



Reweighting prescription for bb4l

Diptaparna Biswas

Bundesministerium für Bildung und Forschung Beyond Flavour Physics Universität Siegen 24th June 2025



Context: Top Yukawa coupling measurement

- Key idea:
 - Higgs boson can appear as virtual propagator between top-pair.
- Analysis channel: $t\bar{t} \to bW^+(\to \ell^+ \nu) \ \bar{b}W^-(\to \ell^- \bar{\nu})$
 - > Currently we use the $e\mu$ channel only.
- Strategy:
 - > The shape of M_{tf} distribution depends on Y_{t} .
 - Use template morphing.
- Observable:
 - > $M_{bb\ell\ell}$ can be used as a proxy.
 - > $M_{t\bar{t}}$ (truth) can be reconstructed using regression.





Methodology: Template morphing

- Parameter of interest: y_t
- Identify a sensitive observable: $m_{t\bar{t}}$
- *Generate* several distributions of this observable for different POI values:
 - > Either from distinct sets of MC events.
 - > Or by reweighting the same set of events.
- *Obtain* the distribution of the same observable from *data*.
- Fit $S(y_t) + B \sim Data$ to get the best-fit value of y_t , along with its error.



The (existing) situation with POWHEG hvq

- Separate MC samples for tW(+jets) and $t\overline{t}$ processes.
 - Overlap is removed using Diagram Removal (DR) scheme, for the nominal sample.
 - An alternate *tW* sample with Diagram Subtraction (DS) is used as systematic variation.



- While producing the y_{t} -varied signal templates:
 - > Only the ttbar events are subjected to additional y_t weights.
 - > No such additional weight is applied to tW events.



Figure 1. Sample Feynman graphs corresponding to the two resonance histories relevant for $pp \rightarrow \mu^+\nu_\mu e^-\bar{\nu}_e\, b\,\bar{b}$ production.



Figure 2. Representative Born diagram for Wt production.

An NLO+PS generator for tt and Wt production and decay including non-resonant and interference effects

Moving to POWHEG bb4l

- The *tW* DR vs. DS systematics is one of the leading uncertainties.
 - > This is currently constrained for the M_{bbll} observable.
- This can be potentially removed through a proper treatment of the interfering diagrams between $t\bar{t}$ and tW.
- Plan: Replace $t\overline{t} + tW$ with $bb4\ell$.
- But how to apply the y_t weights from HATHOR?
 - > Need a way to *identify* the $t\bar{t}$ events in the *bb4l* sample.
 - Recommended approach: Use resonance history projections.

Resonance history projections



Alternate projection scheme:

$$|\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^{2} \longrightarrow |\mathcal{M}_{WWbb}^{\mathrm{LO}}|^{2} - |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^{2} - |\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^{2}$$



An event is labelled as a $t\overline{t}$ event, if the numerical value of $|\mathcal{M}_{t\overline{t}}^{\text{LO}}|^2$ is the largest.

Consequence:

$\begin{split} \mathcal{M}_{t\overline{t}}^{\mathrm{LO}} ^2 \\ \mathcal{M}_{tW\overline{b}}^{\mathrm{LO}} ^2 \\ \mathcal{M}_{\overline{t}Wb}^{\mathrm{LO}} ^2 \end{split}$	= 0.8 = 0.1 = 0.1	
$egin{aligned} \mathcal{M}_{t\overline{t}}^{\mathrm{LO}} ^2 \ \mathcal{M}_{tW\overline{b}}^{\mathrm{LO}} ^2 \ \mathcal{M}_{tW\overline{b}}^{\mathrm{LO}} ^2 \end{aligned}$	= 0.4 = 0.3 = 0.3	



The situation with bb4l

- The *goal* of *bb4l* is to simulate the *pp* → *WbWb* process by properly considering the interferences among all possible Feynman diagrams.
- This already *implies* that a given event cannot be classified into ttbar or tW.
 i.e. to conclude that the event is a *result* of the diagrams from the corresponding process.
- However, in order to apply the y_t weights, we need to *identify* the ttbar events.
 - > Which is an unreasonable demand, in the first place!
- Of course, the best possible way would have been to include the virtual Higgs exchange in *bb4l*, making y_t a tunable parameter.

9 00000

- Not feasible at this moment.
- > We need to stick with HATHOR reweighting.

Coming up with a reweighting prescription

- Since the problem is ill-defined, any solution is going to be only approximate.
- So, we need the followings:
 - 1. A way to quantify the correctness of a given projection scheme.
 - Consequently, include it as a systematic uncertainty in the fit.
 - 2. Decide the best-possible projection scheme.
 - Based on the above criteria.
- As a side-note:

 $|\mathcal{M}_{\underline{t}W\overline{b}}^{\mathrm{LO}}|^2 \sim \mathsf{DS}$

 $|\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^2$

$$\begin{split} &|\mathcal{M}_{WWbb}^{\mathrm{LO}}|^2 - |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^2 - |\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^2 \\ &|\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^2 \\ &|\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^2 \end{split} \sim \mathsf{DR}$$



POWHEG hvq vs POWHEG *bb4l* (with projection)

Normalized entries

 $|\mathcal{M}_{t\overline{t}}^{\mathrm{LO}}|^2$

Possible reweighting prescriptions

• Identify $t\bar{t}$ events based on the highest among:

 $\begin{cases} |\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^{2} \\ |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^{2} \\ |\mathcal{M}_{tWb}^{\mathrm{LO}}|^{2} \end{cases} \text{ or } \begin{cases} |\mathcal{M}_{WWbb}^{\mathrm{LO}}|^{2} - |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^{2} - |\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^{2} \\ |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^{2} \\ |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^{2} \end{cases} \end{cases}$

$$\Rightarrow w_{extra} = w_{yt}, \text{ for } t\overline{t} \text{ events}$$
$$= 1, \text{ for others}$$

- Define $p_{t\bar{t}} = \frac{|\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^2}{|\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^2 + |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^2 + |\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^2} \Rightarrow w_{extra} = 1 * (1 p_{t\bar{t}}) + w_{yt} * p_{t\bar{t}}$
- Same as above, but with $|\mathcal{M}_{t\bar{t}}^{\mathrm{LO}}|^2 \longrightarrow |\mathcal{M}_{WWbb}^{\mathrm{LO}}|^2 |\mathcal{M}_{tW\bar{b}}^{\mathrm{LO}}|^2 |\mathcal{M}_{\bar{t}Wb}^{\mathrm{LO}}|^2$

Time for discussion

- We need the followings:
 - 1. A way to quantify the correctness of a given projection scheme.
 - Consequently, include it as a systematic uncertainty in the fit.
 - 2. Decide the best-possible projection scheme.
 - Based on the above criteria.

Thoughts?



sum(truth.ME_top_status!=22), sum(truth.ME_tbar_status!=22), sum((truth.ME_top_status==22)&(truth.ME_tbar_status==22))
(3296, 3088, 93616)