Measurement of Z plus γ production with the CMS experiment

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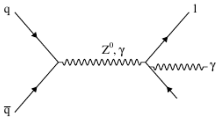
Overview

Content

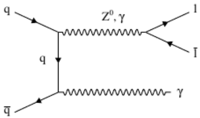
- Photon ID efficiency using FSR
- Measurement of $Z\gamma \to \mu^+\mu^-\gamma$ cross section
- Measurement of $Z\gamma \to e^+e^-\gamma$ cross section
- Exclusion of anomalous $ZZ\gamma$-couplings

Motivation

- Standard model $U(1) \times SU(2)$ gauge invariance fixes the couplings of gauge bosons, $\Rightarrow ZZ\gamma$- and $\gamma\gamma Z$-vertex not allowed.
- Measured photons radiated by incoming quarks (ISR) and outgoing muons (FSR) which can be kinematically separated.
- An enhancement (especially of high E_t-photons) would mean an anomalous coupling beyond the standard model.

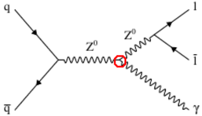


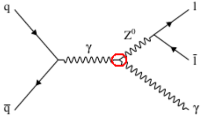
FSR

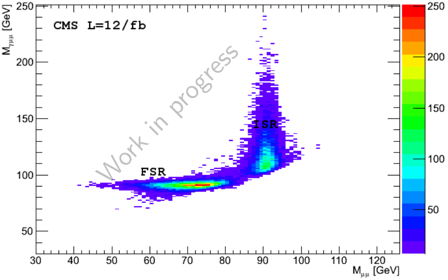


ISR

not allowed







Event Selection

Luminosity: $5\,\mathrm{fb}^{-1}(7\,\mathrm{TeV})$, $12\,\mathrm{fb}^{-1}(8\,\mathrm{TeV})$

Muons/Electrons

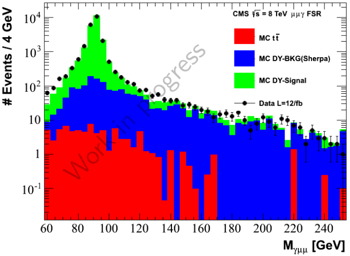
- Opp. charged leptons
- $P_t > 20\,\mathrm{GeV}$
- $|\eta| < 2.4$
- M_{ll} >50 GeV

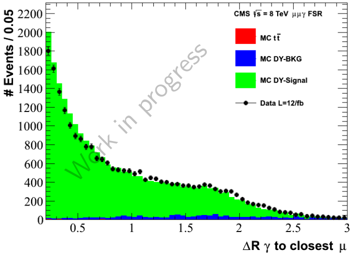
Photons

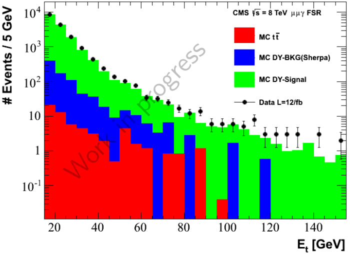
- $|\eta_{sc}| < 2.4$
- $E_t > 15\,\mathrm{GeV}$
- $\Delta R(l, \gamma) > 0.7$

Photon ID

- $E_{had}/E_{em} < 0.05$
- No Pixel Seed
- $I_{track} < 5\,\mathrm{GeV}$
- barrel: $I_{ECAL} < 10\,\mathrm{GeV}$, endcap: $I_{ECAL} < 5\,\mathrm{GeV}$
- barrel: $I_{HCAL} < 10\,\mathrm{GeV}$, endcap: $I_{HCAL} < 5\,\mathrm{GeV}$
- No jet with $P_t(jet) > 2P_t(\gamma)$ in $\Delta R < 0.5$







FSR selection:

$\Delta R(\mu, \gamma) < 1.2$

30 GeV $< M_{ll} <$ 80 GeV

-Clean sample to study photon efficiency.

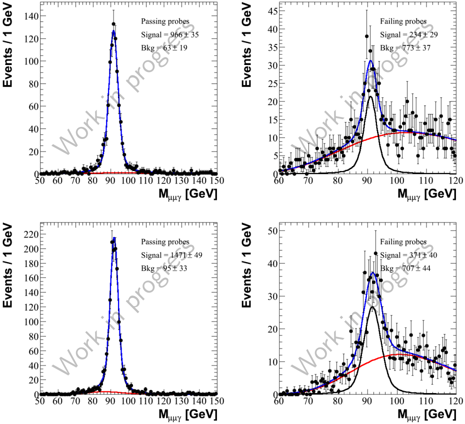
-Will be used as template for signal photons.

Photon ID efficiency using FSR I

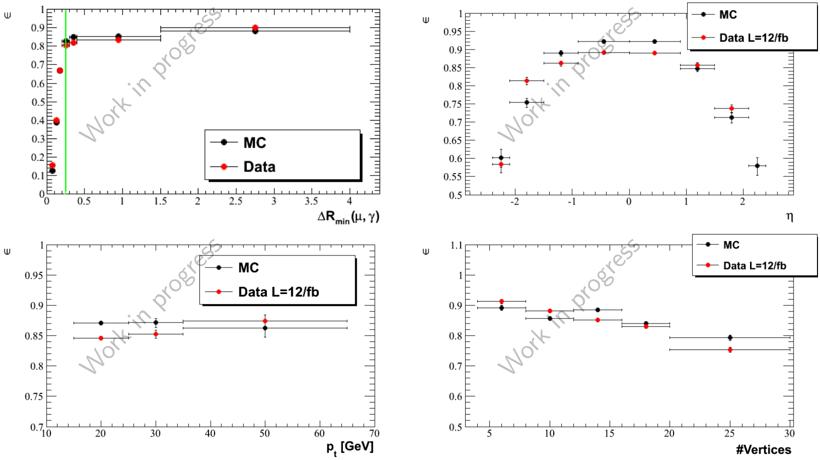
- $M_{\mu\mu\gamma}$ distribution shows Z-Peak which can be used for Tag&Probe
- Tag: dimuon system, $M_{\mu\mu} < 80\,\text{GeV}$
- Probe: loose photon object: $\Delta R_{min}(\mu, \gamma) > 0.25$

Fit data $\rightarrow$
Signal: Breit-Wigner $*$ Crystal Ball function
BKG: LogNormal distribution

Fit MC $\rightarrow$
Number of MC truth can be reconstructed.



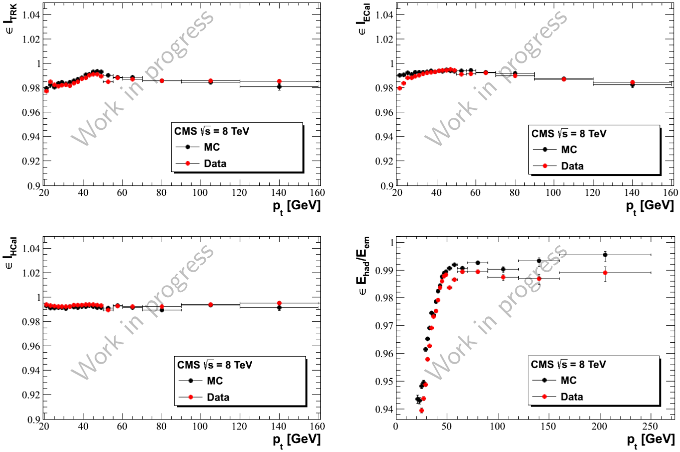
Photon ID efficiency using FSR II



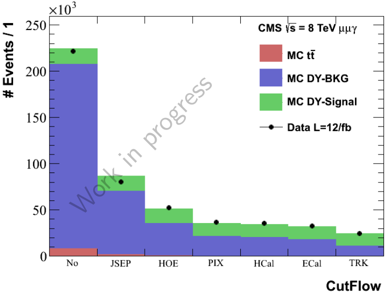
Only small differences between MC and Data observed. Used as p_t-dependet correction factors.

Photon ID efficiency using Electrons

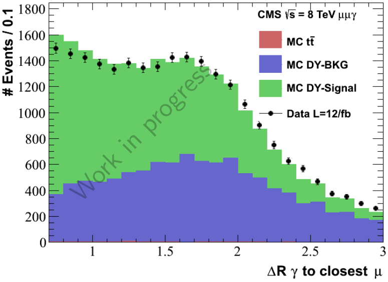
FSR can not be used for high p_t-photons. Electrons are similar except for pixel seed veto.
$\rightarrow$Data and MC are compatible within a few percent.



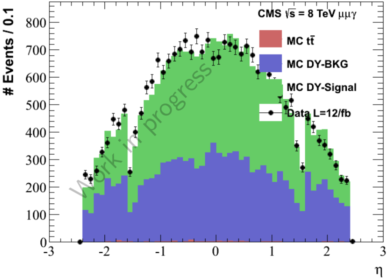
Very good agreement in high p_t region. Difference less than 1%.



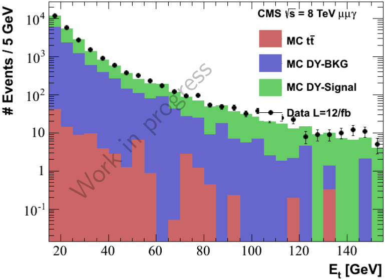
CMS √s = 8 TeV μμγ
MC tt̄
MC DY-BKG
MC DY-Signal
Data L=12/fb
Work in progress
Events / 1
×10³
No JSEP HOE PIX HCal ECal TRK
CutFlow



CMS √s = 8 TeV μμγ
MC tt̄
MC DY-BKG
MC DY-Signal
Data L=12/fb
Work in progress
Events / 0.1
ΔR γ to closest μ

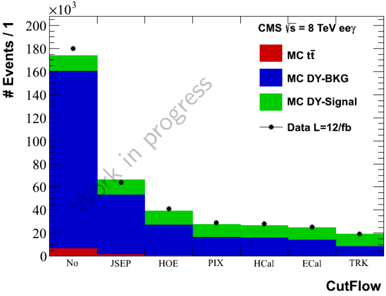


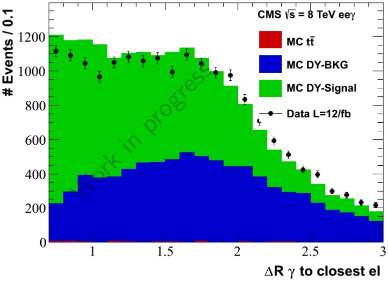
CMS √s = 8 TeV μμγ
MC tt̄
MC DY-BKG
MC DY-Signal
Data L=12/fb
Work in progress
Events / 0.1
η

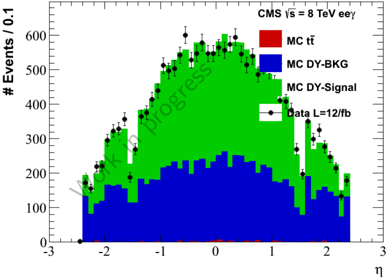


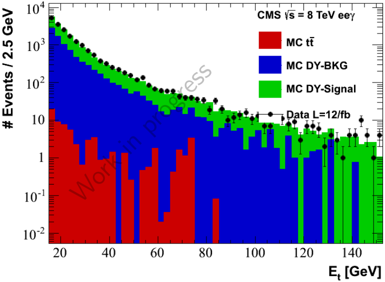
CMS √s = 8 TeV μμγ
MC tt̄
MC DY-BKG
MC DY-Signal
Data L=12/fb
Work in progress
Events / 5 GeV
E_t [GeV]

$ee\gamma$ Signal Distributions $\Delta R(e,\gamma) > 0.7$



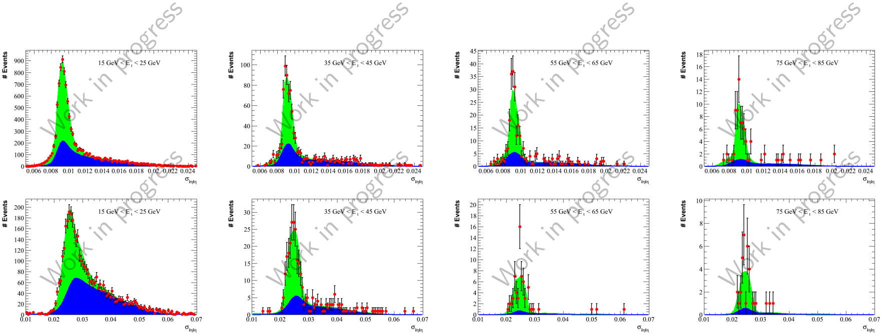






Signal Extraction

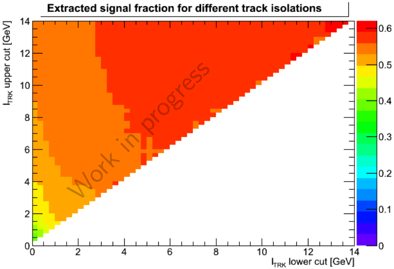
- In contrast to FSR strong contamination of photons from π^0 and jet fragmentation.
- $\sigma_{i\eta i\eta}$-templates (width of photon cluster in η-direction) to extract signal.
- **Signal:** from data FSR $0.2(0.4) < \Delta R(\mu(e), \gamma) < 1.2$.
  -With FSR from electron and muon separately $\rightarrow$difference $< 1\%$.
  -Varying $\Delta R(l, \gamma) < 1.0$, $\Delta R(l, \gamma) < 1.5$ $\rightarrow$difference $< 1\%$.
- **BKG:** lower and upper cut of track isolation are selected in a way that MC-BKG and MC-QCD agree in $\sigma_{i\eta i\eta}$-shape. Same cut used to extract BKG-Template from jet-data.

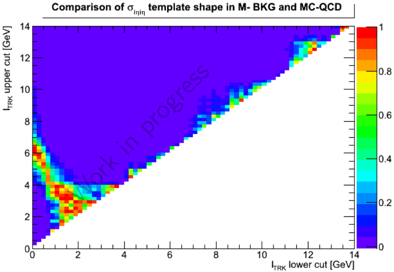


Background $\sigma_{i\eta i\eta}$-Template

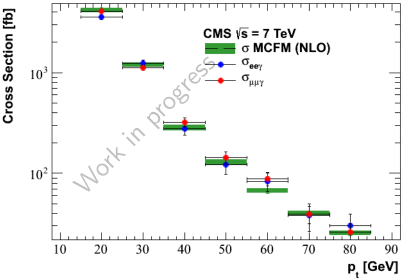
Differences in $\sigma_{i\eta i\eta}$ between MC and Data don't allow direct use of MC templates.

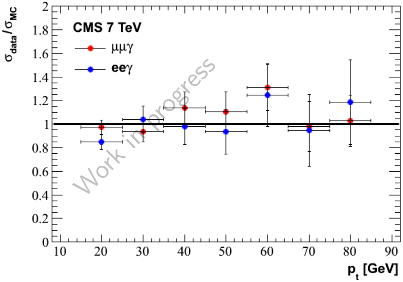
- QCD events with at least two hadronic jets and a photon are selected.
- These photons should fulfill the whole ID except for I_{TRK}.
- The upper and lower threshold of I_{TRK} are varied and the signal fraction extracted.
- Select those regions in I_{TRK}-plane where the $\sigma_{i\eta i\eta}$-shape is consistant with that of photons from QCD-MC.
- This procedure is done for every p_t-bin and for barrel and endcap region.

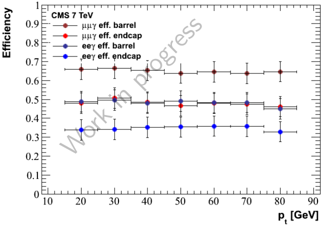




Cross Section 7 TeV







Cross sections phase space:

$\Delta R(l,\gamma) > 0.7,\ M_{ll} > 50\,\mathrm{GeV}$

$ee\gamma$: $5340 \pm 90(stat.) \pm 310(sys.) \pm 120(lumi.)$ fb

$\mu\mu\gamma$: $5830 \pm 80(stat.) \pm 330(sys.) \pm 128(lumi.)$ fb

MCFM (NLO): 5930 ± 330 fb

Uncertainties:

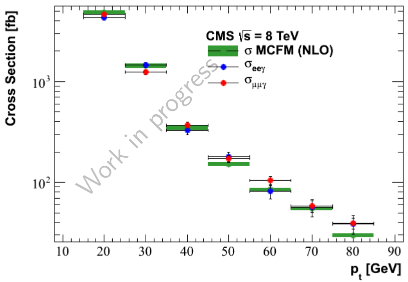
-Lepton efficiency: 2%

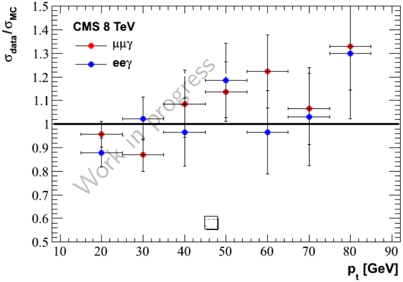
-Photon efficiency: 5%

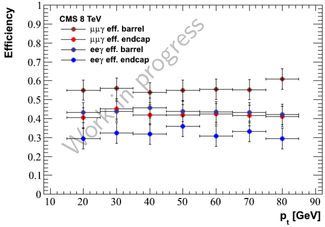
-Luminosity: 2.2%

-Template method bin dependent: 5-20%

Cross section 8 TeV







Cross Sections phase space:

$\Delta R(l,\gamma) > 0.7,\ M_{ll} > 50\,\text{GeV}$

$ee\gamma$: $6410 \pm 70(stat.) \pm 360(sys.) \pm 280(lumi.)$ fb

$\mu\mu\gamma$: $6630 \pm 60(stat.) \pm 370(sys.) \pm 290(lumi.)$ fb

MCFM (NLO): 6940 ± 380 fb

Uncertainties:

-Lepton efficiency: 2%

-Photon efficiency: 5%

-Luminosity: 4.4%

-Template method bin dependent: 5-20%

Anomalous Gauge Couplings I

$$\Gamma^{\alpha\beta\mu} = \frac{P^2 - q_1^2}{m_z^2}\{h_1(q_2^\mu g^{\alpha\beta} - q_2^\alpha g^{\mu\beta}) + h_2 \frac{P^\alpha}{m_Z^2}((P \cdot q_2)g^{\mu\beta} - q_2^\mu P^\beta)$$
$$+ h_3 \epsilon^{\mu\alpha\beta\rho} q_{2\rho} + h_4 \frac{P^\alpha}{m_Z^2} \epsilon^{\mu\beta\rho\sigma} P_\rho q_{2\sigma}\}$$

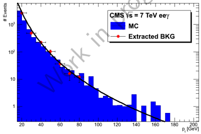
- Most general form of vertex. P incoming Z/γ, q_1 outgoing Z, q_2 outgoing γ. [arXiv:hep-ph/9710416]
- Four new Parameters h_i; h_1, h_2 CP-violating set to zero.
- Scale dependent to avoid unitarity violation $h_i(s)$. All values given at Z mass.

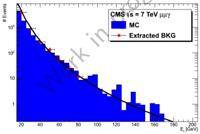
$$|h_3| < \frac{(\frac{2}{3}n)^n}{(\frac{2}{3}n - 1)^{n-3/2}} \frac{0.151\, TeV^3}{\Lambda^3}; n = 3, \Lambda = 1.5\, TeV, h_3 < 0.3$$

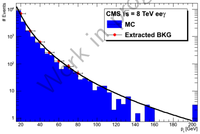
$$|h_4| < \frac{(\frac{2}{5}n)^n}{(\frac{2}{5}n - 1)^{n-5/2}} \frac{2.5 \times 10^{-3}\, TeV^5}{\Lambda^5}; n = 3, \Lambda = 1.5\, TeV, h_4 < 0.001$$

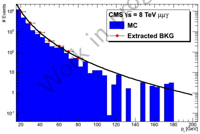
Anomalous Gauge Couplings II

Background from template fits compared to MC background prediction:



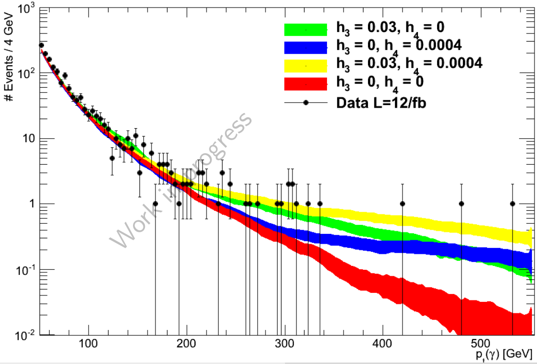




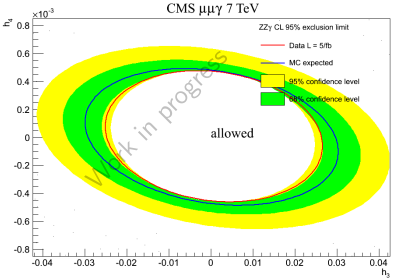


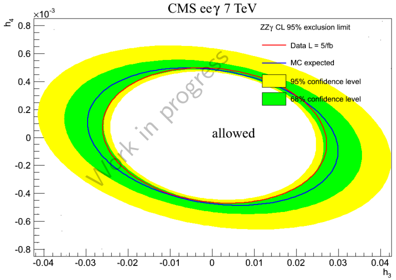
BKG: LogNormal-Fit to BKG from Template-Method

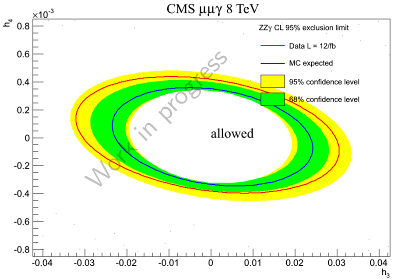
SIG: Sherpa Generator (Fast SIM)

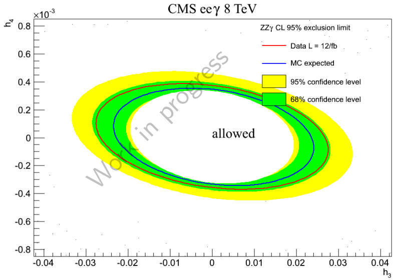


Anomalous Gauge Couplings Result

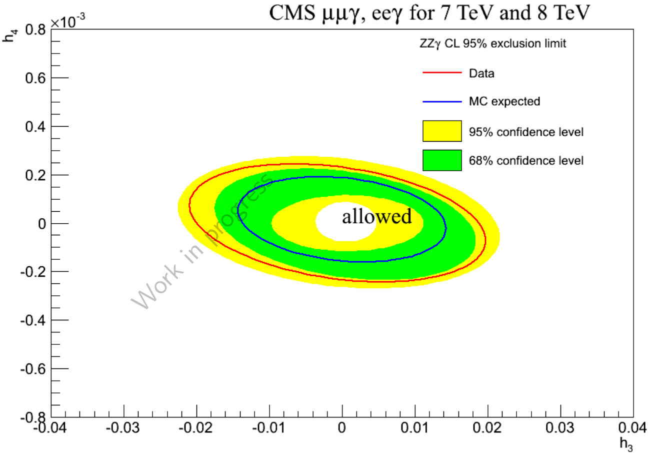








Anomalous Gauge Couplings Combined Result



Conclusion

FSR

Clean sample of photon with simple kinematic cuts:

- Photon reconstruction efficiency.
- Template for Signal.

ISR

- Large number of fake photons but data driven templates for $\sigma_{i\eta i\eta}$ available.
- Cross sections are in good agreement with MC prediction.
- Exclusion of anomalous couplings are within expectations.

BACK UP