The Aligned two-Higgs-doublet model

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The two-Higgs doublet model (2HDM)

In a generic scalar basis

$$\phi_1 = \left[\begin{array}{c} \phi_1^+ \\ \frac{1}{\sqrt{2}}\left(v_1 + \rho_1 + i\eta_1\right) \end{array} \right] \qquad \phi_2 = \left[\begin{array}{c} \phi_2^+ \\ \frac{1}{\sqrt{2}}\left(v_2 + \rho_2 + i\eta_3\right) \end{array} \right]$$

Defining $v \equiv \sqrt{v_1^2 + v_2^2} = (\sqrt{2}G_F)^{-1/2}$ and $\tan\beta \equiv v_2/v_1$

We can perform a basis transformation

$$\left(\begin{array}{c} \Phi_1 \\ -\Phi_2 \end{array} \right) \equiv \left[\begin{array}{cc} \cos\beta & \sin\beta \\ \sin\beta & -\cos\beta \end{array} \right] \left(\begin{array}{c} \phi_1 \\ \phi_2 \end{array} \right) ,$$

In the so-called Higgs basis only one doublet acquires a vev

$$\Phi_1 = \left[\begin{array}{c} G^+ \\ \frac{1}{\sqrt{2}}\left(v + S_1 + iG^0\right) \end{array} \right] \qquad \Phi_2 = \left[\begin{array}{c} H^+ \\ \frac{1}{\sqrt{2}}\left(S_2 + iS_3\right) \end{array} \right]$$

The two-Higgs doublet model (2HDM)

The scalar potential

In the Higgs basis,

$$\begin{aligned}
\mathcal{V} &= \mu_i\, \Phi_i^\dagger \Phi_i + \left[\mu_3\, \Phi_1^\dagger \Phi_2 + \mu_3^*\, \Phi_2^\dagger \Phi_1\right] + \lambda_i\, \left(\Phi_i^\dagger \Phi_i\right)^2 \\
&+ \lambda_3\, \left(\Phi_1^\dagger \Phi_1\right)\left(\Phi_2^\dagger \Phi_2\right) + \lambda_4\, \left(\Phi_1^\dagger \Phi_2\right)\left(\Phi_2^\dagger \Phi_1\right) \\
&+ \left[\left(\lambda_5\, \Phi_1^\dagger \Phi_2 + \lambda_6\, \Phi_1^\dagger \Phi_1 + \lambda_7\, \Phi_2^\dagger \Phi_2\right)\left(\Phi_1^\dagger \Phi_2\right) + \text{h.c.}\right]
\end{aligned}$$

The fact that the minimum is a extremum impose the relations

$$\mu_1 = -\lambda_1\, v^2\,, \qquad \mu_3 = -\frac{1}{2}\,\lambda_6\, v^2\,.$$

The two-Higgs doublet model (2HDM)

The scalar spectrum

Expanding the scalar potential around the vev

$$\mathcal{V} \;\subset\; M_{H^\pm}^2\, H^+ H^- + \frac{1}{2}\,(S_1, S_2, S_3)\;\mathcal{M}\;\begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix} + \cdots$$

$$= \; M_{H^\pm}^2\, H^+ H^- + \frac{1}{2}\, M_h^2\, h^2 + \frac{1}{2}\, M_H^2\, H^2 + \frac{1}{2}\, M_A^2\, A^2$$

by convention $M_H \geq M_h$

The two-Higgs doublet model (2HDM)

The scalar spectrum

$\mathcal{M}$ is a real symmetric matrix
$\Rightarrow$ diagonalized by an orthogonal matrix $\mathcal{R}$

$$\begin{pmatrix} h \\ H \\ A \end{pmatrix} = \mathcal{R} \begin{pmatrix} S_1 \\ S_2 \\ S_3 \end{pmatrix}$$

Assuming CP-conservation in the scalar sector $A = S_3$ and

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{bmatrix} \cos\tilde{\alpha} & \sin\tilde{\alpha} \\ -\sin\tilde{\alpha} & \cos\tilde{\alpha} \end{bmatrix} \begin{pmatrix} S_1 \\ S_2 \end{pmatrix}$$

with

$$\sin 2\tilde{\alpha} = \frac{-2\lambda_6 v^2}{M_H^2 - M_h^2}\,, \qquad \cos 2\tilde{\alpha} = \frac{M_A^2 + 2(\lambda_5 - \lambda_1)v^2}{M_H^2 - M_h^2}$$

Without loss of generality we restrict to $0 \leq \tilde{\alpha} \leq \pi/2$ ($\lambda_6 \leq 0$)

The two-Higgs doublet model (2HDM)

Higgs couplings to massive gauge vector bosons

The scalar doublets couple to the gauge bosons through the covariant derivative

$$\sum_{a=1}^{2} (D_\mu \Phi_a)^\dagger \, D^\mu \Phi_a \;=\; \mathcal{L}_{\phi V^2} + \cdots$$

$$\mathcal{L}_{\phi V^2} \;=\; \frac{2}{v}\, S_1 \left[\frac{1}{2}\, M_Z^2 \, Z_\mu Z^\mu + M_W^2 \, W_\mu^\dagger W^\mu\right]$$

$(S_1 = \cos\tilde\alpha \, h - \sin\tilde\alpha \, H)$
Neutral Higgs couplings with a gauge boson pair scale with

$$\kappa_V^h \;=\; \cos\tilde\alpha\,, \qquad \kappa_V^H \;=\; -\sin\tilde\alpha\,, \qquad \kappa_V^A \;=\; 0$$

where $\kappa_V^{\varphi_i^0} \equiv g_{\varphi_i^0 VV}/g_{hVV}^{\rm SM}$ and $V = W, Z$.

The two-Higgs doublet model (2HDM)

Implications of a SM-like Higgs boson

Current LHC data implies that the 125 GeV boson couples to $VV = \{W^+W^-, ZZ\}$ with SM-like strength.

- If we assume $M_h \simeq 125$ GeV then $\cos\tilde{\alpha} \simeq 1$ (I will focus in this scenario)
- If we assume $M_H \simeq 125$ GeV then $\sin\tilde{\alpha} \simeq 1$

How can we have a Higgs boson with a SM-like coupling to massive gauge vector bosons?

What are the implications of having a SM-like Higgs boson?

The two-Higgs doublet model (2HDM)

The Yukawa sector

The most general Yukawa Lagrangian of the 2HDM is given by

$$\mathcal{L}_Y = -\frac{\sqrt{2}}{v}\Big\{\bar{L}'_L \left(M'_\ell\,\Phi_1 + \Pi'_\ell\,\Phi_2\right)\,\ell'_R$$

$$+\,\bar{Q}'_L \left(M'_d\,\Phi_1 + \Pi'_d\,\Phi_2\right)\,d'_R + \bar{Q}'_L \left(M'_u\,\tilde{\Phi}_1 + \Pi'_u\,\tilde{\Phi}_2\right)\,u'_R\Big\} + \text{h.c.}\,,$$

In the fermion mass basis,

$$\mathcal{L}_Y = -\sum_{\varphi_k,f=u,d,\ell} \varphi_k\,\bar{f}\,Y_f^{\varphi_k}\,P_R\,f$$

$$-\frac{\sqrt{2}}{v}\,H^+\left\{\bar{u}\left[V\,\Pi_d\,P_R - \Pi_u^\dagger\,V\,P_L\right]d + \bar{\nu}\,\Pi_\ell\,P_R\,\ell\right\} + \text{ h.c.}$$

with $\varphi_k = \{h, H, A\}$.

The two-Higgs doublet model (2HDM)

The Yukawa couplings of neutral scalars

$$\mathcal{L}_Y \quad \subset \quad - \sum_{\varphi_k, f=u,d,\ell} \varphi_k \, \bar{f} \, Y_f^{\varphi_k} \, P_R \, f + \text{h.c.}$$

with

$$\begin{aligned} Y_{ij}^h &= \frac{(M_f)_{ij}}{v} \cos\tilde{\alpha} + \frac{(\Pi_f)_{ij}}{v} \sin\tilde{\alpha} \,, \\ Y_{ij}^H &= -\frac{(M_f)_{ij}}{v} \sin\tilde{\alpha} + \frac{(\Pi_f)_{ij}}{v} \cos\tilde{\alpha} \,, \\ Y_{ij}^A &= \pm i \, \frac{(\Pi_f)_{ij}}{v} \end{aligned}$$

The plus sign in the expression for Y_{ij}^A is for $f = d, \ell$ while the minus sign is for $f = u$.

The two-Higgs doublet model (2HDM)

Decoupling

For $\mu_2 \gg v^2$, where μ_2 is the coefficient of the quadratic $\Phi_2^\dagger \Phi_2$ term, the second Higgs doublet Φ_2 decouples

$$M_h^2 \simeq 2\lambda_1 v^2 + \mathcal{O}\left(\frac{v^4}{M_{H^\pm}^2}\right) , \qquad M_H^2 \simeq M_A^2 \simeq M_{H^\pm}^2 = \mu_2 + \mathcal{O}(v^2)$$

the couplings of h approach the SM values

$$\cos\tilde{\alpha} \simeq 1 + \mathcal{O}\left(\frac{v^4}{M_{H^\pm}^4}\right) , \qquad Y_f^h \simeq \frac{M_f}{v} + \mathcal{O}\left(\frac{v^2}{M_{H^\pm}^2}\right)$$

Dangerous contributions due to tree-level FCNCs are suppressed by the heavy mass scale $\mu_2 \gg v^2$.

The two-Higgs doublet model (2HDM)

Can we have a SM-like Higgs boson with the other scalars around the weak scale? Yes

When $\mu_3, \lambda_6 \to 0$ and $M_A^2 + 2(\lambda_5 - \lambda_1)v^2 > 0$ one obtains

$$\cos\tilde{\alpha} \simeq 1 + \mathcal{O}(\lambda_6^2)$$

In this case we have a SM-like Higgs boson around 125 GeV, a heavier CP-even Higgs $M_H \geq M_h$.

The masses of the CP-odd Higgs A and the charged Higgs can be either above or below 125 GeV.

EWPD $+$ perturbativity and perturbative unitarity bounds on the quartic-Higgs couplings, imply that both H and A should have masses below the TeV if $M_{H^\pm} \lesssim 500$ GeV

The two-Higgs doublet model (2HDM)

Natural flavour conservation [Glashow, Weinberg (77)], [Paschos (77)]

Impose a discrete $\mathcal{Z}_2$ symmetry in a generic scalar basis under which

$$\phi_1 \to \phi_1\,,\; \phi_2 \to -\phi_2$$

and the left-handed fermion doublets $Q_L \to Q_L\,,\; L_L \to L_L\,.$

- Type I: $f_R \to -f_R \;\; (f = u, d, l)$.
- Type II: $u_R \to -u_R$, $d_R \to d_R$, $l_R \to l_R$.
- Type X: $u_R \to -u_R$, $d_R \to -d_R$, $l_R \to l_R$.
- Type Y: $u_R \to -u_R$, $d_R \to d_R$, $l_R \to -l_R$.

For the type II model, for example,

$$\mathcal{L}_{\mathsf{Y}} \quad = \quad -\bar{Q}'_L\,\Delta'_2\,\tilde{\phi}_2\,u'_R - \bar{Q}'_L\,\Gamma'_1\,\phi_1\,d'_R - \bar{L}'_L\,\Pi'_1\,\phi_1\,\ell'_R + \mathrm{h.c.}$$

Terms with an odd number of ϕ_2 fields in the scalar potential are forbidden by the $\mathcal{Z}_2$ symmetry.

The two-Higgs doublet model (2HDM)

The Aligned 2HDM (A2HDM) [Pich, Tuzon (2009)]

The Yukawa Lagrangian in the Higgs basis

$$\mathcal{L}_Y \;=\; -\frac{\sqrt{2}}{v}\Big\{\bar{L}'_L\,\left(M'_\ell\,\Phi_1 + \Pi'_\ell\,\Phi_2\right)\,\ell'_R$$
$$+\,\bar{Q}'_L\,\left(M'_d\,\Phi_1 + \Pi'_d\,\Phi_2\right)\,d'_R + \bar{Q}'_L\,\left(M'_u\,\tilde{\Phi}_1 + \Pi'_u\,\tilde{\Phi}_2\right)\,u'_R\Big\} + \mathrm{h.c.}\,,$$

The Yukawa alignment condition

$$\Pi_{d,l} = \varsigma_{d,l} M_{d,l}\,, \qquad \Pi_u = \varsigma_u^* M_u$$

ς_f : the alignment parameters are family universal complex quantities.

The Yukawa matrices are aligned in flavour space
$\Rightarrow$ No FCNCs at tree-level

The Aligned 2HDM (A2HDM)

The fermionic couplings of the scalar fields are described in the A2HDM by

$$\mathcal{L}_Y = -\frac{\sqrt{2}}{v}\, H^+ \left\{ \bar{u} \left[\varsigma_d\, V M_d\, P_R - \varsigma_u\, M_u^\dagger V\, P_L \right] d \;+\; \varsigma_l\, \bar{\nu} M_l\, P_R l \right\} - \frac{1}{v} \sum_{\varphi_i^0, f} y_f^{\varphi_i^0}\, \varphi_i^0 \; \left[\bar{f}\, M_f\, P_R f \right] \;+\; \text{h.c.}$$

with

$$y_f^h = \cos\tilde{\alpha} + \varsigma_f \sin\tilde{\alpha}\,, \qquad y_{d,l}^A = i\,\varsigma_{d,l}\,,$$

$$y_f^H = -\sin\tilde{\alpha} + \varsigma_f \cos\tilde{\alpha}\,, \qquad y_u^A = -i\,\varsigma_u$$

The Aligned 2HDM (A2HDM)

The A2HDM contains all models with NFC as particular cases

Model	ς_d	ς_u	ς_l
Type I	$\cot\beta$	$\cot\beta$	$\cot\beta$
Type II	$-\tan\beta$	$\cot\beta$	$-\tan\beta$
Type X (lepton specific)	$\cot\beta$	$\cot\beta$	$-\tan\beta$
Type Y (flipped)	$-\tan\beta$	$\cot\beta$	$\cot\beta$

(*) To take the limit (A2HDM$\rightarrow$NFC 2HDM) one has to take into account also correlations among the scalar potential parameters derived from the Z_2 symmetry.

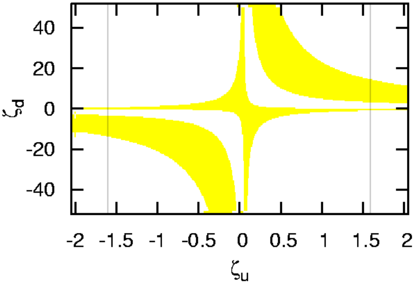
The Aligned 2HDM (A2HDM)

constraints from loop induced processes Jung, Pich, Tuzon [1006.0470]

$|\varsigma_d|$ and $|\varsigma_l|$ not strongly constrained from flavour observables.

$|\varsigma_u| \lesssim 2$ for $M_{H^\pm} < 500$ GeV from $Z \to \bar{b}b$, $B^0 - \bar{B}^0$ and $K^0 - \bar{K}^0$ mixing

Constraints $\varsigma_u - \varsigma_d$ plane from $\bar{B} \to X_s\gamma$

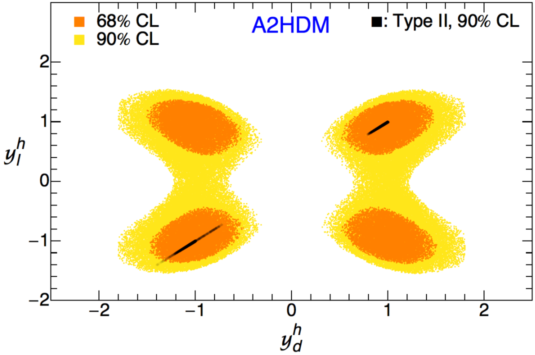


95% CL constraints from $\bar{B} \to X_s\gamma$. $M_{H^\pm} \in [80, 500]$ GeV

The Aligned 2HDM (A2HDM)

constraints from 125 GeV Higgs data [Celis,Ilisie,Pich (13)]

LHC and Tevatron data for the 125 GeV Higgs do not fix the sign of $y^h_{d,l}$. Flipped sign solutions are allowed.



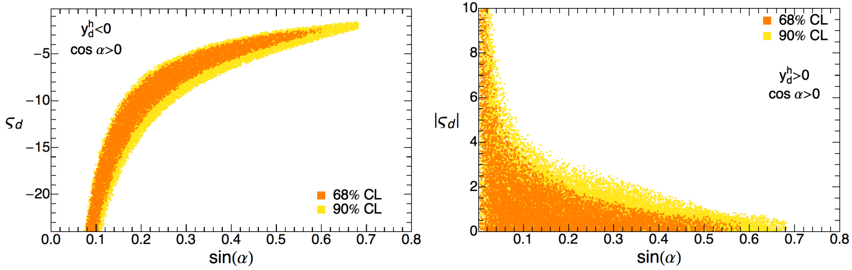
Constraints on the $y^h_d - y^h_l$ plane from 125 GeV Higgs data

The Aligned 2HDM (A2HDM)

constraints from 125 GeV Higgs data

125 GeV Higgs data puts strong constraints on the alignment parameters when $\cos\tilde{\alpha} < 1$

$$y_d^h = \cos\tilde{\alpha} + \varsigma_d \sin\tilde{\alpha}$$



Constraints on the $\sin\tilde{\alpha} - \varsigma_d$ plane from 125 GeV Higgs data

Belle II

SuperKEKB TDR Physics Motivation (Preliminary) June 18, 2014

Violations of lepton universality

Observables		Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Missing E decays	$\mathcal{B}(B \to \tau\nu)$ $[10^{-6}]$	$96(1 \pm 27\%)$ [26]	10%	5%
	$\mathcal{B}(B \to \mu\nu)$ $[10^{-6}]$	< 1.7 [67]	20%	7%
	$R(B \to D\tau\nu)$	$0.440(1 \pm 16.5\%)$ [29]†	5.6%	3.4%
	$R(B \to D^*\tau\nu)^\dagger$	$0.332(1 \pm 9.0\%)$ [29]†	3.2%	2.1%

Lepton flavour violation

Observables		Belle (2014)	Belle II 5 ab^{-1}	Belle II 50 ab^{-1}
Tau	$\tau \to \mu\gamma$ $[10^{-9}]$	< 45 [71]	< 14.7	< 4.7
	$\tau \to e\gamma$ $[10^{-9}]$	< 120 [71]	< 39	< 12
	$\tau \to \mu\mu\mu$ $[10^{-9}]$	< 21.0 [72]	< 3.0	< 0.3

B decays into τ leptons

Brief summary of exp. status

- BaBar excess in semileptonic modes $R(D)$ and $R(D^*)$ [1205.5442]
- BaBar publishes differential distributions for $d\mathrm{Br}(B \to D^{(*)}\tau\nu)/dq^2$ [1303.0571]
- Latest measurements for $B \to \tau\nu$ are in agreement with SM prediction.
- Need of updated Belle results for $R(D^{(*)})$. Differential distributions would be useful as well.

B decays into τ leptons

$$R(D) \equiv \frac{\mathrm{Br}(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{\mathrm{Br}(\bar{\mathrm{B}} \to \mathrm{D}\ell^-\bar{\nu}_\ell)} \stackrel{\text{BaBar}}{=} 0.440 \pm 0.058 \pm 0.042$$

$$R(D^*) \equiv \frac{\mathrm{Br}(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)}{\mathrm{Br}(\bar{B} \to D^*\ell^-\bar{\nu}_\ell)} \stackrel{\text{BaBar}}{=} 0.332 \pm 0.024 \pm 0.018$$

excess of 2.0σ $(R(D))$ and 2.7σ $(R(D^*))$ with respect to the SM

B decays into τ leptons

BaBar analysis [1205.5442] :
$R(D)$ and $R(D^*)$ exclude the type II 2HDM at 98.8% CL as long as $M_{H^\pm} > 10$ GeV, the range $M_{H^\pm} < 10$ GeV is excluded by $\bar{B} \to X_s\gamma$.

- $\bar{B} \to X_s\gamma$ bound depends considerably on the assumed Yukawa structure.
- $\bar{B} \to X_s\gamma$ is a loop-induced process.

Alternative:
Z-width measurement at LEP puts the constraint $M_{H^\pm} > 39.6$ GeV at 95%CL [1301.6065]. The bound is valid in the general 2HDM since the ZH^+H^- vertex is fixed by the gauge symmetry.

B decays into τ leptons

Analysis of flavour transitions mediated at tree-level by the charged Higgs within the A2HDM AC, Jung, Li, Pich [1210.8443] . We take into account

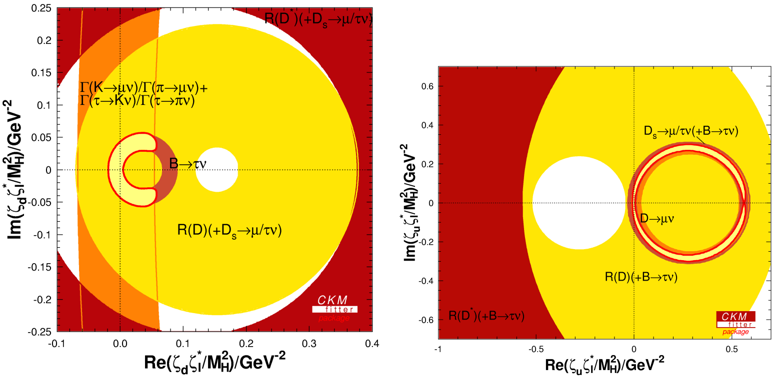
- $R(D)$ and $R(D^*)$
- $\mathrm{Br}(B \to \tau\nu_\tau)$
- $\mathrm{Br}(D_{(s)} \to \mu\nu)$ and $\mathrm{Br}(D_s \to \tau\nu_\tau)$
- $\Gamma(K \to \mu\nu)/\Gamma(\pi \to \mu\nu)$
- $\Gamma(\tau \to K\nu_\tau)/\Gamma(\tau \to \pi\nu_\tau)$

Note: does not include latest $B^+ \to \tau^+\nu_\tau$ measurement by Belle [1409.5269]

B decays into τ leptons

The A2HDM cannot accommodate the excess in $R(D^*)$

$\Rightarrow$ none of the 2HDMs with NFC can accommodate the excess either



B decays into τ leptons

Additional observables

differential distributions, angular asymmetries, polarization fractions, .., what can we learn from the inclusive mode $B \to X_c \tau\nu$?

Observables not sensitive to the charged Higgs

$$\frac{\mathrm{Br}(B \to \tau\nu)}{\mathrm{Br}(B \to \mu\nu)} = \frac{m_\tau^2}{m_\mu^2} \left(\frac{1 - m_\tau^2/m_B^2}{1 - m_\mu^2/m_B^2} \right)^2$$

$$X_1(q^2) \equiv R_{D^*}(q^2) - R_L^*(q^2)$$

with

$$R_{D^{(*)}}(q^2) = \frac{d\Gamma(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)/dq^2}{d\Gamma(\bar{B} \to D^{(*)}\ell^-\bar{\nu}_\ell)/dq^2}\,, \qquad R_L^*(q^2) = \frac{d\Gamma_\tau^L/dq^2}{d\Gamma_\ell^L/dq^2}$$

a charged Higgs does not contribute to the transverse helicity amplitudes.

B decays into τ leptons

Additional observables

Using the τ-spin asymmetry defined in the center-of-mass frame of the leptonic system

$$A_\lambda^{D^{(*)}}(q^2) = \frac{d\Gamma^{D^{(*)}}[\lambda_\tau = -1/2]/dq^2 - d\Gamma^{D^{(*)}}[\lambda_\tau = +1/2]/dq^2}{d\Gamma^{D^{(*)}}[\lambda_\tau = -1/2]/dq^2 + d\Gamma^{D^{(*)}}[\lambda_\tau = +1/2]/dq^2}$$

one can define another observable of this kind

$$X_2^{D^{(*)}}(q^2) \equiv R_{D^{(*)}}(q^2)\left(A_\lambda^{D^{(*)}}(q^2) + 1\right)$$

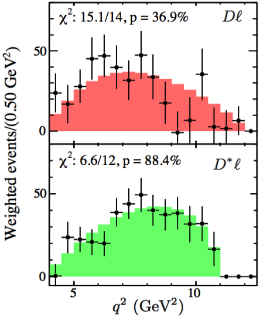
Future studies should go a step beyond by looking for observables more closely related to experiments (D^* and τ decays). For example Nierste,Trine,Westhoff [arXiv:0801.4938] studies $B \to D\bar{\nu}_\tau\tau^-[\to \pi^-\nu_\tau]$

Studies of expected sensitivity at Belle II for additional observables in $B \to D^{(*)}\tau\nu$ transitions would also be very helpful.

B decays into τ leptons

BaBar results for differential distribution $d\mathrm{Br}(B \to D^{(*)}\tau\nu)/dq^2$

[1303.0571]



fitting the diff. distribution in NP models Sakaki, Tanaka, Tayduganov [1412.3761]
The normalization of the data is a free parameter of the fit. This assumes that the total efficiency is constant for all q^2.

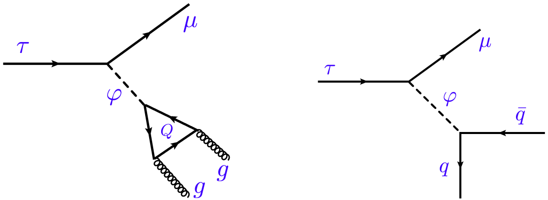
exp. data for $R_{D^{(*)}}(q^2)$ instead would be useful. Cancel dependence on V_{cb} and reduce theoretical uncertainties

LFV $\tau \to \mu$ decays

τ^- decay mode	Upper bound on BR (90 % CL)	Comment
$\mu\,\gamma$	4.4×10^{-8}	BaBar
$\mu^-\,\mu^+\mu^-$	2.1×10^{-8}	Belle
$\mu\,\pi^0$	1.1×10^{-7}	BaBar
$\mu\,\eta$	6.5×10^{-8}	Belle
$\mu\,\eta'$	1.3×10^{-7}	Belle
$\mu\,\pi^+\pi^-$	2.1×10^{-8}	Belle
$\mu\,\rho$	1.2×10^{-8}	Belle
$\mu\,f_0$	3.4×10^{-8}	Belle

LFV τ decays

Different hadronic final states in LFV semileptonic decays offer a great discriminatory tool [AC,Cirigliano,Passemar (13), (14)]

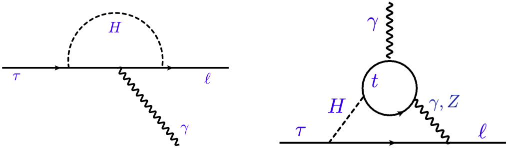


- $\tau \to \ell\pi^0, \ell\eta^{(\prime)}$ mediated by CP-odd Higgs with LFV couplings
- $\tau \to \ell\pi^+\pi^-$ mediated by CP-even Higgs with LFV couplings

This is not the case for $\tau \to \ell\gamma$ which are dominated by loop-diagrams and interference effects are very important

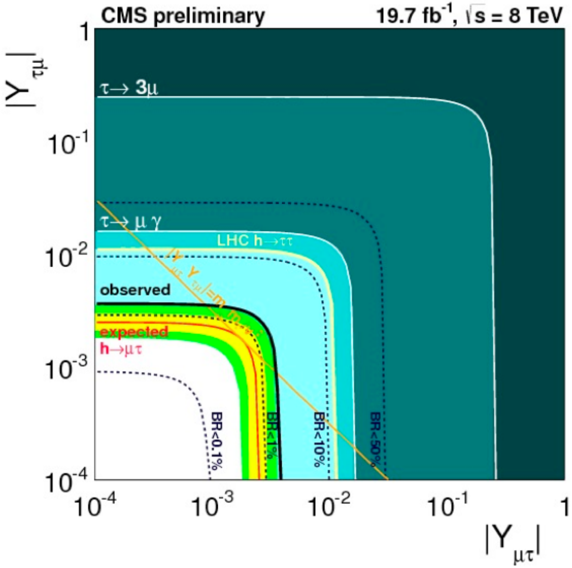
$\tau \to \ell\gamma$ decays

One-loop contribution is accidentally suppressed $\Rightarrow$ two-loop diagrams of the Barr-Zee type can dominate over one-loop contributions.
[Bjorken, Weinberg (77)], [Barr, Zee (90)], [Chang,Hou, Keung (93)]



$\tau \to \ell\gamma$ decays and $h \to \tau\mu$

Probing LFV Higgs couplings: Higgs decays vs τ decays



Conclusions

- The A2HDM provides a general 2HDM setting without FCNC at tree-level
- 2HDMs with NFC are obtained in particular limits of the A2HDM
- Current excess in $B \to D^* \tau \nu$ decays cannot be accommodated in the A2HDM.
- Additional observables in $B \to D^{(*)} \tau \nu$ transitions (differential distributions, angular asymmetries,...) can be exploited in Belle II. For theorist: work with observables more closely related to exp. (consider τ and D^* decays). For exp., what are the expected sensitivities for these observables?, which are interesting?
- Belle II sensitivity improvements for LFV τ decays. Relevant for probing LFV effects associated with the Higgs sector. Keep into account LFV semileptonic τ decays.

The Aligned 2HDM (A2HDM)

Loop corrections introduce misalignment between the Yukawa matrices at the quantum level, giving rise to FCNCs with the following structure Jung, Pich, Tuzon [1006.0470]

$$\mathcal{L}_{\mathsf{FCNC}} = \frac{\mathcal{C}}{4\pi^2 v^3}(1+\varsigma_u^*\varsigma_d)$$

$$\sum_j \varphi_j^0 \Big\{ (\mathcal{R}_{j2}+i\mathcal{R}_{j3})(\varsigma_d-\varsigma_u) \left[\bar{d}_L\, V^\dagger M_u M_u^\dagger V M_d\, d_R\right]$$

$$-(\mathcal{R}_{j2}-i\mathcal{R}_{j3})(\varsigma_d^*-\varsigma_u^*) \left[\bar{u}_L\, V M_d M_d^\dagger V^\dagger M_u u_R\right] \Big\} + \mathrm{h.c.}$$

where $C(\mu) = C(\mu_0) - \log(\mu/\mu_0)$. Assuming Yukawa alignment to be exact at a given energy scale Λ_A, so that $\mathcal{C}_R(\Lambda_A) = 0$, implies that $\mathcal{C}_R(\mu) = \ln(\Lambda_A/\mu)$.

Counter-term contribution to flavour transitions negligible due to strong GIM-like suppresion Braeuninger,Ibarra,Simonetto [1005.5706].