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Measuring Electron Efficiencies at CMS with Early Data

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Abstract

In this note we describe the so called ”Tag and Probe” tools that have been developed within the egamma POG to measure both online and offline electron efficiencies from data at CMS. We present their implementation in CMMSW and their validation with both MC truth and physics observables. We also discuss methods for background estimation and subsequent correction of efficiencies due to this background contamination. We suggest a electron efficiency factorization scheme and apply it using the ”Tag and Probe” tools in support of the measurement of sigma x BR(Z -¿ e+e- being performed as a 2007 analysis in the EWK group.

1 Introduction

Many experimental signatures at CMS, both Standard Model and beyond, involve electrons in the final state. Accurate measurements of electron trigger, reconstruction, and identification efficiencies (without any reliance on MC truth information) are thus an important part of the CMS experimental programme. In consultation with the E/gamma POG, we have developed a set of tools and methods to make such measurements from early CMS data.

The method that we employ has been called the "tag & probe" method. This method, which has been successfully used in some form or another by both Tevatron experiments [1], relies upon $Z \rightarrow e^+e^-$ decays to provide an unbiased, high-purity, electron sample with which to measure the efficiency of a particular cut or trigger. In this method, a single electron trigger sample is used, from which a subset of di-electron events are selected. One of the electrons, the "tag", is required to pass stringent electron identification criteria whilst the other electron, the "probe", is required to pass a set of identification criteria depending on the efficiency under study. The invariant mass of the tag & probe electron candidates are required to be within a window around M_Z. The tight criteria imposed on the tag coupled with the invariant mass requirement is sufficient to ensure high electron purity. Note that the tight criteria imposed on the tag can (and perhaps should) be the same for all efficiency measurements, but that the probe criteria necessarily will vary depending on the specifics of the efficiency that is being measured and how the overall efficiency has been factorized (see Section 4).

We discuss our particular implementation of this method in the following Sections. We then present the validation of these tools by comparing the efficiency obtained by them with that expected from MC truth information. Even though the tag+invariant mass requirement generally provides a high purity di-electron sample, there will inevitably be some residual background contamination due to W+jets and/or QCD events where one or more electrons has been misidentified. We discuss methods for estimating these backgrounds and the procedure for correcting our efficiency measurements due to their presence.

Finally, the remainder of the note is devoted to the illustration of the use of our tools in support of the measurement of $\sigma \times BR(pp \rightarrow \gamma^* Z \rightarrow e^+e^-)$ with 10 pb^{-1} being performed as a 2007 analysis in the EWK group [2]. We discuss an appropriate factorization of the total efficiency for this process and use our methods to obtain the requisite electron efficiencies (both online and offline) needed for that measurement.

2 Description of Tag & Probe Tools

The tag & probe tools are implemented within CMSSW as a series of EDProducers. There are three distinct producers in the construction sequence: ElectronIDProducer, EmObjectProducer and TagProbeProducer. Fig. 1 illustrates the standard construction sequence.

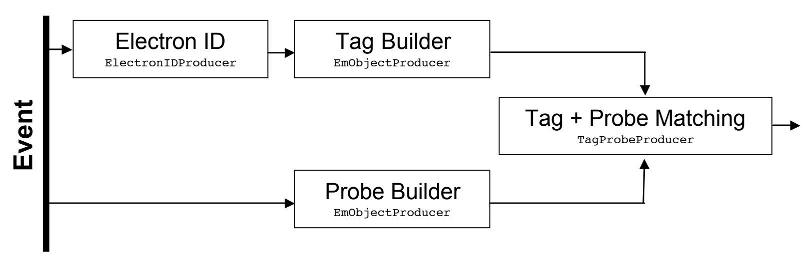

Figure 1: Flow diagram of tag & probe construction

Tag and probe candidates are represented as EmObjects, which inherit from Candidate. This design allows access to standard kinematical variables and methods, but also maintains information about the EmObject's construction (for example, if it was constructed from a SuperCluster, Track, GsfTrack, or a combination of these). The use of EmObjects also allows flexibility in the choice of tag & probe candidates throughout the analysis process.

The ElectronIDProducer is responsible for identifying PixelMatchGsfElectrons which pass a standard selection. The output of this producer is a one-to-one AssociationMap which maps each PixelMatchGsfElectron in the event to a cut decision object. The cuts are user-definable, but a standard recommended set is provided. The EmObject-Producer creates EmObjects using a given algorithm. The currently defined algorithms construct EmObjects from a variety of sources, depending on the measurement requirements:

- PixelMatchGsfElectrons (Tag candidates and measurements of factorized efficiencies)

- CtfWithMaterialTracks (Clustering probe)
- SuperClusters (Tracking probe)
- GsfTracks (PixelMatchGsfElectron reconstruction probe)

The final producer, TagProbeProducer, takes as its input two collections of EmObjects - the tag & probe candidates. For each unique combination of tag & probe candidates, the invariant mass of the pair is computed. The output of this producer is a one-to-many AssociationMap, mapping each tag onto any probes which are within the specified invariant mass window and meet other specified criteria such as vertex or charge constrains. Note that no decision as to how to handle multiple tags, or tags with multiple probes is taken; this is left up to the consuming analysis.

The tag & probe tools are verified to run with CMSSW versions 1_3_X, 1_5_X and 1_6_X. For all CVS tags listed below, example configuration files can be found in EgammaAnalysis/EgammaEfficiencyProducers/data, with ProduceTagProbes.cfi running an example full tag & probe construction sequence. The CVS tags required, on top of a standard CMSSW project area, are listed in Table 1.

Table 1: Required CVS tags for several CMSSW releases.

Package	1_3_X	1_5_X	1_6_X
AnalysisDataFormats/Egamma	V00-00-00	V00-00-00	V00-00-00
AnalysisDataFormats/ElectronEfficiency	V00-00-02	V00-00-02	V00-00-02
EgammaAnalysis/EgammaEfficiencyAlgos	V00-00-05	V00-00-05	V01-00-01
EgammaAnalysis/EgammaEfficiencyProducers	V00-00-05	V00-00-05	V01-00-01
EgammaAnalysis/ElectronIDAlgos	V00-00-00	V00-00-00	V00-00-00
EgammaAnalysis/ElectronIDProducers	eleID131_17Jun07	V00-00-02	V00-00-02

These are the current tags at the time of writing the note, but fresh information can always be found on the E/gamma efficiency Wiki - https://twiki.cern.ch/twiki/bin/view/CMS/EgammaEffCommonTools. Detailed instructions for accessing the tag & probe collections can also be found on the Wiki.

All efficiencies that we will present in this note have been calculated using the CMSSW frame work tools described above. They have all also been independently calculated using a separate analysis using a completely independent set of tools in FWLITE, which we describe in the following section.

2.1 Independent Tag & Probe Tools

The FWLITE implementation of the tag & probe method accesses the relevant reconstructed objects from ROOT files produced by CMSSW. FWLITE loads the relevant libraries needed to access all properties and methods of the reconstructed objects in ROOT as if in the full CMSSW framework. Tags and probes are constructed from the relevant reconstructed objects and efficiency measurements conducted within the same compiled ROOT macro. If an event contains a reconstructed electron that passes the tag requirements then possible probes are identified by calculating the invariant mass of the tag with all other objects meeting the probe criteria. If the tag & probe invariant mass falls within a specified window around M_Z for a given probe then that probe is eligible for use in the efficiency measurement. Additionally, we require that the probe must be the only probe found within the specified mass window or else the event is discarded.

We find excellent agreement between the two different methods employed[1)]. This not only increases confidence in our efficiency calculations, it also provides a good check that FWLITE and CMSSW tools are functioning consistently since the FWLITE analysis uses none of the tools provided in the framework.

2.2 Tag/Probe Combinatorics

As alluded to in the previous sections, for a di-electron event, it is possible that zero, one, or two of electrons may pass the tag criteria. Likewise, it is also possible that zero, one, or two of the electrons may pass the probe

[1)] The discrepancies between efficiencies measured by the two methods are on the order of 0.01 ± 0.01. The reason identical results were not obtained is that unfortunately (due to technical issues) the same exact samples were not available for analysis by both methods.

criteria. There are thus three possible types of events with a tag & probe pair: TT, TP and TF where T =passing tag criteria, P= passing probe + the efficiency under study criteria, but not tag criteria, and F = passing probe but not the efficiency under study criteria. The efficiency determined by a tag paired with a probe passing a certain criteria can therefore be written in terms of these types of events as[2]:

$$\varepsilon = \frac{2N_{TT} + N_{TP}}{2N_{TT} + N_{TP} + N_{TF}} \tag{1}$$

where N_{TT}, N_{TP}, N_{TF} are the number of events observed of each type and the factor of 2 arises from the two permutations of the tag in an event where both electrons pass the tag criteria.

In the efficiency calculations that follow, however, we do not classify events according to the types discussed above. This is because the TagProbeProducer, as described above, simply creates a collection of all possible unique tag & probe pairings in a given event. For example, 2 such pairings would be added for a TT event. Thus, the efficiency can be determined simply by looping over this collection and counting the probes in a given tag & probe pairing which pass the efficiency criteria, divided by the total number of probes. To use the same example again, for a TT event, there would be two pairings both of which would have a probe that would pass the efficiency criteria such that both the numerator and denominator would be incremented twice. Symbolically, we can therefore see that the two methods are equivalent, *i.e.* by counting probes produced by the TagProbeProducer which pass a certain criteria we will arrive a numerator which can be written as $2N_{TT} + N_{TP}$. Similarly, the denominator arrived at by counting all probes can be written as $2N_{TT} + N_{TP} + N_{TF}$ and the efficiency is algebraically identical to that shown in Eq. 1.

Finally, there is a related but distinct topic - the treatment of the rare (less than 1%) instance that more than one satisfactory probe is identified to be paired with a tag. In this case, to avoid any bias that would be introduced by attempting to choose the "correct" probe, we simply discard the entire event, *i.e.* we do not increment the numerator or denominator of a given efficiency calculation.

3 Monte Carlo Truth Validation of Tag & Probe Tools

In order to verify that the tools described in the previous section can be used to accurately measure electron efficiencies in data, we validate them by comparing the results obtained by our tag & probe method with those obtained by checking the Monte Carlo truth information.

To extract an electron reconstruction efficiency from the Monte Carlo truth, we match[3] reconstructed probes to generated electrons from a $W \rightarrow e\nu$ sample[4] These matched electrons provide a pure set of electron objects (a MC probe if you like) against which a given reconstruction (or selection/identification) step's efficiency can be measured by asking what fraction of the matched electrons pass the relevant criteria. We then compare this measurement to the result that we get using the set of probe electrons selected by the tag & probe method described above.

We have performed this check for a wide variety of efficiency measurements and have found good agreement between the measured efficiencies, thereby validating the tag & probe tools. As an example, we show results for the validation performed on a representative efficiency calculation:

$$\varepsilon = \frac{Probes\ with\ SuperCluster\ in\ d\eta < 0.03,\ dR < 0.1}{AllProbes} \tag{2}$$

where $d\eta$ is relative to either the probe from the tag & probe method[5], or a probe that has been matched to generator level electrons that come from $W \rightarrow e\nu$. In Fig. 2 and Fig. 3 we show the agreement obtained with the measurements of this clustering efficiency versus probe p_T produced by both the tag & probe method (blue triangles) and by matching the reconstructed SuperClusters with the MC truth (pink dots).

[2] This formula assumes that the tag criteria is tighter than the probe criteria, which is generally true.

[3] The matching criteria are $\Delta\eta < 0.01$ and $\Delta\phi < 0.03$.

[4] By using electrons from W's we obtain a sample of electrons with different kinematics than the probes from Z's, thereby providing a more thorough validation.

[5] The details of this probe are described in Section 8.

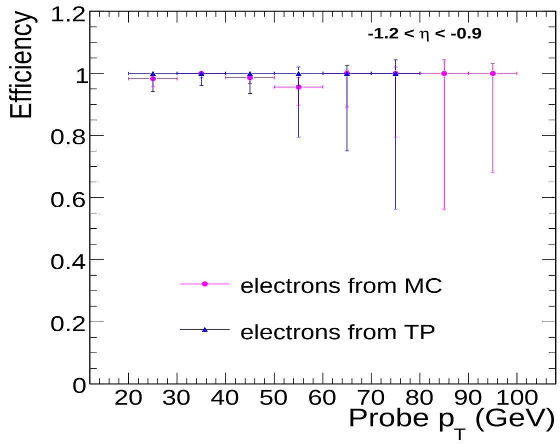

Figure 2: Cluster efficiency vs. probe p_T for $-1.2 < \eta < -0.9$

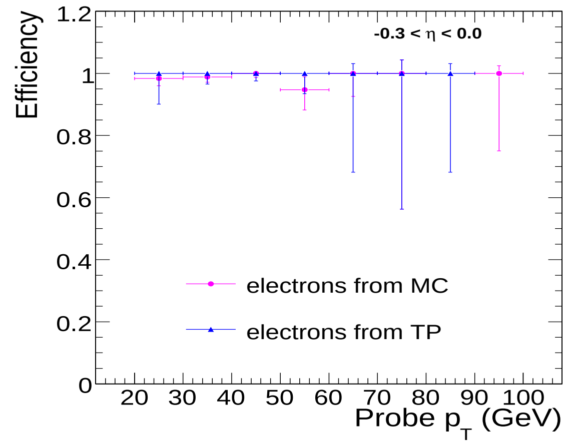

Figure 3: Cluster efficiency vs. probe p_T for $-0.3 < \eta < -0.0$

As a further example, we also show results for the validation performed on another efficiency calculation:

$$\varepsilon = \frac{No.\ of\ SuperClusters\ with\ a\ matching\ GsfTrack}{Total\ no.\ of\ SuperClusters} \tag{3}$$

where the SuperClusters are either probes from the tag & probe method, or SuperClusters that have been matched to generator level electrons that come from $W \to e\nu$. In Fig. 4 and Fig. 5 we show the agreement obtained with the measurements of this track matching efficiency versus E_T produced by both the tag & probe method (blue triangles) and by matching the reconstructed SuperClusters with the MC truth (pink dots).

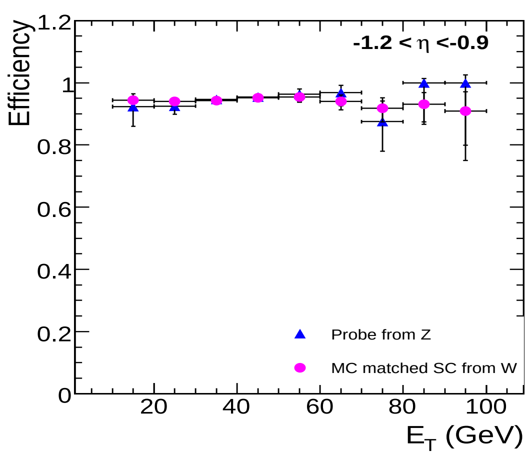

Figure 4: Track matching efficiency vs. SuperCluster E_T for $-1.2 < \eta < -0.9$

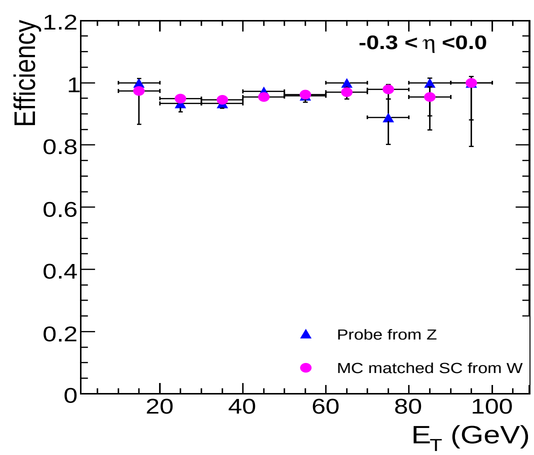

Figure 5: Track matching efficiency vs. SuperCluster E_T for $-0.3 < \eta < -0.0$

4 Factorization of Efficiency

Having established confidence in our tag & probe tools, we seek to apply them to a full suite of efficiency measurements representative of those required in a typical analysis. We wish to multiply each individual measured efficiency in order to obtain the total efficiency for the analysis. We, therefore, choose to factorize the total efficiency as follows:

$$\varepsilon_{total} = \varepsilon_{offline} \times \varepsilon_{online} \tag{4}$$

We further factorize the offline efficiency and the online efficiency:

$$\varepsilon_{offline} = \varepsilon_{\text{clustering}} \times \varepsilon_{\text{tracking}} \times \varepsilon_{\text{gsfele}} \times \varepsilon_{\text{isolation}} \times \sum_i (f^i_{\text{classification}} \varepsilon^{\text{i}}_{\text{eid}}) \tag{5}$$

$$\varepsilon_{online} = \varepsilon_{L1+HLT} \tag{6}$$

where each efficiency "factor" is defined as follows:

- $\varepsilon_{\text{clustering}} \equiv$ the efficiency with which a SuperCluster is reconstructed inside the fiducial region of the ECAL given that a track of a certain p_T has been reconstructed in the tracker.
- $\varepsilon_{\text{tracking}} \equiv$ the efficiency with which a GsfTrack is reconstructed given that a SuperCluster of a certain E_T has been reconstructed in the ECAL
- $\varepsilon_{\text{gsfele}} \equiv$ the efficiency of the preselection for GsfElectron objects formed from a SuperCluster and a GsfTrack.
- $\varepsilon_{\text{isolation}} \equiv$ the efficiency for the GsfElectron to be isolated. The isolation referred to here is a track isolation.
- $f^i_{\text{classification}} \equiv$ the i^{th} fraction of isolated GsfElectrons which are classified as 'golden', 'big brem', 'narrow', 'showering' or 'crack', respectively.
- $\varepsilon^{\text{i}}_{\text{eid}} \equiv$ the efficiency for an isolated GsfElectron classified in the i^{th} classification to pass additional electron identification criteria.
- $\varepsilon_{\text{L1+HLT}} \equiv$ the efficiency to pass the HLT used in the analysis including the fact that the probe considered must have been able to pass the L1 trigger seeding that HLT.

The factorization of the (online) offline efficiency represents the subsequent steps in the (triggering) reconstruction/identification of a particle as an electron.

Correlations between the various efficiencies are taken into account by calculating the efficiency of each requirement in a specific order. The probe used to measure a specific efficiency must satisfy the selection requirements of all previous steps. A disadvantage of this scheme is that the requirements applied first are studied with looser criteria and will suffer from higher backgrounds if the tag selection is uniform over all steps. In the chosen factorization scheme, online trigger efficiencies are measured with respect to the offline selection. This scheme has the benefit of providing offline electron efficiencies suitable for analyses that may select events on a variety of triggers.

The order of the factorization of efficiencies should not have an effect on the final overall efficiency measured. As a particular case, the effect of changing the order of factorization of the offline and online efficiencies was investigated. The alternative factorization scheme measures offline efficiencies relative to the online selection and as such is conceptually chronological. In this scheme, the efficiencies of offline reconstruction and selection are measured using probes that have passed the trigger. We demonstrate the equivalence of the two factorization schemes by repeating all the efficiency calculations we present in Section 8 with the alternative factorization. These results are presented in Appendix A.

5 Triggers and Datasets Used for Studies

In this study we construct a dataset containing signal and background events in the correct proportion for an integrated luminosity of 10 pb^{-1} using data from the Spring07 production. It is important to note that this data assumes a perfectly aligned and calibrated detector, something which clearly will not be available when the first 10 pb^{-1} has been collected. At next-to-leading-order the cross section for $pp \rightarrow \gamma^* Z \rightarrow e^+e^-$ is calculated to be 2100 pb for a di-electron invariant mass above 40 GeV[6]. We select 21,000 events, corresponding to 10 pb^{-1}, in which we have required $m_{ee} > 40$ GeV at the generator level. The dataset we used was:

```
/DY_ee/CMSSW_1_3_1-Spring07-1350/GEN-SIM-DIGI-RECO
```

The principal sources of background to the $Z \rightarrow e^+e^-$ sample that we will use to measure electron efficiencies with the tag & probe method will be W+jets events (where an electron from the $W \rightarrow e\nu$ decay provides the tag, and the probe results from a jet faking an electron) and QCD multijet events (where both tag & probe result from jets faking electrons). Whilst $W \rightarrow e\nu$ events will pass the single electron L1+HLT with high efficiency since they contain a real electron, QCD events will (by design) pass only very rarely. As a result the Spring07 datasets used do not contain a sufficient number of events which pass the trigger to quantitatively address the QCD background contamination.

Consequently, we only consider the background from W+jets at this time[6]. We select an appropriate number of events from each of the following $\hat{p}_T$ bins of Spring07 $W \rightarrow e\nu$ + jets data. While this sample represents only part of the total background it allows the methods of background subtraction to be estimated by data driven methods. The cross sections for each $\hat{p}_T$ bin are computed with PYTHIA and listed in [4].

```
/Wjets_pt_15_20/CMSSW_1_3_1-Spring07-1475/GEN-SIM-DIGI-RECO
/Wjets_pt_20_30/CMSSW_1_3_1-Spring07-1476/GEN-SIM-DIGI-RECO
/Wjets_pt_30_50/CMSSW_1_3_1-Spring07-1477/GEN-SIM-DIGI-RECO
/Wjets_pt_50_80/CMSSW_1_3_1-Spring07-1478/GEN-SIM-DIGI-RECO
/Wjets_pt_80_120/CMSSW_1_3_1-Spring07-1479/GEN-SIM-DIGI-RECO
```

The L1 Emulator and HLT as defined in the HLT Exercise [5] were run on the 10 pb^{-1} ensemble using CMSSW_1_3_1_HLT6. As would be the case with real data, we only analyzed events passing the HLT, specifically the isolated single electron path, `HLT1Electron` [7], for LHC running at a luminosity of 10^{32} as defined in [5].

6 Electron Identification

To discriminate between real and fake electrons a standard set of variables is provided by the E/gamma POG to perform electron identification. In this work, we use the cut-based implementation of the "loose" cuts in the following tags for the standard electron ID tool.

```
V00-00-00          EgammaAnalysis/ElectronIDAlgos
eleID131_17Jun07   EgammaAnalysis/ElectronIDProducers
```

The default cut values are taken from previous work on electron identification and defined separately for each electron classification [3], [7], [8]. The specific cuts that we have used in this note are tabulated in Appendix A

7 Background Estimation and Efficiency Correction

When we attempt to measure a given efficiency, background contamination in the probe sample will affect the efficiency measurement. The level of background contamination obviously depends on the selection criteria applied to the tag, and more importantly, the probe. Ideally, the selection criteria for the tags and probes would be optimized such that they are tight enough to reduce backgrounds to levels which minimize systematic uncertainties on the measurement due to background estimation, whilst remaining loose enough to the minimize the statistical uncertainty of the efficiency measurement due to the number of probes used to make the determination.

In what follows, we describe several techniques which could be used to estimate the level of background contamination from these sources with early CMS data.

[6] Since the release of version 1.0 of this AN, the CSA07 em-enriched QCD samples have become available. We have analysed these samples and our preliminary results indicate that the contribution is comparable to that from W+jets

[7] Due to technical limitations in producing and storing Spring07 data with HLT information the $W \rightarrow e\nu$ + jets data contains HLT information from studies before the completion of the HLT Exercise. The specific trigger used in this case is seeded from a non isolated L1 trigger bit and contains modifications to the very high E_T behavior. In the kinematic range close to the Z pole the behavior of these triggers is similar. Given the remit of this exercise to exercise the background subtraction methods the combination of these datasets was considered valid.

7.1 The Same-Sign Technique

Tag & probe pairs selected from $Z \to e^+e^-$ events should be measured to have opposite electric charge (even if this requirement is not applied in the tag and probe criteria). Under the assumption that the sign of the charge of each leg is random if selected from a background event[8)] the number of probes selected from background events, N_B, can be estimated by counting the number of tag & probe pairs where both legs have opposite sign, N_{SS}. This is related to the number of background probes by $N_B = 2N_{SS}$ as the number of background tag & probe pairs with opposite sign will be equal to the number of background tag & probe pairs with same sign.

The estimated number of background probes is then corrected for the small charge mis-measurement in the signal, f_{mis}, which is computed from fully simulated signal events. The expression for the total number of background probes is then given in equation 7.

$$N_B = 2(N_{SS} - f_{mis}N_S) \tag{7}$$

where N_S is the expected number of signal events and N_B is measured from the data separately for tag & probe pairs where the probe passes the criteria under study, N_B^{PASS} as well as for the total set of pairs N_B^{TOTAL}. The measured background is then separately subtracted from the numerator and denominator to give the background subtracted efficiency according to equation 8.

$$\varepsilon = \frac{N^{PASS} - N_B^{PASS}}{N^{TOTAL} - N_B^{TOTAL}} \tag{8}$$

This method is only applicable if no opposite sign requirement has been made in the tag & probe selection and if a measurement of the sign of the charge is available for both legs. A simple method to estimate the background where this is not the case is described in section 7.2.

7.2 A Simple Side Band Technique

Where a measurement of the sign of the charge of one or both of the legs of the tag & probe selection is unavailable a simple side band technique may be employed to estimate the number of background events in the selection. The total number of tag & probe pairs is counted in a region below and above the mass range used to select pairs for the efficiency measurement. These regions are taken to be $40 < M_{ee} < 60$ and $120 < M_{ee} < 140$ under the assumption that the number of pairs in each side band region is dominated by background.

Given an estimate of the background per invariant mass bin in the lower and upper regions and the assumption of a linear variation in this number between the two regions the number of background probes in the region selected for the efficiency measurement may be estimated. This estimate is made separately from the invariant mass spectrum of the tag & probe pairs where the probe passes the criteria under study as well as the total set of pairs. The subtraction is made on both the numerator and denominator as in equation8.

Compared to the same sign method described in section 7.1 the side band subtraction described here will suffer from the assumption that the side band regions are dominated by background when there is also a contribution from the Drell-Yan continuum.

We use a combination of this simple side-band method and the same-sign technique to estimate the background contributions to the efficiency calculations presented in Section 8. While these methods are over-simplistic and not terribly accurate, they are desirable for the start-up scenario since they are robust. Moreover, for the level of background contamination expected in 10 pb^{-1}, these methods are more than adequate.

In all background estimates detailed in Section 8, we also present the background as known from MC truth for comparison.

7.3 Shape based Background Subtraction

As the integrated luminosity of CMS is expected to rapidly exceed 10 pb^{-1}, we also present a more sophisticated method for background subtraction which one might use once the distributions of discriminating variables between $Z \to e^+e^-$ signal and background processes can be adequately modeled.

8) This assumption is known to be somewhat suspect for some backgrounds. For example, in the W+jets events considered here, there exists a significant charge correlation between the quark and the lepton.

In this method, background is subtracted from the various tag-and-probe samples via an extended, unbinned maximum-likelihood fit to the distribution of those variables in data. For any particular sample of N events, for which each event has a vector $\vec{x}$ of discriminating variables, the extended unbinned likelihood function

$$\mathcal{L} = e^{-(S+B)} \prod_{i=1}^{N} (S\mathcal{P}_S(\vec{x}_i; \vec{s}) + B\mathcal{P}_B(\vec{x}_i; \vec{b}))$$

is simultaneously maximized with respect to signal yield S; background yield B; and also to any parameters $\vec{s}$ or $\vec{b}$ characterizing the PDFs $\mathcal{P}_S$ and $\mathcal{P}_B$, respectively. The central value for S is the one for which $\mathcal{L}$ is maximized, and its 68% CL interval is the variation of S for which $\ln \mathcal{L} \geq \ln \mathcal{L}_{max} - \frac{1}{2}$. This method can be trivially extended to any disjoint collection of samples with unrelated fit parameters: in that case the likelihood function is just the product of individual sample likelihoods, and the maximum likelihood is just the piecewise maximum. It can also be extended to disjoint samples where fit parameters are related, where again the likelihood function is a product over sample likelihoods, but the maximization is now non-trivial, and typically solved numerically using a software package like MINUIT.

For the case of measuring tag-and-probe selection efficiency in the presence of background, the efficiency can be extracted via a maximum likelihood fit with the disjoint collection of the two samples in which the probe candidate passes or fails the selection. In this case the two signal yields, S_{pass} and S_{fail}, are related via the total number of signal events, S_{total}, and the selection efficiency, ϵ:

$$S_{\text{pass}} = \epsilon S_{\text{total}},$$

$$S_{\text{fail}} = (1-\epsilon) S_{\text{total}}.$$

and the likelihood function is

$$\mathcal{L} = e^{-(S_{\text{total}}+B_{\text{pass}}+B_{\text{fail}})} \prod_{i=1}^{N_{\text{pass}}} (\epsilon S_{\text{total}} \mathcal{P}_{S_{\text{pass}}}(\vec{x}_i; \vec{s}_{\text{pass}}) + B_{\text{pass}} \mathcal{P}_{B_{\text{pass}}}(\vec{x}_i; \vec{b}_{\text{pass}})) \times$$

$$\prod_{j=1}^{N_{\text{fail}}} ((1-\epsilon) S_{\text{total}} \mathcal{P}_{S_{\text{fail}}}(\vec{x}_j; \vec{s}_{\text{fail}}) + B_{\text{fail}} \mathcal{P}_{B_{\text{fail}}}(\vec{x}_j; \vec{b}_{\text{fail}}))$$

The above relations between S_{pass}, S_{fail}, and ϵ are valid only in the case where each event has a single tag-probe candidate pair. For example, if probe selection is restricted to a particular range of lepton E_T and η, then there will be one tag-probe pair per event if tag selection is restricted to be outside of the range specified for the probe.

If this restriction is not imposed on the tag selection, then in general there will exist a subset of events for which both the tag and probe candidates have indistinguishable properties, and for this subset there are two tag-probe pairs per event. Define the following three disjoint categories of events:

- (TT) Events for which both leptons are probe candidates, and both leptons pass the tag selection.
- (TP) Events for which one lepton is a tag candidate, and the other lepton is a probe candidate which passes the test selection, but fails the tag selection.
- (TF) Events for which one lepton is a tag candidate, and the other lepton is a probe candidate which fails the test selection.

These three event yields are related to the efficiency via

$$\epsilon = (2S_{\text{TT}} + S_{\text{TP}})/(2S_{\text{TT}} + S_{\text{TP}} + S_{\text{TF}}).$$

A set of relations between signal yields to be used in a likelihood fit which results in this efficiency is given by

$$S_{\text{TT}} = \epsilon_{T|P}^2 \epsilon^2 S,$$

$$S_{\text{TP}} = 2\epsilon_{T|P}(1-\epsilon_{T|P})\epsilon^2 S,$$

$$S_{\text{TF}} = 2\epsilon_{T|P}\epsilon(1-\epsilon) S,$$

where ϵ is the test selection efficiency, and $\epsilon_{T|P}$ and S are auxiliary fit parameters: $\epsilon_{T|P}$ is the ratio $2S_{\mathrm{TT}}/(2S_{\mathrm{TT}}+S_{\mathrm{TP}})$, and S is an efficiency corrected yield of probe candidate pairs, e.g. $S = S_{\mathrm{TT}}/(\epsilon^2_{T|P}\epsilon^2)$. The likelihood function is similar to the simpler case, but with a product of three different terms:

$$\mathcal{L} = e^{-(\epsilon^2_{T|P}\epsilon^2 S + 2\epsilon_{T|P}(1-\epsilon_{T|P})\epsilon^2 S + 2\epsilon_{T|P}\epsilon(1-\epsilon)S + B_{TT} + B_{TP} + B_{TF})} \prod_{i=1}^{N_{\mathrm{TT}}} (\epsilon^2_{T|P}\epsilon^2 S\mathcal{P}_{S_{\mathrm{TT}}}(\vec{x}_i;\vec{s}_{\mathrm{TT}}) + B_{\mathrm{TT}}\mathcal{P}_{B_{\mathrm{TT}}}(\vec{x}_i;\vec{b}_{\mathrm{TT}})) \times$$

$$\prod_{j=1}^{N_{\mathrm{TP}}} 2\epsilon_{T|P}(1-\epsilon_{T|P})\epsilon^2 S\mathcal{P}_{S_{\mathrm{TP}}}(\vec{x}_j;\vec{s}_{\mathrm{TP}}) + B_{\mathrm{TP}}\mathcal{P}_{B_{\mathrm{TP}}}(\vec{x}_j;\vec{b}_{\mathrm{TP}})) \times$$

$$\prod_{k=1}^{N_{\mathrm{TF}}} 2\epsilon_{T|P}\epsilon(1-\epsilon)S\mathcal{P}_{S_{\mathrm{TF}}}(\vec{x}_k;\vec{s}_{\mathrm{TF}}) + B_{\mathrm{TF}}\mathcal{P}_{B_{\mathrm{TF}}}(\vec{x}_k;\vec{b}_{\mathrm{TF}}))$$

For our first attempt at this method, we will use as the discriminating vector $\vec{x}$ the single variable M_{ee}, the invariant mass of the tag & probe pair. The range of M_{ee} considered is 60 – 120 GeV/c^2.

The signal PDF $\mathcal{P}_S$ is given as the superposition of a Voigtian distribution $V(M_{ee};M,\Gamma,\sigma)$ with a bifurcated Gaussian distribution[9] $A(M_{ee};M,\sigma_1,\sigma_2)$,

$$\mathcal{P}_S \propto fV + (1-f)A.$$

M is the pole mass of the Breit-Wigner, Γ is its width, and σ is the Gaussian mass resolution. A is meant to model the asymmetric tail in the mass distribution due to Bremsstrahlung, with a width σ_1 below the pole mass M and width σ_2 above the pole mass M. At present, the same PDF (including identical shape parameters) is assumed for both passing and failing events. A systematic study will be required to understand the efficiency bias of this PDF and whether separate shapes are necessary for passing and failing events.

The background PDF $\mathcal{P}_B$ is modeled by the function,

$$\mathcal{P}_B \propto \mathrm{erfc}(\alpha + \beta x)e^{-bM_{ee}},$$

where the erfc prefactor models a threshold turn-on at low mass, and exponential behavior dominates at high mass. Again, both passing and failing samples are assumed to have the same b, and the more general case should be studied. The functional form describes well the W+jet background distribution; as more realistic background cocktails become available, this PDF will have to be re-evaluated.

The likelihood construction and maximization is performed using the ROOFIT data modelling package, which is distributed with ROOT. The software uses MINUIT with MINOS errors to estimate a selection efficiency from the likelihood function.

While we don't use this method to calculate the efficiencies presented in Section 8, we illustrate its use on a subset of such calculations in Appendix D.

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[9] Alternative PDF's (*e.g.* superposition of a Breit-Wigner with a crystal ball function) may be more representative and are being investigated.

8 Efficiency Measurements

In this section we present the details of the calculation of each efficiency discussed in Section 4. For each calculation we give the precise definitions of the numerator and denominator of the efficiency. We also list the selection criteria for the tags and probes. As noted previously, this analysis was performed with data which had perfect, rather than startup, alignment/calibration constants. Consequently, the selection we present may need to be modified for use in the earliest data. An estimation of background contamination, and the subsequent correction applied to each efficiency calculation is also given in each case.

For each calculation, we provide the efficiency as a function of several illustrative variables. We also provide the same efficiency integrated over those variables, *i.e.* as just a single number. This number is adequate for the demonstrated use in this note, namely the calculation of the $\gamma^* Z \to e^+e^-$ cross-section. For other applications, however, which may have different kinematics than Z's, such as $\sigma \times BR(W \to e\nu)$, it will be necessary to have the efficiencies binned in two (or more) variables. We therefore also provide all the efficiencies we compute in the following sections binned in η and E_T in Appendix F.

8.1 Offline Efficiencies

In the following sections, we detail the calculations of that part of the total efficiency which we have factorized as $\varepsilon_{offline}$.

8.1.1 $\varepsilon_{clustering}$

The formation of a calorimeter cluster is the first step in the reconstruction of an electron. The measurement of the clustering efficiency is made independently from the calorimeter by taking a probe which is a track reconstructed in the silicon tracker using the CTF algorithm. Given a CTF track a matching in η and ϕ is made with the calorimeter in coordinates defined with respect to the same vertex[10]. The requirements to select a tag & probe pair are defined in Table 2

Table 2: Selection criteria for Tags and Probes (Clustering Efficiency)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - E_T >15 GeV - is isolated (track isolation) - classification: 'golden' - loose Electron ID for 'golden' class	A ctfWithMaterialTrack which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - p_T >10 GeV - is isolated (track isolation) - valid Hits > 4 - χ^2/n.d.f<4

It is also demanded that $|\Delta(z_{vtx}^{TAG} - z_{vtx}^{PROBE})|$ <0.1 mm, and 85< m_{TP} <95 GeV. The efficiency is defined in Eq. 9 where the SuperCluster is required to have an $E_T > 5$ GeV. When quoting integrated efficiencies in this note only probes with $p_T > 20$ GeV are considered in the numerator and denominator of Eq. 9.

$$\varepsilon = \frac{Probes\ with\ SuperCluster\ in\ d\eta < 0.03,\ dR < 0.1}{AllProbes} \tag{9}$$

To subtract the background we use the opposite sign method described above. With the tag & probe criteria for this efficiency calculation listed above the fraction of tag probe pairs with same sign, f_{mis}, was measured in signal only simulated events ($f_{mis} = N_{SS}/(N_{SS} + N_{OS})$ [11] In the barrel region f_{mis} was found to be 0.0025 and 0.027 in the endcap. The number of background events estimated is given in Table 3 and the mass spectrum of signal and the assembled signal and background sample is shown in Figs. 6 and 7. The measured efficiency is displayed in

[10] The SuperCluster position is in the detector basis with respect to the nominal vertex by default and the track is with respect to its measured vertex.

[11] If f_{mis} were alternatively defined as the probability for a given electron to have the wrong charge then the formula for the number of background events should be written as $N_B = 2(N_{SS} - 2f_{miss}(1 - f_{mis})N_S)$.

Figs. 8, 9, 10 and 11 . The efficiencies integrated over the entire kinematic range considered are given for reference in Table 4.

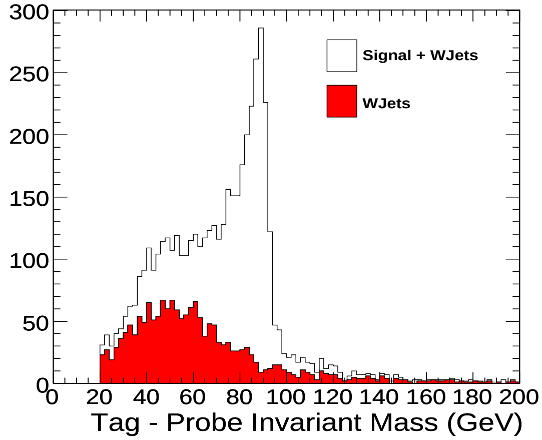


Figure 6: Tag Probe Invariant Mass for Total

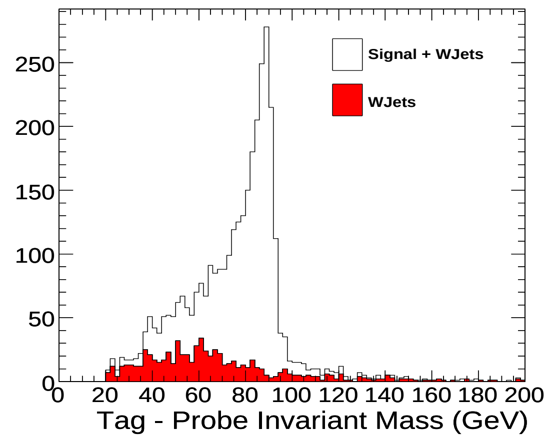


Figure 7: Tag Probe Invariant Mass for Probes passing

Table 3: Background Estimate for Clustering Efficiency Calculation

Method	Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
Same-sign	EB	809 ± 28.4	6.0 ± 3.5	824 ± 28.7	9.9 ± 4.4
	EE	114 ± 10.7	3.8 ± 2.8	121 ± 11.0	13.4 ± 5.2
Side-band	EB	809 ± 28.4	17.5 ± 4.2	824 ± 28.7	25.5 ± 5.1
	EE	114 ± 10.7	3.4 ± 1.9	121 ± 11	6.0 ± 2.4
MC truth	EB	-	13	-	25
	EE	-	5	-	11

Table 4: Integrated efficiencies (Clustering Efficiency for $p_T > 20$ GeV)

Region	Value
EB (Signal Only)	0.996 ± 0.002
EB (Signal + Background)	0.980 ± 0.005
EB (Background Subtracted)	0.986 ± 0.005
EE (Signal Only)	0.982 ± 0.013
EE (Signal + Background)	0.935 ± 0.022
EE (Background Subtracted)	1.00 ± 0.020

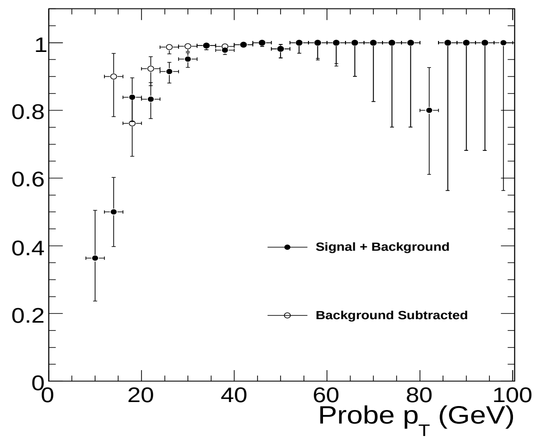


Figure 8: Clustering efficiency versus probe track p_T

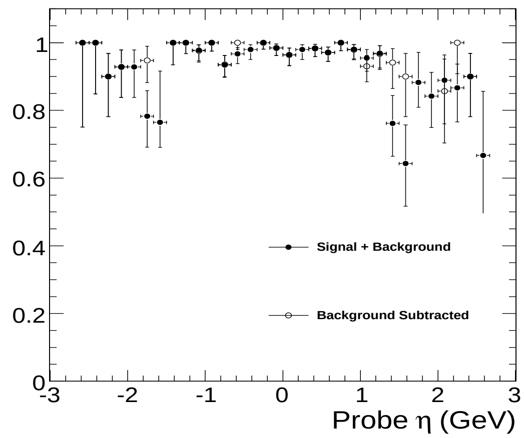


Figure 9: Clustering efficiency versus probe η

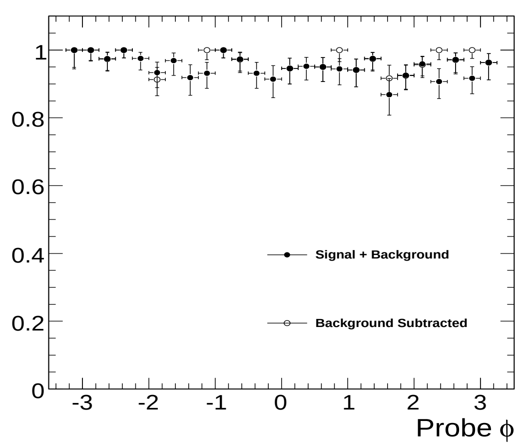


Figure 10: Clustering efficiency versus probe ϕ

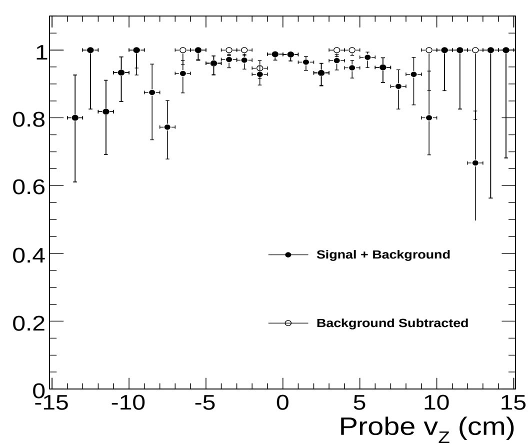


Figure 11: Clustering efficiency versus probe z_{vtx}

8.1.2 $\varepsilon_{tracking}$

Here the efficiency with which a GsfTrack is reconstructed in the silicon tracker is measured. The tag & probe selection criteria used are defined in Table 5.

Table 5: Selection criteria for Tags and Probes (Tracking Efficiency)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A SuperCluster which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - has E_T >20 GeV

In addition to the criteria in Table 5 the invariant mass of the tag & probe pair, m_{TP}, must satisfy : $85\,\mathrm{GeV} < m_{TP} < 95\,\mathrm{GeV}$. The tracking efficiency is defined such that

$$\varepsilon = \frac{Probes\ with\ GsfTrack\ in\ dR < 0.1}{All\ Probes} \tag{10}$$

The number of background events estimated by the side band method described previously is given in Table 6 and the mass spectrum of signal and the assembled signal and background sample is shown in Figs. 12 and 13. The measured efficiency is displayed in Figs. 14, 15, 16 and 17.

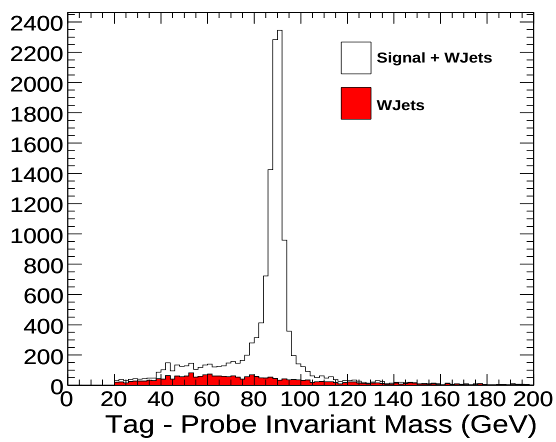


Figure 12: Tag Probe Invariant Mass for Total

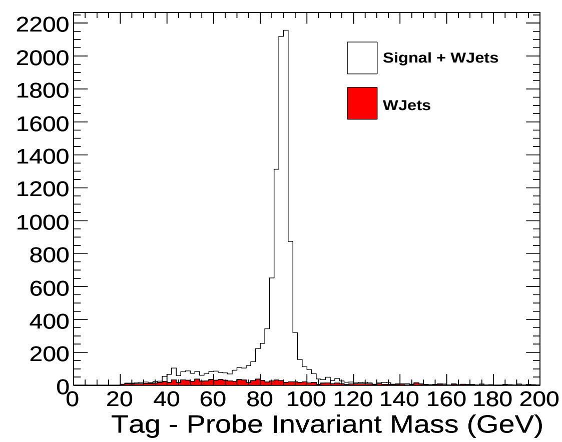


Figure 13: Tag Probe Invariant Mass for Probes passing

Table 6: Background Estimate for Tracking Efficiency Calculation

Method	Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
Same-sign	EB	-	-	-	-
	EE	-	-	-	-
Side-band	EB	4736 ± 68.8	55.9 ± 7.5	5015 ± 70.8	78.4 ± 8.9
	EE	2040 ± 45.2	19.5 ± 4.4	2296 ± 47.9	32.0 ± 5.7
MC truth	EB	-	73	-	105
	EE	-	22	-	46

The efficiencies computed using events integrated over the entire kinematic range considered are given for reference in Table 7. As can be seen, the method of background subtraction using the side bands technique gives

Table 7: Integrated efficiencies (Tracking Efficiency)

Region	Value
EB (Signal Only)	0.950 ± 0.003
EB (Signal + Background)	0.944 ± 0.003
EB (Background Subtracted)	0.948 ± 0.003
EE (Signal Only)	0.897 ± 0.006
EE (Signal + Background)	0.888 ± 0.007
EE (Background Subtracted)	0.892 ± 0.007

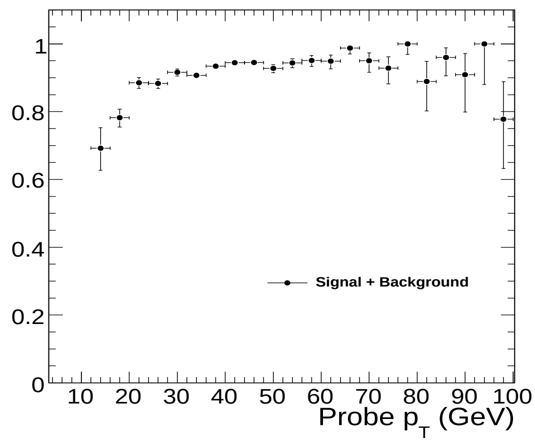


Figure 14: Tracking efficiency versus probe E_T

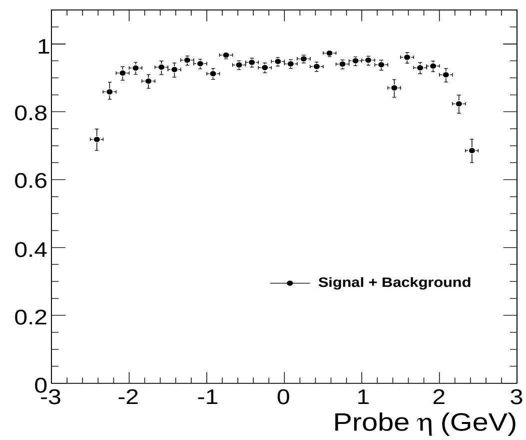


Figure 15: Tracking efficiency versus probe η

reasonable results, bringing the efficiencies back to the expected values obtained with a signal only simulated sample.

8.1.3 ε_{gsfele}

Here the efficiency of the preselection for GsfElectron objects formed from a SuperCluster and a GsfTrack is measured. The tag & probe selection for this efficiency calculation is defined in Table 8.

Table 8: Selection criteria for Tags and Probes (GsfElectron preselection efficiency)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A GsfTrack which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - matches SuperCluster with E_T >20 GeV

In addition to the criteria in Table 8 the invariant mass of the tag & probe pair, m_{TP}, must satisfy : $85\,\text{GeV} < m_{TP} < 95\,\text{GeV}$. The efficiency is defined such that

$$\varepsilon = \frac{Probes\ with\ PixelMatchGsfElectron\ in\ dR < 0.1}{All\ Probes} \tag{11}$$

The number of background events estimated by the opposite sign method is given in Table 9 and the mass spectrum of signal and the assembled signal and background sample is shown in Figs. 18 and 19. With the tag & probe criteria for this efficiency calculation listed above the fraction of tag probe pairs with same sign, f_{mis}, was

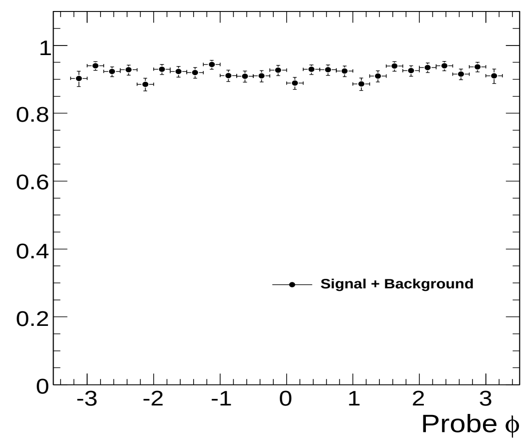


Figure 16: Tracking efficiency versus probe ϕ

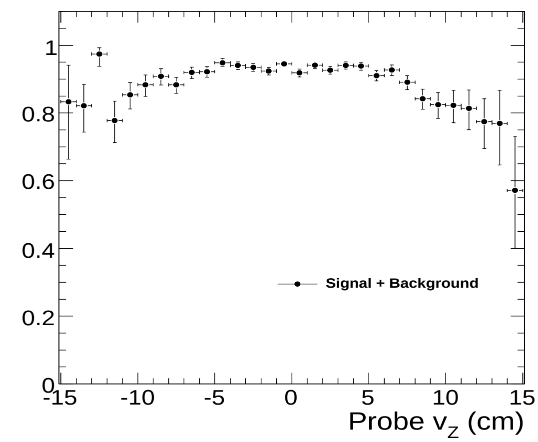


Figure 17: Tracking efficiency versus probe z_{vtx}

measured in signal only simulated events. In the barrel region f_{mis} was found to be 0.038 and 0.096 in the endcap. The measured efficiency is displayed in Figs. 20, 21, 22 and 23.

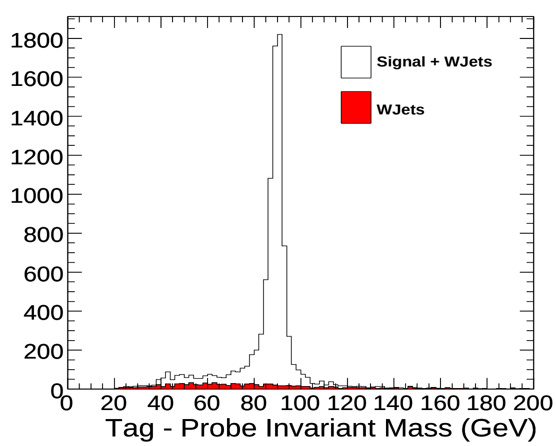


Figure 18: Tag Probe Invariant Mass for Total

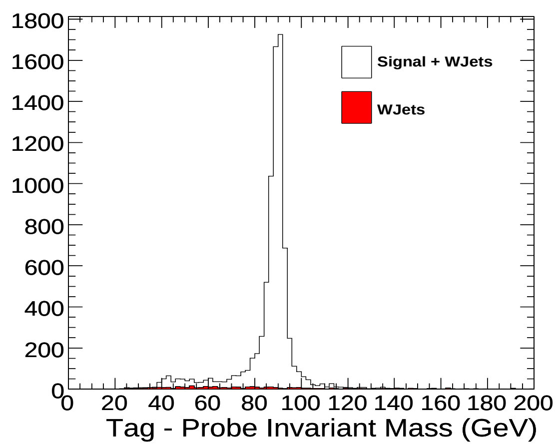


Figure 19: Tag Probe Invariant Mass for Probes passing

8.1.4 $\varepsilon_{isolation}$

Here the efficiency with which a PixelMatchGsfElectron is isolated is measured. Isolation efficiency, $\varepsilon_{\text{isolation}}$, is defined as:

$$\varepsilon = \frac{Probes\ which\ have\ an\ isolated\ track}{All\ Probes} \tag{12}$$

where the track isolation criteria is defined as :

$$\sum_{track} \left(\frac{p_T^{track}}{p_T^{ele}} \right)^2 < 0.02$$

where all CTF tracks with $p_T^{track} > 1.5\,GeV$, within a cone of $0.02 < \Delta R < 0.6$ centered on the reconstructed electron are summed and p_T^{ele} is the momentum of the reconstructed electron at the vertex.

Table 9: Background Estimate for GsfEle Preselection Efficiency Calculation

Method	Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
Same-sign	EE	1563 ± 39.5	0 ± 1	1710 ± 41.4	14.7 ± 5.4
	EB	3820 ± 61.8	7 ± 3.7	3969 ± 63.0	49.7 ± 10.0
Side-band	EE	1564 ± 39.5	10.7 ± 3.3	1711 ± 41.4	17.0 ± 4.2
	EB	3822 ± 61.8	32.0 ± 5.7	3971 ± 63.0	45.9 ± 6.8
MC truth	EB	-	25	-	59
	EE	-	5	-	19

Table 10: Integrated efficiencies (GsfEle preselection efficiency from track matched SuperCluster)

Region	Value
EB (Signal Only)	0.971 $\pm$ 0.003
EB (Signal + Background)	0.961 $\pm$ 0.003
EB (Background Subtracted)	0.973 $\pm$ 0.003
EE (Signal Only)	0.922 $\pm$ 0.006
EE (Signal + Background)	0.914 $\pm$ 0.007
EE (Background Subtracted)	0.935 $\pm$ 0.006

Selection criteria for the tag & probe are listed in Table 11. In addition to these criteria, the invariant mass of the tag & probe pair, m_{TP}, must satisfy : $85\,\text{GeV} < m_{TP} < 95\,\text{GeV}$.

Table 11: Selection criteria for Tags and Probes (Isolation Efficiency)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A PixelMatchGsfElectron which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >20 GeV

Background contamination was estimated with the same-sign technique. In the barrel region f_{mis} was found to be 0.032 and 0.058 in the endcap and the resulting background estimate is given in Table 12. From this step onward we therefore consider the background contribution to be compatible with zero from the results of the same-sign technique. Consequently, in this and further sections we no longer apply any background correction to the efficiency measurements.

The isolation efficiency as a function of probe SuperCluster E_T, η, ϕ and and the probe z_{vtx} is shown in Figs. 24, 25, 26 and 27.

8.1.5 $f_{\text{classification}}$

In this step we determine $f_{\text{classification}}$, which is the fraction of probe electrons with a particular classification, as defined in [3].

The classification fraction is defined such that:

$$f_{\text{classification}} = \frac{Probes\ in\ particular\ classification}{All\ Probes} \tag{13}$$

Selection criteria for the tag & probe can be found in Table 14. In addition to these criteria, the invariant mass of the tag & probe pair, m_{TP}, must satisfy : $85\,\text{GeV} < m_{TP} < 95\,\text{GeV}$..

The fraction of probes in each classification as a function of E_T, η, ϕ and the probe z_{vtx} is shown in Figs. 28, 29, 30 and 31.

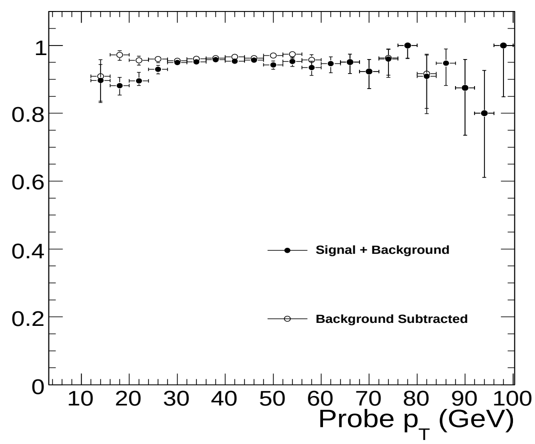


Figure 20: PixelMatchGsfElectron preselection efficiency versus probe E_T

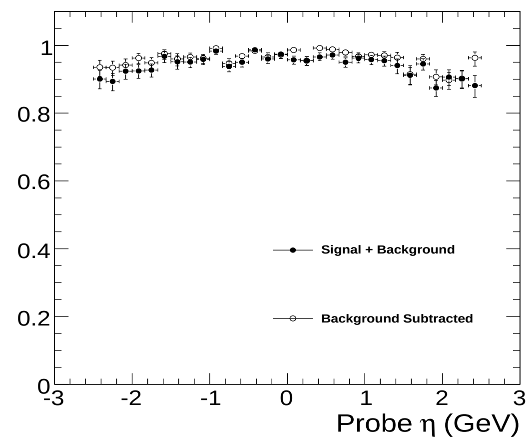


Figure 21: PixelMatchGsfElectron preselection efficiency versus probe η

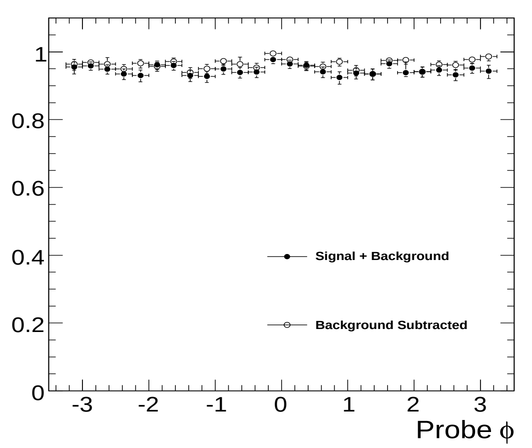


Figure 22: PixelMatchGsfElectron preselection efficiency versus probe ϕ

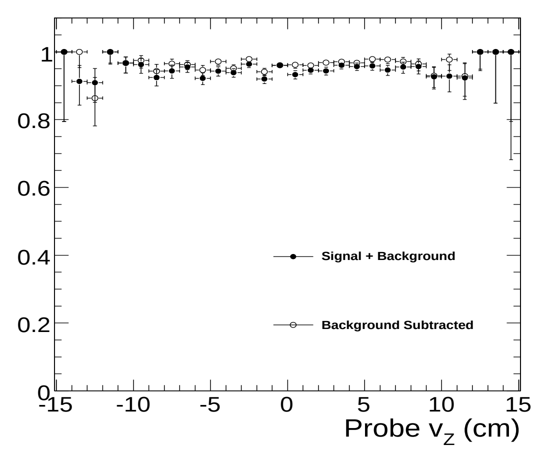


Figure 23: PixelMatchGsfElectron preselection efficiency versus probe z_{vtx}

Table 12: Background Estimate for Isolation Efficiency Calculation

Method	Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
Same-sign	EE	1478 ± 38.4	0 ± 1	1628 ± 40.3	18.5 ± 4.3
	EB	3718 ± 61.0	0 ± 1	3896 ± 62.4	38.4 ± 62.4
Side-band	EE	1660 ± 40.7	10.2 ± 3.2	1749 ± 41.8	12.9 ± 3.6
	EB	4219 ± 64.9	26.9 ± 5.2	4403 ± 66.4	38.2 ± 6.2
MC truth	EB	-	2	-	23
	EE	-	1	-	5

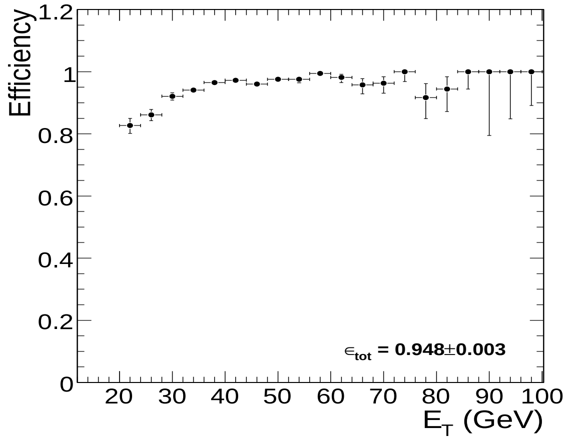


Figure 24: Isolation efficiency, $\varepsilon_{\mathrm{isolation}}$, versus probe E_T.

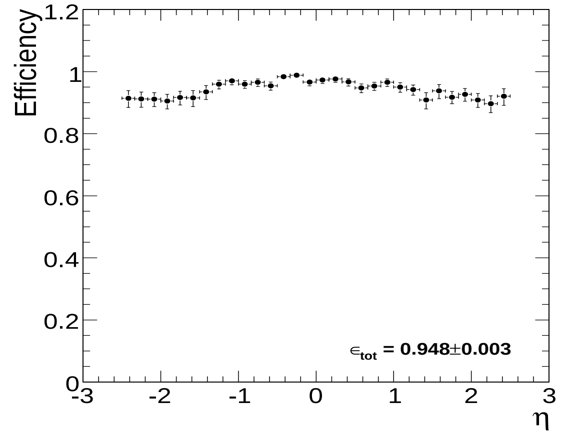


Figure 25: Isolation efficiency, $\varepsilon_{\mathrm{isolation}}$, versus probe η.

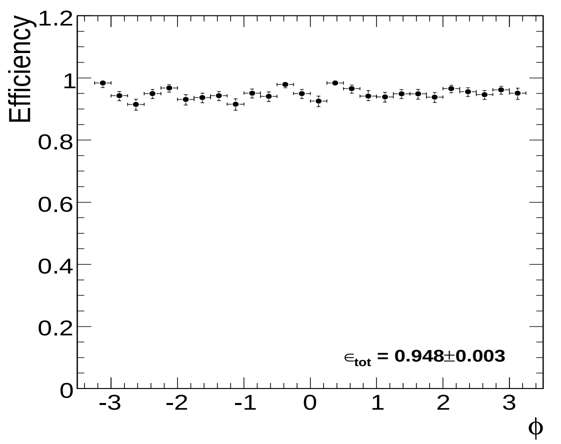


Figure 26: Isolation efficiency, $\varepsilon_{\mathrm{isolation}}$, versus probe ϕ.

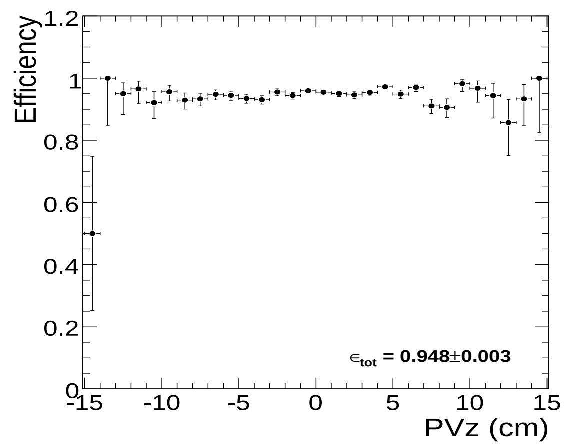


Figure 27: Isolation efficiency, $\varepsilon_{\mathrm{isolation}}$, versus probe z_{vtx}.

Table 13: Integrated efficiencies (Isolation Efficiency from GsfElectron)

Region	Value
EB	0.962± 0.003
EE	0.915 ± 0.003

Table 14: Selection criteria for Tags and Probes (Classification Fraction)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A PixelMatchGsfElectron which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >20 GeV - is isolated (track isolation)

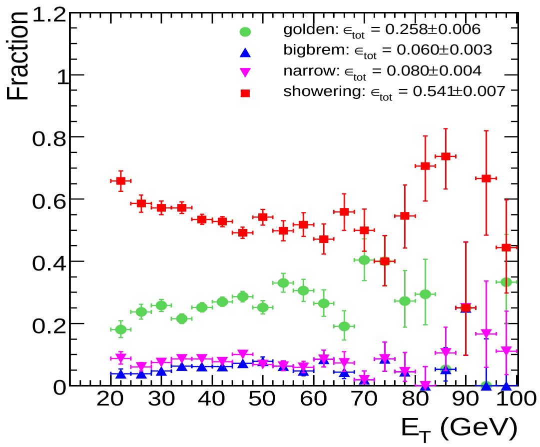


Figure 28: Fraction of probes in each classification, versus probe SuperCluster E_T.

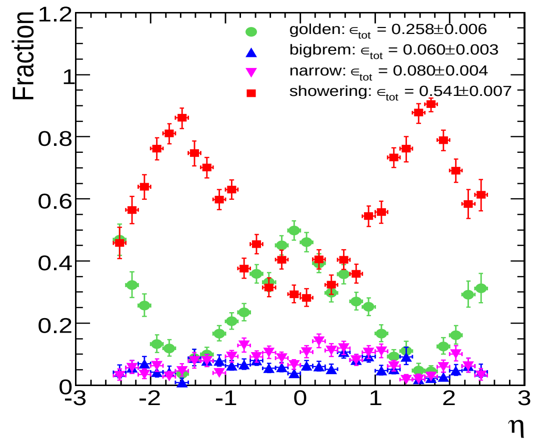


Figure 29: Fraction of probes in each classification, versus probe SuperCluster η.

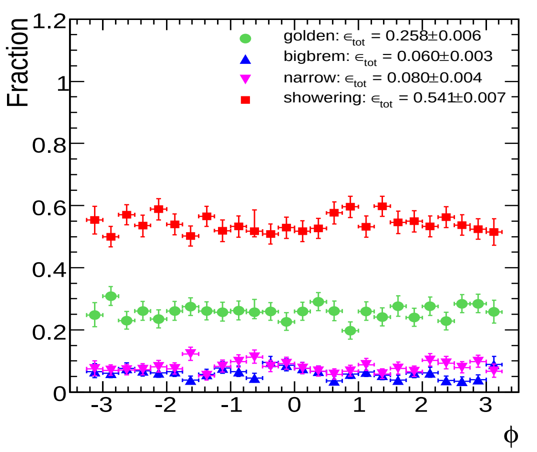


Figure 30: Fraction of probes in each classification, versus probe SuperCluster ϕ.

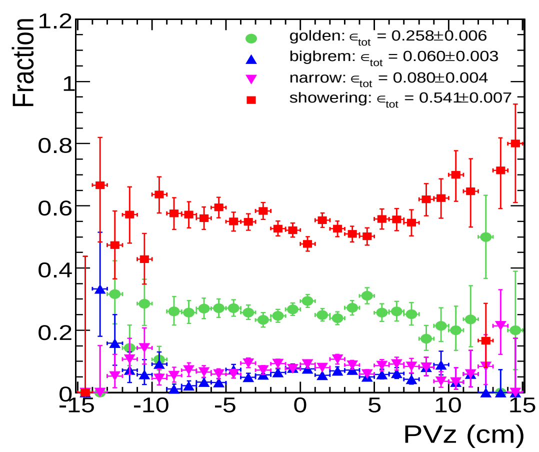


Figure 31: Fraction of probes in each classification versus probe z_{vtx}.

Table 15: Fraction of GsfElectrons in each classification

Class	Region	Value
Golden	EB	0.288 ± 0.007
Golden	EE	0.181 ± 0.010
Big Brem	EB	0.068 ± 0.004
Big Brem	EE	0.040 ± 0.005
Narrow	EB	0.093 ± 0.005
Narrow	EE	0.048 ± 0.005
Showering	EB	0.469 ± 0.008
Showering	EE	0.726 ± 0.011

8.1.6 ε_{id}

The implementation of the ElectronIDProducer considered here applies different cuts on PixelMatchGsfElectrons depending on their classification (and whether they are EE or EB). Even though in Section 9 we will only actually use 'golden' EB electrons, for completeness, we present ID efficiency measurements for all classifications (EE and EB).

The ID efficiency is defined such that:

$$\varepsilon = \frac{Probes\ passing\ ID\ selection\ for\ a\ particular\ class}{All Probes} \tag{14}$$

The selection criteria for the tag & probe can be found in Table 16. In addition to these criteria, the invariant mass of the tag & probe pair, m_{TP}, must satisfy : $85\,\mathrm{GeV} < m_{TP} < 95\,\mathrm{GeV}$.

Table 16: Selection criteria for Tags and Probes (Identification efficiency, given a particular class of electron)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A PixelMatchGsfElectron which: - is in fiducial ($\|\eta\|$ <1.444 and 1.560< $\|\eta\|$ <2.5) - SuperCluster E_T >20 GeV - is isolated (track isolation) - is the appropriate class of electron

The results of these efficiency measurements are listed in Table 17. The efficiencies for the 'golden' classification are shown as functions of E_T and η in Figs. 32 and 33; for 'big brem', Figs. 34 and 35; for 'narrow', Figs. 36 and 37; and for 'showering', Figs. 38 and 39.

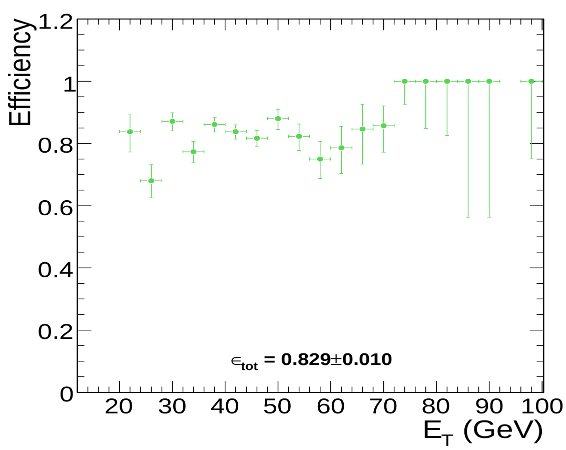


Figure 32: Identification efficiency, $\varepsilon_{\mathrm{eid}}$, for probes classified as 'golden', versus probe E_T.

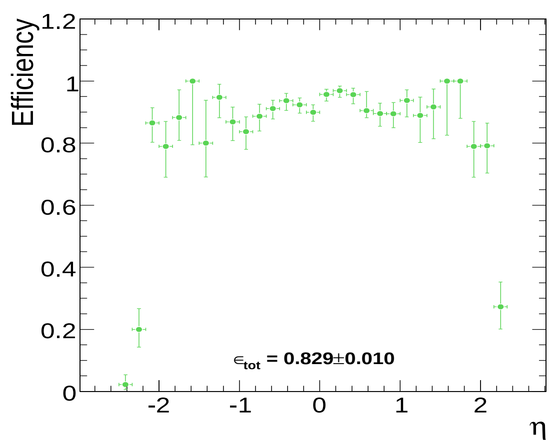


Figure 33: Identification efficiency, $\varepsilon_{\mathrm{eid}}$, for probes classified as 'golden', versus probe η.

8.2 Online Efficiencies

In the following sections, we now turn our attention to that part of the total efficiency which we have denoted ε_{online}.

8.2.1 ε_{L1+HLT}

The efficiency to pass the HLT is measured with respect to the offline selection. The tag & probe definition is given in Table 18. We require that the tag must have passed the HLT path `HLT1Electron` (including the requirement

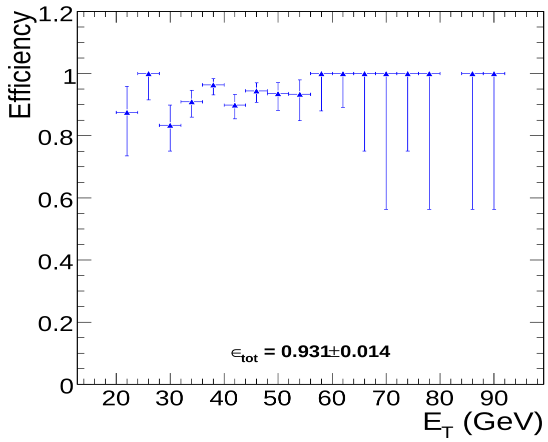


Figure 34: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'big brem', versus probe E_T.

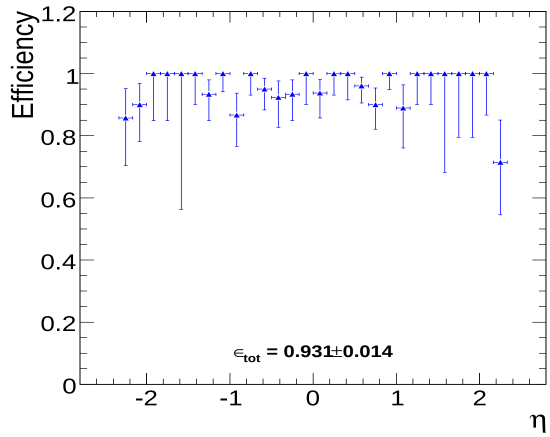


Figure 35: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'big brem', versus probe η.

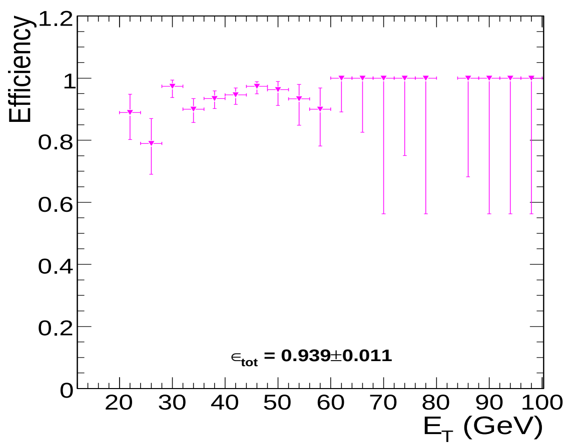


Figure 36: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'narrow', versus probe E_T.

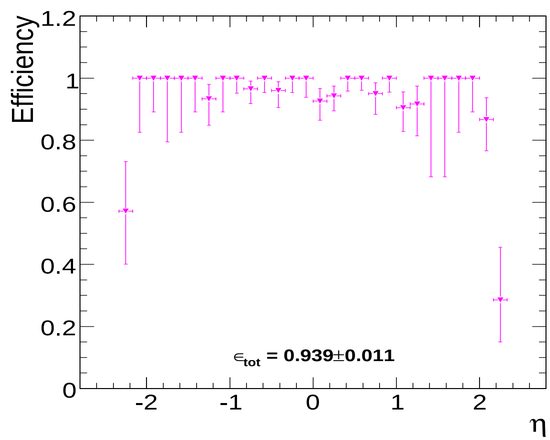
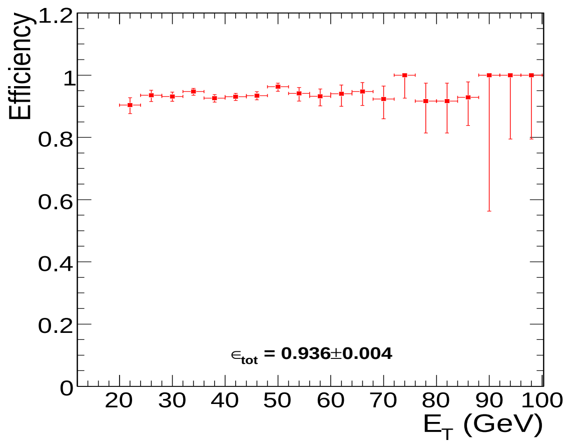


Figure 37: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'narrow', versus probe η.

that it could have passed the Level-1 bit `A_Single_EG12`) to remove the bias due to the online selection of the event. The efficiencies with respect to each classification are shown as a function of E_T and η are given in Figs. 42-48. In addition, the combined efficiencies for all classifications are shown as a function of E_T, η, ϕ and z_{vtx} are given in Figs. 51, 50 and 52, 53.



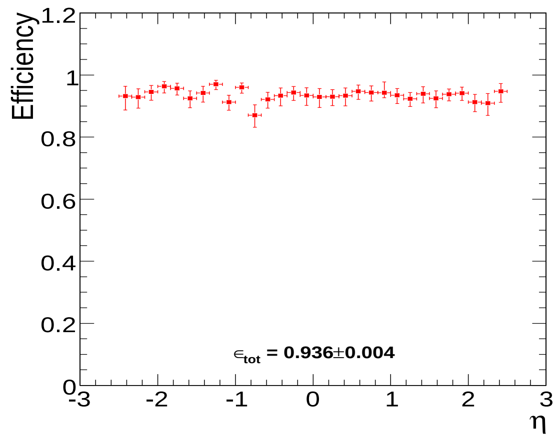


Figure 38: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'showering', versus probe E_T.

Figure 39: Identification efficiency, $\varepsilon_{\rm eid}$, for probes classified as 'showering', versus probe η.

Table 17: Integrated efficiencies (ID efficiency for GsfElectrons in each class)

Class	Region	Value
Golden	EB	0.917± 0.008
Golden	EE	0.468 ± 0.030
Big Brem	EB	0.959± 0.012
Big Brem	EE	0.806 ± 0.050
Narrow	EB	0.970± 0.009
Narrow	EE	0.784 ± 0.048
Showering	EB	0.935 ± 0.006
Showering	EE	0.937 ± 0.007

Table 18: Selection criteria for Tags and Probes (L1+HLT Efficiency)

TAG	PROBE
A PixelMatchGsfElectron which: - is capable of passing the single electron HLT - is in fiducial ($\vert\eta\vert$ <1.444 and 1.560< $\vert\eta\vert$ <2.5) - SuperCluster E_T >15 GeV - is isolated (track isolation)	A PixelMatchGsfElectron which: - is in fiducial ($\vert\eta\vert$ <1.444 and 1.560< $\vert\eta\vert$ <2.5) - SuperCluster E_T >20 GeV - Is Isolated (track isolation) - Passes 'golden' electron Id

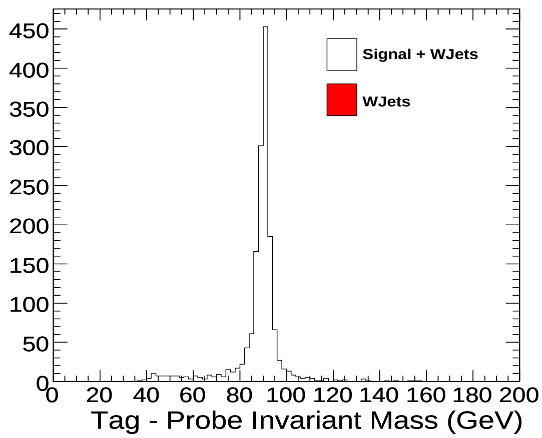


Figure 40: Tag Probe Invariant Mass for Total

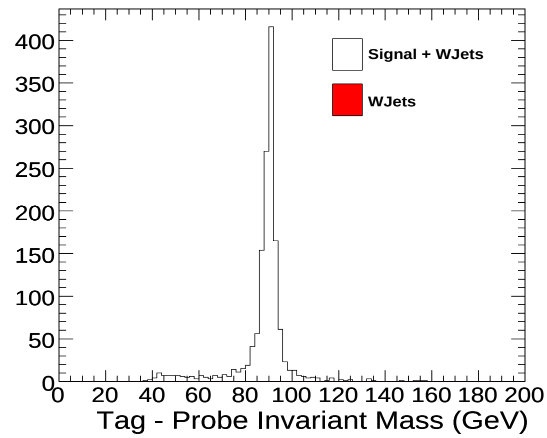


Figure 41: Tag Probe Invariant Mass for Probes passing

Table 19: Integrated efficiencies (L1+HLT)

Class	Region	Value
Golden	EB	0.902± 0.009
Golden	EE	0.973 ± 0.015
Big Brem	EB	0.869± 0.022
Big Brem	EE	0.981 ± 0.019
Narrow	EB	0.893± 0.017
Narrow	EE	0.969 ± 0.021
Showering	EB	0.611 ± 0.013
Showering	EE	0.788 ± 0.012
ALL	EB	0.757 ± 0.007
ALL	EE	0.824 ± 0.011

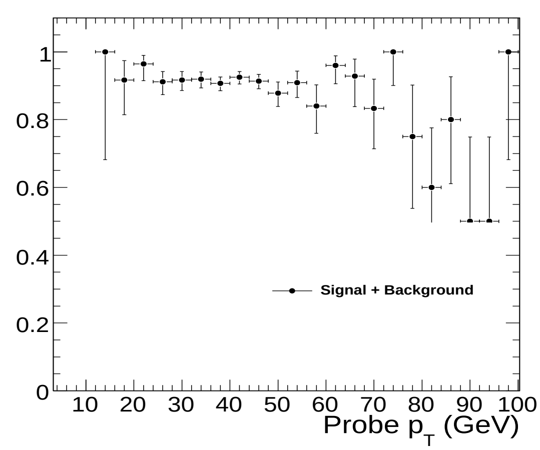


Figure 42: L1+HLT efficiency for probes classified as ‘golden’ versus probe E_T

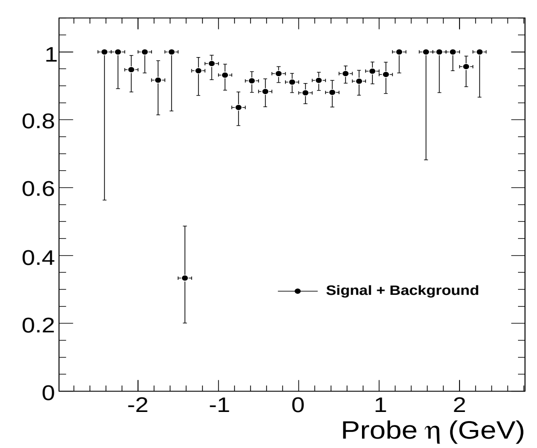


Figure 43: L1+HLT efficiency for probes classified as ‘golden’ versus probe η

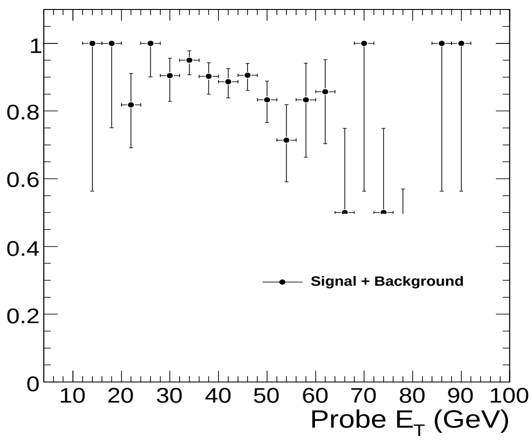


Figure 44: L1+HLT efficiency for probes classified as ‘big-brem’ versus probe E_T

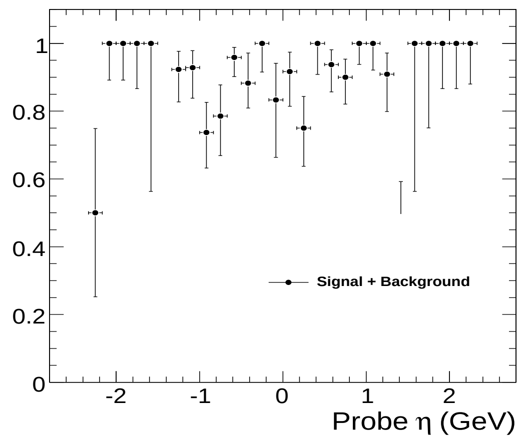


Figure 45: L1+HLT efficiency for probes classified as ‘big-brem’ versus probe η

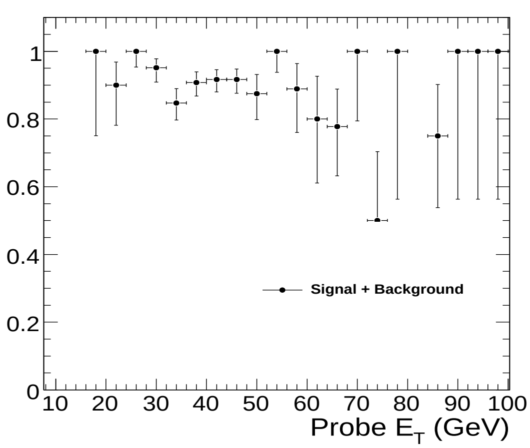


Figure 46: L1+HLT efficiency for probes classified as ‘narrow’ versus probe E_T

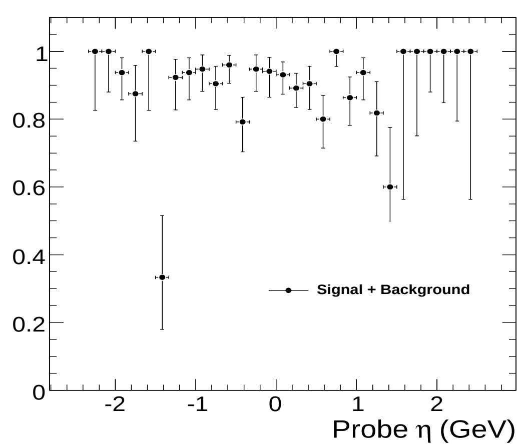


Figure 47: L1+HLT efficiency for probes classified as ‘narrow’ versus probe η

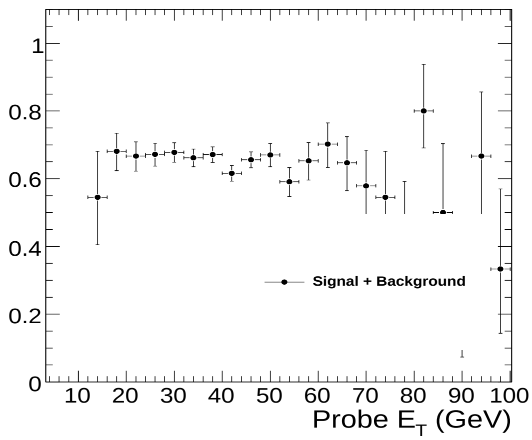


Figure 48: L1+HLT efficiency for probes classified as 'showering' versus probe E_T

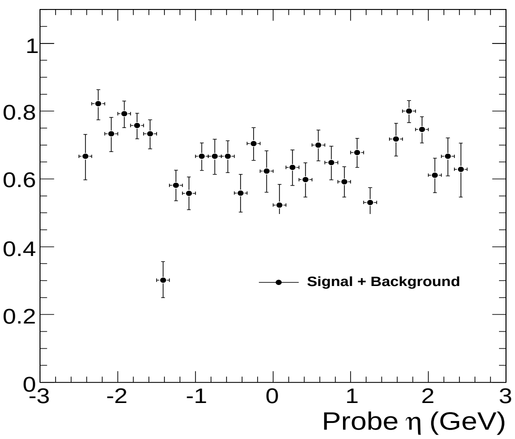


Figure 49: L1+HLT efficiency for probes classified as 'showering' versus probe η

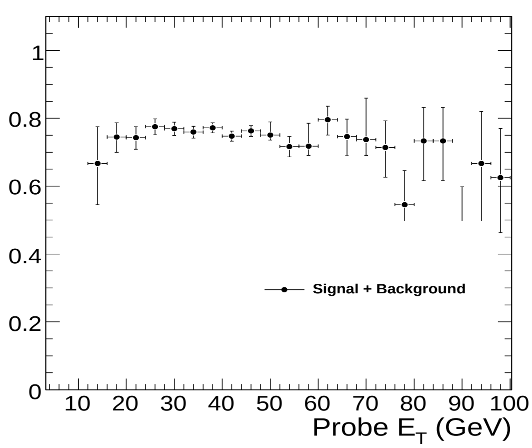


Figure 50: L1+HLT efficiency for probes for ALL classes versus probe E_T

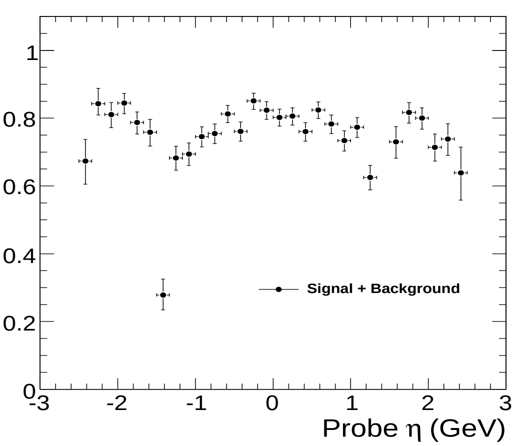


Figure 51: L1+HLT efficiency for probes for ALL classes versus probe η

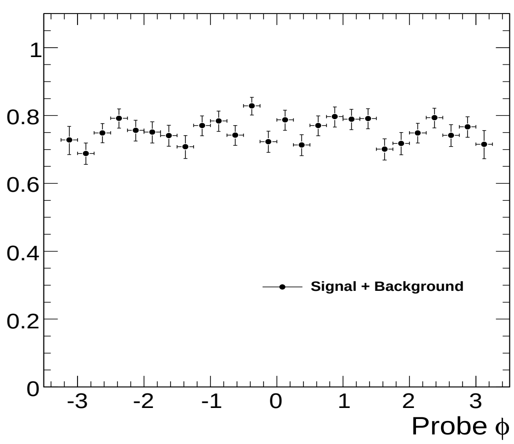


Figure 52: L1+HLT efficiency for probes for ALL classes versus probe ϕ

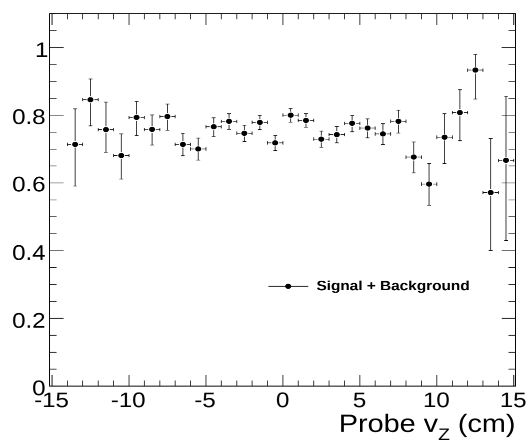


Figure 53: L1+HLT efficiency for probes for ALL classes versus probe z_{vtx}

8.3 Cumulative Offline and Online Efficiency

In this sub-section we present the cumulative offline and online electron efficiencies, *i.e.* our measurement of the efficiency with which one can trigger on and reconstruct an electron at CMS given our choice of trigger, electron id requirements etc. Note that no attempt was made to optimise these choices - the aim of this note is simply to illustrate a method of measuring the efficiency for any choices that CMS might eventually adopt. Note also that in order to apply this efficiency to a measurement of a specific physics process, one will have to take into account the topology of that processes final state as discussed in Section 9.

We measure a cumulative offline and online efficiency for all electron classifications of $0.59 \pm 0005\%$. We also show this result as a function of SuperCluster E_T and η in Figs. 54 and 55.

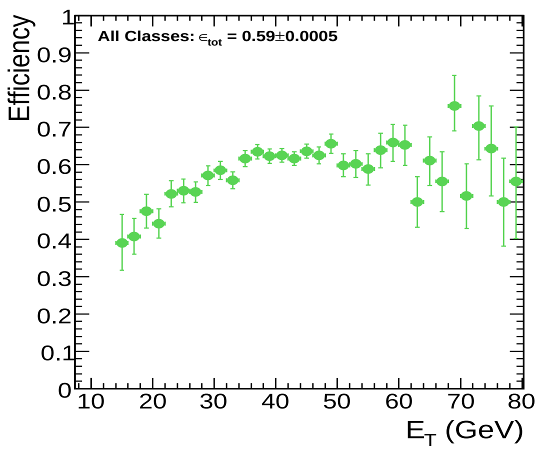


Figure 54: Cumulative offline and online efficiency for all electron classifications versus probe E_T

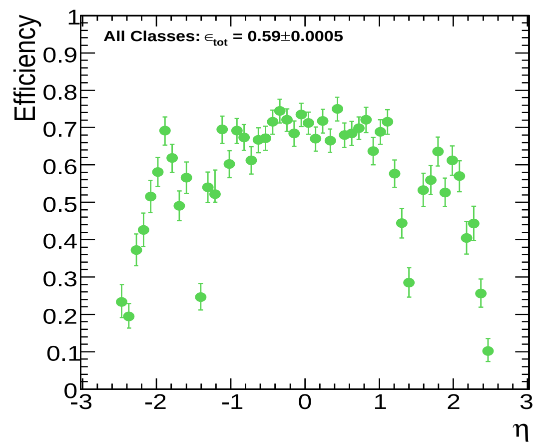


Figure 55: Cumulative offline and online efficiency for all electron classifications versus probe η

9 Application to Cross-Section Measurements

9.1 Representative Measurement of the Z Cross-section

Using an online and offline selection reflecting that for which we have measured the efficiency, a simple estimate of the $pp \rightarrow \gamma^* Z \rightarrow e^+ e^-$ cross section may be made. Events from our signal plus background simulated data sample representing 10 pb^{-1} are selected with the requirement that the `HLT1Electron` trigger has fired. The offline selection of two PixelMatchGsfElectrons is made requiring that both are in the fiducial barrel region ($|\eta| < 1.4442$) with an $E_T > 20$ GeV. Both are required to pass the loose cut based electron ID for the golden classification[12] and be isolated according to the track isolation criteria defined previously.

The cross section is evaluated using the following formula:

$$\sigma \; \times \; BR \left(pp \rightarrow Z/\gamma^* \rightarrow e^+ e^- \right) \; = \; \frac{N_{selected} - N_{bkgd}}{\mathcal{A} \; \times \; \varepsilon_{tot} \; \times \; \int \mathcal{L} dt} \tag{15}$$

where $N_{selected}$ is the sum of the signal and background events that pass the selection criteria, $\mathcal{A}$ is the signal acceptance, and $\int \mathcal{L} dt$ is the integrated luminosity of the dataset, which we take to be 10 pb^{-1} for this study. We estimate N_{bkgd} using the same-sign method described in this work and find it to be consistent with zero.

The total event efficiency is defined as:

$$\varepsilon_{total} \; = \; \varepsilon^2_{offline} \; \times \; \varepsilon_{trigger} \tag{16}$$

[12] This is done for simplicity only. For an actual 10 pb^{-1}measurement of $\sigma(Z)$ where statistical uncertainty would be a concern, the use other classifications besides golden would likely be warranted.

where the $\varepsilon_{offline}$ is the factorized efficiency calculated in Section 8.1. We square $\varepsilon_{offline}$ in order to get the event efficiency since we demand two electrons in the final state.

The trigger efficiency, $\varepsilon_{trigger}$, is the efficiency for an event to pass the single electron trigger described previously. This trigger can be fired by one or both electrons, so the trigger efficiency is equal to one minus the probability that both electrons fail to fire the trigger:

$$\varepsilon_{trigger} = 1 - (1 - \varepsilon_{online})^2 \tag{17}$$

where ε_{online} is the efficiency calculated in Section 8.2. Table 20 gives a summary of the results:

Table 20: Results for the $pp \rightarrow \gamma^* Z \rightarrow e^+e^-$ cross section measurement.

$N_{selected}$	215 ± 14.7
N_{bkgd}	0
$\varepsilon_{clustering}$	0.984 ± 0.005
$\varepsilon_{tracking}$	0.949 ± 0.003
ε_{gsfele}	0.973 ± 0.003
$\varepsilon_{isolation}$	0.962 ± 0.003
$f^{golden}_{classification}$	0.288 ± 0.007
ε_{ID}	0.917 ± 0.008
$\varepsilon_{offline}$	0.231 ± 0.006
ε_{online}	0.902 ± 0.009
$\varepsilon_{trigger}$	0.990 ± 0.015
ε_{total}	0.053 ± 0.002
Acceptance	0.189 ± 0.004
Integrated Luminosity	10 pb^{-1}
$\sigma \times BR(pp \rightarrow \gamma^* Z \rightarrow e^+e^-)$	2.15 ± 0.18 nb
NLO cross-section used to set $\int \mathcal{L}dt$ of the sample (M_{ee} >40)	2.1 nb

As can be seen, the our $pp \rightarrow \gamma^* Z \rightarrow e^+e^-$ cross section determination is consistent with the agreement with the NLO cross-section used to set the integrated luminosity of the sample. This is a positive sign that the selection efficiencies are correctly estimated with the tag & probe method and they don't significantly bias the cross section measurement.

9.2 Measurements of Other Processes

While the use of the efficiencies tabulated in this note for the measurement of the $pp \rightarrow \gamma^* Z \rightarrow e^+e^-$ cross section is straightforward, for measurements of other physics processes things may become more complicated. Other physics processes will, in general, have different kinematics than Z's and it may be necessary to have the efficiencies binned in two (or more) variables as discussed above. For example, the measurement of the $W \rightarrow e\nu$ cross-section detailed in AN-2007/026 efficiencies binned in η and E_T, as in Appendix F are used. If more than two variables are needed to parameterize the efficiency, binned efficiencies would quickly become unsustainable. In this case, the value of the "tag & probe" tools presented in this note might be to use them to calculate scale-factors for the CMS simulation and to use the calibrated simulation to measure acceptance times efficiency directly.[13)]

Other physics processes will, in general, also have different isolation than the $Z \rightarrow e^+e^-$ events which we have used to measure the efficiencies presented in this note, limiting the applicability of the efficiencies we have calculated.[14)].

13) This has the benefit that while the efficiency may well vary as a function of several variables, it is much less likely that any discrepancy between the modelling of the efficiency and that efficiency as measured in data will also vary as a function of those variables.

9.3 Uncertainties on the Measurements

With an integrated luminosity of 10 pb^{-1}, the precision of the most of the efficiency measurements described in this note will be dominated by the statistical uncertainty arising from the number events selected with a suitable tag & probe combination. By the time that 1 fb^{-1} integrated luminosity is collected, however, these same efficiency measurements will likely be limited by systematic uncertainties. Some potential sources of systematic uncertainty are listed below:

- Uncertainties in the Background Estimate
- Uncertainties in the Background Subtraction/Correction
- Correlations that have not been taken into account
- Hidden (or forgotten) sources of inefficiency

10 Summary and Outlook

In this note we have presented the "tag & probe" tools that have been developed within the E/gamma POG to measure both online and offline electron efficiencies from data at CMS. We have described their implementation in CMMSW and shown their validation with MC truth. We have also presented several methods for background estimation and the subsequent correction of efficiencies due to this background contamination. Finally, to demonstrate the use of these tools in a "realistic" measurement, we have applied our "tag & probe" tools to a particular electron efficiency factorization scheme appropriate to the measurement of $\sigma \times BR(pp \rightarrow \gamma^* Z \rightarrow e^+e^-)$. We then compute the resulting cross-section and find agreement with the NLO cross-section used to set the integrated luminosity of the sample.

References

[1] **CDF Note 7309**, C. Hill et. al., *Electron Identification in Offline Release 5.3.* (2005).

[2] **CMS AN 2007/026**, Adams et al., *"Measurement of Inclusive $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$ Cross Sections in pp Collisions at $\sqrt{s} = 14$ TeV "*.

[3] **CMS Note 2006/040**, Baffioni et al., *"Electron Reconstruction in CMS"*.

[4] *https://twiki.cern.ch/twiki/bin/view/CMS/GeneratorProduction2007CMSSW123*

[5] **CERN/LHCC 2007-021 LHCC-G-134**, *CMS Collaboration*

[6] *http://cmsdoc.cern.ch/ anikiten/cms-higgs/sm_cross-sections.txt*

[7] **CMS NOTE 2006/047**, G. Davatz et al., *"Standard Model Higgs Discovery Potential of CMS in the H → WW → $l\nu l\nu$ Channel"*.

[8] **CMS NOTE 2006/115**, S. Baffioni et al., *"Discovery potential for the SM Higgs boson in the H → ZZ(*) → $e^+e^-e^+e^-$ decay channel"*.

[14] With an alternative factorisation scheme where the isolation efficiency is "factored" out, it could be possible to make the remainder of the calculations more generally applicable. Such a possibility may be explored in a future AN

A Electron ID criteria

This appendix details the cuts used for the various electron classifications in the EB and EE that correspond to the "loose" electron identification criteria used through this AN.

Table 21: Loose electron ID used in the measurements in this work

Variable	EB Golden	EB BigBrem	EB Narrow	EB Showering	EE Golden	EE BigBrem	EE Narrow	EE Showering
EoverPInMax	1.3	1.2	1.3	999	999	999	999	99
EoverPInMin	0.9	0.9	0.9	0.6	0.9	0.9	0.9	0.7
deltaEtaIn	0.004	0.006	0.005	0.007	0.007	0.008	0.007	0.008
deltaPhiIn	0.04	0.07	0.04	0.08	0.06	0.07	0.06	0.07
HoverE	0.06	0.05	0.06	0.14	0.1	0.1	0.1	0.12
E9overE25	0.7	0.75	0.8	0	0.85	0.75	0.8	0
EoverPOutMax	2.5	999	999	999	2	999	999	999.
EoverPOutMin	0.6	1.8	1	0.75	0.6	1.5	1	0.8
deltaPhiOut	0.011	999	999	999	0.02	999	999	999
invEMinusInvP	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
bremFraction	0	0.1	0.1	0.1	0	0.2	0.2	0.2
sigmaEtaEtaMax	0.011	0.011	0.011	0.011	0.022	0.022	0.022	0.3
sigmaEtaEtaMin	0.005	0.005	0.005	0.005	0.008	0.008	0.008	0
sigmaPhiPhiMax	0.015	999	999	999	0.02	999	999	999
sigmaPhiPhiMin	0.005	0	0	0	0	0	0	0

B Efficiency estimation and uncertainties

The typical configuration of a tag-and-probe efficiency measurement consists of a tight tag selection for one lepton, and a probe selection for another lepton. Among the set of all N events with exactly one lepton pair satisfying these requirements, a subset of N_{TP} events is selected for which one lepton passes the tag selection t, and another lepton passes a test selection x in addition to a probe selection p. If the tag selection is such that there is no overlap with the probe selection (i.e. no tag candidate satisfies all probe candidate criteria), and if there is no background to be subtracted, then the efficiency of the test selection x relative to the probe selection p is simply $\epsilon(x|p) = N_{TP}/(N_{TP} + N_{TF})$, where N_{TF} is the number of events with one tag candidate, and one probe candidate which fails the test selection. $N = N_{TP} + N_{TF}$, and N_{TP} and N_{TF} are uncorrelated Poisson statistics. Simple uncorrelated error propagation results in a variance $\delta\epsilon^2 = \epsilon(1-\epsilon)/N$, the familiar binomial error formula. For various reasons, the tag and probe selection are usually allowed to overlap. In this more general case, the formula for ϵ and $\delta\epsilon^2$ are modified.

Consider the set e of all leptons passing selections t, p, or x. For simplicity, we shall require that $x \subseteq p$ (the test selection is tighter than the probe selection) and $t \cap p = t \cap x$ (if a tag passes the probe selection, it also passes the test selection)*Have yet to compute the more complicated general case where this last condition does not hold*. Then e is composed of four disjoint subsets: $e = (t-p) \cup (t \cap x) \cup (x - t \cap x) \cup (p - x)$. In words, there are tags which are not probes ($T' \equiv t - p$), tags which pass the probe and test selections ($T \equiv t \cap x$), probes which pass the test selection but not the tag selection ($P \equiv x - t \cap x$), and probes which fail the test selection ($F \equiv p - x$), respectively. The respective probabilities for a lepton to belong to each category are

$$\begin{aligned}
Prob(T') &= 1 - \epsilon_p, \\
Prob(T) &= \epsilon_p \epsilon_{x|p} \epsilon_{t|x|p}, \\
Prob(P) &= \epsilon_p \epsilon_{x|p} (1 - \epsilon_{t|x|p}), \\
Prob(F) &= \epsilon_p (1 - \epsilon_{x|p}),
\end{aligned}$$

where ϵ_p is the relative abundance in e of leptons passing the probe selection, $\epsilon_{x|p}$ is the efficiency of the test selection relative to the probe selection (this is typically the quantity we wish to measure), and $\epsilon_{t|x|p}$ is the probability of passing the tag selection given that the lepton has passed the test selection.

Now consider the set $e \times e$ of lepton pairs. In a tag and probe measurement, we only consider lepton pairs for which at least one lepton passes the tag selection, and the other passes the probe selection. There are six distinct pairings of leptons in the four lepton categories: $T'T$, $T'P$, $T'F$, TT, TP, TF. The respective probabilities for these six different combinations relative to the set $e \times e$ of all lepton pairs are

$$
\begin{aligned}
Prob(T'T) &= 2Prob(T')Prob(T) = 2(1-\epsilon_p)\epsilon_p\epsilon_{x|p}\epsilon_{t|x|p}, \\
Prob(T'P) &= 2Prob(T')Prob(P) = 2(1-\epsilon_p)\epsilon_p\epsilon_{x|p}(1-\epsilon_{t|x|p}), \\
Prob(T'F) &= 2Prob(T')Prob(F) = 2(1-\epsilon_p)\epsilon_p(1-\epsilon_{x|p}), \\
Prob(TT) &= Prob(T)Prob(T) = \epsilon_p^2\epsilon_{x|p}^2\epsilon_{t|x|p}^2, \\
Prob(TP) &= 2Prob(T)Prob(P) = 2\epsilon_p\epsilon_{x|p}\epsilon_{t|x|p}\epsilon_p\epsilon_{x|p}(1-\epsilon_{t|x|p}), \\
Prob(TF) &= 2Prob(T)Prob(F) = 2\epsilon_p\epsilon_{x|p}\epsilon_{t|x|p}\epsilon_p(1-\epsilon_{x|p}),
\end{aligned}
$$

where we have assumed no correlations in category membership between the two leptons. There are two different ways to achieve each combination (e.g. $Prob(TP) = Prob((T\times P)\cup(P\times T)) = Prob(T\times P)+Prob(P\times T) = 2Prob(T)Prob(P)$), except for TT, which can only happen in one way $Prob(TT) = Prob(T\times T) = Prob(T)^2$. If the total number of events in $e \times e$ is N, we can define the following event counts:

$$
\begin{aligned}
N_{TT} &\equiv N \times Prob(TT), \\
N_{TP} &\equiv N \times (Prob(TP) + Prob(T'T) + Prob(T'P)), \\
N_{TF} &\equiv N \times (Prob(T'F) + Prob(TF)).
\end{aligned}
$$

It can be verified by simple substitution that the test selection efficiency $\epsilon_{x|p}$ is given by

$$\epsilon \equiv \epsilon_{x|p} = (2N_{TT} + N_{TP})/(2N_{TT} + N_{TP} + N_{TF}).$$

Assuming all event counts are uncorrelated Poisson statistics, simple error propagation results in the variance

$$\delta\epsilon^2 = (\epsilon(1-\epsilon)/N)(1 + (1-\epsilon)f_{TT}),$$

where $N \equiv 2N_{TT}+N_{TP}+N_{TF}$ (the number of all leptons in the tag-and-probe sample passing the test selection) and $f_{TT} \equiv 2N_{TT}/(2N_{TT} + N_{TP})$ (the relative abundance, of leptons passing the test selection, which belong to double-tag events). If tags and probes are not allowed to overlap, then $f_{TT} = 0$, and we recover the familiar binomial error formula. Otherwise, the variance is enhanced by a factor between 1 and $(2-\epsilon)$, as f_{TT} varies from 0 to 1.

A toy MC study should validate this last claim and be presented here.

B.1 Binned efficiencies

To apply tag-and-probe efficiencies to other samples, it is desirable to compute them in bins of lepton or event characteristics, so that the efficiency in some other sample can be estimated by convolving the binned efficiency with the distribution of the characteristics $(x, y, z, ...)$ in that sample:

$$\epsilon = \sum_{i,j,k,...} \frac{1}{N}\frac{dN(x_i, y_j, z_k, ...)}{dxdydz...}\epsilon_{ijk...}.$$

We can design a binned tag and probe measurement by restricting p and x selection to the ijk...th bin of the $(x, y, z, ...)$ distribution, but applying no such restriction to the tag selection. Without loss of generality, we can renumber the bins so that there is a single index i ranging over all m of them. Then the efficiency of test selection in the ith bin is given by

$$
\begin{aligned}
\epsilon_i &= (2N_{TT,i} + N_{TP,i})/(2N_{TT,i} + N_{TP,i} + N_{TF,i}), \\
N_{TT,i} &= N_{T_iT_i}, \\
N_{TP,i} &= N_{T_iT'} + N_{P_iT'} + \sum_{j\neq i} N_{T_iT_j} + \sum_j N_{P_iT_j}, \\
N_{TF,i} &= N_{F_iT'} + \sum_j N_{F_iT_j},
\end{aligned}
$$

where we have partitioned TT, TP, and TF events from the original unbinned selection into m subcategories. The formula for the variance is as above, where now $f_{TT,i} = f_{T_iT_i} = 2N_{TT,i}/(2N_{TT,i} + N_{TP,i})$.

It would appear that the "double-tag correction factor" $(1 + (1-\epsilon)f_{TT})$ has been reduced relative to the unbinned case; in fact, in the limit of very finely binned data it is easily seen that $f_{TT,i}$ goes to zero. This suggests a paradox, for could one improve the unbinned efficiency error by decomposing it into bins, measuring binned efficiencies (with reduced errors), and then recomposing them via the binned formula for ϵ, all without adding any new statistics? Naively, it would seem that one could, for in the simple case of a uniform, uncorrelated x distribution which is independent of the efficiency, $f_{TT,i} = \frac{f_{TT}}{m}$, and

$$\begin{aligned}
\delta\epsilon^2 &= \sum_i (\frac{1}{N}\frac{dN(x_i)}{dx})^2 \delta\epsilon_i^2 \\
&= \sum_i (\frac{1}{m})^2 (\epsilon(1-\epsilon)/(N/m))(1 + f_{TT}(1-\epsilon)/m) \\
&= \frac{1}{m}\sum_i (\epsilon(1-\epsilon)/N)(1 + f_{TT}(1-\epsilon)/m) \\
&= (\epsilon(1-\epsilon)/N)(1 + f_{TT}(1-\epsilon)/m)
\end{aligned}$$

where we have apparently and magically diluted the effect of the correction factor on the unbinned efficiency! A false assumption has been made on the first line, however, which spoils that result: the ϵ_i have been assumed to be uncorrelated, when in general they won't be. Introducing the correlation terms exactly cancels this apparent reduction in error, resolving the paradox, as described below.

The correct application of binned efficiencies requires the calculation of correlations between the ϵ_i. Inspection of the fomulae for $N_{TT,i}$, $N_{TP,i}$, and $N_{TF,i}$ reveals that each pair of binned efficiencies (ϵ_i, ϵ_j) covary due to the common variable $N_{T_iT_j}$. Performing error propagation on the $(5m^2 + 7m)/2$ independent variables upon which ϵ depends,

$$\begin{aligned}
\delta\epsilon^2 \;=\;& \sum_{i,j:i<j} (\frac{\partial\epsilon}{\partial N_{T_iT_j}})^2 \delta N^2_{T_iT_j} + \sum_{i,j} \{(\frac{\partial\epsilon}{\partial N_{P_iT_j}})^2 \delta N^2_{P_iT_j} + (\frac{\partial\epsilon}{\partial N_{F_iT_j}})^2 \delta N^2_{F_iT_j}\} \\
&+ \sum_i \{(\frac{\partial\epsilon}{\partial N_{T_iT_i}})^2 \delta N^2_{T_iT_i} + (\frac{\partial\epsilon}{\partial N_{T_iT'}})^2 \delta N^2_{T_iT'} + (\frac{\partial\epsilon}{\partial N_{P_iT'}})^2 \delta N^2_{P_iT'} + (\frac{\partial\epsilon}{\partial N_{F_iT'}})^2 \delta N^2_{F_iT'}\},
\end{aligned}$$

where the $\frac{\partial\epsilon}{\partial N_{X_iY_j}}$ are given by

$$\begin{aligned}
\frac{\partial\epsilon}{\partial N_{T_iT_j}} &= f_j \frac{\partial\epsilon_j}{\partial N_{T_jT_i}} + f_i \frac{\partial\epsilon_i}{\partial N_{T_iT_j}} \;=\; f_j \frac{1-\epsilon_j}{N_j} + f_i \frac{1-\epsilon_i}{N_i} \\
\frac{\partial\epsilon}{\partial N_{P_iT_j}} &= \frac{\partial\epsilon}{\partial N_{T_iT'}} \;=\; \frac{\partial\epsilon}{\partial N_{P_iT'}} \;=\; f_i \frac{1-\epsilon_i}{N_i} \\
\frac{\partial\epsilon}{\partial N_{F_iT_j}} &= \frac{\partial\epsilon}{\partial N_{F_iT'}} \;=\; f_i \frac{\epsilon_i}{N_i} \\
\frac{\partial\epsilon}{\partial N_{T_iT_i}} &= f_i \frac{2-\epsilon_i}{N_i}.
\end{aligned}$$

The only correlated terms are the cross terms arising from squaring $\frac{\partial\epsilon}{\partial N_{T_iT_j}}$, so that

$$\delta\epsilon^2 = \sum_i f_i^2 \delta\epsilon_i^2 + \sum_{i,j:i<j} 2 f_i f_j \frac{(1-\epsilon_i)(1-\epsilon_j)}{N_i N_j} \delta N^2_{T_iT_j}$$

Returning to our example of uniform uncorrelated efficiency, $f_i = 1/m$, $\epsilon_i = \epsilon$, $N_{T_iT_j} = 2N_{T_iT_i}$, and $N_i = N/m$ for all i, j, so that

$$\delta\epsilon^2 = \sum_i f_i^2 \delta\epsilon_i^2 + \sum_{i,j:i<j} 2 f_i f_j \frac{(1-\epsilon_i)(1-\epsilon_j)}{N_i N_j} \delta N^2_{T_iT_j}$$

$$
\begin{aligned}
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)/m) + \sum_{i,j:i<j} \frac{(2/m^2)(1-\epsilon)^2(2N_{T_iT_i})}{N_i^2} \\
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)/m) + \frac{m(m-1)}{2}\frac{(2/m^2)(1-\epsilon)^2(2N_{T_iT_i})}{N_i^2} \\
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)/m) + \frac{m-1}{m}(1-\epsilon)^2(f_{TT,i}P_i/N_i^2) \\
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)/m) + \frac{m-1}{m}(1-\epsilon)^2((f_{TT}/m)\epsilon/(N/m)) \\
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)/m) + (\epsilon(1-\epsilon)/N)\frac{m-1}{m}f_{TT}(1-\epsilon) \\
&= (\epsilon(1-\epsilon)/N)(1+f_{TT}(1-\epsilon)),
\end{aligned}
$$

and we recover the correct unbinned efficiency variance.

In general, binned efficiency measurements should include a covariance matrix which accounts for these pair-wise $N_{T_iT_j}$ correlations. Alternatively, the covariance matrix could be assumed to be diagonal, and then the resulting statistical uncertainty could be conservatively amplified by a factor of $\sqrt{2-\epsilon}$.

C Cross-check of Factorization Equivalence

In this section we repeat the calculations presented in Section 8 with the alternative factorization scheme described in Section 4.

The offline and online efficiencies are themselves factorized in the same order in both cases. The measured efficiencies for the online relative to offline case are presented in Table 22 and Fig. 56 and Fig. 57. For the offline efficiencies subsequent to online selection, the results are shown in Table 23 and Fig. 58 and Fig. 59. As expected, the results for the total efficiency are consistent between the two factorizations.

Table 22: Efficiency results for factorization scheme where online efficiencies are measured using probes that have passed offline selection.

	ε_{gsfele}	$\varepsilon_{isolation}$	$f_{classification}$	ε_{elID}	ε_{online}	$f \times \varepsilon_{tot}$
Golden	0.892 ± 0.004	0.948 ± 0.003	0.258 ± 0.006	0.830 ± 0.010	0.886 ± 0.010	0.160 ± 0.005
Big Brem	0.892 ± 0.004	0.948 ± 0.003	0.061 ± 0.003	0.932 ± 0.014	0.868 ± 0.020	0.042 ± 0.003
Narrow	0.892 ± 0.004	0.948 ± 0.003	0.080 ± 0.004	0.933 ± 0.012	0.876 ± 0.017	0.055 ± 0.003
Showering	0.892 ± 0.004	0.948 ± 0.003	0.541 ± 0.007	0.937 ± 0.005	0.465 ± 0.009	0.277 ± 0.006

Table 23: Efficiency results for factorization scheme where offline efficiencies are measured using probes that have passed online selection.

	ε_{online}	ε_{gsfele}	$\varepsilon_{isolation}$	$f_{classification}$	ε_{elID}	$f \times \varepsilon_{tot}$
Golden	0.653 ± 0.006	0.986 ± 0.002	0.965 ± 0.001	0.307 ± 0.008	0.861 ± 0.010	0.164 ± 0.005
Big Brem	0.653 ± 0.006	0.986 ± 0.002	0.965 ± 0.001	0.072 ± 0.004	0.937 ± 0.015	0.042 ± 0.003
Narrow	0.653 ± 0.006	0.986 ± 0.002	0.965 ± 0.001	0.090 ± 0.005	0.938 ± 0.013	0.052 ± 0.003
Showering	0.653 ± 0.006	0.986 ± 0.002	0.965 ± 0.001	0.464 ± 0.008	0.949 ± 0.005	0.274 ± 0.006

Fig. 56 shows the total efficiency vs. probe E_T for probes classified as golden to pass all the offline cuts in the sequence shown in Table 23. Fig. 57 shows the efficiency vs. probe E_T for probes that pass the trigger (L1 and HLT) given that they have already passed the offline cuts and were classified as golden. Fig. 58 displays the trigger efficiency vs. probe SuperCluster E_T for all probe SuperClusters. Fig. 59 shows the efficiency vs. probe SuperCluster E_T for probes passing the golden offline cuts given that they have already passed trigger.

The total efficiency in the case where the offline selection is applied first is the product of offline and online efficiencies $= 0.181 \pm 0.006 \times 0.886 \pm 0.010 = 0.16 \pm 0.01$. The total efficiency in the case where the online selection is applied first is the product of online and offline efficiencies $= 0.653 \pm 0.006 \times 0.251 \pm 0.07 = 0.16 \pm 0.01$. From Table 23 and the corresponding Figs. we can see that as long as the efficiency for a certain cut is measured on a sample of probes that have passed all previous cuts, the order in which the cuts are applied does not effect to total value of efficiency.

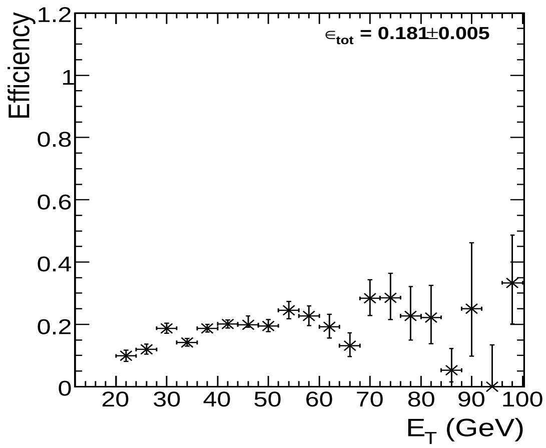


Figure 56: Total offline classification fraction times efficiency vs E_T for golden electrons

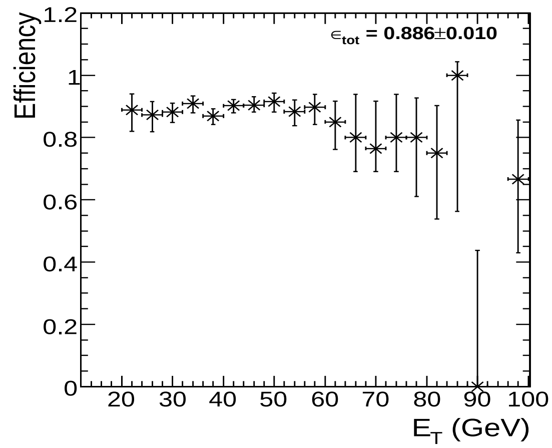


Figure 57: Online efficiency for golden probes passing all offline cuts as a function of probe E_T

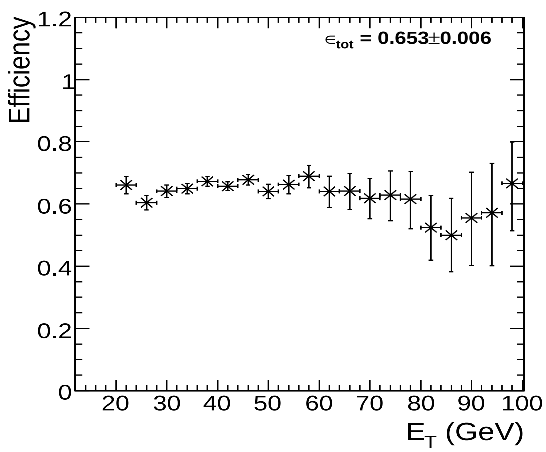


Figure 58: Online efficiency vs E_T for probe SuperClusters

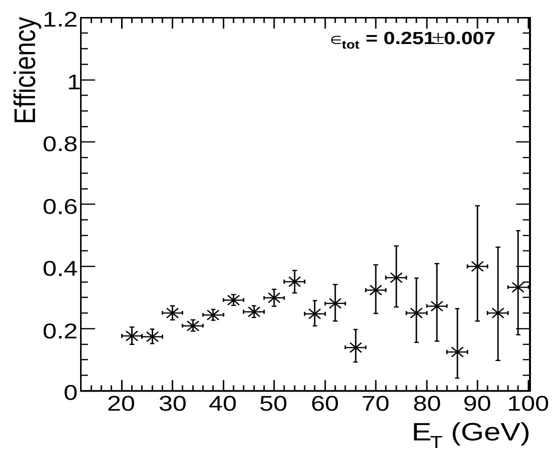


Figure 59: Cumulative offline efficiency times classification fraction for golden electrons as a function of probe E_T for probes that have passed the trigger.

D Illustration of Shape Based Background Subtraction

In order to demonstrate the use of the background subtraction method described in Section 7.3, we present the results of the application of the RooFit based maximum likelihood background subtraction to a subset of the efficiency measurements presented in the body of the note, namely the clustering efficiency $\varepsilon_{\rm clustering}$, and the tracking efficiency $\varepsilon_{\rm tracking}$ versus η.

A typical fit is shown in Fig. 60 for those events that pass and in Fig. 61 for those events which fail. The total fit with the parameters can be seen in Fig. 62. A fit is executed for each efficiency bin and the η trend compared to MC truth is shown in Fig. 63 for the SuperCluster creation efficiency and in Fig. 64 for the tracking efficiency. The background subtracted is consistent with that derived from MC truth as shown in Table 24

Table 24: $10\ pb^{-1}$ Efficiency results for some factorized efficiencies using RooFit background subtraction.

	$\varepsilon_{\rm clustering}$	$\varepsilon_{\rm tracking}$	$\varepsilon_{\rm eid}$	ε_{HLT}
Background With RooFit Subtraction	92.2 ± 0.6	93.3±0.4	93.6±0.4	78.6±0.9
No Background Without Fit (MC Truth)	91.8 ± 0.3	92.0±0.4	92.8±0.3	77.7±0.8

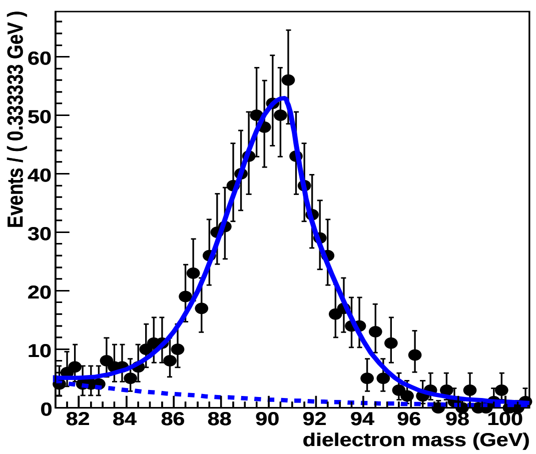


Figure 60: Passing events fitted with respect to the invariant mass PDFs. Dashed is the background shape PDF.

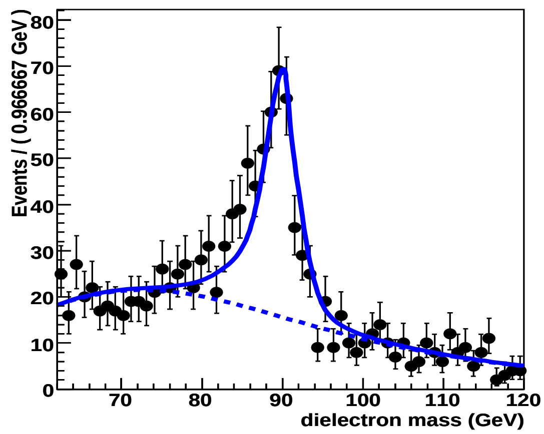


Figure 61: Failing events fitted with respect to the invariant mass PDFs. Dashed is the background shape PDF.

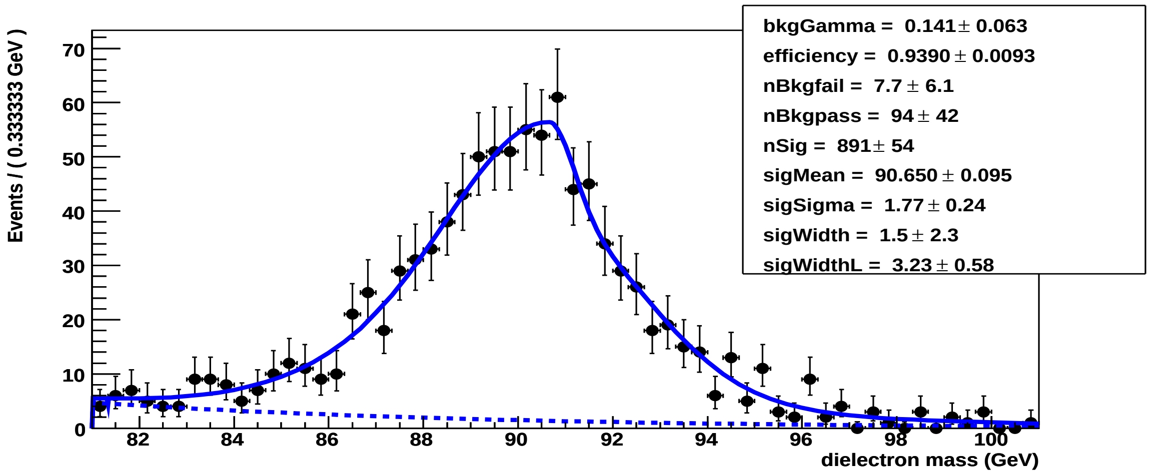


Figure 62: Total events fitted with respect to the invariant mass PDFs. Dashed is the background shape PDF.

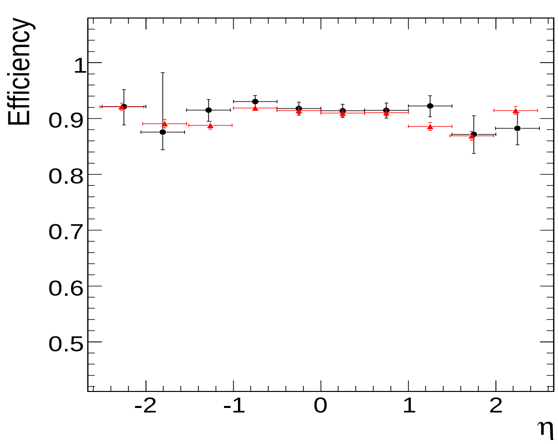


Figure 63: Efficiency of SC creation versus η with background subtracted in black dot, and MC truth in red triangle.

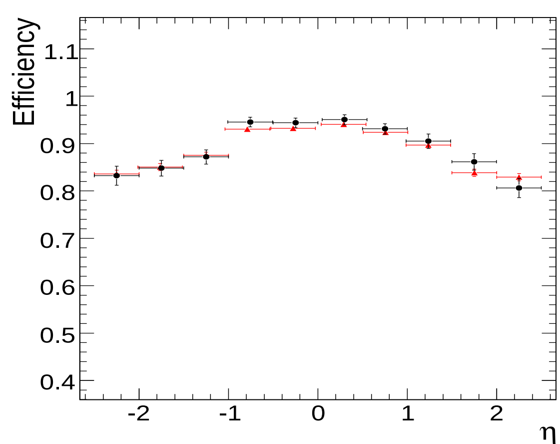


Figure 64: Efficiency of Tracking versus η with background subtracted in black dot, and MC truth in red triangle.

E Alternative factorization using $\varepsilon_{\text{tracking}} \times \varepsilon_{\text{gsfele}}$ combined as a single efficiency

The electron preselection and the tracking efficiency measurement, while useful separately for information on the individual reconstruction steps may be combined for use in analysis. The tag & probe definitions are identical to those given in Table 8 with the exception that in this instance that SuperCluster is not required to match a GSFTrack. In this case the background must be estimated by the sidebands technique and the numbers are given in Table 25 and the invariant mass spectra are shown in Figs. 65 and 66. The measured efficiency is displayed in Figs. 67, 68, 69 and 70.

Table 25: Background Estimates for efficiency of PixelMatchGsfEle from SuperCluster calculation

Region	N^{PASS}	N_B^{PASS}	N^{TOTAL}	N_B^{TOTAL}
EE	1629 ± 40.3609	17.47 ± 0.279	1783 ± 42.2256	52.5 ± 0.315
EB	3917 ± 62.5859	51.8 ± 0.290	4080 ± 63.8749	113.8 ± 0.302

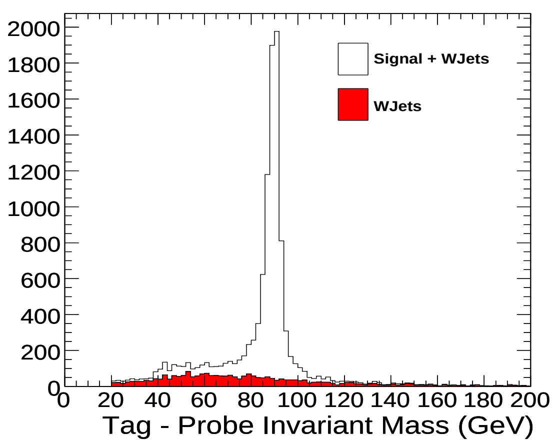


Figure 65: Tag Probe Invariant Mass for Total

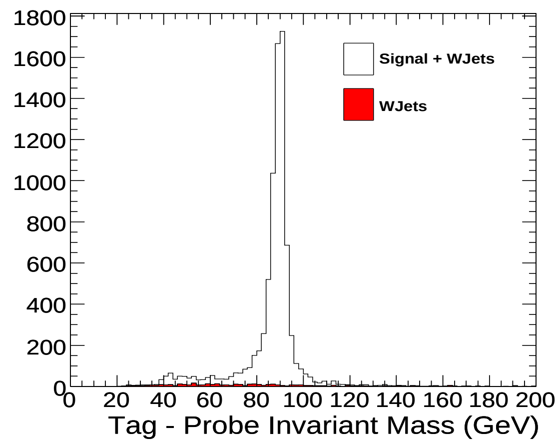


Figure 66: Tag Probe Invariant Mass for Probes passing

Table 26: Integrated efficiencies (GsfEle Creation Efficiency from SuperCluster)

Region	Value
EB (Signal Only)	0.926 ± 0.00405
EB (Signal + Background)	0.902 ± 0.00451
EB (Background Subtracted)	0.916 ± 0.00427
EE (Signal Only)	0.824 ± 0.00857
EE (Signal + Background)	0.798 ± 0.00889
EE (Background Subtracted)	0.812 ± 0.00877

It is expected that the product of the efficiency with which a track matches a SuperCluster and with which a track matched SuperCluster forms a gsf election should equal the efficiency with which a SuperCluster forms a GsfElectron. Using the above results (for the barrel case for example) we obtain (0.949 ± 0.00309) * (0.974 ± 0.00259) = 0.924 ± 0.00388 to be compared with 0.916 ± 0.00427 from the single step determination. The two methods agree within the errors as expected.

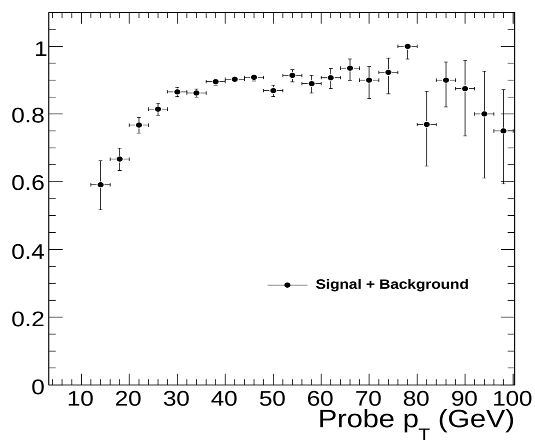


Figure 67: PixelMatchGsfElectron preselection efficiency versus probe E_T

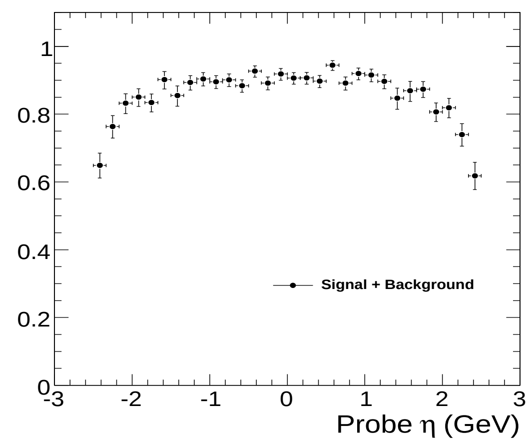


Figure 68: PixelMatchGsfElectron preselection efficiency versus probe η

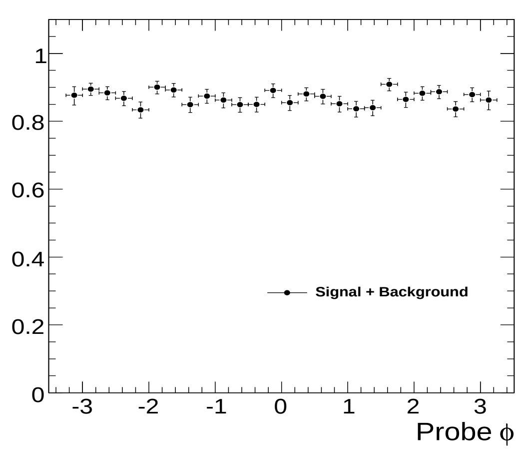


Figure 69: PixelMatchGsfElectron preselection efficiency versus probe ϕ

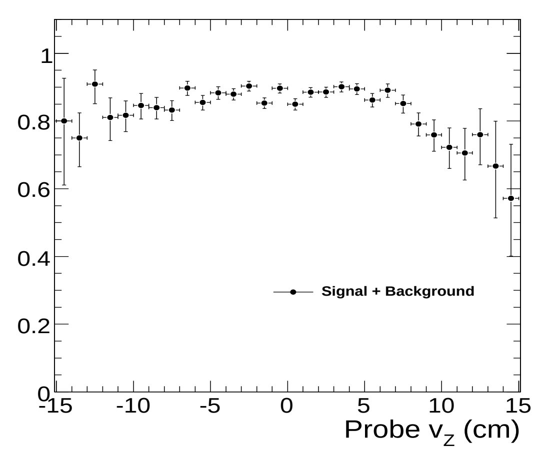


Figure 70: PixelMatchGsfElectron preselection efficiency versus probe z_{vtx}

F Efficiencies binned in η and E_T

Table 27: clustering efficiency results

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$0.00-0.30$	$0.50^{0.50}_{0.50}$	$0.75^{0.15}_{0.21}$	$0.94^{0.04}_{0.08}$	$0.97^{0.02}_{0.03}$	$0.99^{0.01}_{0.02}$	$1.00^{0.00}_{0.04}$	$0.67^{0.15}_{0.18}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.25}$	$0.50^{0.50}_{0.50}$
$0.30-0.60$	$0.50^{0.50}_{0.50}$	$0.00^{0.21}_{0.00}$	$0.73^{0.10}_{0.12}$	$1.00^{0.00}_{0.02}$	$1.00^{0.00}_{0.02}$	$0.97^{0.02}_{0.04}$	$1.00^{0.00}_{0.09}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$
$0.60-0.90$	$0.50^{0.50}_{0.50}$	$0.00^{0.13}_{0.00}$	$1.00^{0.00}_{0.05}$	$0.97^{0.02}_{0.03}$	$1.00^{0.00}_{0.02}$	$0.87^{0.07}_{0.10}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.44}$
$0.90-1.20$	$0.50^{0.50}_{0.50}$	$0.00^{0.13}_{0.00}$	$0.84^{0.05}_{0.07}$	$1.00^{0.00}_{0.02}$	$1.00^{0.00}_{0.03}$	$1.00^{0.00}_{0.10}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$
$1.20-1.50$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.94^{0.04}_{0.08}$	$0.97^{0.02}_{0.04}$	$1.00^{0.00}_{0.06}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$
$1.50-1.80$	$0.50^{0.50}_{0.50}$	$0.50^{0.13}_{0.13}$	$0.77^{0.10}_{0.12}$	$0.90^{0.05}_{0.08}$	$1.00^{0.00}_{0.12}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.80-2.10$	$0.50^{0.50}_{0.50}$	$0.43^{0.17}_{0.16}$	$0.74^{0.08}_{0.09}$	$0.80^{0.09}_{0.11}$	$1.00^{0.00}_{0.12}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$
$2.10-2.40$	$0.50^{0.50}_{0.50}$	$0.71^{0.10}_{0.12}$	$1.00^{0.00}_{0.06}$	$0.60^{0.18}_{0.20}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.40-2.70$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.70-3.00$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 28: gsf ele from sc efficiency results (signal only)

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$0.00-0.30$	$0.50^{0.50}_{0.50}$	$0.94^{0.04}_{0.08}$	$0.93^{0.02}_{0.02}$	$0.93^{0.01}_{0.02}$	$0.93^{0.01}_{0.01}$	$0.92^{0.03}_{0.03}$	$0.94^{0.03}_{0.05}$	$1.00^{0.00}_{0.08}$	$1.00^{0.00}_{0.17}$	$1.00^{0.00}_{0.15}$
$0.30-0.60$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.05}$	$0.91^{0.02}_{0.03}$	$0.92^{0.01}_{0.02}$	$0.95^{0.01}_{0.01}$	$0.95^{0.02}_{0.03}$	$0.93^{0.03}_{0.05}$	$1.00^{0.00}_{0.07}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.32}$
$0.60-0.90$	$0.50^{0.50}_{0.50}$	$0.88^{0.05}_{0.07}$	$0.92^{0.02}_{0.03}$	$0.92^{0.01}_{0.02}$	$0.93^{0.01}_{0.01}$	$0.90^{0.03}_{0.04}$	$0.94^{0.04}_{0.08}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.44}$
$0.90-1.20$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.05}$	$0.92^{0.02}_{0.03}$	$0.92^{0.01}_{0.02}$	$0.94^{0.01}_{0.02}$	$0.96^{0.02}_{0.03}$	$0.97^{0.02}_{0.05}$	$0.92^{0.06}_{0.10}$	$1.00^{0.00}_{0.21}$	$0.50^{0.25}_{0.25}$
$1.20-1.50$	$0.50^{0.50}_{0.50}$	$0.92^{0.06}_{0.10}$	$0.87^{0.03}_{0.04}$	$0.90^{0.02}_{0.02}$	$0.91^{0.02}_{0.02}$	$0.85^{0.04}_{0.05}$	$0.95^{0.04}_{0.07}$	$0.75^{0.15}_{0.21}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.44}$
$1.50-1.80$	$0.50^{0.50}_{0.50}$	$0.87^{0.07}_{0.10}$	$0.86^{0.03}_{0.04}$	$0.84^{0.03}_{0.03}$	$0.97^{0.01}_{0.01}$	$0.91^{0.03}_{0.05}$	$0.83^{0.07}_{0.10}$	$0.89^{0.08}_{0.13}$	$0.75^{0.15}_{0.21}$	$0.50^{0.50}_{0.50}$
$1.80-2.10$	$0.50^{0.50}_{0.50}$	$0.79^{0.06}_{0.07}$	$0.89^{0.03}_{0.03}$	$0.85^{0.02}_{0.03}$	$0.85^{0.02}_{0.03}$	$0.95^{0.02}_{0.03}$	$0.92^{0.05}_{0.10}$	$1.00^{0.00}_{0.17}$	$1.00^{0.00}_{0.21}$	$0.50^{0.20}_{0.20}$
$2.10-2.40$	$0.50^{0.50}_{0.50}$	$0.74^{0.08}_{0.09}$	$0.80^{0.04}_{0.04}$	$0.79^{0.03}_{0.03}$	$0.76^{0.03}_{0.03}$	$0.74^{0.05}_{0.06}$	$0.78^{0.11}_{0.15}$	$1.00^{0.00}_{0.15}$	$0.20^{0.19}_{0.13}$	$0.50^{0.50}_{0.50}$
$2.40-2.70$	$0.50^{0.50}_{0.50}$	$0.50^{0.14}_{0.14}$	$0.61^{0.08}_{0.08}$	$0.58^{0.06}_{0.07}$	$0.68^{0.06}_{0.07}$	$0.71^{0.10}_{0.12}$	$0.67^{0.19}_{0.24}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$
$2.70-3.00$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 29: isolation efficiency results (background considered zero and not subtracted)

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$0.00-0.30$	$0.50^{0.50}_{0.50}$	$0.88^{0.09}_{0.07}$	$0.88^{0.02}_{0.03}$	$0.96^{0.01}_{0.01}$	$1.00^{0.00}_{0.00}$	$1.00^{0.00}_{0.01}$	$1.00^{0.00}_{0.03}$	$0.94^{0.04}_{0.08}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.13}$
$0.30-0.60$	$0.50^{0.50}_{0.50}$	$0.89^{0.05}_{0.07}$	$0.85^{0.03}_{0.03}$	$0.97^{0.01}_{0.01}$	$0.99^{0.00}_{0.01}$	$1.00^{0.00}_{0.01}$	$1.00^{0.00}_{0.03}$	$1.00^{0.00}_{0.05}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.32}$
$0.60-0.90$	$0.50^{0.50}_{0.50}$	$0.86^{0.05}_{0.07}$	$0.87^{0.03}_{0.03}$	$0.97^{0.01}_{0.01}$	$0.99^{0.01}_{0.01}$	$0.99^{0.01}_{0.02}$	$1.00^{0.00}_{0.05}$	$1.00^{0.00}_{0.10}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.32}$
$0.90-1.20$	$0.50^{0.50}_{0.50}$	$0.62^{0.09}_{0.10}$	$0.87^{0.03}_{0.03}$	$0.95^{0.01}_{0.01}$	$0.97^{0.01}_{0.01}$	$0.98^{0.01}_{0.02}$	$1.00^{0.00}_{0.02}$	$1.00^{0.00}_{0.09}$	$1.00^{0.00}_{0.11}$	$1.00^{0.00}_{0.32}$
$1.20-1.50$	$0.50^{0.50}_{0.50}$	$0.67^{0.11}_{0.12}$	$0.85^{0.03}_{0.04}$	$0.91^{0.02}_{0.02}$	$0.96^{0.01}_{0.02}$	$1.00^{0.00}_{0.01}$	$1.00^{0.00}_{0.05}$	$0.67^{0.15}_{0.18}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.32}$
$1.50-1.80$	$0.50^{0.50}_{0.50}$	$0.72^{0.09}_{0.11}$	$0.91^{0.03}_{0.03}$	$0.95^{0.01}_{0.02}$	$0.99^{0.01}_{0.01}$	$0.98^{0.01}_{0.03}$	$1.00^{0.00}_{0.05}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.44}$
$1.80-2.10$	$0.50^{0.50}_{0.50}$	$0.84^{0.06}_{0.07}$	$0.84^{0.03}_{0.03}$	$0.96^{0.01}_{0.01}$	$0.95^{0.02}_{0.02}$	$0.98^{0.01}_{0.02}$	$0.86^{0.07}_{0.11}$	$1.00^{0.00}_{0.17}$	$0.80^{0.13}_{0.19}$	$1.00^{0.00}_{0.25}$
$2.10-2.40$	$0.50^{0.50}_{0.50}$	$0.84^{0.06}_{0.08}$	$0.92^{0.02}_{0.03}$	$0.95^{0.02}_{0.02}$	$0.97^{0.01}_{0.02}$	$0.98^{0.02}_{0.03}$	$0.89^{0.08}_{0.13}$	$0.60^{0.18}_{0.20}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$
$2.40-2.70$	$0.50^{0.50}_{0.50}$	$0.88^{0.08}_{0.14}$	$0.90^{0.04}_{0.06}$	$0.97^{0.02}_{0.04}$	$1.00^{0.00}_{0.03}$	$0.90^{0.07}_{0.12}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.70-3.00$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 30: efficiency results (golden classification background considered zero and not subtracted

	0.00 − 10.00	10.00 − 20.00	20.00 − 30.00	30.00 − 40.00	40.00 − 50.00	50.00 − 60.00	60.00 − 70.00	70.00 − 80.00	80.00 − 90.00	90.00 − 100.00
0.00 − 0.30	$0.50^{0.50}_{0.50}$	$0.27^{0.12}_{0.10}$	$0.38^{0.04}_{0.04}$	$0.50^{0.03}_{0.03}$	$0.45^{0.03}_{0.03}$	$0.56^{0.05}_{0.05}$	$0.49^{0.08}_{0.08}$	$0.67^{0.11}_{0.12}$	$0.50^{0.18}_{0.18}$	$0.43^{0.17}_{0.16}$
0.30 − 0.60	$0.50^{0.50}_{0.50}$	$0.25^{0.09}_{0.08}$	$0.36^{0.04}_{0.04}$	$0.33^{0.03}_{0.03}$	$0.34^{0.03}_{0.03}$	$0.35^{0.05}_{0.05}$	$0.37^{0.07}_{0.07}$	$0.35^{0.11}_{0.10}$	$0.50^{0.18}_{0.18}$	$0.50^{0.25}_{0.25}$
0.60 − 0.90	$0.50^{0.50}_{0.50}$	$0.28^{0.09}_{0.08}$	$0.25^{0.04}_{0.04}$	$0.25^{0.03}_{0.02}$	$0.27^{0.02}_{0.02}$	$0.31^{0.05}_{0.05}$	$0.35^{0.11}_{0.10}$	$0.20^{0.14}_{0.10}$	$0.57^{0.16}_{0.17}$	$0.00^{0.32}_{0.00}$
0.90 − 1.20	$0.50^{0.50}_{0.50}$	$0.00^{0.07}_{0.00}$	$0.13^{0.04}_{0.03}$	$0.19^{0.02}_{0.02}$	$0.20^{0.02}_{0.02}$	$0.30^{0.05}_{0.05}$	$0.23^{0.06}_{0.06}$	$0.18^{0.13}_{0.09}$	$0.00^{0.11}_{0.00}$	$0.00^{0.32}_{0.00}$
1.20 − 1.50	$0.50^{0.50}_{0.50}$	$0.10^{0.12}_{0.07}$	$0.10^{0.04}_{0.03}$	$0.12^{0.03}_{0.02}$	$0.11^{0.02}_{0.02}$	$0.08^{0.03}_{0.03}$	$0.14^{0.09}_{0.06}$	$0.00^{0.21}_{0.00}$	$0.00^{0.25}_{0.00}$	$0.50^{0.25}_{0.25}$
1.50 − 1.80	$0.50^{0.50}_{0.50}$	$0.00^{0.08}_{0.00}$	$0.02^{0.02}_{0.01}$	$0.06^{0.02}_{0.02}$	$0.05^{0.02}_{0.01}$	$0.04^{0.03}_{0.02}$	$0.05^{0.07}_{0.04}$	$0.14^{0.15}_{0.09}$	$0.00^{0.21}_{0.00}$	$0.00^{0.44}_{0.00}$
1.80 − 2.10	$0.50^{0.50}_{0.50}$	$0.22^{0.08}_{0.07}$	$0.19^{0.04}_{0.04}$	$0.10^{0.02}_{0.02}$	$0.11^{0.02}_{0.02}$	$0.13^{0.05}_{0.04}$	$0.25^{0.13}_{0.10}$	$0.00^{0.17}_{0.00}$	$0.00^{0.21}_{0.00}$	$0.67^{0.19}_{0.24}$
2.10 − 2.40	$0.50^{0.50}_{0.50}$	$0.43^{0.11}_{0.10}$	$0.29^{0.05}_{0.05}$	$0.27^{0.04}_{0.04}$	$0.29^{0.04}_{0.04}$	$0.38^{0.07}_{0.07}$	$0.12^{0.14}_{0.08}$	$0.00^{0.25}_{0.00}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$
2.40 − 2.70	$0.50^{0.50}_{0.50}$	$0.29^{0.17}_{0.14}$	$0.32^{0.09}_{0.08}$	$0.29^{0.08}_{0.07}$	$0.47^{0.08}_{0.08}$	$0.44^{0.15}_{0.15}$	$0.33^{0.24}_{0.19}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.70 − 3.00	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 31: golden ID efficiency results (background considered zero and not subtracted)

	0.00 − 10.00	10.00 − 20.00	20.00 − 30.00	30.00 − 40.00	40.00 − 50.00	50.00 − 60.00	60.00 − 70.00	70.00 − 80.00	80.00 − 90.00	90.00 − 100.00
0.00 − 0.30	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.17}$	$0.90^{0.03}_{0.04}$	$0.97^{0.01}_{0.01}$	$0.95^{0.01}_{0.02}$	$0.90^{0.04}_{0.05}$	$0.78^{0.08}_{0.10}$	$1.00^{0.00}_{0.10}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.25}$
0.30 − 0.60	$0.50^{0.50}_{0.50}$	$0.83^{0.11}_{0.17}$	$0.92^{0.03}_{0.05}$	$0.98^{0.01}_{0.01}$	$0.93^{0.02}_{0.02}$	$0.93^{0.03}_{0.05}$	$0.88^{0.09}_{0.07}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$
0.60 − 0.90	$0.50^{0.50}_{0.50}$	$0.86^{0.09}_{0.15}$	$0.96^{0.03}_{0.05}$	$0.91^{0.03}_{0.03}$	$0.88^{0.03}_{0.03}$	$0.93^{0.04}_{0.06}$	$0.78^{0.11}_{0.15}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.21}$	$0.50^{0.50}_{0.50}$
0.90 − 1.20	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.07}$	$0.85^{0.04}_{0.05}$	$0.92^{0.03}_{0.04}$	$0.88^{0.05}_{0.07}$	$0.91^{0.06}_{0.11}$	$0.33^{0.24}_{0.19}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
1.20 − 1.50	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.89^{0.08}_{0.13}$	$0.91^{0.05}_{0.07}$	$0.88^{0.06}_{0.08}$	$0.86^{0.09}_{0.15}$	$1.00^{0.00}_{0.25}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$
1.50 − 1.80	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.25}$	$0.92^{0.05}_{0.10}$	$1.00^{0.00}_{0.09}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
1.80 − 2.10	$0.50^{0.50}_{0.50}$	$0.83^{0.11}_{0.17}$	$0.68^{0.09}_{0.10}$	$0.95^{0.03}_{0.06}$	$0.81^{0.07}_{0.09}$	$0.78^{0.11}_{0.15}$	$1.00^{0.00}_{0.25}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.32}$
2.10 − 2.40	$0.50^{0.50}_{0.50}$	$0.11^{0.13}_{0.08}$	$0.40^{0.09}_{0.08}$	$0.31^{0.07}_{0.06}$	$0.35^{0.07}_{0.07}$	$0.39^{0.11}_{0.11}$	$0.00^{0.44}_{0.00}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.40 − 2.70	$0.50^{0.50}_{0.50}$	$0.00^{0.32}_{0.00}$	$0.00^{0.11}_{0.00}$	$0.00^{0.07}_{0.00}$	$0.00^{0.06}_{0.00}$	$0.00^{0.21}_{0.00}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.70 − 3.00	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 32: hlt efficiency results for golden electrons (background considered zero and not subtracted)

	0.00 − 10.00	10.00 − 20.00	20.00 − 30.00	30.00 − 40.00	40.00 − 50.00	50.00 − 60.00	60.00 − 70.00	70.00 − 80.00	80.00 − 90.00	90.00 − 100.00
0.00 − 0.30	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.21}$	$0.95^{0.03}_{0.04}$	$0.90^{0.02}_{0.03}$	$0.93^{0.02}_{0.02}$	$0.81^{0.06}_{0.07}$	$1.00^{0.00}_{0.08}$	$0.89^{0.08}_{0.13}$	$0.67^{0.19}_{0.24}$	$0.33^{0.24}_{0.19}$
0.30 − 0.60	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.32}$	$0.94^{0.03}_{0.05}$	$0.91^{0.03}_{0.03}$	$0.90^{0.03}_{0.03}$	$0.89^{0.05}_{0.07}$	$0.92^{0.05}_{0.10}$	$0.86^{0.09}_{0.15}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$
0.60 − 0.90	$0.50^{0.50}_{0.50}$	$0.50^{0.25}_{0.25}$	$0.92^{0.05}_{0.07}$	$0.92^{0.03}_{0.04}$	$0.93^{0.03}_{0.03}$	$0.90^{0.05}_{0.08}$	$0.83^{0.11}_{0.17}$	$1.00^{0.00}_{0.32}$	$0.50^{0.20}_{0.20}$	$0.50^{0.50}_{0.50}$
0.90 − 1.20	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.10}$	$0.95^{0.03}_{0.04}$	$0.94^{0.03}_{0.04}$	$0.89^{0.06}_{0.08}$	$1.00^{0.00}_{0.11}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
1.20 − 1.50	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.83^{0.11}_{0.17}$	$0.59^{0.11}_{0.12}$	$0.76^{0.15}_{0.07}$	$0.75^{0.15}_{0.21}$	$0.67^{0.19}_{0.24}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
1.50 − 1.80	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.12}$	$1.00^{0.00}_{0.11}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
1.80 − 2.10	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.08}$	$1.00^{0.00}_{0.06}$	$1.00^{0.00}_{0.07}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.32}$
2.10 − 2.40	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.11}$	$0.92^{0.05}_{0.10}$	$1.00^{0.00}_{0.10}$	$0.83^{0.11}_{0.17}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.40 − 2.70	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.70 − 3.00	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 33: hlt efficiency results for showering electrons (background considered zero and not subtracted)

	0.00 − 10.00	10.00 − 20.00	20.00 − 30.00	30.00 − 40.00	40.00 − 50.00	50.00 − 60.00	60.00 − 70.00	70.00 − 80.00	80.00 − 90.00	90.00 − 100.00
3.00 − 2.70	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.70 − 2.40	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$	$0.67^{0.11}_{0.12}$	$0.63^{0.10}_{0.11}$	$0.62^{0.11}_{0.12}$	$0.67^{0.19}_{0.24}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.40 − 2.10	$0.50^{0.50}_{0.50}$	$0.75^{0.12}_{0.16}$	$0.85^{0.05}_{0.06}$	$0.73^{0.05}_{0.05}$	$0.69^{0.05}_{0.06}$	$0.53^{0.11}_{0.11}$	$0.67^{0.15}_{0.18}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
2.10 − 1.80	$0.50^{0.50}_{0.50}$	$0.69^{0.10}_{0.12}$	$0.68^{0.05}_{0.05}$	$0.77^{0.04}_{0.04}$	$0.75^{0.04}_{0.04}$	$0.80^{0.06}_{0.07}$	$0.88^{0.08}_{0.14}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.44}$	$0.00^{0.44}_{0.00}$
1.80 − 1.50	$0.50^{0.50}_{0.50}$	$0.30^{0.14}_{0.12}$	$0.71^{0.05}_{0.06}$	$0.76^{0.04}_{0.04}$	$0.77^{0.03}_{0.03}$	$0.81^{0.05}_{0.06}$	$0.93^{0.05}_{0.09}$	$0.80^{0.13}_{0.19}$	$0.00^{0.21}_{0.00}$	$0.50^{0.50}_{0.50}$
1.50 − 1.20	$0.50^{0.50}_{0.50}$	$0.50^{0.16}_{0.16}$	$0.38^{0.07}_{0.06}$	$0.49^{0.05}_{0.05}$	$0.48^{0.05}_{0.05}$	$0.45^{0.06}_{0.06}$	$0.56^{0.15}_{0.15}$	$0.33^{0.24}_{0.19}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$
1.20 − 0.90	$0.50^{0.50}_{0.50}$	$0.90^{0.07}_{0.12}$	$0.61^{0.06}_{0.07}$	$0.70^{0.04}_{0.04}$	$0.57^{0.04}_{0.04}$	$0.44^{0.08}_{0.08}$	$0.67^{0.09}_{0.10}$	$0.43^{0.17}_{0.16}$	$0.83^{0.11}_{0.17}$	$0.50^{0.25}_{0.25}$
0.90 − 0.60	$0.50^{0.50}_{0.50}$	$0.89^{0.08}_{0.13}$	$0.69^{0.07}_{0.07}$	$0.64^{0.05}_{0.05}$	$0.65^{0.04}_{0.04}$	$0.56^{0.08}_{0.08}$	$0.38^{0.16}_{0.14}$	$0.50^{0.20}_{0.20}$	$0.50^{0.25}_{0.25}$	$0.50^{0.50}_{0.50}$
0.60 − 0.30	$0.50^{0.50}_{0.50}$	$0.73^{0.11}_{0.14}$	$0.76^{0.06}_{0.07}$	$0.61^{0.05}_{0.05}$	$0.61^{0.04}_{0.05}$	$0.67^{0.08}_{0.09}$	$0.64^{0.13}_{0.14}$	$0.50^{0.16}_{0.16}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
0.30 − 0.00	$0.50^{0.50}_{0.50}$	$0.57^{0.16}_{0.17}$	$0.59^{0.08}_{0.09}$	$0.70^{0.05}_{0.05}$	$0.60^{0.05}_{0.05}$	$0.74^{0.09}_{0.10}$	$0.60^{0.14}_{0.15}$	$0.00^{0.25}_{0.00}$	$0.50^{0.25}_{0.25}$	$0.33^{0.24}_{0.19}$

Table 34: hlt efficiency results for narrow electrons (background considered zero and not subtracted)

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$3.00-2.70$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.70-2.40$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.40-2.10$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.21}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.10-1.80$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.25}$	$0.95^{0.04}_{0.07}$	$1.00^{0.00}_{0.15}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.80-1.50$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.21}$	$0.86^{0.09}_{0.15}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.50-1.20$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.13}$	$0.71^{0.14}_{0.17}$	$0.50^{0.13}_{0.13}$	$0.50^{0.50}_{0.50}$	$0.50^{0.25}_{0.25}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.20-0.90$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.75^{0.15}_{0.21}$	$0.89^{0.06}_{0.09}$	$0.96^{0.03}_{0.05}$	$1.00^{0.00}_{0.13}$	$1.00^{0.00}_{0.25}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$
$0.90-0.60$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.89^{0.08}_{0.13}$	$0.88^{0.05}_{0.07}$	$0.96^{0.03}_{0.05}$	$1.00^{0.00}_{0.12}$	$0.67^{0.19}_{0.24}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$
$0.60-0.30$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.11}$	$0.86^{0.05}_{0.07}$	$0.94^{0.04}_{0.05}$	$0.83^{0.09}_{0.12}$	$0.83^{0.11}_{0.17}$	$0.00^{0.44}_{0.00}$	$0.50^{0.25}_{0.25}$	$0.50^{0.50}_{0.50}$
$0.30-0.00$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.08}$	$0.90^{0.05}_{0.06}$	$0.94^{0.03}_{0.05}$	$1.00^{0.00}_{0.10}$	$0.50^{0.50}_{0.50}$	$0.50^{0.25}_{0.25}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$

Table 35: hlt efficiency results for big-brem electrons (background considered zero and not subtracted)

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$3.00-2.70$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.70-2.40$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.40-2.10$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.12}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.10-1.80$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.12}$	$1.00^{0.00}_{0.07}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.80-1.50$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.32}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.50-1.20$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.83^{0.09}_{0.12}$	$0.50^{0.13}_{0.13}$	$0.56^{0.15}_{0.15}$	$0.00^{0.32}_{0.00}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$1.20-0.90$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.83^{0.11}_{0.17}$	$0.93^{0.05}_{0.09}$	$0.78^{0.08}_{0.10}$	$0.86^{0.09}_{0.15}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$
$0.90-0.60$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$1.00^{0.00}_{0.12}$	$0.91^{0.05}_{0.07}$	$0.94^{0.03}_{0.05}$	$0.80^{0.13}_{0.19}$	$0.50^{0.50}_{0.50}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$
$0.60-0.30$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.67^{0.19}_{0.24}$	$0.94^{0.04}_{0.07}$	$1.00^{0.00}_{0.05}$	$1.00^{0.00}_{0.17}$	$1.00^{0.00}_{0.32}$	$0.00^{0.32}_{0.00}$	$1.00^{0.00}_{0.44}$	$0.50^{0.50}_{0.50}$
$0.30-0.00$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.83^{0.11}_{0.17}$	$0.91^{0.06}_{0.11}$	$0.88^{0.09}_{0.07}$	$0.50^{0.25}_{0.25}$	$1.00^{0.00}_{0.25}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$

Table 36: hlt efficiency results for ALL classes of electrons (background considered zero and not subtracted)

	$0.00-10.00$	$10.00-20.00$	$20.00-30.00$	$30.00-40.00$	$40.00-50.00$	$50.00-60.00$	$60.00-70.00$	$70.00-80.00$	$80.00-90.00$	$90.00-100.00$
$3.00-2.70$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.70-2.40$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$	$0.67^{0.11}_{0.12}$	$0.63^{0.10}_{0.11}$	$0.62^{0.11}_{0.12}$	$0.67^{0.19}_{0.24}$	$0.50^{0.50}_{0.50}$	$0.00^{0.44}_{0.00}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.40-2.10$	$0.50^{0.50}_{0.50}$	$0.78^{0.11}_{0.15}$	$0.89^{0.04}_{0.04}$	$0.78^{0.04}_{0.04}$	$0.76^{0.04}_{0.05}$	$0.58^{0.09}_{0.10}$	$0.67^{0.15}_{0.18}$	$1.00^{0.00}_{0.32}$	$0.50^{0.50}_{0.50}$	$0.50^{0.50}_{0.50}$
$2.10-1.80$	$0.50^{0.50}_{0.50}$	$0.77^{0.08}_{0.09}$	$0.74^{0.04}_{0.05}$	$0.82^{0.03}_{0.03}$	$0.81^{0.03}_{0.03}$	$0.84^{0.05}_{0.06}$	$0.91^{0.06}_{0.11}$	$1.00^{0.00}_{0.21}$	$1.00^{0.00}_{0.44}$	$0.67^{0.19}_{0.24}$
$1.80-1.50$	$0.50^{0.50}_{0.50}$	$0.36^{0.14}_{0.13}$	$0.73^{0.05}_{0.05}$	$0.79^{0.03}_{0.04}$	$0.79^{0.03}_{0.03}$	$0.82^{0.05}_{0.06}$	$0.94^{0.04}_{0.08}$	$0.83^{0.11}_{0.17}$	$0.00^{0.21}_{0.00}$	$0.50^{0.50}_{0.50}$
$1.50-1.20$	$0.50^{0.50}_{0.50}$	$0.56^{0.15}_{0.15}$	$0.49^{0.06}_{0.06}$	$0.54^{0.04}_{0.04}$	$0.50^{0.04}_{0.04}$	$0.48^{0.06}_{0.06}$	$0.50^{0.12}_{0.12}$	$0.25^{0.21}_{0.15}$	$1.00^{0.00}_{0.25}$	$1.00^{0.00}_{0.44}$
$1.20-0.90$	$0.50^{0.50}_{0.50}$	$0.93^{0.05}_{0.09}$	$0.69^{0.05}_{0.05}$	$0.77^{0.03}_{0.03}$	$0.71^{0.06}_{0.02}$	$0.68^{0.05}_{0.06}$	$0.80^{0.06}_{0.07}$	$0.50^{0.16}_{0.16}$	$0.89^{0.08}_{0.13}$	$0.50^{0.25}_{0.25}$
$0.90-0.60$	$0.50^{0.50}_{0.50}$	$0.76^{0.15}_{0.07}$	$0.80^{0.04}_{0.04}$	$0.77^{0.03}_{0.03}$	$0.78^{0.02}_{0.02}$	$0.74^{0.05}_{0.05}$	$0.60^{0.10}_{0.11}$	$0.75^{0.12}_{0.16}$	$0.57^{0.16}_{0.17}$	$0.50^{0.25}_{0.25}$
$0.60-0.30$	$0.50^{0.50}_{0.50}$	$0.82^{0.08}_{0.10}$	$0.85^{0.03}_{0.04}$	$0.78^{0.02}_{0.02}$	$0.79^{0.02}_{0.02}$	$0.78^{0.04}_{0.05}$	$0.84^{0.05}_{0.07}$	$0.60^{0.10}_{0.11}$	$0.83^{0.11}_{0.17}$	$1.00^{0.00}_{0.32}$
$0.30-0.00$	$0.50^{0.50}_{0.50}$	$0.77^{0.10}_{0.12}$	$0.82^{0.04}_{0.04}$	$0.85^{0.02}_{0.02}$	$0.82^{0.02}_{0.02}$	$0.80^{0.04}_{0.05}$	$0.85^{0.06}_{0.08}$	$0.64^{0.11}_{0.13}$	$0.67^{0.15}_{0.18}$	$0.43^{0.17}_{0.16}$