Electroweak Physics and Searches for New Physics at CDF Run II

Koji Ikado

Waseda University

for the CDF Collaboration

JPS @ Kyushu Univ.

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Outline

- Tevatron and CDF Detector
- W and Z production
- Di-boson production ($W\gamma$ and $Z\gamma$)
- W Mass
- Higgs Boson
- Leptoquark
- Excited Lepton
- High Mass Di-lepton
- Summary

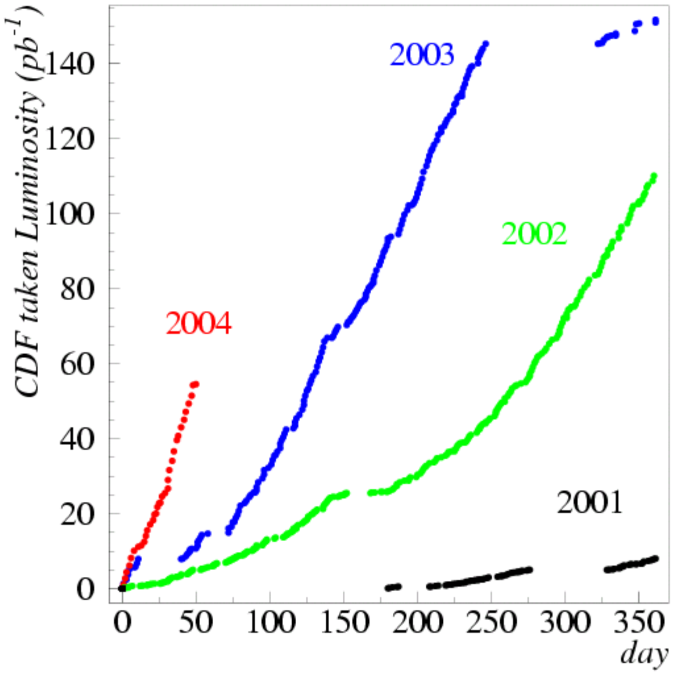
† Only new results will be shown

† All results are preliminary

Tevatron Run II

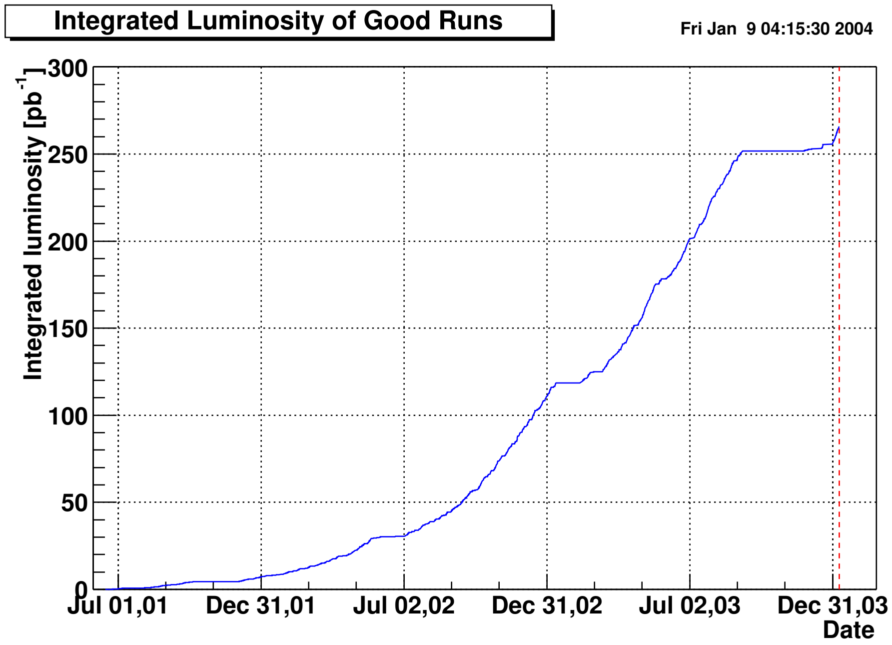
Data taking started in June 01

- $\sqrt{s} = 1.8 \rightarrow 1.96$ TeV
- Instantaneous luminosity
  $2 \times 10^{31} \rightarrow 4 \times 10^{31}$ cm^{-2} s^{-1}
- Data taking efficiency about 90%
- Delivered luminosity : 250 pb^{-1}



† Promising slope in 2004

Luminosity record

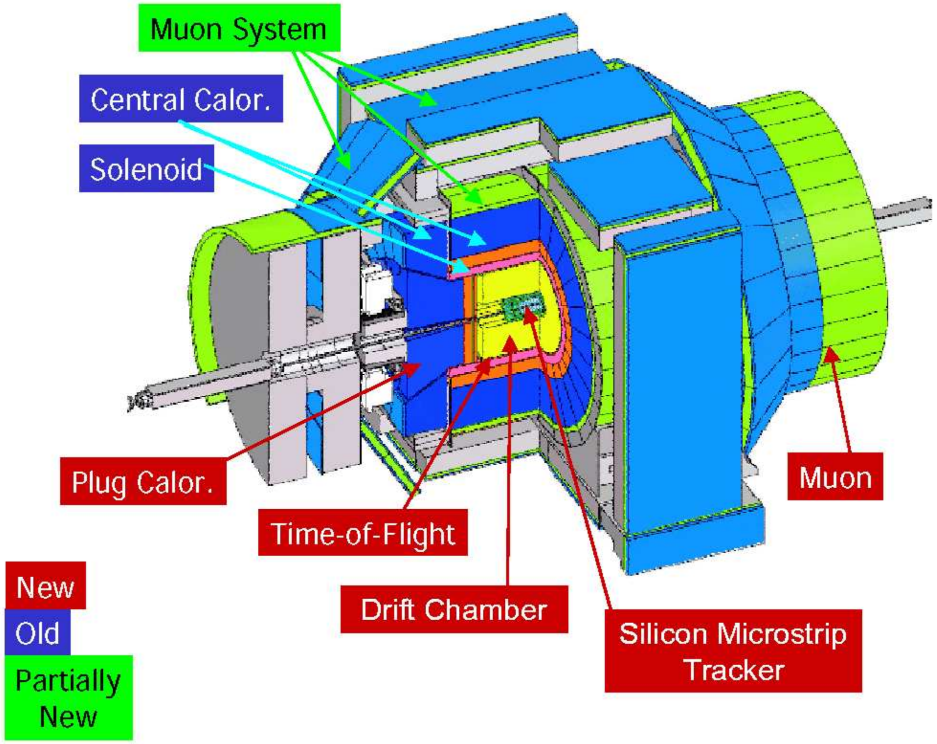


- Use about 200 pb^{-1} of integrated luminosity taken between March 02 and Sept. 03
- Expect :
  - ◇ $2006 \rightarrow 2$ fb^{-1}
  - ◇ $2009 \rightarrow 4.4$-8.6 fb^{-1}

CDF II Detector

Retained from Run I

- Solenoid magnet (1.4 Tesla)
- Central Calorimeters
- Central Muon detectors

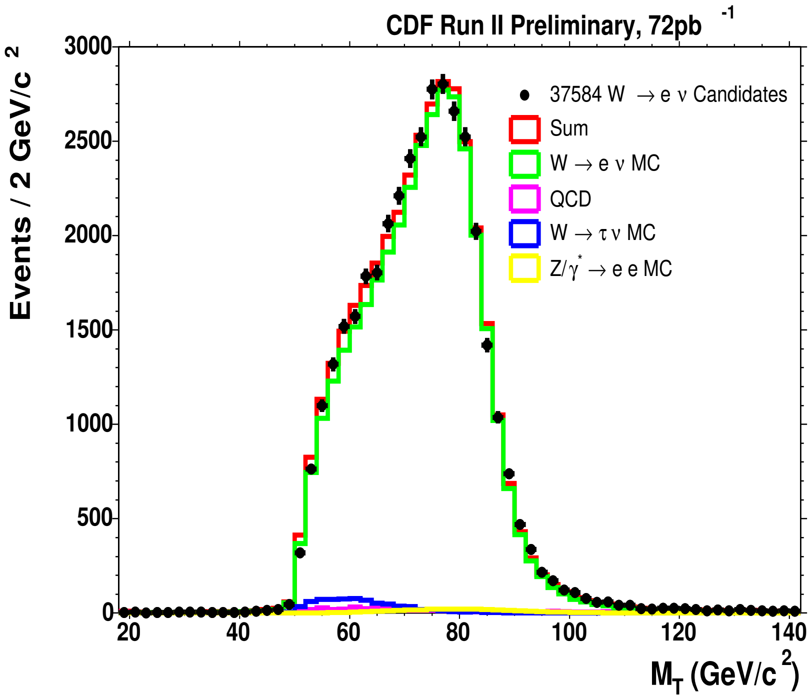


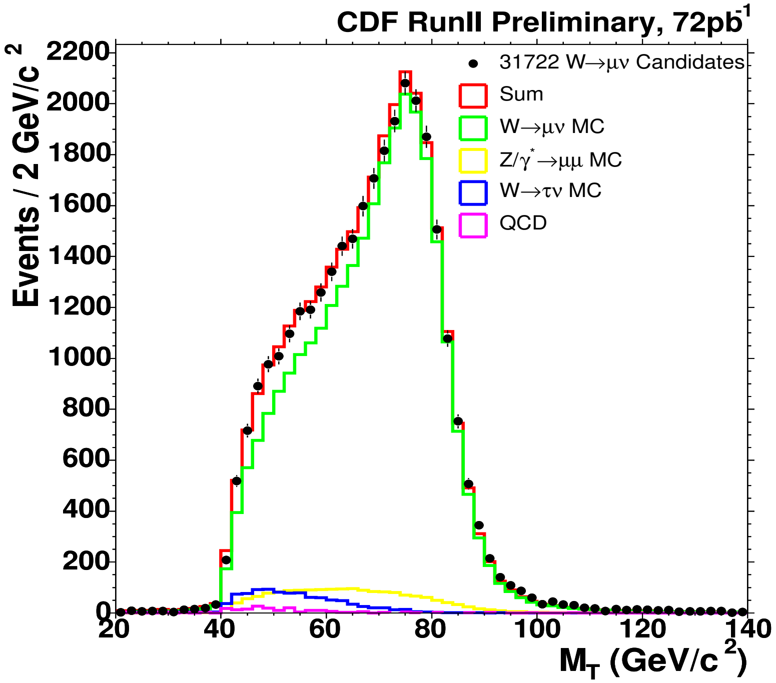
New for Run II

- Tracking system
  - ◇ Silicon Vertex detector (SVX II)
  - ◇ Intermediate silicon layers (ISL)
  - ◇ Central Outer tracker (COT)
- Scintillating tile forward calorimeter
- Intermediate muon detectors
- Time-Of-Flight detector
- Front-end electronics
- Trigger system
- DAQ system

W Production Cross Section

- Signal : $W \to e\nu$ and $W \to \mu\nu$
- Background : QCD, $Z \to \ell\ell$ and $W \to \tau\nu$

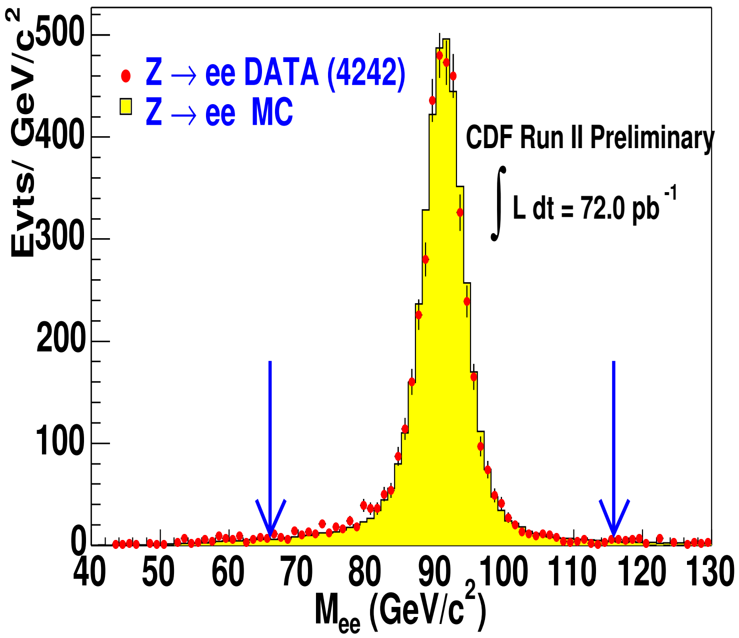


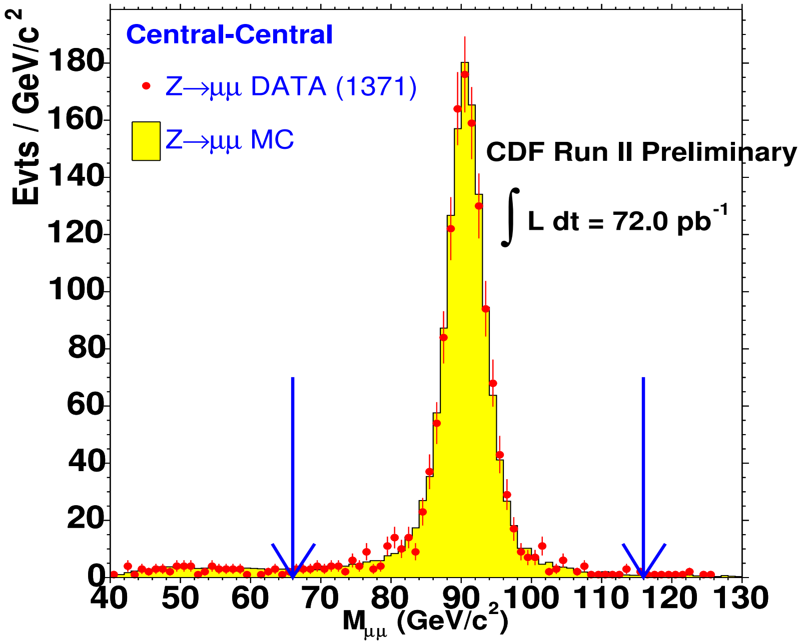


ℓ	$\sigma \times BR(W \to \ell\nu)$ (pb)
e	$2782 \pm 14(stat)\ ^{+61}_{-56}(sys) \pm 167(lum)$
μ	$2772 \pm 16(stat)\ ^{+64}_{-60}(sys) \pm 166(lum)$
$e + \mu$	$2777 \pm 10(stat) \pm 52(sys) \pm 167(lum)$
NLO prediction	2770

Z Production Cross Section

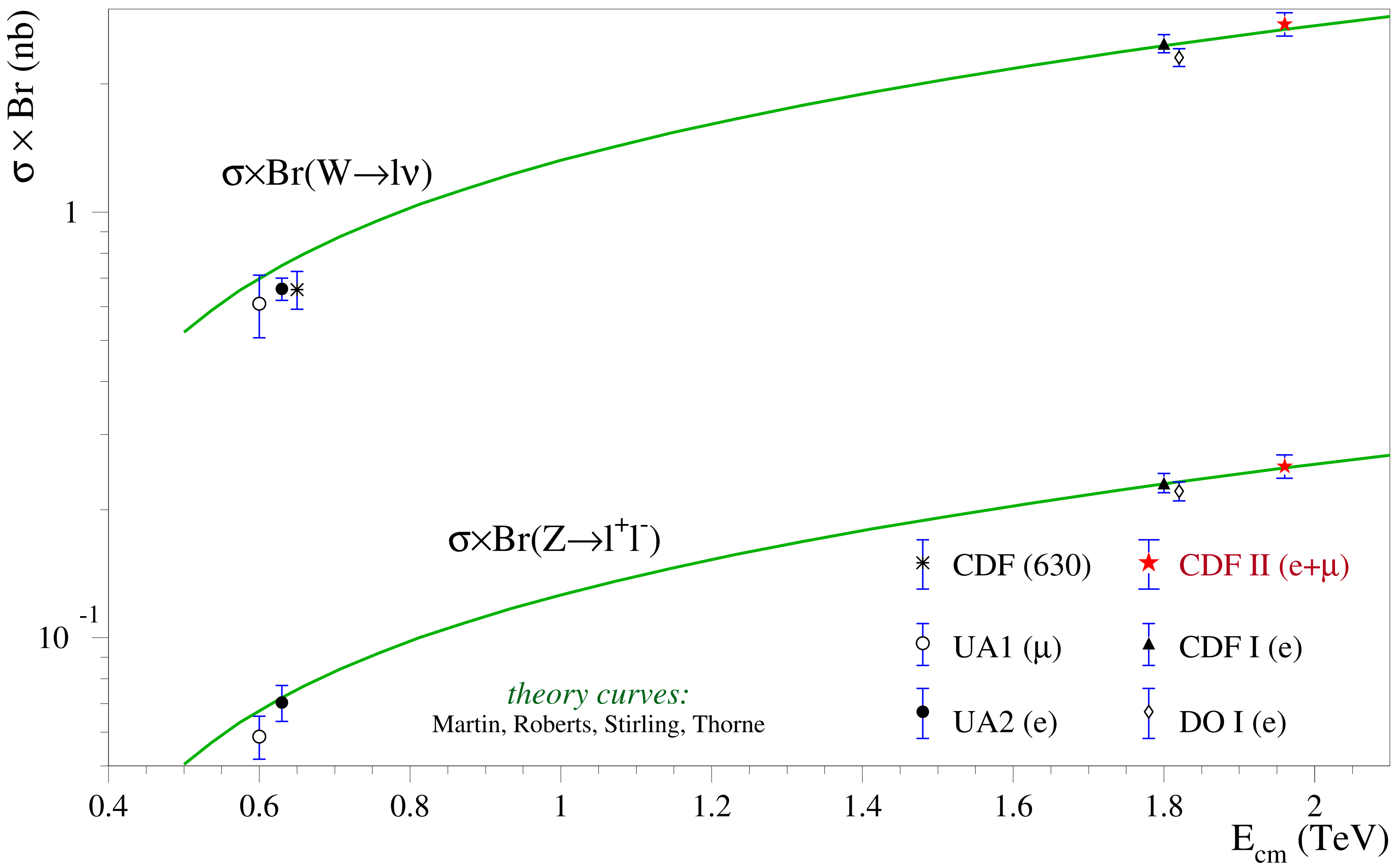
- Signal : $Z \to ee$ and $Z \to \mu\mu$
- Background : QCD, $Z \to \tau\tau$





ℓ	$\sigma \times BR(Z \to \ell\ell)$ (pb)
e	$255.2 \pm 3.9(stat)^{+5.5}_{-5.4}(sys) \pm 15.3(lum)$
μ	$248.9 \pm 5.9(stat)^{+7.0}_{-6.2}(sys) \pm 14.9(lum)$
$e + \mu$	$254.3 \pm 3.3(stat) \pm 4.3(sys) \pm 15.3(lum)$
NLO prediction	250.2

W & Z Cross Sections : Summary



$BR(W \to \ell\nu)$ and Γ_W

$$R = \frac{\sigma(\bar{p}p \to W \to \ell\nu)}{\sigma(\bar{p}p \to Z \to \ell\ell)}$$
$$= 10.93 \pm 0.15(stat) \pm 0.13(sys)$$

$$R = \frac{\sigma(\bar{p}p \to W)}{\sigma(\bar{p}p \to Z)} \cdot \frac{\Gamma(Z)}{\Gamma(Z \to \ell\ell)} \cdot \frac{\Gamma(W \to \ell\nu)}{\Gamma(W)}$$

◇ $\frac{\sigma(\bar{p}p \to W)}{\sigma(\bar{p}p \to Z)} = 3.3677 \pm 0.024$ (PDG)

◇ $\frac{\Gamma(Z \to \ell\ell)}{\Gamma(Z)} = 3.366 \pm 0.0002\%$ (LEP)

$$\downarrow$$

$$BR(W \to \ell\nu) = 0.1093 \pm 0.0021$$

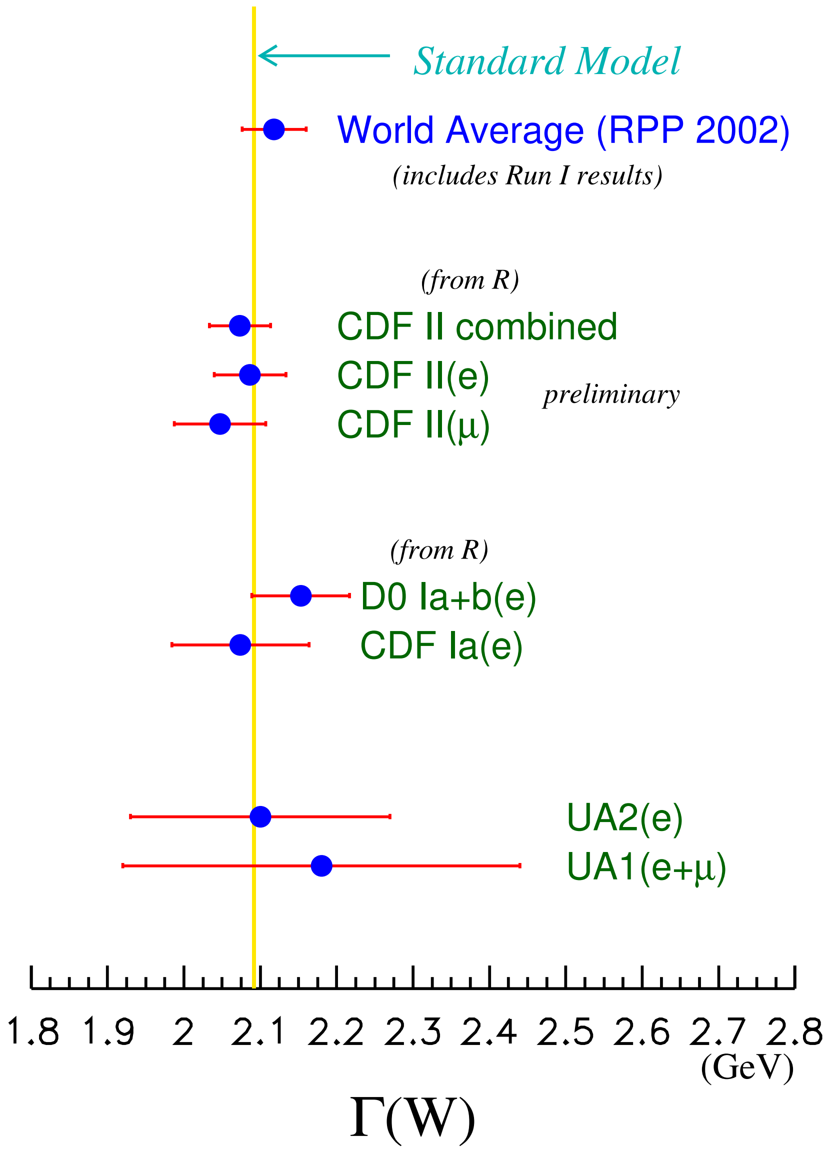
NNLO calculation

$$\Gamma(W \to \ell\nu) = 226.4 \pm 0.4 \text{ MeV (PDG)}$$

$$\downarrow$$

$$\Gamma(W) = 2071 \pm 40 \text{ MeV}$$

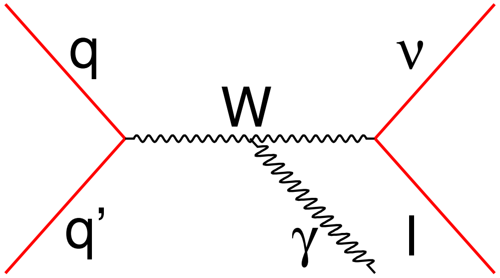
† Current world average : 2092 ± 42 MeV



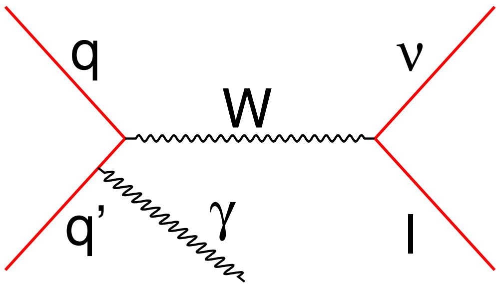
Di-boson Production

$W\gamma$ Production

- Probes triple gauge coupling
- Direct consequence of $SU(2) \times U(1)$ gauge theory
- Sensitive to new physics
- $WW\gamma$



- Initial or final state radiation

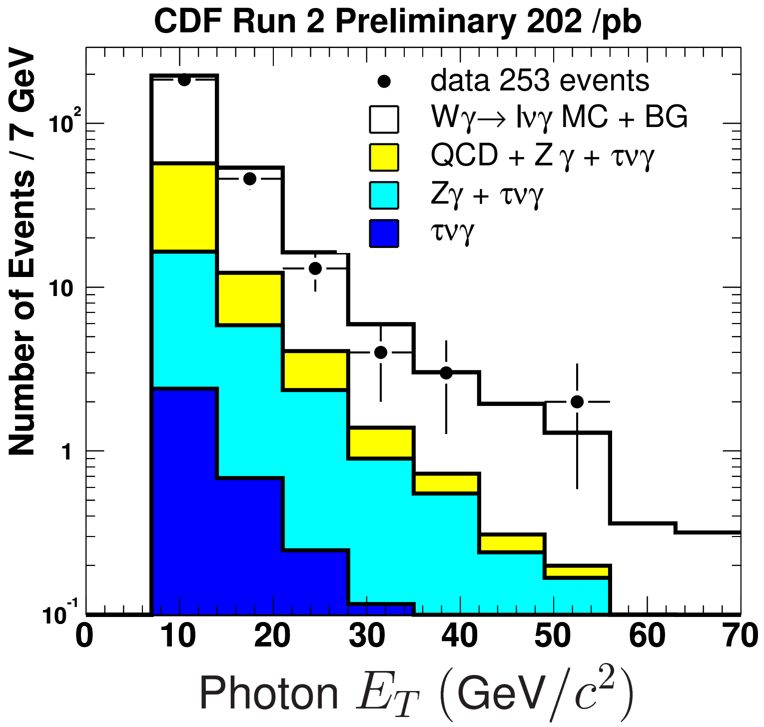


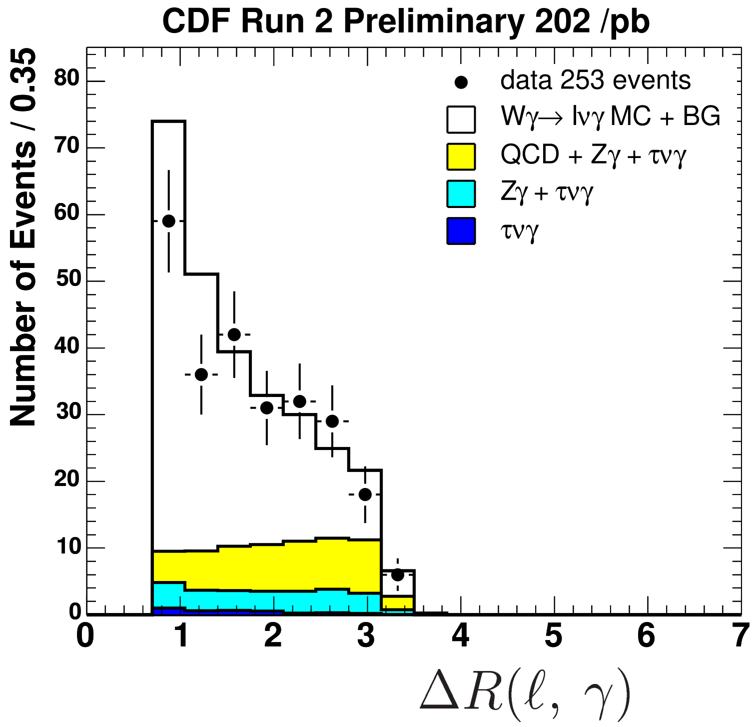
Event selection

- 1 high P_T lepton (e & μ)
- 1 photon with $E_T > 7$ GeV$/c^2$ and $\Delta R(\gamma, \ell) > 0.7$
- 1 neutrino : large missing $E_T > 25$ GeV$/c^2$
- Data is consistent with SM expectation

	Expected for 202 pb^{-1}
$W+\gamma$ MC	$180.51 \pm 2.08 \pm 10.11$
$W+$ jet BG	$49.52 \pm 0.10 \pm 14.95$
$Z+\gamma$	$22.37 \pm 0.38 \pm 1.20$
$W+\gamma\ (\tau)$	$3.23 \pm 0.24 \pm 0.17$
Total	$255.63 \pm 2.13 \pm 26.43$
Data	259

Di-boson Production : $W\gamma$





ℓ	$\sigma \times BR(W\gamma \to \ell\nu\gamma)$ (pb)
$e+\mu$	$19.7 \pm 1.7(stat) \pm 2.0(sys) \pm 1.1(lum.)$
NLO prediction	19.3 ± 1.3

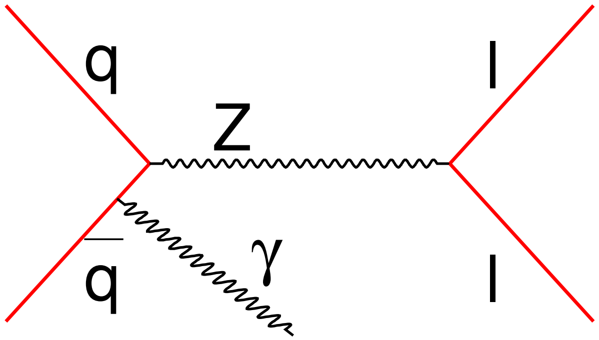
Extracting $WW\gamma$ coupling from photon E_T spectrum in progress

† See N. Tanimoto (Okayama)'s talk on 30aZA in more details

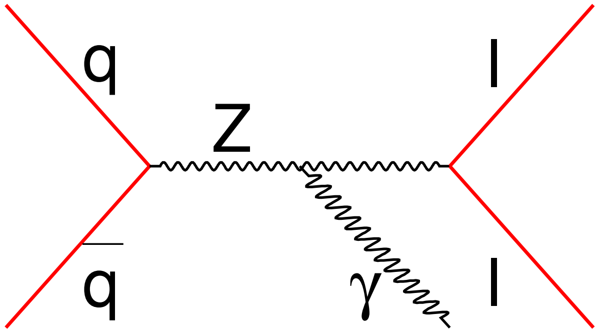
Di-boson Production : $Z\gamma$

$Z\gamma$ Production

- Initial or final state radiation



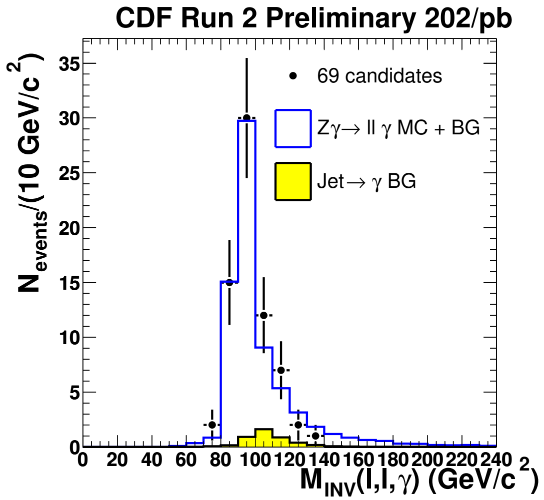
- Non SM



- Small backgrounds ($\sim$ 10%)

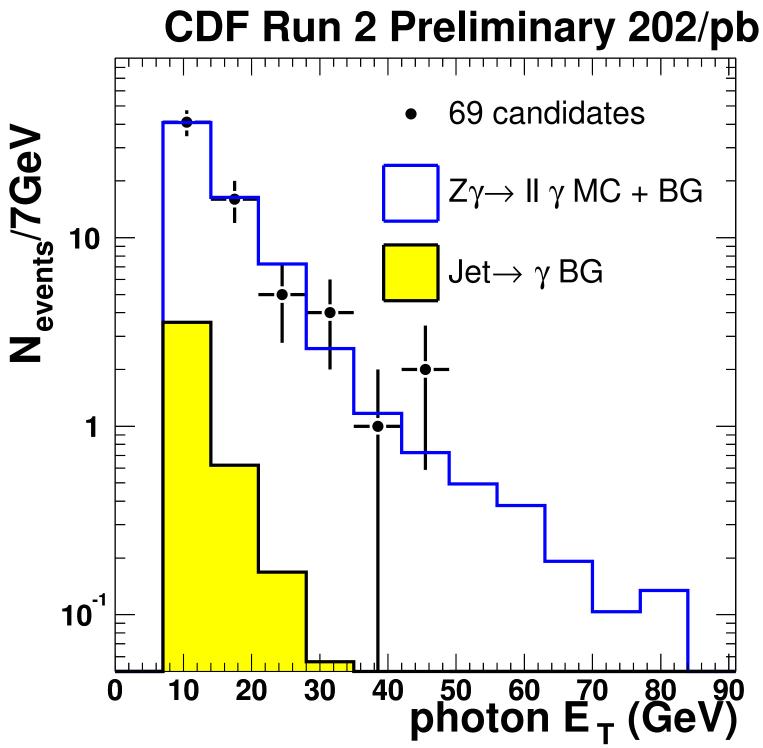
Event Selection

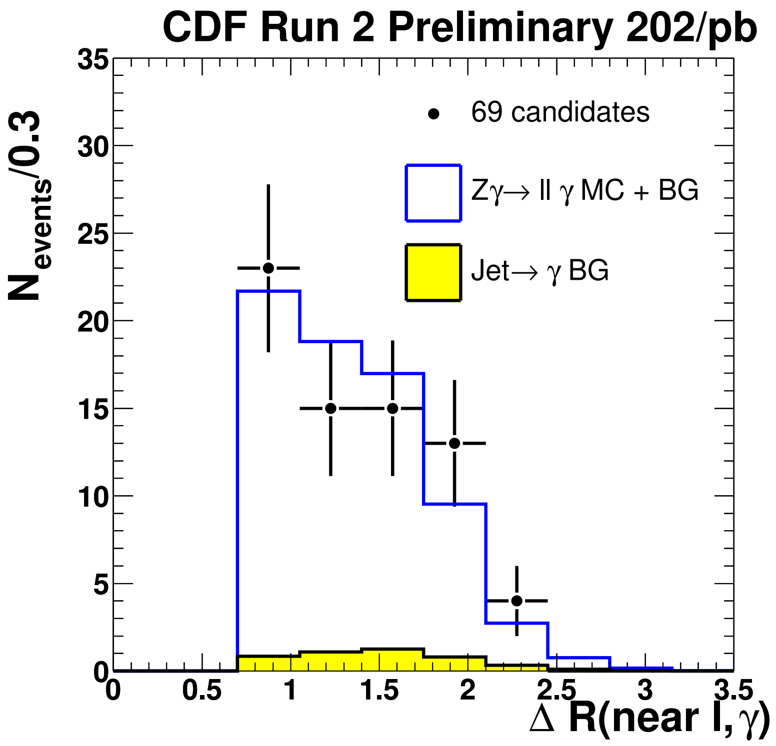
- 2 opposite charge leptons (e,μ)
- 1 photon with $E_T > 7\text{GeV}/c^2$ and $\Delta R(\gamma, \ell) > 0.7$



	Combined e and μ
$Z+\gamma$ MC	65.76 ± 3.76
$Z+$ jet BG	4.44 ± 1.33
Fake $Z+\gamma$	0.26 ± 0.2
Total	70.46 ± 4.0
Data	69

Di-boson Production : $Z\gamma$



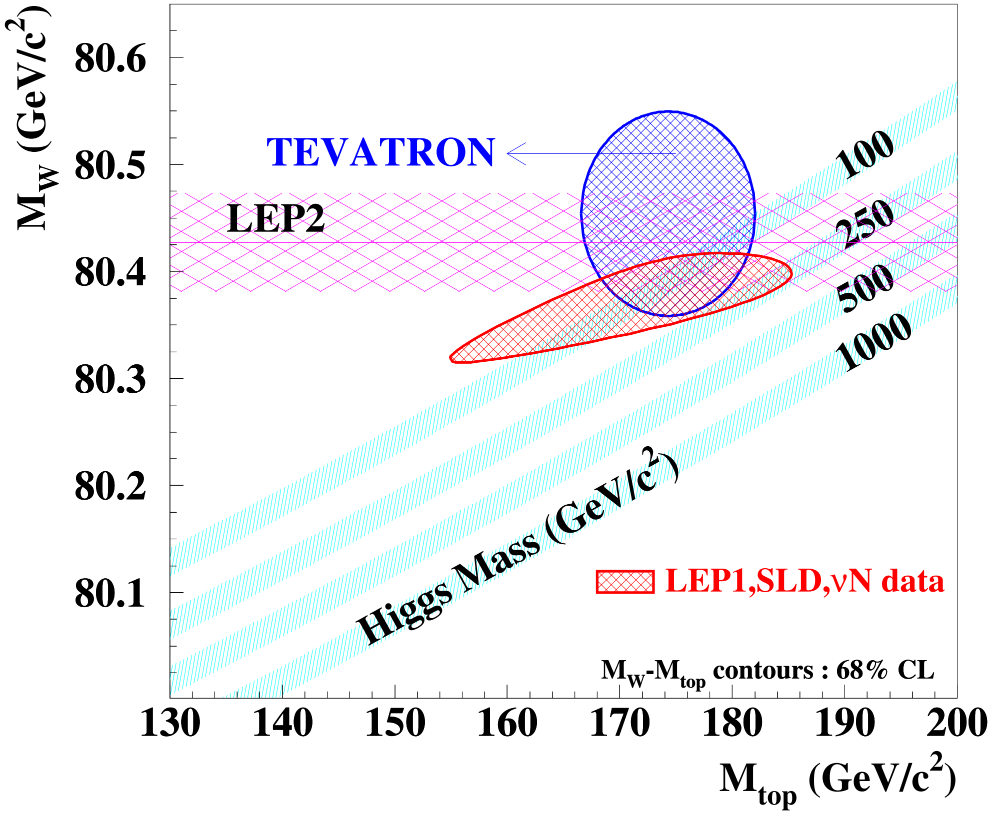


† Data agree with the Standard Model expectation

ℓ	$\sigma \times BR(Z\gamma \to \ell\ell\gamma)$ (pb)
$e + \mu$	$5.3 \pm 0.6(stat) \pm 0.3(sys) \pm 0.3(lum)$
NLO prediction	5.4 ± 0.3

W Mass

- Precision measurements of the mass of the W and top quark
  - $M_W = 80.450 \pm 0.034$ GeV$/c^2$
  - $M_{\rm top} = 174.3 \pm 5.1$ GeV$/c^2$
- Tight constraints on Higgs mass

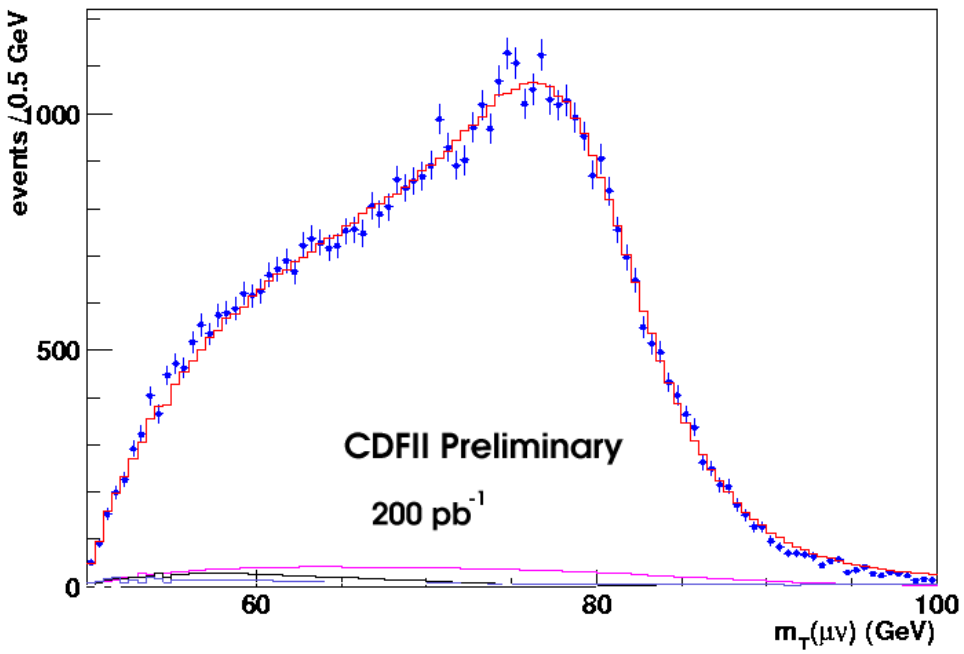


W Mass towards Higgs

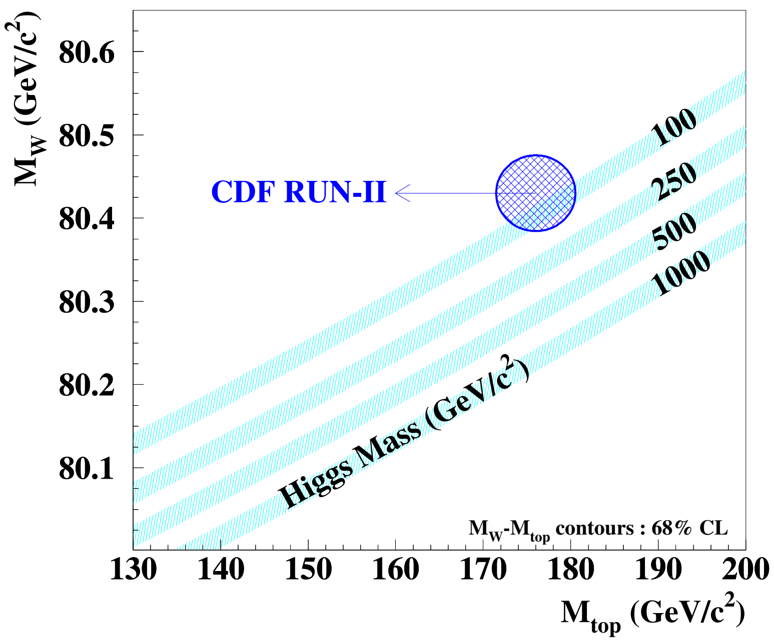
- Difficult measurement $\rightarrow$ Work in progress - no results yet
- CDF alone with 2 fb^{-1} :

$$\Delta M_W = 40 \text{ MeV}$$

$$\Delta M_{\text{top}} = 2\text{-}3 \text{ GeV}$$



Transverse mass from $W \rightarrow \mu\nu$

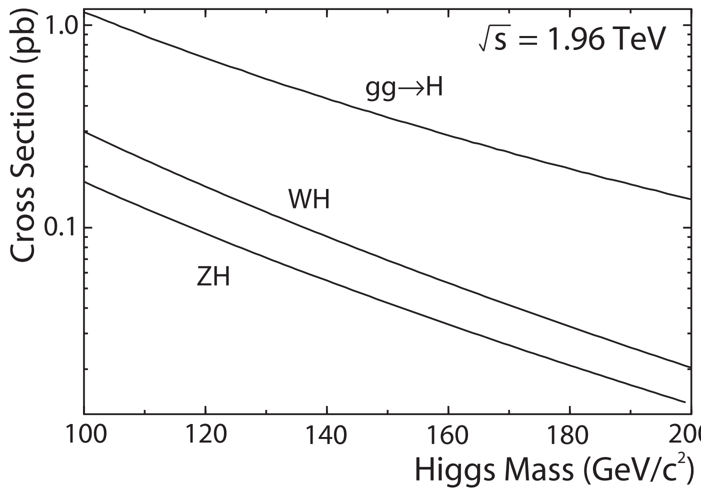


W and top mass prospects

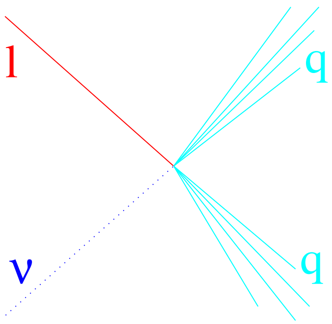
Higgs Boson : SM Higgs

Search in $WH \to \ell\nu b\bar{b}$

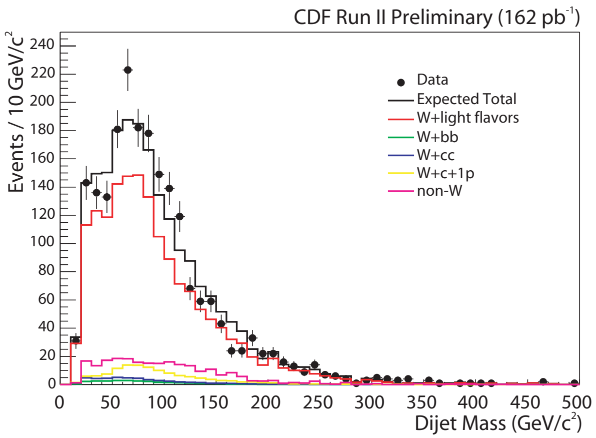
- Production cross section



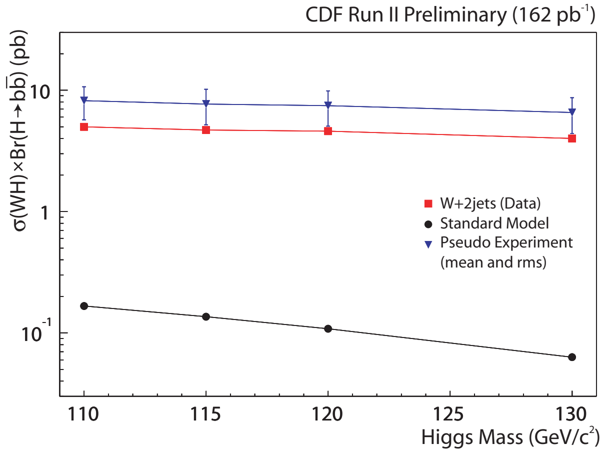
- Signature : 1 high P_T lepton (e or μ), 2 high E_T jets and large missing E_T



- Main background : $Wb\bar{b}, t\bar{t}, WZ$
- Dijet mass distribution



- Cross section limit

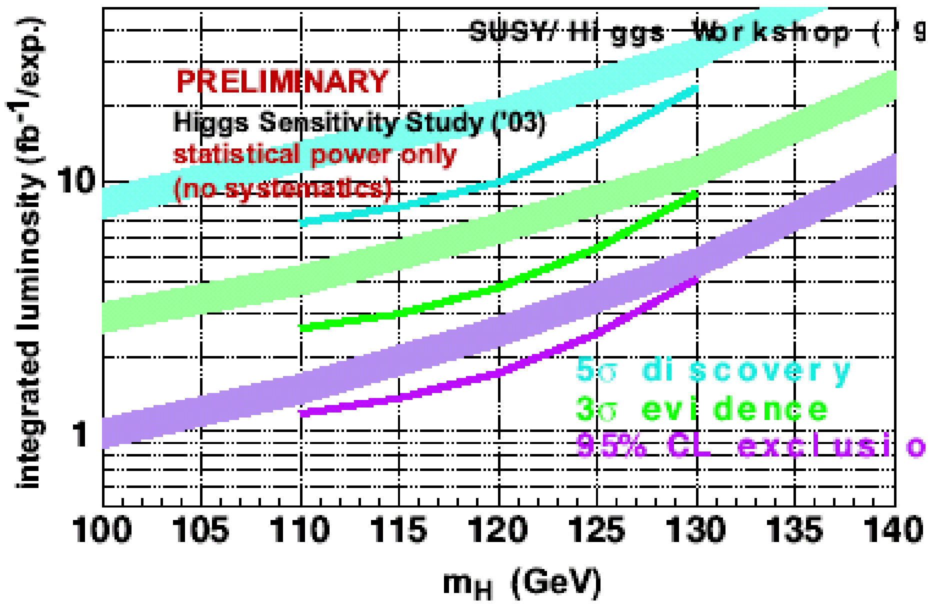


† This work is done by Y. Ishizawa (Tsukuba)

Higgs Boson : Prospects

Standard Model Higgs

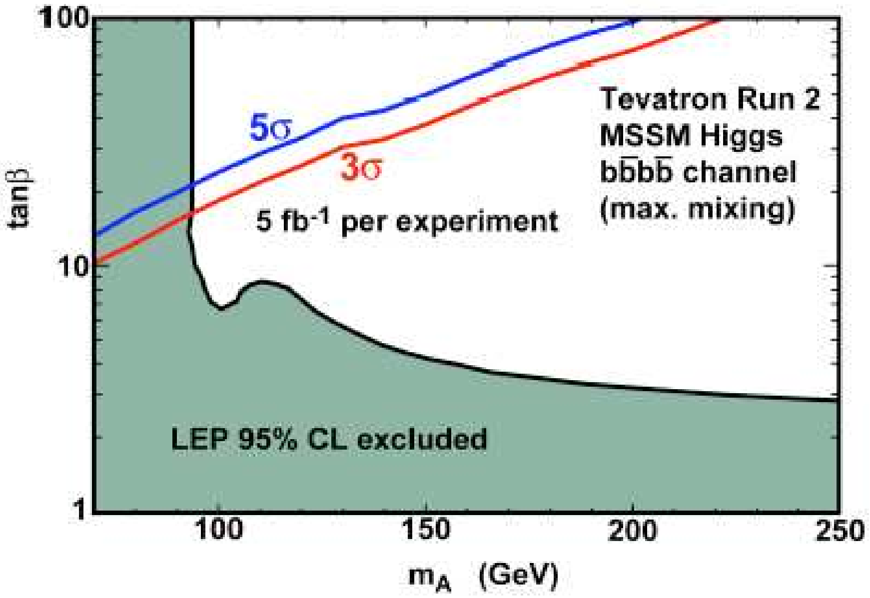
- Recent study confirms earlier study



- Higgs at 115 GeV
  - ◇ 95% C.L. exclusion with 2 fb^{-1}
  - ◇ Discovery unlikely with current luminosity estimates (4.4-8.6 pb^{-1} by 2009)

Better prospects for non-SM Higgs

- SUSY : especially at high $\tan\beta$



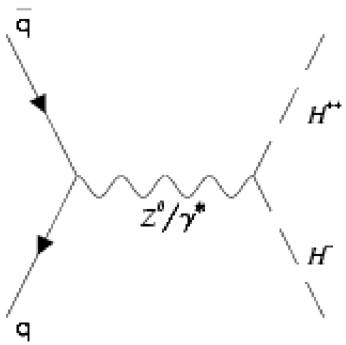
- Bosophilic Higgs

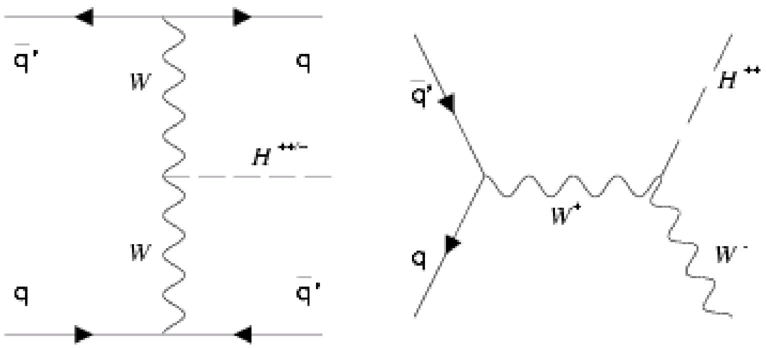
  † See H. Kobayashi (Tsukuba)'s talk on 27aZA

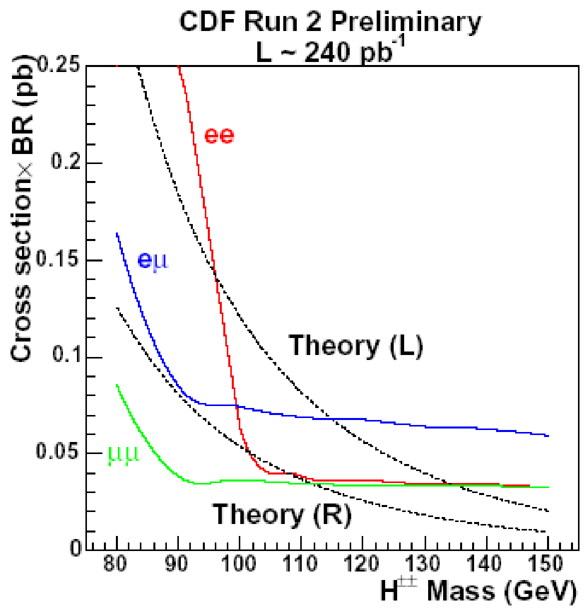
- Doubly charged Higgs (H^{++})

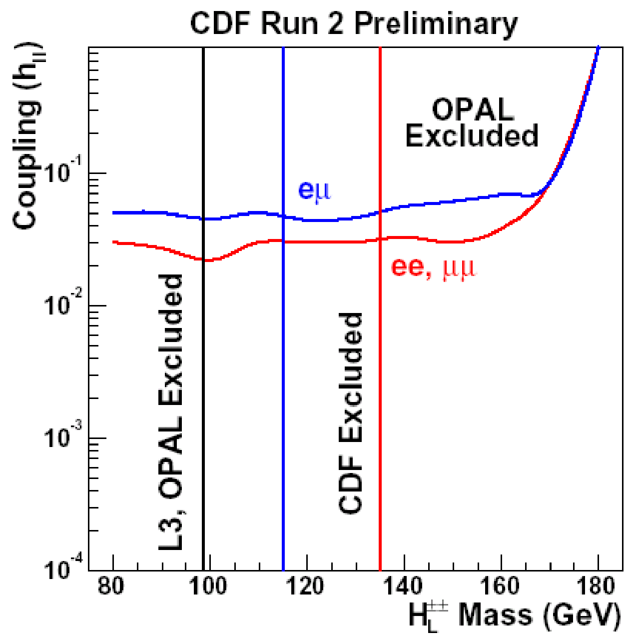
Higgs Boson : Doubly Charged Higgs, H^{++}/H^{--}

- Predicted in some extensions of SM
- Signature : decay into 2 like-sign leptons (ee, $\mu\mu$, $e\mu$)





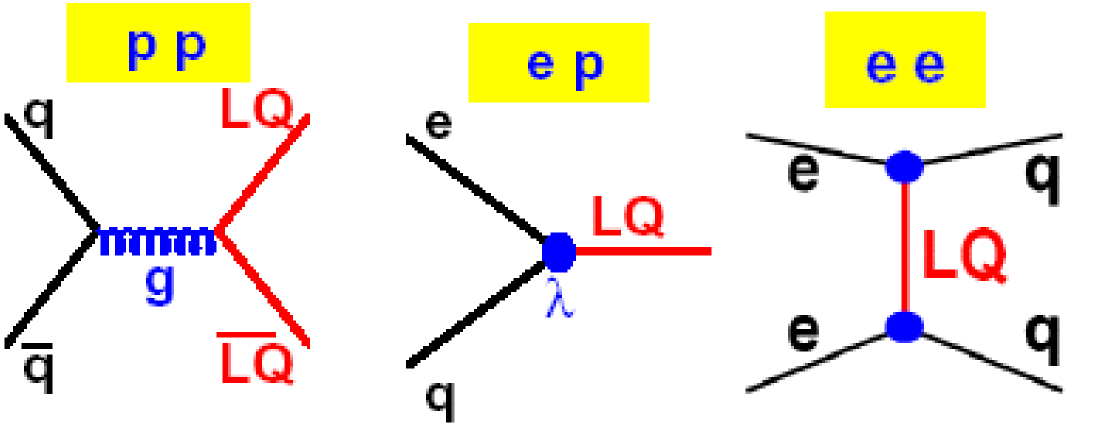




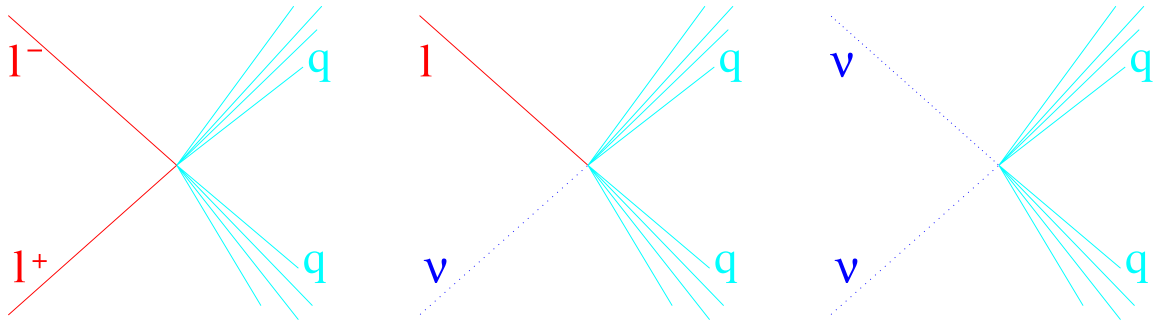
- Sensitive to single and pair production of H^{++}/H^{--}
- Result : $M_{H^{++}} > 130$ GeV

Leptoquark

- Appear in many extensions of SM
- Connect lepton & quark sectors
- Carry both B and L numbers and interact with SM fermions
- Nice competition between world's accelerators



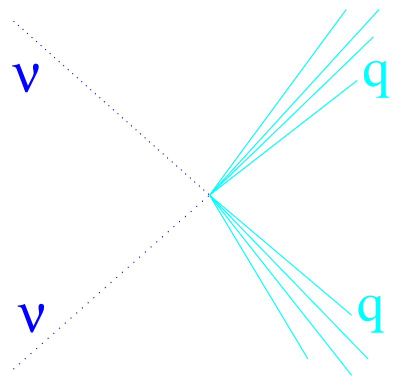
- Signatures at Tevatron



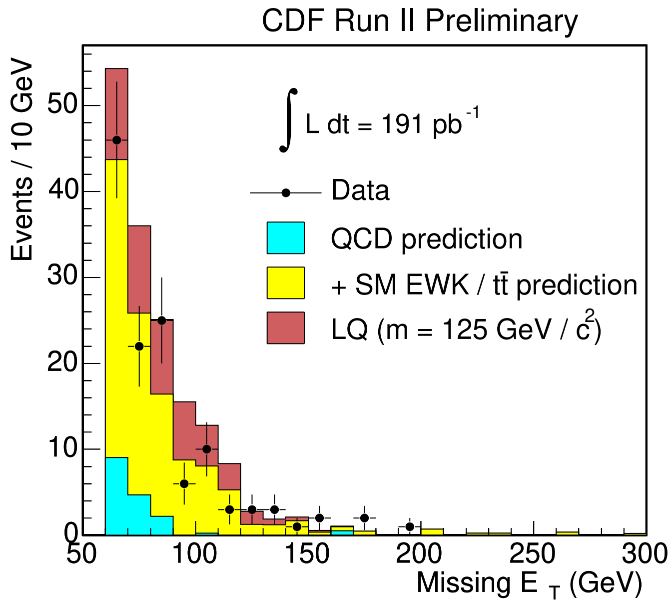
Leptoquark : 1st Generation

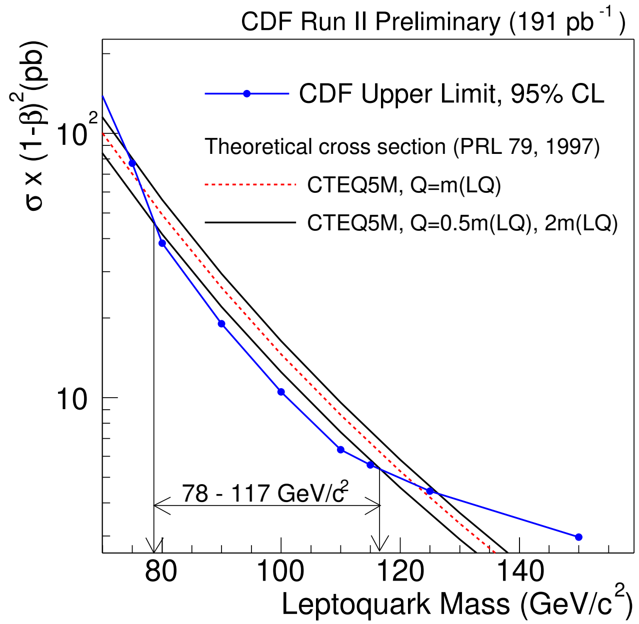
New Analysis in Run II

- Search for $LQ \to \nu q$



- 2 jets and $\not{E}_T > 60$ GeV (Experimentally challenging)
- Result
  - ◇ 124 events observed
  - ◇ 118.3 ± 14.5 expected
  - ◇ Exclude LQ with $78 < M_{LQ} < 117$ GeV

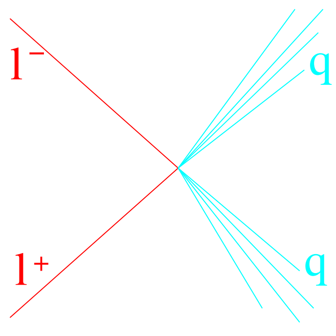




Leptoquark : 2nd Generation

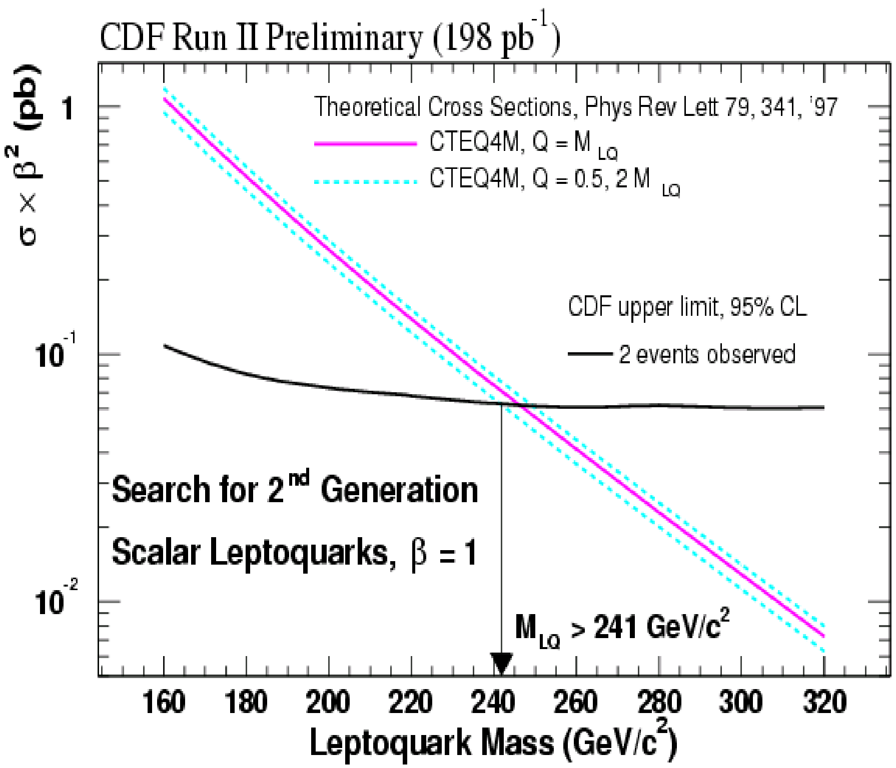
$\mu\mu + jj$ Channel

- $LQLQ \to \mu\mu qq$



- 2 high P_T muons and 2 high E_T jets
- Result

	Expected for 198 pb^{-1}
QCD fake	1.0 ± 1.0
$t\bar{t}$	0.34 ± 0.05
Drell-Yan + 2 jets	1.81 ± 0.12
Total	3.15 ± 1.17
Data	2



- Exclude LQ with $M_{LQ} < 240$ GeV

Excited Lepton

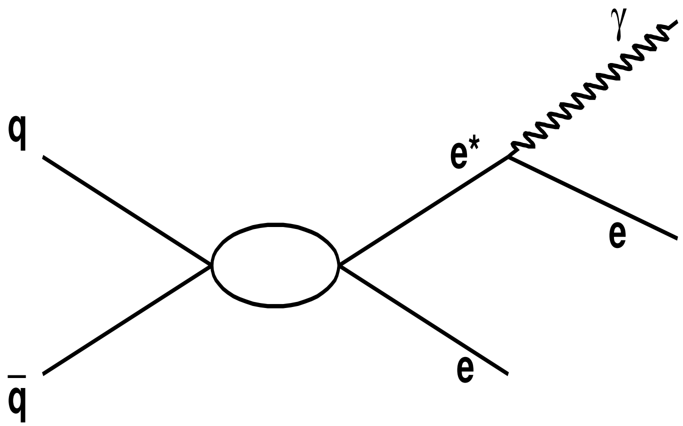
Search for Excited Electrons

- Excited electrons are expected in many compositeness models
- Contact interaction model

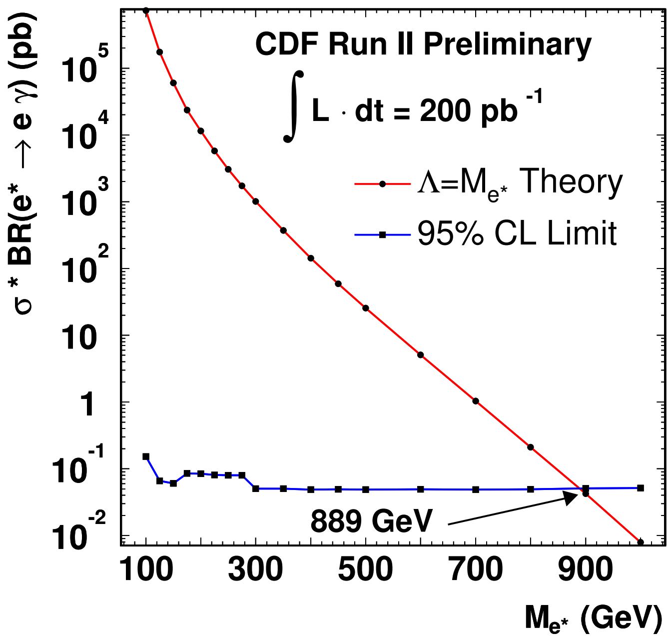
$$\mathcal{L} \propto \frac{4\pi}{\Lambda^2}(\overline{e^*}\gamma^\mu e)(\overline{q}\gamma_\mu q)$$

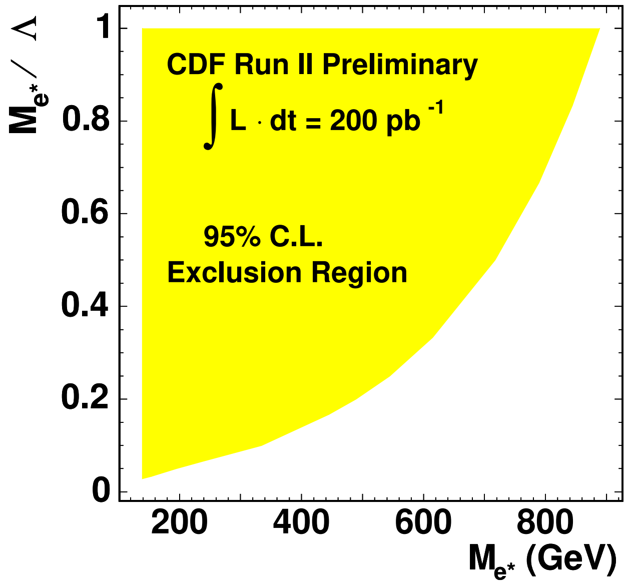
Λ : Compositeness scale

- Signature : $e^* + e \rightarrow e\gamma + e$



2 high-P_T electrons and 1 photon



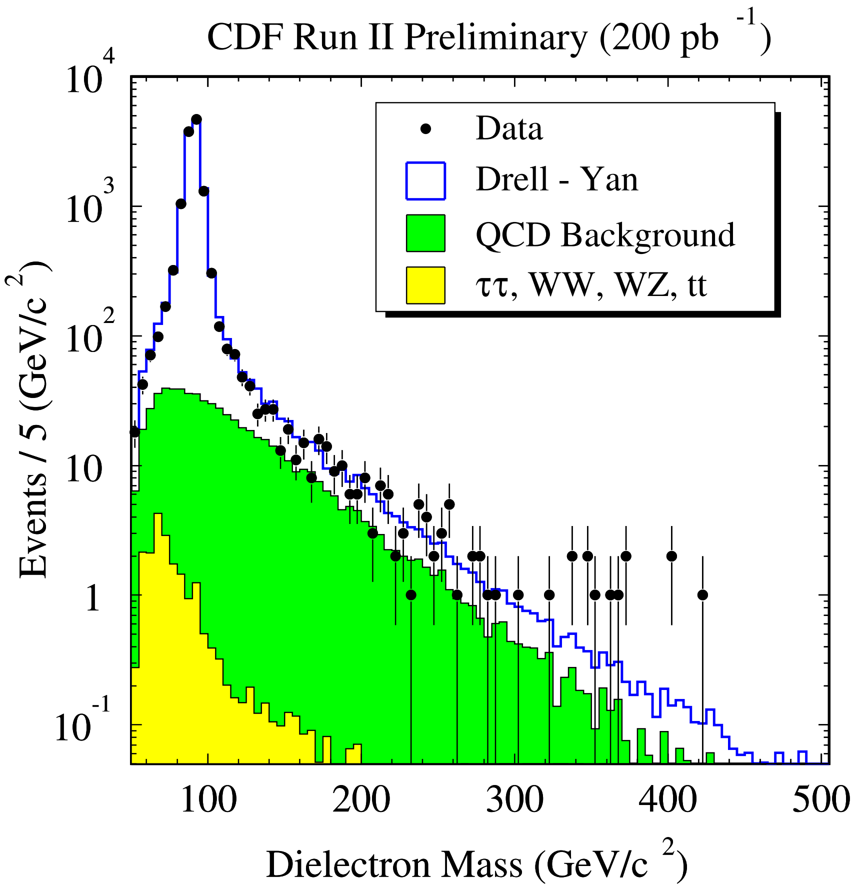


High Mass Di-lepton

Selection criteria

- One good Central electron with $E_T > 25$ GeV
- Second good Central electron or good Plug electron with $E_T > 25$ GeV
- $\not{E}_T/\sqrt{\Sigma E_T} < 2.5$

Comparison of expected background and data



CDF Run II Preliminary (200 pb^{-1})

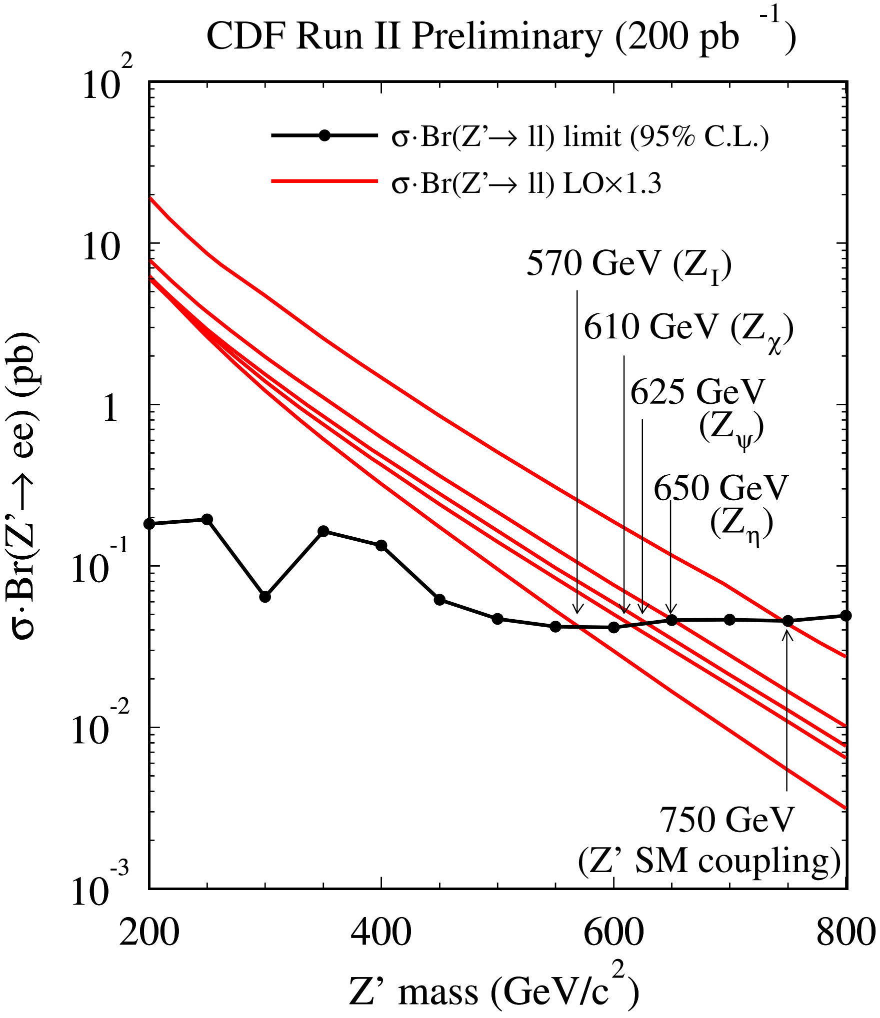
Mass (GeV/c^2)	observed events	expected background
$M > 200$	70	66.9
$M > 250$	29	25.1
$M > 300$	14	10.4
$M > 350$	8	4.7
$M > 400$	3	2.4
$M > 450$	0	1.4

† Data is consistent with SM prediction

High Mass Di-lepton

Z' Bosons

- 95% C.L. cross section limit

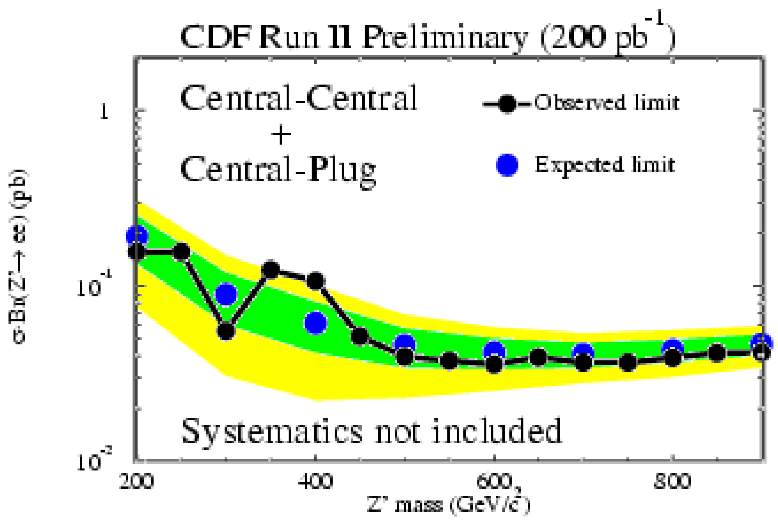


- SM Z' search history

run	Luminosity	95% C.L. Mass limit
RunIa	20 pb^{-1}	505 GeV
RunIb	90 pb^{-1}	640 GeV
RunII	200 pb^{-1}	750 GeV

† Exceeds any published results of direct searches in the world

- Expected Limit



High Mass Di-lepton

Limits on Other Models

- Little Higgs model Z_H :

$$M_{Z_H} > 800 \text{ GeV}/c^2 \qquad (\cot\theta = 0.1)$$

- Randall-Sundrum graviton :

$$M_G > 620 \text{ GeV}/c^2 \qquad (/M_{Pl} = 0.1)$$

- R-parity violating sneutrino :

$$M_{\tilde{\nu}} > 840 \text{ GeV}/c^2 \qquad (\lambda'^2 \cdot Br = 0.1)$$

- Effective Planck scale of large extra dimensions

$$M_s > 987 \text{ GeV}/c^2 \qquad (\lambda < 0, \text{ Hewett convention})$$

Summary

- CDF is taking data actively and producing many results on Electroweak and Exotic physics
  - Have twice the Run I luminosity and excellent detector
- Electroweak measurements in good agreement with Standard Model
  - W and Z production cross section
  - $W\gamma$ and $Z\gamma$ production
  - W mass in progress
- Searches for new physics have started
  - $Z^{'}$, Extra dimensions, Leptoquark, Higgs, Excited leptons, etc.
  - Cover broad range of possible signals
  - No signals yet but constraining theoretical models
- Many new exciting results coming soon

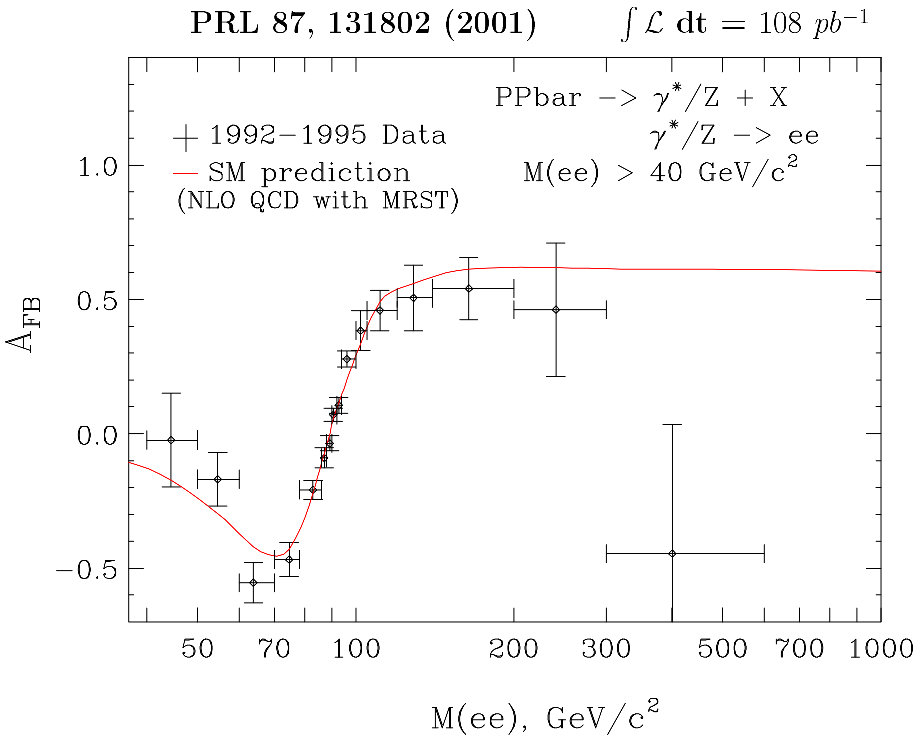
Back up

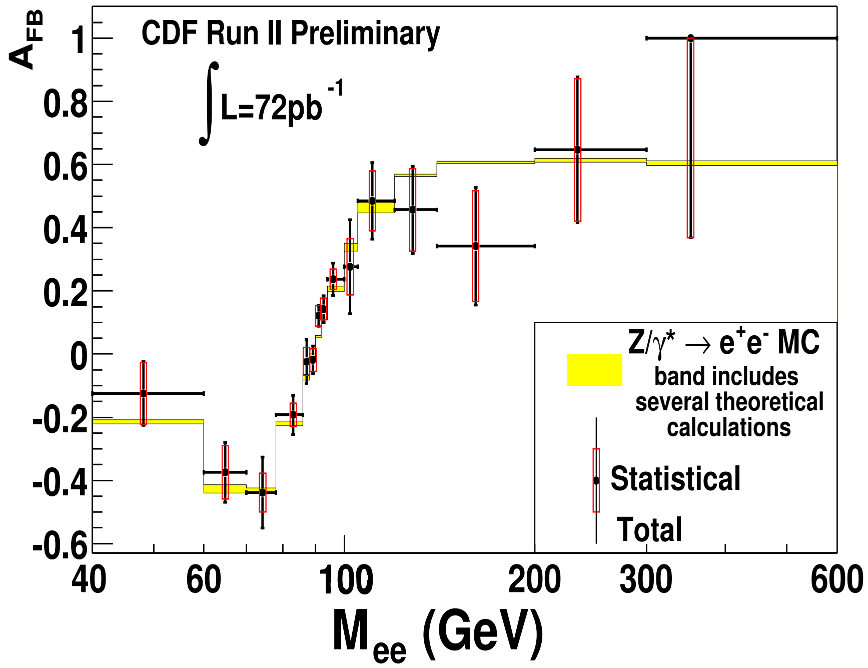
$Z \to ee$ Forward-Backward Asymmetry

- Tevatron uniquely sensitive to $Z - \gamma^*$ interference at high invariant mass
- Shape of the A_{FB} spectrum can be used to extract values for $\sin^2\theta_W$ and u, d couplings to Z boson

$$A_{FB} = \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)}$$

- Run I (108 pb^{-1})
- Run II (72 pb^{-1})

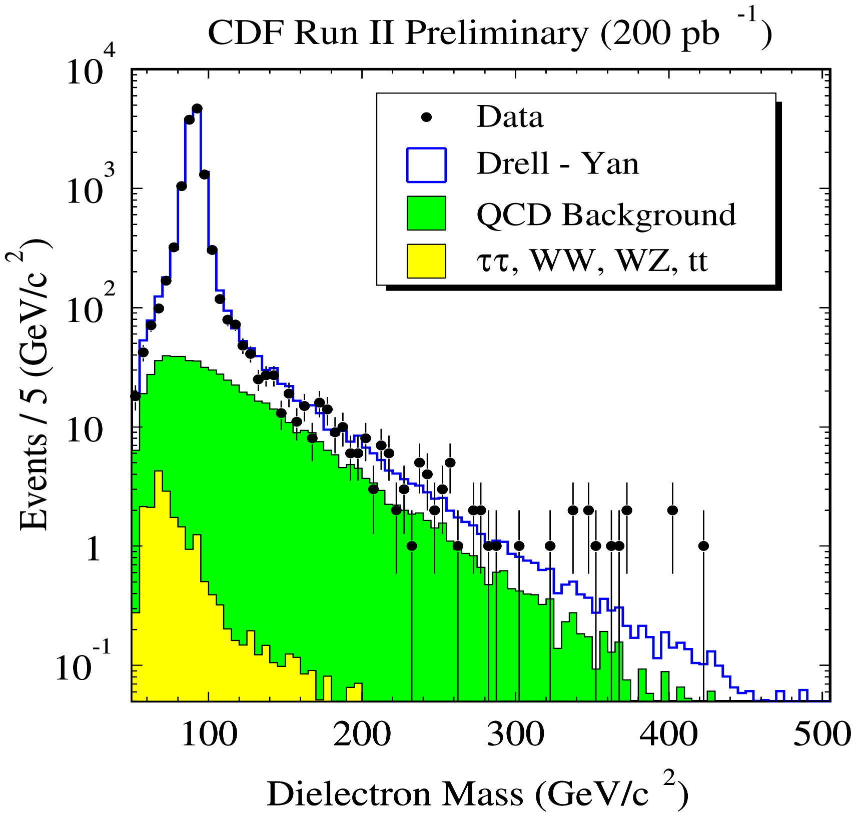




High Mass Dilepton

- 2 central (CC)
- 1 central & 1 forward (CP)
- 2 forward (PP)

– CC + CP



– PP (New result)