Characterisation of the Higgs-top interaction

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Outline

EFT approach to Higgs Characterisation

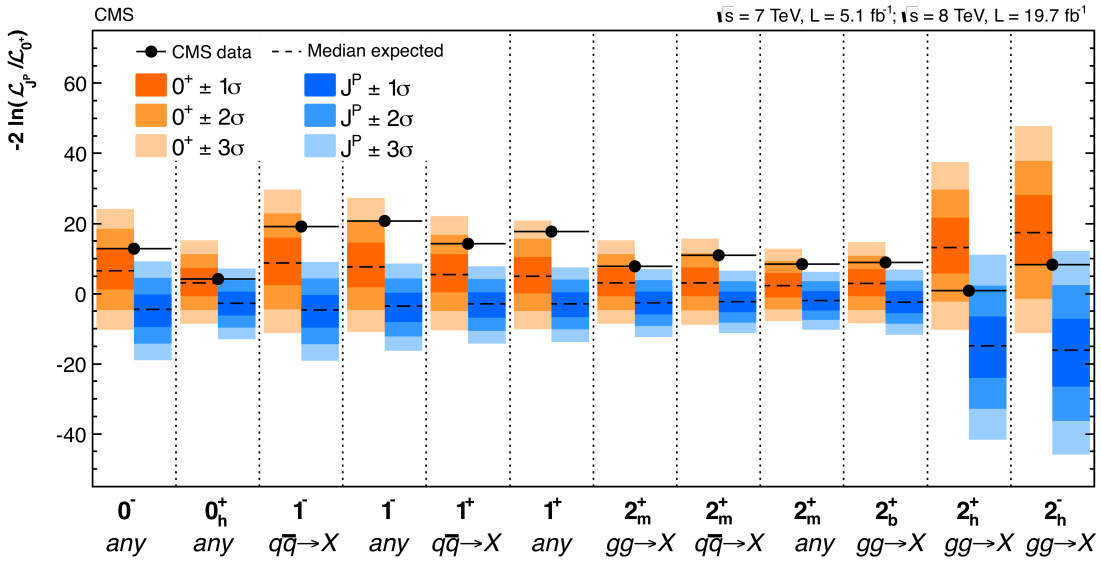
- Motivation and first measurements
- Higgs-top Yukawa EFT Lagrangian
- EFT Lagrangian for Gluon Fusion

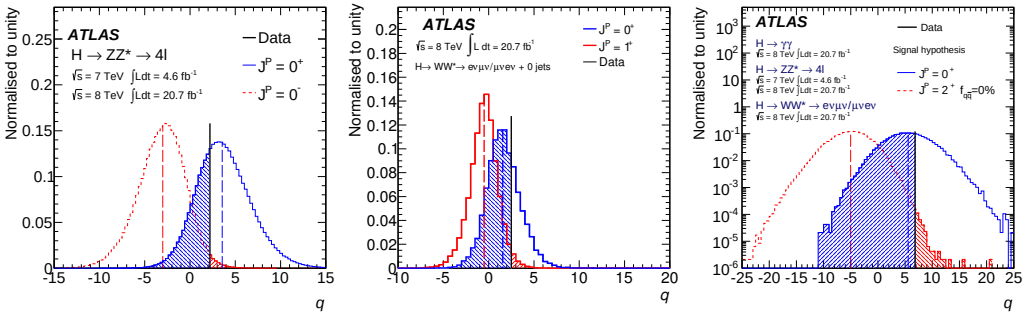
Play the HC game at the LHC

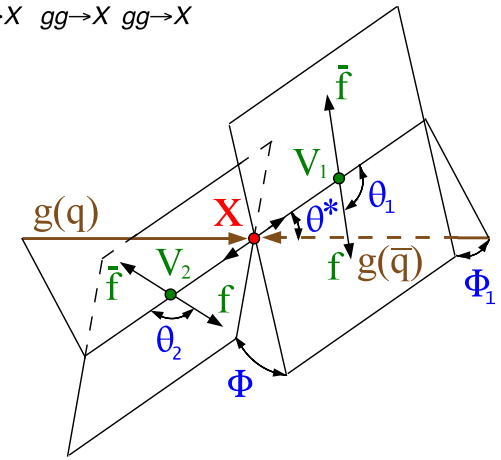
- Gluon Fusion H+2jets production
- $t\bar{t}H$ production
- t-channel tH production

Higgs EFT investigation of J^{CP} properties

used to exclude $J = 1$, 2 and pure pseudoscalar 0^-



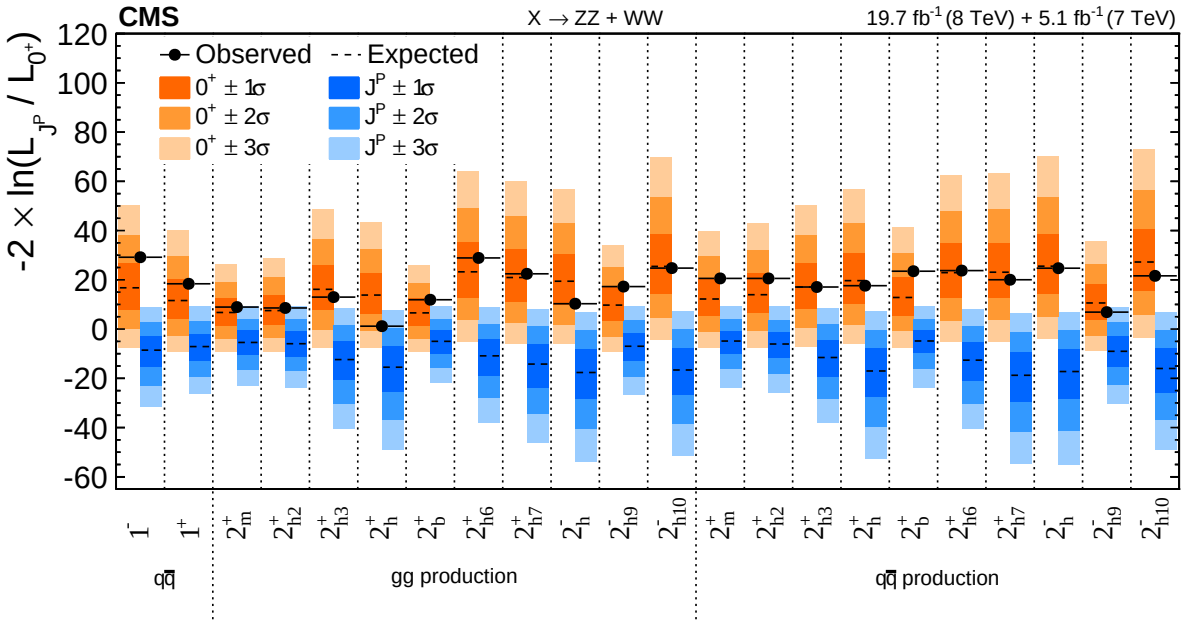


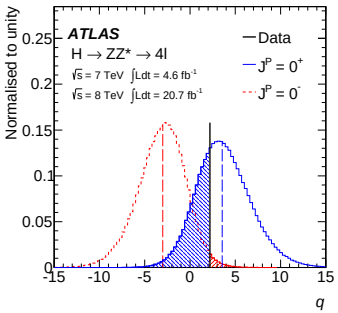


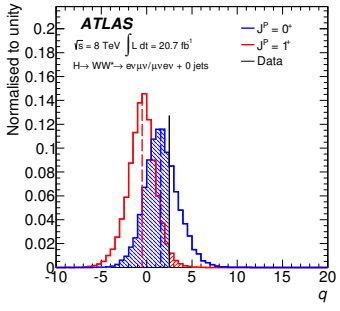
All in the $H \to VV^{(*)}$ decay channels!

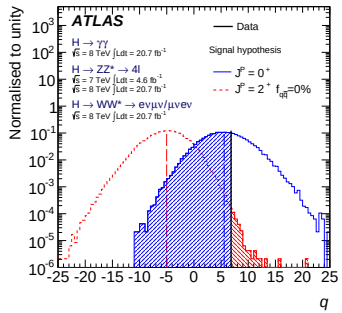
Higgs EFT investigation of J^{CP} properties

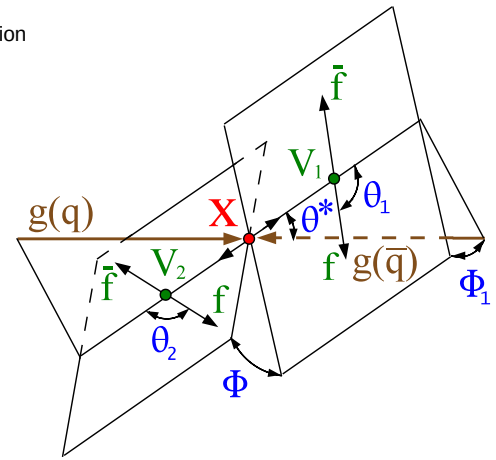
used to exclude $J = 1, 2$ and pure pseudoscalar 0^-







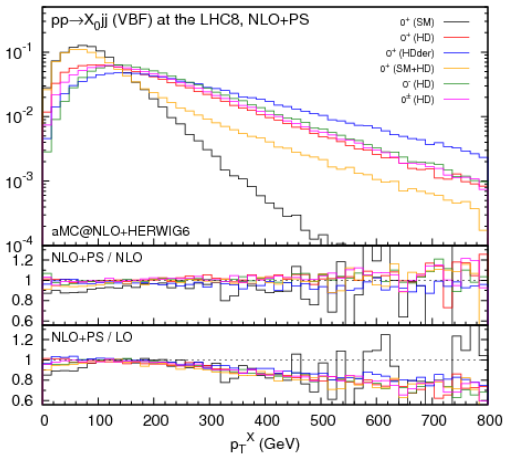


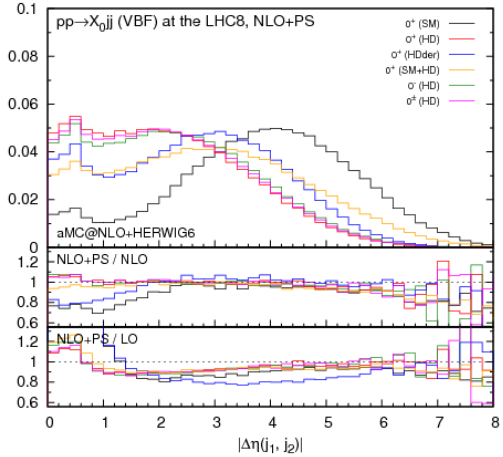


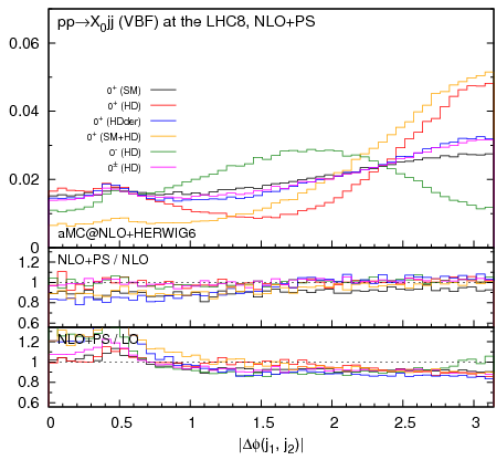
All in the $H \to VV^{(*)}$ decay channels!

$V^*V^* \to H$ production (VBF) for spin-0

$$\mathcal{L}_0^V = \Big\{ c_\alpha \kappa_{\rm SM} \big[\frac{1}{2} g_{HZZ}\, Z_\mu Z^\mu + g_{HWW}\, W^+_\mu W^{-\mu}\big] - \frac{1}{4}\big[c_\alpha \kappa_{H\gamma\gamma} g_{H\gamma\gamma}\, A_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{A\gamma\gamma} g_{A\gamma\gamma}\, A_{\mu\nu} \widetilde{A}^{\mu\nu}\big]$$
$$- \frac{1}{2}\big[c_\alpha \kappa_{HZ\gamma} g_{HZ\gamma}\, Z_{\mu\nu} A^{\mu\nu} + s_\alpha \kappa_{AZ\gamma} g_{AZ\gamma}\, Z_{\mu\nu} \widetilde{A}^{\mu\nu}\big] - \frac{1}{4}\big[c_\alpha \kappa_{Hgg} g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} + s_\alpha \kappa_{Agg} g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}\big]$$
$$- \frac{1}{4}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HZZ}\, Z_{\mu\nu} Z^{\mu\nu} + s_\alpha \kappa_{AZZ}\, Z_{\mu\nu} \widetilde{Z}^{\mu\nu}\big] - \frac{1}{2}\frac{1}{\Lambda}\big[c_\alpha \kappa_{HWW}\, W^+_{\mu\nu} W^{-\mu\nu} + s_\alpha \kappa_{AWW}\, W^+_{\mu\nu} \widetilde{W}^{-\mu\nu}\big]$$
$$- \frac{1}{\Lambda} c_\alpha \big[\kappa_{H\partial\gamma}\, Z_\nu \partial_\mu A^{\mu\nu} + \kappa_{H\partial Z}\, Z_\nu \partial_\mu Z^{\mu\nu} + (\kappa_{H\partial W}\, W^+_\nu \partial_\mu W^{-\mu\nu} + h.c.)\big] \Big\} X_0$$

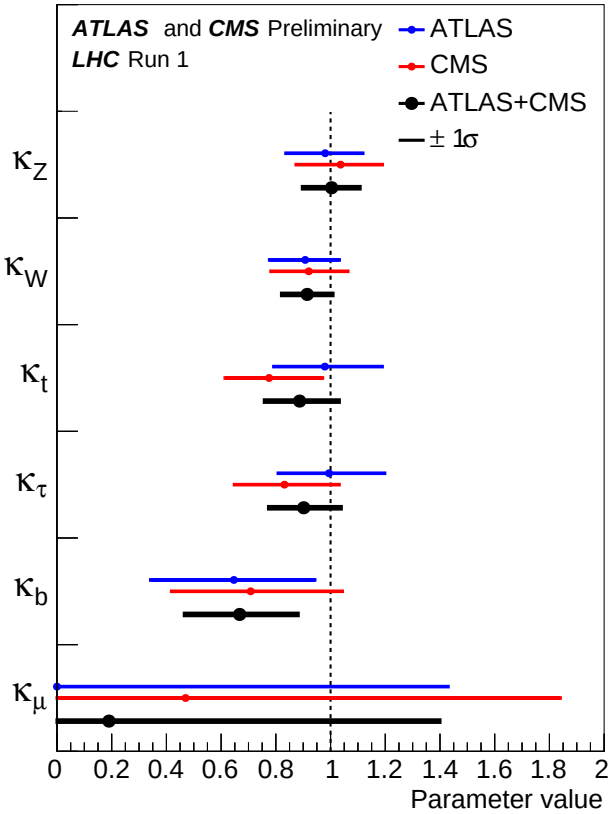


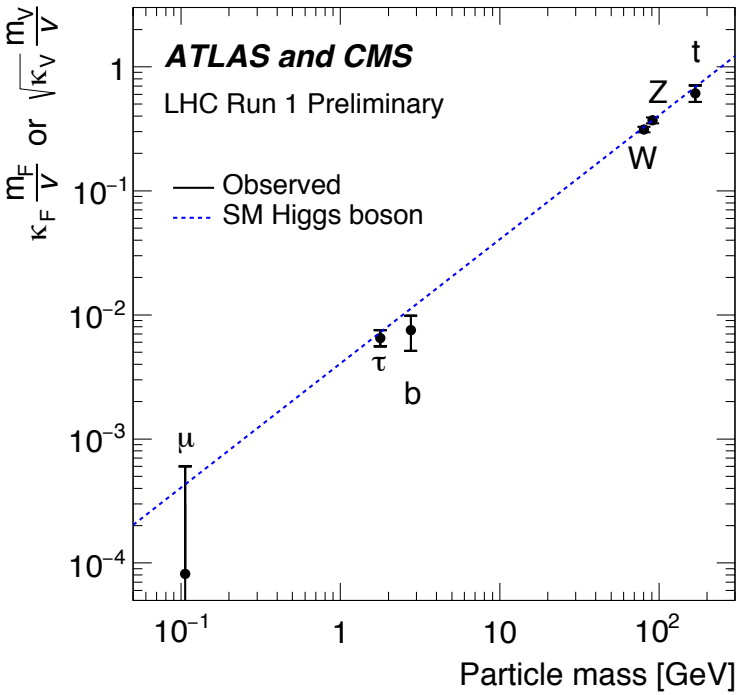




F. Maltoni, K. Mawatari, M. Zaro [arXiv:1311.1829]

What about interaction with fermions?





Only coupling strenght measurements

More thorough study during LHC run II, especially $t\bar{t}H$

Effective Lagrangian for top quark Yukawa

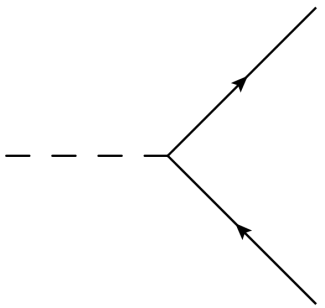
$\mathcal{L}_{SM} \sim -\frac{m_t}{v}\,\bar{Q}_L \cdot \Phi t_R + h.c.\,, \quad \mathcal{L}_6 \sim -\frac{1}{\Lambda^2}\,\Phi^\dagger\Phi\,\bar{Q}_L \cdot \Phi\, t_R + h.c.$

for single Higgs processes, put all $\Phi = v$ except one $\Phi = X_0$

and (easily) pass from gauge to mass basis

$$\mathcal{L}_0^t = -\bar{\psi}_t \frac{m_t}{v}\left(c_\alpha \kappa_{Htt} + i s_\alpha \kappa_{Att}\,\gamma_5\right)\psi_t\, X_0\,,$$

$J^{CP} = 0^+$ (SM operator) $\qquad J^{CP} = 0^-$



$\alpha =$ CP-mixing angle

$\kappa =$ Coupling strength modifier

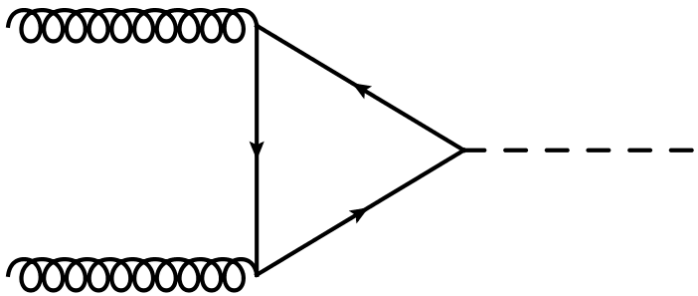
SM $\rightarrow$ $(c_\alpha = 1,\ \kappa_{Htt} = 1)$

Effective Lagrangian for Gluon Fusion

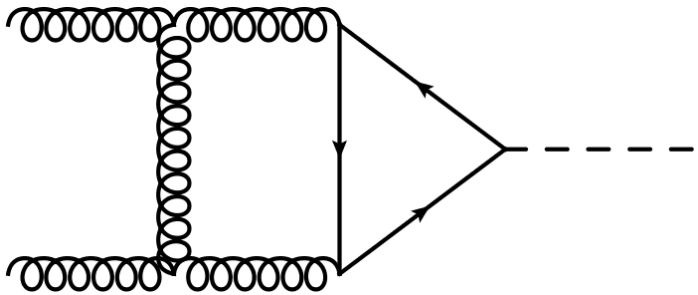
Problem: GF is loop-induced

NLO virtual is 2-loop $\Rightarrow$ not automated!

LO

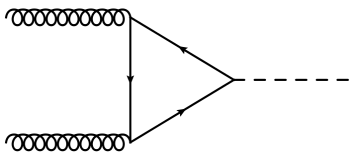


NLO virtual



Effective Lagrangian for Gluon Fusion

Solution: use EFT! Assume top heavier than GF external states
This is an example of SM EFT for scales $< 2m_t$

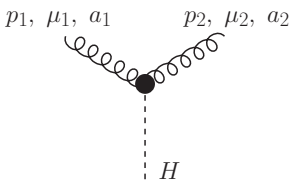


$$= i\frac{\alpha_S}{3\pi v}\delta^{a_1 a_1}\left(p_2^{\mu_1}p_1^{\mu_2} - g^{\mu_1\mu_2}p_1\cdot p_2\right)\times F\left(\frac{m_H^2}{2m_t^2}\right) \qquad F(0)=1$$

no decoupling!

Match to H-gluons effective Lagrangian

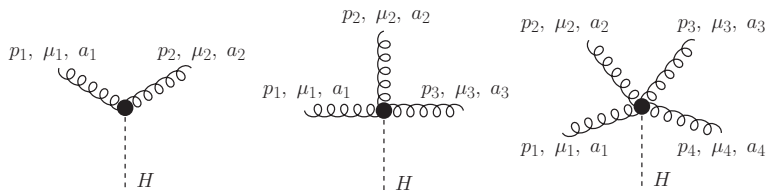
$$\mathcal{L}_{H-glu} = -\frac{1}{4}\,g_{Hgg}\,G^a_{\mu\nu}G^{a,\mu\nu}H\,, \quad g_{Hgg} = -\frac{\alpha_S}{3\pi v}$$

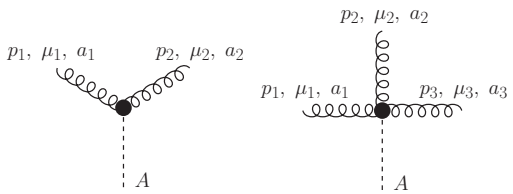


$$= -i\,g_{Hgg}\,\delta^{a_1 a_2}\left(p_2^{\mu_1}p_1^{\mu_2} - g^{\mu_1\mu_2}\,p_1\cdot p_2\right)$$

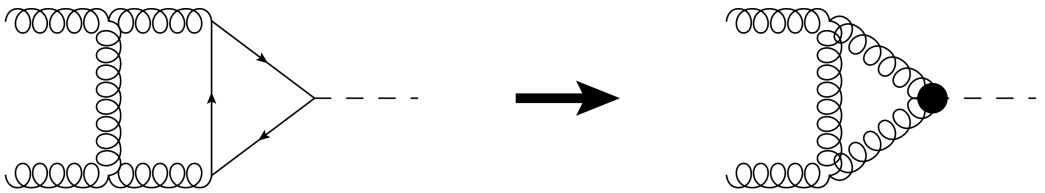
Effective Lagrangian for Gluon Fusion

$$\mathcal{L}_0^{glu} = -\frac{1}{4}\left[c_\alpha\, \kappa_{Hgg}\, g_{Hgg}\, G^a_{\mu\nu} G^{a,\mu\nu} \quad + \quad s_\alpha\, \kappa_{Agg}\, g_{Agg}\, G^a_{\mu\nu} \widetilde{G}^{a,\mu\nu}\right] X_0$$

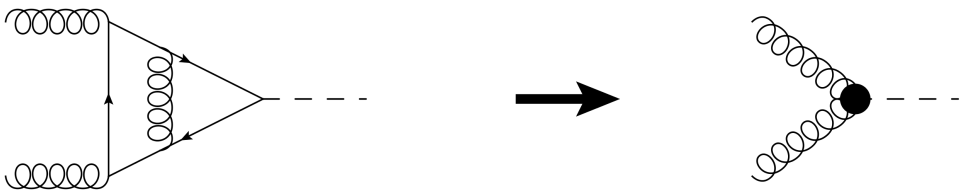




Going to NLO



appear explicitly in the EFT



$$g_{Hgg} \to g_{Hgg}\left(1 + \frac{11}{4}\frac{\alpha_s}{\pi} + \mathcal{O}\left(\alpha_s^2\right)\right),$$

$$g_{Agg} = \frac{\alpha_s}{2\pi v} \quad \text{to all orders in } \alpha_s$$

Code Feynman rules, UV and R2 counterterms
in UFO model `HC_NLO_X0` (public)

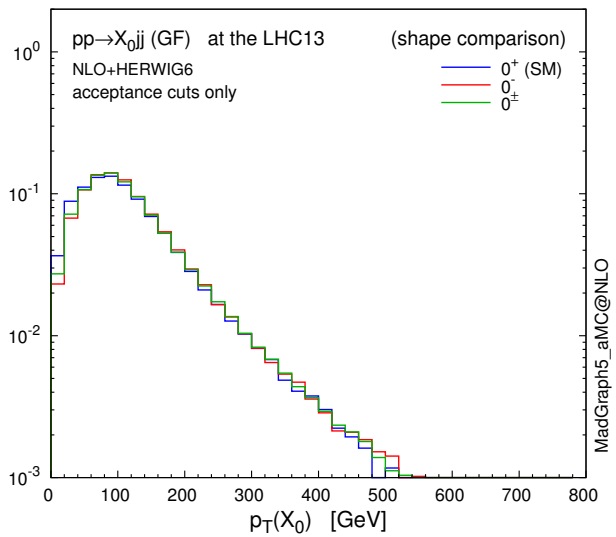
UFO $\Rightarrow$ `MG5_aMC@NLO` $\Rightarrow$ Results

Ready to play the HC game!
(i.e. study the top-quark Yukawa in production channels)

The Higgs Characterisation game

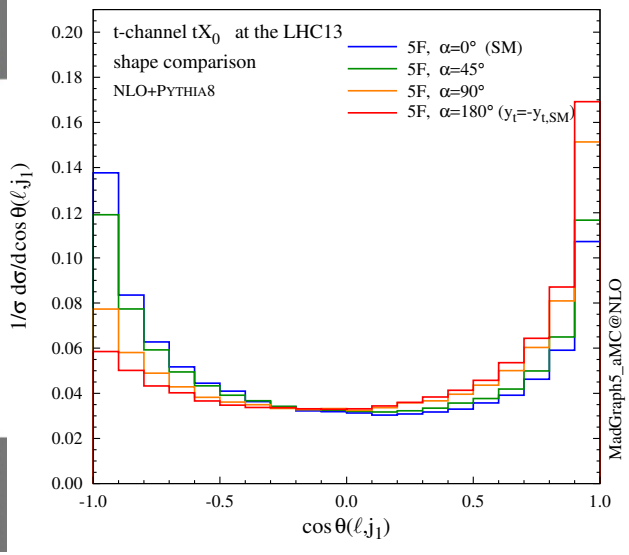
The Higgs Characterisation game

Is he bald? $\Leftrightarrow$ p_T distribution in GF



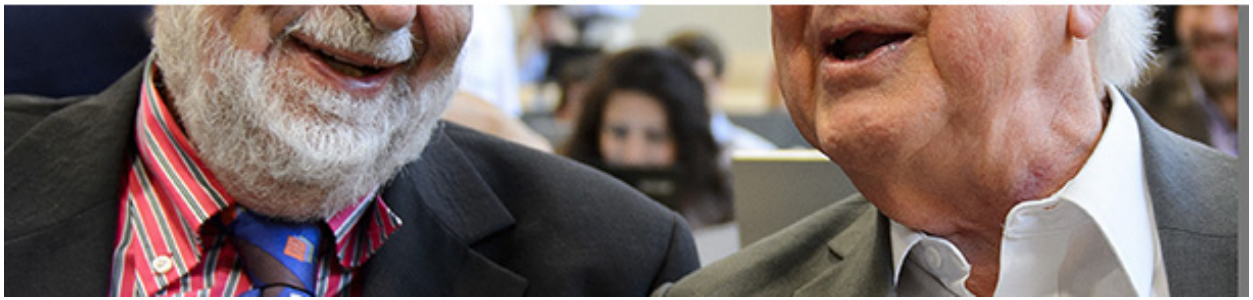
The Higgs Characterisation game

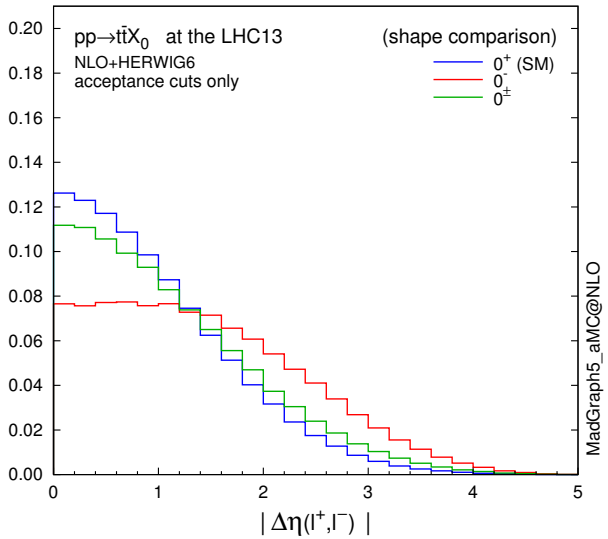
Colorful dress? $\Leftrightarrow \cos\theta_{\ell j}$ in tH



The Higgs Characterisation game

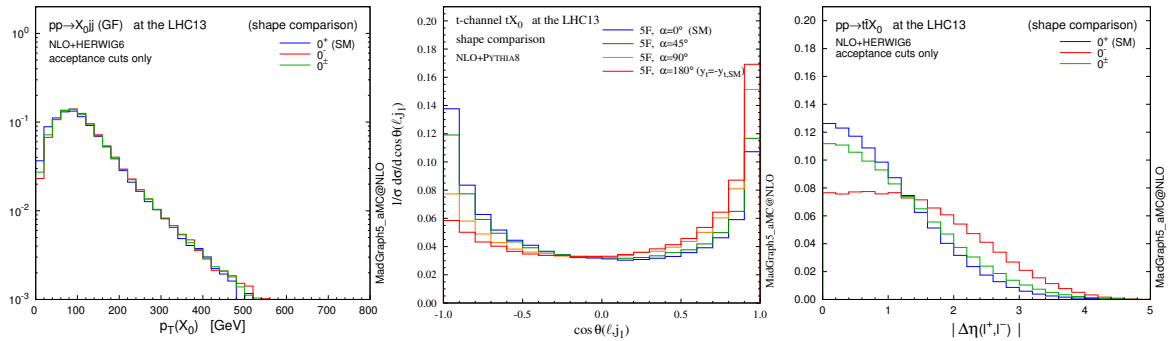
Does he have a beard? $\Leftrightarrow \Delta\eta_{\ell\ell}$ in $t\bar{t}H$





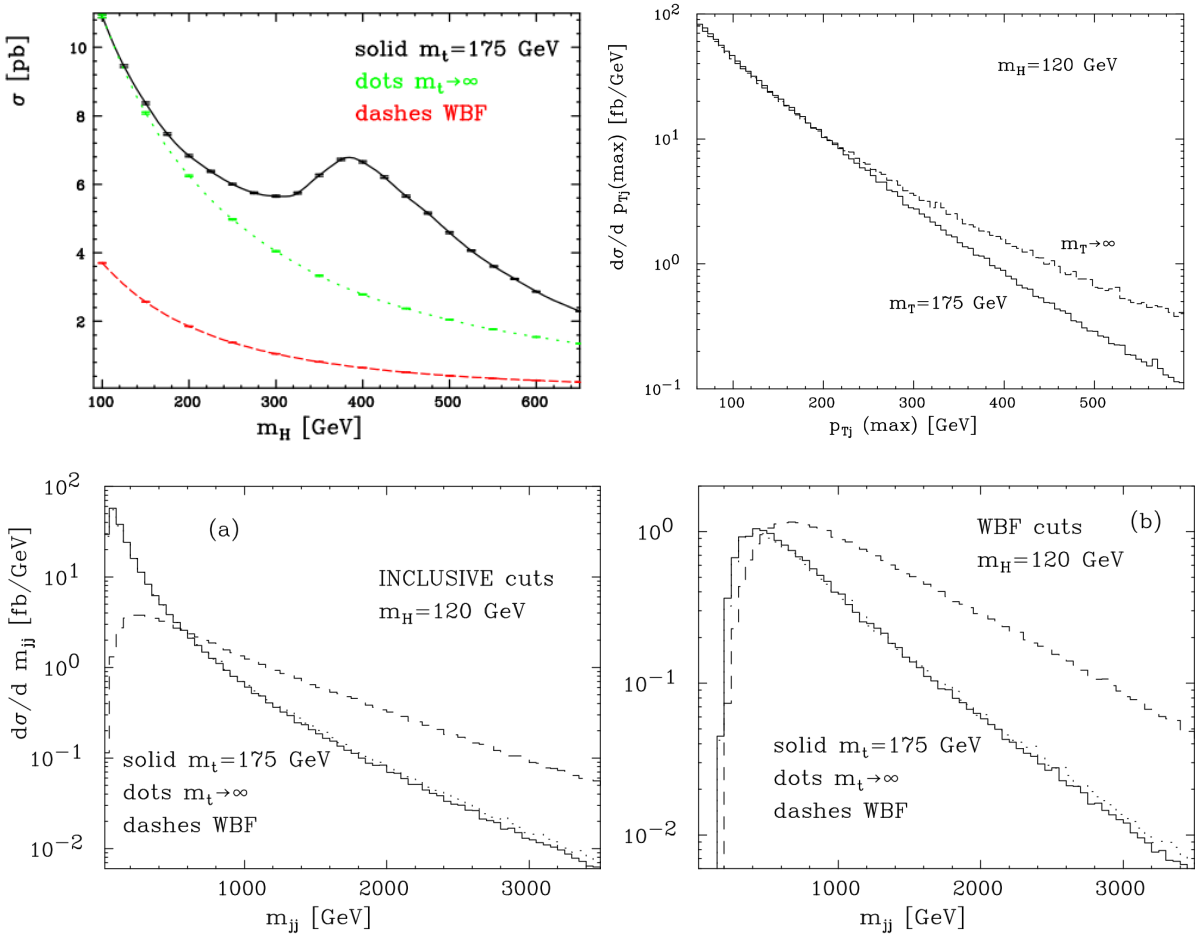
The Higgs Characterisation game

not him! The Higgs!



Gluon Fusion H+2jets production

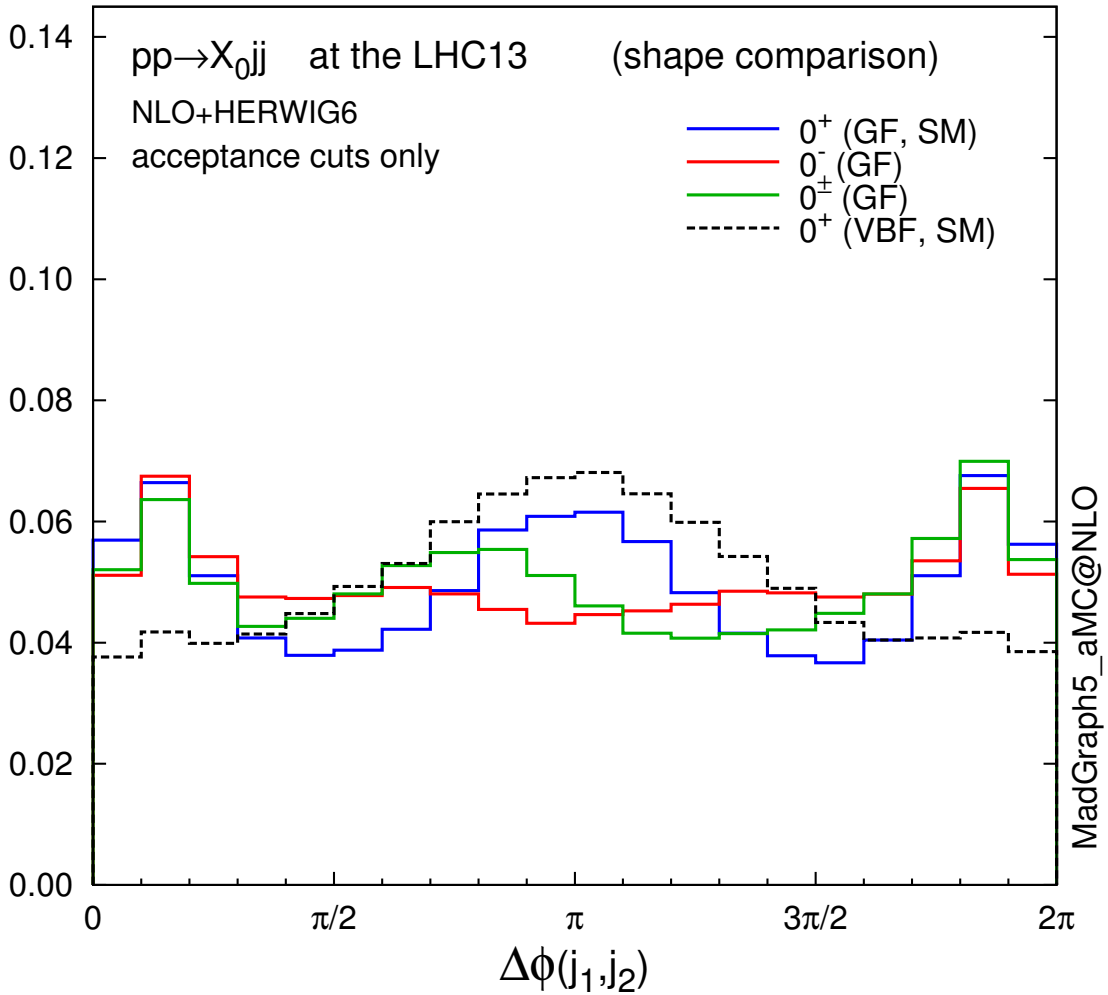
FD, F. Maltoni, K. Mawatari, B. Page, M. Zaro [arXiv:1407.5089]

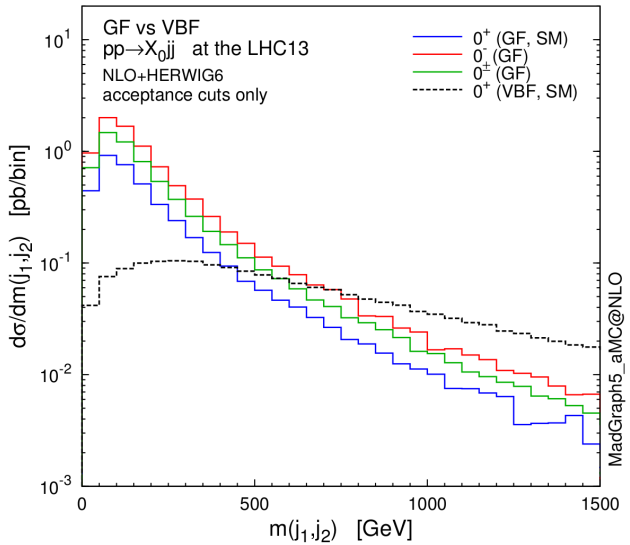


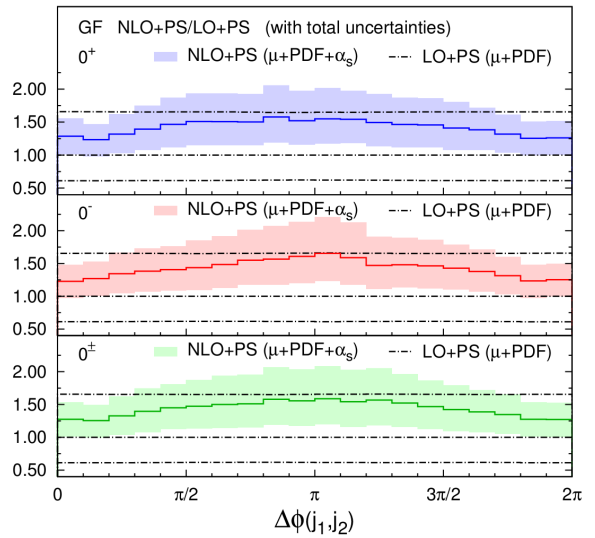
(vintage plots from a ton of papers by Del Duca, Oleari, Zeppenfeld et al., since 2001)

GF H+2jets

$$p_T^j > 30 \text{ GeV}, \quad |\eta^j| < 4.5$$

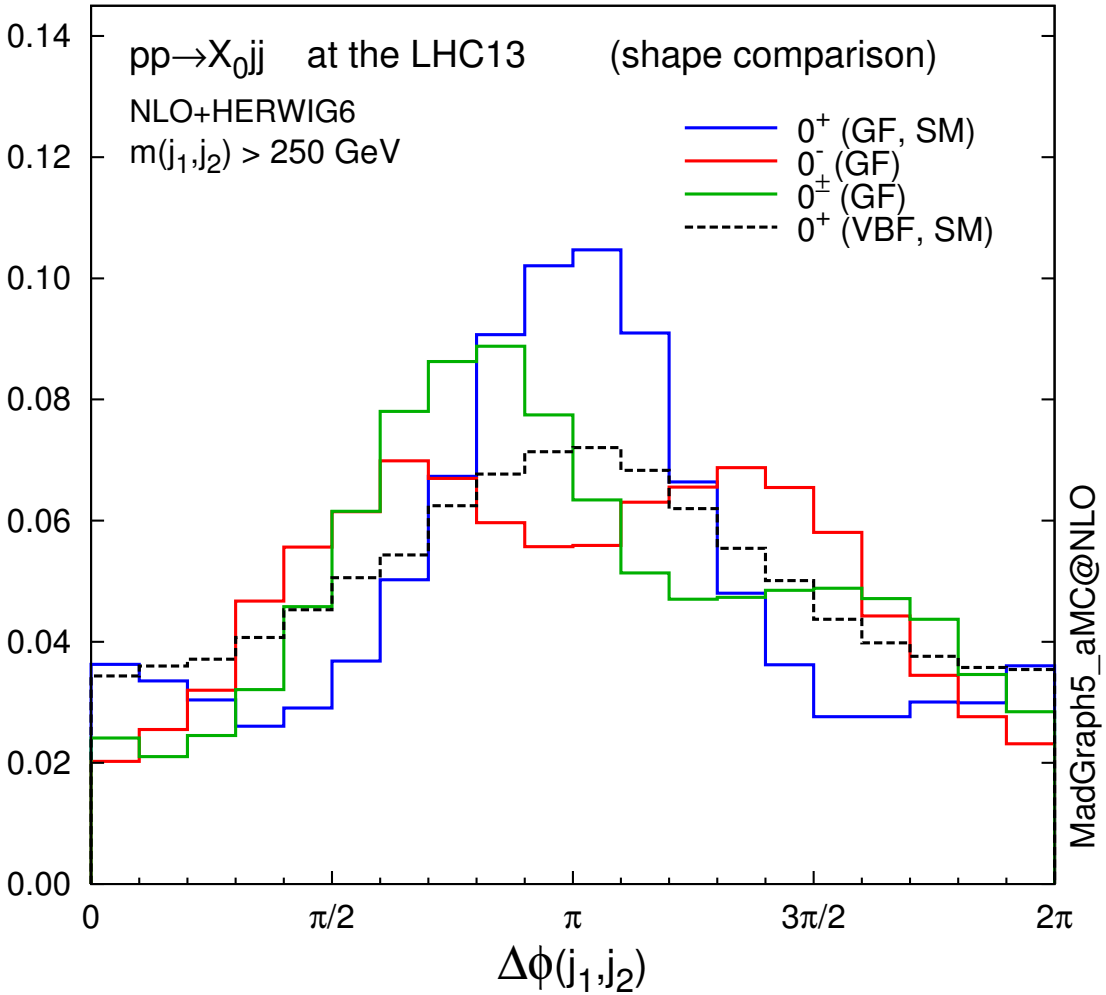


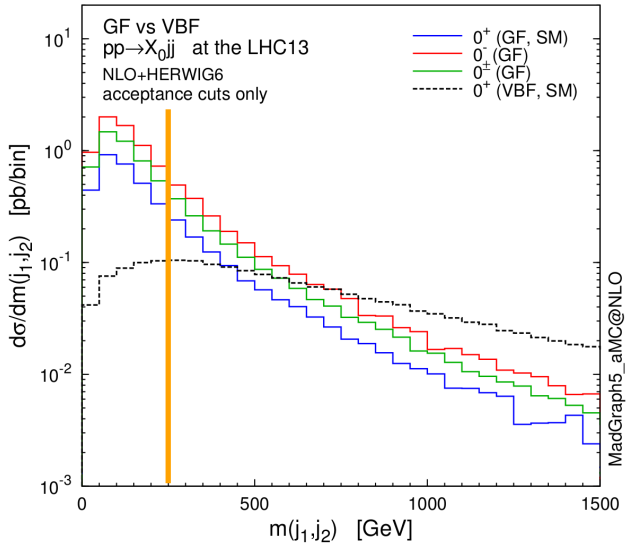


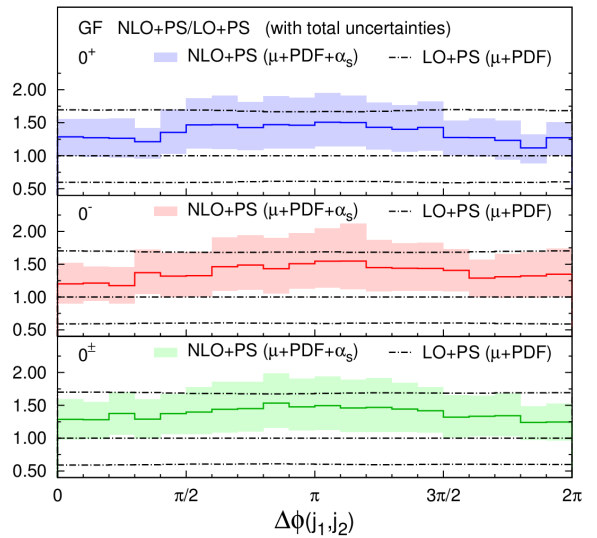


GF H+2jets

$m_{jj} > 250$ GeV



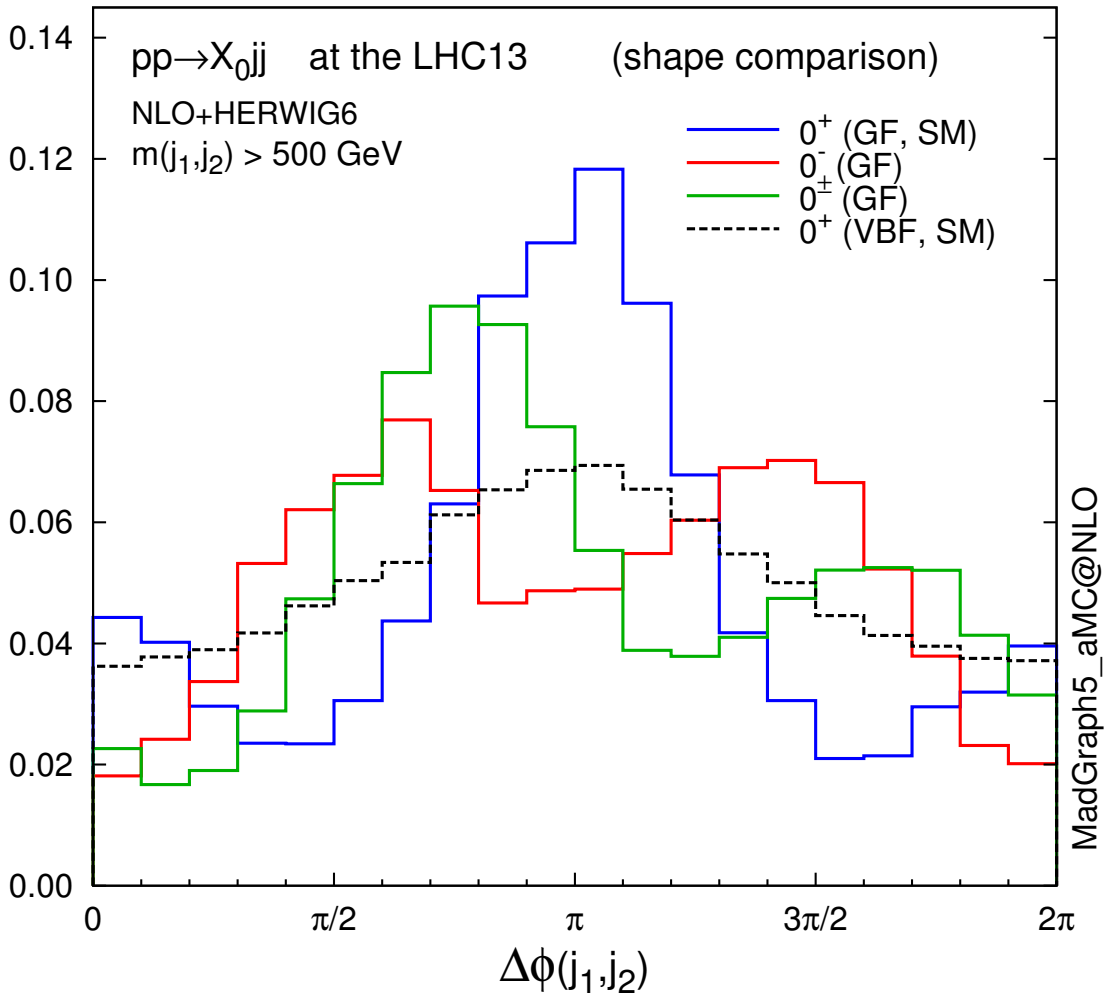


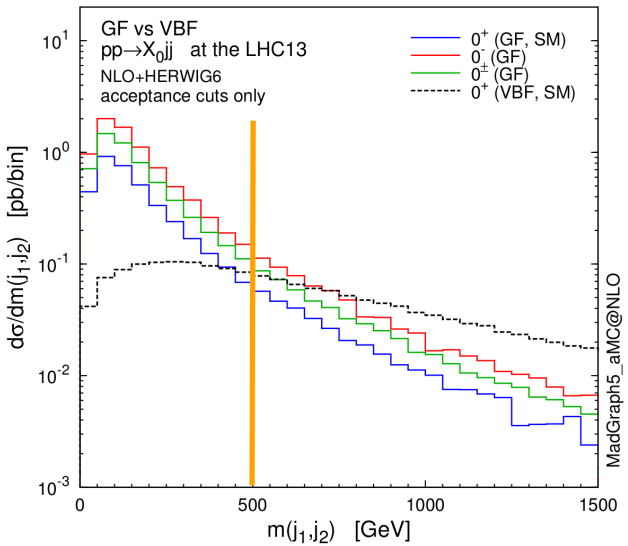


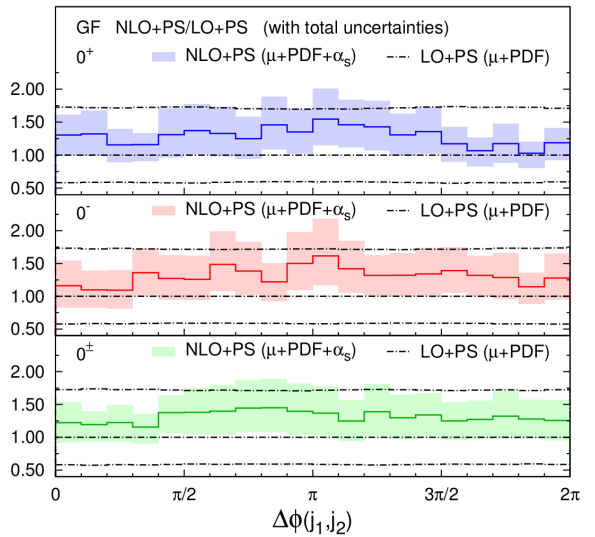
SM VBF modulation doesn't change

GF H+2jets

$m_{jj} > 500$ GeV





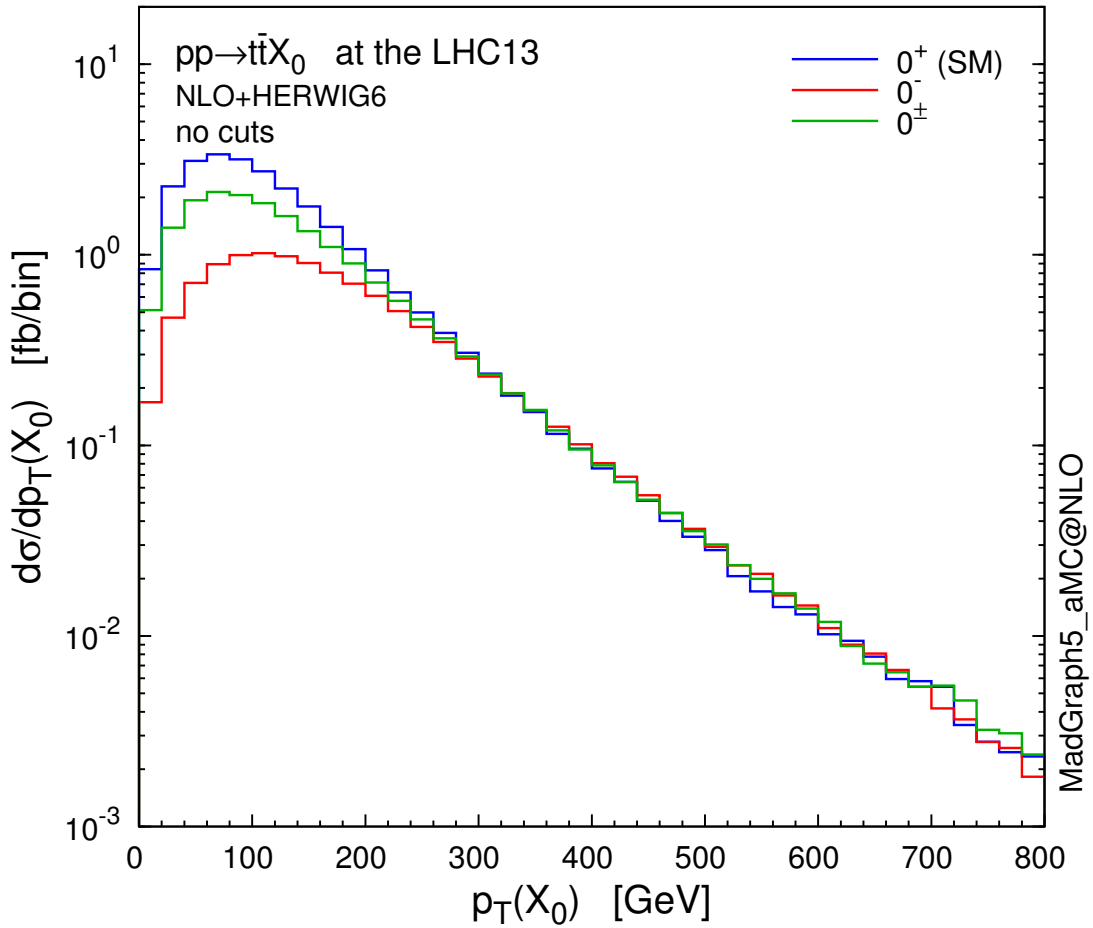


$\Delta\phi_{jj}$ analogous to BSM interaction in VBF
(see e.g. [hep-ph/0312184], [hep-ph/0703202] or [arXiv:1212.0843])

$t\bar{t}H$ production

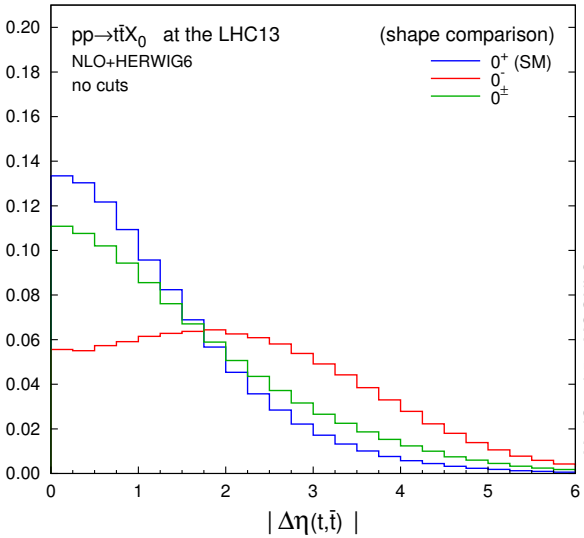
FD, F. Maltoni, K. Mawatari, B. Page, M. Zaro [arXiv:1407.5089]

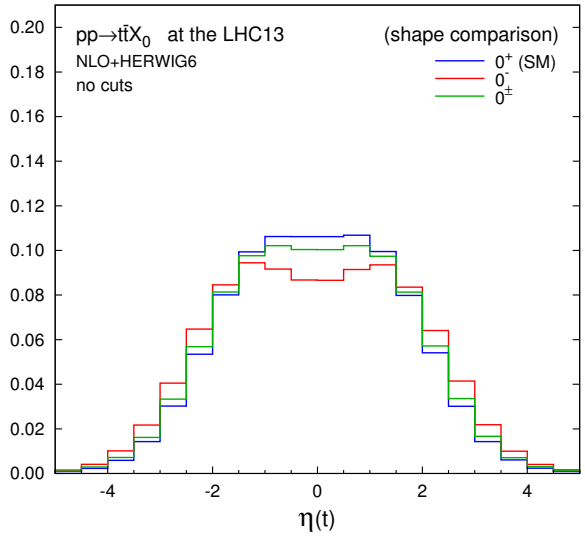
Can a boosted-Higgs analysis ($H \to b\bar{b}$, $p_T(X_0) > 200$ GeV) be sensitive to CP?

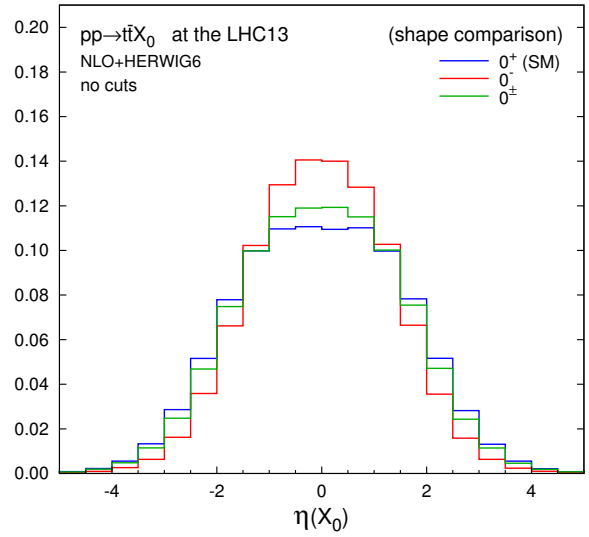


undecayed top quarks

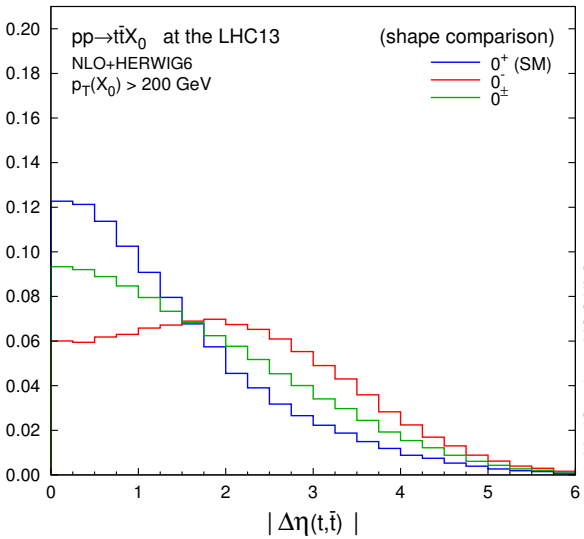
no cuts

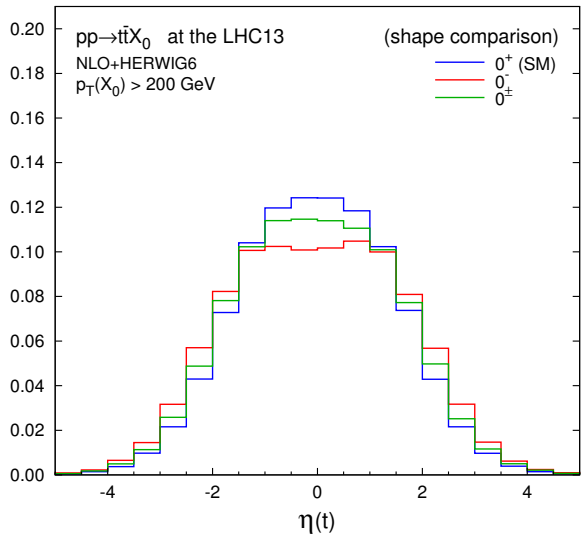


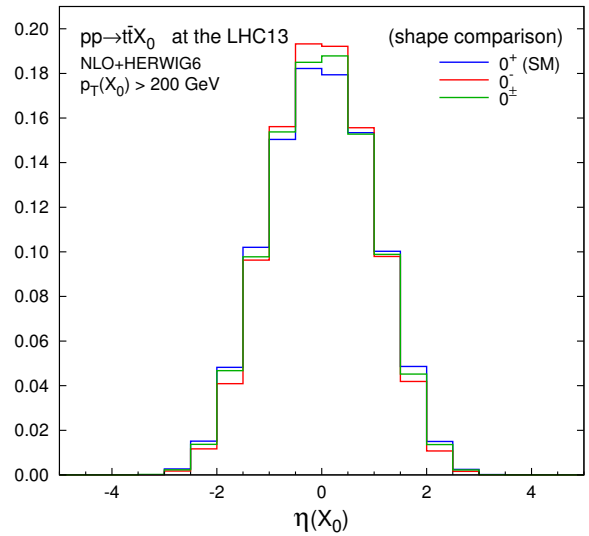




$p_T^H > 200$ GeV

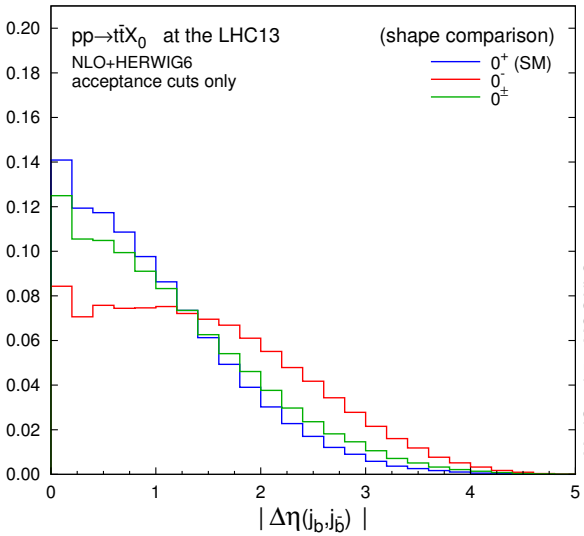


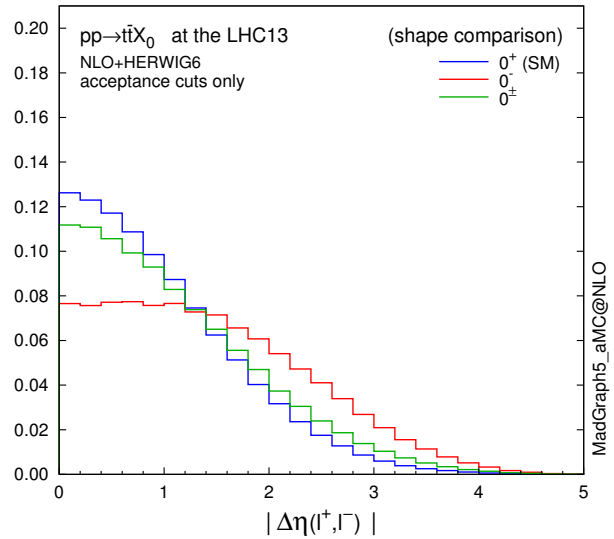


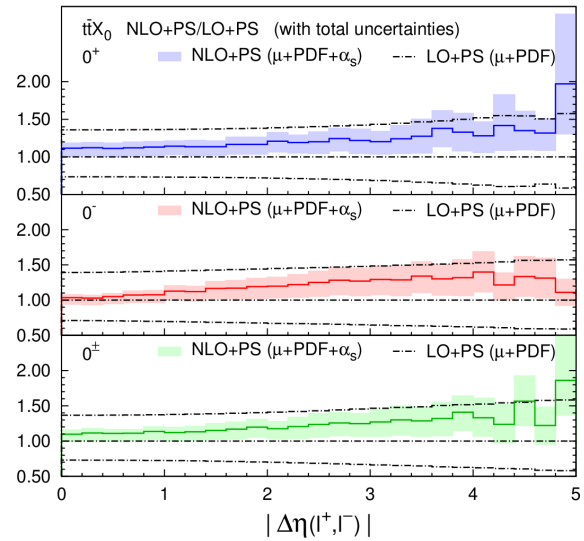


$t\bar{t}H$ top decay products in the lab frame! (w/ spin-correlations)

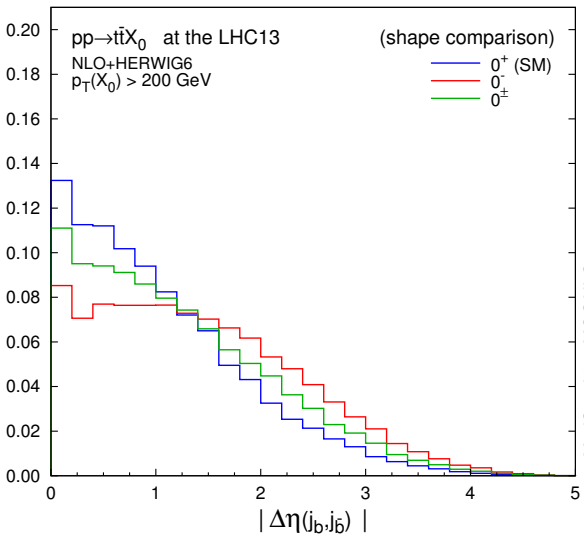
$$p_T^{\ell} > 20 \text{ GeV}, \quad p_T^{bjet} > 30 \text{ GeV}, \quad |\eta| < 2.5$$

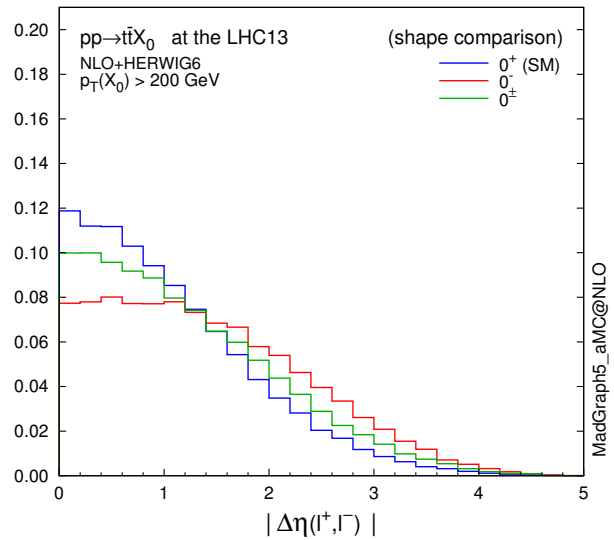


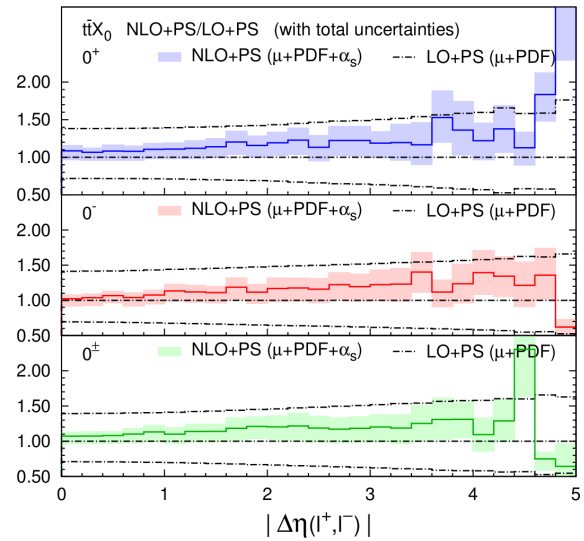




$$p_T^{H} > 200 \text{ GeV}$$

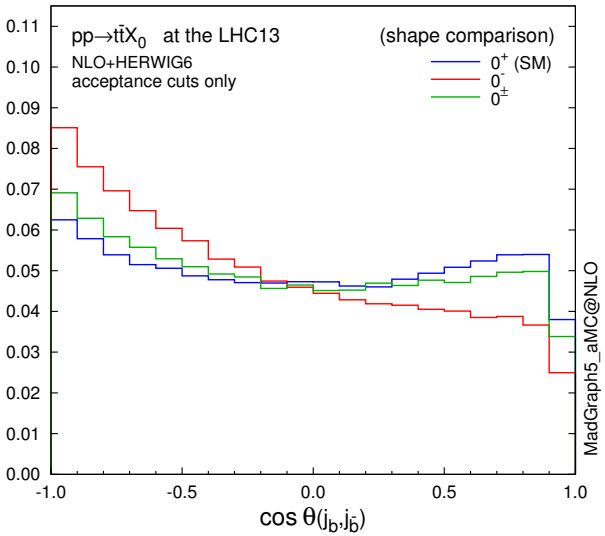


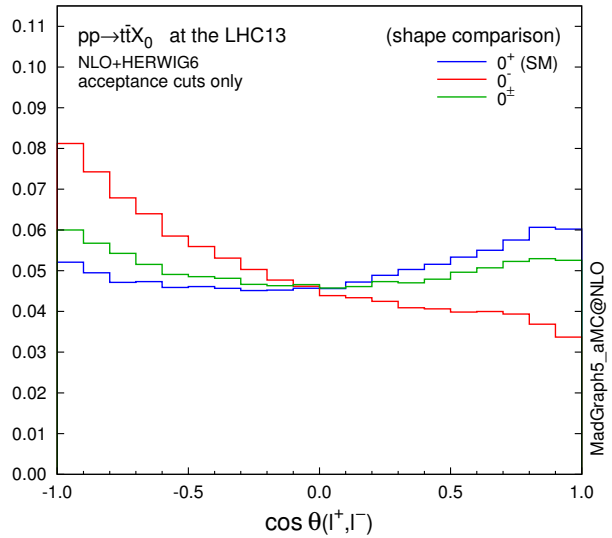


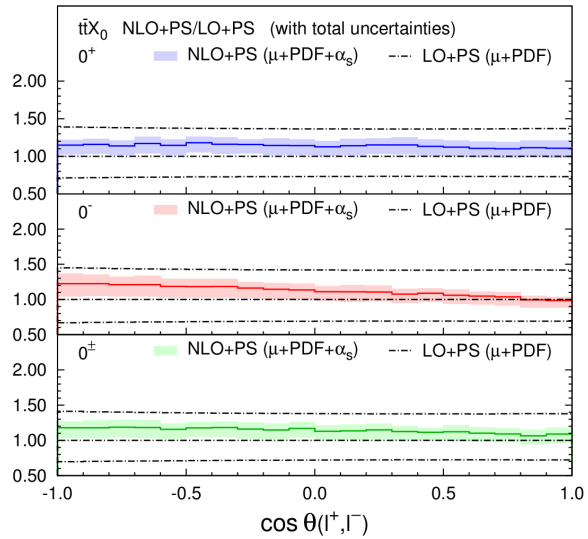


top decay products in the lab frame! (w/ spin-correlations)

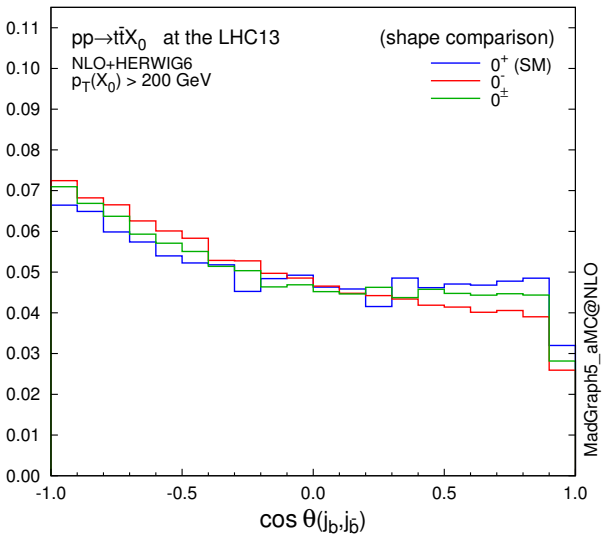
$p_T^{\ell} > 20$ GeV, $p_T^{bjet} > 30$ GeV, $|\eta| < 2.5$

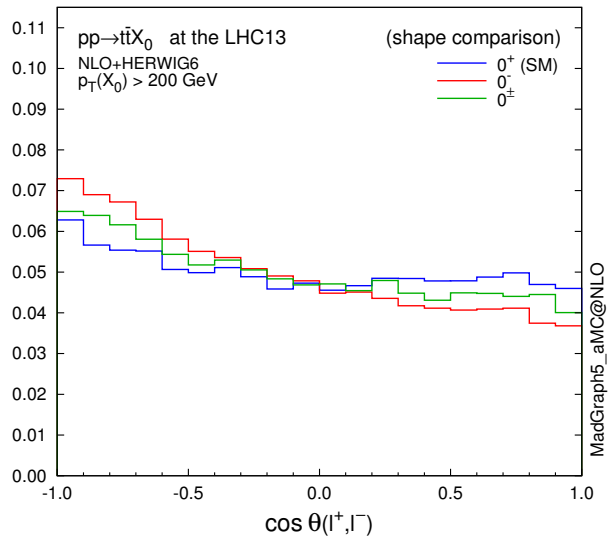


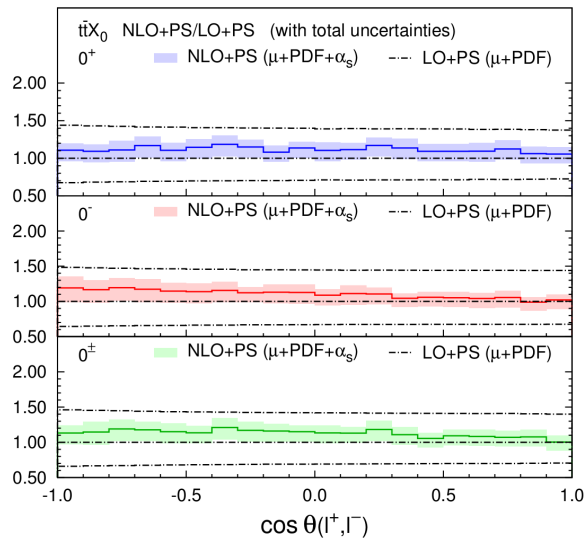




$p_T^H > 200$ GeV

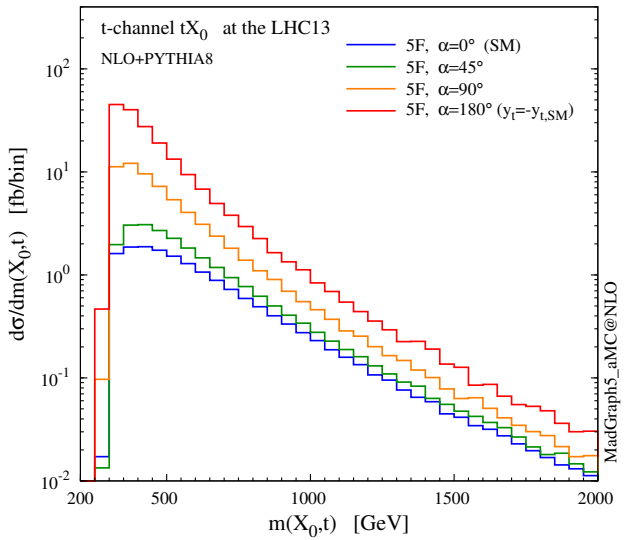






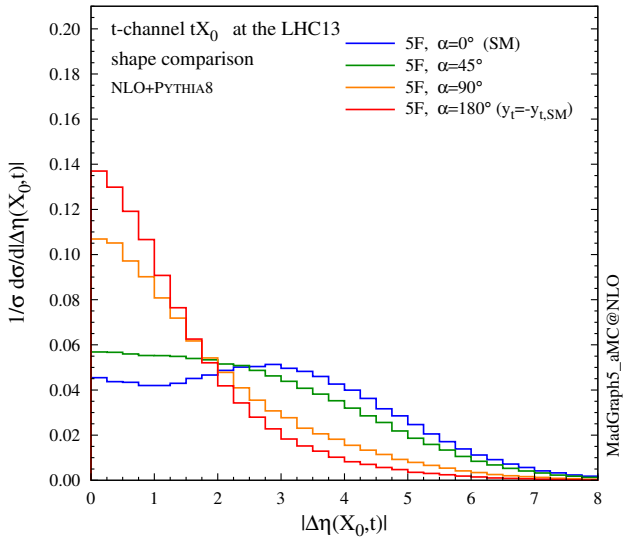
t-channel tH production

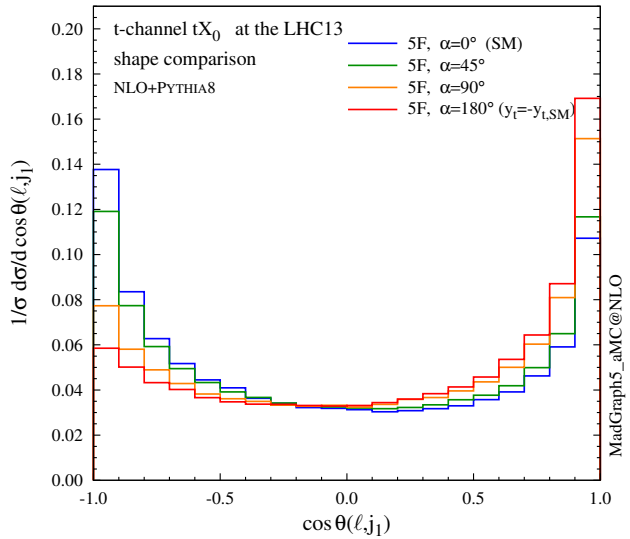
FD, F. Maltoni, K. Mawatari, M. Zaro [arXiv:1504.00611]



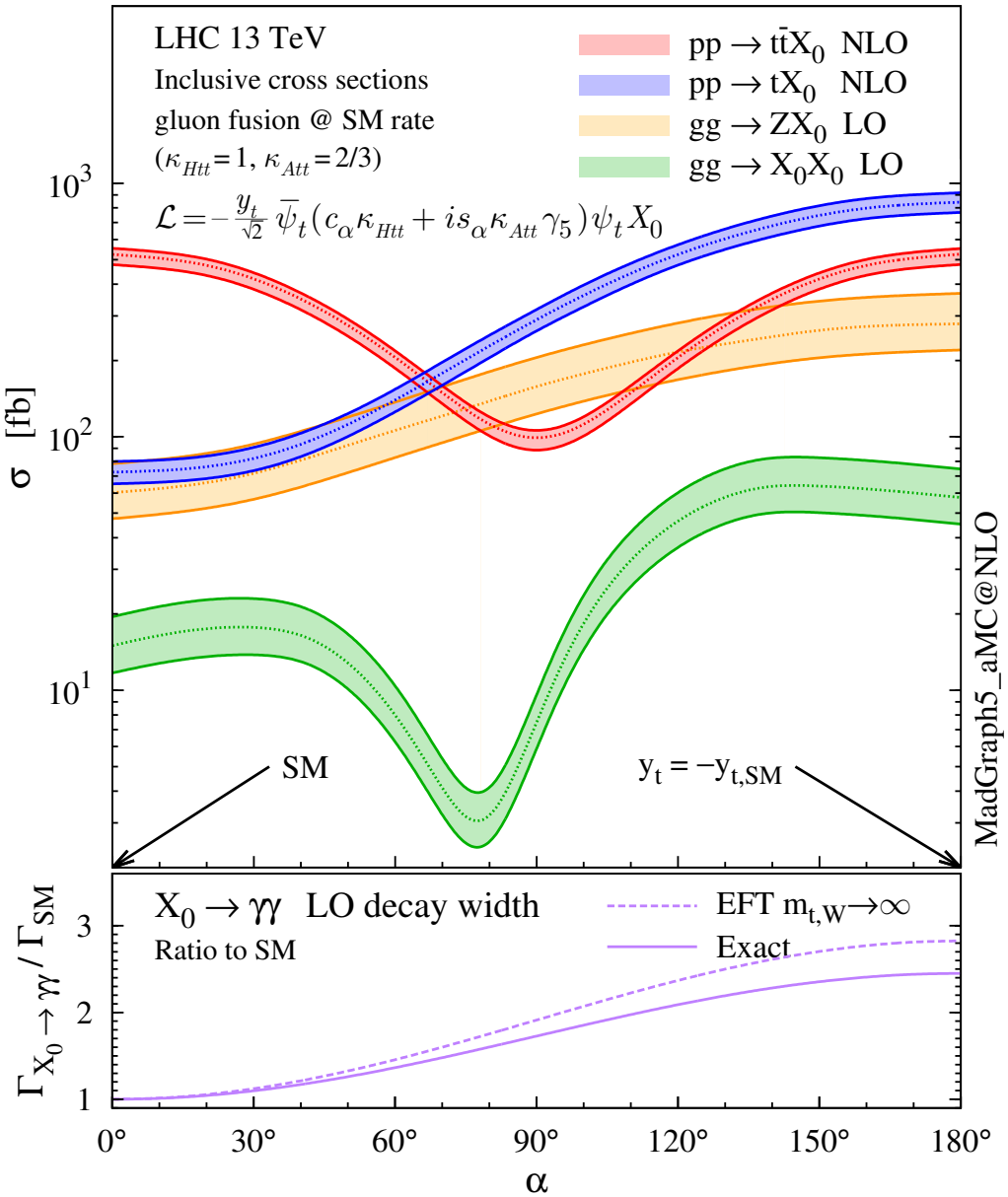
New physics takes place mostly at threshold

Many observables are sensitive to n.p. in *tH*





Higgs characterisation: inclusive observables



α = CP-mixing angle

$\kappa_{Htt} = 1\,, \quad \kappa_{Att} = 2/3$

$\Rightarrow$ Gluon fusion @ SM rate $\forall\alpha$

$t\bar{t}H$ helps to constrain α

tH and other rare processes further lift 2 degeneracies:

$y_t \leftrightarrow -y_t$

$\alpha \leftrightarrow \pi - \alpha$

Thanks for your attention

and happy celebrations!