The IHEP-IPNL Collaboration:
Photon studies and the search for $H \rightarrow \gamma\gamma$ in CMS
A new boson discovered, and now?

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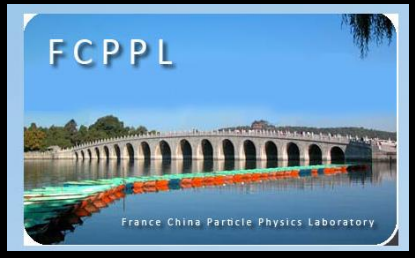
Université Claude Bernard Lyon 1
IN2P3-CNRS

8th France-China Particle Physics Workshop

USTC, Hefei

April 8-10, 2015



Outline

I – A brief history of our collaboration
II – July 4 2012, 9h30…..a new boson is discovered
III – Electromagnetic Cluster and Photon Commissioning
IV – Photon Validation and Energy Scale Extraction
V – $\gamma\gamma$ + X Differential Cross-section Measurements
VI – H→ $\gamma\gamma$: Impact of higher-order calculations on kinematical observables in 2γ processes
VII – H→ $\gamma\gamma$: $\gamma/\pi 0$ discrimination and photon identification
VIII – H→ $\gamma\gamma$: Run 1 Legacy Results
IX – H→ $\gamma\gamma$: Search for a 2nd boson with m<110 GeV
X – Boosted WH resonance search (PKU)
XI – Summary and Proposal for 2015
XII – Acknowledgements

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

The CMS groups of IHEP and of IPN Lyon: A brief history of our collaboration

IHEP Beijing ➔ IPN Lyon:

- 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 proposal)
- FAN Jiawei (Doctoral Student)—August-September 2012) (FCPPL) + October 2012-April 2014 (CSC Scholarship) + November-December 2014 (FCPPL)
- SHEN Yuqiao (Doctoral Student)—May-September 2013 (FCPPL proposal)
- ZHANG Sijing (Doctoral Student)—Asking 5 months in 2015 (FCPPL) + CSC scholarship candidate for Co-Ph.D

IPN Lyon ➔ IHEP Beijing:

- 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)
- Camilo CARRILLO (Postdoc)-September 2014

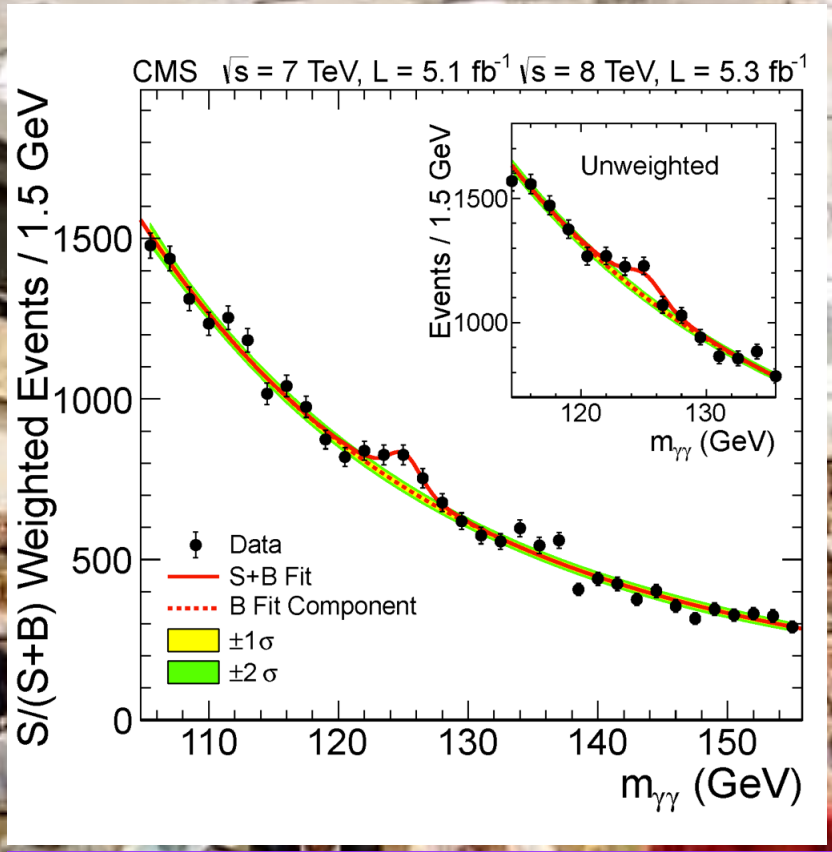
New!

+ participation to the Organising committees of the founding Workshop at IHEP (2006) and of the 1st, 2nd, 3d and 4th FCPPL workshops (IPNL co-chaired the 3d workshop)

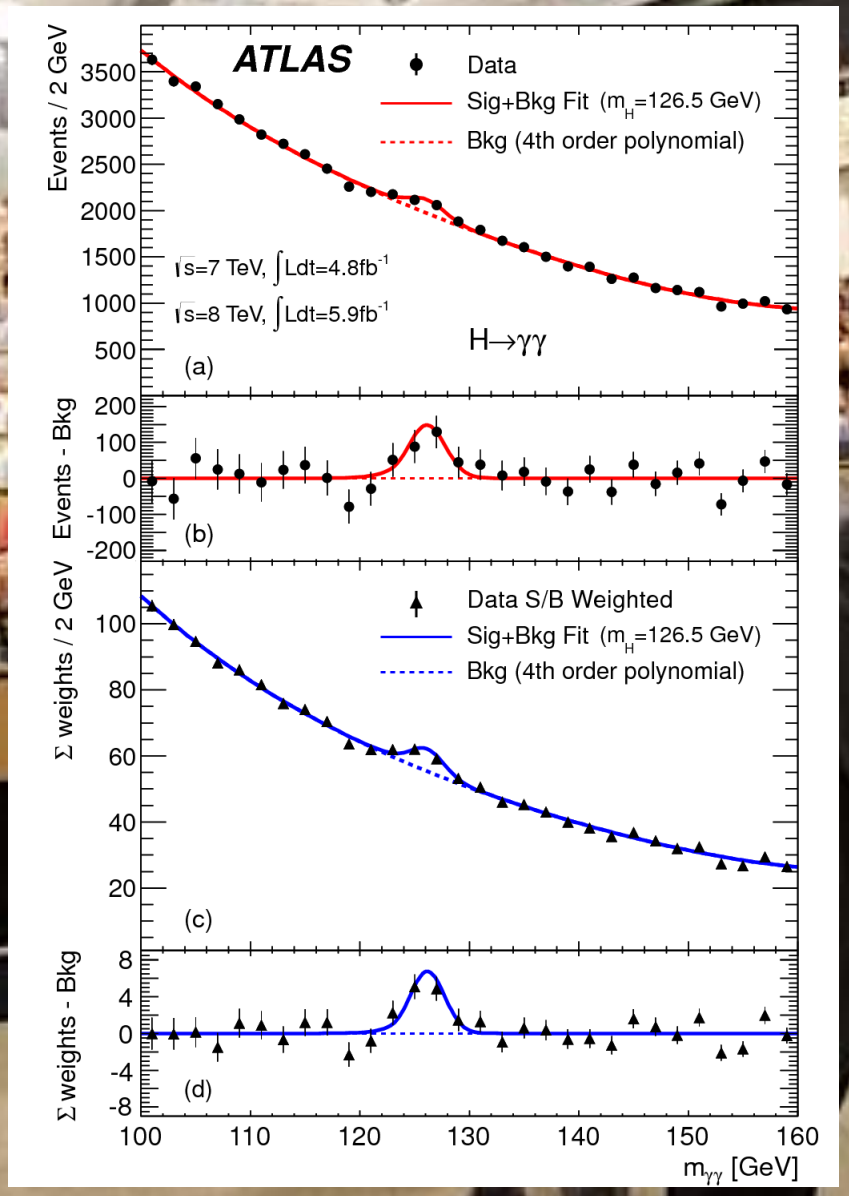
New!

Congratulations to Dr. FAN Jiawei, first IHEP-IPNL Co-Ph.D student, winner of a CSC scholarship, thesis defense yesterday!

July 4th 2012, 9h30……



- "This result constitutes evidence for the existence of a new massive state that decays into two photons."



- "Clear evidence for the production of a neutral boson …is presented."

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 a Higgs boson through analysis of the gamma–gamma channel. But this reward came only after years of painstaking work in many areas of study of photons….

Electromagnetic cluster and Photon Commissioning, Runs 1 and 2

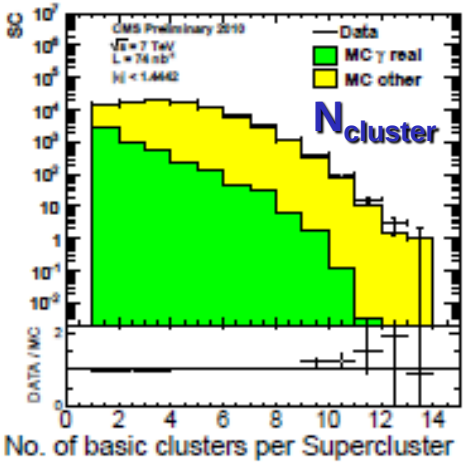
(2008-..): (O. BONDU, H. BRUN, A. FALKIEWICZ, M. LETHUILLIER, S. GASCON, J. FAN, J. TAO, H. XIAO, Z. ZHANG, B. COURBON

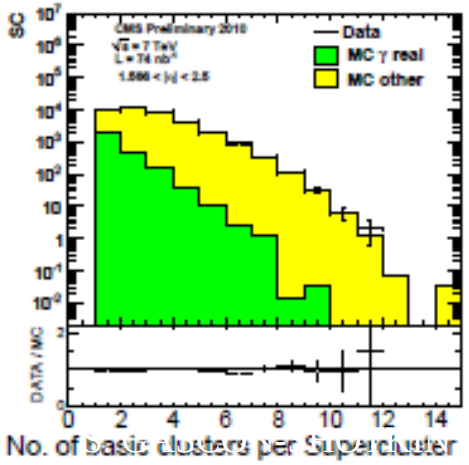
- Run 1 startup (Public results:(EGM-10-001 and EGM-10-005)):
  - Check understanding of key observables for photon reconstruction : Cluster constituent multiplicites, Cluster shapes (used to assign energy determination method, to derive energy corrections and photon identification), Isolation energies
  - Check goodness of GEANT4 simulation of EM shower
- Run 2 startup: Reoptimize and validate regression energy corrections for photons
- Upgrades Technical Proposal: Check photon performance

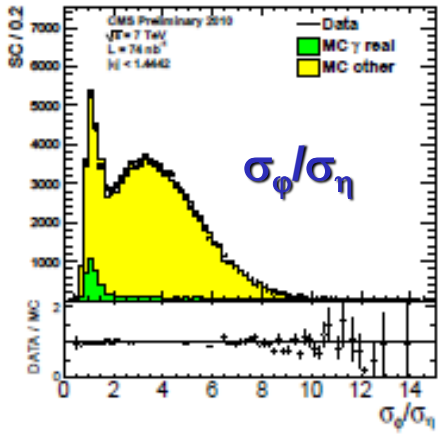
Loose Photon Id

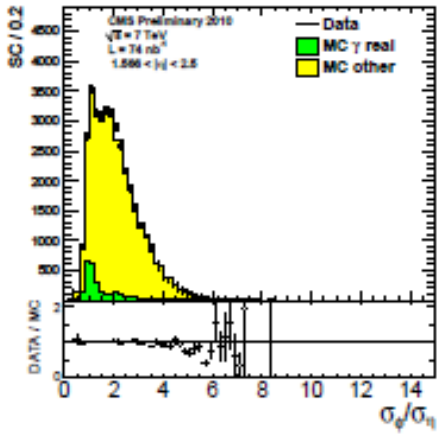
Variable	Barrel	Endcap
pixel seed	require none	
E_T	30 GeV	
Tracker Iso	2.0 GeV	
ECAL Iso	4.2 GeV	
HCAL Iso	2.2 GeV	
H/E	0.05	
$\sigma_{i\eta i\eta}$	0.01	0.03

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









Photon Validation and Energy Scale Extraction

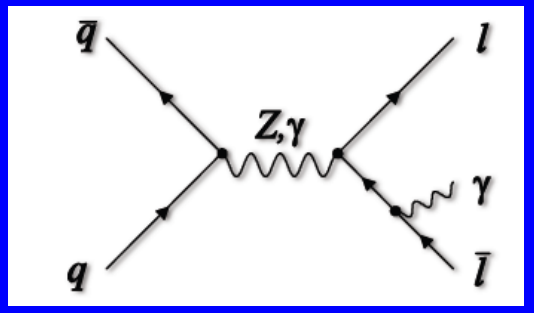
« Certified » photons from Z→μμγ FSR (2007-..): (C. BATY, O. BONDU, H. BRUN, M. LETHUILLIER, S. GASCON, L. SGANDURRA, J. FAN, Y. SHEN, J. TAO, H. XIAO, Z. ZHANG, S. ZHANG)

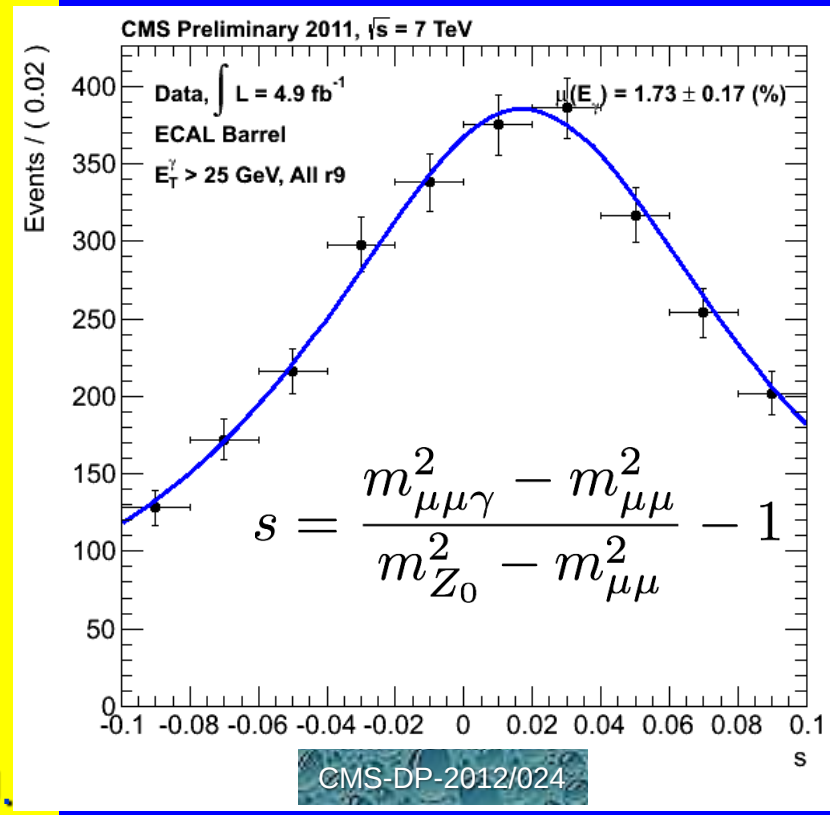
- Isotropic source of relatively high-pT γ enabling extraction of

- Photon energy scale : One of two CMS-approved methods
- Photon energy correction validation
- **Photon trigger efficiency**

Selection: Minimum photon Pt, Veto non-radiative Z, far muon Pt and isolation.

- Result used to estimate systematic error on photon energy scale for first Measurement of the Wγ and Zγ inclusive cross-sections with 2010 dataset (Phys. Lett. B701, 535-555 (2011))
- Used to validate understanding of H→γγ photon ID MVA input variables and compute electron veto efficiency for discovery analysis (Eur. Phys. J. C 74 (2014) 3076) and 7 TeV diphoton cross section measurement (Eur. Phys. J. C 74 (2014) 3129)
- Need to update and reoptimize for Run 2





CMS-DP-2012/024

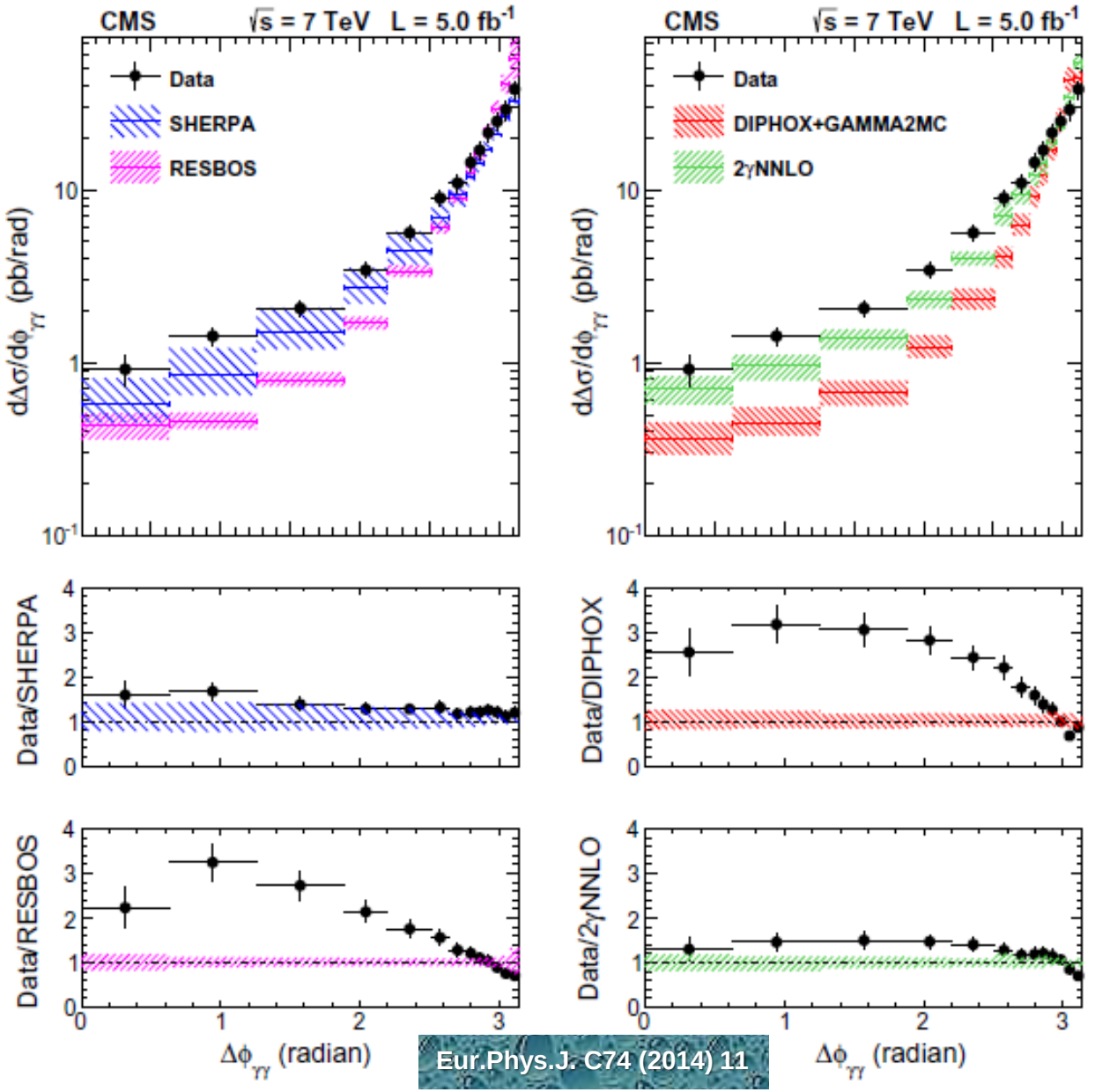
CMS-DP-2011/008, CMS-DP-2012/024

γγ + X Differential Cross Section Measurements

JHEP 01 (2012)133 (36pb-1),
Eur.Phys.J. C74 (2014) 11

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

- For measurement of SM backgrounds to H→γγ : γγ + X and γ + X; Can probe gluon PDF at unprecedented Et and reduce gluon NLO PDF error by ~20%
- Use data-driven EM (2010) or PF (2011) isolation templates
- Comparison to pQCD predictions, determination of efficiencies
- 2012 8 TeV results forthcoming



Eur.Phys.J. C74 (2014) 11

H→γγ analysis: Impact of higher-order calculations on kinematical observables in 2γ processes

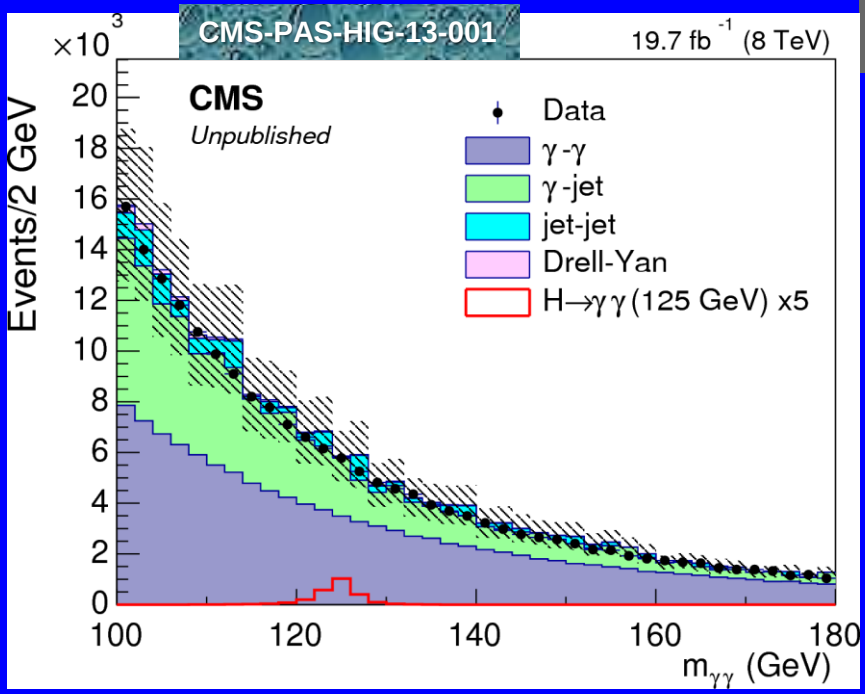
(2007-…): (O. BONDU, N. CHANON, M. LETHUILLIER, S. GASCON, J. TAO)

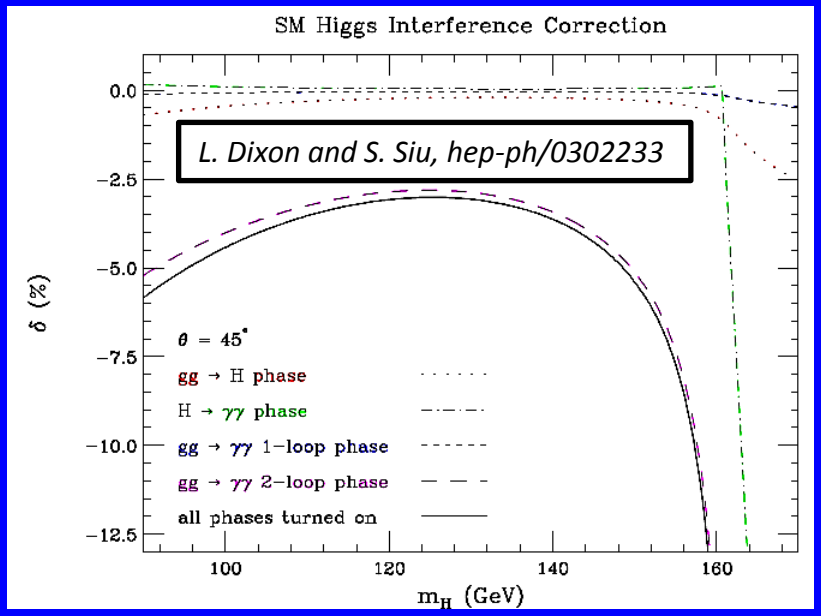
- Incorporate kinematic implications of HO calculations on analysis observables (pt_2γ, Δϕ_2γ , m_2γ, cos θ*…). Collaboration with LAPTH/IPNL/INFN and American theoreticians.

- Implemented doubly-differential reweighting scheme with dynamical k-factors for H→γγ signal and diphoton background, significant contribution to LHC Higgs XS WG 'Yellow Report 2: Handbook of Cross sections: Differential Distributions (CERN-2012-002, arXiv:1201.3084)

- furnished integrated k-factors for the analysis

- Evaluated effect of destructive signal-background interference δ from digluon-induced processes



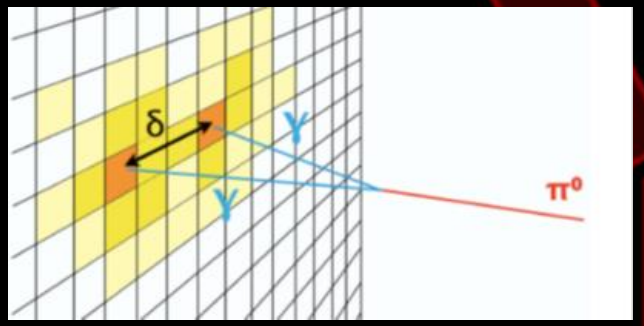


H→γγ analysis: γ/π^0 discrmination and photon identification

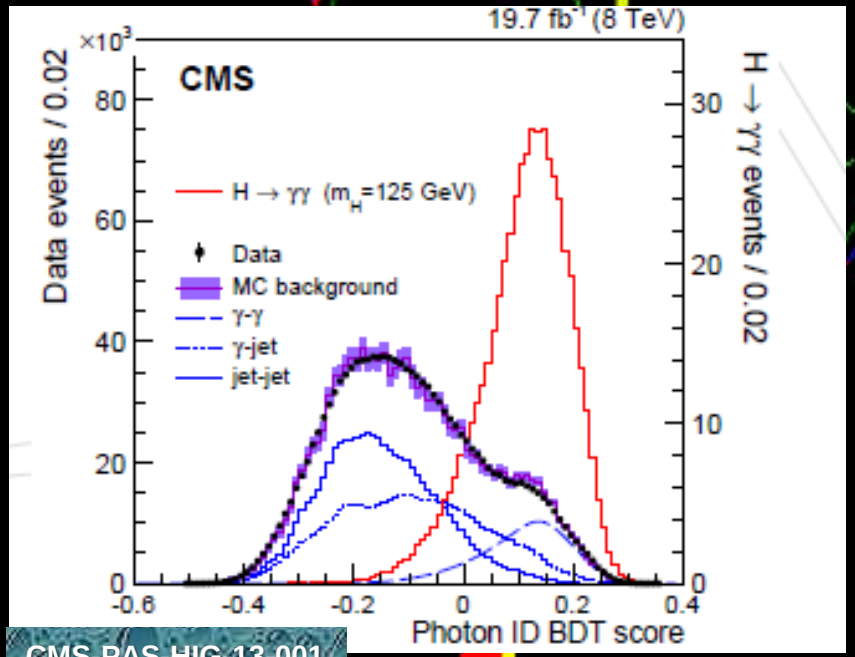
γ/π^0 discrmination (2008-…): (H. BRUN, N. CHANON, G. CHEN, M. LETHUILLIER, S. GASCON, J. FAN, J. TAO, Z. ZHANG, Y. SHEN) for both converted and non-converted photons

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

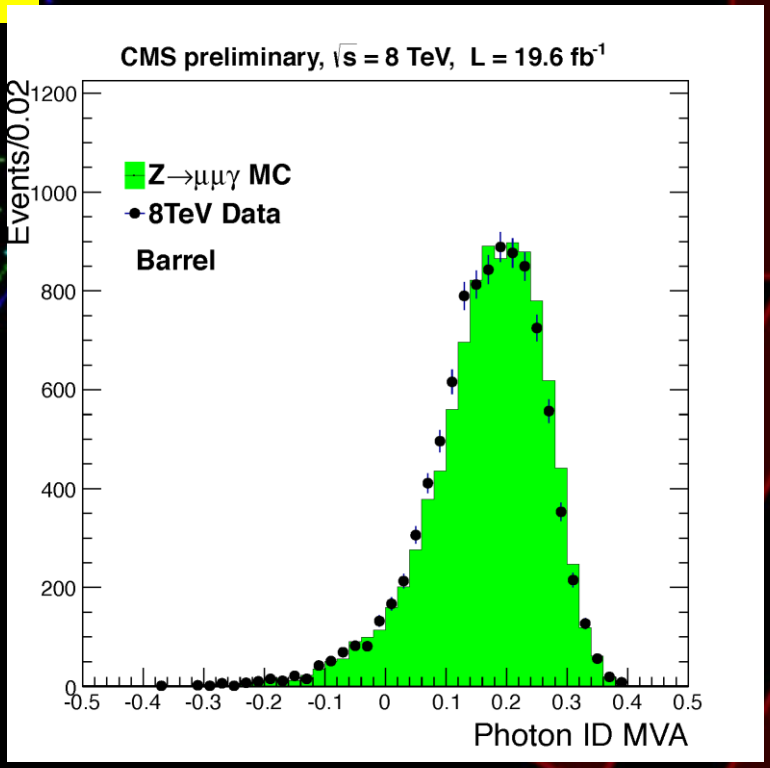
Direct input to the overall MVA analysis for the H→γγ search but possibly also useful in other analyses using photons.



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



CMS-PAS-HIG-13-001



- Validation on Z→ee and Z→μμγ events

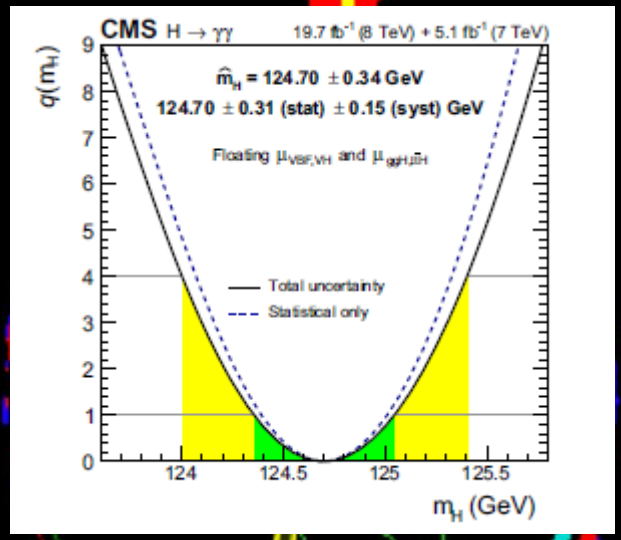
H→γγ Run 1 Legacy Results

CMS Experiment at LHC, CERN
Data recorded: Sun Ju
Run/Event: 140382 / 159943472
Lumi section: 171

(2007-…): (O. BONDU, H. BRUN, N. CHANON, G. CHEN, M. LETHUILLIER, S. GASCON, L. SGANDURRA, J. FAN, J. TAO, Z. ZHANG)

Eur. Phys. J. C (2014) 74:3076

- Mass
- Signal strength
- Spin compatible with 0
- >5σ single-channel significance



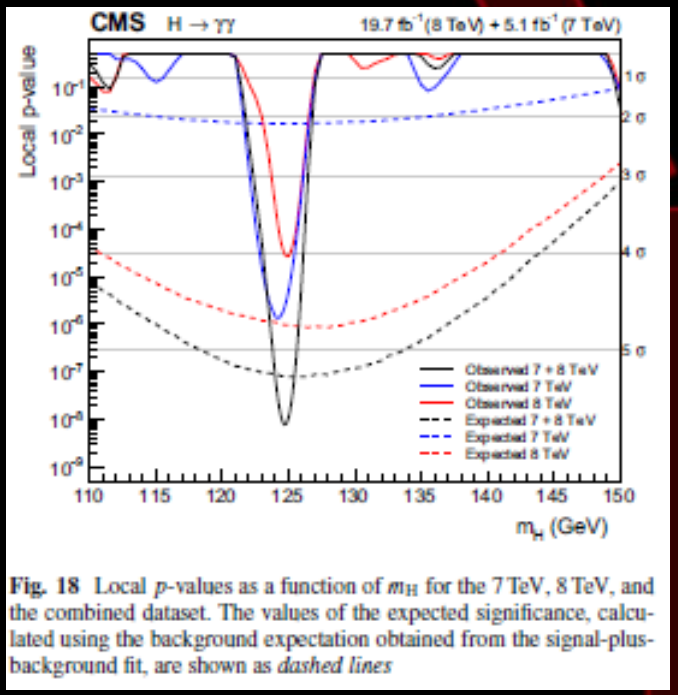
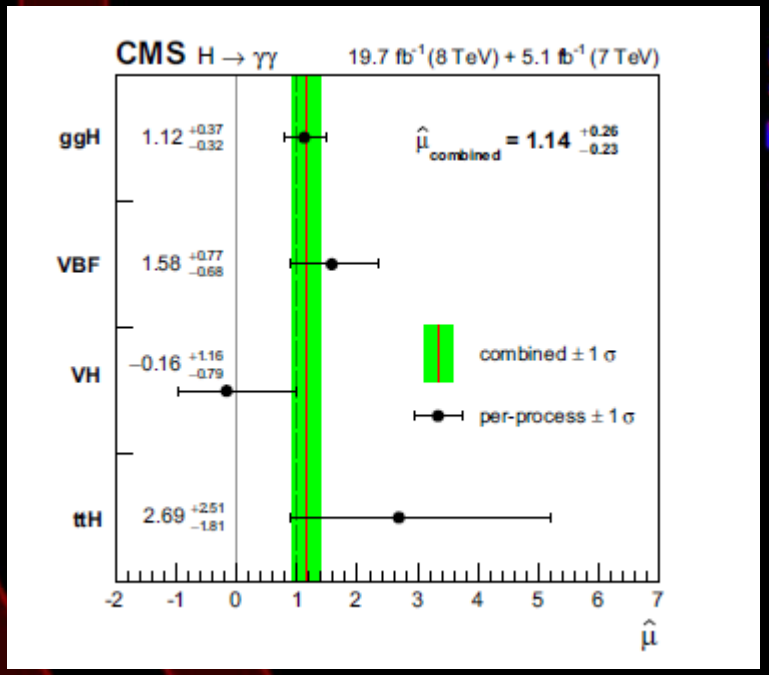
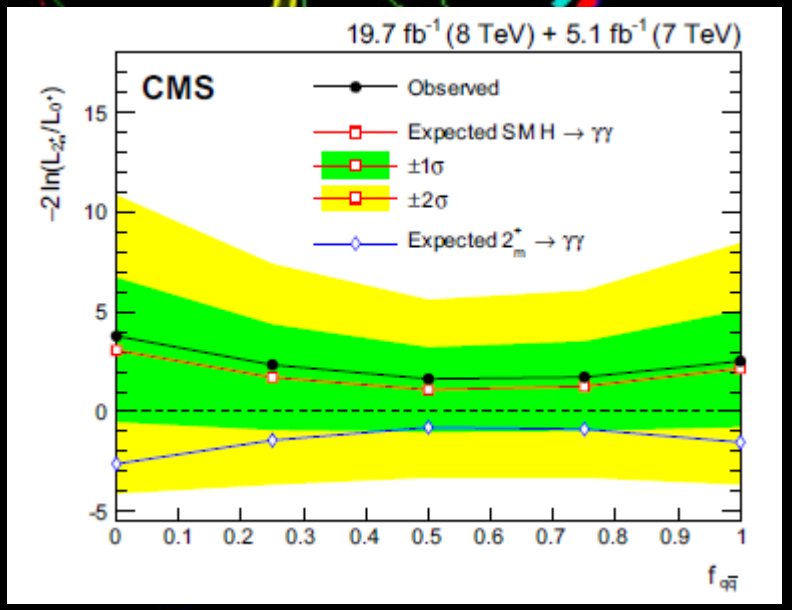


Fig. 18 Local p-values as a function of m_H for the 7 TeV, 8 TeV, and the combined dataset. The values of the expected significance, calculated using the background expectation obtained from the signal-plus-background fit, are shown as *dashed lines*

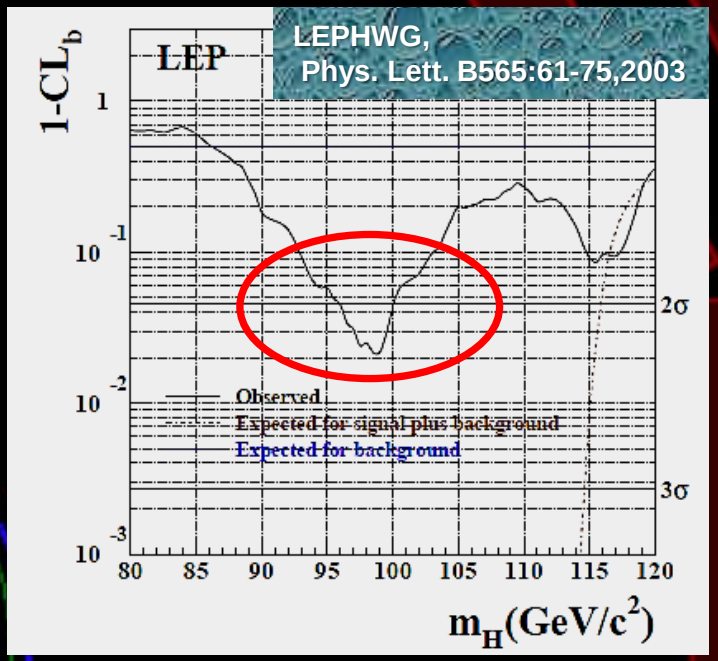




H→γγ: Search for a 2nd boson with m<110 GeV, Runs 1 and 2

(2013-…): (G. CHEN, M. CHEN, M. LETHUILLIER, S. GASCON, C. CARRILLO, D. SABES, L. SGANDURRA, J. FAN (thesis Run 1), J. TAO, Y. SHEN, B. COURBON (thesis Run 2), S. ZHANG)

- A lighter 2nd Higgs boson (h1) with m=[60-110] GeV still a possibility in some BSM models:(N)MSSM, 2HDM….
- Compatible with the already-discovered boson as 2nd lightest (h2)
- Scan within NMSSM shows σ/σ_{SM} for h1 possible up to 4σ, for 60 GeV<m<120 GeV
- Run 1 analysis preapproved (CMS-HIG-037), Run 2 analysis in preparation



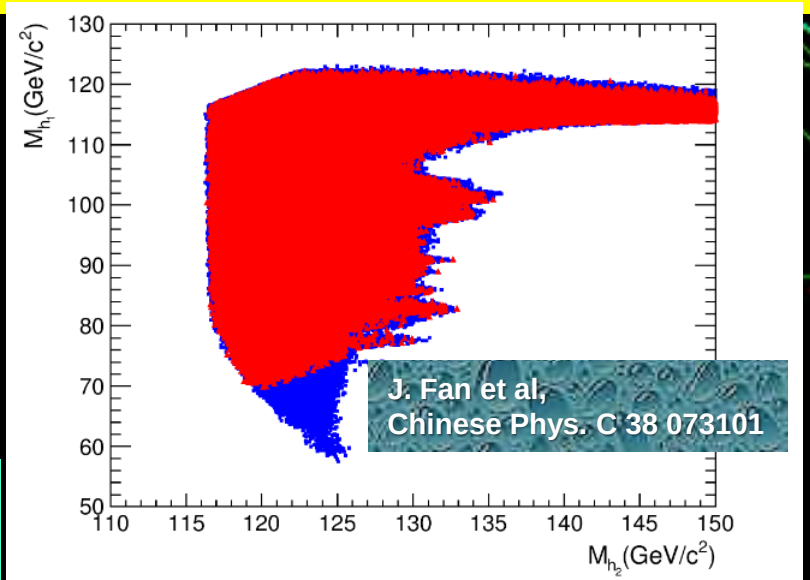
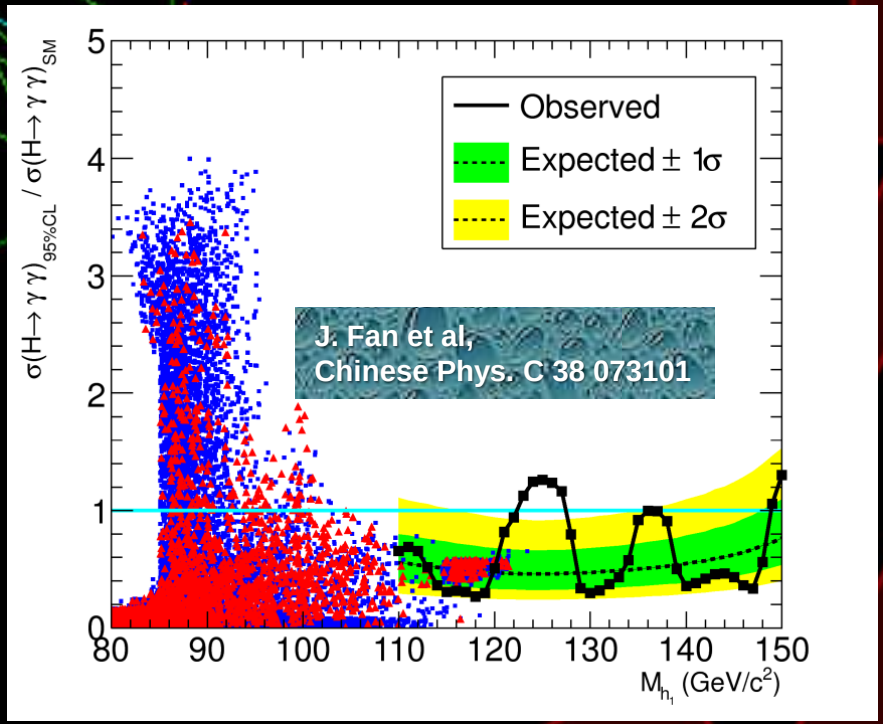


Fig. 1. The NMSSM Higgs boson mass spectrum in the M_{h_1} vs. M_{h_2} plane. Points for case I are represented by blue squares and case II by red triangles.



See dedicated talk by FAN Jiawei

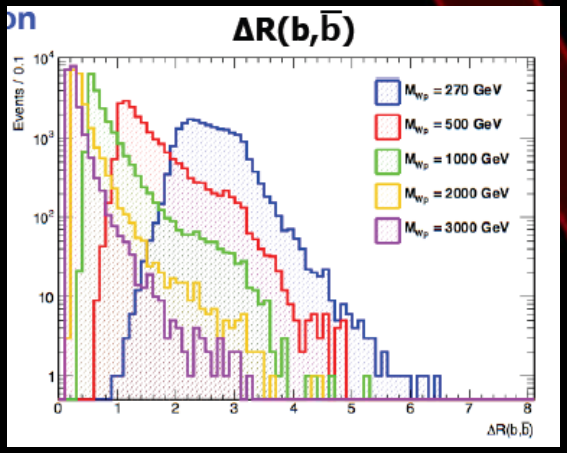
Boosted WH resonance search

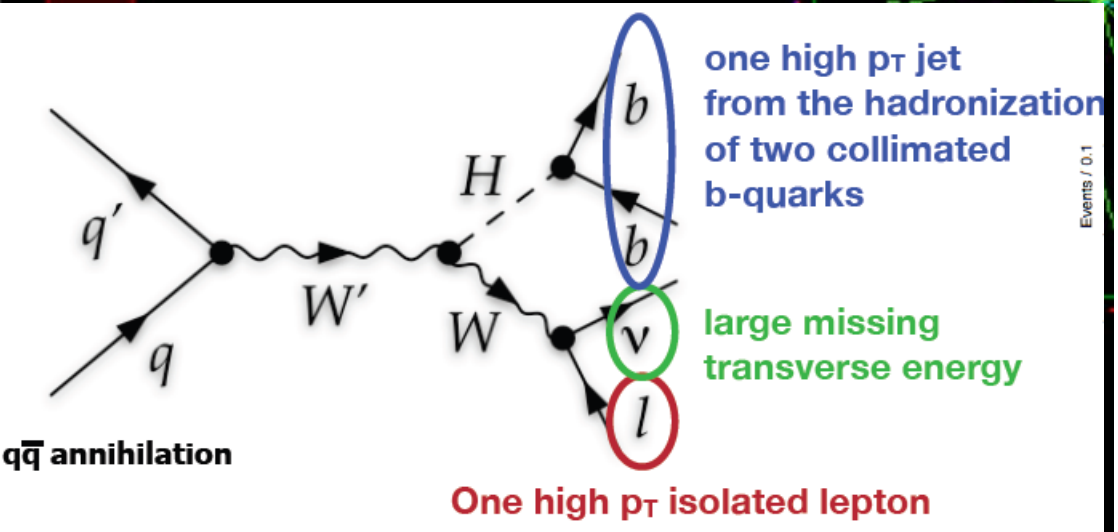
CMS Experiment at LHC, CERN
Data recorded: Sun
Run/Event: 140382 / 159943472
Lumi section: 171

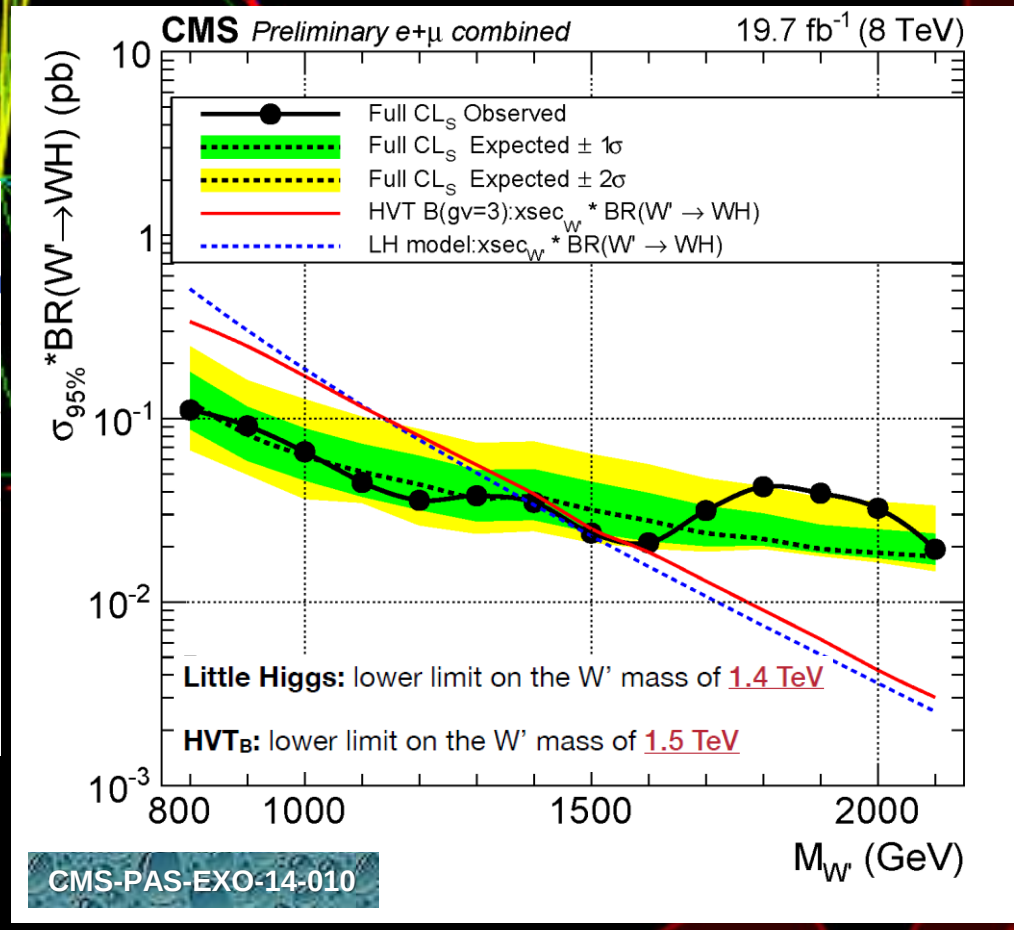
HEP Group, Peking University:

- W'→WH resonances motivated in many BSM models (Extra Dimensions, Composite or Little Higgs…)
- Highly-boosted W' decay products produce 'fat' jets requiring use of jet substructure and/or subjet b-tagging techniques
- **Run 1 analysis just approved (CMS-PAS-EXO-14-010)**

New!







See dedicated talk by LI Qiang

IHEP-IPNL FCPPL Proposal for 2015

- CMS and ATLAS have discovered a new boson with m~125 GeV compatible within experimental uncertainties with the SM Higgs boson hypothesis. The IHEP and IPNL CMS groups working together, with the help of the FCPPL, were able to make key contributions to this discovery in one of the two 'golden' decay channels, H→γγ

- The IHEP and IPNL groups are leading the CMS search, in both Runs 1 and 2, for a new 'peak', a 2nd, lighter Higgs boson decaying into two photons, allowed in the context of several BSM models
- They are also key players in CMS direct photon measurements

- For the LHC Run 2 startup in 2015 as well as for the upgrade Technical Proposal, the IHEP and IPNL CMS groups are also making key contributions to photon commissioning and estimation of performance, as they did for the Run 1 startup.

- We ask for support for a stay of 5 months at IPNL for ZHANG Sijing to reinforce these immediate efforts, plus the monthly required complement to her CSC co-PhD stipend if obtained

Acknowledgements

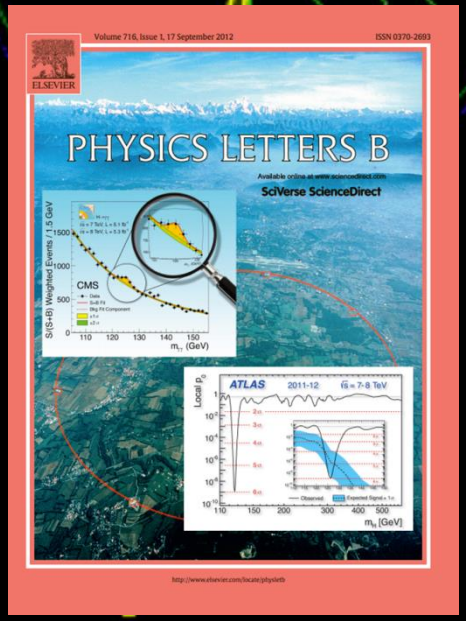
Many thanks: 谢谢

To the IN2P3/CNRS, the IHEP-CAS, and the CSC

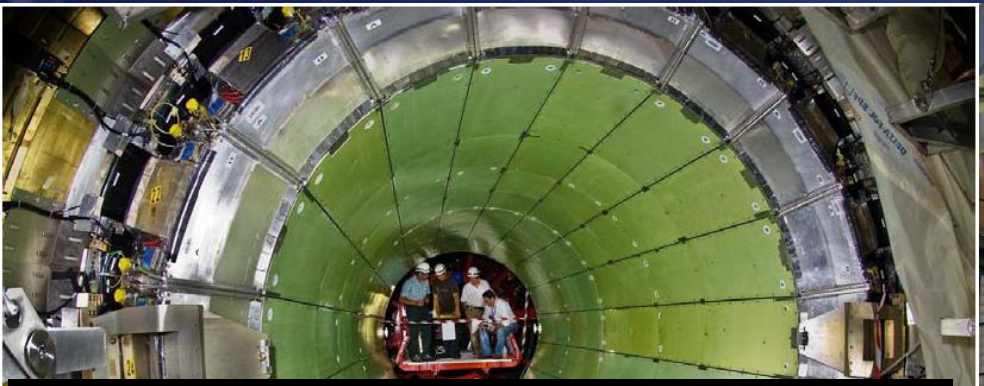
- To the FCPPL directorate and steering committee
- To the local organising committee of this workshop here at USTC for the wonderful hospitality and working environment

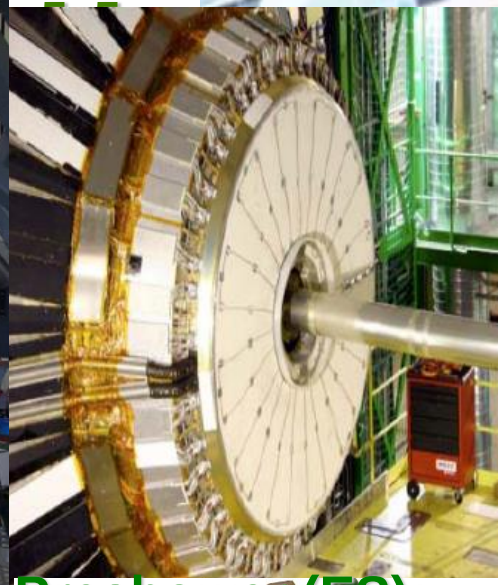
CMS Experiment at LHC, CERN
Data recorded: Sun Jul 18 04:24:49 2010 PDT
Run/Event: 140382 / 159943472
Lumi section: 171

Backup



The Electromagnetic Calorimeter (ECAL) of the CMS Experiment





Barrel (EB):

- 61200xtals (2.2x2.2x23cm3)
- 36 Supermodules (SM), each 1700 crystals
- $|\eta| < 1.48$
- $\Delta\eta \times \Delta\phi = 0.0175 \times 0.0175$
- APD readout

Endcap (EE):

- 14648 crystals
- (3x3x22cm3)
- 4 Dees, SuperCrystals of 5x5 xtals
- $1.48 < |\eta| < 3.0$
- $\Delta\eta \times \Delta\phi = 0.01752 \leftrightarrow 0.052$
- VPT readout

Preshower (ES):

- Pb(2X)-Si(1X)
- 4 Dees
- 4300 Si strips
- $1.65 < |\eta| < 2.6$

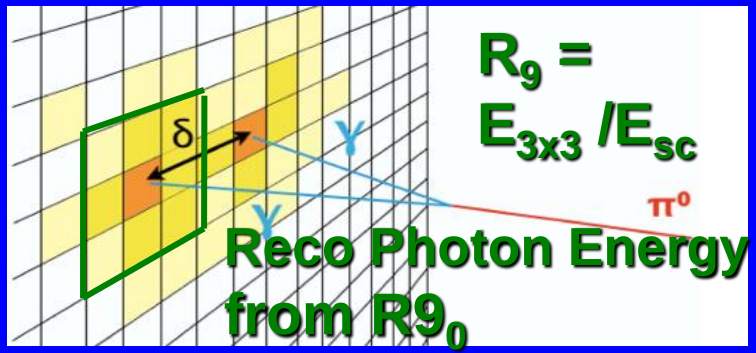
Excellent resolution measured in test beam ($\sigma/E < 0.5\%$ at 100 GeV)
Major issues for realization of this performance in situ:
- Intercalibration
- Showering in tracker material

Definition and Components of Calibration, Clusterisation and Energy Scale

Energy scale on the ECAL/physics object Level (E5x5/SC or Reco Photon) will be adjusted with Algorithmic Corrections F):

$$E = F \times \sum_{cluster} \underbrace{G \times c_i \times A_i}_{\text{Cal. rechit}}$$

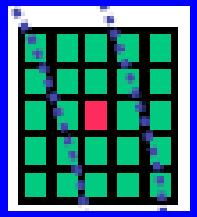
5x5 or SC



Energy scale definition: $k=E_{true}/E_{reco.}$, can be divided into 'constant' (peak position) and 'variable' ('resolution') parts. Variable part: k=k(Et, η, φ)

R9 >$R9_0$

Energy from 5x5 matrix

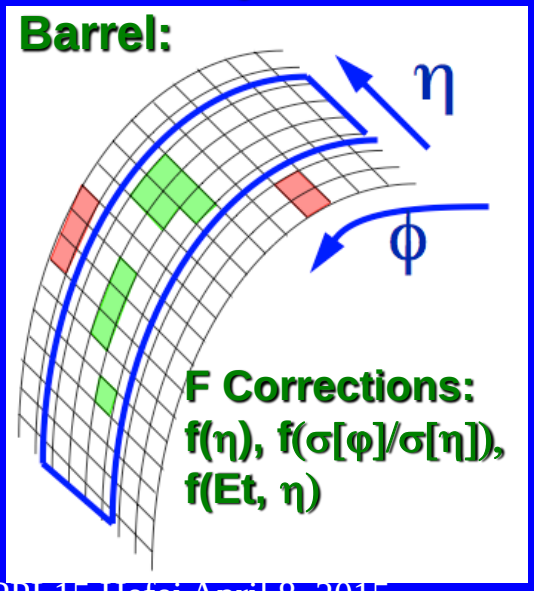


F Corrections: f(η)[barrel only], Local containment

R9 < $R9_0$

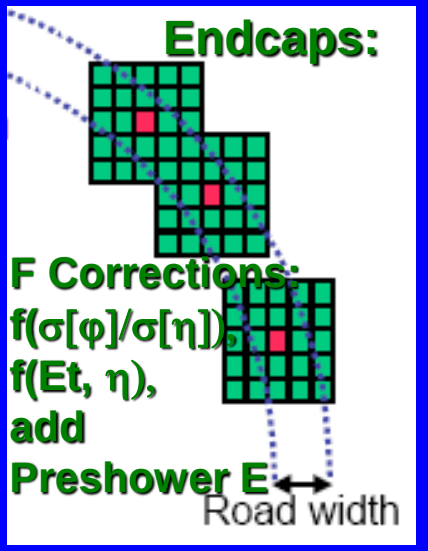
E from Supercluster

Barrel:



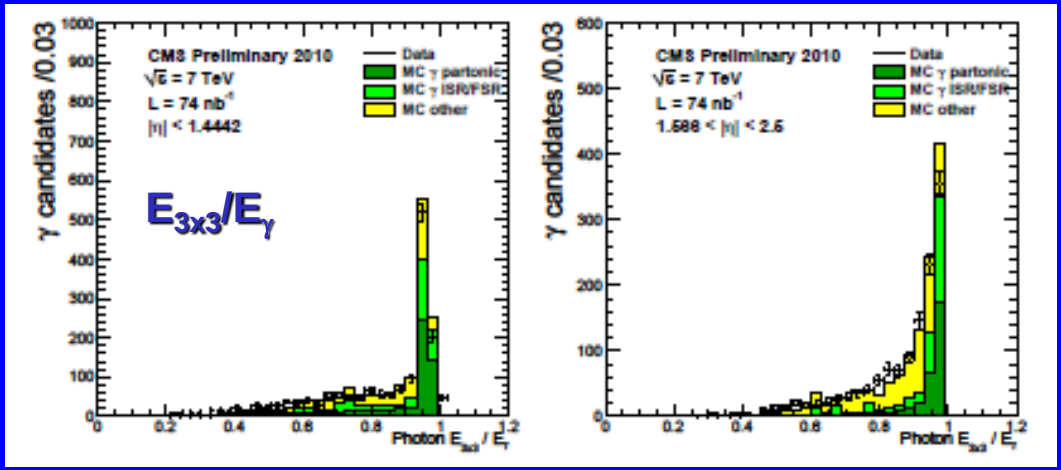
F Corrections: f(η), f(σ[φ]/σ[η]), f(Et, η)

Endcaps:



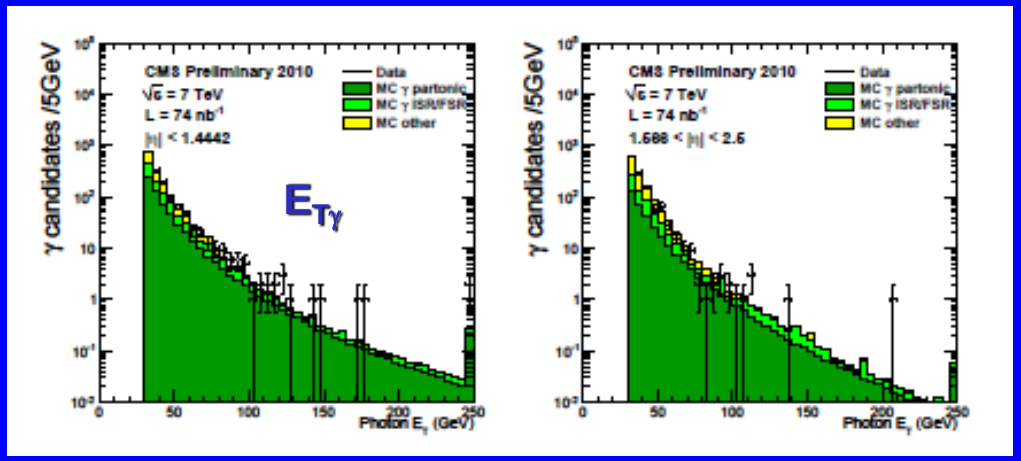
F Corrections: f(σ[φ]/σ[η]), f(Et, η), add Preshower E

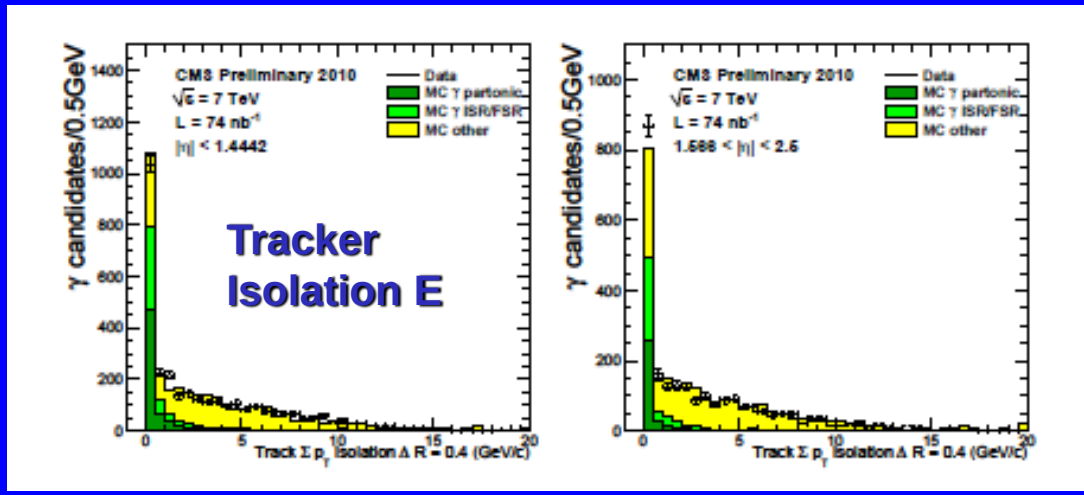
Photon Commissioning in Run 1



Loose Photon Id

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	
$\sigma_{i\eta i\eta}$	0.01	0.03

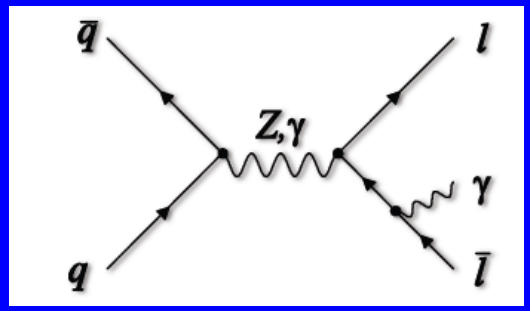




Photon Energy Scale Measurement input to Wγ, Zγ cross-section Measurements

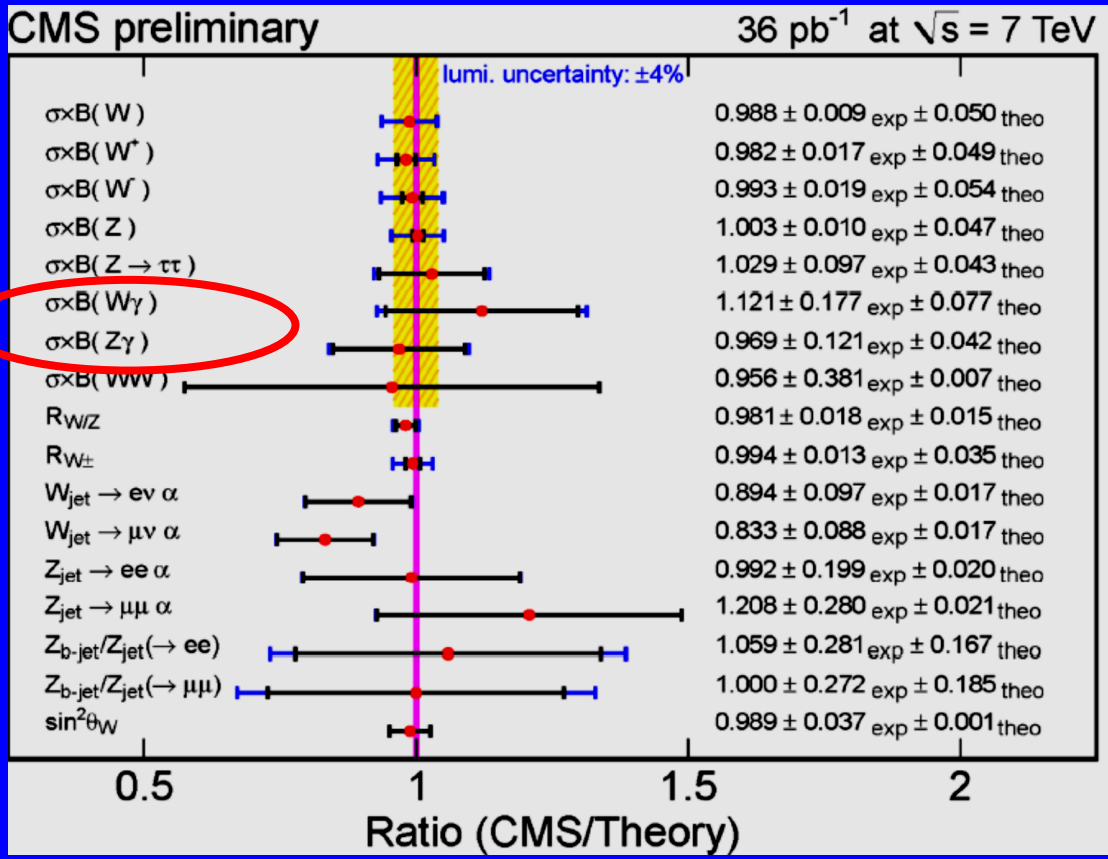
Phys. Lett. B701, 535-555 (2011))

$$\sigma = \frac{N_{\text{Observed}} - N_{\text{Background}}}{A \cdot \epsilon_{\text{MC}} \cdot \rho_{\text{eff}} \cdot \mathcal{L}}$$



Source	Systematic uncertainty	$e\nu\gamma$ Effect on $\mathcal{F} = A \cdot \epsilon_{MC}$	$\mu\nu\gamma$ 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	$ee\gamma$ Effect on $\mathcal{F}$	$\mu\mu\gamma$ 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%



Generators/calculators of SM γγ+X processes

DIPHOX
Binoth, Guillet, Pilon, Werlen, hep-ph/9911340, 2000

RESBOS
Balazs, Berger, Mrenna, Yuan, hep-ph/9712471, 1997

gamma2MC, NLO
Bern, Dixon, Schmidt, hep-ph/0211216, 2002

2gammaNNLO
Catani et al, hep-ph/11102375, 2011

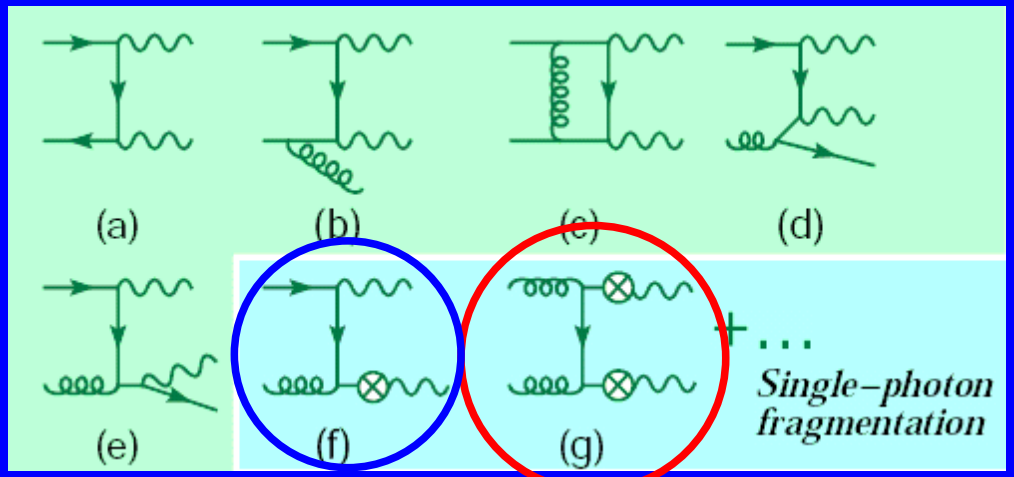
qT SUB : NNLO

FIXED ORDER : NLO

NLO with NNLL Resummation

FIXED ORDER : NLO

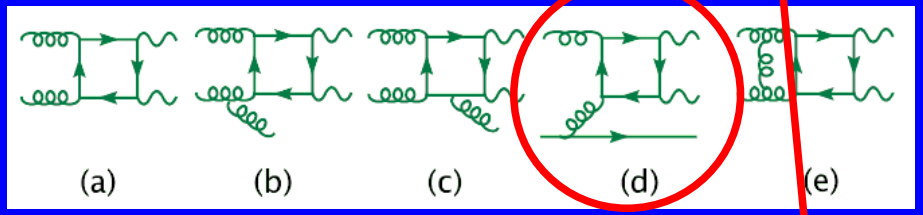
BORN + FRAG (and NLO corrections)



1-frag :
- LO, effectively in Resbos
- NLO in Diphox

2-frag :
DIPHOX only (NLO)

BOX (and NLO corrections)



Resbos only

BORN (up to NNLO corrections)