Measurement of Photon Efficiencies in Radiative Z Decays

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

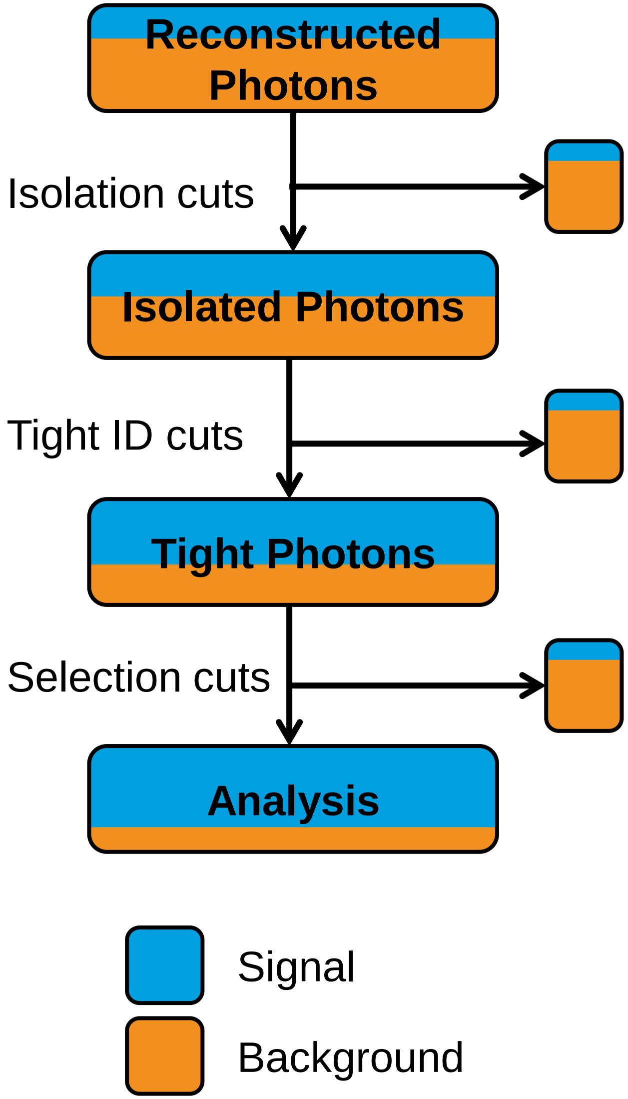
ATLAS EXPERIMENT

DESY.

Introduction

Why do we measure photon efficiencies?

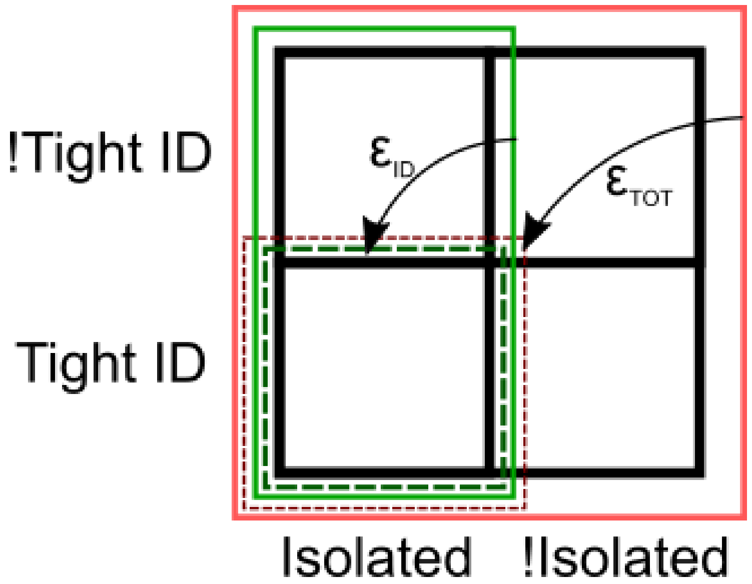
- Many important physics processes involve photons, e.g. $H \rightarrow \gamma\gamma$, BSM decays
- Also background photons from hadronic decays/jets faking photons
- Remove most background using isolation and ID cuts - Also removes some signal
- Must know how many signal events are excluded
- Efficiency ε = Fraction of events retained when making a cut



Introduction

How do we measure efficiencies?

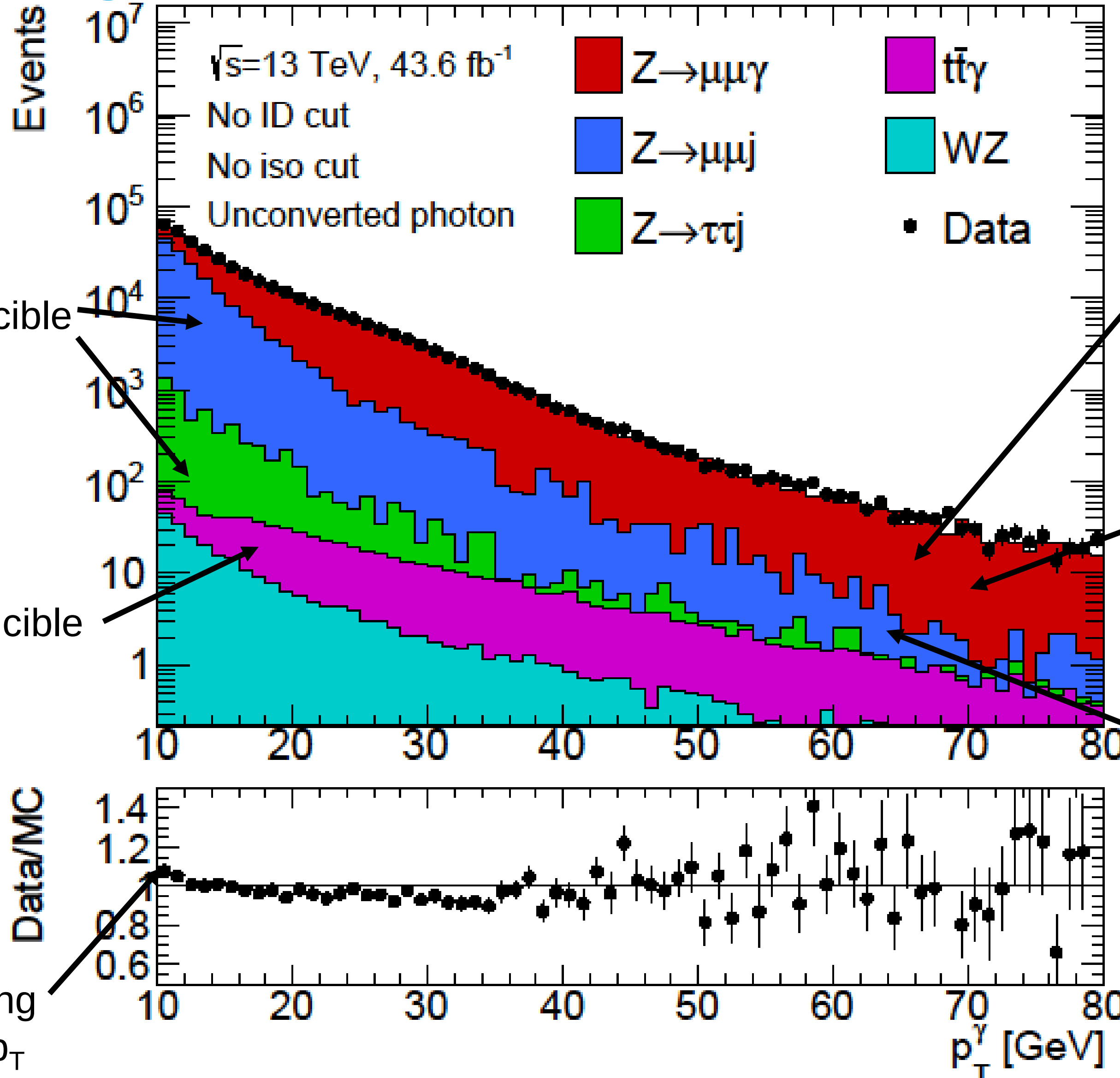
- ε measured in standard candle processes, such as $Z \to \ell\ell\gamma$
- Could be calculated using Monte Carlo (MC), but large uncertainties and ultimately a data-driven measurement is required
- Measurement performed before, but with fractional uncertainties up to 10% → Potential for improved measurement
  - Consider additional backgrounds
  - Utilise control region to increase background statistics
- Measure ε_{ID} and ε_{TOT}



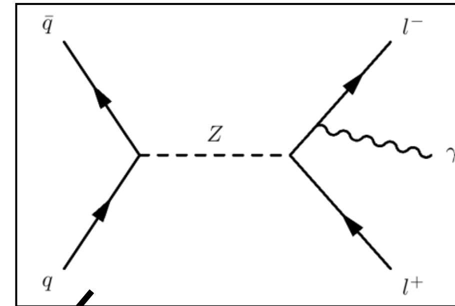
Backgrounds

Reducible

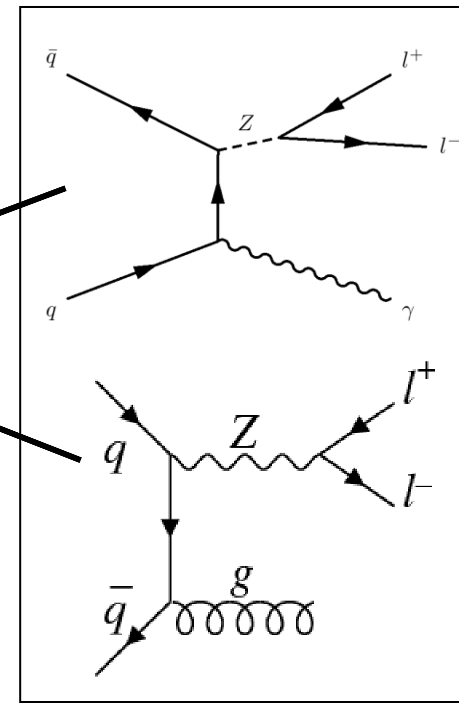
Irreducible



Missing low-p_T background



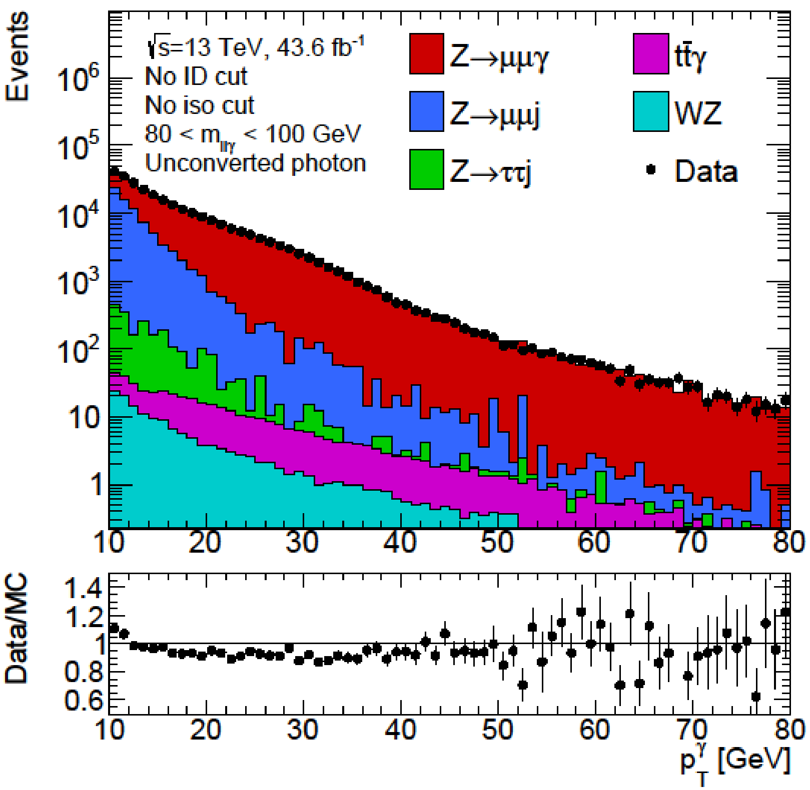
FSR



ISR

Largely excluded by m_{ll} cut

Backgrounds



	ττj	tt̄γ	WZ
$\Delta\varepsilon_{ID}/\varepsilon_{ID}$	0.4%	0.03%	0.01%
$\Delta\varepsilon_{TOT}/\varepsilon_{TOT}$	2%	0.3%	0.05%
Bin	$10<p_T<15$ GeV	$60<p_T<80$ GeV	

Estimate of the maximum fractional error on ε as a result of ignoring backgrounds

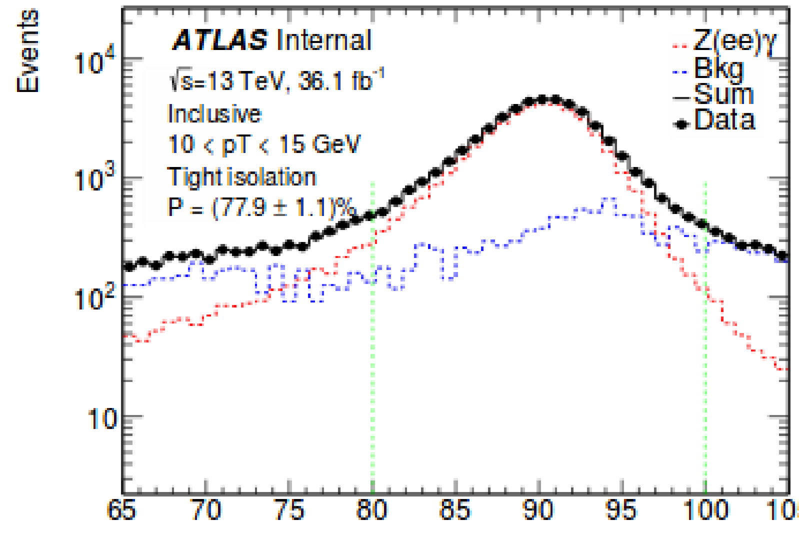
→ ττj significant at low p_T^γ

Using range $80 < m_{ll\gamma} < 100$ GeV: In the bin with the highest fraction of each source of background, Δε when the number of signal events was increased by the number of background events was calculated.

Method

Overview

- ε depends on p_T^{γ}, $|\eta^{\gamma}|$ → Calculate in bins
- $\varepsilon = N_{s,cut} / N_s$ – Determine number of signal events before and after cut
- Existing method:
  - Signal ($Z\to\ell\ell\gamma$) and background ($Z\to\ell\ell j$) templates from MC
  - Fit signal and background templates to data to determine the purity
  - Use purity and number of events before and after cut to evaluate ε

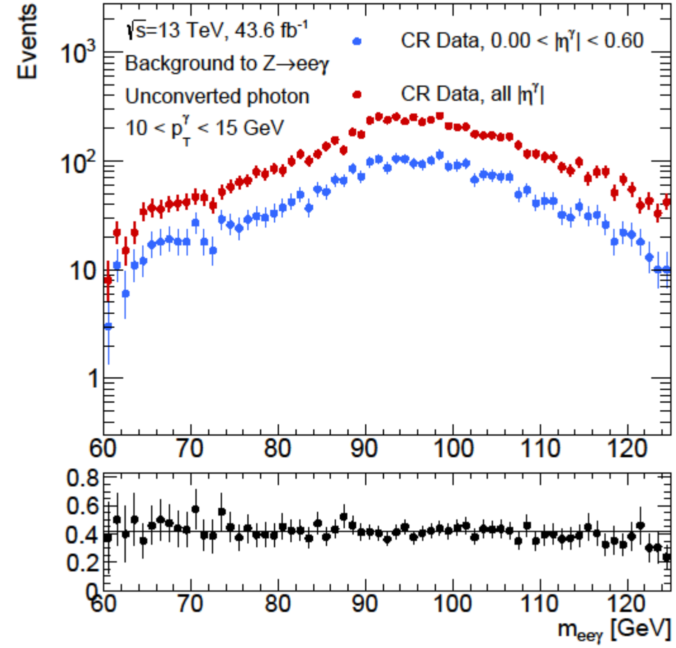


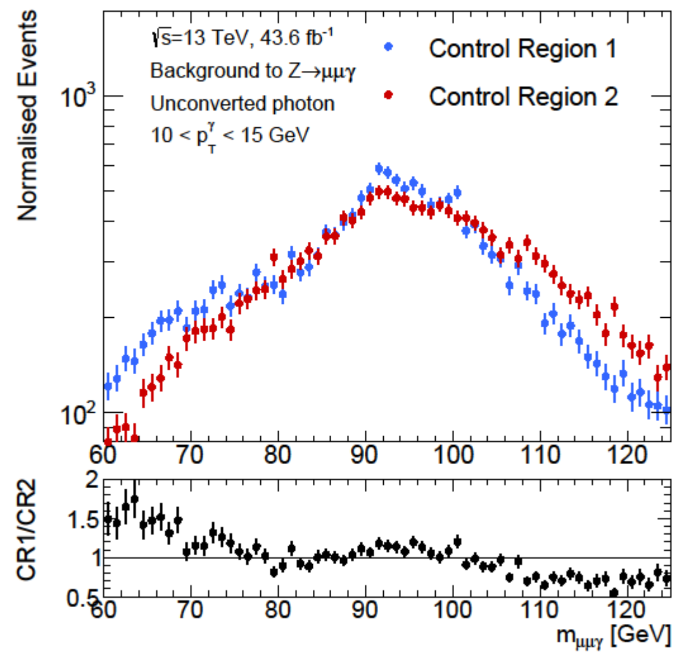
(ATL-COM-PHYS-2017-264)

Method

Reducible Background

- Z→ℓℓj and Z → ττj
- Previously (MC) low available statistics in background
- Increase statistical power by taking reducible background template from data in anti-isolation, anti-ID control region (CR) and using all $|\eta^{\gamma}|$ bins
    - Large number of reducible background events
    - Small amount of signal + irreducible background contamination
    - Assume $m_{ll\gamma}$ for background unbiased with respect to isolation and $|\eta^{\gamma}|$
        - True for $|\eta^{\gamma}|$
        - Not true for isolation → Don’t use events with very low isolation
    - Includes reducible backgrounds missing in MC

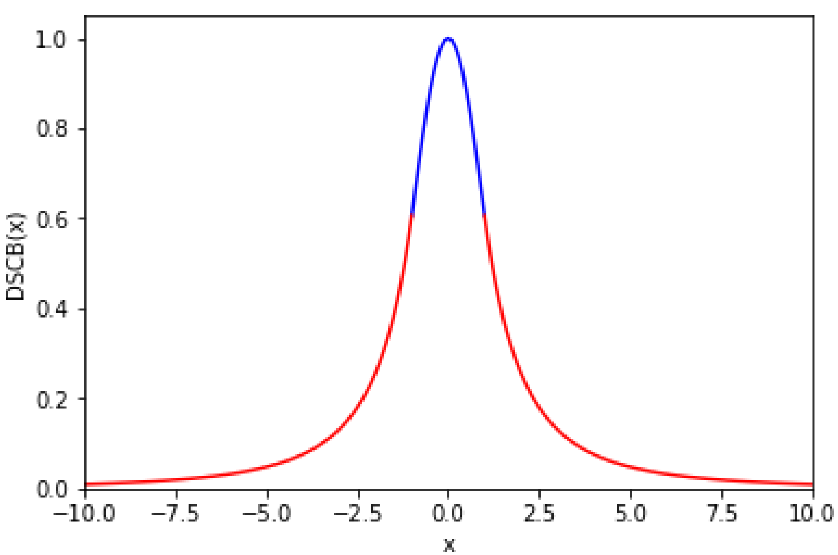


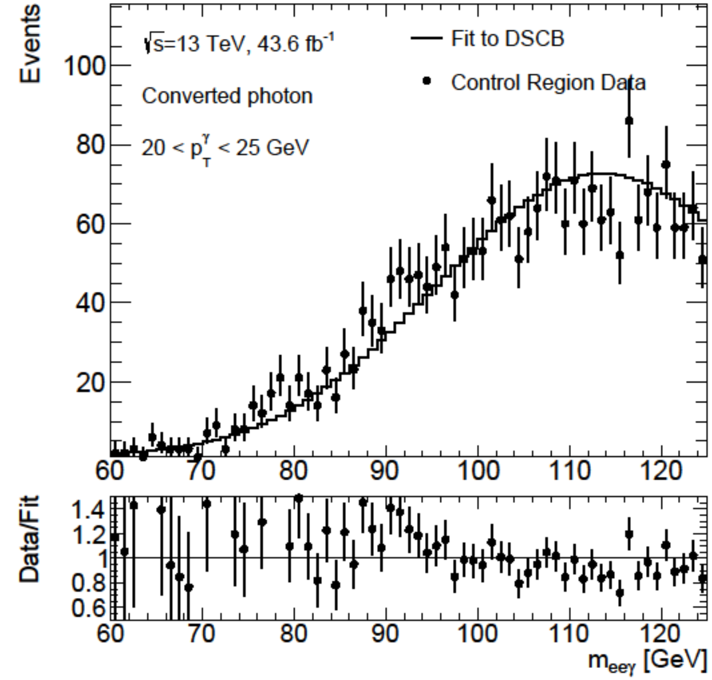


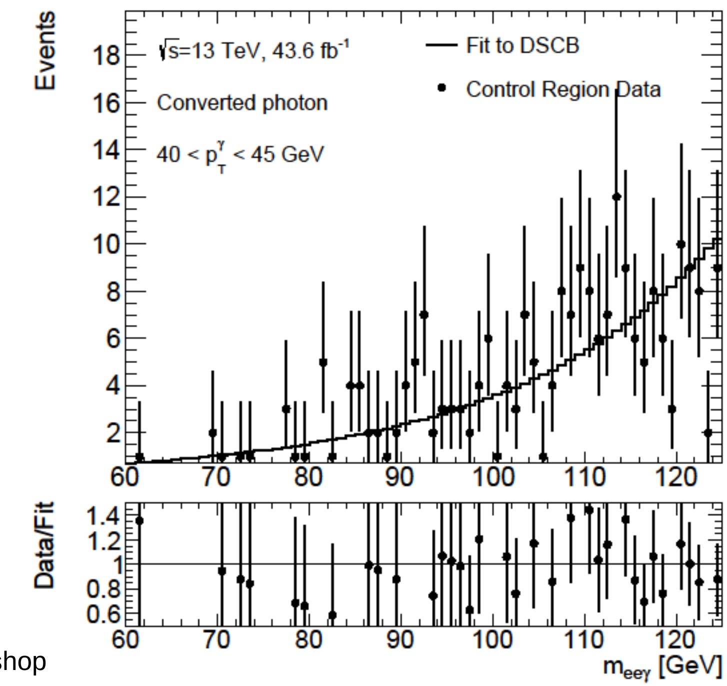
Method

Reducible Background

- Fit CR data to a double-sided crystal ball (DSCB) function to reduce statistical fluctuations
- Gaussian core, power-law tails
- Exclude range [88,93] GeV to avoid contamination



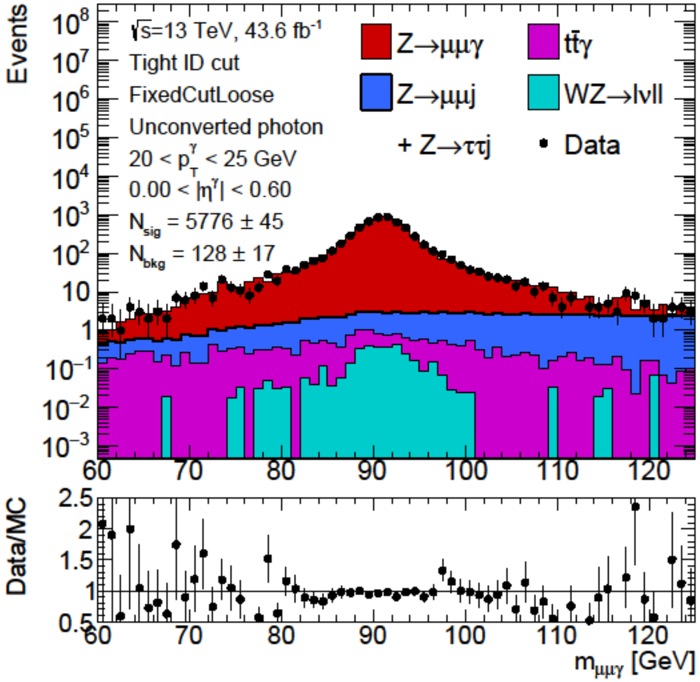


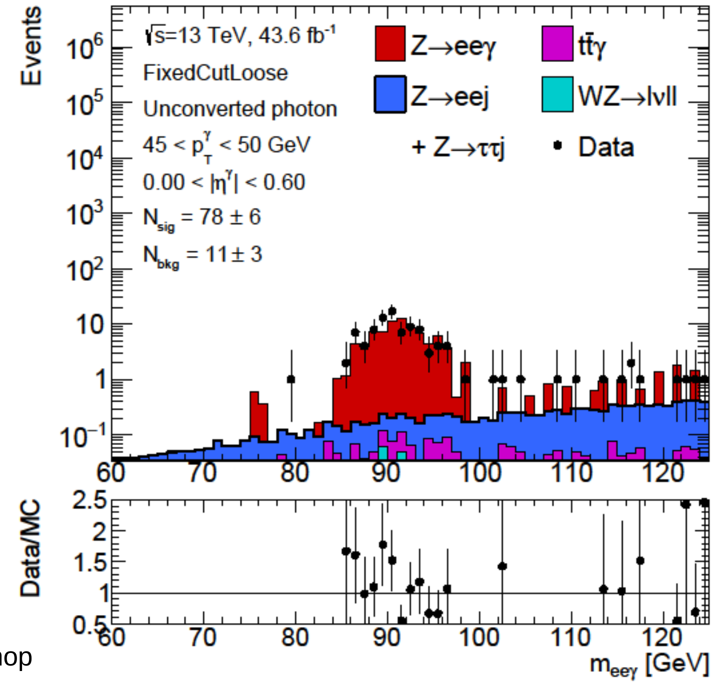


Method

Extended Maximum Likelihood Fit

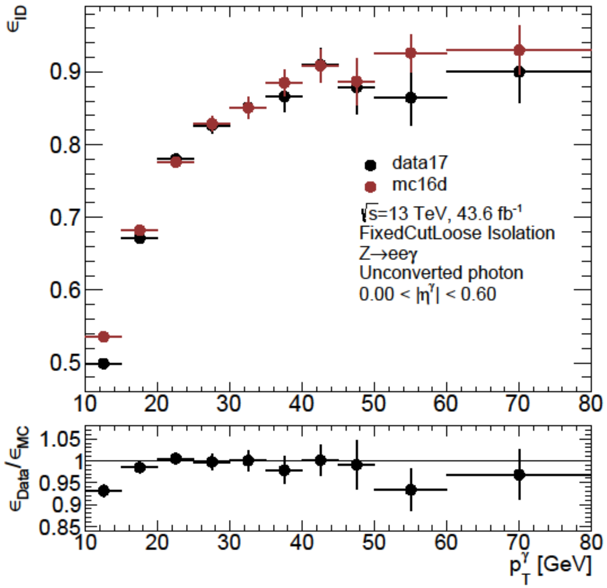
- Signal and irreducible background from MC
- Fit signal + background to data to determine number of signal events
- Treat irreducible background as fixed component scaled by $\sigma_{data}/\sigma_{MC}$
- $|\eta^{\gamma}|$ bins grouped in fit to further improve statistics
- Fit in range [60,125] GeV to utilise sidebands to accurately determine background component
- Calculate ε using range [80,100] GeV

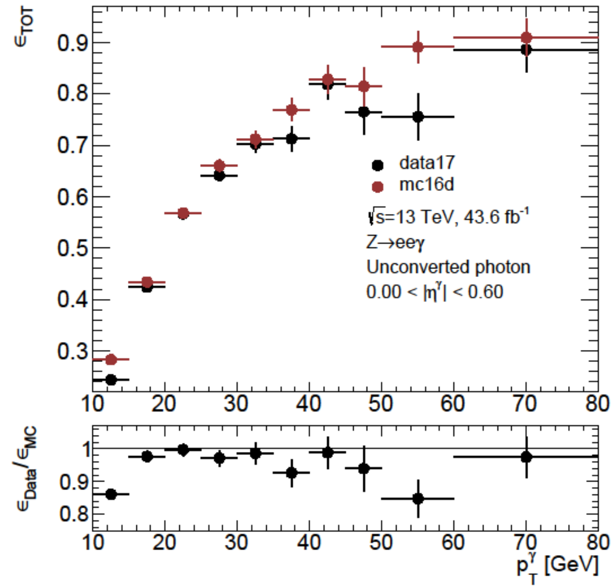


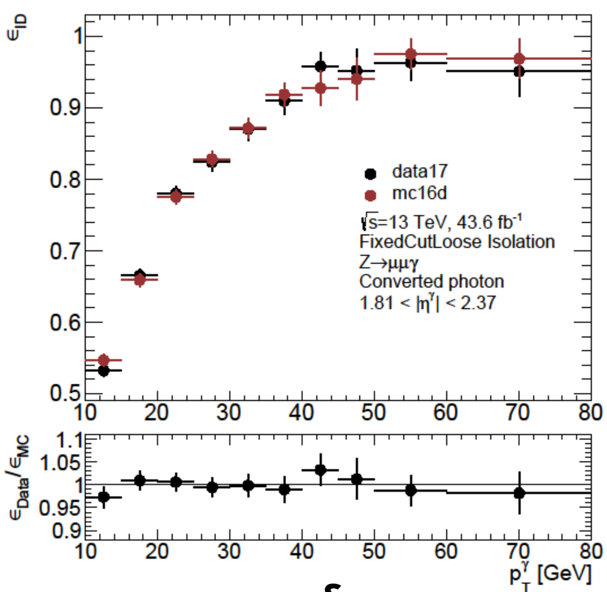


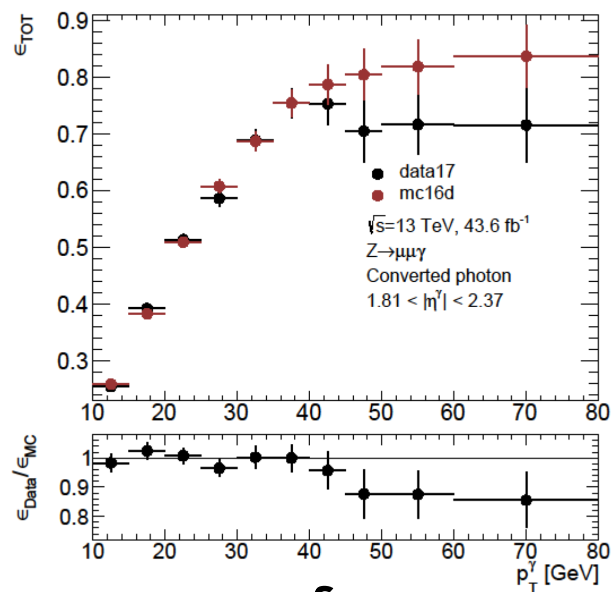
[Error bars show statistical uncertainty only]

Results









$\boldsymbol{\varepsilon_{ID}}$ $\boldsymbol{\varepsilon_{TOT}}$

Uncertainties

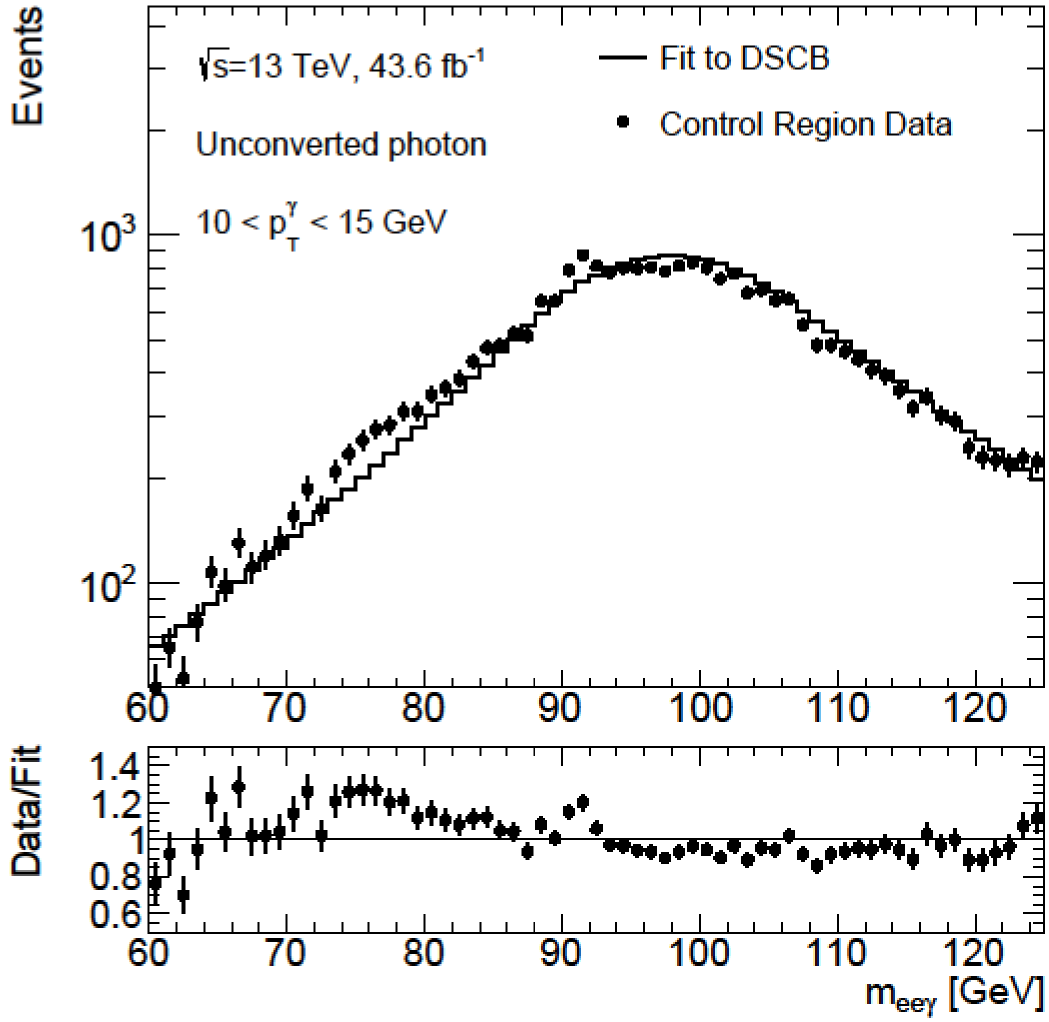
- Statistical
  - Evaluated using binomial approximation
  - Fractional uncertainty 1-5% - Larger at high p_T^{γ}

- Background shape
  - Could estimate as difference between efficiency from a high-tail fit (90-125 GeV) and low-tail fit (60-100 GeV)
- Detector geometry
  - $\Delta\varepsilon_{ID}/\varepsilon_{ID} \leq 7\%$ for $p_T^{\gamma} \leq 25$ GeV, negligible elsewhere (ATL-COM-PHYS-2017-264)
- Irreducible background cross section
  - Extremely small
  - Could be estimated by varying cross sections within uncertainties

Further Work

Reducible background modelling

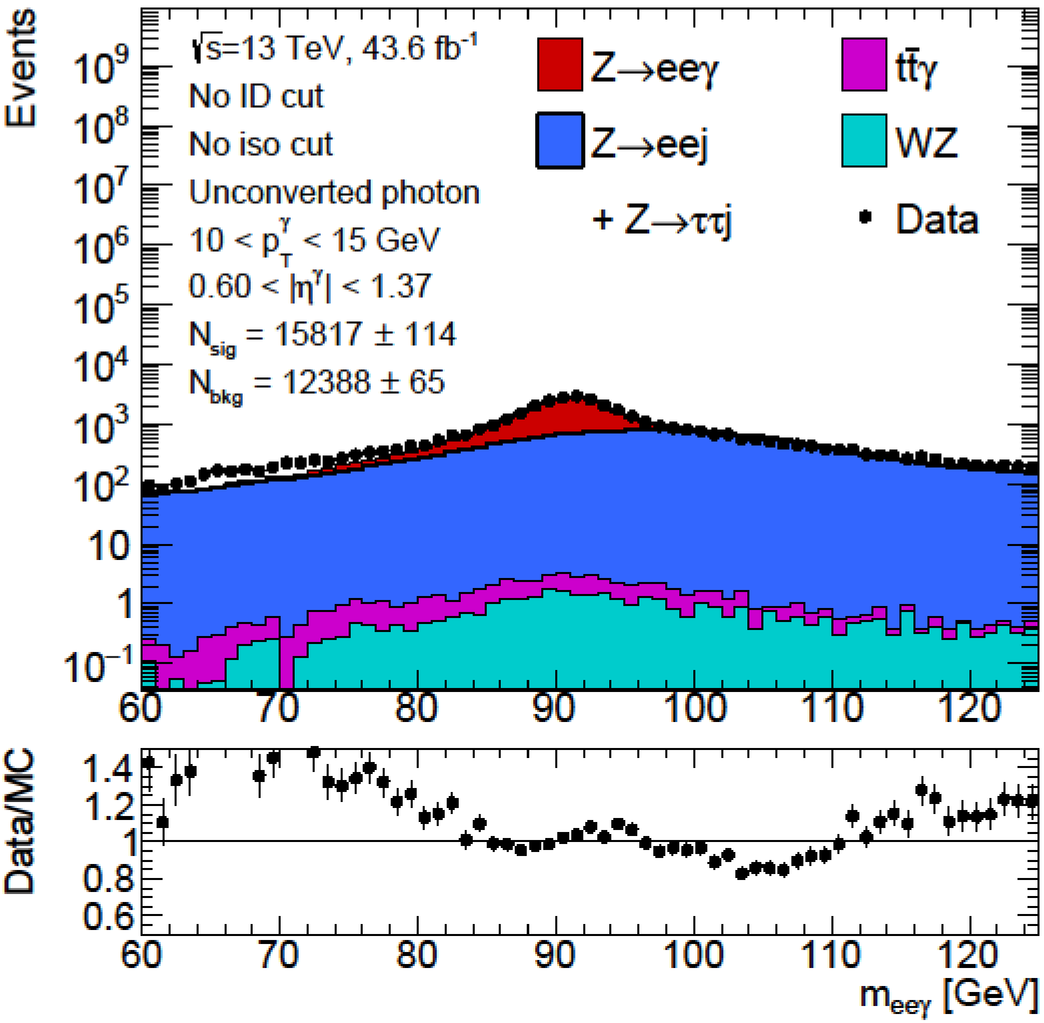
- DSCB does not model shape well for $10 < p_T^\gamma < 20$ GeV
- Bernstein polynomials, triple Gaussian



Further Work

Identification of missing background

- MC is systematically below data in the range $10 < p_T^\gamma < 20$ GeV; $m_{ll\gamma} < 80$ GeV
  - Discrepancy too large to be explained by poor fitting of DSCB to control region data
  - Irreducible background not yet considered:
    - $\tau\tau\gamma$
  - May impact fit



Conclusions

- There are significant sources of background other than $Z \rightarrow \ell\ell j$
- Some background in the range $10 < p_T^\gamma < 20$ GeV; $m_{ll\gamma} < 80$ GeV has not been identified
  - Most likely to be $\tau\tau\gamma$
  - May have a significant impact on measurement
- The use of control region data as a reducible background template is feasible and improves statistical power
  - Fitting to smooth function reduces statistical fluctuations
  - This fitting can be improved

Backup slides

Event selection

- Two same-flavour, opposite sign leptons and one photon
- $40 < m_{ll} < 83$ GeV – Reduces ISR background $Z \rightarrow \ell\ell j$
- $\Delta R_{\gamma,l} > 0.4$ for electrons, > 0.2 for muons – Reduces impact of lepton energy deposition on photon isolation
- Only using events which pass an unprescaled single lepton or dilepton trigger and associated p_T^l cuts

Backup slides

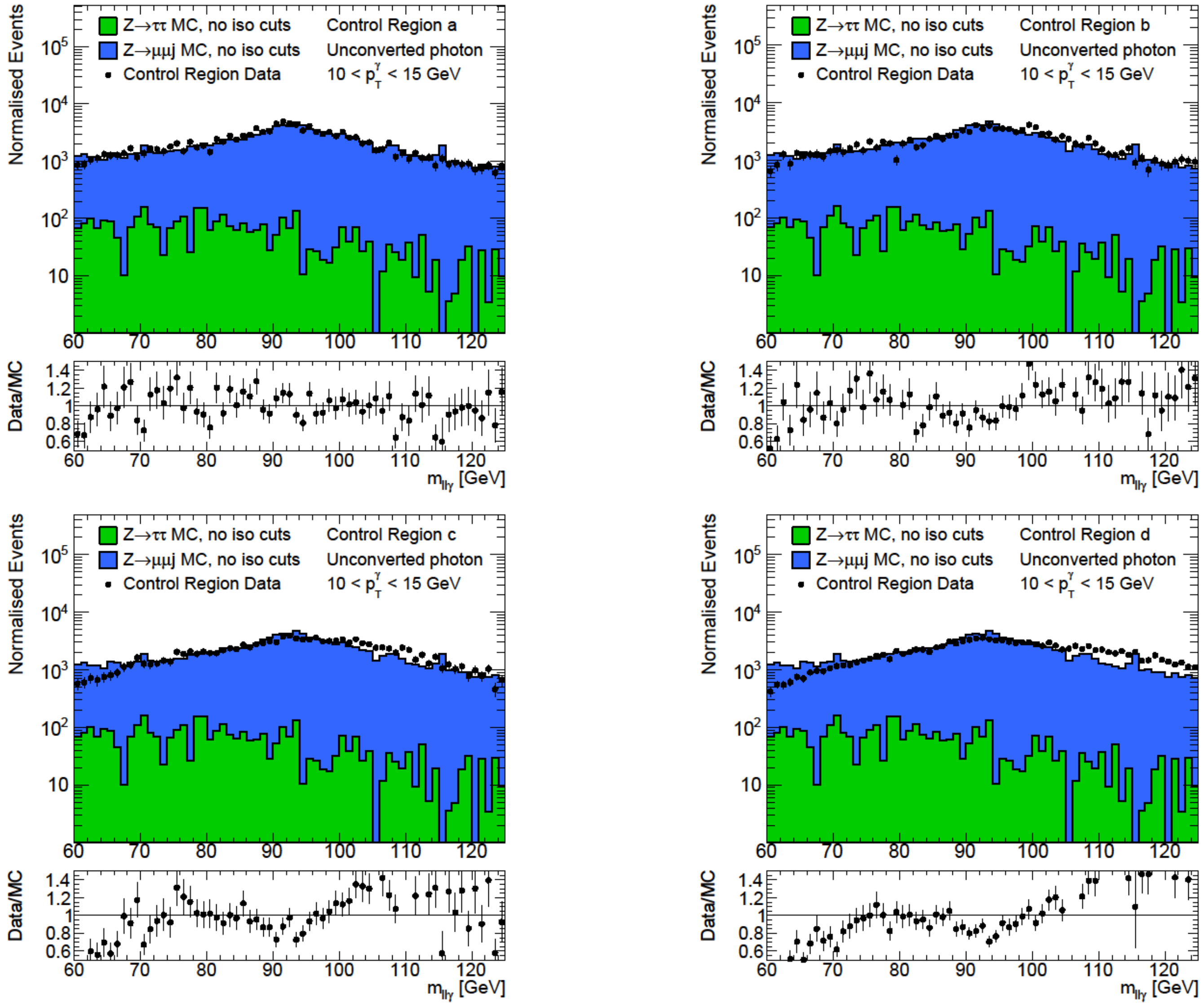
Isolation Cuts

- Isolated == FixedCutLoose
  - $E_T^{cone20}/p_T^{\gamma} < 0.065$ (calorimeter isolation) & $p_T^{cone20}/p_T^{\gamma} < 0.05$ (track isolation)

- Control region
  - $0.20 < E_T^{cone20}/p_T^{\gamma} < 1.00$ & $0.15 < E_T^{cone20}/p_T^{\gamma} < 1.00$
  - Fails tight ID

Backup slides

CR Data / MC comparison at varying isolation – 10 < p_T^γ < 15 GeV



Backup slides

CR/MC comparison at varying p_T^γ