Exploring the global symmetry structure of the Higgs potential

Masashi Aiko

Osaka University

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collaboration with Shinya Kanemura and Kentarou Mawatari
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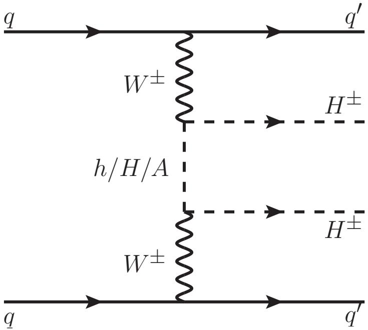
Message

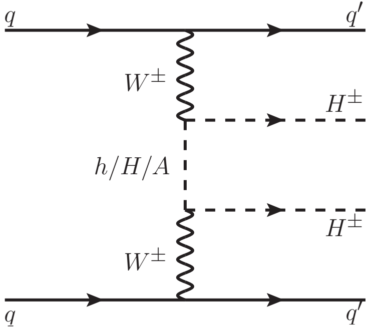
- We find a new process which captures the global symmetry structure of the Higgs potential.



- This process can be feasible at the LHC and the future higher energy colliders.

Message

H^+H^+ production via W^+ fusion is interesting!



Introduction

The standard model works very well !

However, there are problems which can't be explained by the SM,

- Hierarchy problem
- Baryon asymmetry of the universe
- Dark matter
- Tiny neutrino mass   etc.

A new theory is needed from the theoretical and experimental view points.

Q. How can we approach to such beyond SM physics?

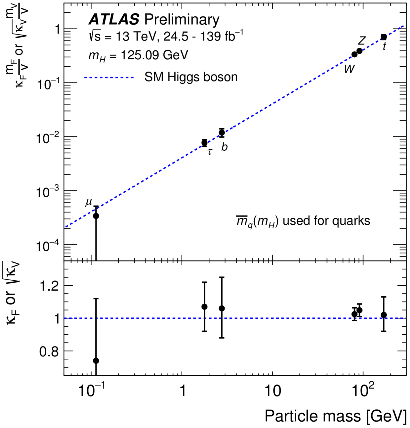
Higgs as a probe of new physics

One way : Study of the discoverd Higgs boson

Higgs couplings :
Those look SM like, but still 10 $\sim$ 20% experimental uncertainties remain.

e.g. Mawatari-san, Yagyu-san's talk

Another way : Searches for additional Higgs bosons



ATLAS-CONF-2019-005, 028

Extended Higgs sector : 2 Higgs doublet model(2HDM)

We consider 2HDM.

$$
\begin{aligned}
V_{\rm 2HDM} = & m_1^2|\Phi_1|^2 + m_2^2|\Phi_2|^2 - m_3^2(\Phi_1^\dagger\Phi_2 + h.c.) \\
& + \frac{1}{2}\lambda_1|\Phi_1|^4 + \frac{1}{2}\lambda_2|\Phi_2|^4 + \lambda_3|\Phi_1|^2|\Phi_2|^2 \\
& + \lambda_4|\Phi_1^\dagger\Phi_2|^2 + \frac{1}{2}\lambda_5[(\Phi_1^\dagger\Phi_2)^2 + h.c.],
\end{aligned}
$$

we assume Z_2 symmetry and CP conservation for simplicity.

There are CP-even h, H, CP-odd A, and $H^\pm$. We assume lightest CP-even scalar h as the discovered Higgs boson.

The 2HDM is a simple extension of the SM, however it often appears in new models which solve BSM phenomena.
Global symmetry in the Higgs potential characterizes new models.

Global symmetry in 2HDM

We focus on the quartic part :

$$
\begin{aligned}
V_4 = &+\frac{1}{8}c_1(|\Phi_1|^2 + |\Phi_2|^2)^2 && [O(8)] \\
&+ \frac{1}{8}c_2(|\Phi_1|^2 - |\Phi_2|^2)^2 && [O(4)\times O(4)] \\
&+ \frac{1}{4}c_3(|\Phi_1|^2 + |\Phi_2|^2)(|\Phi_1|^2 - |\Phi_2|^2) && \\
&+ \frac{1}{2}c_4(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1)^2 + \frac{1}{2}c_5(\Phi_1^\dagger\Phi_2 - \Phi_2^\dagger\Phi_1)^2, && [O(4)\&SU(2)]
\end{aligned}
$$

Deshpande and Ma, Phys. Rev. D18 (1978)

where

$$
c_1 = \lambda_1 + \lambda_2 + 2\lambda_3,\ c_2 = \lambda_1 + \lambda_2 - 2\lambda_3,
$$
$$
c_3 = \lambda_1 - \lambda_2,\ c_4 = \lambda_4 + \lambda_5,\ c_5 = \lambda_4 - \lambda_5.
$$

Experimental constraints

We need to take into account experimental constraints.

- T parameter : $\lambda_4 = \lambda_5$ or $\lambda_4 = -\lambda_5$.
  Pomarol and Vega, Nucl. Phys. B413 (1994), Gerard and Herquet, Phys. Rev. Lett. 98 (2007)
- Natural alignment : $\lambda_1 = \lambda_2 = \lambda_3 + \lambda_4 + \lambda_5$
  Bhupal and Pilaftsis, J. High Energy Phys. 12 (2014)

"Natural" means the condition of the potential parameters which ensures the alignment limit.

These conditions would be approximate one. However we here use them as inputs, and try to extract essential parameters.

Symmetry of the Higgs potential

Under the previous conditions,

$$
\begin{aligned}
V_1 &= \frac{1}{2}\left(\frac{m_h^2}{v^2} - \eta\right)(|\Phi_1|^2 + |\Phi_2|^2)^2 + \frac{1}{2}\eta(|\Phi_1|^2 - |\Phi_2|^2)^2 \\
&\quad + \frac{1}{2}\eta(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1)^2, \qquad (\lambda_4 = \lambda_5), \\
V_2 &= \frac{m_h^2}{2v^2}(|\Phi_1|^2 + |\Phi_2|^2)^2 + \frac{1}{2}\eta(\Phi_1^\dagger\Phi_2 - \Phi_2^\dagger\Phi_1)^2, \quad (\lambda_4 = -\lambda_5),
\end{aligned}
$$

where $\eta = (m_H^2 - m_A^2)/v^2$.

η is a key variable which determines $O(4)$ or $O(8)$.

Question: Can we measure η ?

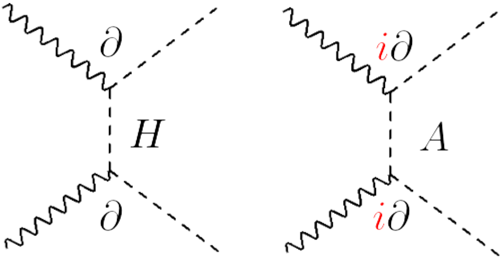
How to observe η ?

Answer: Yes, we can measure it using $W^+W^+ \to H^+H^+$.

The amplitude is

$$\mathcal{M}_{W^+W^+\to H^+H^+} \propto \eta,$$

independent of the W^+ helicity in the alignment limit. This is because diagrams mediated by H and A are destructive.



Cross section of H^+H^+ pair production

We evaluate the cross section of

$$pp \to H^+H^+jj$$

using MadGraph5_aMC@NLO.

- The bigger $\Delta m = m_A - m_H$, the bigger the cross section.
- Because of the PDF, the cross section of H^+H^+ is bigger than H^-H^-.

We assume $m_A > m_H = m_{H^\pm}$, and H^+ dominantly decays into $t\bar{b}$ or $\tau\nu$ following the Z_2 charge.

Aoki, Kanemura, Tsumura, and Yagyu, Phys. Rev. D80 (2009)

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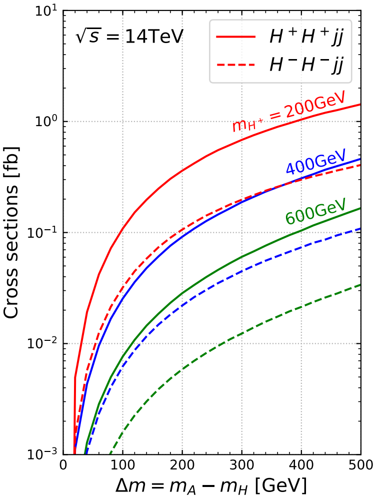

Significance of $H^+ \to t\bar{b}$

The signal

$$H^+H^+jj \to t\bar{b}t\bar{b}jj \to (b\ell^+\nu)\bar{b}(b\ell^+\nu)\bar{b}jj.$$

The background

$$tt\bar{t}\bar{t} \to (b\ell^+\nu)(b\ell^+\nu)(\bar{b}jj)(\bar{b}jj)$$

CMS, Eur. Phys. J. C78, (2018)

The vector boson fusion(VBF) selection

$$\Delta m_{jj} > 500\mathrm{GeV},\ \Delta\eta_{jj} > 2.5\ (4.5)$$

efficiently suppress the BG.

*Significance ($H^+ \to \tau\nu$) in backup.

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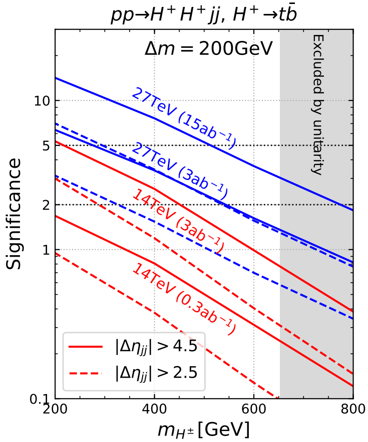
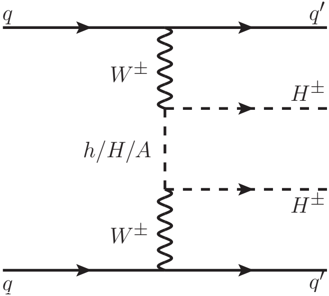


Summary

- We studied H^+H^+ production via W^+ fusion.



- Because $\mathcal{M}_{W^+W^+\to H^+H^+} \propto \eta$, this process is useful to study the global symmetry of the Higgs potential.
- This process can be feasible in the future colliders.

Backup

Significance $H^+ \to \tau\nu$

The signal

$$H^+H^+jj \to \tau^+\nu\tau^+\nu jj$$

The background

$$W^+W^+jj \to \tau^+\nu\tau^+\nu jj$$

CMS, Phys. Rev. Lett. 120, (2018)

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