LEPTON FLAVOUR VIOLATING DECAYS OF THE HIGGS AT THE LHC

María Cepeda on behalf of ATLAS and CMS

Higgs Tasting 2016, Benasque, Spain

Why search for BSM Higgs?

The Run I of the LHC brought the discovery of a new particle, and opened the quest for understanding its properties and decays, in the SM context, and beyond.

Is the new boson *really* the *minimal* SM Higgs?

- Is the ***signal strength***, where seen, at the expected SM level?
- Is this a ***scalar***, and not a pseudo-scalar or tensor?
- Does it ***couple*** to the SM particles at correct level? t,b,τ,μ
- Does it ***couple to itself*** ?
- Is this the ***only*** new non-vector boson, and not one of several?
- Does it ***couple*** unusually ?

Why search for LFV Higgs?

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- **Does it *couple* unusually ?**

Outline

Brief Introduction	LFV Lepton Couplings
	SM Higgs to leptons
	Quark Couplings
LFV Higgs Searches	CMS $H \to ll'$ searches
	ATLAS $H \to ll'$ searches
	Discussion of results
	Current limits on the couplings
LFV Z Searches	$Z \to ll'$ searches
	Current limits on the couplings
FCNC Searches	$t \to Hc(u)$ searches
	Current limits on the couplings

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Exploring the Flavour Sector

- New physics could arise from unexpected corners
- Exploring the Flavor sector can hold surprises:
  - BSM models such as double Higgs models or extra dimensions allow LFV decays of the boson (for instance, to a $\mu\tau$ pair)

SM values

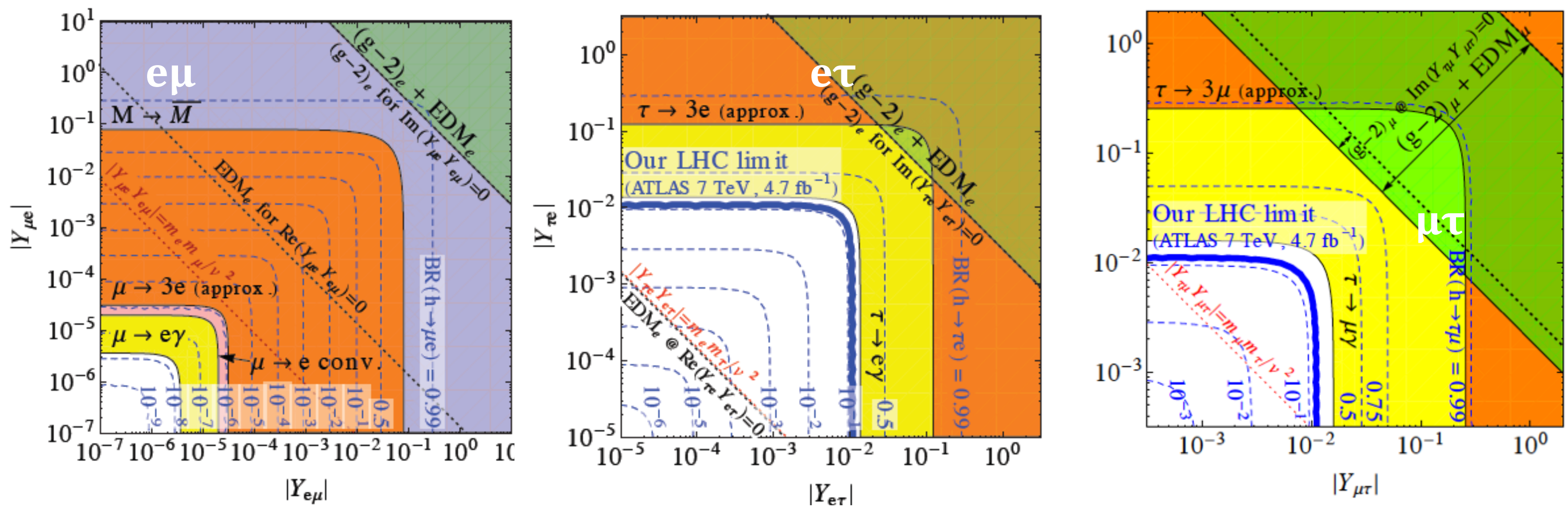
$$Y = \begin{pmatrix} \boxed{Y_{ee}} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & \boxed{Y_{\mu\mu}} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & \boxed{Y_{\tau\tau}} \end{pmatrix}$$

Probing all the values in the Higgs Yukawa matrix - not only the diagonal ones - should be one of the goals for the LHC Run II

Pre-LHC experimental bounds

Channel	Coupling	Bound Pre-LHC	Higgs Br Bound Pre-LHC (⋆)
$\mu \to e\gamma$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$3.6 \cdot 10^{-6}$	$\mathrm{Br}(H \to \mu e) \leq 10^{-8}$
$\tau \to e\gamma$	$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	0.016	$\mathrm{Br}(H \to e\tau) \leq 10\%$
$\tau \to \mu\gamma$	$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	0.014	$\mathrm{Br}(H \to \mu\tau) \leq 10\%$

⋆ In absence of other significant contributions, formalism from arXiv:1209.1397



R. Harnik, J. Kopp, J. Zupan,
arXiv:1209.1397

$$\mathrm{BR}(h \to \ell^\alpha \ell^\beta) = \frac{\Gamma(h \to \ell^\alpha \ell^\beta)}{\Gamma(h \to \ell^\alpha \ell^\beta) + \Gamma_{\mathrm{SM}}}$$

$Z \to ll'$ bounds before the LHC

- To have a coherent picture of LFV decays we should also explore the bounds on LFV decays of the Z
- Similar techniques can be applied to both studies

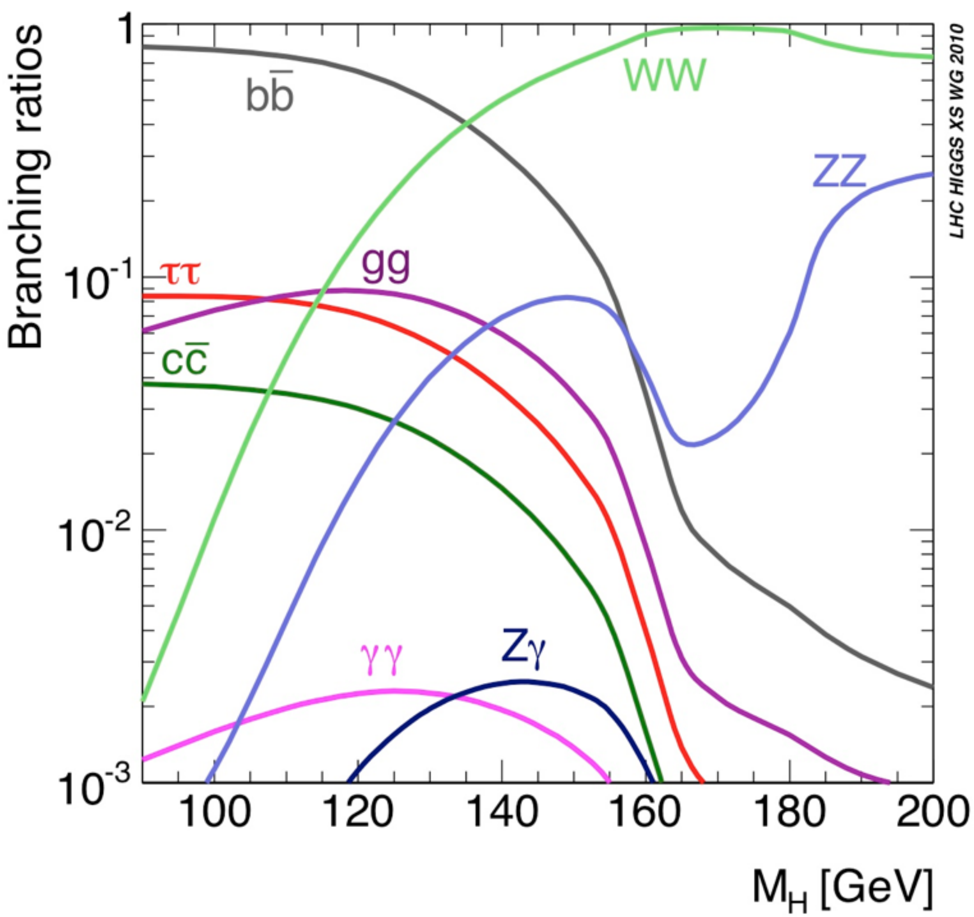
95% CL	$\mathrm{Br}(Z \to e\mu)$	$\mathrm{Br}(Z \to e\tau)$	$\mathrm{Br}(Z \to \mu\tau)$
LEP	$1.7 \cdot 10^{-6}$	$9.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$

OPAL Collaboration, R. Akers et al., *A Search for lepton flavor violating Z^0 decays*, Z. Phys. C **67** (1995) 555–564.

DELPHI Collaboration, P. Abreu et al., *Search for lepton flavor number violating Z^0 decays*, Z. Phys. C **73** (1997) 243–251.

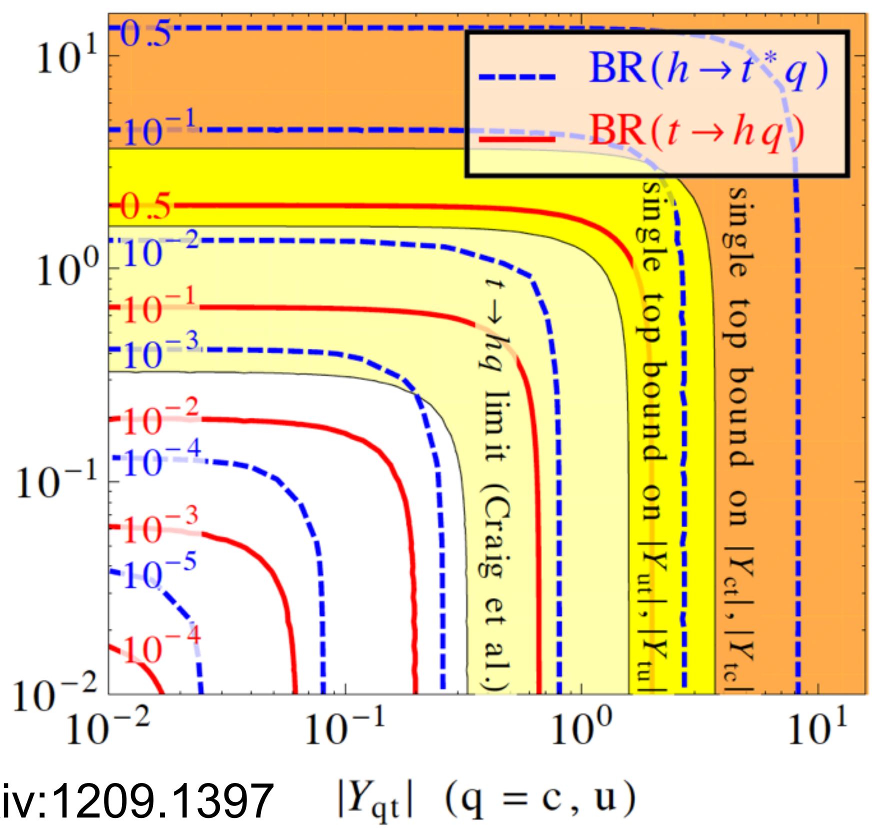
Small parenthesis: SM Lepton Decays

- The searches for LFV decays of the Higgs benefit from the techniques developed for the SM Hll analysis
- For a Higgs of 125 GeV, the SM prediction for lepton branching ratios is low:
  - BR(Hττ)=6.32%
  - BR(Hμμ)=0.0219%
  - BR(Hee)~5×10^{-9}
- Tau couplings will be probed in detail during Run II, Muon ones will necessitate the full Run II statistics to start being accessible if the SM prediction holds



Couplings to quarks

- This talk will mostly focus on off-diagonal leptonic Higgs decays
- This is however not all: we should also consider couplings to quarks



arXiv:1209.1397

Both CMS and ATLAS have a program to study these processes through top decays

SM:
$Br(t \to Hc) \sim 10^{-15}$
$Br(t \to Hu) \sim 10^{-17}$

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CMS: Hμτ and Heτ

- Similar strategy for Hμτ and Heτ
- 2 channels ($l\tau_{had}$, $l\tau_{l'}$), 3 categories (0-1-2 Jets)

- **Two-staged selection**:
  - a first loose selection (2 OS isolated leptons, richer in Zττ) to prove the background modelling techniques work
  - plus a tight, signal enriched one on which the measurement is based
  - final selection driven by pt cuts and angular correlations (more later)

- Signal extraction through a loglikelihood fit **to the collinear mass** distribution of the lτ candidate, done simultaneously for the six categories for each channel
  - The collinear mass is derived from the visible mass of the tau-light lepton system, correcting by the fraction of the energy carried by the visible decay products of the tau:

$$\mathrm{M_{col}} = \mathrm{M_{vis}} / \sqrt{x_{\tau}^{\mathrm{vis}}} \qquad x_{\tau}^{\mathrm{vis}} = p_{\mathrm{T}}^{\tau^{\mathrm{vis}}} / (p_{\mathrm{T}}^{\tau^{\mathrm{vis}}} + p_{\mathrm{T}}^{\nu,\,\mathrm{est}})$$

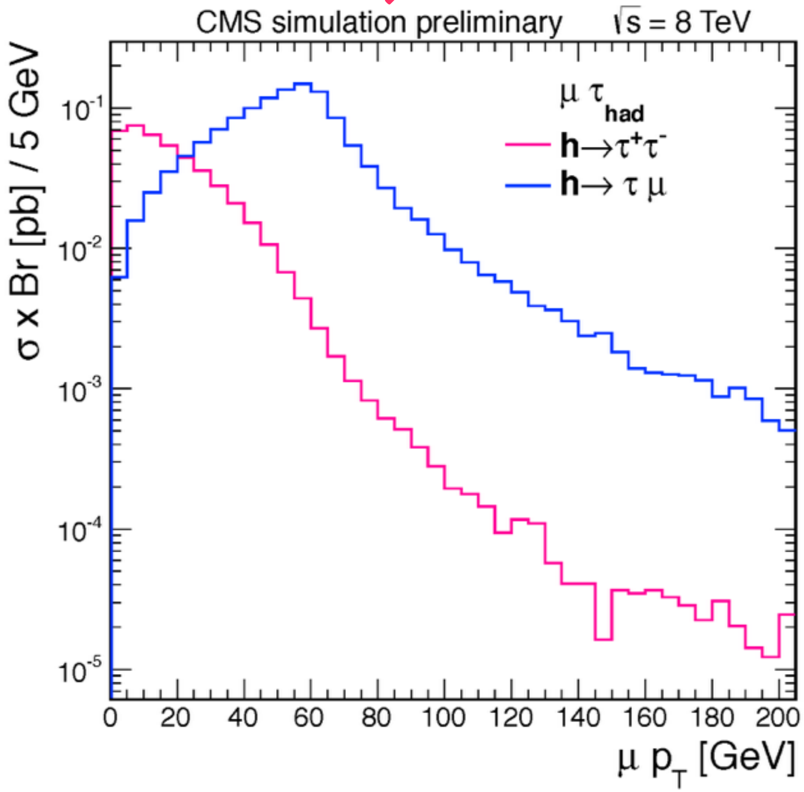
- Leading systematic uncertainties: background modelling

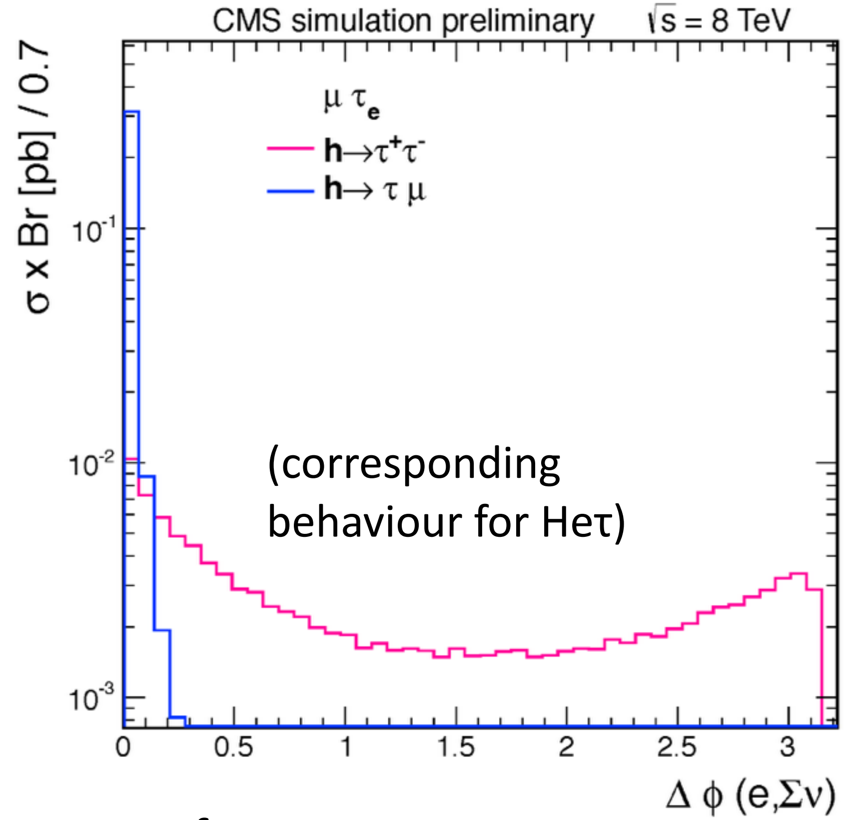
CMS (μτ):
Phys. Lett. B 749 (2015) 337

CMS (eτ):
HIG-14-040

Comparison of Kinematics

H→ ττ vs. H→μτ

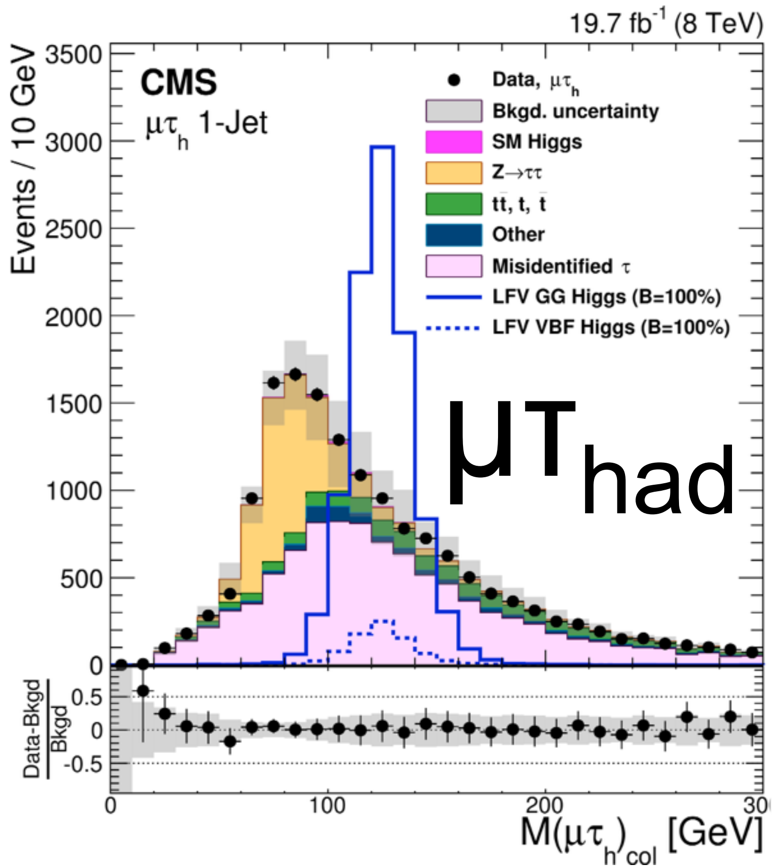


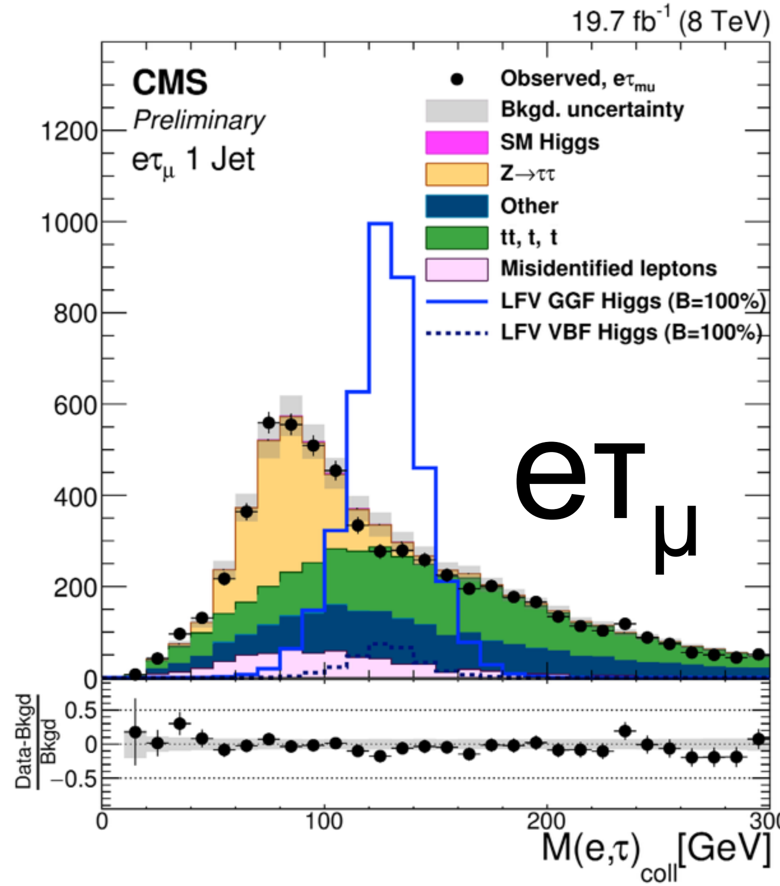


Exploit differences in event topology

- Harder P_T spectrum of muons
- Different angular correlations:
  - Electron/Tau_{had} – Neutrinos → ~ Collinear
  - Muon - Neutrinos → ~ back to back

CMS: Hμτ and Heτ

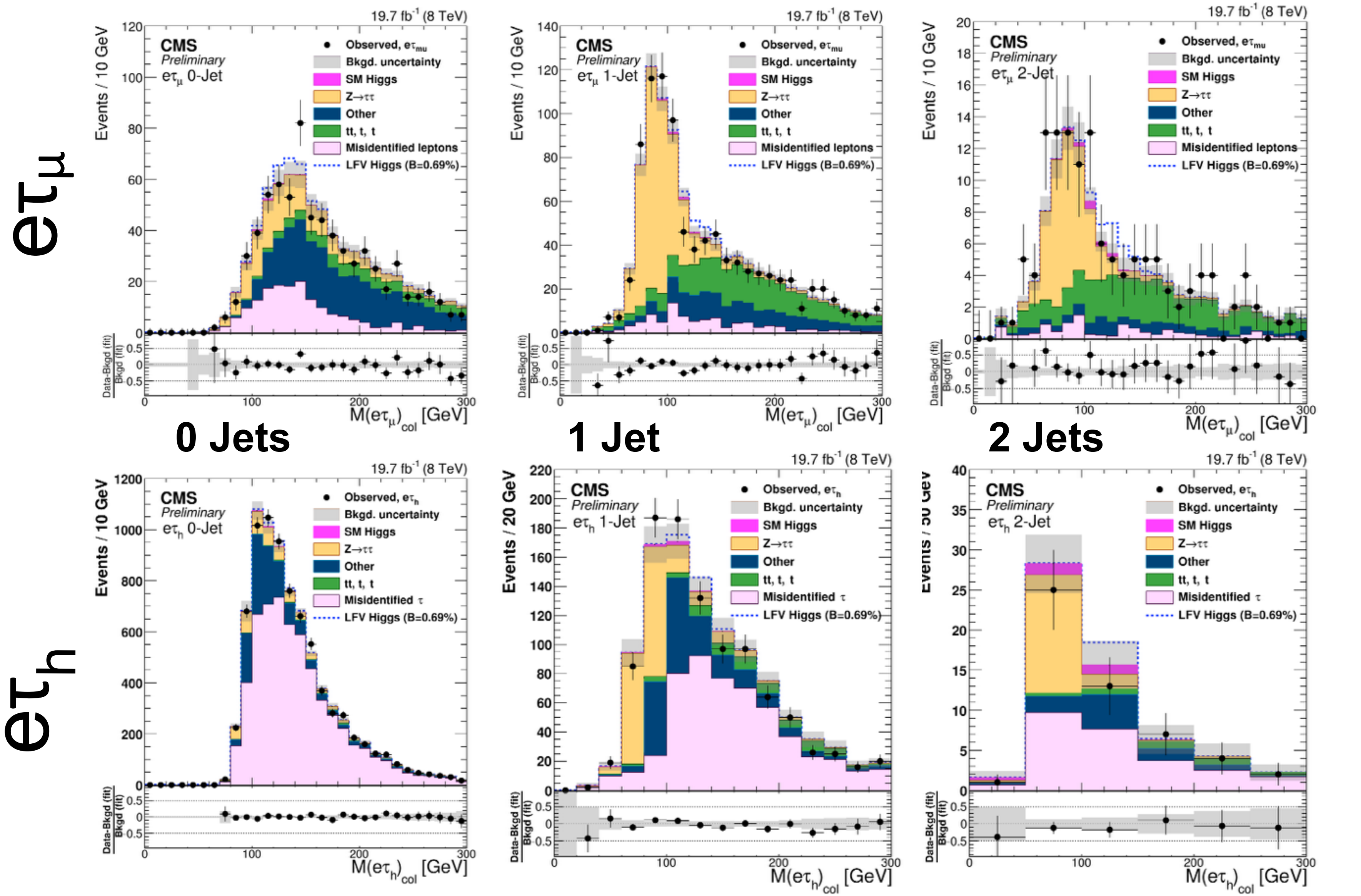




Leading backgrounds:

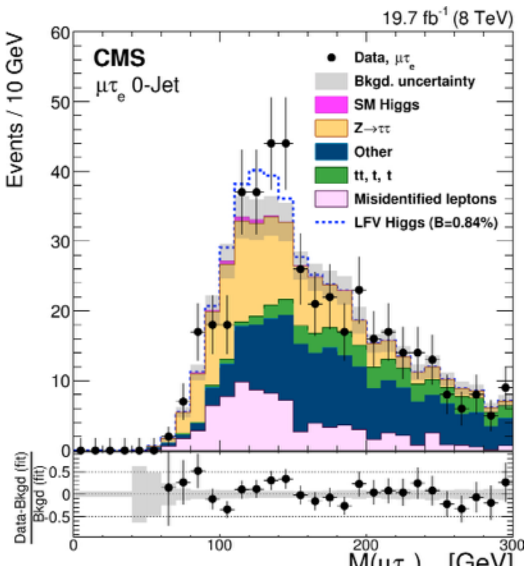
- HTauTau
- ZTauTau → **Tau-Embedding technique**
- SM backgrounds with real tau decays: top, VV → from MC
- Misidentifed Leptons (e, mu, tau) → from data

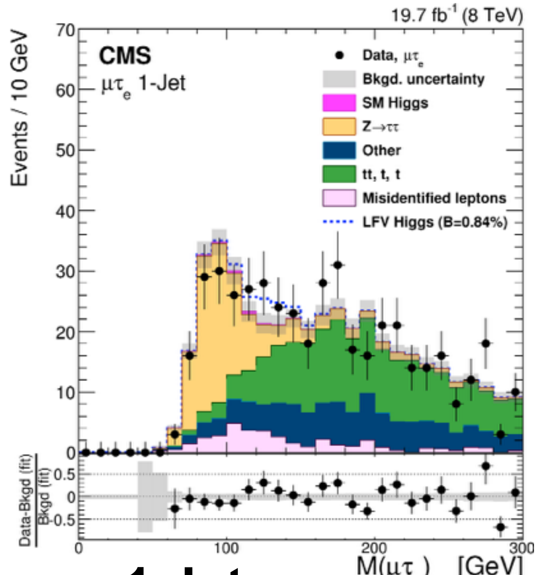
Heτ: Collinear Mass after selection

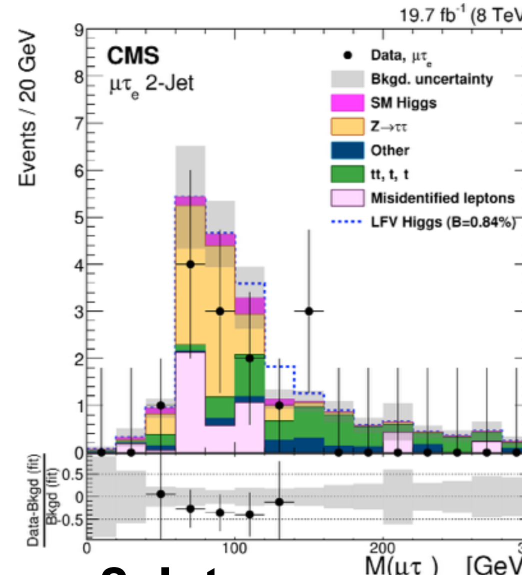


Hμτ: Collinear Mass after selection

$\mu\tau_e$

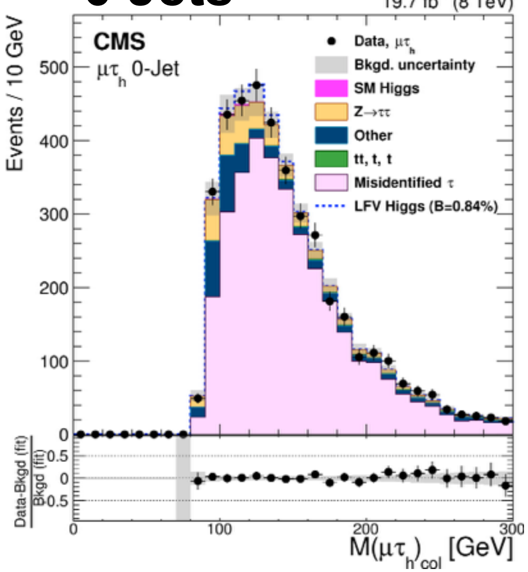


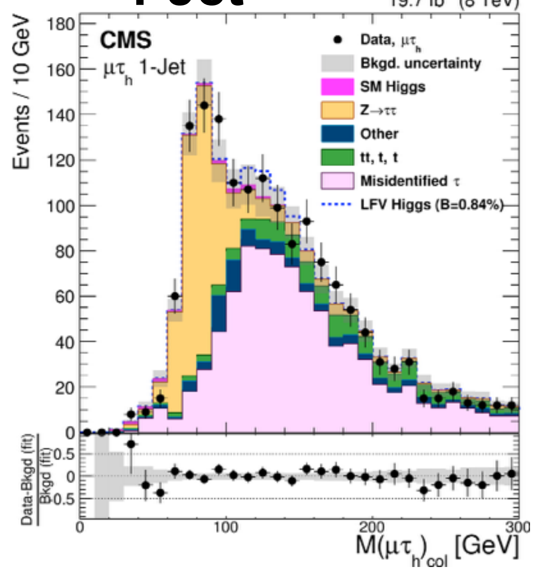


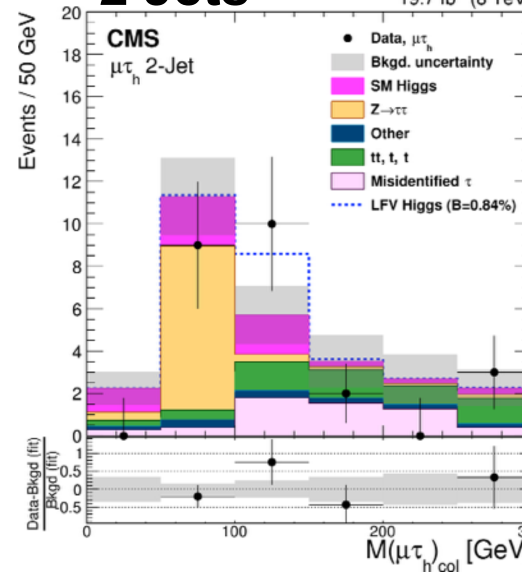


0 Jets **1 Jet** **2 Jets**

$\mu\tau_h$







ATLAS: Hμτ and Heτ

- Similar strategy for Hμτ and Heτ
- **Selection starts with two OS, isolated leptons:**
  - Final selection also driven by pt cuts and angular correlations
  - **Hadronic channels:**
    - 2 categories per analysis (low and high M_T)
    - Template fit to the **MMC (Missing Mass Calculator)** distributions
      - MMC observable is based on the scanning of the likelihood probability, given the kinematic inputs and MET resolution.
    - This simultaneous fit includes a W and a Top control region
  - **Leptonic channels:**
    - 2 for $l\tau_l$ (with and without jets)
    - Template it to the **collinear mass** distribution
  - Final combined fit to all categories to give the final limit

ATLAS: arXiv:1604.07730

ATLAS: JHEP11(2015)211

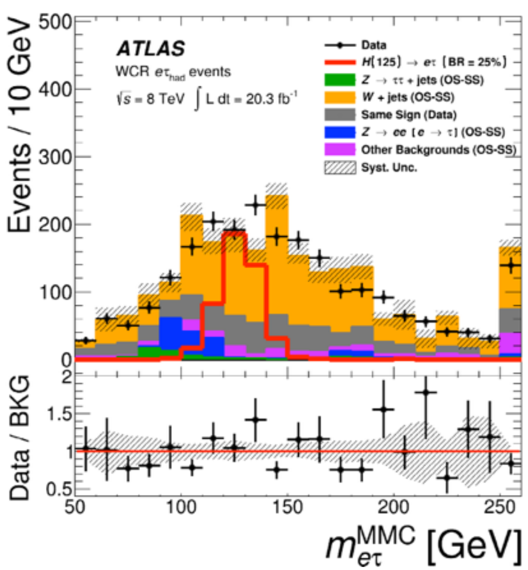
Background Control

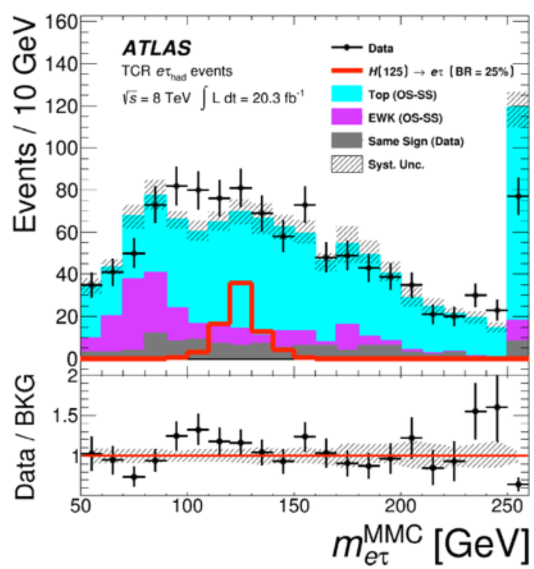
Hadronic channels:

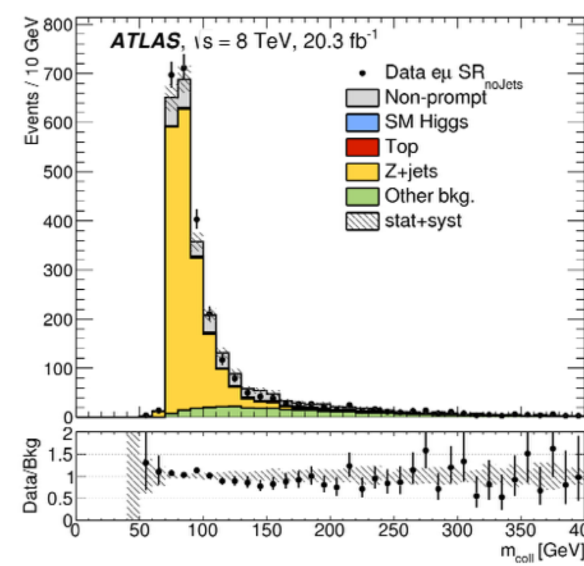
- Ws, Zs, Top, and other minor MC are modelled from MonteCarlo (using only the OS-SS fraction of the simulated prediction)
- QCD events are modelled using directly the SS distributions on data, with a yield correction to account for SS/OS effects, and after removing W/Z/TOP/EWK contamination in SS

Leptonic channels:

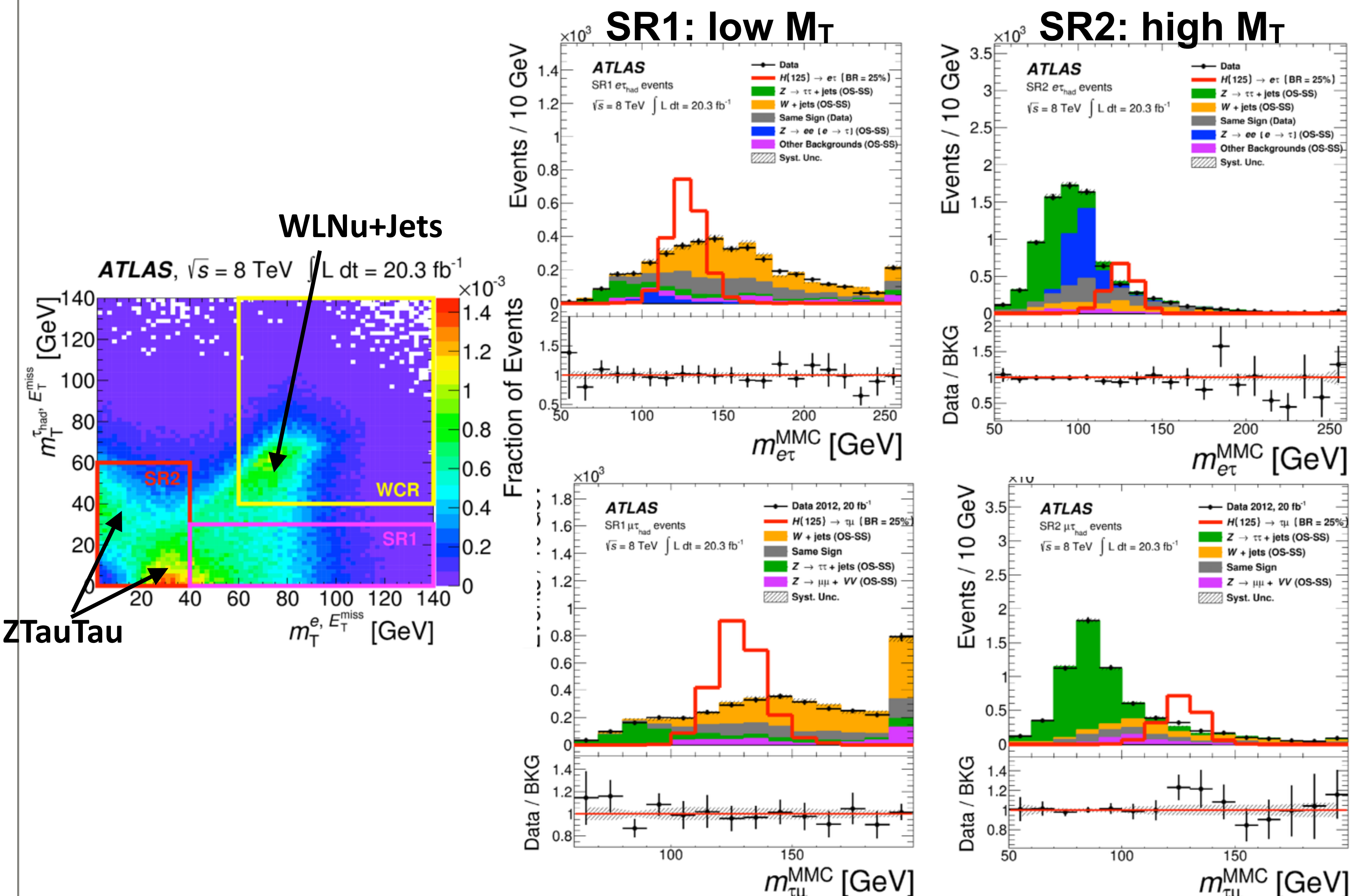
- Background shape derived from data benefitting from symmetric behaviour of SM backgrounds and the inherent asymmetry in LFV decays







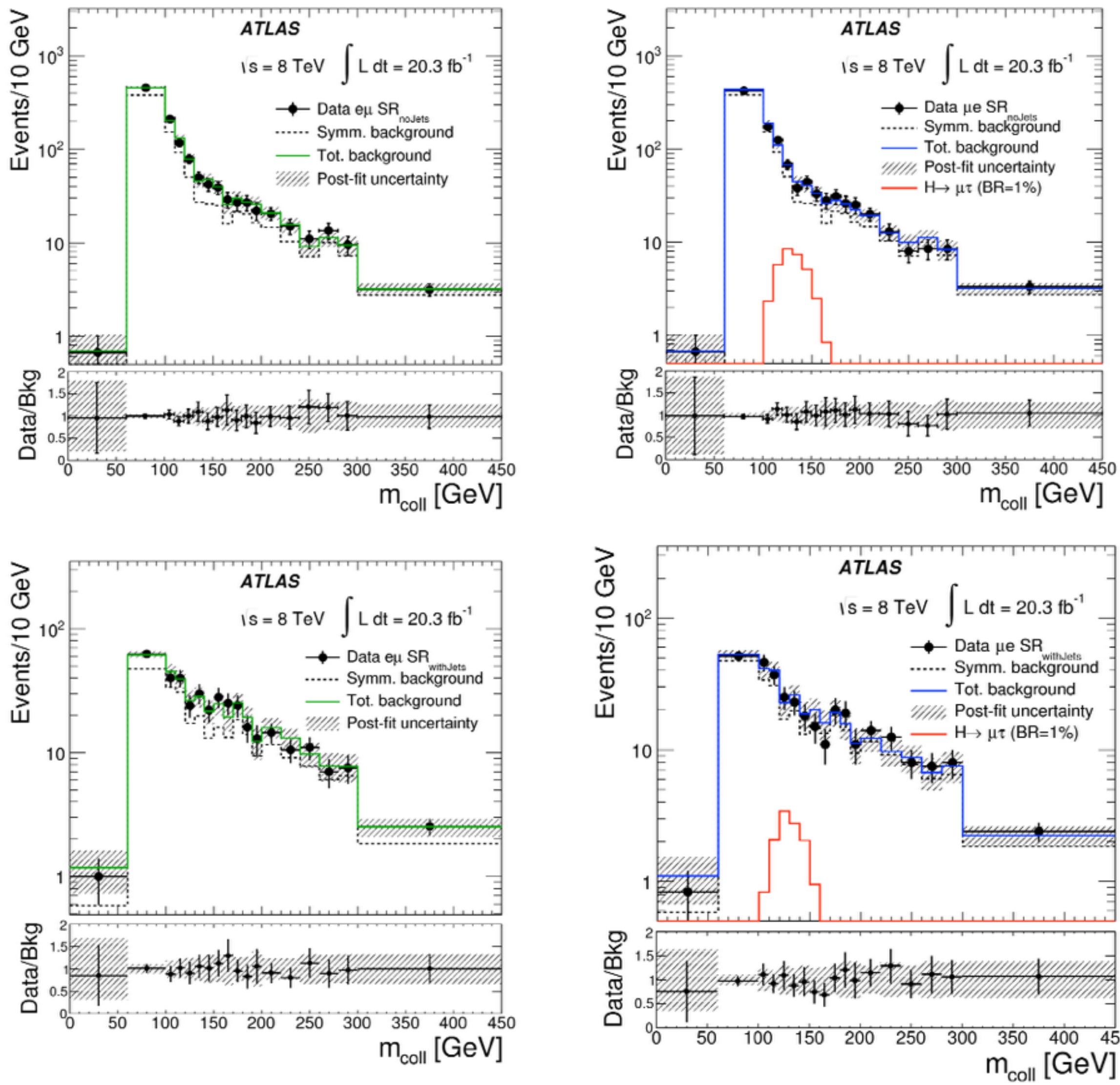
$Hl\tau_{had}$ channels



$Hl\tau_{l'}$ channels

$He\tau_{\mu}$

$H\mu\tau_{e}$



Comparison of Selection Criteria

Hμτ

CMS

Variable [GeV]	$H \to \mu\tau_e$ 0-jet	$H \to \mu\tau_e$ 1-jet	$H \to \mu\tau_e$ 2-jet	$H \to \mu\tau_h$ 0-jet	$H \to \mu\tau_h$ 1-jet	$H \to \mu\tau_h$ 2-jet
$p_T^\mu >$	50	45	25	45	35	30
$p_T^e >$	10	10	10	—	—	—
$p_T^\tau >$	—	—	—	35	40	40
$M_T^e <$	65	65	25	—	—	—
$M_T^\mu >$	50	40	15	—	—	—
$M_T^\tau <$	—	—	—	50	35	35
[radians]						
$\Delta\phi_{\vec{p}_T^\mu - \vec{p}_T^{\tau_h}} >$	—	—	—	2.7	—	—
$\Delta\phi_{\vec{p}_T^e - \vec{E}_T^{miss}} <$	0.5	0.5	0.3	—	—	—
$\Delta\phi_{\vec{p}_T^e - \vec{p}_T^\mu} >$	2.7	1.0	—	—	—	—

VBF: $|\Delta\eta|>3.5$ and $M_{jj} > 550$ GeV

ATLAS

Cut	SR1	SR2	WCR	TCR
$p_T(\mu)$	>26 GeV	>26 GeV	>26 GeV	>26 GeV
$p_T(\tau_{had})$	>45 GeV	>45 GeV	>45 GeV	>45 GeV
$m_T(\mu, E_T^{miss})$	>40 GeV	<40 GeV	>60 GeV	–
$m_T(\tau_{had}, E_T^{miss})$	<30 GeV	<60 GeV	>40 GeV	–
$\|\eta(\mu) - \eta(\tau_{had})\|$	<2	<2	<2	<2
N_{jet}	–	–	–	>1
N_{b-jet}	0	0	0	>0

	SR_{noJets}	$SR_{withJets}$
Light leptons	$e^\pm\mu^\mp$	$e^\pm\mu^\mp$
τ leptons	veto	veto
Central jets	0	≥ 1
b-jets	0	0
$p_T^{\ell_1}$	$\geq 35GeV$	$\geq 35GeV$
$p_T^{\ell_2}$	$\geq 12GeV$	$\geq 12GeV$
$\|\eta^e\|$	≤ 2.4	≤ 2.4
$\|\eta^\mu\|$	≤ 2.4	≤ 2.4
$\Delta\phi(\ell_2, E_T^{miss})$	≤ 0.7	≤ 0.5
$\Delta\phi(\ell_1, \ell_2)$	≥ 2.3	≥ 1.0
$\Delta\phi(\ell_1, E_T^{miss})$	≥ 2.5	≥ 1.0
$\Delta p_T(\ell_1, \ell_2)$	$\geq 7GeV$	$\geq 1GeV$

Higher threshold the muon for the CMS analysis both for leptonic and hadronic channels

M_T categorization in ATLAS hadronic analysis

Tighter angular selection in ATLAS leptonic analysis

Comparison of Selection Criteria

Hετ

CMS

Variable		$H \to e\tau_\mu$ 0-jet	$H \to e\tau_\mu$ 1-jet	$H \to e\tau_\mu$ 2-jet	$H \to e\tau_h$ 0-jet	$H \to e\tau_h$ 1-jet	$H \to e\tau_h$ 2-jet
p_T^e	(GeV)	> 50	> 40	> 40	> 45	> 35	> 35
p_T^μ	(GeV)	> 15	> 15	> 15	-	-	-
$p_T^{\tau_h}$	(GeV)	-	-	-	> 30	> 40	> 30
$M_T(\mu)$	(GeV)	-	< 30	< 40	-	-	-
$M_T(\tau_h)$	(GeV)	-	-	-	< 70	-	< 50
$\Delta\phi_{\vec{p}_{T,e}-\vec{p}_{T,\tau_h}}$	(radians)	-	-	-	> 2.3	-	-
$\Delta\phi_{\vec{p}_{T,\mu}-\vec{E}_T^{miss}}$	(radians)	< 0.8	< 0.8	-	-	-	-
$\Delta\phi_{\vec{p}_{T,e}-\vec{p}_{T,\mu}}$	(radians)	-	> 0.5	-	-	-	-

VBF: $|\Delta\eta| > 3.5$ and $M_{jj} > 550$ GeV

Higher threshold the electron for the CMS analysis both for leptonic and hadronic channels

M_T categorization in ATLAS hadronic analysis

Tighter angular selection in ATLAS leptonic analysis

ATLAS

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$E_T(e)$	>26 GeV	>26 GeV	>26 GeV	>26 GeV
$p_T(\tau_{had})$	>45 GeV	>45 GeV	>45 GeV	>45 GeV
$\lvert\eta(e) - \eta(\tau_{had})\rvert$	<2	<2	<2	<2
$m_T^{e,E_T^{miss}}$	>40 GeV	<40 GeV	>60 GeV	–
$m_T^{\tau_{had},E_T^{miss}}$	<30 GeV	<60 GeV	>40 GeV	–
N_{jet}	–	–	–	≥2
N_{b-jet}	0	0	0	≥1

	SR_{noJets}	$SR_{withJets}$
Light leptons	$e^\pm\mu^\mp$	$e^\pm\mu^\mp$
τ leptons	veto	veto
Central jets	0	≥ 1
b-jets	0	0
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$\lvert\eta^\mu\rvert$	≤ 2.4	≤ 2.4
$\Delta\phi(\ell_2, E_T^{miss})$	≤ 0.7	≤ 0.5
$\Delta\phi(\ell_1, \ell_2)$	≥ 2.3	≥ 1.0
$\Delta\phi(\ell_1, E_T^{miss})$	≥ 2.5	≥ 1.0
$\Delta p_T(\ell_1, \ell_2)$	$\geq 7GeV$	$\geq 1GeV$

2015 13 TeV dataset

- The dataset collected by CMS and ATLAS in 2015 is not large enough to surpass the 8TeV sensitivity

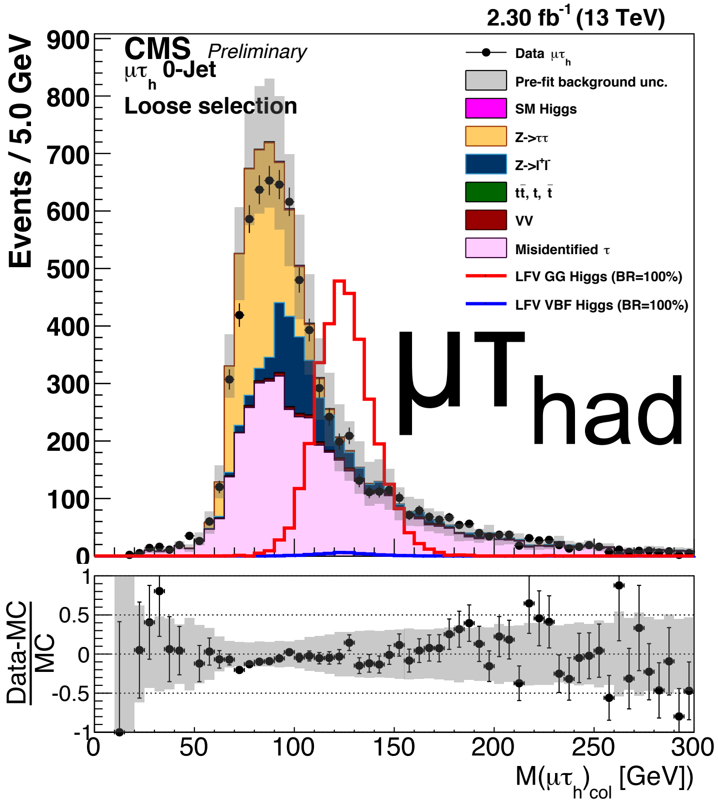
- CMS updated the Hμτ search using the 2015 dataset only - **2.3 fb^{-1}** - as a first step towards a full rerun of the LFV searches to be performed in 2016

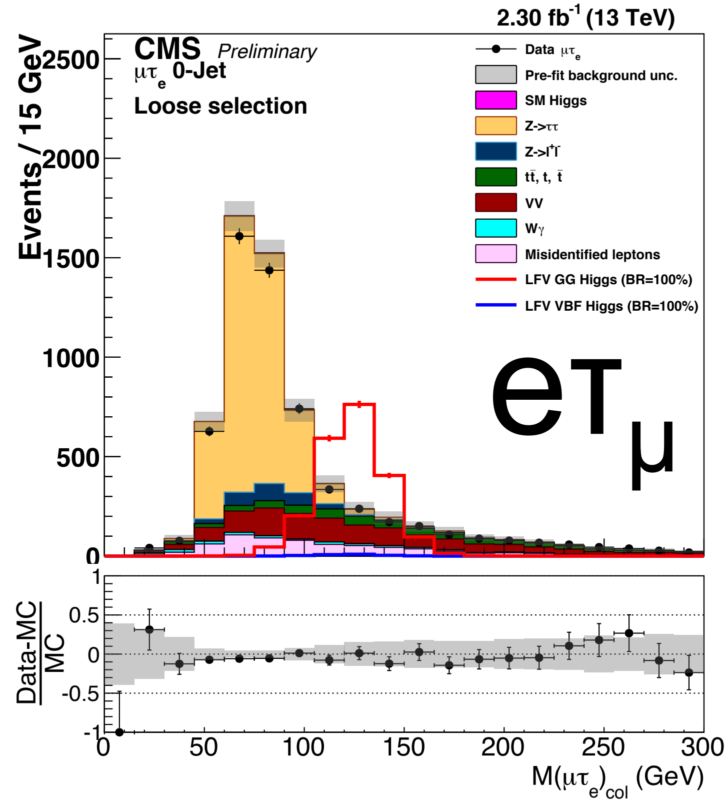
- Analysis strategy kept intentionally very close to Run I
  - Optimization @ 13 TeV will be done for 2016

CMS (New this week!): HIG-16-005

- Few changes:
  - Electron pt down to 10GeV
  - Looser 2Jet selection to account for smaller statistics
    - $|\Delta\eta|>3.5$, $M_{jj} > 200$ GeV, MTe > 40 , no ΔΦ(e,MET) restriction

Hμτ: Collinear Mass before selection





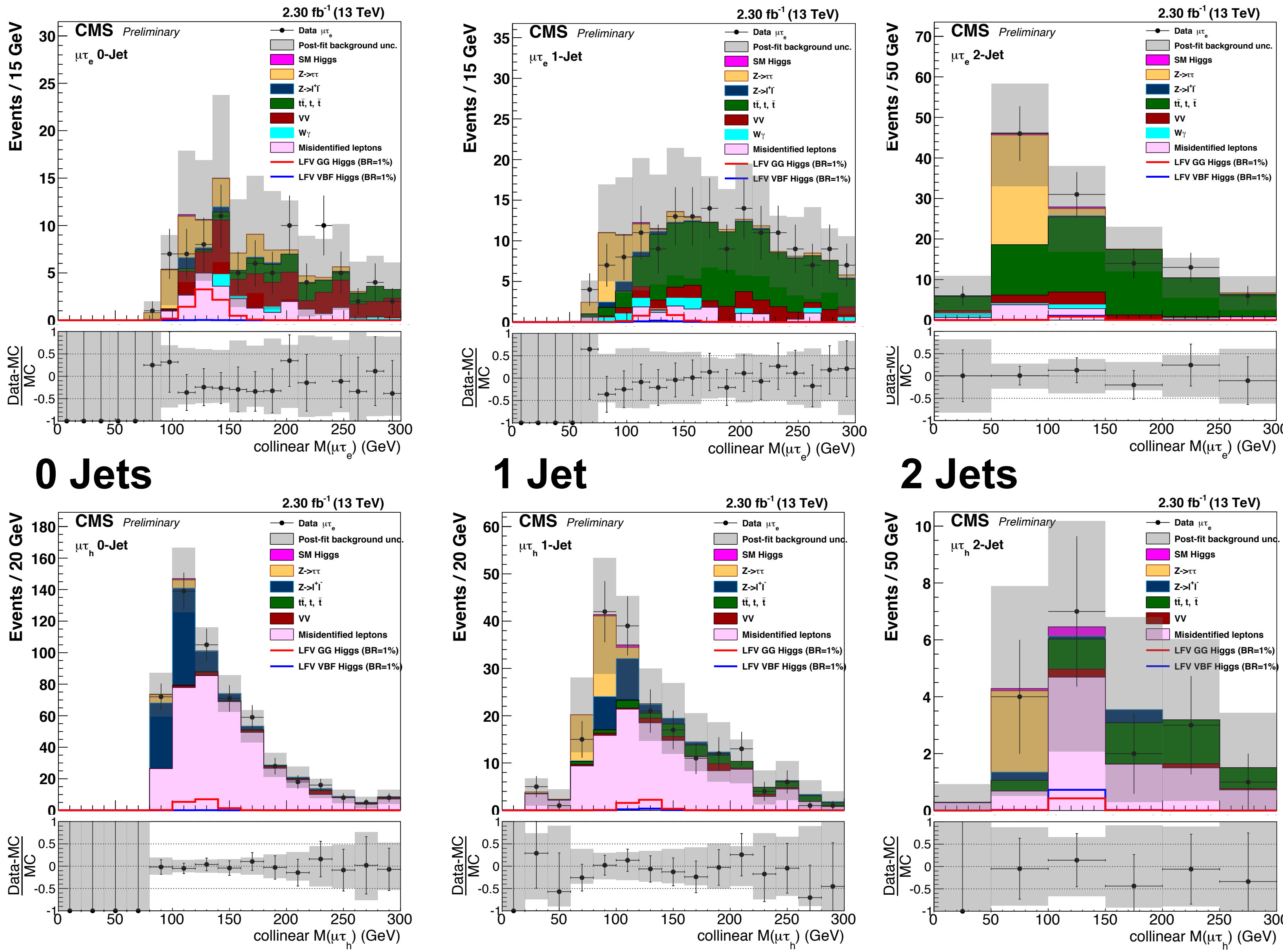
- Background modelling follows Run I techniques
  - Misidentified leptons from data
  - SM backgrounds with real tau decays from Monte Carlo
- Zττ modelled from Monte Carlo (embedding technique will be used again in the future)

Hμτ: Collinear Mass after selection

μτe

Notice the small statistics!

μτh



CMS Heμ

- Very clean in comparison - but targeting a very small Br!
- Backgrounds: TTbar/Diboson/DY tails
- **10 Categories** based on:
  - GGF vs VBF discrimination:
    - inclusive categories: 0-1-2 jets
    - VBF categories (tight/loose) following Hγγ
  - Barrel/Endcap leptons

- 1 Good, Isolated, High p_T **Electron**
- 1 Good, isolated, High p_T **Muon**
- Opposite charge of the **μe** Pair
- Veto on additional leptons
- Btagged Jets veto

	Category	Number of jets	Lepton p_T (GeV)	E_T^{miss} (GeV)	B-tag
0	EB-MB	0	> 25	< 30	-
1	EB-MB	1	> 22	< 30	< 0.38
2	EB-MB	2	> 25	< 25	$< 0.38, < 0.48$
3	EB-ME	0	> 20	< 30	-
4	EB-ME	1	> 22	< 20	< 0.48
5	EB-ME	2	> 20	< 30	$< 0.51, < 0.57$
6	EE-(MB or ME)	0	> 20	< 30	-
7	EE-(MB or ME)	1	> 22	< 20	< 0.48
8	EE-(MB or ME)	2	> 20	< 30	$< 0.51, < 0.57$
	VBF				
9	Tight	2	> 22	< 30	$< 0.58, < 0.244$
10	Loose	2	> 22	< 25	$< 0.62, < 0.30$

CMS: HIG-14-040

Background composition

- Very clean search comparison to Hlτ
- non-LHC limits already constrain the Br tightly

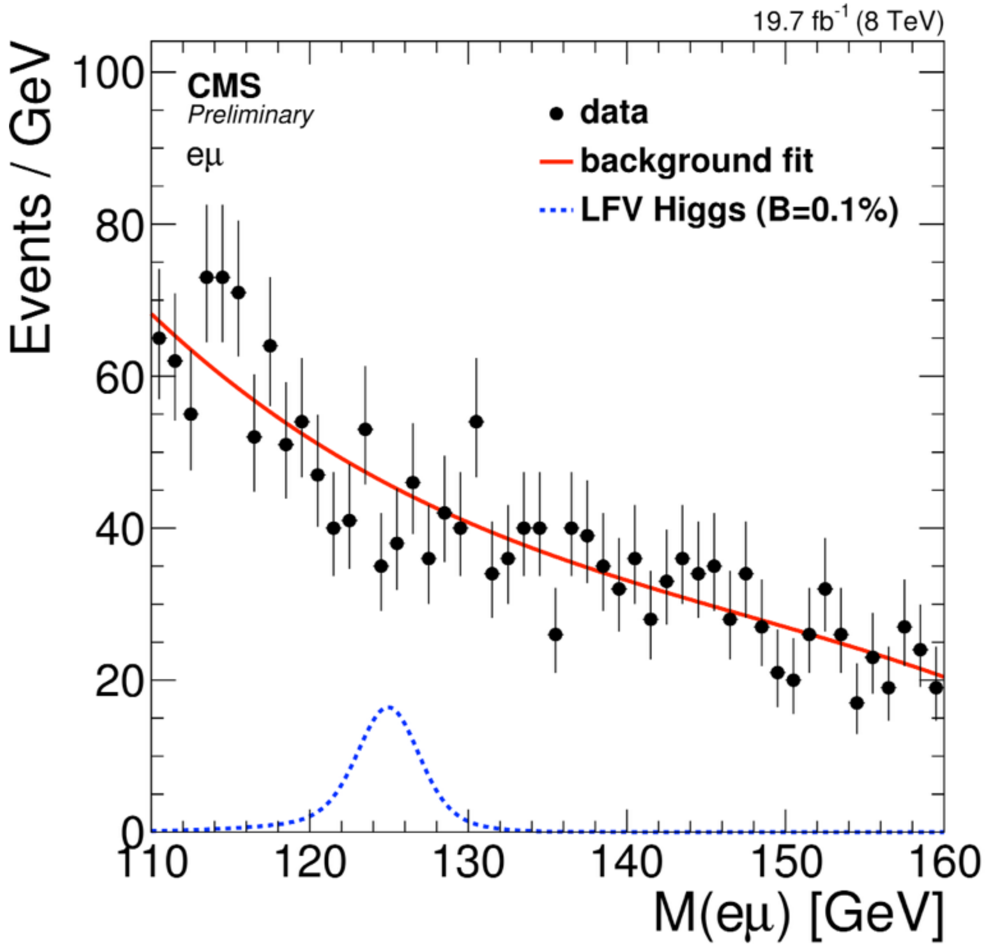
$124 < M_{e\mu} < 126$ GeV

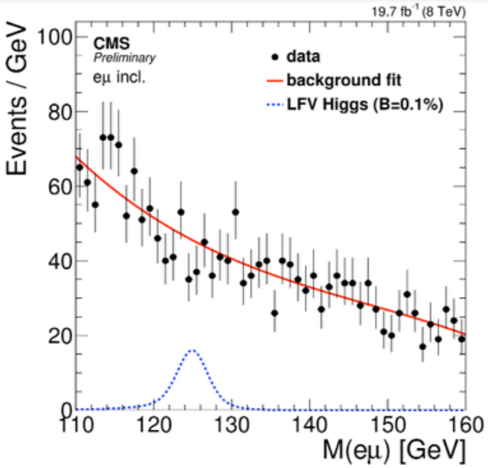
Jet category:	0-Jet	1-Jet	2-Jet	VBF
Drell-Yan	17.8 ± 4.2	4.1 ± 2.0	1.9 ± 1.4	0.0 ± 0.0
$t\bar{t}$	1.4 ± 1.2	3.1 ± 1.8	14.1 ± 3.8	0.4 ± 0.6
$t, \bar{t}$	0.0 ± 0.0	0.0 ± 0.0	2.7 ± 1.6	0.0 ± 0.0
EWK diboson	21.6 ± 4.7	2.3 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
SM Higgs boson background	0.0 ± 0.0	0.1 ± 0.2	0.0 ± 0.0	0.0 ± 0.0
Sum of backgrounds	40.8 ± 6.4	9.6 ± 3.1	18.8 ± 4.3	0.5 ± 0.7
Observed	49	6	17	2
(Data-BG)/Uncert(BG)	1.3	-1.2	-0.4	2.2
LFV Higgs boson signal (B=1%)	21.2 ± 4.6	9.1 ± 3.0	2.6 ± 1.6	1.5 ± 1.2

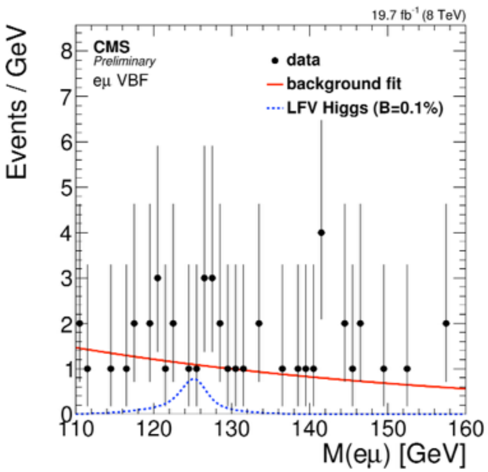
targeting $Br<10^{-4}$

Signal Extraction

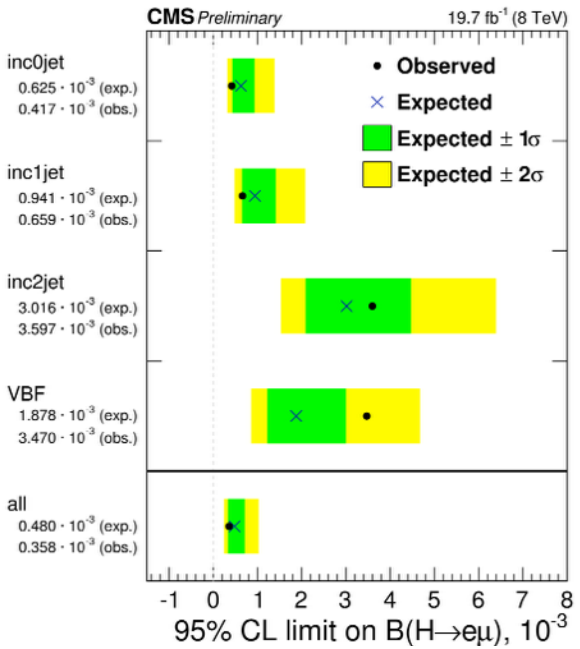
Signal Extraction through a fit to the invariant mass distribution:
Background: Modelled by a combination of polynomials
Signal: Modelled using two gaussians

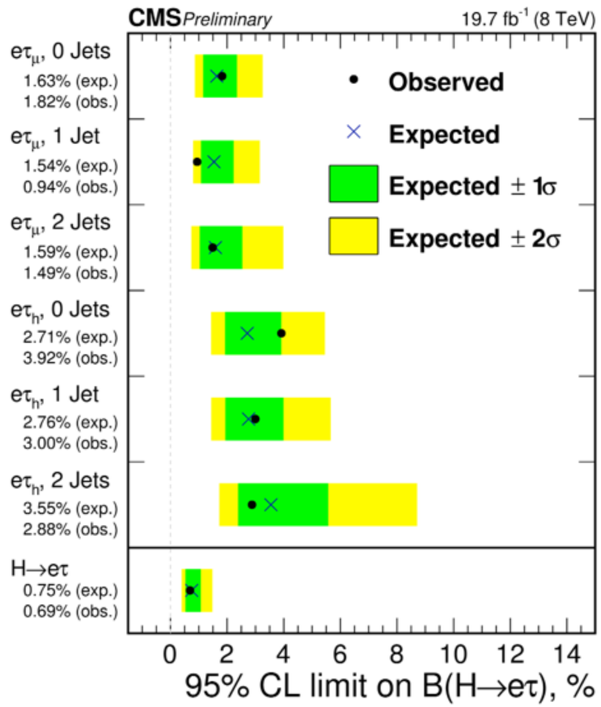


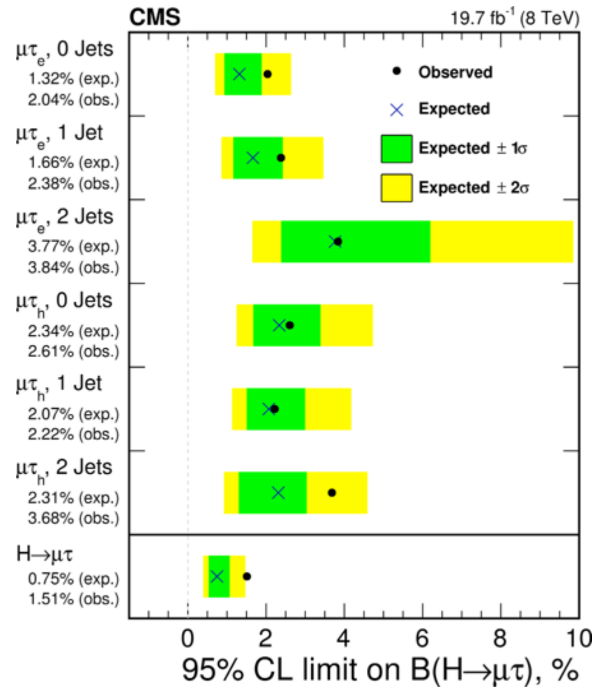




CMS: Run I 95%CL Limits







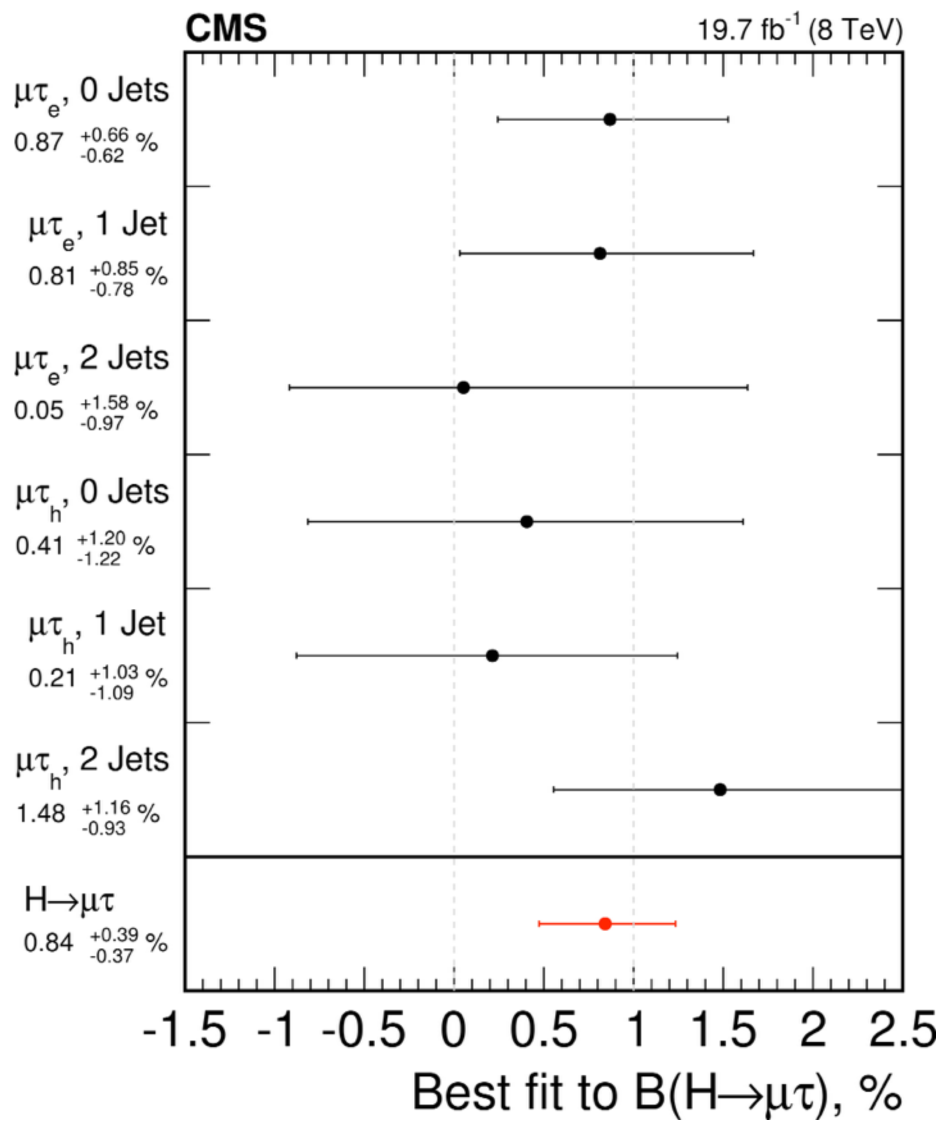
Br(H→eμ)<0.36e-3 (0.48e-3 expected)

Br(H→eτ)<0.69% (0.75% expected)

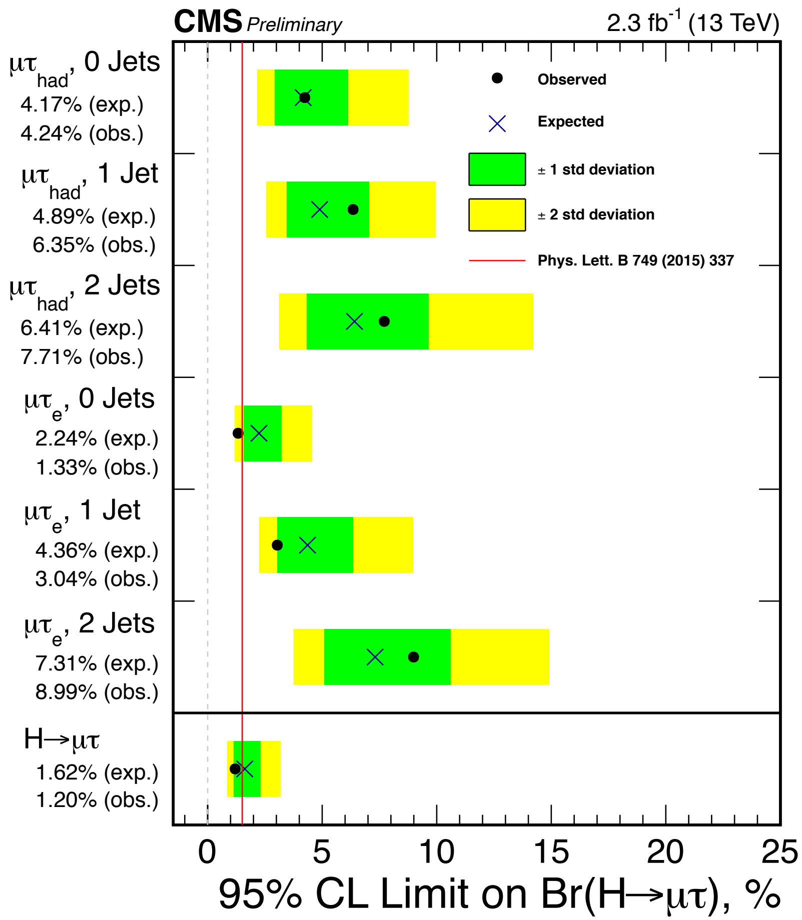
Br(H→μτ)<1.51% (0.75% expected)

CMS: Run I Best Fit

- Small deviations per category (at most ~1sigma)
- Hemu and Heτ fits compatible with 0



CMS: Run II First Look

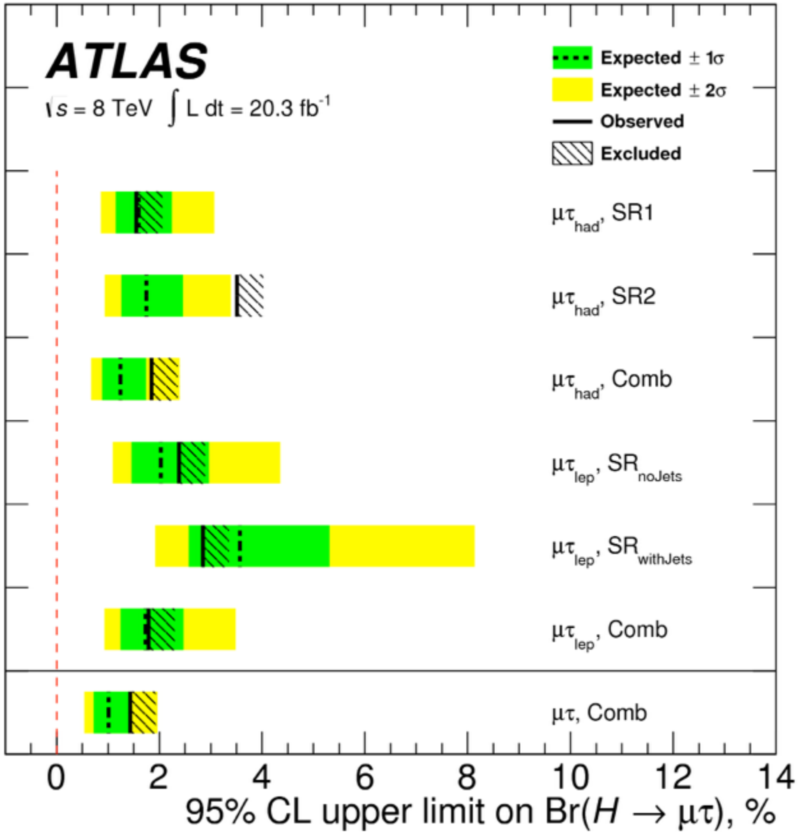


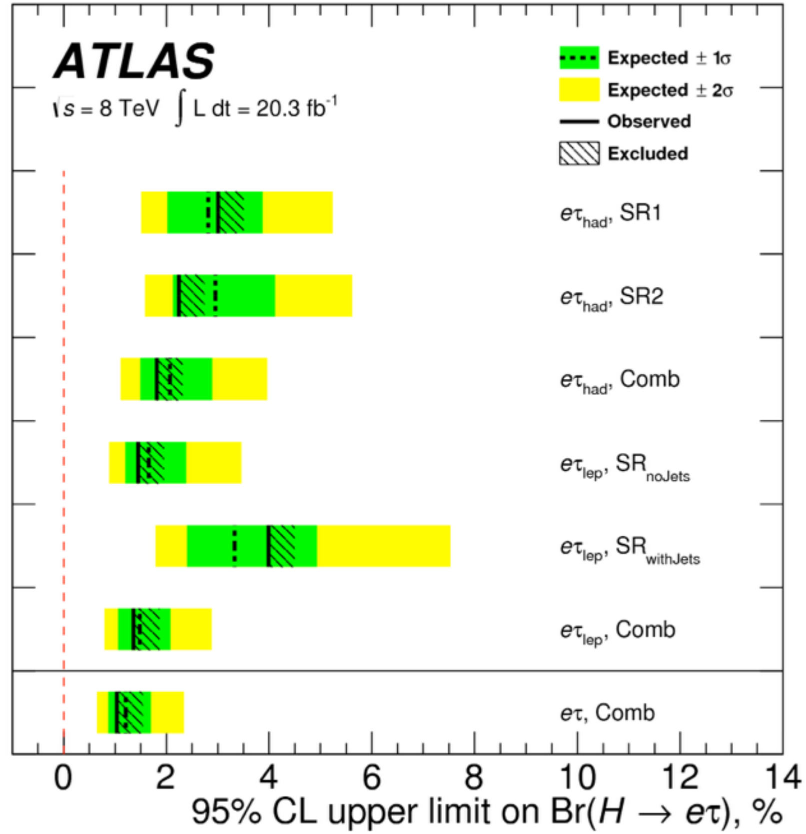
Expected limits				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	<4.17	<4.89	<6.41	<2.98
$\mu\tau_e$	<2.24	<4.36	<7.31	<1.96
$\mu\tau$	<1.62 %			
Observed limits				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	<4.24	<6.35	<7.71	<3.81
$\mu\tau_e$	<1.33	<3.04	<8.99	<1.15
$\mu\tau$	<1.20 %			
Best-fit branching fractions				
	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
$\mu\tau_h$	$0.12^{+2.02}_{-1.91}$	$1.70^{+2.41}_{-2.52}$	$1.54^{+3.12}_{-2.71}$	$1.12^{+1.45}_{-1.40}$
$\mu\tau_e$	$-2.11^{+1.30}_{-1.89}$	$-2.18^{+1.99}_{-2.05}$	$2.04^{+2.96}_{-3.31}$	$-1.81^{+1.07}_{-1.32}$
$\mu\tau$	$-0.76^{+0.81}_{-0.84}$%			

Br(H→μτ)<1.20% (1.62% expected)

- No excess observed, but not sensitive enough to exclude the 8TeV result

ATLAS: 95%CL Limits





Br(H→eτ)<1.04% (1.21% expected)

Br(H→μτ)<1.43% (1.01% expected)

Comparison of Results for H→μτ

CMS

8TeV

	0-Jet (%)	1-Jet (%)	2-Jets (%)
Expected Limits			
$\mu\tau_e$	<1.32 (±0.67)	<1.66 (±0.85)	<3.77 (±1.92)
$\mu\tau_h$	<2.34 (±1.19)	<2.07 (±1.06)	<2.31 (±1.18)
$\mu\tau$	<0.75 (±0.38)		
Observed Limits			
$\mu\tau_e$	<2.04	<2.38	<3.84
$\mu\tau_h$	<2.61	<2.22	<3.68
$\mu\tau$	<1.51		
Best Fit Branching Fractions			
$\mu\tau_e$	$0.87^{+0.66}_{-0.62}$	$0.81^{+0.85}_{-0.78}$	$0.05^{+1.58}_{-0.97}$
$\mu\tau_h$	$0.41^{+1.20}_{-1.22}$	$0.21^{+1.03}_{-1.09}$	$1.48^{+1.16}_{-0.93}$
$\mu\tau$	$0.84^{+0.39}_{-0.37}$		

2015 data

	0-jet (%)	1-jet (%)	2-jets (%)	Combined (%)
Expected limits				
$\mu\tau_h$	<4.17	<4.89	<6.41	<2.98
$\mu\tau_e$	<2.24	<4.36	<7.31	<1.96
$\mu\tau$	<1.62 %			
Observed limits				
$\mu\tau_h$	<4.24	<6.35	<7.71	<3.81
$\mu\tau_e$	<1.33	<3.04	<8.99	<1.15
$\mu\tau$	<1.20 %			
Best-fit branching fractions				
$\mu\tau_h$	$0.12^{+2.02}_{-1.91}$	$1.70^{+2.41}_{-2.52}$	$1.54^{+3.12}_{-2.71}$	$1.12^{+1.45}_{-1.40}$
$\mu\tau_e$	$-2.11^{+1.30}_{-1.89}$	$-2.18^{+1.99}_{-2.05}$	$2.04^{+2.96}_{-3.31}$	$-1.81^{+1.07}_{-1.32}$
$\mu\tau$	$-0.76^{+0.81}_{-0.84}$ %			

ATLAS, 8TeV

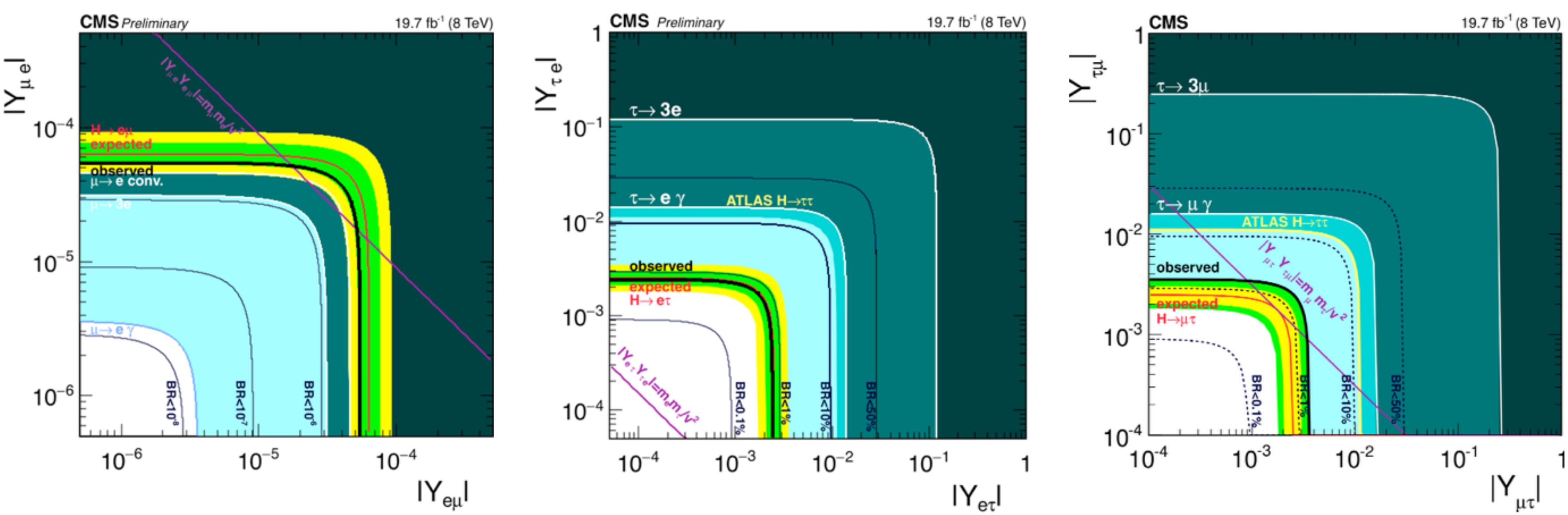
Channel	Category	Expected limit [%]	Observed limit [%]	Best fit Br [%]
$H \to e\tau_{had}$	SR1	$2.81^{+1.06}_{-0.79}$	3.0	$0.33^{+1.48}_{-1.59}$
	SR2	$2.95^{+1.16}_{-0.82}$	2.24	$-1.33^{+1.56}_{-1.80}$
	Combined	$2.07^{+0.82}_{-0.58}$	1.81	$-0.47^{+1.08}_{-1.18}$
$H \to e\tau_{lep}$	SR_{noJets}	$1.66^{+0.72}_{-0.46}$	1.45	$-0.45^{+0.89}_{-0.97}$
	$SR_{withJets}$	$3.33^{+1.60}_{-0.93}$	3.99	$0.74^{+1.59}_{-1.62}$
	Combined	$1.48^{+0.60}_{-0.42}$	1.36	$-0.26^{+0.79}_{-0.82}$
$H \to e\tau$	Combined	$1.21^{+0.49}_{-0.34}$	1.04	$-0.34^{+0.64}_{-0.66}$
$H \to \mu\tau_{had}$	SR1	$1.60^{+0.64}_{-0.45}$	1.55	$-0.07^{+0.81}_{-0.86}$
	SR2	$1.75^{+0.71}_{-0.49}$	3.51	$1.94^{+0.92}_{-0.89}$
	Combined	$1.24^{+0.50}_{-0.35}$	1.85	$0.77^{+0.62}_{-0.62}$
$H \to \mu\tau_{lep}$	SR_{noJets}	$2.03^{+0.93}_{-0.57}$	2.38	$0.31^{+1.06}_{-0.99}$
	$SR_{withJets}$	$3.57^{+1.74}_{-1.00}$	2.85	$-1.03^{+1.66}_{-1.82}$
	Combined	$1.73^{+0.74}_{-0.49}$	1.79	$0.03^{+0.88}_{-0.86}$
$H \to \mu\tau$	Combined	$1.01^{+0.40}_{-0.29}$	1.43	$0.53^{+0.51}_{-0.51}$

- Tension in the results, but not incompatible
- We need 2016 data to confirm or not the excess (2015 statistics not large enough to conclude)

Limits on the Higgs Yukawa couplings

Run I summary

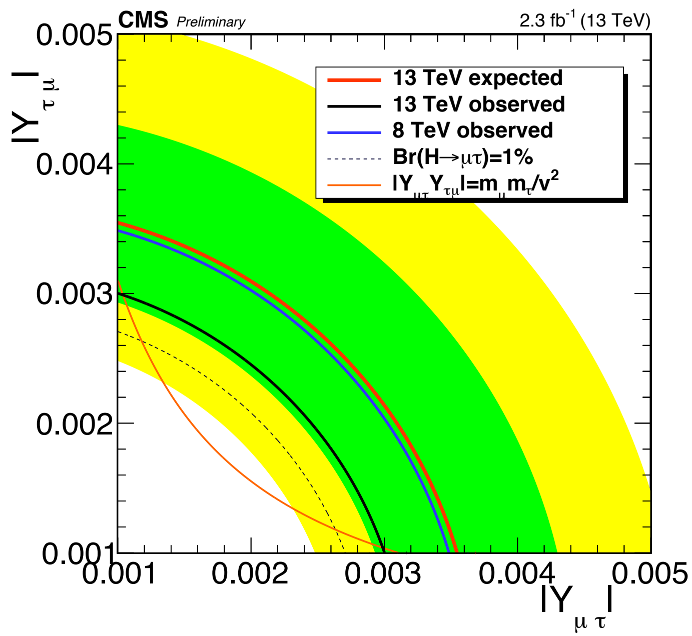
Channel	Coupling	95% CL Limit		
		Pre-LHC	CMS	ATLAS
H→ μe	$\sqrt{\vert Y_{\mu e}\vert^2 + \vert Y_{e\mu}\vert^2}$	$3.6 \cdot 10^{-6}$	$5.4 \cdot 10^{-4}$	-
H→ $\mu\tau$	$\sqrt{\vert Y_{\mu\tau}\vert^2 + \vert Y_{\tau\mu}\vert^2}$	0.016	0.0036	0.0035
H→ $e\tau$	$\sqrt{\vert Y_{e\tau}\vert^2 + \vert Y_{\tau e}\vert^2}$	0.014	0.0024	0.0029



Limits on the Higgs Yukawa couplings

With the new CMS result

Channel	Coupling	95% CL Limit Pre-LHC	CMS	ATLAS
H→ μe	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$3.6 \cdot 10^{-6}$	$5.4 \cdot 10^{-4}$	-
H→ $\mu\tau$	$\sqrt{\lvert Y_{\mu\tau}\rvert^2 + \lvert Y_{\tau\mu}\rvert^2}$	0.016	**0.00316**	0.0035
H→ $e\tau$	$\sqrt{\lvert Y_{e\tau}\rvert^2 + \lvert Y_{\tau e}\rvert^2}$	0.014	0.0024	0.0029



Prospects and Plans for Run II

- Run 2016 dataset will be enough to close the HMuTau discussion @ 1%
- But targeting a signal at 1% is not the end of the story !
- Next (long term) target for the LFV Higgs searches to Leptons: go below the 0.5% threshold on the limits on the branching ratio for tau decays —> 0.1 % ?

SM values

$$Y = \begin{pmatrix} \boxed{Y_{ee}} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & \boxed{Y_{\mu\mu}} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{\tau\mu} & \boxed{Y_{\tau\tau}} \end{pmatrix}$$

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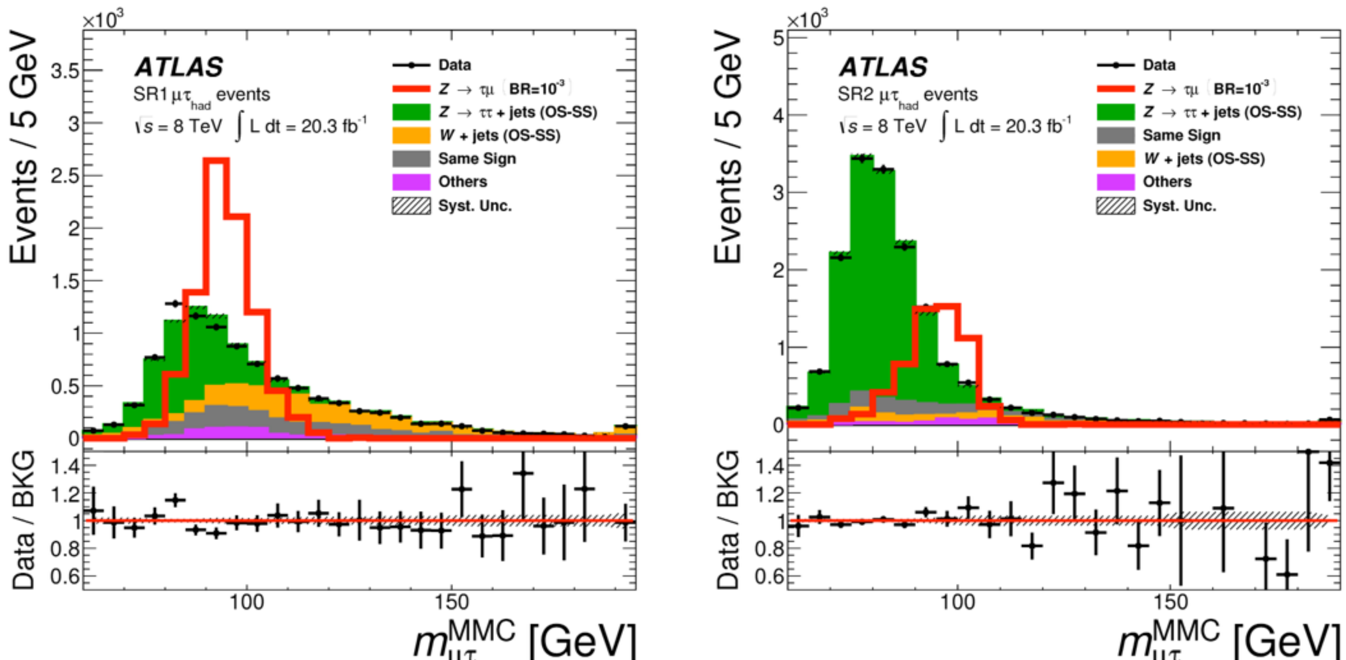
  - Current limits on the couplings
- **LFV Z Searches**
  - **Z→ll’ searches**
  - **Current limits on the couplings**
- FCNC Searches
  - t→Hc(u) searches
  - Current limits on the couplings

Zμτ

- ATLAS: Similar strategy as the one followed for the Higgs search
  - Lower momentum criteria for the leptons
  - Modifications to the shape corrections applied to WJets in SR1

Cut	SR1	SR2	WCR	TCR
$p_T(\mu)$	>30 GeV	>30 GeV	>30 GeV	>30 GeV
$p_T(\tau_{had})$	>30 GeV	>30 GeV	>30 GeV	>30 GeV
$\lvert\eta(\mu)-\eta(\tau_{had})\rvert$	<2	<2	<2	<2
$m_T^{\mu,E_T^{miss}}$	>30 GeV and <75 GeV	<30 GeV	>60 GeV	–
$m_T^{\tau_{had},E_T^{miss}}$	<20 GeV	<45 GeV	>40 GeV	–
N_{jet}	–	–	–	>1
N_{b-jet}	0	0	0	>0

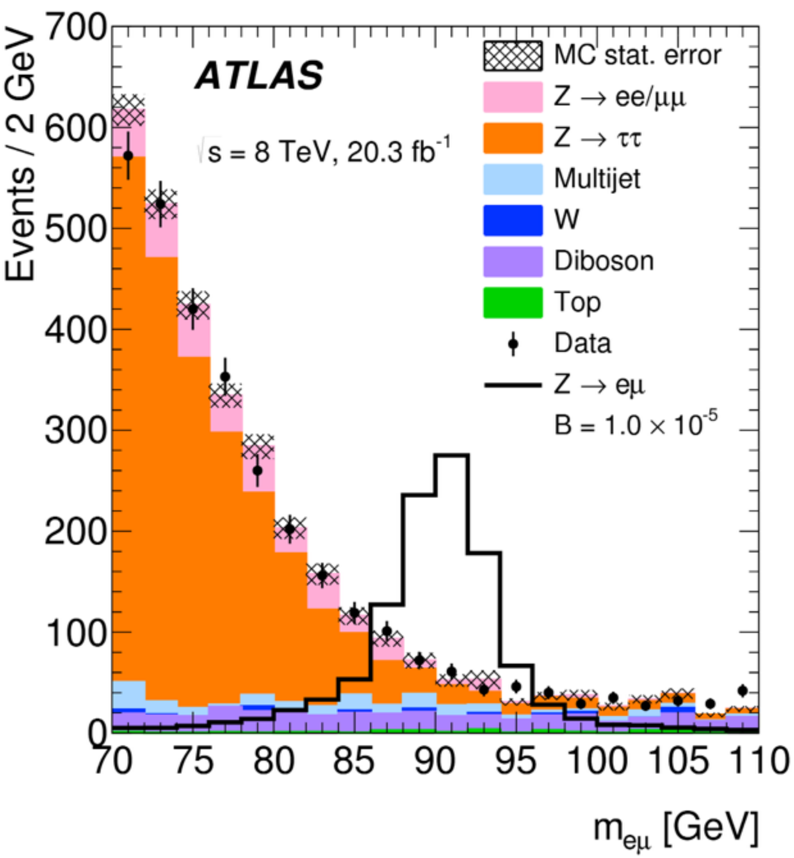


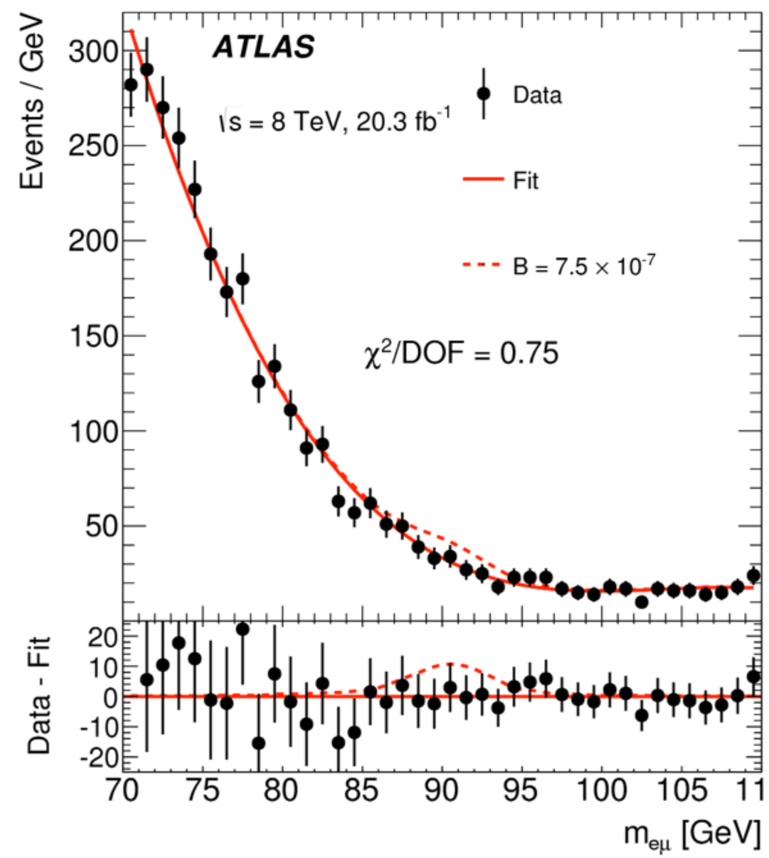
ATLAS: arXiv:1604.07730

Zeμ

- OS, OF selection of high pt isolated leptons
- ttbar and diboson backgounds rejected through ETmiss and jet activity vetos —> after that DrellYan becomes the leading background
- Unbinned fit for signal extraction

ATLAS: Phys. Rev. D. 90, 072010 (2014)

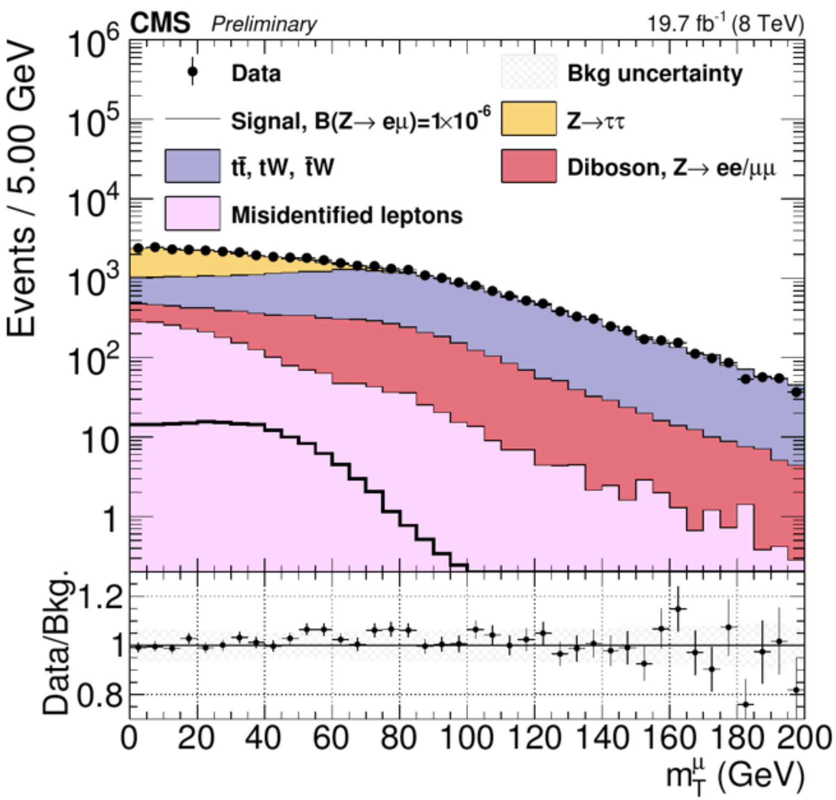


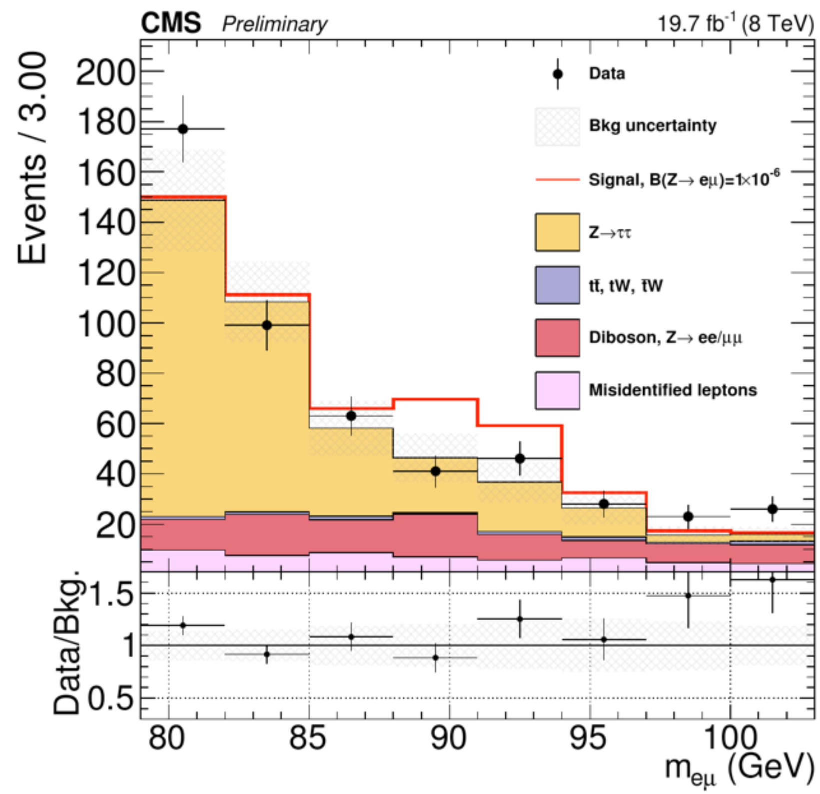


Zeμ

- OS, OF selection of high pt isolated leptons
- ttbar and diboson backgounds rejected through m_T and jet vetos
- DrellYan to taus modelled using the embedded method
- Template binned fit for signal extraction

CMS: HIG-13-005





LFV Z decays

- No deviation from the SM observed
- For the channels probed, the limits on the branching ratio are already almost at the LEP level (mutau) or already tighter (emu)

95% CL	$\mathrm{Br}(\mathrm{Z} \to \mathrm{e}\mu)$	$\mathrm{Br}(\mathrm{Z} \to \mathrm{e}\tau)$	$\mathrm{Br}(\mathrm{Z} \to \mu\tau)$
LEP	$1.7 \cdot 10^{-6}$	$9.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$
CMS	$7.3 \cdot 10^{-7}$ ($6.7 \cdot 10^{-7}$)	-	-
ATLAS	$7.5 \cdot 10^{-7}$	-	$1.69 \cdot 10^{-5}$ ($2.6 \cdot 10^{-5}$)

Brief Introduction	LFV Lepton Couplings
	SM Higgs to leptons
	Quark Couplings
LFV Higgs Searches	CMS H→ll' searches
	ATLAS H→ll' searches
	Discussion of results
	Current limits on the couplings
LFV Z Searches	Z→ll' searches
	Current limits on the couplings
FCNC Searches	**t→Hc(u) searches**
	Current limits on the couplings

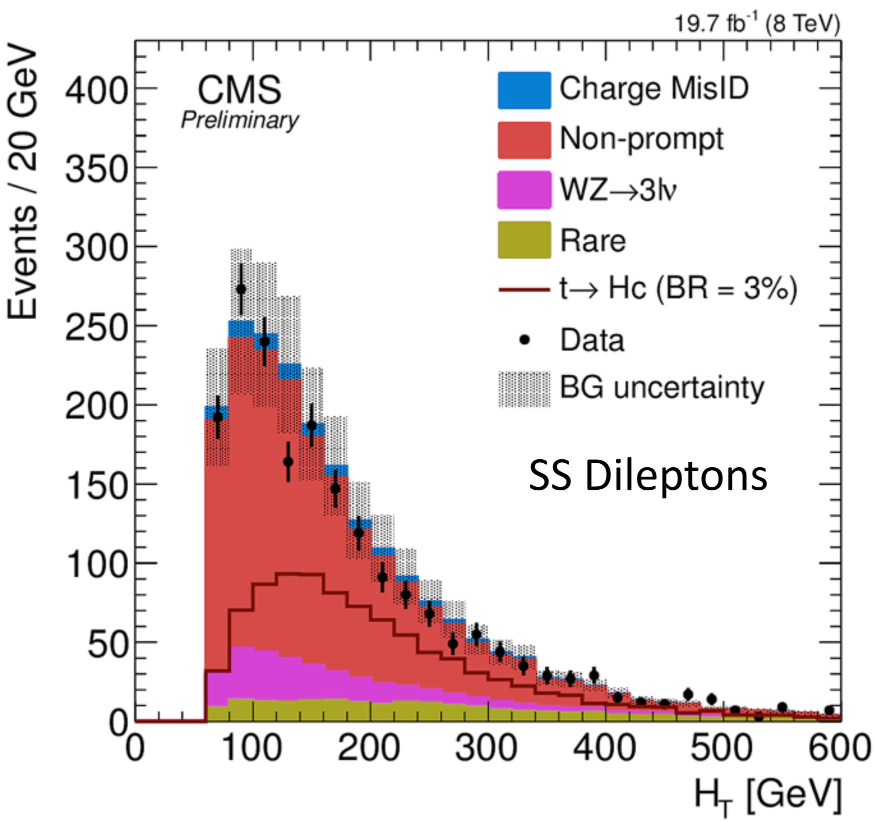
LFV ?

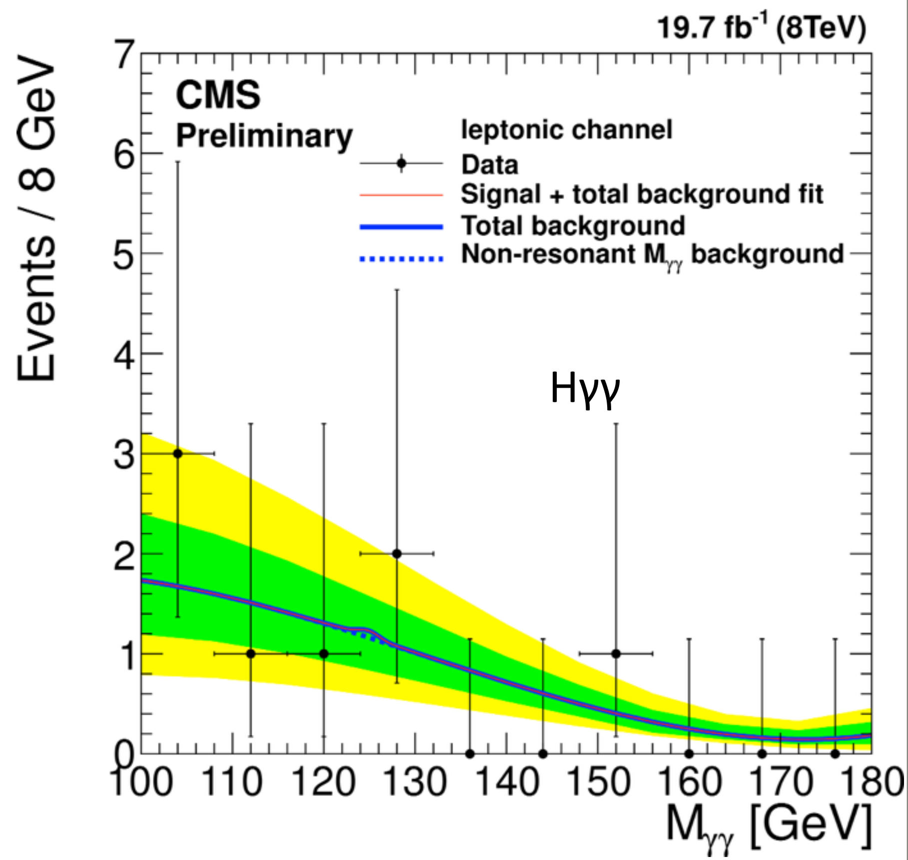
t→Hc and t→Hu

- Studied in tt→ WbHc(u)
- CMS: multilepton / HWW / Hττ / Hγγ final states

CMS: TOP-13-017

CMS: TOP-14-019

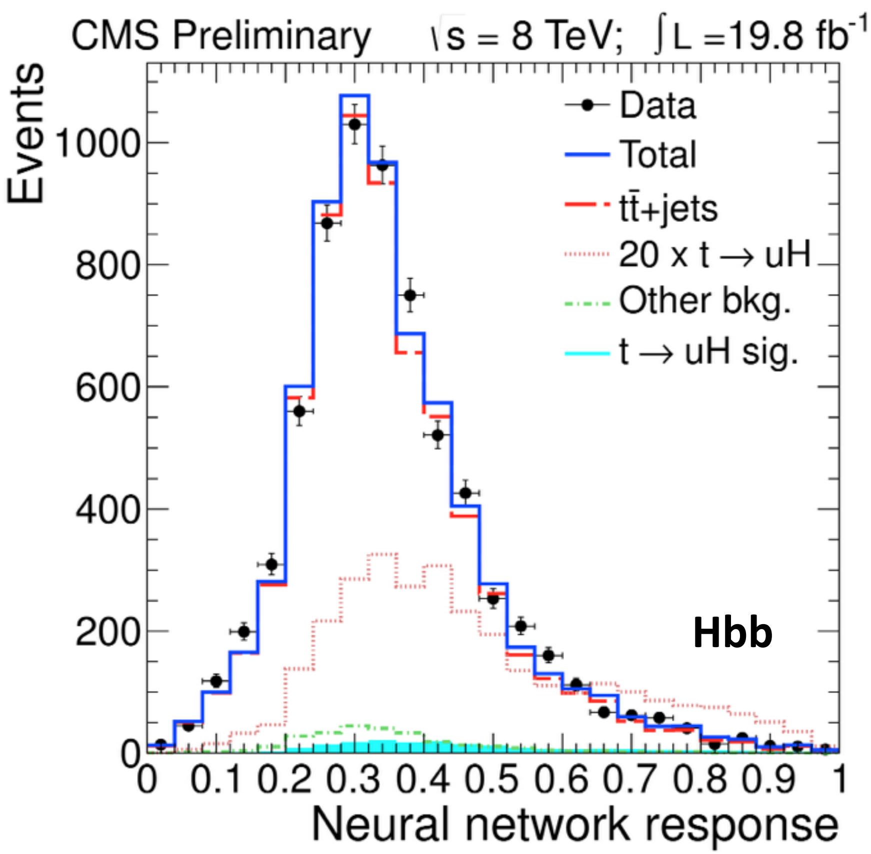


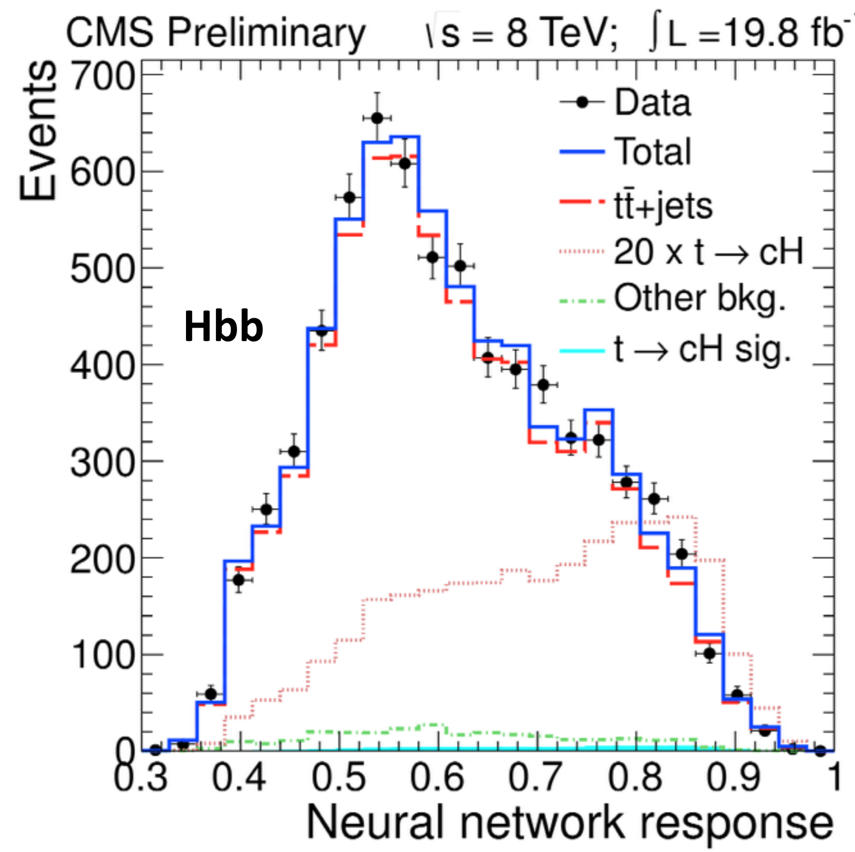


t→Hc and t→Hu

- Studied in tt→ WbHc(u)
- CMS: multilepton / Hbb / Hγγ final states

CMS: TOP-14-020





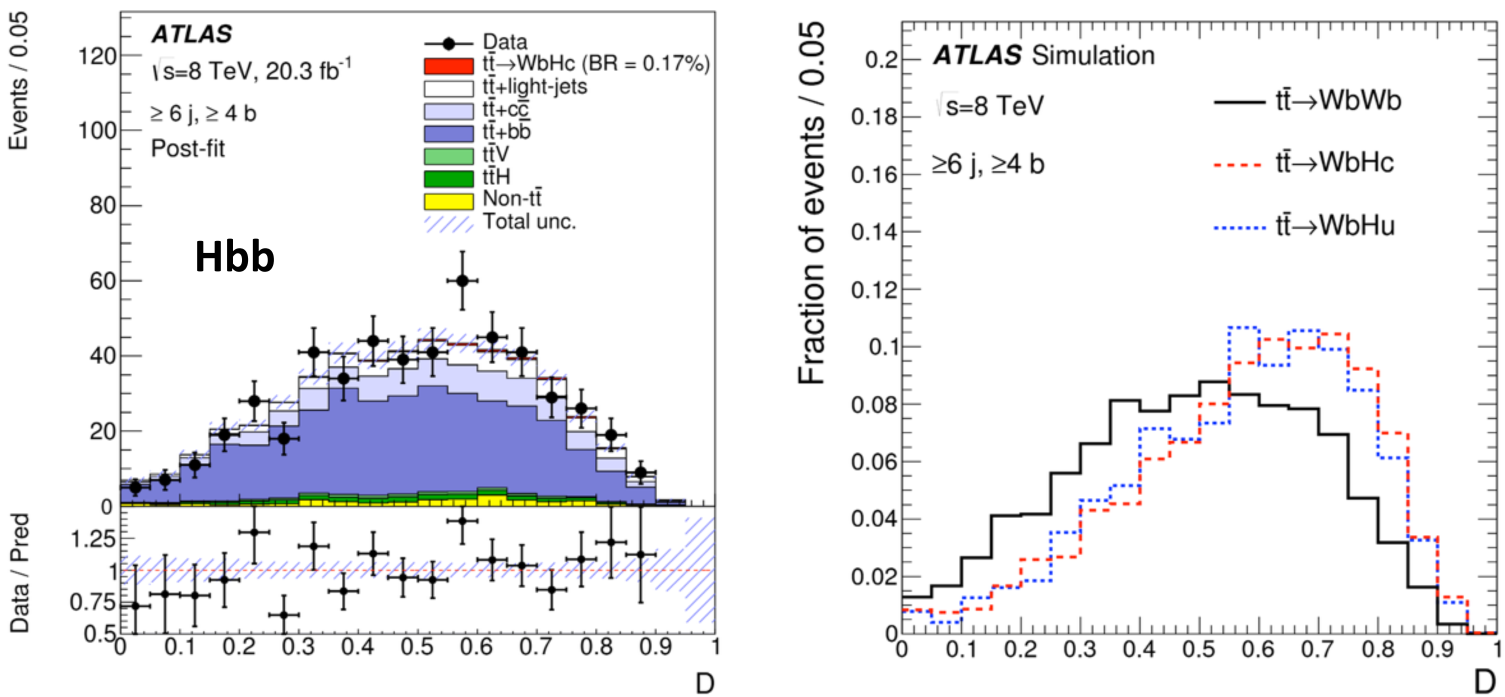
t→Hc and t→Hu

- Studied in tt → WbHc(u)
- ATLAS: Hbb / HWW / Hττ / Hγγ final states

ATLAS: JHEP 12 (2015) 061

- Hbb: Signal extraction through fit to a D discriminator

$$D(\mathbf{x}) = \frac{P^{\mathrm{sig}}(\mathbf{x})}{P^{\mathrm{sig}}(\mathbf{x}) + P^{\mathrm{bkg}}(\mathbf{x})},$$



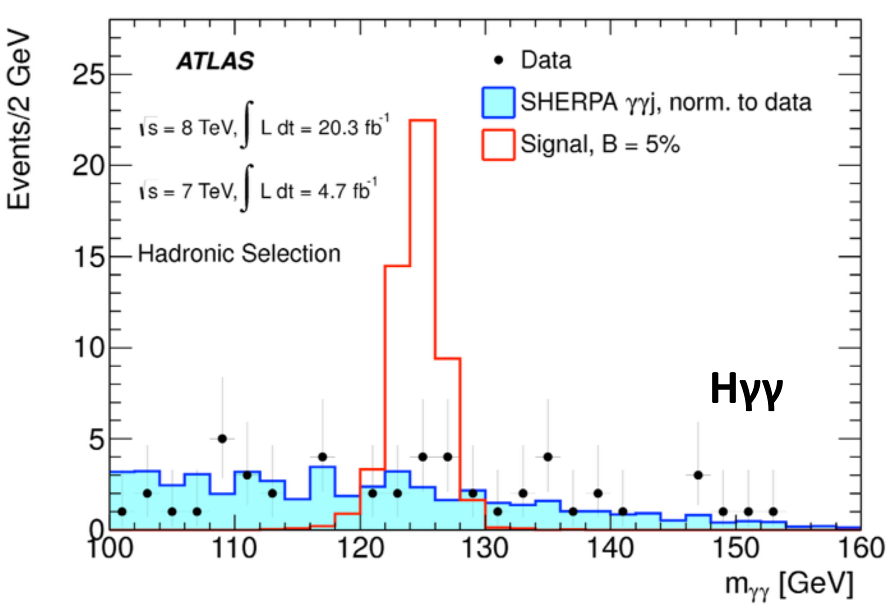
t→Hc and t→Hu

- Studied in tt → WbHc(u)
- ATLAS: Hbb / HWW / Hττ / Hγγ final states

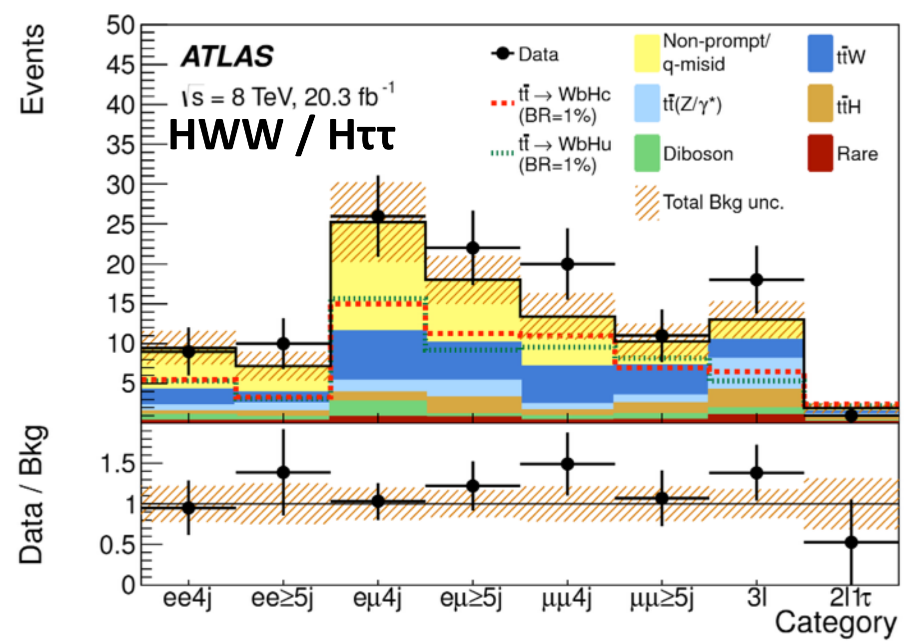
ATLAS: JHEP06(2014)008

ATLAS: Phys. Lett. B 749 (2015) 519

- Hγγ: Signal extraction through fit to diphoton mass distribution

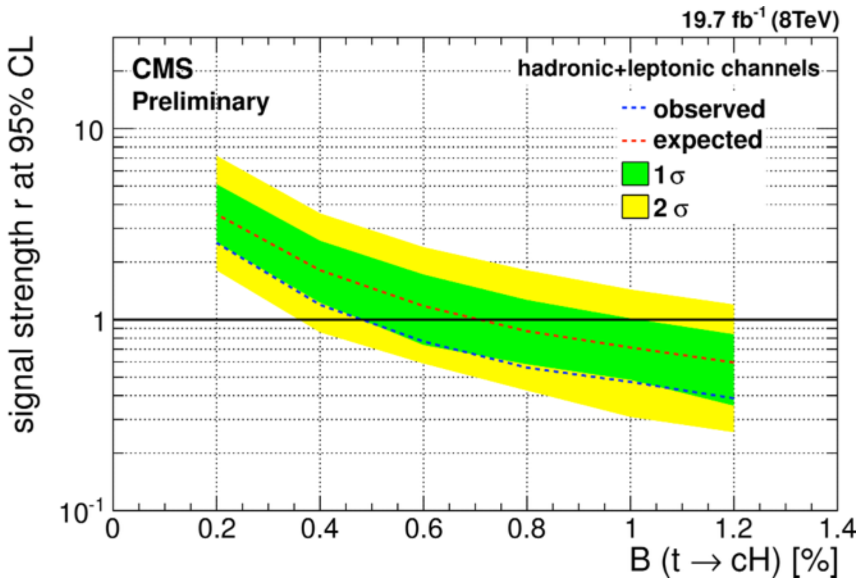


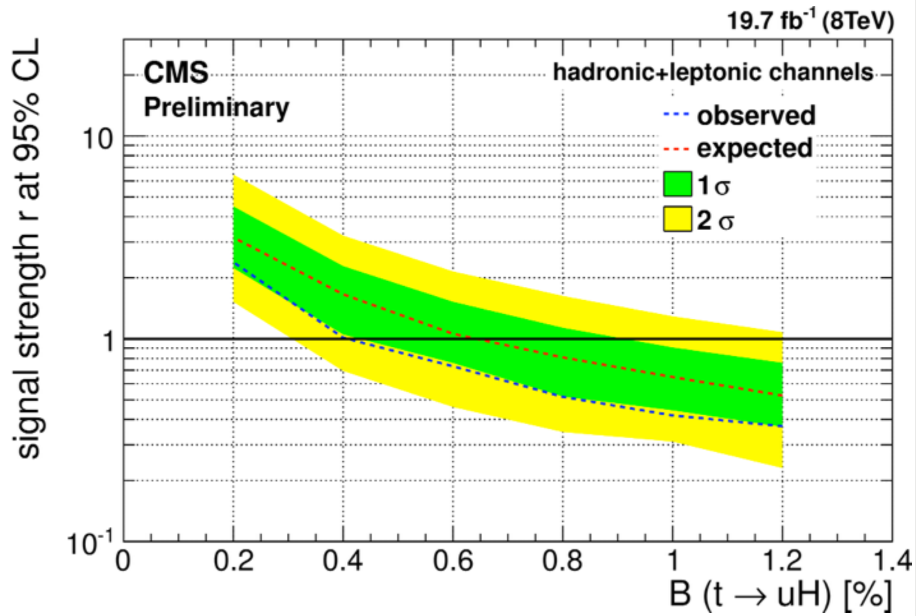
- HWW: categories based on the number of leptons and jets



t→Hc and t→Hu

95% CL	Br($t \to$ Hc)	Br($t \to$ Hu)
CMS Multilepton	0.93% $(0.89\%^{+1.22}_{-0.65})$	-
CMS Hγγ	0.47% (0.71%)	0.42% (0.65%)
CMS Hbb	1.16% (0.89%)	1.92% (0.85%)

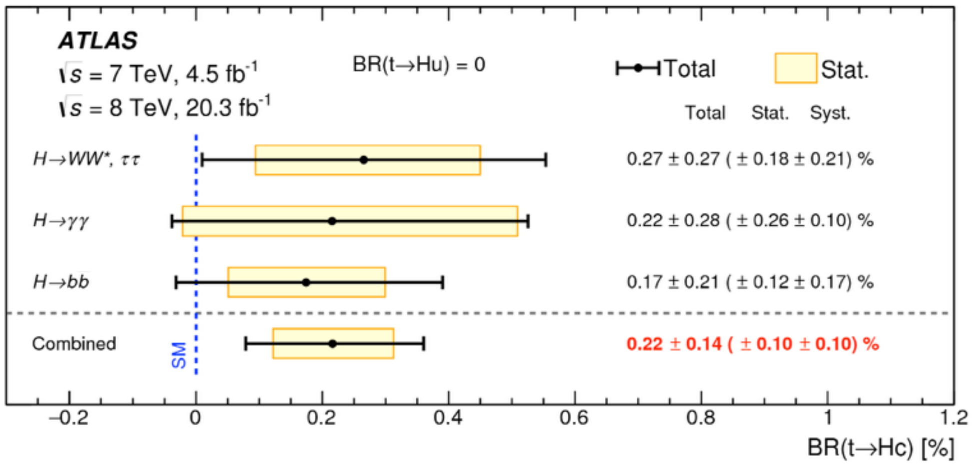


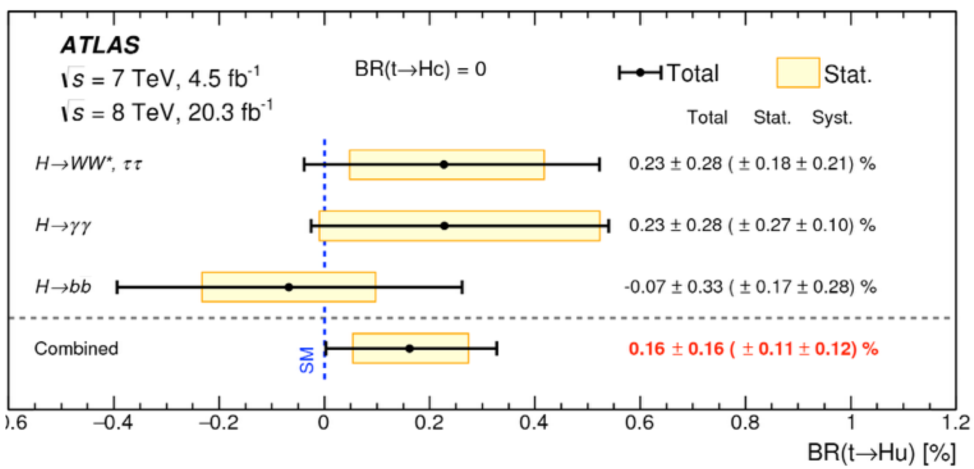


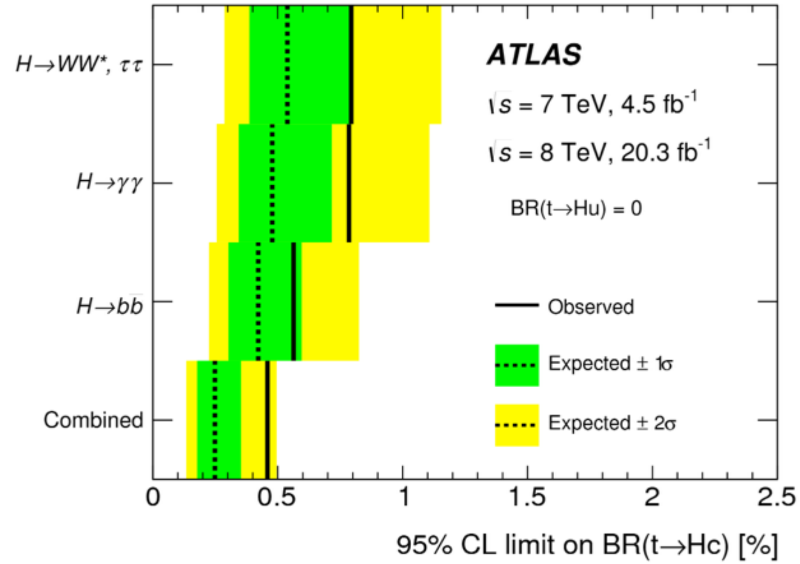
$$\mathcal{B}(\mathrm{t} \to \mathrm{Hc}) \simeq 0.29 \left(|\lambda^H_{tc}|^2 + |\lambda^H_{ct}|^2 \right)$$

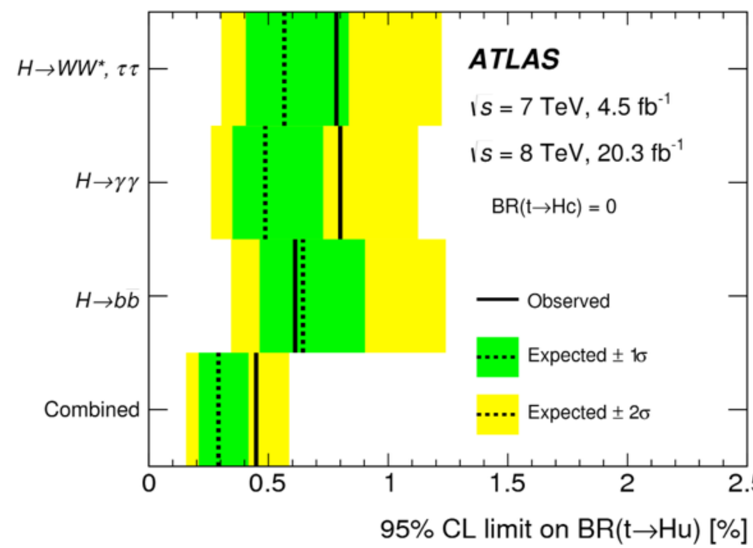
t→Hc and t→Hu

Combined limits: Br(t→Hc)< 0.46% (0.25%) and Br(t→Hu)< 0.45% (0.29%) @ 95% CL





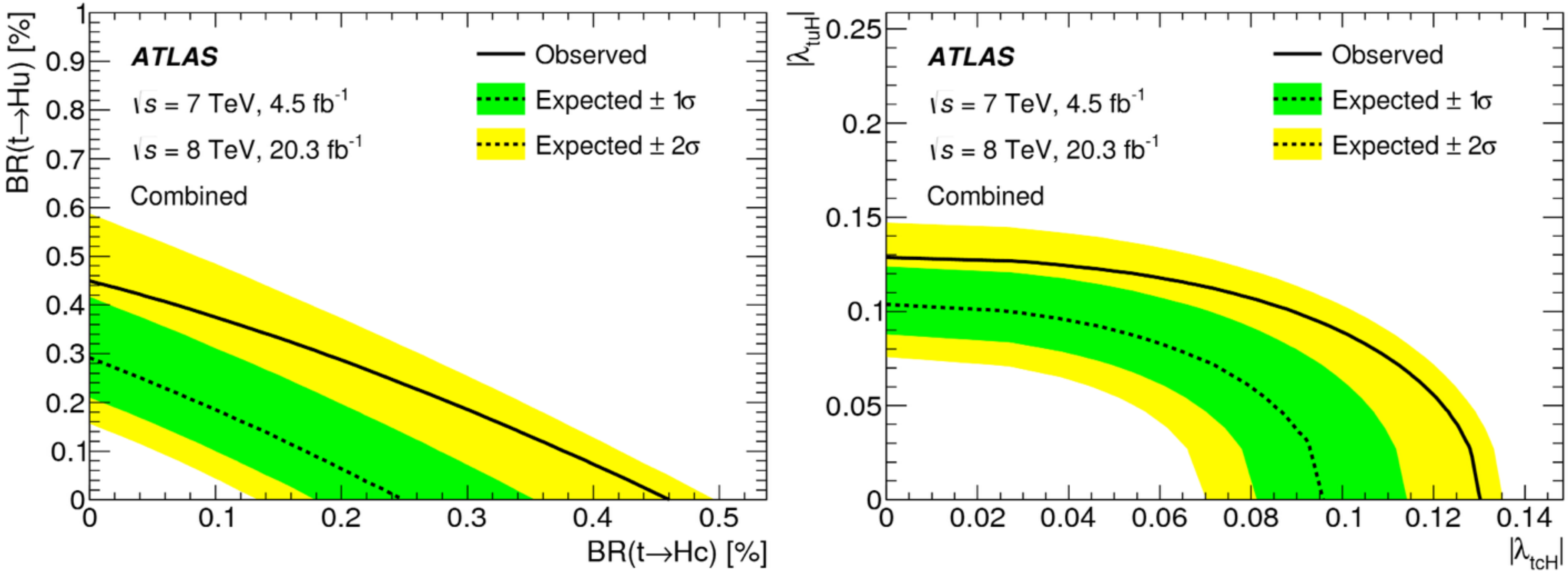




t→Hc and t→Hu

Simultaneous and independent limits for the two couplings

Combined limits: **$|\lambda_{tcH}|< 0.13$ (0.10)** and **$|\lambda_{tuH}|< 0.13$ (0.10)**



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What Next?

Summary

- The SM-like Brout-Englert-Higgs boson discovery opens a era of precision physics
  - → **Comprehensive set of production and decay measurements performed using the 7 and 8 TeV CMS data**
  - → **Searches in rarer modes become sensitive enough for discovery**

- **First direct searches for LFV Higgs decays, in the three decay channels: μτ, μe, eτ, performed by ATLAS and CMS**
  - **The limits on the Br(H->lτ) are one order of magnitude tighter than the preexisting non-LHC ones**
  - **Slight excess of the CMS 8TeV result not confirmed (but not excluded) by ATLAS or by the first preliminary 13TeV results**
  - No deviation from the background-only hypothesis is observed for the **eτ channel or μe channels**
  - **We need 2016 data!!**

- **Searches for LFV Z decays @ the LHC competitive with LEP**

- **FCNC: Probe of λ_{tHq} through ttbar decays to WbHq (stat. limited in Run I)**

Backup

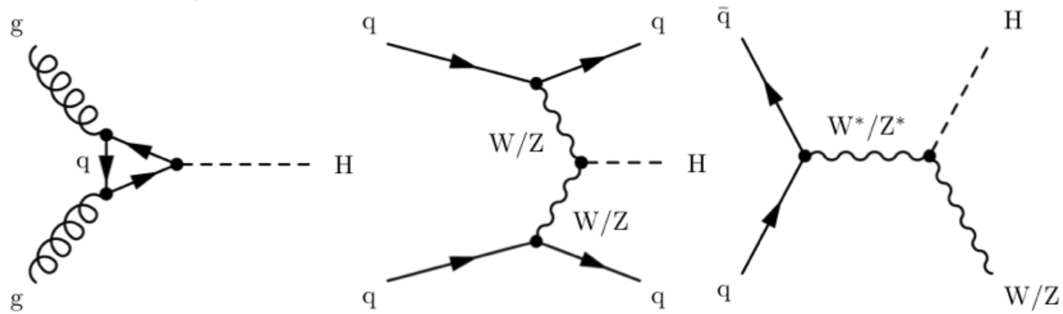
Higgs Decay to Tau Pairs

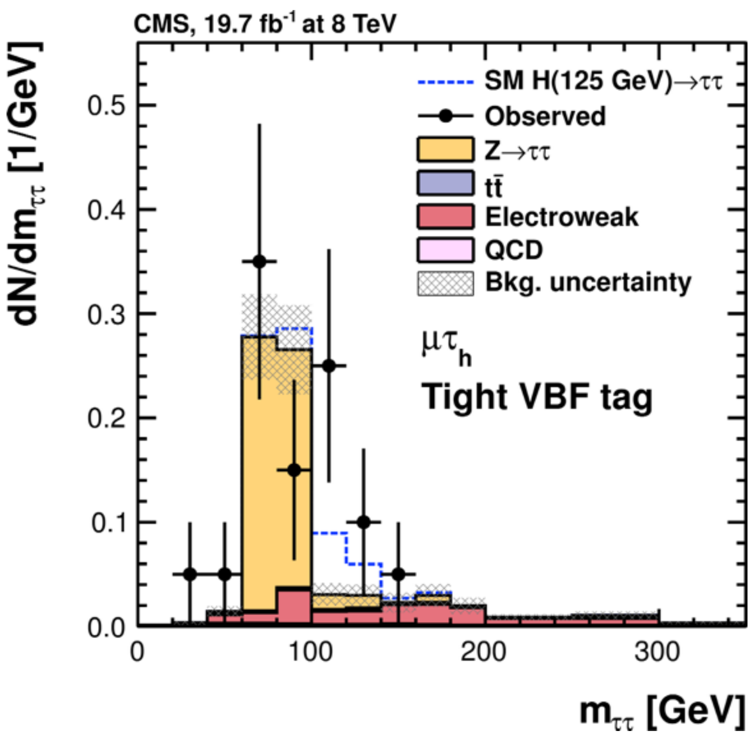
Final states VBF + GF:

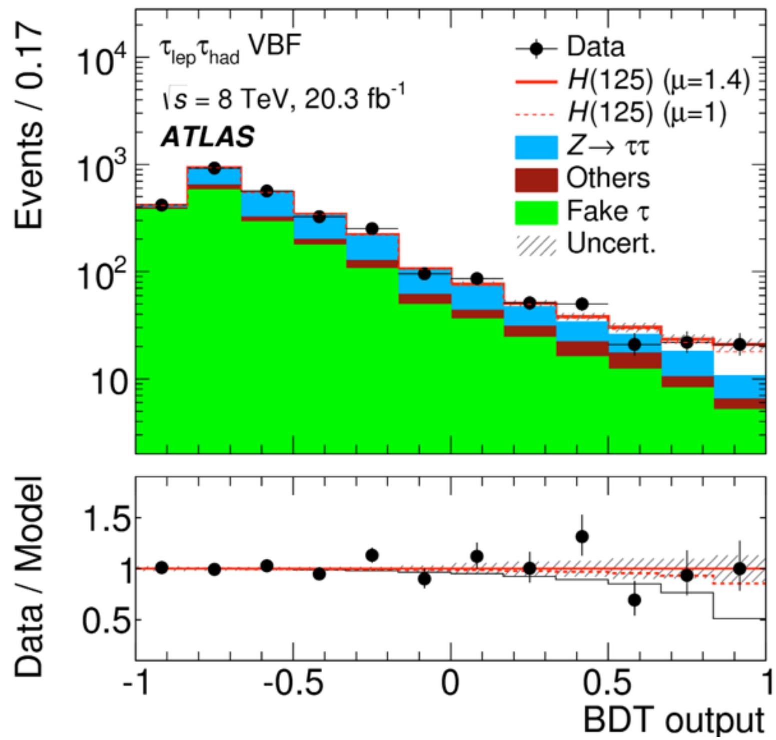
$e\mu$, $\mu\mu$, $e\tau_h$, $\mu\tau_h$, $\tau_h\tau_h$

Also, VH (WH & ZH):

$\ell\ell\tau_h$, $\ell\tau_h\tau_h$, $\ell\ell\tau_h\tau_h$







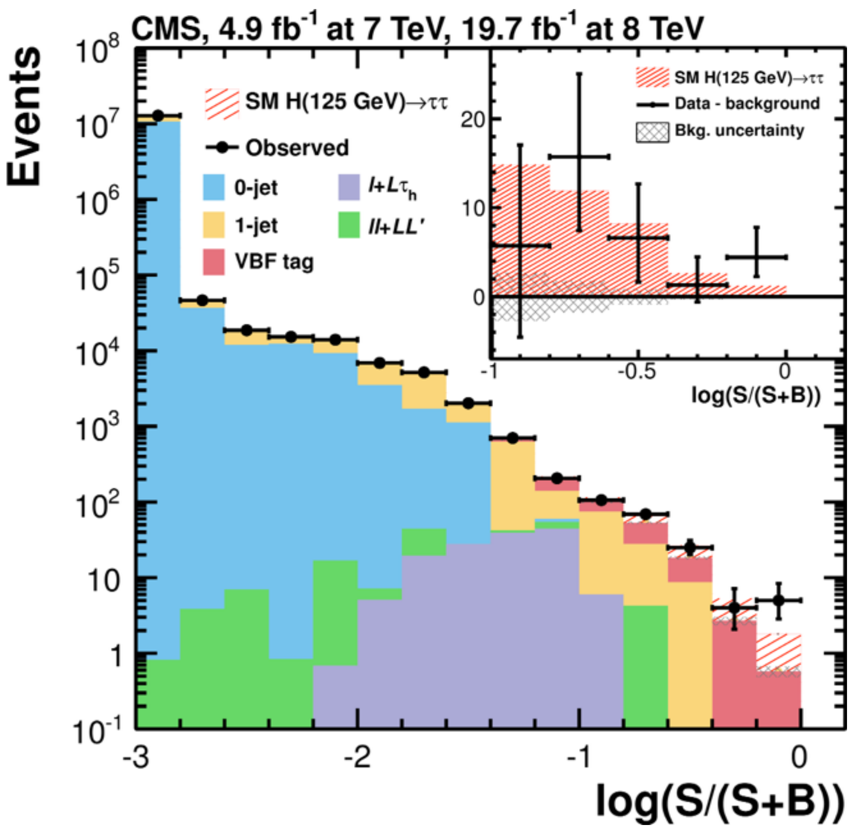
CMS:JHEP 05 (2014) 104

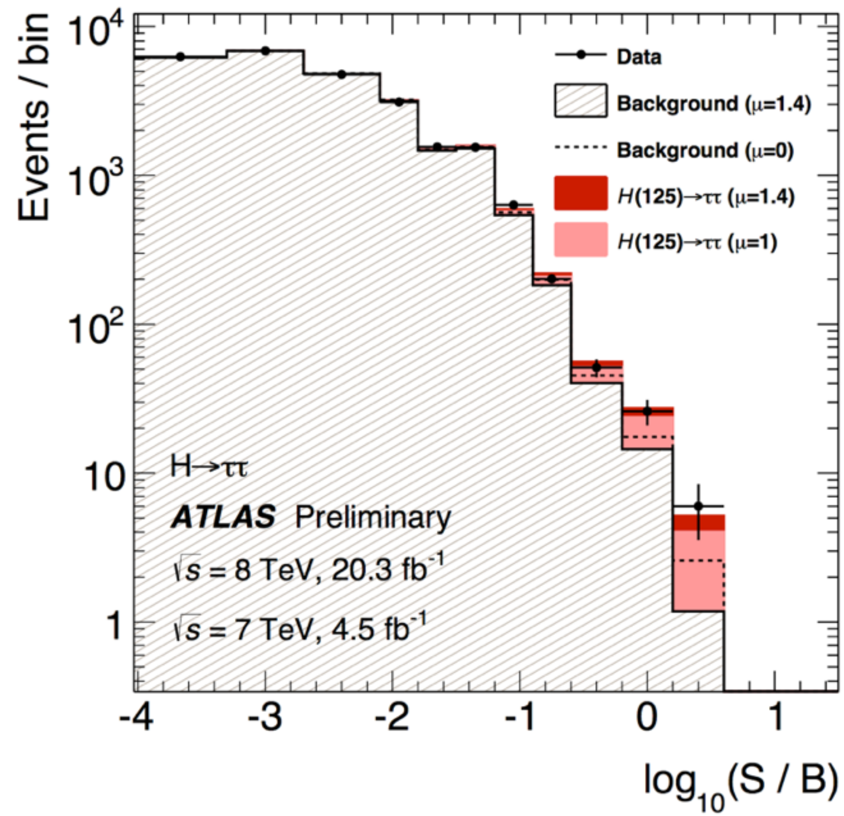
ATLAS: JHEP 04 (2015) 117

Higgs Decay to Tau Pairs

Signal strength μ (σ/σsm):
ATLAS: 1.43 (+0.43, -0.37)
ATLAS Cut Based: 1.43 (+0.55, -0.49)
CMS: 0.78 +/- 0.27

Significance @125 GeV
ATLAS: 4.5 σ (3.4 σ exp.)
ATLAS Cut Based: 3.2 σ (2.5 σ)
CMS: 3.2 σ (3.7 σ Exp.)



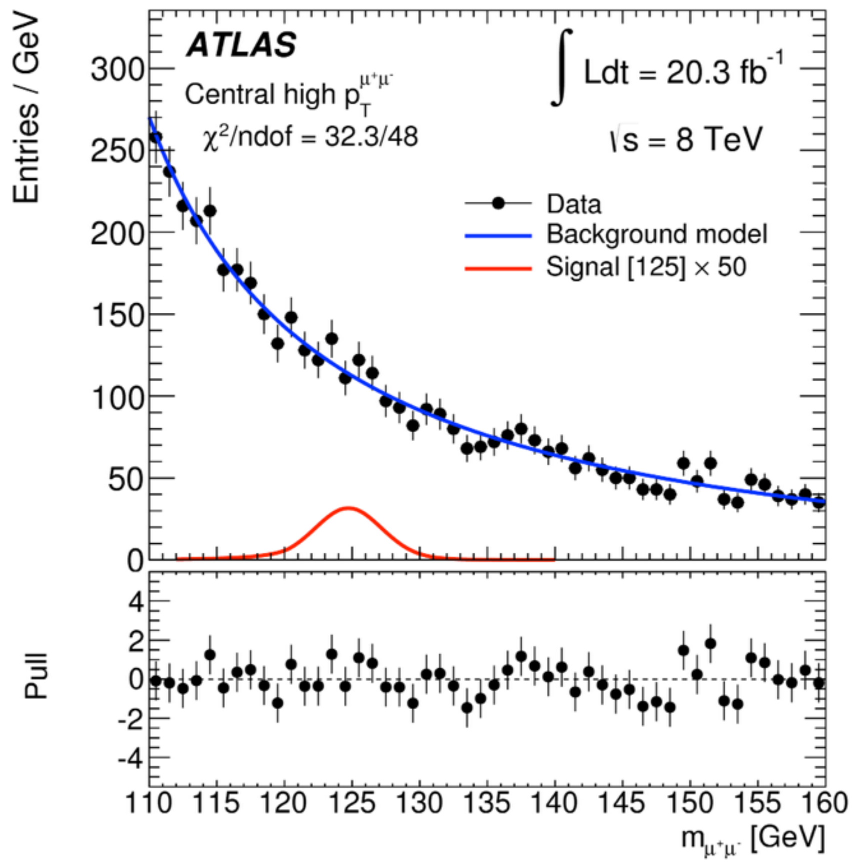


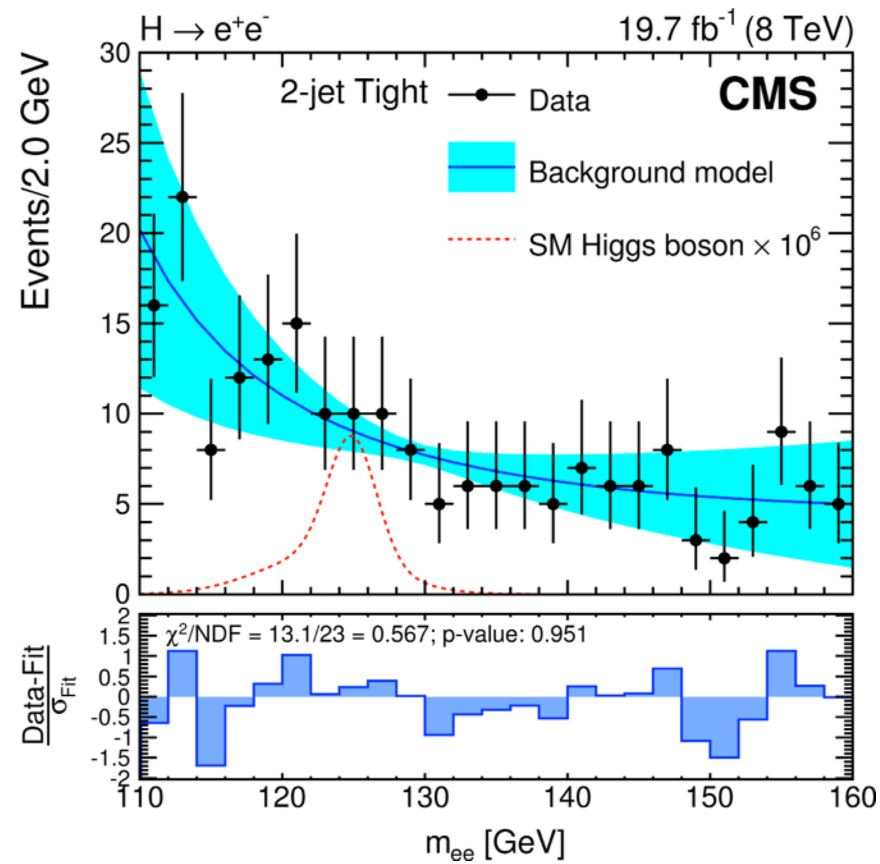
Higgs Decay to Muon or Electron Pairs

Parametric fit; categories depending on the number of jets in the event (to target VBF) and the centrality of both leptons

CMS: **PLB 744 (2015) 184**

ATLAS: **PLB 738 (2014) 68-86**

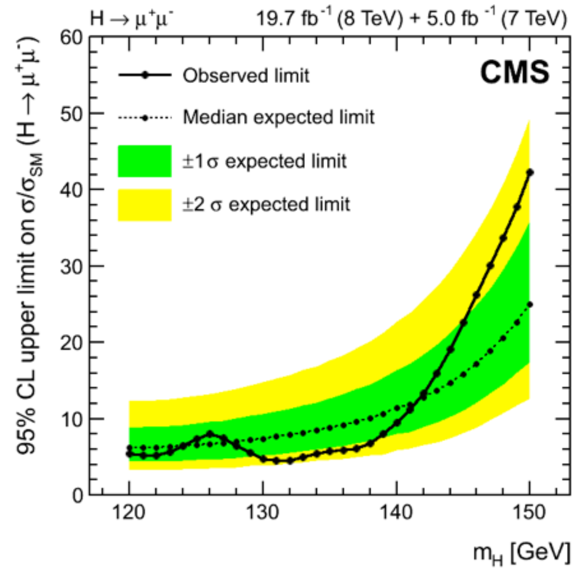


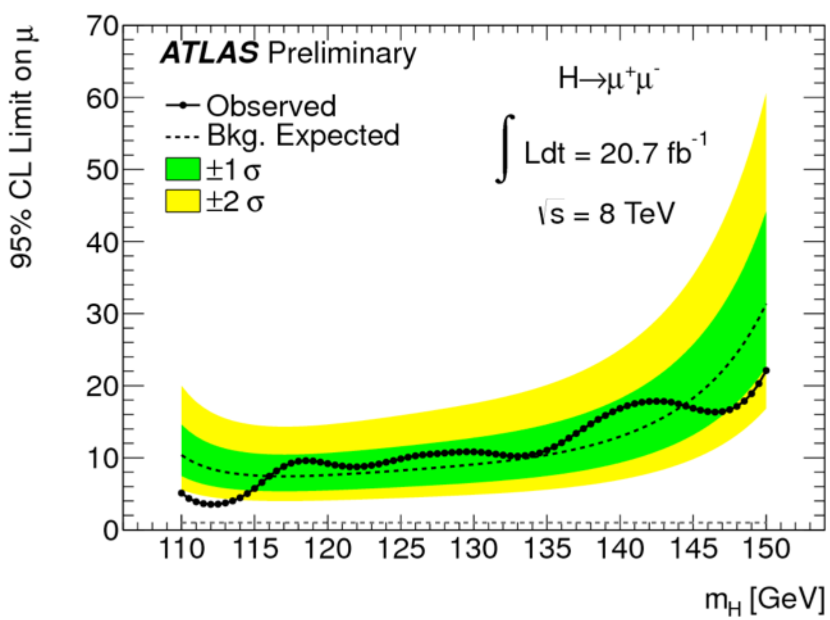


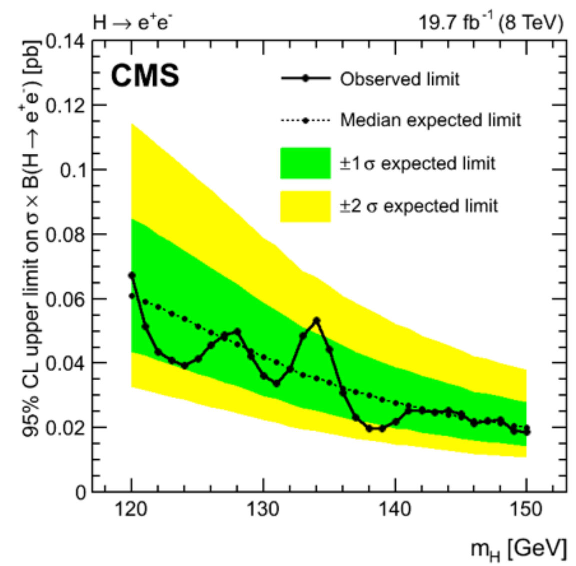
Higgs Decay to Muon or Electron Pairs

ATLAS $H \to \mu\mu$	$\sigma/\sigma_{SM} < 7.0\ (7.2)$
CMS $H \to \mu\mu$	$\sigma/\sigma_{SM} < 7.4\ (6.5^{+2.8}_{-1.9})$
CMS $H \to ee$	$Br(Hee) < 0.0019$ ($3.7 \cdot 10^5$ times the SM)

Together with Hττ, exclusion of universal coupling to leptons

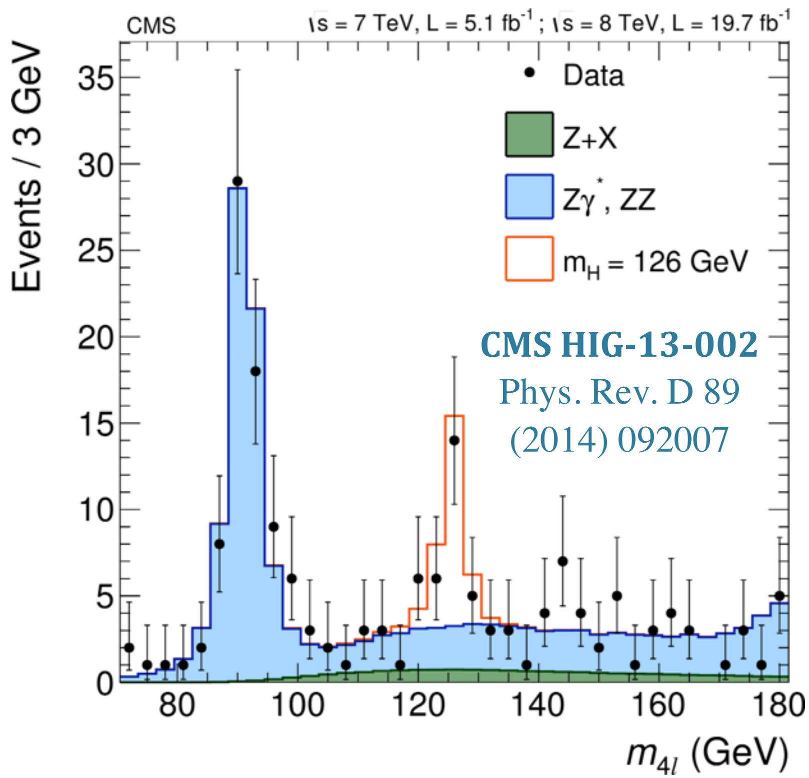


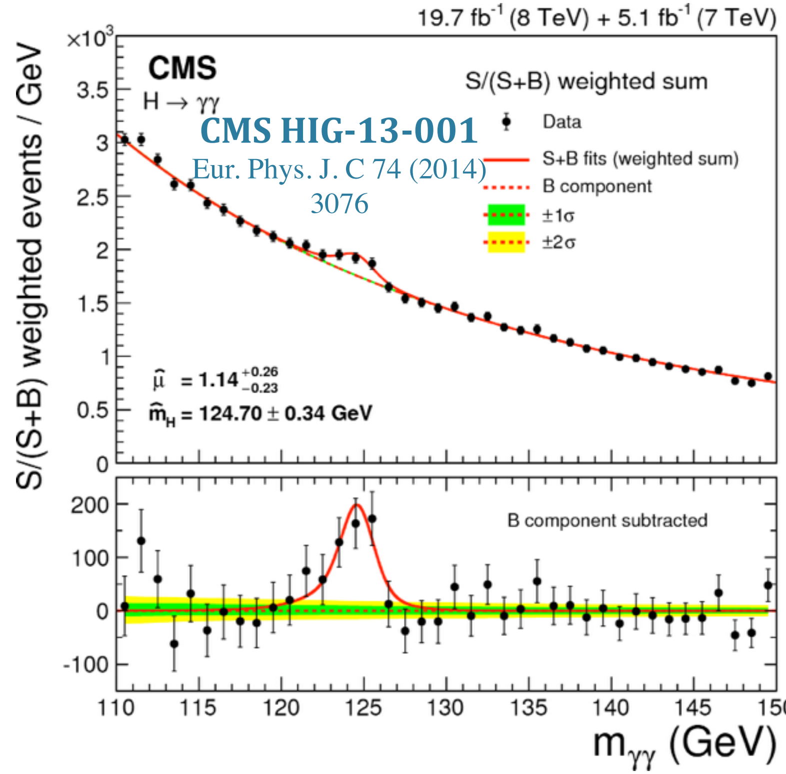




From the LHC Run I…

- The discovery of a new particle





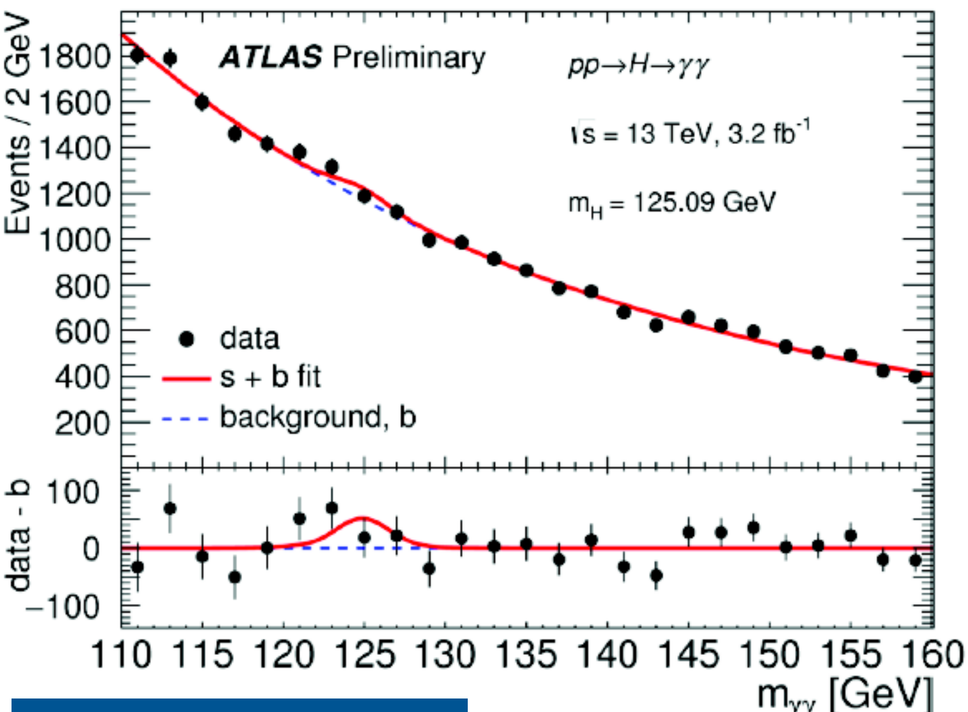
$$m_H = 125.03 \pm 0.30 \left[^{+0.26}_{-0.27}(\text{stat.})^{+0.13}_{-0.15}(\text{syst.}) \right] \text{ GeV}$$

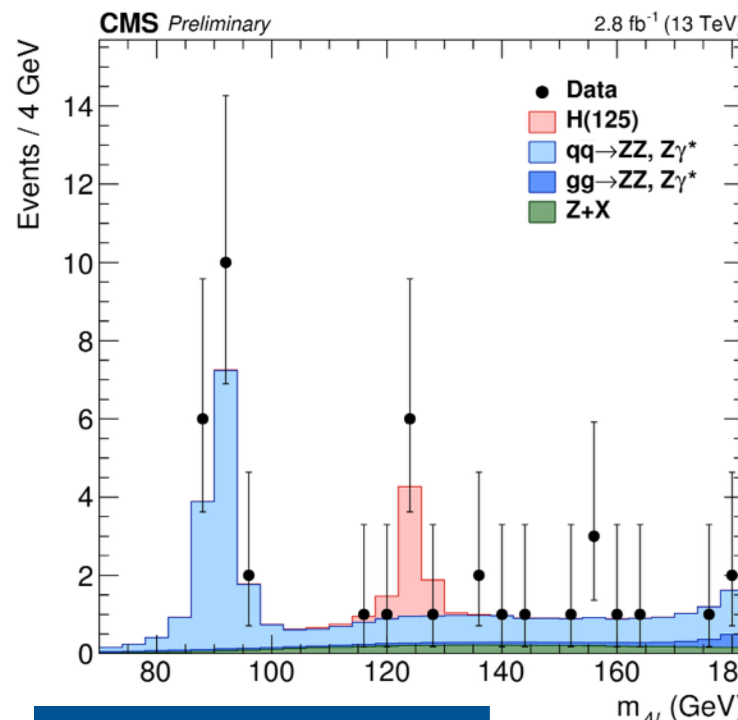
But what is it really?

..to the beginning of Run II

First task of the Higgs groups: re-discovering the Higgs @ 13TeV

- So far results remain consistent with the SM
- Statistics limited in the 2015 run
- Extended picture expected for the summer conferences





ATLAS-CONF-2015-060

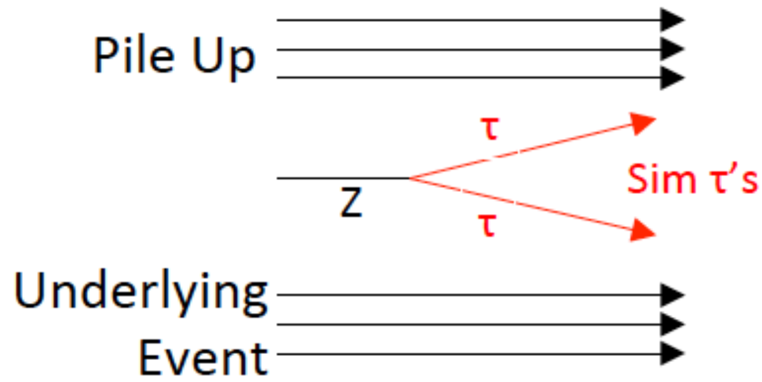
CMS-PAS-HIG-15-005

ATLAS-CONF-2015-059

CMS-PAS-HIG-15-004

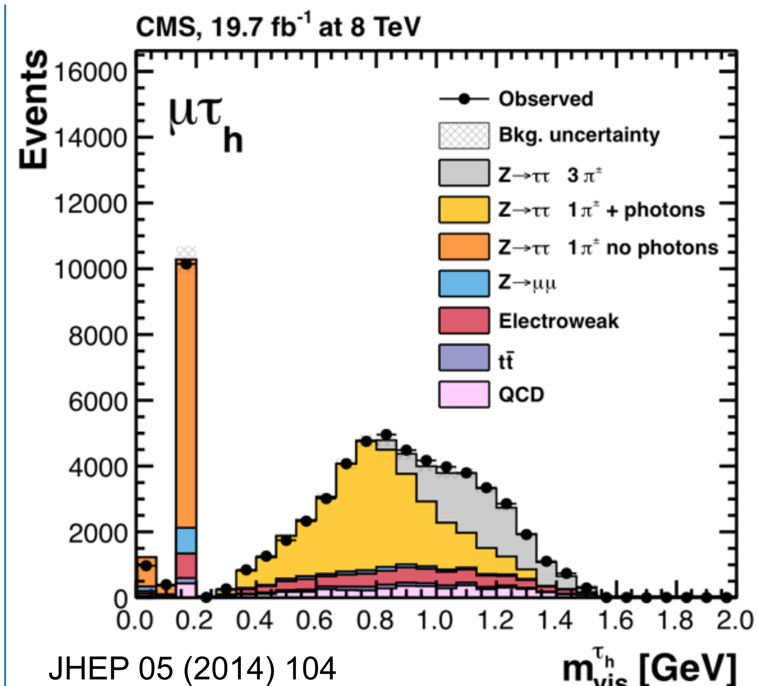
Z→ττ Modeling

- Z→ττ is the dominant background in the $\mu\tau_e$ channel and significant in the $\mu\tau_{had}$ channel
- Very similar kinematics to the SM H→ττ & the signal



  - **Overall 3% yield systematic uncertainty → from Z→ττ cross-section**

- **Shape modeling using the embedded technique developed by H→ττ** → exploits the 20 fb^{-1} CMS Z→μμ dataset to model key issues like PU, MET → we rely on MC only for the tau decay



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CMS-HIG-13-004

From the PDG

$\Gamma(e^-\gamma)/\Gamma_{\text{total}}$ Γ_{178}/Γ

Test of lepton family number conservation.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<3.3 \times 10^{-8}$	90	AUBERT	10B	BABR	516 fb^{-1}, E^{ee}_{cm}=10.6 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<1.2 \times 10^{-7}$	90	HAYASAKA	08	BELL	535 fb^{-1}, E^{ee}_{cm}= 10.6 GeV
$<1.1 \times 10^{-7}$	90	AUBERT	06C	BABR	232 fb^{-1}, E^{ee}_{cm}= 10.6 GeV
$<3.9 \times 10^{-7}$	90	HAYASAKA	05	BELL	86.7 fb^{-1}, E^{ee}_{cm}=10.6 GeV

$\Gamma(\mu^-\gamma)/\Gamma_{\text{total}}$ Γ_{179}/Γ

Test of lepton family number conservation.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$< 4.4 \times 10^{-8}$	90	AUBERT	10B	BABR	516 fb^{-1}, E^{ee}_{cm}=10.6 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$< 4.5 \times 10^{-8}$	90	HAYASAKA	08	BELL	535 fb^{-1}, E^{ee}_{cm} = 10.6 GeV
$< 6.8 \times 10^{-8}$	90	AUBERT,B	05A	BABR	232 fb^{-1}, E^{ee}_{cm}= 10.6 GeV
$< 3.1 \times 10^{-7}$	90	ABE	04B	BELL	86.3 fb^{-1}, E^{ee}_{cm} = 10.6 GeV

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(BABAR)

$\Gamma(e^-\gamma)/\Gamma_{\text{total}}$ Γ_5/Γ

Forbidden by lepton family number conservation.

VALUE (units 10^{-11})	*CL%*	*DOCUMENT ID*		*TECN*	*CHG*	*COMMENT*
< 0.057	90	ADAM	13B	SPEC	+	MEG at PSI
• • • We do not use the following data for averages, fits, limits, etc. • • •						
< 0.24	90	ADAM	11	SPEC	+	MEG at PSI
< 2.8	90	ADAM	10	SPEC	+	MEG at PSI
< 1.2	90	AHMED	02	SPEC	+	MEGA
< 1.2	90	BROOKS	99	SPEC	+	LAMPF

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J. Adam et al.
(MEG Collab.)