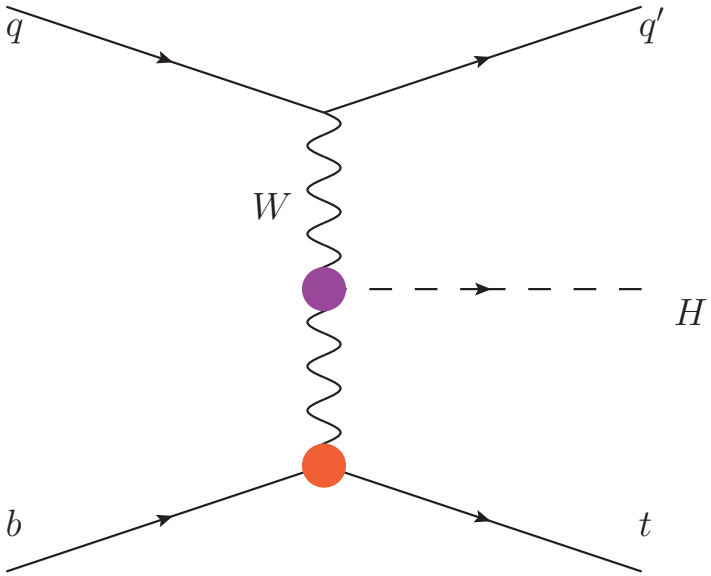
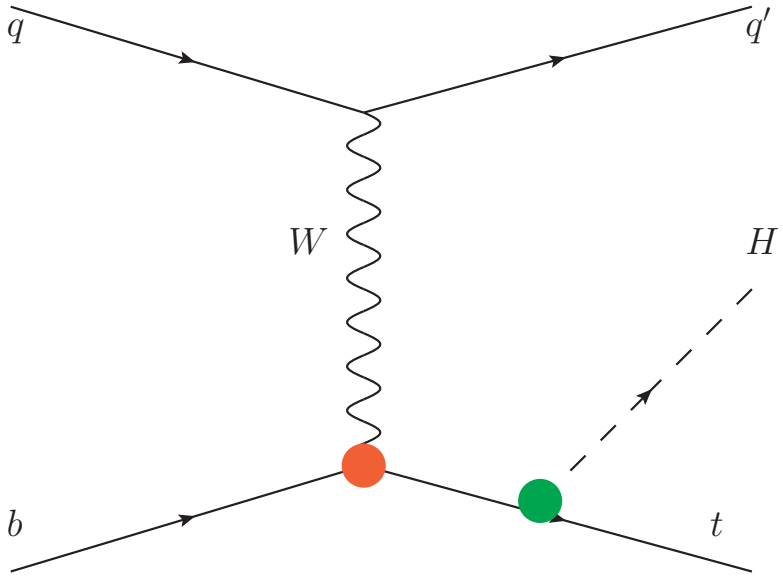
Unravelling the non-standard top and Higgs couplings in associated top-Higgs production at the High-luminosity LHC

Pankaj Sharma

Collaborators: **Saurabh D. Rindani and Ambresh Shivaji**

Production of Single top with Higgs





- Enables direct determination of $\mathbf{t\bar{t}h}$ coupling,

Effective Top quark Couplings

- Using only Lorentz invariance, the **tbW** coupling can be written as:

$$\Gamma^{\mu} = \frac{-g}{\sqrt{2}} V_{tb} \left[\gamma^{\mu} (f_{1L} P_L + f_{1R} P_R) - \frac{i\sigma^{\mu\nu}}{m_W} (p_t - p_b)_{\nu} (f_{2L} P_L + f_{2R} P_R) \right]$$

- In the SM, $f_{1L} = 1$ and $f_{1R} = f_{2L} = f_{2R} = 0$.
- The most general $t\bar{t}h$ coupling is written as:

$$\mathcal{L} = \frac{m_t}{v} \bar{t} \, (\cos \zeta_t + i \sin \zeta_t) t \, h$$

- ζ_t is the CP-violating phase.
- $\zeta_t = 0$ corresponds to pure scalar state while $\zeta_t = \pi/2$ to pure pseudoscalar state.
- Current LHC data on $h \to \gamma\gamma$ and $h \to gg$ constrains $|\zeta_t| < 0.6\pi$

Higgs couplings with **W** bosons

- Using only Lorentz and gauge invariance, the **WWh** couplings upto dimension-5 can be written as:

$$\begin{aligned}\mathcal{L}_{\text{eff}} &= \mathbf{g}^{1}_{\mathbf{Wh}}(\mathbf{G}^{+}_{\mu\nu}\mathbf{W}^{-\mu} + \mathbf{G}^{-}_{\mu\nu}\mathbf{W}^{+\mu})\partial^{\nu}\mathbf{h} + \mathbf{g}^{2}_{\mathbf{Wh}}(\mathbf{G}^{-}_{\mu\nu}\mathbf{G}^{+\mu\nu})\mathbf{h} \\ &- \mathbf{g}^{3}_{\mathbf{Wh}}\frac{\mathbf{m}^{2}_{\mathbf{W}}}{\mathbf{v}}(\mathbf{W}^{+}_{\mu}\mathbf{W}^{-\mu})\mathbf{h} + \mathbf{g}^{4}_{\mathbf{Wh}}(\mathbf{G}^{+}_{\mu\nu}\tilde{\mathbf{G}}^{-\mu\nu} - \mathbf{G}^{-}_{\mu\nu}\tilde{\mathbf{G}}^{+\mu\nu})\mathbf{h}\end{aligned}$$

- In the SM, $\mathbf{g}^{3}_{\mathbf{Wh}} = \mathbf{1}$ and $\mathbf{g}^{1}_{\mathbf{Wh}} = \mathbf{g}^{2}_{\mathbf{Wh}} = \mathbf{g}^{4}_{\mathbf{Wh}} = \mathbf{0}$.
- $\mathbf{g}^{3}_{\mathbf{Wh}}$ and $\mathbf{g}^{2}_{\mathbf{Wh}}$ have SM Lorentz structures.

  $\Rightarrow$ Thus not expected to modify the shape of the distributions.

Top Polarization

- Its life time is $\sim \mathbf{5} \times \mathbf{10^{-25}}$s which is smaller than hadronization scale $\sim \mathbf{3} \times \mathbf{10^{-24}}$s
- In the top-rest frame, the distribution of its decay products is given by

$$\frac{\mathbf{1}}{\mathbf{\Gamma}} \frac{\mathbf{d\Gamma_f}}{\mathbf{d}\cos\boldsymbol{\theta_f}} = \frac{\mathbf{1}}{\mathbf{2}} \left(\mathbf{1} + \boldsymbol{\kappa} \mathbf{P_t} \cos\boldsymbol{\theta_f}\right)$$

- The ℓ^+ and $\mathbf{d}$ quark are the best spin analyzers with $\boldsymbol{\kappa_{\ell^+}} = \boldsymbol{\kappa_{\bar{\mathbf{d}}}} = \mathbf{1}$,
- Thus the ℓ^+ or $\mathbf{d}$ have the largest probability of being emitted in the direction of the top spin,

Top Polarization

- Polar distribution of charged lepton in top rest frame,

  $\Rightarrow$ Requires reconstruction of full top momentum,

$$\mathbf{A_{tl}} = \frac{\sigma(\cos\theta_{tl} > 0) - \sigma(\cos\theta_{tl} < 0)}{\sigma(\cos\theta_{tl} > 0) + \sigma(\cos\theta_{tl} < 0)},$$

Top Polarization

- Polar distribution of charged lepton in top rest frame,

  $\Rightarrow$ Requires reconstruction of full top momentum,

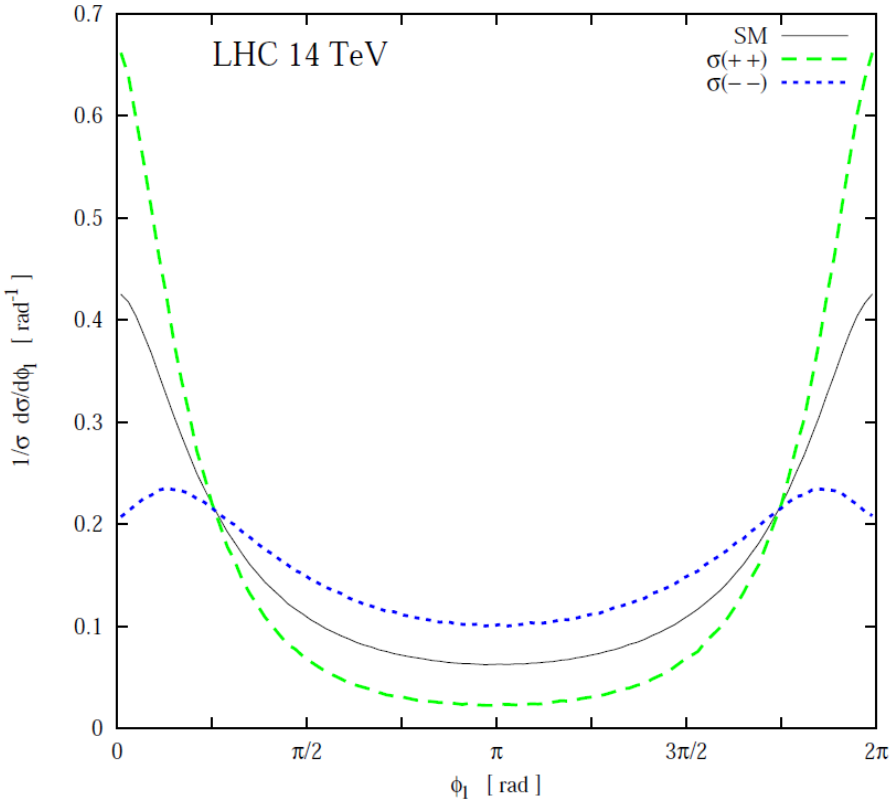
$$\mathbf{A_{tl}} = \frac{\sigma(\cos\theta_{tl} > 0) - \sigma(\cos\theta_{tl} < 0)}{\sigma(\cos\theta_{tl} > 0) + \sigma(\cos\theta_{tl} < 0)},$$

- Azimuthal distribution of charged lepton in lab frame,

  $\Rightarrow$ Requires only reconstruction of top production plane,

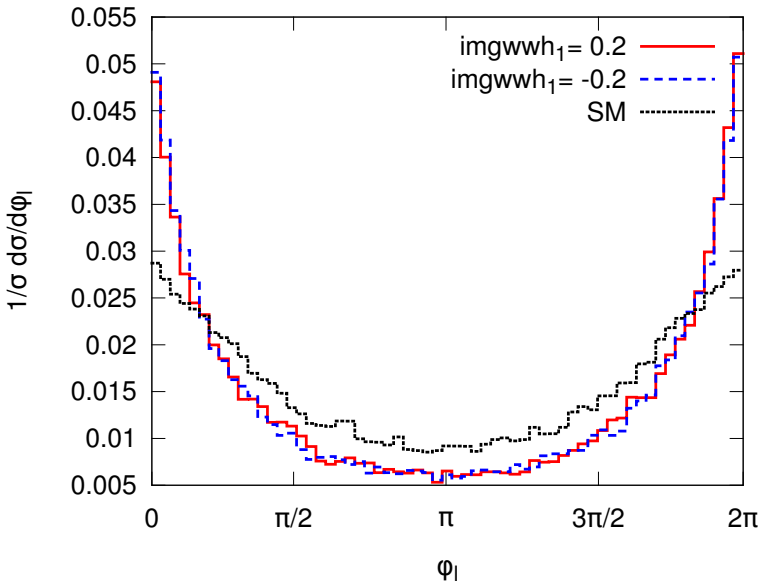
$$\mathbf{A_{\phi}} = \frac{\sigma(\cos\phi_{\ell} > 0) - \sigma(\cos\phi_{\ell} < 0)}{\sigma(\cos\phi_{\ell} > 0) + \sigma(\cos\phi_{\ell} < 0)},$$

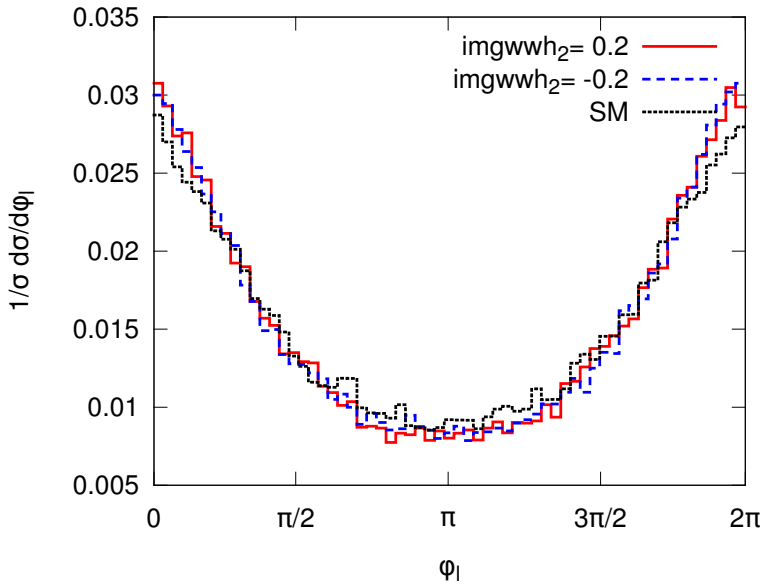
Lepton Azimuthal distribution as top-spin analyzer

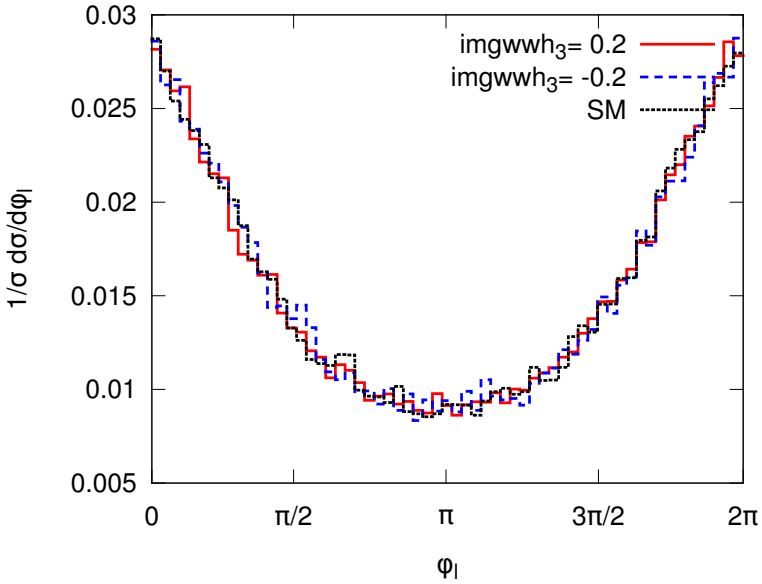


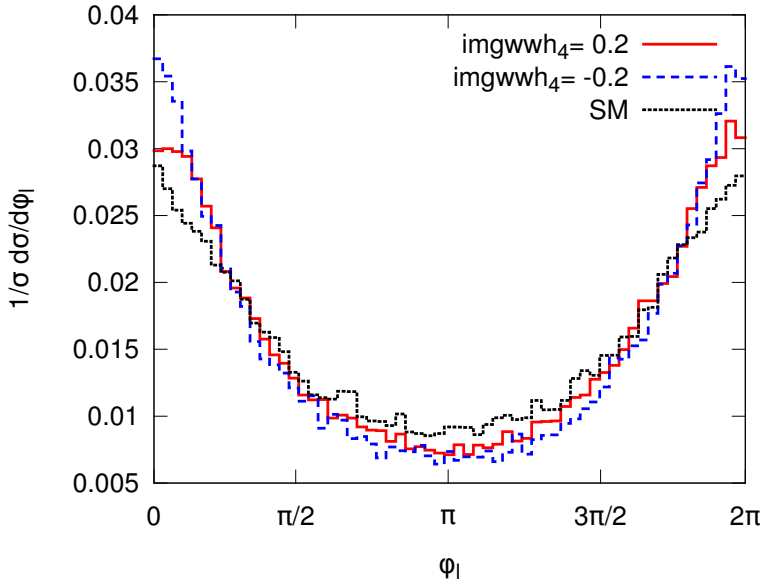
Measured w.r.t top production plane.

Azimuthal Distribution

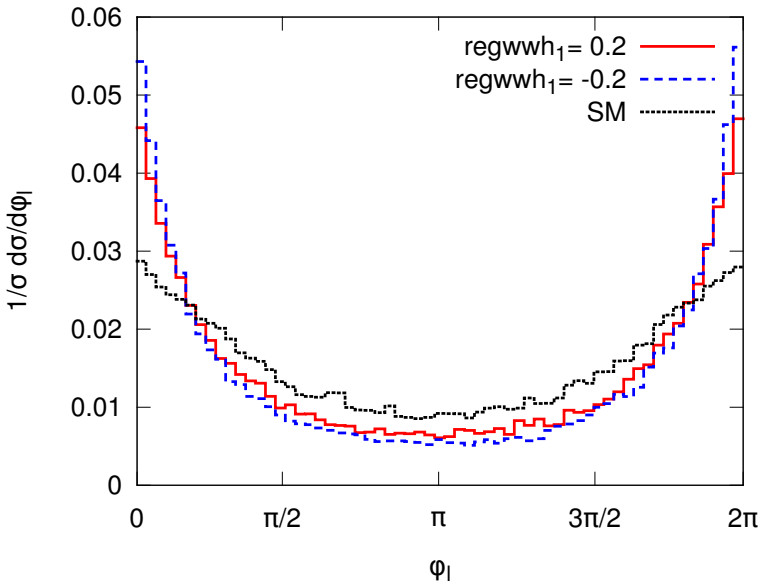


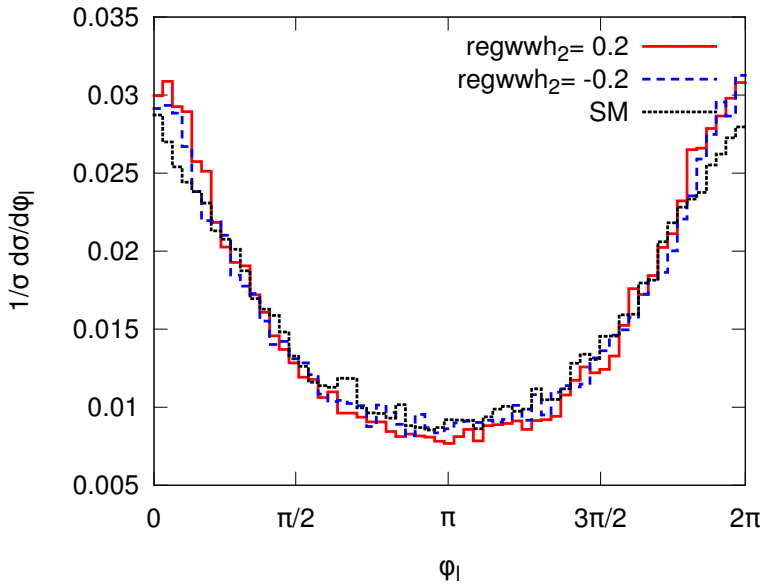


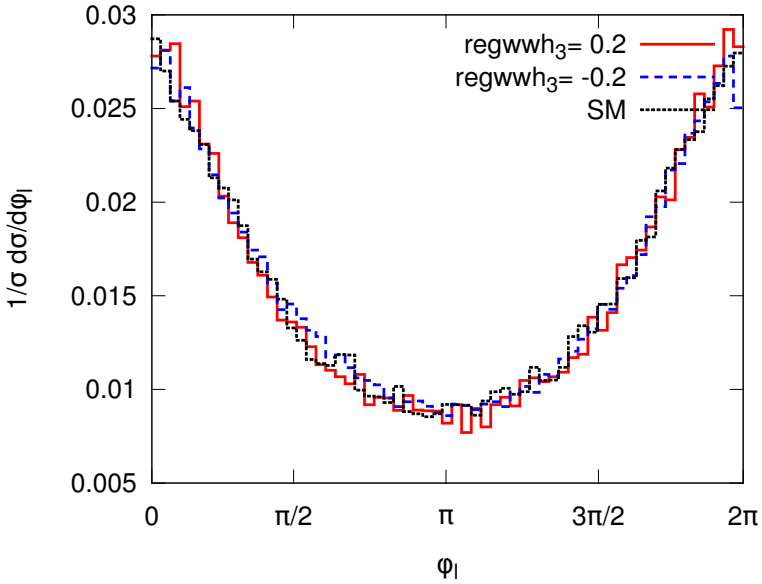


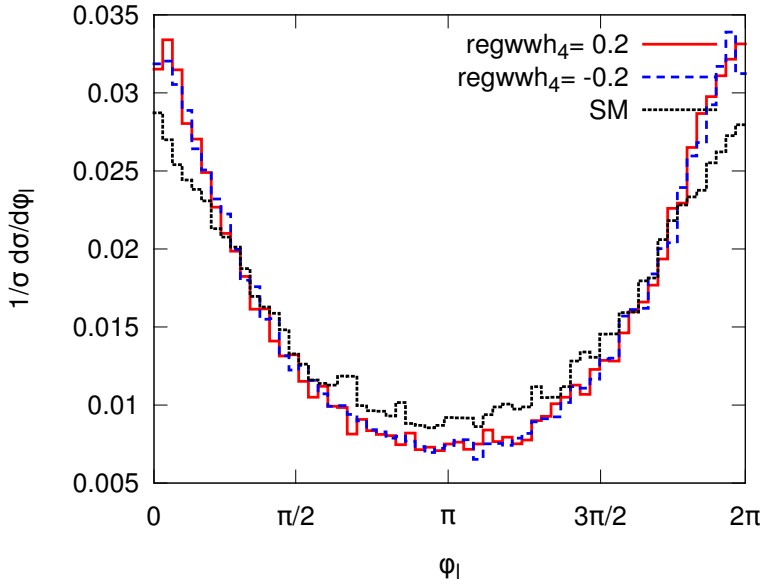


Azimuthal Distribution

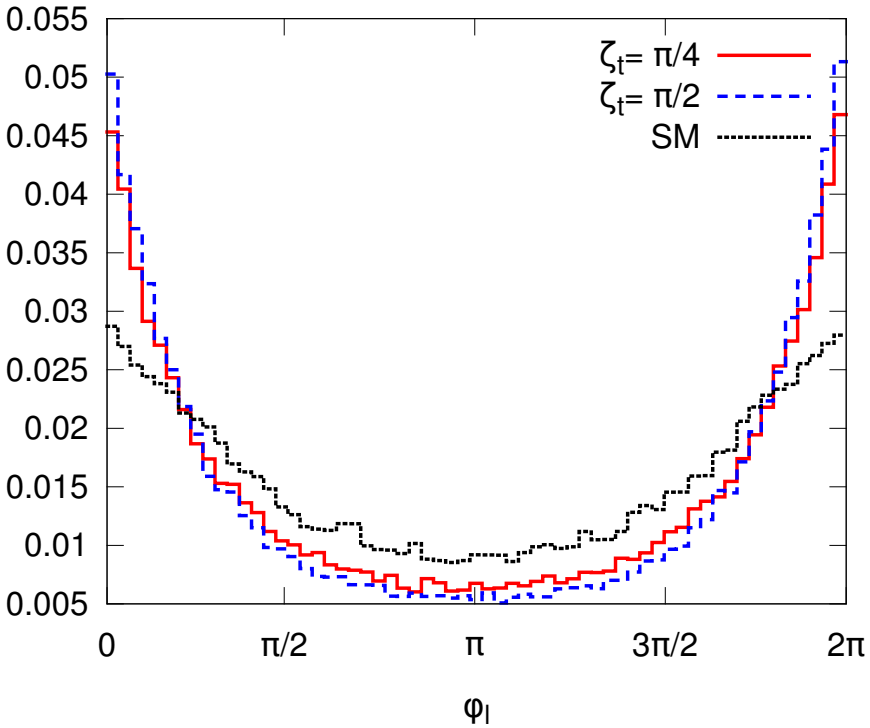


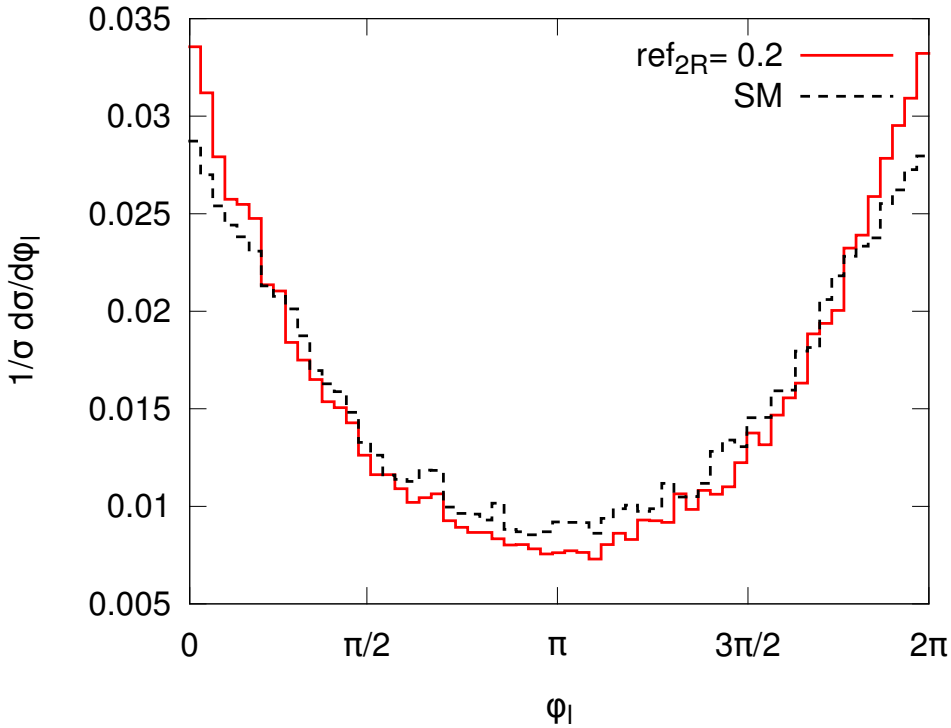




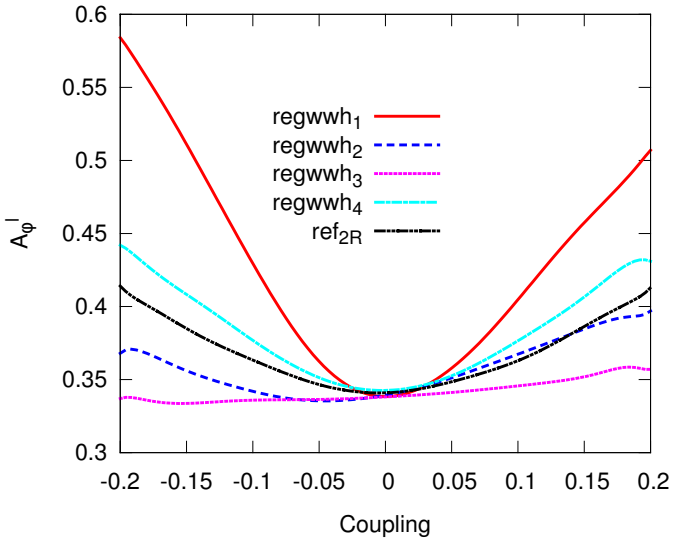


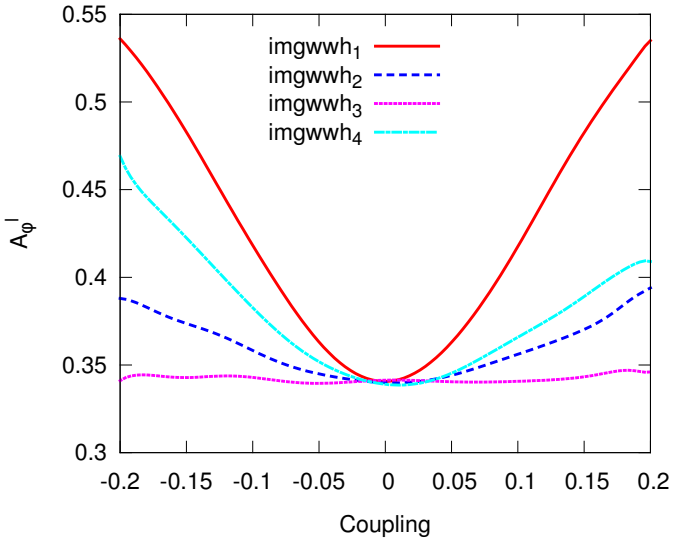
Azimuthal Distribution

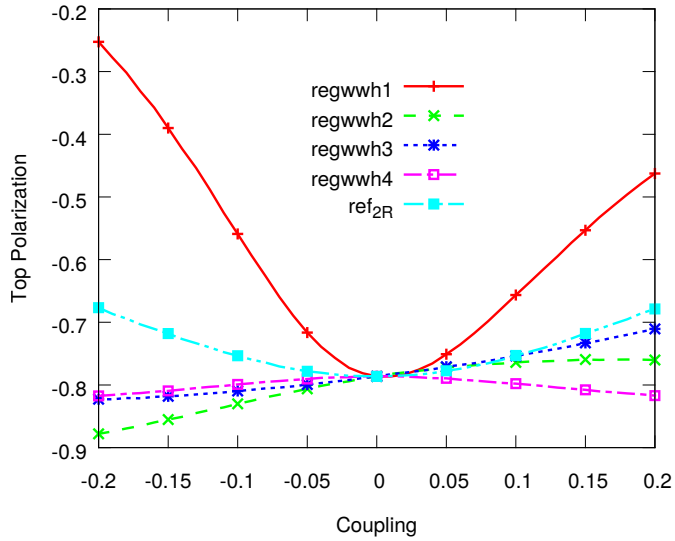


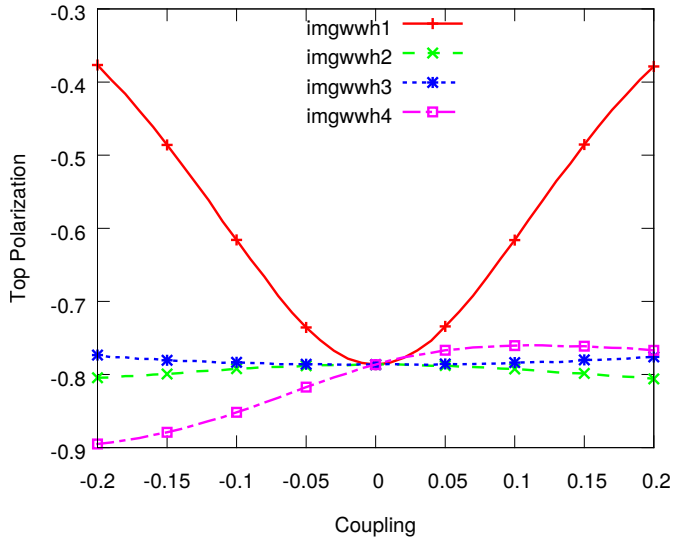


Asymmetry vs Top polarization

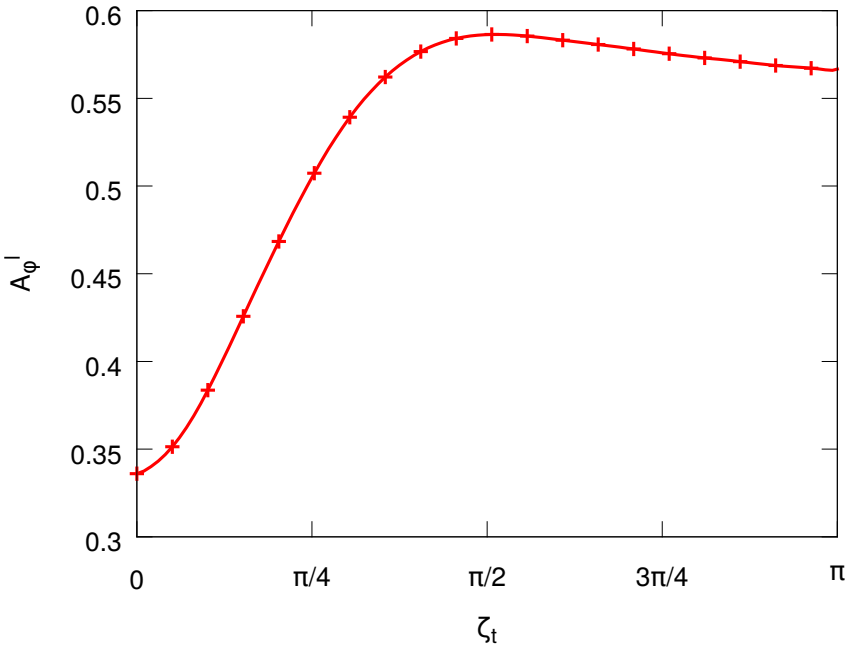


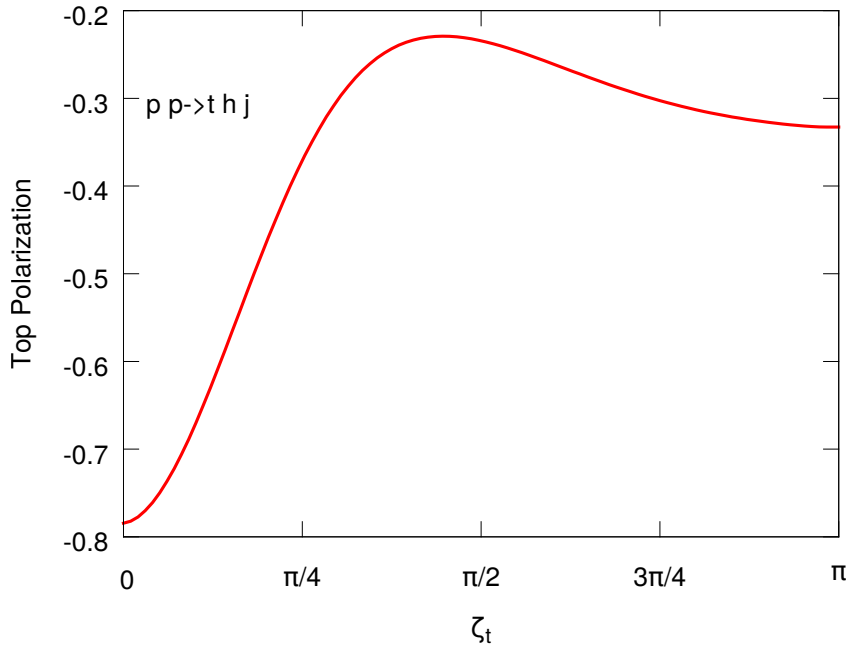






Asymmetry vs Top polarization





$\Rightarrow$ Sensitive in the region $\boldsymbol{\zeta_t < 0.4\pi}$.

Conclusions

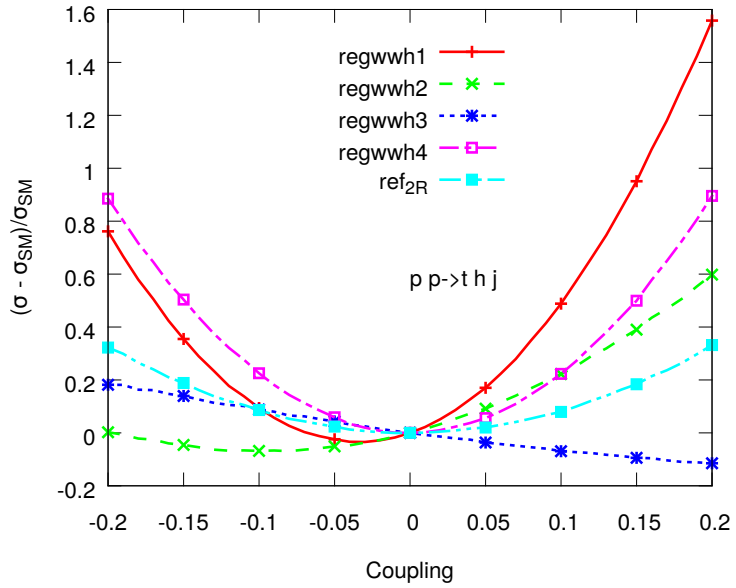
- Top quark polarization provides an additional handle to probe new physics scenarios.
- Associated Single-top and Higgs production provides an opportunity for direct determination of **tth** coupling..
- Azimuthal asymmetry of charged lepton may provide good sensitivity to $\mathbf{gwwh_1}$ and CP-violating phase $\zeta_t < \mathbf{0.4\pi}$,
- Asymmetries are sensitive to ζ_t in the region $-\mathbf{0.4\pi : 0.4\pi}$ while cross section in $> \pi/\mathbf{2}$.

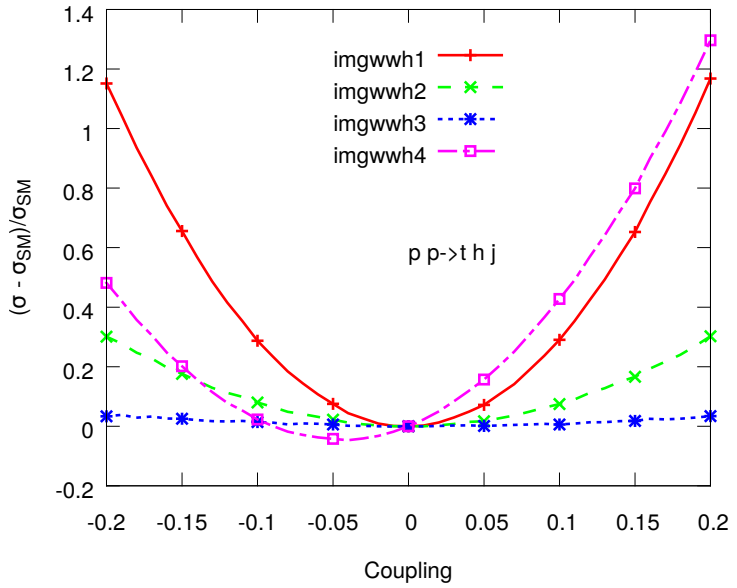
Conclusions

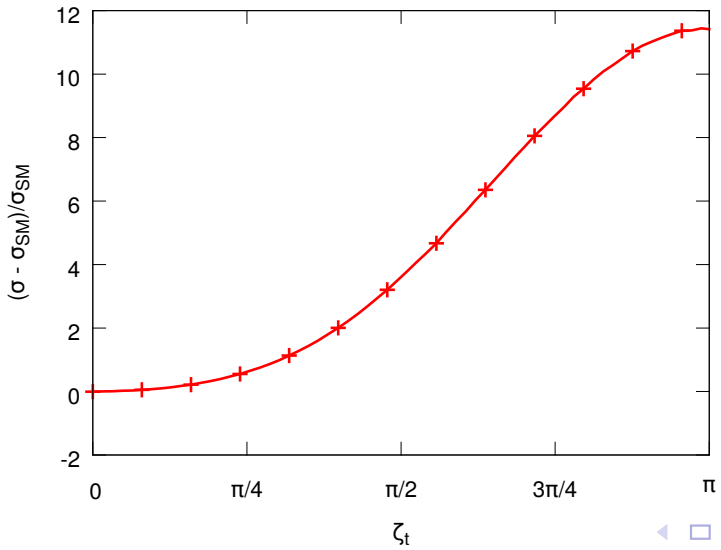
- Top quark polarization provides an additional handle to probe new physics scenarios.
- Associated Single-top and Higgs production provides an opportunity for direct determination of **tth** coupling..
- Azimuthal asymmetry of charged lepton may provide good sensitivity to $\mathbf{gwwh_1}$ and CP-violating phase $\zeta_t < \mathbf{0.4\pi}$,
- Asymmetries are sensitive to ζ_t in the region $-\mathbf{0.4\pi : 0.4\pi}$ while cross section in $> \pi/\mathbf{2}$.

THANKS

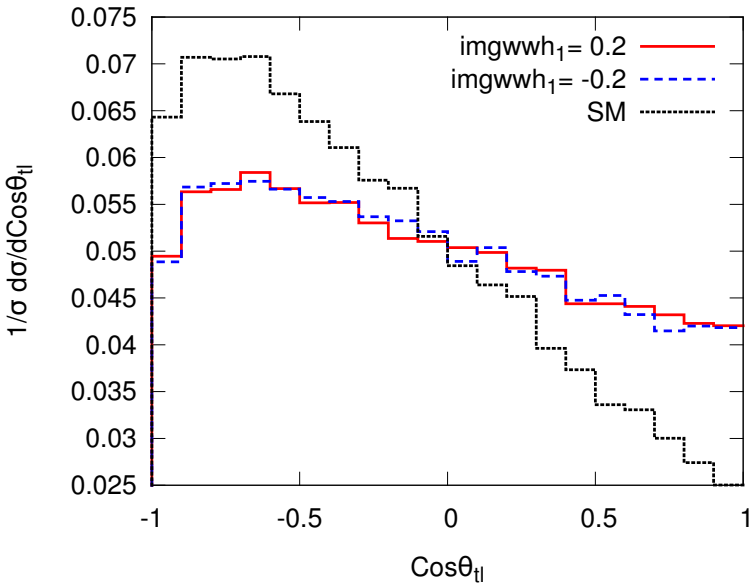
Production of Single top with Higgs

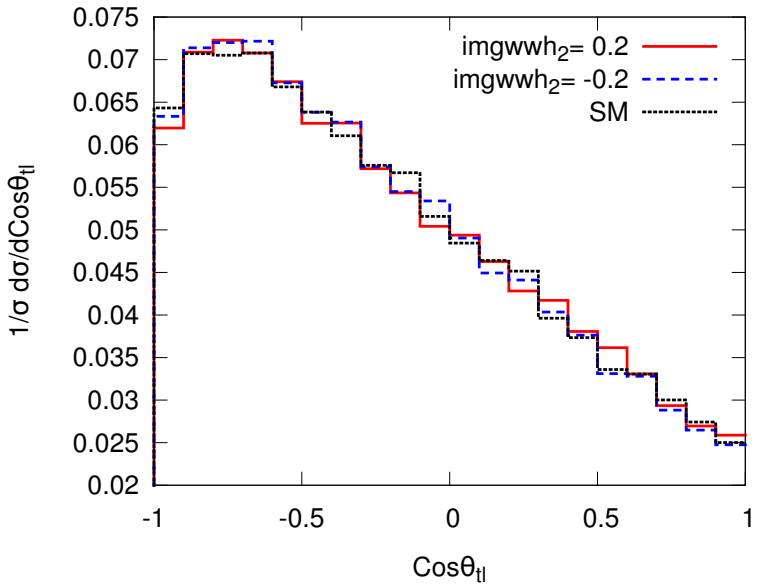


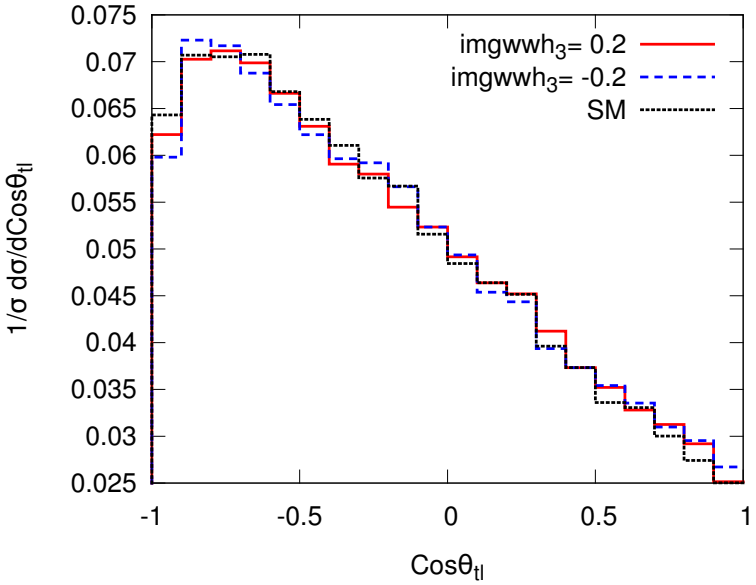


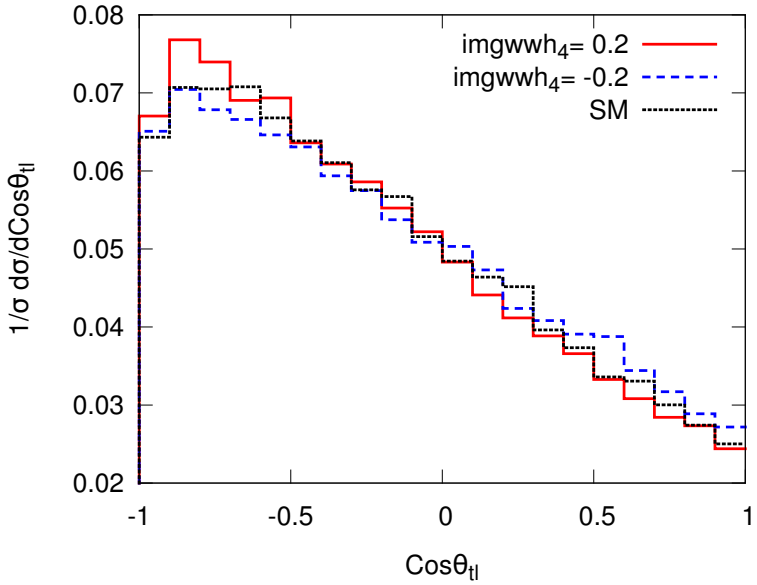


Polar Distribution in top-rest frame

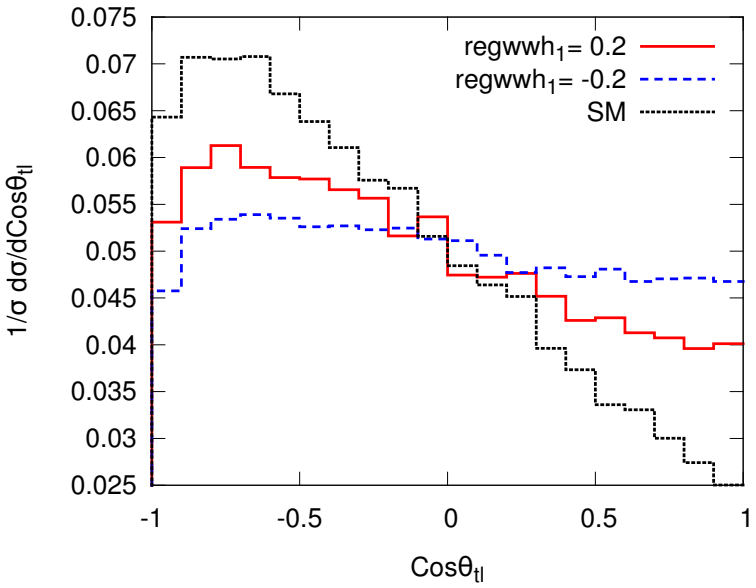


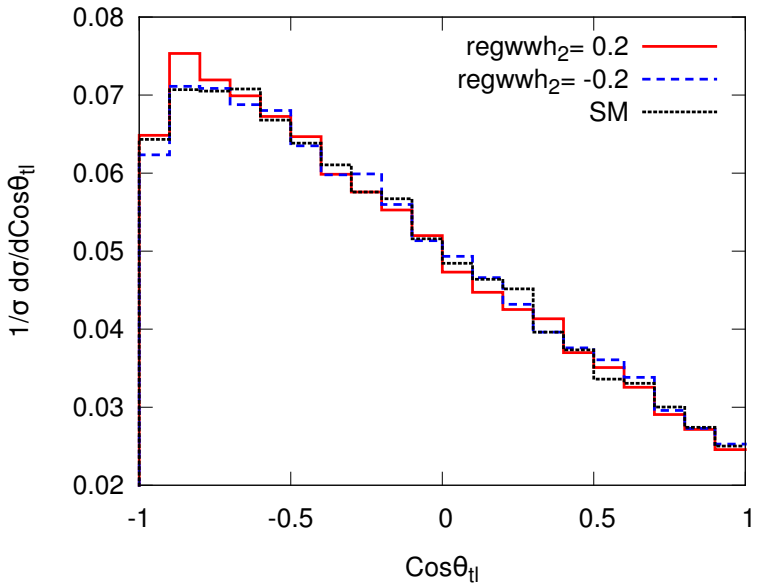


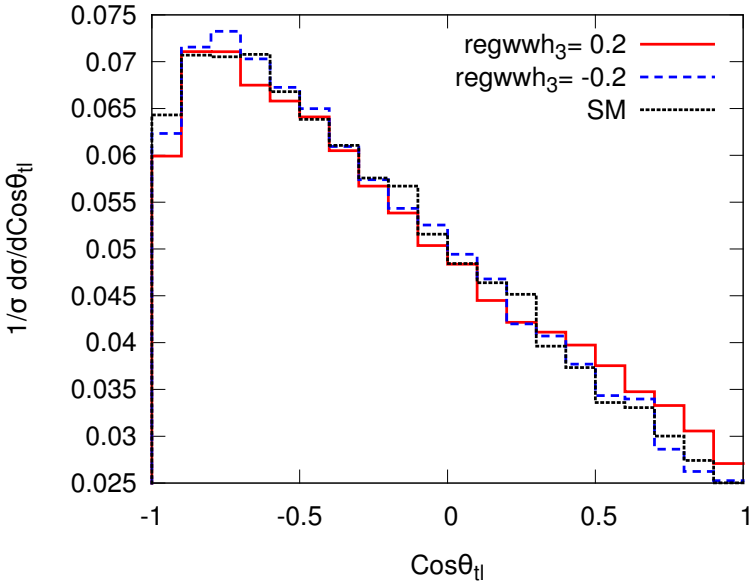


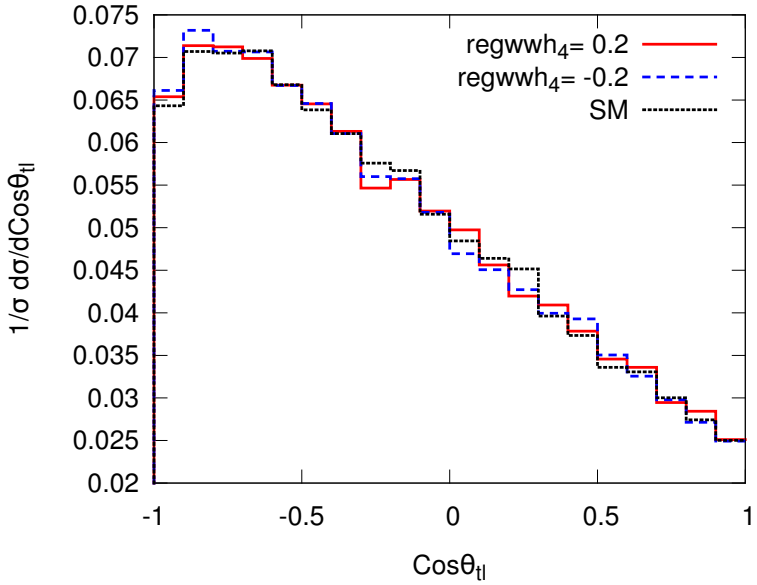


Polar Distribution in top-rest frame

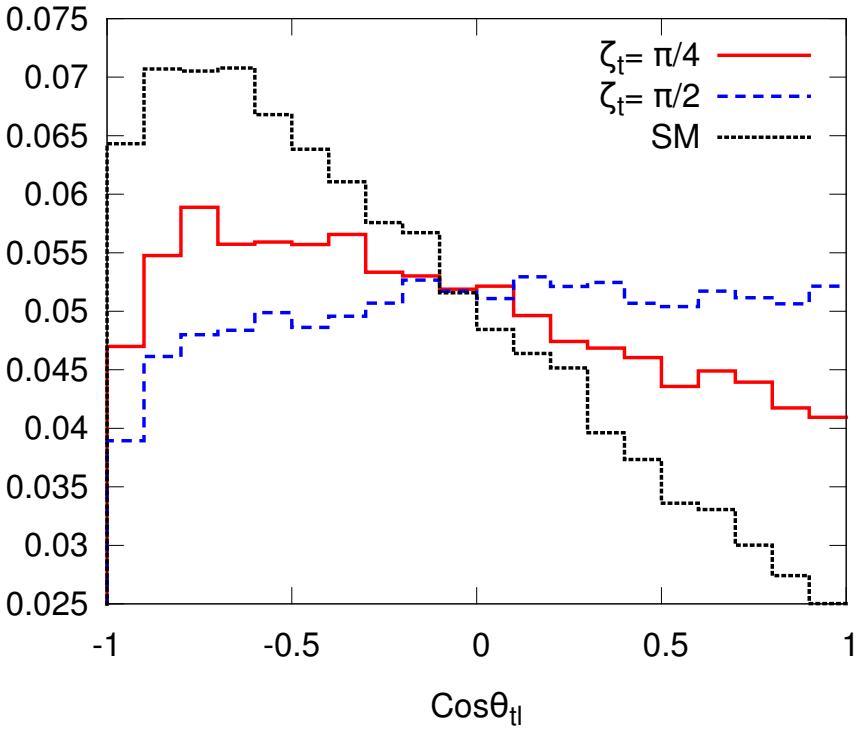


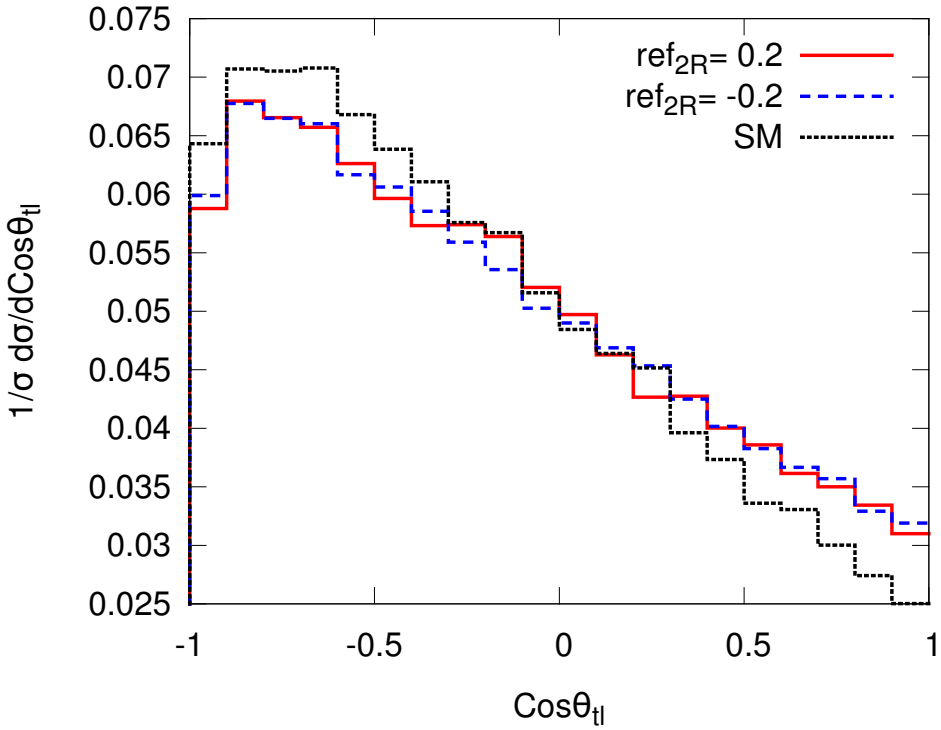






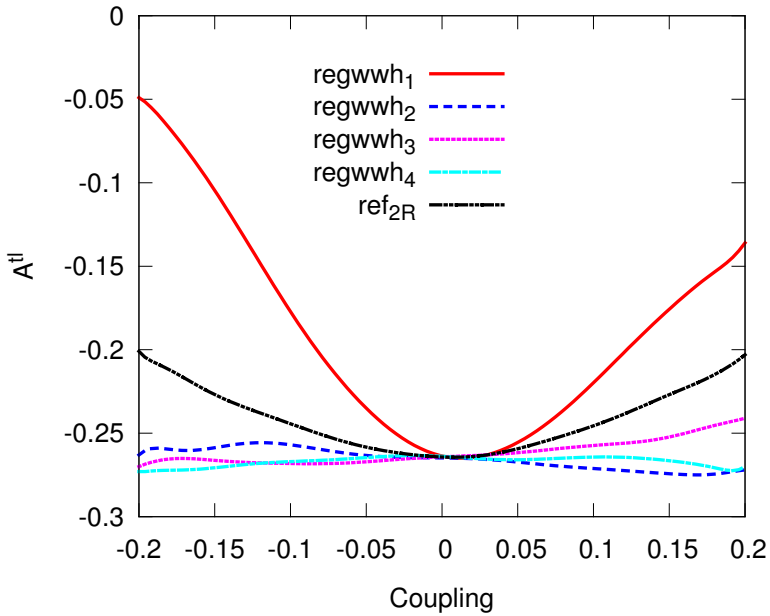
Polar Distribution in top rest frame

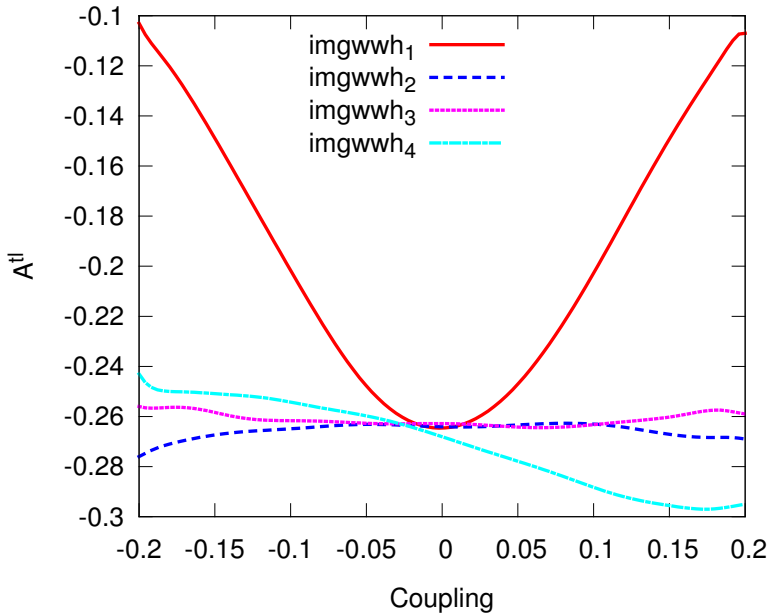




Polar Asymmetry in top rest frame

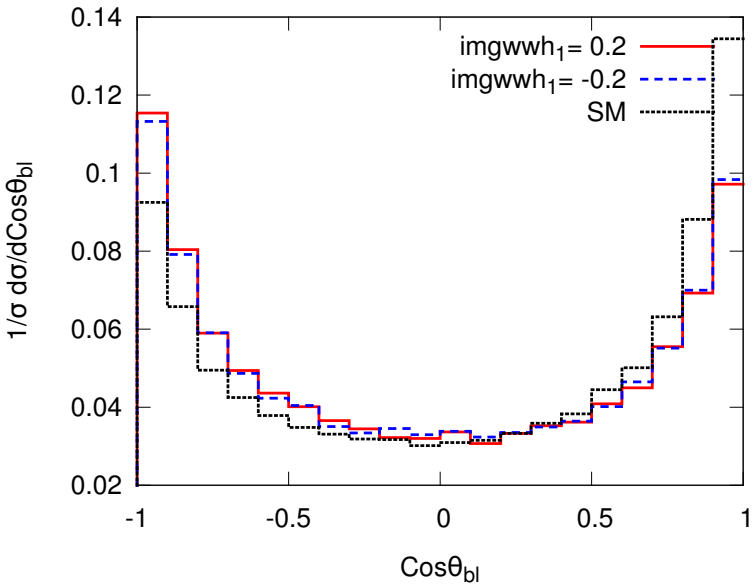
$$\mathbf{A_{tl}} = \frac{\sigma(\cos\theta_{tl} > 0) - \sigma(\cos\theta_{tl} < 0)}{\sigma(\cos\theta_{tl} > 0) + \sigma(\cos\theta_{tl} < 0)},$$

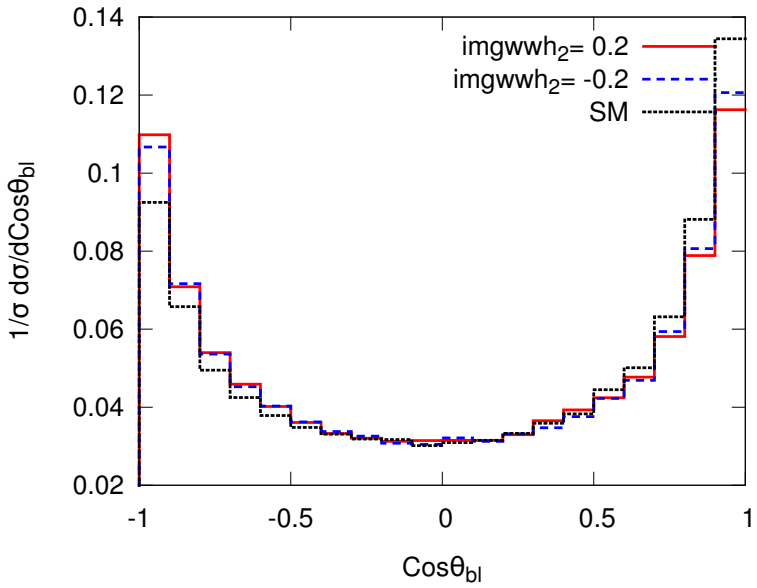


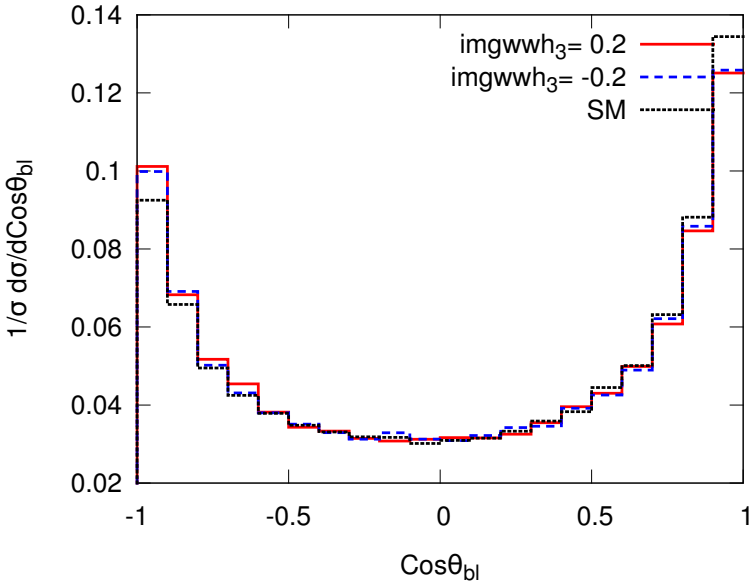


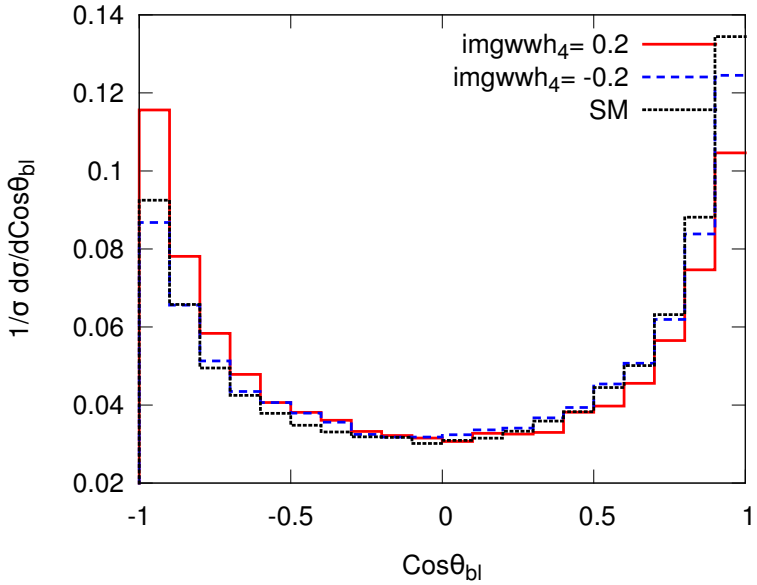
$\Rightarrow$ isolates real and imaginary parts of $\mathbf{gwwh_1}$.

Polar Distribution in lab frame

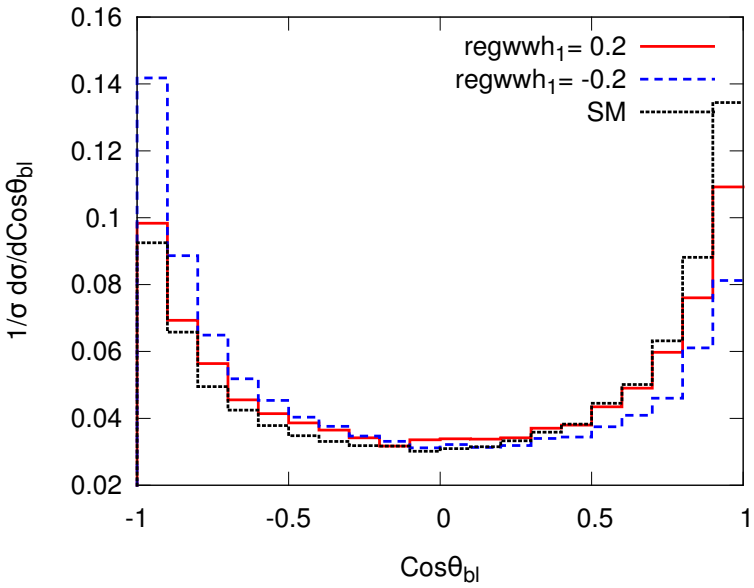


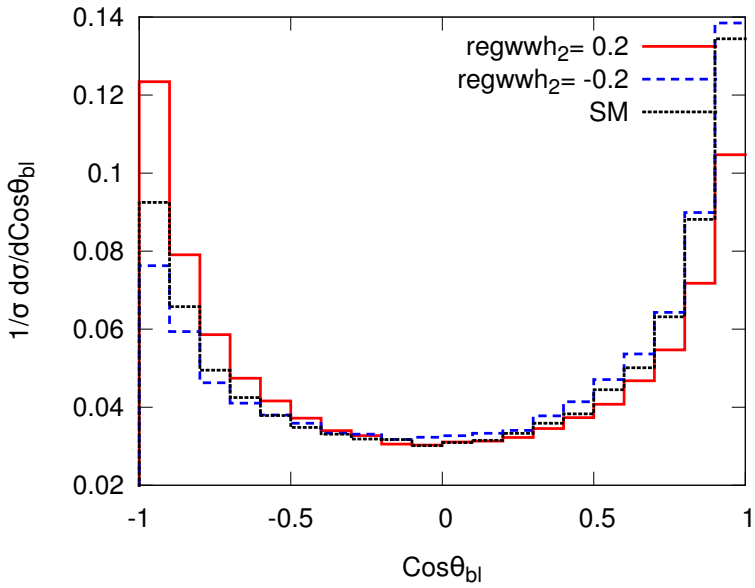


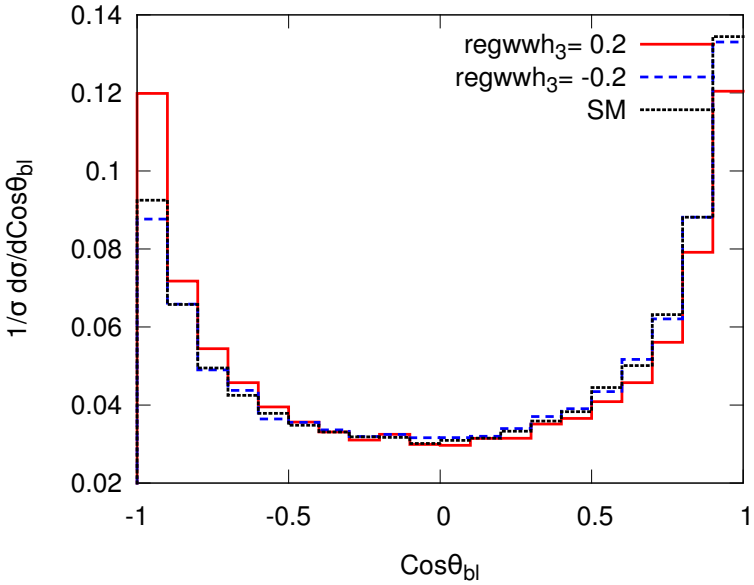


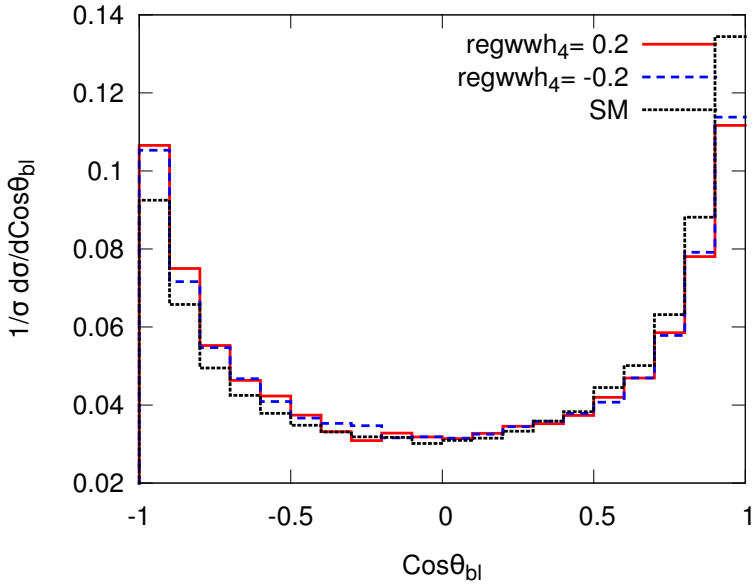


Polar Distribution in lab frame

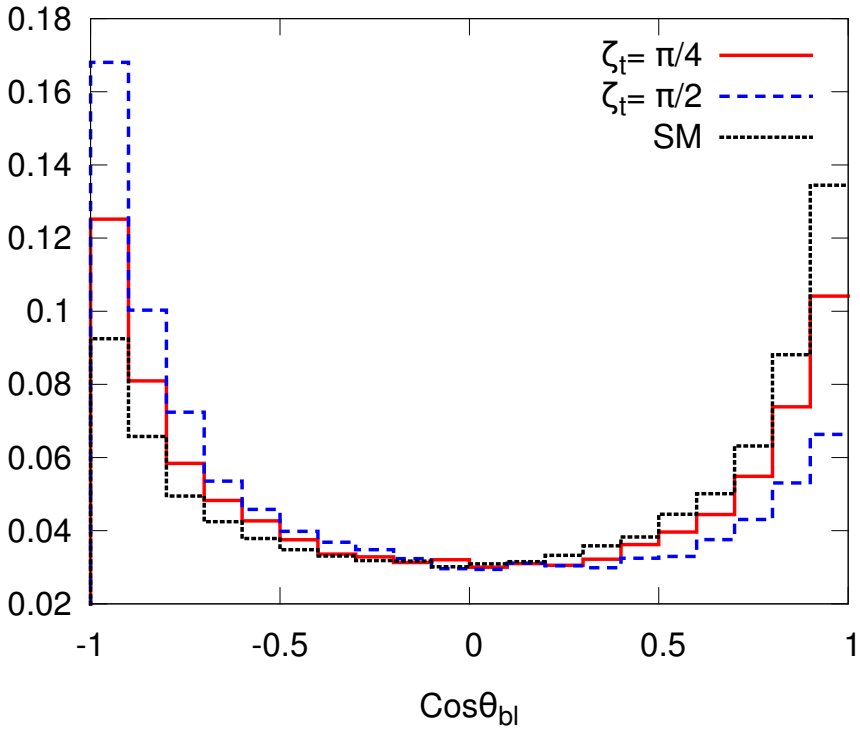


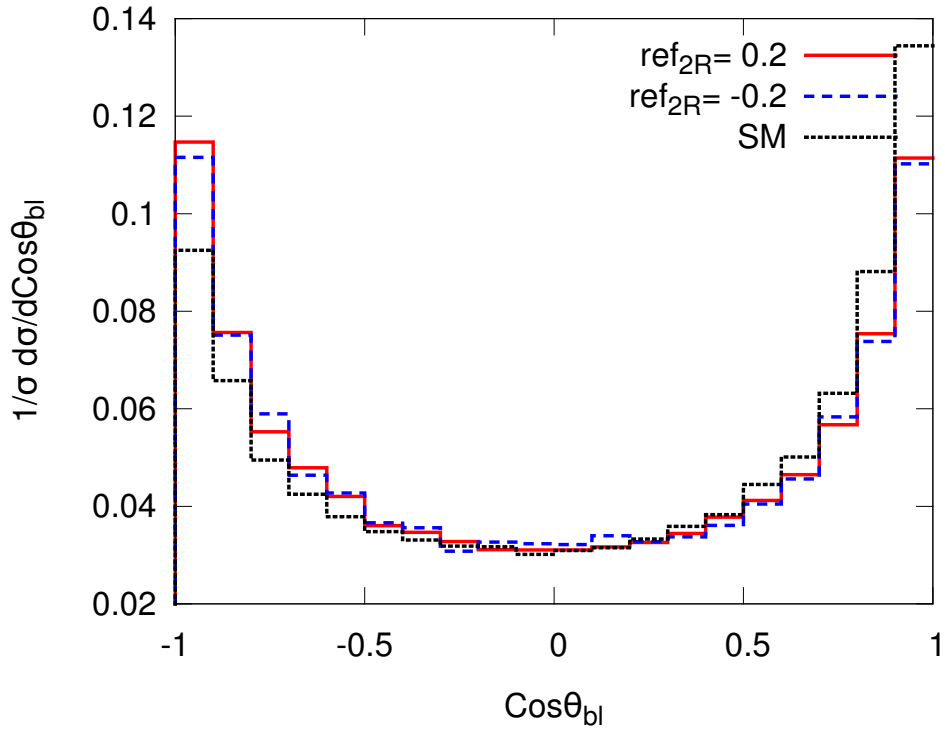




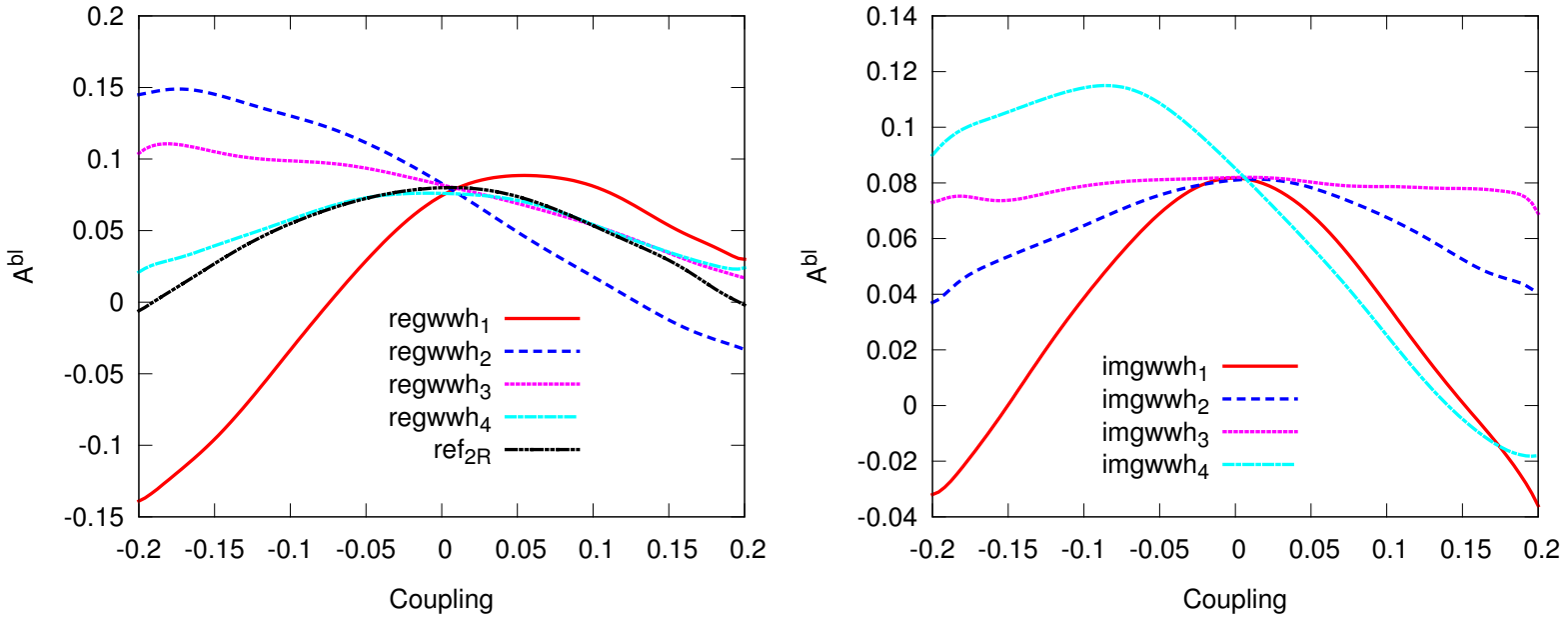


Polar Distribution in lab frame





Polar Asymmetry in lab frame



$\Rightarrow$ Sensitive to imaginary part of CP-odd $\mathbf{gwwh_4}$.