0.1 Electron and Photon Reconstruction and Identification

0.1.1 Overview

Photon reconstruction at Tevatron starts with finding clusters of energy in electromagnetic calorimeter. For electrons, in addition to the calorimeter-seeded algorithms, a track-seeded algorithm also exists, although it's primarily used for reconstruction of non-isolated electrons. For both reconstruction paths, however, the ideas behind identification algorithms are similar and will be described in section **??**.

The main background to electrons and photons comes from jets. Also, a photon can be identified as electron and vice versa. For example, $W\gamma$ events are a major background to multi-lepton SUSY search when the W decays semileptonically and the photon converts in the tracker material [**?**], and to di-photon SUSY search when W decays into electron and it's track is not reconstructed [**?**]. For the CDF's study on exact composition of the electron fakes see [**?**].

Silicon trackers have revolutionized the heavy flavor tagging at hadronic colliders. However the price for having them is large amount of material that electrons and photons must travel before reaching the calorimeter. This presents a significant problem for Tevatron detectors, and will be even bigger for LHC, since both CMS and ATLAS detectors have much more tracker material (up to $\tilde{1}.6$ radiation lengths). We will discuss this in detail in section 0.1.3.

Having more than one radiation length of material in front of the calorimeter is already challenging. But Tevatron experience shows that the amount of the material that is included in the Monte-Carlo (MC) simulation of the detector is significantly smaller than it is in reality. As a result of this and some other effects, at the time of start-up there are substantial disagreements between data and MC simulation.

In situ measurement of the mateirial and tuning of MC parameters is a long and complicated process. The analysis of the first data, however, can not wait for the perfect MC simulation. It is therefore of the uttermost importance to develop algorithms to extract everything needed for analysis (reconstruction and identification efficiency, energy scale and resolution, *etc...*) from the data itself. A lot of experience in that has been accumulated for electrons using Z, J/ψ, and Υ decays into electron pairs. Photons present more of a challenge, since there is no clean large cross-section process with isolated photons at the Tevatron. One of the achievements of this series of workshops is the realization that at LHC the $\mu\mu\gamma$ final state provides such a source. These issues are discussed in section 0.1.4

0.1.2 EM identification

0.1.3 Effects of the Tracker Material

The large (up to 1.6 radiation lengths) amount of the material in front of the ECAL has a large negative effect on reconstructions of electrons and photons. Electrons loose energy by Bremsstrahlung while curving in the magnetic field, making usually narrow EM showers into wide in azimuth sprays, leading to some energy loss because of the imperfect clustering. Even more important is the fact that the Bremsstrahlung photons convert, and the resultant electrons curl in the magnetic field and do not reach the calorimeter. The combination of the two effects results in a non-linear energy scale for electrons that depends on the material distribution in front of ECAL, and therefore on rapidity and (to lesser extent) on azimuth.

Photons propagate in the material in a different way. They stay totally intact until the first conversion. Therefore, for unconverted photons the material-induced non-linearity is not an issue. However, in case a photon converts, its energy is shared between two electrons and the effect of the material is essentially doubled. As a result, the electron and photon energy scales are different and non-linear (see Figure 1 for simulation of DØdetector response)

0.1.4 Extraction of Efficiency and Energy Scale from Data

The experience of previous experiments, including most recently CDF and DØat the Tevatron, is that the amount of the material that is included in the GEANT description of the detector is severely underestimated at the time of the start-up. First, as-built detector is not the same as as-drafted. Second, because the tracking systems have so many elements, some of them are not correctly implemented in the MC. The magnitude of the disagreement can be as large as a factor of two. For CDF, who has built three silicon detectors during Run I and Run II upgrade, the amount of missed material in the MC implementation of the third one at start-up still represented about 50

The above consideration makes it too risky to rely on MC simulation to adequately describe electrons and photons at start-up. The plan for the start-up should therefore be two-pronged:

A. measure amount of the tracker material in situ using combination of several methods (converted photon yields and distributions, mass of low-lying resonances and measurement of transverse momentum change from the beginning to the end of electron tracks. The end result of this activity would

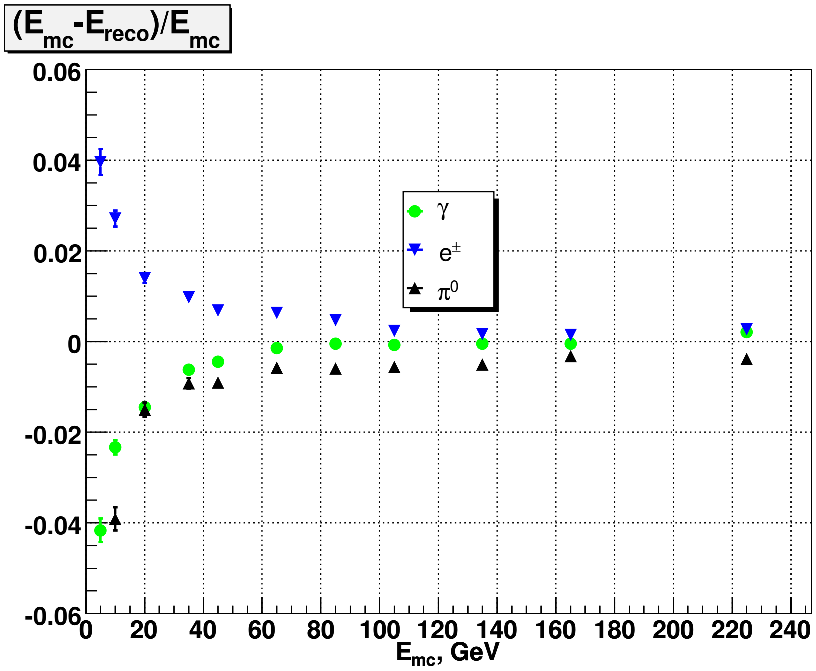

Figure 1: Simulation of the linearity of the response of DØdetector to single electrons, photons and neutral pions

be a MC simulation that describes the real detector

B. in parallel to the work described in **A**, efficiencies, resolutions, and energy scales of electrons and photons should be measured for different detector regions and for different ID cuts.

Tevatron experiments followed this strategy, using Z, Υ and J/ϕ decays to calibrate electrons. At LHC, the center of mass energy and luminosity are high enough to provide a source of clean isolated photons from radiative Z decays. A study using the detailed simulation of CMS detector showed [**?**] that using simple kinematic cuts on dilepton mass ($40 < m_{\mu\mu} < 80$ GeV) and photon-lepton separation ($\sqrt{\Delta\phi^2_{\mu\gamma} + \Delta\eta^2_{\mu\gamma}} < 0.8$) an reasonable signal-to-background ratio can be achieved (see figure 2).

When extracting detector performance from data, one should be wary of biases. For example, DØmeasures electron identification efficiency in $Z \to e^+e^-$ events using "tag-and-probe" method: stringent identification criteria are applied to one of the electrons from the Z decay - the tag, thereby bringing the signal-to-background ratio to acceptable levels, and the second electron is used as a probe of the efficiency. The biases here can arise from correlations between the tag and probe electrons. For example, for an early version of the electron identification, the efficiency turned out to be dependent on the primary vertex position. Therefore, the selection of a tag electron biased the vertex distribution, which in turn biased the probe electron identification efficiency to higher values. Although the full DØMC simulation did not reproduce the effect exactly, it did so well enough to be noticed and suggested a corrective action (i.e., parameterize the efficiency as a function of both rapidity and vertex position in the short term, while developing a new version of electron identification that did not have such a strong vertex dependence).

For energy scale measurements, the biases can arise from both instrumental and physics effects. As an example, let's consider photon energy scale measurement with $Z \to \mu\mu\gamma$ events. The instrumental effect comes from the phootn energy resolution. The photon E_T spectrum in radiative Z decays is sharply falling. Therefore a sample of $\mu\mu\gamma$ events with large photon E_T will be enriched by events where the photon energy has been mis-measured, and the Z peak would shift to larger mass. The second effect arises from large natural width of the Z. Importance of both effects can be estimated using a simple parametrized MC simulation (see figure 3). We fit the three body mass distribution in bins of photon transverse energy, first using generator level information (black points), and then smearing

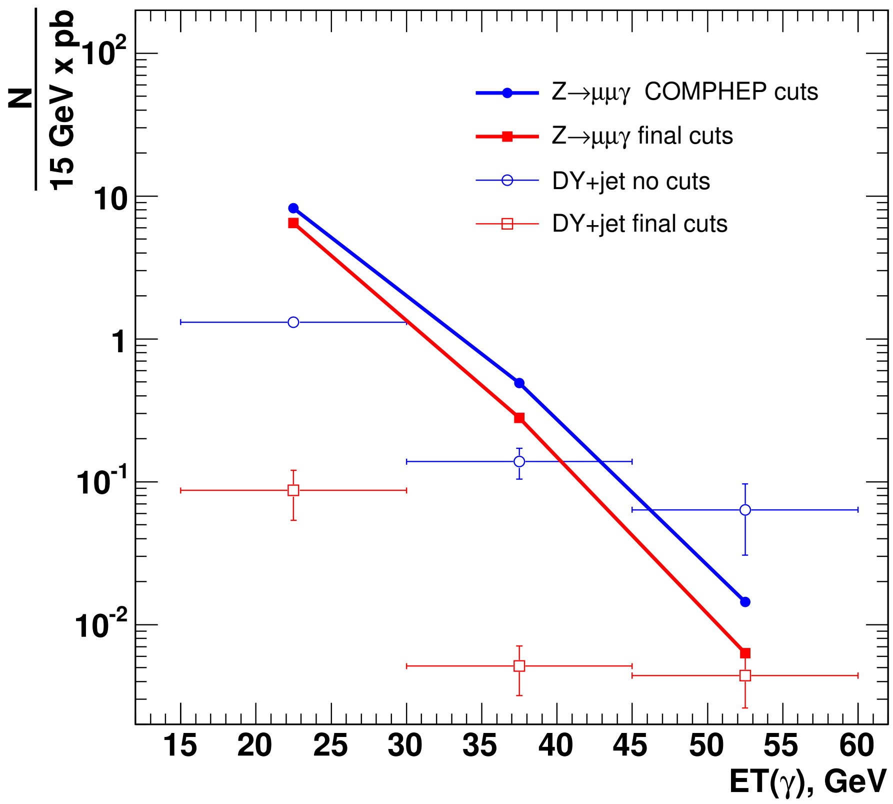

Figure 2: Radiative Z decay signal and background yields before and after the cuts on event kinematics

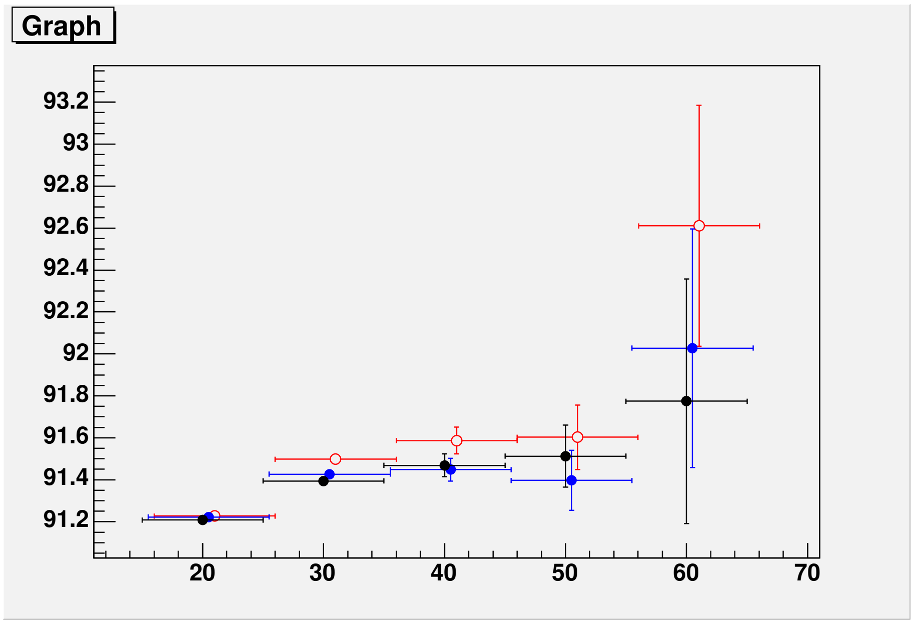

Figure 3: Fitted value of Z mass vs. the photon E_T in GeV. See text for details.

the generator information by best energy resolution that one might expect from an LHC detector [1] (blue points). The red points correspond to the case in which we add an extra 2% constant term to the resolution function. The fitted values of the Z mass can be shifted by almost 0.4 GeV, which corresponds to a photon energy scale shift of 2%.

[1] $\frac{\sigma_E}{E} = \frac{0.027}{\sqrt{E}} \oplus \frac{0.155}{E} \oplus 0.0055$