$Z \rightarrow \mu\mu\gamma$ selection and applications

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Introduction

- ECAL energy reconstruction :

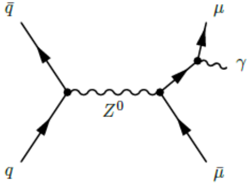
$$E_{e,\gamma} = F_{e,\gamma} \times G(GeV/ADC) \sum_{crystals} S_i(T,t) \times c_i \times A_i$$

  - A_i : reconstructed amplitude in ADC counts
  - c_i : inter-calibration constant
  - S_i : transparence loss correction
  - $F_{e,\gamma}$: object-dependant high-level correction
  - G : global energy scale, need to be calibrated using "standard candles" :
    - $Z \to ee$: main "standard candle"
    - $Z \to \mu\mu\gamma$: cross check

- Advantages of the $Z \to \mu\mu\gamma$ channel :
  - Very pure selection of photons
  - The photons have high P_T compared to the ones from π^0 and η decays
  - Good knowledge of the Z boson
  - Good reconstruction of the muons in CMS

Signal and background

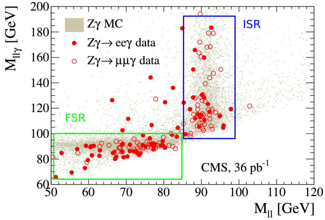
- **Signal :** $Z \to \mu\mu\gamma$ with Final State Radiation (FSR)



- **Backgrounds :**
    - $Z \to \mu\mu\gamma$ non-FSR (ISR or pile-up)
    - $W \to \mu\nu\gamma$ (another μ produced in a recoil jet)
    - $t\bar{t} \to \mu\mu\nu\nu\gamma$
    - QCD

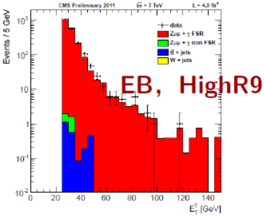
Selection strategy

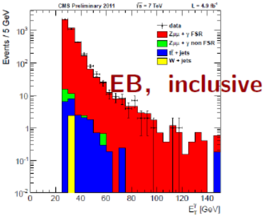
- Dimuon Trigger ($P_{T,\mu_1} > 17$ GeV and $P_{T,\mu_2} > 8$ GeV)
- Collision data cleaning (good vertexing, no beam scrapping...)
- Skimming
- Muon object selection
- Dimuon selection (opposite signs, invariant mass not compatible with the Z)
- Photon selection ($P_T > 25$ GeV)
- FSR selection

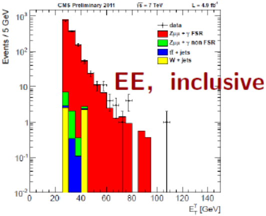


Number of events and purity

- **The purity with the previous selection is** 98%
- Good agreement between DATA and MC
- The rate of selected events is found to be $1.12/pb^{-1}$







Estimator

- Photon energy scale correction : $k = \frac{E_{\gamma,TRUE}}{E_{\gamma,RECO}}$
- We define s :

$$s = \frac{1}{k} - 1 = \frac{E_{\gamma,RECO}}{E_{\gamma,TRUE}} - 1 \simeq \boxed{\frac{M^2_{\mu\mu\gamma,R} - M^2_{\mu\mu,R}}{M^2_Z - M^2_{\mu\mu,R}} - 1}$$

- Approximations :
  - We assume that we reconstruct perfectly the energy and the directions of the muons
  - We replace the true invariant mass $M_{\mu\mu\gamma,T}$ by $M_Z = 91.187$ GeV

$\rightarrow$ We have built a completely data-driven estimator, which has been proven to be unbiased for $P_{T,\gamma} > 20$ GeV

Extraction method

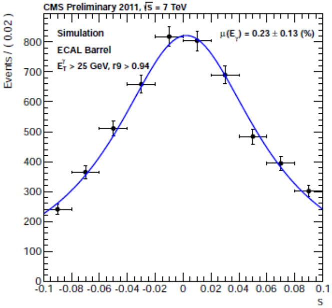
- We compute our estimator for each photon, and we make an unbinned fit of the "s" distribution with a Voigtian (convolution of a Gaussian and a Breit-Wigner). The extracted energy scale is the mean of the Voigtian.
- The choice of the fit range is optimized
- We split events into 3 categories depending on the ECAL region (barrel or endcaps) and the R9 variable (which determines if a photon is converted or not)
- This method is one of the two methods approved by the CMS collaboration ("Direct Fit Method")

- The sources of systematic uncertaincies are :
  - the muon energy scale
  - the fit range choice
  - the fit function choice (not in the next results)

Results (EB, high R9)

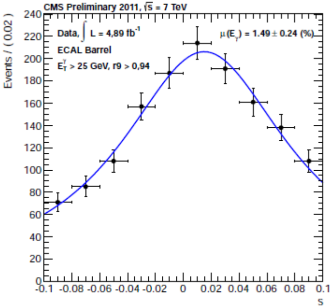
EB : barrel of the ECAL, high R9 : not converted photons

SRECOMC



$\mu(E_\gamma) = 0.23 \pm 0.13$ (stat)
$\pm$ 0.15 (fit range) $\pm$ 0.03 (muons) %

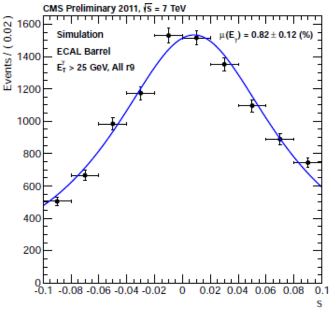
SRECOData



$\mu(E_\gamma) = 1.49 \pm 0.24$ (stat)
$\pm$ 0.05 (fit range) %

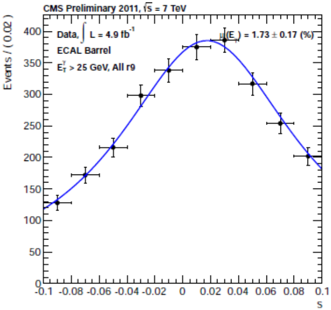
Results (EB, inclusive)

SRECOMC



$\mu(E_\gamma) = 0.82 \pm 0.12$ (stat) $\pm$ 0.10 (fit range) $\pm$ 0.02 (muons) %

SRECOData

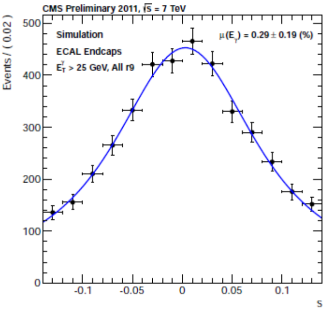


$\mu(E_\gamma) = 1.73 \pm 0.17$ (stat) $\pm$ 0.16 (fit range) %

Results (EE, inclusive)

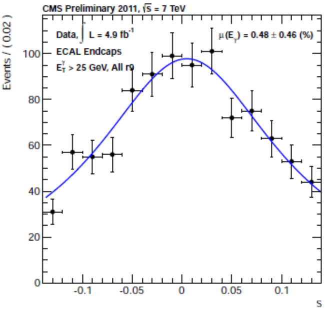
EE : endcaps of the ECAL

SRECOMC



$\mu(E_\gamma) = 0.29 \pm 0.19$ (stat) $\pm\, 0.05$ (fit range) $\pm\, 0.03$ (muons) %

SRECOData



$\mu(E_\gamma) = 0.48 \pm 0.46$ (stat) $\pm\, 0.10$ (fit range) %

Results (Summary table)

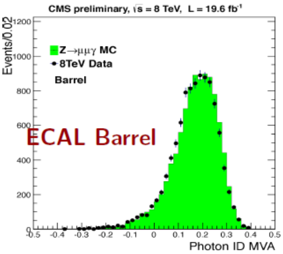
Categories	s_{Data}(%)	s_{MC}(%)
Barrel High R9	$1.49 \pm 0.24 \pm 0.05$	$0.23 \pm 0.13 \pm 0.15$
Barrel inclusive	$1.73 \pm 0.17 \pm 0.16$	$0.82 \pm 0.12 \pm 0.10$
Endcaps inclusive	$0.48 \pm 0.46 \pm 0.10$	$0.29 \pm 0.19 \pm 0.05$

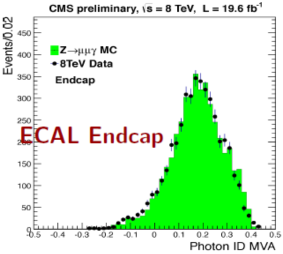
Conclusion

- The photon energy scale agrees to within 1.3% between DATA and MC.
- The energy scale agrees to better than 0.5% with that obtained using the other approved method.

Photon ID MVA validation

- The photon ID is a multivariate analysis which is used to distinguish prompt photons from fake photons (neutral mesons)
- This tool is particularly important in $H \to \gamma\gamma$ analysis
- We can use $Z \to \mu\mu\gamma$ events to compare the photon ID output distributions for data and MC : **good agreement**





Electron veto efficiency and Vγ systematics

- We can use our selection to calculate the **electron veto efficiency**
- The electron veto aims to reject electrons which mimic photons
- To compute the efficiency for photons, we use the method "tag and probe" : we tag the FSR event with the pair of muon, and we probe the efficiency with the assiocated photon
- The efficiency for photons is 96.1% for DATA and 97.4% for MC

- $Z \to \mu\mu\gamma$ channel is also used to compute the systematic uncertaincy on the photon energy scale and resolution in the $V\gamma$ **production measurment**
- This affects the reconstruction efficiency of final state objects by $\sim$ 4% for the energy scale and by $\sim$ 1% for the resolution

Summary

- This channel provides a very pure selection of high P_T photons
- Its main application is the extraction of the photon energy scale (one of two methods approved by the collaboration)
- There are other applications such as the photon ID MVA validation, the electron veto efficiency calculation and the systematics estimation for the $V\gamma$ production measurment...
- This good knowledge of the photon object is then very useful in the $H \rightarrow \gamma\gamma$ analysis

References

- Photon Energy Scale with $Z \rightarrow \mu\mu\gamma$ events, CMS Collaboration, CMS DP -2012/024
- Energy calibration and resolution of the CMS electromagnetic calorimeter in pp collisions at $\sqrt{s} = 7$ TeV, CMS Collaboration, arXiv :1036 :2016v2
- Measurement of W-gamma and Z-gamma production in pp collisions at $\sqrt{s} = 7$ TeV, CMS Collaboration, arXiv :1105.2758
- Extraction of the photon energy scale with $\rightarrow \mu\mu\gamma$ events in CMS, Louis Sgandurra on behalf of the CMS Collaboration, 2013 LHC France Poster Session