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Use of the Kappa Formulation to Achieve a 2HDM Model Independent Scanner

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Project Aims: To investigate the possibility of using kappa formulation to identify, model-type independently, regions with maximal variation between SM σ and 2HDM σ

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Background

Table: 1: SM Higgs sector vs 2HDM Higgs sector

SM	One complex doublet $\langle \Phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \nu \end{pmatrix}$	One VEV	One Higgs boson, h
2HDM	Two complex doublets $\langle \Phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \nu_1 \end{pmatrix}$, $\langle \Phi_1 \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ \nu_2 \end{pmatrix}$	Two VEVs	Five Higgs bosons, h, H, A, H+, H-

Table: 2: Higgs properties

Higgs	CP State	EW Charge	Particle type
h	Even	0	Scalar
H	Even	0	Scalar
A	Odd	0	Scalar
$H^{\pm}$	Undefined	± 1	Mixed Scalar/Pseudo

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Background

Table: 3: Higgs doublet couplings to fermions

Type	UR	DR	LR
Type I	Φ_2	Φ_2	Φ_2
Type II	Φ_2	Φ_1	Φ_1
Type III	Φ_2, Φ_1	Φ_1, Φ_2	Φ_2, Φ_1
Type IV	Φ_2, Φ_1	Φ_2, Φ_1	Φ_1, Φ_2

There are then four types of 2HDM, each couple to the SM fermions differently, as shown in table 3.

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What are the κs?

The κs are a re-scaling of the SM couplings.
Two important variables for the κs expressions:
the mixing angle α and β which are defined by the following:

$$cos\alpha = \sqrt{\frac{\mathcal{M}_{11}{}^2 - M_h{}^2}{M_H{}^2 - M_h{}^2}} \qquad tan\beta = \frac{\nu_2}{\nu_1} \tag{1}$$

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κ Expressions

Each 2HDM type has a different expression due to the differing couplings, as proof of concept we focus on type-II and use the definition for the κs (that are relevant to us) from The Higgs Hunter's Guide [1] which are:

$$
\begin{aligned}
\kappa_{Ht} &= Ht\bar{t} : \frac{sin(\alpha)}{sin(\beta)} & \kappa_{Hb} &= Hb\bar{b} : \frac{cos(\alpha)}{cos(\beta)} \\
\kappa_{ht} &= ht\bar{t} : \frac{cos(\alpha)}{sin(\beta)} & \kappa_{hb} &= hb\bar{b} : \frac{-sin(\alpha)}{cos(\beta)} \\
\kappa_{At} &= At\bar{t} : cot(\beta) & \kappa_{Ab} &= Ab\bar{b} : tan(\beta) \\
\kappa_{H^{\pm}tb} &= \frac{g}{2\sqrt{2}m_W}[m_t cot\beta(1+\gamma_5) + m_b tan\beta(1-\gamma_5)]
\end{aligned}
\tag{2}
$$

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$pp \to th_i j$

Why is this process interesting?

	a & b interference	c	d	σ
SM	Deconstructive interference	Strongly suppressed	Non-existant	Low
2HDM	Potential constructive interference	Potentially increased	Will add to total SIGMA	Potentially significantly higher

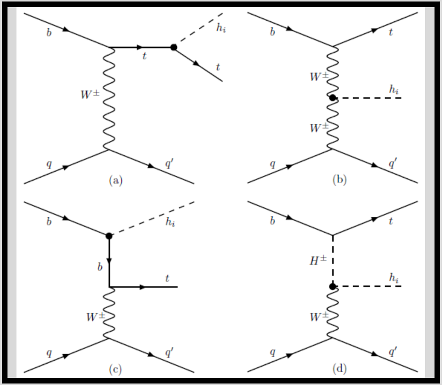

Fig. 1 Tree level Feynman diagrams for $bq \to th_i j$

Figure 1

σ calculations from $sin(\beta - \alpha), tan\beta$

- MadGraph [2] was used with a 2HDM type-II model to calculate the cross-section for the process $bq \to th_ij$, w.r.t $sin(\beta - \alpha)$ and $tan(\beta)$.
- Magellan, (incorporates both Higgsbounds and Higgsignals as well as 2HDMC), to be used to apply experimental constraints.

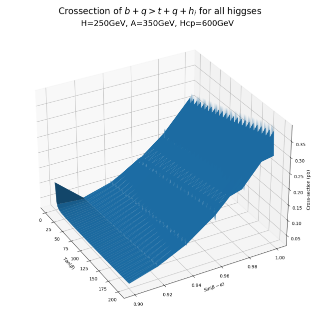

Fig. 1
Cross-section, σ for process $bq \to th_ij$, w.r.t $sin(\beta - \alpha)$ and $tan(\beta)$

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Figure 2

κ_{bb} & κ_{tt} calculations from $sin(\beta - \alpha), tan\beta$

- κs were calculated from the values of $\sin(\alpha - \beta)$, $\tan(\beta)$ and σ
- plan to use Feynrules to create κ input model

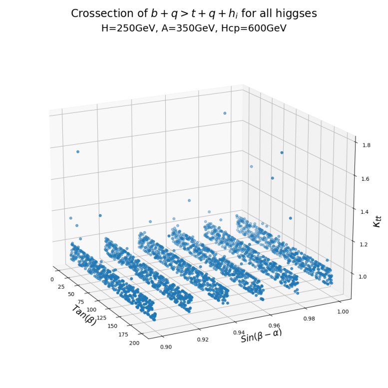

Fig. 2

Cross-section, σ for process $bq \to th_i j$, w.r.t κ_{bb} and κ_{tt}

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Figure 3

σ plotted against κ_{tt}, κ_{bb}

- We plotted the cross-section against the κs to see their relation
- With planned κ input model a plot like this would relate to all model types

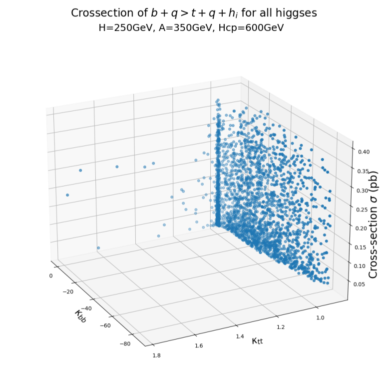

Fig. 3
Cross-section, σ for process $bq \rightarrow th_i j$, w.r.t κ_{bb} and κ_{tt}

Summary & outlook

- Investigating relationship between κ values and σ via $tan(\beta)$ and $sin(\beta - \alpha)$
- Begun creating a toolbox for automating the running of MadGraph via the κs directly.
- Plan to explore the parameter space and identify regions via κs with highest $\sigma \Rightarrow$ corresponds to different α & β in each type of 2HDM $\Rightarrow$ can search in a 'model-independent' fashion.
- $bg \rightarrow tW^- h_i$
- $q\bar{q}' \rightarrow t\bar{b}h_i$

Thank-you for your attention

Bibliography

TEX, LATEX, and Beamer

[1] J.F. Gunion, H.E. Haber, G. Kane and S. Dawson *The Higgs Hunter's Guide*. Perseus Books, 1990. ISBN: 0-7382-0305-X

[2] J. Alwall et al. *The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations*. arXiv:1804.10017 [hep-ph].