Measurement of the W and Z Cross Sections in the Electron Channel for $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV and Extraction of the W Total Width from the Ratio

John Gardner

University of Kansas

November 11, 2008

Inclusive W and Z Cross Sections

- the strength of all interactions resulting in the production of W and Z bosons

$$\sigma_W \equiv \sigma\left(p\,\bar{p} \to W + X\right)$$
$$\sigma_Z \equiv \sigma\left(p\,\bar{p} \to Z + X\right)$$

  - additional decay products, 'X', are allowed

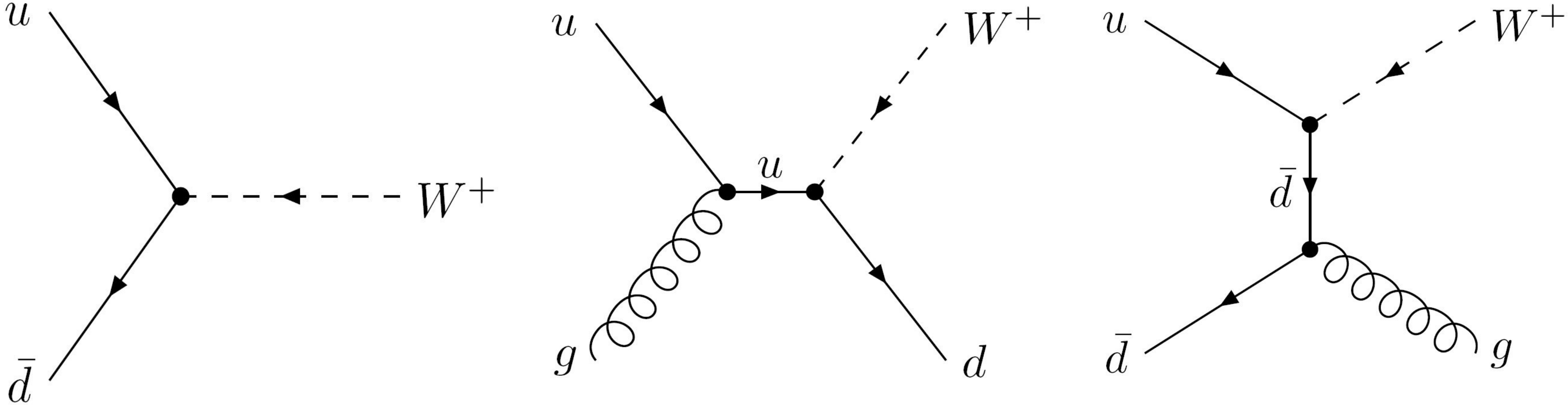
- electron channel cross sections

$$\sigma_W \times B\left(W \to e\,\nu\right)$$
$$\sigma_Z \times B\left(Z \to e\,e\right)$$

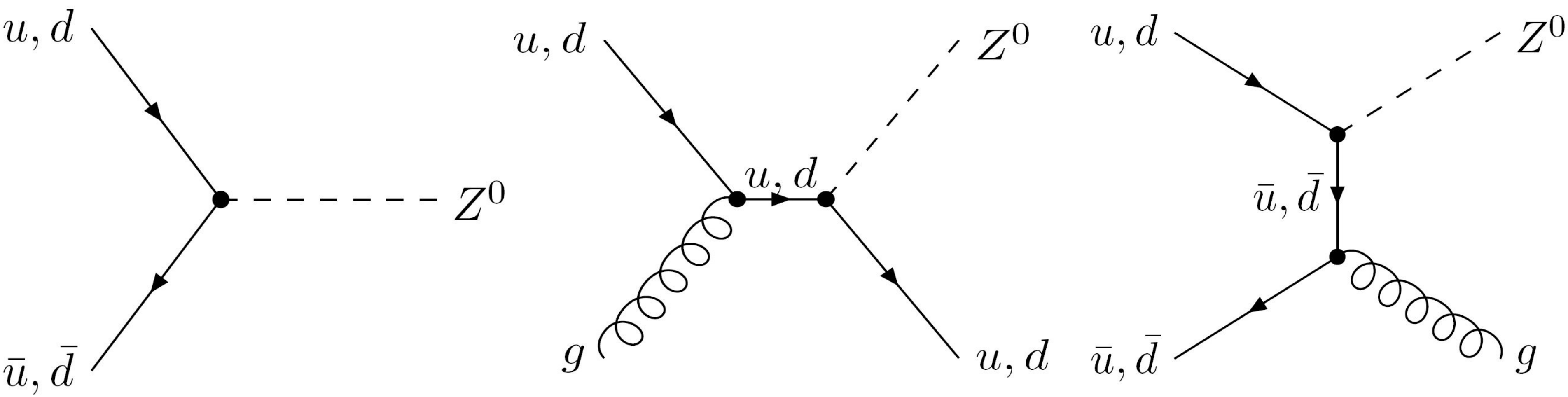
Motivation

- high precision measurement important for understanding detector performance
- cross-check luminosity by comparing cross sections to SM predictions
- test Standard Model predictions
  - expect ~10% increase in cross sections from 1.80 to 1.96 TeV
  - larger than expected W width would indicate unexpected decay modes

W⁺ production

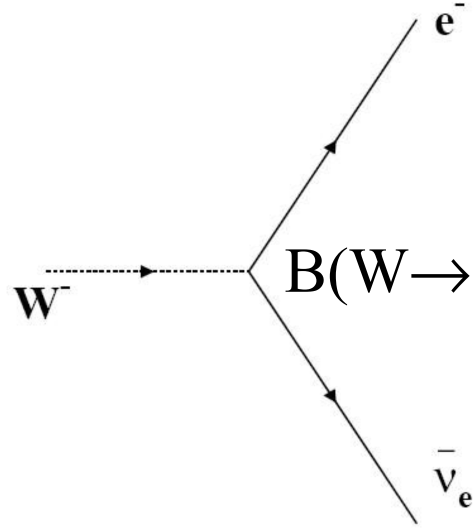


Z production

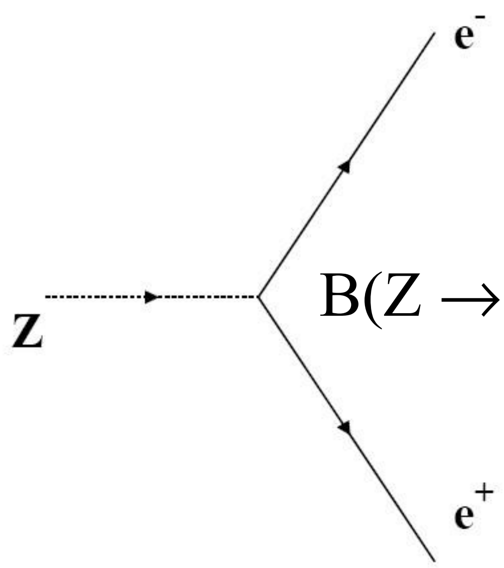


Principle decays

- W decays:
  - leptons: 10.8% for each e,μ,τ
  - hadrons: 68.0%
- Z decays:
  - leptons: 3.36% for each $e^+e^-,\mu^+\mu^-,\tau^+\tau^-$
  - hadrons: 70%
  - invisible: 20% (ν's)



$B(W \rightarrow e\,\nu) = 10.822\%$



$B(Z \rightarrow e\,e) = 3.3655\%$

(indirect) W Width Measurement

$$define\ R = \frac{\sigma_W \times B(W \to e\nu)}{\sigma_Z \times B(Z \to ee)}$$

$$B(W \to e\nu) = R \times \frac{B(Z \to ee)}{\sigma_W / \sigma_Z}$$

SM predictions

Z electronic branching ratio

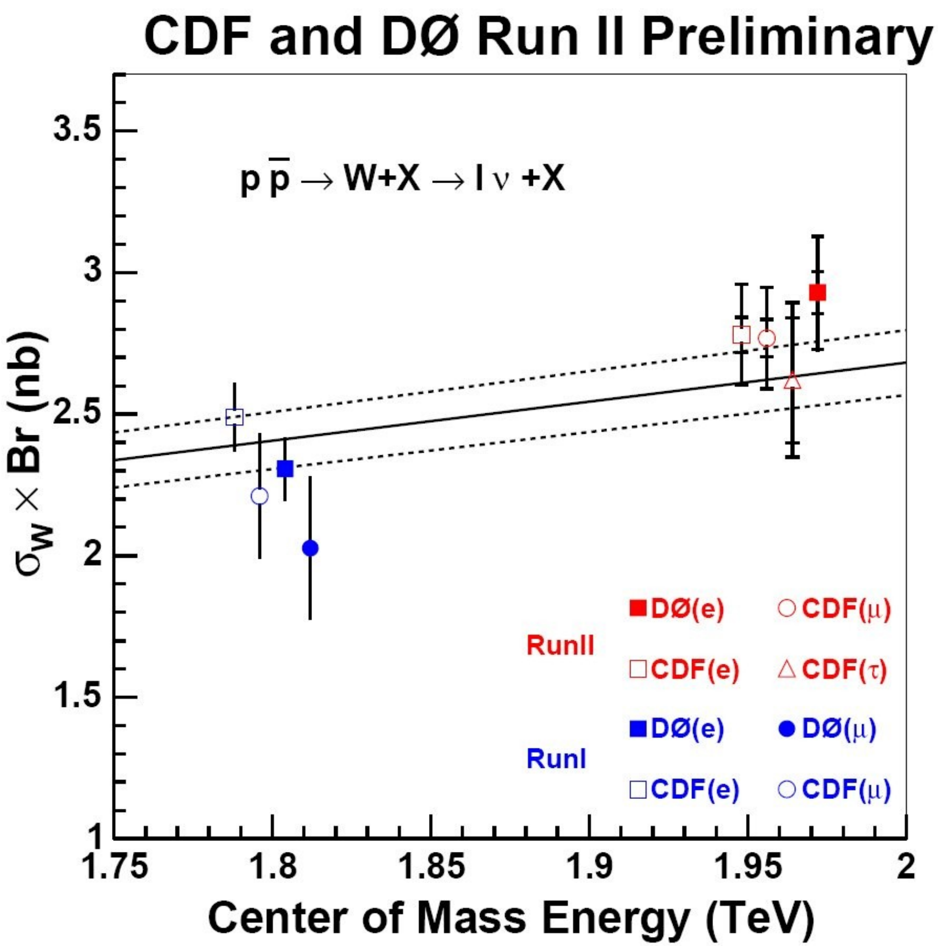
total W/Z cross section ratio

W width: $$\Gamma_W = \frac{\Gamma(W \to e\nu)}{B(W \to e\nu)}$$

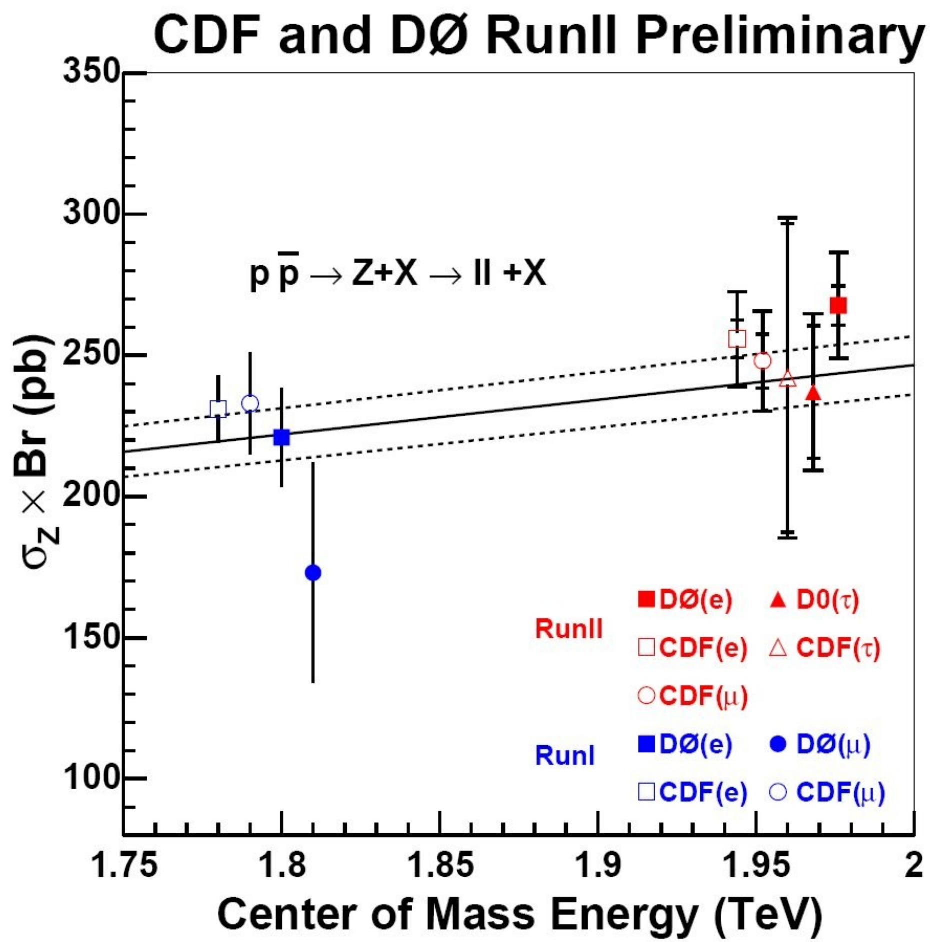
W electronic partial width

Previous Cross Section Results

$$\sigma_W \times B(W \rightarrow e\nu)$$

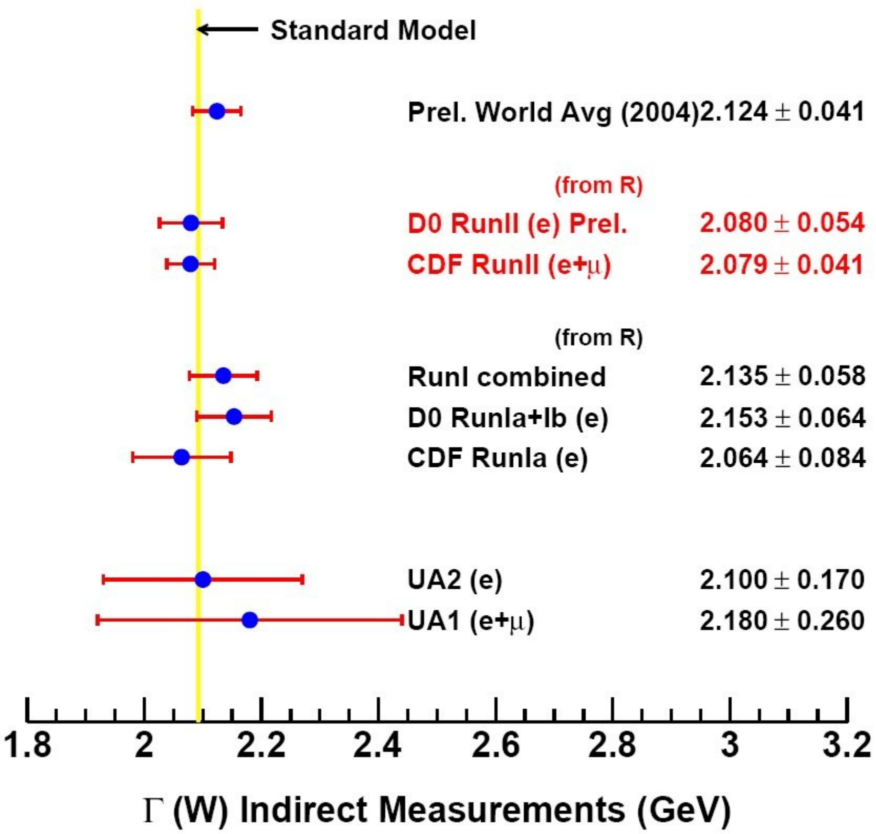


$$\sigma_Z \times B(Z \rightarrow ee)$$

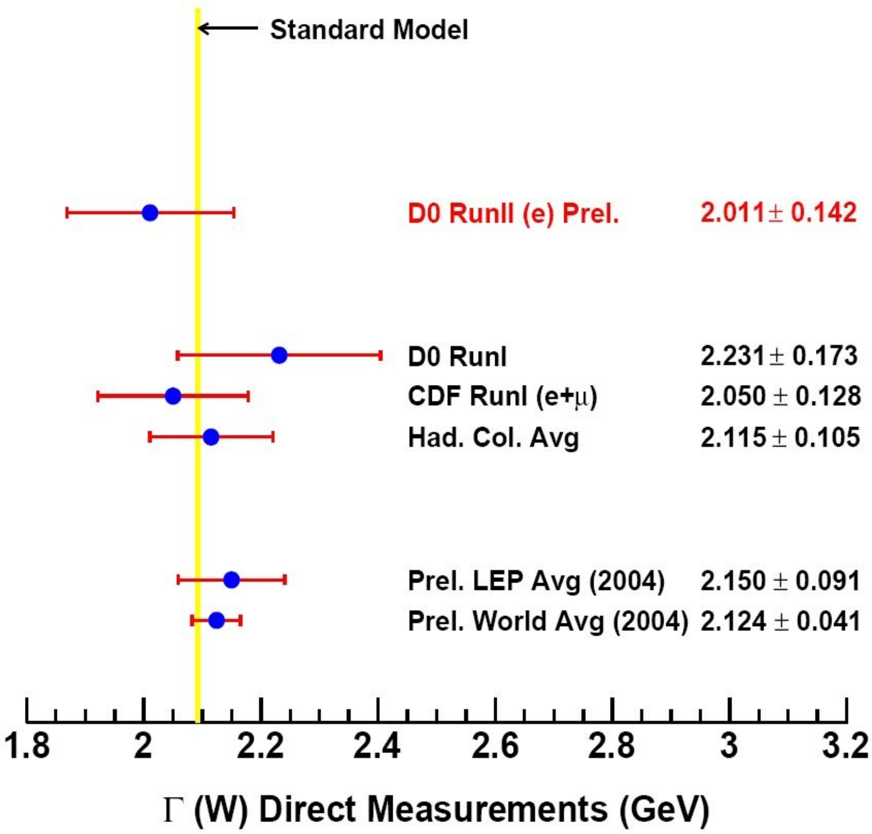


Previous W Width Results

indirect measurement



direct measurement



Measurement Overview

$$\sigma_W \times B(W \rightarrow e\nu) = \frac{N_W}{L} \frac{1}{A_W} (1 - f_\tau^W - f_Z^W)$$

$$\sigma_Z \times B(Z \rightarrow ee) = \frac{N_Z}{L} \frac{1}{A_{Z/\gamma^*}} \times R_\sigma$$

$$R \equiv \frac{\sigma_W \times B(W \rightarrow e\nu)}{\sigma_Z \times B(Z \rightarrow ee)} = \frac{N_W}{N_Z} \frac{A_{Z/\gamma^*}}{A_W} \frac{1 - f_\tau^W - f_Z^W}{R_\sigma}$$

- largest uncertainty at 6.5% from L cancels out for the ratio

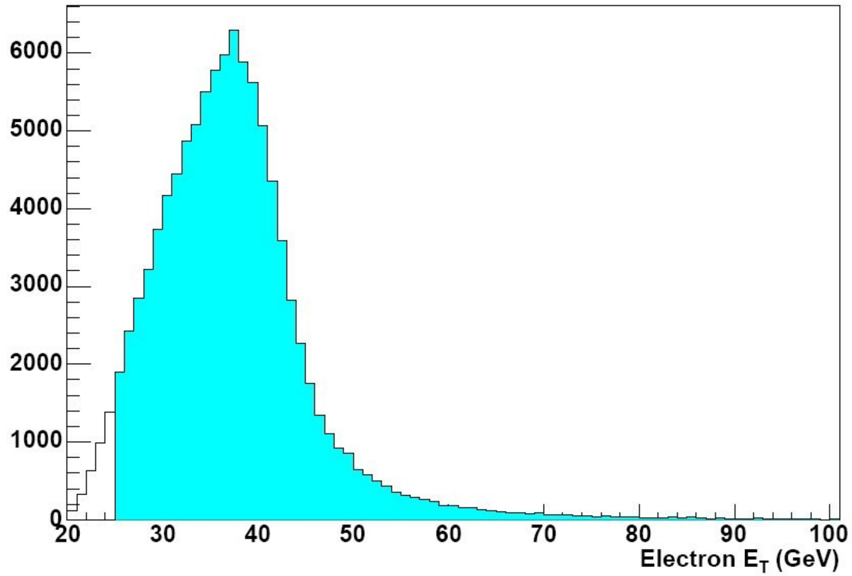
Data Selection

- data set includes 177 ± 12 pb^{-1} integrated luminosity collected between September 2002 and September 2003
- using several calorimeter only triggers designed to fire on a single isolated high E_T electron
- for the acceptance calculation, it is necessary to make sure that at least one of the electrons used in the analysis fires a trigger
  - match trigger objects at each level to the electron

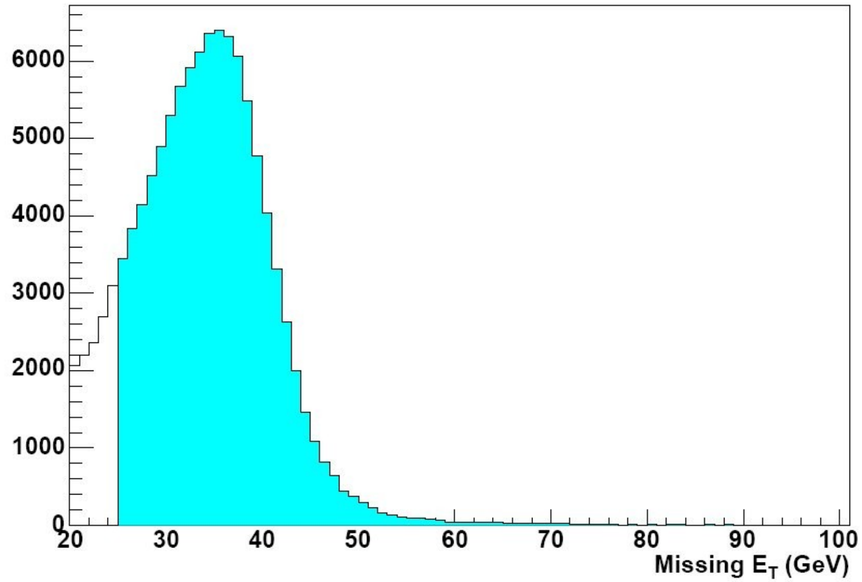
W Candidates (97,757 events)

- high E_T electron (>25 GeV)
- high missing E_T (neutrino) (> 25 GeV)

electron E_T



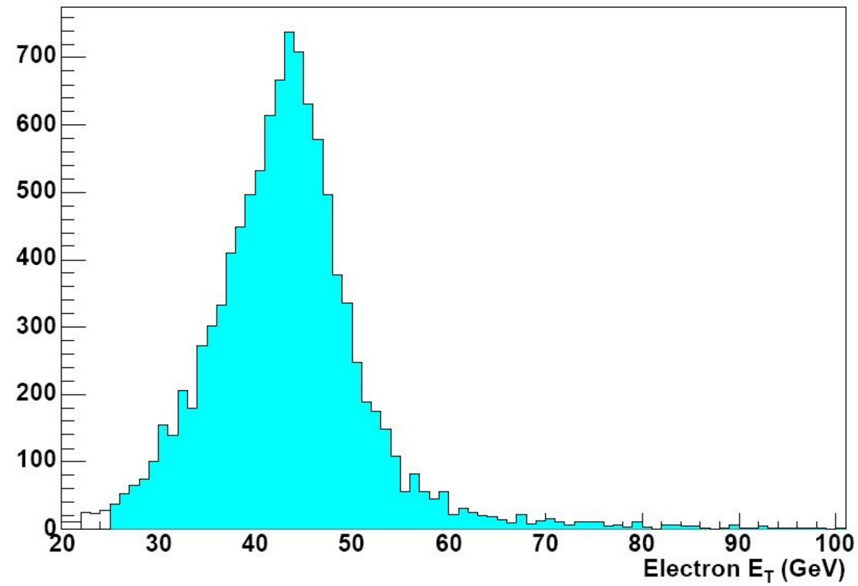
missing E_T



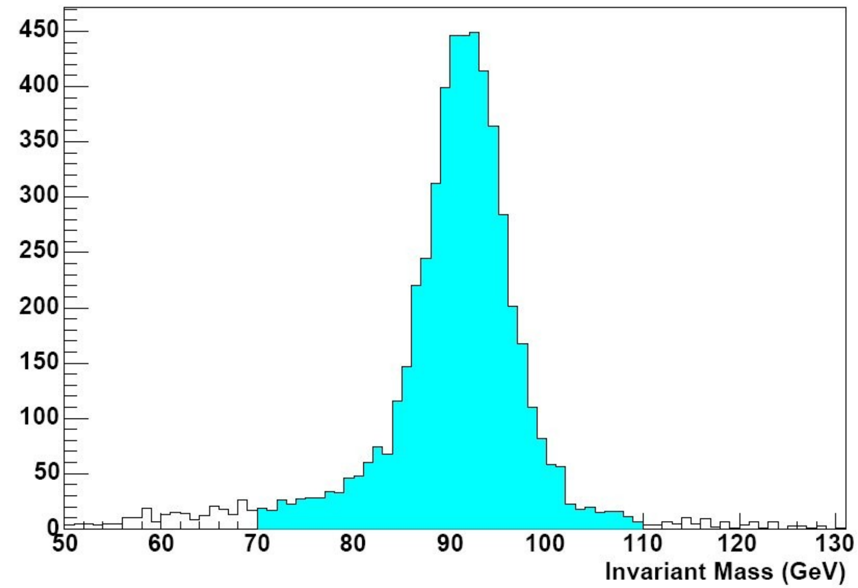
Z Candidates (7928 events)

- 2 high E_T electrons (> 25 GeV)
- invariant mass near 91.2 GeV peak ($70 < M_{ee} < 110$ GeV)

electron E_T



invariant mass



Electron ID

- cuts on the calorimeter cluster to distinguish an electron from background
  - preselection: require that an isolated EM cluster with high EM fraction is formed
  - track-match: an electron is expected to create an isolated high E_T track
  - electron likelihood: compares several different quantities between electron signal and fake samples to optimize electron and fake discrimination

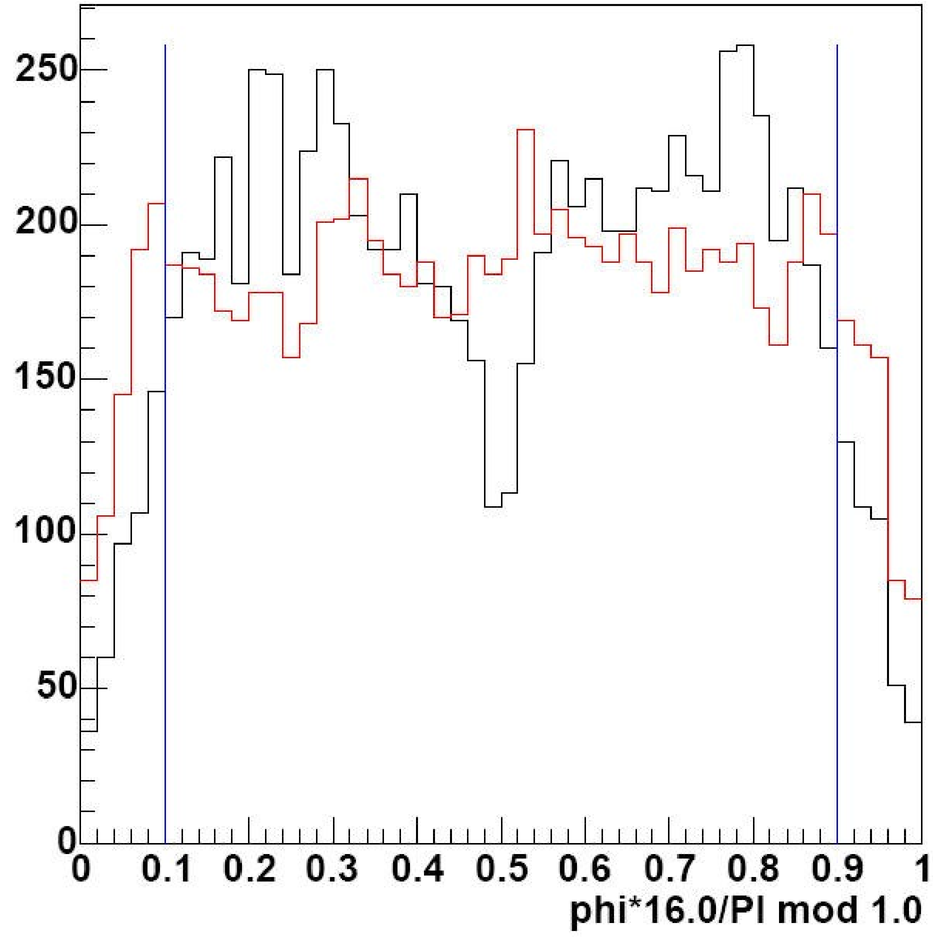
Acceptance

- the fraction of all $W \rightarrow e\upsilon$ & $Z/\gamma^* \rightarrow ee$ events produced at D0 which are successfully identified
  - kinematic acceptance:
    - elec $E_T > 25$ GeV, missing $E_T > 25$ GeV, $70 < M_{ee} < 110$ GeV
  - geometric acceptance: electrons pass through a well instrumented part of the detector
  - electron ID efficiencies (preselection, trigger, track-match and likelihood)
- $A \equiv A_{kinematic} \times A_{geometric} \times \varepsilon_{ID}$

Geometric Acceptance

- η_{det} cuts for the calorimeter
  - CC: $\eta_{det} < 1.05$
  - EC: $1.5 < \eta_{det} < 2.3$
- cut out CC cracks between each of the 32 tower modules along φ
  - $0.1 < (\varphi \cdot 16/\pi)\ \%\ 1 < 0.9$

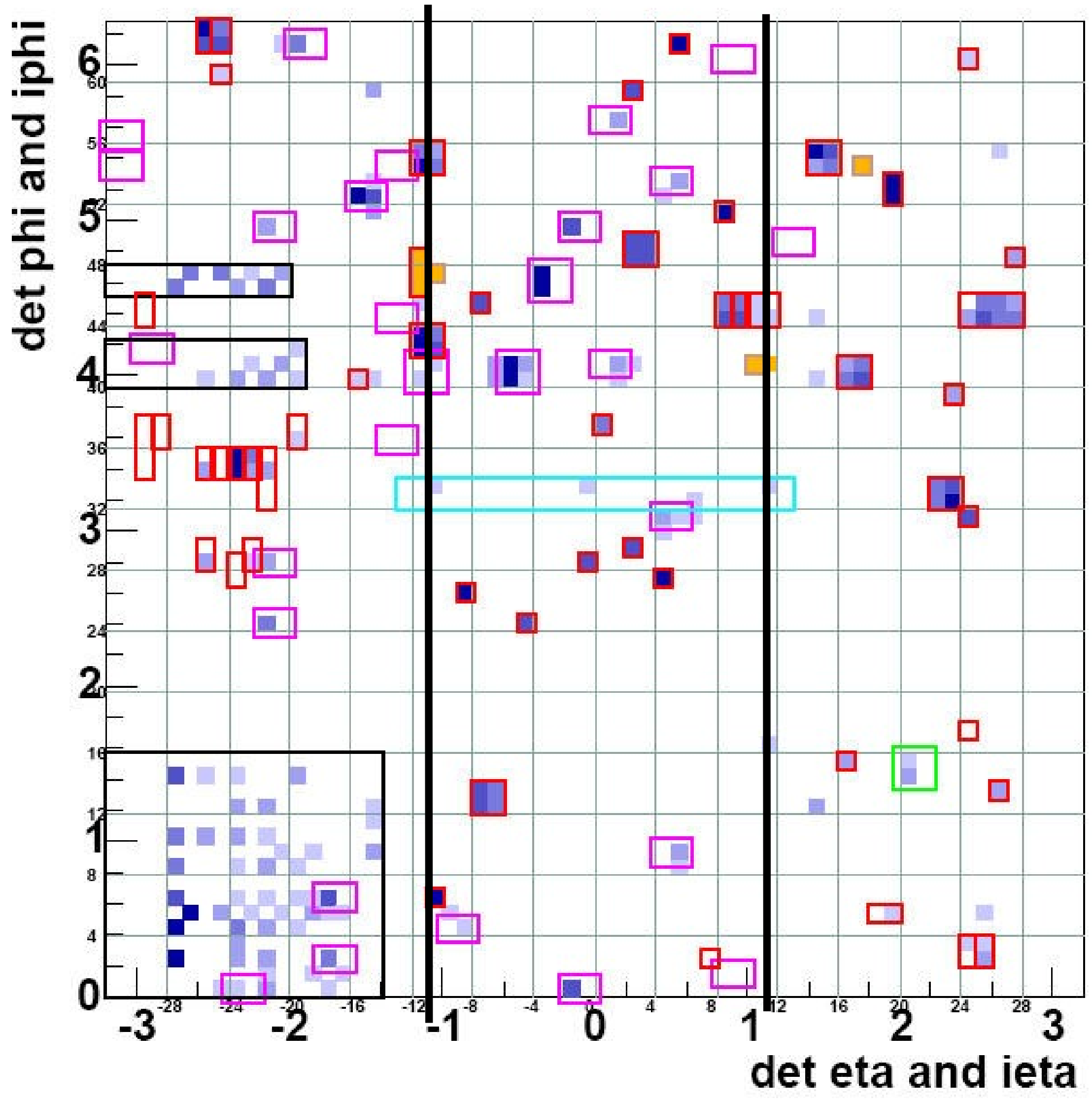
calorimeter EM cluster positions shift away from tower cracks
- increases acceptance by 5%



Calorimeter Quality Cuts

- regions are cut on a cell by cell and a run by run basis
- based on known problems and by studying EM cluster formation for each cell over time

runs 177008 to 178135



Monte Carlo

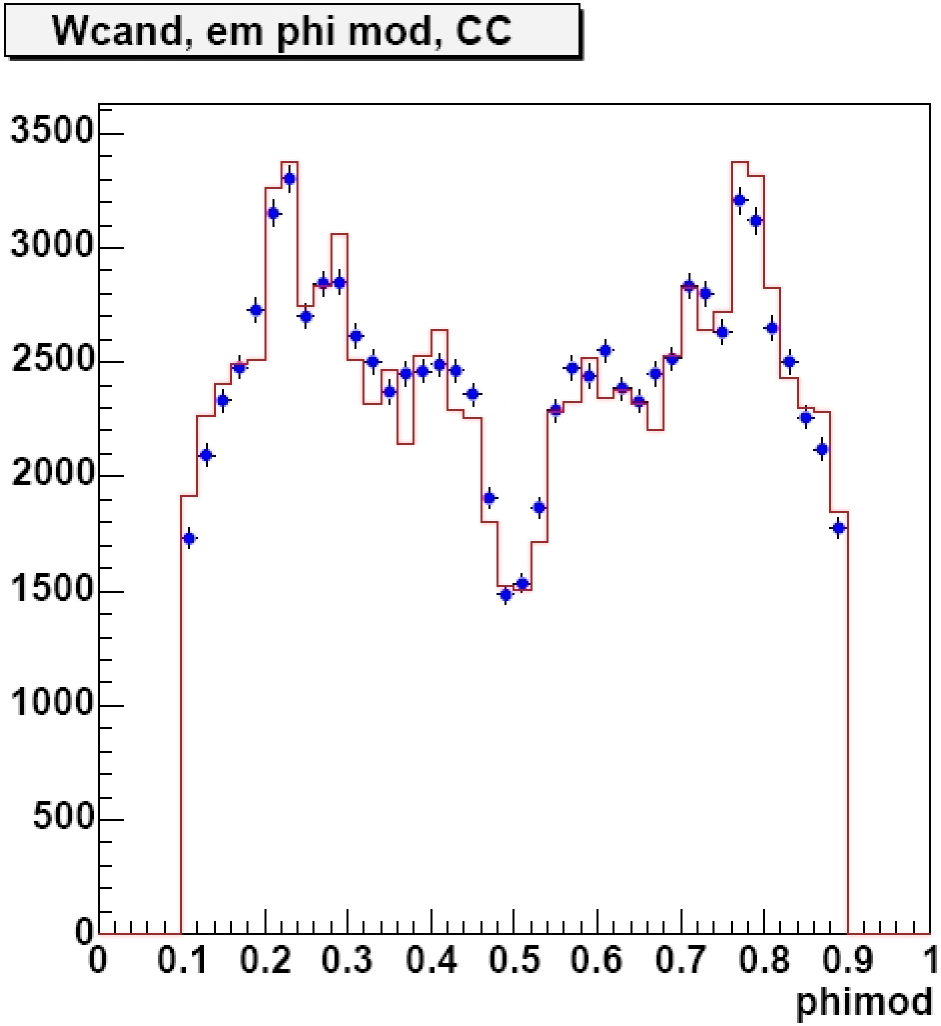
- calculation of theoretical result for σ_W / σ_Z
- check validity of measurement techniques
- calculation of acceptance using a parameterized Monte Carlo simulation (PMCS)
- generate using Resbos with CTEQ6.1 PDF set
  - 40 million $W \rightarrow e\upsilon$ events
  - 20 million $Z \rightarrow ee$, 2 million $\gamma^* \rightarrow ee$ and 2 million $Z/\gamma^* \rightarrow ee$ interference events

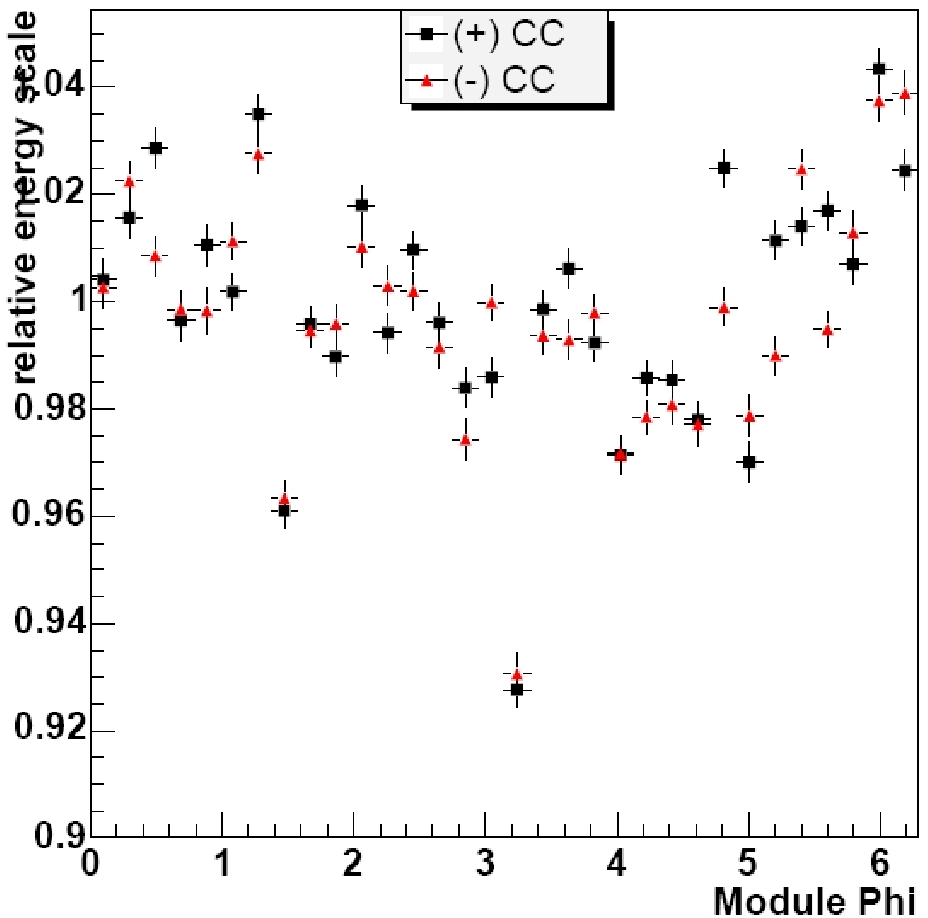
PMCS tuning

- model the detector response using several parameters to tune PMCS to match data
  - parameters for electrons
    - EM energy scale and resolution
    - EM position resolution
    - shifting of EM clusters away from CC module cracks
  - parameters for missing E_T
    - Hadronic energy scale and resolution
    - modeling of the underlying event

modeling of cluster shifting away from module and cell boundaries

relative EM energy scale, module 17 is not used

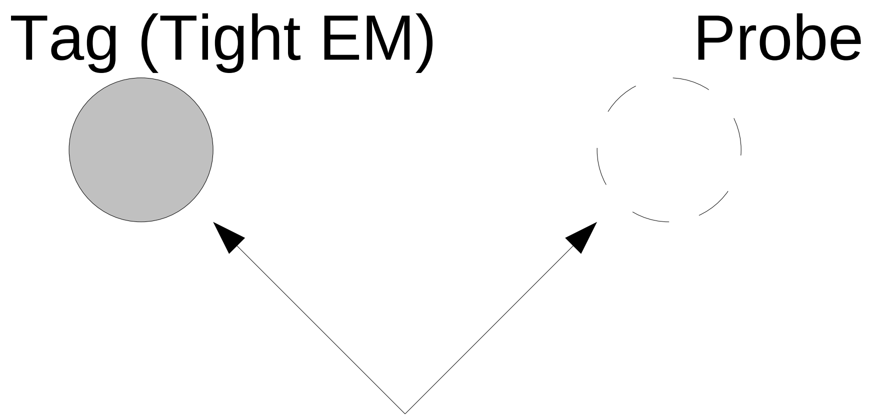




Electron ID Efficiencies

- fraction of high E_T isolated electrons successfully identified
- important to find all variables in which the efficiency is dependent
- simulate acceptance loss in Monte Carlo by inputing efficiency histograms as a function of all dependent variables
- efficiencies applied in the following order:
  - preselection, track-match, trigger and likelihood

Tag & Probe Method



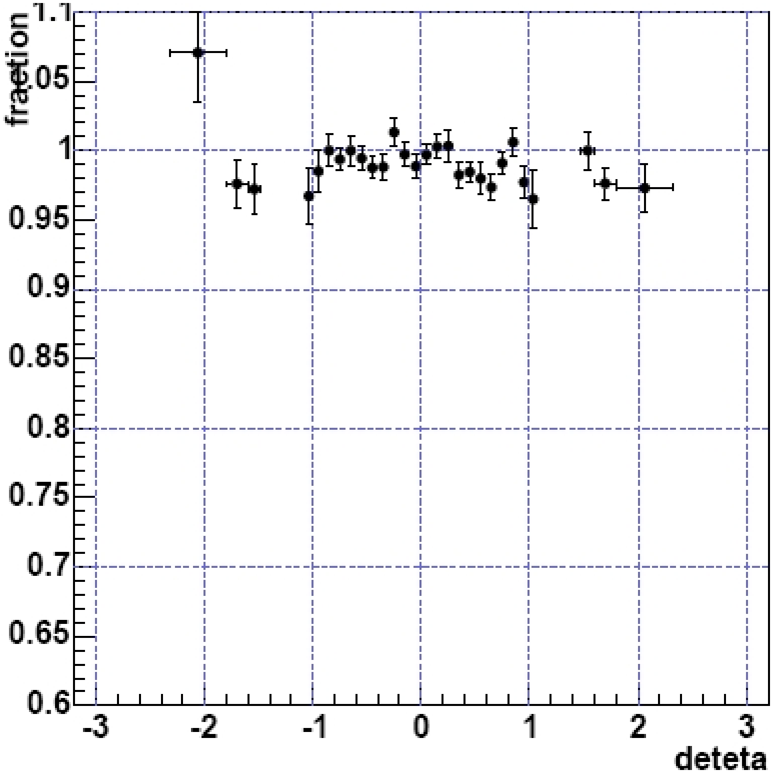
- used to find efficiency of electron ID cuts
- use Z events to get a pure sample of electrons
- require one electron to pass very tight cuts to ensure sample is pure
- use other electron as the "probe"
- cut efficiency = fraction of probes passing the cut

Preselection Efficiency

- efficiency for an electron passing through the calorimeter to form a valid EM object
- use a high p_T track as the probe
- estimate background by comparing the charge sign of the tag and probe tracks
- average efficiency: 99.1% CC and 98.9% EC

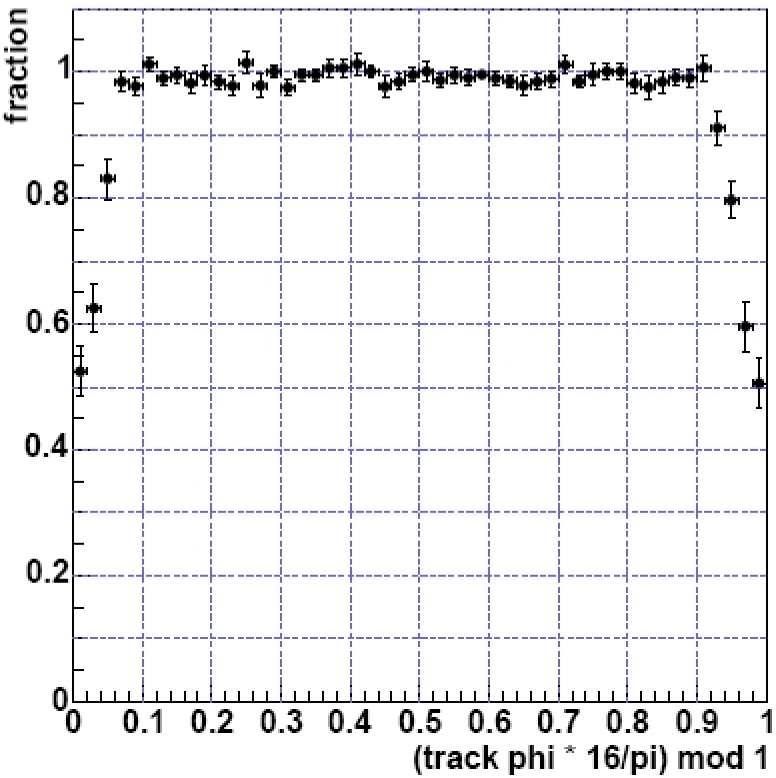
Preselection Plots for Acceptance

use for EC



vs. η_{det}

use for CC

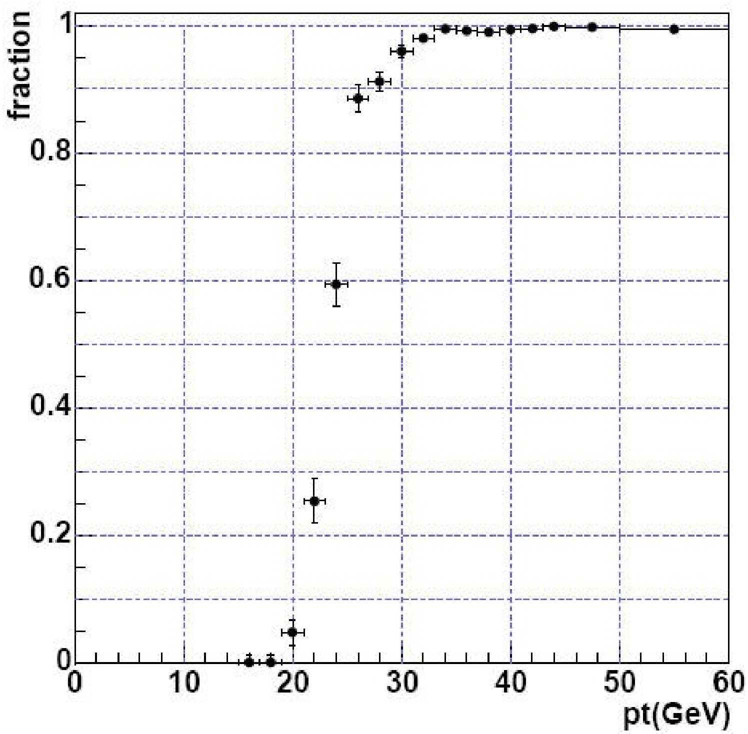


vs. position relative to tower module φ cracks

Trigger Turn on Curve

- trigger efficiency vs reconstructed E_T for trigger requiring 20 GeV trigger object

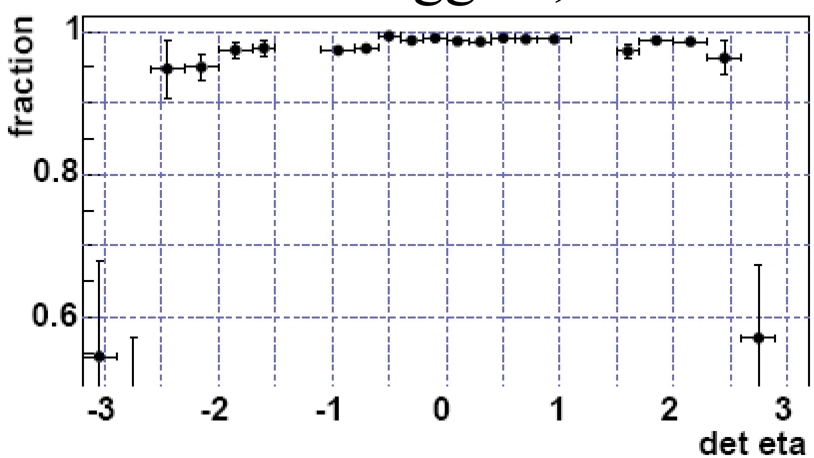
- ideally trigger should be nearly 100% efficient at the kinematic cut of 25 GeV



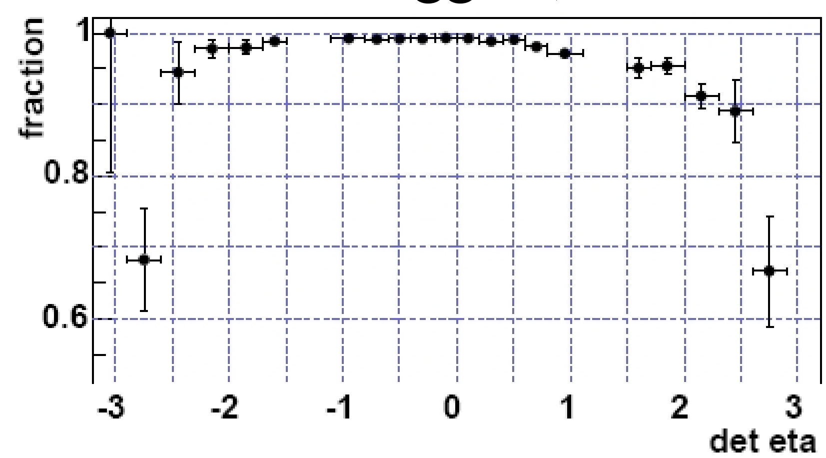
trigger efficiency vs E_T

Trigger Eff vs version, η and Zvtx

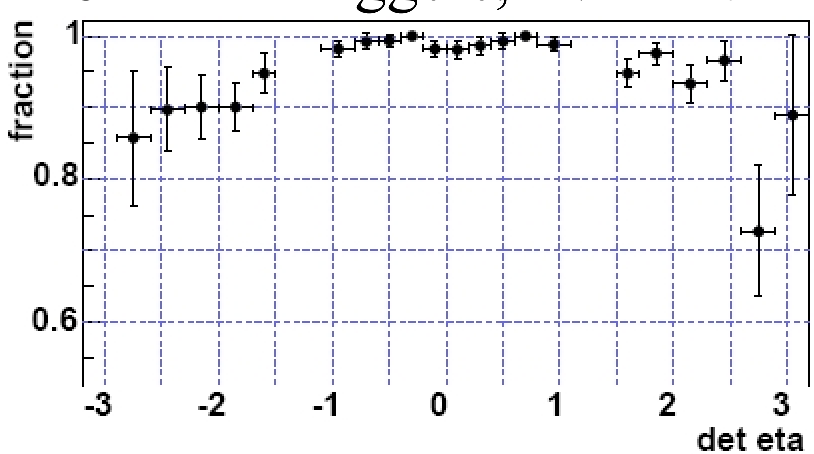
CMT 8-11 triggers, Zvtx < 0



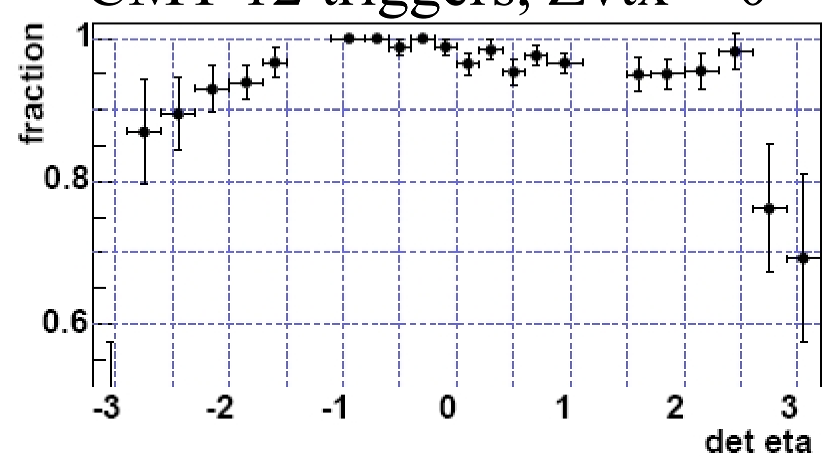
CMT 8-11 triggers, Zvtx > 0



CMT 12 triggers, Zvtx < 0



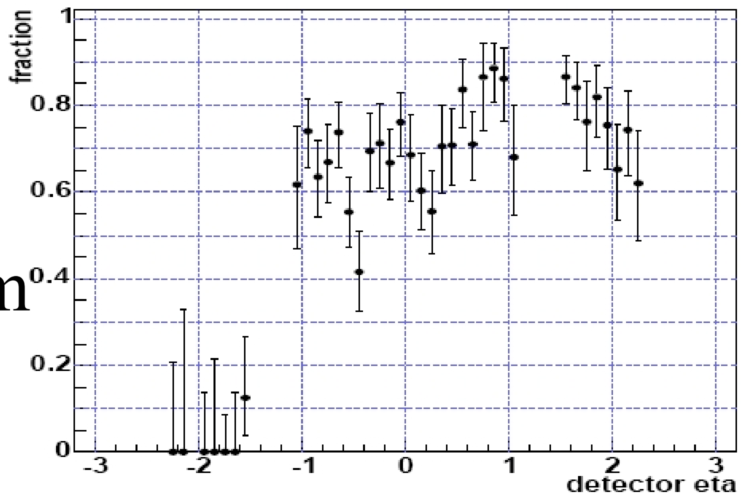
CMT 12 triggers, Zvtx > 0

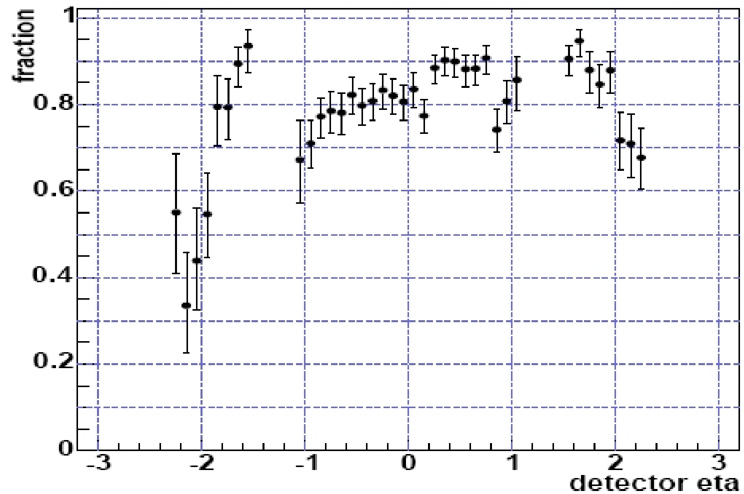


Track-Match Efficiency

- large dependence on primary vertex z and η_{det}
- for acceptance calc, use 10 total histograms vs η_{det} for primary vtx z

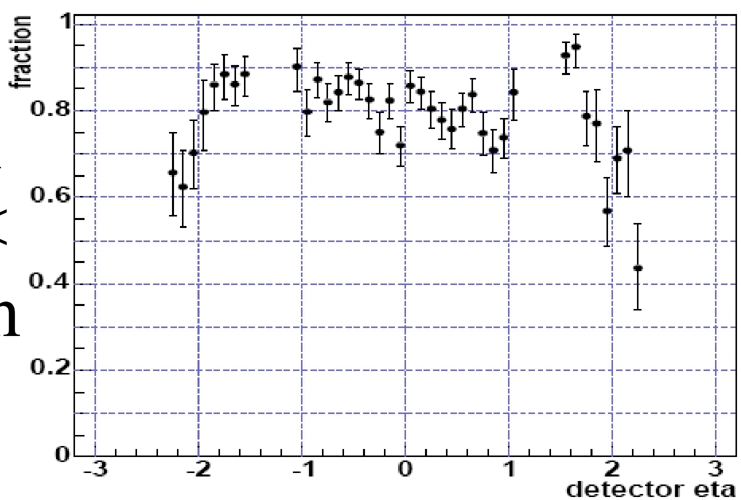
z < -39cm

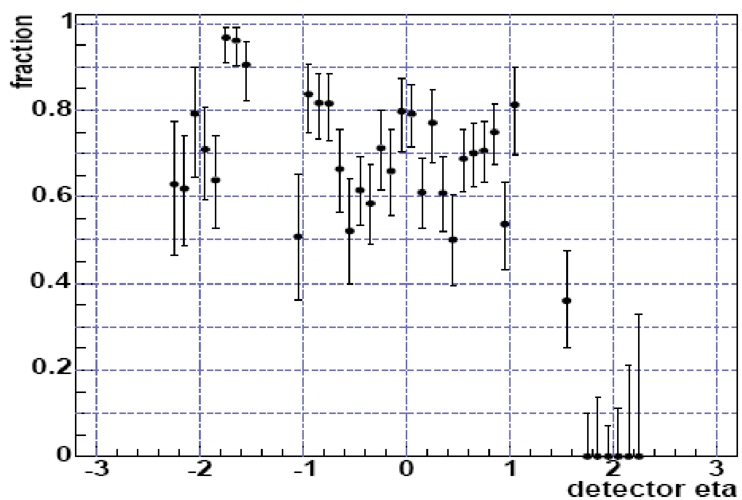




-10cm < z < 0cm

0cm < z < 10cm

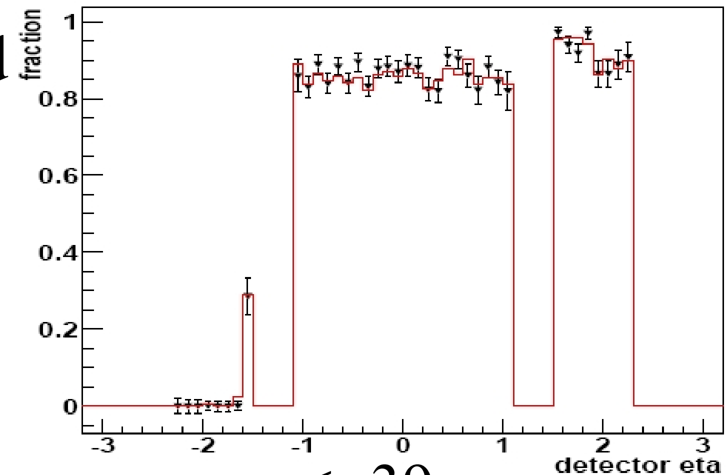




z > 39cm

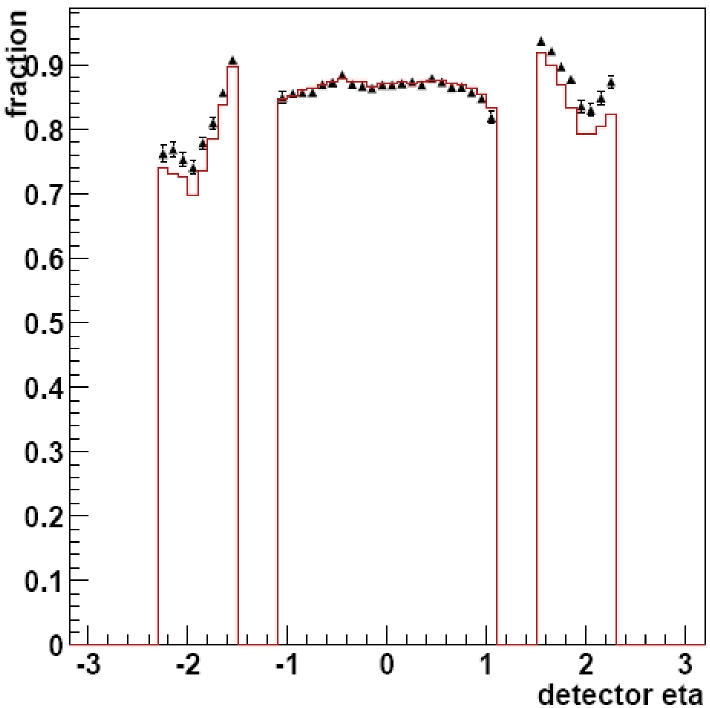
Track-Match: Full MC Check

- use a full Monte Carlo simulation
- verify validity for tag & probe method
- verify adequate binning

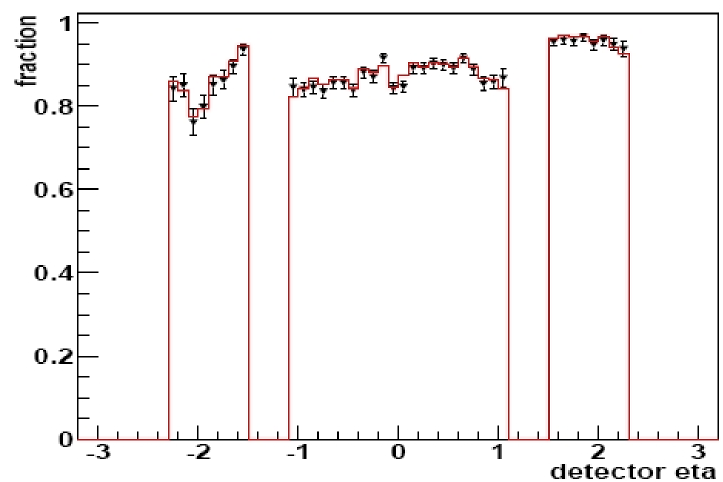


z < -39 cm

red histograms are actual efficiency
black dots are the tag & probe method



no binning in primary vertex z

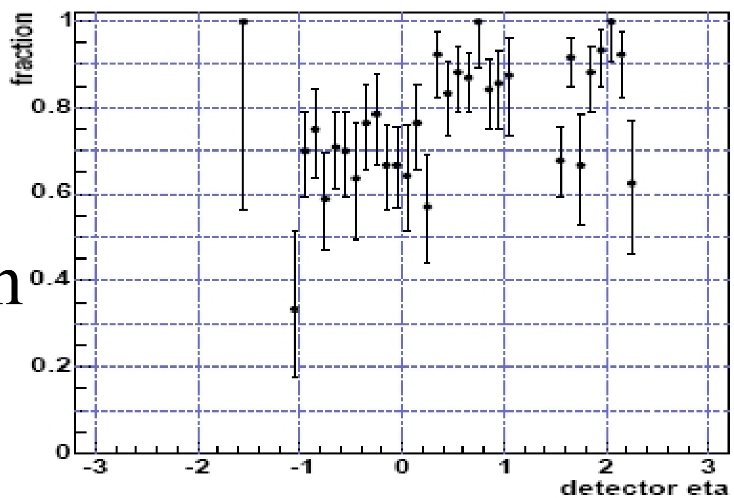


-10 cm < z < 0 cm

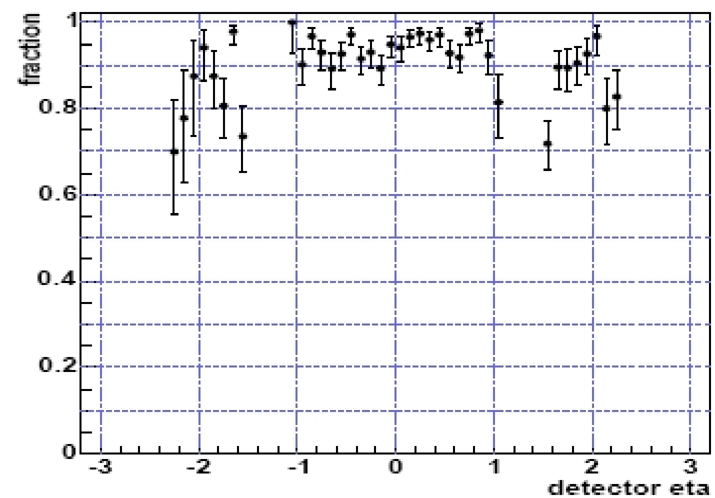
Electron Likelihood Efficieny

- for acceptance calc, use 10 total histograms vs η_{det} for primary vtx z

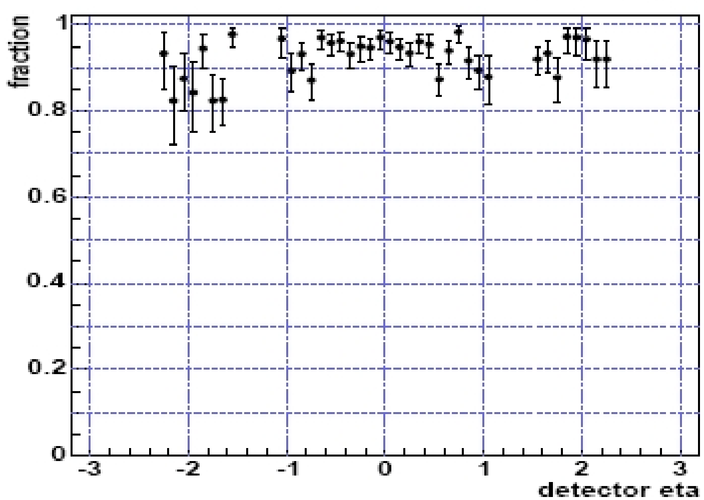
z < -39cm



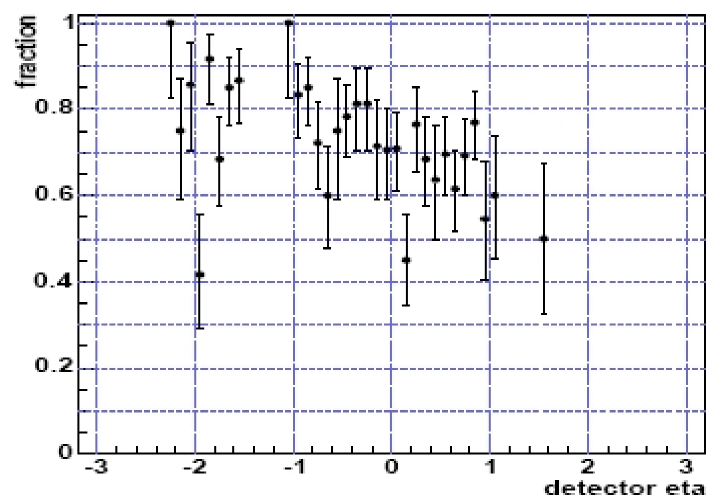
-10cm < z < 0cm



0cm < z < 10cm



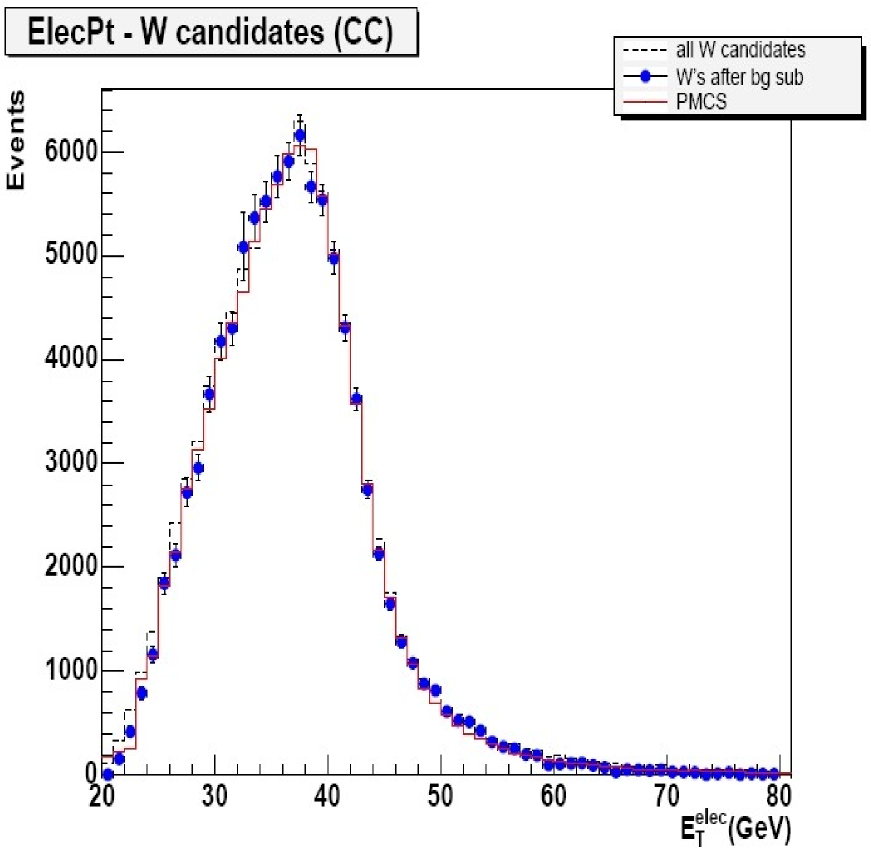
z > 39cm



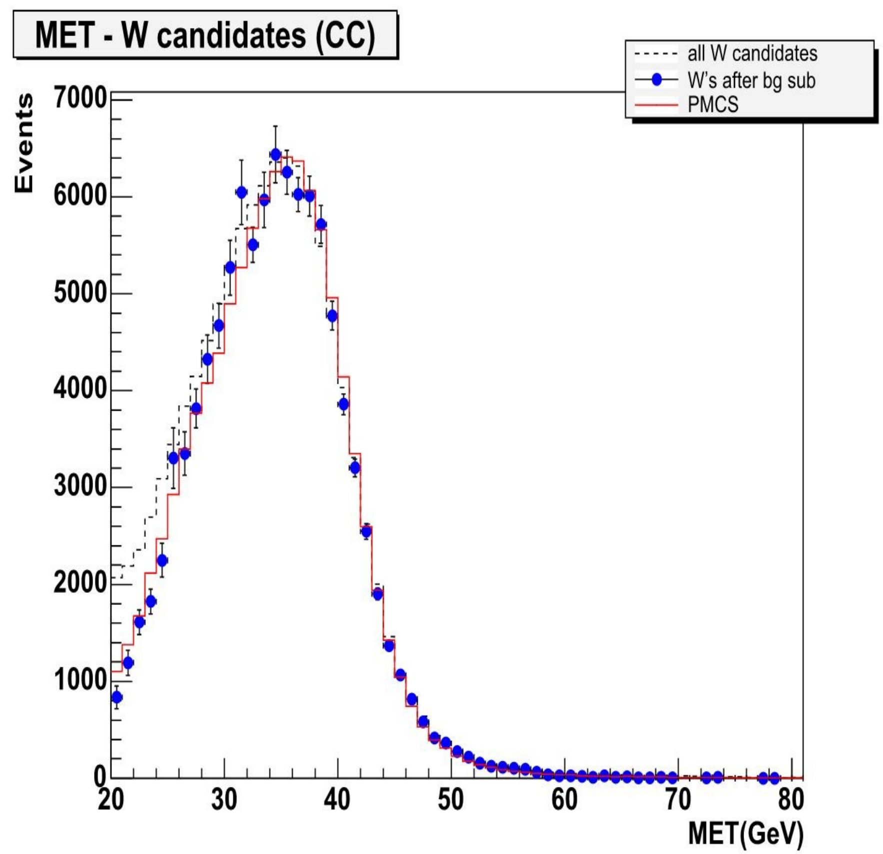
Data – PMCS Comparisons

- must verify good agreement between data and PMCS
- dozens of different plots are compared

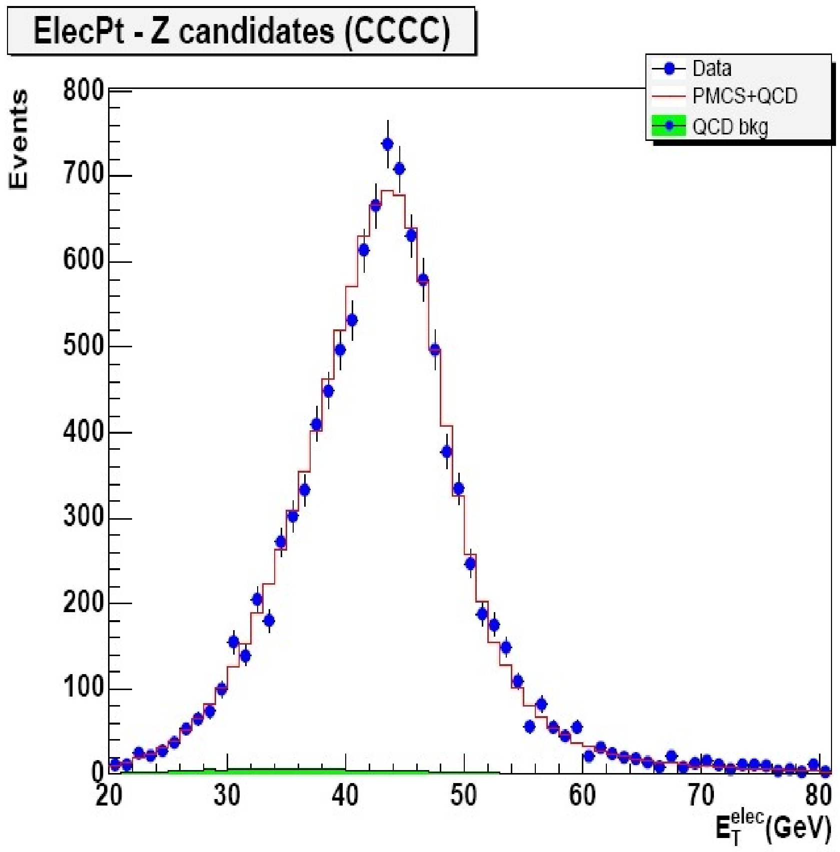
W candidate electron E_T



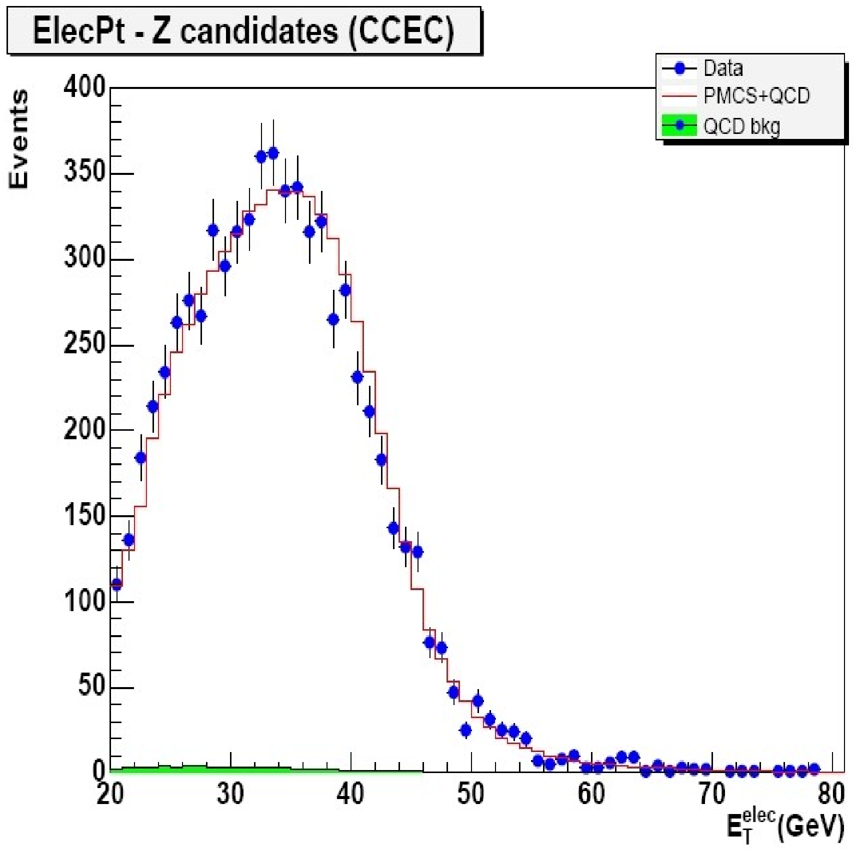
W candidate missing E_T



Z CC-CC candidate electron E_T



Z CC-EC candidate electron E_T



Electron Likelihood Fake Rate

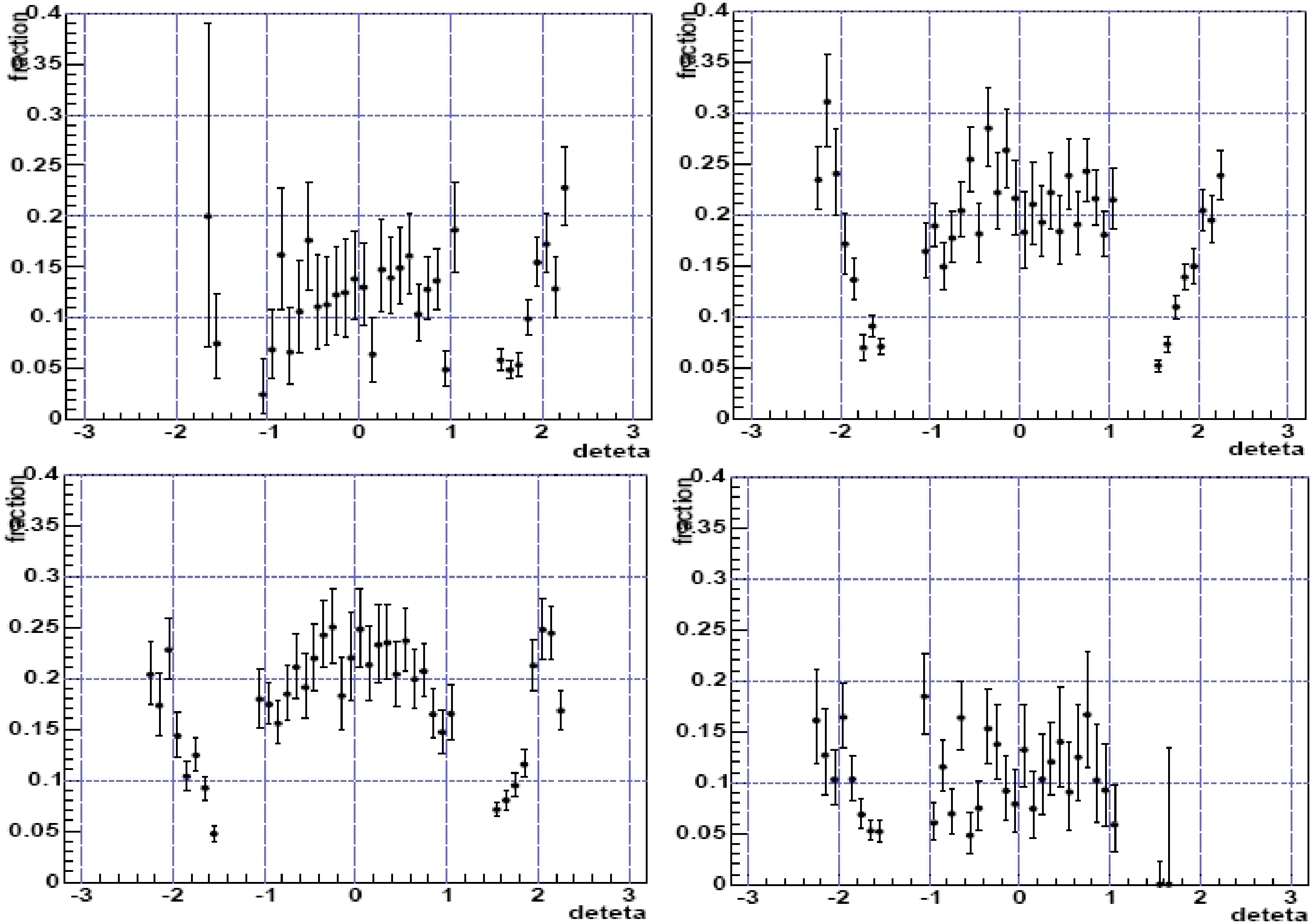
- use back to back di-jet events where one fakes an electron (the probe)
- require the tag to pass tight jet cuts and MET < 10 to remove W + jets
- efficiency for the probe passing all other cuts to also pass elec likelihood

z < -39cm

-10cm < z < 0cm

0cm < z < 10cm

z > 39cm



W QCD Background

- use a “matrix method” to obtain number of true W events
- 1.0% background in the (loose) W candidate sample

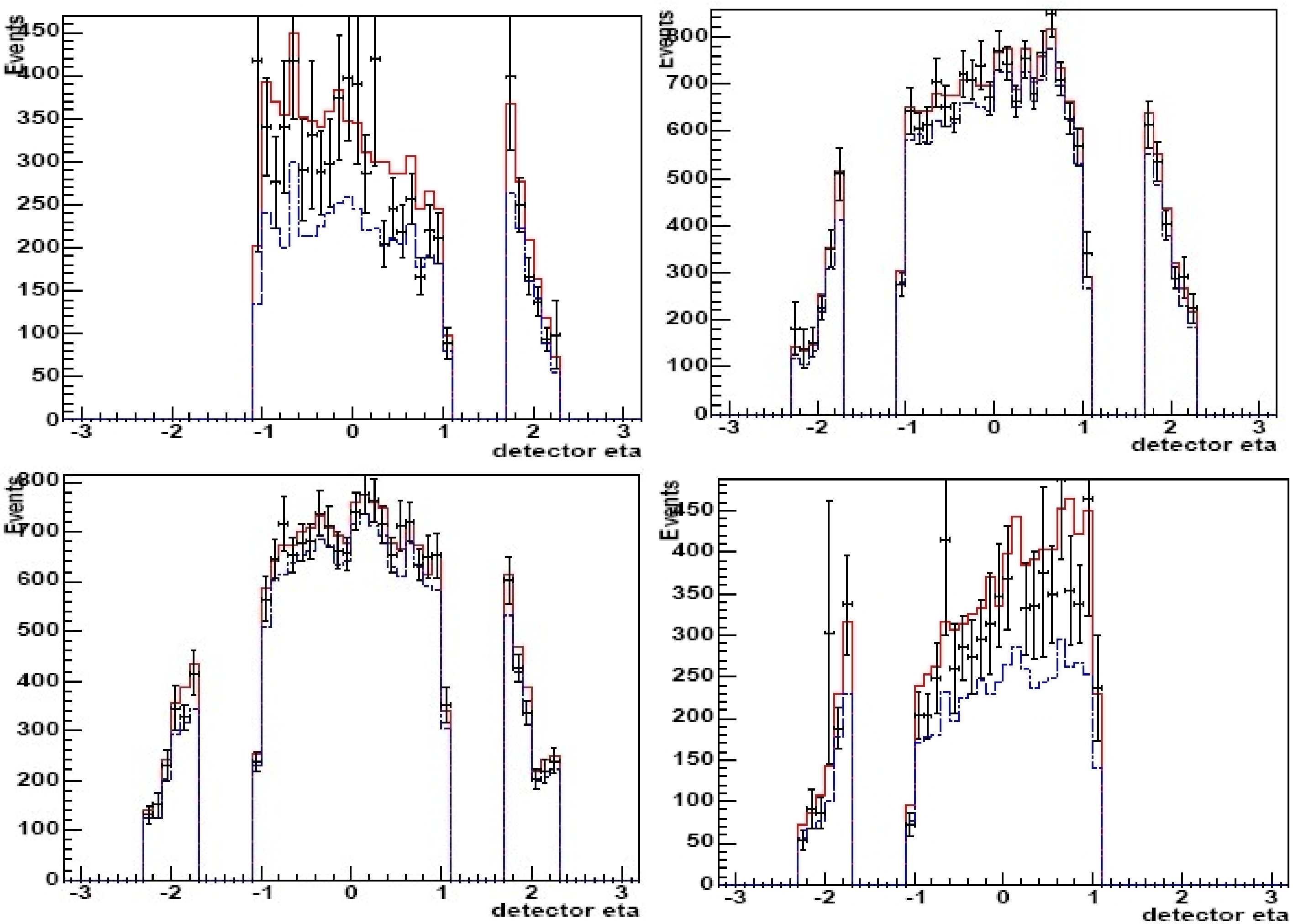
$$N_W = \frac{N^{likelihood}_{WCandidates} - f_{QCD} N_{WCandidates}}{\epsilon_{likelihood} - f_{QCD}}$$

z < -39cm

-10cm < z < 0cm

0cm < z < 10cm

z > 39cm



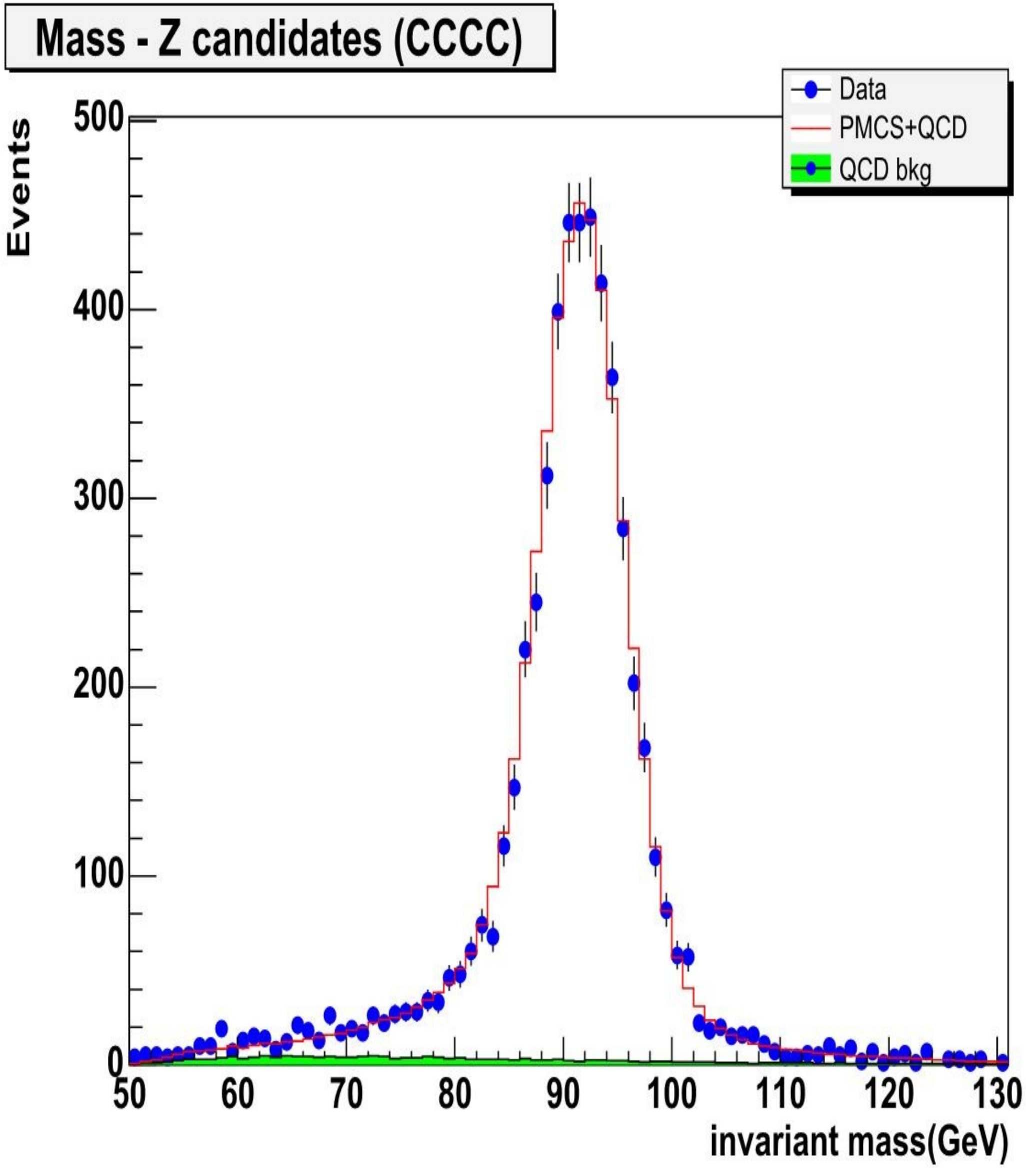
Other W Backgrounds

- run the background Monte Carlo through PMCS in exactly the same way as for $W \to e\nu$ and compare acceptances
- $W \to \tau\nu \to e\,\nu\,\nu$
  - $\text{bkg} = A_{W \to \tau\nu\ \text{bg}} / A_{W \to e\nu} = 1.80\%$
- $Z/\gamma^* \to ee$, one electron is undetected
  - $\text{bkg} = A_{Z/\gamma^*\ \text{bg}} / A_{W \to e\nu}$ times ratio of cross sections

    $= 0.26\%$

Z QCD Background

- events with two electron-like jets
- QCD background:
  CC-CC: 2.0%
  CC-EC: 0.8%
- blue dots: Z candidate events from data
- red histogram: signal shape from PMCS
- solid green: QCD background



Other Z Backgrounds

- Drell-Yan $\gamma^* \to$ ee and $Z/\gamma^* \to$ ee interference terms have final states identical to $Z \to$ ee
  - first find $\sigma_{Z/\gamma^*} \times B(Z/\gamma^* \to ee)$
  - correct using theoretical result for ratio of cross sections

$$R_\sigma = \frac{\sigma_Z \times B(Z \to ee)}{\sigma_{Z/\gamma^*} \times B(Z/\gamma^* \to ee)} = 0.9547$$

- $Z \to \tau\tau$ where both τ's decay into electrons
  - negligible

Relative Uncertainties

- statistical uncertainty (stat) $\propto 1/\sqrt{(\# \text{ of events})}$
  - 0.32% for W, 1.12% for Z and 1.17% for R
- PDF uncertainty (pdf)
  - use 20 pairs of error PDF's provided with CTEQ6.1
  - +1.91/-0.97% for W, +1.48/-1.22% for Z and +1.12/-0.70% for R
- integrated luminosity (lumi)
  - 6.5% for W and Z

Systematic Uncertainty

- from uncertainty in methods for
  - background subtraction
  - efficiencies: statistical limitations and systematics
  - PMCS tuning parameters
- one by one, shift error sources `up' and `down' by their uncertainty and record change in cross sections and R
- total systematic uncertainty (sys)
  - 1.66% for W, 1.69% for Z and 1.30% for R

The W→eν Cross Section

$$\sigma_W \times B(W \to e\nu) = \frac{N_W}{L}\frac{1}{A_W}\left(1 - f_\tau^W - f_Z^W\right)$$

= 2929 ± 9 (stat) ± 57 (sys) +56/ -28 (pdf)

± 190 (lumi) pb

$N_W \equiv$ W candidates after QCD bg sub = 96,799

$L \equiv$ integrated luminosity = 177.3

$A_W \equiv$ W → eν acceptance = 0.18254

$f_\tau^W \equiv$ background from W → τν = 1.80%

$f_Z^W \equiv$ background from Z → ee = 0.26%

The Z→e e Cross Section

$$\sigma_Z \times B(Z \to e e) = \frac{N_Z}{L} \frac{1}{A_{Z/\gamma^*}} \times R_\sigma$$

$= 267.7 \pm 3.0$ (stat) ± 4.8 (sys) $+4.0/-3.3$ (pdf)
± 17.4 (lumi) pb

$N_Z \equiv$ Z candidates after QCD bg sub = 7793
$L \equiv$ integrated luminosity = 177.3
$A_{Z/\gamma^*} \equiv Z/\gamma^* \to$ ee acceptance = 0.15678
$R_\sigma \equiv$ Drell Yan correction = 0.9547

The Ratio of Cross Sections

$$R \equiv \frac{\sigma_W \times B(W \to e\nu)}{\sigma_Z \times B(Z \to ee)} = \frac{N_W}{N_Z} \frac{A_{Z/\gamma^*}}{A_W} \frac{1 - f_\tau^W - f_Z^W}{R_\sigma}$$

R = 10.94 ± 0.13 (stat) ± 0.16 (sys) +0.12/-0.08 (pdf)

combinining all errors....
R = 10.94 ± 0.24

is consistent with the Standard Model prediction:
R = 10.87 ± 0.16

Br(W→e ν) and W Total Width

$$B(W \to e\nu) = R \times \frac{[B(Z \to ee)]}{[\sigma_W / \sigma_Z]}$$

= (10.89 ± 0.13 (stat) ± 0.16 (sys) +0.12/ -0.08 (pdf)
± 0.16 (ext)) %

$$\Gamma_W = \frac{\Gamma(W \to e\nu)}{B(W \to e\nu)}$$

= 2.080 ± 0.024 (stat) ± 0.030 (sys) +0.023/ -0.015 (pdf)
± 0.031 (ext) GeV

- external parameters(ext) based on SM predictions:

$$B(Z \to ee) = (3.3655 \pm 0.0022)\% \quad \sigma_W / \sigma_Z = 3.381 \pm 0.051$$

$$\Gamma(W \to e\nu) = 0.22656 \pm 0.00024 \ \text{GeV}$$

SM & WA Comparisons

combining all errors.....

Br ($W \rightarrow e\nu$) and Γ_W =

$(10.89 \pm 0.29)\%$ and

2.080 ± 0.054 GeV

are consistent with the Standard Model predictions:

$(10.822 \pm 0.016)\%$ and

2.0936 ± 0.0022 GeV

and the experimental World Averages:

$(10.72 \pm 0.16)\%$ and

2.124 ± 0.041 GeV

Recent DØ Cross Sections Work

- a 1 fb^{-1} Z/γ^* electron channel cross section measurement is nearing publication
- a 2 fb^{-1} W and Z electron channel cross sections ratio analysis has begun recently
- improvements for these new measurements
  - increased luminosity
  - better detector understanding:
  - calorimeter regions fixed
  - use Central Preshower detector
  - extended detector coverage in η