מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

$h \rightarrow \tau\mu$: Experiment and Theory

Avital Dery

S. Bressler, AD, A. Efrati, **Phys. Rev. D 90 (2014) Editors' Selection**

[arXiv:1405.4545]

AD, A. Efrati, Y. Nir, Y. Soreq, V. Susic, **Phys.Rev. D90 (2014)**

[arXiv:1408.1371]

CMS search for $h \to \tau\mu$

[CMS-PAS-HIG-14-005]

- Two channels:
  - $h \to \tau_{had}\mu$
  - $h \to \tau_e\mu$
- Three jet categories:
  - 0-jets => targeting ggF production
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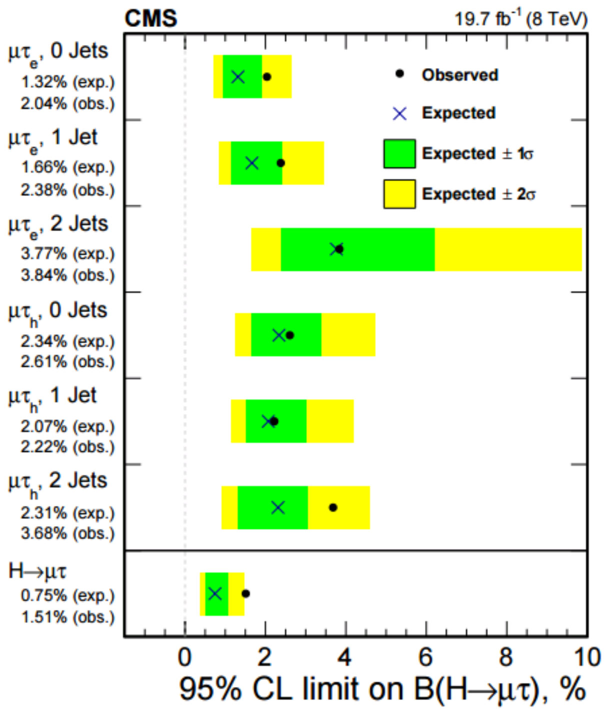
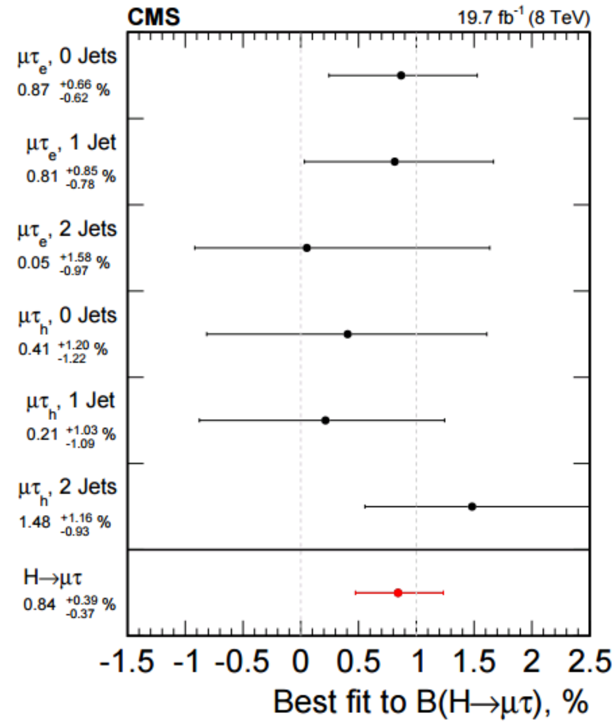
  - 2-jets => targeting VBF production





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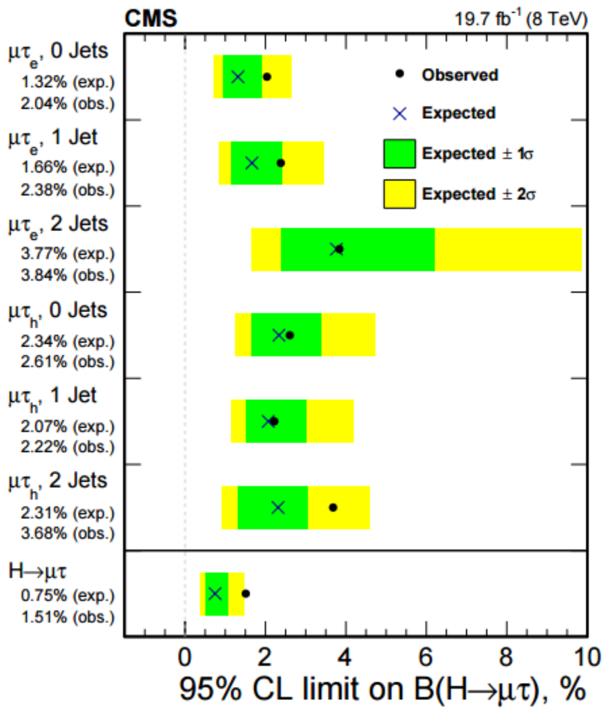

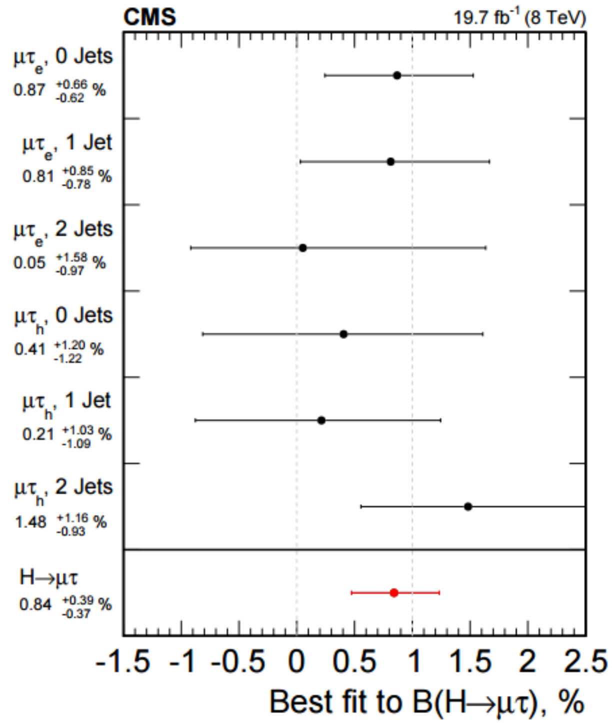

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Best fit value:

$\mathbf{BR(h \to \tau\mu) = (0.84^{+0.39}_{-0.37})\%}$

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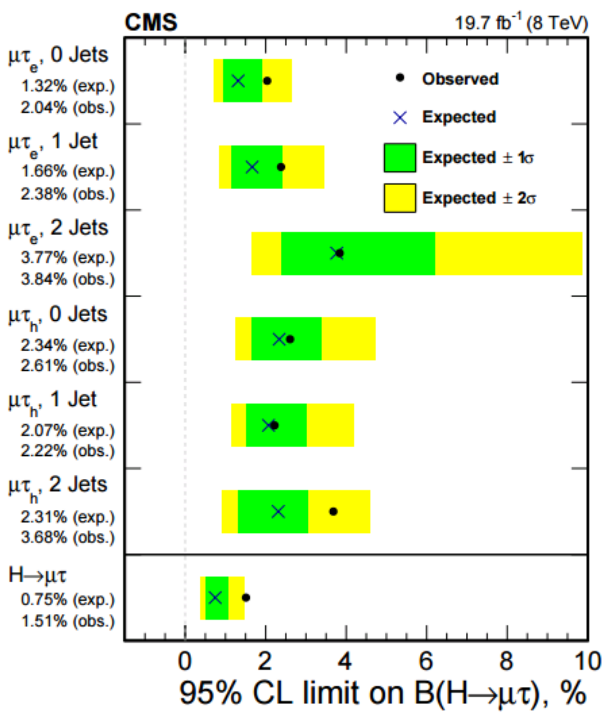

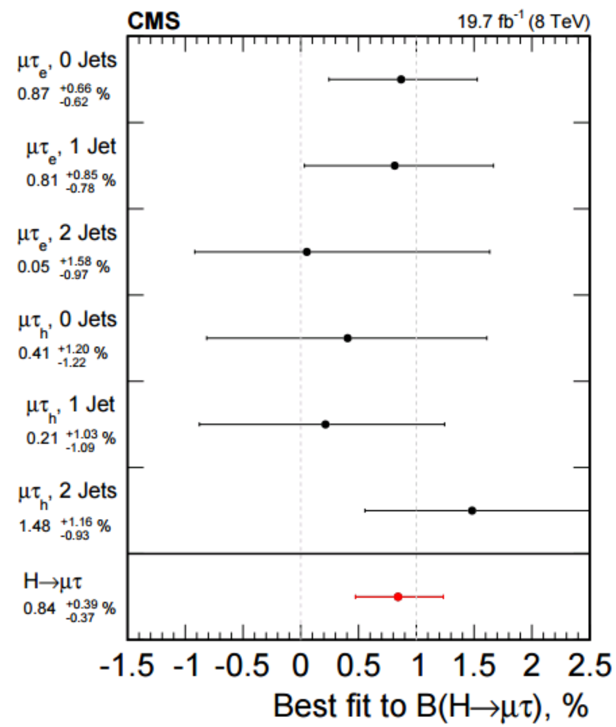

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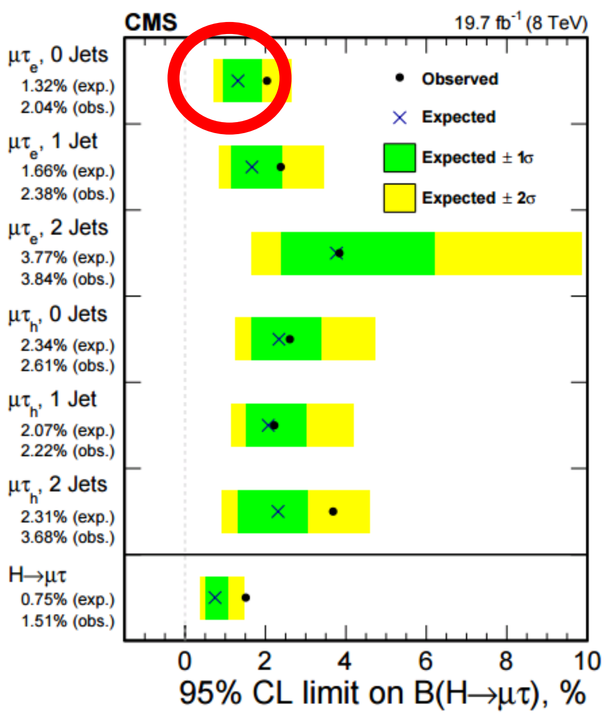
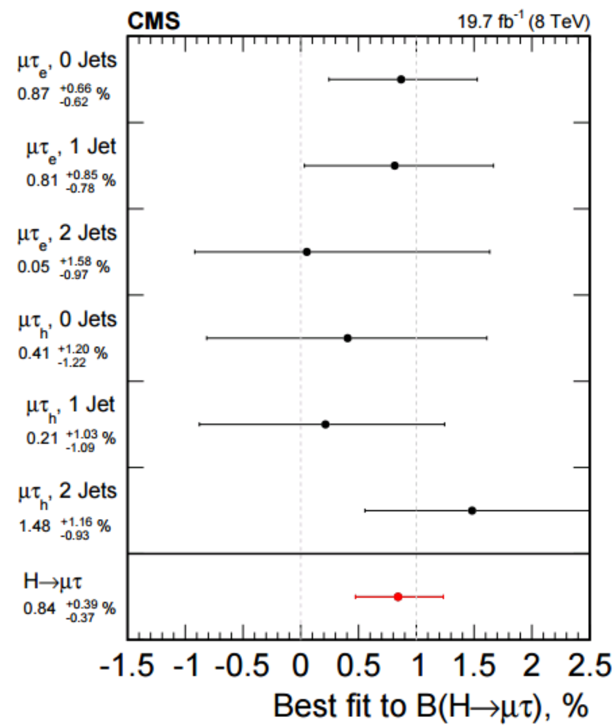
Greatest sensitivity in the $\tau_e\mu$ 0-jets channel





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- assuming no cancellations, $|Y_{\mu\tau}Y_{\tau e}| < 1.7 \times 10^{-7}$
  => $\mathrm{BR}(h \to \tau\mu) \times \mathrm{BR}(h \to \tau e) \leq O(\mathbf{10^{-11}})$

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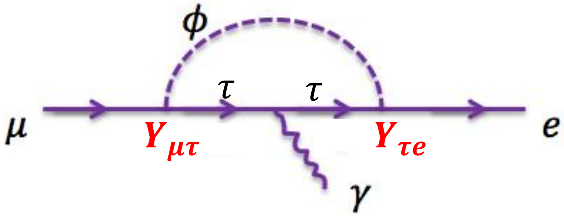

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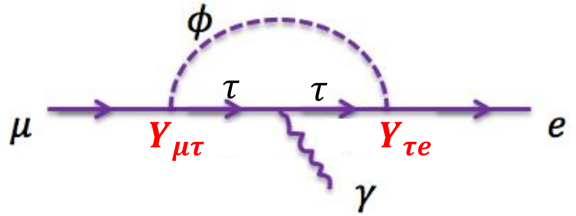

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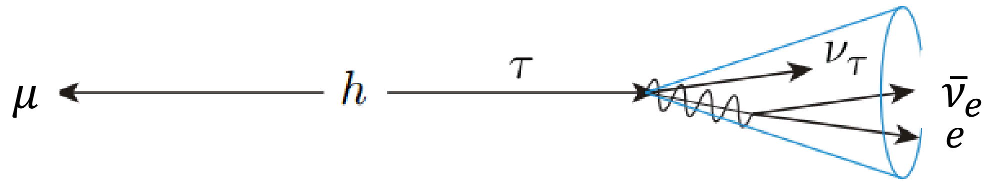
If $BR(h \to \tau\ell) \neq 0$ is established:

- **<u>clear signal of NP</u>.**
- **challenge for motivated BSM models.**

Searching for $h \to \tau_e \mu$

[Davidson and Verdier, arXiv:1211.1248]



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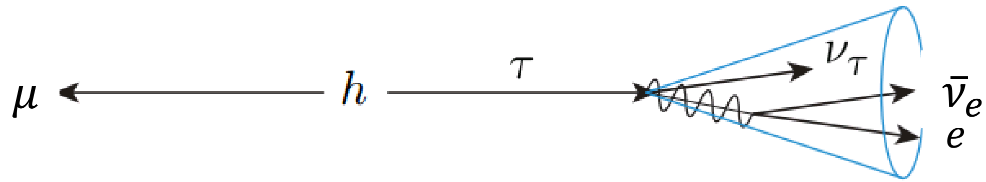
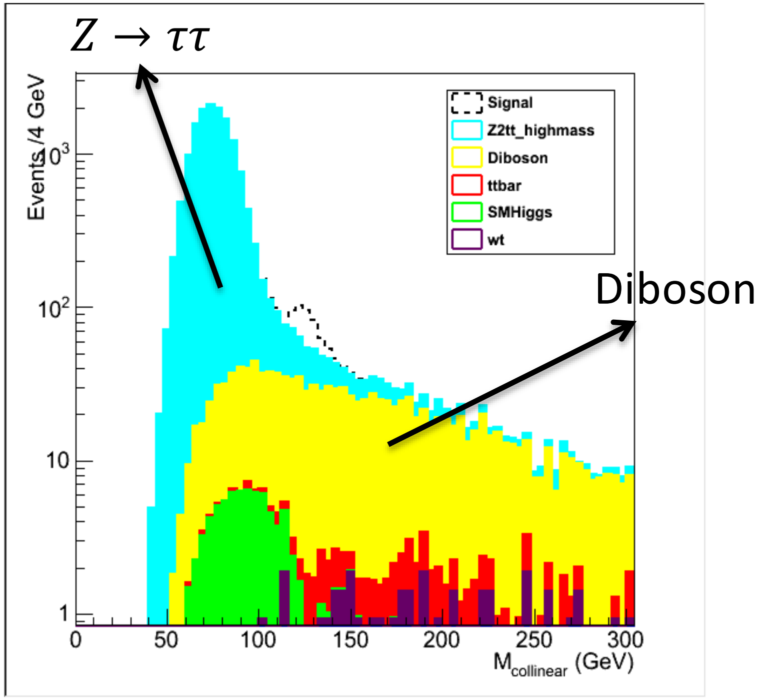


The BG estimation Challenge

- Side band extrapolation would be problematic (wide mass range - different BG shapes on either side)
- MC validation is tricky – no naïve validation region ($Z \rightarrow \tau\tau$ shared kinematics)



$$M_{Collinear} = \sqrt{p^T_{l_0}\left(p^T_{l_1} + MET\right)(cosh\Delta\eta - cos\Delta\phi)}$$

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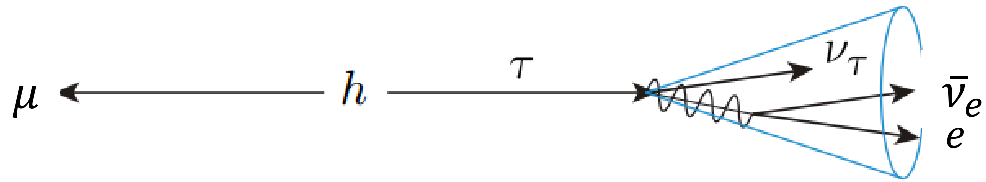

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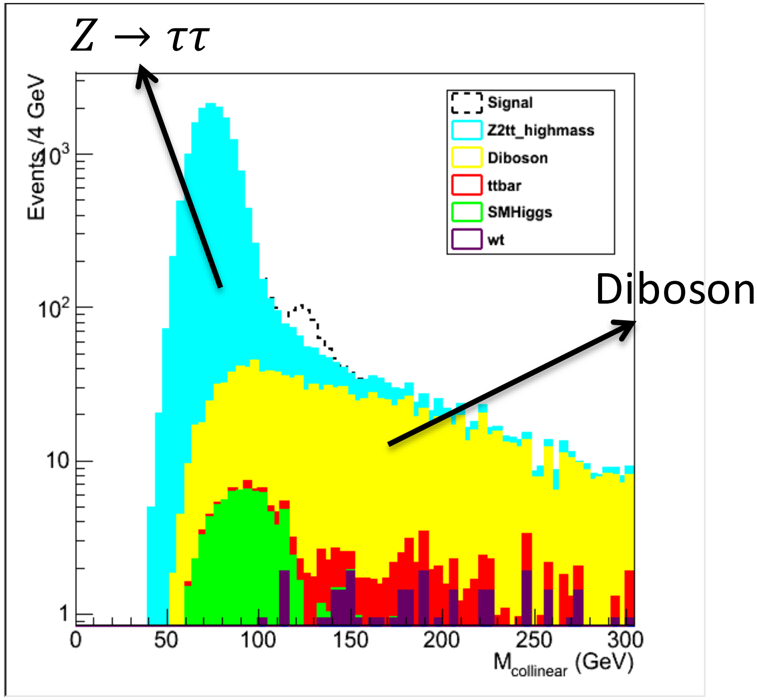
Basic selection cuts:

$p_e^T \geq 12\ GeV$ $\quad \Delta\phi(e,\mu) > 2.5$
$p_\mu^T \geq 45\ GeV$ $\quad \Delta\phi(e, MET) < 0.7$



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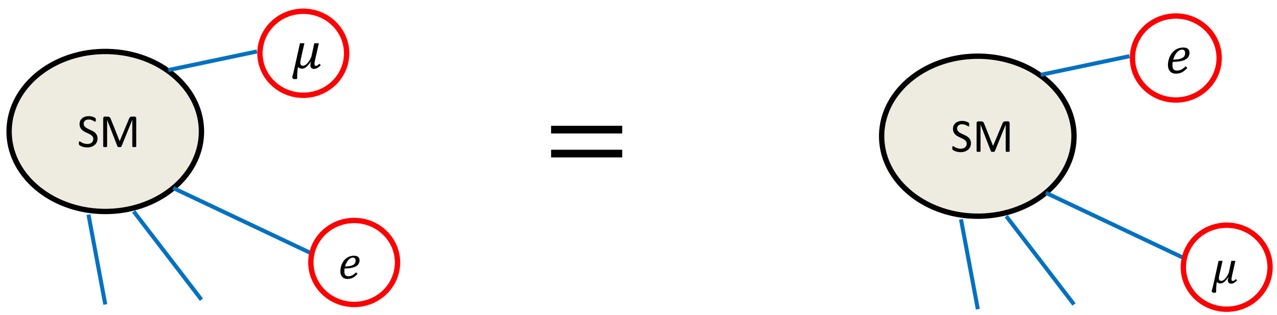

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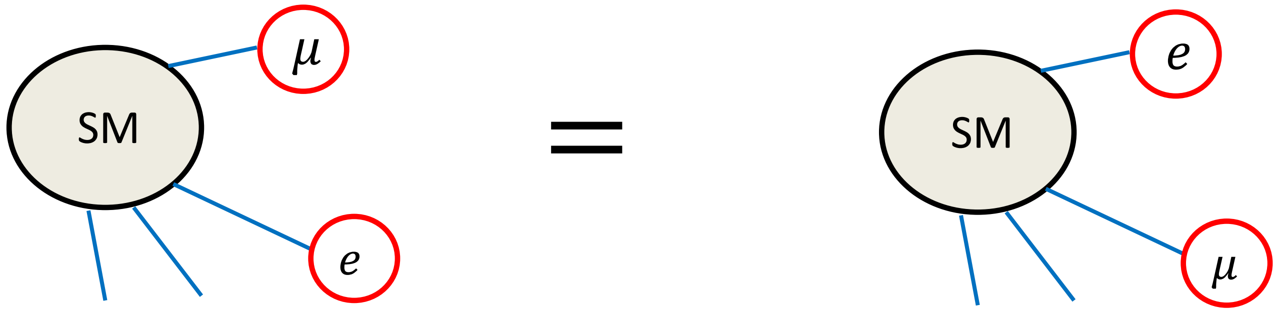

In practice:

Electrons and muons are very different objects in the detector.

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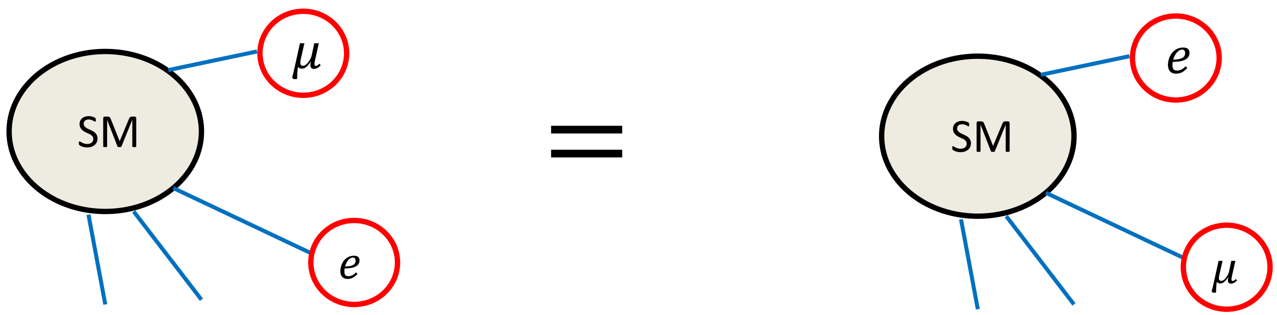

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Electrons and muons are very different objects in the detector.

- Electrons emit Bremsstrahlung radiation- may have lower pT spectrum, mis-measured direction
- Different momentum resolution
- Different reconstruction efficiencies
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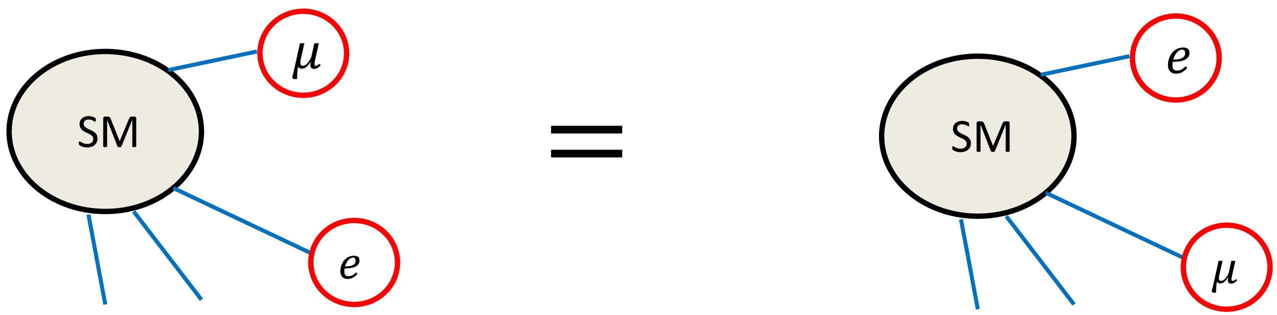

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Having <u>both e and μ in the final state</u> means most of these differences affect the two samples in the same way.

$p_\mu^T > p_e^T$

"μe"

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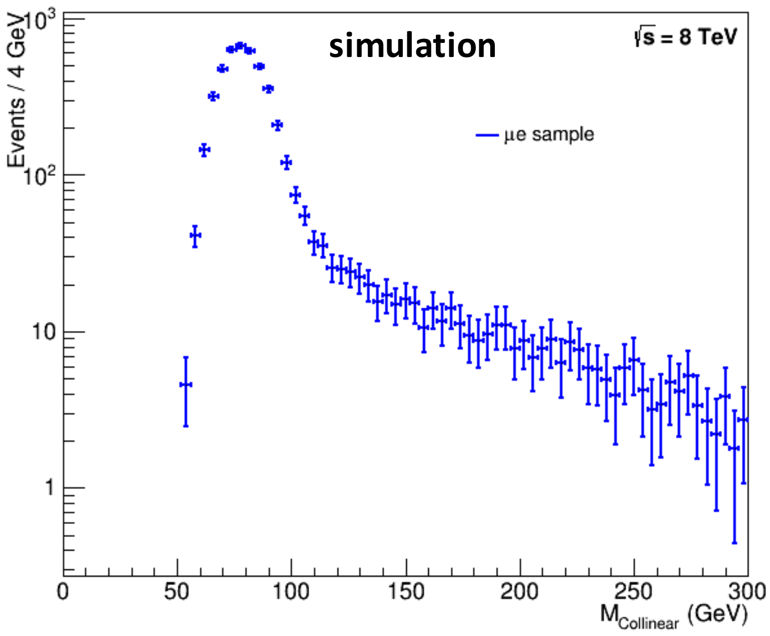
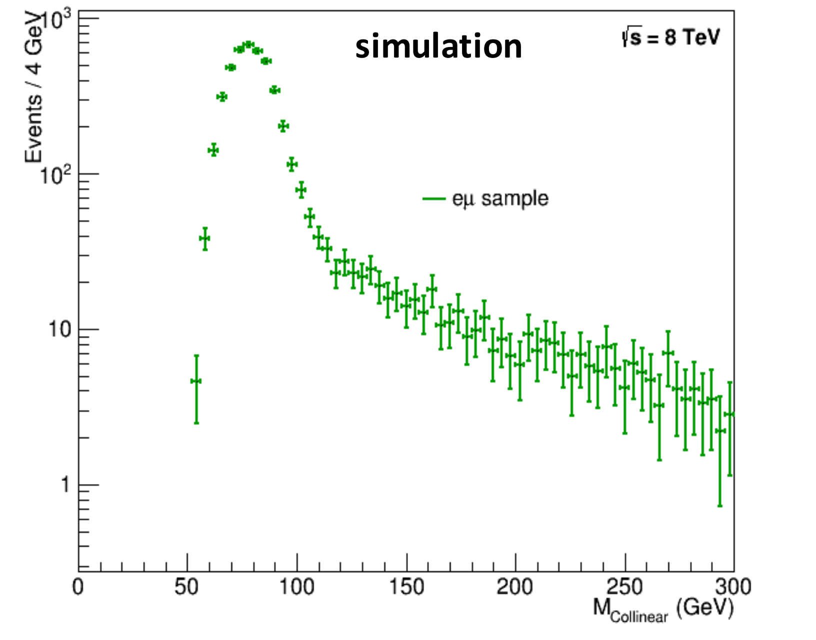
SM Background simulation
Pythia + Delphes ATLAS card





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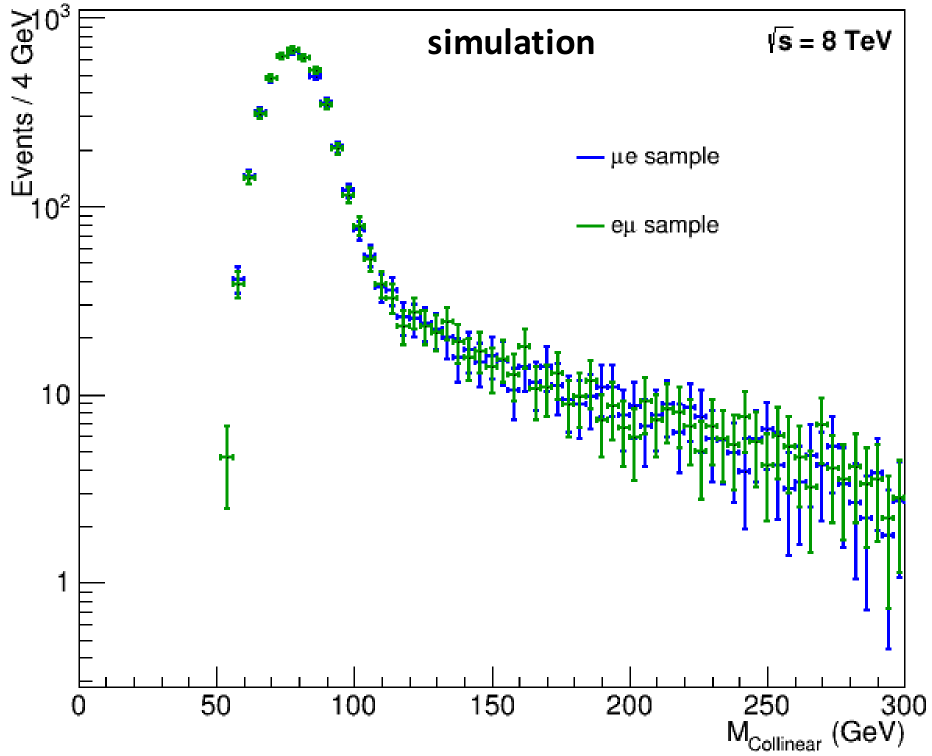

SM Background + BR($h \rightarrow \tau\mu$) = 2%
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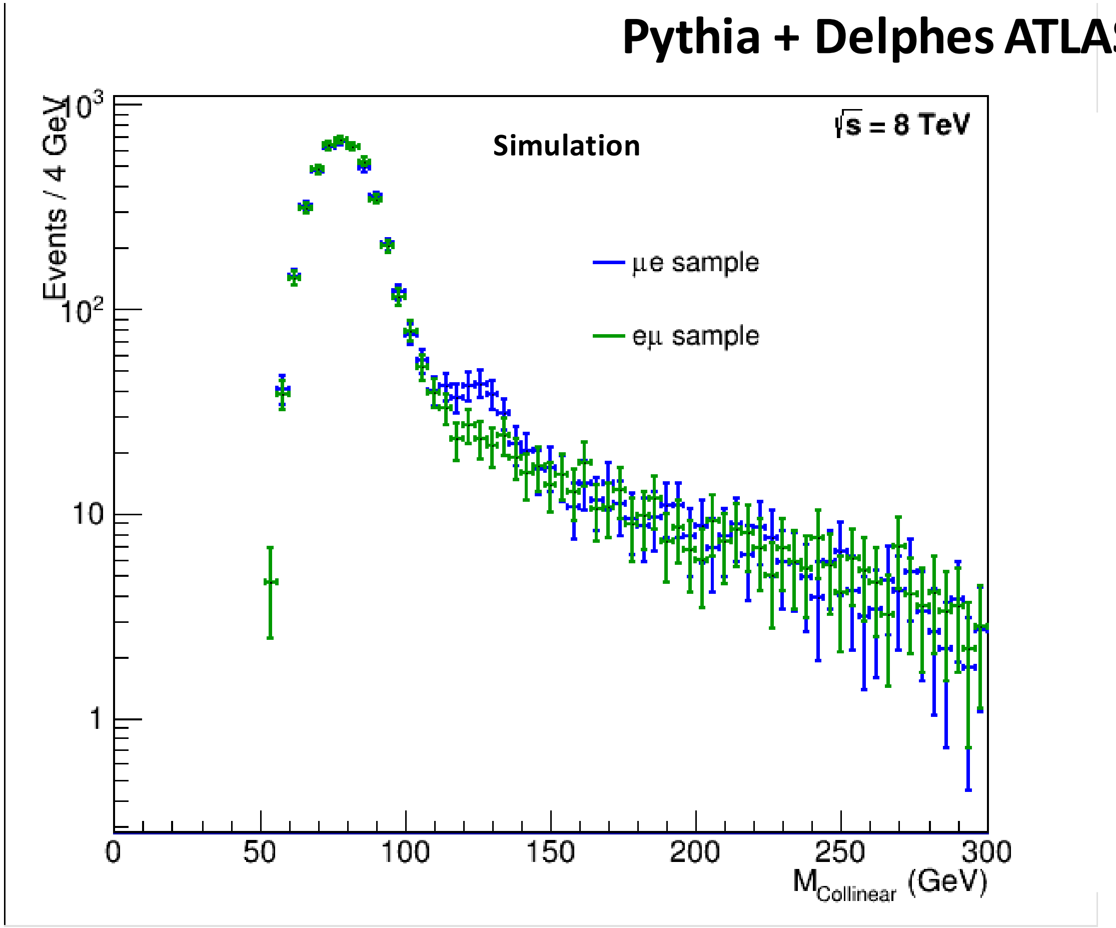

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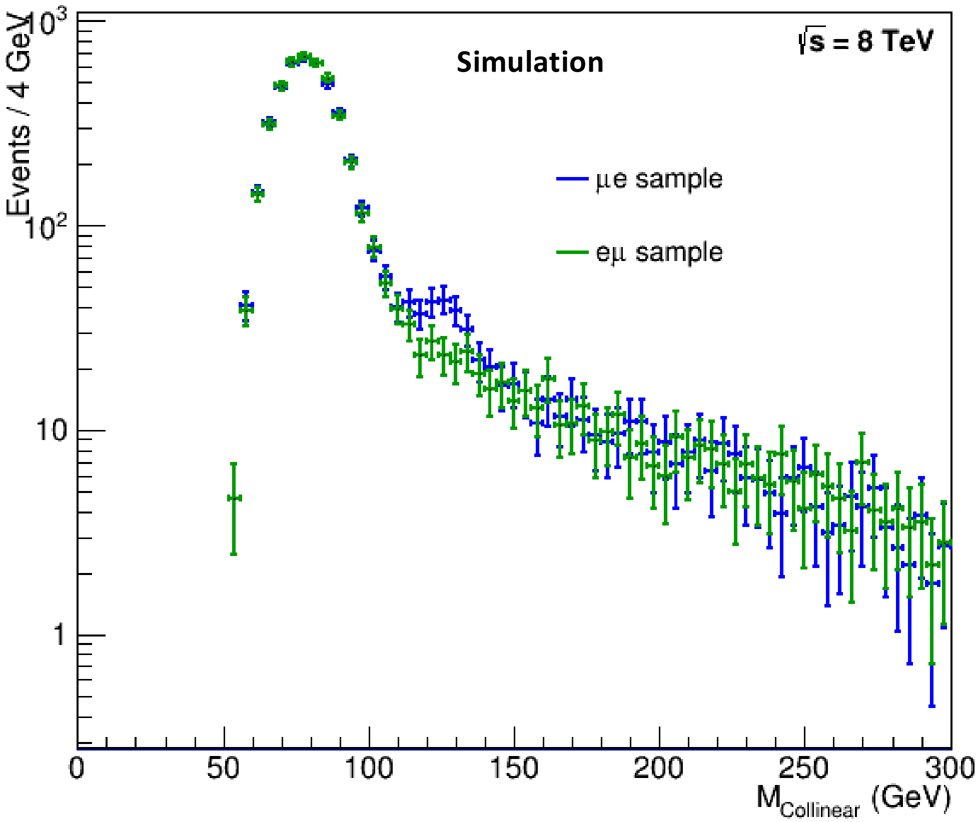


- One sample acts as a Control Region for the other
- Sensitive to the difference of branching ratios

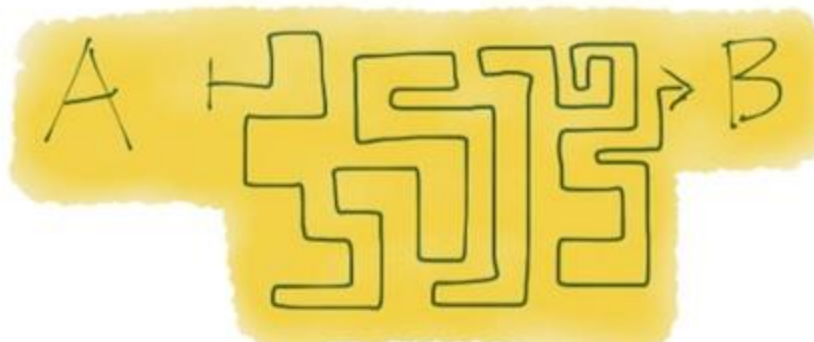
$$BR(h \to \tau\mu) - BR(h \to \tau e)$$

Sensitivity to $\boldsymbol{h \to \tau e}$ as a bonus

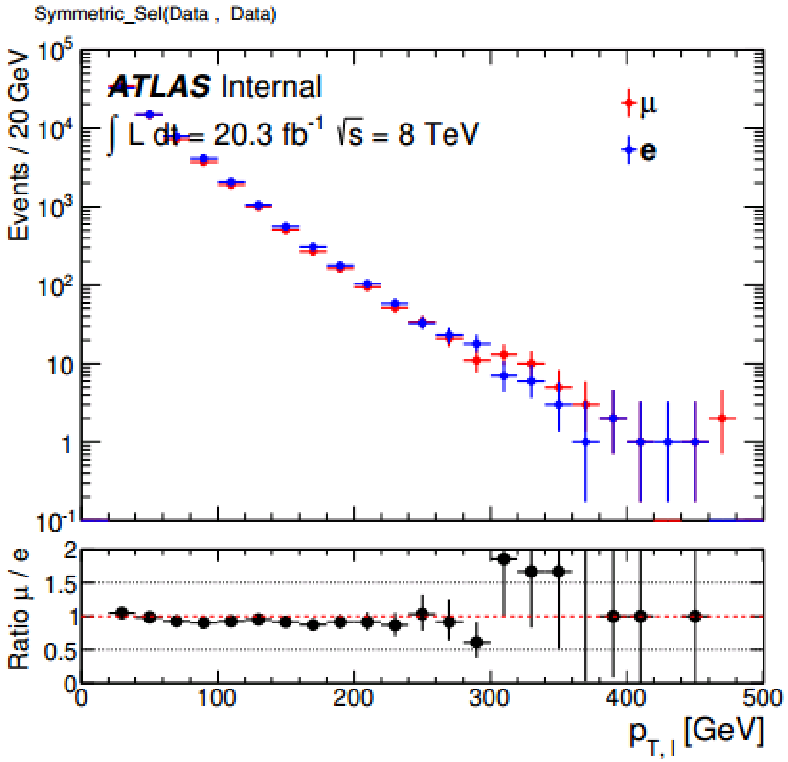
[S. Bressler, AD, A. Efrati, **Phys. Rev. D 90 (2014) Editors' Selection** **arXiv:1405.4545**]

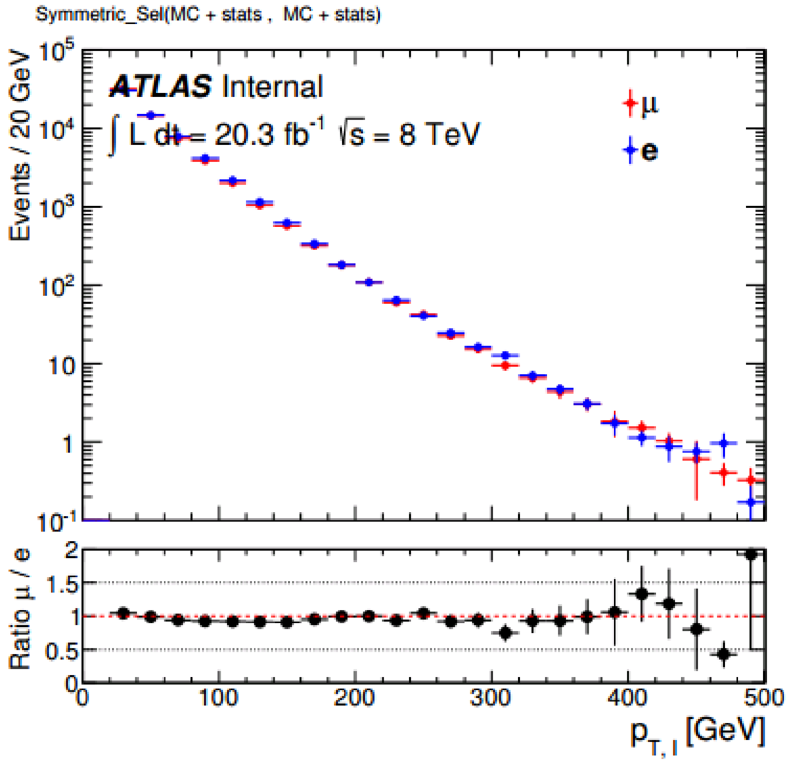
Theory:

Practice:



At first look, things seem very symmetric…





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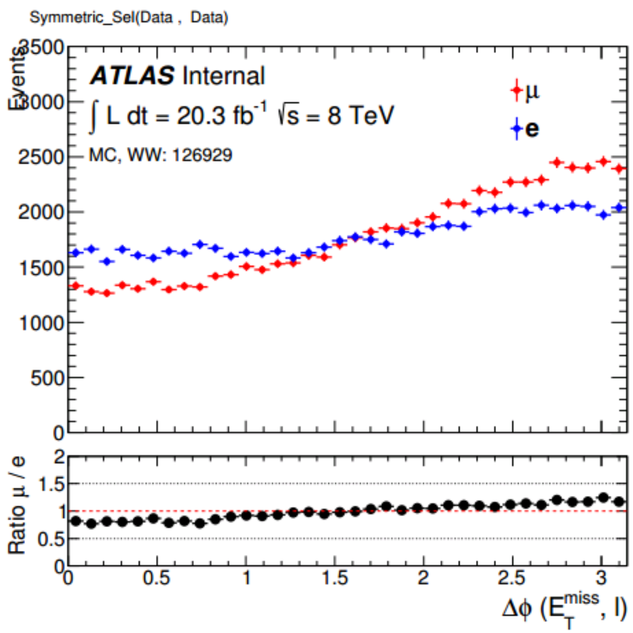
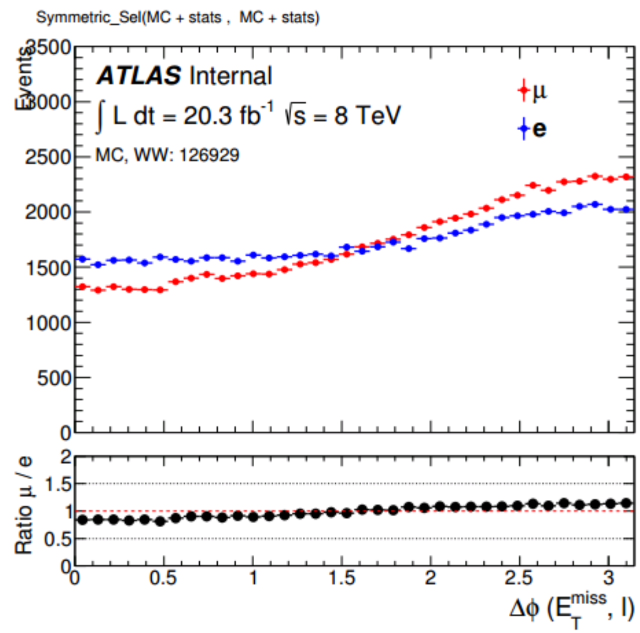


(a) “Standard“ E_T^{miss} 2012 data



(b) “Standard“ E_T^{miss} MC

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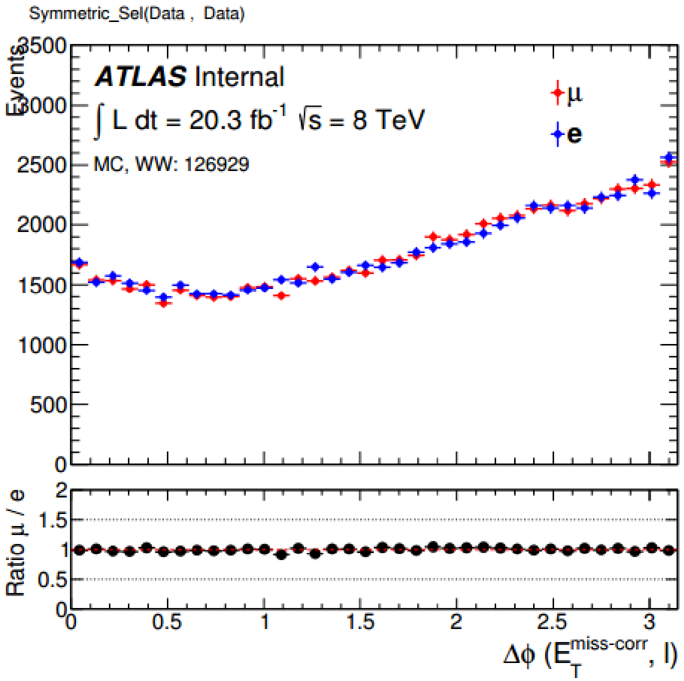
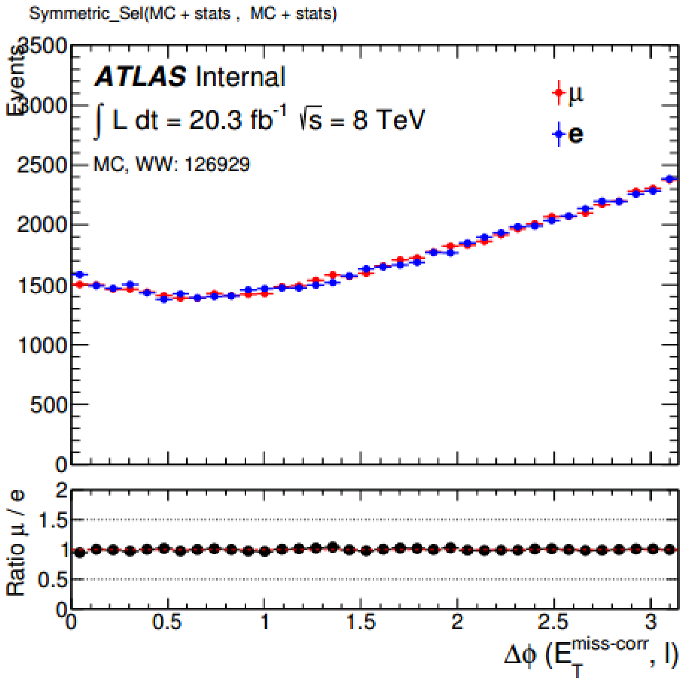
  => solution: remove "soft terms"



(a) E_T^{miss} without the soft terms in 2012 data



(b) E_T^{miss} without the soft terms in MC

Foreseeable complications

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- Fake contribution

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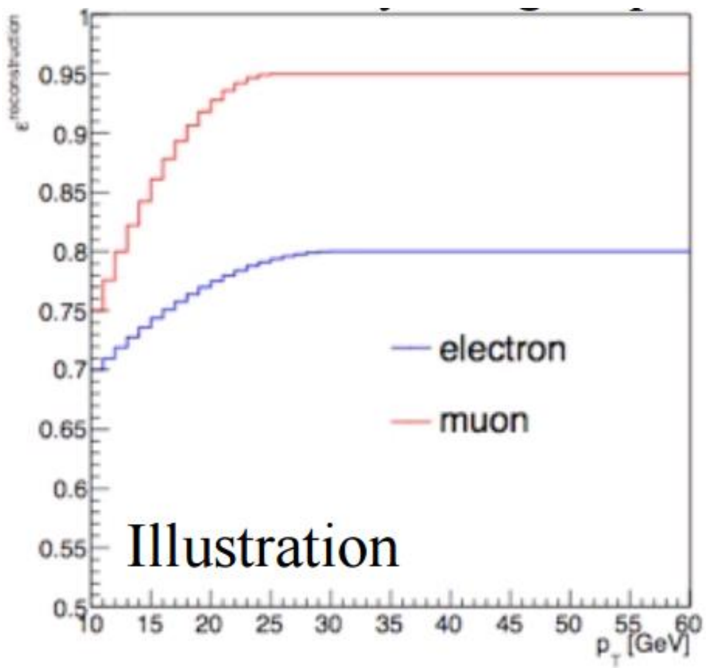
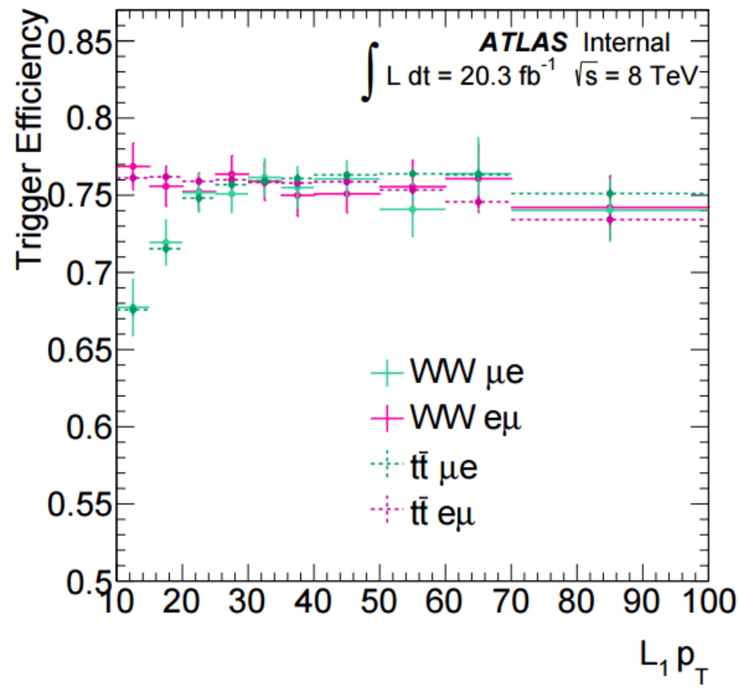
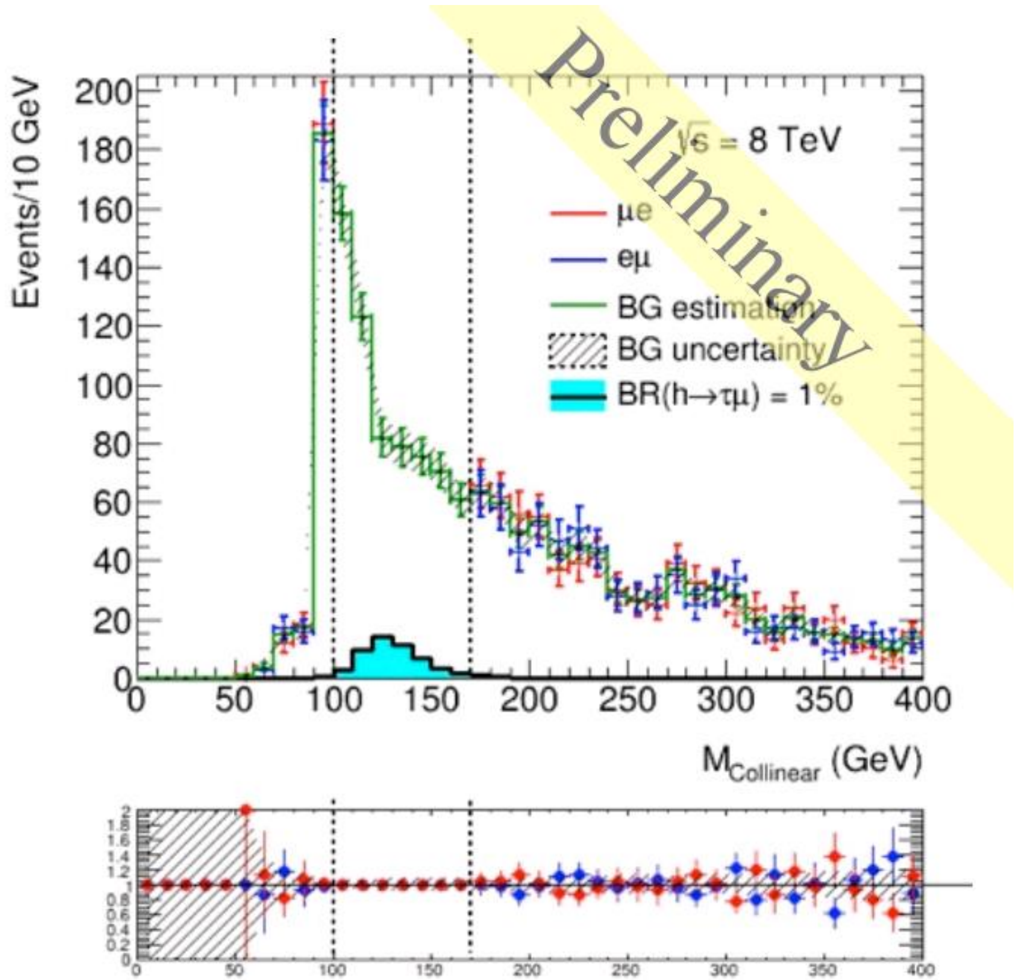
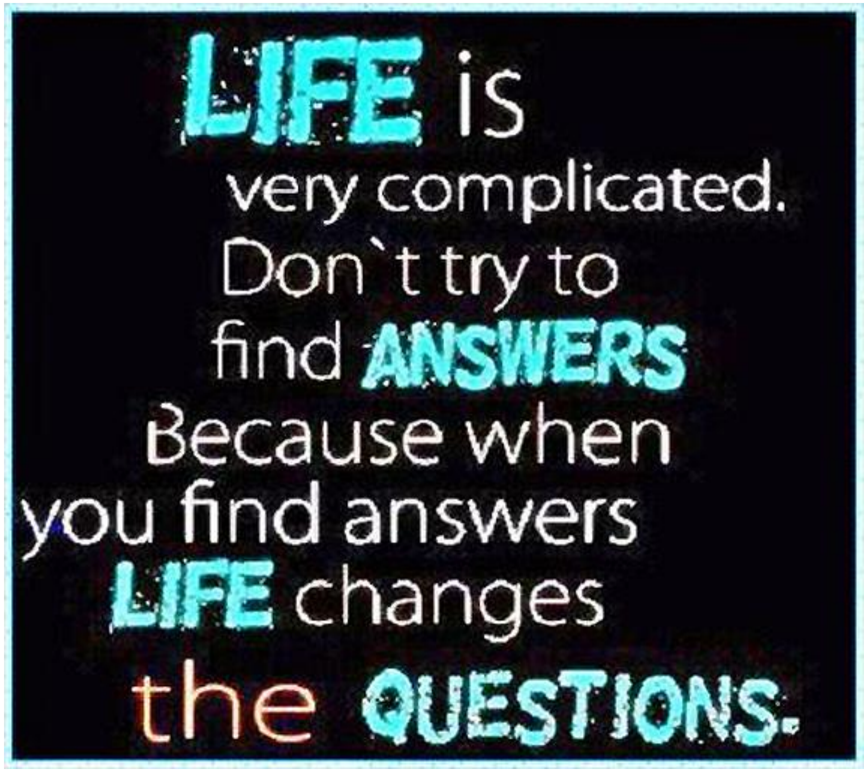
- Efficiency turn-on curves





'Blind' data Illustration




LIFE is
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Don`t try to
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An example of a non "well motivated" model that does the trick:

2HDM, where only one of the doublets carries a VEV.

$$\langle \phi_1 \rangle = v, \quad \langle \phi_2 \rangle = 0$$

$$\mathcal{L}_Y \supset \phi_1 \bar{L}_i Y_1^{ij} E_j + \phi_2 \bar{L}_i \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & y_{\tau\mu} & 0 \end{pmatrix}_{ij} E_j$$

Implications: #1 – Flavor models

[AD, A. Efrati, Y. Nir, Y. Soreq, V. Susic, arXiv:1408.1371]

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$$\mathcal{L}_Y^{d=6} = -\frac{\lambda'^u_{ij}}{\Lambda^2} Q_i \bar{U}_j \phi(\phi^\dagger\phi) - \frac{\lambda'^d_{ij}}{\Lambda^2} Q_i \bar{D}_j \phi^\dagger(\phi^\dagger\phi) - \frac{\lambda'^e_{ij}}{\Lambda^2} L_i \bar{E}_j \phi^\dagger(\phi^\dagger\phi) + \text{h.c.}$$

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$$\Delta Y^e \sim \frac{v^2}{\Lambda^2}\begin{pmatrix} y_e & |U_{e2}|y_\mu & |U_{e3}|y_\tau \\ y_e/|U_{e2}| & y_\mu & |U_{\mu 3}|y_\tau \\ y_e/|U_{e3}| & y_\mu/|U_{\mu 3}| & y_\tau \end{pmatrix}$$

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$$\Delta Y^e \sim \frac{v^2}{\Lambda^2} \begin{pmatrix} y_e & |U_{e2}| y_\mu & |U_{e3}| y_\tau \\ y_e/|U_{e2}| & y_\mu & |U_{\mu 3}| y_\tau \\ y_e/|U_{e3}| & y_\mu/|U_{\mu 3}| & y_\tau \end{pmatrix}$$

FCNC bounds from all three sectors imply $\frac{v^2}{\Lambda^2} \lesssim 10^{-2}$

=> $Y_{\mu\tau}$ is unobservably small

Implications: #1 – Flavor models

[AD, A. Efrati, Y. Nir, Y. Soreq, V. Susic, arXiv:1408.1371]

Flavor models relate off-diagonal couplings in a given sector.

- **Froggatt-Nielsen (FN) mechanism**:
  - An Approximate horizontal $U(1)$ is used to get selection rules that provide a simple explanation for the smallness and hierarchy in the flavor parameters.
  - Any higher order operator involving the SM fields will be subject to the same selection rules.

Bottom Line:

- Non trivial to generate observable rates for $h \to \tau\ell$. SM or MHDM field content + non-renormalizable terms do not suffice.
- There exist viable, though non generic models in the context of **SUSY**, where "holomorphic zeros" allow to suppress certain off-diagonal Yukawas, while keeping others large. => can saturate the current $h \to \tau\ell$ bounds

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  - **Option #3**: neutrinos are Majorana particles. If in addition the seesaw scale is below the flavor scale, then there are more spurions at play, and the bounds can be saturated.

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- The two dim. 6 operators related to $h \to \tau\mu$ and $\tau \to \mu\gamma$, respectively, are:

$$\widehat{\mathrm{O}}_{\mathrm{h}\tau\mu} = \frac{\phi^\dagger \phi}{\Lambda^2} \bar{L} \phi E \qquad \text{and} \qquad \widehat{\mathrm{O}}_{\tau\mu\gamma} = \frac{1}{\Lambda^2} \bar{L} \phi \sigma_{\mu\nu} E F^{\mu\nu}$$

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[Dorsner, Fajfer, Greljo, Kamenik, Kosnik, Nisandzic, arXiv:1502.07784]

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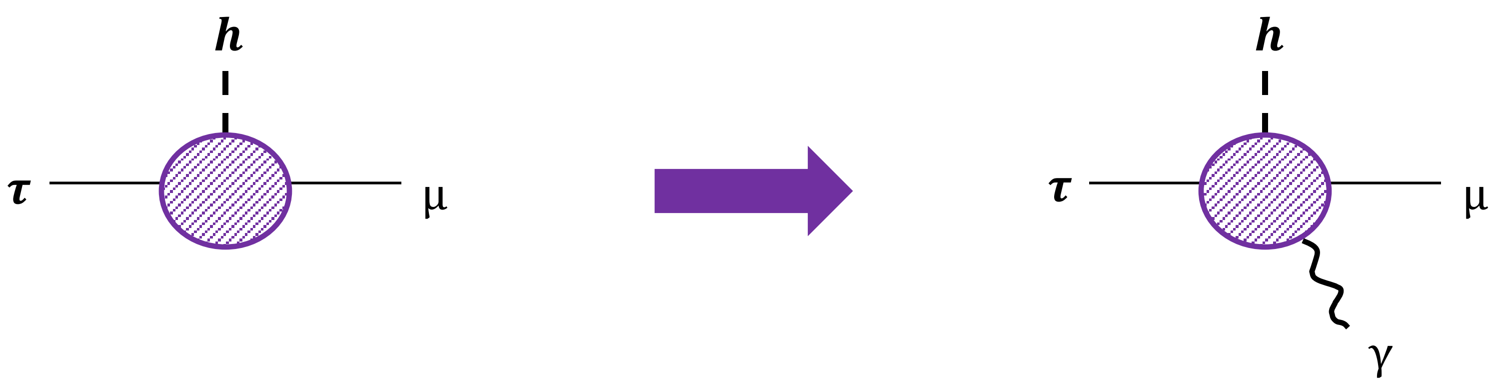
Naïve argument: for any **loop generated** process



MSSM

[Aloni, Stamou, *work in progress]*

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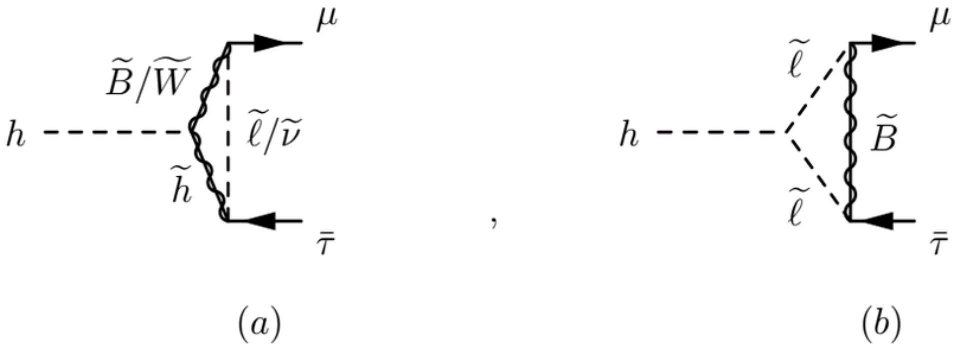

- NFC at tree level. $h \to \tau\mu$ is generated at one loop.

MSSM

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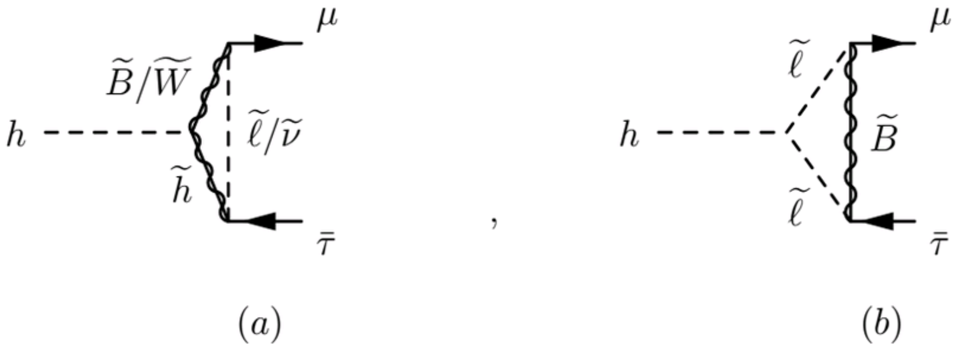

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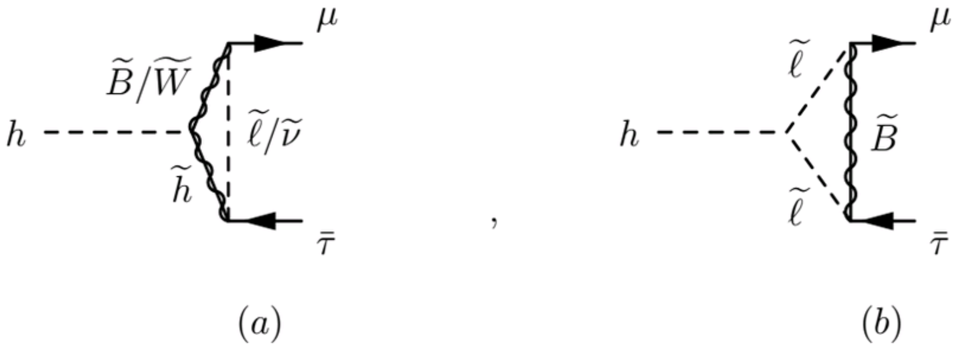

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need to enhance

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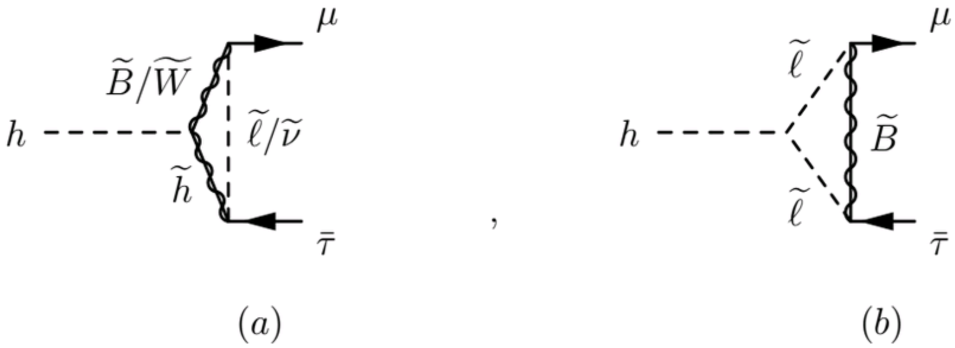

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- In order to avoid large $BR(h \to \mu\mu)$, need to allow only one chirality combination: Either $\boldsymbol{h \to \tau_L \mu_R}$ OR $\boldsymbol{h \to \tau_R \mu_L}$.

MSSM

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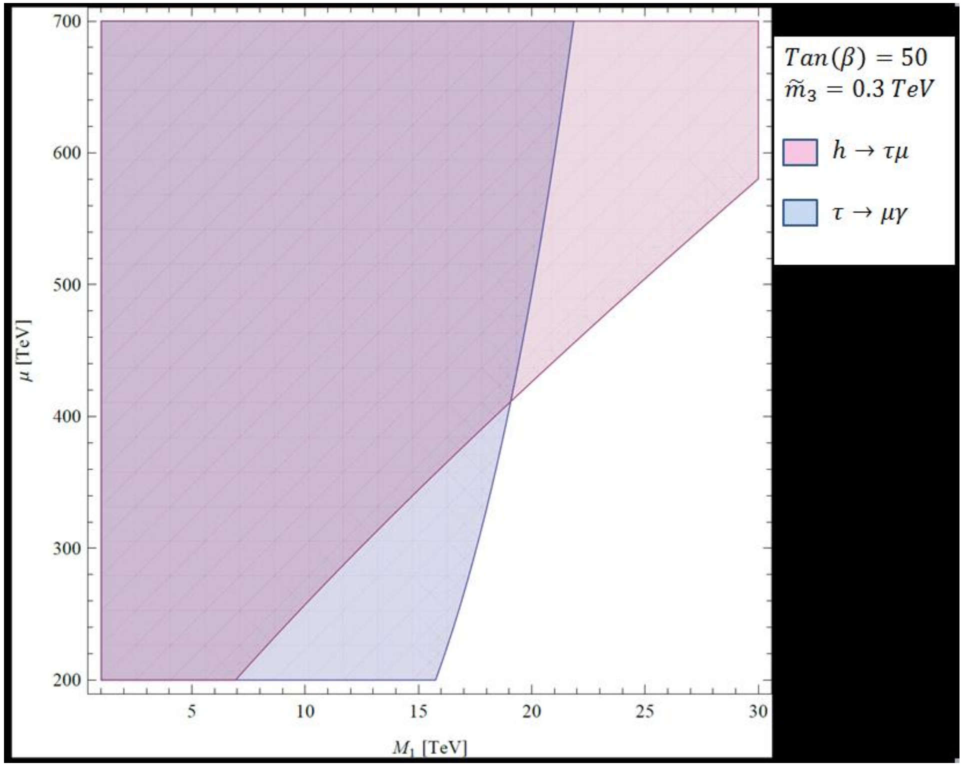
- Taking the trilinear scalar coupling (the higgsino mass) to be large can accomplish an observable $h \to \tau\mu$ branching ratio.

- $BR(\tau \to \mu\gamma)$ is sufficiently suppressed for large higgsino mass.



Thank you