# Searches for New Particles/Phenomena at CDF

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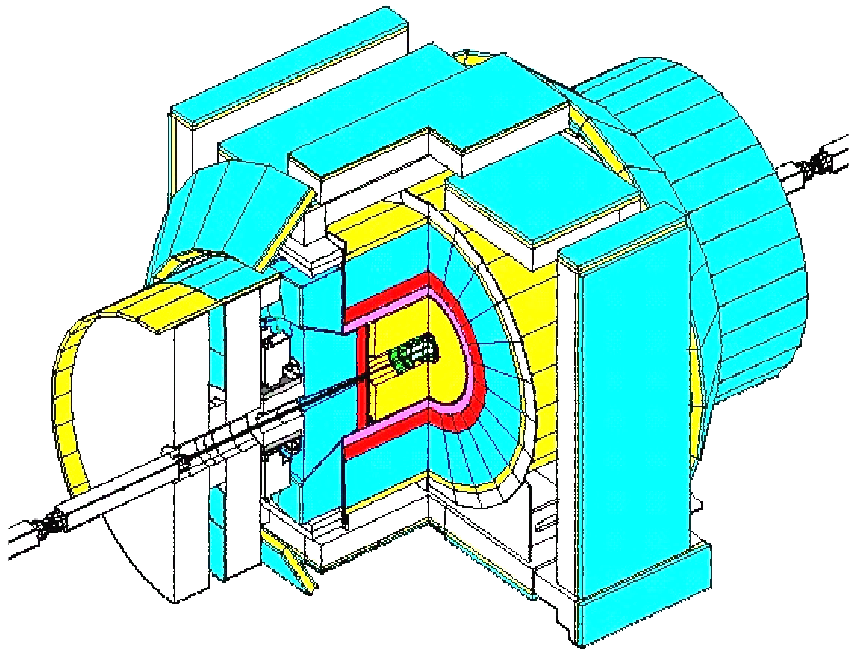
# Outline

- Tevatron/CDF Upgrade
- ***W'*** Searches
- Drell-Yan Production (***Z'***, LED)
- Leptoquarks
- CHAMPs
- Inclusive $\gamma$+lepton Searches
- Missing $\boldsymbol{E_T}$+jet search
- Exclusive missing $\boldsymbol{E_T}+\gamma$
- Stop searches
- Conclusions

# Tevatron/CDF Upgrade

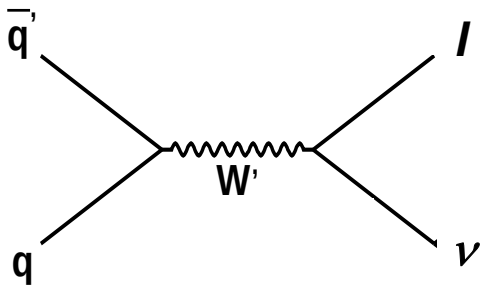
- Refer to Tevatron and CDF status talks for details
- Tevatron (RunI → RunIIa)
  - $\sqrt{s} = 1.8\,\text{TeV} \rightarrow 1.96\,\text{TeV}$
  - Higher instantaneous luminosity (1.6E30 →8.6E31 $cm^{-2}s^{-1}$)
  - Higher expected integrated luminosity (100 $pb^{-1}$ → ~2 $fb^{-1}$)



- CDF
  - New silicon vertex detectors
  - New Central Outer Tracker (COT)
  - Time-of-Flight (TOF)
  - Extended muon coverage ($\eta$=1.0→1.5)
  - New Endplug EM and HAD calorimeters
  - New DAQ and Triggers (***e.g.*** Secondary Vertex Trigger)

# $W' \rightarrow e\nu, \mu\nu$

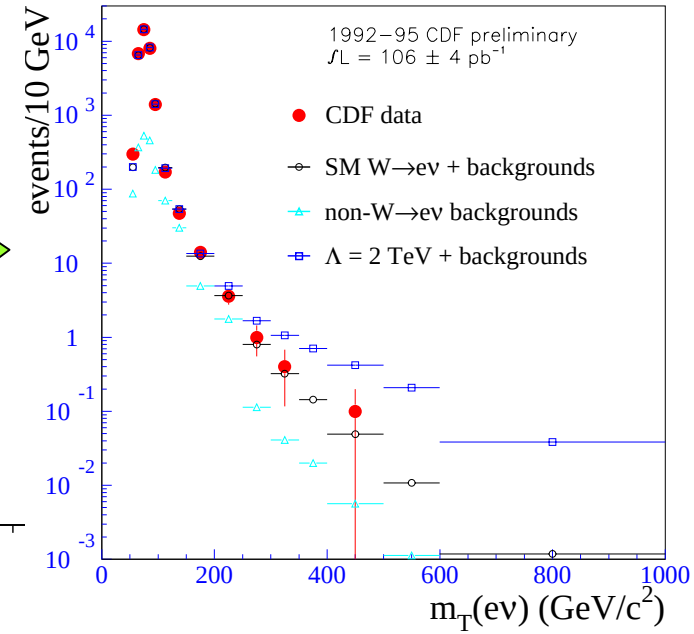
- Extensions of SM predict a new charged vector boson, $W'$.

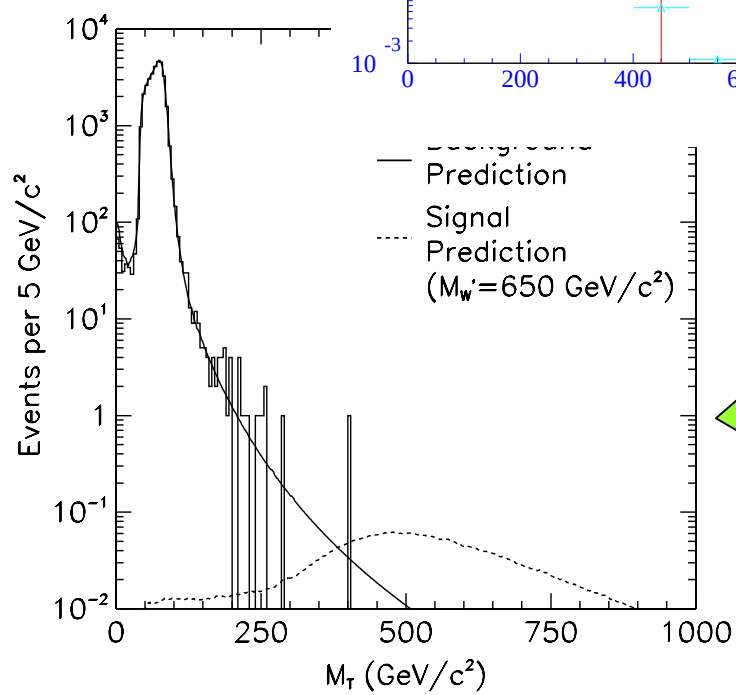



- Limits on $M_{W'}$:
  - > 755 GeV/$c^2$ ($W' \rightarrow e\nu$)
  - > 660 GeV/$c^2$ ($W' \rightarrow \mu\nu$)
  - > 786 GeV/$c^2$ (combined)

- Quark-lepton compositeness (contact interactions):
  - $\Lambda$>2.81 TeV ($e\nu$–channel only):

$e\nu$

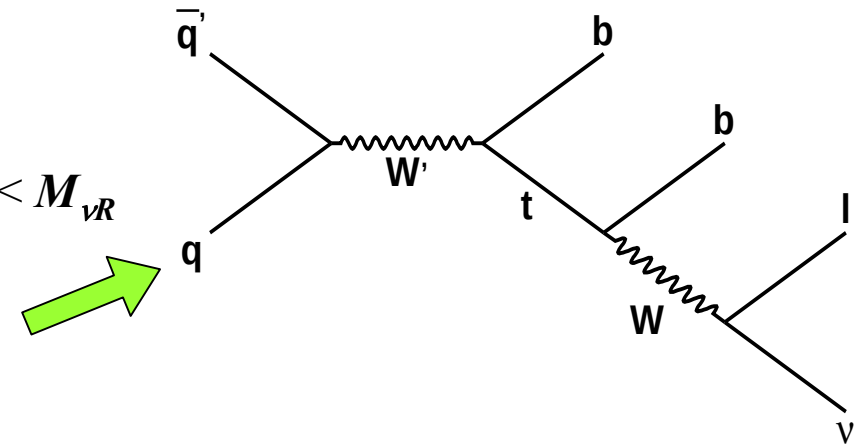



$\mu\nu$

# $W' \rightarrow tb$ in Run I

- In the L-R symmetric model, no guarantee that $\nu_R$ is light.
  If $M_{W'} < M_{\nu R} \rightarrow$ BR($W' \rightarrow l\nu$)=0
  - Two cases: $M_{W'} >> M_{\nu R}$ and $M_{W'} < M_{\nu R}$

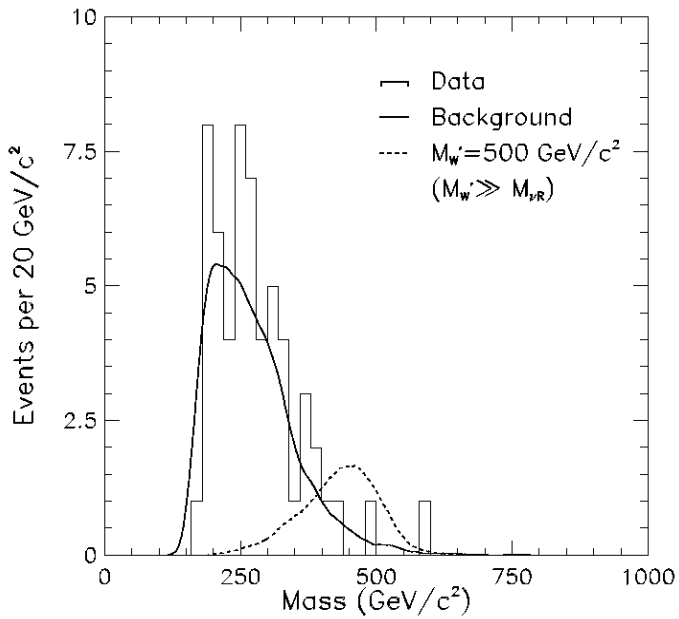



- Same final state as $W^*$ single top production
- $W$ candidate
  - A high $p_T$ lepton
  - Large missing $E_T$
  - Constrained "$l\nu$" invariant mass to $W$ mass
- 2-3 jets with >=1 $b$-tagged jet
- Reconstruct "$l\nu jj$" mass and look for excess

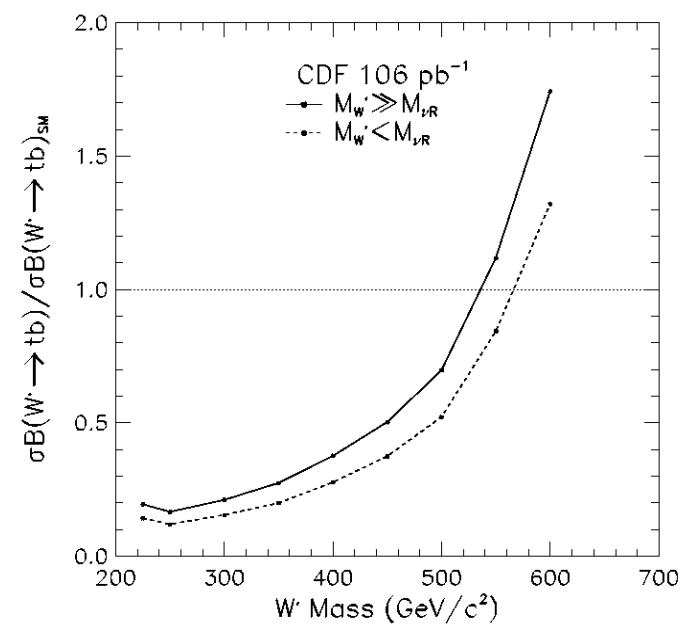
Expected number of signal events in 106 pb$^{-1}$

| $M_{W'}$ (GeV/$c^2$) | Number of events $M_{W'} \gg M_{\nu_R}$ | $M_{W'} < M_{\nu_R}$ |
|---|---|---|
| 225 | 116 | 168 |
| 300 | 115 | 161 |
| 400 | 43 | 58 |
| 500 | 14 | 19 |
| 600 | 4.5 | 5.9 |

# $W' \rightarrow tb$ in Run I




- Background: $W$+jets, $tt$, single $t$
- 57 events observed
- 48 ±6 background expected
- Fit the mass distribution

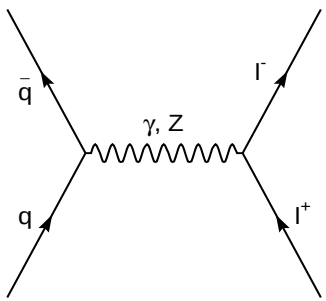



- Limits (exclusion for SM couplings):
  - $225 < M_{W'} < 536$ GeV/$c^2$ ($M_{W'} \gg M_{\nu R}$)
  - $225 < M_{W'} < 566$ GeV/$c^2$ ($M_{W'} < M_{\nu R}$)
- Run IIa expectation: $M_{W'} \sim 800$ GeV/$c^2$ for ($M_{W'} \gg M_{\nu R}$)

# Drell-Yan Production

- Drell-Yan events can be used to look for

***Extra Bosons***

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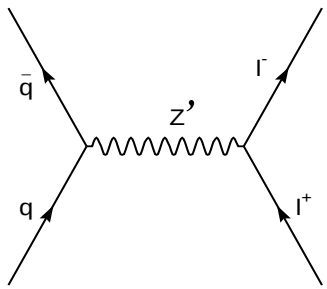


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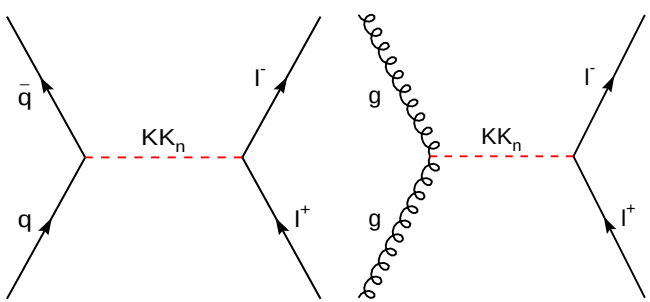
***Large Extra Dimensions***

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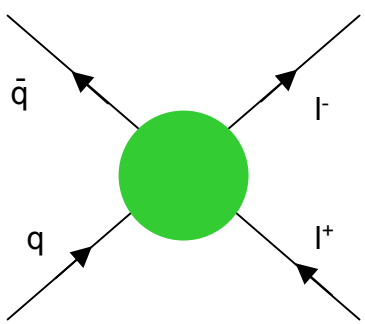
***Compositeness, etc...***

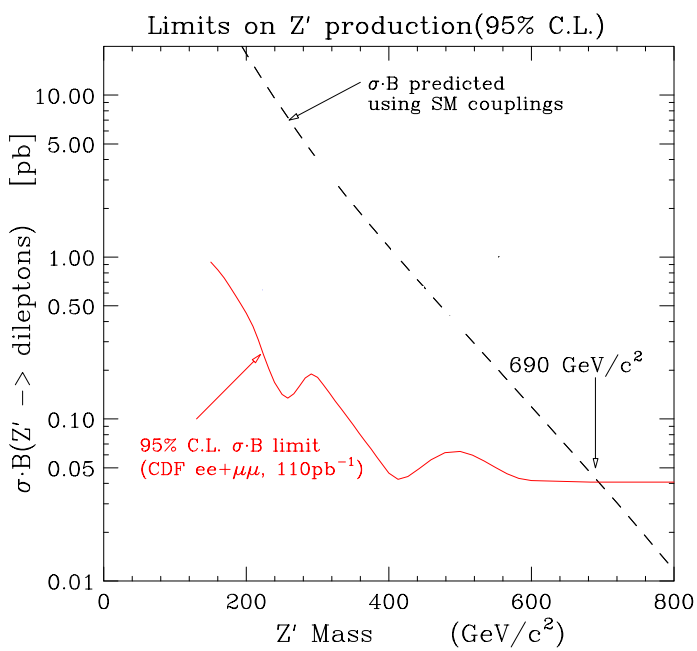


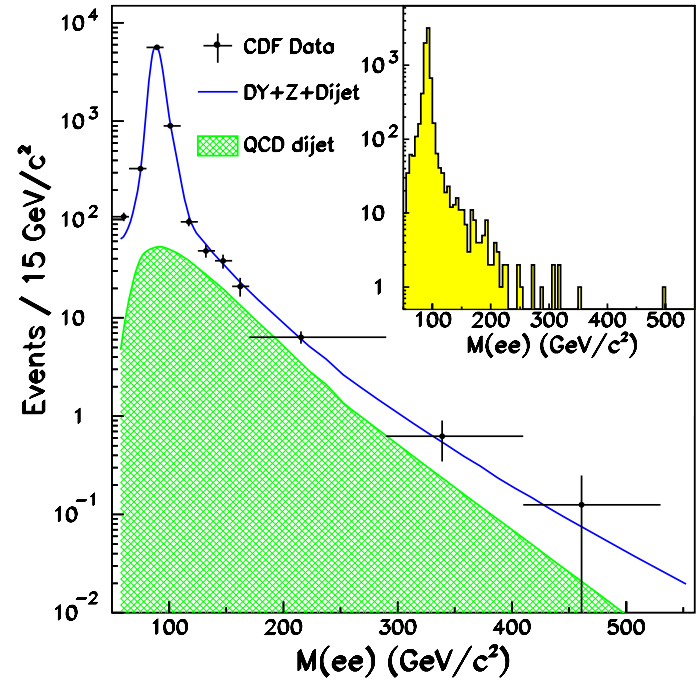

+ ...

→Expect enhancement in the cross section

# *Z'* Search in Run I

- Searched for ***Z'*** in $e^+e^-$ and $\mu^+\mu^-$ (*and dijet*) channels
- Isolated high $p_T$ leptons
- Look for excess in the high invariant mass region
- Limit: $M_{Z'} > 690$ GeV/$c^2$ for SM couplings ($e+\mu$ combined)

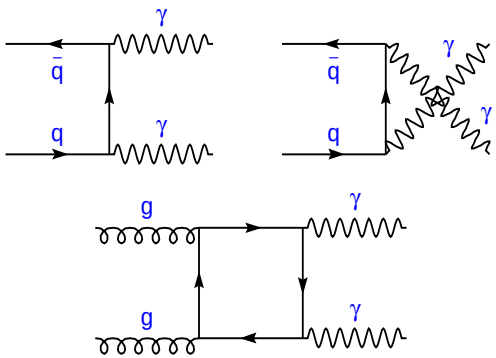


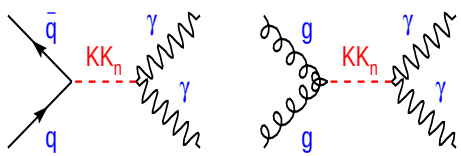

$e^+e^-$ invariant mass distribution overlaid with background distributions

# Large Extra Dimensions in Run I

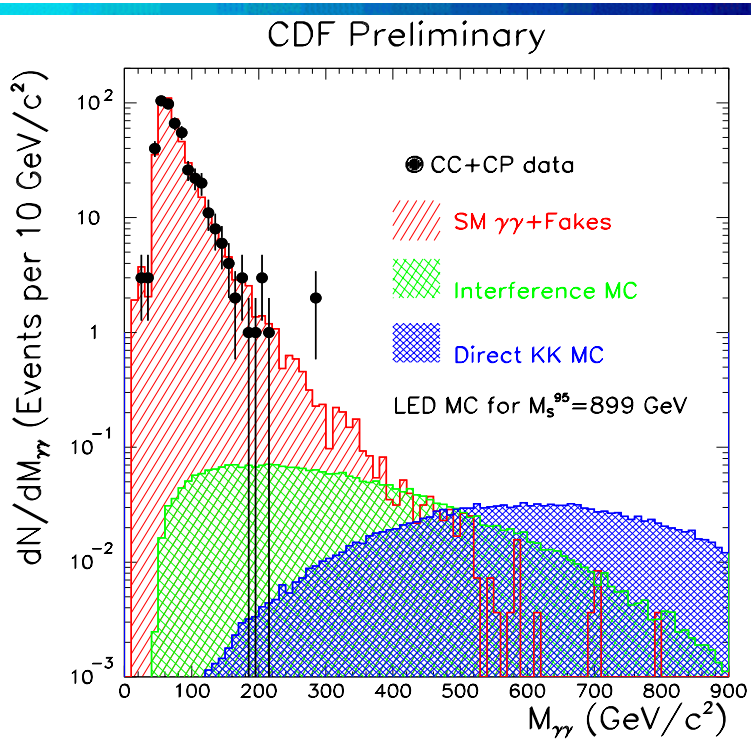
- CDF has searched for Large Extra Dimensions in dielectron and diphoton channels in Run I




$\gamma\gamma$ backgrounds




$\gamma\gamma$ signal

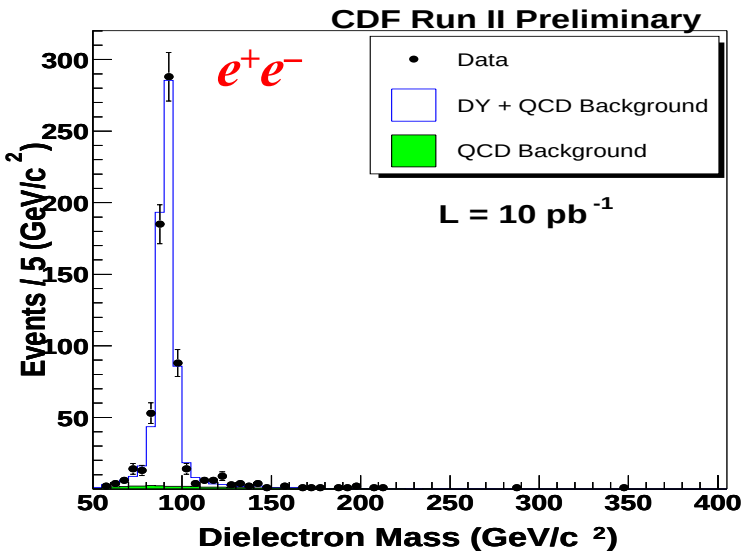


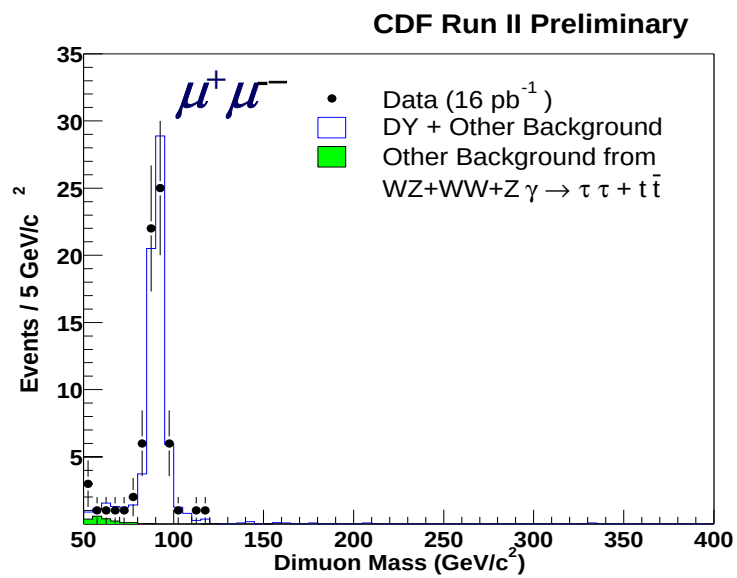

Diphoton invariant mass distribution overlaid with $M_S$=899 GeV ($\Lambda_{Hewitt}$=-1)

- Dielectron and diphoton results were combined to give limits:
  - $K_{LED}$=1.3: $M_S$> 939 GeV ($\Lambda$=–1)
    > 853 GeV ($\Lambda$=+1)

# Drell-Yan Distributions in Run II

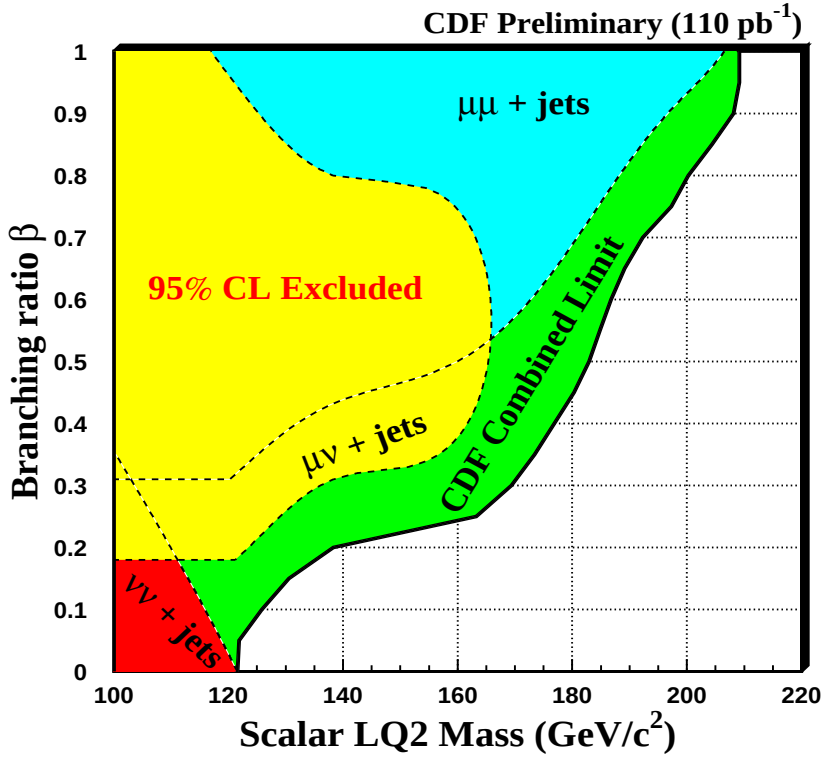
- Searches using Drell-Yan production underway using Run II data:
  - $e^+e^- \rightarrow$10 pb$^{-1}$
    - $\rightarrow M_{Z'}$> 450 GeV/$c^2$
      $M_G$> 340 GeV/$c^2$ (Randall-Sundrum, $k/M_{Pl}$=0.1)
  - $\mu^+\mu^- \rightarrow$16 pb$^{-1}$
    - $\rightarrow M_{Z'}$> 270 GeV/$c^2$
      $M_G$> 255 GeV/$c^2$ (Randall-Sundrum, $k/M_{Pl}$=0.1)
- Expect $M_{Z'}$>1000 GeV for $Z' \rightarrow ll$ (SM couplings) in Run IIa



# Leptoquarks in Run I

- Leptoquarks generally produced in pairs and decays to $(lq)(lq)$, $(lq)(\nu q)$, $(\nu q)(\nu q)$
- 1st generation
  - $eejj$
    - $M_{LQ1} > 210$ GeV/$c^2$ ($\beta$=1)
- 2nd generation
  - $\mu\mu jj$
    - $M_{LQ2} > 202$ GeV/$c^2$ ($\beta$=1)
  - $\mu\nu jj$
    - $M_{LQ2} > 164$ GeV/$c^2$ ($\beta$=0.5)
  - $\nu\nu cc$
    - $M_{LQ2} > 122$ GeV/$c^2$ ($\beta$=1)
  - $\mu\mu jj+\mu\nu jj+\nu\nu jj$
    - $M_{LQ2} > 183$ GeV/$c^2$ ($\beta$=0.5)
- 3rd generation
  - $\tau\tau bb$
    - $M_{LQ3} > 99$ GeV/$c^2$ ($\beta$=1)
  - $\nu\nu bb$
    - $M_{LQ3} > 149$ GeV/$c^2$ ($\beta$=1)

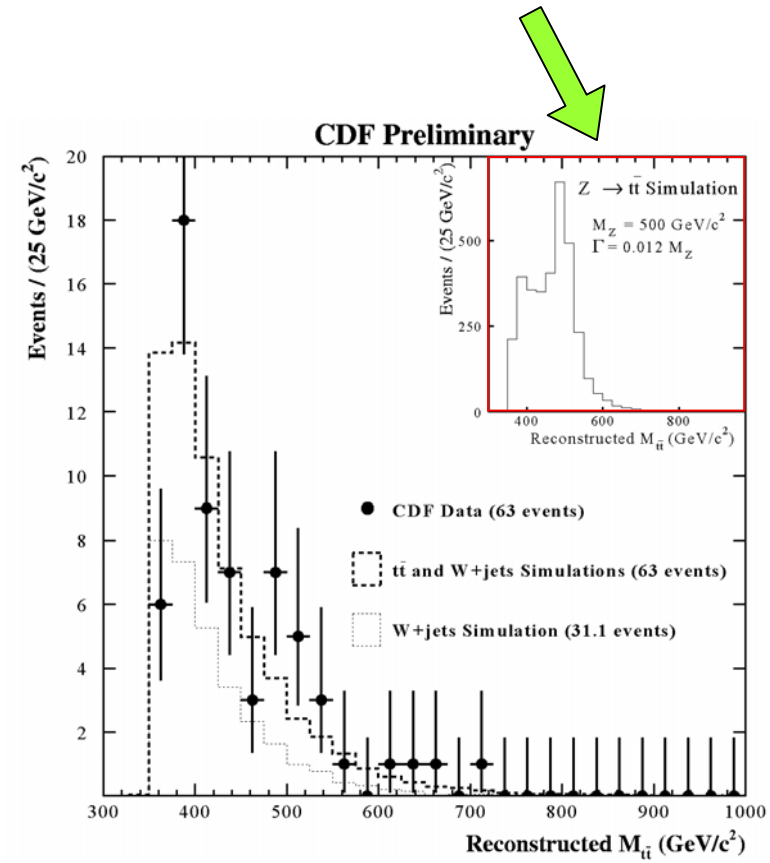


# $X \rightarrow tt$ in Run I

- Looks for particles decaying to a $tt$ pair (Top-color assisted technicolor $Z'$)
- Reconstruct $tt$ invariant mass and look for excess in high mass region
  - One $W$ decaying hadronically and the other leptonically
  - $e/\mu + \not{E}_T + >=4$ jets ($>=1$ $b$-tag)
- Leptophobic $Z'$ limits:
  - $M_{Z'}$>780 (480) GeV/$c^2$ for $\Gamma$=0.04$M_{Z'}$, (0.012$M_{Z'}$)
- Run IIa reach:
  - $M_{Z'}$>1.1 TeV/$c^2$ ($\Gamma$=0.04$M_{Z'}$)

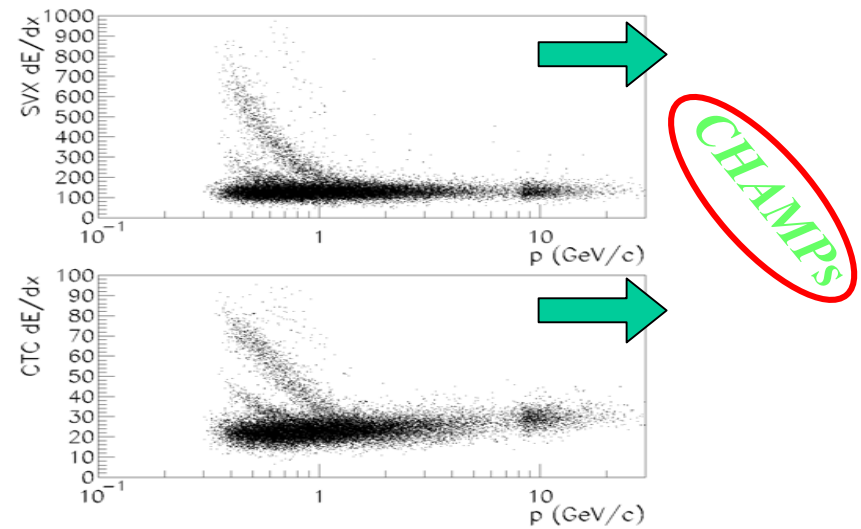
Expected signal $M_{tt}$ distribution

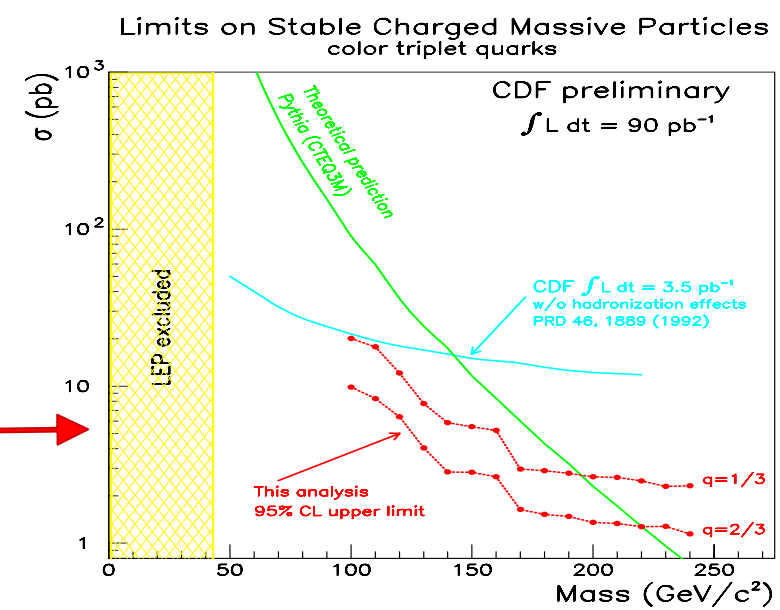
$M_{Z'}$=500 GeV/$c^2$ ($\Gamma$=0.012 $M_{Z'}$)



# CHAMPs in Run I

- CHArged Massive Particles: long-lived enough to leave detector (***e.g.*** sleptons)
- Look for slow heavy charged particles
  - Large ***dE/dx***
  - Large time-of-flight (TOF)
- CDF Run I Analysis
  - high $p_T$ track with large ***dE/dx***
  - used high $p_T$ muon trigger
  - $\beta\gamma < 0.85$
  - 12 events observed/12±2 bkg expected
  - >220 (190) GeV/$c^2$ for stable 4th generation up(down) type quarks

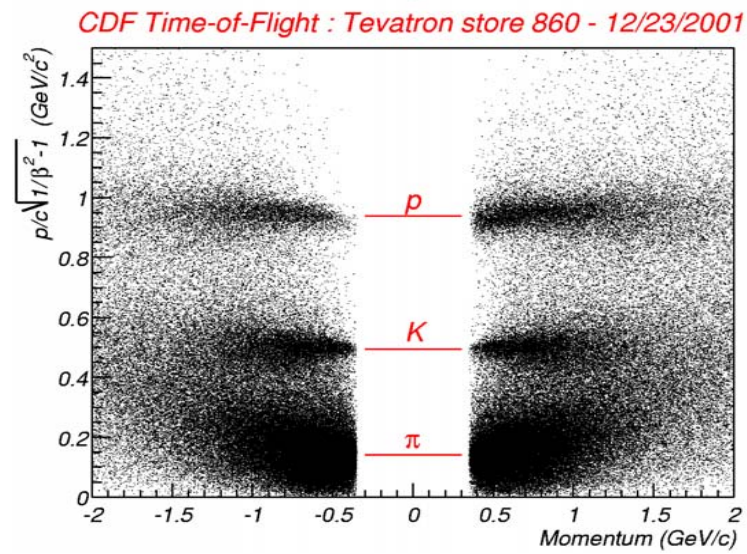


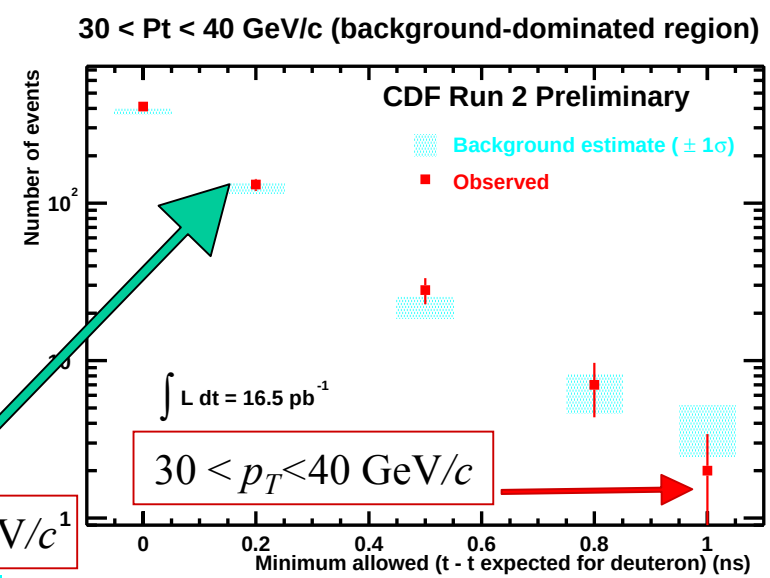



# CHAMPs in Run II

- Use TOF to separate high values of $\beta\gamma \rightarrow dE/dx$ does not have discriminating power at high $p_T$

- Select events with high $p_T$ muon trigger
- Isolated high $p_T$ track with large time-of-flight
- Use TOF assuming track being deuteron as reference ($TOF_{deut}$) to define large TOF
  - $TOF_{Diff}=TOF_{meas}-TOF_{deut}$
  - signal region $TOF_{Diff}>1$ ns




$30 < p_T < 40$ GeV/$c$

$20 < p_T < 30$ GeV/$c$[1]

$p_T > 40$ GeV/$c$

CHAMPs

# Inclusive lepton+γ searches in Run I

- $ee\gamma\gamma\not{E}_T$ event at CDF prompted searches involving high $p_T$ leptons and a photon in the final state
- The search is based on 86 pb$^{-1}$
- $E_T(l,\gamma)$>25 GeV, $\not{E}_T$>25 GeV
- Backgrounds are $Z$+γ, $W$+γ, $l$+jet, $Z \rightarrow ee$, etc.

| Category | $\mu_{SM}$ | $n_o$ | $P(n \geq n_0 \mid \mu_{SM})\%$ |
|---|---|---|---|
| Two-Body $l\gamma X$ | $24.9 \pm 2.4$ | 33 | 9.3% |
| Multi-Body $l\gamma X$ | $20.2 \pm 1.7$ | 27 | 10.0% |
| Multi-Body $ll\gamma X$ | $5.8 \pm 0.6$ | 5 | 68.0% |
| Multi-Body $l\gamma \not{E}_T X$ | $7.6 \pm 0.7$ | 16 | 0.7% |

- Data in agreement with the background prediction except for $l\gamma \not{E}_T X$

→ interesting to see if we would still see this excess with more data in Run II

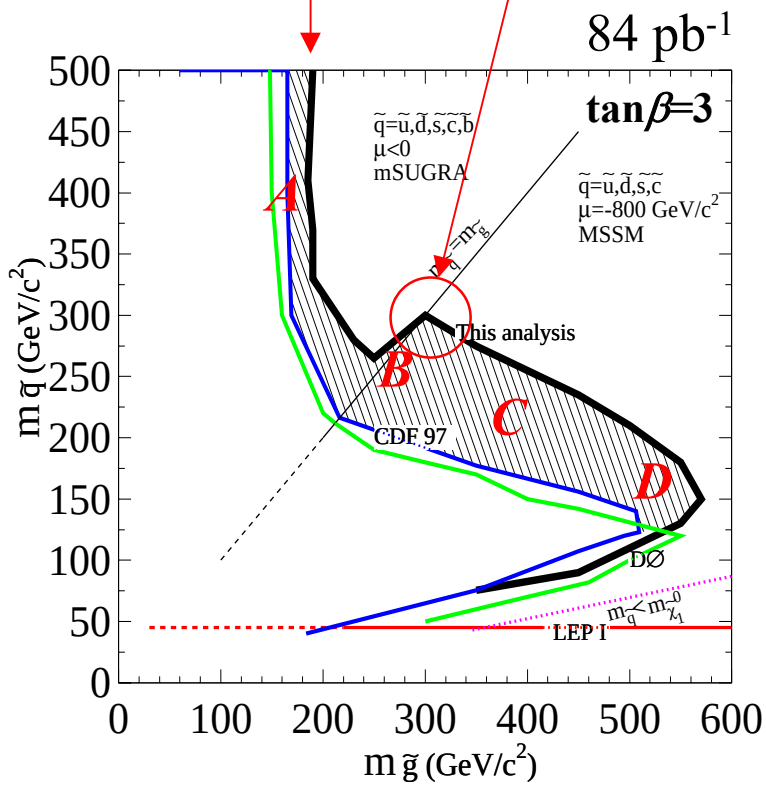
# $\not{E}_T$+Jets in Run I

- R-Parity conserving SUSY → large $\not{E}_T$ due to LSPs
- In searching for gluino or squark pair production
  - 3 or more jets
    - $E_T$>70, 30, 15 GeV
  - $\not{E}_T$>70 GeV
  - $H_T(=E_T^{j2}+E_T^{j3}+\not{E}_T)$>150 GeV
- 74 observed and 76±13 expected background (QCD,*tt*,*W/Z*)
- Final $H_T$ and $\not{E}_T$ cuts are optimised for different regions

•Limits:

$M_{\tilde{g}} > 300\ \mathrm{GeV/c^2}$ $M_{\tilde{q}} \approx M_{\tilde{g}}$

$M_{\tilde{g}} > 195\ \mathrm{GeV/c^2}$



# Exclusive $\not{E}_T+\gamma$ in Run I

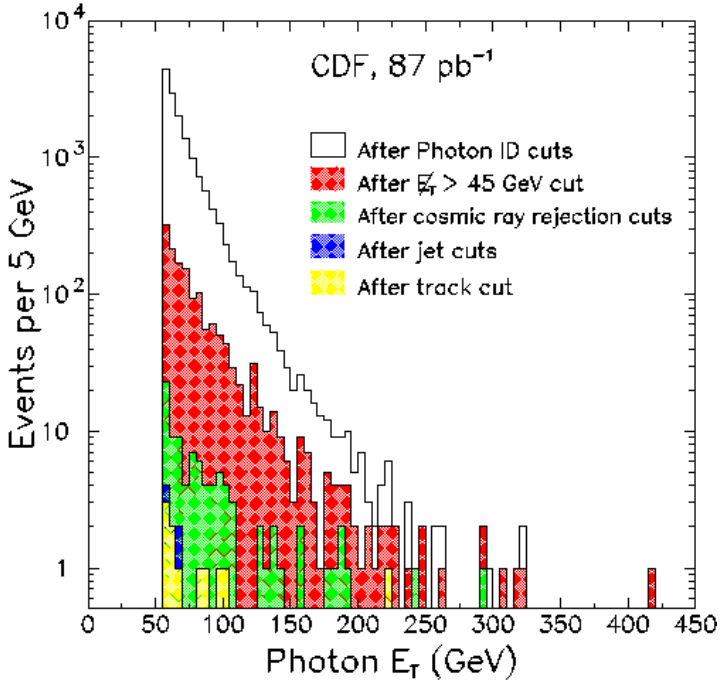
- In GMSB models, gravitino can be the LSP (superlight gravitino)

$$q\bar{q} \rightarrow \gamma\tilde{G}\tilde{G}$$

- In LED, a photon can recoil against a ***KK*** tower of graviton

$$q\bar{q} \rightarrow \gamma G_{KK}$$

- Assuming minimally interacting gravitinos or gravitons
  - $E_T^{\gamma} > 50$ GeV
  - $\not{E}_T > 40$ GeV
  - No jet with $E_T$>15 GeV
  - No track with $p_T$>5 GeV/$c$
- Main backgrounds: Cosmic rays and $Z\gamma \rightarrow \nu\nu\gamma$
- 11 observed and 11.0±2.2 expected




- Limits:
  - $|F|^{1/2}$> 221 GeV
    (> 217 GeV in $\not{E}_T$+jet )
  - $M_S$>549 GeV (n=4)
    >581 GeV (n=6)
    >602 GeV (n=8)

# R-Parity Conserving stop in Run I

- Stop pair produced through R-parity conservation

$$(q\bar{q}, gg \rightarrow \tilde{t}\bar{\tilde{t}})$$

- Assuming very heavy charged sleptons

$$\rightarrow \sum_{l=e,\mu,\tau} BR(\tilde{t} \rightarrow b l^{+} \tilde{\nu}_{l}) = 1$$

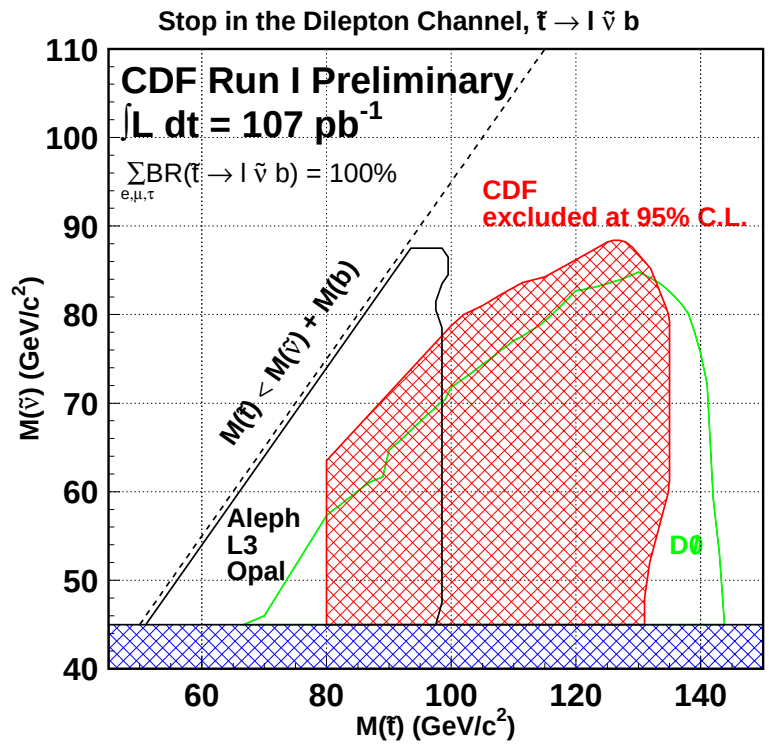
- $\tilde{t}\bar{\tilde{t}} \rightarrow l^{+} l^{-} \tilde{\nu}_{l} \bar{\tilde{\nu}}_{l} b\bar{b}$ final state

  $\rightarrow \boldsymbol{l^{+} l^{-}} + \not{E}_{T} + (>=1)$ jets

- 0 observed

  1.52 ±0.26(stat) ±0.32(syst) background expected

- Limit on sneutrino mass vs stop mass space



# R-Parity Violating stop in Run I

- Stop pair produced through R-parity conservation
- R-Parity violation → stop can decay to a pure SM particle state
- Assuming stop is the LSP or dominant decay mode is $\tilde{t} \to \tau b$

→ $BR(\tilde{t} \to \tau b) = 1$

- $\tilde{t}\bar{\tilde{t}} \to (\tau b)(\tau b) \to l\nu_l \nu_\tau \tau_h bb$ final state

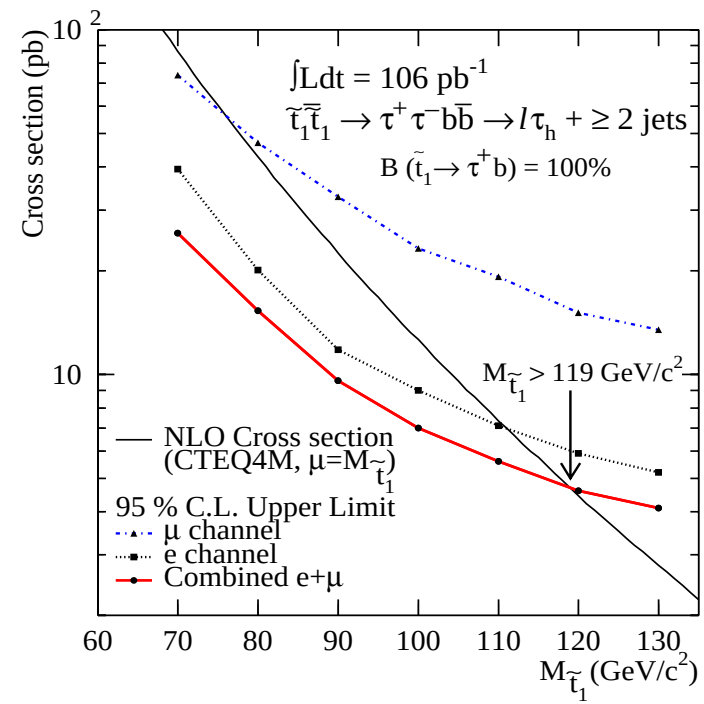
→ $e/\mu + \not{E}_T + \tau_h + (>=2)$ jets

- 0 observed

  $3.2^{+1.4}_{-0.3}$ expected dominated by $(Z \to \tau\tau)$+jets

- Limits:

$$M_{\tilde{t}} > 119\ \mathrm{GeV}/c^2$$



# Conclusions

- CDF has searched for new physics with various signatures
- No evidence for new physics ***yet***
- Searches for new physics/phenomena in Run II already have started.