First Evidence for *WZ* Production

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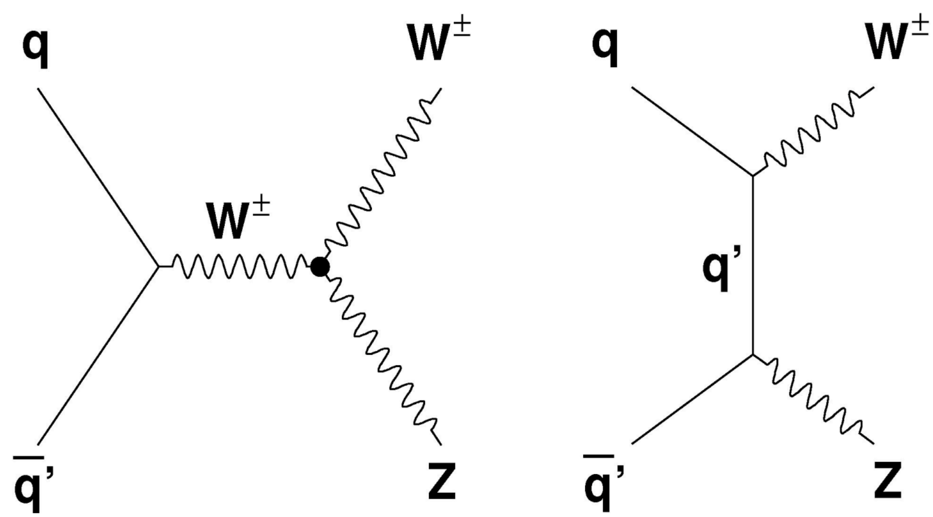
First Evidence for *WZ* Production

- Introduction to *WZ* physics at hadron colliders.
- Event Selection
- Previous Published Result
- 800 pb^{-1} Results
- Measuring the coupling strength of *W* boson to *Z* boson.
- Final Remarks

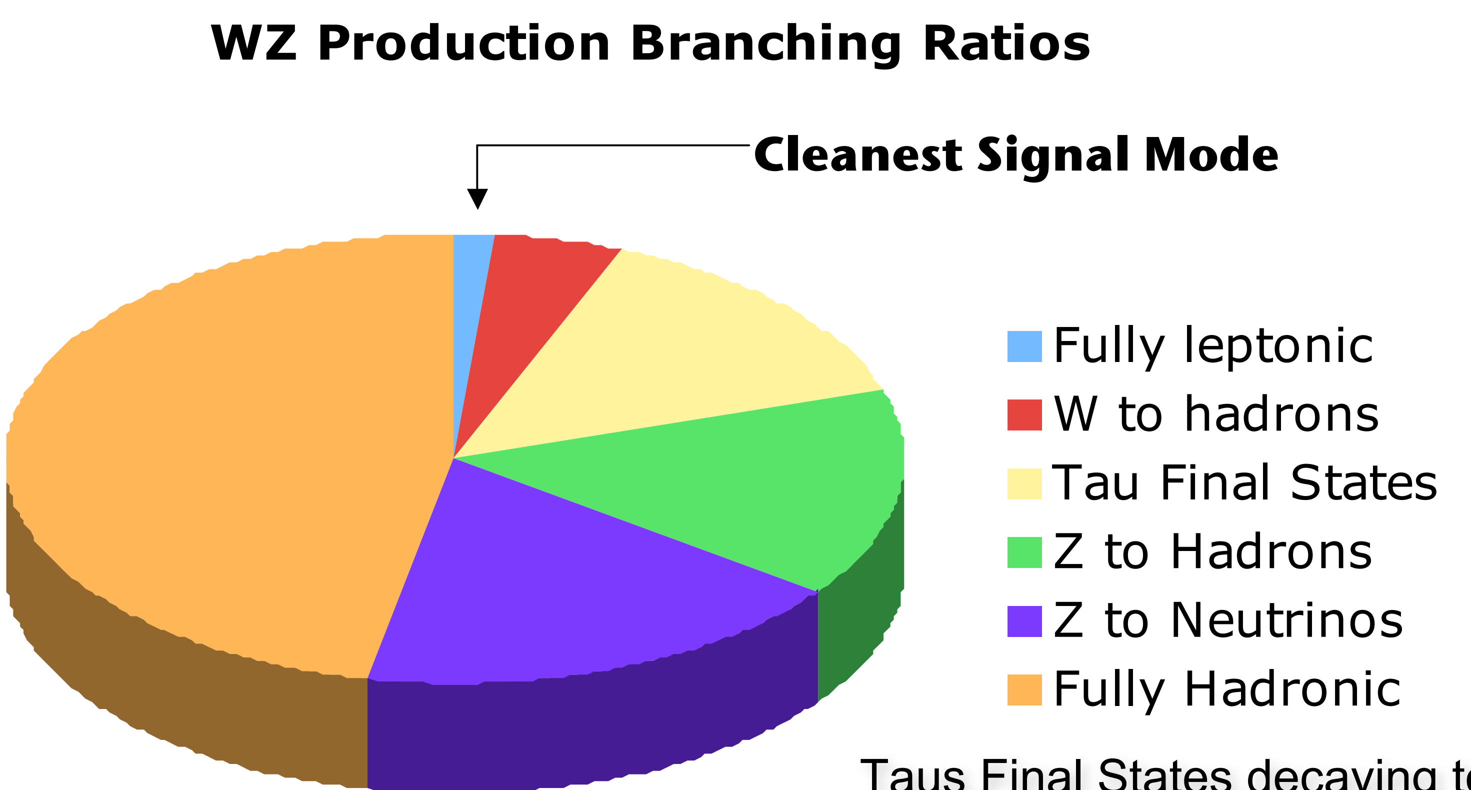
Motivation

- First opportunity to measure exclusive *WZ* final state.
  - Can only be produced at the Tevatron.
    - Need a charged intermediate state to produce associated *WZ.*
    - Need a large center of mass energy to produce *WZ.*
  - Isolates *WWZ* coupling.
- SM test and a probe for new physics.
  - SM predicts a cross section of 3.68 ± 0.25 pb.
  - Larger cross section is a manifestation of new physics.



Motivation

- Cleanest signal is from fully leptonic decay (trileptons).
  - Small branching ratio: 0.37% per channel, 1.435 ± 0.013% for four channels.
  - ✚ Smallest backgrounds.



Taus Final States decaying to signal channels is an additional 0.34 %

Measuring Coupling Strengths

$$\mathcal{L}_{eff}^{WWZ} = ig_{WWZ}(g_1^Z(W_{\mu\nu}^+ W^{-\mu} - W^{+\mu} W_{\mu\nu}^-)Z^\nu$$
$$+\kappa_Z W_\mu^+ W_\nu^- Z^{\mu\nu} + \frac{\lambda_Z}{m_W^2} W_\mu^{+\nu} W_\nu^{-\rho} Z_\rho^\mu)$$

- Cross Section analysis also allows to set limits on *WZ* couplings
- Direct measurement of *WWZ* triple gauge couplings
- Anomalous couplings are manifestations of new physics

Characterized by effective Lagrangian

3 CP Conserving SM Parameters:

$\lambda_Z = 0$

$\Delta\kappa_Z = 0$ ($\Delta\kappa_Z = \kappa_Z - 1$)

$\Delta g^1{}_Z = 0$ ($\Delta g^1{}_Z = g^1{}_Z - 1$)

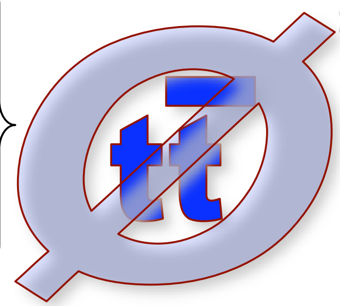
Λ is form factor cut off.

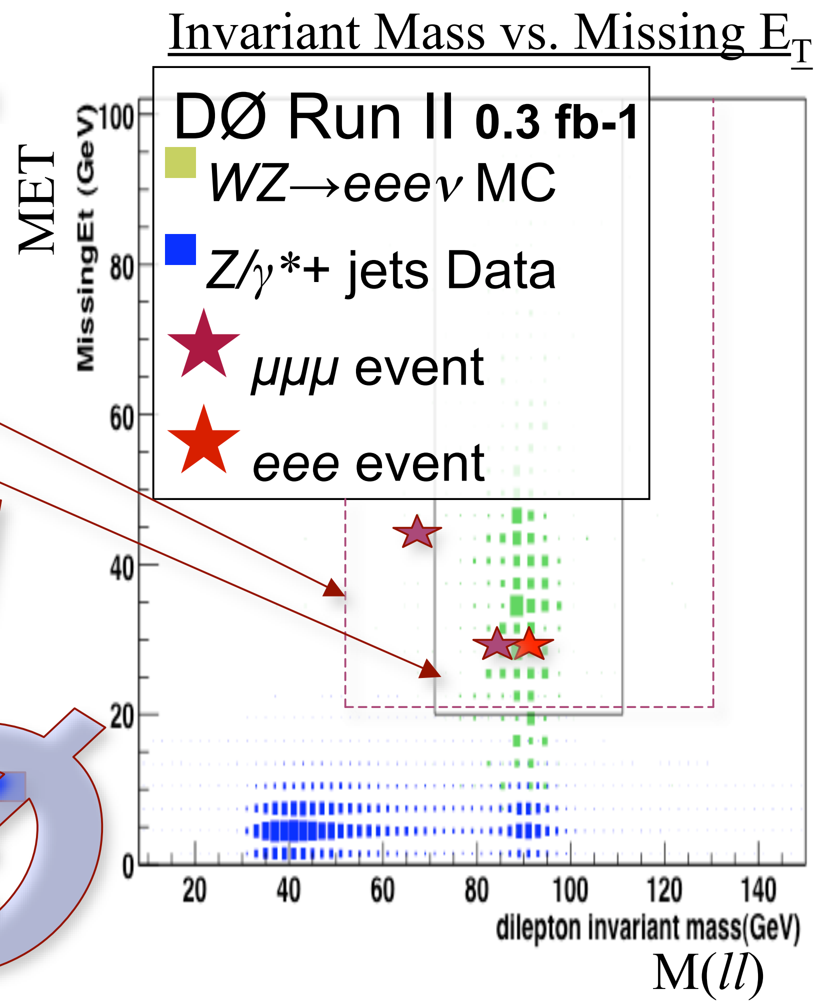
Signal Selection

- Select 2 leptons
  - p_T > 15 GeV.
- Demand they are within the *Z* mass window.
  - 50-130 GeV/c^2 muons
  - 71-111 GeV/c^2 electrons
- Require MET > 20GeV
- Require at least one more high p_T lepton
- Reject Top events with vector E_T^{HAD} > 50 GeV
  - As measured from the leptons in the event.

Z

W

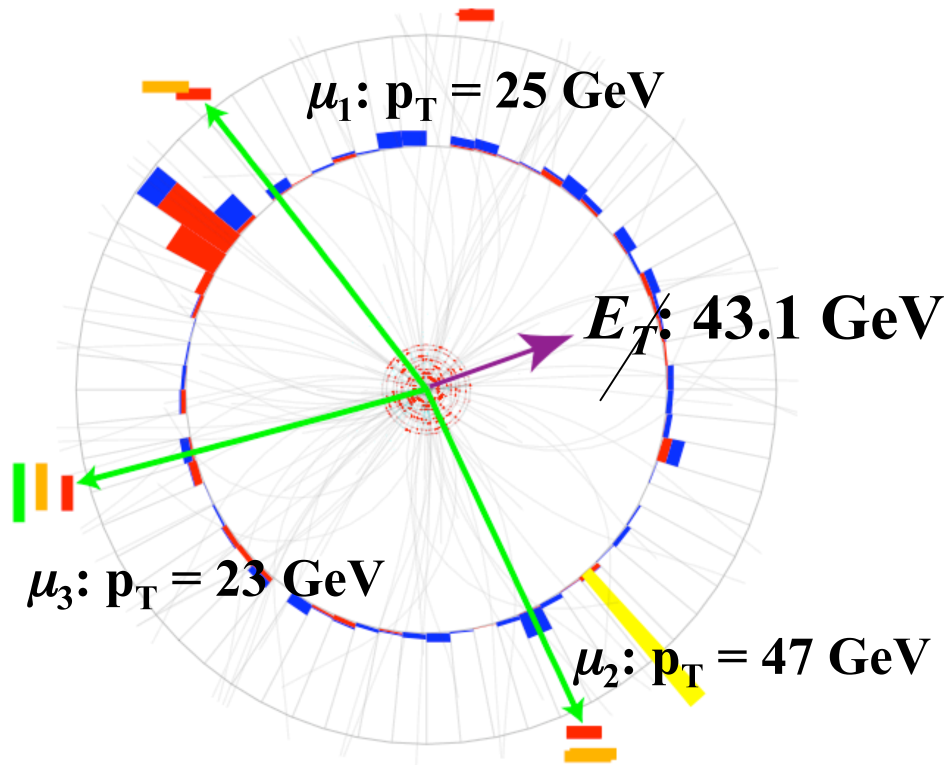




Previous Published Measurement

- Found 3 candidates in 0.3 fb^{-1}
- Estimated 0.71 ± 0.08 bkg events.
- Expected 2.04 ± 0.51 signal events.
- 3.6% probability for background to fluctuate to 3 or more events
- 1.8σ significance
- DØ *WZ* diboson x-sec. results with 0.3 fb^{-1}
  - $\sigma_{WZ} = 4.50\,^{+3.78}_{-2.56}(\text{stat.})\,^{+0.28}_{-0.23}(\text{sys.})$ pb
  - Upper limit at 95%C.L. 13.3 pb

<u>*WZ*→μμμ Event View</u>



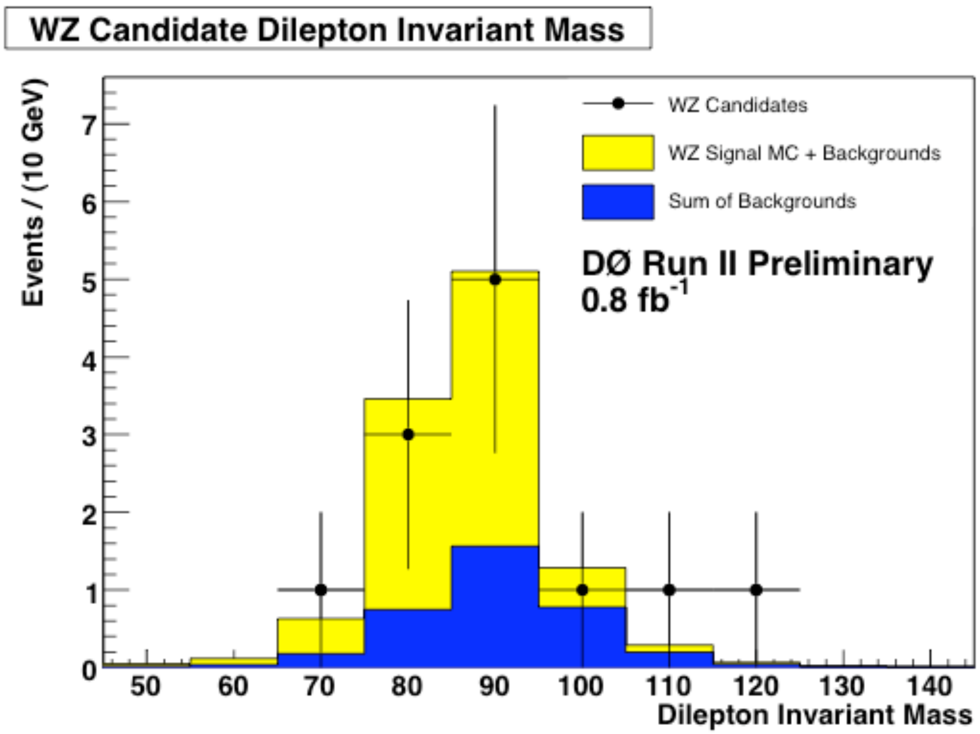
σ_{WZ} at $\sqrt{s}$=1.96 GeV is 3.7±0.1 pb
Campbell & Ellis

PUBLISHED: PRL 95, 141802 (2005).

800 pb^{-1}

- Maintain the same kinematic cuts.
- Improved Electron ID.
- Improved Muon Acceptance.
- Expect 7.5 ± 1.5 events.
- Find 12 candidates.

WZ Backgrounds



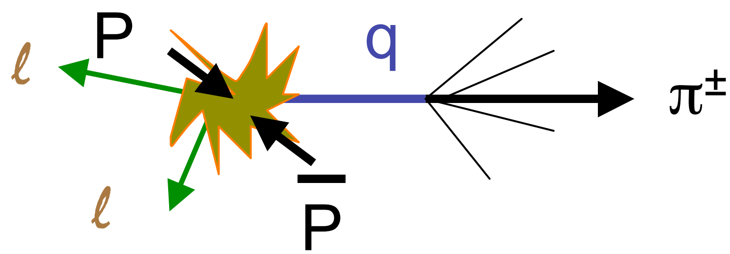
- Major backgrounds are:
  - Fake objects
  - Drell-Yan
  - *ZZ->llll*
- Background + Expected Signal are in good agreement.

Channel	Background Events
eee	0.96±0.07
eeμ	0.49±0.10
μμe	0.96±0.08
μμμ	1.20±0.14
Total	3.61±0.20

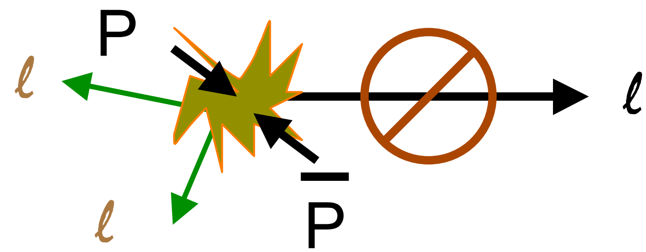
WZ Background Sources

Backgrounds come from Z+X.

X is any of the following….

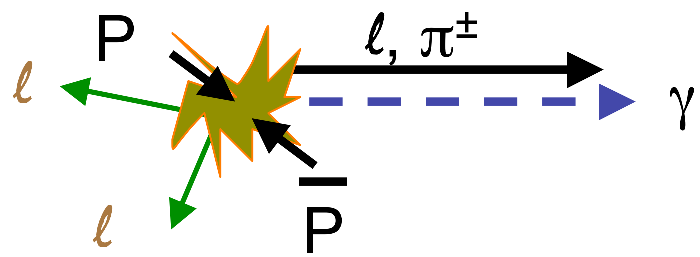


Jet fakes an electron
Estimated using data

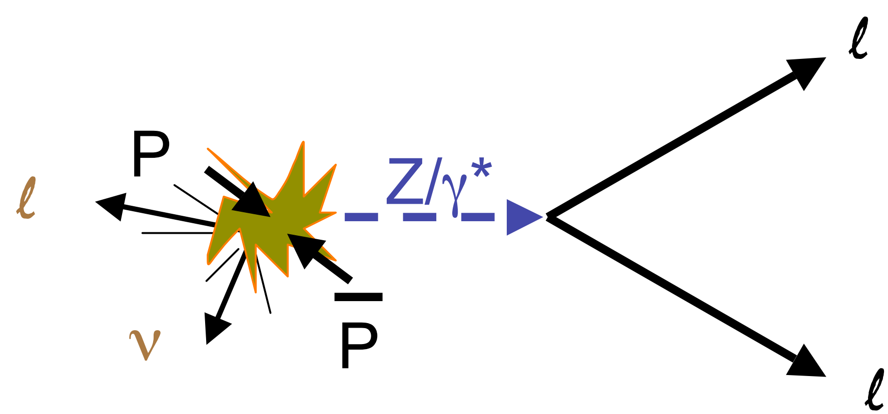


Lepton fakes a neutrino
Estimated using Monte Carlo

WZ Background Sources



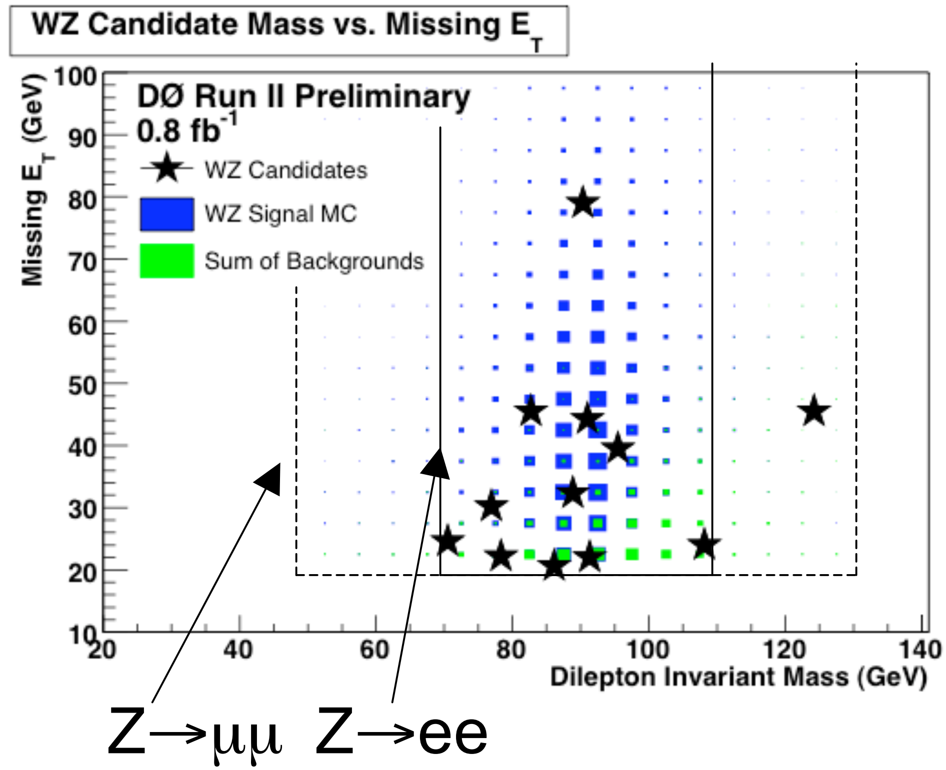
Photon fakes a lepton
Estimated using Data/MC



Drell-Yan
Estimated using Monte Carlo

Results

- Find 12 candidates in 0.8 fb^{-1}
- Expect 7.5 ± 1.2 events from signal.
- Expect 3.6 ± 0.2 events from background.
- Probability for background to fluctuate to 12 or more events is 4.1×10^{-4}.
  - This is a 3.3σ significance.
  - Probability of getting 7 events in one channel is 8.5%.

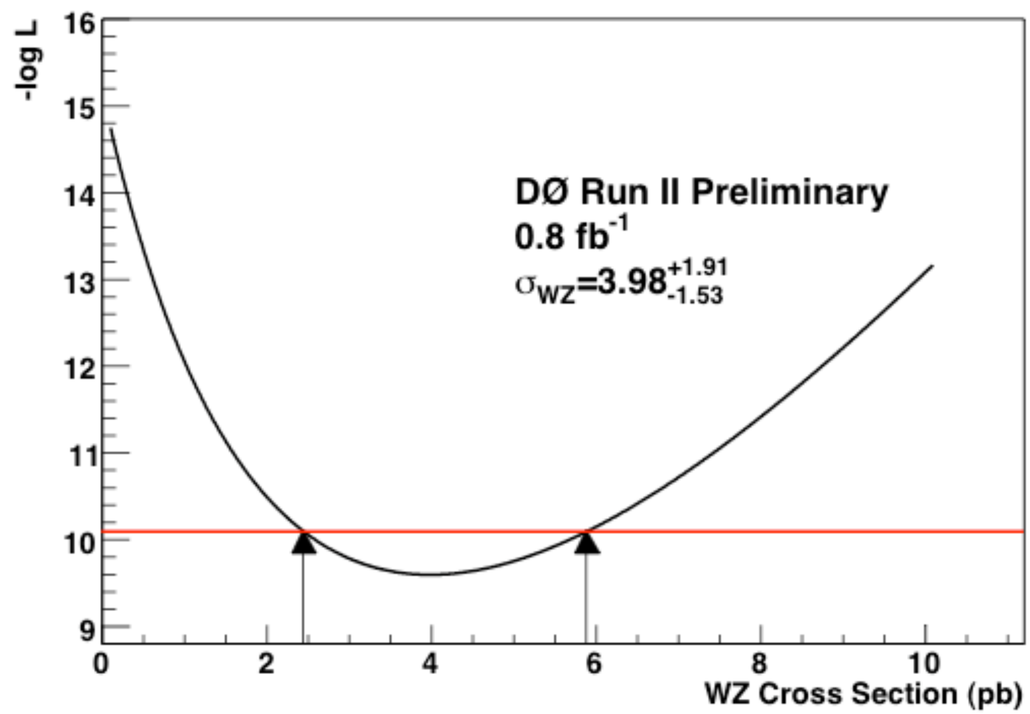


Decay Channel	# of Candidates	Overall Efficiency	Estimated Background
eee	2	0.16±0.01	0.96±0.07
eeμ	1	0.17±0.03	0.49±0.05
μμe	7	0.18±0.04	0.96±0.08
μμμ	2	0.21±0.03	1.20±0.14
Total	12	-	3.6±0.2

Cross-Section

- Using a log-likelihood method
  - Make likelihood in each channel and combine.
  - Minimum is at 3.98pb
  - 1 σ limits at +1.91 and -1.53
- SM prediction is 3.7± 0.3 pb.
- $\sigma_{WZ} = 4.0^{+1.9}_{-1.5}$ pb

<u>WZ Cross Section Log Likelihood</u>

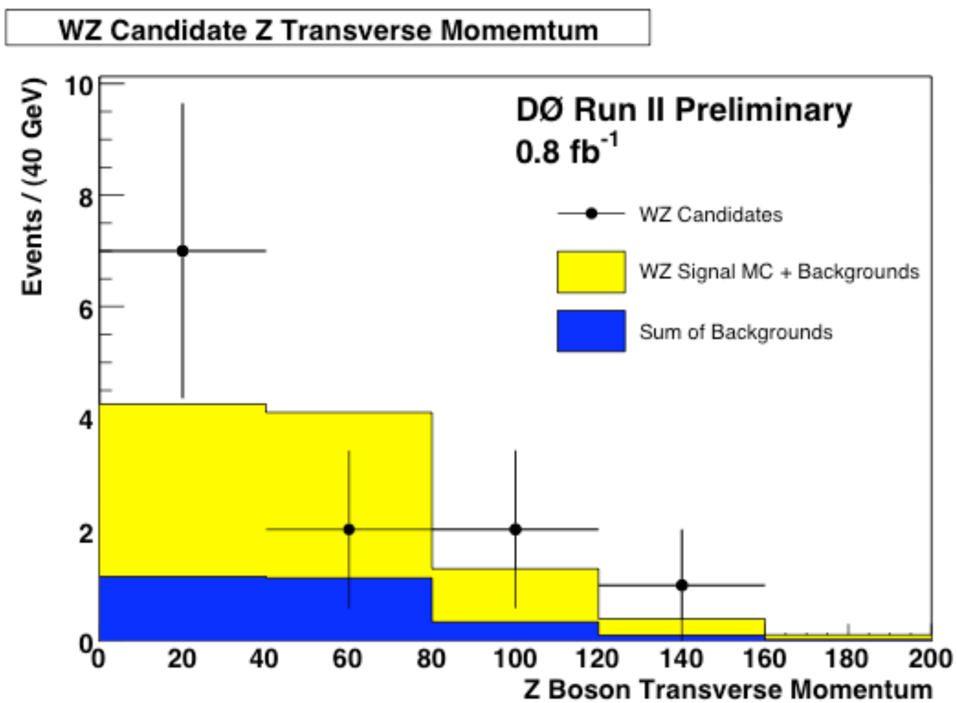


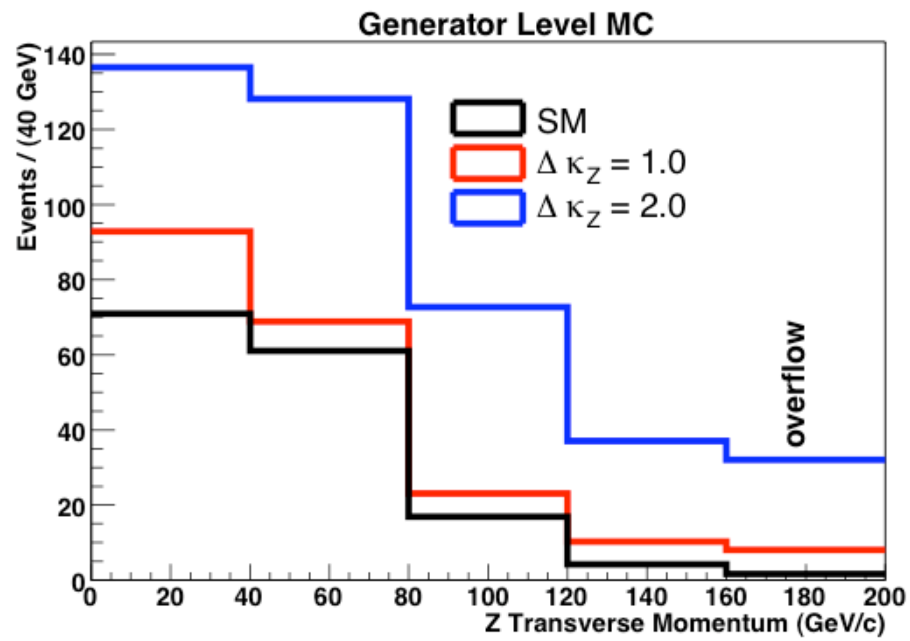
Coupling Strengths

- We can now directly measure the coupling strengths of the W boson to the Z boson.
- Use the effective Lagrangian to set limits on the coupling strengths.
- Excess of events and/or Z boson transverse momentum.

New Method For Setting AC Limits

- Once cross section is finalized:
  - Take advantage of the *Z* p_T spectrum of *WZ* candidates
  - Improve upon *WWZ* trilinear couplings measurements at hadron collider.





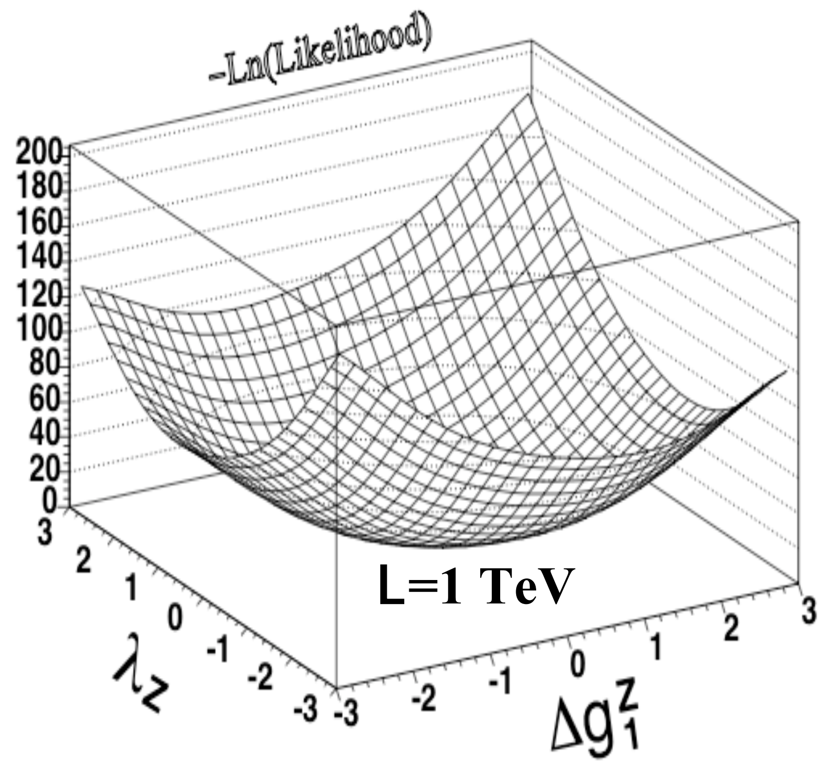
Final Remarks

- We measure the $\sigma_{(WZ)}$ = $\mathbf{4.0^{+1.9}_{-1.5}}$ **pb**
- The first time *WZ* final state has been observed.
- Gives us a direct probe to the weak coupling of the *W* boson to the *Z* boson.

Trilinear Gauge Couplings(TGCs)

- Generate a grid in coupling space using Hagiwara-Zeppenfeld-Woodside event generator.†
- Simulate the detector response using a fast Monte Carlo program.
- Calculate the Log likelihood at each point giving a surface.
- Find the 1-D & 2-D 95% C.L. Limits on the TGCs
- Once cross section is finalized:
  - Take advantage of the *Z* p_T spectrum of *WZ* candidates
  - Improve upon *WWZ* trilinear couplings measurements at hadron collider.

Δg_1^Z vs. λ_Z

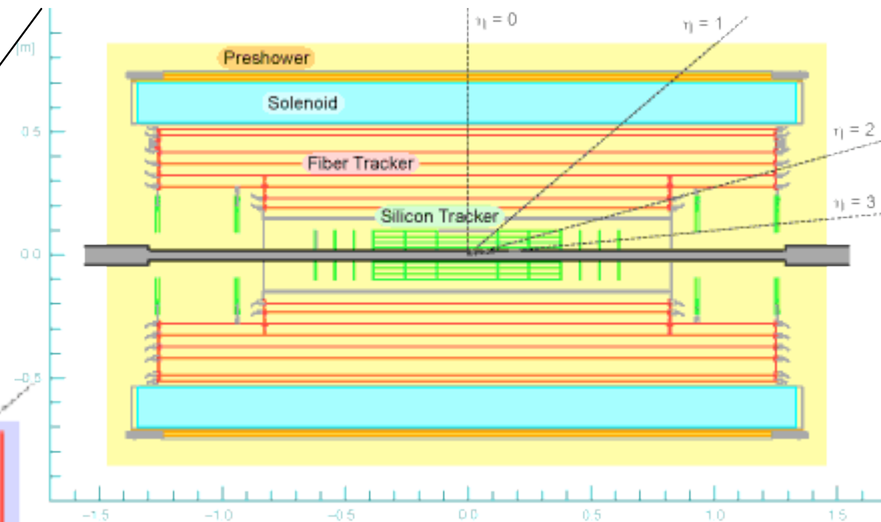


DØ Run II 0.3 fb^{-1}

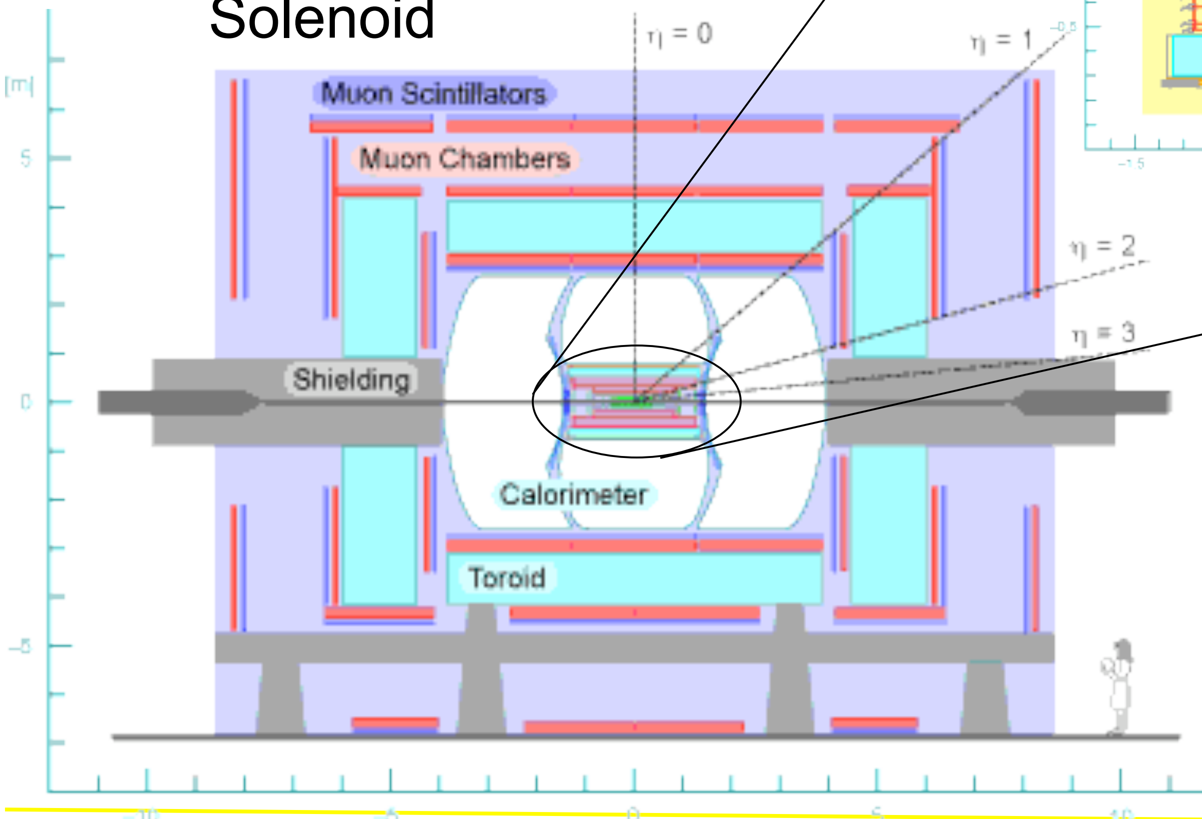
† K. Hagiwara, et al., Phys Rev. D **41**, 2113 (1990).

The DØ Detector

- Multipurpose Particle Detector
- Silicon Micro Strip Tracker
- Scintillating Fiber Tracker
- 2T Super-Conducting Solenoid



Inner Tracker



- Uranium Liquid Argon Calorimeters.
- Three Layers Of Muon Detectors.
- 1.8 T Iron Toroids.

Updated Selection

- Essentially the Same analysis as previously
- Kinematic Selection remains the same
- Improved knowledge of detector leads to:
  - Improved muon acceptance.
  - Improved electron ID efficiency.
  - We see 12 candidates in 0.8 fb^{-1}
  - Estimate 3.6 ± 0.2 events from background.
  - Expect 7.5 ± 1.2 signal events.

Table of signal efficiency × acceptance
for two analyses

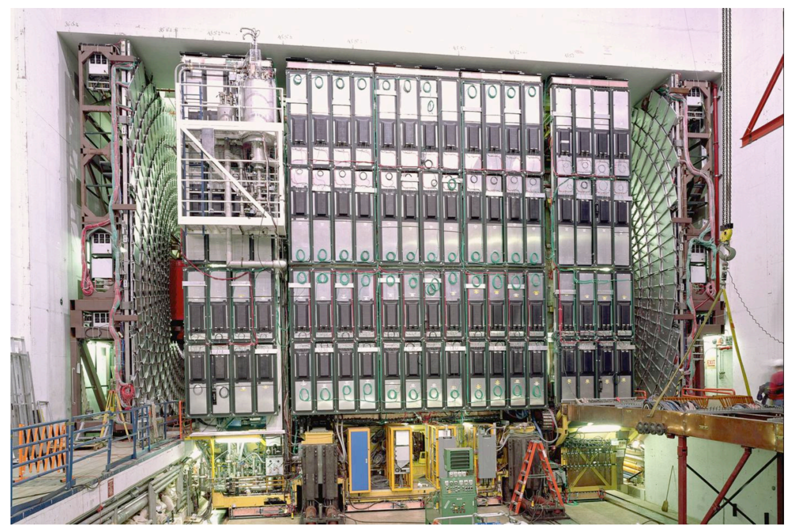
Channel	0.3 fb^{-1}	0.8 fb^{-1}
eee	0.103	0.158
$ee\mu$	0.117	0.167
$\mu\mu e$	0.139	0.175
$\mu\mu\mu$	0.163	0.205

Tevatron

Delivered Luminosity ~1.4 fb^{-1}

To the DØ Detector

with ~1.2 fb^{-1} recorded



Proton anti-proton collider

1.96 TeV with 396ns bunch spacing