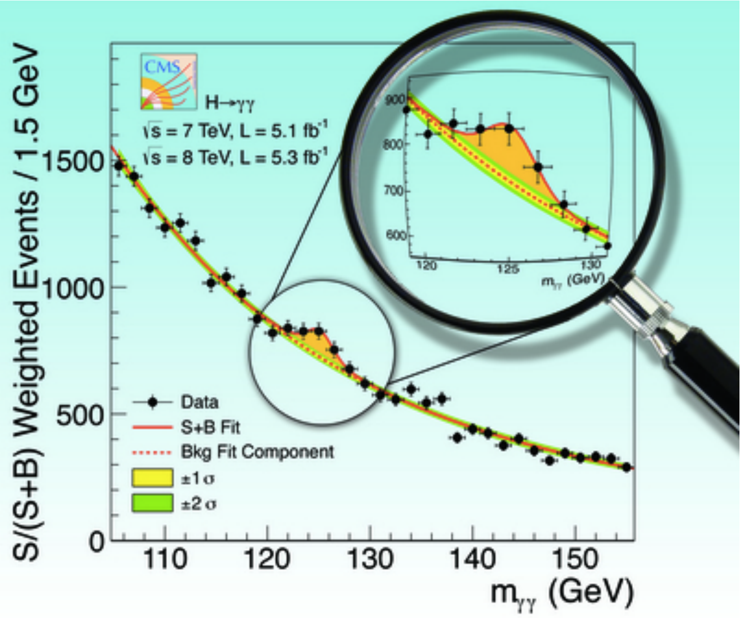

Searches of the Higgs boson in the diphoton decay mode at CMS

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Università and INFN - Milano Bicocca

2014, Dec 5th, LAL Orsay

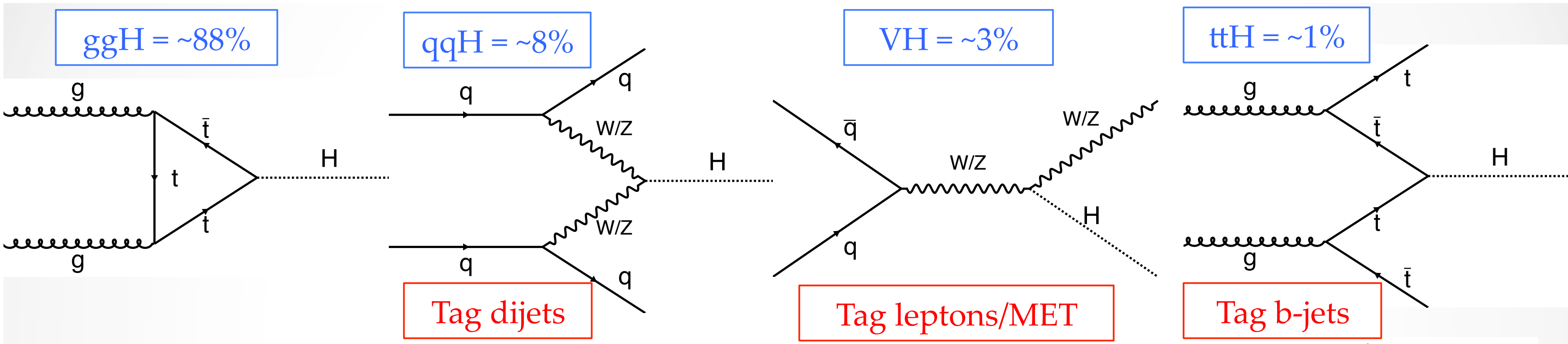
Talk's overview

[EPJ C (2014) 74:3076]

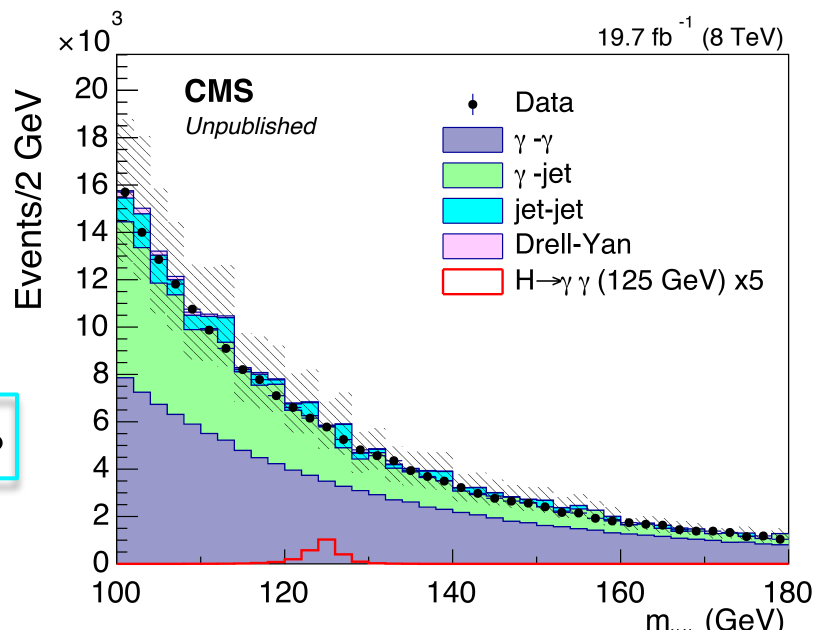
- 2012, Jul – Higgs boson discovery by ATLAS and CMS
- 2013, Feb – Preliminary CMS results on the full dataset (Moriond)
  - **5.1 fb^{-1} at $\sqrt{s}$=7 TeV and 19.7 fb^{-1} at $\sqrt{s}$=8 TeV**

- **2014, Jul – improved analysis of the full dataset:**
  - **Optimized performance of energy reconstruction**
  - **New method for modelling the background**
    - Sensitivity +30%
  - **Accurate modelling and study of the photon response**
    - Systematic uncertainty on mass reduced by 1/3
  - **Selection optimization including tags for exclusive production modes**
    - Improved sensitivity to specific couplings
  - *With details from photon reconstruction paper being submitted*

Higgs production and H→γγ decay



- **Low BR ~ 0.2%, but clean signature**
  - **Narrow resonance of two high-E_T isolated photons**
  - Can reconstruct mass with high precision:
    - $m_{\gamma\gamma} = \sqrt{2E_1E_2(1\text{-}\cos\alpha)}$
- **Sizable continuum background**
  - γγ = 70% | γ+jet = 30% | jet+jet < 1%
- **Quest on the detector:**
  - Excellent energy and angle resolution
  - Excellent photon identification (against π^0 from jets)



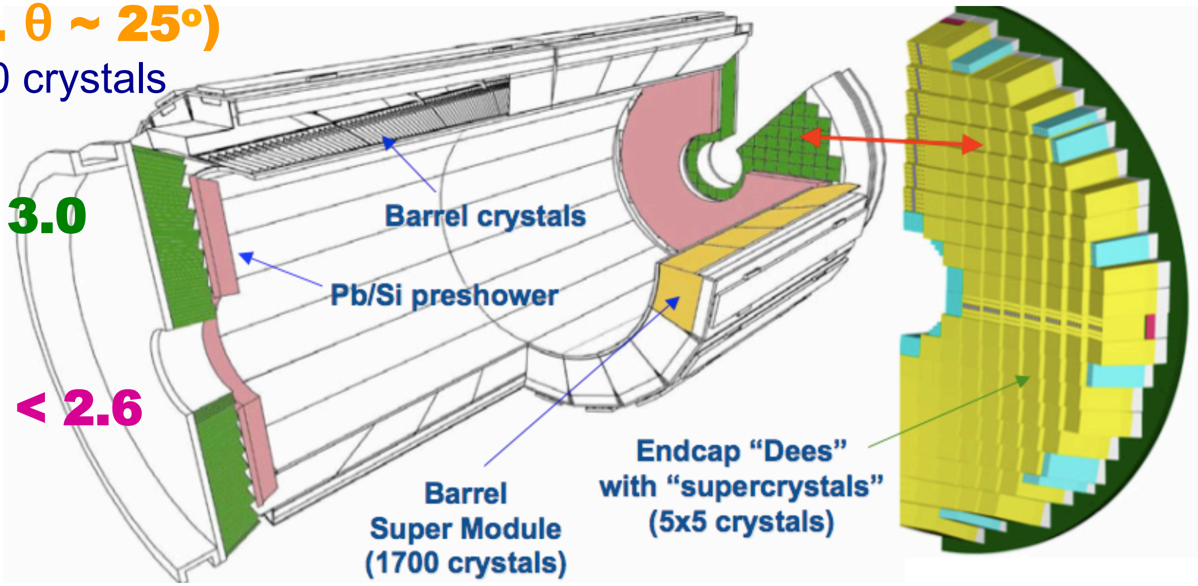
The CMS ECAL

- **Homogeneous, compact, hermetic, fine grain $PbWO_4$ crystal calorimeter**
  - → Emphasis on energy resolution
  - → No longitudinal segmentation (except preshower)

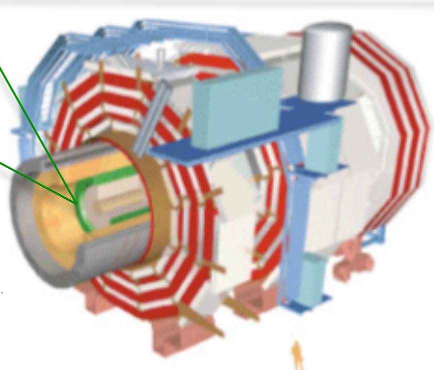
- **Barrel: $|\eta| < 1.48$ (i.e. $\theta \sim 25^o$)**
  - 36 Super Modules: 61200 crystals
  - ($2.2\times2.2\times23$ cm^3) **~$26X_0$**

- **Endcaps: $1.48 < |\eta| < 3.0$**
  - 4 Dee's:14648 crystals
  - ($2.6\times2.6\times22$ cm^3) **~$25X_0$**

- **Preshower: $1.65 < |\eta| < 2.6$**
  - **$3X_0$** of Pb/Si strips
  - 1.90×61 mm^2 x-y view



- **CMS Characteristics:**
  - Tracker coverage: $|\eta| < 2.5$;
  - CMS Magnetic field: B = 3.8 T
  - ECAL fully contained inside the coil



Measurement strategy

1. Photon energy:
- Clustering **independent** of particle type
- Calibration and corrections
  - ***Estimate per-photon resolution***

2. Photon identification
- Shower shapes and isolation variables
  - ***Estimate per-photon quality***

- **Signal model from simulation:**
  - Same corrections on $e^{\pm}$ and γ
- ***Z → ee events to model*** detector response (i.e. tune MC simulation): ***photon energy scale, resolution, and efficiencies***

3. Vertex identification:
- Select vertex among ~20 concurrent collisions (*pileup*)
- ***Per-event probability of correct vertex assignment***

- **Event selection and analysis categories:**
  - All event information in one BDT discriminating variable
    - ***Event kinematics, resolution, photon quality***
  - Dijet BDT + Exclusive mode tags (VBF, VH, ttH)

- **Global fit: signal model + parametric background**

+ systematic uncertainties

BDT = Boosted Decision Tree

Energy reconstruction at CMS

$$E_{e,\gamma} = \mathcal{G}\,\mathcal{F}_{e,\gamma}\sum_i c_i s_i(t)\mathcal{A}_i$$

① **Response uniformity**

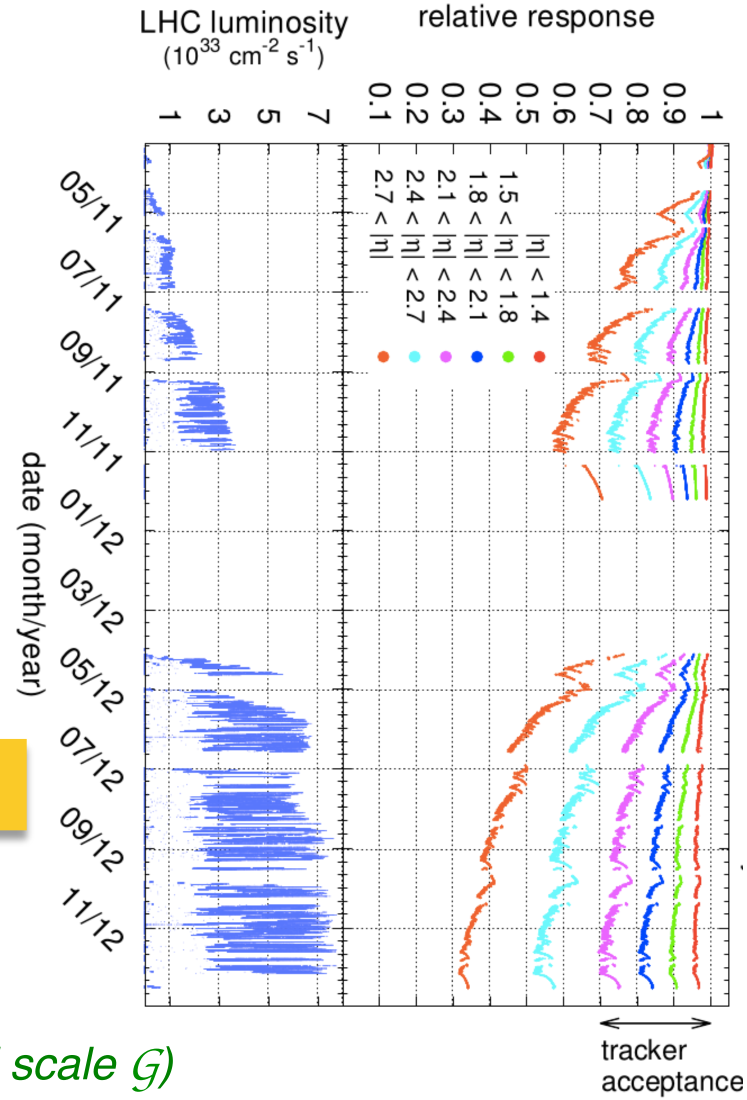
- Crystal light yield (LY) spread *~ 10%*
- Endcap VPT response spread *~ 25%*
  - *Intercalibration*

② **Response stability**

- LY variation with temperature: *-2.2%/ ºC*
- Gain variation (Barrel APDs):
  - *ΔG/ΔT = -2.4%/ ºC; ΔG/ΔV = 3.1%/V*
- Transparency variation with radiation
  - *Stabilization and response corrections*

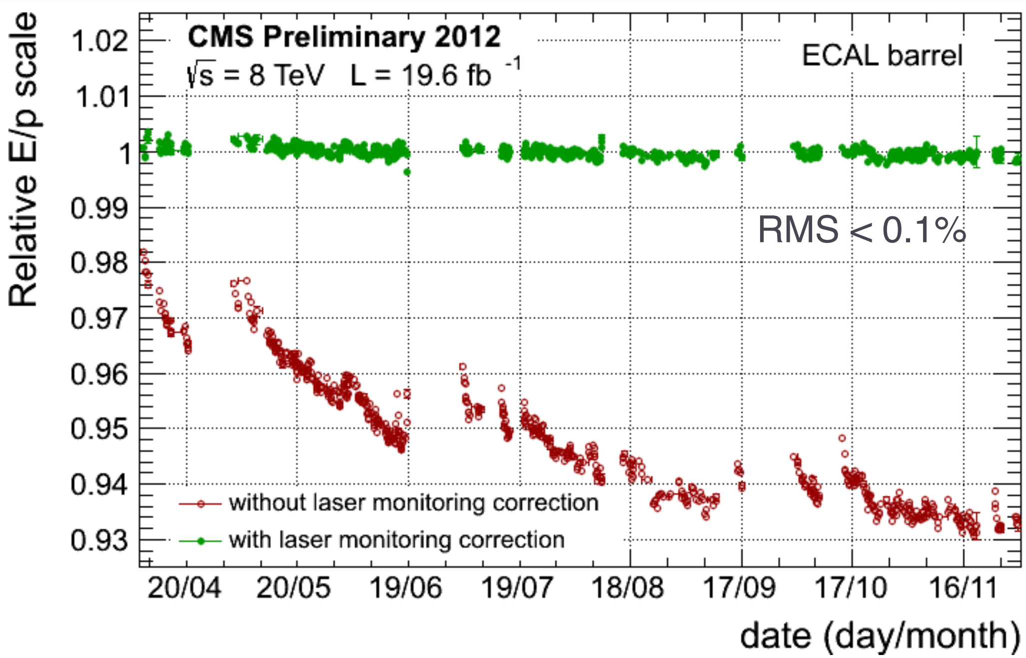
③ **Geometry, tracker material and B field**

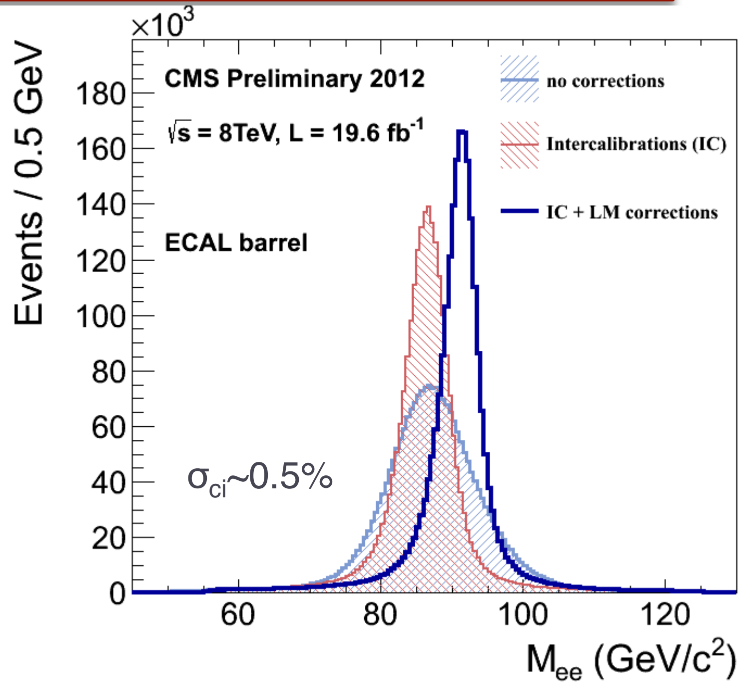
- Photon conversions
- Energy spread along φ at ≈ constant η
  - *Clustering and energy corrections (+ global scale $\mathcal{G}$)*



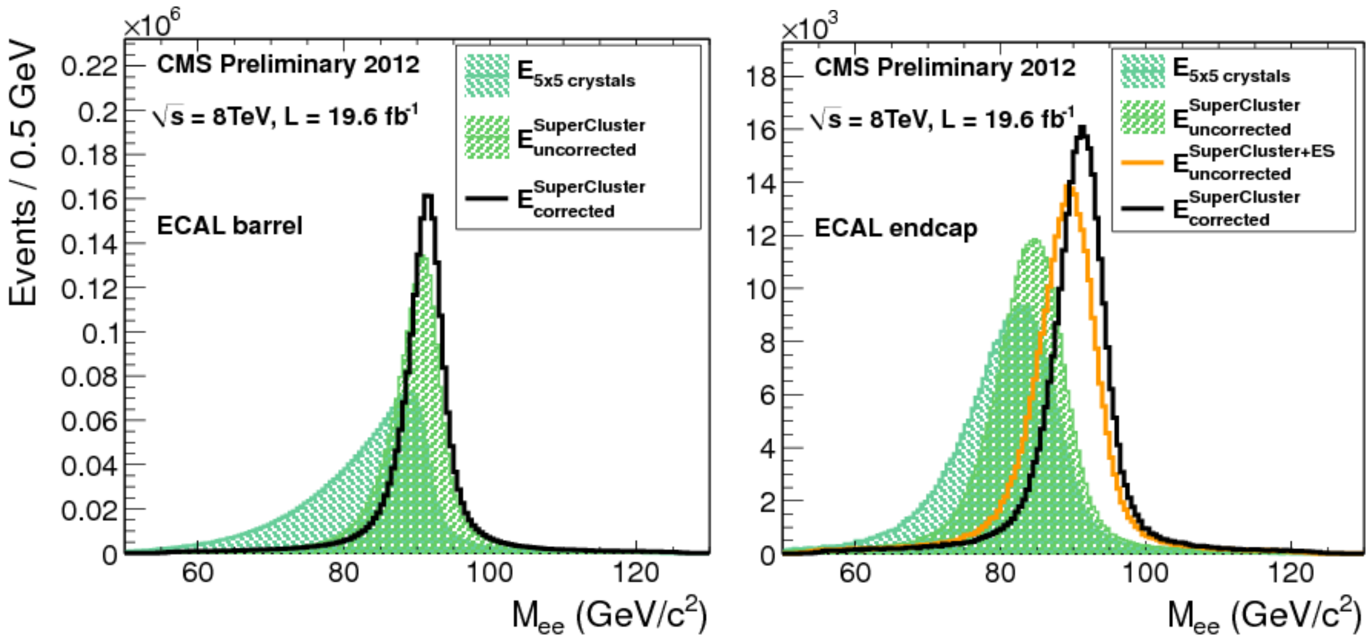
Single crystal calibrations

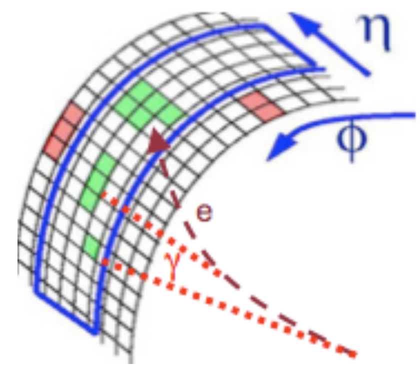
- **Intercalibration and transparency corrections**
  - One transparency measurement (laser light) each crystal every 40 min
  - Monthly intercalibration: $\pi^0/\eta \rightarrow \gamma\gamma$ mass, ϕ-invariance of energy flow
  - Once per year: electron E/p and Z→ee mass
- **By construction $<c_i> = 1$, $s_i(t=0) = 1$**
  - Intercalibration and corrections affect resolution, not the energy scale!





Clustering and energy corrections





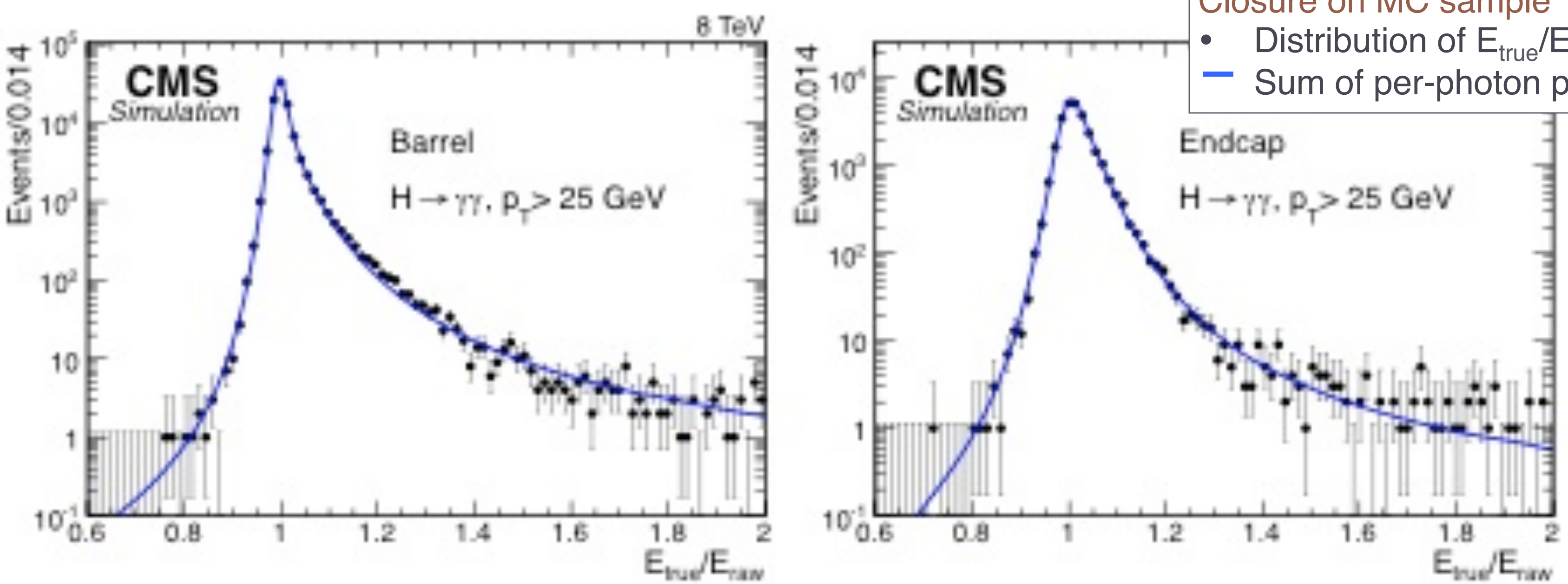
- **Dynamic clustering to recover energy radiated upstream of ECAL**
  - **Super-clusters** of clusters along ϕ (bending direction)
- Ratio of energy in fixed array to super-cluster energy convenient to classify e/γ with radiation/conversions (e.g. **R9=E_{3x3}/E_{SC}**)

- **Energy corrections ($F_{e/\gamma}$) based on MC simulation**
  - *Global (material distribution) and local (voids between crystals) coordinates, shower shape variables (radiation effects), pileup variables, …*

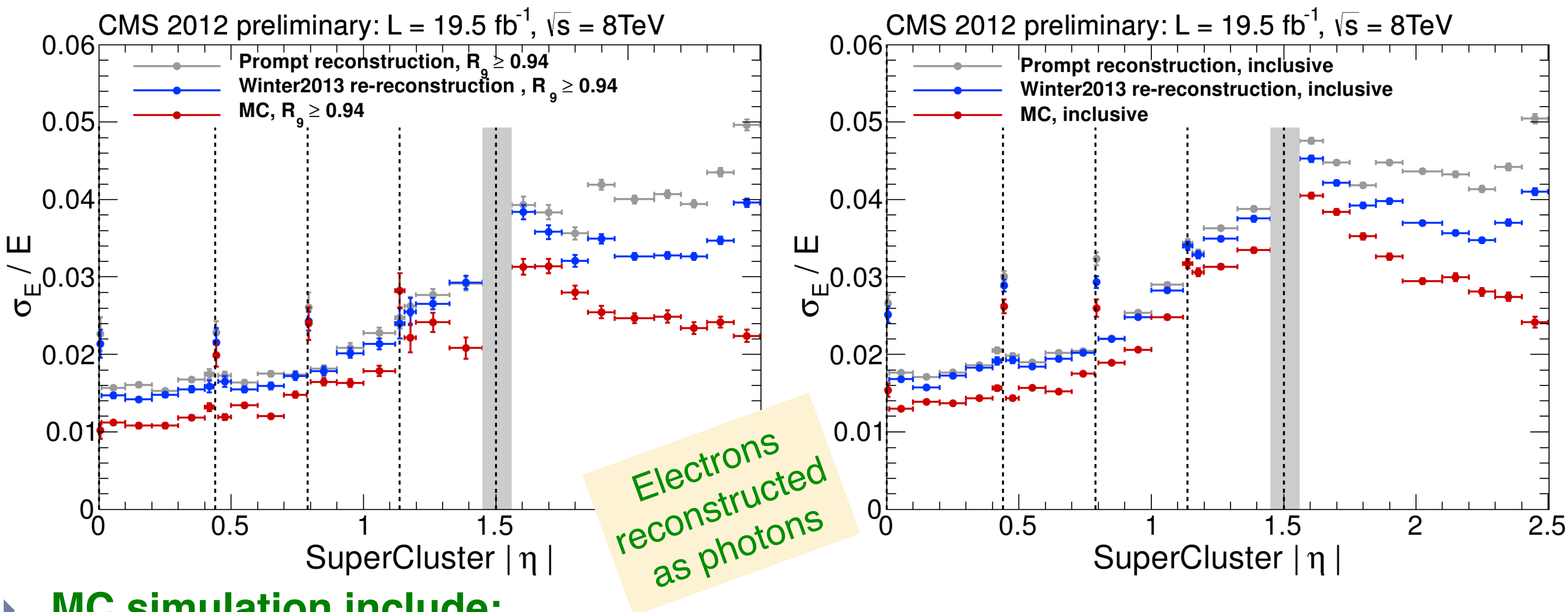
Photon energy corrections

- **Improved input:**
  - Time-dependent simulation (**8 TeV only**) → improved shower shapes
    - *Pileup* in extended time window, equivalent noise and *pileup* evolution
- **Improved BDT algorithm:**
    - *Predict parametric E_{true}/E_{raw} p.d.f. (Gauss+ Crystal-Ball wings)*
  - Corrected energy from the mode
  - Per-event resolution "from the p.d.f. spread" >> input to diphoton BDT

Closure on MC sample
- Distribution of E_{true}/E_{raw}
- Sum of per-photon pdf's



Test resolution with Z → e^+e^-

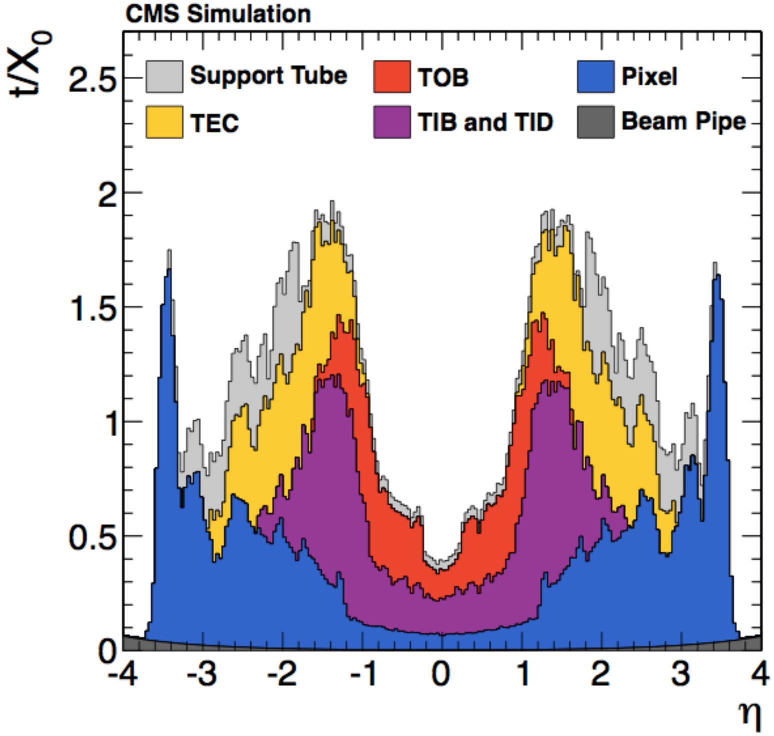


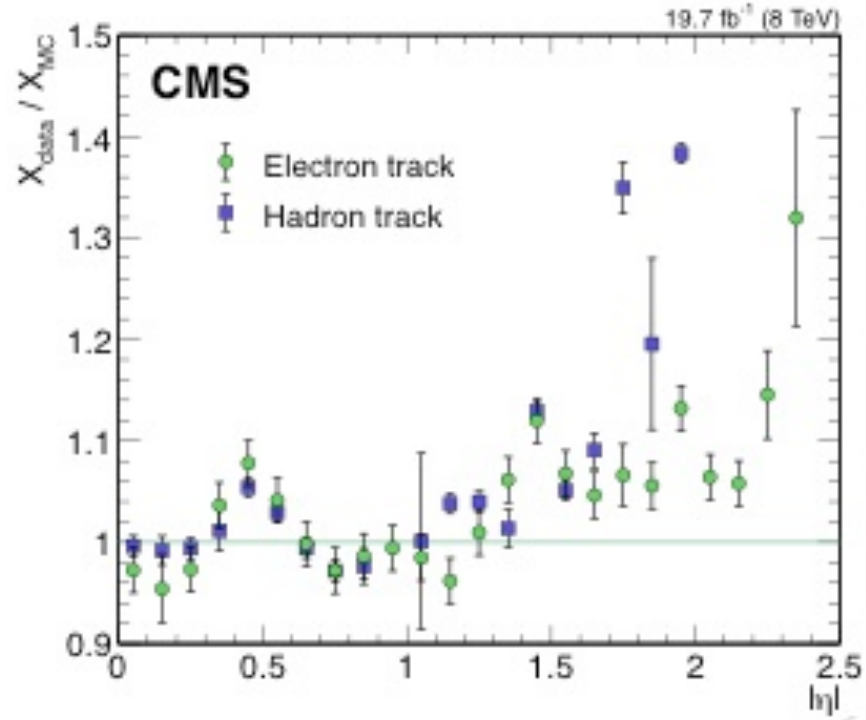
- **MC simulation include:**
  - Geant4 (version 9.4.p03)
  - *Best (prior) knowledge of tracker material*
  - *Ideal ECAL geometry (voids between crystals)*
  - *Single channel residual miscalibration*
  - Digitization with *in-situ* noise spectrum, and pileup
  - Photostatistics and constant term according to test beam results

Match data/MC simulation:

- Add Gauss resolution term to MC: **$a / \sqrt{E_T}$ (+) c**
- Adjust data scale in bins of **R9, η, E_T**

Example of imperfect simulation

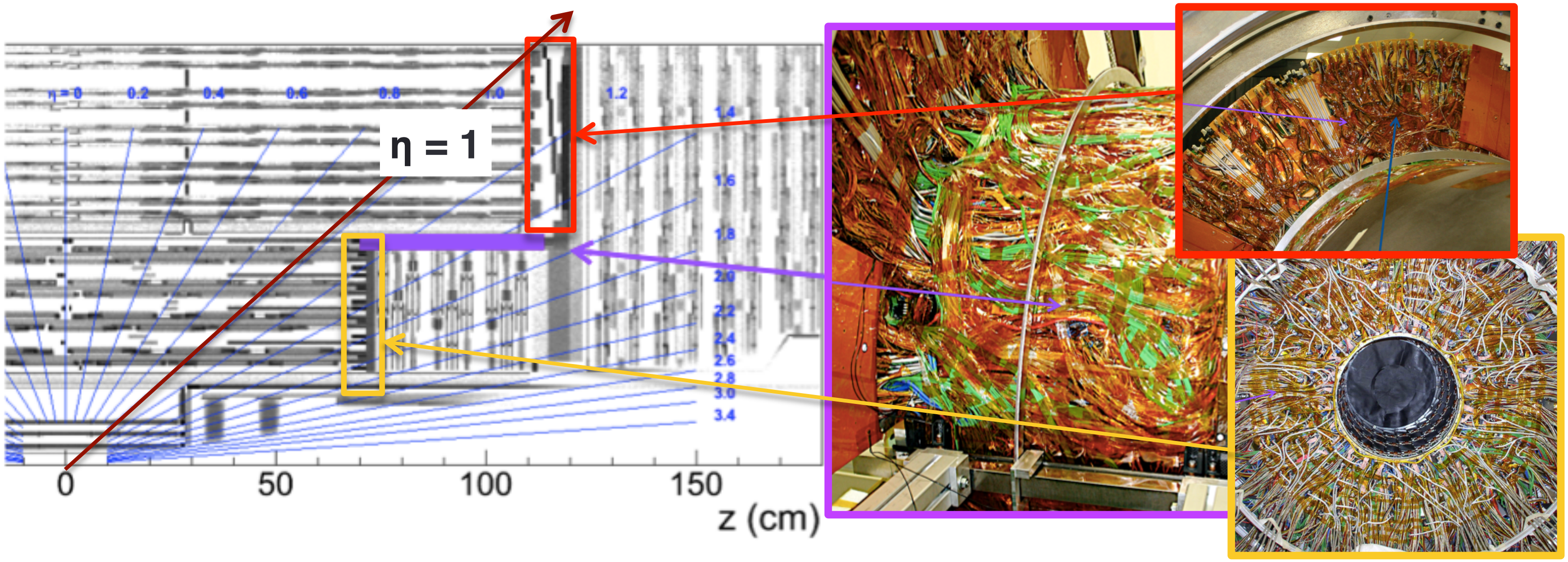




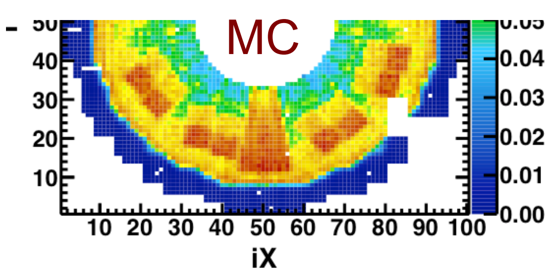
- **Data/MC Tracker material thickness in x_0 from:**
  - Bremsstrahlung of electrons $f = (p_{vtx}-p_{out})/p_{vtx}$
  - Multiple scattering of low momentum pions
    - Differences in TIB/TOB support structure (|η|~0.5) and services in the TK barrel/endcap transition

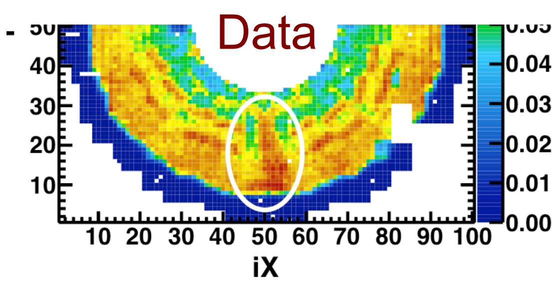
More examples…

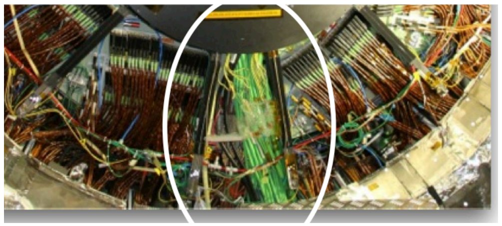
- **Conversions in the tracker volume:**



- **Energy flow in the preshower in Z→ee events:**





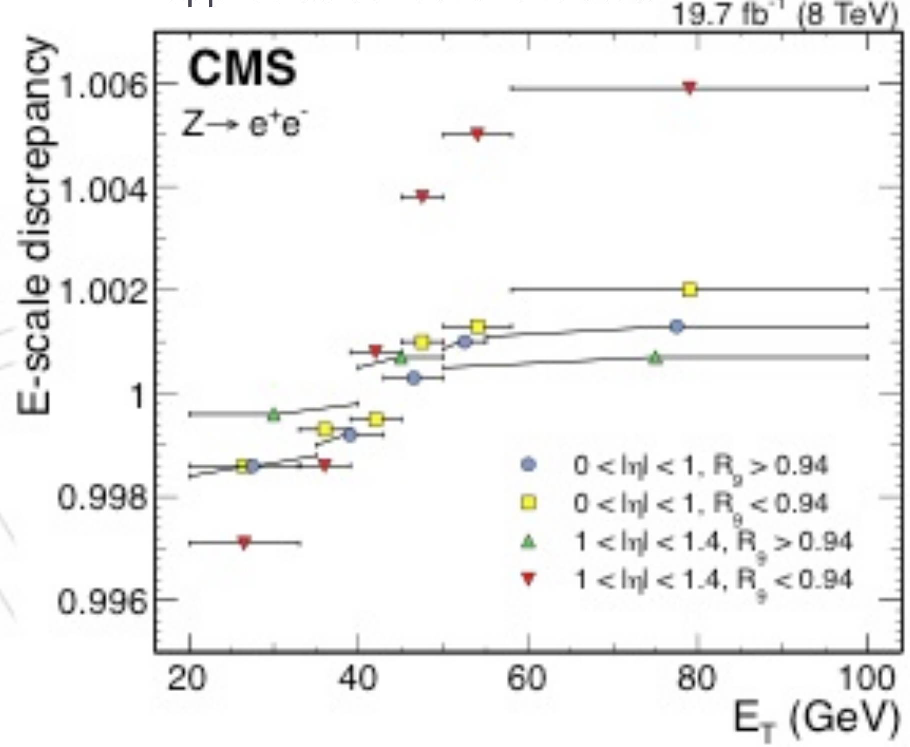


Cables and connectors at the back of the Tracker (not 'mapped' by tracks)

Tuning of calibration and MC resolution

- **Multi-step procedure:**
  - Correct scale for residual time dependence of response in **Run × Iηl** bins
    - Small: <0.1 (0.2) % in EB (EE)
  - Simultaneous fit of scale in data and additional Gauss smearing in MC in (**4 Iηl × 2 R9**) bins
    - In barrel at 8 TeV: $\sigma_{Gauss} = a/\sqrt{E_T}$ (+) c
  - Residual correction scale correction in **E_T × Iηl × R9** bins
    - Only at 8 TeV in the barrel

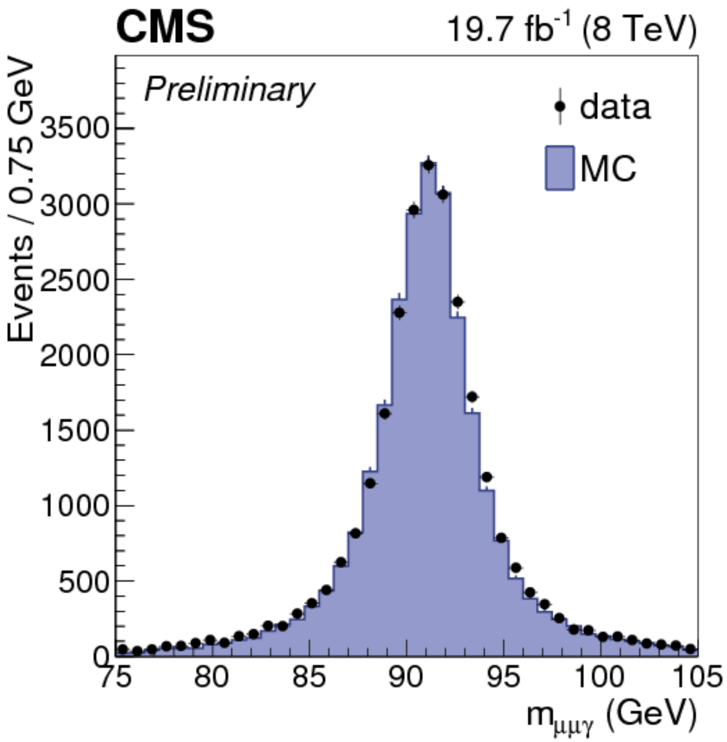
Reciprocals of these values applied as corrections to data

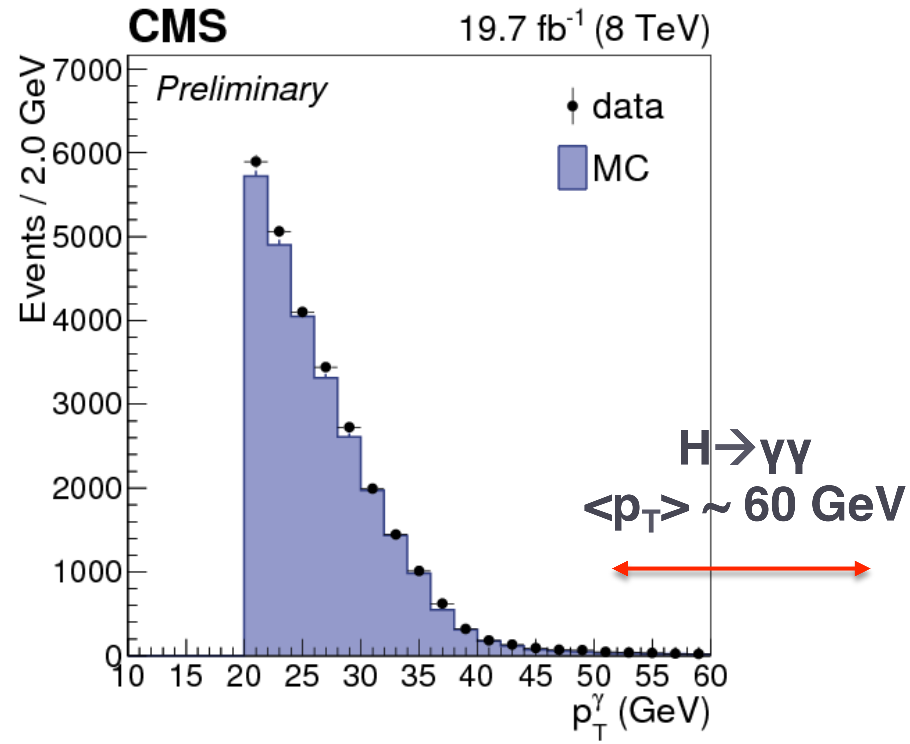


- **There is a systematic uncertainty associated**

NOTE: Consistent non-linearity seen in 7 TeV data, but dataset insufficient to derive corrections

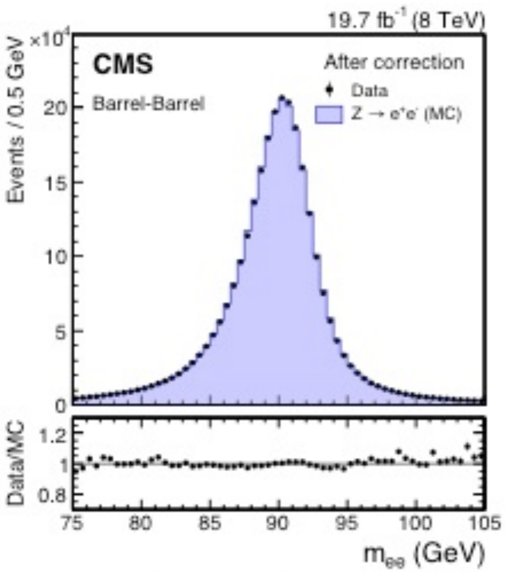
Photon energy scale check: Z→μμγ

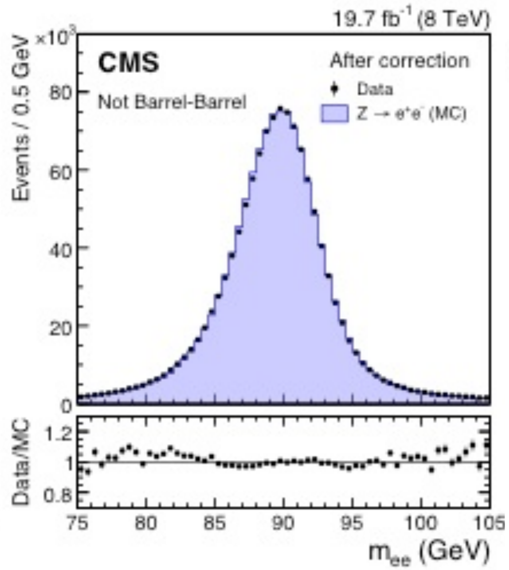


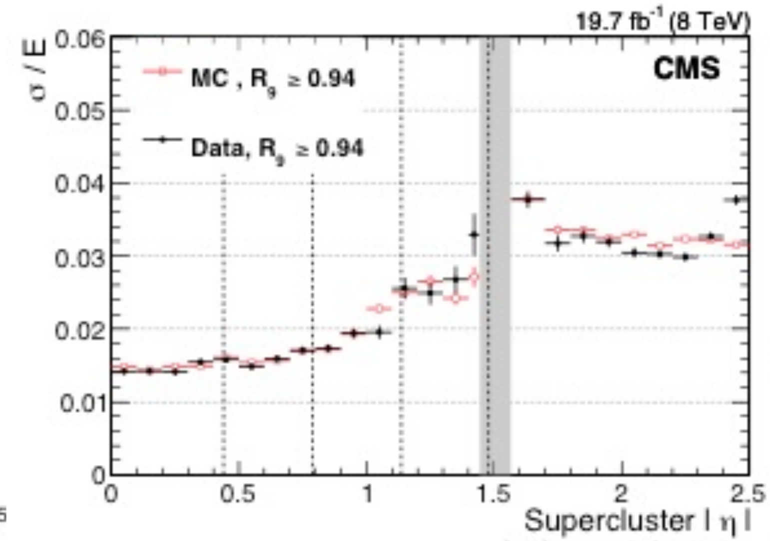


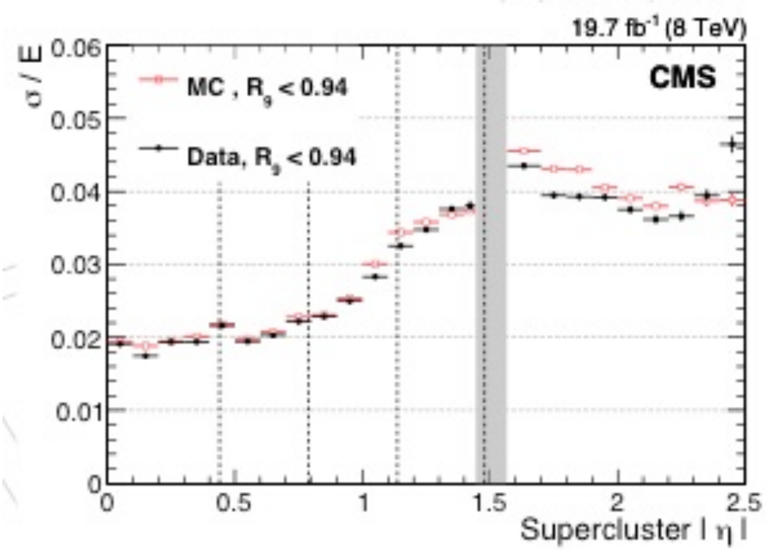
- **Inclusive Data/MC calibration agree to about 1σ**
  - **$\Delta E = (0.25 \pm 0.11_{stat} \pm 0.17_{syst})\ \% = (0.25 \pm 0.20)\ \%$**
  - Systematic uncertainty include fit reproducibility, and selections
- **No strong constraint on the Higgs boson mass uncertainty**
  - Precision in individual R9, |η| bins ~0.3%, $\langle p_T \rangle = 28$ GeV

Effect of smearing added to MC





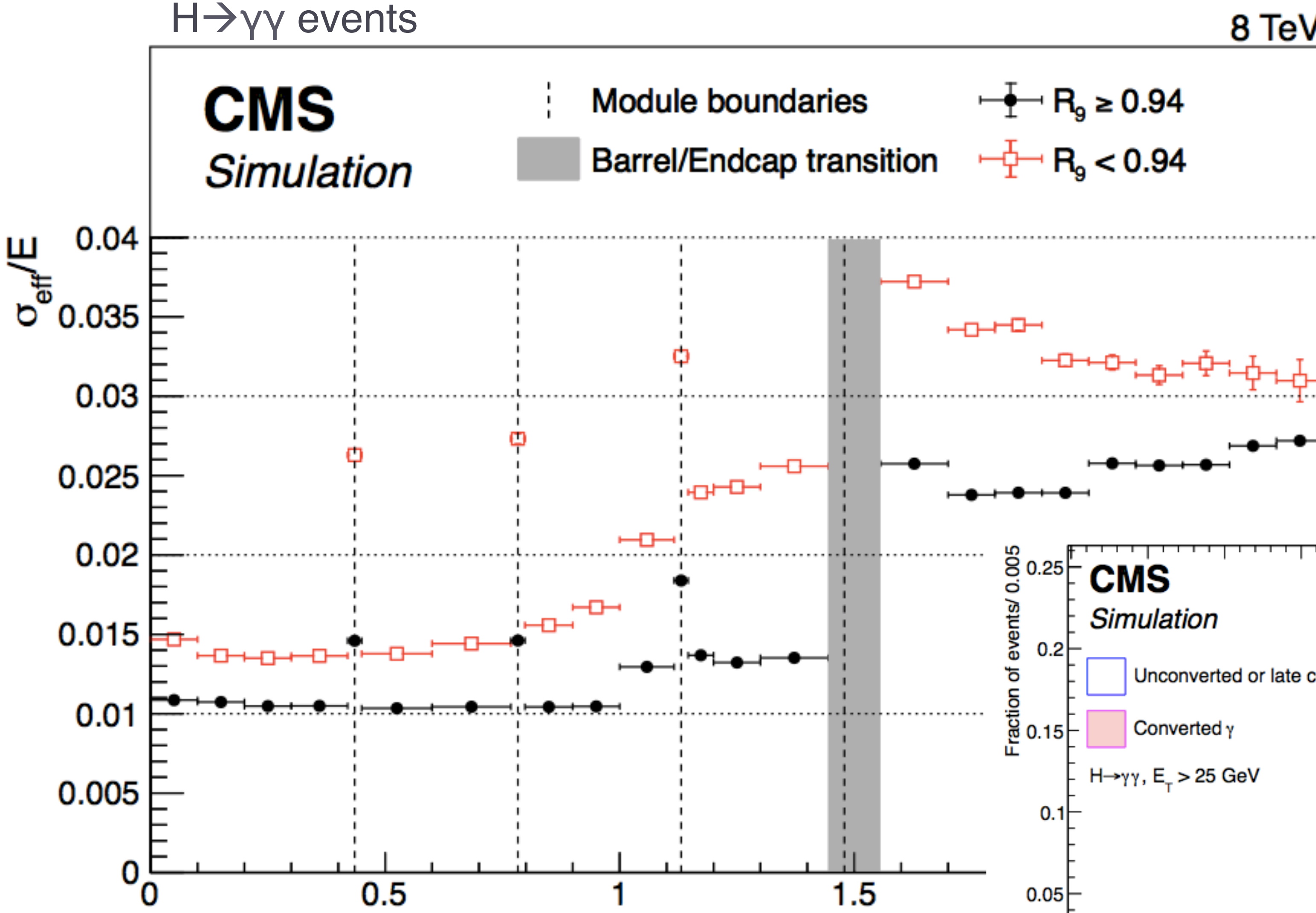


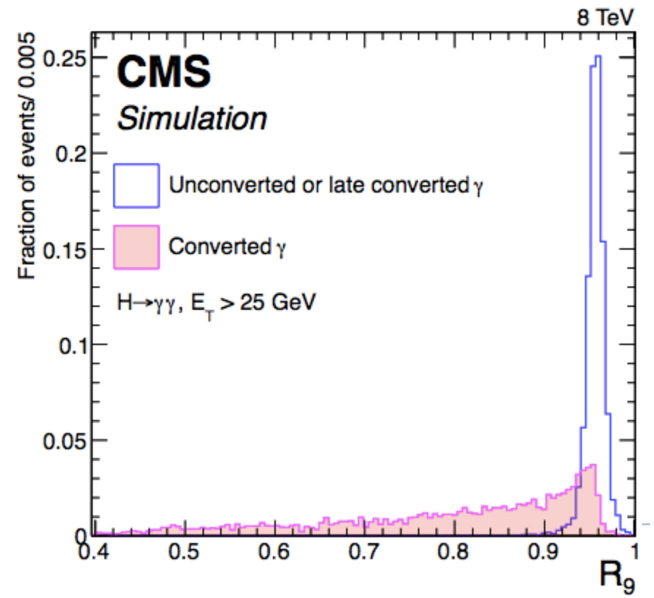


- **Additional smearing:**
  - *Barrel: 0.7% - 1% R9 > 0.94*
    1.6% - 2% R9 < 0.94
  - *Endcaps: 1.6-2%*
- Correlation with R9 → suggests material effect
- Residual discrepancy in the wings
  [resolution not Gaussian, mainly in endcaps]

Photon resolution after MC tuning

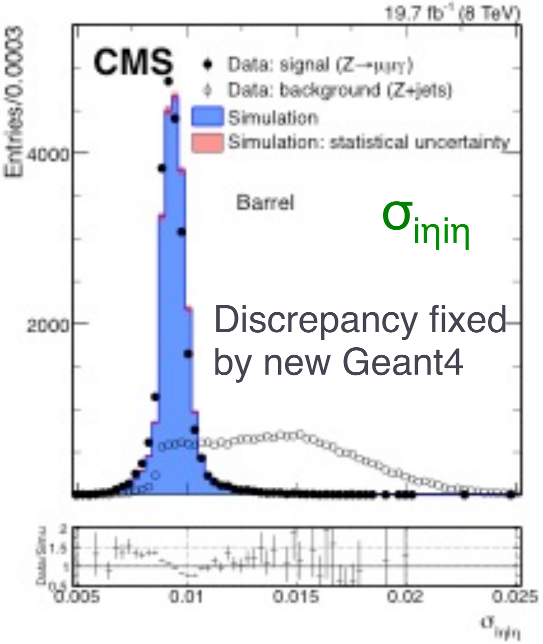
H→γγ events

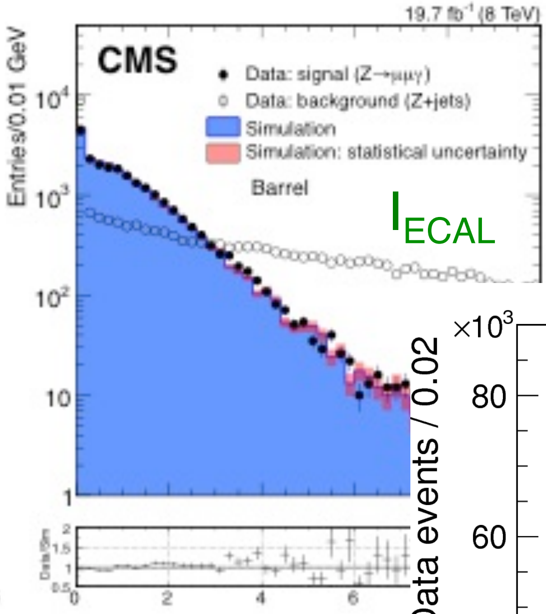




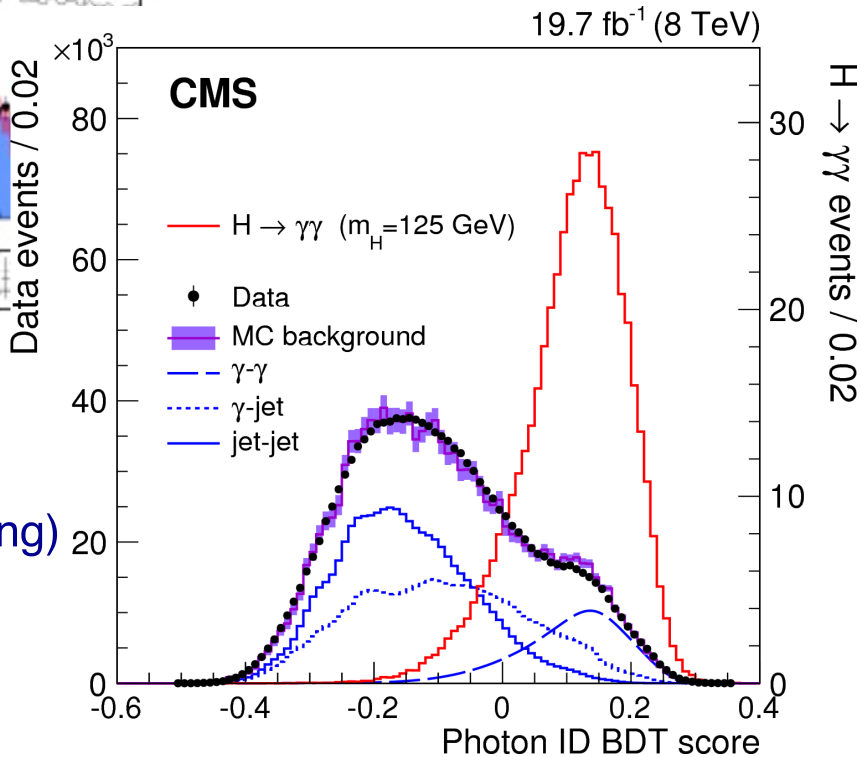
Photon identification

- **Loose (trigger) pre-selection + identification BDT**



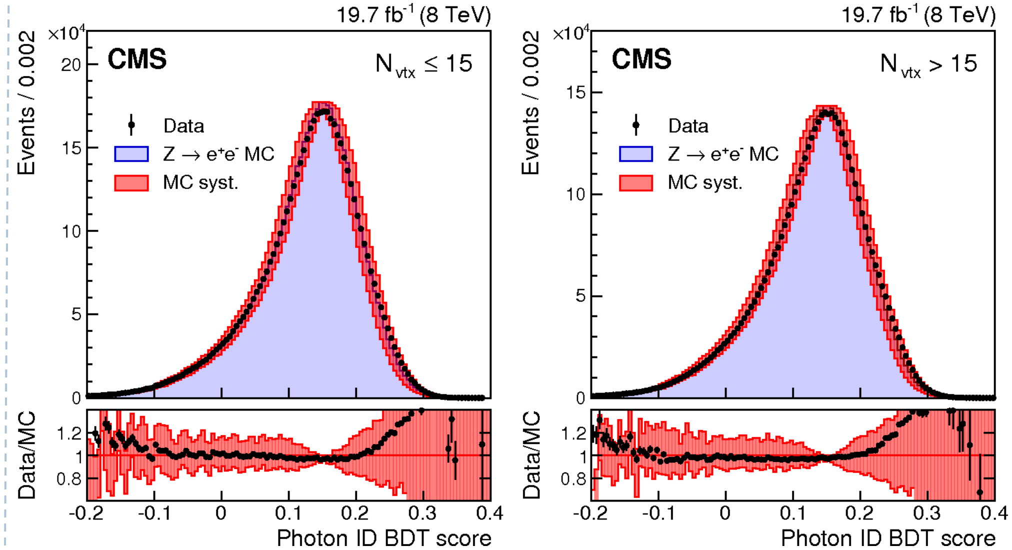


- **Input**
  - Shower shape variables
  - Isolation variables
  - Median energy density (pileup), η and E_{Raw}

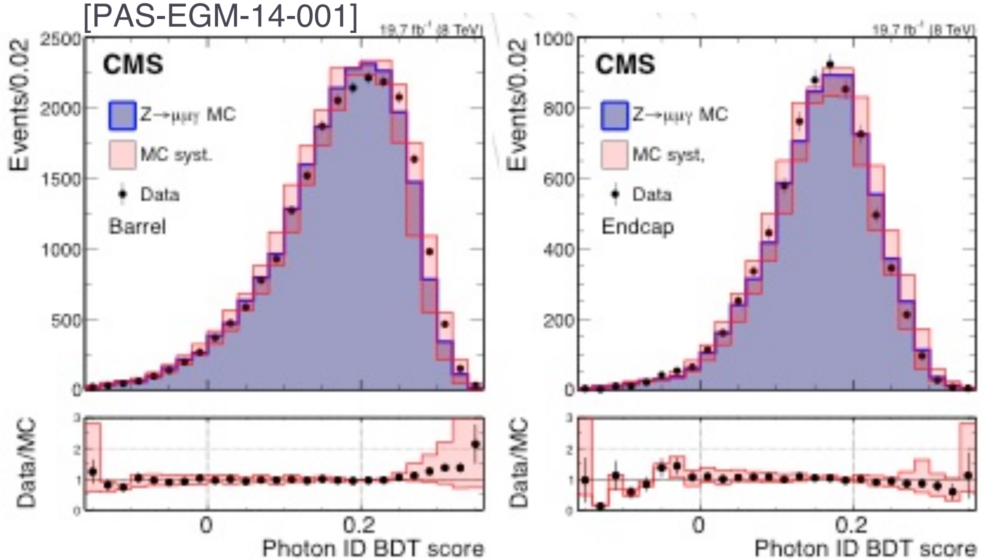


- **Training on γ+jet MC samples**
  - Separate on 7/8 TeV and EB/EE
  - Remove p_T and |η| dependence (weighting)
- **Output**
  - Signal efficiency 99% at BDT>-0.2
  - **BDT score >> input to diphoton BDT**

Uncertainty on the photon ID



[PAS-EGM-14-001]



- **BDT score of electrons in Z→ee events**
  - Reconstructed as photons
  - Systematic uncertainty applied to cover any data/MC discrepancies:
    - **BDT score shift by ±0.01**
- **BDT score of photons in Z→μμγ events**
  - Systematic uncertainty band as from Z→ee study

Vertex identification

- Resolution unaffected if vertex within 10 mm of true position

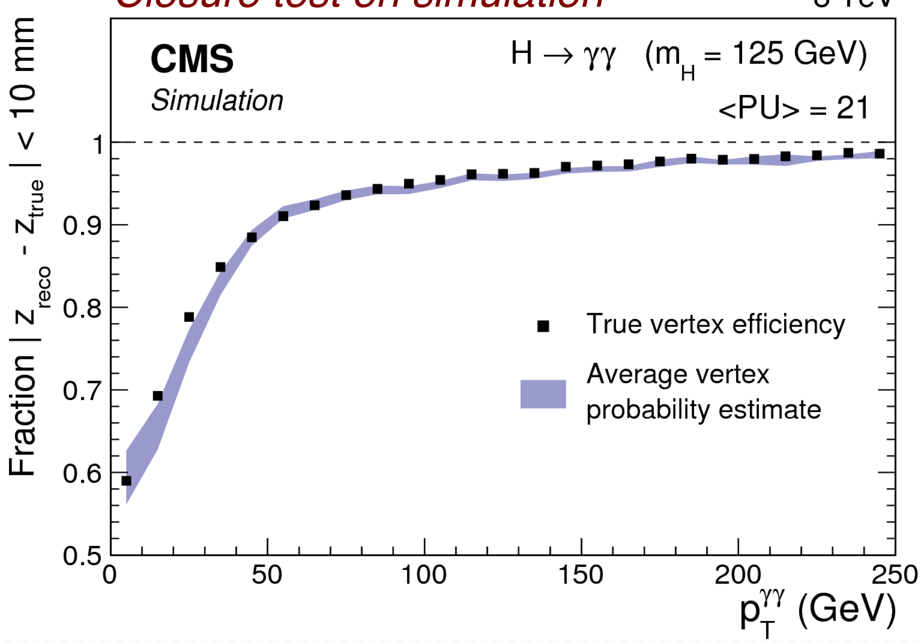
1. BDT to identify vertex

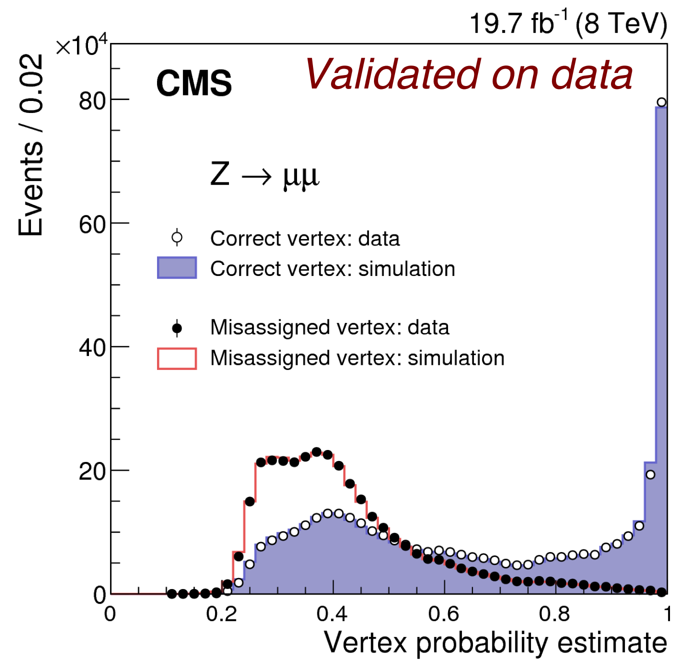
- Hardness of interactions p_T
- Balance of diphoton system and charged tracks
- Conversion information

2. BDT to assign per-event probability of correct vertex id

- BDT score and distance of three most likely vertices
- Number of vertices in the event
- Number of conversion tracks

Closure test on simulation

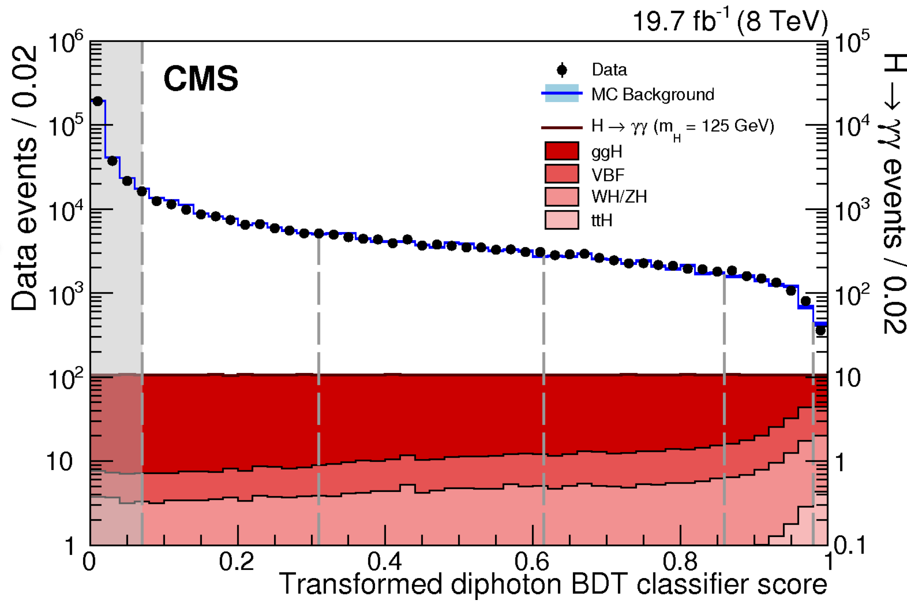




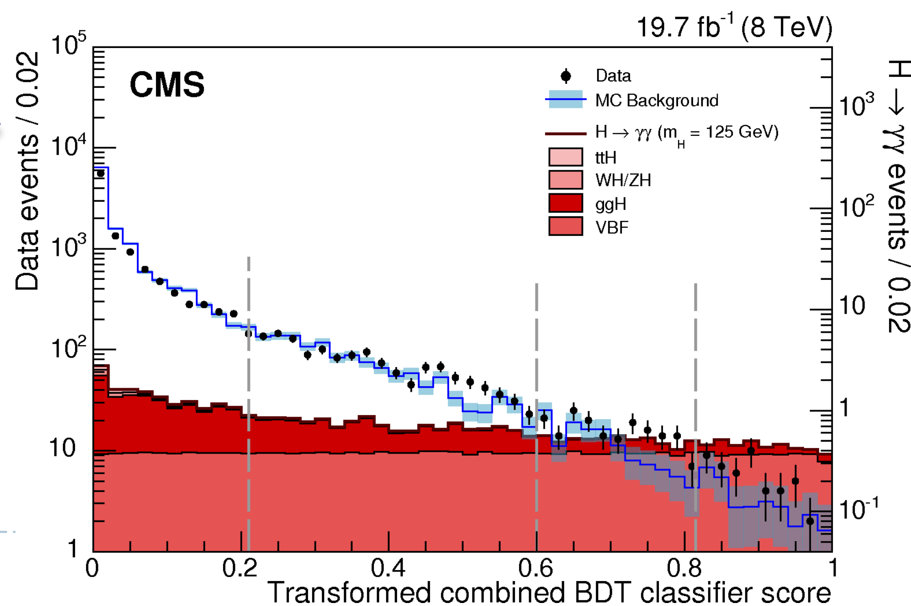
>> Input to diphoton BDT

Event selections and analysis categories

- **Diphoton BDT**
  - Combine event information into one discriminating variable
    - *Event kinematics, mass (photon and vertex) resolution, photon quality*
  - High score for high resolution and high signal-like topology
  - Define cutoff-acceptance and set analysis categories
    - Optimized for maximum sensitivity



- **Dijet BDT to tag VBF production**
  - *Combine dijet variables to tag VBF-like topology and include diphoton BDT*
  - Set categories for maximum sensitivity



- **Exclusive mode tags (VH, ttH)**
  - Leptons, MET and jets consistent with W or Z boson decays
  - b-jets, leptons and MET consistent with top pairs

Exclusive tag mode summary

- **Mutually exclusive classes**
- **Acceptance × efficiency**
  - 7 TeV at m_H = 125 GeV: **48.6%**
  - 8 TeV at m_H = 125 GeV: **49.3%**

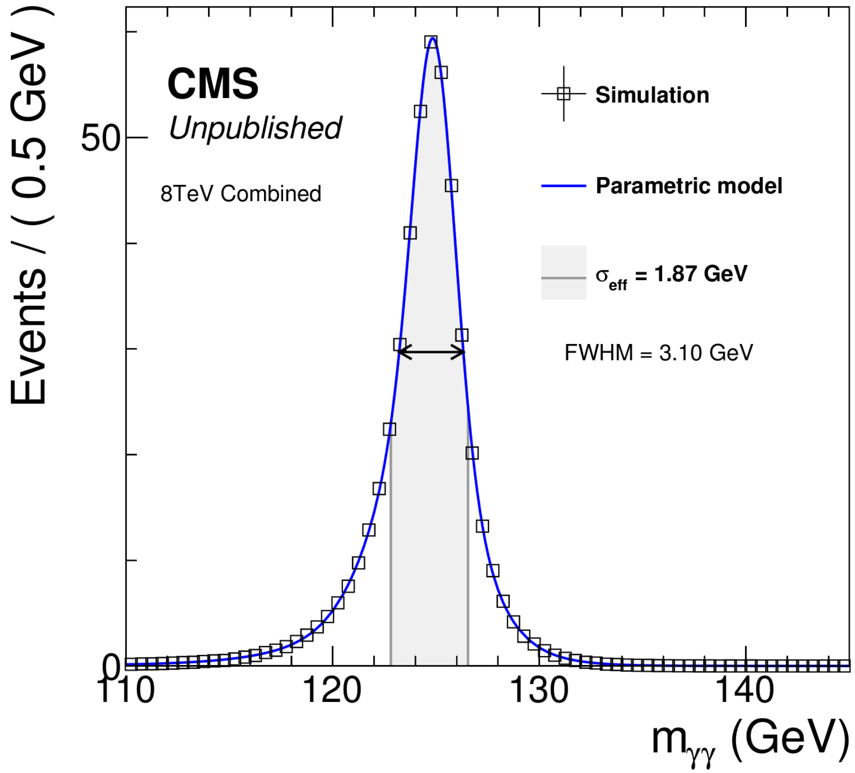
Events tested against tagged classes ranked by expected S/B

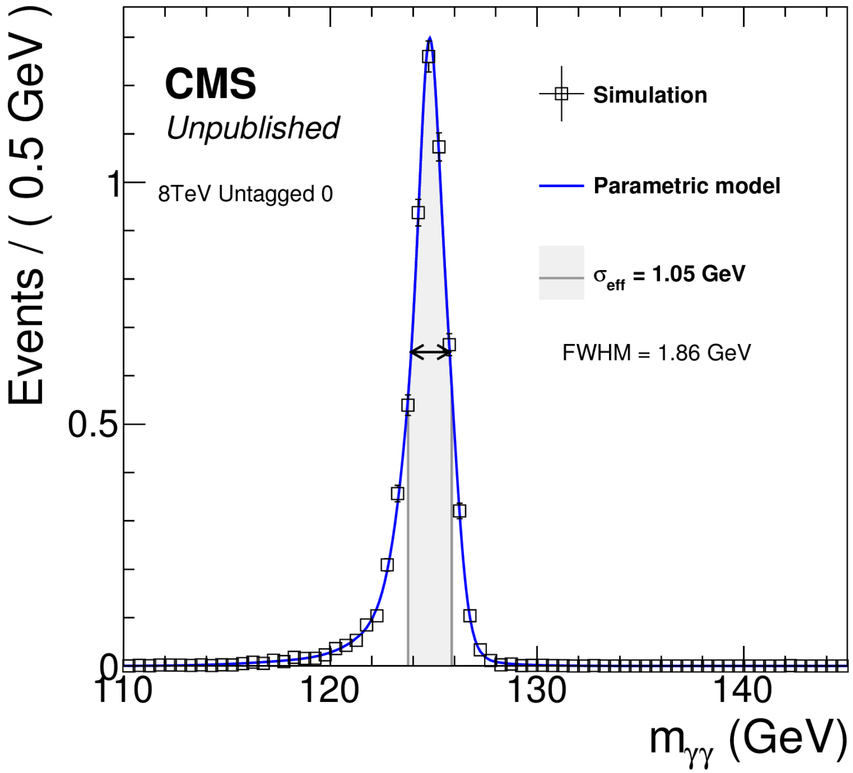
Label	No. of classes 7 TeV	No. of classes 8 TeV	Main requirements
$t\bar{t}$H lepton tag	$\star$	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 1 b-tagged jet + 1 electron or muon
VH tight ℓ tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ [e or μ, $p_T > 20$ GeV, and $E_T^{miss} > 45$ GeV] or [2e or 2μ, $p_T^{\ell} > 10$ GeV; $70 < m_{\ell\ell} < 110$ GeV]
VH loose ℓ tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ e or μ, $p_T > 20$ GeV
VBF dijet tag 0-2	2	3	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 2 jets; classified using combined diphoton-dijet BDT
VH E_T^{miss} tag	1	1	$p_T^{\gamma 1} > 3m_{\gamma\gamma}/8$ $E_T^{miss} > 70$ GeV
$t\bar{t}$H multijet tag	$\star$	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ 1 b-tagged jet + 4 more jets
VH dijet tag	1	1	$p_T^{\gamma 1} > m_{\gamma\gamma}/2$ jet pair, $p_T^{j} > 40$ GeV and $60 < m_{jj} < 120$ GeV
Untagged 0-4	4	5	The remaining events, classified using diphoton BDT

$\star$ For the 7 TeV dataset, events in the $t\bar{t}$H lepton tag and multijet tag classes are selected first, and combined to form a single event class.

Signal model

- **Parametric shape (sum of Gaussians)**
  - Fit diphoton invariant mass in MC simulation
    - Nine m_H values 110-150 GeV; linear interpolation in between
  - Separate fits for each each category





About 20% improvement in resolution compared to Moriond 2013

Expected signal (SM) breakdown

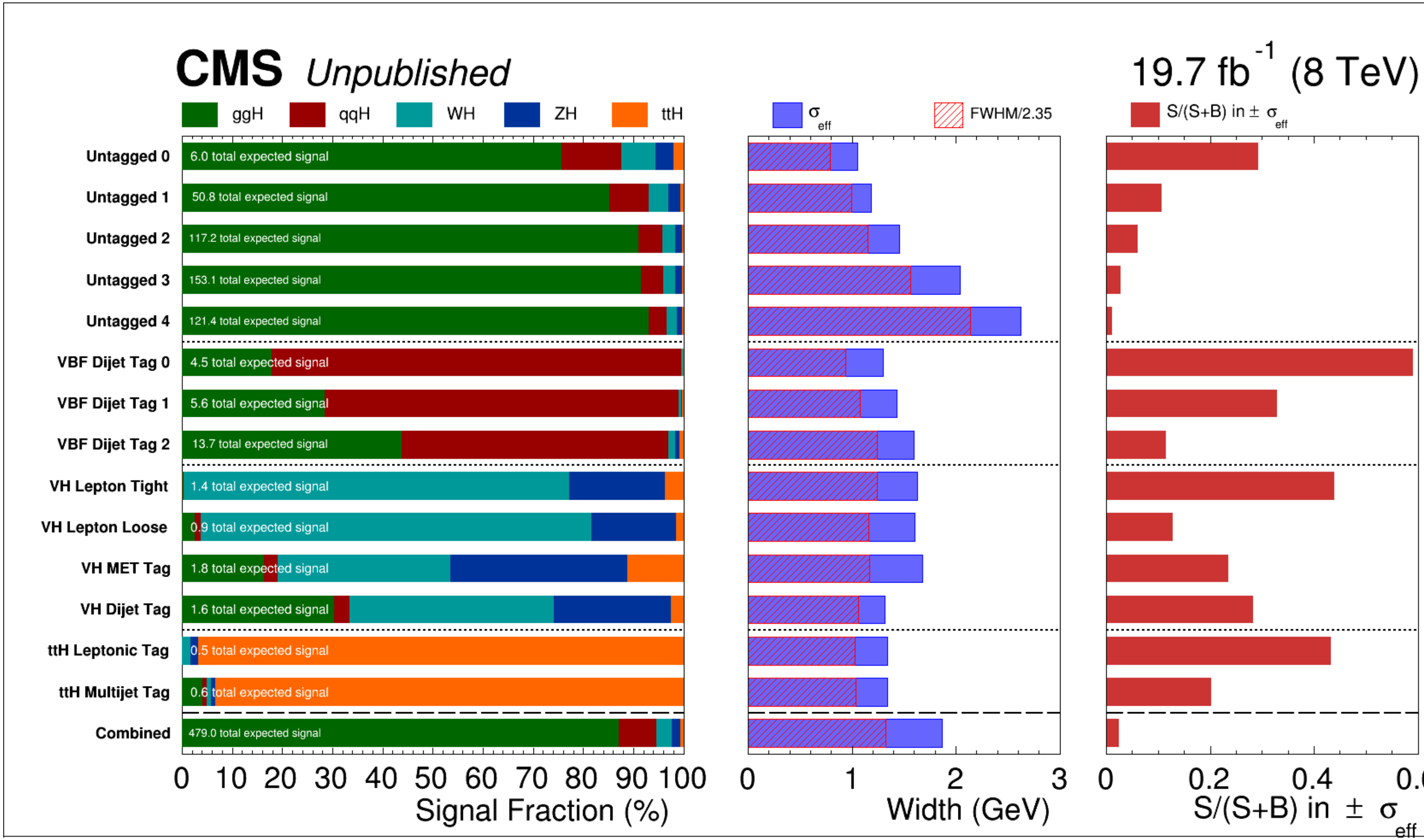
Event classes		Expected SM Higgs boson signal yield (m_H=125 GeV)								Bkg. (GeV^{-1})
		Total	ggH	VBF	WH	ZH	$t\bar{t}H$	σ_{eff} (GeV)	σ_{HM} (GeV)	
7 TeV 5.1 fb^{-1}	Untagged 0	5.8	**79.8%**	9.9%	6.0%	3.5%	0.8%	1.11	0.98	11.0
	Untagged 1	22.7	**91.9%**	4.2%	2.4%	1.3%	0.2%	1.27	1.09	69.5
	Untagged 2	27.1	**91.9%**	4.1%	2.4%	1.4%	0.2%	1.78	1.40	135.
	Untagged 3	34.1	**92.1%**	4.0%	2.4%	1.3%	0.2%	2.36	2.01	312.
	VBF dijet 0	1.6	19.3%	**80.1%**	0.3%	0.2%	0.1%	1.41	1.17	0.5
	VBF dijet 1	3.0	38.1%	**59.5%**	1.2%	0.7%	0.4%	1.65	1.32	3.5
	VH tight ℓ	0.3	—	—	**77.2%**	20.6%	2.2%	1.61	1.31	0.1
	VH loose ℓ	0.2	3.6%	1.1%	**79.1%**	15.2%	1.0%	1.63	1.32	0.2
	VH E_T^{miss}	0.3	4.5%	1.1%	41.5%	**44.6%**	8.2%	1.60	1.14	0.2
	VH dijet	0.4	27.1%	2.8%	**43.7%**	24.3%	2.1%	1.54	1.24	0.5
	$t\bar{t}H$ tags	0.2	3.1%	1.1%	2.2%	1.3%	**92.3%**	1.40	1.13	0.2
8 TeV 19.7 fb^{-1}	Untagged 0	6.0	**75.7%**	11.9%	6.9%	3.6%	1.9%	1.05	0.79	4.7
	Untagged 1	50.8	**85.2%**	7.9%	4.0%	2.4%	0.6%	1.19	1.00	120.
	Untagged 2	117.	**91.1%**	4.7%	2.5%	1.4%	0.3%	1.46	1.15	418.
	Untagged 3	153.	**91.6%**	4.4%	2.4%	1.4%	0.3%	2.04	1.56	870.
	Untagged 4	121.	**93.1%**	3.6%	2.0%	1.1%	0.2%	2.62	2.14	1400.
	VBF dijet 0	4.5	17.8%	**81.8%**	0.2%	0.1%	0.1%	1.30	0.94	0.8
	VBF dijet 1	5.6	28.5%	**70.5%**	0.6%	0.2%	0.2%	1.43	1.07	2.7
	VBF dijet 2	13.7	43.8%	**53.2%**	1.4%	0.8%	0.8%	1.59	1.24	22.1
	VH tight ℓ	1.4	0.2%	0.2%	**76.9%**	19.0%	3.7%	1.63	1.24	0.4
	VH loose ℓ	0.9	2.6%	1.1%	**77.9%**	16.8%	1.5%	1.60	1.16	1.2
	VH E_T^{miss}	1.8	16.3%	2.7%	34.4%	**35.4%**	11.1%	1.68	1.17	1.3
	VH dijet	1.6	30.3%	3.1%	**40.6%**	23.4%	2.6%	1.31	1.06	1.0
	$t\bar{t}H$ lepton	0.5	—	—	1.6%	1.6%	**96.8%**	1.34	1.03	0.2
	$t\bar{t}H$ multijet	0.6	4.1%	0.9%	0.8%	0.9%	**93.3%**	1.34	1.03	0.6

Composition of untagged categories:

- Boosted diphoton pair
- Both in barrel & R9>0.94
- Both in barrel
- …

[EPJ C (2014) 74:3076]

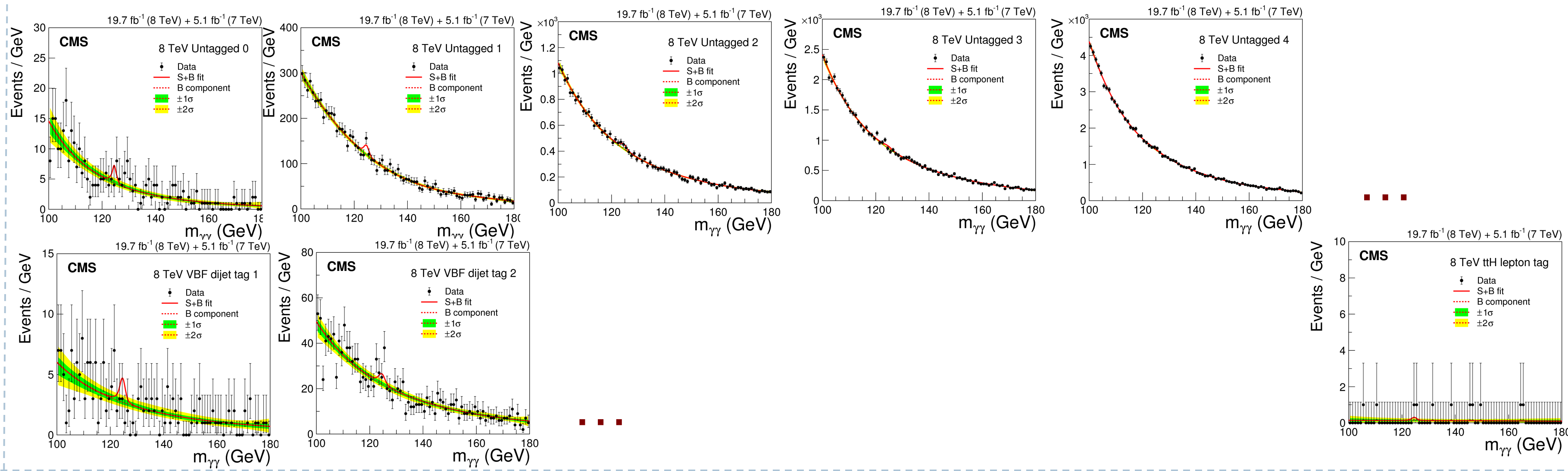
Expected signal breakdown at 8 TeV



For the parallel processors in human brains

Statistical methodology

- **Simultaneous binned Max-likelihood fit to diphoton invariant mass in all the categories:**
  - $\mathcal{L} = \mathcal{L}\ (\text{data} \mid s(p,m_{\gamma\gamma}) + b(m_{\gamma\gamma}))$
- s = signal parametric model from MC simulation
  - Systematic effects included as nuisance parameters on the signal model
- b = background function: shape unknown
  - → Wants a general description with negligible bias in the fit



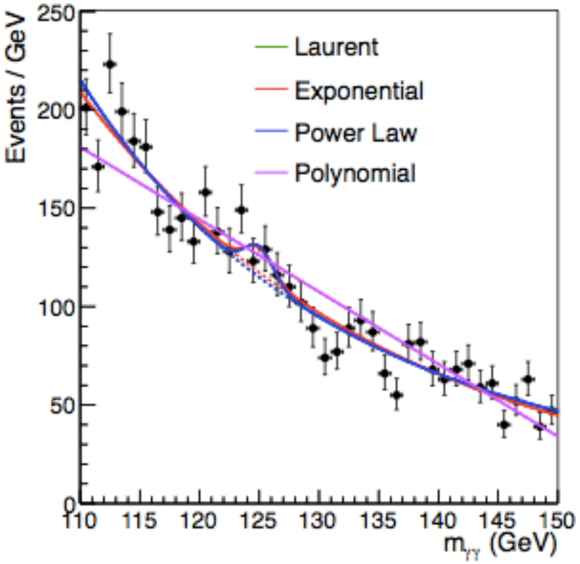
Background description

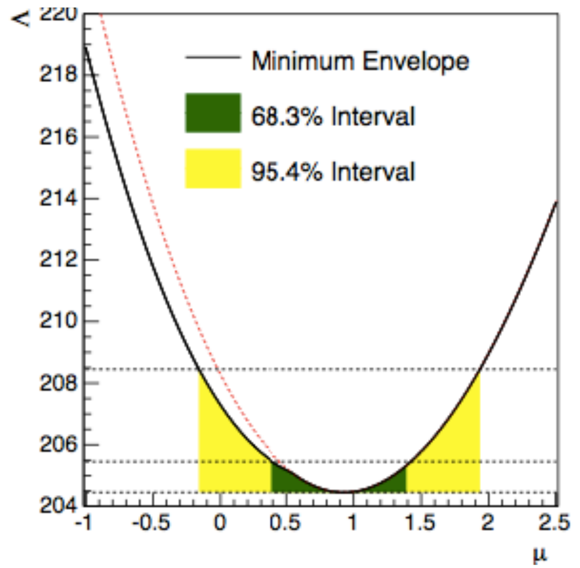
[arXiv:1408.6865]

- **Previous analysis (each category):**
  - Bernstein polynomials with polynomial order set by:
    - Fit bias < 1/5 σ_{fit} *(**)*
      [i.e. add *D.O.F.* until $\sigma_{syst}^2 + \sigma_{stat}^2 \approx \sigma_{stat}^2$]
- **New 'envelope method' (each category):**
  - Max-likelihood to select the function and the order which fit the best
    - Bernstein polynomials, Laurent polynomials, power law, and exponential families
  - Add penalty for different number parameters
    - good coverage and negligible bias with

      $-2\log\lambda' = \min\{-2\log\lambda_i + N_{par}\}_i$

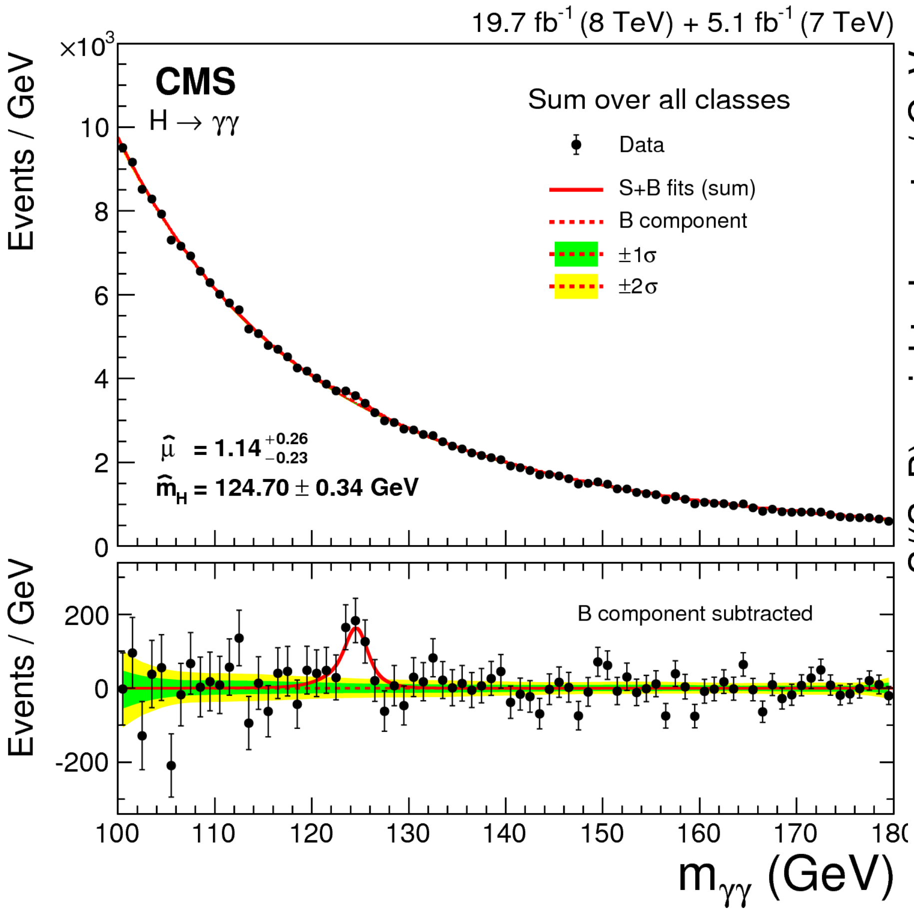
      [Fits satisfying bias condition (**)]
- **'Profile' the likelihood over the function choices**
  - Account for arbitrariness and uncertainty of the choice
  - Overall sensitivity of the analysis improves by +7%
    - *Best fit functions typically have fewer parameters*

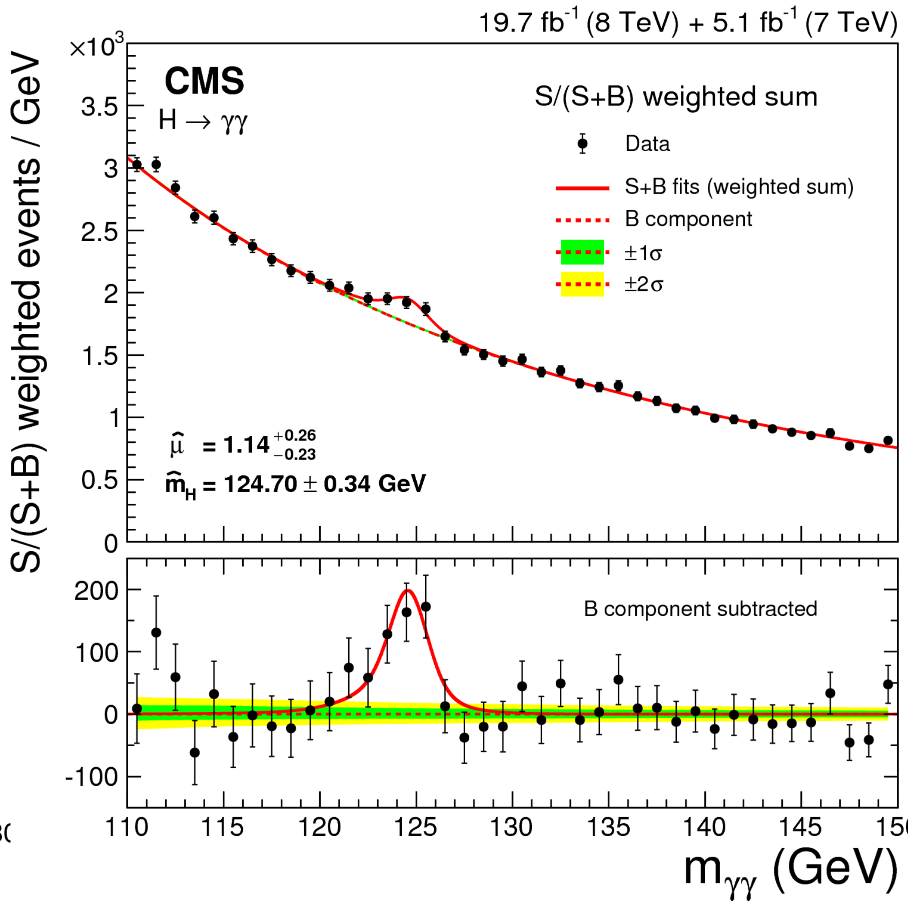




Results

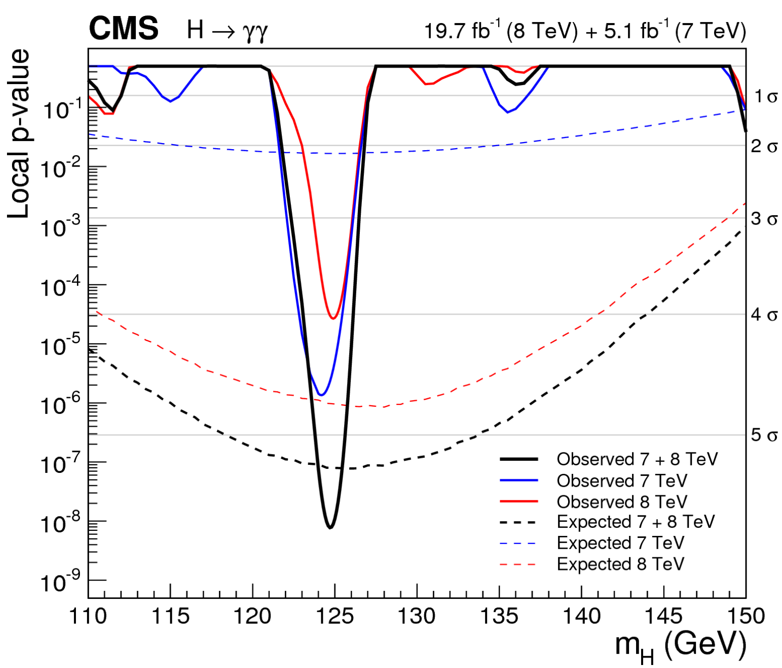
- Inclusive sum of all events selected
- Sum weighted by sensitivity

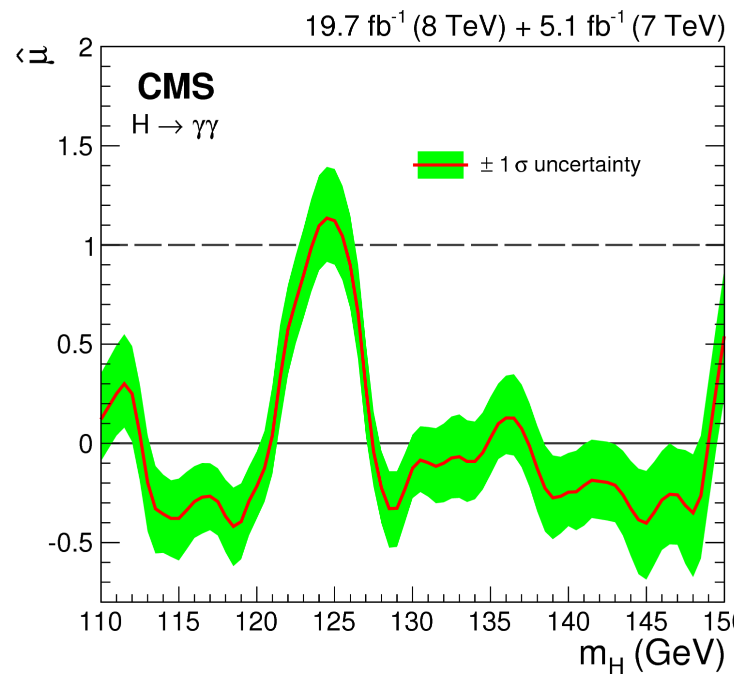




Results: signal yield

Dataset	Significance (obs)	σ/σ_{SM}	m_H (GeV)
7 TeV	4.7 σ	$2.22^{+0.62}_{-0.55}$	124.2
8 TeV	4.0 σ	$0.90^{+0.26}_{-0.23}$	124.9
7+8 TeV	**5.7 σ**	$\mathbf{1.14^{+0.26}_{-0.23}}$	**124.7**

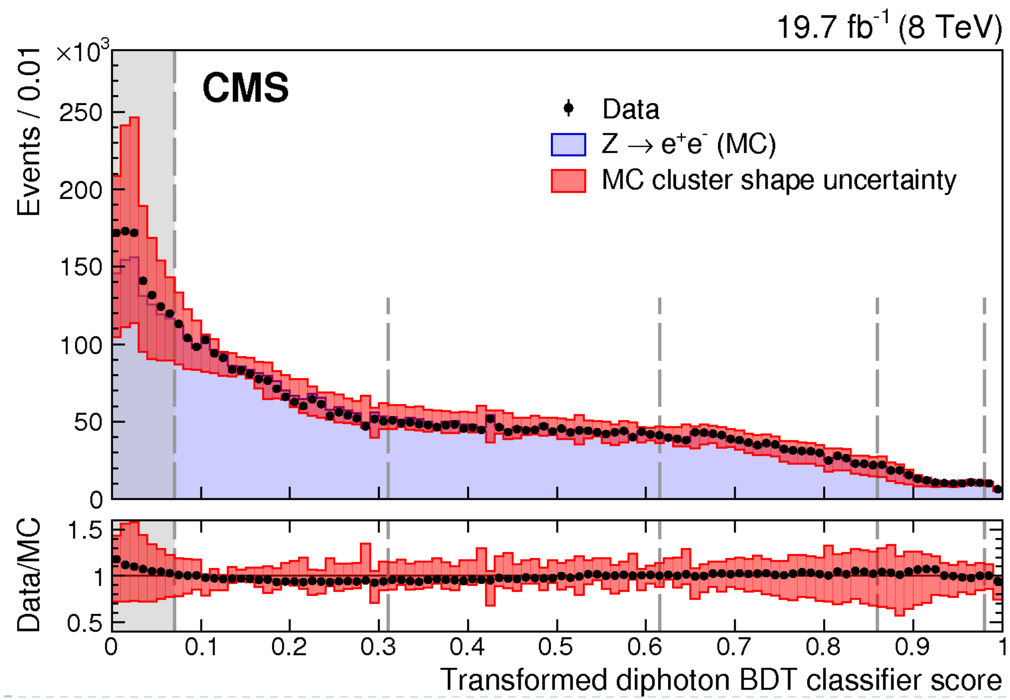




$$\sigma/\sigma_{SM} = 1.14^{+0.26}_{-0.23} \left[^{+0.21}_{-0.21}(\text{stat.})^{+0.09}_{-0.05}(\text{syst.})^{+0.13}_{-0.09}(\text{th.}) \right]$$

Systematic uncertainties on the signal yield

Source	**Effect**
Theory	±0.11
Diphoton BDT mismodelling	**±0.06**
Energy and resolution corrections	±0.02
Other experimental	±0.04

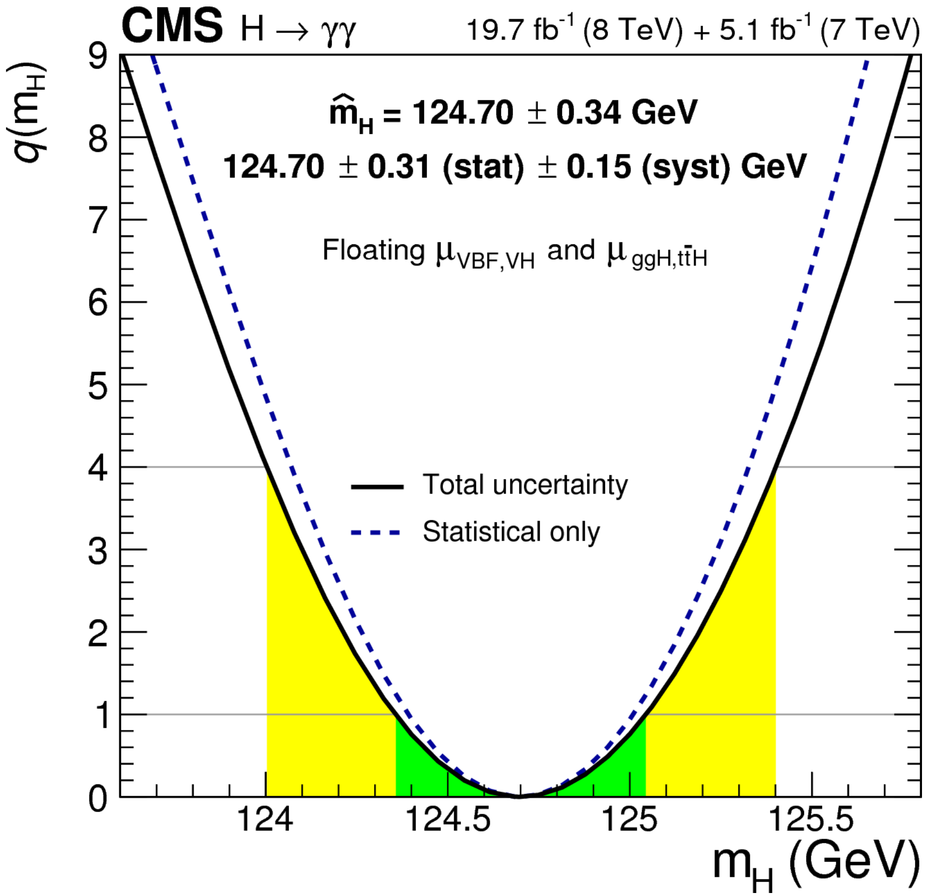


- **Largest uncertainty of instrumental origin**
  - Studied by modifying inputs that distort the diphoton BDT score and affect categorization
    1. Photon BDT score
    2. Energy resolution estimate
- **Test of the uncertainty on the BDT score with Z→ee events**

→ Slightly overestimated

  - *[Shift of the two inputs chosen to cover discrepancies in the tails of the respective distributions]*

Results: mass measurement



$m_H = 124.7 \pm 0.3_{stat} \pm 0.15_{syst}$ GeV

Constraint from $Z \rightarrow \mu\mu\gamma$ weak

- **MC: Propagate to $m_{\gamma\gamma}$ per-photon energy uncertainties from:**

Energy corrections and resolution
Electrons at m_z
$\delta m_H = 0.05$ GeV

↓

Response linearity
m_z ----> m_H
$\delta m_H = 0.10$ GeV

↓

Simulation of
e/γ response difference
photons at m_H
$\delta m_H = 0.10$ GeV

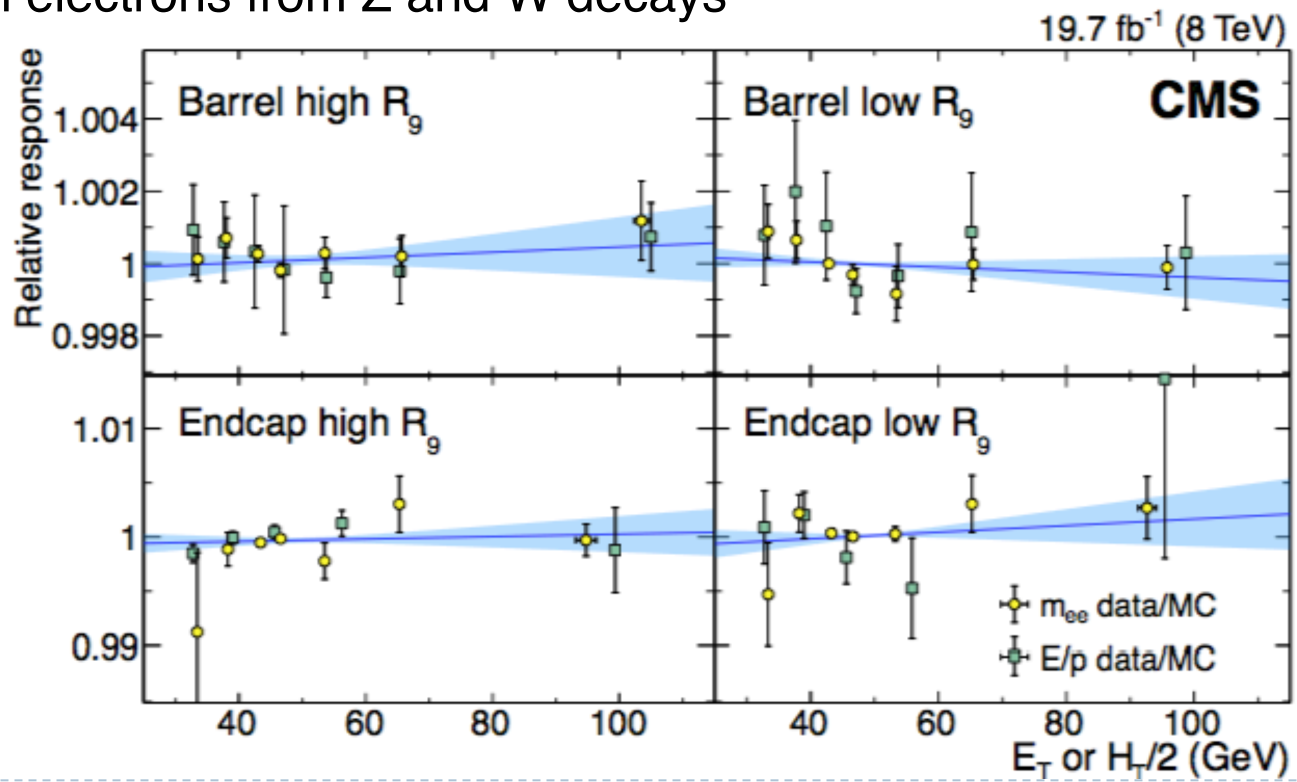
Energy corrections (at m_Z) and linearity

- **Photon energy corrections : *δm_H = 0.05 GeV***
  - Method stability against R9 reweighting, selections, fit range
- **Residual non linearity : *δm_H = 0.10 GeV***
  - Dielectron invariant mass vs $H_T = ½ (E_{T,1} + E_{T,2})$ in boosted Z→ee
  - E/p vs E_T with electrons from Z and W decays

- Error band scaled to get X^2/dof =1
- Also verified with parabola

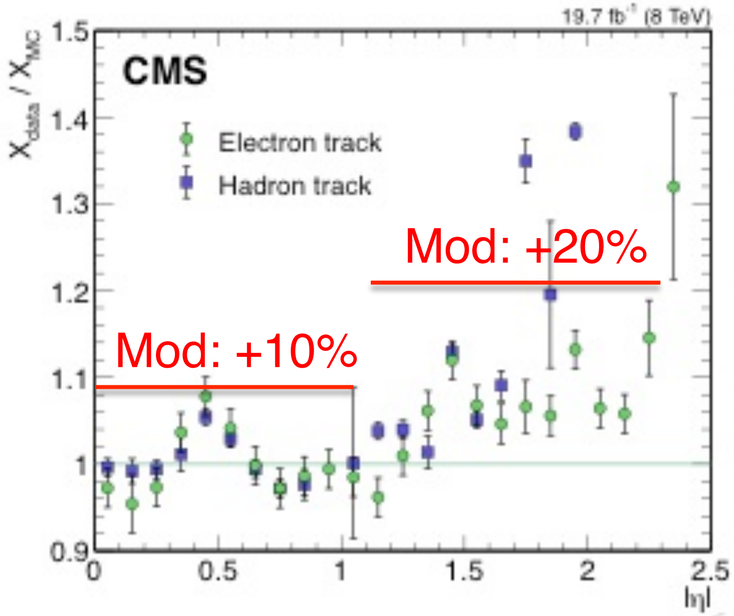
Additional checks

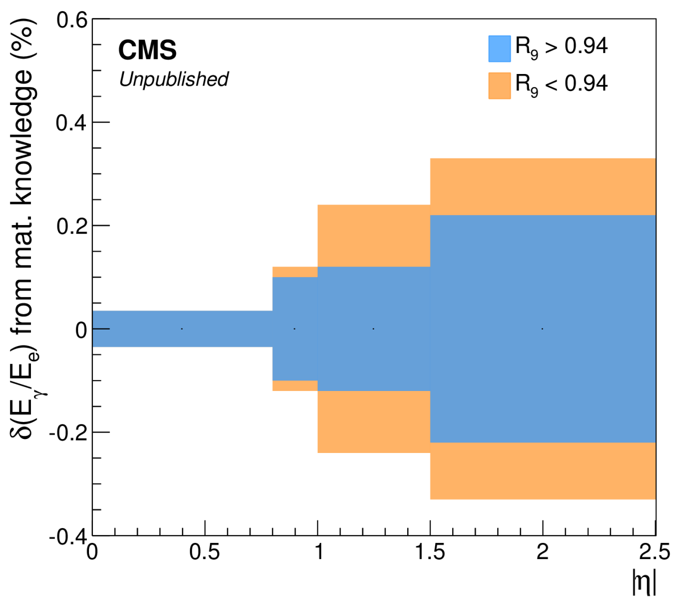
- Gain switch of electronics in < 2% of events → negligible



Photon/ electron response difference

- **Imperfect simulation of e/γ difference : $\delta m_H = 0.10$ GeV**
  - Per-photon effect from ***double ratio of e/γ response difference*** in ***modified*** and ***default*** simulation
- *Longitudinal non-uniformity of light collection : 0.02 GeV (next)*
- **Imperfect EM shower simulation : 0.05 GeV**
  - *G4 modified with Seltzer-Berger model*
- **Imperfect description of material : 0.07 GeV**

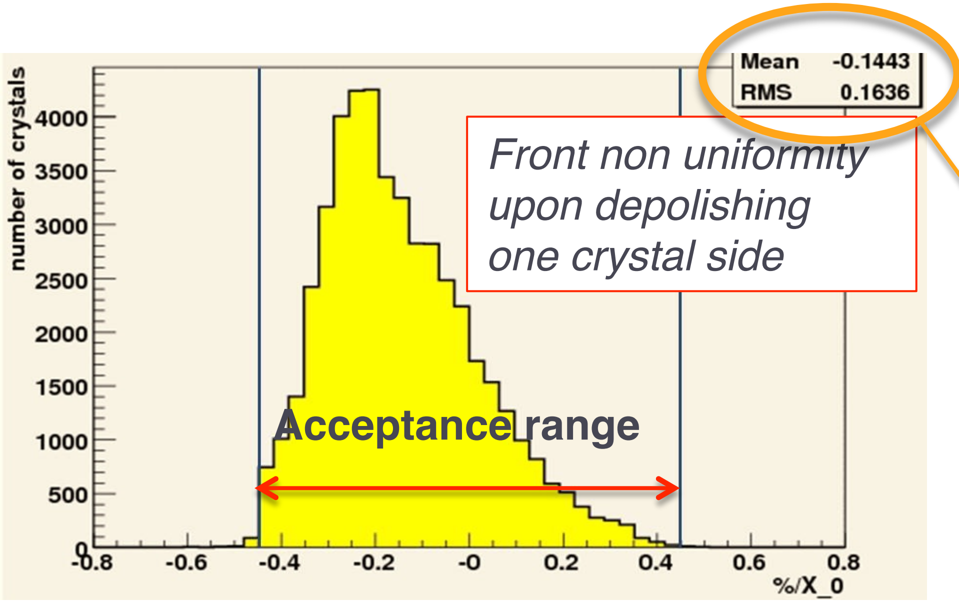




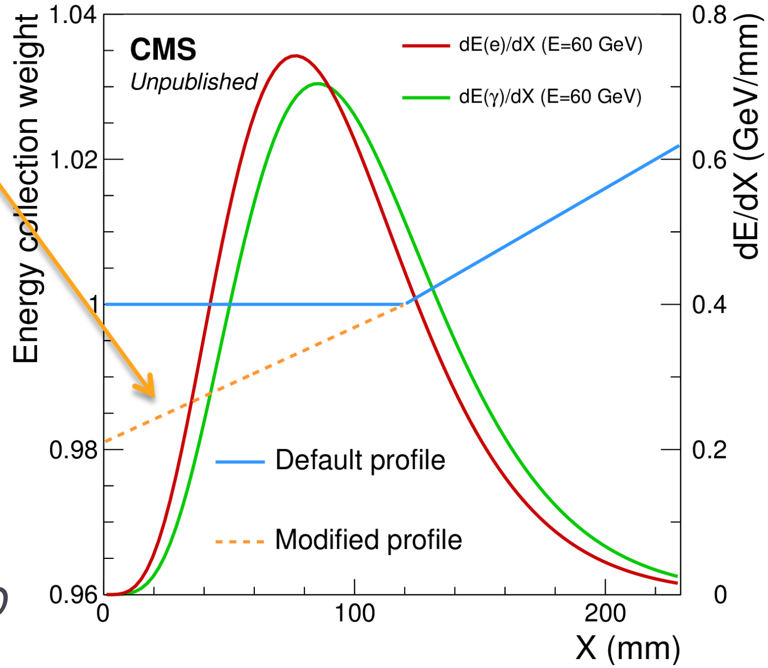
Photon/ electron response difference (2)

- **Imperfect simulation of e/γ difference : $\delta m_H = 0.10$ GeV (cont'd)**
  - **Longitudinal non-uniformity of light collection : 0.02 GeV**
    - Residual non-uniformity from lab tests (all crystals!): 0.14%/X_0
    - e/γ response difference from difference in shower depth

→ Per-photon scale change (including radiation effects): **~0.05% anti-correlated between R9>0.94 and R9<0.94 photons**

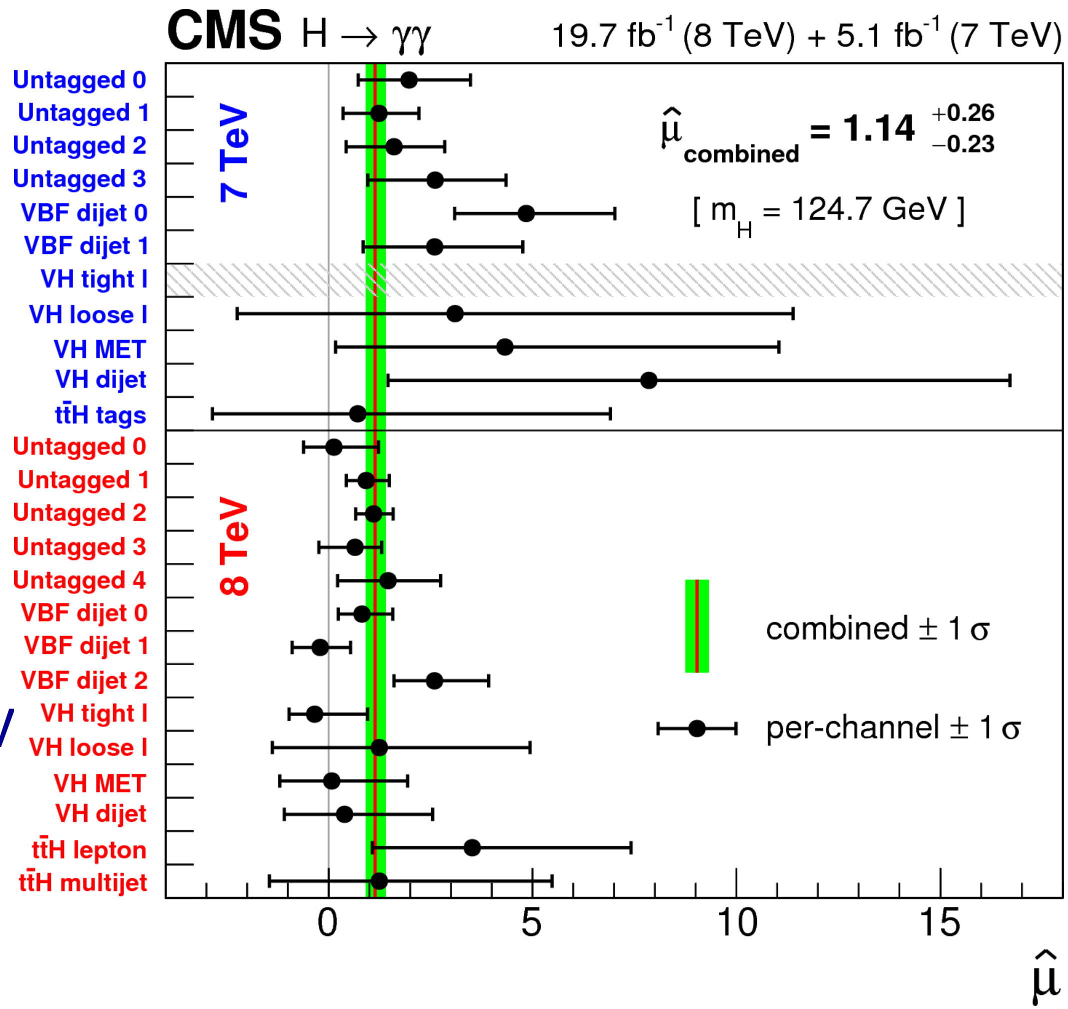


Dependence on radiation damage also studied in R&D



Result cross checks: compatibility

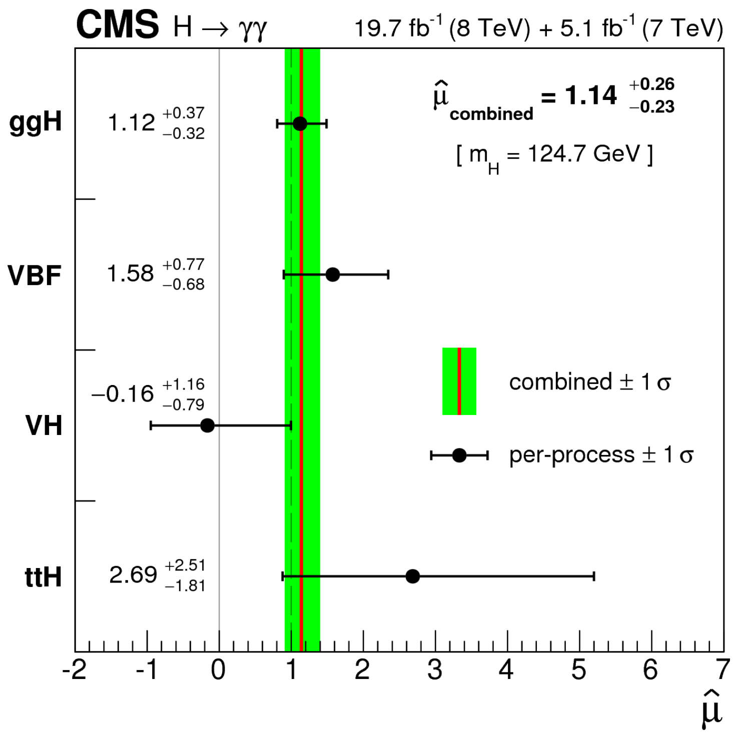
- Three alternative analyses
  - OK at 1σ level
- Compatibility with preliminary result
  - OK at <2σ using jackknife technique to account for correlations
- Compatibility among channels
- Compatibility of 7 and 8 TeV
  - At 2σ (most from VBF)

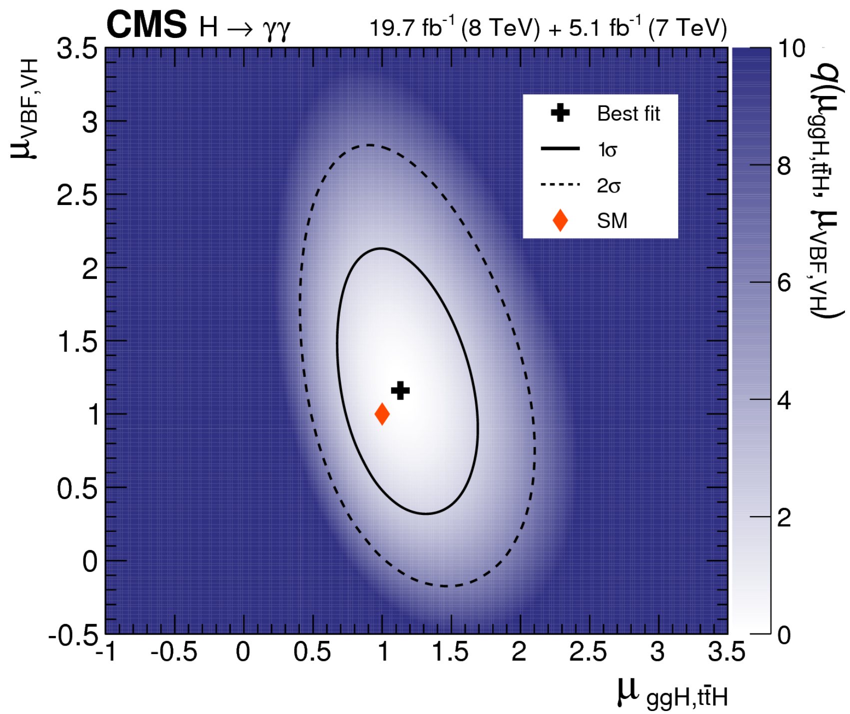


More results on Higgs properties

- **Production mechanism and coupling modifiers**

$$\mu_{ggH+ttH} = 1.13^{+0.37}_{-0.32}$$
$$\mu_{qqH+VH} = 1.16^{+0.58}_{-0.60}$$





- **More in the paper** [EPJ C (2014) 74:3076]
  - Higgs boson decay width, search for additional states, high mass search, spin hypotheses

Summary

- **Reported CMS analysis in search for SM H→γγ**
  - **Dataset: 5.1 fb^{-1} at √s=7 TeV and 19.7 fb^{-1} at √s=8 TeV**

- Discussed the steps to optimize the performance of photon energy reconstruction, the accurate modelling of the photon response for the H→γγ analysis, and the associated systematic uncertainties
  - *Additional details in CMS photon performance paper being submitted*

- Described the new analysis optimization with tags for exclusive production modes

- **Signal :** $\sigma/\sigma_{SM} = 1.14^{+0.26}_{-0.23} \left[^{+0.21}_{-0.21}(\text{stat.})^{+0.09}_{-0.05}(\text{syst.})^{+0.13}_{-0.09}(\text{th.}) \right]$
- **Mass :** $m_H = 124.70^{+0.35}_{-0.34} \left[0.31\ (\text{stat}) \pm 0.15\ (\text{syst}) \right]\ \text{GeV}$
- **Couplings :** $\mu_{ggH+ttH} = 1.13^{+0.37}_{-0.32}$

  $\mu_{qqH+VH} = 1.16^{+0.58}_{-0.60}$

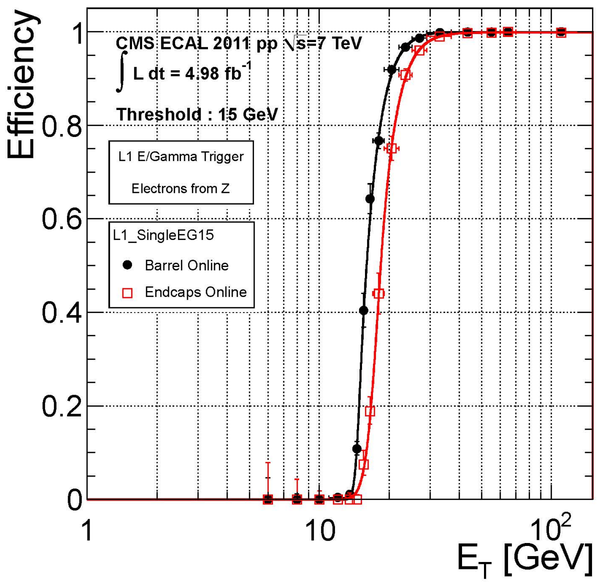
Standalone observation of 5.7σ
Properties consistent with a
SM Higgs boson

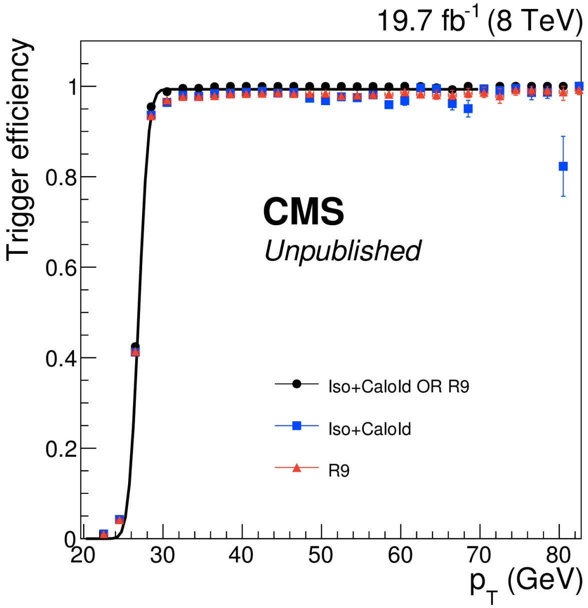
Appendix

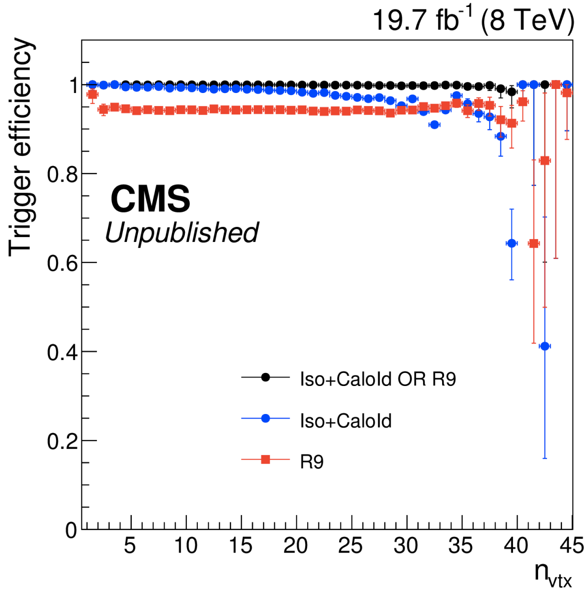
Trigger selections and efficiencies

Level-1:
E_T sum of adjacent Trigger Towers
(e.g. 5x5 crystals in barrel)

High Level Trigger



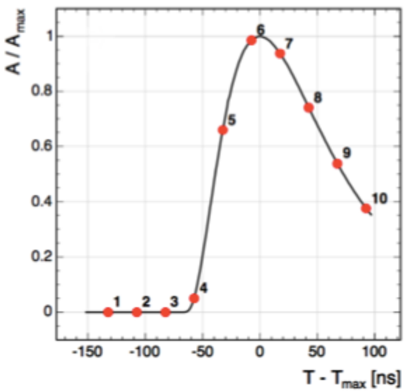


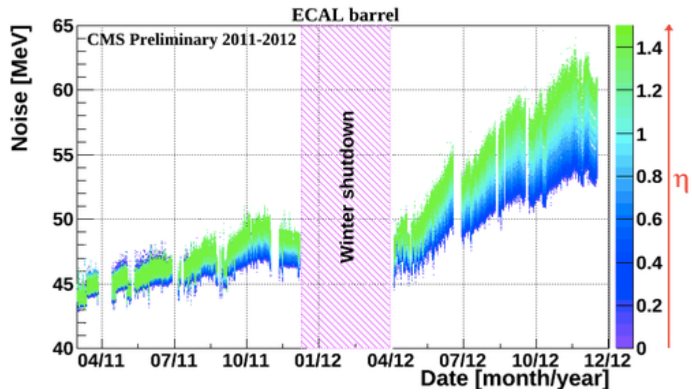


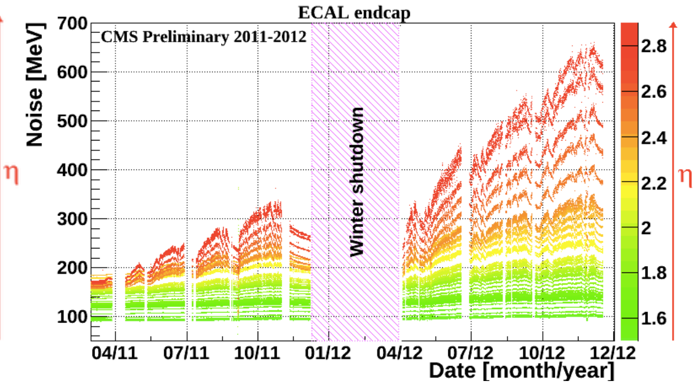
High Level Trigger

- Asymmetric E_T thresholds on two photons
- Photons pass EITHER loose calo ID (shower shape + iso) OR high R_9 (i.e. unconverted)
- Trigger efficiency for preselection is 99.4 %

Time dependent simulation



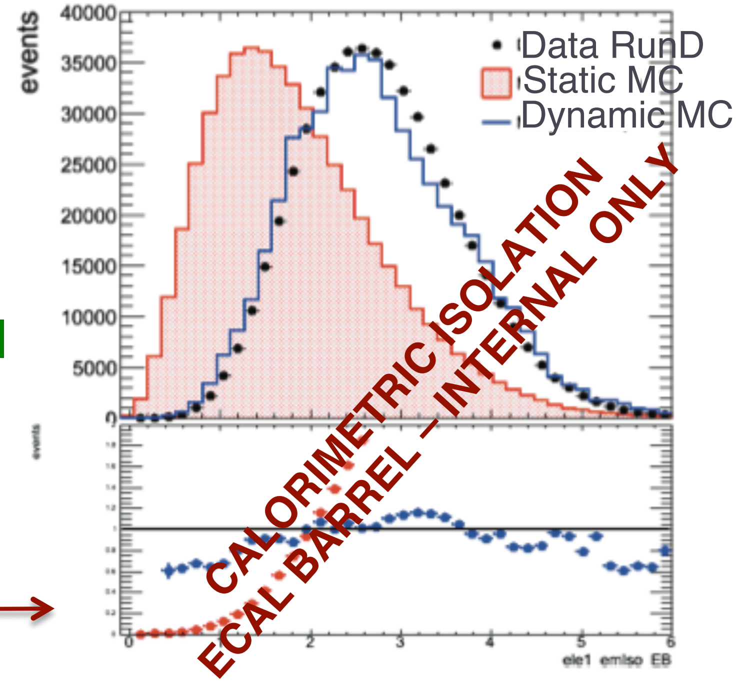




I. **Out-of-time pileup collisions simulated in an extended window**
- Collisions in previous beam crossings impact on the amplitude reconstruction (dynamic pedestal subtraction)

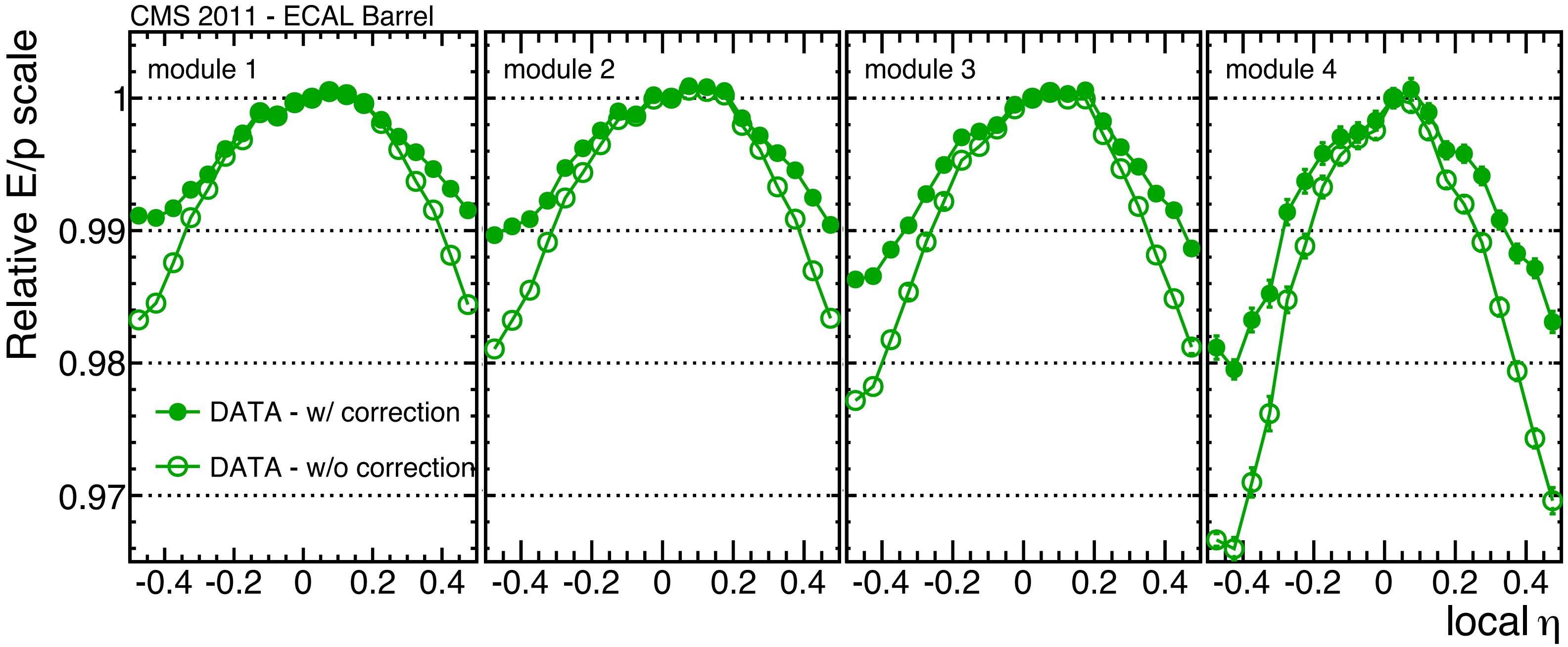
II. **Dynamic evolution of the per-channel noise level**
- Three run periods in 2012

- **Improved Data/MC agreement**

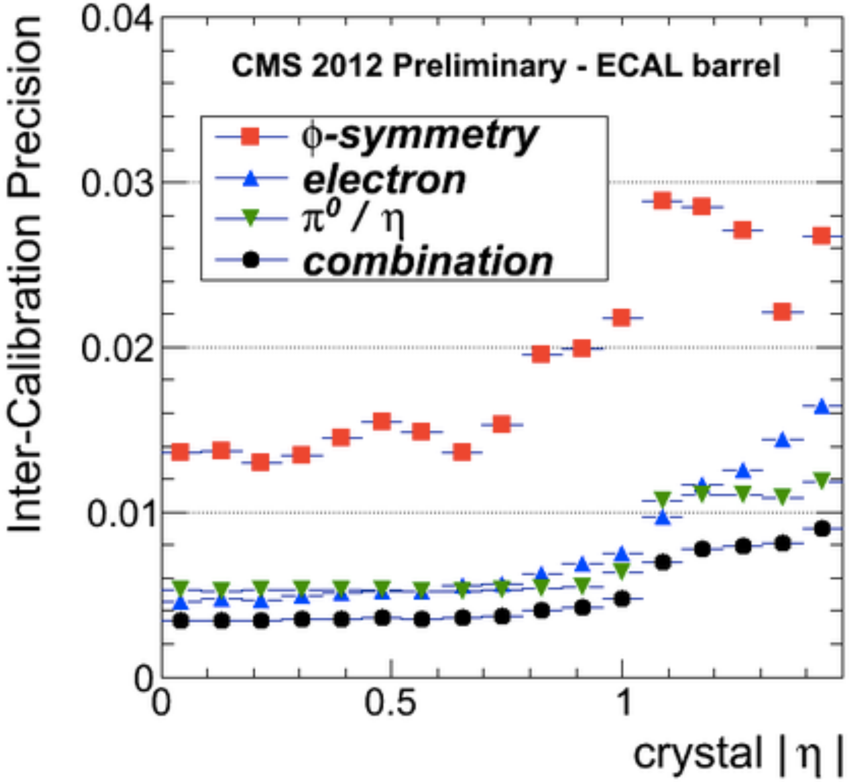


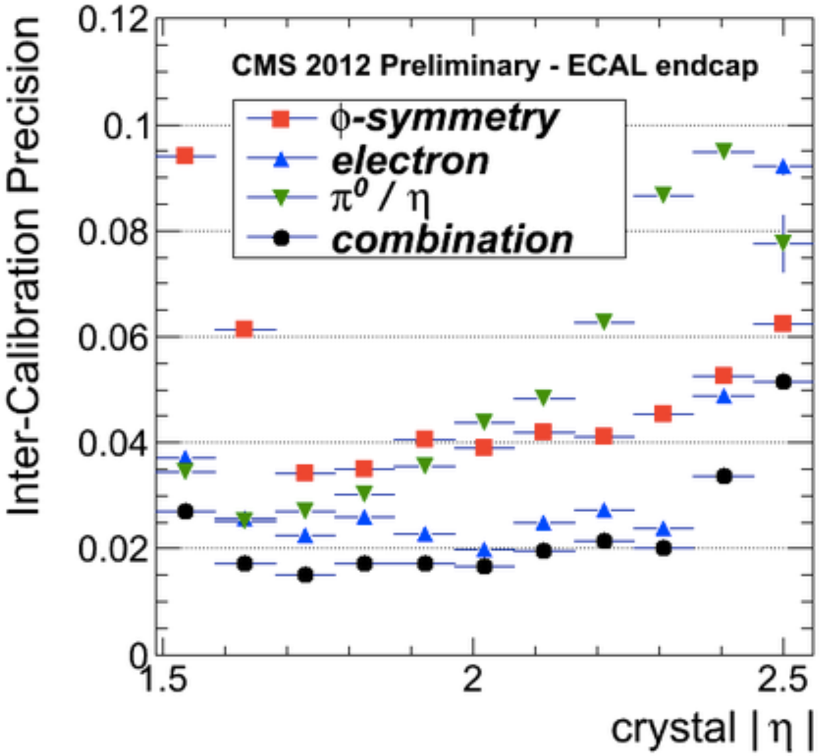
Imperfections in simulations

- **Effect of inter-crystal voids:**



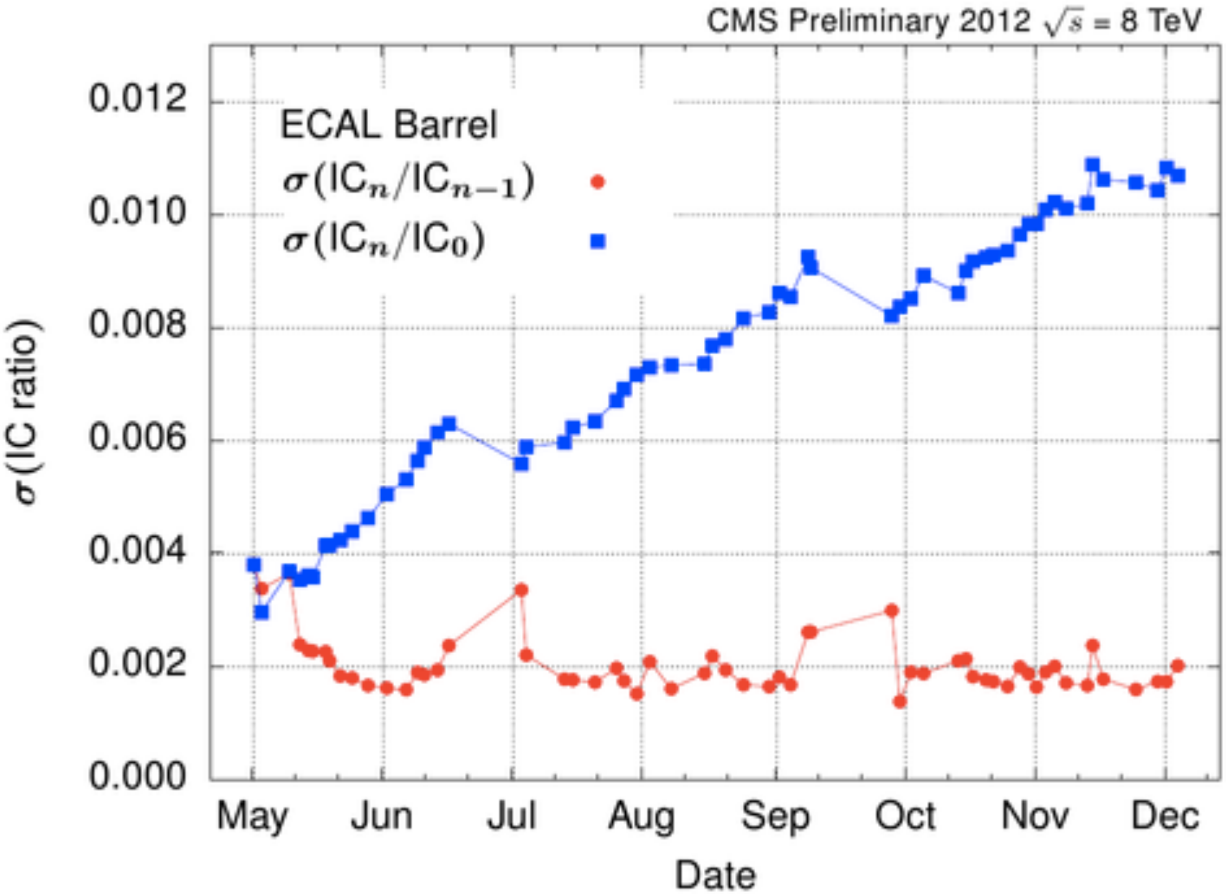
Channel intercalibration





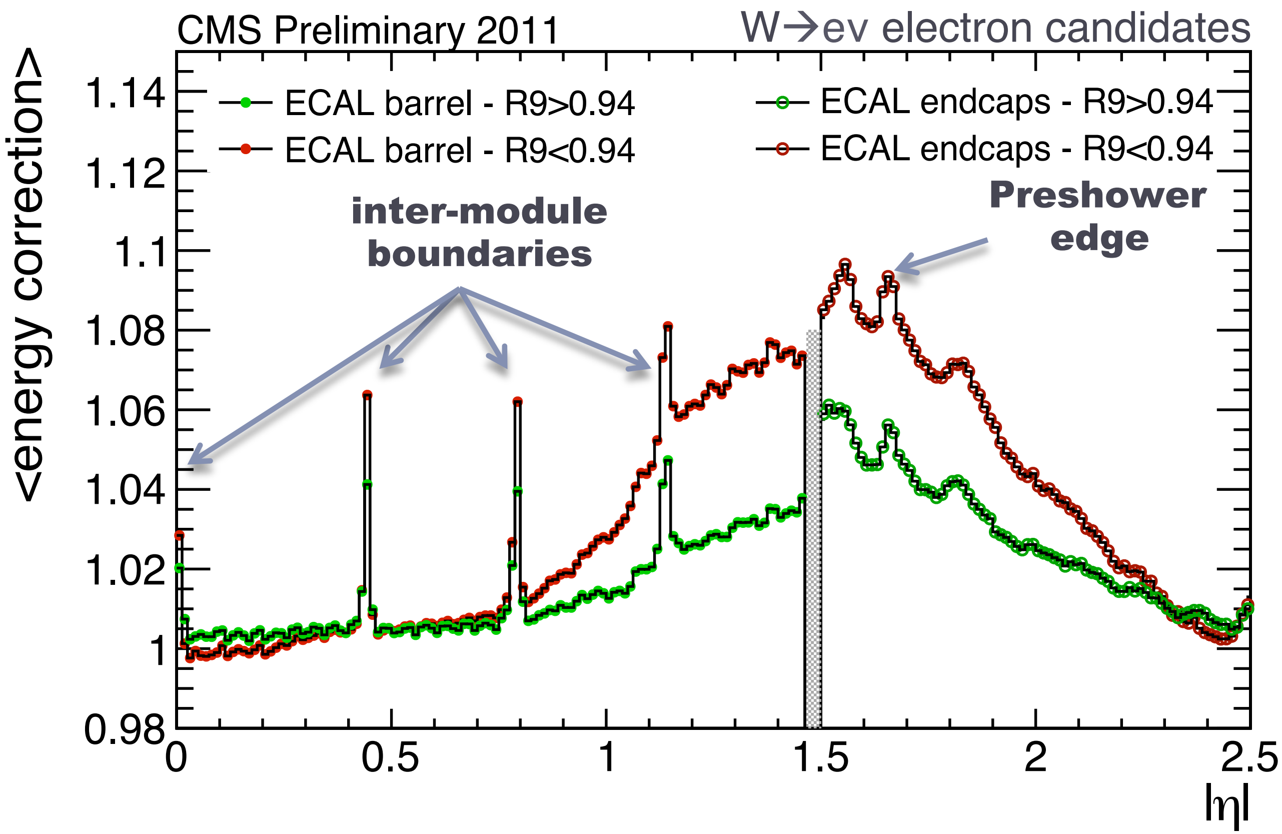
Monitoring and correction of imperfect monitoring corrections

- **Phi-simmetry of energy flow to monitor the evolution with time of the spread in intercalibration constants**

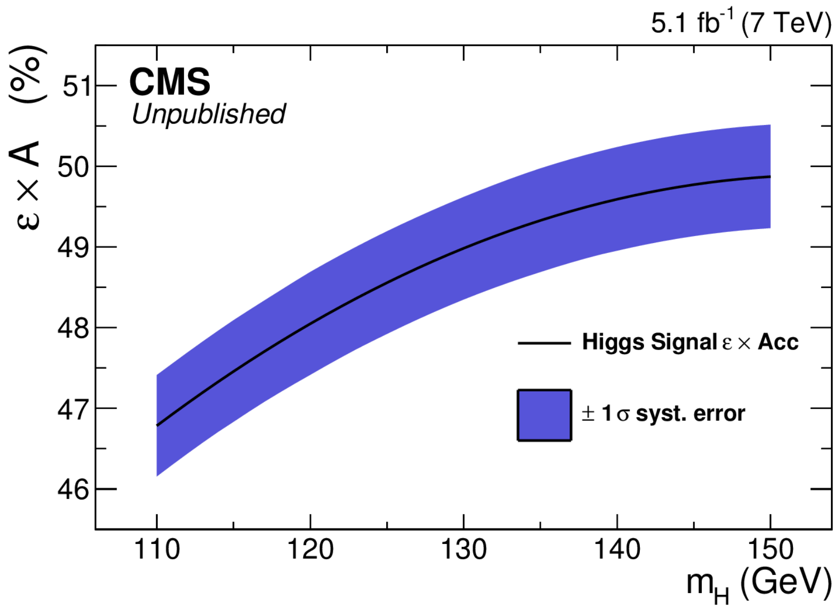


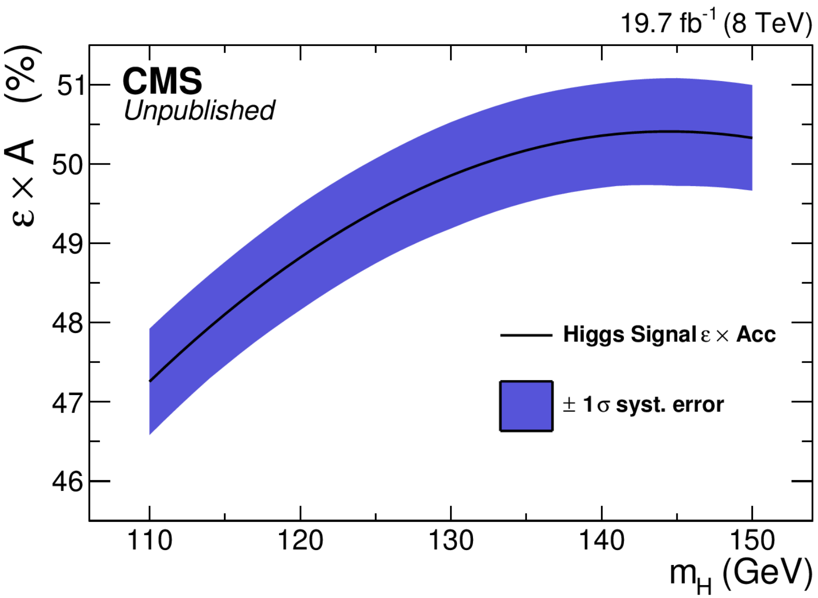
‘Measurement of energy corrections’

- **Energy correction in data: E_{corr}/E_{raw}**
  - Electrons from W→eν events

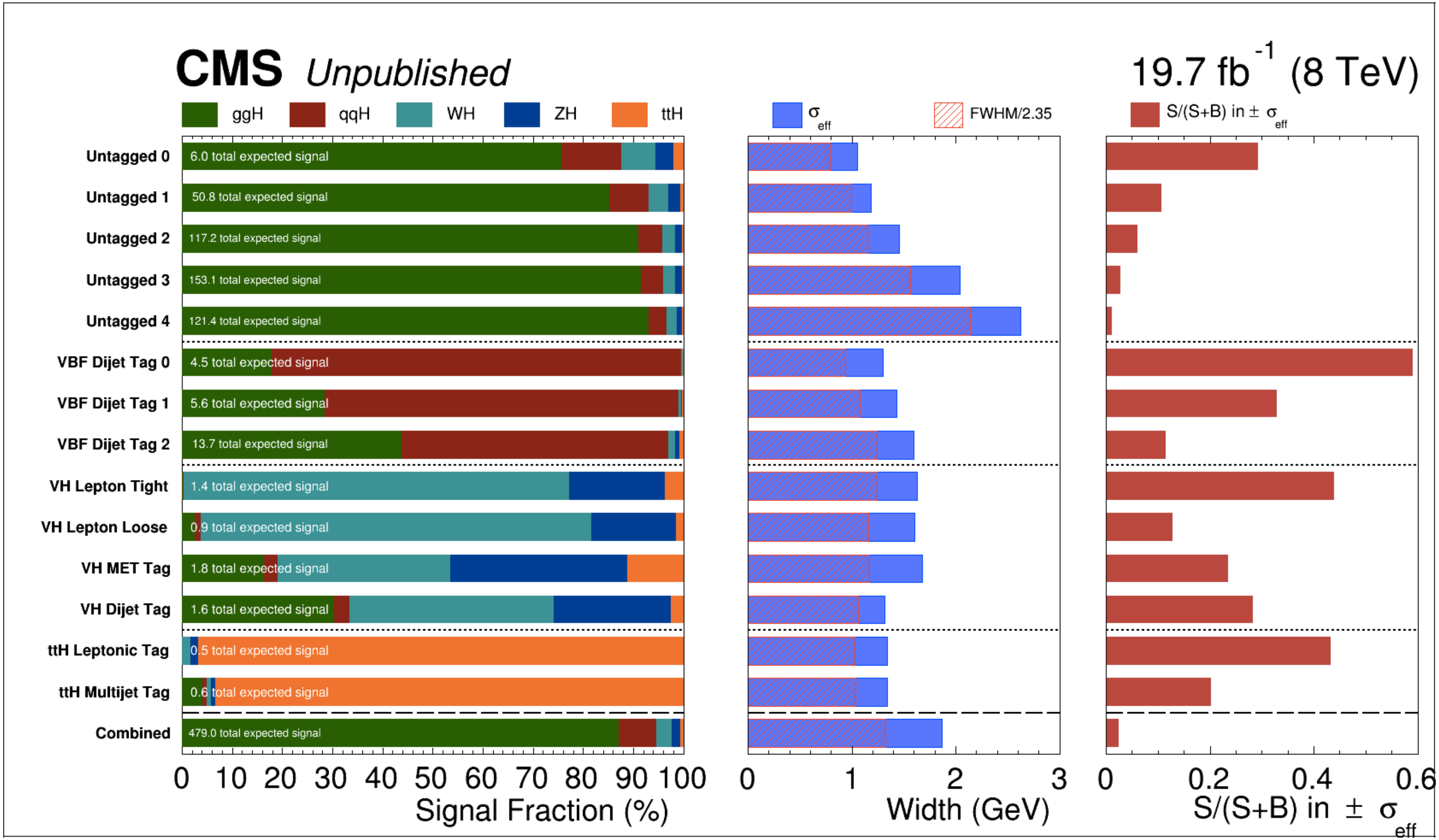


Efficiency and acceptance



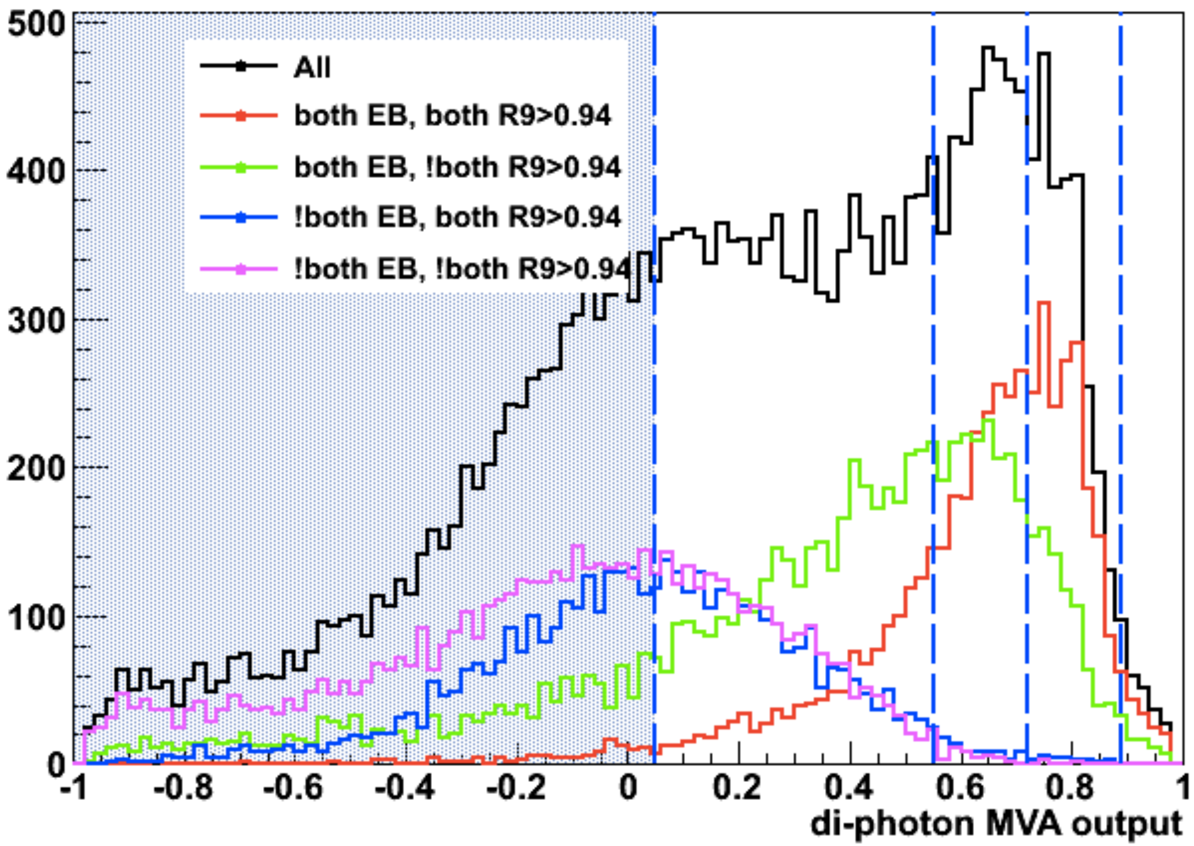


Signal composition: 7 TeV data



Diphoton BDT and photon quality

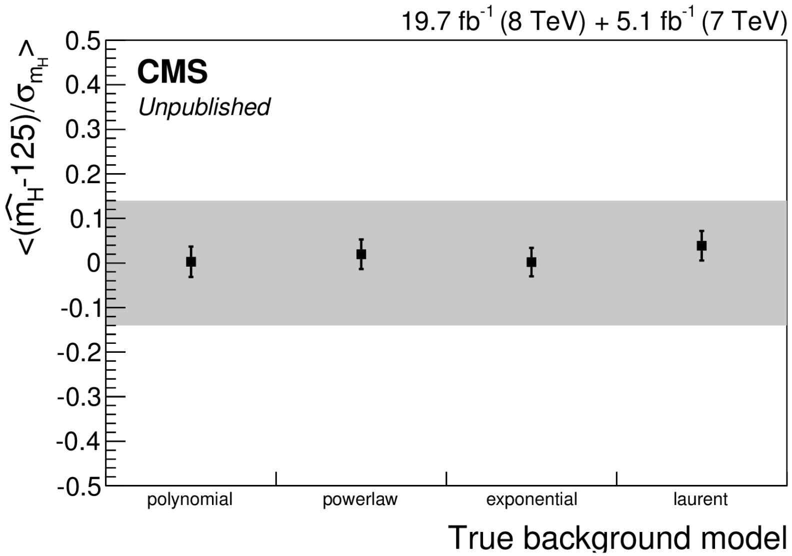
- **Mapping of diphoton BDT score to R9 / η regions**



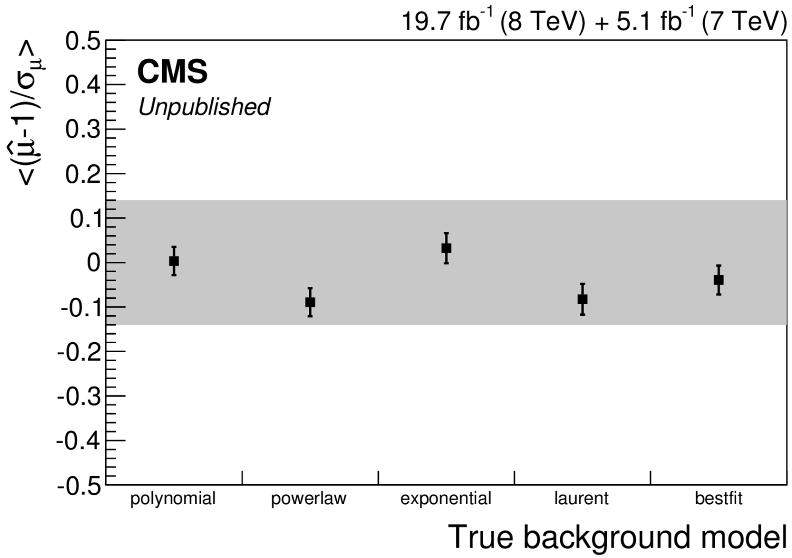
7 TeV data

OLD ANALYSIS

Background: bias studies



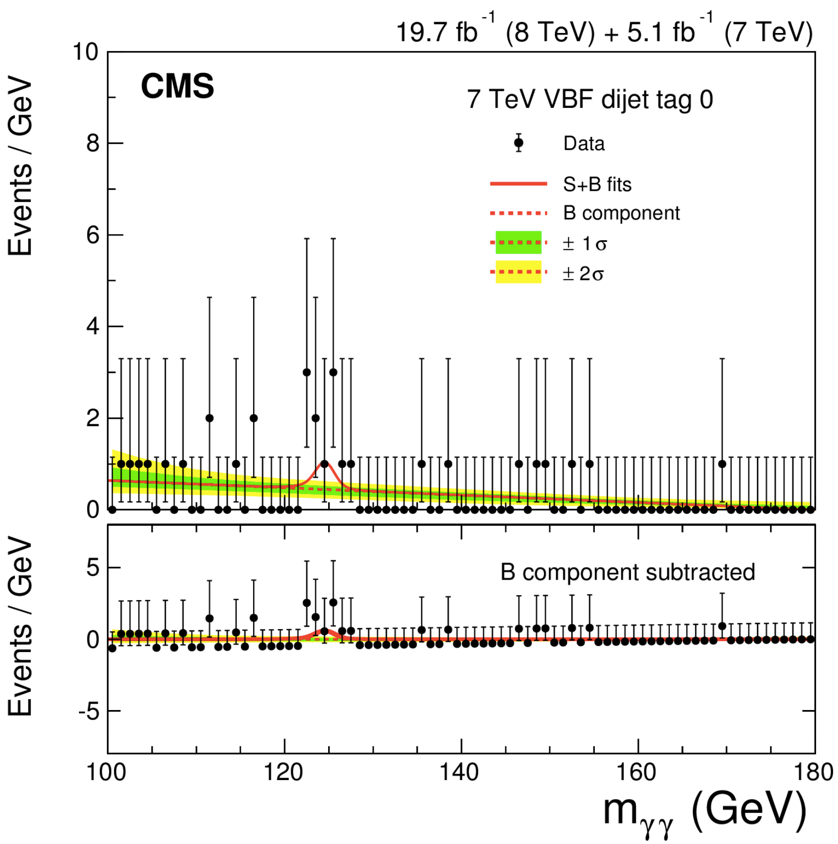
- **Mass**

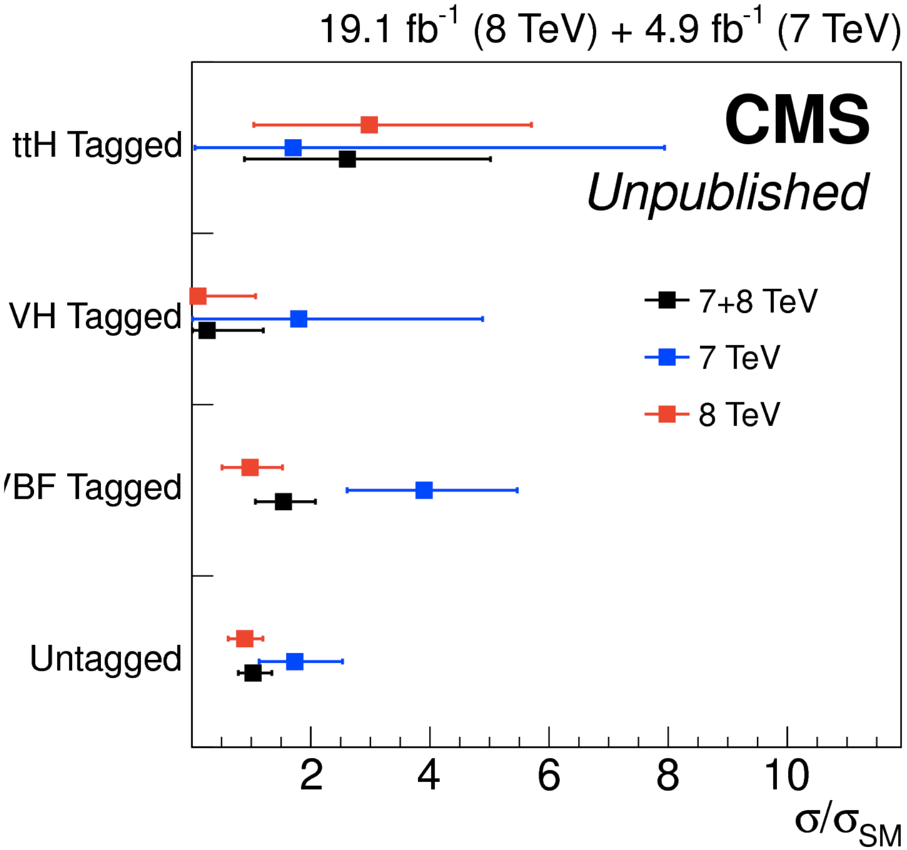


- **Signal strength**

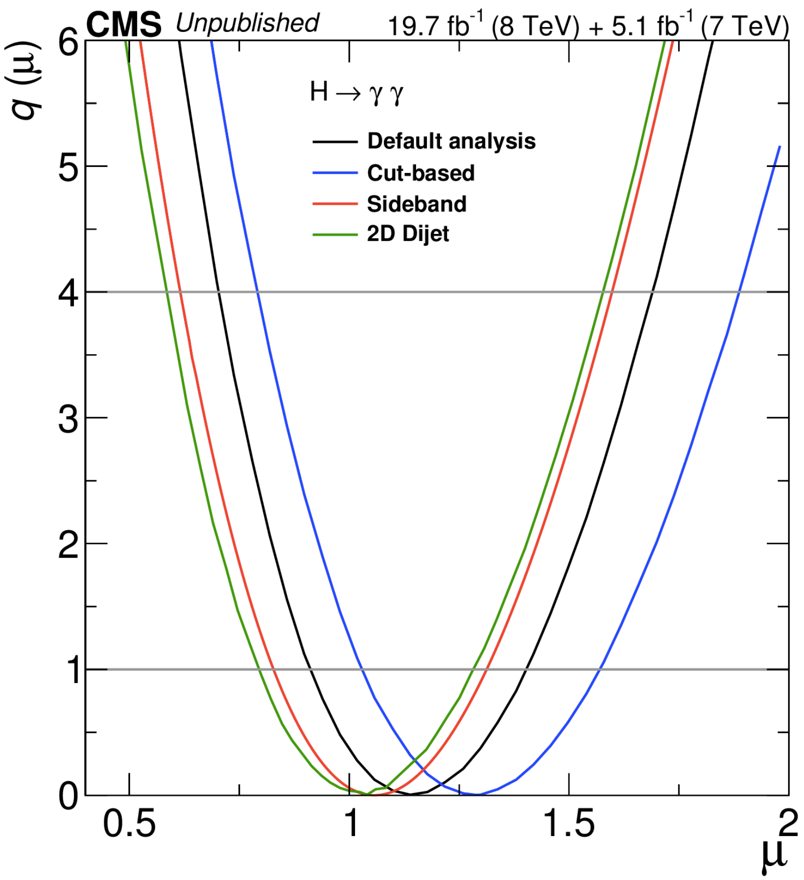
Compatibility 7 TeV/8 TeV

- **Most (1.5σ) from one VBF category**



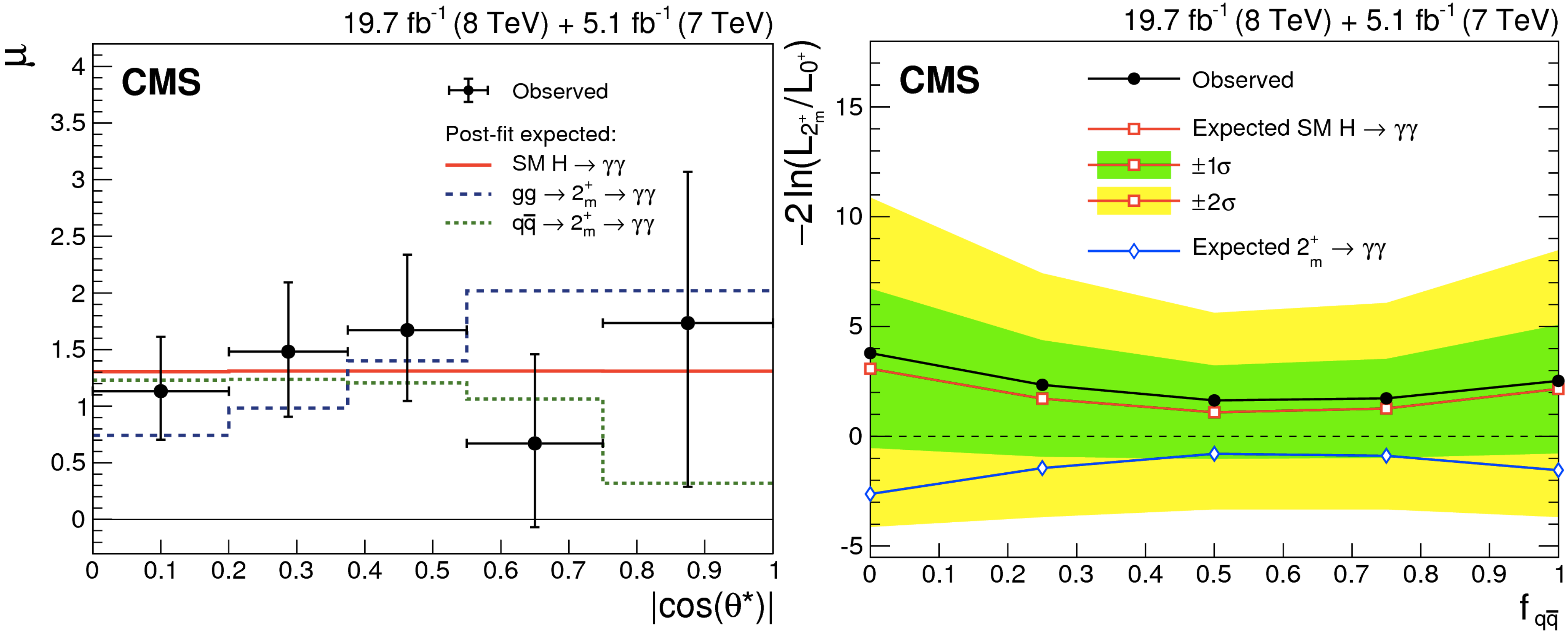


Cross-check – different analyses



Systematic	Value	Error
Baseline (obs)	1.14	+0.26 -0.23
Cut-based (obs)	1.29	+0.29 -0.26
Sideband (obs)	1.06	+0.26 -0.23
2D Dijet (obs)	1.04	+0.25 -0.25

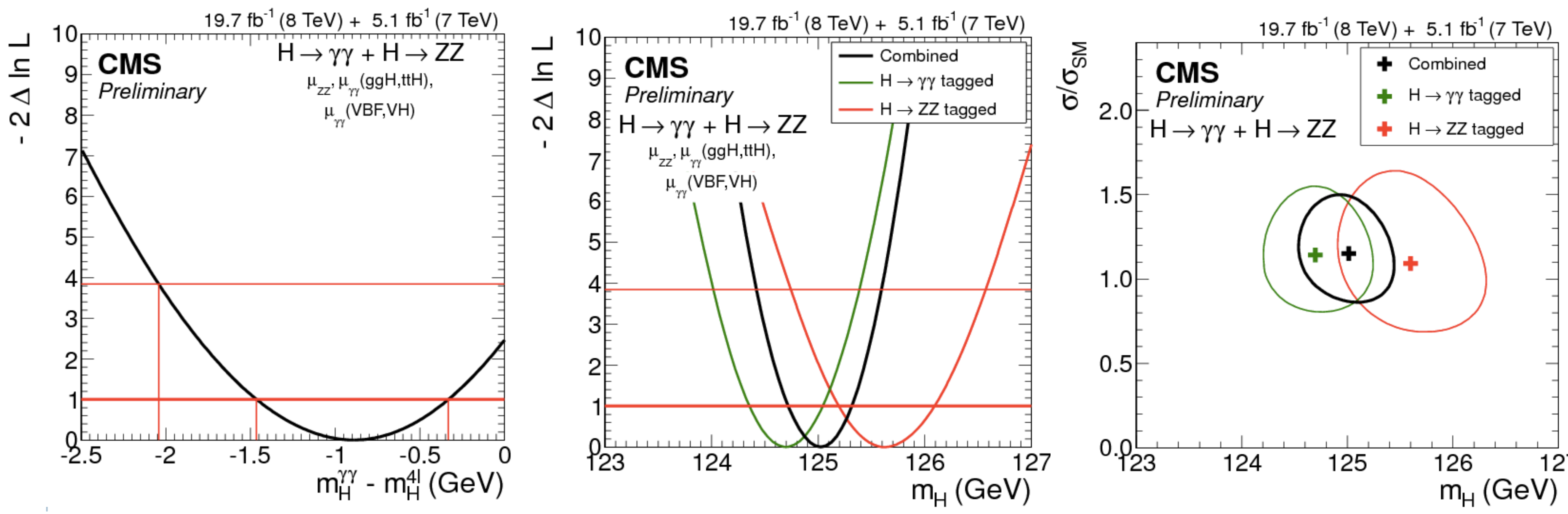
Spin



- **Cut based analysis**
  - less model dependence in selections
  - No exclusive tag categories
- **Fit signal strength in |η|,R9 categories and five bins of spin sensitive angle**
  - Collins-Soper

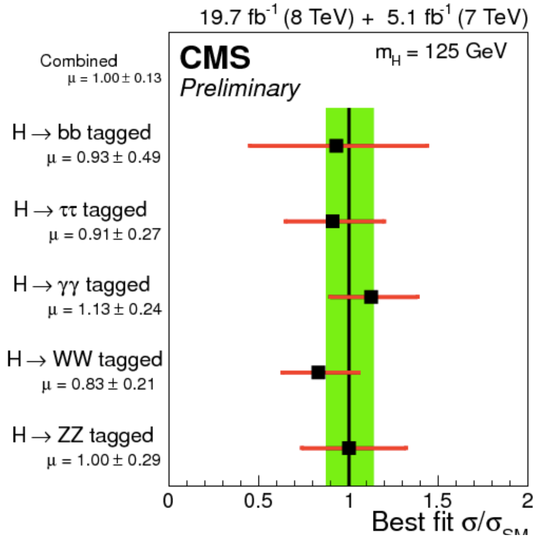
Higgs properties from ZZ* and γγ

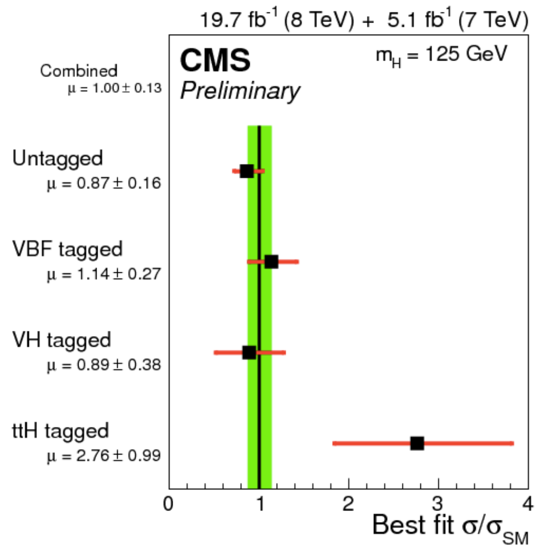
- **Combined mass measurement:** $125.03\,^{+0.26}_{-0.27}\,(\text{stat.})\,^{+0.13}_{-0.15}\,(\text{syst.})$ GeV

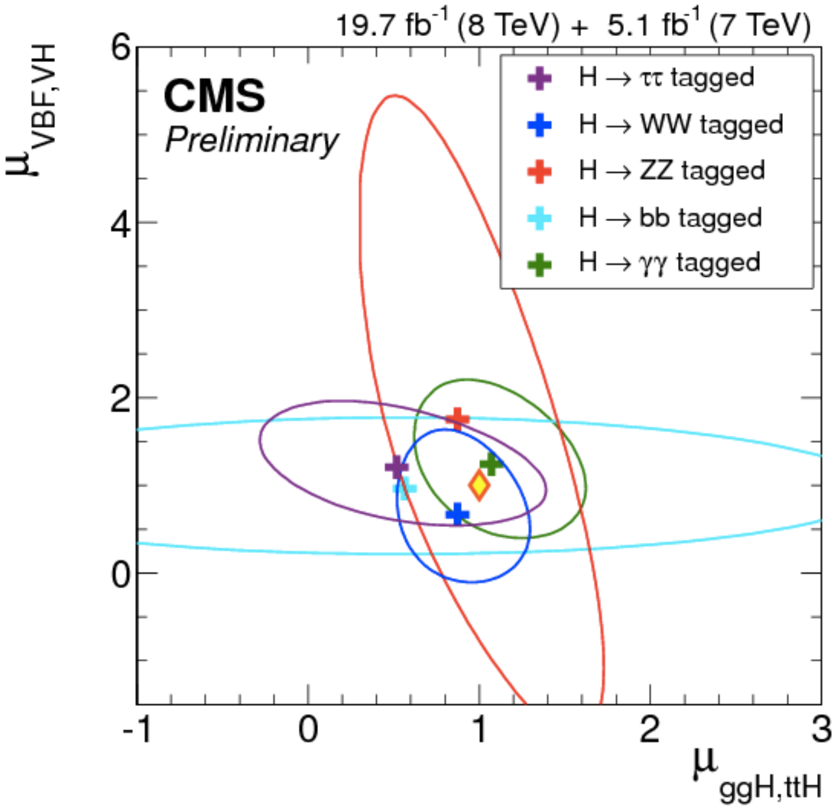


[CMS-PAS-HIG-14-009]

Higgs properties all decay modes

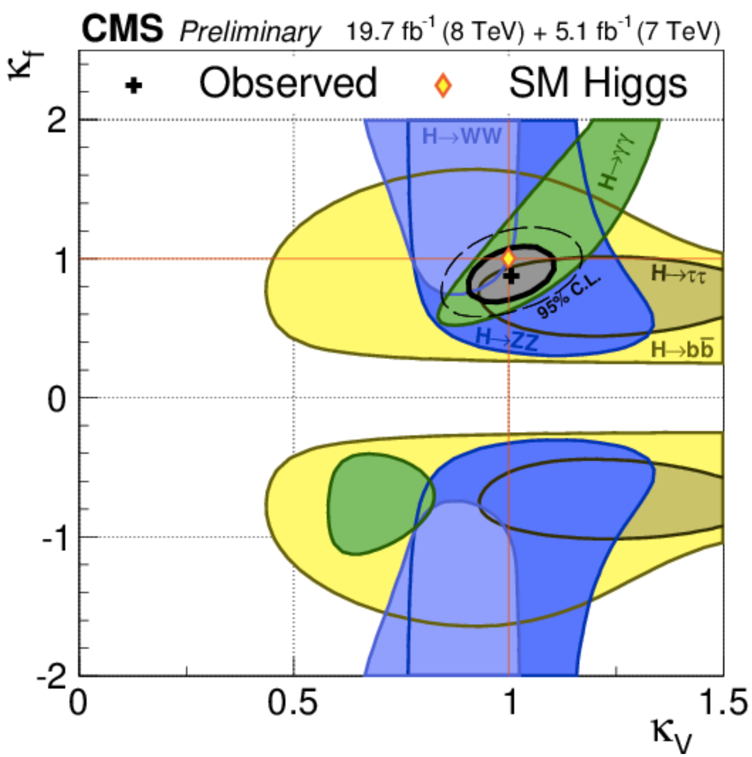


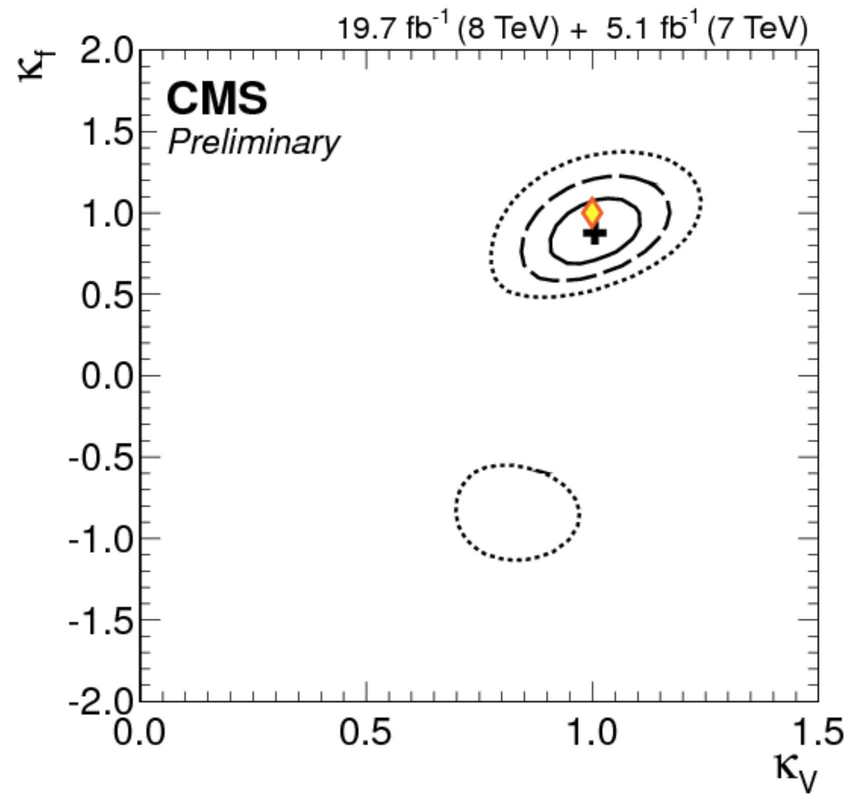




[CMS-PAS-HIG-14-009]

Modifiers of fermion and vector-boson couplings





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