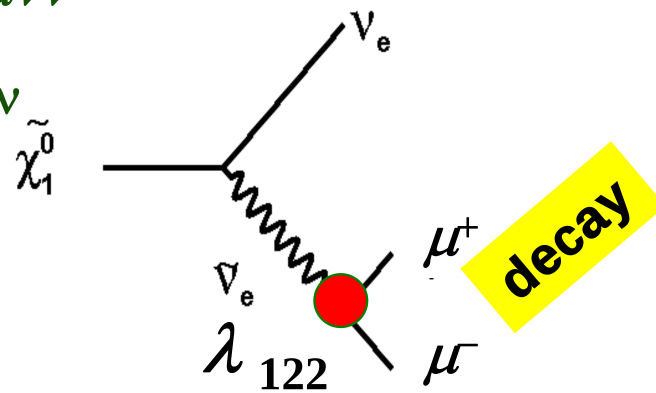
The result will be updated soon.

RPV – Lightest Neutralino

RPV decay of LSP ($\tilde{\chi}_1^0$) with λ_{ijk}

- ➡ **3ℓ (ℓ=e,μ) + $\not{E}_T$ + [channel dependent cuts]**
  - $\lambda_{122} \rightarrow \mu\mu\mu\mu,\ \mu\mu\mu e,\ \mu\mu ee,\ \mu\mu\nu\nu$
  - $\lambda_{121} \rightarrow eeee,\ eee\mu,\ ee\mu\mu,\ ee\nu\nu$
  - $\lambda_{133} \rightarrow ee\tau$

Similar to the trilepton analysis



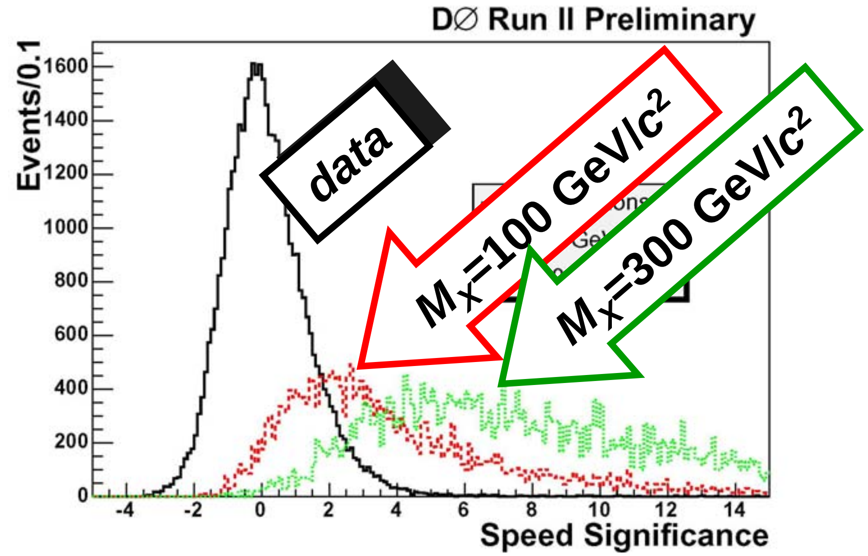
	N_{SM}	N_{OBS}	
1) 160 pb^{-1} : λ_{122}	0.6±1.9	2	⇨ $M(\tilde{\chi}_1^{0(+)}) > 84\ (165)$ GeV/c^2
2) 238 pb^{-1} : λ_{121}	0.5±0.4	0	⇨ $M(\tilde{\chi}_1^{0(+)}) > 95\ (181)$ GeV/c^2
3) 200 pb^{-1} : λ_{133}	1.0±1.4	0	⇨ $M(\tilde{\chi}_1^{0(+)}) > 66\ (118)$ GeV/c^2

Charged Massive Stable Particles

CHArged Massive stable Particles (X)

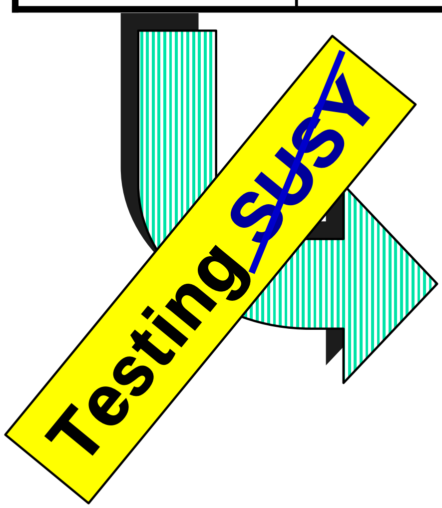
- -2 μ-like objects with p_T> 15 GeV/c, isolated
- -Speed ($\beta = v/c$) significantly slower than 1

$$S_\beta \equiv \frac{1-\beta}{\sigma_\beta}$$

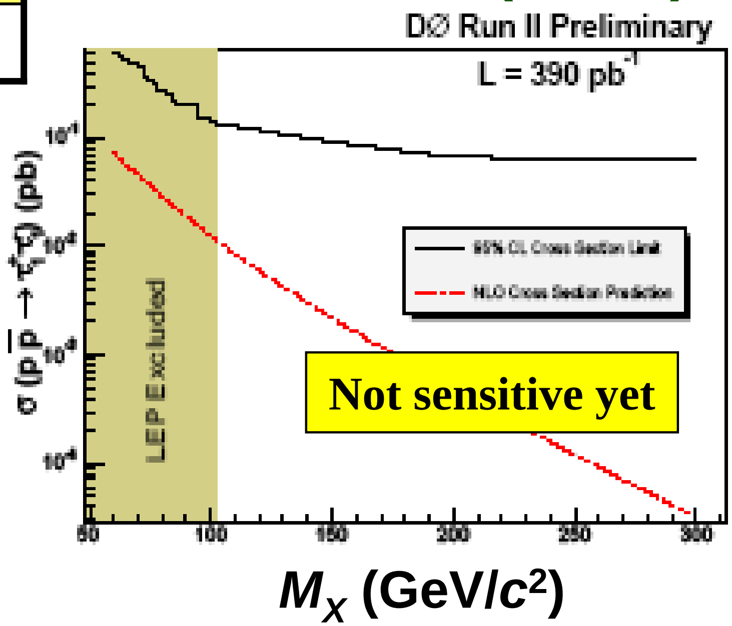


-SM backgroud: estimated from data

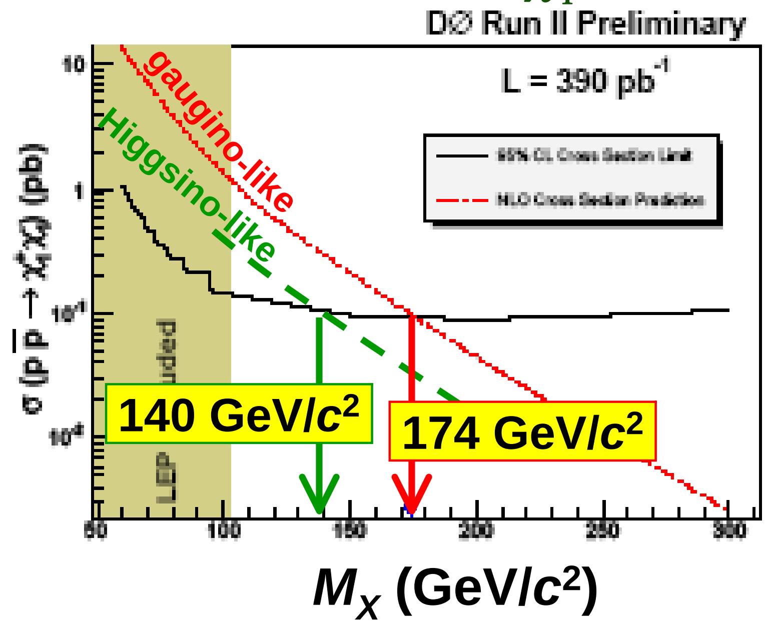
N_{SM}	N_{obs}
0.66±0.06	0



GMSB $X = \tilde{\tau}$ (NLSP)



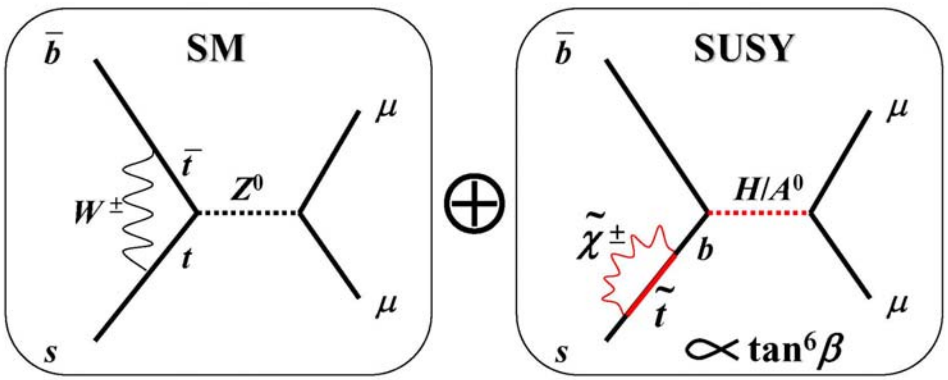
AMSB $X = \tilde{\chi}_1^\pm$



See talk by T. Adams (DØ)

Powerful Probe: $B_{s(d)} \rightarrow \mu^+\mu^-$

$\mathcal{B}_{\mathrm{SM}} = 3.4\times 10^{-9}$ $\mathcal{B}_{\mathrm{SUSY}} \propto (\tan\beta)^6$



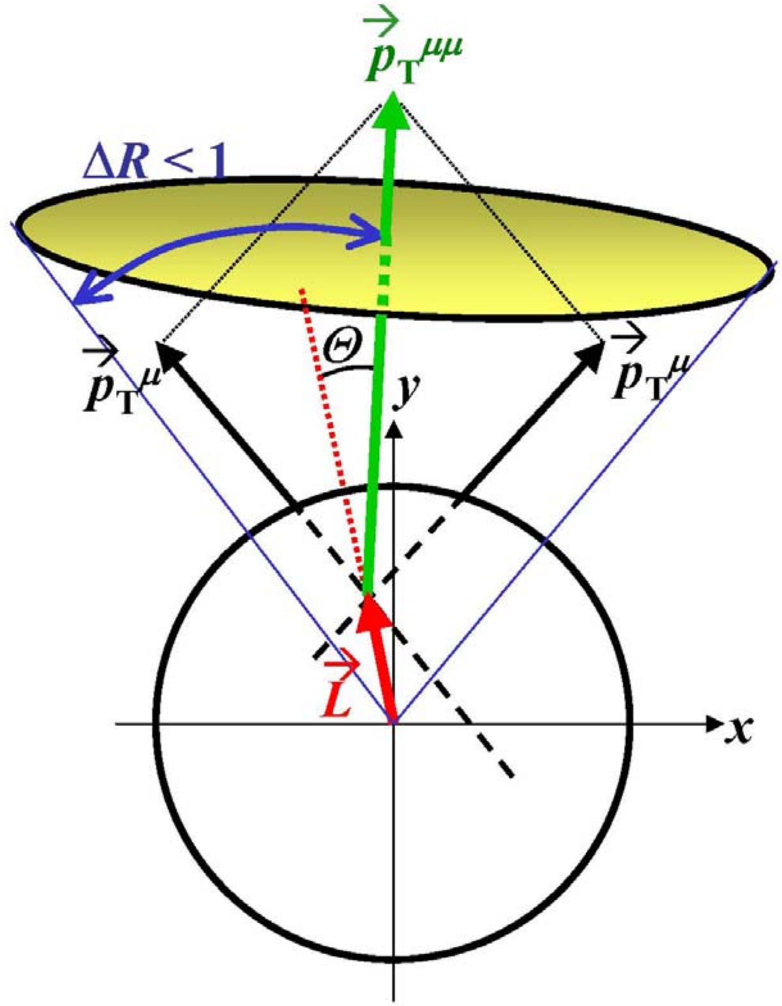
S. Baek, P. Ko, and W.-Y. Song,
PRL 89 (2002) 27801; hep-ph/0205259

The Tevatron could exclude:

a) **GMSB with lower N_m**

b) **Minimal AMSB**

if the $B_s \rightarrow \mu\mu$ decay is observed with $Br > 10^{-8}$.

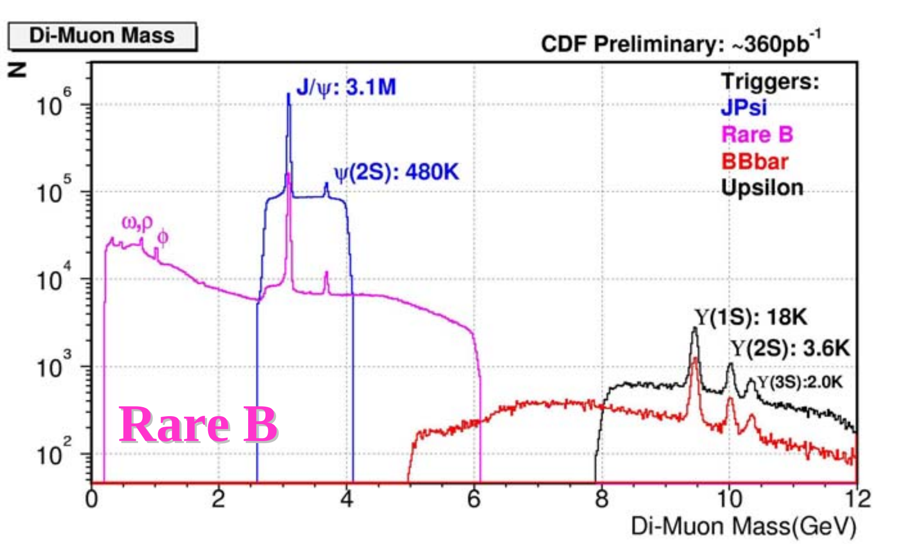


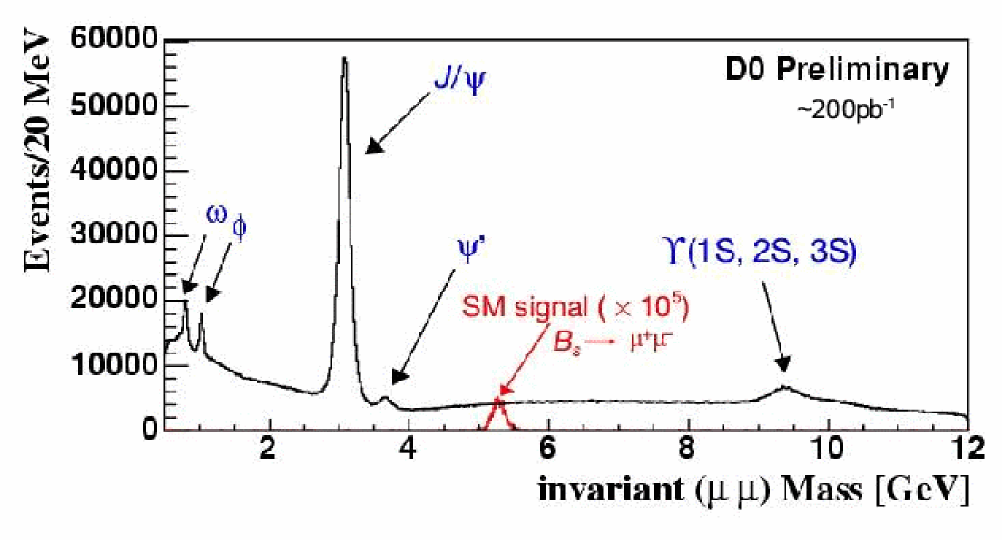
$$\frac{N_{B_s}}{N_{B^+}} = \frac{\mathcal{L}\cdot\sigma(p\bar{p}\rightarrow b\bar{b})}{\mathcal{L}\cdot\sigma(p\bar{p}\rightarrow b\bar{b})} \bullet \frac{f_s}{f_u} \bullet \frac{\mathcal{B}(B_s\rightarrow\mu^+\mu^-)}{\mathcal{B}(B^+\rightarrow J/\psi\,K)\cdot\mathcal{B}(J/\psi\rightarrow\mu^+\mu^-)} \bullet \frac{(\varepsilon^{\mu\mu}_{\mathrm{trig}}\cdot A)^{\mathrm{total}}_{Bs}}{(\varepsilon^{\mu\mu}_{\mathrm{trig}}\cdot A)^{\mathrm{total}}_{B^+}}$$

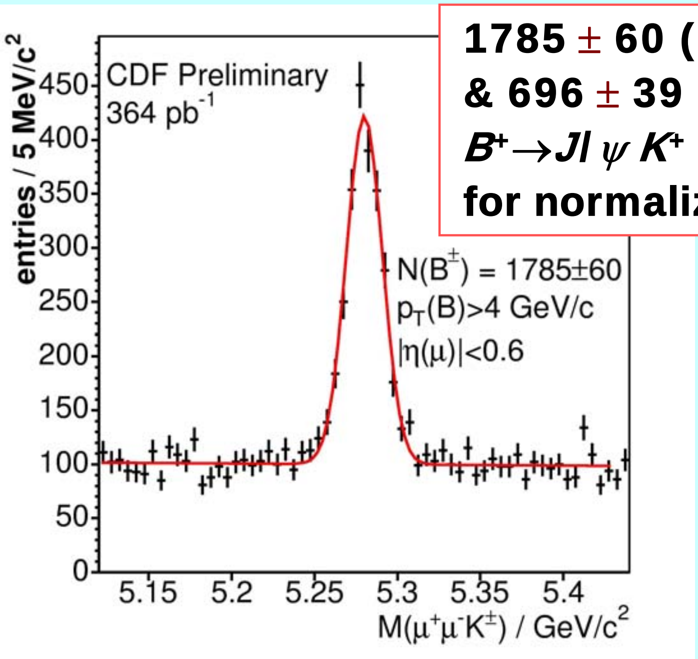
CDF Analysis

DØ Analysis

Largest systematic uncertainty: $f_u / f_s = 3.83 \pm 0.57$ (HFAG2004)

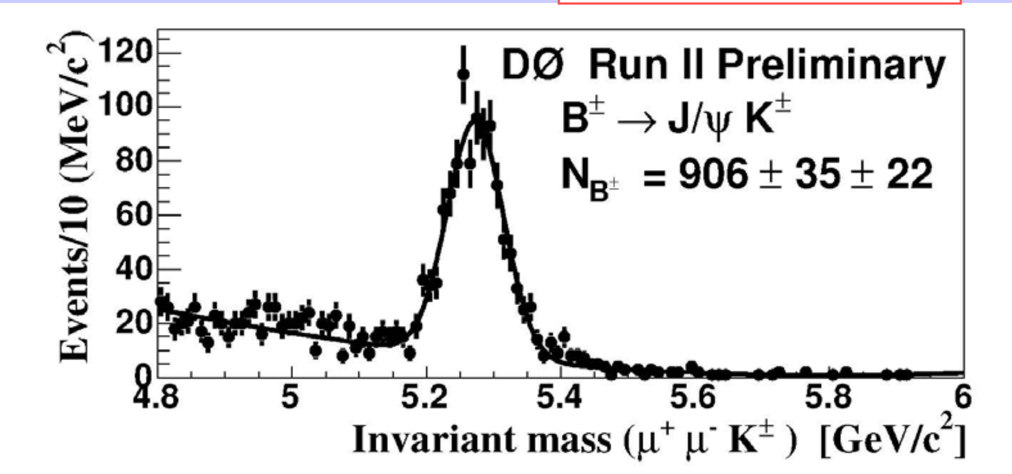






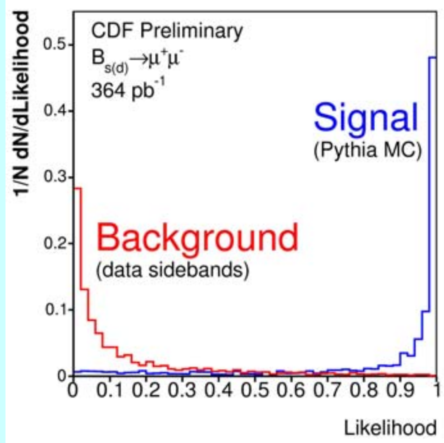
1785 ± 60 ($|\eta|<0.6$)
& 696 ± 39 ($|\eta|<1.0$)
$B^+ \to J/\psi K^+$
for normalization

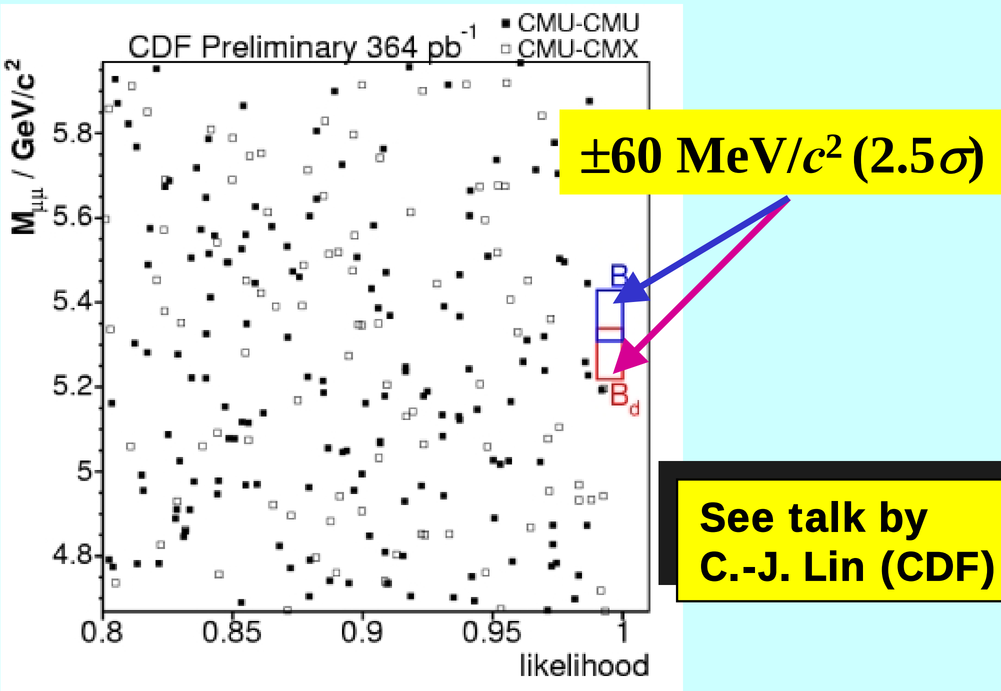
$906 \pm 35 \pm 22$
$B^+ \to J/\psi K^+$
for normalization



Powerful Likelihood method to reduce BG events with LH > 0.99

- N_{BG} = 1.47± 0.18
- N_{obs} = 0

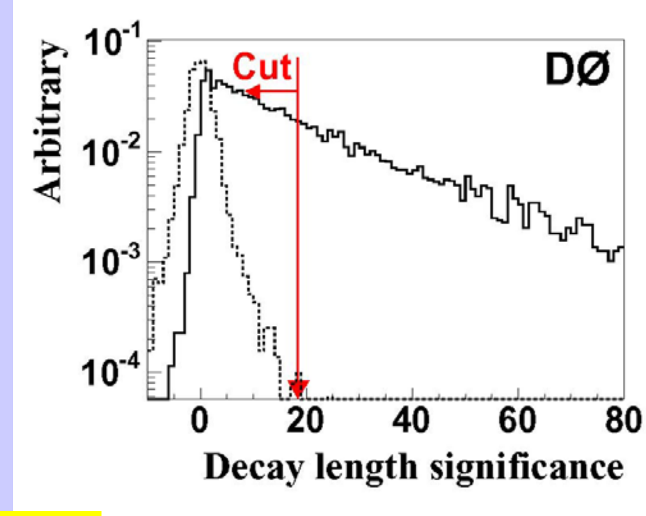


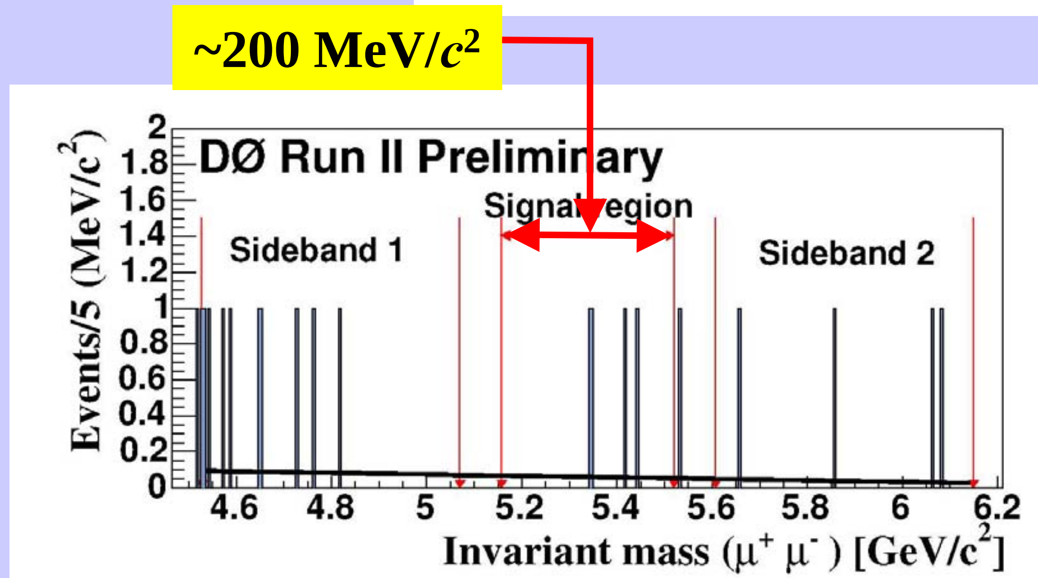


See talk by C.-J. Lin (CDF)

Powerful lifetime information to reduce BG events

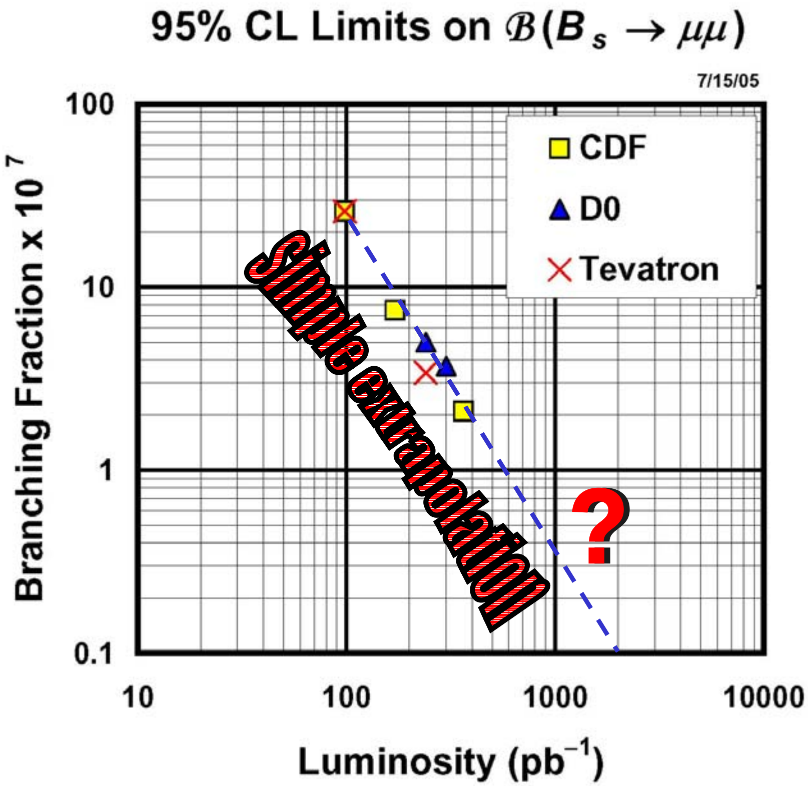
- N_{BG} = 4.3 ± 1.2
- N_{obs} = 4



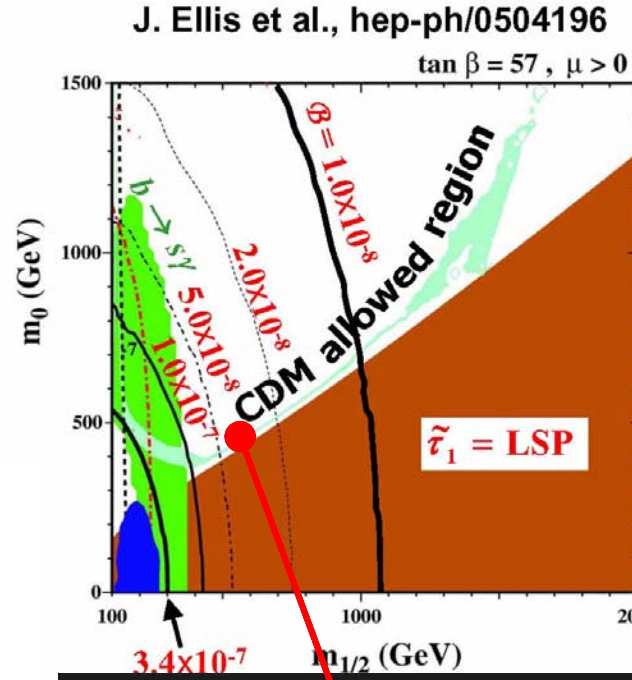


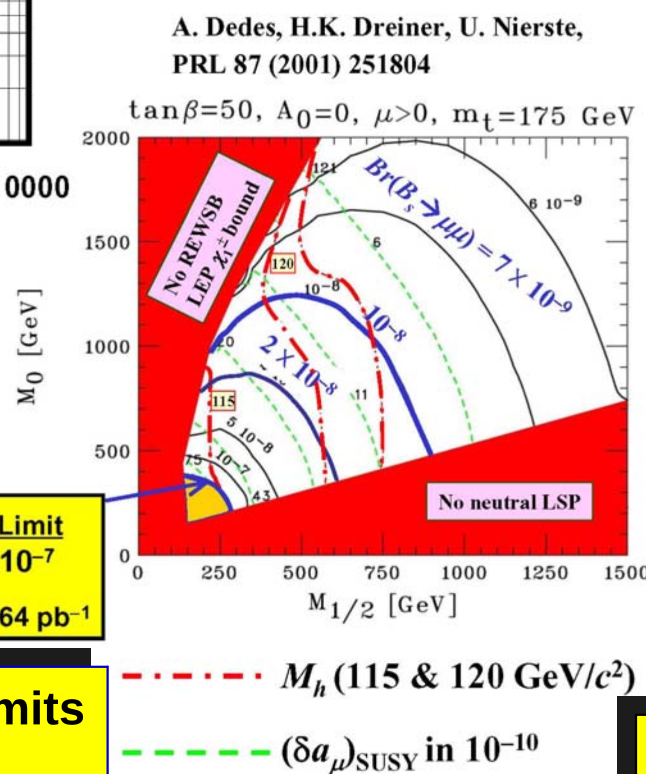
95%CL	CDF	D0	Tevatron
$Br(B_s \to \mu^+\mu^-)$	2.0×10^{-7}	4.1×10^{-7}	$X.X\times10^{-7}$
$Br(B_d \to \mu^+\mu^-)$	4.9×10^{-8}	11.1×10^{-8}	$Y.Y\times10^{-8}$

$\mathcal{B}(B_s \to \mu\mu)$ and Cosmological Connection

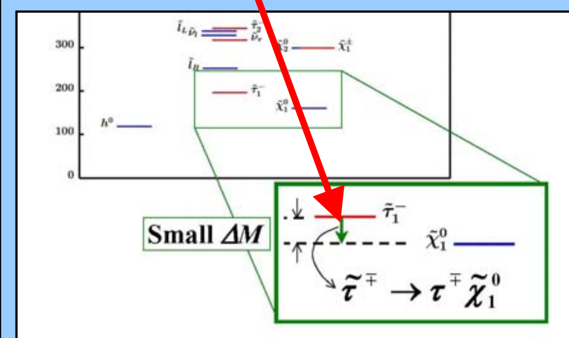


Tevatron
→LHC/ILC
→Cosmology





CDF Limit
2.0×10^{-7}
CDF : 364 pb^{-1}



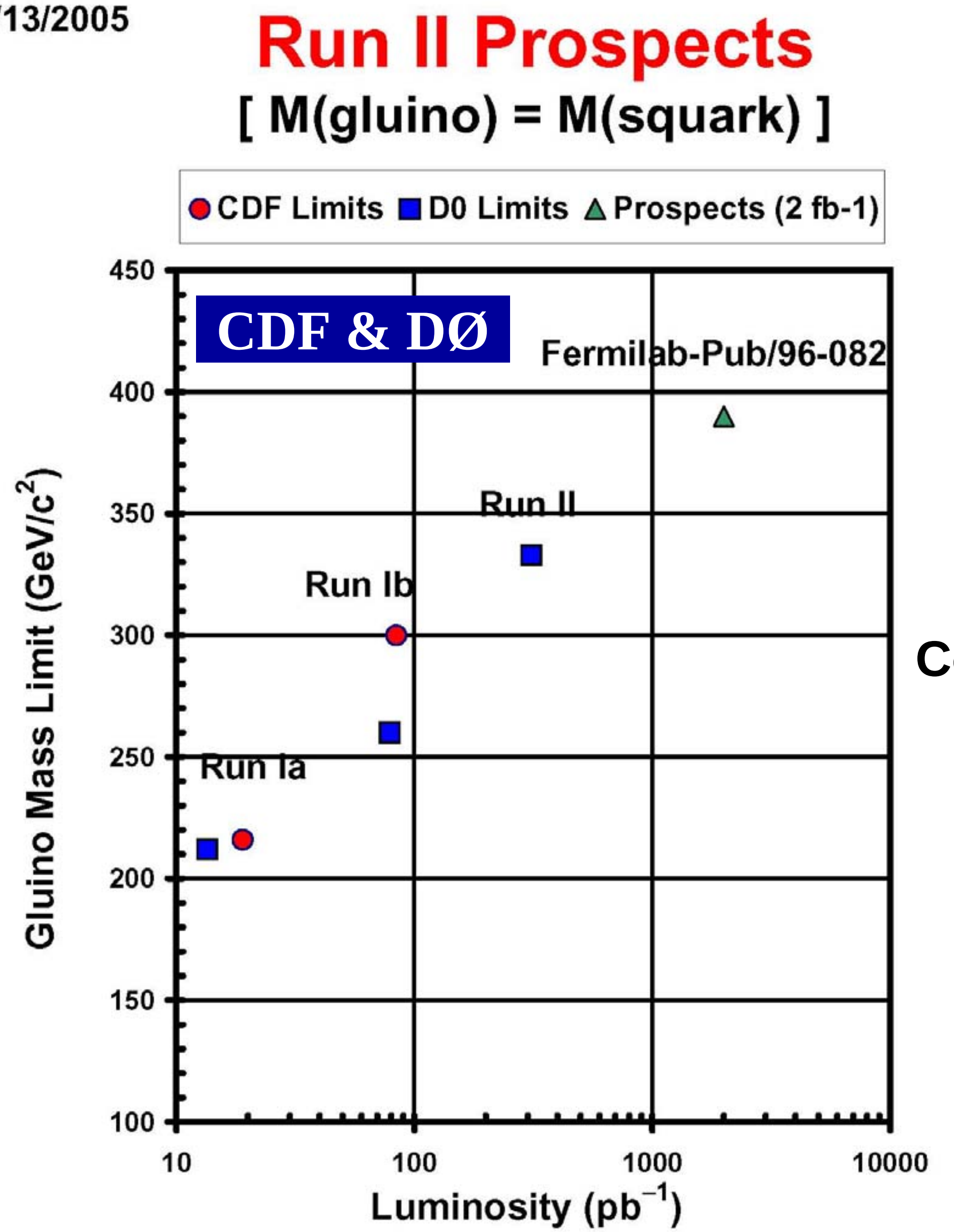
SUSY co-annihilation signals at LHC and ILC?

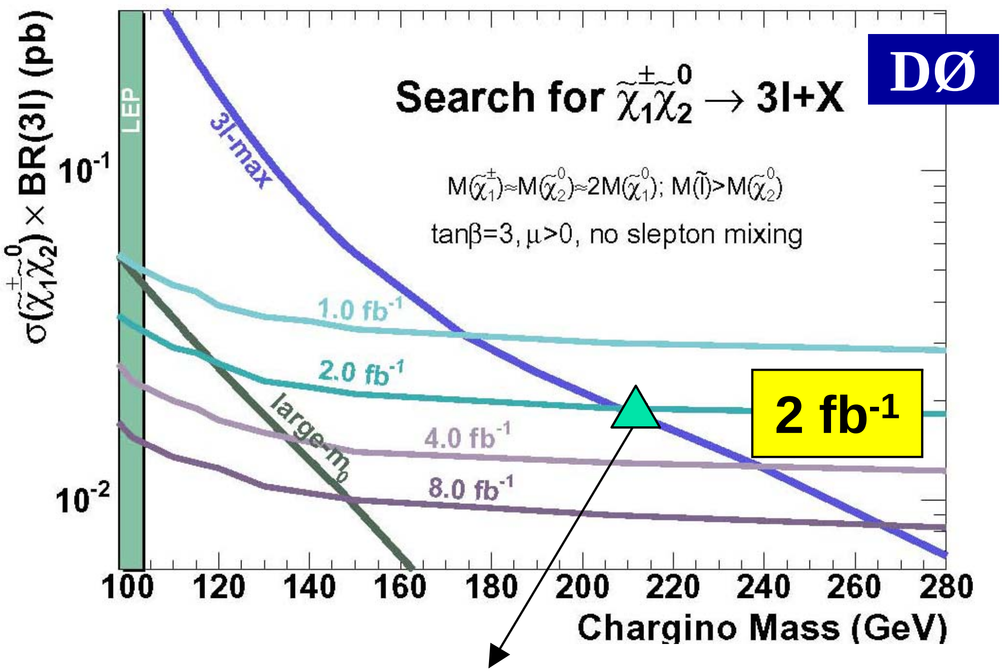
Note: "Tevatron" limits will be ready soon.

See, for example, talk by B. Dutta (Regina)

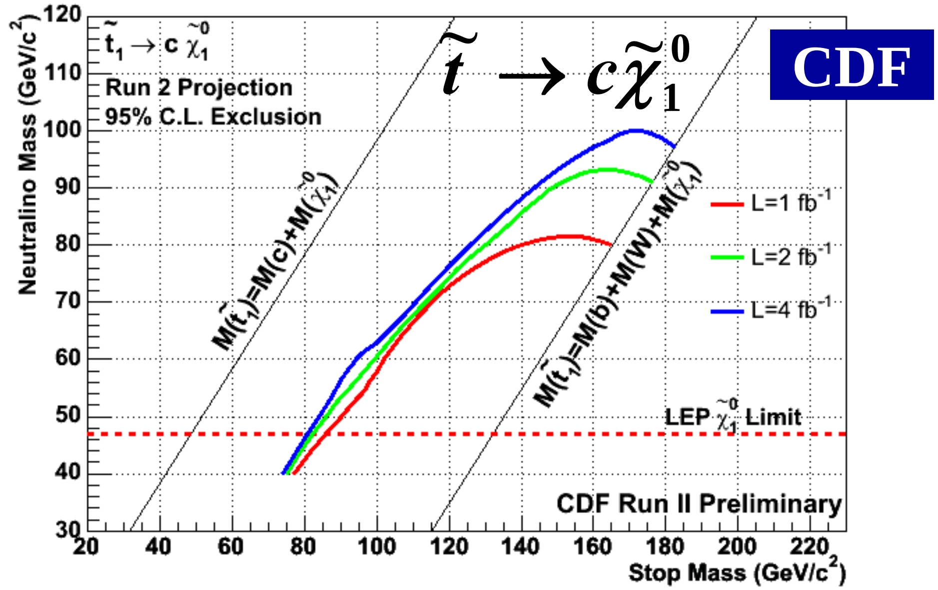
Prospects : Gaugino & Stop Masses

7/13/2005

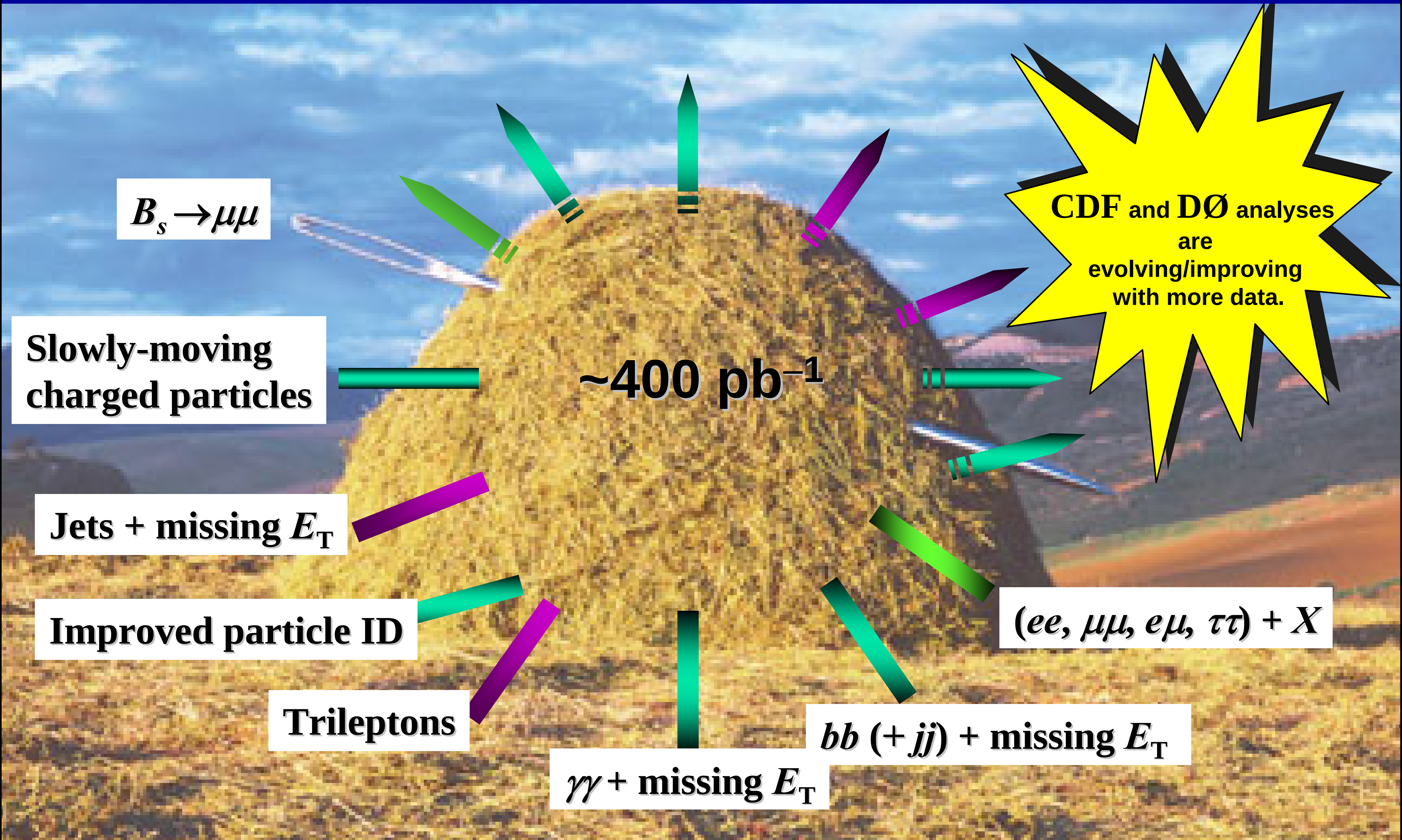




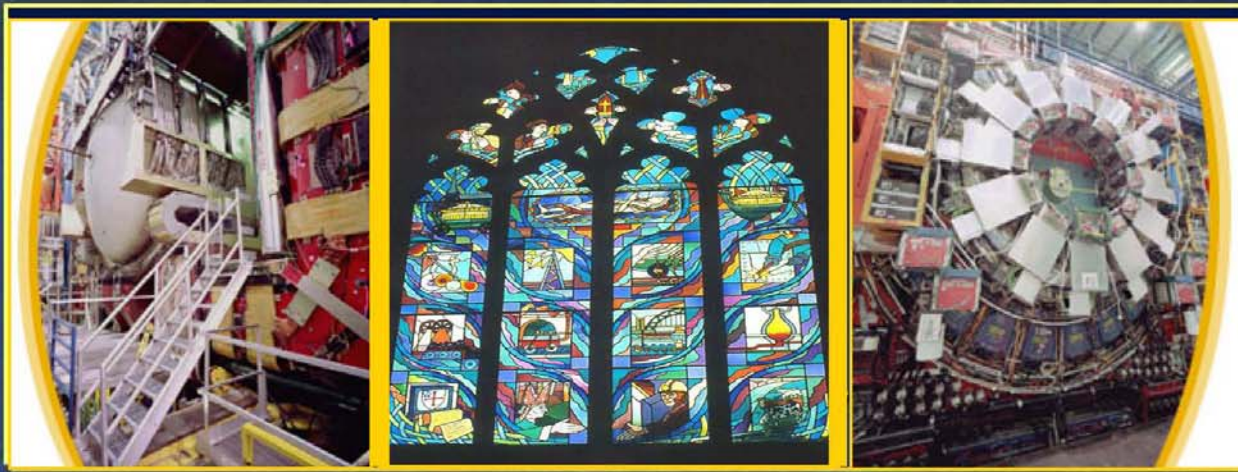
Corresponding to ~600 GeV/c^2 gluino mass



Summary

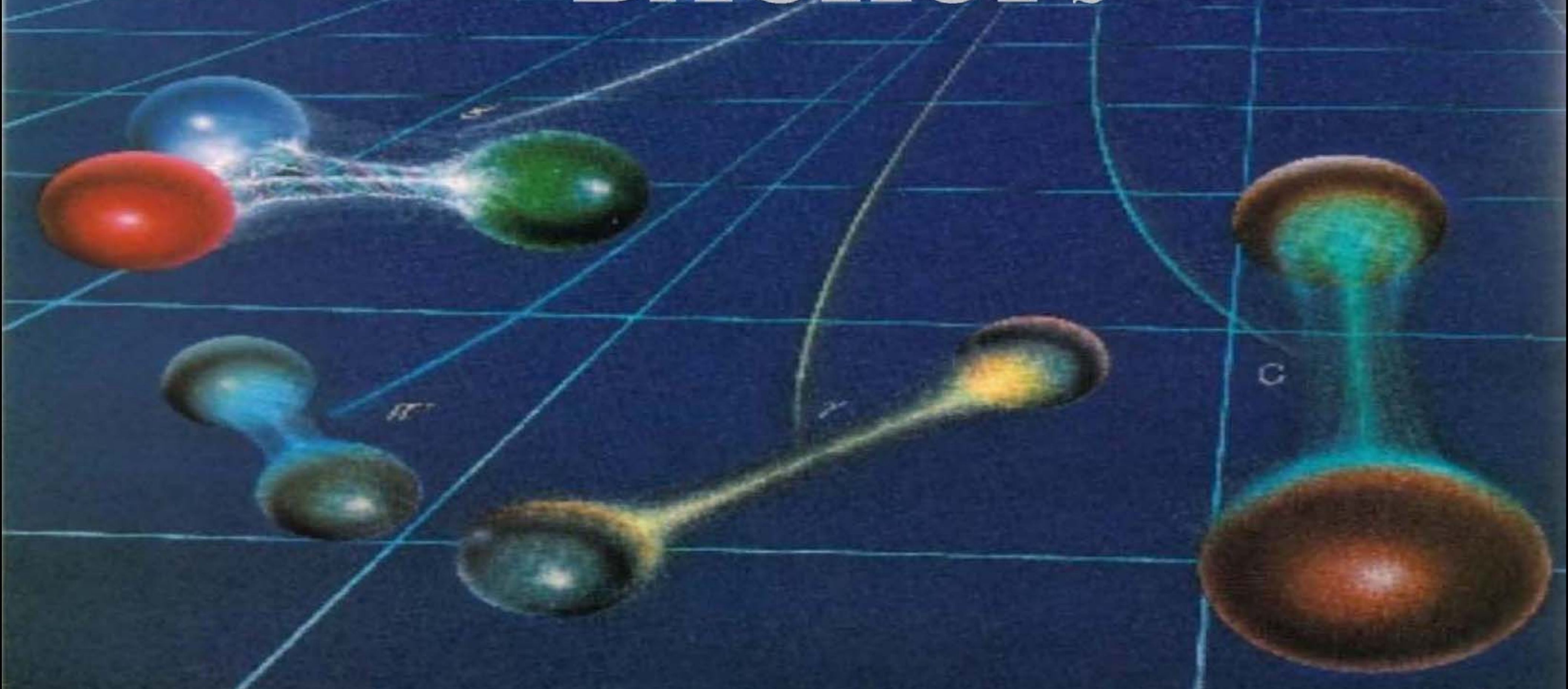


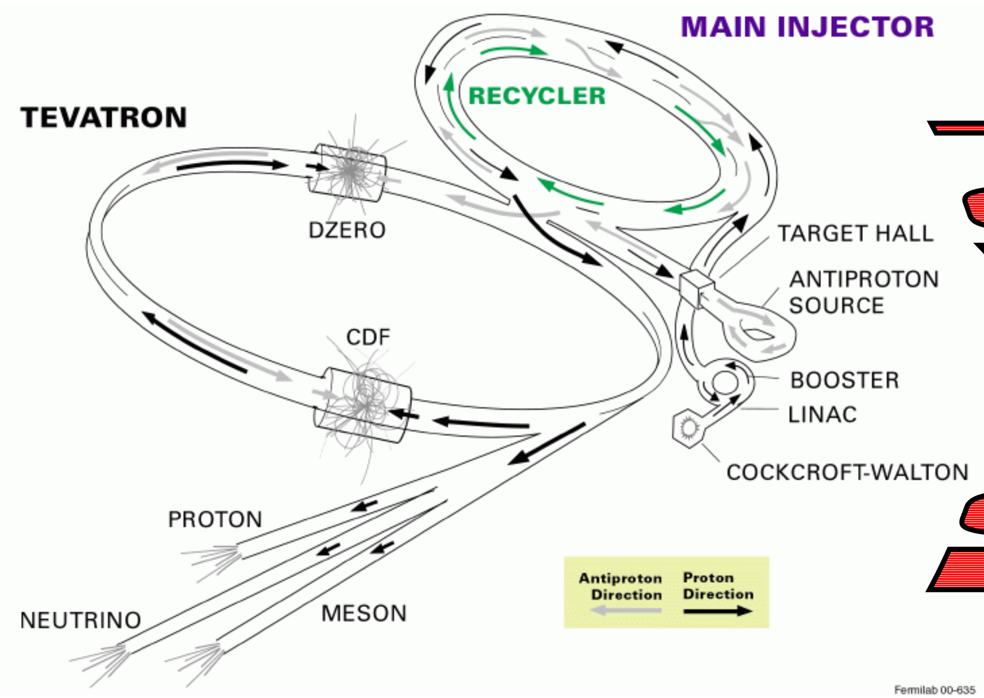
$B_s \rightarrow \mu\mu$
Slowly-moving charged particles
Jets + missing E_T
Improved particle ID
Trileptons
$\gamma\gamma$ + missing E_T
bb (+ jj) + missing E_T
(ee, $\mu\mu$, $e\mu$, $\tau\tau$) + X
~400 pb^{-1}
CDF and DØ analyses are evolving/improving with more data.



From サイエンス '82

BACKUPs





Tevatron

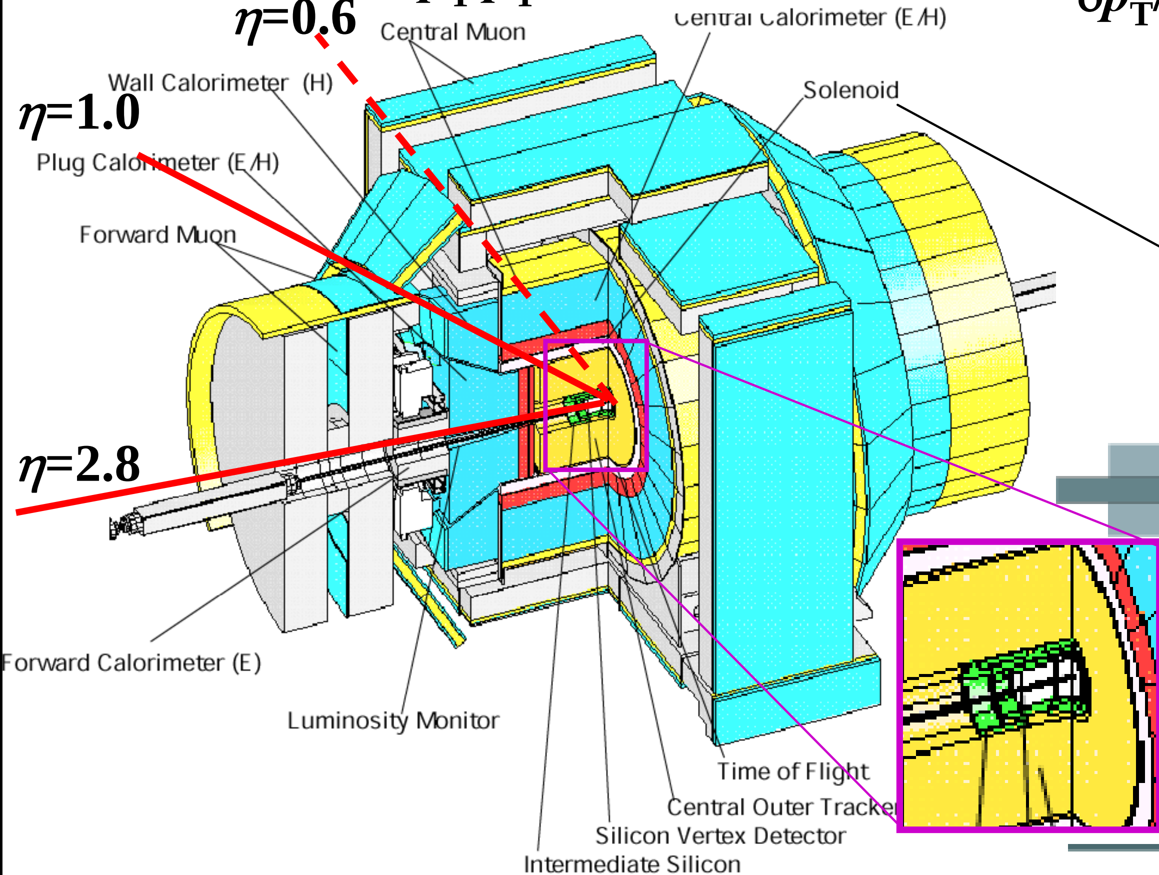
	Run 2
$N_{bunches}$	36 x 36
$\sqrt{s}$ (TeV)	1.96
Highest $\mathcal{L}$ ($cm^{-2}s^{-1}$)	1.3×10^{32}
Bunch Crossing (ns)	396
Interactions/Crossing	~3

CDF and DØ

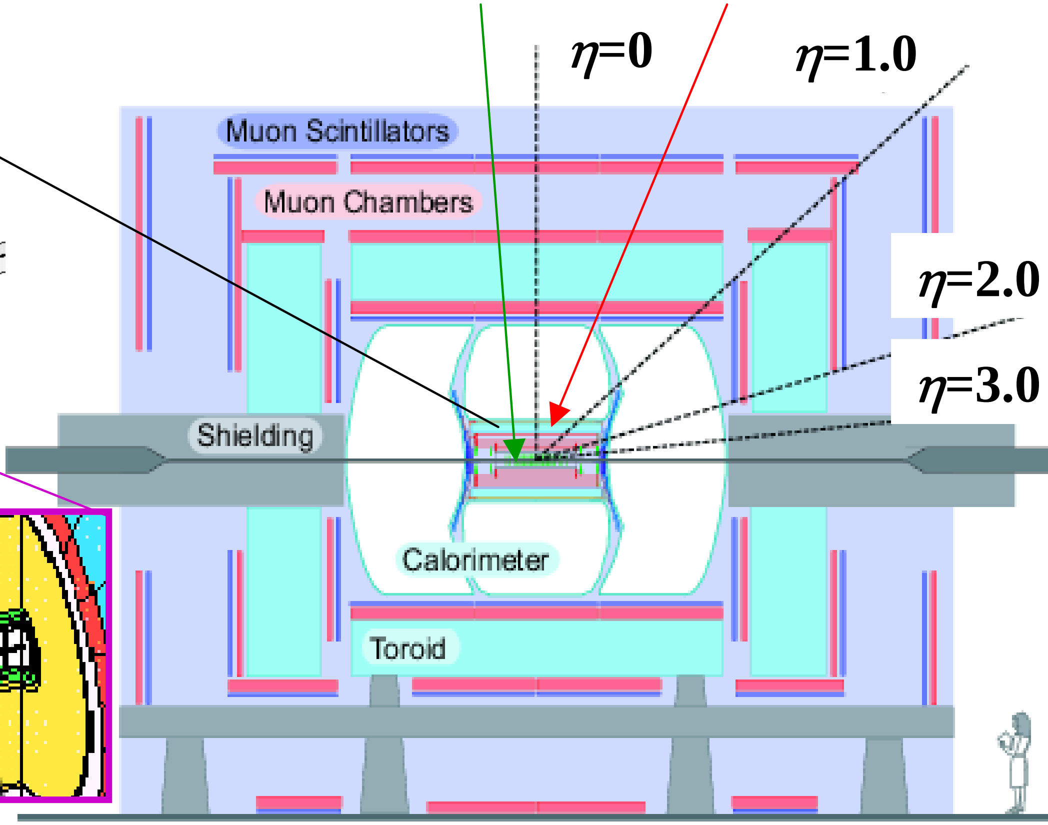
(Fermilab-Pub-96/390-E, Fermilab-Pub-96/357-E)

Tracking, Calorimeter, Muon, Trigger, DAQ

$\delta p_T/p_T^2 = 0.001$



$\delta p_T/p_T^2 = 0.002$ (w/ Silicon + Fiber trackers)



$\|\eta\|$ range	e^{trig}	e	μ^{trig}	μ	τ_h^{trig}	τ_h	j	b	c
CDF	1.1	2.4	1.0	2.0	1.0	2.0	3.0	2.0	2.0
DØ	1.5	3.0	1.7	2.0	1.7	2.0	3.0	2.0	2.0