

Summary of IPNL/IHEP Collaboration and Parallel CMS Talks

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On behalf of the IPNL/IHEP CMS groups

7th FCPPL Workshop

Laboratoire de Physique Corpusculaire (LPC), Blaise Pascal
University, Clermont-Ferrand

8th -10th April, 2014

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Outline



➤ A brief history about the IPNL/IHEP collaboration

➤ **Activities of IPNL/IHEP collaboration at CMS**

- ❖ SM $H \rightarrow \gamma\gamma$
- ❖ $Z \rightarrow \mu\mu\gamma$: Energy Scale Extraction and Photon validations
- ❖ QCD $\gamma\gamma + X$ Differential Cross-section Measurements
- ❖ Others on photon-related studies

3 parallel talks

➤ FCPPPL Proposal for 2014

➤ Summary and Conclusion

➤ Acknowledgements

Note/Apology: CMS rules require that only formally approved results can be shown.



A brief history of IPNL/IHEP collaboration



IHEP Beijing → IPN Lyon: (5 persons 9 times)

- TAO Junquan (Doctoral Student)—January-May 2007 (IN2P3)
- ZHANG Zhen (Doctoral Student)— November 2007-May 2008 (FCPPL)
- TAO Junquan (Postdoc)—March-August 2009 (PICS 4162)
- XIAO Hong (Doctoral Student)—January-July 2010 (PICS 4162)
- FAN Jiawei (Doctoral Student)---April-October 2011 (PICS 4162)
- XIAO Hong (Doctoral Student)---June-July 2011 (FCPPL)
- FAN Jiawei (Doctoral Student)—August-September 2012) (FCPPL)
- SHEN Yuqiao (Doctoral Student) September 2013-January 2014 (FCPPL)
- FAN Jiawei (first IHEP-IPNL Co-Ph.D student) October 2012-April 2014 (CSC scholarship)

IPN Lyon → IHEP Beijing: (4 persons 4 times)

- Nicolas CHANON (Doctoral Student)—March-May 2009 (FCPPL)
- Hugues BRUN (Doctoral Student)— October-December 2010 (FCPPL)
- Olivier BONDU (Doctoral Student)— April-May 2011 (FCPPL)
- Louis SGANDURRA (Doctoral Student)-October-December 2012 (FCPPL)

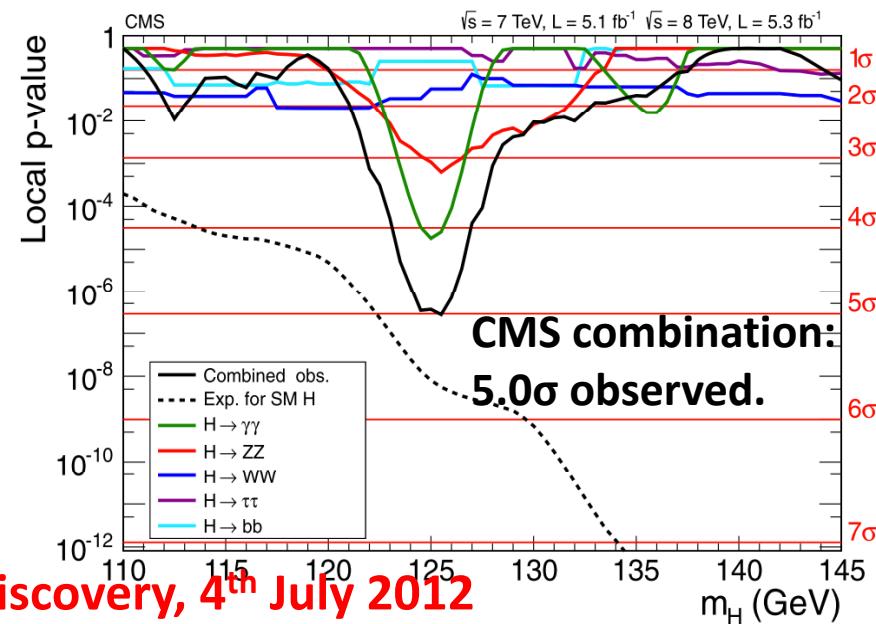
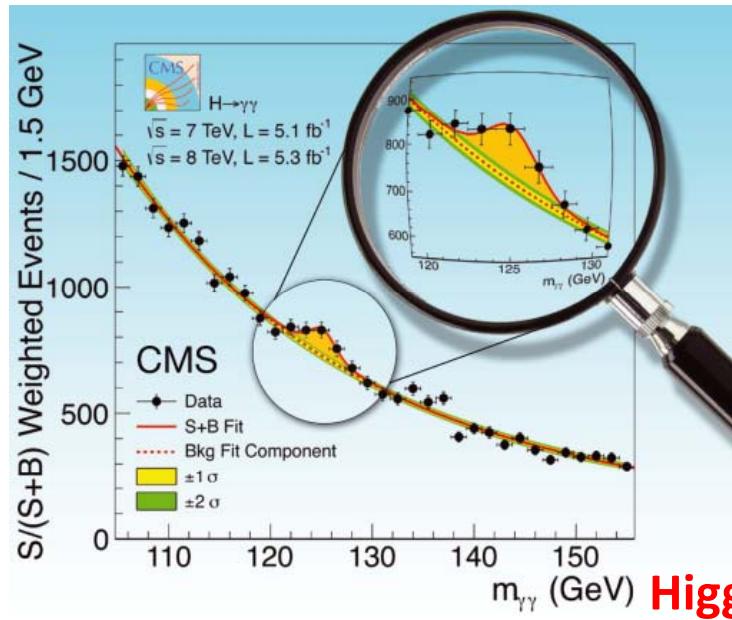
+ participation to the organising committees of the **founding workshop at IHEP in 2006** and of the 1st to 7th FCPPL workshops
(IPNL co-chaired the 3rd workshop)



SM H $\rightarrow\gamma\gamma$ search



Thanks largely to FCPPL support, the CMS groups of IHEP and IPNL, working together since 2007, were able to contribute significantly to the discovery of Higgs boson through analysis of the H $\rightarrow\gamma\gamma$ channel.



- Improved legacy results for final paper is forthcoming but not yet public
- Only results from EPS13/LHCP13/Moriond13 reported in the ATLAS-CMS parallel session



Strategy of $H \rightarrow \gamma\gamma$ baseline analysis



❑ Baseline analysis of $H \rightarrow \gamma\gamma$ is based on Multivariate(MVA) analysis

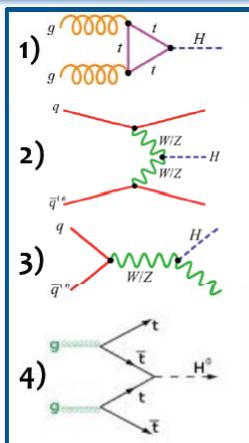
- Event selection and categorization using a di-photon MVA
- Inputs: Event-by-event mass resolution, photon id discriminant, di-photon kinematic variables and vertex probability combined using boosted decision tree (BDT)

❑ Selected events are separated into “tagged” exclusive categories enriched in VBF and VH signal production and “untagged” inclusive categories, with different S/B and mass resolution

- Improve the sensitivity of the analysis for the coupling measurements
- The categorization proceeds in the following order:

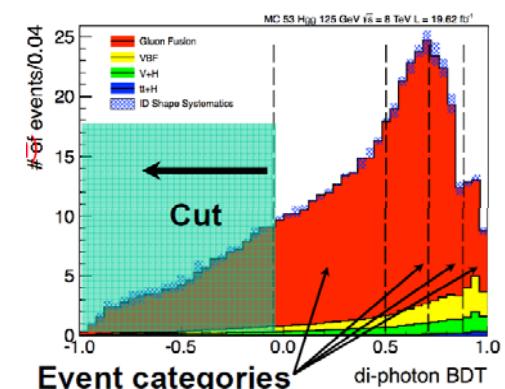
Production mechanisms

Muon Electron Dijet MET Untagged



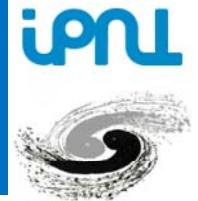
- 1) For VBF two energetic jets: two classes based on the output of the di-jet BDT
- 2) For W/Z+H tag to address: $W \rightarrow l\nu$, $Z \rightarrow vv$: 3 categories
- 3) 4 untagged categories based on diphoton MVA

9 categories in total

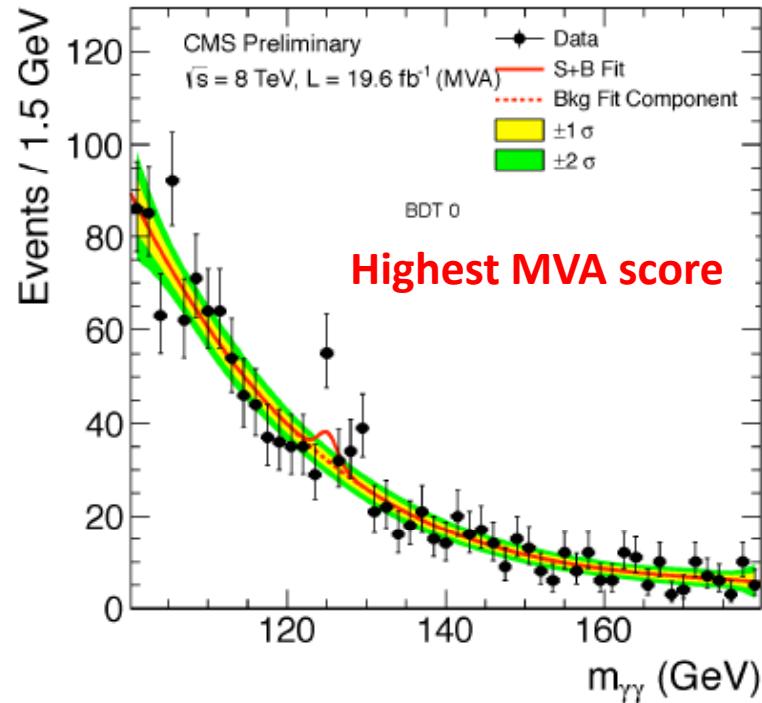




Sig and bkg modeling for statistic analysis

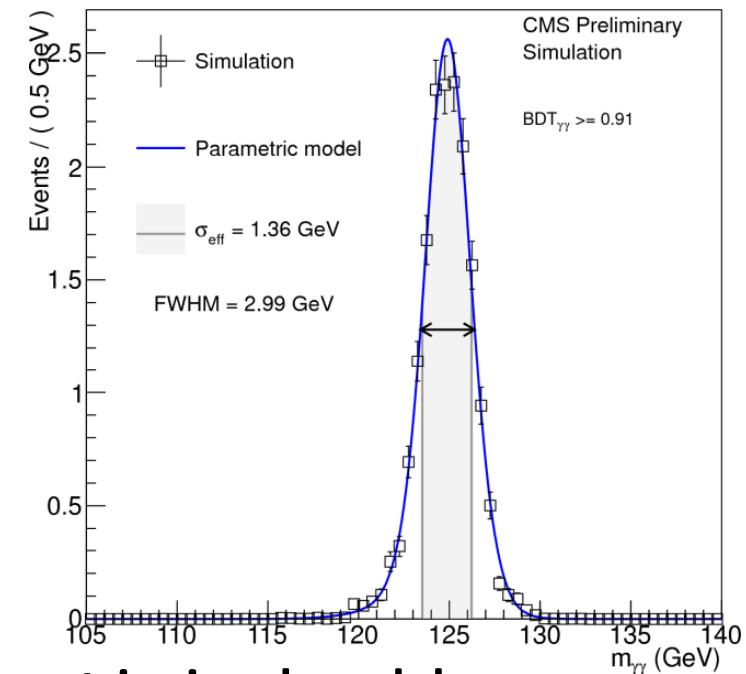


Statistic analyses were based on the mass spectrum for each event category



Background modeling:

Background is measured from data
Bernstein shape with order from 2 to 5

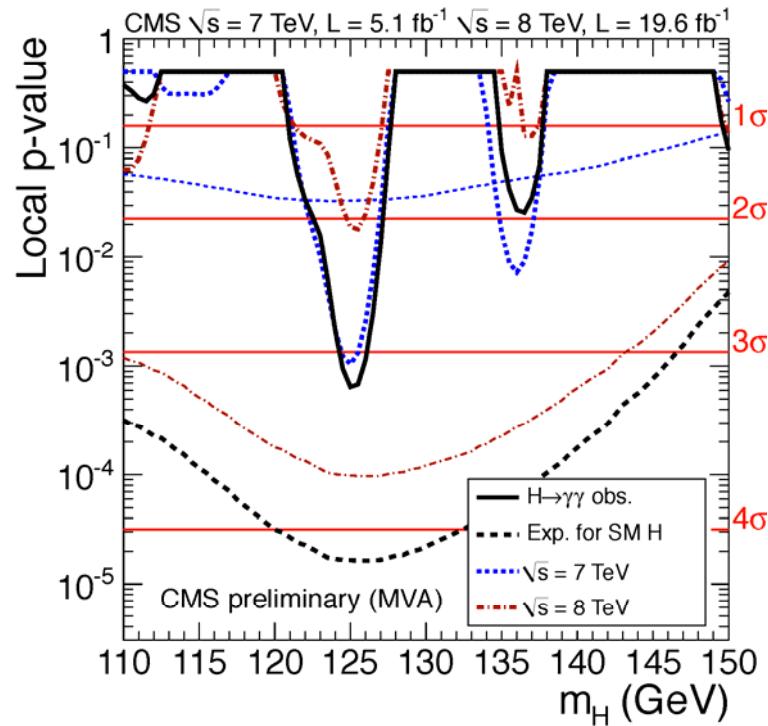


Parametric signal model:

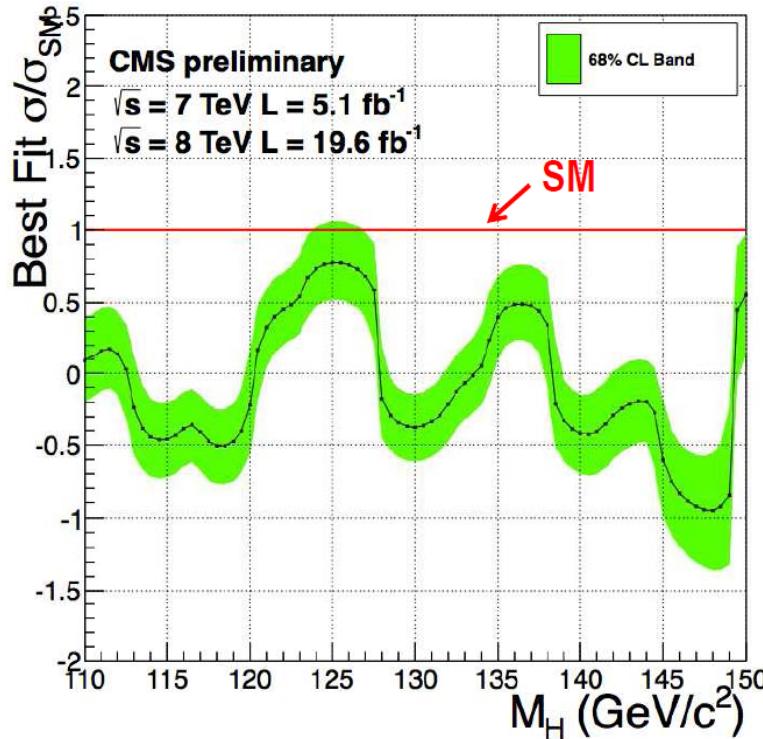
Obtained from MC simulation using the next-to-leading order (NLO) matrix-element generator POWHEG after reweighting to the HQT(NNLO+NNLL) spectrum
Constructed with the sum of two or three Gaussians



H \rightarrow $\gamma\gamma$ public results: p-value



Significance at 125GeV:
3.2 σ (4.2 σ expected)

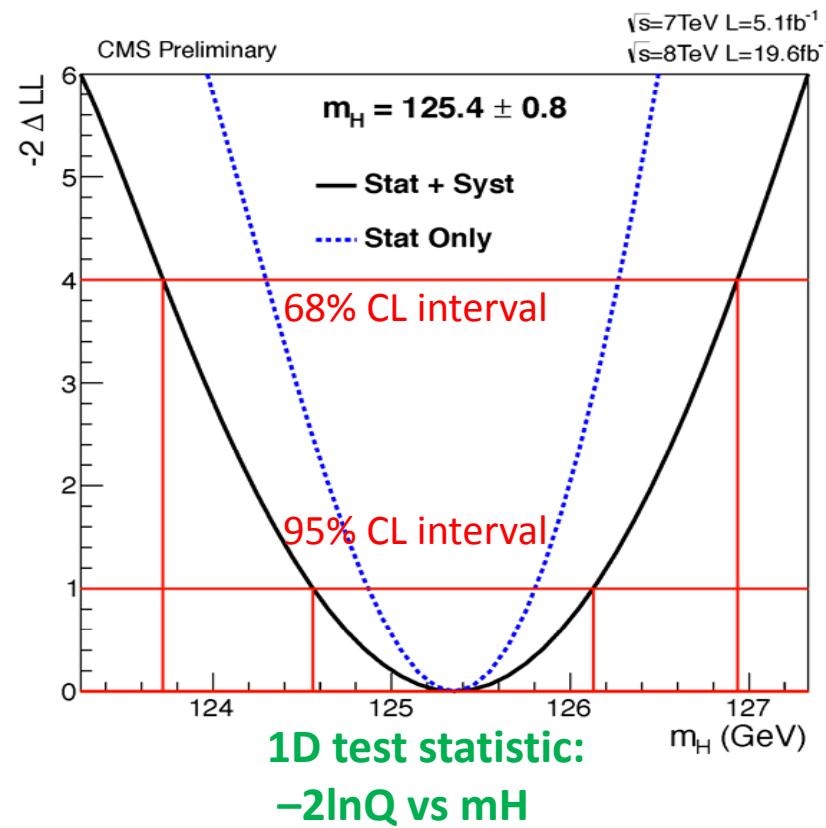
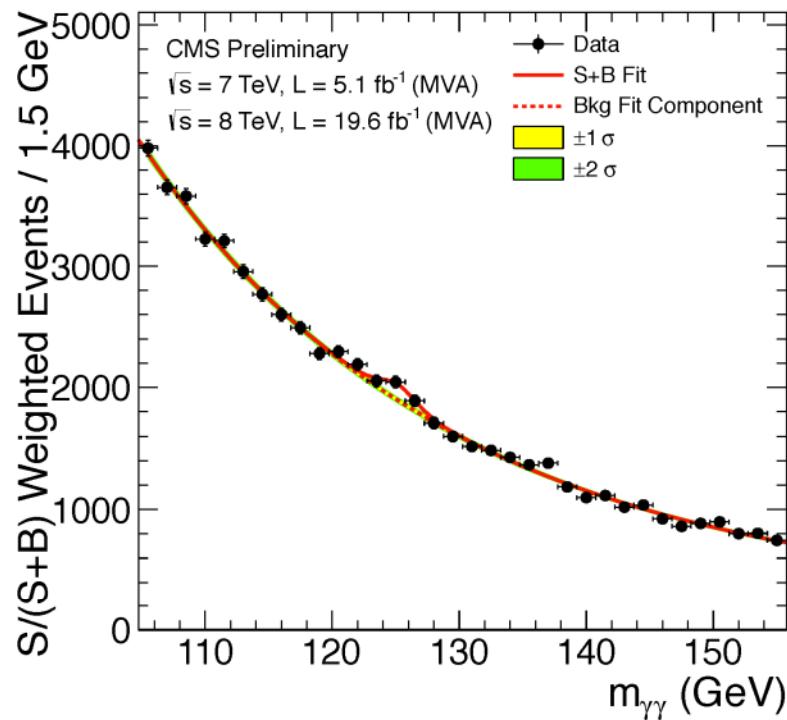


Signal strength wrt SM prediction at 125GeV

$$0.78^{+0.28}_{-0.26}$$



H \rightarrow $\gamma\gamma$ public results: mass



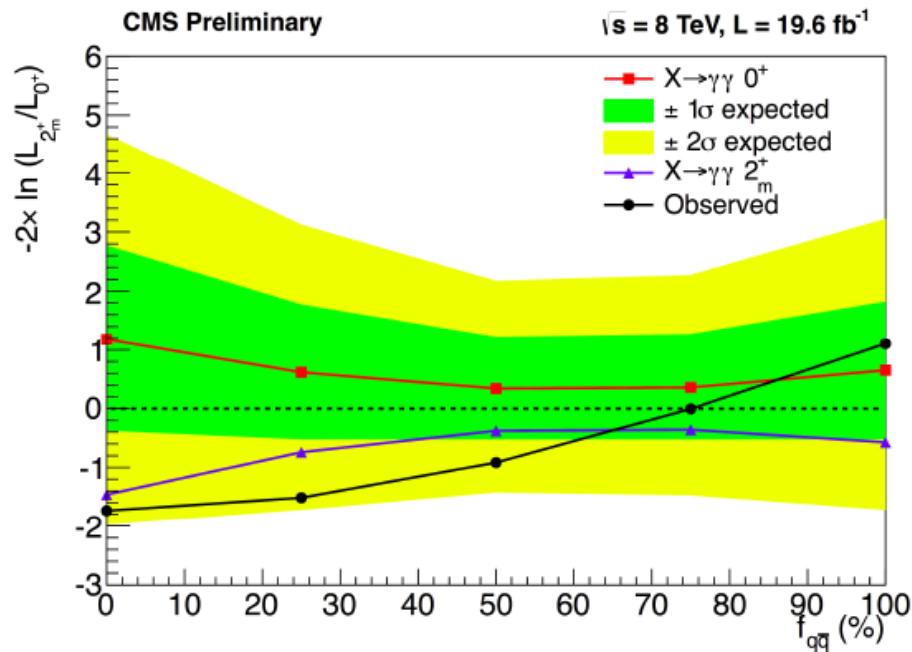
$m_H = 125.4 \pm 0.5 \text{ (stat.)} \pm 0.6 \text{ (syst.)}$



H \rightarrow $\gamma\gamma$ public results: spin and width

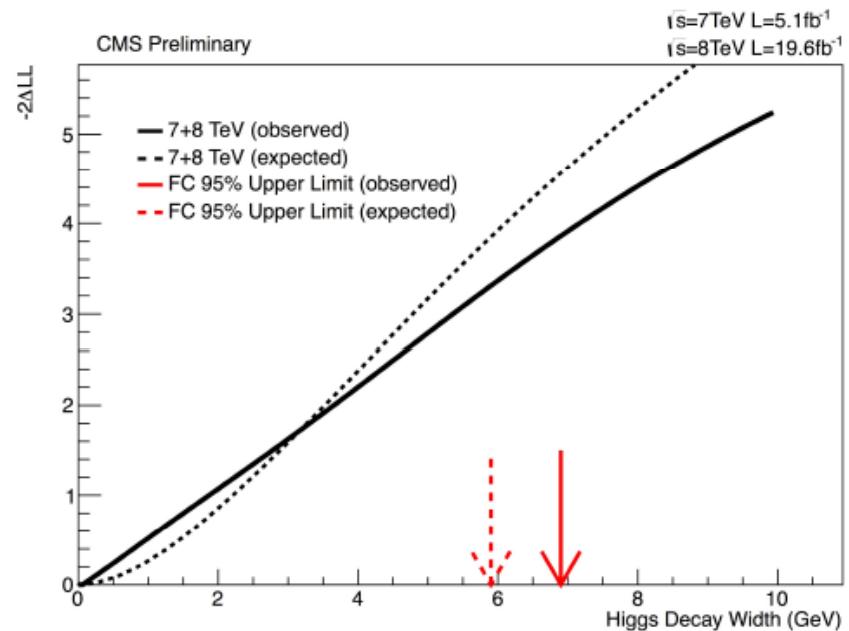


Spin measurement



Compatible with the prediction of the Standard Model: Higgs boson is a 0 spin state

Width measurement



Measurement of the width limited by experimental resolution:
 $\Gamma_H < 6.9 \text{ GeV}$ at 95% C.L. (expected 5.9 GeV)



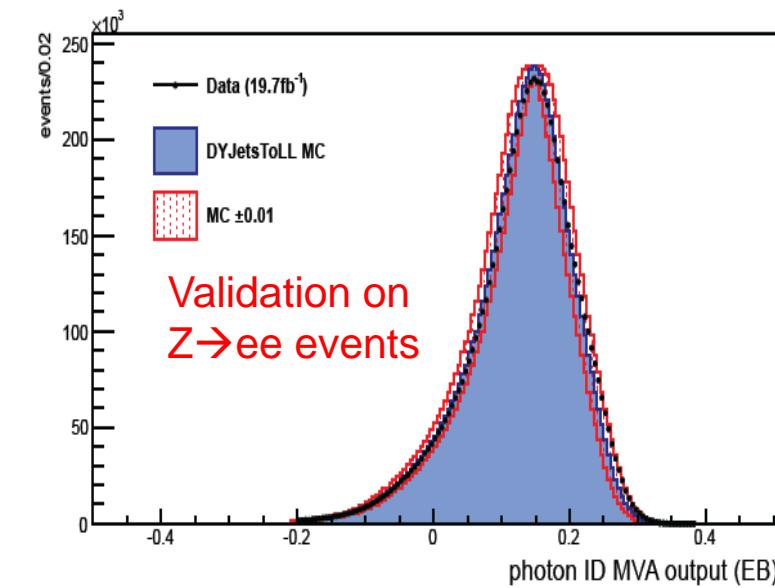
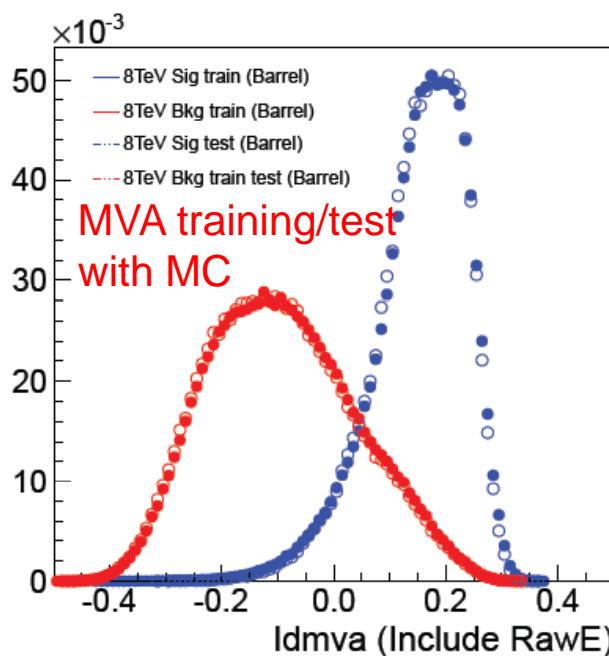
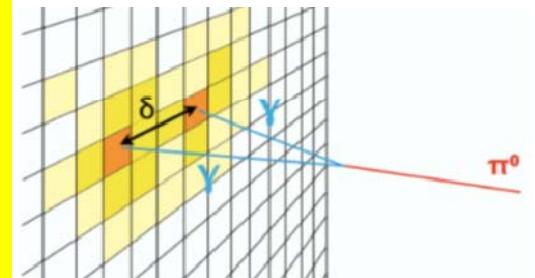
H $\rightarrow\gamma\gamma$: γ/π^0 discrimination and photon identification



γ/π^0 discrimination (2008-...): (H. BRUN, N. CHANON, G. CHEN, J. FAN, S. GASCON, M. LETHUILLIER, Y. SHEN, J. TAO, H. XIAO, Z. ZHANG) for both converted and non-converted photons

Exploit particular cluster and shower shape observables proper to our crystal calorimeter in a photon id using multivariate approach (boosted decision tree).

Photon ID MVA: direct input to the overall diphoton MVA analysis for the H $\rightarrow\gamma\gamma$ analysis



Fight reducible background, mostly from π^0 (~30% after preselection)

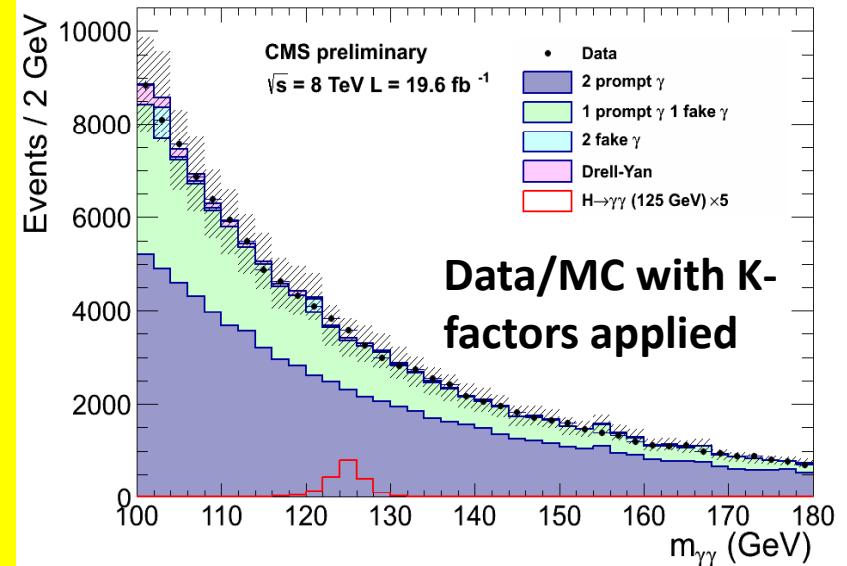


H \rightarrow $\gamma\gamma$: Impact of higher-order calculations on kinematical observables

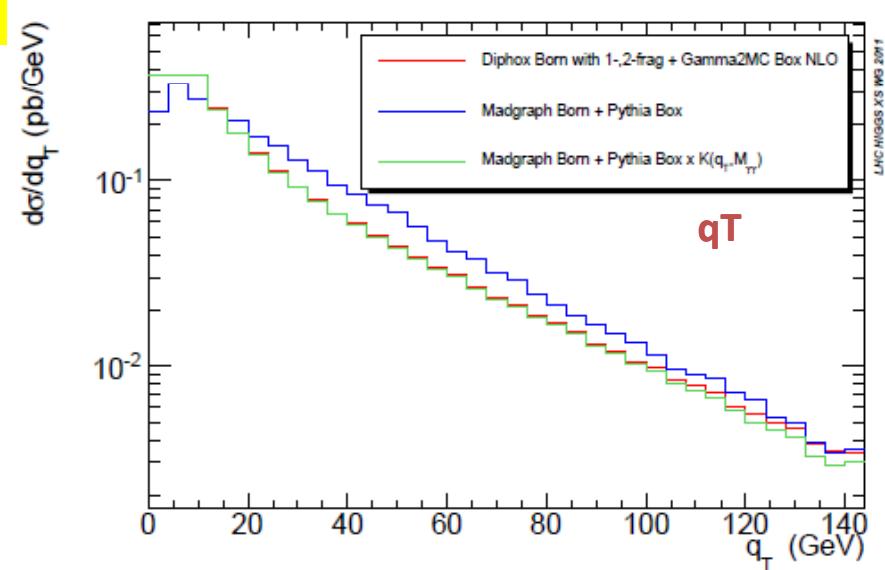
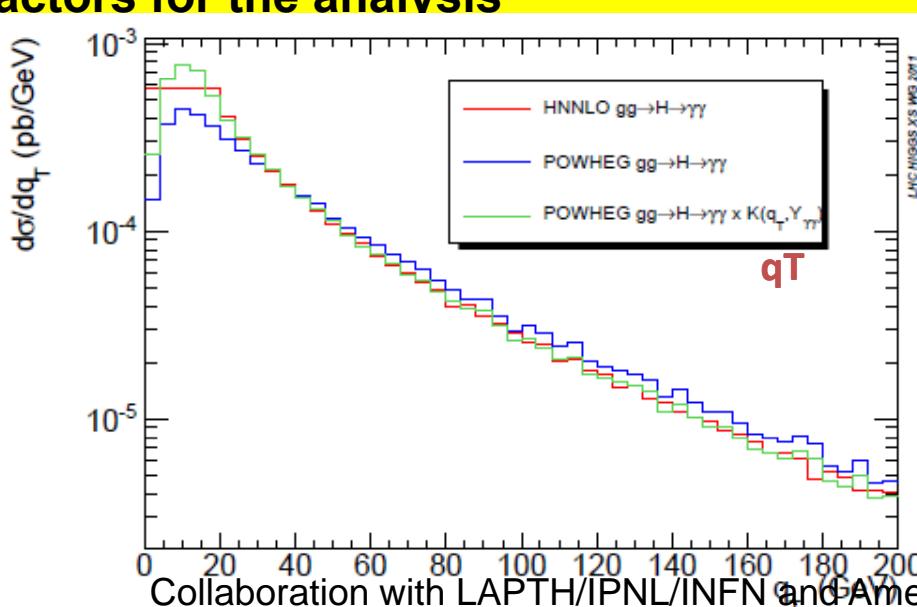


(2007-...): (O. BONDU, N. CHANON, M. LETHUILLIER, S. GASCON, J. Tao)

- Implemented doubly-differential reweighting scheme with dynamical k-factors for H \rightarrow $\gamma\gamma$ signal (NNLO/NLO) and diphoton background (NLO/LO)
- Contributed significantly to LHC Higgs XS WG 'Yellow Report 2: Handbook of Cross sections: Differential Distributions (CERN-2012-002, arXiv:1201.3084), furnished the integrated k-factors for the analysis



Data/MC with K-factors applied



Collaboration with LAPTH/IPNL/INFN and American theoreticians

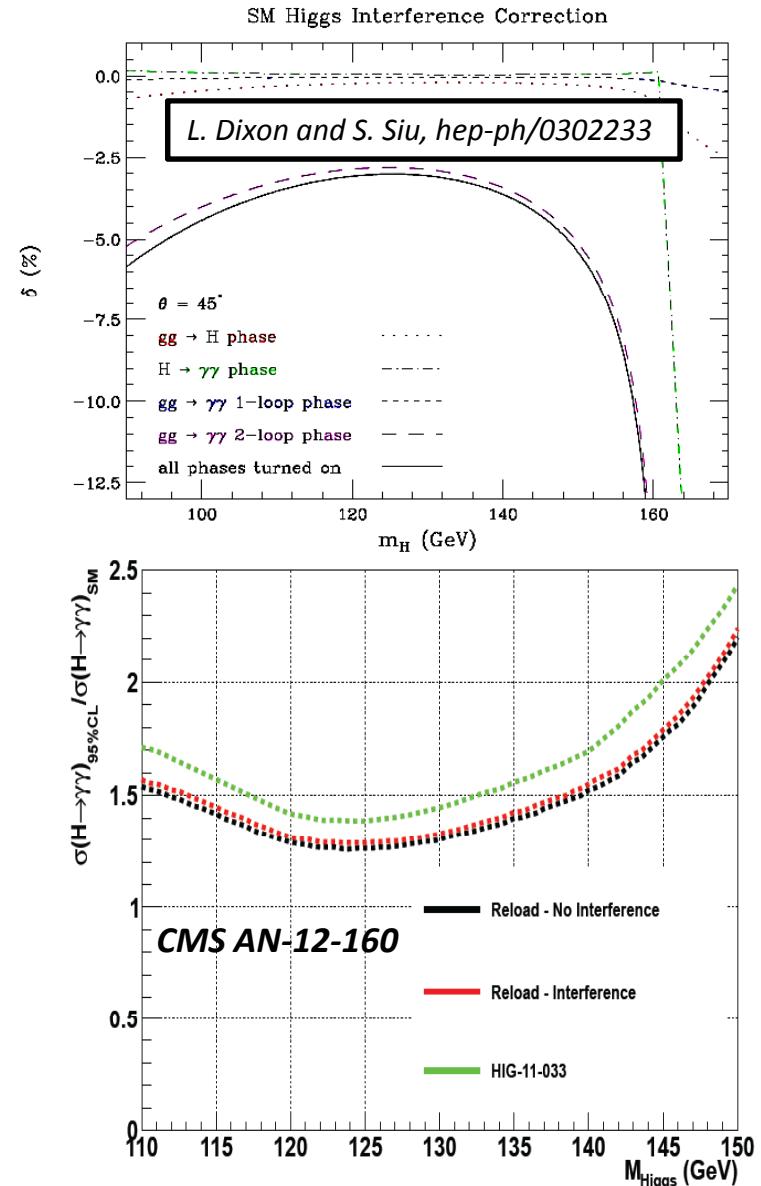


H $\rightarrow\gamma\gamma$: destructive signal-background interference



(2012-...): (G. CHEN, J. FAN, S. GASCON,
M. LETHUILLIER, L. SGANDURRA, Y.
SHEN, J. TAO)

- Destructive interference between gg fusion resonance gg \rightarrow H $\rightarrow\gamma\gamma$ and continuum gg $\rightarrow\gamma\gamma$ (box) background processes
- Evaluated effect of destructive signal-background interference with CMS MC samples
- The average effect on the signal strength is about -2.5% used in the discovery result





Z \rightarrow $\mu\mu\gamma$: Energy Scale and Photon Validation



« Certified » photons from Z $\rightarrow\mu\mu\gamma$ FSR (2007-..): (C. BATY, O. BONDU, H. BRUN, J. FAN, S. GASCON, M. LETHUILLIER, L. SGANDURRA, Y. SHEN, J. TAO, H. XIAO, Z. ZHANG)

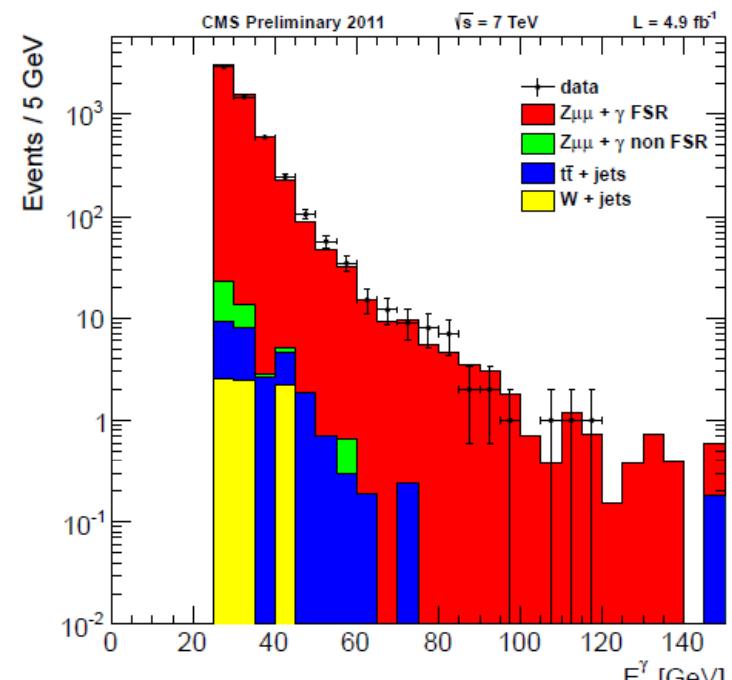
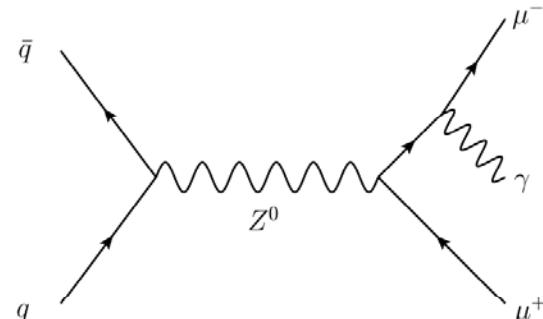
Source of relatively high-pT γ enabling extraction of

- **Photon energy scale** : One of two CMS approved methods (CMS-DP-2011/008 and CMS-DP-2012/024)

- **Photon energy correction parametrisation**

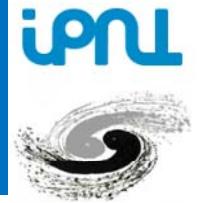
- **Photon id efficiency**

...





Z → μμγ : Energy Scale Extraction



Photon energy scale correction

$$k = \frac{E_{\gamma, \text{TRUE}}}{E_{\gamma, \text{RECO}}}$$

Definition

We call photon energy scale the quantity:

$$s = \frac{1}{k} - 1 = \frac{E_{\gamma, \text{RECO}}}{E_{\gamma, \text{TRUE}}} - 1$$

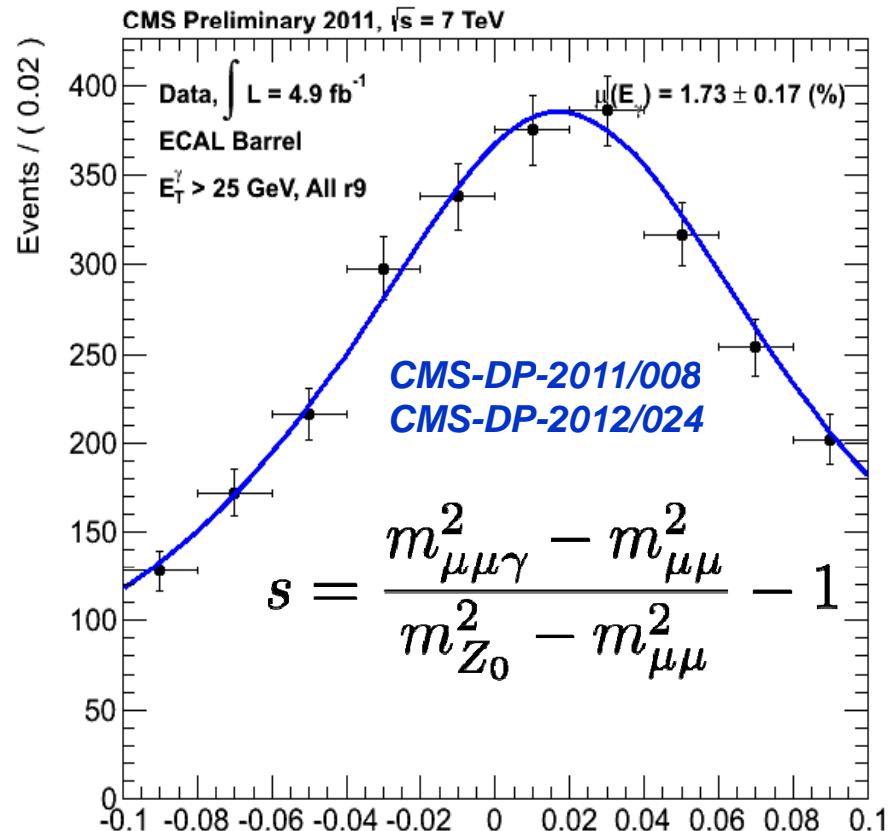
(offset with respect to expected scale)

The $Z^0 \rightarrow \mu\mu\gamma$ case

From the FSR kinematics:

$$s_{\text{RECO}} = \frac{m_{\mu\mu\gamma}^2 - m_{\mu\mu}^2}{m_{Z^0}^2 - m_{\mu\mu}^2} - 1 = \frac{E_{\text{reco}}^\gamma}{E_{\text{kinematics}}^\gamma} - 1$$

(assuming uncertainty in muon momentum small compared to photon energy uncertainty)



The energy scale was extracted by direct χ^2 fit of the “s” distribution with a Voigtian (convolution of a Gaussian and a Breit-Wigner).



$Z \rightarrow \mu\mu\gamma$: Application of Energy Scale

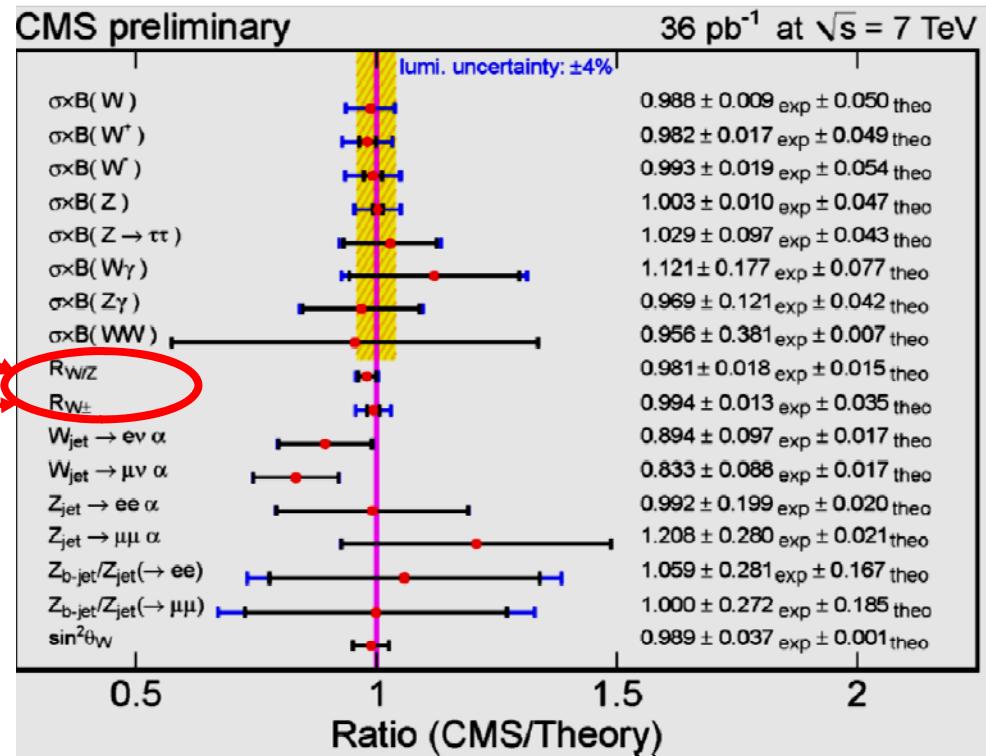


Photon Energy Scale Measurement was used to estimate systematic error on photon energy scale for first measurement of the $W\gamma$ and $Z\gamma$ inclusive cross-sections

Source	Systematic uncertainty	$e\nu\gamma$	$\mu\nu\gamma$
		Effect on $\mathcal{F} = A \cdot \epsilon_{MC}$	
Electron energy scale	2% (EB), 3% (EE)	2.3%	n/a
Electron energy resolution	5%	0.3%	n/a
Muon p_T scale	1%	n/a	1.0%
Muon p_T resolution	1%	n/a	0.2%
Photon energy scale	2% (EB), 9% (EE)	4.5%	4.2%
Photon energy resolution	5%	0.4%	0.7%
Pileup		2.7%	2.3%
PDF		2.0%	2.0%
Total uncertainty on $\mathcal{F} = A \cdot \epsilon_{MC}$		6.1%	5.2%

Source	Systematic uncertainty	$ee\gamma$	$\mu\mu\gamma$
		Effect on \mathcal{F}	
Electron energy scale	2% (EB), 3% (EE)	2.8%	n/a
Electron energy resolution	5%	0.5%	n/a
Muon p_T scale	1%	n/a	1.5%
Muon p_T resolution	1%	n/a	0.7%
Photon energy scale	2% (EB), 9% (EE)	3.7%	3.0%
Photon energy resolution	5%	1.7%	1.4%
Pileup		2.3%	1.8%
PDF		2.0%	2.0%
Total uncertainty on $A \cdot \epsilon_{MC}$		5.8%	4.6%

Phys. Lett. B701, 535-555 (2011)



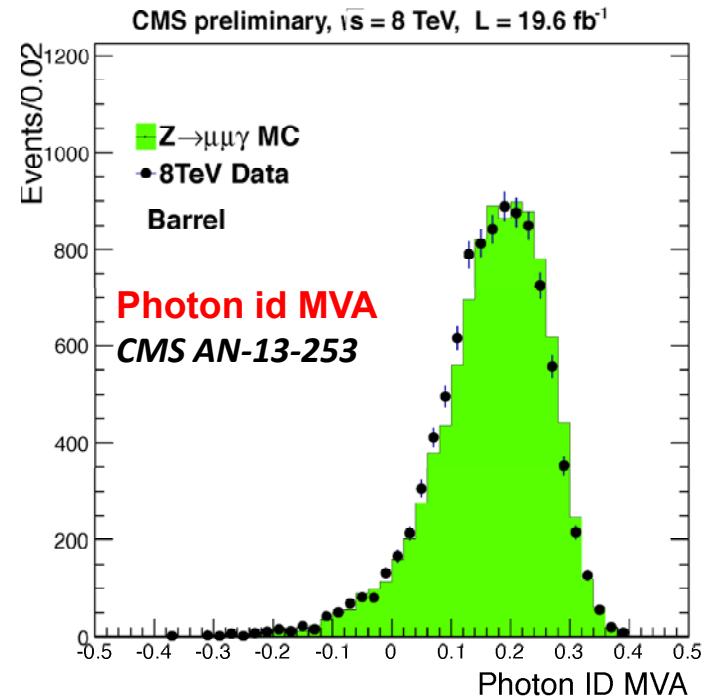


Z \rightarrow $\mu\mu\gamma$: Photon Validation



In H $\rightarrow\gamma\gamma$ analysis:

- Used to validate the photon ID MVA to help understanding of the input variable of diphoton MVA (CMS-HIG-13-001)
- Used to study electron veto efficiency



Electron veto eff. in H $\rightarrow\gamma\gamma$ CMS AN-13-253

	DATA		MC		R	
	Eff.	Stat. Err.	Eff.	Stat. Err.	Eff.	Err.
Barrel; $R_9 > 0.94$	0.9984	0.0003	0.9991	0.0003	0.9994	0.0004
Barrel; $R_9 < 0.94$	0.9867	0.0012	0.9930	0.0009	0.9937	0.0014
Endcap; $R_9 > 0.94$	0.9893	0.0016	0.9938	0.0012	0.9955	0.0020
Endcap; $R_9 < 0.94$	0.9639	0.0033	0.9738	0.0030	0.9899	0.0045

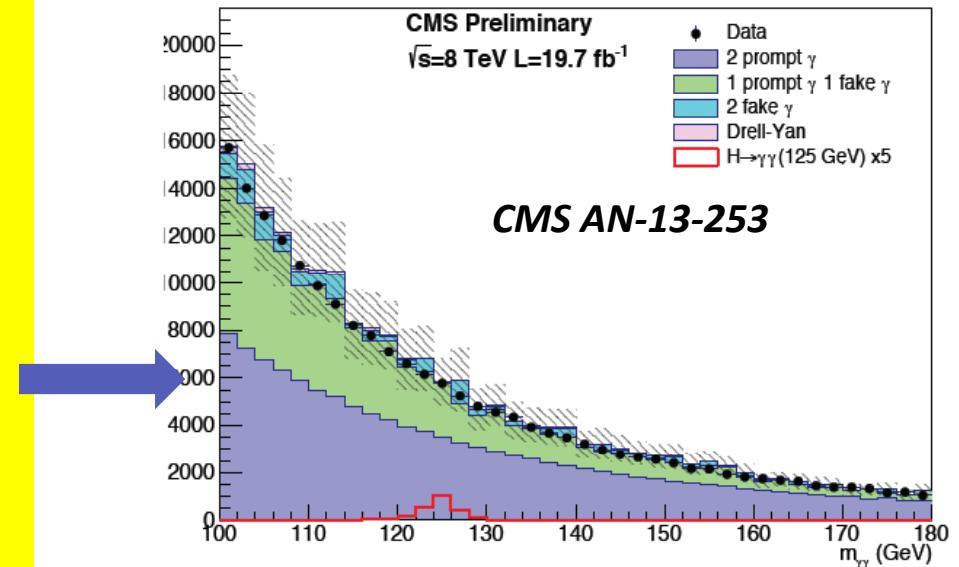


$\gamma\gamma + X$ Differential σ Measurements



$\gamma\gamma + X$ differential cross-section measurements (2010-...): (H. BRUN, N. CHANON, G. CHEN, S. GASCON, M. LETHUILLIER, J. TAO, H. XIAO, J. FAN, Y. SHEN)

- the irreducible SM backgrounds to $H \rightarrow \gamma\gamma$ and some new physics (BSM): $\gamma\gamma + X$
- Used as a probe of perturbative QCD
- Four differential observables: $X = M_{\gamma\gamma}$, $pT_{\gamma\gamma}$, $\Delta\phi_{\gamma\gamma}$, $\cos\theta_{\gamma\gamma}^*$
- Compared with NLO (2010 7TeV data, $L=36/\text{pb}$) and NNLO/NLO/LO (2011 7TeV data, $L=5/\text{fb}$)
- Analysis with 2012 8TeV data ongoing

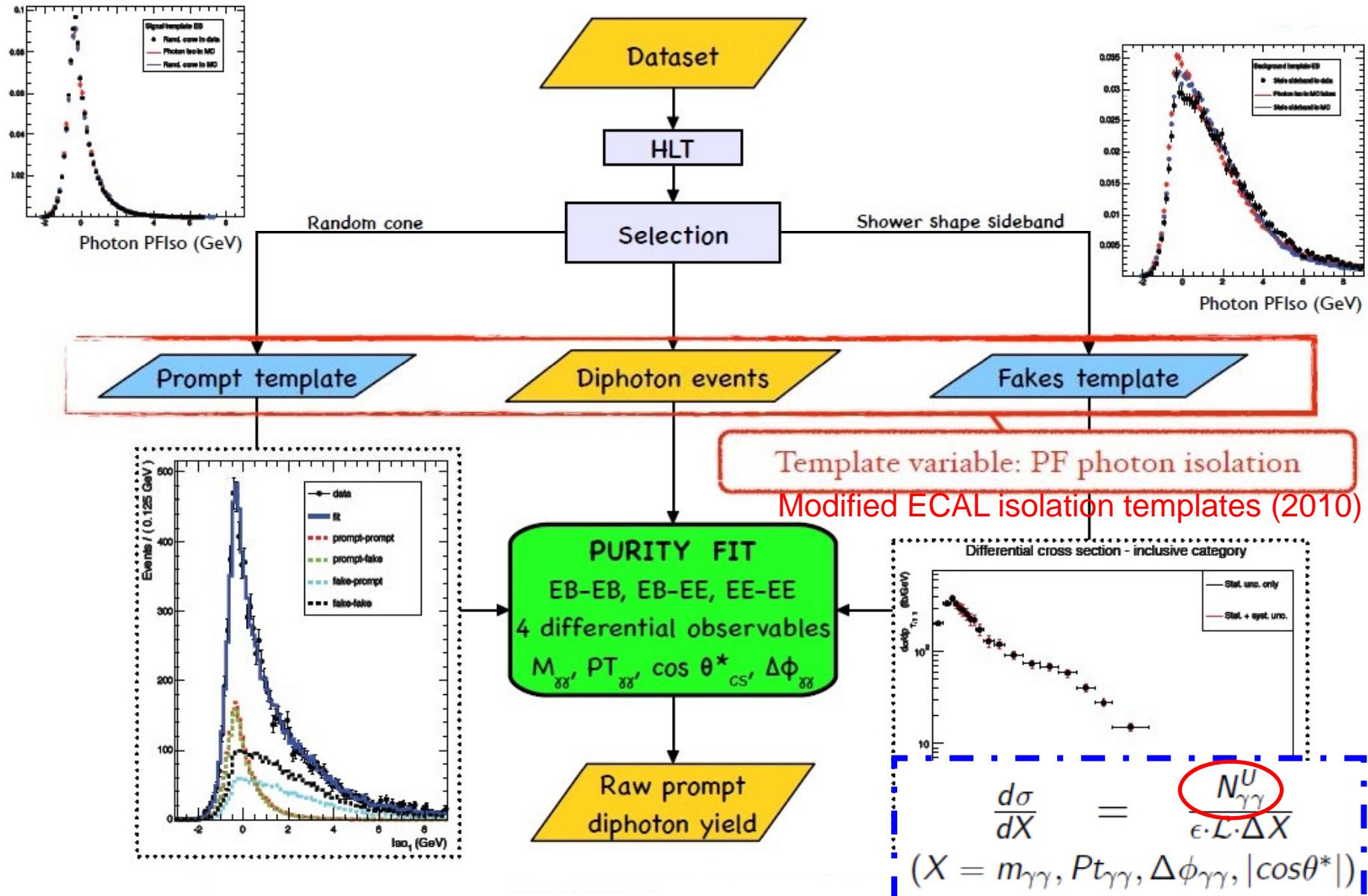


$$\frac{d\sigma}{dX}(X_i) = \frac{N_{\gamma\gamma}^U(X_i)}{\mathcal{L}\Delta X_i \mathcal{C}(X_i)}$$

- Unfolded signal event yield
- Acceptance x efficiency correction
- Bin width
- Luminosity

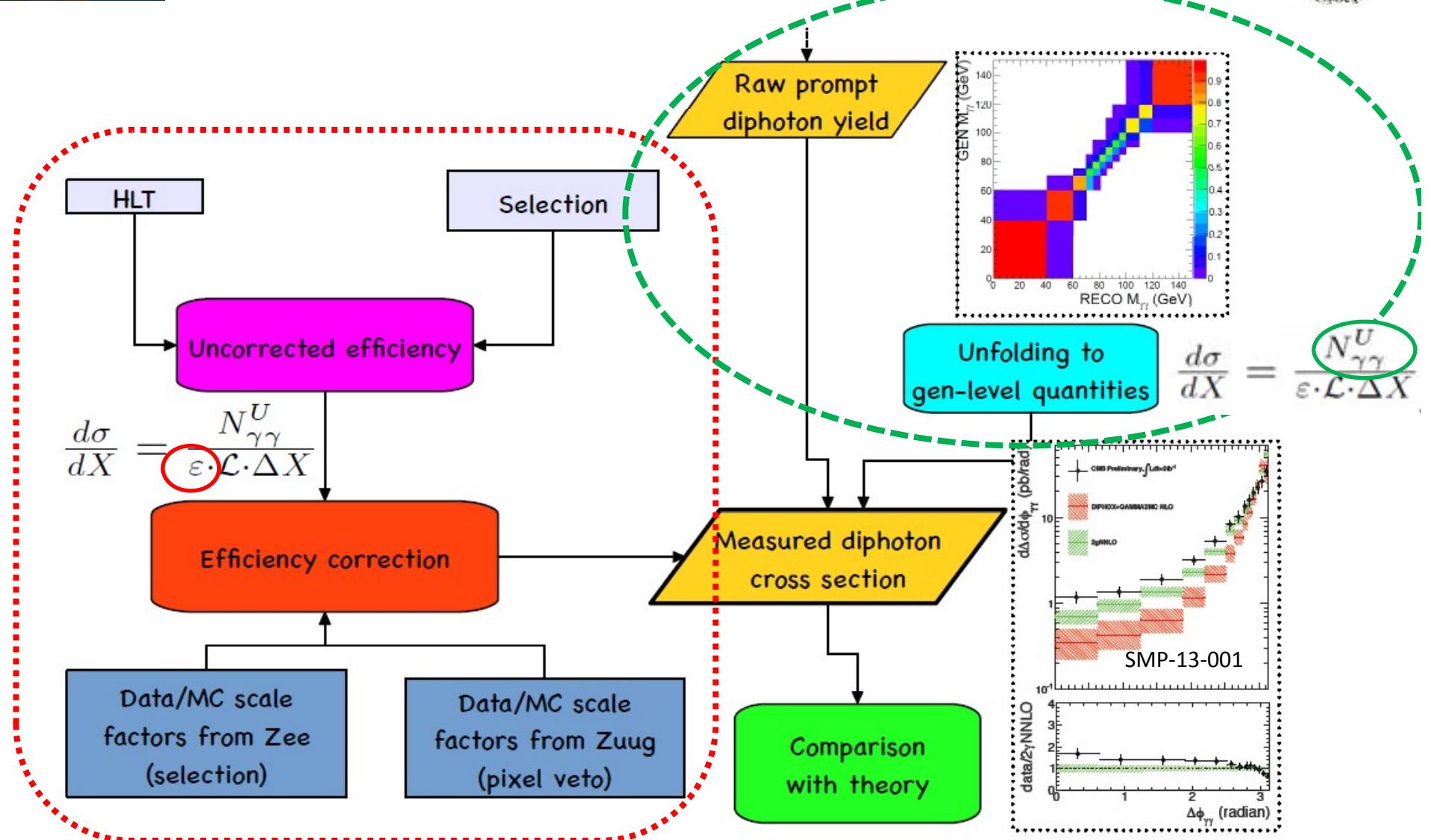


Workflow of differential $\sigma(\gamma\gamma)$ measurements (I)





Workflow of differential $\sigma(\gamma\gamma)$ measurements (II)





Differential $\sigma(\gamma\gamma + X)$ with 2010 data

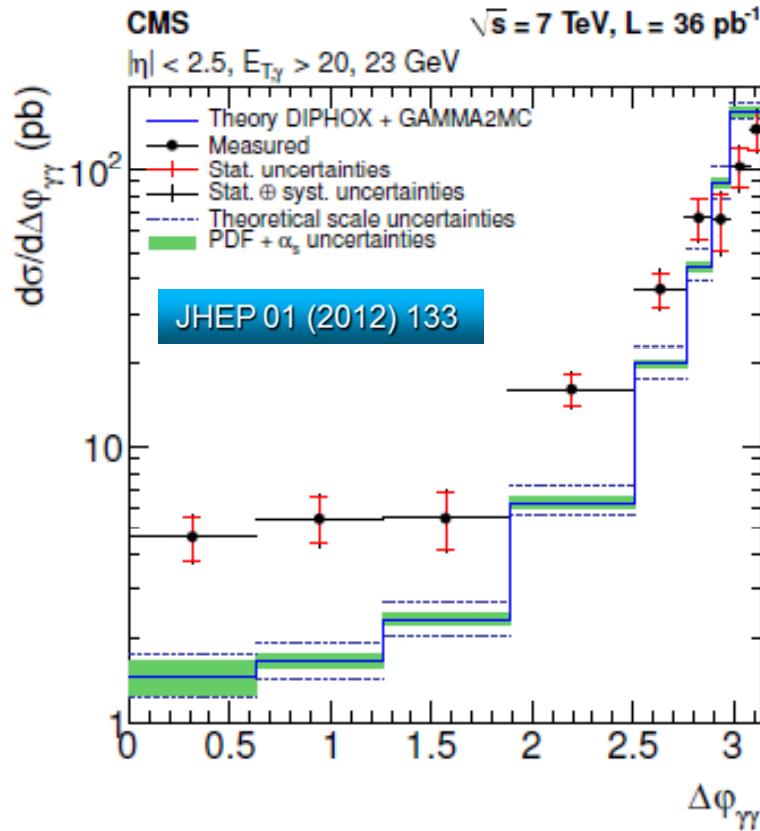


2010 7TeV, 36/pb data:

$$\sigma(pp \rightarrow \gamma\gamma)|_{|\eta| < 2.50} = 62.4 \pm 3.6 \text{ (stat.)} \quad {}^{+5.3}_{-5.8} \text{ (syst.)} \quad \pm 2.5 \text{ (lumi.)} \text{ pb}$$

Theoretical prediction: NLO

$$\sigma(pp \rightarrow \gamma\gamma)|_{|\eta| < 2.50} = 52.7 \pm {}^{+5.8}_{-4.2} \text{ (scales)} \quad \pm 2.0 \text{ (PDF)} \text{ pb}$$



- ❑ NLO not an effective correction at low $\Delta\phi_{\gamma\gamma}$ etc.
- ❑ Published by JHEP 1 (2012) 133

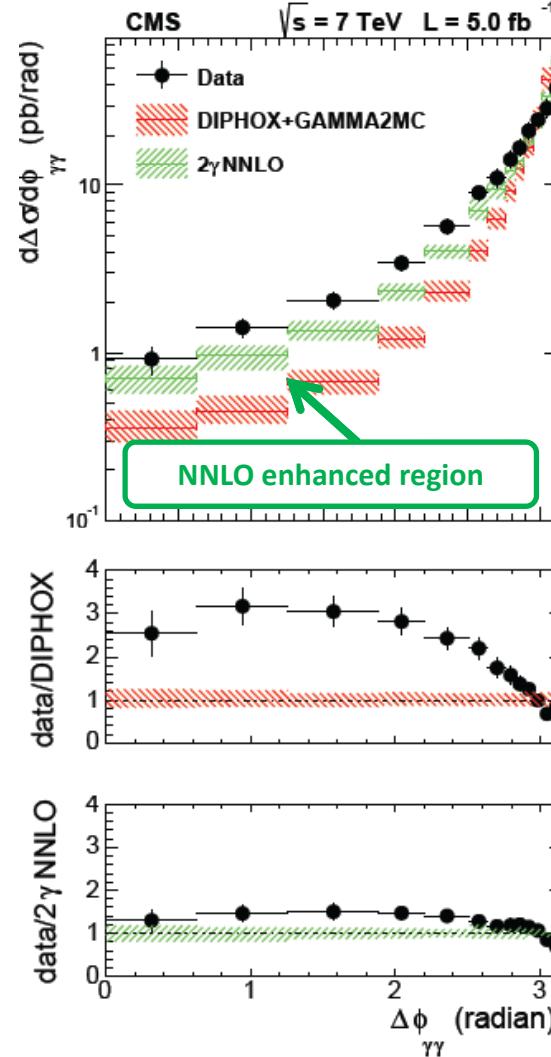
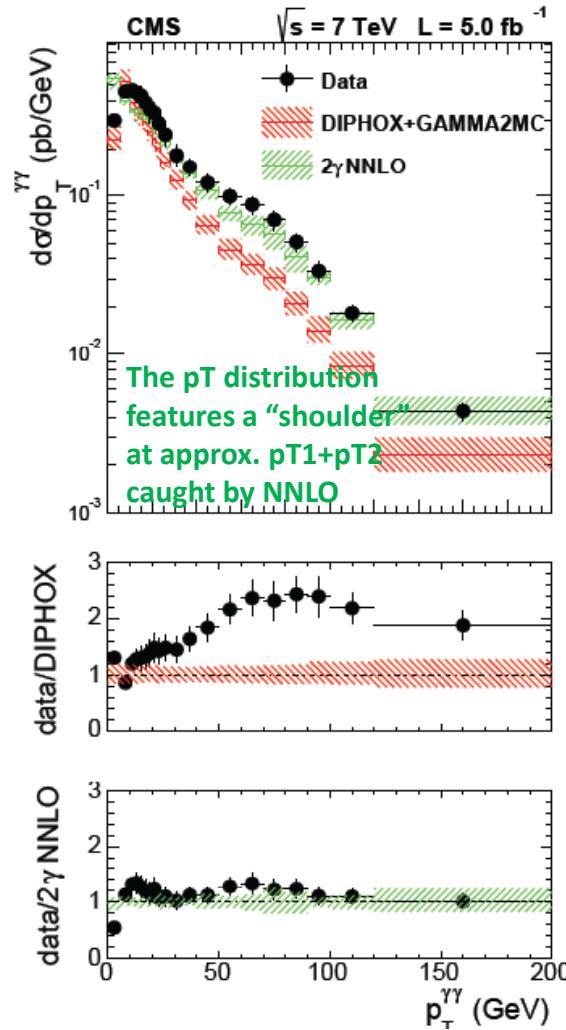
Cooperated with CEA Saclay



Differential $\sigma(\gamma\gamma + X)$ with 2011 data



- 2011 7TeV 5/fb data: CMS approved (CMS AN-13-034/SMP-13-001), EPJC
- Compared with NNLO/NLO/LO calculations



- Yields were determined by data-driven pf photon isolation templates
- NNLO gives the best agreement with the data

$p_T > 40, 25 \text{ GeV}, |\eta| < 1.44 \text{ or } 1.56 < |\eta| < 2.5$
 $dR(\gamma_1, \gamma_2) > 0.45$

Uncertainty induced on the inclusive cross section:

Prompt template shape EB	3%
Prompt template shape EE	5%
Fakes template shape EB	5%
Fakes template shape EE	10%
Effect of fragmentation component	1.5%
Template stat. fluctuation	3%
Selection efficiency	2-4%
Integrated luminosity	2.2%

cooperated with ETHZ

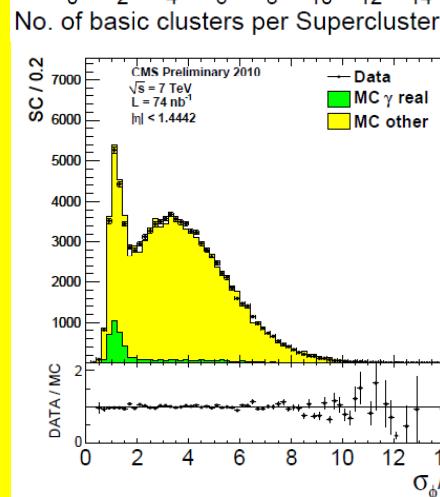
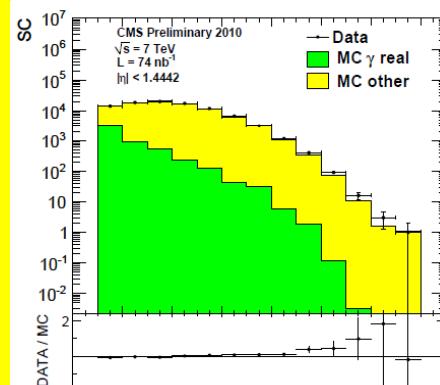


Supercluster and Photon Commissioning

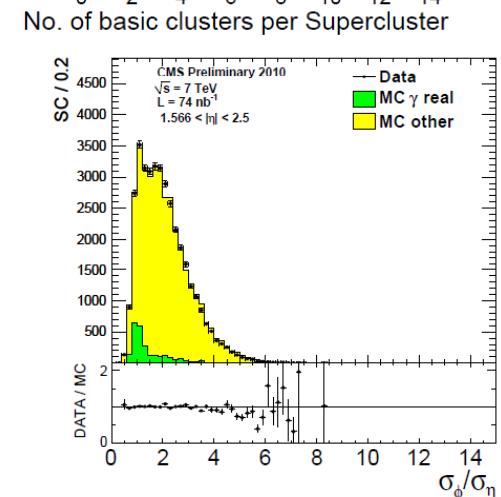
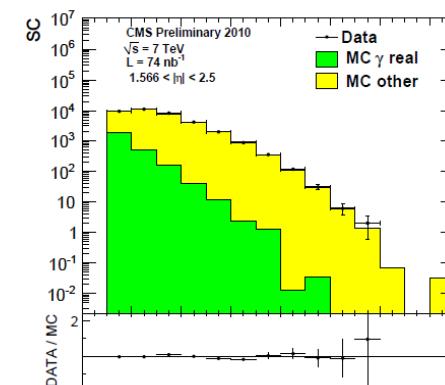


(2008...): (O. BONDU, H. BRUN, A. FALKIEWICZ, J. FAN, S. GASCON, M. LETHUILLIER, J. TAO, H. XIAO, Z. ZHANG)

- ❖ Check understanding of key variables for photon reconstruction (starting with ~80nb-1 in 2010) :
 - Cluster constituent multiplicites
 - Cluster shapes used to assign energy determination method, to derive energy corrections and photon identification
 - Isolation energies used for photon identification
 - Determine and address problem of goodness of GEANT4 simulation of EM shower
- ❖ Public results for ICHEP2010 (EGM-10-001 and EGM-10-005)



Variable	Barrel	Endcap
pixel seed	require none	
E_T	30 GeV	
Tracker Iso	2.0 GeV	
ECAL Iso	4.2 GeV	
HCAL Iso	2.2 GeV	
H/E	0.05	
$\sigma_{\eta/\eta}$	0.01	0.03



$$\sigma_\eta = \sqrt{\sum_{i=1}^n \frac{E_i}{E_{SC}} (\eta_i - \eta_{SC})^2}$$

Loose Photon Id

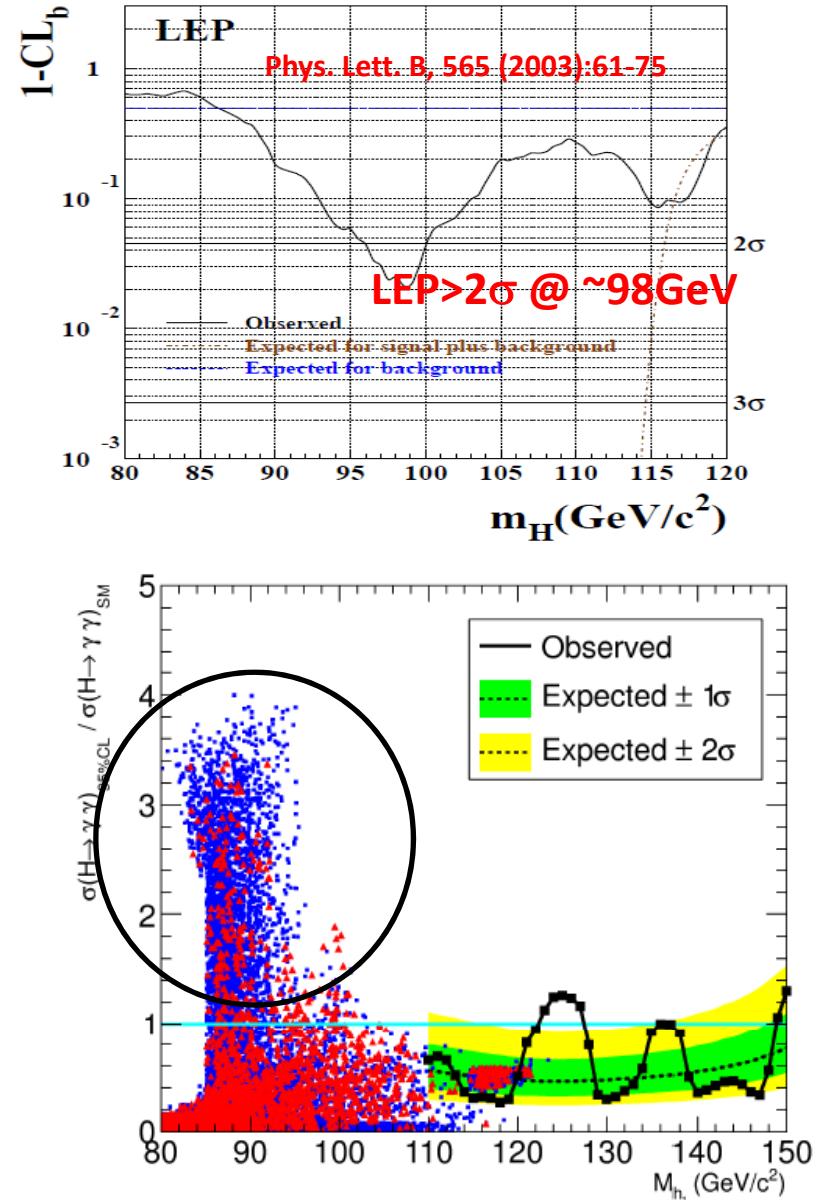


Lower mass $h \rightarrow \gamma\gamma$



(2012...): (B. COURBON, J. FAN, S. GASCON, M. LETHUILLIER, C. Carrillo, L. SGANDURRA, Y. SHEN, P. SOULET, J. TAO)

- ❖ New discovered Higgs Boson consistent with SM prediction, can be also other BSM Higgs, such as SUSY
- ❖ Study the lightest scalar Higgs boson $h_1 \rightarrow \gamma\gamma$ in the Next-to-Minimal Supersymmetric Standard Model (NMSSM) by restricting the next-to-lightest scalar Higgs boson h_2 to be the observed 125 GeV/c² state
- ❖ In the lower mass range (~90GeV), the predicted $\sigma(h_1 \rightarrow \gamma\gamma)$ wrt σ_{SM} can be higher up to ~3.5 (Chin. Phys. C)
- ❖ Lower mass $h \rightarrow \gamma\gamma$ analysis with CMS data ongoing





IPNL-IHEP FCPPPL Proposal for 2014



- For 2014, the IPNL and IHEP CMS groups will continue to work on improvements to the $H \rightarrow \gamma\gamma$ analyses, as well as further probing the data for any evidence of a second resonance in the lower mass region and the double differential cross section measurement of $\gamma\gamma + X$,
...
● We ask for FCPPPL supports for
 - 1) a stay of 1 month at IHEP for Camilo Carrillo
 - 2) 2 months of a four-month stay at IPNL for FAN Jiawei to reinforce these immediate efforts.



Summary and Conclusion



- ❖ We contributed significantly to the analyses of
 - photon “infrastructure” (photon commissioning and reconstruction, calibration and identification)
 - direct diphoton differential $\sigma(\gamma\gamma)$ measurements
 - the $H \rightarrow \gamma\gamma$ search, observation and measurements through our cooperation efforts, which have continued to expand.

- ❖ We look forward to continue our efforts in more and more common activities.



Acknowledgements



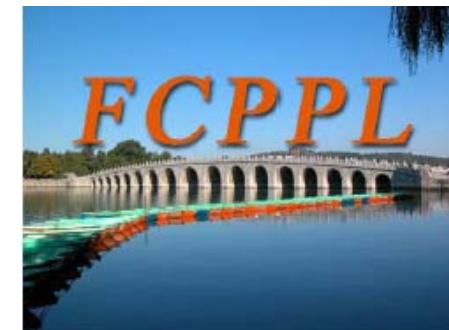
Many thanks:

- To F. Le Diberder and Chen Hesheng in helping us get our collaboration efforts started
- To the IN2P3/CNRS, the IHEP-CAS, and the CSC
- To the FCPPL directorate and steering committee
- To the local organising committee of this workshop for the wonderful hospitality and working environment

Thanks

Merci

谢谢



Backup slides