WZ Cross Section & Anomalous Coupling Limits

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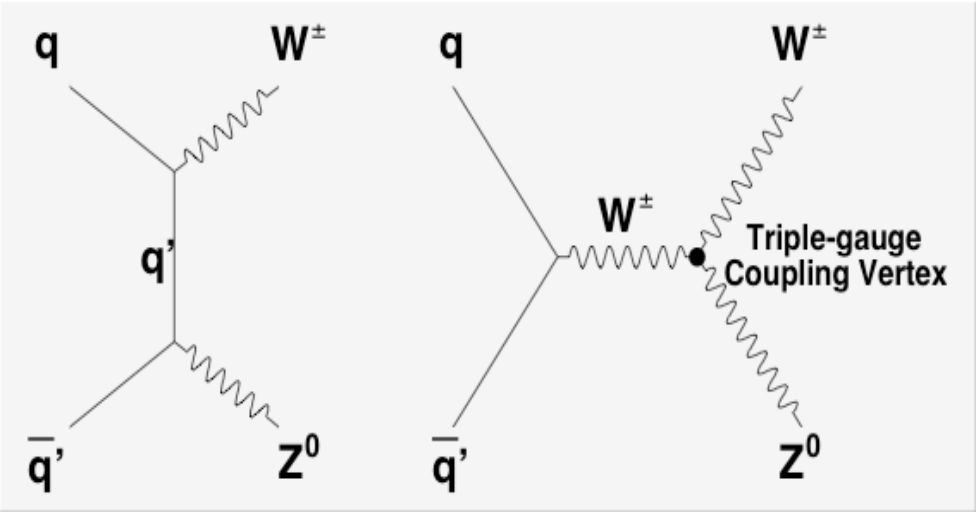
Introduction

- First opportunity to measure exclusive *WZ* final state.
  - Can only be made at the Tevatron.
  - Need a charged intermediate state to produce associated *WZ*.
  - Need a large center of mass energy to produce *WZ*.

•SM test and a probe for new physics.

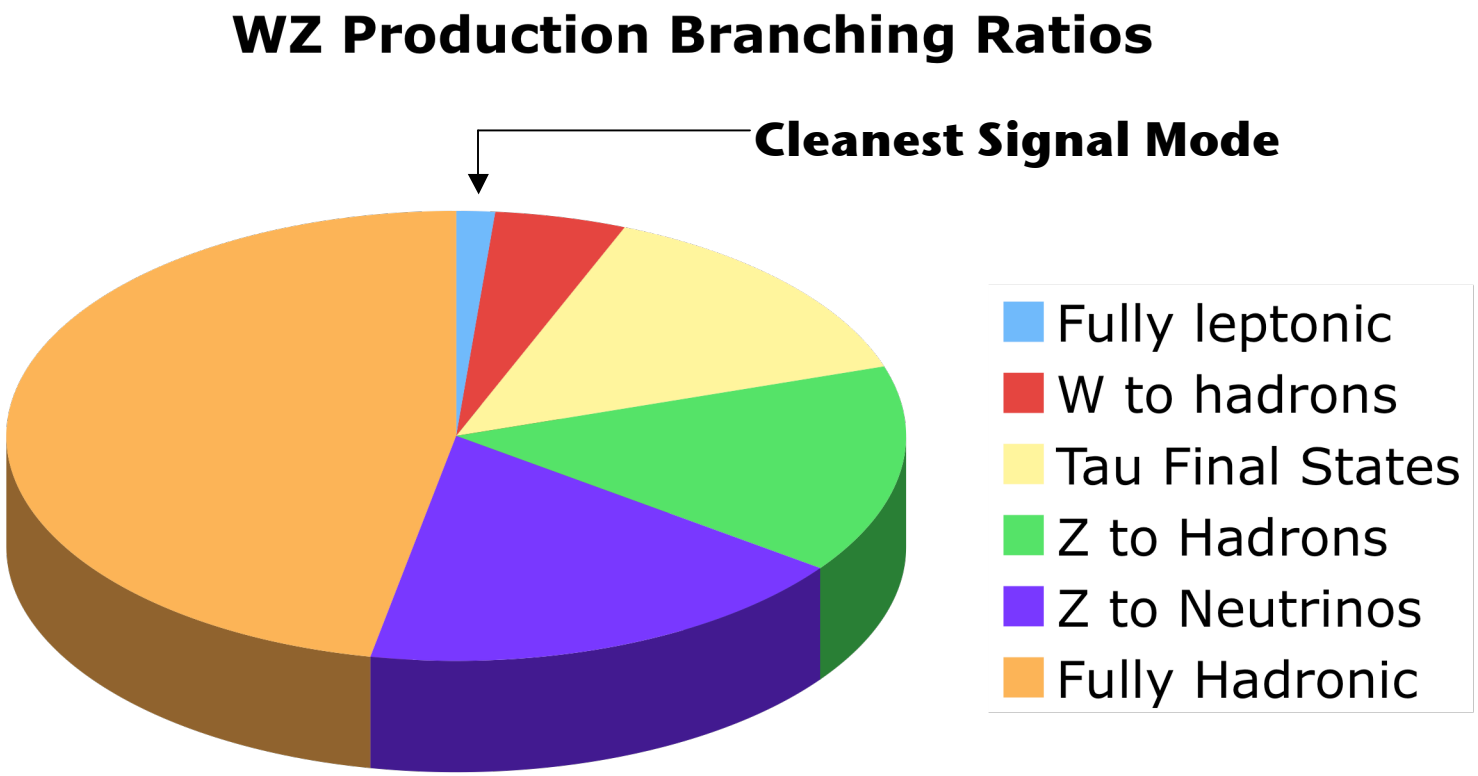
–SM predicts a cross section of 3.7 ± 0.1 pb.

–Larger cross section is a manifestation of new physics.



Introduction

- Cleanest signal is from fully leptonic decay (trileptons).
  - Small branching ratio: 0.37% per family, 1.5% for two families.

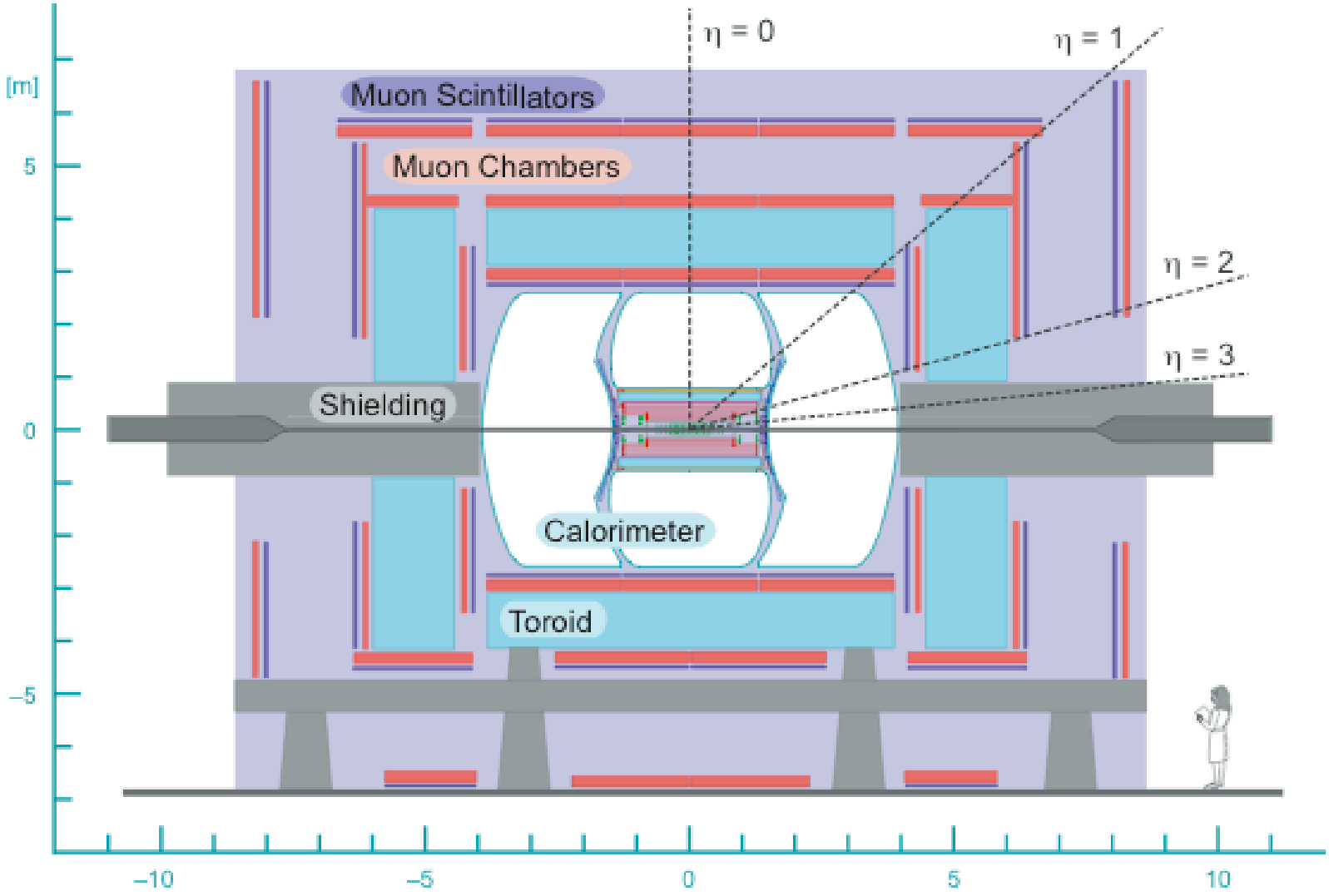


Other Tevatron Measurements

- DØ RunI
- Using *evee*, and *μvee* channels
- Found 1 event in $\mathcal{L}$ = 92 pb^{-1}
- expected signal=0.25±0.02
- expected bkgd=0.50±0.17
- cross section upper limit 47 pb @ 95% C.L.
- Phys. Rev. D **60** 072002 (1999)

- CDF RunII measures *WZ*+*ZZ* together.
- Look for $ll+\nu\nu$, $lll+\nu$.
- Find 3 events in 194 pb^{-1}.
- 9% probability for background to fluctuate to 3 or more events.
- Set a limit at 15.2 pb.
- Hep-Ex/0501021

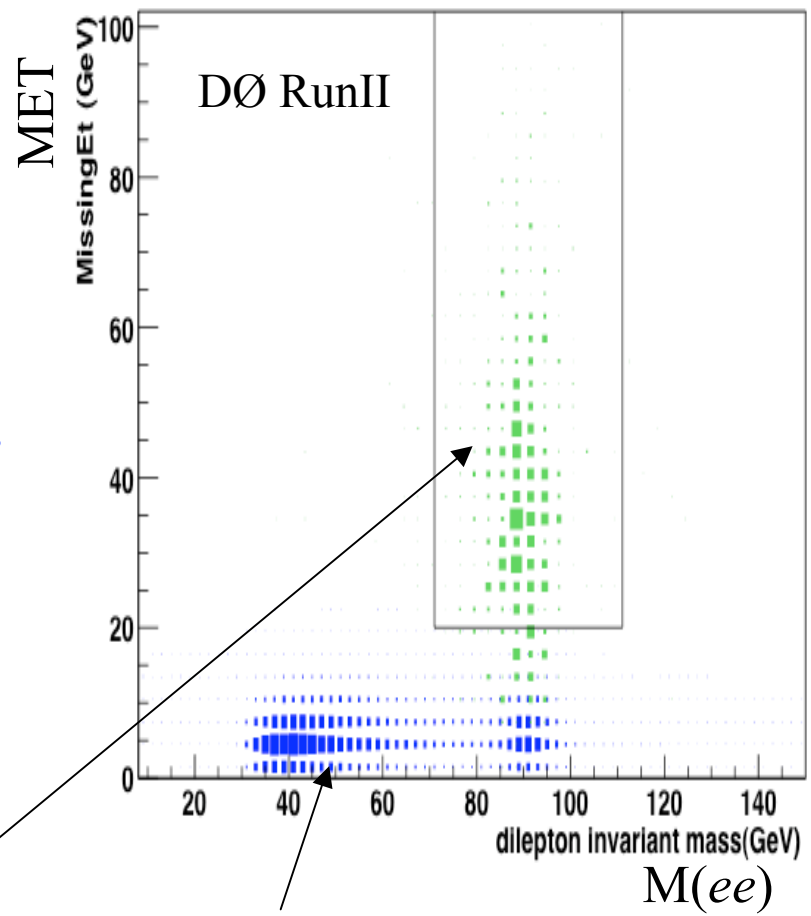
DØ Detector v2.0



WZ Candidate Event Selection

- We look for events with *W Z* boson associated production.
  - These bosons decay too fast for our detector to see them.
  - Decay length is less than size of a proton.
- Look for three isolated leptons.
  - *eee*, *eeμ*, *μμe*, *μμμ*, with p_T > 15 GeV
- Two same family, oppositely charged leptons have an invariant mass in the Z_{mass} window.
  - 50 GeV to 110 GeV for electron pairs
  - 30 GeV to 130 GeV for muon pairs
- Look for an imbalance in the transverse energy from the lost neutrino.
  - Greater than 20 GeV
- Veto other sources of backgrounds.
  - $t\bar{t}$

Invariant Mass vs. Missing E_T



MC Signal

Z/γ* + Jets Background

Backgrounds to *WZ* Events

- Backgrounds are Z + X and $t\,\bar{t}$, where X is a mis-identified or mis-measured physics object.
- Total background is: 0.71 ± 0.08 events

Channel	Source	Est. Bkgnd
$eee\nu$	ee+jets	0.069±0.002
	t $t$bar	0.003±0.003
	ZZ	0.061±0.043
	$Z\gamma$	0.022±0.003

Channel	Source	Est. Bkgnd
$ee\mu\nu$	ee +jets	0.014±0.007
	e+iso-μ+jets	0.029±0.001
	t $t$bar	0.002±0.002
	ZZ	0.028±0.028

Channel	Source	Est. Bkgnd
$\mu\mu e\nu$	$\mu\mu$+jets	0.190±0.005
	e+iso-μ+jets	0.005±0.003
	t $t$bar	0.002±0.002
	ZZ	0.027±0.027
	$Z\gamma$	0.125±0.020

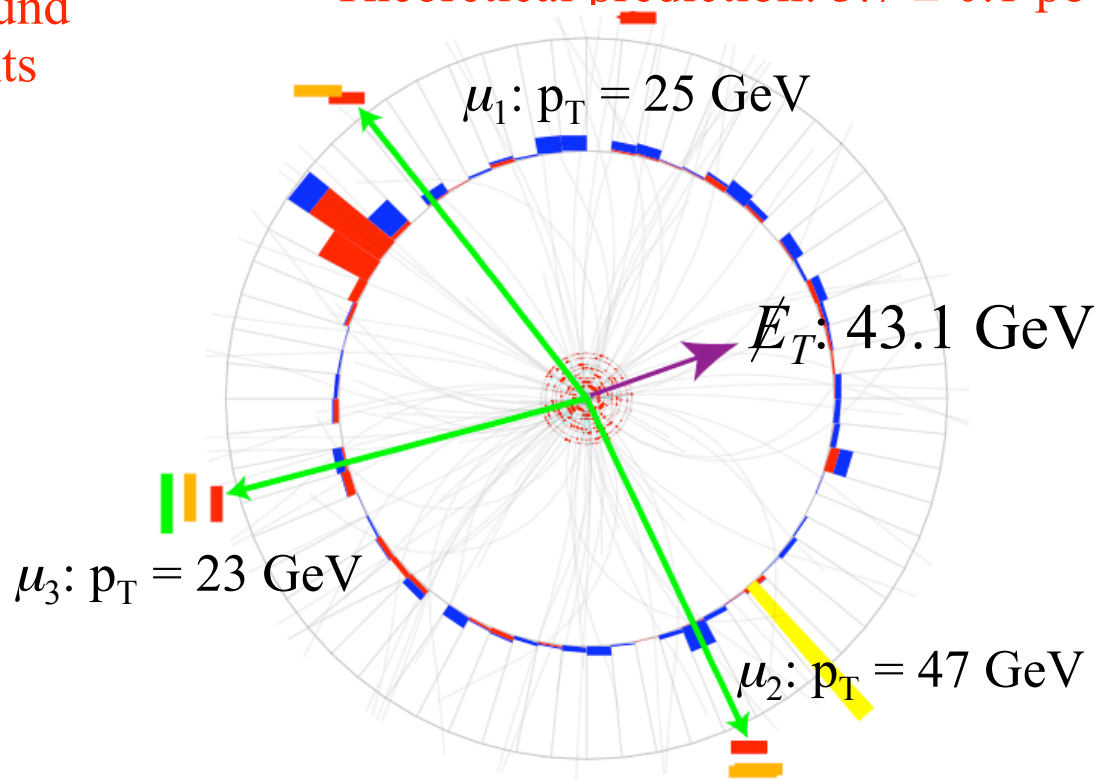
Channel	Source	Est. Bkgnd
$\mu\mu\mu\nu$	$\mu\mu$ + jets	0.049±0.022
	t $t$bar	< 0.002
	ZZ	0.083±0.048

Cross Section Results

- Found Three $WZ \rightarrow l'\nu'_l ll$ events
  - 1 $e\nu ee$ and 2 $\mu\nu\mu\mu$
  - 2.04±0.13 signal events expected
  - 0.71±0.08 estimated background
  - 3.4% probability for background to fluctuate to 3 or more events
  - 0.3 fb^{-1} of data.

Channel	M_{inv} (GeV/c^2)	M_T (GeV/c^2)
eee	91.9	72.3
$\mu\mu\mu$	82.1	56.4
$\mu\mu\mu$	68.5	62.5

- DØ WZ diboson x-section preliminary results
  - Up limit at 95%C.L. 13.3 pb
  - $4.50\ ^{+3.78}_{-2.56}(\text{stat.})^{+0.28}_{-0.23}(\text{sys.})$pb
  - Theoretical prediction: 3.7 ± 0.1 pb



Anomalous Coupling

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

- Cross Section analysis also allows to determine *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:**

    $\lambda_Z = 0$

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

    $\Delta g_1^Z = 0 \quad (\Delta g_1^Z = g_1^Z - 1)$

W^+ Boson Static Properties

$\mu_W = e(1+\kappa+\lambda) / 2M_W$

$Q^e_W = -e(\kappa-\lambda) / M^2_W$

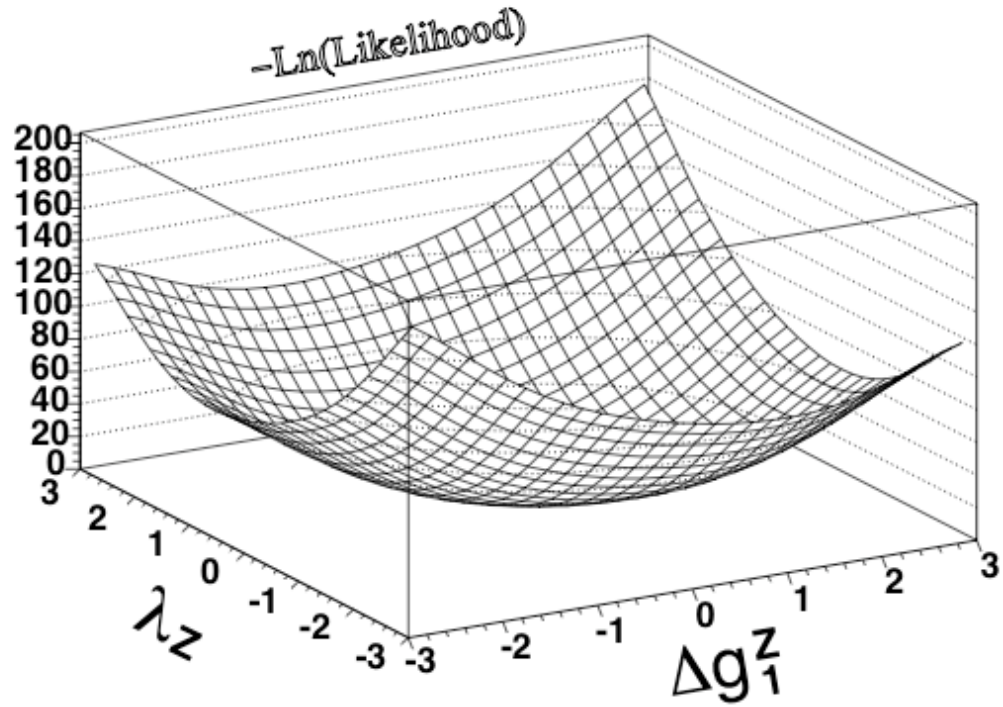
Anomalous Coupling Measurement Technique

- Generate a grid in coupling space using Hagiwara-Zeppenfeld-Woodside event generator.
  - K. Hagiwara, et al., Phys Rev. D **41**, 2113 (1990).
- 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 C.L.

$$L_{95\%C.L.} = L_{min} + \delta$$

δ = 3.0 for 2-D, & 1.92 for 1-D

Δg_1^z vs. λ_z

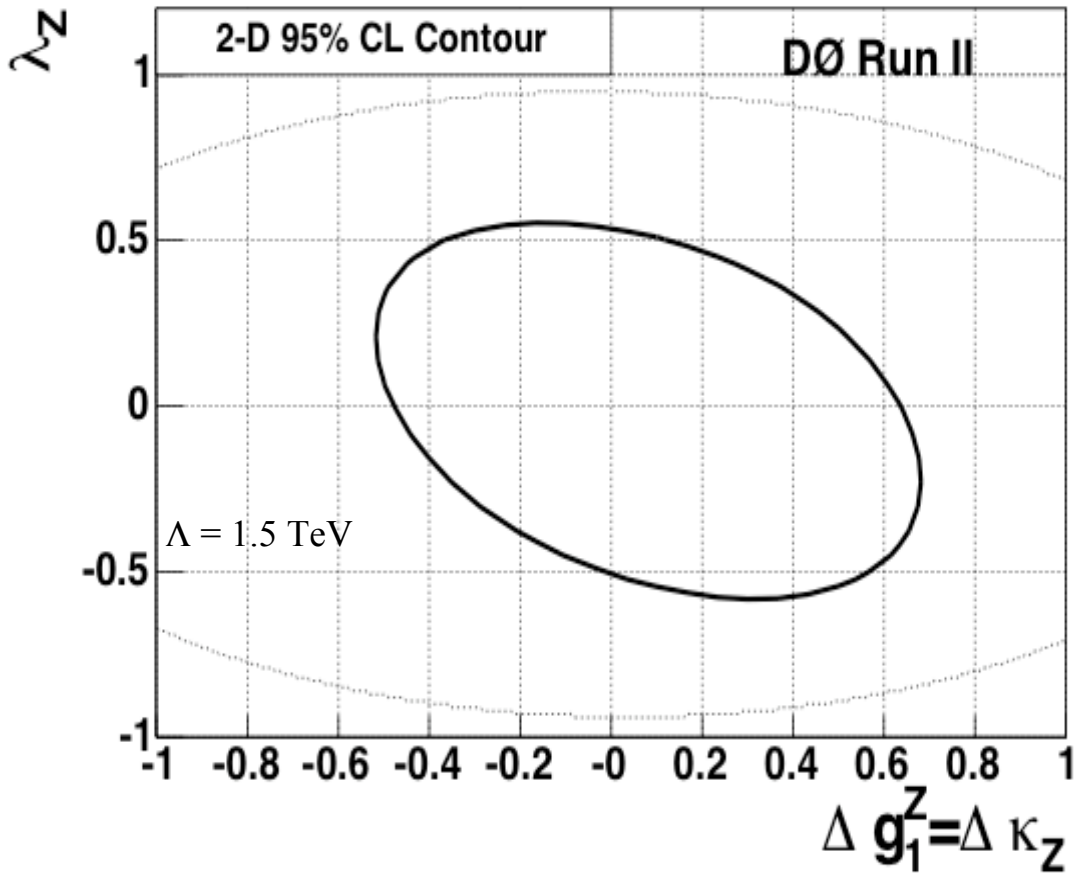


Λ=1 TeV

Anomalous Coupling Results

1-D Limits (Λ = 1.5 TeV)
$-0.48 < \lambda_Z < 0.48$
$-0.49 < \Delta g^Z_1 < 0.66$
$-2.0 < \Delta\kappa_Z < 2.4$ *
$-0.43 < \Delta g^Z_1 = \Delta\kappa_Z < 0.57$

*Limit using Λ=1.0 TeV.



Outer contour is unitarity limit from theory.

Inner contour is limit from experiment.

Summary

- The best cross section limit for *WZ* production has been presented.
- It is also the first attempt to measure the cross section for *WZ* production.
- These are the tightest available limits on anomalous couplings derived from a *WZ* final state.
- Pre-print number is hep-ex/0504019 .
- We are continually collecting more data.
- You will hear from us soon.

STOP!!!!

Barrier Slide

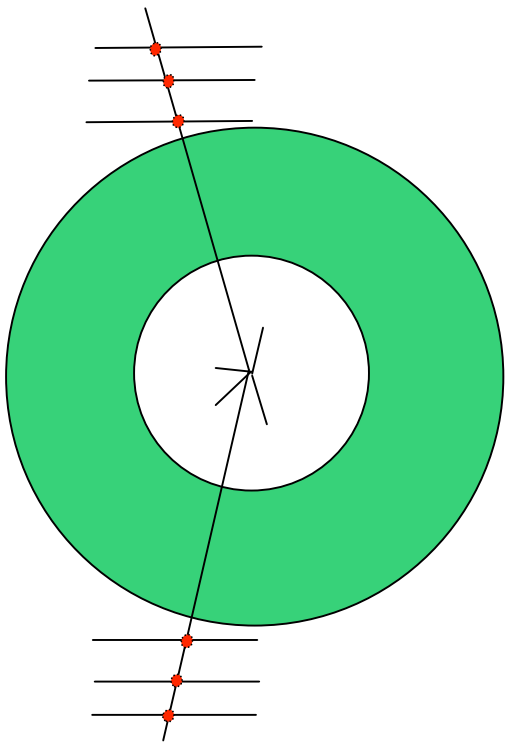
Do Not Pass Go
Do Not Collect $100

10 Slide Maximum

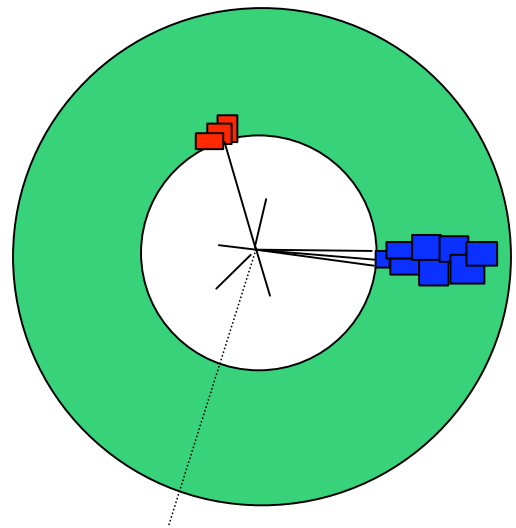
Time is limited to 12 min.

Detecting the W and Z

$Z \rightarrow \mu\mu$



$W \rightarrow e\nu$



Two leptons:
- fully reconstruct Z

Low background.

Reconstruct electron
Infer neutrino from
missing transverse energy.

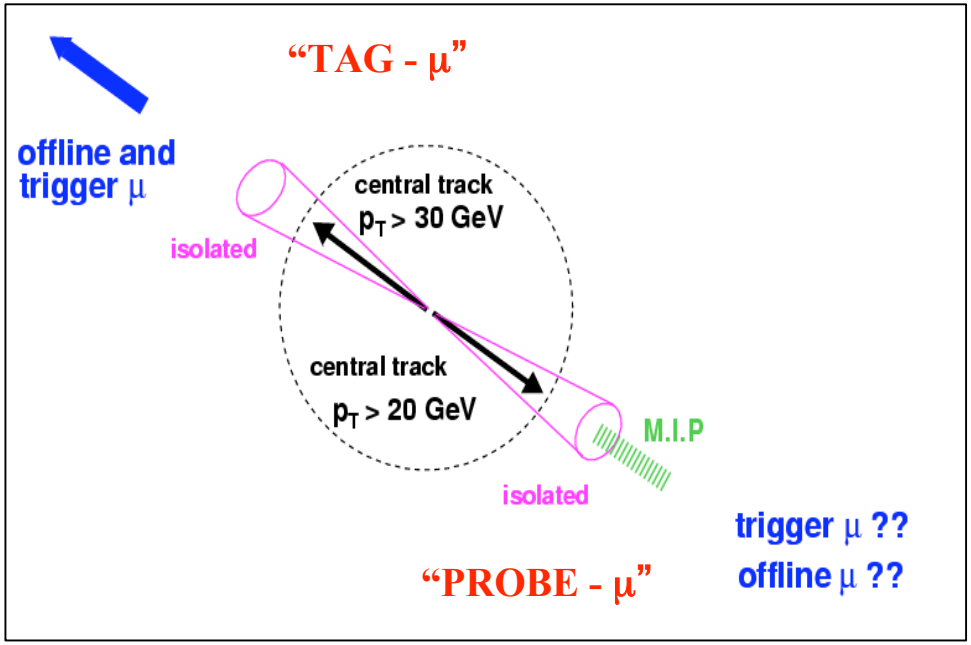
A Cross Section Measurement

$$\sigma \cdot B = \frac{N_{obs} - N_{bkg}}{A\varepsilon \int \mathcal{L} dt}$$

A = acceptance
ε = efficiency

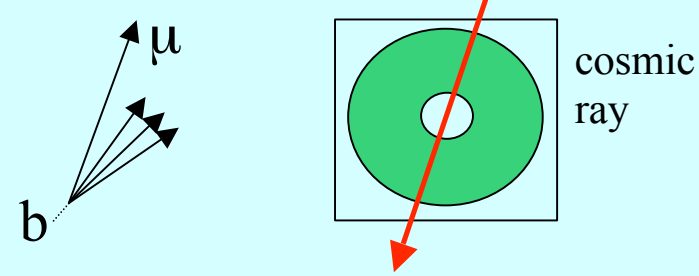
Measurement strategy:

- measure all efficiencies with data
- tune 'fast' detector simulation
- use Pythia MC for acceptance
- use MC for small backgrounds
- measure other backgrounds in data

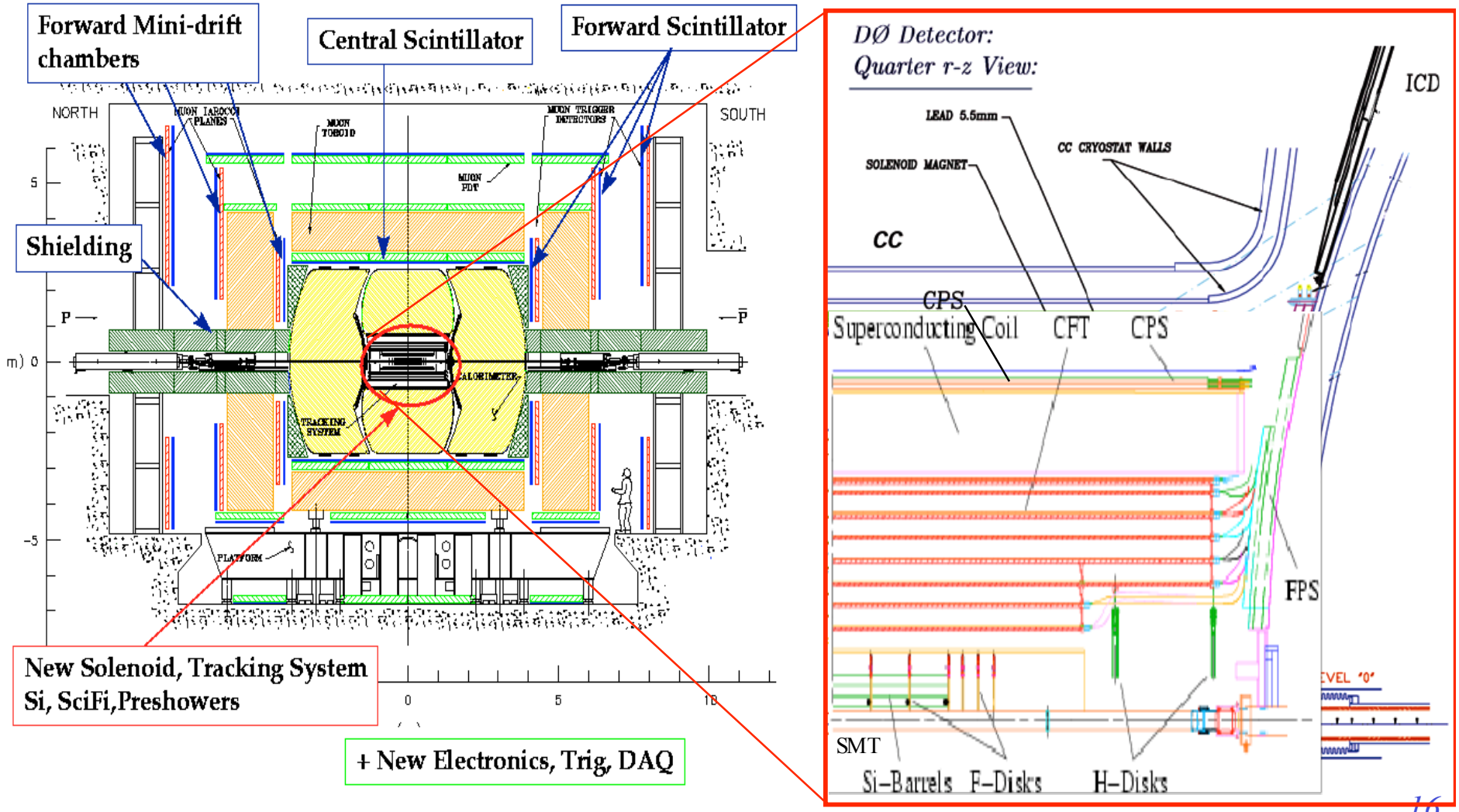


Backgrounds:

- W,Z → τ
- QCD: hadron decays
- cosmic ray muons
- fake electrons



DØ Detector v2.0



Data Sample

- CS Skim data in SAM
  - 2EM/2EMhighpt/2MU/2MUhighpt
  - EMMU/QCD
- EM Data
  - Remove data of BAD CAL
  - Use triggers: 2EM_HI, EM_HI, EM_MX, EM_MX_SH, E1_SHT20, E2_SHT20, E1_SH30, etc, in different run ranges
- Muon Data
  - Remove data of BAD MUON (not REASONABLE or GOOD)
  - Use triggers: mu2ptxatxx_fz, mu2ptxctxx_fz, 2MU_A_L2ETAPHI, 2MU_A_L2M0_L3L6, etc., in different run ranges
- Generate badLBNList files to be used in code
- 320.1 pb^{-1} *eee*, 291.6 pb^{-1} $ee\mu$,
- 285.4 pb^{-1} $\mu\mu e$, 289.1 pb^{-1} $\mu\mu\mu$

Candidate Selection

- Electron ID
  - E_T> 15 GeV
  - Iso< 0.15, HM7(8) < 12(20),EMFracCut> 0.9
  - TRKMatch=true
  - CC: $|\eta|$<1.1 in_fiducial; edge: $|\eta|$<1.1 not fiducial;
  - EC:1.5<$|\eta|$<2.5
- Muon ID
  - Loose muon with central track match
  - E_T> 15 GeV
  - Isolated-muons:EtHalo<2.5 and EtCone5<2.5
- Event Selection
  - Total number of leptons ≥3
  - Missing E_T > 20.0 GeV
  - ΔR(leptons)<0.2, Δϕ(mE_T, *W*-lepton)<0.2
  - Individual channel cuts
    - *eee*: *Zee* mass windows (71,111)
    - *eeμ*: *Zee* mass windows (71,111)
    - *μμe*: Zevent selection (50,130)
    - *μμμ*: Zevent selection (50, 130)

- Muon Pairs
  - *dca*<0.2 cm
  - Pseudo-acoplanarity >0.05

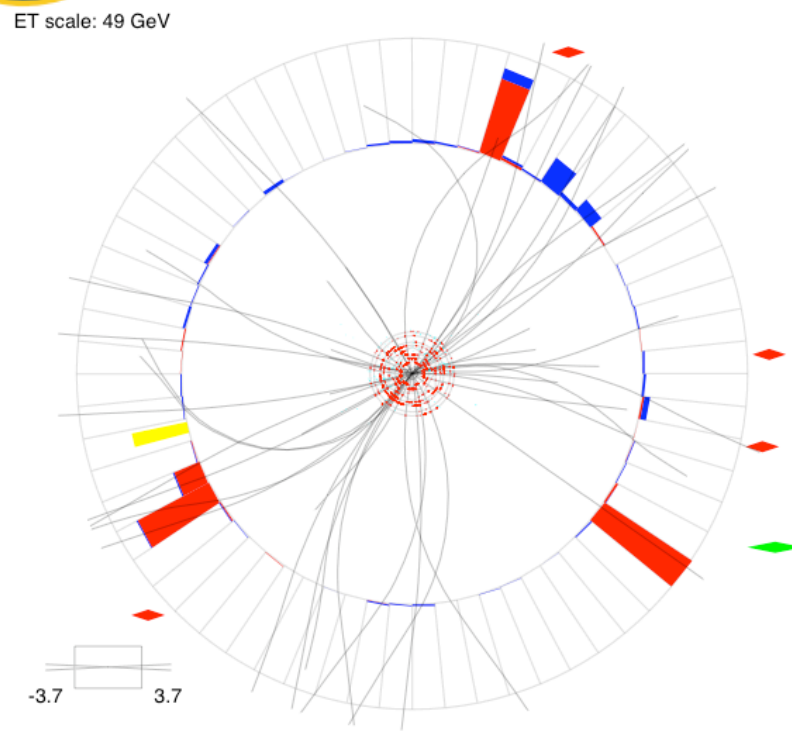
- $|VET_{had}| < 50.0$ GeV

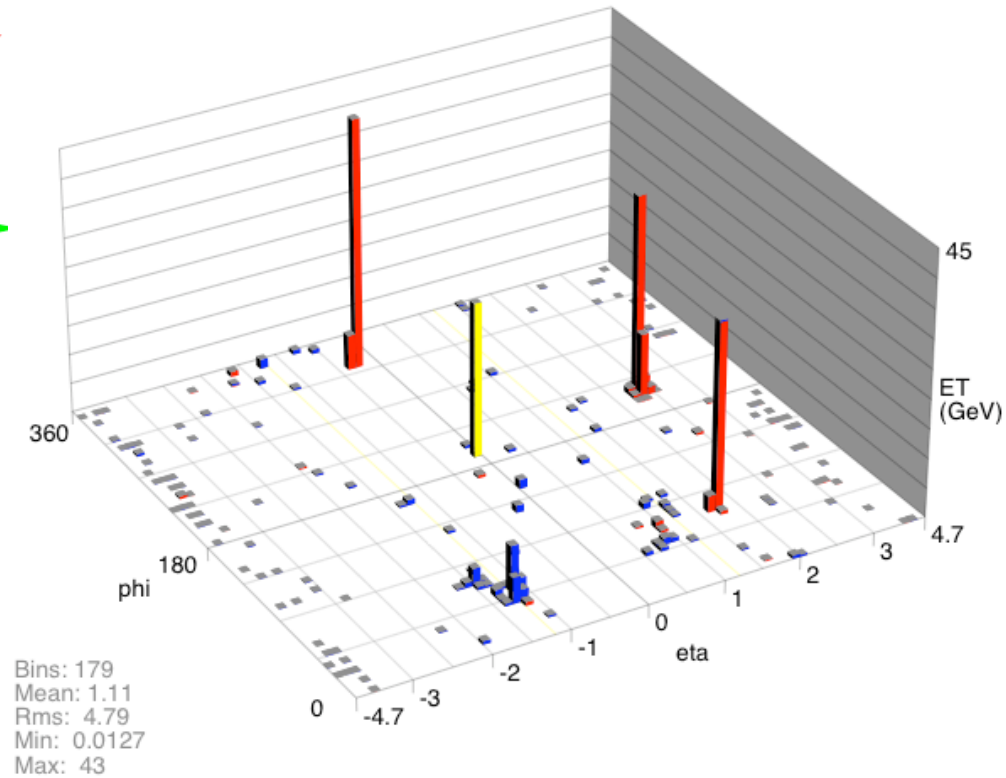
Candidates Cut Flow

Channel	*eee*	*eeμ*	*eμμ*	*μμμ*
Number of leptons >3	8	18	27	12
mE_T> 20 GeV	1	15	7	8
Z mass-window	1	11	5	5
$\Delta R>0.2$, $\Delta\phi<0.2$	1	2	0	4
VET_{had}	1	2	0	4
Vertex	1	0	0	2
Number of Candidates	1	0	0	2

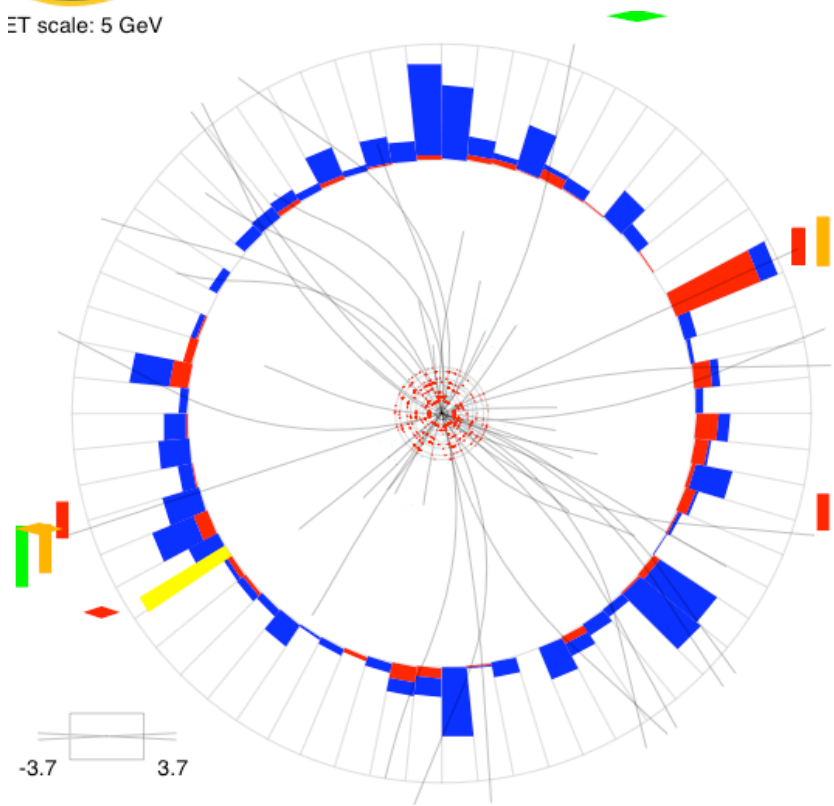
•Find 3 candidates among 300 pb^{-1}

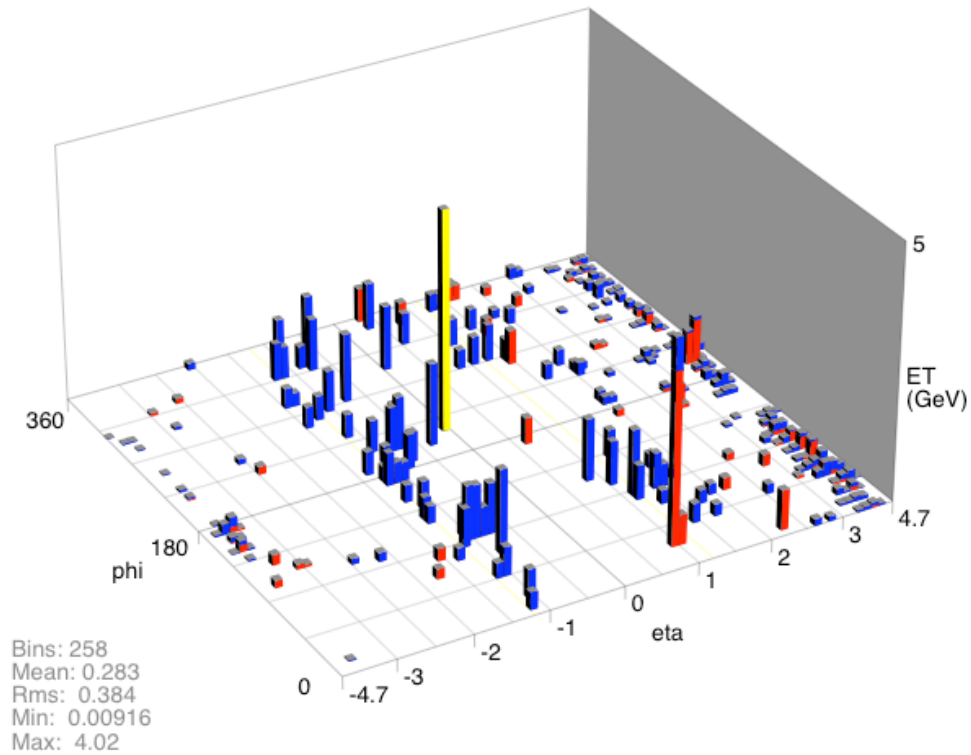
Candidate 1


ET scale: 49 GeV
-3.7
3.7

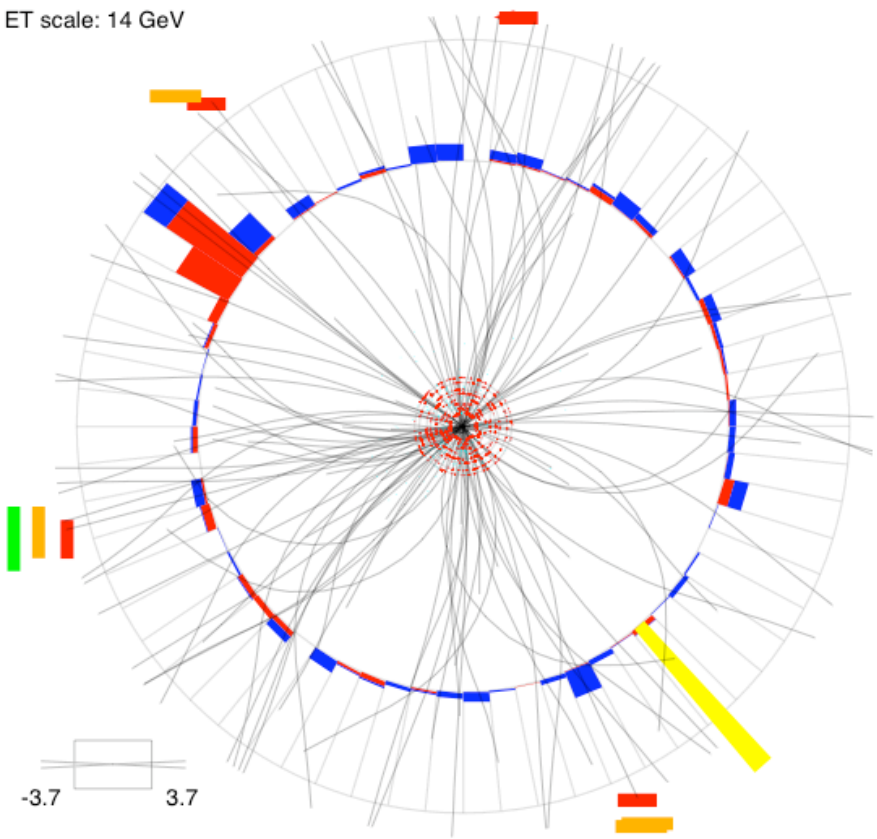

45
ET
(GeV)
360
180
phi
0
-4.7
-3
-2
-1
0
1
2
3
4.7
eta
Bins: 179
Mean: 1.11
Rms: 4.79
Min: 0.0127
Max: 43

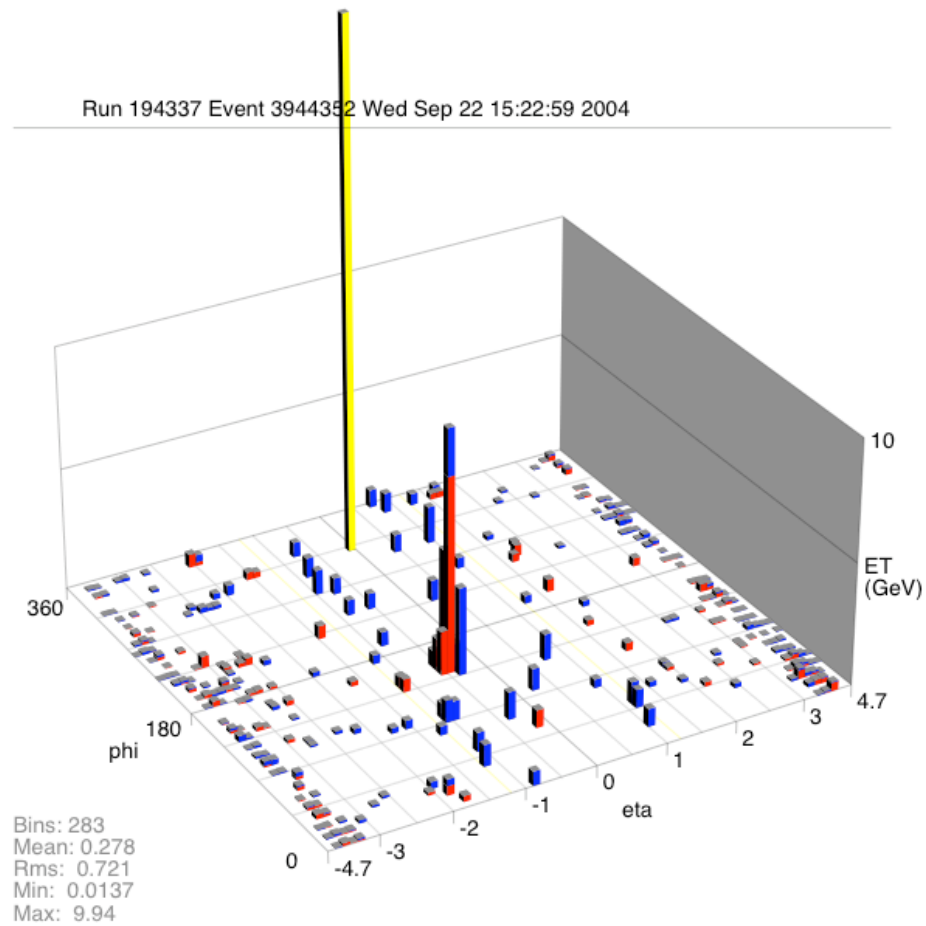
Candidate 2


ET scale: 5 GeV
-3.7
3.7


360
180
phi
0
-4.7
-3
-2
-1
0
1
2
3
4.7
eta
5
ET
(GeV)
Bins: 258
Mean: 0.283
Rms: 0.384
Min: 0.00916
Max: 4.02

Candidate 3


ET scale: 14 GeV
-3.7
3.7


Run 194337 Event 3944352 Wed Sep 22 15:22:59 2004
10
ET
(GeV)
360
180
phi
0
-4.7
-3
-2
-1
0
1
2
3
4.7
eta
Bins: 283
Mean: 0.278
Rms: 0.721
Min: 0.0137
Max: 9.94

Overall Efficiency

$$\varepsilon = \sum_{i,j,k=cc,edge,ec,muon} accpt(i,j,k) * \varepsilon_{id}(i)*\varepsilon_{trk}(i)*\varepsilon_{id}(j)*\varepsilon_{trk}(j)*\varepsilon_{id}(k)*\varepsilon_{trk}(k)$$

- Acceptances from MC samples
- Overall efficiency
  - *eee* channel: 0.1034 ± 0.0147
  - *eeμ* channel: 0.1165 ± 0.0084
  - *eμμ* channel: 0.1387 ± 0.0127
  - *μμμ* channel: 0.1628 ± 0.0178
- $(BR_i*\varepsilon_i*\mathcal{L}_i)$over (i=*eee*/*eeμ*/*μμe*/*μμμ*)= 2.04 ± 0.13 events
  - Br($WZ \rightarrow$ 3 leptons) = (0.359 ±0.0024)%
  - $\mathcal{L}(eee)$= 320.1 pb^{-1} $\mathcal{L}(ee\mu)$= 291.6 pb^{-1}
  - $\mathcal{L}(e\mu\mu)$= 285.4 pb^{-1} $\mathcal{L}(\mu\mu\mu)$= 289.1pb^{-1}

ID/Track Efficiency

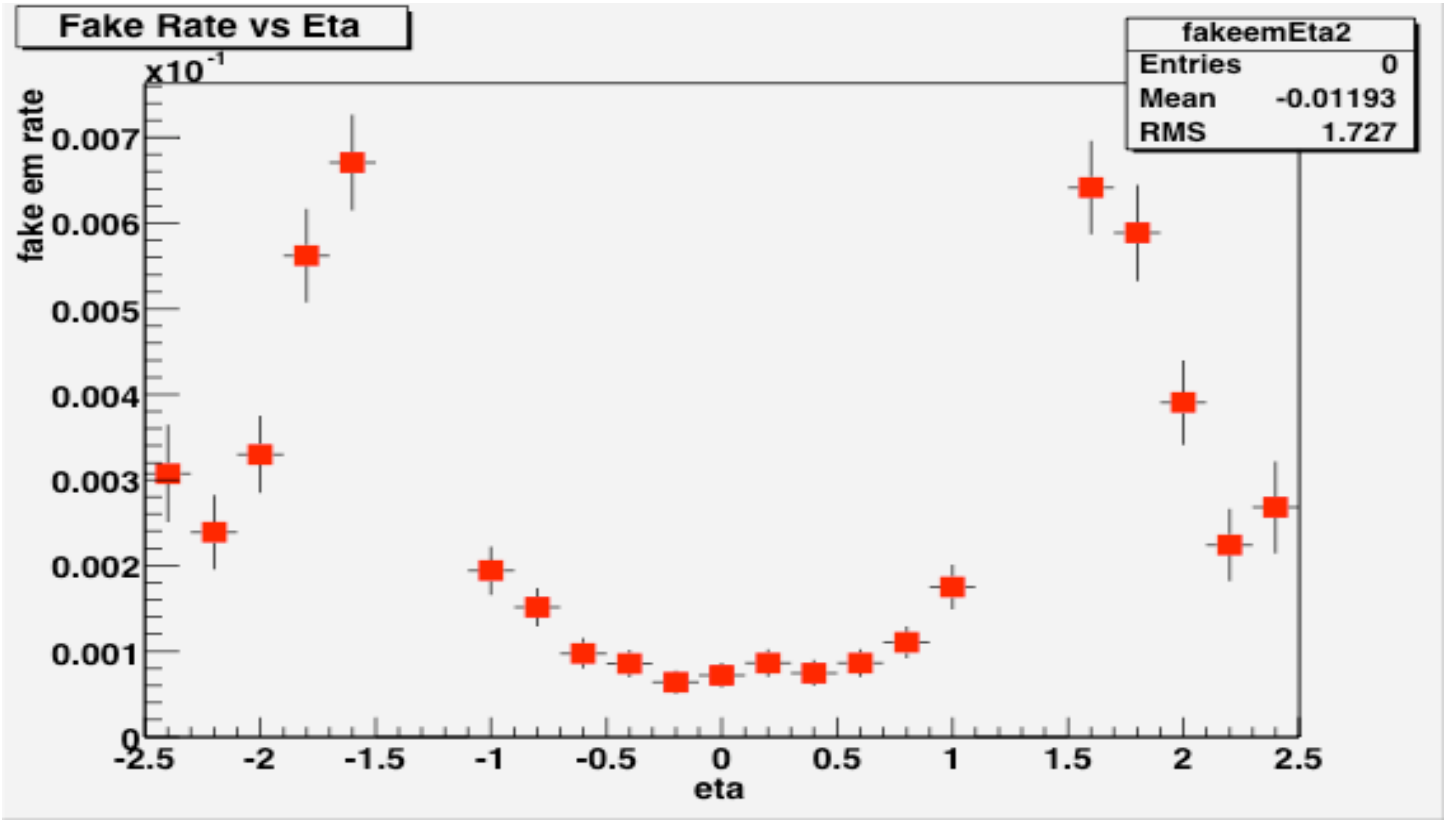
Use Tag & Probe Method

Efficiency	ID	Track
CC	0.9291 ± 0.0134 0.9291 ± 0.0015 ± 0.0133	0.8174 ± 0.0022 0.8174 ± 0.0021 ± 0.0007
Edge	0.7156 ±0.0194 0.7156 ± 0.0062 ± 0.0184	-
EC	0.9649 ±0.0075 0.9649 ± 0.0014 ± 0.0074	0.6735 ± 0.0064 0.6735 ± 0.0035 ± 0.0056

Fake Rate

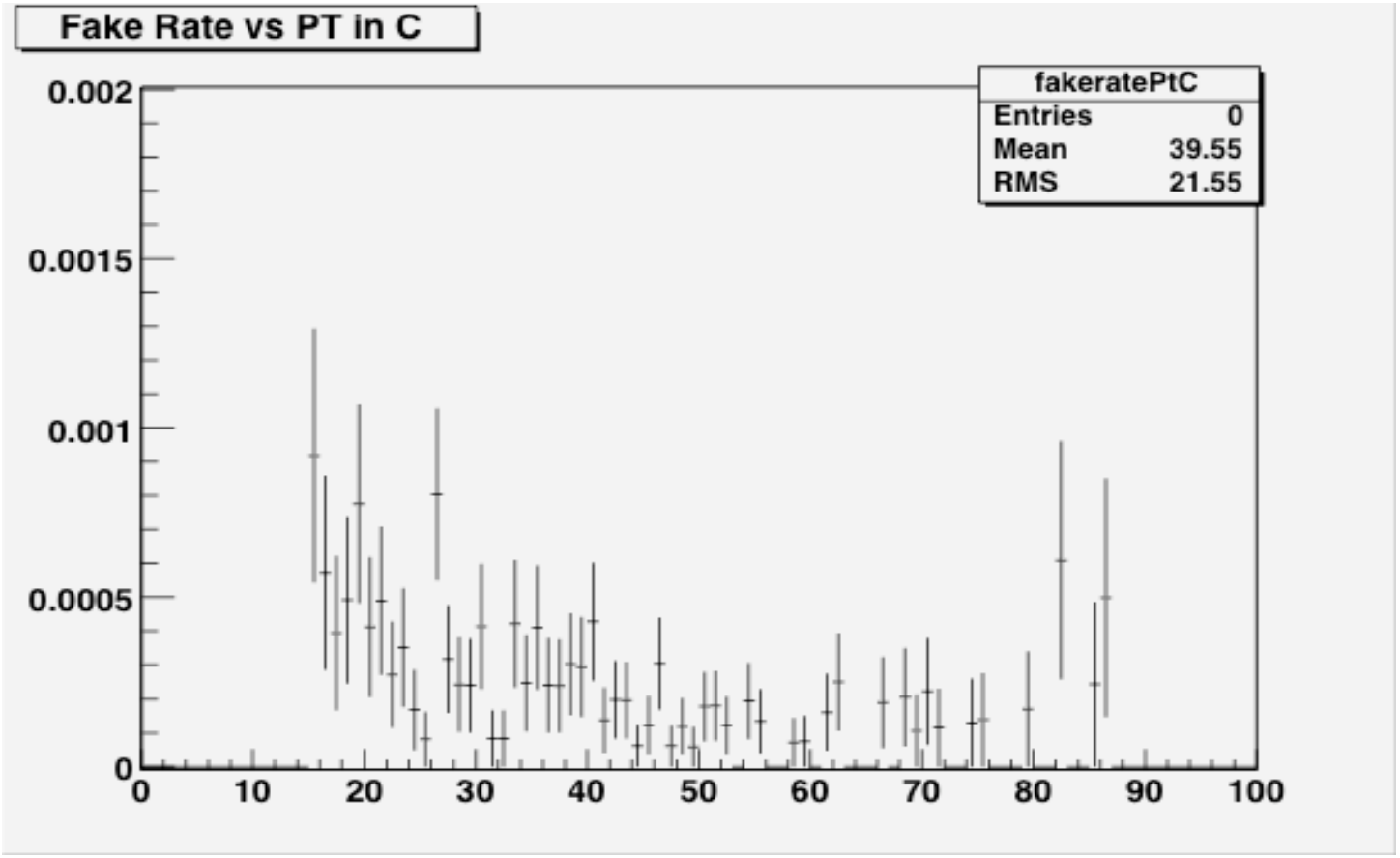
- The rate for a jet to appear as a electron/muon in the detector
  - Physics: semi-leptonic decay
  - Detector: jet fakes a lepton
- Method
  - Use di-jet sample (CSskim-QCD-*), collected by jet trigger
  - 1st jet pass jet quality cuts
  - 2nd jet: opposite in ϕ, Pt ratio < 3.0
  - Missing E_T < 10 to exclude *W*
  - EM/MU object: pass all ID cuts
- Results
  - CC: $(1.73\pm0.14)*10^{-4}$
  - EC: $(1.02\pm0.03)*10^{-3}$
  - Muon: $(3.69\pm0.23)*10^{-3}$
  - Iso-Muon: $(8.33\pm3.53)*10^{-6}$

Fake Rate



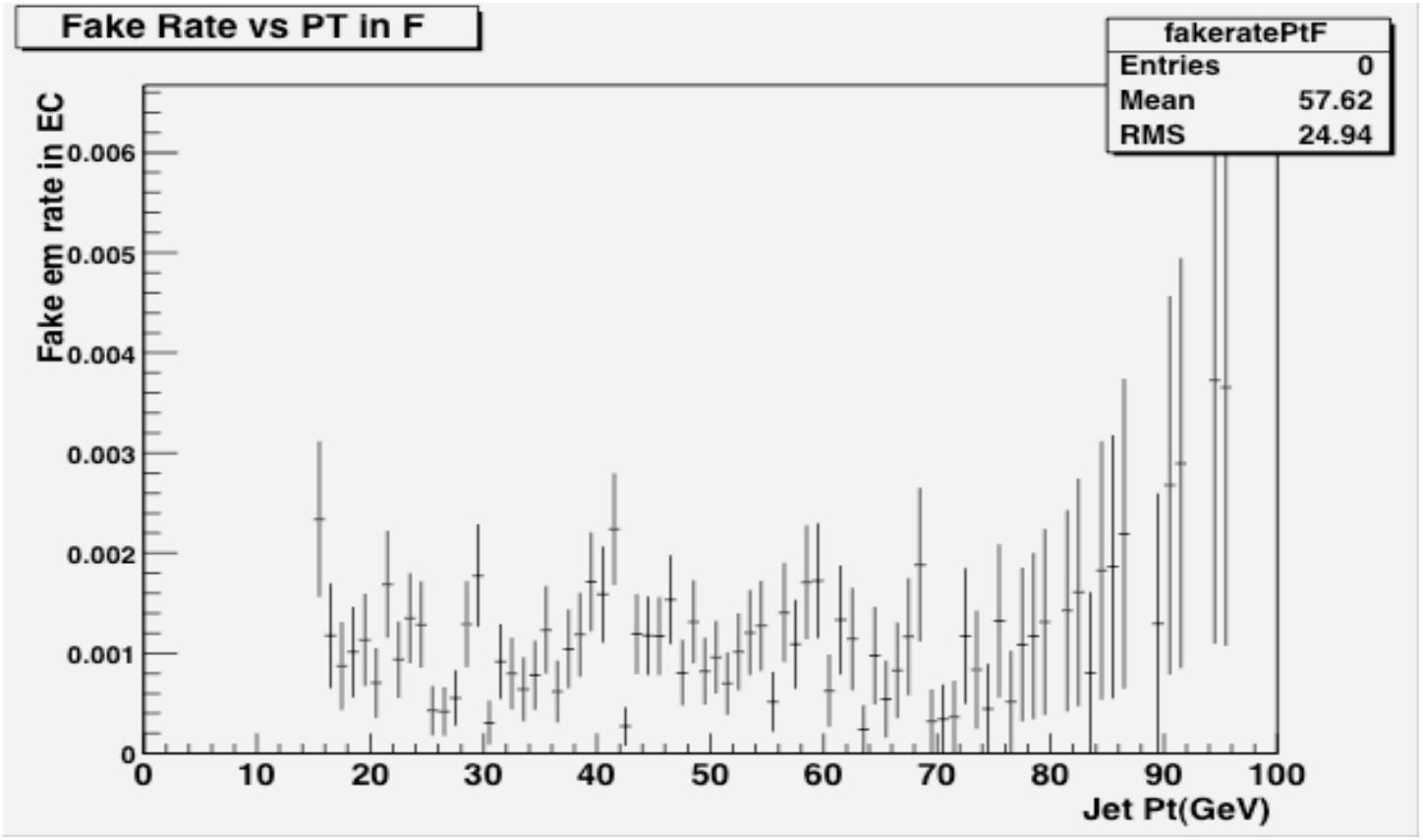
Rate for a jet to fake an electron versus jet η.

Fake Rate



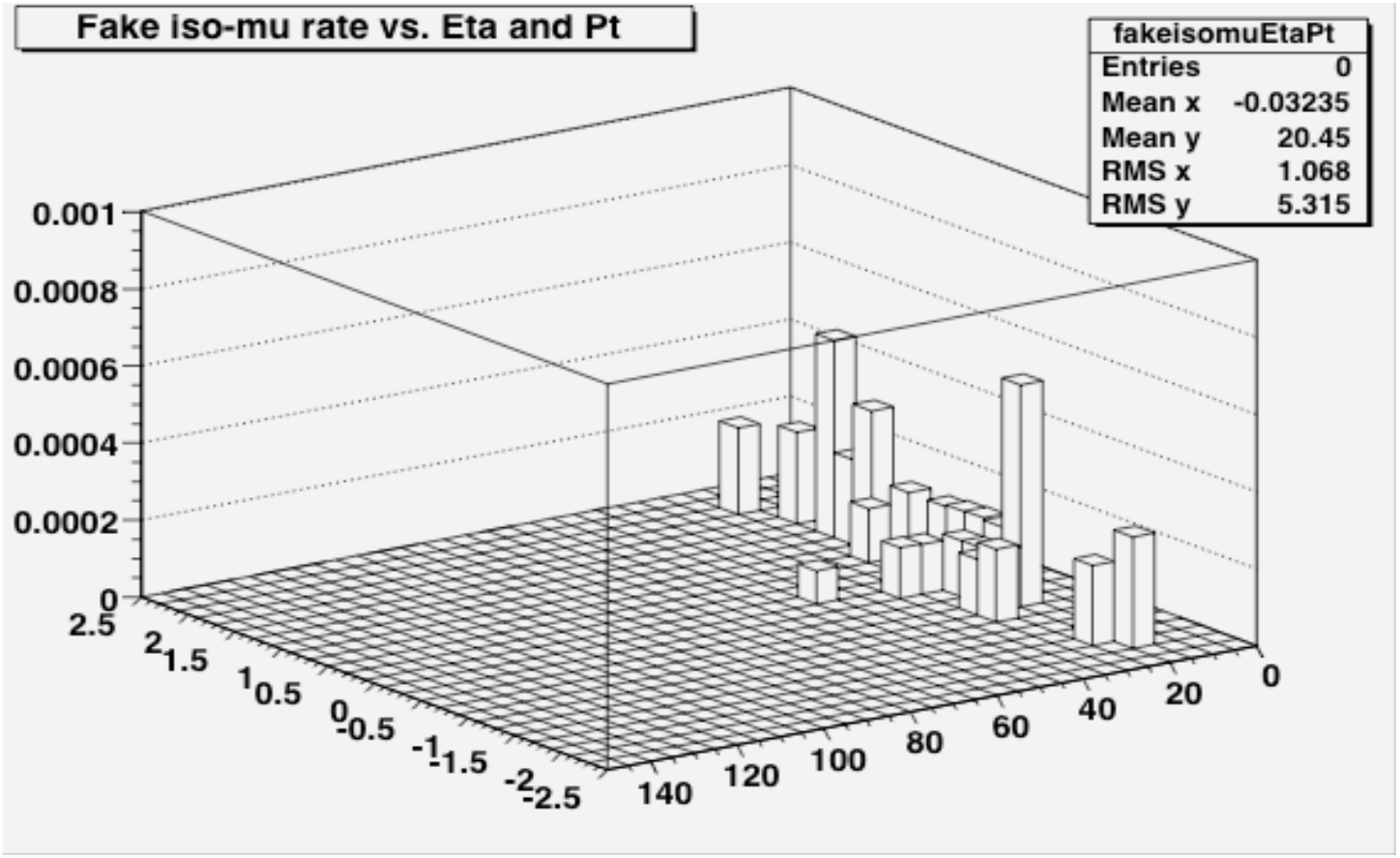
Rate for a jet to mimic an electron in the central calorimeter.

Fake Rate



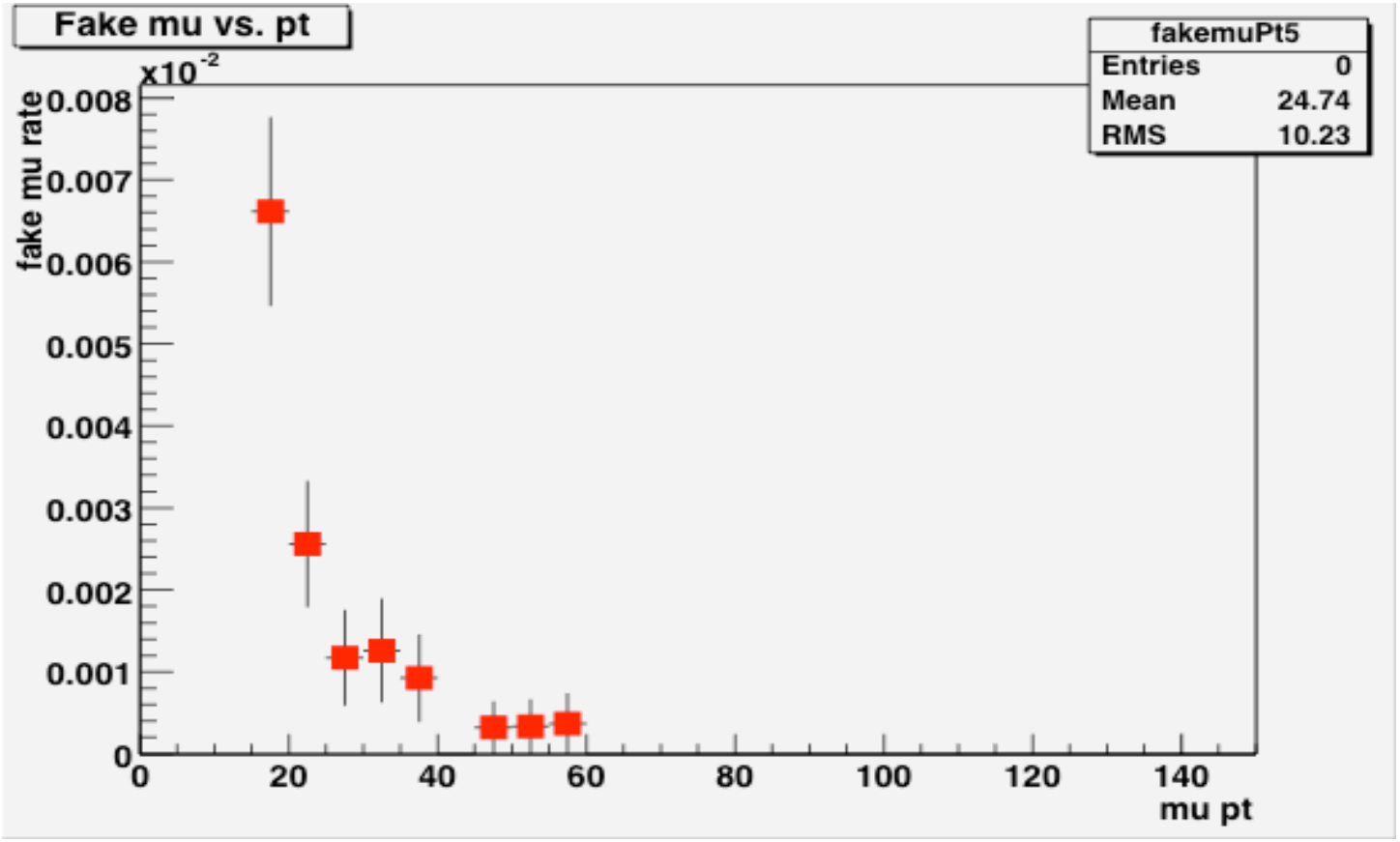
Rate for a jet to mimic an electron in the forward calorimeter

Fake Rate



Rate for a jet to mimic an isolated muon in η P_T space.

Fake Rate



Rate for a jet to mimic a muon versus P_T(jet)

Candidate Information

Channel	l_1	l_2	M_{inv}	l_3	mE_T, ϕ	M_T
eee	-47.3, -25.9 291.8,296.7	13.3, 37.6, 110.8 117.8	91.9	45.3, -32.1, -16.5, 57.9	30.6, 3.364	72.3
μμμ	24.5, 11.6, 29.7, 40.2	-38.7, -12.4 -17.1, 44.1	82.1	-19.3, -16.7, 101.4, 104.6	31.2 0.665	56.4
μμμ	-15.1, 19.9, 24.4, 35.0	20.2, -42.5, 57.1, 74.0	68.5	-21.9, -5.9, -16.4, 28	43.1 0.338	62.5

QCD Background

- Fake Data Samples
  - *Zee*+jets, *Zμμ*+jets, *e*+iso-*μ*+jets
- *eee* channel: 0.069 ± 0.002
  - *Zee*+jet and jet→ *e*
- *eeμ* channel: 0.043 ± 0.007
  - *Zee*+jet and jet→ iso-*μ*:0.014 ± 0.007
  - *e*+iso-*μ*+jet and jet→ *e*: 0.029 ± 0.001
- *μμe* channel: 0.195 ± 0.006
  - *Zμμ*+jet and jet→ *e*: 0.190 ± 0.005
  - *e*+iso-*μ*+jet and jet→ *μ*: 0.005 ± 0.003
- *μμμ* channel: 0.049 ± 0.022
  - *Zμμ*+jet and jet→ iso-*μ*: 0.049 ± 0.022

$t\bar{t}$ Background

- $t\bar{t}$ event can become background in trilepton
  - $WW \rightarrow$ 2 isolated leptons
  - b or $\bar{b}$ semi-leptonic decay into a non-isolated lepton
- Use dilepton $t\bar{t}$ MC sample
  - Top MC sample @ m_t =175
  - Select tri-lepton events and normalize to data
    - use the equivalent luminosity of MC sample
- Estimated $t\bar{t}$ background
  - eee: 0.003 ± 0.003
  - $ee\mu$:0.002 ± 0.002
  - $\mu\mu e$:0.002 ± 0.002
  - $\mu\mu\mu$: < 0.002
- Total estimated background: 0.012 ± 0.005

$Z\gamma$ Background

- $Z\gamma$ becomes a background when a γ shower "matches" a track
- Measure the fake track match rate by using di-jet events.
  - 1st em object pass all but HMX cuts.
  - 2nd em object is back2back and outside Z mass window
- Fake track rates
  - Central: 0.0192 ± 0.0034
  - Forward: 0.0287 ± 0.0040
- $Z\gamma$ background
  - eee: 0.022 ± 0.003
  - $\mu\mu e$: 0.125 ± 0.003

ZZ Background

- *ZZ* is a background when one lepton is lost which gives a missing E_T
- Estimated using fully simulated MC samples.
- *ZZ* background normalized with σ = 1.43 pb
  - *eee*: 0.061 ± 0.043
  - *eeμ*: 0.028 ± 0.028
  - *μμe*: 0.083 ± 0.027
  - *μμμ*: 0.083 ± 0.048