Search for rare and exotic Higgs Boson decay modes with CMS

Junquan Tao (IHEP/CAS, Beijing) on behalf of the CMS collaboration

中國科學院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

6th International Conference on New Frontiers in Physics (ICNFP 2017)

17-26 Aug 2017, Kolymvari (Greece)

Higgs rare and exotic decays

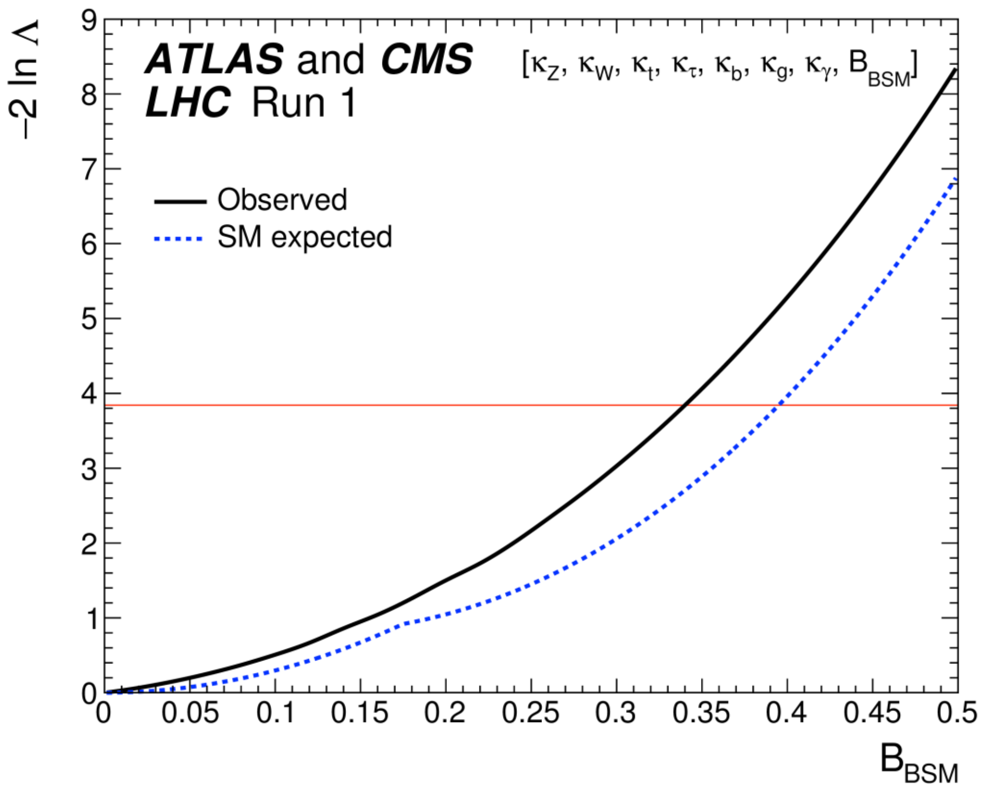
- Higgs boson has been observed in several decay channels. All results so far **are compatible with the SM Higgs boson**

- Constraints on **new physics** are still relatively loose. Still room for beyond the standard model (BSM) physics : Run 1 limit B(H→BSM) < 34%

- Many Higgs **rare decays** have yet to be observed: may be **sensitive to new physics** if additional Higgs couplings exist

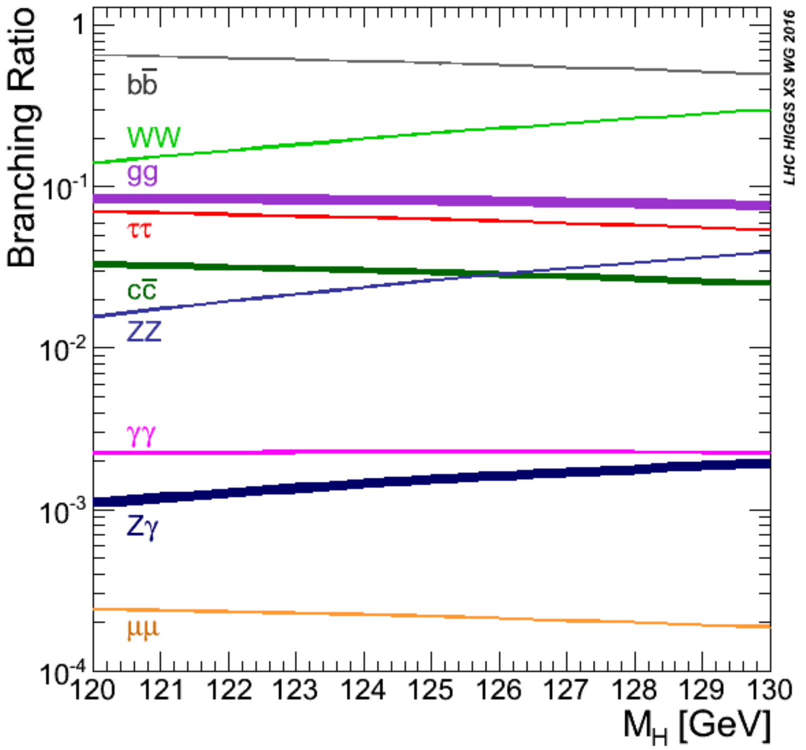
- **Exotic decays** of the Higgs is a fertile ground to look for **physics beyond the SM**

JHEP08 (2016) 045



In this talk

- ✓ H→X(Z/γ*)γ→ℓℓγ
- ✓ H→μμ/ee
- ✓ H→invisible
- ✓ Lepton flavour violating (LFV) decays : H→μτ/eτ/eμ
- ✓ Higgs decay to light (pseudo)scalars : H→aa



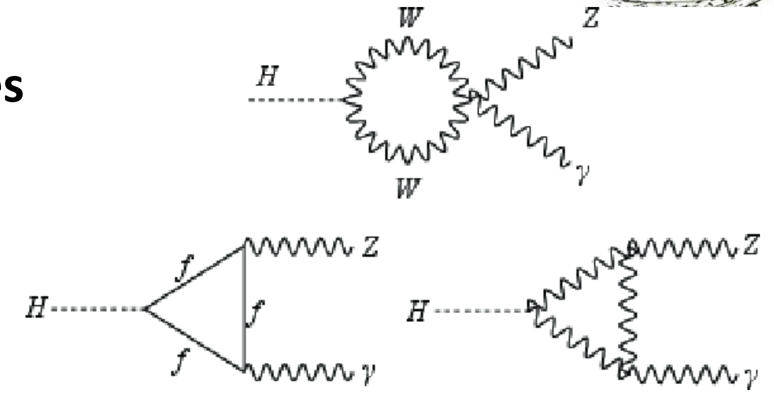
https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHXSWG

More and details of CMS Higgs Physics Results:

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

$H \rightarrow Z\gamma$

- **Modifications in $H \rightarrow Z\gamma$ branching ratio predicted in various BSM theories**

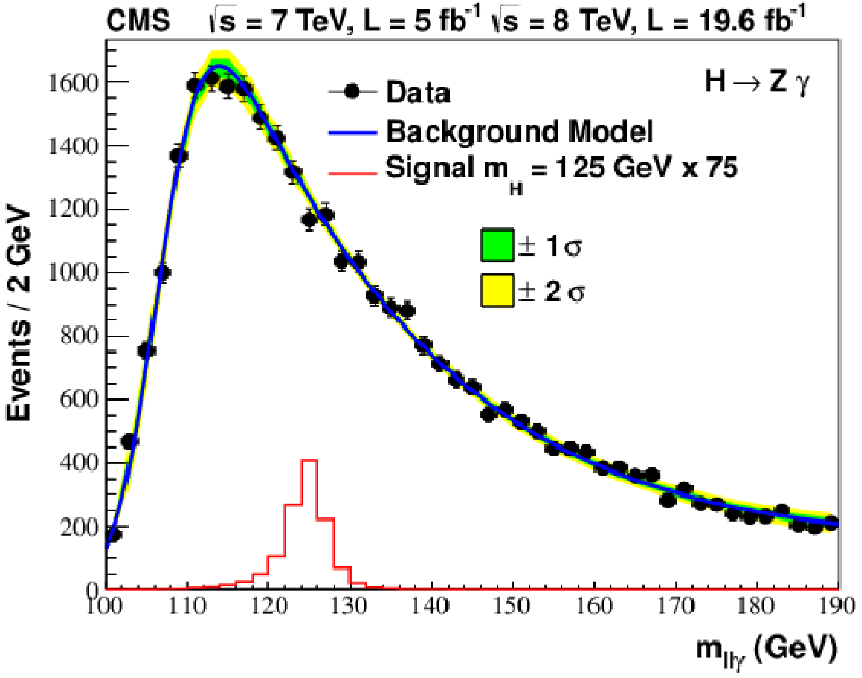


- **$H \rightarrow Z\gamma$ proceeds by loop diagrams similar to $H \rightarrow \gamma\gamma$**
- **SM BR~10^{-4} (m_H=125GeV) and sensitivity limited by $Z \rightarrow \ell\ell$**
- **Search in Z(ee)+γ and Z(μμ)+γ final states based on 7+8 TeV (5+19.7 fb^{-1}) data**
- **5 event categories (jets, leptons, photon) in each final state are used to enhance sensitivity :** both leptons in EB/at least one in EE + higher/lower R_9 photon, and Dijet-tagged class

Signal extracted by signal + background fit to $m_{\ell\ell\gamma}$

- ✓ Bkg: convolution of a Gaussian with a step function multiplied by a polynomial (order depend on the event class); obtained by fitting the observed $\ell\ell\gamma$ mass distributions for each of the five event classes
- ✓ Sig: obtained from MC simulated events

Phys. Lett. B 726 (2013) 587-609



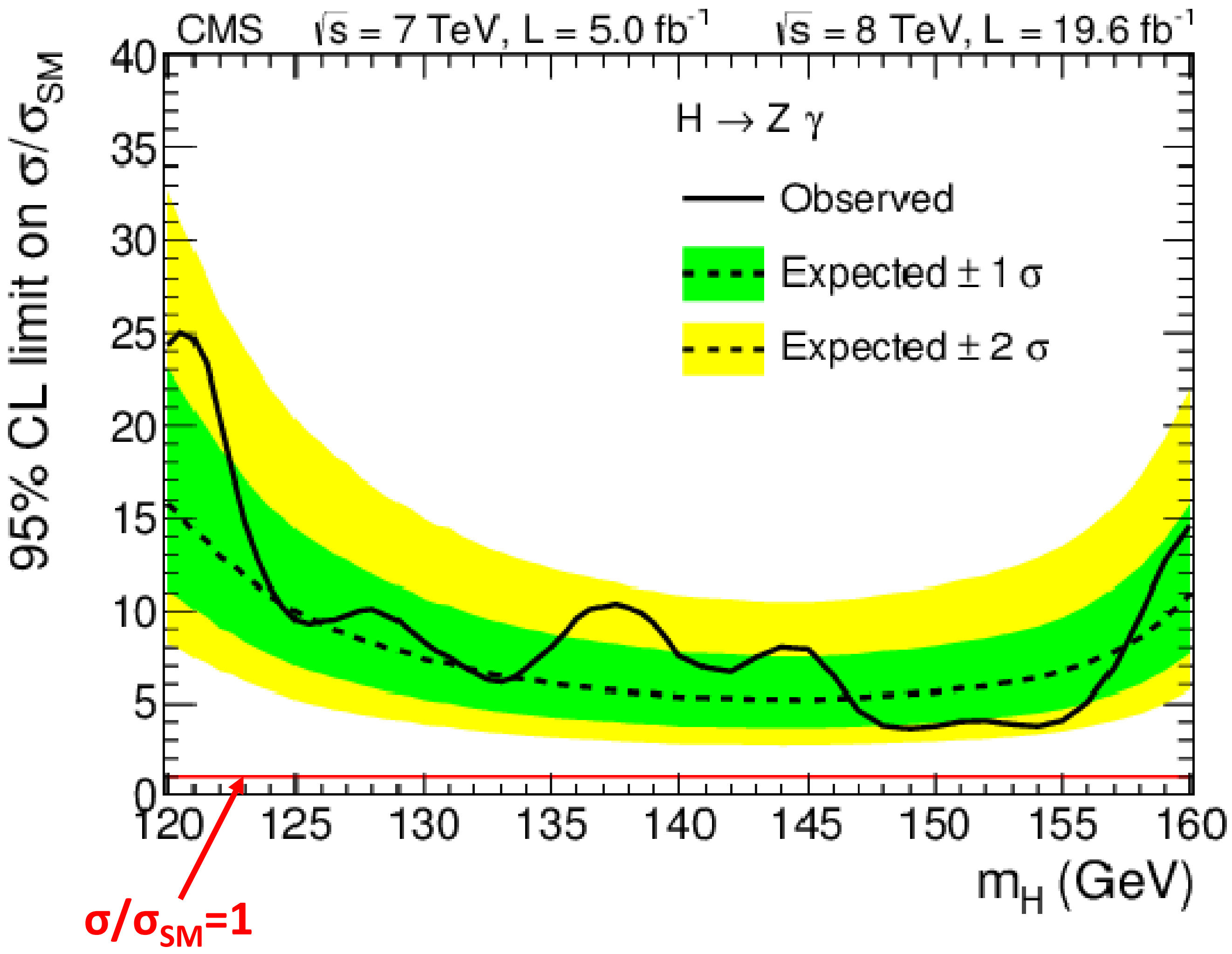
$H \to Z\gamma$

[Phys. Lett. B 726 (2013) 587-609]()

- **No excess** above standard model predictions has been found in the 120-160 GeV mass range

- Observed limits at 95% confidence level are between about **4 and 25** times the standard model cross section times the branching fraction

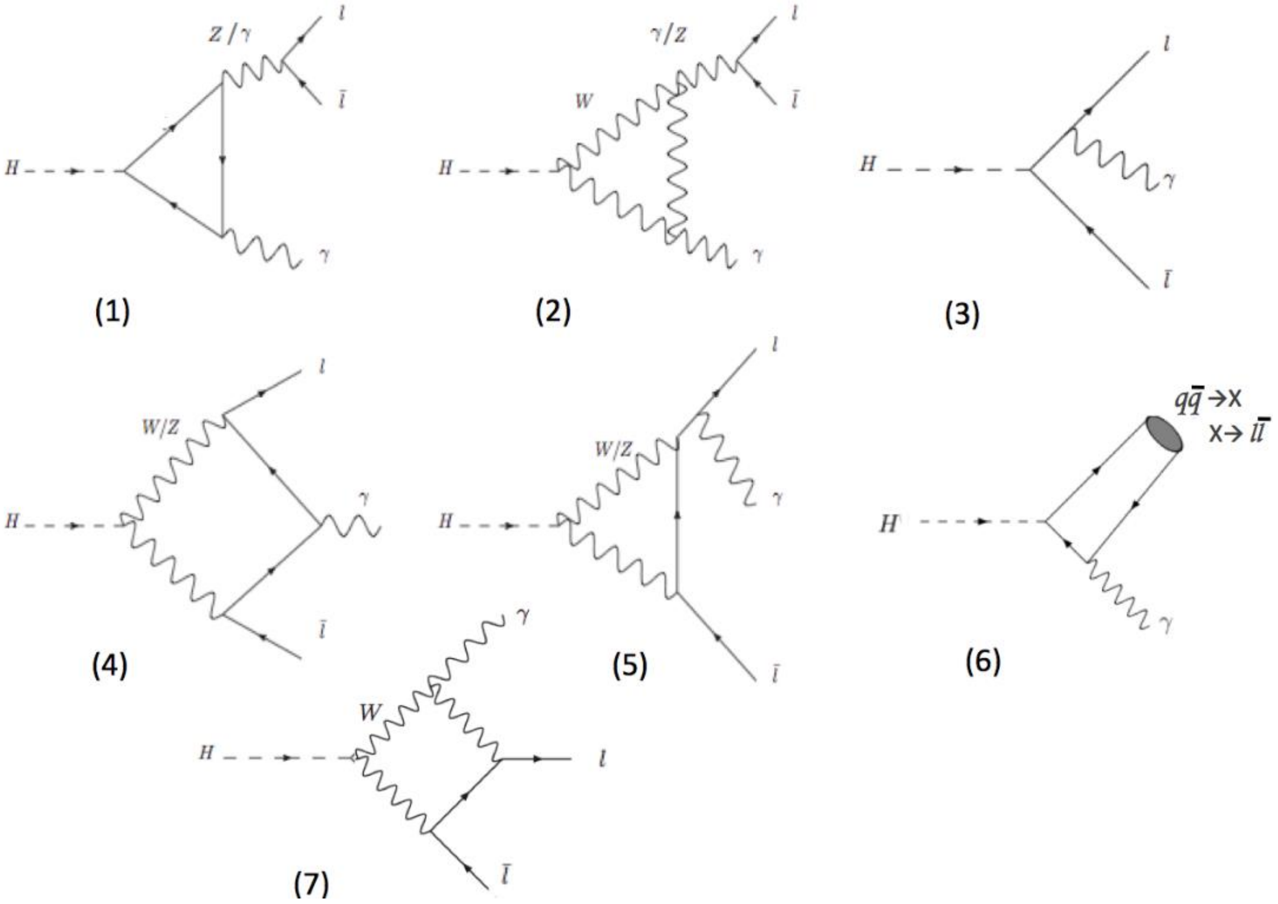
- Upper limit **at 125 GeV**
  BR < **9.5 x BR_{SM}** obs (10 exp.)



$H \to \gamma^*\gamma \to \ell\ell\gamma$

Rare Dalitz decay

- Various contributions to same final state
- Sensitive to e.g. new resonances
- **Search in ee+γ and μμ+γ final states with 8 TeV 19.7 fb^{-1} data**
- Selection w.r.t. Zγ: $m_{\ell\ell}$<20 GeV

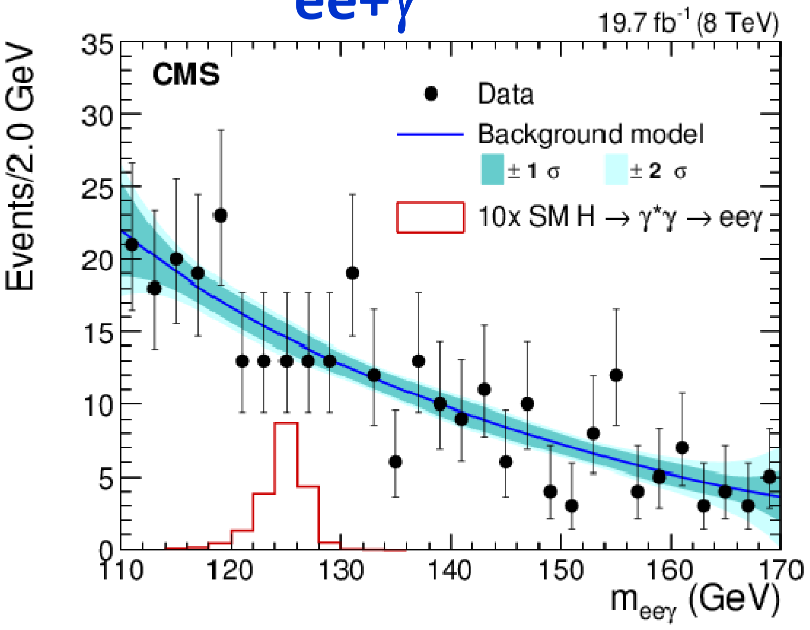


(1) and (2) dominate; (3) final-state radiation; (4), (5) and (7) are negligible; (6) contributions from resonances

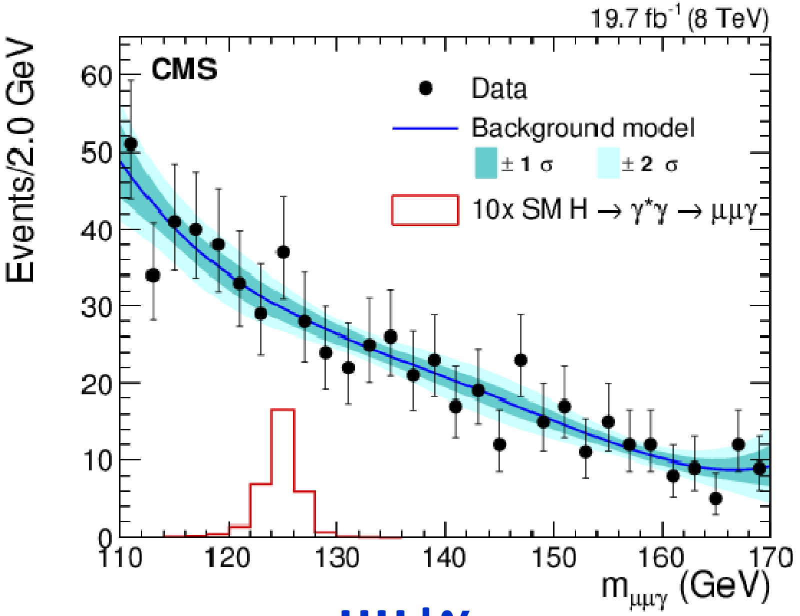
$H \to \gamma^*\gamma \to \ell\ell\gamma$

- Signal extracted by signal + background fit to $\mathbf{m}_{\ell\ell\gamma}$
  - ✓ Background: 2nd degree polynomial
  - ✓ Signal: Crystal Ball + Gaussian

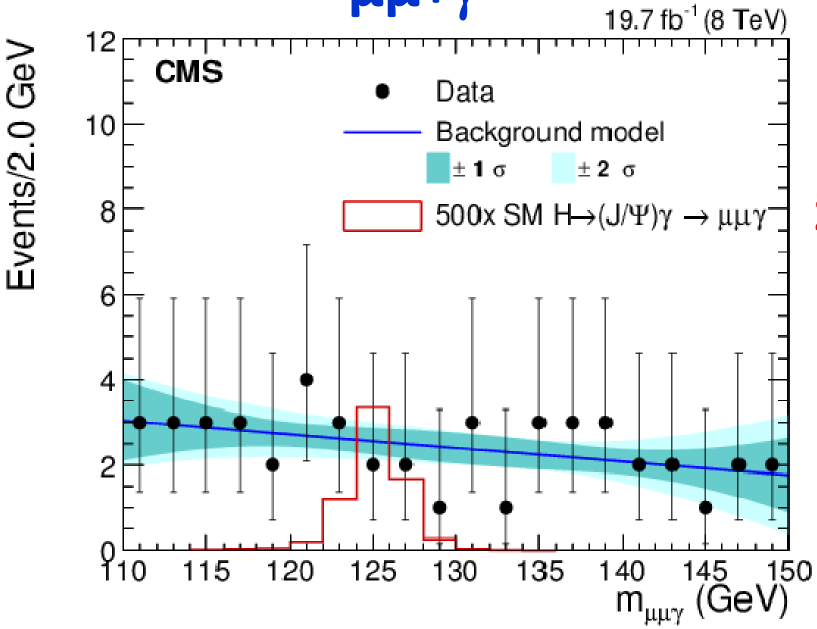
ee+γ



[PLB 753 (2016) 341]

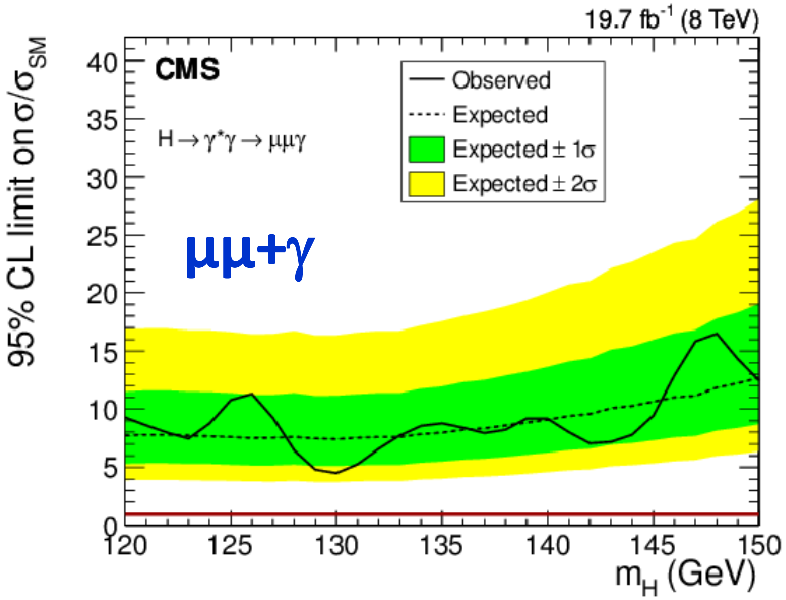


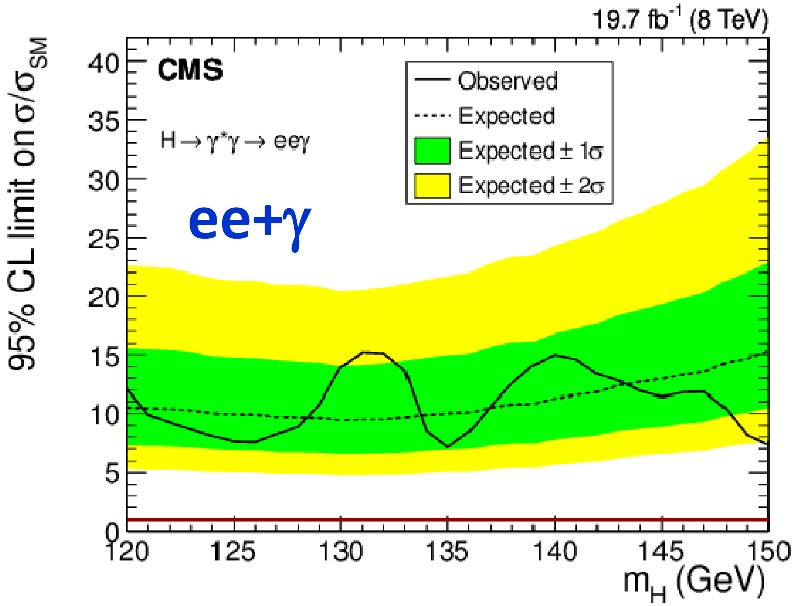
μμ+γ



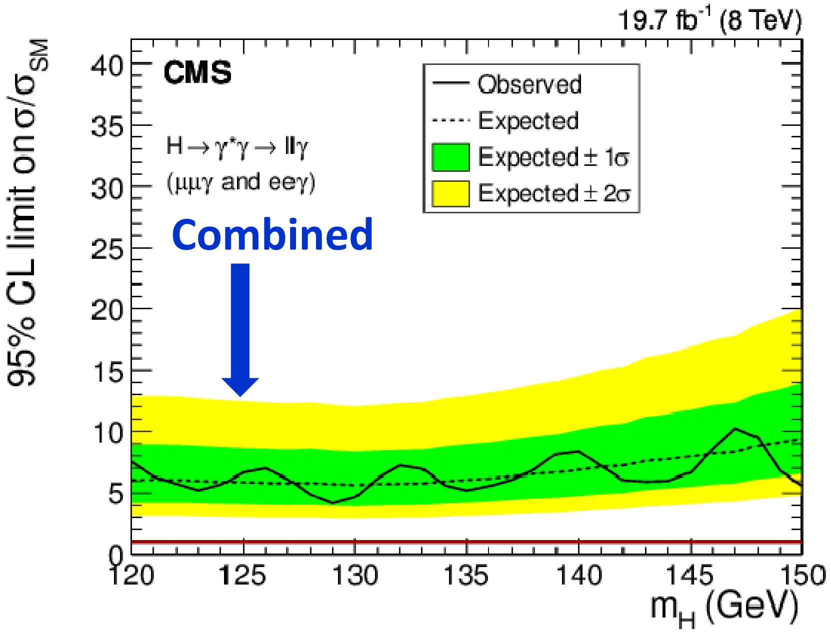
$2.9 < m_{\mu\mu} < 3.5$ GeV

$H \rightarrow \gamma^{*}\gamma \rightarrow \ell\ell\gamma$





- **No excess** above standard model predictions has been found in the 120-150 GeV mass range
- Observed (expected) limit is **6.7** **(5.9 $^{+2.8}_{-1.8}$)** times the standard model prediction at m_H=125GeV (95% CL)
- Additionally, an upper limit at 95% CL on the **branching fraction of $H \rightarrow (J/\psi)\gamma$** for the 125GeV Higgs is set at **1.5×10^{-3} ,** still **$O(10^3)$** away from SM BR 2.8×10^{-6}



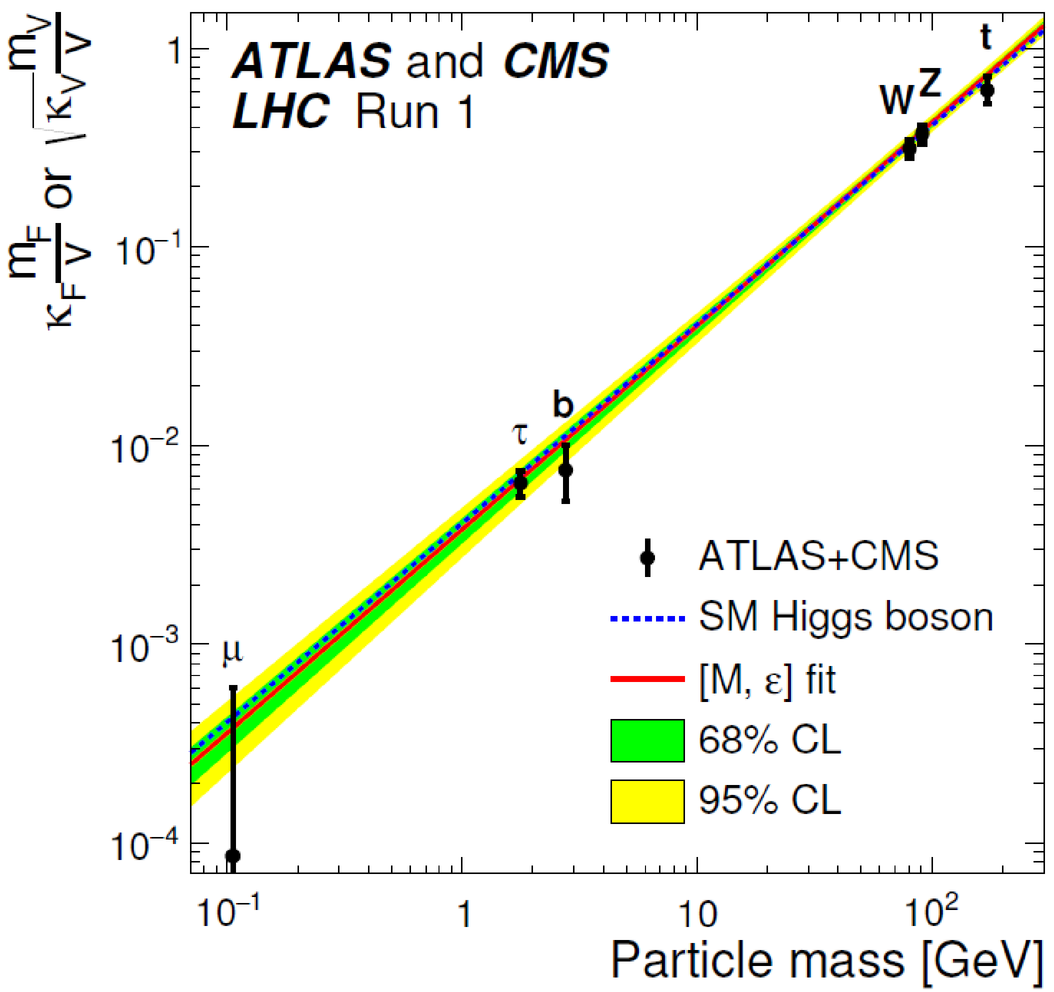
PLB 753 (2016) 341

Red line : σ/σ_{SM}=1

H→μμ

- H→μμ is the cleanest channel to observe **Higgs coupling to second generation fermions**
- H→μμ is an important input in understanding the mechanism of **electroweak symmetry breaking** in the SM
- **Deviations** from the SM expectation could also be a sign of **BSM physics**
- The branching fraction in this channel for a 125 GeV SM Higgs boson is **2.2×10^{-4}**, about ten times smaller than that for H→γγ.
- The dominant and irreducible background arises from the **Z/γ*→μμ process** which has a rate several orders of magnitude larger than that from the SM Higgs boson signal.
- Small but narrow signal on top of a smoothly falling bkg.

JHEP08 (2016) 045



H→μμ

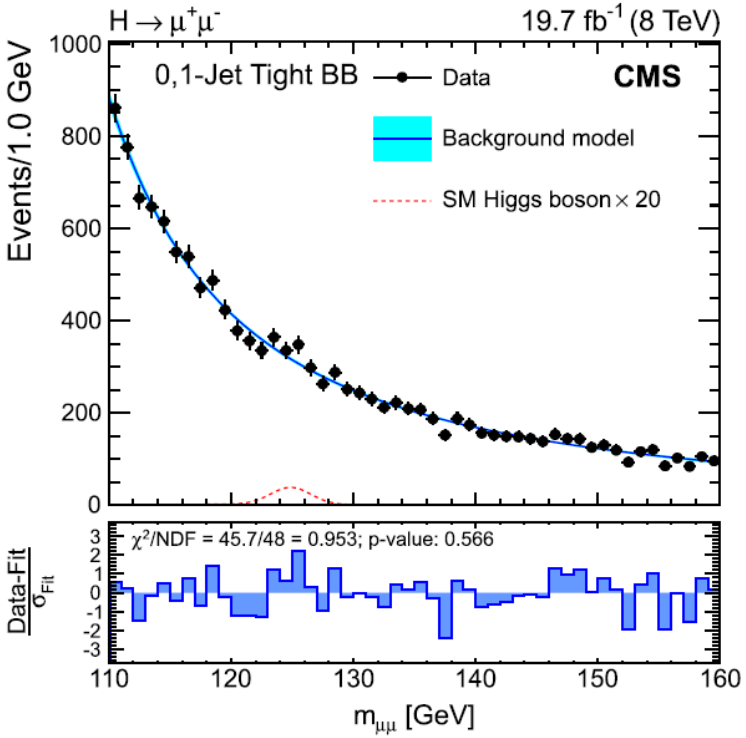
- H→μ⁺μ⁻ search is performed on data corresponding to integrated luminosities of **5.0 fb^{-1} at 7TeV and 19.7 fb^{-1} at 8TeV**. For m_H=125GeV, the SM predicts 19(95) H → μ⁺μ⁻ events at 7TeV (8TeV)

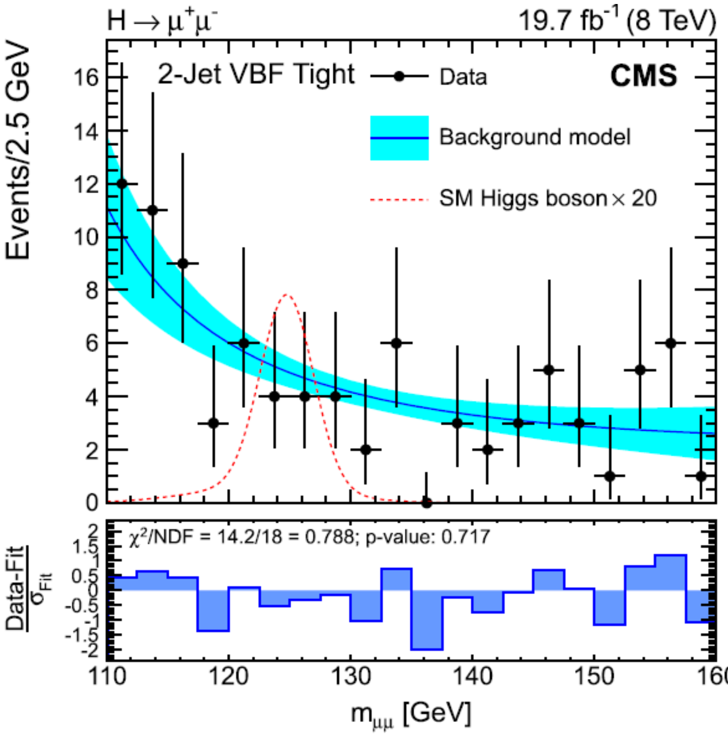
- **Dimuon events are classified into two general categories: a 2-jet category and a 0, 1-jet category**.
  - ✓ 2-jet category is further divided into VBF Tight, GF Tight, and Loose subcategories
  - ✓ In the 0, 1-jet category, events are split into two subcategories based on the value of $p_T^{\mu\mu}$ (>/< 10GeV): six Tight subcategories, and six 0, 1-jet Loose subcategories, based on |η|of each muon (Barrel 0-0.8, overlap 0.8-1.6, Endcap 1.6-2.1)

Physics Letters B 744 (2015) 184–207

- **Signal shape** parameterized by a **double-Gaussian function**.

- **Background shape** parameterized as the sum of a **Breit–Wigner function and a 1/$m_{\mu\mu}^2$ term**, both multiplied by **an exponential function** to approximate the effect of the PDF on the mass distribution.

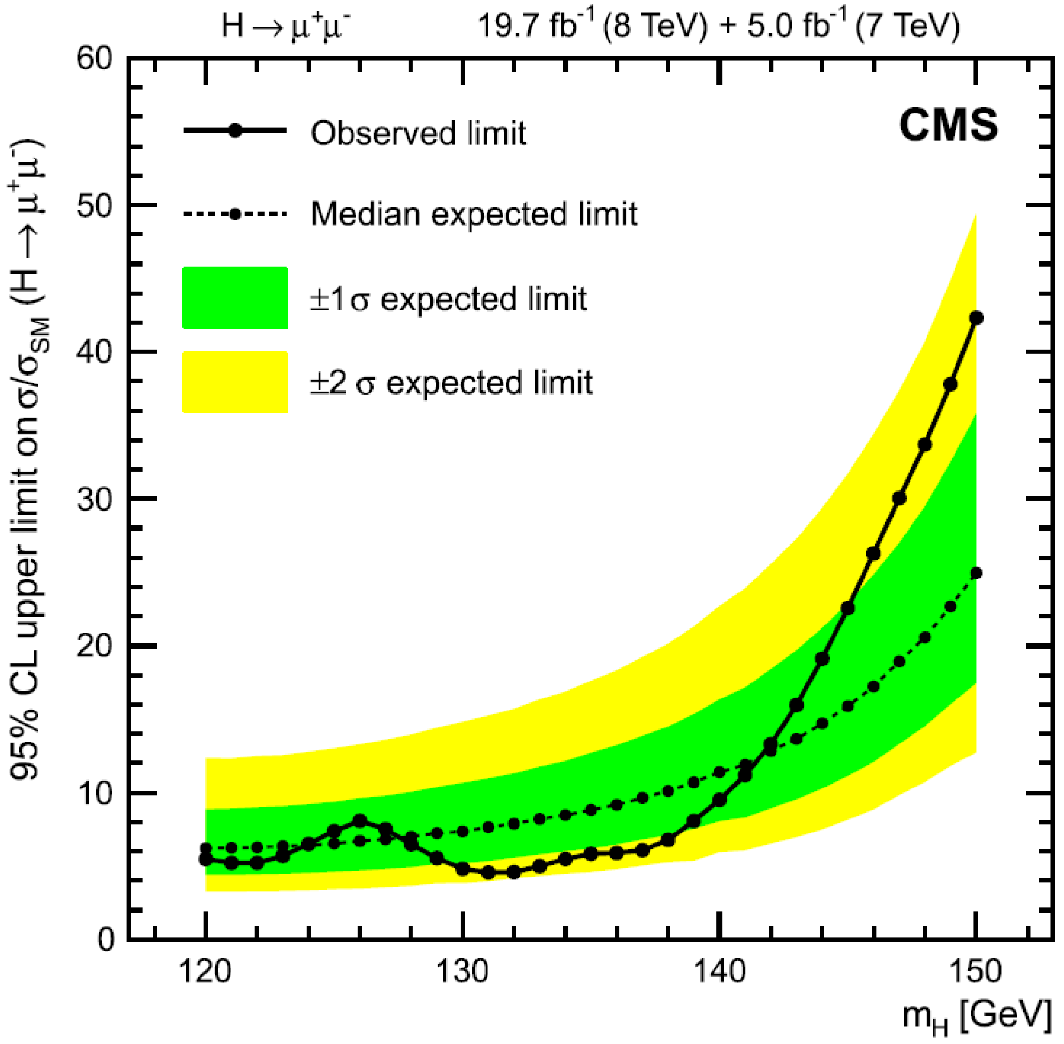




H→μμ search results

__Physics Letters B 744 (2015) 184–207__

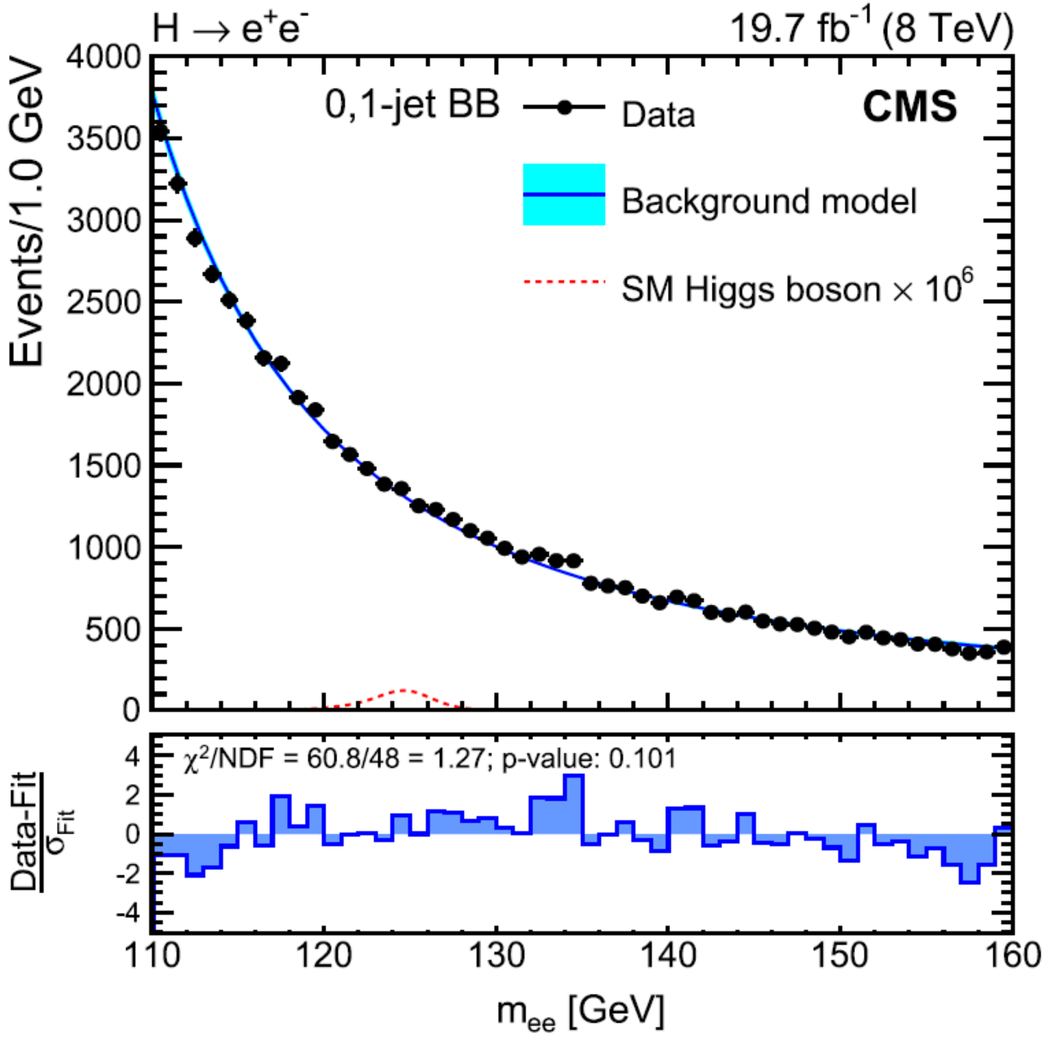
- No significant excess is observed.
- Upper limits (Exclusion limits) at the 95% CL for Higgs boson masses from ***120 to 150 GeV*** are presented using the CLs criterion
- Run 1: m_H = 125 GeV, 95% CL upper limits < **7.4** (6.5) x σ_{SM} obs (exp)
- Best fit value of the signal strength for a Higgs boson mass of 125 GeV is $\mathbf{0.8^{+3.5}_{-3.4}}$



H→ee

- H→ee is also the cleanest of the fermionic decays, only performed on the 8TeV data with 19.7 fb^{-1}
- The **branching fraction** in this channel for a 125 GeV SM Higgs boson is ***5.9×10^{-9}***
- Irreducible background is dominated by *Drell–Yan* production, with smaller contributions from *ttbar* and *diboson* production
- Parameterizations used for the signal and background are the same as used in the H→μμ
- For m_H=125GeV, the SM predicts **~2×10^{-3} H→ e^+e^- events at 8TeV**
- Sample split into **four distinct categories**: two 0, 1-jet categories (Barrel-Barrel, not in BB) and two 2-jet tight/loose categories (pT^j>30/20GeV, m_{jj}>500/250GeV).

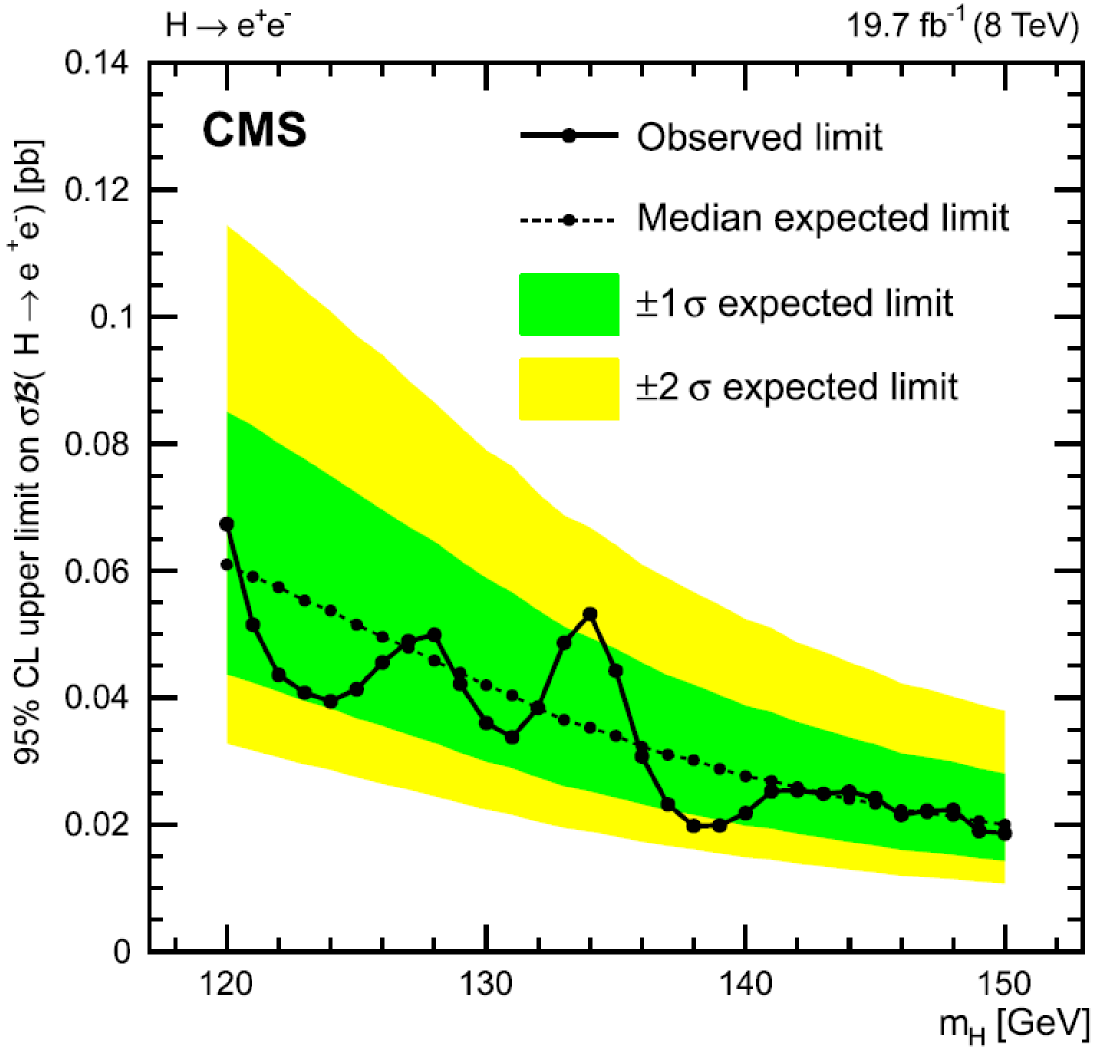
Physics Letters B 744 (2015) 184–207



H→ee result

- No significant excess of events is observed
- Upper limits on σ(8TeV)xBR for Higgs boson masses from 120 to 150GeV at the 95% CL is reported
- Observed 95% CL **upper limit on σ(8TeV)xBR** at 125GeV is **0.041pb** while the background-only expected limit is $0.052^{+0.022}_{-0.015}$ pb
- Assuming the SM production cross section, this corresponds to an observed **upper limit on B(H →e^+e^-)** of **0.0019**, which is approximately 3.7×10^5 times the SM prediction

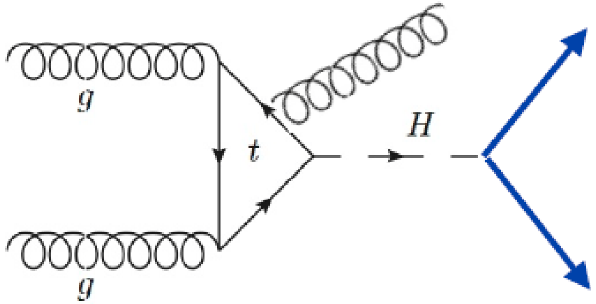
Physics Letters B 744 (2015) 184–207



H→invisible

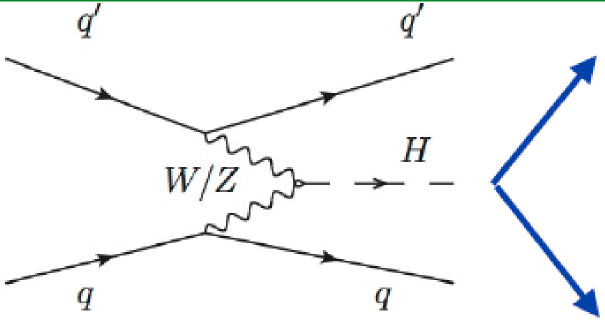
- Really small BR in the SM: **BR(H → invisible) ~ 0.1%** (from H→ZZ*→4v)
  - ✓ Any measurable rate will be a sign for new physics

- Need to tag Higgs event via production mode
  - ✓ ggF(gg →gH), VBF, VH

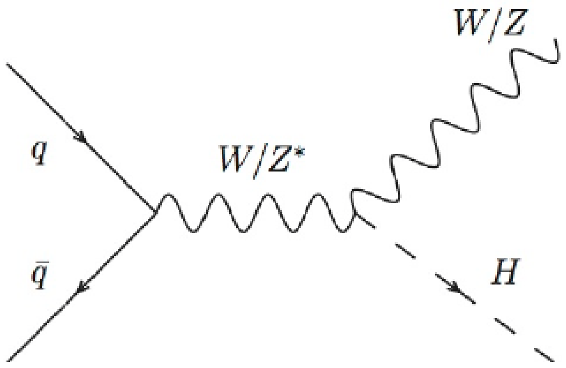


Largest σ
Low S/B

High p_T jet recoiling against large E_T^{miss}



medium σ
high S/B
Dijet system with large rapidity gap - $\Delta\eta(j_1,j_2)$
large dijet mass - m_{jj}



$Z\rightarrow\ell\ell$:smallest σ
high S/B
2 OS/SF leptons with mass close to m_Z

$W/Z\rightarrow qq$:medium σ
medium S/B
2 resolved or boosted jet with mass close to m_Z/m_W

H→invisible at CMS

- Searches for invisible decays of the Higgs boson are performed at CMS with 5.0 fb^{-1} data at 7 TeV, and 19.7 fb^{-1} data at 8 TeV and 2.3 fb^{-1} data at 13 TeV (*JHEP02(2017)135*).

- A large $E_{\mathrm{T}}^{\mathrm{miss}}$, with the jets or leptons recoiling against the $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$, consistent with one of the production topologies.

- A summary of the analyses included in the combination and the expected signal composition in each of them

Analysis	Final state	Int. $\mathcal{L}$ (fb^{-1})			Expected signal composition (%)	
		7 TeV	8 TeV	13 TeV	7 or 8 TeV	13 TeV
qqH-tagged	VBF jets	—	19.2 [17]	2.3	7.8 (ggH), 92.2 (qqH)	9.1 (ggH), 90.9 (qqH)
VH-tagged	Z($\ell^+\ell^-$)	4.9 [17]	19.7 [17]	2.3	100 (ZH)	
	Z($\mathrm{b\bar{b}}$)	—	18.9 [17]	—	100 (ZH)	
	V(jj)	—	19.7 [61]	2.3	25.1 (ggH), 5.1 (qqH), 23.0 (ZH), 46.8 (WH)	38.7 (ggH), 7.1 (qqH), 21.3 (ZH), 32.9 (WH)
ggH-tagged	Monojet	—	19.7 [61]	2.3	70.4 (ggH), 20.4 (qqH), 3.5 (ZH), 5.7 (WH)	69.3 (ggH), 21.9 (qqH), 4.2 (ZH), 4.6 (WH)

JHEP02(2017)135

H→invisible analyses

➢ VBF analysis

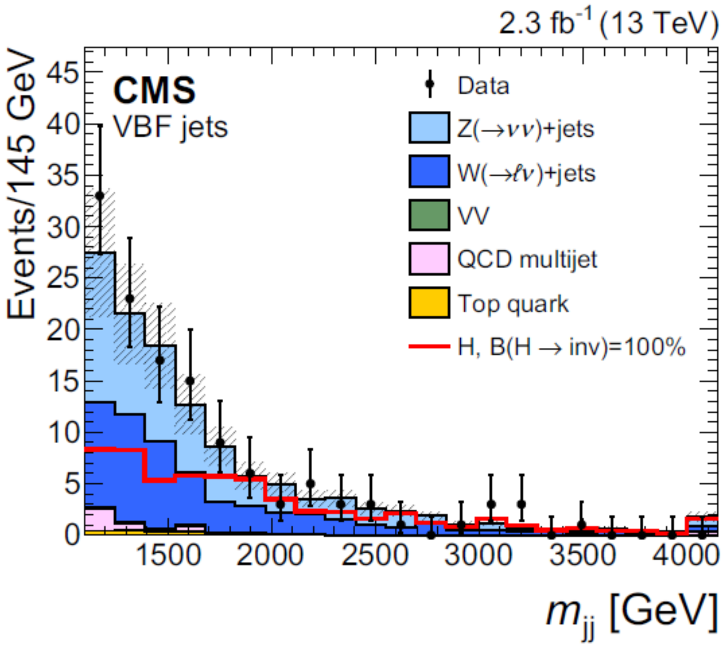
	8 TeV	13 TeV
$p_{\mathrm{T}}^{\mathrm{j}_1}$	>50 GeV	>80 GeV
$p_{\mathrm{T}}^{\mathrm{j}_2}$	>45 GeV	>70 GeV
m_{jj}	>1200 GeV	>1100 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	>90 GeV	>200 GeV
$S(E_{\mathrm{T}}^{\mathrm{miss}})$	$>4\sqrt{\mathrm{GeV}}$	—
$\min\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{j})$	>2.3	
$\Delta\eta(\mathrm{j}_1, \mathrm{j}_2)$	>3.6	

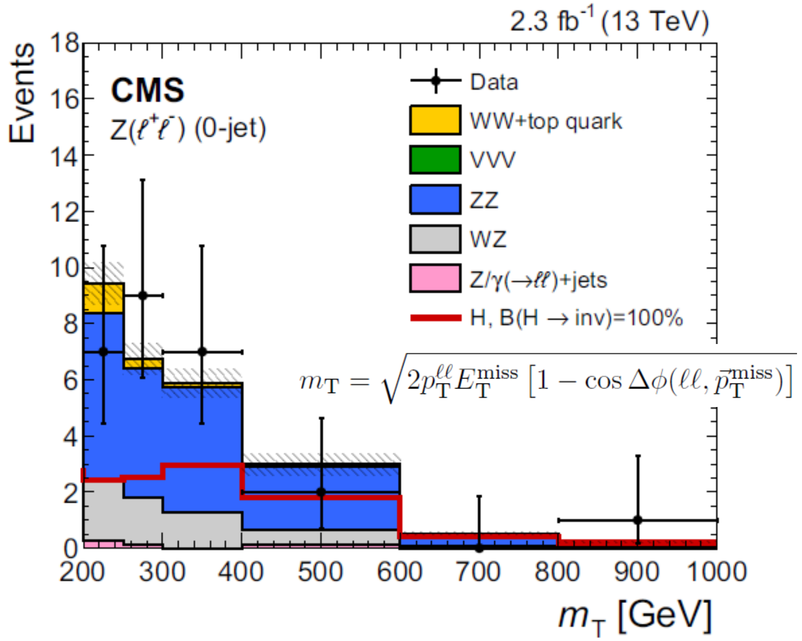
➢ Z(ℓ⁺ℓ⁻) analysis

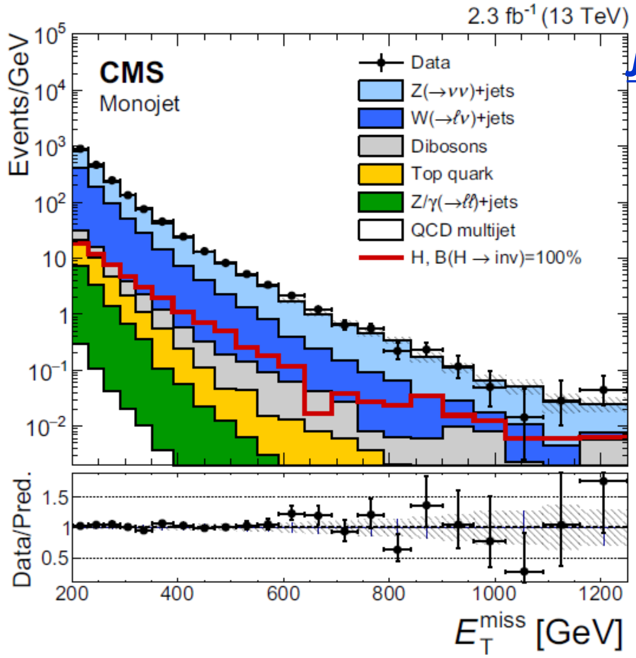
	7 and 8 TeV	13 TeV
$p_{\mathrm{T}}^{e,\mu}$	>20 GeV	
$m_{\ell\ell}$	76–106 GeV	
$\Delta\phi(\ell,\ell)$	—	$<\pi/2$
$E_{\mathrm{T}}^{\mathrm{miss}}$	>120 GeV	>100 GeV
$\Delta\phi(\ell\ell, \vec{p}_{\mathrm{T}}^{\mathrm{miss}})$	>2.7	>2.8
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{j})$	—	>0.5
$\lvert E_{\mathrm{T}}^{\mathrm{miss}} - p_{\mathrm{T}}^{\ell\ell}\rvert / p_{\mathrm{T}}^{\ell\ell}$	<0.25	<0.4
m_{T}	>200 GeV	

➢ V(jj) and monojet analyses

	8 TeV		13 TeV	
	V(jj)	Monojet	V(jj)	Monojet
$p_{\mathrm{T}}^{\mathrm{j}}$	>200 GeV	>150 GeV	>250 GeV	>100 GeV
$\lvert\eta\rvert^{\mathrm{j}}$	<2		<2.4	<2.5
$E_{\mathrm{T}}^{\mathrm{miss}}$	>250 GeV	>200 GeV	>250 GeV	>200 GeV
τ_2/τ_1	<0.5	—	<0.6	—
m_{prune}	60–110 GeV	—	65–105 GeV	—
$\min\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{j})$	>2 rad		>0.5 rad	
N_{j}	=1		—	



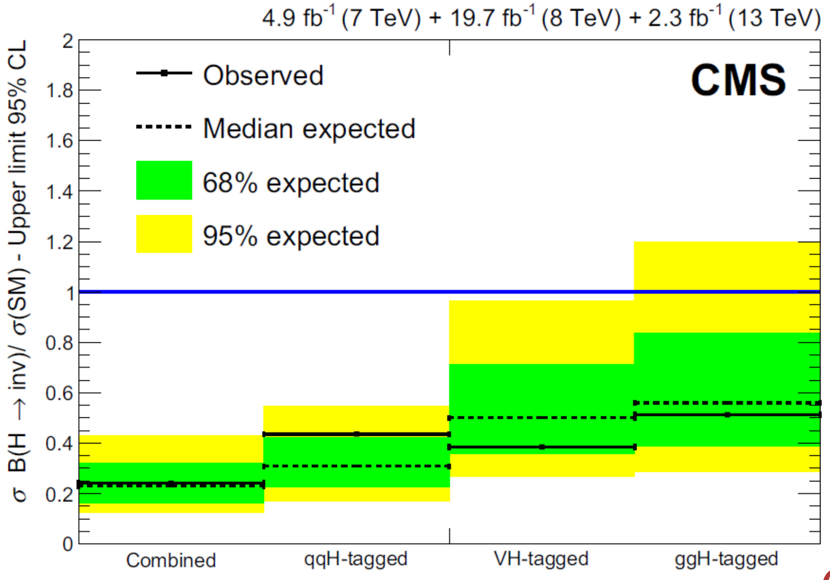




JHEP02(2017)135

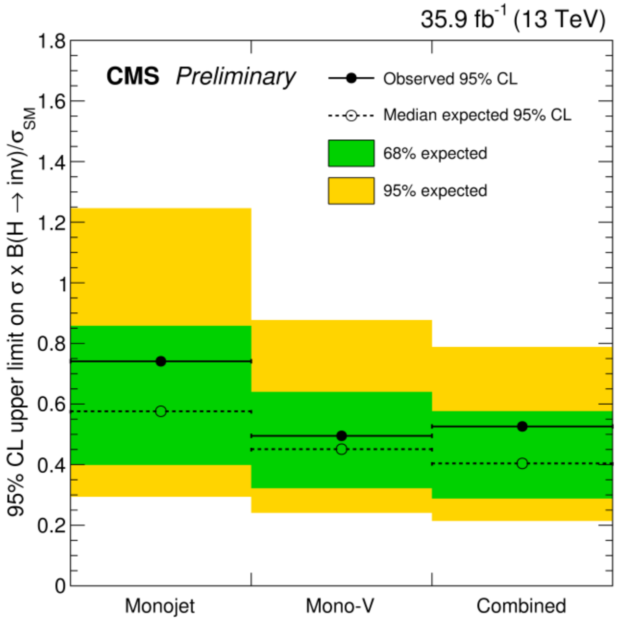
H→invisible results

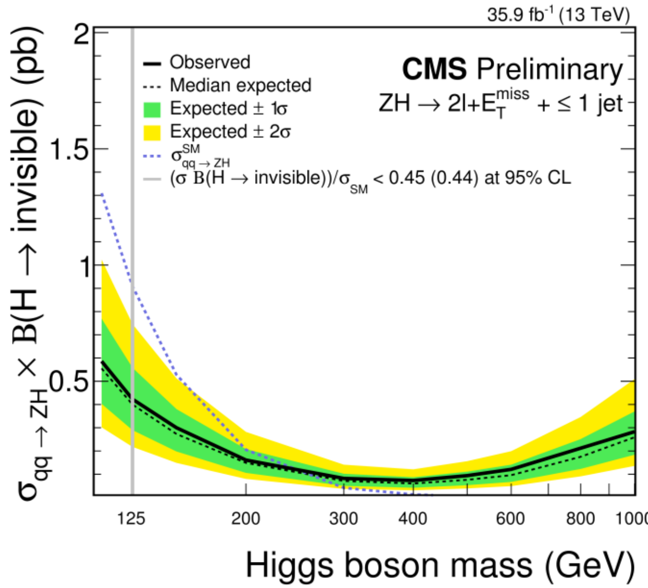
- No excess observed
- Combination of 2011 (7 TeV), 2012 (8TeV) and 2015 (13 TeV) results: *BR(H→inv) < 0.24/0.23 (obs/exp)* assuming a Higgs boson with a mass of 125 GeV
- Monojet and Mono-V analyses updated with full 2016 dataset: *BR(H->inv)<0.53/0.40(obs/exp)*
- Z(ll) + MET analyses updated with full 2016 dataset: *BR(H->inv)<0.45/0.43(obs/exp)*



JHEP02(2017)135

CMS-PAS-EXO-16-52





Higgs LFV decays

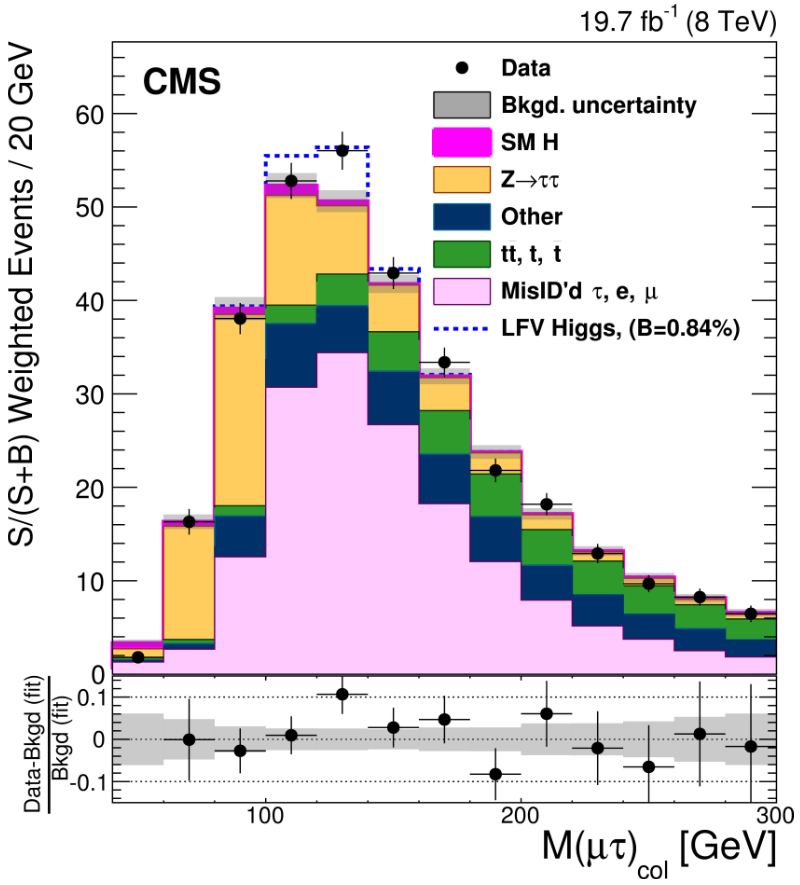
- Direct searches for LFV Higgs decays, in the three decay channels: **μτ, μe, eτ**, have been performed
  - ✓ Complementary to the SM H→ττ and H→μμ searches
- BSM models (double Higgs models or extra dimensions) allow LFV decays of Higgs
  - ✓ Only loose indirect limits prior to LHC for H→μτ and H→eτ
- Analyses summary

Channel	Data	**Reference**
H→μe	8 TeV 19.7 fb^{-1}	*Phys. Lett. B 763C (2016) 472*
H→eτ	8 TeV 19.7 fb^{-1} **13TeV 35.9 fb^{-1}**	*Phys. Lett. B 763C (2016) 472* *CMS-PAS-HIG-17-001*
H→μτ	8 TeV 19.7 fb^{-1} 13 TeV 2.3 fb^{-1} **13TeV 35.9 fb^{-1}**	*Phys. Lett. B 749 (2015) 337* *CMS-PAS-HIG-16-005* *CMS-PAS-HIG-17-001*

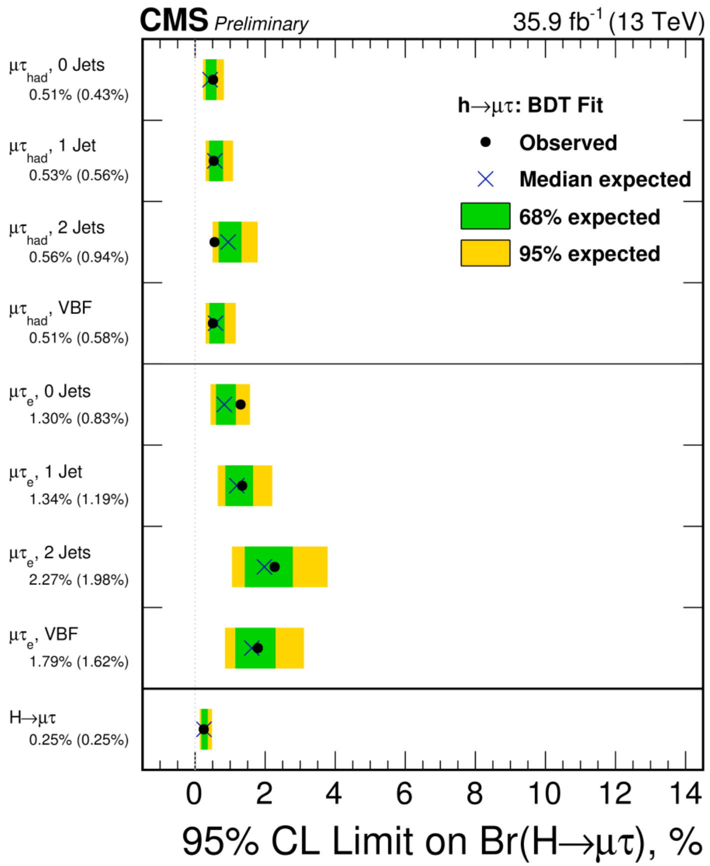
See also Swagata's talk

H→μτ/eτ/eμ results

- **Slight excess** from ***μτ*** channel with ***8TeV (19.7 fb^{-1}) data***: *p*-value at m_H=125GeV is 0.010 (significance **2.4σ**)
- But has been **ruled out** by the **13TeV results with 35.9 fb^{-1} data** collected in 2016 by CMS
- No obvious excess observed in data for the ***eτ*** channel or ***eμ*** channels
- Upper limits on the branching fractions, **B(H → μτ)<0.25%** *and* **B(H → eτ)<0.61%** *(13TeV 35.9 fb^{-1})*, and ***B(H → eμ) <0.035%*** *(8TeV 19.7 fb^{-1})*, are set at the 95% confidence level

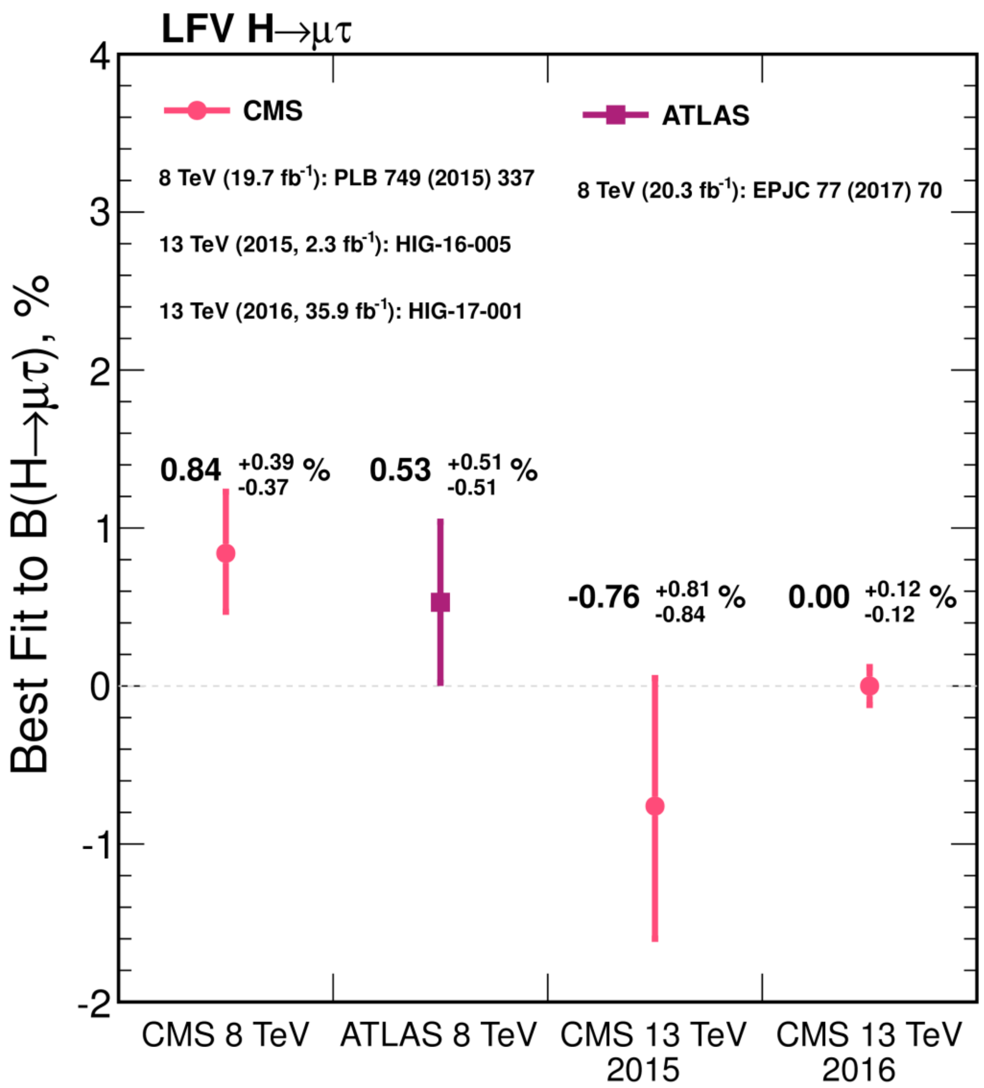


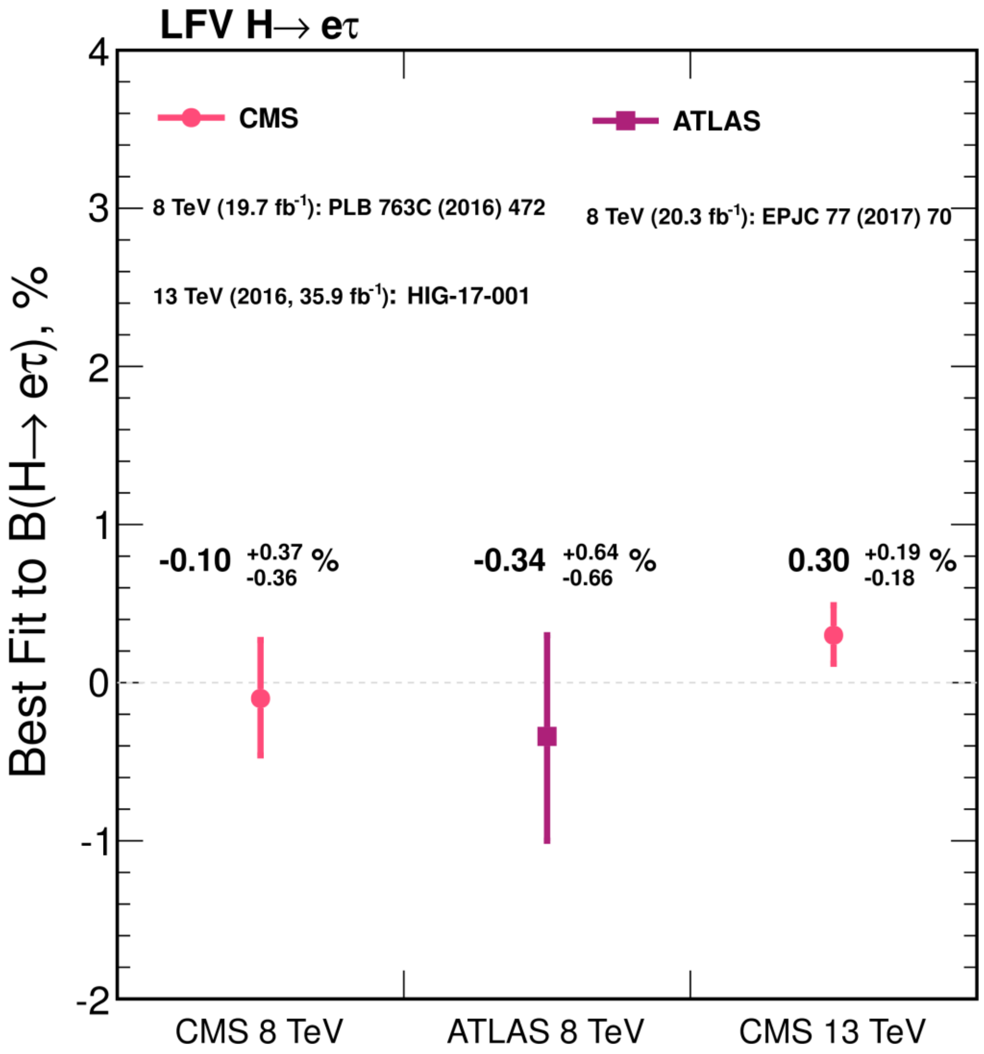
[Phys. Lett. B 749 (2015) 337]



[CMS-PAS-HIG-17-001]

Chronology of LFV Higgs results





Best fit branching fraction

Higgs decay to light (pseudo)scalars

- Well **motivated by BSM models** like NMSSM and 2HDM+S **(**a complex $SU(2)_L$ singlet field S added to 2HDM**)**

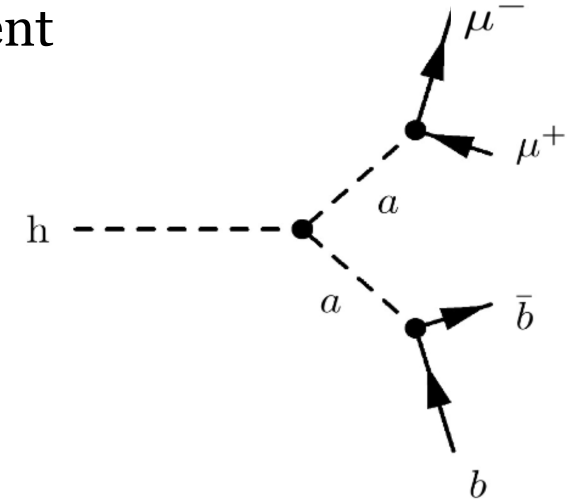
- Higgs boson production cross section **may be enhanced** compared to the SM depending on the specific parameters of the model

- Several channels:

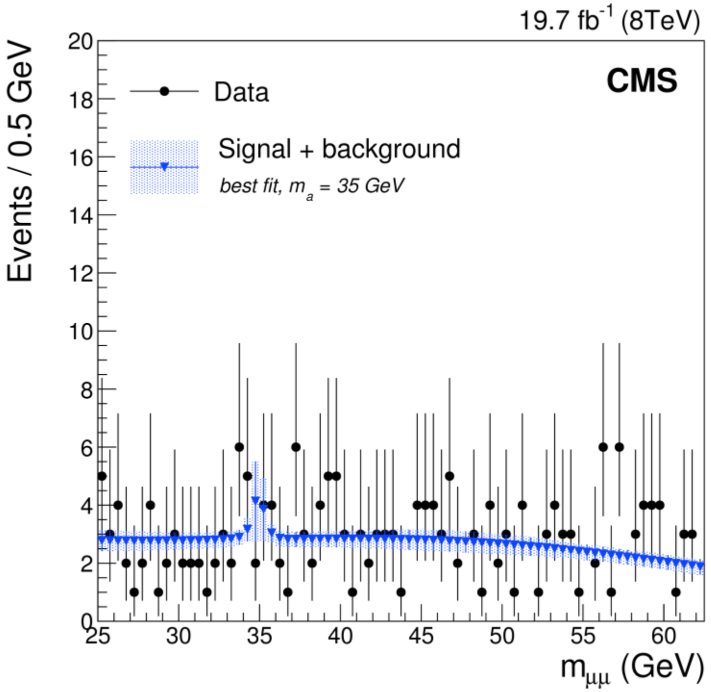
Channel	Data	**Reference**
$H \rightarrow aa \rightarrow 2\mu 2b$	8 TeV 19.7 fb^{-1}	*CMS-PAS-HIG-16-015* (**arXiv:1701.02032**)
$H \rightarrow aa \rightarrow 4\tau$	8TeV 19.7 fb^{-1}	*CMS-PAS-HIG-16-015* (**arXiv:1701.02032**)
$H \rightarrow aa \rightarrow 2\mu 2\tau$	8TeV 19.7 fb^{-1}	*CMS-PAS-HIG-16-015* (**arXiv:1701.02032**)
$H \rightarrow aa \rightarrow 4\mu$	13TeV 2.8 fb^{-1}	*CMS-PAS-HIG-16-035*

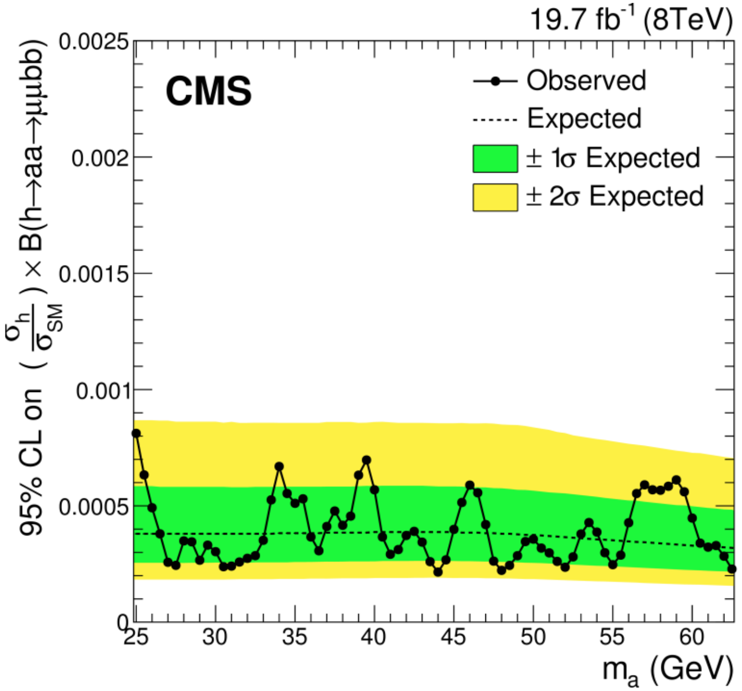
H→aa→μμbb

- Two isolated opposite sign muons firing the trigger; 2 b-tagged jets in the event
- Invariant mass of 4 objects in a 100-150 GeV window
- **ggH production only** (others add little sensitivity)
- Signal discrimination through a fit to the dimuon distribution : benefits from narrow dimuon resonance



25 <ma< 62.5 [GeV]



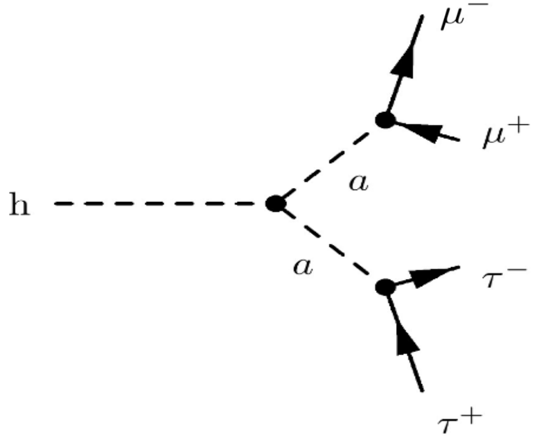


CMS-PAS-HIG-16-015

No significant excess of data observed

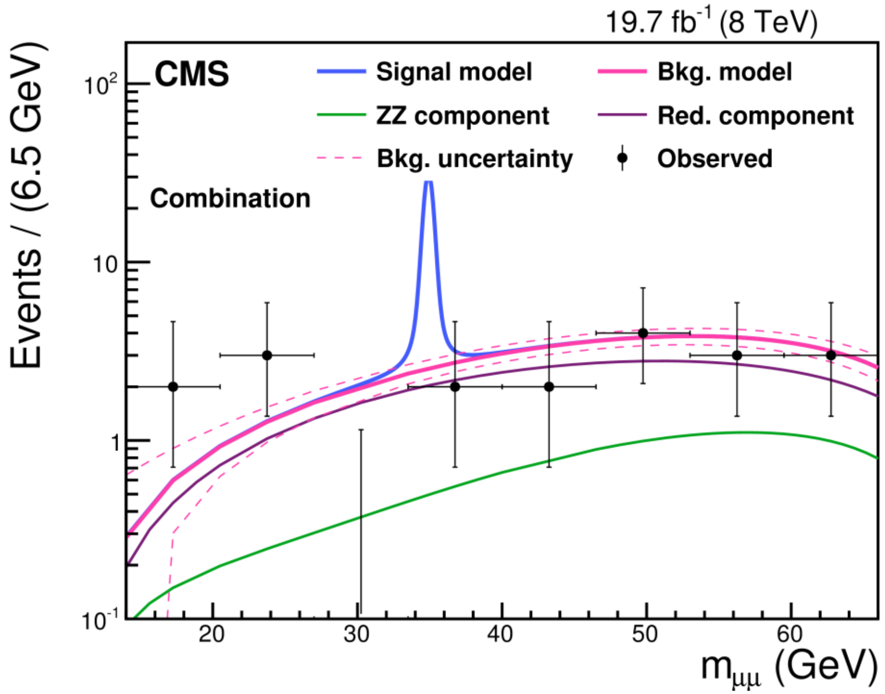
H→aa→μμττ

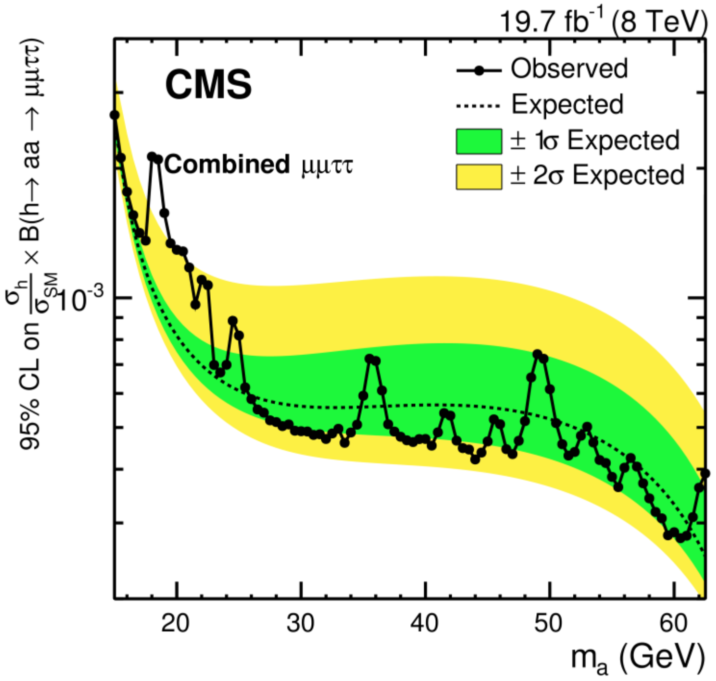
- Categorized depending on the **tau decay** ($\tau_e\tau_e$, $\tau_\mu\tau_h$, $\tau_e\tau_h$, $\tau_e\tau_\mu$, $\tau_h\tau_h$)
- Targets **non-boosted tau pairs**, and requires **4 well reconstructed and isolated leptons**
- Main backgrounds estimated from data
- Signal discrimination through a **fit to the dimuon distribution** : benefits from narrow dimuon resonance



15 <ma< 62.5 [GeV]

CMS-PAS-HIG-16-015

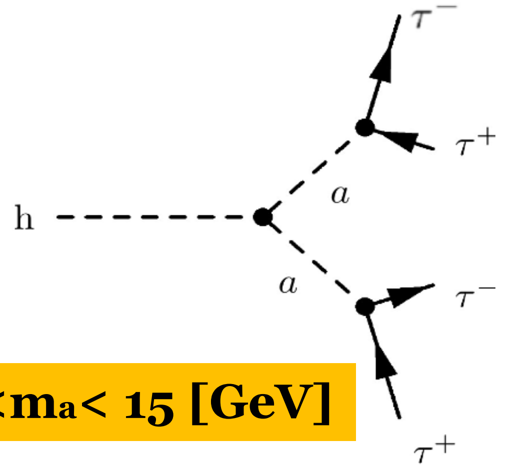


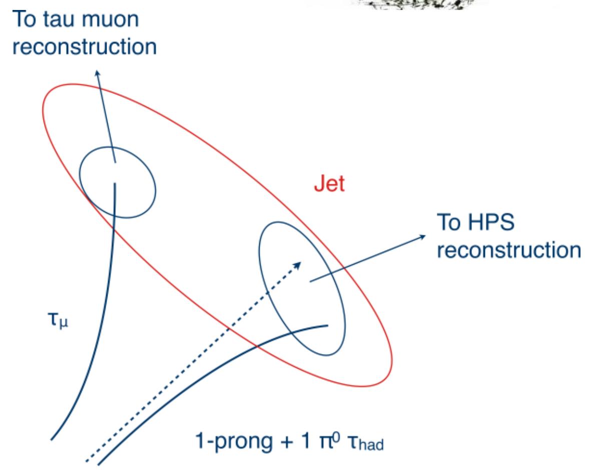


No significant excess of data observed

H→aa→ττττ

- **Dominant decay mode for $m_a<2m_b$**
- Di-tau decay of **highly boosted a** → Collimated ττ pairs
  → focus on the decay **$a \to \tau_\mu \tau_x$** --> Special boosted ττ pair reconstruction technique





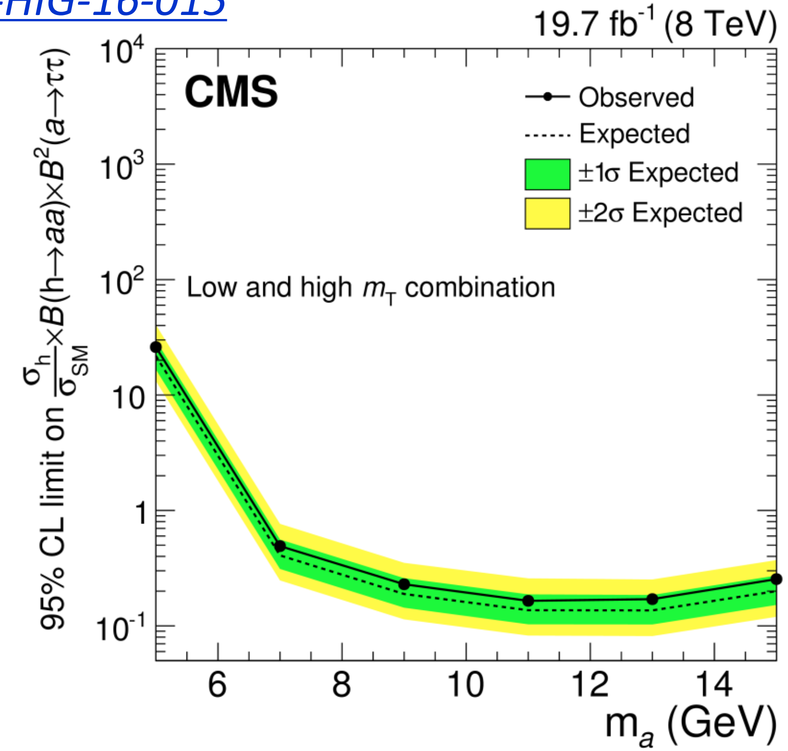
5 <m_a< 15 [GeV]

CMS-PAS-HIG-16-015

- Two categories in **MT (μ, MET)** :

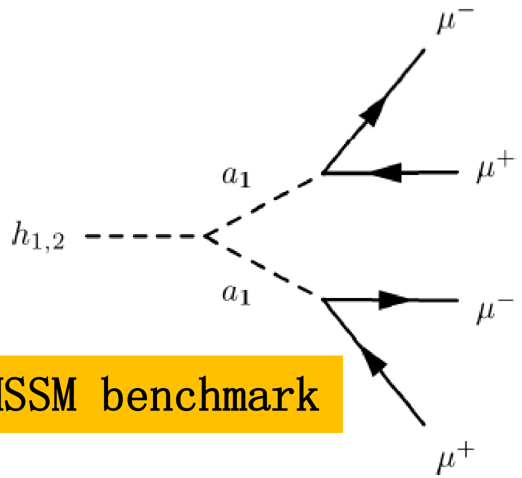
Low-MT targeting ggH and VBF
High-MT: targets WH production

- Main backgrounds have jets reconstructed as τ_X objects:
  - ✓ Z → μμ+jets, W → μν+jets, QCD ..
  - ✓ Shape estimated from data CRs with relaxed isolation, and simulations

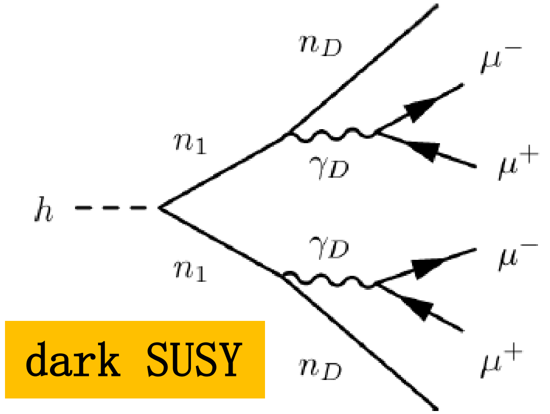


H→aa→μμμμ

- Largest a boson decay mode for $\mathbf{m_a<2m_\tau}$
- Opposite sign muons with invariant mass < 9 GeV
- Background dominated by ***bb* and *J/Ψ*** events: estimated using data-driven techniques
- Number of events in data compatible with background



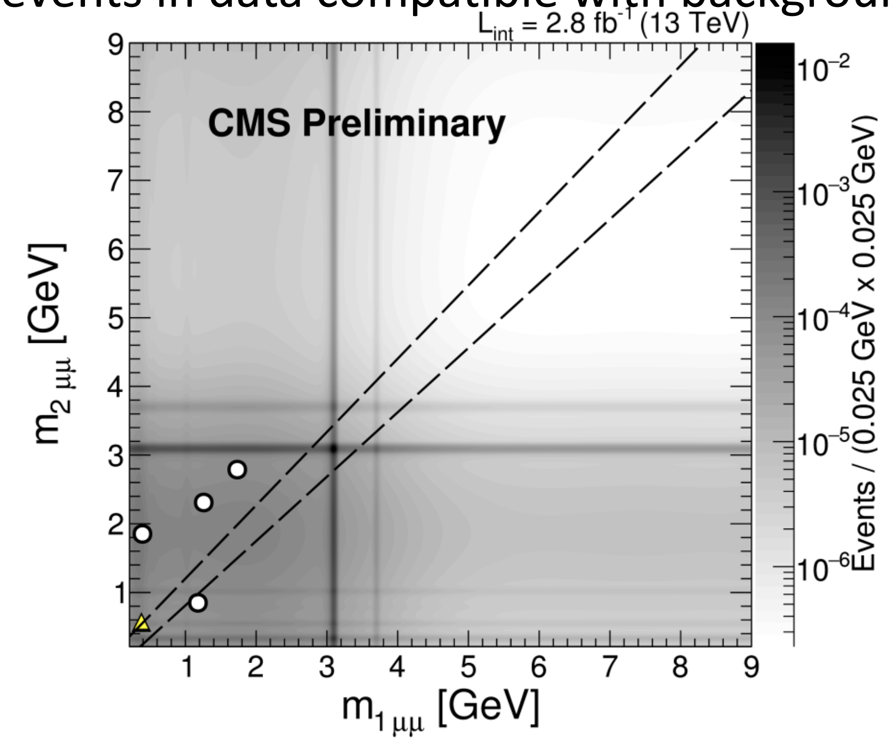
NMSSM benchmark

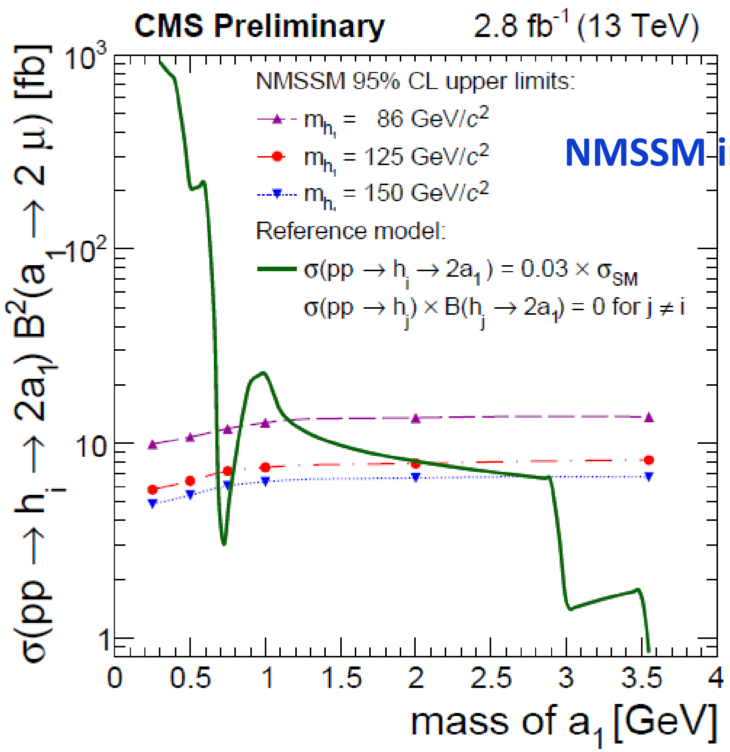


dark SUSY

Points represent the data surviving all selection except the invariant mass cut

Triangle: observed event in signal region





NMSSM interpretation

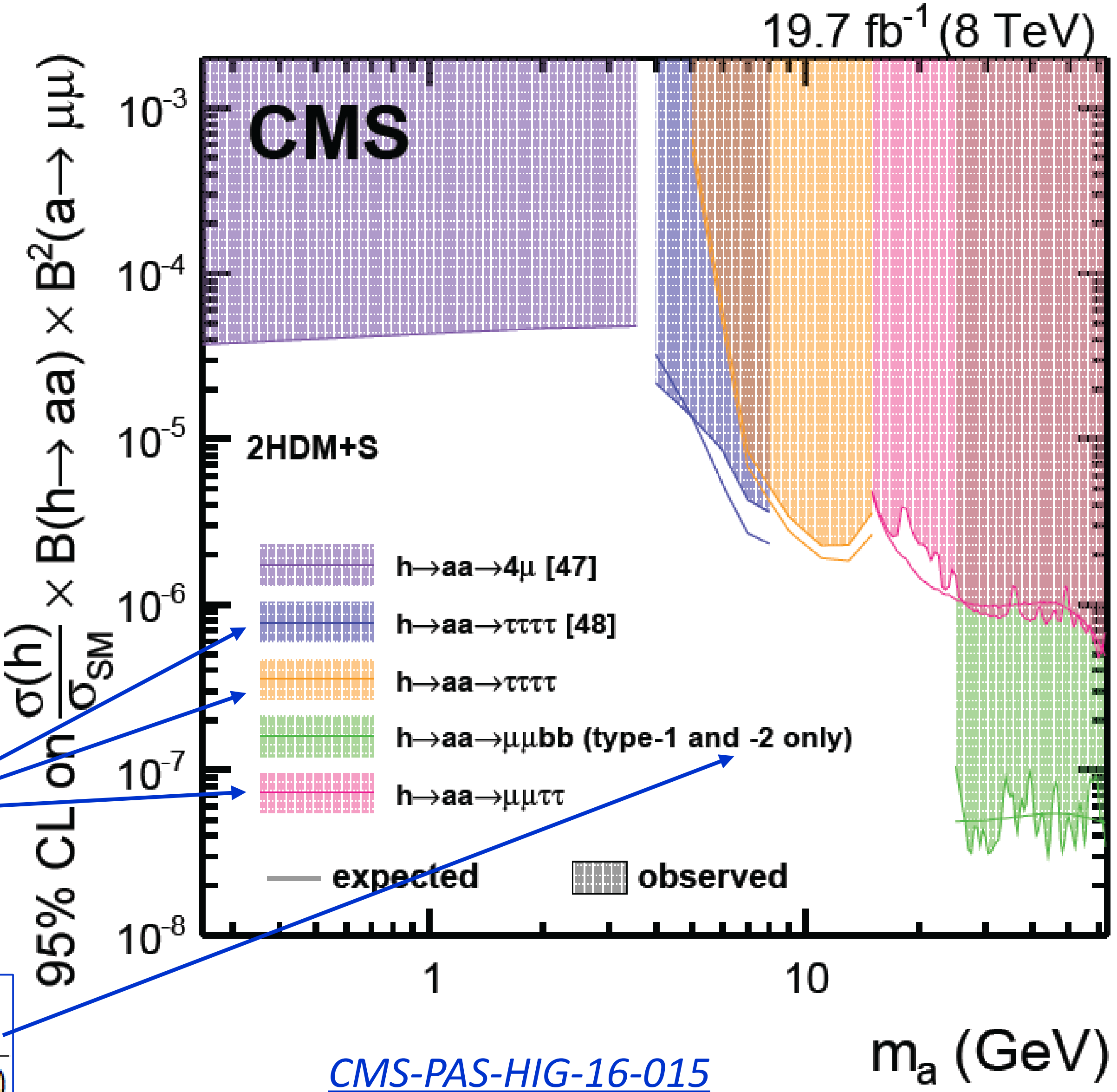
[CMS-PAS-HIG-16-035]

Joint interpretation of CMS H→aa searches

- Searches for non standard decays of the SM-like Higgs boson to ***a pair of light pseudoscalar bosons*** are interpreted in the context of **2HDM+S (**a complex $SU(2)_L$ singlet field S added to 2HDM**)**
- Expected and observed 95% CL exclusion **limits on (σ_h/σ_{SM}) B(h → aa) $B^2(a \to \mu^+\mu^-)$** for various exotic h boson decay searches
- Limit shown for h → aa → 2μ2b is valid only in type-1 and -2 2HDM+S

$$\frac{\Gamma(a\to\mu^+\mu^-)}{\Gamma(a\to\tau^+\tau^-)} = \frac{m_\mu^2\sqrt{1-(2m_\mu/m_a)^2}}{m_\tau^2\sqrt{1-(2m_\tau/m_a)^2}}$$

$$\frac{\Gamma(a\to\mu^+\mu^-)}{\Gamma(a\to b\bar{b})} = \frac{m_\mu^2\sqrt{1-(2m_\mu/m_a)^2}}{3m_b^2\sqrt{1-(2m_b/m_a)^2}\times(1+\text{QCD corrections})}$$



CMS-PAS-HIG-16-015

Summary

- The **Higgs(125)** opens a new era of precision physics and provides a portal to probe physics beyond the standard model

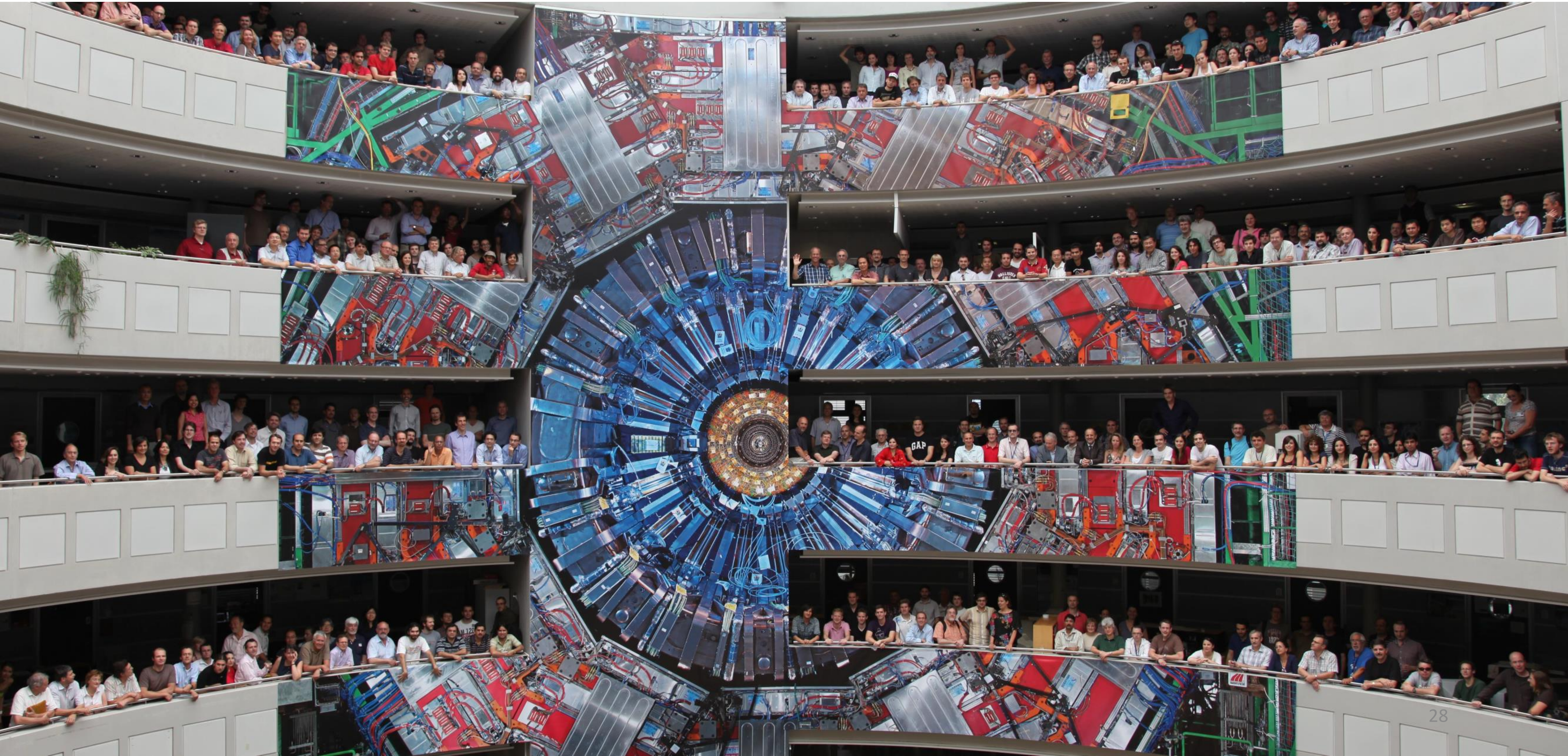
- **Rare Higgs decays** are extremely powerful to **new physics** if additional Higgs couplings exist : many rare decays have not been observed yet but may become observable in the next few years

- **Exotic decays** would bring direct evidence of such **new physics** : Tight limits on $H \rightarrow \mu\tau$ and $H \rightarrow e\tau$ have been set by CMS using data collected in 2016 and the 2.4σ excess observed in $H \rightarrow \mu\tau$ Run I has been ruled out; No hint for new physics has been found when looking for $H \rightarrow$invisible and $H \rightarrow$ aa searches

- All analyses **will be updated** with more data in Run II

Stay tuned !

Thanks for your attention!



Backup

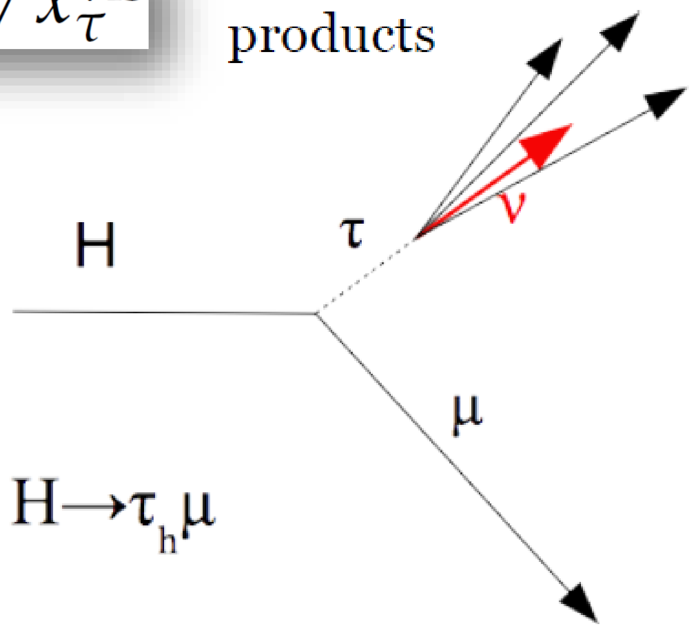
Important Signal Variable – Collinear Mass (M_{col})

$$M_{\text{col}} = M_{\text{vis}} / \sqrt{x_\tau^{\text{vis}}}$$

x_τ^{vis} is the fraction of energy carried by the visible decay products of the τ

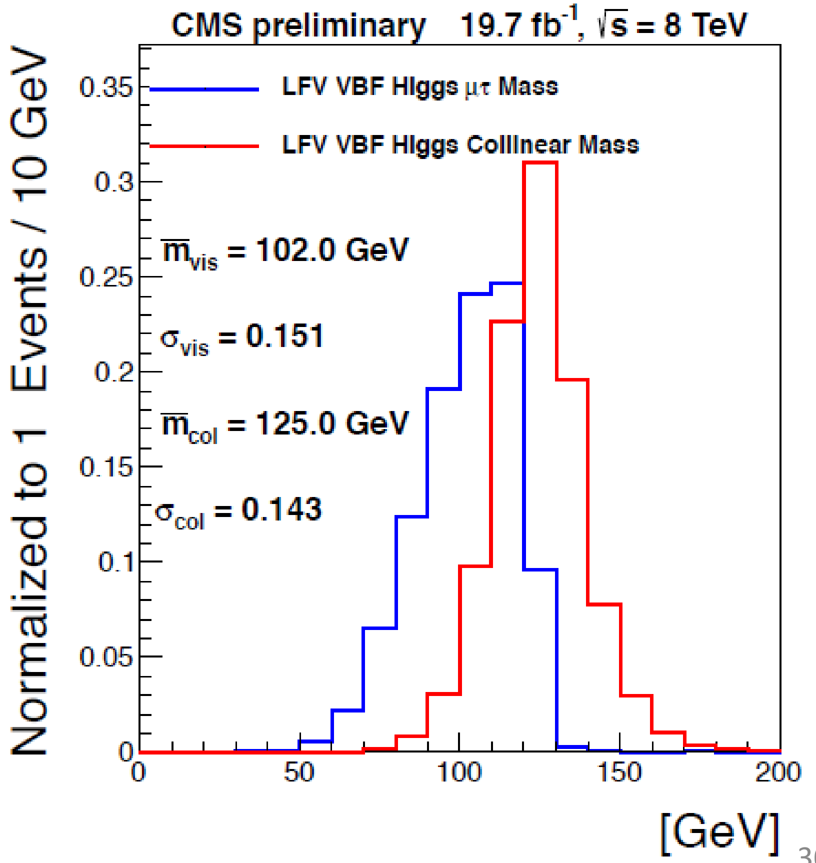
$$x_\tau^{\text{vis}} = p_{\text{T}}^{\tau^{\text{vis}}} / (p_{\text{T}}^{\tau^{\text{vis}}} + p_{\text{T}}^{\nu,\,\text{est}})$$

Visible decay products



Approximate neutrino as collinear with the visible products of the tau decay

100



Collinear Mass reduces bias and improves resolution versus visible Mass

Performance for this analysis comparable to other techniques of estimating neutrino momentum such as SVFit and MMC

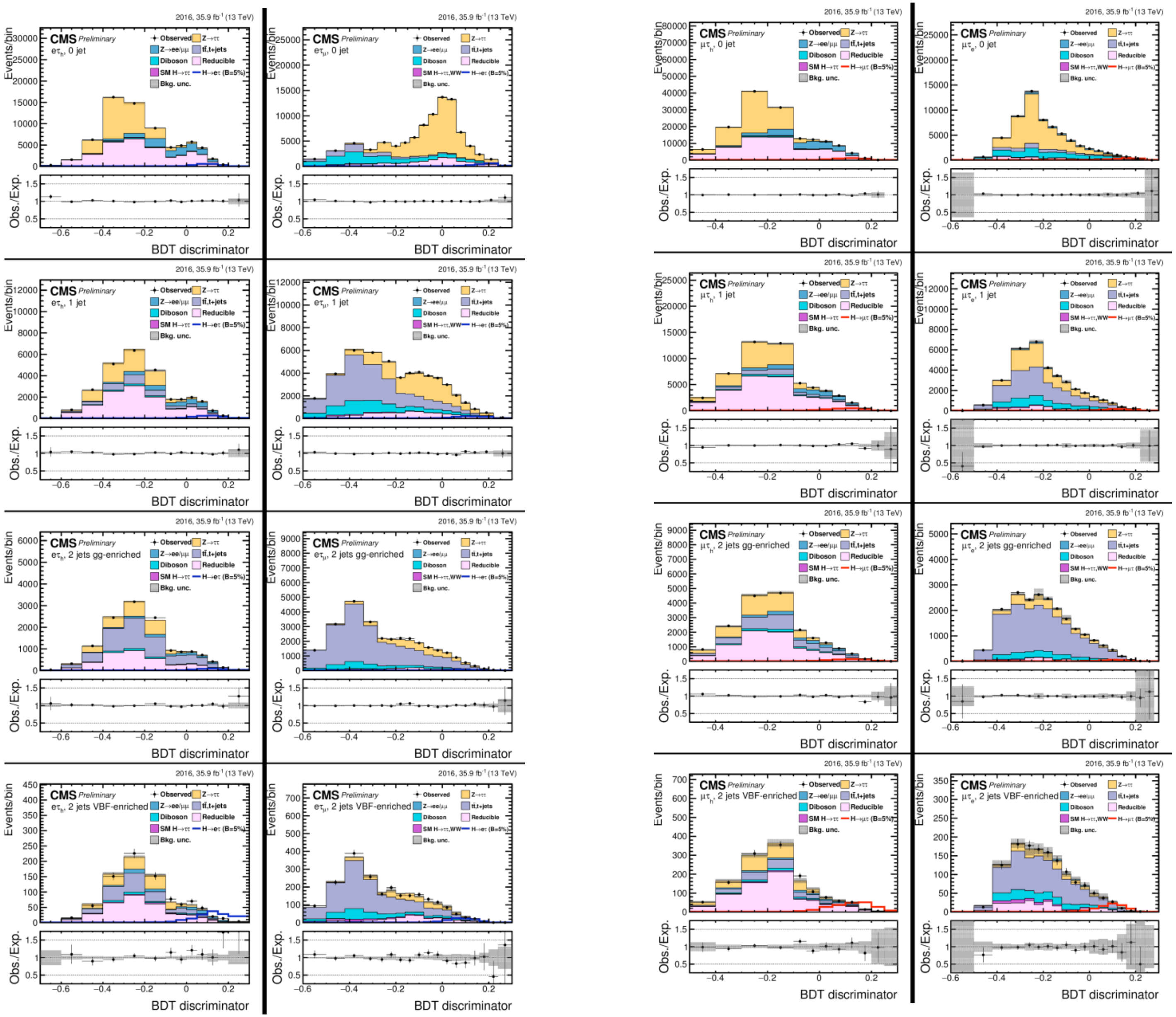
BDT output distributions

0-jet

1-jet

2-jet
(low m_{jj})

2-jet
(high m_{jj})

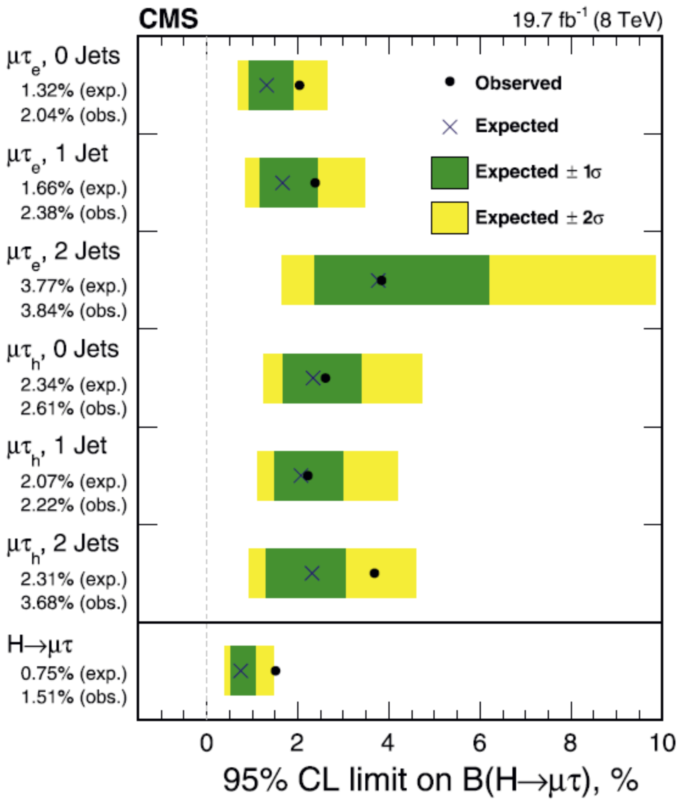


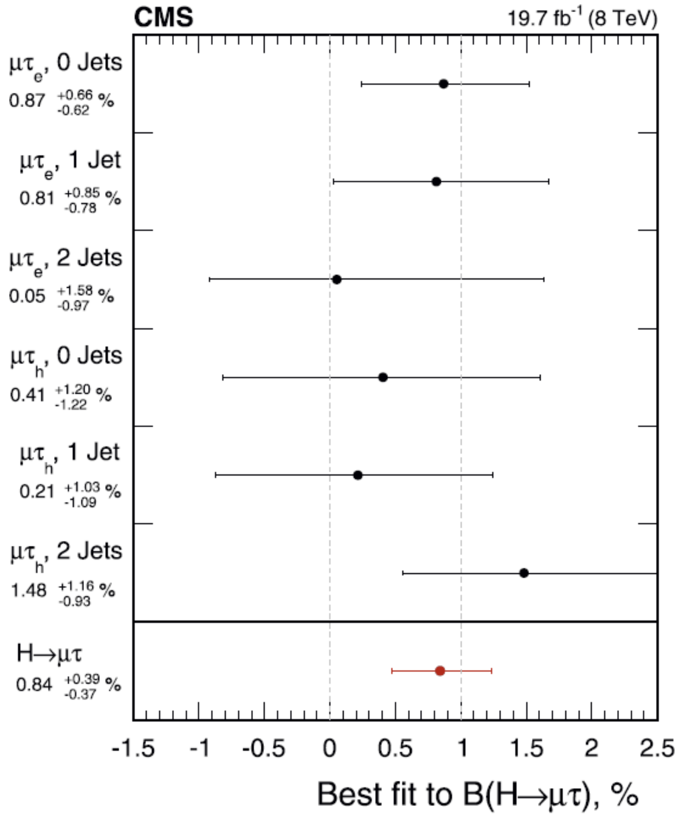
$H \rightarrow e\tau_h$ $H \rightarrow e\tau_\mu$ $H \rightarrow \mu\tau_h$ $H \rightarrow \mu\tau_e$

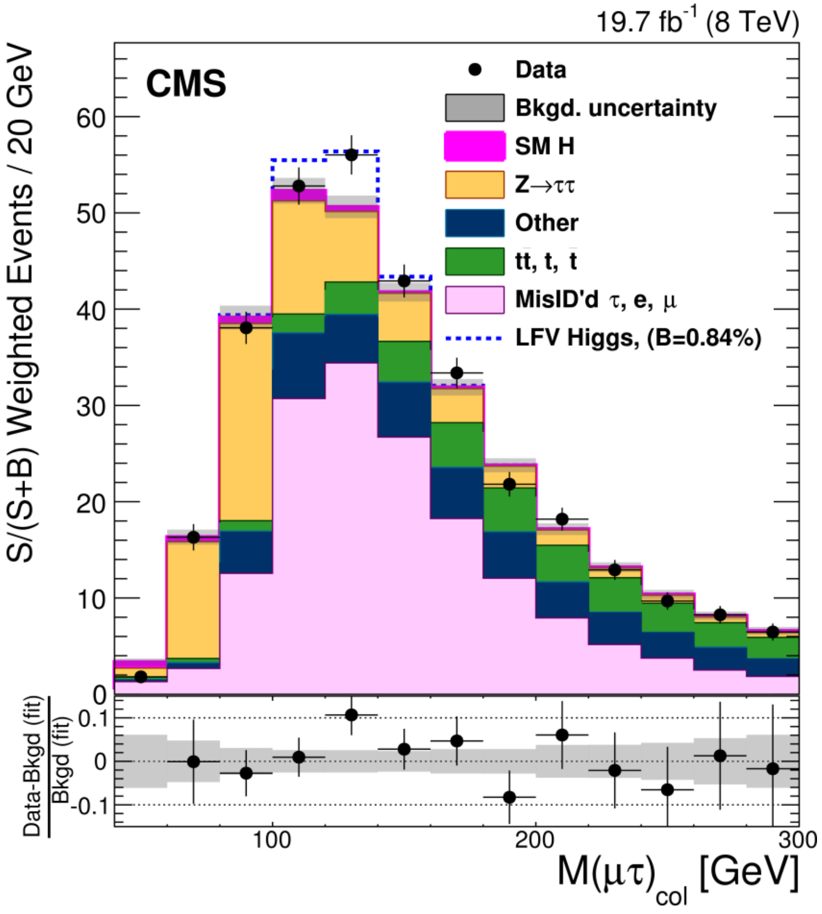
H→μτ results : 8TeV

[*Phys. Lett. B 749 (2015) 337*]

- **Slight excess** from ***μτ*** channel : *p*-value at m_H=125GeV is 0.010 (significance **2.4σ**)
- A constraint on the branching fraction, ***B(H →μτ) <1.51%*** at 95% confidence level is set. This limit is subsequently used to constrain the *μ–τ Yukawa couplings* to be less than **3.6 ×10⁻³**
- Best fit branching fraction is ***B(H →μτ) =(0.84$^{+0.39}_{-0.37}$)%*** at m_H=125GeV







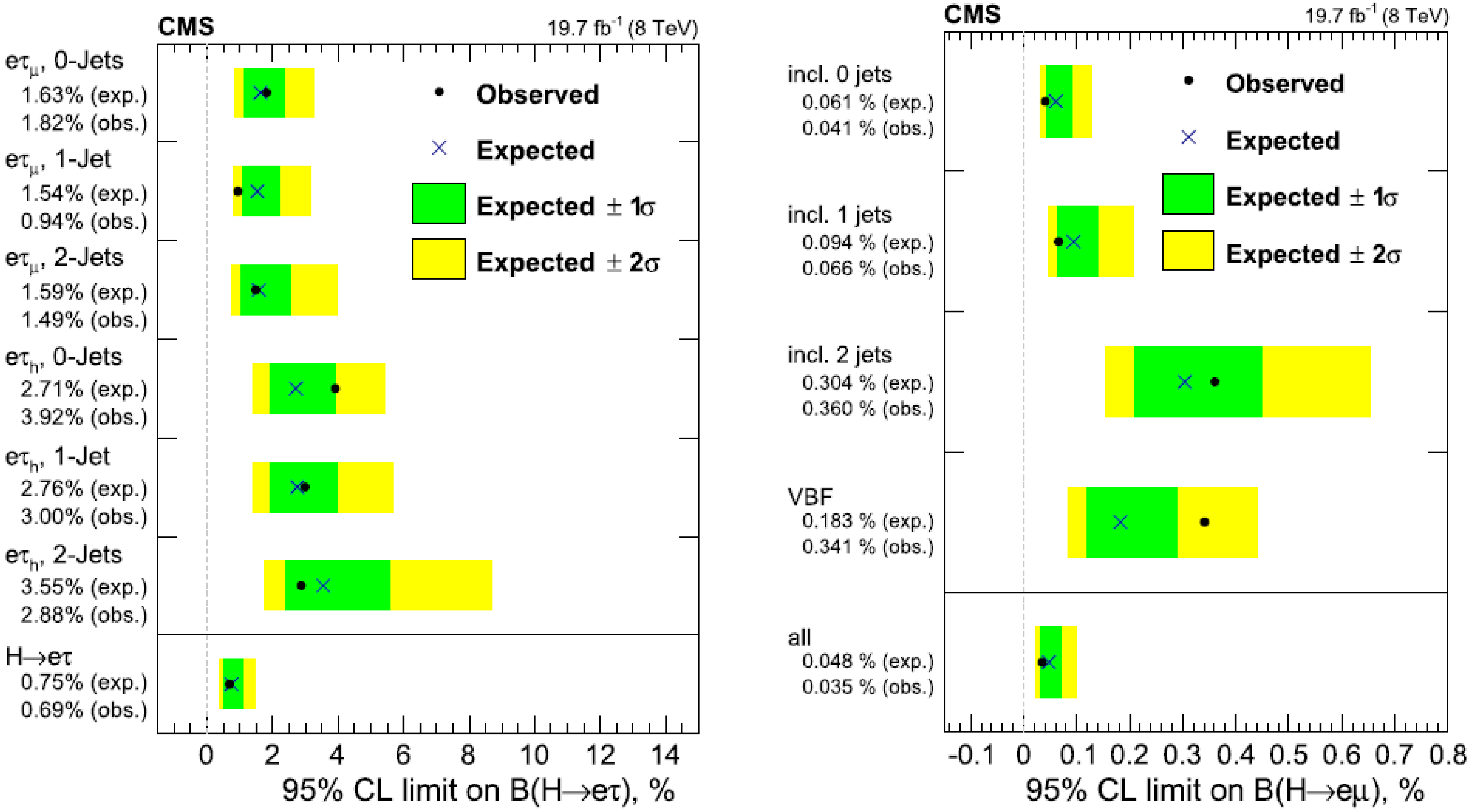
H → eτ/eμ results : 8TeV

[Phys. Lett. B 763C (2016) 472]

- A direct search for lepton flavour violating decays of the Higgs boson (H) in the **H→eτ** and **H→eμ** channels is performed with 8 TeV 19.7 fb^{-1} data

- No deviation from the background-only hypothesis is observed for the ***eτ*** channel or ***eμ*** channels

- Upper limits on the branching fractions, ***B(H→eτ) <0.69%*** and ***B(H→eμ) <0.035%***, are set at the 95% confidence level.

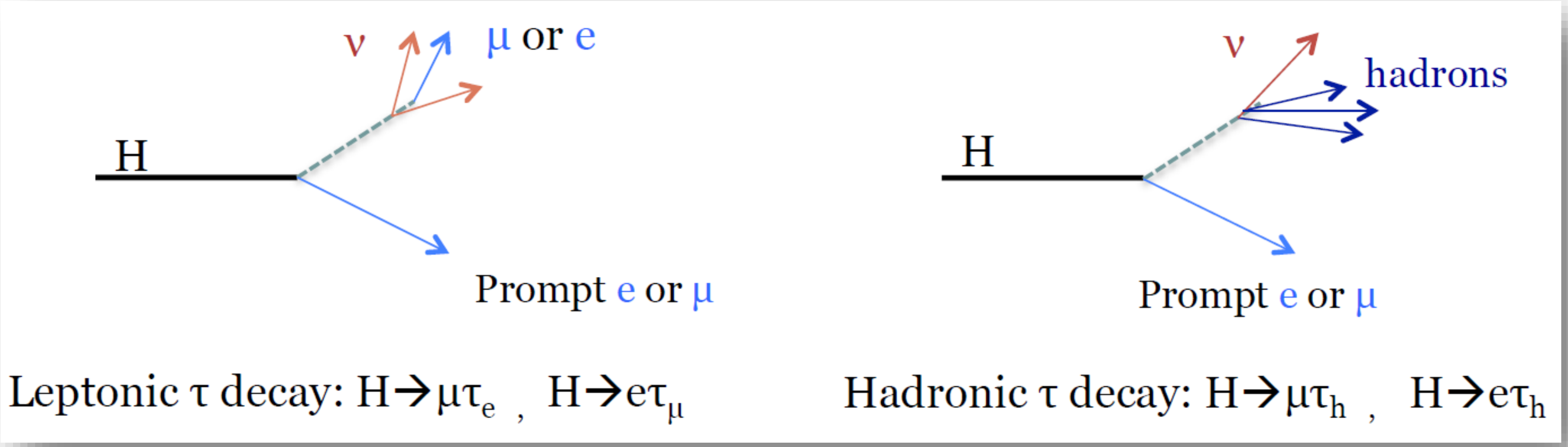


H→μτ/eτ : 13TeV

- Slight excess of the CMS 8 TeV result from ***μτ*** channnel **not confirmed** (but not excluded) by the first preliminary 13TeV results with 2.3 fb^{-1} data collected in 2015 by CMS (*CMS-PAS-HIG-16-005*)

- *H→μτ* and *H→eτ* updated with **35.9 fb^{-1}** dataset collected by CMS in 2016

- Search in four channels



- Four categories for signal extraction targeting different production modes:
  - ✓ 0-jet: targets ggH events
  - ✓ 1-jet: targets ggH events produced in association with a jet
  - ✓ 2-jet, m_{jj}<550(500) GeV: targets ggH events with additional jets
  - ✓ 2-jet, m_{jj}>550(500) GeV: targets VBF events

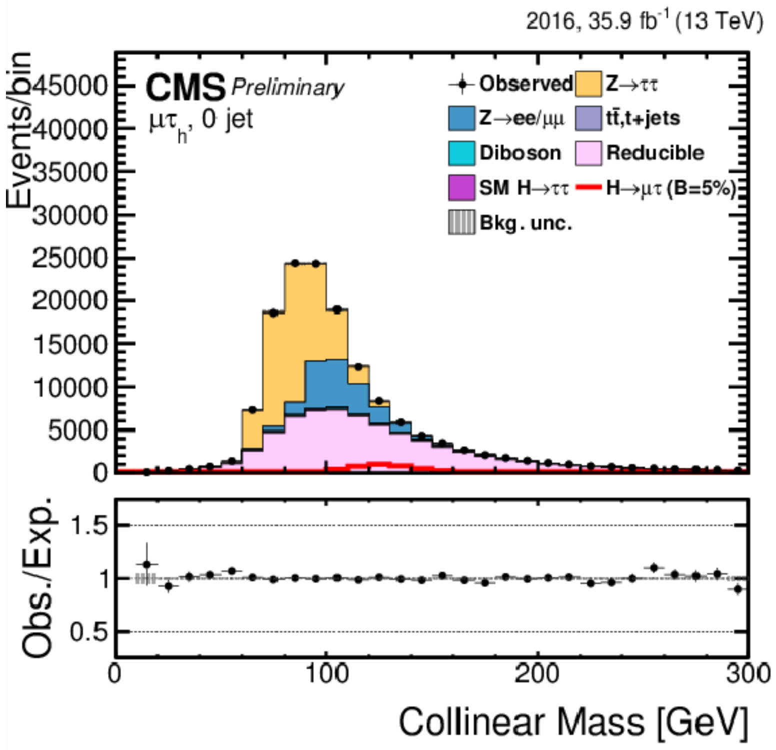
* Threshold 500GeV for e*μ* channel

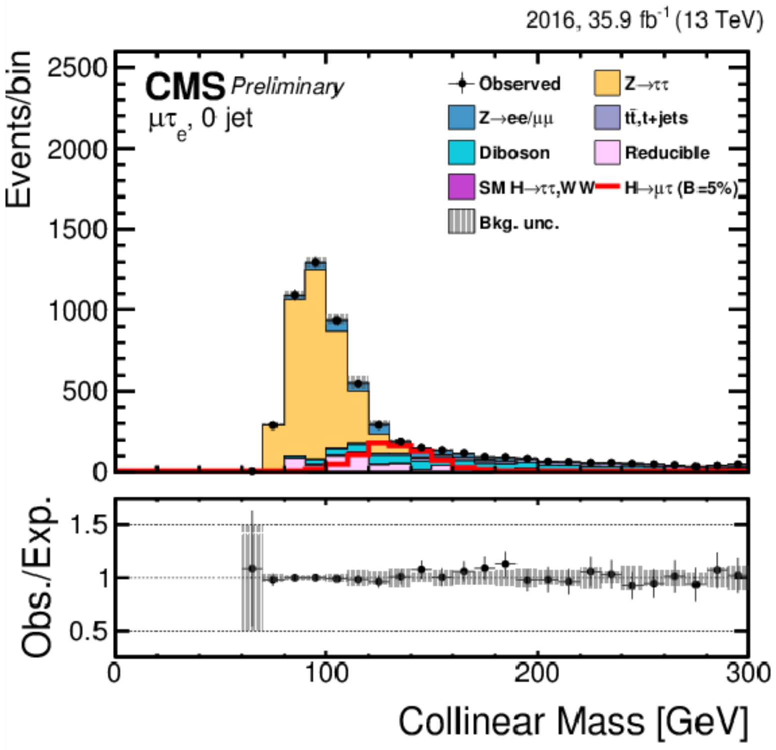
H->μτ *2 channels*4 categories **H->eτ *2 channels*4 categories**

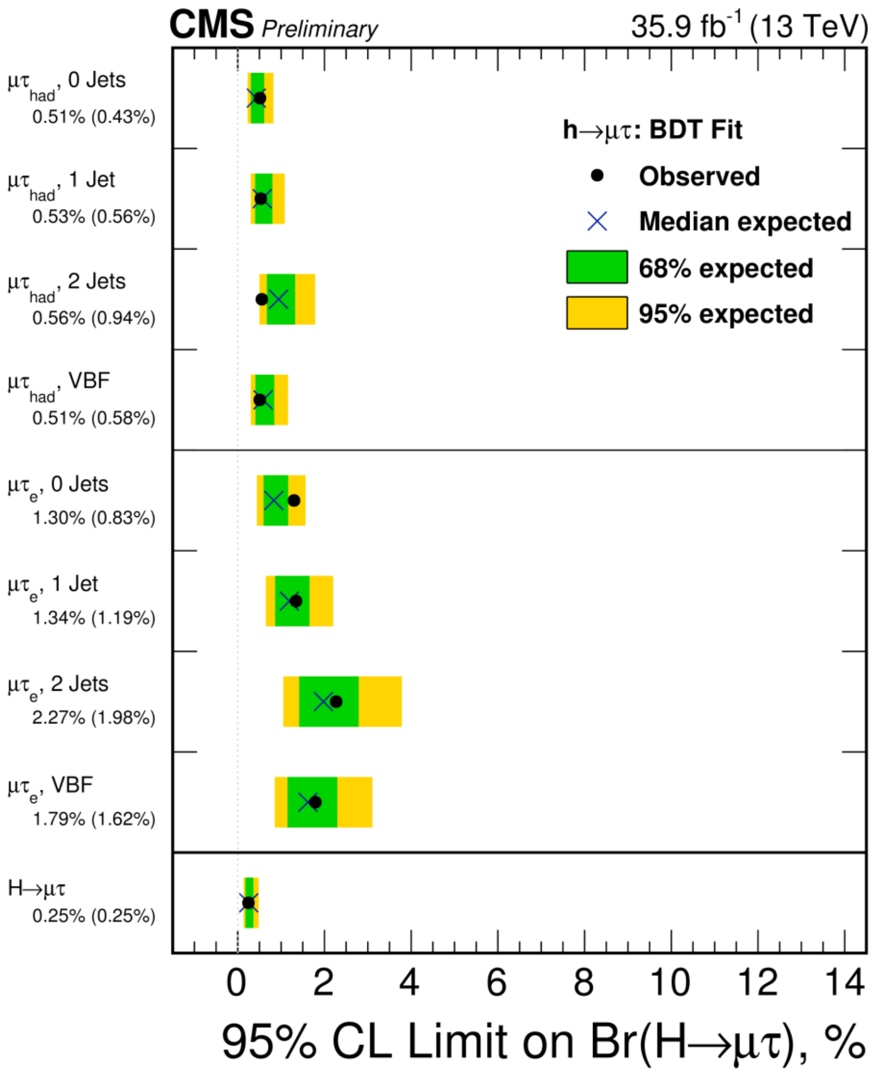
H→μτ search results : 13TeV

- Slight excess of the CMS 8 TeV result from ***μτ*** channnel still has been **ruled out** by the 13TeV results with 35.9 fb^{-1} data collected in 2016 by CMS

- No excess observed in data : best fit branching fraction 0.00±0.12 and **Br(H → μτ)<0.25% at 95% CL**



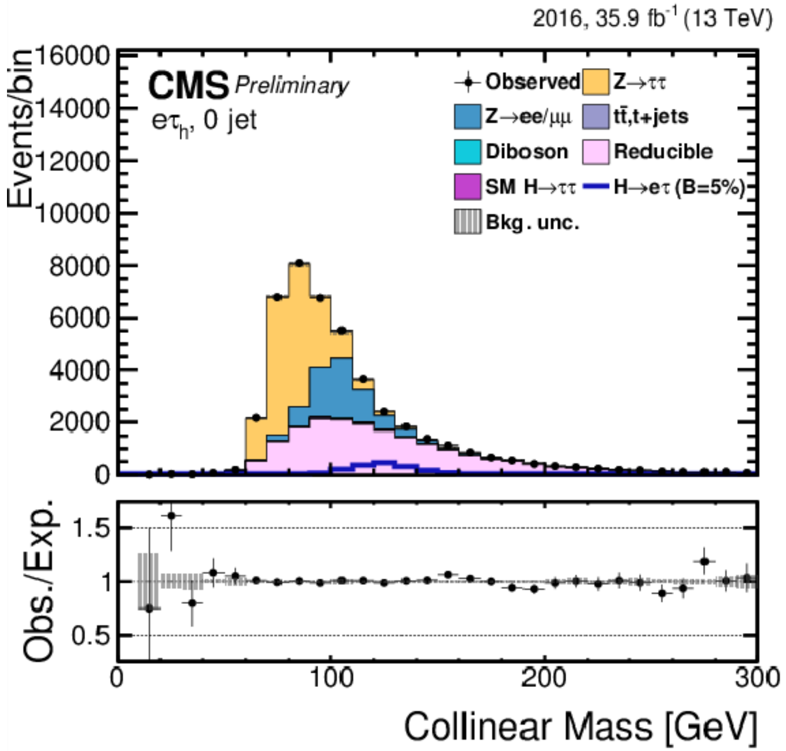


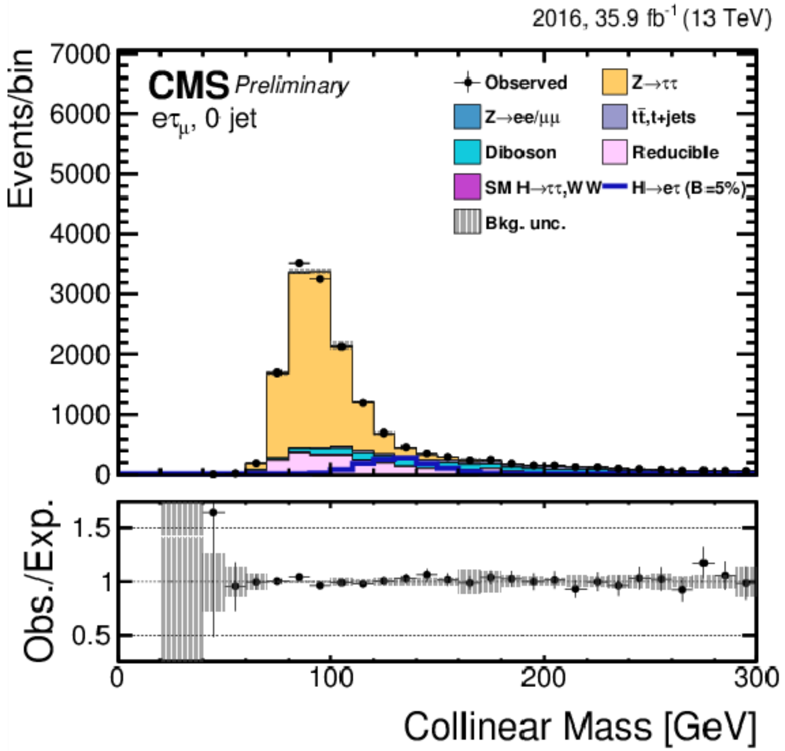


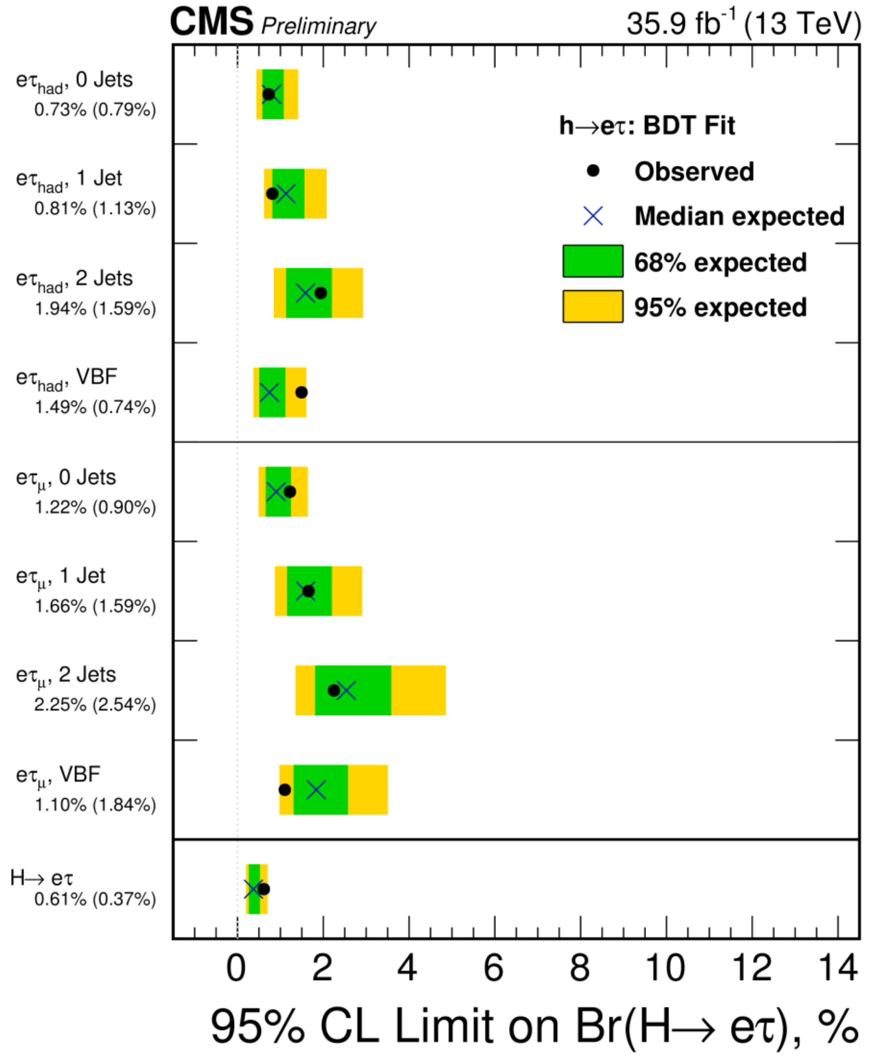
[CMS-PAS-HIG-17-001](CMS-PAS-HIG-17-001)

H→eτ search results : 13TeV

- ➢ Very small excess of data (**1.6σ**)
- ➢ Best fit branching fraction 0.30±0.18
- ➢ **Br(H → eτ)<0.61% at 95% CL**





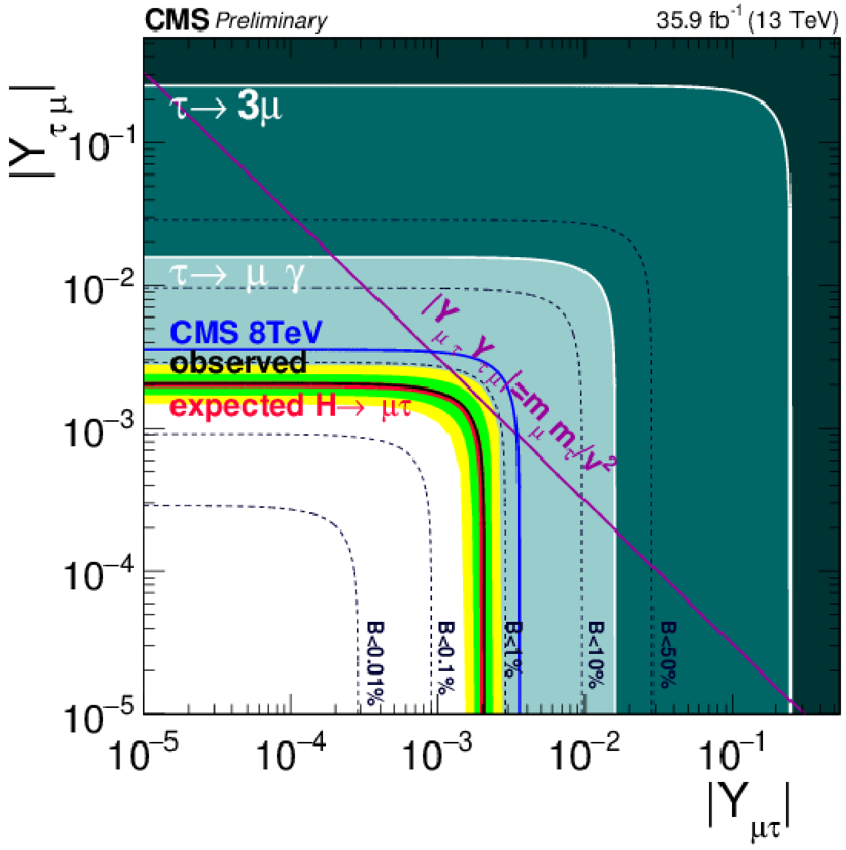


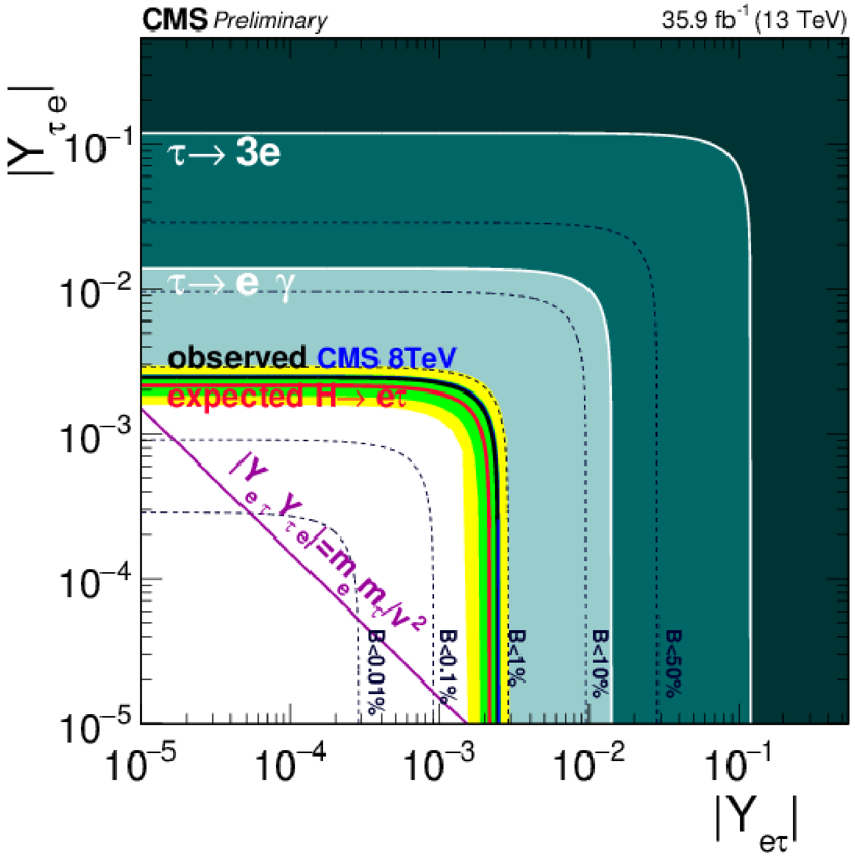
CMS-PAS-HIG-17-001

Constraints on the flavour violating Yukawa couplings

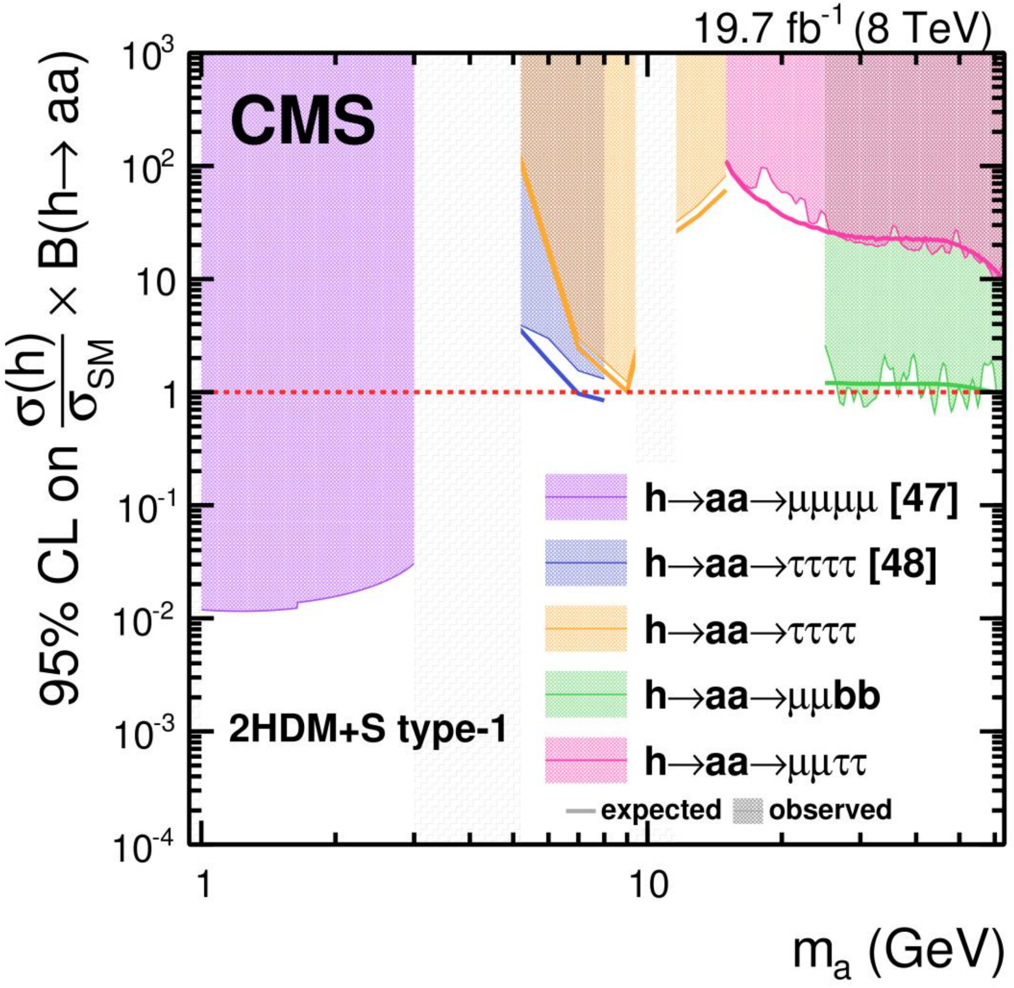
	M_{col}-fit	BDT-fit
$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	$< 2.05 \times 10^{-3}$	$< 1.43 \times 10^{-3}$
$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	$< 2.45 \times 10^{-3}$	$< 2.26 \times 10^{-3}$

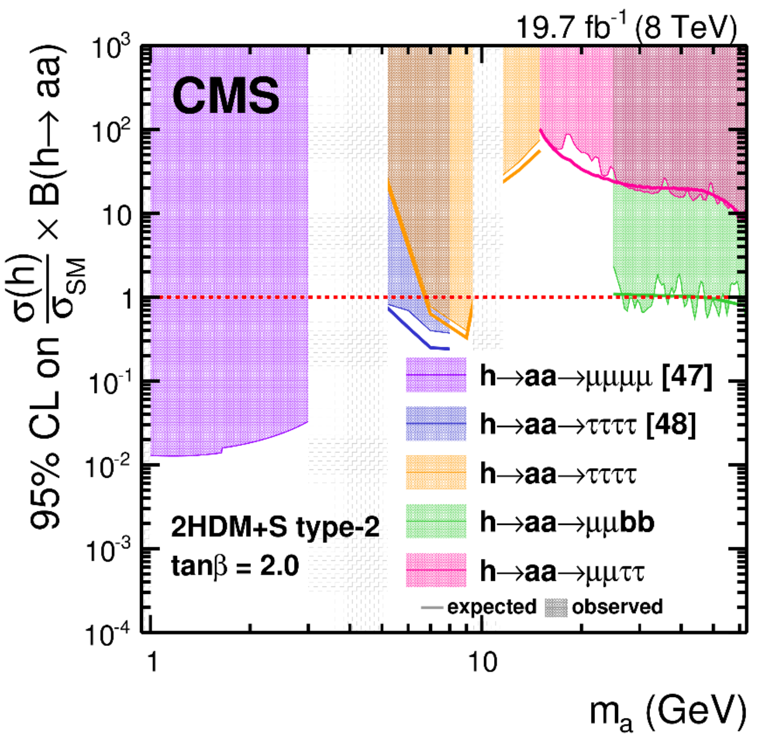
CMS-PAS-HIG-17-001

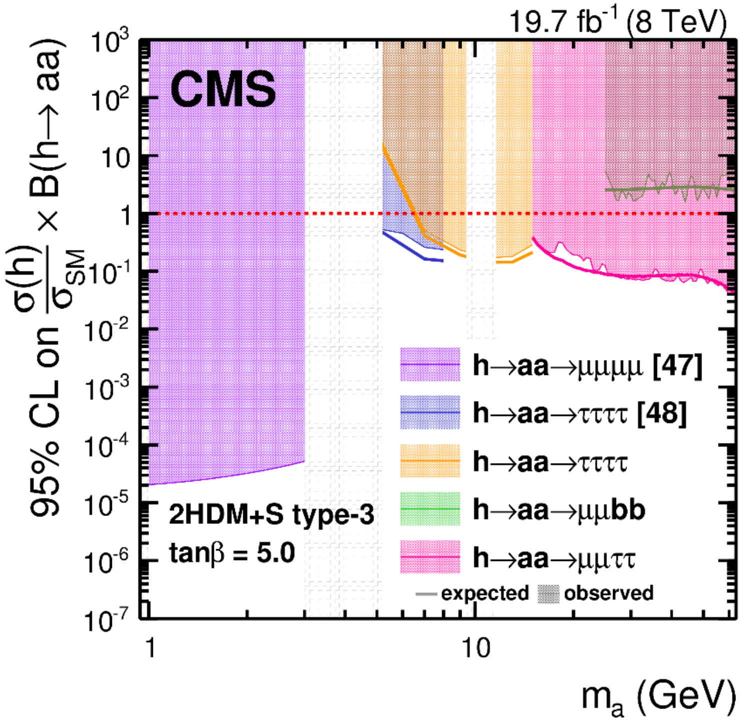




Joint interpretation of H→aa searches (more)







2HDM + S summary

CMS-PAS-HIG-16-15