Photon physics at CMS

03/12/2013 - LAL, Orsay

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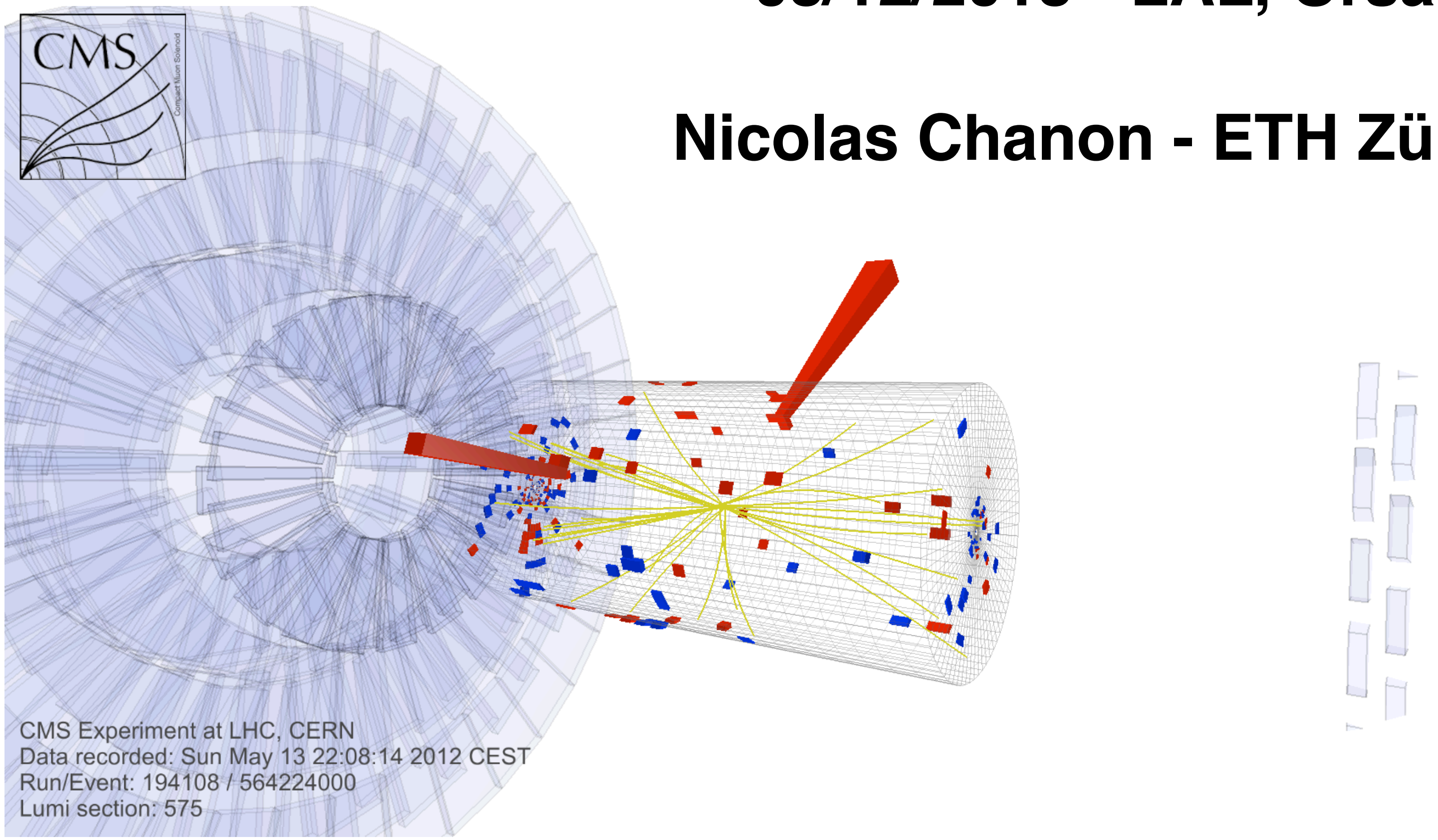


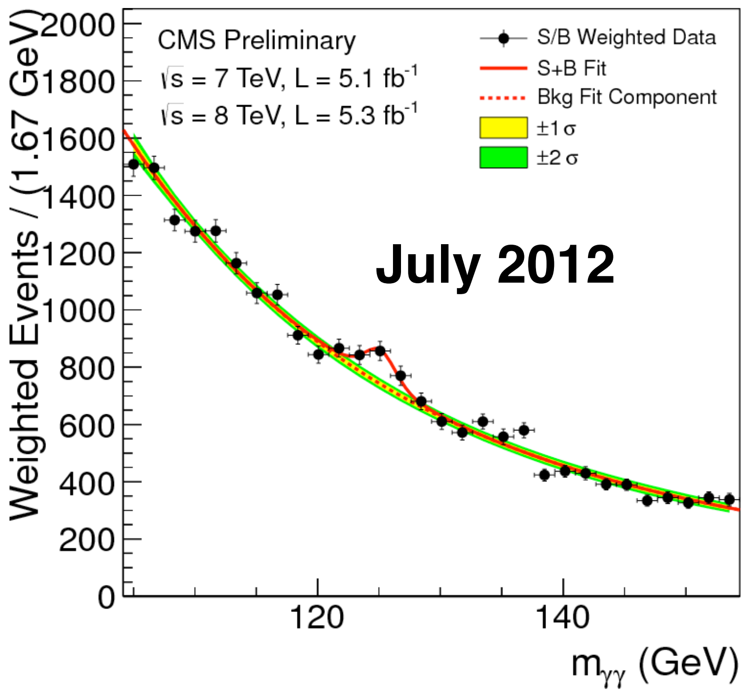
Introduction

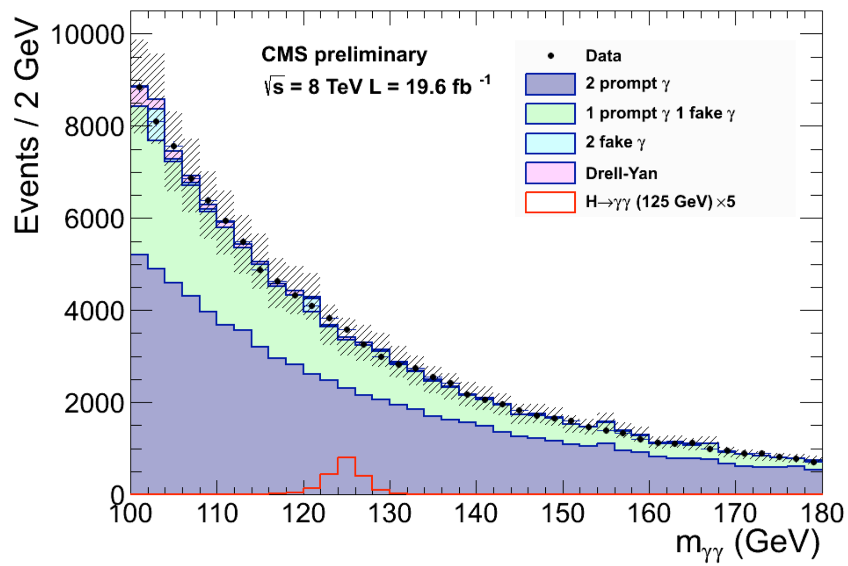
Why photon physics at hadron colliders?

- Photon measurements: important **tests of perturbative QCD**
- Photon data helps to **constrain parton distribution functions**
- γ+jets and γγ processes are **background to Higgs searches and searches beyond the standard model**

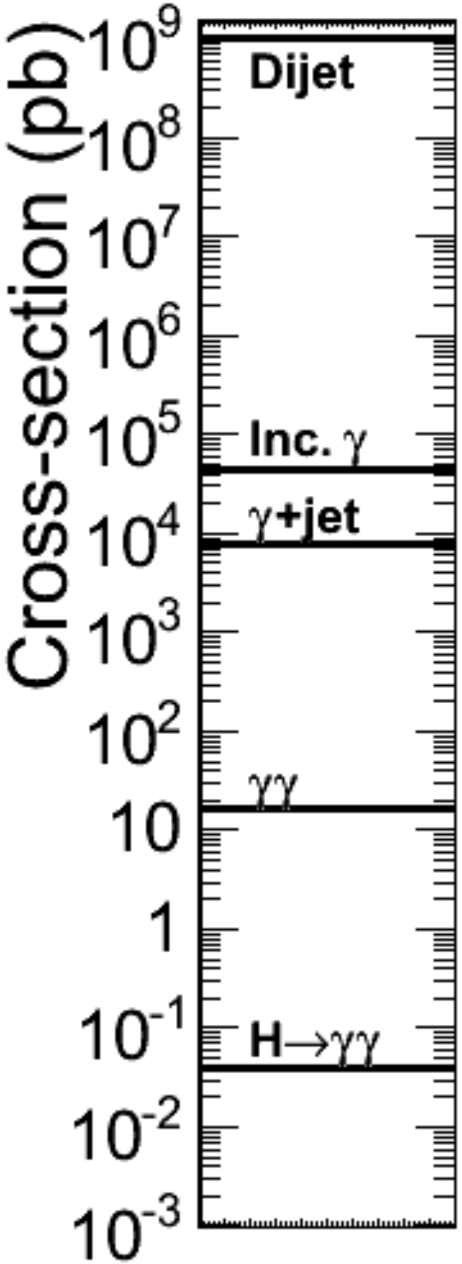
H→γγ channel: major player in the Higgs searches

- Excellent mass resolution thanks to the electromagnetic calorimeter (ECAL)





Photon production cross-sections

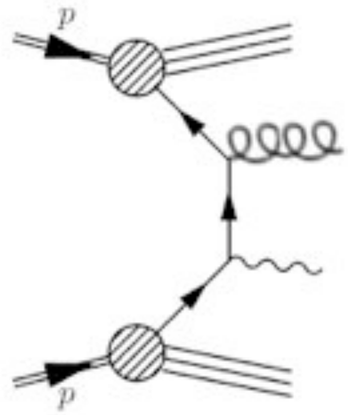


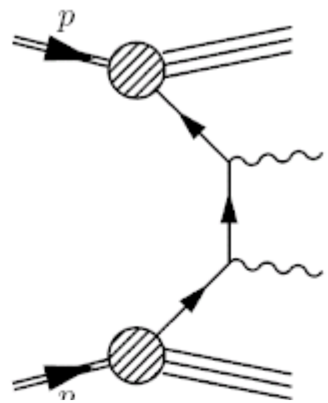
Inclusive photon production

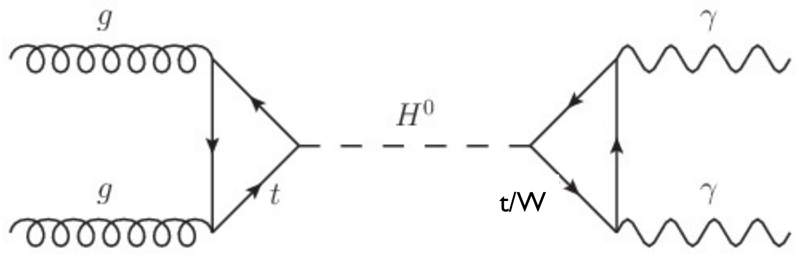
Gamma+jet production

Diphoton production

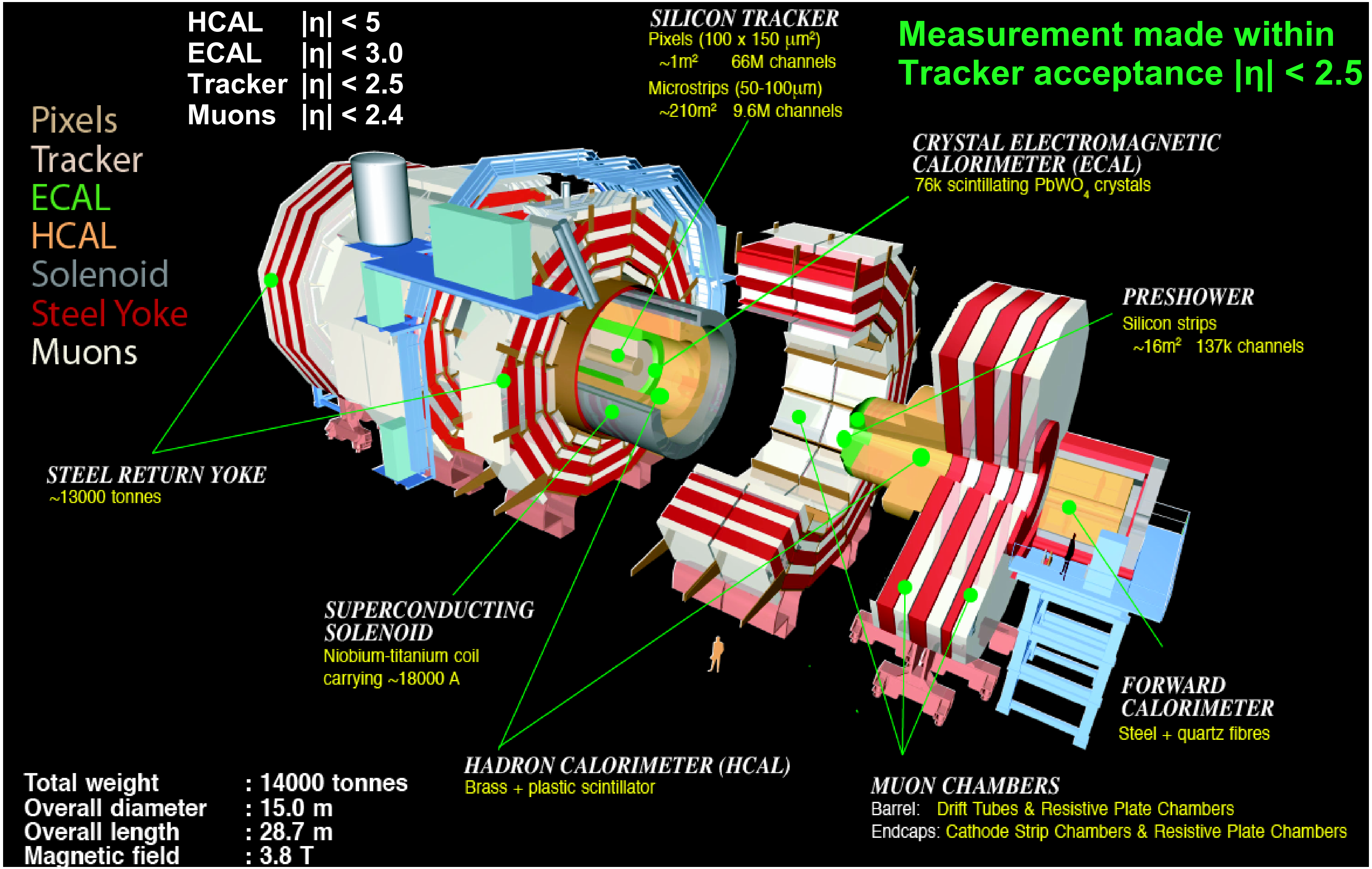
H→γγ searches





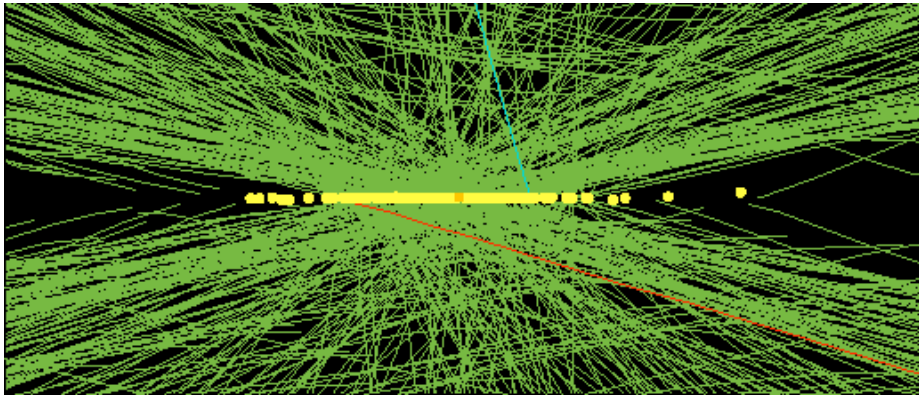


Compact Muon Solenoid (CMS) detector



Luminosity conditions

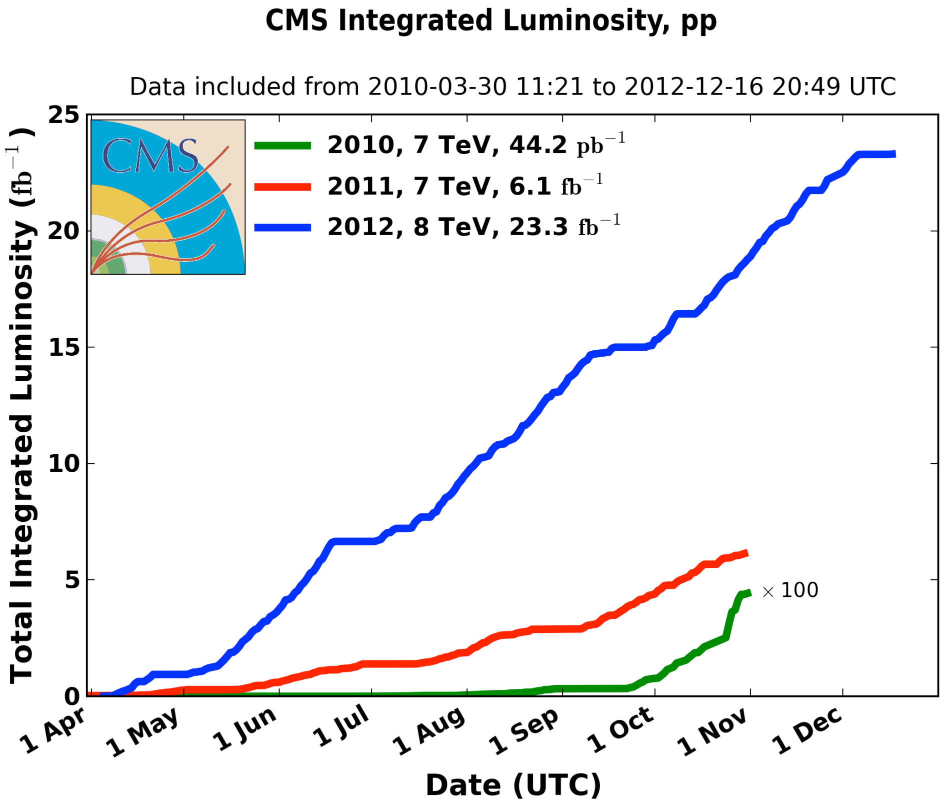
Event with 70 reconstructed vertices (special run)

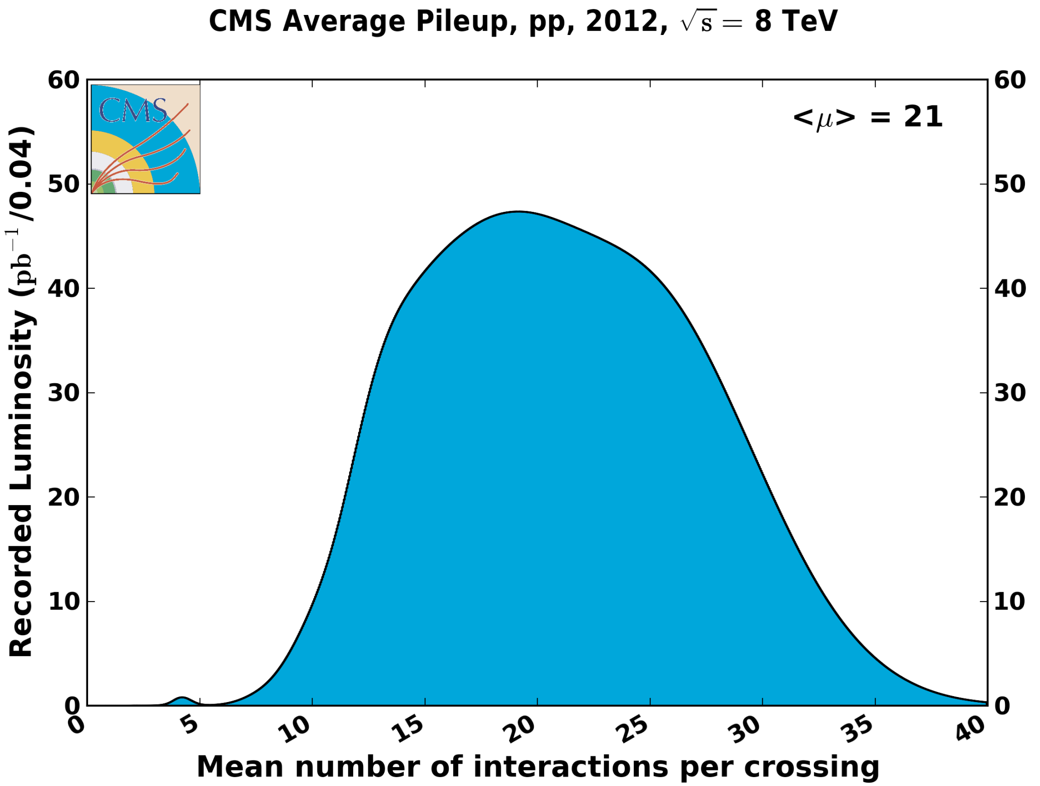


Analyses presented in this talk are using:

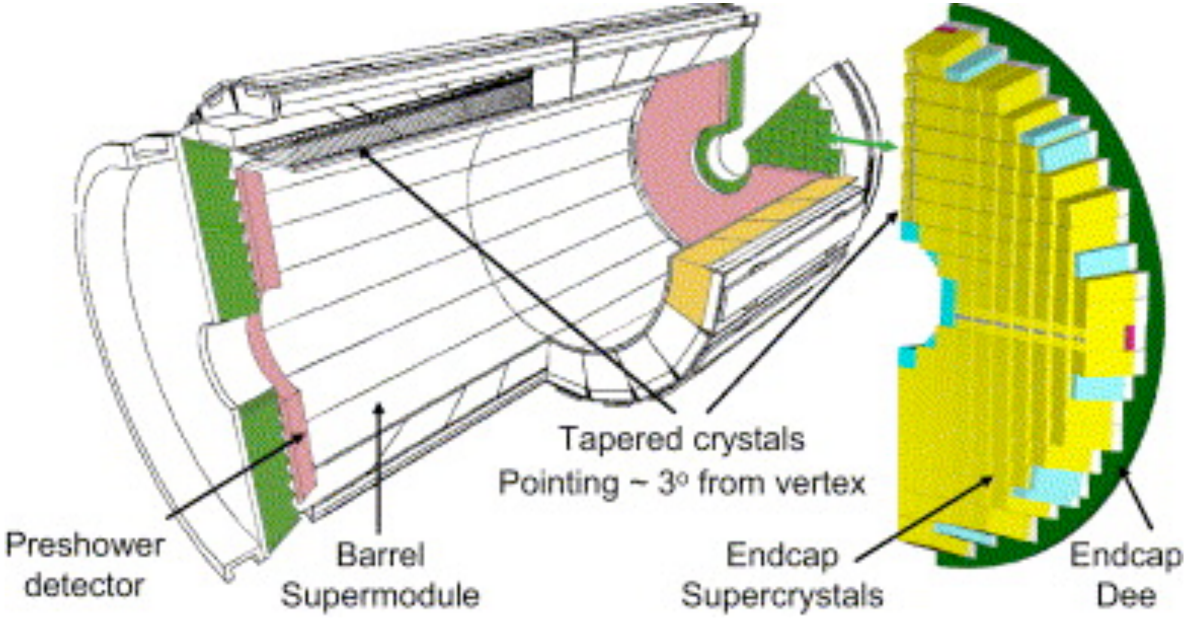
- **5.1 fb-1 of 7 TeV data** in 2011
- **Up to 19.6 fb-1 of 8 TeV data** in 2012

Pileup mean interaction ~21 in 2012 (~10 in 2011)





CMS electromagnetic calorimeter (ECAL)



CMS Electromagnetic calorimeter (ECAL) :

- 75848 $PbWO_4$ crystals
- **Excellent** energy resolution (design: 1% for H→γγ barrel photons)

The **ECAL** is made of scintillating crystals of PbWO4 :

-**Barrel** : 36 "supermodules" with 1700 crystals each (coverage $|\eta|<1.48$)

-**Endcaps** : 268 "supercrystals" with 25 crystals each (coverage $1.48<|\eta|<3.0$)

A **preshower** made of silicon strip sensors is located in front of the endcaps ($1.65<|\eta|<2.6$)

Energy resolution (measured in electron test beam) :

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E(GeV)}} \oplus \frac{b}{E(GeV)} \oplus c$$

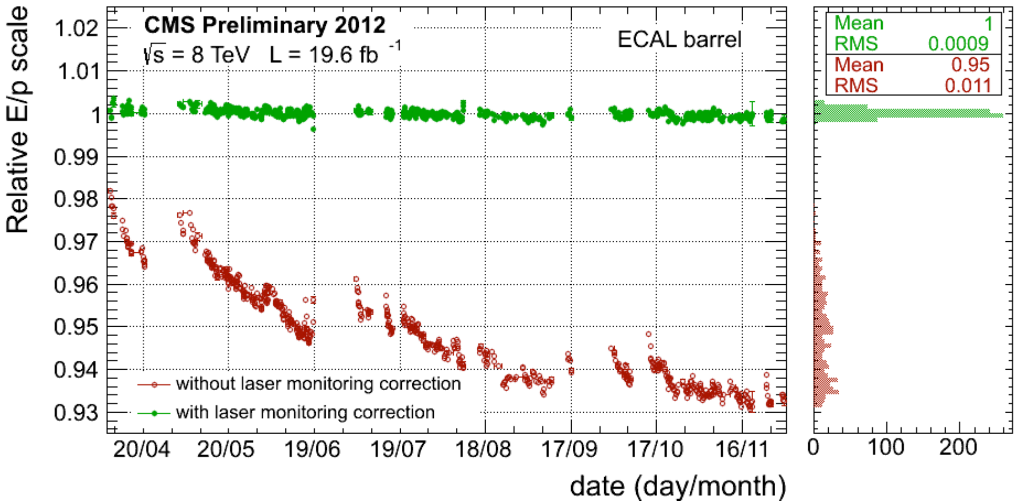
a = 2.8% stochastic term

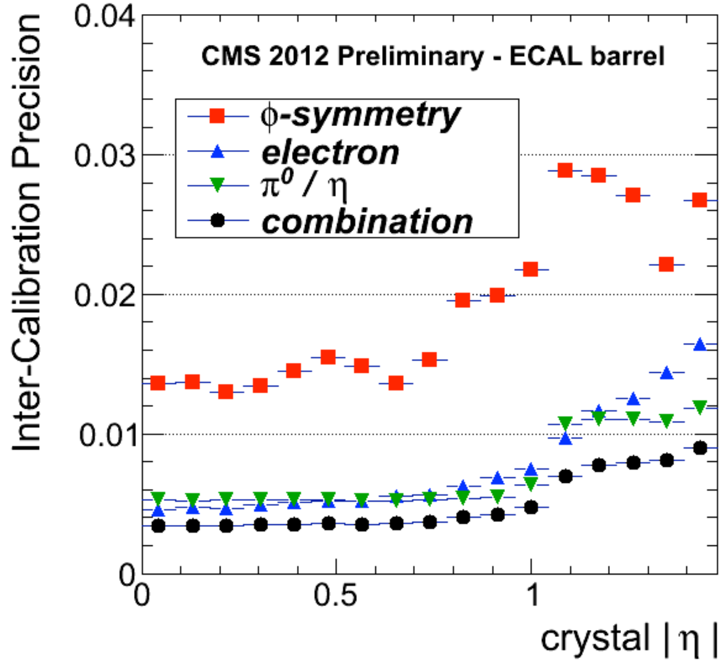
b = 12% noise term

c = 0.3% constant tern

ECAL Calibration

Laser monitoring → **Crystal Intercalibration ($\pi^0 \to \gamma\gamma$)** → **Cluster energy correction (MC)** → **Energy scale ($Z \to ee$)**





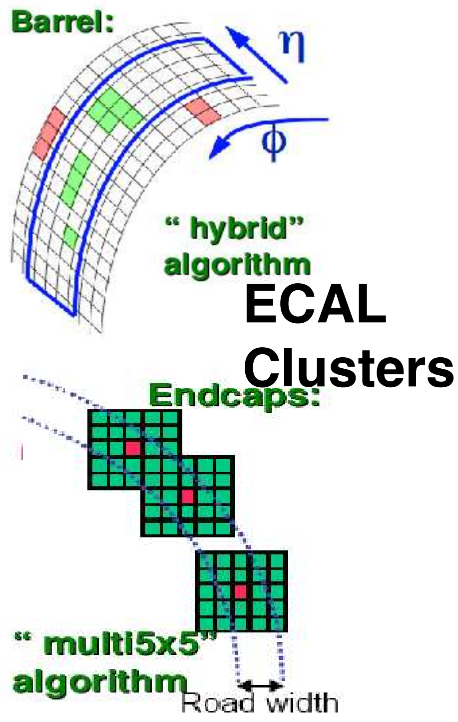
Laser calibration:

- Correct for ECAL crystals **transparency loss due to electromagnetic damage**
- RMS stability after corrections 0.09% (barrel), 0.28% (Endcap)

Inter-calibrations

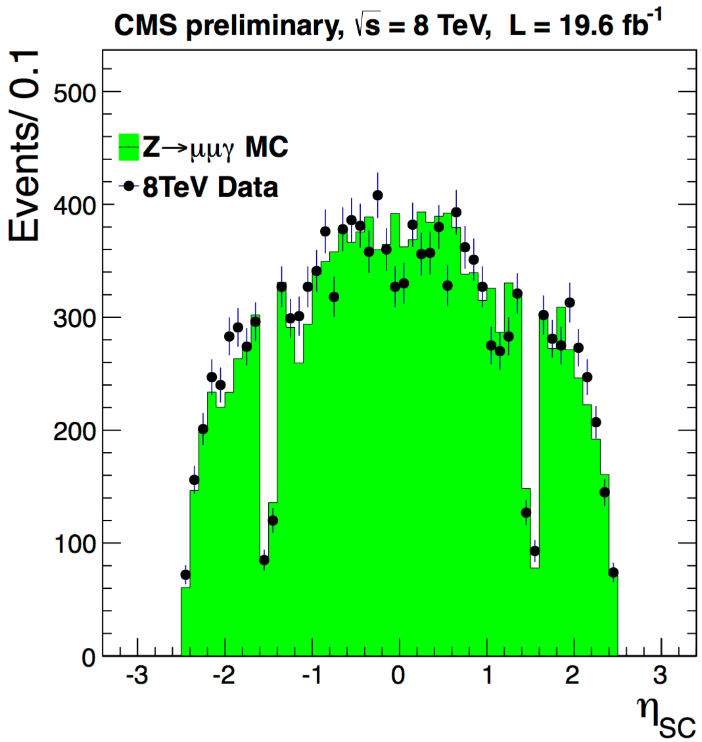
- Correct for response non-uniformity
- Use π^0 and η (mass), **ϕ-symmetry** (minimum bias), **W→eν** (E/p)
- **Precision**: better than **0.5% in central barrel**

Photon reconstruction



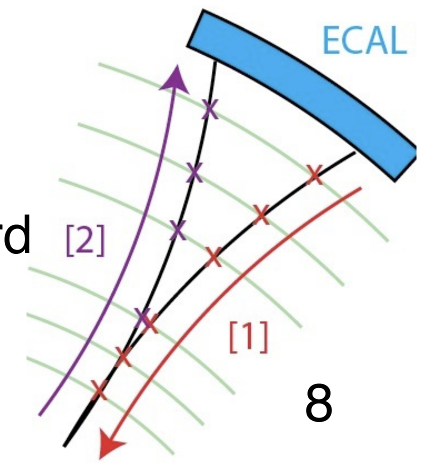
Photon reconstruction:

- **Barrel**: take advantage of the 3.8 T magnetic field which bends the charged particles trajectories in the electromagnetic shower
- **Endcap**: merge contiguous 5x5-crystal matrices around the most energetic crystals
- **Reconstruction efficiency 98%** (outside of Barrel-Endcap gap)

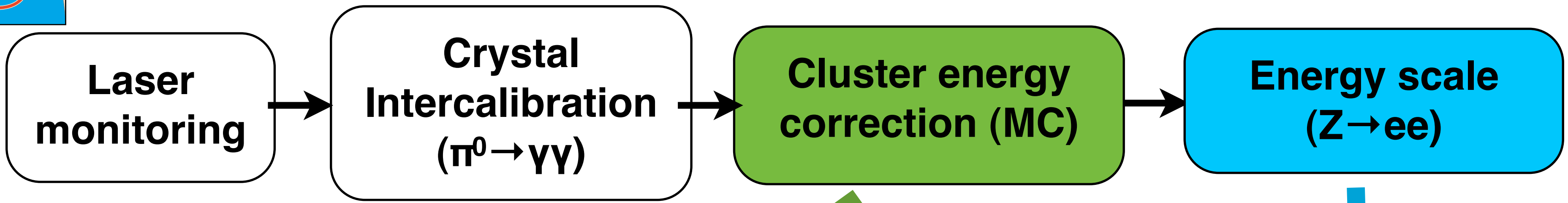


Electron rejection: the energy deposit should not be matched to hits in the pixel detector.

Converted photons:
- Start from ECAL cluster
- Track-finding proceeds inward outward taking into account bremsstrahlung
- Select e+/e- pair with best vertex fit



Photon Energy corrections

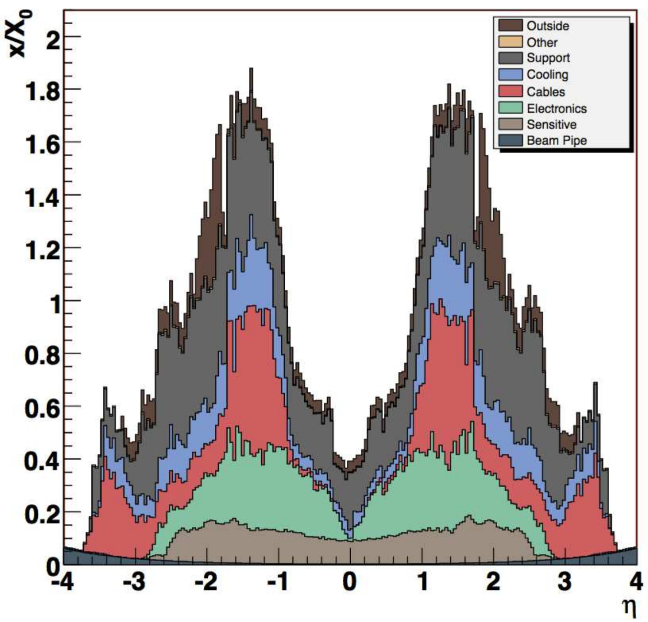


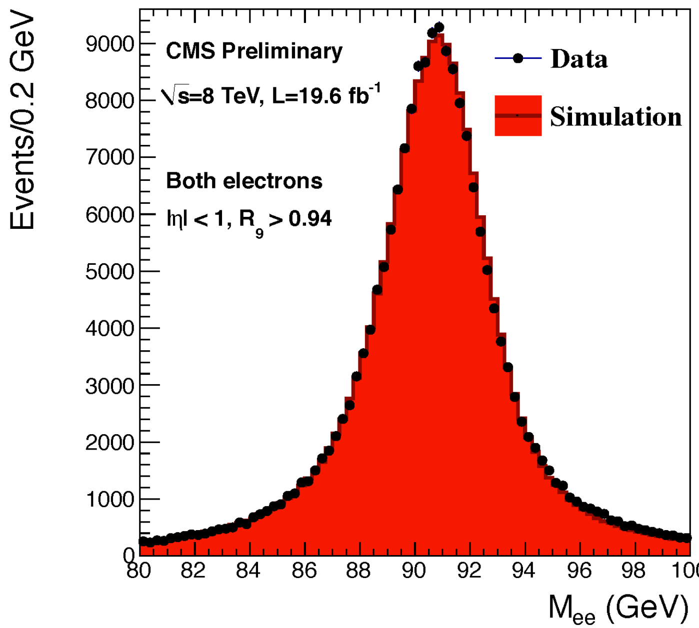
Cluster energy corrections

- Correct for **energy loss** in the **material** upstream ECAL and in ECAL cracks
- Using energy, shower shape and geometry variables
- Energy regression: 1-2% mass resolution (depends on categories)

Energy scale:

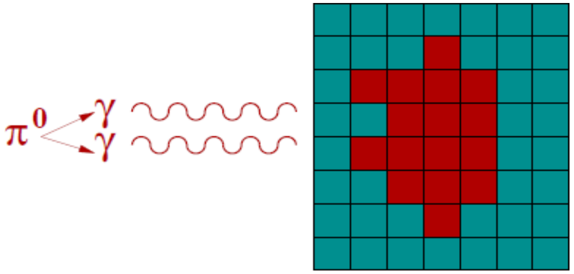
- Correct for data/MC residual differences in scale and resolution using Z mass shape
- Stable along data-taking period

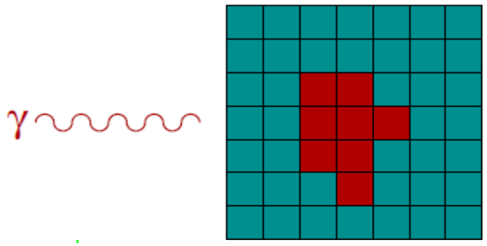




Photon identification: shower shapes

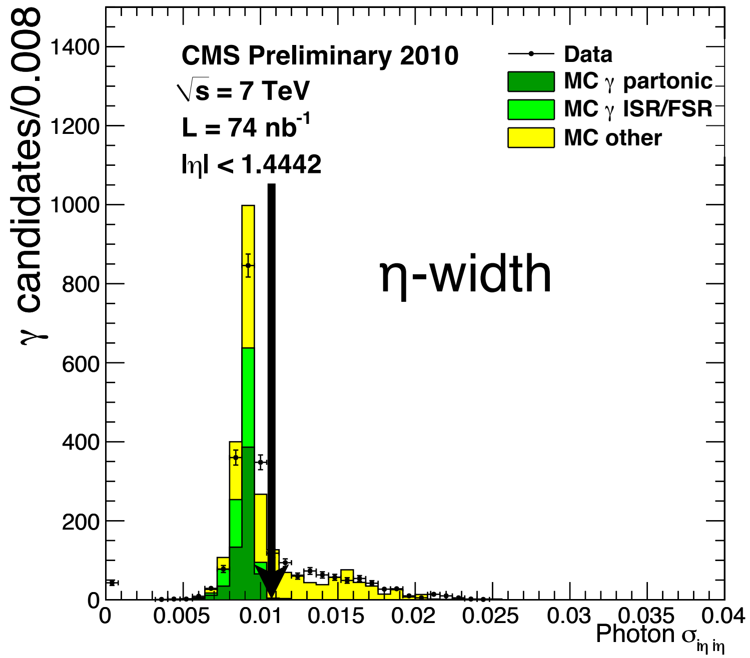
Photon background: boosted neutral mesons (π^0...) in jets reconstructed as a single photon (“fake”)
=> need to be reduced, and then statistically subtracted

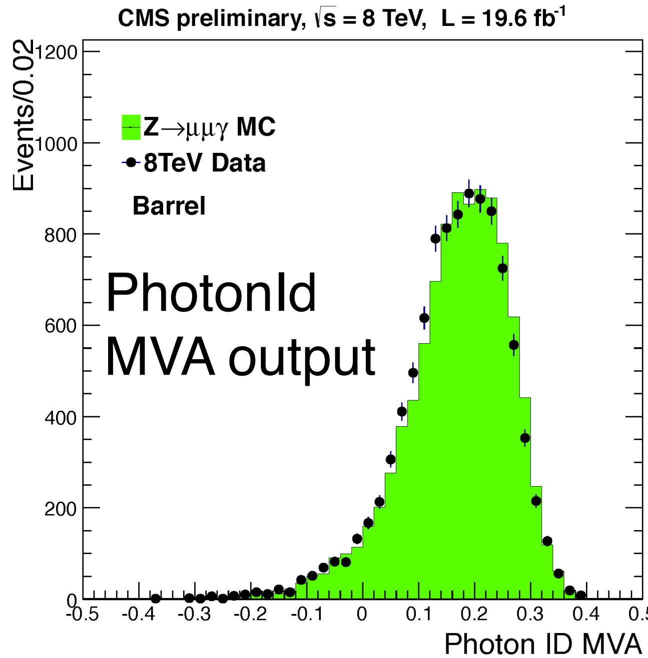




Transverse shape of the energy deposits in the ECAL should be compatible with a single photon shower

- Measurements: Use **η-width** of the energy deposit
- Higgs searches: use **MVA** method

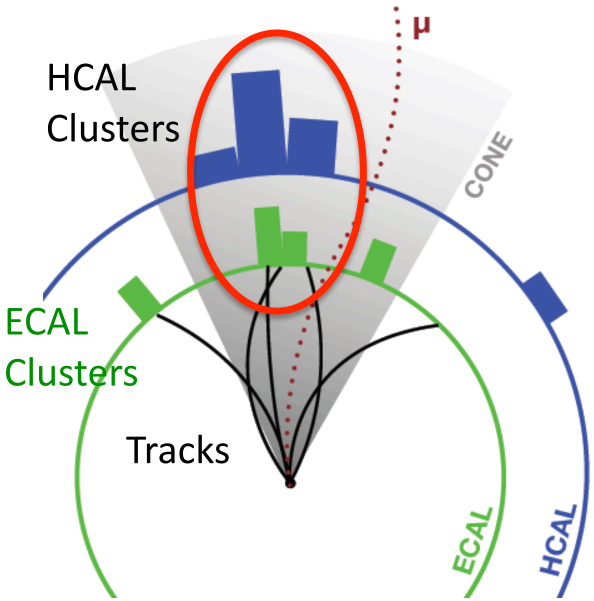


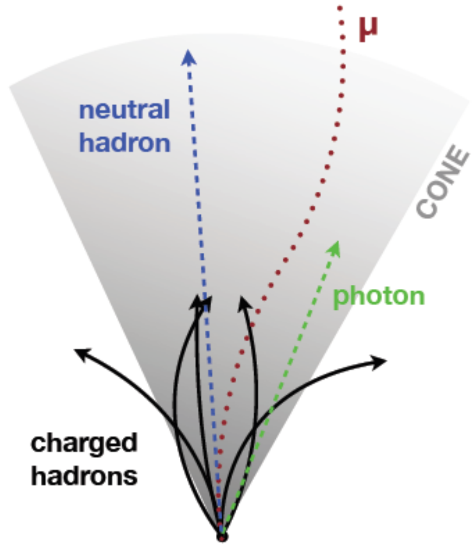


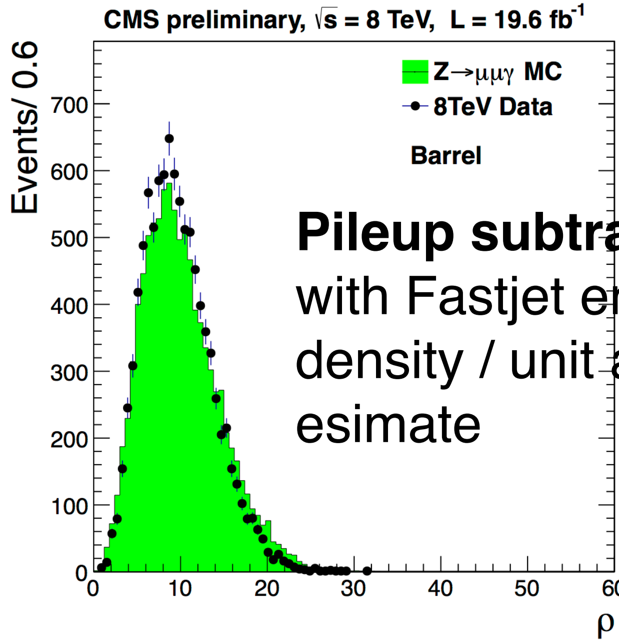
Photon identification: isolation

Particle-Flow algorithm: Aim at reconstructing all particles using information of all sub-detectors

Clusters and tracks <-> Particles







Pileup subtraction with Fastjet energy density / unit area esimate

Detector-based Isolation:

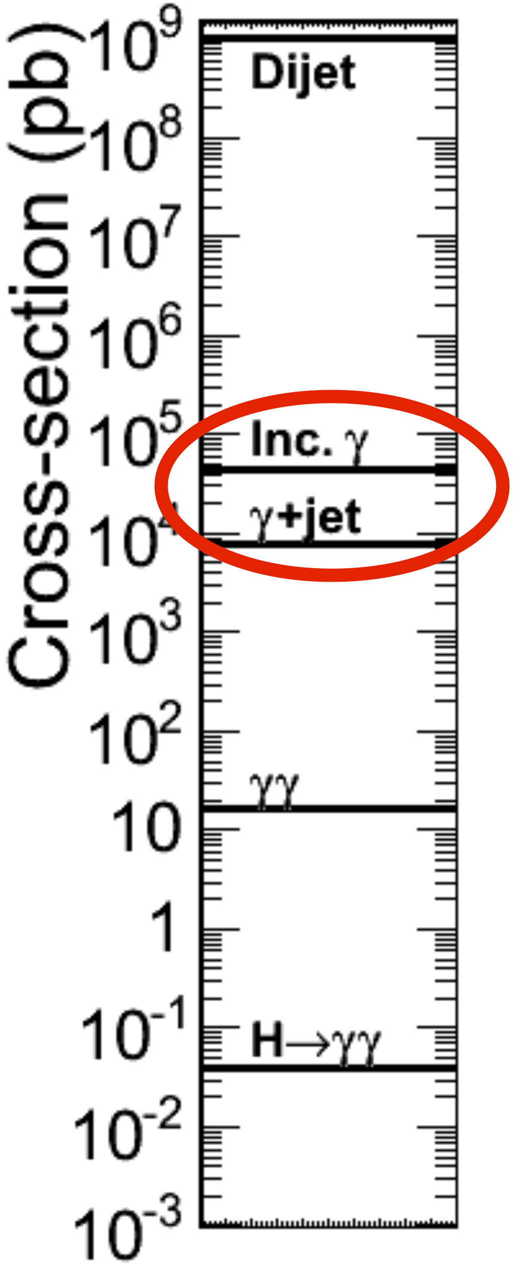
(Early analyses, mostly 2011)

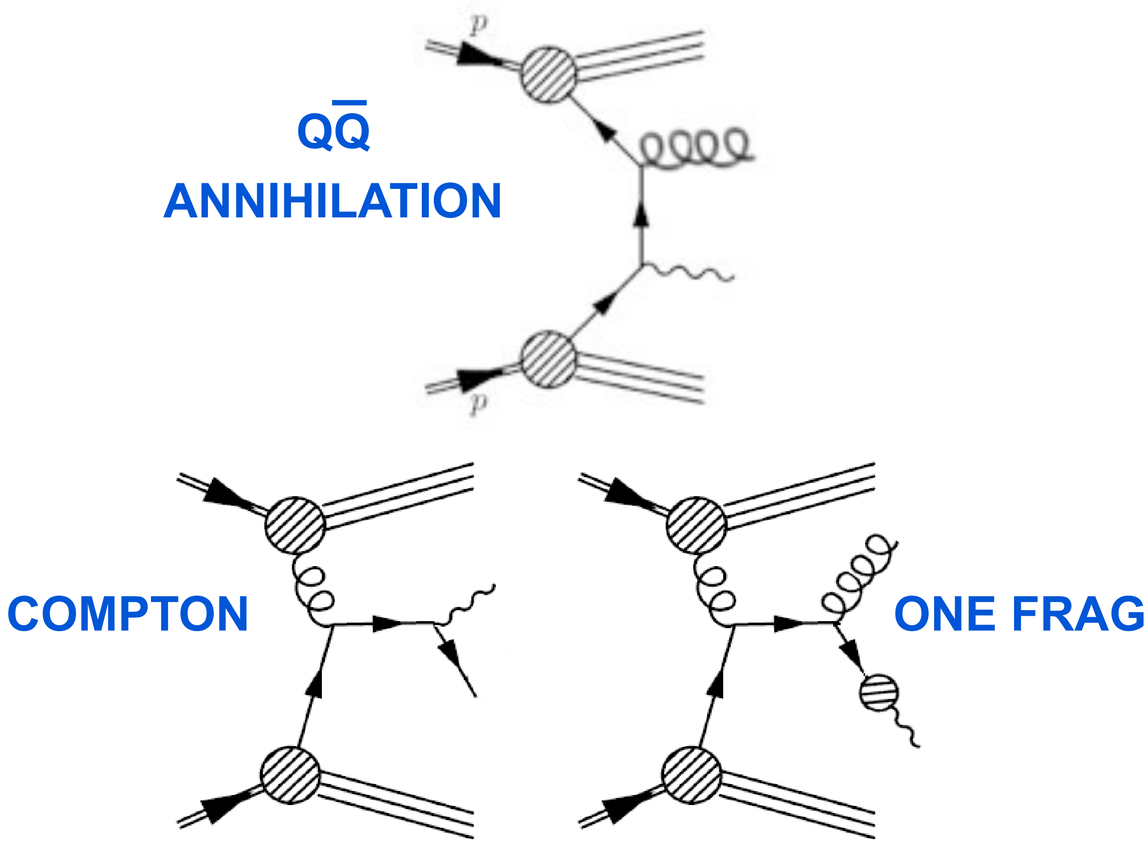
- In a cone (typically $\Delta R<0.4$) around the photon, use sum E_T of ECAL, HCAL and p_T of charged particles measured in the tracker

Particle-Flow isolation:

- No double counting of energy (tracker/HCAL)
- Better performance than detector-based isolation
- Exact photon footprint removal event-by-event

Inclusive isolated photon and γ+jets cross-section measurement





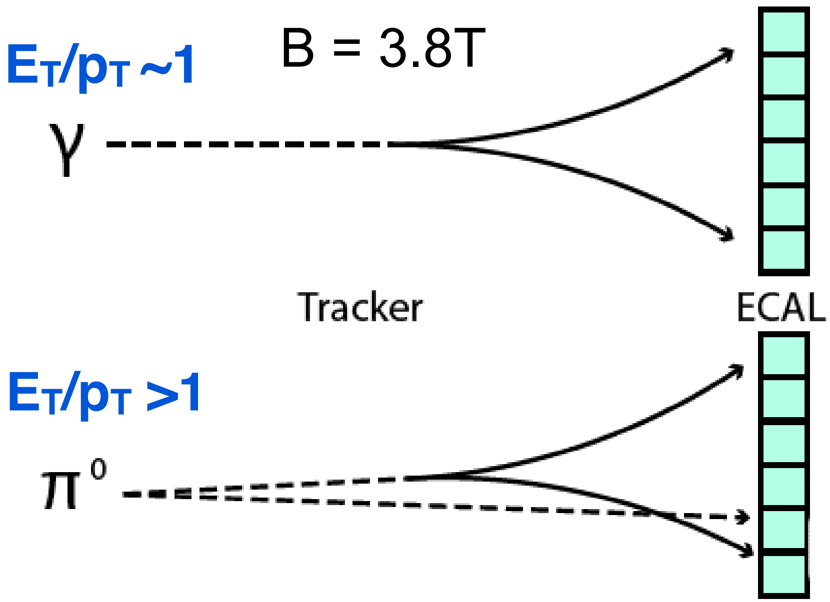
Inclusive isolated photon production

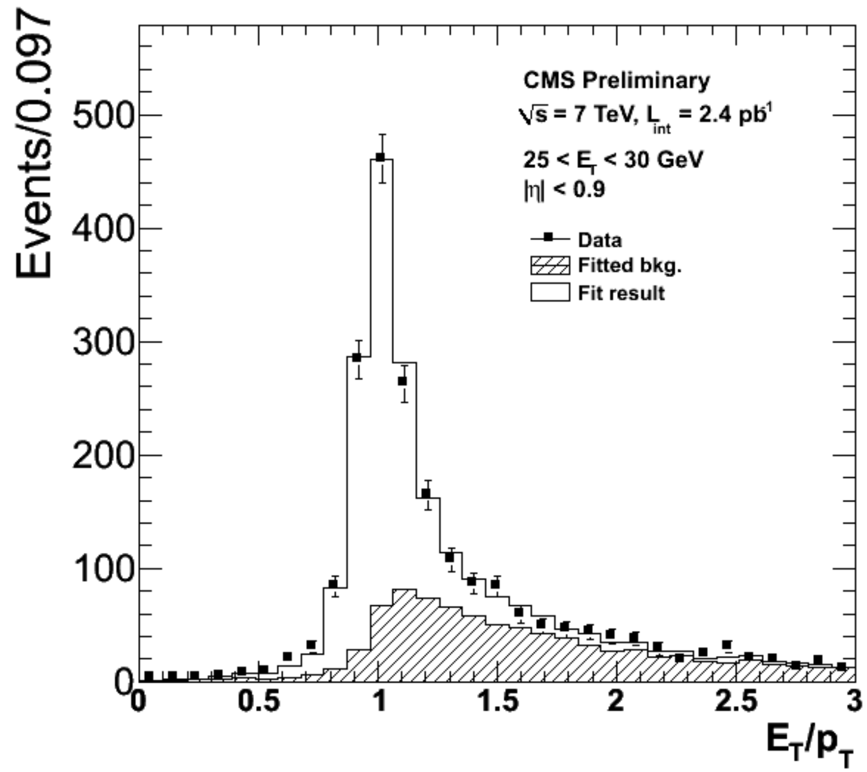
QCD-10-037 (Phys. Rev. D 84, 052011 (2011)), **36pb^{-1} at 7 TeV**

Photon conversion method : competitive at low E_T

Use the shape of E_T/p_T variable (two-tracks conversions only):

- E_T transverse energy measured in ECAL,
- p_T transverse momentum of the e^+/e^- pair measured in tracker.



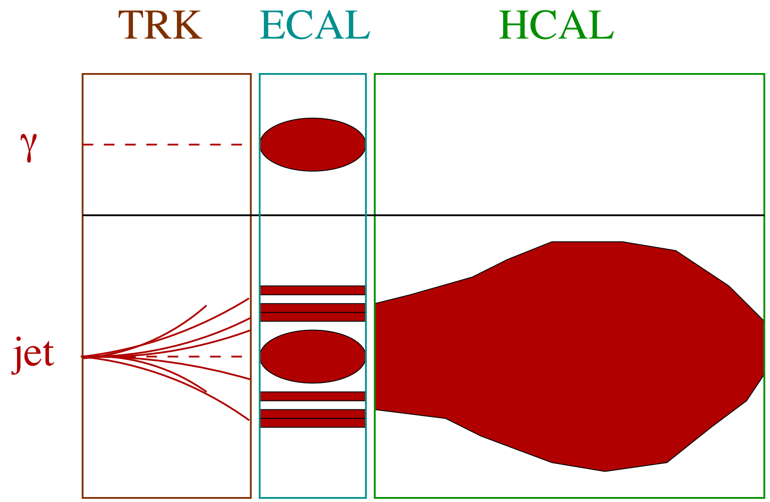


Extract the **signal yield** with a binned **likelihood fit** :

- Signal and background pdf from Monte-Carlo
- Background shape uncertainties: from isolation and cluster shape sidebands in data

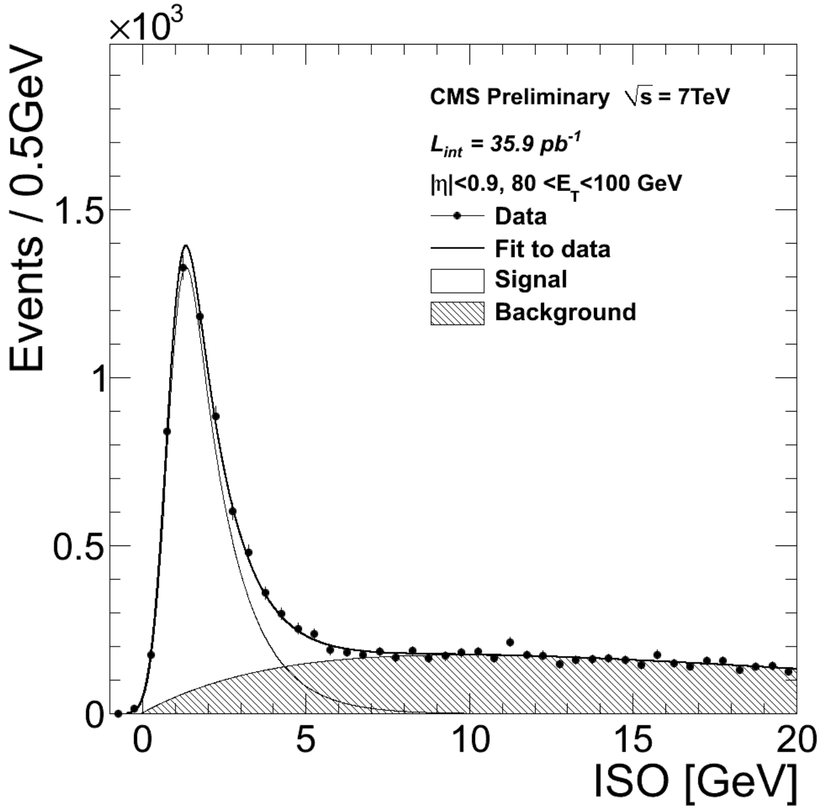
Inclusive isolated photon production

QCD-10-037 (Phys. Rev. D 84, 052011 (2011)), 36pb^{-1} at 7 TeV



Isolation method : competitive at high E_T

- Use **ISO**, the **sum of the isolation energies** measured in the ECAL, HCAL and tracker
- Signal photons have low ISO values



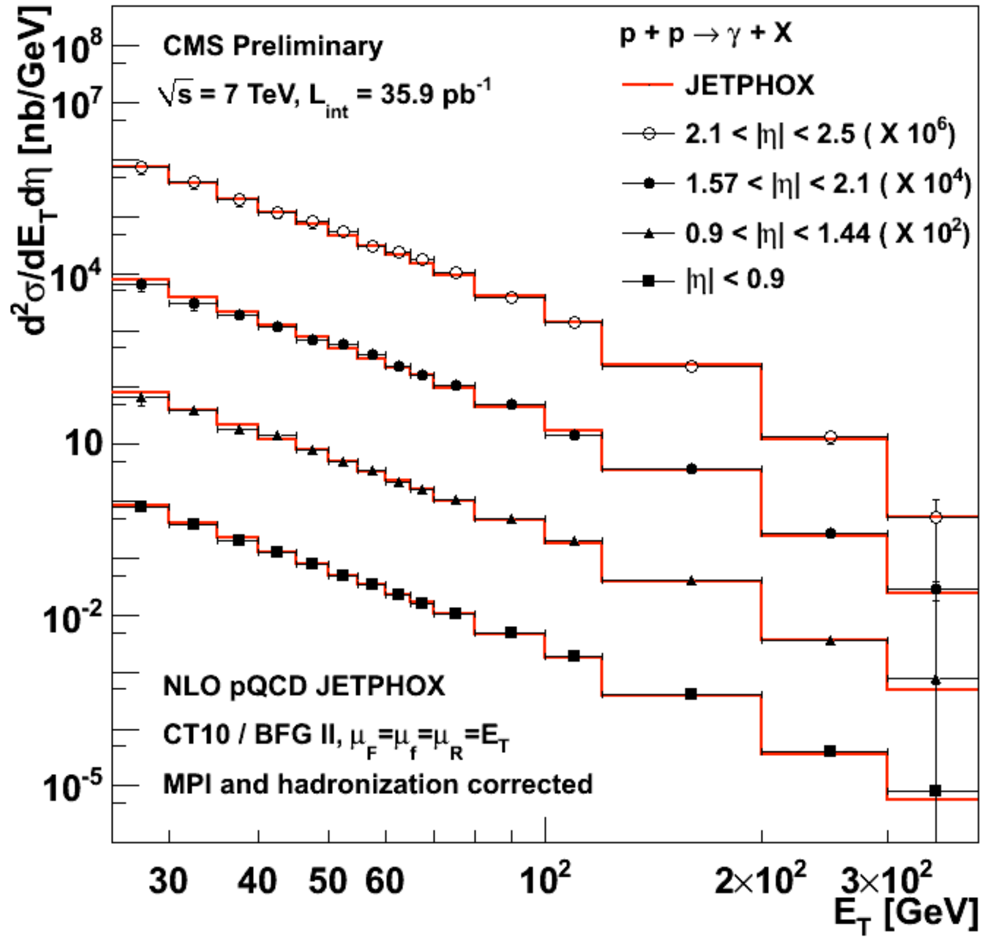
Extract the **signal yield** with an unbinned **likelihood fit** :

- Signal and background pdf estimated from Monte-Carlo and controlled with data
- **Signal shape** corrected for data / Monte-Carlo difference in Z→ee events
- **Background shape** constrained with **shower shape sidebands** in data

Inclusive isolated photon production

$$d^2\sigma/dE_T d\eta = N^\gamma \cdot \mathcal{U}/(L \cdot \epsilon \cdot \Delta E_T \cdot \Delta\eta),$$

- **Isolation and conversion results** are **statistically combined** with the BLUE method (Best Linear Unbiased Estimate)
- **NLO predictions for isolated photon with JetPhox**, corrected for multiple parton interaction and hadronization effects (estimated with Pythia, ~0.97%)



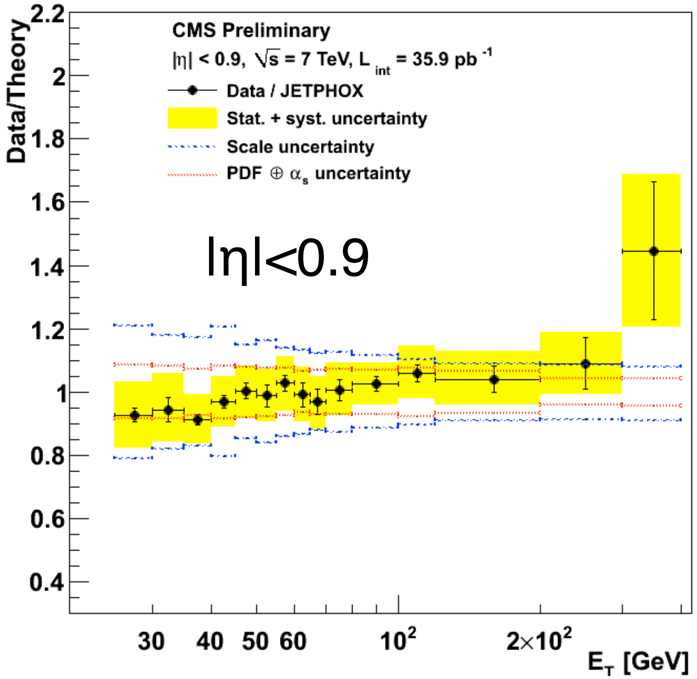
Agreement between data and theory in the whole η and E_T range considered

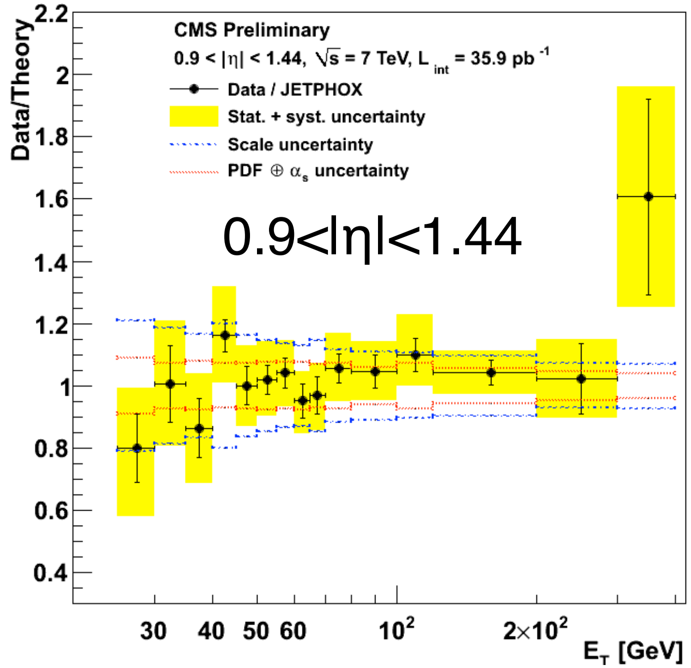
Data / theory comparison

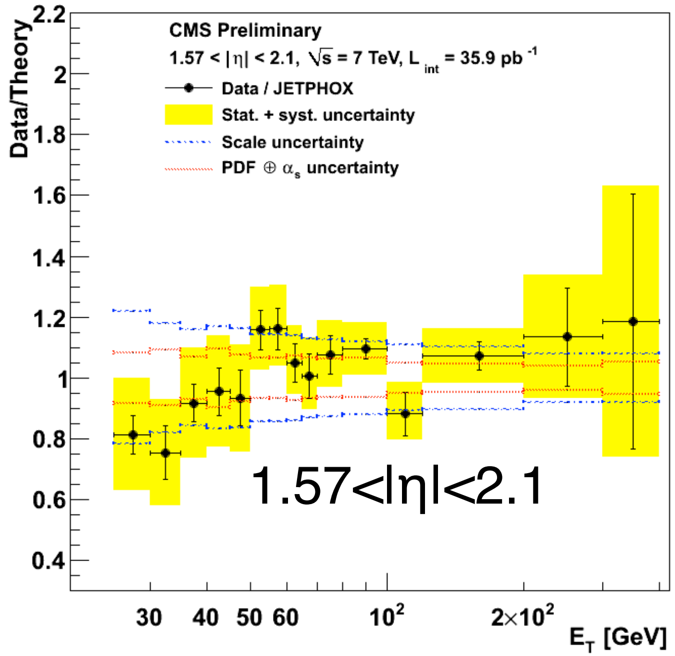
- **Measurement driven by conversion method at low E_T and by isolation method at high E_T**

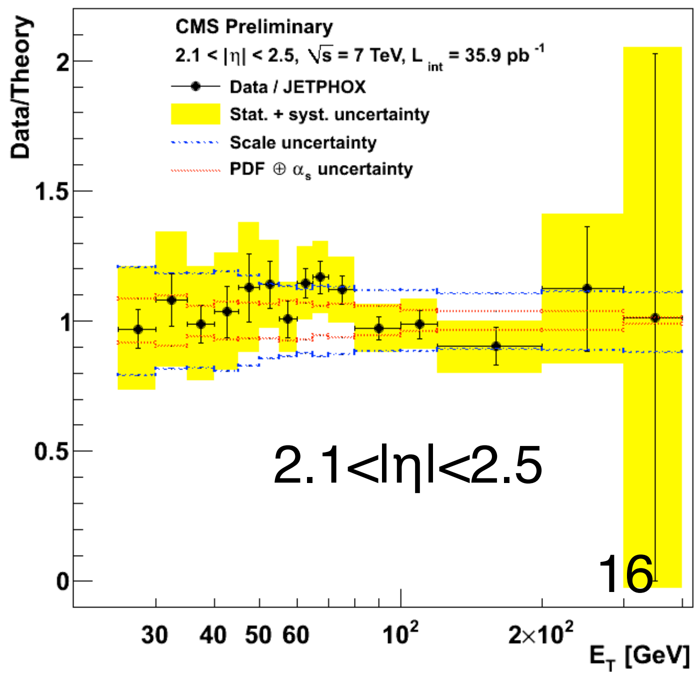
- Data below prediction in the low E_T region, agreeing within uncertainties

- Largest theoretical uncertainty from renormalization / factorization / fragmentation scales

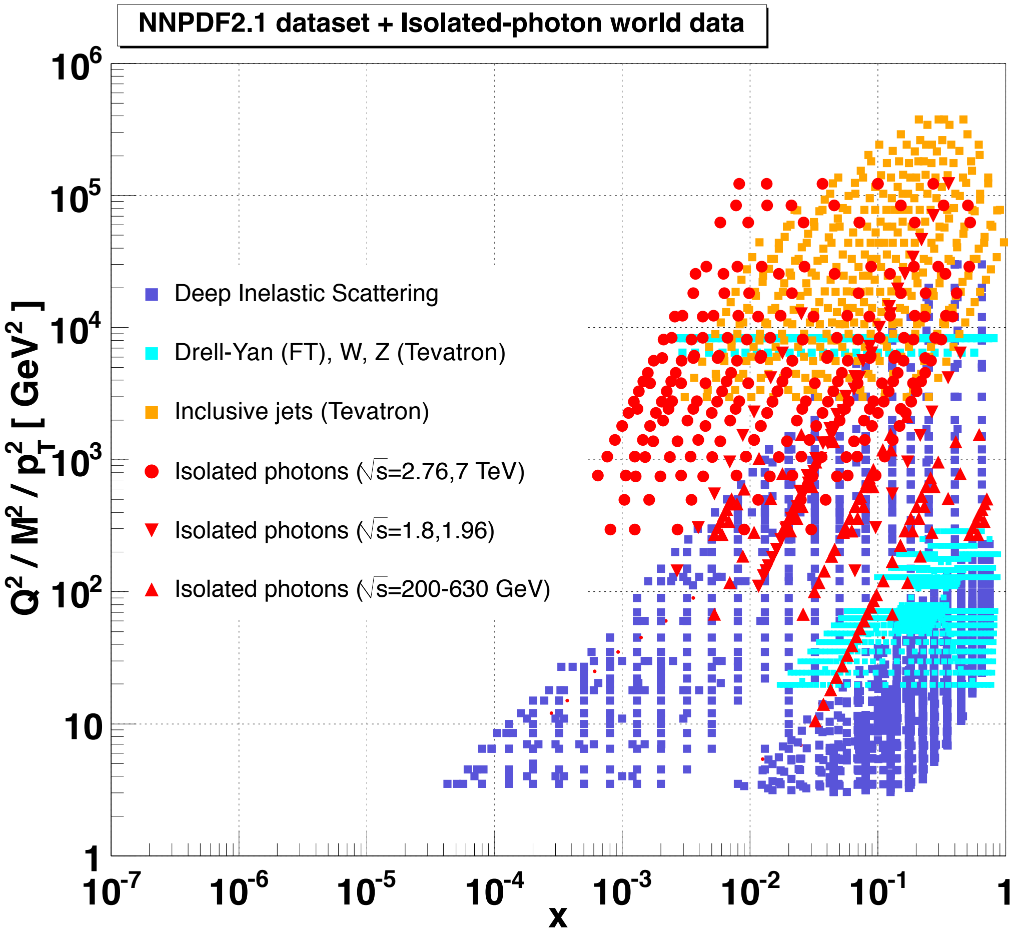






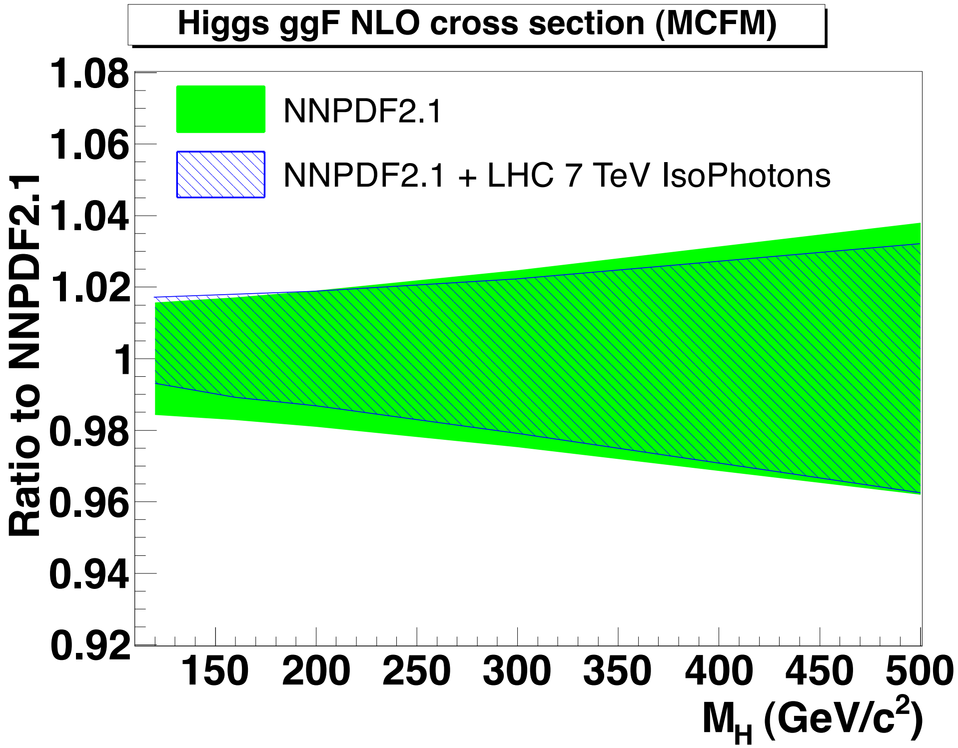


LHC Photon data in PDFs



arxiv:1202.1762 **(D'Enterria, Rojo)**

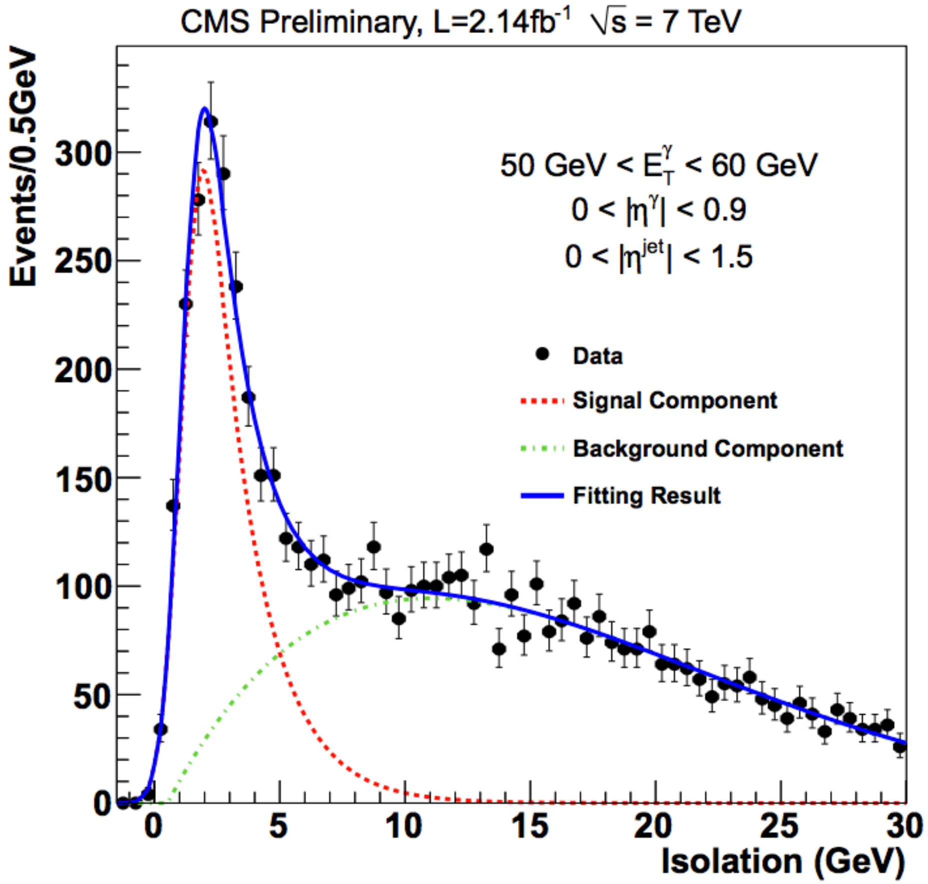
- Including LHC photon measurements in pdf fits helps to constrain **gluon pdf** relatively high Q, intermediate x region
- **Improve pdf uncertainty** on Higgs cross-section by 20%
- See also *arXiv:1212.5511*



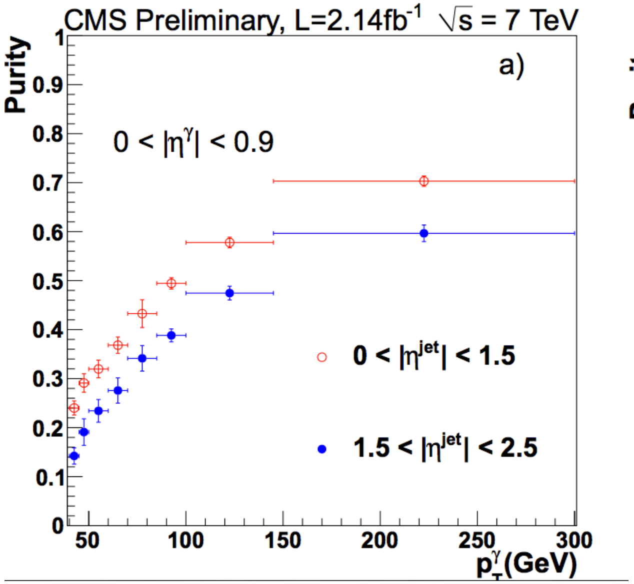
γ+jets triple differential cross-section

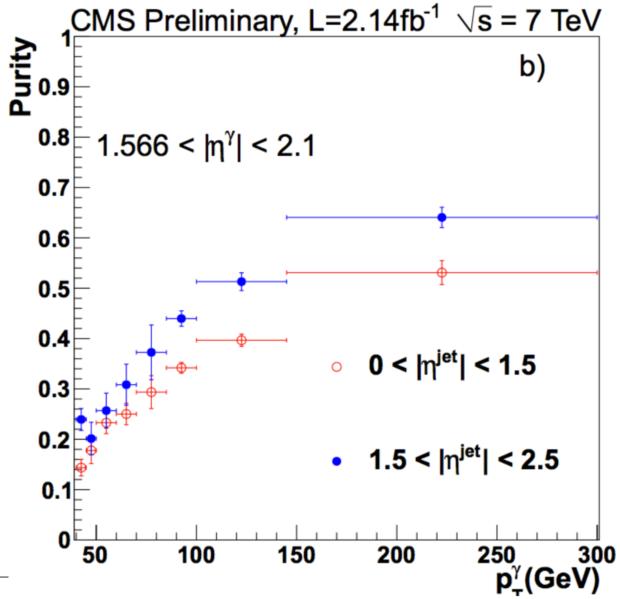
QCD-11-005 (arXiv:1311.6141), 2.1fb^{-1} at 7 TeV

- Acceptance: **$E_{T\gamma}$ > 40 GeV, p_{Tj} > 30 GeV**
- Performed in **2 jet η regions and 4 photon η**
- **Selection**: shower shape requirement and HCAL/ECAL energy < 0.05
- **Efficiency: >90% (|η|<0.9)** to >70% (2.1<|η|<2.5)
- Measuring **isolated photons with very loose isolation** requirement



- Uses **Photon Isolation method** (sum of ECAL, HCAL, tracker isolation)
- Background from **shower shape sidebands**



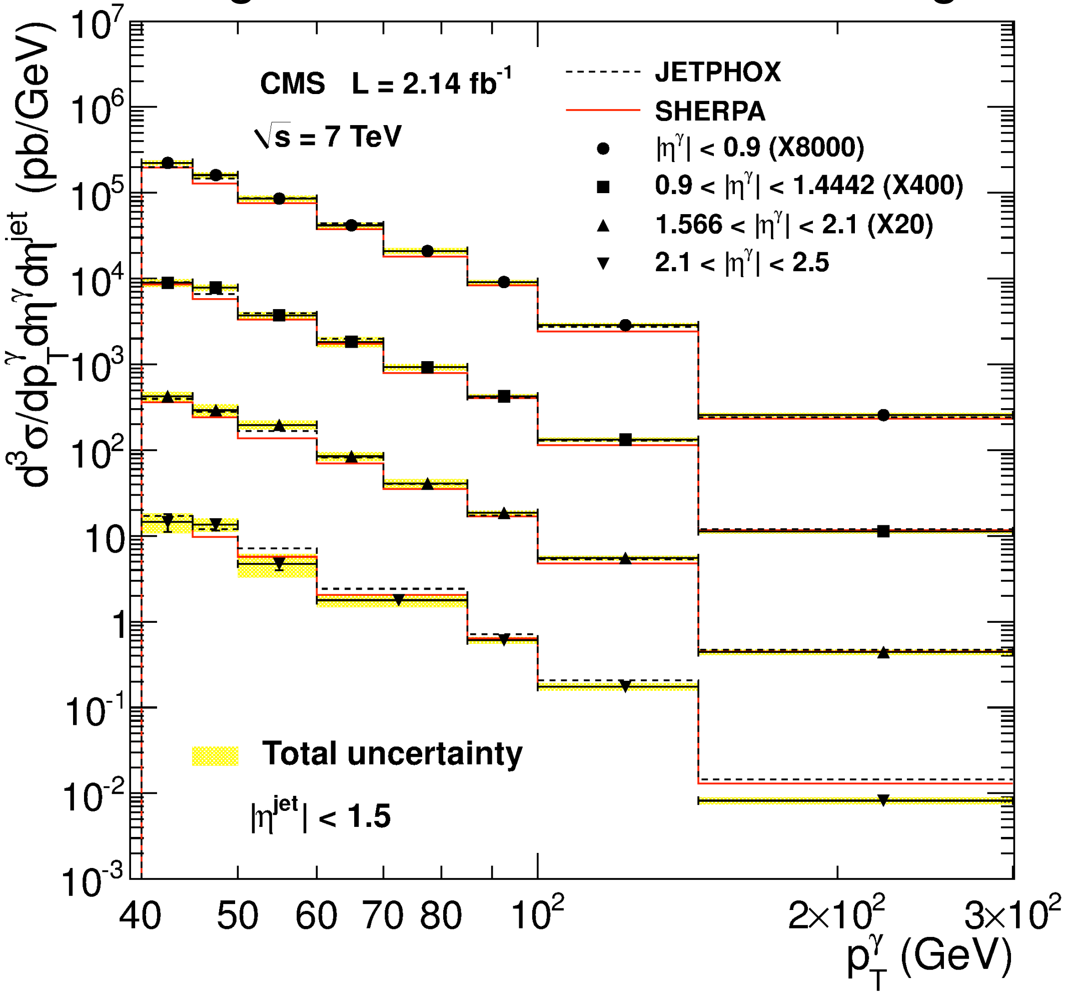


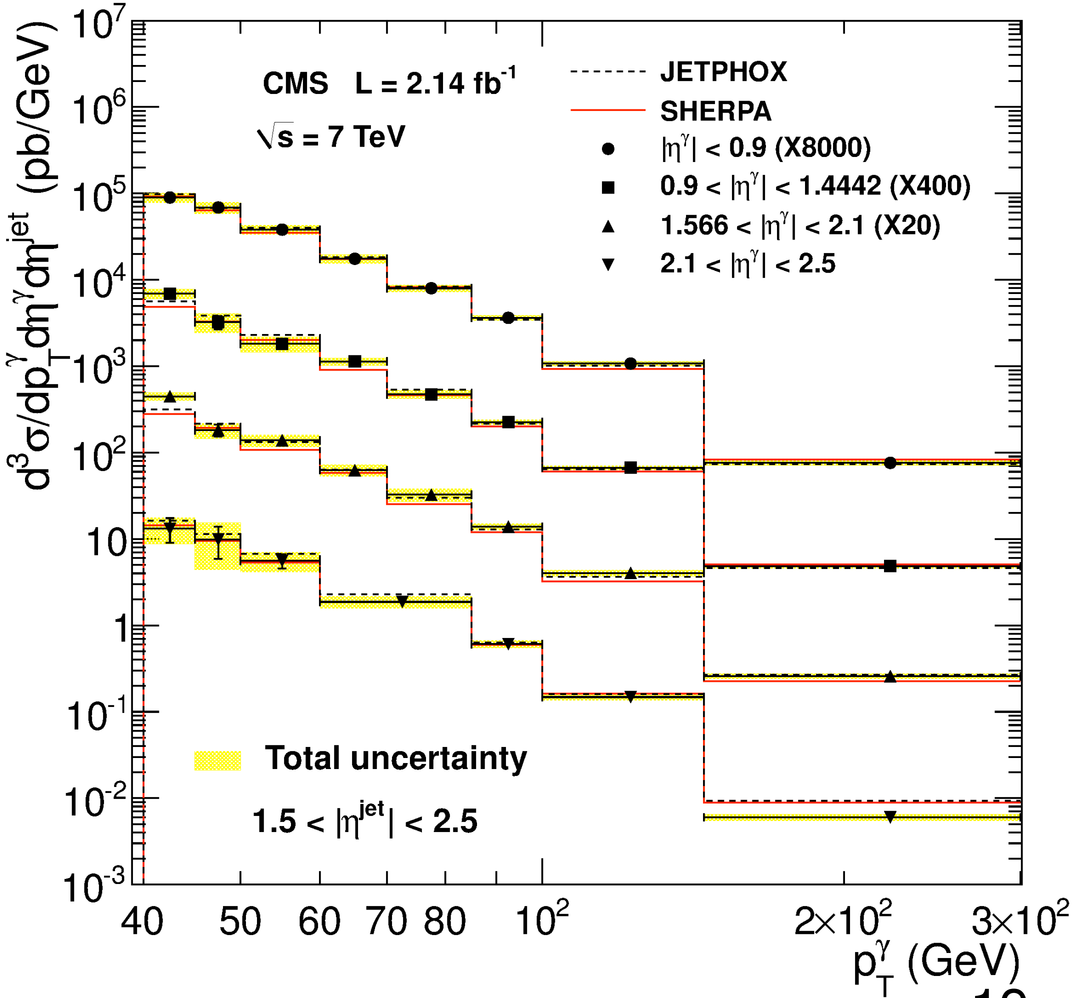
γ+jets triple differential cross-section

QCD-11-005 (arXiv:1311.6141), 2.1fb^{-1} at 7 TeV

Comparison with theory:

- **Jetphox** at **NLO**, **Sherpa** with **γ+jet+up to 3 extra-jets at LO**
- Good agreement over 7 orders of magnitude





γ+jets triple differential cross-section

QCD-11-005 (arXiv:1311.6141), 2.1fb^{-1} at 7 TeV

- Also measured **triple differential cross-section ratios** for various **jet orientations with respect to the photons**

- In general, **good agreement** between data and theory predictions

$$\frac{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}<0}{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}>0}$$

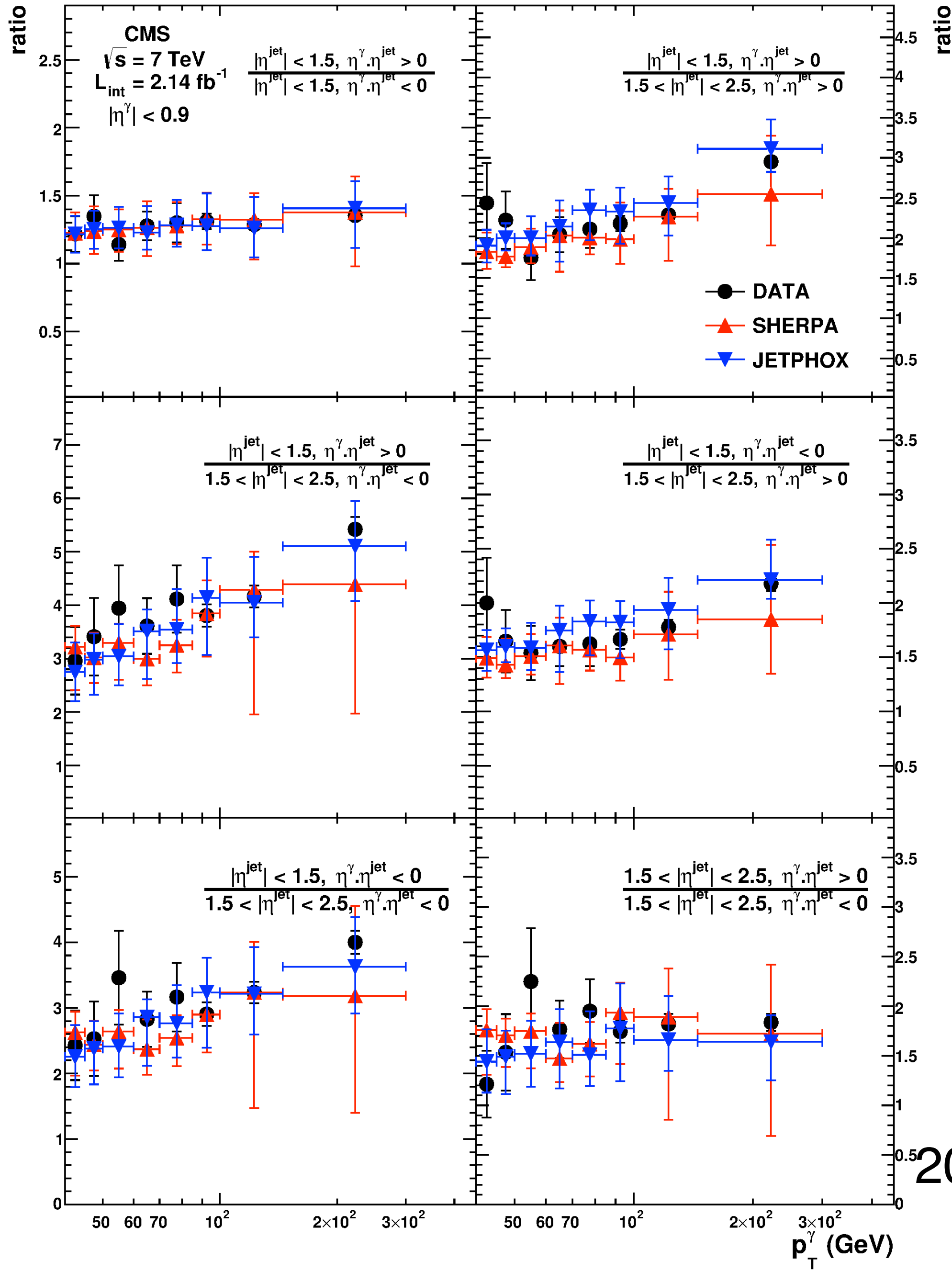
$$\frac{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}>0}{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}>0}$$

$$\frac{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}>0}{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}<0}$$

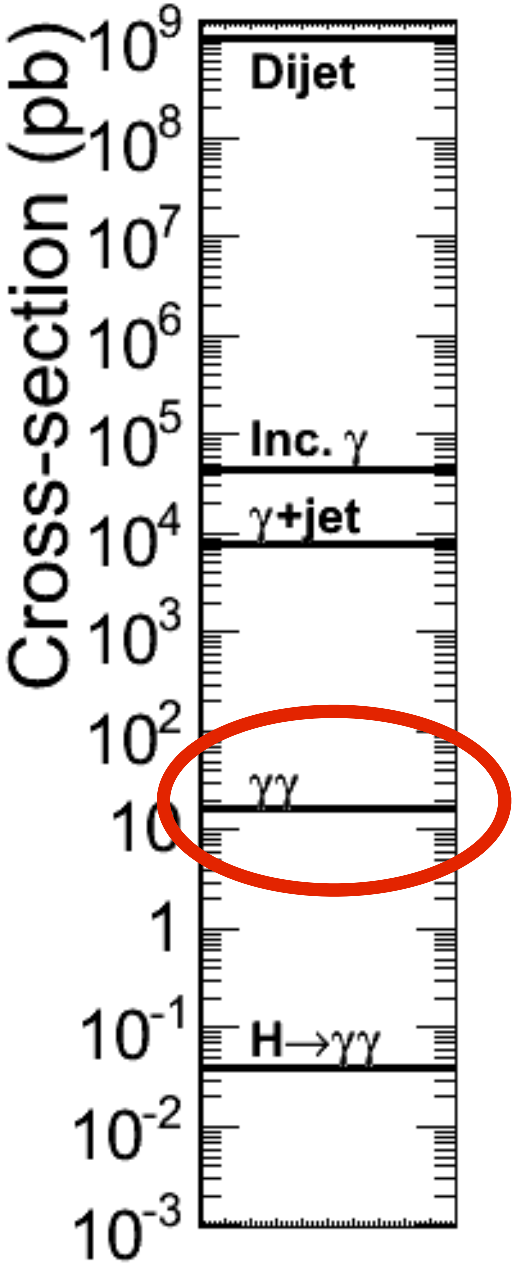
$$\frac{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}<0}{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}>0}$$

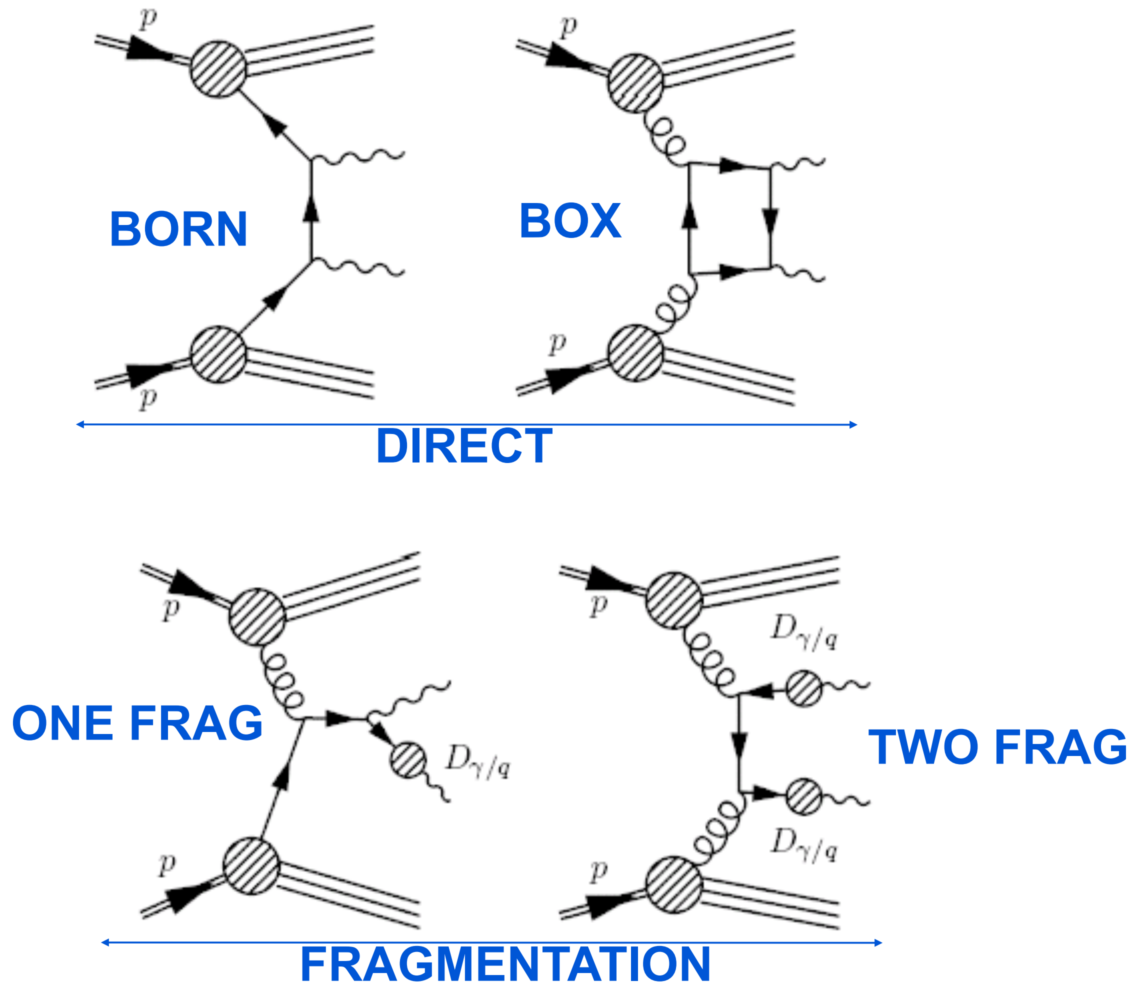
$$\frac{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}<0}{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}>0}$$

$$\frac{|\eta_{jet}|<1.5, \eta_\gamma \eta_{jet}<0}{1.5<|\eta_j|<2.5, \eta_\gamma * \eta_{jet}<0}$$



Isolated diphoton differential cross-section

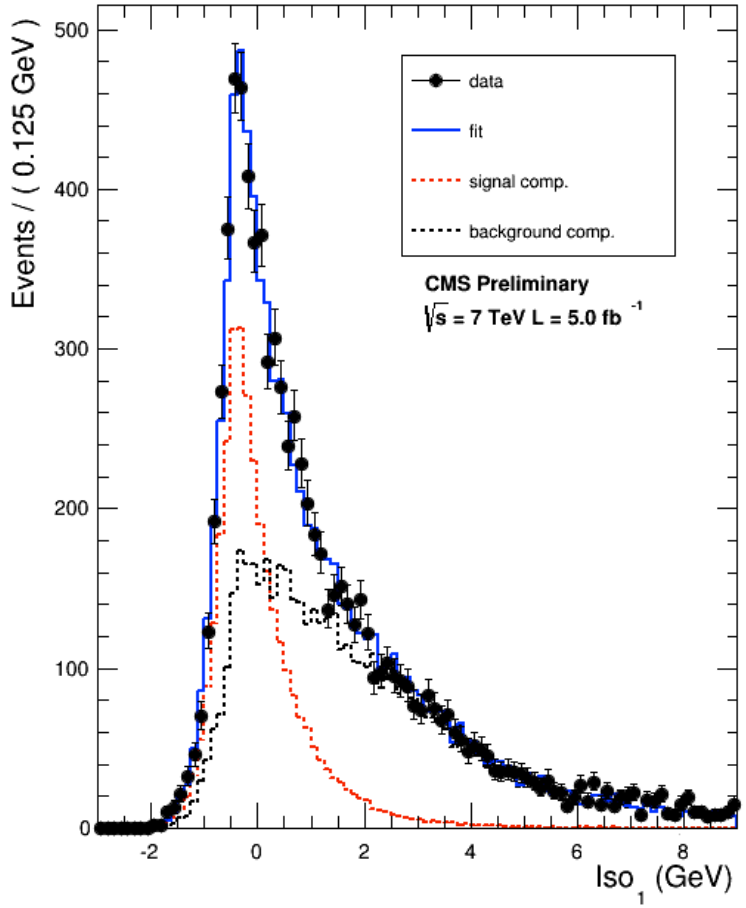


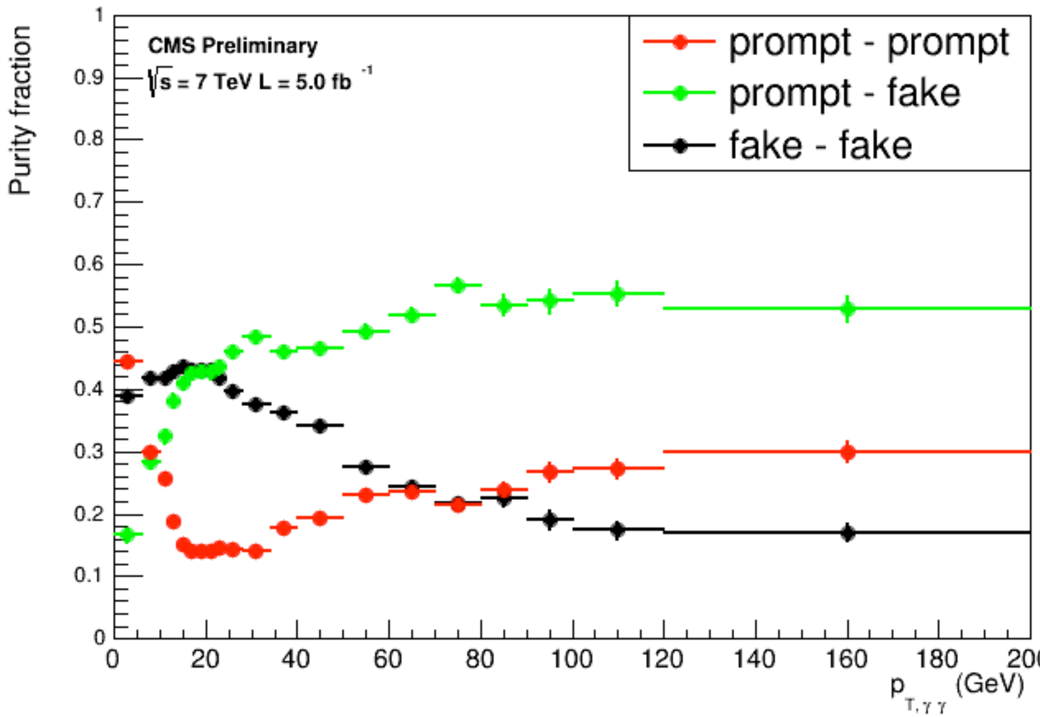


Diphoton cross-section

SMP-13-001, 5.0fb^{-1} at 7 TeV

- **Kinematical range:** $|\eta_\gamma|<2.5$, $\mathbf{E_{T,\gamma1}>40}$, $\mathbf{E_{T,\gamma2}>25}$ **GeV**, $\Delta R(\gamma_1,\gamma_2)>0.45$
- **Asymmetric E_T** cut enhances **higher order** diagram contributions
- Apply **loose selection** to maximize efficiency, level-arm for the template, phase-space for background estimate
- **Method**: **particle-flow photon isolation** template



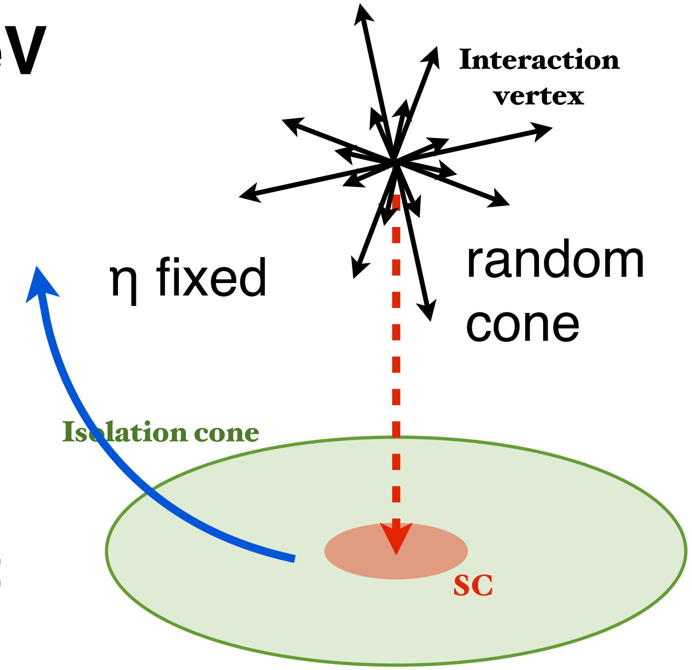


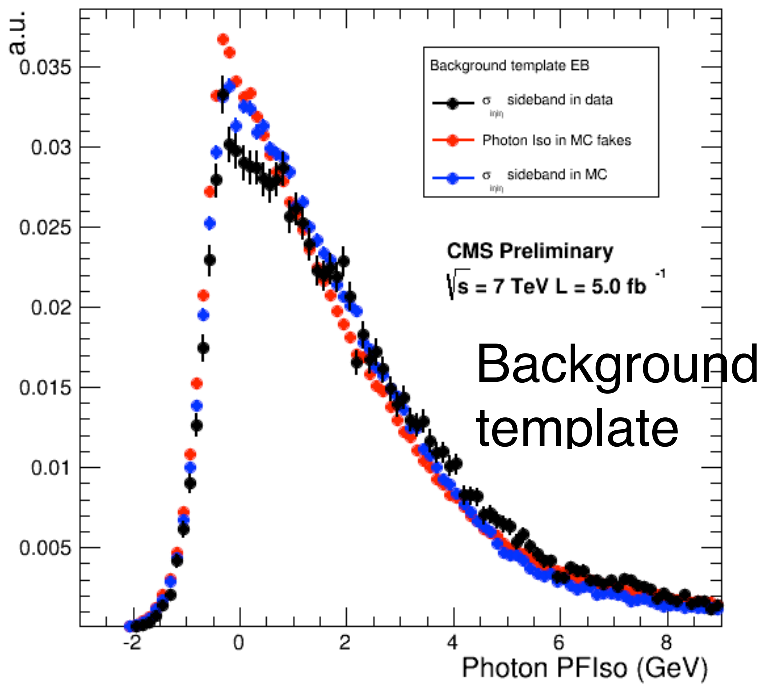
Diphoton cross-section

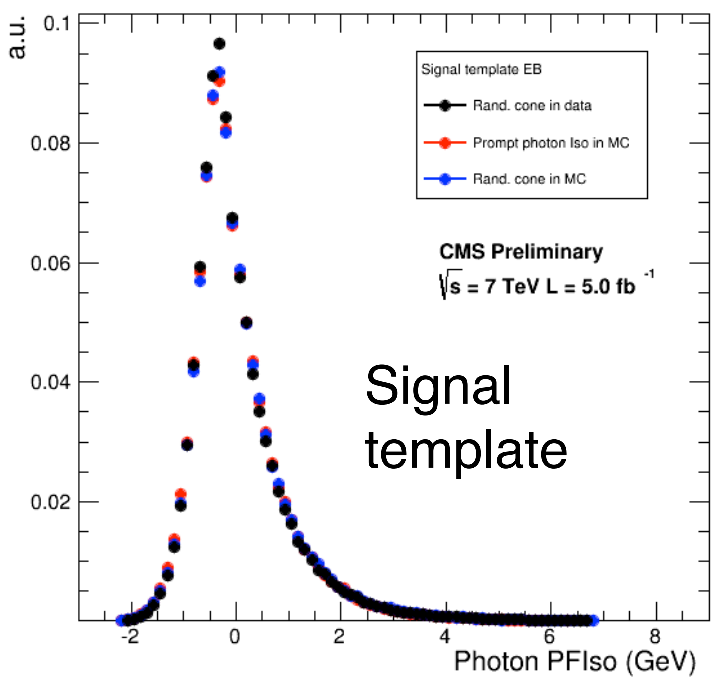
SMP-13-001, 5.0fb^{-1} at 7 TeV

Particle-flow photon isolation method

- Templates are purely **data-driven**:
- **Signal** template: **random cone** method
- **Background** template: **shower shape sideband**
- **2D fit** in data taking into account **correlations** (mainly due to pileup)
- Templates reproduce data kinematics thanks to event-mixing: improves close photon candidates description







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%

Total ~10% systematic uncertainties

Diphoton cross-section: predictions

SMP-13-001, 5.0fb^{-1} at 7 TeV

Generator	ME/PS	Resumation	Born	1-frag	2-frag	Box
$2\gamma NNLO$	ME	-	NNLO	-	-	LO
DIPHOX	ME	-	NLO	NLO	NLO	(LO)
+ GAMMA2MC	ME	-	-	-	-	NLO
RESBOS	ME	NNLL	NLO	LO	-	NLO
Sherpa	ME+PS	LL	LO + up to 3 jets	-	-	LO

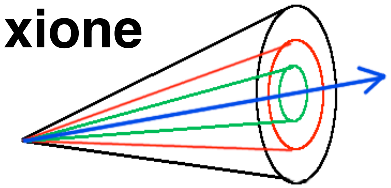
Generator level isolation: < 5 GeV is used

Frixione isolation with n=1 and ε=5 GeV gives almost the same cross-section (differentially as well)

2gNNLO uses Frixione isolation

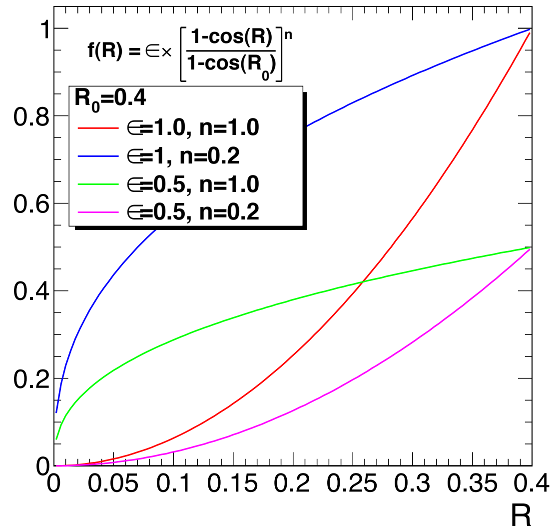
$E_T^{iso} < f(R)$

$f(R) \to 0$ for $R \to 0$



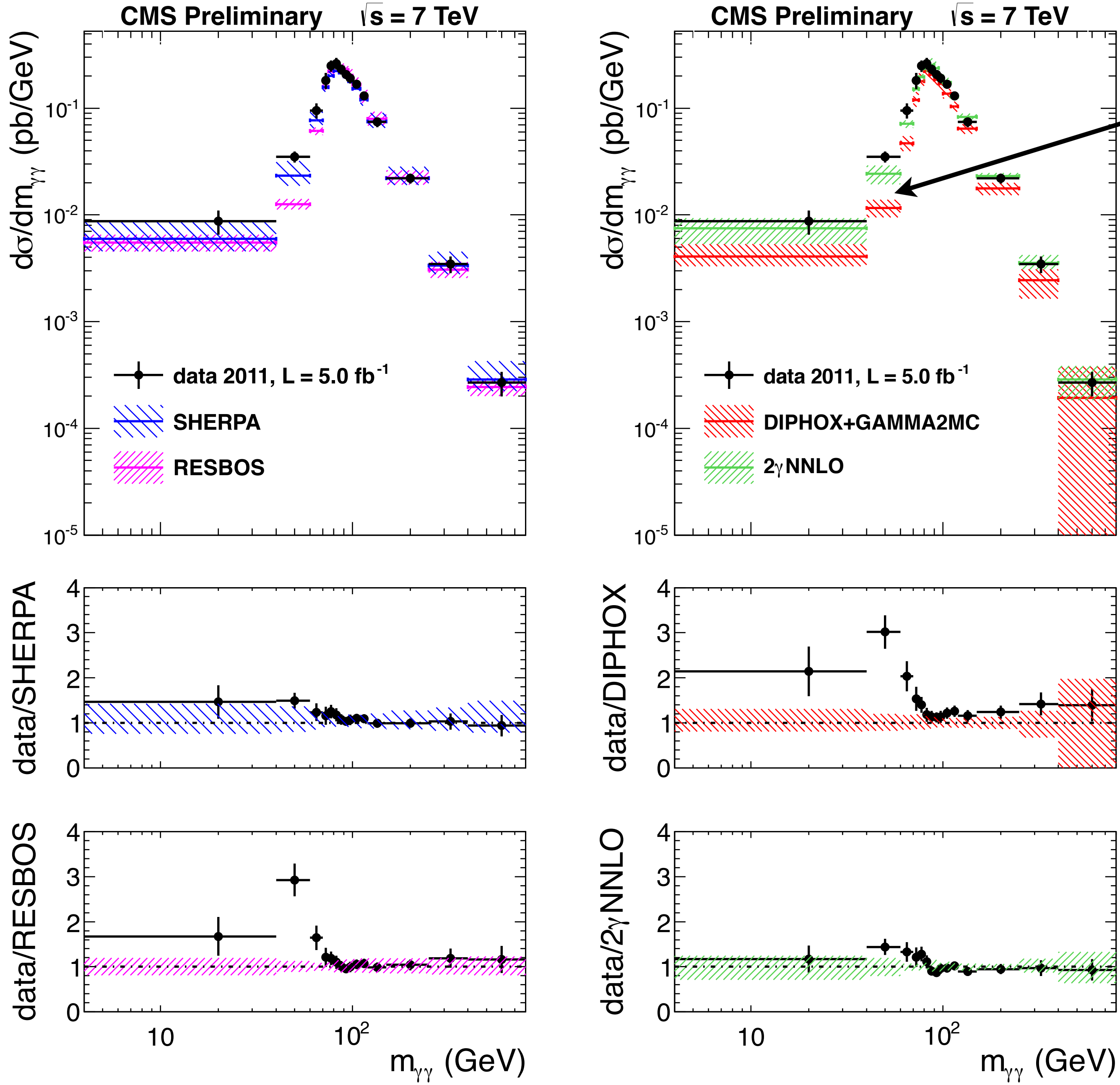
D. de Florian, L. Cieri

$E_{T\,max}^{had}$	standard/smooth	Frag. comp. (cone)
2 GeV	< 1%	6%
3 GeV	< 1%	10%
4 GeV	1%	13%
5 GeV	3%	16%
0.05 p_T	< 1%	8%
0.5 p_T	11%	52%



Diphoton cross-section

SMP-13-001, 5.0fb^{-1} at 7 TeV



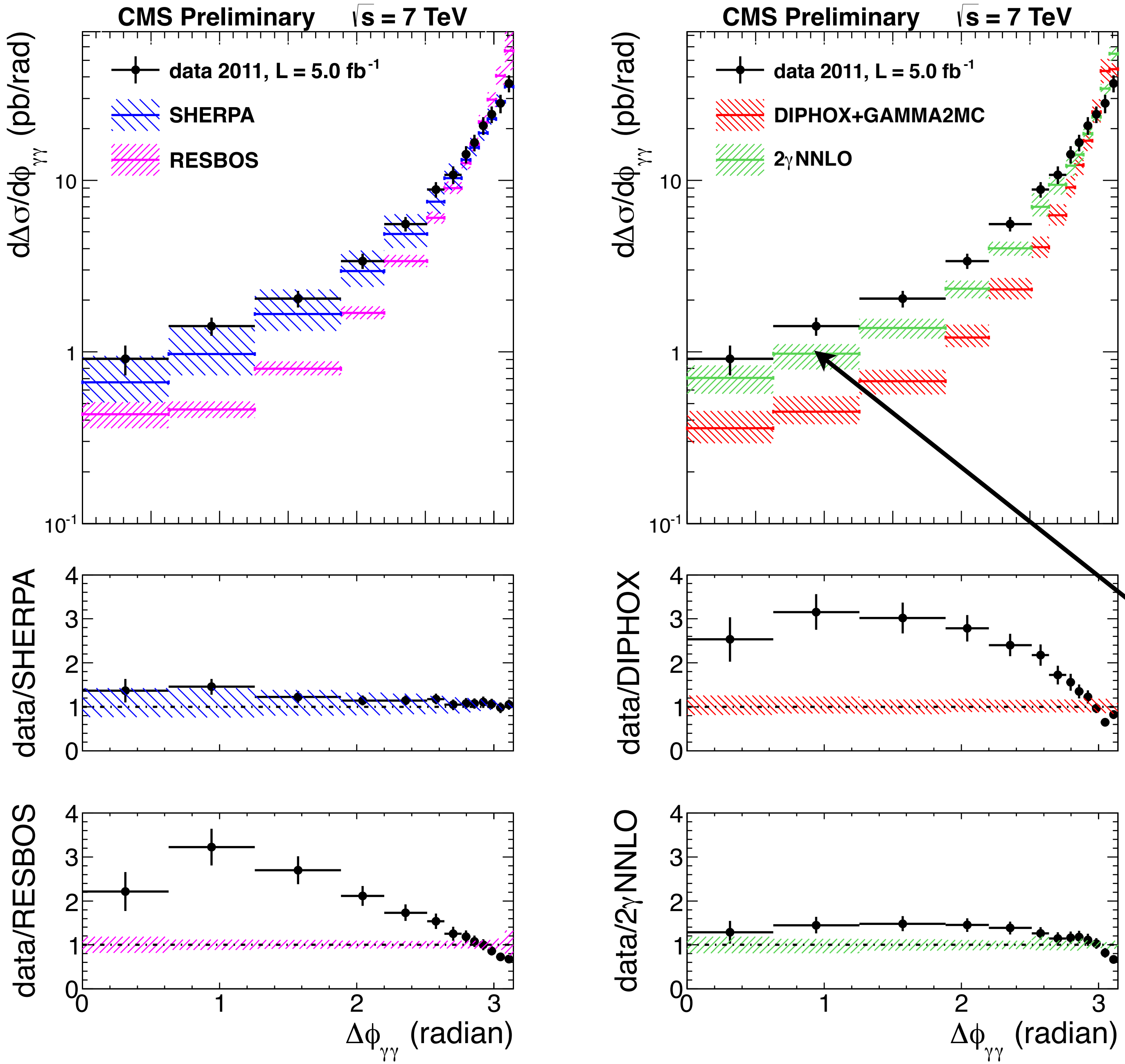
NNLO enhanced region

- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (with up to 3 matrix-element extra-jets) shows also a good agreement

Diphoton cross-section

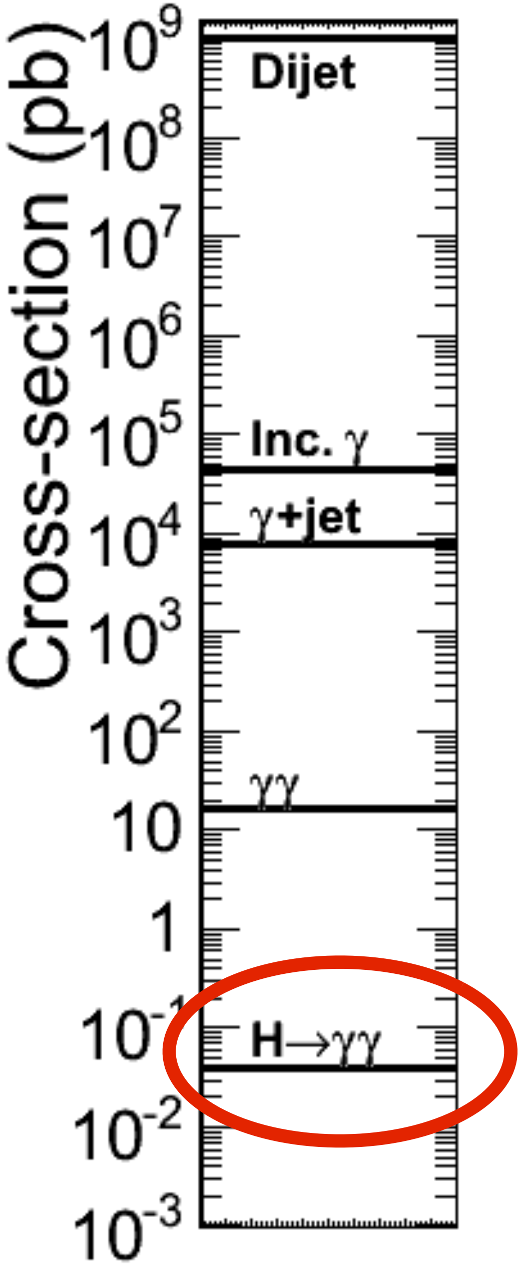
SMP-13-001, 5.0fb^{-1} at 7 TeV



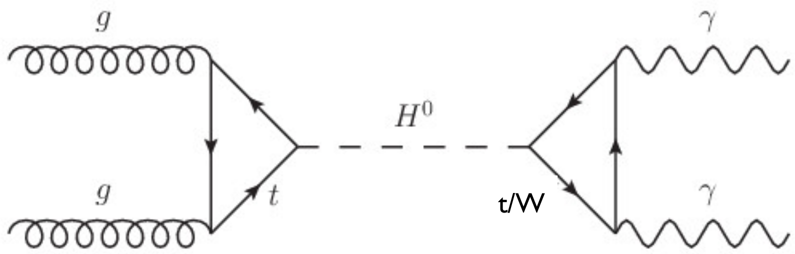
- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (up to 3 ME extra-jets) shows also a good agreement

- Still an **excess in data at low ΔΦ** (sensitive to missing higher order QCD effects)

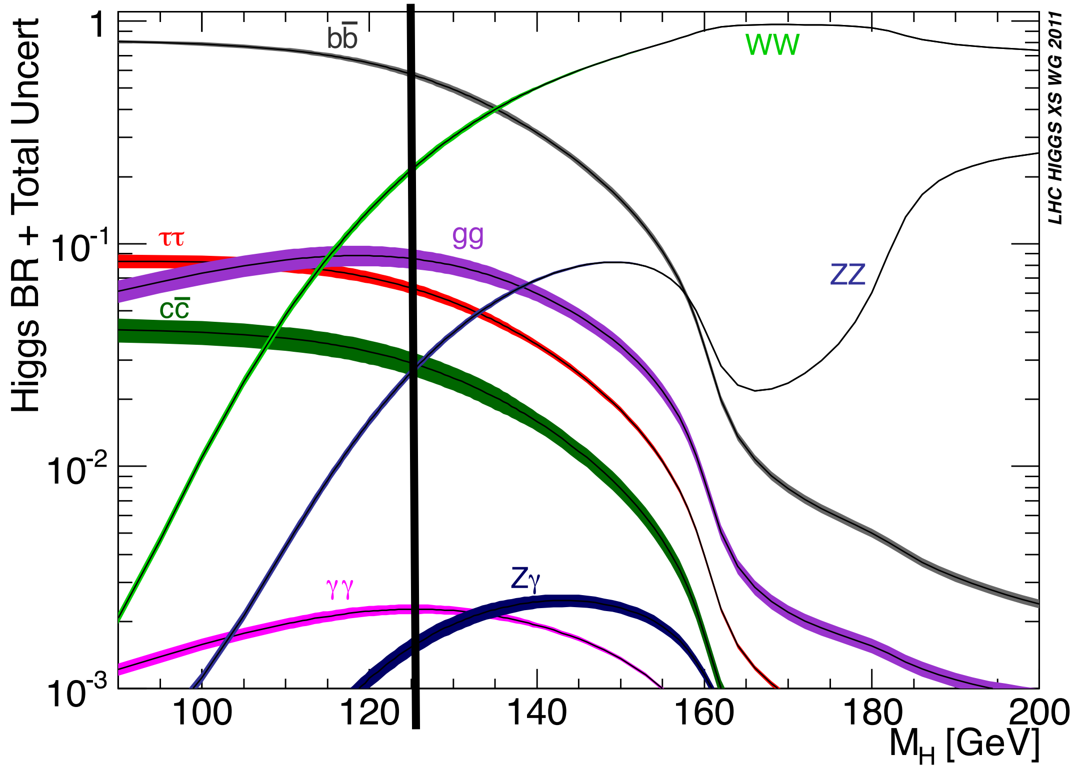


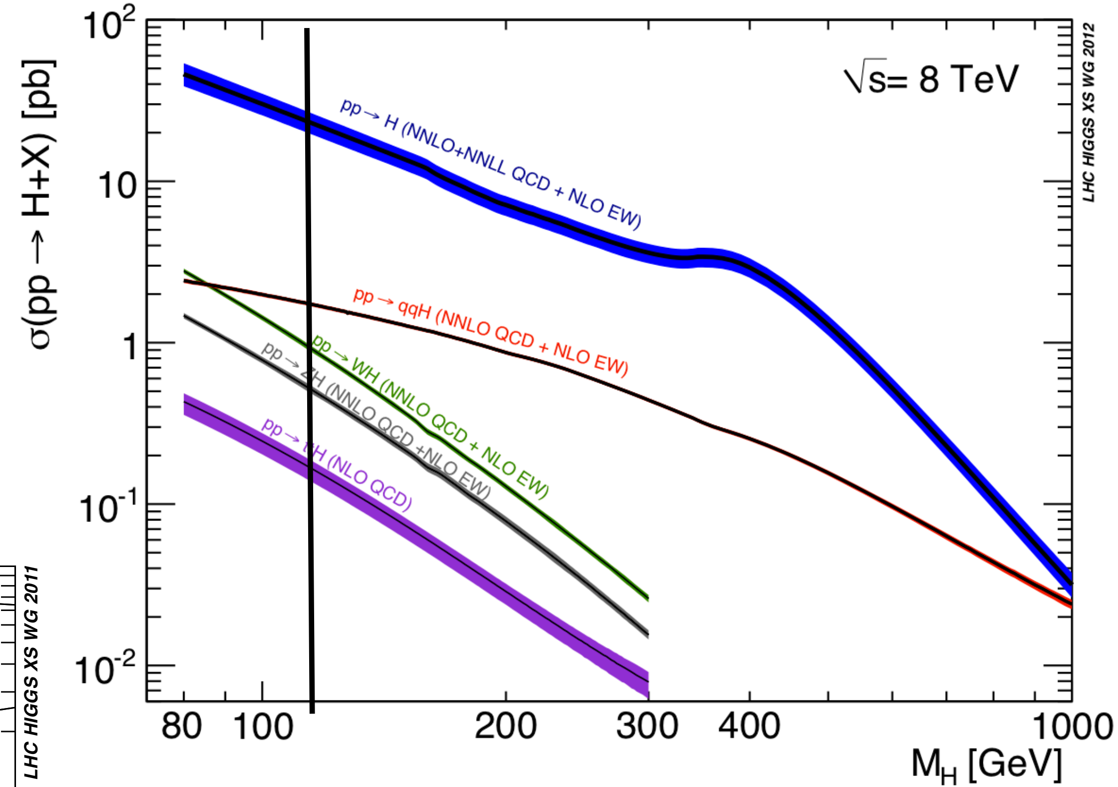
H→γγ searches

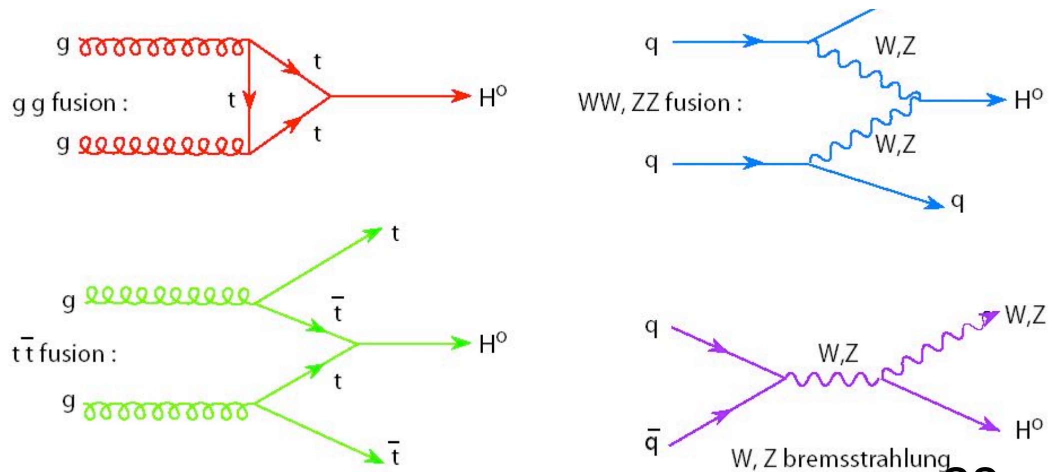


Higgs boson channels at LHC

- At the LHC, the main **Higgs production** mechanism in the SM is **gluon fusion** followed by **VBF** and associated production with W,Z or tt
- **Higgs decay to γγ**: very small branching ratio, ~2.10^{-3}

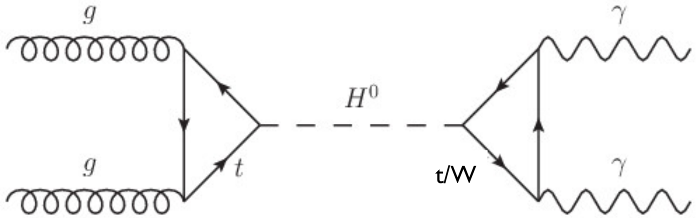




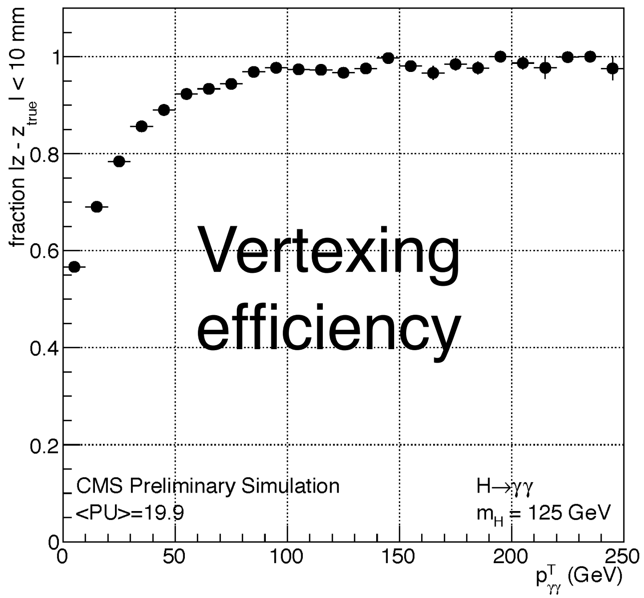


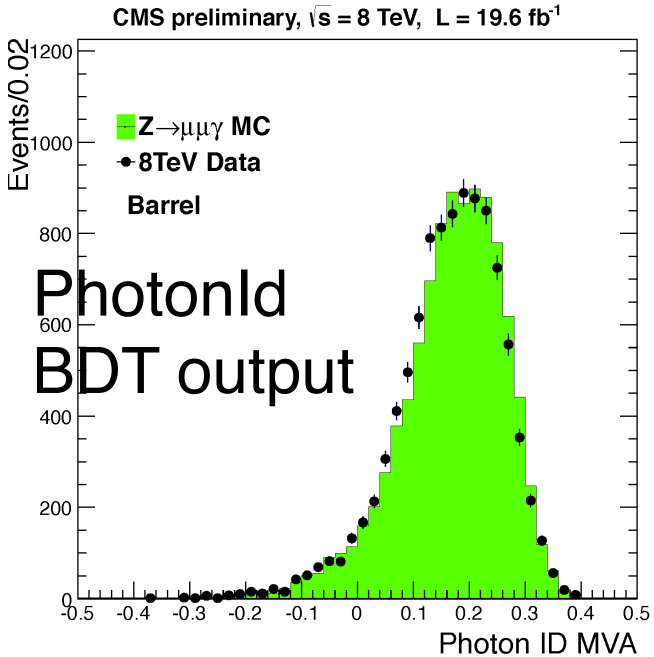
H→γγ analysis

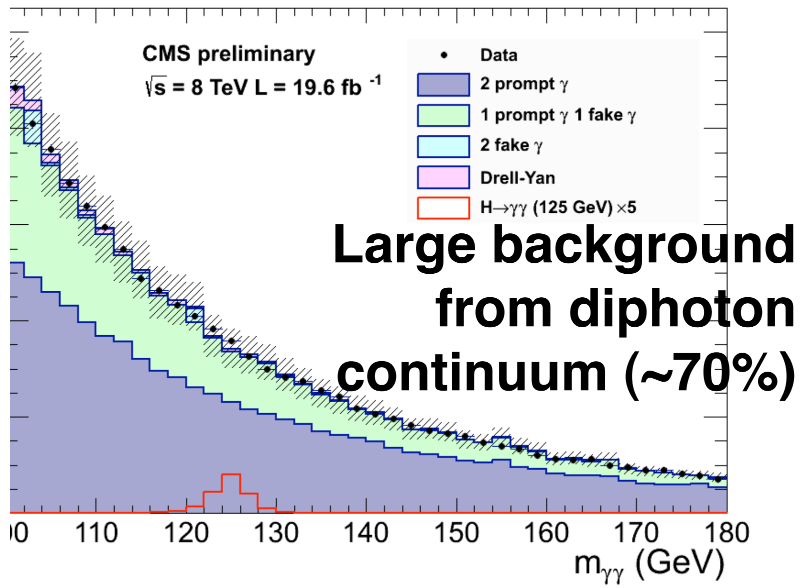
HIG-13-001, 5.1fb-1 at 7 TeV, 19.6fb-1 at 8TeV



- **Look for small signal peak over large background**
- **Main analysis is MVA - cut-based analysis and 2nd MVA analyses as cross-checks**
- Select two high pt photons
- **Vertexing MVA**: tracks, diphoton kinematics, conversions
- **Photon identification MVA** to reject fake photons: shower shape and isolation
- Energy regression to improve **mass resolution: 1-2%**



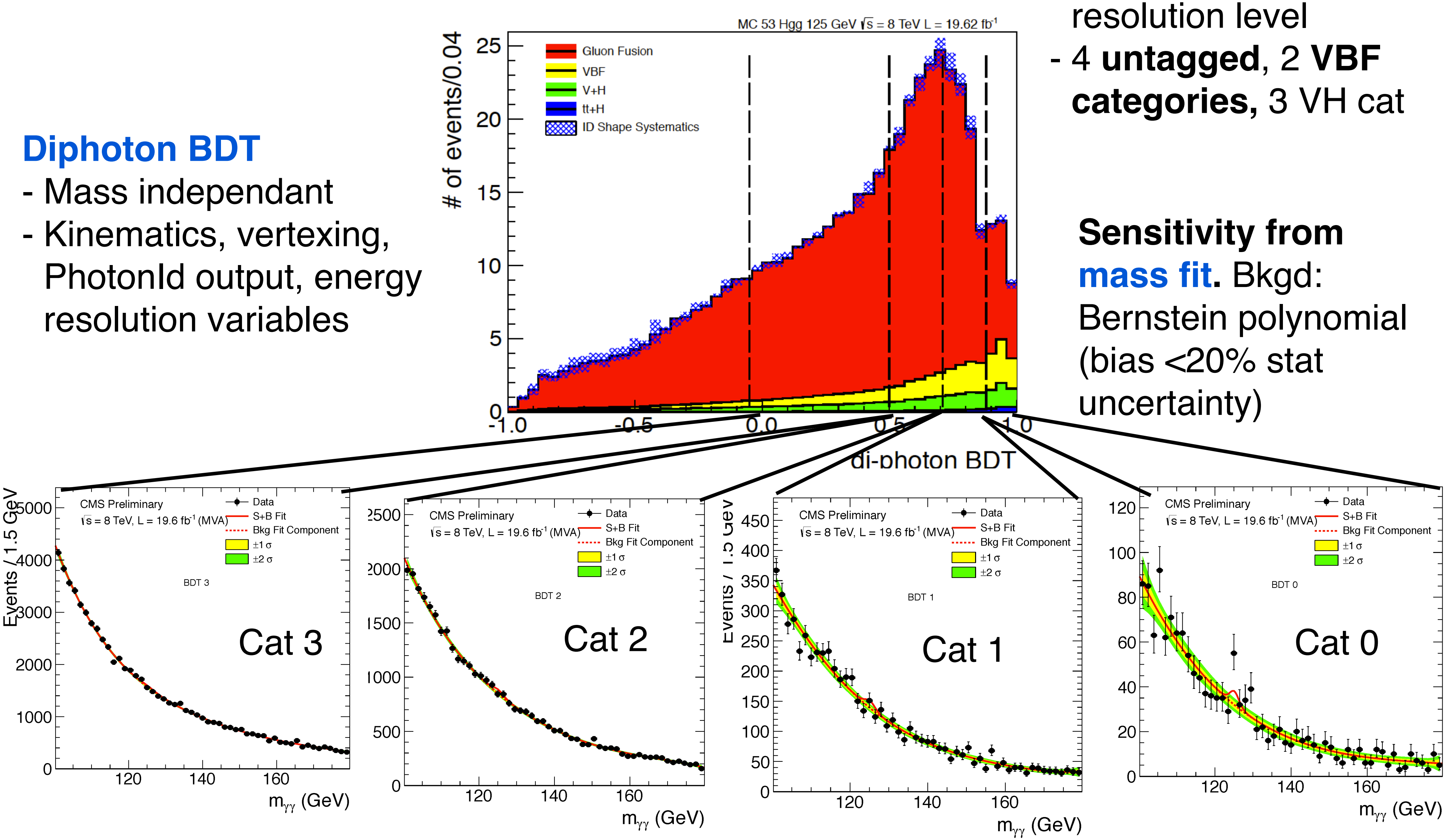




H→γγ: categories

Categories:
- Defined with s/b and resolution level
- 4 **untagged**, 2 **VBF categories,** 3 VH cat

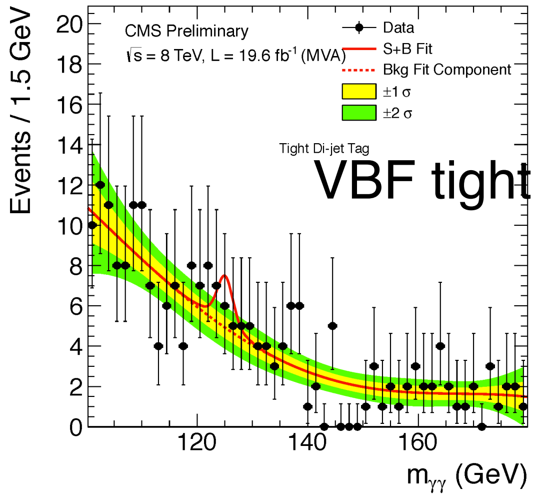
Diphoton BDT
- Mass independant
- Kinematics, vertexing, PhotonId output, energy resolution variables

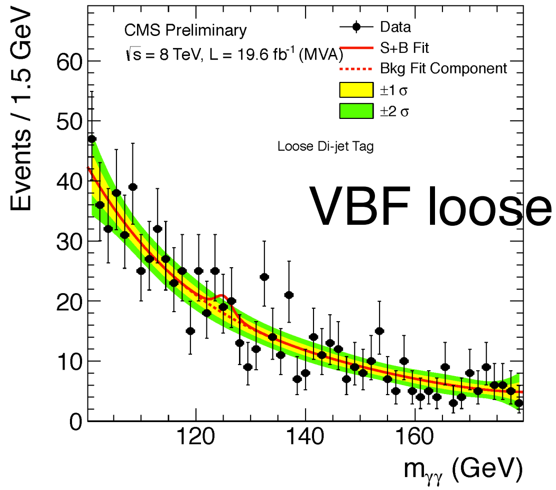


Sensitivity from mass fit. Bkgd: Bernstein polynomial (bias <20% stat uncertainty)

Exclusive channels: VBF and VH

Sensitivity to production mechanisms and Higgs-Vector boson coupling





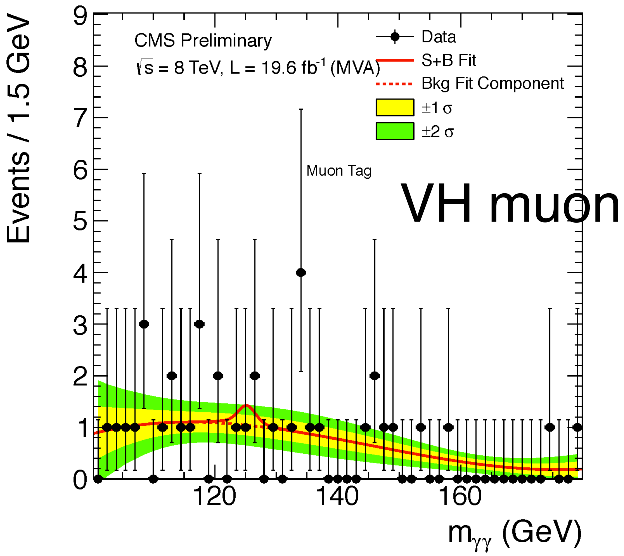
VBF tags:

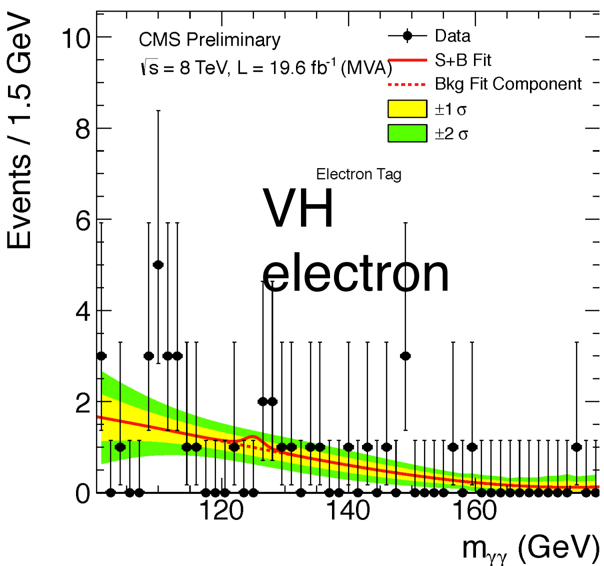
- VBF is higher γγ p_T, two forward jets
- **Dijet BDT** using diphoton/jets kinematics
- Define two categories: s/b~0.5 and s/b~0.2

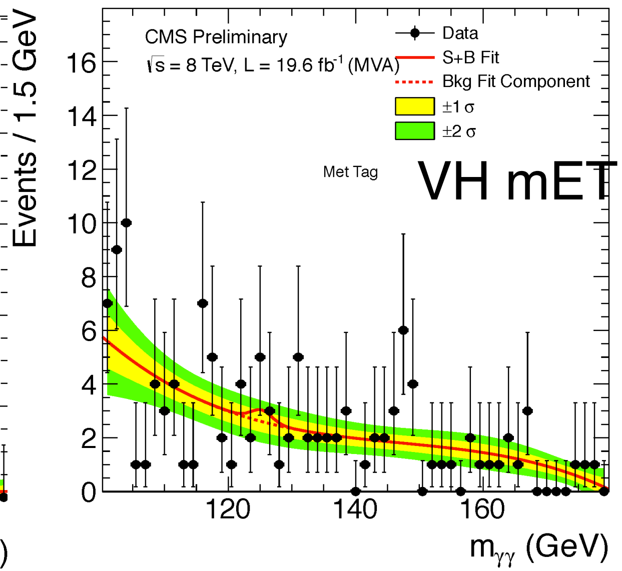
Gluon-gluon fusion contamination in VBF categories ~20-50%

VH tags (WH, ZH production):

- Two lepton categories, **muon or electron**
- One **mET** category



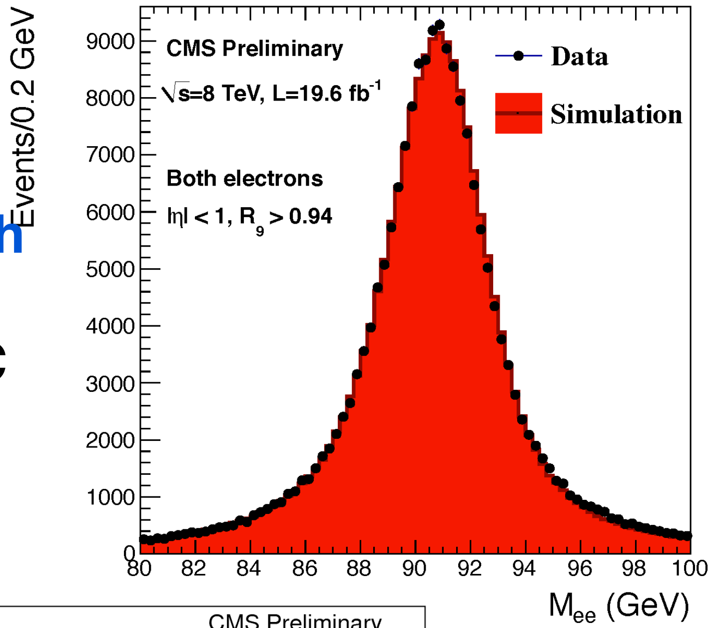


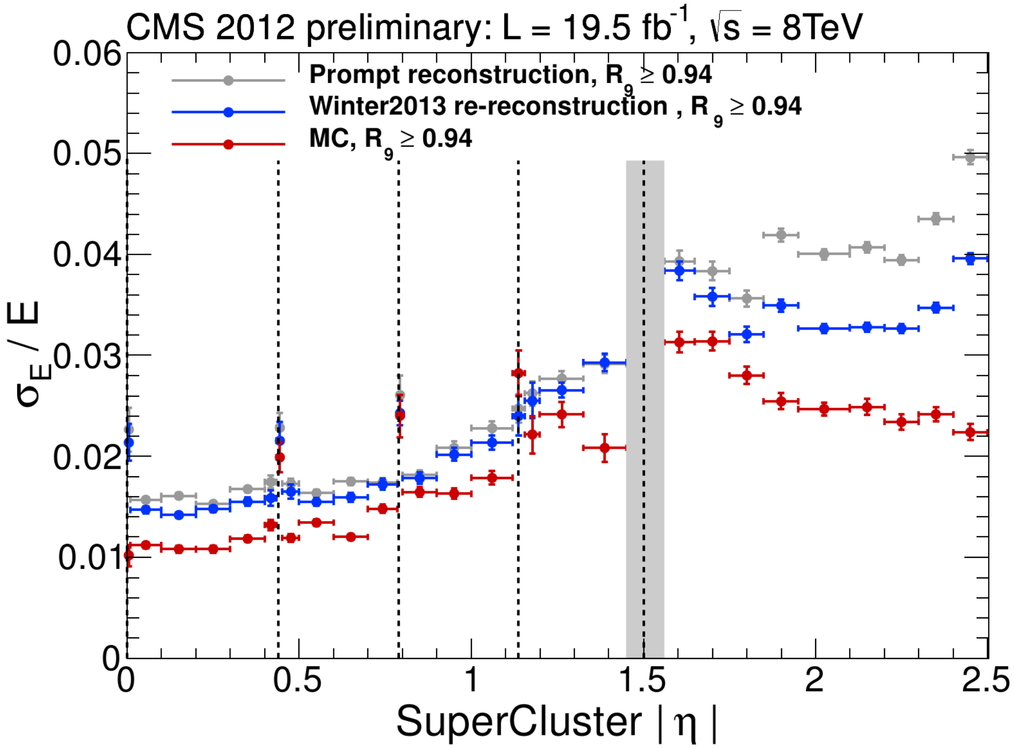


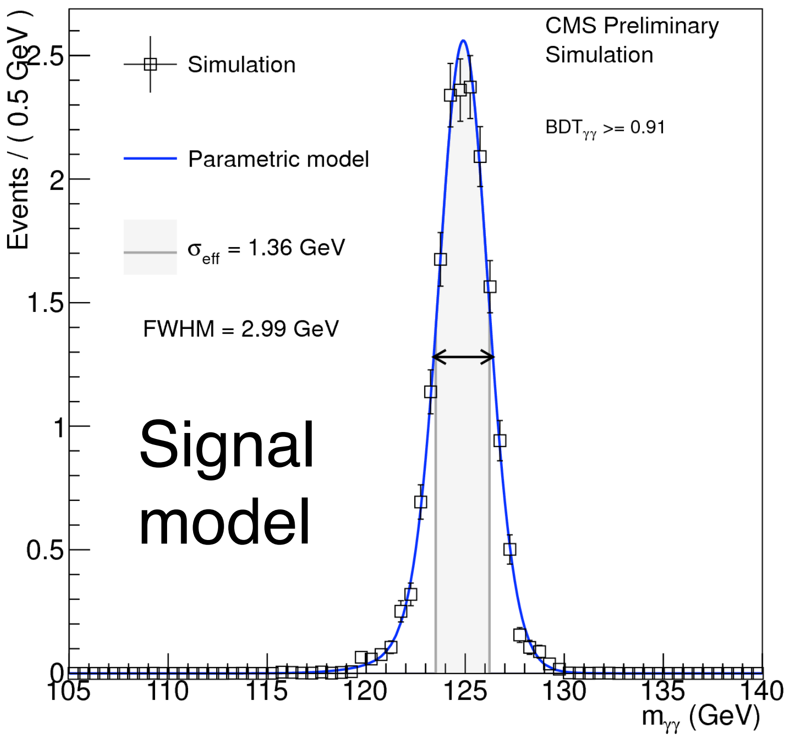
H→γγ mass resolution

Mass scale/ resolution measured with Z→ee events

=> correct MC to match data



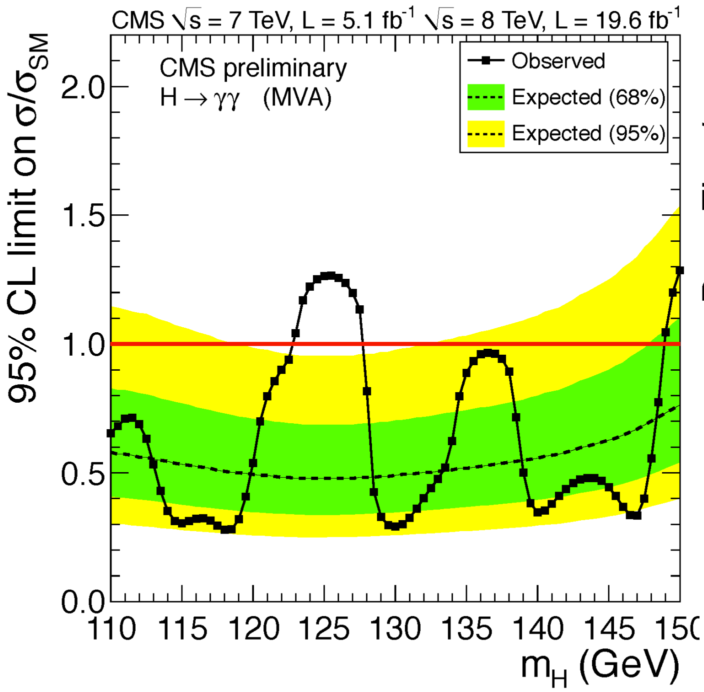


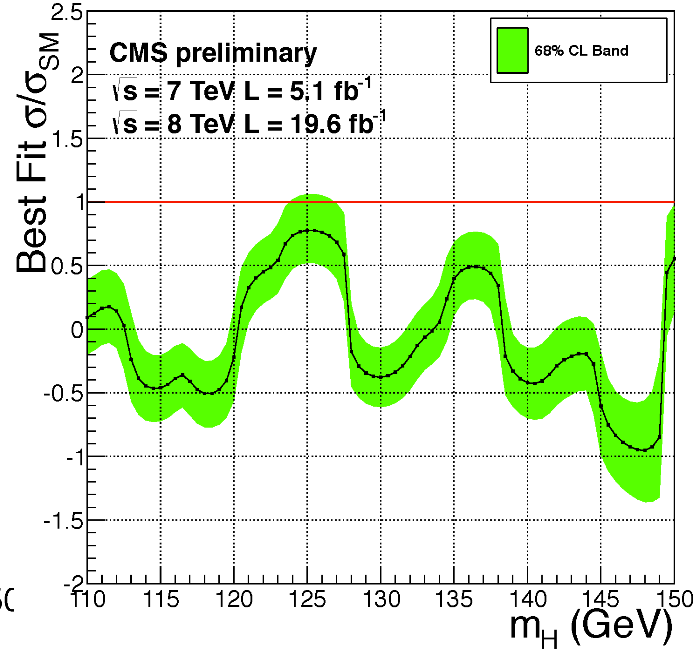


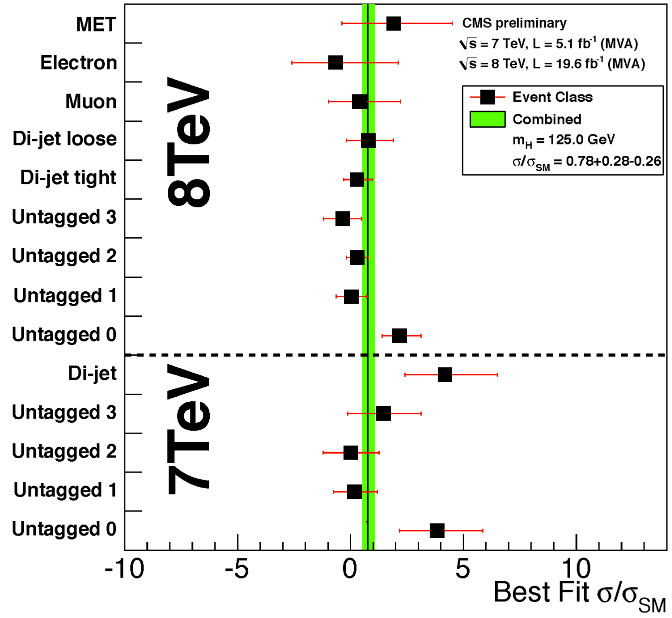
Energy resolution improved with energy regression

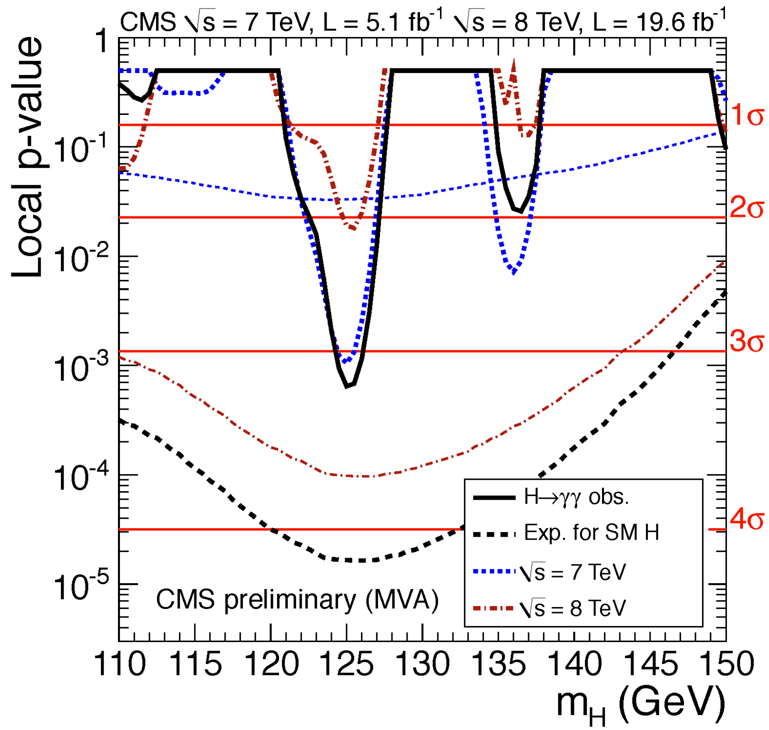
- ECAL **geometry** (crack information), **shower profile** variables, energy deposited in **preshower**
- **Best untagged category**: 1.36 GeV effective sigma (narrow shower shape in barrel or high diphoton p_T events)

H→γγ MVA results





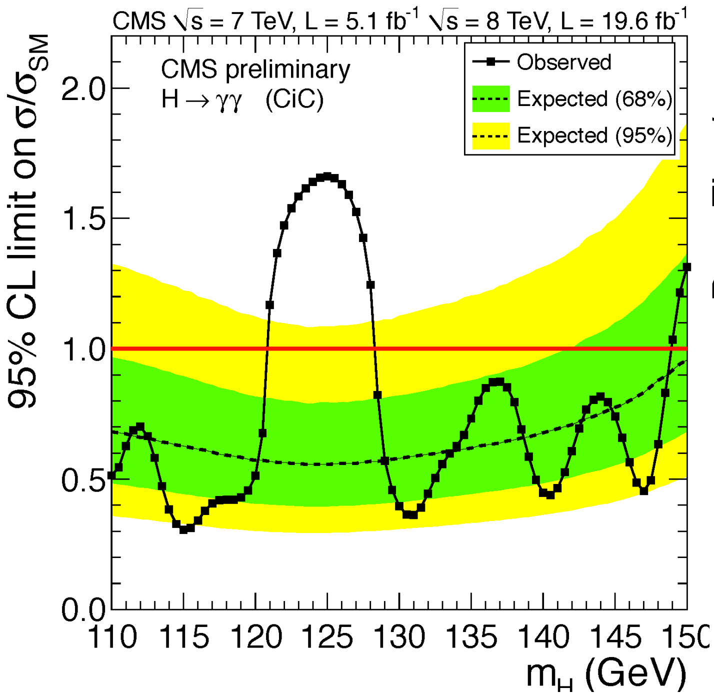


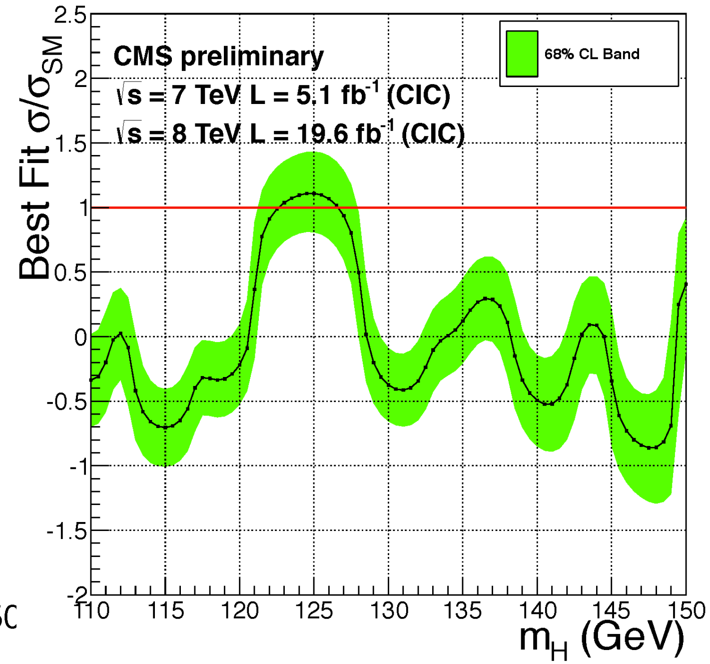


MVA

- **Observed local significance above 3.2σ (expected 4.2σ)**
- Measure best fit **μ=0.78 ± 0.27 at 125 GeV**
- **Mass measurement** 125.4 ± 0.5(stat.) ± 0.6(syst.)

H→γγ cross-check with cut-based analysis

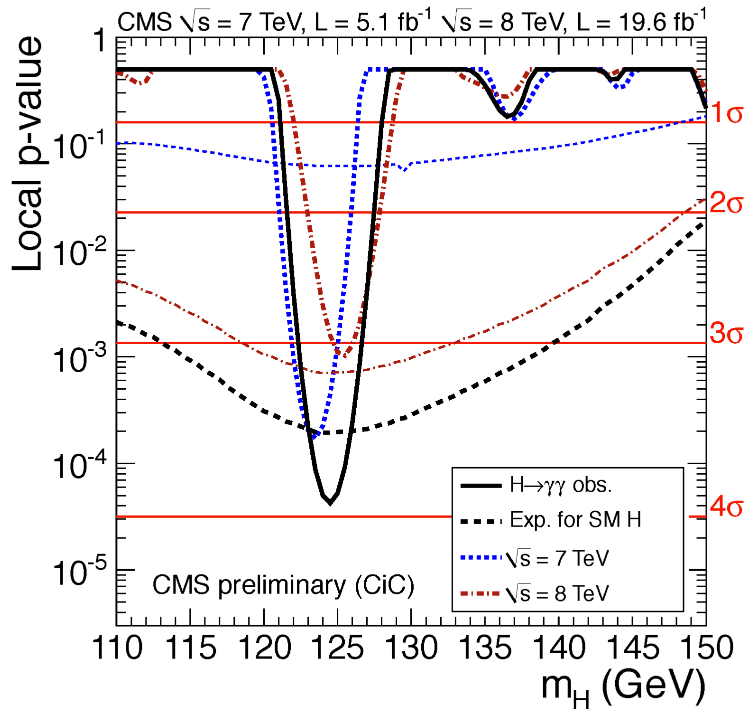




Cut-based:

- **Observed local significance above 3.9σ (3.5σ expected)**
- Measure best fit **μ=1.11 ± 0.31 at 125 GeV**

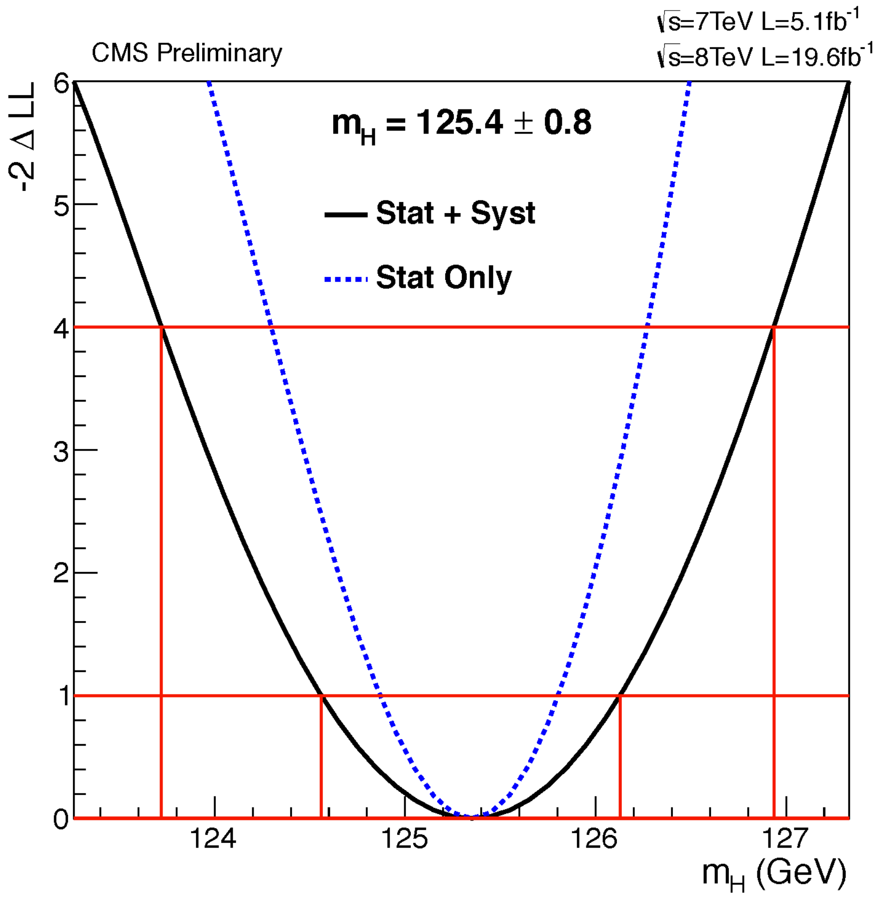
	MVA analysis (at m_H=125 GeV)	cut-based analysis (at m_H=124.5 GeV)
7 TeV	$1.69^{+0.65}_{-0.59}$	$2.27^{+0.80}_{-0.74}$
8 TeV	$0.55^{+0.29}_{-0.27}$	$0.93^{+0.34}_{-0.32}$
7 + 8 TeV	$0.78^{+0.28}_{-0.26}$	$1.11^{+0.32}_{-0.30}$

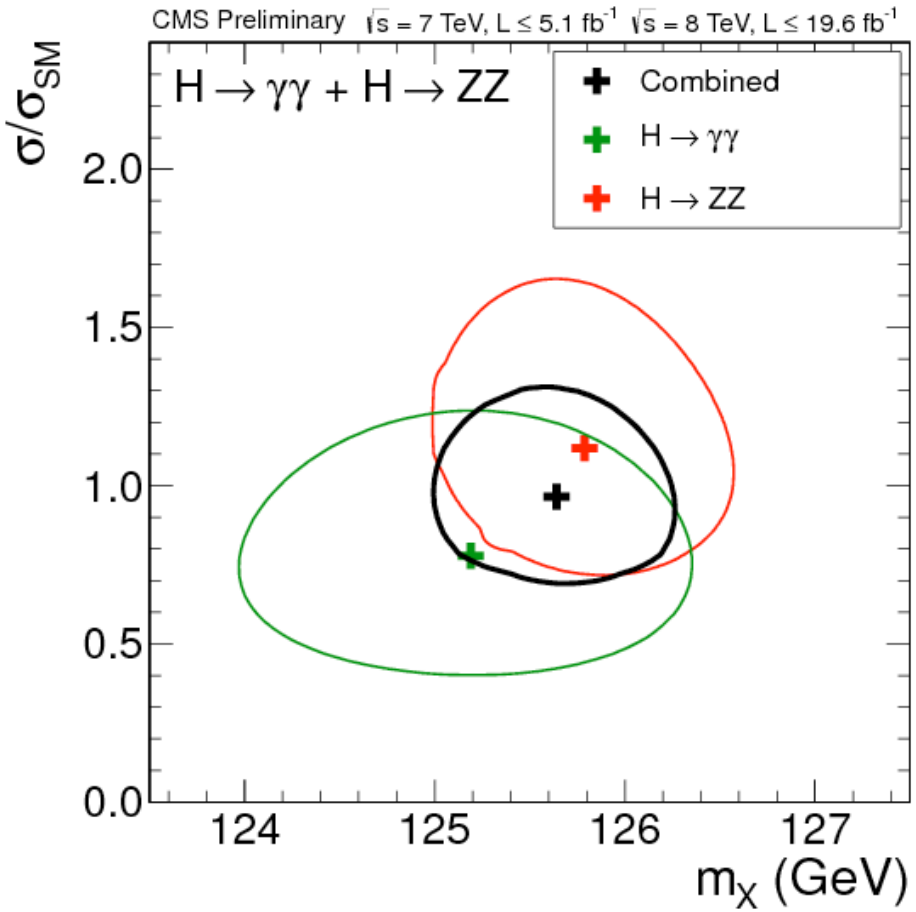


Compatibility of cut-based and MVA: within 1.5σ

Mass measurement

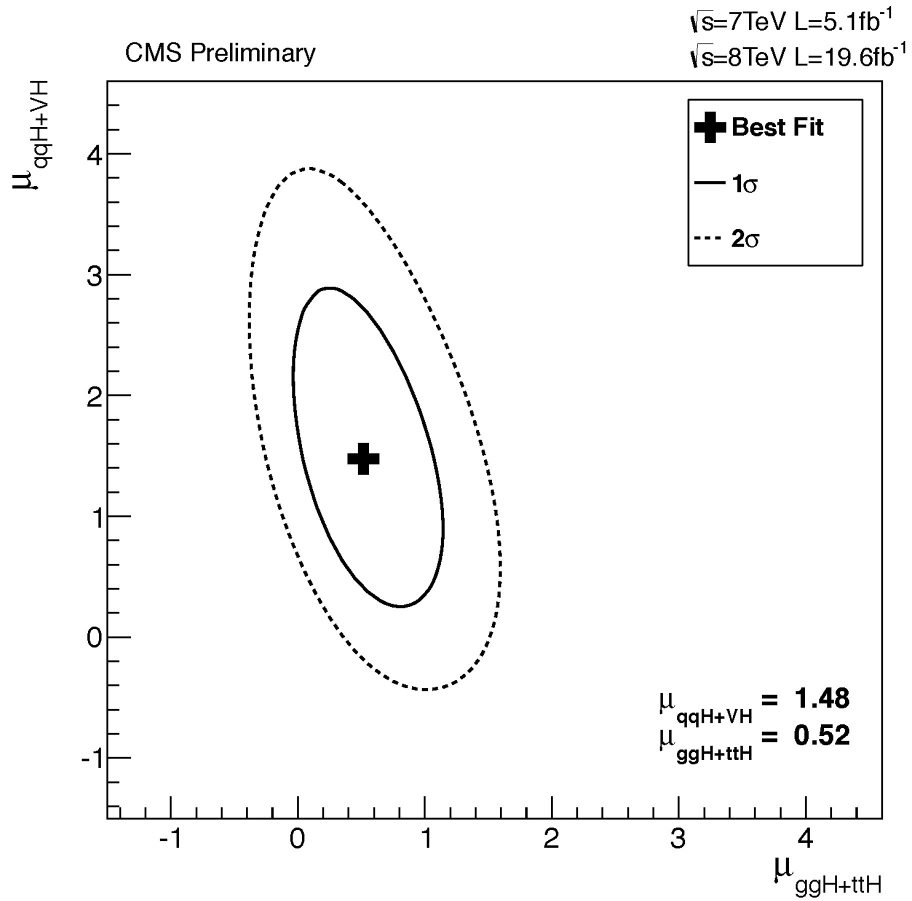
- Mass measured with H→γγ full dataset **125.4 ± 0.5(stat.) ± 0.6(syst.) GeV**
- **Main systematics:** energy scale (Z→ee), electron to photon extrapolation, linearity (45 GeV electrons => 60 GeV photons)
- Masses from H→γγ and H→ZZ channels are compatible within 1σ

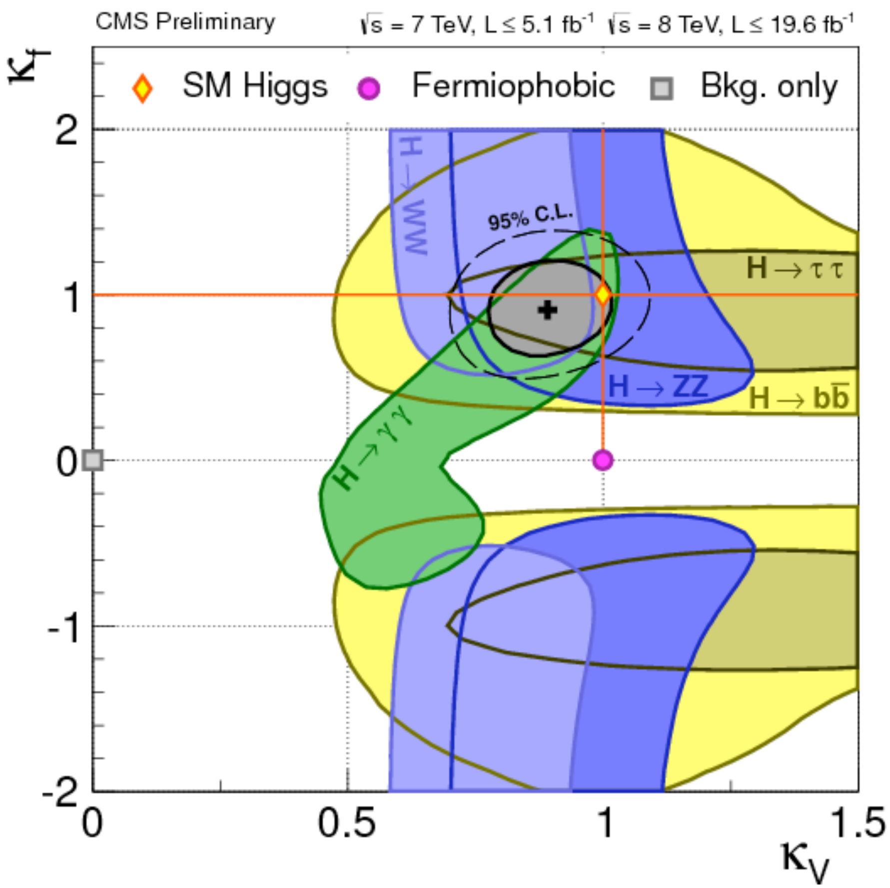




Probing production mechanism and couplings

- The four main production mechanisms are all related to a **fermion-coupling** (top in gluon fusion loop, ttH) or to **vector boson coupling** (VBF,VH).
- $H \to \gamma\gamma$ sensitive to relative sign W and top coupling through decay loop
- Negative coupling to fermions would show up as enhanced tH production

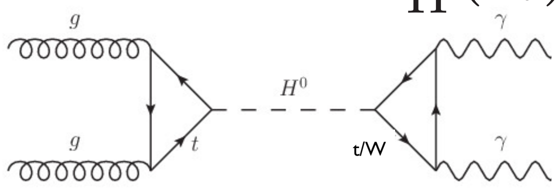


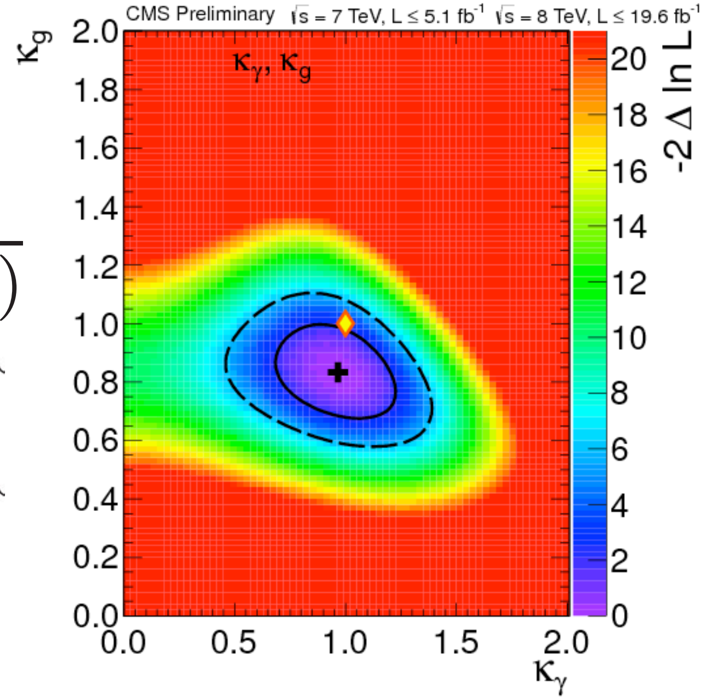


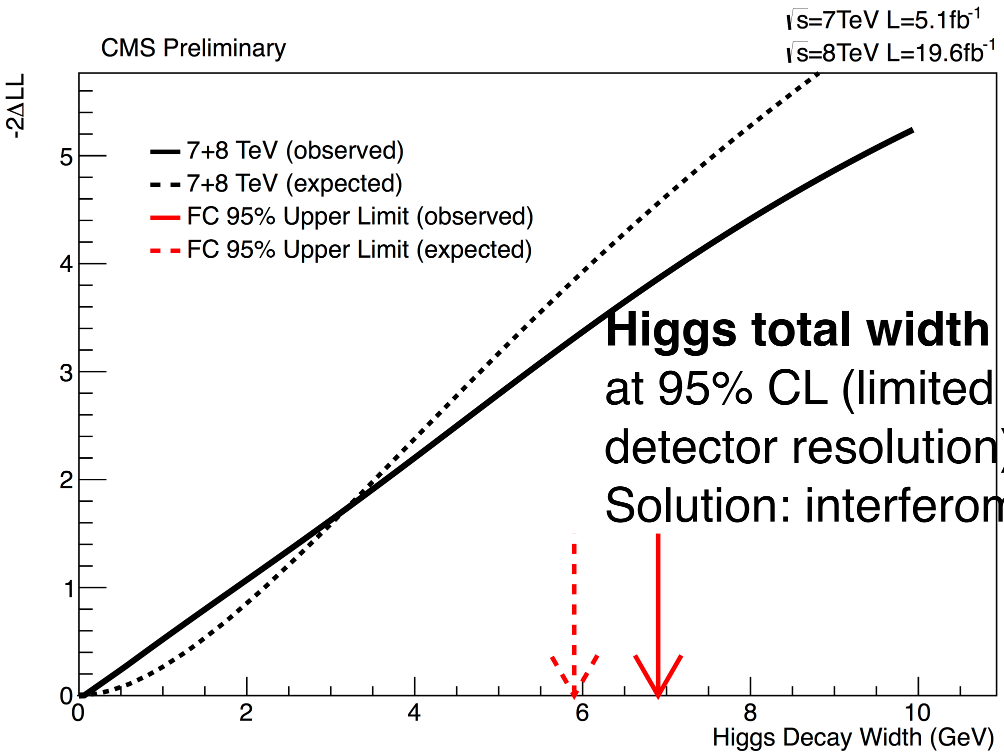
More properties

New heavy particles running in **gg→H→γγ loops** could enhance / decrease the rate: change **couplings to gluon and to photons**

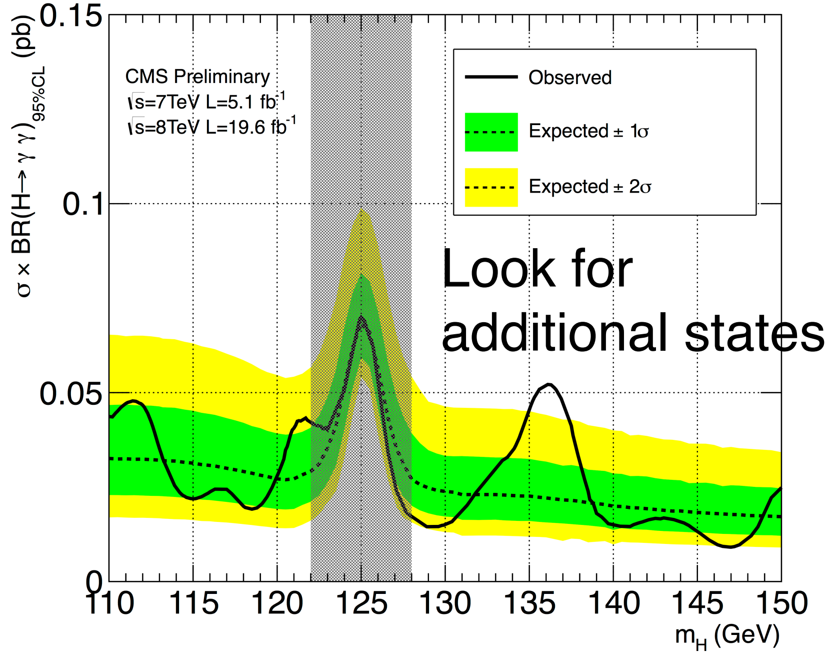
$$\frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2(\kappa_i)}$$







Higgs total width < 6.9 GeV at 95% CL (limited by detector resolution)
Solution: interferometry

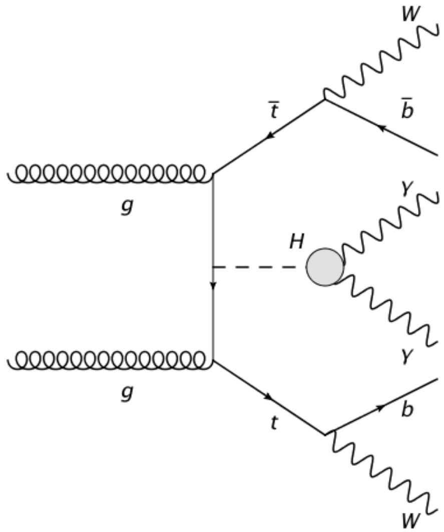


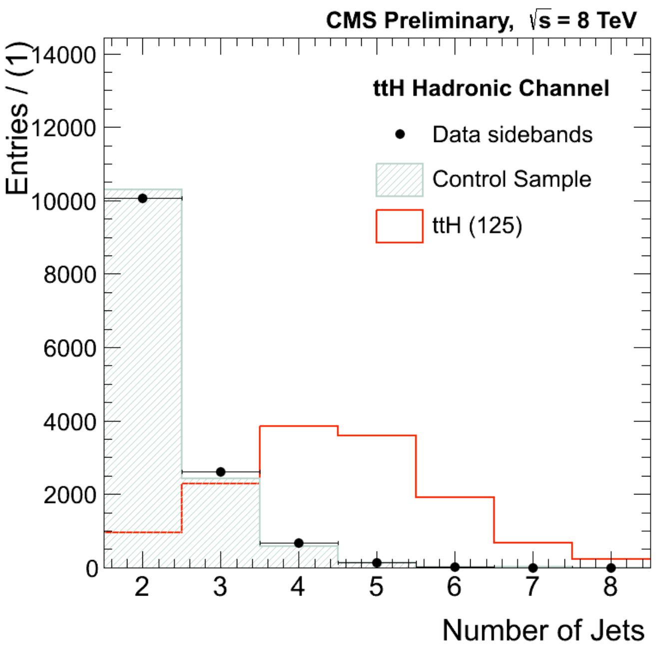
Look for additional states

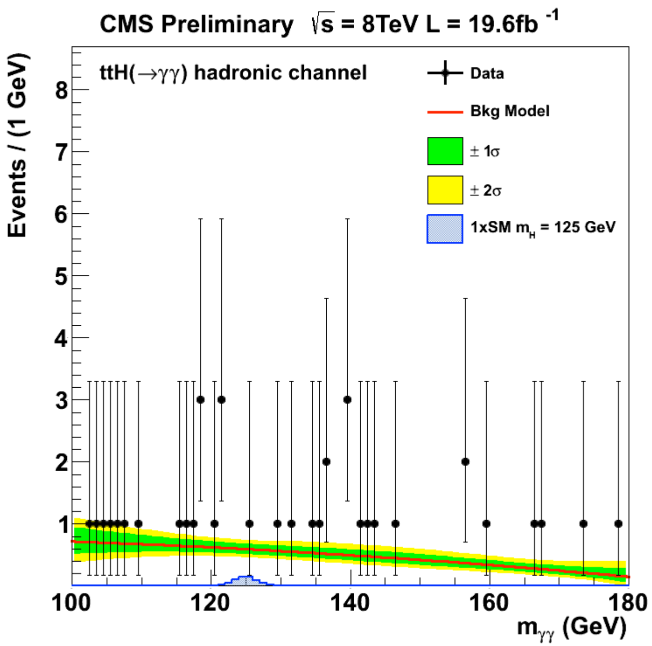
Exclusive searches with ttH, H→γγ

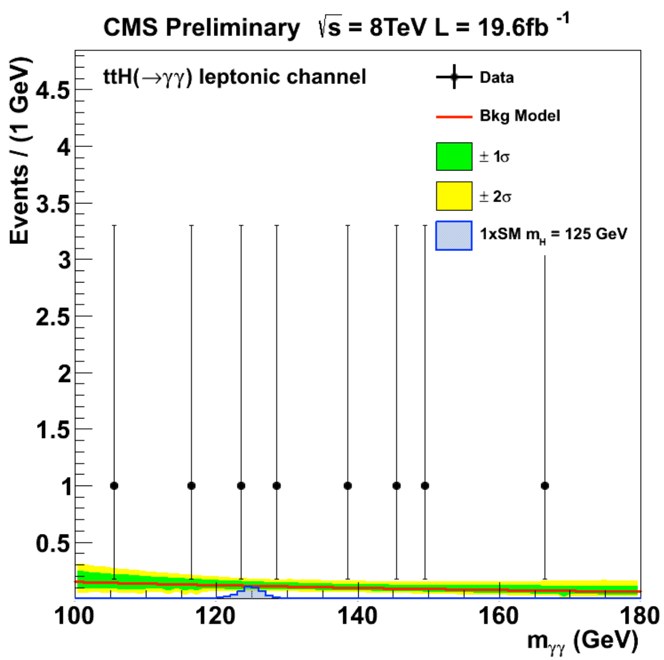
HIG-13-015

- 2 Categories: **hadronic** and **semi-leptonic ttbar decay**
- **Hadronic**: >=5jets,including at least one b-tagged jet.
- **Leptonic**: >=2jets (1 b-tag), 1 electron or muon
- Low statistics: use **control sample** reverting photon identification cuts
- Very **high purity** selection (87% hadronic, 97% leptonic)



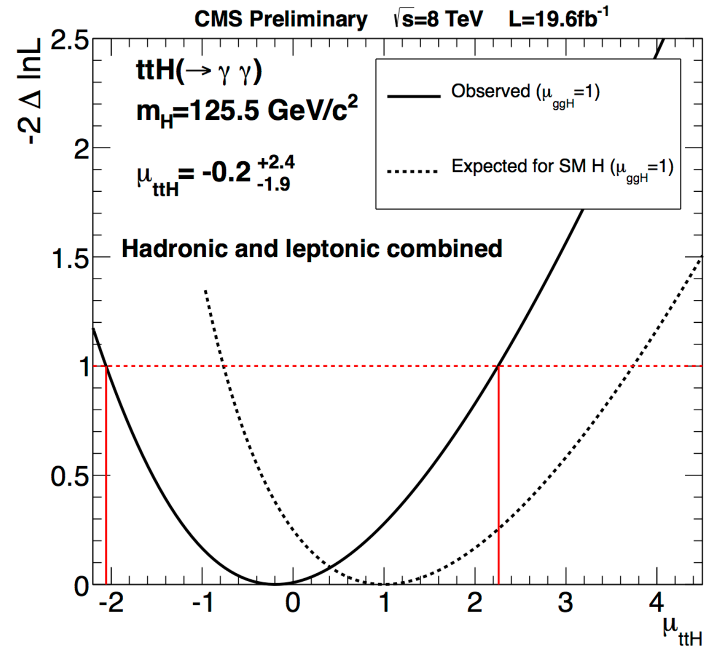




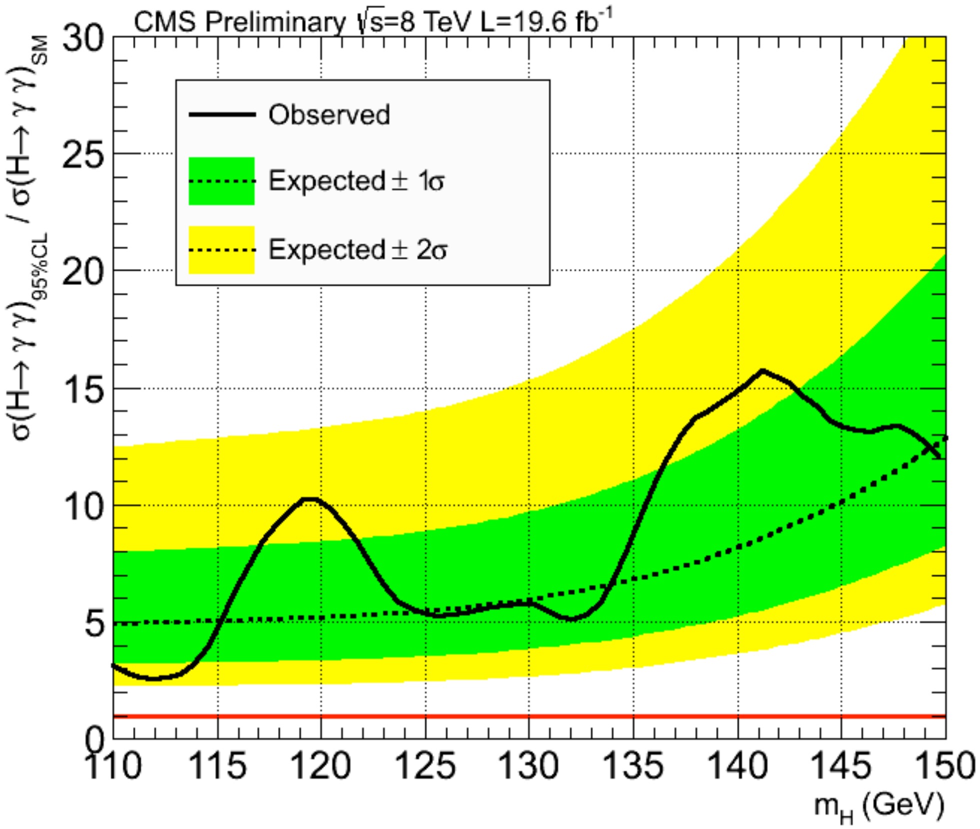


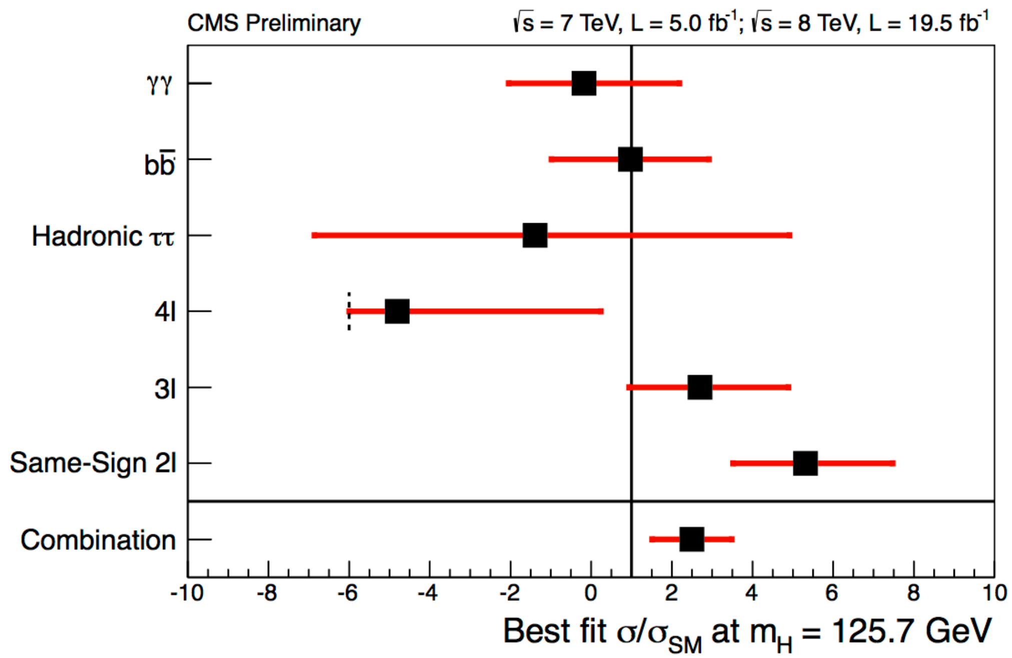
Exclusive searches with ttH, H→γγ

HIG-13-015



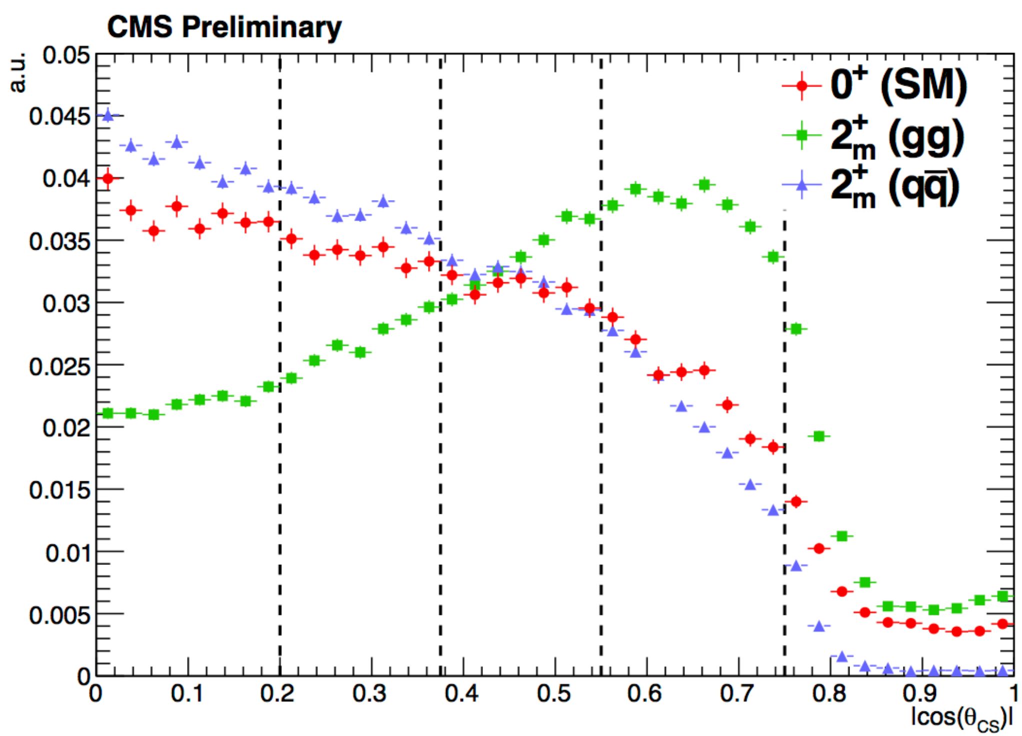
- **Exclude 5.4 (observed) times the SM** (5.1 expected)
- Along with the other decay channels, measure μ ~2.5 +/- 1

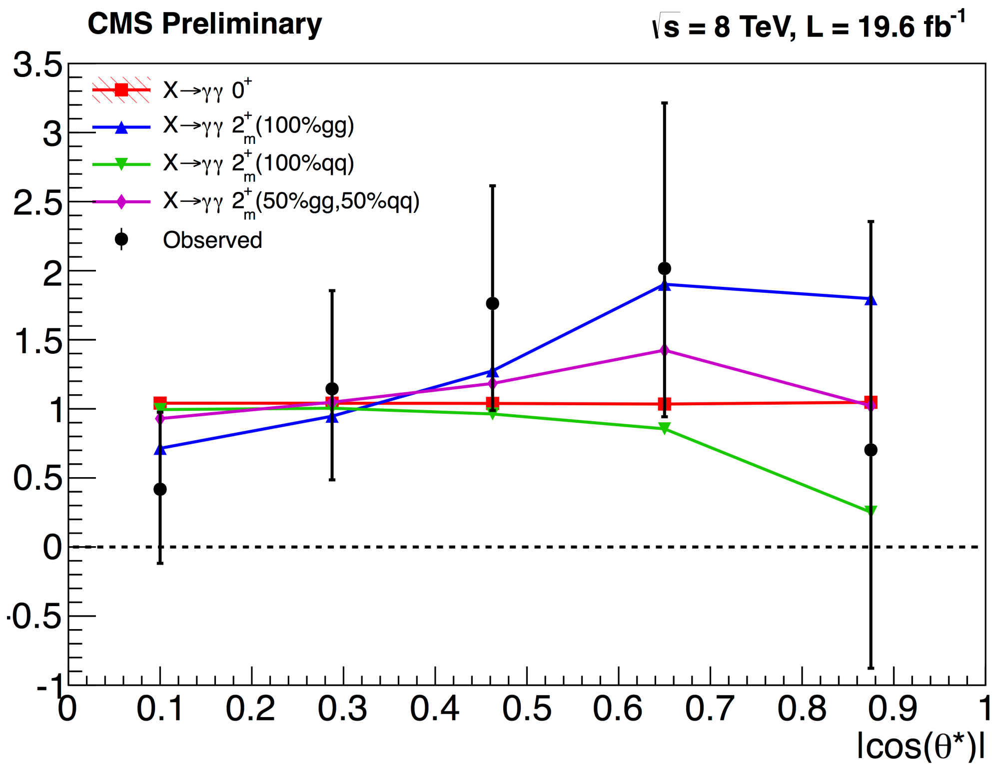




Spin/Parity measurement
HIG-13-016

- Landau-Yang: resonance observed in $H\rightarrow\gamma\gamma$ **cannot be spin 1**
- Cannot measure directly spin (too many parameters in the lagrangian, not enough statistics) => Need to **test some reasonable benchmark models**
- Test **spin 2^+ model with minimal couplings: graviton-like coupling**
- Initiated by **gluon fusion** or **qq**
- Use angular distribution: **diphoton angle in the Collin-Sopper frame**
- So far compatible with both hypothesis





Conclusions

Photon physics important probe of perturbative QCD

- Inclusive photon and photon+jets measurements in agreement with NLO and matched extra-jets generators at LO
- Diphoton Data/Theory predictions improved with NNLO predictions. Collinear regime still difficult.

Impact of photon on pdfs

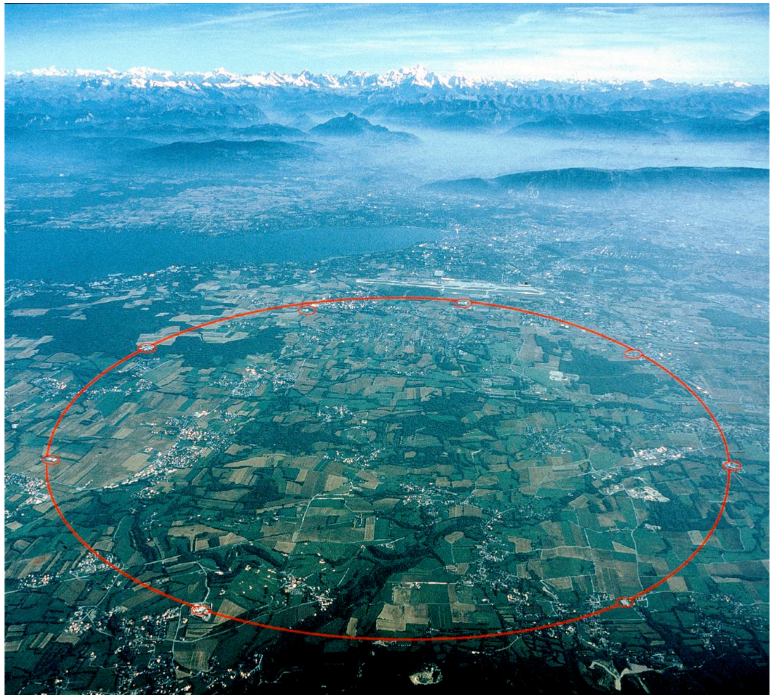
- Inclusive photon improves uncertainty on gg→H cross-section by 20%, analysis to be repeated will full Run 1 data

H→γγ searches

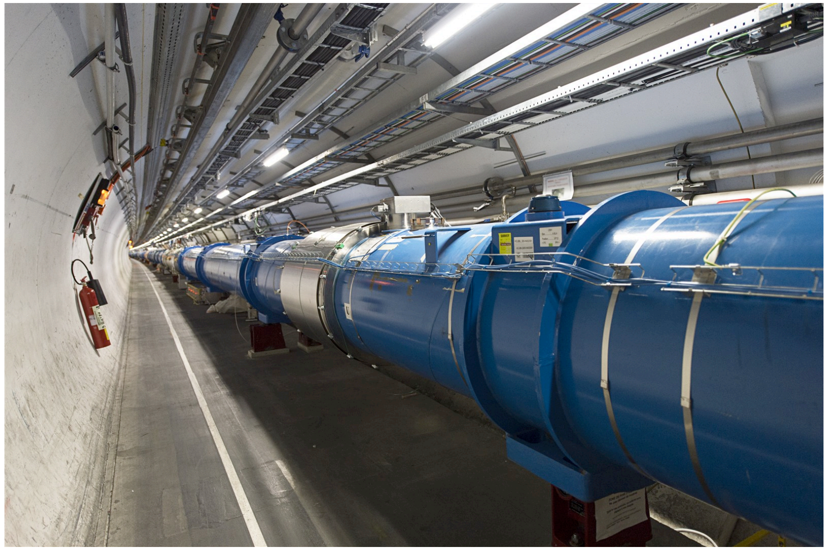
- Rely on excellent ECAL calibration
- **Observed local significance above 3.2σ (expected 4.2σ)**
- Measure best fit **μ=0.78 ± 0.27 at 125 GeV**
- **Mass measurement** 125.4 ± 0.5(stat.) ± 0.6(syst.)
- VBF, VH, ttH channels are investigated

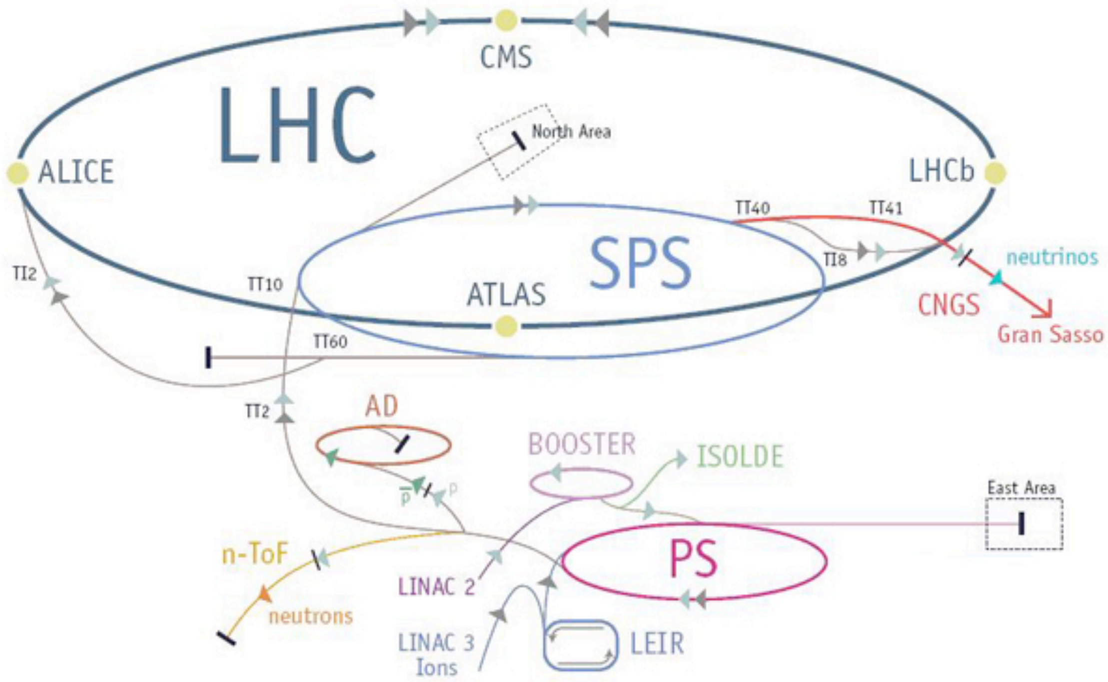
BACK-UP SLIDES

Large Hadron Collider (LHC)

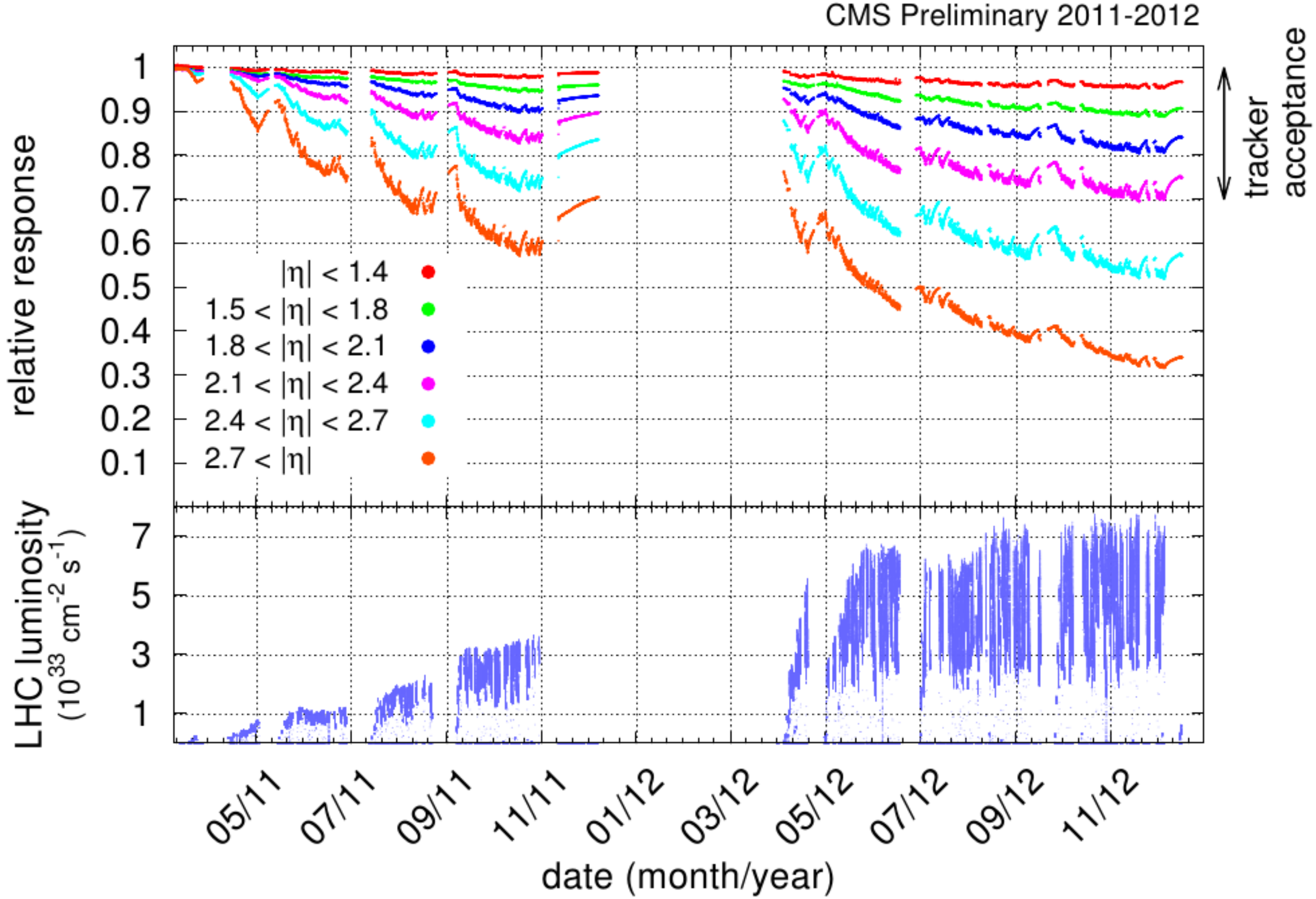


- **Proton-proton** collider at **CERN**, Geneva
- 27 km circumference, fully supra-conducting magnets at 100m depth
- 7 TeV center of mass energy in 2010 and 2011, 8 TeV in 2012
- Instantaneous luminosity: reached peak 7.7×10^{33} $cm^{-2}s^{-1}$

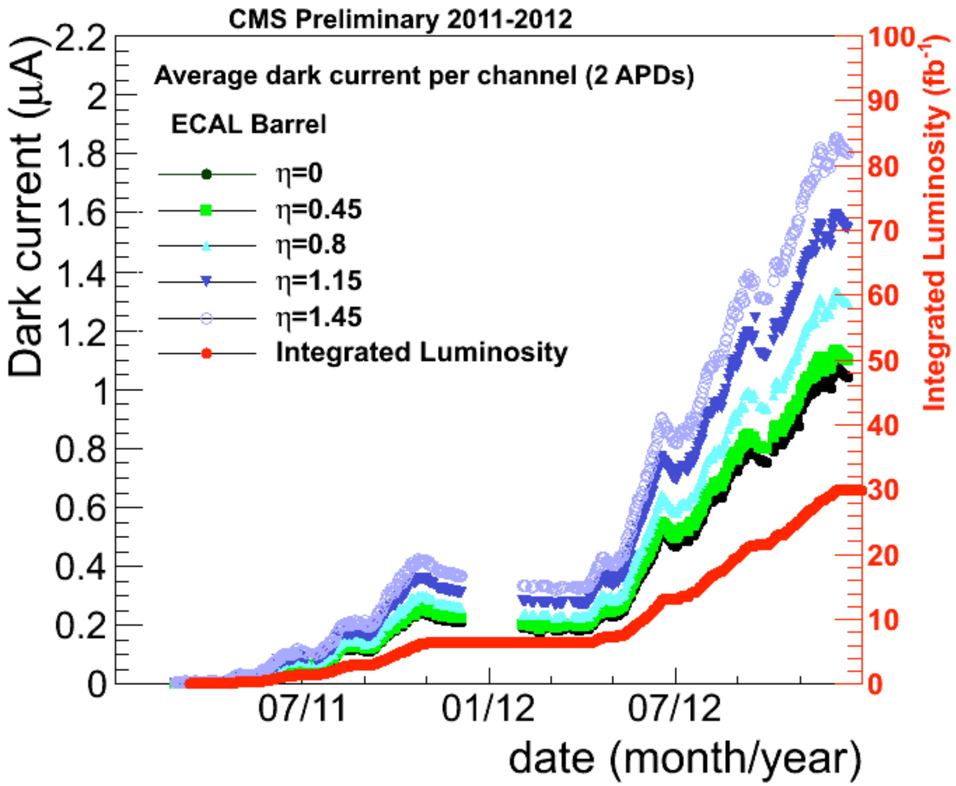


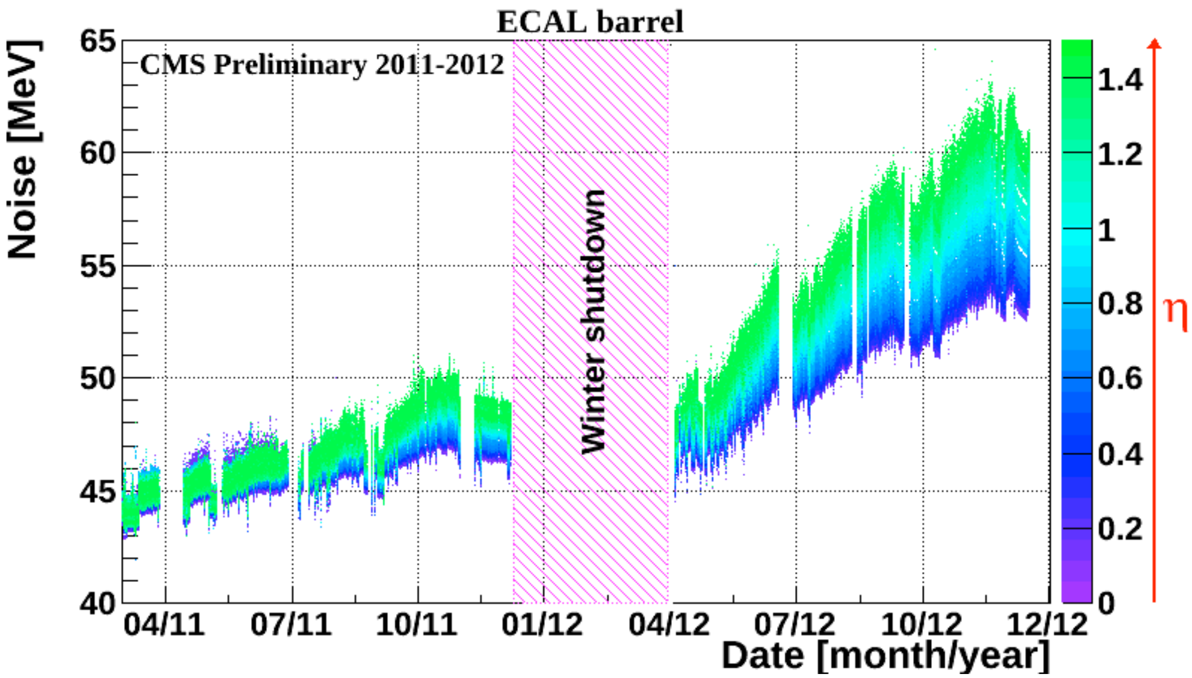


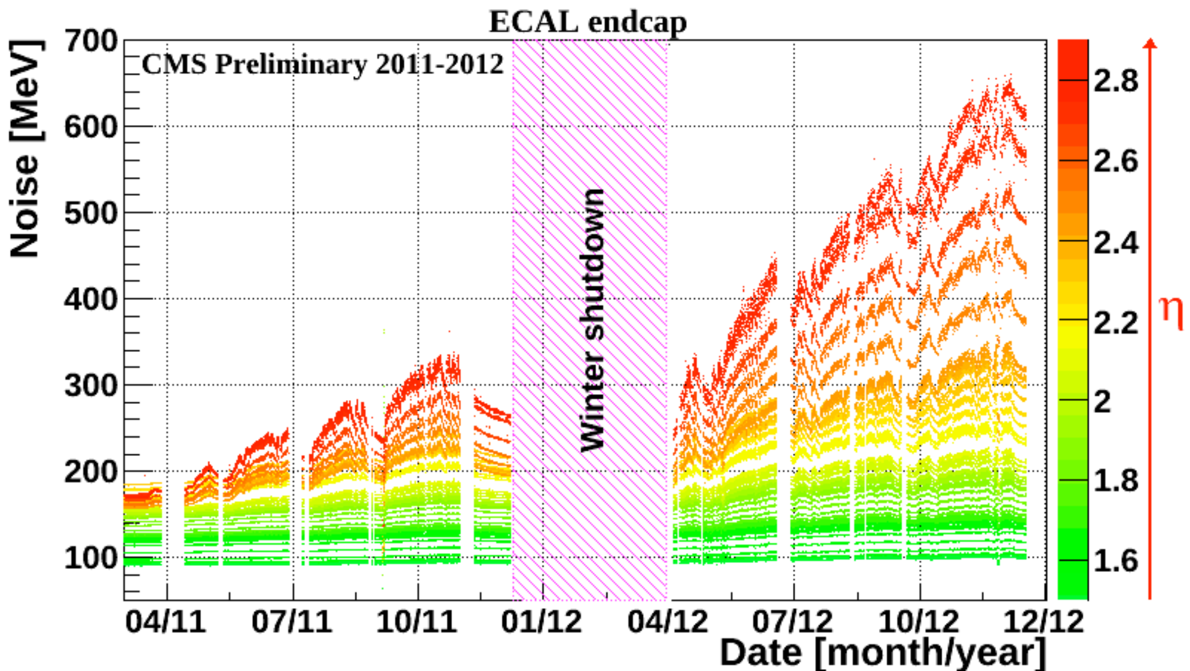
Laser monitoring



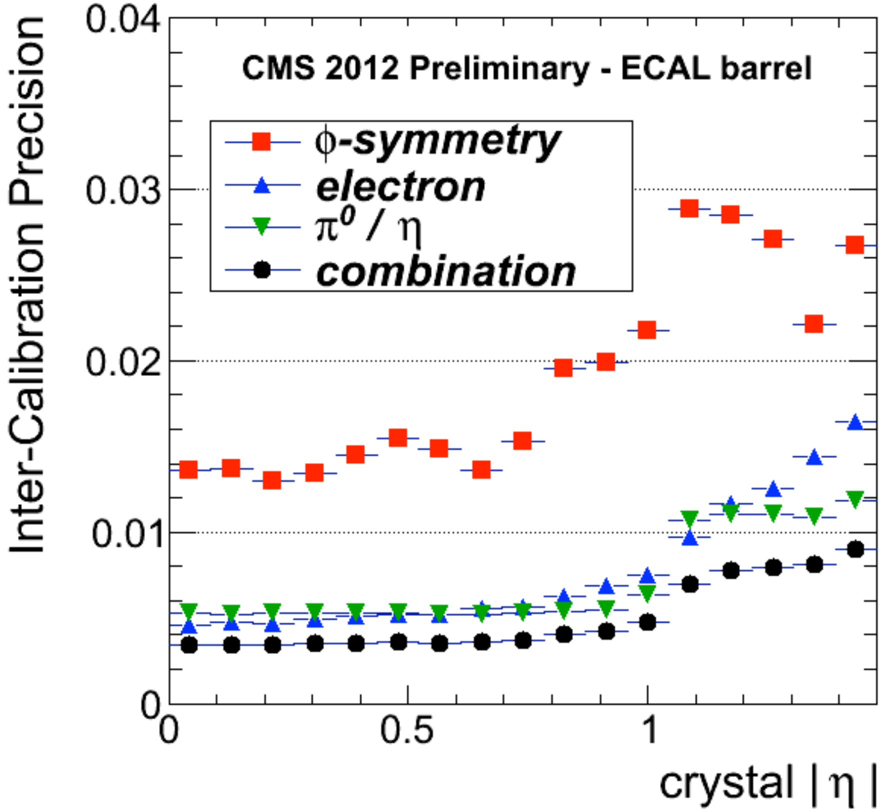
Noise in APD/VPT

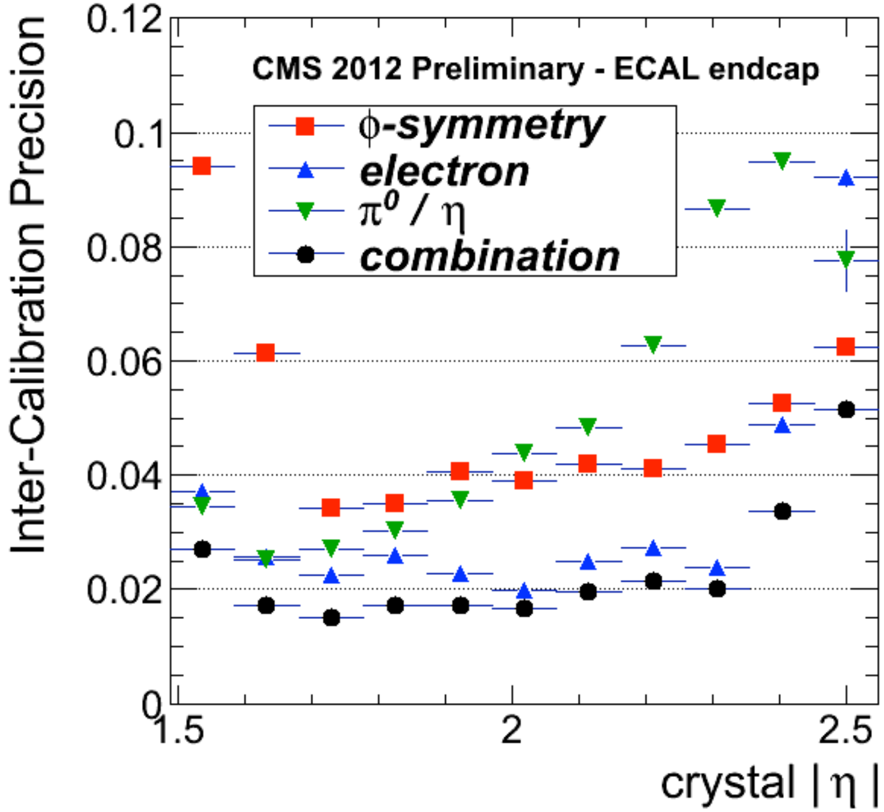




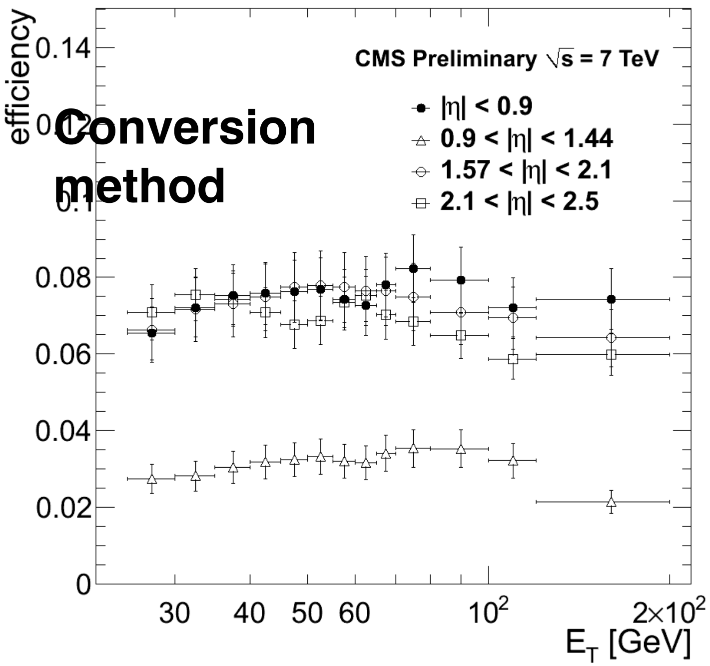


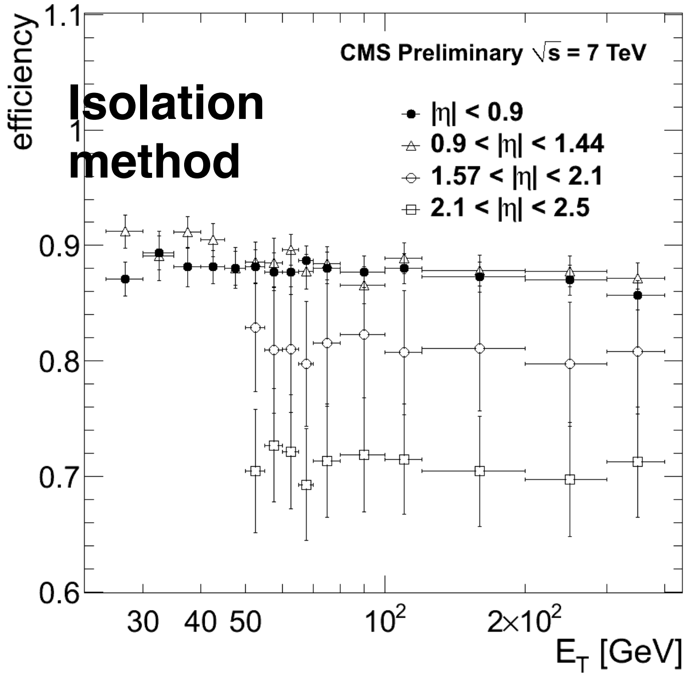
Intercalibration precision





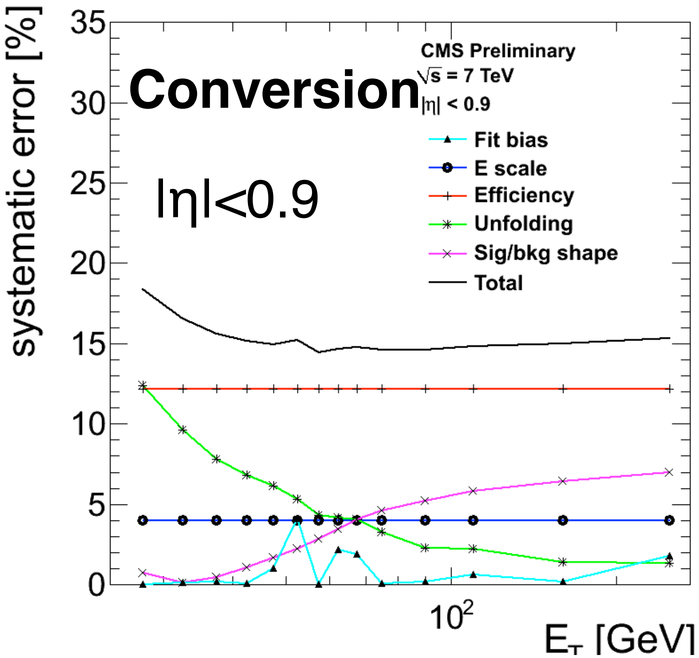
Inclusive photon: efficiency

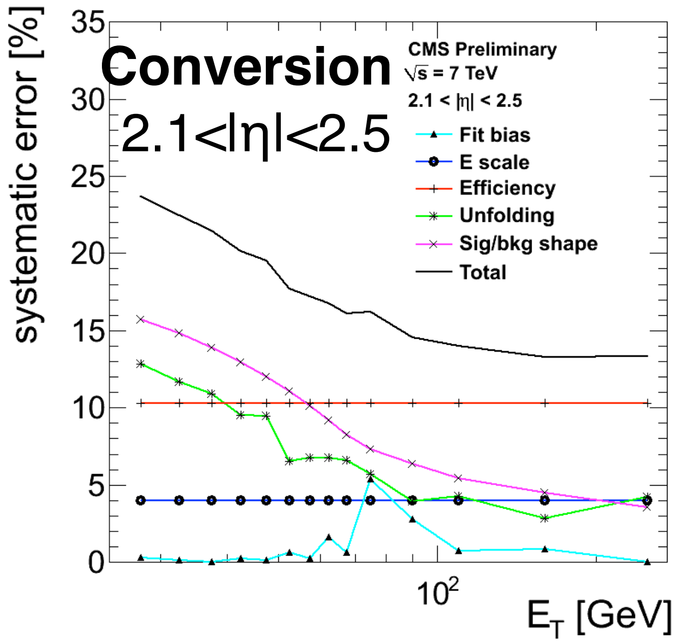




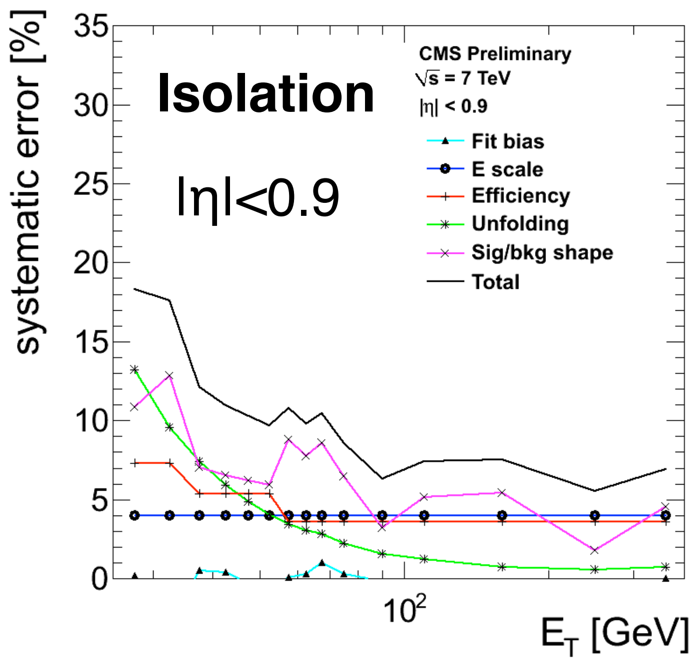
Inclusive photon: systematics

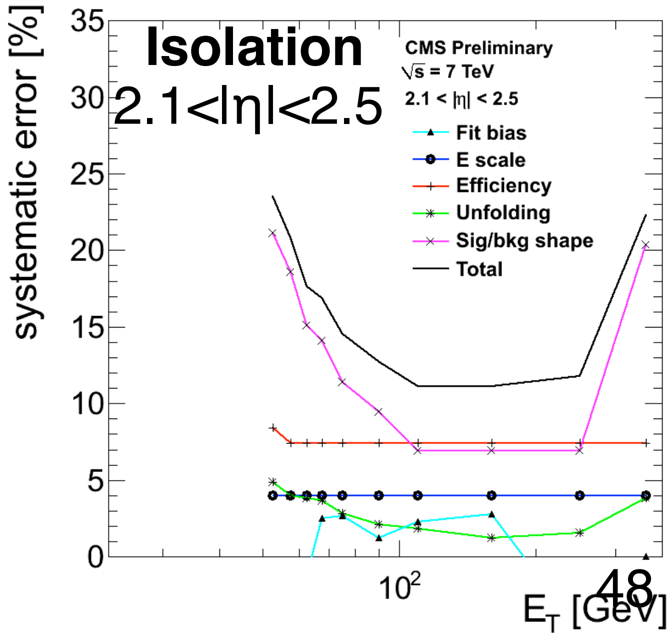
Conversion method : biggest uncertainty from conversion efficiency, estimated conservatively





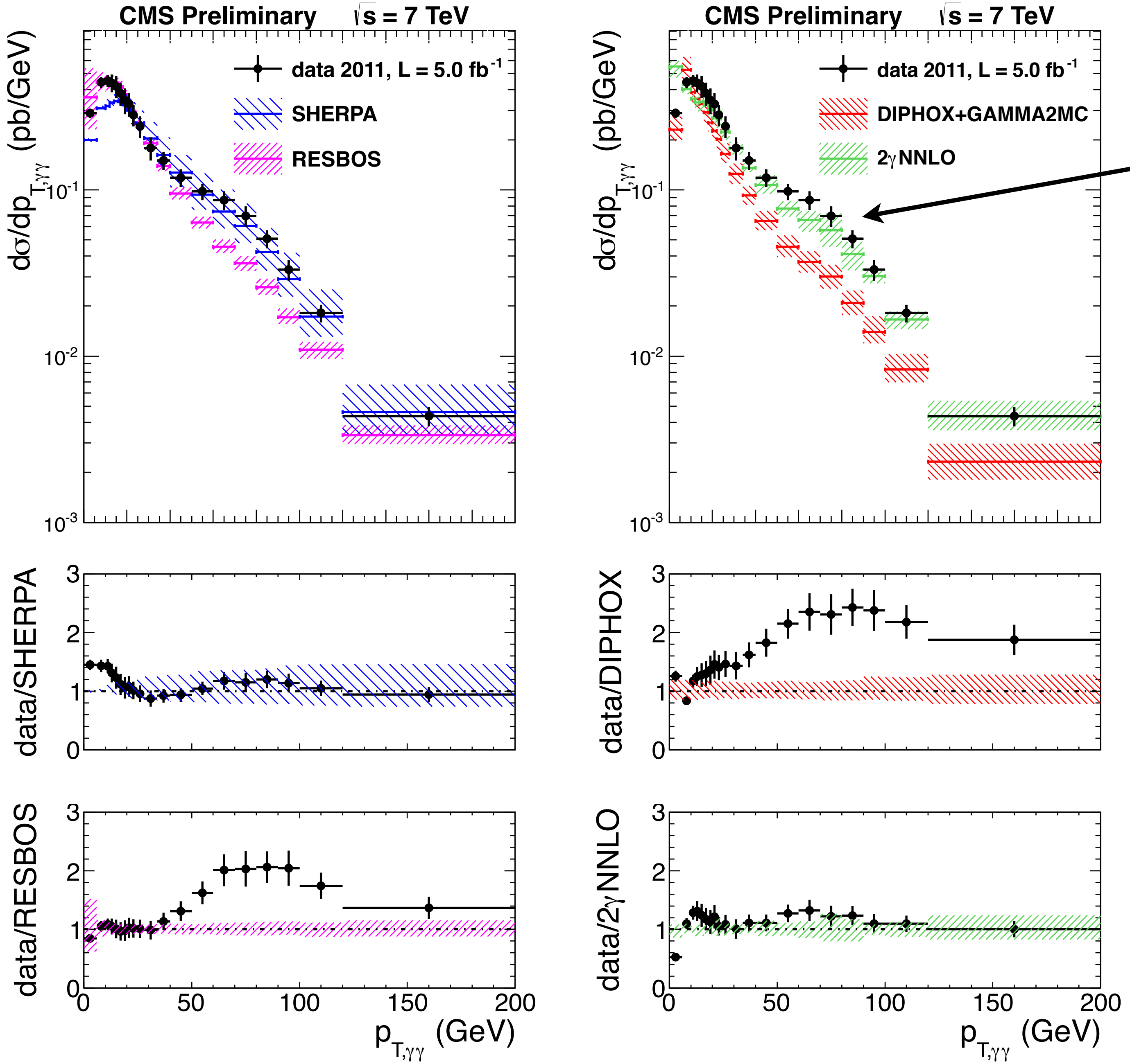
For **isolation method,** the biggest uncertainty comes from the signal and background shapes





Diphoton cross-section

SMP-13-001, 5.0fb^{-1} at 7 TeV



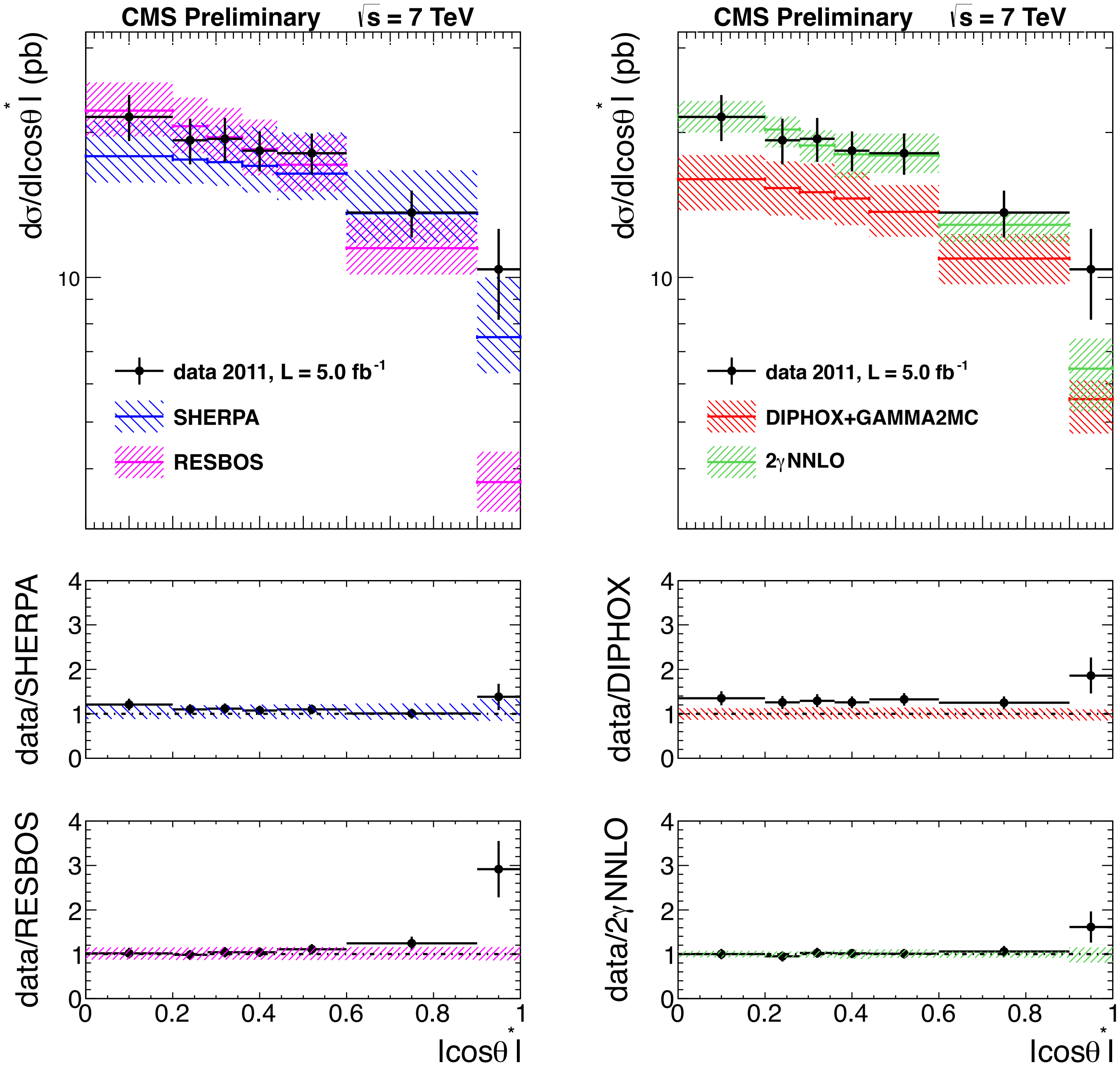
Kink at $p_{T1}+p_{T2}$, not completely reproduced by Sherpa or NNLO

- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (up to 3 ME extra-jets) shows also a good agreement

Diphoton cross-section

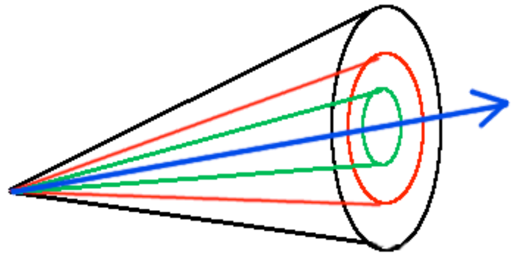
SMP-13-001, 5.0fb^{-1} at 7 TeV



- **NNLO** predictions improve a lot the data/MC agreement

- **Sherpa** (up to 3 ME extra-jets) shows also a good agreement

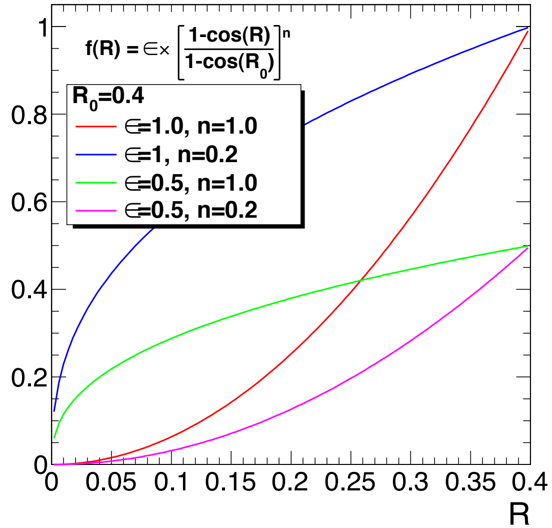
Suppression de la composante de fragmentation

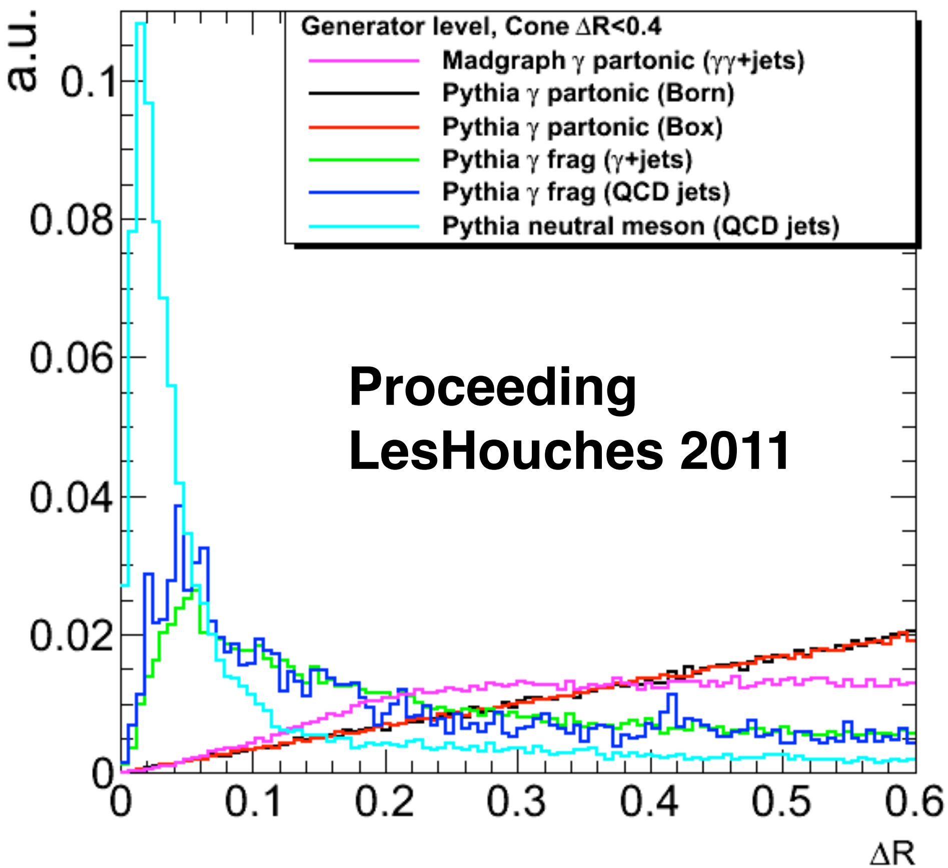


Isolation Frixione

$E_T^{iso} < f(R)$

$f(R) \rightarrow 0$ quand $R \rightarrow 0$

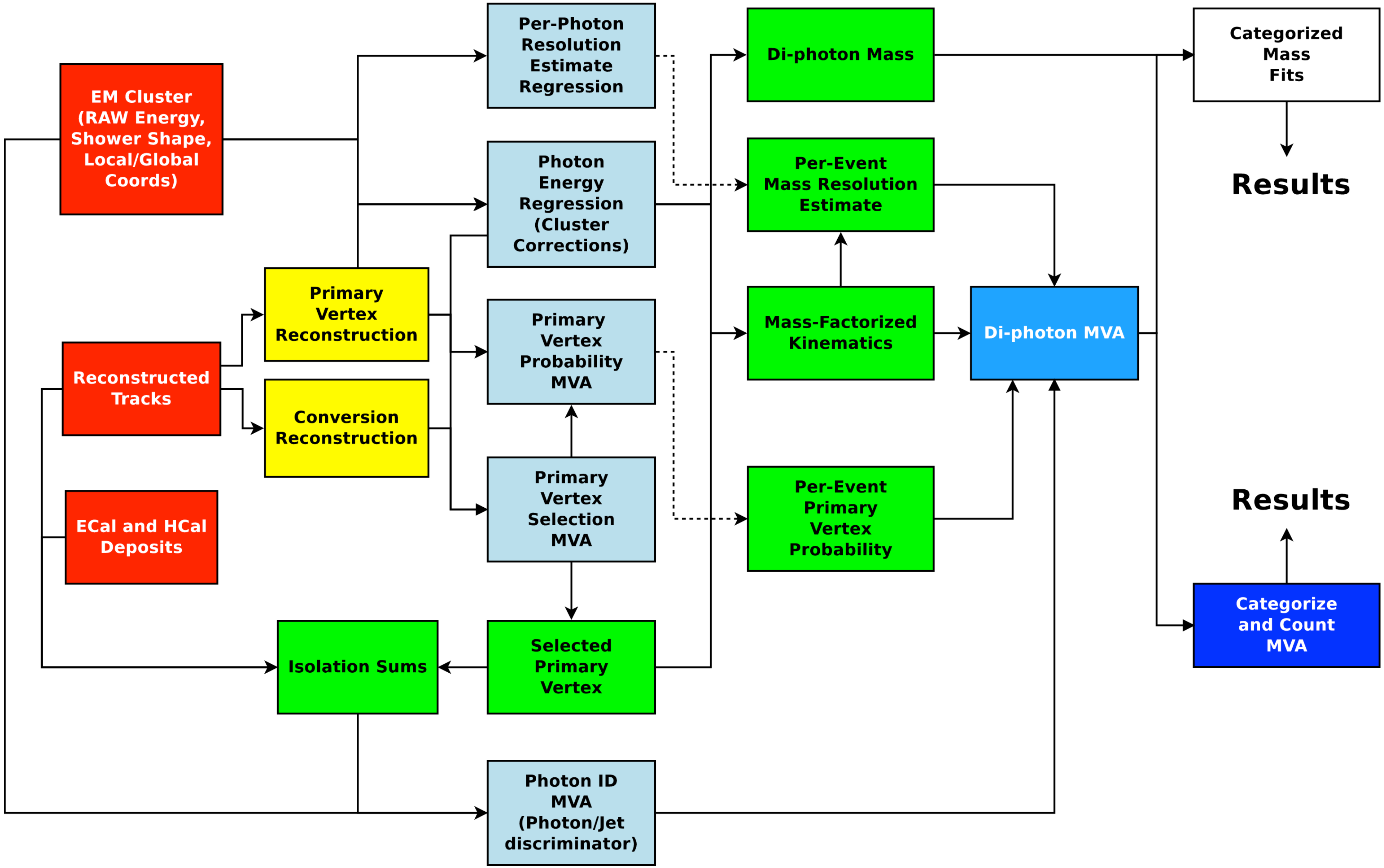




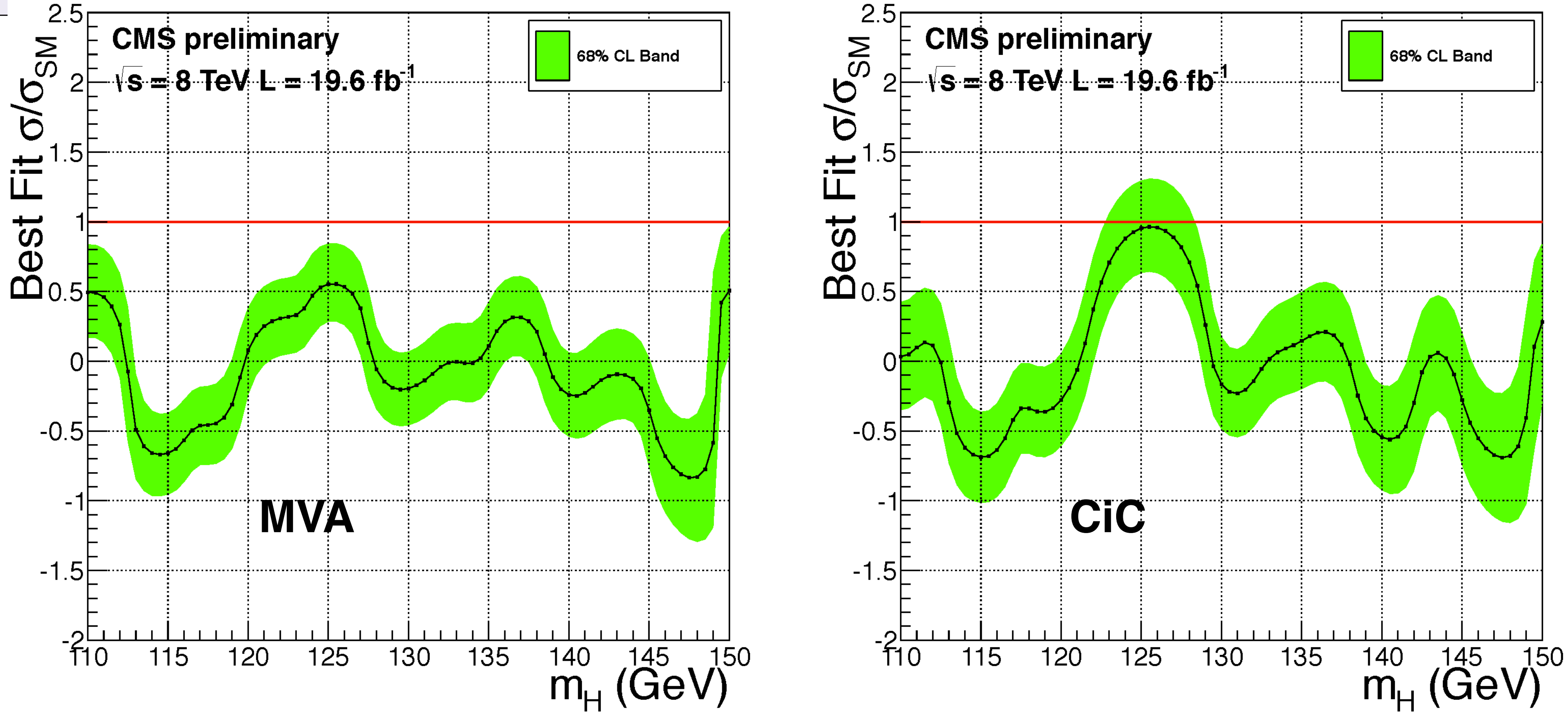
Critère Frixione pour la réduction de la composante de fragmentation dans les générateurs à gerbe partonique (PS) :

- Débris de **fragmentation non colinéaire dans les générateurs PS**

$H \to \gamma\gamma$ flowchart



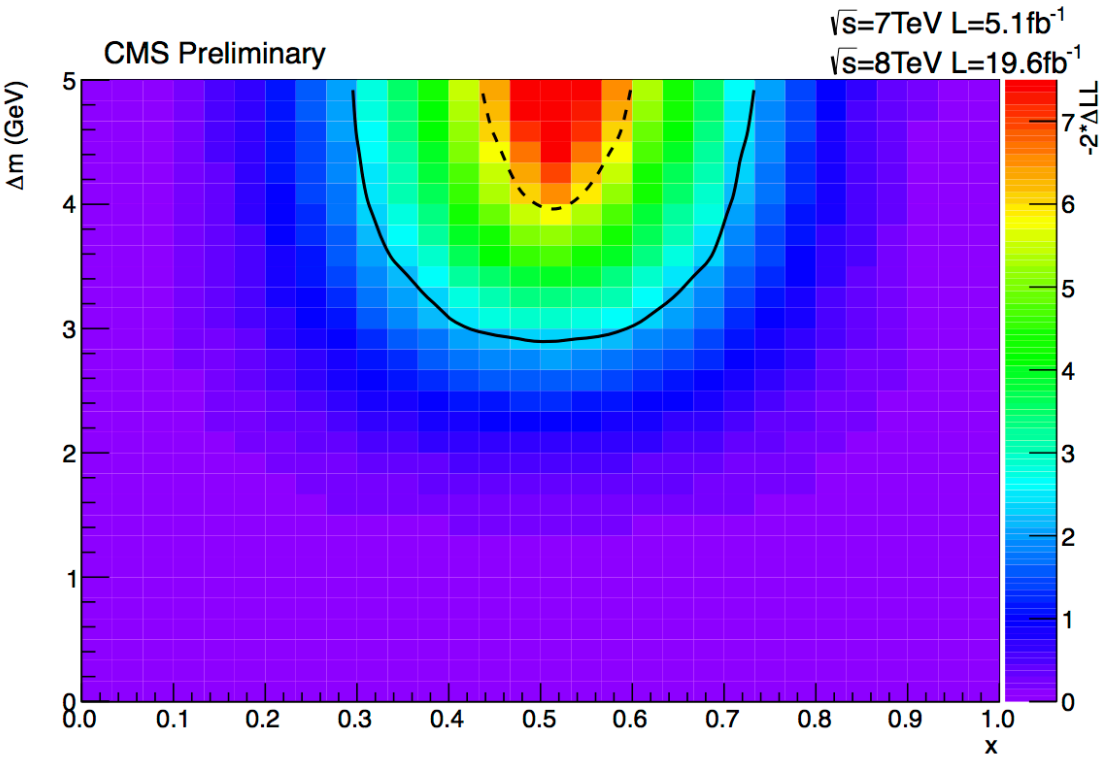
H→γγ 8 TeV only



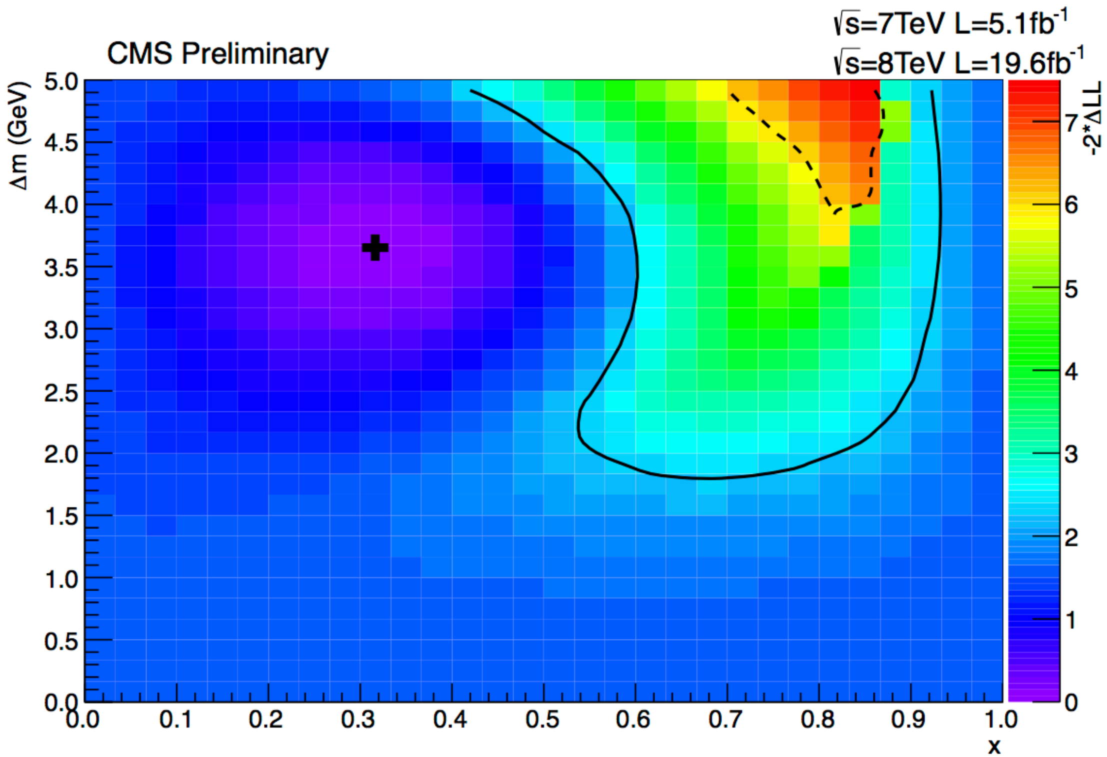
	MVA analysis (at m_{H}=125 GeV)	cut-based analysis (at m_{H}=124.5 GeV)
7 TeV	$1.69^{+0.65}_{-0.59}$	$2.27^{+0.80}_{-0.74}$
8 TeV	$0.55^{+0.29}_{-0.27}$	$0.93^{+0.34}_{-0.32}$
7 + 8 TeV	$0.78^{+0.28}_{-0.26}$	$1.11^{+0.32}_{-0.30}$

H→γγ additional state

Expected



Observed



Coupling measurement

Model: EFT with the chiral lagrangian in the EW sector

- Grojean et al. [arXiv:1207.1717], Azatov et al. [arXiv:1202.3415], Kuflik et al. [arXiv:1206.4201]...
- **Assumptions:** spin-parity 0+, new other states are heavy enough, EWSB possesses a custodial symmetry, no FNCN at three level with the Higgs, kinematics not affected

$$L = c_V \frac{2m_W^2}{v} W_\mu^+ W_\mu^- + c_V \frac{2m_W^2}{v} Z_\mu Z_\mu - c_b \frac{m_b}{v} h\, \bar{b}b - c_\tau \frac{m_b}{v} h\, \bar{\tau}\tau$$
$$+ c_g \frac{\alpha_s}{12\, \pi\, v} h\, G_{\mu\nu}^a G_{\mu\nu}^a + c_\gamma \frac{\alpha}{\pi\, v} h\, A_{\mu\nu} A_{\mu\nu} + c_\chi\, h \bar{\chi}\chi$$

- A simplified **model is recommended by the LHC Higgs Low Mass WG** [arXiv:1209.0040], to be used by ATLAS and CMS to measure Higgs couplings
- Higgs production cross-sections and branching ratios are scaled by various parameters
- **Coupling to bosons (κ_V) and fermions (κ_f):**

$$\text{Free parameters: } \kappa_V (= \kappa_W = \kappa_Z), \kappa_f (= \kappa_t = \kappa_b = \kappa_\tau)$$
$$\kappa_i^2 = \Gamma_{ii} / \Gamma_{ii}^{SM}$$

High mass diphotons

EXO-11-038, 1.1fb-1 at 7 TeV