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Reconstructing Higgs masses in 2HDMX for muon g-2

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Outline

- 2HDMX for muon g-2

  A. Broggio, M. Passera, K.M. Patel, S.K. Vempati, 1409.3199

- Constraints from lepton universality

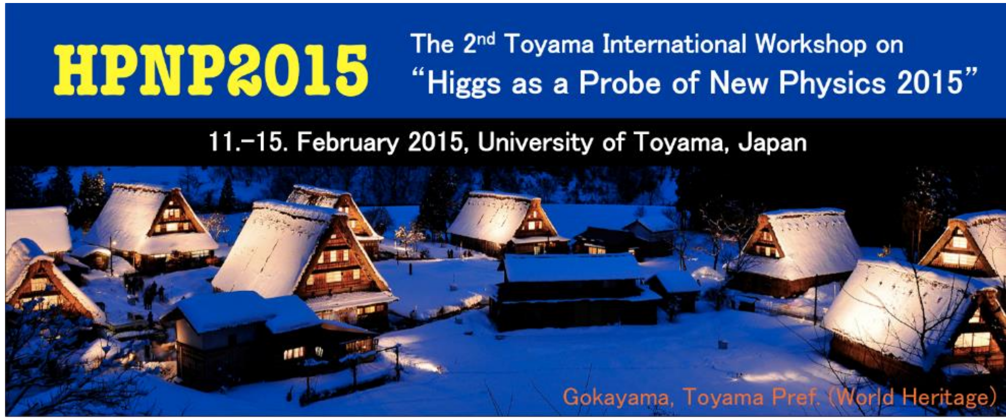
  J. Kim, 1605.06298

- Reconstructing extra Higgs bosons

  S. Dwivedi, T. Mondal, B. Mukhopadhyaya, 1707.07928
  +S. K. Rai, 1807.0379

- Higgs-portal dark matter

  P. Bandyopadhyay, R. Mandal, 1709.08581



Two-Higgs-Doublet-Model (2HDM)

- 8(+2) parameters in the scalar potential;

$$V_{2HDM} = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left[m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.} \right] + \frac{1}{2}\lambda_1 \left(\Phi_1^\dagger \Phi_1\right)^2 + \frac{1}{2}\lambda_2 \left(\Phi_2^\dagger \Phi_2\right)^2$$
$$+\lambda_3 \left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) + \lambda_4 \left(\Phi_1^\dagger \Phi_2\right)\left(\Phi_2^\dagger \Phi_1\right) + \left\{ \frac{1}{2}\lambda_5 \left(\Phi_1^\dagger \Phi_2\right)^2 + \left[\lambda_6 \left(\Phi_1^\dagger \Phi_1\right) + \lambda_7 \left(\Phi_2^\dagger \Phi_2\right) \right] \left(\Phi_1^\dagger \Phi_2\right) + \text{h.c.} \right\}.$$

Z_2 symmetry: $\Phi_{1,2} \rightarrow \mp \Phi_{1,2}$

$$\Phi_{1,2} = \left(\phi_{1,2}^+, \frac{1}{\sqrt{2}}[v_{1,2} + \rho_{1,2} + i\,\eta_{1,2}]\right)$$

- 4 masses+2 angles+1 VEV: $h(125), H, A, H^\pm;\ \beta, \alpha;\ v = \sqrt{v_1^2 + v_2^2};$

$$G^0 = \eta_1 c_\beta + \eta_2 s_\beta \qquad h = \rho_1 c_\alpha - \rho_2 s_\alpha \qquad \tan\beta = \frac{v_2}{v_1}$$
$$A = \eta_1 s_\beta - \eta_2 c_\beta \qquad H = \rho_1 s_\alpha + \rho_2 c_\alpha$$

Flavor problem

- Generic Yukawa couplings leads to FCNC:

$$\mathcal{L}_Y = y_{ij}^{u1,2}\widetilde{\Phi}_{1,2} q_i u_j^c + y_{ij}^{d1,2}\Phi_{1,2} q_i d_j^c + y_{ij}^{e1,2}\Phi_{1,2} l_i e_j^c + h.c.$$

$$\rightarrow (y_{ij}^{f1} c_\beta + y_{ij}^{f2} s_\beta)\frac{v}{\sqrt{2}} f_i f_j^c \quad \text{vs.} \quad (y_{ij}^{f1} c_\alpha - y_{ij}^{f2} s_\alpha) h f_i f_j^c + \ldots$$

m_{ij}^f Mass $\not\approx$ Yukawa y_{ij}^f

$$= \tilde{m}_i^f \tilde{f}_i \tilde{f}_i^c + \tilde{y}_{ij}^f h \tilde{f}_i \tilde{f}_j^c + \cdots$$

Models with natural flavor conservation

- To avoid dangerous flavor-changing processes,

Impose Z_2 to couple only one Higgs to each Yukawa type (d, e)

$$\Phi_2(+), \Phi_1(-); t_R(+), d_R(\pm), e_R(\pm)$$

$$-\mathcal{L}_Y = y^u_{ij}\widetilde{\Phi}_2 q_i u^c_j + y^d_{ij}\Phi_{1,2} q_i d^c_j + y^e_{ij}\Phi_{1,2} l_i e^c_j + h.c.$$

Model	u^i_R	d^i_R	e^i_R
Type I	Φ_2	Φ_2	Φ_2
Type II	Φ_2	Φ_1	Φ_1
Lepton-specific	Φ_2	Φ_2	Φ_1
Flipped	Φ_2	Φ_1	Φ_2

Yukawa couplings

	y_u^A	y_d^A	y_l^A	y_u^H	y_d^H	y_l^H	y_u^h	y_d^h	y_l^h
Type I	$\cot\beta$	$-\cot\beta$	$-\cot\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$
Type II	$\cot\beta$	$\tan\beta$	$\tan\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
Type X	$\cot\beta$	$-\cot\beta$	$\tan\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
Type Y	$\cot\beta$	$\tan\beta$	$-\cot\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$

$$-\mathcal{L}_{\rm Yukawa}^{\rm 2HDMs} = \sum_{f=u,d,l} \frac{m_f}{v}\left(y_f^h h\bar{f}f + y_f^H H\bar{f}f - iy_f^A A\bar{f}\gamma_5 f\right)$$

125 GeV

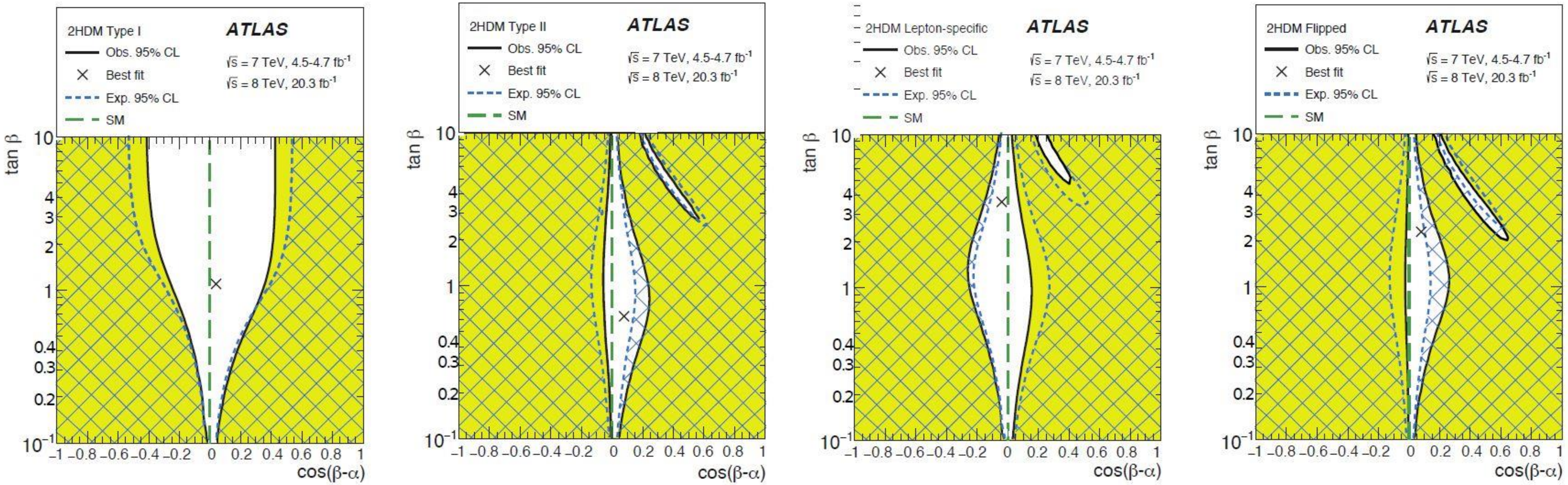
$$+\left[\sqrt{2}V_{ud}H^+\bar{u}\left(\frac{m_u}{v}y_u^A P_L + \frac{m_d}{v}y_A^d P_R\right)d + \sqrt{2}\frac{m_l}{v}y_l^A H^+\bar{\nu}P_R l + h.c.\right]$$

Gauge couplings

$$\mathcal{L}_{gauge} = g_V m_V (s_{\beta-\alpha} h + c_{\beta-\alpha} H) VV + \cdots$$

$s_{\beta-\alpha} \to 1$

ATLAS 1509.00672



SM limit

$$\sin(\beta-\alpha)\approx 1, \qquad |y_f^h|\approx 1, \qquad |y^{A,H}|\approx \frac{1}{t_\beta}, t_\beta$$

	y_u^A	y_d^A	y_l^A	y_u^H	y_d^H	y_l^H	y_u^h	y_d^h	y_l^h
Type I	$\cot\beta$	$-\cot\beta$	$-\cot\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$
Type II	$\cot\beta$	$\tan\beta$	$\tan\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
Type X	$\cot\beta$	$-\cot\beta$	$\tan\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$
Type Y	$\cot\beta$	$\tan\beta$	$-\cot\beta$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\cos\beta}$	$\frac{\sin\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$	$\frac{\cos\alpha}{\sin\beta}$

$\approx$

± 1

$$-\mathcal{L}_{\rm Yukawa}^{\rm 2HDMs} = \sum_{f=u,d,l} \frac{m_f}{v}\left(y_f^h h\bar{f}f + y_f^H H\bar{f}f - i y_f^A A\bar{f}\gamma_5 f\right)$$

125 GeV

$$+\left[\sqrt{2}V_{ud}H^+\bar{u}\left(\frac{m_u}{v}y_u^A P_L + \frac{m_d}{v}y_A^d P_R\right)d + \sqrt{2}\frac{m_l}{v}y_l^A H^+\bar{\nu}P_R l + h.c.\right]$$

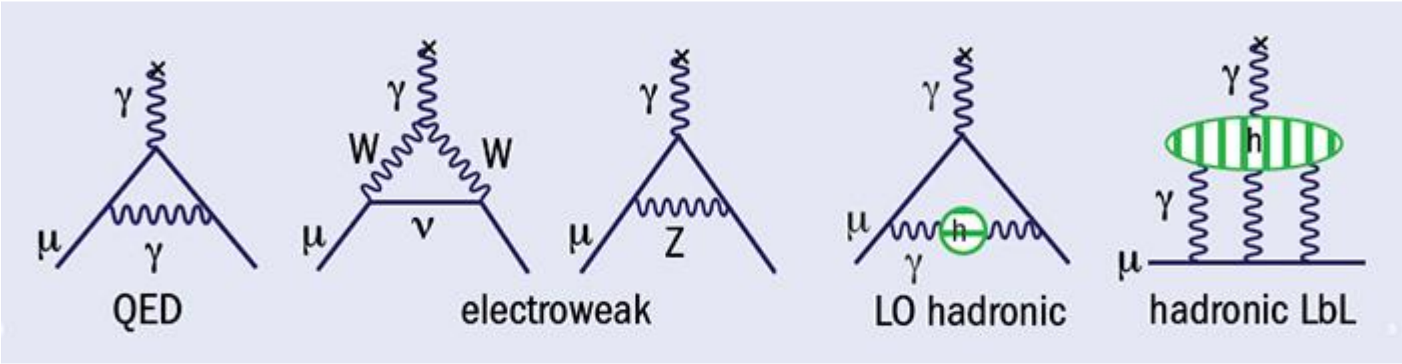
Muon g-2 anomaly

Magnetic moment:

$$\vec{\mu} = g_\mu \frac{e}{2m_\mu} \vec{s}$$

$$a_\mu = \frac{g_\mu - 2}{2}$$

	Value ($\times 10^{-11}$) units
QED	116 584 718.95 ± 0.08
HVP	6 850.6 ± 43
HLbL	105 ± 26
EW	153.6 ± 1.0
Total SM	116 591 828 ± 49



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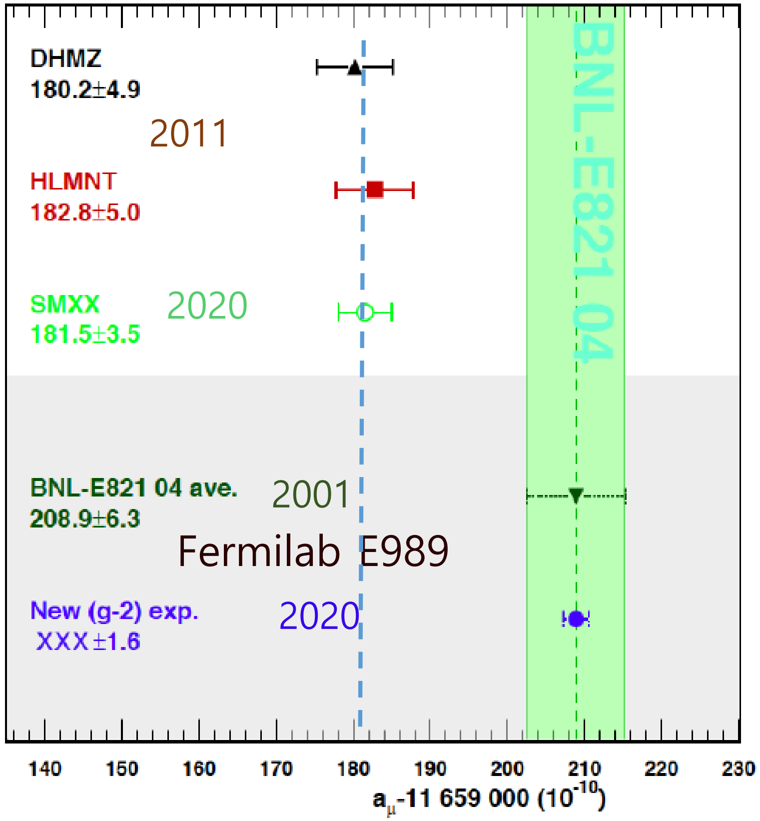
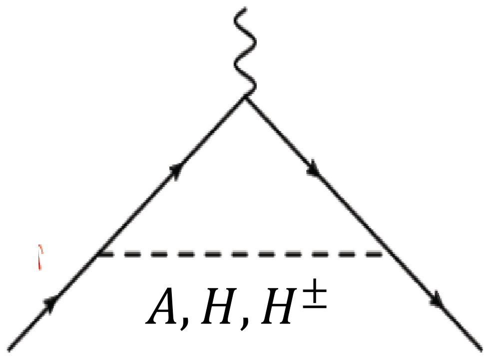


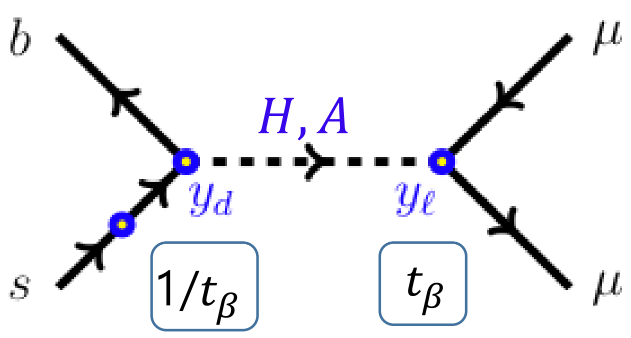
Muon g-2 at 1-loop – excluded

- A light H and/or large $y_\mu^H \approx t_\beta$:

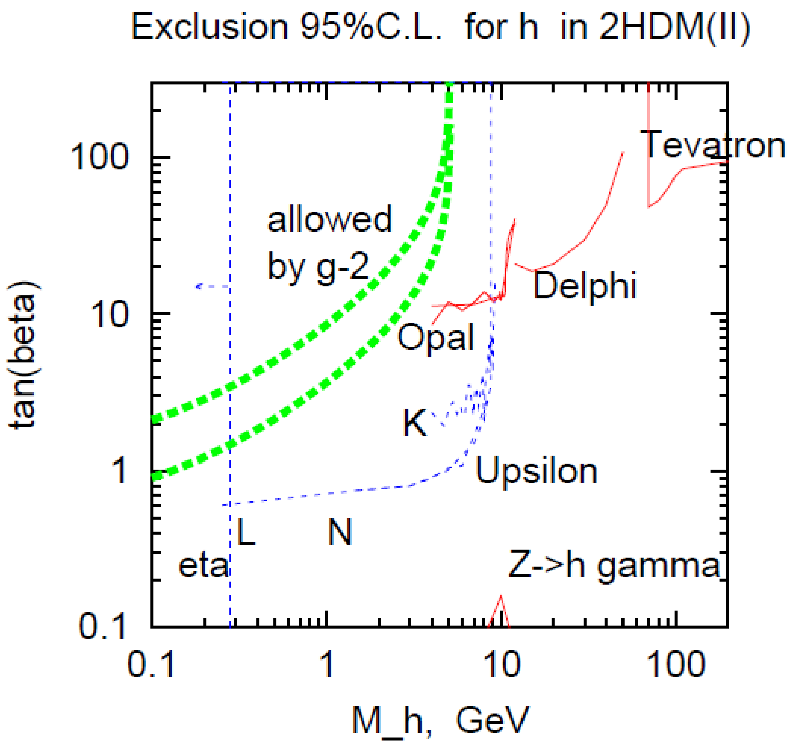
$$\delta a_\mu^{2\mathrm{HDM}}(1\mathrm{loop}) = \frac{G_F\, m_\mu^2}{4\pi^2\sqrt{2}} \sum_{j=h,H,A,H^\pm} \left(y_\mu^j\right)^2 r_\mu^j\, f_j(r_\mu^j)$$



- $B_s \to \mu^+\mu^-$



$m_{H,A} \gtrsim 10\ GeV$



Krawczyk, 0208076

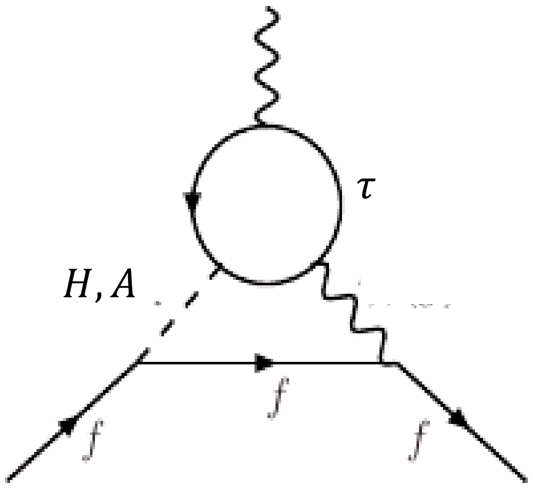
Muon g-2 at 2-loop – viable

- A light A and large $y^A_{\mu,\tau} \approx t_\beta$:

$$\delta a_\mu^{\rm 2HDM}(\text{2loop}-\text{BZ}) = \frac{G_F\, m_\mu^2}{4\pi^2\sqrt{2}}\,\frac{\alpha_{\rm em}}{\pi}\sum_{f;\, i=h,H,A} N_f^c\, Q_f^2\, y_\mu^i\, y_f^i\, r_f^i\, g_i(r_f^i)$$

$y_\mu^i\, y_f^i \rightarrow t_\beta^2$, $\quad r_f^i \rightarrow m_\tau^2/m_\mu^2$

$$g_{h,H}(r) < 0$$
$$g_A(r) > 0$$



- Type X at large t_β, being leptophilic, strongly limited by precision data for lepton universality.

Lepton universality in Z decays

- Precision EW measurements on Z poles determine

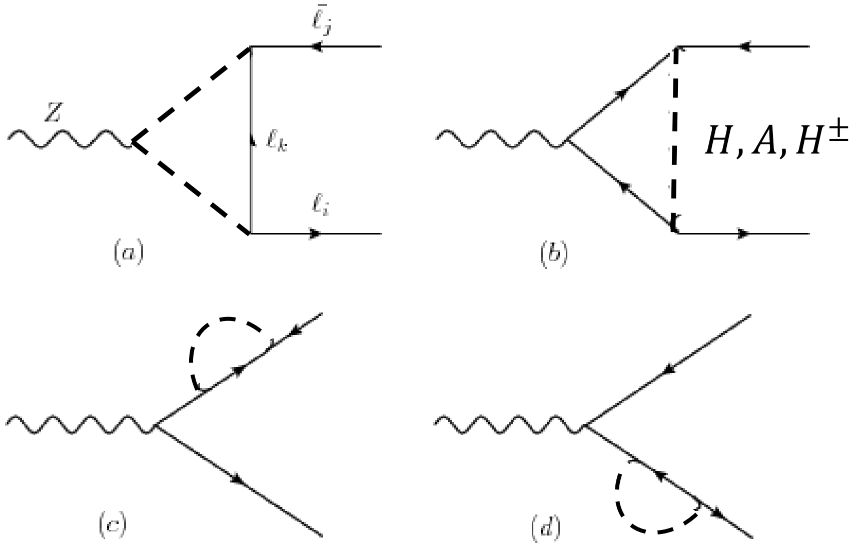
$$\frac{\Gamma_{Z\to\mu^+\mu^-}}{\Gamma_{Z\to e^+e^-}} = 1.0009 \pm 0.0028\,,$$

$$\frac{\Gamma_{Z\to\tau^+\tau^-}}{\Gamma_{Z\to e^+e^-}} = 1.0019 \pm 0.0032\,,$$

LEP EWWG, 0509008

with correlation +0.63

- One-loop corrections mediated by extra Higgs bosons can be sizable for large $\tan\beta$.



L2HDM corrections

- Large corrections to $Z \to \tau\tau$ at large $\tan\beta$:

$$-\mathcal{L} = \frac{g}{c_W} Z^\mu \{ \bar{f}\gamma_\mu (g_L P_L + g_R P_R) f + i(-\frac{1}{2} + s_W^2) H^+ \overleftrightarrow{\partial_\mu} H^- + A \overleftrightarrow{\partial_\mu} H \}$$

- Deviation from lepton universality:

$$\delta_{ll} = (\Gamma_{Z\to l^+ l^-} / \Gamma_{Z\to e^+ e^-}) - 1$$

$$\delta_{\mu\mu} \simeq 0\,,$$

$$\delta_{\tau\tau} = \frac{2g_L^e \mathrm{Re}(\delta g_L^{\mathrm{2HDM}}) + 2g_R^e \mathrm{Re}(\delta g_R^{\mathrm{2HDM}})}{{g_L^e}^2 + {g_R^e}^2}\,,$$

Hollik, Kuehn, 1991

$$\delta g_L^{\rm 2HDM} = \frac{1}{16\pi^2}\frac{m_f^2}{v^2}t_\beta^2 \Big\{ -\frac{1}{2}B_Z(r_A) - \frac{1}{2}B_Z(r_H) - 2C_Z(r_A, r_H)$$
$$+s_W^2 \left[B_Z(r_A) + B_Z(r_H) + \tilde{C}_Z(r_A) + \tilde{C}_Z(r_H)\right] \Big\},$$

$$\delta g_R^{\rm 2HDM} = \frac{1}{16\pi^2}\frac{m_f^2}{v^2}t_\beta^2 \Big\{ 2C_Z(r_A, r_H) - 2C_Z(r_{H^\pm}, r_{H^\pm}) + \tilde{C}_Z(r_{H^\pm}) - \frac{1}{2}\tilde{C}_Z(r_A) - \frac{1}{2}\tilde{C}_Z(r_H)$$
$$+s_W^2 \left[B_Z(r_A) + B_Z(r_H) + 2B_Z(r_{H^\pm}) + \tilde{C}_Z(r_A) + \tilde{C}_Z(r_H) + 4C_Z(r_{H^\pm}, r_{H^\pm})\right] \Big\}$$

$$r_\phi = \boxed{m_\phi^2/m_Z^2} \text{ with } \phi = A, H, H^\pm$$

$$B_Z(r) = -\frac{\Delta_\epsilon}{2} - \frac{1}{4} + \frac{1}{2}\log(r),$$
$$C_Z(r_1, r_2) = \frac{\Delta_\epsilon}{4} - \frac{1}{2}\int_0^1 dx \int_0^x dy \, \log[r_2(1-x) + (r_1 - 1)y + xy],$$
$$\tilde{C}_Z(r) = \frac{\Delta_\epsilon}{2} + \frac{1}{2} - r[1 + \log(r)] + r^2\left[\log(r)\log(1 + r^{-1}) - {\rm dilog}(-r^{-1})\right]$$
$$-\frac{i\pi}{2}\left[1 - 2r + 2r^2\log(1 + r^{-1})\right].$$

Larger correction for larger hierarchy: $m_A \ll m_H \approx m_{H^\pm}$ and $m_\phi \gg m_Z$

Lepton Universality & τ decay

HFAG, 1412.7515

- From pure leptonic processes:

$$\frac{\tau \to e\nu\nu}{\mu \to e\nu\nu}, \frac{\tau \to \mu\nu\nu}{\mu \to e\nu\nu}, \frac{\tau \to \mu\nu\nu}{\tau \to e\nu\nu}$$

$$\left(\frac{g_\tau}{g_\mu}\right) = 1.0011 \pm 0.0015$$

$$\left(\frac{g_\tau}{g_e}\right) = 1.0029 \pm 0.0015$$

$$\left(\frac{g_\mu}{g_e}\right) = 1.0018 \pm 0.0014$$

Note) Only two ratios are independent: The redundant direction should be projected out.

- From semi-hadronic processes: $\frac{(\tau \to \nu\pi/K)}{(\pi/K \to \mu\nu)}$

$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 0.9963 \pm 0.0027$$

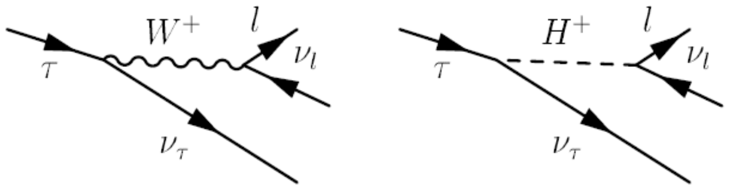
$$\left(\frac{g_\tau}{g_\mu}\right)_K = 0.9858 \pm 0.0071$$

- Correlation matrix:

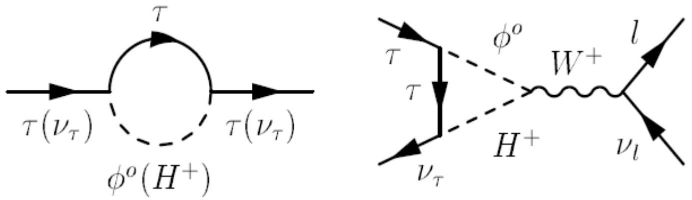
$$\begin{pmatrix} 1 & +0.53 & -0.49 & +0.24 & +0.12 \\ +0.53 & 1 & +0.48 & +0.26 & +0.10 \\ -0.49 & +0.48 & 1 & +0.02 & -0.02 \\ +0.24 & +0.26 & +0.02 & 1 & +0.05 \\ +0.12 & +0.10 & -0.02 & +0.05 & 1 \end{pmatrix}$$

L2HDM corrections

- Tree-level contribution from $H^{\pm}$:



- One-loop corrections mediated by $A, H, H^{\pm}$:



$$\delta_{tree} = \frac{m_\tau^2 m_l^2}{8\, m_{H^\pm}^4} t_\beta^4 - \frac{m_l^2}{m_{H^\pm}^2} t_\beta^2\, \kappa(m_l^2/m_\tau^2)$$

Krawczyk, Temes, 0410248

$$\delta_{loop} = \frac{m_\tau^2 t_\beta^2}{16\pi^2 v^2}\left(1 + \frac{1}{4}\left[H\left(\frac{m_A}{m_{H^\pm}}\right) + s_{\beta-\alpha}^2\, H\left(\frac{m_H}{m_{H^\pm}}\right) + c_{\beta-\alpha}^2 H\left(\frac{m_h}{m_{H^\pm}}\right)\right]\right)$$

$$\Rightarrow \left(\frac{g_\tau}{g_\mu}\right) = 1 + \delta_{\rm loop}, \quad \left(\frac{g_\tau}{g_e}\right) = 1 + \delta_{\rm tree} + \delta_{\rm loop}, \quad \left(\frac{g_\mu}{g_e}\right) = 1 + \delta_{\rm tree},$$

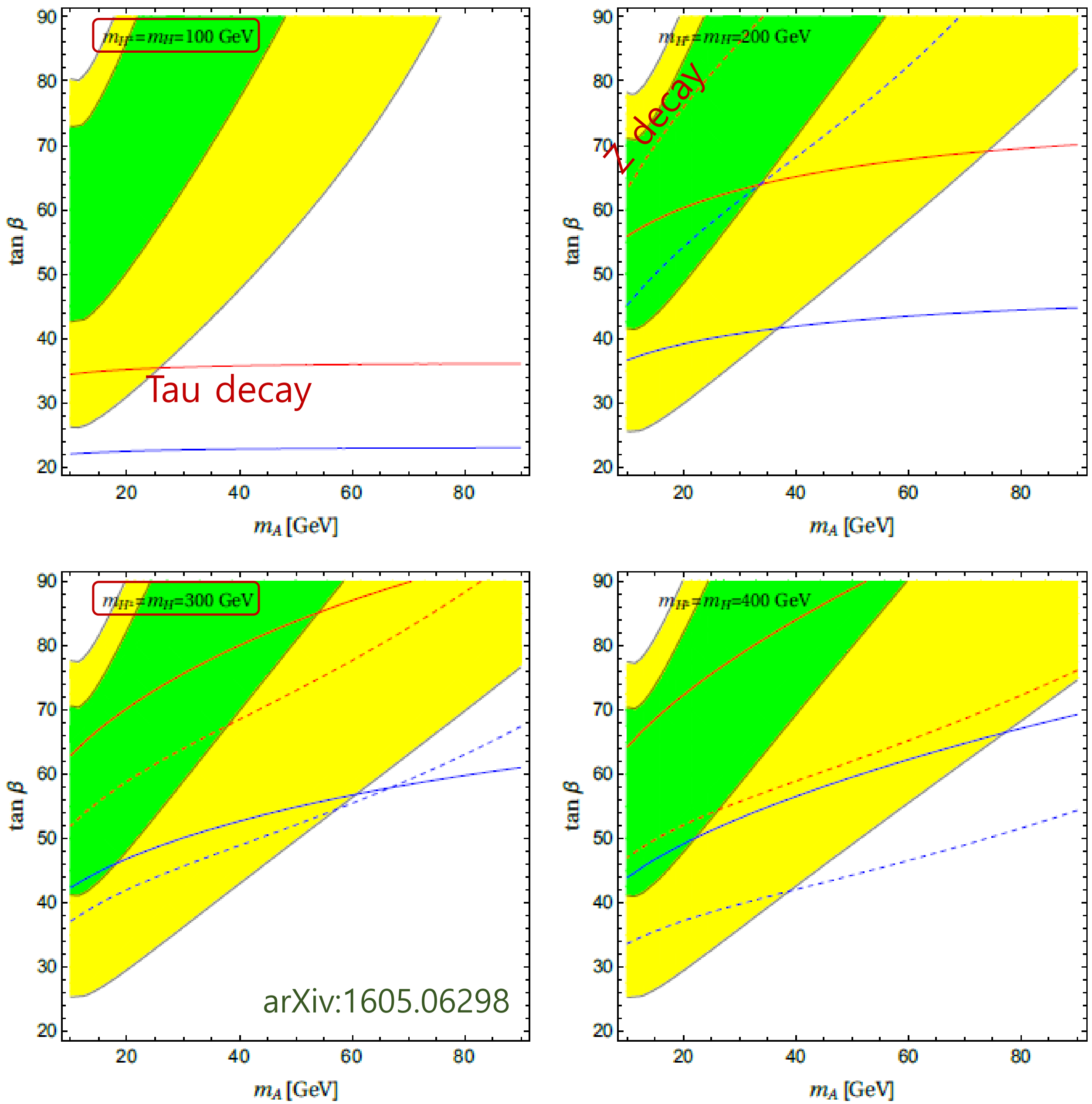
$$\left(\frac{g_\tau}{g_\mu}\right)_\pi = 1 + \delta_{\rm loop}, \quad \left(\frac{g_\tau}{g_\mu}\right)_K = 1 + \delta_{\rm loop}.$$

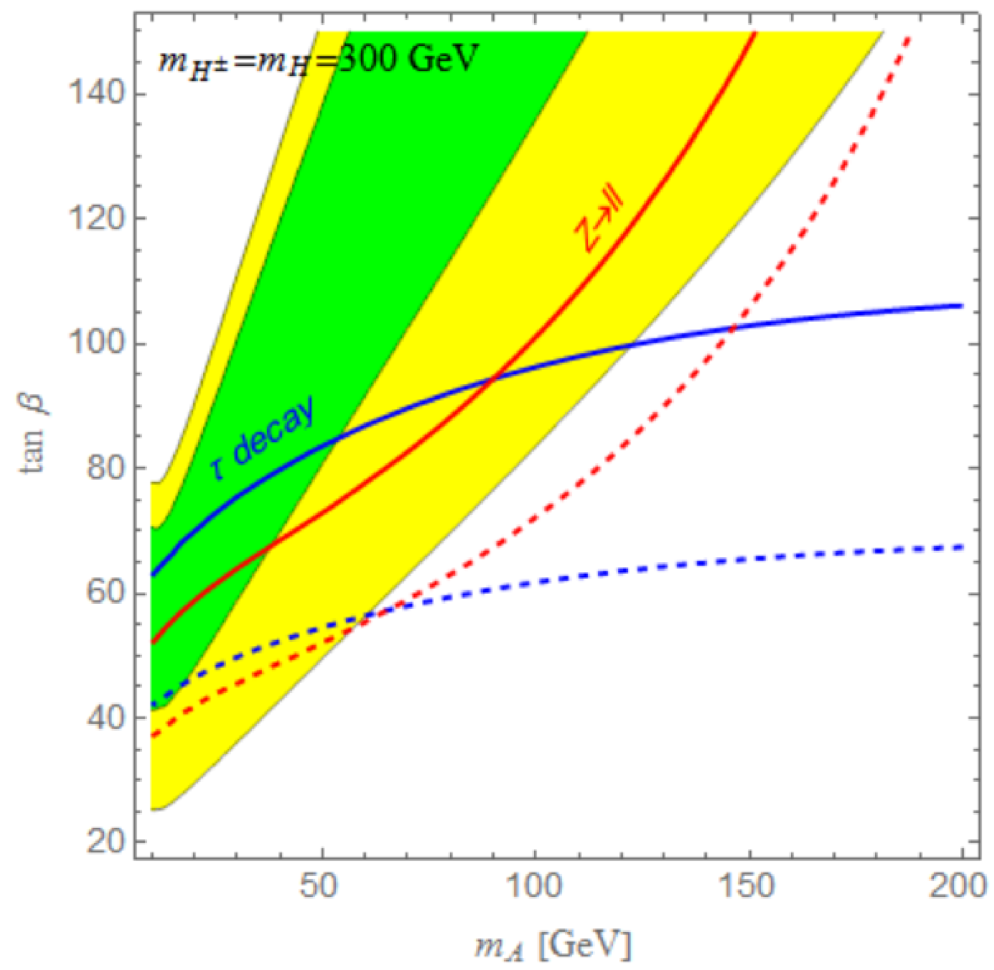
Results

1 and 2σ regions for constraints from the muon g-2, Z and tau decays.

Poor χ^2_{min}~12 for tau decay; SM about 2σ away

Allowed region larger than in the previous studies: 1504.07059, 1507.08067.




$m_{H^\pm}=m_H=300$ GeV
140
120
100
80
60
40
20
50
100
150
200
tan β
m_A [GeV]
τ decay
Z→ll

LHC tests

- Discover a light pseudo-scalar with large tanbeta:

$$B(A \to \tau\tau) \simeq 100\%$$

- Electroweak production of $H^{\pm}A$ & HA leading to 3&4τ
- Electroweak production of $H^{\pm}A$ & $HA \to W(Z)AA \to 2\mu\, 2\tau$

Mass reconstruction

- Exotic Higgs decay: $h \to AA \to 2\tau\, 2\mu$

LHC search for $h \to AA \to \mu\mu\tau\tau$

Assume: $B(h \to AA) = 15\%$

$$\sigma(h \to AA) \approx 7.5\, pb; \quad \sigma(h \to AA \to \mu\mu\tau\tau) \approx 52\, fb$$

$m_A = 50\ (60)\ \mathrm{GeV};\ \tan\beta = 60;\ \cos(\beta - \alpha) = 0.03;\ \lambda_{hAA} = 0.02\ (0.03)$

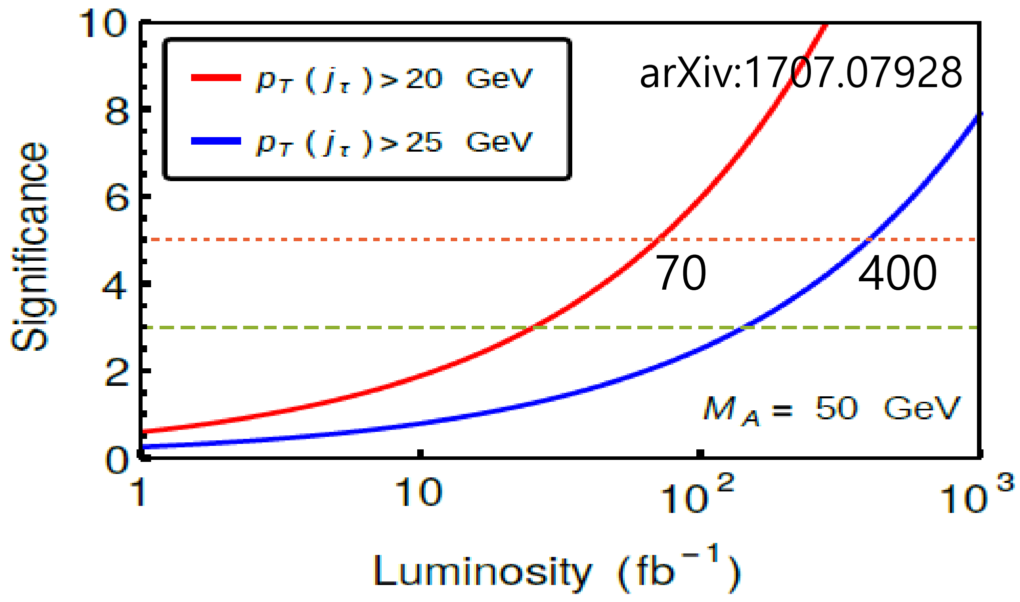
Event selection

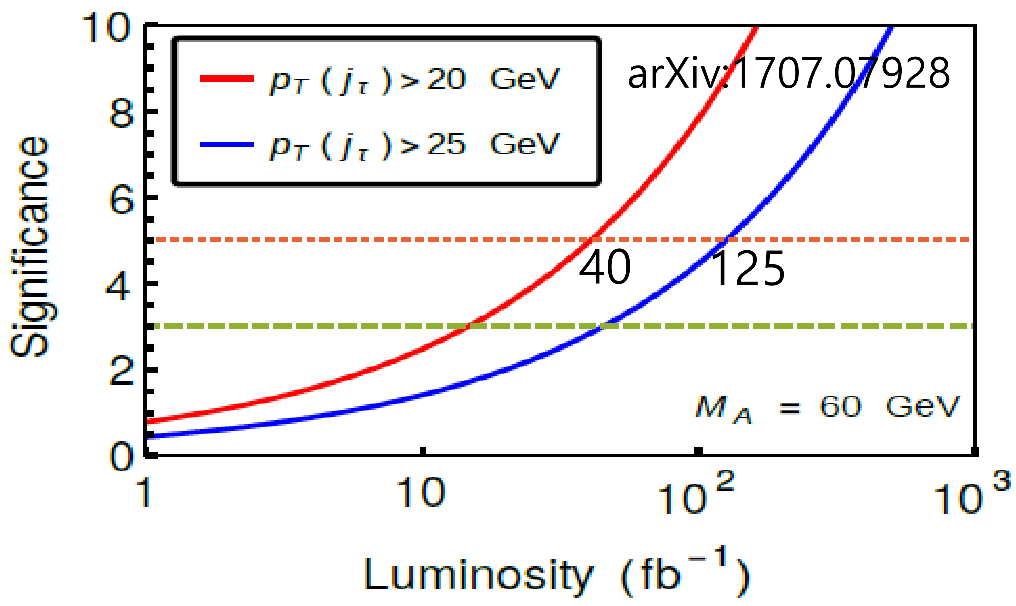
$m_A = 50\ (60)$ GeV $\mathcal{L} = 3/ab$

$\mu^+\mu^-\ j_\tau j_\tau$
$p_T(\mu) > 10$ GeV
$p_T\ (j_\tau) > 20\ (25)$GeV
$|\eta| < 2.5$

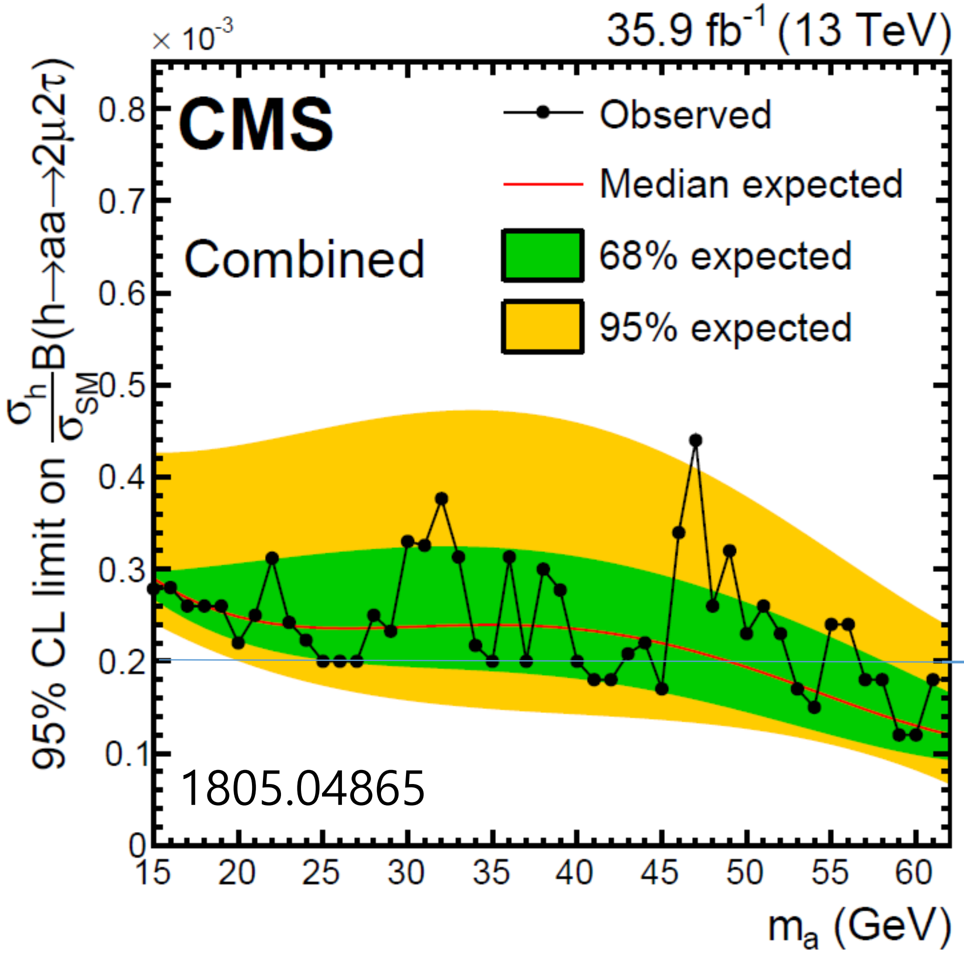
Cuts	Signal	$pp \to \mu^+\mu^-$ $+jets$	$pp \to VV$ $+jets$	$pp \to t\bar{t}$ $+jets$
$p_T(j_\tau) > 20$ GeV				
Preselection	858 (1480)	41041 (41041)	107890 (107890)	14486 (14486)
$\|M_{\mu\mu} - M_A\| < 7.5$ GeV	836 (1430)	909 (779)	1189 (1325)	1637 (1697)
$M_{j_\tau j_\tau} > M_A - 20$ & $M_{j_\tau j_\tau} < M_A + 10$ GeV	760 (1336)	130 (390)	307 (654)	330 (419)
$M_{2\mu 2j_\tau} > M_h - 20$ & $M_{2\mu 2j_\tau} < M_h + 10$ GeV	698 (1283)	$< 130\ (< 390)*$	81 (109)	65 (51)
$p_T(j_\tau) > 25$ GeV				
Preselection	277 (493)	28833 (28833)	75209 (75209)	11629 (11629)
$\|M_{\mu\mu} - M_A\| < 7.5$ GeV	269 (475)	649 (390)	794 (924)	1324 (1396)
$\|M(j_\tau j_\tau) - M_A\| < 15$ GeV	228 (420)	< 649 (130)	112 (416)	182 (196)
$\|M_{2\mu 2\,j_\tau} - M_h\| < 15$ GeV	211 (410)	$< 649\ (< 130)*$	20 (15)	27 (27)

LHC prospect





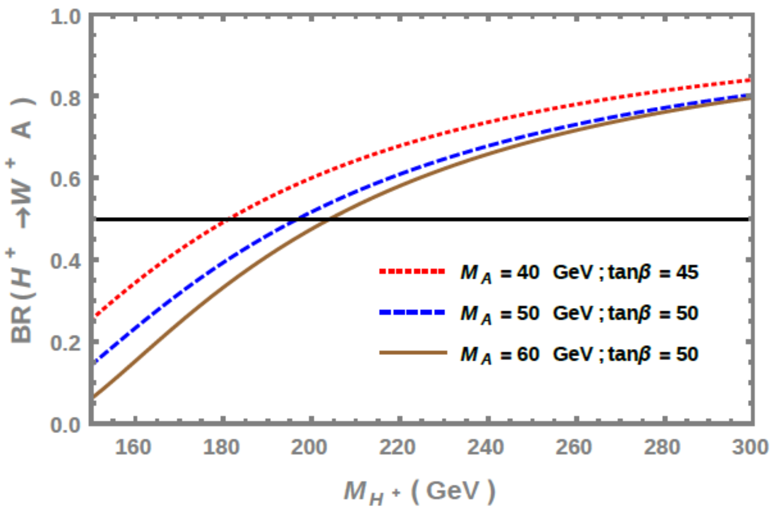
CMS result

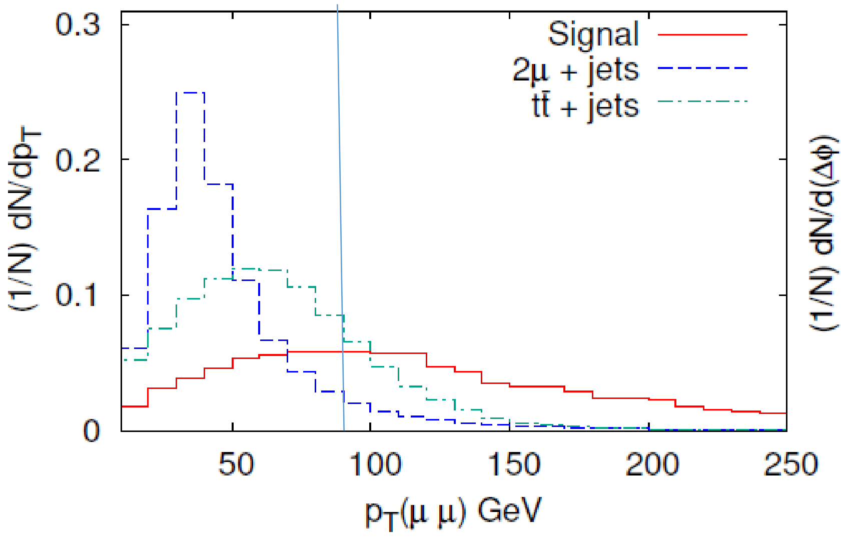


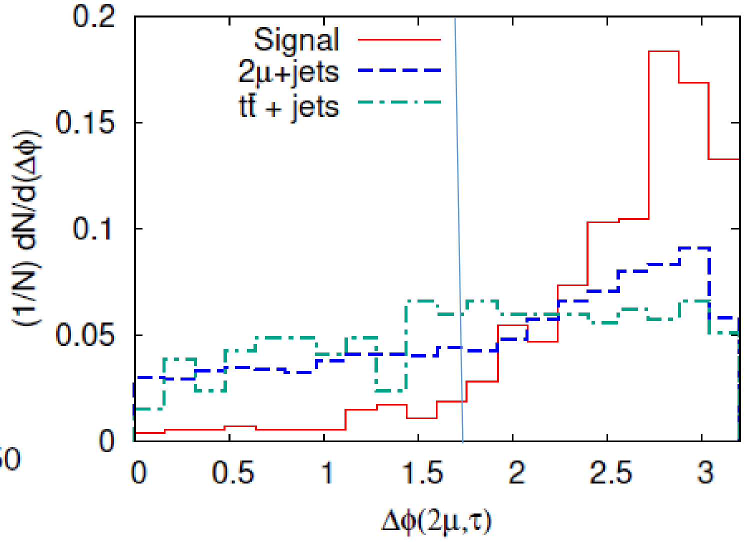
$B(h \to aa) = 0.03$

Reconstruction of heavy Higgses

- Signal: $pp \to H^{\pm}A/HA \to W^{\pm}/Z\ A(\mu\mu)A(\tau\tau)$
- Background: $pp \to \mu\mu, tt, VV + jets$





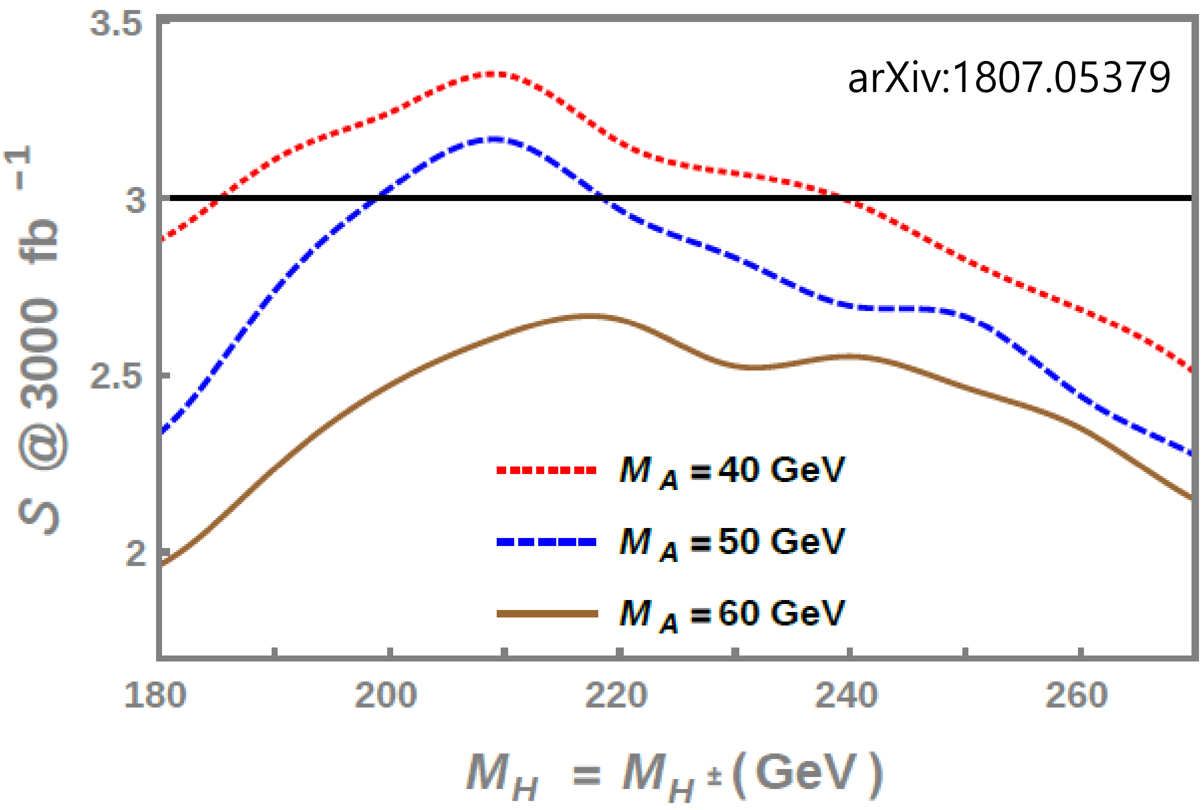


Event selection

$M_{H^\pm,H} = 210$ GeV, $M_A = 50$ GeV, $\mathcal{L} = 3/ab$

Cuts	Signal		Background		Significance
	$H^\pm A$	HA	$\mu^+\mu^-$+jets	$t\bar{t}$+jets	
$\mu^+\mu^-$, $p_T(\mu) > 10$ GeV	179	79	38610	25424	1.0
$0b$	173	72	37755	10125	1.1
$\lvert M_{\mu\mu} - M_A \rvert < 2.5$ GeV	151	63	9228	2444	2.0
$p_T(\mu\mu) > 90$ GeV	108	44	2351	605	2.8
$\Delta\Phi(\mu\mu, j_\tau) > 1.6$	98	40	1742	354	3.0

$M_{\mu\mu jj}$



arXiv:1807.05379
3.5
3
2.5
2
180
200
220
240
260
S @3000 fb^{-1}
$M_H = M_{H^\pm}$ (GeV)
M_A = 40 GeV
M_A = 50 GeV
M_A = 60 GeV

Scalar DM through Higgs Portal

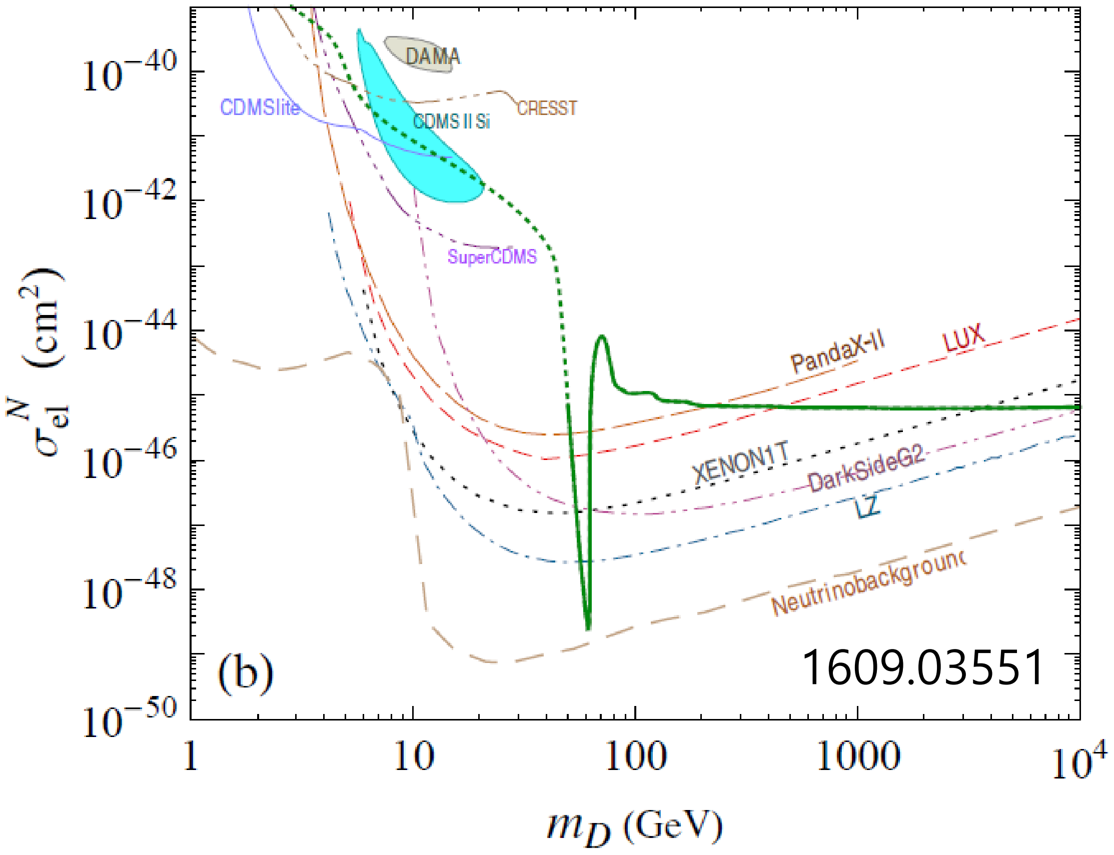
- Introduce a stable singlet scalar in SM – the minimal (simplest-minded) model:

Silveira, Zee, 85
McDonalds 94
Bird, et.al., 06 and many

$$V = \mu_H^2|H|^2 + \lambda_H|H|^4 + \lambda_{HS}\,|H|^2|S|^2 + \mu_S^2|S|^2 + \lambda_S|S|^4$$

- Right relic density through freeze-out controlled by the DM annihilation rate of $S\,S \to h\,h, S\,S \to h^* \to \bar{f}\,f$ for an appropriate range of $\lambda_{HS}\,\&\,m_S$.
- Strongly disfavored by direct detection experiments.
- Different features in 2HDM+SDM

Constrained Higgs-portal SDM



L2HDM+Scalar DM

P. Bandyopadhyay, EJC, R. Mandal, 1709.08581

$$V = \frac{1}{2}m_0^2 S^2 + \frac{\lambda_S}{4}S^4 + \frac{1}{2}S^2\left[\kappa_1|\Phi_1|^2 + \kappa_2|\Phi_2|^2\right]$$

$\Phi_1 \sim A, H, H^\pm$

$\Phi_2 \sim h$

$$V = \frac{1}{2}S^2\left[2v(\kappa_h h + \kappa_H H) + \kappa_{hh}h^2 + 2\kappa_{hH}hH + \kappa_{HH}H^2 + \kappa_{AA}(A^2 + 2H^+H^-)\right]$$

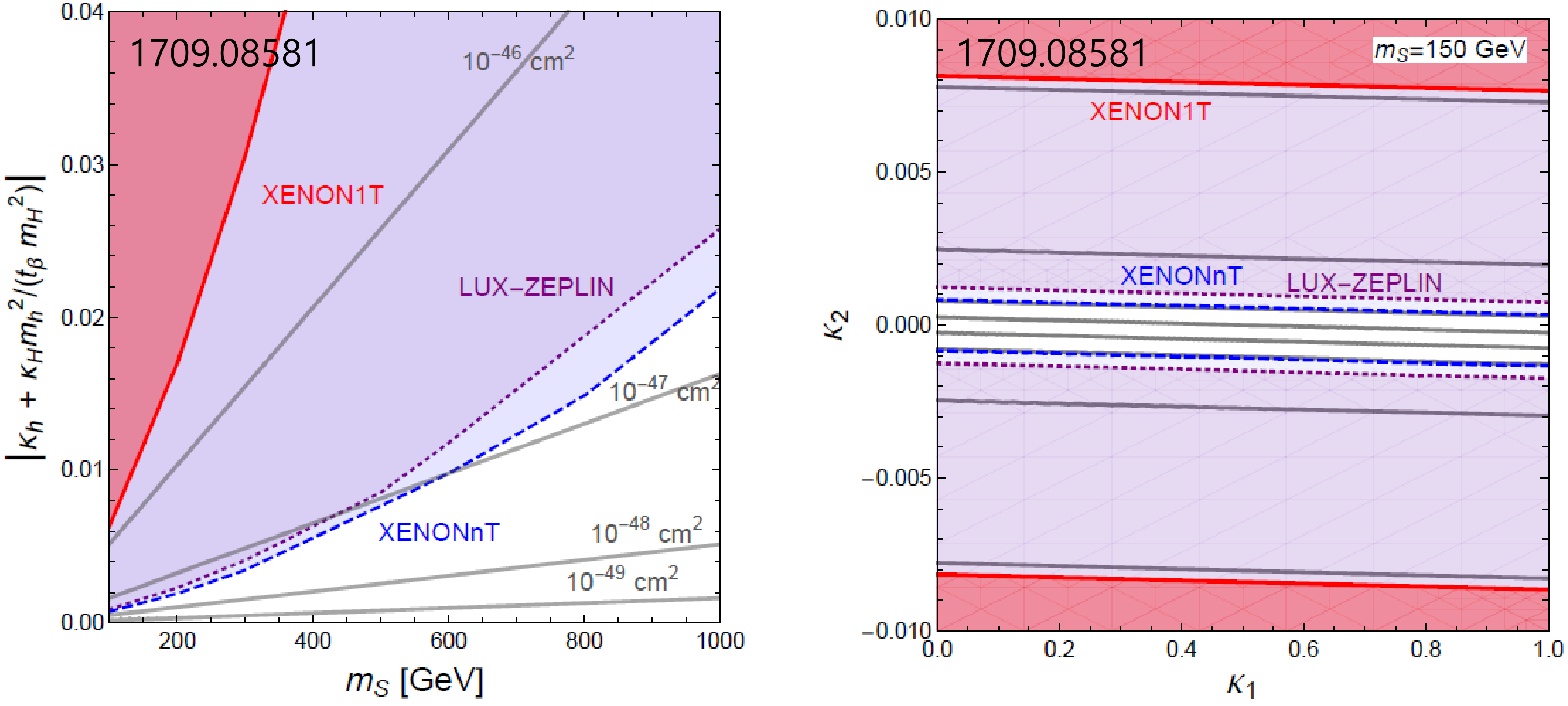
where
$$\begin{aligned}
\kappa_h &= -\kappa_1 s_\alpha c_\beta + \kappa_2 c_\alpha s_\beta \approx \kappa_1 c_\beta^2 + \kappa_2 s_\beta^2, \\
\kappa_H &= +\kappa_1 c_\alpha c_\beta + \kappa_2 s_\alpha s_\beta \approx (\kappa_1 - \kappa_2)c_\beta s_\beta. \\
\kappa_{hh} &= \kappa_1 s_\alpha^2 + \kappa_2 c_\alpha^2 \approx \kappa_1 c_\beta^2 + \kappa_2 s_\beta^2, \\
\kappa_{hH} &= -(\kappa_1 - \kappa_2)c_\alpha s_\alpha \approx (\kappa_1 - \kappa_2)c_\beta s_\beta, \\
\kappa_{HH} &= \kappa_1 c_\alpha^2 + \kappa_2 s_\alpha^2 \approx \kappa_1 s_\beta^2 + \kappa_2 c_\beta^2, \\
\kappa_{AA} &= \kappa_1 s_\beta^2 + \kappa_2 c_\beta^2
\end{aligned}$$

$\overset{t_\beta \gg 1}{\Longrightarrow}$

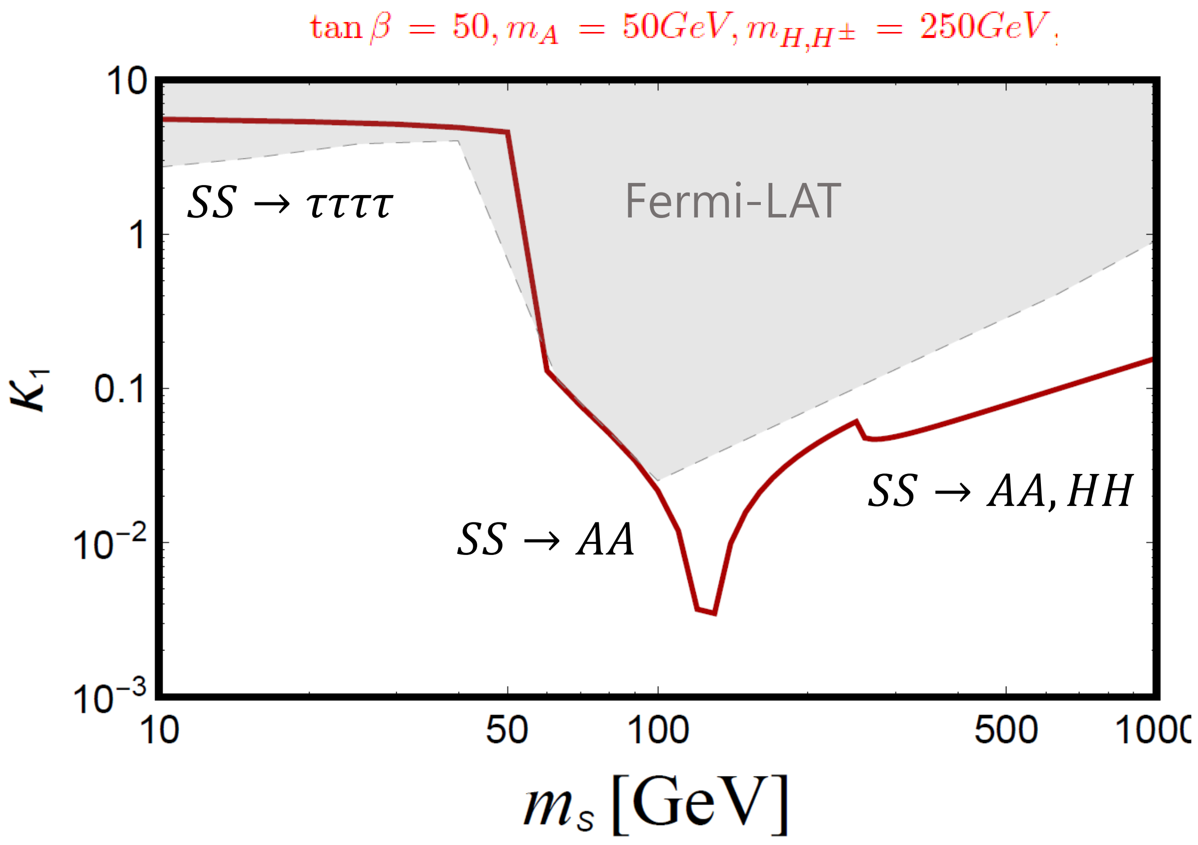
$$\begin{aligned}
&\kappa_h \to \kappa_2 \\
&\kappa_H, \kappa_{hH} \to (\kappa_1 - \kappa_2)/t_\beta \\
&\kappa_{hh} \to \kappa_2 \\
&\kappa_{HH}, \kappa_{AA} \to \kappa_1
\end{aligned}$$

DM-Nucleon scattering

$\tan\beta = 50, m_A = 50GeV, m_{H,H^\pm} = 250GeV$,



DM annihilation to 4τ



Conclusion

- X2HDM with large $\tan\beta$ and light A is a viable option for the muon g-2.
- Lepton universality tests in Z and tau decays strongly limit the parameter space $(m_A, \tan\beta)$.
- No region is allowed at 1σ, but large region opens up at 2σ, particularly, for $m_H \approx m_{H^\pm} = 200 - 400\ GeV$.
- Higgs boson masses could be reconstructed at LHC through

$$h \to AA^{(*)} \to 4\tau\ (2\mu 2\tau); \quad H^{0,\pm} A \to AA \to 4\tau\ (2\mu 2\tau).$$

- Higgs-portal Scalar DM can be realized successfully.