Measurement of the Wγ Charge-Sign Rapidity Difference at DØ

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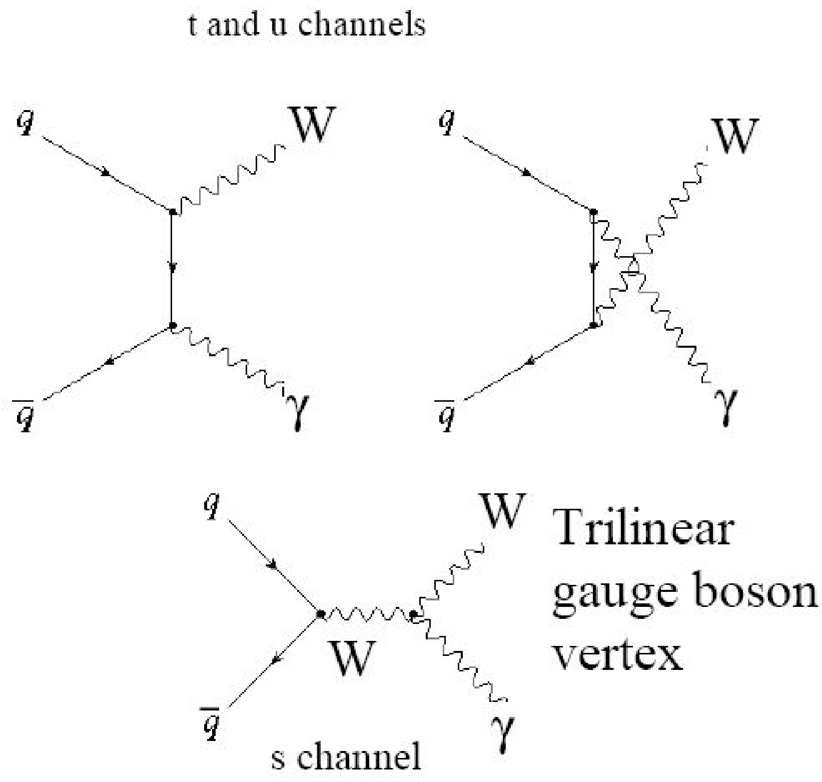
DØ Experiment

Introduction

Studying $q\bar{q} \rightarrow W\gamma$ production

- Measurement is important
- Couplings at interaction vertices are fixed in Standard Model gauge theory
- Variation in $W\gamma$ production is sign of new physics
- $W\gamma$ production provides a means to measure anomalous moments of the W boson
- Analyzing the $W\gamma \rightarrow e\nu\gamma$ and $W\gamma \rightarrow \mu\nu\gamma$ final states
  - Cleanest signal
  - Hadronic channel dominated by QCD



Anomalous Couplings

Potential electromagnetic moments compatible with Lorentz and EM gauge invariance and CP conservation can be parameterized in an effective Lagrangian:

$$L_{WW\gamma} = -ie\left[\left(W^{\dagger}_{\mu\nu}W^{\mu}A^{\nu} - W^{\dagger}_{\mu}A_{\nu}W^{\mu\nu}\right) + \kappa_{\gamma}W^{\dagger}_{\mu}W_{\nu}F^{\mu\nu} + \frac{\lambda_{\gamma}}{M_W^2}W^{\dagger}_{\lambda\mu}W^{\mu}_{\nu}F^{\nu\lambda}\right]$$

Minimal coupling of γ and W
Fixed by W charge

κ and λ relate to magnetic dipole and electric quadrupole moments

Magnetic dipole moment

$$\mu_W = \frac{e}{2M_W}\left(1 + \kappa_{\gamma} + \lambda_{\gamma}\right)$$

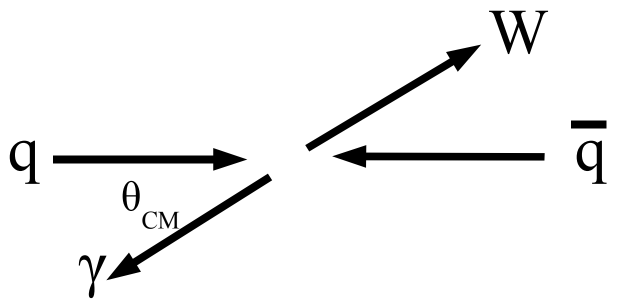
Electric quadrupole moment

$$Q_W = \frac{-e}{M_W^2}\left(\kappa_{\gamma} - \lambda_{\gamma}\right)$$

In the Standard Model: $\kappa_{\gamma} = 1$ and $\lambda_{\gamma} = 0$

Radiation Amplitude Zero

Standard Model couplings at leading order produce an amplitude zero in the center-of-mass production angle



$u\bar{d} \to W^{+}\gamma$ has zero at $\cos\theta_{CM} = -1/3$

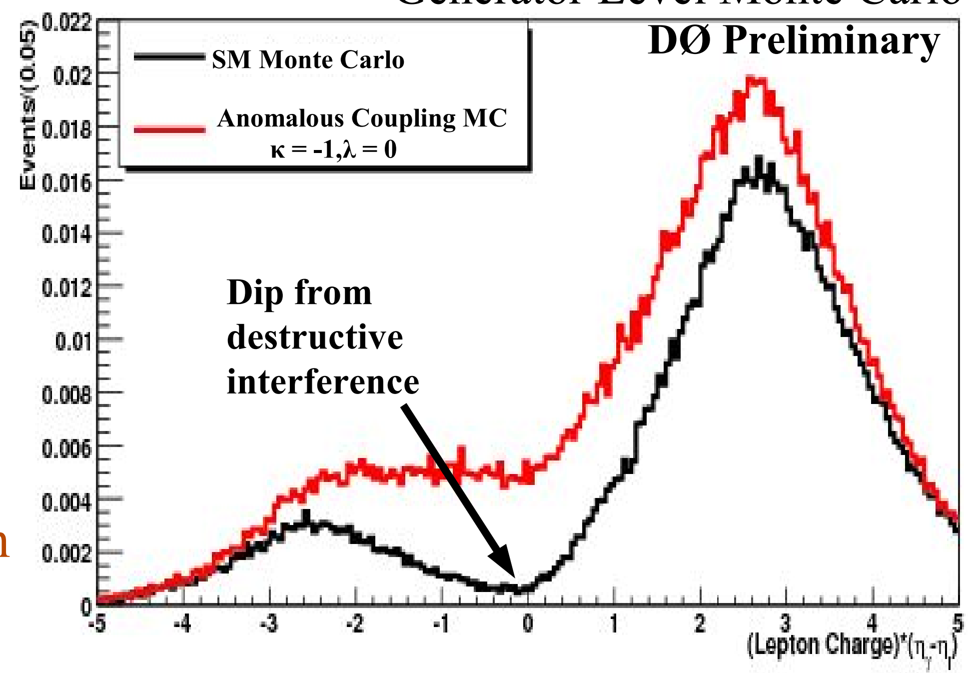
$d\bar{u} \to W^{-}\gamma$ has zero at $\cos\theta_{CM} = +1/3$

Angle dependent only on charges

Ambiguity in θ_{CM} (neutrino P_Z)

Correlations lead to dip in $\gamma\ell$ charge-sign rapidity difference

Generator Level Monte Carlo



Important Measurement

- Probes WWγ vertex
  - Anomalous moments spoil cancellation
- Never been observed

Reconstruction Efficiencies

Object efficiencies measured with data from resonances

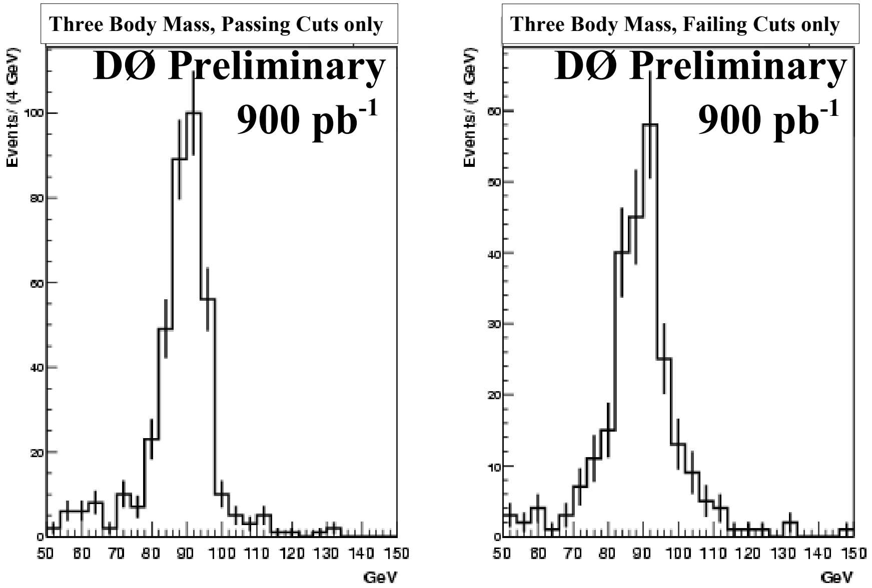
- Clean samples

Lepton efficiencies obtained from $Z \to \ell\ell$ events

- Tag-and-Probe method
- Tag lepton satisfies event selection requirements (trigger, etc.)
- Probe lepton unbiased sample for efficiency estimate

Photon efficiencies

- Use $Z \to \ell\ell \to \ell\ell\gamma$ events (three body mass = Z mass)
- Leptons satisfy event selection requirements (trigger, etc.)
- Photon sample is clean
- DØ lacked the integrated luminosity to do this before



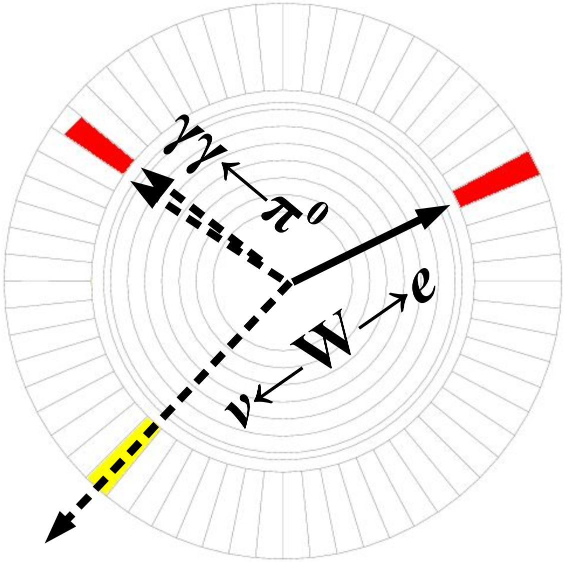
Backgrounds

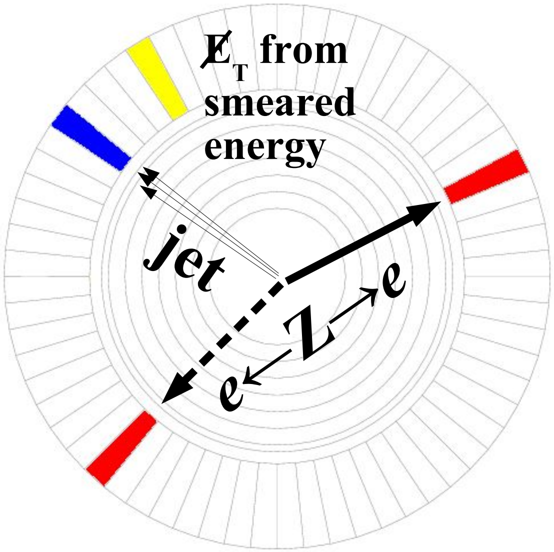
W+j

Jet fragments to significant electromagnetic component (*i.e.* π^0,η, etc.) to produce a photon signature

Dominant background in both channels, on order of signal events

Estimated with data





***ℓe*X**

lepton + electron + missing E_T events where electron fakes photon because of lost track

Significant background in electron channel *i.e.* Z → ee

Estimated with data

Backgrounds

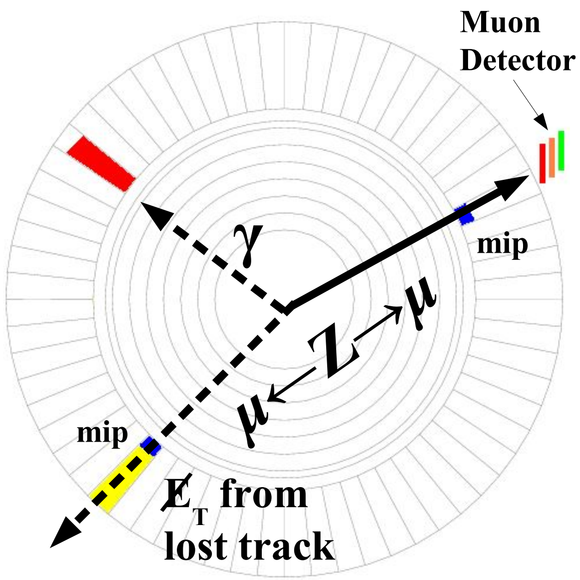
Zγ

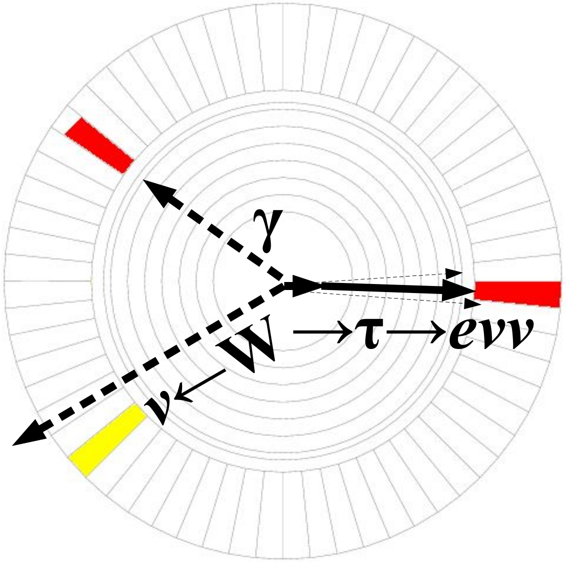
Mis-measured missing E_T produces W signature

Caused by mis-measured or unreconstructed lepton

More significant for muon channel
(lost muon ➞ missing E_T)

Estimated with MC





Wγ→τνγ

τ+γ+missing energy → ℓ+γ+missing energy

Estimate with MC

Preliminary Results

Electron Channel (933 pb^{-1})	
Candidates:	**389**
Wj:	148 ± 17
ℓeX:	34 ± 4
τ:	1.7 ± 0.2
Zγ:	--
Expected Signal:	**211 ± 14**
Measured Signal:	**205 ± 26**

$\sigma(p\bar{p}\to e\nu\gamma+X)$:

$3.12 \pm 0.49_{stat.+sys.} \pm 0.19_{lumi.}$ pb

Muon Channel (878 pb^{-1})	
Candidates:	**245**
Wj:	98 ± 12
ℓeX:	6 ± 2
τ:	2.6 ± 0.4
Zγ:	8 ± 1
Expected Signal:	**130 ± 9**
Measured Signal:	**130 ± 18**

$\sigma(p\bar{p}\to \mu\nu\gamma+X)$:

$3.21 \pm 0.49_{stat.+sys.} \pm 0.20_{lumi.}$ pb

SM $\sigma(p\bar{p}\to \ell\nu\gamma+X) = 3.21 \pm 0.08_{PDF}$ pb

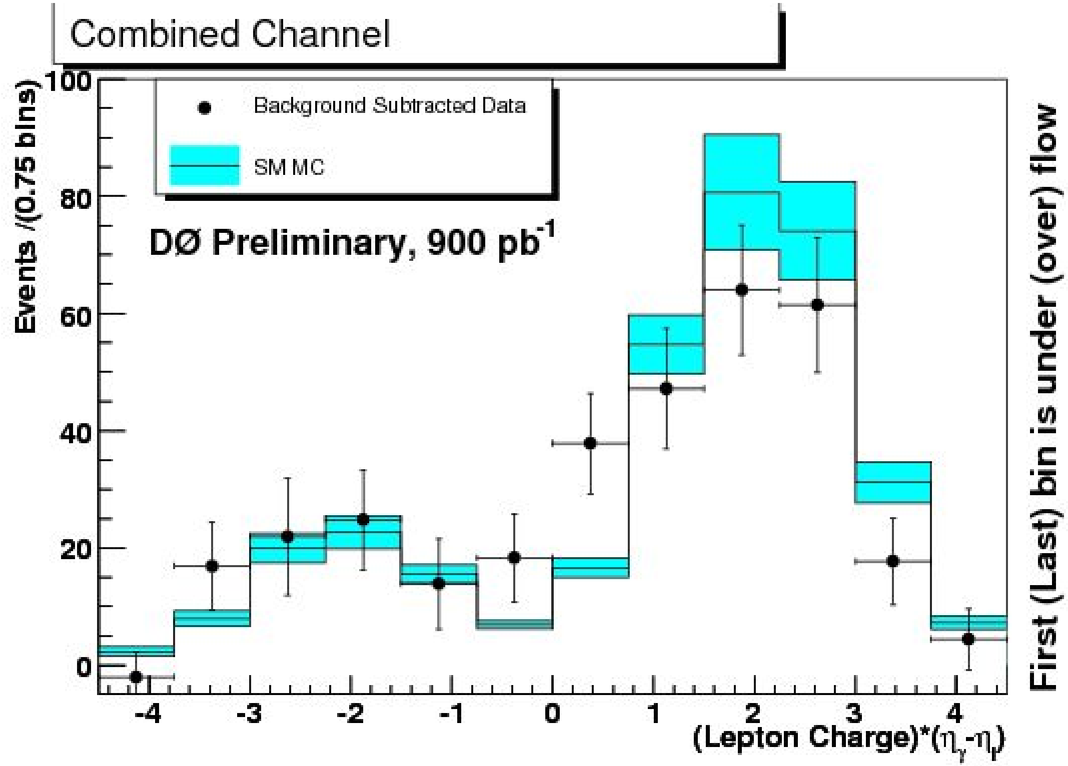
w.r.t. $E_T(\gamma)$>7 GeV, $\Delta R_{\ell\gamma}$>0.7, $M_T(W,\gamma)$ > 90 GeV

Study Prompt Wγ not $W\to\ell\ell\to\ell\ell\gamma$

Rapidity Distribution

The rapidity distribution is consistent with the Standard Model

χ^2 of 16 for 12 dof (DØ Preliminary)



Shape is indicative of destructive interference from amplitude zero

The next slides address how to quantify this ...

Examining the Distribution

2 methods are presented to examine the rapidity distribution

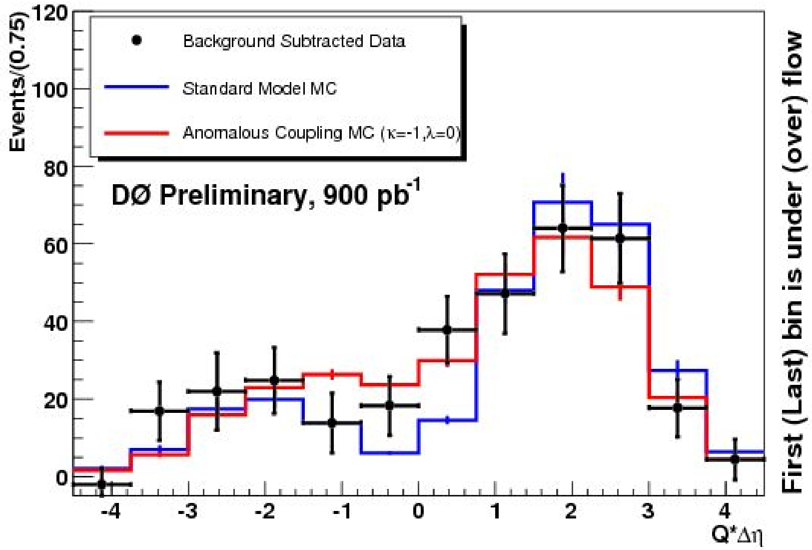
- 1st method: Shape Test
  - Compare the data shape to an alternative hypothesis
  - χ^2 test of the normalized distributions
  - Alternative hypothesis is anomalous WWγ coupling (κ=-1,λ=0)
    - Physically motivated -- turns off W magnetic dipole moment
    - Theoretic distribution expected to be unimodal (dipless)
- 2nd method: Dip Test
  - Measure statistical significant of observed dip.
  - Compare number of candidates in expected dip region to number in peak
  - Answers question:
    - Could this be a statistical fluctuation, or are we observing a real process that leads to a depletion of events in the distribution such as the radiation zero?

Shape Test

Fit shape of an anomalous coupling (κ=-1,λ=0) MC distribution to the data

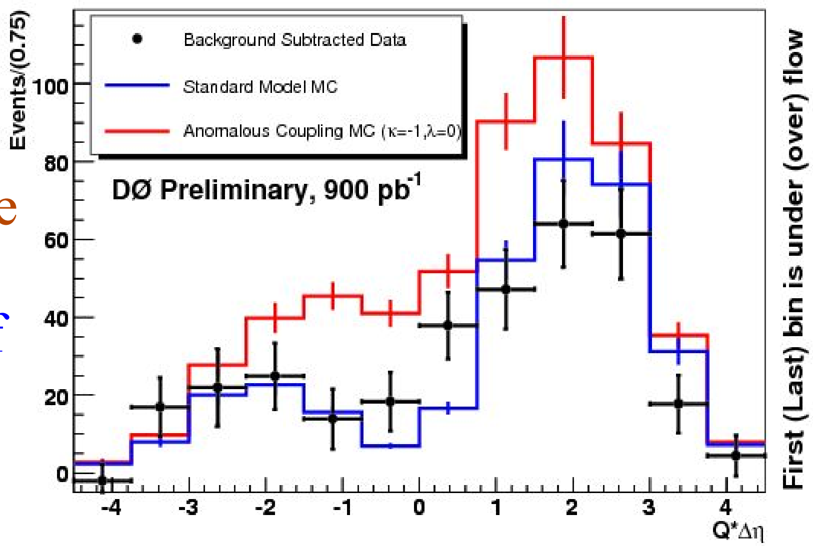
Normalization allowed to float

- Preliminary Result:
  - Unimodal hypothesis is consistent with data with a χ^2 of 9 for 11 d.o.f.
- Result dependent on binning
- Takes weight away from region of interest



Normalization set by cross section

- Note anomalous couplings enhance the Wγ cross section
- With cross section normalization the alternate hypothesis has a χ^2 of 55 for 12 d.o.f.
- Consider test that is independent of choice of couplings



Dip Test

Purpose:

Measure the probability that the observed depletion of events in the expected region is a statistical fluctuation

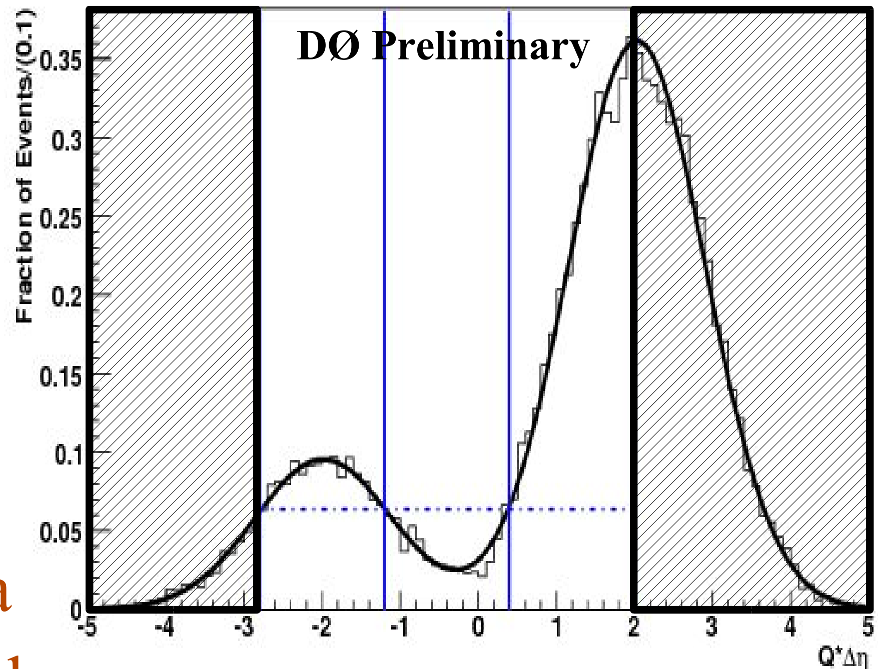
Method:

Use 3 bins

- 1st bin samples the small peak
- 2nd bin samples the dip
- 3rd bin samples the big peak

Measure $R_1 = \frac{N_{Dip}}{N_{Peak1}}$, and $R_2 = \frac{N_{Dip}}{N_{Peak2}}$

By definition if $R_1, R_2 < 1$ there is a depletion of events in the Standard Model expected region



Use SM MC to find expected positions of peaks and dip

Dip Test

R_1 and R_2 are the relevant test statistics

Probability there is no dip = Probability for $R_1 \geq 1$ or $R_2 \geq 1$

Data Candidates:

$R_1 = 0.841 \pm 0.117$ (DØ Preliminary)

$R_2 = 0.508 \pm 0.064$ (DØ Preliminary)

Preliminary Result:

Assuming Gaussian errors on R_1 and R_2, the dipless hypothesis is ruled out at 90% C.L.

Cross Check:

Also used a standardized method of dip hunting[1] that is model independent and obtained consistent results.

[1] J.A. Haritgan and P.M. Hartigan "The Dip Test of Unimodality", Annals of Statistics **13**, 70-84 (1985)

Conclusion

- The Wγ final state has been observed with high statistics in two W decay modes
- The production rate is consistent with SM expectations
- The charge-sign rapidity distribution is consistent with the SM
  - The shape that is indicative of the radiation amplitude zero with the unimodal hypothesis being ruled out to 90% C.L.
- As our integrated luminosity increases, we will be able to maker even stronger statements.
- Looking immediately ahead, we intend to investigate combining measurements of the charge-sign rapidity distribution with the photon E_T spectrum to set limits on anomalous WWγ couplings