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Electroweak Physics at CDF

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Abstract PA07-29

ELECTROWEAK PHYSICS AT CDF

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FOR THE CDF COLLABORATION

The CDF collaboration is engaged in a broad program of electroweak measurements. The production of WW, WZ, ZZ, $W\gamma$, $Z\gamma$ and the high mass Drell Yan charge asymmetry will be discussed, along with a status report on extracting a new W mass from the most recent 90 pb^{-1} data sample.

1 Introduction

The Tevatron Collider has produced collisions of antiprotons and protons at a center of mass energy of 1800 GeV. The Collider Detector at Fermilab (CDF) is a general purpose magnetic detector, used by a collaboration of $\sim$ 450 physicists, to study these collisions. In 1988/89 CDF recorded $4pb^{-1}$ of data, denoted "Run 0." In 1992/93 we recorded $20pb^{-1}$, denoted "Run 1a," and in 1994/95 we recorded $90pb^{-1}$, denoted "Run 1b." A further small sample from 1995/96 is denoted "Run 1c." Most up to date analyses combine the datasets of 1a and 1b to use samples of about $110pb^{-1}$.

This represents a prolific source of W and Z bosons (IVB's), with the proviso of leptonic decays to provide a trigger. The cross section times electronic branching ratio is 2.49 ± 0.12 nb for W's and 0.231 ± 0.012 nb for Z's, as measured in 1a.[1] Electron and muon datasets are available with efficiencies for W's typically 20 and 15%.

These data can be useful in QCD studies of jet multiplicity and p_T dependence in IVB production,[2] and structure functions from the forward backward charge asymmetry observed for W's.[3] Electroweak measurements turned into calibrations by the LEP1 program are the Z mass and leptonic decay forward backward charge asymmetry. The asymmetry above the Z peak has not quite been overwhelmed yet by the LEP2 program and will be discussed below. The top mass measurement is perhaps our most constraining electroweak measurement; this (176 ± 9 GeV/c^2) is discussed elsewhere.[4] Measurements in direct competition with the LEP2 program are the W mass and the trilinear gauge couplings (TGCs). These measurements are also discussed below.

2 Z and Higher Charge Asymmetry

The interference between the photon and the Z gives a forward-backward charge asymmetry which changes sign moving through the Z pole; the value at the pole is a measurement of weak mixing. Below the pole this has been well measured at KEK, and at the peak LEP measurements are much more accurate than what CDF can do. Our measurement above the pole has not yet been completely outclassed by LEP and we concentrate on that, using a pole measurement as a reference point.

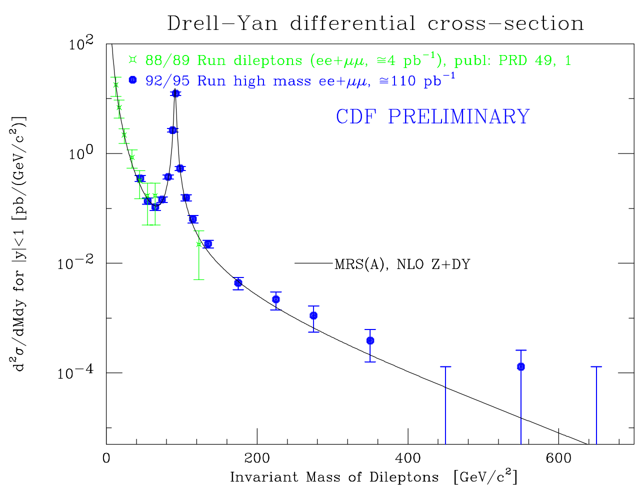

Figure 1: CDF Drell Yan Mass Spectrum.

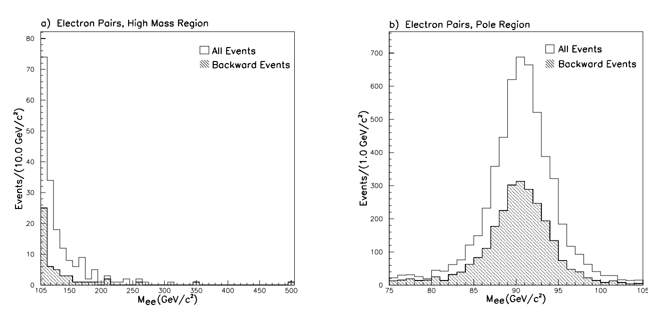

Figure 2: CDF e^+e^- mass spectrum for a) high and b) pole regions. Shaded area is for backward events.

Our preliminary and run 0[5] Drell Yan mass spectrum is shown in Fig. 1. For this analysis we need good acceptance out to reasonably high absolute pseudorapidity (η), so we use e^+e^- pairs where only one electron

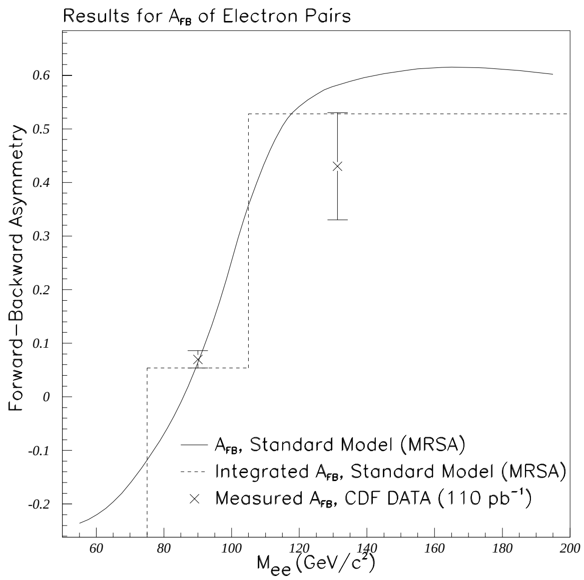

Figure 3: CDF pole and high charge asymmetry. The smooth curve is the prediction averaged into the bins used in the histogram.

is required to be within $|\eta| < 1.1$ and has a well determined charge. This central electron must pass strict ID cuts including isolation. The second electron is within $|\eta| < 2.4$ and has less stringent selection but also requires isolation. For each event, $\cos(\theta^*)$ is determined in the Collins-Soper frame.

We define a pole region as $75 < M_{ee} < 105$ and a high region $105 < M_{ee}$ ($\mathrm{GeV/c^2}$). The mass distributions for the 5463 pole region and 183 high mass events and the split between forward and backward are shown in Fig. 2. After corrections for background, mass resolution and efficiency we obtain A_{FB}(pole) to be $0.070 \pm 0.015(\mathrm{stat}) \pm 0.004(\mathrm{sys})$. Using the 1994 PDG weak mixing angle and MRSA proton structure with radiative corrections we predict A_{FB}(pole) to be 0.054 ± 0.001. For the high mass region we predict 0.528 ± 0.006 and observe $0.43 \pm 0.08(\mathrm{stat}) \pm 0.06(\mathrm{sys})$. The systematic uncertainties have comparable contributions from background and mass deconvolution effects. The measurements are in good agreement with expectations as shown in Fig. 3.

3 W Mass Measurement

CDF does not yet have a measurement from the 1b data to add to our previous W mass measurements of 79.91 ± 0.39 GeV/c^2 from run 0 and 80.41 ± 0.18 GeV/c^2 from 1a[6]. So far most uncertainties seem to scale at least as well as the square root of the ratio of luminosities. The two which will not scale that well are the statistical uncertainty, which is slightly degraded ($\sim 10\%$) by the overlapping minimum bias events in the higher luminosity 1b data, and the uncertainty associated with pro-

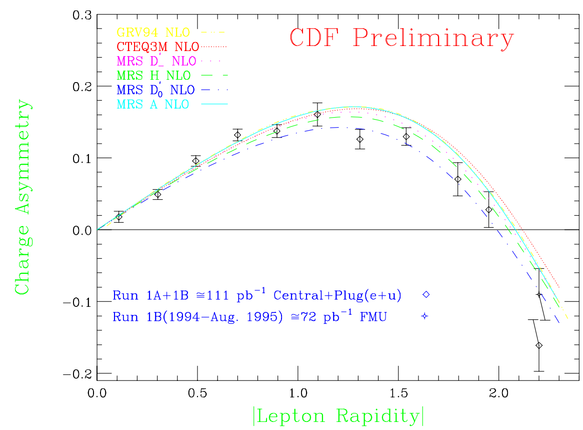

Figure 4: CDF preliminary W lepton charge asymmetry. The theory curves use the DYRAD generator by Walter Giele.

duction models, in particular structure functions. The latest measurement of the W charge asymmetry, shown in Fig. 4, has gained both in statistics and in η coverage. The higher η data seem to demand that more attention be paid to the W p_T distribution in generating theory expectations. In any case, even if the asymmetry were perfectly measured, a ~ 25 MeV/c^2 structure function uncertainty would remain on the W mass.

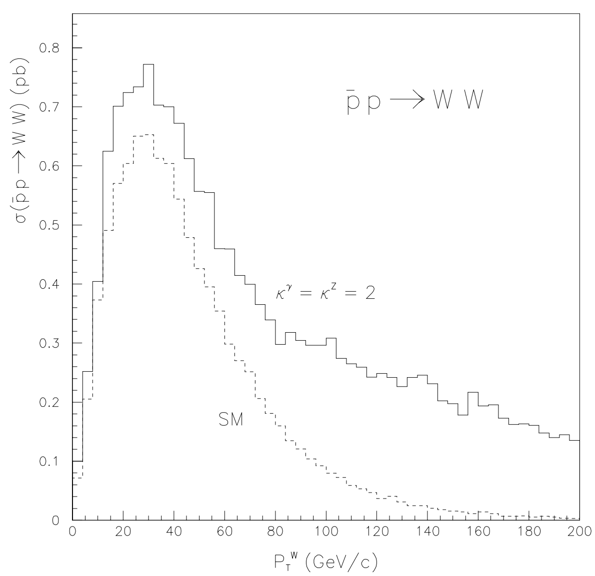

Figure 5: Illustration of the increase of high p_T cross section for W pairs with nonstandard coupling.

4 Trilinear Gauge Coupling

We can limit possible nonstandard contributions to TGC's directly, by studying the production of $W\gamma$ events where the IVB's decay to electrons or muons, and we can limit such contributions by searching for WW and WZ

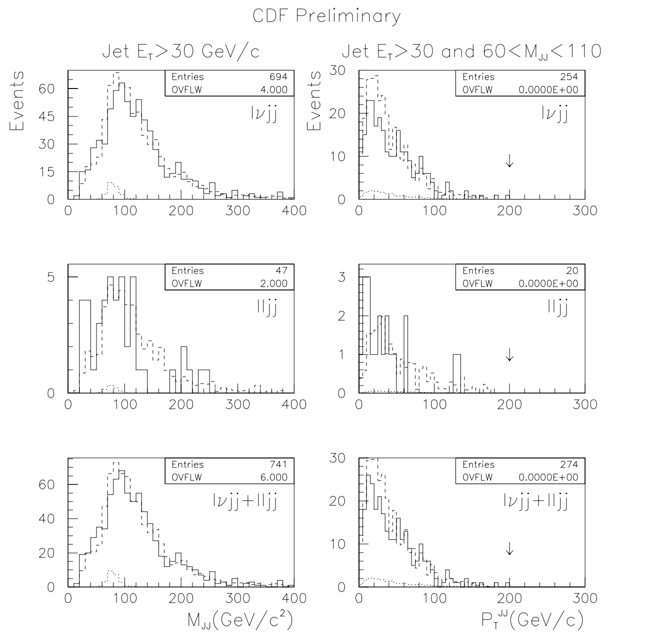

Figure 6: CDF jet pair selection, jet pair mass left and p_T right. The data is the solid histogram and W+jets simulation is the similar dashed histogram and standard model expected signal is the little dotted histogram.

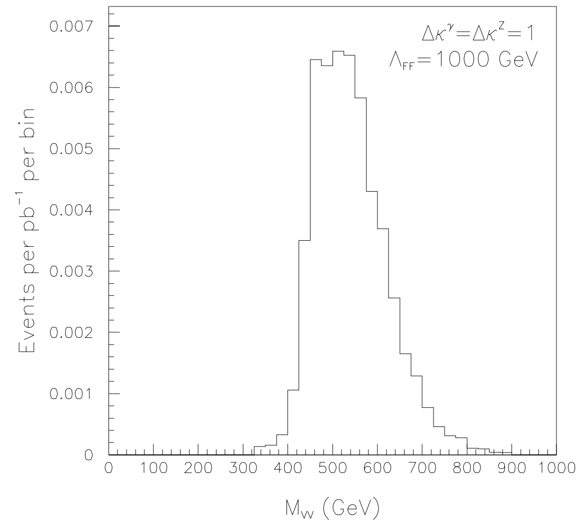

Figure 7: IVB pair invariant mass region relevant for the jet pair coupling study.

production at high p_T where one IVB decays to a jet pair. With electrons and muons only, we look for a signal in WW, WZ, and ZZ. We use the Lagrangian parameters g_1^Z, κ_γ, κ_Z, λ_γ and λ_Z. We may assume γ and Z parameters are the same and we also use the HISZ assumptions.[7] Note that $\Delta\kappa$ is κ-1. We have nothing new on anomalous $Z\gamma$ couplings.[8]

4.1 $W\gamma$ Production

Our published result from 1a[9] was extended in updates last summer,[10] and initial studies of the charge asymmetry and radiation zero were also reported. The parameter limits with 67 pb^{-1}, using only central photons, of $-1.8 < \Delta\kappa < 2.0$ and $-0.7 < \lambda < 0.6$ (95% CL) should be updated soon using the full luminosity and higher $|\eta|$ photons.

4.2 WW and WZ Using Jet Pairs

This analysis looks for IVB pairs with an electron or muon decay of one W or Z accompanied by a jet pair from the other. The mass of the jet pair must be consistent with coming from the decay of a W or Z. Nonstandard couplings tend to enhance production at high p_T as illustrated in Fig. 5. The p_T of the jet pair is required to be high enough to suppress background from single W or Z plus jets. The analysis for 1a[11] has been extended to the full 110 pb^{-1}.

Table 1: CDF IVB pair jet pair analysis preliminary lower and upper coupling parameter bounds at 95% CL with all other coupling fixed as standard.

Coupling	Λ_{FF} = 1000 GeV	Λ_{FF} = 2000 GeV
g_1^Z	0.09, 2.05	0.39, 1.68
$\Delta\kappa_Z$	-0.95, 1.01	-0.58, 0.68
λ_Z	-1.67, 1.60	-1.05, 1.05
$\Delta\kappa_{\gamma=Z}$	-0.67, 0.85	-0.49, 0.54
$\lambda_{\gamma=Z}$	-0.51, 0.51	-0.35, 0.32
$\Delta\kappa_\gamma$ (HISZ)	-0.83, 1.02	-0.61, 0.67
λ_γ (HISZ)	-0.51, 0.52	-0.34, 0.33

The jet pair mass and p_T selection is illustrated in Fig. 6. The jet pair p_T requirement of 200 GeV/c was calculated to give the desired background suppression for both W and Z events. Jet merging makes finding jet pairs above $\sim$ 300 GeV/c inefficient, but that is not a significant loss in this analysis.

In calculating the effects of nonstandard coupling we assume that unitarity is restored by modulating the deviations of the Lagrangian parameters from standard model values with a form factor $1/(1+\hat{s}/\Lambda_{FF}^2)^2$; the relevant region for our data is shown in Fig. 7. We obtain preliminary limits as listed in Table 1 and illustrated in Fig. 8.

4.3 Leptonic IVB Pairs

One can hope to extract an actual signal for W pair production when both W's decay to electron or muon. This analysis closely follows the dilepton top search, with a 108 pb^{-1} sample. Two oppositely charged isolated leptons are required above 20 GeV p_T. A Z mass window of

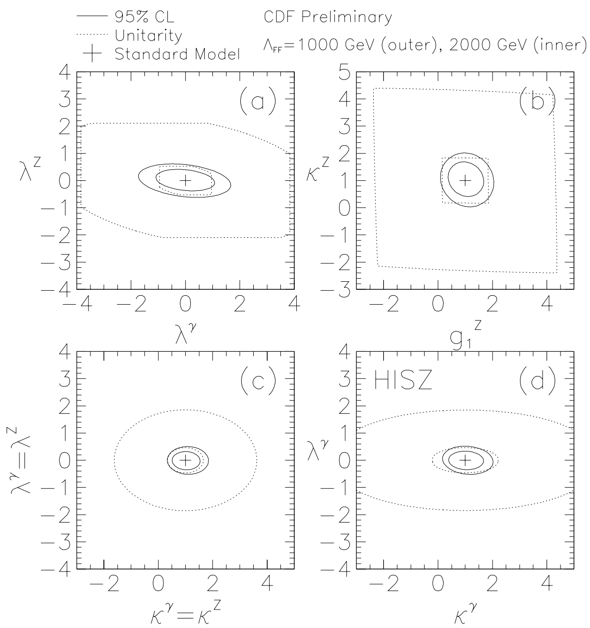

Figure 8: CDF preliminary pairwise coupling limits for the jet pair study.

Table 2: CDF WW leptonic background contributions. Drell-Yan is estimated from events in the Z window and fakes are predominantly W + jet events where the jet fakes a lepton.

Process	Events expected
$t\bar{t}$	< 0.1
$Z \rightarrow \tau\tau$	0.2 ± 0.1
Drell Yan	0.4 ± 0.2
WZ	~ 0.1
Fake	0.4 ± 0.2

75-105 GeV/c^2 is removed as appropriate. Missing E$_T$ of at least 25 GeV is required. To reduce background for τ's, the missing E$_T$ must either point at least 20° away from both leptons or exceed 50 GeV. To avoid background from top, events with jets above 10 GeV are removed. With this selection and for the predicted cross section[12] of 9.5 pb, we expect 3.5 WW events. Background processes, detailed in Table 2, are expected to yield 1.2 ± 0.3 events.

We observe 5 events, 2 ee and 3 eμ. Very roughly one expects the ratio 1:1:2 for ee, $\mu\mu$ and eμ. The excess corresponds to a cross section of $10.2^{+6.3}_{-5.1}$(stat) ± 1.6(sys) pb. The systematic uncertainty is mainly from acceptance ($\pm 12\%$) and overall luminosity ($\pm 7\%$). The agreement with expectations of this value is illustrated in Fig. 9. With no reference to the information of lepton p$_T$, the cross section implies coupling limits shown in Fig. 10.

We have a three electron WZ candidate, shown in Fig. 11, and the full luminosity gives a standard model

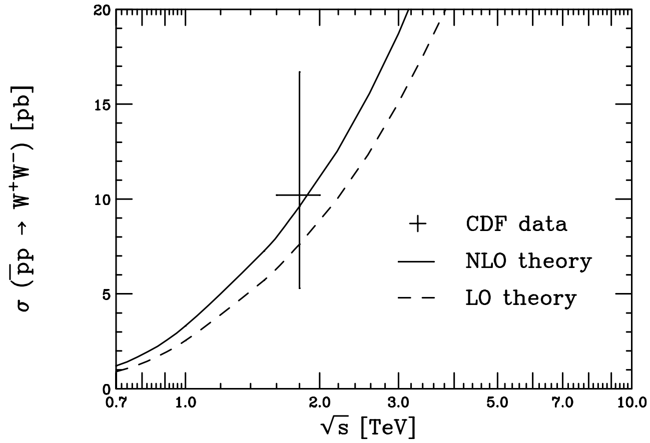

Figure 9: CDF preliminary observed WW cross section and NLO and LO predictions.

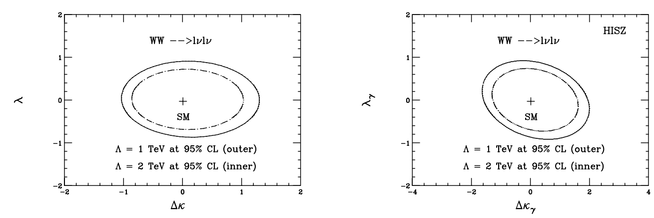

Figure 10: CDF preliminary pairwise limits on non standard couplings from the WW leptonic cross section, γ and Z coupling equal left, and HISZ right.

expectation of 0.6 WZ events. In the most recent small 1c dataset, not yet fully digested, we obtained a four muon ZZ candidate, shown in Fig 12. We would expect perhaps ~ 0.1 ZZ events. After all the discussions about detecting 4 lepton Z pairs, it is nice to see one.

5 Conclusions

Within the next year or so we should be able to get the W mass and coupling measurements from our large dataset. We hope to get to δm(W) of about 100 MeV/c^2, improved TGC constraints and evidence for the radiation zero in $W\gamma$ production. While we are preparing for an eventual several inverse Femtobarn dataset to come, we hope we will have given a reasonable challenge to the LEP2 program.

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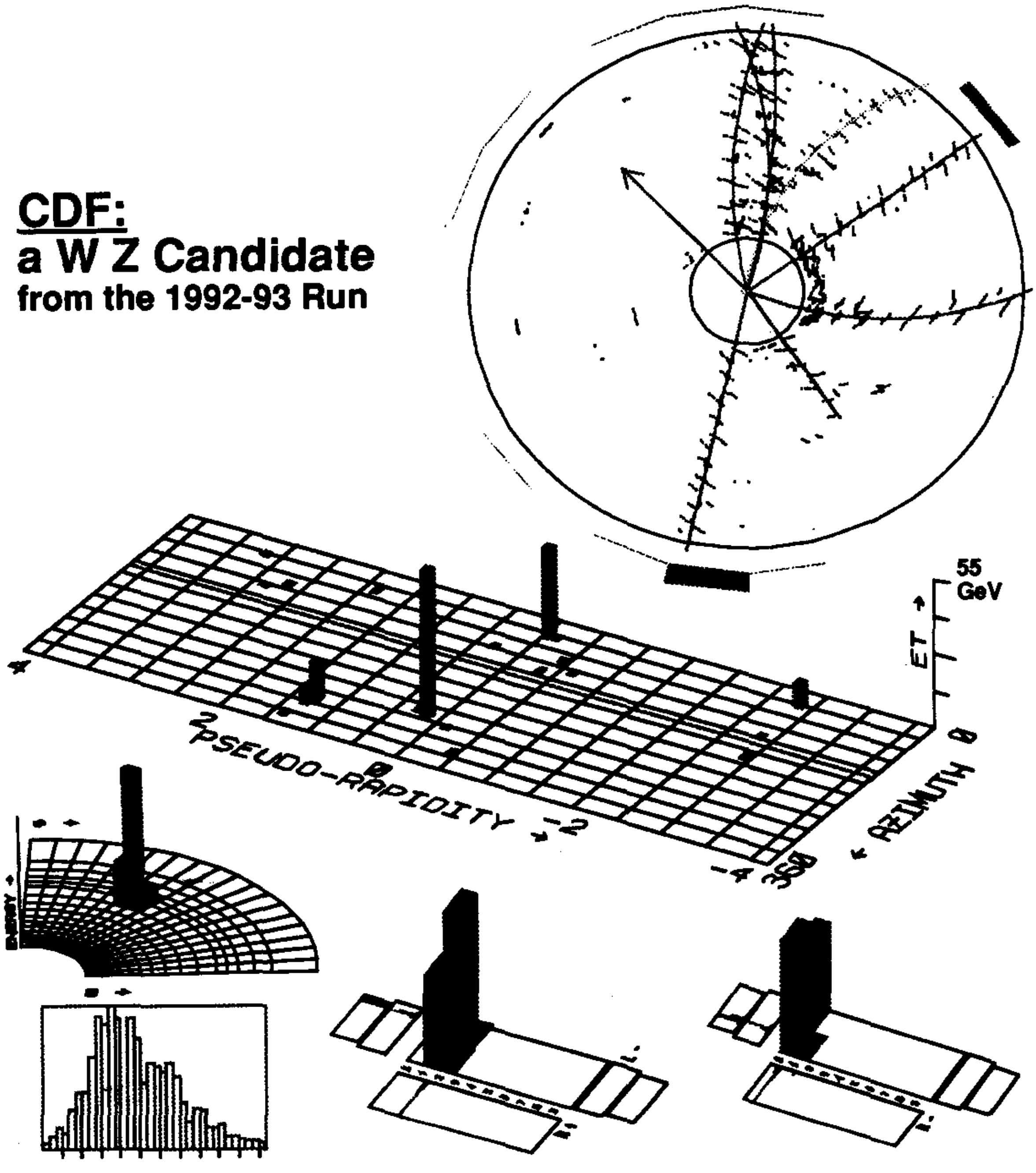

Figure 11: CDF three electron WZ candidate. The central PMT, shower max and preradiator display is given for the central electrons and the local plug pads and depth for the plug electron. A color version of this can be found at http://www-cdf.fnal.gov/physics/ewk/eee.ps.

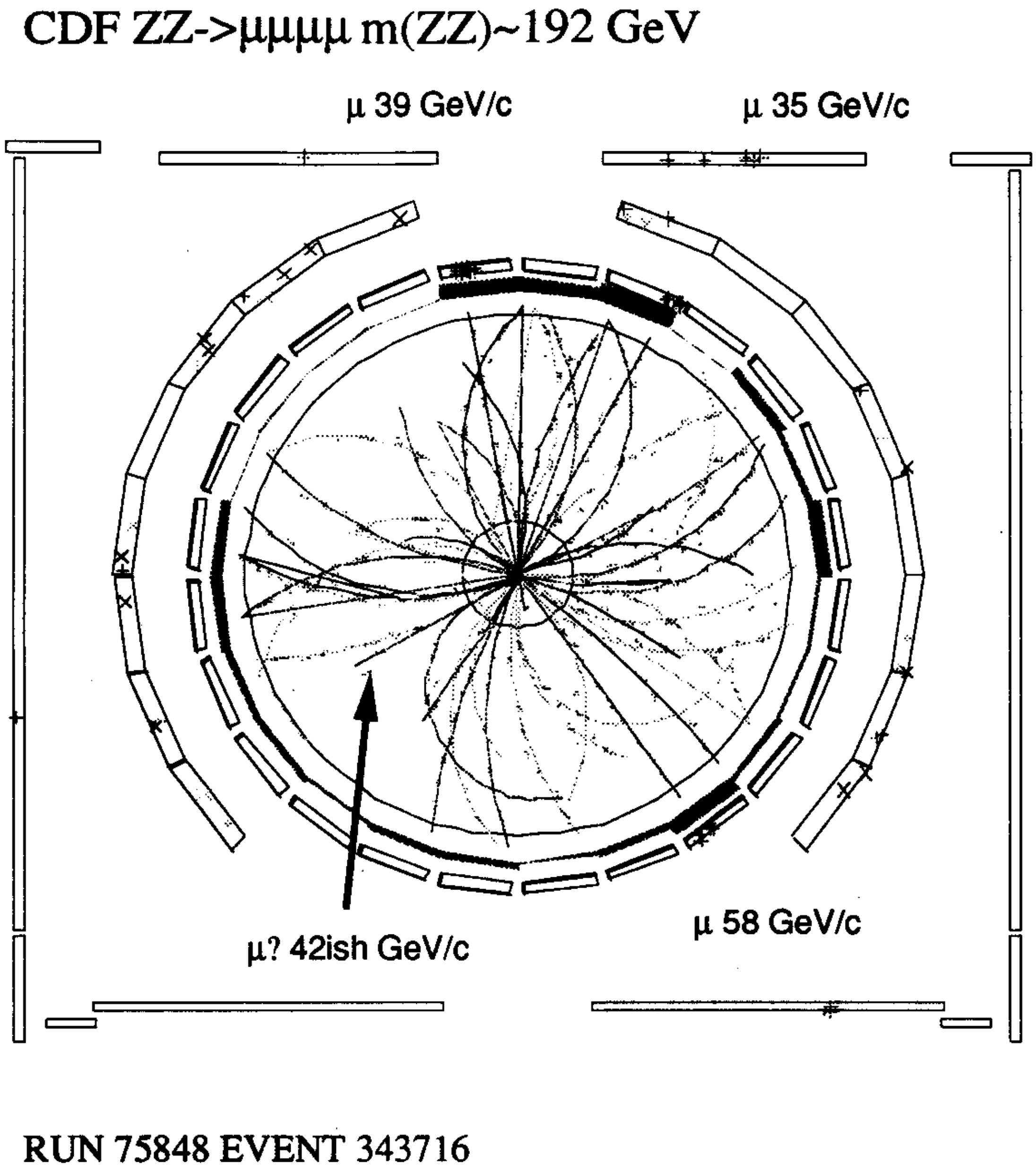

Figure 12: CDF four muon ZZ candidate. From inside to outside, muon hits are from chambers on the back of central calorimeters, on arches at higher η, and behind steel walls. A color version of this can be found at http://www-cdf.fnal.gov/physics/ewk/mmmm.ps.