Extraction of the photon energy scale of the ATLAS detector from radiative Z events

Journées de rencontre jeunes chercheurs 2015

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Introduction

PhD subject : study of the CP properties of the Higgs boson in the diphoton final state :

- Two jets in the final state.
- Use the angular distribution of the jets to constrain the CP number of the Higgs.

First year in ATLAS : qualification task to become an author :

- Extraction of the photon energy scale to provide a data-driven validation of the calibration procedure.

Higgs CP number

Standard Model : scalar Higgs boson, CP $= +1$.

Beyon Standard Model : richer Higgs sector.

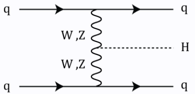
Two Higgs doublet models : 3 neutral particles :

- A (CP = -1).
- H, h (CP $= +1$).

Possible miwing between CP eigen-states :

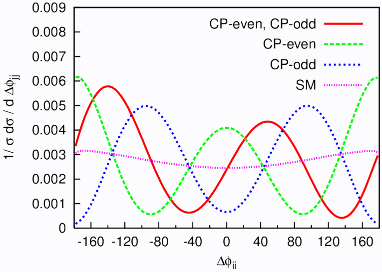
$$\Phi = H \cos\alpha + A \sin\alpha$$

Constraining Higgs CP number



General structure of the HVV vertex :

$$T^{\mu\nu}(q_1, q_2) = a_1(q_1, q_2) g^{\mu\nu} \quad \text{SM}$$
$$+ a_2(q_1, q_2) \left[q_1.q_2 \, g^{\mu\nu} - q_1^\nu \, q_2^\mu \right] \quad \text{CP-even}$$
$$+ a_3(q_1, q_2) \, \varepsilon^{\mu\nu\rho\sigma} \, q_{1\rho} \, q_{2\sigma} \quad \text{CP-odd}$$



V. Hankele, G. Klämke, D. Zeppenfeld, arXiv : hep-ph/0609075

Extraction of the photon energy scale

The in-situ calibration applied to photons comes from $Z \to e^+e^-$.

Any residual mis-calibration between data and MC can be parametrised as :

$$E^{\mathsf{MC}} = \frac{E^{\mathsf{data}}}{1+\alpha}$$

Extraction of the energy scale-factor α from $Z \to ll\gamma$ events :

- Photon energy scaled by $1/(1+\alpha)$ in data.
- Three-body invariant mass recalculated in data.
- Recalculated mass compared to MC.

The value of α that provides the best agreement is the energy scale factor.

Double ratio method

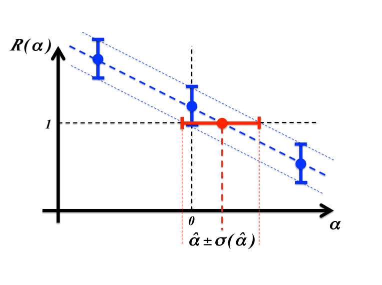
- Agreement between data and MC quantified by the double-ratio R :

$$R(\alpha) = \frac{\langle m_{ll\gamma}^{\text{data}}(\alpha)\rangle / \langle m_{ll}^{\text{data}}\rangle}{\langle m_{ll\gamma}^{\text{MC}}\rangle / \langle m_{ll}^{\text{MC}}\rangle}$$

$\rightarrow$ Ratio in data : cancel out the leptons scales uncertainty.

- Fit with a straight line :

$$R(\alpha) = 1 - \frac{\Delta R}{\hat{\sigma}_\alpha}(\alpha - \hat{\alpha})$$



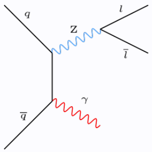
$$R(\hat{\alpha}) = 1$$

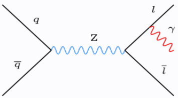
$$R(\hat{\alpha} \pm \sigma_\alpha) = 1 \mp \Delta R$$

$Z(\to ll)\gamma$ production

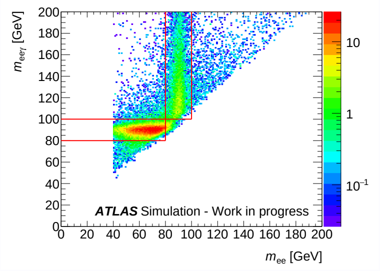
Two production modes :

- Initial state radiation (ISR).
- Final state radiation (FSR).





Identified by comparing invariant masses distributions :



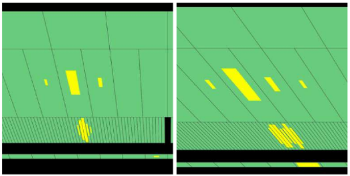
Two regions :

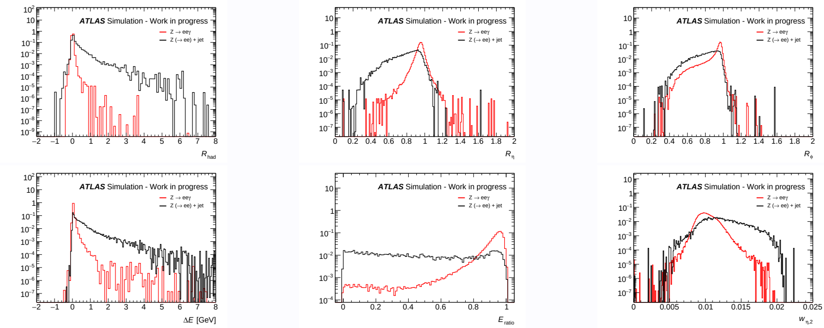
- FSR : $80 < m_{ll\gamma} < 100$ GeV, $m_{ll} < 80$ GeV.
- ISR : $80 < m_{ll} < 100$ GeV, $m_{ll\gamma} > 100$ GeV.

Background rejection : photon identification

Main background : $Z(\rightarrow ll)$ + jet, with a "fake" photon from a neutral hadron decay (ie. π^0).

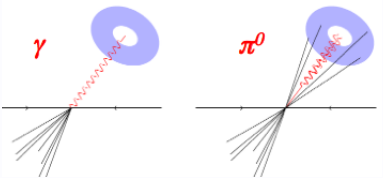
Reject fakes using electromagnetic shower shapes in the calorimeter :

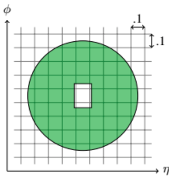


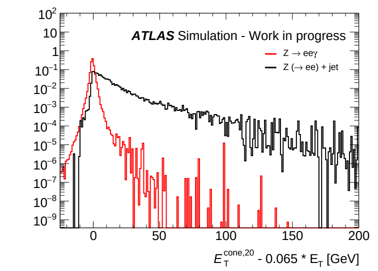


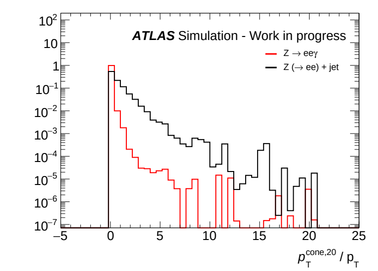
Background rejection : photon isolation

Additional background rejection using photon isolation :









Radiative Z candidates selection

- Leptons :
  - Two leptons with opposite charges.
  - $p_T > 15$ GeV.
  - $|\eta| < 1.37$ or $1.52 < |\eta| < 2.47$ for electrons.
  - $|\eta < 2.4$ for muons.

- Photons :
  - Photons with $p_T > 10$ GeV.
  - $|\eta| < 1.37$ or $1.52 < |\eta| < 2.37$.
  - Identification : tight criteria.
  - Isolation : loose criteria.

- Selected triplet :
  - $\Delta R_{l\gamma} > 0.4$ to avoid contamination of the photon cluster (shower in the electron channel, MIP deposit in the muon channel).
  - Select only one candidate per event : choose triplet with invariant mass closest to m_Z.

Selected radiative $Z \to ee\gamma$

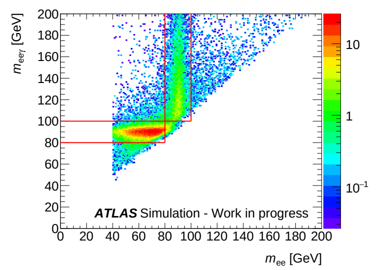
$Z \to ee\gamma$ events simulated with Sherpa generator :

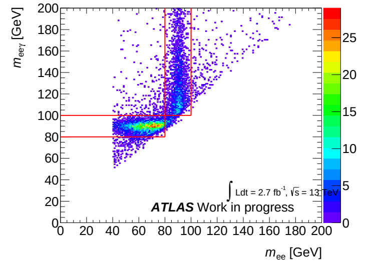
- $m_{ee} > 40$ GeV.
- Up to 3 additional jets.
- Different photon p_T slices.

Data : 2.7 fb^{-1} at 13 TeV from Run 2.

	FSR	ISR
$10 < p_T < 35$ GeV	131182	29488
$35 < p_T < 70$ GeV	7875	10164
$70 < p_T < 140$ GeV	2842	17818
$p_T > 140$ GeV	732	5304
Data	4266	2408

ISR/FSR ratio is different between the MC slices and between data and MC.





Selected radiative $Z \to \mu\mu\gamma$

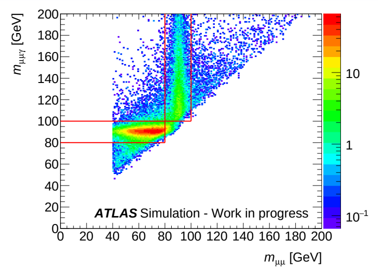
$Z \to \mu\mu\gamma$ events simulated with Sherpa generator :

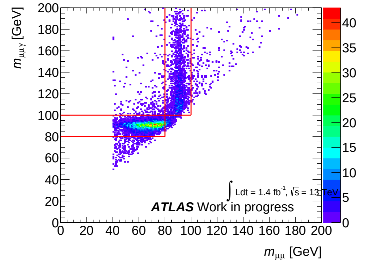
- $m_{\mu\mu} > 40$ GeV.
- Up to 3 additional jets.
- Different photon p_T slices.

Data : 1.4 fb^{-1} at 13 TeV from Run 2.

	FSR	ISR
$10 < p_T < 35$ GeV	195498	42725
$35 < p_T < 70$ GeV	11588	14322
$70 < p_T < 140$ GeV	4154	24801
$p_T > 140$ GeV	1017	7125
Data	3572	2014

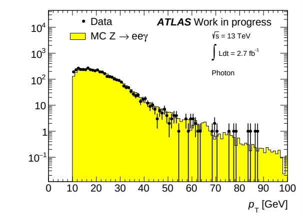
ISR/FSR ratio is different between the MC slices and between data and MC.

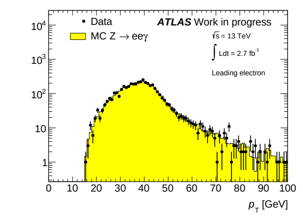


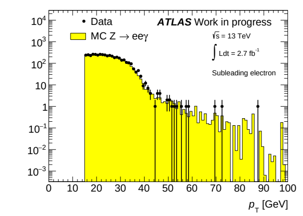


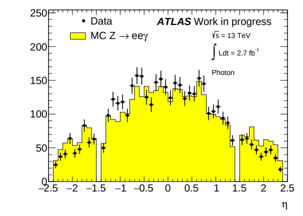
Control plots for FSR events $Z \to ee\gamma$

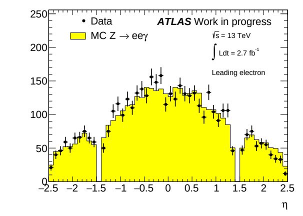
Events selected in the FSR region only ($80 < m_{ll\gamma} < 100$ GeV) :

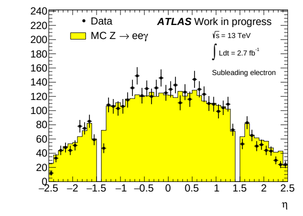






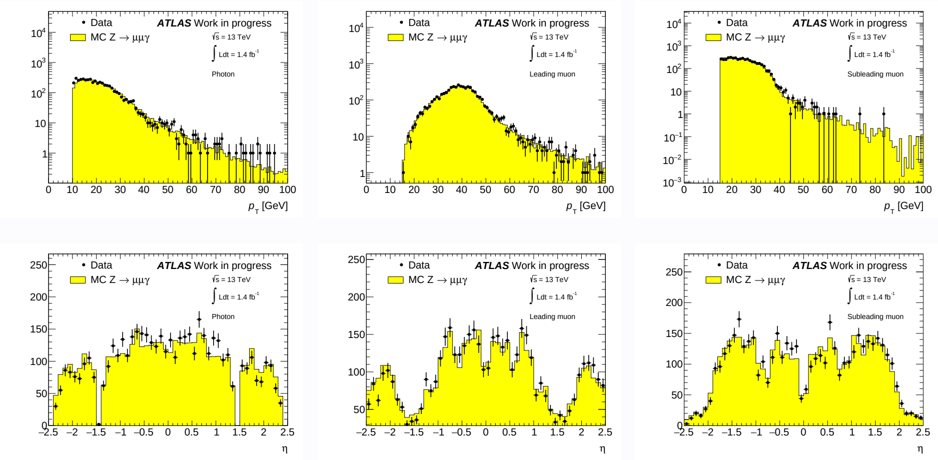






Control plots for FSR events $Z \rightarrow \mu\mu\gamma$

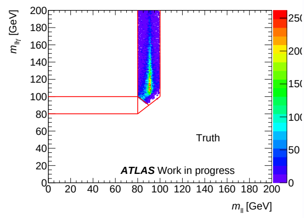
Events selected in the FSR region only ($80 < m_{ll\gamma} < 100$ GeV) :

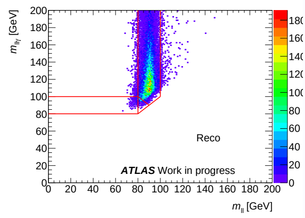


MC composition

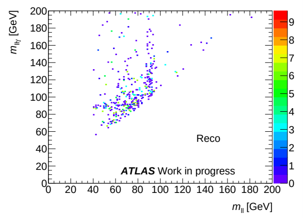
Two background contributions :

True ISR events leakage in FSR region :





Z + fake : selected using information at truth level.
Peak at 91 GeV due to the selection.

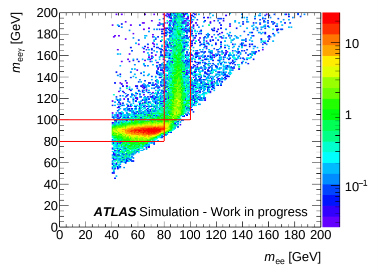


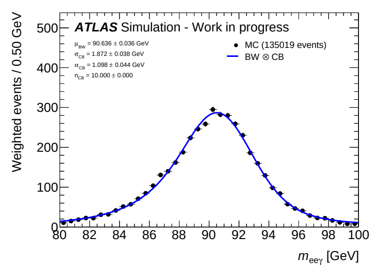
MC $ee\gamma$ (true FSR)

Use truth information to select true FSR events only.

Pure signal : fit with a Breit-Wigner convoluted with a Crystal-Ball.

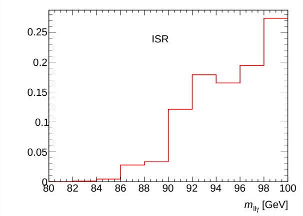
$$CB(x) = N \cdot \begin{cases} \exp(-\frac{(x-\bar{x})^2}{2\sigma^2}), & \text{for } \frac{x-\bar{x}}{\sigma} > -\alpha \\ \left(\frac{n}{|\alpha|}\right)^n \cdot \exp\left(-\frac{|\alpha|^2}{2}\right) \cdot (\frac{n}{|\alpha|} - |\alpha| - \frac{x-\bar{x}}{\sigma})^{-n}, & \text{for } \frac{x-\bar{x}}{\sigma} \leqslant -\alpha \end{cases}$$

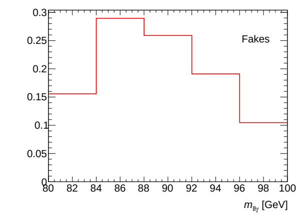




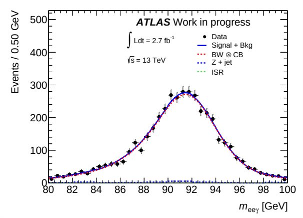
Data $ee\gamma$

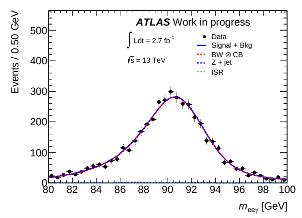
Extract background components from MC as histogram pdfs.

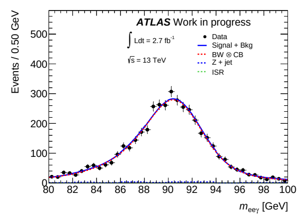




Fit data with bkg component fixed to Sherpa ratio / without bkg : negligible change in peak position ($< 10^{-4}$).







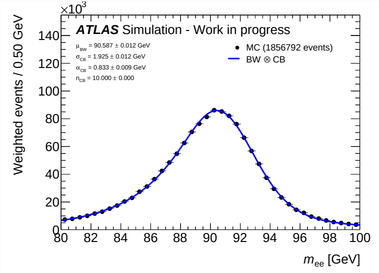
$Z \to ll$

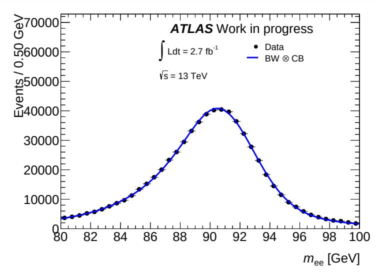
Using $Z \to ll$ inclusive samples (generated with Powheg + Pyhtia) :

- Increase statistics.
- Cleaner signal.

Same selection for leptons, no photon required.

Very clean selection, fit with signal only :



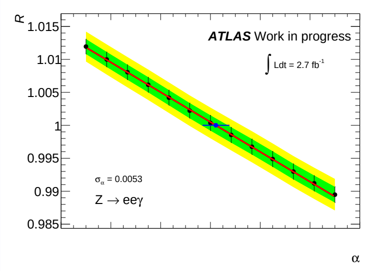


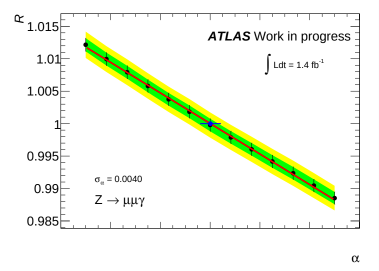
$Z \to \mu\mu$: Breit-Wigner $\otimes$ Crystal-Ball does not fit that well, still working on it (but not big deal : such discrepancies are cancelled out by the double ratio).

Energy scale

Compute double ratio as a fonction of α to extract the photon energy scale :

$$R(\alpha) = \frac{\langle m_{ll\gamma}^{\text{data}}(\alpha)\rangle / \langle m_{ll}^{\text{data}}\rangle}{\langle m_{ll\gamma}^{\text{MC}}\rangle / \langle m_{ll}^{\text{MC}}\rangle}$$





Still blind analysis : do not show value of α.

Statistical uncertainty dominated by $m_{ll\gamma}$ from data.

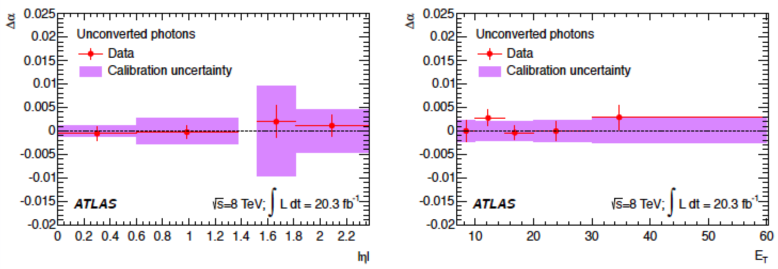
Combined measurement : 0.32% precision.

Ongoing work

Need higher statistics to perform a binned analysis :

- E_T bins.
- $|\eta|$ bins.
- Unconverted/converted photons.

Estimate systematics.



Summary

- Photon scale factor :
  - Provides a data-driven validation of the calibration.
  - Double ratio method : robust against lepton scales uncertainties.
- Use FSR events to fit $Z \to ll\gamma$ peak :
  - Two background components : ISR and Z + fake, extracted from MC.
  - $\sim$ 0.1% precision on peak position in data with current statistics.
  - Leads to 0.5% (0.4%) precision on α in $Z \to ee\gamma$ ($Z \to \mu\mu\gamma$).
- Ongoing work :
  - Binned analysis : E_T, $|\eta|$, converted/unconverted.
  - Systematics.
  - Closure test to validate the method.