Prospects for SUSY Discovery at the Tevatron

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for
CDF and DØ Collaborations

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on Supersymmetry
and Unification of Fundamental Interactions
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Outline

Motivation

Tevatron Upgrades

- Luminosity *Profile*
- Luminosity *Now*

CDF and DØ Upgrades

- Improvements
- Trigger Rates

Selected Topics

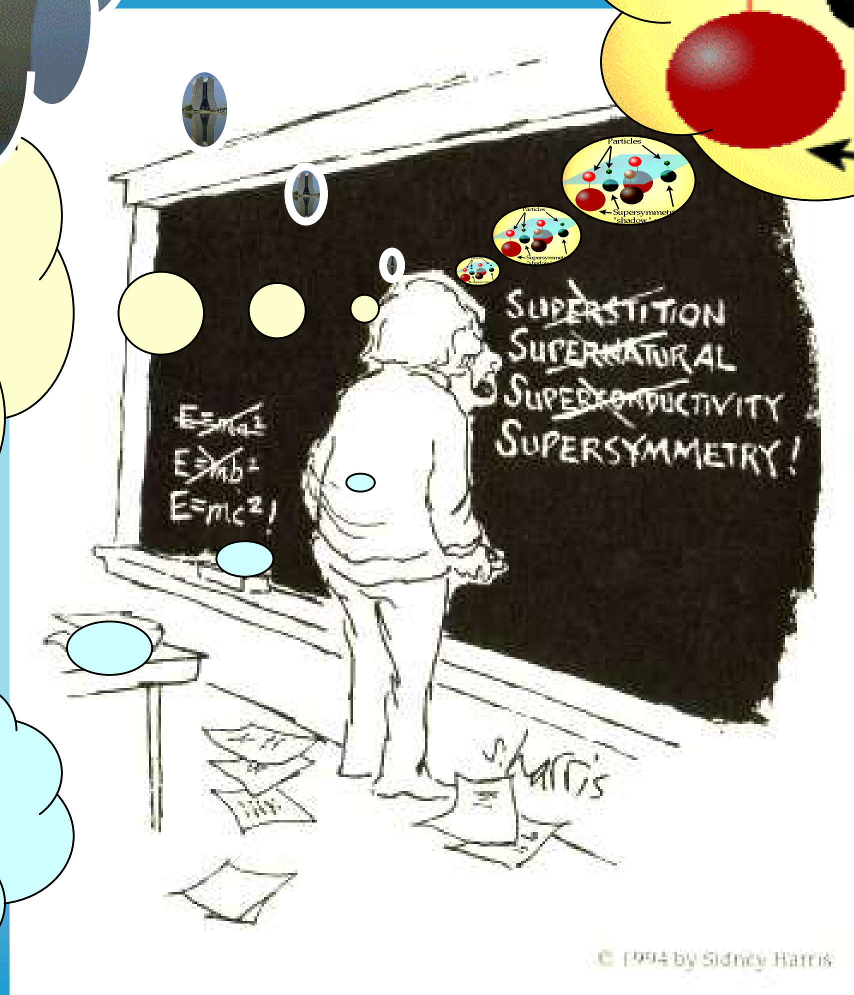
- Direct Searches
- SUSY in $B_s \rightarrow \mu\mu$

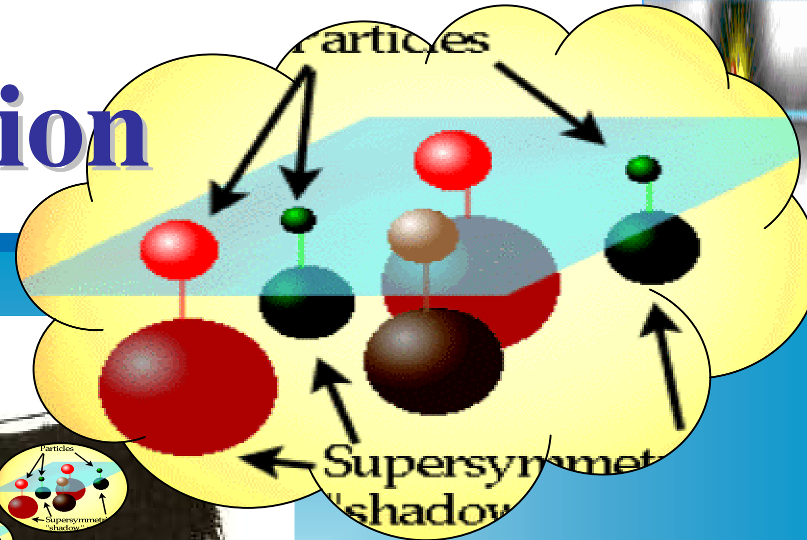
Summary

Motivation

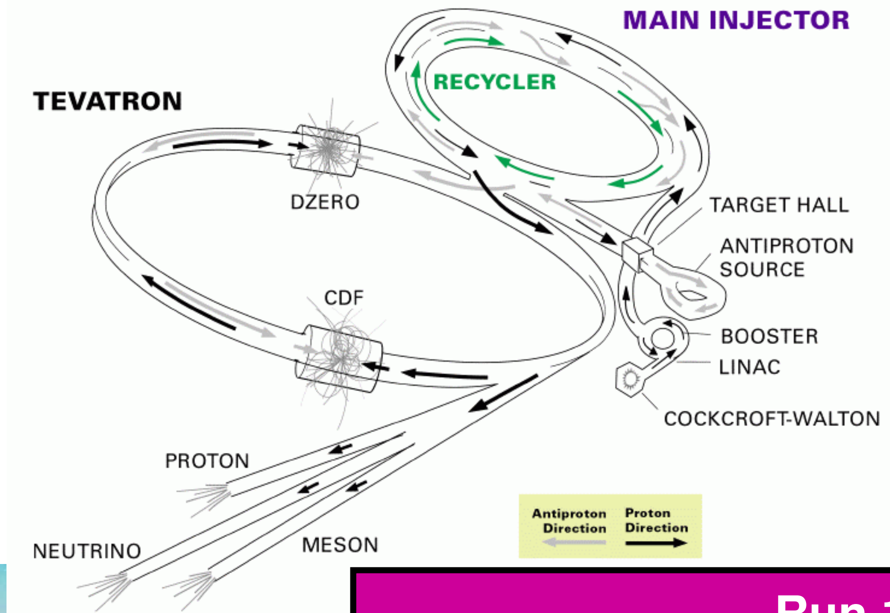
SUGRA
GMSB
AMSB
$\tilde{g}$MSB

R_p or $\not{R}_p$

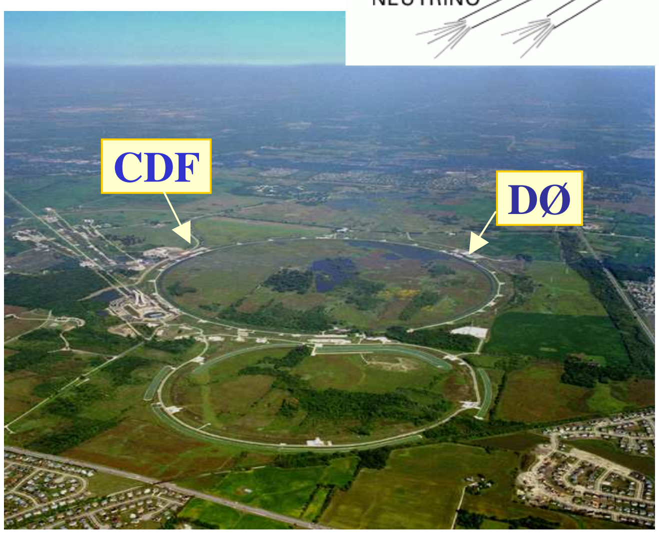




Tevatron



$\int L dt = 15\ \text{fb}^{-1}$



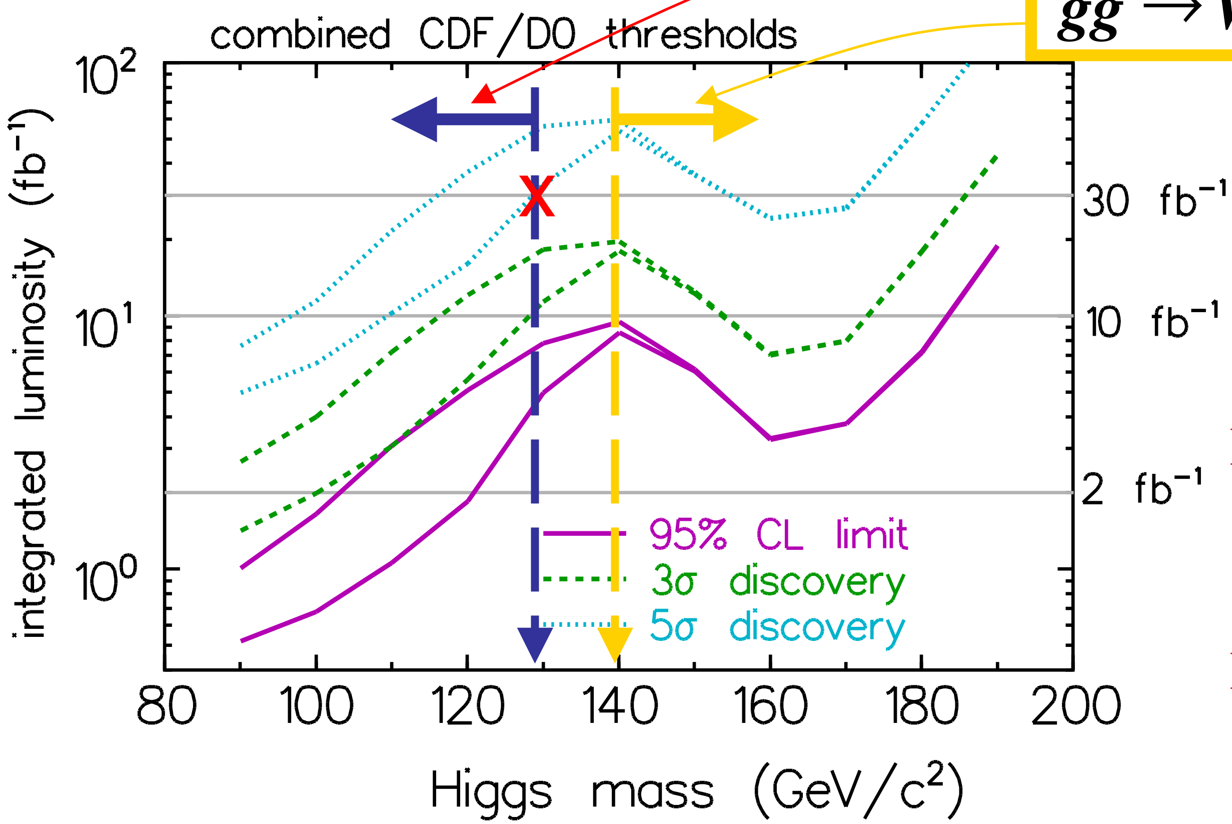
	Run 1b	Run 2a	Run 2b
$N_{bunches}$	6x6	36x36	140x103
$\sqrt{s}$ (TeV)	1.8	1.96	1.96
typ L ($cm^{-2}s^{-1}$)	1.6×10^{30}	8.6×10^{31}	5.2×10^{32}
$\int L dt$ (pb^{-1}/week)	3.2	17.3	105
Bunch xing (ns)	3500	396	132
Interactions/xing	2.5	2.3	4.8

Why 15 fb^{-1}?

Tevatron (Run IIa/IIb)

$q\bar{q} \to W(Z)\,h \to l\nu(\nu\nu)\,b\bar{b}$

$gg \to WW^* / ZZ^* \to l^+ l^- X$



Run IIb

Run IIa

KEY:
$\sigma(M_{bb})/M_{bb}$ improved by 30%

Source: Higgs working group report (SUSY/Higgs Workshop, 1998)

Luminosity *Profile*

Source: Steve Holmes, October 25, 2000

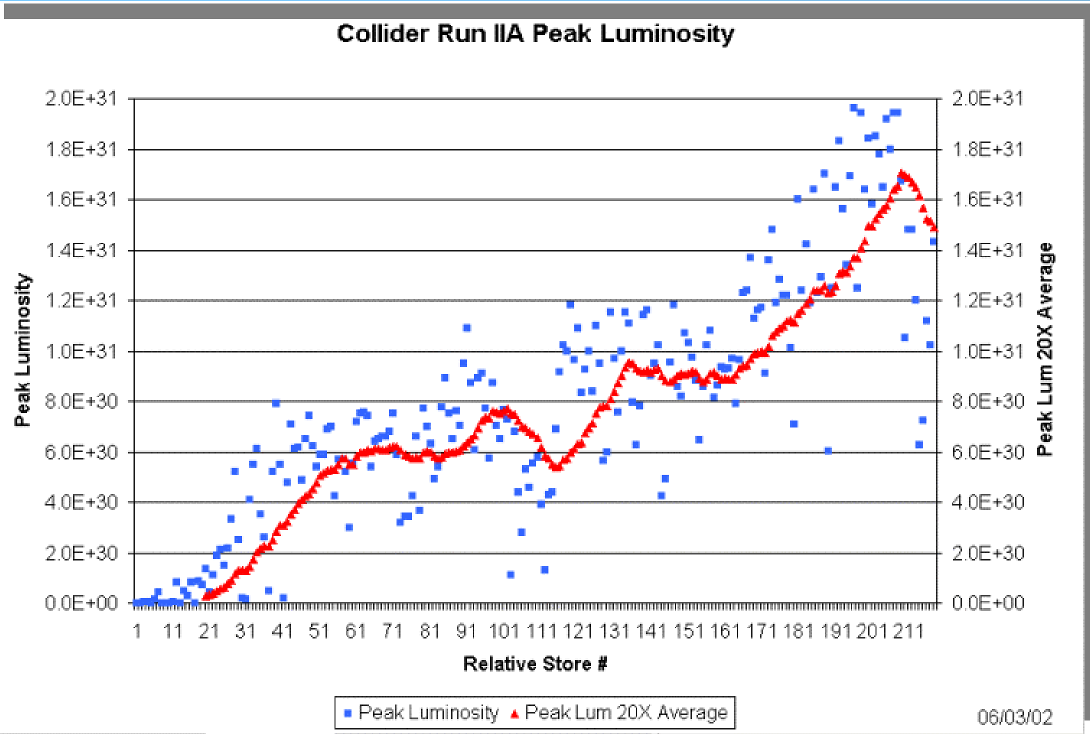
C.Yr	Lum.	Operation [months]	Integrated Luminosity (cumulative) [fb-1/yr]	Shutdown [months]	Comments
2001	3.0E+31	9	0.3 (0.3)	1	Hope to average slightly in excess of best previous performance.
2002	8.0E+31	10	0.8 (1.1)	2	Install 132 nsec equipment late in year.
2003	1.2E+32	8	1.0 (2.0)	4	Go to 132 nsec. Make Recycling work. Achieve 2E+32 by end of year. Shutdown for electron cooling.
2004	2.0E+32	11	1.8 (3.8)	1	Initiate NuMI (20% uminosity impact)
2005	4.0E+32	8	2.6 (6.4)	4	Shutdown for Run IIb silicon (could be in 2003 if ready). C-0 IR.
2006	5.0E+32	11	4.4 (10.8)	1	
2007	5.0E+32	10	4.0 (14.8)	1	Initiate Kaon program and BTeV

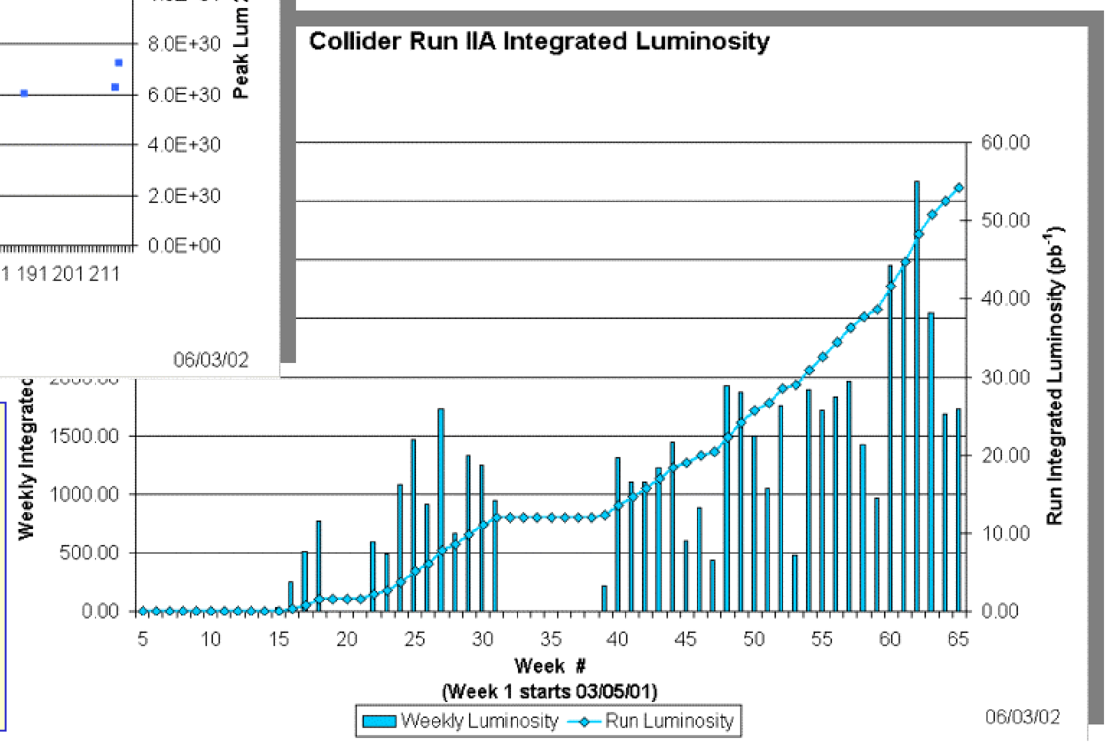
Run IIa (2001–2004)

Run IIb (2004–2007)

Also see Dave McGinnis, "Tevatron Collider Luminosity Upgrades," Joint Experiment Theoretical Physics Seminar, March 8, 2001

Luminosity *Now*



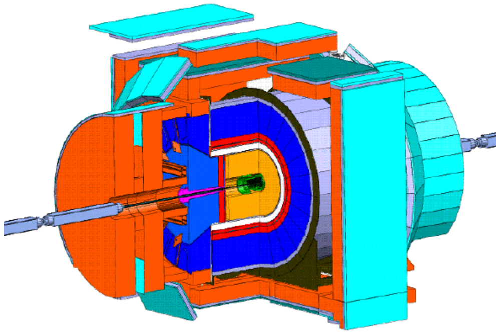


Peak Luminosity:

1.95×10^{31} (actual @6/01/02)

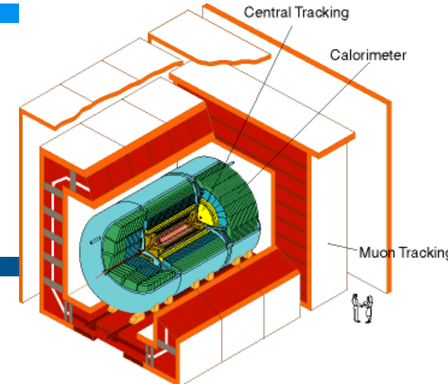
3.93×10^{31} (goal @6/01/02)

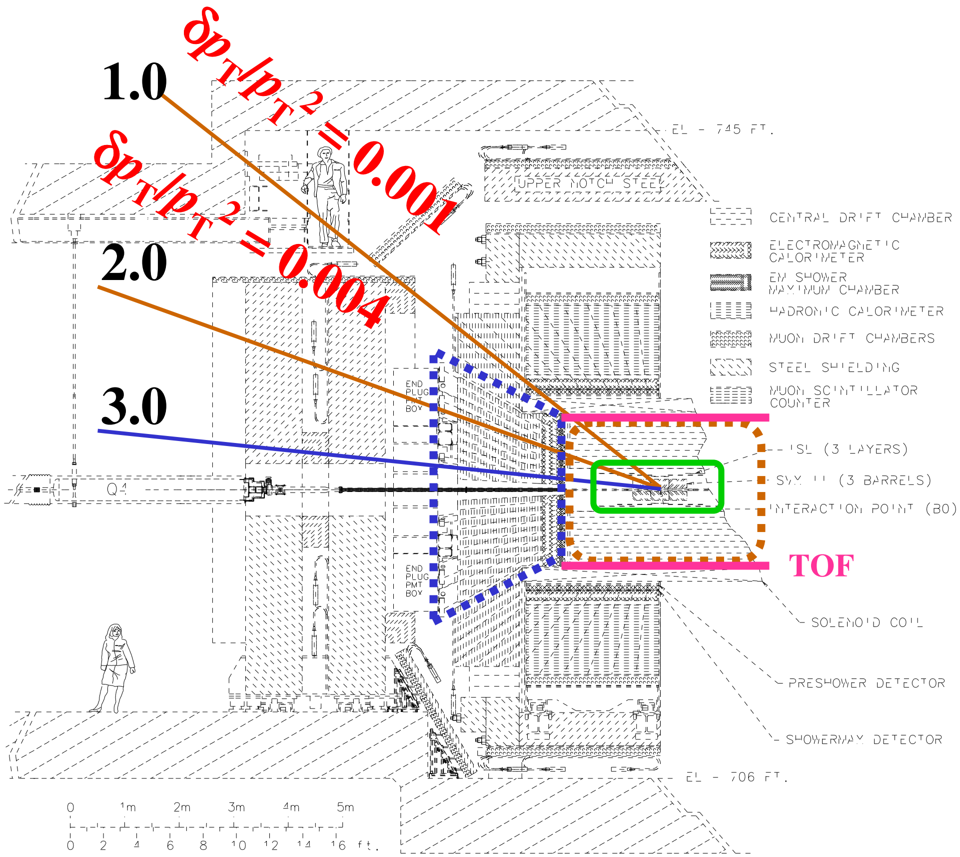
8.64×10^{31} (goal @12/31/02)



CDF and DØ

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

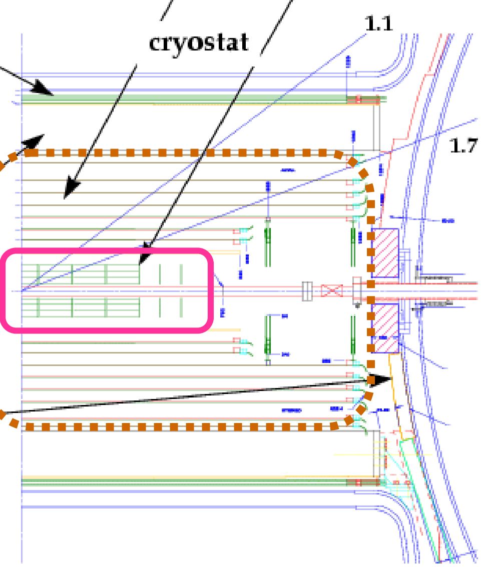




$\delta p_T/p_T^2 = 0.002$

(with SMT + fiber tracker)

- Silicon Tracker
  - Four layer barrels (double/single sided)
  - Interspersed double sided disks
  - 840,00 channels
- Fiber Tracker
  - Eight layers sci-fi ribbon doublets (z-u-v, or z)
  - 74,000 830um fibers w/ VLPC readout
- Central Preshower
  - Scintillator strips, WLS fiber readout
  - 6,000 channels
- Solenoid
  - 2T superconducting
- Forward Preshower
  - Scintillator strips, stereo, WLS readout
  - 16,000 channels



→ **Also new front-end, DAQ and trigger electronics for both detectors**

CDF and DØ Upgrades

CDF

- New front-end, DAQ and trigger electronics
- New silicon vertex (SVX) detector
- New central tracker drift chamber
- New scintillation-tile end-plug EM and HAD calorimeters
- Increased η-ϕ coverage for muon detector
- New time-of-flight (TOF) system

DØ

- New front-end, DAQ, and trigger electronics
- New silicon micro-strip tracker (SMT)
- New scintillation-fiber tracking system
- New 2T solenoid magnet
- New preshower detector added to the existing calorimetry
- New muon system

$\|\eta\|$ range	e^{trig}	e	μ^{trig}	μ	τ_h^{trig}	τ_h	j	b	c
CDF	1.1	2.4	1.2(1.5)	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

CDF and DØ Improvements

CDF

$\vec{p}$: $\delta p_T/p_T^2 = 0.004$ for $1 < |\eta| < 2$ (with SVX)

[Still $\delta p_T/p_T^2 = 0.001$ for $|\eta| < 1$]

e: η coverage, 33% up for tt

μ: η coverage, 12% up for tt (30% up for W)

η^{trig}: 0.6-1.0 to 1.2(1.5) at the beginning (later) of Run II

τ: ID in $1 < |\eta| < 2$

b: Increase $\varepsilon_b(\mathrm{SVX})^2$ for tt by 62%

SVX trigger (SVT) at Level 2

DØ

$\vec{p}$: $\delta p_T/p_T^2 = 0.002$ (with SMT + fiber tracker)

e: Add an inclusive e trigger with $E_T > 7$ GeV

μ: Trigger/ID: $p_T > 1.5$ GeV/c (from 4 GeV/c)

High p_T resolution, improved by a factor of 2

τ: $\varepsilon^{ID} \sim 40\%$ (from 13%)

b: $\varepsilon_b(\mathrm{SMT}) \simeq 50\%$ for $t \rightarrow Wb$

SMT trigger (STT) at Level 2

CDF and DØ Trigger Rates

11 MHz

$L = 2 \times 10^{32}\ cm^{-2}s^{-1}$

CDF

- Level 1
- 45 kHz
- Level 2
- 300 Hz
- Level 3
- 75 Hz
- Offline

DØ

- Level 1
- 5 kHz
- Level 2
- 1000 Hz
- Level 3
- 50 Hz
- Offline

"Balance" the trigger budget between QCD-Bottom-EW-Top-Higgs-Others

History/Herstory of Prospect …

TeV2000 Report (Fermilab-Pub-96/082), Section 6 – SUSY Physics

a) Based on MSSM or mSUGRA

b) Experimental signatures

- Trilepton ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$)
- $\not{E}_T$ + jets ($\tilde{g}$ and $\tilde{q}$)
- $\not{E}_T + cc$ ($\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$)
- $\not{E}_T + bb$ ($\tilde{t}_1 \rightarrow b\tilde{\chi}_1^{\pm}$)

Proceedings of Run-II SUSY/Higgs Workshops (May & Nov. 1998)

- hep-ph/0003154 (SUGRA)
- hep-ph/0008070 (GMSB)
- hep-ph/0006160 (BTMSSM)
- hep-ph/0010338 (Higgs)

→ Trigger/ID for b, τ, low $\not{E}_T$, and γ (pointing back, timing): key in success

Alternative to Inclusive $\not\!\!E_T$, Jet, Lepton Triggers for Higher Luminosity

Low $\not\!\!E_T$(25)+J(10)+J(10) Trigger

- High mass gluino search with the canonical $\not\!\!E_T$+jets signature – much more efficient with lower $\not\!\!E_T$ threshold
- Lower $\not\!\!E_T$ threshold at Level 2 will drive the stop and sbottom analyses
- OK (80%) for $W(\rightarrow l\nu,\ \tau\nu)$+jets
- OK efficiency (60%) for top
- OK efficiency for Higgs
  - 56% for $W(\rightarrow jj)H_{125}(\rightarrow \tau\tau)$
  - 72% for $Z(\rightarrow \nu\nu)H_{140}(\rightarrow bb)$

Reliable parametrization of QCD high $\not\!\!E_T$ tails to reduce the systematic uncertainty

Two *b*'s Trigger w/ SVT

$H(\rightarrow bb) + X$

Calibration: $Z(\rightarrow bb) + X$

Lepton(8) + Track(5) Trigger

$\tau\tau(\rightarrow l\tau_h)$ final state as well as ll

e.g., $\tilde{\chi}_1^{\pm}(\rightarrow \tau\nu\tilde{\chi}_1^0)\tilde{\chi}_2^0(\rightarrow \tau\tau\tilde{\chi}_1^0)$

$bb+A(\rightarrow \tau\tau)$

Caliblation: $Z\rightarrow \tau\tau(\rightarrow l\tau_h)$

Source: SUGRA working group report (SUSY/Higgs Workshop, 1998)

Trigger for $\tau\tau + X$

Many interesting di-τ final states in SUSY and Higgs:

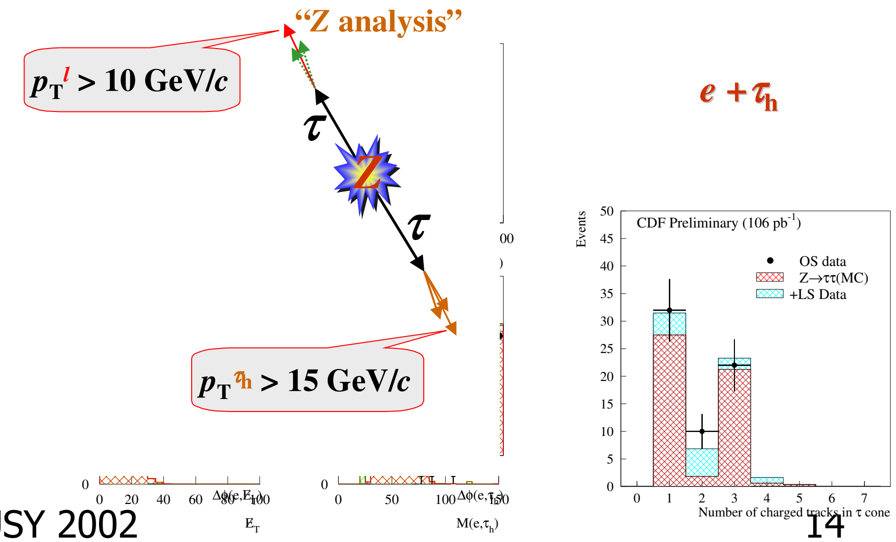
1) $l\tau\tau$ and $\tau\tau\tau$ are dominant final states in chargino-neutralino production at large tanβ of SUGRA
2) $\tilde{t}_1 \rightarrow b\tilde{\tau}\nu$ in mSUGRA
3) Stau NLSP in GMSB
4) $\tilde{t}_1 \rightarrow \tau b$ in R_p violation (λ'_{333})
5) $h/A \rightarrow \tau\tau$
6) $bb+A(\rightarrow\tau\tau)$ or $b+A(\rightarrow\tau\tau)$

Experimental challenge:

Trigger (and ID) for relatively low P_T τ leptons for higher luminosity

→ Lepton+track trigger is promising, compared to Di-τ_h trigger and $\not{E}_T + \tau_h$ trigger (including $W \rightarrow \tau\ \nu$)

Run I $e+\tau_h$ Analysis

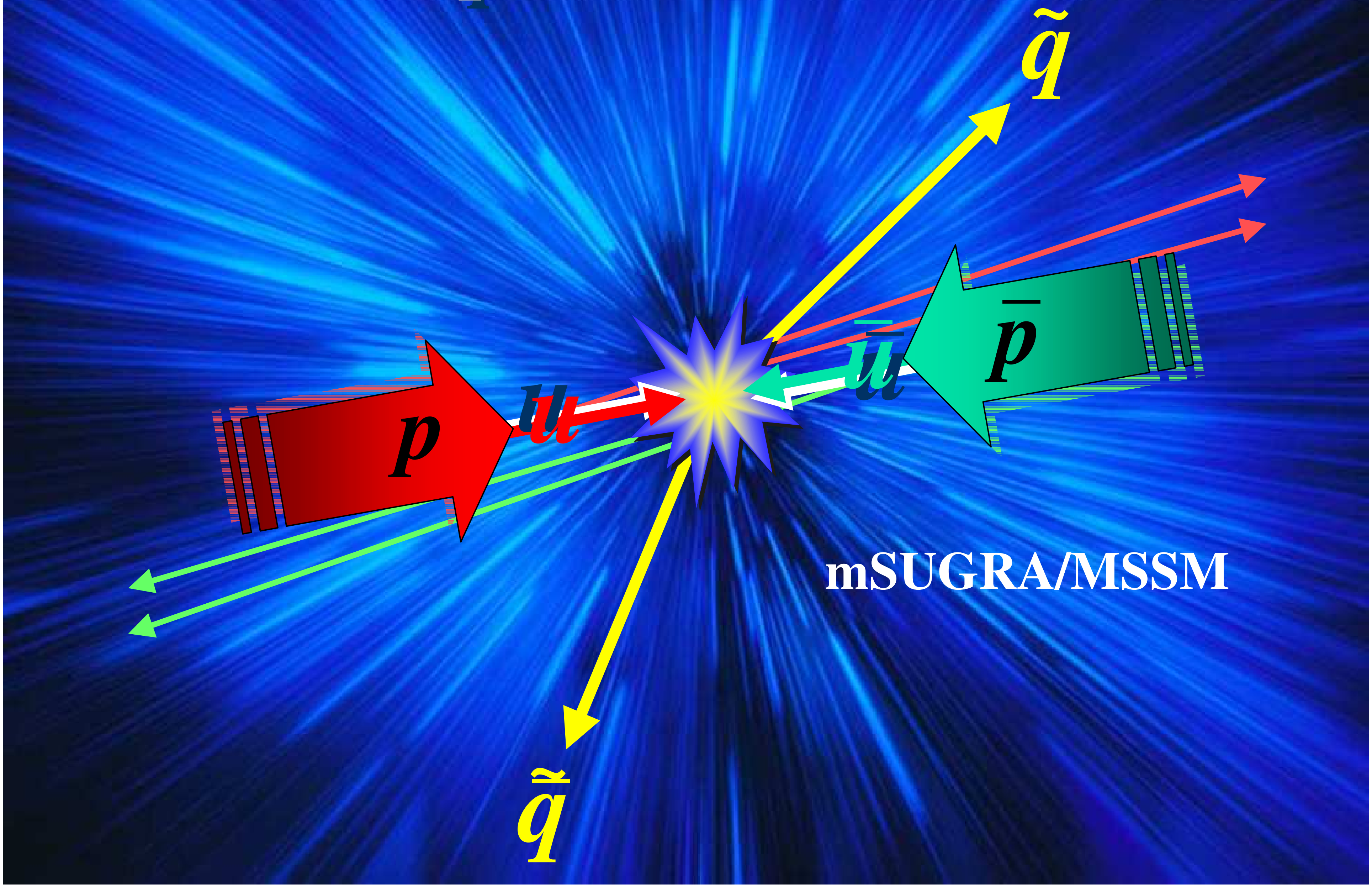


Prospects

including new ideas …

"Higgs and beyond …"

Squarks/Gluinos



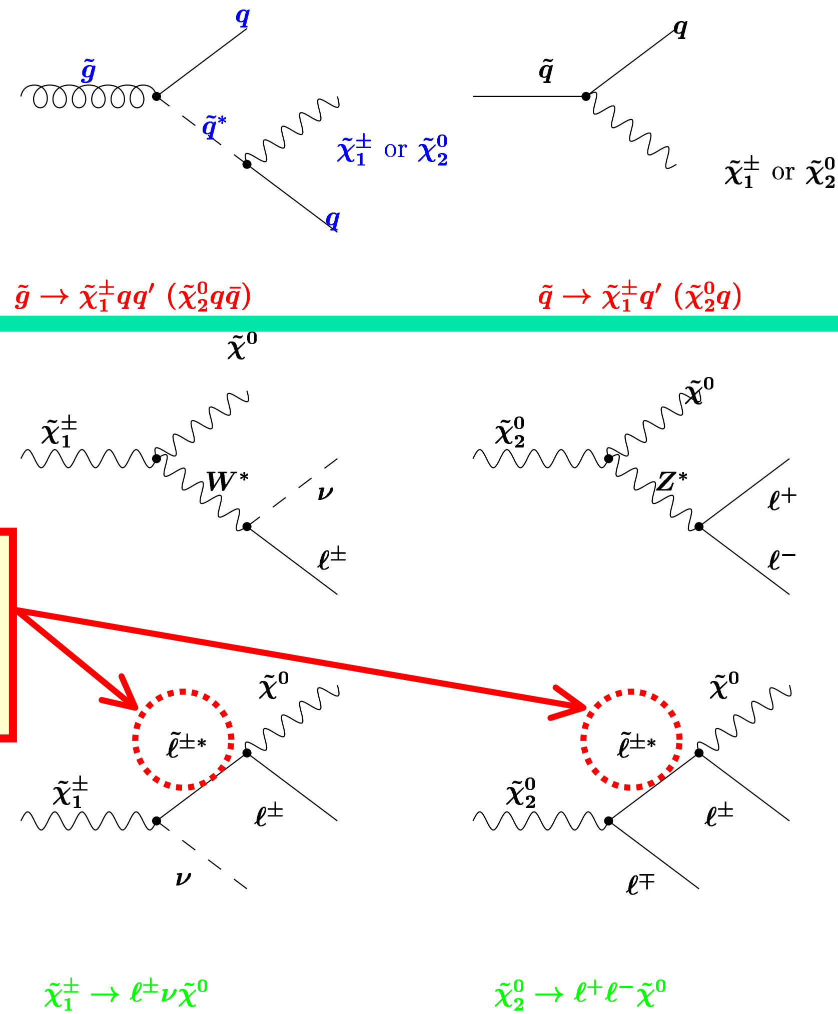
Signatures for $\tilde{g}/\tilde{q}$

Experimental Signatures

Cleaner, but small *Br*

a) $\not{E}_T$ + jets + 0 lepton
b) $\not{E}_T$ + jets + 1 lepton
c) (Like-sign) dilepton
d) …

The first signature is *less* sensitive to tan*β*.



$\tilde{g}/\tilde{q}$: Jets + $\not\!\!E_T$ + 0 Lepton

CDF, PRL 88 (2002) 041801

$N_{j15} \geq 3$, $\Delta\phi^{min}(j,\not\!\!E_T) > 0.5$ rad (28.6°)

$N_{trk10}^{iso} = 0$, $E_T^{j1} > 70$, $E_T^{j2} > 30$ GeV

$\not\!\!E_T > 70$, $H_T = \not\!\!E_T + E_T^{j2} + E_T^{j3} > 150$ GeV

V. Krutelyov *et al.*, PLB 505 (2001) 161

$N_{j15} \geq 4$, $\Delta\phi^{min}(j,\not\!\!E_T) > 30°$

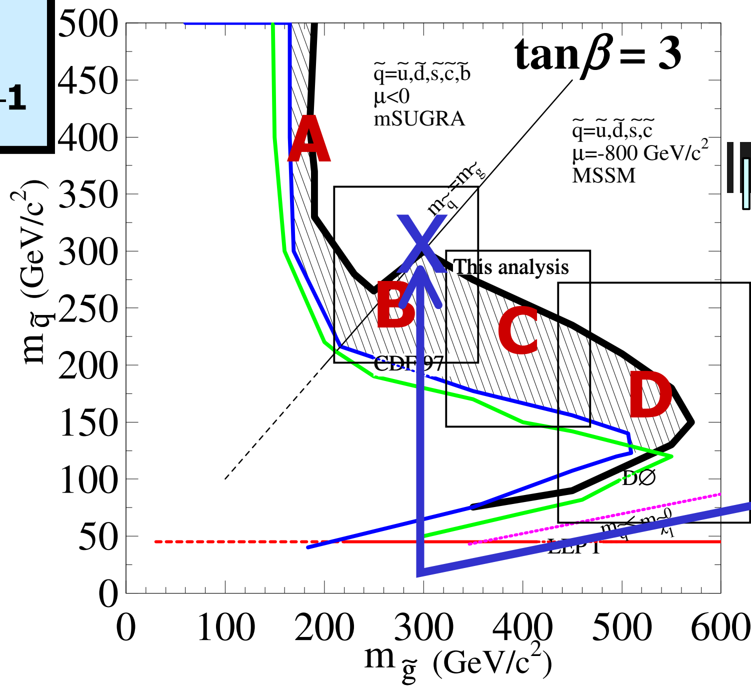
$N_{l15} = 0$

$\not\!\!E_T > 100$, $\not\!\!E_T + E_T^{j1} + E_T^{j2} > 350$ GeV

$N_{obs} = 74$, $N_{BG(QCD,tt,W/Z)} = 76 \pm 13$

Run I
84 pb^{-1}

Blind Search

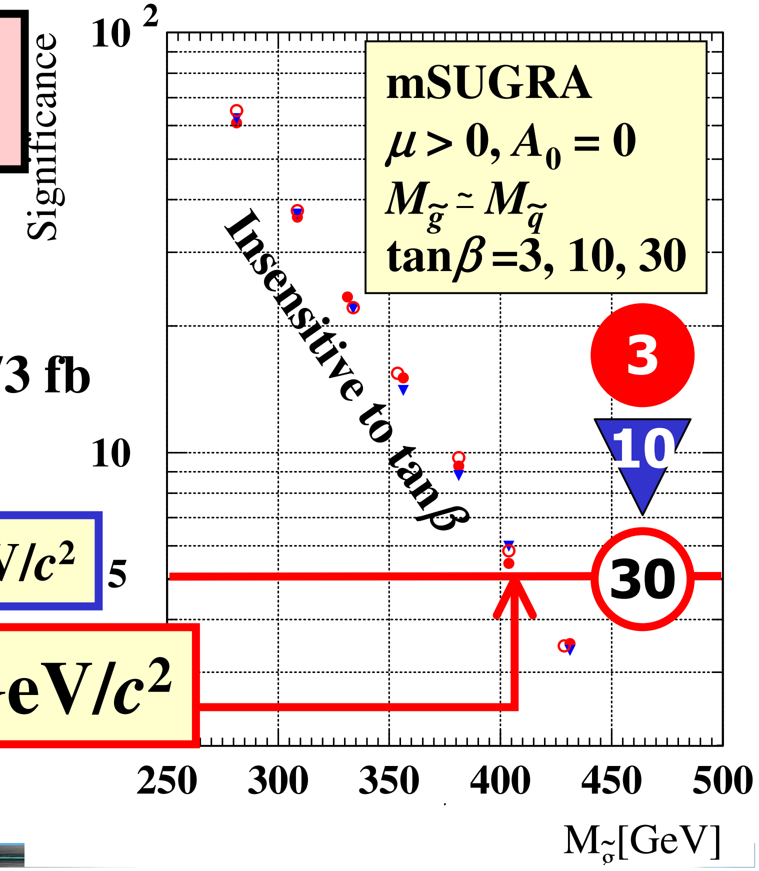


Run II
15 fb^{-1}

N_{BG} = 73 fb

300 GeV/c^2

410 GeV/c^2



Final $\not\!\!E_T$ and H_T cuts are optimized for each box. (*e.g.*, $\not\!\!E_T$>110, H_T>230 in **B**)

Backup Slide

$\tilde{g}/\tilde{q}$: Jets + $\not{E}_T$ + 0 Lepton

CDF, PRL 88 (2002) 041801

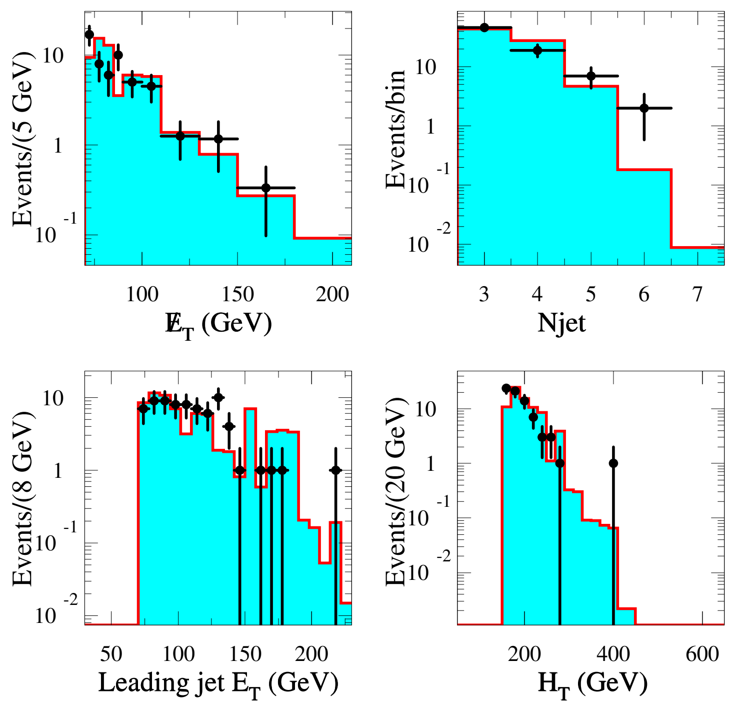
$N_{j15} \geq 3$, $\Delta\phi^{min}(j,\not{E}_T) > 0.5$ rad (28.6^o)

$N_{trk10}^{iso} = 0$, $E_T^{j1} > 70$, $E_T^{j2} > 30$ GeV

$\not{E}_T > 70$, $H_T = \not{E}_T + E_T^{j2} + E_T^{j3} > 150$ GeV

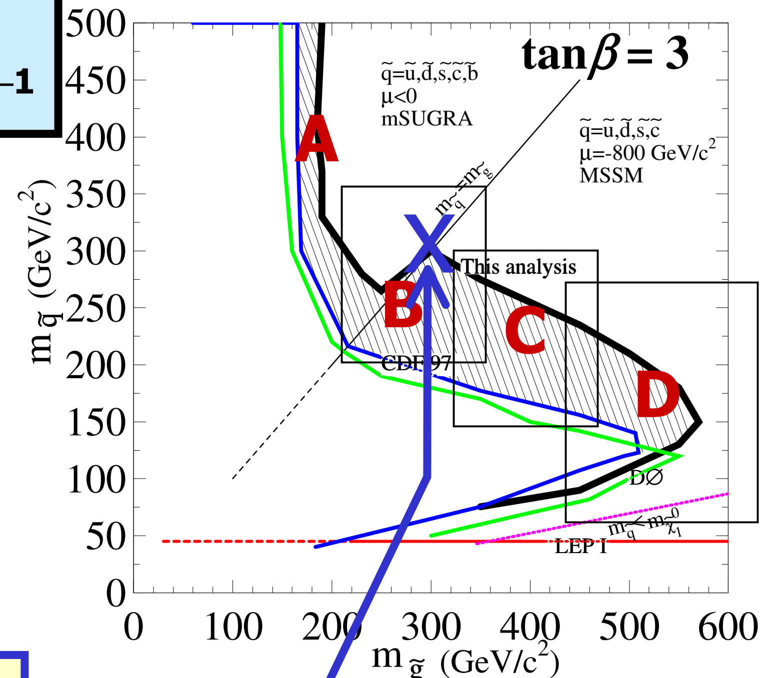
$N_{obs}=74$, $N_{BG(QCD,tt,W/Z)}=76 \pm 13$

Final $\not{E}_T$ and H_T cuts are optimized for each box. (*e.g.*, $\not{E}_T$>110, H_T>230 in **B**)



Run I
84 pb^{-1}

Blind Search



m_0 =170 GeV
$m_{1/2}$=100 GeV

300 GeV/c^2

Backup Slide

$\tilde{g}/\tilde{q}$: Jets + $\not{E}_T$ + 0 Lepton

DØ, PRL 83 (1999) 4937

$N_{j25} \geq 3$, $\Delta\phi^{min}(j,\not{E}_T) > 0.1$ rad (5.7°)

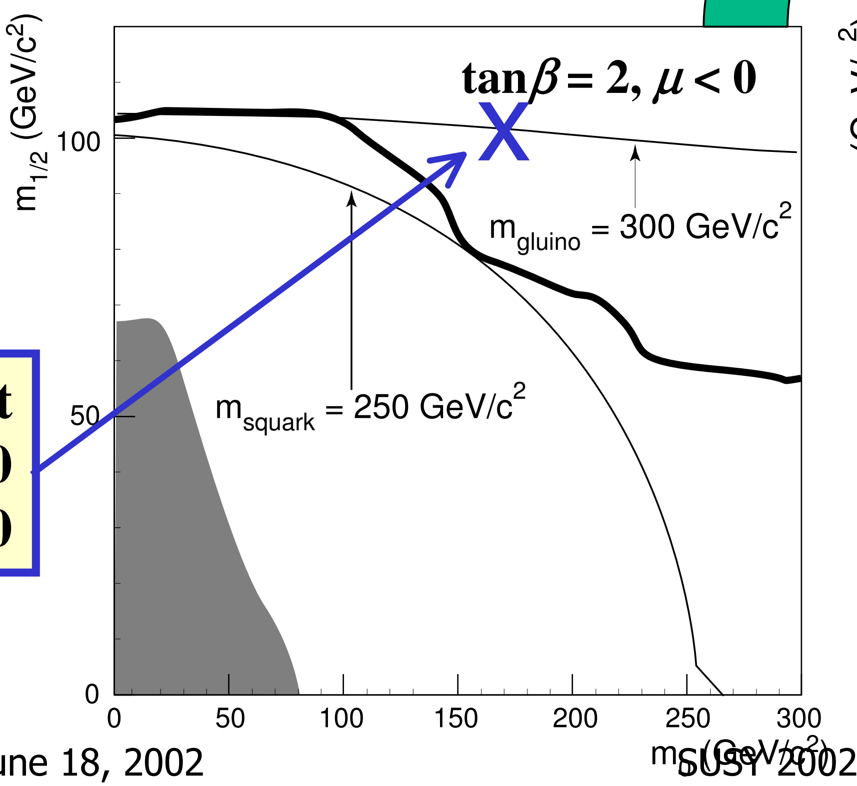
$N_{l15} = 0$, $E_T^{j1} > 115$ GeV

$\not{E}_T > 75$, $H_T = E_T^{j2} + E_T^{j3} + \ldots > 100$ GeV

$N_{obs} = 49$, $N_{BG(QCD,tt,W/Z)} = 43.0 \pm 8.5$

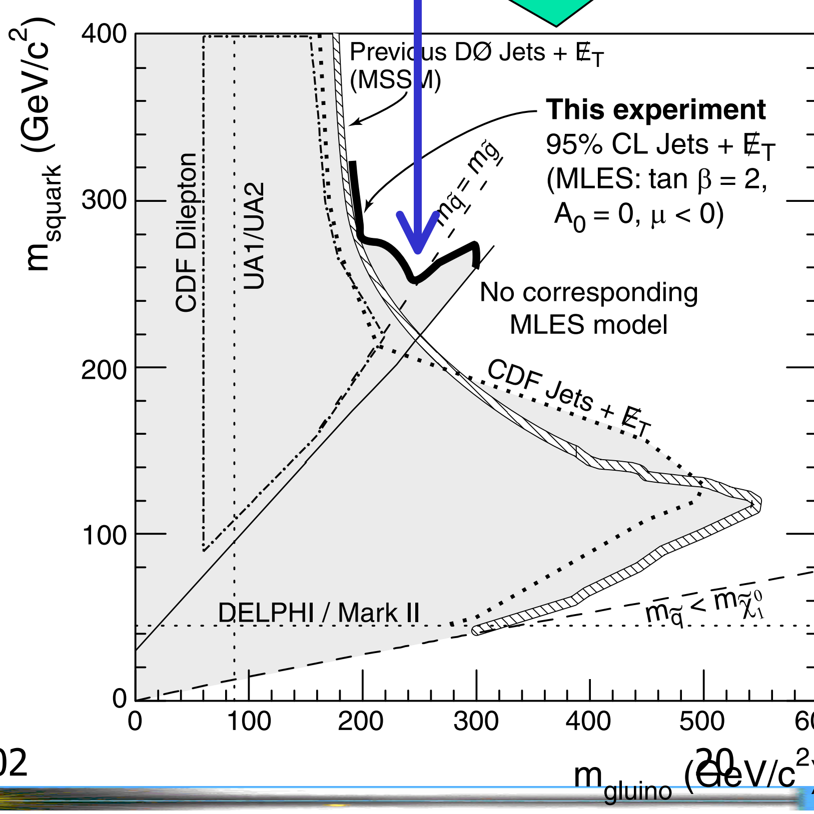
Run I

79 pb^{-1}



CDF limit
$m_0 = 170$
$m_{1/2} = 100$

260 GeV/c^2



$\tilde{g}/\tilde{q}$: Jets + $\not{E}_T$ + 1 Lepton

DØ, hep-ex/0205002, to PRD

$N_{j15} \geq 4$

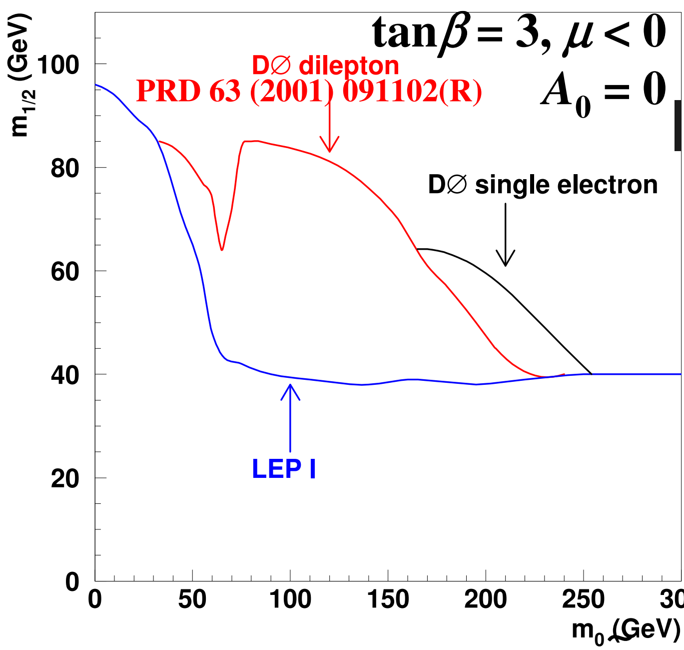
$N_{e20} = 1$

$\not{E}_T > 25$, Neural Net (NN) Analysis

$N_{obs}=72$, $N_{BG(W+4j,QCD,tt,W+2j)}=80.3 \pm 10.4$

Run I
93 pb^{-1}

Neural Net



V. Krutelyov *et al.*, PLB 505 (2001) 161

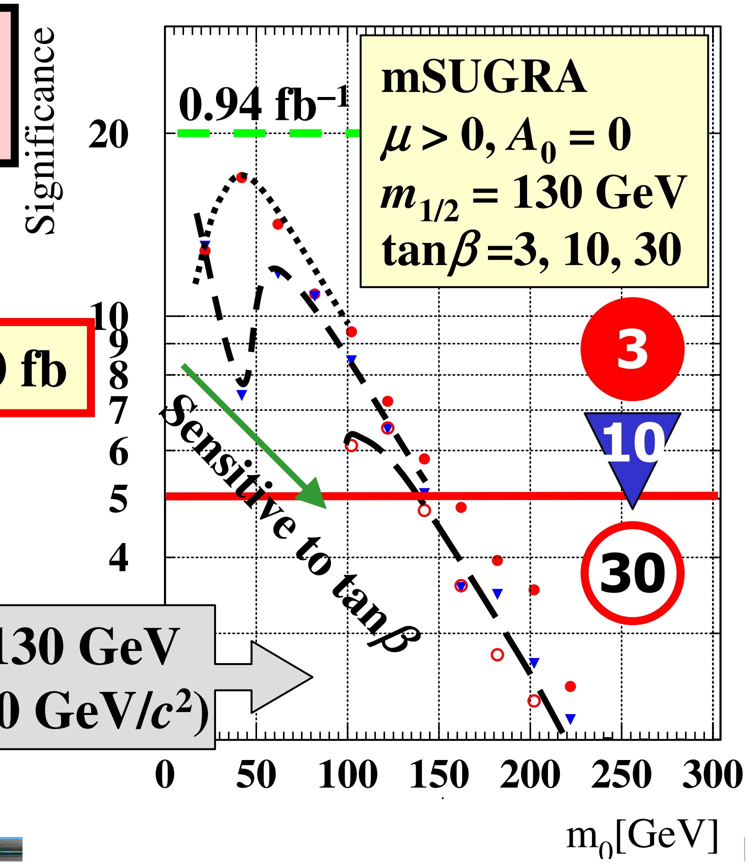
$N_{j15} \geq 2$, $\Delta\phi^{min}(j,\not{E}_T) > 30^o$

$N_{l15} = 1$, $M_T^{l\nu} < 50$ or >110 GeV/c^2

$\not{E}_T > 40$, $\not{E}_T + E_T^{j1} + E_T^{j2} > 350$ GeV

Run II
15 fb^{-1}

N_{BG} = 70 fb



$m_{1/2}$ = 130 GeV
($M_{\tilde{g}} \simeq$ 300 GeV/c^2)

Backup Slide

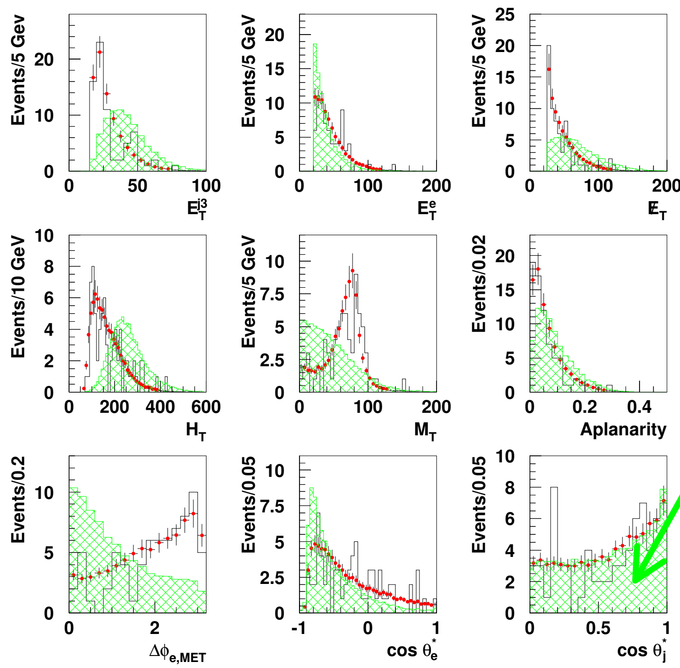
$\tilde{g}/\tilde{q}$: Jets + $\not{E}_T$ + 1 Lepton

DØ, hep-ex/0205002, to PRD
$N_{j15} \geq 4$
$N_{e20} = 1$
$\not{E}_T > 25$, Neural Net (NN) Analysis

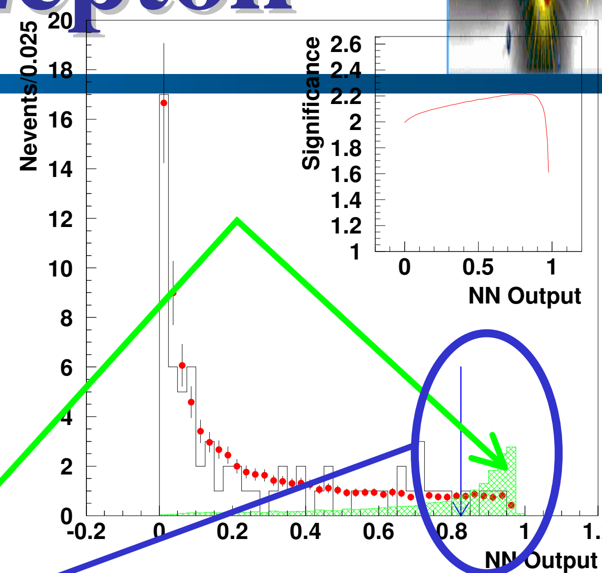
Run I
93 pb^{-1}

$N_{obs}=72$, $N_{BG(W+4j,QCD,tt,W+2j)}=80.3 \pm 10.4$

NN Variables

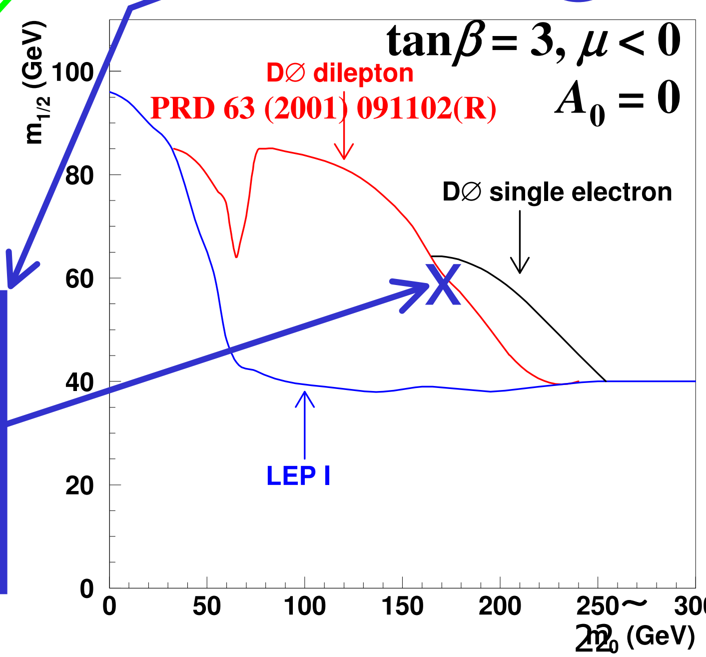


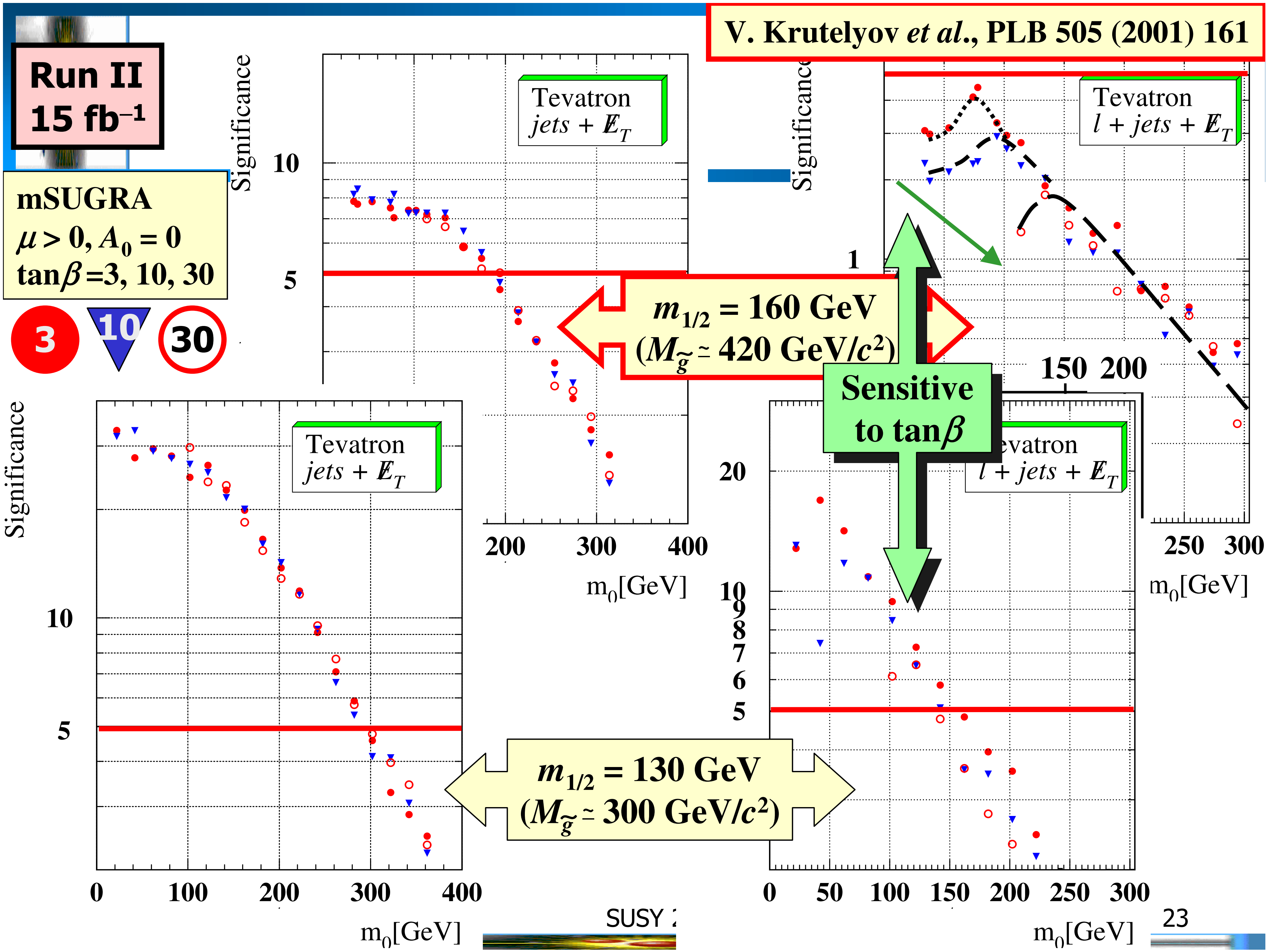
NN Outputs



$m_0 = 170$ GeV
$m_{1/2} = 58$ GeV

$NN_{output} > 0.8$
$N_{sig}=10.4$
$N_{BG}=4.4$
$N_{obs}=4$





V. Krutelyov et al., PLB 505 (2001) 161
Run II
15 fb⁻¹
mSUGRA
μ > 0, A₀ = 0
tanβ=3, 10, 30
3
10
30
Significance
Tevatron
jets + E_T
l + jets + E_T
m_{1/2} = 160 GeV
(M_g̃ ≃ 420 GeV/c²)
m_{1/2} = 130 GeV
(M_g̃ ≃ 300 GeV/c²)
Sensitive to tanβ
m₀[GeV]
0
50
100
150
200
250
300
400
5
6
7
8
9
10
20
1

Limits on $M_{\tilde{g}}$ in Jets + $\not{E}_T$

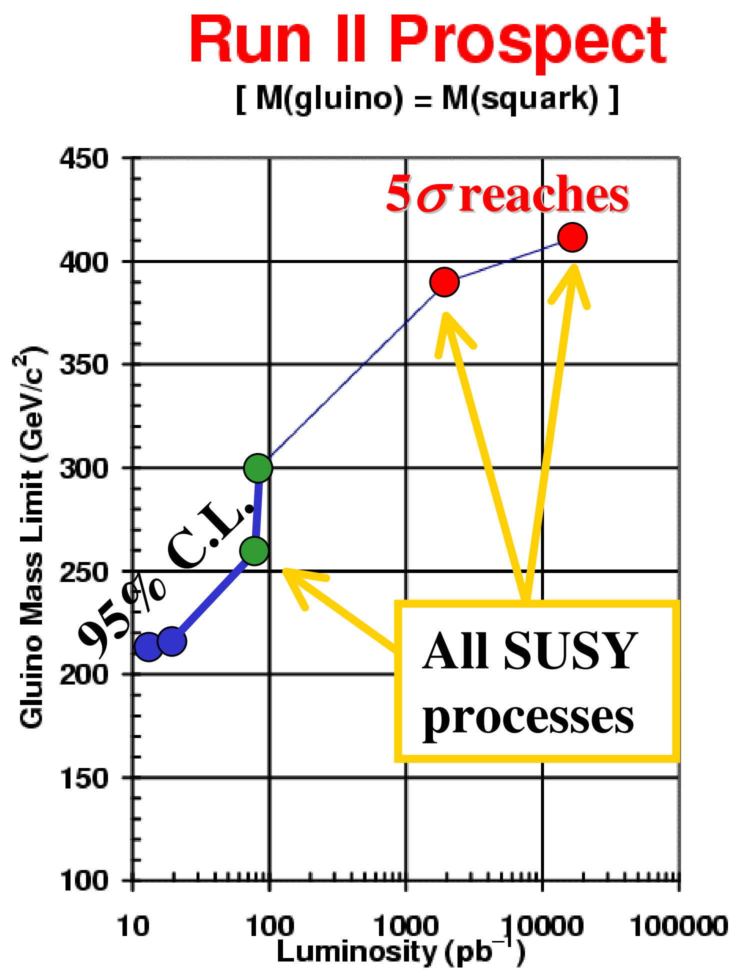
1. DØ, PRL 75(1995) 618
2. CDF, PRD 56(1997) 1357
3. DØ, PRL 83(1999) 4937
4. CDF, PRL 88(2002) 041801

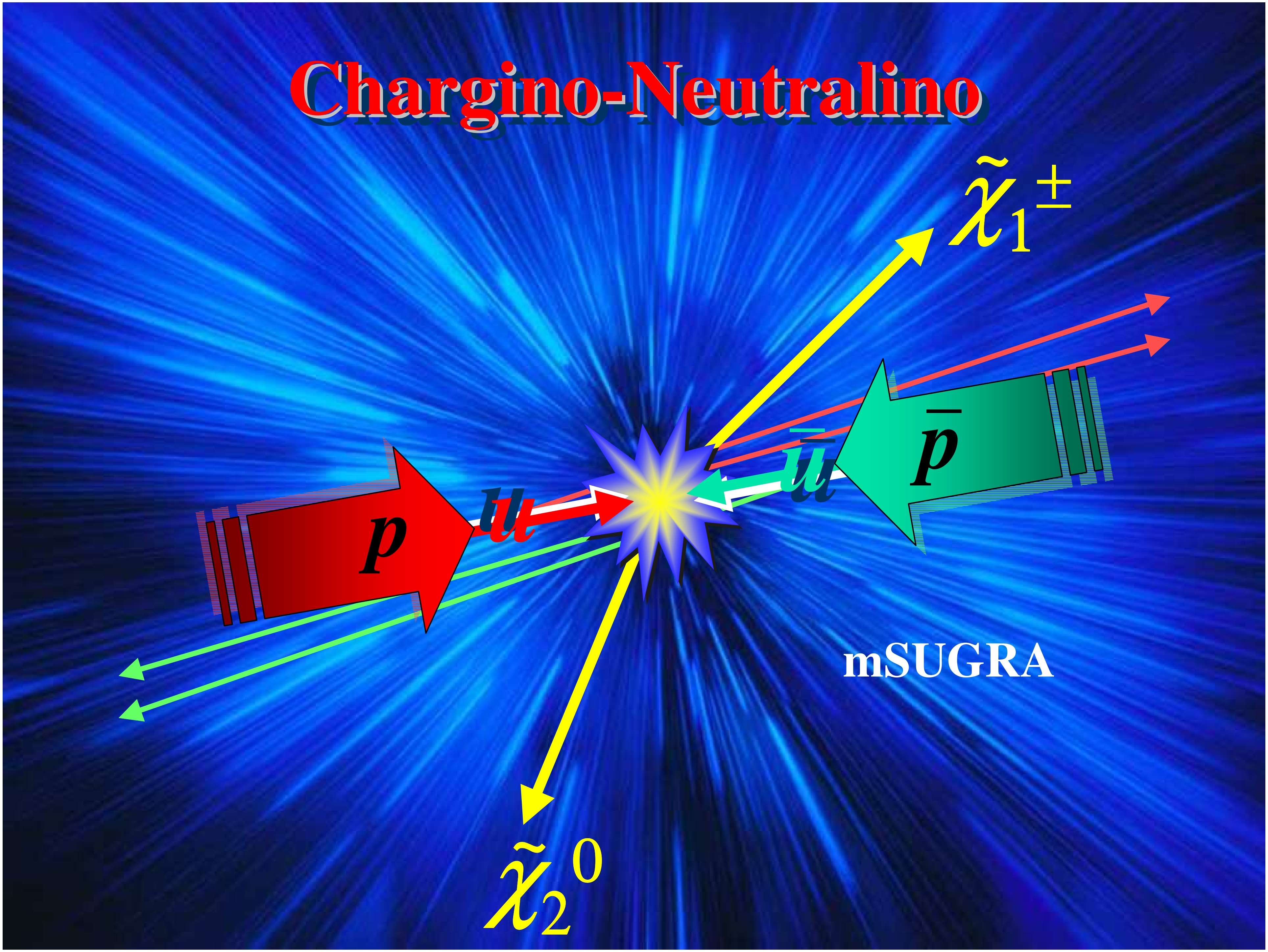
Low $\tan\beta$
$\mu < 0$

5. S. Mrenna *et al*., PRD 53 (1996) 1168
   using PYTHIA with
   a toy detector simulation

6. V. Krutelyov *et al*., PLB 505 (2001) 161
   $\tan\beta = 3, 10, 30$ & $\mu > 0$
   using ISAJET v7.48 with
   "SHW" detector simulation

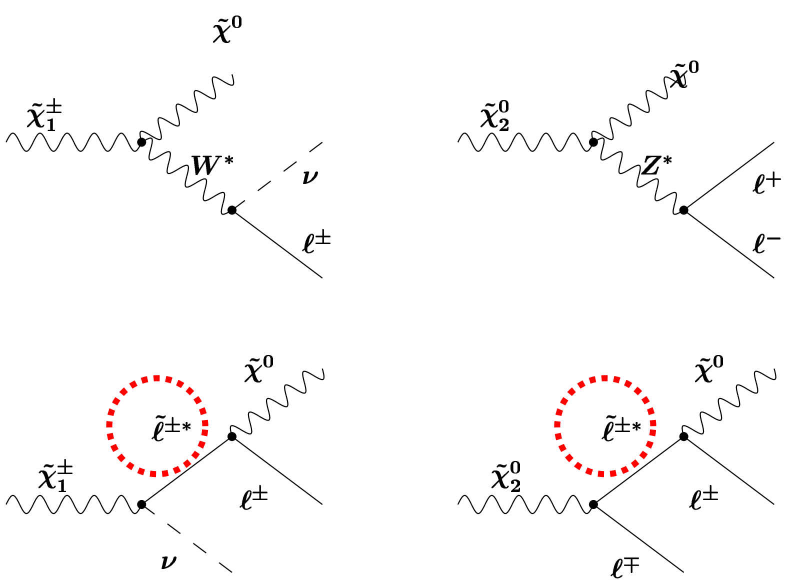
→They are consistent with many other papers such as H. Baer *et al*., …..




Chargino-Neutralino
$\tilde{\chi}_1^{\pm}$
p
u
$\bar{u}$
$\bar{p}$
mSUGRA
$\tilde{\chi}_2^{0}$

3 Leptons + $\not\!\!E_T$

Trilepton plus missing E_T from chargino-neutralino production is one of the most cleanest (promising) signatures in hadron colliders.



$\tilde{\chi}_1^\pm \rightarrow \ell^\pm \nu \tilde{\chi}^0$ $\tilde{\chi}_2^0 \rightarrow \ell^+ \ell^- \tilde{\chi}^0$

Run I:

Searched for clean trilepton final state (*eee*, *ee*μ, *e*$\mu\mu$, $\mu\mu\mu$) with low p_T (*e.g*, 11, 5, 5 GeV/*c*).

CDF: PRL 80 (1998) 1591

N_{obs} = 0 (1.5±0.5 expected)

DØ : PRL 80 (1998) 5275

N_{obs} = 0 (1.2±0.2 expected)

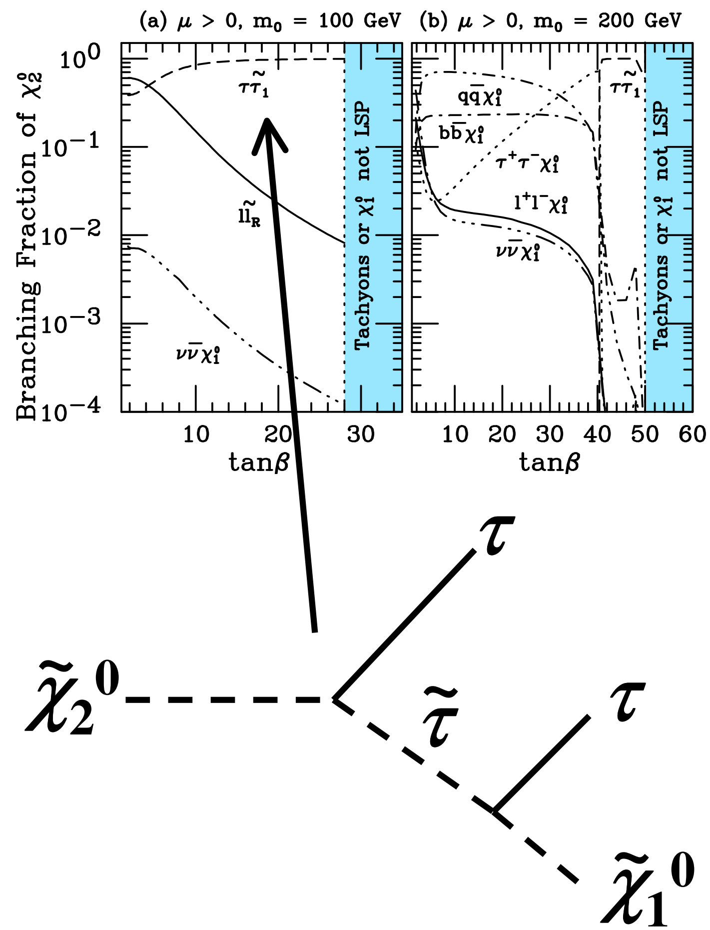
Within MSSM/mSUGRA, the maximum reach on the chargino mass was up to about 70 GeV/c^2 for small tanβ scenario (*e.g.*, tanβ = 2) with lighter slepton mass.

3 Leptons + $\not{E}_T$

$\tilde{\tau}_1$ could be lighter for large tanβ and small m_0

V. Barger and C. Kao, hep-ph/9811489, PRD 60 (1999) 115015

Strong tanβ Dependence



Large tanβ – $l\tau\tau$ and $\tau\tau\tau$ are dominant final states from chargino-neutralino production.

To maximize the reach, low p_T Lepton(e/μ)+track trigger is crucial to detect hadronically decaying tau lepton (τ_h).

3 Leptons + $\not{E}_T$

1) Look for clean trilepton final state (eee, $ee\mu$, $e\mu\mu$, $\mu\mu\mu$) with $p_T(l_1,l_2,l_3)$>11,7,5 GeV/c, where soft leptons (e or μ) from τ decays are also accepted. See, for example,

V. Barger and C. Kao,

hep-ph/9811489,

PRD 60 (1999) 115015

[the SM background calculations including effects from W^*, Z^* and γ^* are substantially improved.]

2) Also accept τ_h

H. Baer *et al*.,

hep-ph/9802441

PRD 58 (1998) 075008

J. Lykken and K. Matchev,

hep-ph/9903238

PRD 60 (2000) 015001

K. Matchev and D. Pierce,

hep-ph/9904282

PRD 60 (1999) 075004

lll and LS $ll+\tau_h$ final states are the best channels for the study of chargeno-neutralino production.

3 Leptons + $\not{E}_T$

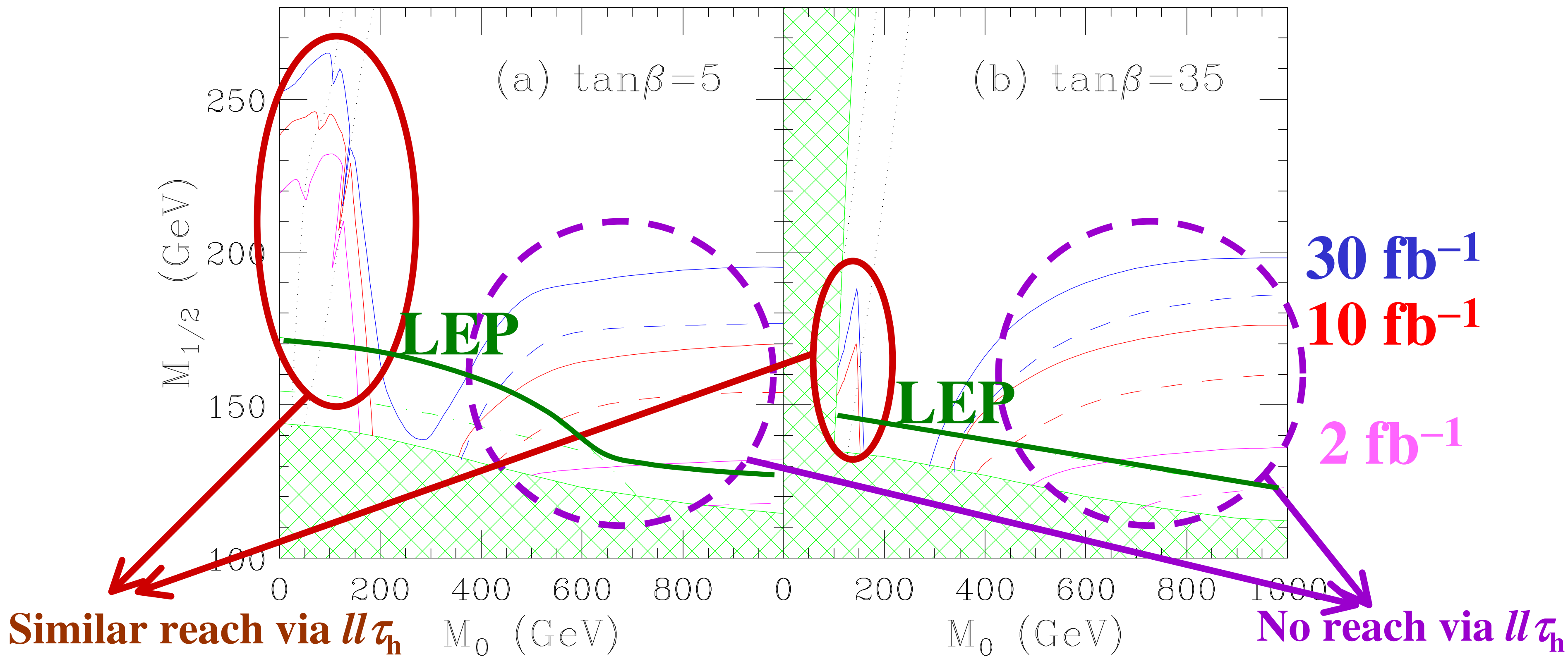
K. Matchev and D. Pierce, hep-ph/9904282, PRD 60 (1999) 075004

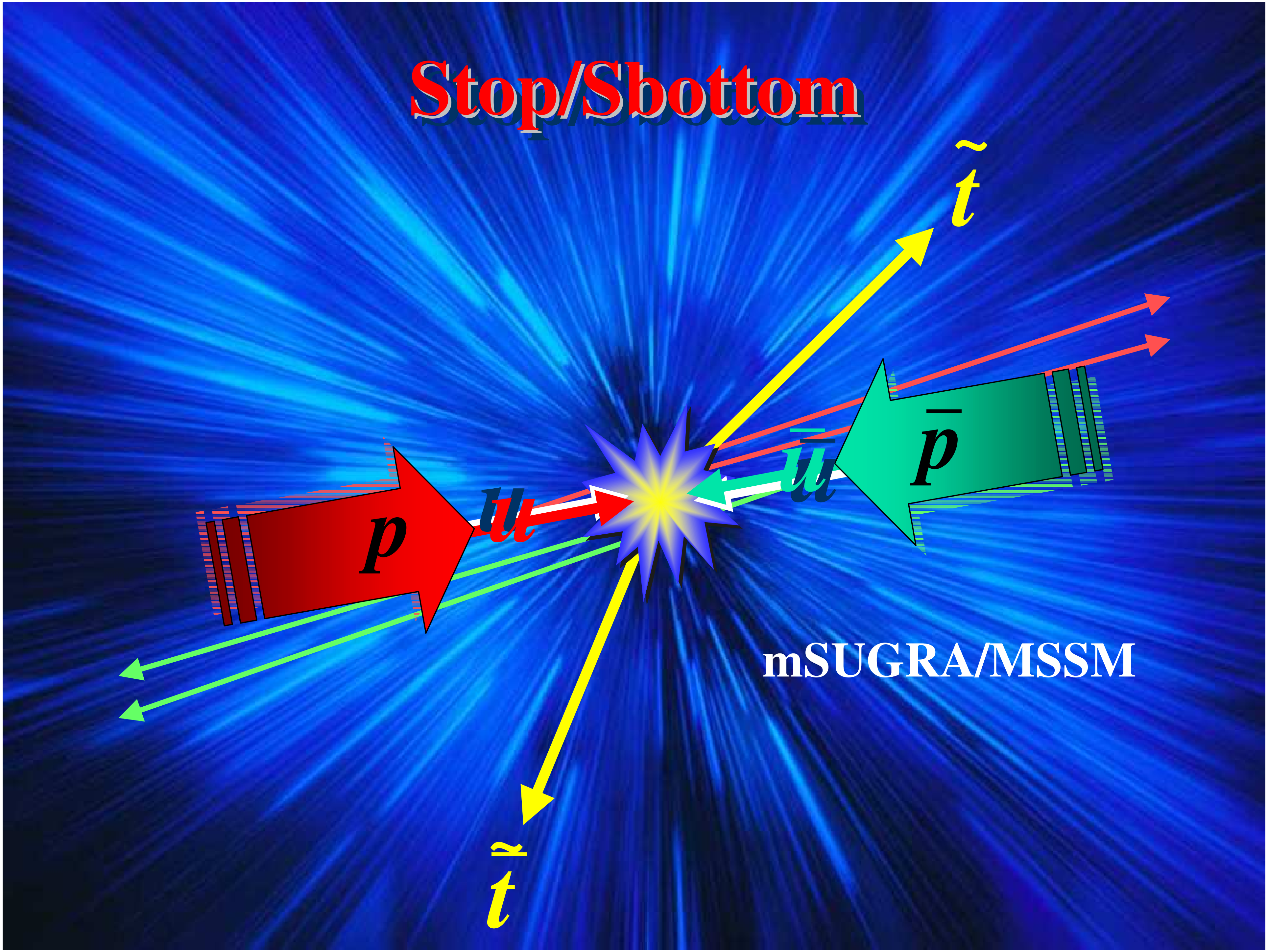
Dashed curves – 3σ reaches w/ "standard" cuts

$p_T(l_1,l_2,l_3)$>11,7,5 GeV/c; $\not{E}_T$>25 GeV; M_{l+l-} cuts

Solid curves - 3σ reaches w/ optimized cuts

11,7,5;25;70 for small m_0; 11,11,11;15;70 for large m_0





Stop/Sbottom
$\tilde{t}$
u
p
$\bar{u}$
$\bar{p}$
mSUGRA/MSSM
$\bar{\tilde{t}}$

Stop

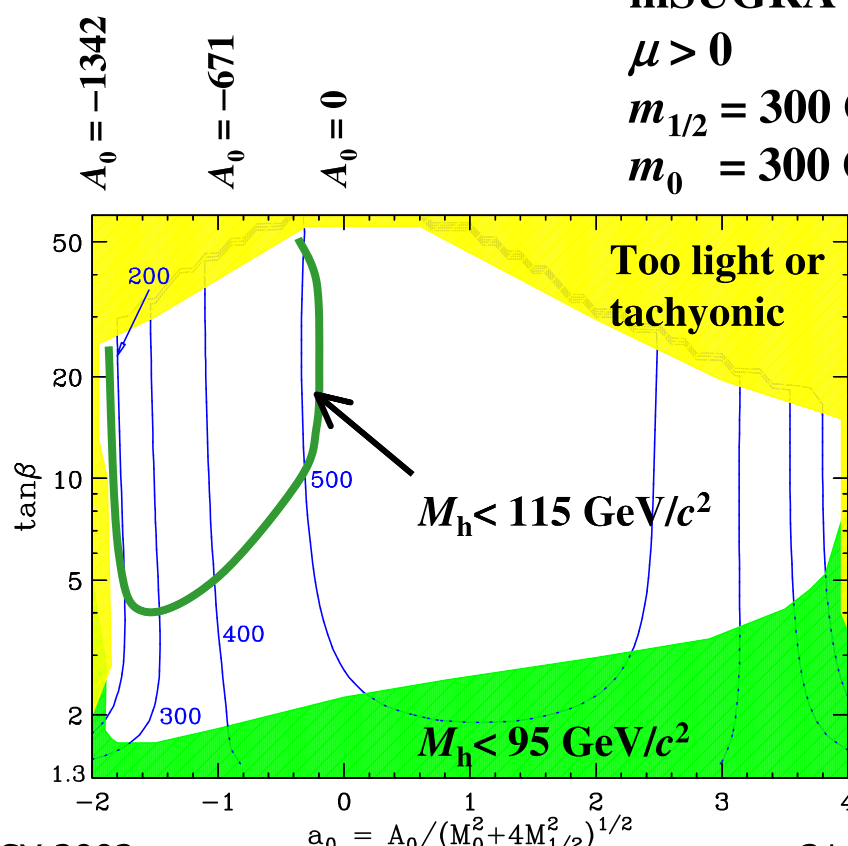
R. Demina *et al.*,
hep-ph/9910275,
PRD 62 (2000) 035011

The lightest stop, $\tilde{t}_1$, is a very good candidate for studying at the Tevatron:

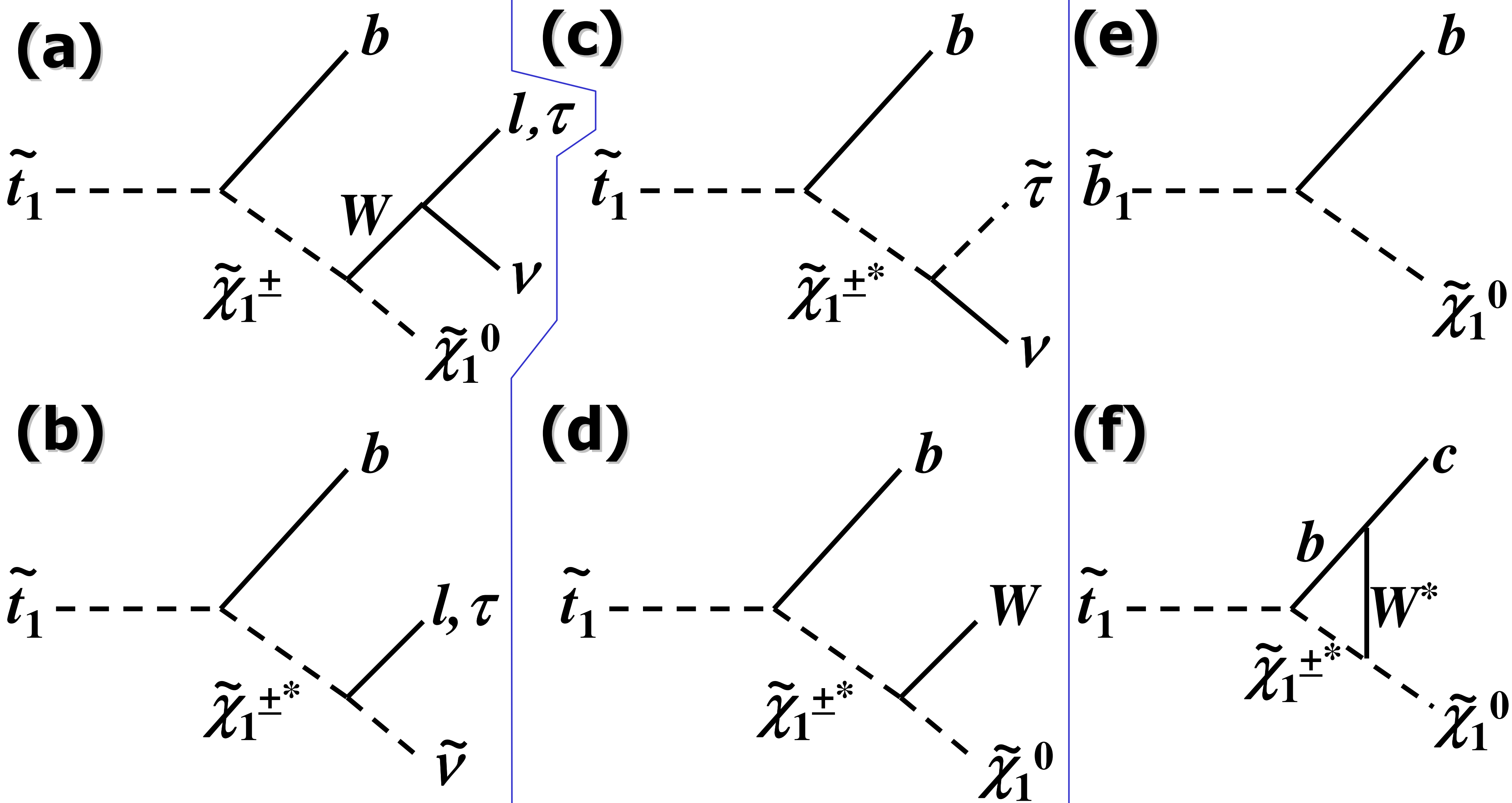
a) Experimentally, larger cross section compared to that for sleptons

b) Theoretically, lighter stop mass preferred for larger tanβ & $|A_0|$

mSUGRA
$\mu > 0$
$m_{1/2}$ = 300 GeV
m_0 = 300 GeV



Stop/Sbottom Decays



R. Demina *et al.*,
hep-ph/9910275,
PRD 62 (2000) 035011

Stop

$M_{\tilde{t}} > M_{\tilde{\chi}_1^\pm}$

p_T or E_T cuts

$M_{\tilde{l}} < M_{\tilde{t}} < M_{\tilde{\chi}_1^\pm}$

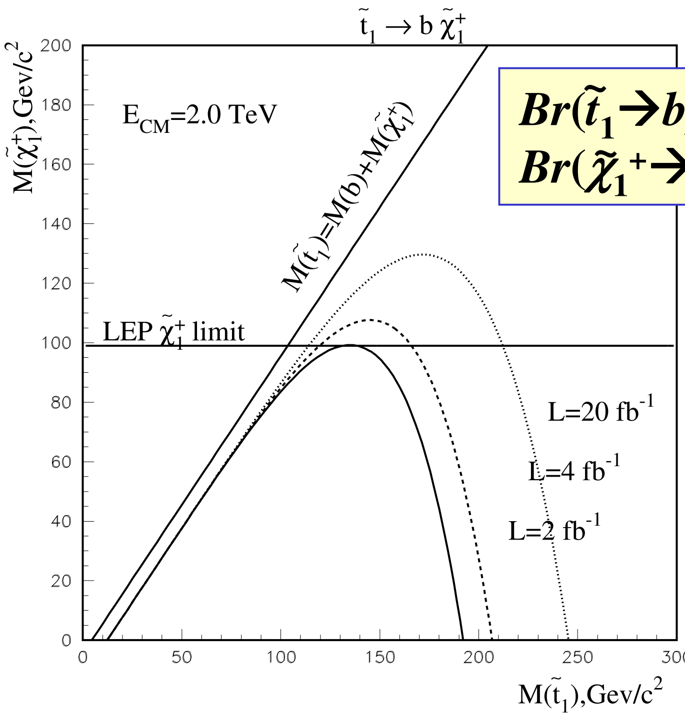
($m_0 < 0.55\, m_{1/2}$ in mSUGRA)

$l_{10}+b_{12}+j_8+\not{E}_{T25}$

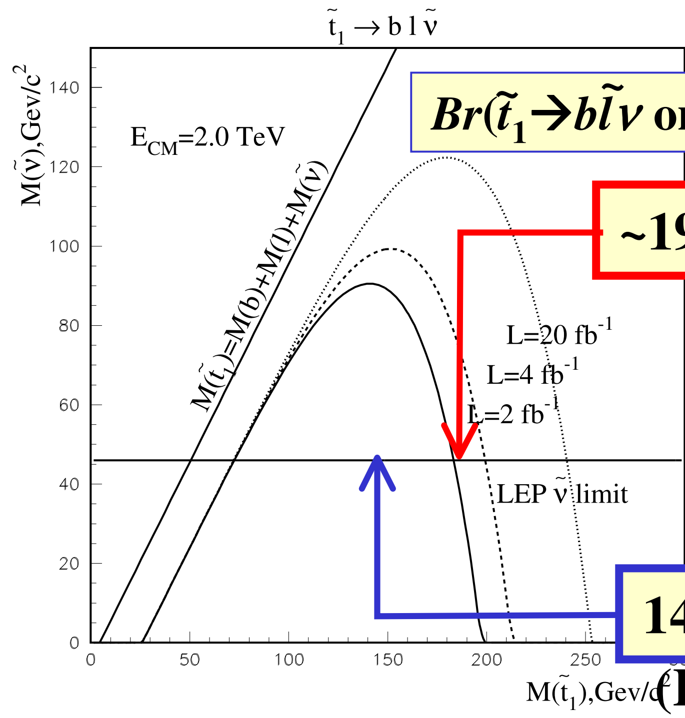
$\sigma_{BG(W\text{+jets,top,QCD,..})} = 980$ fb

$l^+_8+l^-_5+j_{15}+\not{E}_{T30}$

$\sigma_{BG(QCD,Z/\gamma^*\text{+jets,top,..})} = 50$ fb



$Br(\tilde{t}_1 \to b\tilde{\chi}_1^+)=1$
$Br(\tilde{\chi}_1^+ \to l\nu\tilde{\chi}_1^0)=0.22$



$Br(\tilde{t}_1 \to b\tilde{l}\nu$ or $bl\tilde{\nu})=2/3$

~190 GeV/c^2
(Run IIa)

144 GeV/c^2
(Run I/DØ)

Backup Slide

Review of Run-I Stop (sneutrino LSP)

DØ, hep-ex/0108018, PRL 88 (2002) 171802

$N_{e15} = 1$, $N_{\mu 15} = 1$, $N_{j15} \geq 0$

$\not{E}_T > 20$, $15^o < \Delta\phi_{e\mu} < 165^o$, $|\eta_e+\eta_\mu| < 2.0$

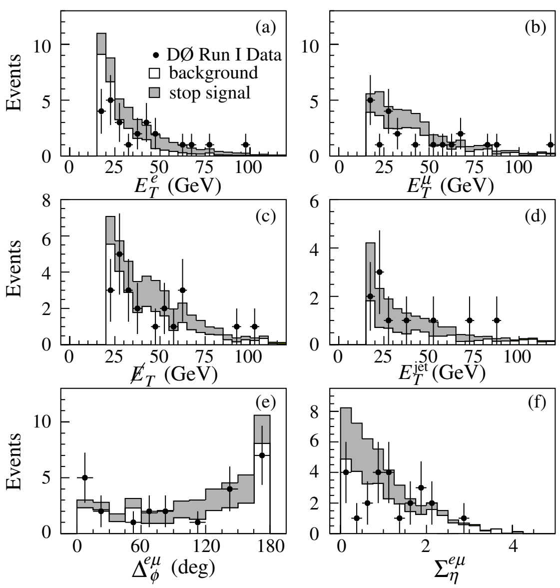
Run I
108 pb^{-1}

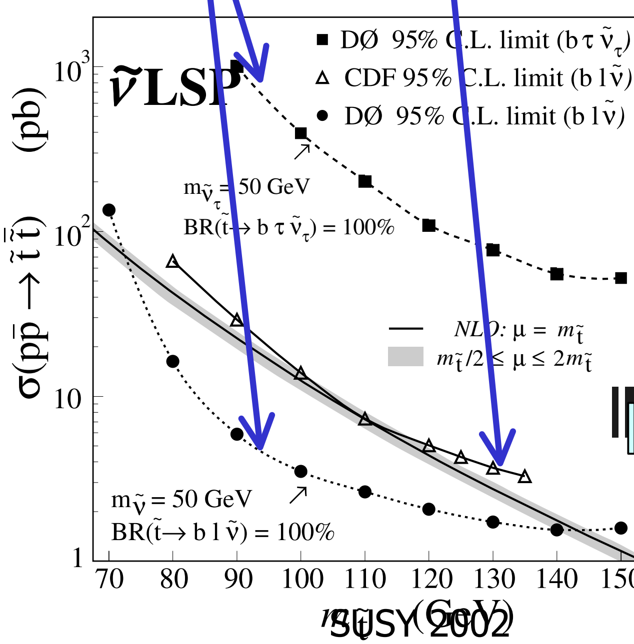
$N_{obs}=10$, $N_{BG(QCD,WW,tt,Z)}=13.7 \pm 1.5$

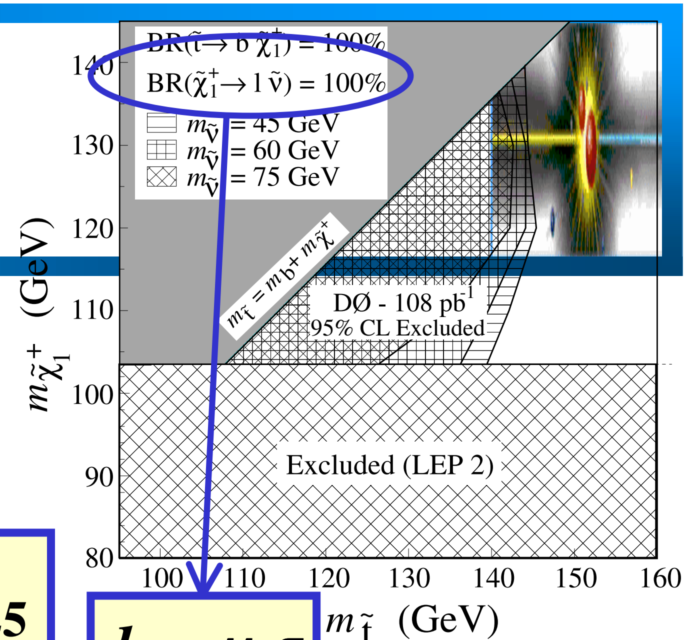
$e\mu\not{E}_T+X$

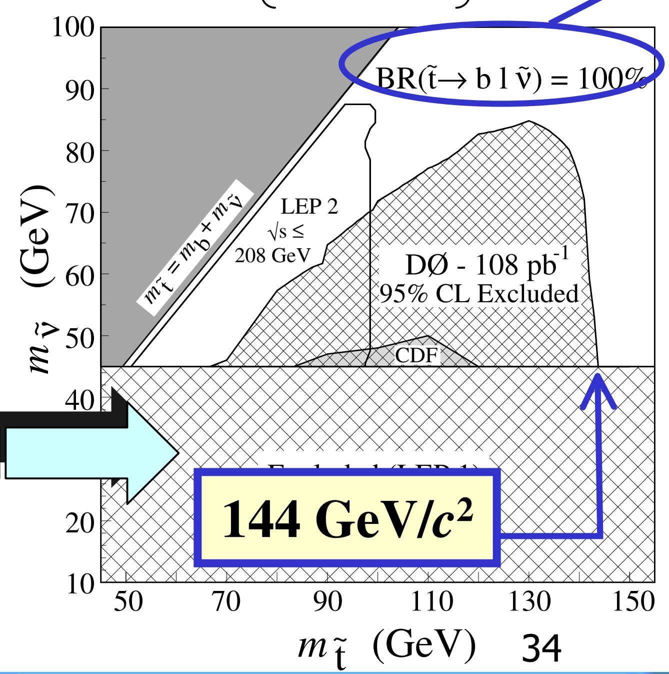
$l_{10}j_{12}j_8\not{E}_{T25}$ (w/ ≥1b-tag)

$l=e,\mu,\tau$ → e,μ





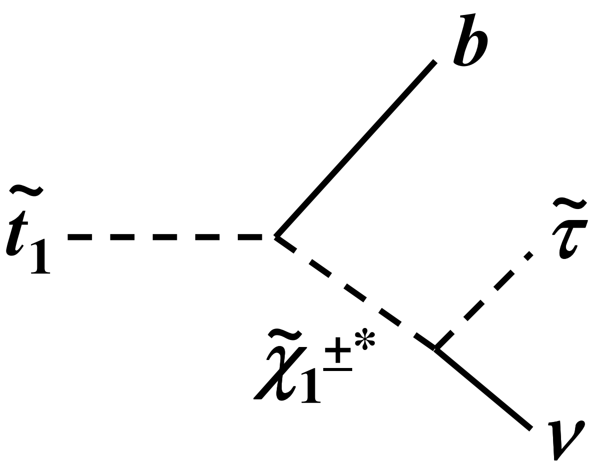




144 GeV/c^2

R. Demina *et al.*,
hep-ph/9910275,
PRD 62 (2000) 035011

Stop

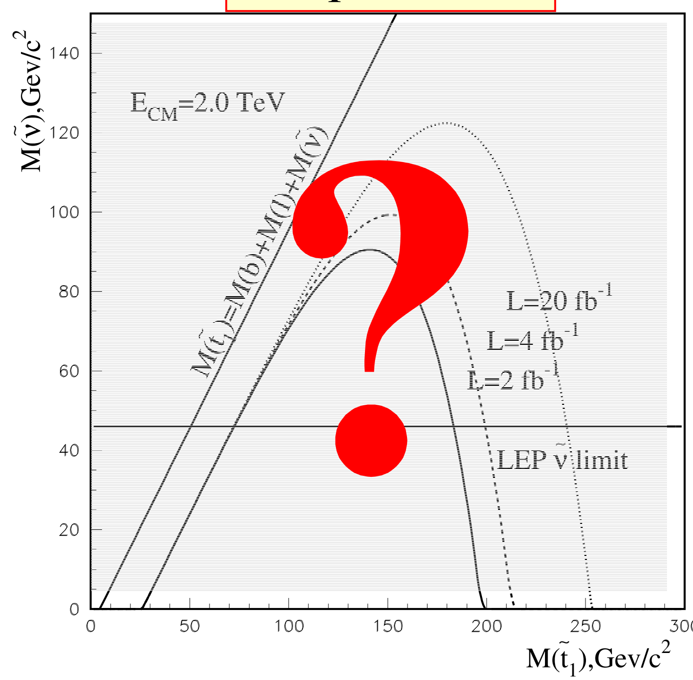


$$M_{\tilde{\tau}} < M_{\tilde{t}} < M_{\tilde{\chi}_1^\pm}$$

($m_0 \lesssim 5\, m_{1/2}$, large $\tan\beta$ in mSUGRA)

$$l_{10} + \tau_{h15} + j_{15} + j_{15} + \not{E}_{Txx}$$

$Br(\tilde{t}_1 \to b\,\tilde{\tau}\,\nu) = 1$



τ channel sensitivity to be checked …

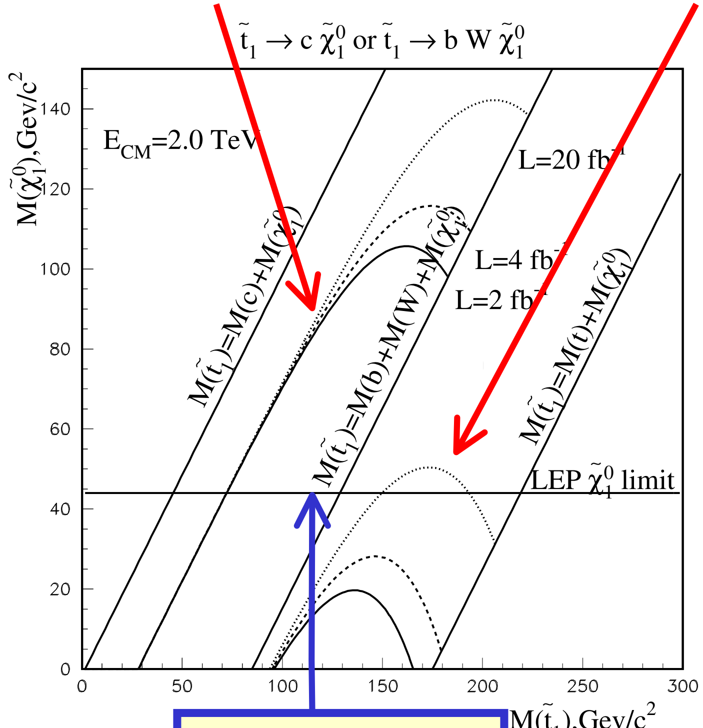
R. Demina *et al.*,
hep-ph/9910275,
PRD 62 (2000) 035011

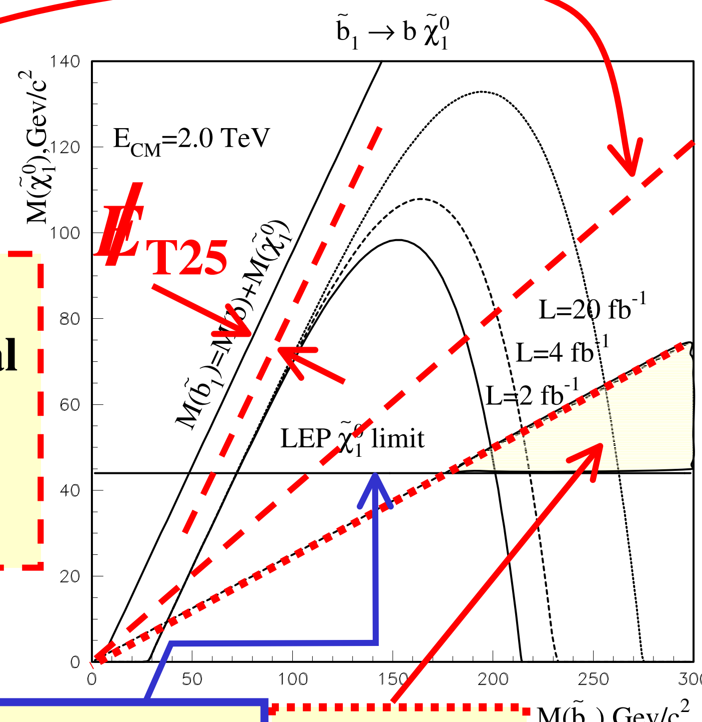
Stop/Sbottom

$M_{\tilde{t}} > M_{\tilde{\chi}_1^0}$ $\qquad$ $M_{\tilde{b}} > M_{\tilde{\chi}_1^0}$

$c_{15}+j_{15}(+j_{15})+\not{E}_{T40}$ $\qquad$ $l_{10}+b_{12}+j_8+\not{E}_{T25}$ $\qquad$ $b_{15}+j_{15}(+j_{15})+\not{E}_{T40}$

$\sigma_{BG(W+\text{jets,QCD,..})} = 160$ fb $\qquad$ $\sigma_{BG(W+\text{jets,top,QCD,..})} = 980$ fb





SUGRA (non-universal scalar mass) $\tan\beta > 20$ & $\mu < 0$

~115 GeV/c^2 ← **(Run I/CDF)** → **~145 GeV/c^2** **mSUGRA**

Review of Run-I Stop/Sbottom (CDF)

Backup Slide

CDF, PRL 84 (2000) 5704

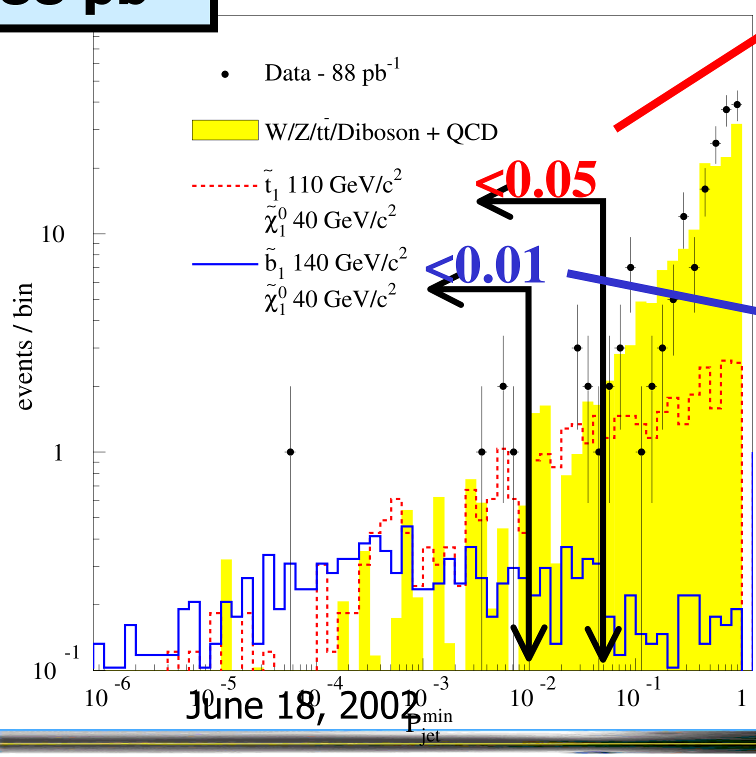
N_{j15} = 2 or 3, $\Delta\phi^{min}(j,\not{E}_T) > 45^o$

N_{l10} = 0, $\Delta\phi^{min}(j_1,\not{E}_T) > 165^o$

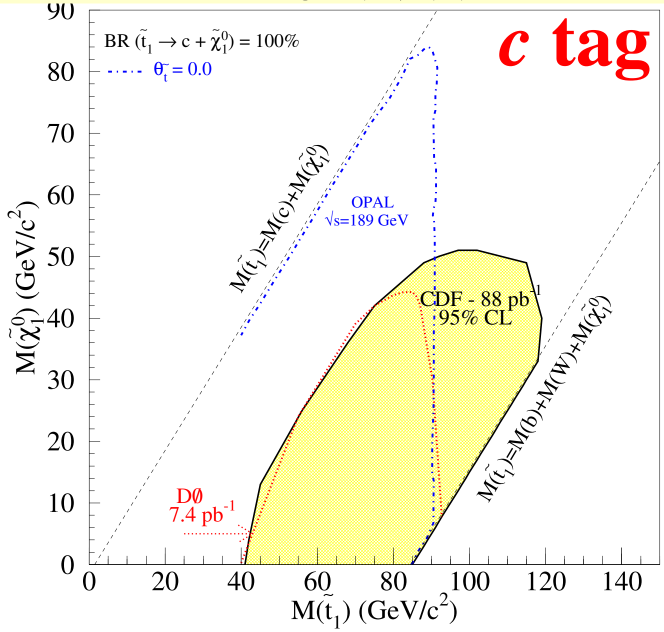
$\not{E}_T > 40$, $45^o < \Delta\phi(j_1,j_2) < 165^o$

Run I
88 pb^{-1}

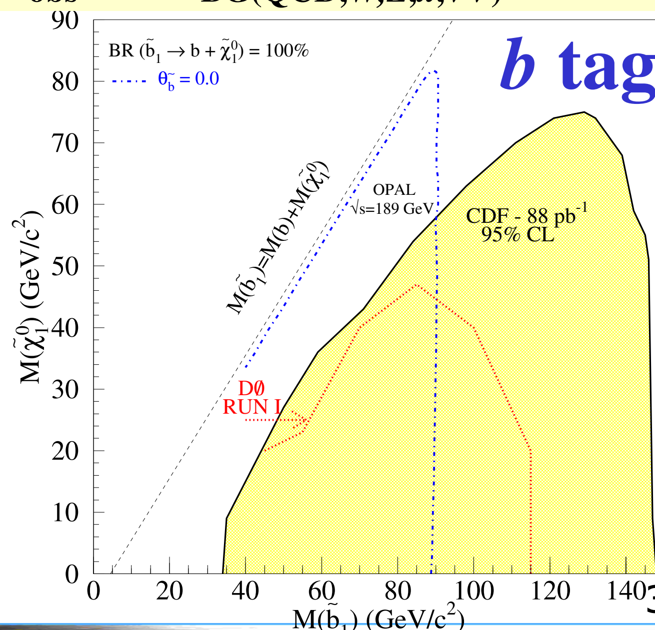
N_{obs} = 396



N_{obs}=11, $N_{BG(QCD,W,Z,tt,VV)}$=14.5±4.2



N_{obs}=5, $N_{BG(QCD,W,Z,tt,VV)}$=5.8±1.8

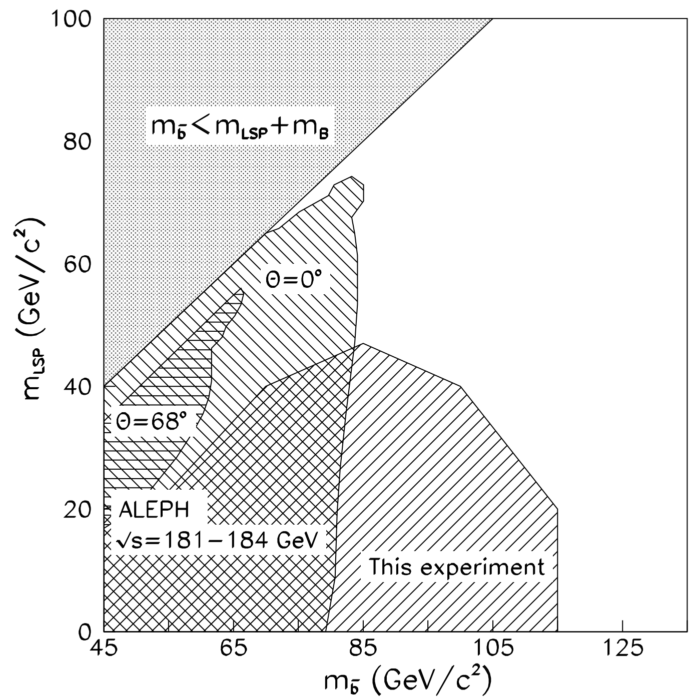


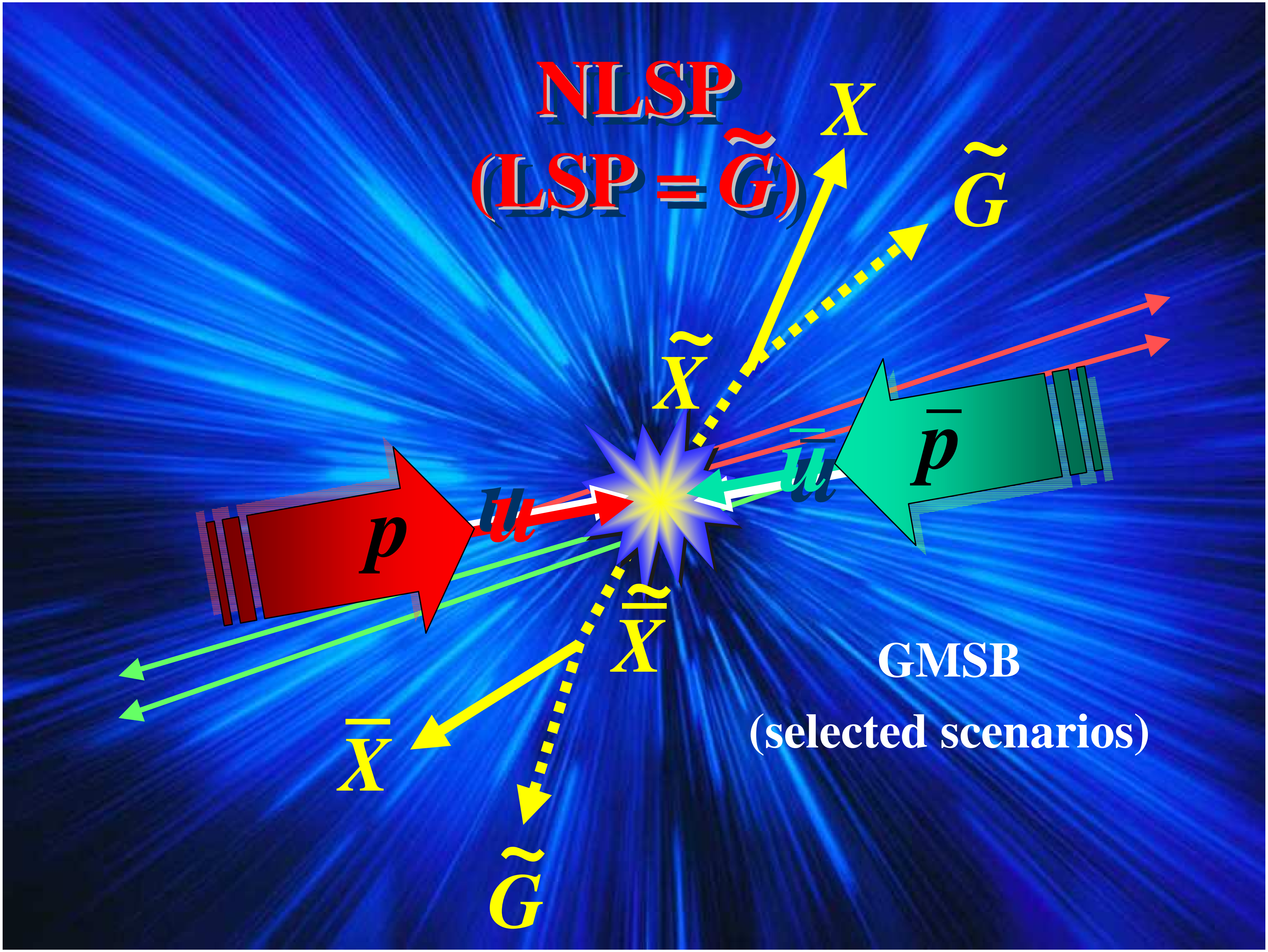
Backup Slide

Review of Run I Sbottom (DØ)

DØ, hep-ex/9903041, PRD 60 (1999) 031101

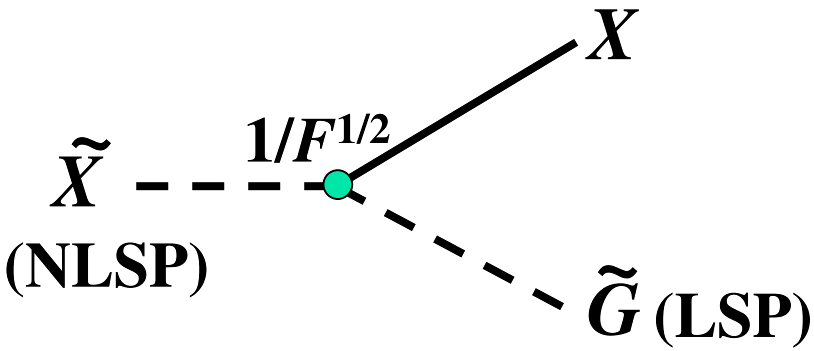
Run I
108 pb^{-1}

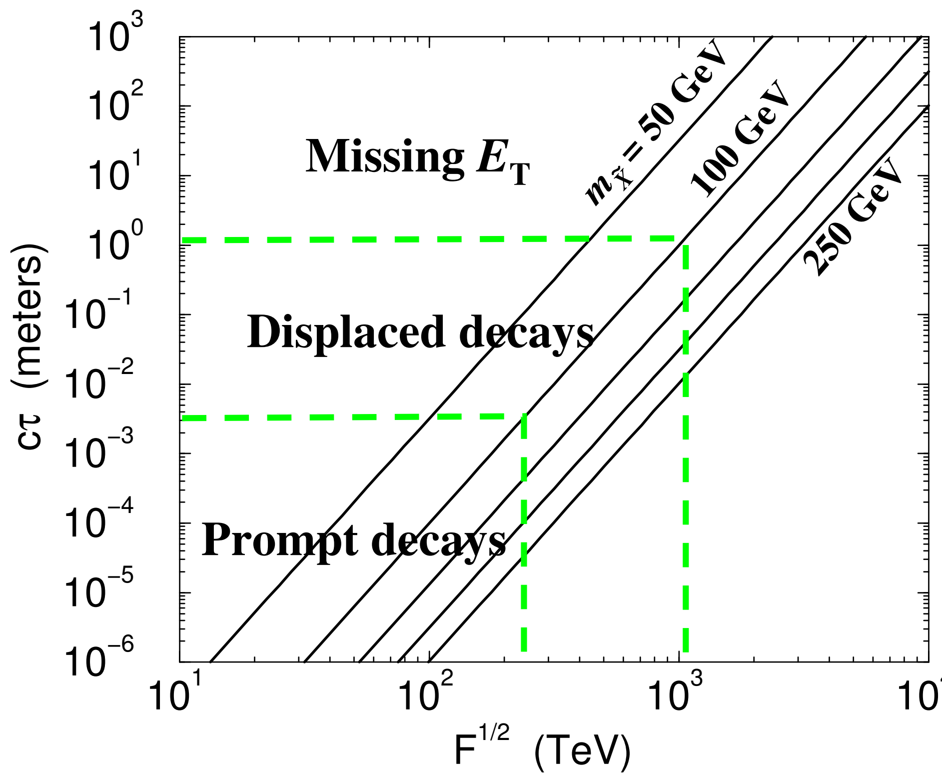



NLSP
(LSP = $\tilde{G}$)
X
$\tilde{G}$
$\tilde{X}$
p
u
$\bar{u}$
$\bar{p}$
$\tilde{\bar{X}}$
$\bar{X}$
$\tilde{G}$
GMSB
(selected scenarios)

GMSB

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





$\Lambda = F/(C_G\, M_m)$

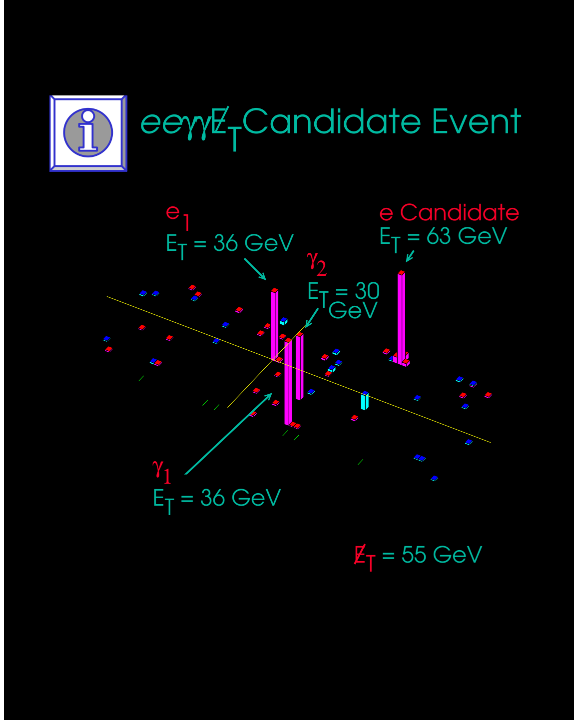
N_m (# of Messengers)

M_m (Messenger Mass)

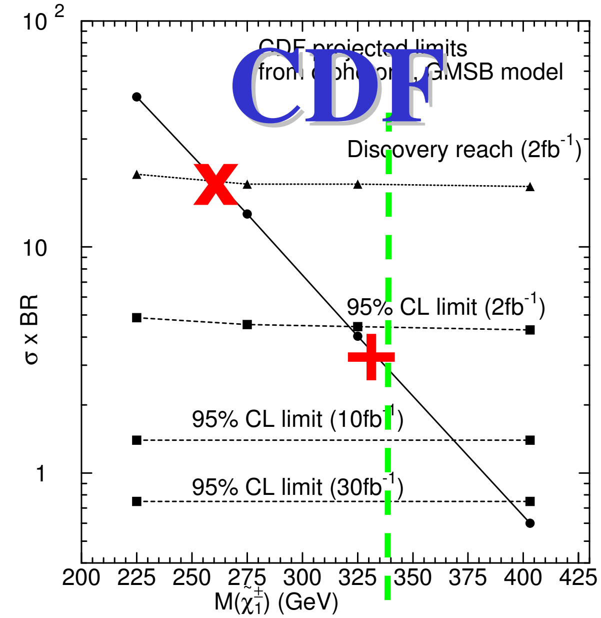
$\tan\beta$, sign(μ), C_G

Gaugino mass:

$$M_i = k_i N_m \Lambda\left(\frac{\alpha_i}{4\pi}\right)$$



NLSP = $\tilde{\chi}_1^0$



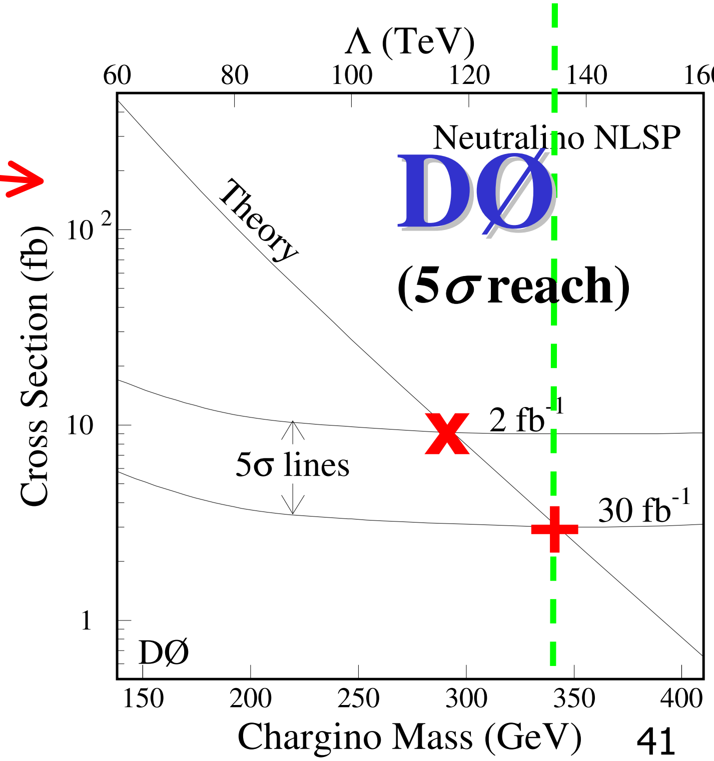
...rt, hep-ph/0008070

$\chi\chi$ in $\gamma\gamma + \not{E}_T + X$

N=1, M_m/Λ=2, tanβ=2.5, μ>0

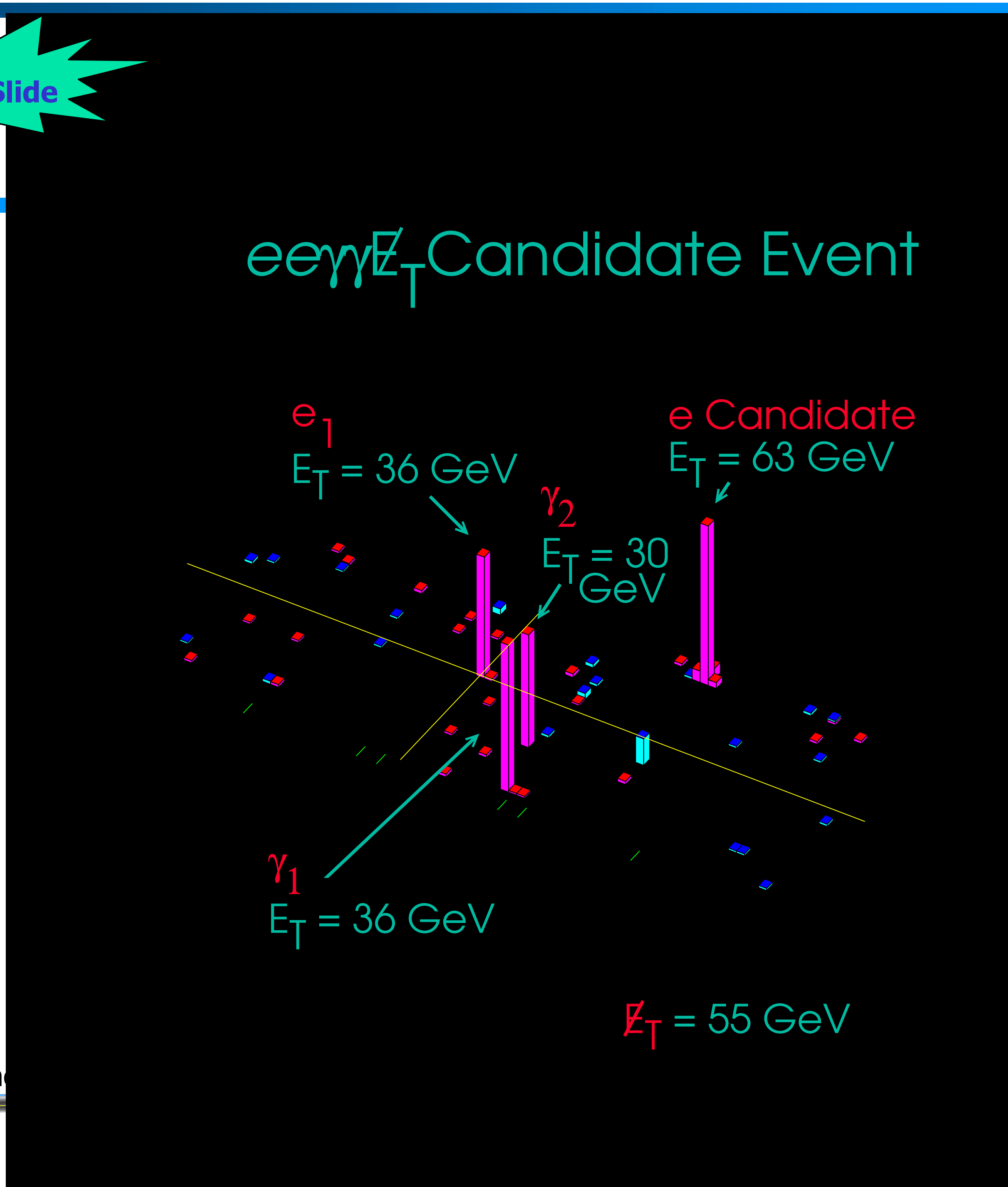
$F^{1/2}$ < a few TeV → Prompt γ

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

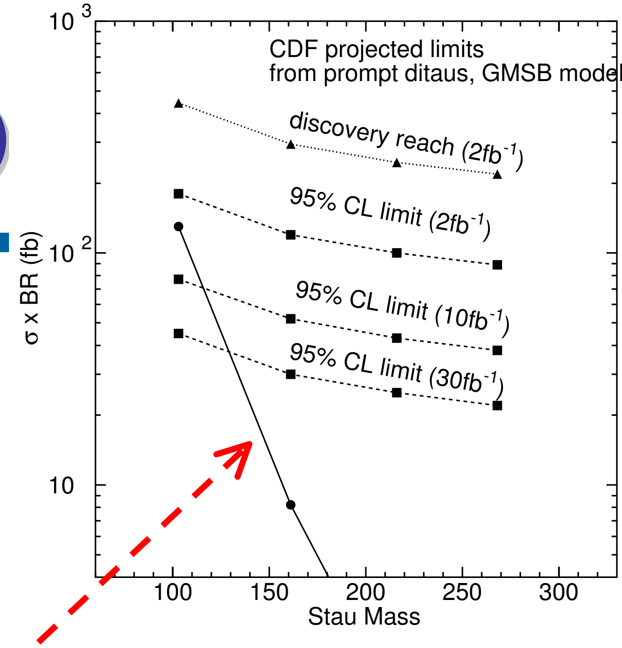


5σ reach	Selection	2 fb^{-1} x	30 fb^{-1} +
CDF	$\gamma_{14}\gamma_{14}\not{E}_{T40}$	250	330
DØ	$\gamma_{20}\gamma_{20}\not{E}_{T50}$	290	340

Backup Slide



Stau NLSP (I)



Prompt or short-lived stau:

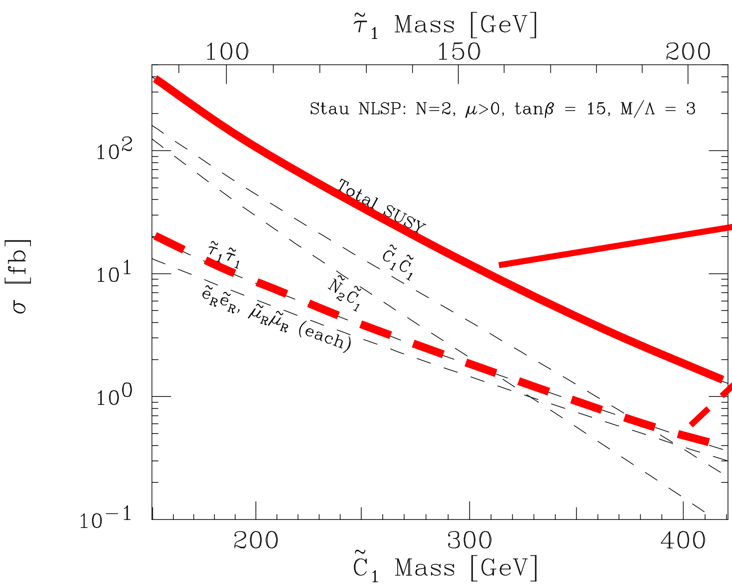
CDF: $\tau_{h30}\tau_{h30}\not{E}_{T30}$

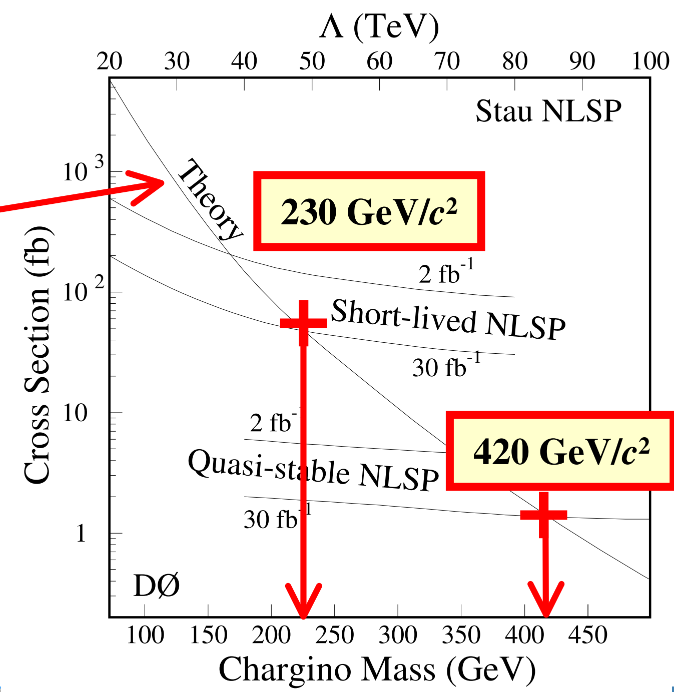
DØ : $l_{15}l_5l_5j_{20}\not{E}_{T20}$ & LS $l_{15}l_{15}+j_{20}j_{20}\not{E}_{T20}$

Quasi-stable NLSP

DØ : $l_{50}l_{50}$ ($M_{ll}>150$) + ("μ", large dE/dx)

N=2, $M_m/\Lambda=3$, $\tan\beta=15$, $\mu>0$





Stau NLSP (II)

Long-lived stau in stau+stau production:

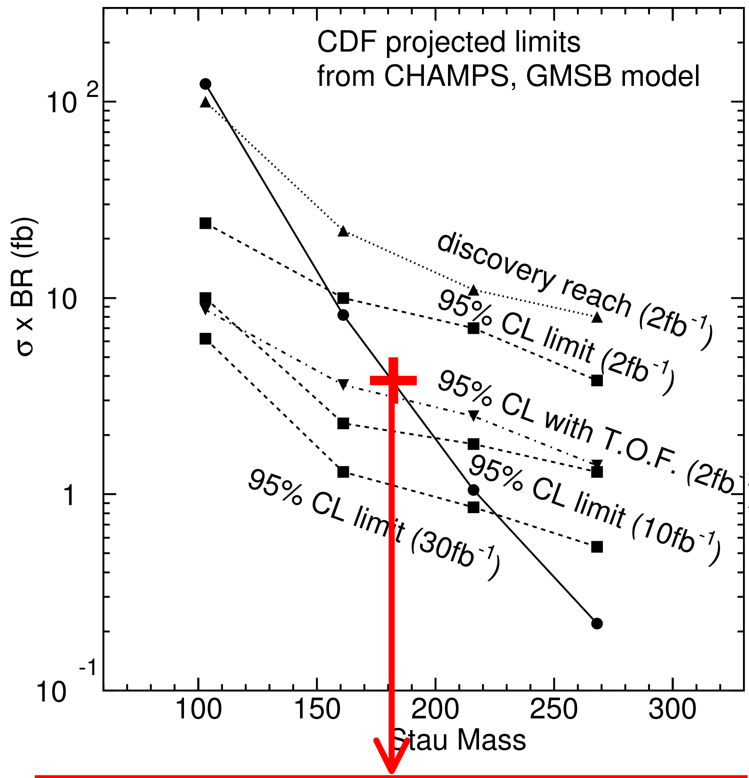
CDF: "μ" + X

with $p > 35$ GeV/c

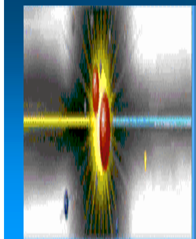
$\beta\gamma < 0.85$ (←→ dE/dx)

$M_{stau} > 60$ GeV/c^2

(via dE/dx, p_T)



180 GeV/c^2 (5σ@30fb^{-1})

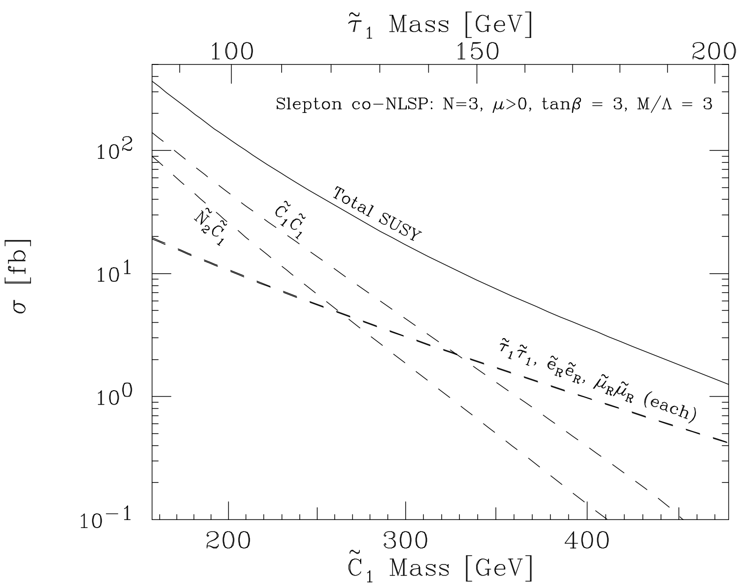


Slepton Co-NLSP

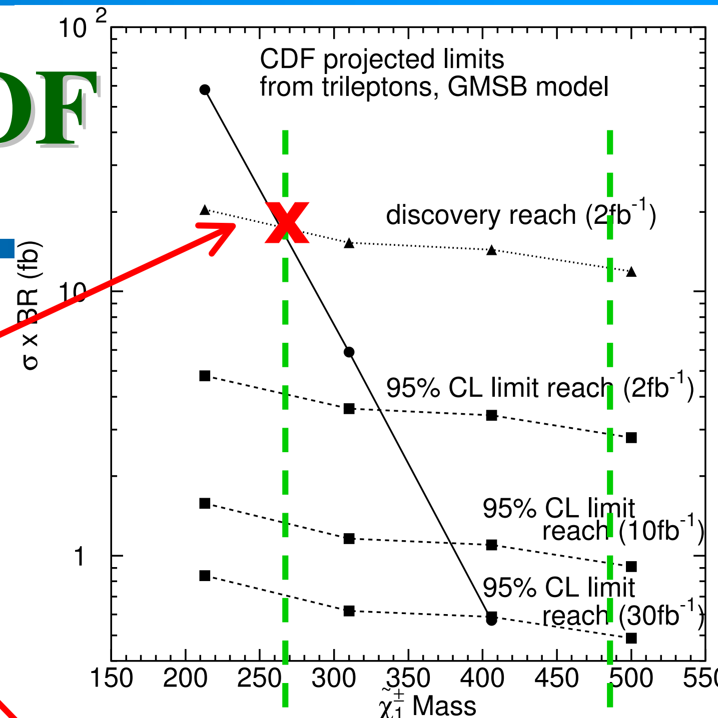
Run-II GMSB WG Report, hep-ph/0008070

- **x** $\tilde{\chi}\tilde{\chi}\,(\tilde{l}$ co-NLSP) in $lll + j + \not{E}_T$
- **+** $\tilde{\chi}\tilde{\chi}\,(\tilde{l}$ co-NLSP) in $ll + dE/dx$
  $\gamma c\tau > 3$ cm, $\tilde{l} \sim$ "μ"

N=3, M_m/Λ=3, tanβ=3, μ>0

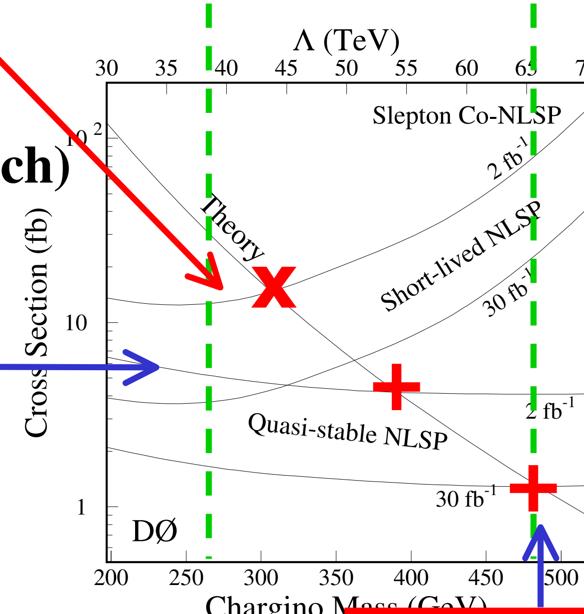


CDF



DØ

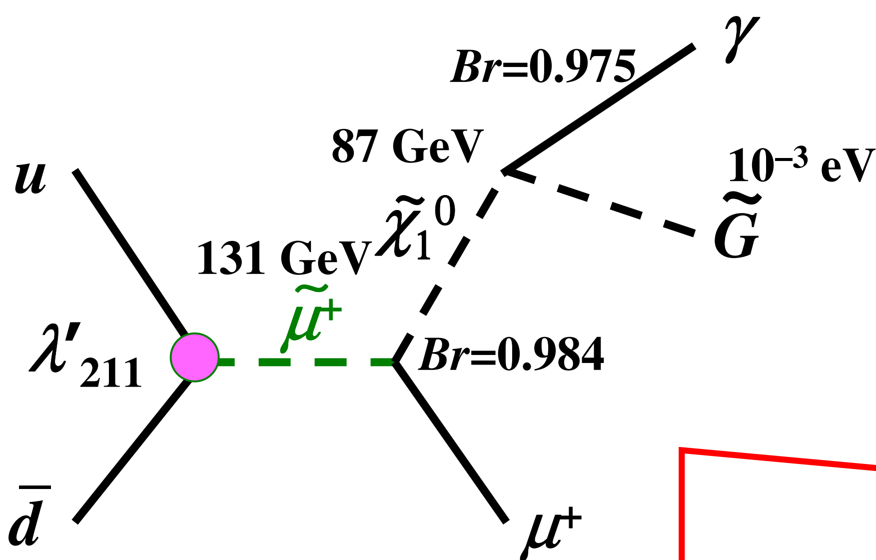
(5σ reach)

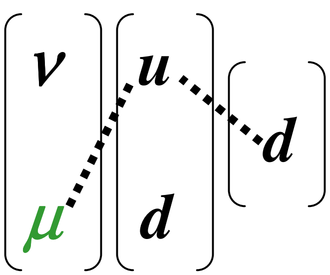


480 GeV/c^2

$\tilde{G}$ LSP + R_P Violation

B.C. Allanach, S. Lola, K. Sridhar, hep-ph/0111014





λ'_{211}=0.01
tanβ=10

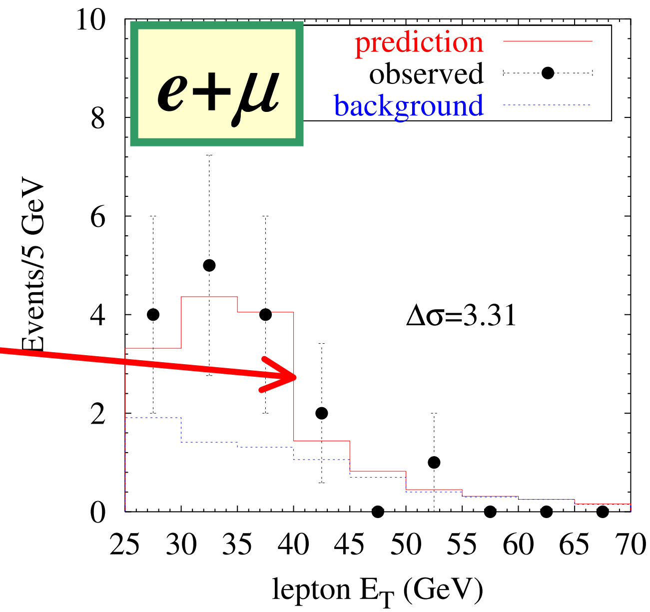
1) CDF, hep-ex/0110015 (86 pb^{-1})

$l_{25} + \gamma_{25} + \not{E}_{T25}$

$N_{obs}^{e\gamma}$ = 5 (3.4$\pm$0.3 expected)

$N_{obs}^{\mu\gamma}$ = 11 (4.2$\pm$0.5 expected)

2)



3) Prediction (2 fb^{-1}):

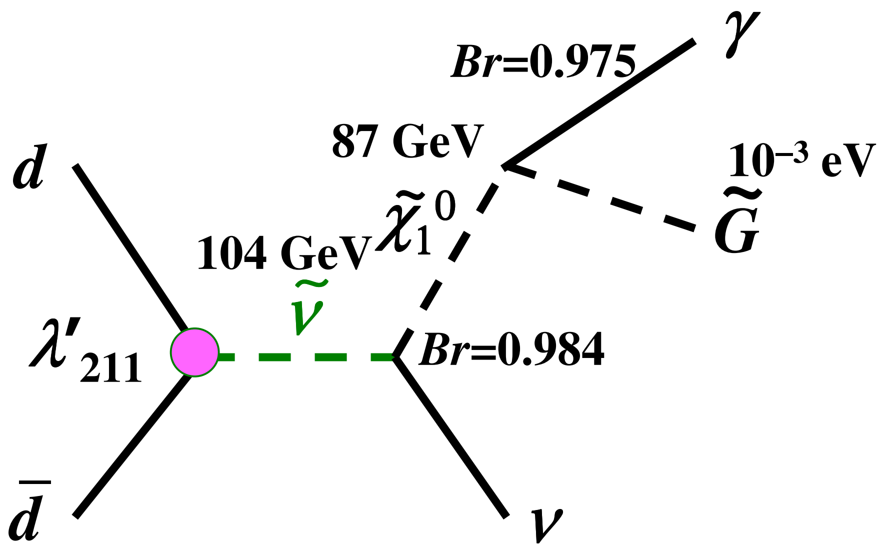
$N(\mu\gamma\not{E}_T)$ = 195 events

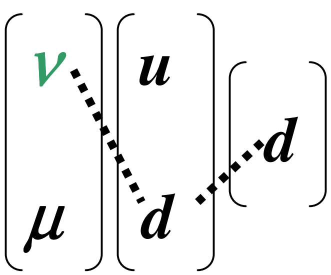
$N(\gamma\not{E}_T)$ = 720 events

Backup Slide

$\tilde{G}$ LSP + R_P Violation

B.C. Allanach, S. Lola, K. Sridhar, hep-ph/0111014





$\lambda'_{211}=0.01$
$\tan\beta=10$

1) CDF, hep-ex/0110015 (86 pb^{-1})

$l_{25} + \gamma_{25} + \not{E}_{T25}$

$N_{obs}^{e\gamma} = 5$ (3.4±0.3 expected)

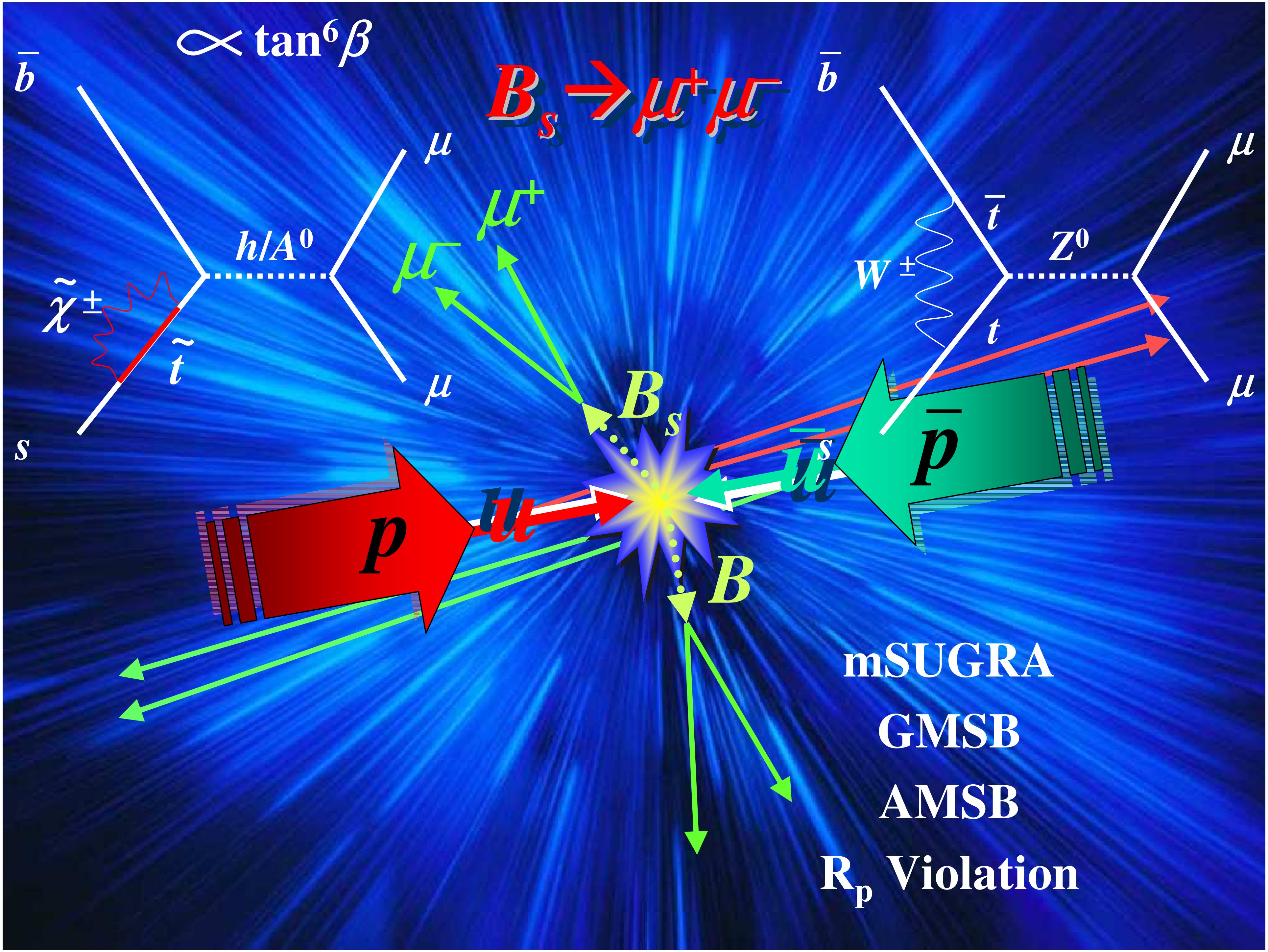
$N_{obs}^{\mu\gamma} = 11$ (4.2±0.5 expected)

2) ?

3) Prediction (2 fb^{-1}):

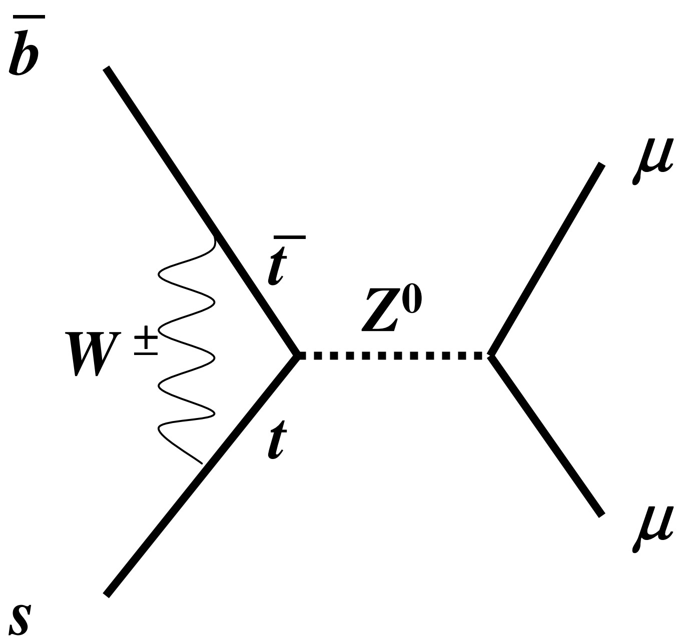
$N(\mu\gamma\not{E}_T) = 195$ events

$N(\gamma\not{E}_T) = 720$ events

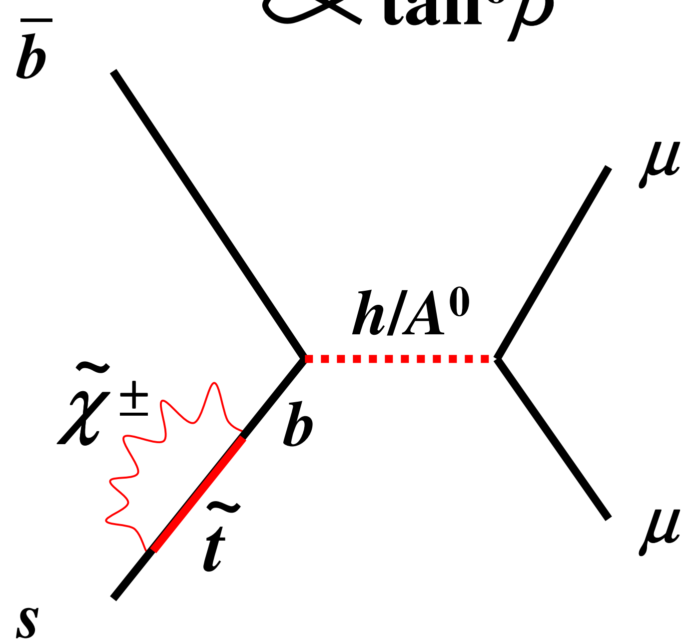


∝ tan⁶β
Bs → μ+μ−
b
s
h/A0
μ
μ
t
μ+
μ−
W ±
Z0
p
u
Bs
B
mSUGRA
GMSB
AMSB
Rp Violation

SM/SUSY FCNC in $B_s \rightarrow \mu\mu$



$\propto \tan^6\beta$



FCNC → loop

SM (3-4 x 10^{-9}) + **SUSY + Higgs**

(large $\tan\beta$ and small m_0)

→ We use the Run-I data for an extrapolation.

Review of $B_{d(s)} \rightarrow \mu\mu$ in Run I

CDF, PRD 57 (1998) 3811

Lum = 98 pb^{-1}

- B_d: **5.205-5.355 GeV/c^2**
- B_s: **5.300-5.450 GeV/c^2**

N_{obs} = 1 with 5.344 GeV/c^2

- $Br(B_d \rightarrow \mu\mu) < 8.6\times10^{-7}$ (95% C.L.)
- $Br(B_s \rightarrow \mu\mu) < 2.6\times10^{-6}$ (95% C.L.)

DØ, PLB 423 (1998) 419

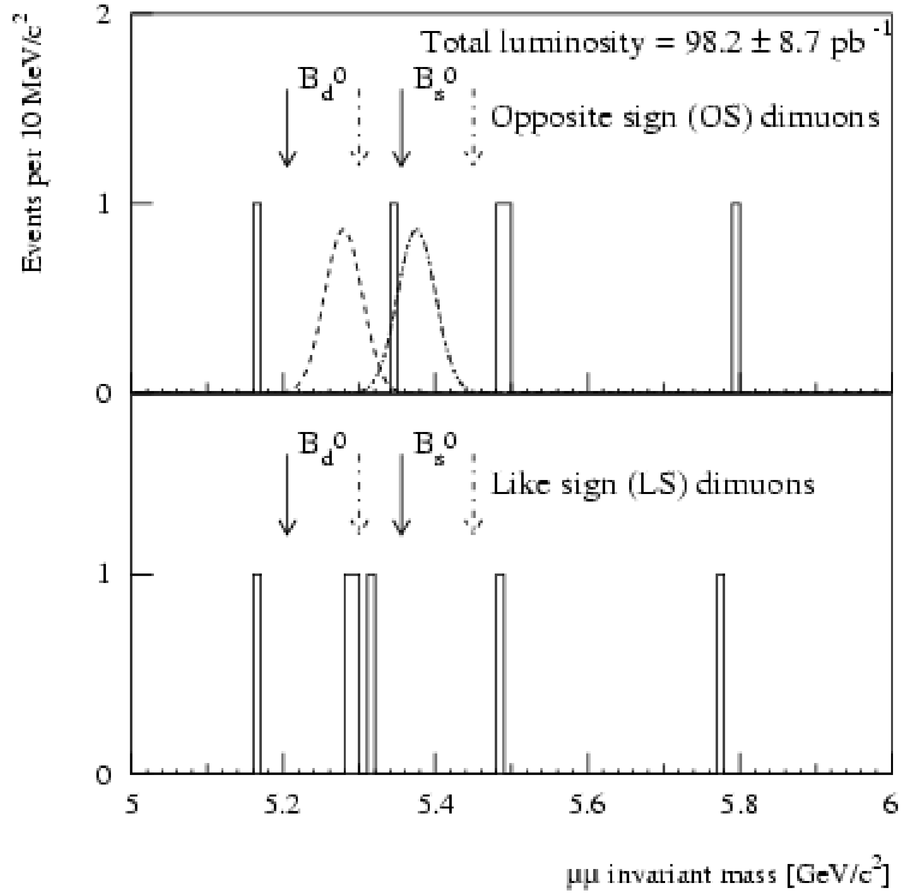
Lum = 50 pb^{-1}

- $B_{d/s}$: **4.8-5.8 GeV/c^2**

N_{obs} = 15 where $N_{BG} = 15\pm2$

- $Br(B_{d/s} \rightarrow \mu\mu) < 4.0\times10^{-5}$ (90% C.L.)

CDF



→ We use the CDF Run-I data for an extrapolation.

Run I (CDF): $B_s \rightarrow \mu\mu$

Review of the CDF Analysis:

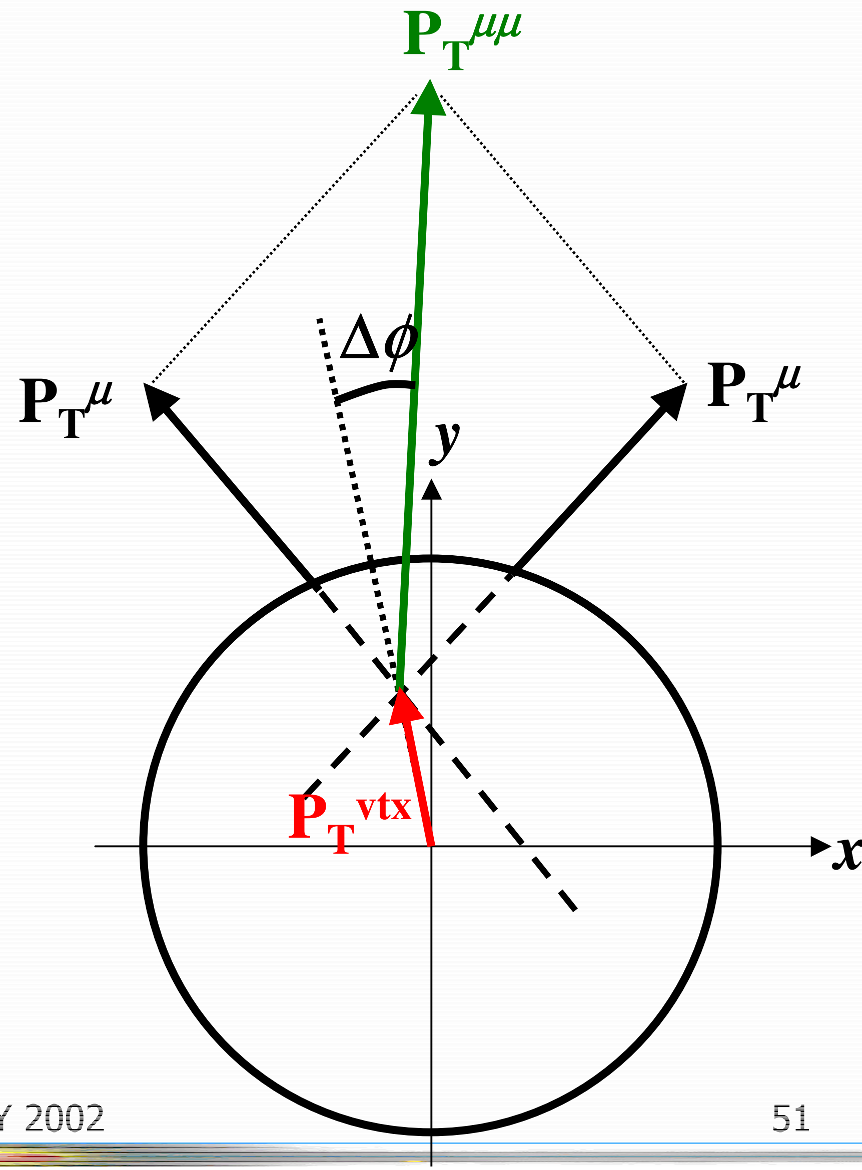
Primary Cuts:

a. $P_T^{\mu\mu} > 6$ GeV/c

b. $c\tau = L_{xy} M_B / P_T^{\mu\mu}$
$> 100\ \mu$m

c. $Iso = P_T^{\mu\mu} / [P_T^{\mu\mu} + \Sigma P_T^{trk}]$
> 0.75
($\Delta R < 1$ and $|z_{trk}-z_{vtx}| < 5$ cm)

d. $\Delta\phi = \Delta\phi(P_T^{\mu\mu}, P_T^{vtx})$
< 0.1 rad



Run II Plan: $B_s \rightarrow \mu\mu$

Two major BG sources

1) Fake
2) Gluon-splitting ($g \rightarrow bb \rightarrow \mu\mu$)

Primary Cuts:

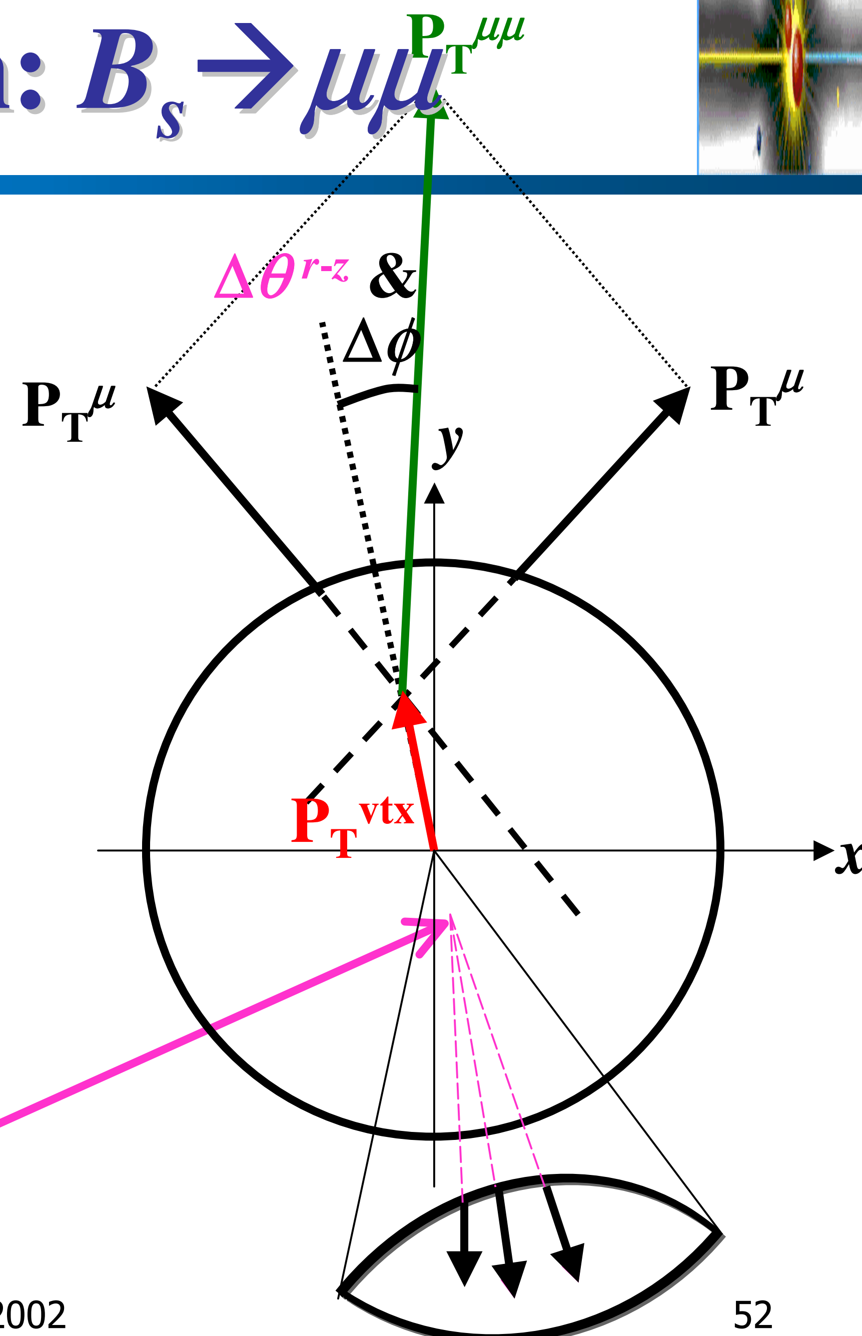
a. $P_T^{\mu\mu} > 6$ GeV/c

b. $L_{xy} > 400$ μm
   with $d/\sigma_d > 2$ for both tracks
   → $R_2/R_1 \cong 120$, $\varepsilon_2/\varepsilon_1 \cong 0.5$ (Run I)

c. $Iso > 0.8$
   ($\Delta R < 1$ and $|z_{trk}-z_{vtx}| < 5$ cm
   for tracks w/ $d/\sigma_d > 2$)

d. $\Delta\phi = \Delta\phi(P^{\mu\mu}, P^{vtx}) < 0.1$ rad
   $\Delta\theta^{r\text{-}z} < 0.1$ rad

e. B in away side



Backup Slide

Run I Fact: $B \to K\mu\mu$

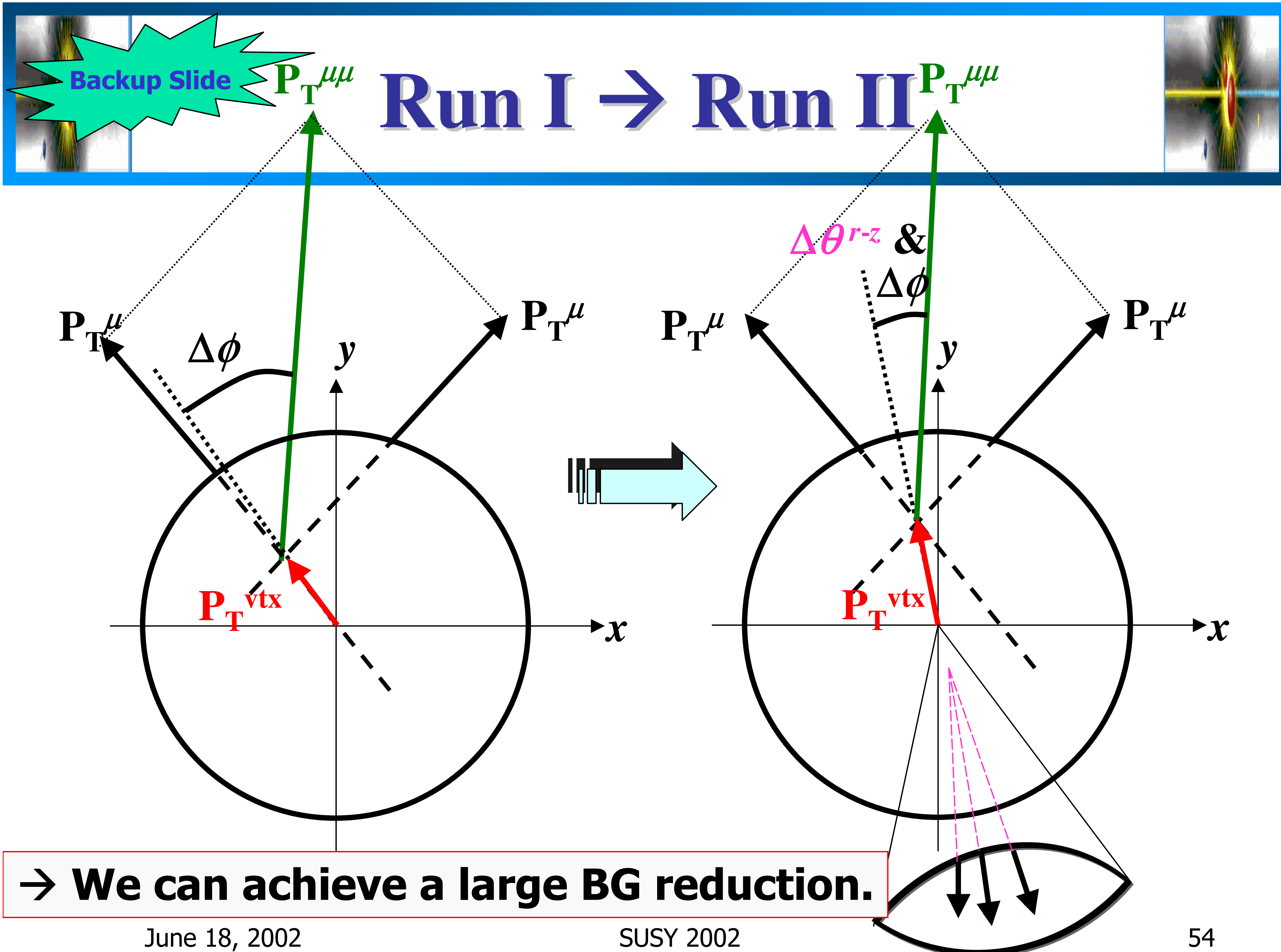
CDF, PRL 83 (1999) 3378
Using high-mass sideband events

Rejection for events in a baseline sample (*i.e.*, after *Iso*>0.6, no $\Delta\phi$)

No cuts on d/σ in Run I $B_s \to \mu\mu$

Run I		B^+ --> K^+ μμ		B^0 --> K^*0 μμ	
d/σ	Lxy (μm)	R/R0	ε/ε0	R/R0	ε/ε0
0,0	100	1	1	1	1
0,0	200	2.3	0.91	2.6	0.91
0,0	400	6.3	0.75	6.3	0.76
0,2	100	13	0.65	x	x
0,2	400	46	0.59	x	x
1,2	400	73	0.54	x	x
2,2	100	61	0.51	186	0.43
2,2	200	73	0.51	186	0.43
2,2	400	121	0.49	186	0.41
2,2	600	121	0.44	371	0.38
2,2	800	121	0.38	x	0.34
2,2	1000	121	0.32	x	0.30

$P_T^{\mu\mu}$ Run I → Run II $P_T^{\mu\mu}$



→ We can achieve a large BG reduction.

Backup Slide

Run II (CDF): $B_s \rightarrow \mu\mu$

Run-II *b*–physics Workshop Report, hep-ph/0201071

[CDF II]/[CDF I]

1. Improved muon coverage
   x1.3
2. SVX-II
   60 cm → 90 cm
   Stereo readout
3. Improved Triggers
   2μ (one CMUP#) x1.7
   2μ + 1 SVT x2.1

→ $A_{\mu\mu}^{\text{Run II}} = 2.8 \times A_{\mu\mu}^{\text{Run I}}$

= at least one μ in outer muon chamber

Single Event Sensitivity (*S*)

$S(B_s \rightarrow \mu\mu) = Br/N_{obs}$
$= (1.0\times10^{-8})\times(2\ \text{fb}^{-1})/\text{Lum}$

a. Lum = 2 fb^{-1}
   $S(B_s \rightarrow \mu\mu) = 1.0\times10^{-8}$

b. Lum = 15 fb^{-1}
   $S(B_s \rightarrow \mu\mu) = 1.1\times10^{-9}$
   … a few events at CDF

Run II (CDF): $B_s \rightarrow \mu\mu$

Run I: ε_1~0.45 & R_1~450 for a baseline sample

N_{BG} ~ 1 event

Run II: We assume "ε_2=0.45x0.45 & R_2=450x450" is possible.

a. Scaling: $R_2 = 450$ ^ $(0.45/\varepsilon_2)$

→ $\varepsilon_2/\varepsilon_1 = 1 / [1 + \log(R_2/R_1)/\log(450)]$

b. $N_{BG\ (Run\ I\ cuts)}$ ~ 57 @ 2 fb^{-1} → R_2/R_1 = 57 → $\varepsilon_2/\varepsilon_1$ ~ 0.60

$N_{BG\ (Run\ I\ cuts)}$ ~ 429 @ 15 fb^{-1} → R_2/R_1 = 429 → $\varepsilon_2/\varepsilon_1$ ~ 0.50

c. Scaling down using $Br(B_s \rightarrow \mu\mu) < 2.6\times10^{-6}$ (with one event)

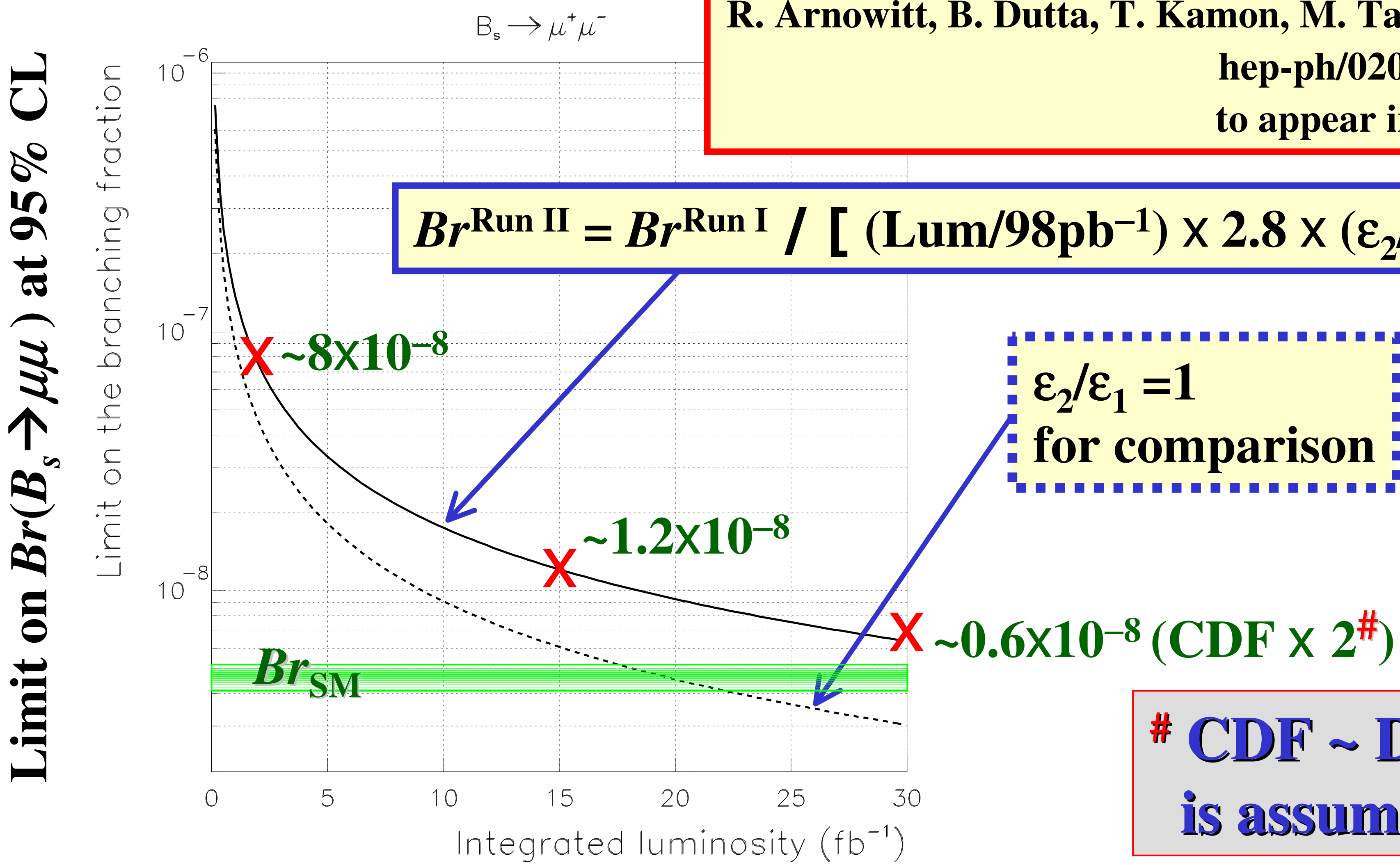
→ $A_{\mu\mu}^{Run\ II} = 2.8 \times A_{\mu\mu}^{Run\ I}$

→ $Br^{Run\ II} = Br^{Run\ I} / [(Lum/98pb^{-1}) \times 2.8 \times (\varepsilon_2/\varepsilon_1)]$

Run II Prospect: 95% CL Limits

R. Arnowitt, B. Dutta, T. Kamon, M. Tanaka, hep-ph/0203069, to appear in PLB

$Br^{\text{Run II}} = Br^{\text{Run I}}$ / [(Lum/98pb^{-1}) x 2.8 x ($\varepsilon_2/\varepsilon_1$)]



$\varepsilon_2/\varepsilon_1 = 1$ for comparison

CDF ~ DØ is assumed.

Backup Slide

Comments on DØ's $B_s \to \mu\mu$

- **Very impressive muon detection system:**

  $|\eta^{\mu}| < 1.6$, $P_T^{\mu} > 1.5$ GeV/c, $P_T^{\mu\mu} > 5$ GeV/c

- ***We should combine both* CDF *and* DØ *data.***

Backup Slide

What we can tell about SUSY?

See, for recent analyses,

1. A. Dedes, H. Dreiner, and U. Nierste,
hep-ph/0108037, PRL 87 (2001) 251804
$(g-2)_\mu$ in mSUGRA

2. R. Arnowitt, B. Dutta, T. Kamon, and M. Tanaka,
hep-ph/0203069, to appear in PLB
$(g-2)_\mu$ and CDM in mSUGRA, Run II prospect

3. S. Baek, P. Ko, and W.-Y. Song, hep-ph/0205259
mSUGRA, GMSB and AMSB

4. H. Baer *et al.*, hep-ph/0205325
implemented in ISAJET

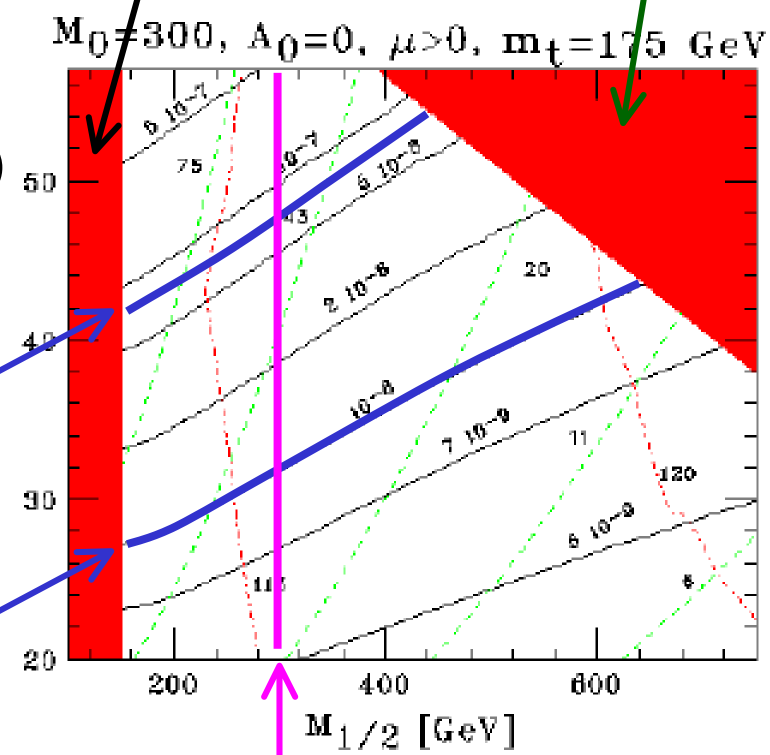
mSUGRA: tanβ vs. $m_{1/2}$

A. Dedes, H.K. Dreiner, U. Nierste., hep-ph/0108037, PRL 87 (2001) 251604

M_h (115 & 120 GeV/c^2)

$(\delta a_\mu)_{SUSY}$ in 10^{-10}

$Br(B_s \rightarrow \mu\mu)$



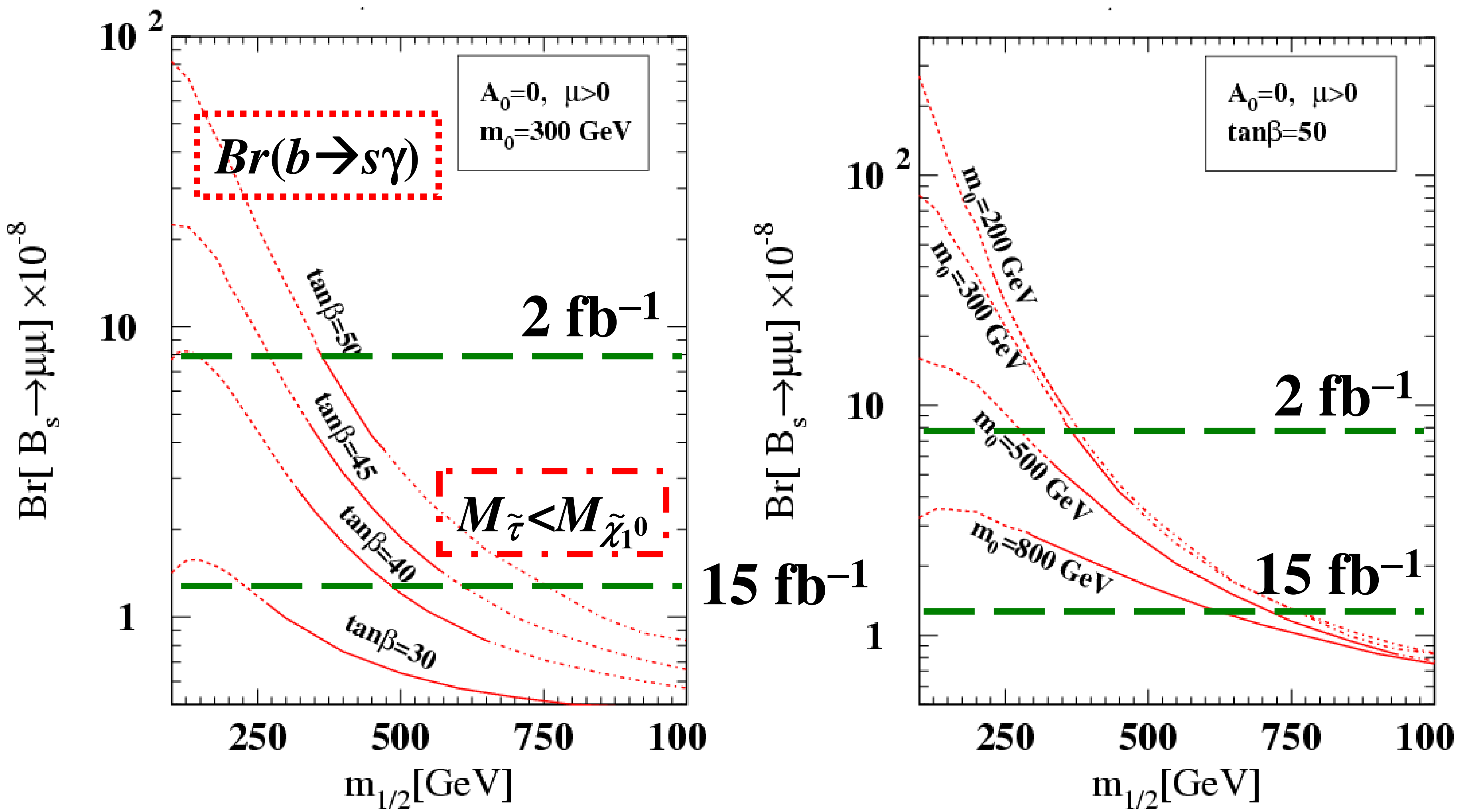
Beyond the Tevatron reach via direct searches

$M_{\tilde{g}}$ ~ 700 GeV/c^2

Backup Slide

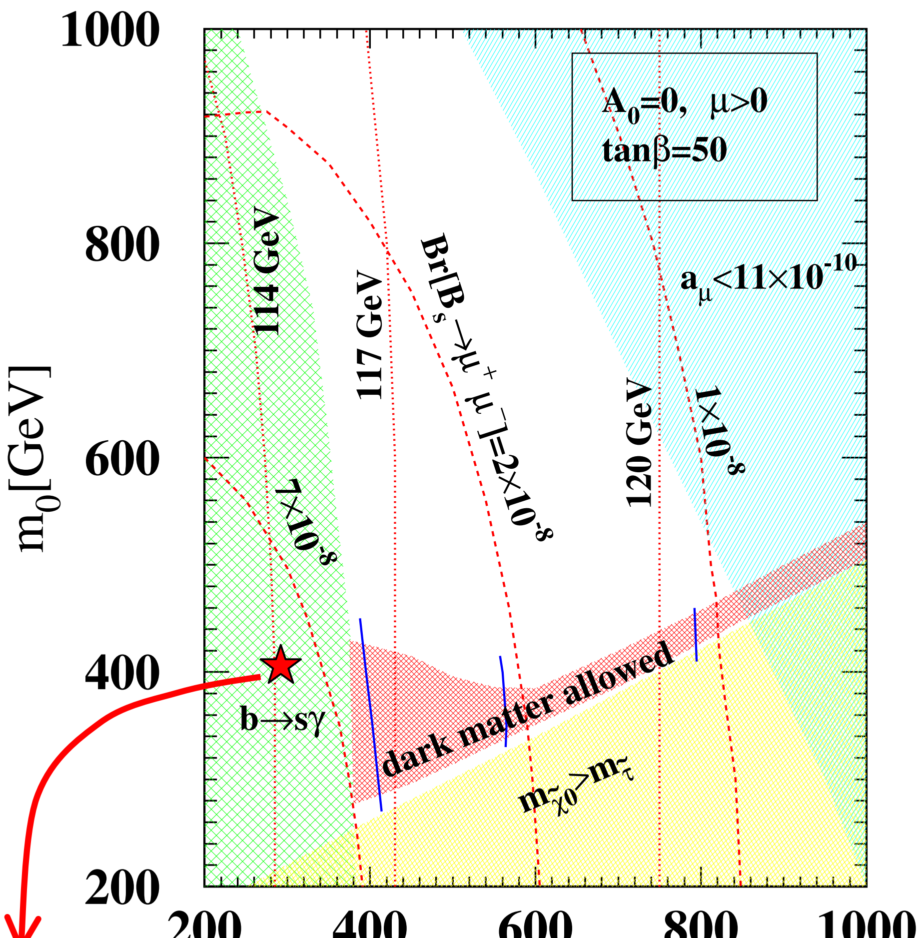
Br vs. $m_{1/2}$

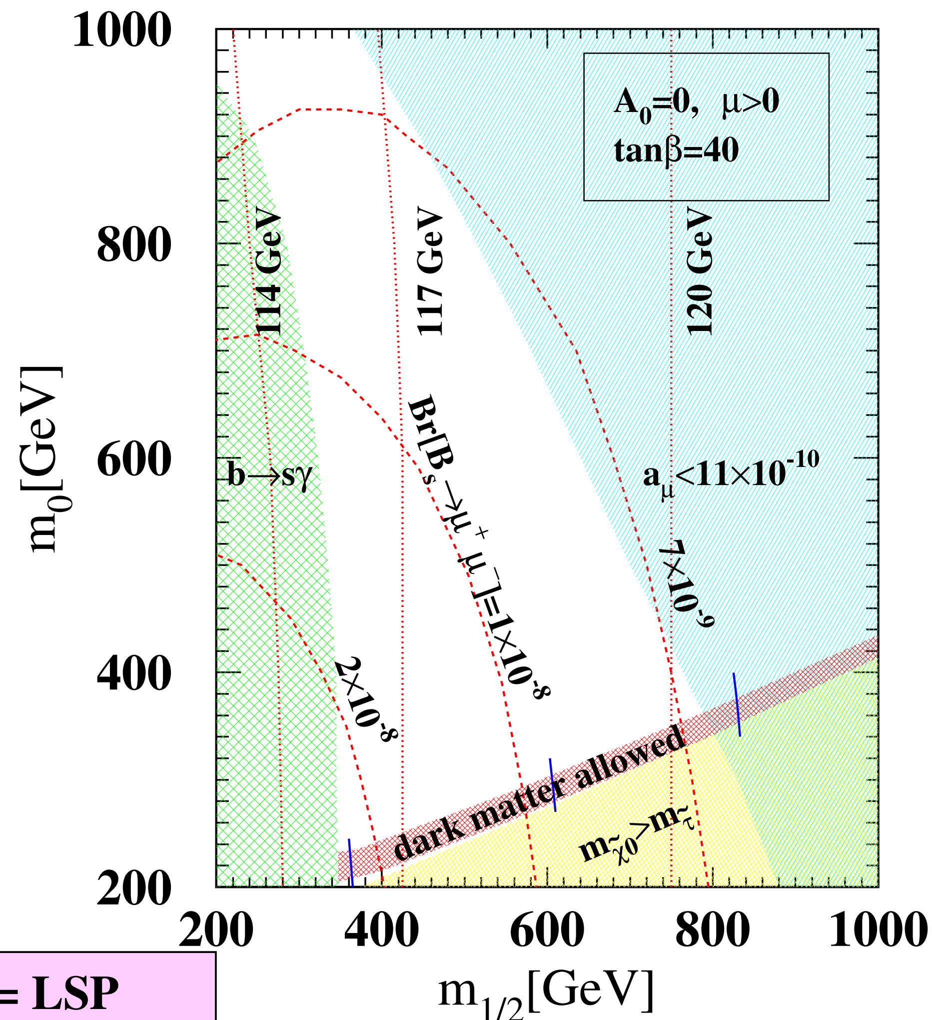
R. Arnowitt *et al.*, hep-ph/0203069, to appear in PLB



m_0 vs. $m_{1/2}$ ($A_0 = 0$)

R. Arnowitt *et al.*, hep-ph/0203069, to appear in PLB





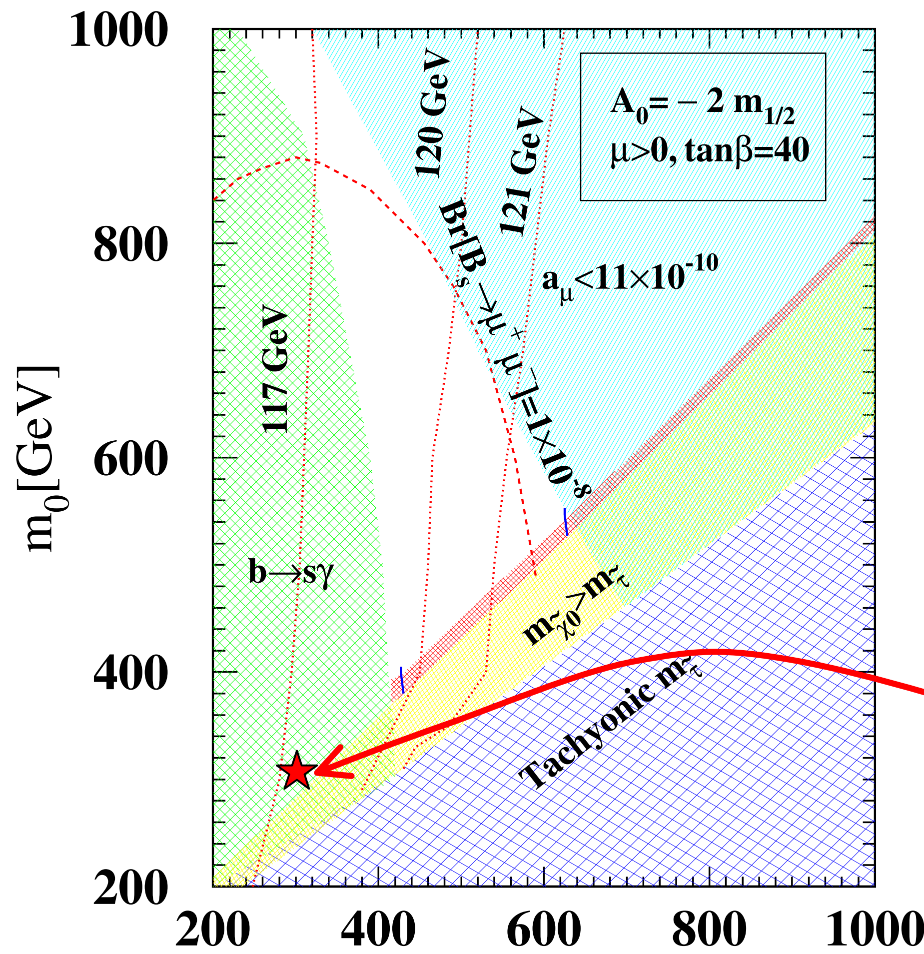
Snowmass Pt.4
A/H→bb,ττ

CDM: $\tilde{\chi}_1^0$ = LSP
$0.07 < \Omega_{LSP} h^2 < 0.25$

Backup Slide

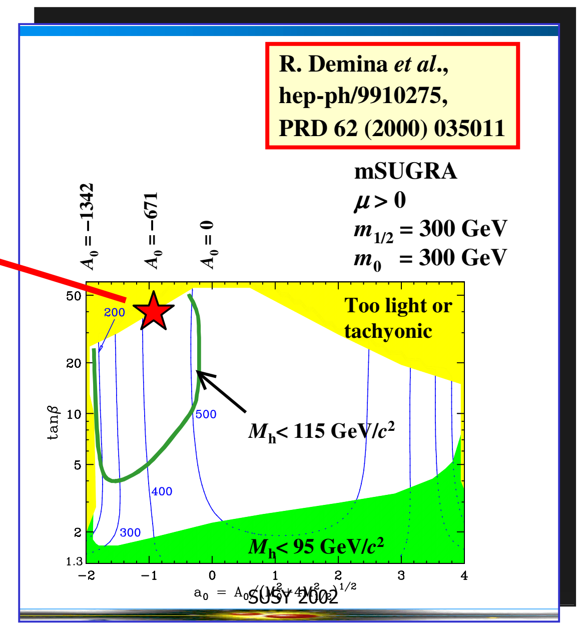
m_0 vs. $m_{1/2}$ ($A_0 = -2m_{1/2}$

R. Arnowitt *et al.*, hep-ph/0203069, to appear in PLB



CDM: $\tilde\chi_1^0$ = LSP

$0.07 < \Omega_{LSP} h^2 < 0.25$



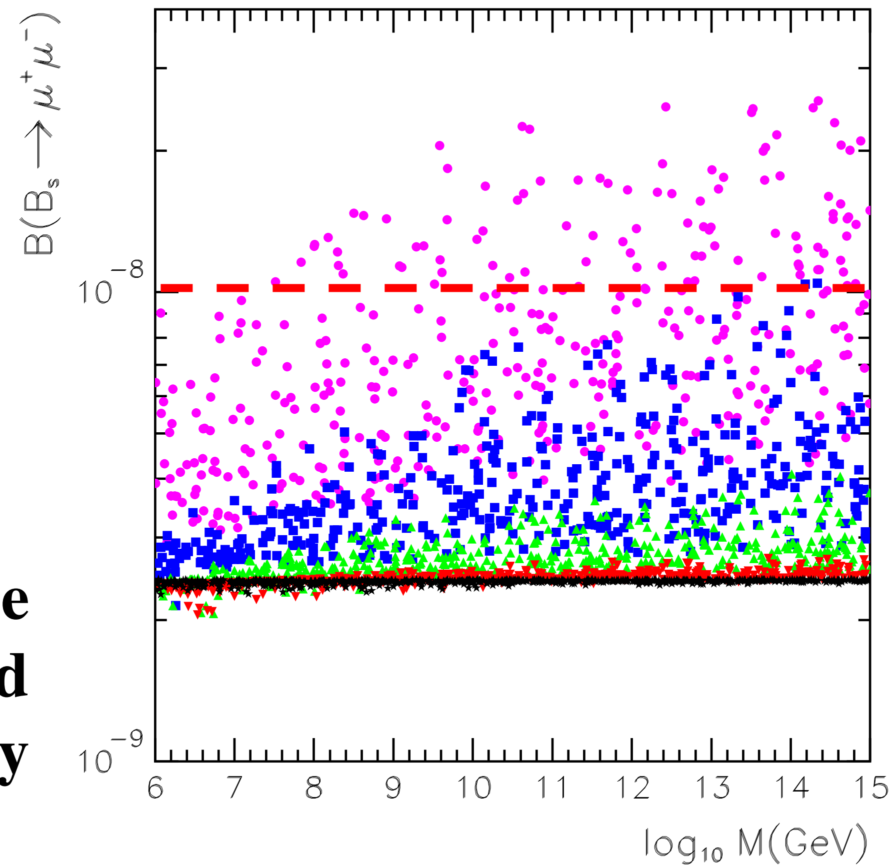
→ **Heavy stop!**

Testing ~~SUSY~~ Mechanism

S. Baek, P. Ko, W.-Y. Song,
hep-ph/0205259

GMSB (N_m=1)

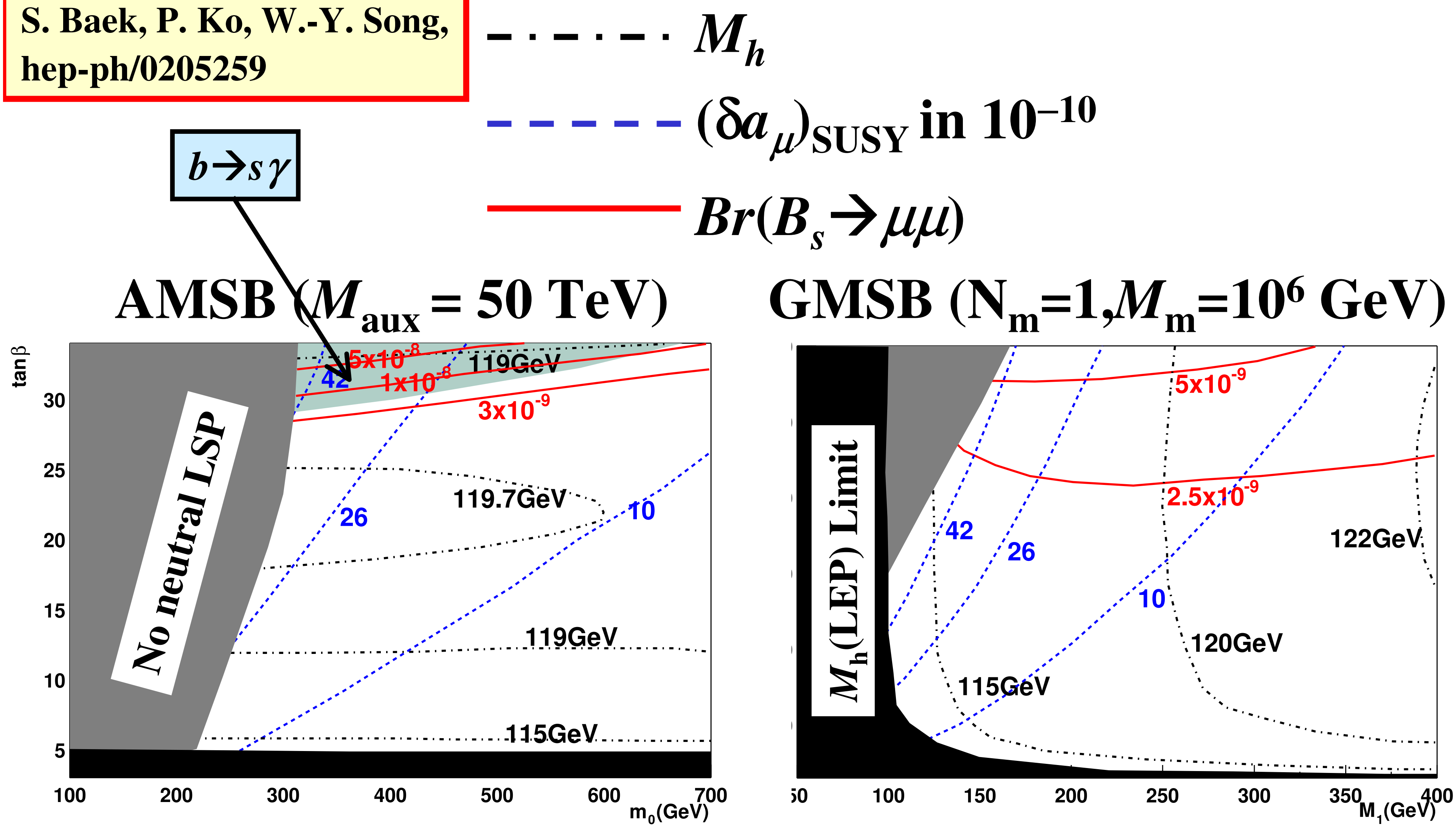
- ● $\tan\beta = 50\text{-}60$
- ● $\tan\beta = 40\text{-}50$
- ● $\tan\beta = 30\text{-}40$
- ● $\tan\beta = 20\text{-}30$
- ● $\tan\beta = 3\text{-}20$



→ **The Tevatron could exclude GMSB with $\tan\beta < 40$ and lower N_m if the $B_s \to \mu\mu$ decay is observed with $Br > 10^{-8}$.**

Testing ~~SUSY~~ Mechanism

S. Baek, P. Ko, W.-Y. Song, hep-ph/0205259



Testing ~~SUSY~~ Mechanism

S. Baek, P. Ko, W.-Y. Song,
hep-ph/0205259

The Tevatron could exclude

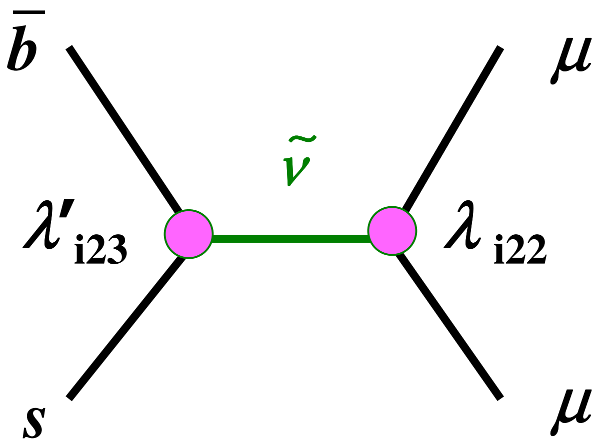
a) **GMSB with lower N_m**
b) **Minimal AMSB**

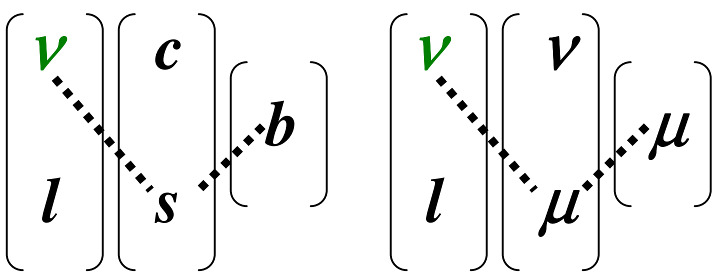
if the $B_s \rightarrow \mu\mu$ decay is observed with $Br > 10^{-8}$.

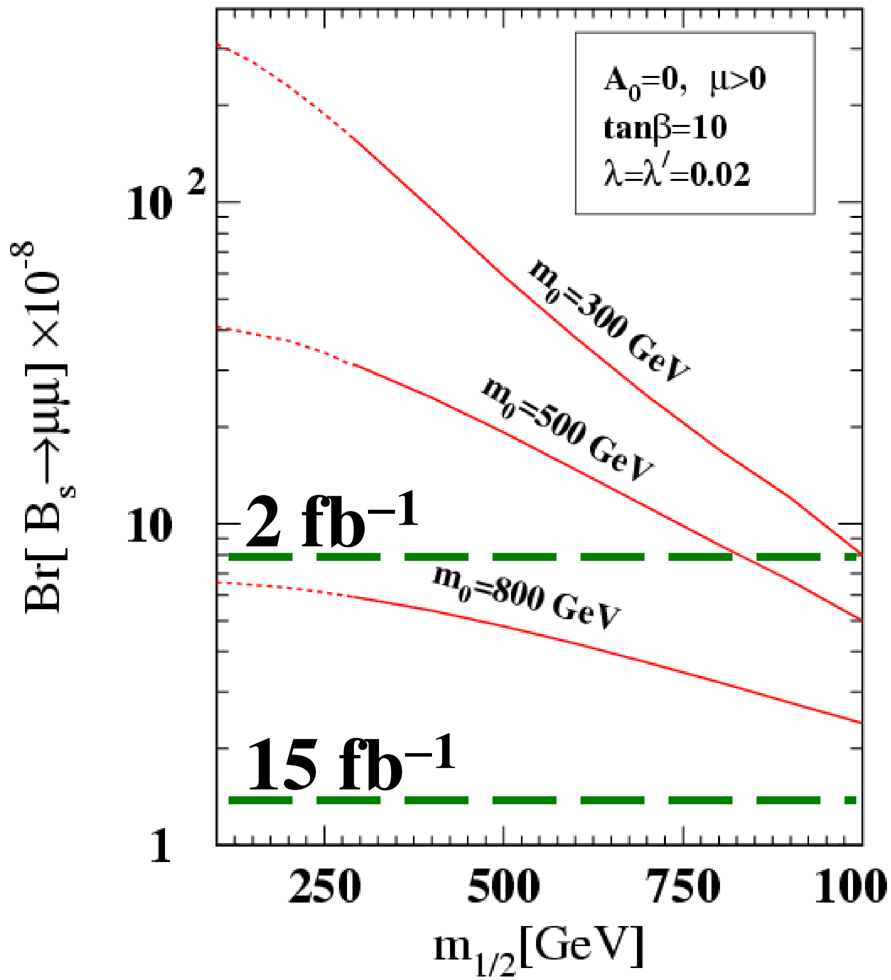
R_P Violation: *Br* vs. $m_{1/2}$

R. Arnowitt *et al.*, hep-ph/0203069, to appear in PLB

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







Summary: Prospects for SUSY Discovery at the Tevatron

Run II (15 fb^{-1}) at the Tevatron

A unique opportunity in the coming 5+ years to hopefully penetrate the SUSY world in a crucial mass range.

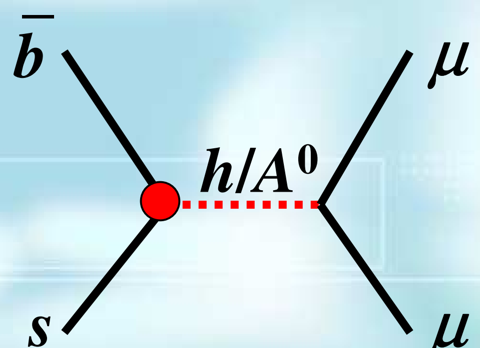
τ's and b's: the keys for direct searches

The direct searches are limited by Luminosity and E_{cm}.

The Tevatron will deliver 230 pb^{-1} and both CDF and DØ will take 100-150 pb^{-1} on tape by the end of 2002.

$B_s \rightarrow \mu\mu$ in SUSY

A unique opportunity to penetrate the SUSY world if $\tan\beta$ is large…



Prospects (95% C.L. limits):

2 fb^{-1} → $Br < 8 \times 10^{-8}$

15 fb^{-1} → $Br < 1.2 \times 10^{-8}$

e.g., mSUGRA reach @15 fb^{-1}

$m_{1/2} < 800$ GeV @$\tan\beta = 50$

(beyond the direct search at the Tevatron)