Flavor Violating Higgs Decays

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MAX-PLANCK-GESELLSCHAFT

Based on work done in collaboration with
Roni Harnik and Jure Zupan
arXiv:1209.1397

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Outline

Flavor Mixing in the Higgs Sector

Motivation

Scenario 1: Several sources of EW symmetry breaking

- If fermion masses have more than one origin, they do not need to be aligned with the Yukawa couplings

Simplest example: Type III 2-Higgs-Doublet Model

$$\mathcal{L}_Y \supset -Y^{(1)}_{ij} \bar{L}^i e^j_R H^{(1)} - Y^{(2)}_{ij} \bar{L}^i e^j_R H^{(2)} + h.c.$$
$$\longrightarrow -m_i \bar{e}^i_L e^i_R - Y^{\text{eff}}_{ij} \bar{f}^i_L f^j_R h + \text{couplings to heavier Higgs bosons} + h.c.$$

(h = Lightest neutral Higgs boson, $m_h \sim 125$ GeV)

Assume heavy Higgs boson are decoupled.

see for instance Davidson Greiner, arXiv:1001.0434

Motivation (2)

Scenario 2: Extra Higgs couplings

Assume existence of heavy new particles, which induce effective operators of the form

$$\Delta\mathcal{L}_Y = -\frac{\lambda'_{ij}}{\Lambda^2}(\bar{f}^i_L f^j_R)H(H^\dagger H) + h.c. + \cdots ,$$

$\rightarrow$ after EWSB, new (but misaligned) contributions to mass matrices and Yukawa couplings

Effective Lagrangian is again

$$\mathcal{L}_Y \supset -m_i \bar{e}^i_L e^i_R - Y^{\text{eff}}_{ij} \bar{f}^i_L f^j_R h + h.c.$$

see for instance Giudice Lebedev, arXiv:0804.1753

Effective Yukawa Lagrangfian

Effective Yukawa Lagrangian

$$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^i - Y_{ij}^a (\bar{f}_L^i f_R^j) h^a + h.c. + \cdots$$

Previously studied by many authors:

Bjorken Weinberg, PRL **38** (1977) 622
McWilliams Li, Nucl. Phys. B **179** (1981) 62
Shanker, Nucl. Phys. B **206** (1982) 253
Barr Zee, PRL **65** (1990) 21
Babu Nandi, hep-ph/9907213
Diaz-Cruz Toscano, hep-ph/9910233
Han Marfatia, hep-ph/0008141
Kanemura Ota Tsumura, hep-ph/0505191
Blanke Buras Duling Gori Weiler, arXiv:0809.1073
Casagrande Goertz Haisch Neubert Pfoh, arXiv:0807.4937
Giudice Lebedev, arXiv:0804.1753
Aguilar-Saavedra, arXiv:0904.2387
Albrecht Blanke Buras Duling Gemmler, arXiv:0903.2415
Buras Duling Gori, arXiv:0905.2318
Azatov Toharia Zhu, arXiv:0906.1990
Agashe Contino, arXiv:0906.1542
Davidson Greiner, arXiv:1001.0434
Goudelis Lebedev Park, arXiv:1111.1715
Blankenburg Ellis Isidori, arXiv:1202.5704
Arhrib Cheng Kong, arXiv:1208.4669
McKeen Pospelov Ritz, arXiv:1208.4597
...

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Effective Yukawa Lagrangian

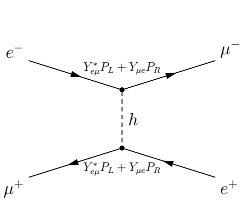
$$\mathcal{L}_Y = -m_i \bar{f}_L^i f_R^i - Y_{ij}^a (\bar{f}_L^i f_R^j) h^a + h.c. + \cdots$$

New in this talk:

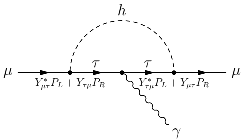
- Comprehensive list of up-to-date constraints (including subdominant ones)
- Omit approximations where feasible
- First LHC limits
- Strategy for future LHC searches

Couplings to Leptons

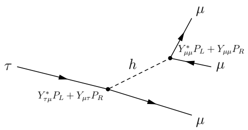
Low-energy constraints on LFV in the Higgs sector



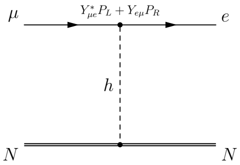
M–$\bar{M}$ oscillations



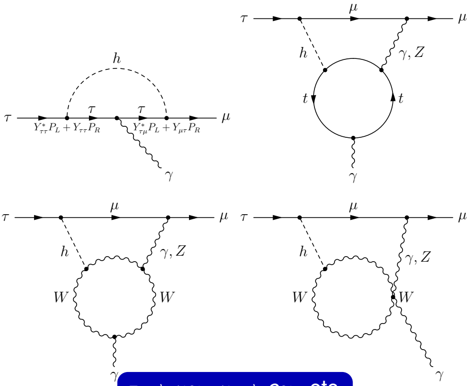
$g - 2$, EDMs



$\tau \to 3\mu$, μee, etc.

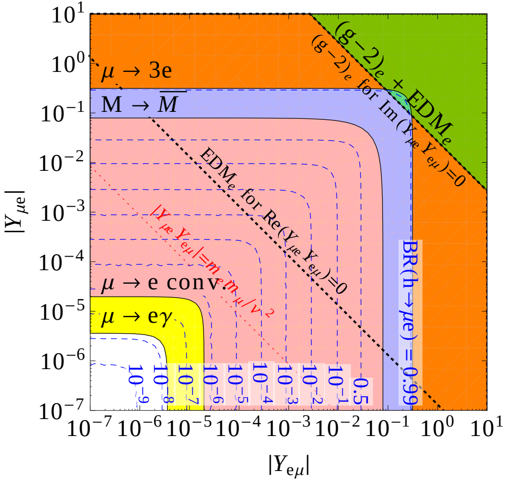


μ–e conversion



$\tau \to \mu\gamma$, $\mu \to e\gamma$, etc.

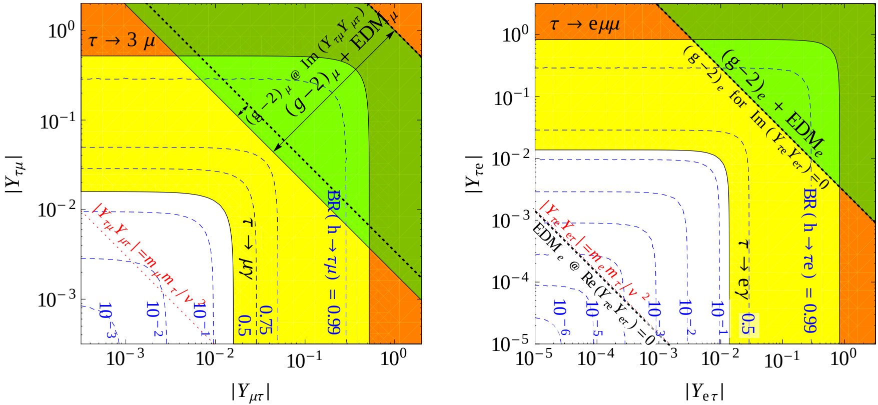
Constraints on $h \to \mu e$



Assumption here:
Diagonal Yukawa coupling unchanged from their SM values.

see also: Blankenburg Ellis Isidori, arXiv:1202.5704
Goudelis Lebedev Park, arXiv:1111.1715

Constraints on $h \to \tau\mu$ and $h \to \tau e$



Substantial flavor violation ($BR(h \to \tau\mu, \tau e) \sim 0.01$) perfectly viable.

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Goudelis Lebedev Park, arXiv:1111.1715
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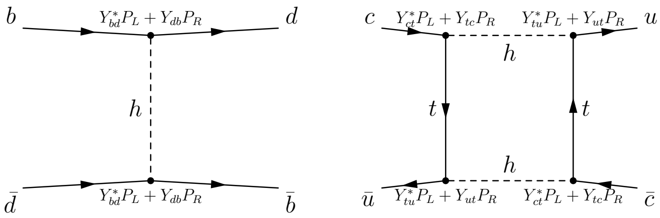
Couplings to Quarks

Constraints on Higgs couplings to light quarks

- Tight constraints from neutral meson oscillations



Constraints on Higgs couplings to light quarks

- Tight constraints from neutral meson oscillations
- Work in Effective Field Theory:

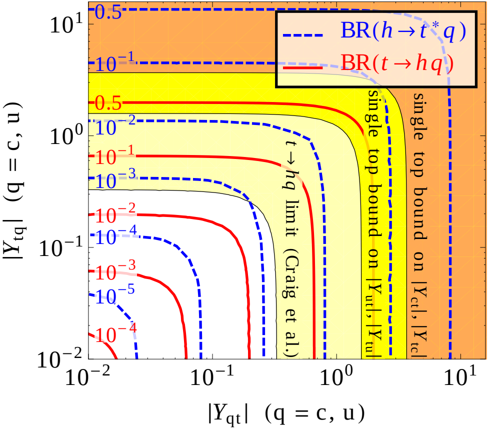
$$H_{\text{eff}} = C_2^{db}(\bar{b}_R d_L)^2 + \tilde{C}_2^{db}(\bar{b}_L d_R)^2 + C_4^{db}(\bar{b}_L d_R)(\bar{b}_R d_L) + \dots$$

- Wilson coefficients constrained in UTfit (Bona et al.), arXiv:0707.0636

see also Blankenburg Ellis Isidori, arXiv:1202.5704

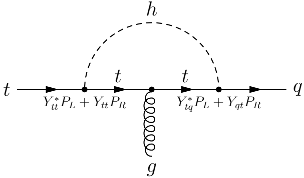
Technique	Coupling	Constraint
D^0 oscillations	$\lvert Y_{uc}\rvert^2$, $\lvert Y_{cu}\rvert^2$	$< 5.0 \times 10^{-9}$
	$\lvert Y_{uc} Y_{cu}\rvert$	$< 7.5 \times 10^{-10}$
B_d^0 oscillations	$\lvert Y_{db}\rvert^2$, $\lvert Y_{bd}\rvert^2$	$< 2.3 \times 10^{-8}$
	$\lvert Y_{db} Y_{bd}\rvert$	$< 3.3 \times 10^{-9}$
B_s^0 oscillations	$\lvert Y_{sb}\rvert^2$, $\lvert Y_{bs}\rvert^2$	$< 1.8 \times 10^{-6}$
	$\lvert Y_{sb} Y_{bs}\rvert$	$< 2.5 \times 10^{-7}$
K^0 oscillations	$\Re(Y_{ds}^2)$, $\Re(Y_{sd}^2)$	$[-5.9 \dots 5.6] \times 10^{-10}$
	$\Im(Y_{ds}^2)$, $\Im(Y_{sd}^2)$	$[-2.9 \dots 1.6] \times 10^{-12}$
	$\Re(Y_{ds}^* Y_{sd})$	$[-5.6 \dots 5.6] \times 10^{-11}$
	$\Im(Y_{ds}^* Y_{sd})$	$[-1.4 \dots 2.8] \times 10^{-13}$

Couplings involving top quarks



Constraints from

- Single top production



CDF 0812.3400, DØ 1006.3575
ATLAS 1203.0529

- $t \to hq$

Craig et al. 1207.6794
based on CMS multilepton search
1204.5341

Not sensitive

- $t \to Zq$

CMS 1208.0957

Flavor-Violating Higgs Decays at the Large Hadron Collider

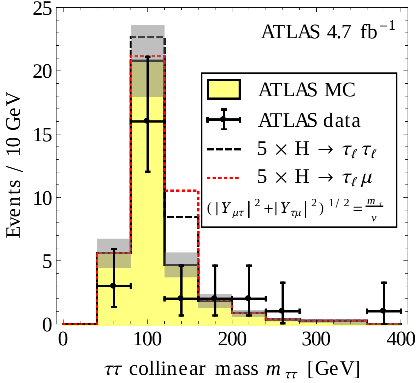
$h \to \tau\mu$ and $h \to \tau e$ at the LHC

Basic idea:

- $h \to \tau\ell$ has the same final state as $h \to \tau\tau_\ell$
  (but is enhanced by $1/\text{BR}(\tau \to \ell)$)
- Recast $h \to \tau\tau$ search
  here: ATLAS, arXiv:1206.5971
- We consider only 2-lepton final states
- Use VBF cuts
  (much lower BG than gg fusion)

see however
Davidson Verdier, arXiv:1211.1248

based on ATLAS, arXiv:1206.5971

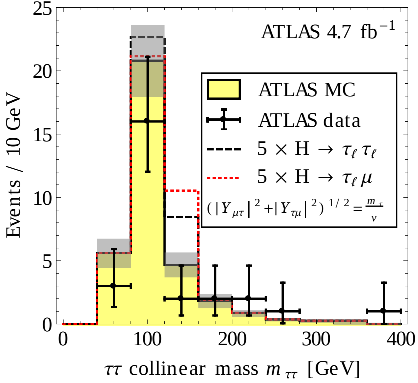


$h \to \tau\mu$ and $h \to \tau e$ at the LHC

Most important cuts

- 2 forward jets ($p_{T,j1} > 40$ GeV, $p_{T,j2} > 25$ GeV, $|\Delta\eta| > 3.0$, $m^{\text{inv}}_{j1,j2} > 350$ GeV)
- no hard jet activity in between
- no b tags
- 2 opposite sign leptons ℓ_1, ℓ_2 with $p_{T,\ell} \gtrsim 10$–20 GeV (depending on flavors)
- τ momentum fraction x carried by ℓ_1, ℓ_2 satisfies $0.1 < x_{1,2} < 1.0$ (computed in collinear approximation)
- 30 GeV $< m_{\ell\ell} <$ 75 (100) GeV for same (opposite) flavor leptons
- $\not{E}_T > 20$ (40) GeV for same (opposite) flavor leptons

based on ATLAS, arXiv:1206.5971

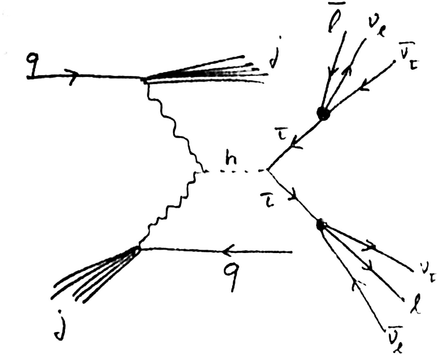


Mass reconstruction for $h \to \tau_\ell \tau_\ell$

Problem: 4 neutrinos in final state

Solution: Assume all τ decay products collinear

Ellis Hinchliffe Soldate van der Bij, NPB 1987



Per τ:

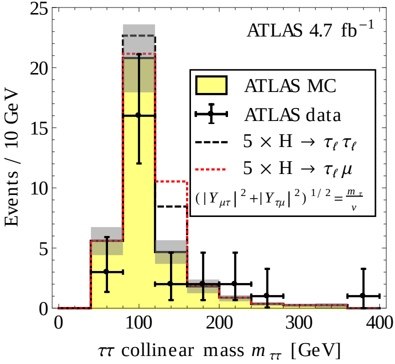
- 2 unknown ($|p_{\nu_\tau}|$, $|p_{\nu_\ell}|$)
- 2 constraints: $\not{E}_{T,x}$, $\not{E}_{T,y}$

Limits on $h \to \tau\mu$ and $h \to \tau e$ from the LHC

Technicalities

- Use MadGraph 5, v1.4.6, Pythia 6.4, PGS
- Use only 120–160 GeV bin
- Derive one-sided 95% CL limit

based on ATLAS, arXiv:1206.5971

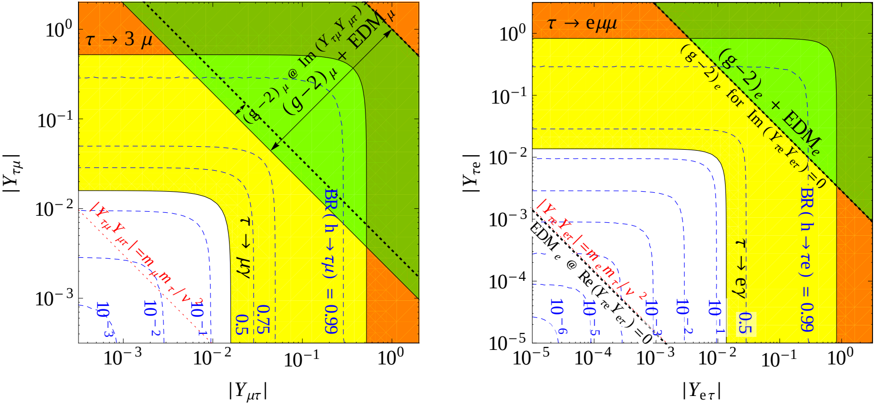


Result

$$\mathrm{BR}(h \to \tau\mu) < 0.13 \qquad \sqrt{Y_{\tau\mu}^2 + Y_{\mu\tau}^2} < 0.011$$

$$\mathrm{BR}(h \to \tau e) < 0.13 \qquad \sqrt{Y_{\tau e}^2 + Y_{e\tau}^2} < 0.011$$

LHC constraints on $h \to \tau\mu$ and $h \to \tau e$



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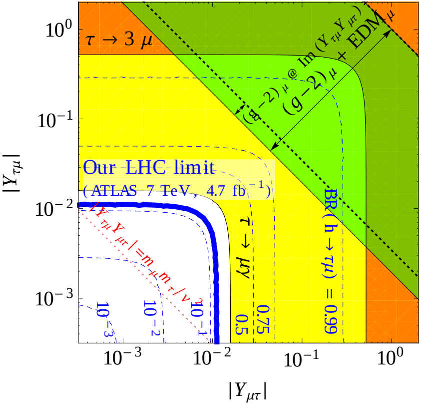

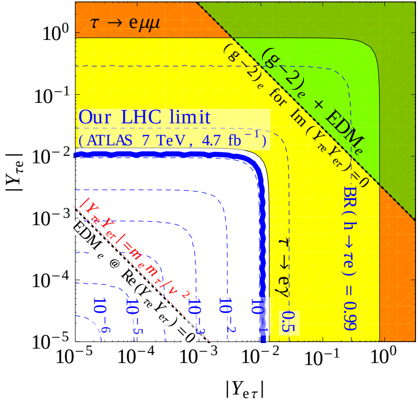

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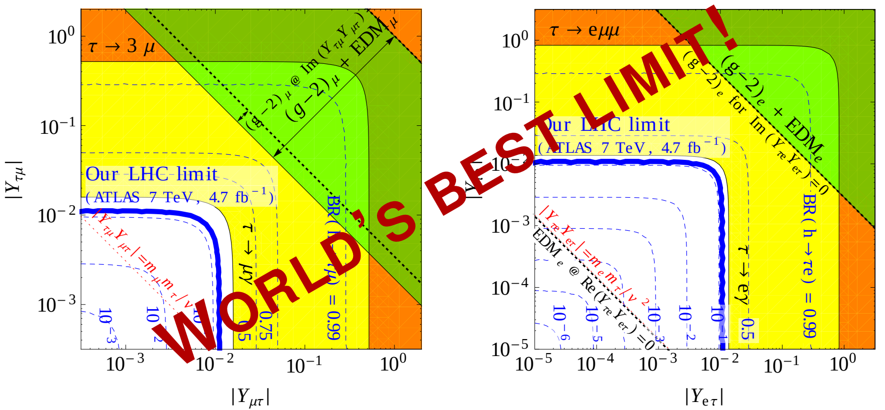

Strategy for a dedicated $h \to \tau\mu$ and $h \to \tau e$ search

Possible improvements

- Different invariant mass formula (assuming 1 neutrino rather than 3)
  - Avoids smearing of signal
  - Shifts $Z \to \tau\tau$ peak to lower invariant mass
- Consider hadronic τ's (especially for CMS)
- Modified cuts
  - CMS $h \to \tau_{\text{had}}\tau_\ell$ search requires $m_T(\ell, \not{p}_T) < 40$ GeV to suppress $W +$ jets
  - In $h \to \tau_{\text{had}}\mu$, neutrino and muon typically not collinear $\to$ large $m_T(\ell, \not{p}_T)$

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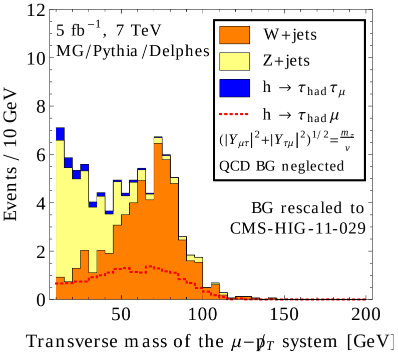

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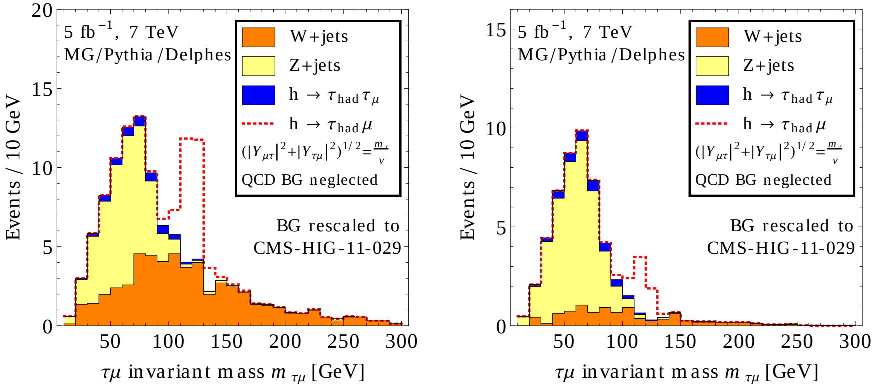


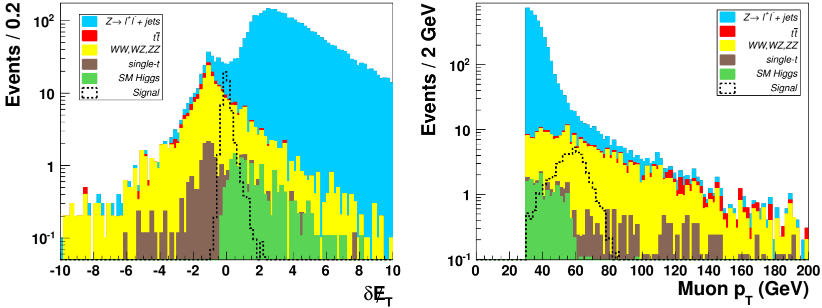
For $Y_{\mu\tau}$, $Y_{\tau\mu}$ close to the current upper limits, spectacular signals possible.

Exploiting Higgs production in gluon-gluon fusion

Davidson Verdier, arXiv:1211.1248

Observations

- Computed $p_{T,\nu}$ (using collinear approximation) is $\simeq \not{E}_T$
- Muon in $h \to \tau\mu$ is much harder than in $h \to \tau_\ell \tau_\ell$.



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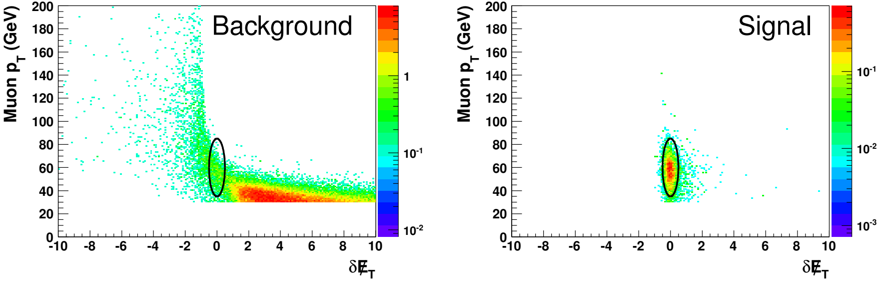

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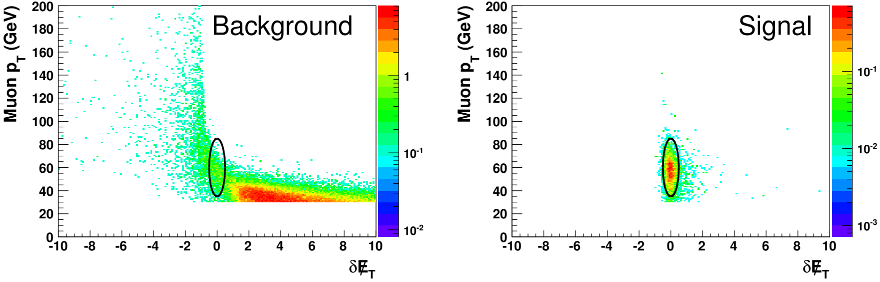

Projected sensitivity

Davidson Verdier, arXiv:1211.1248

$$\mathrm{BR}(h \to \tau\mu),\ \mathrm{BR}(h \to \tau e) < 4.5 \times 10^{-3}$$

Summary

- Flavor-violating Higgs couplings arise in
  - Models with several sources of electroweak symmetry breaking
  - Models with heavy fields coupled to the Higgs
- In the lepton sector:
  - Constraints from $\ell_1 \to \ell_2 + \gamma$, $\ell_1 \to \ell_2 + X$, μ–e conversion in nuclei, $g - 2$, EDMs, M–$\bar{M}$ oscillations
  - Strong constraints in the μ–e sector
  - Very weak constraints in the τ–e and τ–μ sectors
- In the quark sector:
  - Strong constraints on couplings to light quarks
  - Very weak constraints on couplings to top quarks
- At the LHC
  - Constraints on anomalous top–Higgs couplings from single top production
  - A recast ATLAS $h \to \tau_\ell \tau_\ell$ search already provides strongest limits on $h \to \tau\mu$ and $h \to \tau e$
  - A dedicated search would be much more sensitive

Thank you!