Leptonic $g-2$ anomalies in a class of flavor conserving Two-Higgs-Doublet Model

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Based on the work
arXiv:2205.01115
in collaboration with
Francisco J. Botella, Fernando Cornet-Gomez & Miguel Nebot

Motivation

- Two anomalies concerning the anomalous magnetic moments of μ and e: $\delta a_\ell^{\rm Exp} \equiv a_\ell^{\rm Exp} - a_\ell^{\rm SM}$ ***N.B.*** $a_\ell = \frac{(g-2)_\ell}{2}$

Muon anomaly	***Electron anomaly***

Muon anomaly

$$\delta a_\mu^{\rm Exp} = (2.5 \pm 0.6) \times 10^{-9} \quad (4.2\sigma)$$

Muon $g-2$ Collaboration, *Phys. Rev. Lett. 126 (2021) 141801*

T. Aoyama et al., *Phys. Rept. 887 (2020) 1*

Unsettled discrepancies concerning HVP in $a_\mu^{\rm SM}$

S. Borsanyi et al., *Nature 593 (2021) 51*

M. Cè et al., *arXiv:2206.06582*

C. Alexandrou et al., *arXiv:2206.15084*

⇩

Solving the muon anomaly by enhancing HVP would create a discrepancy of the same size in the EW fit

A. Crivellin et al., *Phys. Rev. Lett. 125 (2020) 091801*

Electron anomaly

$$\delta a_e^{\rm Exp,Cs} = -(8.7 \pm 3.6) \times 10^{-13} \quad (2.4\sigma)$$

R. H. Parker et al., *Science 360 (2018) 191* α Cs recoil

$$\delta a_e^{\rm Exp,Rb} = (4.8 \pm 3.0) \times 10^{-13} \quad (1.6\sigma)$$

L. Morel et al., *Nature 588 (2020) 61* α Rb recoil

Opposite sign of $\delta a_\mu^{\rm Exp}$ and $\delta a_e^{\rm Exp,Cs}$: some sort of effective decoupling between between μ and e beyond mass proportionality

- General Flavor Conserving Two-Higgs-Doublet Model (2HDM) may provide an explanation of both $g-2$ anomalies

  + CDF W mass anomaly — CDF Collaboration, *Science 376 (2022) 170*
  + ATLAS excess $S(400\ {\rm GeV}) \to \tau\tau$ — ATLAS Collaboration, *Phys. Rev. Lett. 125 (2020) 051801*

General Flavor Conserving 2HDM

Yukawa sector

- The Yukawa sector in 2HDMs reads (assuming massless neutrinos)

N.B. $\tilde{\Phi}_j = i\sigma_2 \Phi_j^*$

$$\mathscr{L}_{\rm Y} = -\bar{Q}_L^0 \left(\Phi_1 Y_{d1} + \Phi_2 Y_{d2}\right) d_R^0 - \bar{Q}_L^0 \left(\tilde{\Phi}_1 Y_{u1} + \tilde{\Phi}_2 Y_{u2}\right) u_R^0 - \bar{L}_L^0 \left(\Phi_1 Y_{\ell 1} + \Phi_2 Y_{\ell 2}\right) \ell_R^0 + \mathrm{h.c.}$$

Rotating the scalar fields into the "Higgs basis" ↓ $\langle H_1 \rangle = \frac{v}{\sqrt{2}} \begin{pmatrix} 0 \\ 1 \end{pmatrix} \quad \langle H_2 \rangle = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$

$$\mathscr{L}_{\rm Y} = -\frac{\sqrt{2}}{v} \bar{Q}_L^0 \left(H_1 M_d^0 + H_2 N_d^0\right) d_R^0 - \frac{\sqrt{2}}{v} \bar{Q}_L^0 \left(\tilde{H}_1 M_u^0 + \tilde{H}_2 N_u^0\right) u_R^0 - \frac{\sqrt{2}}{v} \bar{L}_L^0 \left(H_1 M_\ell^0 + H_2 N_\ell^0\right) \ell_R^0 + \mathrm{h.c.}$$

Going to the fermion mass basis ↓

$$\mathscr{L}_{\rm Y} = -\frac{\sqrt{2}}{v} \bar{Q}_L \left(H_1 M_d + H_2 N_d\right) d_R - \frac{\sqrt{2}}{v} \bar{Q}_L \left(\tilde{H}_1 M_u + \tilde{H}_2 N_u\right) u_R - \frac{\sqrt{2}}{v} \bar{L}_L \left(H_1 M_\ell + H_2 N_\ell\right) \ell_R + \mathrm{h.c.}$$

Diagonal fermion mass matrices *New flavor structures (may explain the anomalies!)*

Model I-gℓFC

F. J. Botella et al., *Phys. Rev. D 102 (2020) 035023*

N.B. $t_\beta \equiv \tan\beta = v_2/v_1$

Type I or X quark sector: $N_d = t_\beta^{-1} M_d \quad N_u = t_\beta^{-1} M_u$

General Flavor Conserving lepton sector (gℓFC): $N_\ell = \mathrm{diag}(n_e, n_\mu, n_\tau)$

$\mathbb{Z}_2$ **symmetry**

$$\left[Y_{\ell a} Y_{\ell b}^\dagger, Y_{\ell c} Y_{\ell d}^\dagger\right] = 0 = \left[Y_{\ell a}^\dagger Y_{\ell b}, Y_{\ell c}^\dagger Y_{\ell d}\right]$$

F. J. Botella et al., *Phys. Rev. D 98 (2018) 035046*

N_ℓ *diagonal (no FCNC), arbitrary and one loop stable under RGE*

Effective decoupling between μ and e to explain $(g-2)_\ell$ anomalies ⇔ Independence of n_e and n_μ

General Flavor Conserving 2HDM

Scalar sector

Model $\text{I-g}\ell\text{FC}$

Type I or X quark sector: $N_d = t_\beta^{-1} M_d \quad N_u = t_\beta^{-1} M_u$

General Flavor Conserving lepton sector (gℓFC): $N_\ell = \text{diag}(n_e, n_\mu, n_\tau)$

$\mathbb{Z}_2$ symmetry

$$\left[Y_{\ell a} Y_{\ell b}^\dagger, Y_{\ell c} Y_{\ell d}^\dagger\right] = 0 = \left[Y_{\ell a}^\dagger Y_{\ell b}, Y_{\ell c}^\dagger Y_{\ell d}\right]$$

Completing our $\text{I-g}\ell\text{FC}$ *model…*

- The scalar potential is shaped by a $\mathbb{Z}_2$ symmetry softly broken by $\mu_{12}^2 \neq 0$
- CP-conserving scalar and Yukawa sectors:

$$H_1 = \begin{pmatrix} G^+ \\ \frac{v + H^0 + iG^0}{\sqrt{2}} \end{pmatrix} \qquad H_2 = \begin{pmatrix} H^+ \\ \frac{R^0 + iI^0}{\sqrt{2}} \end{pmatrix}$$

$H^\pm$ *physical charged scalars*

$G^0, G^\pm$ *would-be Goldstone bosons*

CP-even

CP-odd

$$\begin{pmatrix} h \\ H \\ A \end{pmatrix} = \begin{pmatrix} s_{\alpha\beta} & c_{\alpha\beta} & 0 \\ -c_{\alpha\beta} & s_{\alpha\beta} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} H^0 \\ R^0 \\ I^0 \end{pmatrix}$$

Physical neutral scalars — *Block diagonal* — *Weak eigenstates*

$$s_{\alpha\beta} \equiv \sin(\alpha+\beta)$$
$$c_{\alpha\beta} \equiv \cos(\alpha+\beta)$$

$\text{Im}(n_\ell) = 0$ → *Absence of new contributions to EDM*

New contributions to δa_ℓ

One loop

Full theoretical prediction: $a_\ell^{\mathrm{Th}} = a_\ell^{\mathrm{SM}} + \delta a_\ell$

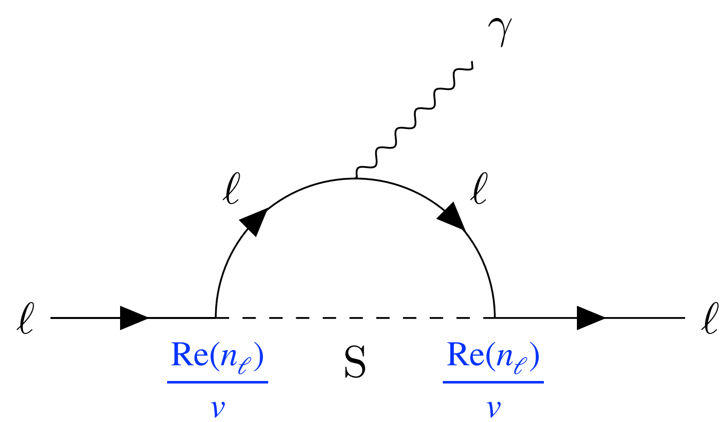
$$\delta a_\ell = \frac{1}{8\pi^2}\left(\frac{m_\ell}{v}\right)^2 \Delta_\ell$$

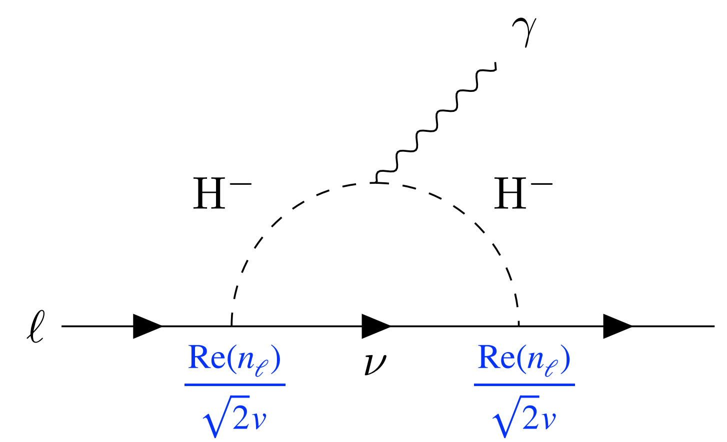
Our aim…

$$\delta a_e = \delta a_e^{\mathrm{Exp,Cs}} \Rightarrow \Delta_e^{\mathrm{Cs}} \simeq -16$$

$$\delta a_\mu = \delta a_\mu^{\mathrm{Exp}} \Rightarrow \Delta_\mu \simeq 1$$

To gain some insight: $\mathcal{O}\left(m_\ell^2/m_S^2\right)$ *and* $s_{\alpha\beta} \to 1$





$$\Delta_\ell^{(1)} \simeq |n_\ell|^2\left(\frac{I_{\ell H}}{m_H^2} - \frac{I_{\ell A}-2/3}{m_A^2} - \frac{1}{6m_{H^\pm}}\right)$$

where

$$I_{\ell S} = -\frac{7}{6} - 2\ln\left(\frac{m_\ell}{m_S}\right) > 0$$

$$m_S \in [0.2; 2.5]\ \mathrm{TeV}$$

Muon anomaly

$$1 \simeq \frac{|n_\mu|^2}{m_H^2} I_{\mu H} \Rightarrow |n_\mu| \sim \frac{1}{4} m_H$$

One loop explanation for light H $(m_H \lesssim 1\ \mathrm{TeV})$

Electron anomaly

$$-16 \simeq -\frac{|n_e|^2}{m_A^2} I_{eA} \Rightarrow |n_e| \sim \frac{4}{5} m_A$$

One loop explanation NOT feasible

New contributions to δa_ℓ

Two loop Barr-Zee

Full theoretical prediction: $a_\ell^{\text{Th}} = a_\ell^{\text{SM}} + \delta a_\ell$

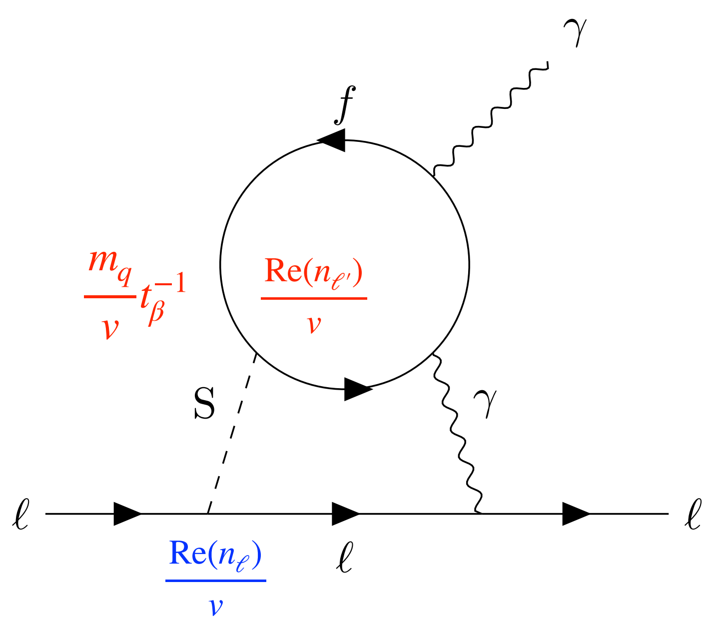
$$\delta a_\ell = \frac{1}{8\pi^2}\left(\frac{m_\ell}{v}\right)^2 \Delta_\ell$$

Our aim…

$\delta a_e = \delta a_e^{\text{Exp,Cs}} \Rightarrow \Delta_e^{\text{Cs}} \simeq -16$

$\delta a_\mu = \delta a_\mu^{\text{Exp}} \Rightarrow \Delta_\mu \simeq 1$

To gain some insight: $\mathcal{O}\left(m_\ell^2/m_S^2\right)$ *and* $s_{\alpha\beta} \to 1$



$$\Delta_\ell^{(2)} = -\frac{2\alpha}{\pi}\frac{\text{Re}(n_\ell)}{m_\ell} F$$

$$F = \frac{t_\beta^{-1}}{3}\left[4\left(f_{tH} + g_{tA}\right) + \left(f_{bH} - g_{bA}\right)\right] + \frac{\text{Re}(n_\tau)}{m_\tau}\left(f_{\tau H} - g_{\tau A}\right)$$

Muon anomaly

Needs two loops for heavy scalars → $\text{Re}(n_\mu)\, F \simeq -23\,\text{GeV}$

Electron anomaly

Must be explained at two loops → $\text{Re}(n_e)\, F \simeq 1.8\,\text{GeV}$

For large scalar masses…

$\text{Re}(n_\mu) \simeq -13\,\text{Re}(n_e)$

The origin of the different sign of δa_μ and δa_e relies on the freedom to have $\text{Re}(n_\mu)$ and $\text{Re}(n_e)$ with opposite signs

Constraints

- Global χ^2, sum of all separate contributions, is used to drive the analyses

$g-2$ lepton anomalies

$\delta a_\mu^{\rm Exp}$ and $\delta a_e^{\rm Exp}$

Higgs signal strengths of

$m_h = 125\,\mathrm{GeV}$ scalar

Alignment limit $c_{\alpha\beta} \ll 1$

EW precision data

(oblique parameters)

$m_{H^\pm} \simeq m_A$ or $m_{H^\pm} \simeq m_H$

Independent

parameters of I-gℓFC

$t_\beta\,,\, m_H\,,\, m_A\,,\, m_{H^\pm}\,,\, \mu_{12}^2\,,\, c_{\alpha\beta}$

from the scalar sector

$\mathrm{Re}(n_e)\,,\, \mathrm{Re}(n_\mu)\,,\, \mathrm{Re}(n_\tau)$

from the Yukawa sector

Scalar sector perturbativity,

pert. unitarity and boundedness

Softly broken $\mathbb{Z}_2$ to allow

$m_S > 1\,\mathrm{TeV}$ and $t_\beta > 8$

LHC direct searches of

new scalars

$m_A > m_H$ for light scalars

Perturbative Yukawa

couplings

$|n_\ell| \leq 250\,\mathrm{GeV}$

LEP data from

$e^+e^- \to \mu^+\mu^-, \tau^+\tau^-$ up to

$\sqrt{s} = 210\,\mathrm{GeV}$

$m_S > 210\,\mathrm{GeV}$

$b \to s\gamma$ and $B_q - \bar{B}_q$ mixing

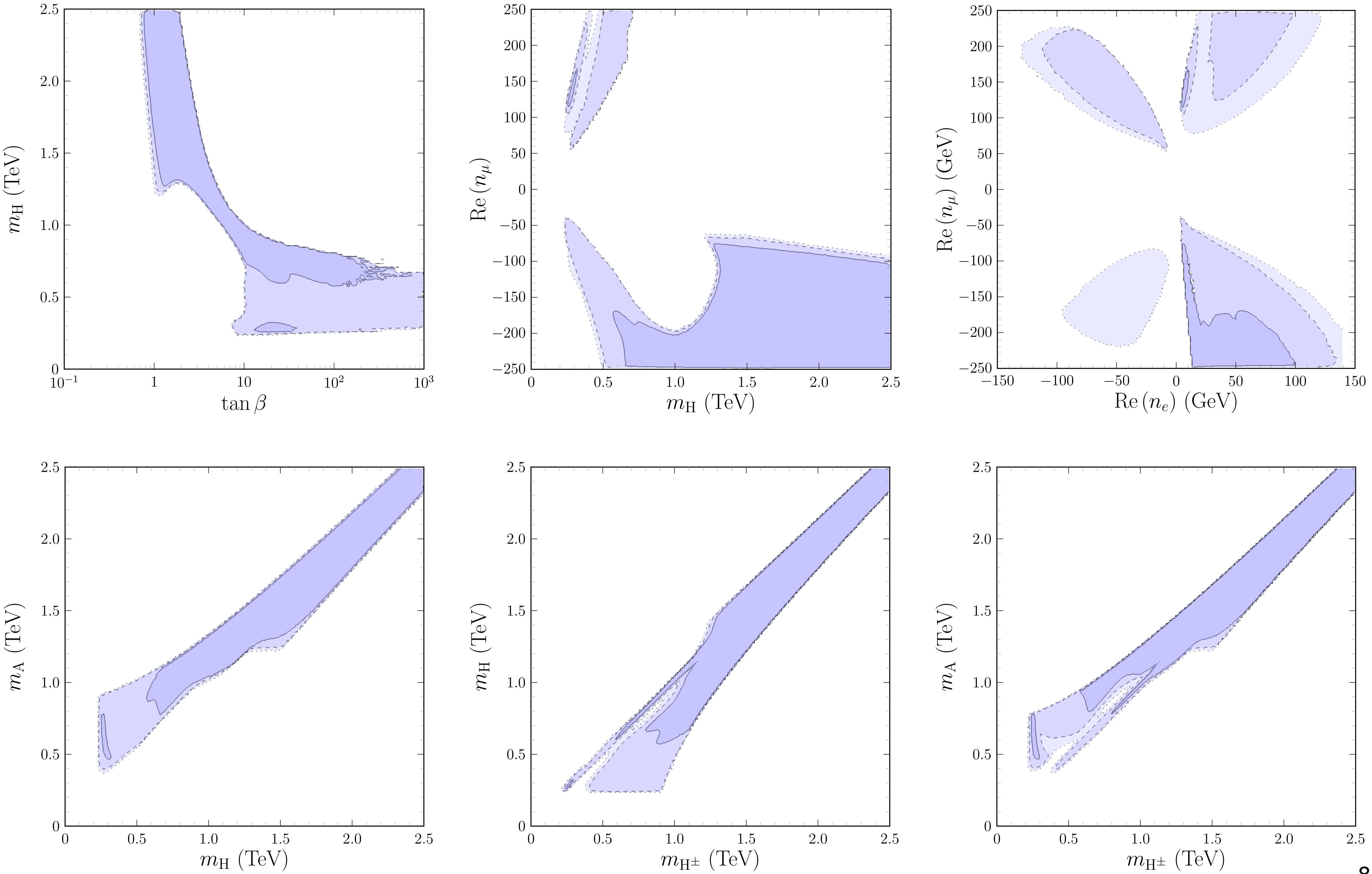
Lower bound on t_β for each $m_{H^\pm}$

Lepton Flavor Universality

$\ell \to \ell' \nu\nu$ and $P \to \ell\nu$

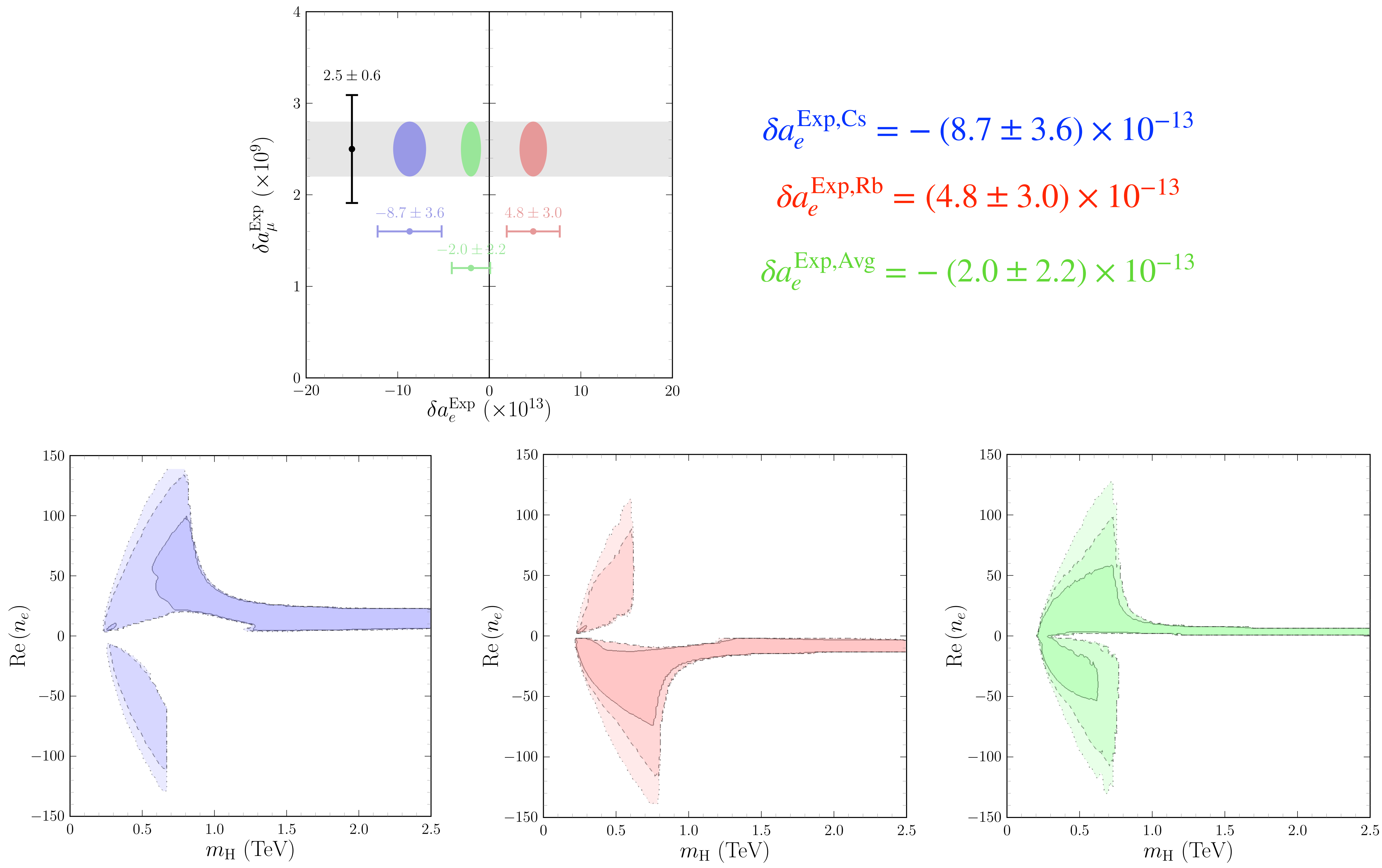
Results

Darker to lighter coloring corresponds to 2D-$\Delta\chi^2$ 1, 2 and 3σ regions ($\Delta\chi^2 = \chi^2 - \chi^2_{\mathrm{Min}}$)



Results

Different δa_e



$$\delta a_e^{\rm Exp,Cs} = -(8.7 \pm 3.6) \times 10^{-13}$$

$$\delta a_e^{\rm Exp,Rb} = (4.8 \pm 3.0) \times 10^{-13}$$

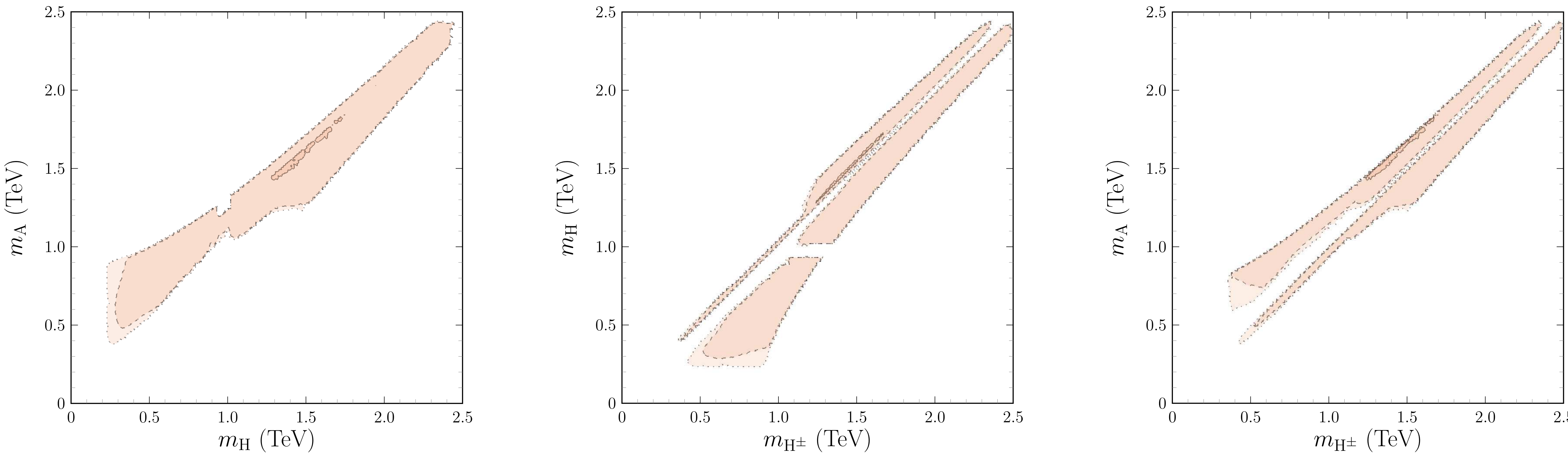
$$\delta a_e^{\rm Exp,Avg} = -(2.0 \pm 2.2) \times 10^{-13}$$

Results

The CDF M_W anomaly: an *oblique* view

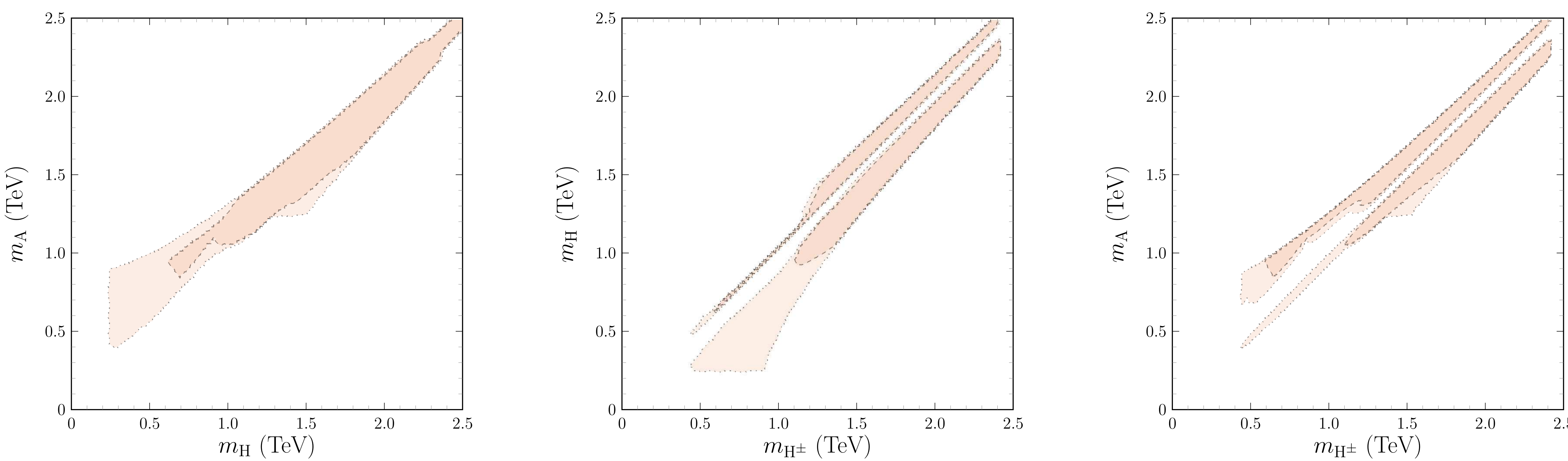
"Conservative" average with previous measurements of M_W

J. de Blas et al., *arXiv:2204.04204*



Only using CDF M_W value

C.-T. Lu et al., *arXiv:2204.03796*



Conclusions

- Model $\mathrm{I\text{-}g\ell FC}$: type I (or X) quark sector + general Flavor Conserving lepton sector
- General Flavor Conserving lepton sector one loop stable under RGE
- Lepton Flavor Universality Violation beyond the mass proportionality
- Two regimes in the allowed parameter space to solve the $(g-2)_\ell$ anomalies:

  (i) δa_μ and δa_e two loop dominated (linear relation), $m_S \in [1.0; 2.5]$ TeV, $t_\beta \sim 1$

  (ii) δa_μ one loop dominated and δa_e explained at two loops, $m_S \in [0.2; 1.0]$ TeV, $t_\beta \gg 1$
- Different assumptions for $\delta a_e^{\mathrm{Exp}}$ can be accommodated
- CDF W boson anomaly via oblique corrections: $m_{H^\pm} \simeq m_H$, $m_{H^\pm} \simeq m_A$ and masses above 2 TeV are disfavored
- ATLAS excess in $pp_{\mathrm{ggF}} \to S \to \tau^+\tau^-$ might be explained within this framework (*work in progress…*)

THANK YOU

Back up

Two-Higgs-Doublet Model

Scalar sector

- The most general scalar potential in 2HDMs:

$$\begin{aligned}\mathscr{V}(\Phi_1,\Phi_2) &= \mu_{11}^2\Phi_1^\dagger\Phi_1 + \mu_{22}^2\Phi_2^\dagger\Phi_2 + (\mu_{12}^2\Phi_1^\dagger\Phi_2 + \mathrm{h.c.})\\ &\quad+\lambda_1(\Phi_1^\dagger\Phi_1)^2 + \lambda_2(\Phi_2^\dagger\Phi_2)^2 + 2\lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + 2\lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1)\\ &\quad+[\lambda_5(\Phi_1^\dagger\Phi_2)^2 + \mathrm{h.c.}] + [\lambda_6(\Phi_1^\dagger\Phi_1)(\Phi_1^\dagger\Phi_2) + \lambda_7(\Phi_2^\dagger\Phi_2)(\Phi_1^\dagger\Phi_2) + \mathrm{h.c.}]\end{aligned}$$

Imposing a $\mathbb{Z}_2$ ***symmetry:*** $\mu_{12}^2 = 0$ *and* $\lambda_6 = \lambda_7 = 0$ ➡ $\mu_{12}^2 \neq 0$ *softly breaks the symmetry*

$\mathscr{V}(\langle\Phi_1\rangle,\langle\Phi_2\rangle)$ ***has a minimum at:*** $\langle 0|\Phi_j|0\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v_j e^{i\theta_j}\end{pmatrix} \longrightarrow \Phi_j = e^{i\theta_j}\begin{pmatrix}\varphi_j^+\\ (v_j+\rho_j+i\eta_j)/\sqrt{2}\end{pmatrix}$

- Rotation to the *Higgs basis*:

$$\begin{pmatrix}H_1\\ H_2\end{pmatrix} = \begin{pmatrix}c_\beta & s_\beta\\ -s_\beta & c_\beta\end{pmatrix}\begin{pmatrix}e^{-i\theta_1}\Phi_1\\ e^{-i\theta_2}\Phi_2\end{pmatrix}$$

$$c_\beta \equiv \cos\beta \equiv v_1/v \qquad s_\beta \equiv \sin\beta \equiv v_2/v \qquad t_\beta \equiv \tan\beta = v_2/v_1$$

$$\beta \in [0;\pi/2] \qquad v^2 = v_1^2 + v_2^2 = (\sqrt{2}G_F)^{-1} \simeq (246\,\mathrm{GeV})^2$$

$$\langle H_1\rangle = \frac{v}{\sqrt{2}}\begin{pmatrix}0\\1\end{pmatrix},\quad \langle H_2\rangle = \begin{pmatrix}0\\0\end{pmatrix} \quad\longrightarrow\quad H_1 = \begin{pmatrix}G^+\\ \frac{v+H^0+iG^0}{\sqrt{2}}\end{pmatrix},\quad H_2 = \begin{pmatrix}H^+\\ \frac{R^0+iI^0}{\sqrt{2}}\end{pmatrix}$$

Model I-gℓFC

Yukawa couplings

- Neutral currents:

$$\mathcal{L}_{\rm N} = -\frac{m_{u_j}}{v}\left(s_{\alpha\beta} + c_{\alpha\beta}t_\beta^{-1}\right) h\,\bar{u}_j u_j - \frac{m_{d_j}}{v}\left(s_{\alpha\beta} + c_{\alpha\beta}t_\beta^{-1}\right) h\,\bar{d}_j d_j - \frac{m_{\ell_j}}{v}\left(s_{\alpha\beta} + c_{\alpha\beta}\frac{\mathrm{Re}(n_{\ell_j})}{m_{\ell_j}}\right) h\,\bar{\ell}_j \ell_j$$

$$-\frac{m_{u_j}}{v}\left(-c_{\alpha\beta} + s_{\alpha\beta}t_\beta^{-1}\right) H\,\bar{u}_j u_j - \frac{m_{d_j}}{v}\left(-c_{\alpha\beta} + s_{\alpha\beta}t_\beta^{-1}\right) H\,\bar{d}_j d_j - \frac{m_{\ell_j}}{v}\left(-c_{\alpha\beta} + s_{\alpha\beta}\frac{\mathrm{Re}(n_{\ell_j})}{m_{\ell_j}}\right) H\,\bar{\ell}_j \ell_j$$

$$+ i\frac{m_{u_j}}{v}t_\beta^{-1} A\,\bar{u}_j\gamma_5 u_j - i\frac{m_{d_j}}{v}t_\beta^{-1} A\,\bar{d}_j\gamma_5 d_j - i\frac{\mathrm{Re}(n_{\ell_j})}{v} A\,\bar{\ell}_j\gamma_5\ell_j$$

Absence of Flavor Changing Neutral Currents

- Charged currents:

$$\mathcal{L}_{\rm Ch} = \frac{H^-}{\sqrt{2}v}\,\bar{d}_i V_{ji}^* t_\beta^{-1}\left[(m_{u_j} - m_{d_i}) + (m_{u_j} + m_{d_i})\gamma_5\right] u_j + \frac{H^+}{\sqrt{2}v}\,\bar{u}_j V_{ji} t_\beta^{-1}\left[(m_{u_j} - m_{d_i}) - (m_{u_j} + m_{d_i})\gamma_5\right] d_i$$

$$-\frac{H^-}{\sqrt{2}v}\,\bar{\ell}_j \mathrm{Re}(n_{\ell_j})\left(1 - \gamma_5\right)\nu_j - \frac{H^+}{\sqrt{2}v}\,\bar{\nu}_j \mathrm{Re}(n_{\ell_j})\left(1 + \gamma_5\right)\ell_j$$

Constraints

δa_ℓ anomalies and perturbativity bounds on n_ℓ

- Given their special role in the analyses, we impose a stronger requirement:

$$\chi^2(\delta a_e, \delta a_\mu) = \begin{cases} 0 & \text{if} \quad \chi_0^2(\delta a_e, \delta a_\mu) \leq \frac{1}{4} \\ C \times \left(\chi_0^2(\delta a_e, \delta a_\mu) - \frac{1}{4}\right) & \text{if} \quad \chi_0^2(\delta a_e, \delta a_\mu) \geq \frac{1}{4} \end{cases}$$

where $C = 10^6$ and

$$\chi_0^2(\delta a_e, \delta a_\mu) = \left(\frac{\delta a_e - c_e}{s_e}\right)^2 + \left(\frac{\delta a_\mu - c_\mu}{s_\mu}\right)^2$$

$c_\ell \equiv$ central experimental value
$s_\ell \equiv$ experimental uncertainty

This modification guarantees that we are definitely reproducing both anomalies within less than $\frac{1}{2} s_\ell$

- Perturbativity bounds on the new Yukawa lepton couplings are imposed as a smooth version of a sharp cut:

$$\chi^2_{\text{Pert}}(n_\ell) = \begin{cases} 0 & \text{for} \quad |n_\ell| \leq n_0 \\ \left(\frac{|n_\ell| - n_0}{\sigma_{n_0}}\right)^2 & \text{for} \quad |n_\ell| > n_0 \end{cases}$$

$n_0 = 250\,\text{GeV}$
$\sigma_{n_0} = 1\,\text{GeV}$

One loop correction to the imaginary part of m_H controlled by $\Gamma(H \to \ell\bar{\ell})$ ⇒

$$\frac{\Gamma}{m_H} = \frac{1}{8\pi}\frac{|n_\ell|^2}{v^2} \xrightarrow{|n_\ell| = v \sim 250\,\text{GeV}} \frac{\Gamma}{m_H} \sim 4\,\%$$

Conservative approach

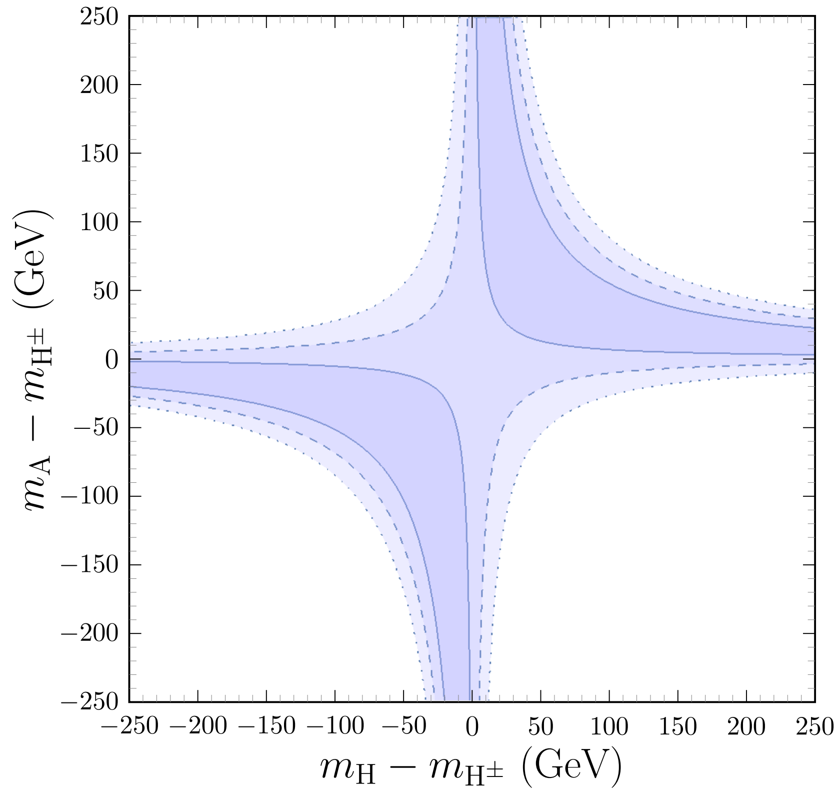
Constraints

Oblique parameters

- Electroweak precision measurements constrain deviations in the oblique parameters S and T:

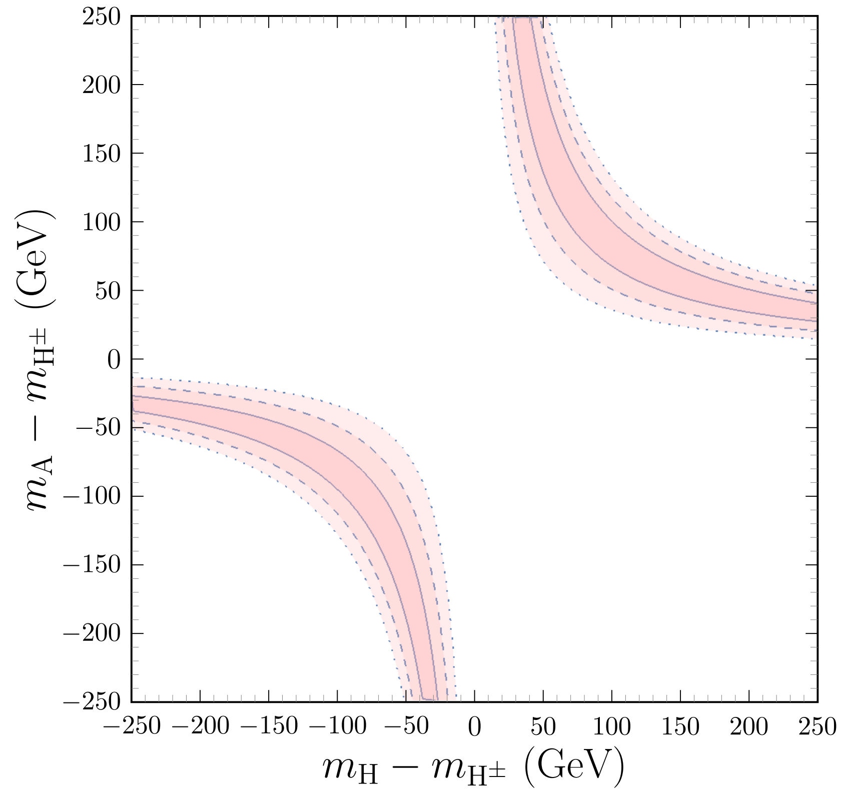
No CDF

$\Delta S = 0.00 \pm 0.07, \quad \Delta T = 0.05 \pm 0.06, \quad \rho = 0.92$



"Conservative" average

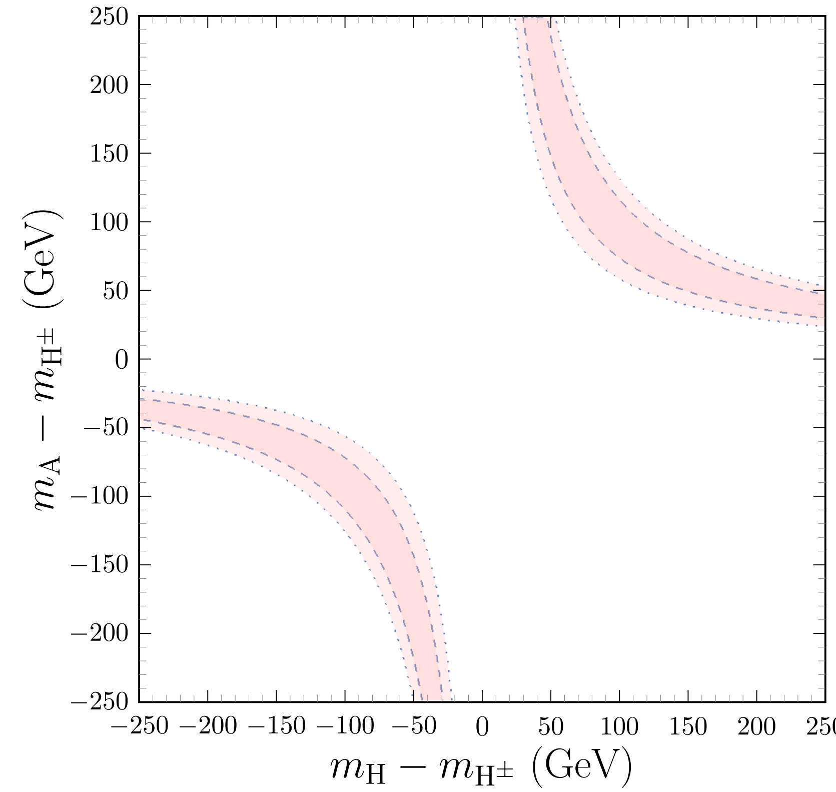
$\Delta S = 0.086 \pm 0.077, \quad \Delta T = 0.177 \pm 0.070, \quad \rho = 0.89$



J. de Blas et al., *arXiv:2204.04204*

Only CDF

$\Delta S = 0.15 \pm 0.08, \quad \Delta T = 0.27 \pm 0.06, \quad \rho = 0.93$



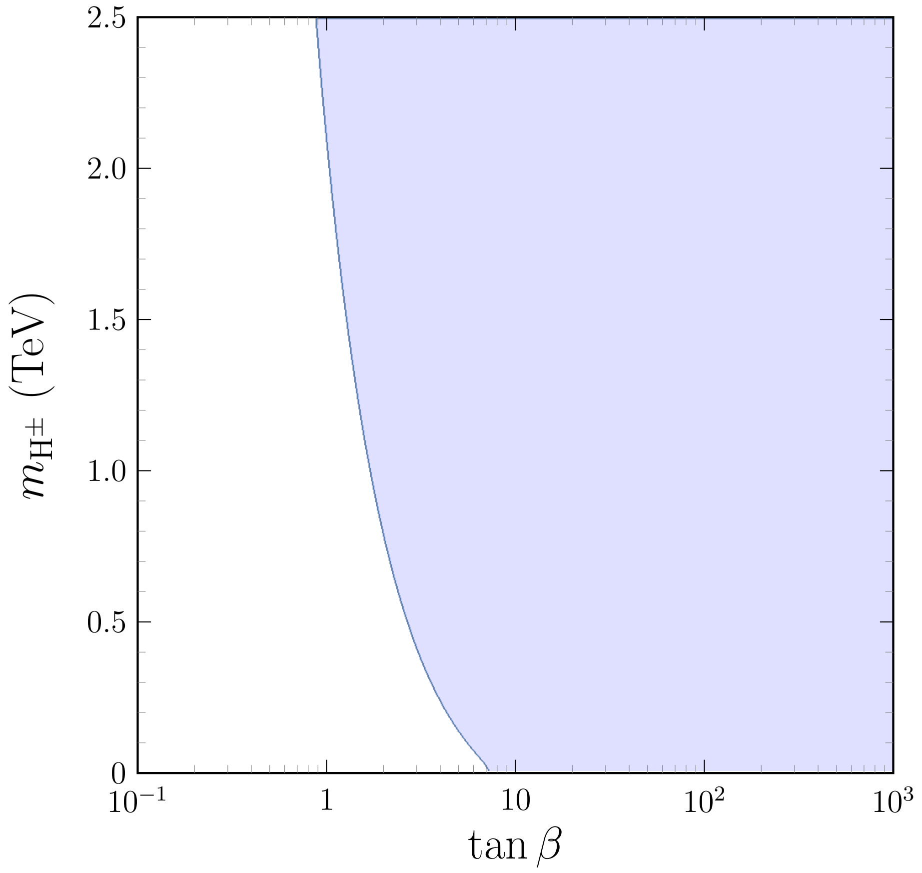
C.-T. Lu et al., *arXiv:2204.03796*

N.B. $s_{\alpha\beta} \to 1$ and $m_{H^\pm} = 1\,\mathrm{TeV}$

ΔU negligible in this model

Constraints
$H^{\pm}$-induced FCNC

- Contributions of $H^{\pm}$ to $B_q - \bar{B}_q$ box diagrams are kept below the experimental uncertainty in ΔM_{B_q}



For each value of $m_{H^{\pm}}$ there is a lower bound on t_β

Constraints

Gluon-gluon fusion production cross sections

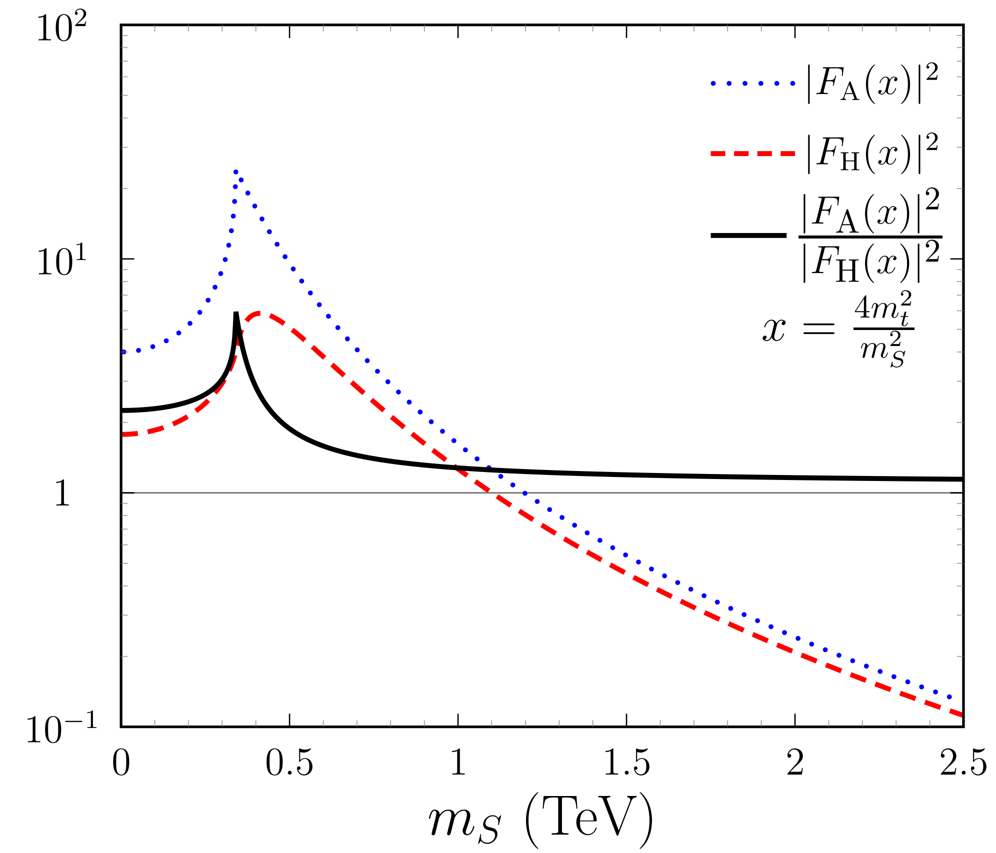
- In the scalar alignment limit $s_{\alpha\beta} \to 1$

$$\sigma(pp \to S)_{\rm ggF} \propto t_\beta^{-2} |F_S(x)|^2, \quad x = 4m_t^2/m_S^2, \quad S = H, A$$

$$F_H(x) = -2x[1 + (1-x)f(x)]$$

$$F_A(x) = -2xf(x)$$

$$f(x) = \begin{cases} \arcsin^2(1/\sqrt{x}), & x \geq 1 \\ -\dfrac{1}{4}\left[\ln\left(\dfrac{1+\sqrt{1-x}}{1-\sqrt{1-x}}\right) - i\pi\right]^2, & x < 1 \end{cases}$$



Since $pp_{\rm ggF} \to S \to \mu^+\mu^-$ searches at the LHC are rather constraining for $m_S < 1\,{\rm TeV}$, one might expect $m_A > m_H$ in this region

Constraints

Lepton flavor universality

- Leptonic decay modes of pseudoscalar mesons

$$R^P_{\mu e} = \frac{\Gamma(P^+ \to \mu^+ \nu)}{\Gamma(P^+ \to \mu^+ \nu)_{\rm SM}} \frac{\Gamma(P^+ \to e^+ \nu)_{\rm SM}}{\Gamma(P^+ \to e^+ \nu)} = \frac{|1-\Delta^P_\mu|^2}{|1-\Delta^P_e|^2}\,, \qquad |1-\Delta^P_\ell|^2 = \left|1 - \frac{M_P^2}{t_\beta m_{H^\pm}^2}\frac{{\rm Re}(n_\ell)}{m_\ell}\right|^2$$

For $\Delta^P_\ell \ll 1$: $R^P_{\mu e} \simeq 1 + 2\frac{M_P^2}{t_\beta m_{H^\pm}^2}\left(\frac{{\rm Re}(n_e)}{m_e} - \frac{{\rm Re}(n_\mu)}{m_\mu}\right)$

Constraint on kaons: $R^K_{\mu e} = 1 - (4.8 \pm 4.7) \times 10^{-3}$

$$\Rightarrow \quad {\rm Re}(n_e) < 5\frac{t_\beta m_{H^\pm}^2}{1\,{\rm TeV}^2}\,{\rm GeV}$$

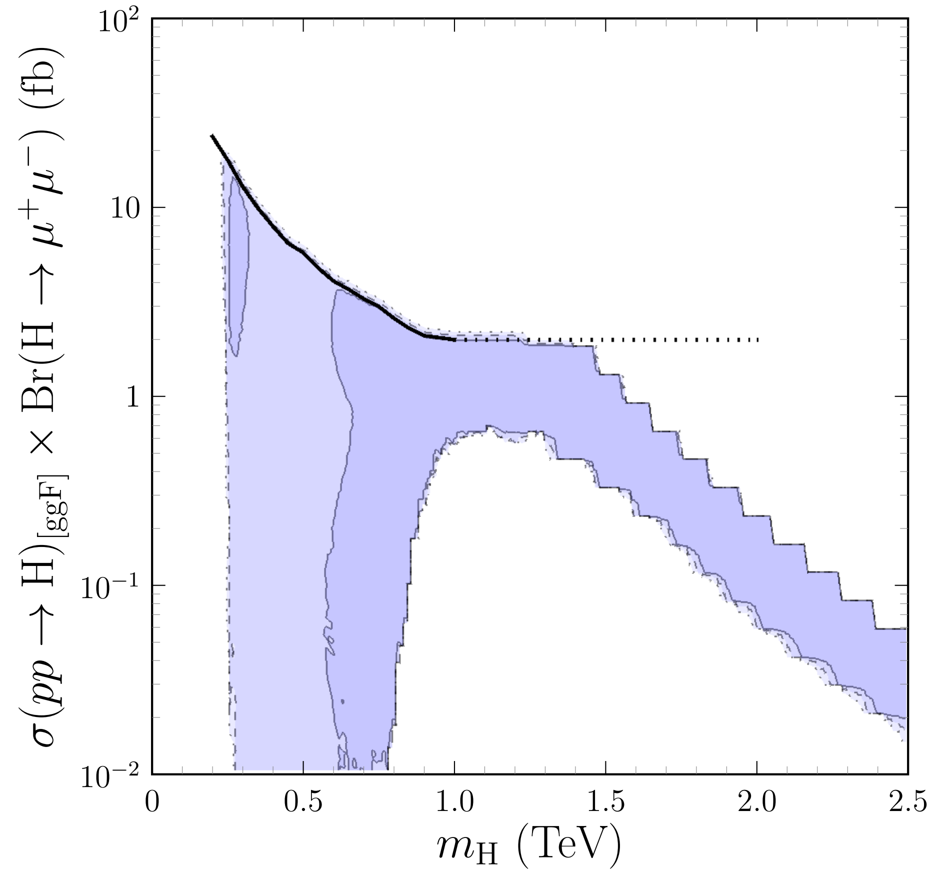
- for $t_\beta \simeq 1$, $m_{H^\pm} \simeq 2\,{\rm TeV} \to {\rm Re(n_e)} < 20\,{\rm GeV}$
- for $t_\beta \simeq 100$, $m_{H^\pm} \simeq 0.5\,{\rm TeV} \to {\rm Re(n_e)} < 125\,{\rm GeV}$

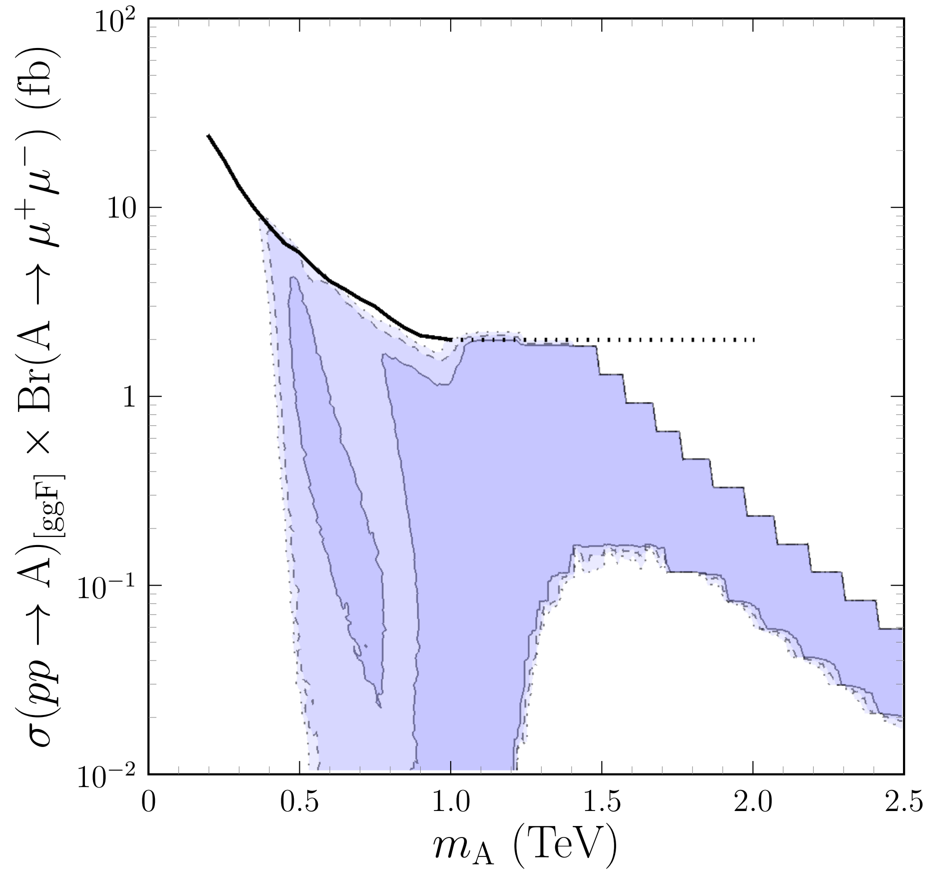
- $\mu \to e\nu\bar{\nu}$ decay constraints on the $H^\pm$ contributions

Relevant in the low mass region: $\left|\frac{n_e n_\mu}{m_{H^\pm}^2}\right| < 0.035 \xrightarrow{|n_\mu| \simeq 100\,{\rm GeV}} |n_e| < 87\left(\frac{m_{H^\pm}}{0.5\,{\rm TeV}}\right)^2 {\rm GeV}$

This simple numerical analysis suggests that $\delta a_e^{\rm Exp}$ cannot be explained through one loop contributions

Results



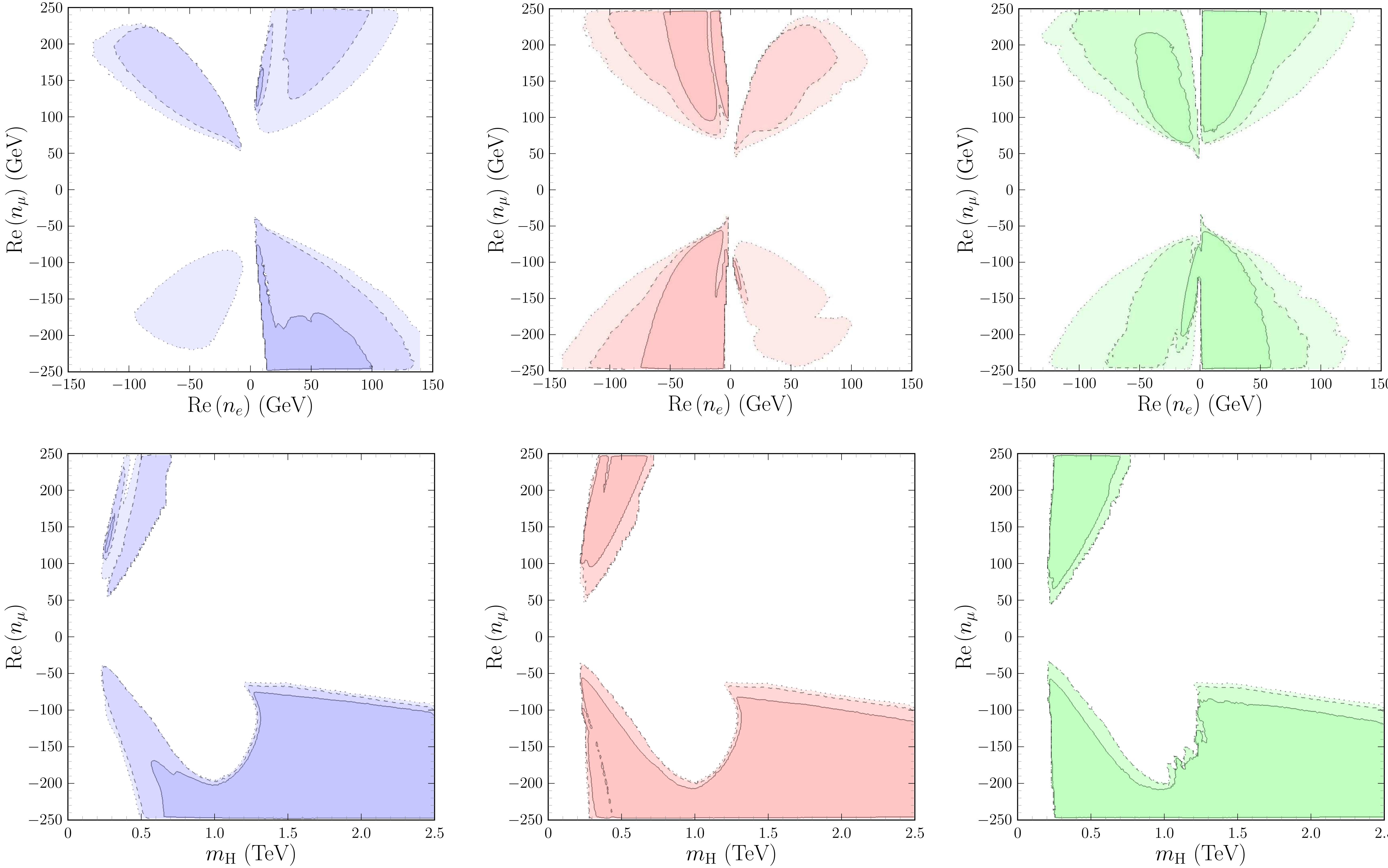


Black line corresponds to the limit observed by CMS

CMS Collaboration, *Phys. Lett. B 798 (2019) 134992*

Results

Different δa_e

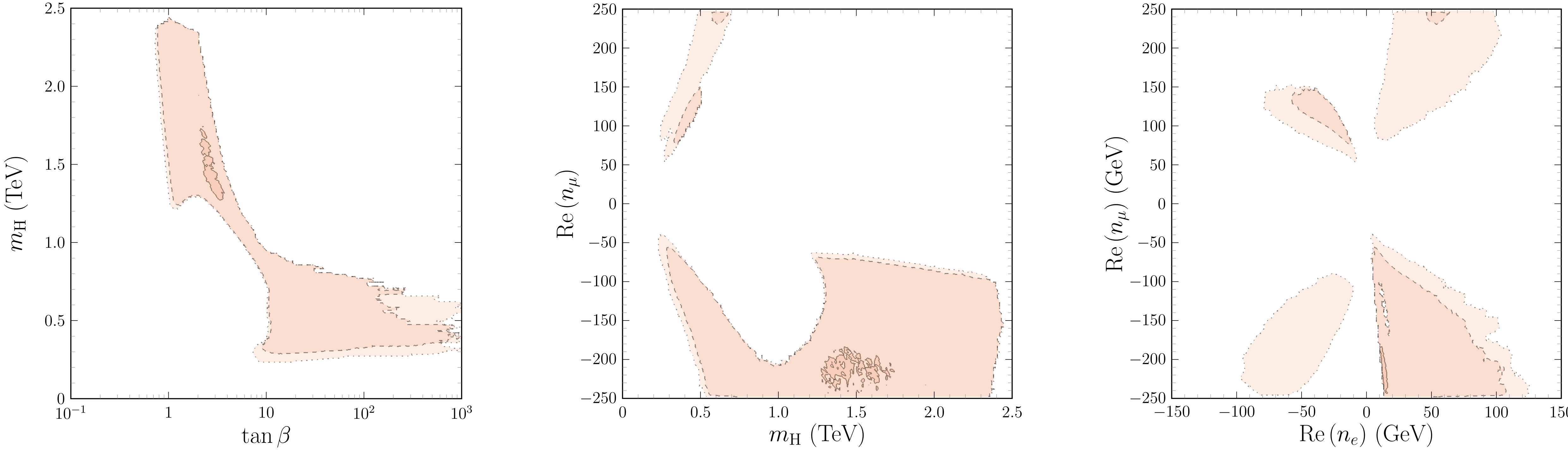


Results

The CDF M_W anomaly: an *oblique* view

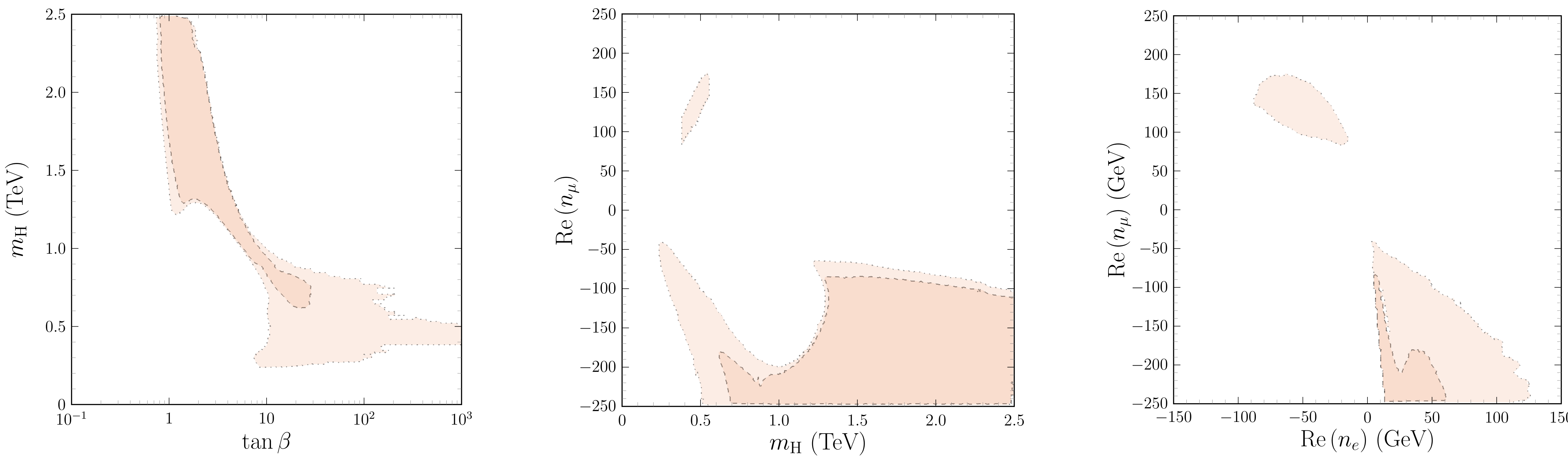
“Conservative” average with previous measurements of M_W

J. de Blas et al., *arXiv:2204.04204*



Only using CDF M_W value

C.-T. Lu et al., *arXiv:2204.03796*



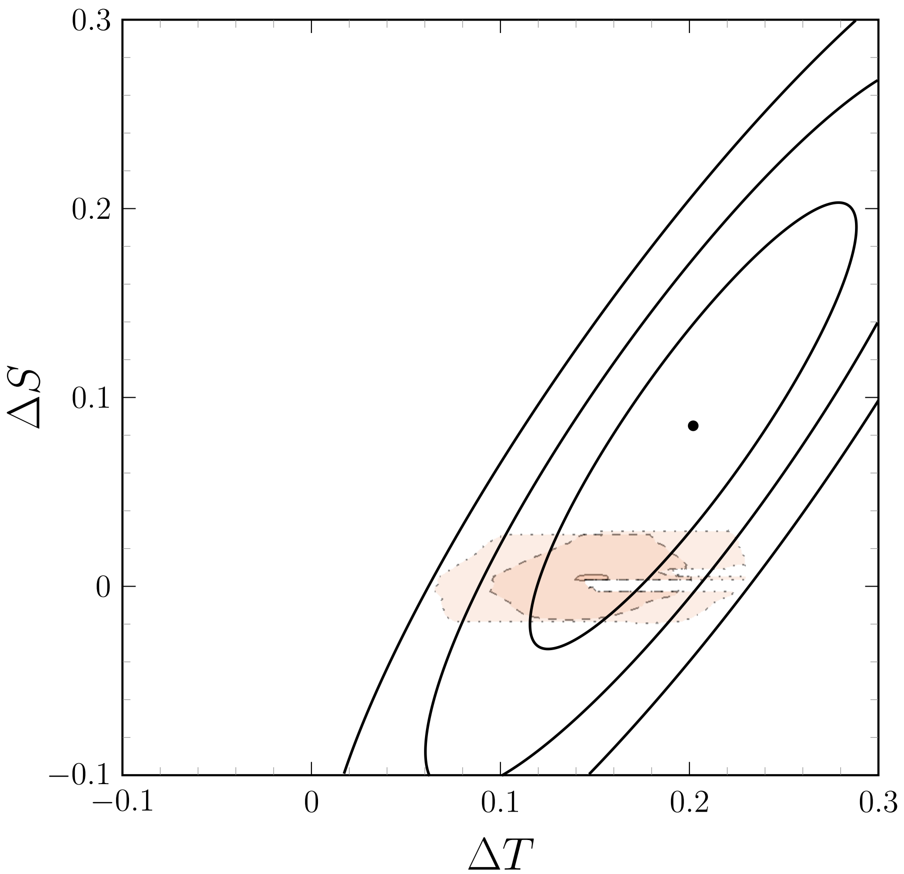
Results

The CDF M_W anomaly: an *oblique* view

- 2D-$\Delta\chi^2$ 1, 2 and 3σ contours from the oblique parameters constraint together with the allowed regions

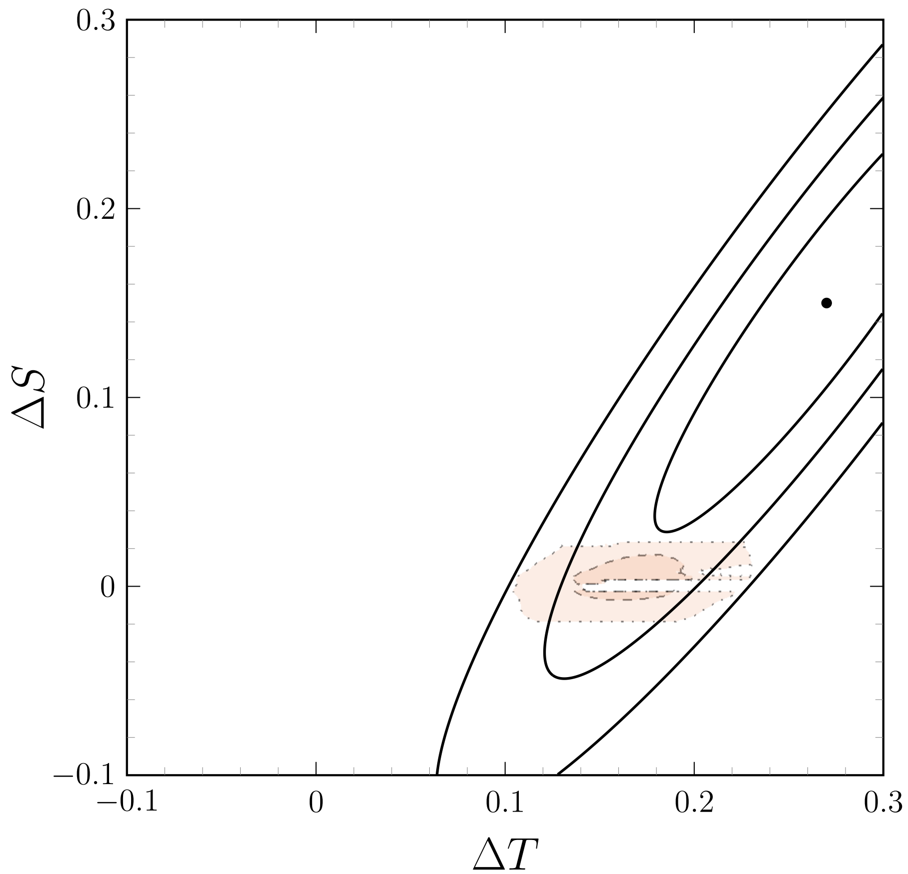
“Conservative” average

J. de Blas et al., *arXiv:2204.04204*



Only using CDF M_W value

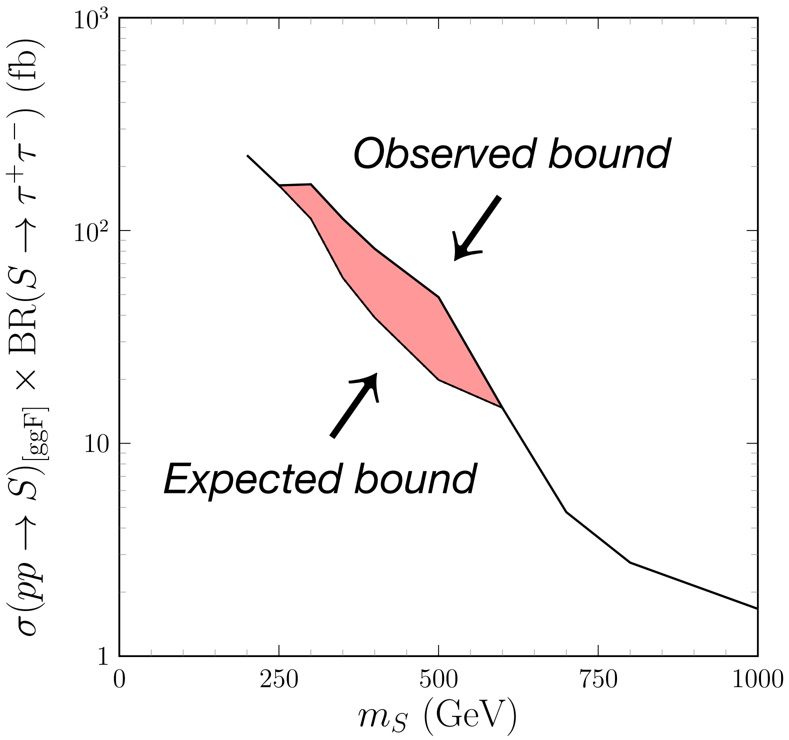
C.-T. Lu et al., *arXiv:2204.03796*

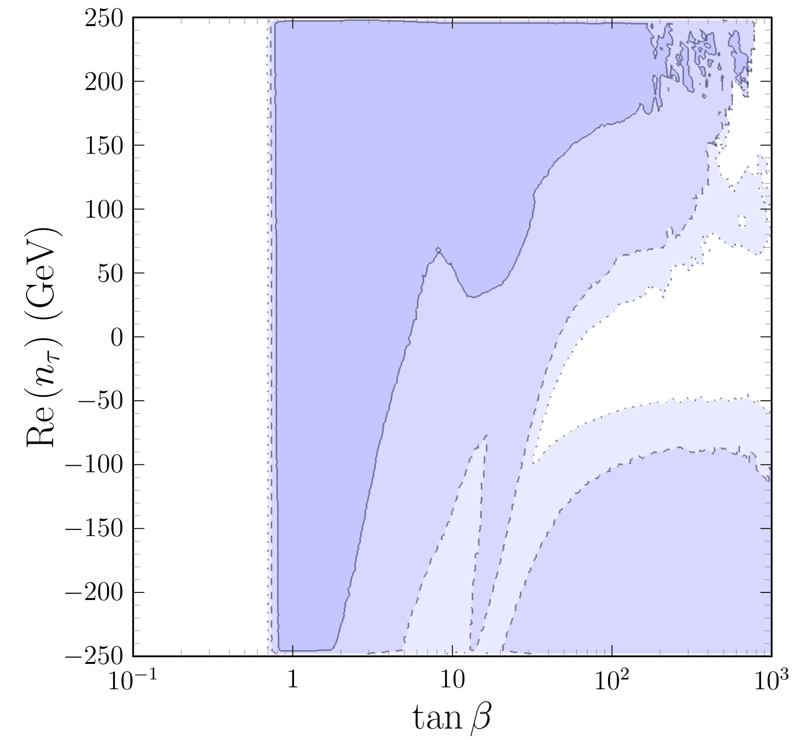


The model appears to be unable to accommodate values $\Delta T > 0.22$ together with $\Delta S > 0.02$

Results

ATLAS excess in $pp_{\text{ggF}} \to S \to \tau^+\tau^-$



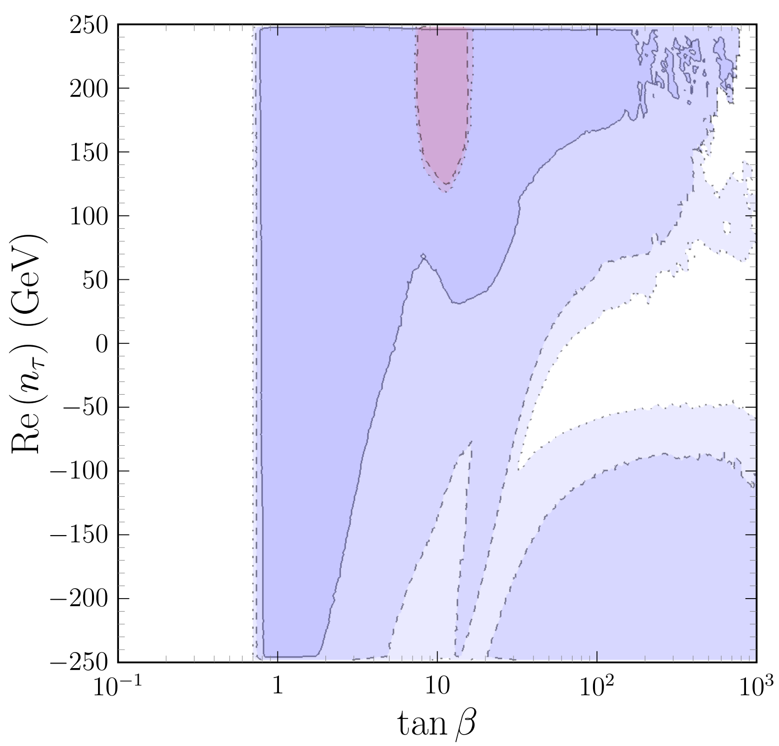


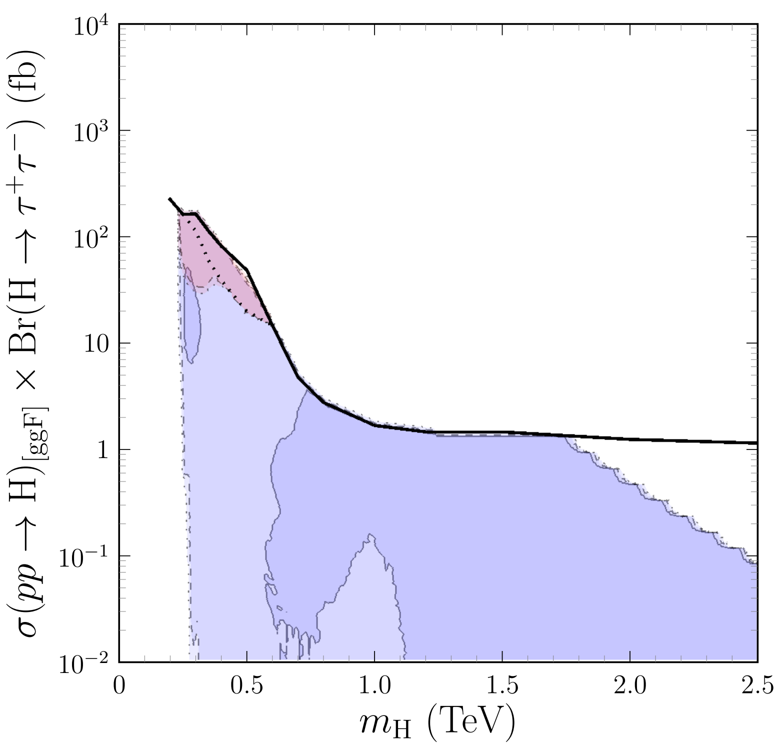
ATLAS excess (2σ around 400 GeV): new neutral scalars in the range $[250; 600]\,\text{GeV}$ which couple significantly to τ leptons

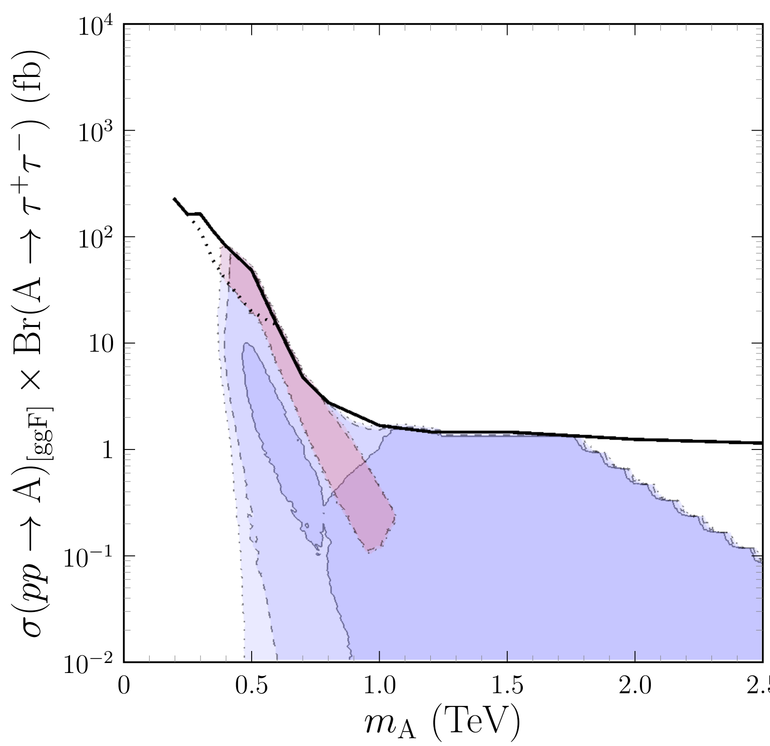
$\text{Re}(n_\tau)$ is rather unconstrained: may play a relevant role to accommodate the excess

ATLAS Collaboration, *Phys. Rev. Lett. 125 (2020) 051801*

Work in progress…







Results

Other LHC excesses

- Can we also accommodate the ATLAS excess in $\sigma(pp \to S)_{b-\mathrm{assoc}} \times \mathrm{Br}(S \to \tau^+\tau^-)$ with b-associated production?

Within a type-I quark sector

$$\sigma(pp \to S)_{\mathrm{ggF}} = t_\beta^{-2}\sigma(pp \to S)^{\mathrm{SM}}_{\mathrm{ggF}}$$
$$\sigma(pp \to S)_{b-\mathrm{assoc}} = t_\beta^{-2}\sigma(pp \to S)^{\mathrm{SM}}_{b-\mathrm{assoc}}$$

$$\frac{\sigma(pp \to S)_{\mathrm{ggF}} \times \mathrm{Br}(S \to \tau^+\tau^-)}{\sigma(pp \to S)_{b-\mathrm{assoc}} \times \mathrm{Br}(S \to \tau^+\tau^-)} = \frac{\sigma(pp \to S)^{\mathrm{SM}}_{\mathrm{ggF}}}{\sigma(pp \to S)^{\mathrm{SM}}_{b-\mathrm{assoc}}}$$

$\mathcal{O}(1)$ $\mathcal{O}(10^3 - 10^4)$

ATLAS Collaboration,
Phys. Rev. Lett. 125 (2020) 051801

Explanation with a type-II quark sector and $t_\beta \sim 10$ forbidden by universality constraints in decays of pseudoscalar mesons

- And the CMS di-top excess $gg \to t\bar{t}$?

CMS Collaboration, *JHEP 04 (2020) 171*

However…

Interference with New Physics processes
$gg \to S \to t\bar{t}$ *may be helpful…*

t_β^{-2} *suppression at the amplitude level:*
quite important since $t_\beta > 8$ for $m_S \in [250; 600]\,\mathrm{GeV}$

Neither of these two excesses can be simultaneously accommodated together with the one previously considered in
$\sigma(pp \to S)_{\mathrm{ggF}} \times \mathrm{Br}(S \to \tau^+\tau^-)$