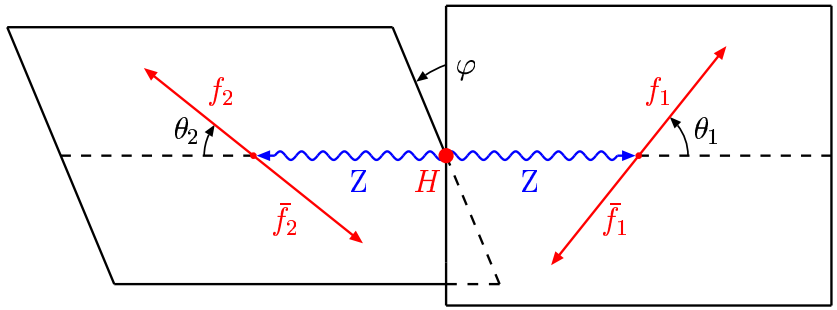
Sensitivity of the LHC to $\mathcal{CP}$ violating Higgs bosons

D.J.Miller, S.Moretti, MMM, R.Godbole

Ref.: Choi,Miller,MM,Zerwas, Phys.Lett.B553(2003)61

◇ Determination of spin and parity in

$$gg \to H \to ZZ^{(*)} \to (f_1\bar{f}_1)(f_2\bar{f}_2)$$



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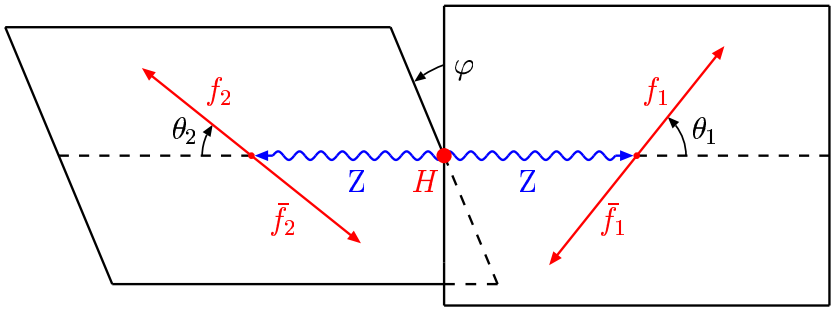

◇ Helicity methods $\rightsquigarrow$ arbitrary spin, parity

HZZ vertex: $\mathcal{J} = \frac{g_W M_Z}{\cos\theta_W} T_{\mu\nu\beta_1\ldots\beta_{\mathcal{J}}} \epsilon^*(Z_1)^\mu \epsilon^*(Z_2)^\nu \epsilon(H)^{\beta_1\ldots\beta_{\mathcal{J}}}$

◇ Double polar angular distribution ($\mathcal{CP}$ invariant theory)

$$\begin{aligned}\frac{d\Gamma_H}{d\cos\theta_1 d\cos\theta_2} \sim\ & \sin^2\theta_1 \sin^2\theta_2 |\mathcal{T}_{00}|^2 + \frac{1}{2}(1+\cos^2\theta_1)(1+\cos^2\theta_2)\left[|\mathcal{T}_{11}|^2 + |\mathcal{T}_{1,-1}|^2\right] \\ & +(1+\cos^2\theta_1)\sin^2\theta_2 |\mathcal{T}_{10}|^2 + \sin^2\theta_1 (1+\cos^2\theta_2)|\mathcal{T}_{01}|^2 \\ & +2\eta_1\eta_2\cos\theta_1\cos\theta_2\left[|\mathcal{T}_{11}|^2 - |\mathcal{T}_{1,-1}|^2\right]\end{aligned}$$

SM: $\mathcal{T}_{00} = M_H^2/(2M_Z^2) - 1,\ \mathcal{T}_{11} = -1,\ \mathcal{T}_{10} = \mathcal{T}_{01} = \mathcal{T}_{1,-1} = 0$

Determination of spin and parity - $\mathcal{CP}$ Violation

$M_H < 2M_Z$	$M_H > 2M_Z$
$d\Gamma/dM_*^2 \sim \beta$ for $\mathcal{J}^{\mathcal{P}} = 0^+$, rules out $\mathcal{J}^{\mathcal{P}} = 0^-, 1^-, 2^-, 3^\pm, 4^\pm$	$\mathcal{J}^{\mathcal{P}} = 0^-, 1^\pm, 2^-, 3^\pm, ...$ excluded by non-zero $\sin^2\theta_1 \sin^2\theta_2$
no $[1+\cos^2\theta_1]\sin^2\theta_2$, $[1+\cos^2\theta_2]\sin^2\theta_1$ rules out $\mathcal{J}^{\mathcal{P}} = 1^+, 2^+$	$\frac{d\sigma}{d\cos\theta}[gg/\gamma\gamma \to H \to ZZ]$ only isotropic for spin 0 rules out $\mathcal{J}^{\mathcal{P}} = 2^+, 4^+$

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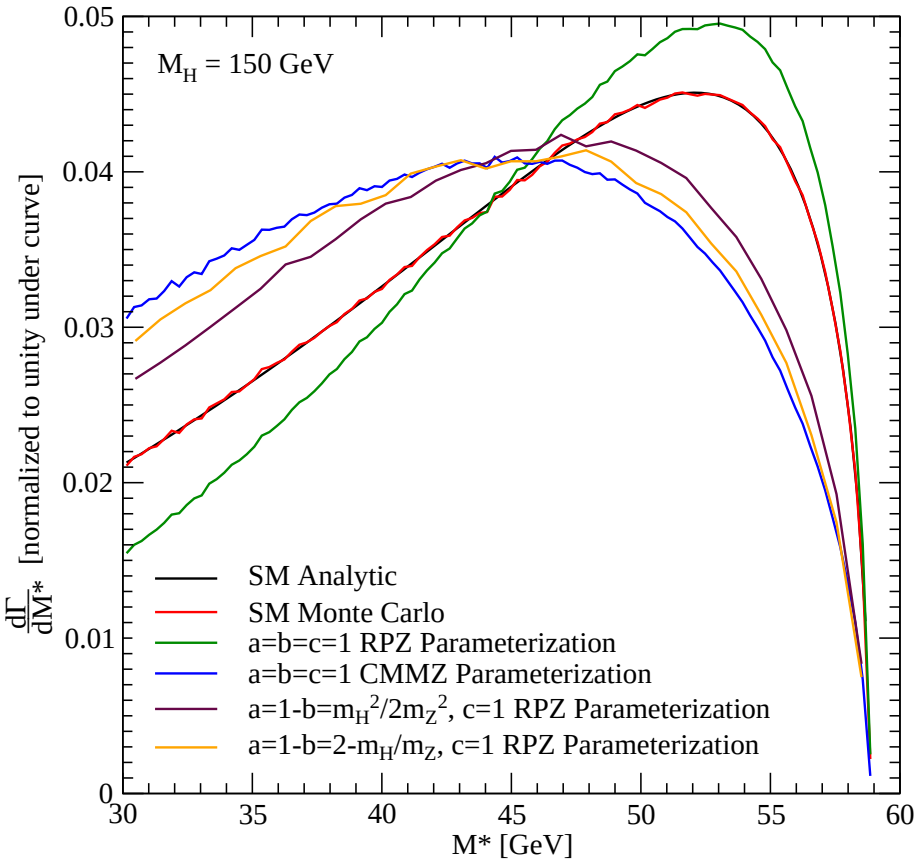
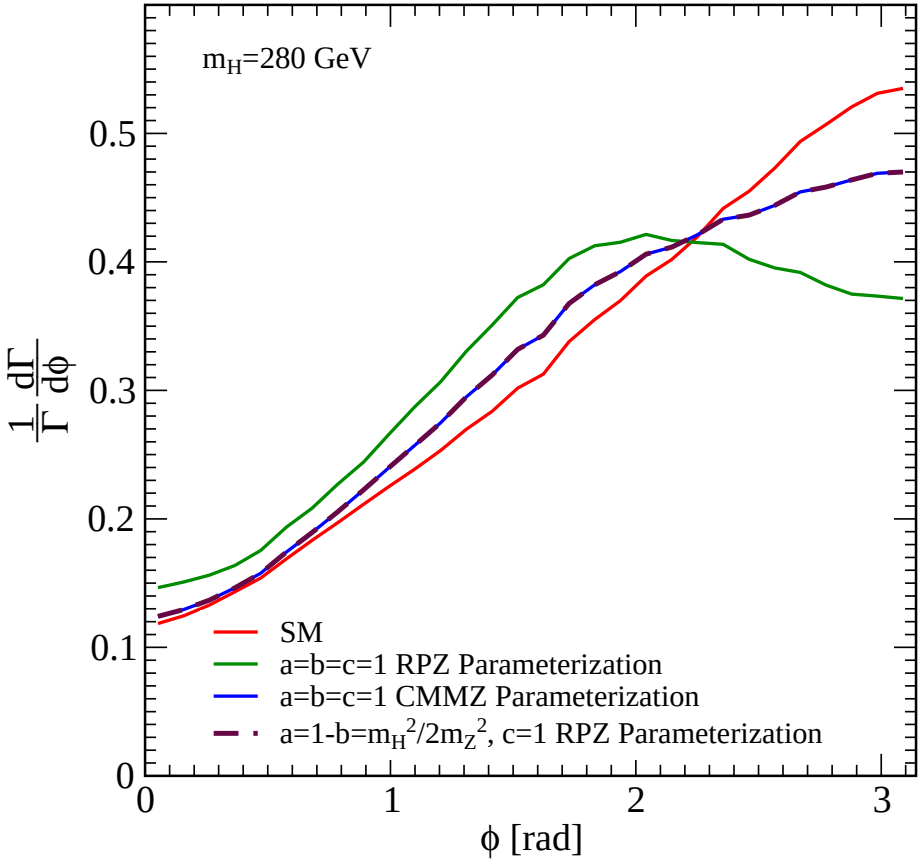
- **$\mathcal{CP}$ Violation:** $\mathcal{M}$ost general vertex = $\mathcal{S}$um of even and odd normality tensors
- **$\mathcal{C}$ase spin 0:** $p = p_{Z_1} + p_{Z_2}$, $k = p_{Z_1} - p_{Z_2}$, Vertex HZZ

$$\frac{igM_Z}{\cos\theta_W}\left[\, a\, g_{\mu\nu} + \frac{b}{M_Z^2}\, p_\mu p_\nu + i\, \frac{c}{M_Z^2}\, \epsilon_{\mu\nu\alpha\beta}\, p^\alpha k^\beta\right]$$

Parameterization RPZ: $\frac{igM_Z}{\cos\theta_W}\left[\, a\, g_{\mu\nu} + b\,(g_{\mu\nu} - \frac{4p_\mu p_\nu}{p^2-k^2}) + i\, \frac{c}{M_Z^2}\, \epsilon_{\mu\nu\alpha\beta}\, p^\alpha k^\beta\right]$

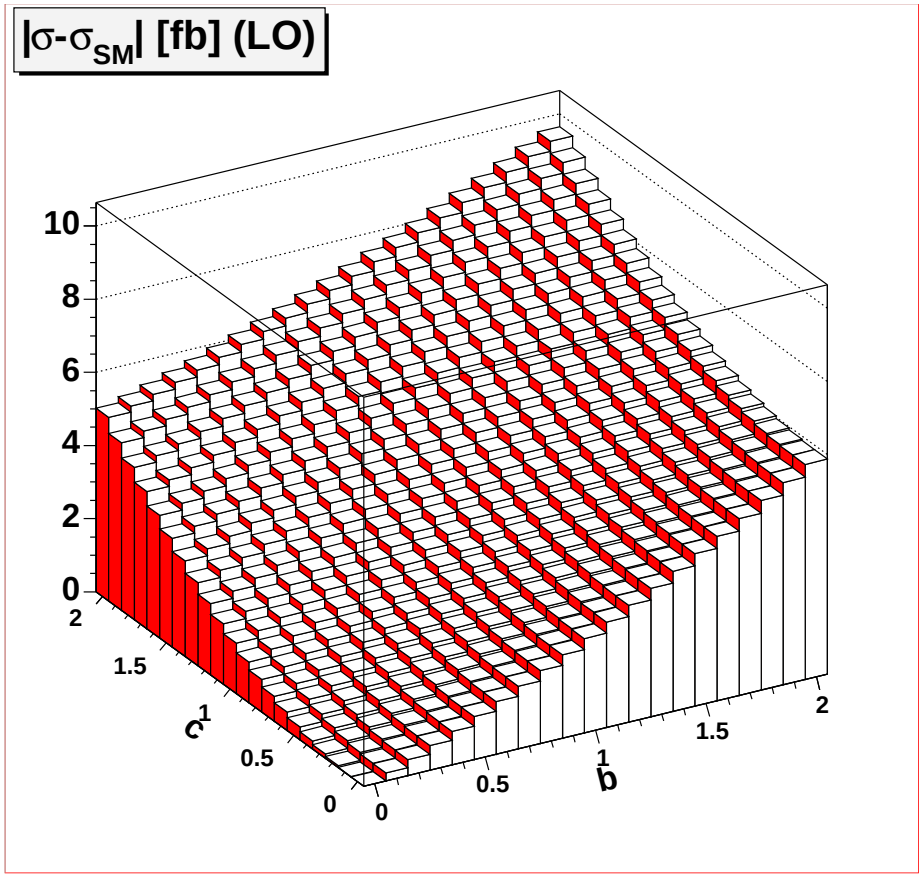
Distributions

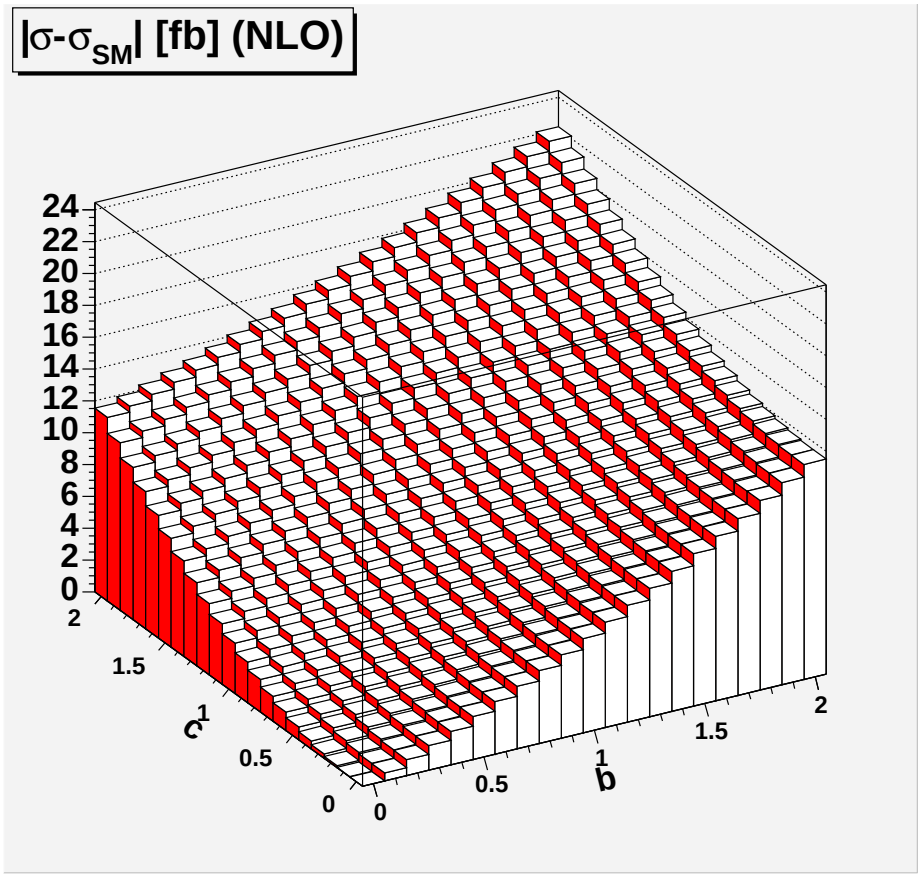




Scatter plots

For $gg \to H \to ZZ^* \to llll,\ l = e, \mu$ calculate $[\sigma(a = 1, b, c \neq 0) - \sigma^{\mathrm{SM}}(a = 1, b = c = 0)]$





Next steps

- ♣ $\mathcal{C}$alculate $\sigma(gg \to H \to ZZ^* \to llll)$ for $\mathcal{J} = 1,2$
- ♣ $\mathcal{S}$tudy various $\mathcal{CP}$ violating models to put values for b,c
- ♣ $\mathcal{S}$tart experimental simulation to extract sensitivity of the LHC to $\mathcal{CP}$ violation in $H \to ZZ^{(*)}$