Diboson Physics at CDF

European Physical Society
Conference on High Energy Physics
Manchester, 2007

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on behalf of the CDF collaboration

Why diboson physics?

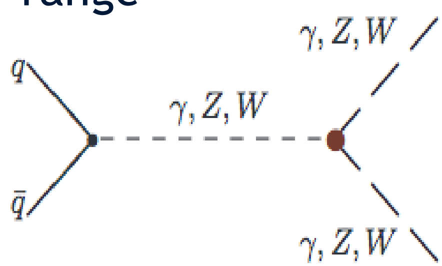
A step towards the higgs and new physics!

- **Verification of the Standard Model (SM) predictions**
  - Cross section measurements
  - Trilinear Gauge Coupling (TGC) measurements
    - Sensitive to new physics
      - eg. ZZZ, ZZγ, Zγγ absent in SM
    - TeV ($p\bar{p}$) with respect to LEP (e^+e^-):
      - sensitive to different TGC combinations
      - explores higher energy range

Absent at LEP

Process		
$q\bar{q}' \to W^{(*)}$	$\to W\gamma$:	$WW\gamma$ only
$q\bar{q}' \to W^{(*)}$	$\to WZ$:	WWZ only
$q\bar{q} \to Z/\gamma^{(*)}$	$\to WW$:	$WW\gamma, WWZ$
$q\bar{q} \to Z/\gamma^{(*)}$	$\to Z\gamma$:	$ZZ\gamma, Z\gamma\gamma$
$q\bar{q} \to Z/\gamma^{(*)}$	$\to ZZ$:	$ZZ\gamma, ZZZ$

Absent in SM



- **Significant backgrounds for several interesting processes**
  - eg. $H \to WW$, SUSY channels
- **Processes topologically similar to WH, ZH, SUSY**
  - Techniques developed in these analyses also applicable there

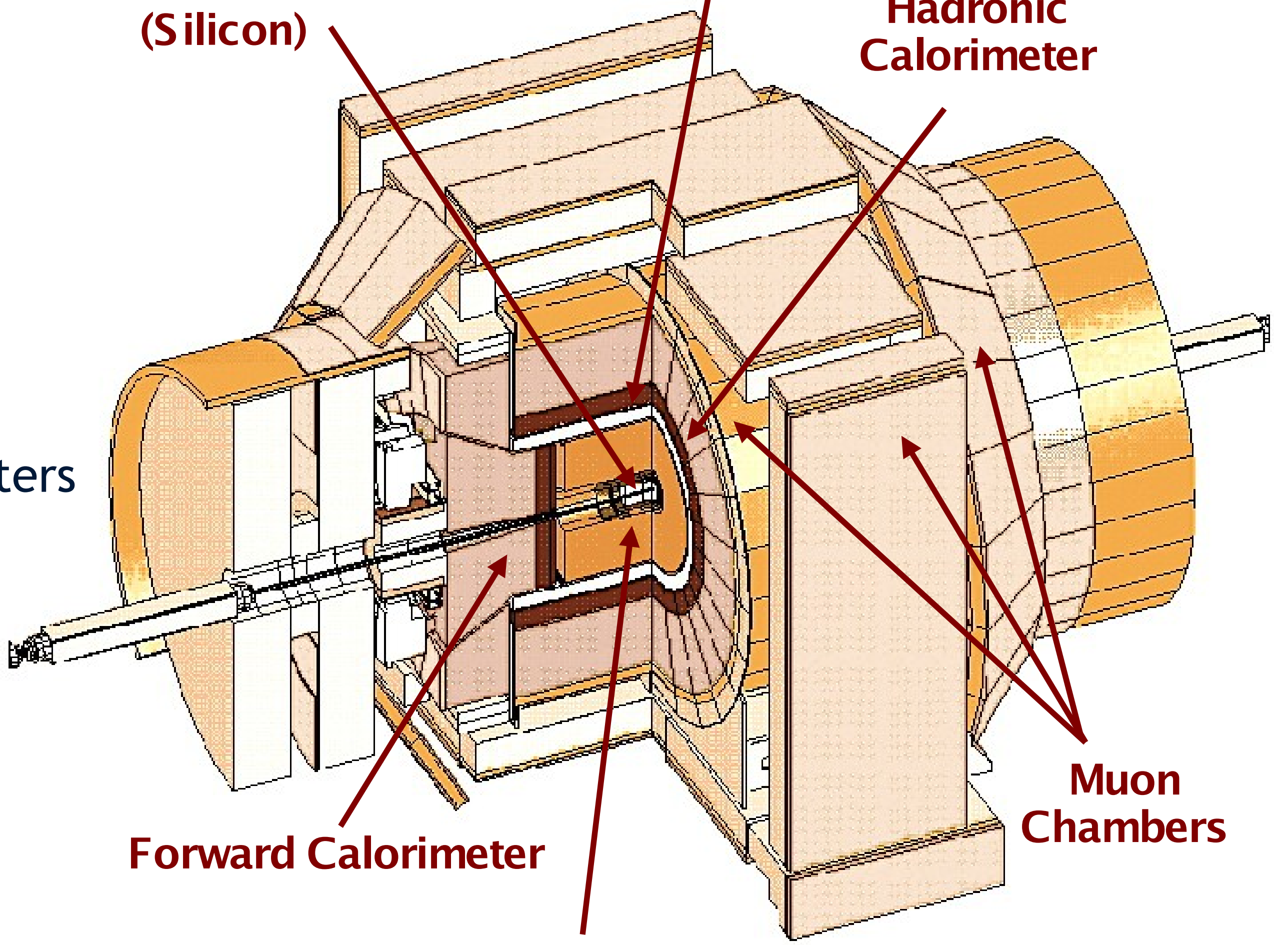
The CDF II Detector

A general purpose detector at FNAL
Designed with the classical layered structure

Precise tracking
- Silicon Detector
- Central Drift Chamber

Calorimetry
- EM and Hadronic scintillator-based calorimeters
- Coverage up to |η|<3.0

Muon Chambers
- System of scintillators and proportional chambers
- Coverage up to |η|<2.0

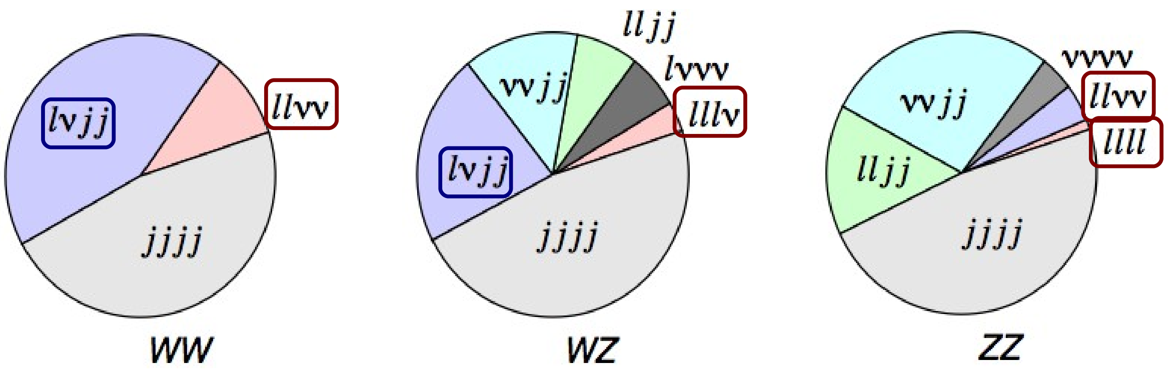


Heavy Boson + Photon Production

$W(\rightarrow l\,\nu)+\gamma$
$Z\,(\rightarrow e^+e^-)+\gamma$

Clean Signatures and High Yields

Heavy Diboson Production



Leptonic Decay Channels

$WW \rightarrow l\nu l\nu$
$WZ \rightarrow lll\nu$
$ZZ \rightarrow llll$ / $ll\nu\nu$

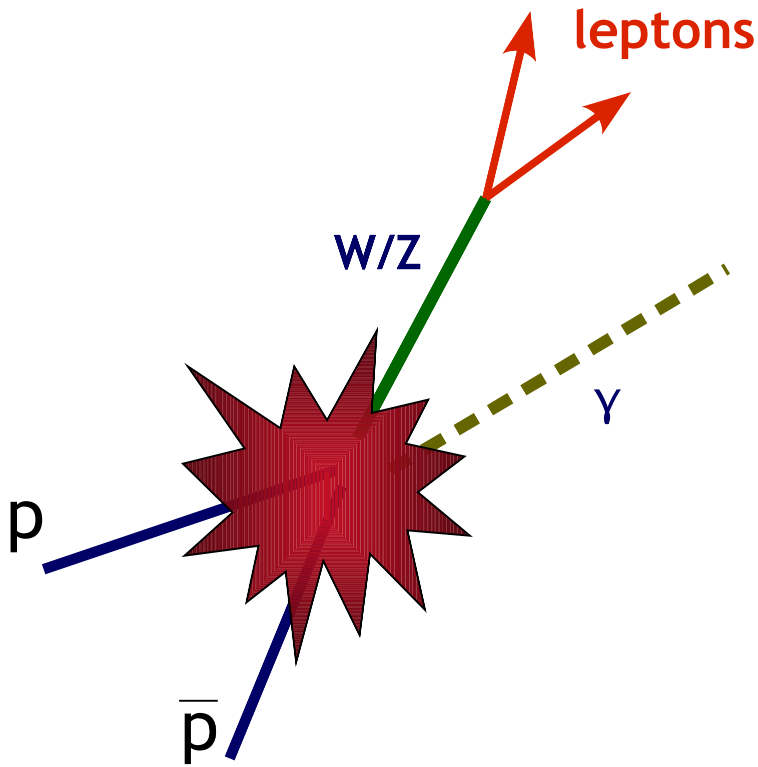
Small Branching Fraction & Low Backgrounds
⇒ **Clean Signals but Low Yields**

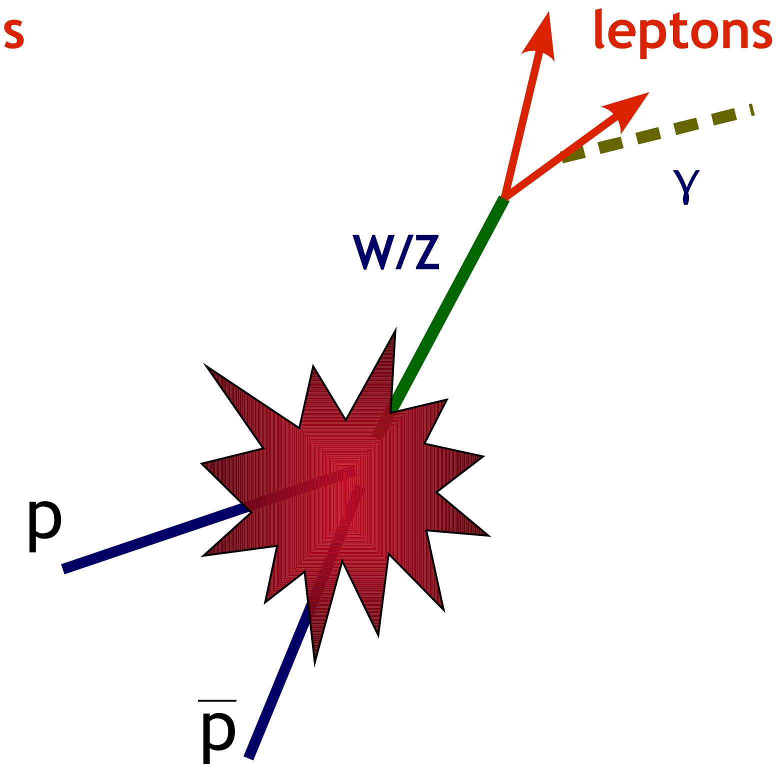
Semileptonic Decay Channels

$WW+WZ \rightarrow l\nu jj$

Larger Branching Fraction & Much Larger Backgrounds
⇒ **Signal / Background < 0.5%**

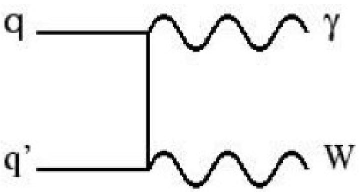
Heavy boson + γ



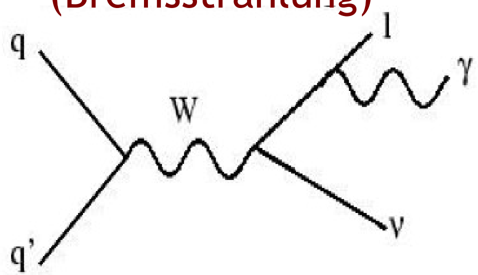


$W(\to l\nu)+\gamma$

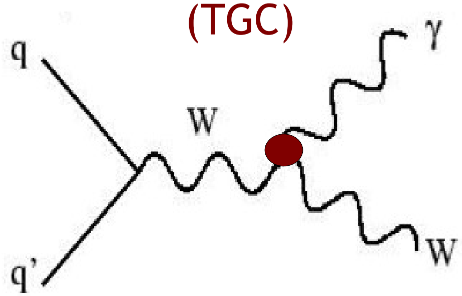
Initial State Radiation



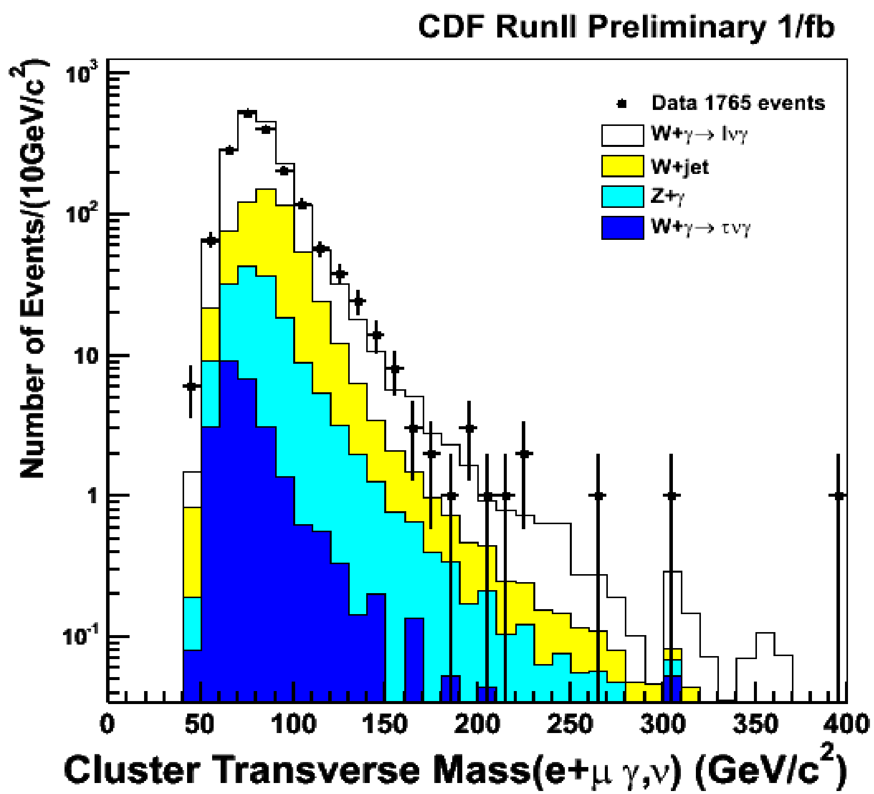
Final State Radiation (Bremsstrahlung)



Photon Radiated from a W (TGC)



Combined e/μ result



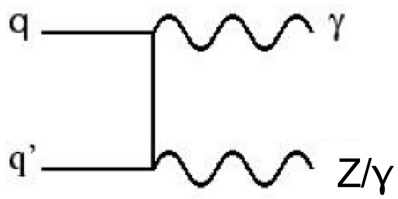
$\sigma(W\gamma)$*BR($W\to l\nu$) = 18.03±0.65(stat)±2.55(sys)±1.05(lumi) pb

NLO prediction: $\sigma(W\gamma)$*BR($W\to l\nu$) = 19.3±1.4 pb

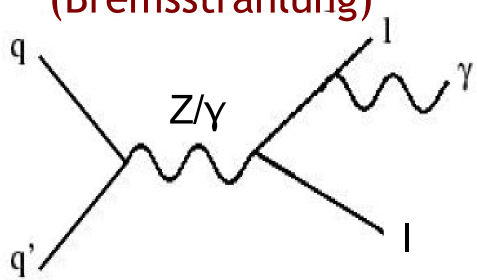
Result compatible with the SM expectations!

$Z(\rightarrow e^+e^-)+\gamma$

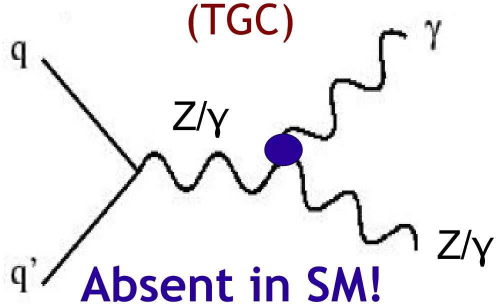
Initial State Radiation



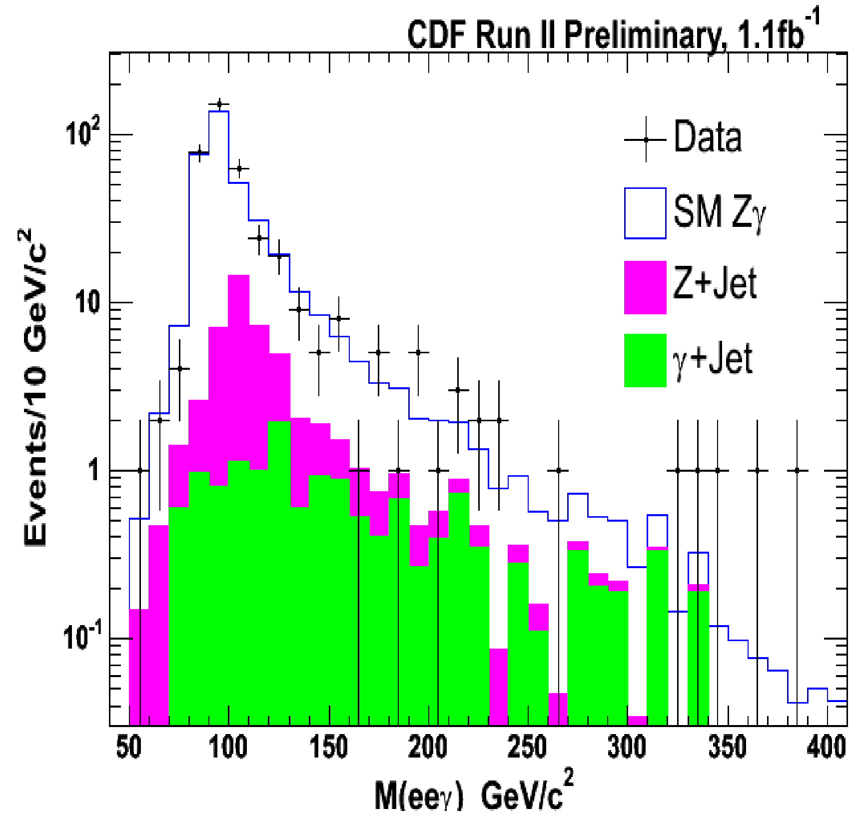
Final State Radiation (Bremsstrahlung)



Photon Radiated from a Z (TGC)



Absent in SM!

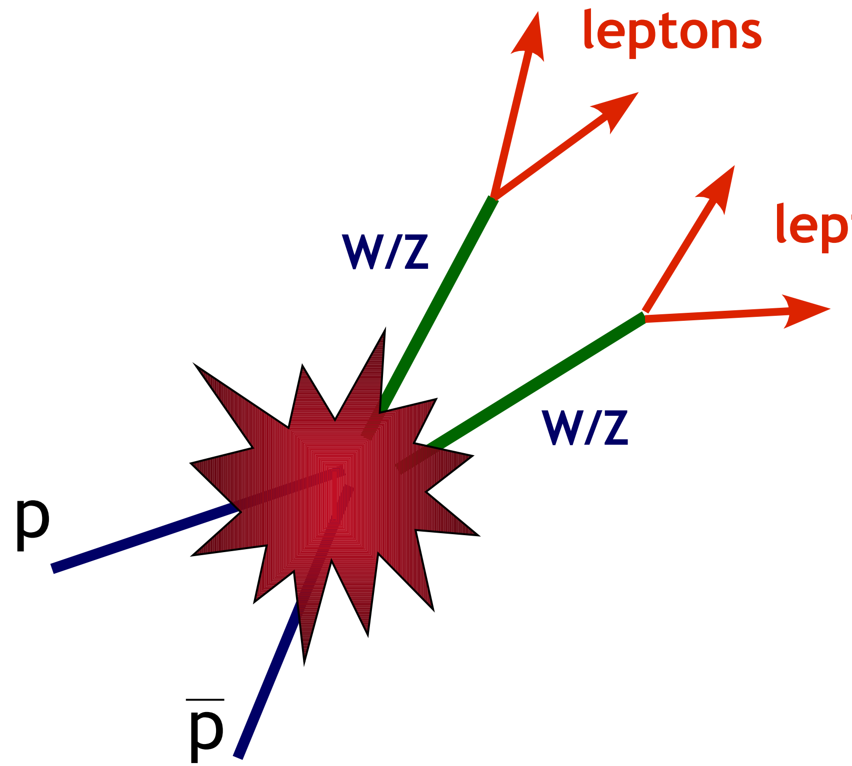


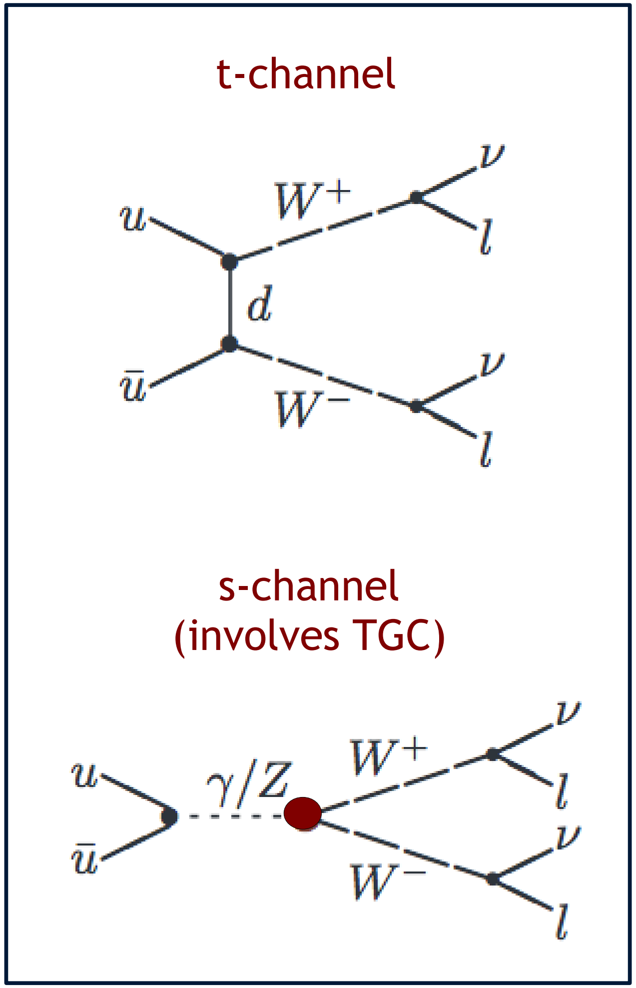
$\sigma(Z\gamma)*BR(Z\rightarrow e^+e^-) = 4.9\pm0.3(stat)\pm0.3(sys)\pm0.3(lumi)$ pb

NLO prediction: $\sigma(Z\gamma)*BR(Z\rightarrow e^+e^-) = 4.7\pm0.4$ pb

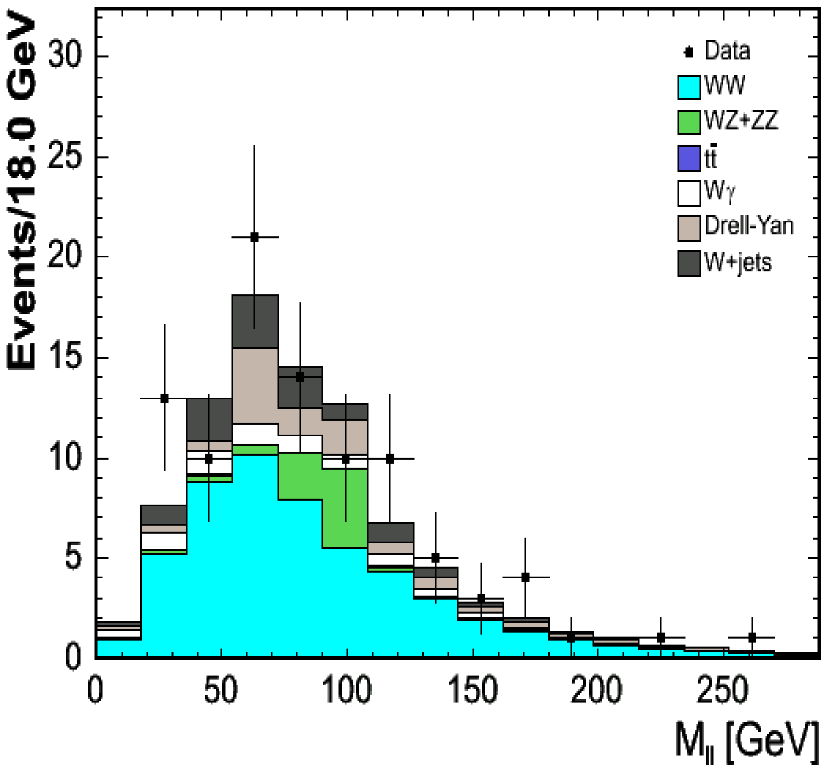
Result compatible with the SM expectations!

Heavy dibosons decaying leptonically





using $\int L\,dt = 825\ pb^{-1}$



~57 WW events observed

σ(WW) = 13.6±2.3(stat)±1.6(sys)±1.2(lumi) pb

NLO prediction: σ(WW) = 12.4 ± 0.8 pb

Result compatible with the SM expectations!

Exploit WW Kinematics in Higgs and New Physics Searches!

(see later talk by E.Lipeles)

Improved Lepton Selection

Lepton acceptance is a key in final states with 3 or more leptons!

- Try to use all tracks and electromagnetic objects found
- Use as much information as possible for each candidate

Electrons

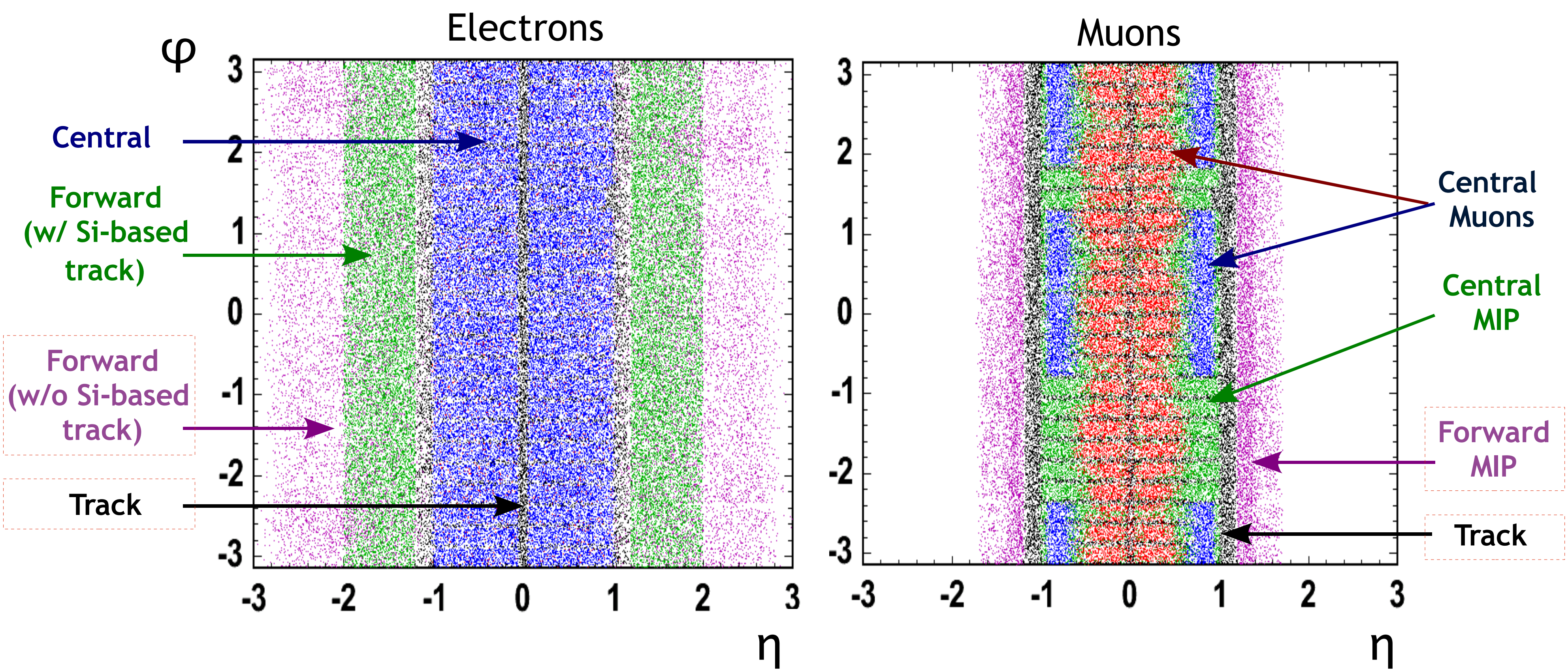
- ✓ Central calorimeter
- ✓ Forward calorimeter
  - w/ or w/o Si-based track

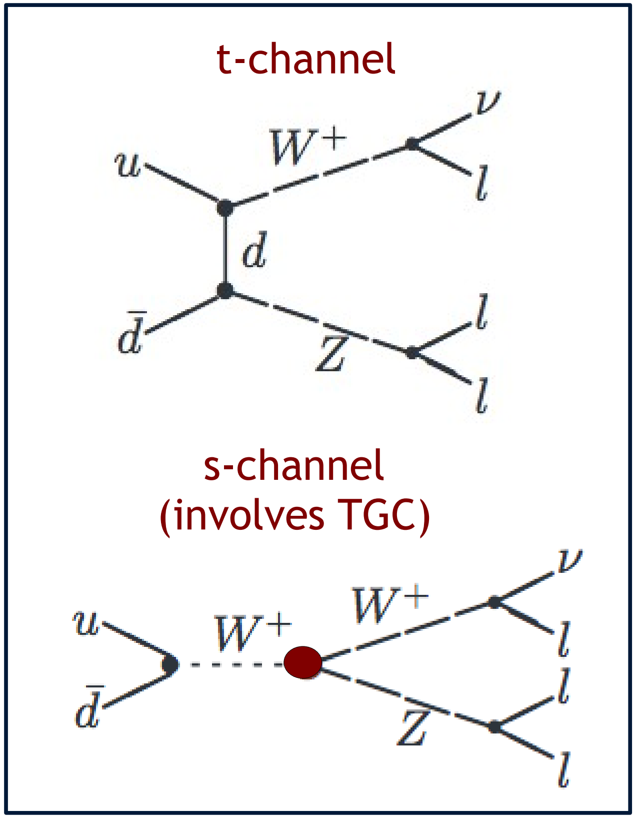
Muons

- ✓ Central muons with matched muon chamber hits
- ✓ Minimum Ionizing Particle (MIP)
  - central and forward regions

Tracks

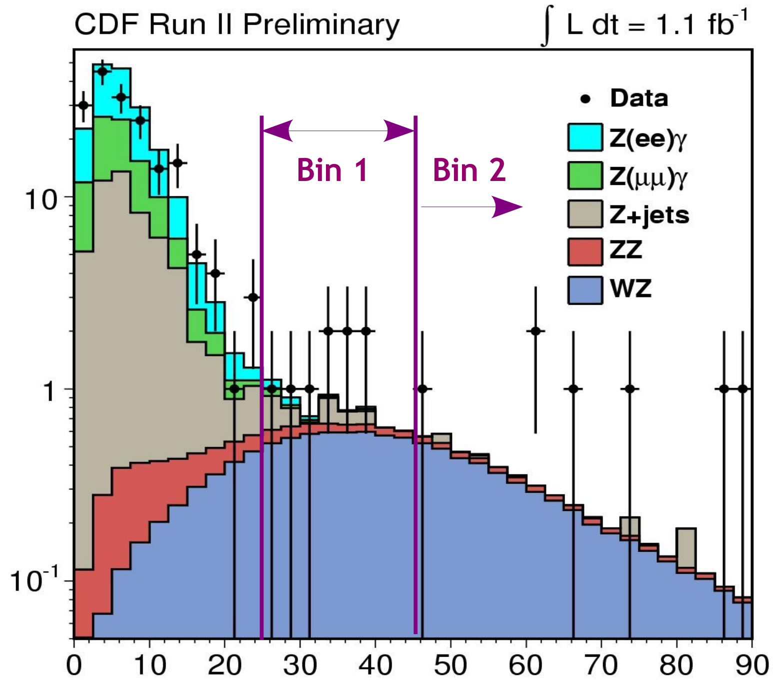
- ✓ Fill in regions not fiducial to calorimeters
- ✓ No distinction between e and μ





Improved lepton selection ~ doubles the acceptance!

⇒ **First observation of a tri–lepton signal at TeV**



$\not{E}_T$ plot used in a 2-bin fit

Expected number of signal events

9.75±0.03(stat)±0.31(sys)±0.59(lumi)

Expected number of background events

2.65±0.28(stat)±0.33(sys)±0.09(lumi)

Observed

16 events

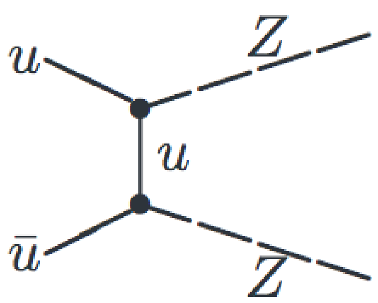
⇒ *significance 6σ*

$$\sigma(\mathrm{WZ}) = 5.0^{+1.8}_{-1.6}\ (\mathrm{stat.+syst.})\ \mathrm{pb}$$

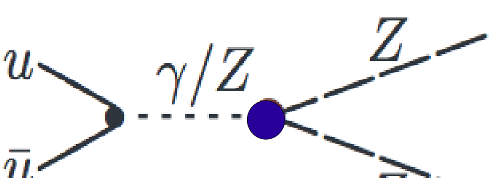
NLO prediction: σ(WZ) = 3.7 ± 0.3 pb

Result compatible with the SM expectations!

t-channel



s-channel
(involves TGC)

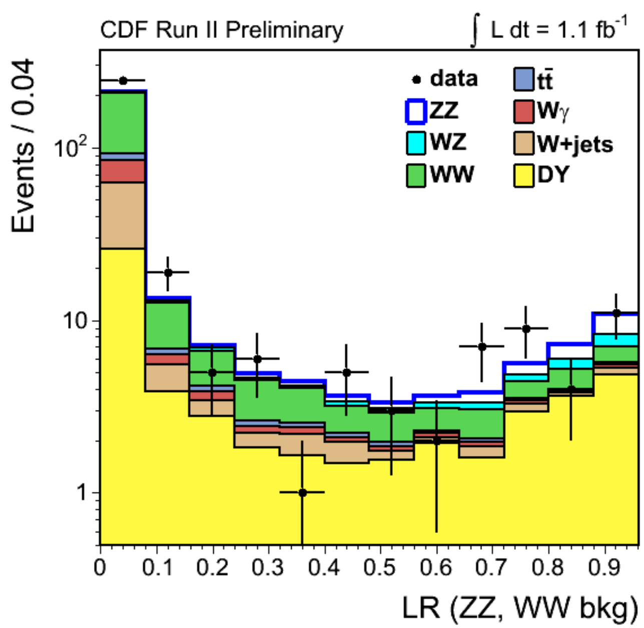


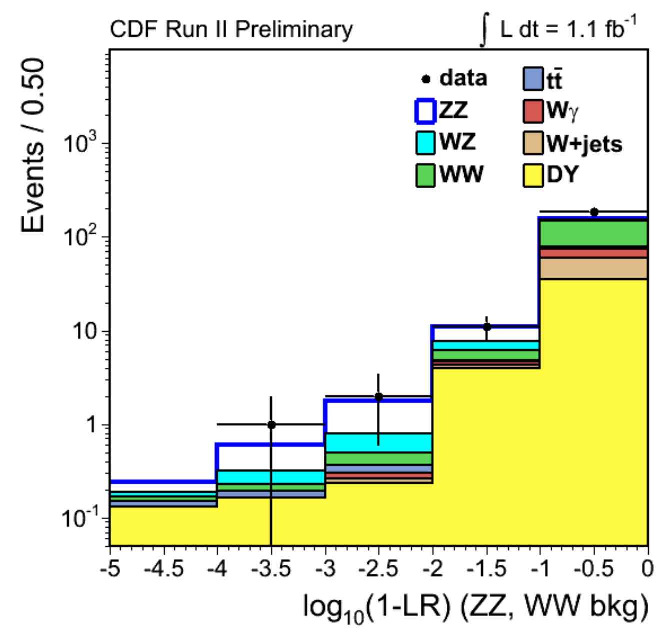
Absent in SM!

First evidence of ZZ at TeV

Analysis built from the two different modes independently

- ZZ→llll (1.5 fb^{-1})
  - Very clean but very small BR
  - 1 4-lepton event observed!
- ZZ→llνν (1.1 fb^{-1})
  - Several significant backgrounds but larger BR
  - WW/ZZ separation achieved using an event-by-event calculation of the matrix element probability





Combined result

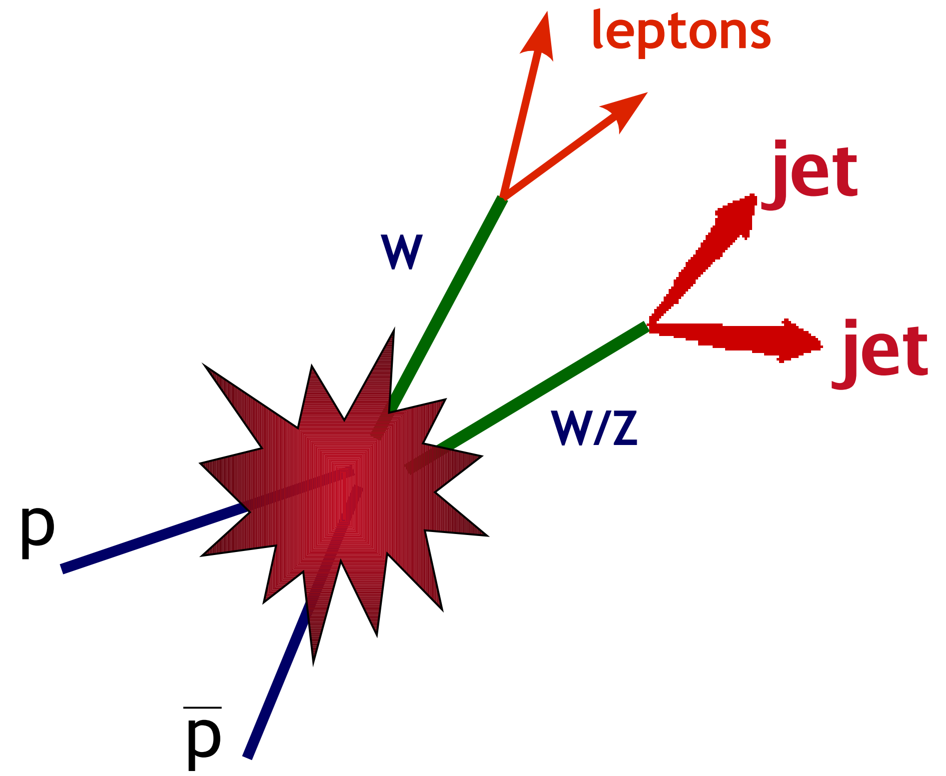
3σ significance

$$\sigma(ZZ) = 0.75^{+0.71}_{-0.54}\ (\text{stat.+syst.})\ \text{pb}$$

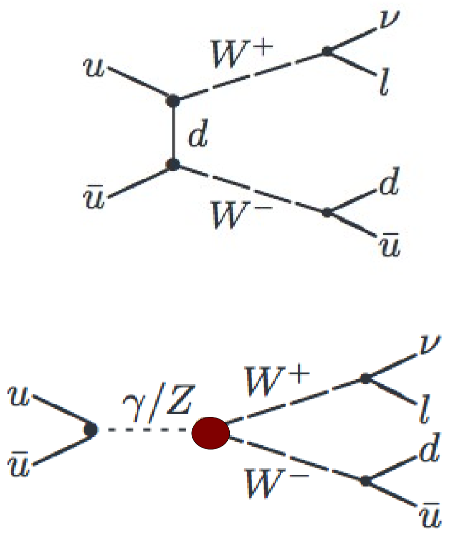
NLO prediction: σ(WZ) = 1.4 ± 0.1 pb

Result compatible with the SM expectations!

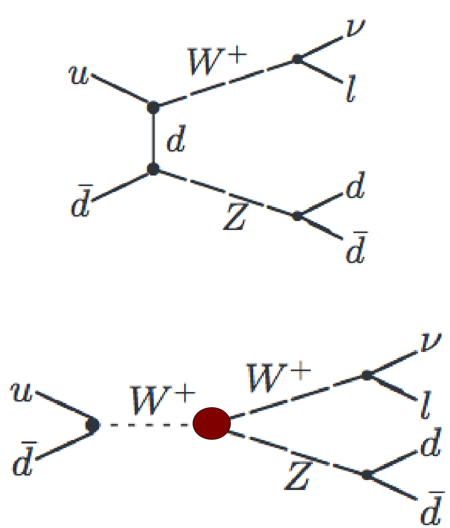
Heavy dibosons decaying semi-leptonically



WW Production



WZ Production



WW/WZ observed so far only in the fully leptonic decay channel, at TeV

Aim of this analysis the observation in the semi-leptonic channel!

Favorable channel for measuring triple gauge couplings due to the big branching ratio with respect to the leptonic channel

Signal Definition

- Exactly 1 Central Electron
- Missing Transverse Energy > 25 GeV
- 2 or more Jets (P_T>15GeV)

Backgrounds

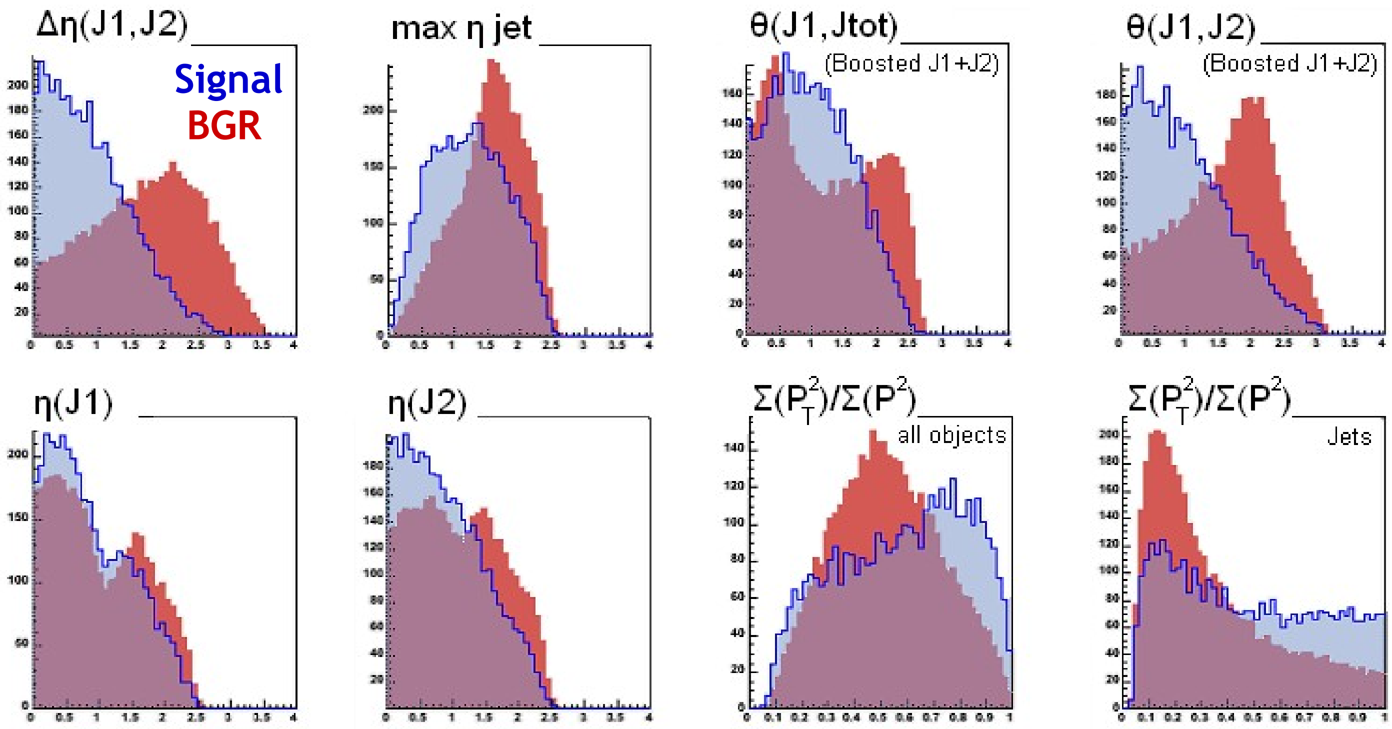
W(→eν) + jets
W(→τν) + jets
Z(→ee) + jets
QCD
t-tbar

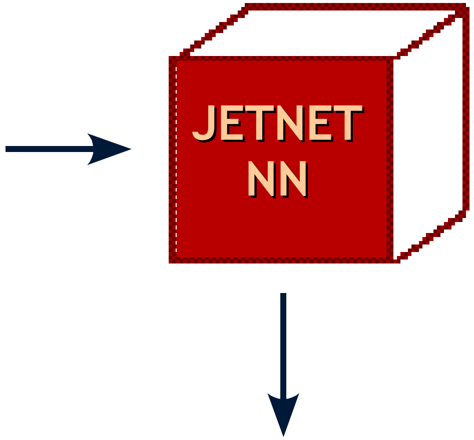
$\sigma_{WW}^{th}\times BR$ = 1.81 pb
$\sigma_{WZ}^{th}\times BR$ = 0.28 pb
$\sigma_{W(e)jj}^{th}$ = 320.4 pb

Signal/Background initially very poor

Need for a tool with big discriminative power!
⇒ Neural Network

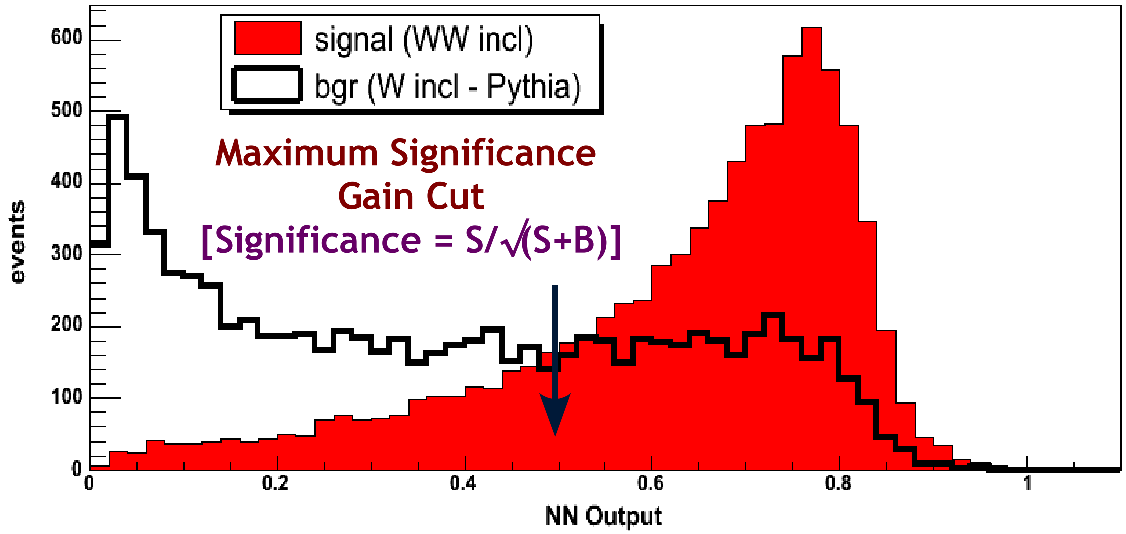
Neural Network Selection



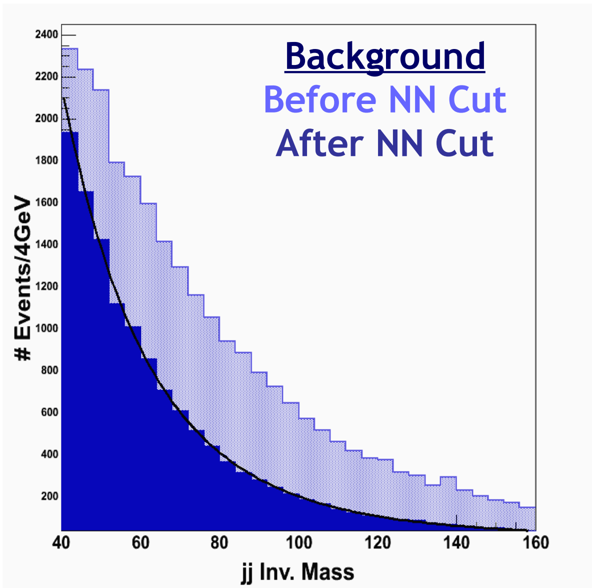


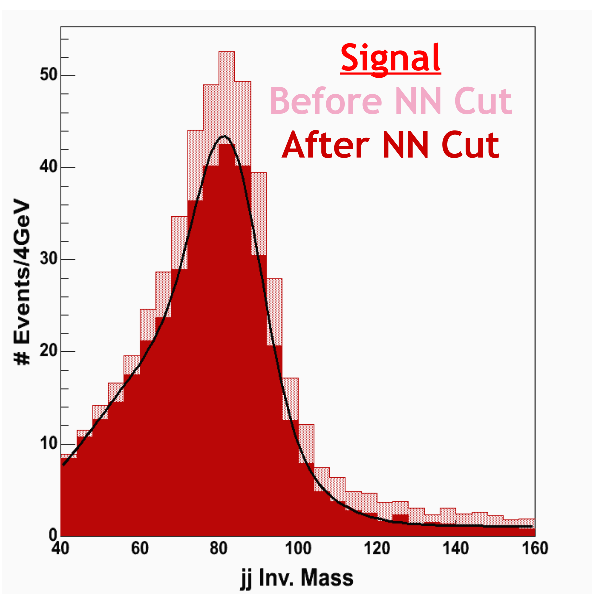
NN Input
angles or angle-related variables

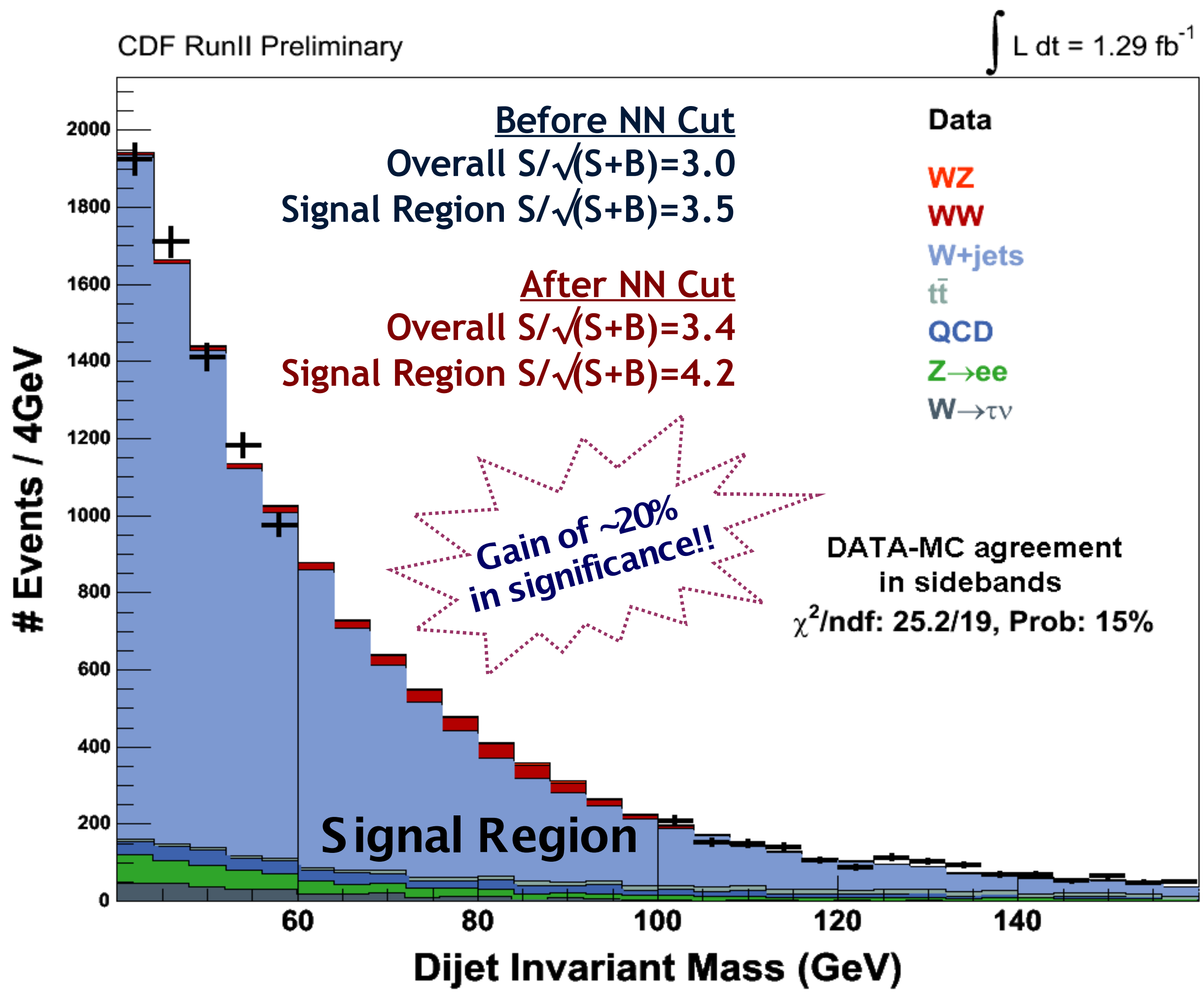
NN Output
as uncorrelated as possible with the dijet invariant mass



Dijet invariant mass after NN cut

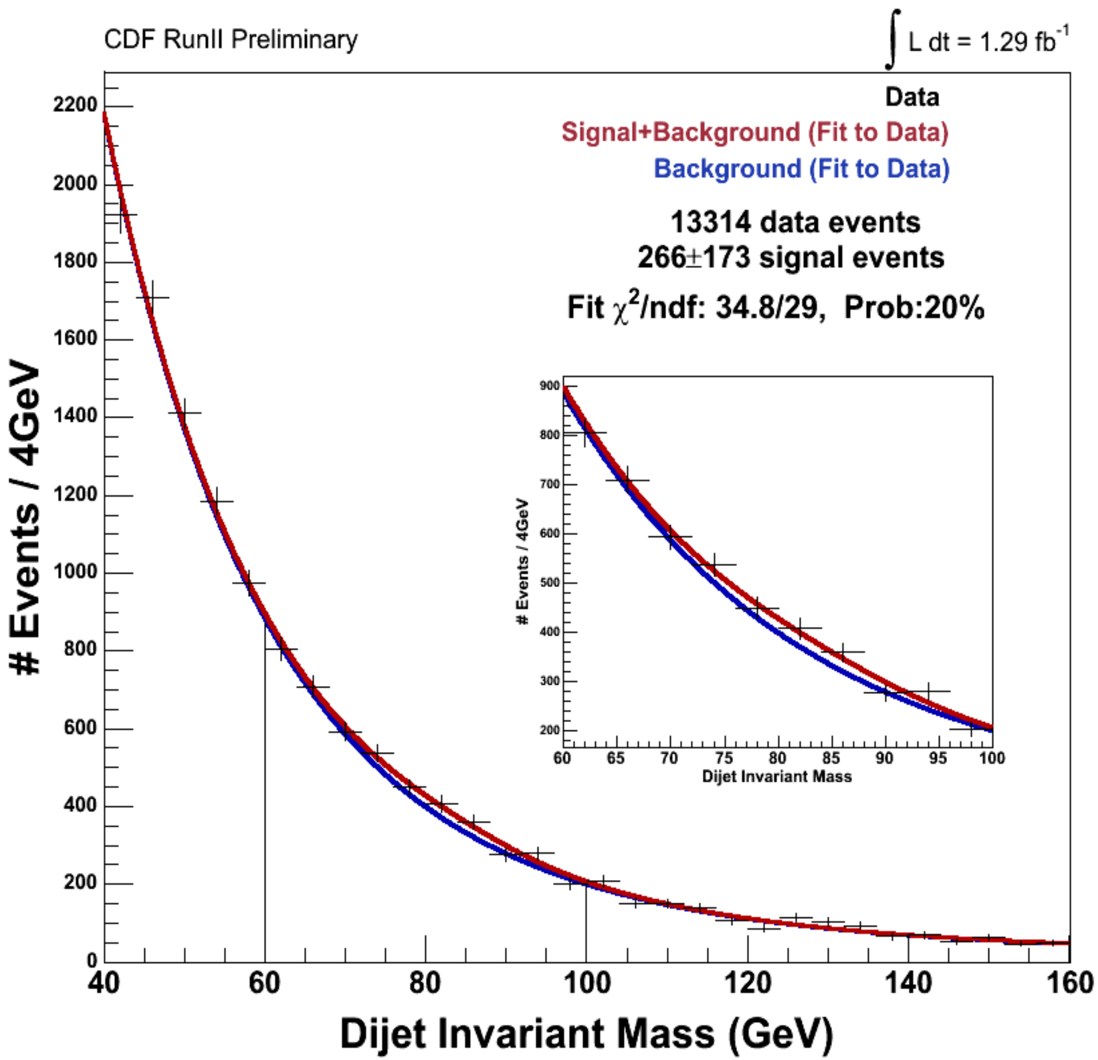






- Signal shape fixed using MC
- Background parameterization motivated by MC
- Both plugged into a likelihood fitter
- Background parameters and signal fraction given by fit to data

WW/WZ→eνjj Results



Using 1.3 fb^{-1} of data & central electrons

Significance < 2σ

(statistically limited)

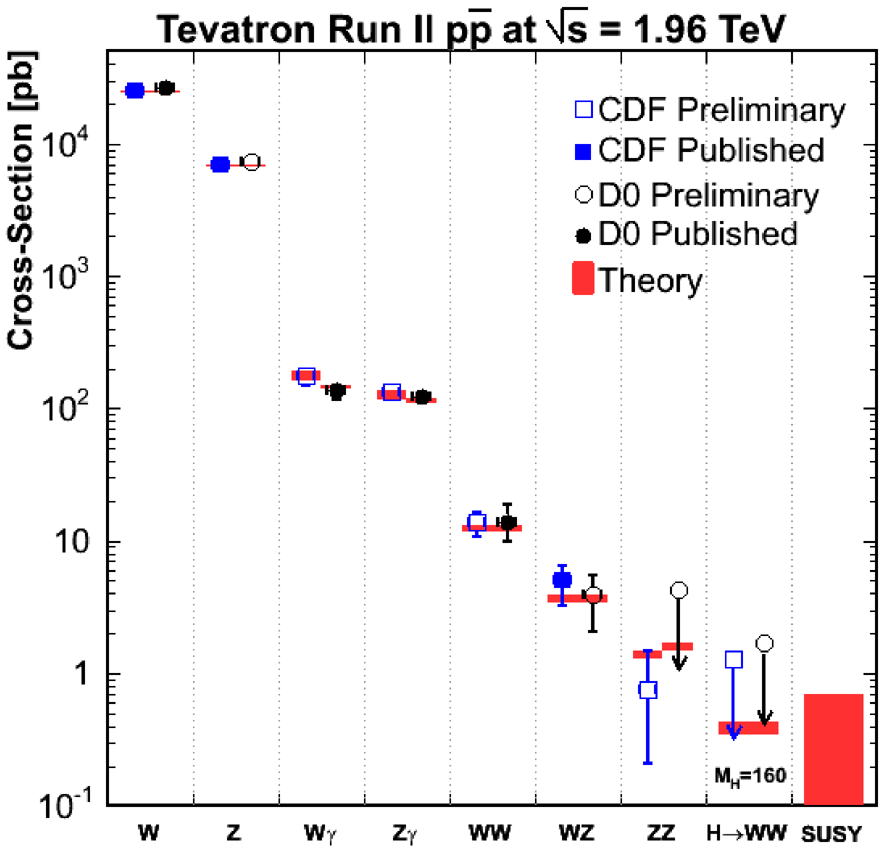
Measured Cross Section
($m_{jj} \in$ [40,160]GeV)
σ×BR = (1.45±0.95(stat)±0.29(sys)) pb

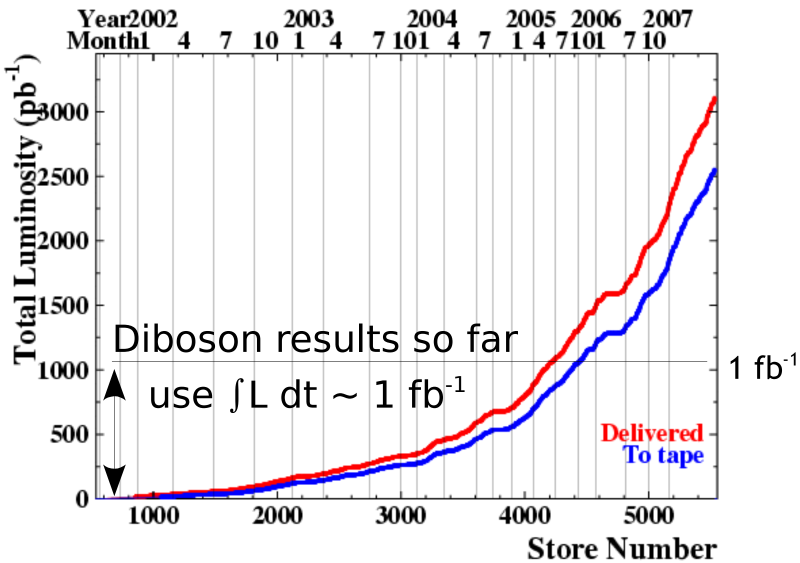
95%CL upper limit
σ×BR(W→eν,W/Z→jj) < 3.4 pb

Theoretical Cross Section
σ×BR = 2.1±0.2 pb

CDF has an intensive diboson program

- W/Z+γ precision measurements
- WW→llνν most precise measurement at TeV
- WZ 6σ observation in the leptonic channel
- ZZ 3σ evidence in the leptonic channel
- WW/WZ in the semileptonic channel
  - limit set using the electron channel
  - work on the muon channel in progress



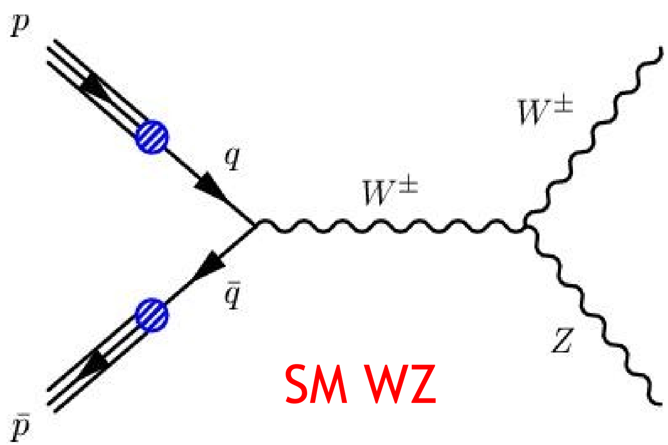


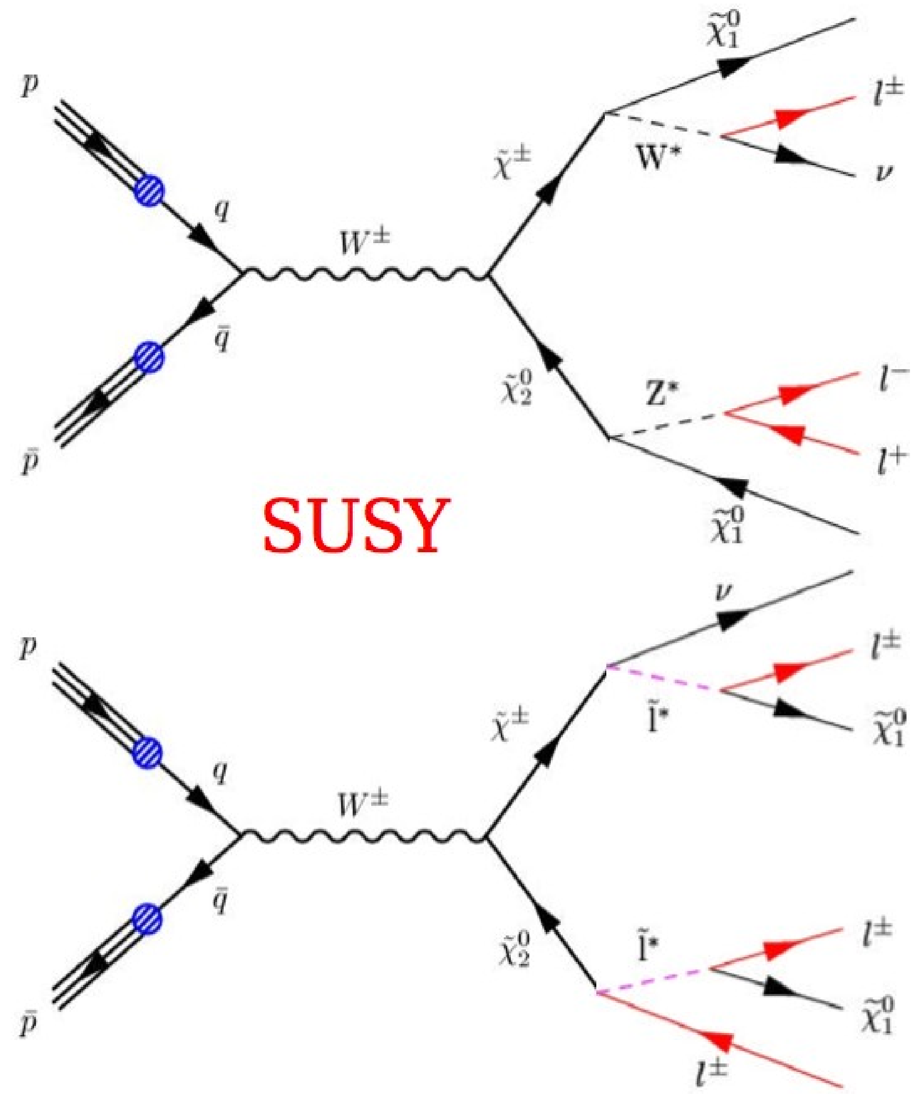
Future

- Much more data to be analyzed!
- Searches for Anomalous TGC in progress

...Stay Tuned!

Back-Up Slides





Higgs / SUSY / ???
may be hiding somewhere
in our diboson samples...

ZZ Event Yields

4-lepton Yields

Z+jets	0.026 ± 0.021 (stat.) ± 0.004 (syst.) ± 0.000 (lumi.)
$Z\gamma\gamma$	0.003 ± 0.001 (stat.) ± 0.000 (syst.) ± 0.000 (lumi.)
ZZ	2.516 ± 0.020 (stat.) ± 0.032 (syst.) ± 0.151 (lumi.)
Total Bkg	0.029 ± 0.021 (stat.) ± 0.004 (syst.) ± 0.000 (lumi.)
Total	2.545 ± 0.029 (stat.) ± 0.032 (syst.) ± 0.151 (lumi.)
Observed	**1**

Leptons+MEt Yields

Category	WW	WZ	ZZ	$t\bar{t}$	DY	$W\gamma$	W+jets	Total	Data
e e	22.8	2.8	4.3	1.5	4.8	10.8	12.1	59.1 ± 5.0	61
μ μ	17.7	2.1	3.5	1.4	15.9	0.0	2.6	43.1 ± 4.2	50
e trk	18.7	1.4	1.8	1.4	2.2	2.5	5.2	33.1 ± 2.4	42
μ trk	10.0	0.8	1.2	0.8	1.1	0.3	3.4	17.5 ± 1.3	29
Total	69.2	7.1	10.7	5.1	24.0	13.6	23.2	152.9 ± 11.6	182