Structure of derivative interactions in *N* pseudo Nambu-Goldstone-Higgs doublet models

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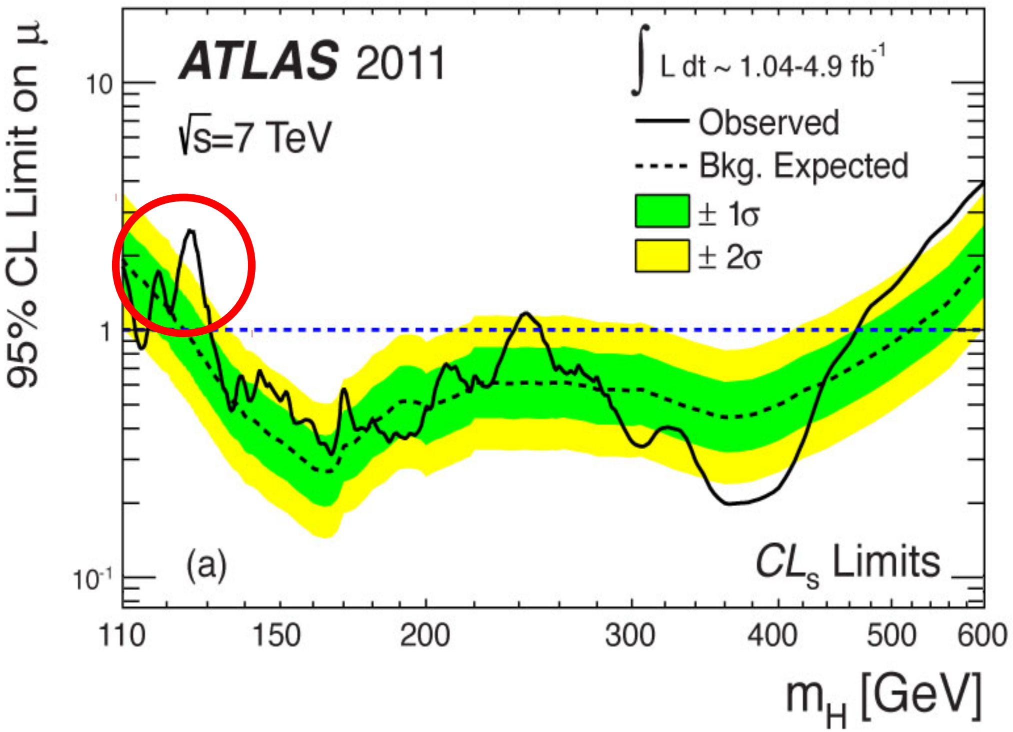
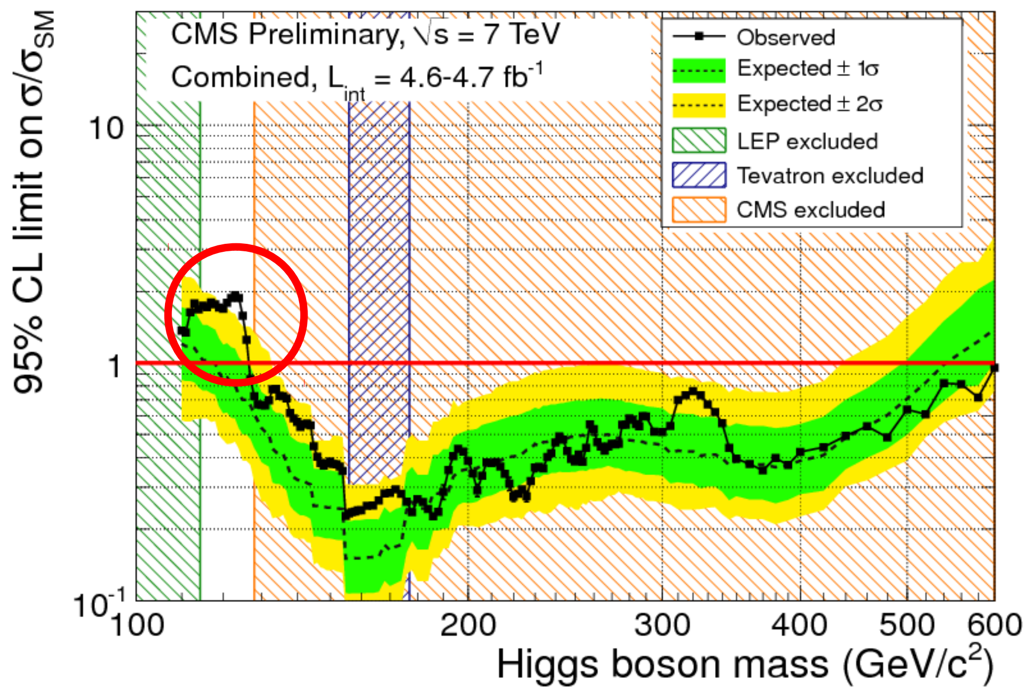
Based on arXiv:**1111.2120** (published in PRD)

Higgs hunting (hunted?)

Higgs (probably) will be observed by LHC8



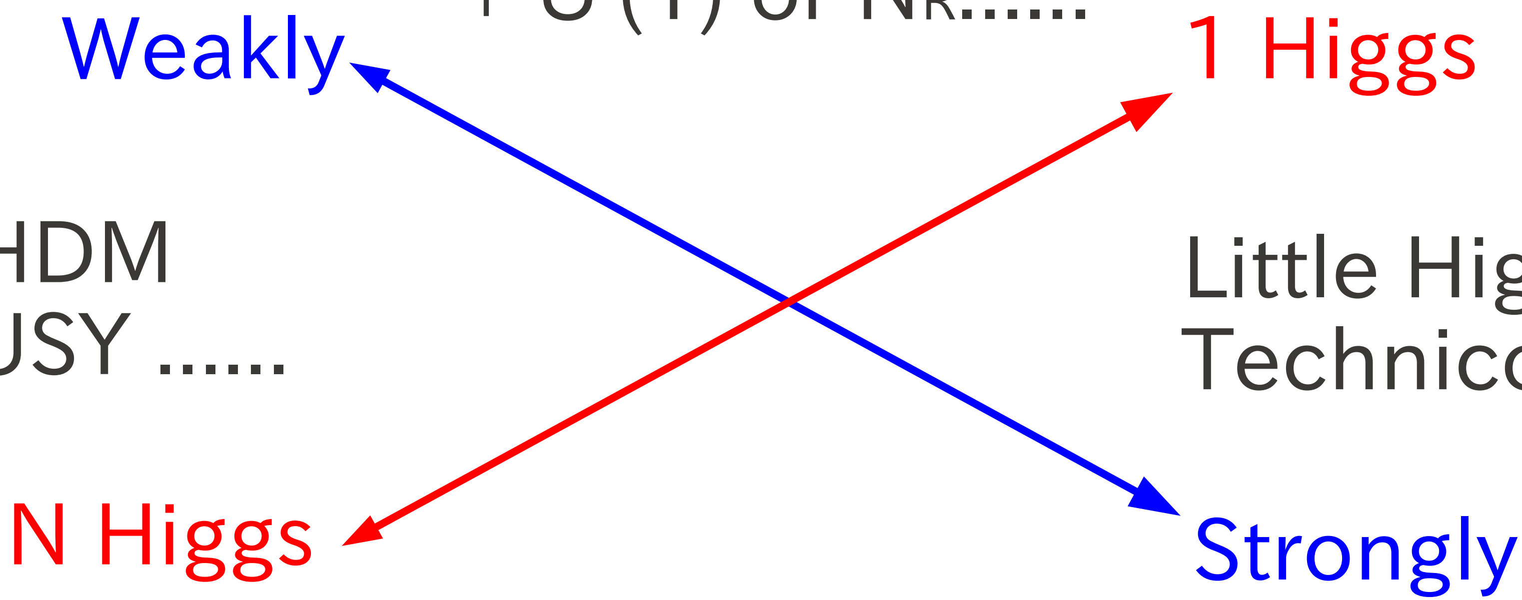


$$V_h = -\mu^2 H^\dagger H + \frac{\lambda}{2}(H^\dagger H)^2$$

How to break the electroweak symmetry?

Beyond the Standard Models

Standard Model
+ U'(1) or N_R......

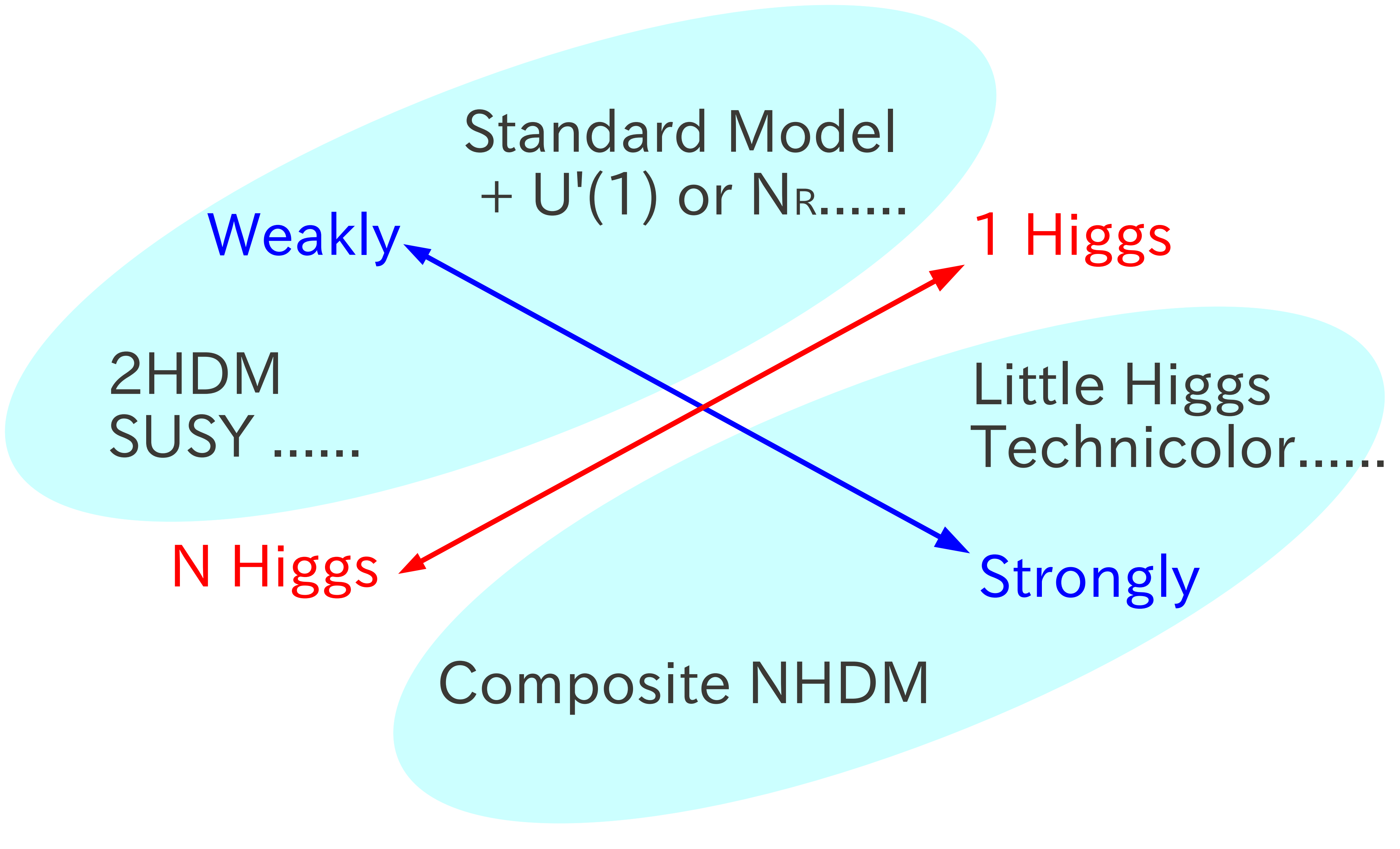


2HDM
SUSY ......

Little Higgs
Technicolor......

Composite NHDM

Beyond the Standard Models



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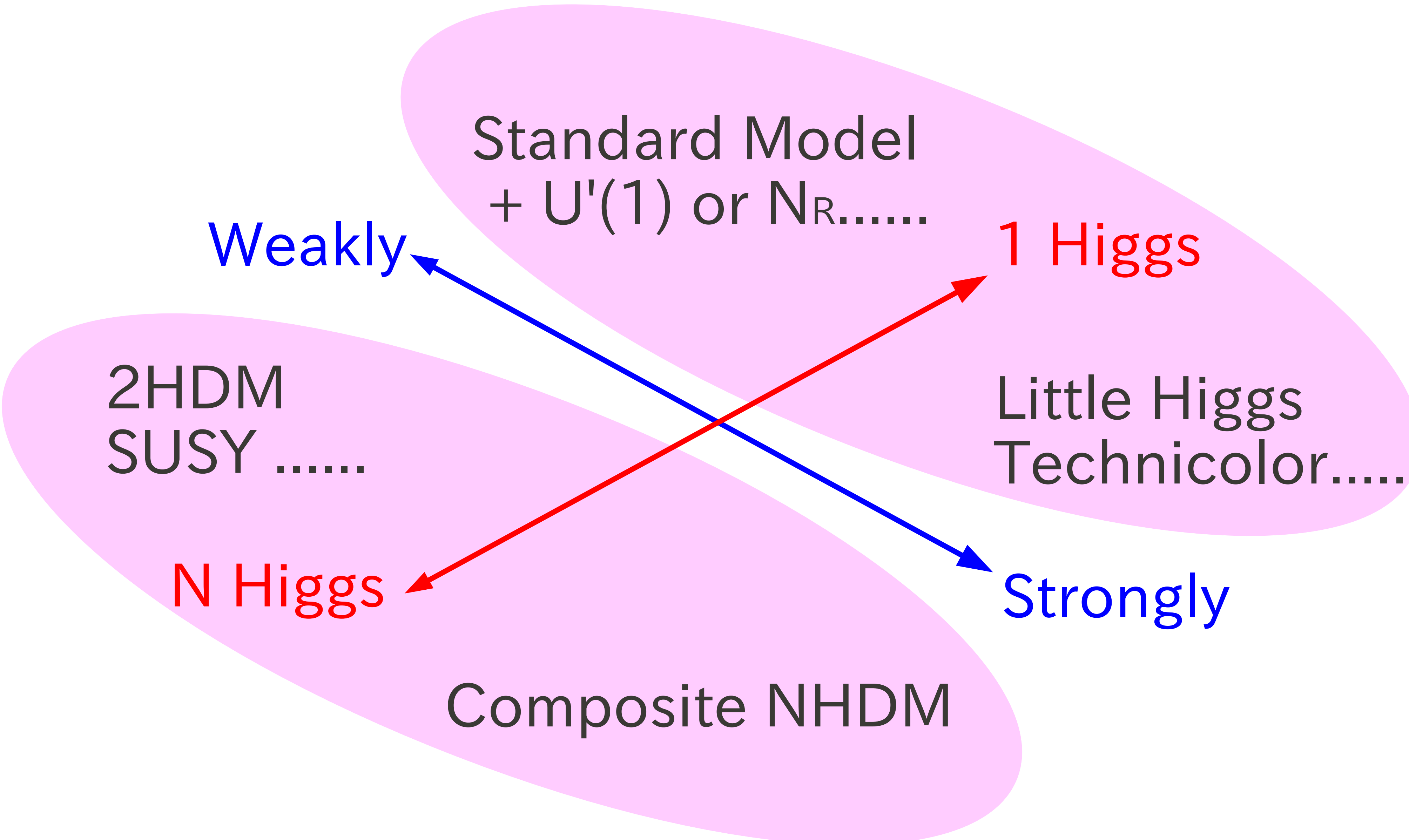

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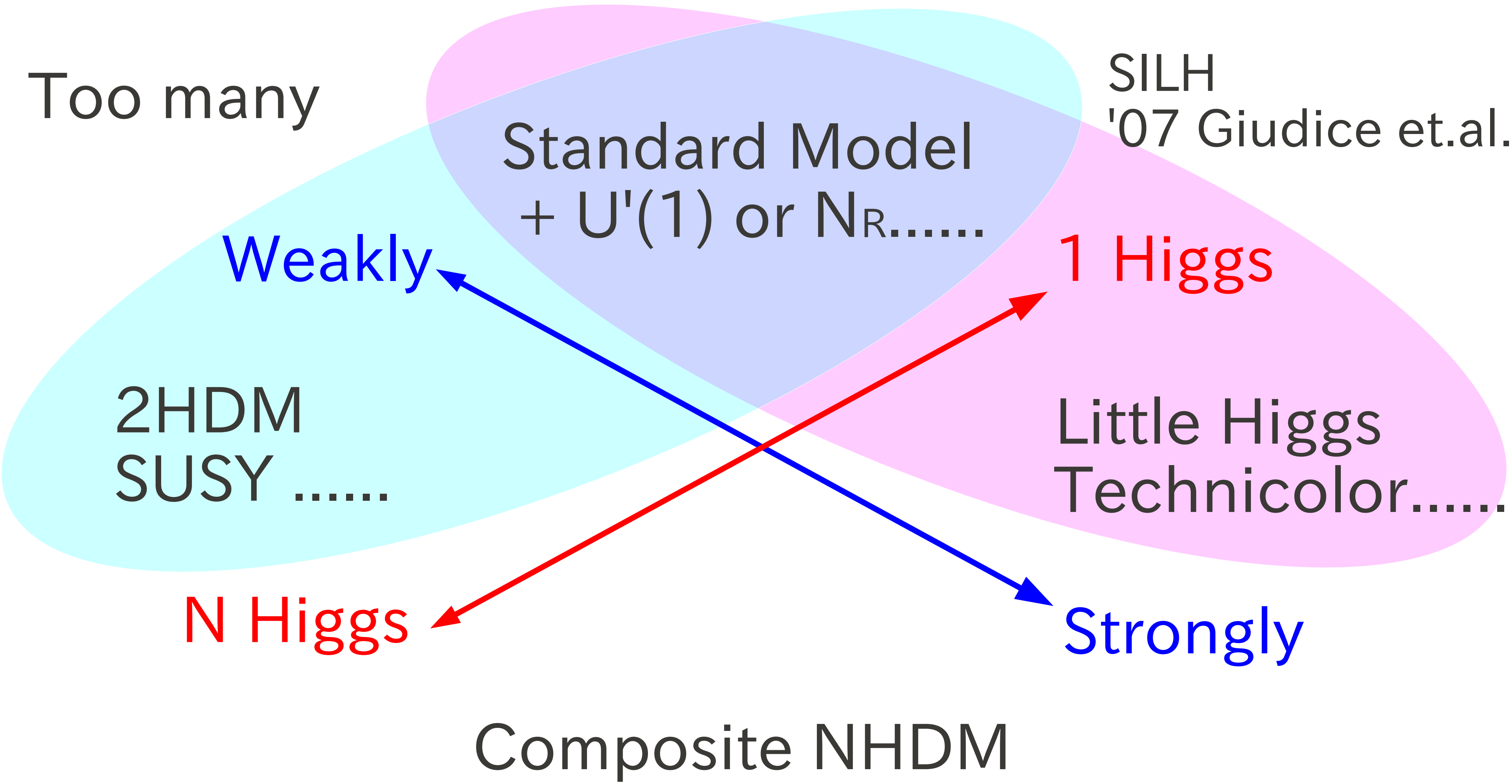

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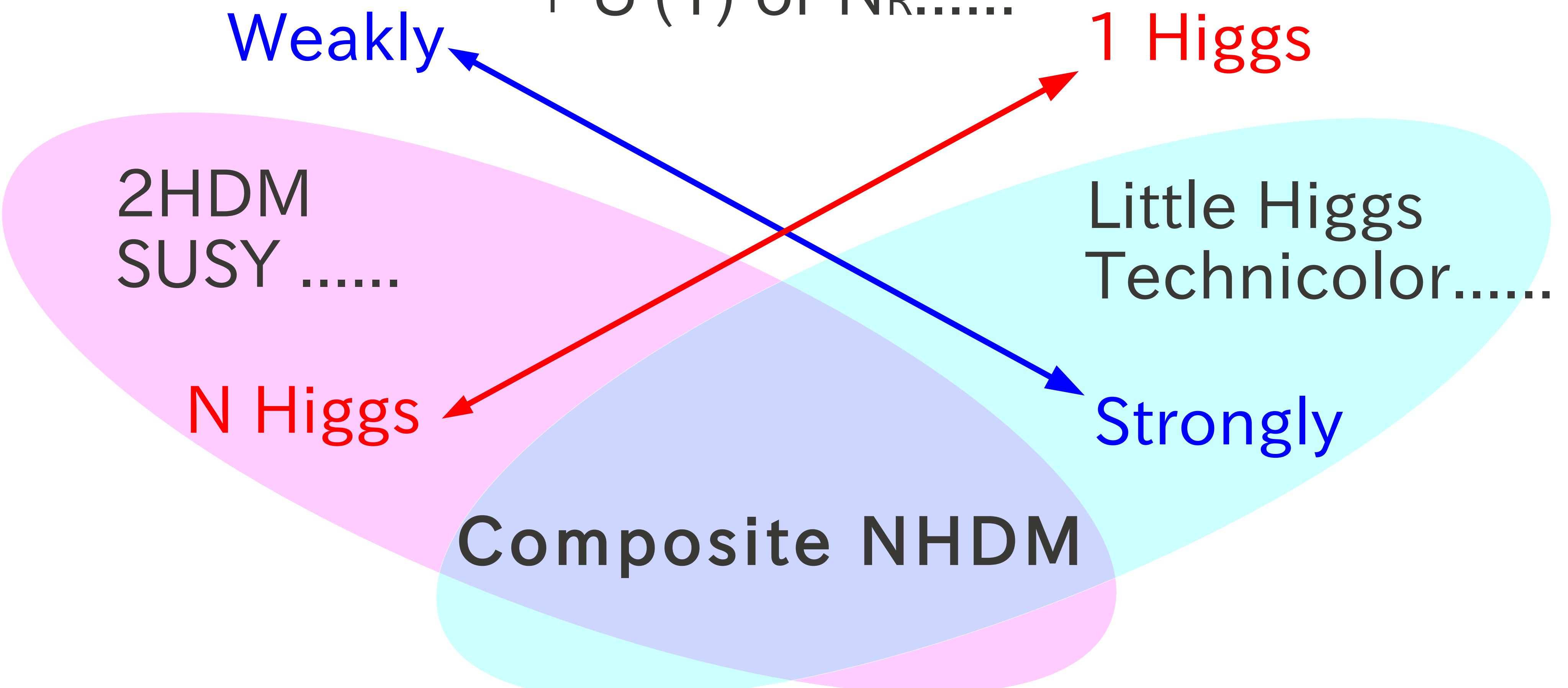


Derivative interactions of the Higgs

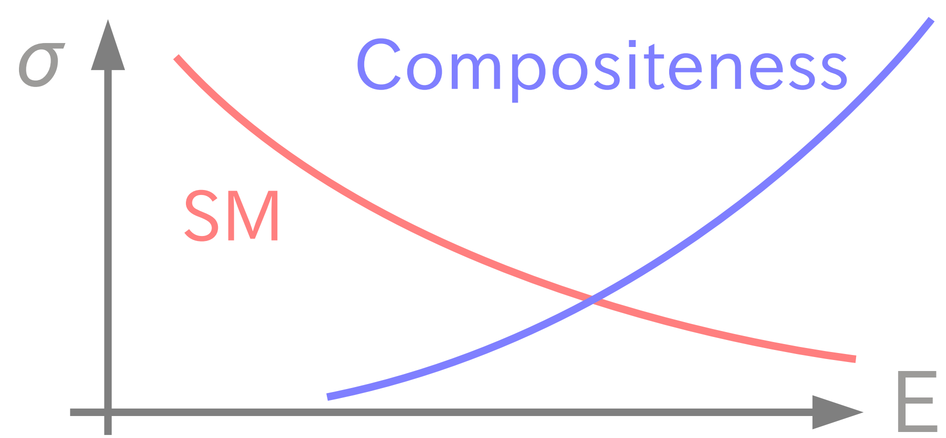
$$\frac{c^H}{f^2}\partial^\mu(H^\dagger H)\partial_\mu(H^\dagger H),\ldots$$

- Any interactions with the Higgs are changed.

$$\Rightarrow \frac{1}{2}\left(1+c^H\frac{v^2}{f^2}\right)(\partial h)^2 \qquad \Rightarrow h \to \frac{h}{\sqrt{\left(1+c^H\frac{v^2}{f^2}\right)}}$$

- Cross sections of VBF grow @ high energy region.

$$\Rightarrow \frac{c^H}{f^2}h(\partial h)\phi(\partial\phi)$$



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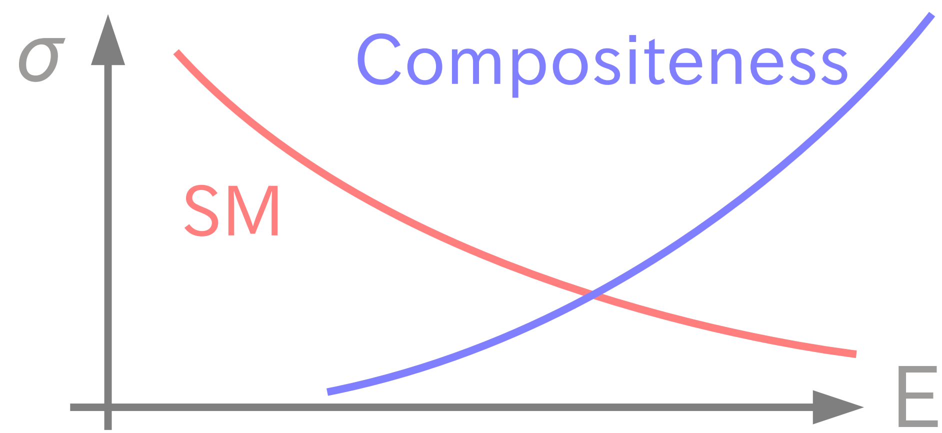

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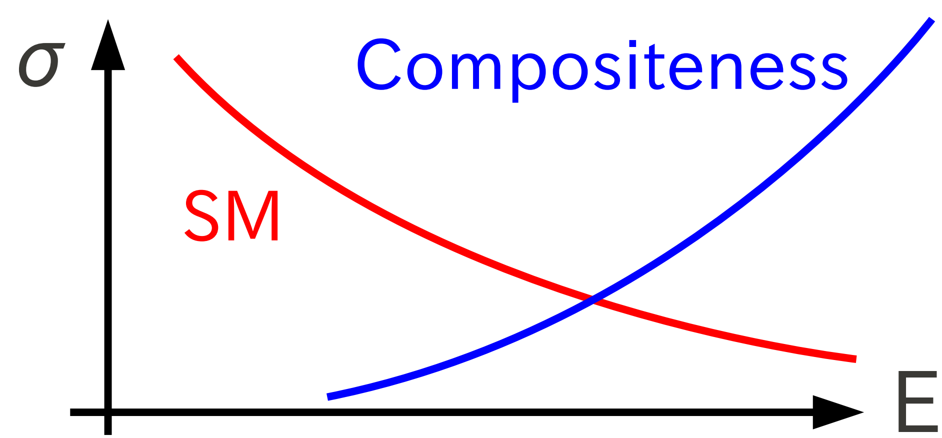

Derivative int. and nonlinear rep.

$$\mathcal{L}_{\mathrm{NG}} = \frac{f^2}{2}\mathrm{tr}\left[(\partial e^{-i\pi/f})(\partial e^{i\pi/f})\right]$$

Scalar multiplet of the Higgs

$$\Rightarrow \frac{1}{2}\partial h \partial h - \frac{1}{24 f^2}\left(4 f^{aci} f^{bdi} + f^{ace} f^{bde}\right) h^a h^b (\partial h^c)(\partial h^d) + \cdots$$

Antisymmetric for (a,c) or (b,d).

Derivative interactions are constrained.

'09 Low, Rattazzi and Vichi

Extend the analysis to the *N* Higgs doublet model.

→ Application to the 2HDM.

'11 Y. Kikuta, Y. Okada and YY

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4 real scalars

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$$\longrightarrow h T^{so(4)} \partial h \quad (T^{so(4)} \in \{T^{L\alpha}, T^{R\beta}\})$$

$$\Rightarrow a^L (h T^{L\alpha}\partial h)(h T^{L\alpha}\partial h) + a^R (h T^{R\beta}\partial h)(h T^{R\beta}\partial h)$$

$$+ a^Y (h T^{R3}\partial h)(h T^{R3}\partial h)$$

$$= \frac{a^L + a^R}{4 f^2}(O^H - 4 O^r) + \frac{a^Y}{4 f^2} O^T$$

$$O^H = (\partial H^\dagger H)(\partial H^\dagger H)$$

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$$O^r = (H^\dagger H)(\partial H^\dagger \partial H)$$

$$O^{HT} = (\partial H^\dagger H)(H^\dagger \overleftrightarrow{\partial} H)$$

	Re	Im
General	3	1
Nonlinear	2	0

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The case of *N* Higgs

$$\mathscr{L}_{\rm NG} = \frac{f^2}{2}{\rm tr}\left[(\partial e^{-i\pi/f})(\partial e^{i\pi/f})\right]$$

4N real scalars

$$\Rightarrow \frac{1}{2}\partial h \partial h - \frac{1}{24 f^2}\left(4 f^{aci} f^{bdi} + f^{ace} f^{bde}\right) h^a h^b (\partial h^c)(\partial h^d) + \cdots$$

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$$SU(2)_L \times SU(2)_R : (\mathbf{3},\mathbf{1}),\ (\mathbf{1},\mathbf{3}),\ (\mathbf{3},\mathbf{3}),\ (\mathbf{1},\mathbf{1})$$

$$O^H_{ijkl} = (\partial H_i^\dagger H_j)(\partial H_k^\dagger H_l) \qquad O^r_{ijkl} = (H_i^\dagger H_j)(\partial H_k^\dagger \partial H_l)$$

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General	$(3/2)N^2(N^2+1)$	$(1/2)N^2(3N^2-1)$
Nonlinear	$(1/2)N^2(N^2+3)$	$(1/2)N^2(N^2-1)$

1/3

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1/3

O(4) symmetric Lagrangian for 2HDM

$$\mathscr{L}_{2\mathrm{HDM}} = \frac{c^H_{1111}}{2f^2} O^H_{1111} + \frac{c^H_{1112}}{f^2}(O^H_{1112} + O^H_{1121}) + \frac{c^H_{1122}}{f^2} O^H_{1122}$$
$$+ \frac{c^H_{1221}}{f^2} O^H_{1221} + \frac{c^H_{1212}}{2f^2}(O^H_{1212} + O^H_{2121})$$
$$+ \frac{c^H_{2221}}{f^2}(O^H_{2212} + O^H_{2221}) + \frac{c^H_{2222}}{2f^2} O^H_{2222}$$
$$+ \frac{c^T_{1122}}{f^2} O^T_{1122} + \frac{c^T_{1221}}{f^2} O^T_{1221} + \frac{c^T_{1212}}{2f^2}(O^T_{1212} + O^T_{2121})$$

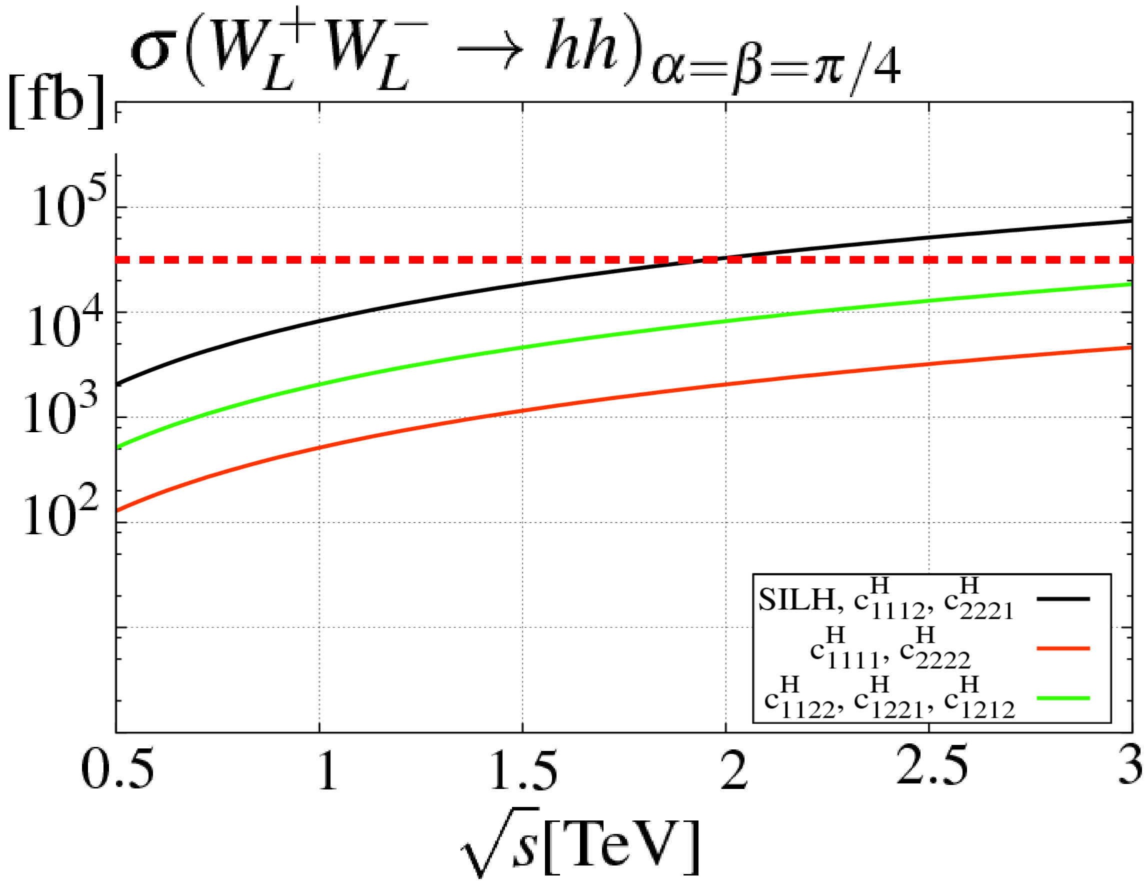
where $c^T_{1122} = -(c^T_{1221} + c^T_{1212}) = -\frac{1}{3}(c^H_{1221} - c^H_{1212})$

α : the mixing angle of CP-even Higgses

$\beta = v_1/v_2$

Weakly or strongly?

$$c^{H,T}/f^2 = 1/(750\mathrm{GeV})^2$$



$$\sigma(W_L^+ W_L^- \to W_L^+ W_L^-)_{\mathrm{SILH}} \sim 10^{3\sim5}\,\mathrm{fb}$$

$$\sigma(W^+ W^- \to hh)_{\mathrm{SM}} \sim 5\times10^4\,\mathrm{fb}$$

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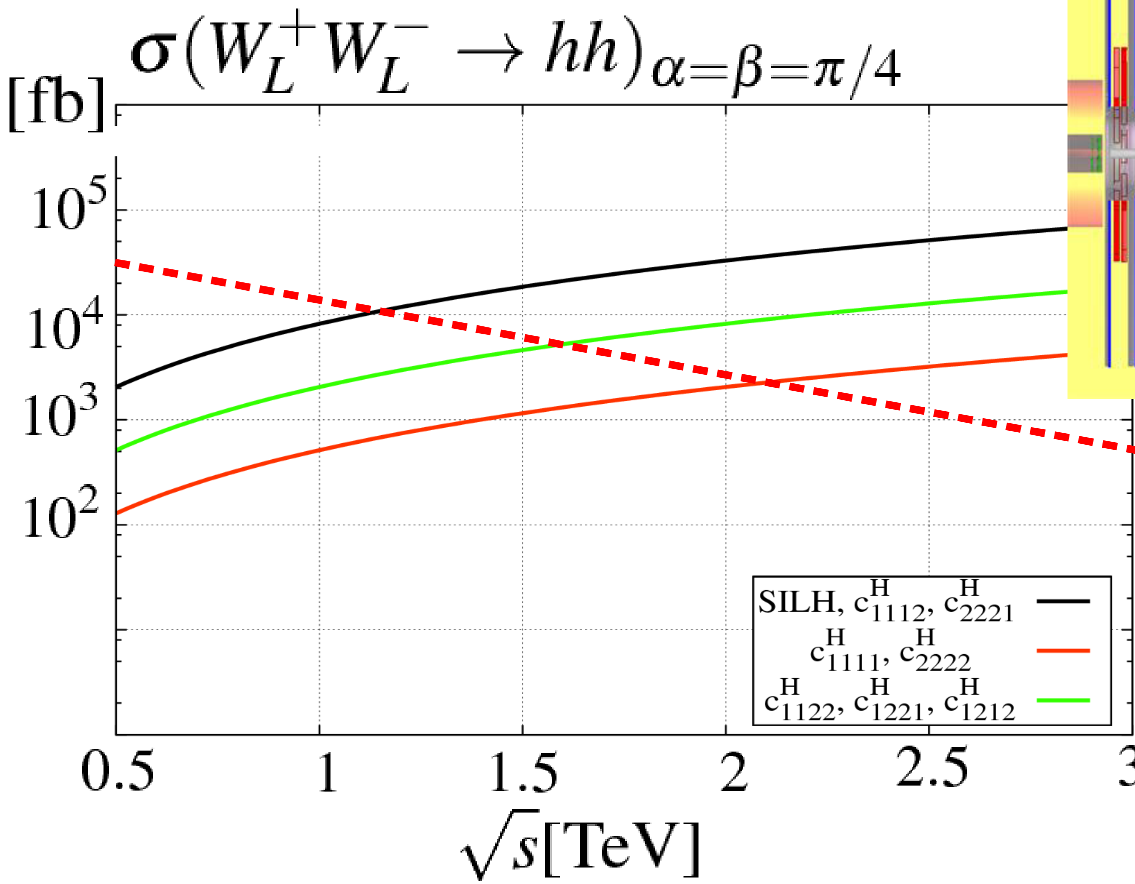

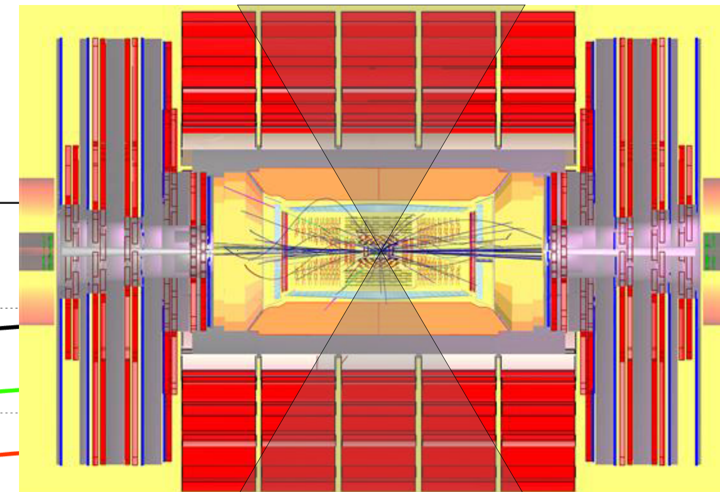

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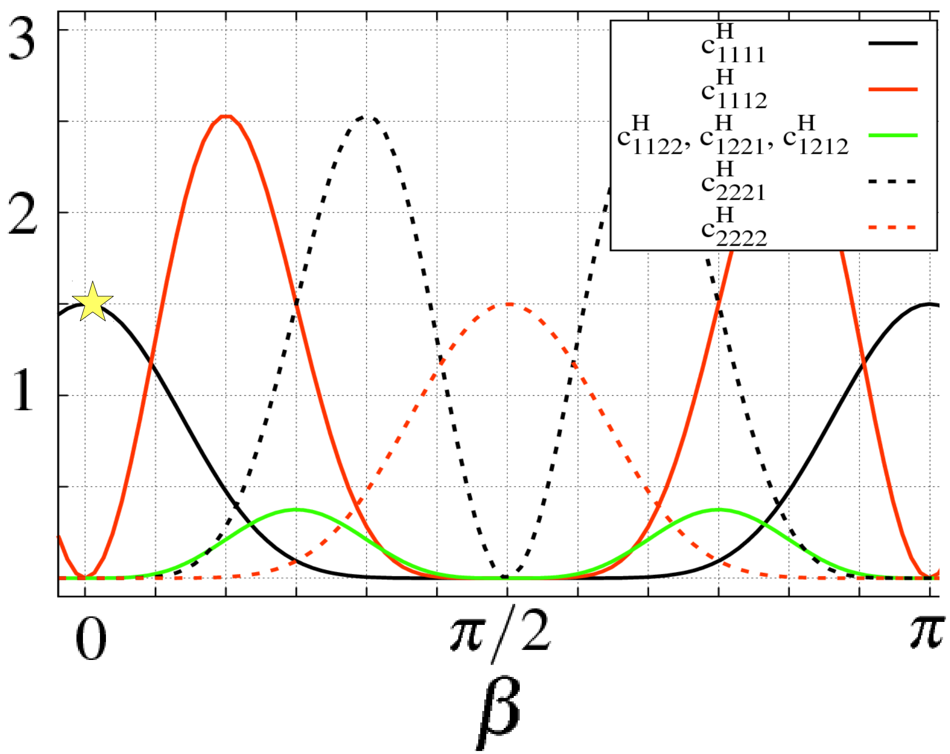
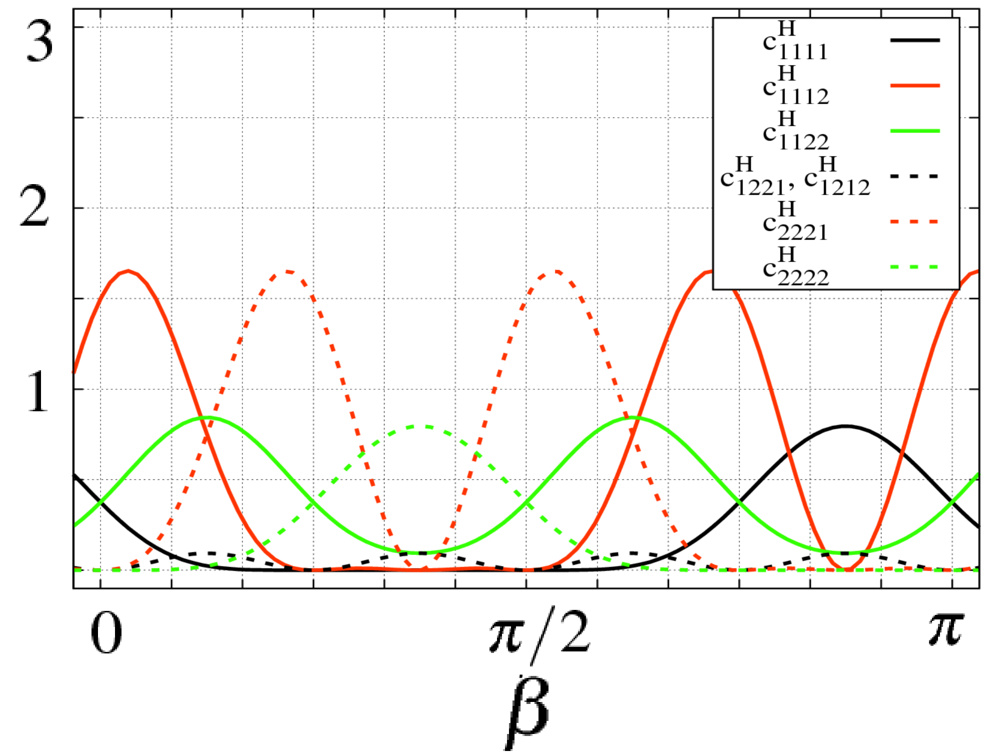
One Higgs or many Higgses?

$$\frac{\sigma(W_L^+ W_L^- \to hh)}{\sigma(W_L^+ W_L^- \to W_L^+ W_L^-)_{\rm SILH}}$$

$\alpha - \beta = 0$



$\alpha - \beta = \pi/4$



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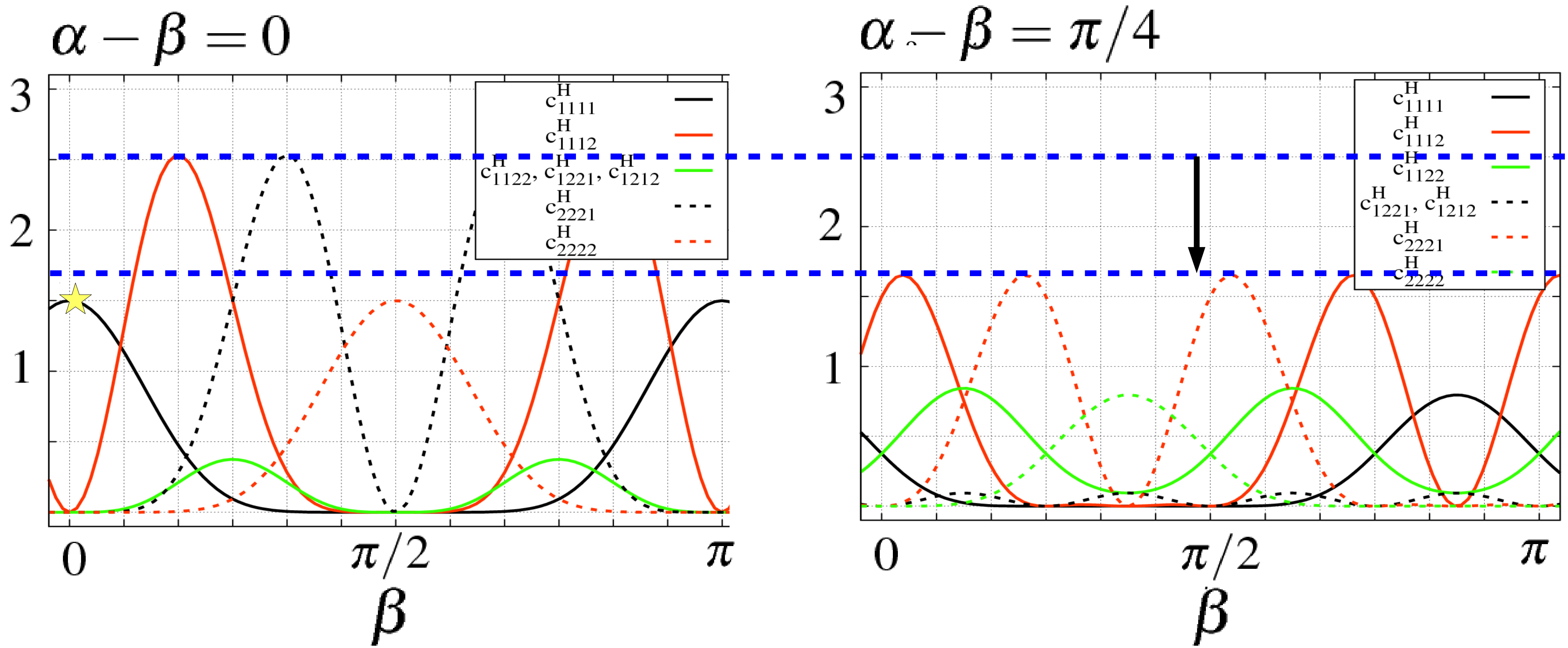

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Conclusion

①

	Re	Im
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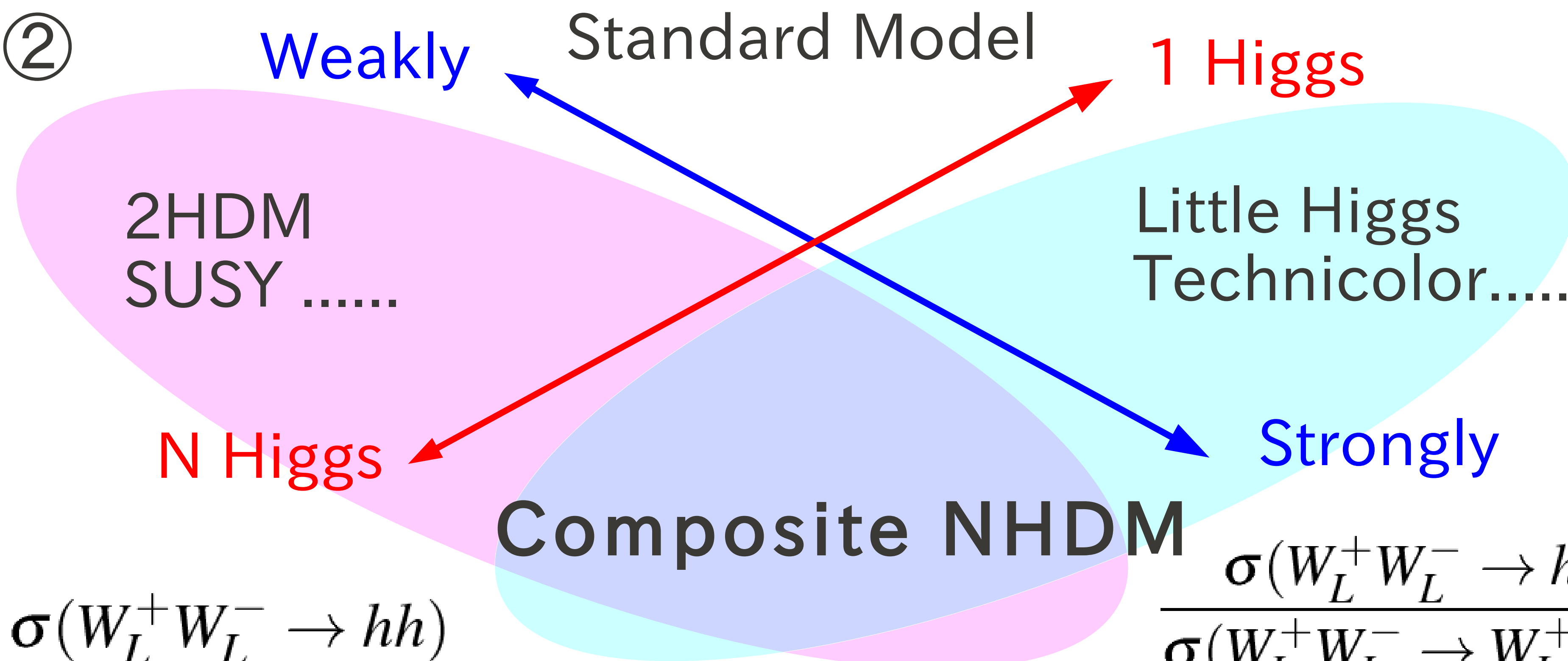
②



$\sigma(W_L^+W_L^- \to hh)$

high energy behavior

$$\frac{\sigma(W_L^+W_L^- \to hh)}{\sigma(W_L^+W_L^- \to W_L^+W_L^-)}$$

α - β dependence