# Dark sectors and enhanced $h \to \tau\mu$ transitions

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based on arXiv:1701:08767 [hep-ph] w. J. Zupan
seeded by arXiv:1610.08060 [hep-ph] w. P. Tanedo and A. Kwa

# Last Year - w. P. Tanedo and A. Kwa

Explaining: **Fermi-LAT's** Galactic Center Excess (GCE) in the GeV $\gamma$-ray spectrum w.

$$\chi\bar{\chi} \to 2(3)\varphi \to 2(3)\bar{\ell}_i\ell_j$$

where

$\chi$ - Dark Matter

$\varphi$ - Complex Scalar Mediator

leptons - produce the $\gamma$-ray signature via prompt decays to hadrons, or via ICS of starlight

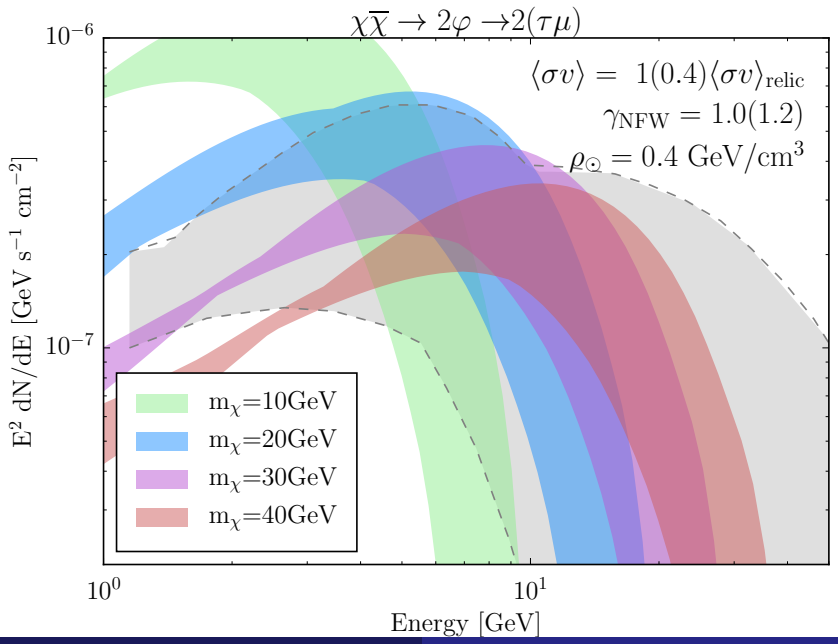
$$m_\chi > m_\varphi(\frac{3}{2}m_\varphi) > m_{\ell_i} + m_{\ell_j}$$

A *single* off-diagonal coupling $c_{ij}\ \varphi\bar{\ell}_i\ell_j$

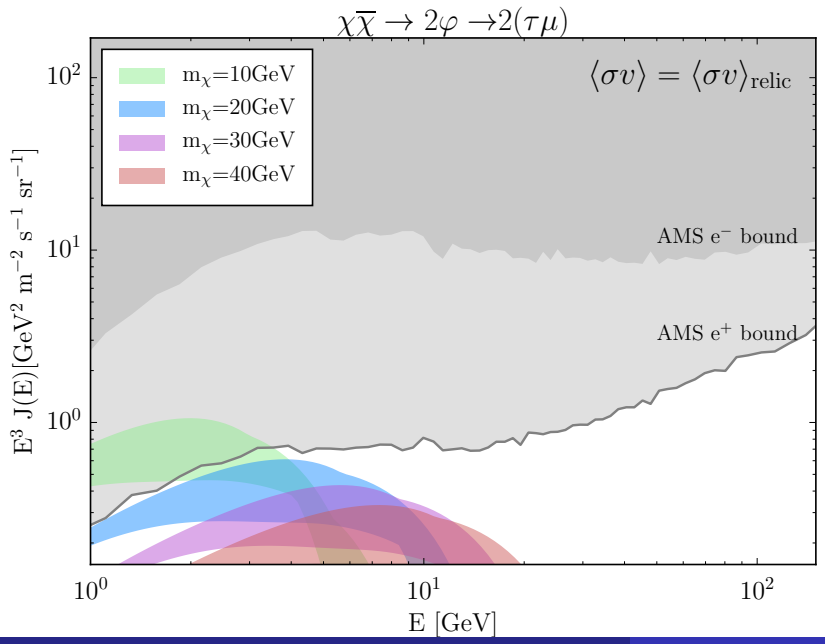
# Last Year - w. P. Tanedo and A. Kwa

- residual $L_i - L_j$ symmetry $\Rightarrow$ avoids:
  - line shapes from $\varphi \to \gamma\gamma$
  - low-energy CLFV bounds
- heavy lepton decays $\Rightarrow$ softer $e^{\pm}$ - avoids AMS-02 bounds

FERMI-LAT $\gamma$-ray




AMS-02 $e^+$-spectrum



# Motivation - Flavor in the Leptonic Sector

In the SM:

$$y^{\ell}_{ij}\bar{L}_i\tilde{H}E_j + \frac{c^{\nu}_{ij}}{\Lambda^2}L_iHL_jH \quad \overset{EWSB}{\Longrightarrow} \quad m^{\ell}_i\delta_{ij}\left(1+\frac{h}{v}\right)\bar{\ell}_i\ell_j + m^{\nu}_{ij}\nu_i\nu_j$$

**Higgs Physics drives flavor structure**

- Flavor puzzle:

$$(y_e,\ y_\mu,\ y_\tau) \approx 10^{(-6,-4,-2)}, \quad m_\nu - \text{tiny}, \quad U_{PMNS} - \mathcal{O}(1)\ \text{mix}$$

- @LHC - can probe underlying flavor theory $\Longrightarrow$ **New Physics**

# Leptonic Flavor Anomalies

Several Hints of (Flavor) New Physics:

- Higgs LFV decays: $h \to \tau\mu$
- $(g-2)_\mu$ $\Longrightarrow$
- Proton radius
- $B$ leptonic decay ratios

$$BR(h \to \tau^\pm \mu^\mp)\Big|_{\sqrt{s}=8\ \mathrm{TeV}} \quad \text{in } \%$$

| | |
|---|---|
| CMS | $0.89 \pm 0.39$ |
| ATLAS | $\tau_h$ $0.53 \pm 0.51$<br>$\tau_e$ $0.77 \pm 0.62$ |

**CMS result** $\sim 2.4\sigma$

# 13 TeV Update

In a recent update w. 35.9 $\mathrm{fb}^{-1}$ the slight excess seems to be gone.

$$BR(h \to \tau^{\pm}\mu^{\mp})\Big|_{\sqrt{s}=13\ \mathrm{TeV}} \text{ in } \% = \begin{cases} 0.02 \pm 0.20 & \mathrm{M_{col}} - \mathrm{fit} \\ 0.00 \pm 0.12 & \mathrm{BDT} - \mathrm{fit} \end{cases}$$

CMS-PAS-HIG-17-001

Can still: learn something about LHC-searches for $\tau$ signatures

# $\tau$ Physics

The dominant $\tau$ decay modes

Leptonic:

$$\tau \to \ell \nu_\tau \bar{\nu}_\ell \qquad \sim 35\%$$

Hadronic:

$$\tau \to \nu_\tau \pi$$
$$\tau \to \nu_\tau \pi\pi \qquad \sim 65\%$$
$$\tau \to \nu_\tau \pi\pi\pi$$

**inherent Missing-Energy signature**

# $\tau$'s @ The LHC

Trigger on the visible-$\tau$ decay products

- leptonic, $\tau_e \Longrightarrow$ lepton triggers: $\sim p_T > 20$ GeV
- hadronic, $\tau_h \Longrightarrow$ 1-prong, 3-prong: "hadron + strips"

$$\boxed{\text{fully reconstructs } \tau_{vis}}$$

but

$$\boxed{\text{partially reconstructs } \tau_{inv} \ (1\nu, \text{ or } 2\nu)}$$

$\tau$-LHC searches are $\not{E}_T$-inclusive

# $\tau$'s @ The LHC

$\tau$ Reconstruction:

- **The collinear approximation**

Ellis, Hinchliffe, Soldate, & van der Bij (1988)

$$\text{boosted } \tau: \quad \tau_{vis} \,||\, \tau_{inv} \implies \begin{cases} \vec{p}_{\tau_{inv}} = \hat{p}_{\tau_{vis}} \left( \vec{p}_{\tau_{vis}} \cdot \vec{\not{E}_T} \right) \\ p^2_{\tau_{inv}} = 0 \end{cases}$$

- **The Missing Mass Calculator** (MMC) / **SVFIT**

Elagin, Murat, Pranko, & Safonov

Bianchini, Conway, Friis, & Veelken

# CMS $h \to \tau\mu$

In $h \to \tau\mu$ CMS uses

$$m^{\mathrm{Coll}} = \sqrt{(p_\mu + p_{\tau_{vis}} + p_{\nu's})^2}$$

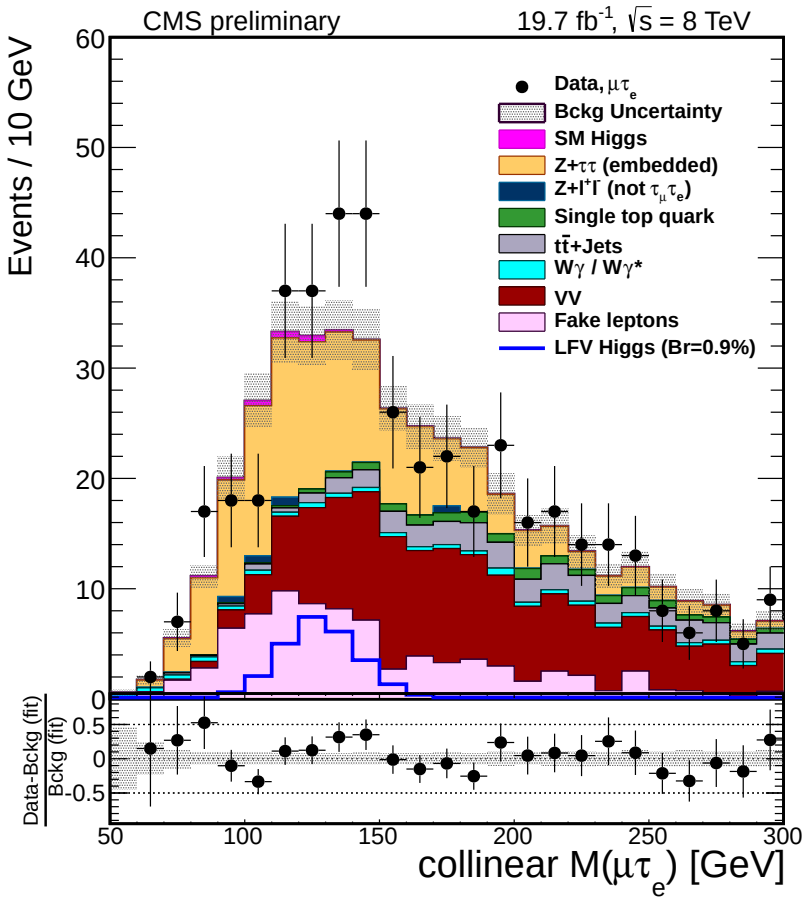
<u>SR:</u> 100 GeV $< \mathrm{m}^{\mathrm{Coll}} <$ 150 GeV, with cuts

| Variable | $\mathrm{H} \to \mu\tau_{\mathrm{e}}$ | | | $\mathrm{H} \to \mu\tau_{\mathrm{h}}$ | | |
|---|---|---|---|---|---|---|
| [GeV] | 0-jet | 1-jet | 2-jet | 0-jet | 1-jet | 2-jet |
| $p_{\mathrm{T}}^{\mu} >$ | 50 | 45 | 25 | 45 | 35 | 30 |
| $p_{\mathrm{T}}^{\mathrm{e}} >$ | 10 | 10 | 10 | — | — | — |
| $p_{\mathrm{T}}^{\tau_{\mathrm{h}}} >$ | — | — | — | 35 | 40 | 40 |
| $M_{\mathrm{T}}^{\mathrm{e}} <$ | 65 | 65 | 25 | — | — | — |
| $M_{\mathrm{T}}^{\mu} >$ | 50 | 40 | 15 | — | — | — |
| $M_{\mathrm{T}}^{\tau_{\mathrm{h}}} <$ | — | — | — | 50 | 35 | 35 |
| [radians] | | | | | | |
| $\Delta\phi_{\vec{p}_{\mathrm{T}}^{\mu} - \vec{p}_{\mathrm{T}}^{\tau_{\mathrm{h}}}} >$ | — | — | — | 2.7 | — | — |
| $\Delta\phi_{\vec{p}_{\mathrm{T}}^{\mathrm{e}} - \vec{E}_{\mathrm{T}}^{\mathrm{miss}}} <$ | 0.5 | 0.5 | 0.3 | — | — | — |
| $\Delta\phi_{\vec{p}_{\mathrm{T}}^{\mathrm{e}} - \vec{p}_{\mathrm{T}}^{\mu}} >$ | 2.7 | 1.0 | — | — | — | — |

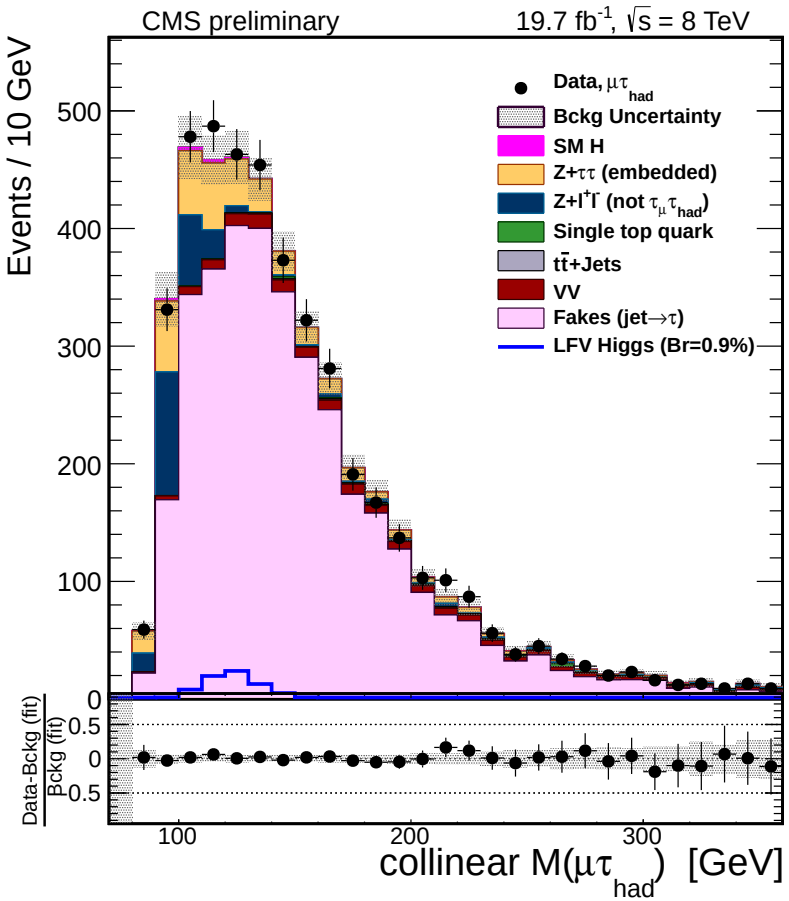
from CMS-HIG-14-005

# CMS $h \to \tau\mu$

$\tau_e + 0j$




$\tau_h + 0j$




from CMS-HIG-14-005

fit 0, 1, & 2 jet channels $\Rightarrow BR(h \to \tau\mu) = 0.89\%$

# LFV Higgs Couplings

Simplest SM-extensions (w. only $h \to EWSB$):

$$\mathcal{L} \supset Y^{\ell}_{ij} \bar{L}_i H E_j + \frac{\lambda_{ij}}{\Lambda^2} \bar{L}_i H E_j \left(H^\dagger H\right)$$

Kopp, Harnik & Zupan

implies

$$m = \frac{v}{\sqrt{2}} V_L \left( Y + \frac{v^2}{2\Lambda^2} \lambda \right) V_R^\dagger, \qquad y = \frac{1}{\sqrt{2}} V_L \left( Y + 3 \frac{v^2}{2\Lambda^2} \lambda \right) V_R^\dagger$$

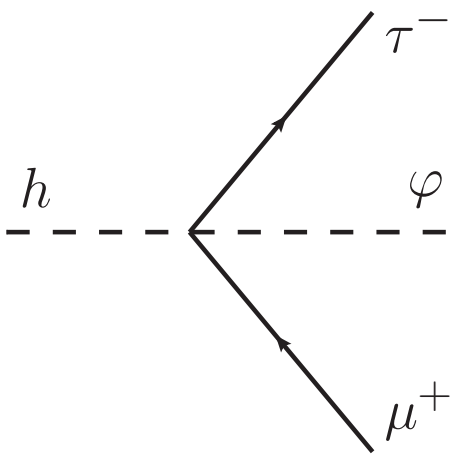
Then in the mass basis

$$\boxed{y_{ij} = \frac{m_i}{v} \delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2} V_L \lambda V_R^\dagger}$$

# Conspiracy and Dark Matter

Additional $\not{E}_T$ source: new light complex scalar $\varphi$

$$\frac{1}{\Lambda}\frac{h}{\sqrt{2}}\bar{\tau}_L\mu_R\varphi, \quad \text{or} \quad \frac{1}{\Lambda}\frac{h}{\sqrt{2}}\bar{\mu}_L\tau_R\varphi^*$$




2- & 3-body BR's are comparable

$$\frac{Br(h \to \tau^\pm\mu^\mp\varphi\ /\varphi^*)}{Br(h \to \tau^+\tau^-)} \simeq \frac{1}{6}\left(\frac{m_h}{4\pi\Lambda y_\tau}\right)^2 = 0.66\times\left(\frac{500\mathrm{GeV}}{\Lambda}\right)^2\left(\frac{0.01}{y_\tau}\right)^2$$

# Conspiracy and Dark Matter

In $h \to \tau\mu$: $\not{E}_T \supset 1$ or $2$ $\nu'$s

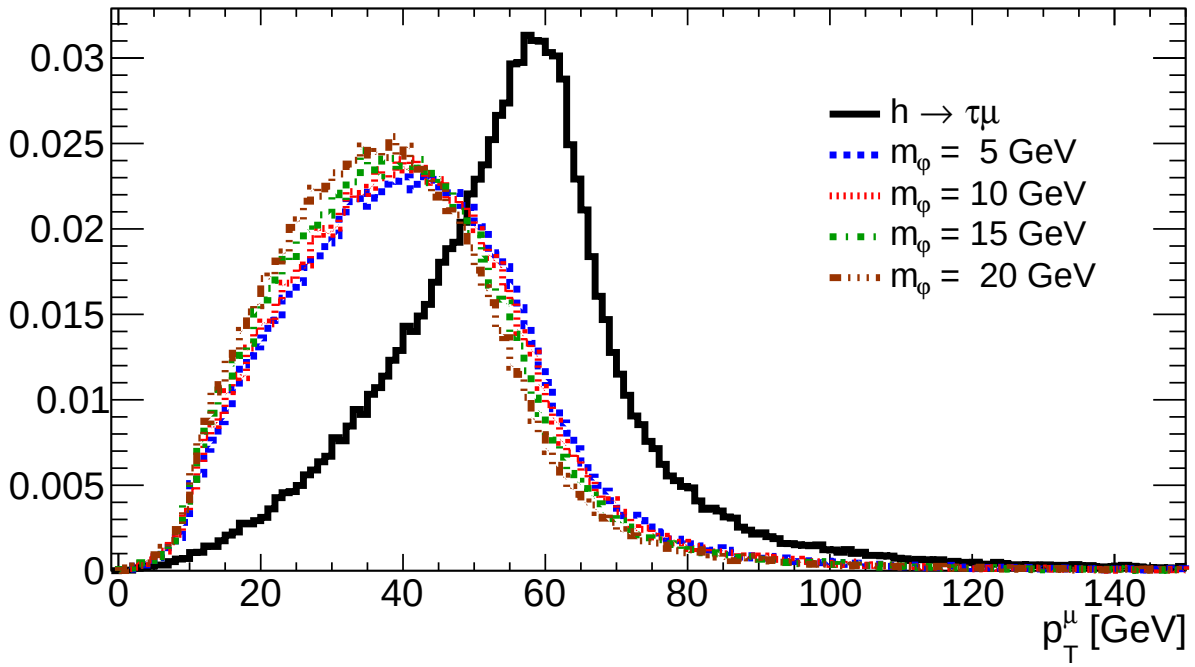
In $h \to \tau\mu\varphi$: $\not{E}_T \supset 1$ or $2$ $\nu'$s $+ \varphi$

$\varphi$ is captured by reconstructing $m^{\mathrm{Coll}}$

# Conspiracy and Dark Matter

Can $h \to \mu\tau\phi$ mimic $h \to \mu\tau$:

- softer decay products



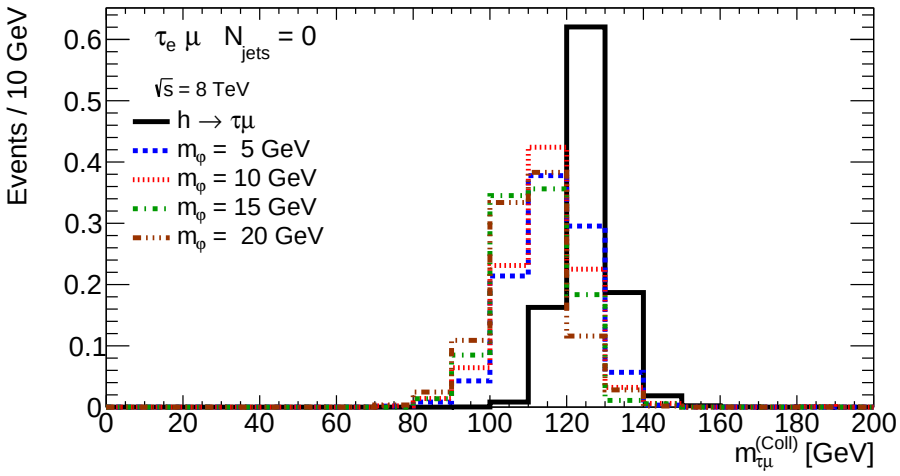

- angularly denser

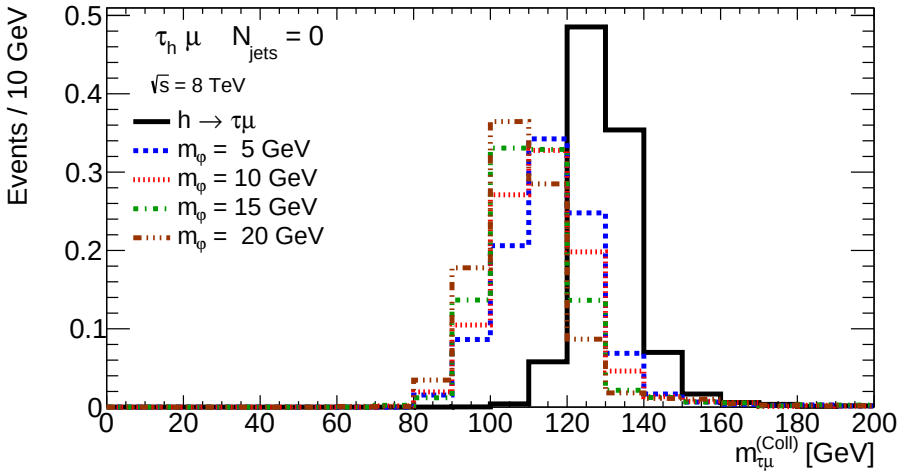
**search acceptance reduced**

# Conspiracy and Dark Matter

Can $h \to \mu\tau\phi$ mimic $h \to \mu\tau$:

- Broadening and shifting of $m_{\tau\mu}^{\mathrm{Coll}}$, (worry about $Z \to \tau_h\mu\Big|_{MMC}$)




(with similar plots for 1 & 2 jets)

# Recast Results

For $\Lambda = 1\ \mathrm{TeV}$:

| Decay | $m_\varphi$ [GeV] | Br | Coupling |
|---|---|---|---|
| $h \to \tau\mu$ | – | $3.6 \times 10^{-3}$ | $Y_{23} = 2.4 \times 10^{-3}$ |
| $h \to \tau\mu\varphi$ | 5 | $1.9 \times 10^{-2}$ | $c_{23} = 1.4$ |
| $h \to \tau\mu\varphi$ | 10 | $2.6 \times 10^{-2}$ | $c_{23} = 1.7$ |
| $h \to \tau\mu\varphi$ | 15 | $3.4 \times 10^{-2}$ | $c_{23} = 2.1$ |
| $h \to \tau\mu\varphi$ | 20 | $4.8 \times 10^{-2}$ | $c_{23} = 2.7$ |

Reasonable agreement with CMS: $Y_{\tau\mu} = (3.7 \pm 0.8) \cdot 10^{-3}$

# Recast Results - Upshot

**To account for $h \to \tau\mu$:**

- $m_\varphi \sim \mathcal{O}(10\ \mathrm{GeV})$ - light(ish) New Physics
- $c_{23} \sim \mathcal{O}(1)$ - very different than the SM Yukawa structure
- $\varphi$ invisibly decays $\Longrightarrow$ Dark Matter

# Model Building

<u>The model:</u> $\varphi =$ mediator to flavorful Dark-Sector

$$\mathcal{L}_{\text{vis.}} \supset -y^{\ell}_{ij}\bar{L}_i H E_j + \text{h.c.}$$

$$\mathcal{L}_{\text{vis-med.}} \supset \frac{c_{ij}}{\Lambda}\bar{L}_i H E_j \varphi + \frac{c'_{ij}}{\Lambda}\bar{L}_i H E_j \varphi^* + \text{h.c.}$$

$$\mathcal{L}_{\text{dark}} \supset g^L_{ab}\varphi\,\bar{\chi}_a P_L \chi_b + g^R_{ab}\varphi\,\bar{\chi}_a P_R \chi_b + \text{h.c.}, \qquad a, b = 1, 2.$$

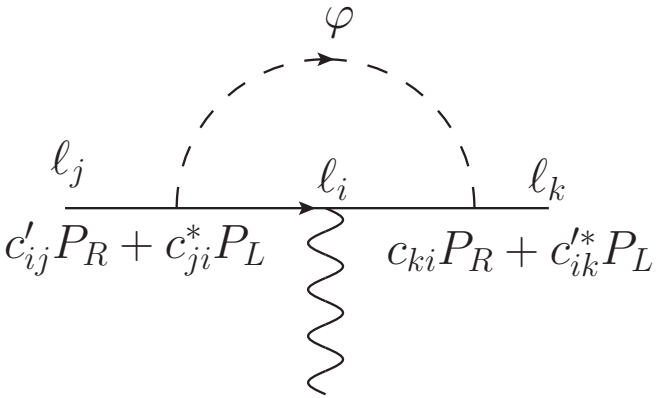
**A flavor theory at $\Lambda = 1\ \text{TeV}$ determines all couplings**

# Model Building - Feasibility

Account for both $Y$, $c$, $c'$, and $g^L$, $g^R$ ?

$$\mathcal{L}^{EWSB}_{\text{vis-med.}} \supset \frac{v}{\sqrt{2}\Lambda}\left[\bar{\ell}_i\left(c_{ij}P_R + c'^*_{ji}P_L\right)\ell_j\varphi + \bar{\ell}_i\left(c'_{ij}P_R + c^*_{ji}P_L\right)\ell_j\varphi^*\right]$$

- mediate tree-level LFV processes
- induces LFV dipoles




$$\mathcal{L}_{\text{dipole}} \supset \frac{e}{8\pi^2} m_j\, \bar{\ell}_k \sigma^{\mu\nu}\left(c^L_{kj}P_L + c^R_{kj}P_R\right)\ell_j F_{\mu\nu}$$

# Constraints

Flavor Violating constraints:

- $\ell_j \to \ell_k \gamma$
- $\ell_j \text{ Nuc} \to \ell_\text{k} \text{ Nuc}$
- $\ell_j \to \ell_i \ell_m \bar{\ell}_k$
- $\ell_j \to \ell_i \ell_m \bar{\ell}_k \nu \bar{\nu}$

Flavor Conserving constraints:

- $\Delta a_{\ell_j}$
- $Z \to \ell_i \bar{\ell}_i$ Universality
- FB-asymmetry

Other constraints:

- $Z \to \ell_j \bar{\ell}_m \varphi$
- $Z \to \text{inv}(2\varphi)$
- $\ell_j \to \ell_i \chi \bar{\chi}$
- $\ell \to 3\ell\varphi/\varphi^*$

# Symmetry Arguments

SM lepton flavor symmetry

$$U(1)_e \otimes U(1)_\mu \otimes U(1)_\tau$$

Naively broken by $c$, $c'$ couplings
Unless,

Turn on a single Off-Diagonal coupling, $c_{\mu\tau}$

Then break to residual subgroup

$$U(1)_e \otimes U(1)_{\mu-\tau}$$

# Symmetry Arguments

Now $\varphi$ has charge 2:

- Suppressed CLFV transitions (arise at higher-loop)
- Still contribute to flavor diagonal observables

Can we build such a Flavor Theory realization at $\Lambda = 1\ \mathrm{TeV}$ ?

$$\boxed{\text{Non-trivial, need } y,\ c_{\mu\tau} + \text{Symmetry Structure}}$$

# Froggatt-Nielsen 101

$U(1)$ flavor symmetry $\Longrightarrow$ higher-dim op's $\Longrightarrow$ Flavorful couplings

$$\mathcal{L}_{\text{vis.}} \supset -\alpha_{ij}\bar{L}_i H E_j \left(\frac{S \text{ or } S^*}{M}\right)^{|n_{ij}^Y|}.$$

- $\alpha_{ij} \sim \mathcal{O}(1)$
- $S$ - complex is a scalar SM-signlet, $[S]_Q = -1$
- $n_{ij}^Y = [\bar{L}_i]_Q + [E_j]_Q + [H]_Q, \quad \begin{cases} n_{ij}^Y > 0 \Rightarrow S \\ n_{ij}^Y < 0 \Rightarrow S^* \end{cases}$
- $\lambda = \frac{\langle S \rangle}{M} \simeq 0.2$ (Cabibo angle)

Then

$$\boxed{Y_{ij}^{\ell} = \alpha_{ij}\lambda^{|n_{ij}^Y|}}$$

# Froggatt-Nielsen 101 + New Scalar

If $\varphi$ is light we can also expect

$$\mathcal{L}_{\text{med.}} \supset \beta_{ij}\bar{L}_i H E_j \left(\frac{S \text{ or } S^*}{M}\right)^{|n^c_{ij}|} \frac{\varphi}{\Lambda} + \beta'_{ij}\bar{L}_i H E_j \left(\frac{S \text{ or } S^*}{M}\right)^{|n^{c'}_{ij}|} \frac{\varphi^*}{\Lambda}$$

leading to

$$\mathcal{L}_{\text{vis-med.}} \supset \frac{c_{ij}}{\Lambda}\bar{L}_i H E_j \varphi + \frac{c'_{ij}}{\Lambda}\bar{L}_i H E_j \varphi^*$$

with

$$c_{ij} \sim \lambda^{|n^c_{ij}|}, \qquad c'_{ij} \sim \lambda^{|n^{c'}_{ij}|}$$

Similarly, $\chi - \varphi$ interactions can be generated and chosen to be dominant.

# The Model

$$
\begin{aligned}
[\bar{L}_1]_Q &= (7,1), & [E_1]_Q &= (-7,7),\\
[\bar{L}_2]_Q &= (-6,-2), & [E_2]_Q &= (6,-3),\\
[\bar{L}_3]_Q &= (-2,-4), & [E_3]_Q &= (1,6),\\
[H]_Q &= (0,0), & [\varphi]_Q &= (5,-4).
\end{aligned}
$$

These are consistent with the lepton mass eigenvalues

$$\{m_e,\ m_\mu,\ m_\tau\} \sim \frac{v}{\sqrt{2}}\{\lambda^8, \lambda^5, \lambda^3\},$$

$$c \sim \begin{pmatrix} \lambda^9 & \lambda^{18} & \lambda^{10} \\ \lambda^9 & \lambda^8 & 1 \\ \lambda^5 & \lambda^{14} & \lambda^6 \end{pmatrix}, \quad c' \sim \begin{pmatrix} \lambda^{17} & \lambda^{10} & \lambda^{14} \\ \lambda^{19} & \lambda^6 & \lambda^{14} \\ \lambda^{17} & \lambda^4 & \lambda^{12} \end{pmatrix}.$$

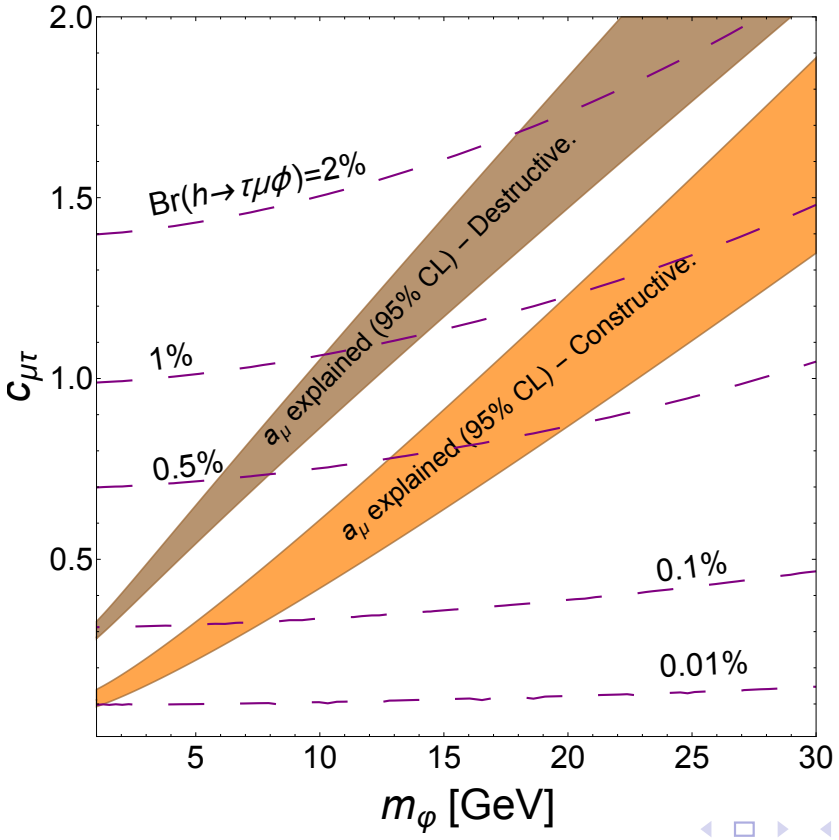
# Flavor Checklist

| LFV Process | Present Bound | Our Model |
|---|---|---|
| **Radiative Decays** | | |
| $\mathrm{Br}(\mu^+ \to \mathrm{e}^+\gamma)$ | $5.7 \times 10^{-13}$ [?] | $3.1 \times 10^{-17}$ |
| $\mathrm{Br}(\tau^\pm \to \mathrm{e}^\pm\gamma)$ | $3.3 \times 10^{-8}$ [?] | $1.1 \times 10^{-16}$ |
| $\mathrm{Br}(\tau^\pm \to \mu^\pm\gamma)$ | $4.4 \times 10^{-8}$ [?] | $1.8 \times 10^{-11}$ |
| $\mu \to e$ **Conversion in Nuclei** | | |
| $\Gamma(\mu \to e)_{\mathrm{Au}}/\Gamma_{\mathrm{capture\,Au}}$ | $7 \times 10^{-13}$ at 90% CL [?] | $1.2 \times 10^{-19}$ |
| **3-Body Decays** | | |
| $\mathrm{Br}(\mu^+ \to \mathrm{e}^+\mathrm{e}^+\mathrm{e}^-)$ | $1.0 \times 10^{-12}$[?] | $D$ $1.9 \times 10^{-19}$ |
| $\mathrm{Br}(\tau^- \to \mu^-\mu^+\mu^-)$ | $2.1 \times 10^{-8}$[?] | $T$ $1.4 \times 10^{-9}$ |
| $\mathrm{Br}(\tau^- \to \mathrm{e}^-\mathrm{e}^+\mathrm{e}^-)$ | $2.7 \times 10^{-8}$[?] | $D$ $1.1 \times 10^{-18}$ |
| $\mathrm{Br}(\tau^- \to \mathrm{e}^-\mu^+\mu^-)$ | $2.7 \times 10^{-8}$[?] | $T$ $1.9 \times 10^{-13}$ |
| $\mathrm{Br}(\tau^- \to \mu^-\mathrm{e}^+\mathrm{e}^-)$ | $1.8 \times 10^{-8}$[?] | $\begin{cases} D\ 1.8 \times 10^{-13} \\ T\ 1.9 \times 10^{-13} \end{cases}$ |
| $\mathrm{Br}(\tau^- \to \mathrm{e}^+\mu^-\mu^-)$ | $1.7 \times 10^{-8}$[?] | $T$ $4.9 \times 10^{-26}$ |
| $\mathrm{Br}(\tau^- \to \mu^+\mathrm{e}^-\mathrm{e}^-)$ | $1.5 \times 10^{-8}$[?] | $T$ $2.1 \times 10^{-27}$ |
| **Muon** $g-2$ | | |
| $\Delta a_\mu$ | $288(80) \times 10^{-11}$ [?] | $4.3 \times 10^{-9}$ |

# $(g-2)_\mu$

The anomalous magnetic moment we express as

$$a_\mu = \frac{m_\mu}{16\pi^2}\int_0^1 dx(1-x)^2 \frac{x m_\mu |c_{23}|^2 + m_\tau 2Re\{c_{23}c_{32}^*\}}{x m_\varphi^2 + (1-x)m_\tau^2 - x(1-x)m_\mu^2},$$



# Conclusions

- Searches with $\tau$ signatures at the LHC are $\not{E}_T$-inclusive, and are therefore sensitive to additional invisible particles in the event
- Interestingly, an invisibly decaying $\mathcal{O}(10\ \mathrm{GeV})$ scalar with $\mathcal{O}(1)$ $\tau\mu$ couplings can account for the observed CMS-8TeV $h \to \tau\mu$ excess
- Surprisingly, the $(g-2)_\mu$ anomaly can also be accounted for this mass and coupling range
- A TeV-scale theory of flavor can generate the SM Leptonic Yukawas, as well as the couplings which account for the excess
- Low-energy constraints may be avoid, if the couplings exhibit a residual global symmetry structure $U(1)_e \otimes U(1)_\mu \otimes U(1)_\tau \to U(1)_e \otimes U(1)_{\tau-\mu}$

Thank you for your attention

# Backup Slides

# $(g-2)_\mu$

The anomalous magnetic moment we express as

$$a_{\ell_j} = \frac{m_j}{16\pi^2} \sum_i \int_0^1 dx (1-x)^2 \frac{x m_j S_i^{(j)} + m_i P_i^{(j)}}{x m_\varphi^2 + (1-x) m_i^2 - x(1-x) m_j^2},$$

where

$$\begin{aligned} S_i^{(j)} &= \frac{v^2}{2\Lambda^2} \left( c_{ij}^* c_{ij} + c_{ij}'^* c_{ij}' + c_{ji}^* c_{ji} + c_{ji}'^* c_{ji}' \right), \\ P_i^{(j)} &= \frac{v^2}{2\Lambda^2} \left( c_{ji}'^* c_{ij} + c_{ij}^* c_{ji}' + c_{ij}'^* c_{ji} + c_{ji}^* c_{ij}' \right). \end{aligned}$$

# The Model - Flavor Basis

The flavor dependent couplings in the flavor-basis are

$$Y^\ell \sim \begin{pmatrix} \lambda^8 & \lambda^{15} & \lambda^{15} \\ \lambda^{18} & \lambda^5 & \lambda^9 \\ \lambda^{12} & \lambda^{11} & \lambda^3 \end{pmatrix},$$

$$c \sim \begin{pmatrix} \lambda^9 & \lambda^{24} & \lambda^{16} \\ \lambda^9 & \lambda^{14} & 1 \\ \lambda^5 & \lambda^{20} & \lambda^6 \end{pmatrix}, \quad c' \sim \begin{pmatrix} \lambda^{17} & \lambda^{10} & \lambda^{14} \\ \lambda^{27} & \lambda^6 & \lambda^{18} \\ \lambda^{21} & \lambda^4 & \lambda^{12} \end{pmatrix}.$$

generate the rotation matrices

$$V_{L_L} \sim \begin{pmatrix} 1 & \lambda^{10} & \lambda^{12} \\ \lambda^{10} & 1 & \lambda^6 \\ \lambda^{12} & \lambda^6 & 1 \end{pmatrix}, \qquad V_{E_R} \sim \begin{pmatrix} 1 & \lambda^{13} & \lambda^9 \\ \lambda^{13} & 1 & \lambda^8 \\ \lambda^9 & \lambda^8 & 1 \end{pmatrix}$$

# CMS $h \to \tau\mu$

event yields (minor differences between CDS and arXiv versions)

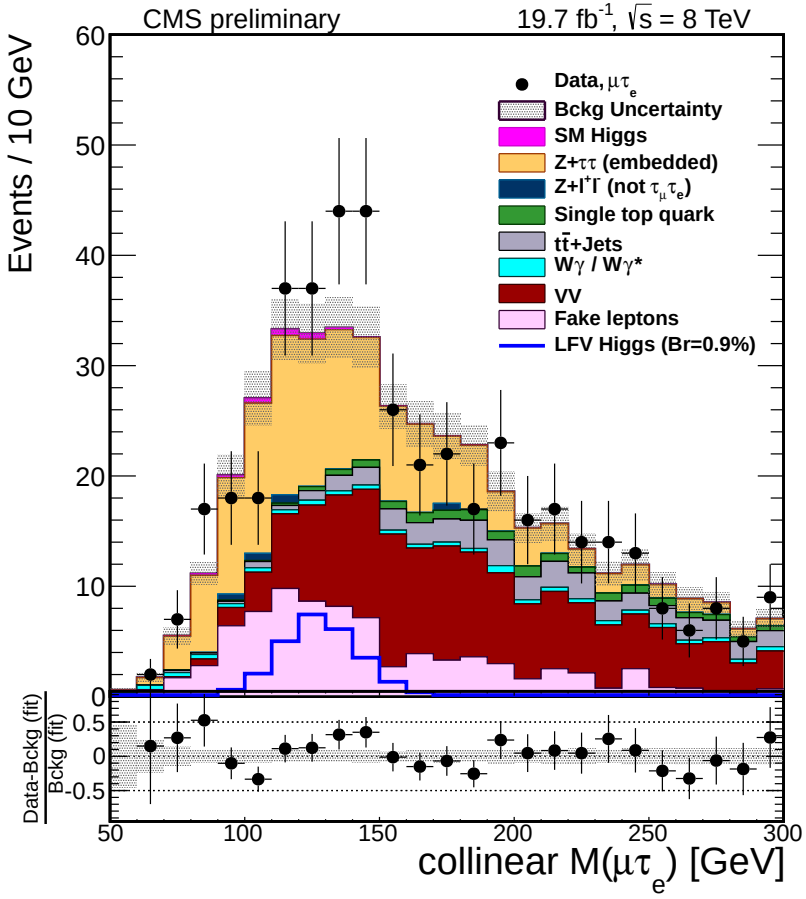
| Sample | $H \to \mu\tau_{had}$ | | | $H \to \mu\tau_e$ | | |
|---|---|---|---|---|---|---|
| | 0-jet | 1-jet | 2-jet | 0-jet | 1-jet | 2-jet |
| Fakes | $1858.1 \pm 558.8$ | $362.9 \pm 110.0$ | $0.5 \pm 0.5$ | $41.5 \pm 17.3$ | $16.1 \pm 6.8$ | $1.1 \pm 0.7$ |
| $Z \to \tau\tau$ | $198.8 \pm 11.0$ | $50.5 \pm 3.5$ | $0.4 \pm 0.2$ | $65.0 \pm 3.0$ | $38.6 \pm 2.0$ | $1.3 \pm 0.2$ |
| $ZZ, WW$ | $47.0 \pm 8.0$ | $14.6 \pm 2.6$ | $0.3 \pm 0.2$ | $40.8 \pm 6.6$ | $21.2 \pm 3.5$ | $0.7 \pm 0.2$ |
| $W\gamma$ | – | – | – | $2.0 \pm 2.1$ | $1.9 \pm 1.9$ | – |
| $Z \to ee$ or $\mu\mu$ | $94.5 \pm 25.2$ | $17.6 \pm 6.7$ | $0.1 \pm 0.1$ | $1.6 \pm 0.8$ | $1.8 \pm 0.8$ | – |
| $t\bar{t}$ | $2.5 \pm 0.6$ | $24.3 \pm 3.2$ | $0.7 \pm 0.3$ | $4.8 \pm 0.7$ | $30.0 \pm 3.4$ | $1.8 \pm 0.3$ |
| $t, \bar{t}$ | $2.7 \pm 1.2$ | $19.9 \pm 3.9$ | $0.4 \pm 0.5$ | $1.9 \pm 0.2$ | $6.8 \pm 0.8$ | $0.2 \pm 0.1$ |
| SM Higgs background | $7.0 \pm 1.3$ | $4.9 \pm 0.7$ | $1.9 \pm 0.7$ | $1.9 \pm 0.3$ | $1.6 \pm 0.2$ | $0.6 \pm 0.1$ |
| Sum of backgrounds | $2210.4 \pm 559.6$ | $494.7 \pm 110.4$ | $4.3 \pm 1.1$ | $159.4 \pm 18.9$ | $118.1 \pm 8.9$ | $5.6 \pm 0.9$ |
| LFV Higgs signal | $69.7 \pm 17.0$ | $29.7 \pm 6.7$ | $3.0 \pm 1.0$ | $24.2 \pm 5.7$ | $13.6 \pm 3.1$ | $1.2 \pm 0.4$ |
| data | $2255.0 \pm 47.5$ | $506.0 \pm 22.5$ | $8.0 \pm 2.8$ | $180.0 \pm 13.4$ | $128.0 \pm 11.3$ | $6.0 \pm 2.4$ |

from CMS-HIG-14-005

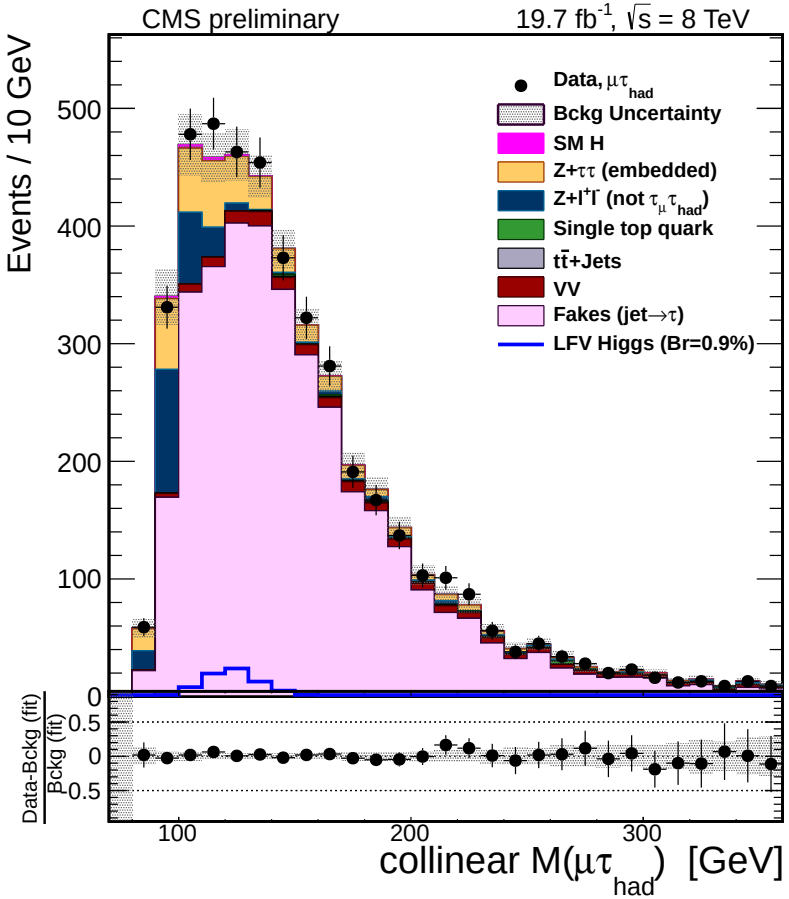
where $BR(h \to \tau\mu) = 0.89\%$

# CMS $h \to \tau\mu$

$\tau_e + 0j$



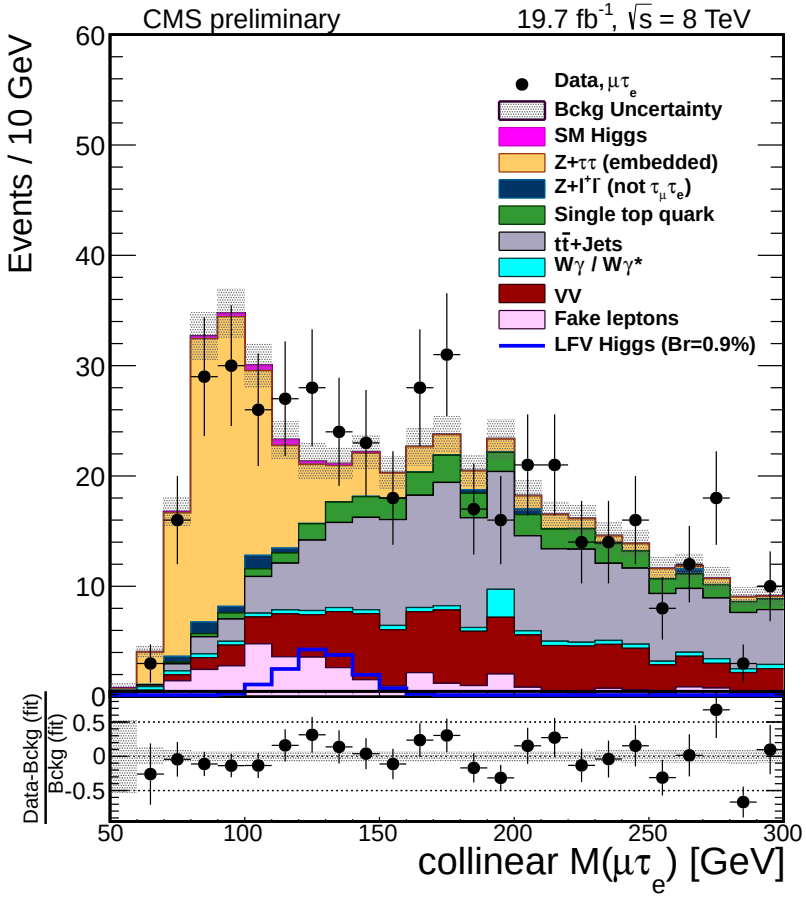

$\tau_h + 0j$



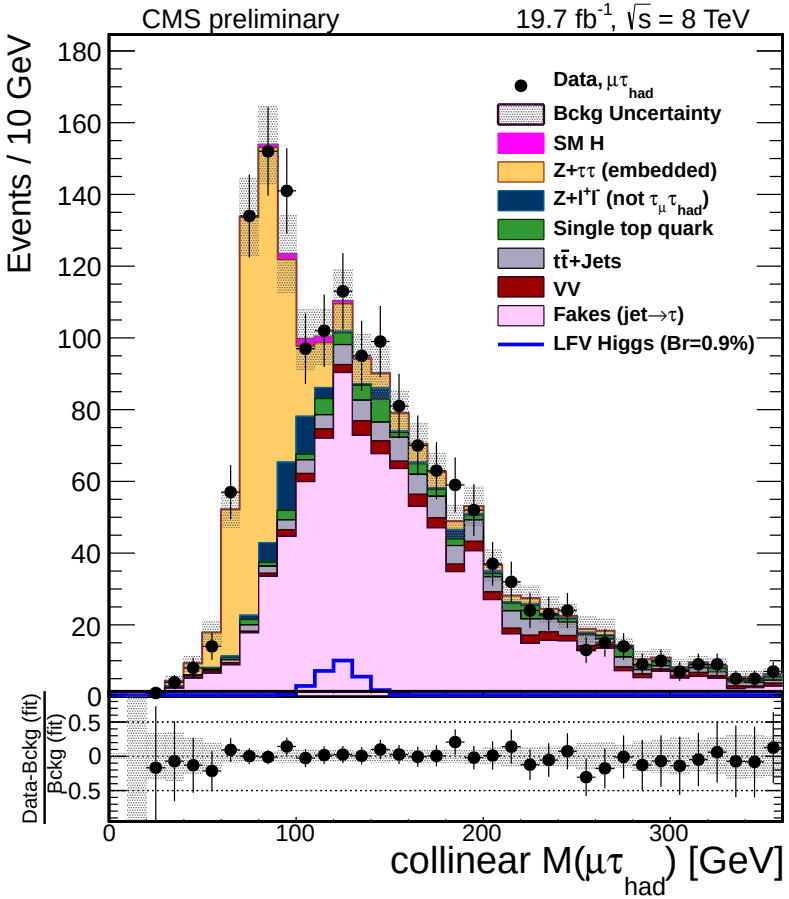

from CMS-HIG-14-005

# CMS $h \to \tau\mu$

$\tau_e + 1j$



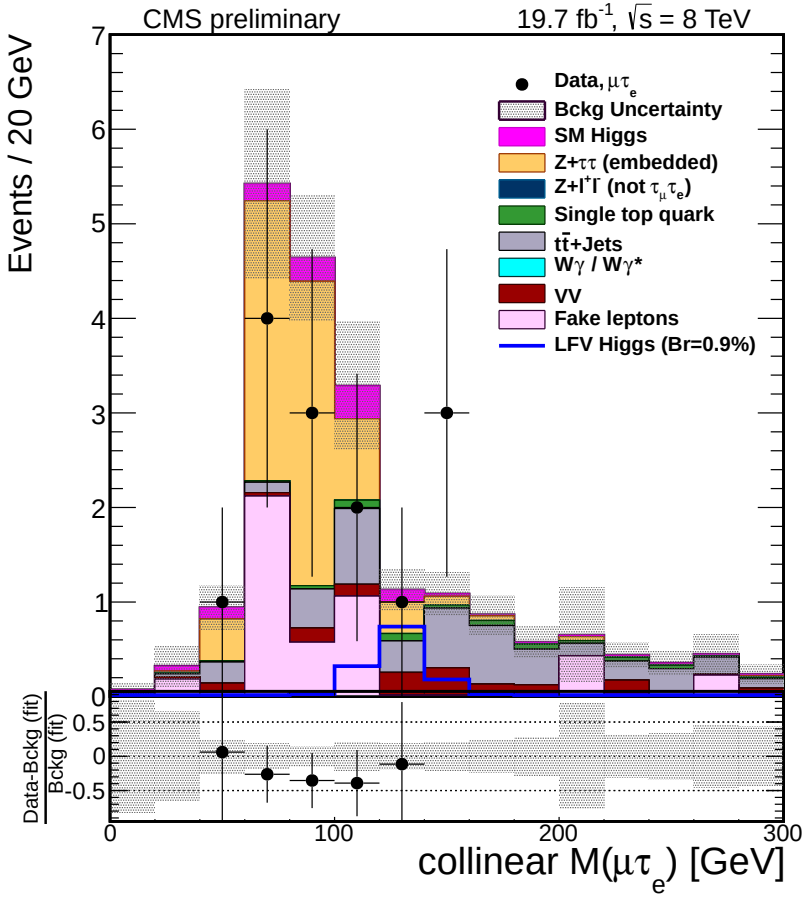

$\tau_h + 1j$



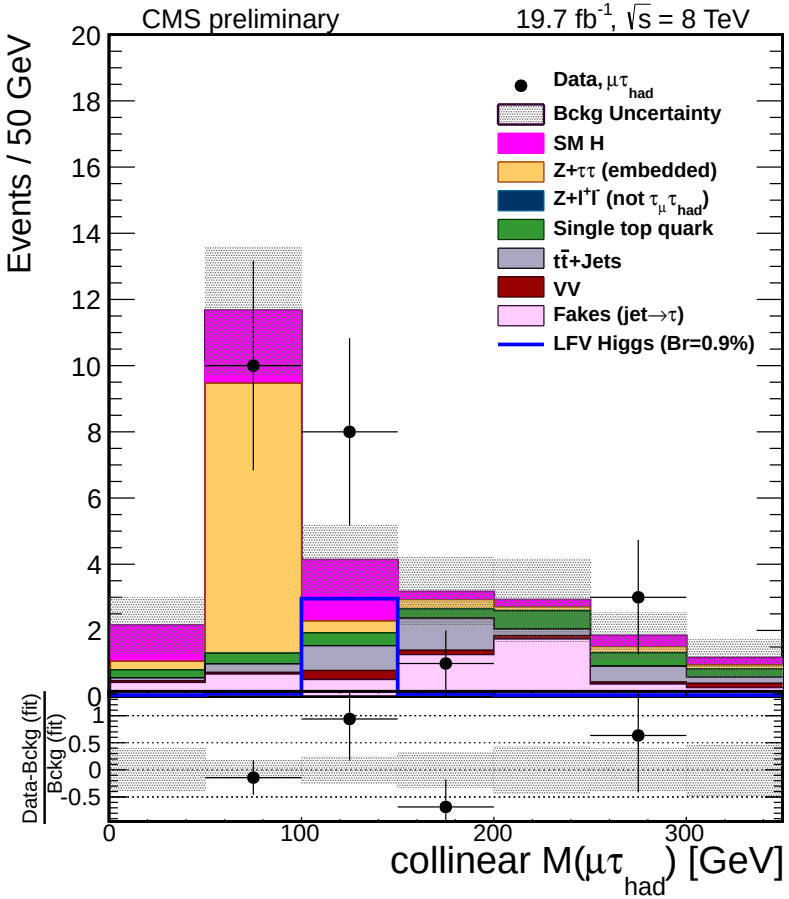

from CMS-HIG-14-005

# CMS $h \to \tau\mu$

$\tau_e + 2j$




$\tau_h + 2j$

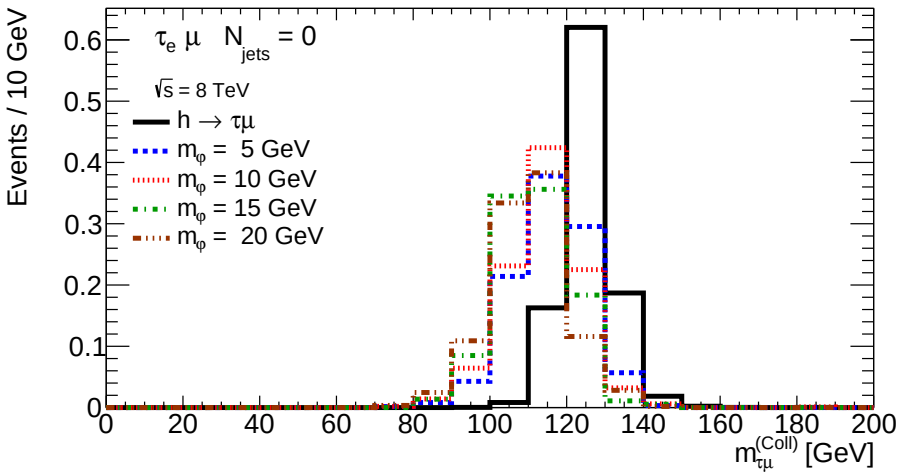


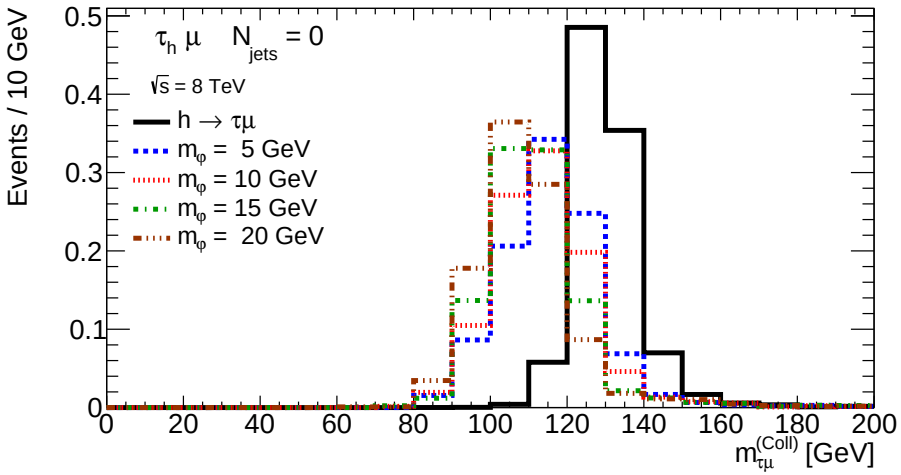

from CMS-HIG-14-005

# Conspiracy and Dark Matter

Can $h \to \mu\tau\phi$ mimic $h \to \mu\tau$:

- Broadening and shifting of $m_{\tau\mu}^{\mathrm{Coll}}$, worry about $Z \to \tau\mu$



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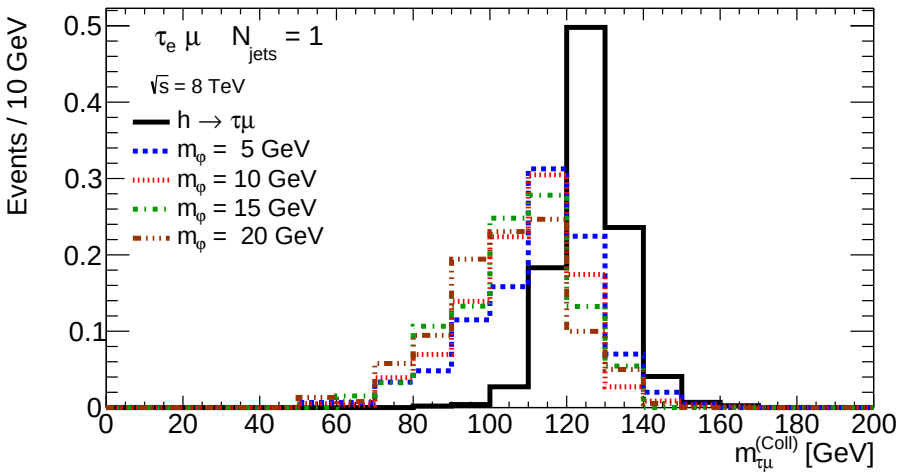
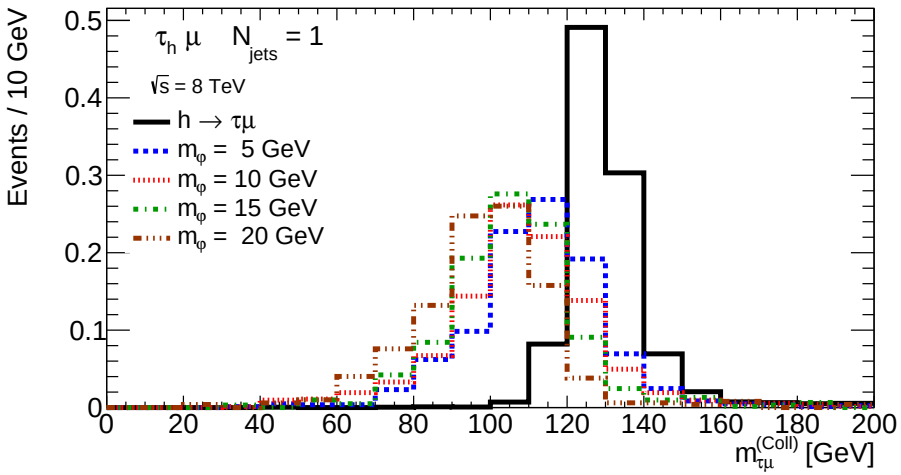
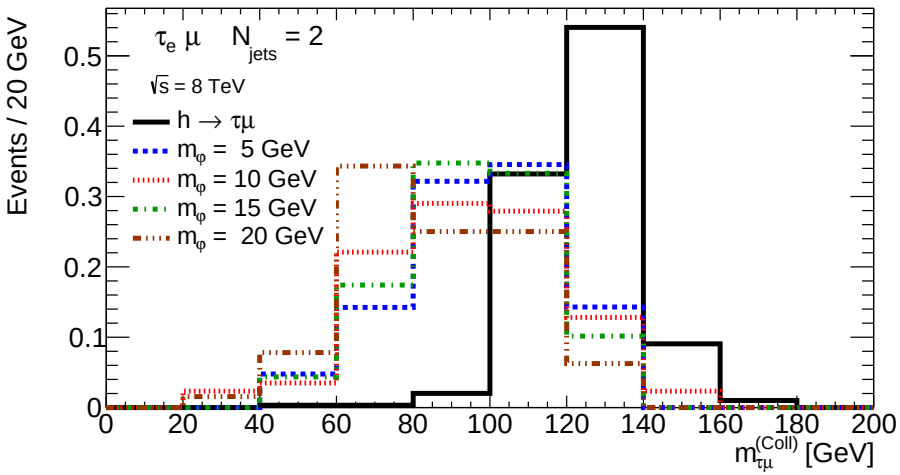
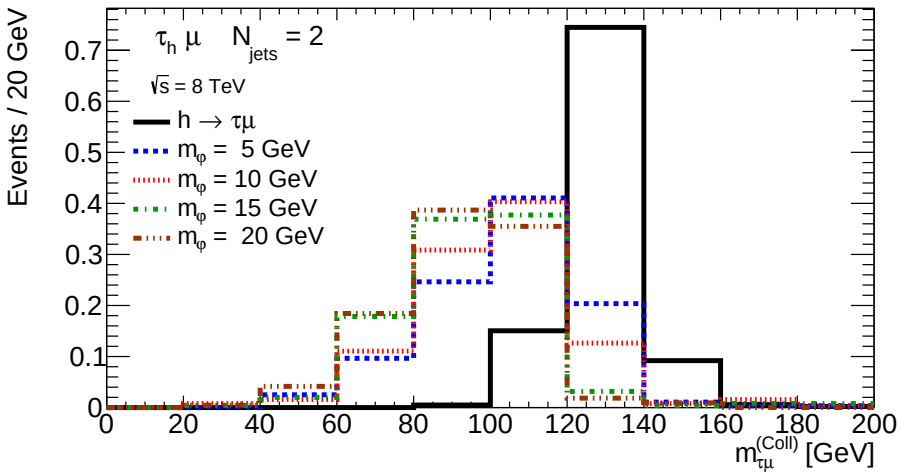


# Conspiracy and Dark Matter

Can $h \to \mu\tau\phi$ mimic $h \to \mu\tau$:

- Broadening and shifting of $m_{\tau\mu}^{\mathrm{Coll}}$, worry about $Z \to \tau\mu$