SMEFT Studies for ttH(bb) Channel

Punnawich Chokeprasert,

Aliya Nigamova, Rainer Mankel

DESY-CMS group

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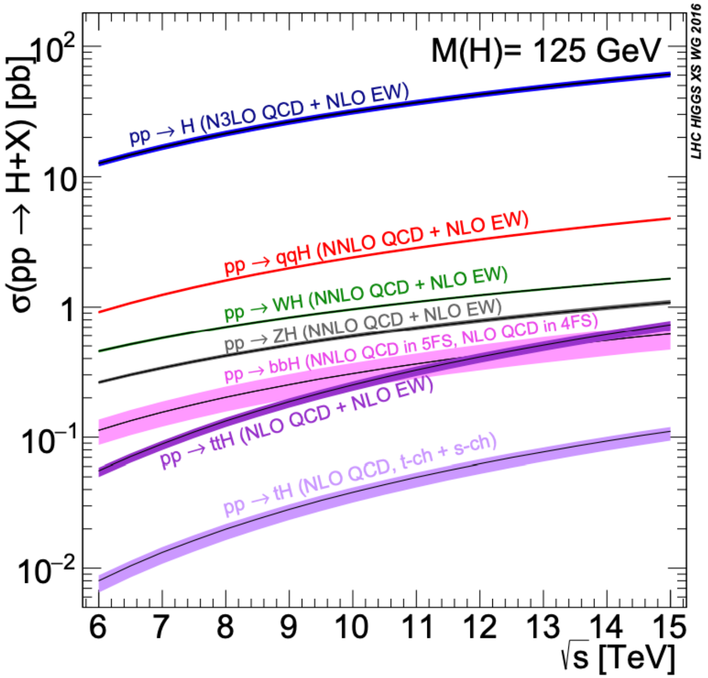
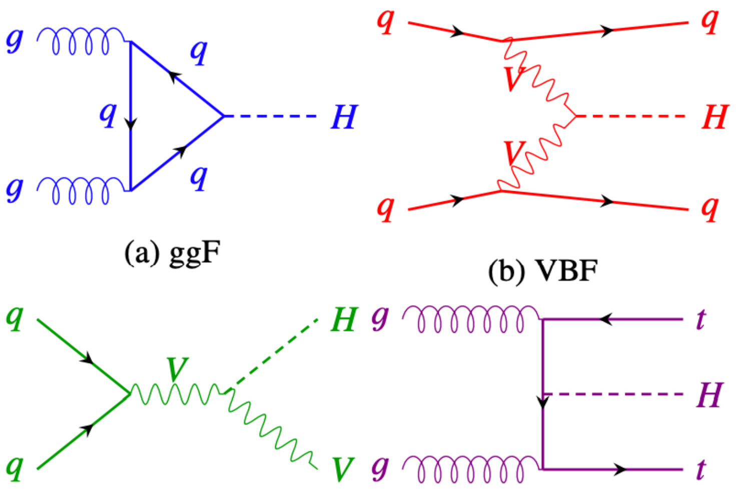
Observation of Higgs and ttH to bb channel

- Higgs measurements in Run 2 at LHC
  - The production of Higgs in different mode:





(a) ggF

(b) VBF

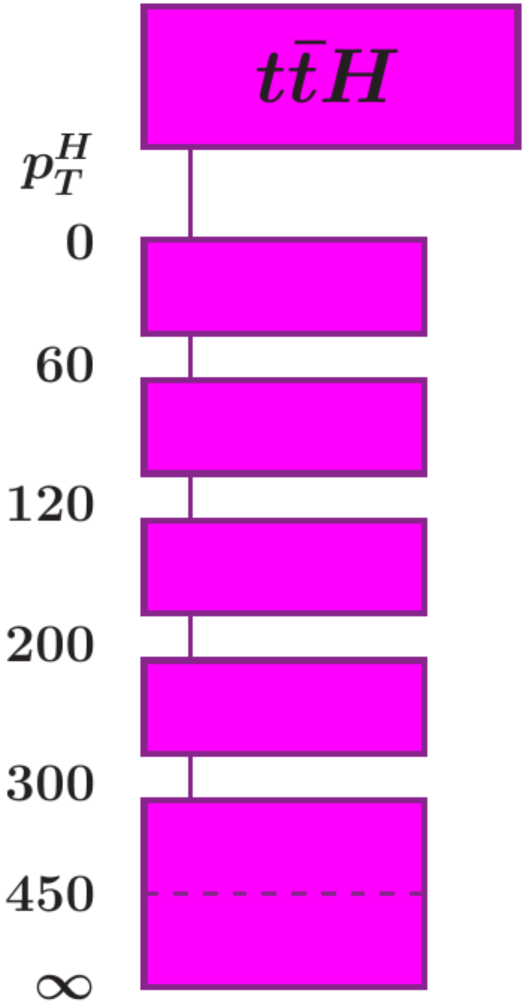
(c) VH

(d) ttH

- Especially ttH allows a direct measurement of the Higgs boson coupling to the top (the heaviest particle in the SM) ⟶ interesting to search for hints of BSM physics

Simplified Template Cross Sections (STXS)

- Many measurements? ⟶ combine them ⟶ **STXS**
- Separate more clean measurement and interpretation steps to reduce the theoretical uncertainties that are folded into the measurements
- Breaking Higgs creation into different categories **bins**
- Criteria for selecting bins:
  - Capture deviations from the SM predictions
  - Avoid regions with high theoretical uncertainty
  - Try to match the experimental methods used to detect the Higgs as closely as possible, reducing the need for guesses about how things work



Effective Field Theory (EFT) approach

- Just Quantum Field Theory (QFT) but without restriction of renomalizability
- Assume the quantum numbers of SM particles are correct (the structure of dimension ≤ 4 terms in the Lagrangian)
- Contain all possible higher-dimentional operators

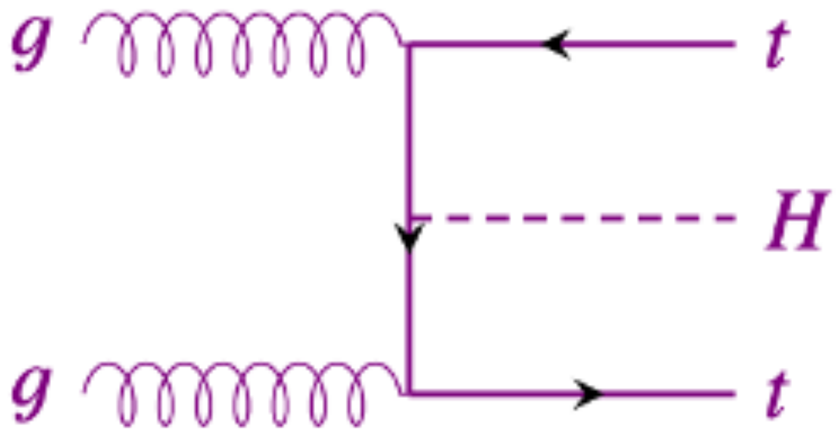
Warsaw basis

$$L_{EFT} = L_{SM} + \sum_j \mathcal{O}_j c_j$$

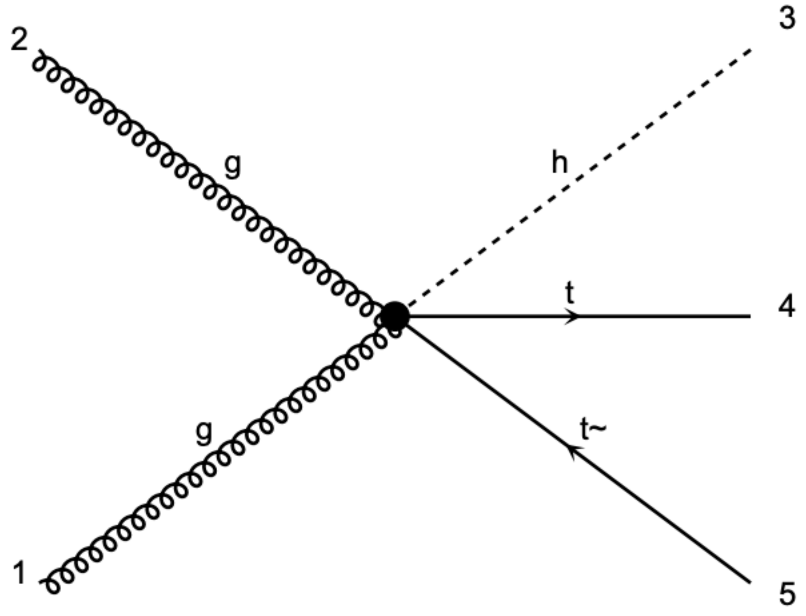
Wilson coefficient

Wilson coefficient	Operator	Wilson coefficient	Operator
$c_{H\Box}$	$(H^\dagger H)\Box(H^\dagger H)$	c_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{H}\,G^A_{\mu\nu}$
c_{HDD}	$(H^\dagger D^\mu H)^*\,(H^\dagger D_\mu H)$	c_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{H}\,W^I_{\mu\nu}$
c_{HG}	$H^\dagger H\,G^A_{\mu\nu}G^{A\mu\nu}$	c_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{H}\,B_{\mu\nu}$
c_{HB}	$H^\dagger H\,B_{\mu\nu}B^{\mu\nu}$	c'_{ll}	$(\bar{l}_p\gamma_\mu l_t)(\bar{l}_r\gamma^\mu l_s)$
c_{HW}	$H^\dagger H\,W^I_{\mu\nu}W^{I\mu\nu}$	$c^{(1)}_{qq}$	$(\bar{q}_p\gamma_\mu q_t)(\bar{q}_r\gamma^\mu q_s)$
c_{HWB}	$H^\dagger\tau^I H\,W^I_{\mu\nu}B^{\mu\nu}$	$c^{(3)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$
c_{eH}	$(H^\dagger H)(\bar{l}_p e_r H)$	c_{qq}	$(\bar{q}_p\gamma_\mu q_t)(\bar{q}_r\gamma^\mu q_s)$
c_{uH}	$(H^\dagger H)(\bar{q}_p u_r\widetilde{H})$	$c^{(31)}_{qq}$	$(\bar{q}_p\gamma_\mu\tau^I q_t)(\bar{q}_r\gamma^\mu\tau^I q_s)$
c_{dH}	$(H^\dagger H)(\bar{q}_p d_r\widetilde{H})$	c_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
$c^{(1)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{l}_p\gamma^\mu l_r)$	$c^{(1)}_{uu}$	$(\bar{u}_p\gamma_\mu u_t)(\bar{u}_r\gamma^\mu u_s)$
$c^{(3)}_{Hl}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{l}_p\tau^I\gamma^\mu l_r)$	$c^{(1)}_{qu}$	$(\bar{q}_p\gamma_\mu q_t)(\bar{u}_r\gamma^\mu u_s)$
c_{He}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{e}_p\gamma^\mu e_r)$	$c^{(8)}_{ud}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$
$c^{(1)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{q}_p\gamma^\mu q_r)$	$c^{(8)}_{qu}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
$c^{(3)}_{Hq}$	$(H^\dagger i\overleftrightarrow{D}^I_\mu H)(\bar{q}_p\tau^I\gamma^\mu q_r)$	$c^{(8)}_{qd}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$
c_{Hu}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{u}_p\gamma^\mu u_r)$	c_W	$\epsilon^{IJK}W^{I\nu}_\mu W^{J\rho}_\nu W^{K\mu}_\rho$
c_{Hd}	$(H^\dagger i\overleftrightarrow{D}_\mu H)(\bar{d}_p\gamma^\mu d_r)$	c_G	$f^{ABC}G^{A\nu}_\mu G^{B\rho}_\nu G^{C\mu}_\rho$

SM



EFT



Standard Model Effective Field Theory (SMEFT)

- Introduce the framework includes additional higher-order interactions that follow the symmetries of the SM ⟶ **SMEFT**
- Analyzing Higgs data alongside all Higgs production precision measurements
- Generally exploration and model-independent

dimension-6 dimension-8

$$\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \sum_{i}^{N_{d6}} \frac{c_i}{\Lambda^2} O_i^{(6)} + \sum_{j}^{N_{d8}} \frac{b_j}{\Lambda^4} O_j^{(8)} + \ldots,$$

BSM effects SM particles

dimension-5 & 7 violate lepton and/or baryon number conservation and not relevant for Higgs physics

EFT2Obs

- How do the operators of SMEFT affect the differential cross sections that we measure?
- Scaling of each bin i ..of course, automatically

$$\sigma_i^{SMEFT} = \sigma_i^{SM} + \sigma_i^{int} + \sigma_i^{BSM}$$

$$\frac{\sigma^{int}}{\sigma^{SM}} = \sum_i c_i A_i$$

$$\mu_i = 1 + \sum_j c_j A_{i,j} + \sum_{j,k} c_j c_k B_{i,jk}$$

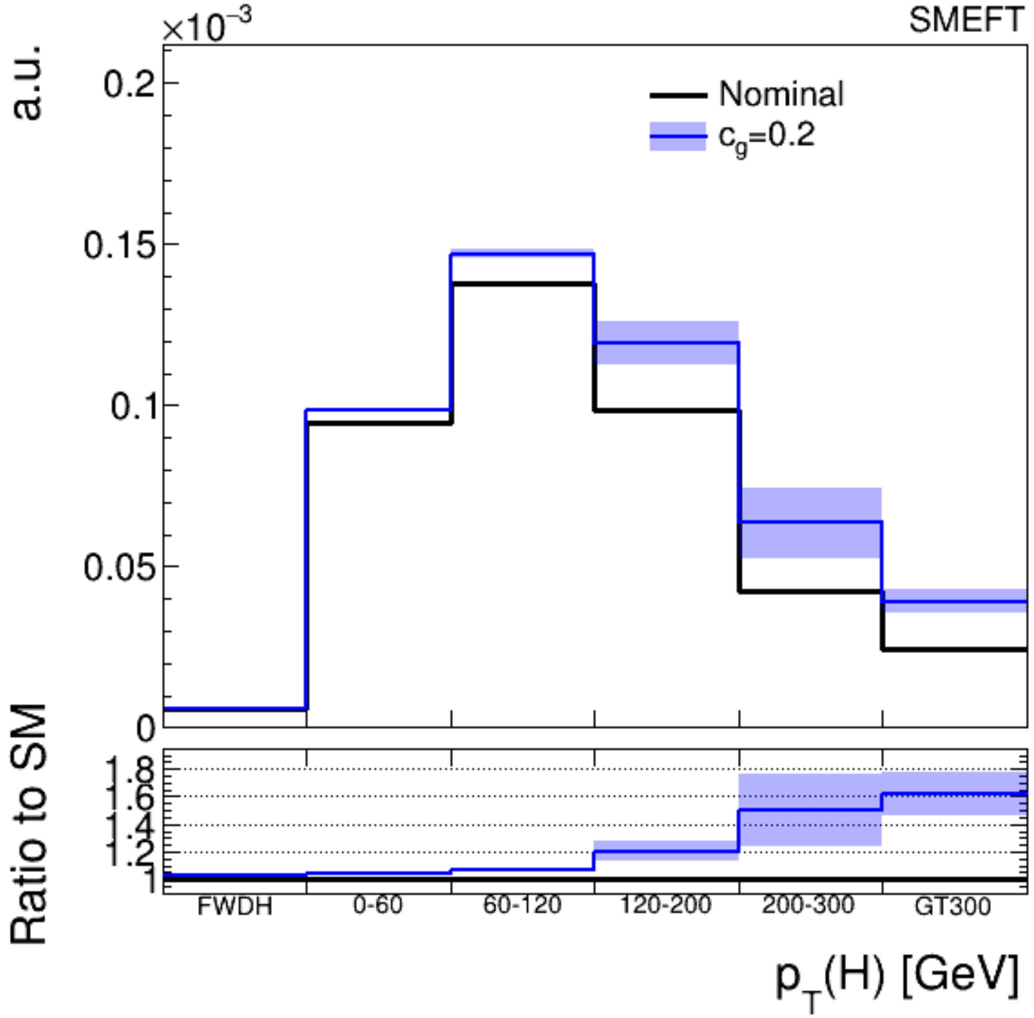
$$\frac{\sigma^{BSM}}{\sigma^{SM}} = \sum_{i,j} c_i c_j B_{i,j}$$

- By EFT2Obs - **A tool to automatically parametrize the effect of EFT coefficients**
- Based on Madgraph5_aMC@NLO + RIVET

Madgraph5_aMC@NLO: used with many UFO models: SMEFTsim

RIVET: define Higgs STXS

EFT2Obs



EFT introduce shape effect especially noticeable in large pT(H) range

the histogram overlaying the expectation for arbitrary values of the parameters

NanoAOD-tools

- In real analysis, phase space is modified by event selection.
- SMEFT prediction produced for all ttH events might not represent the analysis phase space correctly.
- Since it is costly and time-consuming to generate SMEFT events, we reweight SM samples using Madgraph Matrix Element reweighting.

Model → Weights (c_i) → Event generation → Full simulation→ Hypothesis (c_i)

➡ Move the EFT reweighting to the last step:

Model → Weights → Event generation → Full simulation

→ Weights (c_1) → Hypothesis (c_1)

…

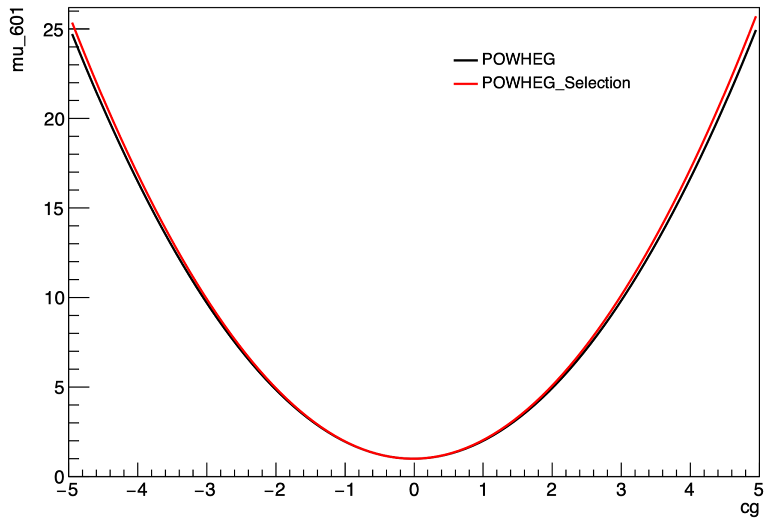
→ Weights (c_i) → Hypothesis (c_i)

$$W_{C_j>0} = \frac{\mathcal{M}_{\text{SMEFTsim}}(C_j > 0)}{\mathcal{M}_{\text{SM}}} \cdot W_{\text{SM}}$$

Compared Measurement

Acceptance effects become non-negligible in high pT(H) region

601: cg



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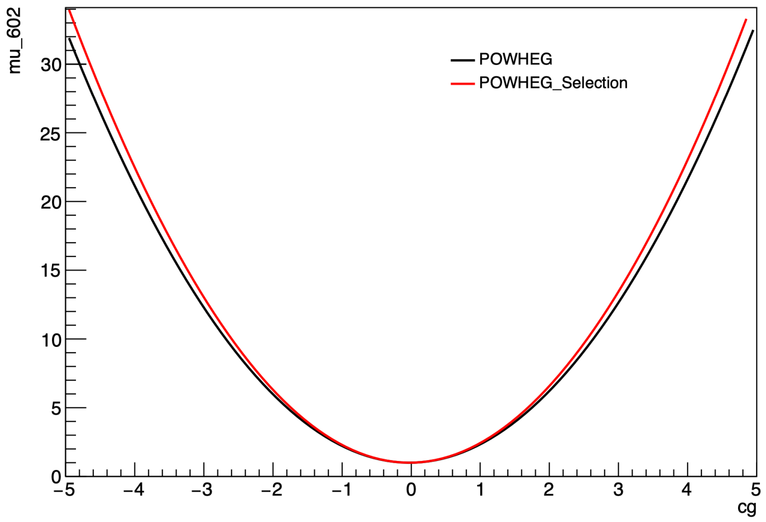

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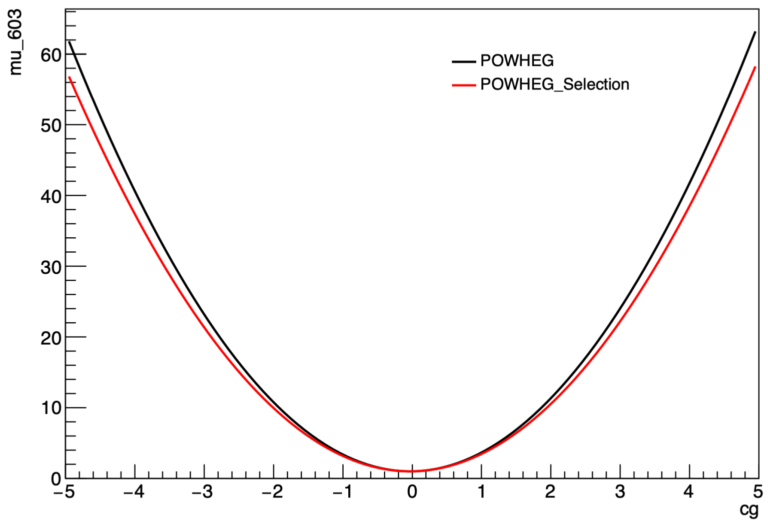

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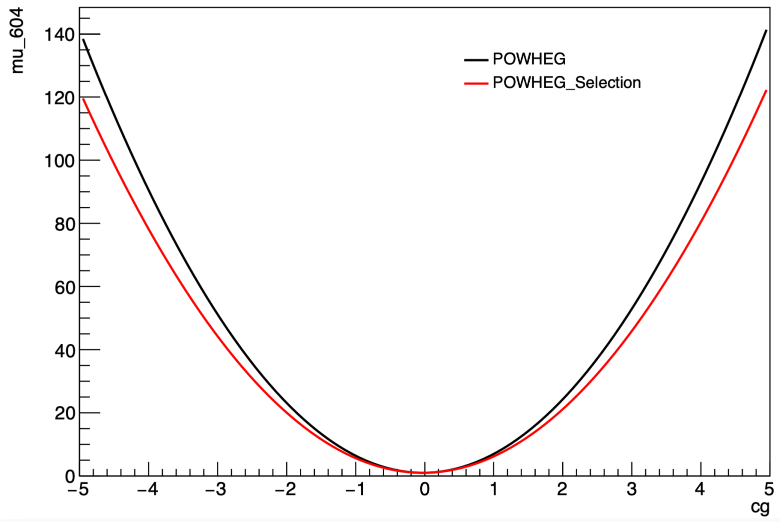

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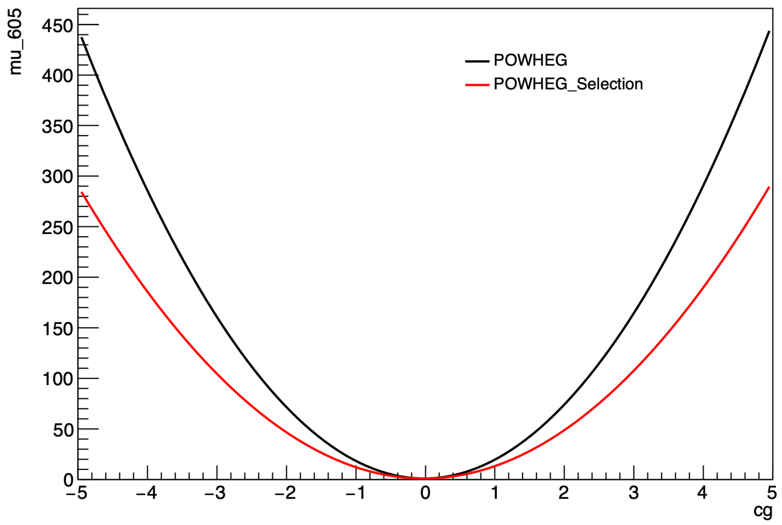

DESY.

Summary

- This studies will be use in CMS Run 2 Higgs combination.
- In this project, I learn about Higgs physics, EFT, SMEFT, STXS, combined measurements techniques, analysis techniques etc.
- I use EFT2Obs to produce SMEFT events winth Madgraph also write a scripts to extract files and make plots of parametrization.
- Therefore, I used NanoAOD-tools to analyze and reweight CMS MC events.
- I would like to say 99% of this work is what I learn from this programme and it’s very helpful for me, I’m enjoy to learn it.