Measurement of the differential cross section for the production of isolated diphotons in pp collisions at $\sqrt{s} = 7\,TeV$

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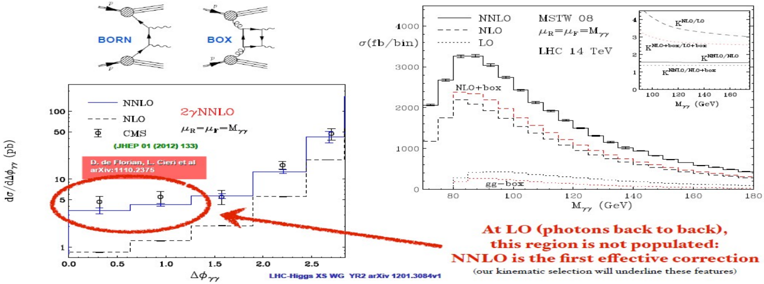
Outline

Diphoton differential cross sections

- Diphoton events as a probe of perturbative QCD @NNLO
- Major source of background for the $H \to \gamma\gamma$ analysis
- CMS approved analysis(**AN-2013/034**, **SMP-13-001**), CMS Final Reading, will submit to EPJC
- Recent theory result: 10.1103/PhysRevLett.108.072001(Catani, Cieri, de Florian, Ferrera, Grazzini)



Analysis strategy

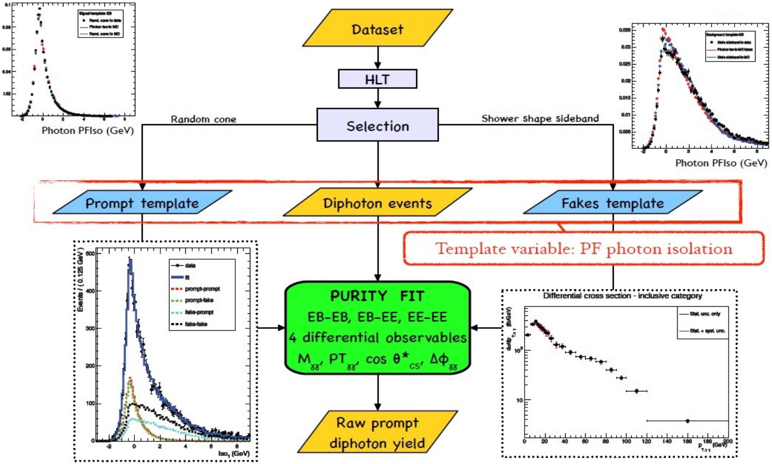
$$\frac{d\sigma}{dX} = \frac{N^U_{\gamma\gamma}}{\epsilon \cdot \mathcal{L} \cdot \Delta X}$$
$$(X = m_{\gamma\gamma}, Pt_{\gamma\gamma}, \Delta\phi_{\gamma\gamma}, |cos\theta^*|)$$

Goal: extract, on a statistical basis, the number of events with two prompt isolated photons

- Data samples: CMS 2011 7TeV data
- Integrated luminosity: $(5.0 \pm 0.1)/\text{fb}$
- High-level Trigger: Diphoton triggers with pt threshholds $\{22, 36\}$ GeV
- Selections:
  1. **Preselection cuts as in 2011 $H \to \gamma\gamma$**
  2. **Selection on ratio of the energy deposited in HCAL and Ecal, selection on shower shapes**
  3. **Kinematic selection**

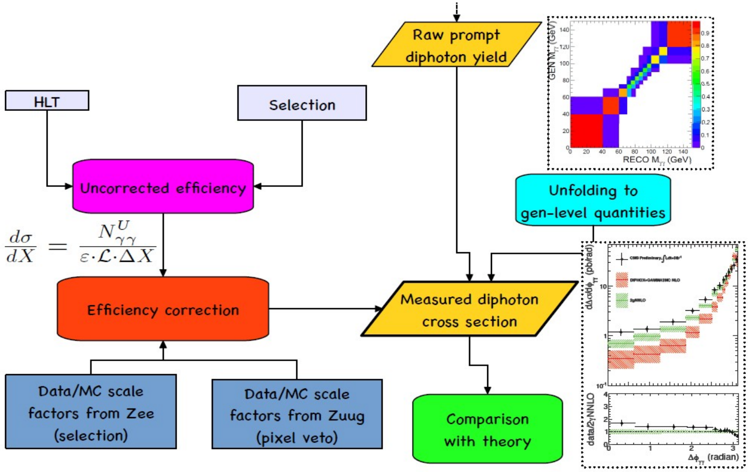
Analysis strategy

Analysis workflow I

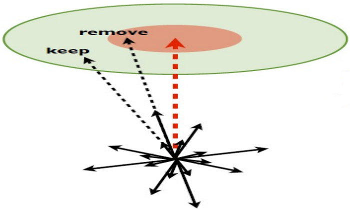


Analysis strategy

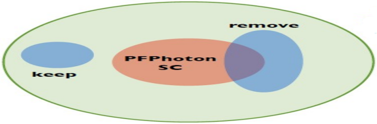
Analysis workflow II



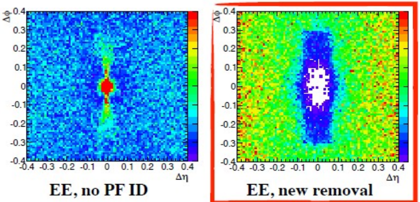
SuperCluster footprint removal method



PF(Particle Flow) candidates that are overlapping with its SuperCluster are considered part of its footprint and removed from the isolation.



- propagate the reconstructed PFCandidate until the surface of ECAL
- check if it hits the surface of a crystal inside the SuperCluster
- if it does, remove it from isolation sum

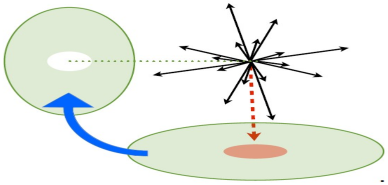


Removel example

Prompt photon template

The template for prompt photons is built from data with the random cone technique

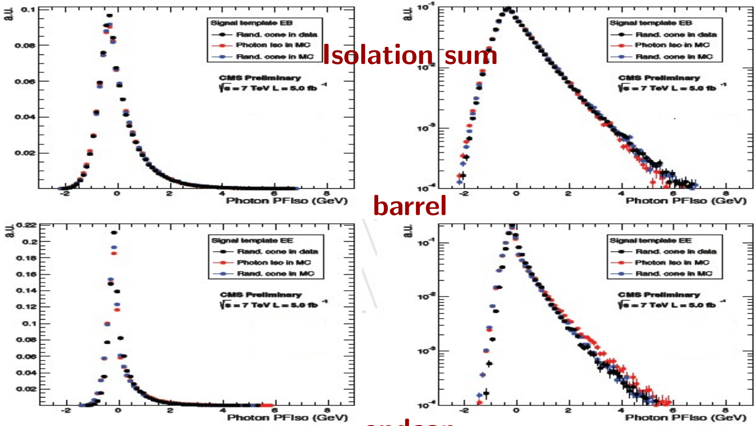
- Rotate the isolation cone by a random angle in ϕ
- Underlying activity does not change (same η)
- Check that no other SC or jet is nearby
- compute the isolation sum in the rotated cone for each event and build its distribution



Assumption:

Once the photon footprint has been removed, the isolation sum for prompt photons is due only to pileup and underlying event.

Prompt photon template



Isolation sum

barrel

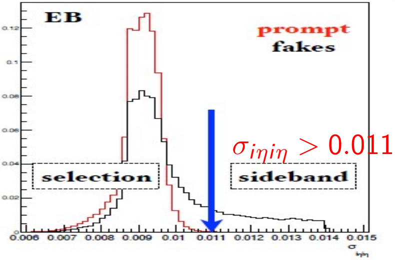
endcap

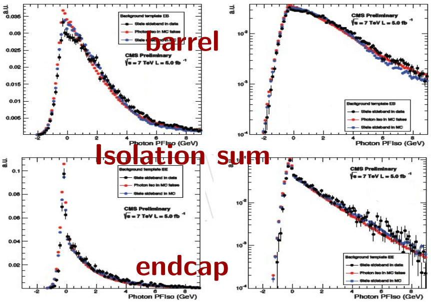
> Random cone reproduces very well
> the isolation around prompt photons

Fake photon template

- Fake photons are jets passing the selection, i.e. isolated neutral mesons
- $\sigma_{i\eta i\eta}$: the transverse shape of the electromagnetic cluster
- Template for fake photons is built with the $\sigma_{i\eta i\eta}$ sideband method
- Inverting the cut on $\sigma_{i\eta i\eta}$

The sideband method reproduces very well the isolation for the fakes





Fitting technique

- One event two photons, the likelihood model should describe their correlations
- Sources of correlation: Pileup, Fluctuation of pile-up energy density
- 2D likelihood to fit for prompt-prompt (pp), prompt-fake (pf), fake-prompt (fp) and fake-fake (ff) fractions

(Iso_1, Iso_2) "factorized" likelihood does not work:

$$\mathcal{L}(Iso_1, Iso_2) =$$
$$= pp \cdot T_p(Iso_1)T_p(Iso_2) + pf \cdot T_p(Iso_1)T_f(Iso_2) + fp \cdot T_f(Iso_1)T_p(Iso_2) + ff \cdot T_f(Iso_1)T_f(Iso_2)$$

⇒ a full 2D likelihood is used:

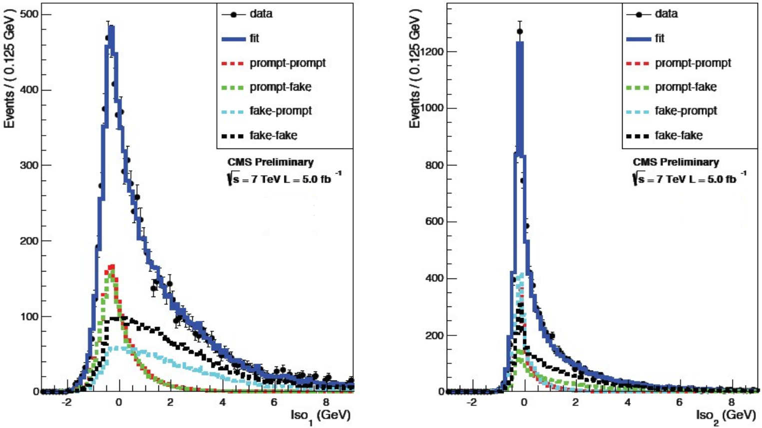
$$\mathcal{L}_{2D}(Iso_1, Iso_2) =$$
$$= pp \, T_{pp}(Iso_1, Iso_2) + pf \cdot T_{pf}(Iso_1, Iso_2) + fp \cdot T_{fp}(Iso_1, Iso_2) + ff \cdot T_{ff}(Iso_1, Iso_2)$$

likelihood function

Fitting technique

Result of the 2D fit: extraction of prompt-prompt purity

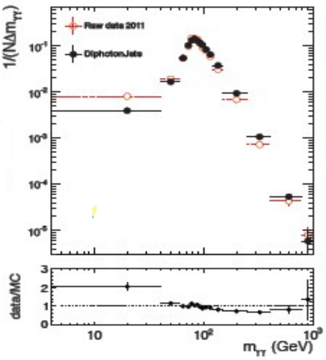
1D projections of the 2D fit

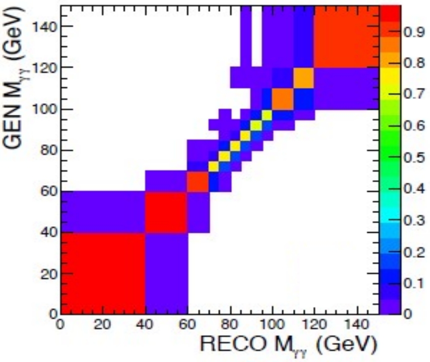


Example of EB-EE final fit

Unfolding

- The measured diphoton yield is unfolded to gen-level quantities
- Observable distributions reweighted to raw measured yields





Typical order of magnitude of the effect of unfolding: 5%

Efficiency correction

The raw diphoton yield is corrected for efficiency:

- Trigger efficiency
- Selection efficiency from diphoton MC
- Data/MC scale factor from $Z \to ee$ and $Z \to \mu\mu\gamma$(for pixel veto)

$$\epsilon_{\gamma\gamma} = \epsilon_{trigger} x \epsilon_{reco\&sel} x C_{\gamma 1}^{Z\to e^+e^-} x C_{\gamma 2}^{Z\to e^+e^-} x C_{\gamma 1}^{Z\to \mu^+\mu^-\gamma} x C_{\gamma 2}^{Z\to \mu^+\mu^-\gamma}$$

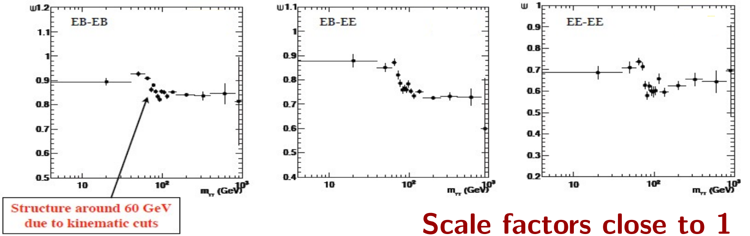
Trigger efficiency w.r.t. selection is measured from $Z \to ee$ Tag and Probe:

Both photons in barrel		One or more in endcap	
$min(R_9)$ >0.94	$min(R_9)$ <0.94	$min(R_9)$ >0.94	$min(R_9)$ <0.94
100.00±0.01±0.00%	99.3±0.04±0.10%	100.00±0.02±0.00%	98.8±0.06±0.4%

Efficiency correction

The diphoton "raw" selection efficiency is taken from the MC

$$\epsilon_{reco\&sel} = \frac{N^{sim}_{reco}(X_i)[\eta_{reco} \in Acc, E_T^{\gamma 1reco} > 40GeV, E_T^{\gamma 2reco} > 25GeV, \text{IDselection}, X_{gen} \in Bin_i]}{N^{sim}_{gen}(X_i)[\eta_{gen} \in Acc, E_T^{\gamma 1gen} > 40GeV, E_T^{\gamma 2gen} > 25GeV, X_{gen} \in Bin_i]}$$



Scale factors close to 1

- Data/MC selection scale factor from $Z \to ee$(T&P)

Probe object in ECAL barrel			
E_T bin (GeV)	ϵ_{data}	ϵ_{MC}	$\epsilon_{data}/\epsilon_{MC}$
25-35	0.948±0.001(stat.)±0.007(syst.)	0.956±0.004(stat.)±0.007(syst.)	0.991±0.008(tot.)
35-40	0.949±0.001(stat.)±0.007(syst.)	0.961±0.002(stat.)±0.007(syst.)	0.988±0.007(tot.)
40-45	0.966±0.001(stat.)±0.007(syst.)	0.972±0.001(stat.)±0.007(syst.)	0.993±0.007(tot.)
45-50	0.974±0.001(stat.)±0.007(syst.)	0.977±0.001(stat.)±0.007(syst.)	0.996±0.007(tot.)
>50	0.981±0.002(stat.)±0.007(syst.)	0.985±0.005(stat.)±0.007(syst.)	0.996±0.009(tot.)
Probe object in ECAL endcap			
E_T bin (GeV)	ϵ_{data}	ϵ_{MC}	$\epsilon_{data}/\epsilon_{MC}$
25-35	0.935±0.007(stat.)±0.008(syst.)	0.934±0.004(stat.)±0.008(syst.)	1.001±0.012(tot.)
35-40	0.949±0.002(stat.)±0.008(syst.)	0.936±0.007(stat.)±0.008(syst.)	1.014±0.011(tot.)
40-45	0.968±0.001(stat.)±0.008(syst.)	0.958±0.002(stat.)±0.008(syst.)	1.010±0.008(tot.)
45-50	0.978±0.001(stat.)±0.008(syst.)	0.967±0.003(stat.)±0.008(syst.)	1.011±0.008(tot.)
>50	0.989±0.001(stat.)±0.008(syst.)	0.979±0.002(stat.)±0.008(syst.)	1.010±0.008(tot.)

- The data/MC scale factor for the pixel veto efficiency extracted from $Z \to \mu\mu\gamma$

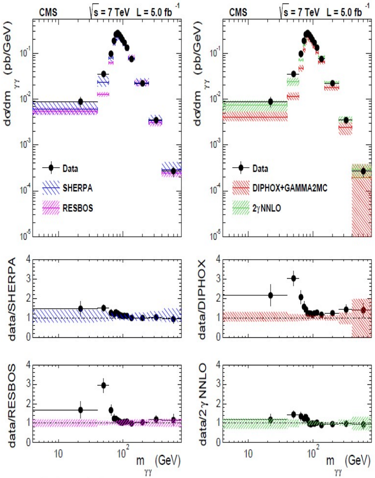
$\lvert\eta\rvert$ bin	ϵ_{data}	ϵ_{MC}	$\epsilon_{data}/\epsilon_{MC}$
0-1.4442	0.963 ± 0.006(stat.)	0.959 ± 0.003(stat.)	1.004 ± 0.009(total)
1.566-2.5	0.871 ± 0.017(stat.)	0.850 ± 0.011(stat.)	1.025 ± 0.021(total)

Systematic uncertainties

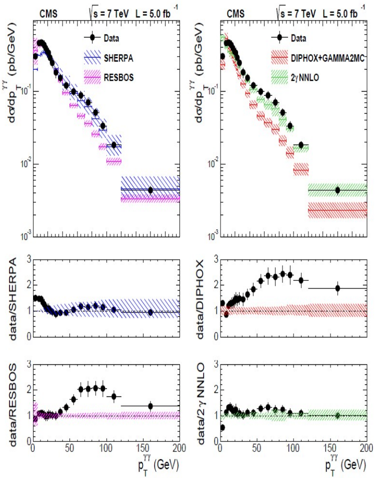
- Systematics on the purity measurement:
  1. **Template shape description**
  2. **Statistical fluctuations of the templates**
  3. **Uncertainty on $Z \to ee$ subtraction(max 2%)**
  4. **Bias from the fit procedure($< 0.5\%$)**
- Other systematics on:
  1. **Efficiency correction(typically 4%)**
  2. **Unfolding(1%)**
  3. **Integrated luminosity(2.2%)**

Source of uncertainty	
Prompt template shape (EB)	3%
Prompt template shape (EE)	5%
Non-prompt template shape (EB)	5%
Non-prompt template shape (EE)	10%
Effect of fragmentation component	1.5%
Template stat. fluctuation	3%
Selection efficiency	2-4%
Integrated luminosity	2.2%

Cross Section Result compared to Theoretical predictions

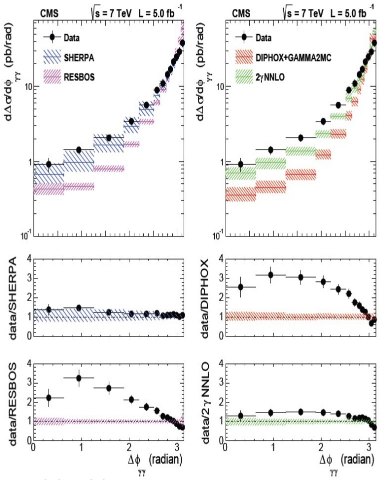


$m_{\gamma\gamma}$

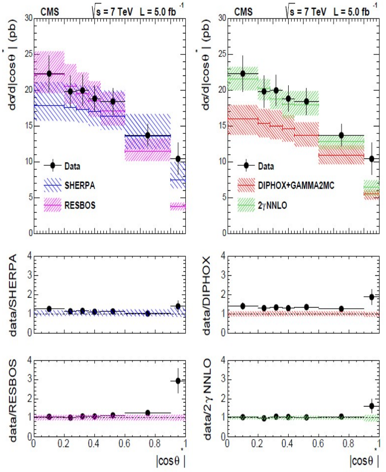


$Pt_{\gamma\gamma}$

Cross Section Result compared to Theoretical predictions



$\Delta\phi_{\gamma\gamma}$



$|cos\theta^*|$

Cross Section Result compared to Theoretical predictions

The total cross section measured in data (with a total uncertainty of 11%) is:

$$\sigma_{data} = 17.2 \pm 0.2(stat.) \pm 1.9(syst.) \pm 0.4(lumi) pb$$

This compares to theory predictions:

$$\sigma_{\mathrm{NNLO}}(2\gamma\mathrm{NNLO}) = 16.2^{+1.5}_{-1.3}(\mathrm{scale})\ \mathrm{pb}$$

$$\sigma_{\mathrm{NLO}}(\mathrm{DIPHOX+GAMMA2MC}) = 11.7^{+1.2}_{-1.1}(\mathrm{scale})^{+0.6}_{-0.6}(\mathrm{pdf}+\alpha_s)\ \mathrm{pb}$$

$$\sigma_{\mathrm{NLO}}(\mathrm{RESBOS}) = 14.9^{+2.2}_{-1.7}(\mathrm{scale}) \pm 0.6(\mathrm{pdf}+\alpha_s)\ \mathrm{pb}$$

$$\sigma_{\mathrm{LO}}(\mathrm{SHERPA}) = 15.2^{+3.2}_{-1.9}(\mathrm{scale})\ \mathrm{pb}$$

Very good agreement with the NNLO calculation

Conclusion

- Differential variables: $m_{\gamma\gamma}, Pt_{\gamma\gamma}, \Delta\phi_{\gamma\gamma}, |cos\theta^*|$
- The differential cross section for prompt diphoton production has been measured with CMS 2011 7TeV 5/fb data
- Fully data-driven methods have been used to build the templates for the determination of prompt diphoton yields
- Results have been compared to different theory predictions, best agreement with the NNLO calculation

Backup