Higgs Production and Decay at CMS
Channel Specific

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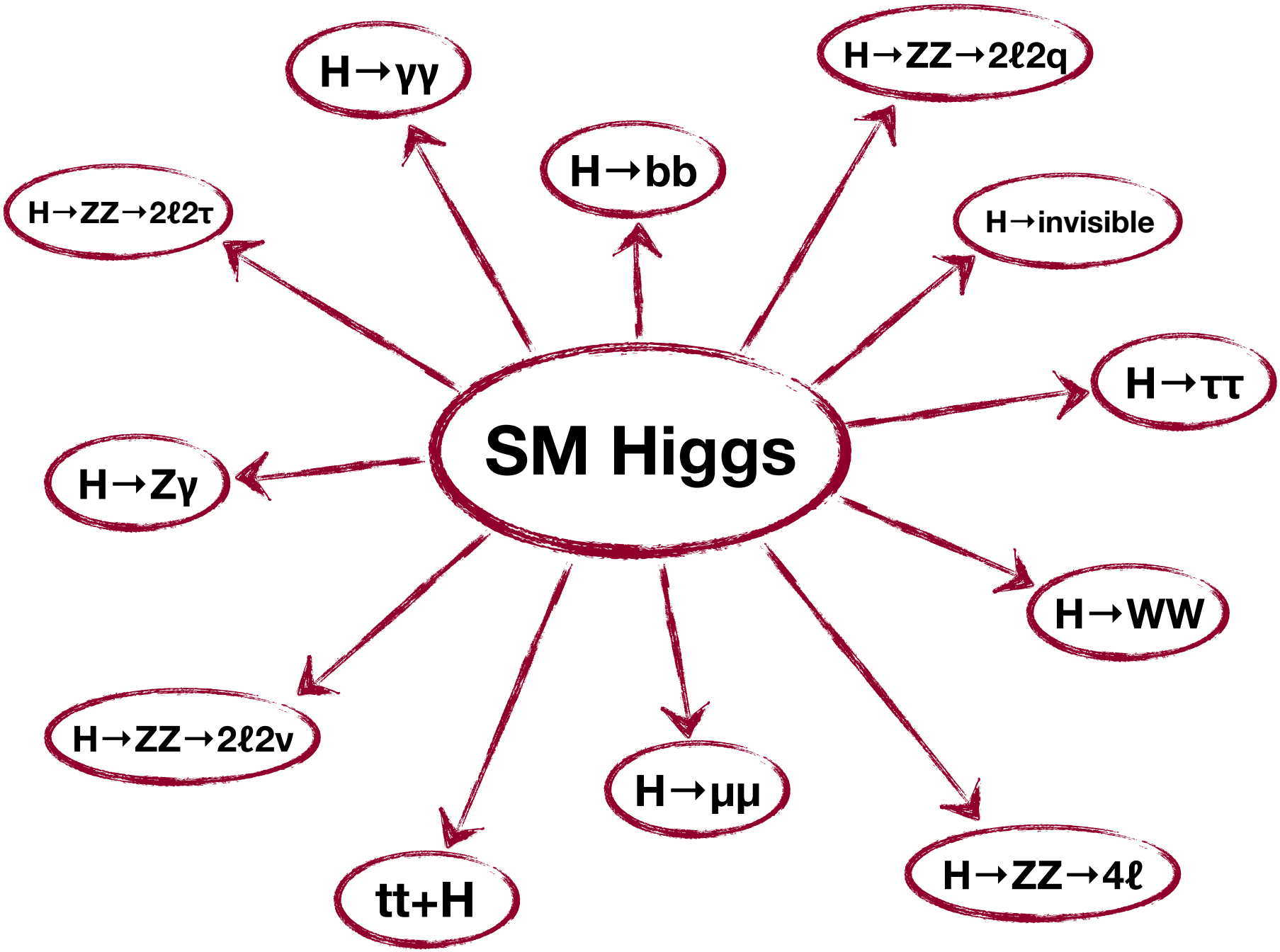
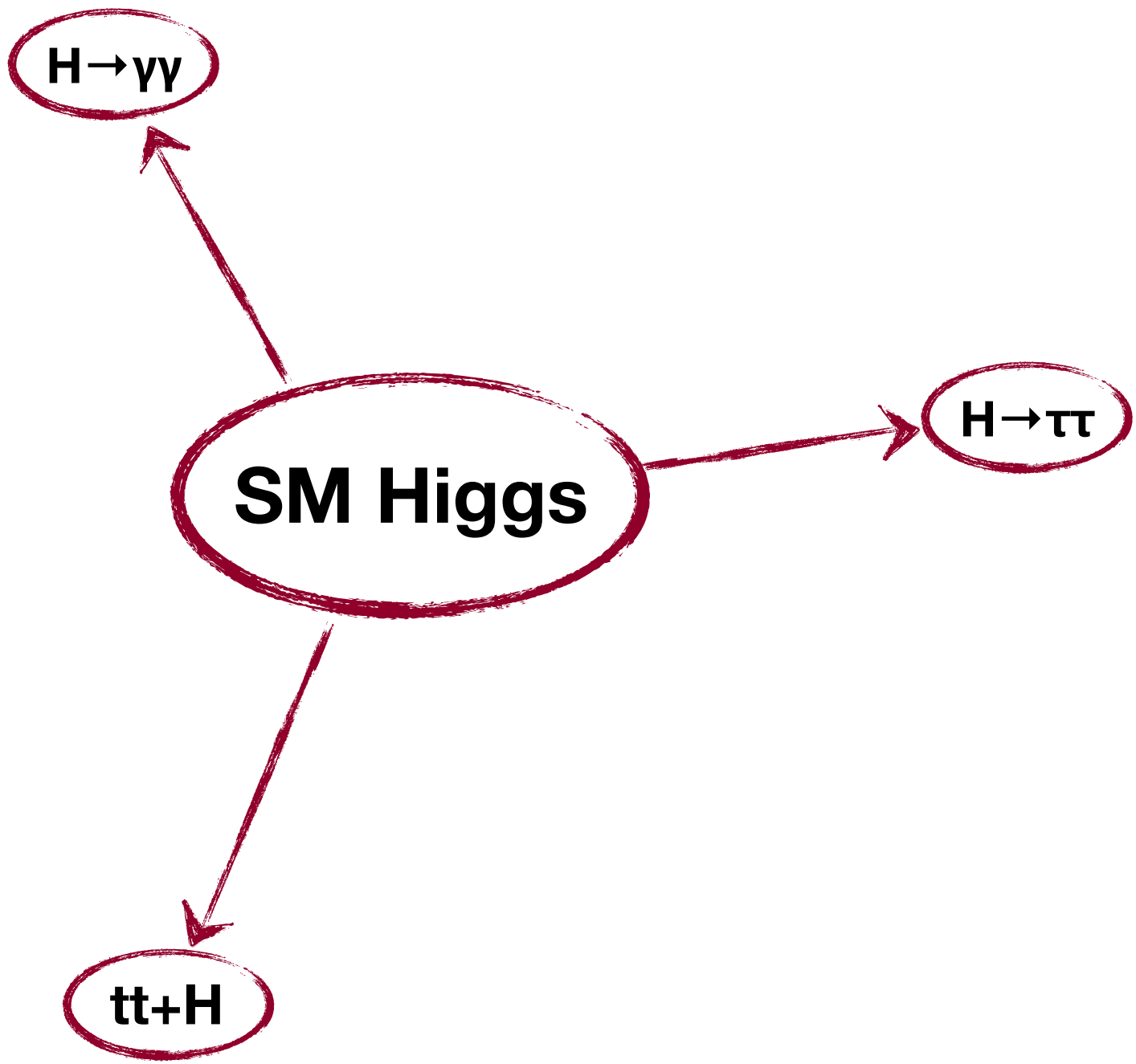
on behalf of the CMS collaboration

LHC Days in Split
29.09.2014


SM Higgs
H→γγ
H→bb
H→ZZ→2ℓ2q
H→ZZ→2ℓ2τ
H→invisible
H→ττ
H→Zγ
H→WW
H→ZZ→2ℓ2ν
H→μμ
tt+H
H→ZZ→4ℓ


H→γγ
SM Higgs
H→ττ
tt+H

H → Photons

CMS HIG-13-001

Updated: July 2014

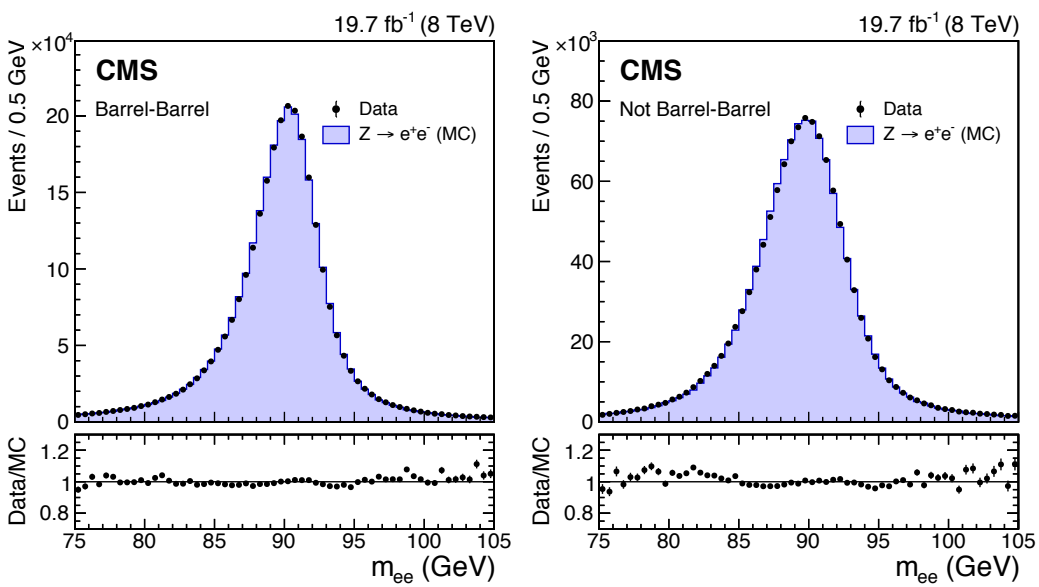
Analysis Overview

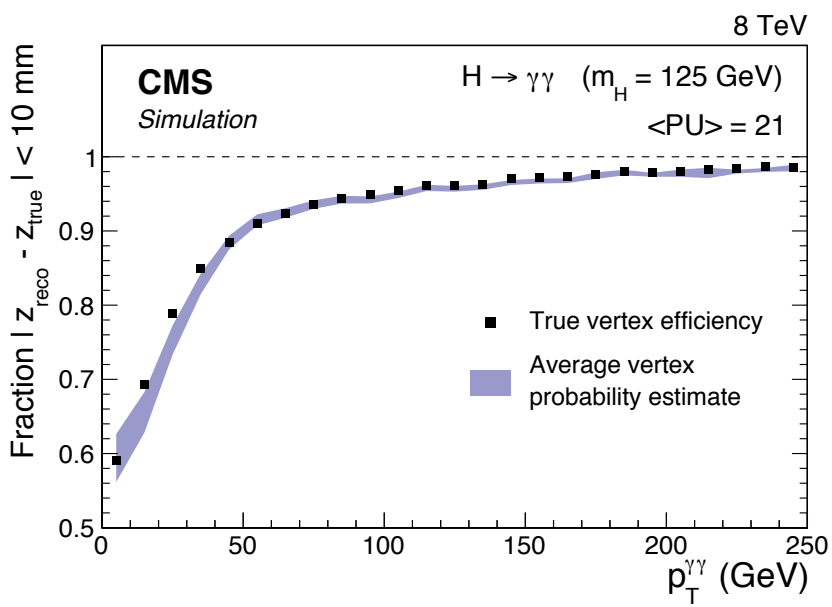
- **Benchmark physics challenge** for CMS electromagnetic calorimetry
- Search for a narrow resonance over large background
- Main analysis strategy directives:
  - **Optimal mass resolution** to narrow peak
  - **Powerful photon ID** to limit ‘fake photon’ backgrounds
  - **Categorization** to favour high signal/background events

Achieving Ultimate Diphoton Mass Resolution

$$M^2 = 2E_1E_2 \cdot (1 - \cos \Delta\theta)$$

- **Energy** resolution term
  - Single-photon resolution ~1% for central photons
  - MC smeared to describe data
- **Angular** term (vertexing)
  - Negligible if vertex $| z_{reco} - z_{true} | < 10$mm
  - 3-variable BDT using tracks and $p_T(\gamma\gamma)$: correct vertex chosen in >80% events



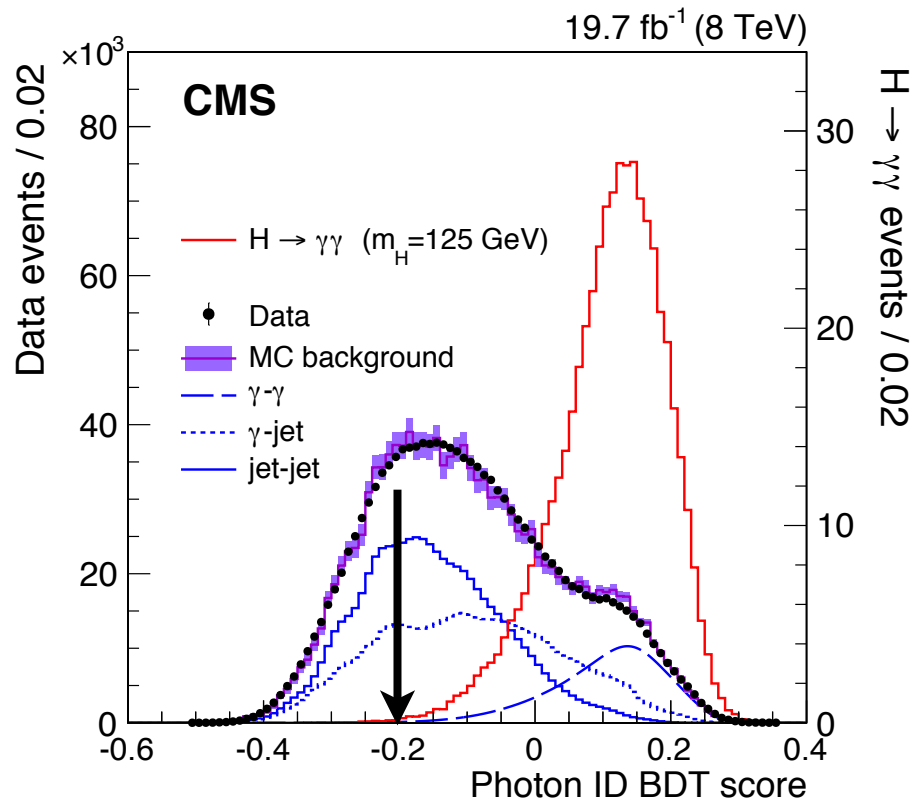


Limiting the Impact of Photons from Jets

- ~30% of BG from **jet fragments** ($\pi^0 \rightarrow \gamma\gamma$)

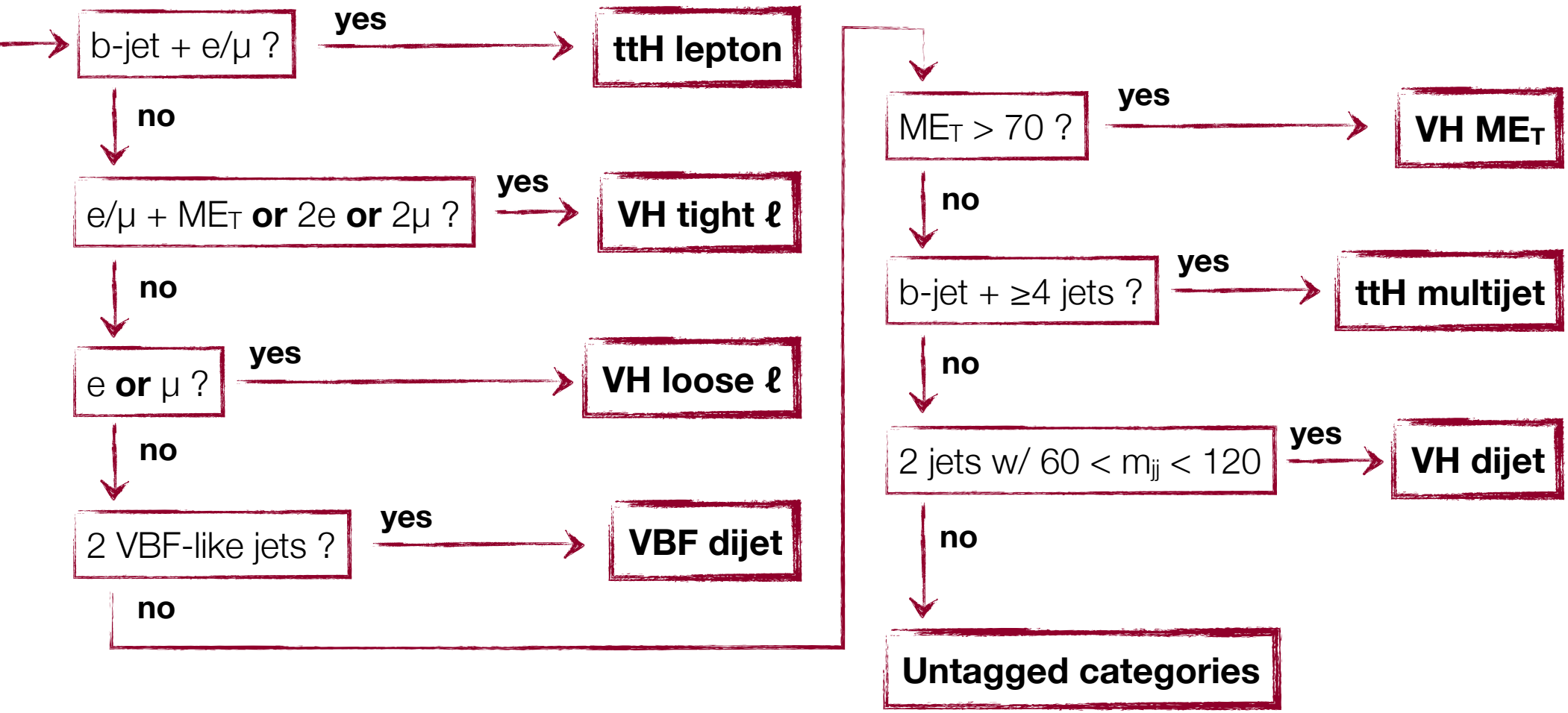
- BDT to identify **prompt** γ's based on:
  - Lateral shower shapes
  - Isolation variables
  - Energy median density per area (ρ)
  - Candidate E and η

- Preselection: BDT > -0.2
  - ε(signal) > 99%, ε(BG) ~ 75%



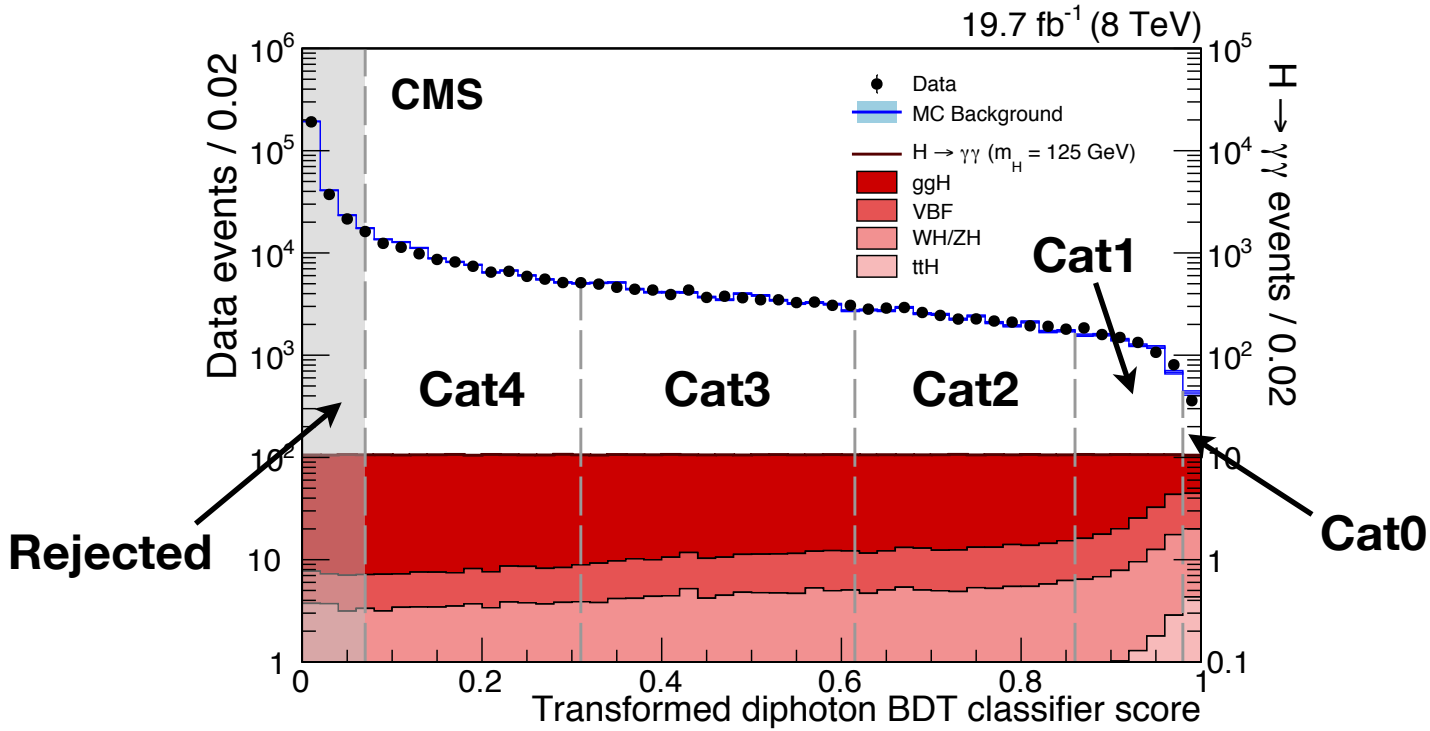
Tagging Exclusive Signatures

- Events tested against exclusive channel signatures, in **fixed order**



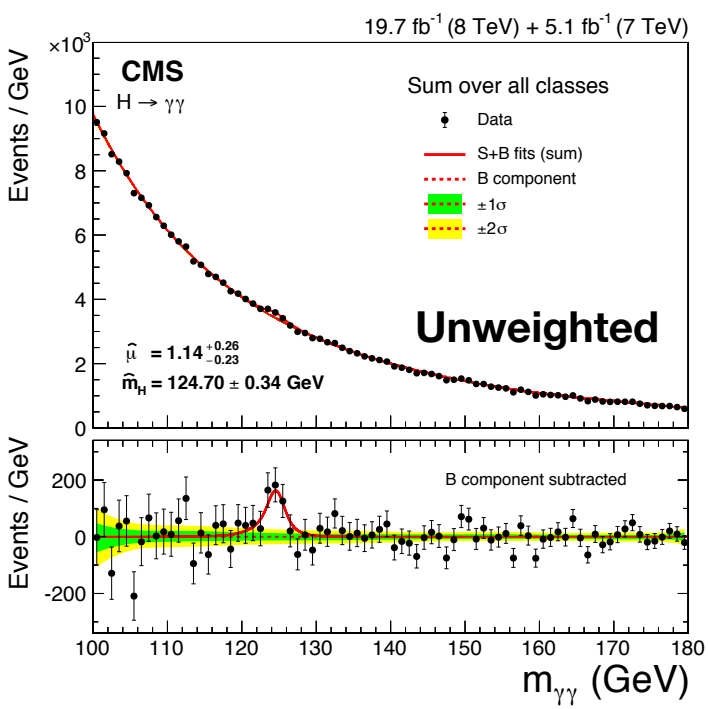
‘Untagged’ Events

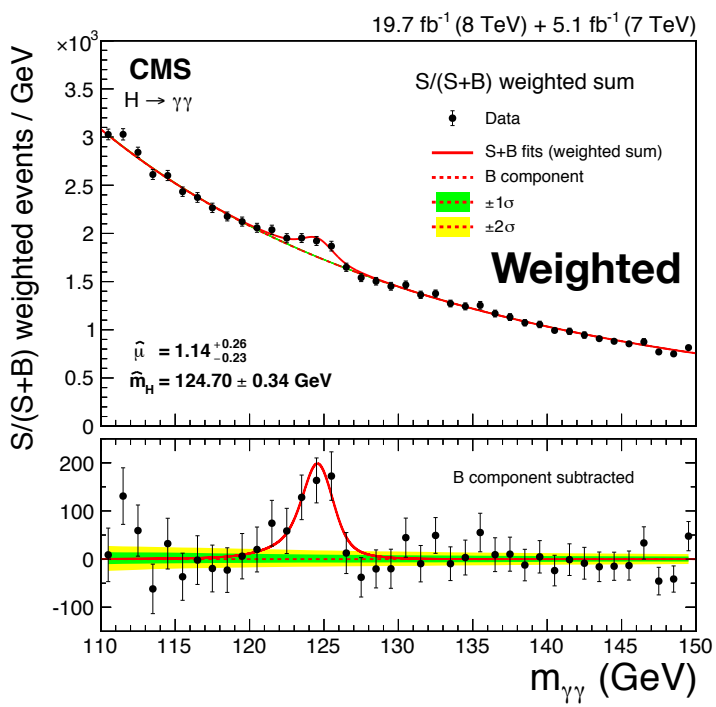
- ‘Diphoton BDT’ to **classify** events
  - Mass independent training
  - 5 exclusive categories
- BDT gives **high score** to events with
  - good diphoton mass resolution
  - high s/b probability

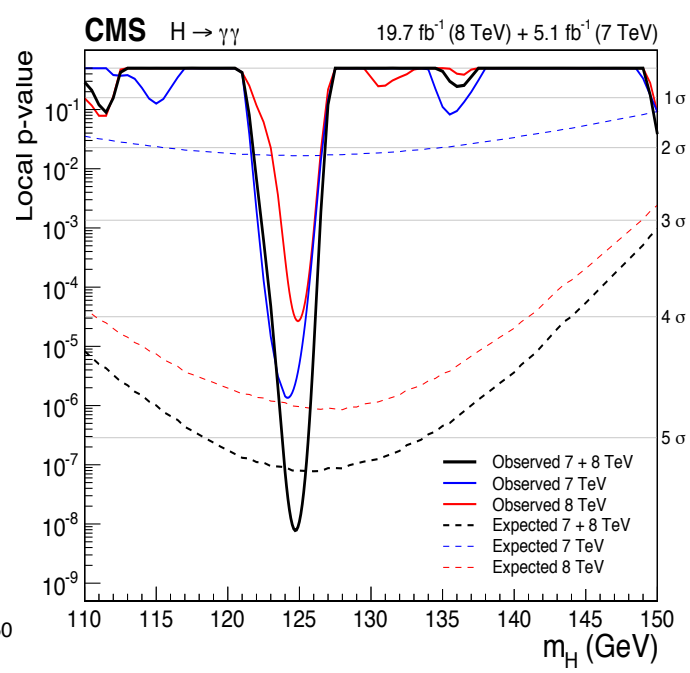


Observation of a Narrow Resonance

- **Narrow resonance** found in diphoton spectrum
  - Compatible with a Higgs boson of about 125 GeV
- Local significance: 5.7σ (5.2σ expected) for **diphoton channel only**

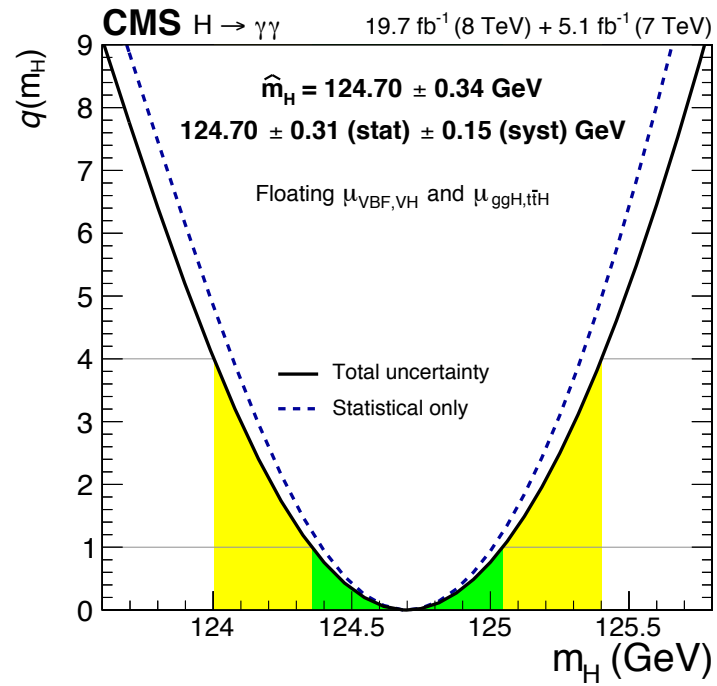


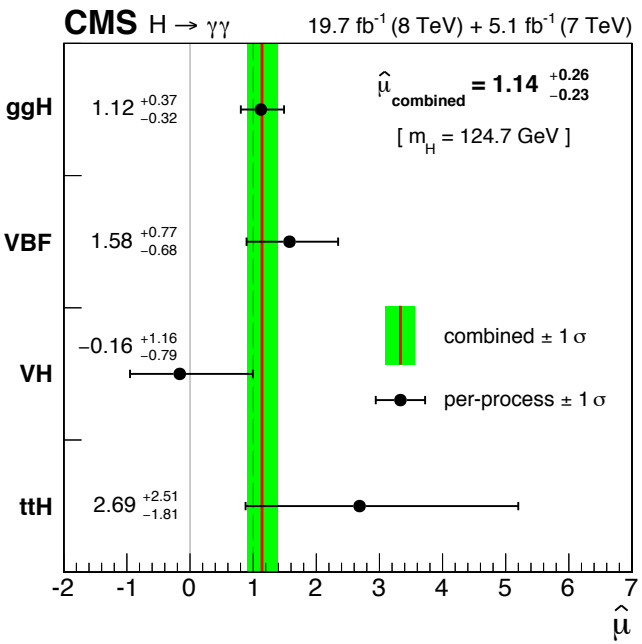




Mass Measurement and Signal Strength

- Higgs mass extracted from **likelihood fit**
  - $\mu_{ggH,ttH}$ and $\mu_{VBF,VH}$ independent nuisance parameters
  - Measure m_H = 124.70 ± 0.34 GeV





- Signal strength **compatible with SM**
  - Combined: $\mu = 1.14\ ^{+0.25}_{-0.23}$
  - Four production modes compatible with $\mu = 1$

$H \rightarrow \tau\,\tau$

CMS HIG-13-004

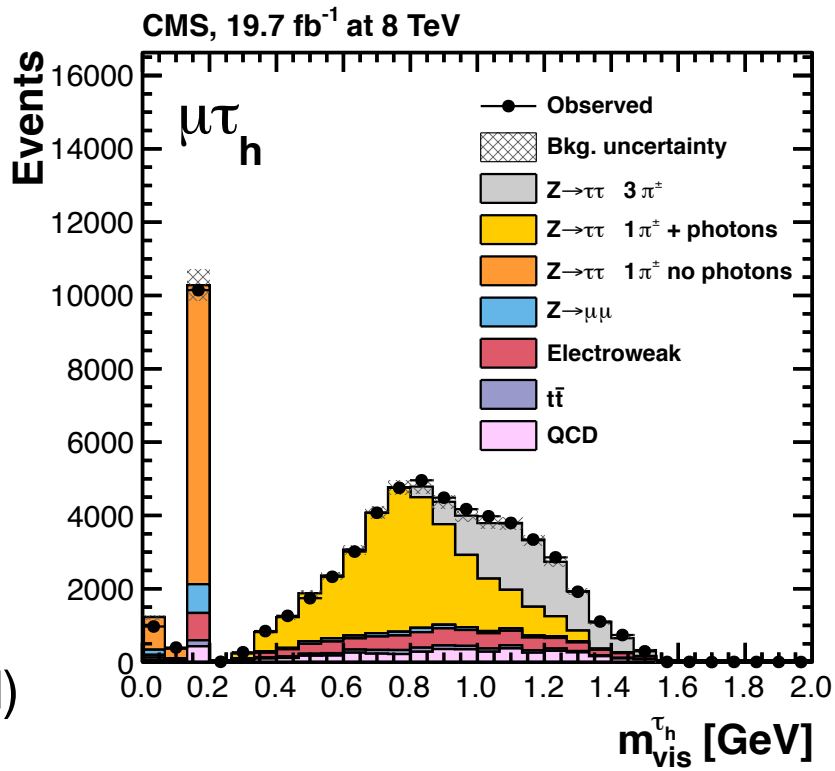
Updated: June 2014

Covering All Signatures

- All H→ττ **decay modes**

ee	μμ	τ
eμ	τ	τ

$\tau_h = \tau \rightarrow$ hadrons



- **Categories** to catch all production modes
  - Binning in jet multiplicity
  - **VBF tag**: dijets with large rapidity gap
  - **VH tag**: extra lepton (WH) or dilepton (ZH)

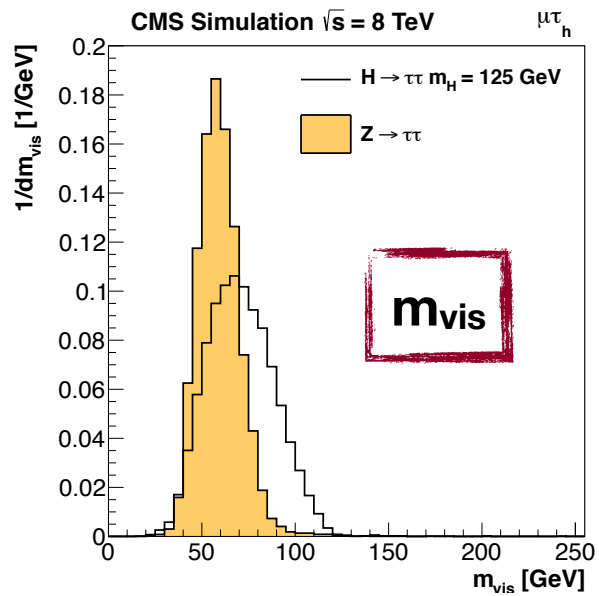
- Total of 46 (38) categories for 8 (7) TeV

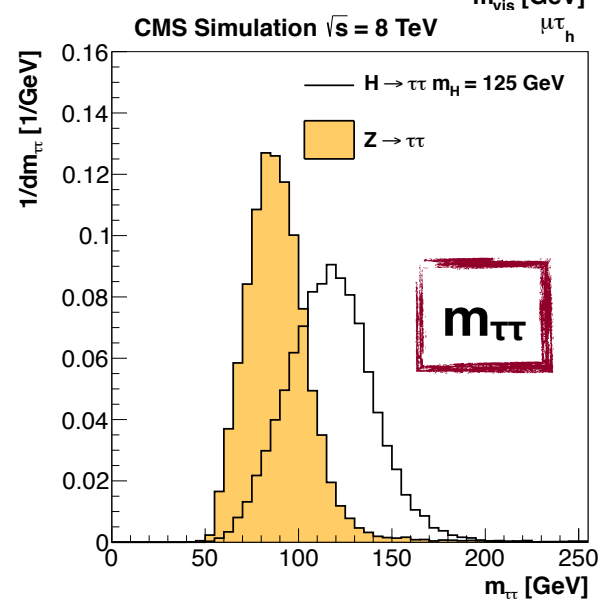
Improving the ττ Mass Reconstruction

- Reconstructed ττ mass: used to **extract signal**
  - Main (irreducible) background: $Z \rightarrow \tau\tau$
  - Neutrinos **limit** power of visible mass (m_{vis})
- **Maximum likelihood fit** to estimate true $m_{\tau\tau}$
  - Inputs: 4-vectors of visible decay, ME_T
  - **Matrix elements** for τ decays
- **Better Z discrimination**: +40% exp. significance

Expected $m_{\tau\tau}$ resolution:

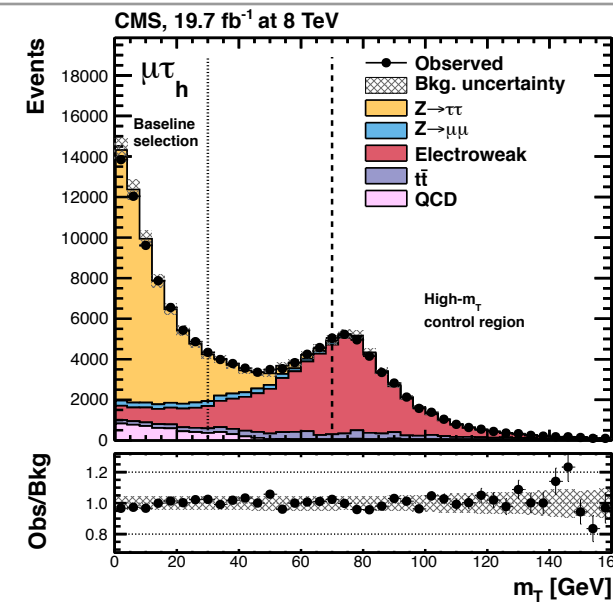
τ	ℓ	ℓℓ
10%	15%	20%



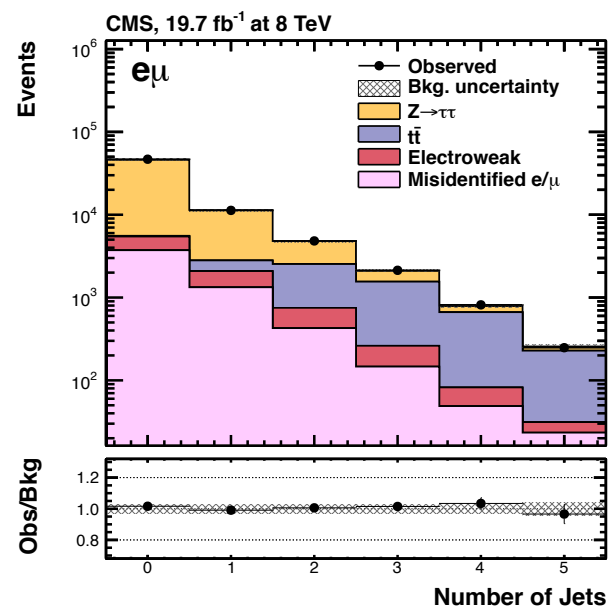


Background Estimation

- Main background: $Z \rightarrow \tau\tau$
  - From **data $Z \rightarrow \mu\mu$ events**: remove muons, embed MC reco τ decays
  - Negligible JES, ME_T and lumi uncertainties
- **EWK and tt**: taken from simulation
  - Normalized in data control regions
- **QCD multijet** from control regions:
  - $\ell^{\pm}\tau_h^{\pm}$ same-sign
  - $\tau_h\tau_h$: inverted isolation

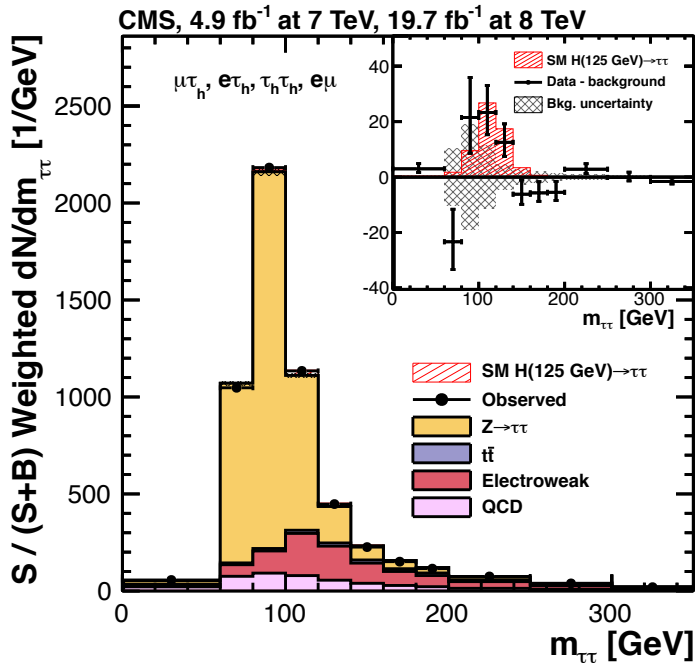


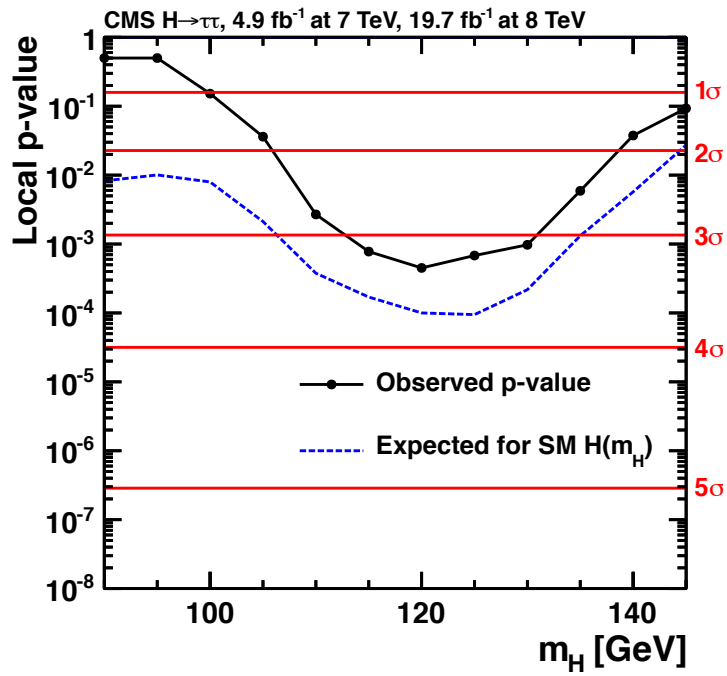
EWK control region



tt control region

An Evidence is Found





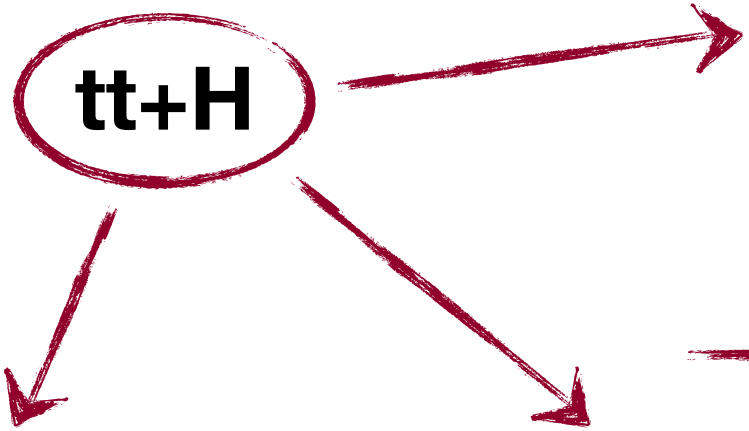
- **Excess** observed around 120 GeV
  - Corresponds to a 3-σ significance → **evidence**
- Best fit to all channels: $\mu(m_H=125) = 0.78 \pm 0.27$

tt + H

CMS HIG-13-029

Updated: August 2014

A Combination of Many Channels



H → photons

- Leptonic
- Hadronic

H → γγ

(see previous slides)

H → hadrons

- Lepton + jets
- Dilepton
- Hadronic τ

H → bb
H → $\tau_h\tau_h$
H → WW

H → leptons

- Same-sign dilepton
- Trilepton
- Tetralepton

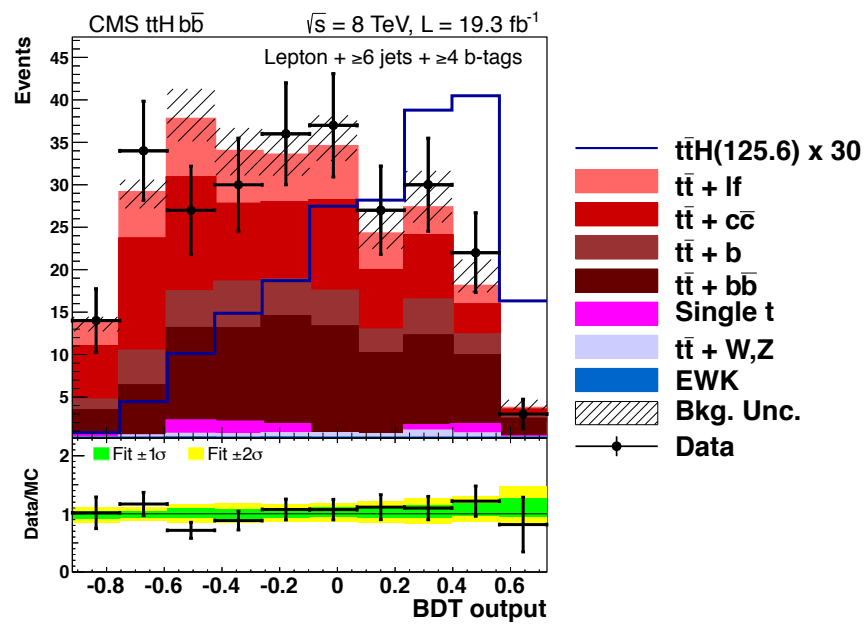
H → WW
H → ττ
H → ZZ

ttH, H→Hadrons: Analysis Strategy

- **Large backgrounds**: all channels require ≥1 lepton from tt
- **Three main channels**, split in multiple jet/b-tag categories

Channel	Jet / b-tag Categories
Single lepton: tt→bℓνbqq, H→bb	**7**
Double lepton: tt→bℓνbℓν, H→bb	**3**
Hadronic τ	**6**

Example:
Lep + ≥6 jets (≥4 b-tags)



- **BDTs** trained to maximize BG discrimination
  - From which signal is **extracted**

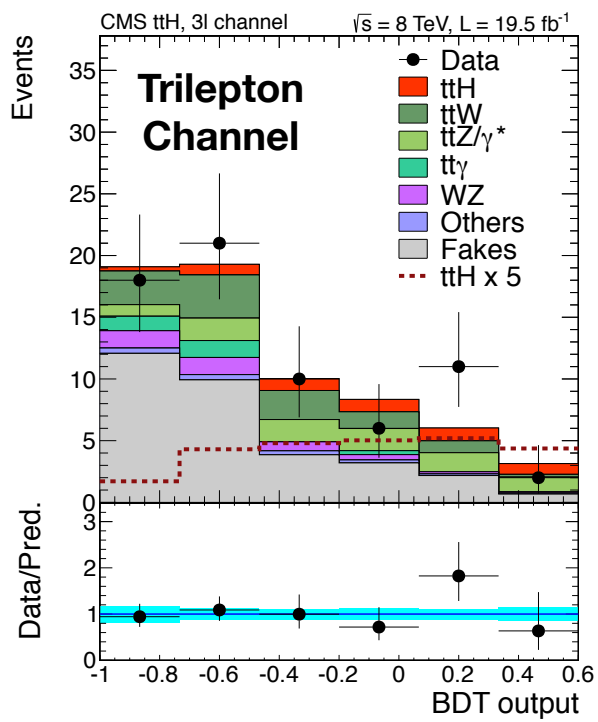
ttH, H→Leptons: Analysis Strategy

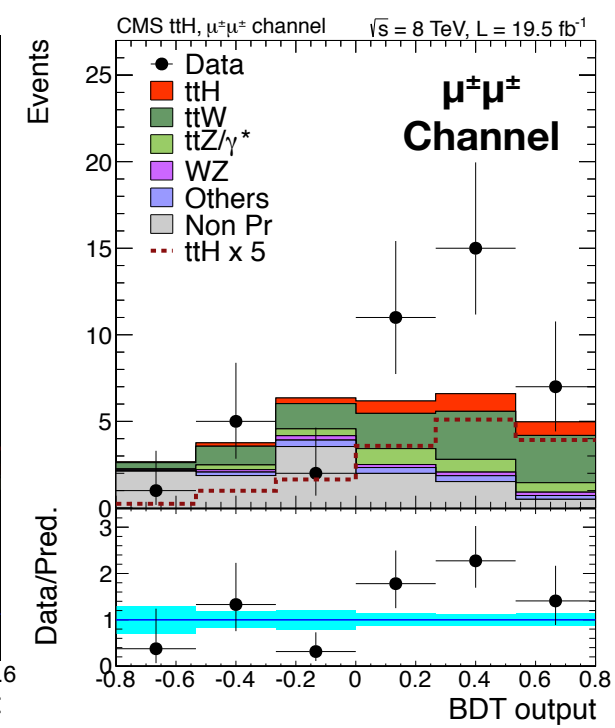
- Main backgrounds: **non-prompt** leptons (from b-jets)
  - MVA trained to separate prompt/non-prompt leptons
  - **Fake-rate method** to estimate non-prompt BG from data

- Signal extracted from:

$e^{\pm}$	BDT*
Trilepton	BDT*
Tetralepton	N(jets)

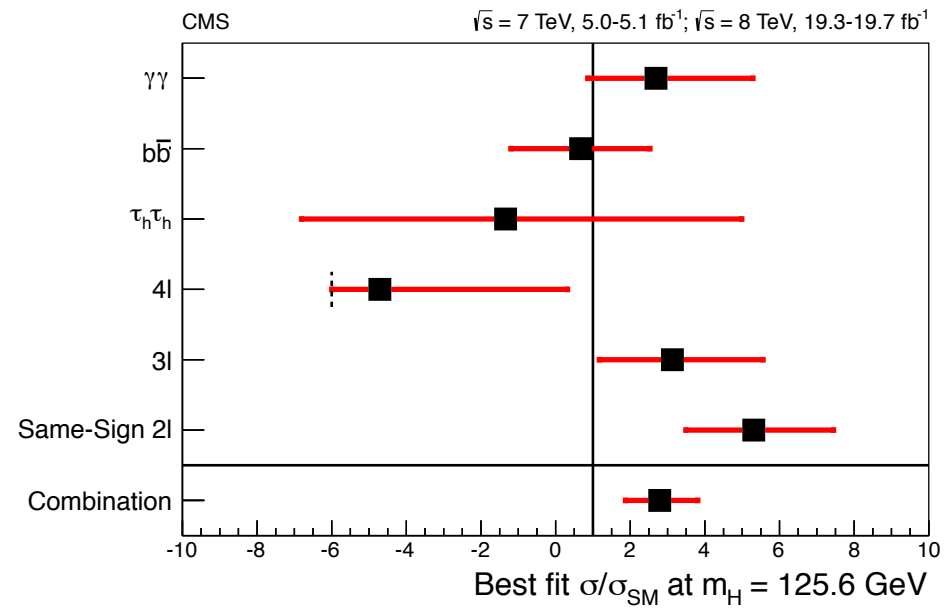
* BDT trained on event kinematics to separate signal and BG

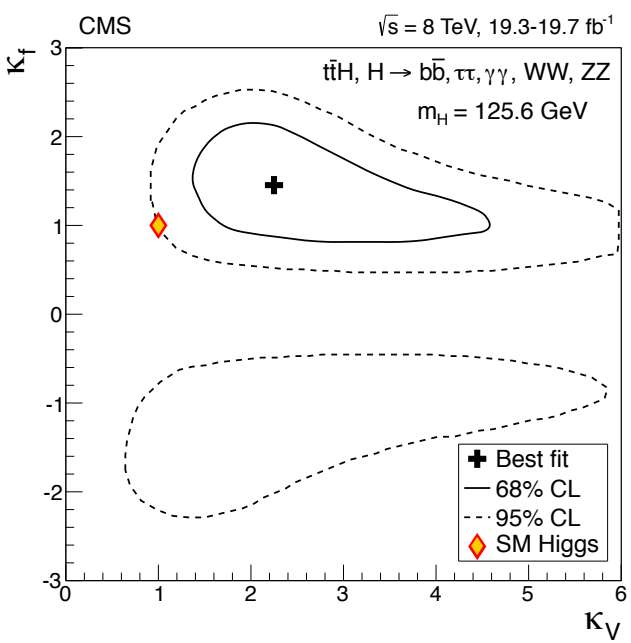




ttH Combination Sees Excess

- **Excess** observed in combination
  - Driven by dilepton ($\mu^{\pm}\mu^{\pm}$) channel
- Combination **best fit** $\mu = 2.8\ ^{+1.0}_{-0.9}$
  - Local significance = 3.4σ from BG





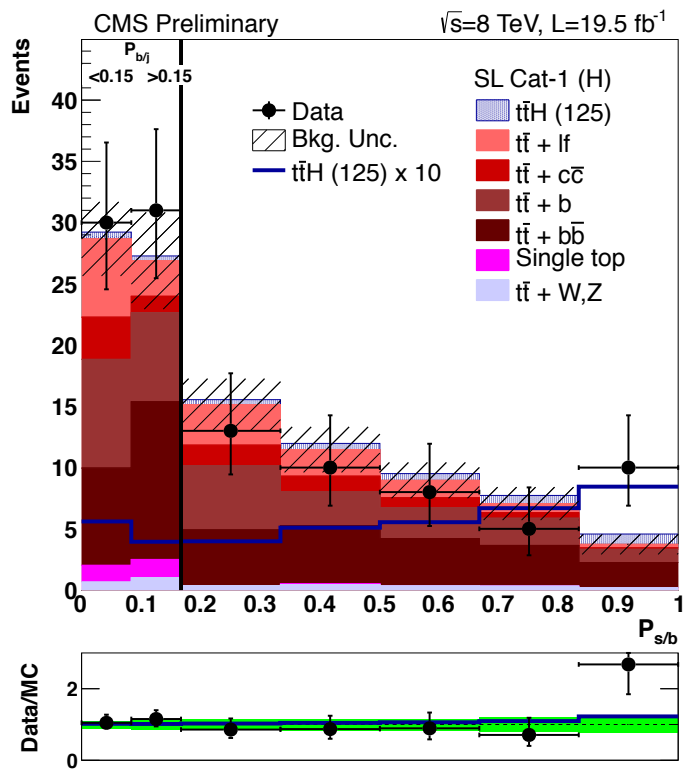
- About 2σ away from SM Higgs
  - **More compatible** with BG+Higgs wrt BG
- Result **stable** for masses close to 125 GeV

A Novel Approach to Hadronic ttH

HIG-14-010

- Matrix Element Method: events assigned s/b **probability**
  - **Numerical integration** on final state particle phase space
  - **All possible** parton-jet assignments
- Signal extracted in **four categories**

	Best Fit μ	Observed 95% UL	Expected 95% UL Median	Expected 95% UL Median Signal Injected
BDT Analysis	0.7	4.1	3.5	5.0
MEM Analysis	0.67	3.3	2.9	3.9

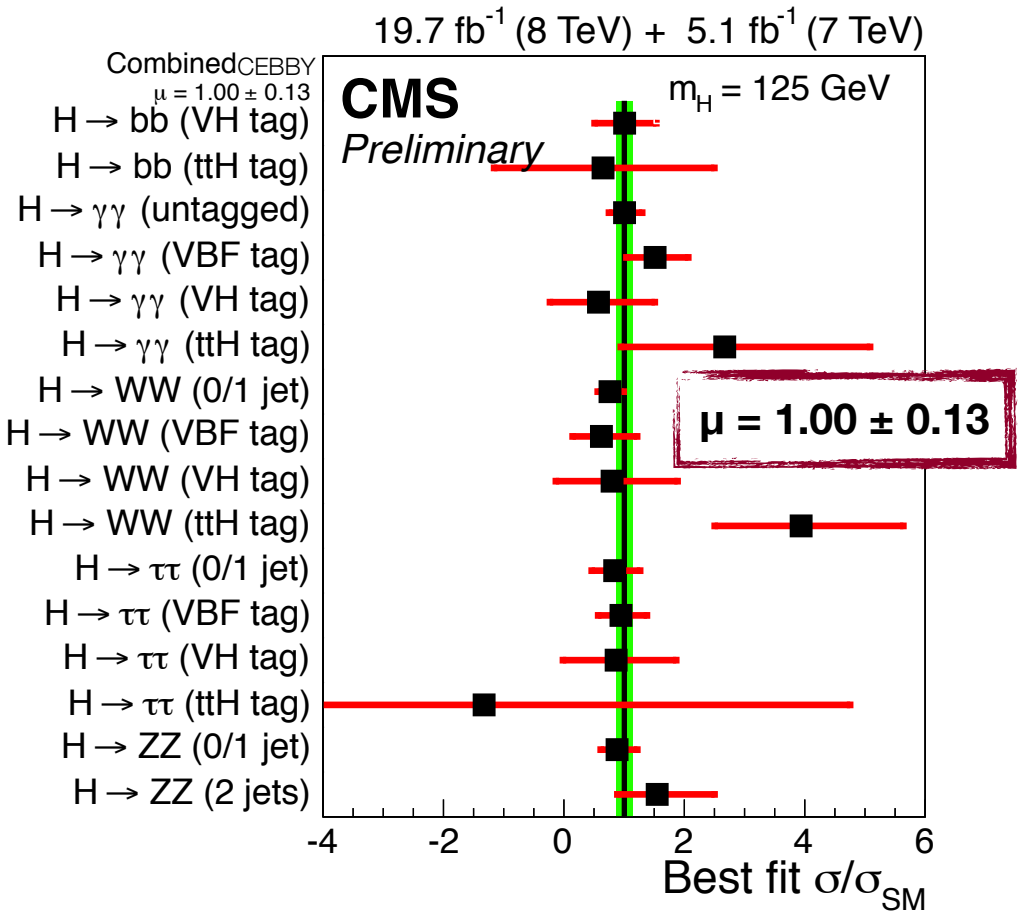


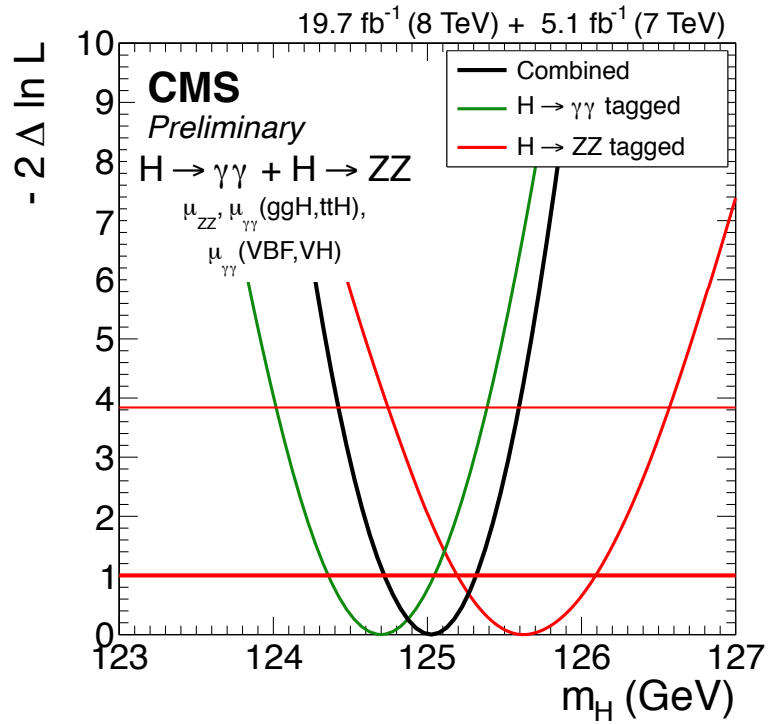
- 20-30% **improvement** over BDT analysis

The Grand Combination

HIG-14-009

- Combining H→γγ and H→ZZ: **m_H = 125.03 $^{+0.26}_{-0.27}$ (stat) $^{+0.13}_{-0.15}$ (syst) GeV**





- Across all channels, **no significant deviation** from Standard Model

Conclusions

- Lots of (new) results on Higgs from CMS!

- H→γγ: **discovery**
  - 124.7 Higgs boson found with 5.7σ significance

- H→ττ: **evidence**
  - 3.2σ-significant excess, compatible with 125 GeV Higgs

- ttH combination: **excess**
  - Overall excess, driven by leptonic channels

- CMS **discovered a Higgs boson** with $m_H = 125.03\ ^{+0.29}_{-0.31}$ GeV