Non-SM Electroweak Symmetry Breaking Searches at the Tevatron

19th International Workshop on
Weak Interactions & Neutrinos

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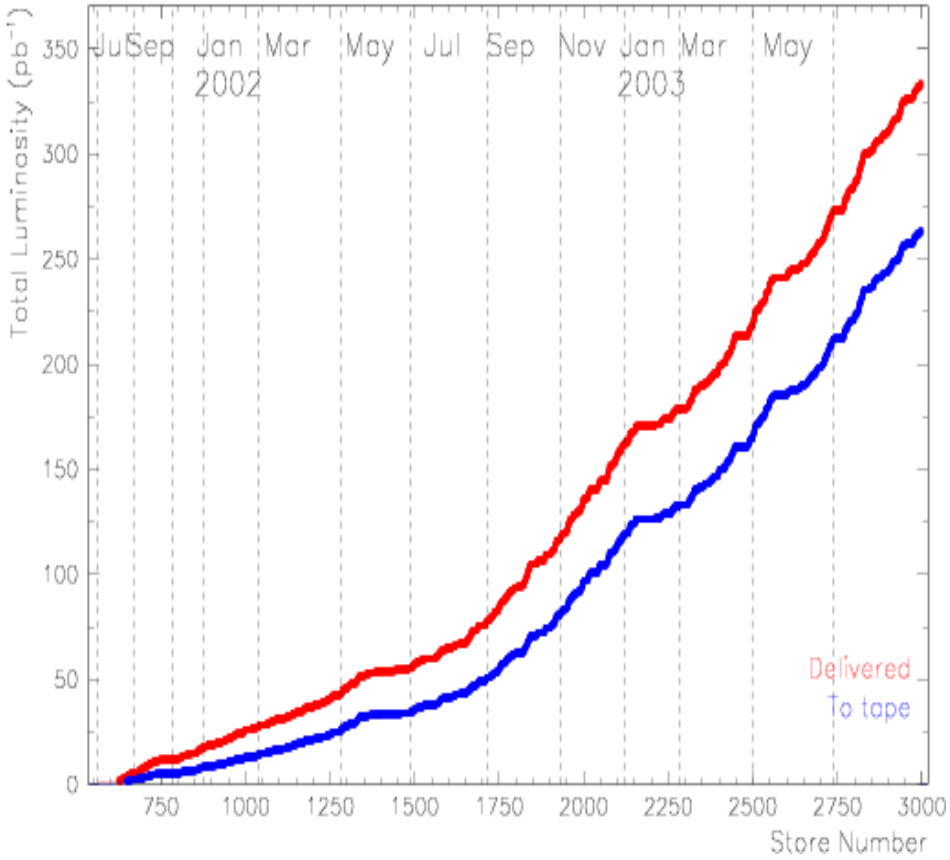
for the CDF Collaboration

Outline :

- CDF, Run-I and Run-II
- Review results on CDF searches for Non-SM Electroweak Symmetry Breaking
- Summary

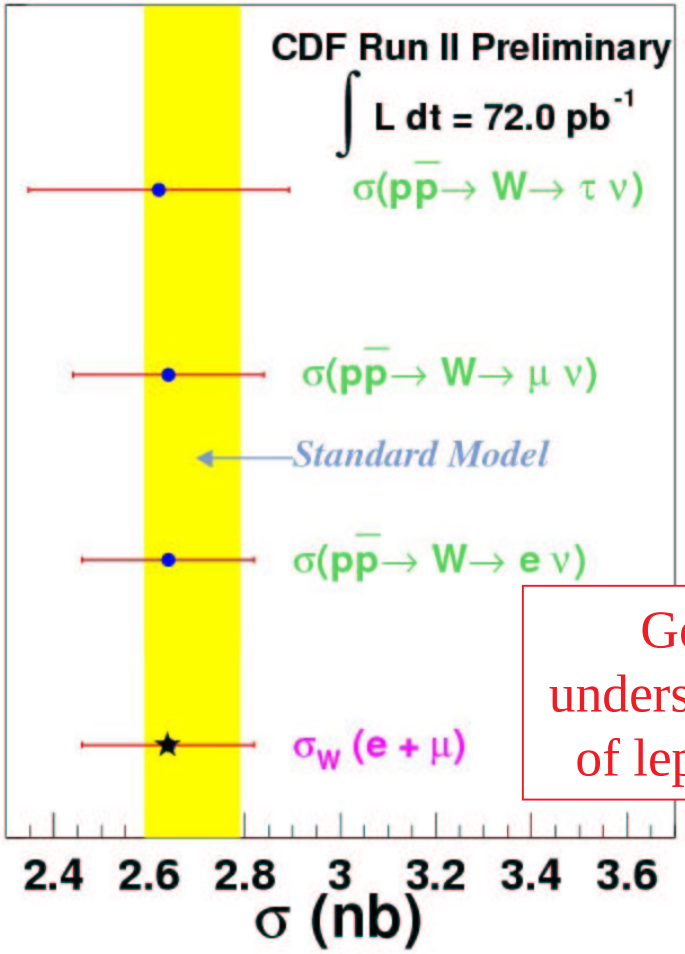
CDF in Run-I and Run-II

- In Run-I (1992-1996) CDF used ~100pb^{-1} data to investigate electroweak symmetry breaking in SM/Non-SM approach
  - Applied several important tools for these studies
    - $e/\mu/\tau$ identification
    - Good calorimetry for jet/MET measurements
    - Tagging b,c jets
- Run-II upgrades :
  - New data acquisition electronics to cope with higher luminosity
  - Extend lepton acceptance
  - Larger geometrical acceptance for silicon tracker
- Have collected ~200pb^{-1} data

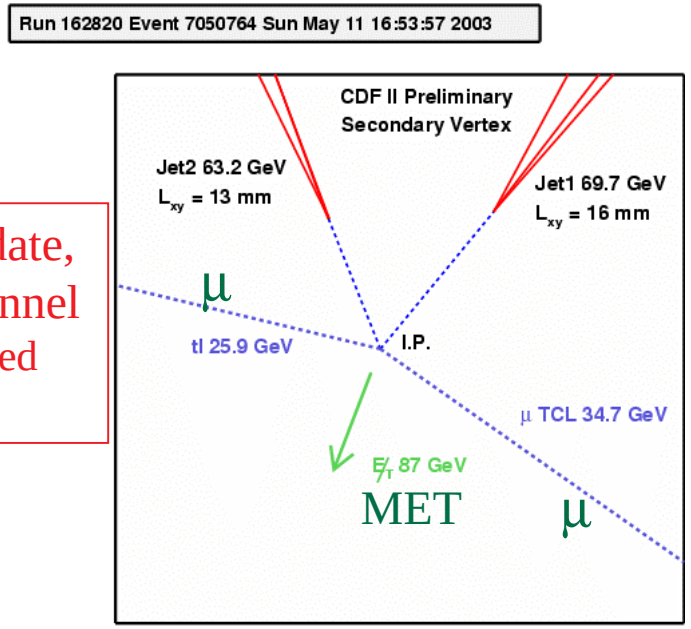


Understanding the Run-II Detector

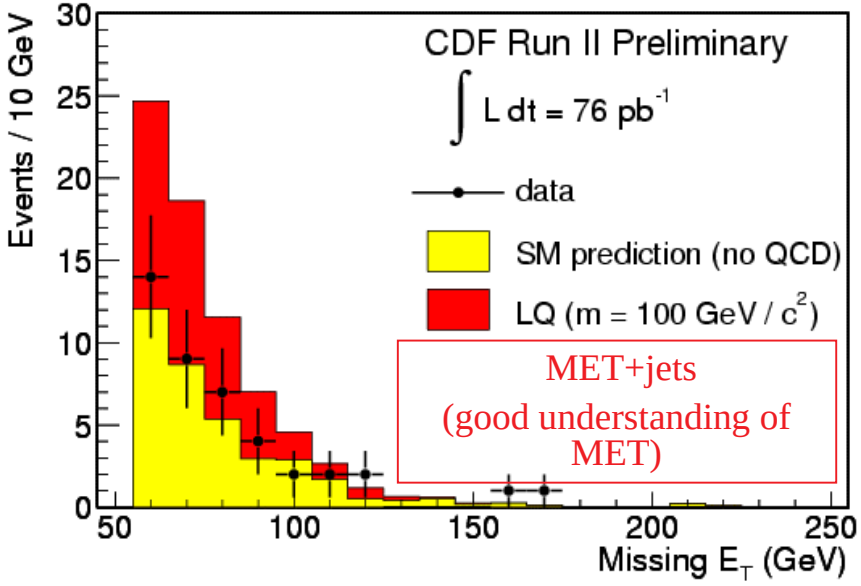
- Have made baseline measurements to demonstrate the level of understanding of our new detector and the new operating enivronment



Good understanding of lepton Id



t-tbar candidate, di-lepton channel (two displaced vertices)



MET+jets (good understanding of MET)

Non-SM Electroweak Symmetry Breaking

Several models created to solve the hierarchy problem, and to explain the origin of EW symmetry breaking

- Extra Dimensions
- Technicolor
- SUSY/MSSM
- Little Higgs

Review CDF results on searches for the predicted phenomena based on these models

Searches for Extra Dimensions

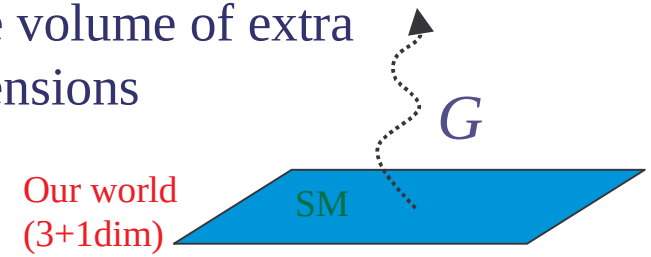
Extra Dimensions (ED)

- The large gap between EW and Planck scales is assumed to be due to the geometry of the extra dimensions
- The gap is narrowed by reducing the effective fundamental scale to ~ 1 TeV
- Only Graviton propagates in the ED, other SM particles are trapped in our 3-D brane
- In the compactified ED, the gravity expands into a series of Kaluza-Klein (KK) states

Large Extra Dimensions (ADD) Model

("ADD" => Arkani-Hamed, Dimopoulos, and Dvali)

- Hierarchy between EW and Planck scales is generated by large volume of extra dimensions



(for M_D~1TeV, n=2 => R_c~mm)

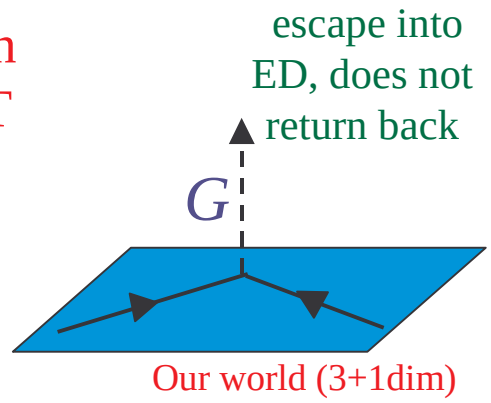
- Gravity propagates freely in ED
- $M_{Pl}^2 \sim R_c^n M_D^{2+n}$
  - M_{Pl}: Planck scale
  - R_c : radius of ED
  - M_D: new effective fundamental scale
  - n : # extra dimensions

Search for ADD ED at Tevatron

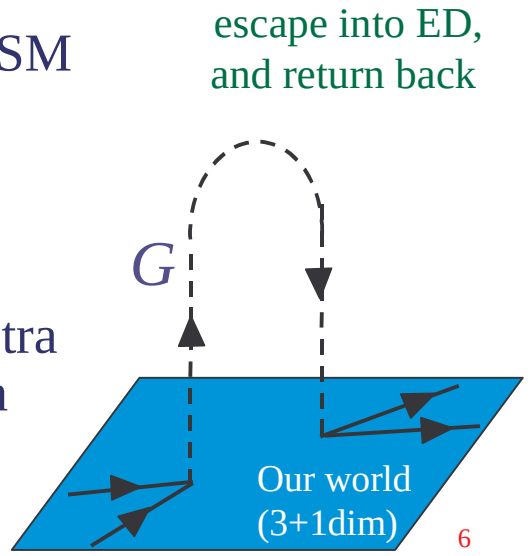
- **Direct G emission :**

$q\bar{q} \rightarrow \gamma G$ } Photon +MET

$q\bar{q} \rightarrow Gg$
$qg \rightarrow Gq$
$gg \rightarrow Gg$ } jet+ MET

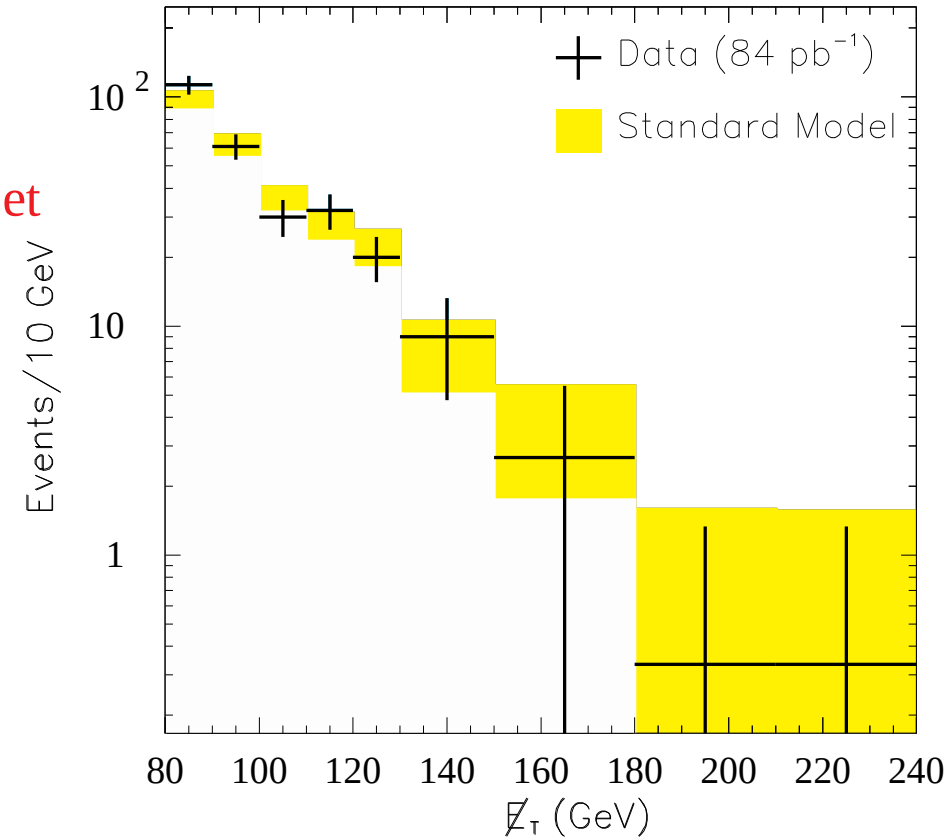


- **Virtual G exchange :**
  - $q\bar{q} \rightarrow l^+l^-, q\bar{q}, \gamma\gamma$
  - contribute to normal SM scattering amplitude
  - Enhancement tail in ee/μμ/jj spectra
  - No resonance in spectra because KK spectrum uniformly spaced => continuous spectrum



Searches for Extra Dimensions (ADD)
Direct *G* Emission (MET+jet)

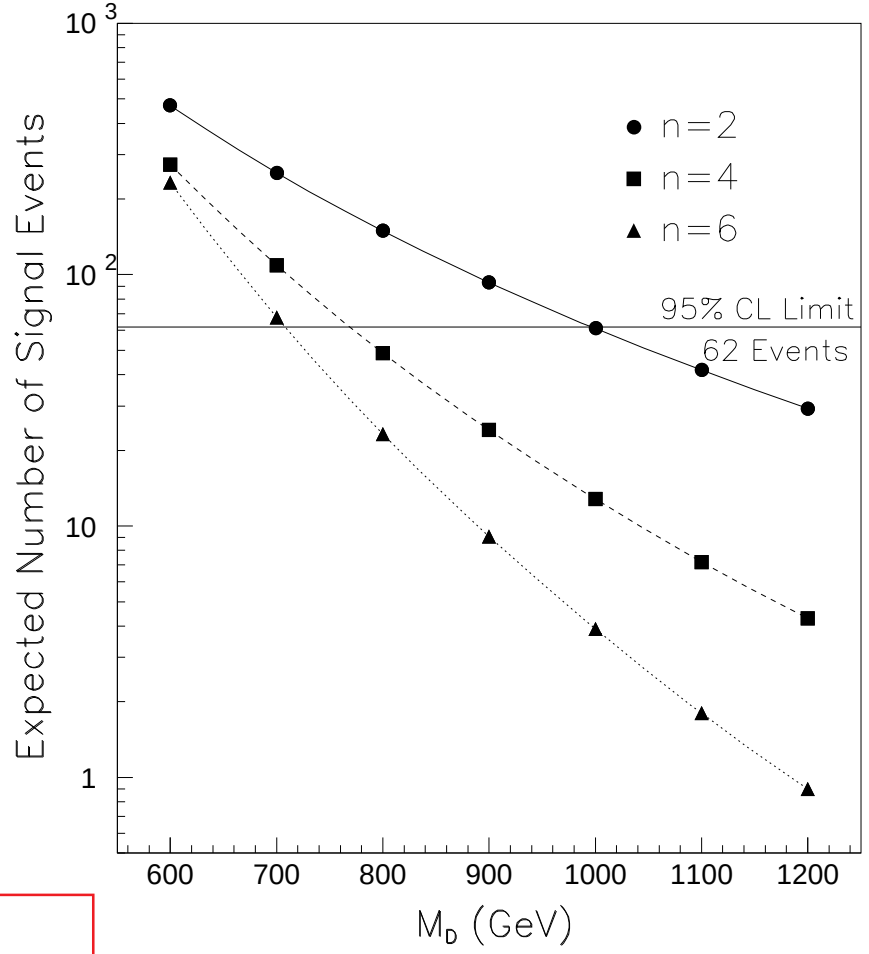
- Search events with large MET and 1 or 2 jets
  - MET > 80 GeV
  - Et(jet1) > 80 GeV, Et(jet2) > 30 GeV (if 2nd jet present)
- Reduce QCD multi-jets :
  - $\Delta\phi$(MET,jets) > 0.3 rad (MET due to jet energy mis-measurement)
- Reduce W($\rightarrow l\nu$), Z($\rightarrow l^+l^-$) :
  - Two highest energy jets not purely electromagnetic
  - No isolated track
- Remaining background from:
  - Z($\rightarrow\nu\nu$)+jets, W($\rightarrow l\nu$)+jets (l : e,μ,τ)
  - QCD
  - tt, single t, diboson
- #Observe=284, #Expected=274.1 +- 15.9



Searches for Extra Dimensions (ADD)
Direct *G* Emission (MET+jet)

- No excess in observed events, thus excluded effective Planck scale (M_D)

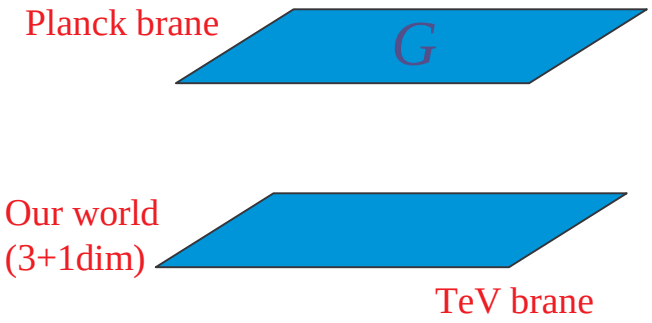
	M_D(TeV)		
n	CDF (K=1.0)	D0 (K=1.0)	D0 (K=1.34)
2	1.00	0.89	0.99
4	0.77	0.68	0.73
6	0.71	0.63	0.65



Best limit from the Tevatron on search for direct graviton emission

Randall-Sundrum (RS) Model

- Hierarchy between EW and Planck scales is generated by a large curvature of the extra dimensions

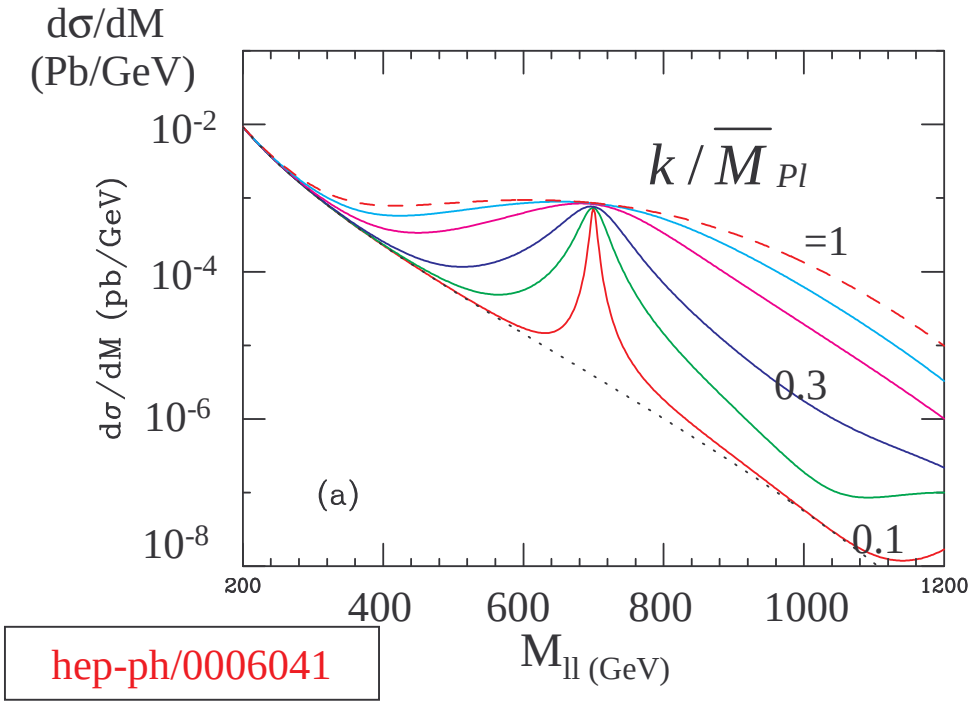


- *G* is localized in the Planck brane
- The scale of physical phenomena on the TeV brane is $\Lambda_\pi = M_{Pl} e^{-kR_c\pi}$

k: parameter governs the degree of curvature

Search for RS ED at Tevatron

- Virtual *G* exchange :
  - Virtual contribution to scattering processes
  - Spectrum of KK states are discrete, and unevenly spaced
  - Look for bumps in M_{ee}, $M_{\mu\mu}$, M_{jj}



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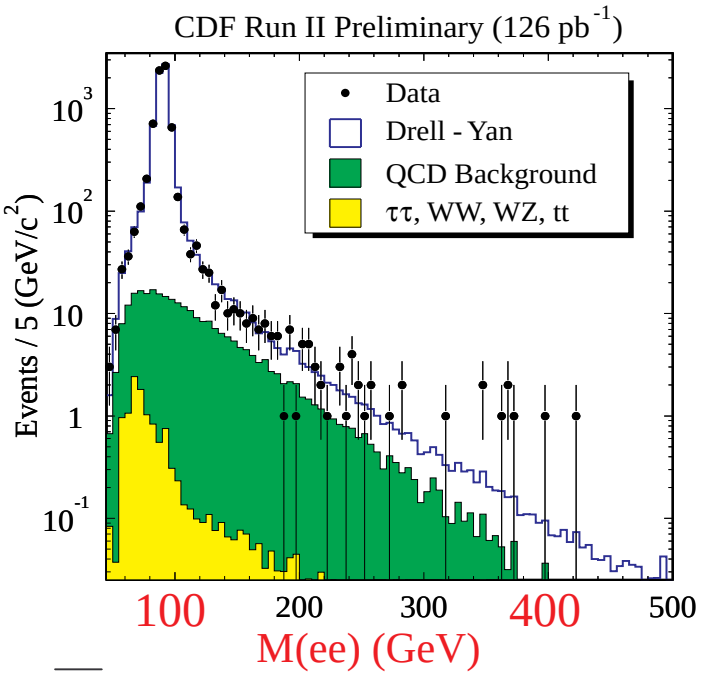
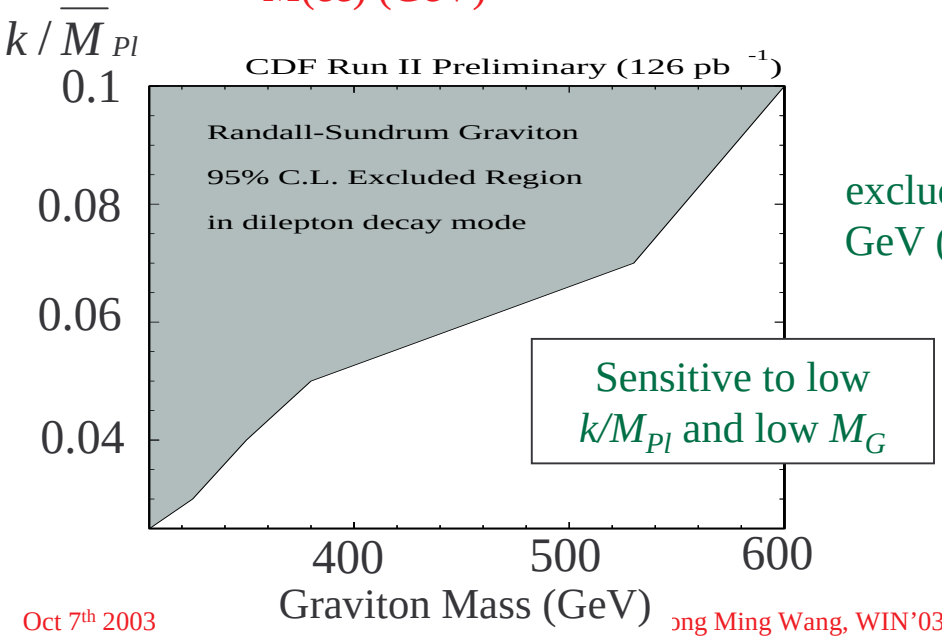
Searches for Extra Dimensions (RS) (Di-lepton)

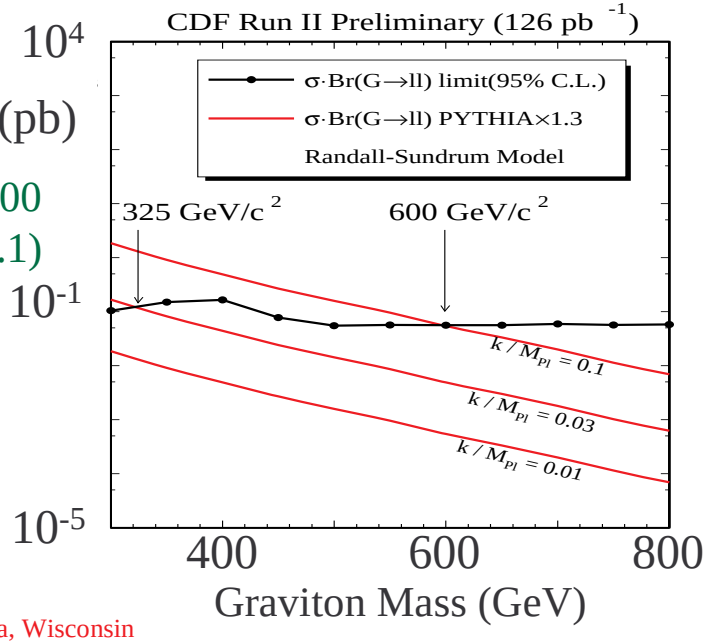


- Using Inclusive high Pt $e(\mu)$ data sample, select events w/ 2 energetic lepton candidates, Et>25 GeV (Pt>20 GeV)
- Reconstruct invariant mass (M_{l+l-}) to search for resonance at high mass
- Observe no excess at high mass in e^+e^- and $\mu^+\mu^-$
- Combine e and μ results to set limits for Randall-Sundrum model



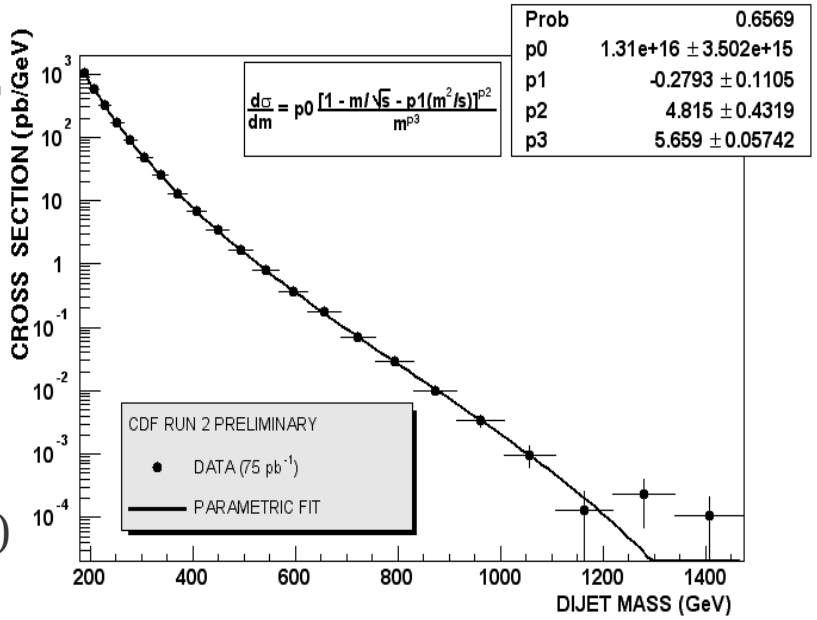
exclude M_G<600 GeV (k/M_{Pl}=0.1)

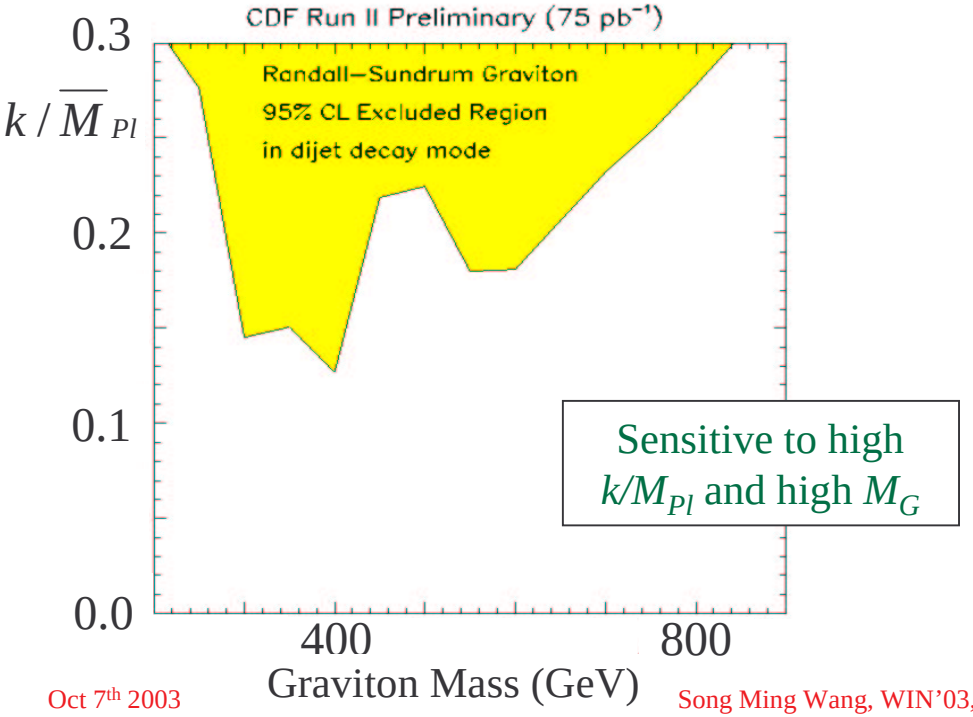
Sensitive to low k/M_{Pl} and low M_G



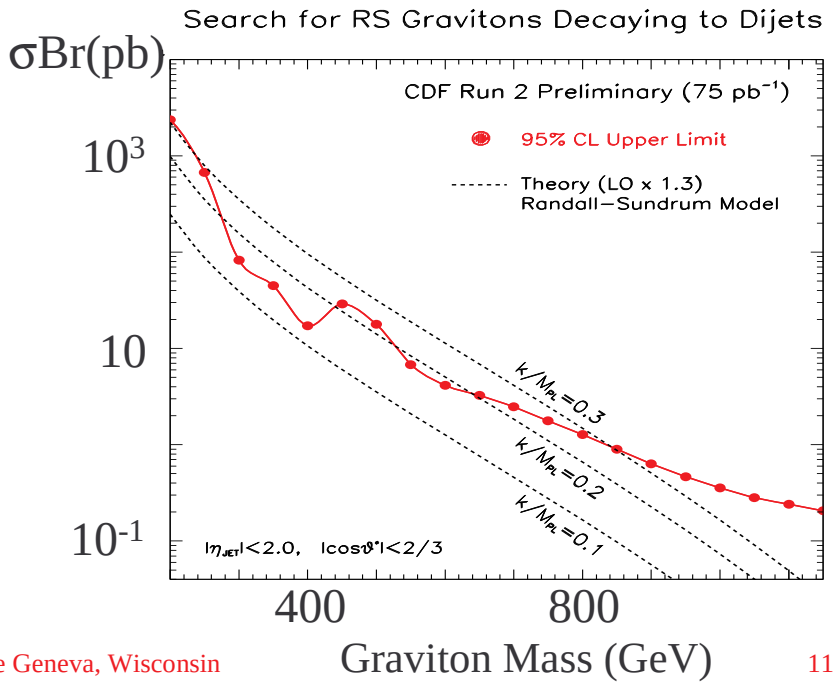
Searches for Extra Dimensions (RS) (Di-jet)

- Look for SM deviation in the inclusive jet sample (75 pb^{-1})
- Select two highest Et jets in event with $|\eta_{jet}|<2$
- Observe no resonance in the di-jet mass spectrum
- Set 95% CL excluded regions
  - Randall-Sundrum *G*: 220<M<840 GeV ($k / \overline{M}_{Pl}$=0.3)





Sensitive to high k/M_{Pl} and high M_G



Searches for Technicolor

- Technicolor is a dynamic version of the Higgs mechanism, does not contain elementary scalar boson
- Introduce a new strong gauge force (technicolor) and new fermions (technifermions)
- Technicolor acts between technifermions to form bond states
- "Higgs" boson replaced by states of two techniquarks (technipion)

Previous CDF searches:

- $\omega_T \to \gamma\pi_T^0 \to \gamma b\bar{b}$
- $\rho_T \to \pi_{LQ}\bar{\pi}_{LQ} \to \tau^+\tau^- b\bar{b}$
  $\to c\bar{c}\nu\nu$
  $\to b\bar{b}\nu\nu$

$\rho_T^{\pm} \to W^{\pm}\pi_T^0 \to l\nu b\bar{b}$

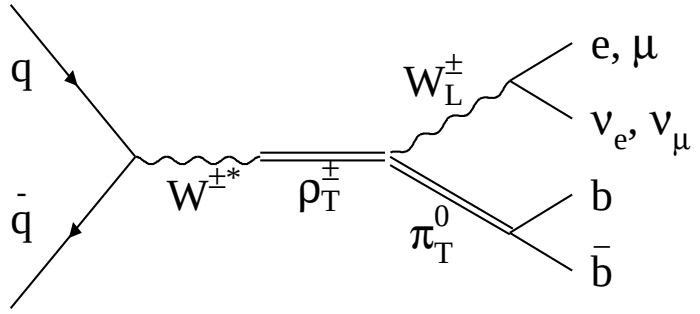
$\rho_T^0 \to W^{\pm}\pi_T^{\pm} \to l\nu b\bar{c}$

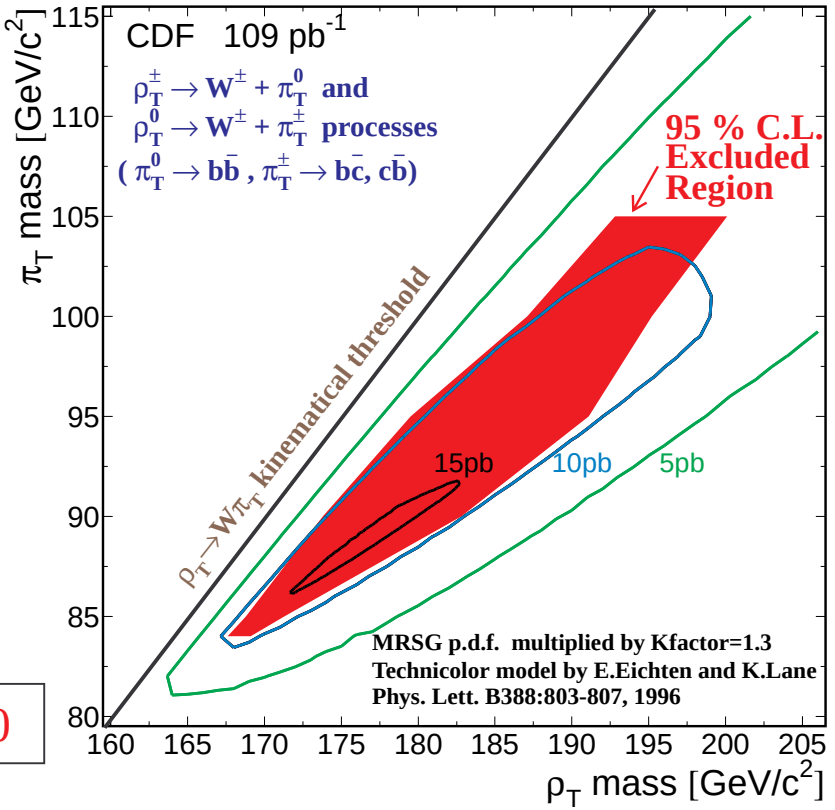
π_T expect to have Higgs boson like coupling to ordinary fermion, => perfer couple to 3rd gen. fermions

→ Describe this analysis next

Searches for Technicolor (Lepton+MET+jets)

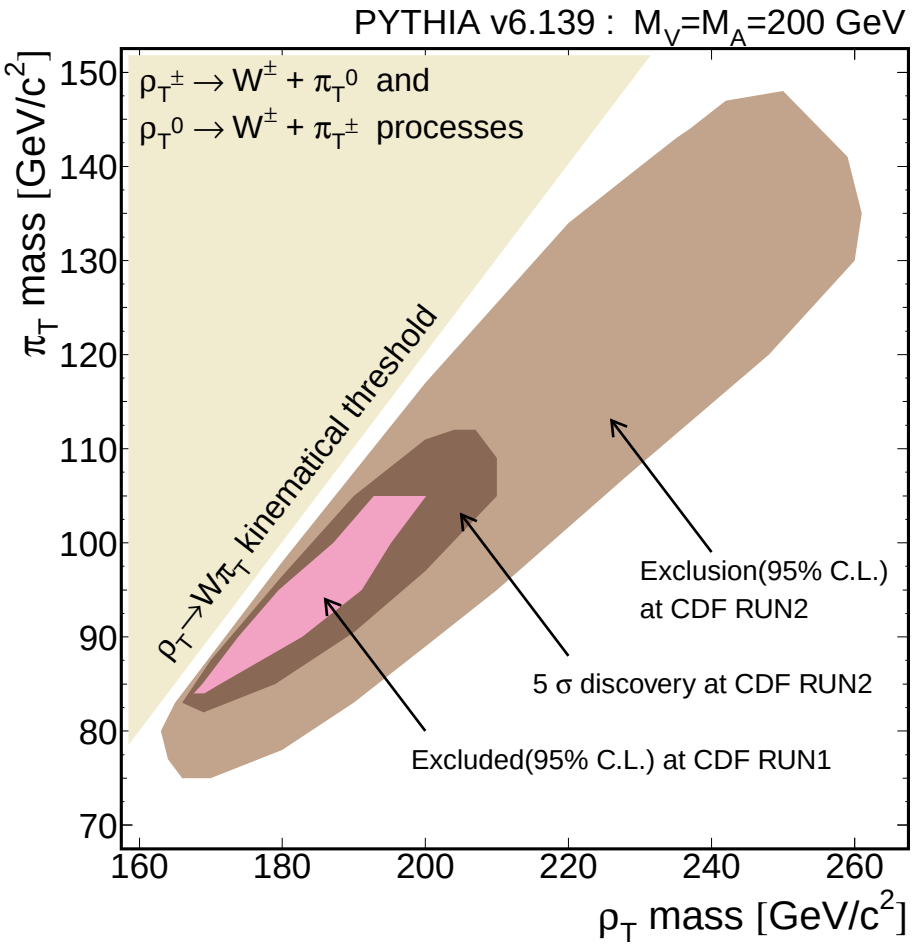
- Search for color singlet ρ_T and π_T in lepton (e or μ) + MET + jets
- Select isolate e (Et>20 GeV) or isolate μ (Pt>20 GeV) in central region ($|\eta|<1$)
- MET>20 GeV
- Only 2 jets, Et>15 GeV, $|\eta|<2$, at least one jet tagged as b-jet candidate
- Major background from:
  - $Wb\bar{b}$, $Wc\bar{c}$, Wc
- Set 95% CL exclusion region in $M(\pi_T)$ vs $M(\rho_T)$ plane





PRL,84,1110

Run-II Technicolor Sensitivity (Lepton+MET+jets)



- Predicted reach for L~2fb^{-1}
- Assume the same selections and systematic uncertainty as in Run-I search, but double signal efficiency (due to larger coverage in lepton id, and b-jet tagging)

hep-ph/0007304

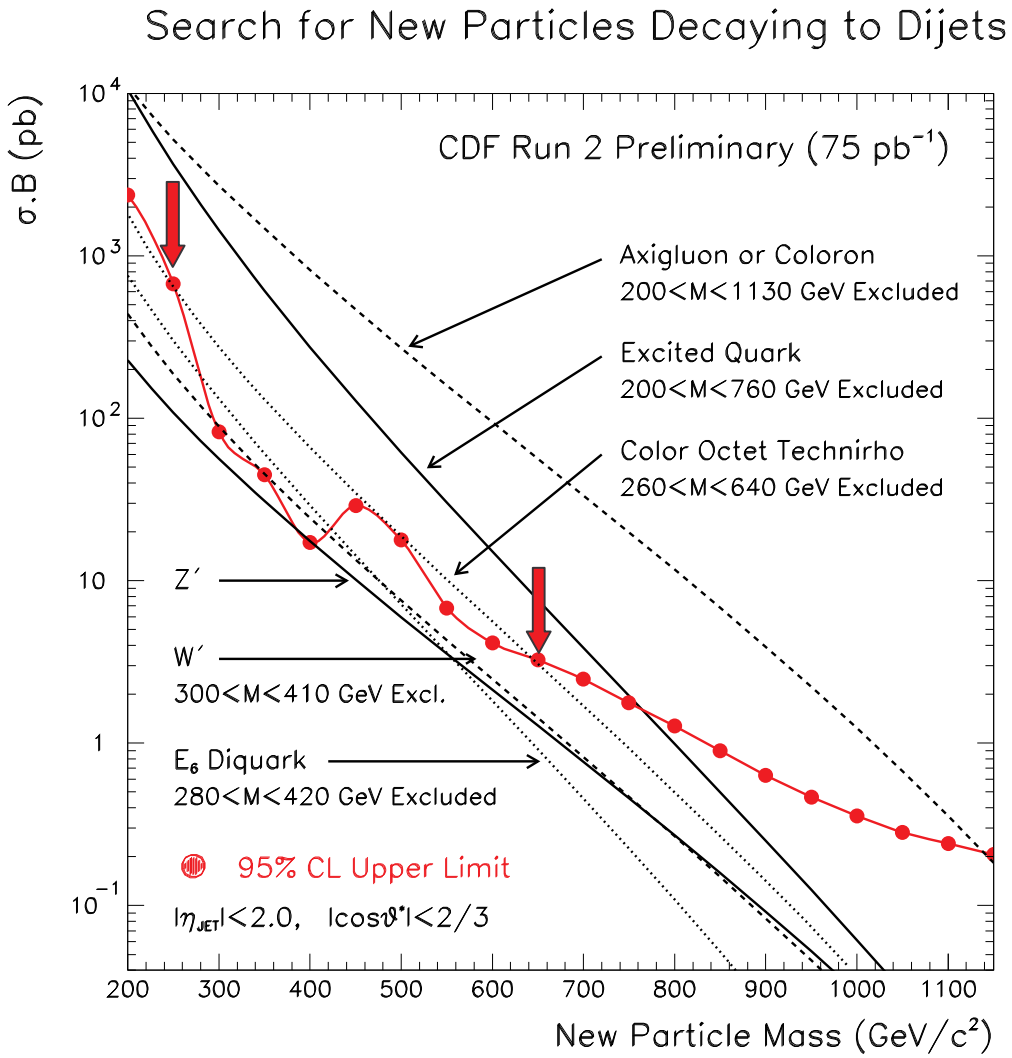
Searches for Technicolor (Di-jet)

Di-jet

- Use results from the search for resonance at high di-jet mass to set limits for the mass of Color Octet Technirho

Exclude the mass range:
260<M<640 GeV (Run-II)

CDF Run-I exclusion:
260<M<480 GeV



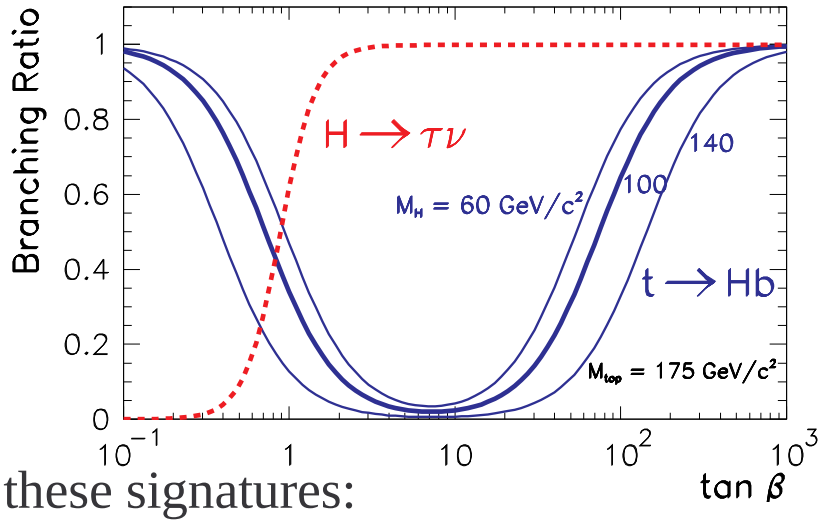
Searches for Non-SM Higgs

Results on CDF searches for :

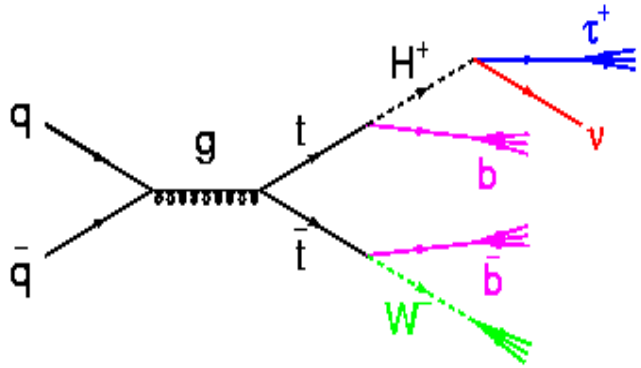
- Higgs from SUSY/MSSM
- Double Charged Higgs

Searches for Charged Higgs (MSSM)

- If $m_{H^+} < m_t - m_b$, then $t \to H^+ b$
- BR($t \to H^+ b$) depends on tan(β)



Direct Search:



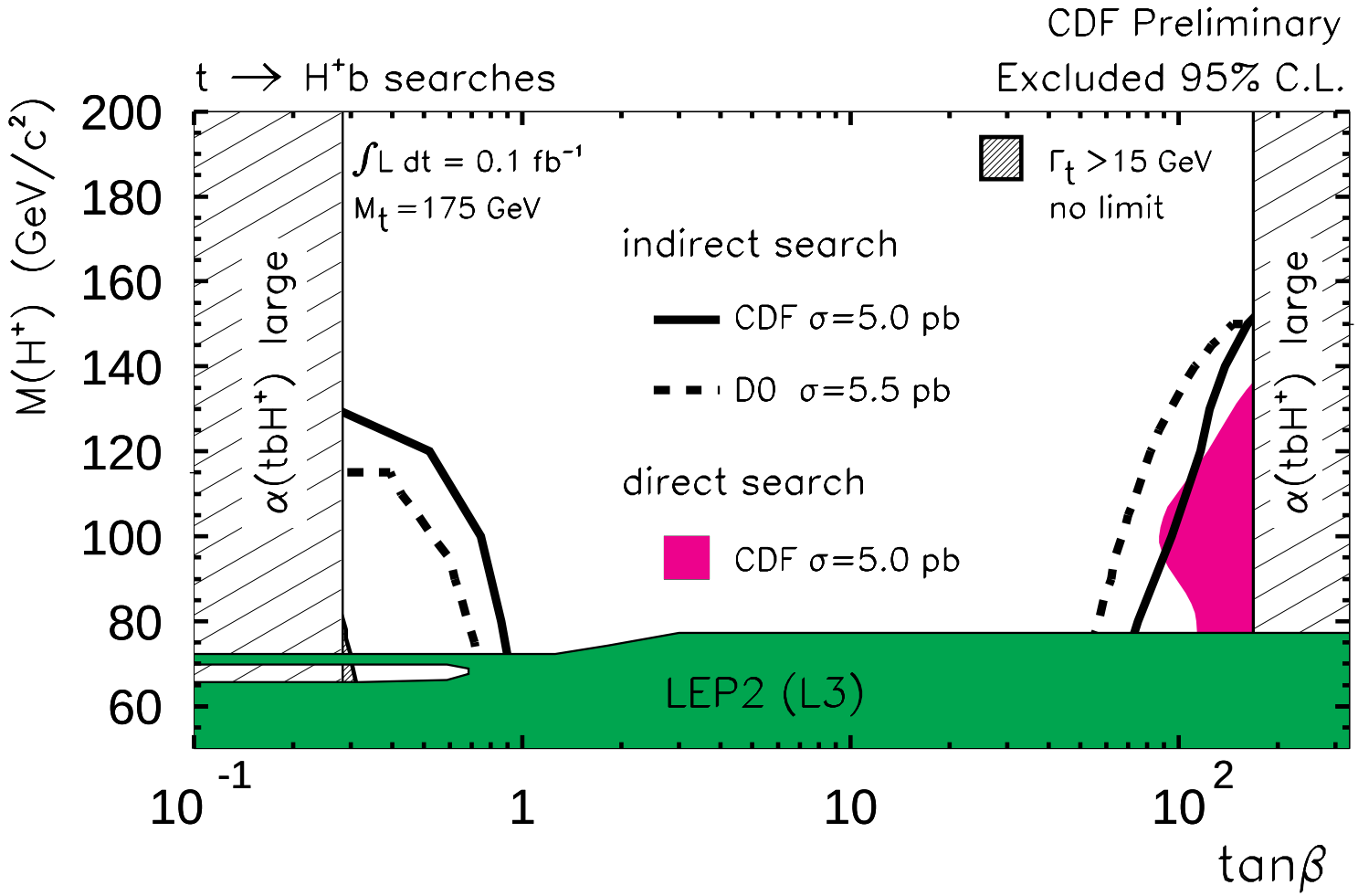
- Select events of these signatures:
  - $e/\mu + \tau$ + jets + MET
  - $\tau\tau$ + jets + MET

τ identified in hadronic decay mode

Indirect (Disappearance) Search:

- Observe if the di-lepton and lepton+jets top events (lepton : e, μ) are suppressed
- For given σ(t tbar) and {M(H^+), tan(β)} , how likely is it to observe N events
- Set exclusion regions in {M(H^+), tan(β)}

Searches for Charged Higgs (MSSM)



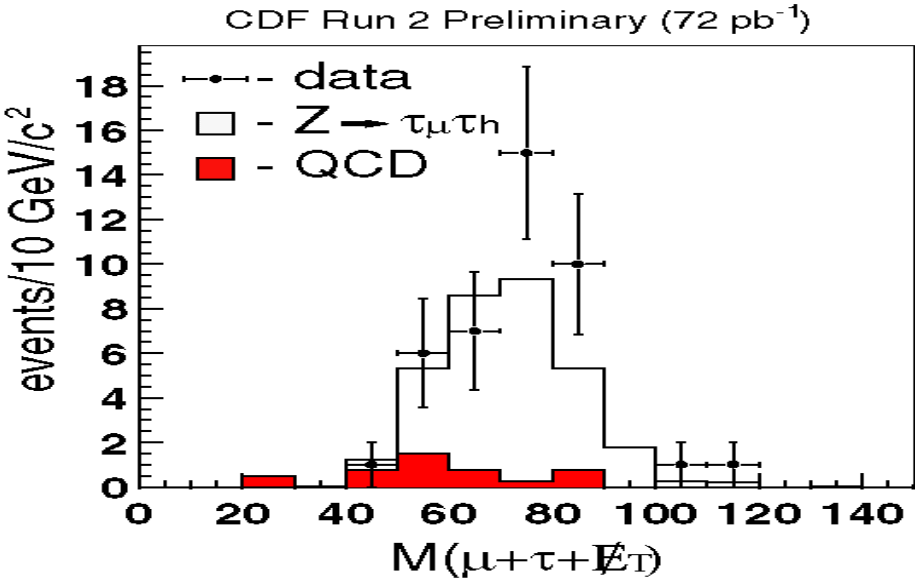
Searches for Neutral Higgs (MSSM)

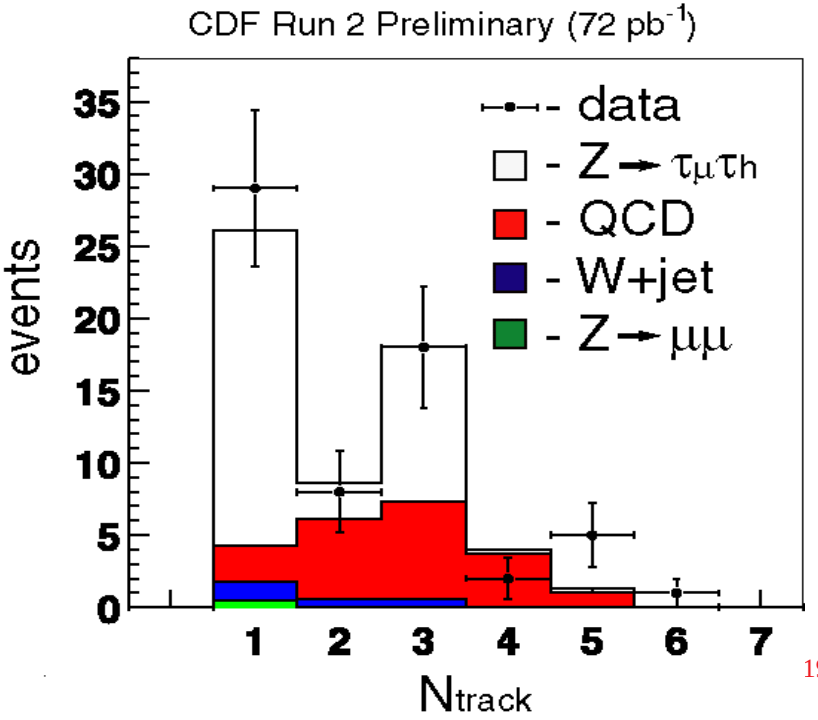
$gg \rightarrow \phi$ (ϕ=h,H,A)

- Look at the channel $\phi \rightarrow \tau\tau$ with Run-I data (BR~10%)
- Use high Et electron dataset (Pt>18 GeV), no Tau trigger
- Select events with one hadronic τ and one isolated electron candidate
- Observe no excess of events
- Cannot set limit, since search is not sensitive enough due to low acceptance by the trigger

Implementation Tau Triggers in Run-II

- Lepton(Pt>8) + track(Pt>5)
- MET+tau
- Di-tau (2 narrow jets)

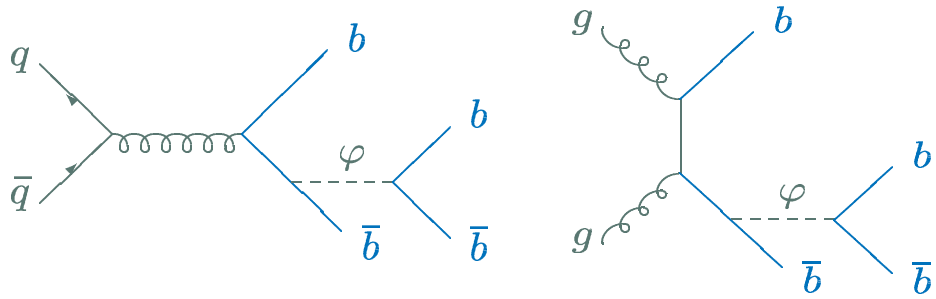




Searches for Neutral Higgs (MSSM)

$gg, qq \rightarrow \phi + b\bar{b} \rightarrow b\bar{b}b\bar{b}$ (ϕ=h,H,A)

BR($\phi \rightarrow b\bar{b}$) ~ 90%

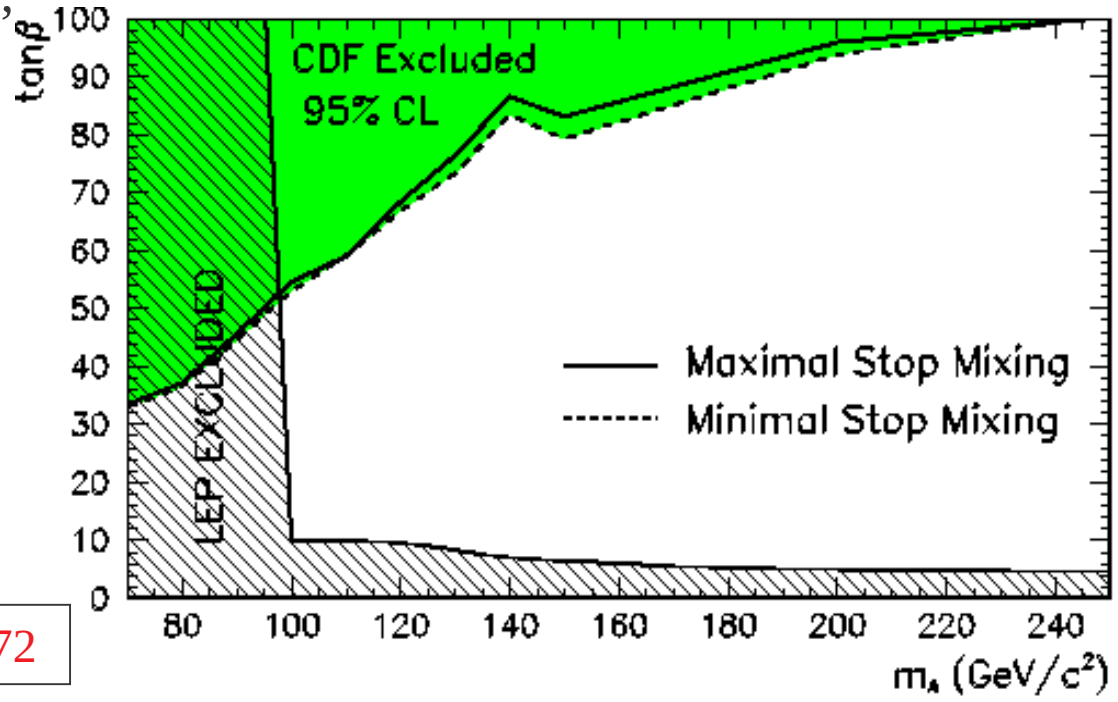


Event Selection:

- ≥ 4 jets , $|\eta_{jet}|$<1.5
- ≥ 3 jets tagged as b-quark candidate
- $\Delta\phi$(bb) > 1.9 (bb well separated) , to reduce $gg \rightarrow bbbb$
- Signal acceptance:
  - ~0.2% - 0.6%

Background:

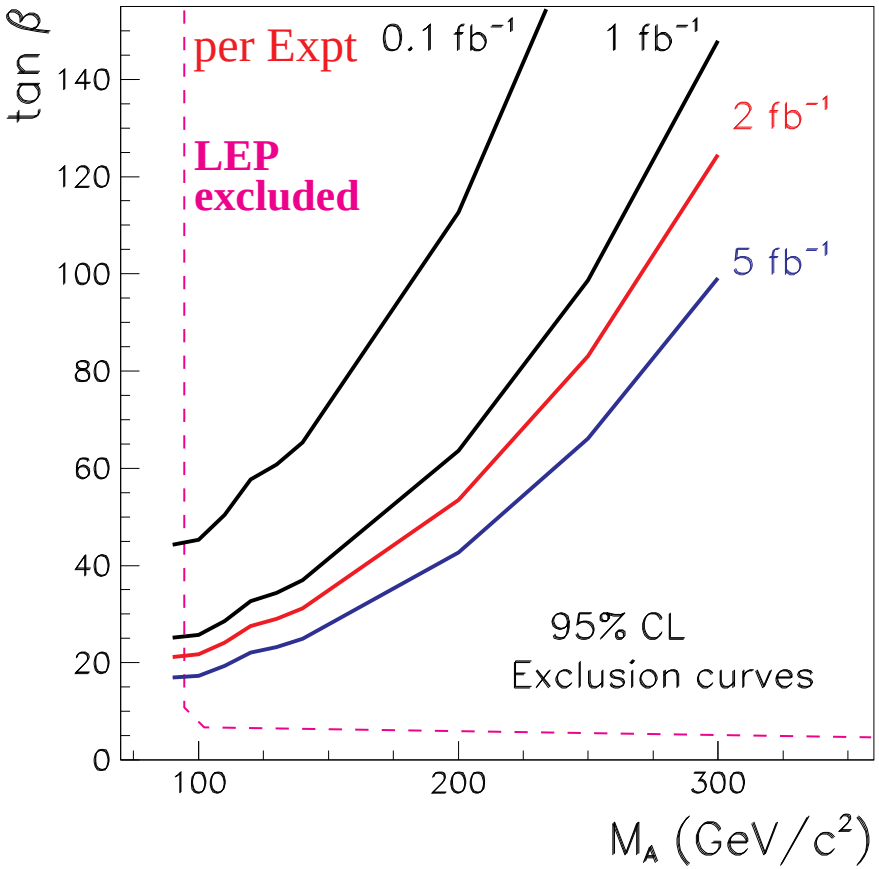
QCD, ttbar, W/Zbb, W/Zcc

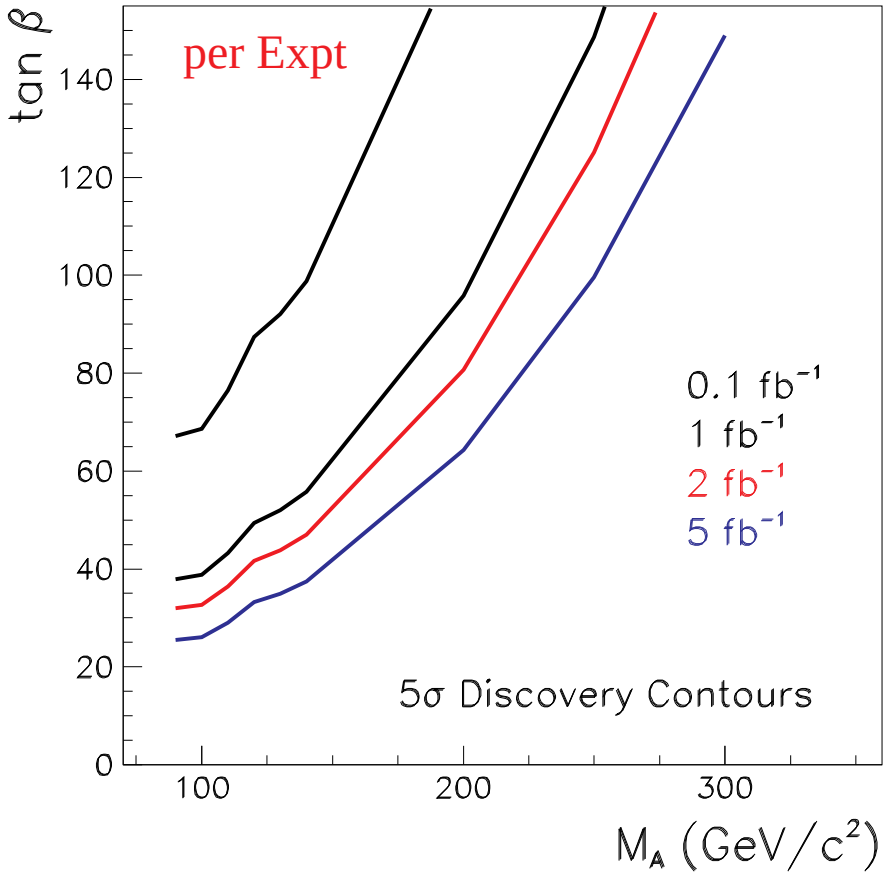


PRL,86,4472

Searches for Neutral Higgs (MSSM) (Run-II Sensitivity)

$$gg, qq \rightarrow \phi + b\bar{b} \rightarrow b\bar{b}b\bar{b}$$

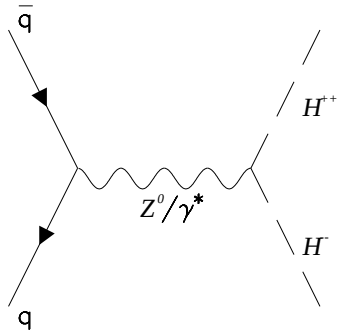




- ϕ+b bbar : best discovery channel for new Fermilab Run-II luminosity baseline

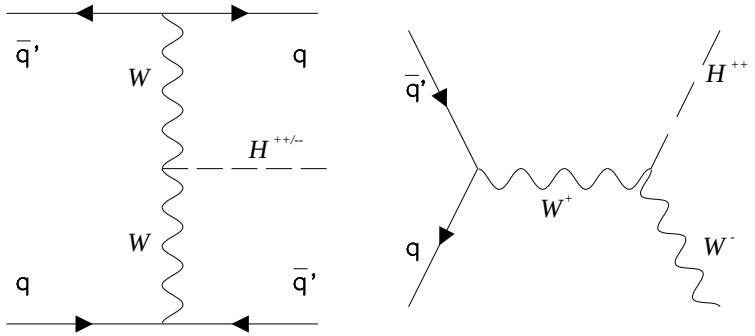
Searches for Doubly Charged Higgs

- Doubly charged Higgs are predicted in models that contain Higgs triplets
  - Models w/ extension to Higgs sector of SM
  - Left-Right symmetric models
  - Supersymmetric Left-Right models
- In the Left-Right symmetric models, the Higgs triplets are one of the Higgs multiplets that breaks the symmetry between L and R handed weak interactions at low energy



Event Selection:

- Select $H^{++/--}$ pair or singly produced
- Search for 1 pair of same sign *ee*, or μμ, or *e*μ
  - same sign leptons decay contains low SM backgrounds, provide clean environment for new physics search
- Datasets : inclusive high Pt electron/muon samples (~90 pb^{-1} for both)

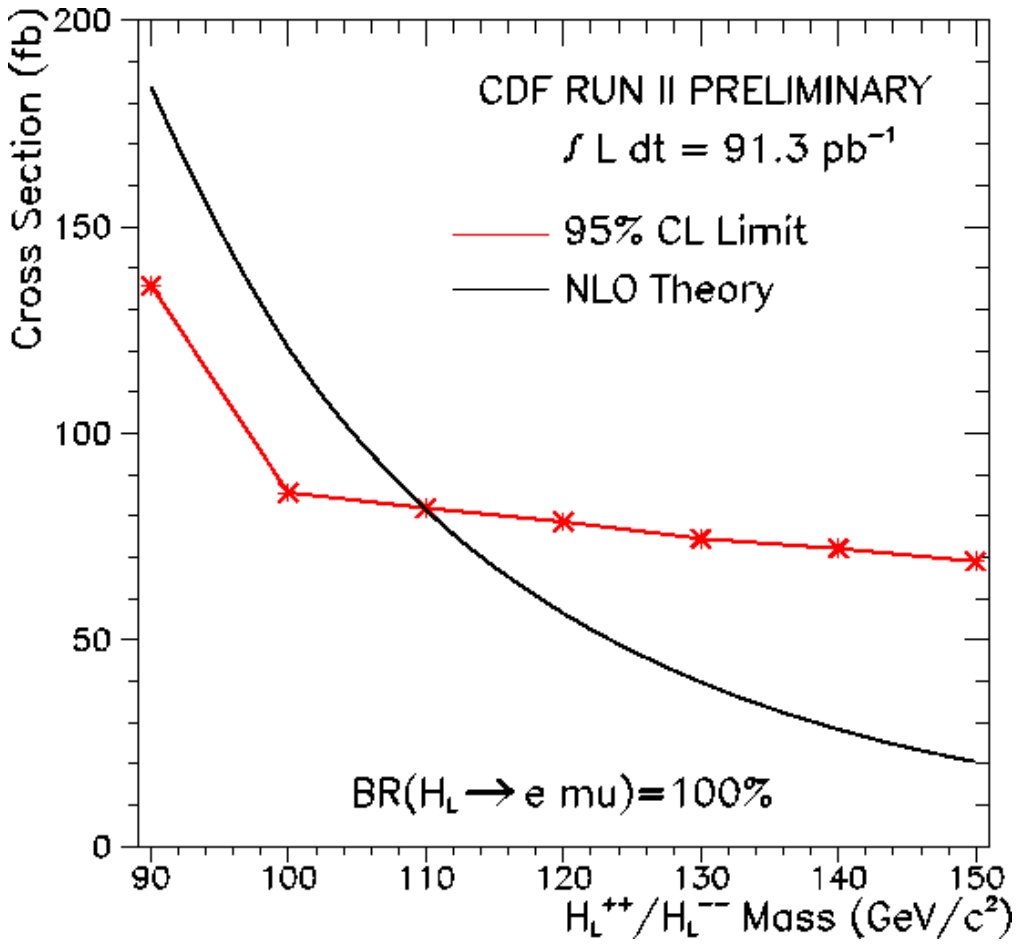


Searches for Doubly Charged Higgs

- No excess in observed events
- Example in the same sign eμ for $M_{e\mu}$>80 GeV
  - #Obs=1, #Bgd= $3.2^{+1.6}_{-0.9}$

Exclusion mass region :

- *ee* : no exclusion
- μμ : $M_{H^{++/--}} < 110$ GeV
- *e*μ : $M_{H^{++/--}} < 110$ GeV



Summary

- Non-SM Electroweak Symmetry breaking searches have been performed in several channels at CDF
- No evidence of deviation from SM expectation observed so far
- Limits are set for various Non-SM parameters
- CDF Run-II has started successfully. The upgrades will improve the sensitivities to these searches
- Integrated luminosity of data collected at sqrt(s)=1.96 TeV is ~2X that of Run-I

=>STAY TUNED for more NEW results in the next winter conferences!!!