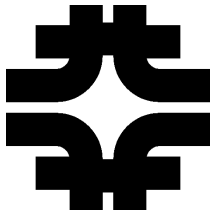

# Searches for New Phenomena in CDF


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*Padova University & INFN*

for the CDF Collaboration

**XVII Rencontres de Physique de la Vallee d'Aoste**

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LaThuile, Italy

# Outline

Accelerator and Detector Upgrades

Model Based Searches

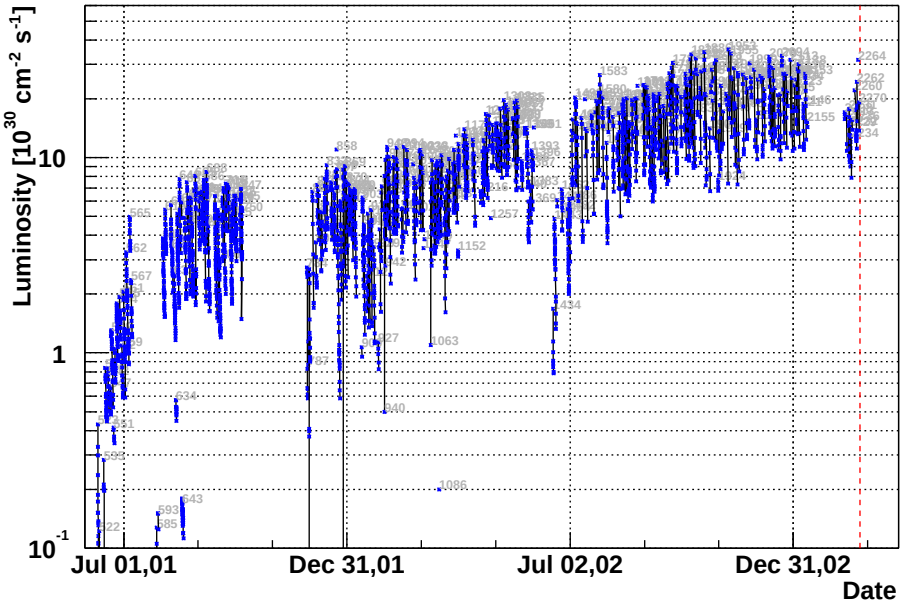
- ◇ New Gauge Bosons
- ◇ Extra Dimensions
- ◇ Leptoquarks
- ◇ Higgs
- ◇ Susy

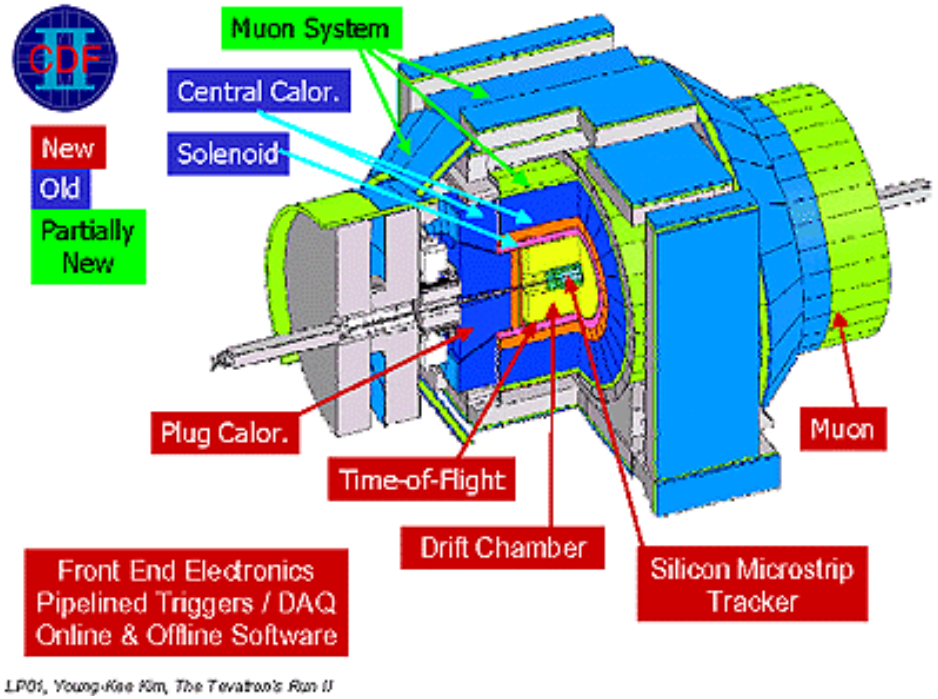
Signature Based Searches

- ◇ CHAMPs
- ◇ Dijet Mass Bump
- ◇ Missing $E_T$
- ◇ Photons
- ◇ Tau Leptons

## Accelerator Status

- $\sqrt{s} = 1.96\ TeV$
- $\mathcal{L} \sim 2 \div 3\ \times 10^{31}\ cm^{-2}s^{-1}$
- $\mathcal{L}^{int} = 180\ pb^{-1}$




LP01, Young-Kee Kim, The Tevatron's Run II

## Detector Upgrades

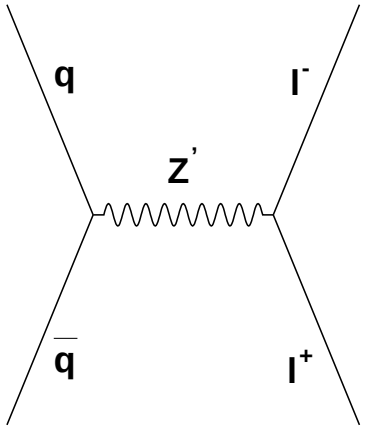
- New plug calorimeter and tracking chamber to faster response
- New silicon detectors:
  - 3-D reconstruction
  - tracking extended to $|\eta| = 2$
- Time-Of-Flight (TOF System)
- Extended Muon coverage ($|\eta| = 1. \rightarrow 1.5$)
- Renewed trigger and DAQ systems

# Drell-Yan Dilepton Production

High Mass Dileptons allow to search for new particle production:

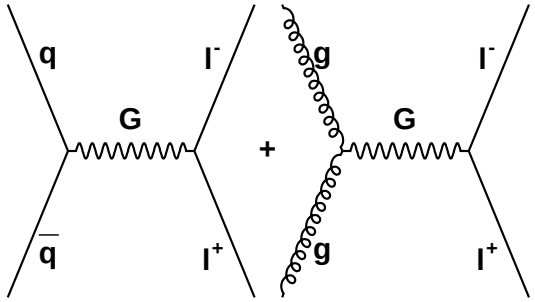
## New Neutral Gauge Boson $Z'$

- SM coupling assumed;




## Randall-Sundrum Graviton

- small extra-dimension solution to the hierarchy problem by means of a non-factorizable geometry;
- Excited graviton in 5 dimensions;
- Free parameters: mass $M_G$ and coupling $k/M_{PL}$;

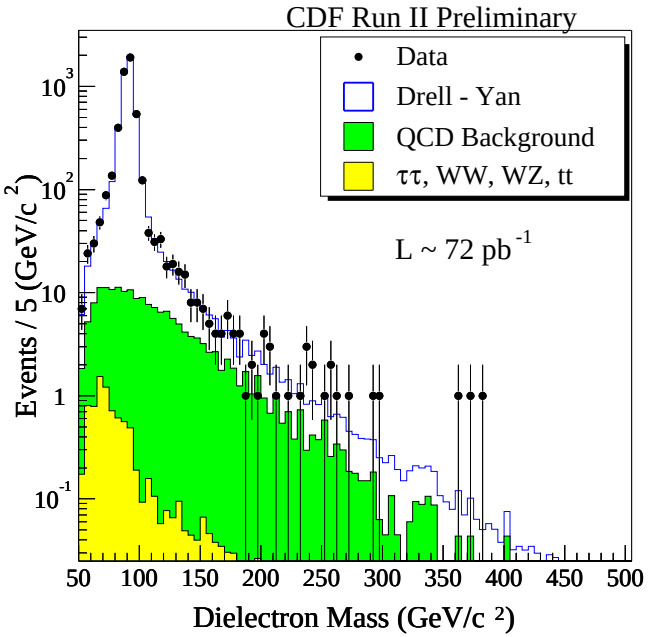


# Search for New Neutral Gauge Boson $Z'$ in Dielectron Channel

## Selection

- Drell-Yan production $q\bar{q} \rightarrow Z' \rightarrow e^+e^-$;
- one good central electron $E_T > 25\ GeV$;
- a second good central electron OR one good plug electron $E_T > 25\ GeV$;
- $\not\!\!E_T/\sqrt{\Sigma E_T} < 2.5$.

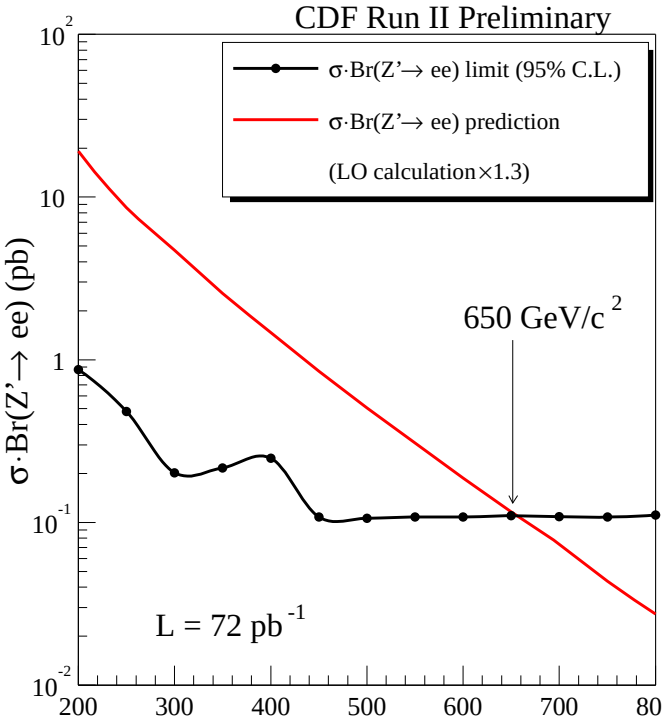
## Results ($72\ pb^{-1}$)




No Excess Observed

## Limit

(SM coupling assumed)

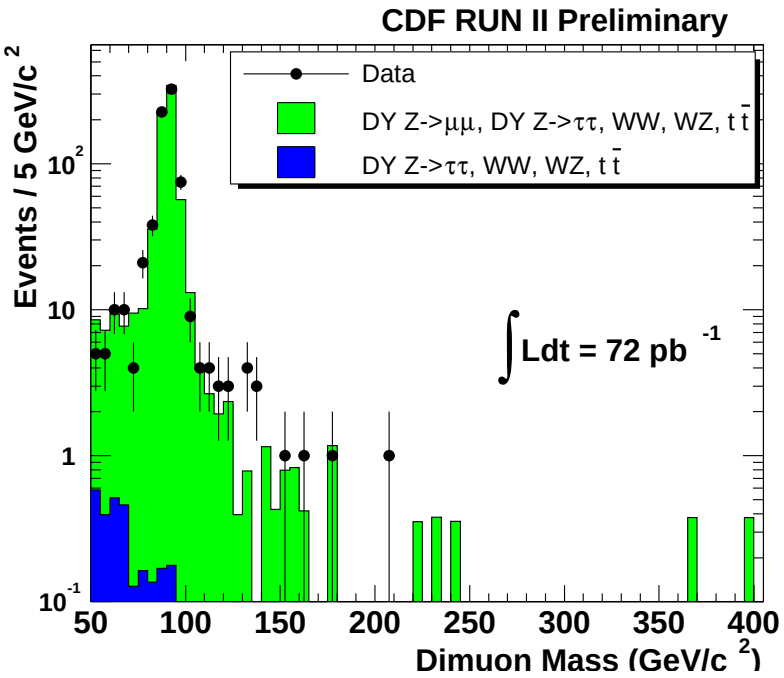


# Search for New Neutral Gauge Boson $Z'$ in Dimuon Channel

## Selection

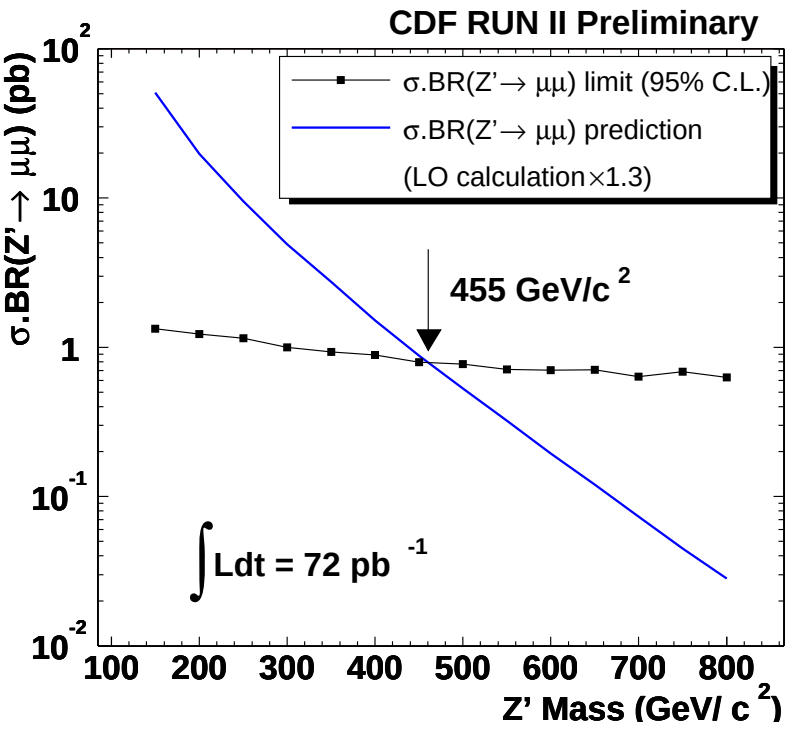
- two good muons $P_T > 20\ GeV/c$;
- cosmic ray rejection by vertex, impact parameter and timing cuts;
- QCD rejection: $\Sigma^{0.4}_{cal.\ tow.} E_T < 0.1 \cdot P_T$.

## Results ($72\ pb^{-1}$)



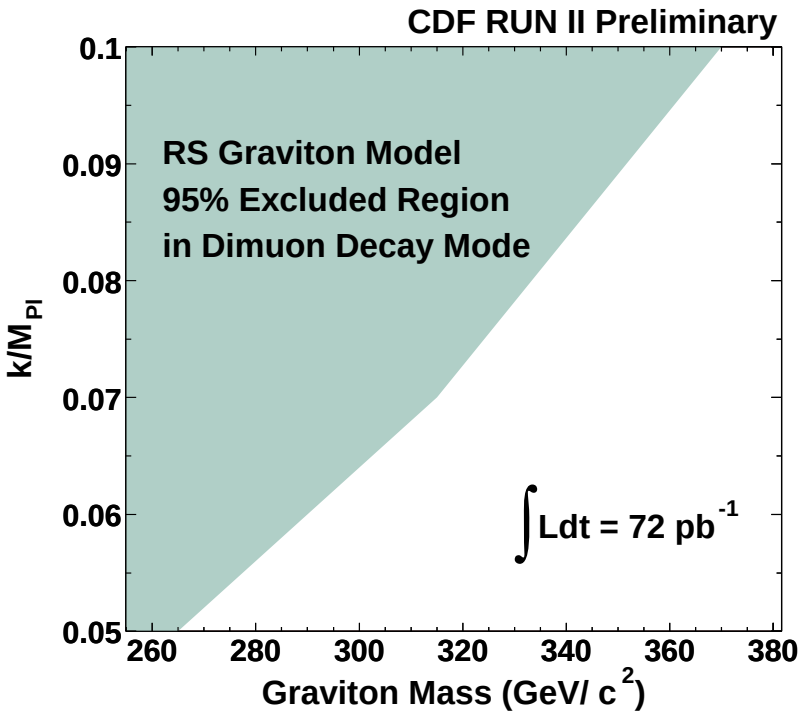

No Excess Observed

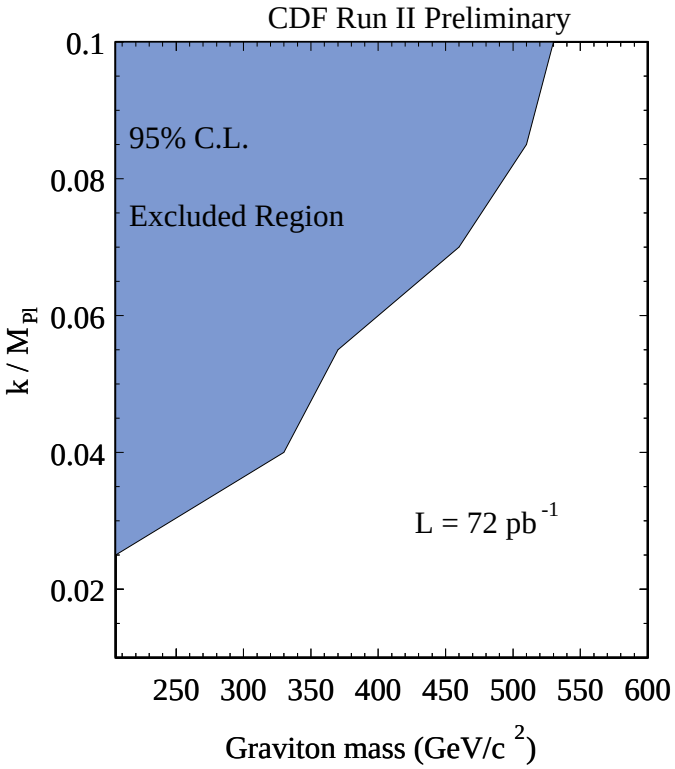
## Limit



# Results for Graviton Searches

Results for resonance searches in high mass dilepton used to set limits on Randall-Sundrum graviton too:



# Leptoquark Searches in Run II

Leptoquarks generally pair produced and decaying to $(lq)(lq)$, $(lq)(\nu q)$ or $(\nu q)(\nu q)$.

No generation mixing expected from FCNC constraints.

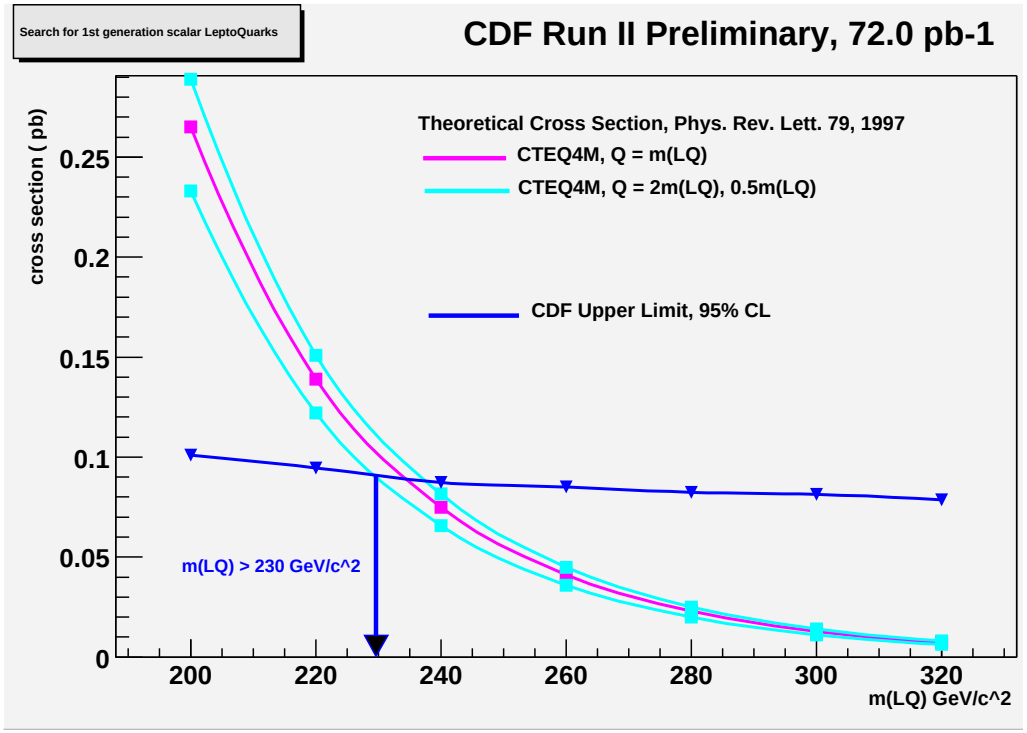
$\beta(LQ- > lq)$ model dependent.

A search for first generation leptoquark has been performed in dielectron+jets channel

## Selection

- inclusive electron triggers used ($72\ pb^{-1}$)
- Two central electron w/ $E_T > 25\ GeV$
- Two jets ($E_T^{j1} > 30\ GeV$,$E_T^{j2} > 15\ GeV$)
- events w/ $76 < M_{ee} < 110\ GeV/c^2$ removed for $Z \rightarrow e^+e^-$ rejection
- $E_T^{j1} + E_T^{j2} > 85\ GeV$
- $E_T^{e1} + E_T^{e2} > 85\ GeV$
- $\sqrt{((E_T^{j1} + E_T^{j2})^2 + (E_T^{e1} + E_T^{e2})^2)} > 200\ GeV$
- 0 events observed

## Limits




$M_{LQ} < 230\ GeV/c^2$ excluded (95% CL)

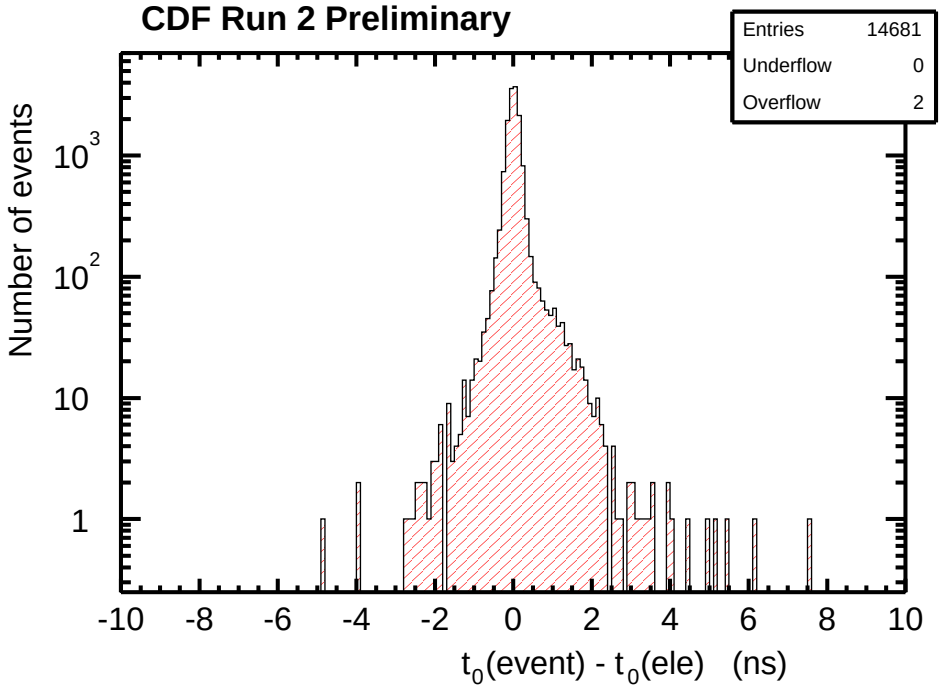
# CHArged Massive Particles

## Signature and Selection

- Long-lived particles escaping CDF detector $\Rightarrow$ look at high-$P_T$ muon triggers
- Isolated, slow moving $\Rightarrow$
  - $P_T > 40\ GeV/c$ to have full tracking efficiency for 100 $GeV/c^2$ CHAMPs
  - long time $-$ of $-$ flight through the detector

## Time Of Flight Measurements

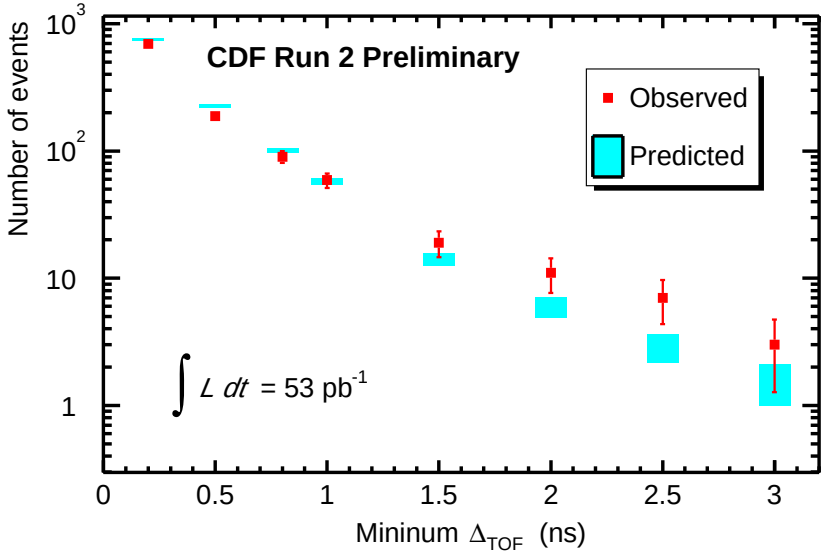
- Run II TOF system provides sensitivity to higher $\beta\gamma$ values than $dE/dx$
- Event $t_0$ from tracks w/ $P_T < 20\ GeV/c$
- Event $t_0$ tested with $W \rightarrow e\nu$ sample
- Look for track with high $TOF_{track} - t_0$

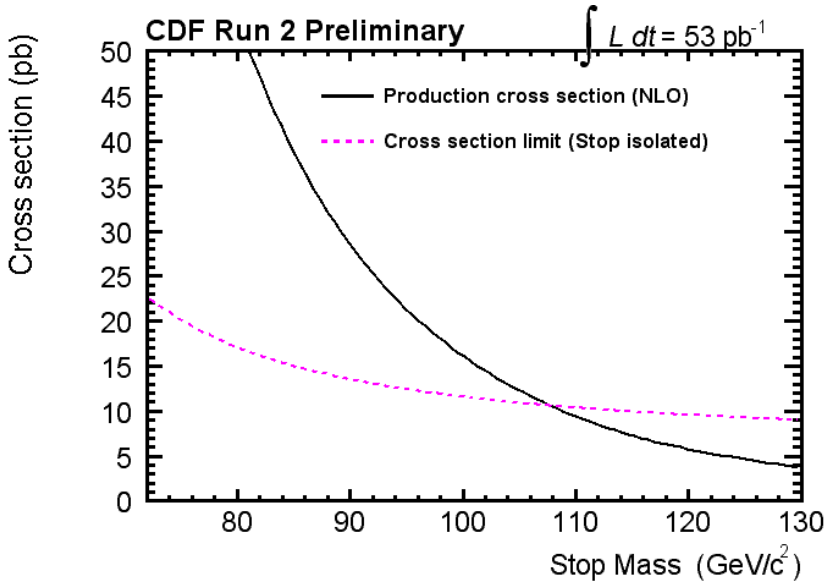


# CHArged Massive Particles

## Results

- Maximize probability of discovery: $TOF_{track} - t_0 > 2.5\ ns$;
- Background predictions from tracks with $20 < P_T < 40\ GeV/c$;
- Exp. $2.9 \pm 0.7$ (stat) $\pm 3.1$ (sys) events
- Observed 7 events



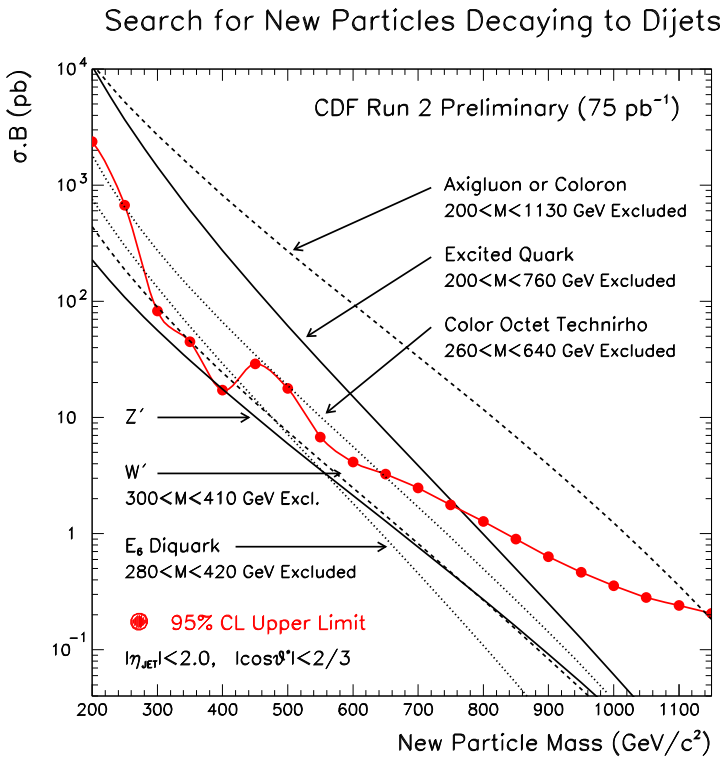

## Limits ($53\ pb^{-1}$)

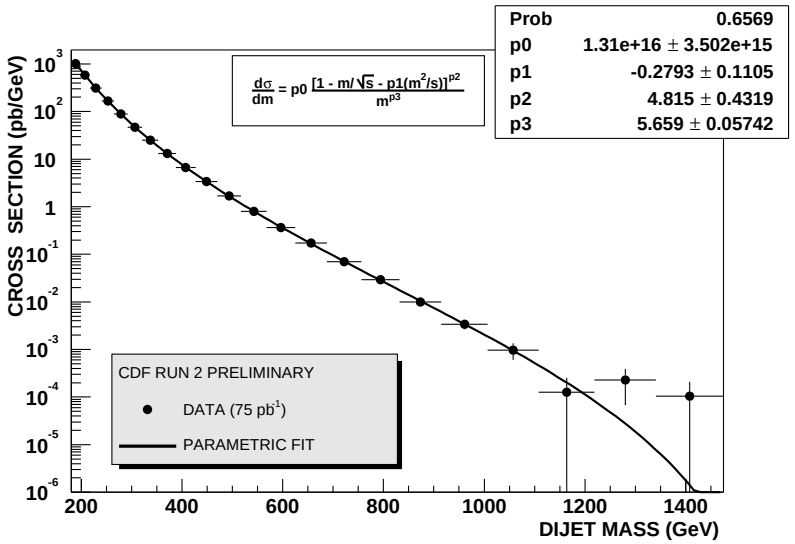
- stable stop model considered;
- NLO cross section ($\mu = M(t_1)$);
- $m_{\tilde{t}} < 107\ GeV/c^2$ excluded (95% CL);

# Dijet Mass Bumps

## Event Selection

- Inclusive jet samples ($75\ pb^{-1}$)
- Get two highest $E_T$ jets w/ $|\eta| < 2$ & $|tanh((\Delta\eta)/2)| < 2/3$
- No evidence for new particles




## Limits

95% CL excuded mass regions:

- Axigluon or Coloron: $200 < M < 1130\ GeV/c^2$
- Excited Quarks: $200 < M < 760\ GeV/c^2$
- E6 Diquark: $280 < M < 420\ GeV/c^2$
- Color Octet Technirho: $260 < M < 640\ GeV/c^2$
- Extra Gauge Boson $W'$: $300 < M < 410\ GeV/c^2$

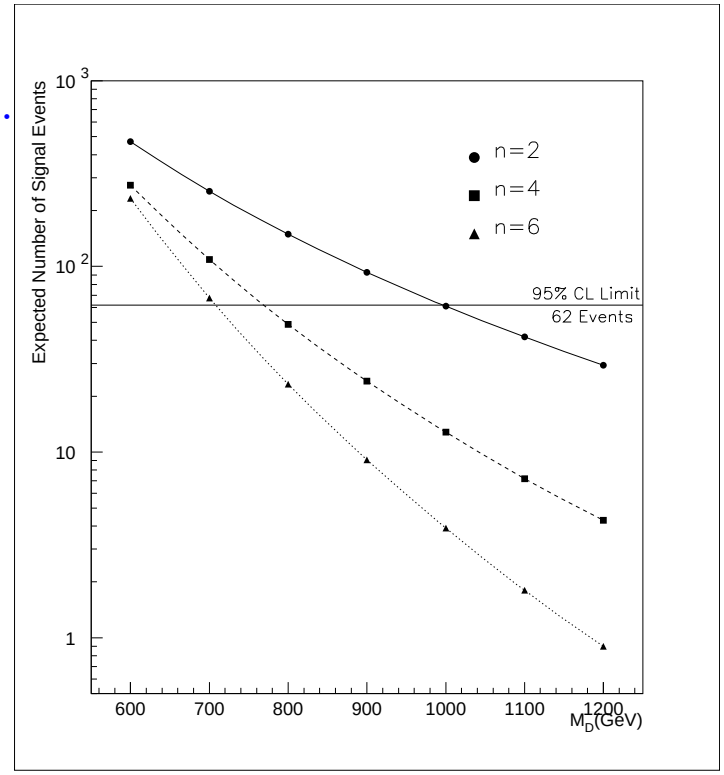
# Exclusive $\not\!\!E_T$+ Jet in Run I

## Model

- Extra dimensions provide solution to the hierarchy problem;
- Graviton propagates in $4+n$ dimensions;
- New effective Plank scale $M_D$: $M_{PL}^2 \sim R^n M_D^{2+n}$.

## Signature and Selection

- Graviton emission: $q\bar{q} \rightarrow gG$, $qg \rightarrow qG$, $gg \rightarrow gG$;
- Graviton escaping detector: $\not\!\!E_T > 80\ GeV$;
- Additional jet $\Delta\phi(jet - \not\!\!E_T) > 0.3$.
- Expected $274 \pm 16$ events (main from $Z \rightarrow \nu\bar{\nu}$)
- Observed 284 events.




| 95% CL Limits | $n = 2$ | $n = 4$ | $n = 6$ |
|---|---|---|---|
| $M_D$ | 995 $GeV$ | 768 $GeV$ | 707 $GeV$ |

# Inclusive Missing $E_T$ and Photon Searches in Run II

Several triggers implemented to study weakly interacting particle production...

- MET35+2JETS
  $\not\!\!E_T > 35\ GeV$ & 2 jets w/ $E_T > 10\ GeV$
- MET_BJET
  $\not\!\!E_T > 20\ GeV$ & 2 disp. tracks ($|d_0| > 100\ \mu m$)
- MET45
  $\not\!\!E_T > 45\ GeV$
- MET_L3PS100
  $\not\!\!E_T > 25\ GeV$ & prescale 100

...and new phenomena leading to photons in the final states

- INCLUSIVE PHOTON
  $E_T^\gamma > 25$ or 50 or 70 $GeV$
- DIPHOTON
  $E_T^\gamma > 12$ or 18 $GeV$
- TRIPHOTON
  $E_T^\gamma > 10\ GeV$
- PHOTON+B JET
  $E_T^\gamma > 10\ GeV$ & disp. track ($|d_0| > 120\ \mu m$)
- PHOTON+ MUON
  $E_T^\gamma > 16\ GeV$ & $P_T^\mu > 4\ GeV$
- PHOTON+ DIJET
  $E_T^\gamma > 18\ GeV$ & $E_T^{jet1} > 18$, $E_T^{jet2} > 10\ GeV$

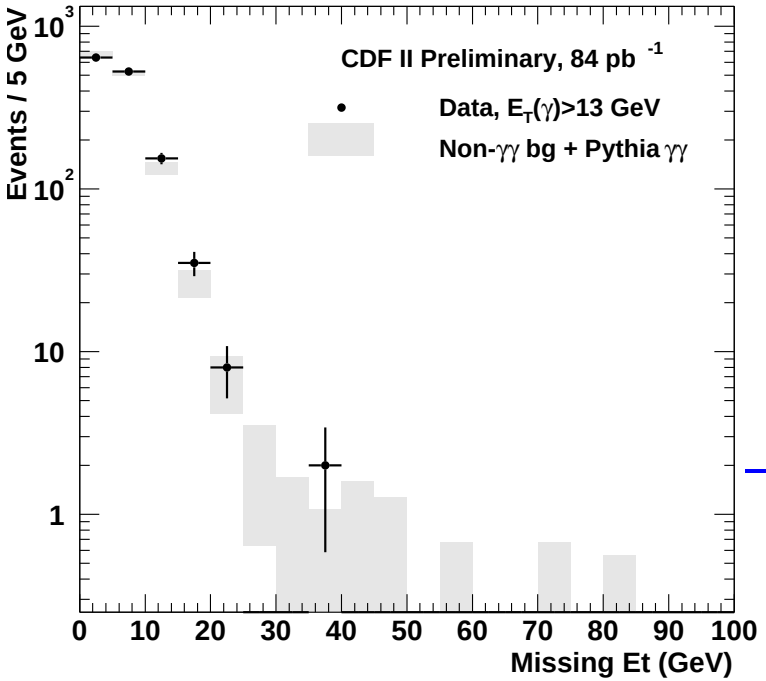
Large samples are being collected and tested

# Inclusive Diphoton Searches in Run II

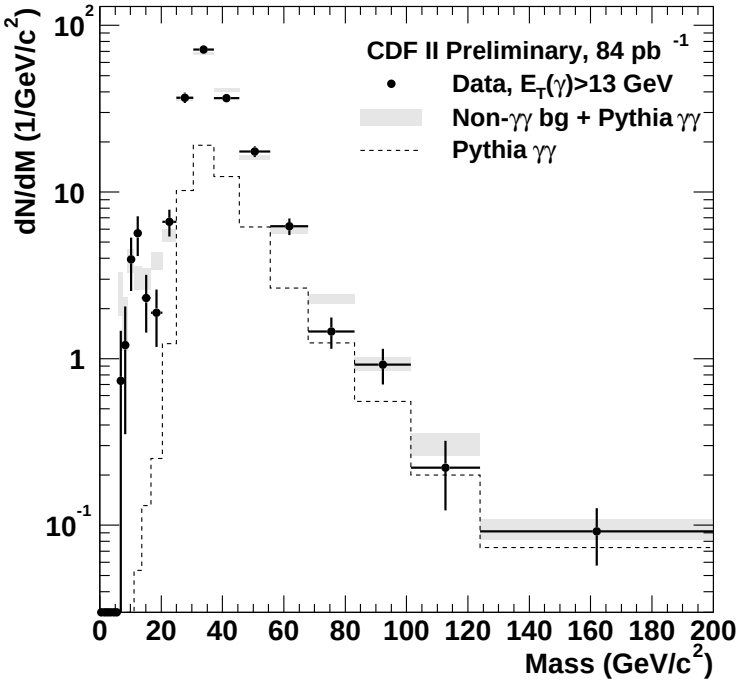
## Sample Selection ($84\ pb^{-1}$)

- Two central photon $E_T > 13\ GeV$;
- cosmic ray and beam halo rejection cuts
- Observed 1365 events
- Observed 95 events w/ $E_T^{\gamma} > 25\ GeV$

**Missing Et in Diphoton Events**



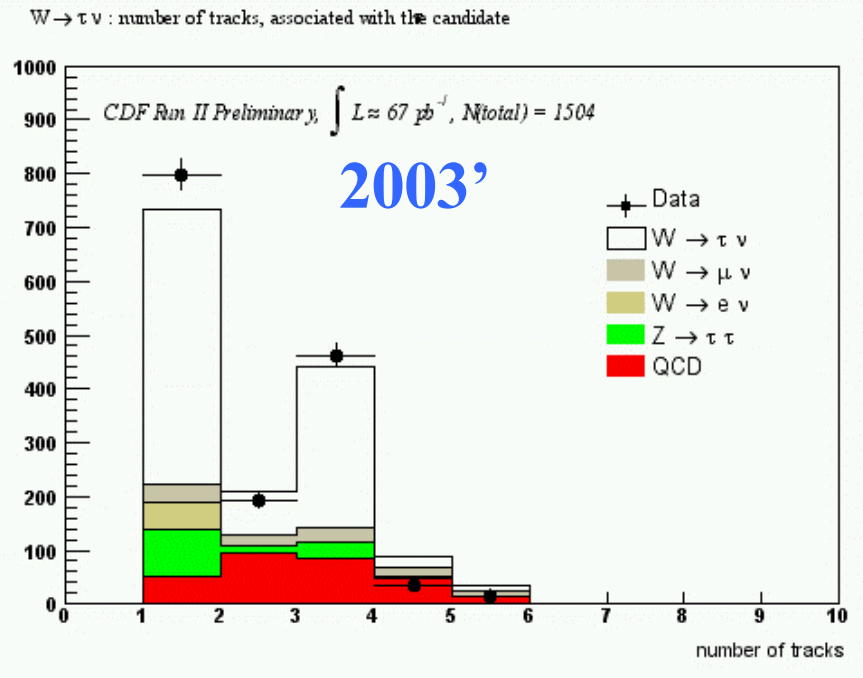

**Diphoton Mass**




## Diphoton + Lepton Events

| | Obs. | Exp. $E_T^{\gamma} > 13\ GeV$ | Exp. $E_T^{\gamma} > 25\ GeV$ |
|---|---|---|---|
| $e\gamma\gamma$ | 0 | $0.27 \pm 0.10 \pm 0.14$ | $0.04 \pm 0.03 \pm 0.02$ |
| $\mu\gamma\gamma$ | 0 | $0.04 \pm 0.007 \pm 0.02$ | $0.007 \pm 0.005 \pm 0.004$ |

# Tau Lepton Based Searches




## Detection of $\tau$ leptons

- Large cross sections into final states with $\tau$ for SUSY Higgs production ($tan\beta >> 1$)
- Implemented single tau and ditau triggers:
  - $\tau + \not{E}_T$ ($H^{\pm}$ searches)
  - $\tau_h + \tau_l$ $(l = e, \mu)$ ( $h^0, H^0, A^0$)
  - $\tau_h \tau_h$ ($h^0, H^0, A^0$)
- clear $W \rightarrow \tau\nu$ signal visible

Improved $\tau$ detection and reconstruction also offers interesting perspectives for SUSY searches like for example:

- $R$-parity violating stop decays $p\bar{p} \rightarrow \tilde{t}\bar{\tilde{t}} + X \rightarrow (b\tau^+)(\bar{b}\tau^-) + X$.
- Chargino-Neutralino searches $p\bar{p} \rightarrow W^{\pm} \rightarrow \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \rightarrow (\tau^{\pm}\nu\tilde{\chi}_1^0)(\tau^{\pm}\tau \mp \tilde{\chi}_1^0)$.

Results for these analyses expected for APS

# $R$-parity Violating Scalar Top Quarks (Run I Data)

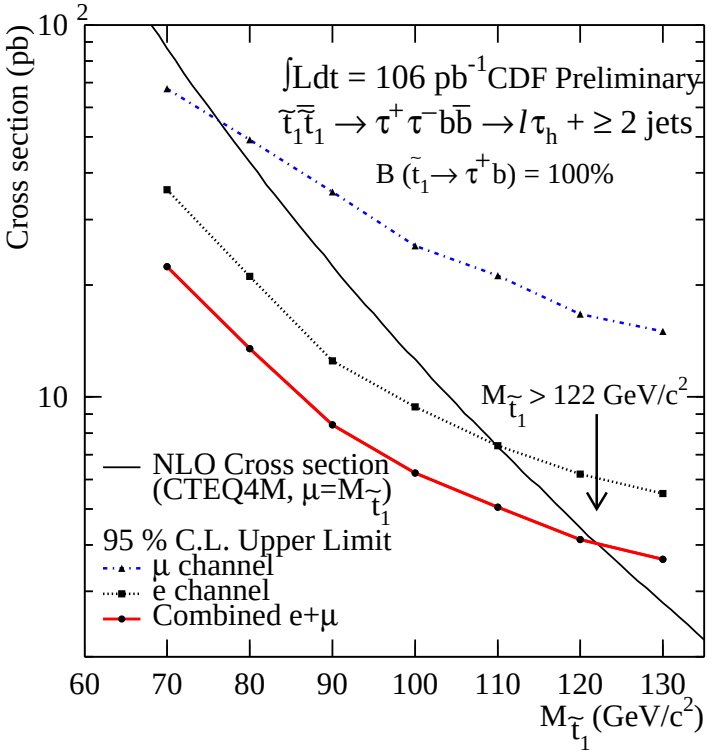
## Model

- $R$-parity conserving scalar top pair production;
- Stop decay via $\not{R}_P$ Yukawa interaction to $\tau b$;
- Look for the signatures $\tilde{t}\bar{\tilde{t}} \rightarrow \tau^+\tau^- b\bar{b} \rightarrow l\tau_h + \geq 2$ jets;

## Selection

- Opposite sign $l\tau$;
- $l\tau + \geq 2$ jets;
- $M_T(l, \not{E}_T) < 35\ GeV/c^2$;
- $\Sigma|P_T(l, \tau, \not{E}_T)| > 75\ GeV/c$;
- Expected $3.2^{+1.4}_{-0.3}$ events;
- Observed 0 events;
- Limit for $\beta(\tilde{t} \rightarrow b\tau) = 1$;

## Limits



# $R$-parity Violating Sneutrinos (Run I Data)

## Model

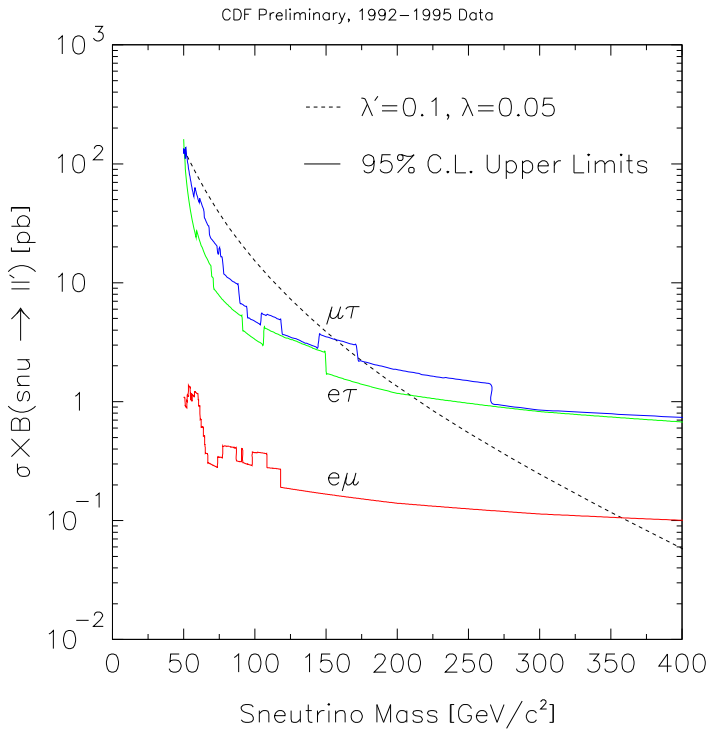
- Single $\tilde{\nu}$ production from $d\bar{d}$ annihilation via $\not{R}_P$ Yukawa interaction;
- Decay via separate $\not{R}_P$ Yukawa interaction to opposite sign leptons;
- Look for the signatures $\tilde{\nu} \to e\mu$, $\tilde{\nu} \to \tau\mu \to e\mu\nu\nu$, $\tilde{\nu} \to \tau e \to e\mu\nu\nu$;

## Selection

- $|z_{vertex}| < 60\ cm$;
- $\geq 1$ good $\mu$ w/ $P_T > 15\ GeV/c$;
- $\geq 1$ good $e$ with $E_T > 20\ GeV$;
- opposite sign & $\Delta\phi(e,\mu) > 120^o$;
- for $\tau$ channels : $\Delta\phi(l,\tau) < 60^o$;

| | $e\mu$ | $e\tau$ | $\mu\tau$ |
|---|---|---|---|
| Data | 19 | 4 | 12 |
| Bkg. | $20 \pm 1$ | $6.0 \pm 0.5$ | $9.6 \pm 0.8$ |

## Limits



# Search for Doubly-Charged Higgs

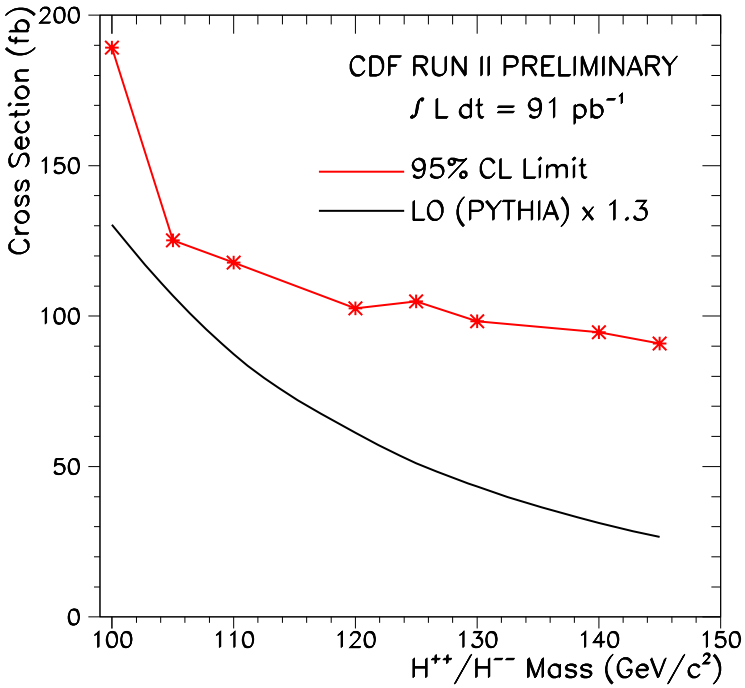
- Left-Right Symmetry breaking: $SU(2)_L \otimes SU(2)_L \otimes U(1)_{B_L} \rightarrow SU(2)_L \otimes U(1)_L$
- Higgs fields are a left-right doublet $\phi(1/2, 1/2, 0)$ and two triplets:

$$\Delta_{L,R} = \begin{pmatrix} \frac{1}{\sqrt{2}} H^+_{L,R} & H^{++}_{L,R} \\ H^0_{L,R} & \frac{-1}{\sqrt{2}} H^+_{L,R} \end{pmatrix}$$

- Light neutrino masses successfully predicted via see-saw mechanism!
- Supersymmetric models suggest low mass doubly charged Higgs

## $H^{++}$ Properties and Selection

- Pair ($Z$ exchange) or singly ($WW$ fusion) produced in $p\bar{p}$ collisions
- Same-sign leptons decay mode providing strong experimental signature
- Inclusive electron trigger used (91 $pb^{-1}$)
- Two central same-sign electrons required
- $M_H \pm 10\%$ dielectron mass windows explored



# Conclusions

- CDF detector is collecting data from March 2001
- Run II searches for new phenomena have started
- First limits using dileptons and dijet mass spectra have been already set for various phenomena
- Specific theories beyond the Standard Model have been tested
- New Time-Of-Flight system has been exploited to search for CHAMPS
- Results are already improving Run I ones
- Larger samples are being collected and tested for searches based on $\tau$ lepton, Missing $E_T$ and photon signature
- High integrated luminosity will provide the best opportunity for new physics discoveries until LHC starts to run.