EFT Analysis of the VVV process: a Letter of Interest for Snowmass 2022

Saptaparna Bhattacharya[1], Claudius Krause[2], Stefan Höche[3], Richard Ruiz[4], Michael Schmitt[1]
[1]Northwestern University
[2]Rutgers University
[3]Fermi National Accelerator Laboratory
[4]Institute of Nuclear Physics Polish Academy of Sciences

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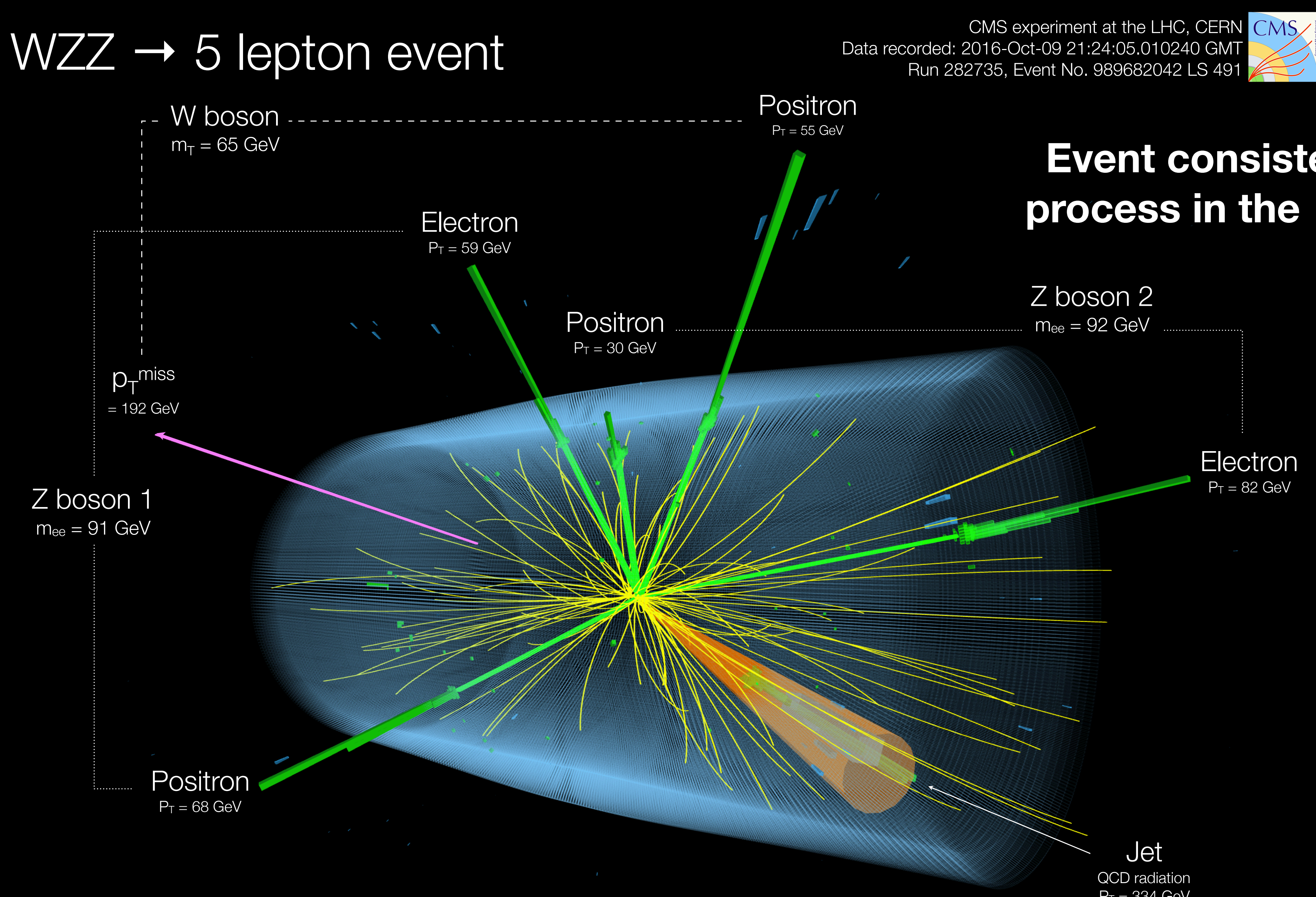
CMS Collaboration reports first observation of the VVV process in 2020



Event consistent with WZZ process in the CMS analysis

ATLAS Collaboration reports first observation of the WWW process in 2021

Major milestone in Standard Model physics

☑ Multi-boson, specifically VVV exploration, expected to lead to stringent tests of the non-Abelian gauge sector of the Standard Model (SM)

☑ Provides access to the SM quartic coupling (only other way is through the vector boson scattering topology)

☑ At the precipice of launching a full scale VVV program at the LHC

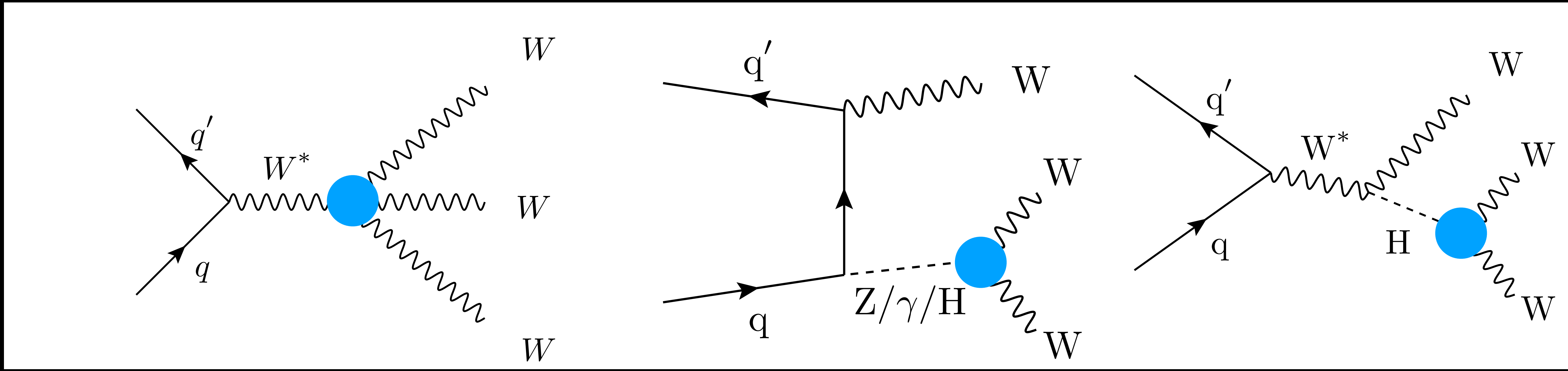
- ☑ As of now multi-leptonic final states explored (≥ 2 leptons)

☑ Simplistic projections for HL-LHC conditions lead to prediction of observing WZZ and ZZZ processes with 5 σ significance

☑ Effective Field Theory exploration in the VVV final state is topical → allows for BSM exploration in the newly observed final states

The Effective Field Theory Framework

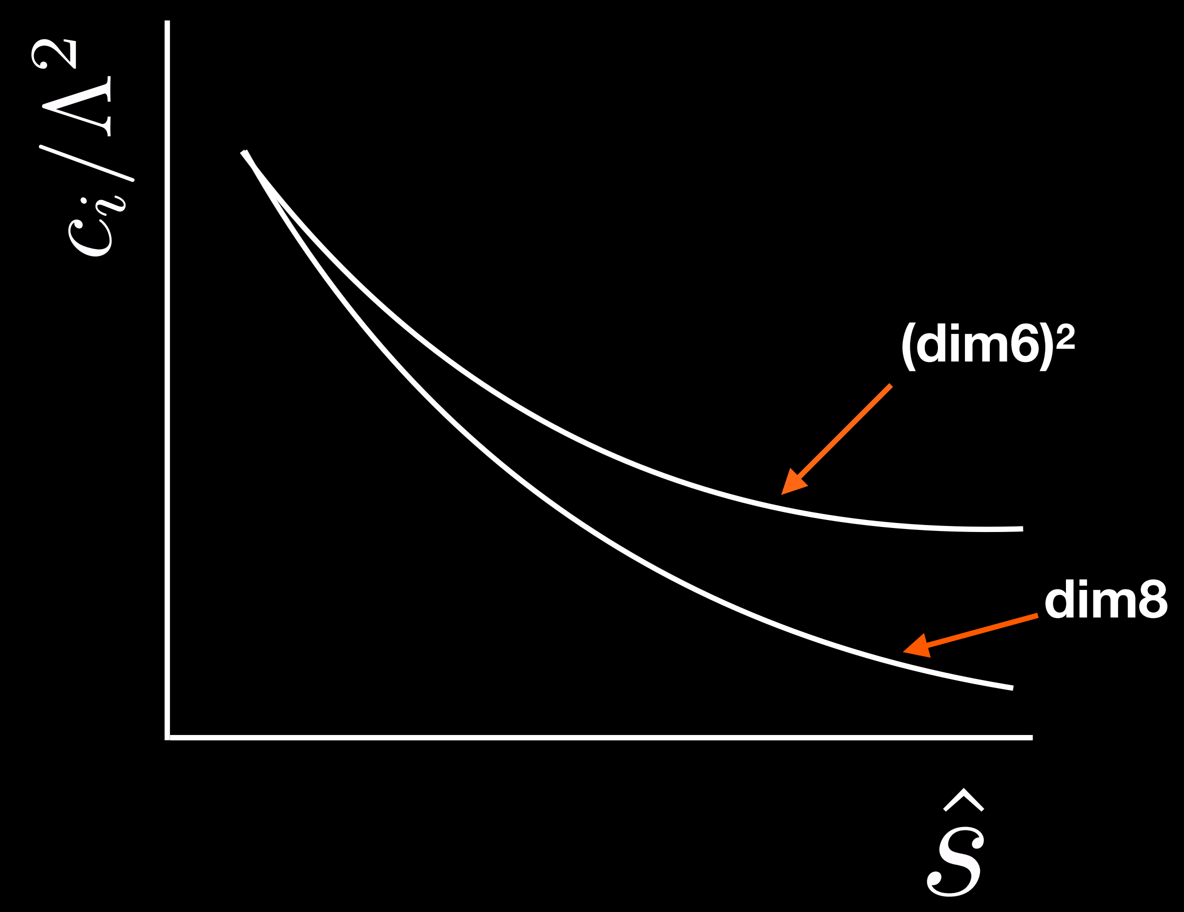
$$\mathcal{L} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\lambda^2}\mathcal{O}_i + \sum_j \frac{f_j}{\lambda^4}\mathcal{O}_j$$



- VVV process proceeds through trilinear and quartic coupling as well as the Higgs mediated mode
- Both dim-6 and dim-8 exploration possible

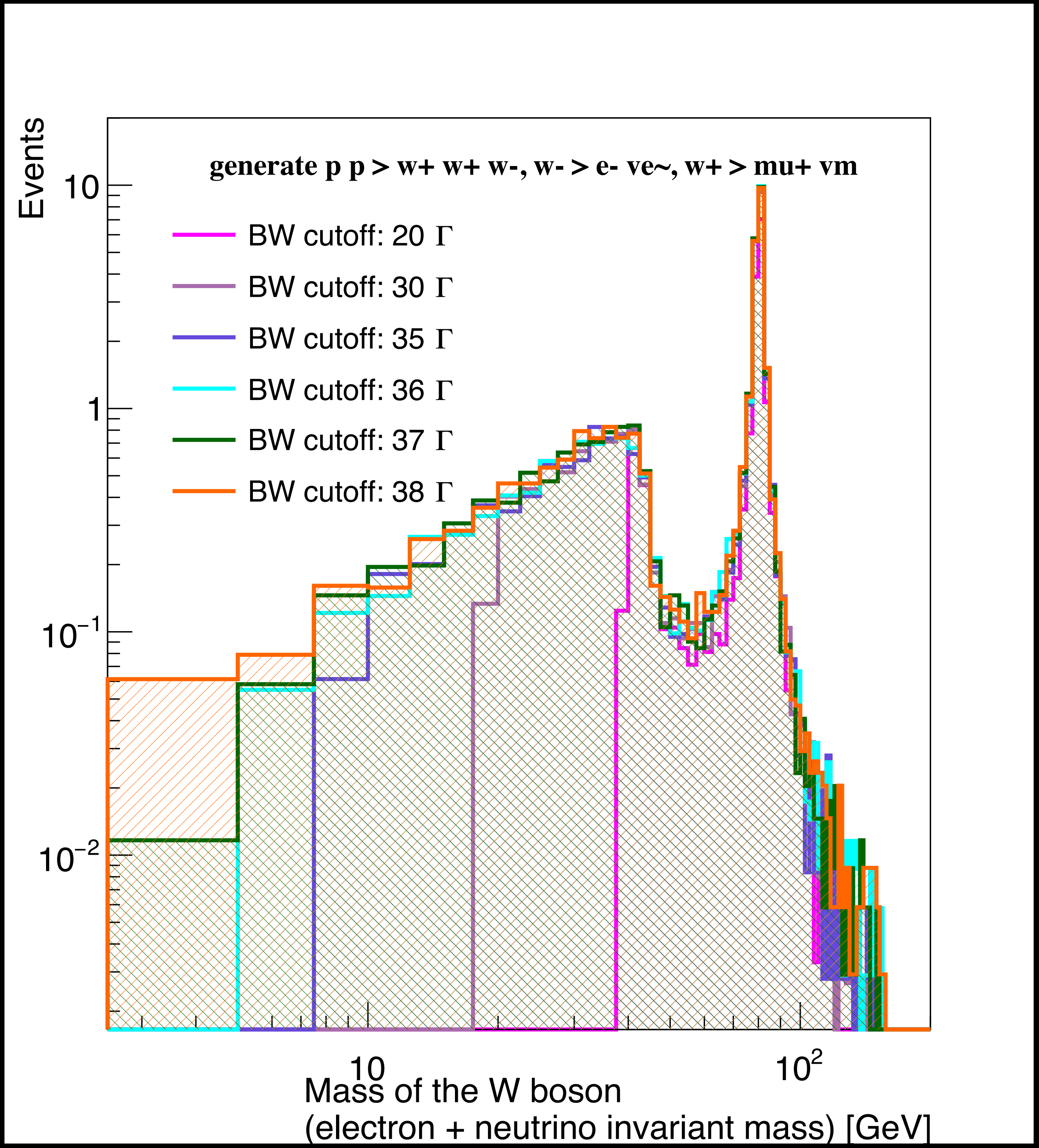
Salient features associated with VVV

- Study of the Higgs sector possible
  - Best way to include Higgs mediated mode?
  - Can we quantify the interference between the Higgs-mediated modes and other modes of production?
- Critical questions such as (dim6)^2 vs. dim8 contributions possible to address
  - Pertinent in the context of global EFT fits
- Explore sensitive variables: proxy for $\hat{s}$ and angular variables ($\Delta\Phi$)
  - Absence of “golden” variables as in the case of vector boson scattering topologies



Technical interlude: how to include the Higgs mode?

- Using MG5 2.6.7 primarily for studies
  - For polarization studies using MG5 2.9.1.2
- Can we extend the Breit-Wigner cutoff (BWCutoff) to generate off-shell W's from the Higgs
- Posed question to Olivier Mattelaer: https://answers.launchpad.net/mg5amcnlo/+question/696189
  - Answer is no! Madgraph assumes narrow width approximation within the BWCutOff range
  - The recommended range of 15Γ carefully chosen to optimize the phase-space integrator
- Recommendation:
  - generate p p > w w w $h (sans Higgs)
  - generate p p > w h

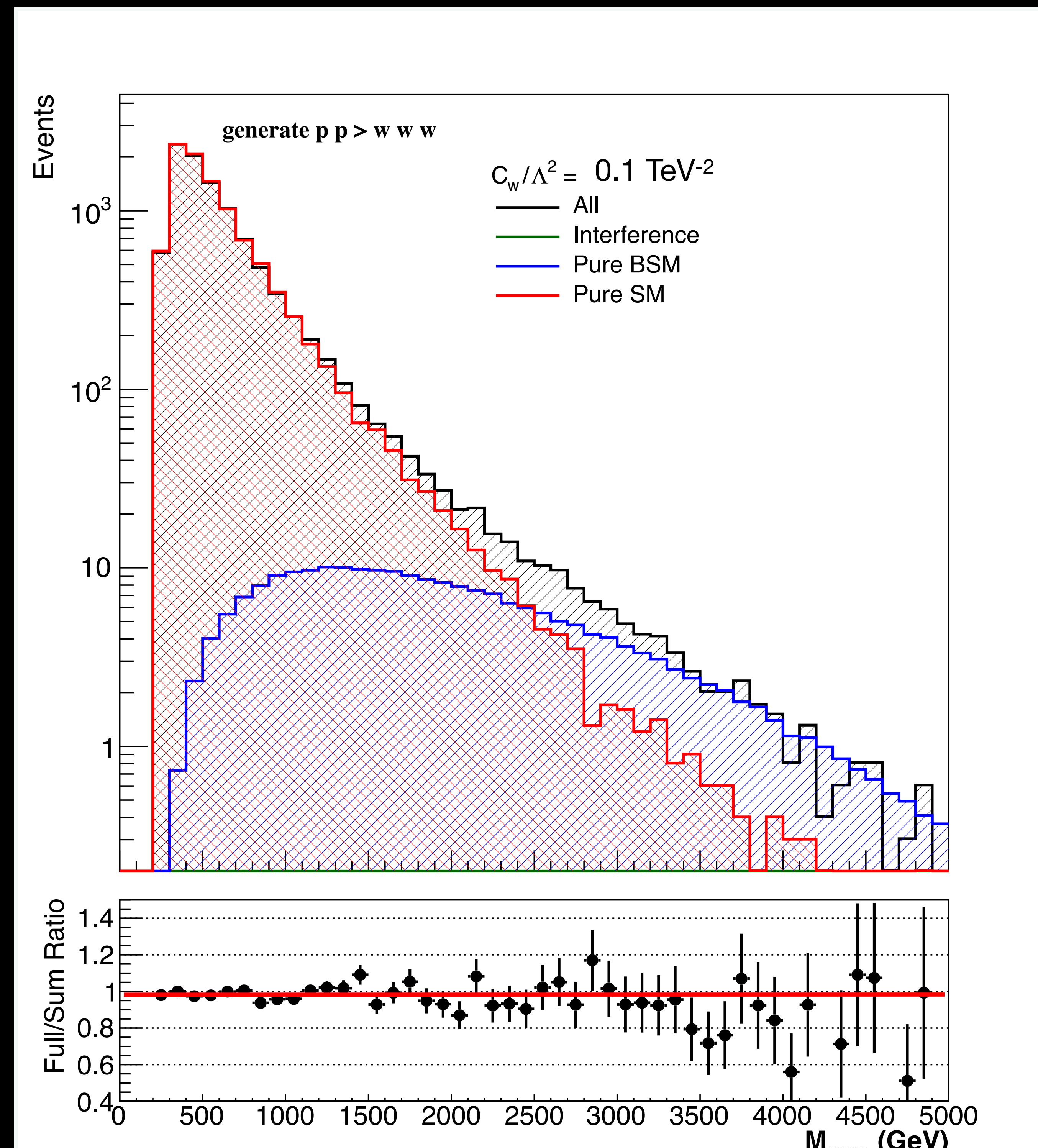


EFT sensitivity with on-shell bosons as a starting point

- Start with gauge-boson self interaction operators
- Used SMEFTSim package and used the most flavor restrictive set of operators ($U(3)^5$ total 59 operators)

$$\mathcal{O}_{3W} = \epsilon^{abc} W_{\mu}^{a\nu} W_{\nu}^{b\rho} W_{\rho}^{a\mu}$$

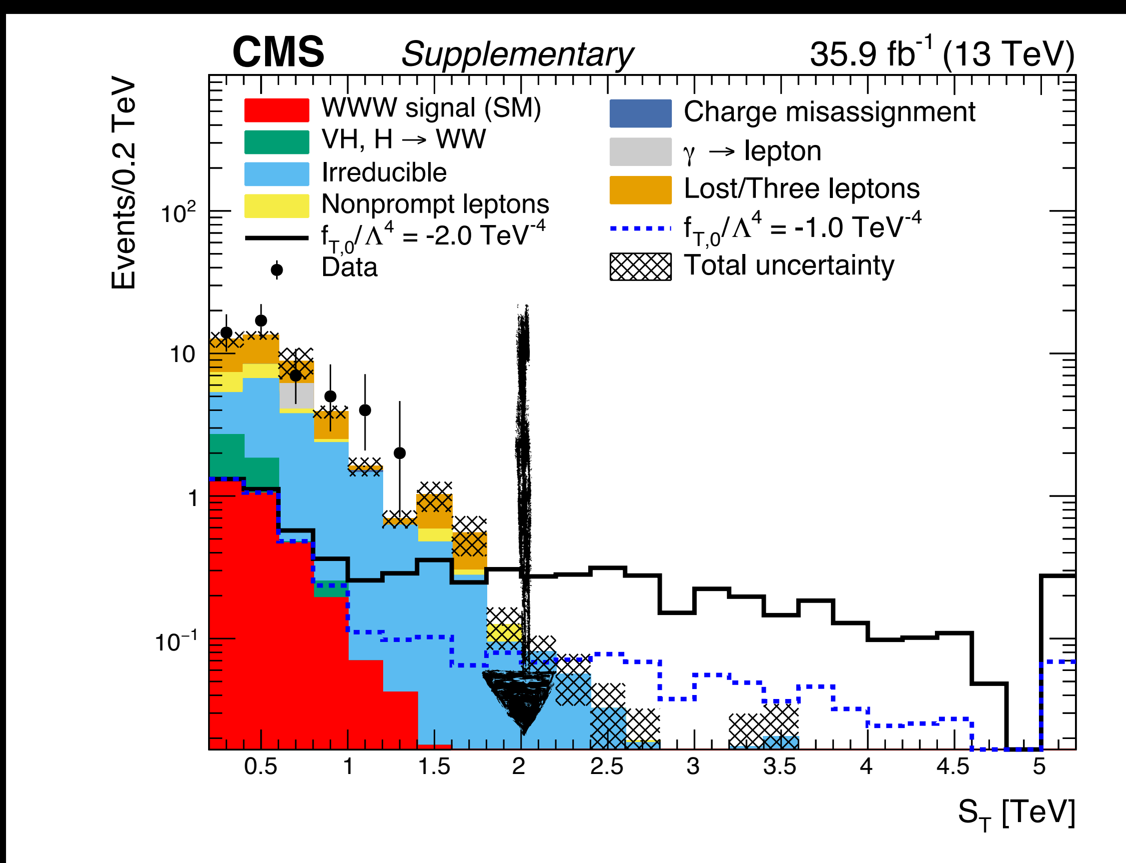
- Process definitions:
  - Full: includes SM+interference+BSM
    - generate p p > w w w NP=1 NPcW=1
  - Interference
    - generate p p > w w w NP^2==1 NPcW^2==1
  - BSM
    - generate p p > w w w NP^2==2 NPcW^2==2
  - SM
    - generate p p > w w w

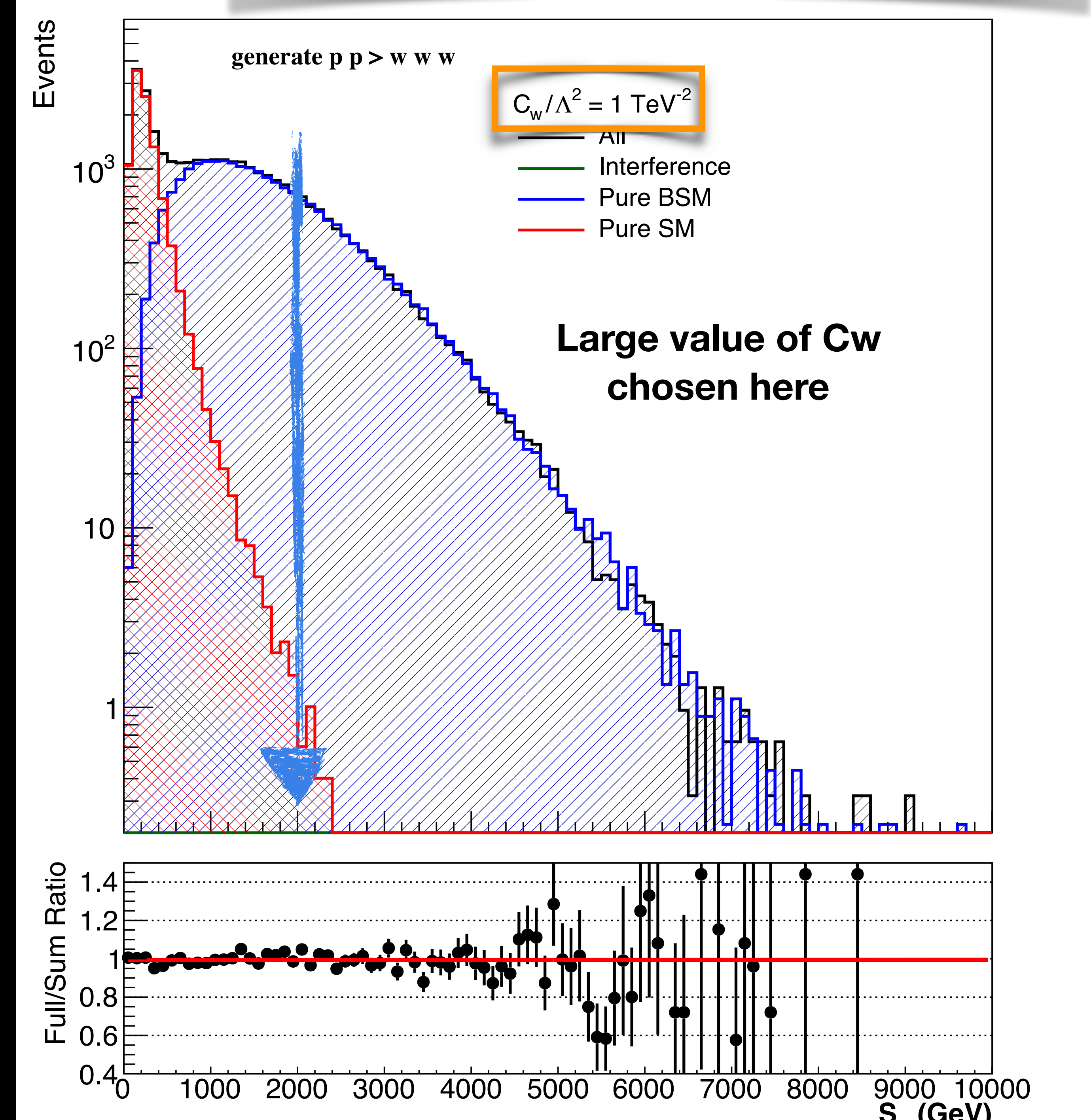


EFT sensitivity with on-shell bosons as a starting point

$$\mathcal{O}_{3W} = \epsilon^{abc} W_{\mu}^{a\nu} W_{\nu}^{b\rho} W_{\rho}^{a\mu}$$

- ☑ Assumed SM process is the only background
- ☑ Computed yields with $S_T > 2000$ GeV

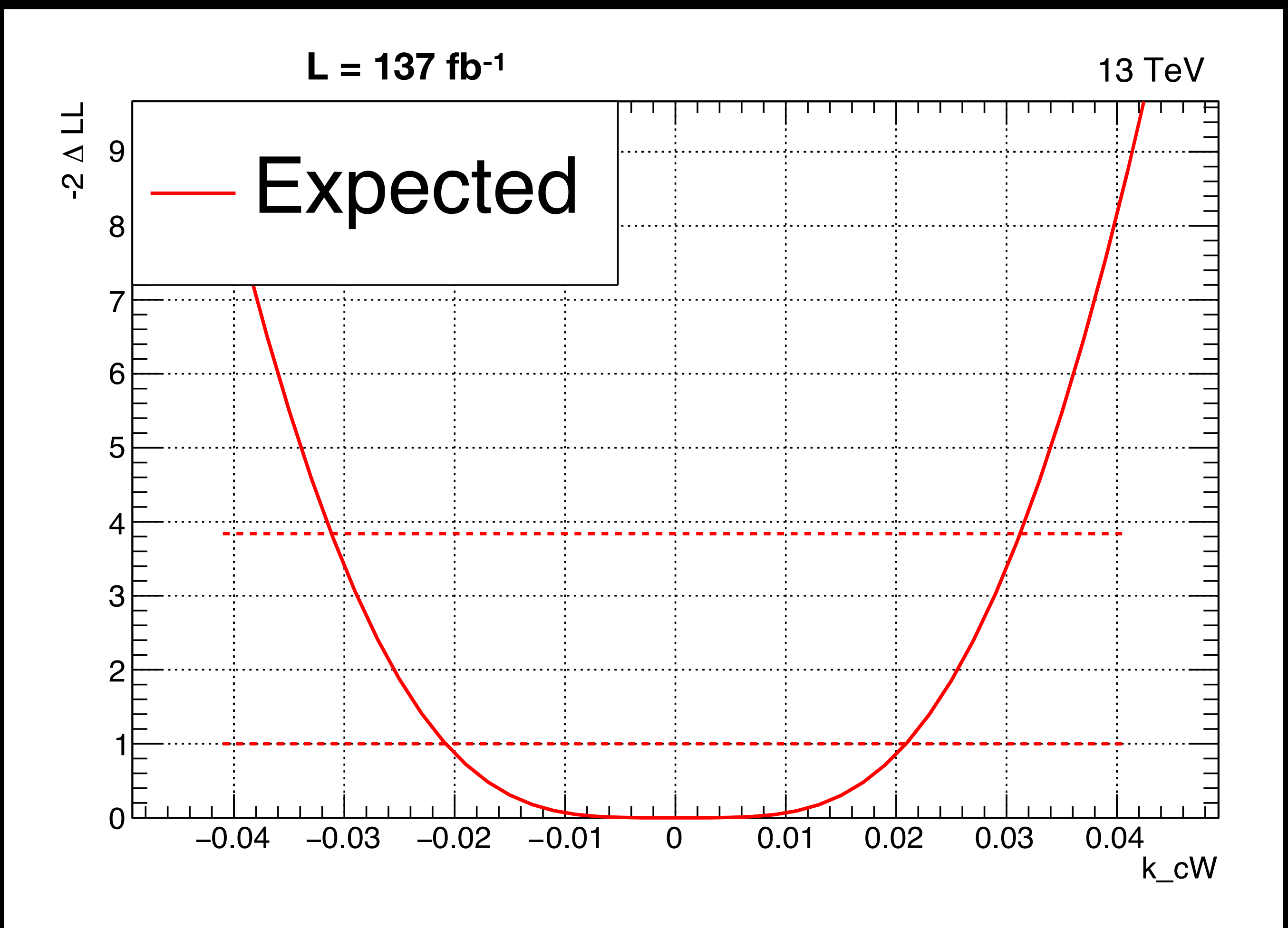


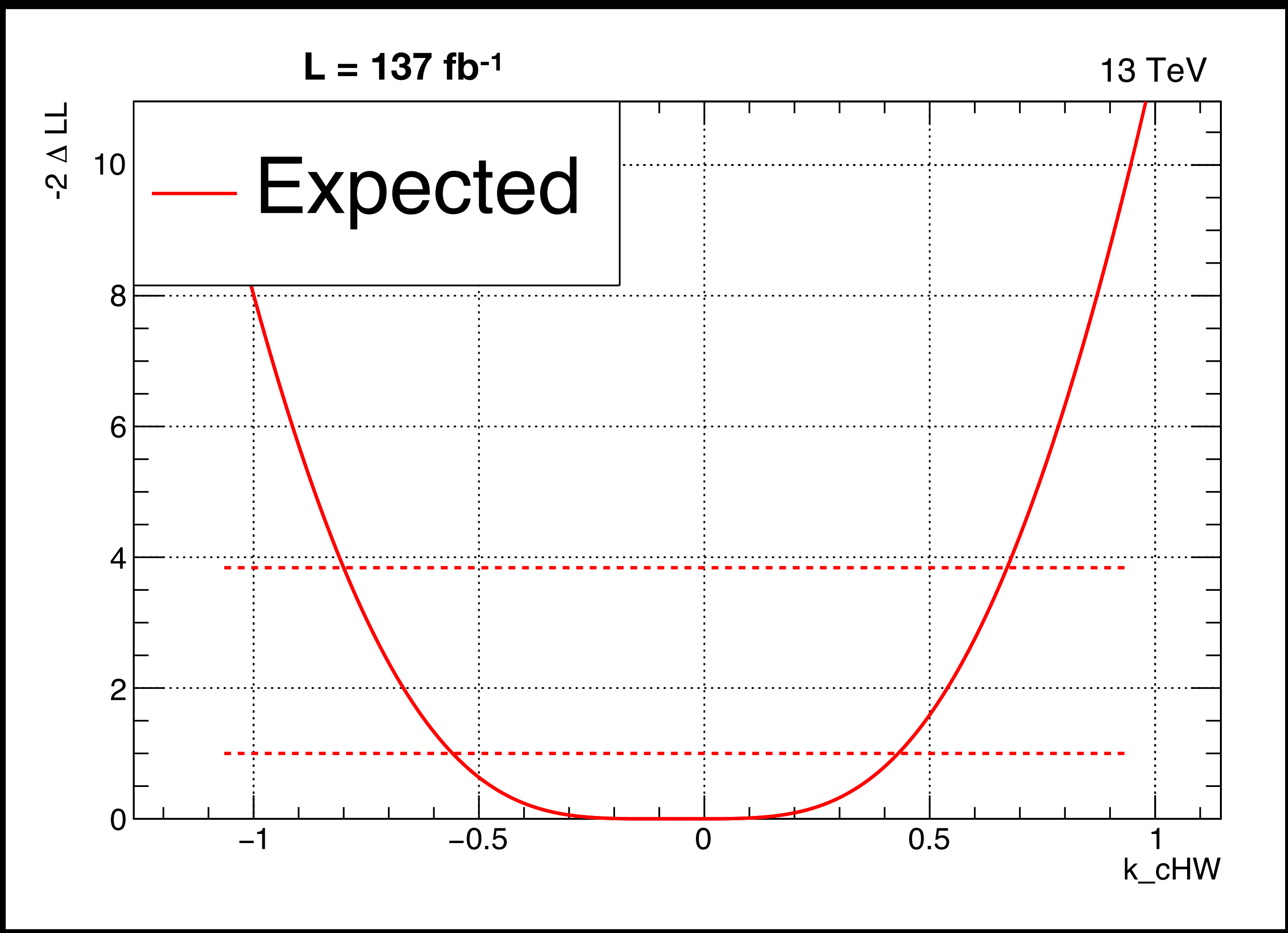


- ☑ Assumption based on CMS paper

EFT sensitivity with on-shell bosons as a starting point

- ☑ Used the same limit setting setup as those used here: https://arxiv.org/pdf/2108.03199.pdf
- ☑ Exploring possible collaboration with the group





$$\mathcal{O}_{3W} = \epsilon^{abc} W_{\mu}^{a\nu} W_{\nu}^{b\rho} W_{\rho}^{a\mu}$$

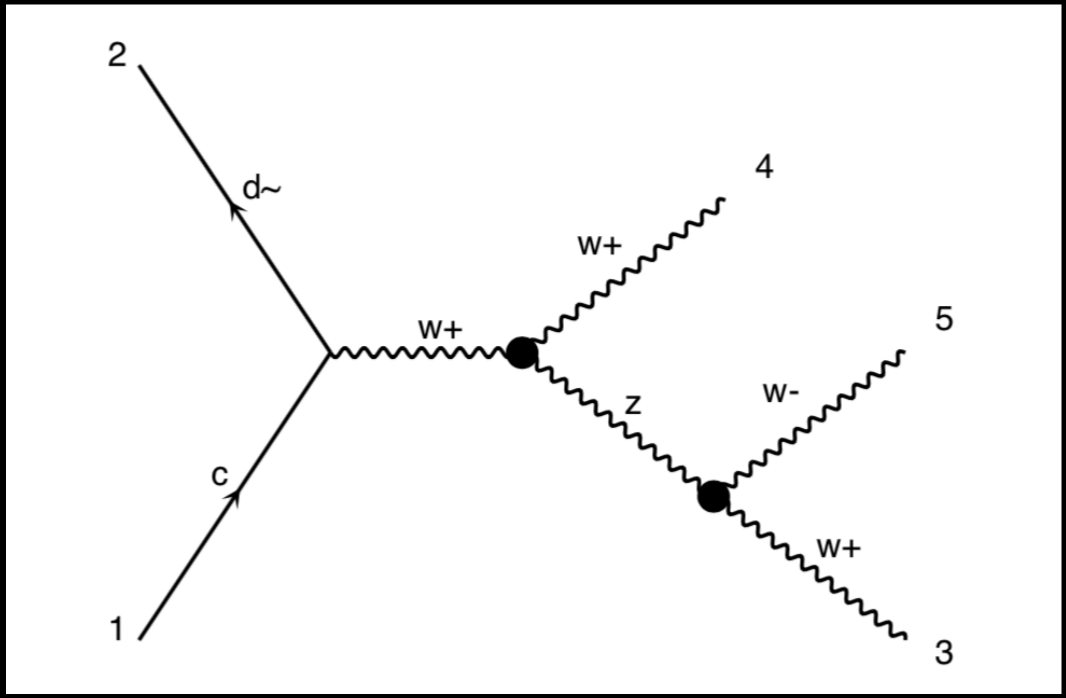
$$\mathcal{O}_{HW} = \phi^{\dagger} \phi W_{\mu\nu} W^{\mu\nu}$$

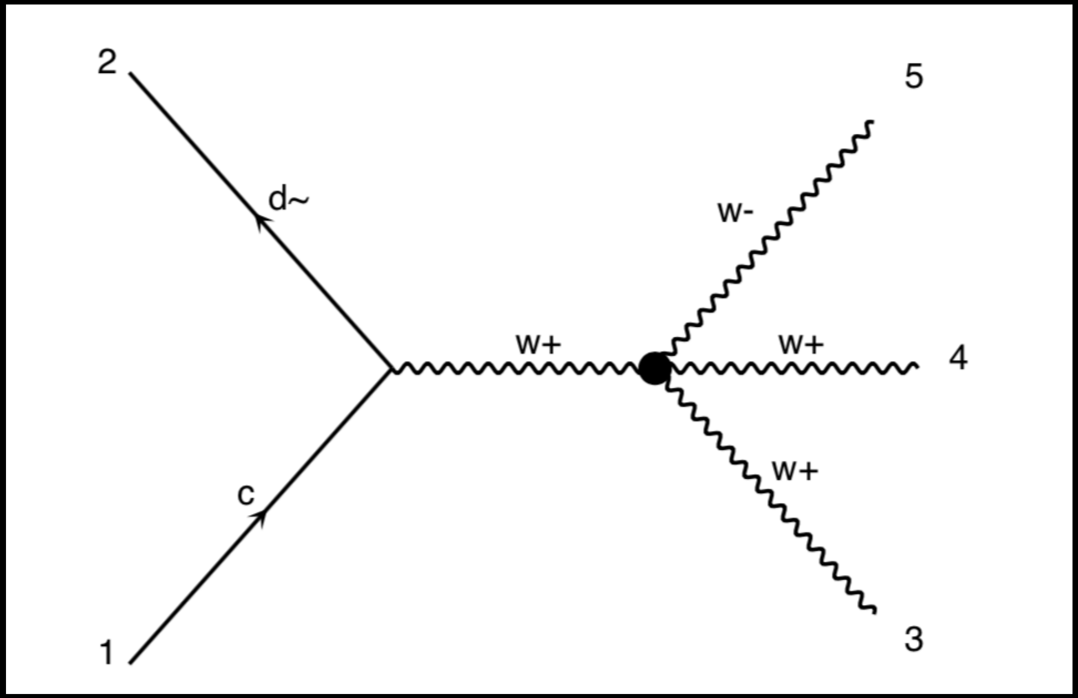
Comparable to sensitivities from VBS processes as explored in the above mentioned reference

(Dim6)² vs. Dim8 contributions

$$\mathcal{O}_{3W} = \epsilon^{abc} W_{\mu}^{a\nu} W_{\nu}^{b\rho} W_{\rho}^{a\mu}$$

$$\mathcal{L}_{T,0} \quad = \quad \mathrm{Tr}\left[\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}\right] \times \mathrm{Tr}\left[\hat{W}_{\alpha\beta}\hat{W}^{\alpha\beta}\right]$$

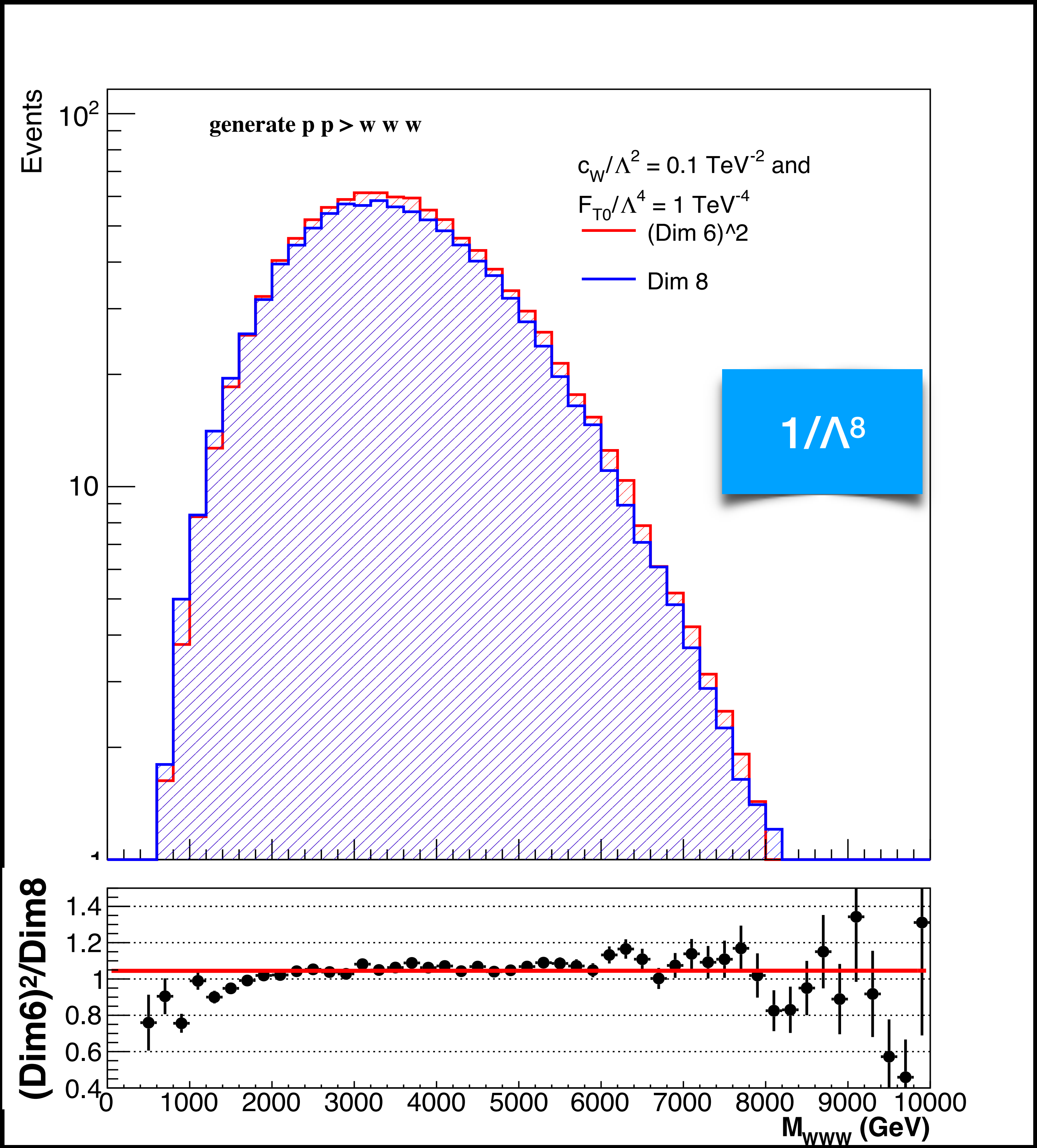




- Generating BSM for (dim6)²:
  - generate p p > w w w $h NP==2 NPcW^2==4
- Generating BSM for dim8:
  - generate p p > w w w $h T0^2==2

Many thanks to Ilaria Brivio for guidance!

(Dim6)² vs. Dim8 contributions: Pure BSM



- It is imperative that the representative values are chosen for the Wilson Coefficients for both dim6 and dim8 operators
- The question really is one of characterizing an excess in terms of (dim6)² or dim8 if the shapes of the BSM parts of the distributions are the same
- Extracting pure (dim6)² interference is difficult because there are two 1/Λ⁴ contributions
    - Syntax includes double insertions interference + single insertions squared or pure BSM

Path forward…

- ☑ Started assessing sensitivities to various dim6 EFT operators
- ☑ Beginning to address $(\text{dim6})^2$ vs. dim8 contributions: pertinent in the context of discussions in the LHC EFT Working Group
- ☑ Exploring various polarization states of the V in the VVV process
- ☑ Plan to address how VVV EFT bounds contribute to global fits
- ☑ Plan on extending current collaboration to include colleagues from Torino and Milano
- ☑ Could be interesting to compare with EFT sensitivities from lepton colliders