SUSY Searches at the Tevatron

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For the CDF and D0 Collaborations

Outline

- The experiments
  - The Tevatron
  - D0
  - CDF
- Multilepton signatures
  - Trileptons
  - Tetraleptons
  - Dileptons
- Stop and Sbottom squarks
- Diphoton Events
- Summary

This will be a very signature-oriented discussion.

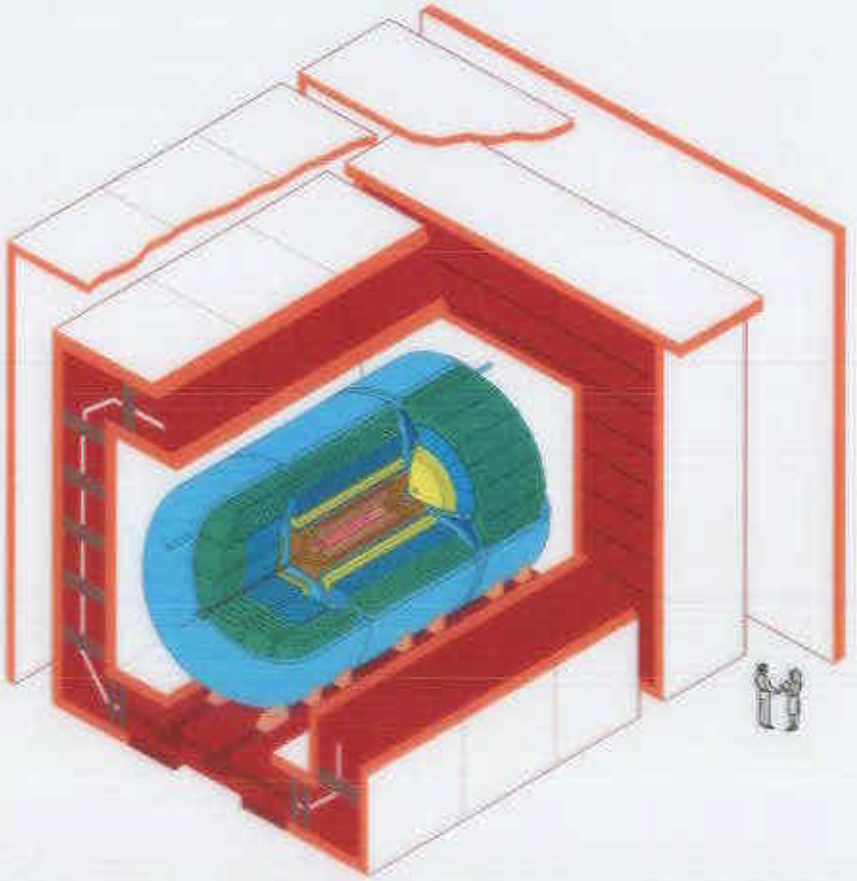
The Fermilab Tevatron

- As seen by experimenters:
  - A Proton-Antiproton collider
  - Center-of-mass energy of 1.8 TeV
  - Collisions every 3.5 μs
- As seen by theorists:
  - A quark-antiquark collider with variable energy up to approximately 600 GeV
  - Also a gluon-gluon collider with variable energy up to approximately 400 GeV

- Delivered luminosity 1992-1996: ~110 pb^{-1}
  - Run 1A: ~20 pb^{-1}
  - Run 1B: ~90 pb^{-1}

The D0 Detector

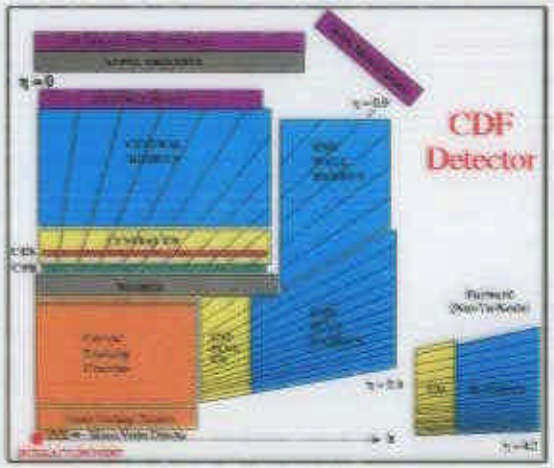
- Emphasizes large acceptance and good calorimetery
  - Particularly missing E_T
  - Muons out to $|\eta| < 3.3$
  - Calorimetry to $|\eta| < 4$
    - $\Delta E/E \sim 15\% / E^{½}$
      - (Electromagnetic)
    - $\Delta E/E \sim 50\% / E^{½}$
      - (Hadronic)
- No central magnetic field



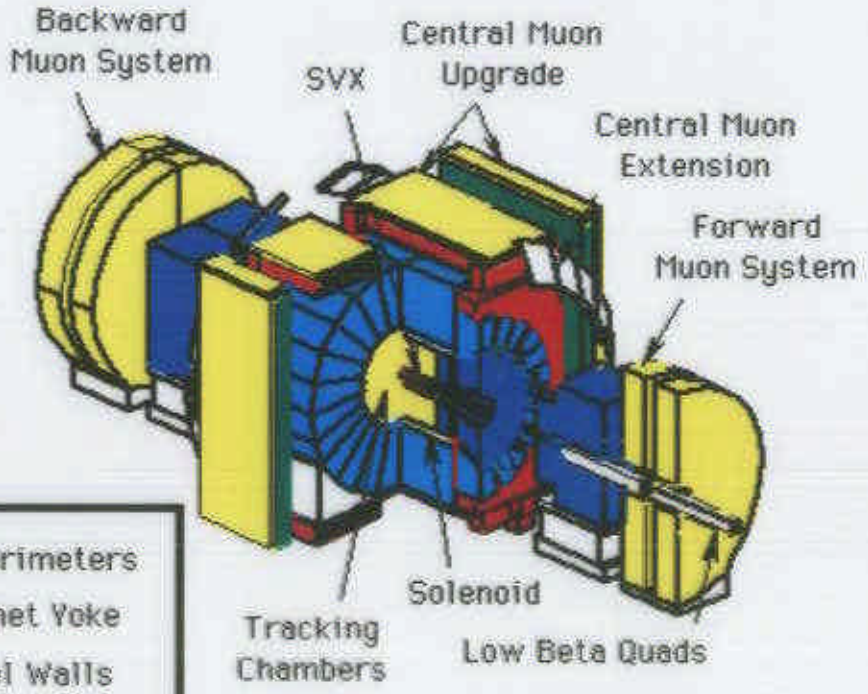
DØ Detector

The CDF Detector

- Emphasizes central charged particle tracking:
  - 1.4 T central magnetic field
  - $\Delta p_T/p_T \sim 0.1\%\ p_T$
- Silicon detector to identify secondary vertices

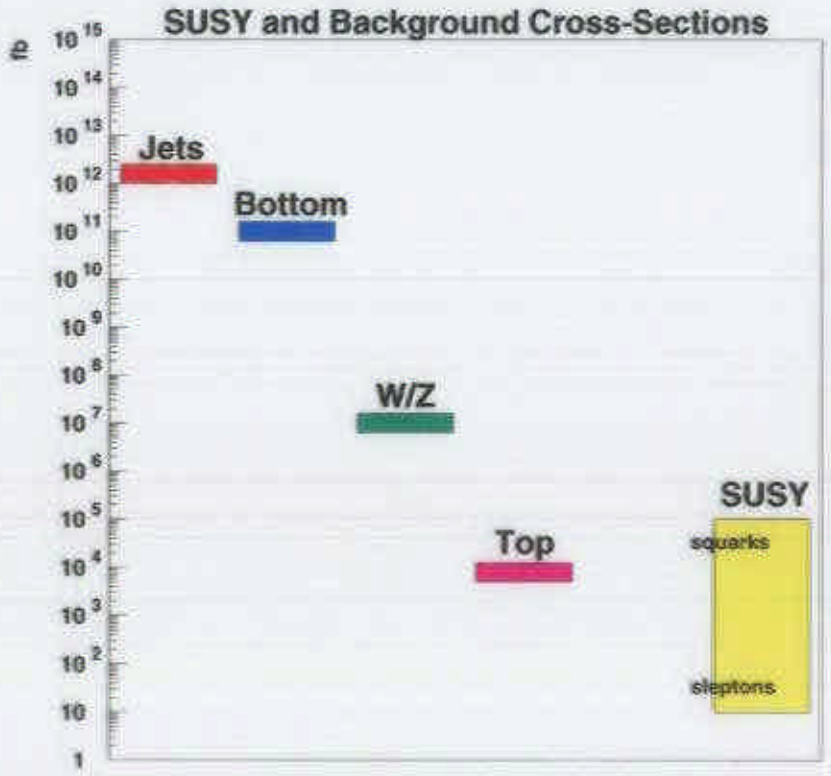


CDF Detector



Cross-Sections

- Predicted SUSY cross-sections are within reach of the Tevatron
  - Compare to e.g. the top quark cross-section
  - SUSY cross-sections are strongly dependent on particle mass, less so on model parameters
- Backgrounds can be orders of magnitude larger than the signal
  - Leptons, heavy flavor, missing E_T and energetic photons are some of the mechanisms for background reduction

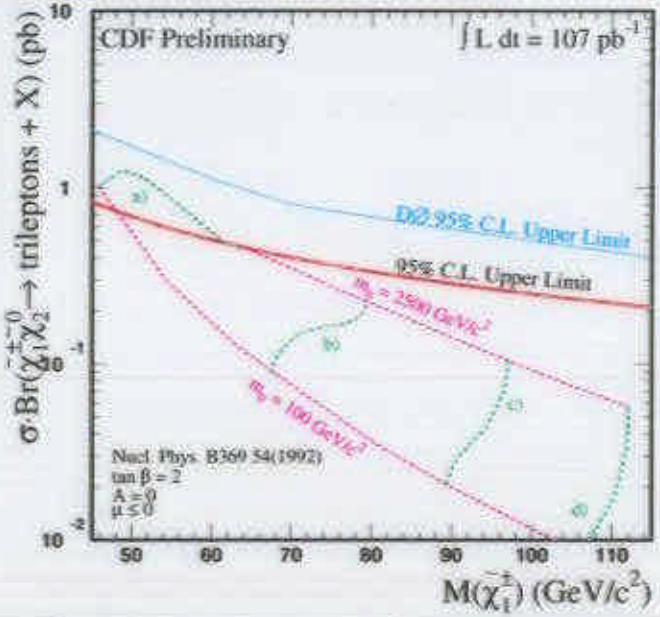


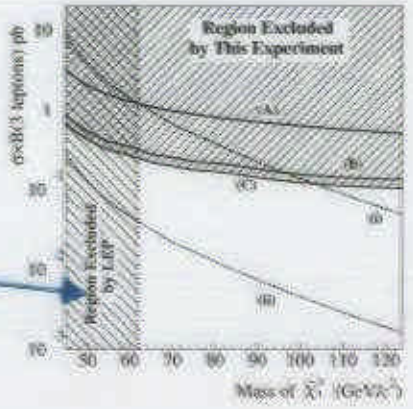
Trilepton Searches

- Experimentally, very very clean
  - Not many events have even one or two isolated leptons, much less three
- The "classic" chargino-neutralino search: $q + \bar{q}' \rightarrow W^{\pm} \rightarrow \tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$
- In this model, the LSP is the $\tilde{\chi}_1^0$ $\tilde{\chi}_1^{\pm} \rightarrow l^{\pm} \nu \tilde{\chi}_1^0$
  - It manifests itself as missing energy
- Both CDF and D0 searched for trilepton events: $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$
  - 3 leptons with minimum p_T above 5-11 GeV
  - Require a pair of e's or μ's to have opposite sign (CDF only)
  - Missing E_T of at least 10-15 GeV
  - Topological and kinematic (mass) cuts

Trilepton Results

- No events were seen in either CDF or D0.
  - CDF background is 1.2 ± 0.2
  - D0 background is 1.3 ± 0.4
    - Largest background is *eee*: Drell-Yan *ee* plus a fake electron
  - Limits are interpreted assuming $m(\tilde{\chi}_1^{\pm}) \approx m(\tilde{\chi}_2^0) \approx 2m(\tilde{\chi}_1^0)$
  - Typical efficiencies are 2-6% for D0 and 3-12% for CDF (depending on chargino mass)
- Excluded region complementary to LEP data





PRL 80, 1591 (1998)
PRL 80, 5275 (1998)

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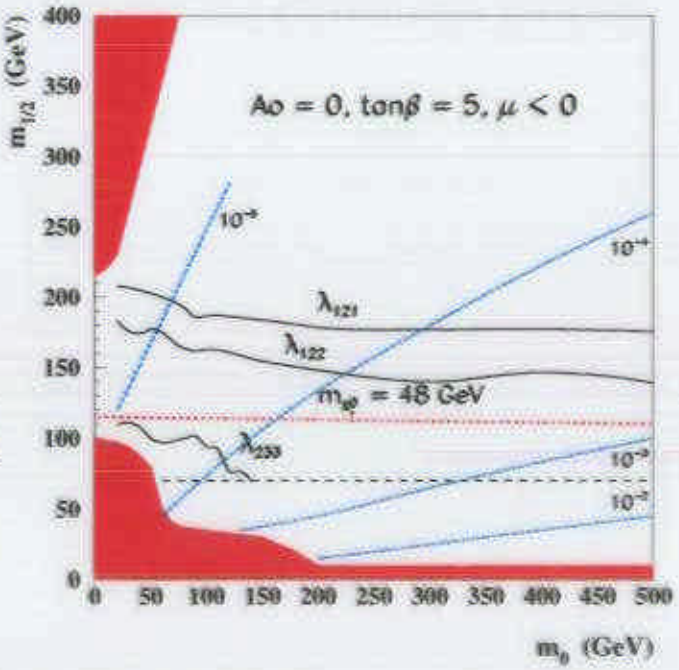
R-Parity Violating (RPV) Trileptons

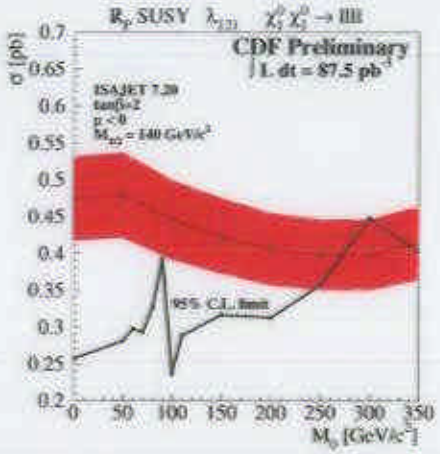
- Sparticles are produced in an R-parity conserving process, but the LSP is not stable. It can decay via an RPV coupling of strength λ_{ijk}.
  - Consider analogy with strange particles – produced strongly, but decay weakly
  - Sensitive to 1st and 2nd lepton family couplings in the range $10^{-3} - 10^{-4}$
- That gives 4 leptons in the final state. D0 has reinterpreted their trilepton analysis in the context of RPV

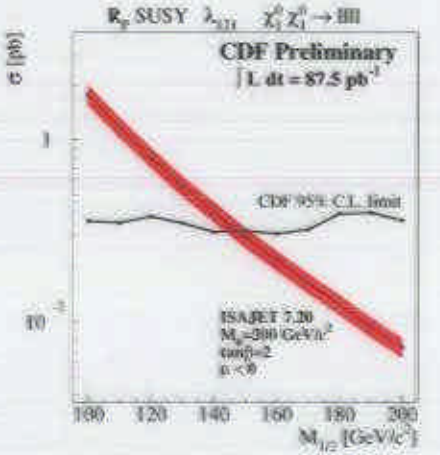
$$\tilde{\chi}_1^0 \rightarrow \nu + l^+ + l^-$$

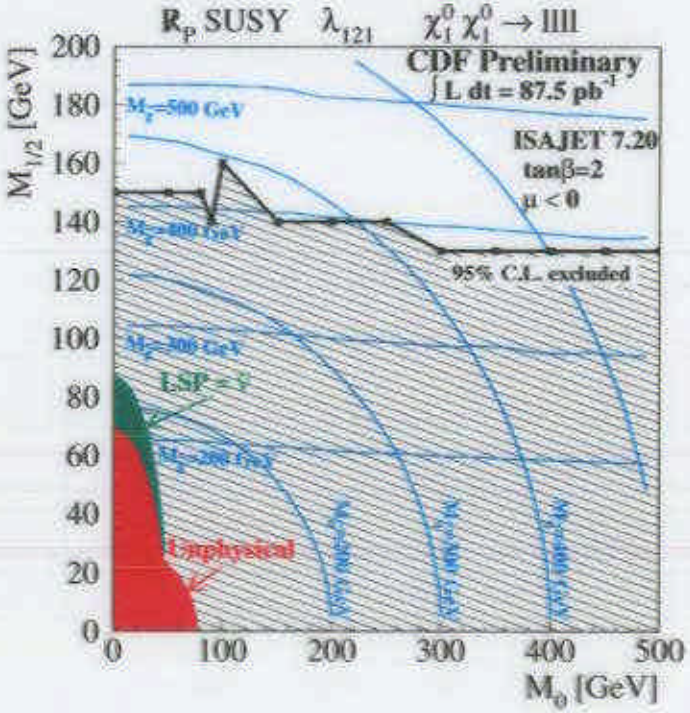


RPV Tetraleptons

- Same basic idea, but require all 4 leptons to be detected
  - One has to be at least 12 GeV
  - The others must be at least 5 GeV
- One signal event
  - $ee\mu\mu$
    - Muons not isolated
    - Suggestive of heavy flavor
  - Expect 1.2 ± 0.2 background events
  - 185 trileptons
  - ε is 10-20%





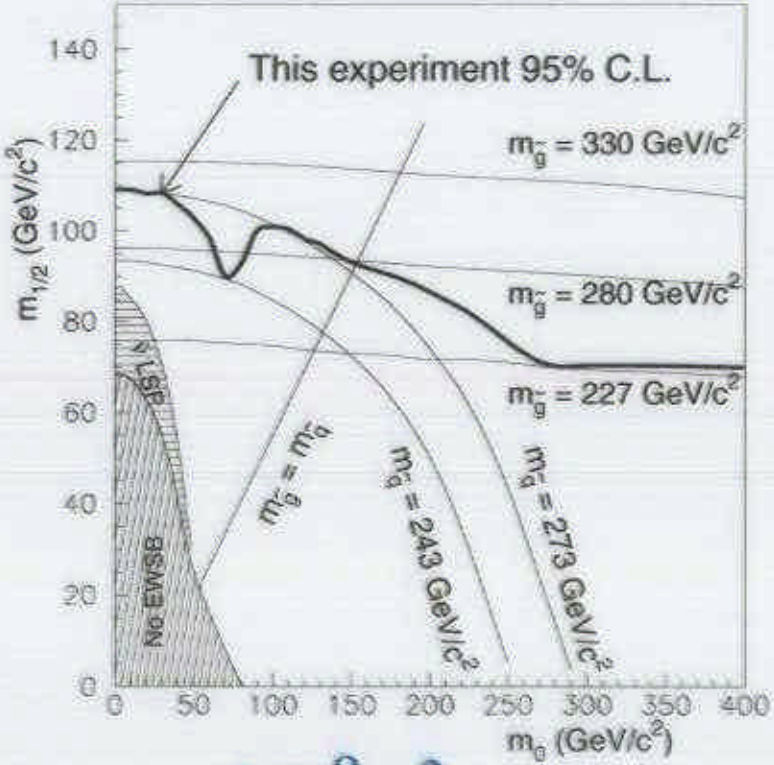


RPV Dileptons at D0

- Require two electrons
  - No sign requirement
  - Above 15 and 10 GeV
  - At least four 15 GeV jets
  - Remove Z decays to dielectrons
- Two events seen, 1.8 ± 0.4 expected from background
  - Background dominated by Drell-Yan and misidentification
- Assumes only LSP decays via RPV

PRL 83, 4476 (1999)

$$\tilde{\chi}_1^0 \rightarrow e^+ + d + \bar{u}$$



tan β= 2

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Same Sign Dileptons from RPV

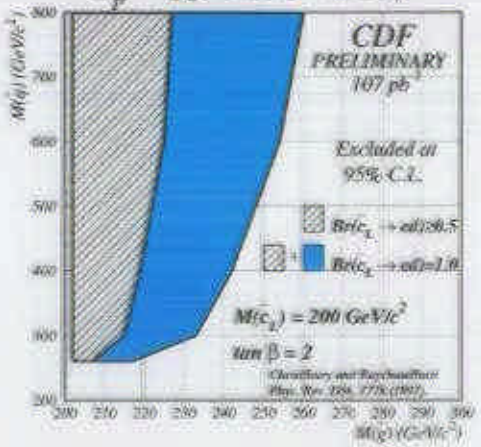
- Motivated to explain HERA excess
- Signature:
  - Like sign dielectrons
  - At least two 15 GeV jets
  - No substantial missing energy
- No events seen
  - Background is 0.3 ± 0.3
- Probes only λ_{121} coupling.

$$e^+ + p \to \tilde{c}_L \to e^+ + d$$

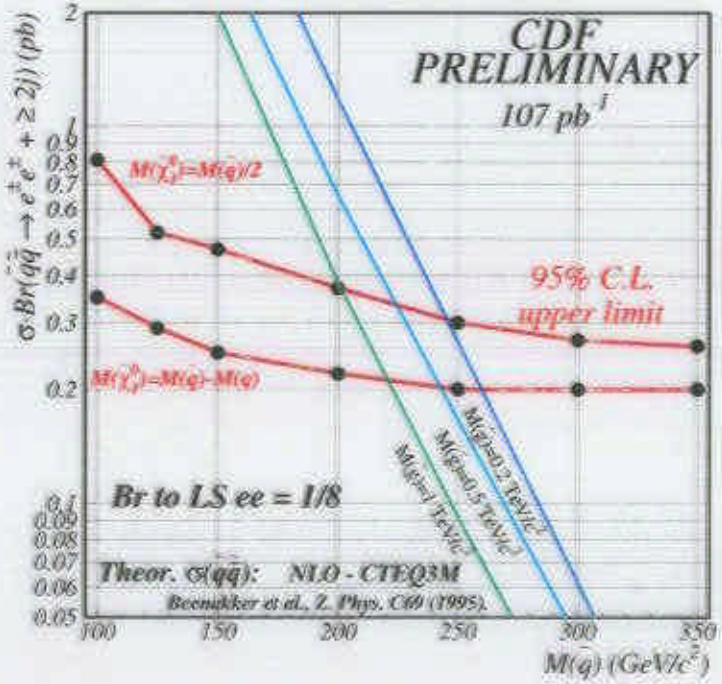
$$p + \bar{p} \to \tilde{g}\tilde{g}, \tilde{g} \to (\bar{c}\tilde{c}_L) \to \bar{c}(e^+ d)$$

$$p + \bar{p} \to \tilde{q}\bar{\tilde{q}}, \tilde{q} \to (q\tilde{\chi}_1^0) \to q(e^+ q\bar{q})$$

R_p $\tilde{g}\tilde{g} \to e^\pm e^\pm + \geq 2j$



R_p $\tilde{q}\bar{\tilde{q}} \to q\tilde{\chi}_1^0 \bar{q}\tilde{\chi}_1^0 \to e^\pm e^\pm + \geq 2j$



CDF PRL 83, 2133 (1999)

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Stop and Sbottom

- In many models, sbottom and especially stop can be lighter than the other squarks
  - That means their production rate is larger
- Many decay channels
  - Most involve heavy flavor in the final state
- Some typical signatures:
  - SM Top-like signatures
    - Kinematics somewhat different
  - Two charm jets plus MET
  - Two b jets, 2 leptons + MET
  - Two b jets + MET

$$\tilde{t} \to b + \tilde{\chi}_1^+ \to Wb + \tilde{\chi}_1^0$$

$$\tilde{t} \to b + \tilde{\chi}_1^+ \to bl + \tilde{\nu}$$

$$\tilde{t} \to c + \tilde{\chi}_1^0$$

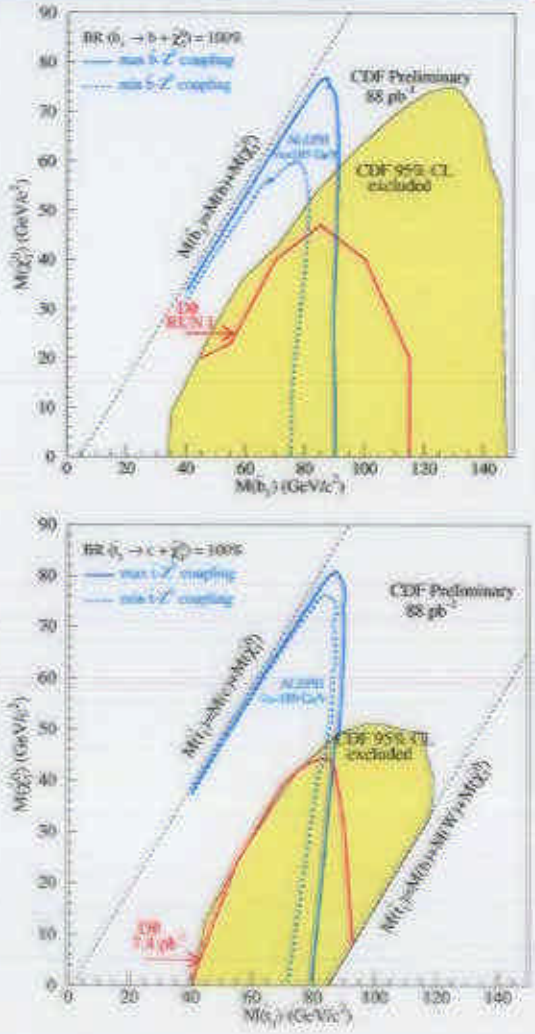
$$\tilde{t} \to t + \tilde{\chi}_1^0$$

$$\tilde{b} \to b + \tilde{\chi}_1^0$$

Note similarity of final state

CDF Limits on stop and sbottom

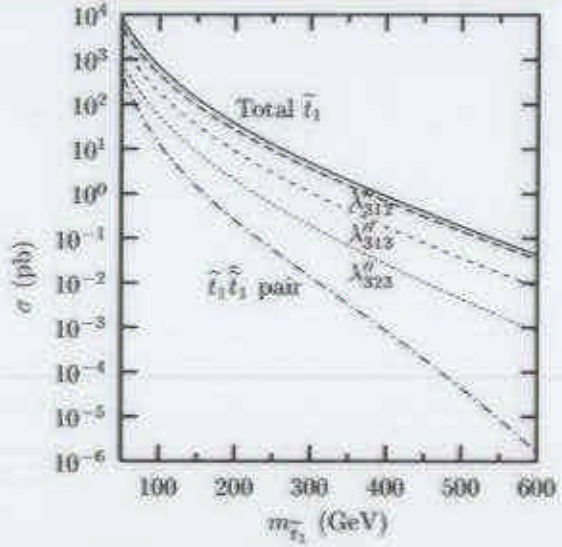
- Select 2 (or 3) acollinear jets with 40 GeV missing E_T.
- Remove leptons
- Use silicon vertex detector to tag b and c jets
  - 11 charm jets observed
  - Background is 15 ± 4
  - 5 bottom jets observed
  - Background is 6 ± 2
- Tagging bottom is easier than tagging charm
- D0 can also tag heavy flavor with muons, but this is less efficient
- Large regions of parameter space are excluded

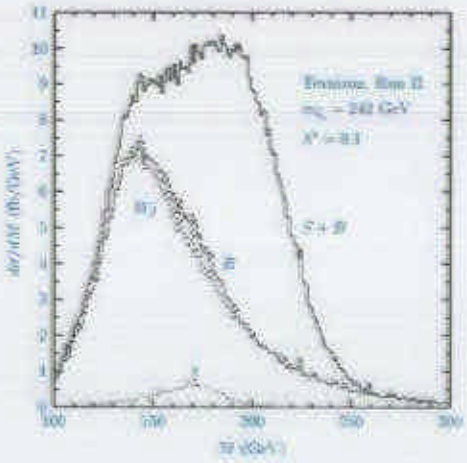


CDF PRL 84, 5704 (2000)

Single Stop via RPV Production

- Suppose you produced stop via an RPV process, and it decayed via an RPV conserving process
  - Production via λ''_{312} coupling
    - $d + s \rightarrow \tilde{t}$
  - You lose in the coupling
  - You gain in the phase space (because you only need to make one squark)
- Cross-section can increase by a factor of 100!



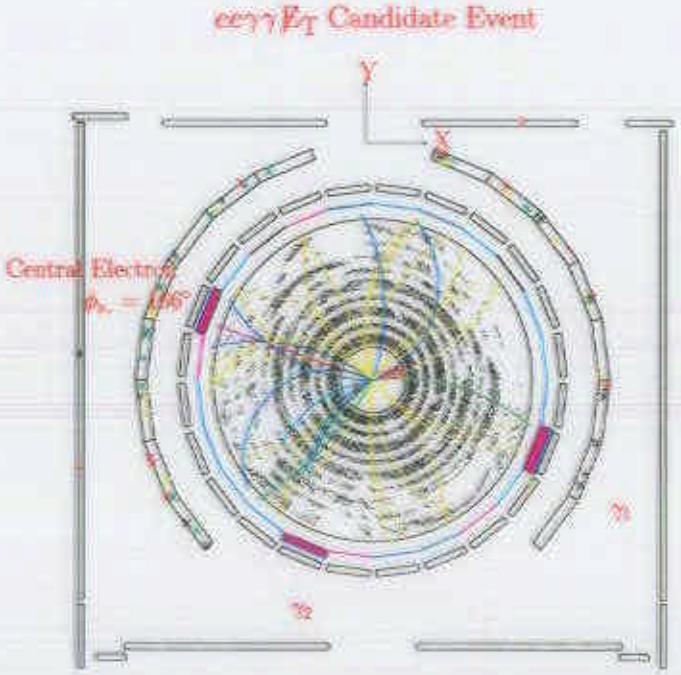


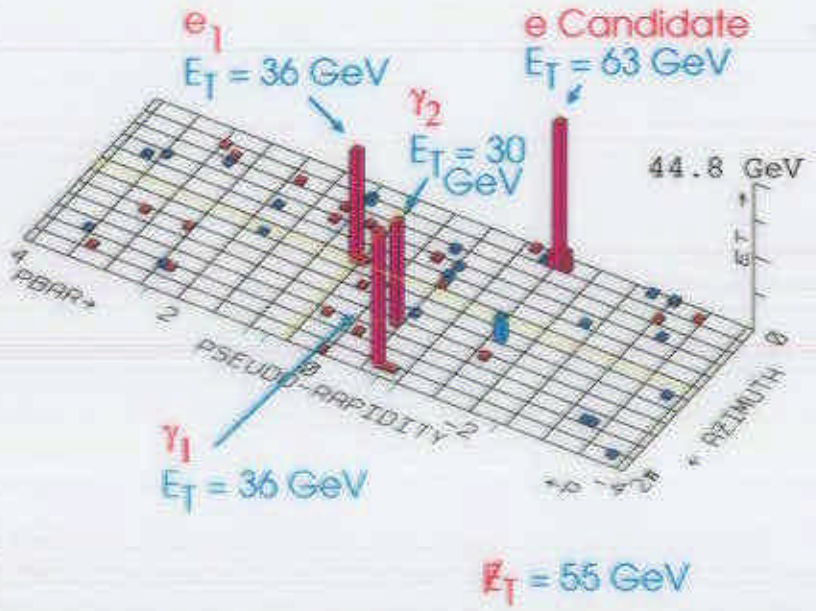
Berger, Harris and Sullivan
PRL 83, 4472 (1999)
ANL-HEP-PR-00-062

Events with Photons

- Interest in events with photons picked up after CDF's "$ee\gamma\gamma$" event.

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



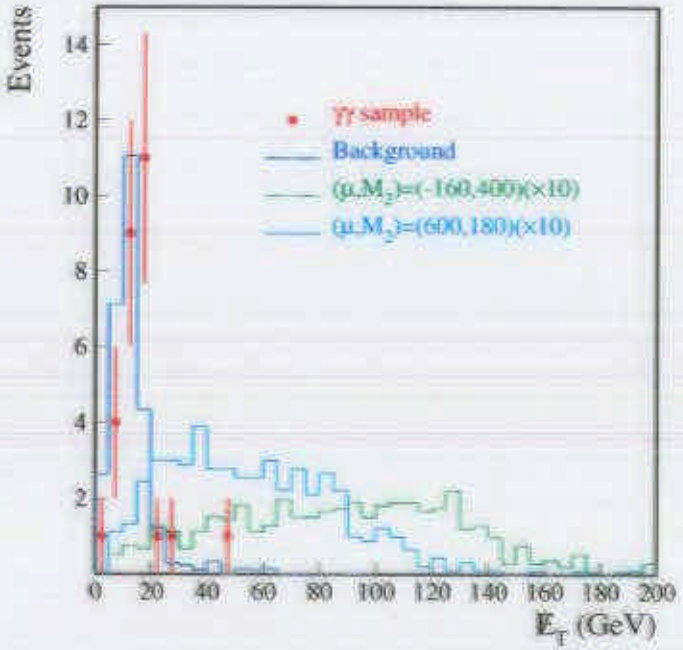


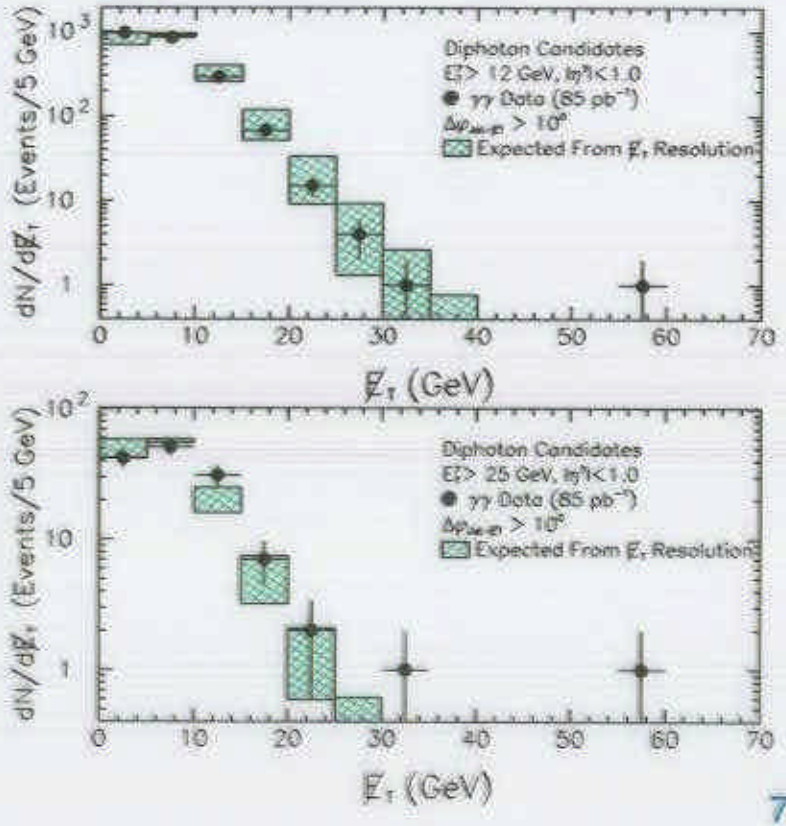
Interpretation of the event

- One possibility is $p\bar{p} \to \tilde{e}\tilde{e}X, \tilde{e} \to e\tilde{\chi}_1^0, \tilde{\chi}_1^0 \to \gamma\tilde{G}$
- Experimentally, there are still open questions
  - Is the event really $ee\gamma\gamma$?
  - The high η electron candidate passes all cuts, but upon detailed investigation doesn't look like one (P < 0.3%).
  - All alternative explanations are also improbable. We simply do not have enough information to establish the origin of that cluster.
- No matter whether this event was SUSY or some strange background (and we'll likely never know), it did cause people (theory and experiment) to direct their efforts towards understanding events with photons.

Diphoton Searches

- Both CDF and D0 searched for events with two photons and missing energy and no significant excess was found. Fortunately for the search, these events are very unusual.

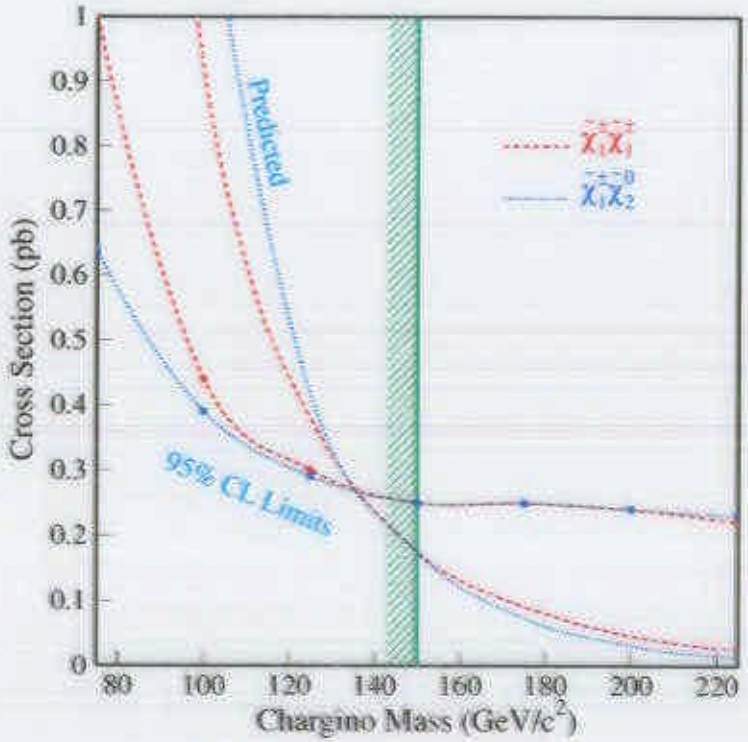


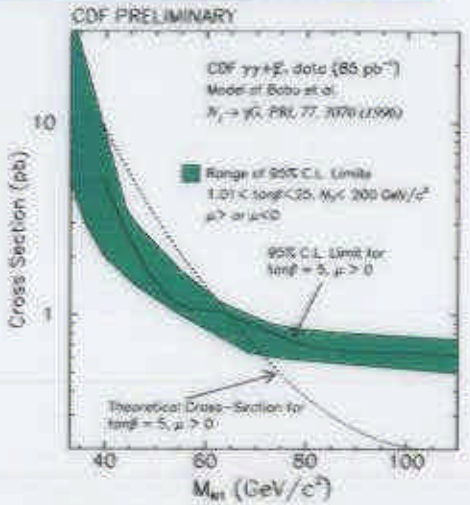


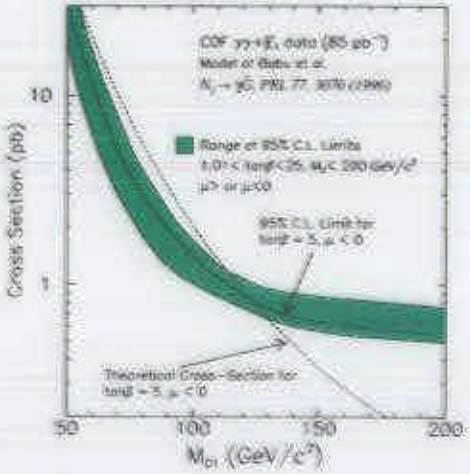
PRD 59, 092002 (1999).
PRL 80, 442 (1998)

Limits from Diphotons

- Several (model dependent) limits can be extracted – these are representative







A Few Words on Run II

- Run II begins in March
- Upgraded Accelerator
  - Higher energy (2 TeV vs. 1.8)
  - More beam bunches (132/396 ns)= higher luminosity
  - New Main Injector
    - More beam into Tevatron
    - More antiproton production
- Upgraded Detectors
  - D0 gets a central magnet, a new tracker and silicon
  - CDF gets a new tracker, more silicon, extended muon identification and more hermetic calorimeters
  - Both experiments are starting to look more like each other
- Fermilab anticipates a factor 20 more data for this run
  - And is looking to a long-term program of 150x the data

Conclusions

- Tevatron results are
  - Negative – we haven't seen supersymmetry (that we can tell)
  - Complementary to LEP & HERA
  - Already excluding significant parts of SUSY parameter space
- However…
  - If you believed in SUSY before, you probably still do.
  - If you didn't, the null results from Tevatron searches certainly didn't convince you SUSY was **more** likely!
- Run II begins in March with
  - 20 x the data
  - Substantially upgraded CDF and D0 detectors
  - ***SUSY will be running out of places to hide.***