Exploring CP Violation in the Higgs Sector Through Higgs Boson Production in Association of Three Jets

Dr. Terrance Figy

Associate Professor

Department of Mathematics, Statistics, and Physics

Wichita State University

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WICHITA STATE UNIVERSITY

References and Collaborators

- Higgs boson CP-properties of the gluonic contributions in Higgs plus three jet production via gluon fusion at the LHC
- CP-violating Higgs boson production in association with three jets via gluon fusion
- Azimuthal angle correlations for Higgs boson plus multi-jet events
- Collaborators: Francisco Campanario and Michael Kubocz

Model Setup

$$\mathcal{L}_{\text{Yukawa}} = \overline{q}\,(Y_q + \mathrm{i}\gamma_5 \tilde{Y}_q)\,q\,\Phi\,. \quad Y_q = y_q \cos\alpha \;\text{ and }\; \tilde{Y}_q = \tilde{y}_q \sin\alpha.$$

$$\mathcal{L}_{\text{eff}} = \left(Y_t \cdot \frac{\alpha_s}{12\pi m_t}\, G^a_{\mu\nu}\, G^{a\,\mu\nu} + \tilde{Y}_t \cdot \frac{\alpha_s}{8\pi m_t}\, G^a_{\mu\nu}\, \tilde{G}^{a\,\mu\nu} \right) \Phi\,. \qquad \tilde{G}^{a\,\mu\nu} = 1/2\, G^a_{\rho\sigma}\, \varepsilon^{\mu\nu\rho\sigma}$$

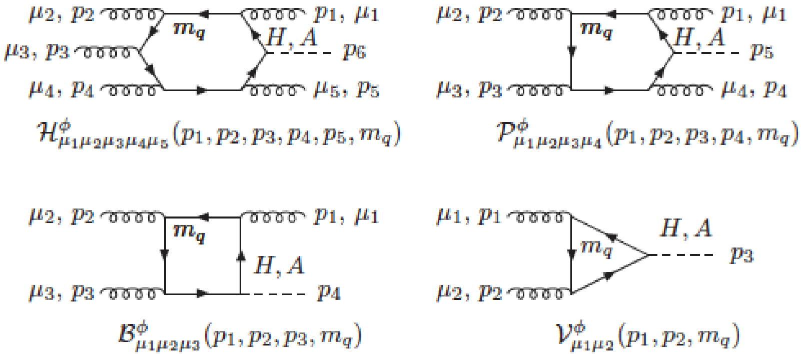
- Pure CP-odd: $\tan(\beta) = \pi/2$
- CP-violating: $\tan(\beta) = 2/3$
- Pure CP-even: $\tan(\beta) = 0$

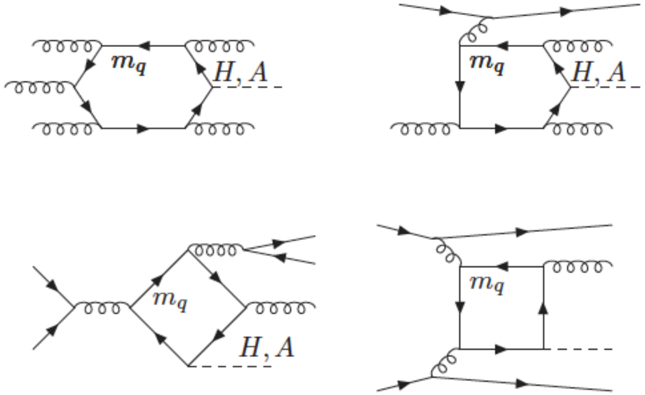
Type-II Two Higgs Double Model

$$\tilde{y}_u^{\text{II}} = -\frac{\cot\beta}{v} m_u \quad \text{and} \quad \tilde{y}_d^{\text{II}} = -\frac{\tan\beta}{v} m_d\,,$$

Feynman Diagrams (Yes, we still use them.)

$$q\,\bar{q} \to q\,\bar{q}\,g\,\Phi, \quad Q\,\bar{q} \to Q\,\bar{q}\,g\,\Phi,$$
$$q\,g \to q\,g\,g\,\Phi, \quad g\,g \to g\,g\,g\,\Phi.$$





The gluonic contributions were computed by Campanario and Kubocz. ***New: quark gluon, quark quark channels.***

Input Parameters and Selection Cuts

VBNLO 3.0
MMHT2014nlo68lo parton distributions functions
Kt-jet with p=-1

Collider Energies: 13 TeV
27 TeV

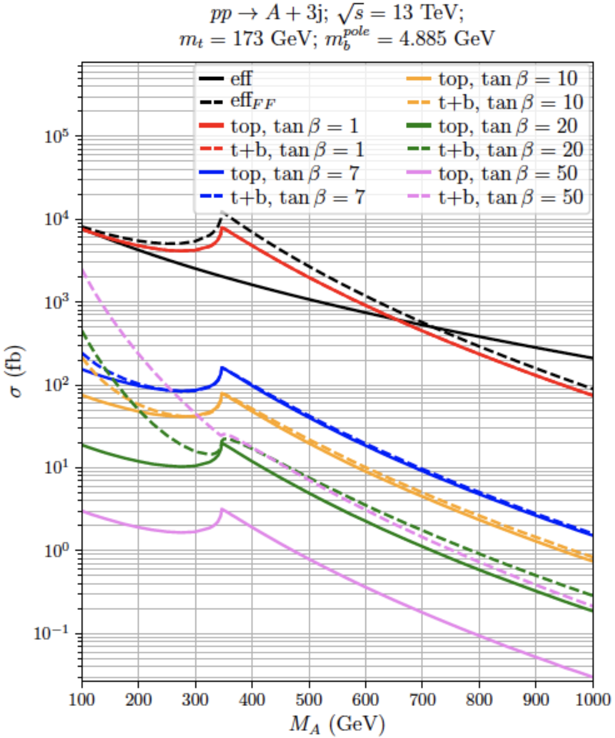
$$\mu_F = \mu_R = \frac{1}{4}\left(\sum_{jets} p_T^{(i)} + E_{T,\text{higgs}}\right)$$

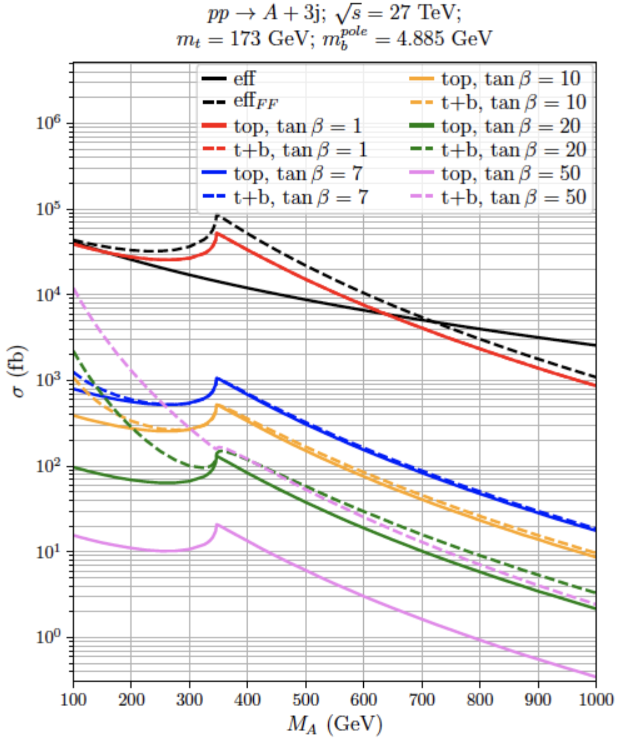
$$p_T^{j_i} > 30 \text{ GeV}\,, \qquad |y_j| < 4.4\,, \qquad R_{jj} > 0.4\,,$$

$$R_{jj} = \sqrt{\Delta y_{jj}^2 + \phi_{jj}^2}\,,$$

$$\Delta y_{jj} = |y_{j1} - y_{j2}| \text{ and } \phi_{jj} = \phi_{j1} - \phi_{j2}.$$

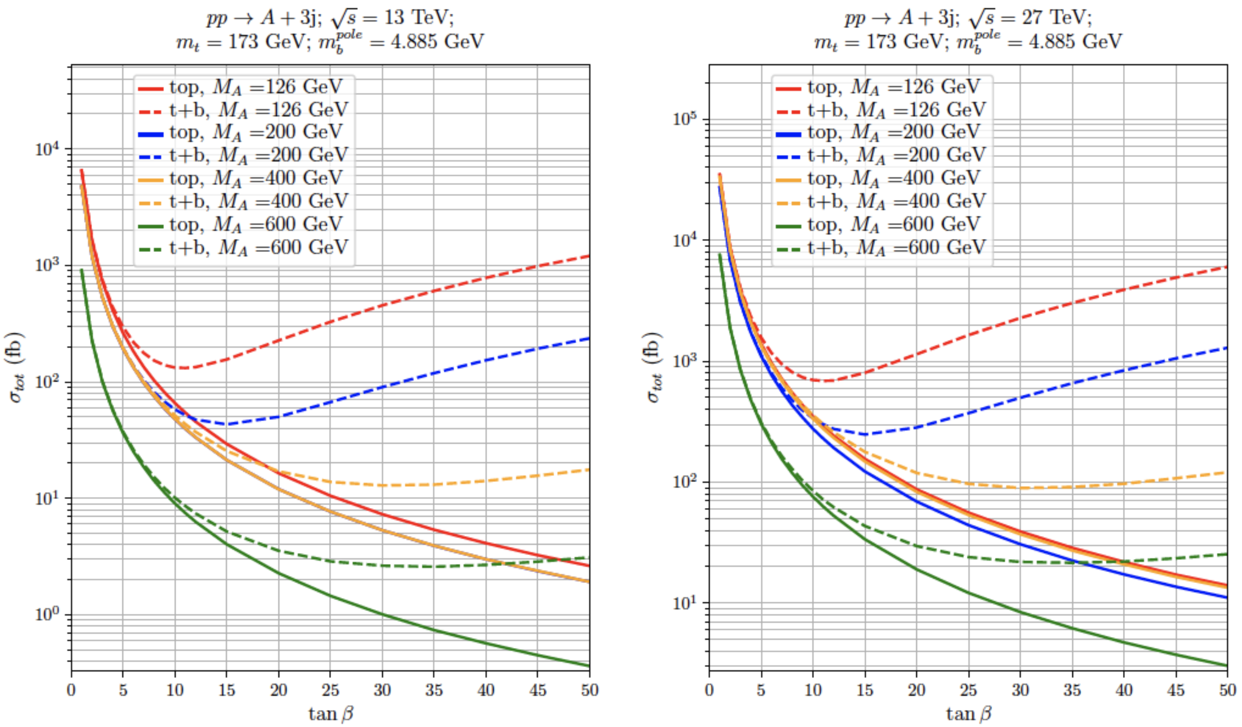
Parametric Dependence (Pure CP-odd)





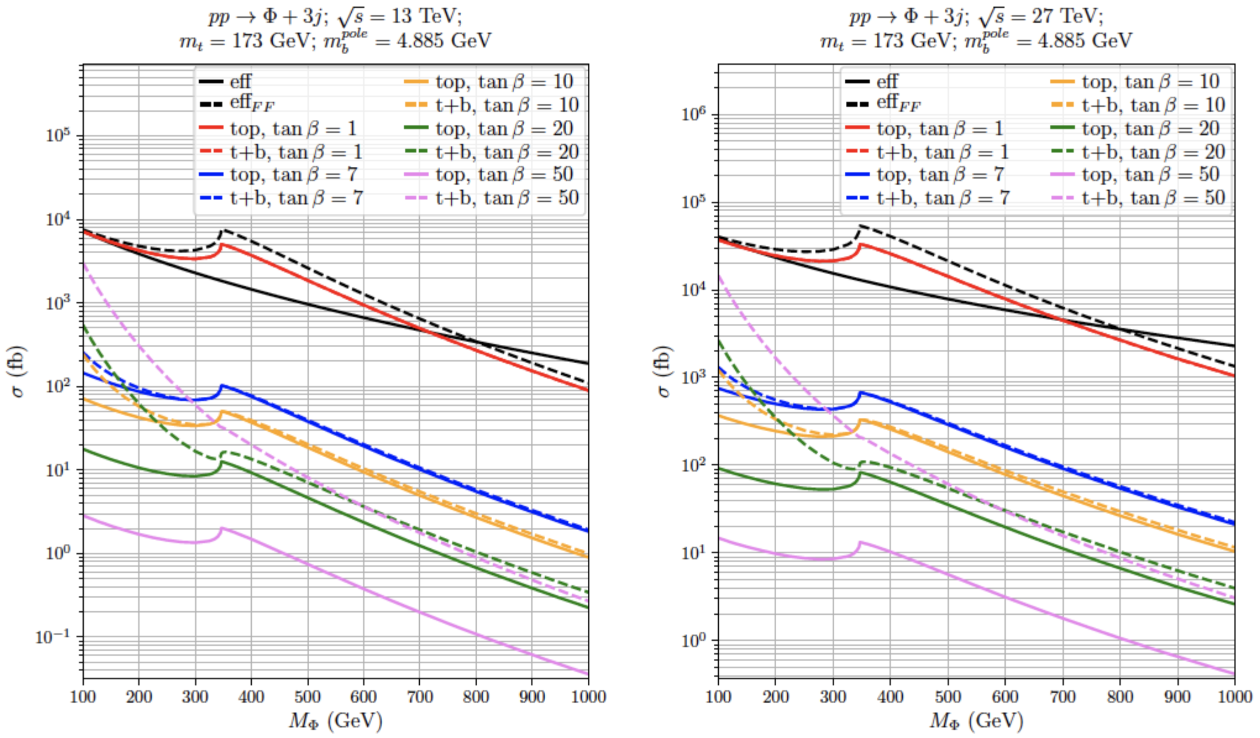
Total Cross-sections vs. M_A

Parametric Dependence (Pure CP-odd)



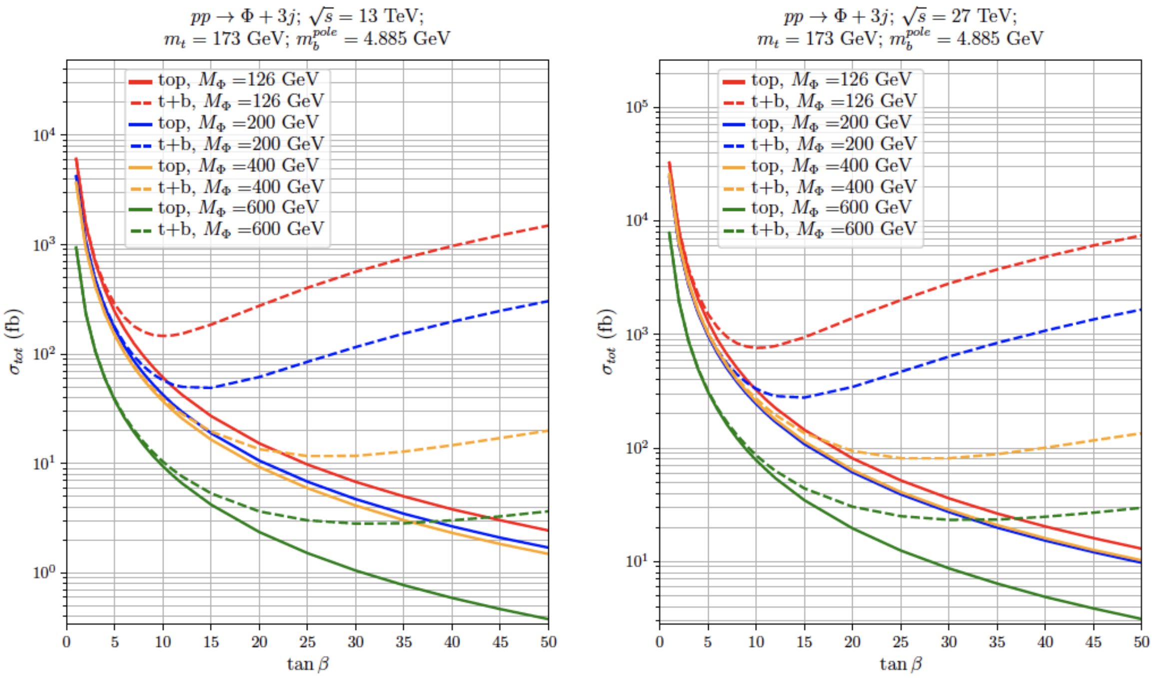
Total cross-sections vs. $\tan(\beta)$

Parametric Dependence (CP-violating)



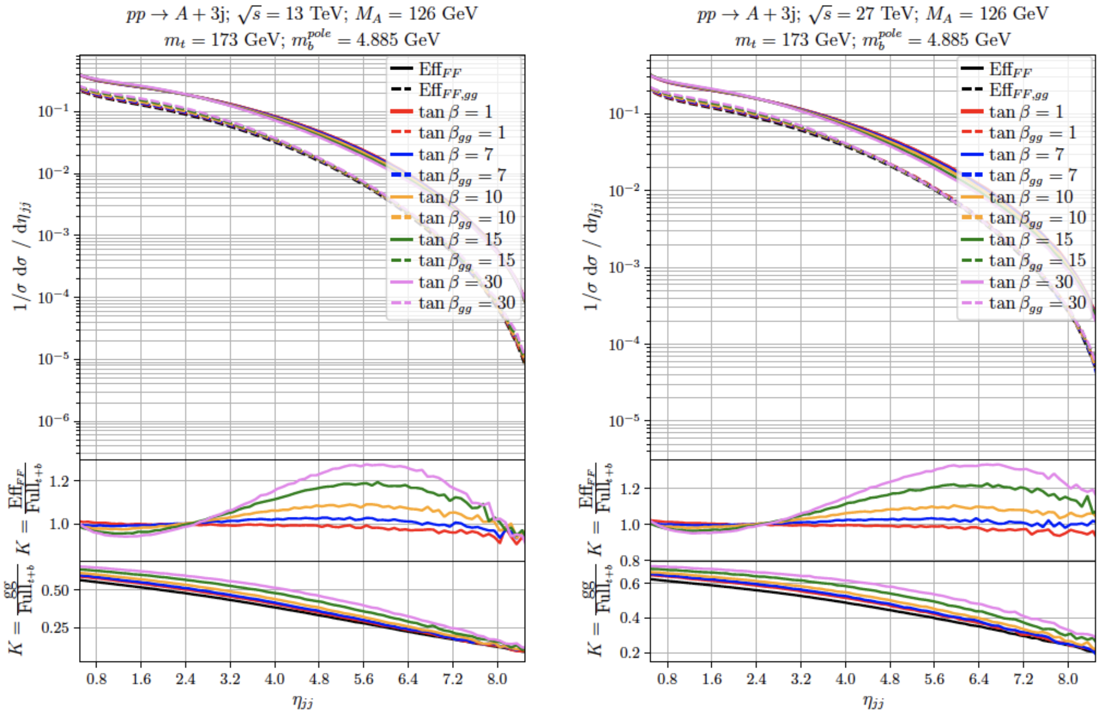
Total cross-sections vs. M_Φ

Parametric Dependence (CP-violating)



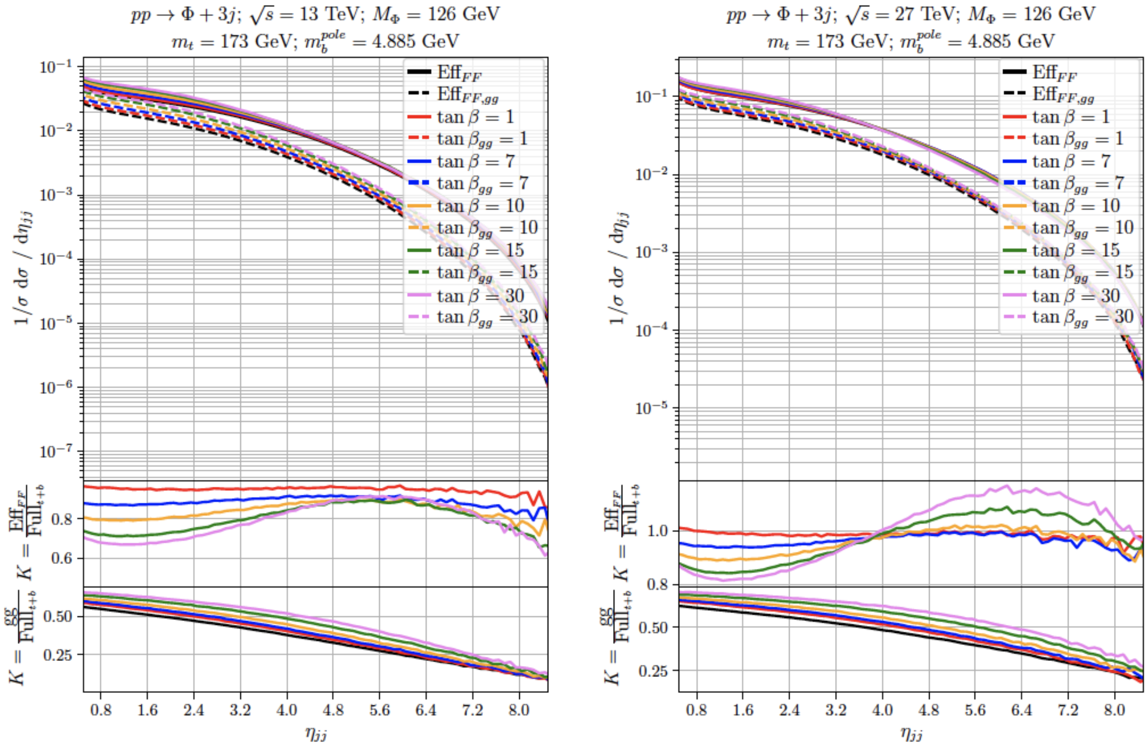
Total cross-sections vs. $\tan(\beta)$

Rapidity Separation (Pure CP-odd)



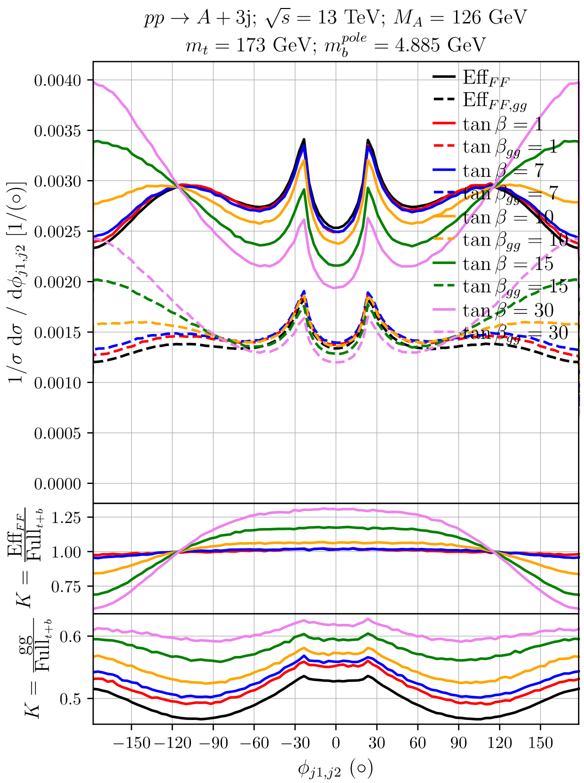
Rapidity separation of leading two jets

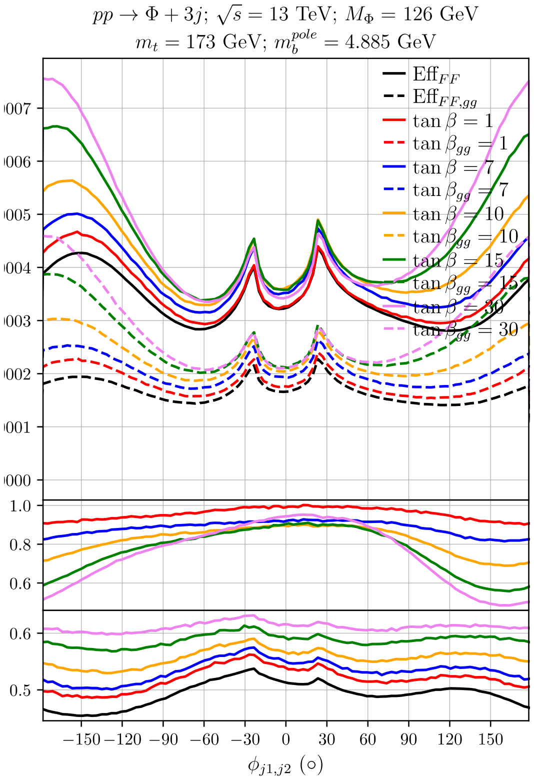
Rapidity Separation (CP-violating)



Rapidity separation of leading two jets

Azimuthal Angle Correlations: $\phi_{jj} = \phi_f - \phi_b$





The sharp peak is due to the jet radius. The extra radiation decorrelates the two hard jets. However, this can be fixed.

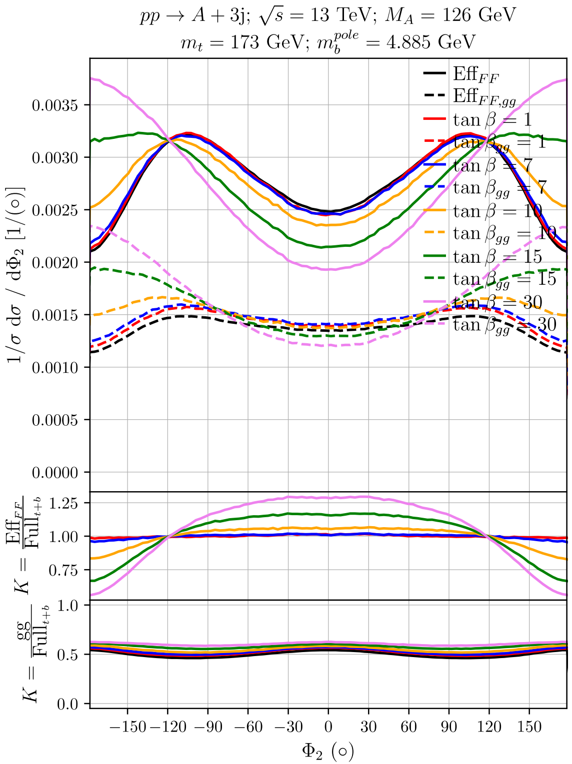
Azimuthal Angle Correlations

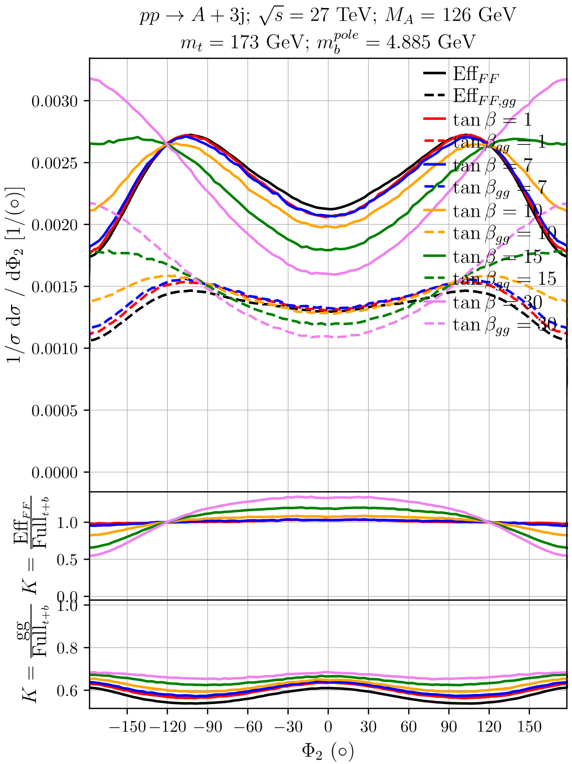
https://doi.org/10.1007/JHEP06(2010)091 [Arnold, Andersen, and Zeppenfeld]

$$q_a = \sum_{j \in \{\text{jets}: y_j < y_h\}} p_j , \qquad q_b = \sum_{j \in \{\text{jets}: y_j > y_h\}} p_j ,$$

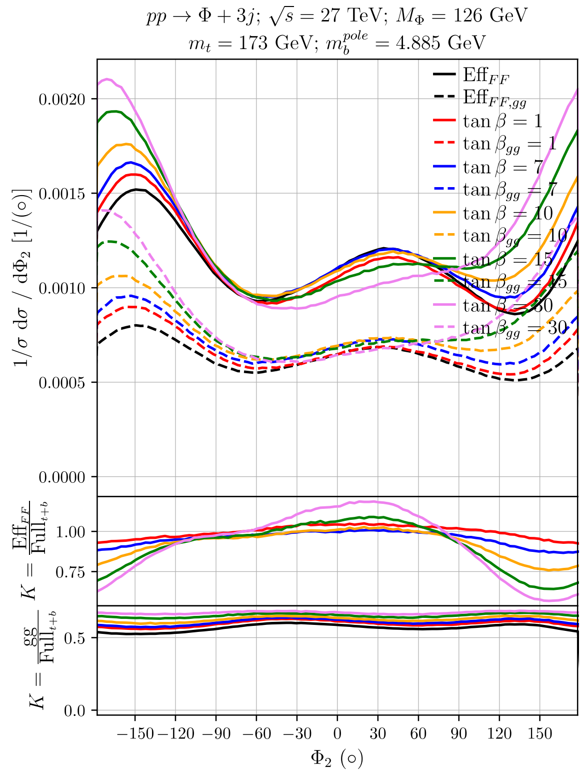
$$\phi_2 = \angle(\mathbf{q}_{a\perp}, \mathbf{q}_{b\perp})$$

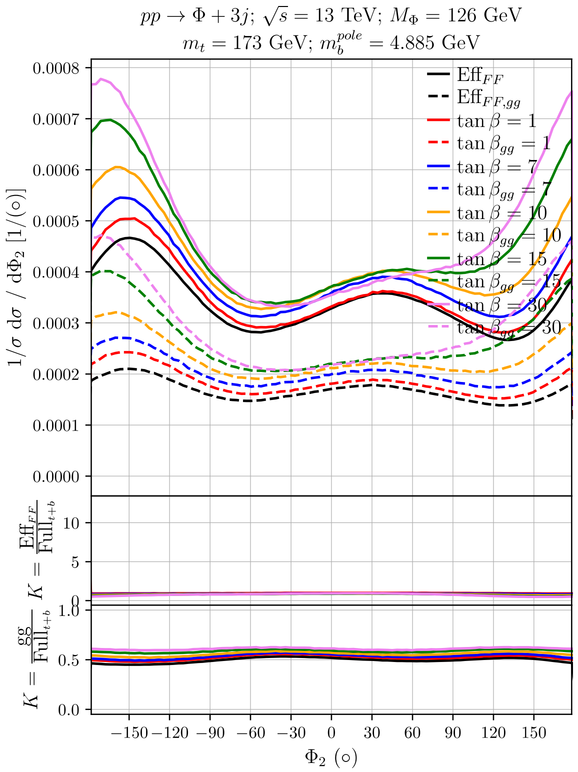
Azimuthal Angle Correlations (Pure CP-odd)





Azimuthal Angle Correlations (CP-violating)



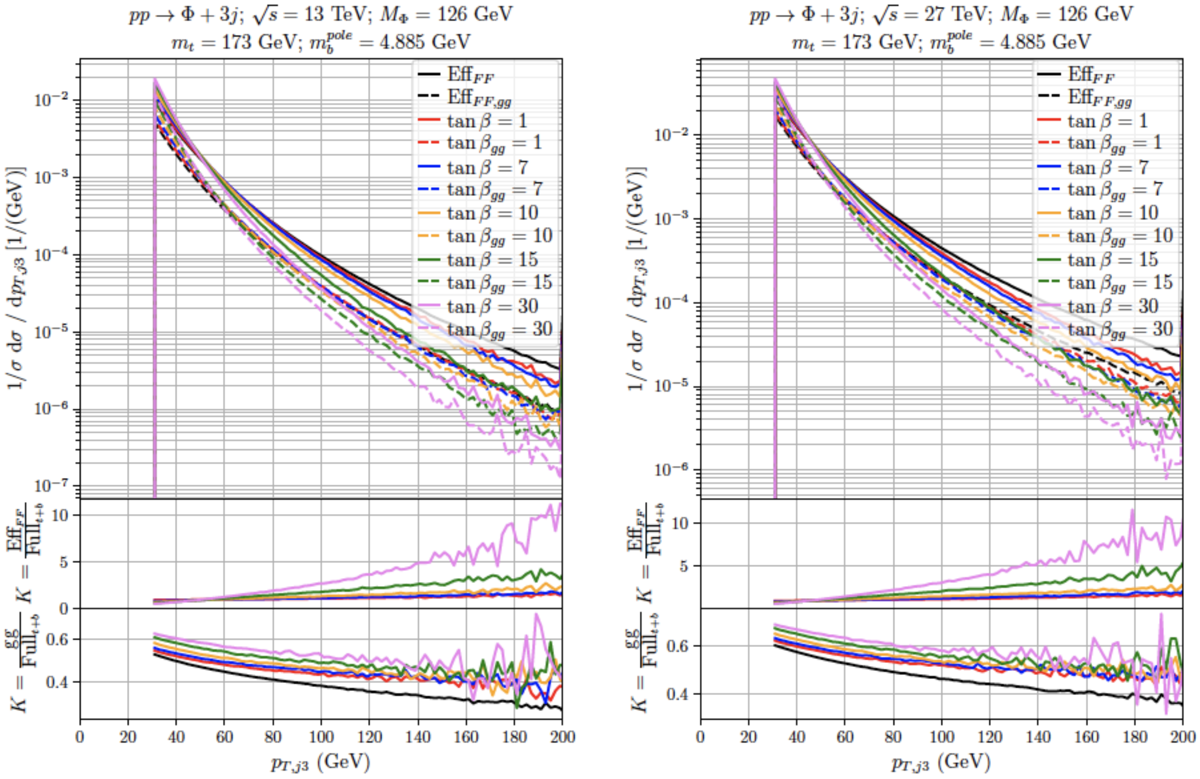


Concluding Remarks

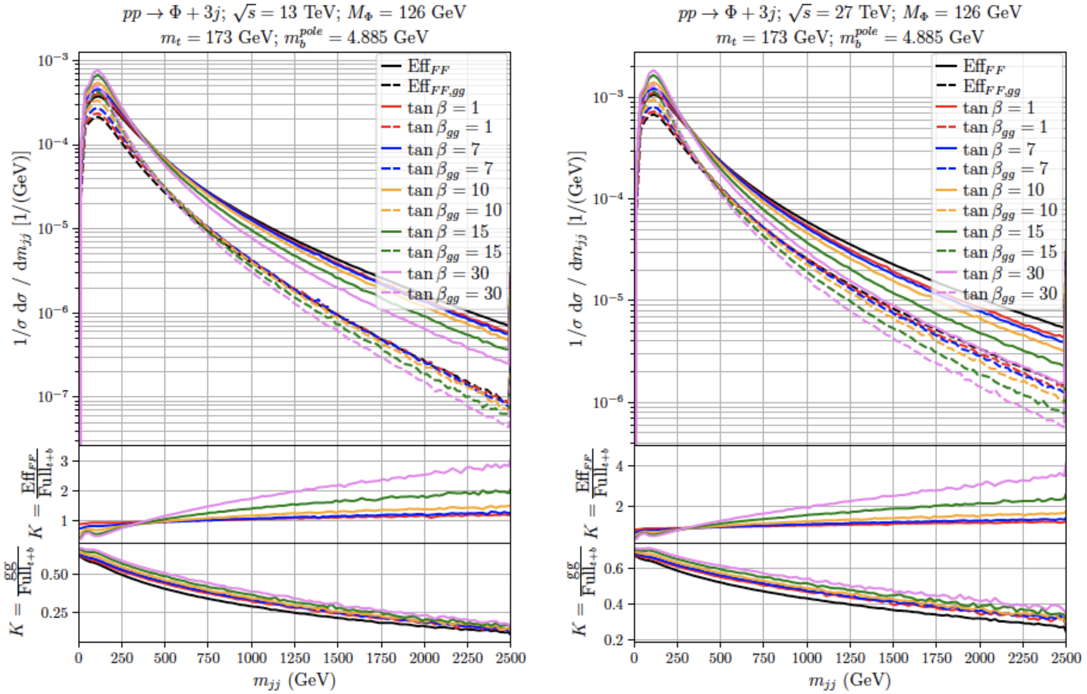
- We have implemented the remaining subprocesses into VBFNLO for Higgs boson production in association of three jets.
- We can generate prediction the include finite top and bottom mass effects (i.e. full loops) and we can operate in the Higgs effective theory (heavy top limit).
- We can simulate pure CP-odd, -even, -violating with finite top and bottom mases running in loops for Higgs boson production in association of three jet.

Auxiliary Slides

Transverse Momentum of Third Jet (CP-violating)

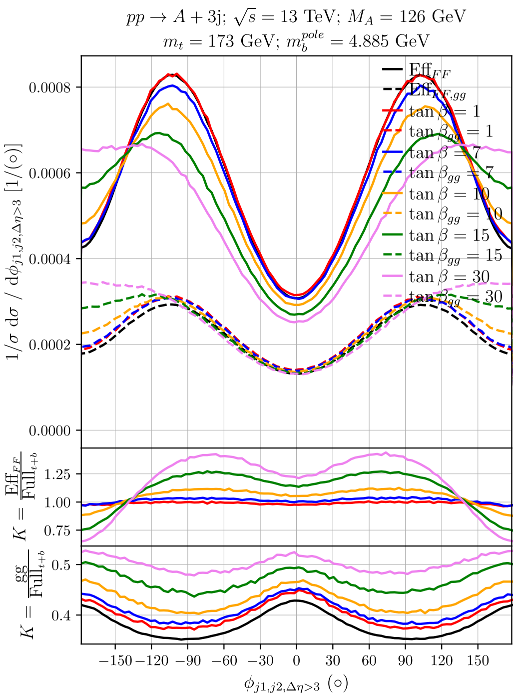


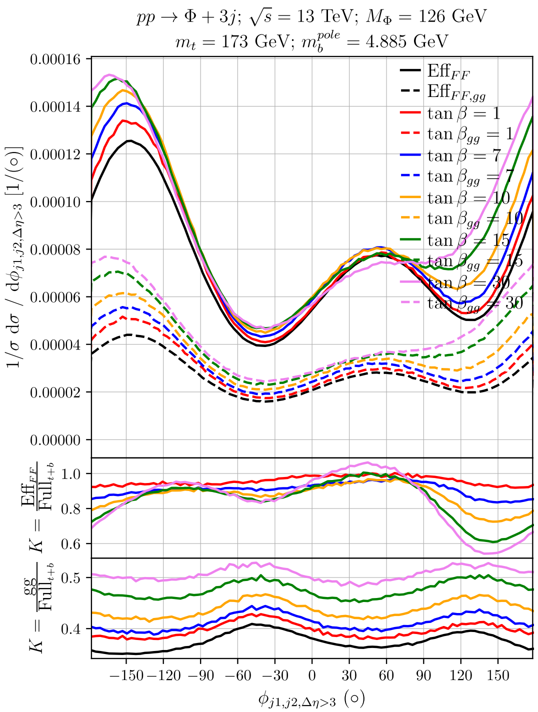
Invariant Mass of Leading Two Jets (CP-violating)



Invariant mass of leading two jets

Azimuthal Angle Correlations (Rapidity Gap)





$\Delta\eta_{j1j2} > 3$

The rapidity gap essentially promotes t-channel exchange graphs.