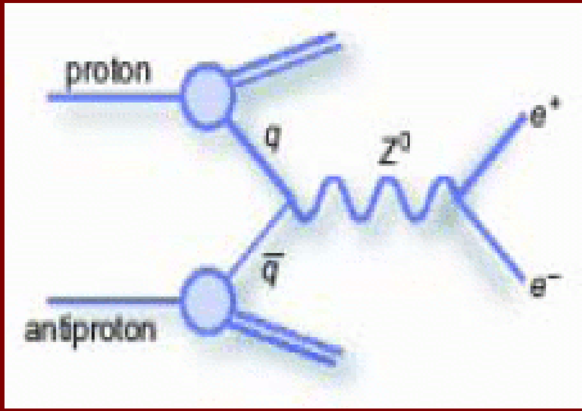
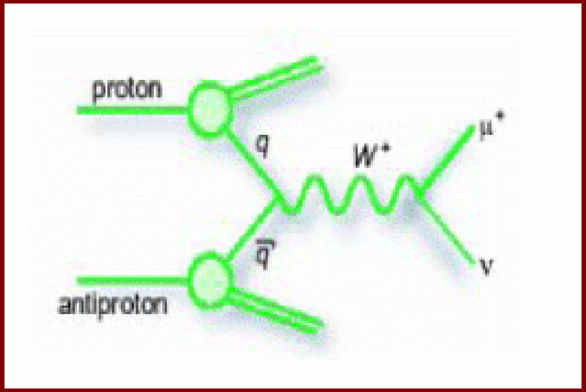
Recent Diboson and Electroweak Results from DØ

Andrew Askew,
Joint Experimental Theoretical Physics Seminar

Electroweak Physics



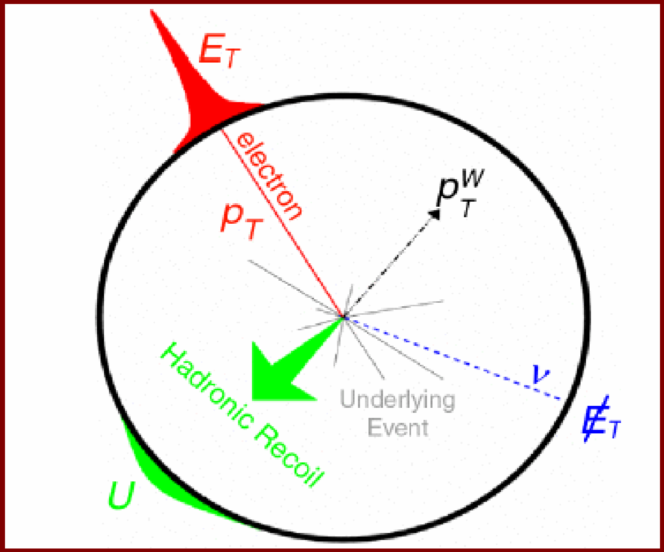


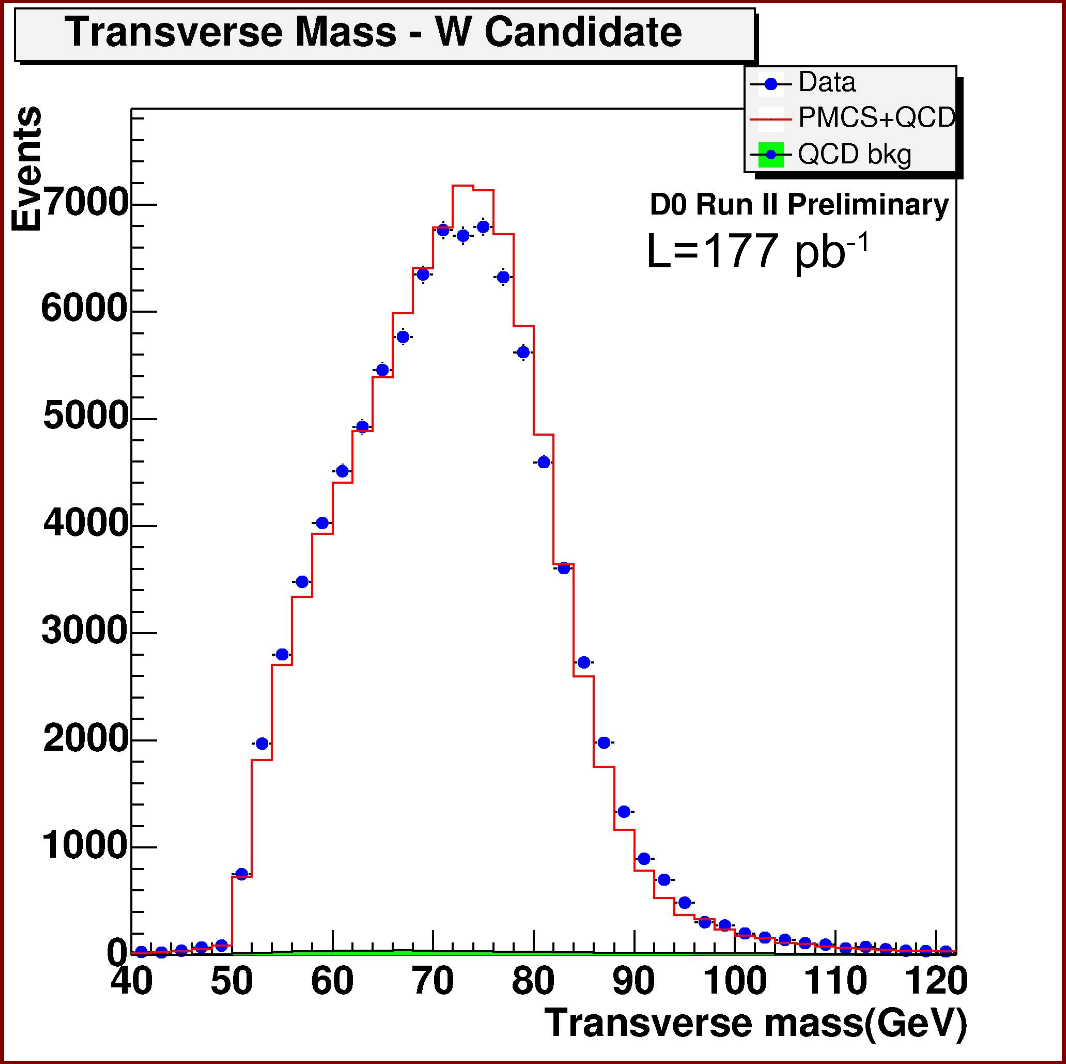
- Many opportunities in W and Z production:
  - Clean signals, through leptonic decays.
  - Wealth of physics:
    - Structure of SM through diboson production.
    - PDFs through W asymmetry, Z rapidity.
    - Constraints on Higgs through W mass.

Identifying W events:

W

- High E_T e or μ.
- Missing E_T from ν.





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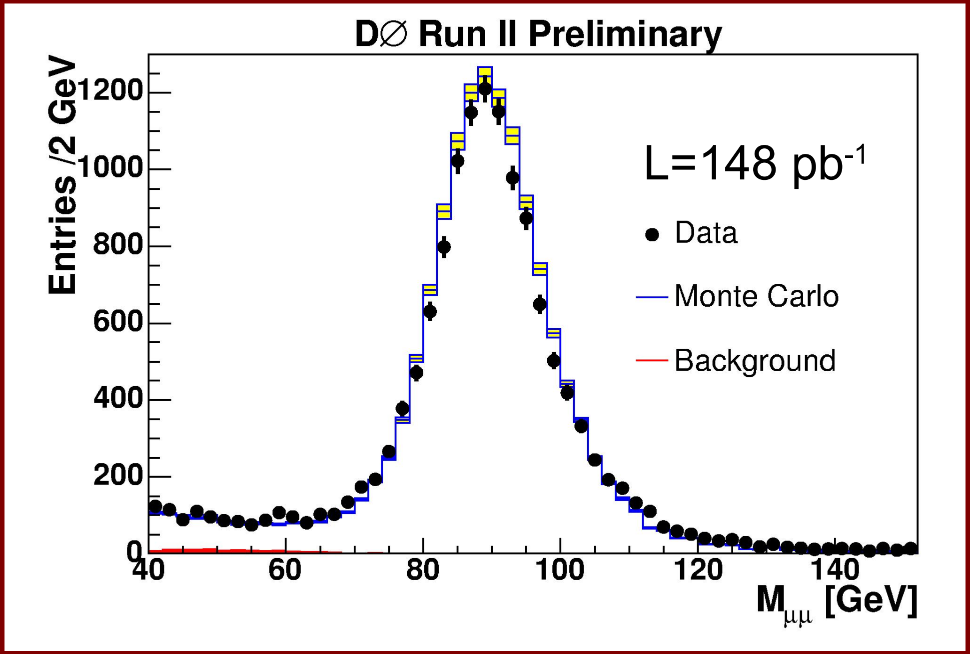
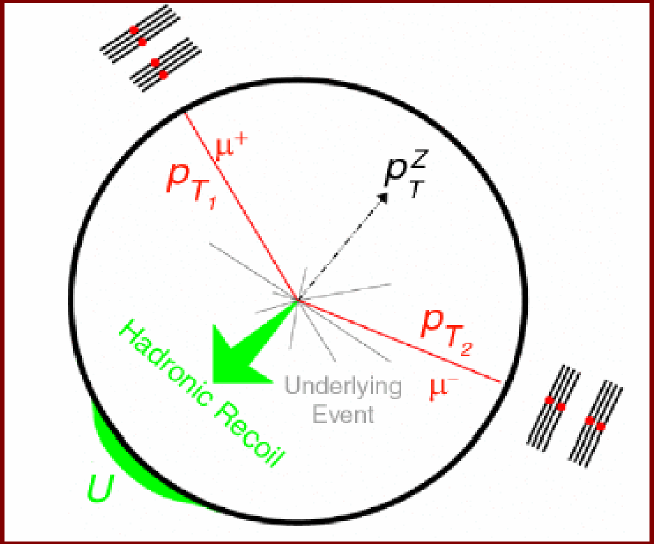
Identifying Z events



Z

- Two oppositely charged high E_T leptons.



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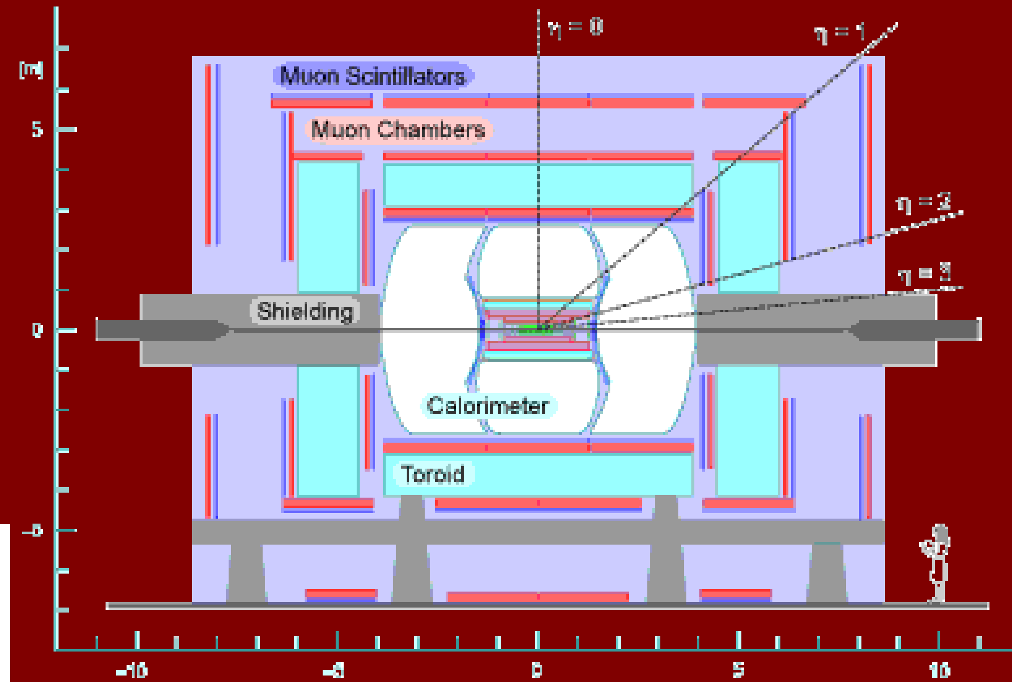
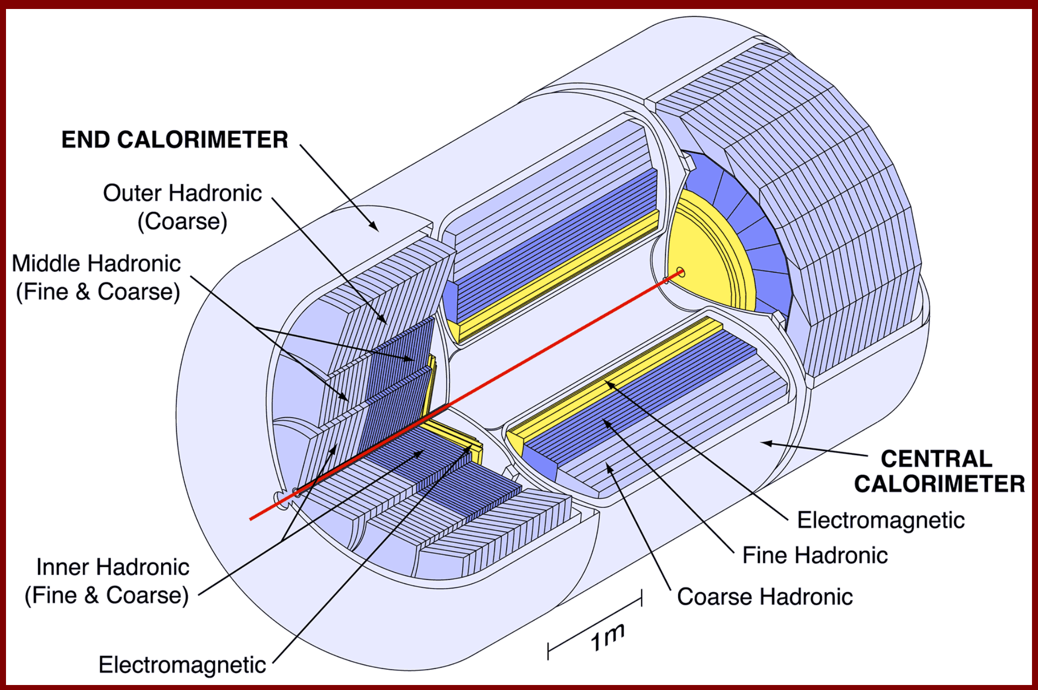
The DØ Detector

- Excellent coverage for both muons (|η|< 2.0) and electrons (|η|<2.5).

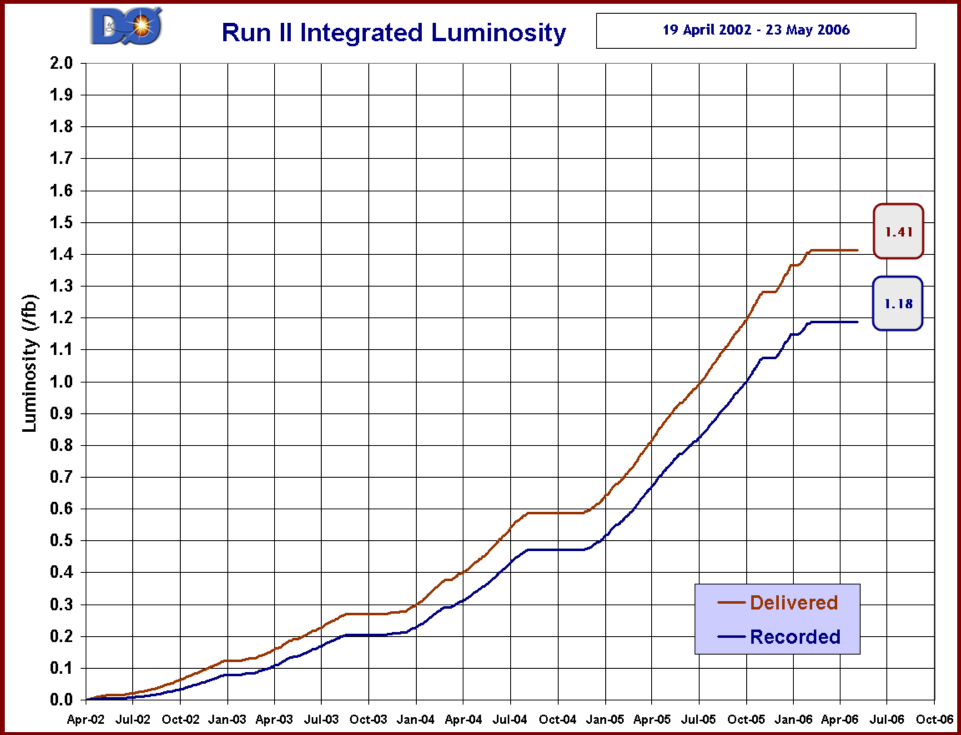


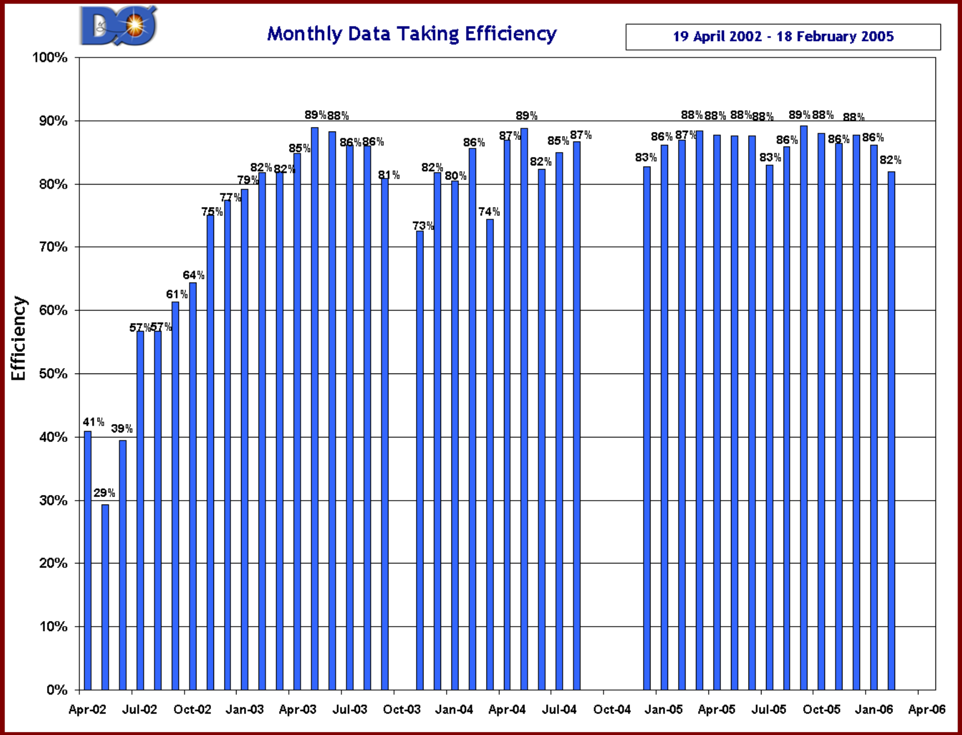


- Hermetic calorimetry for measurement of missing E_T.

Luminosity and Efficiency:

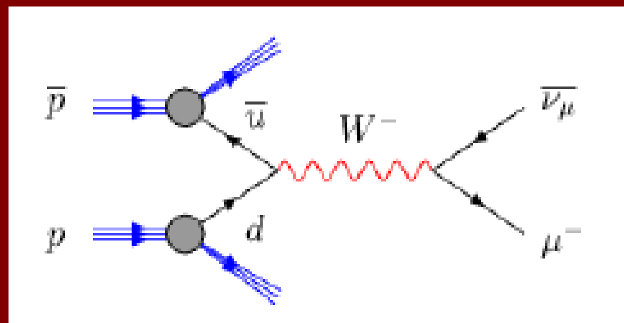
Could not show these results without the performance of the Tevatron.
Results shown use 0.2-0.8 fb^{-1}





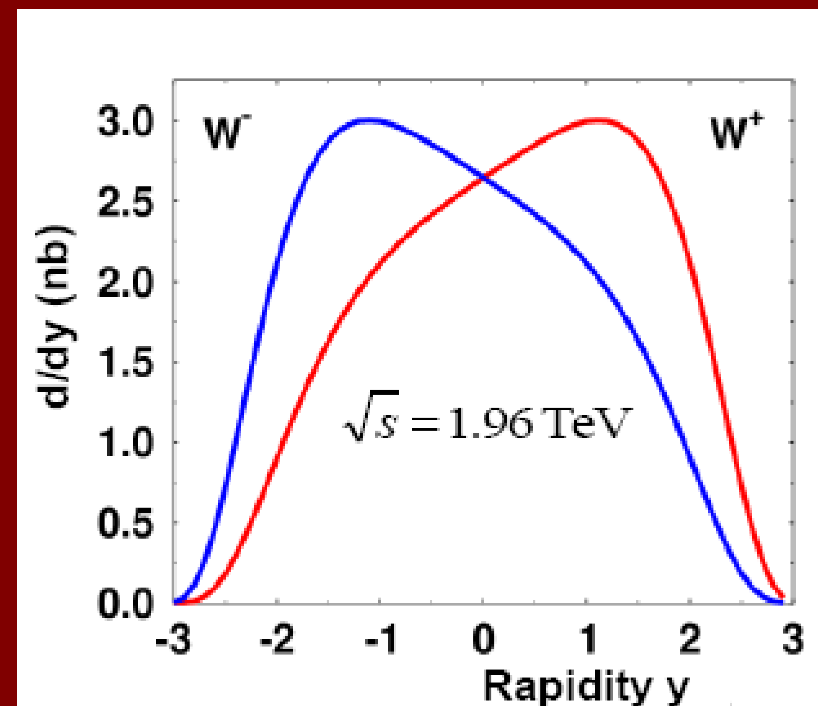
Doing our best to make use of that luminosity we're delivered.

W Charge Asymmetry:



$$u + \bar{d} \rightarrow W^{+} \rightarrow \mu^{+} + \nu_{\mu}$$
$$\bar{u} + d \rightarrow W^{-} \rightarrow \mu^{-} + \bar{\nu}_{\mu}$$

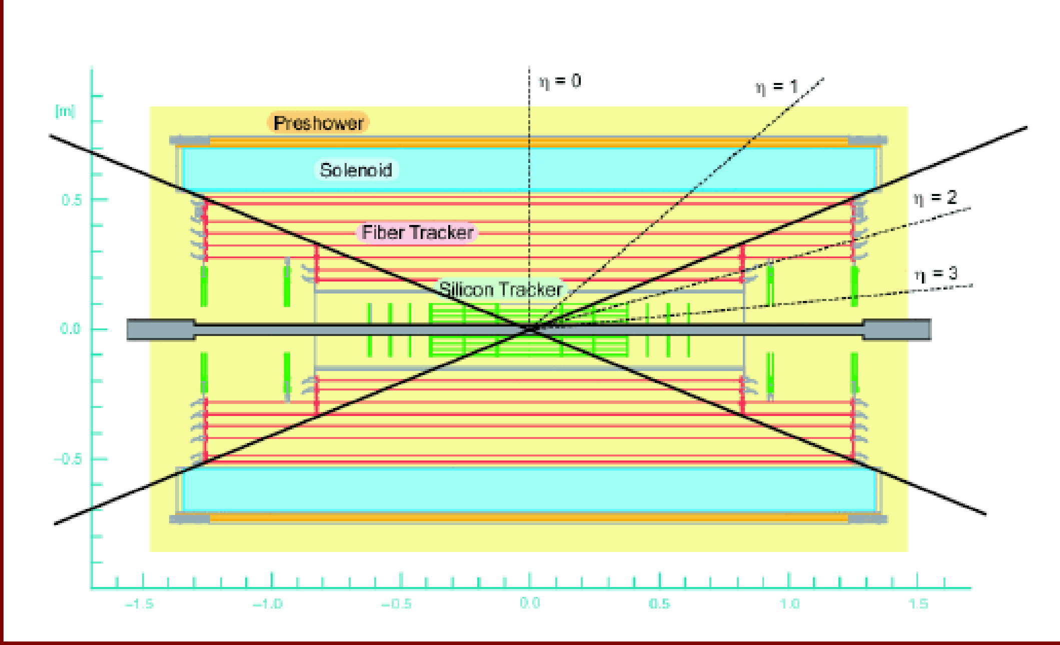
- Typically the u quark carries more of the proton momentum:
  - Thus the W^{+} is boosted in the direction of the proton.



$$A(y_{\mu}) = \frac{N_{\mu^{+}}(y_{\mu}) - N_{\mu^{-}}(y_{\mu})}{N_{\mu^{+}}(y_{\mu}) + N_{\mu^{-}}(y_{\mu})}$$

Selection:

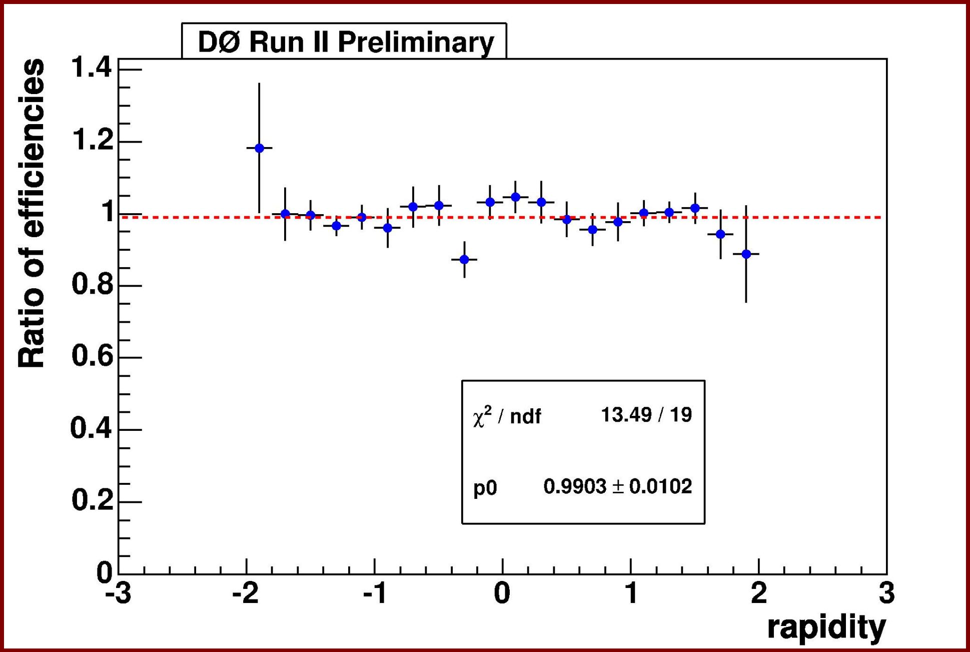
- $p_T > 20$ GeV, MET > 20 GeV, $M_T > 40$ GeV. Must be isolated.
  - nSMT >=1, nCFT >= 7.
  - $\chi^2 < 3.3$, DCA < 0.011 cm
  - Reject additional isolated muons, high p_T tracks.



- Two keys here:
  - 1.) ε- and ε+ are the same (or known).
  - 2.) charge mis-id is known.

Efficiencies:

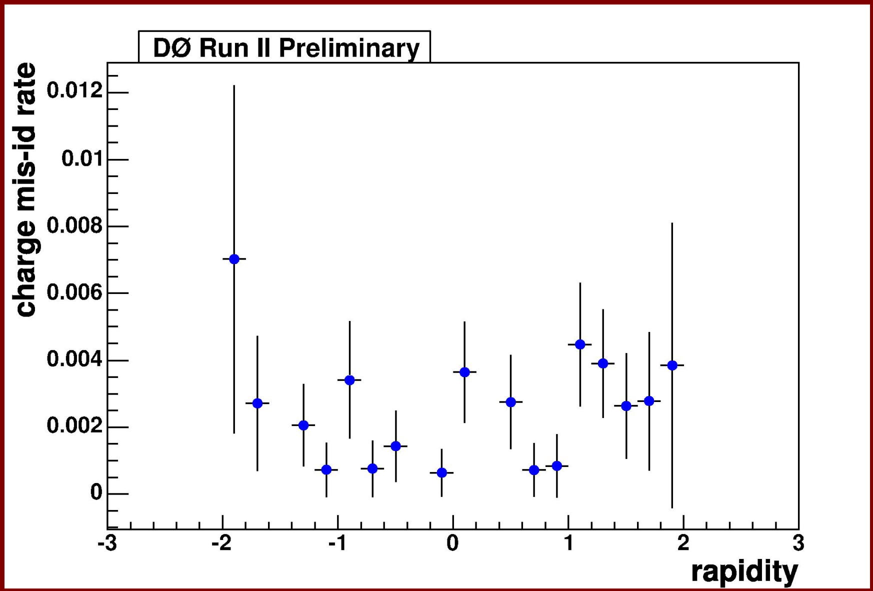
- Look for biases in every selection cut made:
  - Track matching
  - Isolation
  - Trigger
- Find efficiencies separately for positive and negative.
- No significant bias found.

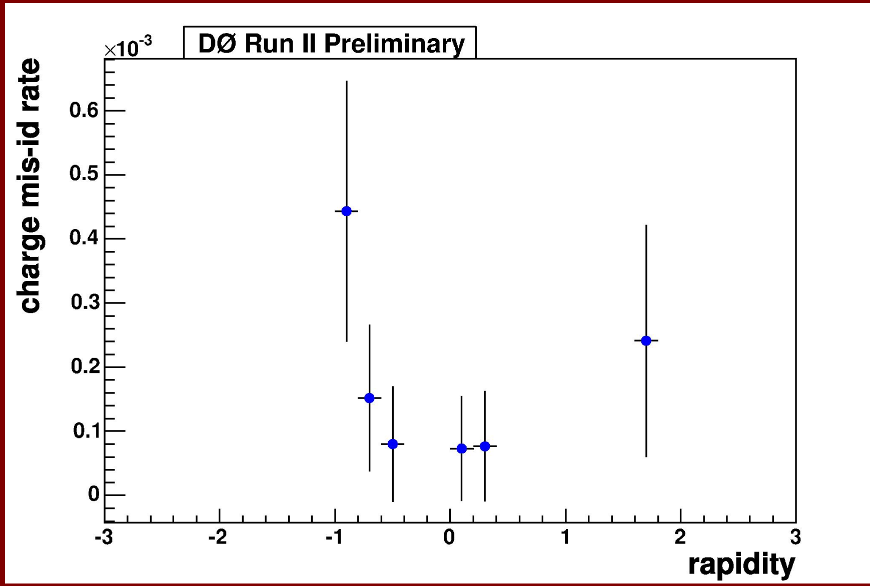


Ratio of total efficiencies as a function of rapidity.

Charge Misidentification:

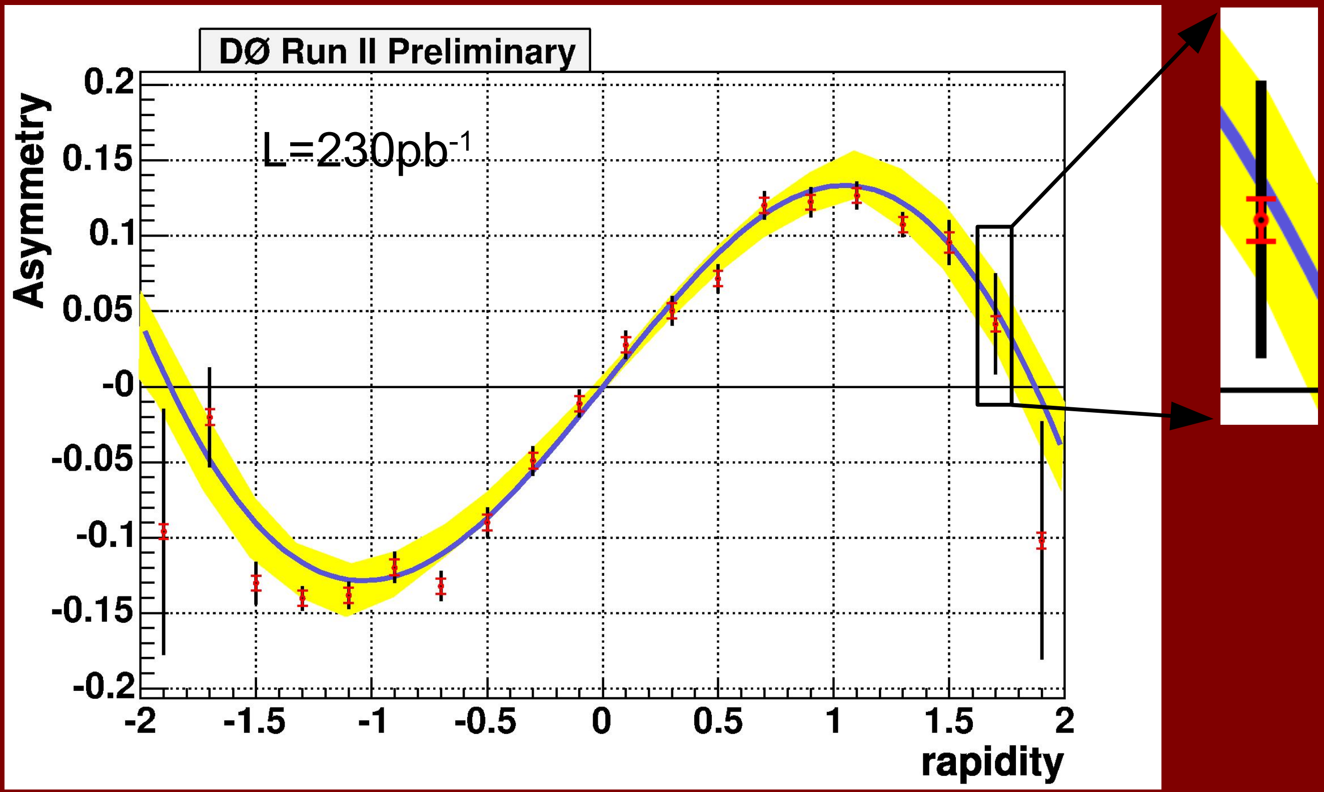
- For μ, two separate measurements of p_T:
  - Can use tag-probe method without biasing track p_T.
  - Can measure charge misidentification from Z events in data.
  - Plot is prior to (top) and after (bottom)final track quality cuts (to exaggerate effect).
  - Charge mis-id = 0.01%





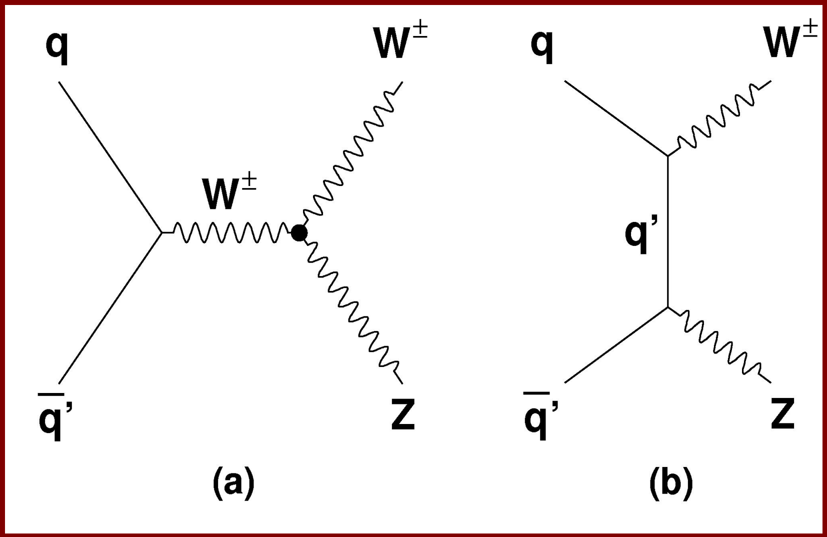
Asymmetry:

- After background subtraction, the asymmetry is formed.
- Note that the red error bars are our systematic errors.
  - Small compared to statistical in places.
  - We have much more data to add too!

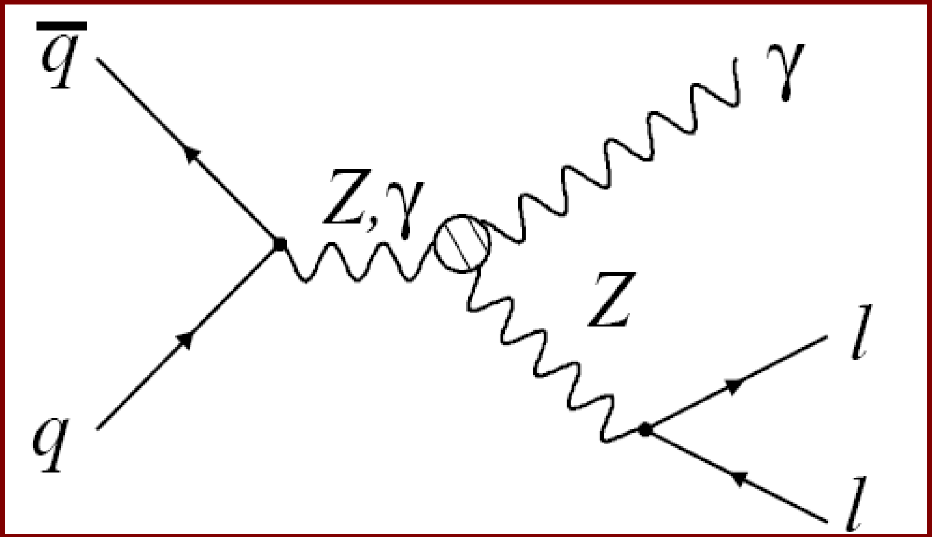


Yellow band is CTEQ6 uncertainty envelope.
Blue line is MRST02 central value.

Diboson Physics



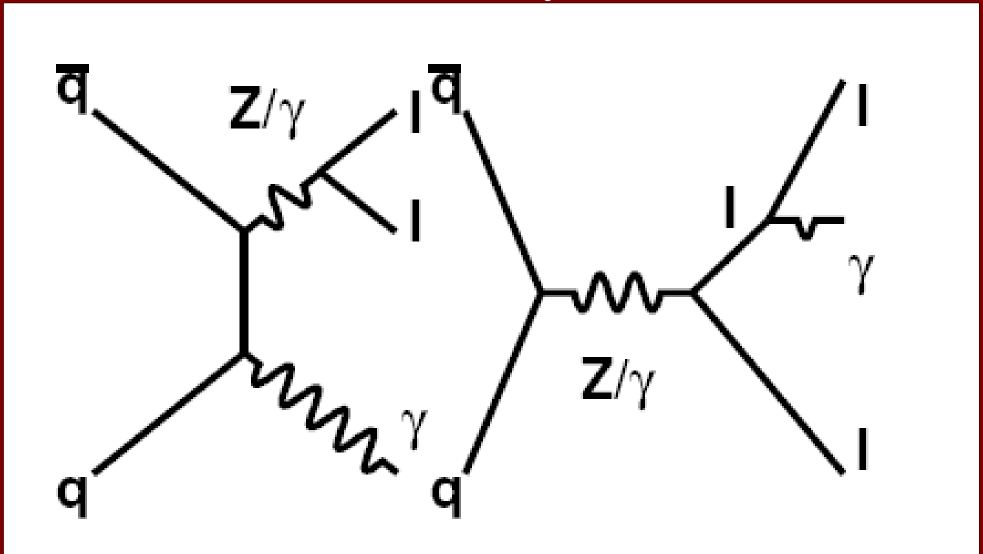
Allowed



Not Allowed

- Important checks on the Standard Model:
  - No wiggle room! Anomalous vector boson couplings are signs for new physics. PERIOD.
  - Changes both cross sections and kinematics.
  - Important backgrounds to Higgs/SUSY searches.

Zγ



- Published analysis:
  - PRL. 95, 051802, (2005).
- Included measurement of the Zγ cross section, and anomalous couplings.
  - Coupling limits were set using the photon E_T spectrum.

Zγ Analysis

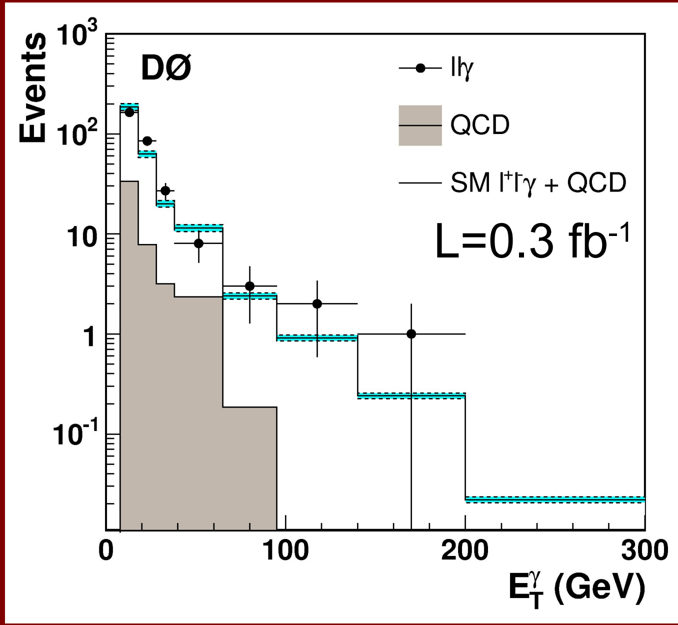
- Two isolated electrons w/ E_T>15 GeV. One or more w/ E_T>25 GeV.
- All central electrons must have a track match.
- M(ee)>30 GeV.

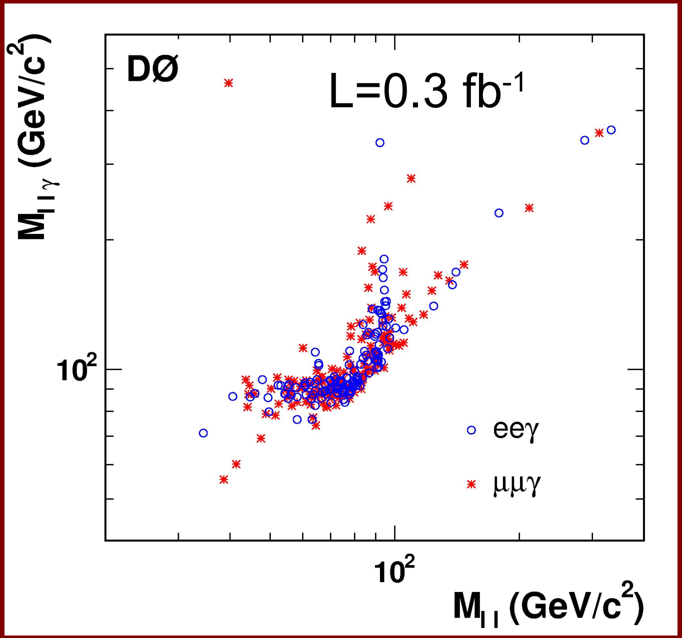
- Two isolated μ, w/ p_T > 15 GeV.
- M(μμ)>30 GeV

$E_{T(photon)}$>8 GeV

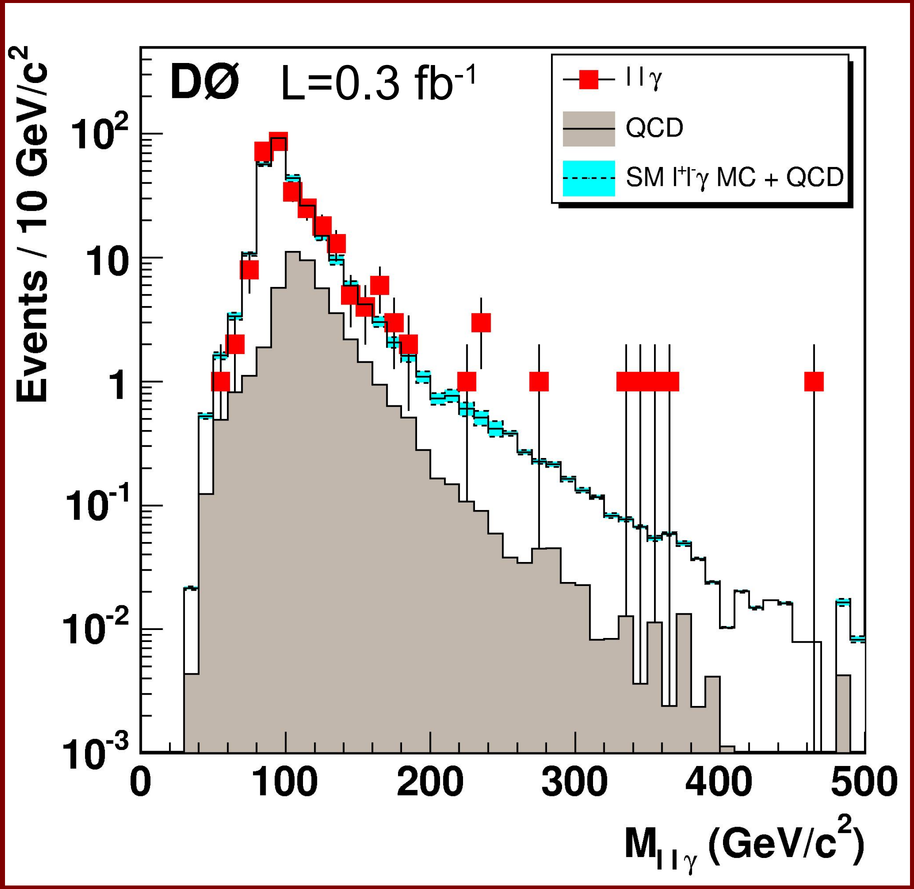
$\Delta R(l,\gamma)>0.7$

$|\eta_\gamma|<1.1$



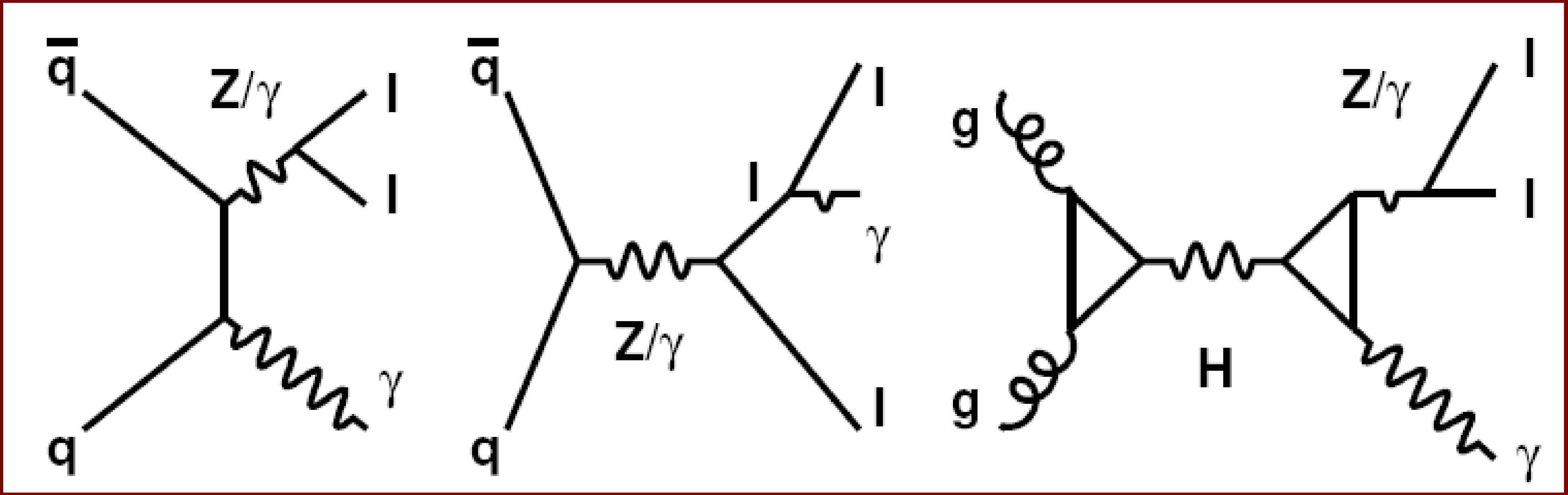


Lumpy or Bumpy?



- Slight excess of events in both channels in similar places. Are these a hints of new physics, or simply fluctuations?

X->Zγ

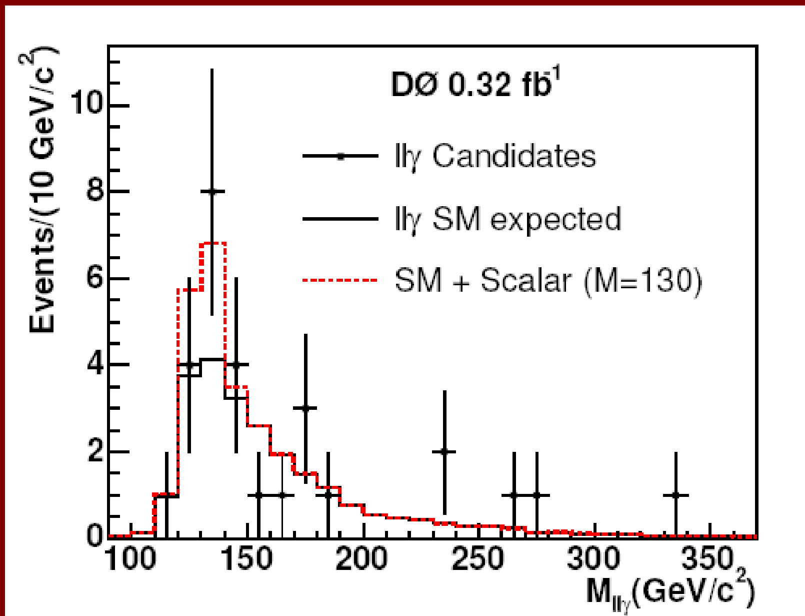


- Because of diagrams such as the third one shown here, the Zγ data was examined more closely, searching for possible particle resonances.
  - The most famous of which would be Fermiphobic Higgs, though there are others.

Methodology:

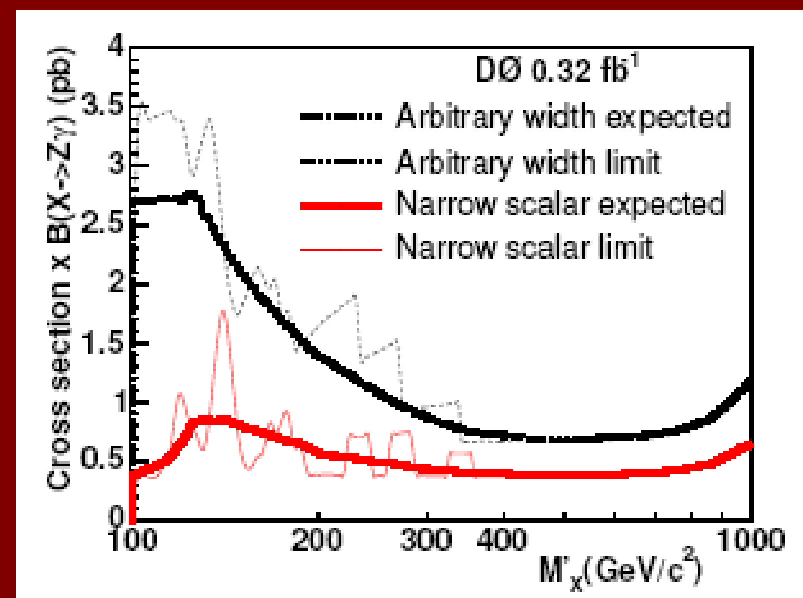
- For both techniques, the SM Higgs at various masses is used for the model of the signal scalar particle (herein called X).
  - $M_{ll} > 75$ GeV, $p_T^{\gamma} > 25$ GeV.
- Two different techniques:
  - Take a narrow mass window (optimized on MC) and scan across the Zγ three body mass distribution. This is for a narrow scalar.
  - Take a single threshold and use the integral of events above it. This is for an arbitrary width scalar.

X->Zγ Limits



- Total: 28 Candidates
- SM background 24.1+/1.0
- <-- Particle X with σ x B =1 pb for illustration only

- Limits are well within the expected range.
- No statistically significant evidence for X->Zγ.
- Submitted to PLB (hep-ex/0605064).



From Bump Hunting to Coupling Limits:

- The previous analysis was fairly straightforward:
  - Look for peaks in the three body mass spectrum that could be indicative of new particles.
- Testing triple gauge couplings is somewhat different:
  - Manifest in a larger cross section (of course).
  - Also change the kinematics, thus more information than simply the number of events.

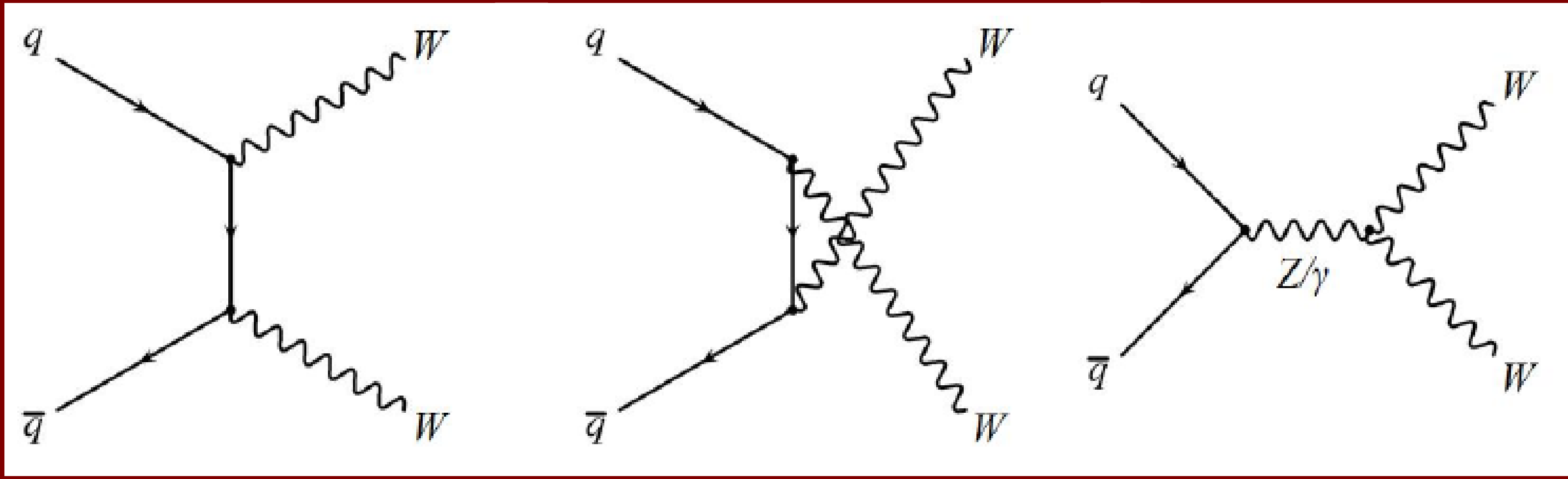
Coupling Limits:

$$L_{WWV}/g_{WWV} = ig_1^V (W^\dagger_{\mu\nu} W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + i\kappa_V W^\dagger_\mu W_\nu V^{\mu\nu} + i\frac{\lambda_V}{M_W^2} W^\dagger_{\lambda\mu} W^\mu{}_\nu V^{\nu\lambda}$$

- General Effective Lagrangian (trilinear vertices).
  - (CP conserving only, V=Z, γ).
- Standard Model is then merely a special case of this general form:
  - κ_γ, $\kappa_z = 1$, λ_γ, $\lambda_z = 0$, $g^1{}_\gamma = -e$, $g^1{}_Z = -e \cot \theta_W$.
- Introduce a form factor scale to preserve unitarity:

$$a = \frac{a_0}{(1 + \frac{\hat{s}}{\Lambda^2})^2}$$

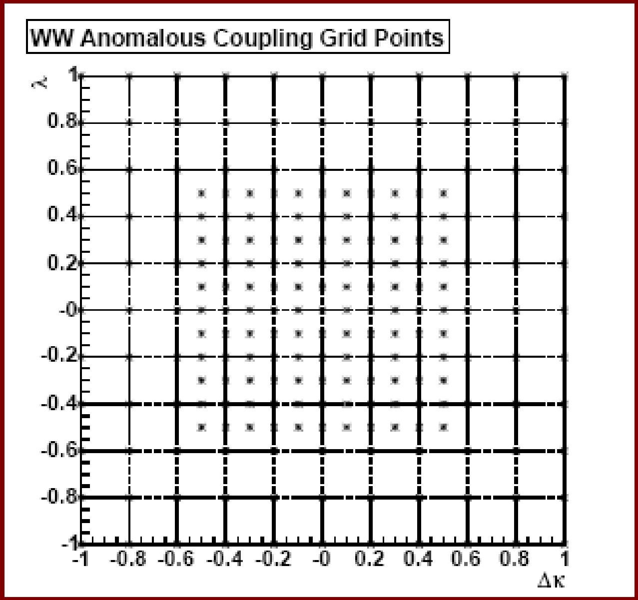
WW Anomalous Coupling Limits

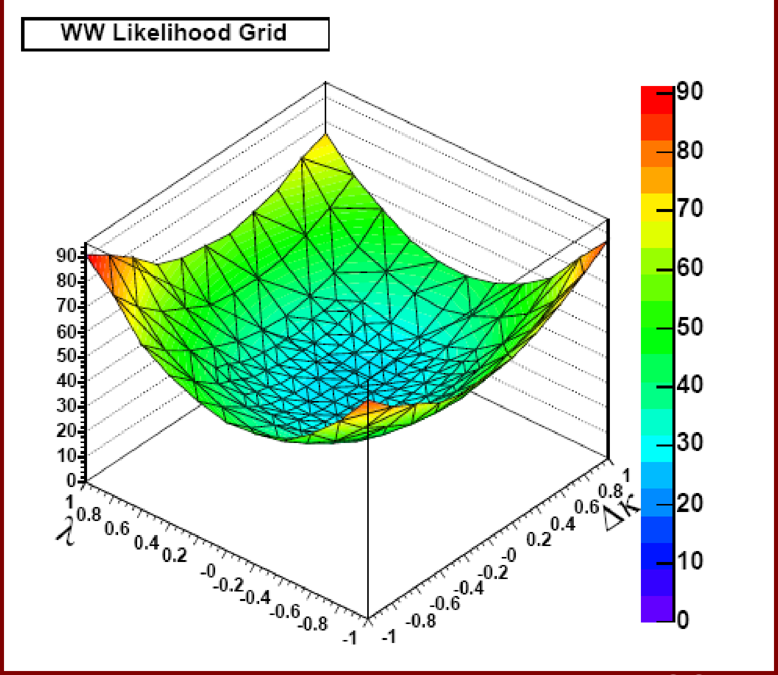


- WW production has contributions from both the WWγ and WWZ vertices.
- The cross section in dilepton states was measured previously (PRL. 94, 151801, (2005)).
  - $\sigma_{WW} = 13.8^{+4.3}_{-3.8}(\text{stat})^{+1.2}_{-0.9}(\text{sys}) \pm 0.9(\text{lum})$ pb
- As a follow-up the result can be used for anomalous coupling limits.

Anomalous Coupling Limits:

- Choose a relationship between couplings.
  - WWγ=WWZ
  - HISZ
    - $\Delta\kappa_Z = \Delta\kappa_\gamma(1-\tan^2\theta_W)$
    - $\Delta g^1{}_Z = \Delta\kappa_\gamma / (2\cos^2\theta_W)$
    - $\lambda_Z = \lambda_\gamma$
- Form a 'grid' of coupling values:
  - Calculate likelihood.
  - Fit likelihood and integrate for limits.



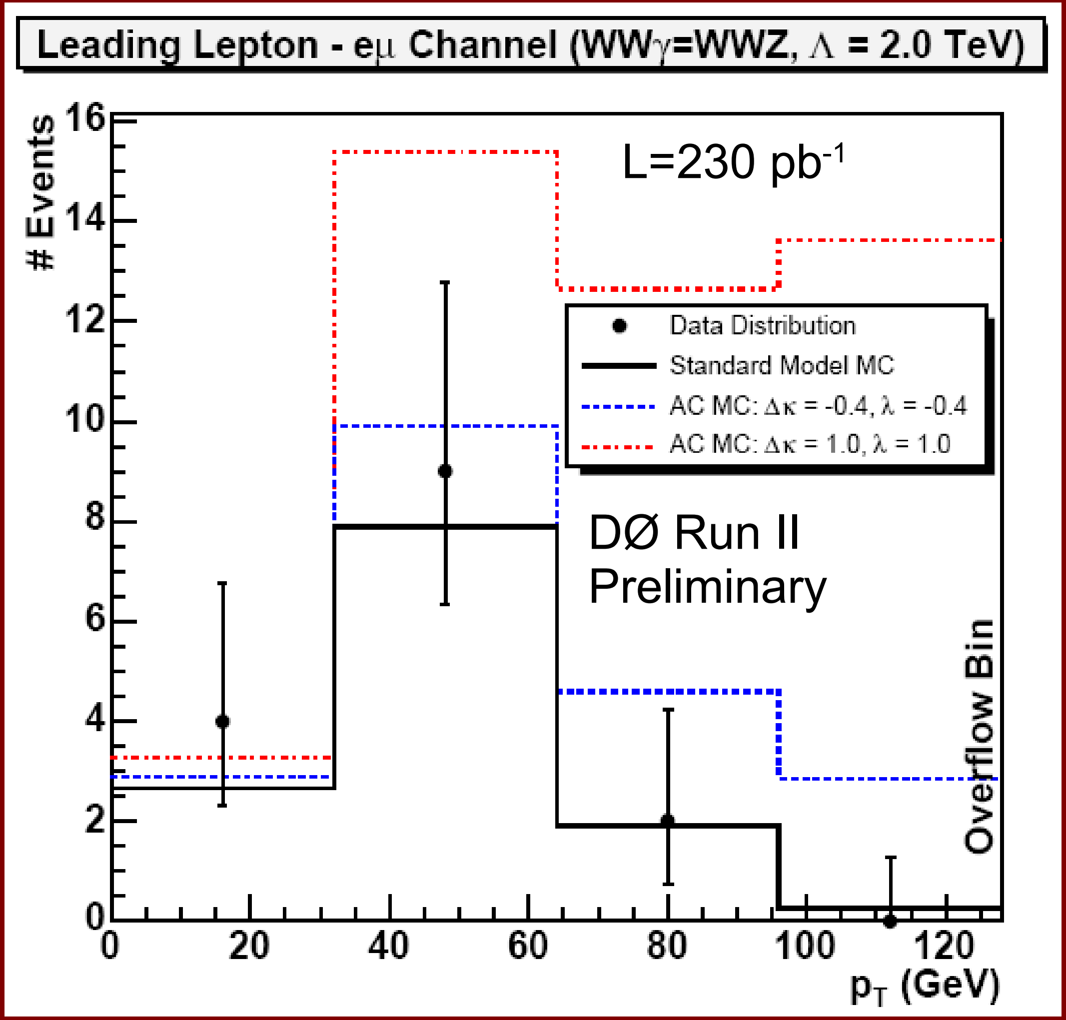


WW Selection:

- Two leptons (e or μ):
  - Leading p_T>20 GeV,
  - Trailing p_T>15 GeV.
- Missing ET > 30 (ee) GeV, 20(eμ) GeV, 40 (μμ) GeV.
- Primary backgrounds, DY, WZ/ZZ, W+j, Top.
- Observed:
  - ee: 6 candidates, expected 5.56.
  - eμ: 15 candidates, expected 14.6.
  - μμ: 4 candidates, expected 3.95.

WW Coupling Results:

- Binned likelihood formed in leading and trailing lepton p_T.



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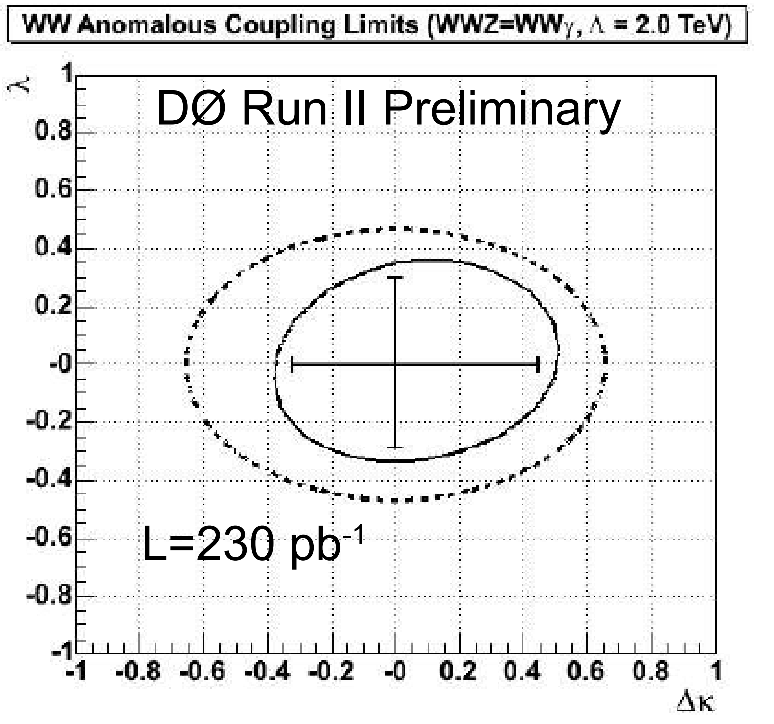
Limits:

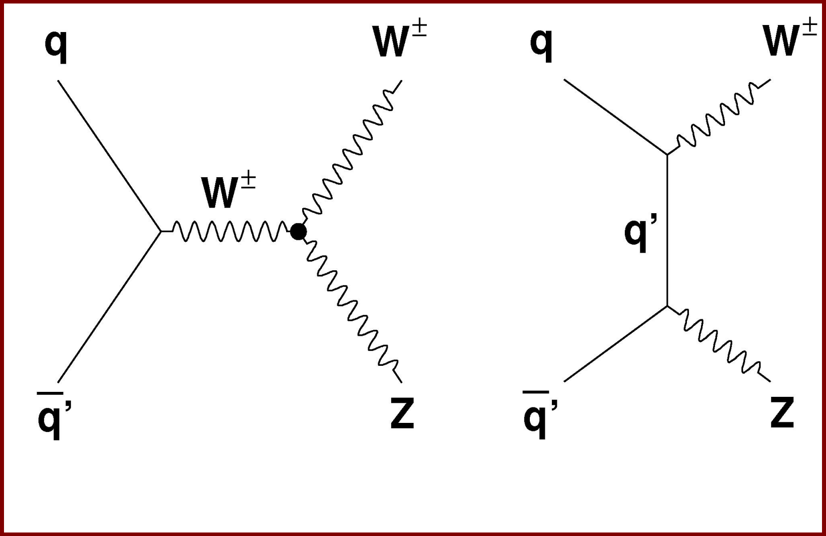
DØ Run II Preliminary

Coupling	Λ (TeV)	95% C.L. Limits
$\lambda_\gamma = \lambda_Z$ ($\Delta\kappa_\gamma = \Delta\kappa_Z = 0$)	1.5	$-0.31, 0.33$
$\Delta\kappa_\gamma = \Delta\kappa_Z$ ($\lambda_\gamma = \lambda_Z = 0$)	1.5	$-0.36, 0.47$
$\lambda_\gamma = \lambda_Z$ ($\Delta\kappa_\gamma = \Delta\kappa_Z = 0$)	2.0	$-0.29, 0.30$
$\Delta\kappa_\gamma = \Delta\kappa_Z$ ($\lambda_\gamma = \lambda_Z = 0$)	2.0	$-0.32, 0.45$
$\lambda_\gamma = \lambda_Z$ (HISZ)	1.5	$-0.34, 0.35$
$\Delta\kappa_\gamma$ (HISZ)	1.5	$-0.57, 0.75$
λ_Z (SM $WW\gamma$, $\Delta\kappa_Z = 0$)	2.0	$-0.39, 0.39$
$\Delta\kappa_Z$ (SM $WW\gamma$, $\lambda_Z = 0$)	2.0	$-0.45, 0.55$
λ_γ (SM WWZ, $\Delta\kappa_\gamma = 0$)	1.0	$-0.97, 1.04$
$\Delta\kappa_\gamma$ (SM WWZ, $\lambda_\gamma = 0$)	1.0	$-1.05, 1.29$



- Surpass Run I limits from WW in dilepton channel.
- Still not as tight as DØ Run I Combined.

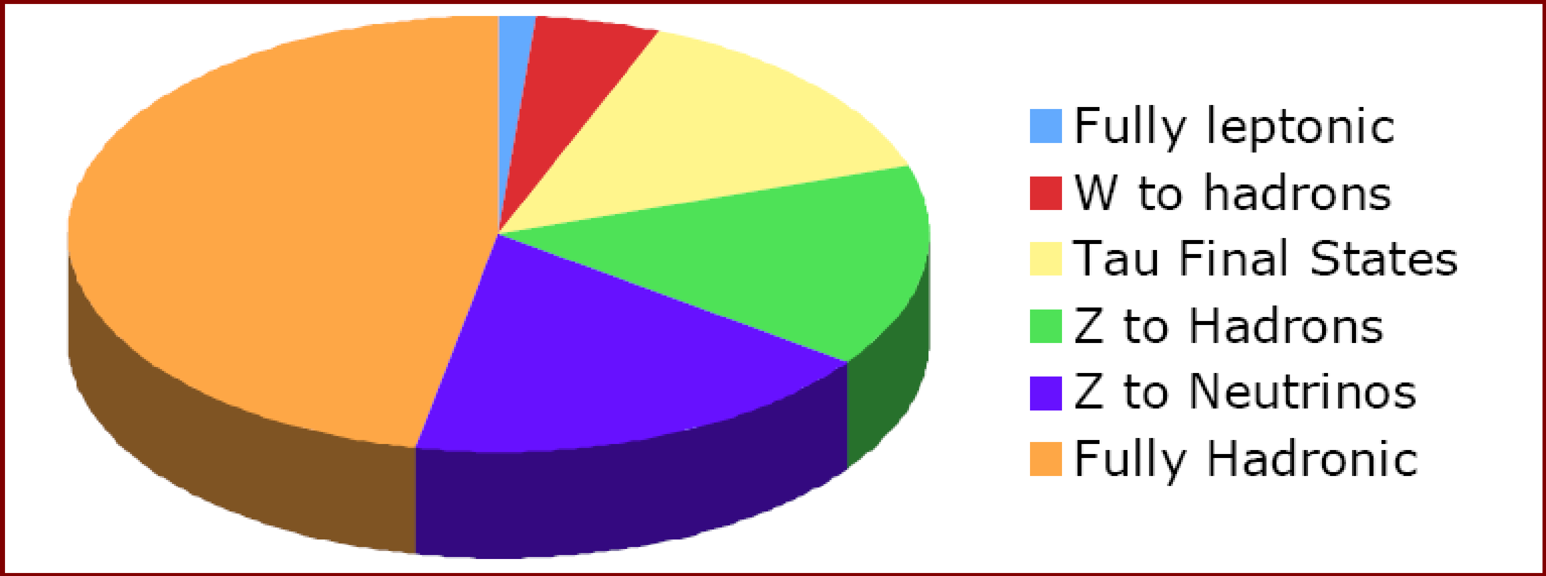
WZ Production



- A unique opportunity: produce W and Z together in final state.
- Directly probe the WWZ Trilinear Vertex, independent of the WWγ.
  - Unlike WW.
- CDF Limit: $\sigma_{WZ} < 6.3$ @ 95% CL

Purest of Channels

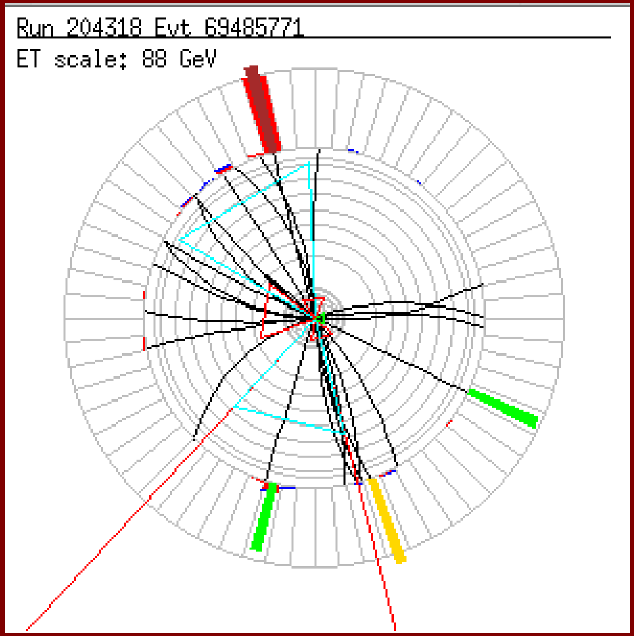
WZ Branching Ratios



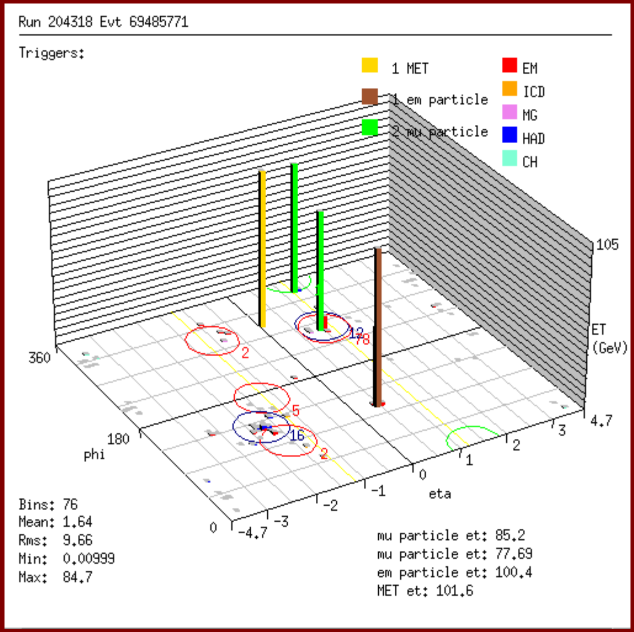
- Fully leptonic mode:
  - Plus: Three lepton + missing E_T very pure, low backgrounds from jets.
  - Minus: Smallest fraction of WZ production events (1.4%).

Selection:

- Select 2 leptons (ee,μμ)
  - $p_T > 15$ GeV.
- Require *Z* peak window.
  - 50-130 GeV muons
  - 71-111 GeV electrons
- Require MET > 20 GeV
- Require at least one more high p_T lepton
- Reject Top events:
  - Require $E_T^{HAD} < 50$ GeV.



r-φ



η-φ

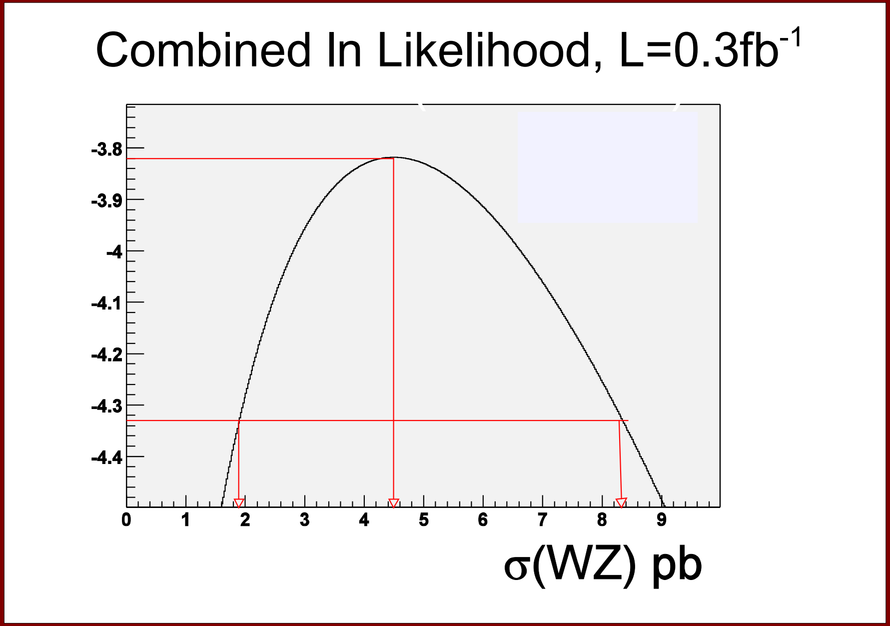
Instrumental Backgrounds:

- Z + j:
  - j mimics an additional lepton.
  - Measure this rate in Data:
    - Select QCD events, use jet triggers:
    - Associate lead jet with trigger criteria
    - Use opposite hemisphere of event to calculate the probability that the other jet was mis-reconstructed.
  - Normalize to Z+j events.
    - Takes into account real Z-fake lepton, and Fake Z–Fake Lepton.

Physics Background

- ZZ, where one lepton is lost, particularly significant in channels with μ.
  - Muon escapes providing missing E_T.
  - Electrons deposit energy->much smaller background.
- Top pairs, in dilepton modes.
- W+DY: Off mass γ^* instead of resonant Z.

Previous result: 0.3 fb^{-1}



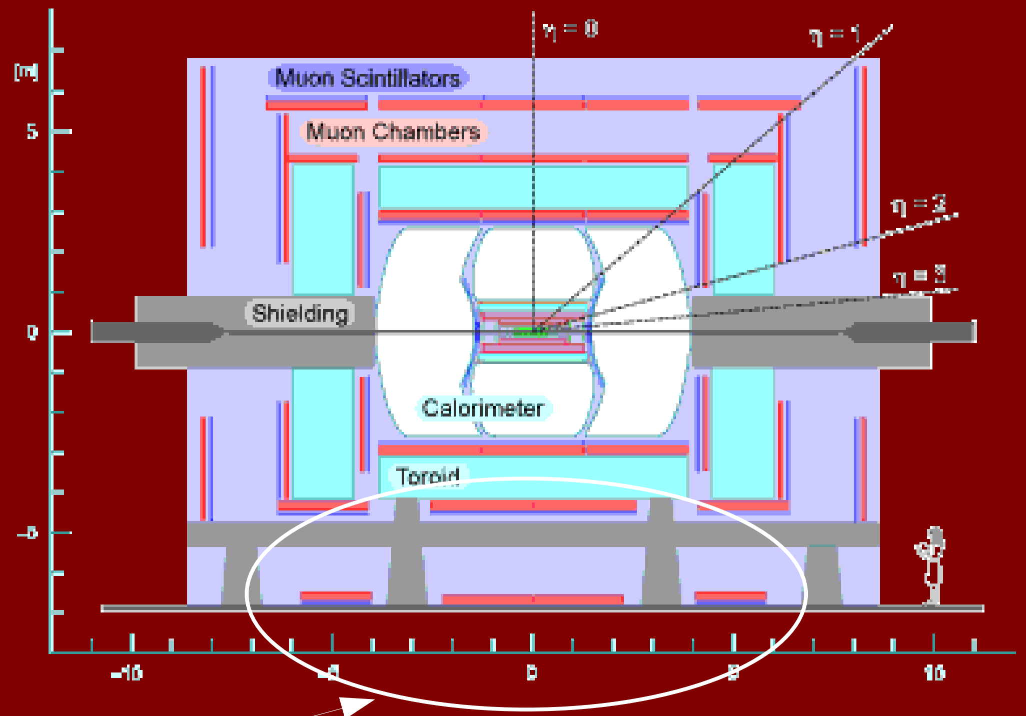
- 2 μμμν Candidates
- 1 eeeν Candidates
- Estimated background 0.71±0.08.

- P(0.71 bkgd) –> 3 Candidates is 3.5%
- Interpreting the Events as Signal + Background:
  - $\sigma_{WZ} = 4.5^{+3.5}_{-2.4}$ pb
  - Set a limit of $\sigma_{WZ} < 13.3$ pb (95% CL)
  - PRL 95, 141802 (2005).

0.8 fb^{-1} Analysis:

- Electron ID substantially improved (track+cluster likelihood).
- Improved muon coverage.

Decay Channel	A x ϵ (0.8 fb^{-1})	A x ϵ (0.3 fb^{-1})
eee	0.158 ± 0.012	0.103 ± 0.015
$ee\mu$	0.167 ± 0.029	0.117 ± 0.008
$\mu\mu e$	0.175 ± 0.043	0.139 ± 0.013
$\mu\mu\mu$	0.205 ± 0.033	0.163 ± 0.018



Previously the area about the calorimeter supports was cut out.

Backgrounds for 0.8 fb^{-1}:

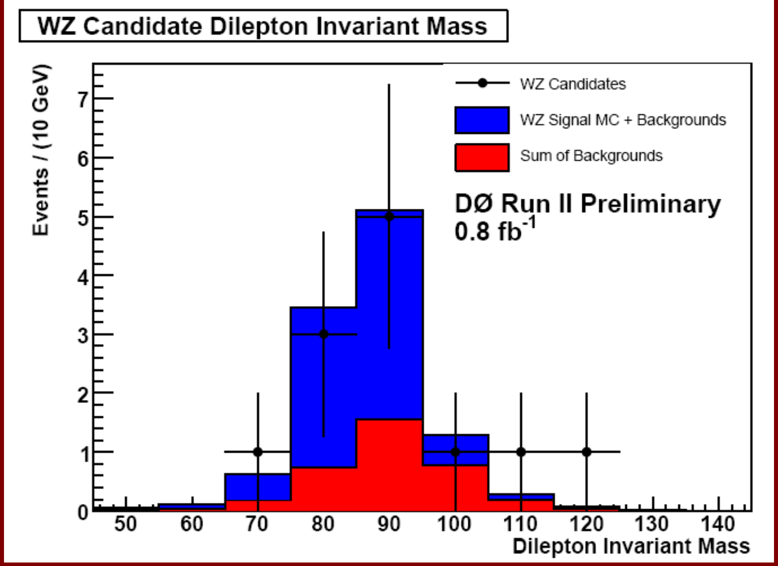
- Here is a table:
  - I will try not to read it to you.
  - Z+j larger where the electron is the fake object.
  - ZZ larger in states that have muons.
  - Total background: 3.6 ± 0.2.

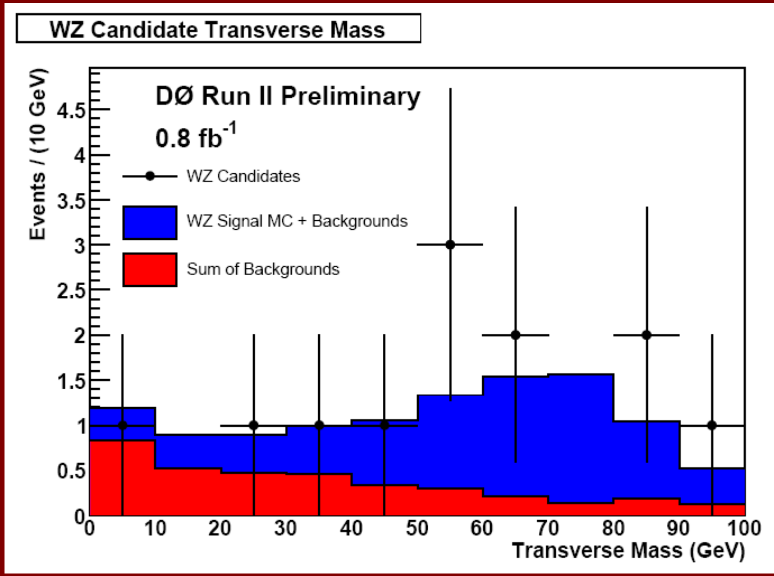
Channel	Source	Estimated background Events ± Stat. ± Syst.
eee	$Z \to ee$ + jets	$0.702 \pm 0.014 \pm 0.056$
	ZZ	$0.058 \pm 0.005 \pm 0.006$
	$Z\gamma$	$0.0004 \pm 0.0003 \pm 0.0001$
	$t\bar{t}$	$0.012 \pm 0.009 \pm 0.002$
	Drell-Yan	$0.188 \pm 0.001 \pm 0.036$
subtotal		$0.960 \pm 0.016 \pm 0.067$
$ee\mu$	$e + \mu$+ jets	$0.029 \pm 0.001 \pm 0.002$
	$Z \to ee$+ jets	$0.077 \pm 0.002 \pm 0.022$
	ZZ	$0.224 \pm 0.004 \pm 0.021$
	$t\bar{t}$	$0.006 \pm 0.006 \pm 0.001$
	Drell-Yan	$0.149 \pm 0.001 \pm 0.042$
subtotal		$0.485 \pm 0.008 \pm 0.052$
$\mu\mu e$	$Z \to \mu\mu$+ jets	$0.699 \pm 0.013 \pm 0.054$
	$e + \mu$ + jets	$0.004 \pm 0.0004 \pm 0.001$
	ZZ	$0.092 \pm 0.002 \pm 0.009$
	$Z\gamma$	$0.001 \pm 0.0007 \pm 0.0001$
	$t\bar{t}$	$0.005 \pm 0.005 \pm 0.001$
	Drell-Yan	$0.161 \pm 0.001 \pm 0.057$
subtotal		$0.963 \pm 0.015 \pm 0.079$
$\mu\mu\mu$	$Z \to \mu\mu$ + jets	$0.078 \pm 0.002 \pm 0.020$
	ZZ	$0.823 \pm 0.011 \pm 0.077$
	$t\bar{t}$	<0.0001
	Drell-Yan	$0.302 \pm 0.002 \pm 0.082$
subtotal		$1.203 \pm 0.011 \pm 0.143$
Total		$3.612 \pm 0.026 \pm 0.202$

Signal and Observed Candidates

Decay Channel	Number of Candidates	Overall Efficiency	Expected Signal	Estimated Background
eee	2	0.158 ± 0.012	1.81 ± 0.18	0.960 ± 0.069
$ee\mu$	1	0.167 ± 0.029	1.88 ± 0.52	0.485 ± 0.053
$\mu\mu e$	7	0.175 ± 0.043	1.77 ± 0.66	0.963 ± 0.080
$\mu\mu\mu$	2	0.205 ± 0.033	2.04 ± 0.54	1.203 ± 0.143
Total	12	-	7.5 ± 1.36	3.61 ± 0.20

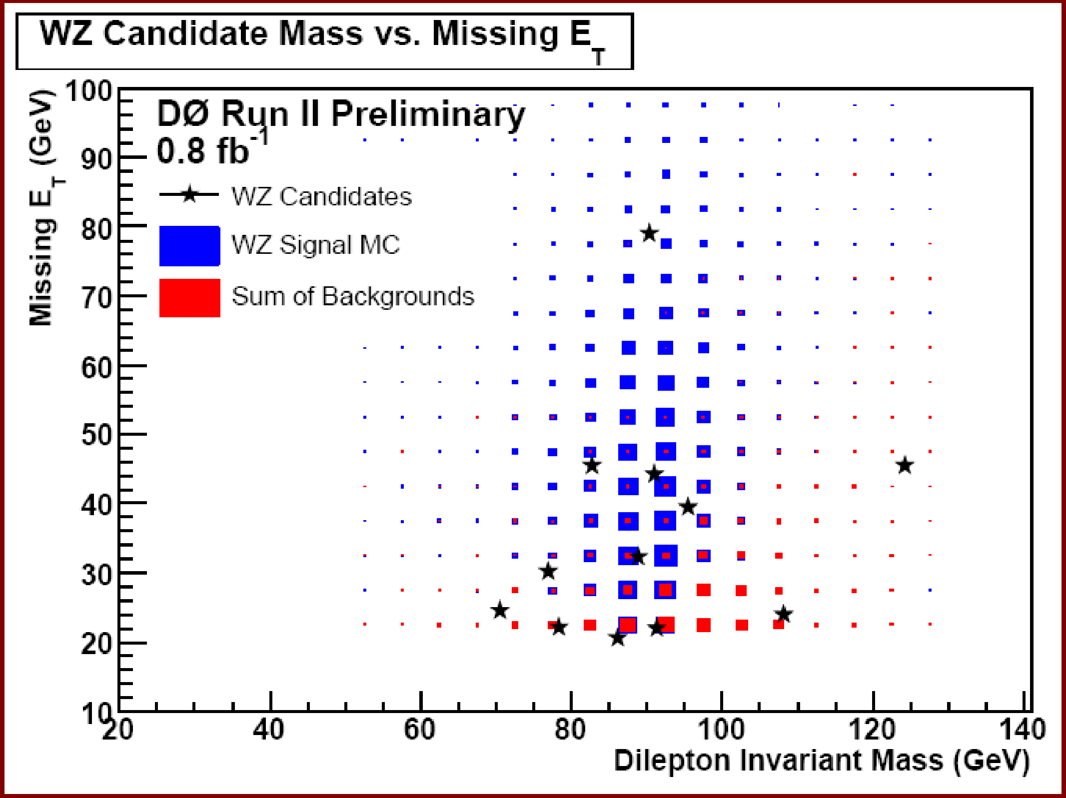
- 12 Total candidate events, spread over all four channels.
- Good agreement with expected total events.
  - Probability of 7 or more events in one channel 8.5%.





WZ Candidates:

- SM Expectation:
  - Signal: 7.5 ± 1.2
  - Bkg: 3.6 ± 0.2
  - Observe 12.
- Consistent with expected number of events, and distribution.



A Word About Significance:

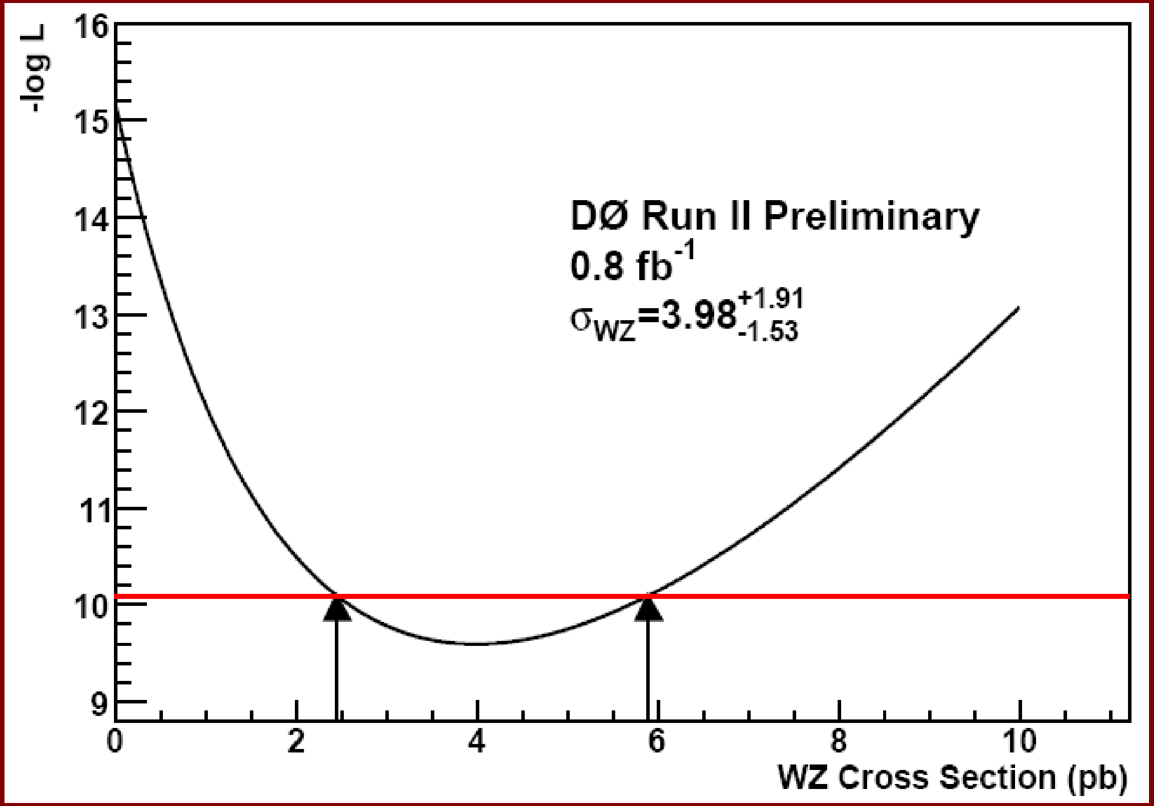
- Herein we shall define Significance as the probability with which the estimated background can fluctuate to the number of observed candidates or greater than the number of observed candidates.
  - We observe 12 events, on a background estimate of 3.6±0.2.
  - P(3.6->12) = 4.1 x 10^{-4}
  - When translated to Gaussian significance (σ), this probability corresponds to 3.3 σ (evidence for WZ production).

WZ/ZZ

- One may ask what happens to the significance should we search for WZ+ZZ, instead of WZ exclusively:
  - ZZ backgrounds then become signal expectation.
  - Now the relevant probability is for 2.4 events of background to fluctuate to 12 observed candidates.
  - The probability is 1.2×10^{-5}.
  - This corresponds to 4.23 σ

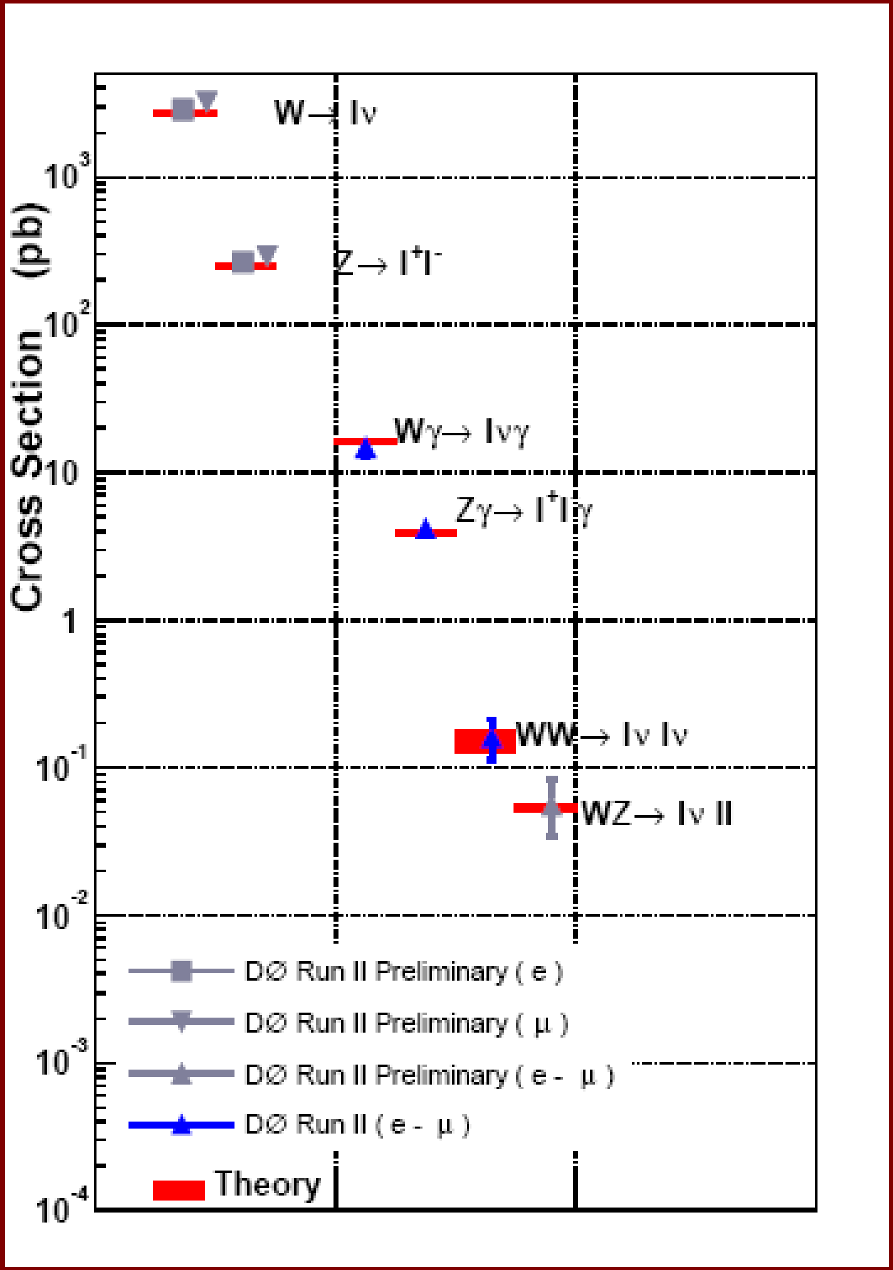
WZ Cross Section:

- Since these are still low statistics, the cross section is found by forming the likelihood in each channel and combining.
- $\sigma_{WZ} = 3.9^{+1.9}_{-1.5}$ pb
- SM σ_{WZ}=3.7±0.3 pb



Summary

- More exciting times ahead.
- WZ Anomalous coupling results using Z p_T.
- Expanded datasets.
- Combined anomalous couplings.
- You'll be hearing more from us soon!

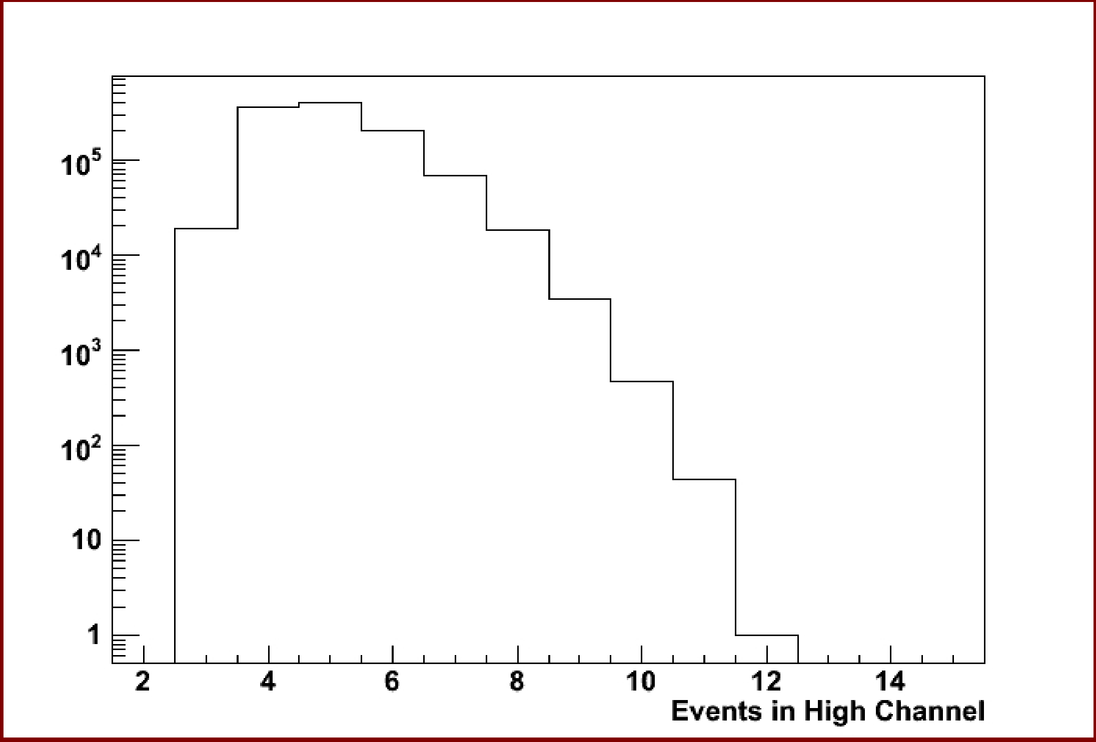


BACKUP SLIDES

HERE THERE BE DRAGONS...

Statistical Fluctuations:

- Probability for 7 or more events in one channel is 8.5% (Given 12 candidates, with the expectations for SM + Bkg).
- Shown is the distribution of the number of events in the highest channel.



A Word on Cosmics:

- One CAN imagine a background in which a cosmic ray muon undergoes bremsstrahlung, and then the photon converts, yielding μμe.
  - Acolinearity cut applied reduces possible cosmic contamination.
  - Timing of all candidates consistent with muons from collisions.

Run	Event	$\Delta\phi$	$T_{\mu 1}$(ns)	$T_{\mu 2}$(ns)	ΔT (ns)
207094	10178395	1.77	-2.20	0.70	-2.9
188371	23177216	2.47	0.70	1.77	-1.07
207769	23761167	2.07	-0.24	-0.27	0.03
210156	24837747	1.71	-2.08	0.76	2.84
206332	20605317	3.13	-1.80	-2.25	-0.45
204318	69485771	1.41	1.01	-3.36	4.37
207596	12955559	2.44	2.99	0.92	2.07

Strategy:

- All analyses use leptonic decays of W and Z bosons.
  - Clean signals.
  - Straightforward triggering.
- Where possible, use loose lepton criteria such that the full acceptance of the detector may be utilized.
  - Single lepton triggers for multilepton states-> higher efficiency.
  - Loose criteria for multiple lepton states: background controllable, high efficiency.