CP-Violation in the Top-Higgs Interaction at Future Muon Colliders

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SM + CPV

The Standard Model is a largely successful theory describing fundamental particles and their interactions but doesn't explain phemonena such as :

1. dark matter,
2. matter-antimatter asymmetry,
3. neutrino mass, or
4. gravity.

The project propose a search for finding a new physics by studying a CP-Violating top Yukawa coupling The tth Lagrangian interaction term can be modeled by:

$$\mathcal{L}_{htt} = -g_{htt} h\bar{t}(\cos\alpha + i\gamma_5 \sin\alpha)t$$

parameterized with CP-violating phase, α. In the weak interaction, the combined CP-symmery is not conserved. Since, in the SM, α = 0, we use non-zero α-values for signal processes, to look for a new source of CP-violation. According to the ATLAS Collaboration, |α| > 43° is excluded at 95% confident level [1]. Our study focuses on the **α = 3π/16** case and we show the results at **√s = 10 TeV**.

Cross-Section

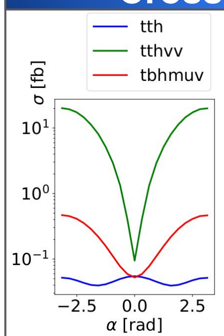

Fig.1 Cross-section varying with CP-phase for signal processes (not decayed) at √s = 10 TeV. At large CP-angles, the cross-section of $tth\nu\nu$ and $tbh\mu\nu$ signals increase significantly.

Kinematic Distributions

We study different kinematic distributions to characterize the signal and background. Of interest is the study of the invariant mass of the higgs boson's decay products. We show the invariant mass of the reconstructed higgs from two bottom jets.

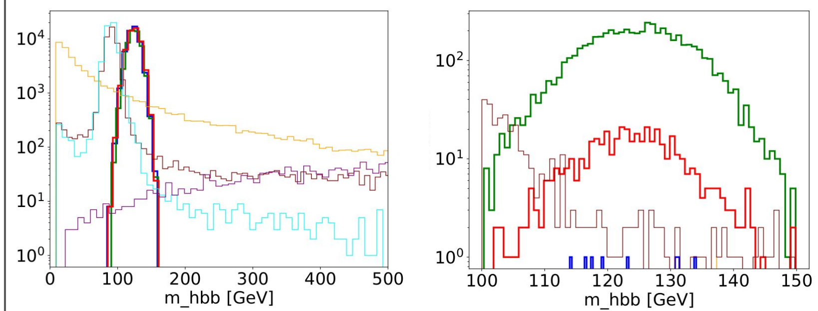

Fig.3 Invariant mass distributions. The left figure is before cuts including detector effects, and the right distribution is after acceptance cuts.

2σ Exclusion

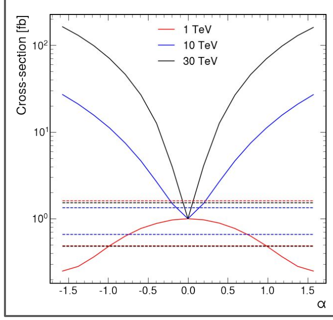

Fig.4 Distribution showing the total signal cross-section varying with α at 1 TeV, 10 TeV, and 30 TeV. The dashed lines correspond to 2σ exclusion (95% CL) bands on α and represent how much α can vary to still be consistent with Standard Model like data. The bands are limited (with statistical uncertainty only) within |α| < 55°, |α| < 9°, and |α| < 3°, for 1 TeV, 10 TeV, and 30 TeV respectfully.

Cutflow & Significance

Cut	tth [fb]	tthvv [fb]	tbhmv [fb]	Bkgrd [fb]	S	B	Sig.
generation cuts	6.95E-03	0.184	6.60E-02	1.46E+00	2.57E+03	1.46E+04	19.6
eta + dR	2.22E-06	0.037867	4.09E-04	3.02E-02	3.83E+02	3.02E+02	14.6
eta + dR + m(bb)	2.22E-06	0.037716	4.08E-04	2.55E-03	3.81E+02	2.55E+01	18.9

Table 1 Cross-sections for signal and background before and after cuts, using a luminosity of 10,000 (fb^{-1}) and significance calculated by S/√S+B.

Muon Collider

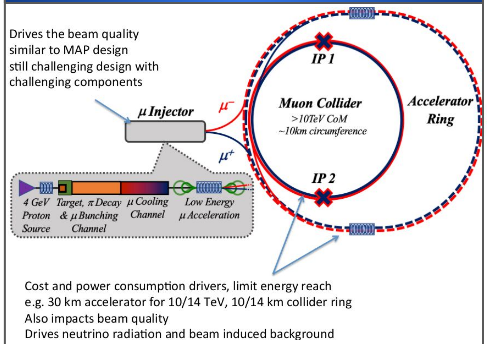

Fig.2 Design of muon collider [2].

The advantages of a muon collider are that it can have **clean collision environments**, reach **high energy**, and have **less energy loss**. Disadvantages include muons' short lifetime and that muons are hard to collimate.
To better simulate the detector environment and improve the signal's significance, we apply

1. **Jet smearing**,
2. **eta (< 2.5 rad)**,
3. **ΔR (> 0.4 rad)**
4. **invariant mass (100 GeV ~ 150 GeV).**

Because the muon collider is a proposed new type of collider, we use **MadGraph5_aMC@NLO** [3], a Monte Carlo simulation framework, to generate and analyze events.

References

[1]. CP Properties of Higgs Boson Interactions with Top Quarks in the $t\bar{t}H$ and tH Processes Using H→γγ with the ATLAS Detector, ATLAS (2020)
[2]. Muon Collider KEK-PH lectures and workshops, D. Schulte (2021 Jun.) https://indico.cern.ch/event/1056654/attachments/2276509/3867446/Japan.pdf
[3]. MadGraph 5: Going Beyond, J. Alwal et al (2011)