Update of H-b CP studies

Yingying Li, Mingyi Liu, Yan Luo, Keping Xie, Hongtao Yang, Yangfan Zhang

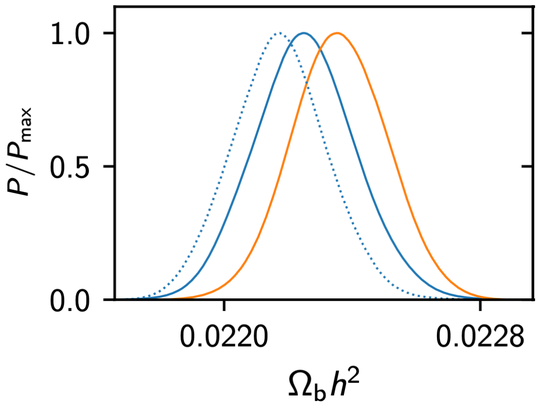
2026.10.30

Outline

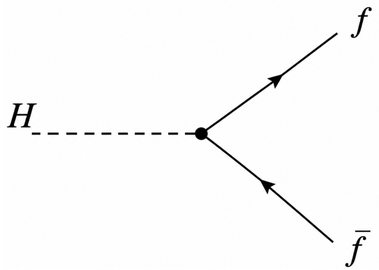
- Introduction
- Preliminary studies on decay-only $H \to bbg$
- Preliminary studies on $pp \to ZH, H \to bbg$
- Summary and next steps

Introduction

- The Planck satellite measurement reports a baryon asymmetry of $\eta_B = (n_B - n_{\bar{B}})/n_\gamma \sim 10^{-10}$, larger than what SM can provide
  - Need extra CP-violation sources!
- Higgs boson and its coupling with other SM particles are the most recently discovered fundamental interactions
- Higgs-fermion coupling allows a more natural term for CP-odd effect at tree-level



$$\mathcal{L} = -\frac{m_f}{v}\{\overline{\psi_f}\kappa_f[\cos(\alpha) + \mathrm{i}\sin(\alpha)\gamma_5]\psi_f\}H$$



- Direct constraint on Higgs-top CP structure is probed via ttH and tH production for nearly a decade
- But there's no direct constraint on Higgs-bottom CP structure on LHC
- This project is to perform a phenomenology study to understand the sensitivity of probing H-b CP structure on LHC via $H \to bbg$ decay channel

Decay-only $H \to bbg$ studies

QCD production

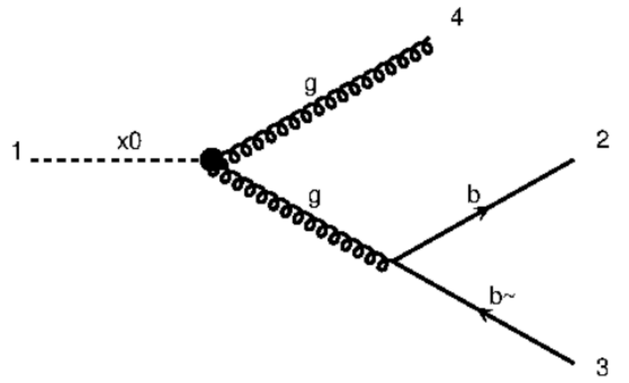


diagram 1 QCD=1, QED=0, QNP=1

H-b coupling dependent productions

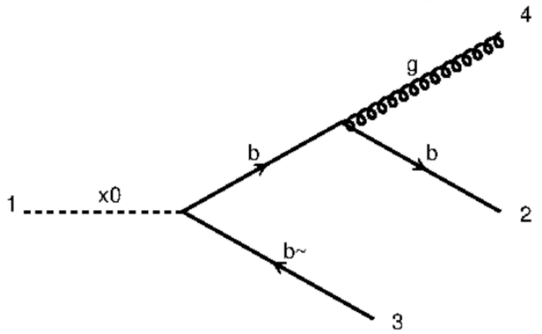


diagram 2 QCD=1, QED=1, QNP=0

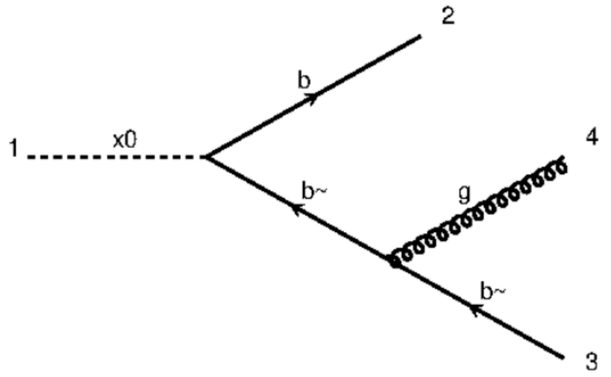
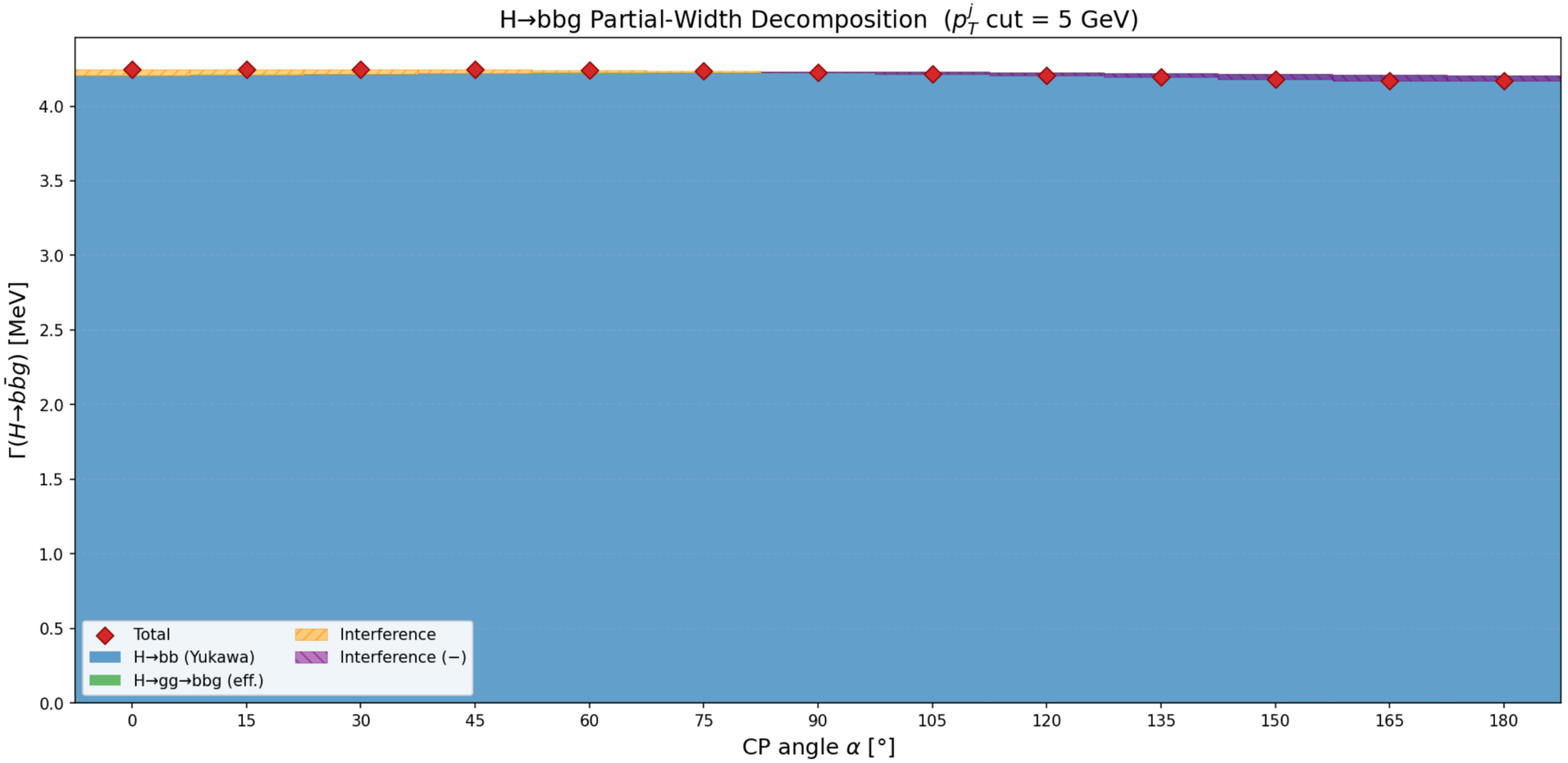


diagram 3 QCD=1, QED=1, QNP=0

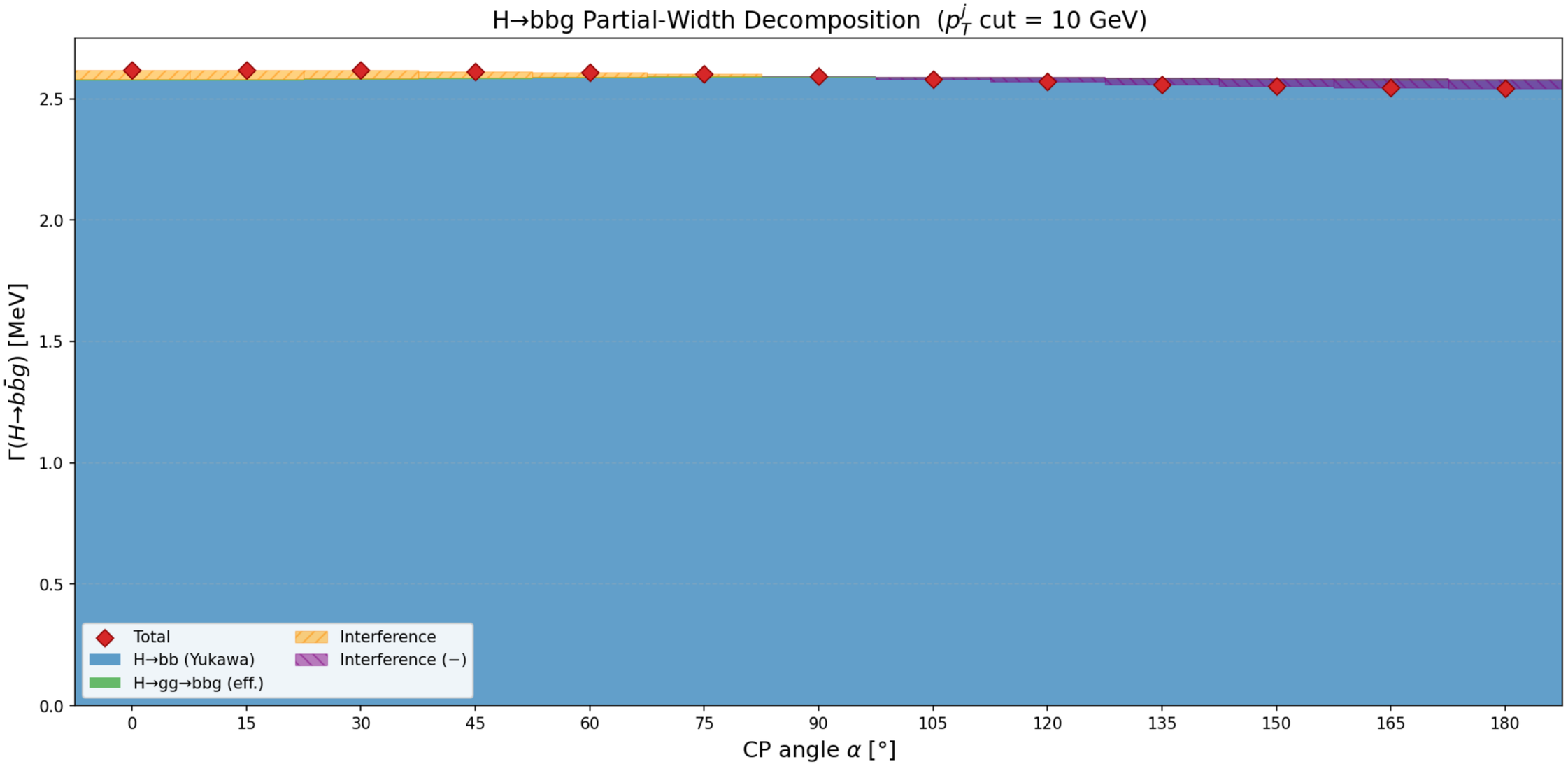
- The interference between QCD and H-b induced diagrams provide sensitivity to H-b coupling CP structure
- However, branching ratios of $H \to gg$ and $H \to bb$ are very different:
  - $H \to bb \sim 58\%$ vs $H \to gg \sim 8\%$
- So the idea is to find the phase space with enhanced QCD production
- Madgraph samples were generated at LO for $H \to bbg$, and produced with gluon pT cut

p_T^g cut = 5 GeV

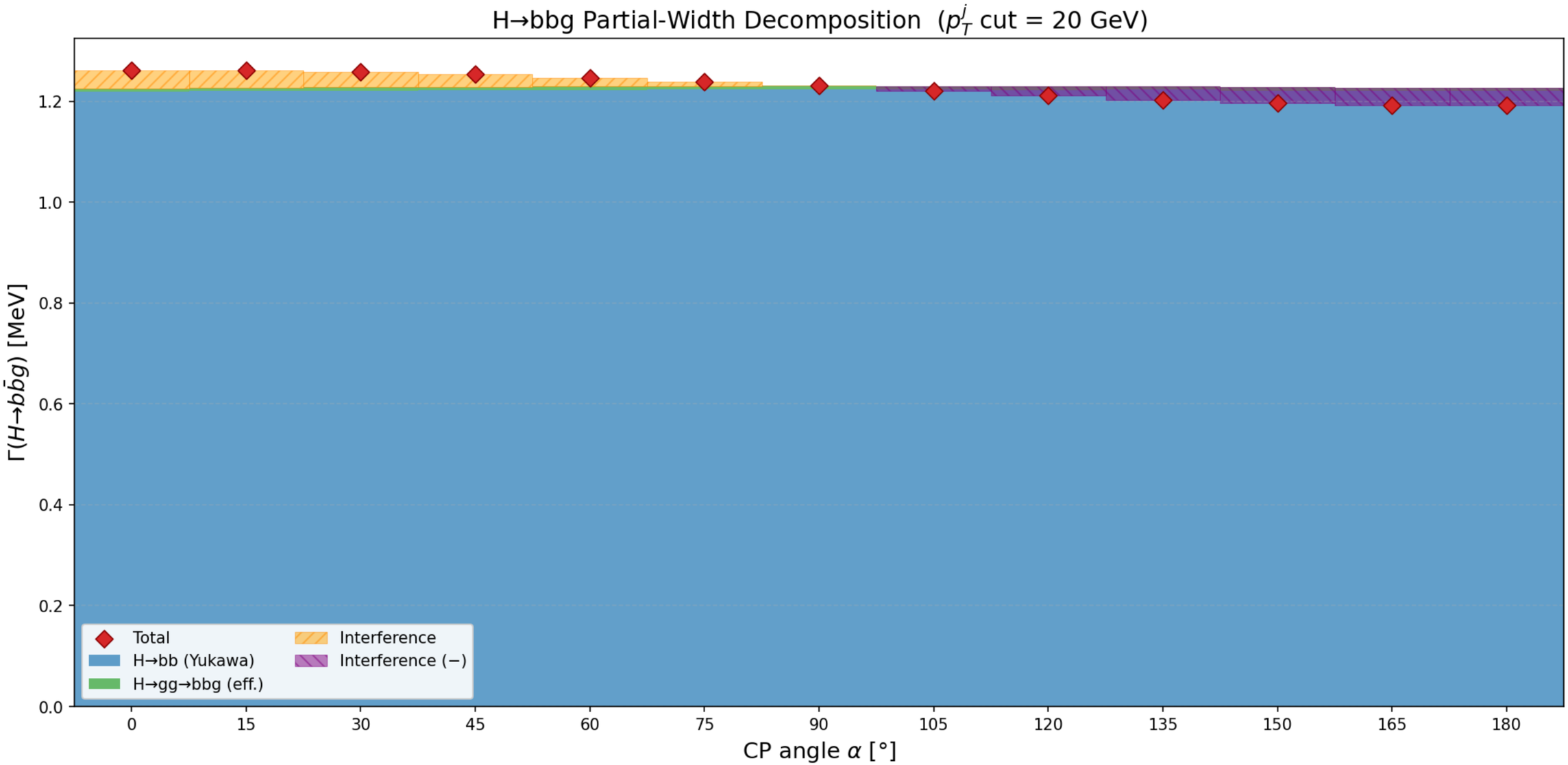
- Samples for different CP-mixing angle α in H-b coupling
- Samples for pure $H \to bb \to bbg$, pure $H \to gg \to bbg$, and inclusive $H \to bbg$



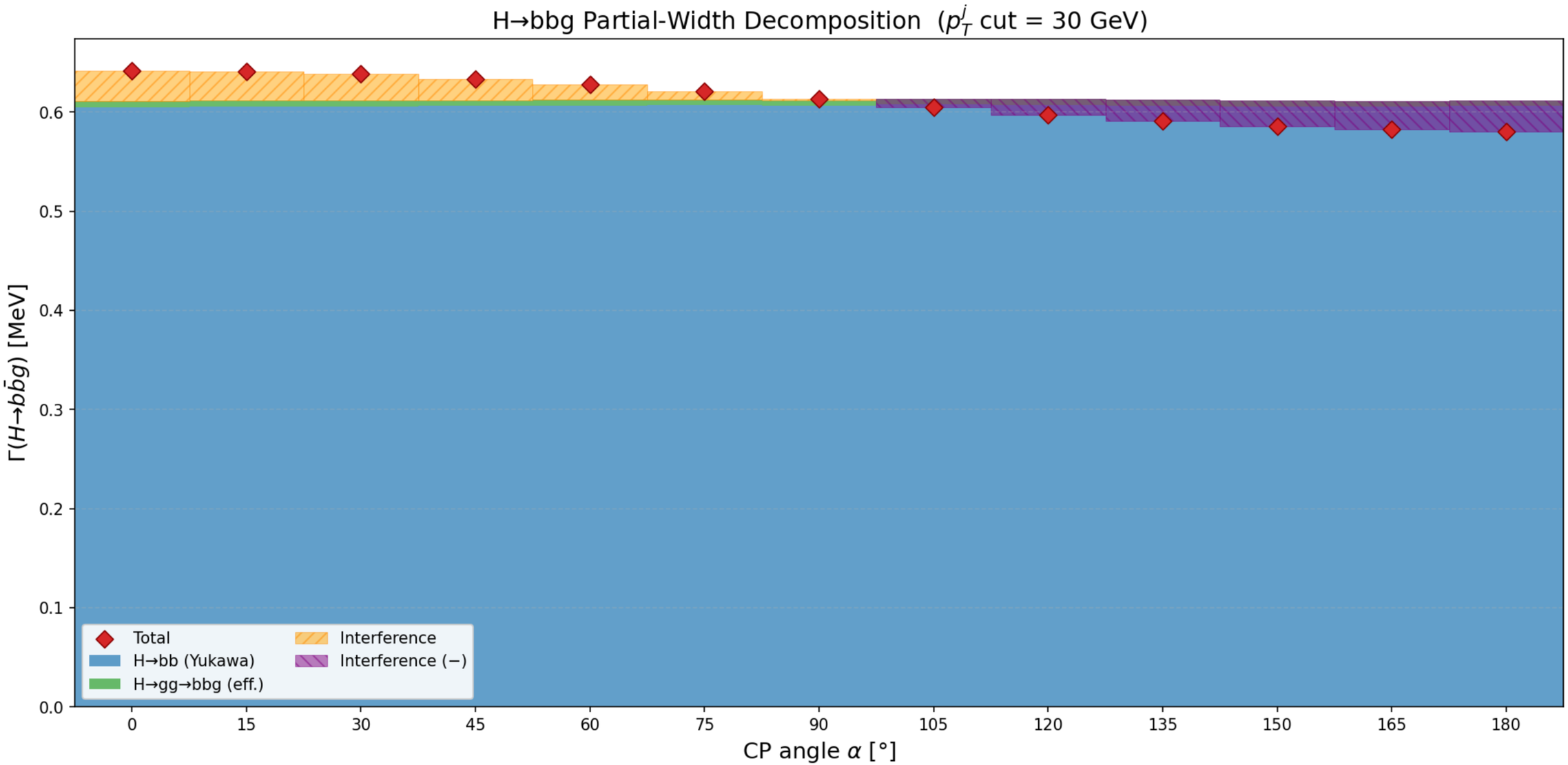
p_T^g cut = 10 GeV



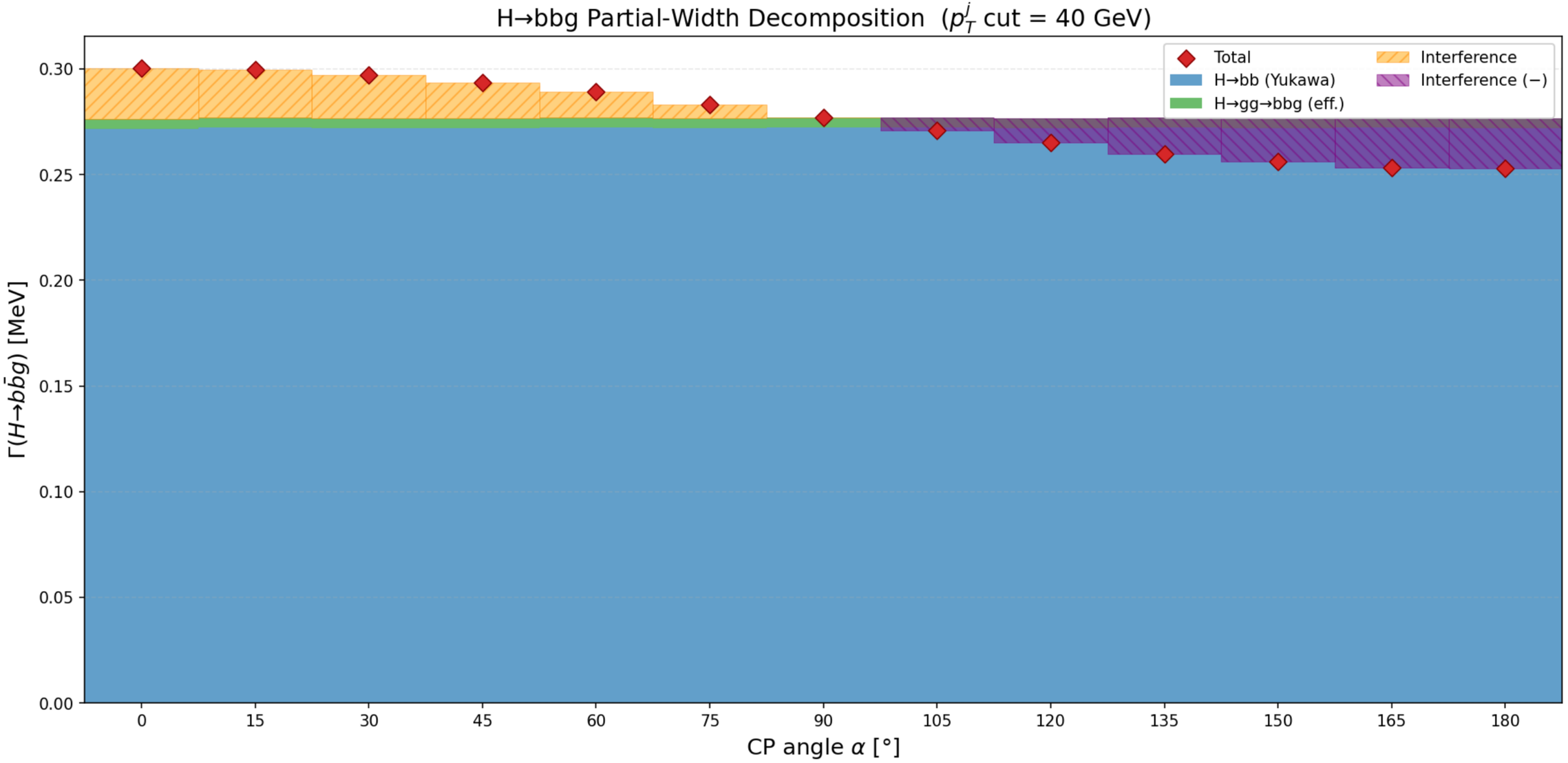
p_T^g cut = 20 GeV



p_T^g cut = 30 GeV



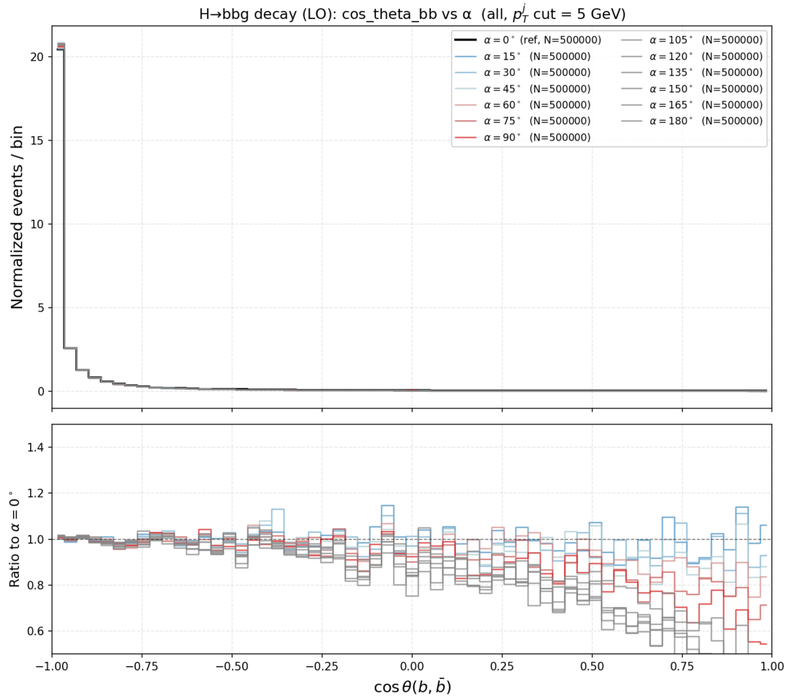
p_T^g cut = 40 GeV



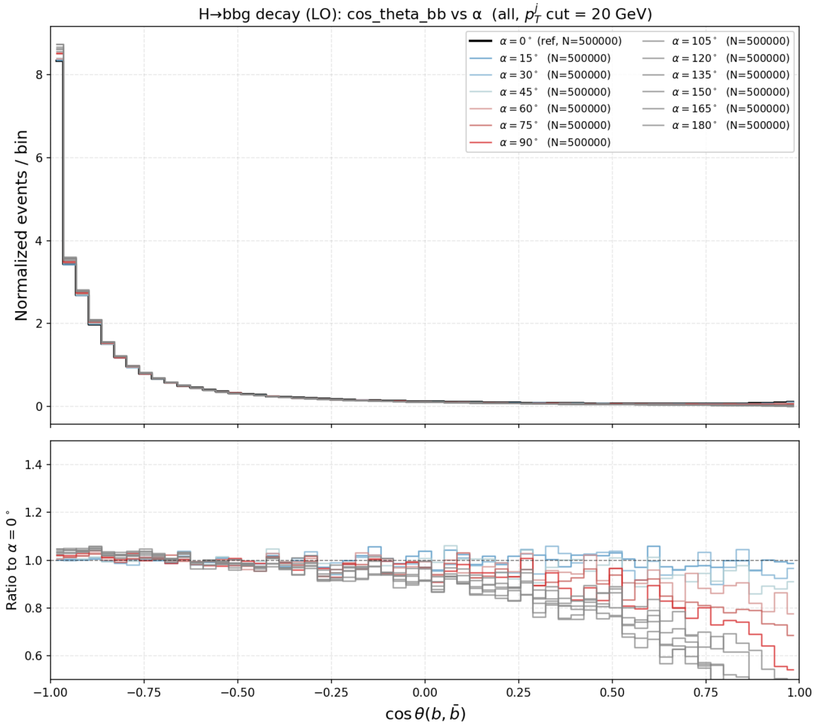
Understanding of the results

- Larger gluon pT threshold → more energetic gluon (especially in the forward region) → more likely collinear bb → enhancement of QCD production
- This can be checked with $\cos\theta(b,\bar{b})$ distribution:

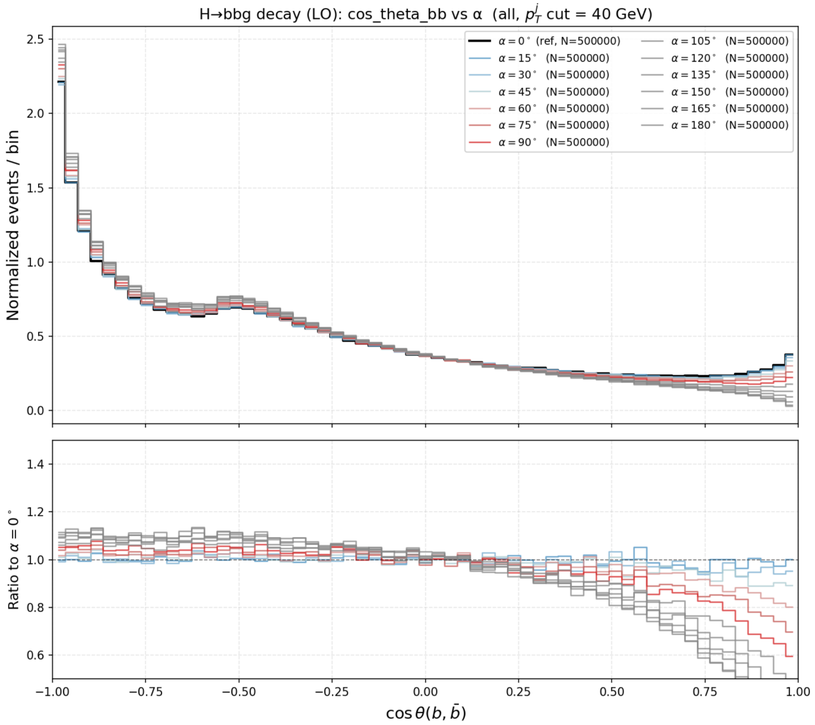
p_T^g cut = 5 GeV



p_T^g cut = 20 GeV



p_T^g cut = 40 GeV



Move to add production: $ZH, H \to bb/bbg$

Example diagrams with leptonic Z decay

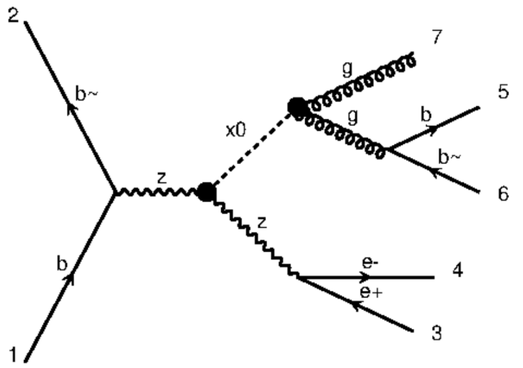


diagram 1 QCD=1, QED=2, QNP=2

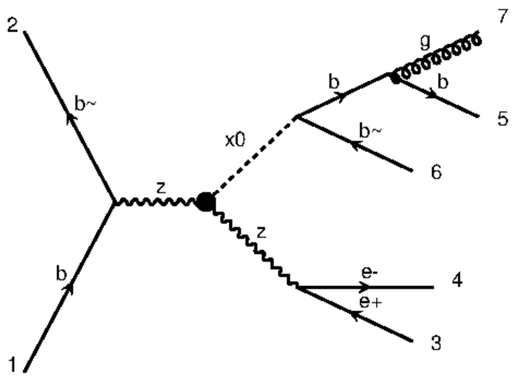


diagram 2 QCD=1, QED=3, QNP=1

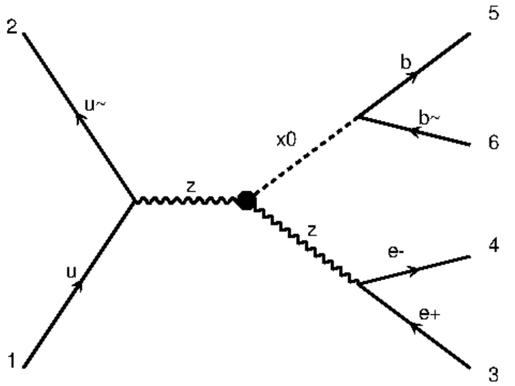


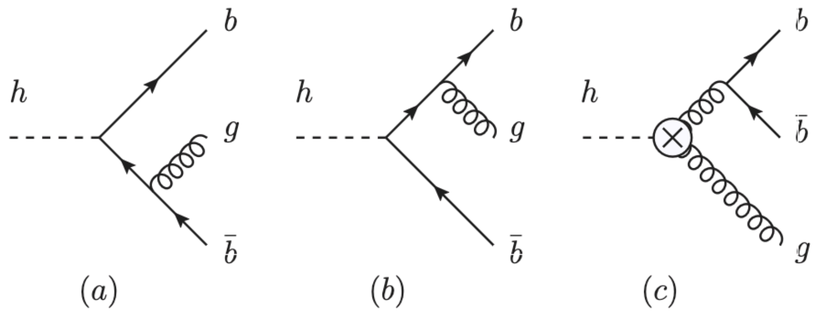
diagram 1 QCD=0, QED=3, QNP=1

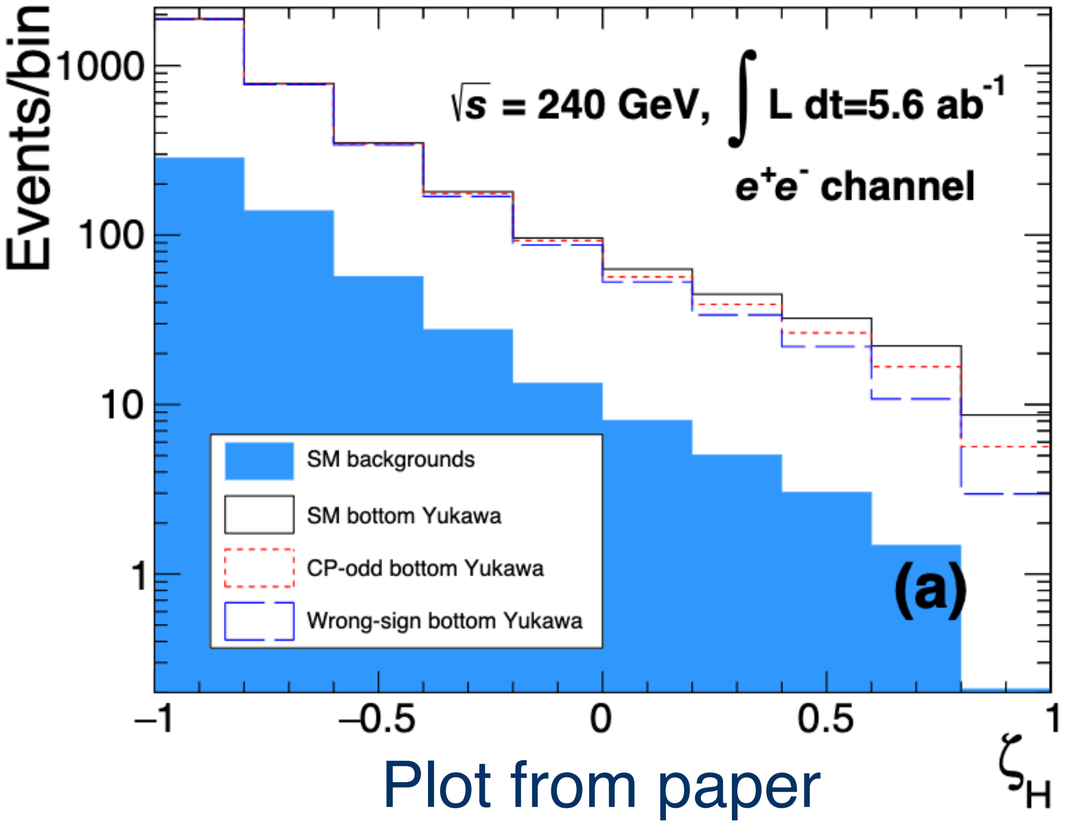
- MG5_aMC@NLO Higgs Characterization model + Pythia8:
  - Include CP-odd term only in H-b coupling, keep H-Z coupling as SM
  - Default pdf (NNPDF2.3), default tune
- Currently generated 8 processes at LO: $Z \to \ell\ell/qq$, $H \to bb/bbg$, $\alpha = 0°/90°$
- 50k events in each case, with the generator-level filter: pT(g) > 20 GeV, no requirement on pT(jet)
- Yukawa mass for b quark chosen as $m_b(m_H)$ = 2.787 GeV

Understanding the sensitive observable

Observable in paper (2009.02000):

$$\zeta_H = \frac{2E_{b_1}E_{b_2}}{E_{b_1}^2 + E_{b_2}^2}\cos\theta_{b_1,b_2}, \text{ in Higgs rest frame}$$

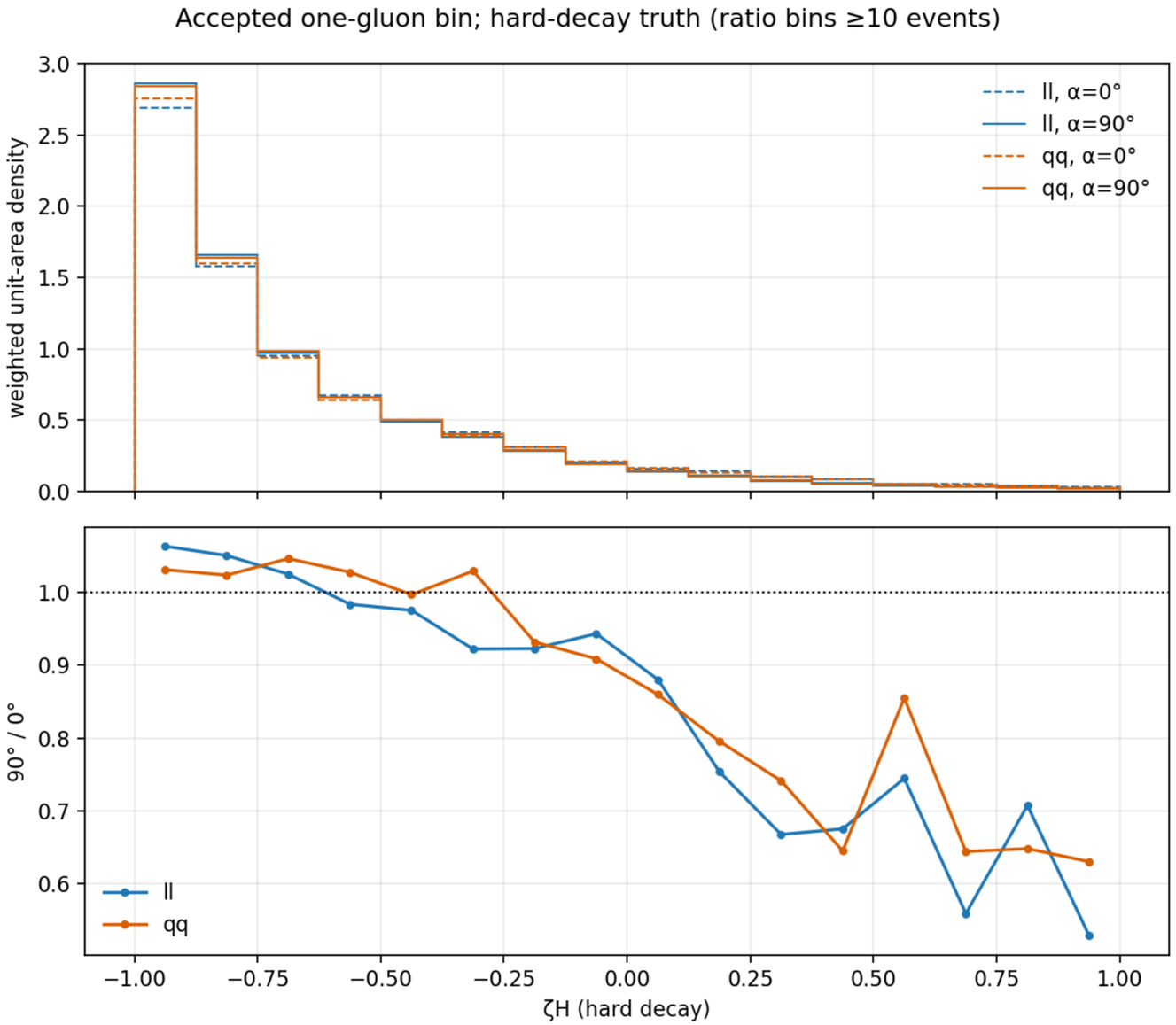




Plot from paper

- Idea is to find the phase space enriched by diagram (c): $H \to gg \to bbg$
- In $H \to gg \to bbg$:
  - Collinear b1 and b2: $\cos\theta$ term
  - Balanced energy of b1 and b2: first term
  - Both terms in ζ_H will reach its max (i.e. 1) in the enhanced phase space region
- Higher ζ_H region has better sensitivity for CP-violation
  - Interference term controlled by $H \to gg \to bbg$ contribution

ζ_H distribution from the produced samples



- No extra cuts yet
- Only use the $H \rightarrow bbg$ events, i.e. signal-only
- ζ_H calculated at truth-level: directly find the b1,b2 and gluon from truth
- Larger ζ_H bins show larger difference between CP-odd and CP-even samples
  - Clear trend under limited stats
  - Agrees with the expectation

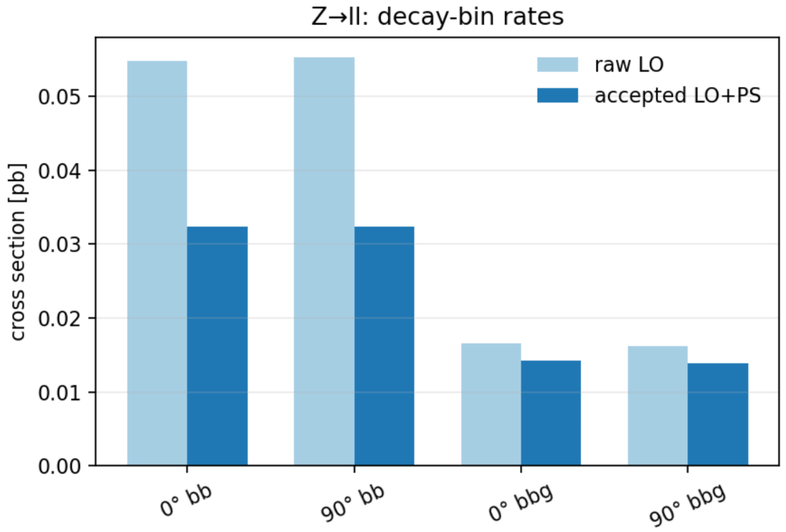
Summary and next steps

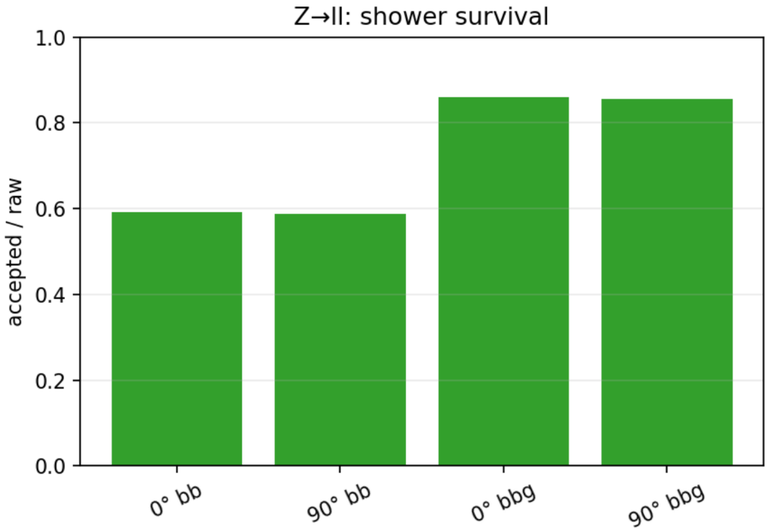
- Preliminary studies using $H \to bbg$ and $pp \to ZH, H \to bbg$ samples
- Good progress on understanding the sensitivities in phase space
- Next steps:
  - Define and study the matching criteria for $H \to bb$ and $H \to bbg$ at NLO level
  - Add more generator-level preselection filters, e.g. ΔR of jets and leptons
  - Study new observables that are sensitive to H-b CP structure
  - Study and apply analysis-level cuts, categorization etc

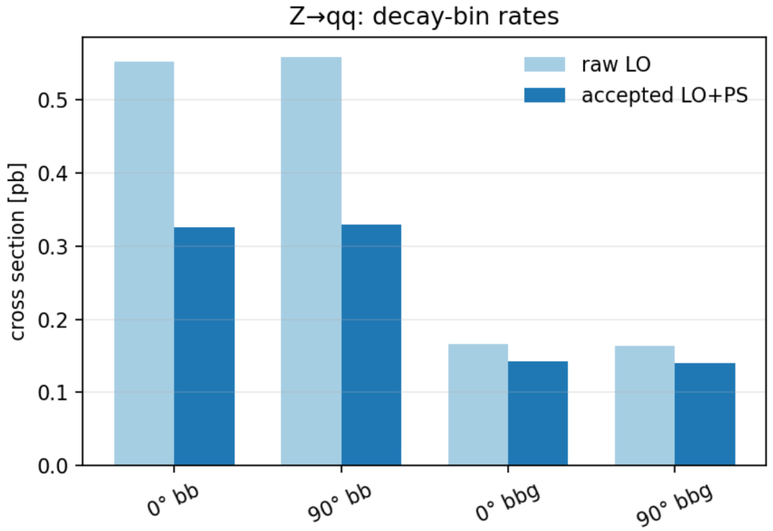
Back up

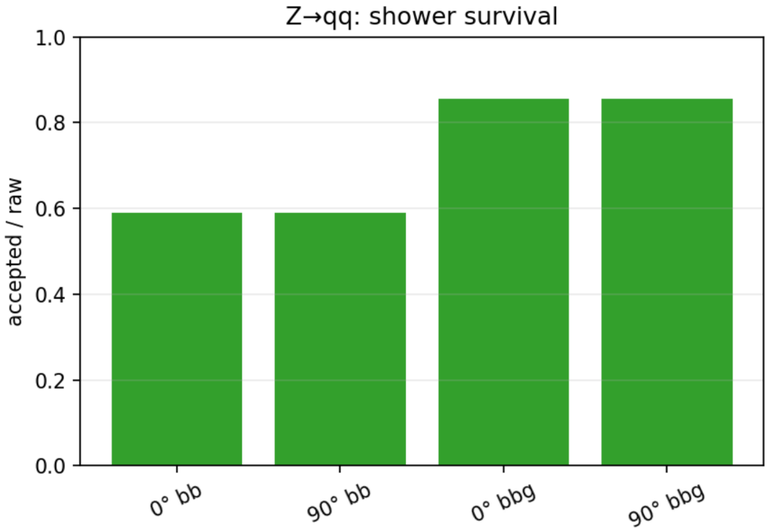
- In order to merge H->bb and H->bbg, performed the following matching criteria during showering:
  - H->bb: FSR pT < 20 GeV
  - H->bbg: pT(g) from ME > 20 GeV & FSR pT < pT(g) from ME

Before and after matching criteria









- H->bb:
  - Generated with no cut on pT(jet)
  - After showering, rejects hard emissions
  - Loses ~ 40% events
- H->bbg:
  - Generated with pT(g) > 20 GeV
  - After showering, selects the pT(g) with the same criteria, rejects harder emissions
  - Therefore loses less (< 20%)