Variable	Selection (Barrel)
Full 5x5 $\sigma_{i\eta i\eta}$	< 0.0102
H/E	< 0.0396
charged hadron isolation	< 0.441
neutral hadron isolation	$< 5.931 + 0.0163 \times p_T + 1.4 \times 10^{-5} \times {p_T}^2$
photon isolation	$< 2.571 + 0.0034 \times p_T$
Conversion safe electron veto	Yes

Table 7: Tight photon identification criteria.

selection measured in data and simulation as measured by the e-gamma POG relative to the Summer-16 MC samples. We assign a 2% systematic uncertainty on the efficiency of the photon selection in the analysis.

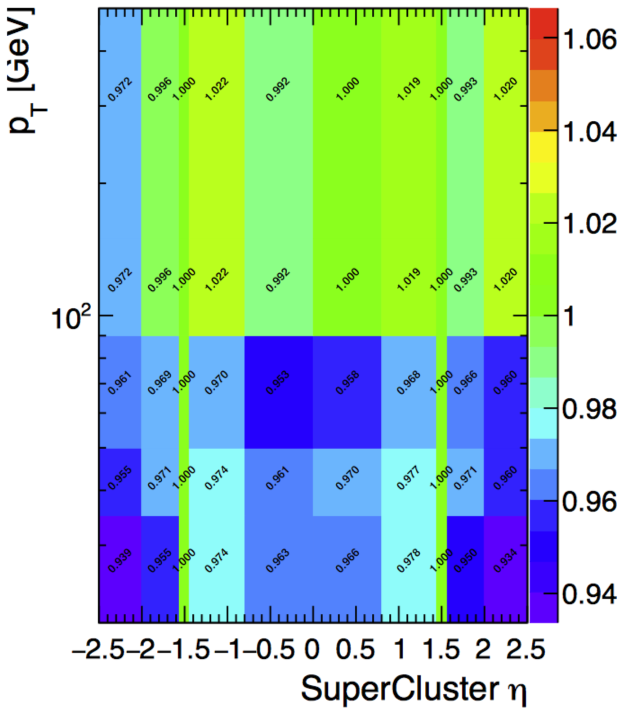


Figure 30: The data-MC scale factors for the photon identification and isolation requirements as measured by e-gamma POG asaf of photon probe p_{T} and η

5.9 Photon Purity

The γ+jets events in data suffer from contamination from QCD multijet events in which a jet is misidentified as a photon, or π^0 decays get identified as prompt photons. In order to reliably estimate this QCD background in the γ+jets control region of the analysis, we measure the photon purity (or jet-to-photon fake rate) directly in data. Two alternative techniques are employed to perform this measurement: in one case a template fit is performed to the isolation sum computed using photon candidates, while in the other one a template fit is performed on the shower shape variable $\sigma_{i\eta i\eta}$ of the photon. Results from both the measurements are found to be agreement within the estimated uncertainties.

5.9.1 Isolation Template Fit

In the 'isolation template fit' method, the purity is extracted through a fit to the photon (electromagnetic) component of the photon-candidate isolation. This photon isolation component is derived after removing the photon footprint [34] from the isolation sum (isolation cone defined with $\Delta R = 0.3$). The fit procedure is entirely data-driven. Events in data are considered in the fit if and only if they fulfill a basic set of requirements:

- Pass the high p_T single photon triggers (Photon165+H/E or Photon175).
- At least one reconstructed photon with p_T larger than 175 GeV and $|\eta_{SC}| < 1.4442$.
- Accepted by $E_{\mathrm{T}}^{\mathrm{miss}}$ filters.
- Veto loosely identified muons, electrons and tau-jets as done in the analysis.
- B-jet veto.
- At least one jet not in overlap with the photon candidate with $p_T > 100$ GeV, $|\eta| < 2.5$, charged hadron fraction larger than 0.1 and neutral hadron fraction smaller than 0.8.
- Minimum $\Delta\phi$ between jets and hadronic recoil larger than 0.5 radians.
- The leading photon candidate in the event should pass the Spring-16[4] photon ID requirements except for the photon isolation one.

Signal templates are derived in data by throwing random cones in $\gamma +$ jets events, while ensuring that the random cone does not overlap with the photon or a jet in the event. Background templates are also derived from data using a $\sigma_{i\eta i\eta}$ sideband region. In particular, we take photon candidates that pass all the identification requirements except those on the photon isolation and the $\sigma_{i\eta i\eta}$, obtaining a QCD enriched event sample by selecting events with $0.01 < \sigma_{i\eta i\eta} < 0.014$. An binned Likelihood fit is performed on data using these signal and background templates to obtain the relative contribution of $\gamma +$ jets events, thus yielding the purity estimate. To improve the agreement between the fit result and data (χ^2 of the fit), additional degrees of freedom are introduced in the Likelihood model. In particular, the signal template is smeared by a Gaussian-peak to accommodate for a possible difference in resolution, while the background template is multiplied by an exponential function to allow a better fit of the photon isolation tail which is dominated by jets with large EM fraction. The measurement is performed in several bins of photon p_{T}.

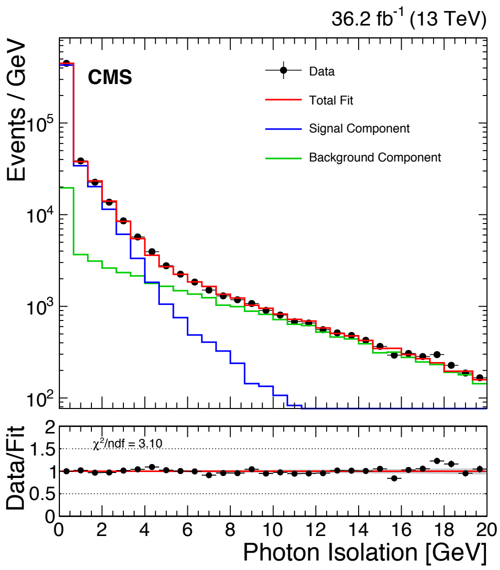
Systematic uncertainty on the purity measurement is assessed by comparing the purity measured with different setups:

- Nominal fit: used to define the central value of the photon purity estimate. It is obtained using a data-driven signal template from random cone (R = 0.4) smeared by a Gaussian p.d.f, while the background template is taken from the $\sigma_{i\eta i\eta}$ sideband in data and is multiplied by an exponential function.
- Alternative signal templates: they are taken from both data, using a random cone with a different R-size (R = 0.8), and γ+jets MC as already described in Ref. [35].
- Alternative background templates: they are obtained using simulated QCD EM-enriched events, requiring the photon candidate not to be matched with a prompt photon in the final state as in Ref. [35].
- Fix the nominal data-driven signal template (from random cone R = 0.4) and the background model, while change the smearing function from a Gaussian to a Crystal-Ball p.d.f. The difference is considered as additional systematic uncertainty.
- Fix the nominal signal model and the data-driven background template (from $\sigma_{i\eta i\eta}$

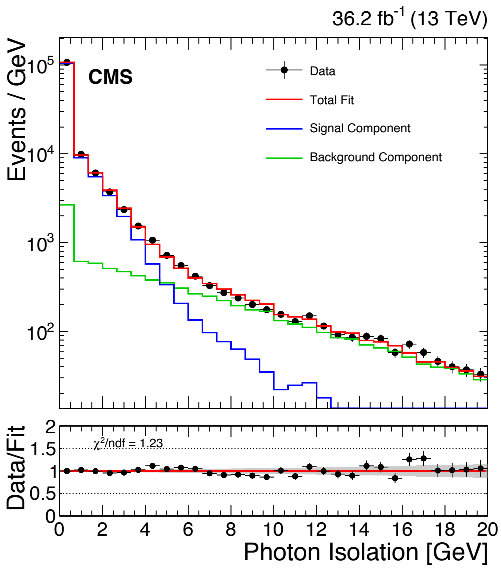
[4] https://twiki.cern.ch/twiki/bin/view/CMS/CutBasedPhotonIdentificationRun2#Recommended_Working_points_for_2

sideband), while change the background analytical tail from an exponential function to a power-law. The difference is considered as additional systematic uncertainty.

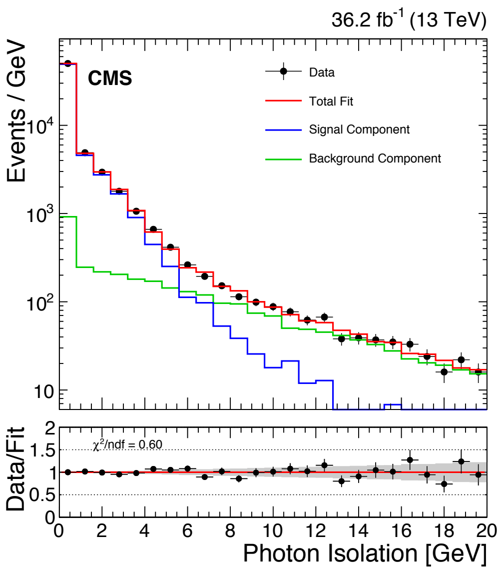
Fig. 31 shows the results of the nominal fit for different p_{T} regions. The photon purity measurements as a function of photon p_T obtained from the alternative fit setups are shown in Fig. 32. Eventually, Fig. 33 shows the nominal fit estimate in each photon p_T bin together with the systematic uncertainty taken as the sum in quadrature of the residuals shown in Fig. 32. Values are also listed in Table 8. The purity varies between 94% to 98%, while systematic uncertainty on these purity estimates varies between 1.7% to 3.2%.



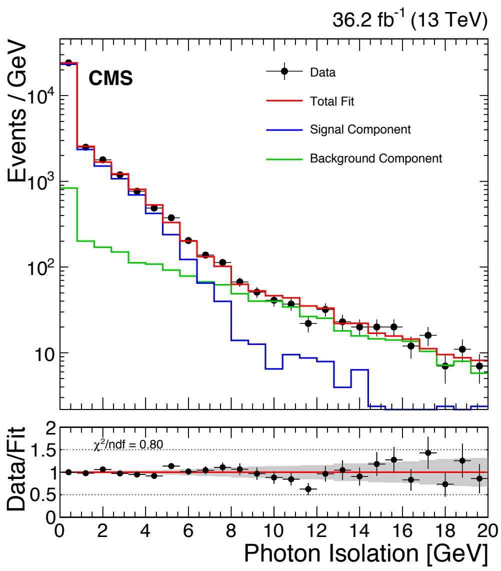
(a) $175 < p_{\mathrm{T}} < 200$ GeV



(b) $250 < p_{\mathrm{T}} < 280$ GeV



(c) $320 < p_{\mathrm{T}} < 375$ GeV



(d) $425 < p_{\mathrm{T}} < 480$ GeV

Figure 31: Photon purity fits using the isolation templates.

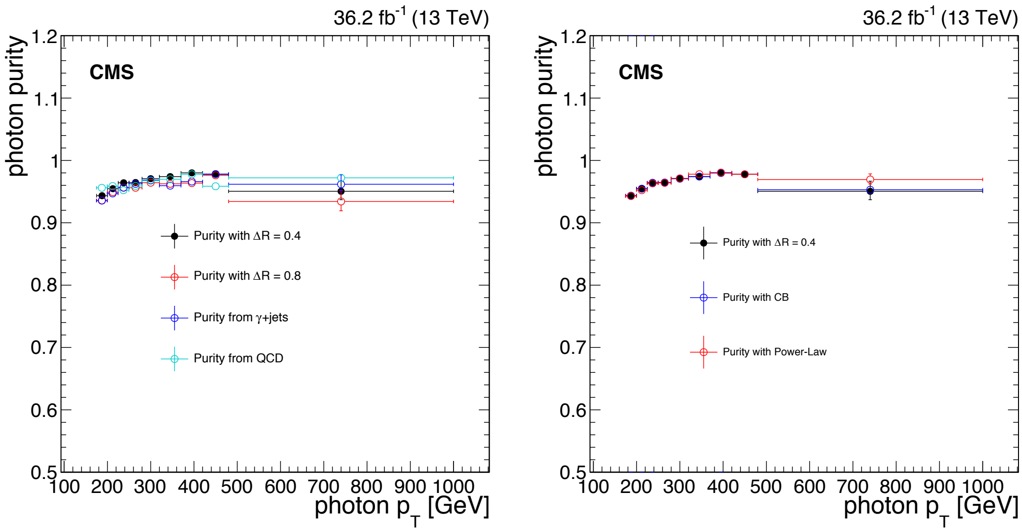


Figure 32: Purity fractions measured in data from different fit setups varying signal/background template (left) or smearing/tail function (right) as a function of photon p_{T}.

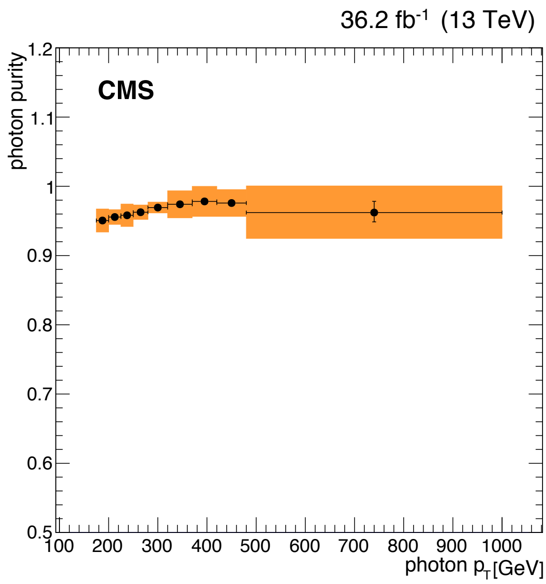


Figure 33: Purity fractions measured in data with their statistical (black bar) and systematic (orange band) uncertainty as a function of photon p_{T}.

5.9.2 $\sigma_{i\eta i\eta}$ Template Fit

To determine the purity (or impurity: 1 - purity) of photons in an alternative approach, to the previous isolation fits, we perform a template fit to the shower shape variable $\sigma_{i\eta i\eta}$ since true photons have a well defined peak in $\sigma_{i\eta i\eta}$ while fakes have a smaller peak as well as plateau at higher values.

We measure the impurity of photons using a EM object+jet control region where we require one jet passing some loose identification requirements, with $p_T > 100$ GeV and $|\eta| < 2.5$, and an EM object passing the follow selection