Post comments to:

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0.1 Residual Efficiency Corrections

The efficiency in detector data for electron id (hmatrix) and loose and tight track-matching
cuts on individual electrons is not perfectly modeled by the FullMC simulation. To correct
for this, the efficiency is measured in detector data as a function of various dependent vari-
ables. The data efficiency is then divided by the analogous efficiency measured in FullMC,
and the ratio is applied in PMCS to adjust the parameterized simulation to better model
the data. Dependent variables used to determine the necessary adjustment are the z-vertex,
$\eta_{\text{det}}$, SET, instantaneous luminosity, and $p_T$. There is not enough data to measure the ef-
ficiency simultaneously as a function of all these variables, so the dependence is separated
for variables which are not significantly correlated. $\eta_{\text{det}}$ and z-vertex dependence is measured
simultaneously, $p_T$ dependence is measured separately, and SET and instLumi are measured
separately for loose/tight and simultaneously for hmatrix. (VERIFY - this is not exactly
true, Jenny, please point me in direction of description of your 3D? method.)

0.1.1 Data Sample for Extracting Signal Counts in Efficiency Bins

In data, we cannot determine with absolute certainty whether individual electrons are signal
electrons or not, so we use a template method to estimate the number of signal electrons
passing or failing a given selection cut. We apply this method to the “2EM” data sample
described in section 3.1 with a relaxed set of selection requirements, particularly, we remove
the selection requirements of the cut whose efficiency we are trying to measure. This results
in a data sample that includes signal electrons which pass the cut, signal electrons which fail
the cut, and background. The template method therefore involves estimate the shape of the
background and signal spectra for electrons that pass or fail the cut in question, in bins of
the dependent variable.
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0.1.2 Anti-Selection Cuts to Model Background Contribution to Data Sample in Efficiency

Measurement Bins

The background template is derived from collider data with selections applied to exclude
signal events. Two of the three samples described in section 3.1 are suitable for extracting a
background, the “2EM” sample and the “EM+jet” sample. They are combined to maximize
statistics in the background template.

A good background selection selectively removes most signal events. It will also remove
some background events, but it should do so in a way that does not alter the shape of the
background. The general strategy to get the background sample for a given selection cut
is to combine that selection cut with the required failure of other selection cuts, e.g. for
the failing hmatrix background selection, use the failing hmatrix selection, and in addition
require that both electrons fail the loose track-matching criterion.

The background selections used in RunIIb34 are similar to the ones used in RunIIb12, with
the slight difference that events are now excluded if either electron contains dead cells, and
the background also includes the trigger requirement to better match the data selection.

0.1.3 Pure background selection criteria for H-Matrix efficiency study

Base selection criteria applied to $Z \rightarrow ee$ events to select pure background for H-Matrix
efficiency study:

- The event has at least two reconstructed electrons. If more than two, take the leading
two according to $p_T(e)$.

- The invariant mass $M(ee)$ is between 60 and 130 GeV.

- Recoil $p_T (u_T)$ satisfies $u_T < 30$ GeV.
• Both electrons do not fall in Phi Cracks (calorimeter inter-module gaps in $\phi$).

• Both electrons satisfy $p_T(e) > 25$ GeV.

• Both electrons satisfy EMFraction $> 0.9$.

• Both electrons satisfy ISO $< 0.15$.

• Both electrons can be either in CC or EC. There is no requirement for both electrons to be in CC at the same time.

• Both electrons fail loose-track-match criterion.

• Both electrons fail tight-track-match criterion.

Electrons pass or fail H-Matrix criterion to determine the pure background shape is defined as:

- **Pass:** *this electron* is in CC, HMx7$<12$, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.

- **Fail:** *this electron* is in CC, HMx7$>12$, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.

### 0.1.4 Pure background selection criteria for loose-track-match efficiency study

Base selection criteria applied to $Z \rightarrow ee$ events to select pure background for loose-track-match efficiency study:

- The event has at least two reconstructed electrons. If more than two, take the leading two according to $p_T(e)$.

- The invariant mass $M(ee)$ is between 60 and 130 GeV.
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1. Recoil $p_T (u_T)$ satisfies $u_T < 30$ GeV.

2. Both electrons do not fall in Phi Cracks (calorimeter inter-module gaps in $\phi$).

3. Both electrons satisfy $p_T(e) > 25$ GeV.

4. Both electrons satisfy ISO < 0.15.

5. Both electrons fail H-Matrix criterion.

6. No EMFraction criterion for both electrons.

Electrons pass or fail loose-track-match criterion to determine the pure background shape is defined as:

- **Pass:** *this electron* is in CC, pass loose-track-match criterion, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.

- **Fail:** *this electron* is in CC, fail loose-track-match criterion, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.

0.1.5 Pure background selection criteria for tight-track-match efficiency study

Base selection criteria applied to $Z \rightarrow ee$ events to select pure background for tight-track-match efficiency study:

1. The event has at least two reconstructed electrons. If more than two, take the leading two according to $p_T(e)$.

2. The invariant mass $M(ee)$ is between 60 and 130 GeV.

3. Recoil $p_T (u_T)$ satisfies $u_T < 30$ GeV.

4. Both electrons do not fall in Phi Cracks (calorimeter inter-module gaps in $\phi$).
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- Both electrons satisfy \( p_T(e) > 25 \) GeV.
- Both electrons satisfy ISO < 0.15.
- Both electrons fail H-Matrix criterion.
- Both electrons pass loose-track-match criterion.
- No EMFraction criterion for both electrons.

Electrons pass or fail tight-track-match criterion to determine the pure background shape is defined as:

- **Pass:** this electron is in CC, pass tight-track-match criterion, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.
- **Fail:** this electron is in CC, fail tight-track-match criterion, neither electron’s reconstruction window contains dead cells, and other electron passes trigger.

Once the background is selected, it is fit with an ad-hoc template function of form:

\[
B(x) = p_0 \cdot e^{\frac{(x-p_1)^2}{2p_2^2}} + \sum_{i=3}^{13} p_i \cdot x^{i-3} \tag{1}
\]

where \( p_0 \) to \( p_{13} \) are the parameters. This is the sum of a Gaussian and an 11th order polynomial. The center of the Gaussian is allowed to vary between XXX and XXX, and its width is allowed to vary between XXX and XXX. After the template shape is created, it is normalized to 1.
0.1.6 Kernel Estimation Procedure to Model Signal Contribution to Data Sample in Efficiency Measurement Bins

The signal template for the background subtraction procedure is derived from either a fast or full Monte Carlo sample of $Z \rightarrow ee$ events. The fast Monte Carlo sample was originally used for the signal template in all cases, because the high statistics allows a smooth data shape. However, since it has been tuned with the best quality candidates from the Full Monte Carlo sample - events which pass all the cuts, it was found that PMCS does not describe well the $M_{ee}$ spectrum of electrons which fail the loose track matching cut as well as full Monte Carlo does, so for those data cuts, candidates from the full Monte Carlo sample which failed the loose cut were used for the signal template. At the expense of statistics, a better match to the signal shape was attained.

Even so, the Full and Fast Monte Carlo samples do not perfectly describe the signal in data, because the energy resolution and response of the detector is not adequately modeled as a function of the efficiency dependent variables. Therefore, we use a modified version of the “Kernel Density Estimation Method”, described in detail in [3] and [5] where we include a shift and smearing parameter that we allow to float. The shift and smearing parameters are applied as follows:

The Monte Carlo sample for the signal template is put into a histogram of 1 GeV bins in $M_{ee}$. This histogram is converted into a function where every $M_{ee}$ bin is represented by a Gaussian function with peak position equal to the bin center, magnitude equal to the bin content, and width equal to 1 GeV. Parameters are added to allow the peak to shift and the Gaussian to widen, while keeping the magnitude (i.e. the number of $Z \rightarrow ee$ events) the same.

Thus the function representing the signal spectrum template is
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\[ S(x; s, \sigma) = \frac{1}{N} \sum_{i=1}^{m} \frac{n_i}{\sqrt{2\pi (h_i + \sigma)^2}} e^{-\frac{(x - s)^2}{2(h_i + \sigma)^2}} \]  

\[ h_i = \frac{1}{2} \cdot \left( \frac{4}{3} \right)^{1/2} \cdot \sqrt{\frac{\Delta x_i}{3\sqrt{2}}} \cdot \sqrt{\frac{N}{n_i}} \]  

where the \( \Delta x_i \) is the bin width of the \( i \)th bin. This template function is automatically normalized to 1.

More about kernel estimation at \[6\], \[5\]

0.1.7 Calculating the Estimated Signal in an Efficiency Bin

The signal and background templates are normalized and fit to the data spectrum with the Root MINUIT fitter. For fitting stability, the overall magnitude of the data spectrum is allowed to float between 0.9 and 1.1 times the magnitude of the input data histogram. From this data fit function, the signal fraction which is the coefficient of the signal template in the fit. Then, the estimated signal count from the bin for the efficiency calculation is calculated via:

\[ n = N_{\text{eff}} - k_{\text{eff}} \cdot (1 - f) \cdot N_{\text{fit}}. \]  

\[ k_{\text{eff}} = \frac{N_{\text{eff}}^{\text{bkg}}}{N_{\text{fit}}^{\text{bkg}}}, \]  

Where \( k_{\text{eff}} \) is the ratio of selected background electrons (from the “pure background histogram”) that are in the efficiency window to background electrons that are in the fit window. This ratio is assumed to be the same for the total background electrons in the bin, a
number that cannot be directly measured. \((1 - f)\) is the fraction of the data electrons that is background, estimated via the fit. Therefore, the product \(k_{\text{eff}}(1 - f)\) is the fraction of the total sample of electrons in the fit window that we expect to be in the efficiency window and also be background electrons.

By standard error propagation, the uncertainty in \(k_{\text{eff}}\) is

\[
\sigma_{k_{\text{eff}}}^2 = \frac{(N_{\text{bkg}}^{\text{fit}})^2 \cdot N_{\text{bkg}}^{\text{eff}} + (N_{\text{eff}}^{\text{bkg}})^2 \cdot N_{\text{fit}}^{\text{bkg}}}{(N_{\text{bkg}}^{\text{fit}})^4} = \frac{k_{\text{eff}} \cdot (1 + k_{\text{eff}})}{N_{\text{fit}}^{\text{bkg}}} \cdot (1 + k_{\text{eff}}),
\]

(6)

Therefore, the error of \(n^+\) or \(n^-\) is given by:

\[
\sigma_n^2 = N_{\text{eff}} + k_{\text{eff}}^2 \cdot (1 - f)^2 \cdot N_{\text{fit}} + k_{\text{eff}}^2 \cdot N_{\text{fit}}^2 \cdot \sigma_f^2 + (1 - f)^2 \cdot N_{\text{fit}}^2 \cdot \sigma_{k_{\text{eff}}}^2.
\]

(7)

**0.1.8 Deriving the Residual Correction for the Simulation of the \(p_T\) dependent efficiency in PPMCS**

The efficiency in the Fullmc sample is also measured, however, the background subtraction is not needed since the sample is all signal. Instead, we merely count the electrons which remain after applying the correct selection criteria and mass window. We calculate the efficiency using the truth \(p_T\) of the electrons. (We can also calculate it using the RECO Fullmc sample with energy scale correction applied, as described above, we get essentially the same shape of \(p_T\).) Then, the efficiency is calculated bin by bin using the signal counts which pass and signal counts which fail in each bin. The Data Efficiency is divided by the Fullmc sample, and the resulting values are converted to a polynomial function to modify the efficiency applied in PMCS. We conserve efficiency by scaling the overall efficiency shape so that it is never larger than 1. (This is permitted because overall magnitude of the efficiency has no
effect on the measured W mass.)

0.1.9 Dead Cells and Energy Scale Effects

The reconstructed energy for a dilepton event is not exactly equal to the truth energy. For events with an electron that falls in a “dead cell region” the energy mismeasurement is so catastrophic that the event cannot be used. For electrons that fail certain cuts, the bin migration due to energy mismeasurement is strong enough to cause a significant systematic error in the efficiency measurement, but mild enough that it can be corrected by correcting the $p_T$ with a scale factor. This section will describe the evidence for these two effects, which can be seen clearly in the FullMC sample.

In figures (1), dilepton mass distributions relevant to the bin with $p_T$ between (PT MIN) and (PT MAX) are shown. The (COLOR=BLACK) curve shows the dilepton mass distribution for events where the truth $p_T$ is in the bin (hereafter called the “truth $M_{ee}$ distribution”). The (COLOR=BLUE) curve shows the dilepton mass distribution for events where the reconstructed $p_T$ is in the bin (hereafter called the “reco $M_{ee}$ distribution”). There are two important features to notice in the differences between the two curves. The first is that, for events where this electron fails hmatrix, there is a significant extra bump in the reconstructed curve below the mass peak. It is found that these events are mismeasured due to at least one electron falling on a dead cell. Once dead cells are removed (solid lines), the reco $M_{ee}$ distribution has better agreement with the truth $M_{ee}$ distribution, but there is still a discrepancy in the shape, and more importantly, with the total count of electrons in the bin.

Figure (1) illustrates the source of this discrepancy. The plot with the truth $M_{ee}$ distribution (right) is broken into three stacked histograms. The largest contribution is from electrons that did not migrate out of the bin. The other two contributions are from electrons that migrated to a higher $p_T$ bin (reco energy too high) (COLOR=MAGENTA) and from elec-
trons that migrated to a lower $p_T$ bin (reco energy too low) (COLOR=CYAN). The plot with the reco $M_{ee}$ distribution (COLOR=RED) is also broken into three stacked histograms. The largest contribution is (SHOULD BE - MUST FIX) identical to the largest contribution in the truth $M_{ee}$ distribution - it is electrons that stayed in the bin (COLOR=RED). The other two contributions are from electrons that migrated into the bin from above (reco energy too low) (COLOR=MAGENTA), and electrons that migrated into the bin from below (reco energy too high) (COLOR=CYAN). In general, different numbers of electron migrate in than migrate out, resulting in an incorrect count of electrons in the bin. This non-symmetric “smearing” of electron $p_T$ can be modeled with a scale factor that describes the net flow of electrons along the $p_T$ axis. Dividing by the appropriate scale factor will restore the numbers of electrons in bins to more correct values. The method to determine this scale factor will be described in Section (0.1.10), and the effect of this method will be demonstrated in Section (0.1.11).

0.1.10 Correcting Energy Scale of Failing Electrons to Match Passing Electrons for $p_T$ Dependent Efficiency

It is found that the energy scale of electrons which fail selection cuts is different from the energy scale of electrons which pass selection cuts. Since PMCS is tuned to signal electrons which pass the selection cuts, and since a different energy scale for passing and failing electrons means that failing electrons will migrate between $p_T$ bins differently than passing electrons, a correction for this relative energy scale difference must be applied before calculating the efficiency. The correction takes the form of a relative scale correction factor which is multiplied by the electron $p_T$. The correction factor is dependent on the $p_T$ of the electron, as well as its “cut status”, i.e. which cuts it passes or fails.

To determine the relative scale correction for electrons which fail a cut, we look at the position of the Z boson mass peak, for electron pairs where the pT bin electron (“this” electron)
Figure 1: run12, FAIL hmatrix. Left: reco in bin. Right: truth in bin. Top: show dead cell contribution. Bottom: show contribution from truth (left) and reco (right) pt above/below/in bin.
Figure 2: run12, PASS hmatrix. Left: reco in bin. Right: truth in bin. Top: show dead cell contribution. Bottom: show contribution from truth (left) and reco (right) pt above/below/in bin.
Figure 3: run34, FAIL hmatrix. Left: reco in bin. Right: truth in bin. Top: show dead cell contribution. Bottom: show contribution from truth (left) and reco (right) pt above/below/in bin.
Figure 4: run34, PASS hmatrix. Left: reco in bin. Right: truth in bin. Top: show dead cell contribution. Bottom: show contribution from truth (left) and reco (right) pt above/below/in bin.
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fails the cut and the “other” electron passes all cuts. We compare this to the position of
the Z boson mass peak for electron pairs where both “this” and the “other” electron pass
all cuts. The Z boson mass peak position is a proxy for the energy scale in a pT bin, since
it should not depend on whether the signal electrons pass or fail the cut. The Z boson mass
peak position in a data pT bin is calculated from the sum of the original peak position in the
PMCS template function (calculated via a simple Gaussian fit) and the shift parameter that
was determined in the background subtraction described above. The Z boson mass peak
position in a fullmc pT bin is calculated via a simple Gaussian fit.

Since the dilepton mass is calculated via

\[ m_{e^e} = \sqrt{2E(e_1)E(e_2)(1 - \cos(\phi(e_1) - \phi(e_2)))} \] (8)

The scale is calculated via

\[ \alpha = \left( \frac{M_{Z,\text{pass,pass}}}{M_{Z,\text{fail,pass}}} \right)^2 \] (9)

\( \alpha \) is fit via an ad-hoc function that is the sum of Gaussians. This function is multiplied by
the pT of the failing electrons, which are then re-binned by their corrected pT value. Then
the efficiency is re-calculated according to the procedure described above.

When the relative scale correction is applied to the Fullmc sample, there is a significant
improvement in the agreement between the reconstructed efficiency and the efficiency calcu-
lated in truth pT bins; thus we expect that the method should also correctly adjust the data
efficiency to have a more correct dependence on pT.

This method differs from the scale correction method used in RunIIb12 in three ways:

1) Scales are measured not only for electrons which fail hmatrix, but also for the populations
of electrons which a) pass hmatrix but fail loose, and b) pass loose and hmatrix but fail tight.

2) The passing (failing) Z mass peak is determined from a sample of electrons where “this”
electron fulfills the requirements of the passing (failing) electron, but the “other” electron
passes all the cuts. This results in a larger signal to background ratio which allows for more
precise determination of the peak. It also assures that there will be no contamination from
the scale “other” electron, which might fall in a different $p_T$ bin from this electron, and which
might neither fail the cut in question nor pass all cuts.

3) A scale is measured for Fullmc in addition to Data. In RunIIb12 it was found that there
was not a significant scale difference between passing and failing electrons in Fullmc, but in
RunIIb34 there is a significant difference which results in a very different efficiency shape for
truth vs reco. Applying the scale correction modifies the reconstructed efficiency to closely
match the truth efficiency, confirming that the method works as expected.

0.1.11 Verifying the scale correction procedure using the Full MC sample

To test that the scale derived as described above works as expected, i.e. that the efficiency
calculated from the sample with rescaled $p_T$ is the correct efficiency, we apply the same pro-
cedure to the Full MC sample. For the Full MC sample, there is no background to remove
in order to locate the peak; it is well defined and we need only fit the peak with a Gaussian
function (or, more accurately, the convolution of a Gaussian and Breit-Wigner function,
which results in essentially the same peak measurement).

Examples of the peak measurement are shown in Figure (REFERENCE). The bin of elec-
trons passing/failing the tight track-matching cut (already having passed the hmatrix and
loose track-matching cut) with $p_T$ from XX-XX are shown on the left/right. The tight peak
is at XX.XX and the loose peak is at XX.XX. In Figure (REFERENCE), the dilepton mass
positions as a function of $p_T$ are shown for events where “this” electron fails hmatrix, and for events where “this” electron passes all cuts. These events all have the “other” electron passing all cuts to isolate the effect of “this” electron’s scale, as described above.

Since we wish to correct the scale of “failing” electrons to match the scale of our best measured electrons (to which PMCS has been tuned), it is most accurate to correct them to match the scale of electrons which pass hmatrix, loose, and tight. However, the next paragraph will justify using a scale derived using the standard pass/fail hmatrix selections, used for the calculation of the hmatrix efficiency, which is the method used in the analysis of RunIIb12.

0.1.12 Differences between RunIIb12 and RunIIb34

For RunIIb12, the residual efficiency corrections were created by taking the ratio between the measured data efficiency and the Full Monte Carlo efficiency, where the Full Monte Carlo efficiency was derived in bins of reconstructed $p_T$ and applying the 80-100 GeV efficiency window to the reconstructed dilepton mass values for the bin electrons. In fact, because PMCS is tuned using Full MC truth information, the explicitly correct approach would be to use the Full MC efficiency derived in bins of truth $p_T$ and applying the 80-100 GeV efficiency to the truth dilepton mass, i.e. the true mass of the parent Z boson. However, in RunIIb12 the truth and reco efficiencies were so similar that there was no significant difference between using one or the other.

In contrast, a significant mismatch was found between the Full MC truth and reconstructed efficiency of the loose cut when applied to the RunIIb34 sample. In Figure 7, the truth and reconstructed efficiencies of the hmatrix, loose, and tight cuts are compared for RunIIb12 and RunIIb34.
In the sample of electrons which fail the loose track-matching cut (having passed the hmatrix cut), a bump of severely mismeasured electrons can be seen in the dilepton mass distribution of individual $p_T$ bins. The bump can be seen most prominently at high and low $p_T$, because it a wide bump centered approximately on a mass $\approx 2p_T$. As can be seen in Figure (7), this bump is much more prominent in RunIIb34 than in RunIIb12, and requires some additional care in counting the signal electrons to calculate the loose efficiency.

Assuming only one of the electrons is severely mismeasured, the mismeasured electron may be “this” electron, in which case the electron is most likely not in the correct bin, or it may be the “other” electron, in which case “this” electron is in the correct bin, but it is in the wrong place in the mass histogram. WHICH CASE CONTRIBUTES MORE TO THE BUMP, OR DO THEY BOTH CONTRIBUTE EQUALLY?

We are also forced to assume that the mismeasured electrons that show up in these $p_T$ bins, and hence are not counted in the bin to which they actually belong, do not leave their “home” bins in such a way that would significantly bias the shape of the efficiency. That is, we must assume that an equal fraction of the electrons in each bin that are mismeasured so severely as to migrate out of their bin.

(Note about why we use the “other III” version.)

The peak position of events where “this” electron fails hmatrix is very sensitive to the shape of the background and signal templates, particularly for $p_T < 29$ GeV where the statistics are very low.

NEED FULLMC RELATIVE SCALE PLOTS HERE WITH DISCUSSION.

NEED DATA EFFICIENCY PLOTS HERE WITH DISCUSSION, UNCORRECTED AND CORRECTED.
Figure 5: Relative scale correction derived from standard hmatrix pass/fail selections. Top Row: RunIIb12 and combined RunIIb34. Bottom Row: Individual RunIIb3 and RunIIb4.
Figure 6: Relative scale correction derived from “this” electron pass all cuts/fail hmatrix selections with requirement that other electron pass all cuts. Top Row: RunIIb12 and combined RunIIb34. Bottom Row: Individual RunIIb3 and RunIIb4.
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0.1.13 Systematic Uncertainty due to Efficiencies

The uncertainty in the W mass due to variation in the parameterized residual correction to the full Monte Carlo uncertainty is derived in the following way. For a given residual correction to the efficiency with \( n \) parameters, there are \( 2n \) uncertainties in parameters, \( \sigma_i \). Two PMCS samples are generated for each parameter, one sample with the parameter varied in the positive and negative directions by the magnitude of the uncertainty in that parameter. These two samples represent the 1\( \sigma \), uncertainty in the PMCS sample due to that parameters. Then, these two samples are used as pseudodata to determine the W mass, using the PMCS sample with the central value of the parameters as the template functions. The sensitivity in the W mass due to a single parameter \( a_n \) is \( \frac{\partial W}{\partial a_n} \) and is determined via a linear fit to the central value and 1\( \sigma \) error bounds of the W mass. The sensitivity for each parameter is determined, and then the total uncertainty in the W mass due to the residual correction is calculated using the covariance matrix from the fit of the parametric residual correction function.

\[
\frac{\delta M_W}{\delta \mathbf{p}_i} C_{ij} \frac{\delta M_W}{\delta \mathbf{p}_j}
\]  

(10)

The uncertainty in the W mass due to the residual hmatrix and track match efficiency correction is \( xxx.xxx \)GeV for run3 and \( xxx.xxx \)GeV for run4.
BIBLIOGRAPHY

[1] W mass group; W mass measurement in Full Geant Monte Carlo in RunIIb, DØ Note 6267 (2012)


[5] Hengne Li, Jan Stark; W mass measurement in Full Geant Monte Carlo in RunIIb, DØ Note 6266 (Feb. 7, 2012)


