Isolated Prompt Diphoton Cross Section Measurement at CMS

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on behalf of the CMS collaboration

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Providence, RI

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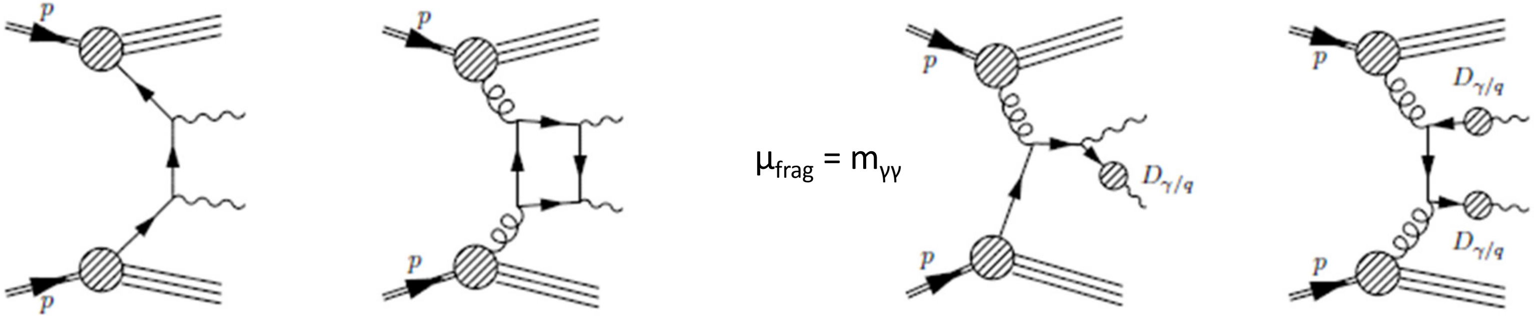
Diphotons at the LHC

Testing the Standard Model

Probing Quantum Chromodynamics in the perturbative regime (pQCD)

Processes contributing to the diphoton cross section:

Direct Born | **Direct Box** | **One Fragmentation** | **Two Fragmention**



@ LHC: enhanced by high gluon densities

In the jet fragmentation process, a hard isolated photon is emitted.

Higgs boson searches

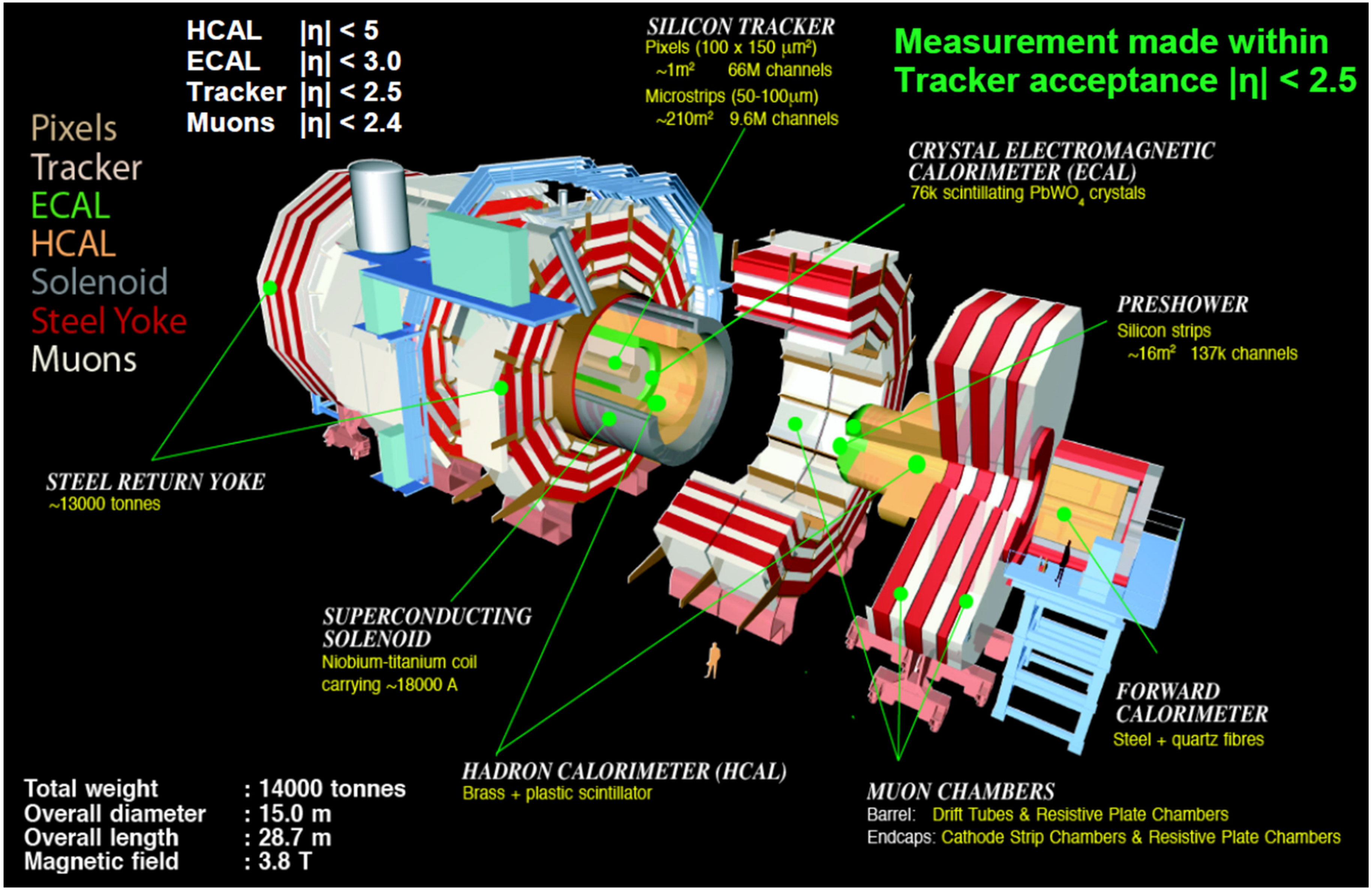
Understanding the irreducible background to H → γγ (see talk by C.Palmer)

Measurement differential cross section versus four observables

$$\cos\theta^* = \left|\tanh\left(\frac{y_1 - y_2}{2}\right)\right|$$

$m_{\gamma\gamma}$	diphoton invariant mass	$\Delta\phi$	azimuthal angle difference
$p_{T,\gamma\gamma}$	diphoton transverse momentum	$\cos\theta^*$	cosine of Collins-Soper scattering angle

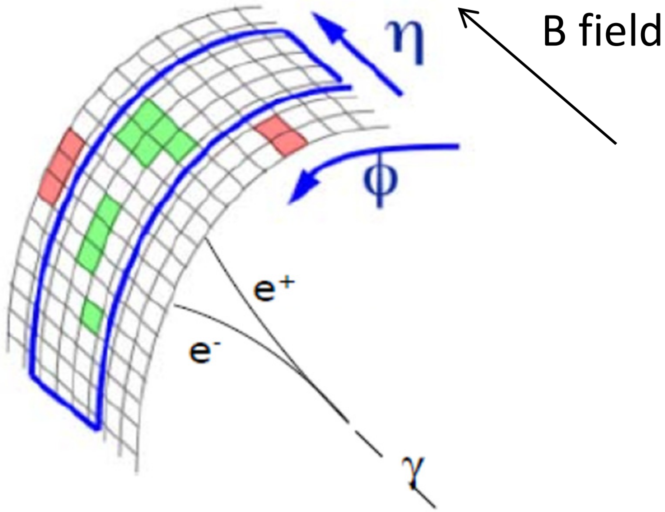
The CMS Detector



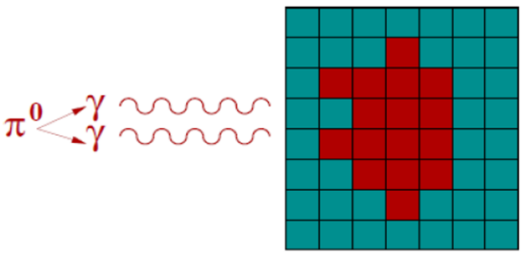
Photon Reconstruction & ID

Photon reconstructed from clusters of ECAL crystals

- Photons deposit energy in crystals of ECAL
- About 60 % of photons convert to e^+e^- pairs in the tracker the 3.8 T magnetic field spreads their energy along φ
- Photon energy is reconstructed from clusters of crystals extended along φ and limited in η direction

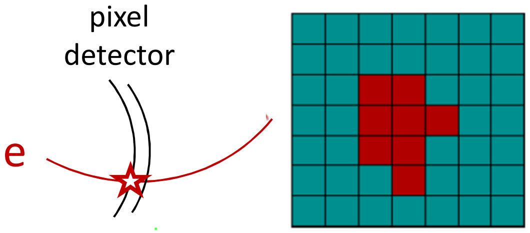


Photon (Mis)identification



Photons from jets (eg. $\pi^0 \rightarrow \gamma\gamma$ reconstructed as one photon) are rejected by a selection on

- shower-shape variables (cluster size in η)
- isolation variables (energy/momentum around the photon in ECAL, HCAL, tracker)



Electrons are rejected by requiring

- no hits in the pixel detector matched to the ECAL cluster

Measurement Outline

Acceptance and event selection

Two photons with $E_{T\,1,2} > 23, 20$ GeV separated by $R > 0.45$
photon cluster with $|\eta| < 1.44$ (barrel) or $1.57 < |\eta| < 2.5$ (endcap)
Requirements on isolation (HCAL, tracks) and shower shape

Avoid soft gluon divergences in NLO fixed order calculation → asymmetric E_T thresholds

Cross section measured in the stated acceptance

For generic observable Ω :

$$\frac{d\sigma}{d\Omega}(\gamma\gamma + X) = \frac{N^{\gamma\gamma}_{\mathrm{unf.}}}{\mathcal{A}\epsilon \cdot \Delta\Omega \cdot \mathcal{L}}$$

Efficiencies

For integrated cross section A.ε = **76.2 ± 3.3 %**

Bin width

- Trigger efficency 100 % (simulation)
- Reconstruction correction (simulation)
- Identification
  - isolation and shower shape (tag & probe on data)
  - veto on the matched pixel hits (simulation)
  - veto on tracks (random cones on data)

Dataset

collected in the 2010 run

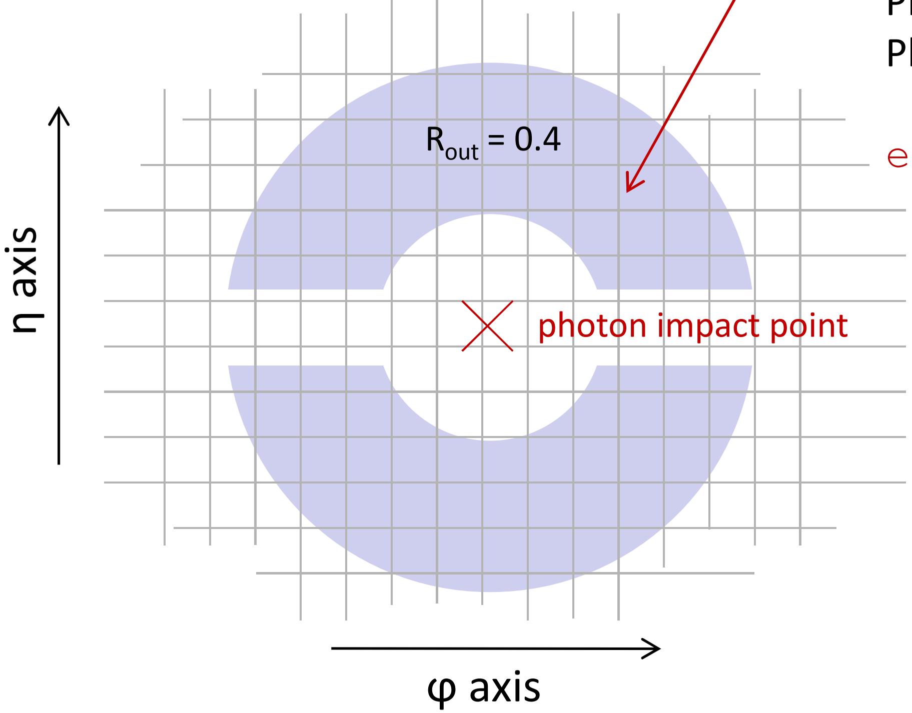
Total integrated luminosity $36.0 \pm 1.4\ \mathrm{pb}^{-1}$

Background Discrimination

Statistical extraction of signal yield with fit on an ECAL isolation variable "`ecalIso`"

Sum of the transverse energies in the isolation surface around the photon impact point in ECAL

`ecalIso` = Σ E_T (crystal) in

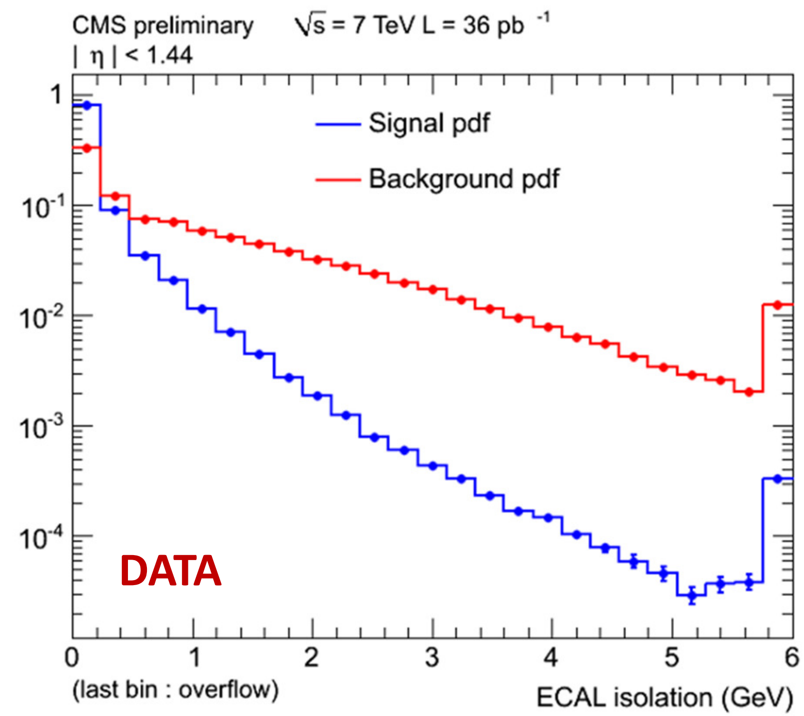


Discriminating

Prompt photons (sig) are "ECAL isolated"

Photons from jets (bkg) likely to be non-"ECAL-isolated"

`ecalIso` templates used in a maximum likelihood fit



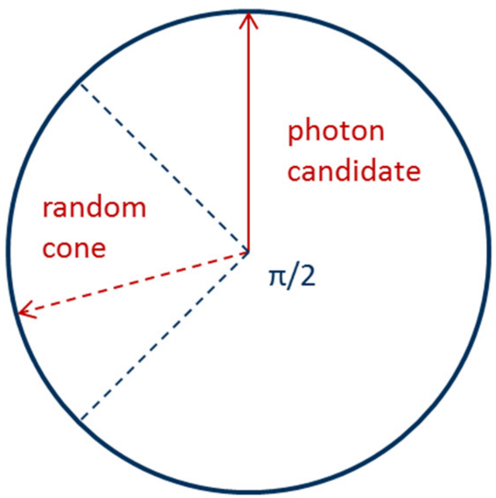
Signal and background templates extracted from data

Data-driven Template Extraction

Signal: Random Cones

Only contributions to `ecalIso` of signal from pileup and underlying event.

→ collect deposits cone @ about π/2



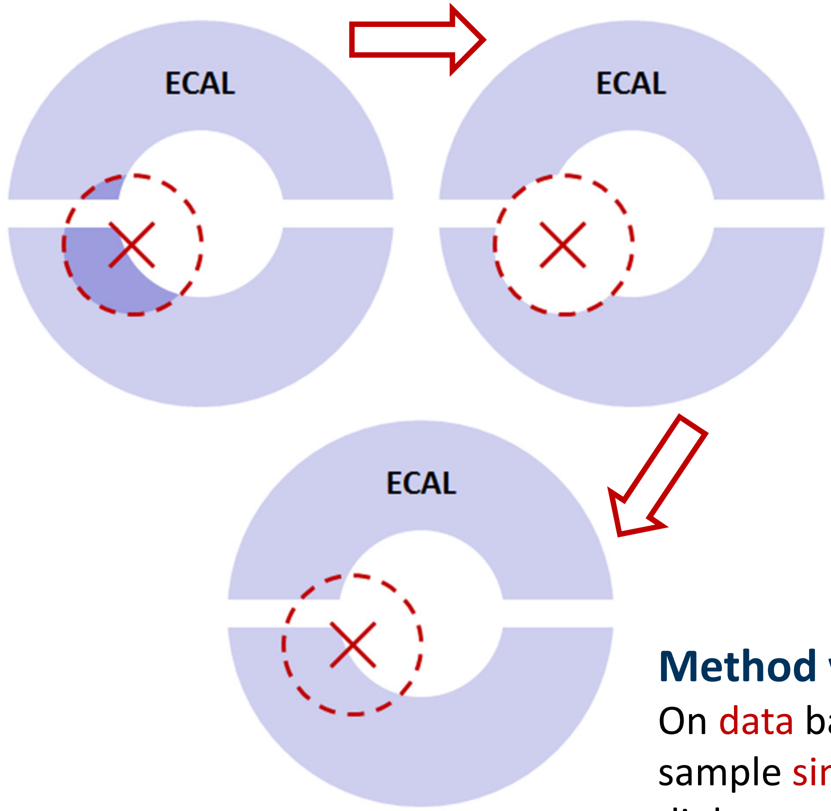
CMS / ECAL
plane transverse to beam axis

Method validated

On data electrons from Z and W and simulated diphoton events

Background: Impinging track

Pure background sample: require one track from hard interaction to hit ECAL close to photon (R<0.4) and remove deposits of the track in ECAL



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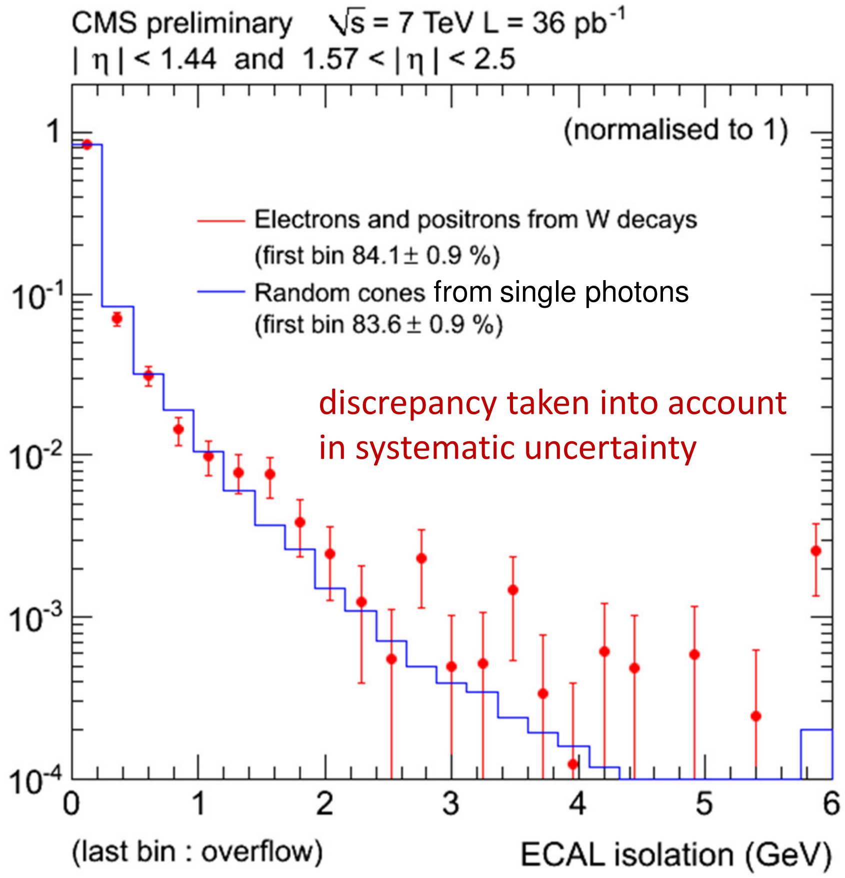
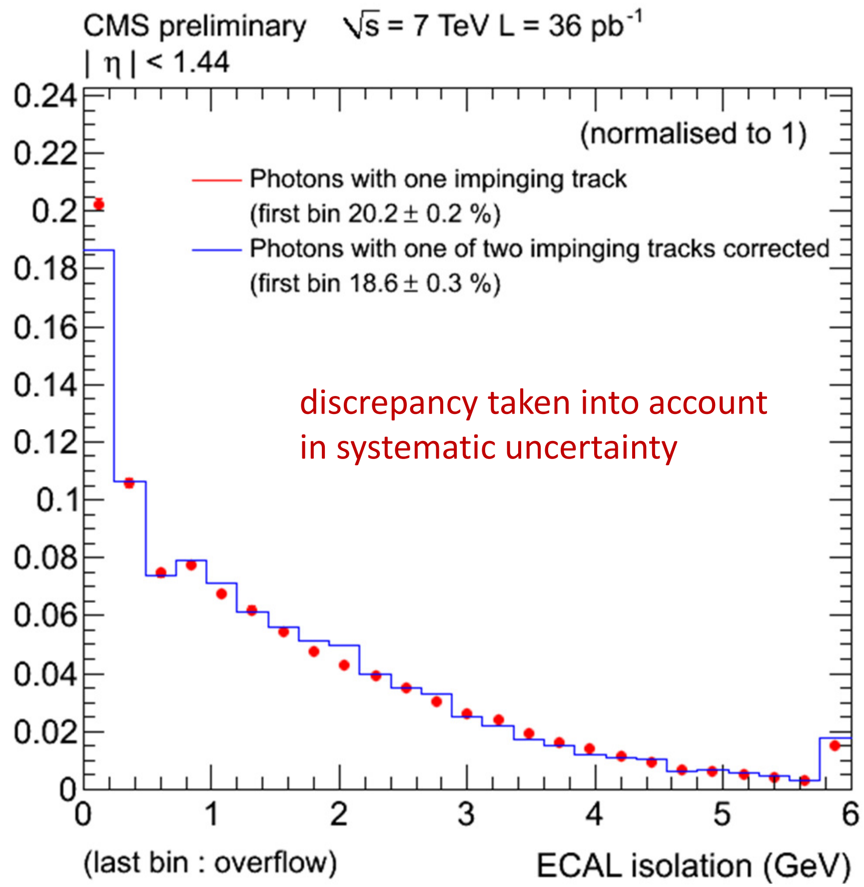


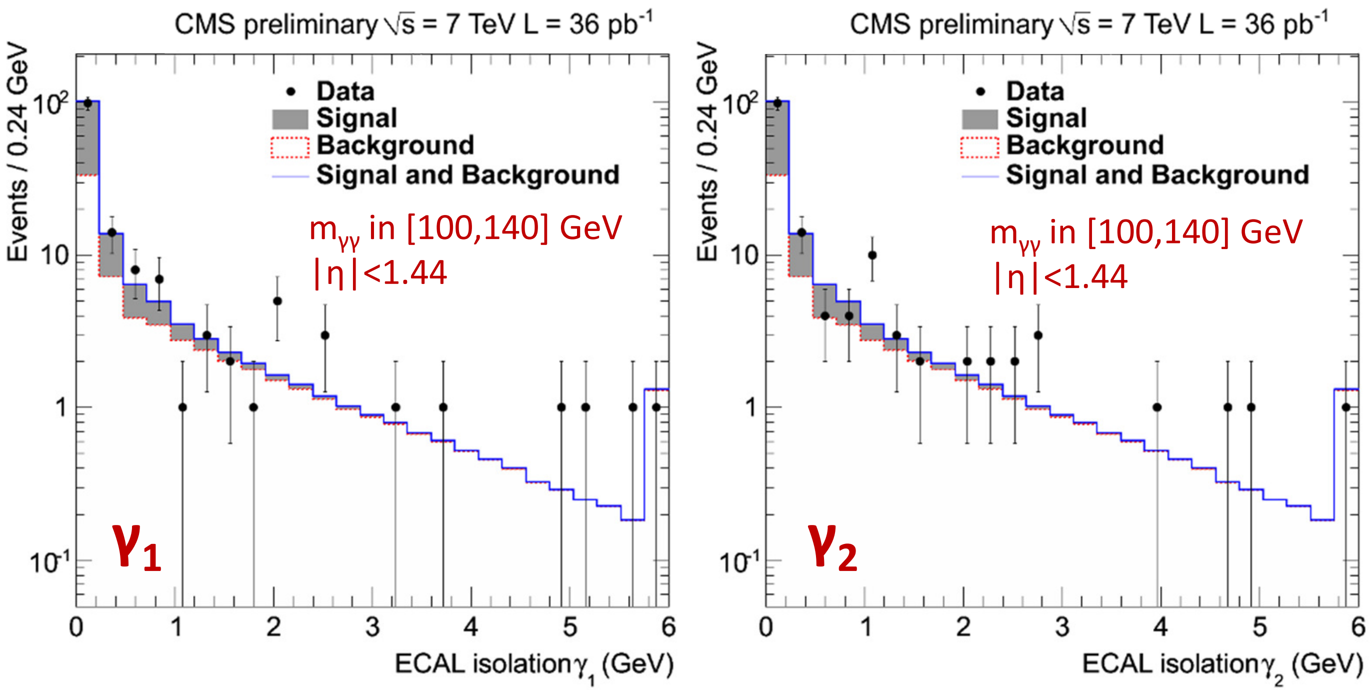


Diphoton Fit

Extract the number of prompt diphotons in each bin of the spectra with a 2D fit

ECAL isolations of photon 1 and 2 are independent
→ express two-dimensional templates
as product of one-dimensional templates

$$f_{pp}(e_1, e_2) = f_p(e_1) \times f_p(e_2)$$



- Template dependence on photon E_T , |η| and pileup taken into account.
- Unfolding the detector resolution. Response obtained from simulated diphoton events

Correcting the Signal Yield

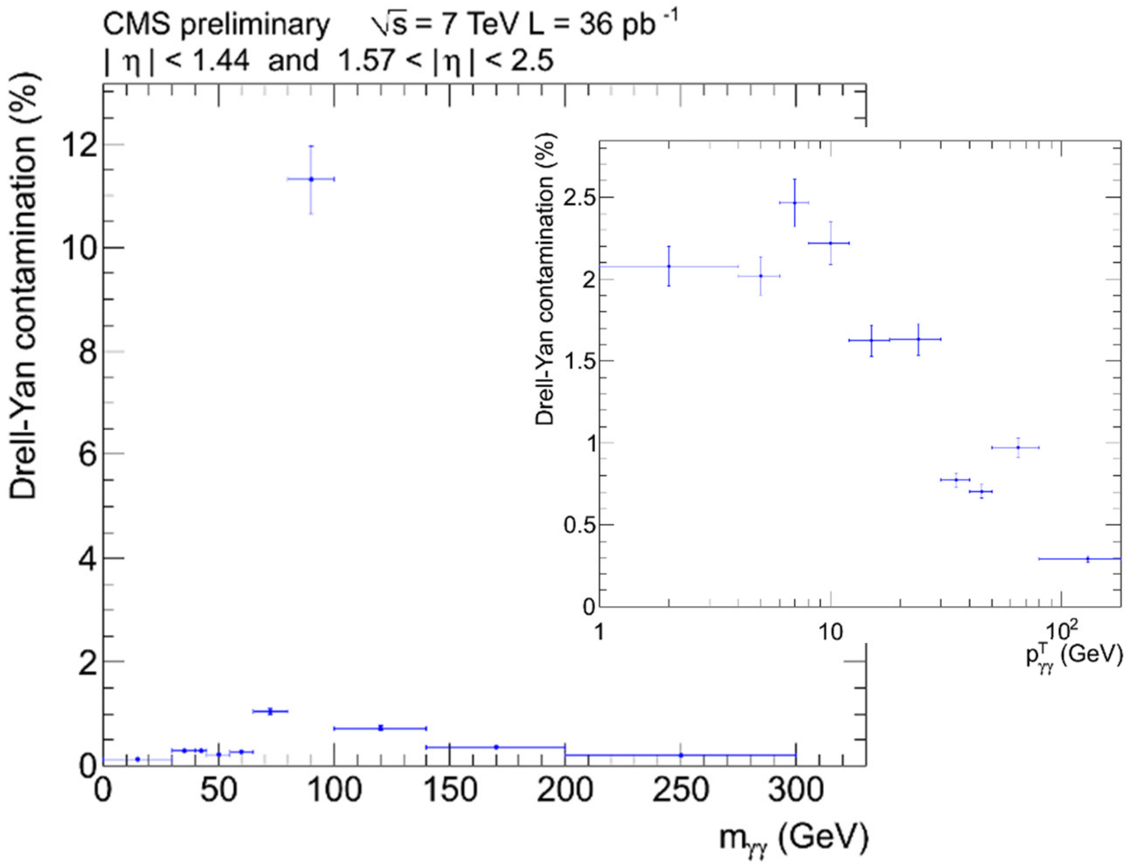
Correction for Drell-Yan contamination

Rejection of Drell-Yan events: 99.9 %

σ (Drell-Yan) >> σ (Diphoton)
(two orders of magnitude)

Contamination (from simulation)
→ Small contamination
in the $p_{T,\gamma\gamma}$ Δφ and cosθ* spectra

→ Significant contamination
in the bin @ m_Z = 91 GeV
in the $m_{\gamma\gamma}$ spectrum



Systematic Uncertainties

Template extraction
Knowledge of the signal and background templates
From validation discrepancies

Photon energy scale

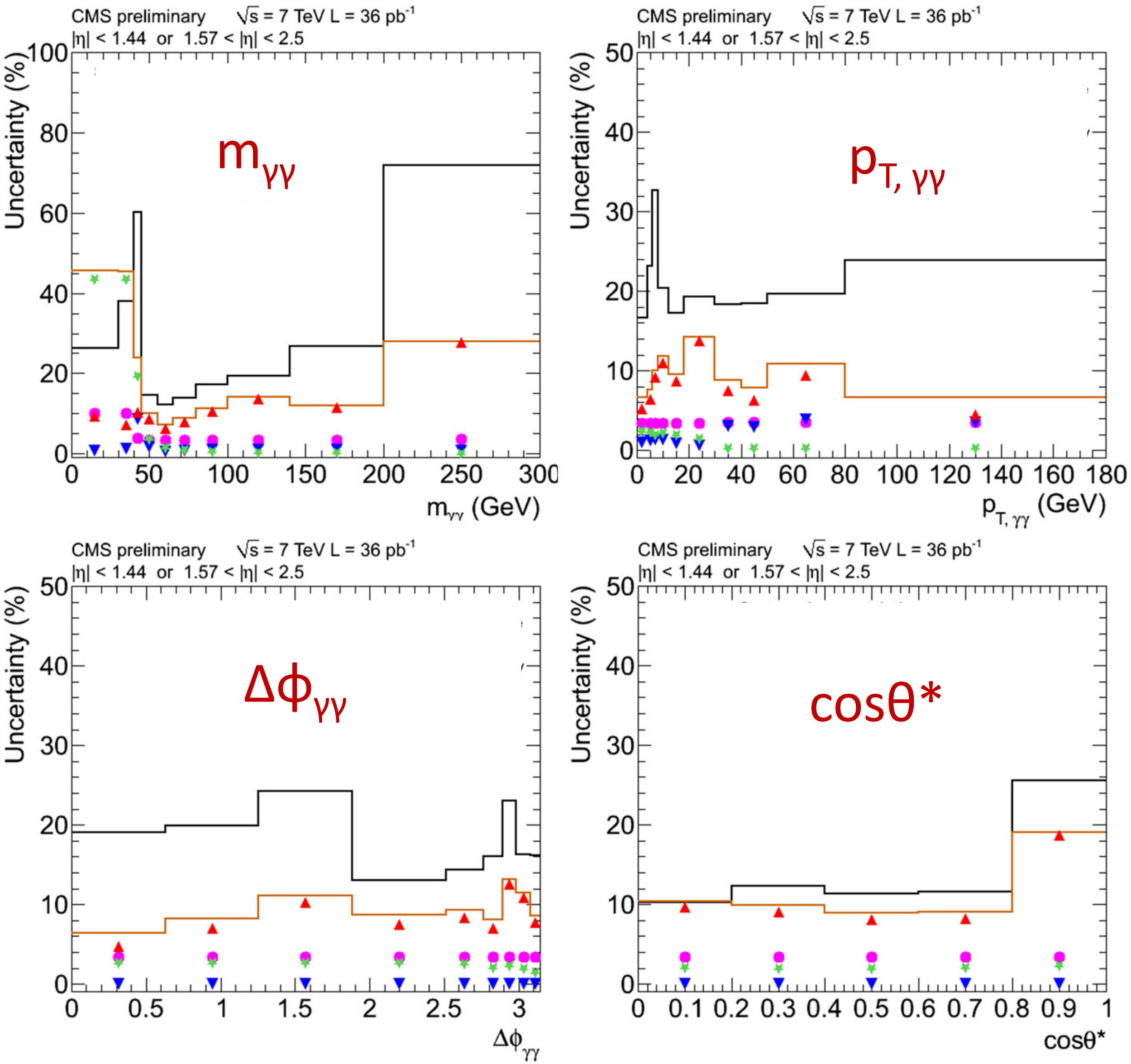
Number of diphotons passing the E_T threshold

Bin-to-bin migration in the $m_{\gamma\gamma}$ and $p_{T,\gamma\gamma}$ spectra

Efficiency/acceptance
From data/simulation comparison

Total uncertainties ~	**11 %**
+ luminosity	**4 %**

Total systematic uncert.
Statistical uncert.



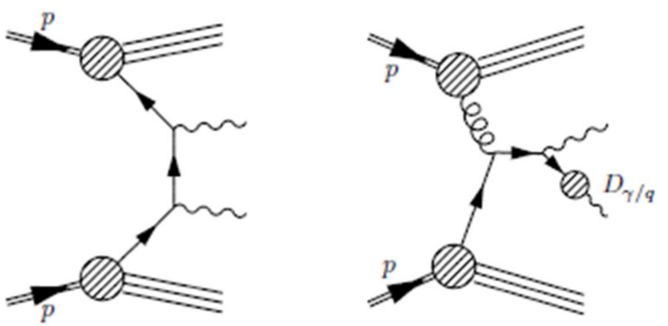
Theoretical Prediction

State-of-the art fixed order NLO theoretical calculation compared to the measurement

Each process computed at next-to-leading order (NLO) (example diagrams are shown)

using: DIPHOX @ order $\alpha^2 \alpha_S^2$

Direct Born	One Fragmentation	Two Fragmention

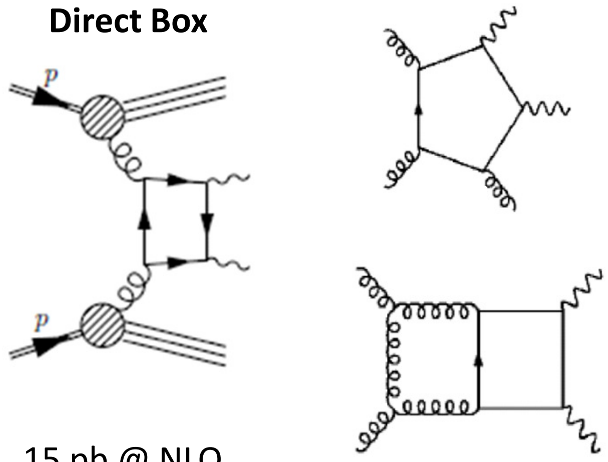


26 pb @ NLO	10 pb @ NLO	0.5 pb @ NLO

T. Binoth, J.P. Guillet, E. Pilon, M. Werlen

gamma2mc @ order $\alpha^2 \alpha_S^4$

Direct Box



15 pb @ NLO

Z. Bern, L. Dixon, C. Schmidt

Uncertainties

- Uncertainties on parton distribution function (PDF) and α_S ~ 4 %
  Following the PDF4LHC recommendations
- Uncertainties on the fragmentation, renormalisation, factorisation scales ~ 11 %
  Varying the scales $m_{\gamma\gamma} / 2 < \mu < 2 \times m_{\gamma\gamma}$ with $\mu_1 / \mu_2 \leq 2$

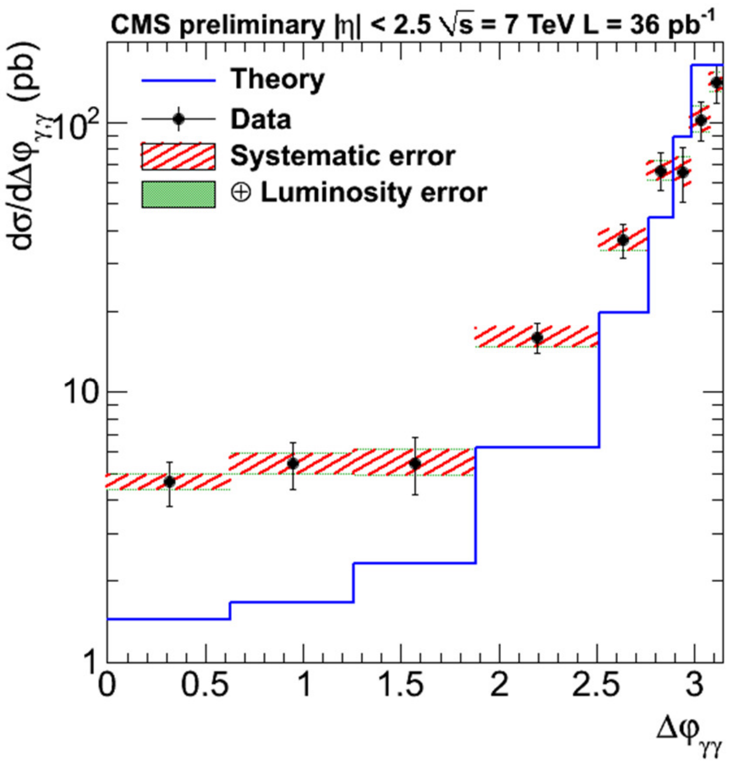
Results for |η| < 2.5

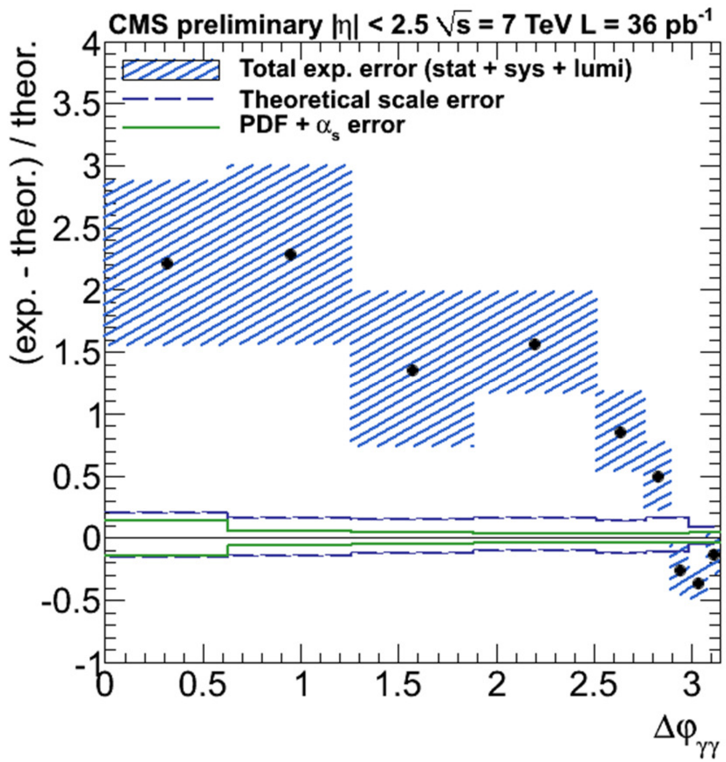
Integrated cross section
→ good agreement

Measurement	62.4 ± 3.6 (stat) + 5.3 - 5.8 (syst) ± 2.5 (lumi) pb
Prediction	52.7 + 5.8 / - 4.2 (scale) ± 2.0 (PDF) pb

Disagreement in region: $\Delta\varphi < \pi$

- leading-order diagrams predict back-to-back photons, ie. $\Delta\varphi = \pi$
- diphotons with small $\Delta\varphi$ are described by only one order (NLO) hence underestimated





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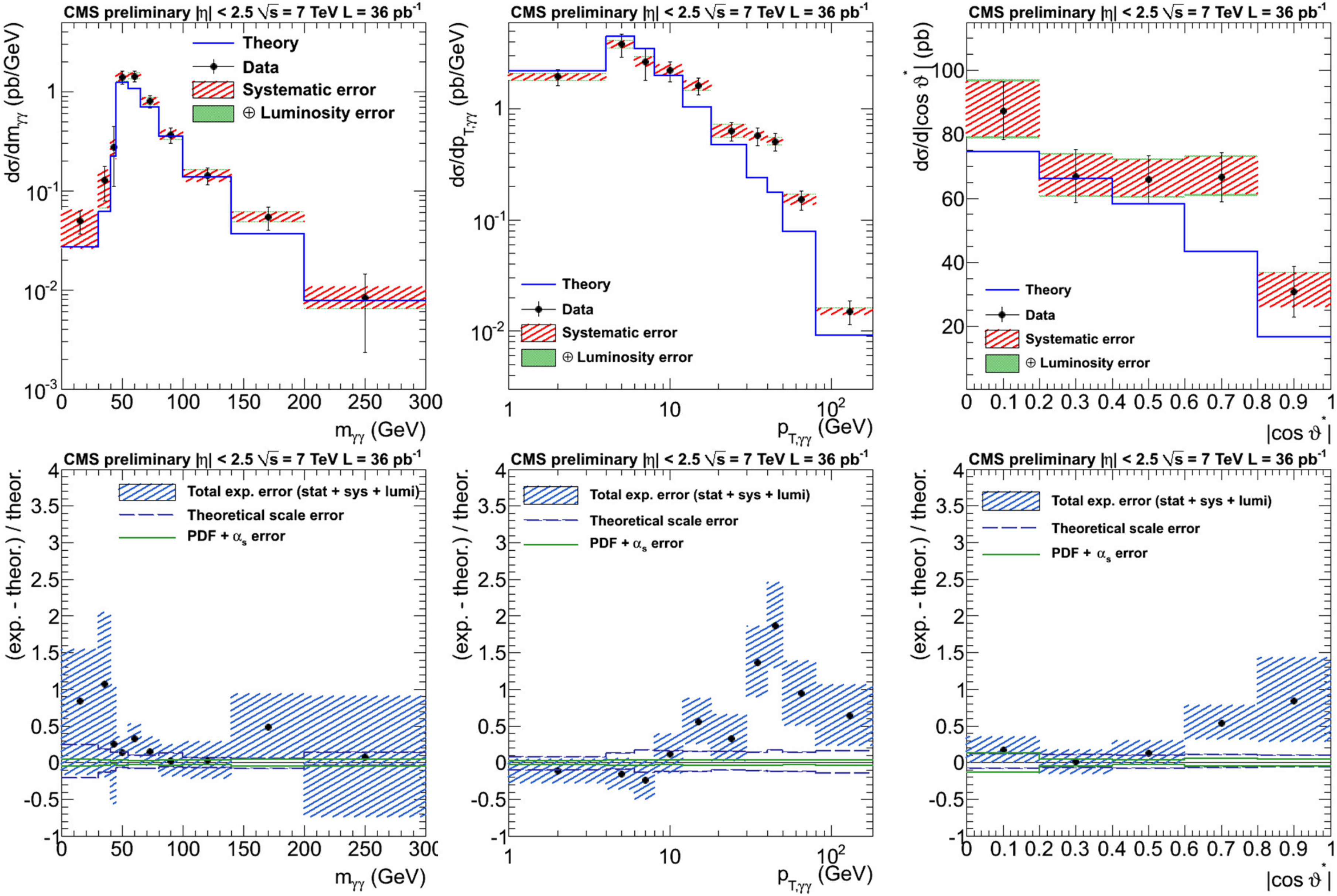


Conclusion

Measurement of the inclusive prompt isolated diphoton cross section in proton-proton collisions at sqrt(s) = 7 TeV

Performed on the 2010 dataset, with $L = 36\ pb^{-1}$ in the acceptance:

> $|\eta| < 1.44$ (barrel) and $|\eta| < 1.44$ or $1.57 < |\eta| < 2.5$ (barrel and endcaps)
> for photons with $E^T_{1,2} > 23,20$ GeV and separated by $R > 0.45$
> isolated at parton level $\Sigma E_T < 5$ GeV

Integrated and differential cross sections versus four observables : $m_{\gamma\gamma}$, $p^T_{\gamma\gamma}$, $\Delta\phi$, $\cos\theta^*$

State-of-the-art NLO cross section prediction compared to the measurement

- overall — good agreement
- differences — in the region of phase-space where the two photons are close and contributions from higher orders are significant
- input for theorists

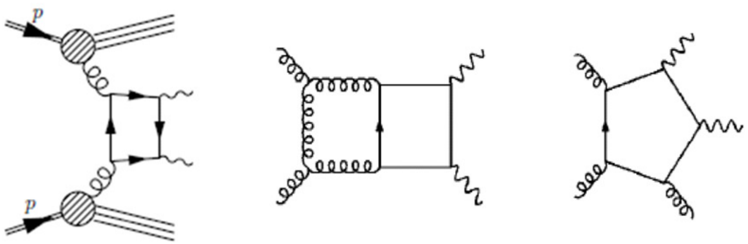
Backup

Staggered E_T cuts

Theoretical aspect

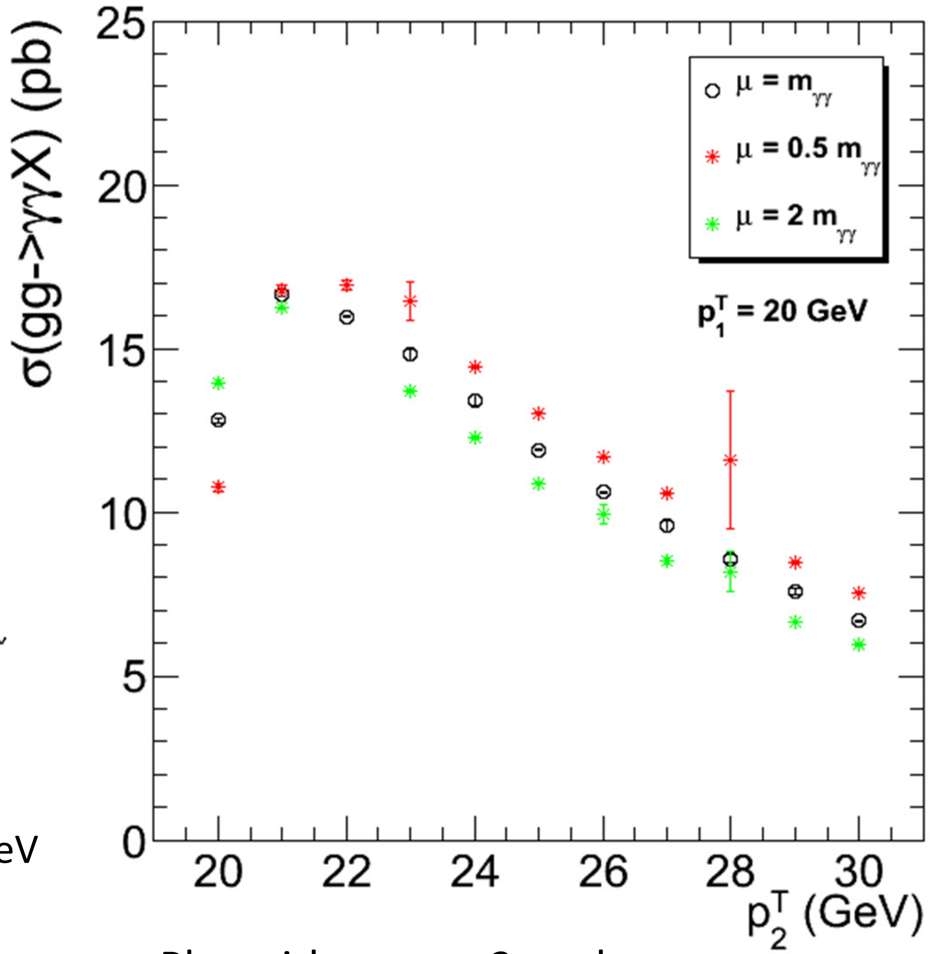
Fixed order calculation is IR sensitive for symmetric cuts in the $\Delta\varphi_{\gamma\gamma}$~π region. (hep-ph/9707345, Frixione and Ridolfi)
→ slow convergence adding orders

Plot shows the
NLO computation of the BOX diagram



for a fixed cut on the trailing photon: $E_T > 20$ GeV versus the cut on the leading photon E_T.

This cross section is expeted to decrease, which it does only from $\Delta E_T > 3$ GeV

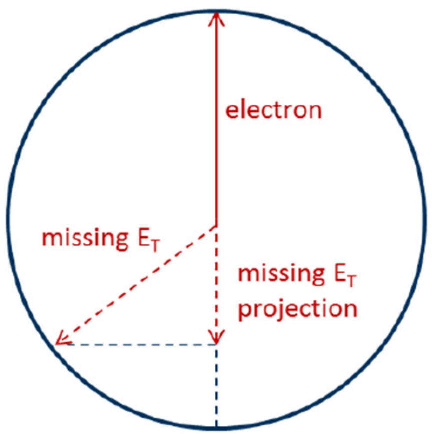


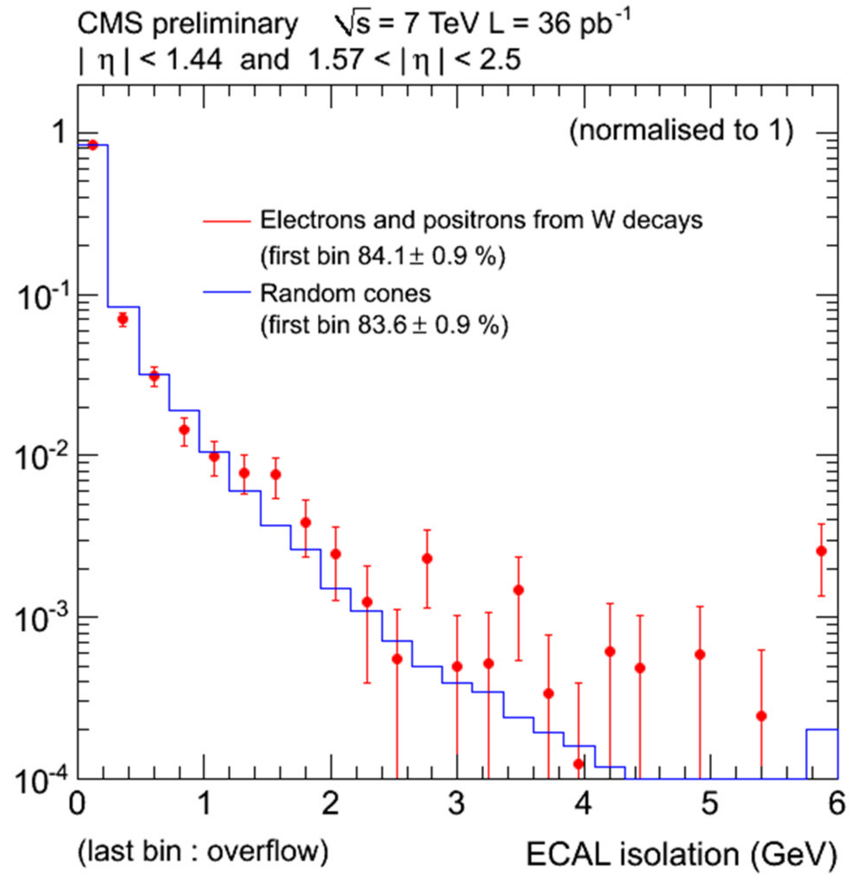
Plot with gamma2mc, by
Z. Bern, L. Dixon, C. Schmidt
(arXiv:hep-ph/0211216)

sPlot technique

Extracting the `ecalIso` distribution of electrons from W decays

The sPlot technique exploits the fact that W electrons and QCD/GammaJet background have different distributions of the variable
$mET_{//}$, the projection of the missing E_T on the axis parallel to the electron.

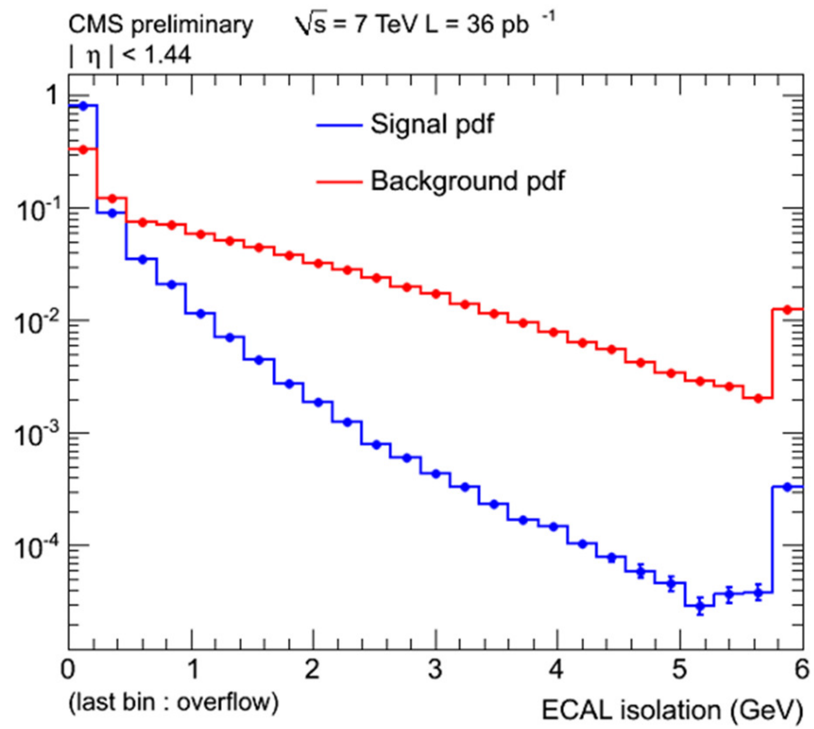


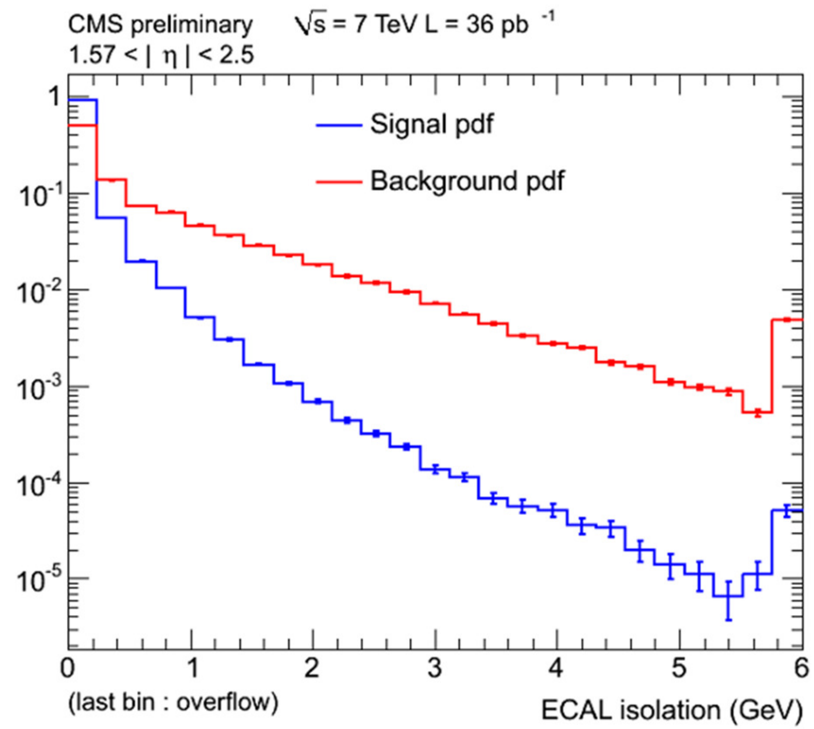


A fit on this variable gives the probability for each event to be a W-electron.
By applying these probabilities as weights to the entire sample of electron candidates, one can obtain the `ecalIso` distribution of W electrons only.

Templates

`ecalIso` templates shown in the ECAL barrel and the endcap



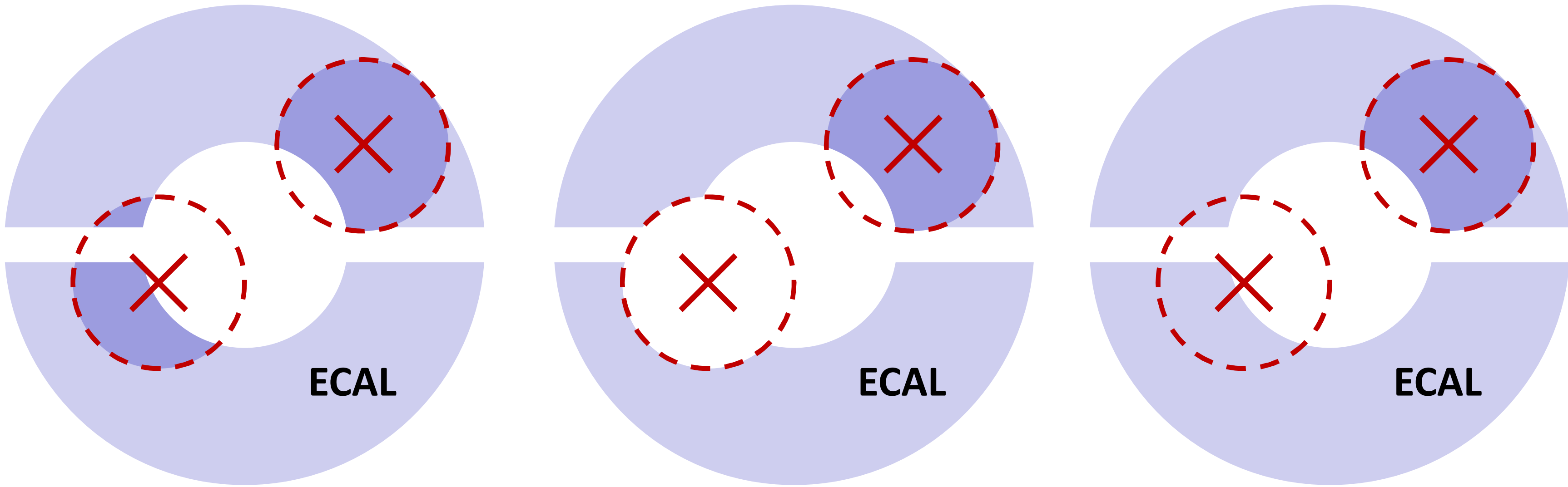


Background Extraction

Background template extraction: validation on data

Require two impinging tracks, with separated impact points, correct one track's ECAL deposits.

Separated: impinging track impact points more than 2R = 0.1 away
where R = 0.05 is the removal cone size



Diphoton Fit

`ecalIso` templates depend on:

- photon transverse energy E_T
- photon pseudorapidity $|\eta|$
- number of vertices in event N_V

E_T and $|\eta|$ distributions can vary with the considered bin of the differential measurement.

Reweight the events used for the template extraction so that their E_T, N_V, $|\eta|$ distributions agree with the diphoton candidates.

Difference between in reweighting with diphoton candidates and diphoton MC are taken into account in the systematic uncertainties.

Note: this is an integrated distributions, in some bins (eg. $m_{\gamma\gamma} > 120$) the reweighting will have a greater impact