Measurement of Higgs decaying into two photons with CMS

EPS Conference on High Energy Physics

July 6th 2017

Michael Planer (University of Notre Dame)
on behalf of the CMS collaboration

Introduction

H->γγ analysis with full 2016 data at 13 TeV collected by CMS

- Precision measurement of Higgs' boson properties
- Diphoton invariant mass range $100<m_{\gamma\gamma}<180$ GeV
- Classify diphotons by additional objects related to production mode to enhance sensitivity

Improved measurement of signal strength and coupling constants

- Overall and per process (signal strength)
- Two-dimensional fit for fermionic vs vector boson production modes (signal strength)
- Two-dimensional fit for gluon vs photon coupling
- Two-dimensional fit for fermionic vs vector boson coupling

Documentation:

- CMS-PAS-HIG-16-040 (all figures and results from this PAS)

Higgs to two photons

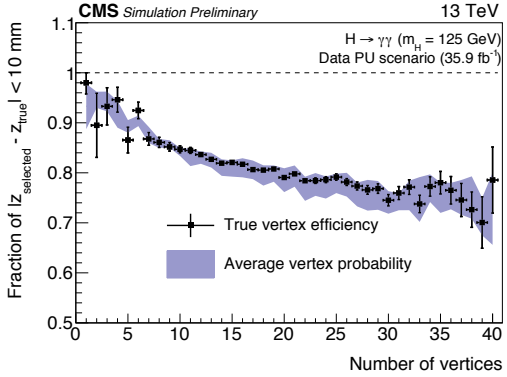
- **Signal signature**
  - Two isolated and high E_T photons
  - Final state fully reconstructed with high resolution
  - Mass resolution: σ 1-2% $m_{\gamma\gamma}$
- **Large backgrounds**
  - Continuum γγ (irreducible)
  - Fakes from γ+jet/jet+jet (reducible)
- **Photon energy:** well calibrated and corrected, Z->ee peak used as reference

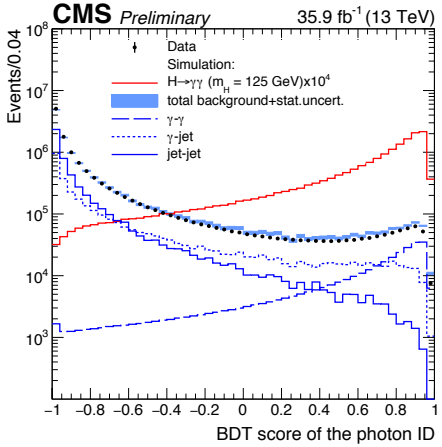
$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

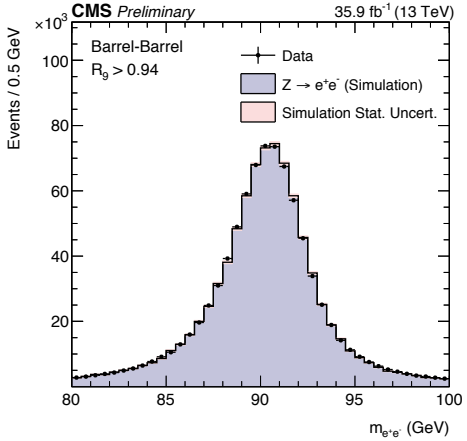
- **Primary vertex:** BDT for selection; within 1cm->negligible impact on resolution

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta)}$$

- **Photon ID:** BDT discriminates real vs fake photons from jet fragment



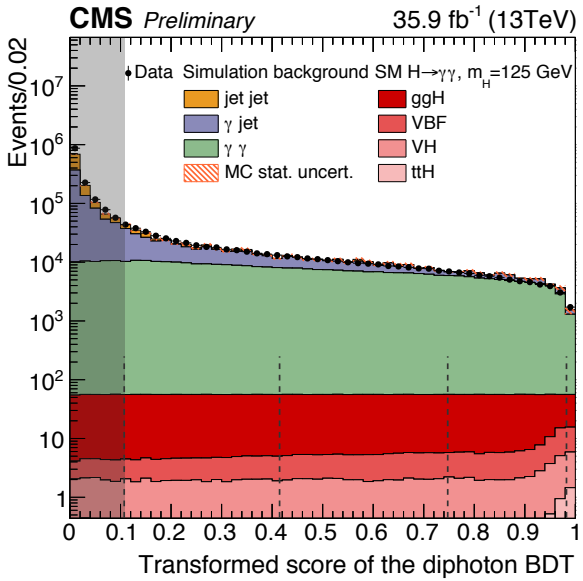


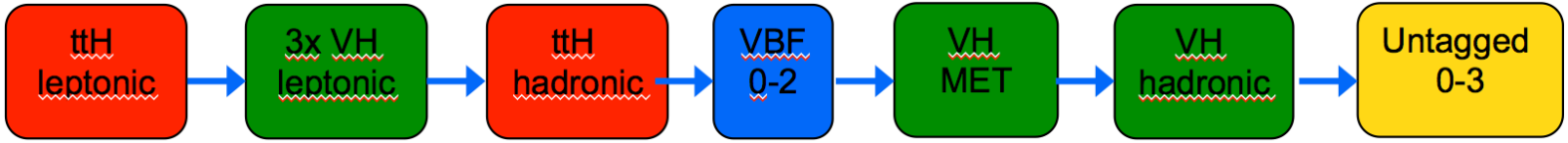


Michael Planer
mplaner@nd.edu

Analysis strategy

- **Event tagging**: events are sorted into 14 categories depending on Higgs production modes and kinematics, to improve the analysis sensitivity
- **Top fusion (ttH)**: cut-based leptonic and mva-based hadronic (2 categories)
- **VH**: cut-based and split into leptonic, hadronic, MET (5 categories)
- **VBF**: dijet+diphoton BDTs with categories based on significance (3 categories)
- **Untagged**: split by diphoton BDT score, corresponds to different S/B and invariant mass resolutions (4 categories)

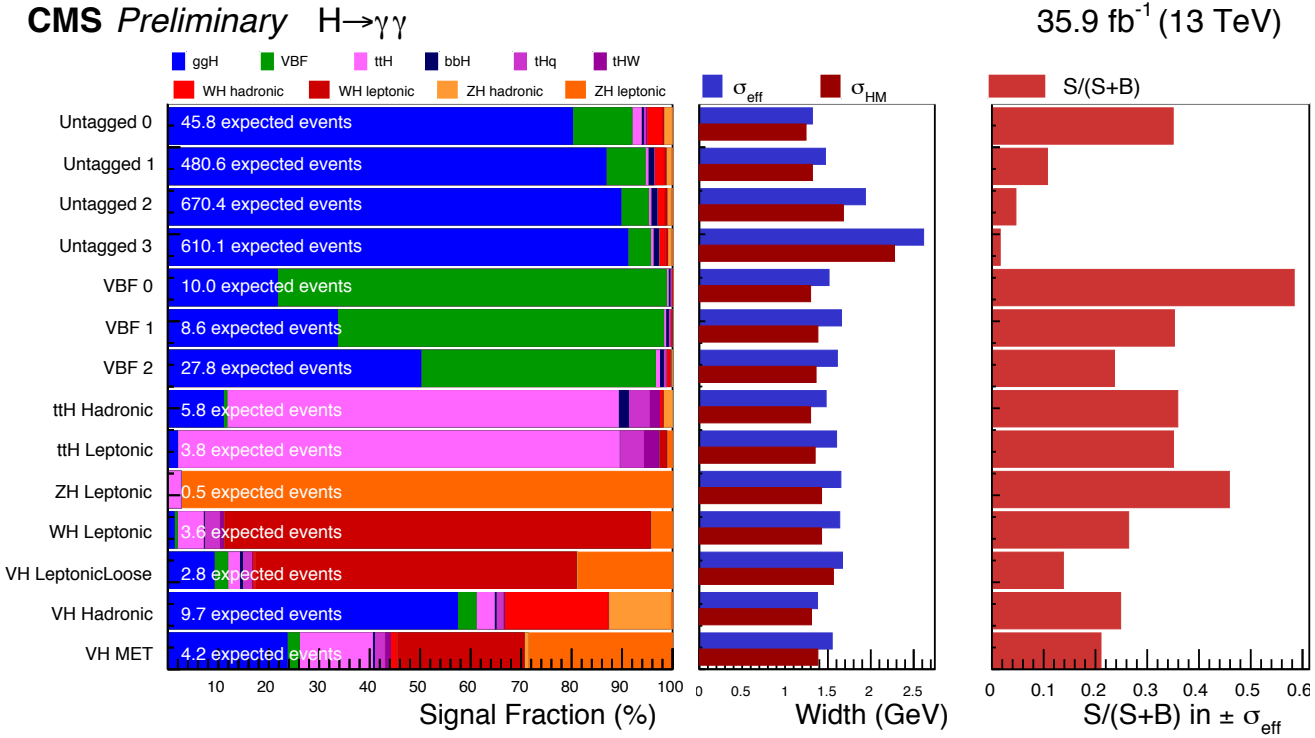




- **Category priority:** Tags are prioritized in order of S/B

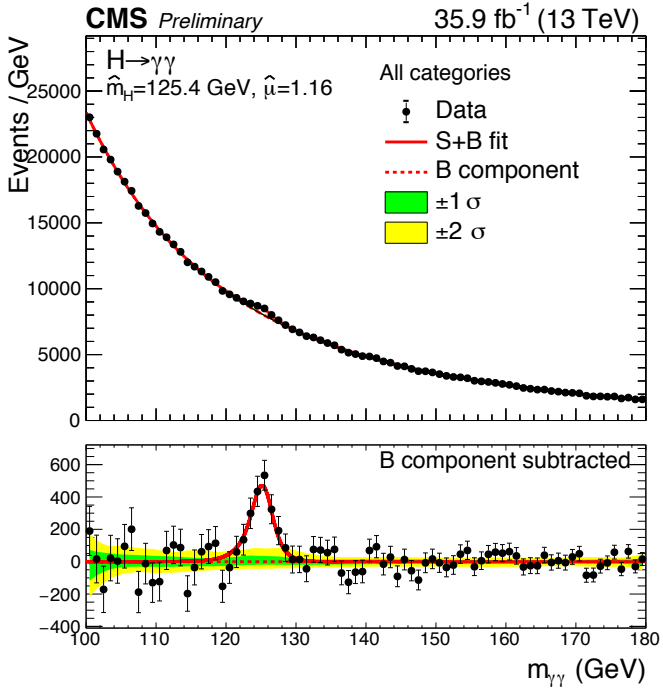
Signal fractions and expected yields

- **Expected yields for the full 2016 dataset**

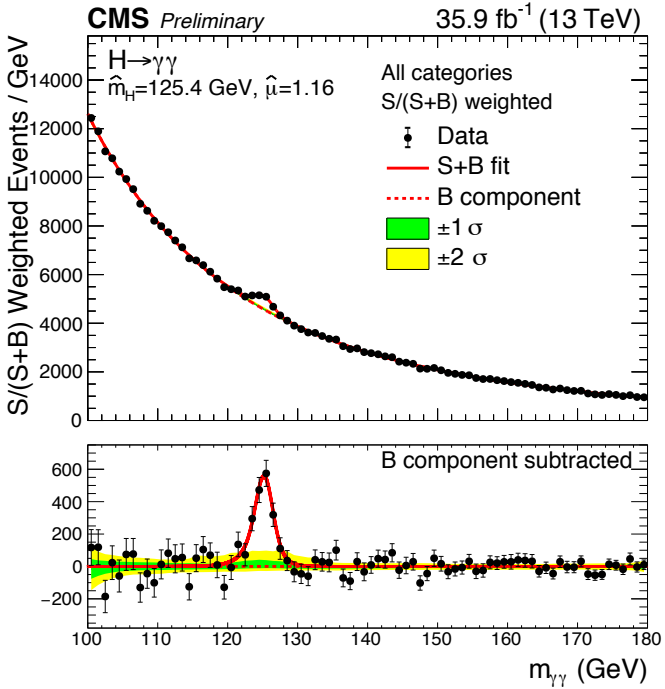


Mass distributions

All categories



All categories weighted by sensitivity



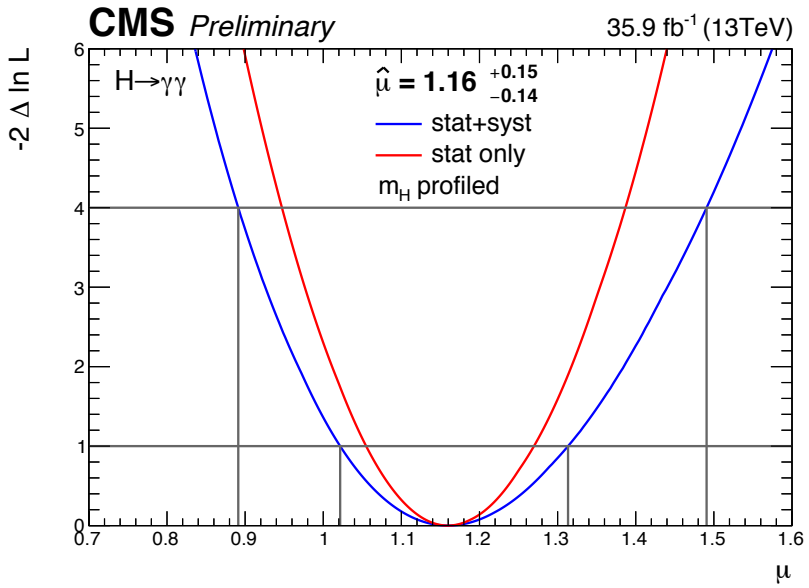
Michael Planer
mplaner@nd.edu

Signal strength

Overall signal strength is consistent with standard model

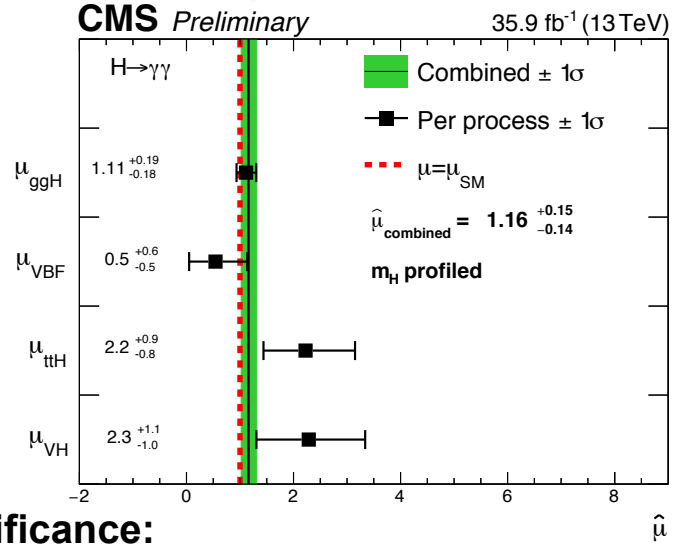
m_H profiled

$$\mu = 1.16^{+0.15}_{-0.14}(stat+syst) = 1.16^{+0.11}_{-0.10}(stat.)^{+0.09}_{-0.08}(syst.)^{+0.06}_{-0.05}(theo.)$$

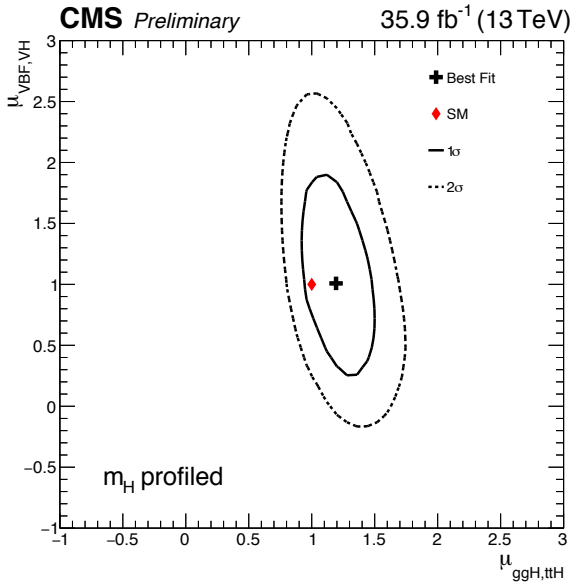


Signal strength

Per production mode



Bosonic and fermionic components



Significance:

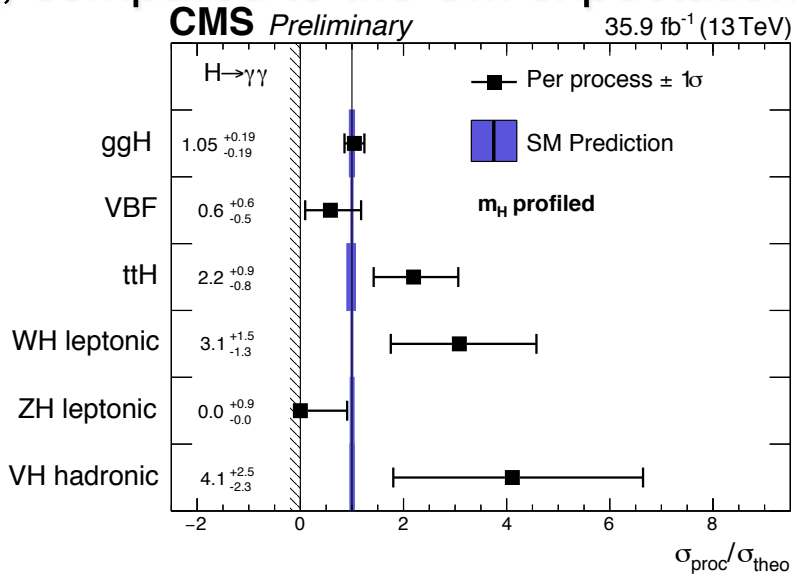
	Expected	Observed
• VBF	1.90σ	1.11σ
• ttH	1.47σ	3.30σ
• VH	1.21σ	2.45σ

$$\mu_{ggH,t\bar{t}H} = 1.19^{+0.20}_{-0.18}(stat + syst)$$

$$\mu_{VBF,VH} = 1.01^{+0.57}_{-0.51}(stat + syst)$$

Cross section

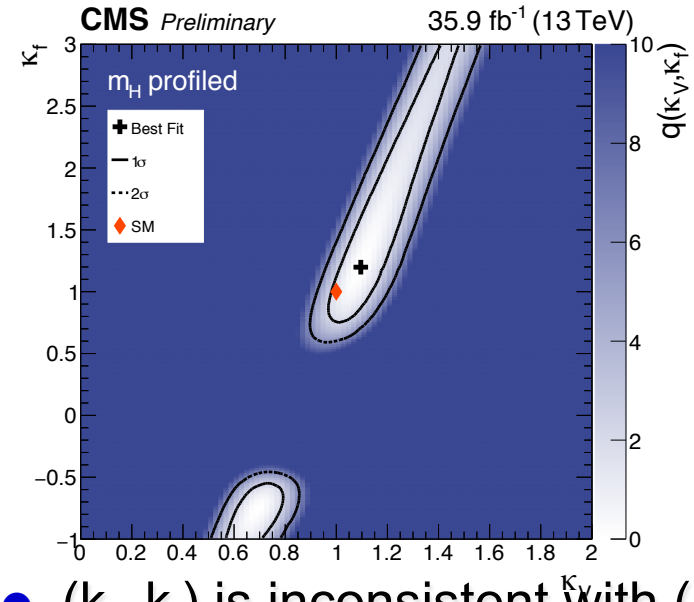
- Cross section ratios are measured for each process using the Higgs Simplified Template Cross Section (STXS)[1] framework for profiled m_H, compared to the SM expectation and uncertainties

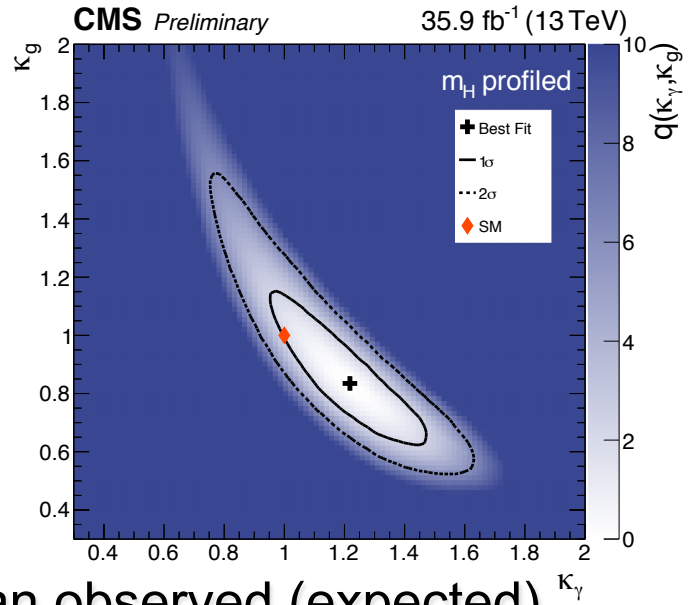


[1]: LHC Higgs Cross Section Working Group Collaboration, “Handbook of LHC Higgs Cross Sections: 4. Deciphering the Nature of the Higgs Sector”, technical report, 2016. arXiv:1610.07922

Coupling constants

- Measurements of coupling modifiers to vector bosons and fermions (k_V,k_f) and to photons and gluons (k_γ,k_g)





- (k_V,k_f) is inconsistent with (1,-1) to an observed (expected) level of 5.6σ (6.3σ)

Further measurements of Higgs boson in two photon final state

Measurement of fiducial and differential cross section

- CMS-PAS-HIG-17-015
- Vittorio will be giving a talk covering this tomorrow at 9:30 in detail
- Measure the differential fiducial cross-section binned in transverse Higgs momentum and number of jets

Search for low-mass Higgs resonance

- CMS-PAS-HIG-14-037
- Linda will be giving a talk covering this tomorrow at 12:45 in detail
- Search results for low-mass resonance from Run1 data

Summary and outlook

- Latest results of Higgs measurements with H->γγ from Run2 data (35.9 fb^{-1}) collected by CMS detector at 13 TeV were presented
- Measurements of its properties are largely compatible with SM expectations
- Results are still statistically limited
- Expected >100 fb^{-1} to be delivered by the end of Run2
  - improve precision on the measurements

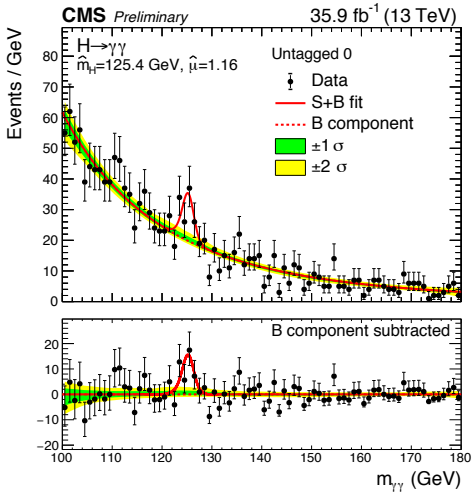
Extra material

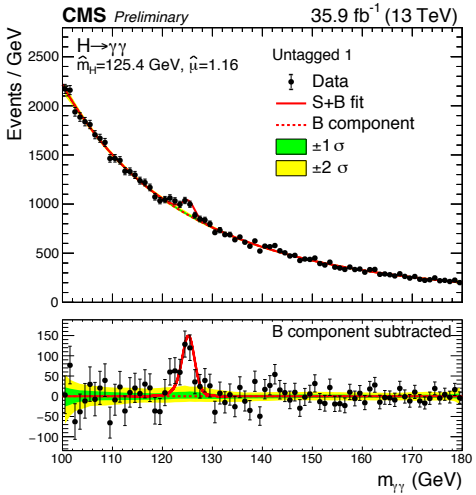
Michael Planer
mplaner@nd.edu

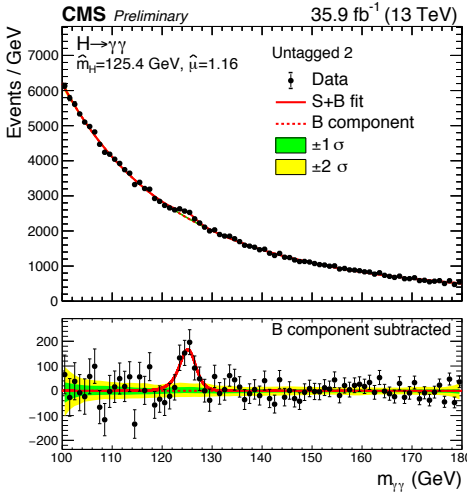
Photon energy

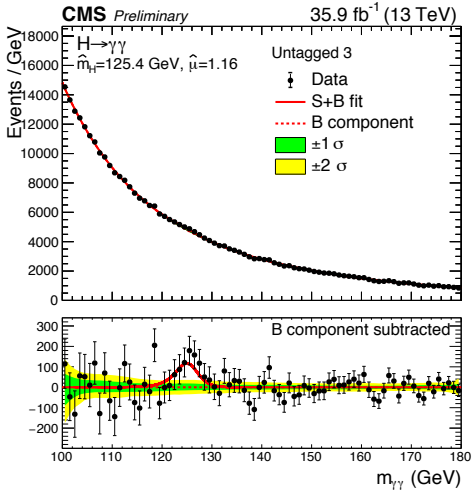
- Electromagnetic calorimeter response
  - Corrected for change in time
  - intercalibrated for η/φ uniformity
  - adjustment of absolute scale
- Energy and its uncertainty corrected for local and global shower containment:
  - regression targeting E_{true}/E_{reco}
- Scale vs time and resolution calibration:
  - Z->ee peak used as reference
- Fully corrected energies and resolutions used in the analysis

Untagged Categories



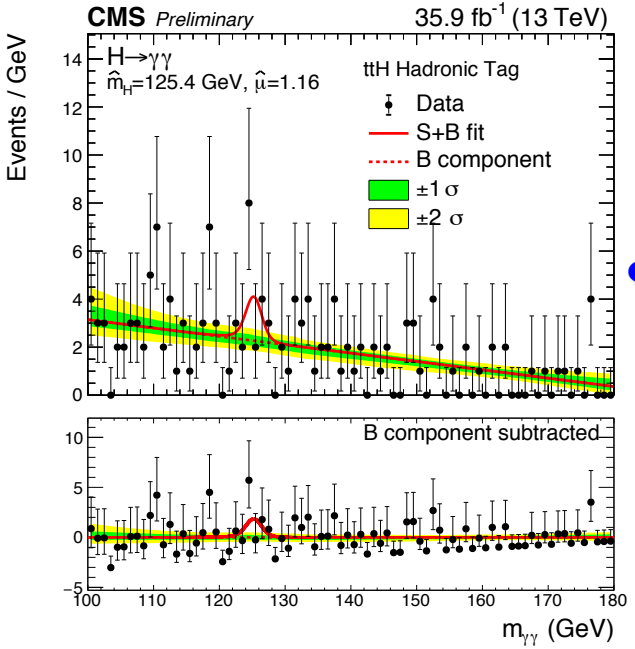






ttH hadronic category

- $t\bar{t} \rightarrow bq\bar{q}'\bar{b}q\bar{q}'$
- Cut-based strategy replaced with mva to improve μ_{ttH} sensitivity
- Input variables
  - Number of jets
  - Maximum b-tag value
  - Second maximum b-tag value
  - Leading jet pT
- BDT trained with MC ttH vs MC diphoton
- **Preselection:**
  - at least 3 jets
  - at least 1 loose b-jet



- **Control Sample**:
  - one photon ID requirement inverted
  - 2 jets and 0 leptons in event
  - reweighted for pT, η of photons and pT of lead jet
- 2-d optimization of diphoton MVA and ttH MVA
  - diphoton MVA > 0.577
  - ttH MVA > 0.75

ttH leptonic category

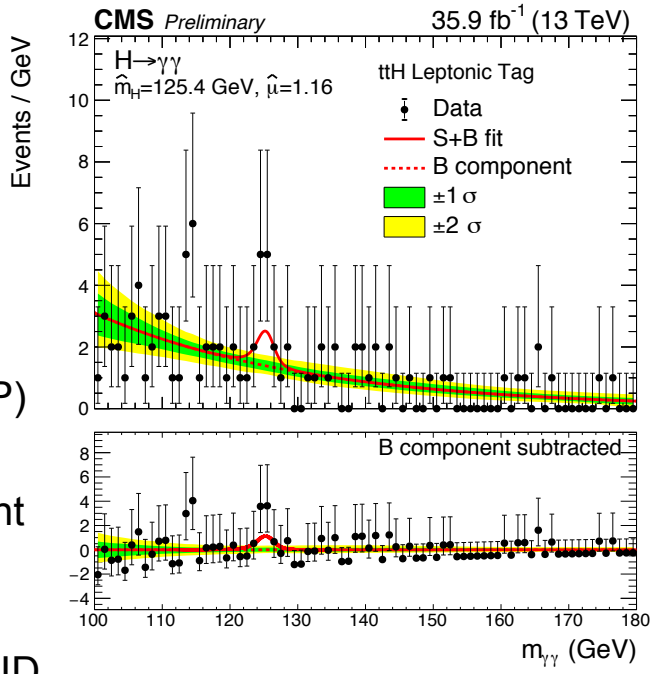
$t\bar{t} \rightarrow bl\nu_l \bar{b}q\bar{q}$ or $t\bar{t} \rightarrow bl\nu_l \bar{b}l'\nu_{l'}$

Control sample:

- 2 jets 1 lepton and invert ID requirement of one photon

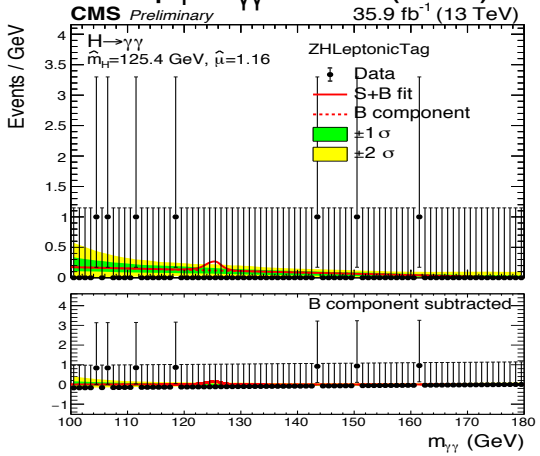
- **Selection**
  - (sub)leading photon $p_T/M_{\gamma\gamma}$>0.5(.25)
  - At least 2 jets with ΔR(j, γ or l) >0.4
  - At least one b-tagged jet
  - At least 1 lepton ΔR(l,γ)>0.35
  - For electron: $|M_{e\gamma}-M_Z|$>5 GeV
  - diphoton mva > 0.107

- **Jets**:
  - ak4PFCHS; pT>25 GeV; |η|<2.4
- **Bjets**:
  - PF CSV v2 (medium WP)
- **Muons**:
  - p_T>20 GeV; |η|<2.4; "tight muon"; miniIso<0.06
- **Electrons**:
  - p_T>20 GeV; loose EGM ID |η|<2.5; 1.442<|η|<1.566;

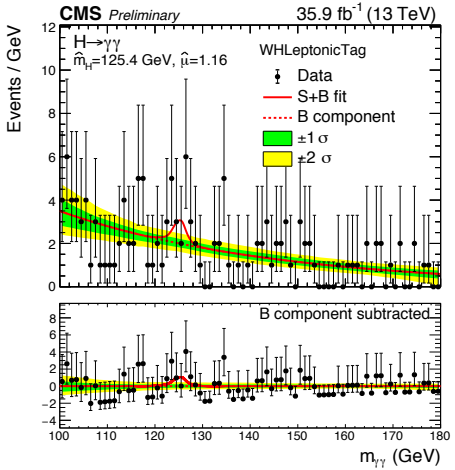


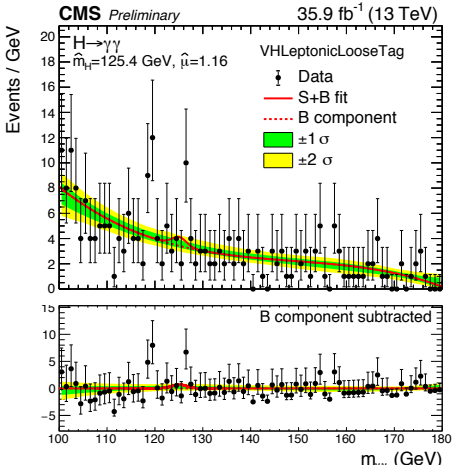
3 VH leptonic categories

- $W \rightarrow l\nu$ or $Z \rightarrow l\bar{l}$
- **Muons**
  - pf isolation < 0.25 (loose WP)
- **Electrons**
  - loose EGM ID
- **Photons**
  - (sub)leading $p_T/m_{\gamma\gamma}$>0.375(0.25)



- **WH leptonic:**
  - one lepton:
  - p_T^{miss} > 45 GeV
  - ΔR(γ, l) >1.0
  - diphoton mva>0.28
  - <=2 jets
- **ZH leptonic:**
  - two leptons:
  - 70<m_{ll}<110 GeV
  - ΔR(γ, μ(e)) >0.5(1.0)
  - diphoton mva>0.107
- **VH leptonic loose:**
  - one lepton:
  - p_T^{miss} < 45 GeV
  - ΔR(γ, l) >1.0
  - diphoton mva>0.28
  - <=2 jets



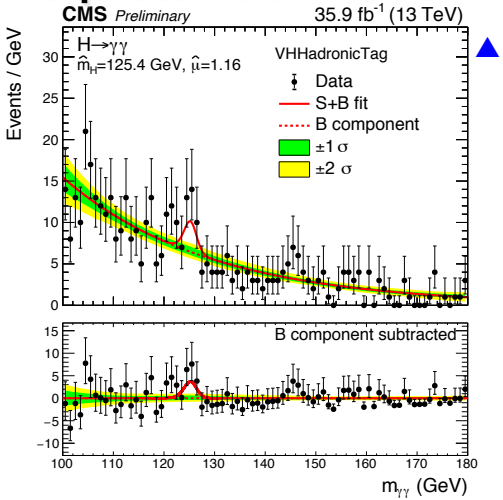


VH hadronic

VH Hadronic

- W->jj or Z->jj
- **Photons**
  - (sub)leading $p_T/m_{\gamma\gamma}$>0.5(0.25)
  - $p_T^{\gamma\gamma}/m_{\gamma\gamma}$>1.0
- **Jets**
  - At least two jets
  - p_T > 40 GeV
  - $|\eta|$ < 2.4
  - 60<m_{jj} < 120 GeV
  - $|\cos\theta^*|$ < 0.5

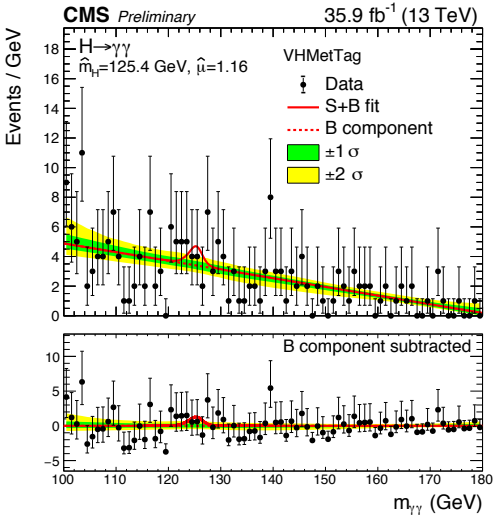
Diphoton MVA > 0.906



VH MET categories

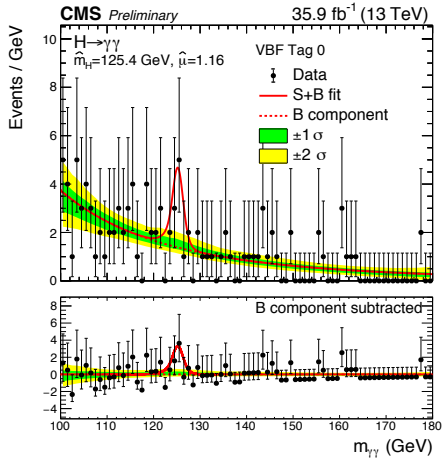
VH MET

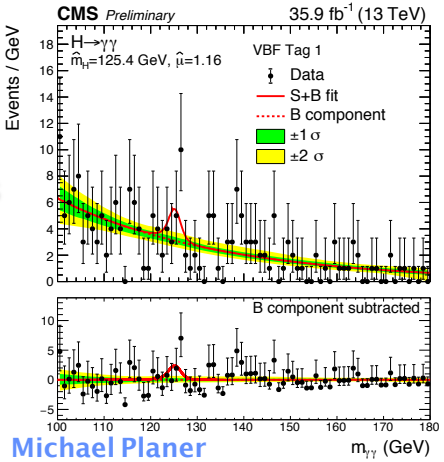
- $W \rightarrow l\nu$ (lepton out of acceptance) or $Z \rightarrow \nu\nu$
  - p_T^{miss} > 85 GeV
  - $\Delta\varphi(\gamma\gamma, p_T^{miss})$ >2.4
  - diphoton MVA > 0.790
- Control region
  - $\Delta\varphi(\gamma\gamma, p_T^{miss})$ <2.0 (for MVA optimization)
  - 0.278<MVA<0.79 (for p_T^{miss} variables optimization)

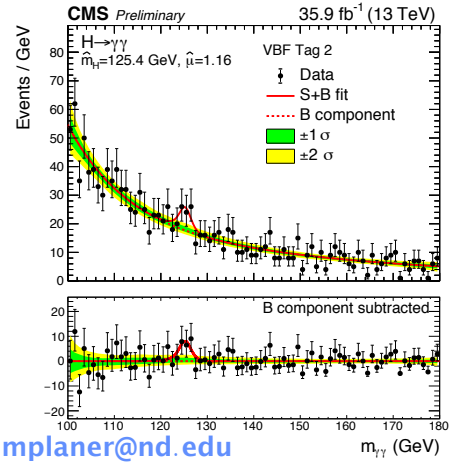


VBF categories

- VBF production contains two jets in addition to diphoton pair
- **Jet definition**:
  - ak4PFCHS, reclustered and corrected wrt to vertex, “pile-up jets” are removed using PUJID algorithm (Tight WP)
- **Kinematic dijet MVA**: identify VBF events
  - Input: $p_T/m_{\gamma\gamma}$ of both photons, p_T of both jets, mjj, Δn_{jj}, $\Delta\varphi_{jj,\gamma\gamma}$, $\Delta\varphi_{jj}$, $\Delta R_{\gamma j}$, and centrality variable
- **Combined dijet MVA** to categorize events
  - **inputs**: diphoton BDT, kinematic dijet MVA, $p_T^{\gamma\gamma}/m_{\gamma\gamma}$
- 3 VBF-tagged categories using the combined MVA







Michael Planer
mplaner@nd.edu

Expected yields

Expected yields for full 2016 dataset

Event Categories	SM 125GeV Higgs boson expected signal													Bkg	Bkg	naive expected
	Total	GG2H	VBF	TTH	BBH	THQ	THW	QQ2HLNU	QQ2HLL	WH2HQQ	ZH2HQQ	σ_{eff}	σ_{HM}	(GeV^{-1})	(GeV^{-1} fb^{-1})	
Untagged Tag 0	45.83	80.19 %	11.75 %	1.83 %	0.40 %	0.47 %	0.22 %	0.41 %	0.19 %	2.96 %	1.58 %	1.32	1.24	21.92	0.61	4.10
Untagged Tag 1	480.56	86.81 %	7.73 %	0.56 %	1.15 %	0.13 %	0.02 %	0.47 %	0.27 %	1.81 %	1.04 %	1.47	1.32	924.21	25.74	6.27
Untagged Tag 2	670.45	89.76 %	5.48 %	0.44 %	1.18 %	0.08 %	0.01 %	0.51 %	0.34 %	1.40 %	0.81 %	1.94	1.68	2419.53	67.40	4.71
Untagged Tag 3	610.07	91.13 %	4.51 %	0.48 %	1.07 %	0.07 %	0.01 %	0.55 %	0.30 %	1.21 %	0.69 %	2.62	2.28	4855.00	135.24	2.60
VBF Tag 0	10.01	21.69 %	77.09 %	0.34 %	0.35 %	0.29 %	0.03 %	0.03 %	0.00 %	0.19 %	-0.01 %	1.51	1.30	1.60	0.04	3.09
VBF Tag 1	8.64	33.58 %	64.64 %	0.39 %	0.52 %	0.36 %	0.04 %	0.13 %	0.03 %	0.24 %	0.07 %	1.66	1.38	3.25	0.09	1.79
VBF Tag 2	27.76	50.14 %	46.46 %	0.81 %	0.73 %	0.53 %	0.07 %	0.20 %	0.06 %	0.71 %	0.27 %	1.61	1.36	18.89	0.53	2.42
TTH Hadronic Tag	5.85	10.99 %	0.70 %	77.54 %	2.02 %	4.13 %	2.02 %	0.09 %	0.05 %	0.63 %	1.82 %	1.48	1.30	2.40	0.07	1.49
TTH Leptonic Tag	3.81	1.90 %	0.05 %	87.48 %	0.08 %	4.73 %	3.04 %	1.53 %	1.15 %	0.02 %	0.02 %	1.60	1.35	1.50	0.04	1.18
ZH Leptonic Tag	0.49	0.00 %	0.00 %	2.56 %	0.00 %	0.02 %	0.13 %	0.00 %	97.30 %	0.00 %	0.00 %	1.65	1.43	0.12	0.00	0.53
WH Leptonic Tag	3.61	1.26 %	0.59 %	5.18 %	0.18 %	3.03 %	0.73 %	84.48 %	4.33 %	0.12 %	0.09 %	1.64	1.43	2.09	0.06	0.94
VH LeptonicLoose Tag	2.75	9.16 %	2.70 %	2.34 %	0.57 %	1.81 %	0.13 %	63.62 %	18.87 %	0.56 %	0.23 %	1.67	1.56	3.50	0.10	0.55
VH Hadronic Tag	9.69	57.38 %	3.68 %	3.61 %	0.35 %	1.39 %	0.27 %	0.17 %	0.42 %	20.47 %	12.26 %	1.38	1.31	7.22	0.20	1.48
VH Met Tag	4.25	23.63 %	2.46 %	14.45 %	0.41 %	2.00 %	1.14 %	25.17 %	28.60 %	1.32 %	0.82 %	1.55	1.38	3.49	0.10	0.88
Total	1883.77	86.96 %	7.09 %	1.00 %	1.09 %	0.15 %	0.04 %	0.81 %	0.42 %	1.55 %	0.89 %	1.95	1.62	8264.73	230.22	10.57