Connecting UV completions with HEFTs

Veronica Sanz (Sussex)

HEFT2014

Outline

- The HEFT approach, briefly
- Framework for HEFT studies
- Complete analysis of HEFT
- Limitations of HEFTs
- Benchmarks for HEFTs

The HEFT approach , briefly

HEFT

Bottom-up approach

operators w/ SM particles and symmetries,
plus the newcomer, the Higgs

in this talk
linear realization, a choice of basis

$$
\begin{aligned}
\mathcal{L} \;\supset\; & \frac{\bar{c}_H}{2v^2}\partial^\mu\left[\Phi^\dagger\Phi\right]\partial_\mu\left[\Phi^\dagger\Phi\right] + \frac{g'^2\ \bar{c}_\gamma}{m_W^2}\Phi^\dagger\Phi B_{\mu\nu}B^{\mu\nu} + \frac{g_s^2\ \bar{c}_g}{m_W^2}\Phi^\dagger\Phi G^a_{\mu\nu}G_a^{\mu\nu} \\
+ & \frac{2ig\ \bar{c}_{HW}}{m_W^2}\left[D^\mu\Phi^\dagger T_{2k}D^\nu\Phi\right]W^k_{\mu\nu} + \frac{ig'\ \bar{c}_{HB}}{m_W^2}\left[D^\mu\Phi^\dagger D^\nu\Phi\right]B_{\mu\nu} \\
+ & \frac{ig\ \bar{c}_W}{m_W^2}\left[\Phi^\dagger T_{2k}\overleftrightarrow{D}^\mu\Phi\right]D^\nu W^k_{\mu\nu} + \frac{ig'\ \bar{c}_B}{2m_W^2}\left[\Phi^\dagger\overleftrightarrow{D}^\mu\Phi\right]\partial^\nu B_{\mu\nu} \\
+ & \frac{\bar{c}_t}{v^2}y_t\Phi^\dagger\Phi\ \Phi^\dagger\cdot\bar{Q}_L t_R + \frac{\bar{c}_b}{v^2}y_b\Phi^\dagger\Phi\ \Phi\cdot\bar{Q}_L b_R + \frac{\bar{c}_\tau}{v^2}y_\tau\ \Phi^\dagger\Phi\ \Phi\cdot\bar{L}_L\tau_R\,.
\end{aligned}
$$

Contino et al. 1303.3876

How do we look for New Physics using HEFTs

Higgs anomalous couplings

HDOs generate HVV interactions with more derivatives

$$-\frac{1}{4} h\, g^{(1)}_{hVV} V_{\mu\nu} V^{\mu\nu}$$

$$-h\, g^{(2)}_{hVV} V_{\nu} \partial_{\mu} V^{\mu\nu}$$

$$-\frac{1}{4} h\, \tilde{g}_{hVV} V_{\mu\nu} \tilde{V}^{\mu\nu}$$

example.

$$g^{(1)}_{hww} = \frac{2g}{m_W}\, \bar{c}_{HW}$$

$$g^{(2)}_{hww} = \frac{g}{m_W}\, \left(\bar{c}_W + \bar{c}_{HW}\right)$$

Alloul, Fuks, VS. 1310.5150

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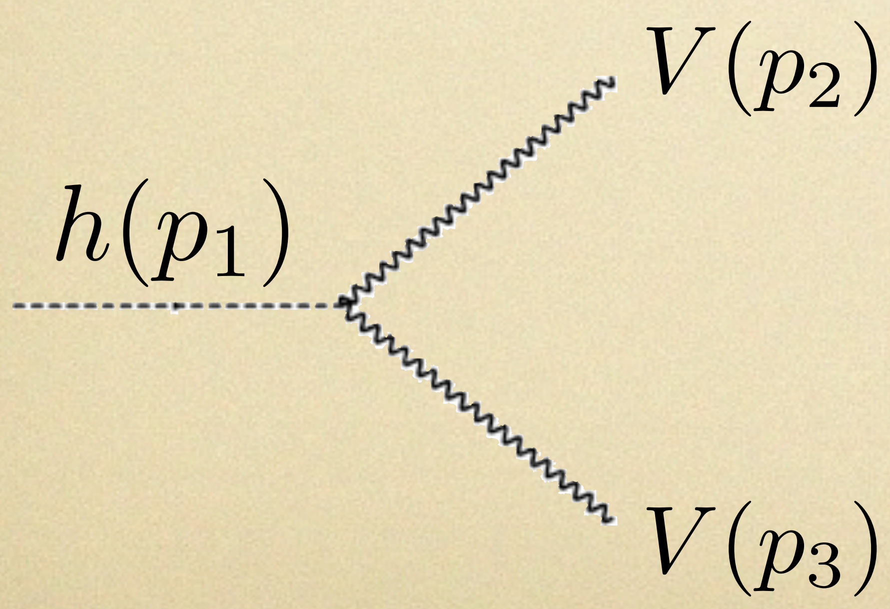
ex. Feynman rule if mh>2mV



$$i\eta_{\mu\nu} \left(g^{(1)}_{hVV} \left(\frac{\hat{s}}{2} - m_V^2 \right) + 2 g^{(2)}_{hVV} m_V^2 \right)$$

$$-i g^{(1)}_{hVV} p_3^{\mu} p_2^{\nu}$$

$$-i \tilde{g}_{hVV} \epsilon^{\mu\nu\alpha\beta} p_{2,\alpha} p_{3,\beta}$$

How do we look for New Physics using HEFTs

Higgs anomalous couplings

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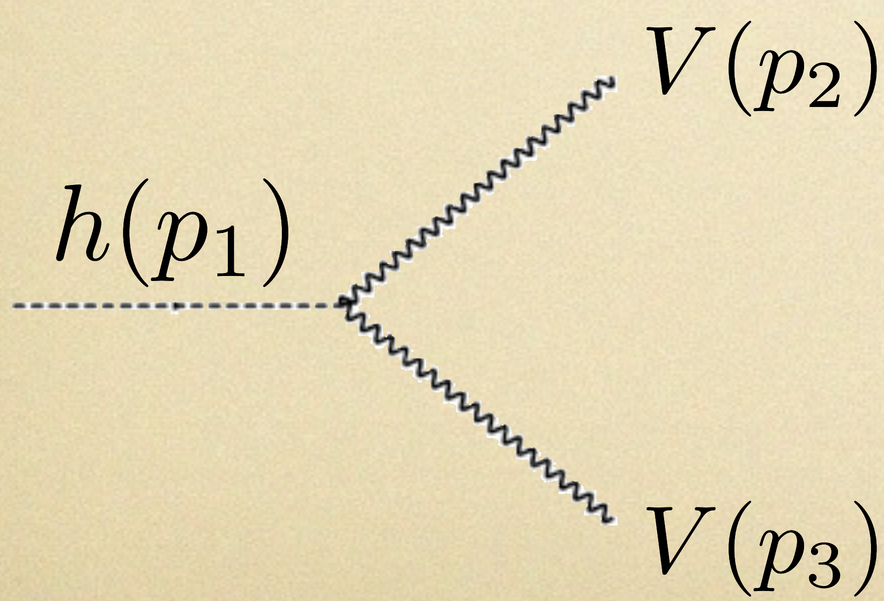


total rates, COM, angular, inv mass and pT distributions

Framework for HEFT studies

Alloul, Fuks, VS. 1310.5150
VS and Williams. In prep.

Higgs BRs   eHDECAY   Contino et al. 1303.3876

Higgs BRs eHDECAY Contino et al. 1303.3876

Production rates and kinematic distributions

depend on cuts

need radiation and detector effects

Simulation tools

Higgs BRs eHDECAY Contino et al. 1303.3876

Production rates and kinematic distributions

depend on cuts

need radiation and detector effects

Simulation tools

coefficients

$$\mathcal{L}_{eff} = \sum_i \frac{f_i}{\Lambda^2} \mathcal{O}_i$$

→ **Collider simulation**

observables

Limit coefficients = new physics

In this talk we use

1. Feynrules HDOs involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

links to CalcHEP, LoopTools, Madgraph...

HEFT->Madgraph-> Pythia... -> FastSim/FullSim

In this talk we use

1. Feynrules HDOs involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

links to CalcHEP, LoopTools, Madgraph...

HEFT->Madgraph-> Pythia... -> FastSim/FullSim

2.QCD NLO HDOs involving Higgs and TGCs

VS and Williams. In prep.

MCFM and POWHEG

Pythia, Herwig... -> FastSim/FullSim

MC@NLO : see talk of M. Zaro

also VBF@NLO

Complete analysis of HEFT

Ellis, VS and You. 1404.3667+work in preparation

Number of independent operators in HEFT

In the SILH basis

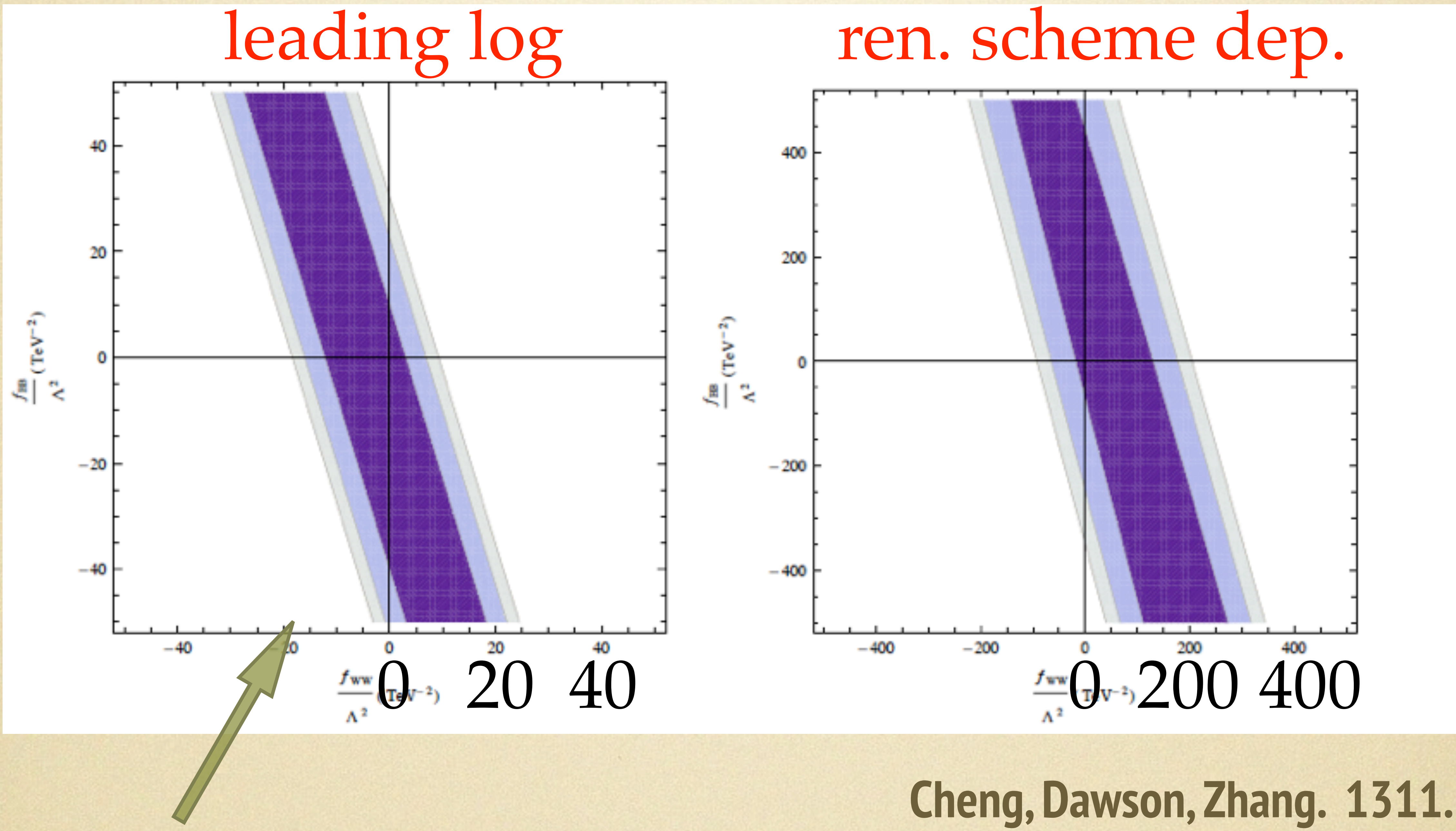
$$\bar{c}_i \equiv \{\bar{c}_H, \bar{c}_{t,b,\tau}, \bar{c}_W, \bar{c}_{HW}, \bar{c}_{HB}, \bar{c}_\gamma, \bar{c}_g\} .$$

Note that

We have eliminated operators which contribute to STU at tree level, (LHC cannot compete)

but kept operators at loop order in STU...

renormalization/matching is important

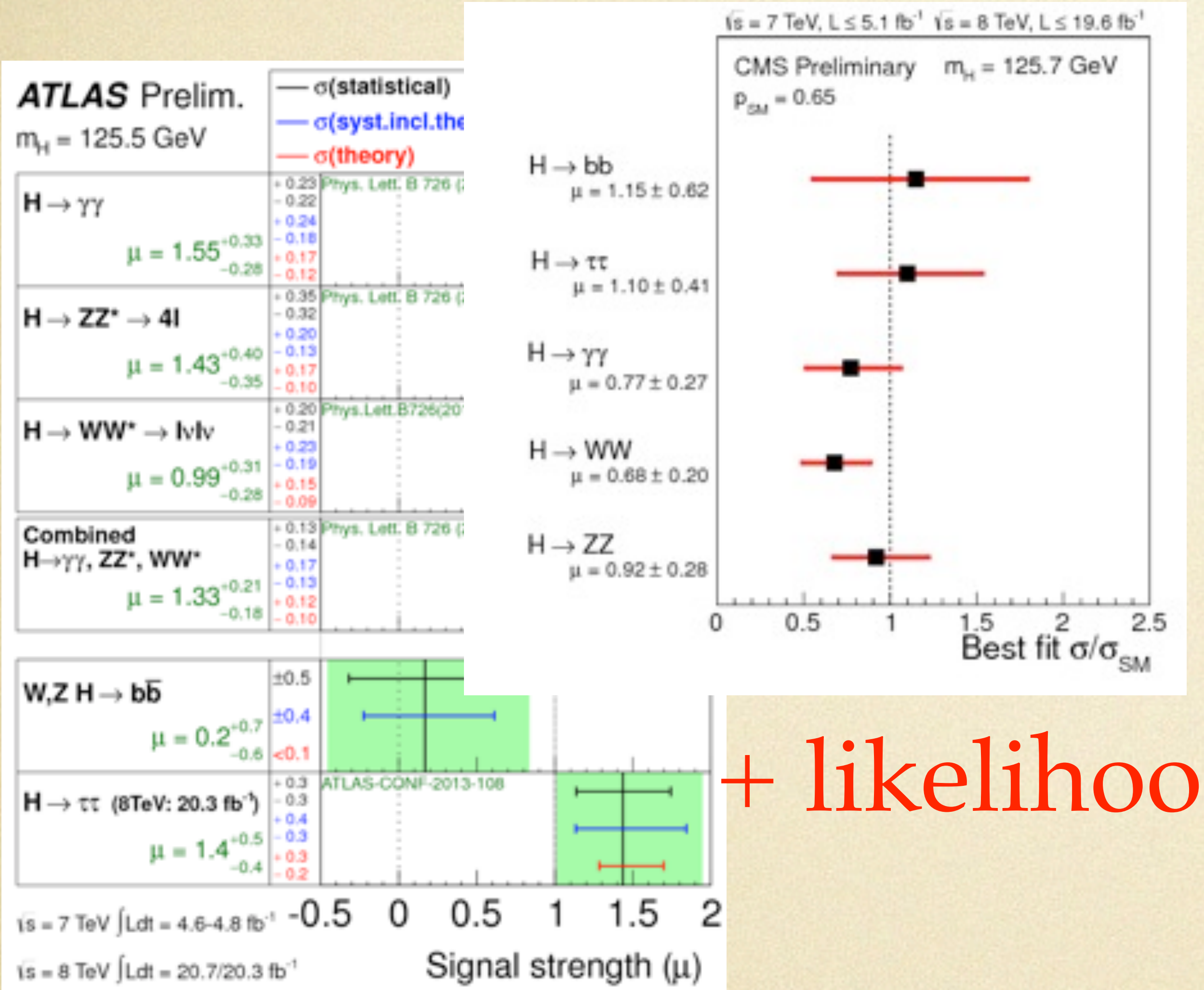


Cheng, Dawson, Zhang. 1311.3107

Masso, VS. 1211.1320

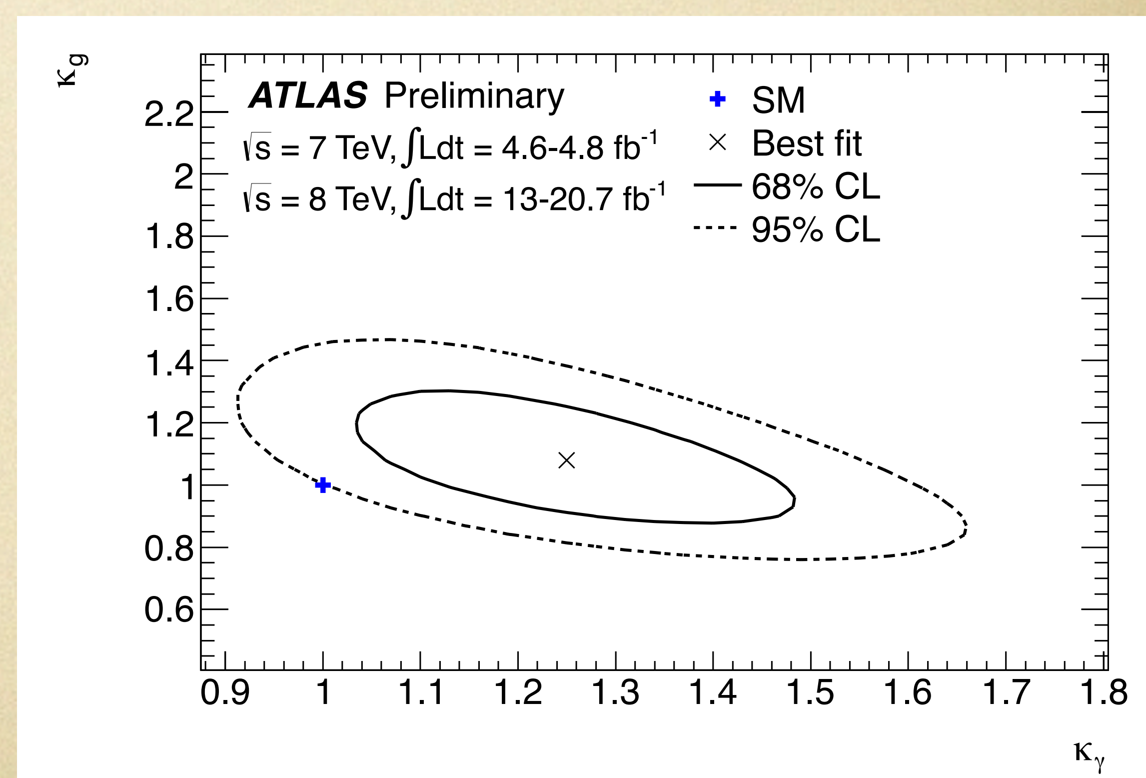
operators at loop-order in STU

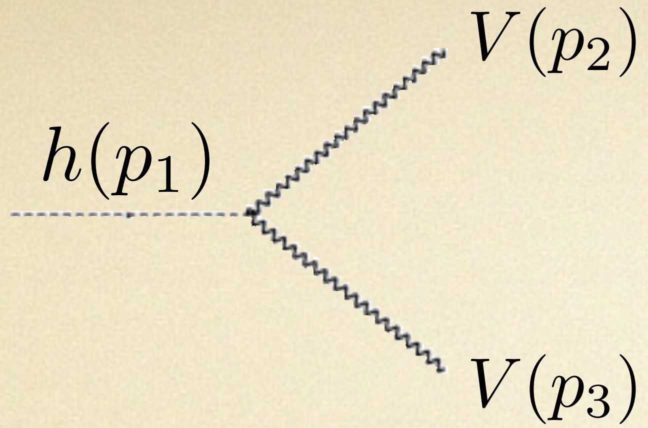
Usually, maximize information on signal strengths



+ likelihoods

make some assumptions





$$i\eta_{\mu\nu}\left(g^{(1)}_{hVV}\left(\frac{\hat{s}}{2}-m_V^2\right)+2g^{(2)}_{hVV}m_V^2\right)$$

$$-ig^{(1)}_{hVV}p_3^{\mu}p_2^{\nu}$$

$$-i\tilde{g}_{hVV}\epsilon^{\mu\nu\alpha\beta}p_{2,\alpha}p_{3,\beta}$$

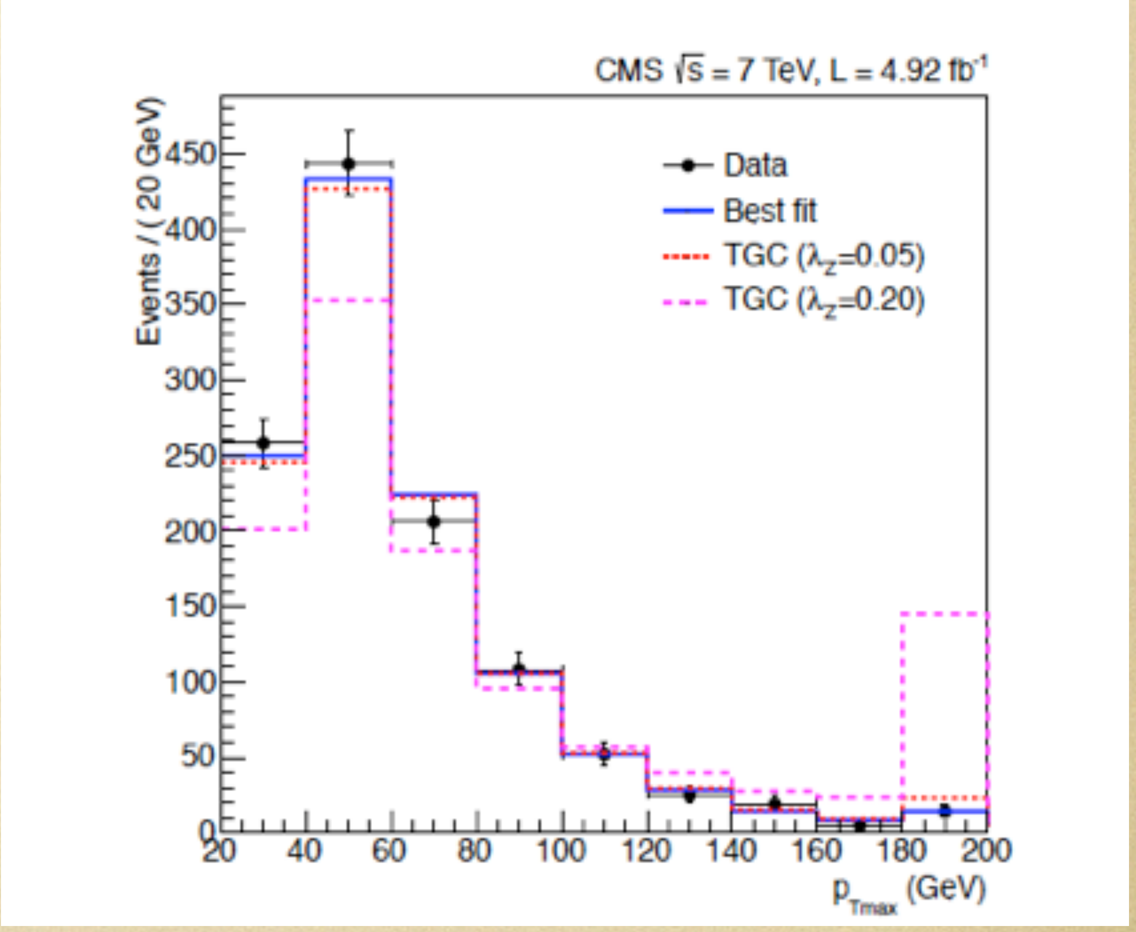
More information in kinematic distributions

For example, in EW physics

TGCs

instead of total rates

More Higgs data:
total rates-> kinematics



leading lepton pT

What is the most sensitive Higgs channel to kinematics at LHC8?

What is the most sensitive Higgs channel to kinematics at LHC8?

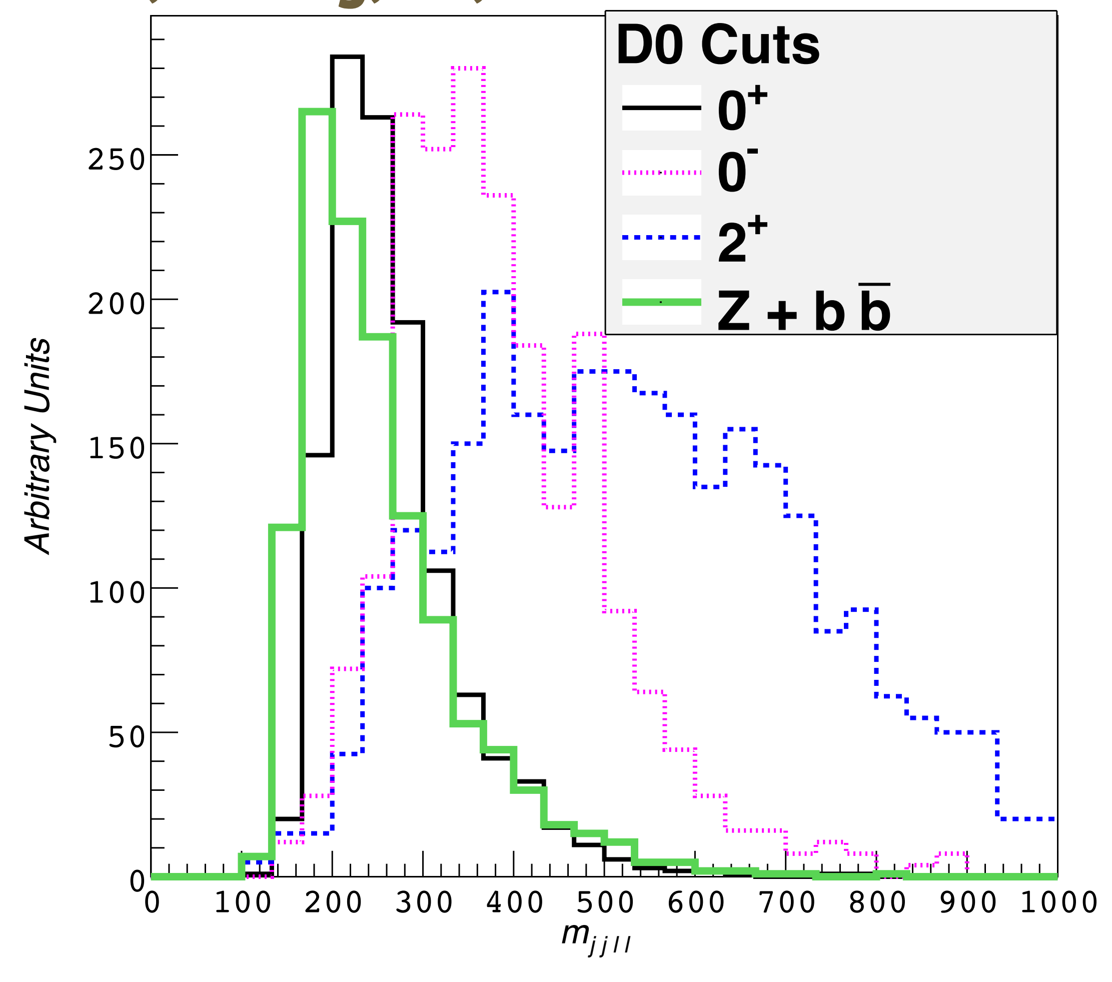
Associated production

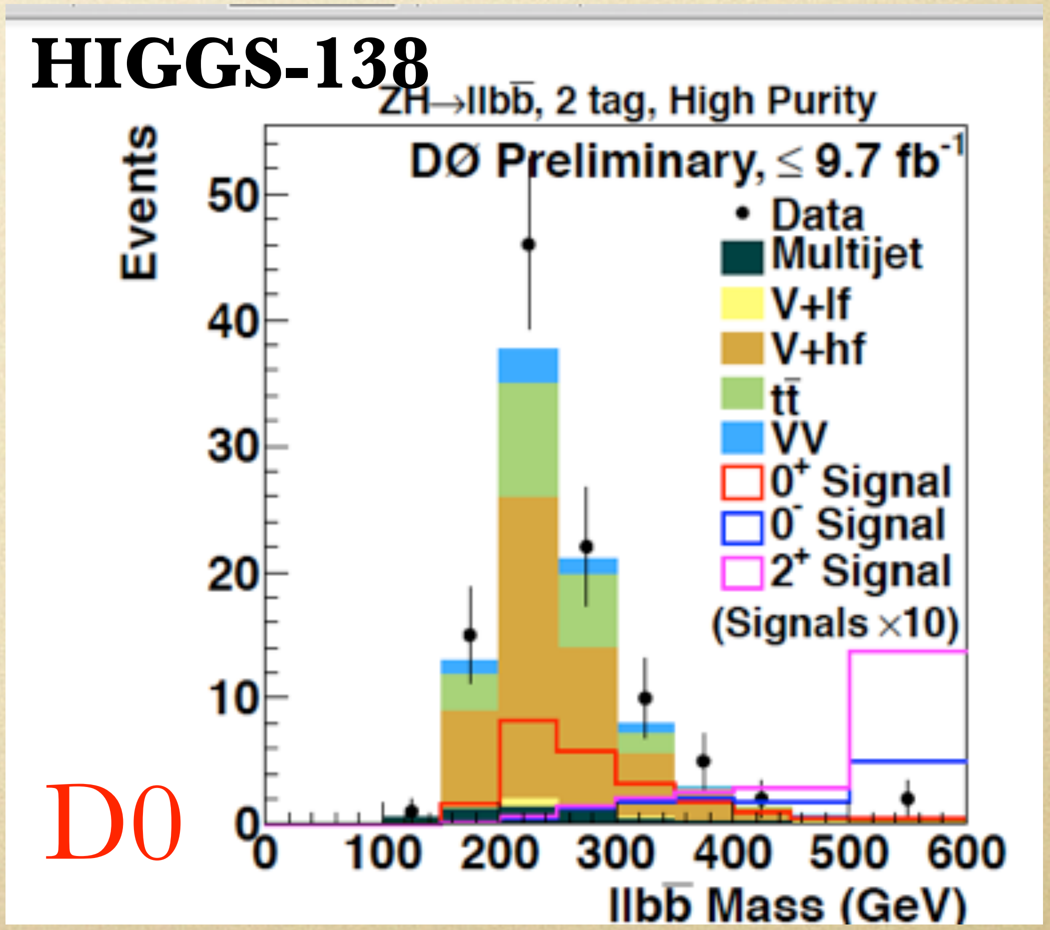
very sensitive to the Lorentz structure of the vertex

Test JCP of the Higgs

m_{Vh}

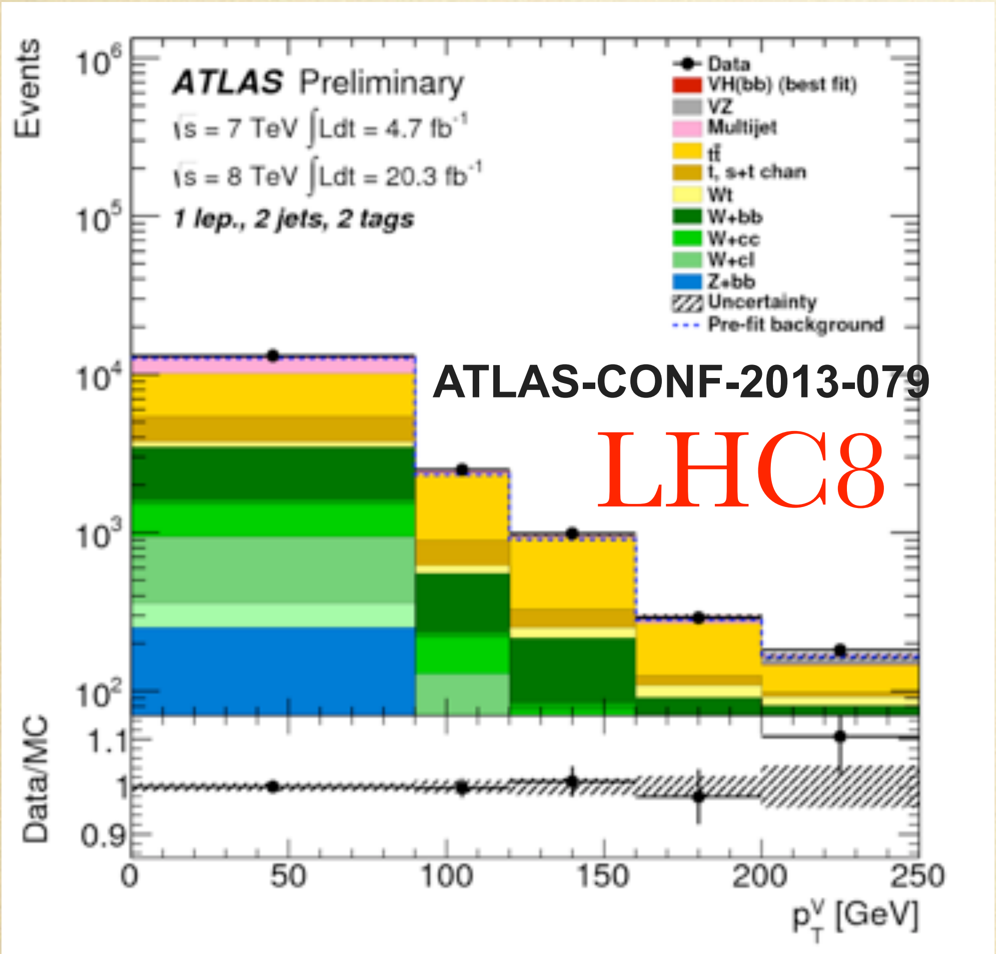
Ellis, Hwang, VS, You. 1208.6002

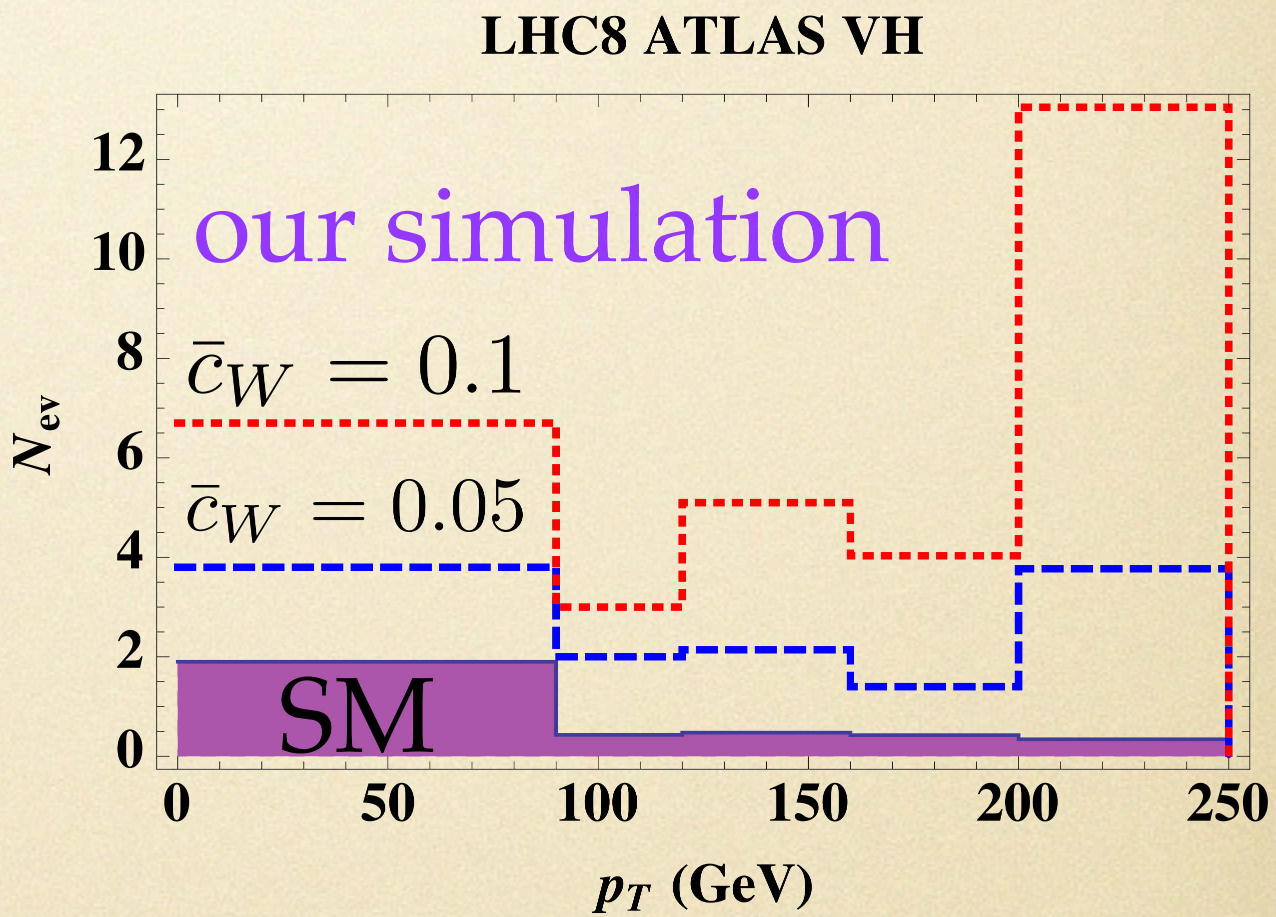




For the scalar Higgs boson

Kinematics of associated production at LHC8





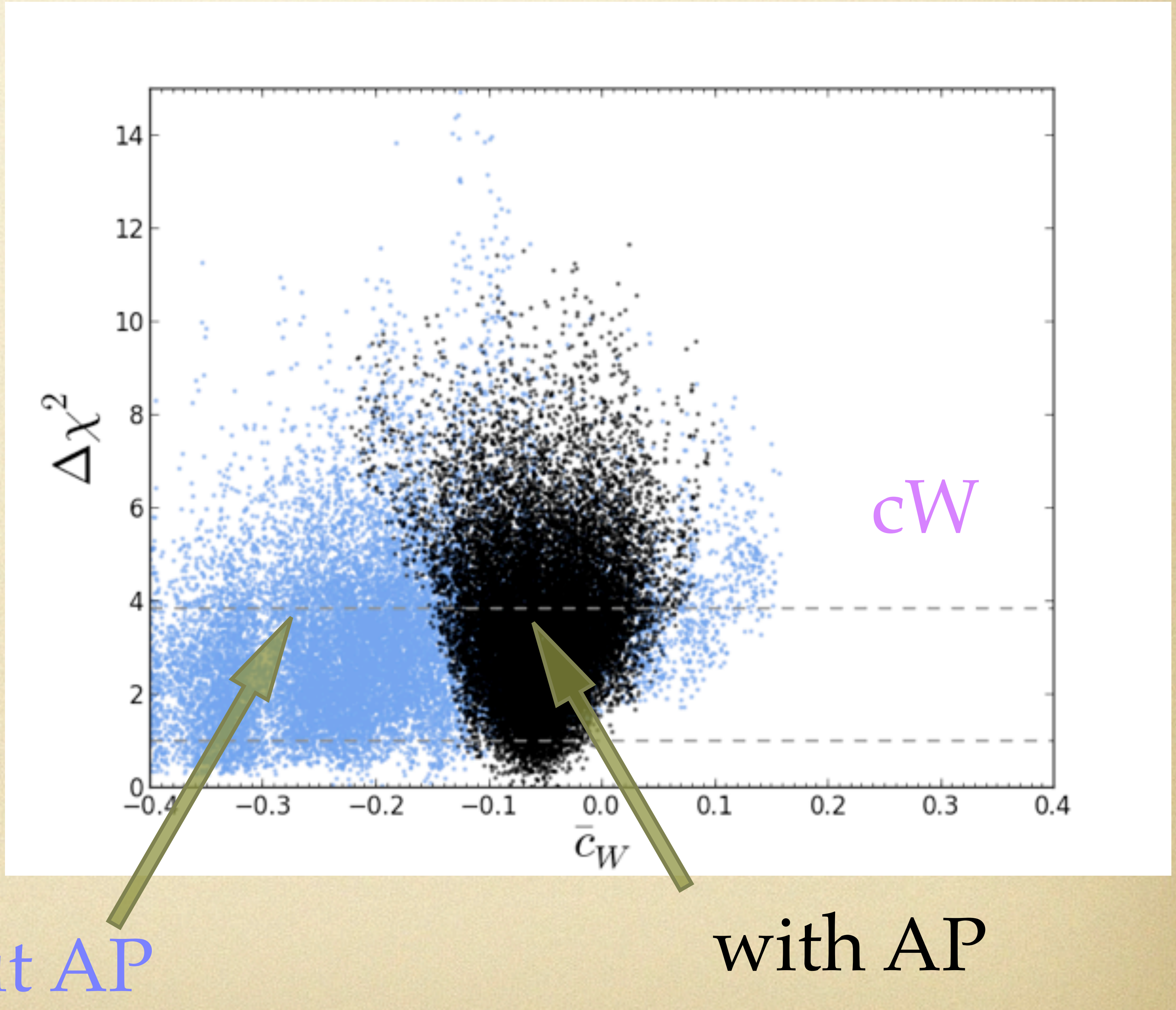
Feynrules -> MG5-> pythia->Delphes3

verified for SM/BGs => expectation for HEFT

inclusive cross section is less sensitive than distribution

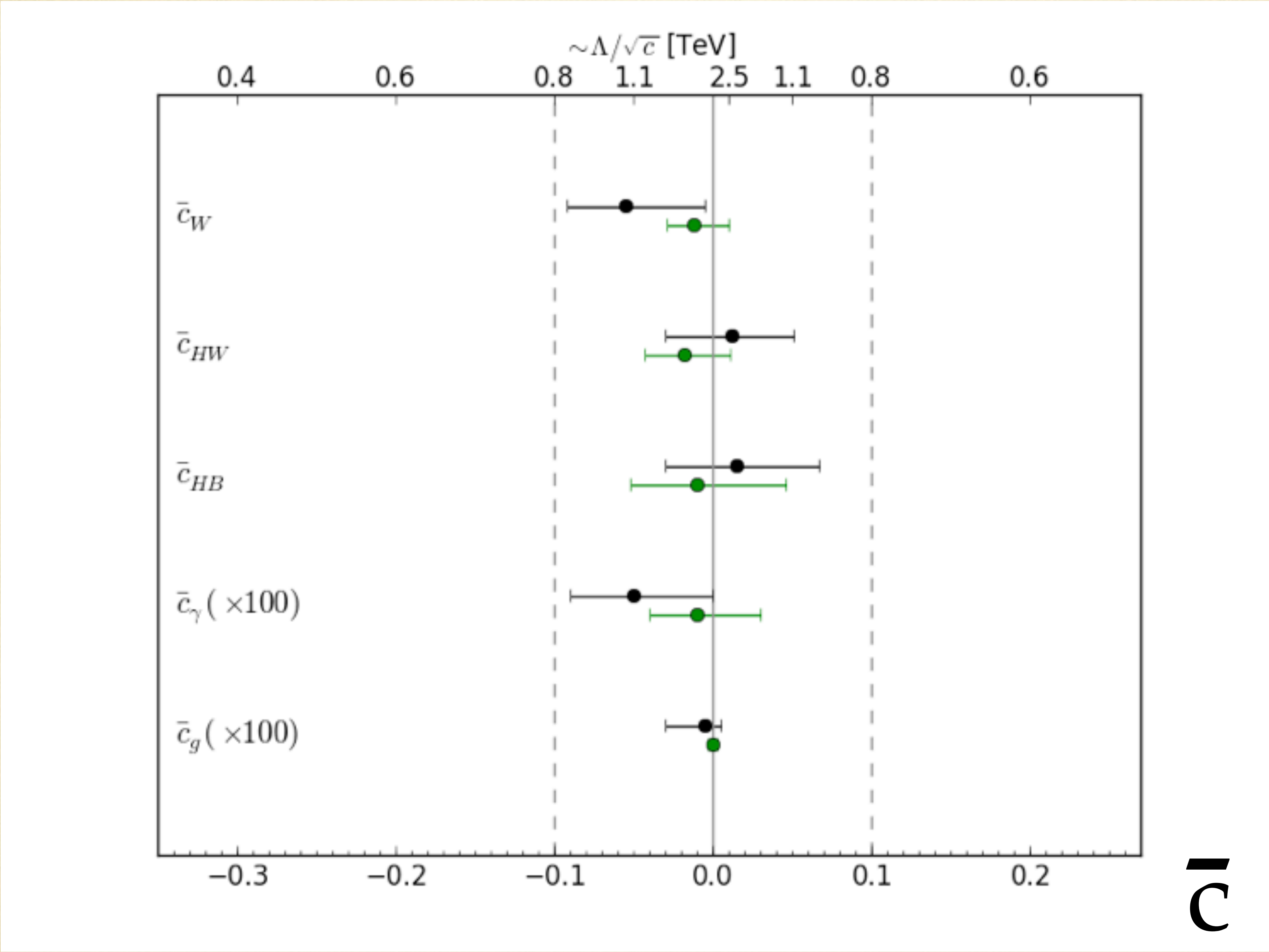
Besides, breaking of blind directions requires information on HV production

Global fit to 8 parameters



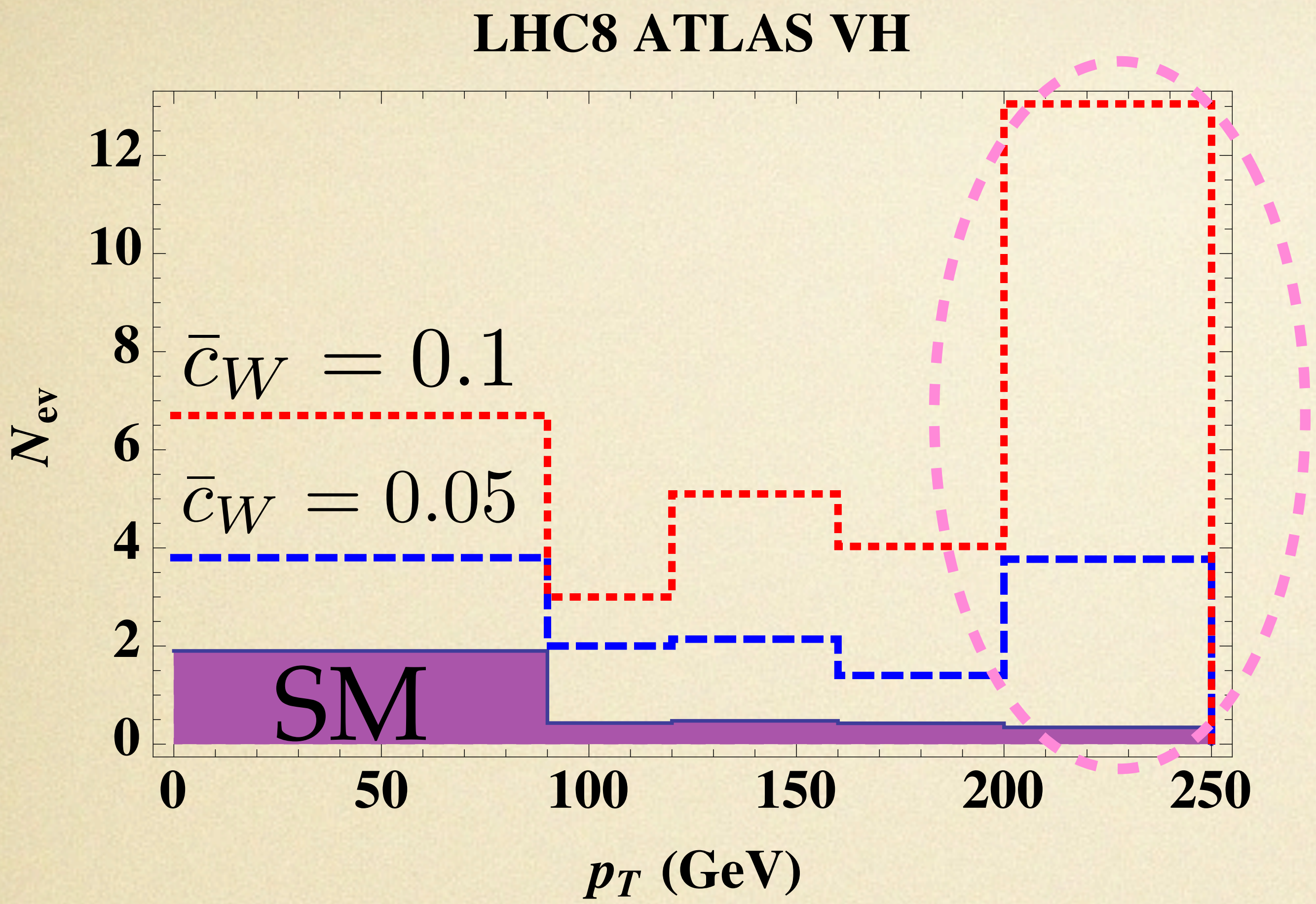
Putting it all together

black global fit
green one-by-one fit



ct,cd,cH: weaker constraints

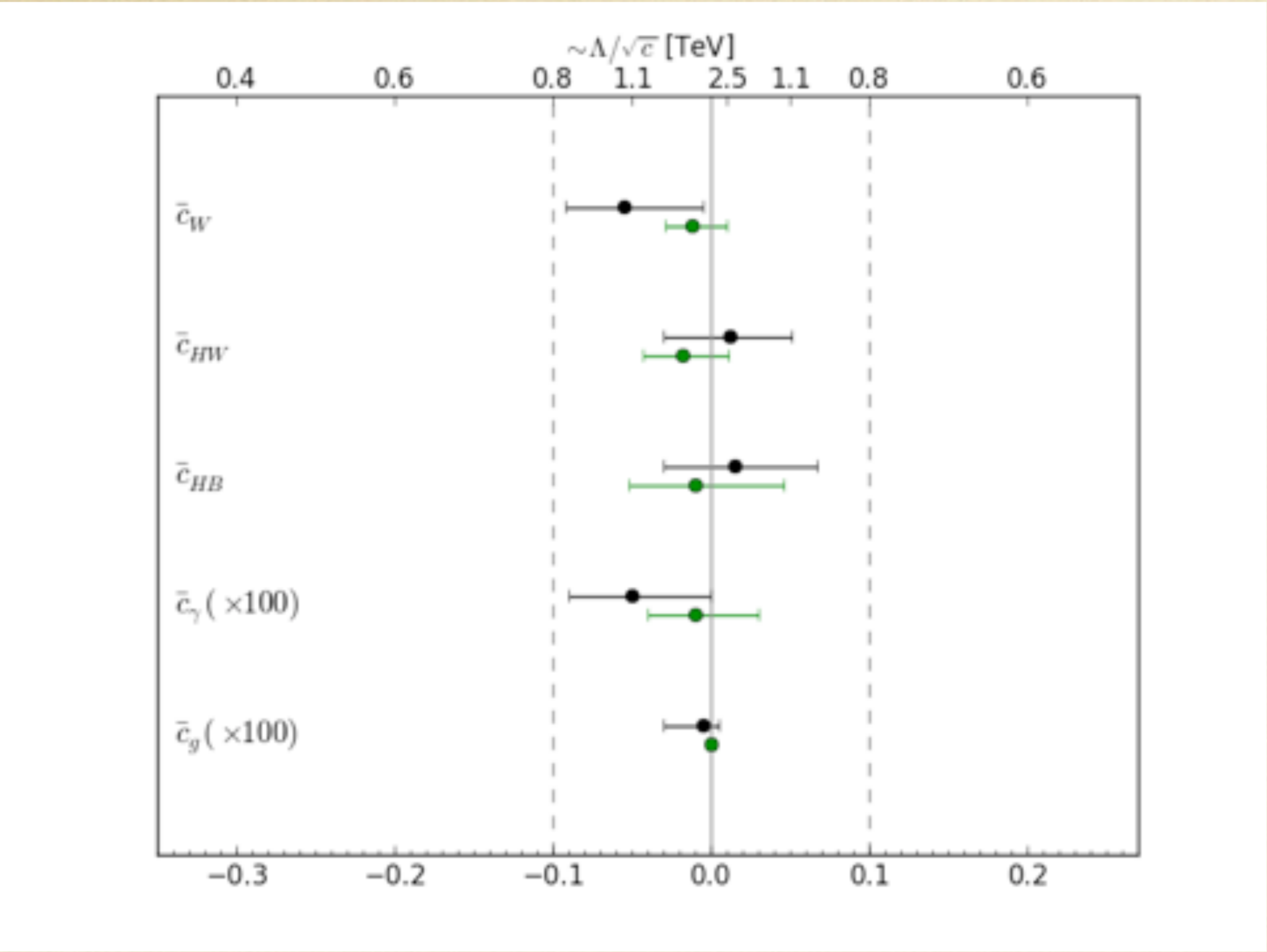
Limitations of HEFTs



most sensitive bin:
overflow (last) bin

At high-pT
sensitive to dynamics of new physics
breakdown of EFT
To what extent can we use this bin?

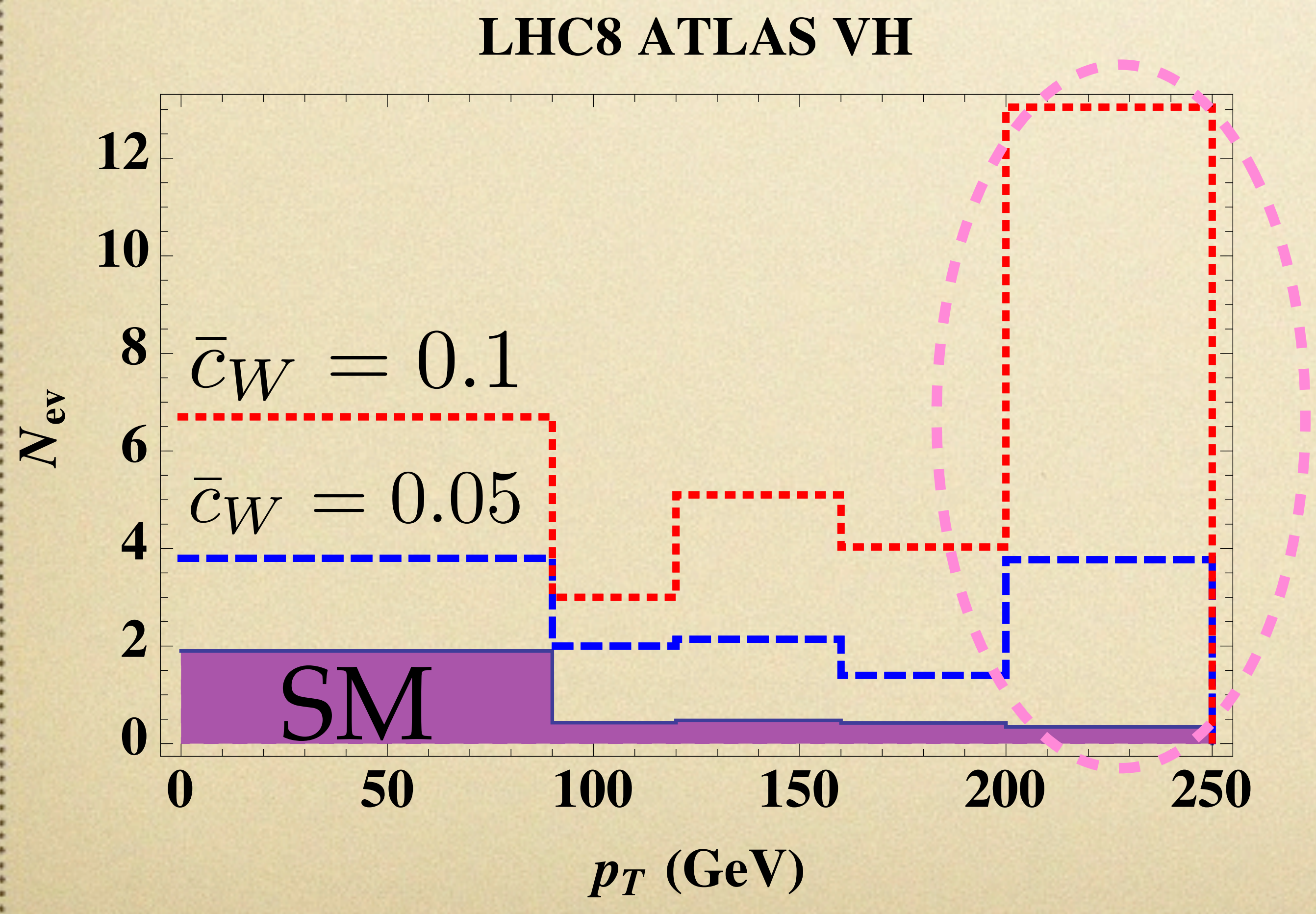
see also, F. Riva, S. Dawson and M. McCullough talks,
and Englert+Spannowsky. 1408.5147
Non-linear realization studies?



roughly speaking

$$\sqrt{\hat{s}} \sim \mathcal{O}(\ 800\text{-}1000\ )\ \text{GeV}$$

validity:
need to compare with UV completions



Benchmarks for HEFTs

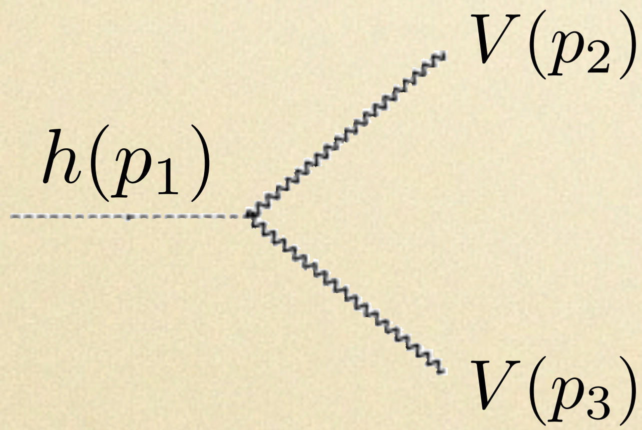
Masso and VS. 1211.1320

Gorbahn, No and VS. In preparation

HEFT (linear realization) vs UV-completions

Kinematics most sensitive to operators with Lorentz structure *different* from SM

example of h to VV



$$i\eta_{\mu\nu}\left(\underline{g^{(1)}_{hVV}}\left(\frac{\hat{s}}{2}-m_V^2\right)+2\underline{g^{(2)}_{hVV}}m_V^2\right)$$

$$-i\underline{g^{(1)}_{hVV}}p_3^\mu p_2^\nu$$

$$-i\underline{\tilde{g}_{hVV}}\epsilon^{\mu\nu\alpha\beta}p_{2,\alpha}p_{3,\beta}$$

looking for UV models generating cW, cHW-types

$$g^{(1)}_{hww}=\frac{2g}{m_W}\,\bar{c}_{HW}$$

$$g^{(2)}_{hww}=\frac{g}{m_W}\,(\bar{c}_W+\bar{c}_{HW})$$

HEFT (linear realization) vs UV-completions

UV models

Example 1.

tree-level operators

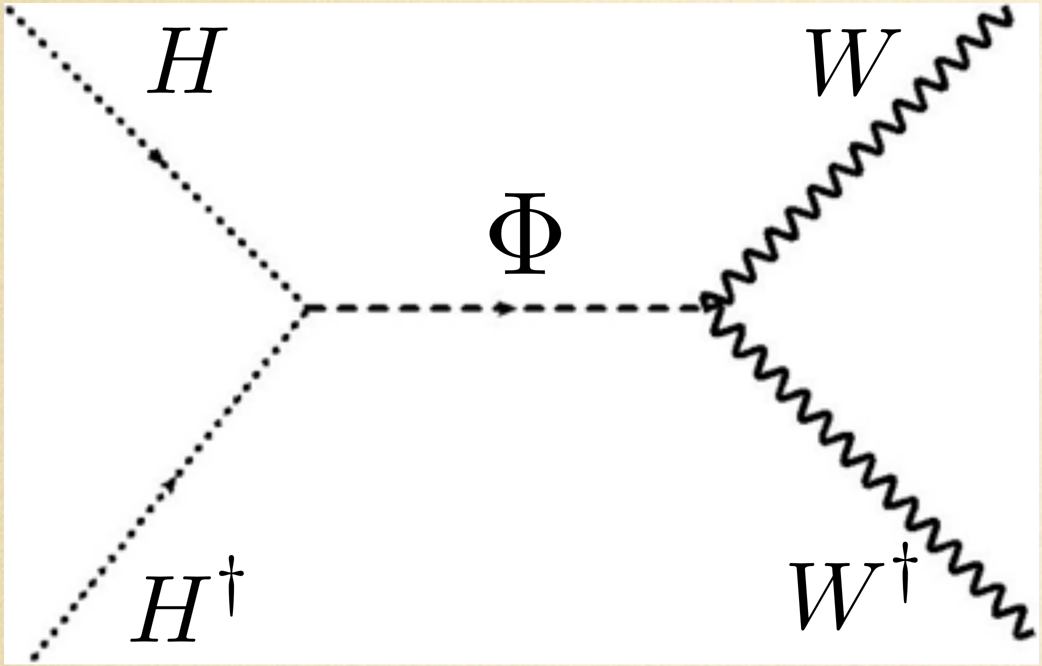
radion/dilaton exchange

Example 2.

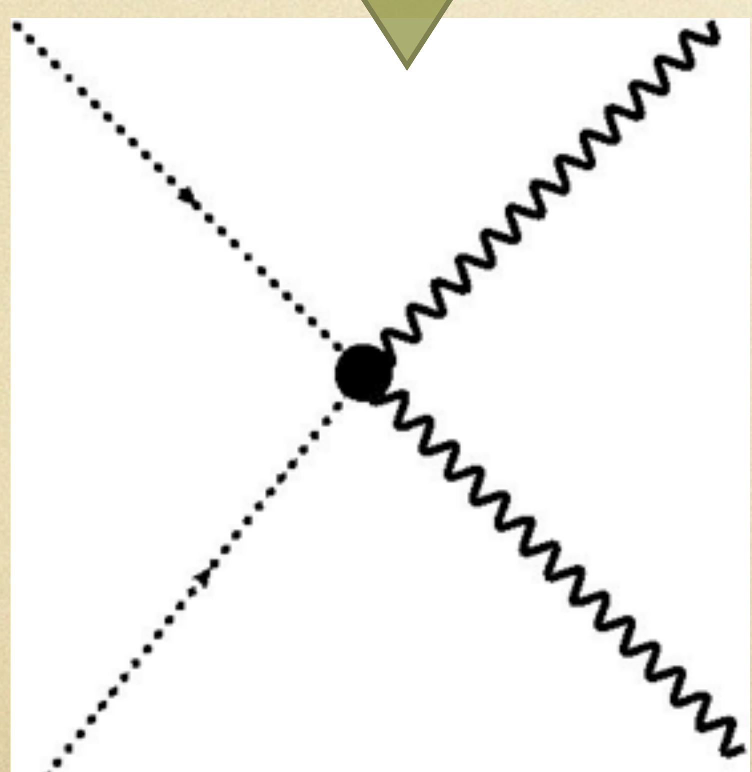
loop-induced operators

2HDM and SUSY spartners

Example 1. Tree-level exchange *radion/dilaton*



HEFT

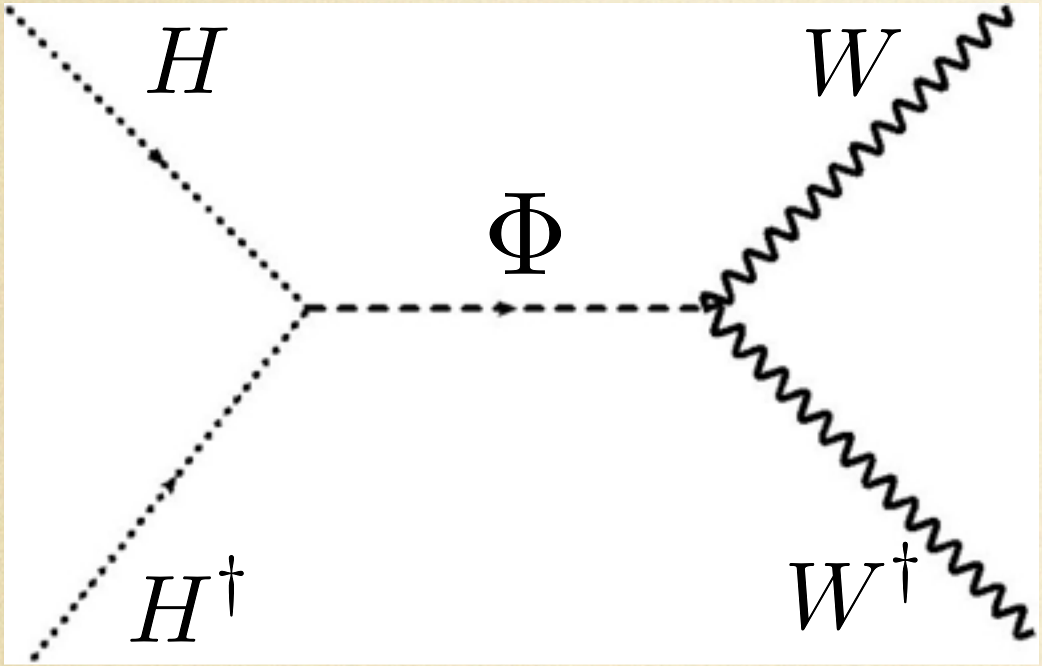


$$\frac{g_\Phi^2}{\hat{s} - M_\Phi^2} \simeq -\frac{g_\Phi^2}{M_\Phi^2}\left(1 - \frac{\hat{s}}{M_\Phi^2} + \dots\right)$$

$$\hat{s} \lesssim M_\Phi^2$$

$$\bar{c}_W \simeq \left(\frac{m_H v}{\Lambda M_\Phi}\right)^2$$

Example 1. Tree-level exchange *radion/dilaton*



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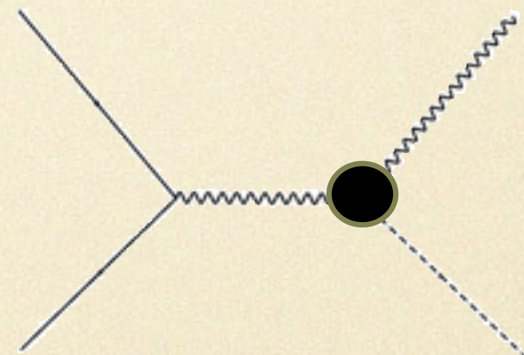
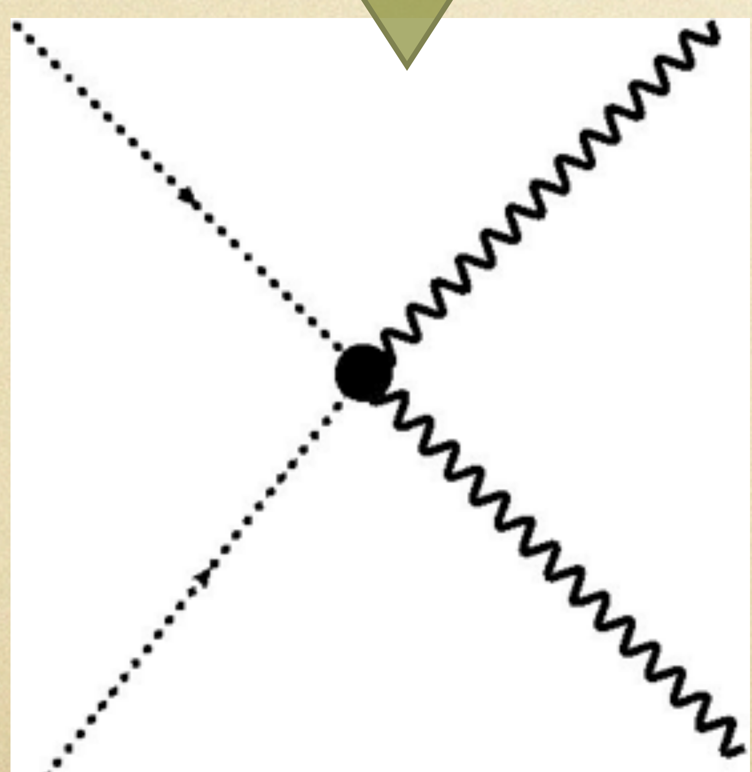
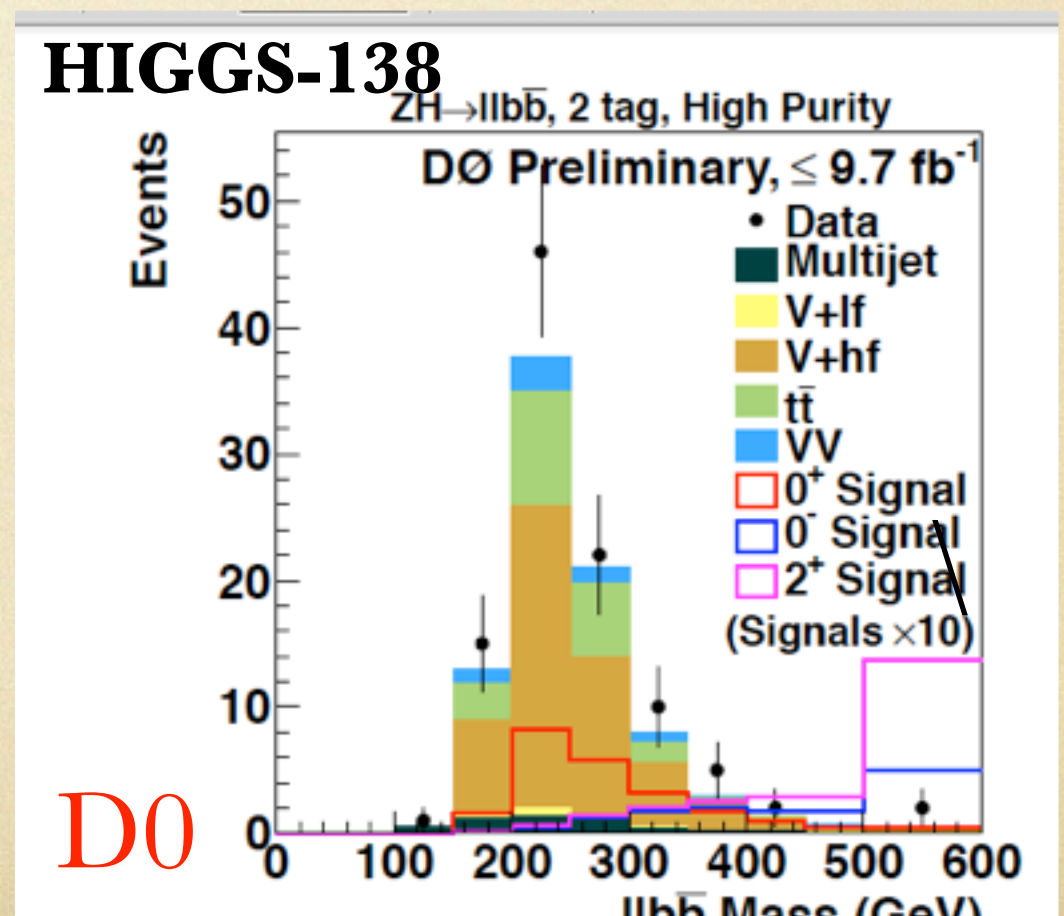
m_{Vh}

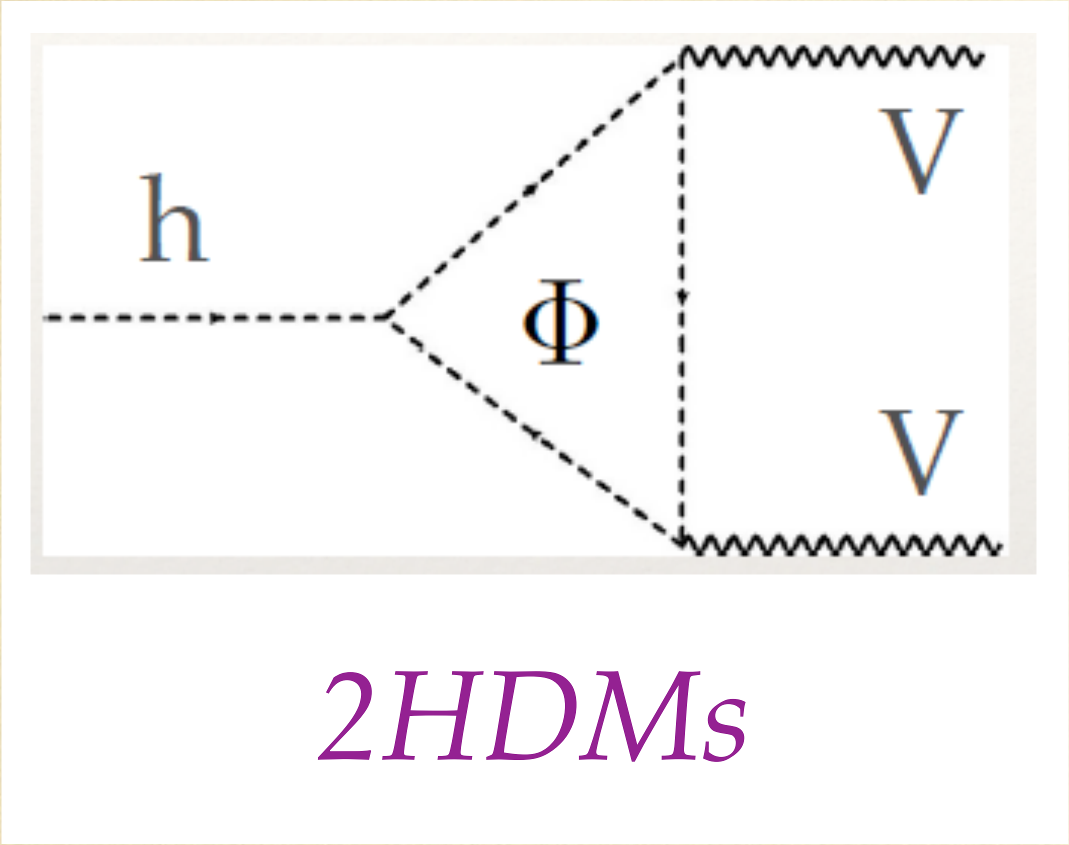


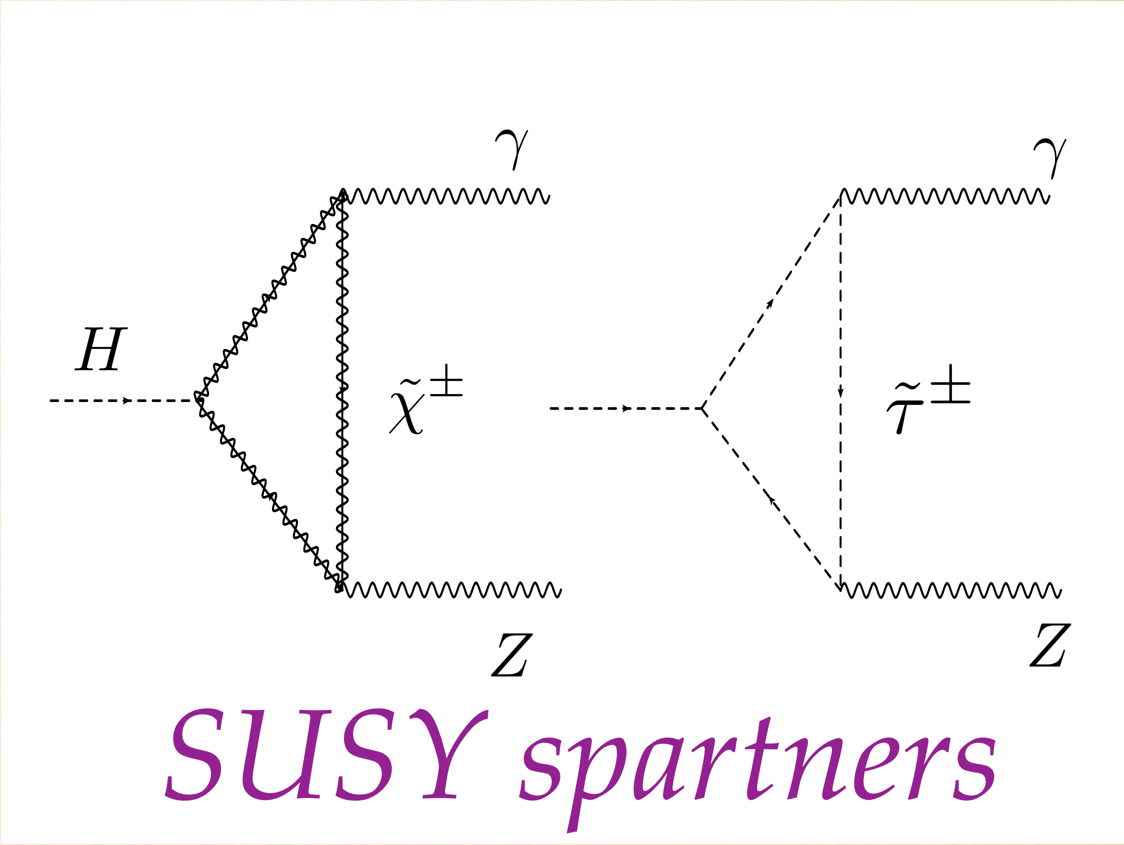
HEFT





Example 2. Loop-induced

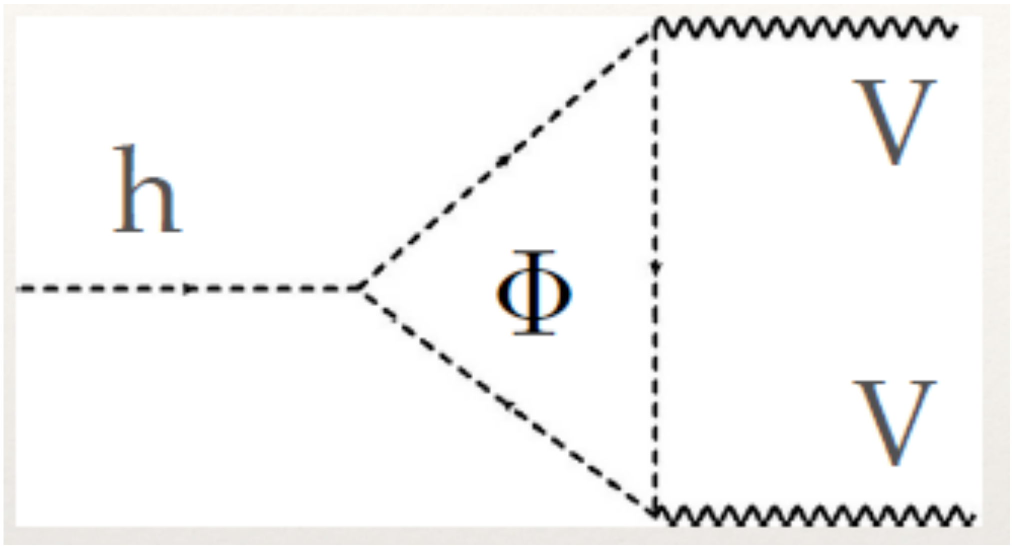




validity is now

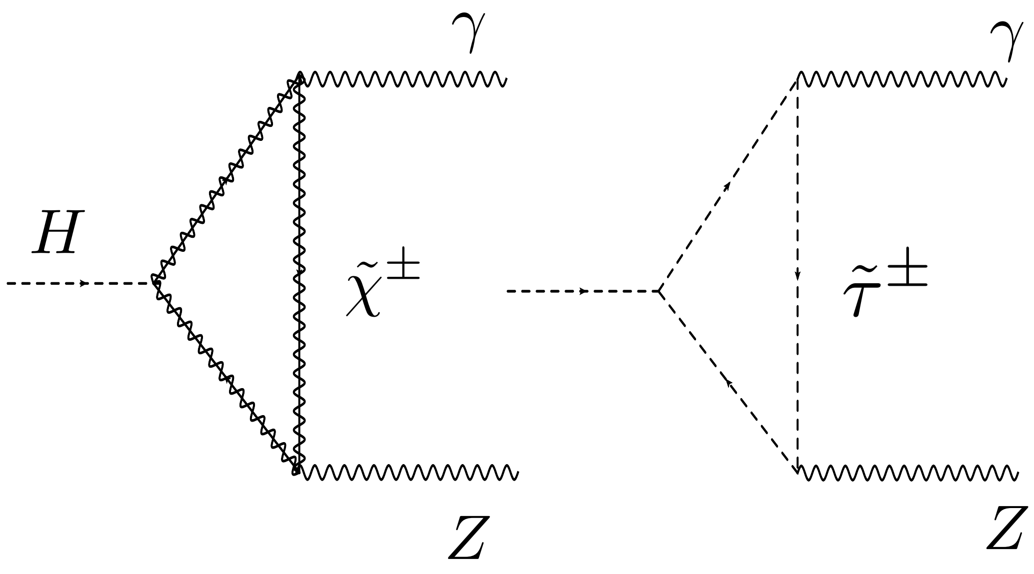
$$\hat{s} \lesssim 4M_{\Phi}^2$$

Example 2. Loop-induced



2HDMs

Gorbahn, No and VS. In preparation



SUSY spartners

Masso and VS. 1211.1320

General predictions:

$$\bar{c}_W - \bar{c}_B = -(\bar{c}_{HW} - \bar{c}_{HB}) = 4\,\bar{c}_\gamma$$

$$\bar{c}_{HW} = -\bar{c}_W \qquad\qquad \bar{c}_{HB} = -\bar{c}_B$$

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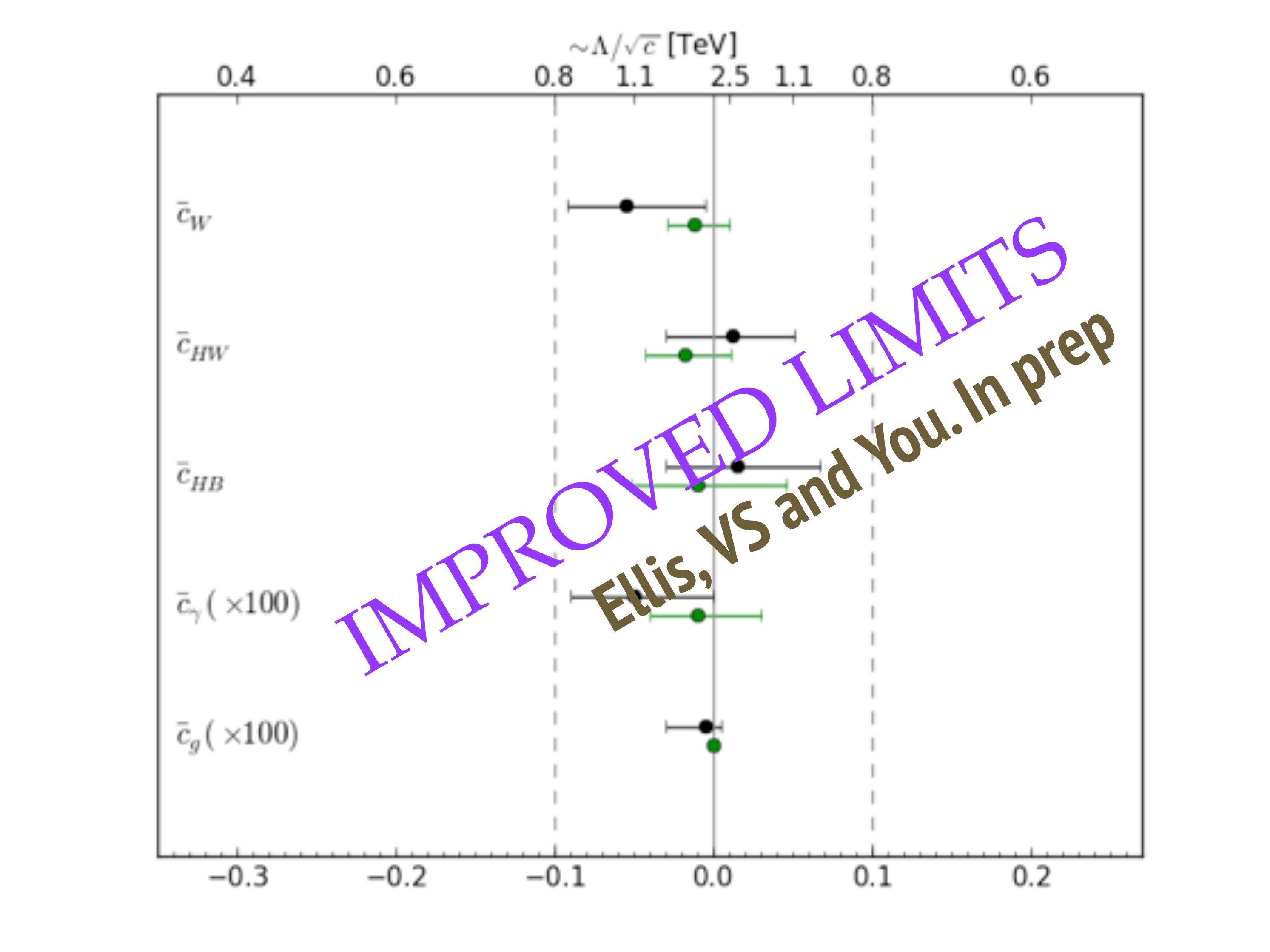

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Matching to UV model

e.g. in the alignment limit

$$\bar{c}_{HW} = -\bar{c}_W = \frac{1}{6(16\pi^2)}(1 - x_0) \simeq 10^{-3}(1 - x_0)$$

where $x_0 = \left(\frac{m_{H^0}}{m_{A^0}}\right)^2$

Conclusions

Absence of hints in direct searches
EFT approach to Higgs physics

Higgs anomalous couplings:
rates but also kinematic distributions

Complete global fit to Higgs physics
enhanced using differential information

SM precision crucial: excess as genuine new physics

Exploring the validity of HEFT
propose benchmarks

Benchmarks:
correlations among coefficients, input for fit

Framework for HDO studies

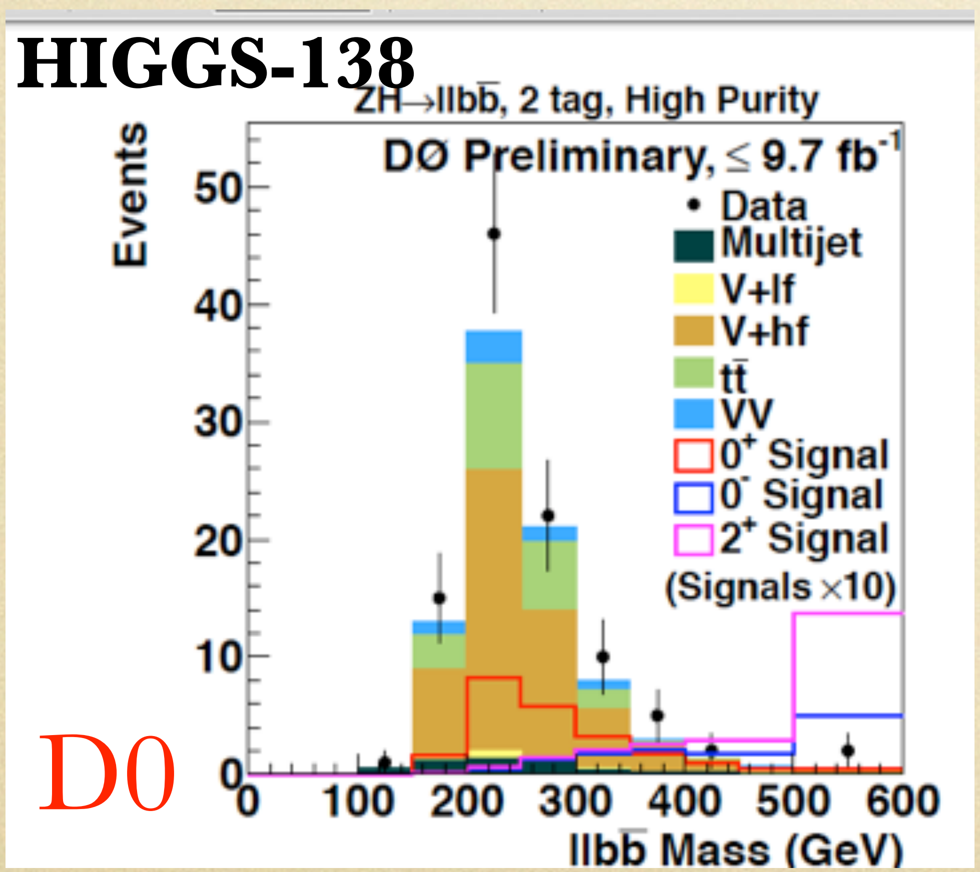
Feynrules HDOs involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

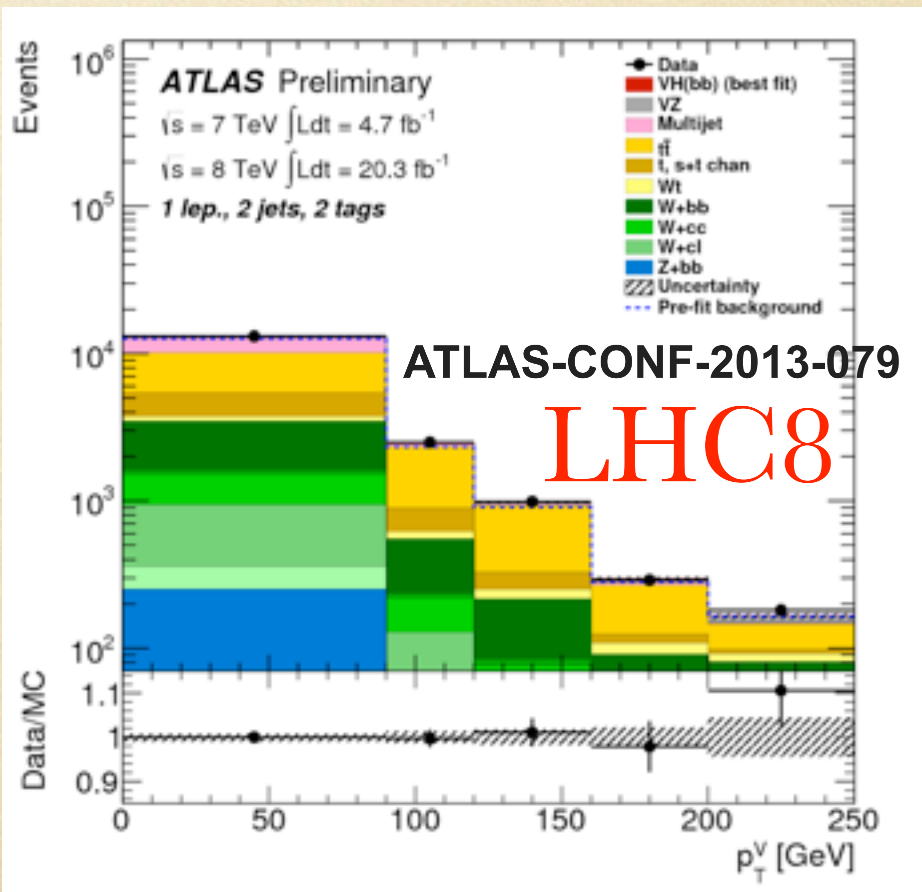
links to CalcHEP, LoopTools, Madgraph...

simulations: HDOs->Madgraph-> Pythia... -> FastSim/FullSim

ex. Higgs in associated production



m_{Vh}



p_T^V

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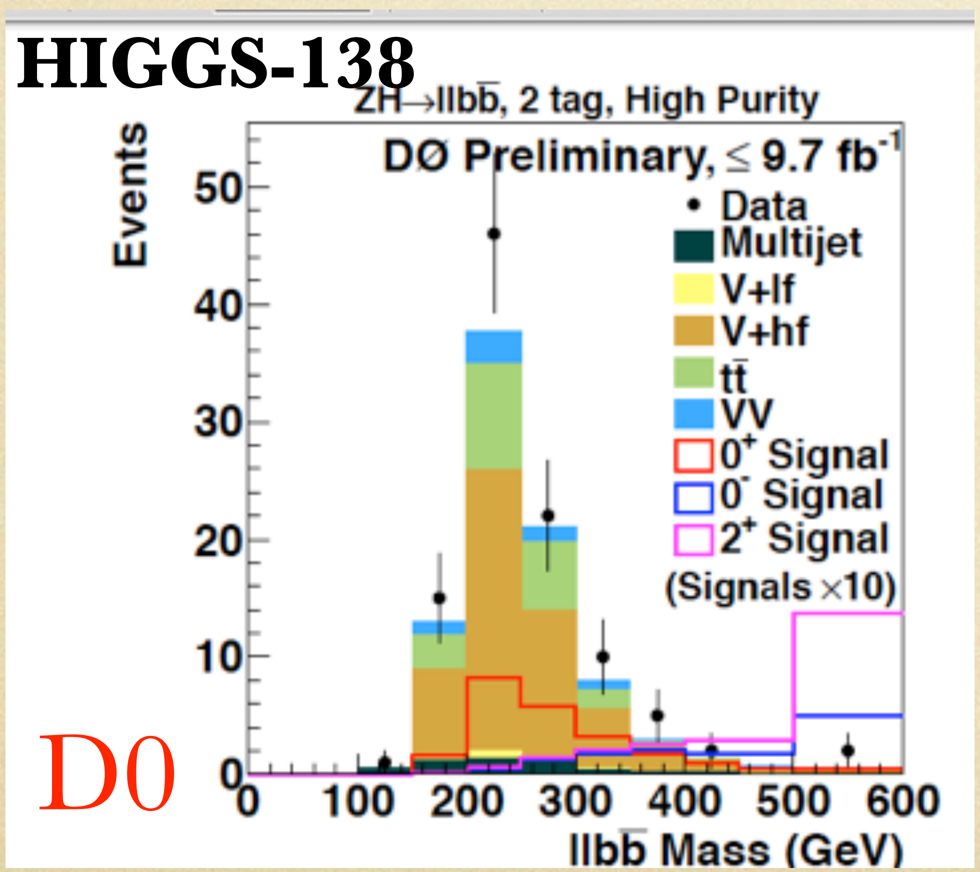
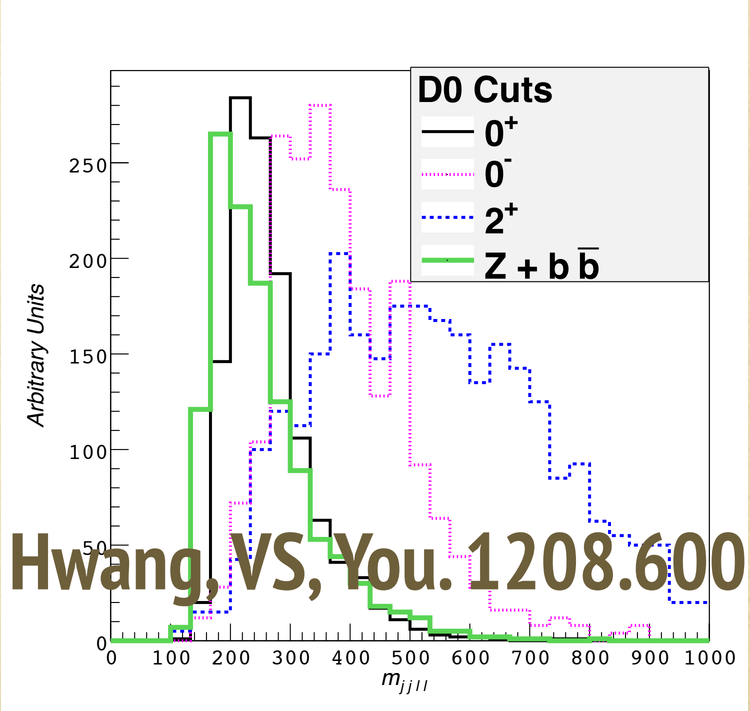


m_{Vh}

Test other JCP



Ellis, Hwang, VS, You. 1208.6002

Three CP-conserving operators affect TGCs

$$\mathcal{L}_{\rm TGC}^{D=6} = \frac{c_{WB}\,g_L g_Y}{m_W^2} B_{\mu\nu} W^i_{\mu\nu} H^\dagger \sigma^i H + \frac{i c_W\, g_L}{2 m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)(D^\nu W_{\mu\nu})^i + \frac{c_{3W}\, g_L^3}{m_W^2}\epsilon^{ijk} W^i_{\mu\nu} W^j_{\nu\rho} W^k_{\rho\mu}$$
$$+ \tilde{c}_{WB}\frac{g_L g_Y}{m_W^2}\tilde{B}_{\mu\nu} W^i_{\mu\nu} H^\dagger \sigma^i H + \frac{\tilde{c}_{3W}\, g_L^3}{m_W^2}\epsilon^{ijk} W^i_{\mu\nu} W^j_{\nu\rho}\tilde{W}^k_{\rho\mu}. \qquad (8)$$

$$\mathcal{L}_{\rm TGC}^{+} = i(1+\delta g_1^V)\left(W^+_{\mu\nu}W^-_\mu - W^-_{\mu\nu}W^+_\mu\right)V_\nu + i(1+\delta\kappa_V)\, V_{\mu\nu}\, W^+_\mu W^-_\nu$$
$$+ i\frac{\lambda_V}{m_W^2} W^+_{\mu\nu} W^-_{\nu\rho} V_{\rho\mu} - g_5^V \epsilon_{\mu\nu\rho\sigma}\left(W^+_\mu \partial_\rho W^-_\nu - \partial_\rho W^+_\mu W^-_\nu\right) V_\sigma,$$

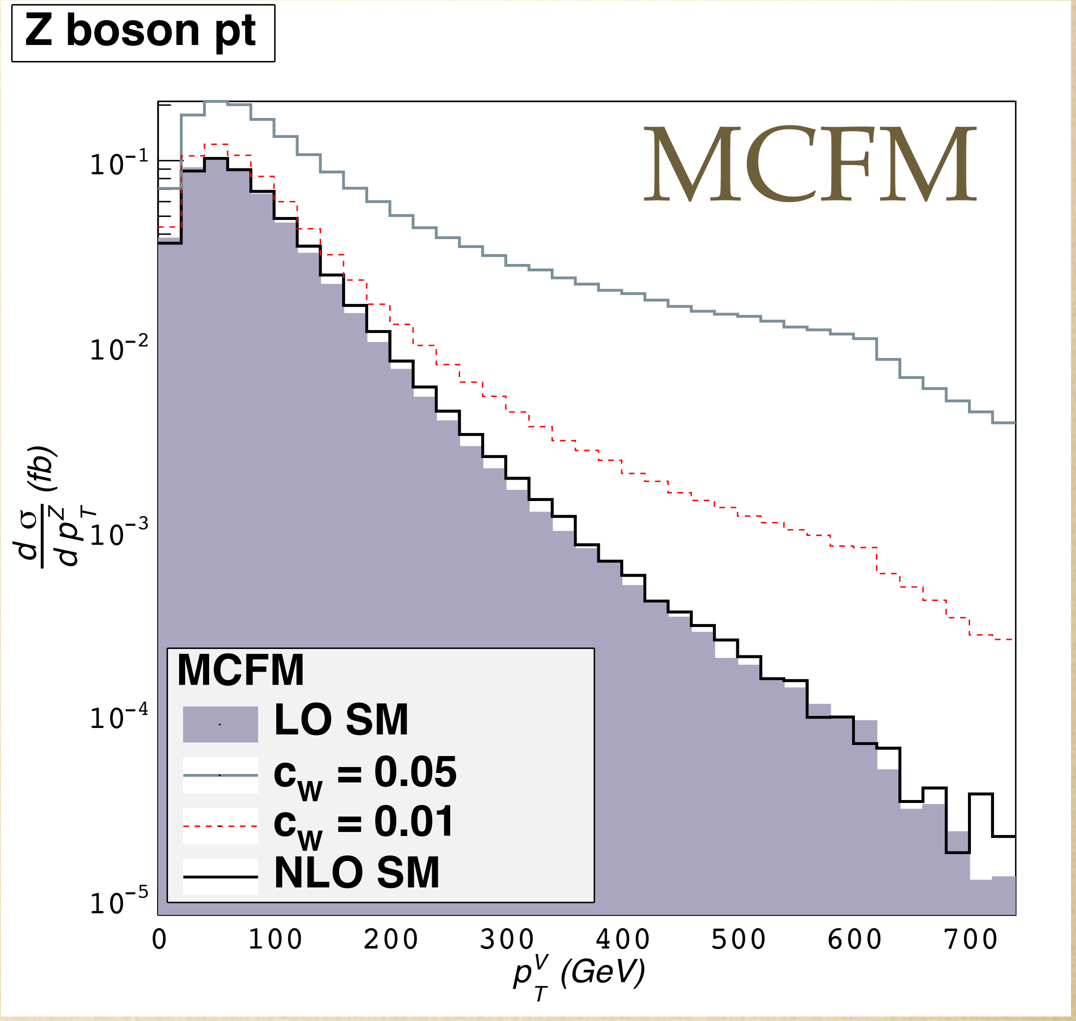
dim-6 and TGCs

cW and cWB
affect Higgs physics
and S-parameter,
but more independent
operators involved

$$\begin{aligned}
\delta\kappa_\gamma &= 4 c_{WB}, \\
\delta\kappa_Z &= -4\frac{g_Y^2}{g_L^2} c_{WB} - \frac{g_L^2+g_Y^2}{2g_L^2} \\
\delta g_Z &= -\frac{g_L^2+g_Y^2}{2g_L^2} c_W, \\
\lambda_\gamma = \lambda_Z &= -6 g_L^2 c_{3W}, \\
\tilde\kappa_\gamma &= 4\tilde{c}_{WB}, \\
\tilde\kappa_Z &= -4\frac{g_Y^2}{g_L^2}\tilde{c}_{WB}, \\
\tilde\lambda_\gamma = \tilde\lambda_Z &= -6 g_L^2 \tilde{c}_{3W},
\end{aligned}$$

Kinematics of associated production

comment 1:
pTV is more sensitive than mVH to QCD NLO
but effect not yet at the level of operator values we can bound



comment 2:
Sensitivity to quadratic orders in c's (dim-8) is less than current errors.

VS and Williams. In prep.

Boring and necessary details

Bottom-up approach:
operators w/ SM particles and symmetries,
plus the newcomer, the Higgs

Boring and necessary details

Bottom-up approach:
operators w/ SM particles and symmetries,
plus the newcomer, the Higgs

A

Realization of EWSB

Linear or non-linear

Boring and necessary details

Bottom-up approach:
operators w/ SM particles and symmetries,
plus the newcomer, the Higgs

A

Realization of EWSB

Linear or non-linear

B

And the Higgs could be

Weak doublet or singlet

Once this choice is made, expand...

$$\frac{1}{\Lambda^2}$$

Integrating out new physics

$$\frac{v^2}{f^2}$$

Non-linearity $U = e^{i\Pi(h)/f}$

...order-by-order

For example, some operators
Higgs-massive vector bosons

ex.

$$\mathcal{L}_{eff} = \sum_i \frac{f_i}{\Lambda^2}\mathcal{O}_i$$

$$\mathcal{O}_W = (D_\mu\Phi)^\dagger \widehat{W}^{\mu\nu}(D_\nu\Phi)$$

$$\mathcal{O}_B = (D_\mu\Phi)^\dagger (D_\nu\Phi)\ \widehat{B}^{\mu\nu}$$

$$\mathcal{O}_{WW} = \Phi^\dagger \widehat{W}^{\mu\nu}\widehat{W}_{\mu\nu}\Phi$$

$$\mathcal{O}_{BB} = (\Phi^\dagger\Phi)\ \widehat{B}^{\mu\nu}\widehat{B}_{\mu\nu}$$

For example, some operators
Higgs-massive vector bosons

ex.

$$\mathcal{L}_{eff} = \sum_i \frac{f_i}{\Lambda^2}\mathcal{O}_i$$

$$\mathcal{O}_W = (D_\mu\Phi)^\dagger \widehat{W}^{\mu\nu}(D_\nu\Phi)$$

$$\mathcal{O}_B = (D_\mu\Phi)^\dagger (D_\nu\Phi)\ \widehat{B}^{\mu\nu}$$

$$\mathcal{O}_{WW} = \Phi^\dagger \widehat{W}^{\mu\nu}\widehat{W}_{\mu\nu}\Phi$$

$$\mathcal{O}_{BB} = (\Phi^\dagger\Phi)\ \widehat{B}^{\mu\nu}\widehat{B}_{\mu\nu}$$

C

UV theory: tree-level or loop
may need a model bias

ex. SILH

$$\frac{2igc_{HW}}{m_W^2}(D^\mu\Phi^\dagger)\hat{W}_{\mu\nu}(D^\nu\Phi)$$

Giudice, Grojean, Pomarol, Rattazzi. 0703164 redundancies trade off operators using EOM

D Choice of basis

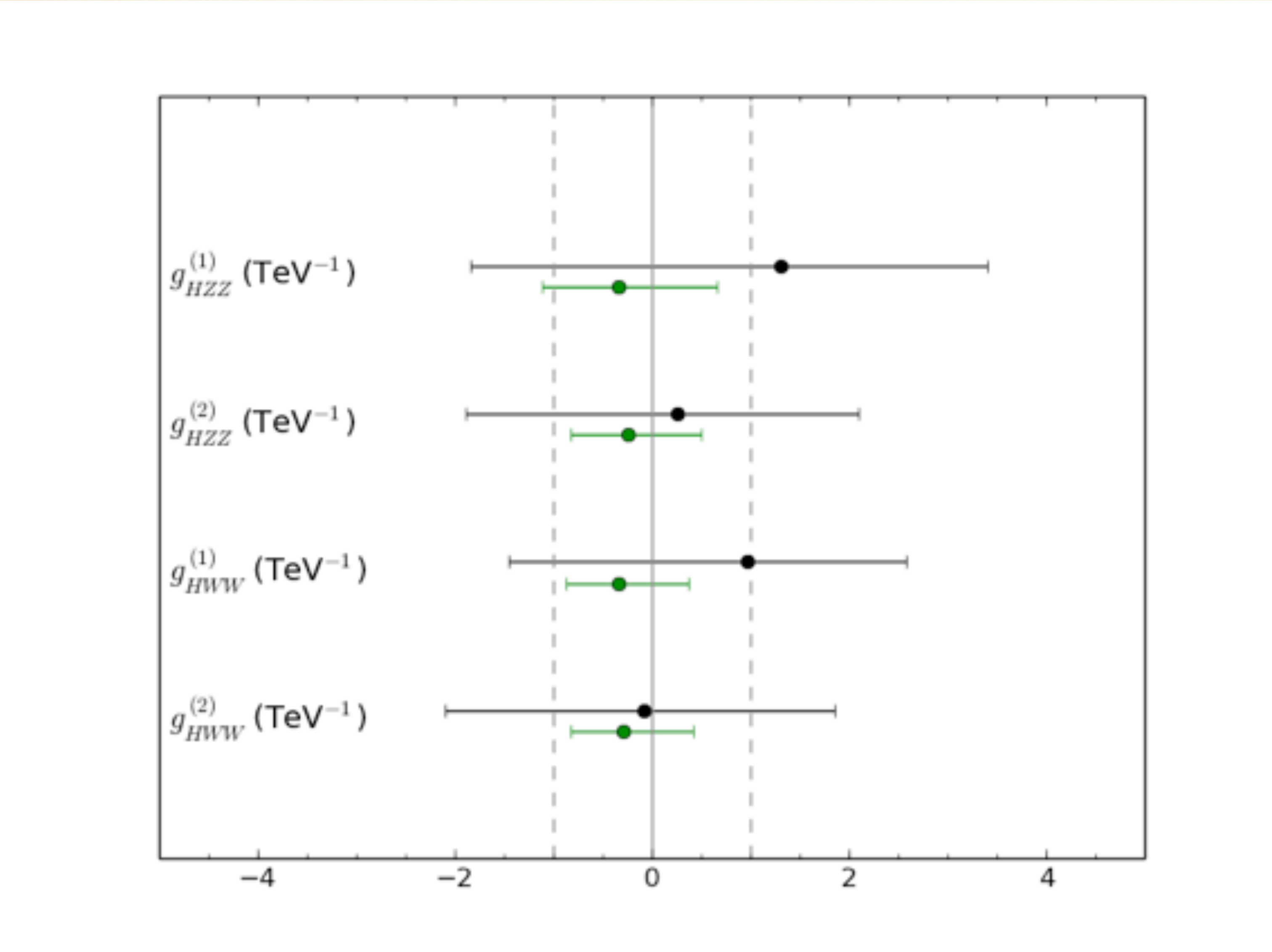
And, **finally**

Observables as a function of HDOs coefficients

In summary

In terms of Higgs' anomalous couplings

$$\mathcal{L} \supset -\frac{1}{4} g^{(1)}_{HZZ} Z_{\mu\nu} Z^{\mu\nu} h - g^{(2)}_{HZZ} Z_\nu \partial_\mu Z^{\mu\nu} h$$
$$-\frac{1}{2} g^{(1)}_{HWW} W^{\mu\nu} W^\dagger_{\mu\nu} h - \left[g^{(2)}_{HWW} W^\nu \partial^\mu W^\dagger_{\mu\nu} h + \text{h.c.} \right],$$



black global fit

green one-by-one fit

Global fit to signal strengths and kinematic distributions

Conclusions of the analysis

1. Breaking of blind directions requires information on associated production (AP)

2. Kinematic distributions in AP is as sensitive (or more) than total rates

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