Searches for lepton-flavor violating Higgs boson decays at ATLAS

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on behalf of the ATLAS collaboration

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Introduction & Motivations

So far, no significant deviations from the Standard Model have been observed in experimental measurement for the Higgs sector at the LHC ...

however ...

1. Higgs Yukawa couplings are a fundamentally new type of interactions, yet to be studied with the same level of precision as gauge interactions
2. The fermion mass pattern remains a puzzle yet to be fully explained in the SM
3. Observable sensitive to flavor-violations can give additional information on the role of higher-order operator effects on fermion masses
4. LFV decays allowed by several BSM models (2HDMs, composite Higgs, ...)

The leptonic sector *offers particular sensitivity to LFV effects thanks to the smallness of lepton Yukawa couplings*

sensible to NP effects suppressed by higher energy scales

Today showing two recent ATLAS searches for LVF Higgs decays

$H \to e\tau$, $\mu\tau$

$H \to e\mu$

Lepton-flavor violation in **Higgs→lepton+τ**

Previous ATLAS results based on Run-1 dataset: BR<1.0% (1.4%) for eτ (μτ)

Recently updated with **36.1fb^{-1} Run-2 dataset @ 13TeV**

Accepted by PLB on July 13 HIGG-2017-08

Signature similar to SM H→ττ, with harder momenta for leptons and neutrinos collinear to τ decay products

Baseline Analysis Selection:

- single-lepton triggers
- opposite-sign leptons l (e,mu) + identified τ
  decaying to different-flavor lepton $\tau_{l'}$, or hardonically τ_{had}
- veto extra charged leptons and b-jets
- specific background rejection cuts

Dedicated Categorization for each lepton-flavor: eτ, μτ

- leptonic vs hadronic τ decay
- VBF-like vs non-VBF topology

→ **4 Signal Regions SR**

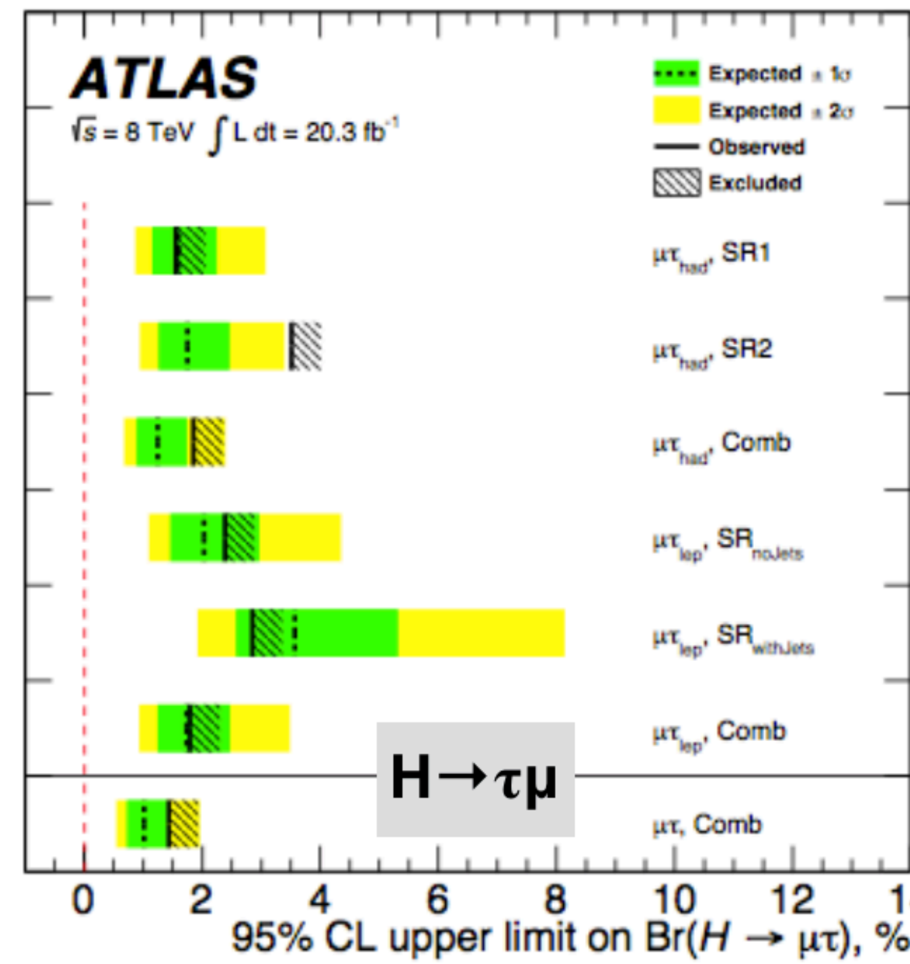
Background Control Region for the lτ_{lep} decay channel

[separately for VBF / non-VBF]

- Top CR:
  at least 1 b-jet [95% purity]
- Z→ττ CR:
  pT(leading-lepton)<45GeV [60-80% purity]

→ **4 Control Regions CR**

EPJ C 77 (2017) 70



VBF-like

$$\geq 2 \text{ jets}, p_T^{j_1} > 40 \text{ GeV}, p_T^{j_2} > 30 \text{ GeV}$$
$$|\Delta\eta(j_1, j_2)| > 3, m(j_1, j_2) > 400 \text{ GeV}$$

non-VBF-like

$$m_T(\ell_1, E_T^{miss}) > 50 \text{ GeV}$$
$$m_T(\ell_2, E_T^{miss}) < 40 \text{ GeV}$$
$$|\Delta\phi(\ell_2, E_T^{miss})| < 1.0$$
$$p_T^{\tau}/p_T^{\ell_1} > 0.5$$

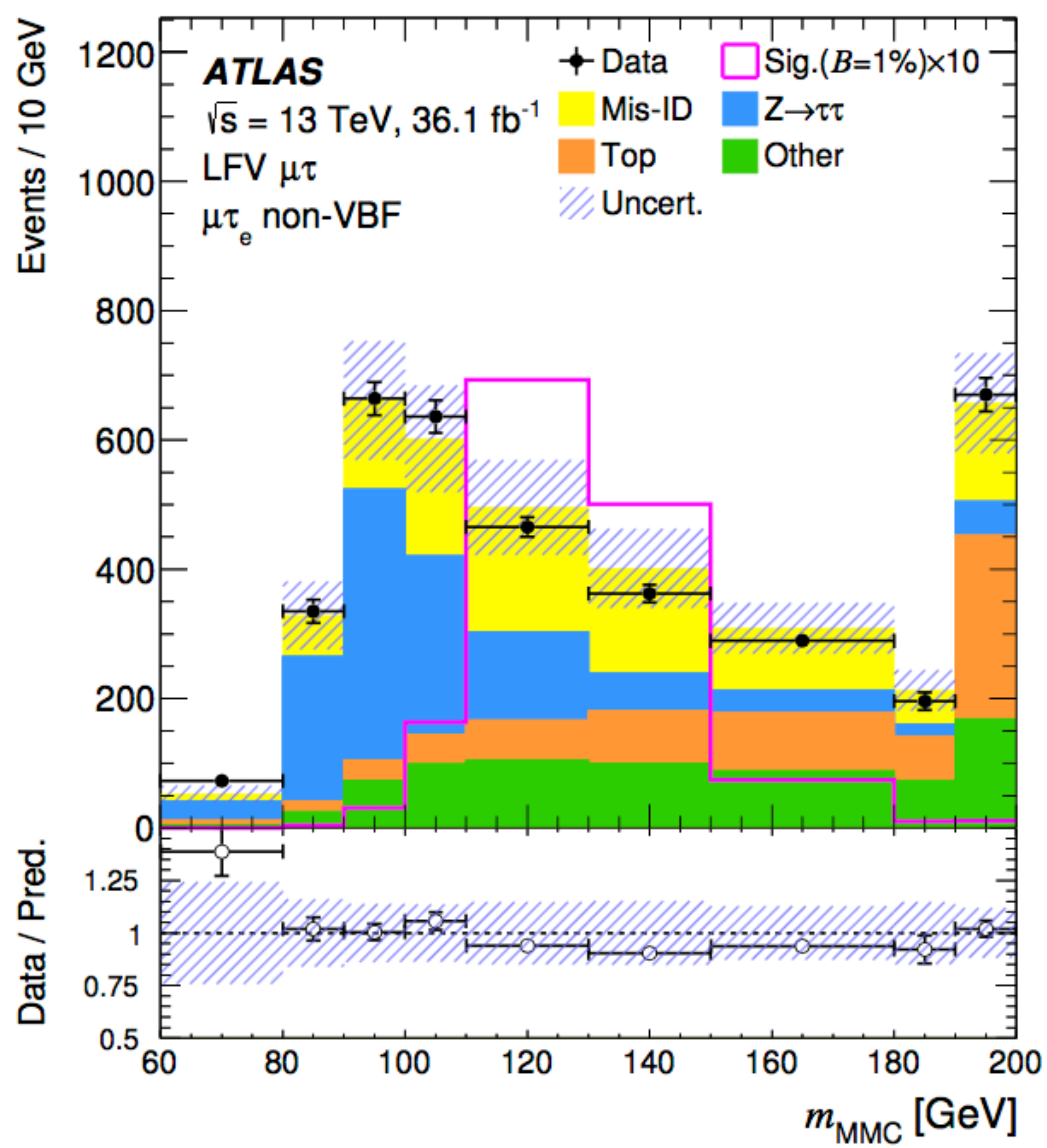
Lepton-flavor violation in **Higgs→lepton+τ**

Multivariate approach for signal extraction - Boosted Decision Trees BDT

Separately trained for each **signal region**, with dedicated input variables

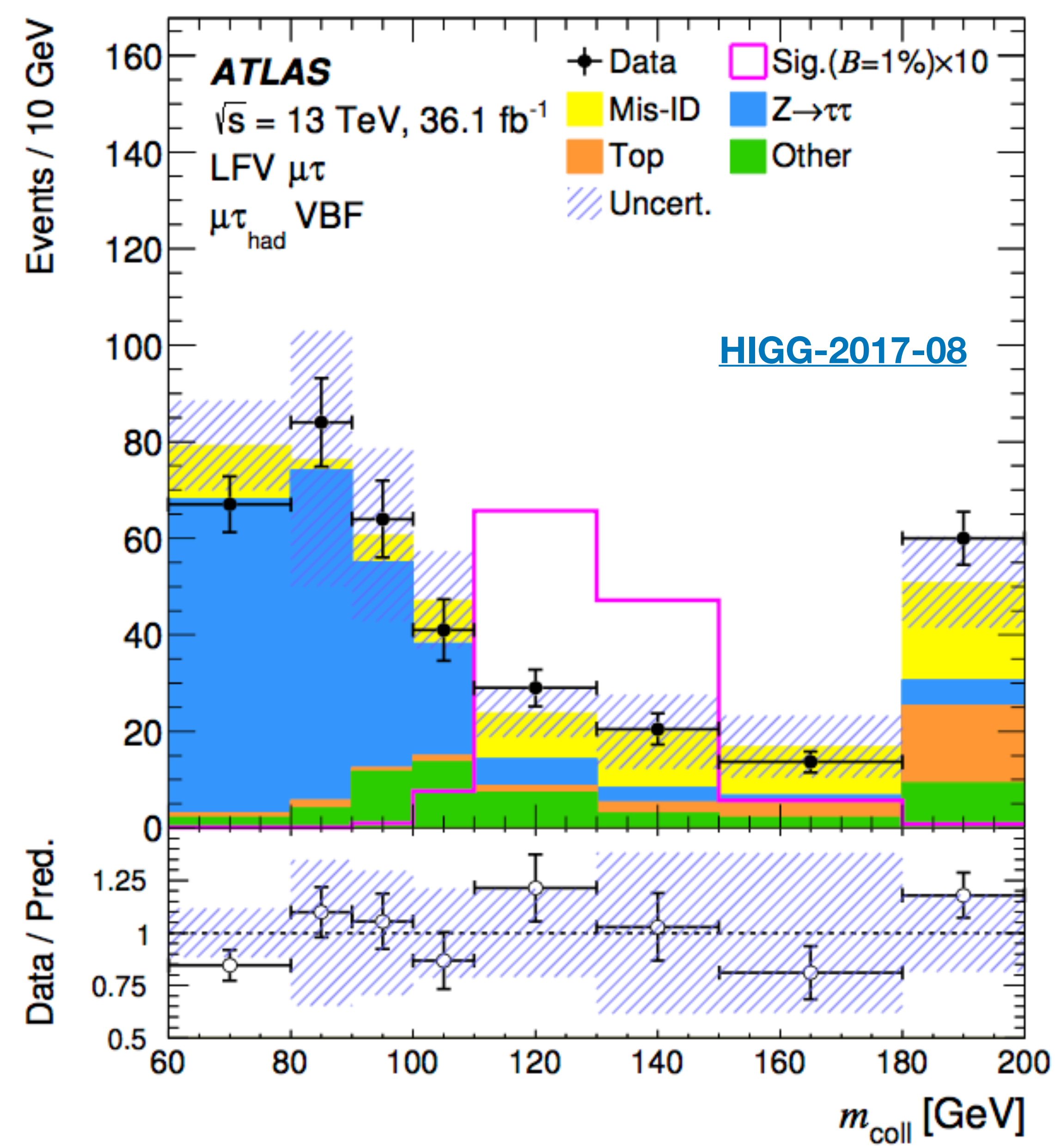
- 4-momenta of analysis objects
- derived variables: invariant/transverse masses, angular quantities, typical VBF observables, ...

Higgs reconstructed invariant mass [H→lepton+τ] highest S/B separation



"MMC" missing mass calculator

from H→lτl' kinematic constraints

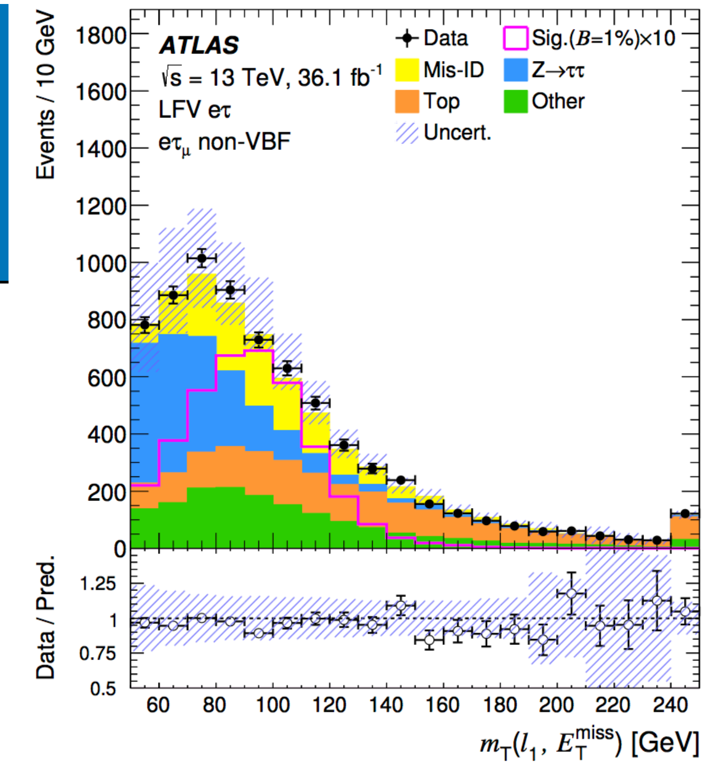


"collinear approximation" m_{coll}

Lepton-flavor violation in **Higgs→lepton+τ**

Main SM Background Processes

Background	Fraction in $\ell\tau_\ell$ channel	Fraction in $\ell\tau_{had}$ channel	Modeling
Z→ττ	20-35%	45-55%	Shape from MC, normalisation from CRs
Top	20-55%	1-10%	
Misidentified jets (W+jets, top, multijet) **or electrons** (Z→ee)	5-25%	25-45%	Fully data-driven →



$\ell\tau_\ell$

Shape from events with non-isolated leptons; normalisation from same-sign events

*Other backgrounds come from: **Z→μμ, diboson, H→ττ, H→WW** and are modeled by MC simulations constrained to the SM prediction*

Background modeling **for BDT input variables** studied across high-statistics CRs

Lepton-flavor violation in **Higgs→lepton+τ**

Simultaneous Profile Likelihood Fit to BDT in SRs and CRs

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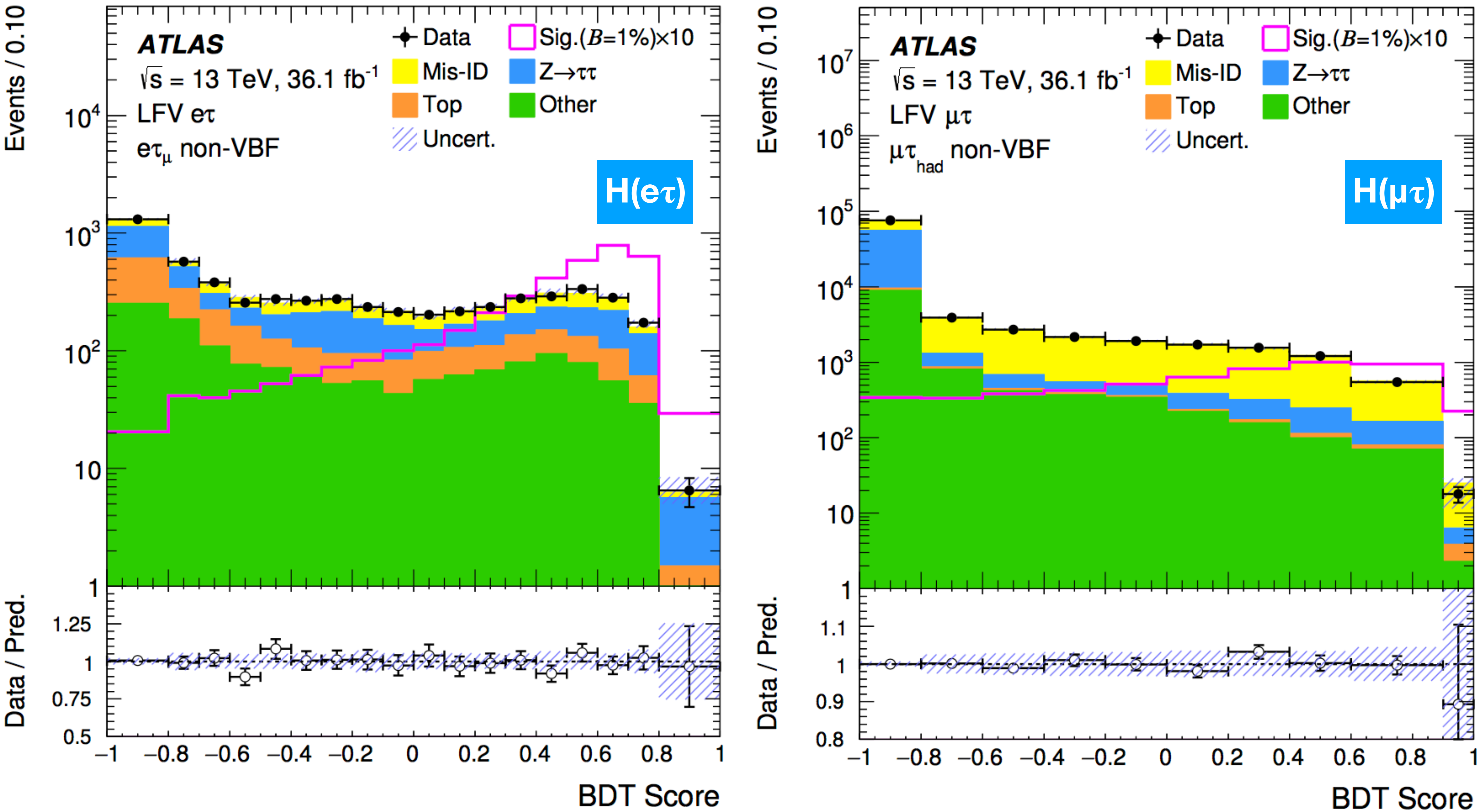

- main systematic uncertainties: misidentified background and jet experimental performance
- no significant excess over SM prediction: **BR(LFV) consistent with 0 within 1σ**

Lepton-flavor violation in **Higgs→lepton+τ**

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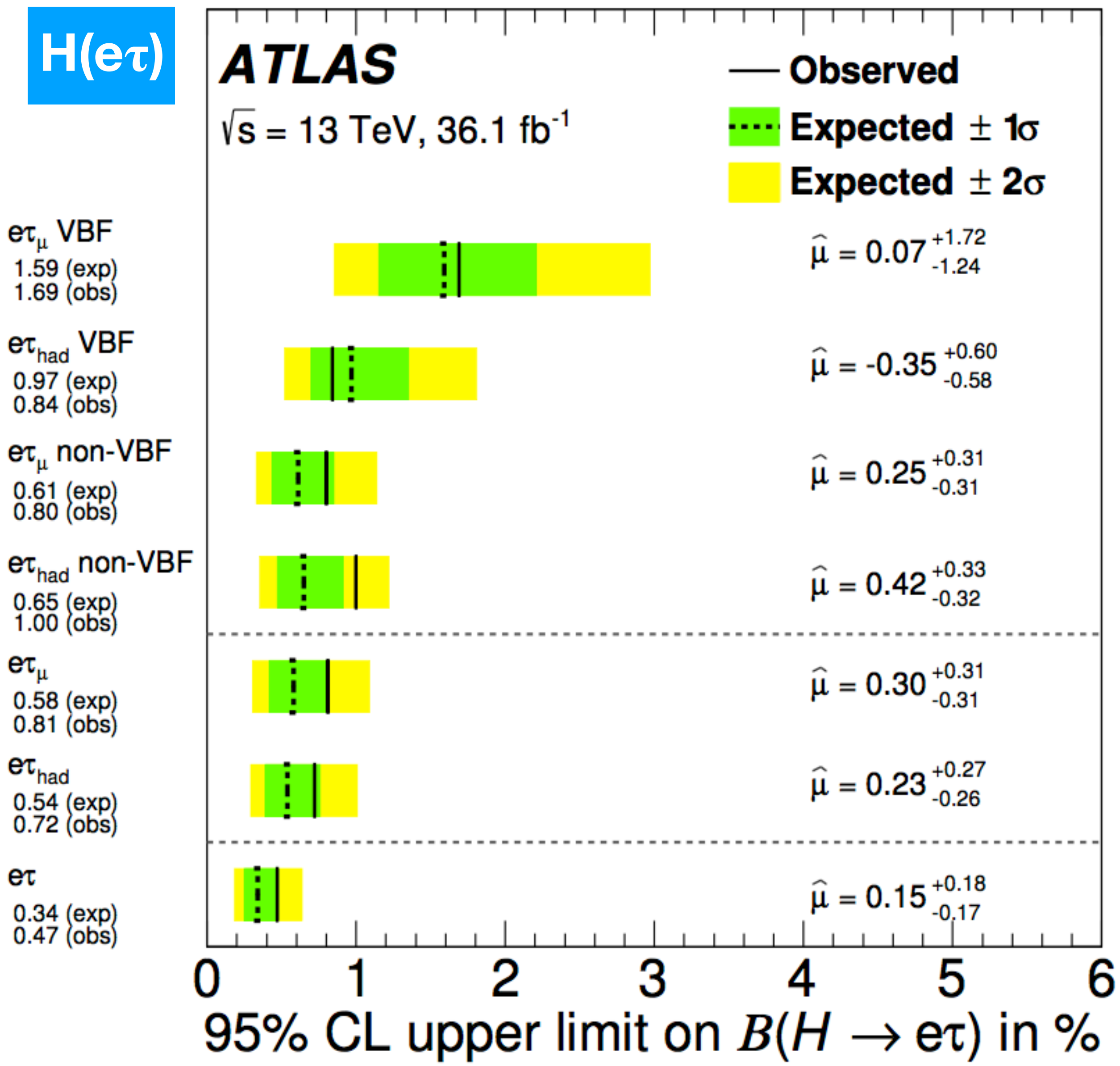
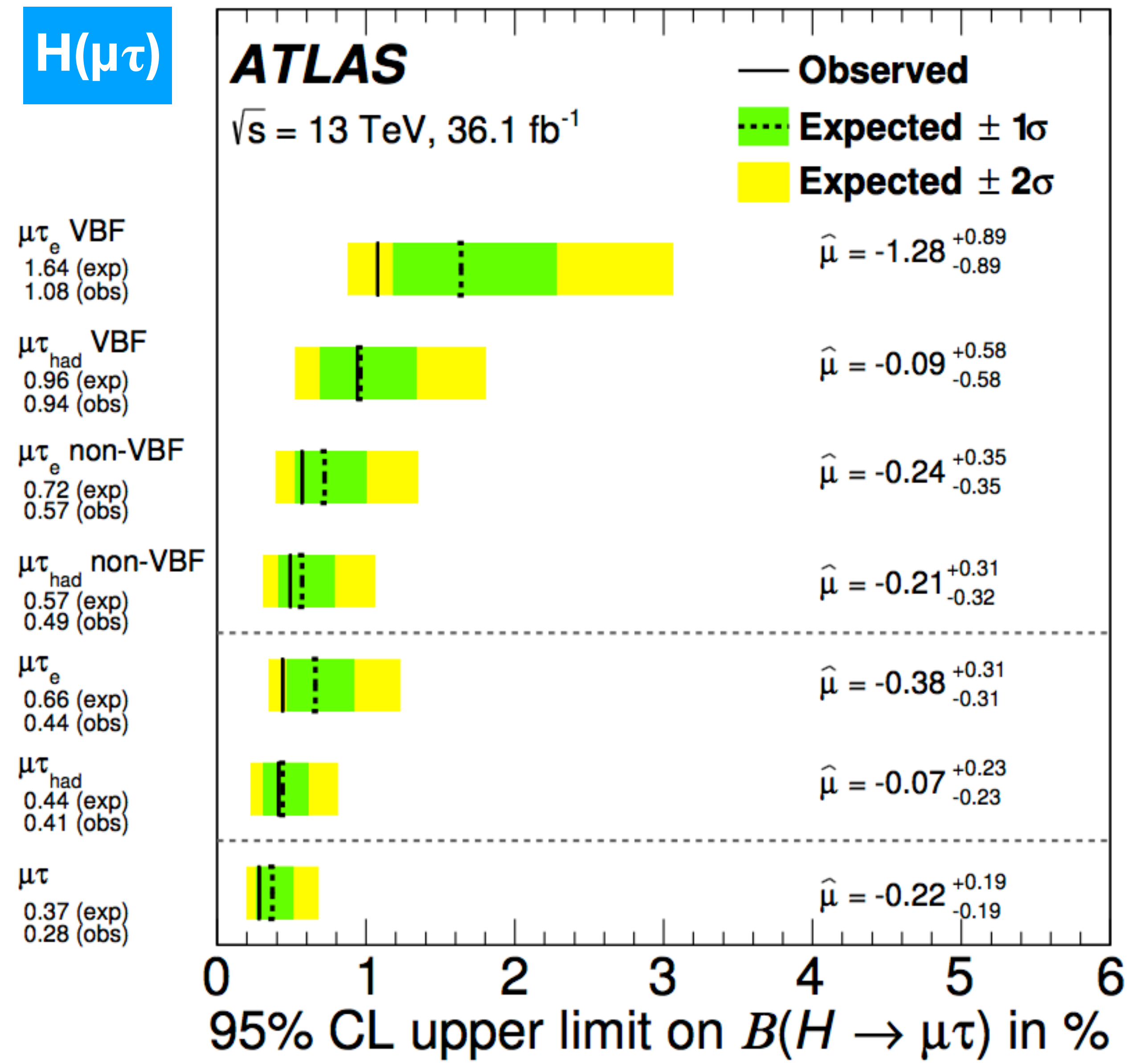
H(eτ)



H(μτ)



95% CL upper limit on BR	H(eτ)	H(μτ)
observed	0.47 %	0.28 %
median expected	$0.34^{+0.13}_{-0.10}$%	$0.37^{+0.14}_{-0.10}$%

Improvement by a factor of 2 (5) over Run-1 ATLAS results for H→eτ (H→μτ) channel

Consistent with CMS upper limits quoted with same 13TeV dataset

Lepton-flavor violation in **Higgs→eμ**

First ATLAS search for LFV Higgs decays in the **eμ** channel: **140fb^{-1} Run-2 data @ 13TeV**
(along with H→ee search)

see Jan Kretzschmar's talk

NEW: submitted to PLB on September 23
HIGG-2018-58

Analysis strategy closely following the H→μμ approach:

- single lepton triggers
- exactly 1 electron + 1 muon ($p_{T(l1)}$>27GeV, $p_{T(l2)}$>15GeV)
- veto extra charged leptons and b-jets
- specific background rejection cuts

Sensitivity increased by split in 8 categories based on S/B:

VBF-like
|Δη|>3
m(jj) > 500GeV

Central-leptons
$|\eta(l_{1,2})| < 1$

Forward-leptons
$|\eta(l_{1,2})| > 1$

⊗

Low p_T^l
15<$p_{T(l2)}$<27GeV
enhanced fake-lepton contribution

Low p_T^{ll}
p_T^{ll} < 15GeV

Medium p_T^{ll}
15 < p_T^{ll} < 50GeV

High p_T^{ll}
p_T^{ll} > 50GeV

Category	S	B	S/B	Data
Central Low $p_T^{\ell\ell}$	210	150	1.35	171
Forward Low $p_T^{\ell\ell}$	400	560	0.72	532
Central Medium $p_T^{\ell\ell}$	250	290	0.86	277
Forward Medium $p_T^{\ell\ell}$	450	830	0.54	854
Central High $p_T^{\ell\ell}$	180	280	0.65	299
Forward High $p_T^{\ell\ell}$	300	700	0.43	707
VBF	83	100	0.82	102
Low p_T^{ℓ}	89	600	0.15	558

*Signal extracted from **simultaneous binned maximum-likelihood fit** across the 8 categories of the observed m(ll) distribution in the 110GeV < m(ll) < 160GeV range*

Lepton-flavor violation in **Higgs→eμ**

Narrow mass peak around m_H=125GeV separates signal from background

- lepton-pair invariant mass described via **analytical functions**: Gaussian+Crystal Ball for signal; Bernstein polynomial for background
- **main background**: Z/γ*→ττ→eμ+ν's, top, diboson, W+jets, multijet events

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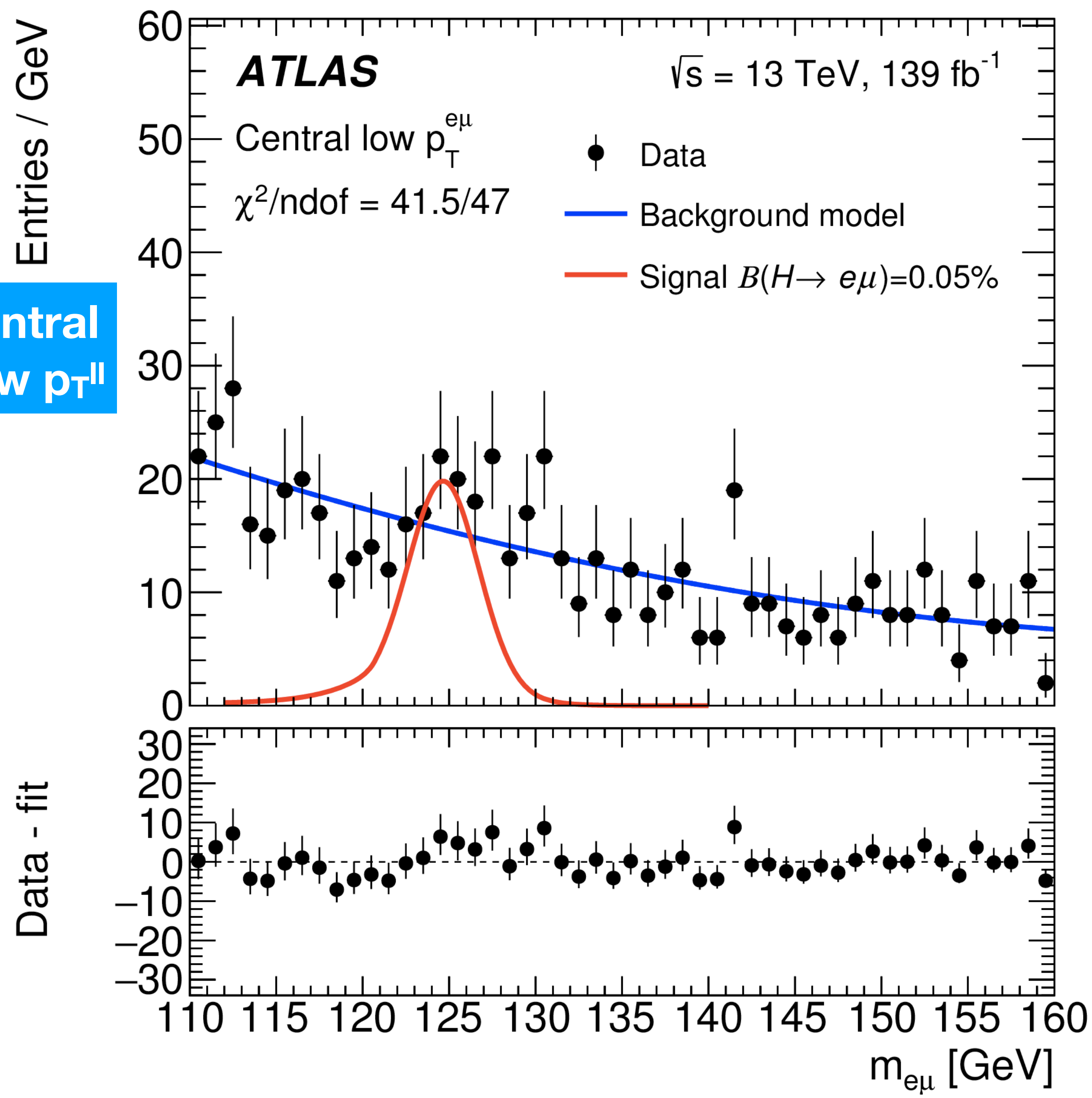
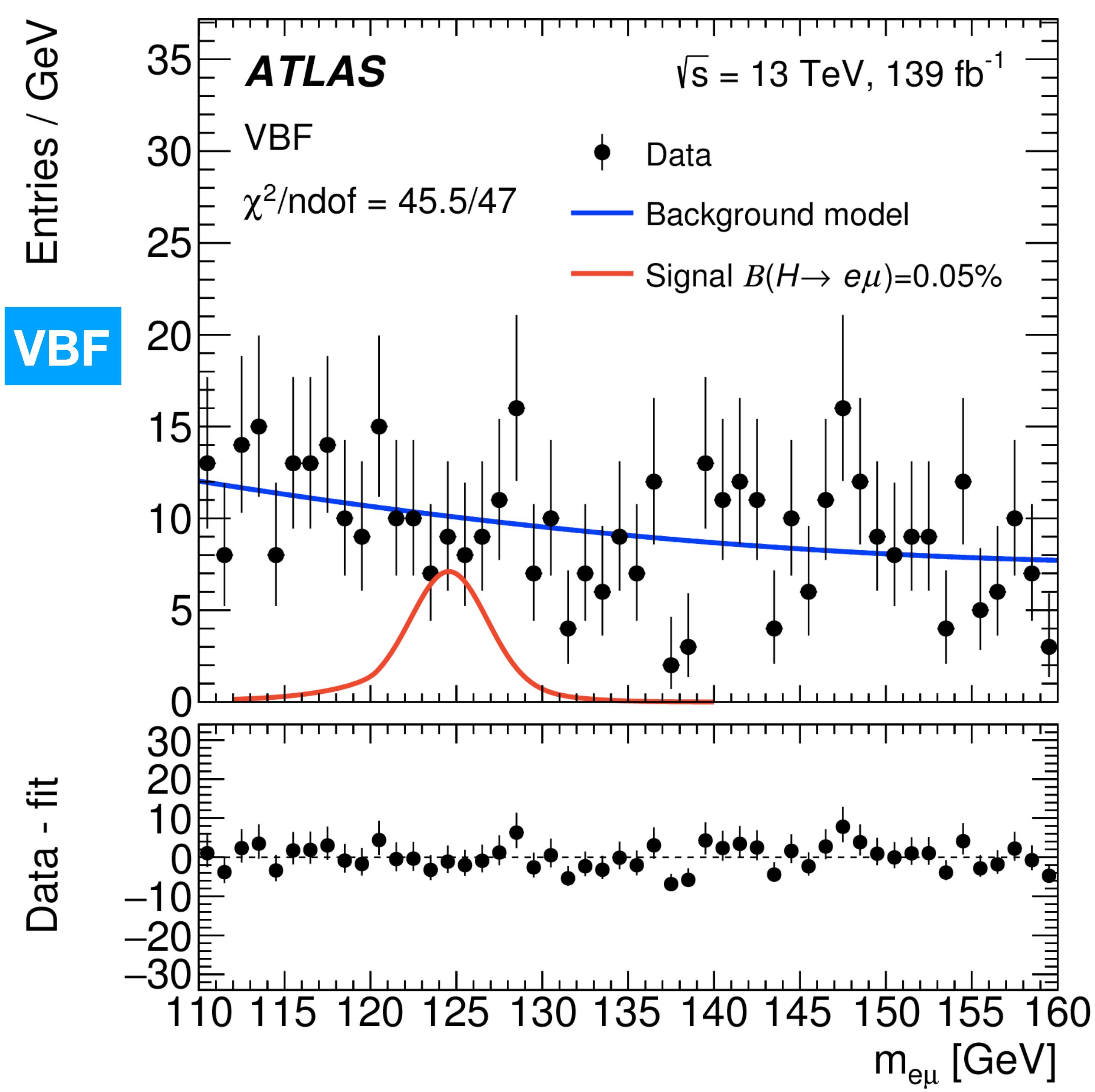
Central Low p_T^{ll}



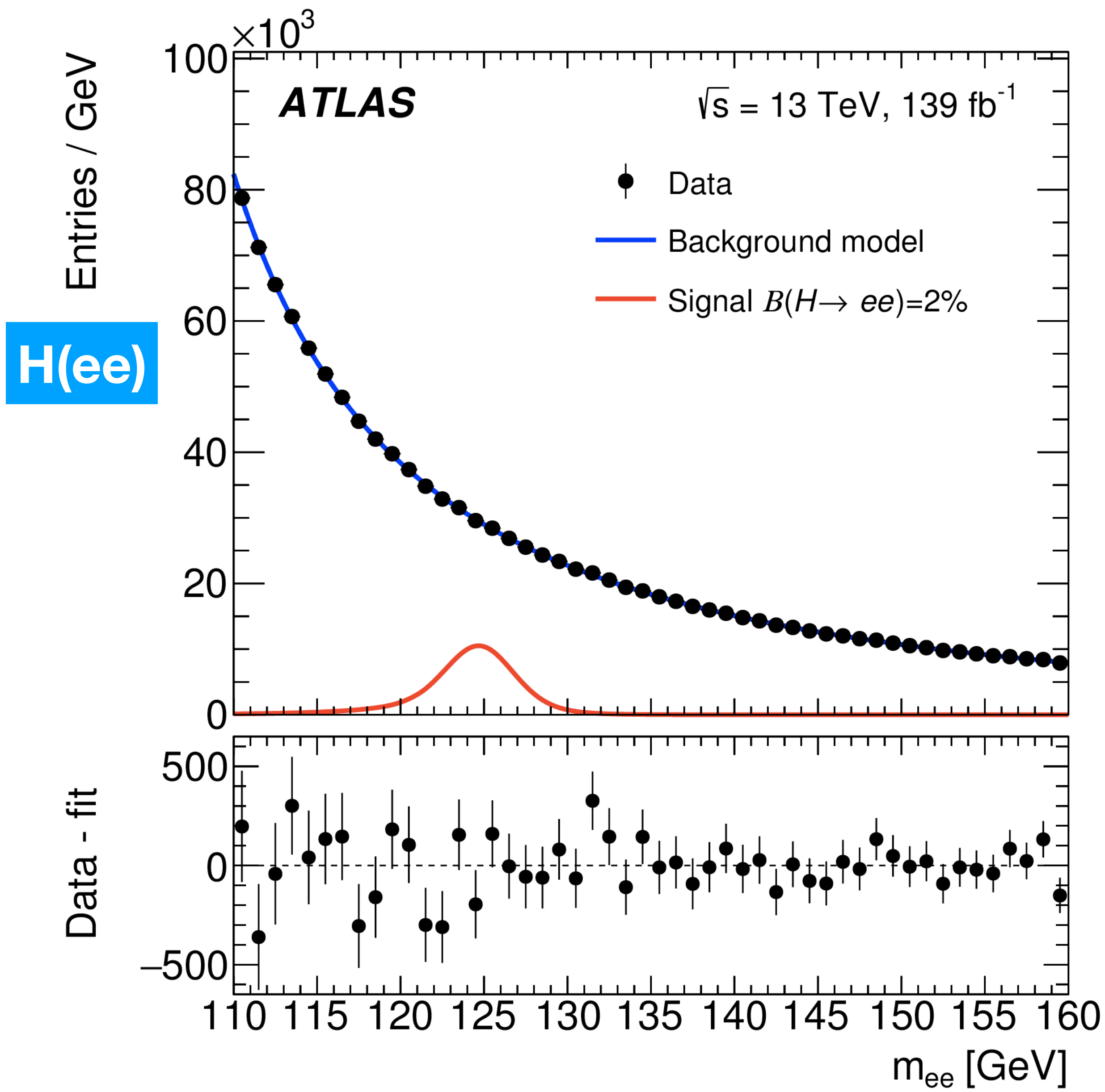
VBF



*Both searches are statistically limited: dominant systematics come from **luminosity**, **E_T^{miss} soft-term**, **pileup effects**, **Higgs TH cross-section** (and jet energy scale and resolution for VBF-like categories)*

Lepton-flavor violation in **Higgs→eμ**

No evidence of lepton-flavor violating Higgs decays in the (eμ) channel
(and no significant evidence of H→ee decays)



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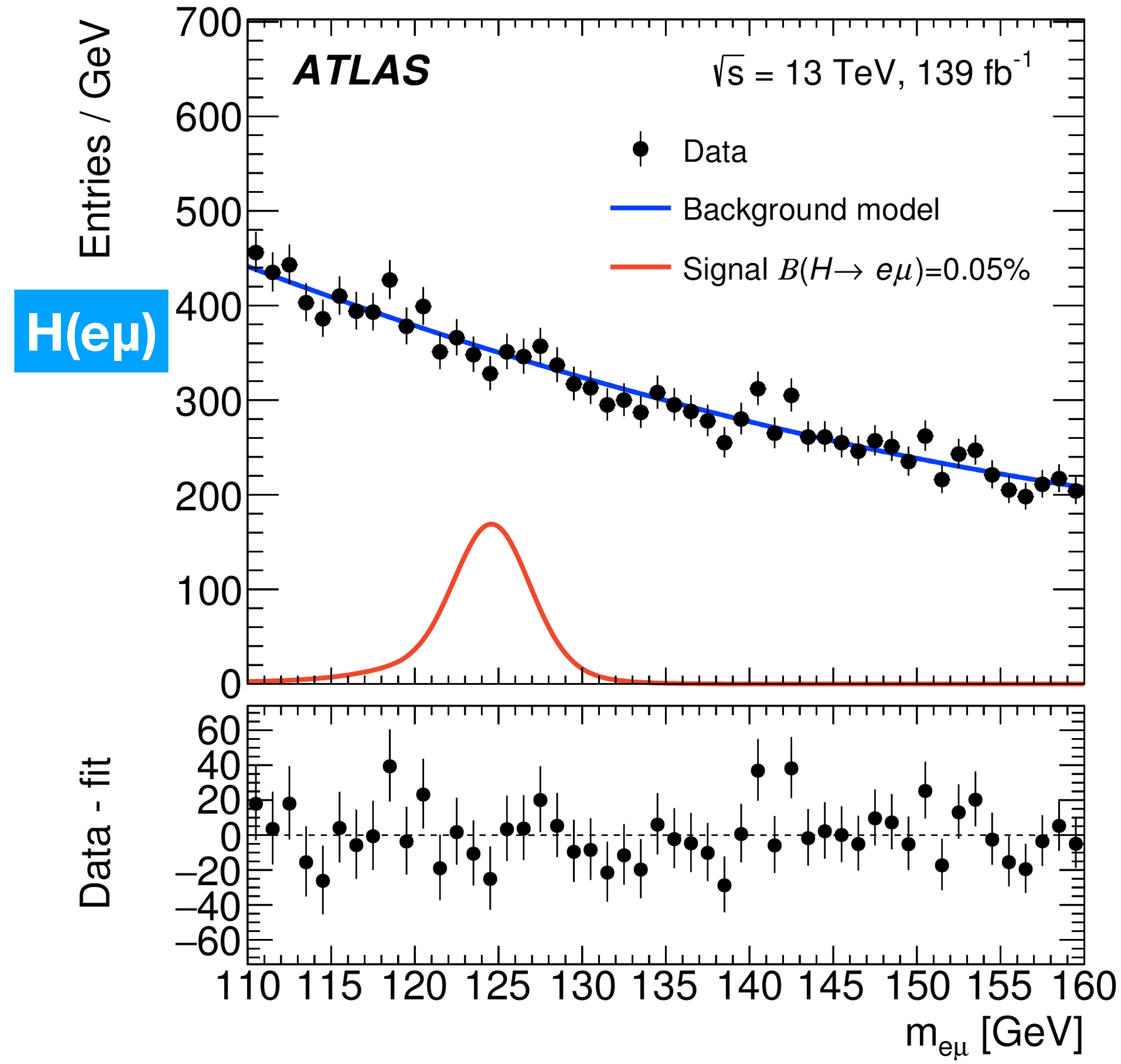


95% CL BR upper limit	H(ee)	H(eμ)
observed	**$3.6 \cdot 10^{-4}$**	$6.1 \cdot 10^{-5}$
expected	**$3.5 \cdot 10^{-4}$**	$5.8 \cdot 10^{-5}$

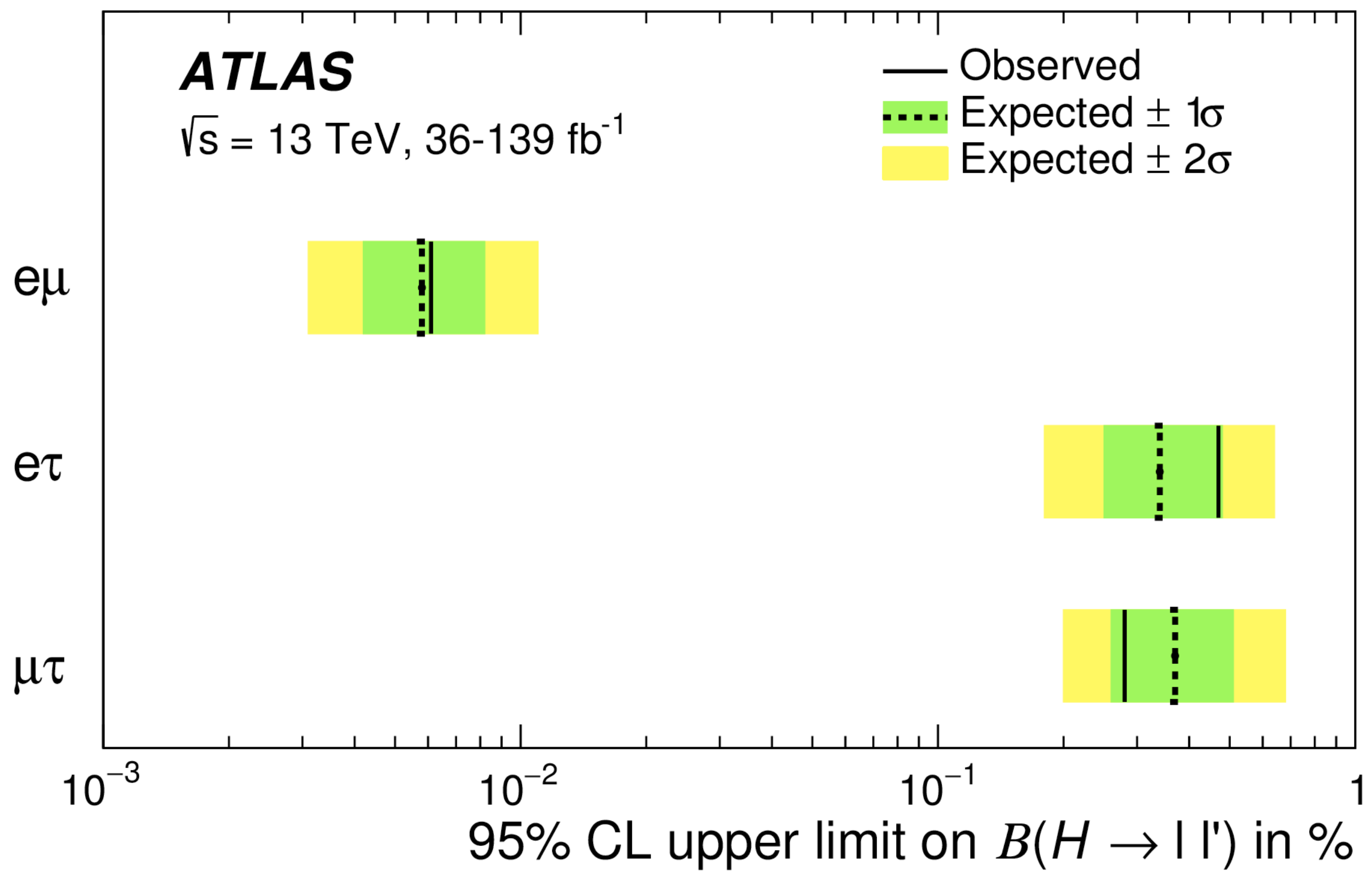
$BR^{best\text{-}fit}(H\to e\mu)$

0.4 ± 2.9 (stat.) $\pm$ 0.3 (syst.) $\cdot 10^{-5}$

Considerable improvement over
*CMS Run-1 BR(eμ) upper limit at **$3.5 \cdot 10^{-4}$***

Conclusions and Outlook

Lepton-flavor violation searches in Higgs decay at ATLAS: Higgs→eτ, μτ, eμ



No significant signs of LFV in Higgs decays so far...

- **H→eτ,μτ important systematic uncertainties,** control over misidentified backgrounds and hadronic jets *[Higgs→lepton+τ now only covering ~1/3 of Run-2 LHC statistics]*
- **H→eμ statistically limited,** moving to larger dataset critical (Run-3 → HL-LHC)
- lepton sector remains highly sensitive to LFV thanks to small Yukawa couplings: important direction to investigate the flavor puzzle of the SM

Looking forward towards Run-3 and HL-LHC data!

Thanks for your attention!

BACK-UP

(All public ATLAS Higgs results are available here)

Lepton-flavor violation in **Higgs→lepton+τ**

Table 2: Baseline event selection and further categorization for the $\ell\tau_{\ell'}$ and $\ell\tau_{\text{had}}$ channels. The same criteria are also used for the control region (CR) definitions in the $\ell\tau_{\ell'}$ channel (Section 5), but one requirement of the baseline selection is inverted to achieve orthogonal event selection. There is no CR in the $\ell\tau_{\text{had}}$ channel.

Selection		$\ell\tau_{\ell'}$	$\ell\tau_{\text{had}}$	
Baseline		exactly $1e$ and 1μ, OS	exactly 1ℓ and $1\tau_{\text{had-vis}}$, OS	
	vs SM Htautau	$p_{\text{T}}^{\ell_1} > 45$ GeV	$p_{\text{T}}^{\ell} > 27.3$ GeV	
		$p_{\text{T}}^{\ell_2} > 15$ GeV	$p_{\text{T}}^{\tau_{\text{had-vis}}} > 25$ GeV, $\lvert\eta^{\tau_{\text{had-vis}}}\rvert < 2.4$	
	vs ttbar / top	$30\,\text{GeV} < m_{\text{vis}} < 150\,\text{GeV}$	$\sum\limits_{i=\ell,\tau_{\text{had-vis}}} \cos\Delta\phi(i, E_{\text{T}}^{\text{miss}}) > -0.35$	vs W+jets
	vs Z(mumu)	$p_{\text{T}}^{e}(\text{track})/p_{\text{T}}^{e}(\text{cluster}) < 1.2$ ($\mu\tau_e$ only)	$\lvert\Delta\eta(\ell, \tau_{\text{had-vis}})\rvert < 2$	vs misidentified bkg
		b-veto (for jets with $p_{\text{T}} > 25$ GeV and $\lvert\eta\rvert < 2.4$)		vs ttbar / top
VBF		Baseline		
		≥ 2 jets, $p_{\text{T}}^{\text{j}_1} > 40$ GeV, $p_{\text{T}}^{\text{j}_2} > 30$ GeV		
		$\lvert\Delta\eta(\text{j}_1, \text{j}_2)\rvert > 3$, $m(\text{j}_1, \text{j}_2) > 400$ GeV		
		–	$p_{\text{T}}^{\tau_{\text{had-vis}}} > 45$ GeV	
Non-VBF		Baseline plus fail VBF categorization		
		$m_{\text{T}}(\ell_1, E_{\text{T}}^{\text{miss}}) > 50$ GeV	–	
		$m_{\text{T}}(\ell_2, E_{\text{T}}^{\text{miss}}) < 40$ GeV	–	
		$\lvert\Delta\phi(\ell_2, E_{\text{T}}^{\text{miss}})\rvert < 1.0$	–	
		$p_{\text{T}}^{\tau}/p_{\text{T}}^{\ell_1} > 0.5$ vs misidentified bkg	–	
Top-quark CR VBF and non-VBF		inverted b-veto: ≥ 1 b-tagged jet ($p_{\text{T}} > 25$ GeV and $\lvert\eta\rvert < 2.4$)		
$Z \to \tau\tau$ CR VBF and non-VBF		inverted $p_{\text{T}}^{\ell_1}$ requirement: $35\,\text{GeV} < p_{\text{T}}^{\ell_1} < 45\,\text{GeV}$		

Lepton-flavor violation in **Higgs→lepton+τ**

Table 3: BDT input variables used in the analysis. For each channel and category, used input variables are marked with HR (indicating the five variables with the highest rank) or a bullet. Analogous variables between the two channels are listed on the same line.

$\ell\tau_{\ell'}$			$\ell\tau_{\text{had}}$		
Variable	VBF	non-VBF	Variable	VBF	non-VBF
m_{MMC}	HR	HR	m_{coll}	HR	HR
$p_T^{\ell_1}$	•	•	p_T^{ℓ}	•	HR
$p_T^{\ell_2}$	HR	HR	$p_T^{\tau_{\text{had-vis}}}$	•	HR
$\Delta R(\ell_1, \ell_2)$	HR	•	$\Delta R(\ell, \tau_{\text{had-vis}})$	•	•
$m_T(\ell_1, E_T^{\text{miss}})$	•	HR	$m_T(\ell, E_T^{\text{miss}})$	HR	•
$m_T(\ell_2, E_T^{\text{miss}})$	HR	•	$m_T(\tau_{\text{had-vis}}, E_T^{\text{miss}})$	HR	HR
$\Delta\phi(\ell_1, E_T^{\text{miss}})$	•	•	$\Delta\phi(\ell, E_T^{\text{miss}})$	HR	•
$\Delta\phi(\ell_2, E_T^{\text{miss}})$		HR	$\Delta\phi(\tau_{\text{had-vis}}, E_T^{\text{miss}})$	•	
$m(j_1, j_2)$	•		$m(j_1, j_2)$	•	
$\Delta\eta(j_1, j_2)$	HR		$\Delta\eta(j_1, j_2)$	•	
$p_T^{\tau}/p_T^{\ell_1}$		HR	$\sum_{i=\ell,\tau_{\text{had-vis}}} \cos\Delta\phi(i, E_T^{\text{miss}})$	•	•
			E_T^{miss}	HR	•
			m_{vis}		HR
			$\Delta\eta(\ell, \tau_{\text{had-vis}})$		•
			η^{ℓ}		•
			$\eta^{\tau_{\text{had-vis}}}$		•
			ϕ^{ℓ}		•
			$\phi^{\tau_{\text{had-vis}}}$		•
			$\phi(E_T^{\text{miss}})$		•

Lepton-flavor violation in **Higgs→lepton+τ**

	$e\tau_\mu$ non-VBF	$e\tau_\mu$ VBF	$e\tau_{\text{had}}$ non-VBF	$e\tau_{\text{had}}$ VBF
Signal	379 ± 31	19.8 ± 2.7	1180 ± 110	25 ± 4
$Z \to \tau\tau$	2470 ± 230	221 ± 34	$73\,800 \pm 1900$	290 ± 40
Top-quark	1640 ± 140	490 ± 40	1580 ± 190	56 ± 12
Mis-identified	1330 ± 250	73 ± 33	$74\,400 \pm 1600$	140 ± 50
$Z \to ee$ (d.d.)			$15\,900 \pm 1800$	82 ± 13
Other	1700 ± 80	220 ± 15	2960 ± 200	
Total background	7130 ± 100	1003 ± 33	$168\,700 \pm 1000$	570 ± 40
Data	7128	992	168 883	572

	$\mu\tau_e$ non-VBF	$\mu\tau_e$ VBF	$\mu\tau_{\text{had}}$ non-VBF	$\mu\tau_{\text{had}}$ VBF
Signal	287 ± 23	14.6 ± 1.9	1200 ± 120	25 ± 5
$Z \to \tau\tau$	1860 ± 130	144 ± 26	$96\,100 \pm 2000$	274 ± 33
Top quark	1260 ± 130	390 ± 34	1620 ± 210	51 ± 10
Misidentified	1340 ± 210	41 ± 21	$63\,900 \pm 1600$	149 ± 33
Other	1180 ± 140	168 ± 18	$23\,000 \pm 1000$	104 ± 15
Total background	5640 ± 100	743 ± 29	$184\,500 \pm 1200$	580 ± 30
Data	5664	723	184 508	583

Lepton-flavor violation in **Higgs→lepton+τ**

Table 6: Summary of the systematic uncertainties and their impact on the best-fit value of $\mathcal{B}$ in the $H \to e\tau$ and $H \to \mu\tau$ searches. The measured values are obtained by the fit to data, while the expected values are determined by the fit to a background-only sample.

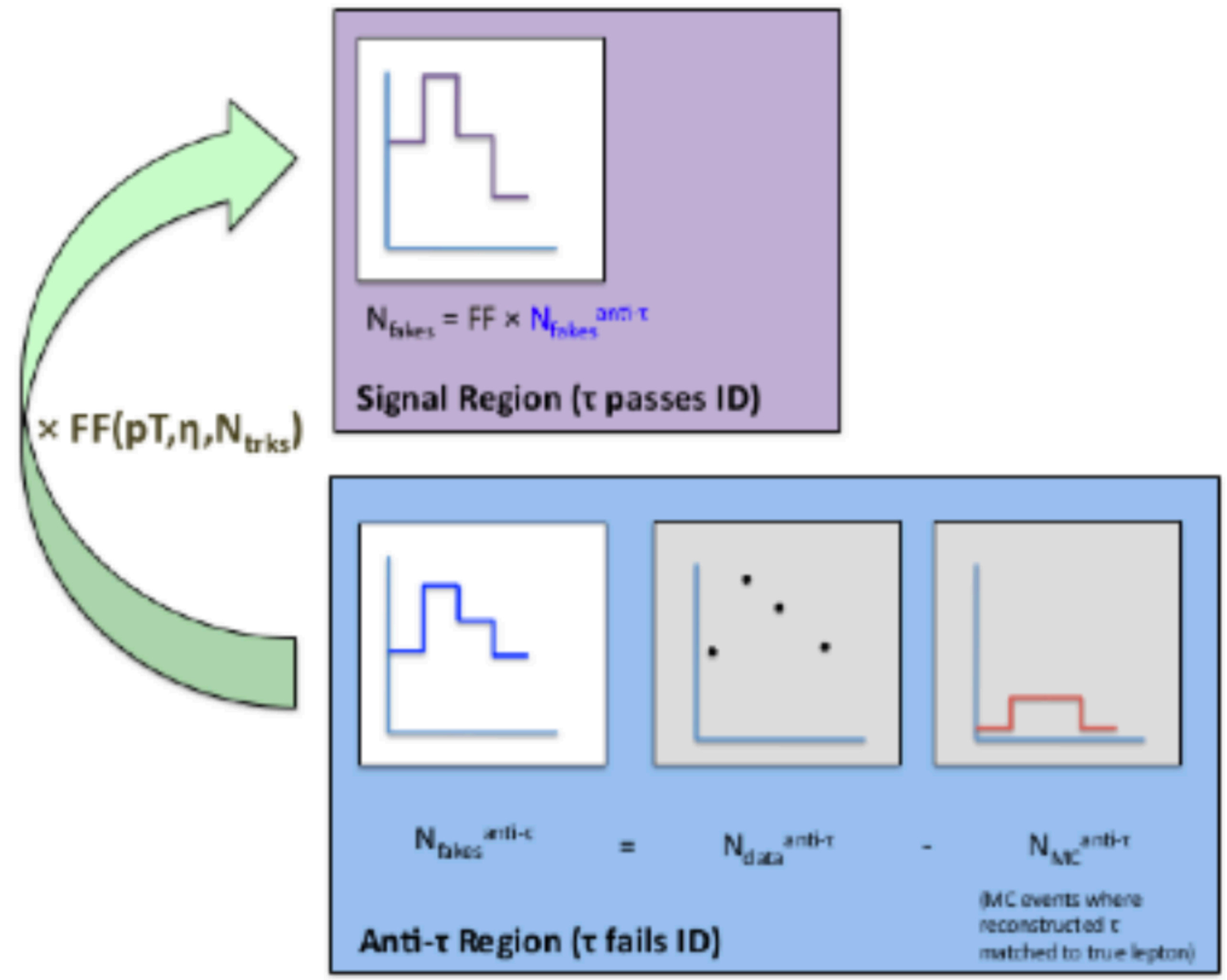
Source of uncertainty	Impact on $\mathcal{B}(H \to e\tau)$ [%] Measured	Impact on $\mathcal{B}(H \to e\tau)$ [%] Expected	Impact on $\mathcal{B}(H \to \mu\tau)$ [%] Measured	Impact on $\mathcal{B}(H \to \mu\tau)$ [%] Expected
Electron	$+0.05/-0.05$	$+0.06/-0.06$	$+0.03/-0.03$	$+0.02/-0.02$
Muon	$+0.04/-0.04$	$+0.04/-0.04$	$+0.10/-0.10$	$+0.08/-0.10$
$\tau_{\text{had-vis}}$	$+0.02/-0.02$	$+0.02/-0.02$	$+0.04/-0.04$	$+0.04/-0.05$
Jet	$+0.09/-0.08$	$+0.09/-0.09$	$+0.11/-0.12$	$+0.11/-0.12$
$E_{\text{T}}^{\text{miss}}$	$+0.02/-0.02$	$+0.02/-0.03$	$+0.05/-0.08$	$+0.03/-0.05$
b-tag	$+0.02/-0.03$	$+0.03/-0.03$	$+0.01/-0.01$	$+0.01/-0.01$
Mis-ID backg. ($\ell\tau_{\ell'}$)	$+0.08/-0.07$	$+0.09/-0.08$	$+0.07/-0.07$	$+0.07/-0.07$
Mis-ID backg. ($\ell\tau_{\text{had}}$)	$+0.12/-0.11$	$+0.11/-0.12$	$+0.11/-0.11$	$+0.10/-0.10$
Pile-up modelling	$+0.02/-0.01$	$+0.01/-0.01$	$+0.05/-0.03$	$+0.08/-0.06$
Luminosity	< 0.01	< 0.01	< 0.01	< 0.01
Background norm.	$+0.05/-0.04$	$+0.05/-0.03$	$+0.04/-0.02$	$+0.05/-0.03$
Theor. uncert. (backg.)	$+0.04/-0.03$	$+0.04/-0.03$	$+0.08/-0.07$	$+0.09/-0.09$
Theor. uncert. (signal)	$+0.01/-0.01$	$+0.01/-0.01$	$+0.04/-0.02$	$+0.02/-0.02$
MC statistics	$+0.04/-0.04$	$+0.03/-0.03$	$+0.04/-0.04$	$+0.05/-0.04$
Full systematic	$+0.17/-0.16$	$+0.17/-0.17$	$+0.18/-0.18$	$+0.19/-0.20$
Data statistics	$+0.07/-0.07$	$+0.07/-0.07$	$+0.07/-0.07$	$+0.08/-0.08$
Total	$+0.18/-0.17$	$+0.18/-0.18$	$+0.19/-0.19$	$+0.20/-0.21$

Lepton-flavor violation in **Higgs→lepton+τ**

$$N^{\mathrm{ID}}_{j\to\tau} = (N^{\mathrm{anti-ID}}_{\mathrm{data}} - N^{\mathrm{anti-ID}}_{\mathrm{MC,not\,j\to\tau}}) \times FF$$

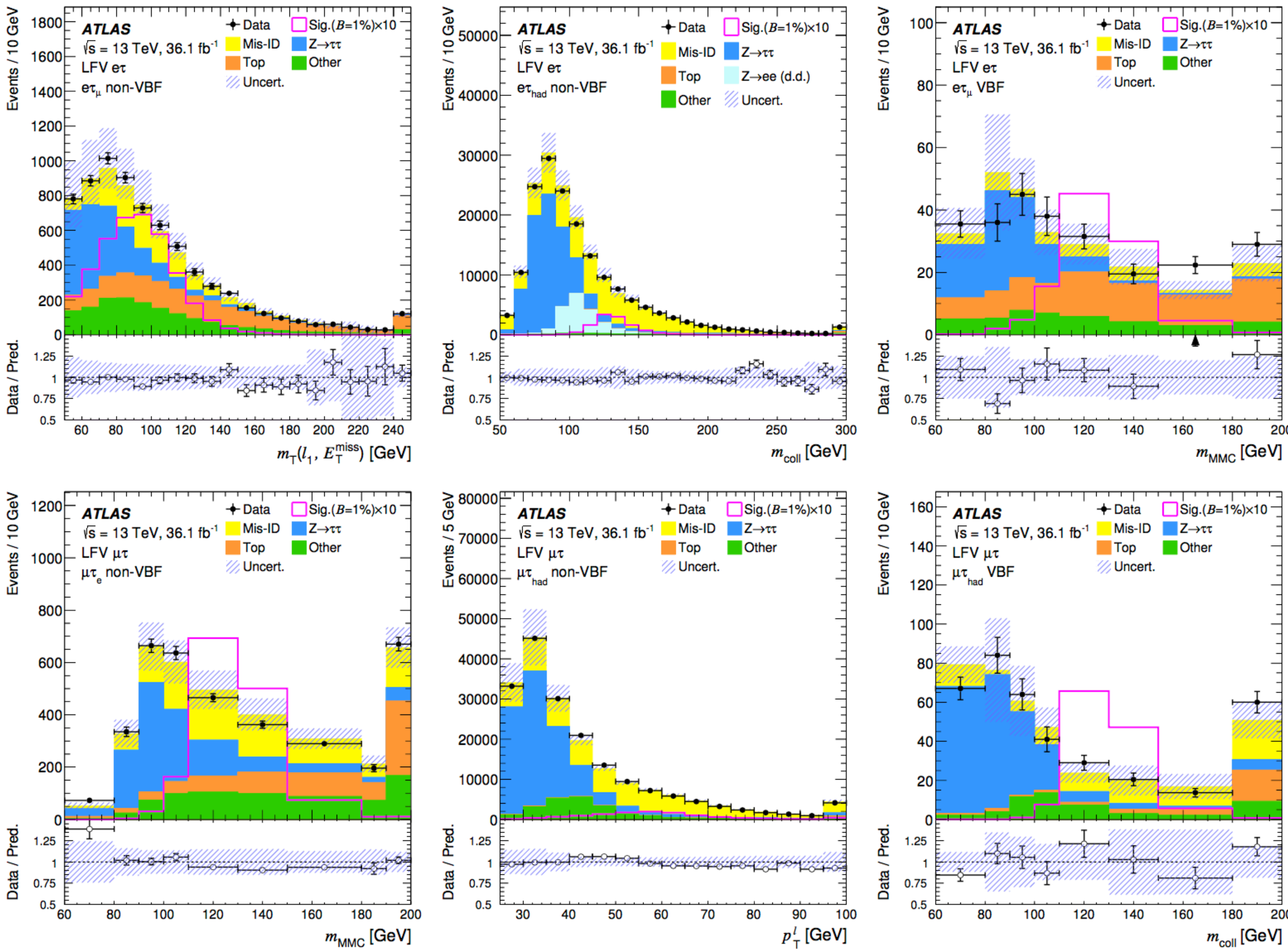
$$FF = R_{\mathrm{W}} \times FF_{\mathrm{W}} + R_{\mathrm{QCD}} \times FF_{\mathrm{QCD}}$$

$$FF_i = \frac{N^{\mathrm{ID}}_{\mathrm{data,CR_i}} - N^{\mathrm{ID}}_{\mathrm{MC,not\,j\to\tau,CR_i}}}{N^{\mathrm{anti-ID}}_{\mathrm{data,CR_i}} - N^{\mathrm{anti-ID}}_{\mathrm{MC,not\,j\to\tau,CR_i}}}$$



- uncertainty on individual FFs estimate (stat. term quite relevant)
- uncertainty on estimate of Rqcd from data
- stat. unc. in anti-ID region (where FFs are applied)

Lepton-flavor violation in **Higgs→lepton+τ**



Lepton-flavor violation in **Higgs→lepton+τ**

$$|Y_{\ell\tau}|^2 + |Y_{\tau\ell}|^2 = \frac{8\pi}{m_H} \frac{\mathcal{B}(H \to \ell\tau)}{1 - \mathcal{B}(H \to \ell\tau)} \Gamma_H(\mathrm{SM}),$$

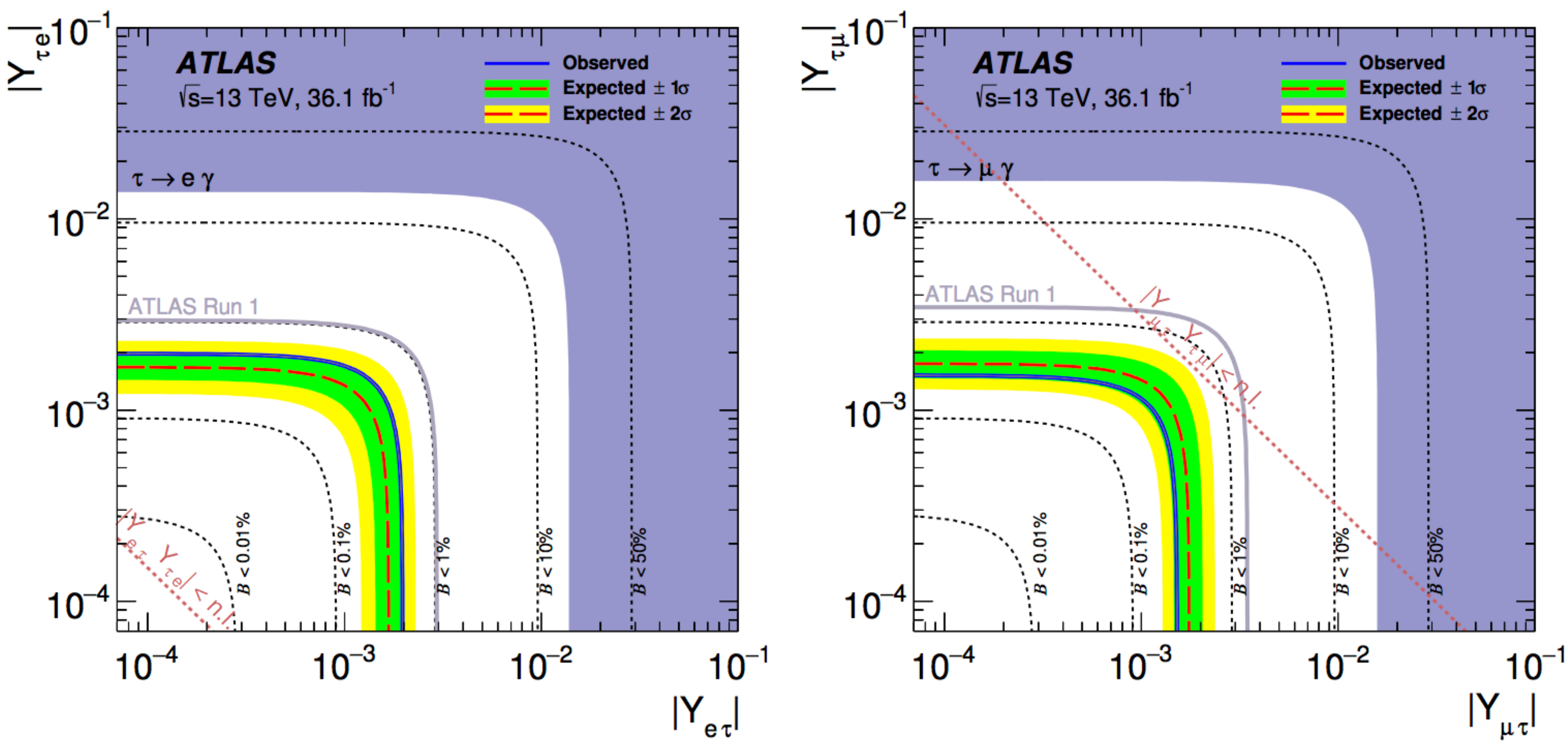


Figure 5: Upper limits on the absolute value of the couplings $Y_{\tau\ell}$ and $Y_{\ell\tau}$ together with the limits from the ATLAS Run 1 analysis (light grey line) and the most stringent indirect limits from $\tau \to \ell\gamma$ searches (dark purple region). Also indicated are limits corresponding to different branching ratios (0.01%, 0.1%, 1%, 10% and 50%) and the naturalness limit (denoted n.l.) $|Y_{\tau\ell}Y_{\ell\tau}| \lesssim \frac{m_\tau m_\ell}{v}$ [84] where v is the vacuum expectation value of the Higgs field.

Lepton-flavor violation in **Higgs→eμ**

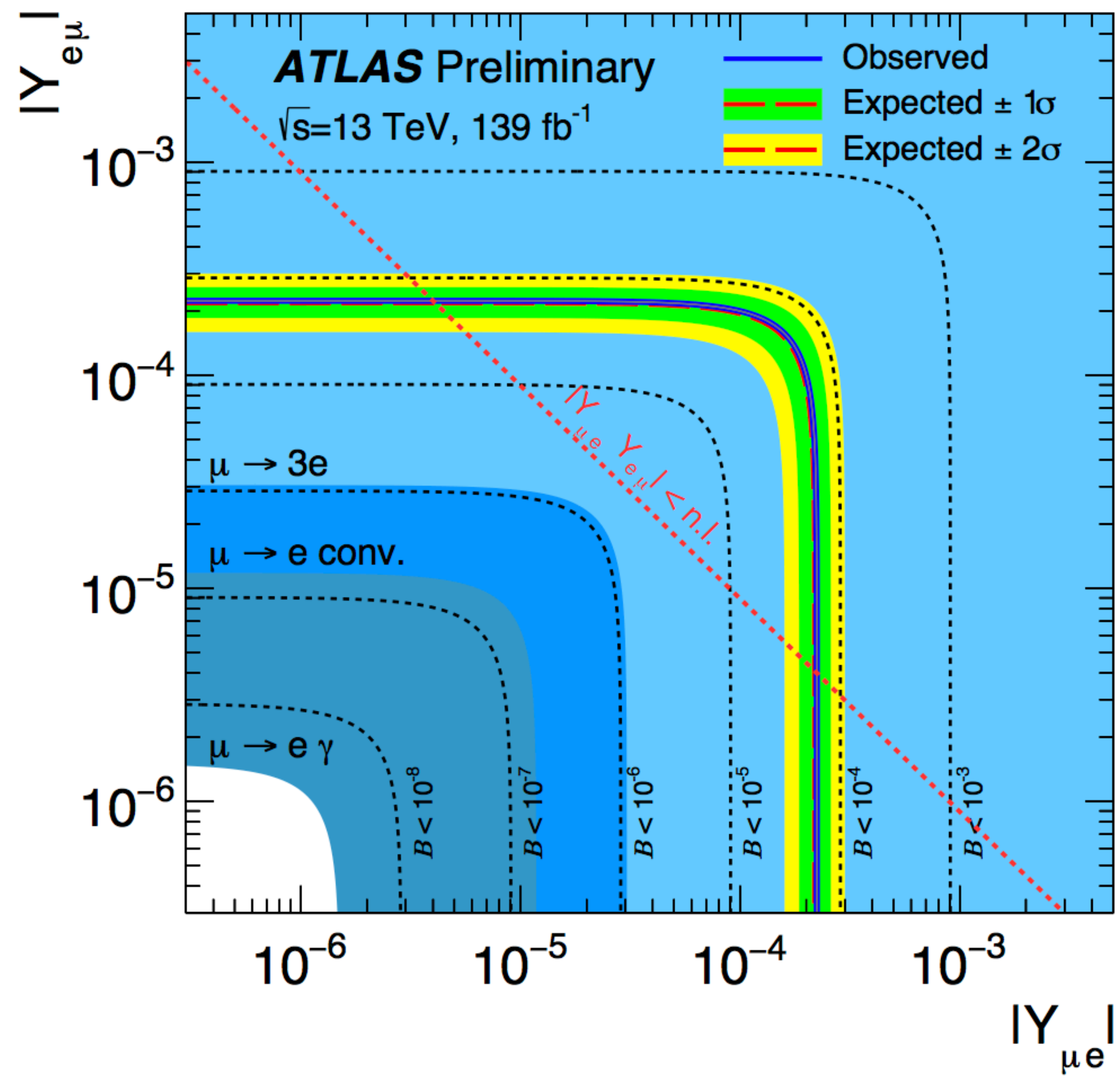


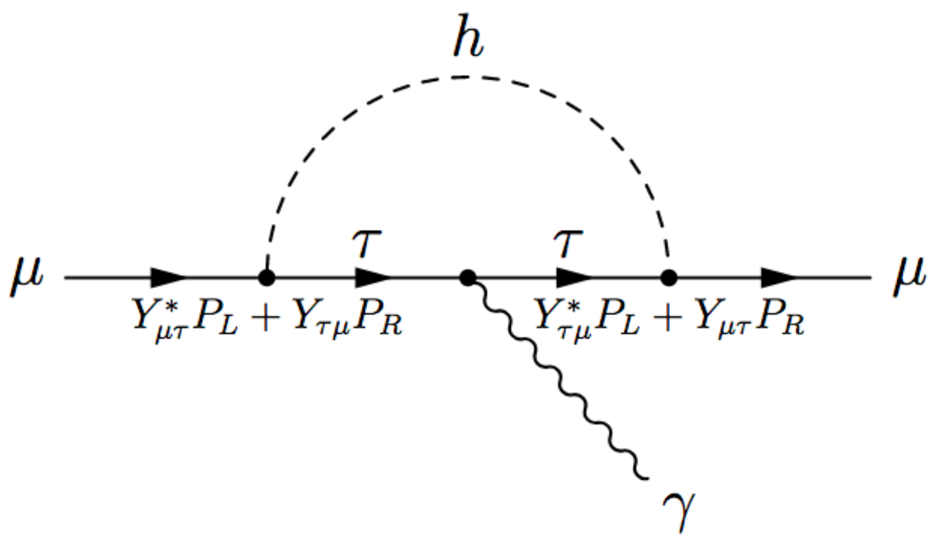
Figure 5: Constraints on the flavour violating Yukawa couplings $Y_{e\mu}$ and $Y_{\mu e}$ that are related to the branching ratio of the LFV Higgs boson decay $\mathcal{B}(H \to e\mu)$ following Ref. [19] as $|Y_{e\mu}|^2 + |Y_{\mu e}|^2 = 8\pi\Gamma_H^{\mathrm{SM}}/m_H \cdot \mathcal{B}(H \to e\mu)/(1 - \mathcal{B}(H \to e\mu))$, where $m_H = 125.09$ GeV and $\Gamma_H^{\mathrm{SM}} = 4.07$ MeV are the mass and SM width of the Higgs boson. The expected (red dashed line) and observed (blue solid line) limits are derived from the limits on $\mathcal{B}(H \to e\mu)$ from the present analysis. The green (yellow) band indicates the range that is expected to contain 68% (95%) of all observed limit excursions. The shaded regions show the indirect constraints derived using the model calculations of Ref. [19] from null searches for $\mu \to e\gamma$ [93], $\mu \to 3e$ [94] and $\mu \to e$ conversions on gold nuclei [95]. For these calculations the flavour diagonal Yukawa couplings are taken to be the SM values. The diagonal line indicates the so-called naturalness limit $|Y_{e\mu}Y_{\mu e}| < m_e m_\mu/v^2$, where $v = 246$ GeV is the vacuum expectation value of the Higgs field.

Limits from low-energy measurements

1209.1397

Channel	Coupling	Bound
$\mu \to e\gamma$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 3.6 \times 10^{-6}$
$\mu \to 3e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$\lesssim 3.1 \times 10^{-5}$
electron $g-2$	$\mathrm{Re}(Y_{e\mu}Y_{\mu e})$	$-0.019 \ldots 0.026$
electron EDM	$\lvert\mathrm{Im}(Y_{e\mu}Y_{\mu e})\rvert$	$< 9.8 \times 10^{-8}$
$\mu \to e$ conversion	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 1.2 \times 10^{-5}$
M-$\bar{M}$ oscillations	$\lvert Y_{\mu e} + Y_{e\mu}^*\rvert$	< 0.079
$\tau \to e\gamma$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	< 0.014
$\tau \to 3e$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	$\lesssim 0.12$
electron $g-2$	$\mathrm{Re}(Y_{e\tau}Y_{\tau e})$	$[-2.1 \ldots 2.9] \times 10^{-3}$
electron EDM	$\lvert\mathrm{Im}(Y_{e\tau}Y_{\tau e})\rvert$	$< 1.1 \times 10^{-8}$
$\tau \to \mu\gamma$	$\sqrt{\lvert Y_{\tau\mu}\rvert^2 + \lvert Y_{\mu\tau}\rvert^2}$	0.016
$\tau \to 3\mu$	$\sqrt{\lvert Y_{\tau\mu}^2 + \lvert Y_{\mu\tau}\rvert^2}$	$\lesssim 0.25$
muon $g-2$	$\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu})$	$(2.7 \pm 0.75) \times 10^{-3}$
muon EDM	$\mathrm{Im}(Y_{\mu\tau}Y_{\tau\mu})$	$-0.8 \ldots 1.0$
$\mu \to e\gamma$	$\left(\lvert Y_{\tau\mu}Y_{e\tau}\rvert^2 + \lvert Y_{\mu\tau}Y_{\tau e}\rvert^2\right)^{1/4}$	$< 3.4 \times 10^{-4}$

Limits from low-energy measurements



Flavor violating contributions from the Higgs-tau loop:

$$a_\mu \equiv \frac{g_\mu - 2}{2} \simeq \frac{\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu})}{8\pi^2}\frac{m_\mu m_\tau}{2m_h^2}\left(2\log\frac{m_h^2}{m_\tau^2} - 3\right),$$

$$\Delta a_\mu \equiv a_\mu^{\mathrm{exp}} - a_\mu^{\mathrm{SM}} = (2.87 \pm 0.63 \pm 0.49) \times 10^{-9},$$

Requires the non-diagonal mu-tau Yukawa to be 3-4 larger than the diagonal tau Yukawa term, tension with limits from tau->mu+gamma

$$\mathrm{Re}(Y_{\mu\tau}Y_{\tau\mu}) \simeq (2.7 \pm 0.75) \times 10^{-3},$$

Possible explanation from enhanced flavor-conserving coupling of muon to Higgs boson (x 280), already ruled out by LHC direct searches

Beyond LHC ...

Briefing Book for the 2020 European Strategy Particle Physics Update

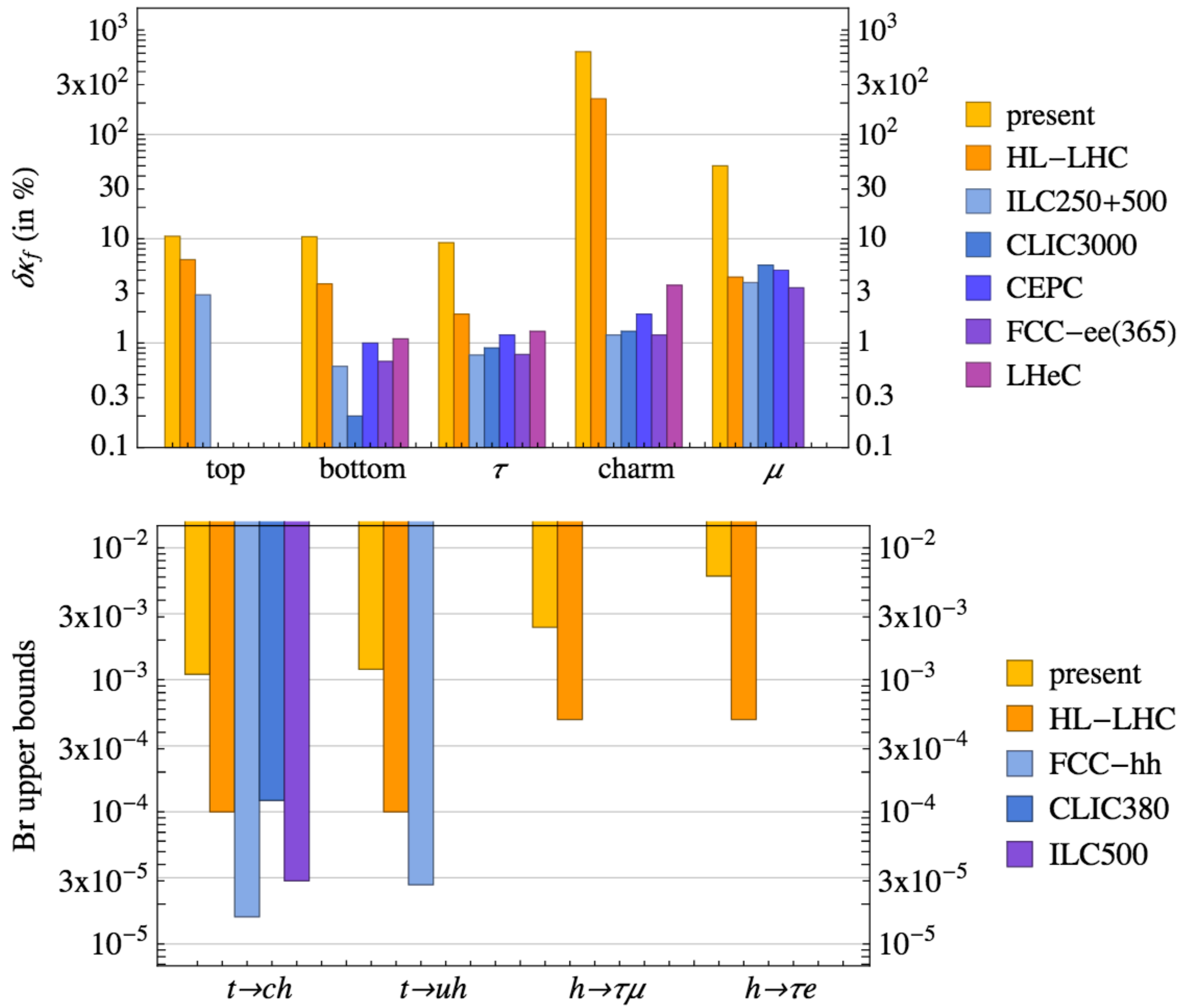


Fig. 5.12: Summary of the available projections for measurements of Higgs Yukawa couplings to quarks and leptons (upper panel), and on select flavour violating decays (lower panel), adapted from Ref. [337] with further input from Refs. [338] and [339].

HL-LHC projections

H(μμ)

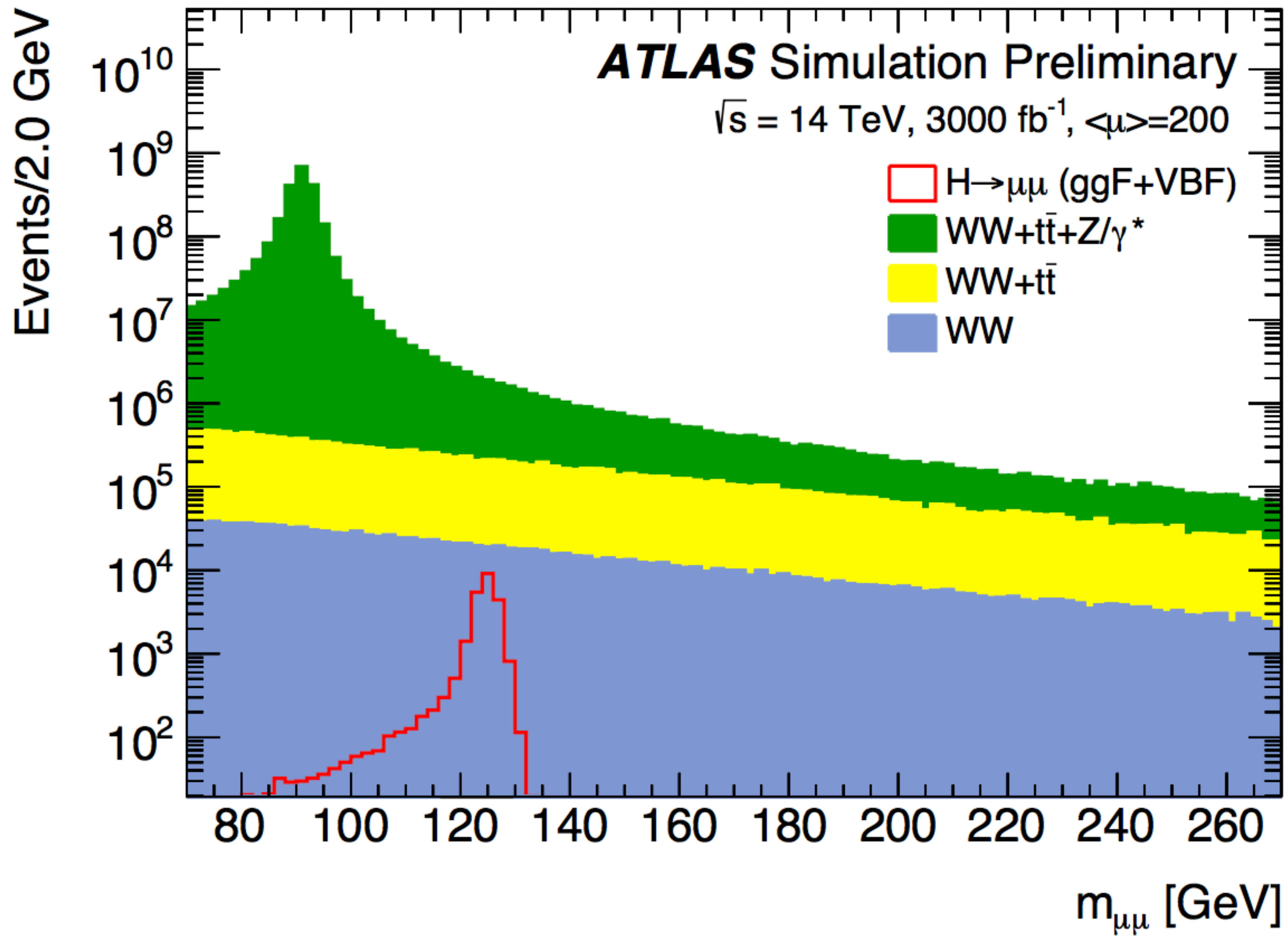


Figure 6: Invariant mass distribution of selected signal and background candidates, scaled to 3000 fb^{-1}, for the reference detector scenario, assuming $\langle\mu\rangle = 200$.

Table 6: The table compares the overall significance and signal strength uncertainty achievable with 3000 fb^{-1} in the three different detector scenarios defined in the ATLAS Scoping Document, based on the event categories defined in the text.

Scoping Scenario	$\langle\mu\rangle$	Overall significance	$\Delta\mu$ w/ syst. errors	$\Delta\mu$ w/o syst. errors
reference	200	9.5	±0.13	±0.12
middle	200	9.4	±0.14	±0.12
low	200	9.2	±0.14	±0.13

Higgs Lepton Flavor Violation

$$-\Delta\mathcal{L} = Y_{ij}^{(0)}\ H\ \bar{L}_{Li} l_{Rj} + Y_{ij}^{(1)} \frac{H^\dagger H}{M^2}\ H\ \bar{L}_{Li} l_{Rj} +\ \dots\ +\ \text{h.c.}\ ,$$

Higher dimensional operators affecting lepton masses, involving Higgs field

Resulting lepton mass and Higgs coupling matrices misaligned in flavor space → Flavor violation mediated by Higgs boson

$$Y_{ij} = Y_{ij}^{(0)} + Y_{ij}^{(1)} \frac{H^\dagger H}{M^2}\ .$$

Higgs-dependent Yukawa interactions

$$M_{ij} = v\left(Y_{ij}^{(0)} + Y_{ij}^{(1)} \frac{v^2}{M^2}\right)$$

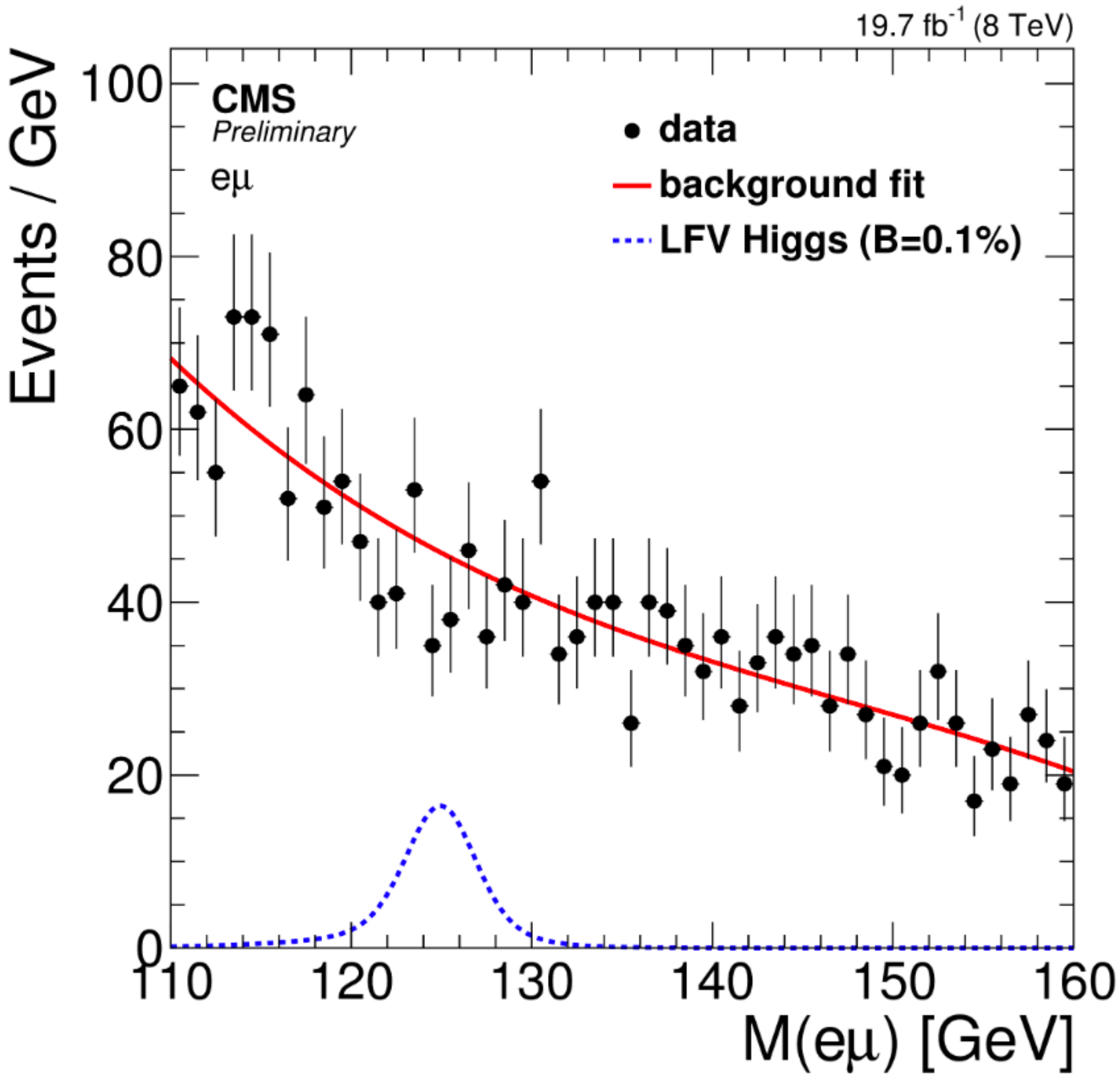
Lepton mass matrix

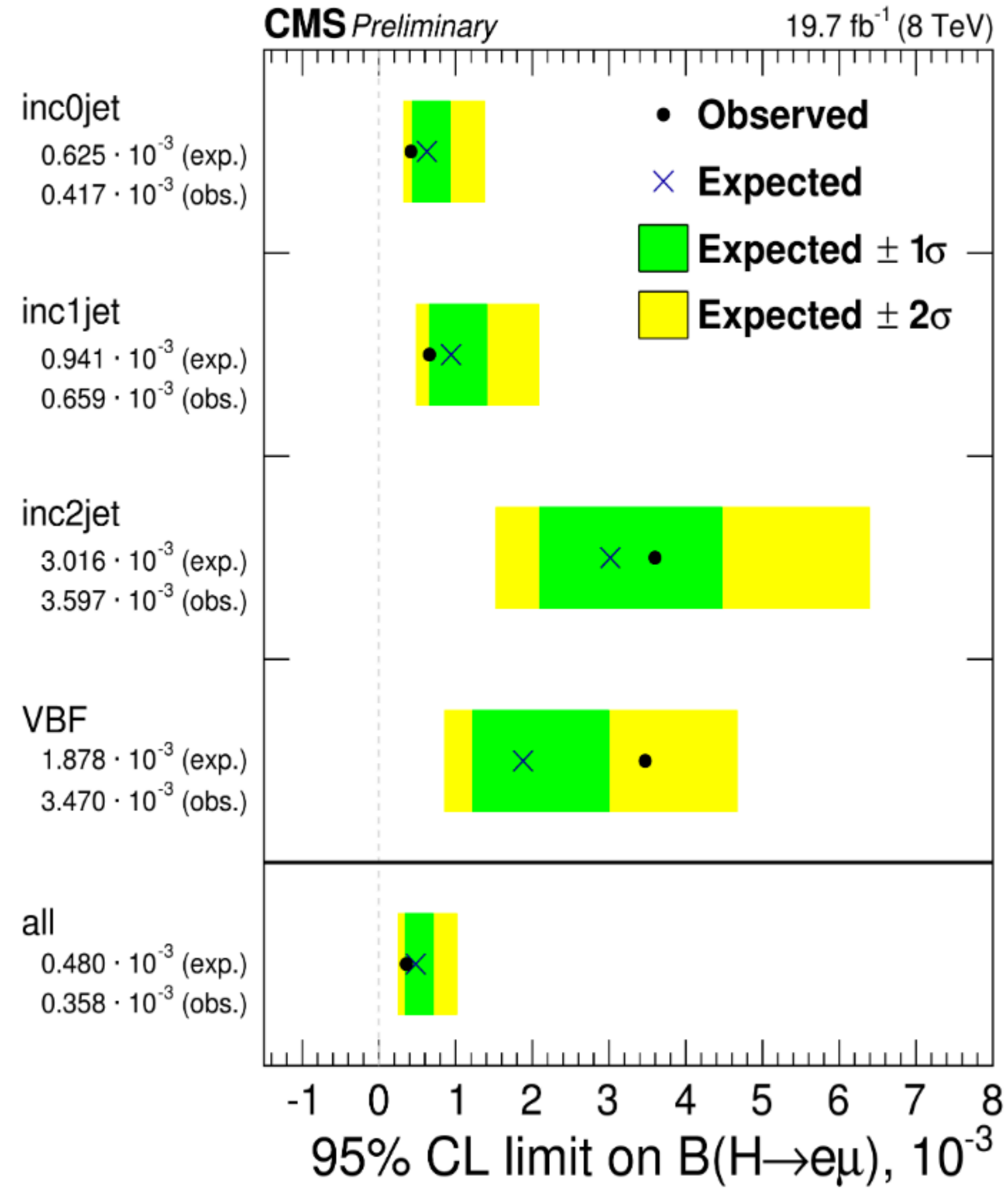
$$\mathcal{Y}_{ij} = Y_{ij}^{(0)} + 3Y_{ij}^{(1)} \frac{v^2}{M^2}$$

Higgs coupling matrix

https://arxiv.org/pdf/1111.1715.pdf

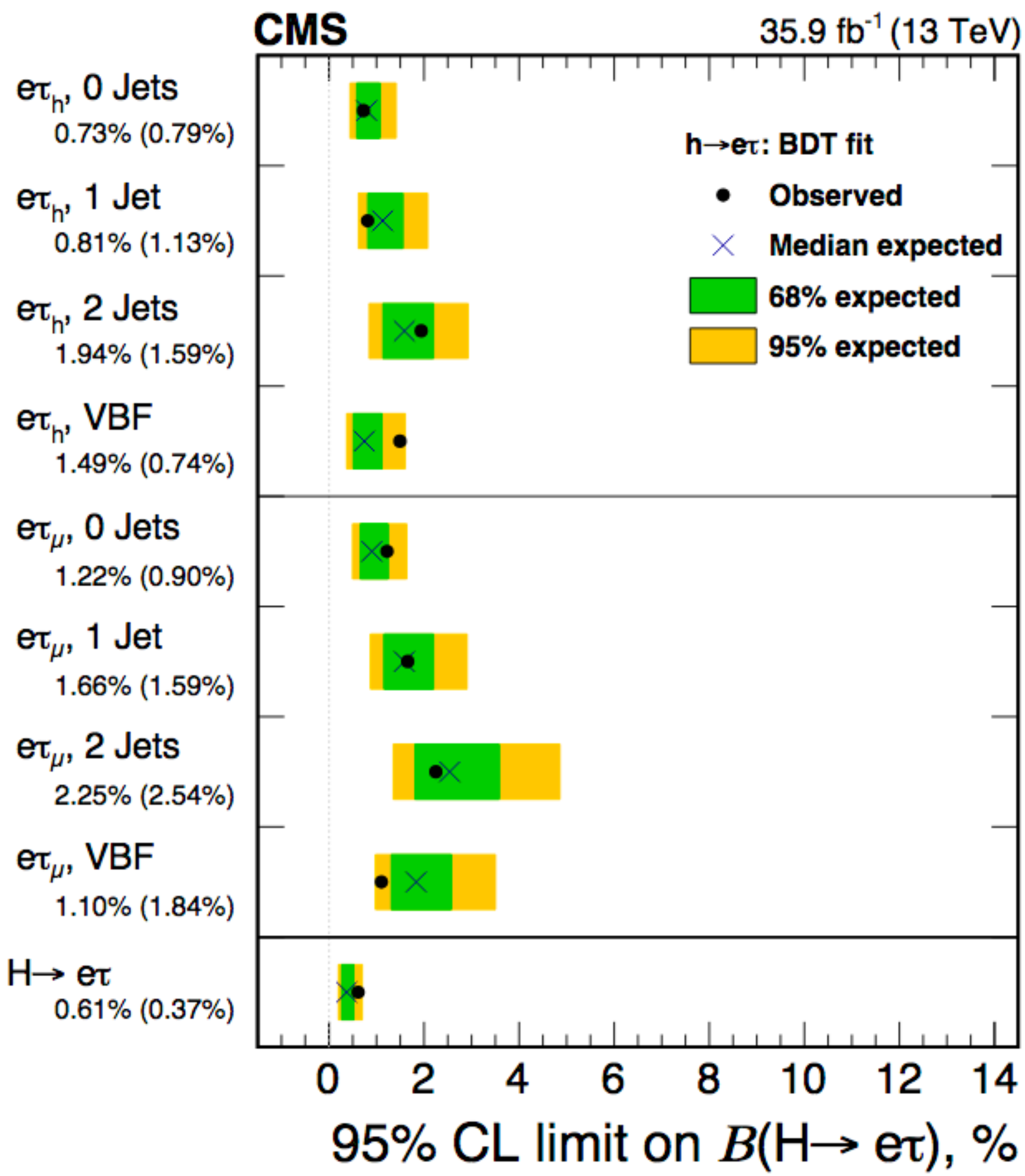
CMS: Lepton-flavor violation in **Higgs→eμ**

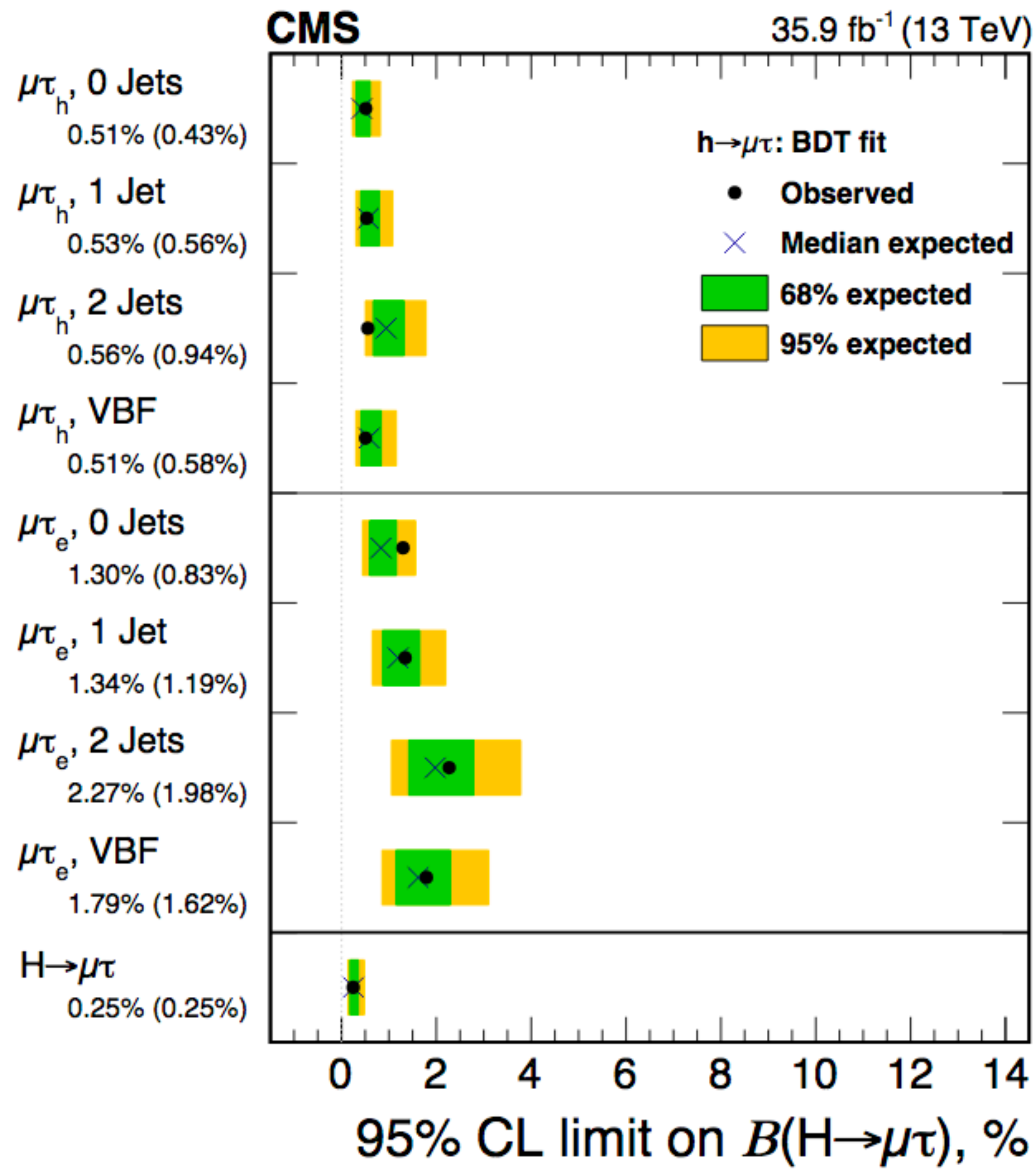




BR(H→eμ)<0.036%

CMS:Lepton-flavor violation in **Higgs→lepton+τ**

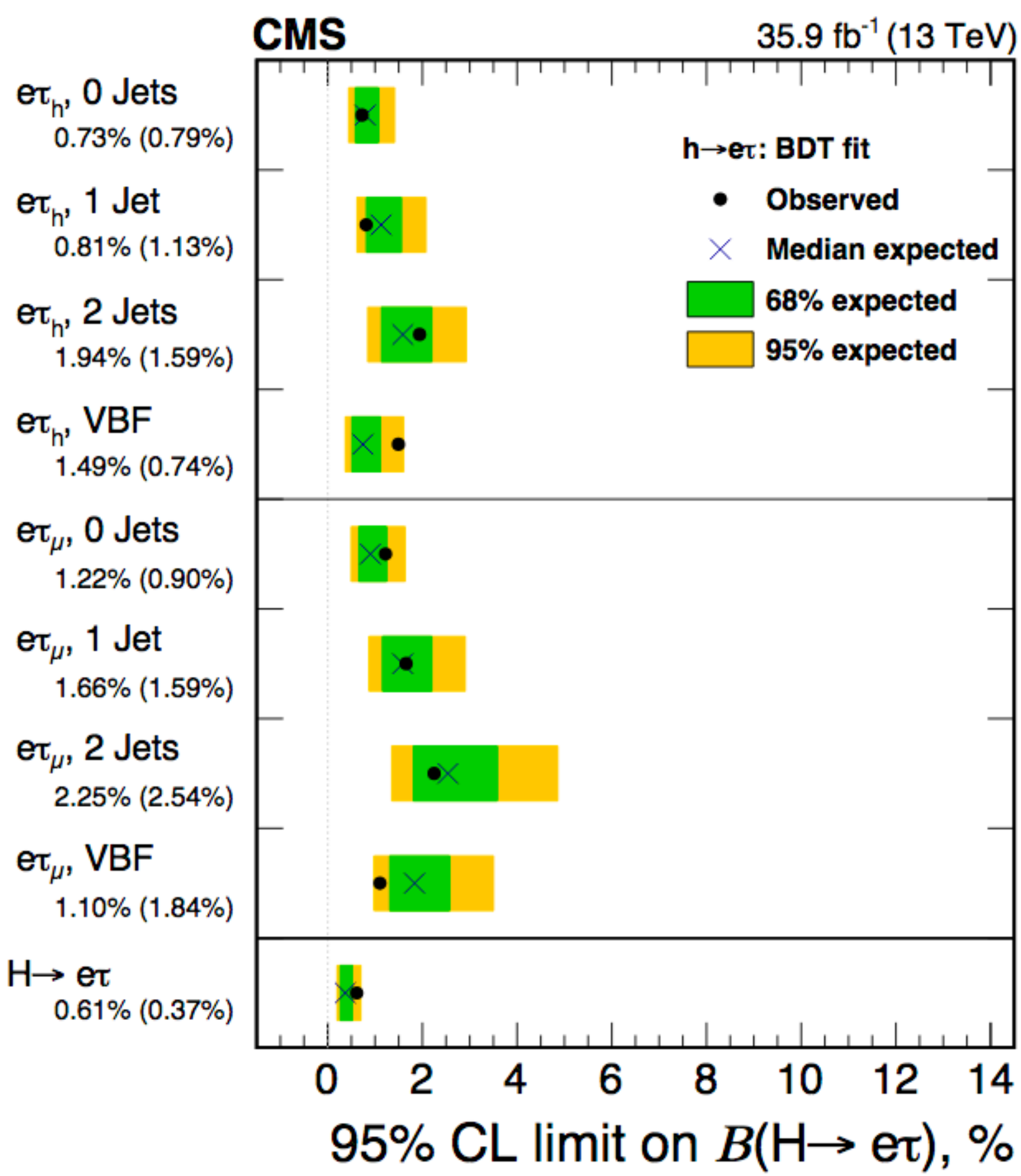


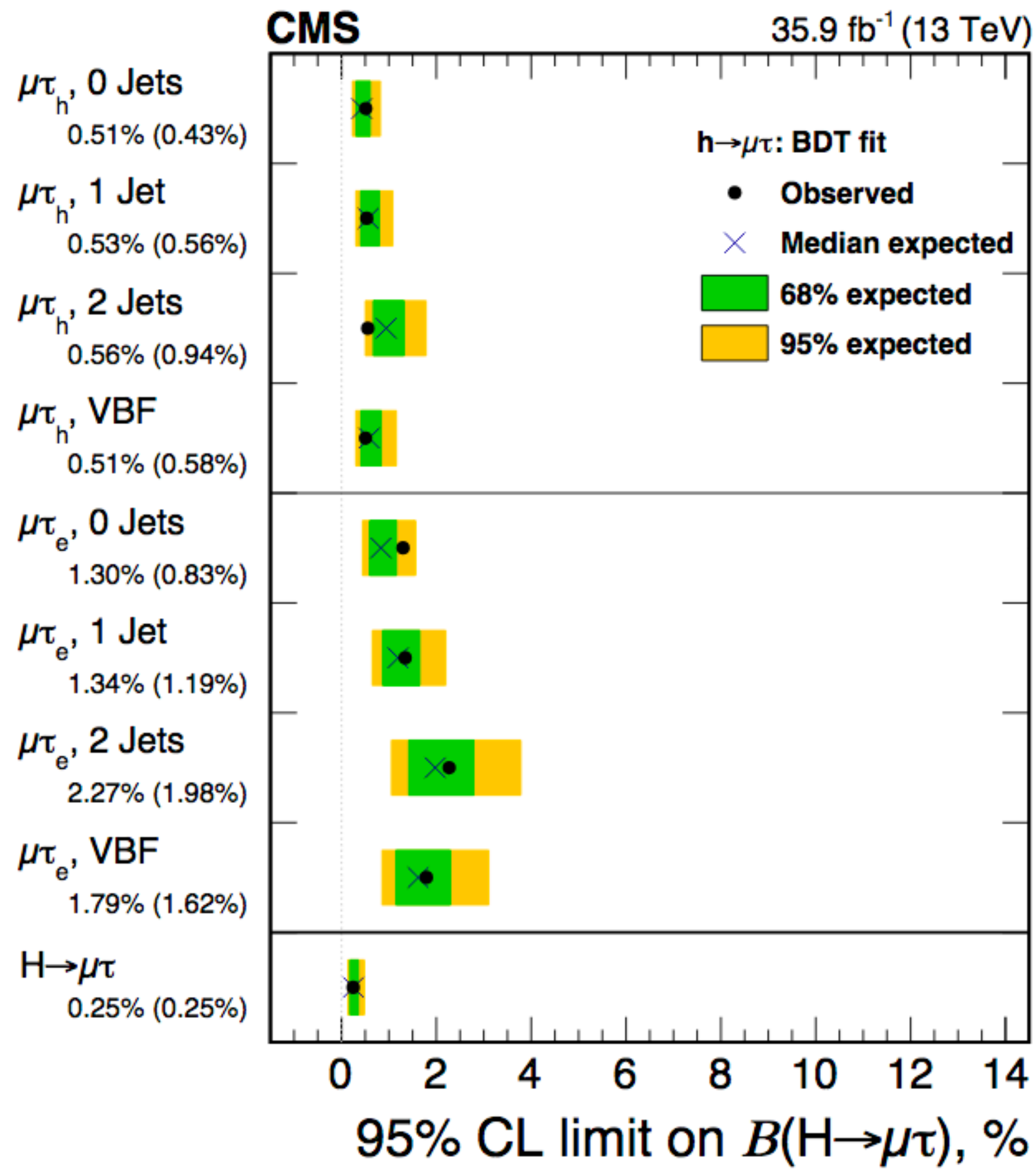


$$\Gamma(\mathrm{H}\to\ell^{\alpha}\ell^{\beta}) = \frac{m_{\mathrm{H}}}{8\pi}\left(|Y_{\ell^{\beta}\ell^{\alpha}}|^2 + |Y_{\ell^{\alpha}\ell^{\beta}}|^2\right),$$

$$\mathcal{B}(\mathrm{H}\to\ell^{\alpha}\ell^{\beta}) = \frac{\Gamma(\mathrm{H}\to\ell^{\alpha}\ell^{\beta})}{\Gamma(\mathrm{H}\to\ell^{\alpha}\ell^{\beta}) + \Gamma_{\mathrm{SM}}}.$$

CMS:Lepton-flavor violation in **Higgs→lepton+τ**





	Observed (expected) limits (%)		Best fit branching fraction (%)	
	BDT fit	M_{col} fit	BDT fit	M_{col} fit
$H \to \mu\tau$	<0.25 (0.25)%	<0.51 (0.49) %	0.00 ± 0.12 %	0.02 ± 0.20 %
$H \to e\tau$	<0.61 (0.37) %	<0.72 (0.56) %	0.30 ± 0.18 %	0.23 ± 0.24 %

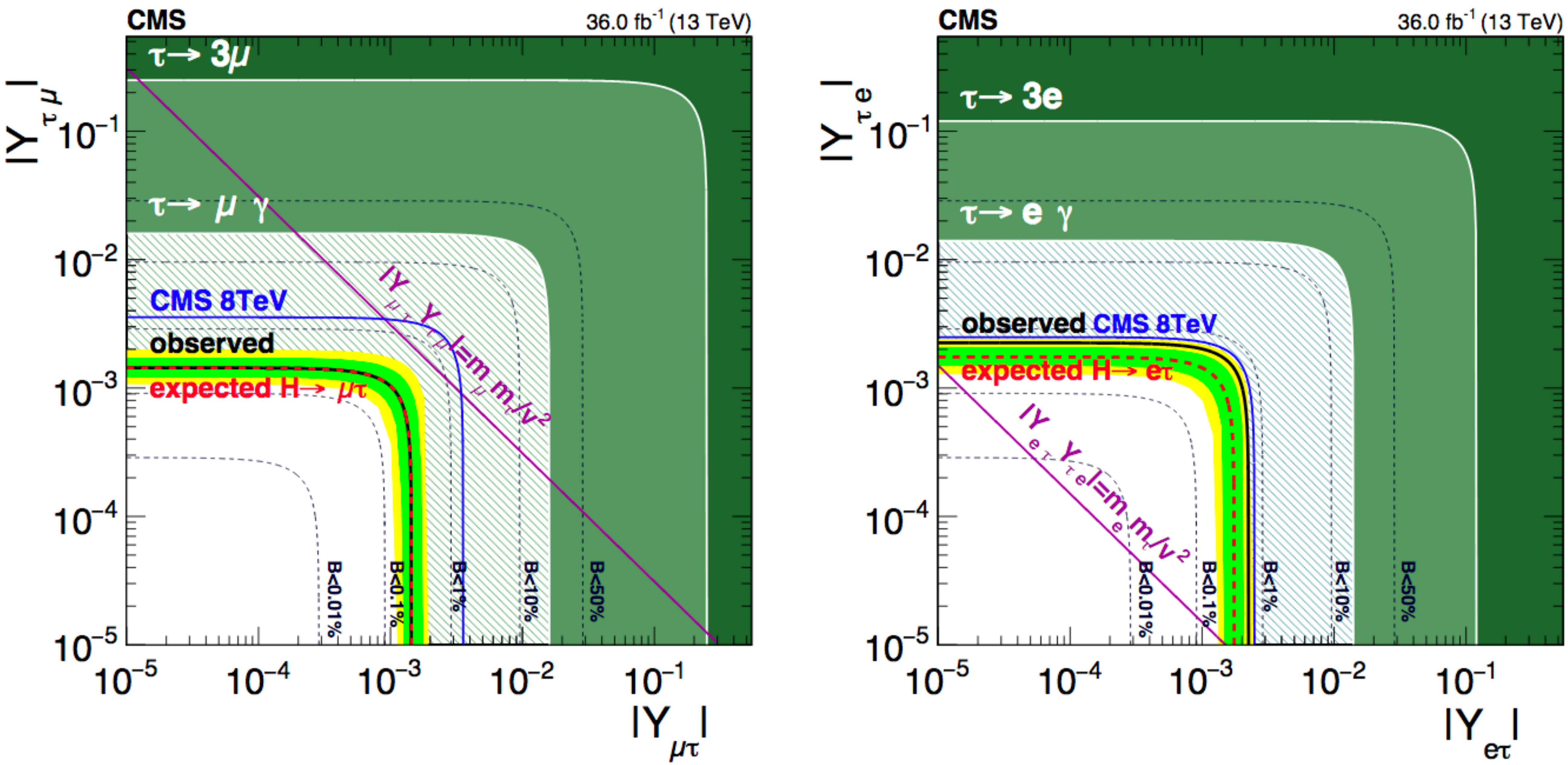
	BDT fit
$\sqrt{\|Y_{\mu\tau}\|^2 + \|Y_{\tau\mu}\|^2}$	$< 1.43 \times 10^{-3}$
$\sqrt{\|Y_{e\tau}\|^2 + \|Y_{\tau e}\|^2}$	$< 2.26 \times 10^{-3}$

CMS:Lepton-flavor violation in **Higgs→lepton+τ**

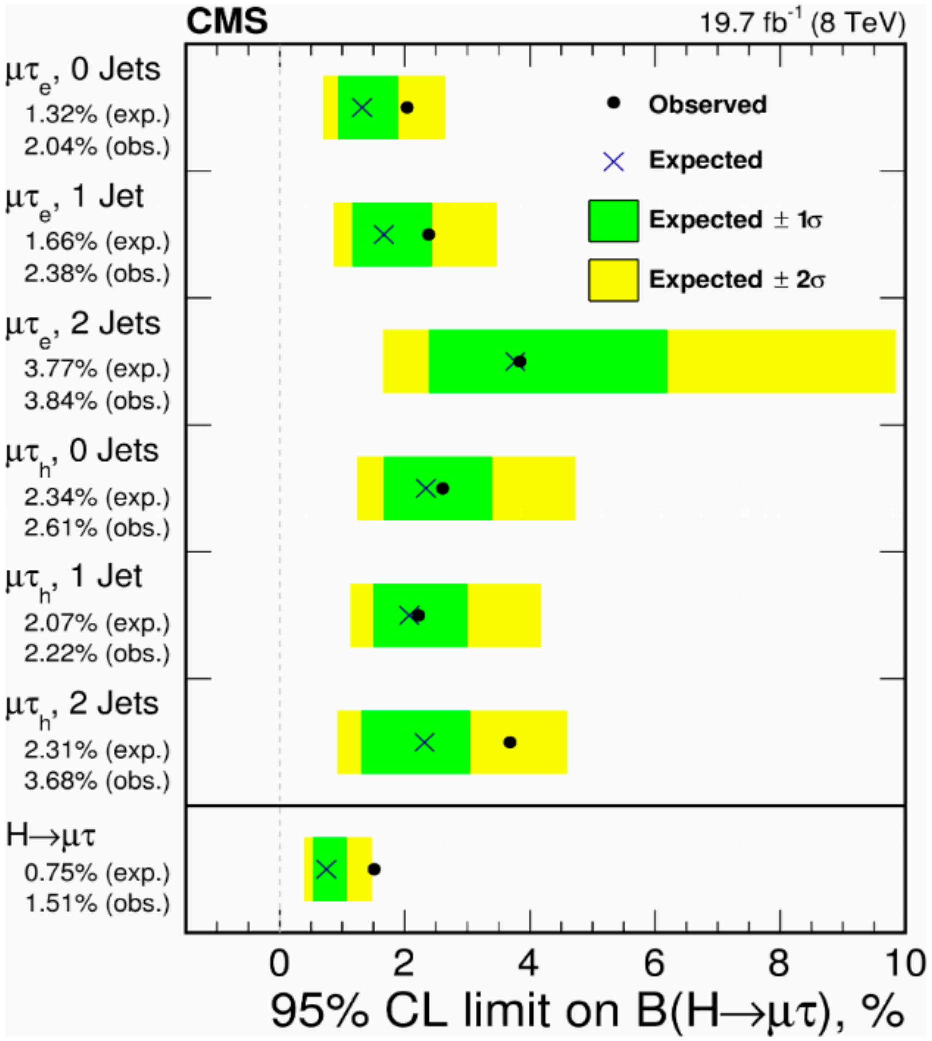
CMS BR upper limit: from 35.9/fb @ 13TeV Run-2 dataset **HIG-17-001**

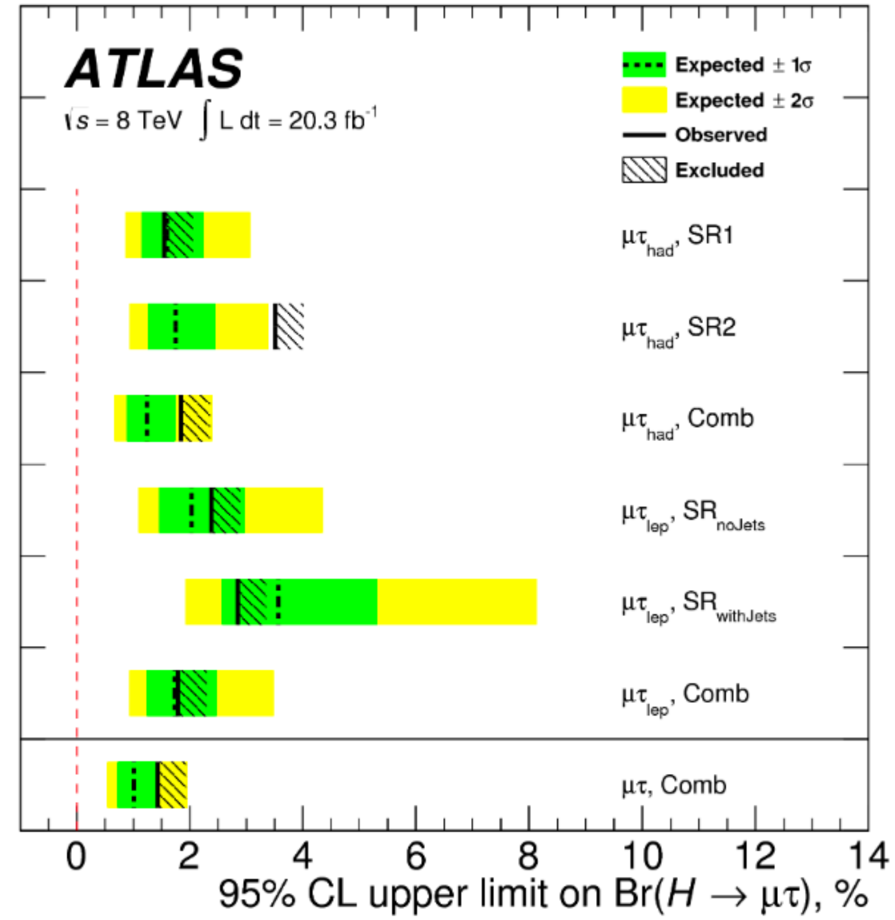
95% CL upper limit on BR	H(eτ)	H(μτ)
observed	**0.61 %**	**0.25 %**
median expected	**0.37 %**	**0.25 %**

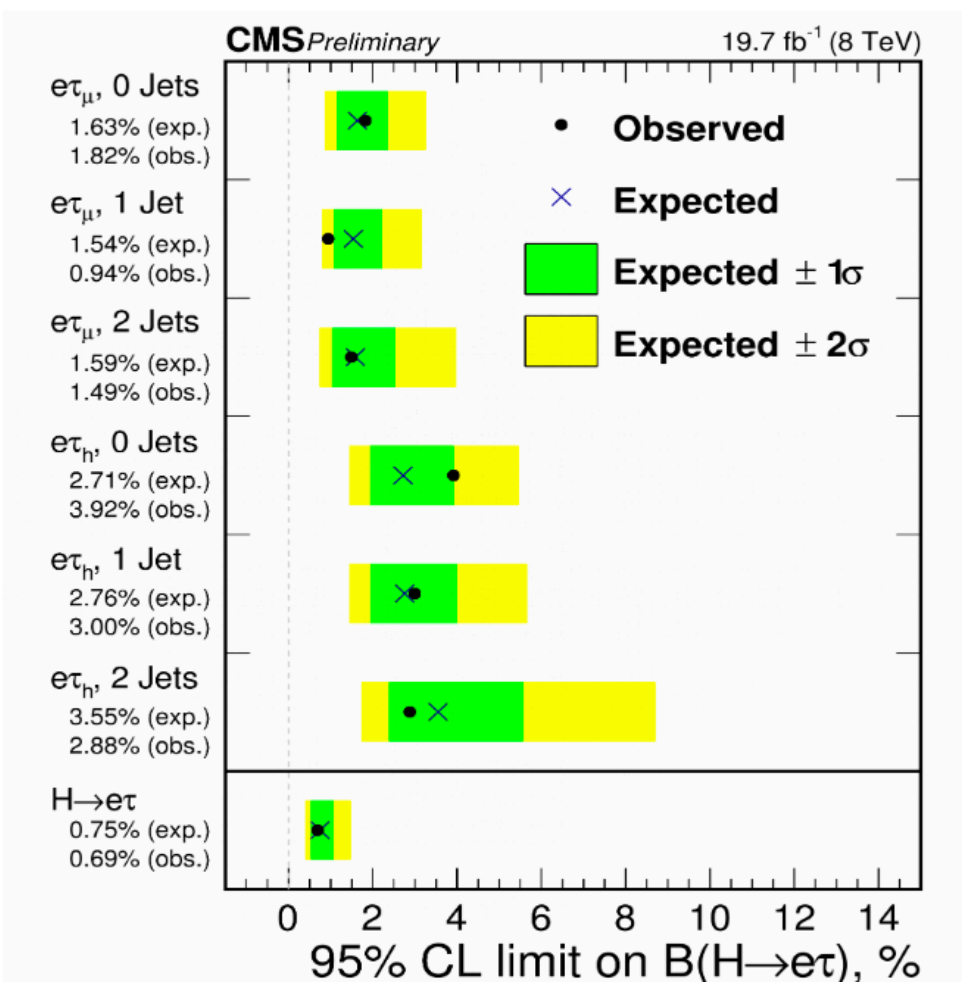
CMS:Lepton-flavor violation in **Higgs→lepton+τ**

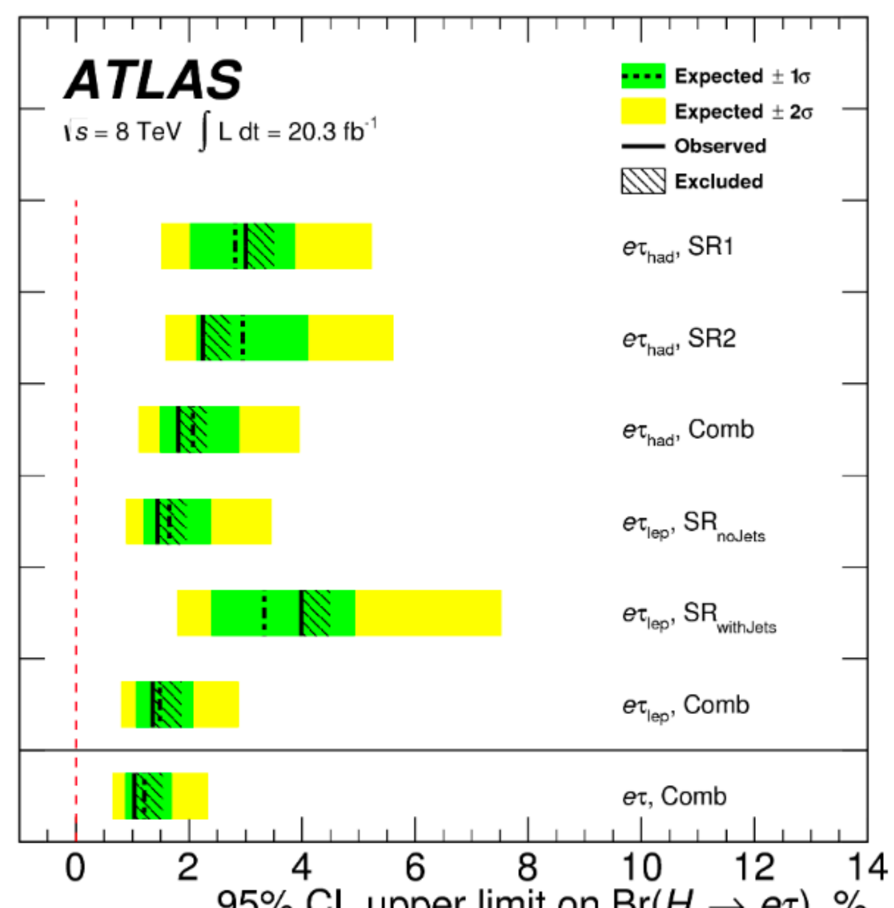


Run-1


CMS
19.7 fb^{-1} (8 TeV)
$\mu\tau_e$, 0 Jets
1.32% (exp.)
2.04% (obs.)
$\mu\tau_e$, 1 Jet
1.66% (exp.)
2.38% (obs.)
$\mu\tau_e$, 2 Jets
3.77% (exp.)
3.84% (obs.)
$\mu\tau_h$, 0 Jets
2.34% (exp.)
2.61% (obs.)
$\mu\tau_h$, 1 Jet
2.07% (exp.)
2.22% (obs.)
$\mu\tau_h$, 2 Jets
2.31% (exp.)
3.68% (obs.)
$H\rightarrow\mu\tau$
0.75% (exp.)
1.51% (obs.)
Observed
Expected
Expected $\pm$ 1σ
Expected $\pm$ 2σ
95% CL limit on B($H\rightarrow\mu\tau$), %


ATLAS
$\sqrt{s}$ = 8 TeV $\int$ L dt = 20.3 fb^{-1}
Expected $\pm$ 1σ
Expected $\pm$ 2σ
Observed
Excluded
$\mu\tau_{had}$, SR1
$\mu\tau_{had}$, SR2
$\mu\tau_{had}$, Comb
$\mu\tau_{lep}$, SR$_{noJets}$
$\mu\tau_{lep}$, SR$_{withJets}$
$\mu\tau_{lep}$, Comb
$\mu\tau$, Comb
95% CL upper limit on Br($H\rightarrow\mu\tau$), %


CMS Preliminary
19.7 fb^{-1} (8 TeV)
$e\tau_\mu$, 0 Jets
1.63% (exp.)
1.82% (obs.)
$e\tau_\mu$, 1 Jet
1.54% (exp.)
0.94% (obs.)
$e\tau_\mu$, 2 Jets
1.59% (exp.)
1.49% (obs.)
$e\tau_h$, 0 Jets
2.71% (exp.)
3.92% (obs.)
$e\tau_h$, 1 Jet
2.76% (exp.)
3.00% (obs.)
$e\tau_h$, 2 Jets
3.55% (exp.)
2.88% (obs.)
$H\rightarrow e\tau$
0.75% (exp.)
0.69% (obs.)
Observed
Expected
Expected $\pm$ 1σ
Expected $\pm$ 2σ
95% CL limit on B($H\rightarrow e\tau$), %


ATLAS
$\sqrt{s}$ = 8 TeV $\int$ L dt = 20.3 fb^{-1}
Expected $\pm$ 1σ
Expected $\pm$ 2σ
Observed
Excluded
$e\tau_{had}$, SR1
$e\tau_{had}$, SR2
$e\tau_{had}$, Comb
$e\tau_{lep}$, SR$_{noJets}$
$e\tau_{lep}$, SR$_{withJets}$
$e\tau_{lep}$, Comb
$e\tau$, Comb
95% CL upper limit on Br($H\rightarrow e\tau$), %