# Diboson Physics

26 Sep. 2008 (FAPPS)

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Contents:

- Intro and Motivation
- Previous Results
- Prospects for the future
- Conclusion

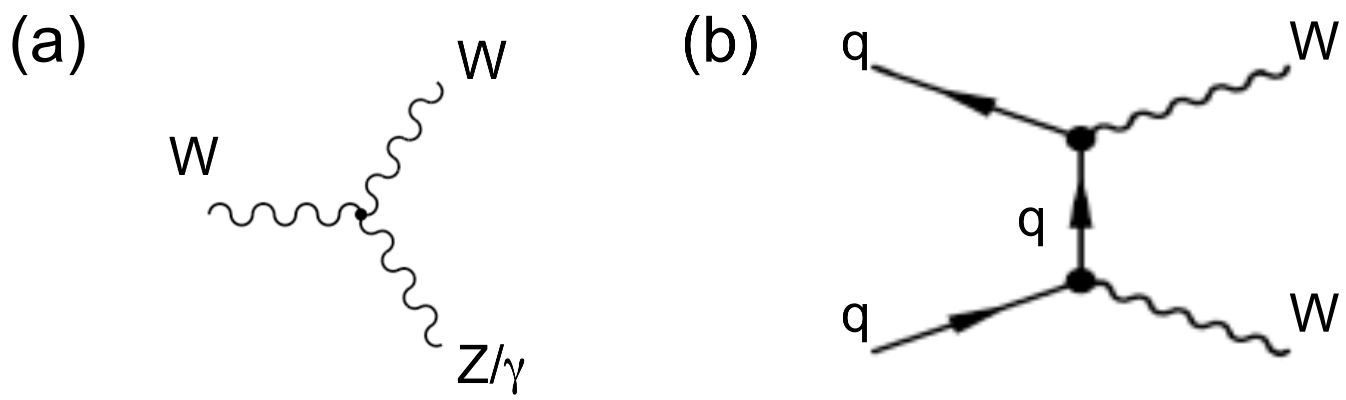
# Introduction and Motivation (1)

- Diboson Physics (in pp collider):

  pp → Boson Boson + X

(a) One can investigate weak gauge boson self interactions, like WWZ($\gamma$) and ZZZ($\gamma$).

(b) Also one can investigate (as background or signal) diboson production in qq (pp) interactions with q in t channel.



# Introduction and Motivation (2)

- The self-interaction of the weak gauge bosons ($W^{\pm}$, Z, $\gamma$) is a consequence of the non-Abelian $SU(2)_L$ gauge symmetry of the standard model. The gauge invariant kinetic term for the gauge field is

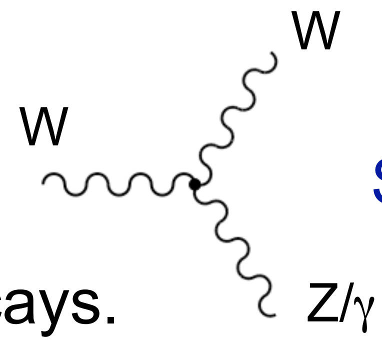
$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4} F^a_{\mu\nu} F^{a\,\mu\nu} \quad \text{with} \quad F^a_{\mu\nu} = \partial_\mu \mathrm{A}^a_\nu - \partial_\nu \mathrm{A}^a_\mu + g\, f^{abc} \mathrm{A}^b_\mu \mathrm{A}^c_\nu$$

- This leads to the 3- and 4- boson self interactions, with strength defined by the so called Three-linear/Quartic Gauge Couplings (TGC/QGC).

- The study of diboson production thus directly tests the predicted Standard Model couplings. Observations of *anomalous* couplings would be an indication of **new physics.**

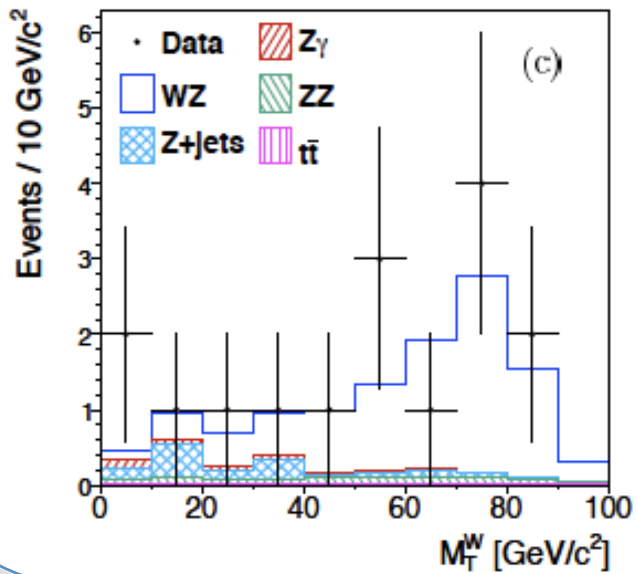
# WW / WZ / Wγ production

- Signal : pp → WW (WZ, Wγ) + X




SM

- W and Z : reconstructed by leptonic decays.
  (qq have many backgrounds.)
  - $l^{\pm}$ : High $E_T$ lepton, ν : Large missing $E_T$.
- γ : High $E_T$.




←WZ Observation at CDF
PRL98, 161801 (2007)

*Example*

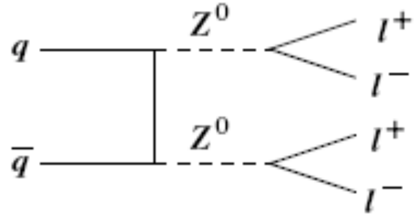
$$\sigma(p\bar{p} \to WZ) = 5.0^{+1.8}_{-1.4}\ (\text{stat.}) \pm\ 0.4\ (\text{syst.})\ \text{pb}$$

<1 deviation from SM expectation

*All results consistent with SM.*

# ZZ production

- Feynman diagram

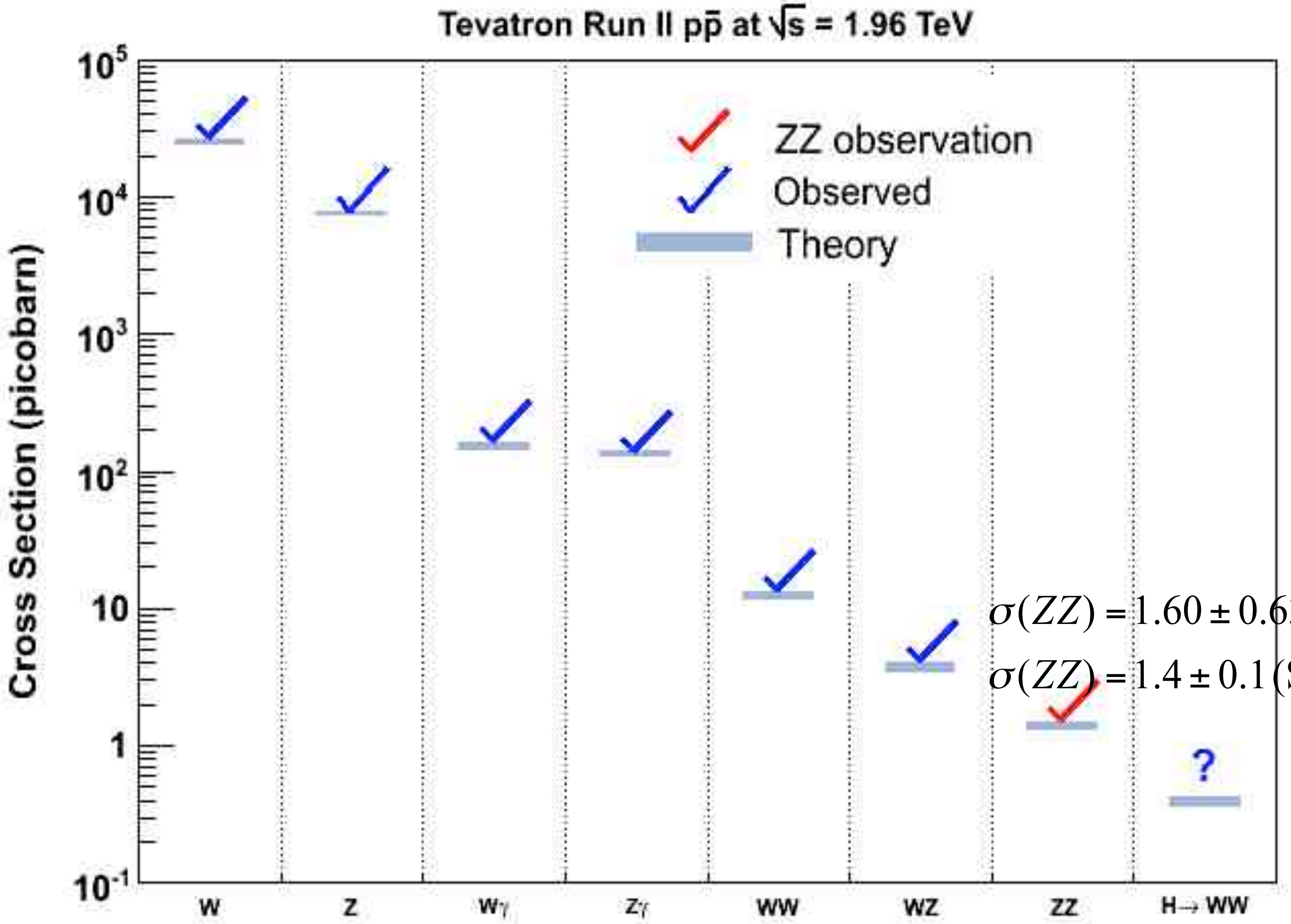



- Involving ZZV (V=Z, $\gamma$) coupling
- Signature:
  - ✓ ZZ → 4μ
  - ✓ ZZ → 4e
  - ✓ ZZ → 2e + 2μ

# ZZ production

- Conditions for selected leptons
  - ✓ Muons:
    Track matched to muon: $p_T > 15\,\text{GeV}$
    Total transverse energy deposited in calorimeter < 2.5 GeV, within R = 0.1 ~ 0.4 centered around the track.
    Muon recontructed must be required to originate from the primary event vertex.
  - ✓ Electrons:
    $E_T > 15\,\text{GeV}$
    $|\eta| < 1.1 \text{ or } 1.5 < |\eta| > 3.2$
    Must be isolated from other clusters in the calorimeter
  Invariant mass of each pair is above 50 GeV
- Main background: “Z + multi-jet” events, “t + anti-t” production

Result: only 3 events of ZZ (2 candidates for 4*e* and 1 for 4μ)




$$\sigma(ZZ) = 1.60 \pm 0.63\,(\text{stat.})\ ^{+0.16}_{-0.17}\,(\text{syst.})$$

$$\sigma(ZZ) = 1.4 \pm 0.1\,(\text{SM prediction})$$

# Diboson production with CMS

- Study $pp \to Z^0 Z^0 \to e^+ e^- e^+ e^-$

  $pp \to W Z^0 \to 3l \quad (l = e, \mu)$

- Data: PYTHIA Monte Carlo generator

| | $e^\pm e^+ e^-$ | $\mu^\pm e^+ e^-$ | $e^\pm \mu^+ \mu^-$ | $\mu^\pm \mu^+ \mu^-$ | Total | Efficiency |
|---|---|---|---|---|---|---|
| $W^\pm Z^0 \to \ell^\pm \ell^+ \ell^-$ | 14.8 | 26.9 | 28.1 | 27.0 | 96.8 | 6.2% |
| $Z^0 Z^0$ | 0.63 | 1.54 | 1.50 | — | 3.68 | 4.2% |
| $t\bar{t}$ | 0.93 | 1.55 | — | 0.31 | 2.79 | 0.02% |
| $\mu^+ \mu^- b\bar{b}$ | — | — | 6.54 | 4.9 | 11.4 | 0.005% |
| $e^+ e^- b\bar{b}$ | 1.21 | 1.82 | — | — | 3.03 | 0.007% |

| | Efficiency | $N_{\text{events}}/1\text{fb}^{-1}$ | $N_{\text{events}}/10\text{fb}^{-1}$ |
|---|---|---|---|
| $Z^0 Z^0$ | 38% | 7.1 | 71.1 |
| $Z^0 \gamma^*$ | 4.5% | 0.16 | 1.60 |
| $Z^0 b\bar{b}$ | 0.07% | 0.08 | 0.84 |
| $t\bar{t}$ | 0.06% | 0.12 | 1.22 |
| $S_{\text{L}}$ | | 4.8 | 13.1 |

With high signal-over-background ratios achieved by the $W^{\pm} Z^0$ and $Z^0 Z^0$ selections, early observation of these channels will take place at LHC.

# Conclusion

- In the SM, the couplings of the gauge bosons are derived from the non-Abelian symmetry.
- Several measurements and searches has been performed at TeVatron, and all the results are consistent with the SM.
- Precise studies at LHC are a stringent test on the SM and a probe into NP.

# Spare Slide 1
# Types of 3-Boson Vertices

- EXISTING:
  - W+(-) W+(-) Z, γ or Higgs --------> 3+3
  - W+ W- --> Z, γ, Higgs --------> 3
  - Higgs^3 ---> 1
  - HZZ ---> 1
- NOT EXISTING:
  - Z Z → Z, γ– no, but H !!!
  - γ^3
  - HZ γ
  - γ γ H, Z (tree level),.
- ???:
  - H H Z, γ

# Di - Bosons

- Don’t forget that the screen in the conference room is not wide enough,
- So make narrower slides !!!

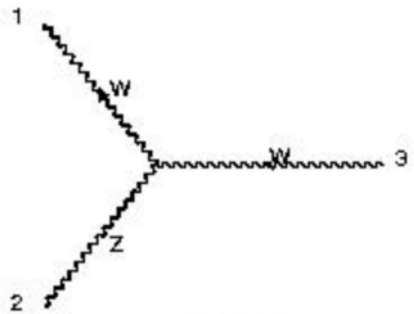
- Also we should include references in the text !!! (maybe just 1 reference for each of the papers that we have read, or if you found something interesting)

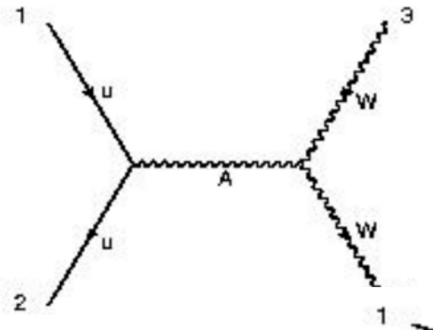
- Contents:
  - Intro and Motivation
  - WWZ
  - ZZ $\gamma$
  - conclusion

# Introduction and Motivation (1)

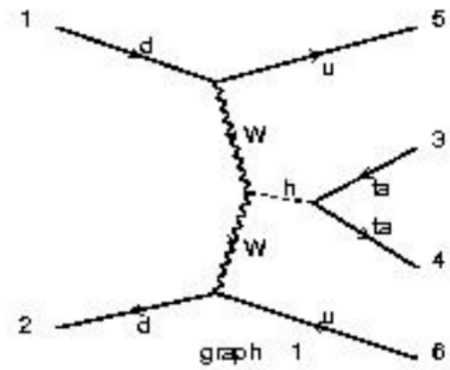
- By Di Boson we mean “process including a vertex with at least 2 Bosons
- One can investigate
  - Weak Gauge Boson (WGB) self interactions → we are going to talk only about some of them, like WWZ(γ) and ZZZ(γ)

    (here we have WWZ; the diagrams for WW γ and ZZZ(γ) look the same)



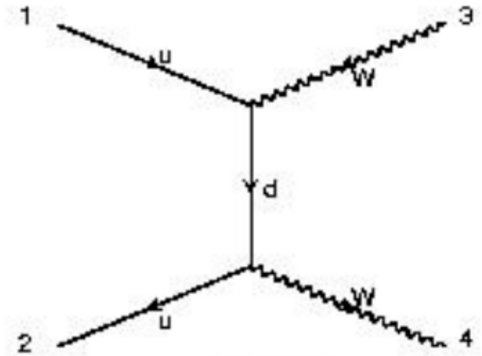




  - WGB and Higgs interactions (e.g. W+W-H, ZZH) (important for the Higgs mass region ~120 GeV where we can look at the Higgs → tau, tau decay; and the higgs comes from vector boson fusion)



# Introduction and Motivation (2)

- Also one can investigate (as background or signal) “DiBoson (ZZ, W+W-) production in qq (pp) interactions with q in t channel)




- Why study dibosons? (Motivation) (maybe we can move this earlier):
  - Test EW sector of SM and Search for New Physics (SUSY)
  - Search Higgs?: diagram qq → WWqq→ qq tau, tau

# Introduction and Motivation (2)

- The self-interaction of the weak gauge bosons (the $W^{\pm}$, the Z, and the photon) is a consequence of the non-Abelian $SU(2)_L$ gauge symmetry of the Standard Model. The gauge invariant kinetic term for the gauge field is

$$\mathcal{L}_{\text{gauge}} = -\frac{1}{4} F^{a}_{\mu\nu} F^{a\,\mu\nu} \quad \text{with} \quad F^{a}_{\mu\nu} = \partial_{\mu} A^{a}_{\nu} - \partial_{\nu} A^{a}_{\mu} + g\, f^{abc} A^{b}_{\mu} A^{c}_{\nu}$$

- This leads to the 3- and 4- boson self interactions, with strength defined by the so called Three-linear/Quartic Gauge Couplings (TGC/QGC)
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- This leads to the 3- and 4- boson self interactions, with strength defined by the so called Three-linear/Quartic Gauge Couplings (TGC/QGC)
- **In practice** the New Physics effects can be parametrized as deviations from the SM couplings in an effective Lagrangian.

$$\mathcal{L}_{\mathrm{WWV}} = g_{\mathrm{WWV}} \left\{ i g_1^{\mathrm{V}} [\mathrm{W}_{\mu\nu} \mathrm{W}^{\mu} \mathrm{V}^{\nu} - \mathrm{W}_{\mu} \mathrm{V}_{\nu} \mathrm{W}^{\mu\nu}] + i\kappa_{\mathrm{V}} \mathrm{W}_{\mu} \mathrm{W}_{\nu} \mathrm{V}^{\mu\nu} + \frac{i\lambda_{\mathrm{V}}}{M_{\mathrm{W}}^2} \mathrm{W}_{\lambda\mu} \mathrm{W}^{\mu}_{\nu} \mathrm{V}^{\nu\lambda} \right\}$$

- The study of diboson production thus directly tests the predicted Standard Model couplings. Observations of *anomalous* couplings would be an indication of **new physics.**

# Introduction and Motivation (3)

- **In practice** the New Physics effects can be parametrized as deviations from the SM couplings in an effective Lagrangian. E.g. for WWZ or WWγ interactions (WWV) one uses

$$\mathcal{L}_{\mathrm{WWV}} = g_{\mathrm{WWV}} \left\{ i g_1^{\mathrm{V}} [\mathrm{W}_{\mu\nu} \mathrm{W}^{\mu} \mathrm{V}^{\nu} - \mathrm{W}_{\mu} \mathrm{V}_{\nu} \mathrm{W}^{\mu\nu}] + i \kappa_{\mathrm{V}} \mathrm{W}_{\mu} \mathrm{W}_{\nu} \mathrm{V}^{\mu\nu} + \frac{i\lambda_{\mathrm{V}}}{M_{\mathrm{W}}^2} \mathrm{W}_{\lambda\mu} \mathrm{W}^{\mu}_{\nu} \mathrm{V}^{\nu\lambda} \right\}$$

  where $g_1^V$, $\kappa_V$ and $\lambda_V$ are 5 C- and P- conserving parameters ($g_1^\gamma$ = 1 by EM gauge invariance)
- If all we have is the SM then $g_1$ and κ should be equal to 1 (λ = 0 in SM ??)
- Normally one looks for deviation of these parameters from 1, i.e. tries to measure $\Delta g_1$ and Δκ ($\Delta g_1 = g_1 - 1$; $\Delta\kappa = \kappa - 1$)

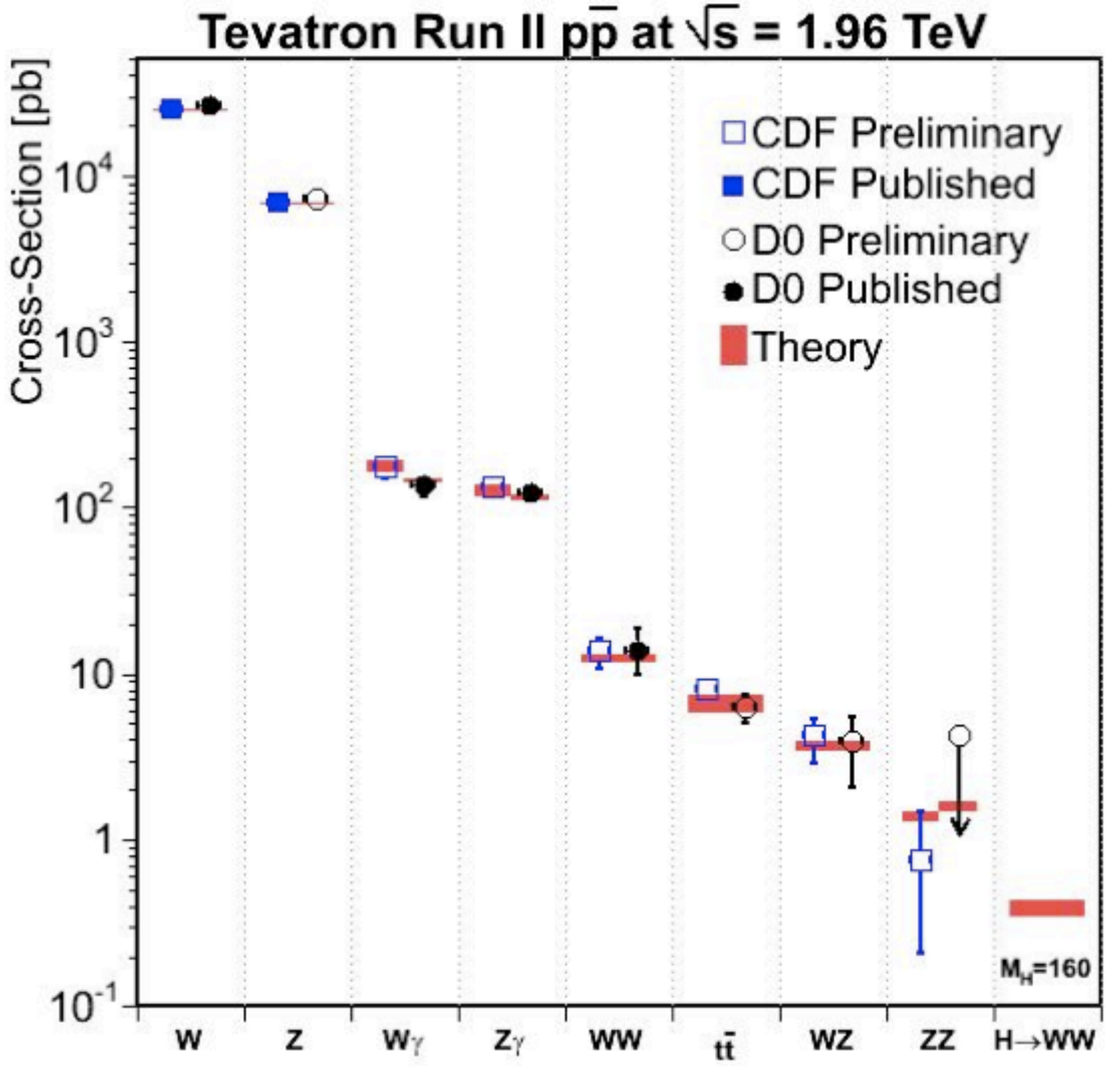
# Systematic uncertainties (CDF)

**Systematic Uncertainties**

| | Fractional Uncertainties (%) | | | | | |
|---|---|---|---|---|---|---|
| Source | $WZ$ | $ZZ$ | $Z\gamma$ | $t\bar{t}$ | $Z$+jets | $\sigma(WZ)$ |
| Cross-section | - | 10.0 | 22.0 | 15.0 | - | 2.0 |
| Energy Scale | 1.0 | 1.0 | 1.0 | - | - | 1.1 |
| $\not{E}_T$ Modeling | 1.0 | 1.0 | 25.0 | 1.0 | - | 2.4 |
| PDF Uncertainty | 2.0 | 2.0 | 2.0 | 2.0 | - | 2.3 |
| LepId $\pm 1\sigma$ | 1.9 | 2.0 | 1.9 | 1.8 | - | 2.2 |
| Trigger Eff | 1.5 | 1.9 | 5.7 | 2.4 | - | 2.0 |
| Jet$\rightarrow$Lepton Mis-Id | - | - | - | - | 19.4 | 2.4 |
| Total | 3.5 | 10.7 | 33.9 | 15.5 | 19.4 | 5.6 |
| Luminosity | 6.0 | 6.0 | 6.0 | 6.0 | - | 6.8 |

consistent with the NLO cross section value of 3.7 ± 0.3 pb.

Result: only 3 events of ZZ (2 candidates for 4$e$ and 1 for 4$\mu$)




CDF Online updates for Aug. 2007