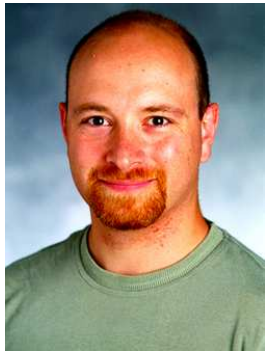
Search for SUSY using Like-sign Dilepton Events

James

Teruki



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1. **Mark Kruse (Chair)**
2. **Steve Worm**
3. **Joao Guimaraes De Costa**

Institutional Review

We thank the following institutions for their constructive comments…

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2. **Ohio State**
3. **Texas Tech**
4. **Toronto**

CDF Notes (J.P. Done *et al.)*

1. **CDF 3472/4182 – Data samples**
2. **CDF 4017 – Eff(μ trigger)**
3. **CDF 4218 – Eff(lepton ID)**
4. **CDF 4291 – Eff(lepton ISO)**
5. **CDF 4401 – $\sigma(J/\psi)$ vs. Run Number**
6. **CDF 4446/4447 – Data samples (Rev.)**
7. **CDF 4901 – ISAJET validation**
8. **CDF 4909 – Main analysis (V3.0)**
9. **CDF 5580 – PRL draft**

Outline

1. **Introduction**
2. **Supersymmetry (SUSY)**
3. **Like-sign Dilepton Signal in SUSY**
4. **Generic Dilepton Sample**
5. **Dilepton + $\geq$2 Jets (+ $\not\!\!E_T$) Sample**

   >>>Data vs. SM Prediction<<<
6. **MSSM**
7. **95% Confidence Level (C.L.) Limits**
8. **Excluded Region in MSSM**
9. **Conclusion**

1. Introduction

Structual defects in the SM, such as the quadratic mass divergence of the Higgs boson → New Physics

***e.g.*, Supersymmetry ($M_{SUSY} < 1$ TeV/c^2)**

Search for Squarks/Gluinos via

Like-sign (LS) dilepton + Jets + $\not\!\!E_T$

1. **Clean – small SM backgrounds**
2. **Complementary to other direct searches**
3. **Useful for testing other theories**

1. Introduction (Cont'd)

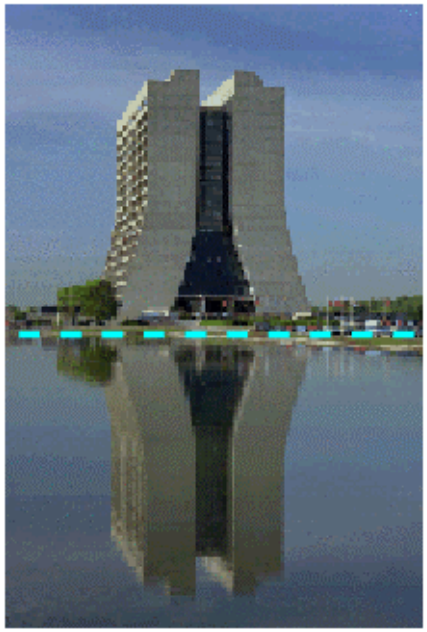
Search Strategy via

LS Dilepton + Jets + $\not\!\!E_T$:

1. **Begin with a generic dilepton sample;**
2. **Apply the same cuts on both OS and LS samples in parallel;**
3. **Require $\not\!\!E_T$ to separate "new physics" from the SM events;**
4. **Use the OS events as a check of the LS backgrounds.**

2. SUSY

SuperSymmetric World



Fermilab

Boselab

$M_{SUSY} \sim O(1\ \mathrm{TeV}/c^2)$

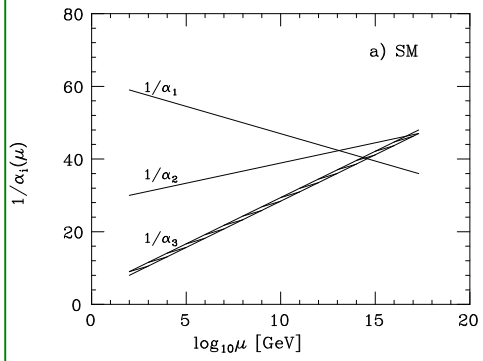
Supersymmetry (SUSY)

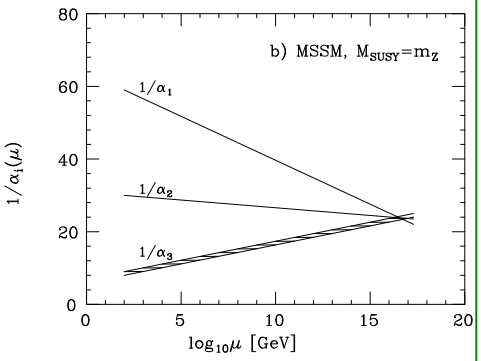
- Last unused symmetry of S-matrix → Attempts to unify Bose and Fermi states within QFT.
- (Only known) solution of fine-tuning problem if

  $M_{SUSY} \lesssim$ a few TeV/c^2.
- First experimental indication of unification with the precision LEP measurements of the SM couplings (α_1, α_2, α_3) if

  $M_{SUSY} \sim \mathcal{O}(1\ \mathrm{TeV}/c^2)$

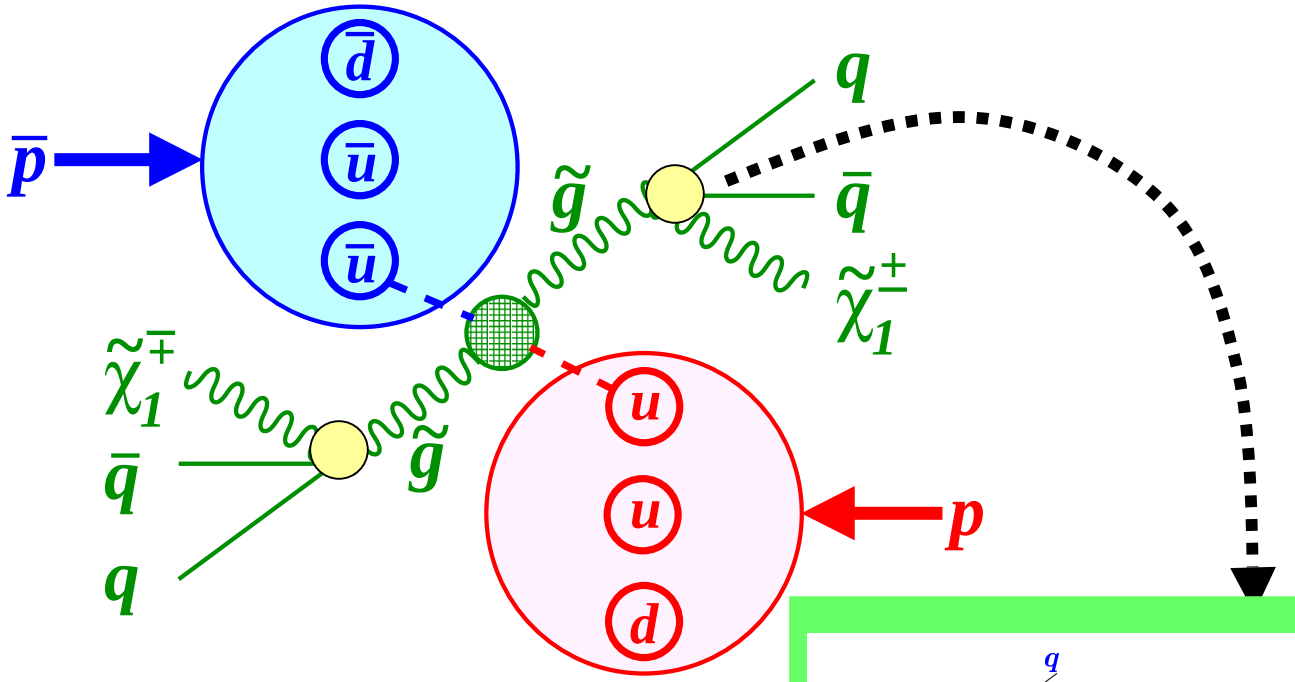
  and two (and only two) Higgs doublets.



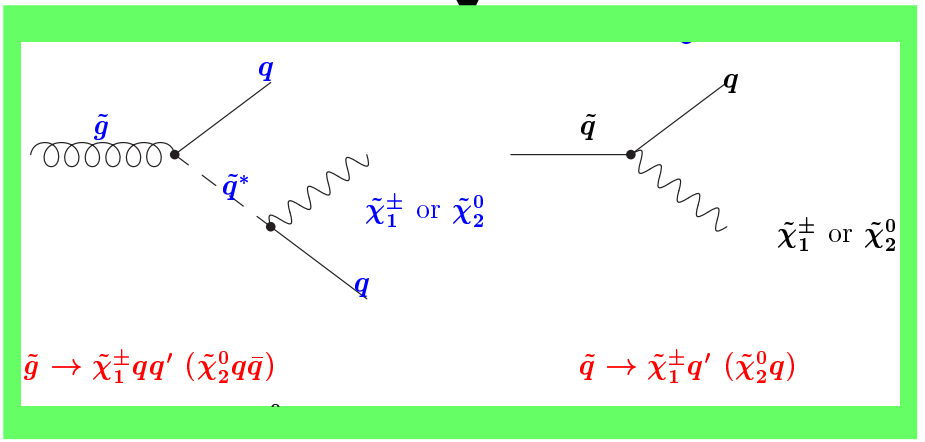


The supersymmetrized Standard Model with two Higgs doublets plus grand unification is consistent with the low energy LEP measurements.

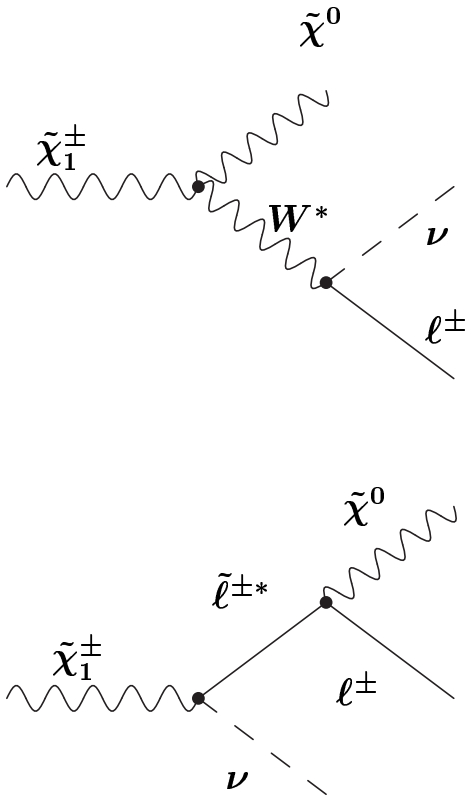
3. LS Dilepton Signal



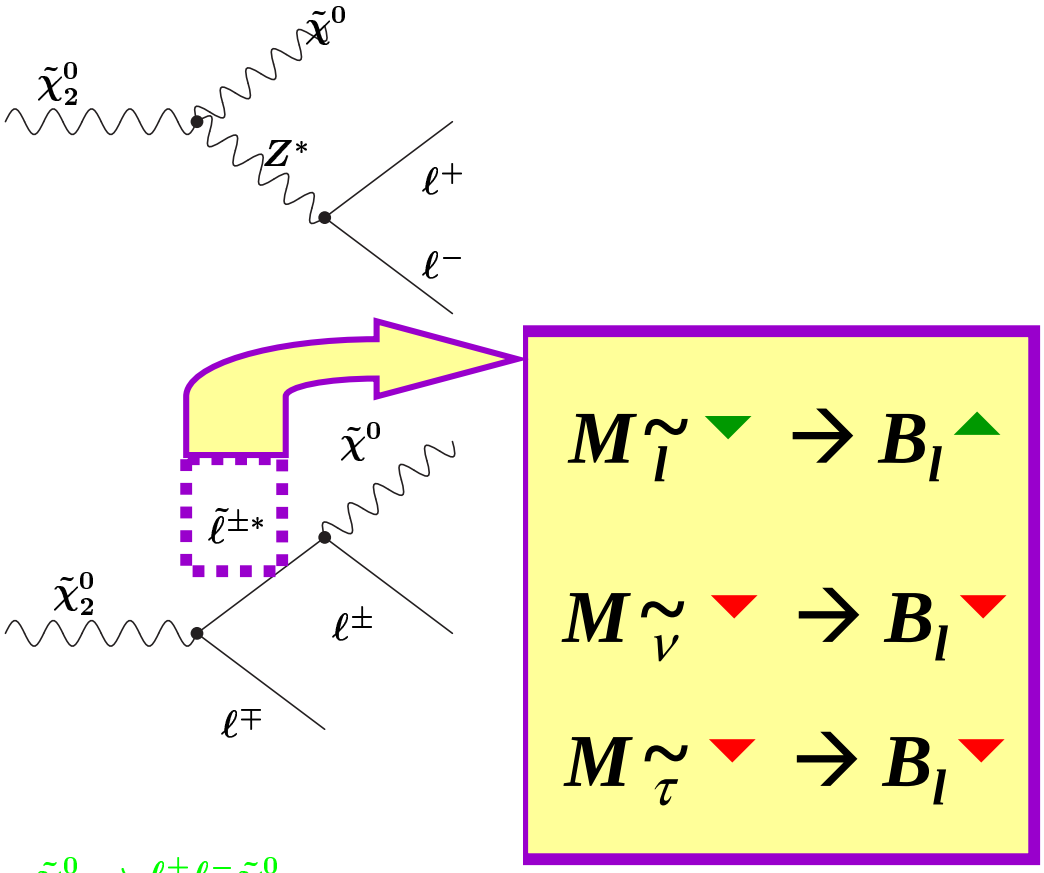
Pair Production + Cascade Decays



3a. Leptonic Decays



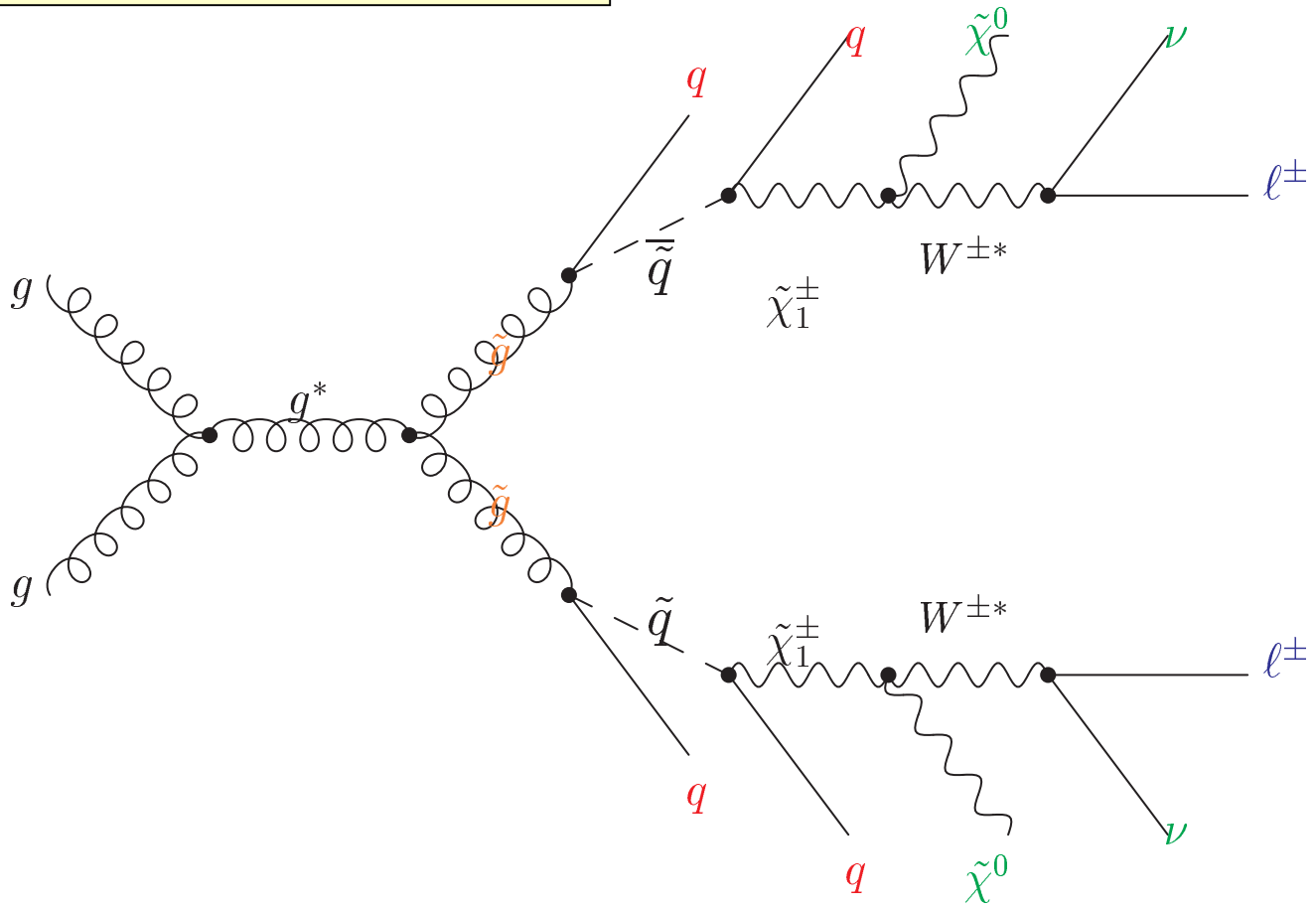
$\tilde{\chi}_1^\pm \to \ell^\pm \nu \tilde{\chi}^0$



$\tilde{\chi}_2^0 \to \ell^+ \ell^- \tilde{\chi}^0$

3b. Gluino Production

LS Dilepton + Jets + $\not\!\!E_T$



4. Generic Dilepton Sample

Run Ia (1992-93) & Ib(1994-95)

- $\sqrt{s}$ = 1.8 TeV
- 106 pb^{-1} (about 5 trillion collisions)

Triggers:

- Level 2 inclusive lepton trigger

Generic Dilepton Sample:

- P_T (l_1) > 8 GeV/c in CEM or CMU/CMP
- P_T (l_2) > 3 GeV/c in CEM or CMU/CMP/CMX
- 515,699 events (including J/ψ, Y, Z^0 events)

4a. Triggers

Electron Triggers

Level	IA	IB
1	L1_CALORIMETER* (Y. Kato)	L1_CALORIMETER* (Y. Kato)
2	CEM_9_SEED_SH_7_CFT_9_2* (CDF 3665)	CEM_16_CFT_12* (CDF 4561) CEM_8_CFT_7_5_XCES* (CDF 4691)
3	ELE1_CEM_8_6* (CDF 2596) ELE1_CEM_9* (CDF 2596) ELE1_CEM_15_10* (CDF 2596)	ELEB_CEM_8_6* (CDF 4700) ELEB_CEM_18* (CDF 4700)

9 GeV/c

Muon Triggers

Level	IA	IB
1	CMU_CMP_6PT0* (CDF 1999)	CMU_CMP_6PT0* (CDF 1999)
2	CMU_CMP_CFT_9_2* (CDF 1999)	CMUP_CFT_12_5DEG* (CDF 4017) CMUP_CFT_7_5_5DEG* (CDF 4017)
3	MUO1_CMU_CMP_7* (CDF 2596)	MUOB_CMU_CMP_8* (CDF 4700) MUOB_CMU_CMP_15*(CDF 4700)

4b. Analysis Family

The data sample has well been studied…

1. **Andrew Scott – Drell-Yan (*ee*, $\mu\mu$)**
2. **Benn Tannenbaum – 3 leptons + $\not\!\!E_T$ (MSSM)**
3. **Max Chertok – LS *ee* + $\geq$2 jets (RPV SUSY)**

… above three were published.

4. **Armin Koengeter – 4 leptons (RPV SYSY)**
5. **Hirotoshi Toyoda – *ll* + $\geq$4 jets (RPV SUSY)**

… above two are in GP reviews.

6. **Jane Nachtman – LS *ll* + $\not\!\!E_T$ (MSSM)**

… exercised for Run II

5. $2l+\geq 2$Jets+$\not\!\!E_T$ Sample

Cuts:

1. Isolated (ISO < 4 GeV) dilepton:

P_T (l_1) > 11 GeV/c in CEM/CMUP

P_T (l_2) > 5 GeV/c in CEM/CMU/CMP/CMX

2. $N_j \geq 2$ (E_T > 15 GeV, $|\eta| < 2.4$)

3. M_{ll} > 12 GeV/c^2 (OS/LS $ee, e\mu, \mu\mu$)

… to remove bb/cc events

4. $Z^0(\rightarrow l^+l^-)$ veto

5. $\not\!\!E_T$ > 25 GeV

5a. SM Sources

Drell-Yan (γ^*/Z^0)

$t\bar{t}$

$b\bar{b}/c\bar{c}$

diboson (WW, WZ, ZZ)

found to be negligible

$W(\rightarrow l\ \nu)$ + $\geq$3 jets where one of the jets is misidentified as a lepton ('l')

(a) P **('l' in *W production*) *based on***

$N_{data}[Z^0(\rightarrow ll) + \text{'}l\text{'}] - N_{SM}[lll]$

(b) $N_{data}[W(\rightarrow l\ \nu) + \geq 3\ j] \times P$

5b. Monte Carlo Estimates

1. Acceptance:

ISAJET

+CTEQ3L

+QFL

2. σ_{prod}:

DY	**CDF**
$t\bar{t}$	**CDF**
$b\bar{b}/c\bar{c}$	**CDF**
diboson	**NLO**

5c. $2l+\geq 2$Jets$+\not\!\!E_T$ Sample (I)

$P_T(l_1) > 11$ GeV/c

$P_T(l_2) > 5$ GeV/c

$N_j \geq 2$ ($E_T > 15$ GeV)

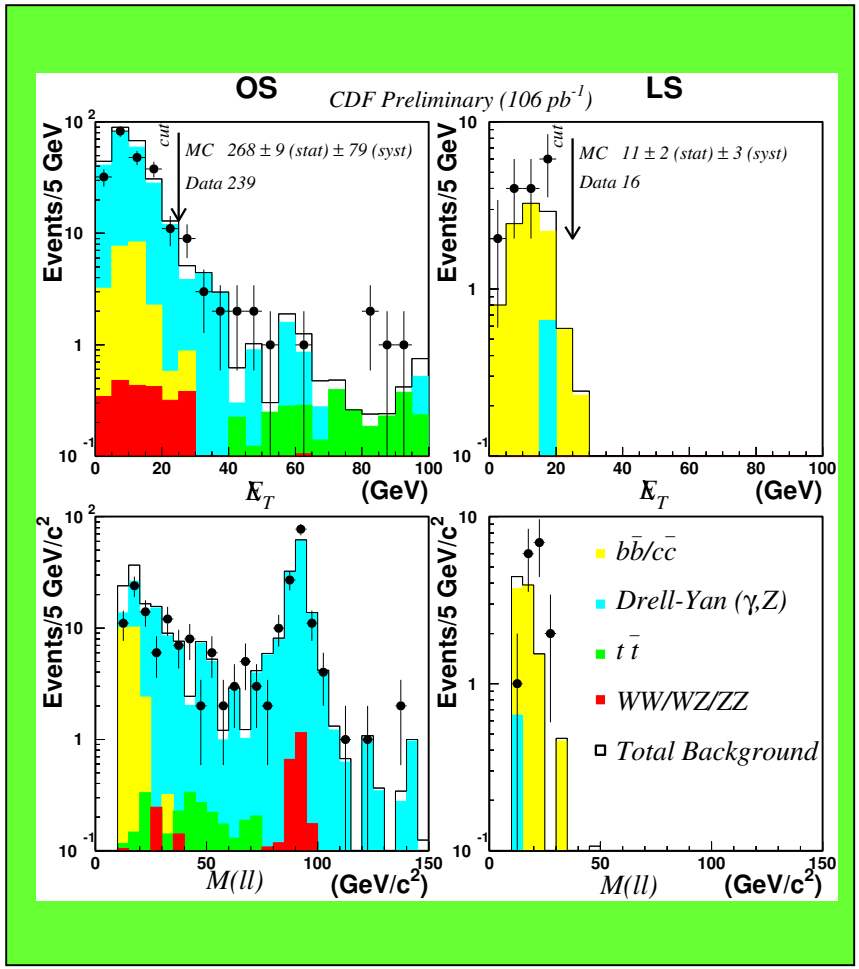
→ 325 OS vs. 25 LS

$M_{ll} > 12$ GeV/c^2

(OS/LS $ee, e\mu, \mu\mu$)

→ 239 OS vs. 16 LS

[SM: 268 ± 80 OS vs. 11 ± 3.6 LS]



5d. 2l+$\geq$2Jets+$\not\!\!E_T$ Sample (II)

$P_T(l_1) > 11$ GeV/c

$P_T(l_2) > 5$ GeV/c

$N_j \geq 2$ ($E_T > 15$ GeV)

$M_{ll} > 12$ GeV/c^2

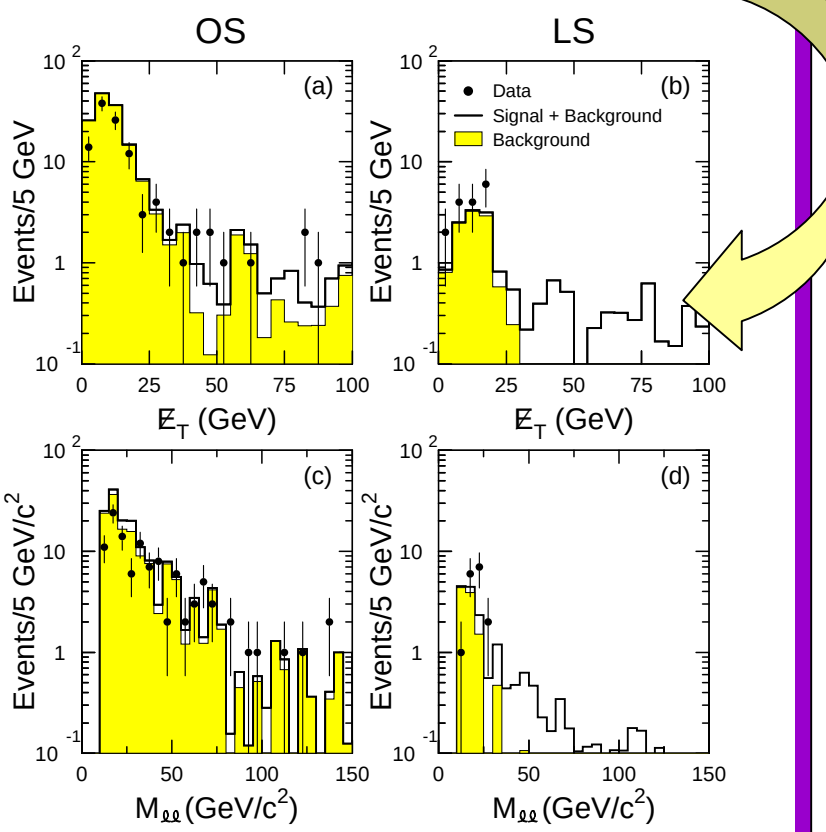
Z^0 veto

→ 112 OS vs. 16 LS

$\not\!\!E_T > 25$ GeV

→ 19 OS vs. 0 LS

$\tilde{M}(q) = \tilde{M}(g) = 210$ GeV/c^2



PRL Fig.1

5e. Data vs. SM Prediction (I)

PRL Table I

Selection	Data	SM Backgounds	SUSY
Dilepton Dataset	515,699		
Dilepton-Dijet	350		
$M_{\ell\ell} \geq 12$ GeV/c^2	255	$279 \pm 9 \pm 79$	$27 \pm 1 \pm 5$
$Z^0(\rightarrow \ell^+\ell^-)$ veto	128	$158 \pm 7 \pm 45$	$27 \pm 1 \pm 5$
$\not\!\!E_T \geq 25$ GeV	19	$14.7 \pm 1.3 \pm 2.8$	$24 \pm 1 \pm 5$
Like-sign Dilepton	0	$0.55 \pm 0.25 \pm 0.08$	$5.9 \pm 0.6 \pm 1.4$

$M(\tilde{q}) = M(\tilde{g}) = 210$ GeV/c^2

→Production of both OS and LS events are consistent with the SM prediction.

5f. Data vs. SM Prediction (II)

PRL Table II

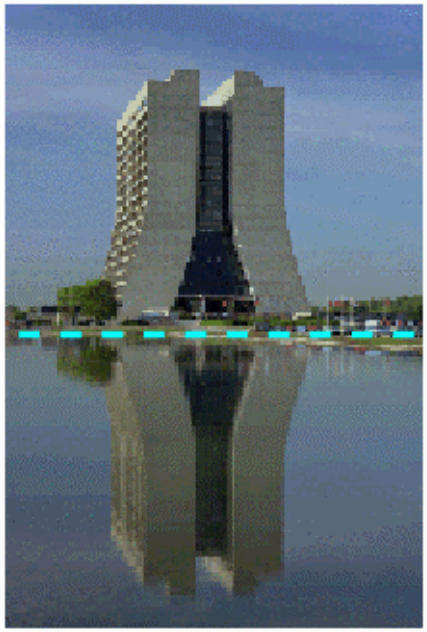
After Z^0 veto and $\not\!\!E_T$>25 GeV cuts…

Source	OS	LS	
Drell-Yan	$8.7 \pm 0.9 \pm 2.5$	$0.00\ ^{+\ 0.01}_{-\ 0.00}$	$^{+\ 0.01}_{-\ 0.00}$
$t\bar{t}$	$4.0 \pm 0.3 \pm 1.2$	0.08 ± 0.04	± 0.02
$b\bar{b}/c\bar{c}$	$0.9 \pm 0.9 \pm 0.3$	0.23 ± 0.23	± 0.07
$WW/WZ/ZZ$	$0.5 \pm 0.1 \pm 0.1$	0.24 ± 0.10	± 0.04
Total	$14.1 \pm 1.3 \pm 2.8$	0.55 ± 0.25	± 0.08
Data	19	0	

→*No evidence for new particle production*

6. MSSM

SuperSymmetric World

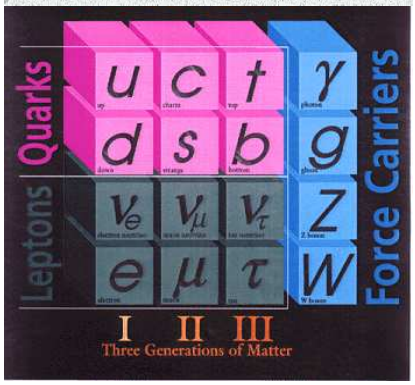


Fermilab

Boselab

Minimal Supersymmetric Standard Model

Particles

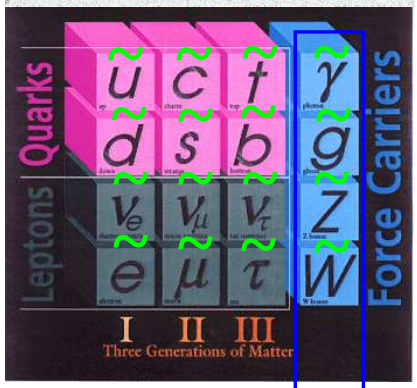


Higgs Bosons

h^0

H^0 A^0 $H^{\pm}$

SParticles



Higgsinos

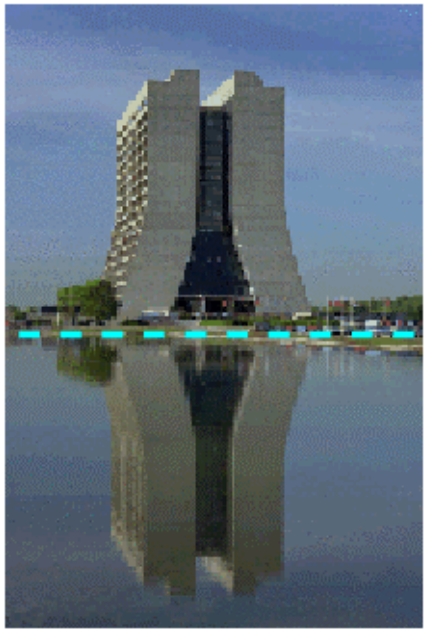
$\tilde{h}^0$

$\tilde{H}^0$ $\tilde{A}^0$ $\tilde{H}^{\pm}$

Gauginos

6a. MSSM

SuperSymmetric World



Fermilab

Boselab

Minimal Supersymmetric Standard Model (MSSM)

Supersymmetrized Standard Model

+ Two Higgs doublets (h^0, H^0, A^0, $H^\pm$)
+ Gaugino unification ($M_{\tilde{g}} = \frac{\alpha_3}{\alpha_2} M_{\tilde{W}} = \frac{3\alpha_3}{5\alpha_1} M_{\tilde{B}}$)
+ R-parity ($R_p = (-1)^{3B+L+2S}$) invariance
+ Lightest SUSY particle (LSP) = $\tilde{\chi}_1^0$ (stable)

- Two Higgs doublets ($\tan\beta = \langle H_2\rangle / \langle H_1\rangle$)

  $H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$ gives masses u-type quarks

  $H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$ gives masses d-type quarks and leptons

  where $\langle H_1\rangle^2 + \langle H_2\rangle^2 = (246\ \text{GeV})^2$

- Supersymmetric partners (quarks, leptons, and gluon):

quarks (q)	$\rightarrow$	squarks $(\tilde{q})$		
leptons (ℓ, ν)	$\rightarrow$	sleptons $(\tilde{\ell}, \tilde{\nu})$		
gluon (g)	$\rightarrow$	gluino $(\tilde{g})$		
(W^+, H_2^+)	$\rightarrow$	$(\tilde{W}^+, \tilde{H}_2^+)$	$\overset{\mu,\tan\beta}{\longrightarrow}$	$(\tilde{\chi}_1^+, \tilde{\chi}_2^+)$
(W^-, H_1^-)	$\rightarrow$	$(\tilde{W}^-, \tilde{H}_1^-)$	$\overset{\mu,\tan\beta}{\longrightarrow}$	$(\tilde{\chi}_1^-, \tilde{\chi}_2^-)$
(B, W^3, H_1^0, H_2^0)	$\rightarrow$	$(\tilde{B}, \tilde{W}^3, \tilde{H}_1^0, \tilde{H}_2^0)$	$\overset{\mu,\tan\beta}{\longrightarrow}$	$(\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0)$

- Higgs-squark-squark trilinear interaction terms (A_b, A_t)

  Higgs-stau-stau trilinear interaction term (A_τ)

μ, $\tan\beta$

6b. Constrained MSSM (I)

Further assumptions:

(a) Mimimal mixing between two helicity states

- **between $\tilde{q}_L$ and $\tilde{q}_R$**
- **between $\tilde{l}_L$ and $\tilde{l}_R$**

(b) Common scalar mass at GUT

Nearly mass-generate squarks →

Allowed to use PROSPINO to calculate σ_{NLO}

(approximately true in SUGRA if $\tan\beta$ is small)

(c) $M(\tilde{l})$, $M(\tilde{\nu})$ ←→ $M(\tilde{g})$, $M(\tilde{q})$ (as in SUGRA)

$M(\tilde{l})$, $M(\tilde{\nu}) > 0$ ←→ $M(\tilde{q}) > 0.9\, M(\tilde{g})$

(d) $M(A^0) = 500$ GeV/c^2 (to decouple our search from the Higgs sector)

6c. Constrained MSSM (II)

Parameters in a constrained framework of MSSM:

1. **tanβ**
2. μ
3. $M(\tilde{g})$
4. $M(\tilde{q})$ **[** $\gtrsim$ **0.9** $M(\tilde{g})$ **]**

SUSY production:

$\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$, $\tilde{q}\bar{\tilde{q}}$ **(excluding** $\tilde{t}\,\bar{\tilde{t}}$**)**

7. 95% C.L. Limits

$$\sigma \cdot B_{2\ell} = \frac{N_{cand} - N_{BG}}{A \cdot \int Ldt}$$

where :

$$A = \frac{N_{LS}^{acc}}{N_{OS} + N_{LS}}$$

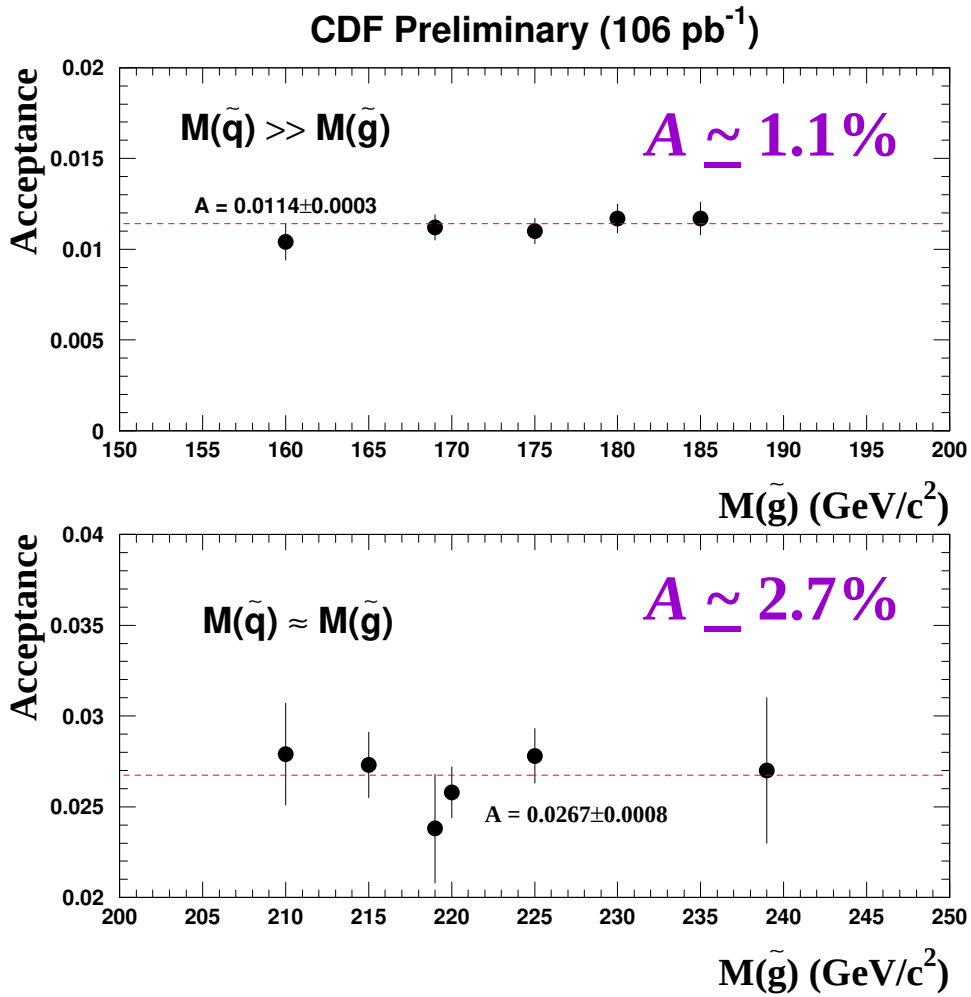
$$N_{cand} = 0 \rightarrow N_{95\%CL}$$

7a. Acceptance (I)

Nominal choice:

$\tan\beta = 2$

$\mu = -800\ \mathrm{GeV/c^2}$



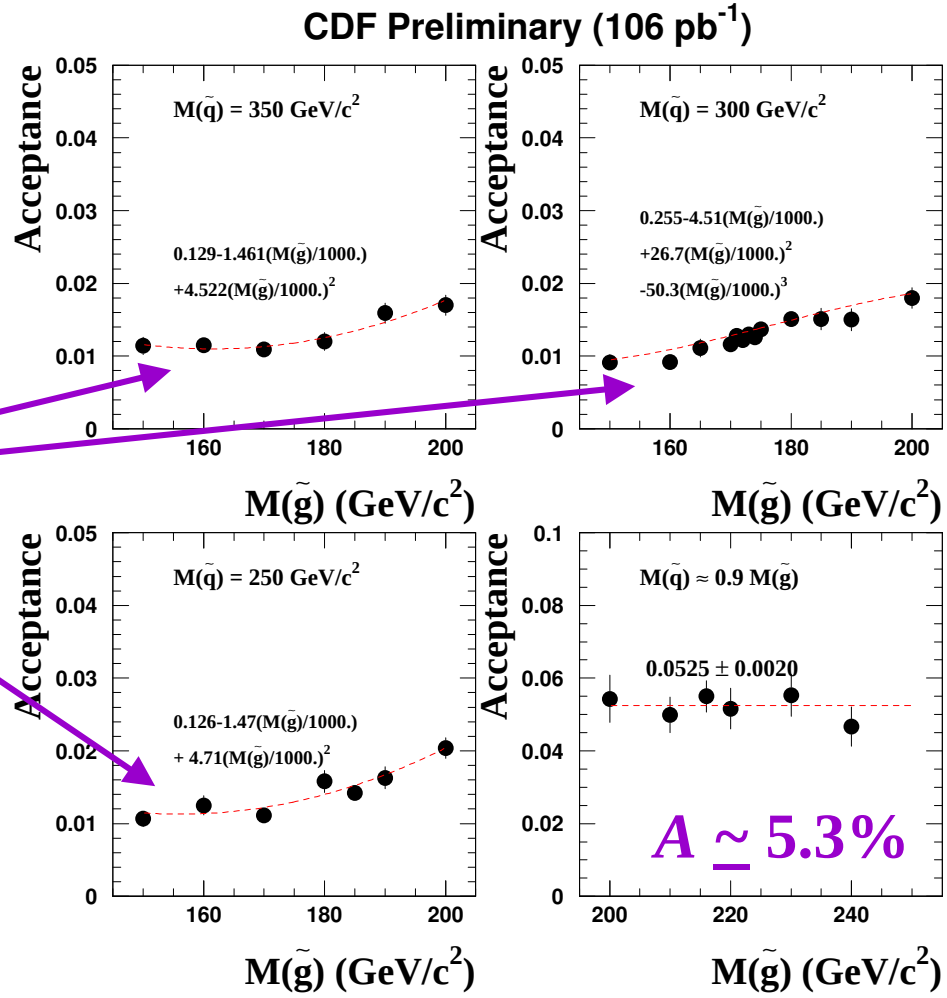
7b. Acceptance (II)

Nominal choice:

$\tan\beta = 2$

$\mu = -800\ \text{GeV/c}^2$

$A \simeq 1\text{-}2\%$



7c. Systematic Uncertainties (I)

- **Trigger Efficiency and Acceptance**
  - **Lepton trigger**
  - **Lepton ISO (Z^0 + $\geq$2 jets Sample)**
  - **Lepton ID ($Z^0 \rightarrow l^+l^-$)**
  - **Jet energy scale**
  - **ISR/FSR**
- **NLO cross section - PROSPINO**
  - **Q^2 [$Q_0^2/4 \leftarrow Q_0^2 \rightarrow 4Q_0^2$]**
  - **PDFs [MRS(G) $\leftarrow$ CTEQ3M $\rightarrow$ GRV94HO]**

7d. Summary of Uncertainties

Systematic Uncertainty

Source		
Lepton Isolation	11%	(*limited by Z^0 sample*)
Gluon Radiation	7%	(*ISR/FSR turned on/off*)
Trigger Efficiency	5%	
Jet Energy Scale ($\pm 5\%$)	5%	
Lepton Identification	3%	
MC Statistics	3%	
σ_{NLO} (Q^2)	21%	(*at most*)
σ_{NLO} (PDFs)	8%	(*at most*)
Luminosity	4%	
Total Uncertainty	28%	(*added in quadrature*)

7e. Setting 95% C.L. Limits

$$(\sigma \cdot B_{2\ell})_{95\%CL} = \frac{N_{95\%CL}}{A \cdot \int Ldt}$$

where :

$$N_{95\%CL} = 3.46$$

/home/lv53/conway/poilim

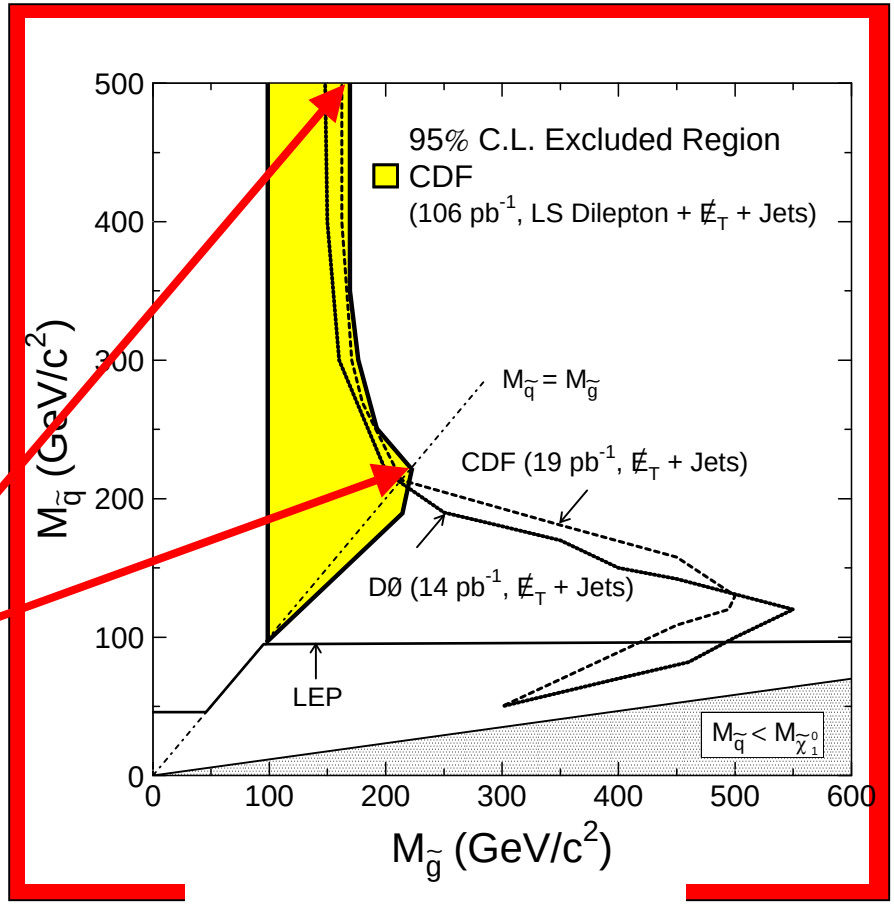
(a) with systematic uncertainty of 28%

(b) without the background subtraction

8. Excluded Region (MSSM)

$M(\tilde{g}) > 168\ \text{GeV/c}^2$

$M(\tilde{g}) > 221\ \text{GeV/c}^2$



→ μ dependence ?

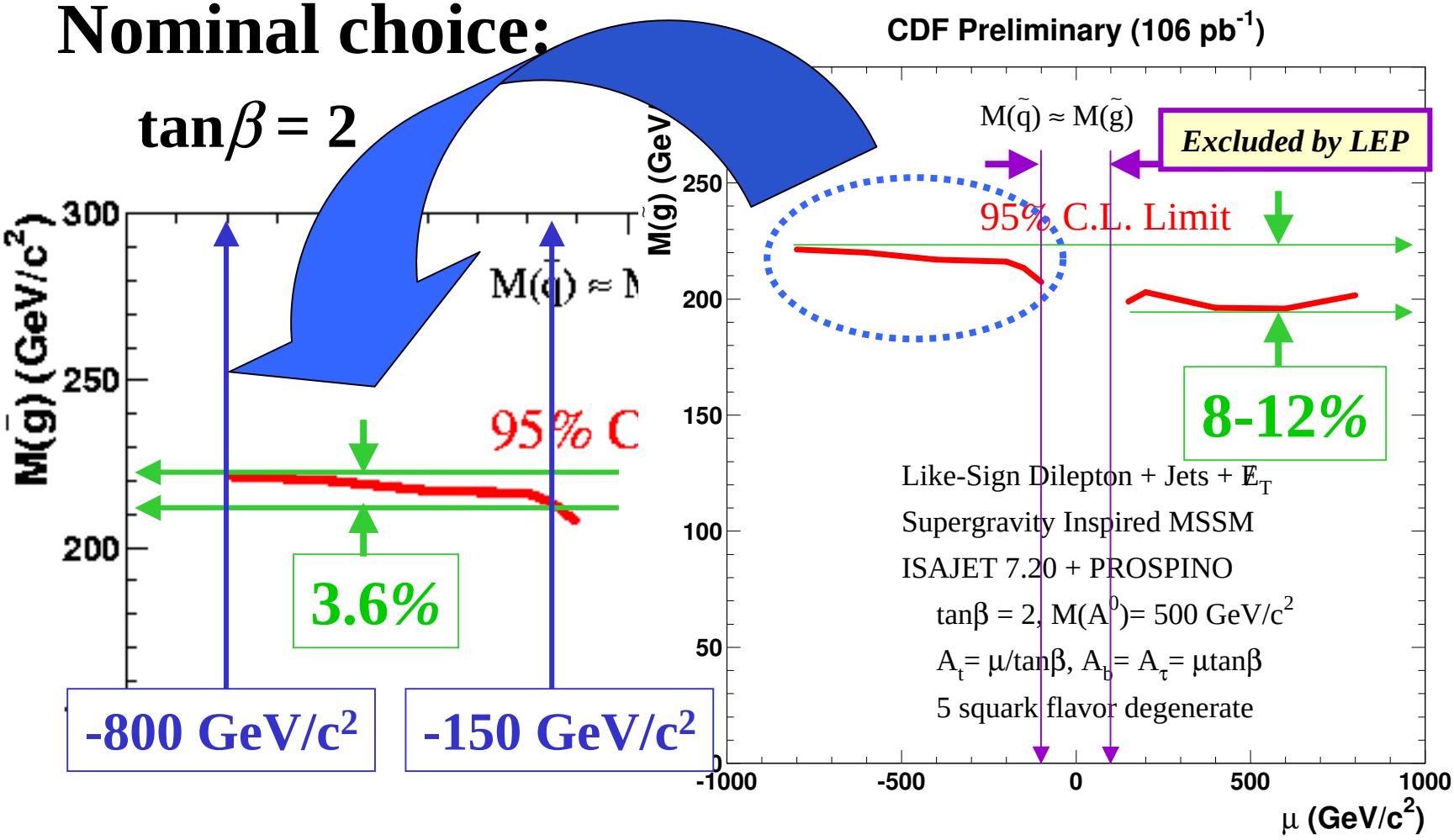
→ $\tan\beta$ dependence ?

PRL Fig.2

8a. μ Dependence

Nominal choice:

$\tan\beta = 2$

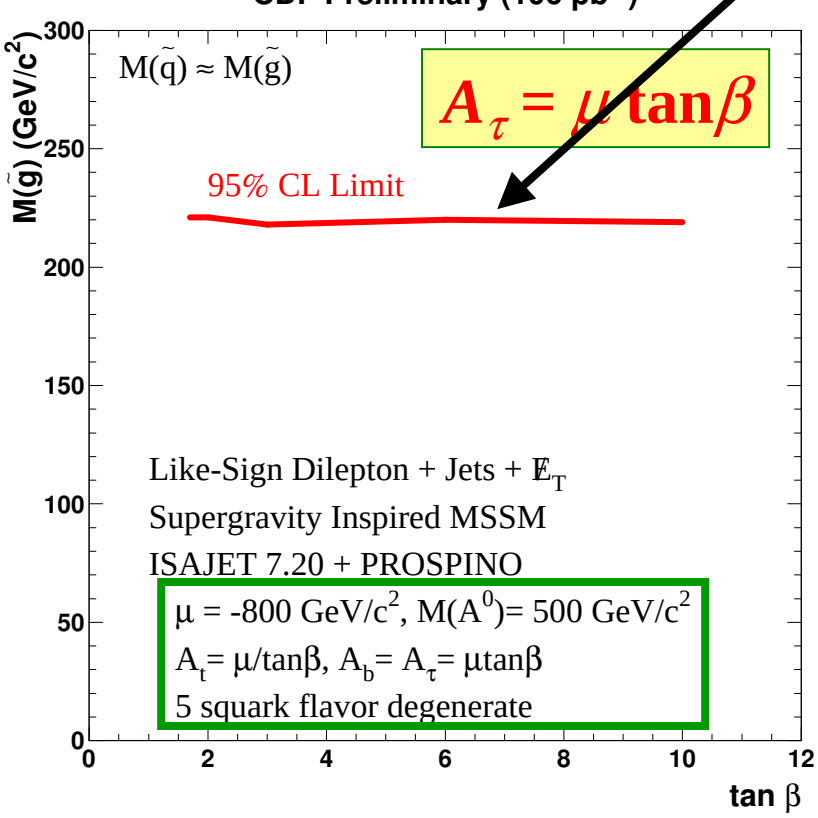


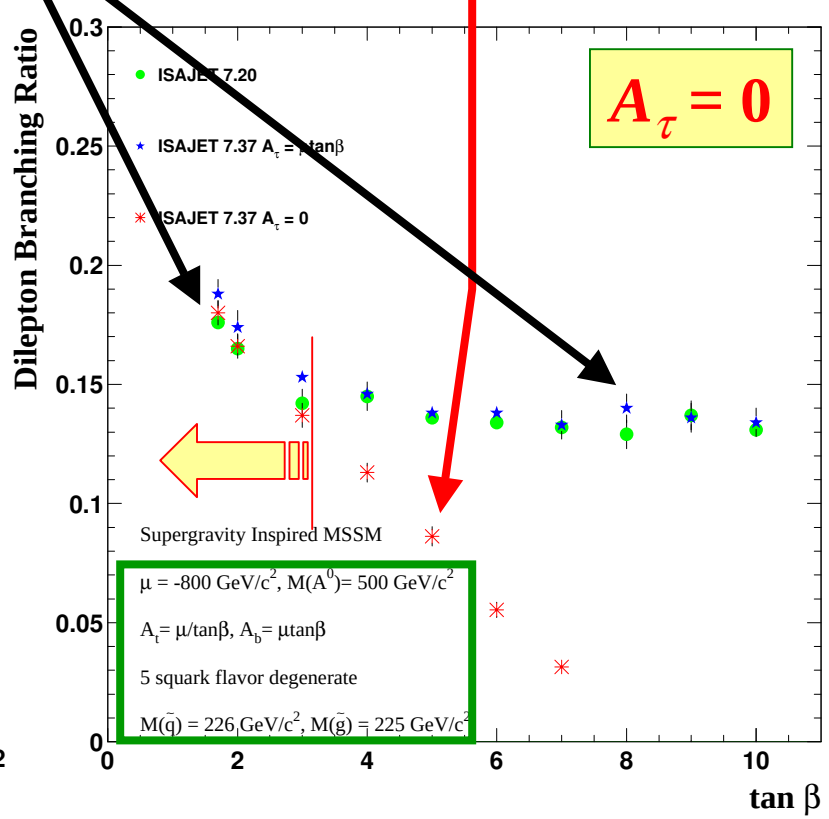
8b. tanβ Dependence

Nominal Choice: μ = -800 GeV/c^2

$M(\tilde{\tau}_1) \simeq M(\tilde{l})$

$M(\tilde{\tau}_1) < M(\tilde{l})$





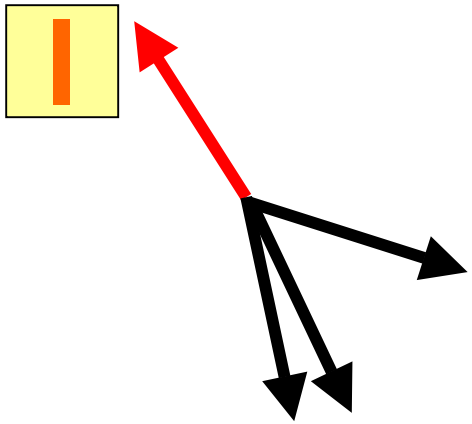
9. Conclusion

In conclusion, we have searched for new physics using LS dilepton events in association with two or more jets and $\not\!\!E_T$ in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Production of both OS and LS dilepton events are consistent with the SM expectations. Within a framework of constrained MSSM (5 degenerate squarks, $M_{\tilde{q}} \gtrsim 0.9\ M_{\tilde{g}}$), for small $\tan\beta$ we set mass limits of $M_{\tilde{g}} > 168\ \mathrm{GeV}/c^2$ for $M_{\tilde{q}} \gg M_{\tilde{g}}$, and $M_{\tilde{g}} > 221\ \mathrm{GeV}/c^2$ for $M_{\tilde{q}} \simeq M_{\tilde{g}}$, both with small variation as a function of μ.

Misc. Run-II Lepton+Track Trigger

Run I:

Inclusive lepton trigger

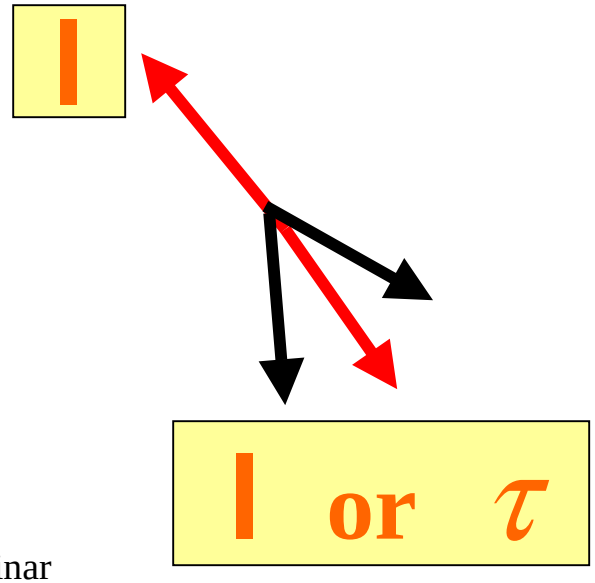


Run II: for high L

Dilepton trigger

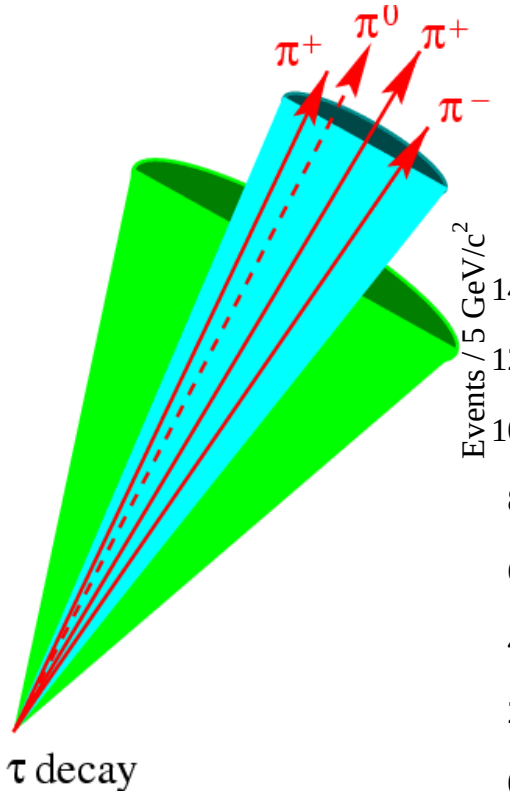
Lepton+track trigger

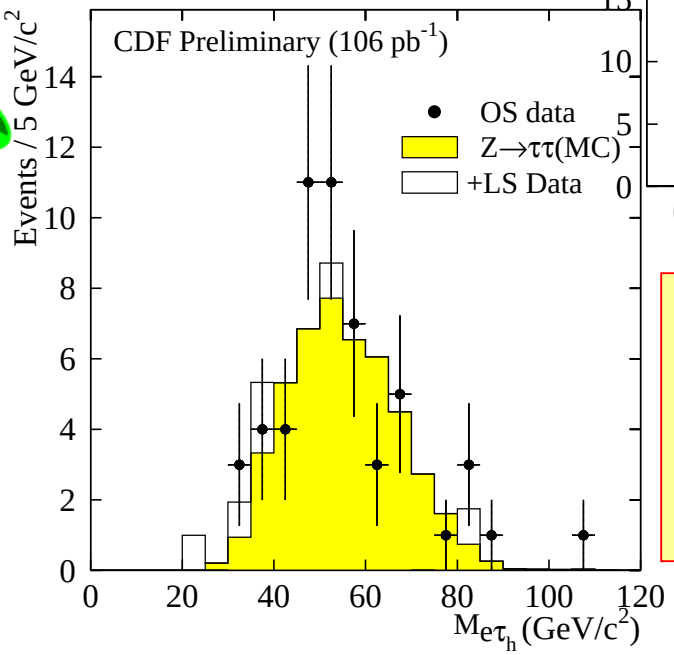
(New !)

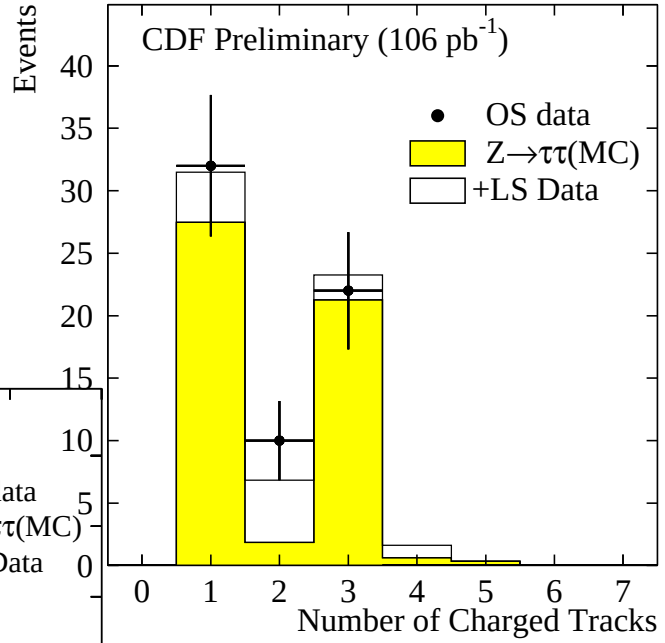


Misc. Tau (τ) Identification

$Z^0 \rightarrow \tau^+ \tau^- \rightarrow e\ \tau_h$







Run Ia+Ib
Y.Miyazaki
M.-J. Kim

Misc: Abstract

We present results of the first search for like-sign dilepton ($e^{\pm}e^{\pm}$, $e^{\pm}\mu^{\pm}$, $\mu^{\pm}\mu^{\pm}$) events associated with multijets and large missing energy using 106 pb^{-1} of data in $p\overline{p}$ collisions at $\sqrt{s} =$ 1.8 TeV collected during 1992-95 by the CDF experiment. Finding no events that pass our selection, we examine pair-production of gluinos ($\tilde{g}$) and squarks ($\tilde{q}$) in a constrained framework of the Minimal Supersymmetric Standard Model. At $\tan\beta = 2$ and $\mu = -800$ GeV/c^2, we set 95% confidence level limits of $M_{\tilde{g}} > 221$ GeV/c^2 for $M_{\tilde{g}} \simeq M_{\tilde{q}}$, and $M_{\tilde{g}} > 168$ GeV/c^2 for $M_{\tilde{q}} \gg M_{\tilde{g}}$, both with small variation as a function of μ.

PACS numbers: 14.80.Ly, 12.60.Jv, 13.85.Rm, 11.30.Pb

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