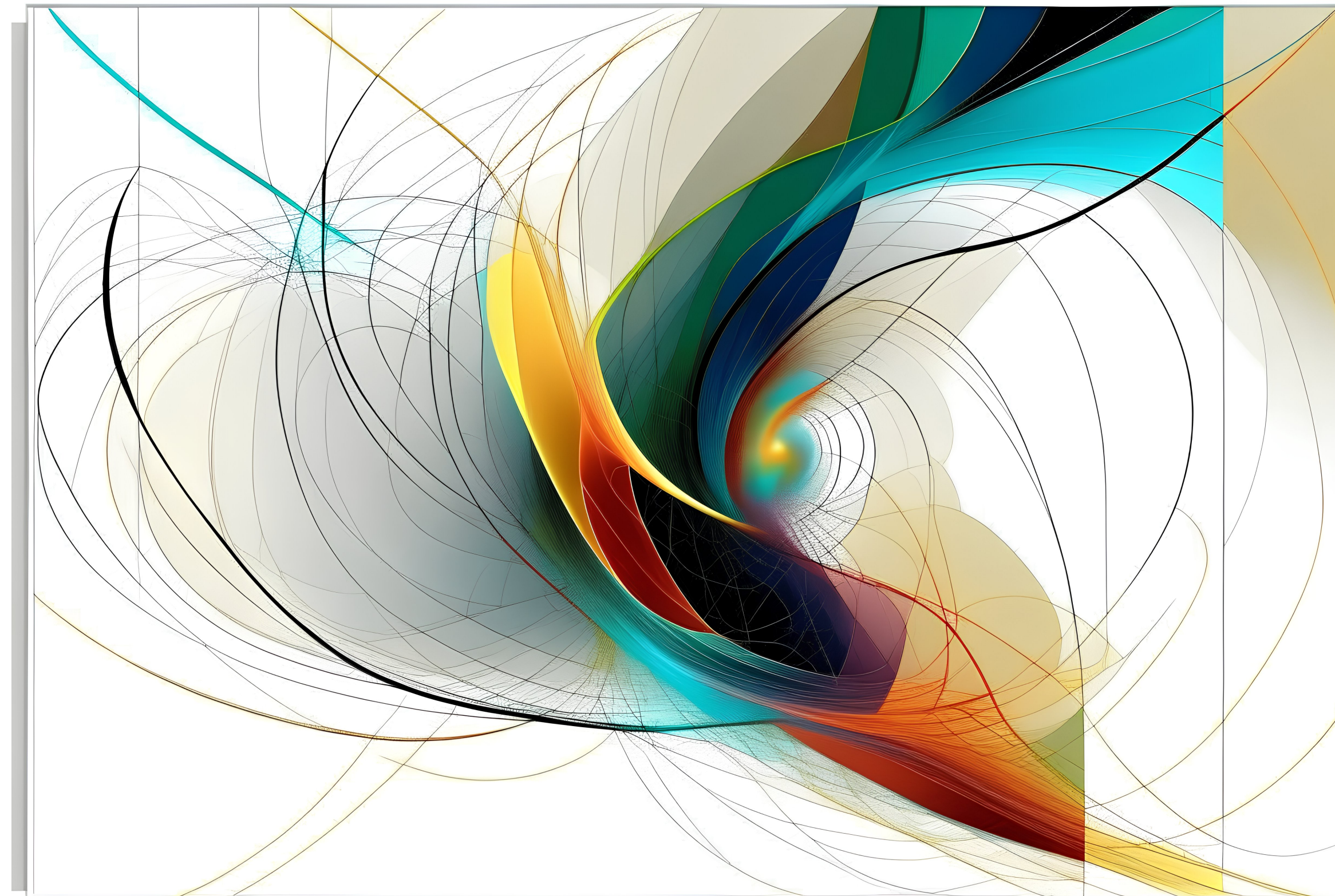


A Monte Carlo Implementation of the Two-Scalar-Extended SM



[made with stablecog]

Andreas Papaefstathiou
HHH Follow-Up Discussion on Simplified Models [12/09/2023]



The “twoscalar_generic” Implementation:

- **Goal:** To describe all processes, up to one-loop, within the framework of the Standard Model plus two scalar particles.
- **Achieved** by careful modification of the “loop_sm” model of MadGraph5_aMC@NLO [originally by Valentin Hirschi].

The “twoscalar_generic” Scalar Couplings:

- The scalar part of the Lagrangian described by this model is a “**phenomenological**” one:

$$V \supset \sum_{i,j,k} \lambda_{ijk} h_i h_j h_k + \sum_{i,j,k,l} \lambda_{ijkl} h_i h_j h_k h_l ,$$

where h_i with $i, j, k = 1, 2, 3$ represent the **three scalar mass eigenstates**,

and λ_{ijk} and λ_{ijkl} are the **physical** scalar triple and quartic couplings.

The “twoscalar_generic” SM Couplings:

- The couplings of the h_i scalars to the rest of the SM are each re-scaled by a single parameter, κ_i :

$$g_{h_i X} = g_{hX}^{\text{SM}} \kappa_i,$$

where g_{hX}^{SM} is the **SM Higgs coupling** to the “ X ” set of fields.

- If we identify h_1 with the SM-like Higgs boson, then $\kappa_1 \lesssim 1$ and $\kappa_{2,3} \simeq 0$ following SM-like Higgs signal strength measurements.

The “twoscalar_generic” MG5_aMC model:

Parameter	MadGraph5_aMC@NLO
λ_{ijk}	Kijk
λ_{ijkl}	Kijkl
κ_i	ki
Particle	
h_1	h
h_2	eta0
h_3	iota0

The “twoscalar_generic” MG5_aMC model:

- This MC model can encompass any two-scalar model, e.g. the “**TRSM**”:

(i.e. the \mathcal{L}_2 -symmetric two-singlet extension of the SM):

$$V(\Phi, X, S) = \mu_{\Phi}^2 \Phi^\dagger \Phi + \lambda_{\Phi} \left(\Phi^\dagger \Phi \right)^2 + \mu_S^2 S^2 + \lambda_S S^4 + \mu_X^2 X^2 + \lambda_X X^4 \\ + \lambda_{\Phi S} \Phi^\dagger \Phi S^2 + \lambda_{\Phi X} \Phi^\dagger \Phi X^2 + \lambda_{SX} S^2 X^2 ,$$

[See, e.g.: T. Robens, T. Stefaniak, J. Wittbrodt, Eur. Phys. J. C 80 (2020) 151, [arXiv:1908.08554](#),
AP, T. Robens, G. Tetlalmatzi-Xolocotzi, JHEP 05 (2021) 193, [arXiv:2101.00037](#)]

A “twoscalar_generic” Example: $gg \rightarrow h_2 h_3$

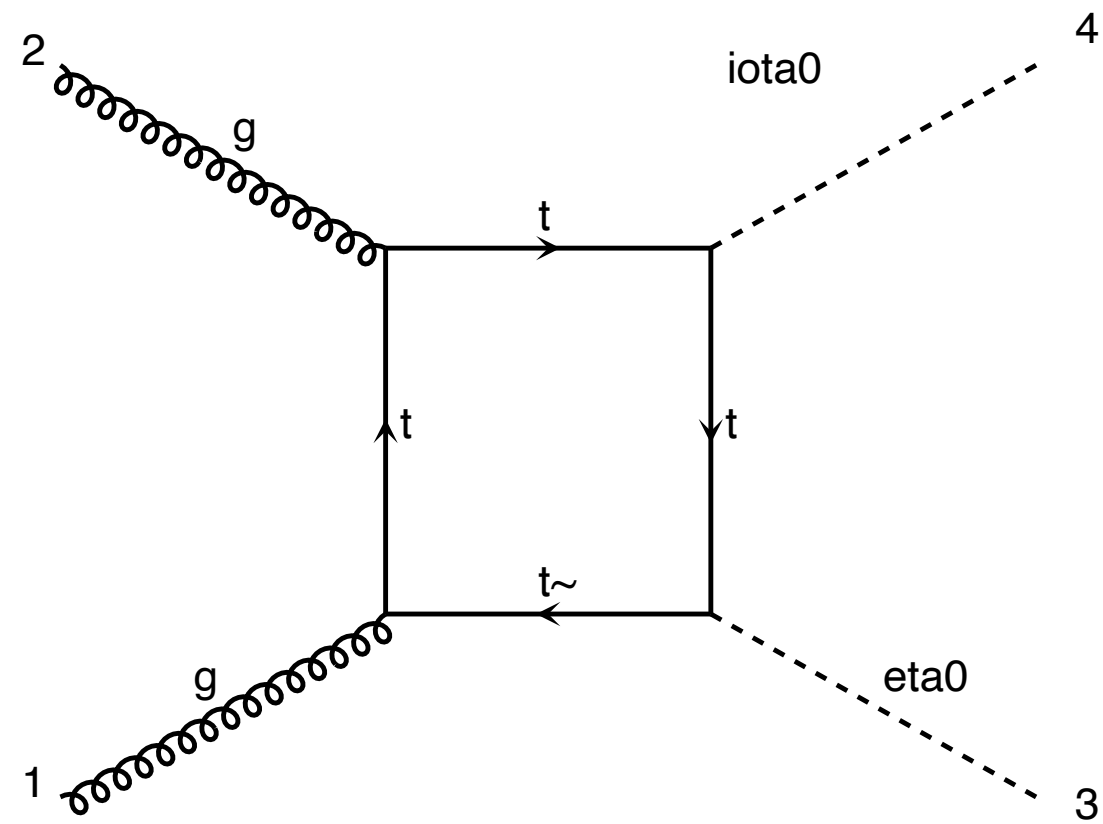


diagram 13 QCD=2, QED=2

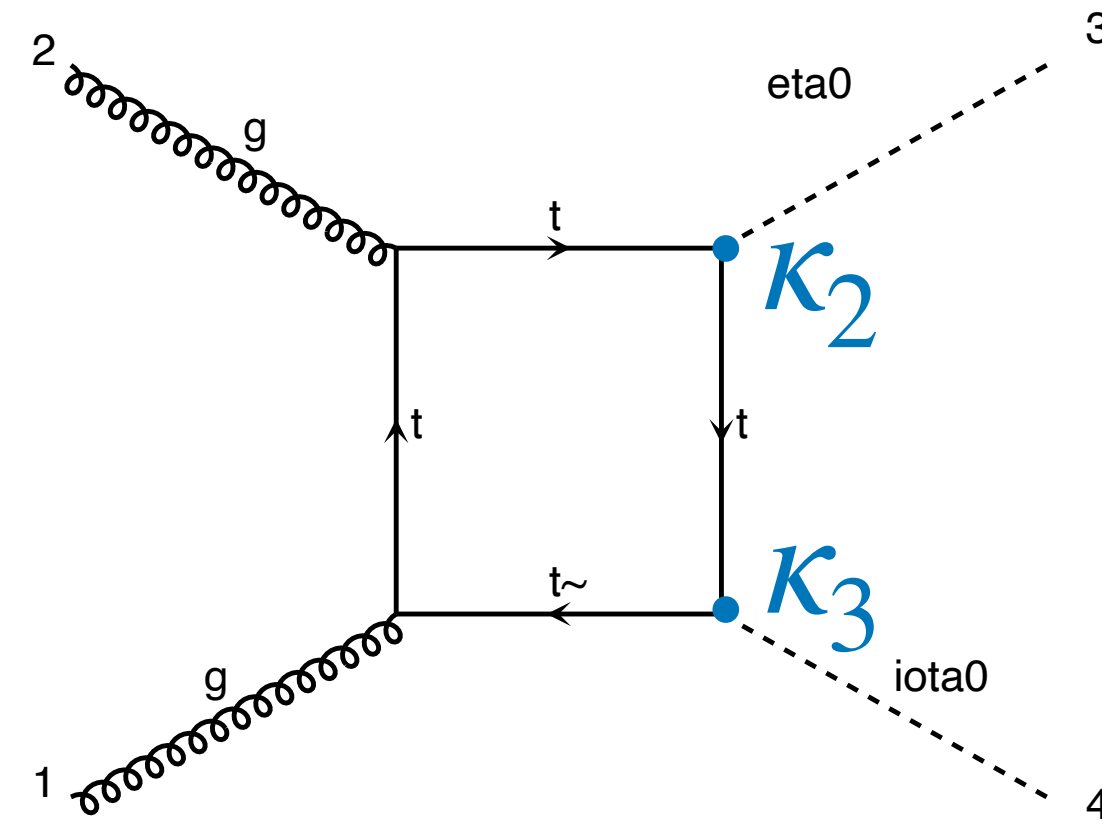


diagram 14 QCD=2, QED=2

generate $g g > \text{eta0 iota0}$ [QCD]

[Sample diagrams]

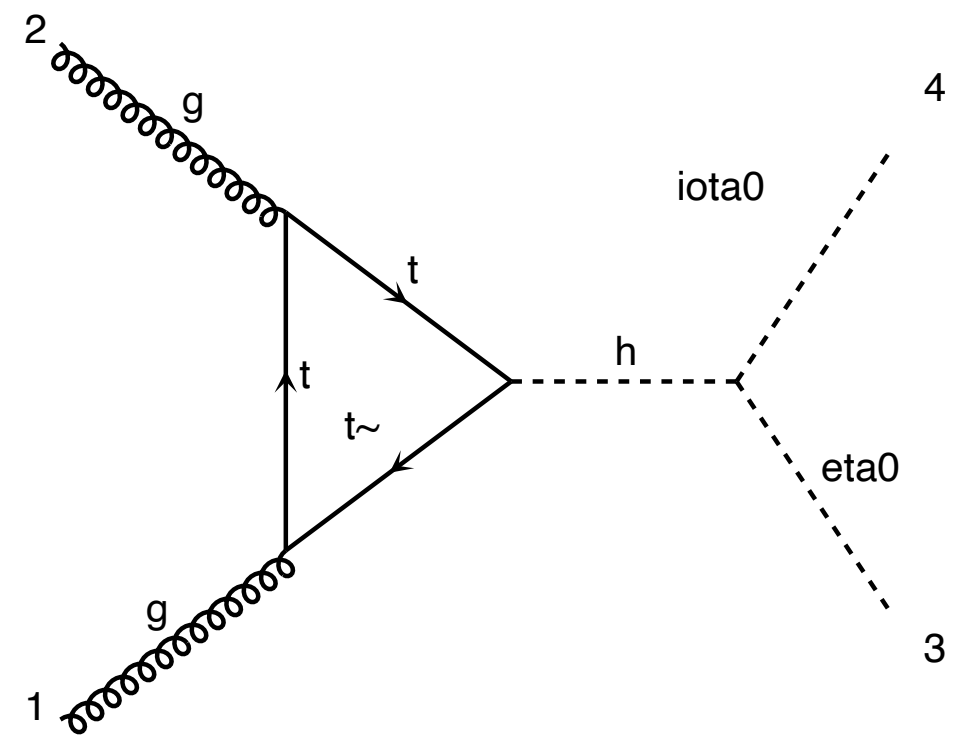


diagram 15 QCD=2, QED=3

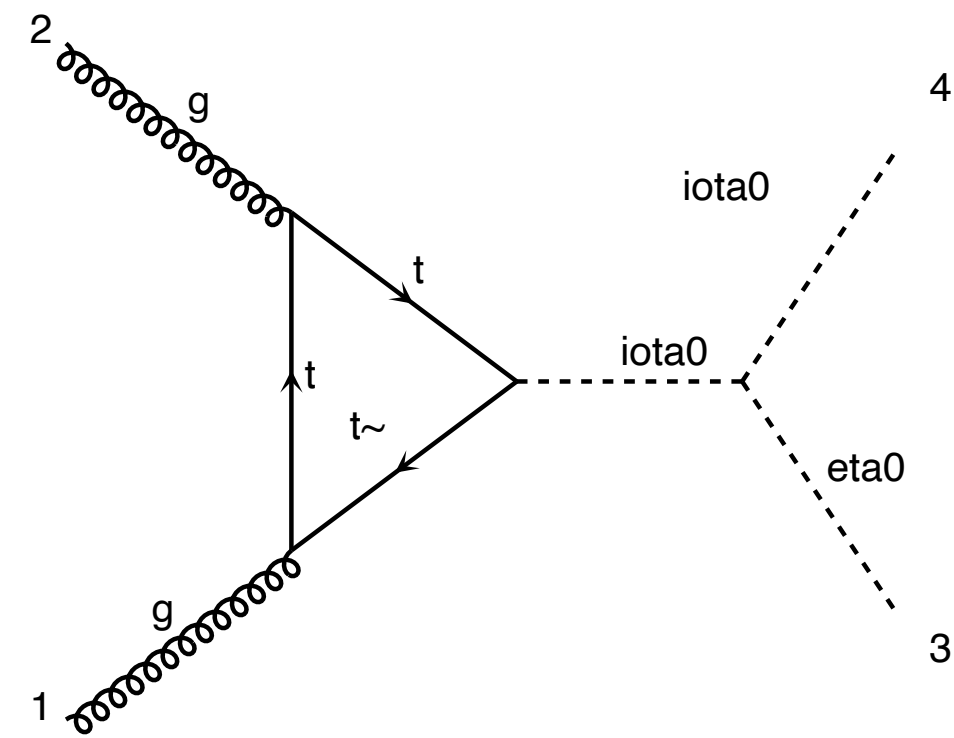


diagram 16 QCD=2, QED=3

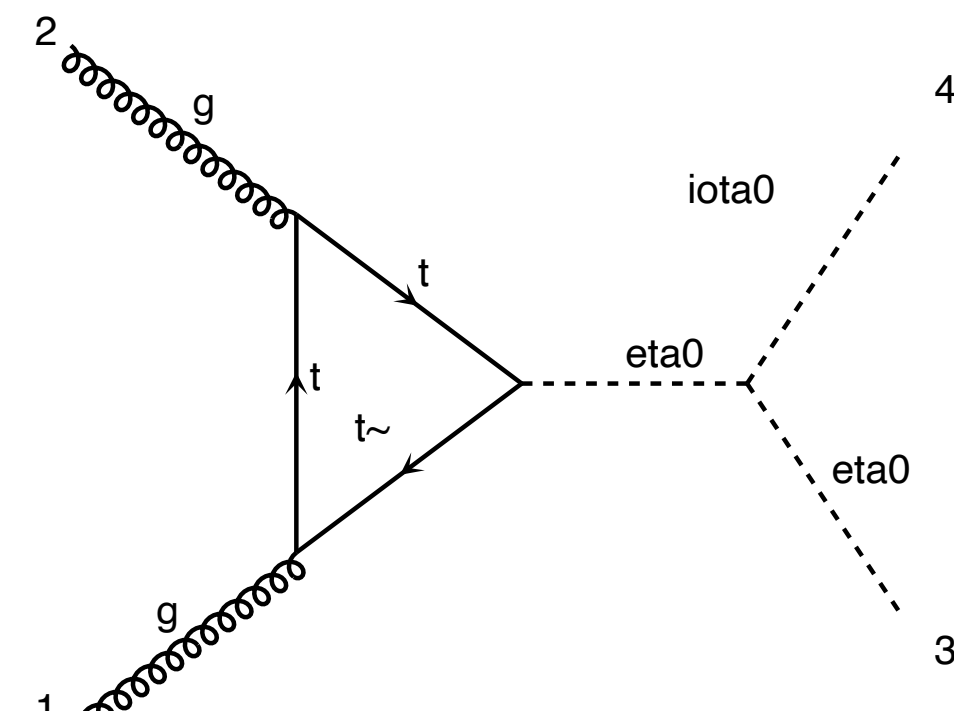


diagram 17 QCD=2, QED=3

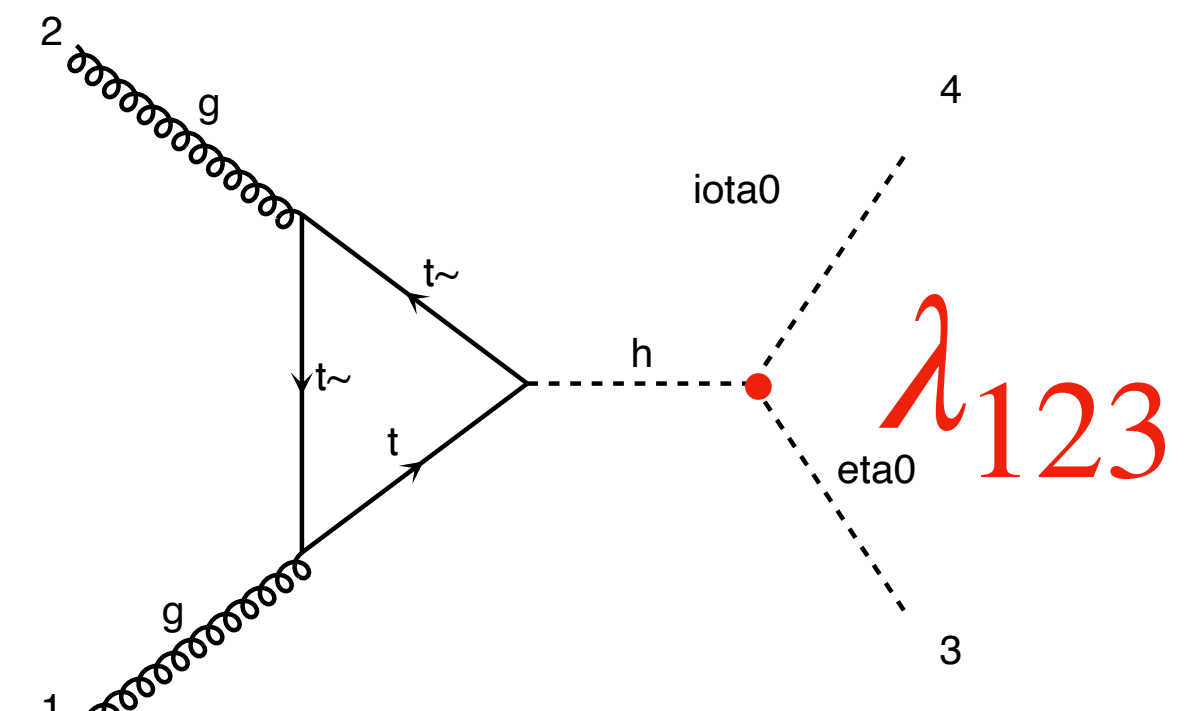
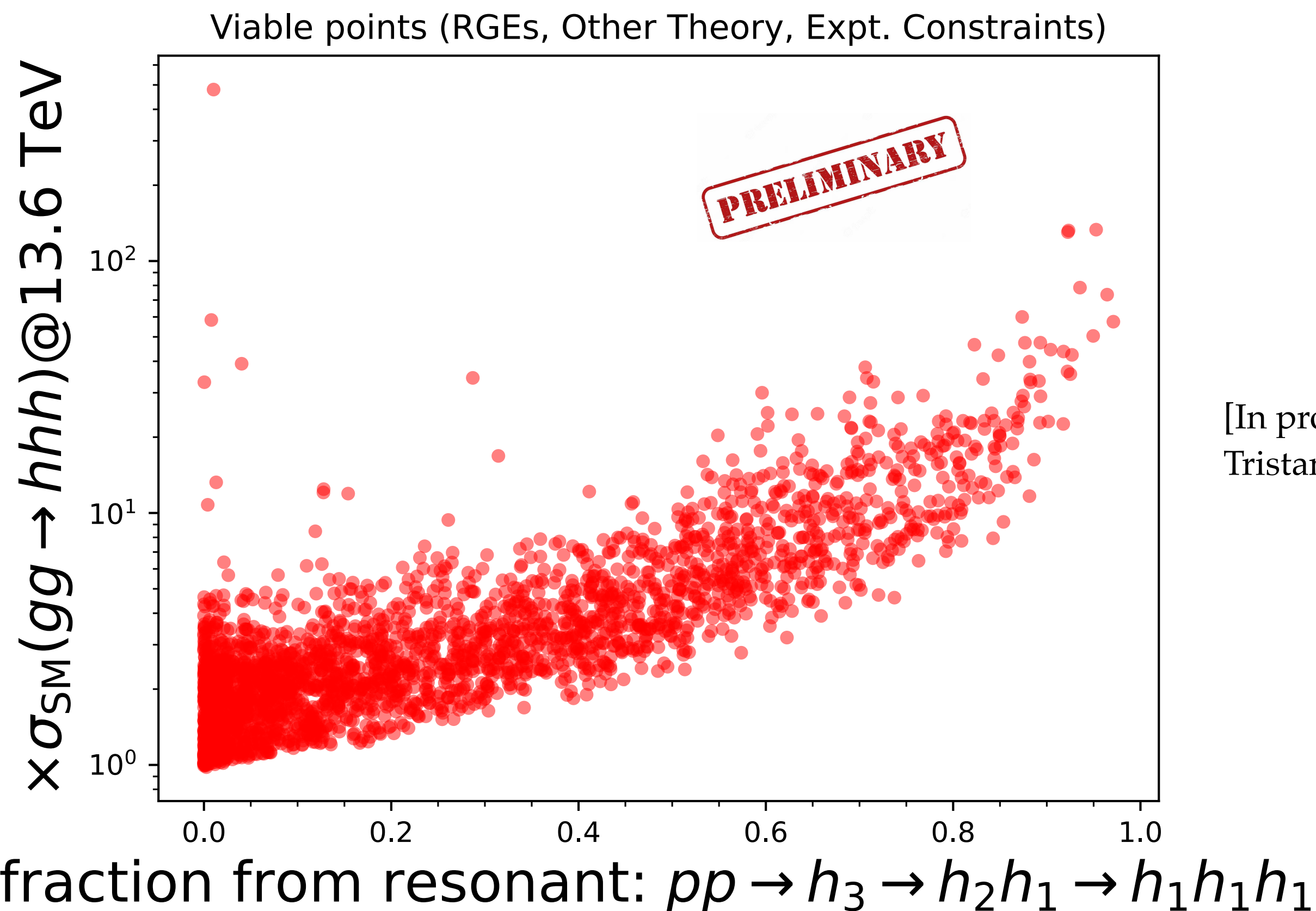


diagram 18 QCD=2, QED=3

A Question Regarding Triple Higgs Boson Production

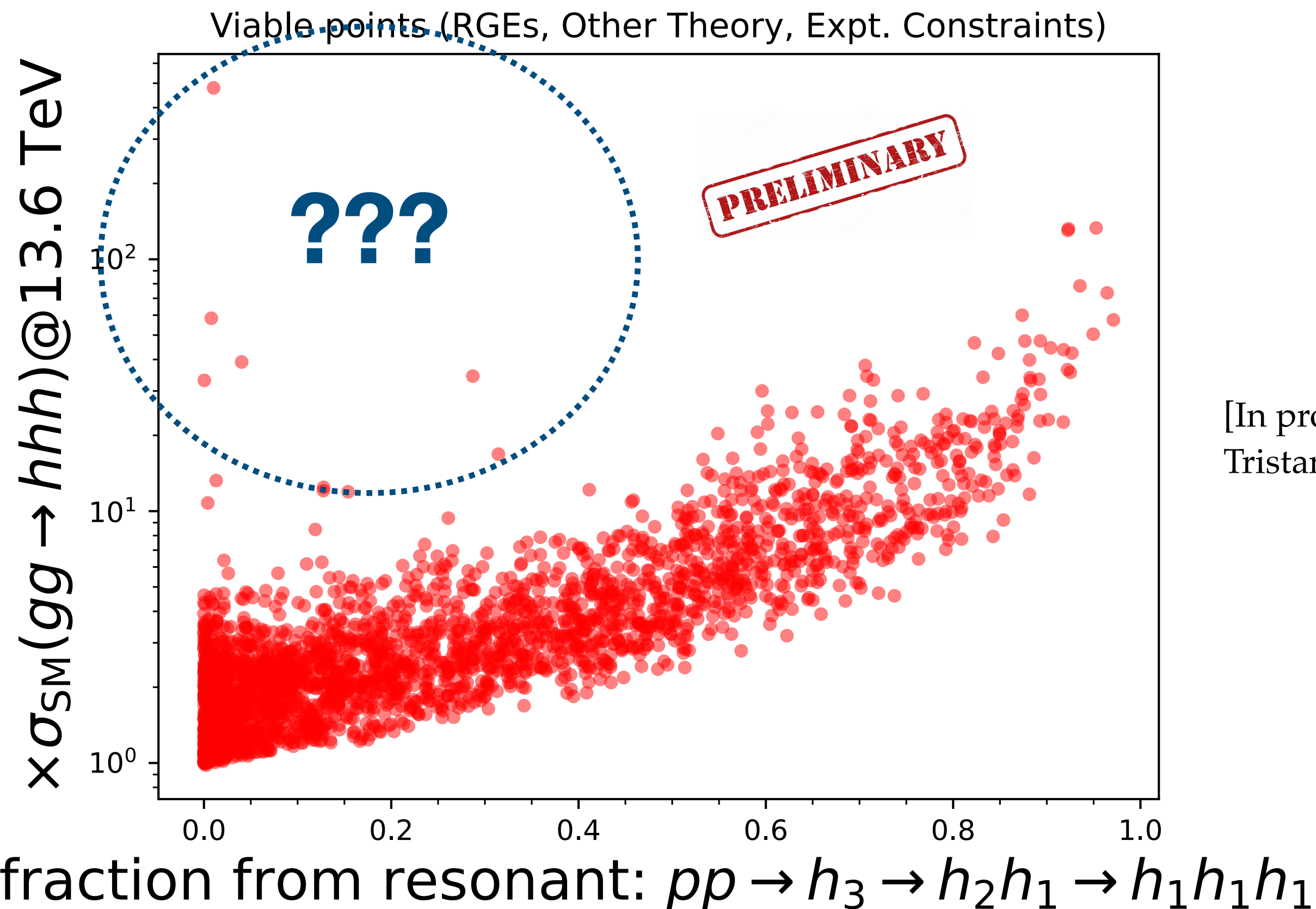
- Within viable parameter-space points of the two-scalar model (e.g. the TRSM or in general), how much of the enhancement in $gg \rightarrow h_1 h_1 h_1$ is due to $gg \rightarrow h_3 \rightarrow h_2 h_1 \rightarrow h_1 h_1 h_1$?



[In progress, Osama Karkout, Carlo Pandini, [AP](#), Marieke Postma, Tristan du Pree, Gilberto Tetlalmatzi-Xolocotzi, Jorinde van de Vis, ...]

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The “twoscalar_generic” Implementation:

- **Get the model at:**

https://gitlab.com/apapaefs/twoscalar_generic/

- [And the **TRSM-specific** implementation at:

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[Along with a MG5_aMC parameter card generator]

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Thanks!