# SUGRA Results from CDF

- Status of CDF Run II
- Searches with Jets and $\not\!\!E_T$
- Searches with Leptons and $\not\!\!E_T$
- The Search for $B_s \to \mu^+\mu^-$
- Concluding Remarks

*Michael Schmitt*
*(Northwestern University)*

**SUGRA20**
Northeastern University
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# *CDF Run II Upgrades*

*Improved Detector Capabilities:*

- Main Ring is gone!

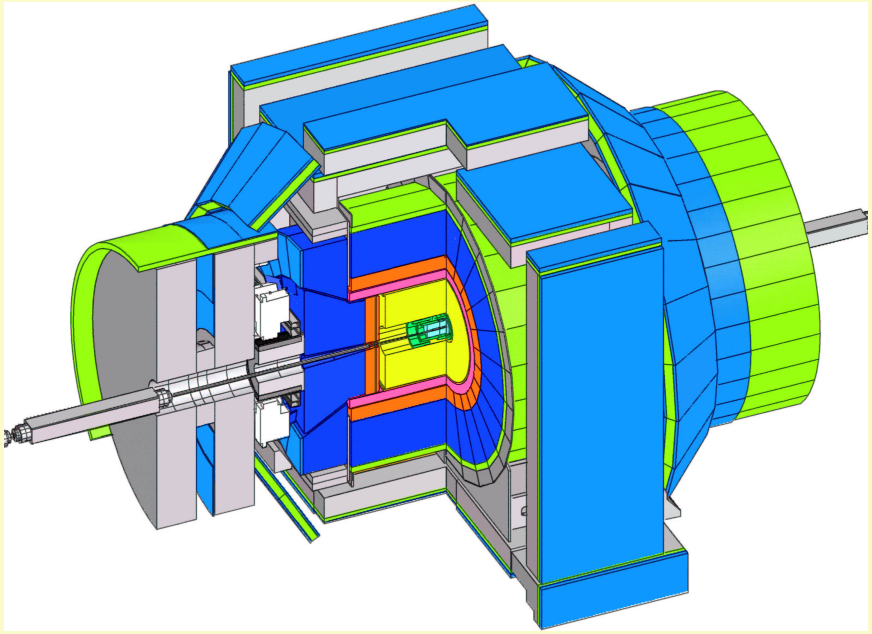
  ⇒ easier time with acc. bg's
- plug calorimetry

  ⇒ better $\not{E}_T$ coverage
- extended lepton coverage

  ⇒ higher acceptance
- better $\not{E}_T$ triggers

  lower thresholds → higher eff.
- better timing in HCAL

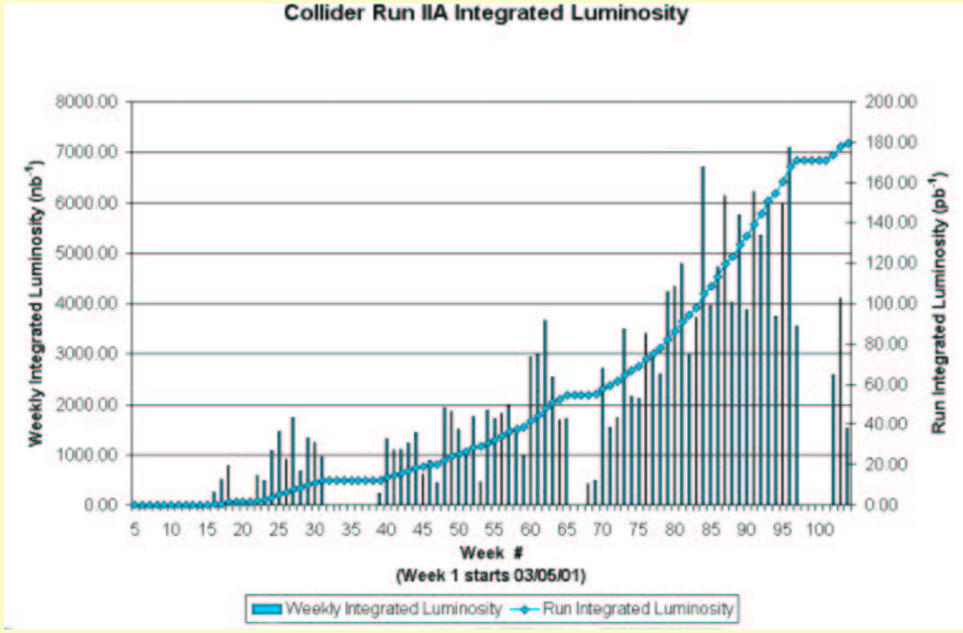
  ⇒ better non-coll BG rej'n



# *Accelerator Performance and Luminosity*

Tevatron Run II:

- higher energy $\sqrt{s} = 1.96$ TeV
- higher luminosities...
  below expectations –
  *but improving!*
  - record $3.6 \times 10^{31}$ cm$^{-2}$s$^{-1}$
  - 4–7 pb$^{-1}$ / week
  - 180pb$^{-1}$ delivered,
    130pb$^{-1}$ recorded
    $\Rightarrow$ typ. op. eff $\sim 90\%$
- real physics data since a year –
  $> 70$pb$^{-1}$ for most analyses




*This is not enough to surpass the Run I results.*
*However, we are working toward probing new territory in the next year.*

# *Relevant Searches*

**SUGRA!**

- ⋆ Very Parsimonious w/ Parameters…
- ⋆ main mass param's $m_0$ & $m_{1/2}$

$$M_{\text{gauginos}} \sim m_{1/2}$$
$$M^2_{\text{scalars}} \quad \text{like} \quad m_0^2 + m_{1/2}^2$$

- ⋆ $3^{\text{rd}}$ generation 'edge effects'

  make $\tan\beta$ important, too.

  $\longrightarrow$ high/low $\tan\beta$ dichotomy

Assume R-parity conservation

$\longrightarrow$ $\tilde{\chi}_1^0$ is the LSP

*Today* set aside RPV and photon-based searches.

Hadron colliders good for producing squarks and gluinos.

$\Rightarrow$ Jets! Missing Energy!

Electroweak fermions $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_2^0$ show up in decay chains

$\Rightarrow$ Leptons, too!

Associated production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ also interesting

$\Rightarrow$ Leptons and $\not{E}_T$ w/o jets

Today we emphasize the newest Run I results,
and give some hints of the status of non-SUSY Run II searches…

PRL 88 041801-1 (2002) RUN I 84pb$^{-1}$

# *Multiple Jets and Missing Energy*

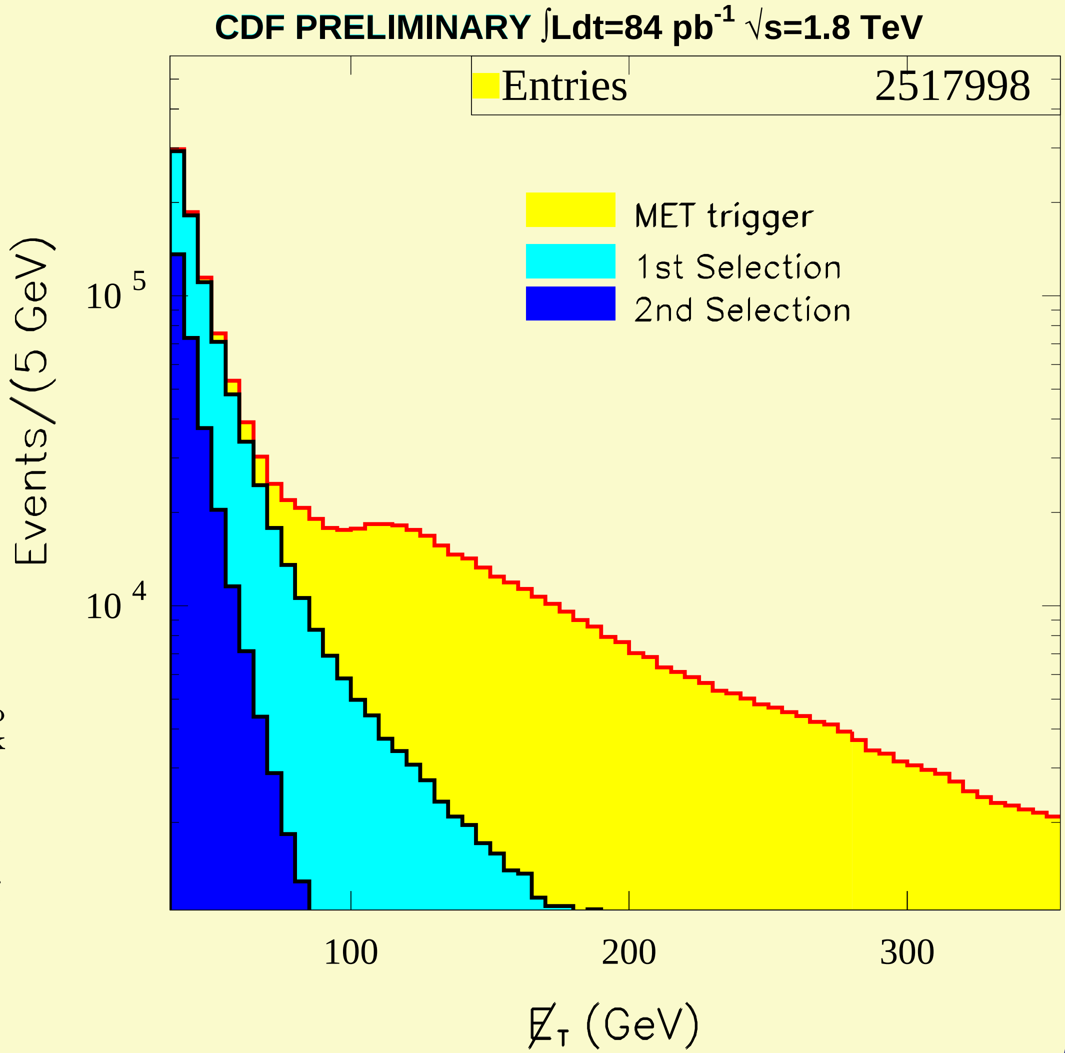
Intended for $\tilde{q}$, $\tilde{g}$ signals.

- 2-stage selection
  - ⇒ get rid of accel'r bg.
  - ⇒ $E_J$ & topology cuts kill QCD

QCD, EWK+top bg's roughly equal

- The "Blind Box"
  define signal / control regions acc:
  $\not{E}_T$, $H_T \equiv E_{J2} + E_{J3} + \not{E}_T$, $N_{\rm trk}^{\rm iso}$

→ check normalization and kinematic dist's in control regions before looking at events in the signal region.



## NO SIGNAL / NO EXCESS.

| | |
|---|---|
| 74 | observed |
| $76 \pm 13$ | expected |
| | (35 EWK + 41 QCD) |

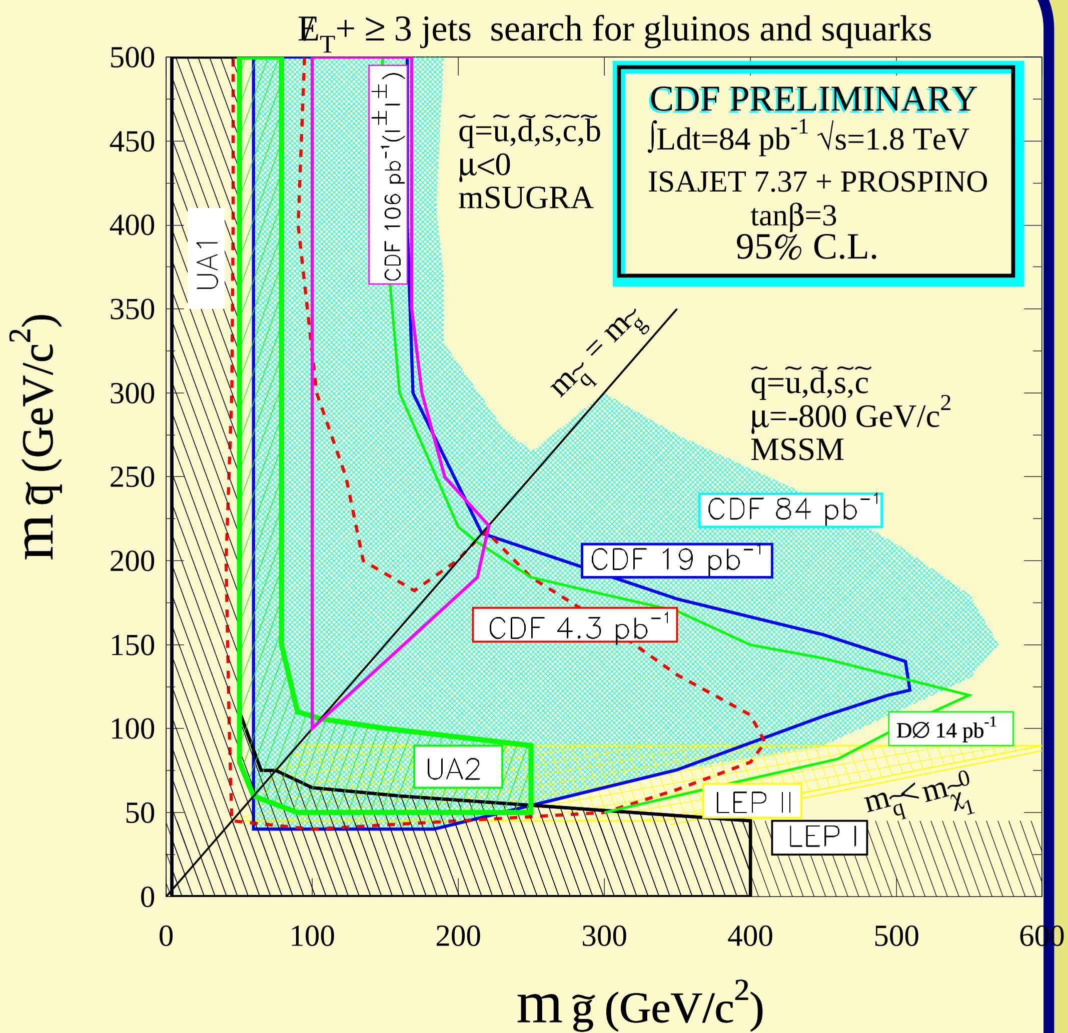
Tighten cuts on $\not\!\!E_T$ and $H_T$ in order to improve sensitivity in four general cases of $M_{\tilde{q}}$ and $M_{\tilde{g}}$.

Again, no excess. $\longrightarrow$ set limits.

*Exclusion:* **World's Best Limit**

$M_{\tilde{g}} > 300$ GeV for $M_{\tilde{q}} \sim M_{\tilde{g}}$

$M_{\tilde{g}} > 195$ GeV for $M_{\tilde{q}} \gg M_{\tilde{g}}$

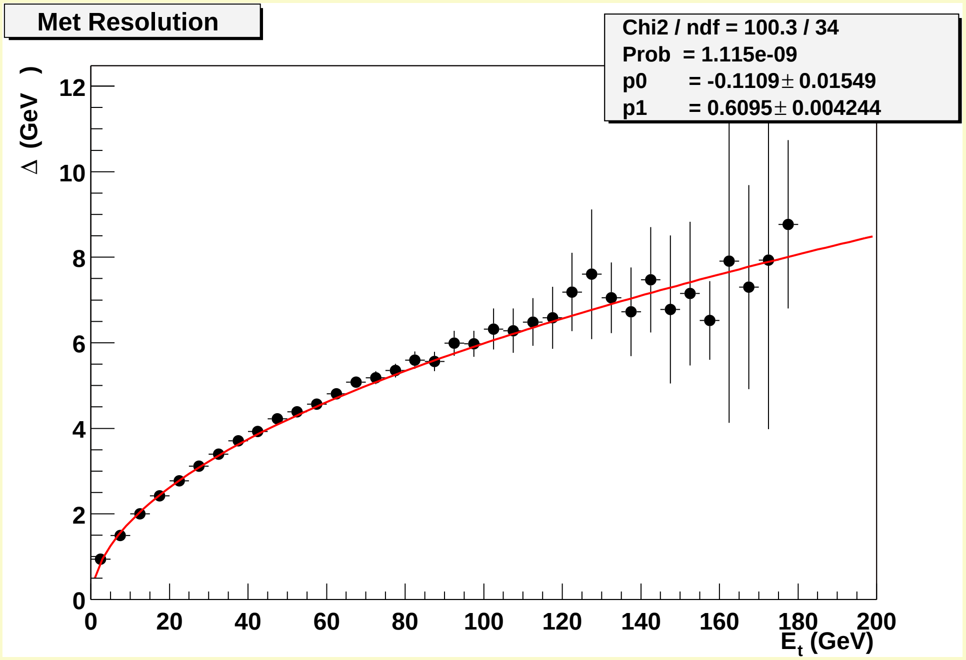



This results represents a substantial improvement in sensitivity over earlier work. $\longrightarrow$ reason for some optimism?

## $\not{E}_T$ Resolution vs. $\sum E_T$

*Run II Improvements:*

- ⋆ no MR splash!
- ⋆ plug calorimeter
- ⋆ better $\not{E}_T$ triggers
- ⋆ better HCAL timing




$\not{E}_T$ measurements sensitive to

- calorimeter uniformity
- em / had calibration
- *beam position!*

Much work has been done...

$\longrightarrow$ understand $\not{E}_T$ at a level sufficient for searches.

*(best) Run I:* $(\sum E_T)^{0.58}$

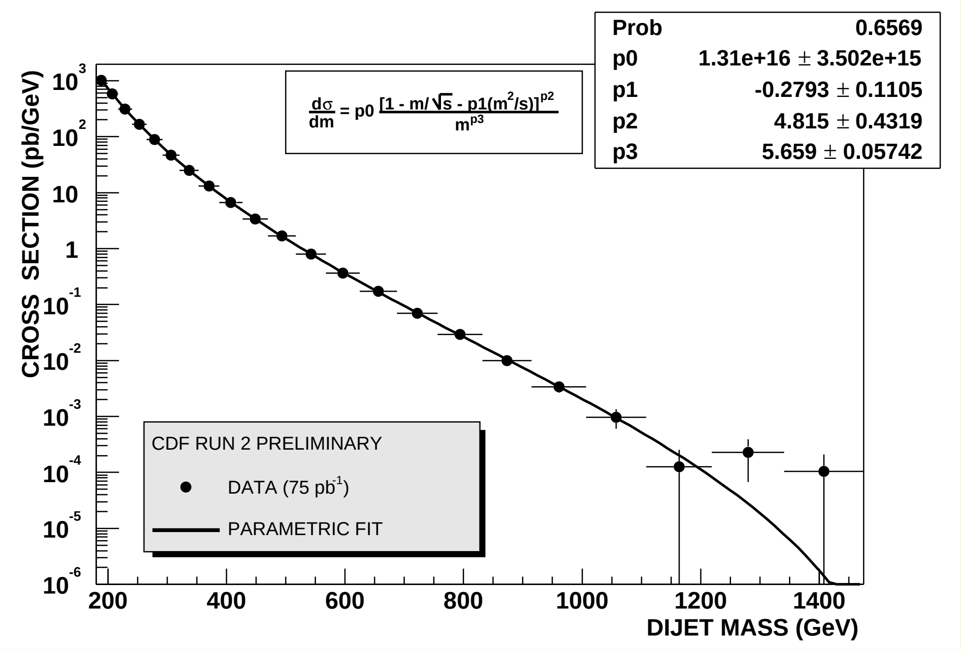
*now:* $(\sum E_T)^{0.60}$

Results from a Leptoquark search will be ready in the Spring.

*Related Work in Run II:* **Search for Dijet Resonances**

*New result from Run II !!*

- combine several di-jet samples
- di-jet mass calculated from corrected jet energies




→ fit corrected spectrum to empirical smooth function

→ ratio and residuals show no signs of 'bumps'

Upper limits on $\sigma \cdot B$:

0.3–1.5 pb for masses in the 800-1000 GeV range

⟶ significantly extends exclusion of axigluons and excited quarks.

## *Phenomenological Studies of the Reach of Run II*

Run II SUGRA Working Group:

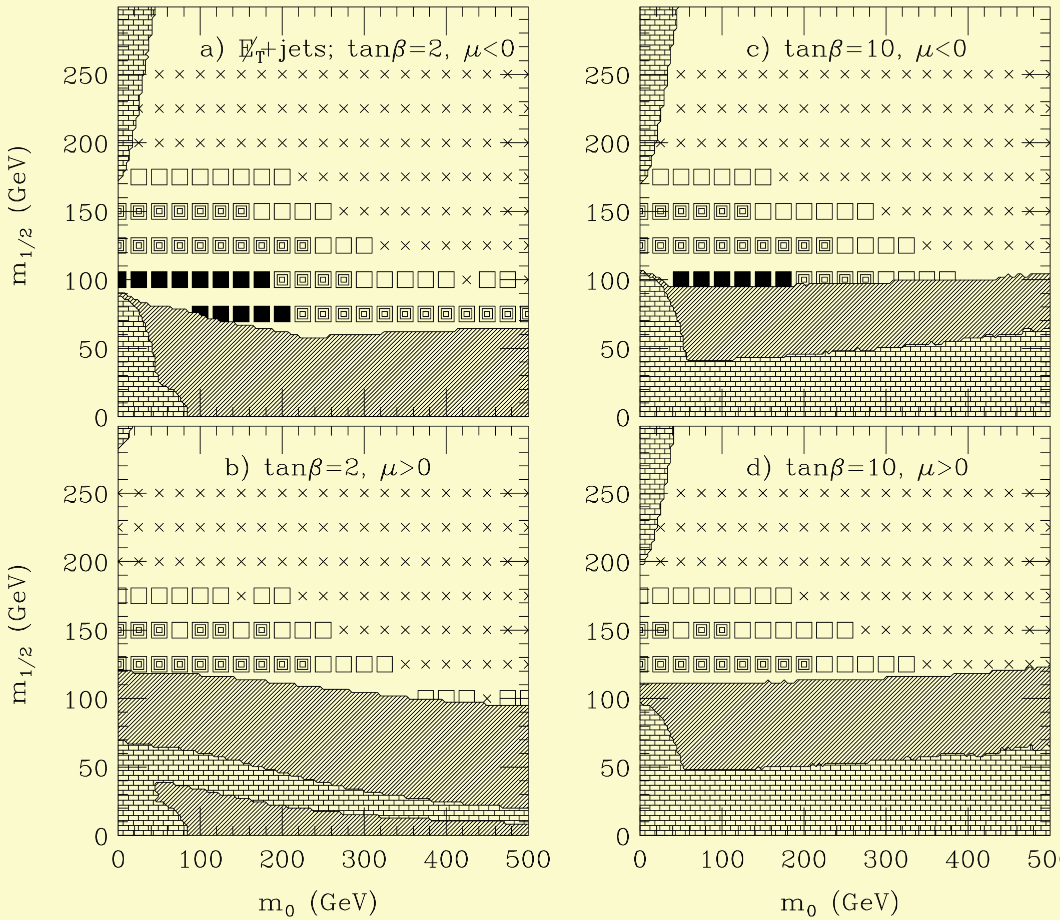
(also, Baer *et al.* PRD64 1996)

Take queues from Run I analyses, and assume $\mathcal{L} = 2\ \mathrm{fb}^{-1}$.

Rough criteria appropriate for *discovery.*

Results in $(m_0, m_{1/2})$ plane correspond roughly to

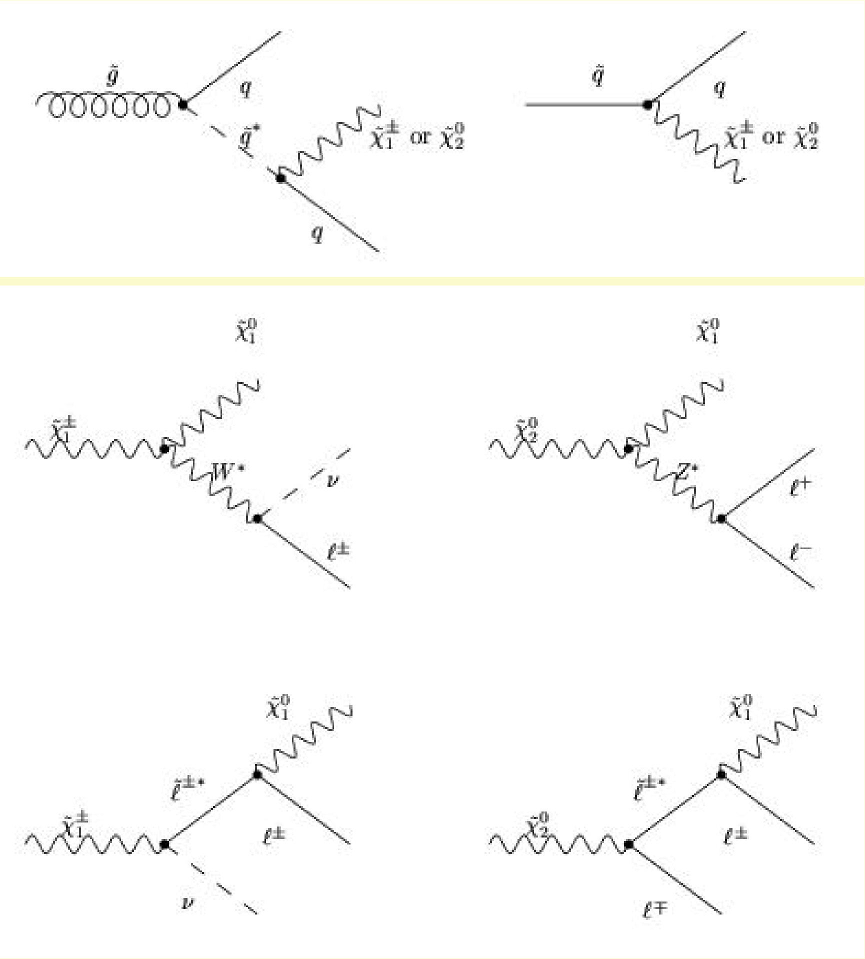
$$M_{\tilde{g}} > 400\ \mathrm{GeV}.$$




Presumably a 'real' analysis will do even better…

PRL 87 251803-1 (2001) RUN I – 106pb$^{-1}$

# *Like-Sign Leptons, Jets and Missing Energy*




Another possibility for $\tilde{q}$ & $\tilde{g}$

If EWK gauginos light enough, they appear in the cascade decays of $\tilde{q}$ and $\tilde{g}$, and decay sometimes to leptons.

*Like-Sign* lepton pairs are unusual
⇒ low SM backgrounds.

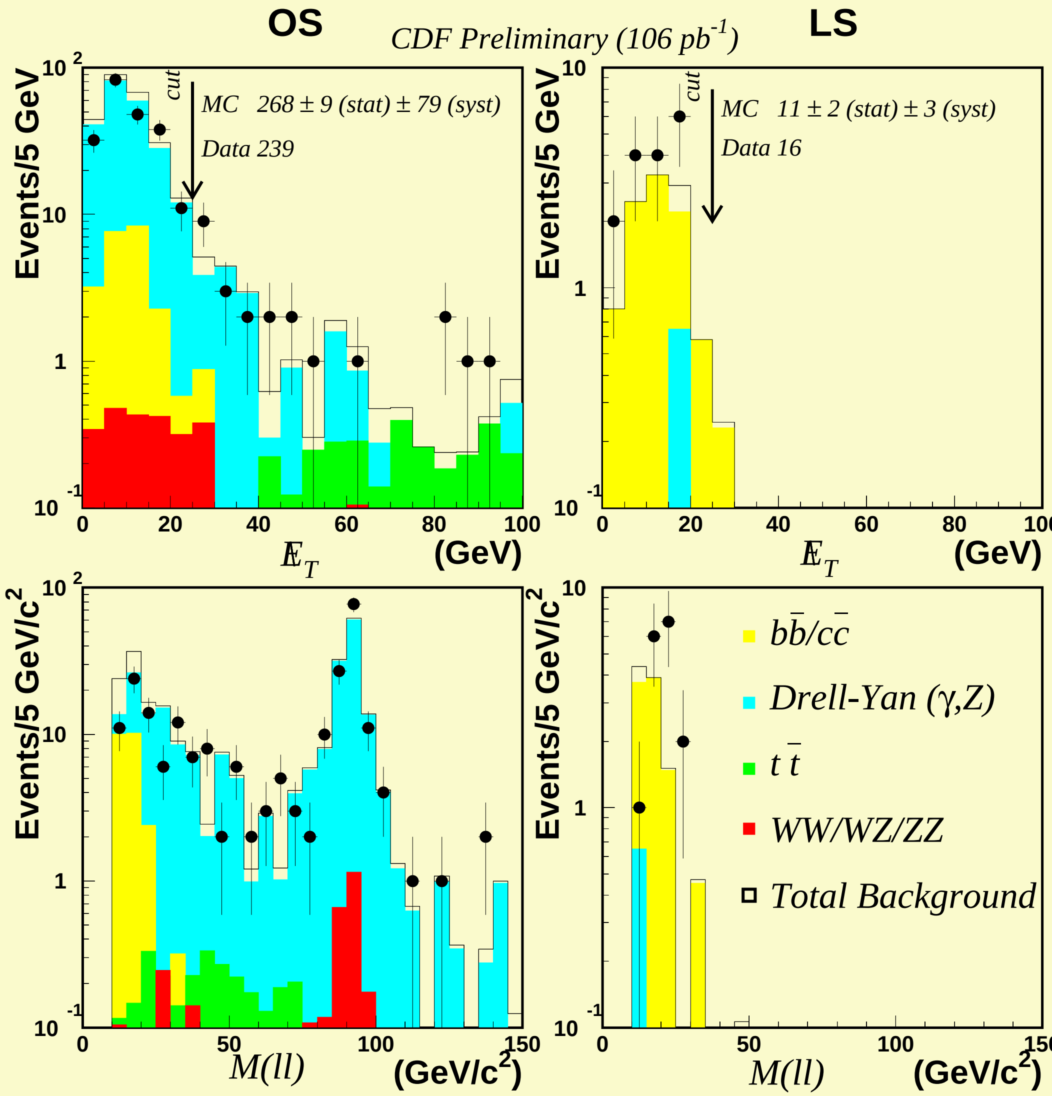
⋆ complements Jets+$\not\!\!E_T$ search

Assume no decays to Higgs bosons.

*What do we need to know, experimentally speaking?*

- What leptons do we have?
  - $\longrightarrow$ reconstruction and ID
  - $\longrightarrow$ fake, non-prompt sources
- Large opposite-sign sources
  $Z$'s, $J/\psi$, $b\bar{b} + c\bar{c}$, etc.
- missing energy measurement
  resolution and tails
  (non-collision bg)

*OS/LS comparisons are the key.*




PRL 87 251803-1 (2001) Run I – $106\mathrm{pb}^{-1}$

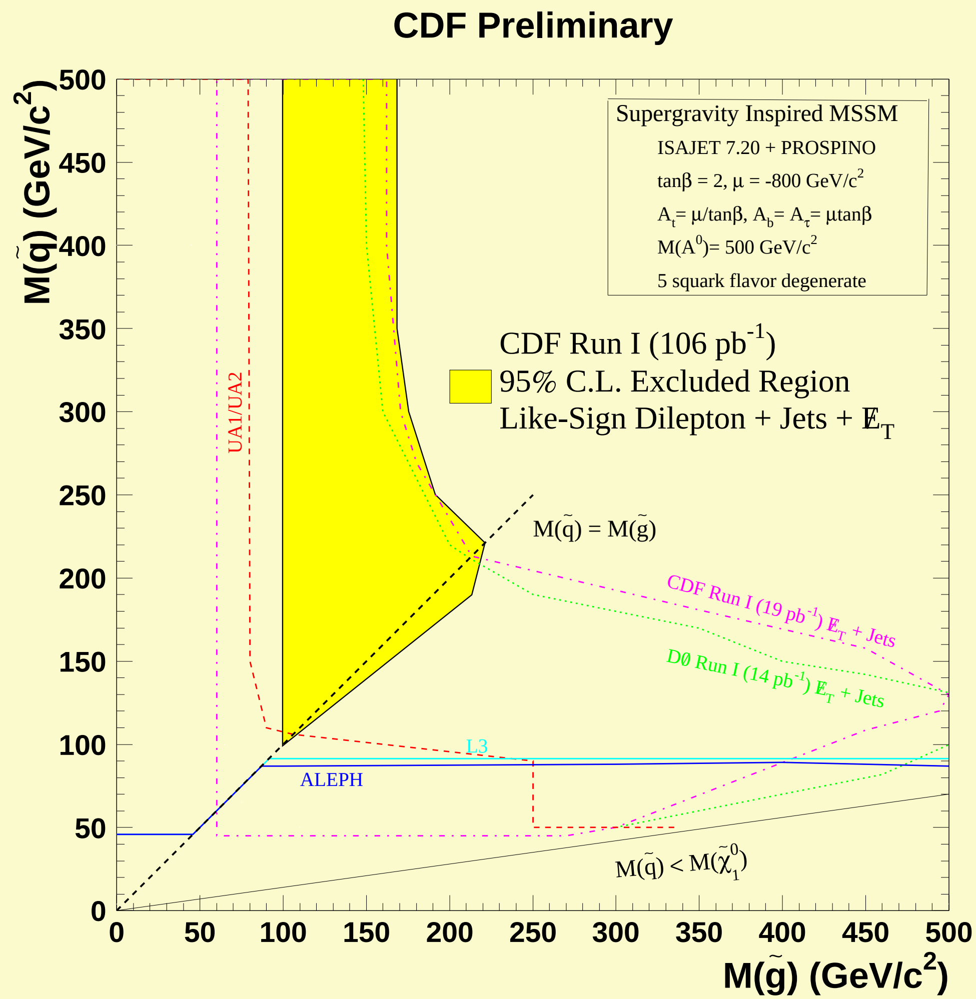
## No Excess.

| | *expect* | *observe* |
|---|---|---|
| opposite-sign: | $14.1 \pm 3.1$ | 19 |
| like-sign: | $0.55 \pm 0.26$ | 0 |

$\longrightarrow$ set limits

$M_{\tilde{g}} > 221$ GeV for $M_{\tilde{q}} \sim M_{\tilde{g}}$

$M_{\tilde{g}} > 168$ GeV for $M_{\tilde{q}} \gg M_{\tilde{g}}$




The multi-jet+$\not{E}_T$ searches appear to be more powerful.

*In fact* they apply to scenarios differing in the way in which $\tilde{q}$'s and $\tilde{g}$'s decay. *Both searches are important!*

# *Related Work in Run II:* Leptoquark Searches

*New result from Run II !!*

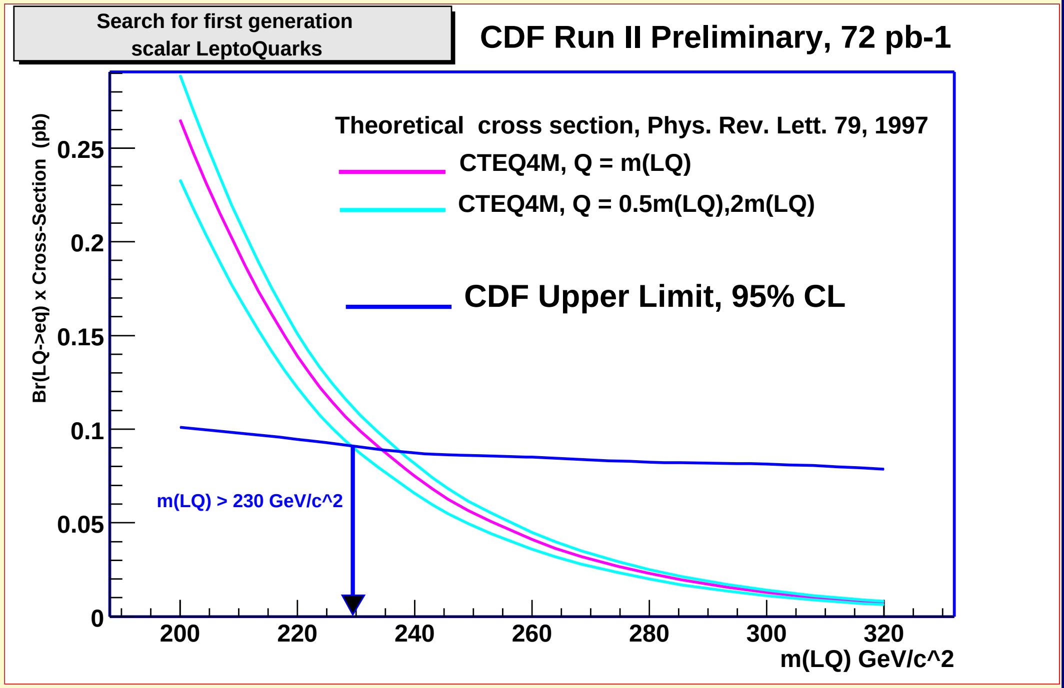
$e^+e^- JJ$ channel

(opposite-sign, no $\not{E}_T$)

- demand tight $e^+e^-$
  $\longrightarrow$ testing lepton ID
  in a jetty environment

- main bg $Z \rightarrow e^+e^- +$ ISR
  $\longrightarrow$ understood

| | |
|---|---|
| total background | $3.39 \pm 3.15$ |
| observed | zero |




$\sigma \times Br$ *sensitivity to* $\sim 0.1$ pb *for* $72\ \text{pb}^{-1}$

# *Tri-leptons*

PRL 80 5275 (1998) Run I – $87 pb^{-1}$

**Associated Production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$**

⋆ pertinent to gauginos with significant leptonic BR's

$\longrightarrow M_{\tilde{g}} < M_{\tilde{q}} < 2\,M_{\tilde{g}}$

probe $150 < M_{\tilde{g}} < 340$ GeV

⋆ low backgrounds

dibosons, $t\bar{t}$, $b\bar{b}$

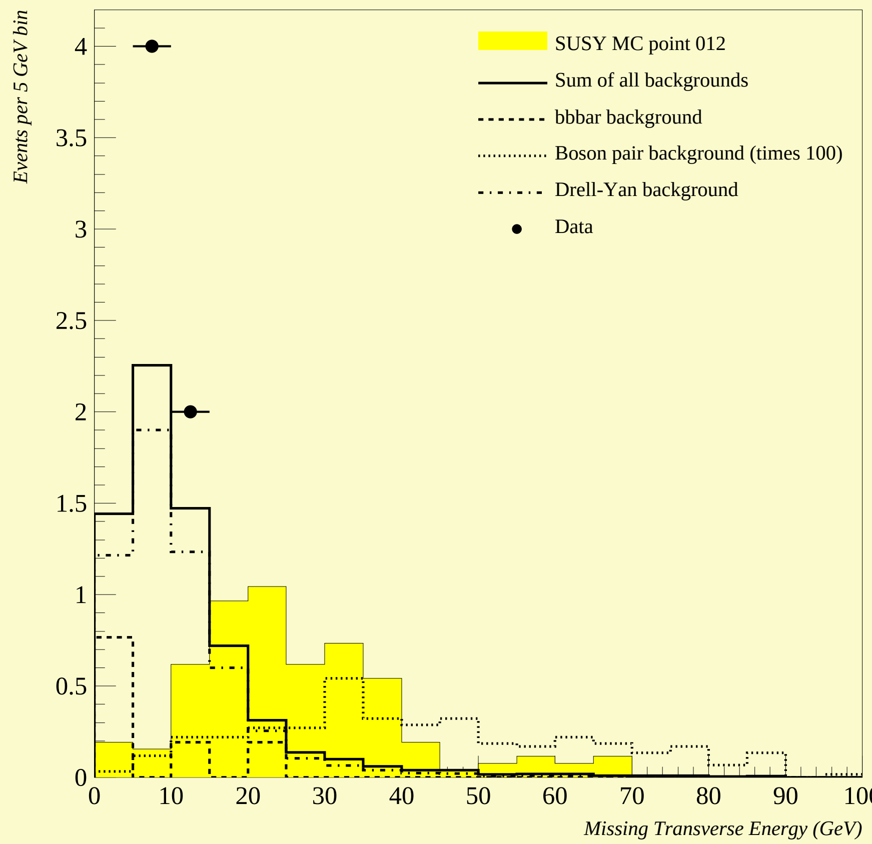
$WW$, Drell-Yan + fake lepton

expect $6.6 \pm 1.1$, observe 6

⋆ require $\not\!\!E_T > 15$ GeV

expect $1.1 \pm 0.2$, observe zero

sensitivity at $\sigma \times B \sim 0.3$ pb




*Not very constraining, needs more luminosity.*
*New result on LSDL available at DPF...*

# *Related Work:* $Z'$ Searches in $e^+e^-$ and $\mu^+\mu^-$ channels

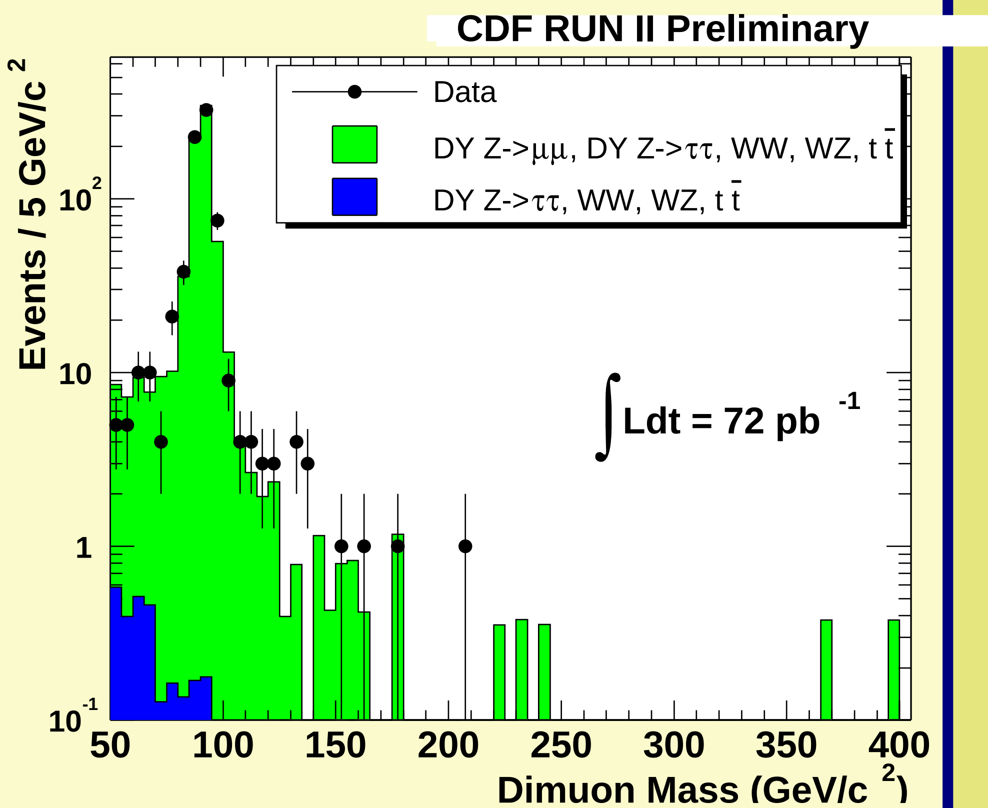
*New result from Run II !!*

- two tight leptons
  $\longrightarrow$ understand lepton ID
- eliminate QCD and CR backgrounds, leaving DY processes
- define mass region $M_{\ell+\ell-} > 150$ GeV

| | |
|---|---|
| total expected background | $5.2 \pm 0.3$ |
| observed | 4 |

sensitivity to $\sim$ 1pb ($\mu$) $\sim$ 0.1pb (e)

| | |
|---|---|
| muons | $M_{Z'} > 455$ GeV |
| electrons | $M_{Z'} > 650$ GeV |




*Work proceeds with low-$p_T$ multilepton sample – more challenging. . .*

*Phenomenological Studies of the Reach of Run II*

*Several studies showing gains in sensitivity.*

⋆ some useful ideas there.

BG from off-shell bosons important

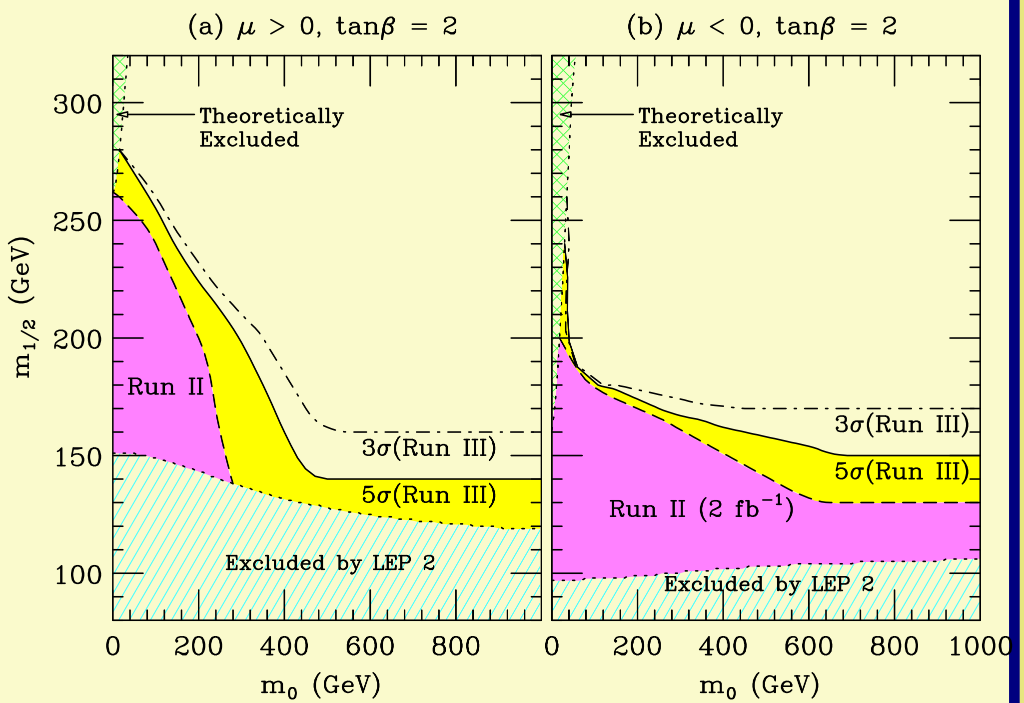
decays to $\tau$'s play important role

→ try to reconstruct them

→ lower $p_T$ thresholds

Trileptons most effective at low $\tan\beta$

– high $\tan\beta$ scenario is complicated.




Barger & Kao, 1998

Work on $\tau$ identification is intense. . .

Clean signals seen in $W \to \tau\nu_\tau$ and $Z \to \tau^+\tau^-$.

# A Search for $\tilde{t}_1 \to b\ell\tilde{\nu}$

hep-ex/0302009 Run I – $107\text{pb}^{-1}$

*Opposite-Sign Leptons, Jets and $\not\!\!E_T$*

Latest published CDF SUSY result!

Careful control of OS-dilepton sample

→ DY large in OS (not LS)

→ HF large in both (not equally)

→ mis-ID significant in both

→ $t\bar{t}$, diboson present OS

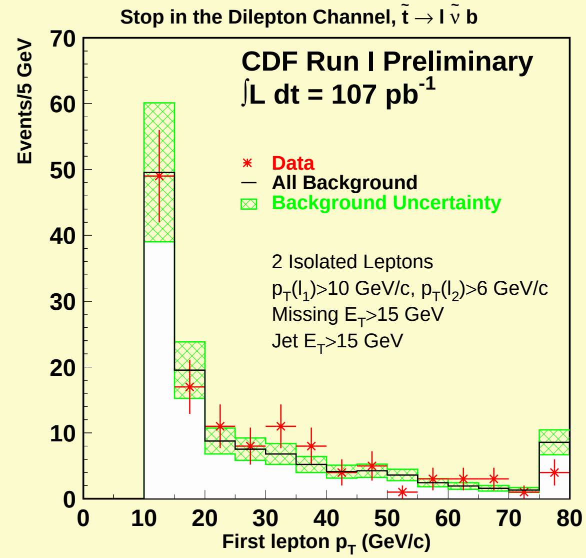
- check high/low $p_T$ and $\not\!\!E_T$
  - ⋆ good agreement!

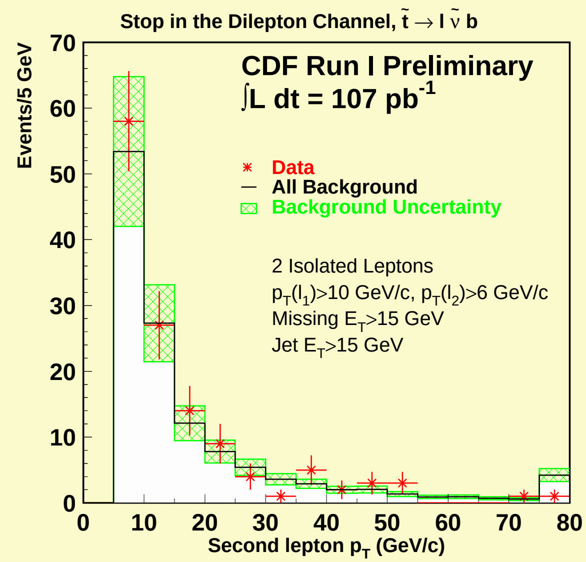
Impose (single) $b$-tag

Gain sensitivity with $\not\!\!E_T > 30$ GeV & angle cuts.

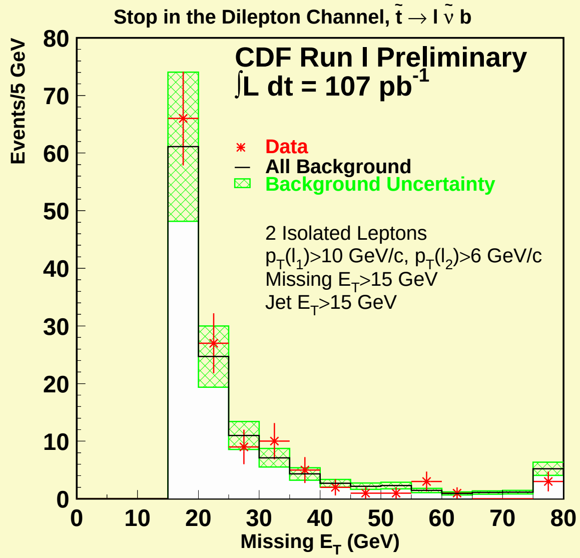
*Two 'Blind Analyses'*

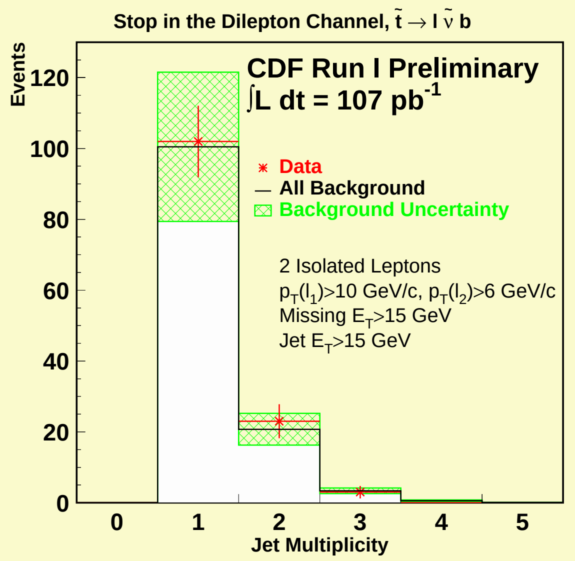
| $M_{\tilde{t}} - M_{\tilde{\nu}}$ | obs. | expect. | signal |
|---|---|---|---|
| small | 0 | $1.5 \pm 0.5$ | $5.7 \pm 2.1$ |
| large | 0 | $2.1 \pm 0.5$ | $8.2 \pm 3.1$ |



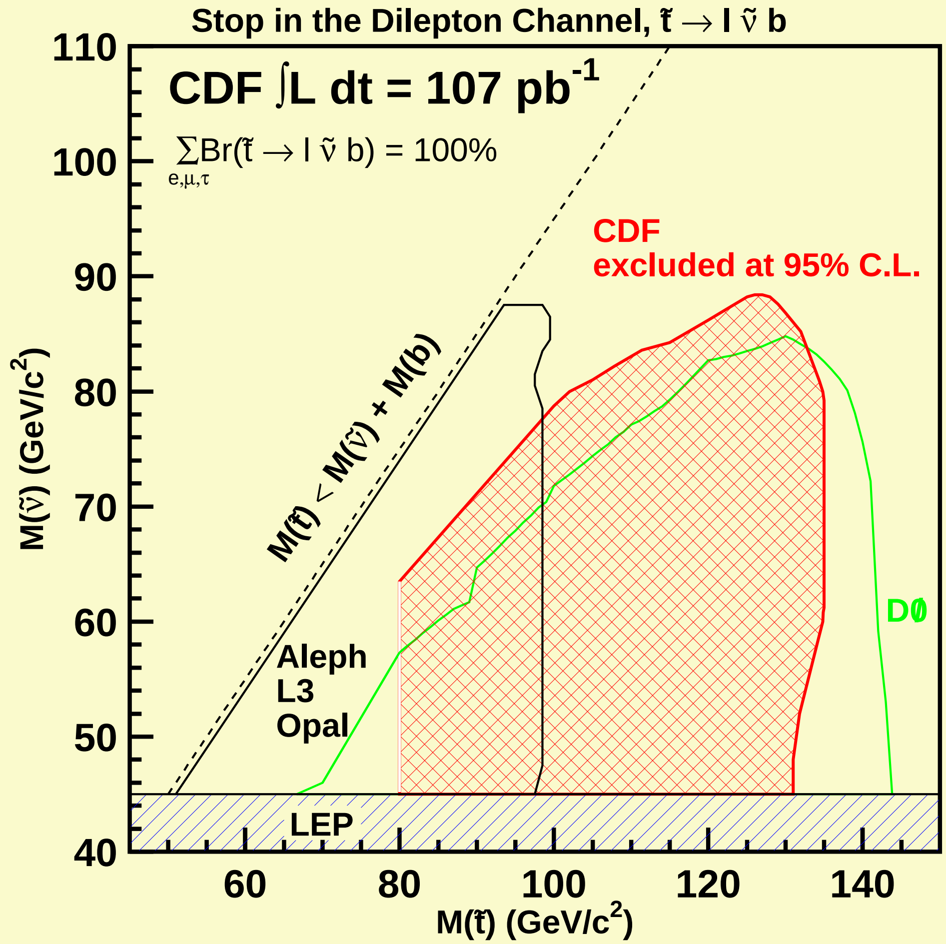



hep-ex/0302009 Run I – $107 pb^{-1}$




## Exclusions:



PRL 84 5704 (2000) RUN I – 88pb$^{-1}$

# *Heavy Flavor Jets & Missing Energy*

Intended for $\tilde{t}_1$ and $\tilde{b}_1$ signals.

- assume prototypical decay modes

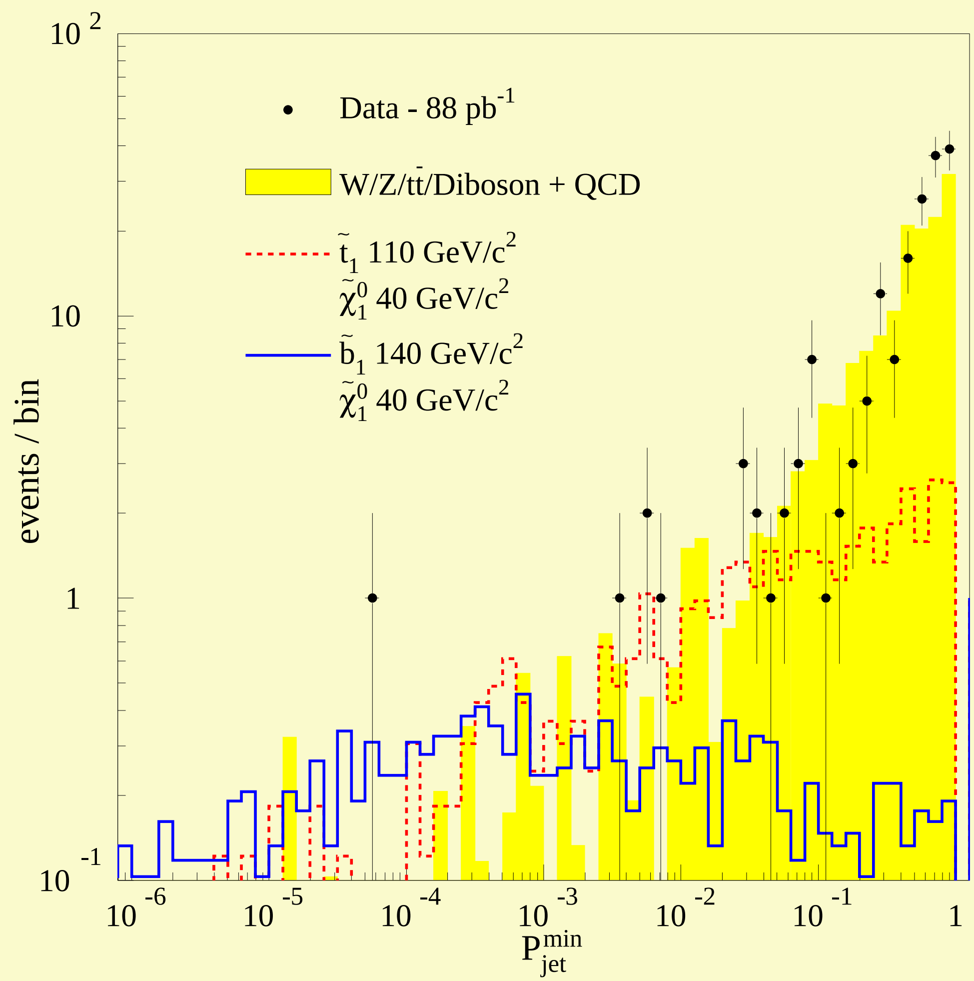
  $\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0 \qquad \tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$

- signature is 2 HF jets and $\not{E}_T$

  use 'jet probability'

  tighter cut for bottom

  looser cut for charm

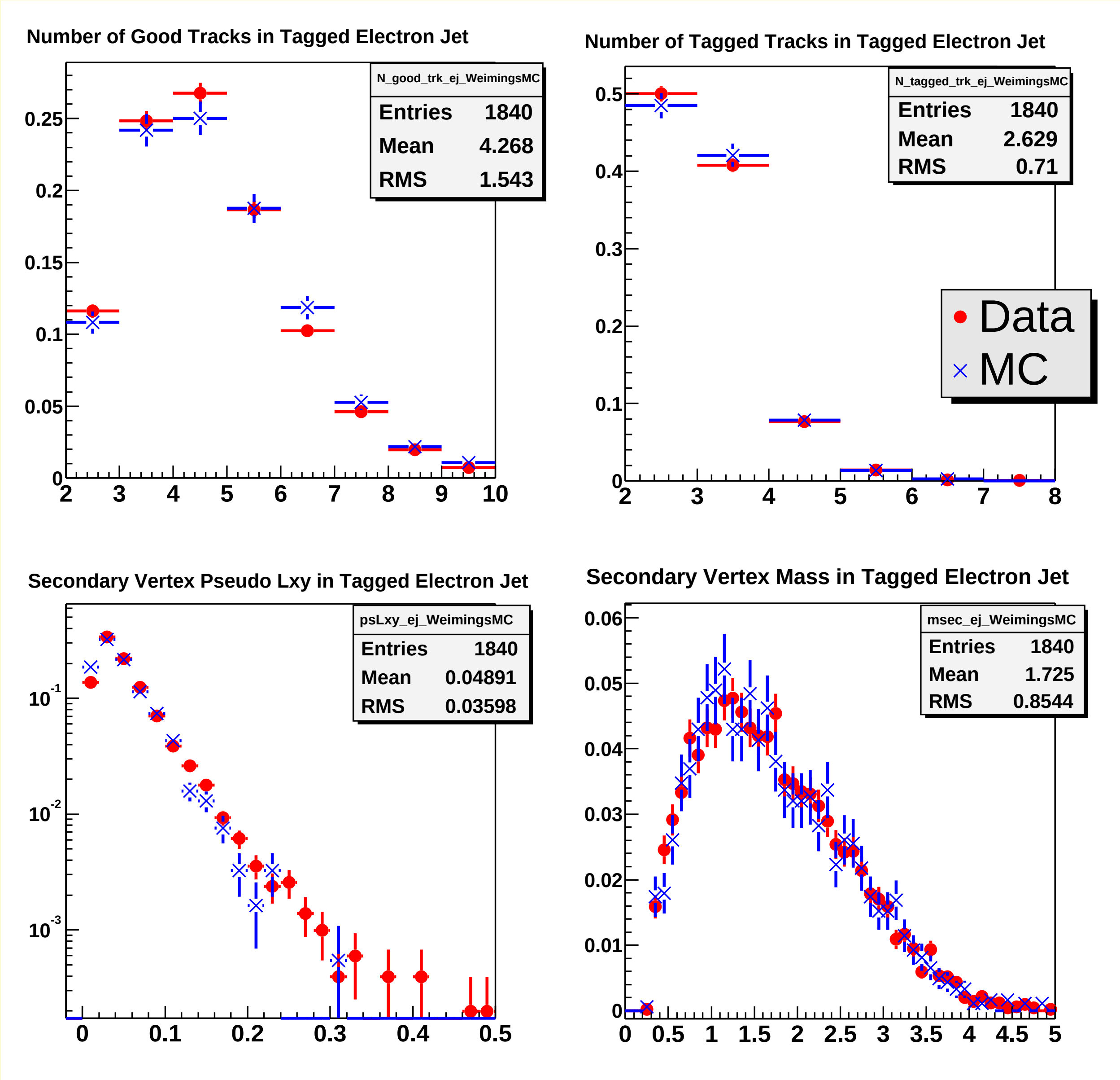



*Run II Progress –*

- Run 1-style algorithms working
- tagging rates measured in data
- simulation compares well to data

  $\Longrightarrow$ HF Jets + $\not{E}_T$ looking good.

# *Examples of Studies of Heavy Flavor Tagging*



# *The Search for $B_s \to \mu^+\mu^-$*

⋆ This rare decay can be very strongly enhanced for high-tan $\beta$ SUSY.

$\tan^6 \beta$ !!

⋆ Complements the tri-lepton search (which is weak due to enhanced $\tau$'s)

Dedes, Dreiner, Nierste, Richardson

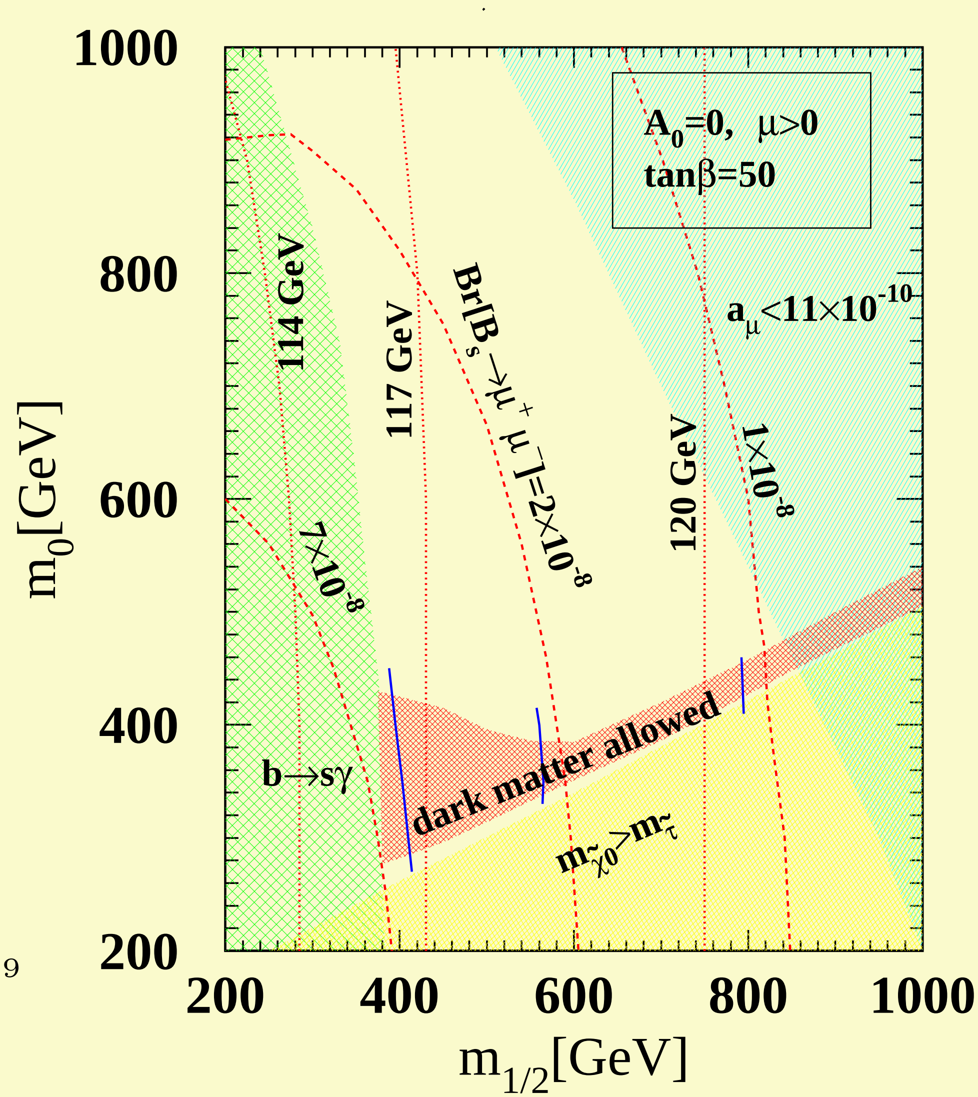
hep-ph/0207026

- CDF set upper limit in Run I

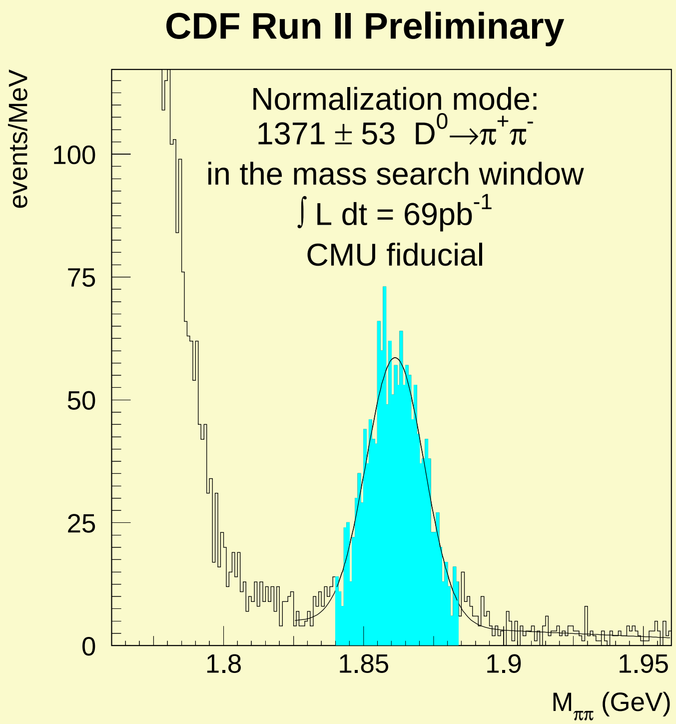
  $B < 2.6 \times 10^{-6}$ 95% C.L.

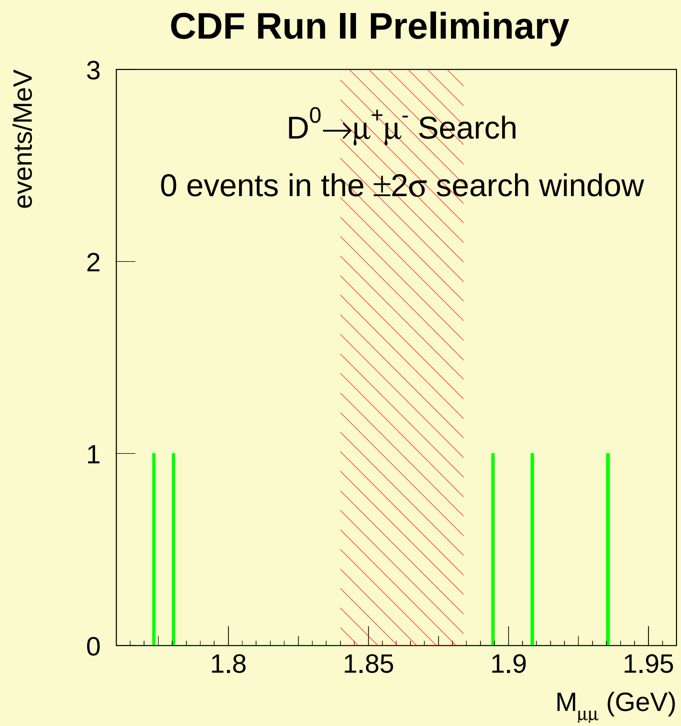
- Recent studies indicate sensitivity could reach $\sim 10^{-8}$ for 15 fb$^{-1}$.

Arnowitt, Dutta, Kamon, Tanaka hep-ph/0203069



## *Related Work in Run II:* $D^0 \to \mu^+\mu^-$ *New!* $69\text{pb}^{-1}$




expect: $1.7 \pm 0.7$ events

observe: zero

$$BF(D^0 \to \mu^+\mu^-) < 3.1 \times 10^{-6} \quad 95\%\ \text{C.L.}$$

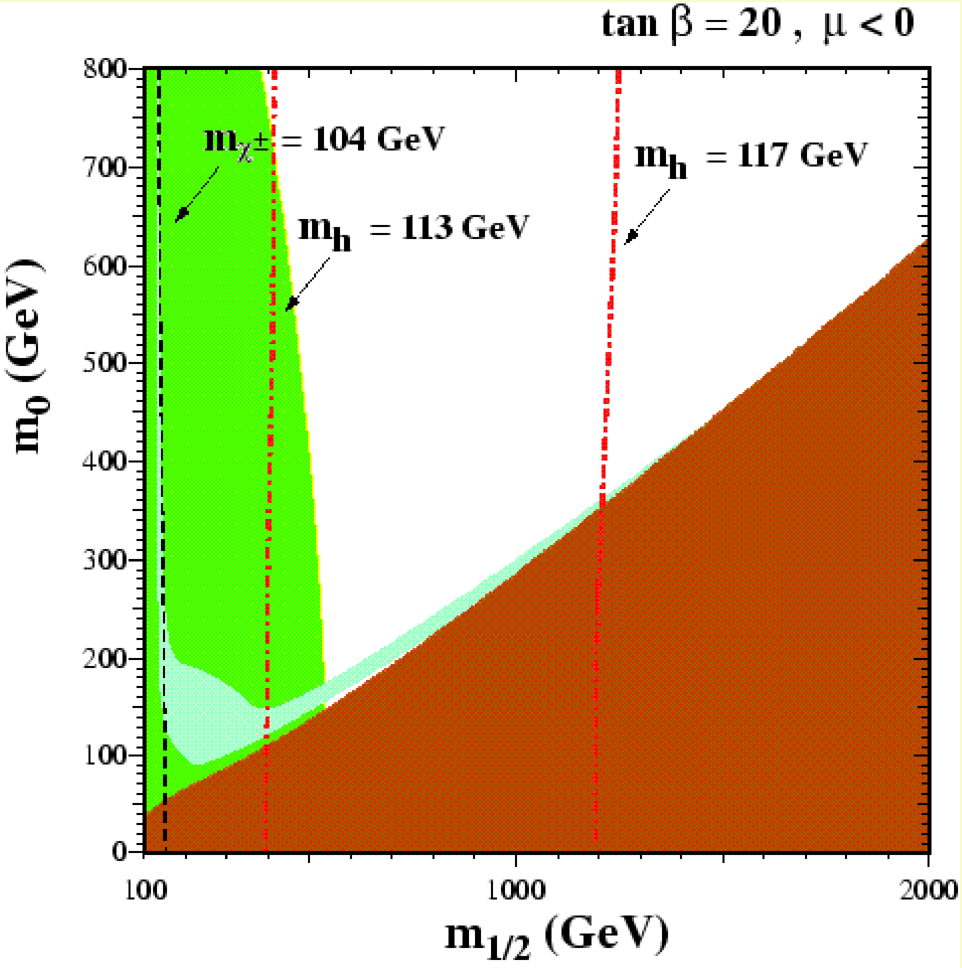
Already 2× better than previous limit. $B_s \to \mu^+\mu^-$ results are on the way...

## *Higgs Searches*

In mSUGRA, Higgs mass bounds cover more parameter space than TEVATRON squark & gluino searches.

With $\mathcal{L} \sim 10\ \text{fb}^{-1}$ the mass reach for a SM-like Higgs boson was estimated to be about 140 GeV – well beyond the maximum mSUGRA mass of $\sim$ 122 GeV. (FNAL WS 1998-99)

The CDF and DØ Collaborations are re-examining these estimates in the context of current detector and accelerator performance.




Ellis *et al.* PL B510 (2001) 236

## *Summary and Conclusions*

- Searches for non-SM particles are 'turning on' this year.
- Sensitivity in the mSUGRA scenario should soon surpass that of Run I.
  - ⋆ thanks to better detector & triggers
  - ⋆ hope for $\mathcal{L} > 200\text{pb}^{-1}$ by end of year
  - ⋆ current $\mathcal{L} \times \sigma$ roughly the same as Run I
    since $\sigma(2\text{TeV}) > \sigma(1.8\text{TeV})$.
- Some new results should be ready this summer,
  with many more by the next *SUSY* conference.
- **For the next several years, FERMILAB is the place for SUSY!**

Thanks to the organizers!