Effective Theory approach to Higgs analyses

Veronica Sanz (Sussex)

Benasque

Shouldn't we focus on discovery searches?

New Physics could be heavy
as compared with the channel we look at

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as compared with the channel we look at
EFT: expansion in higher-dimensional
operators (HDOs)

Buchmuller and Wyler. NPB (86)

Advantages of EFT

model independent

Systematic studies

One operator, corrs.

Translation to thy

Boring and necessary details

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

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Realization of EWSB

A

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 $\quad U = e^{i\Pi(h)/f}$

...order-by-order

For example, some operators Higgs-massive vector bosons

ex.

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

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

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

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

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

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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

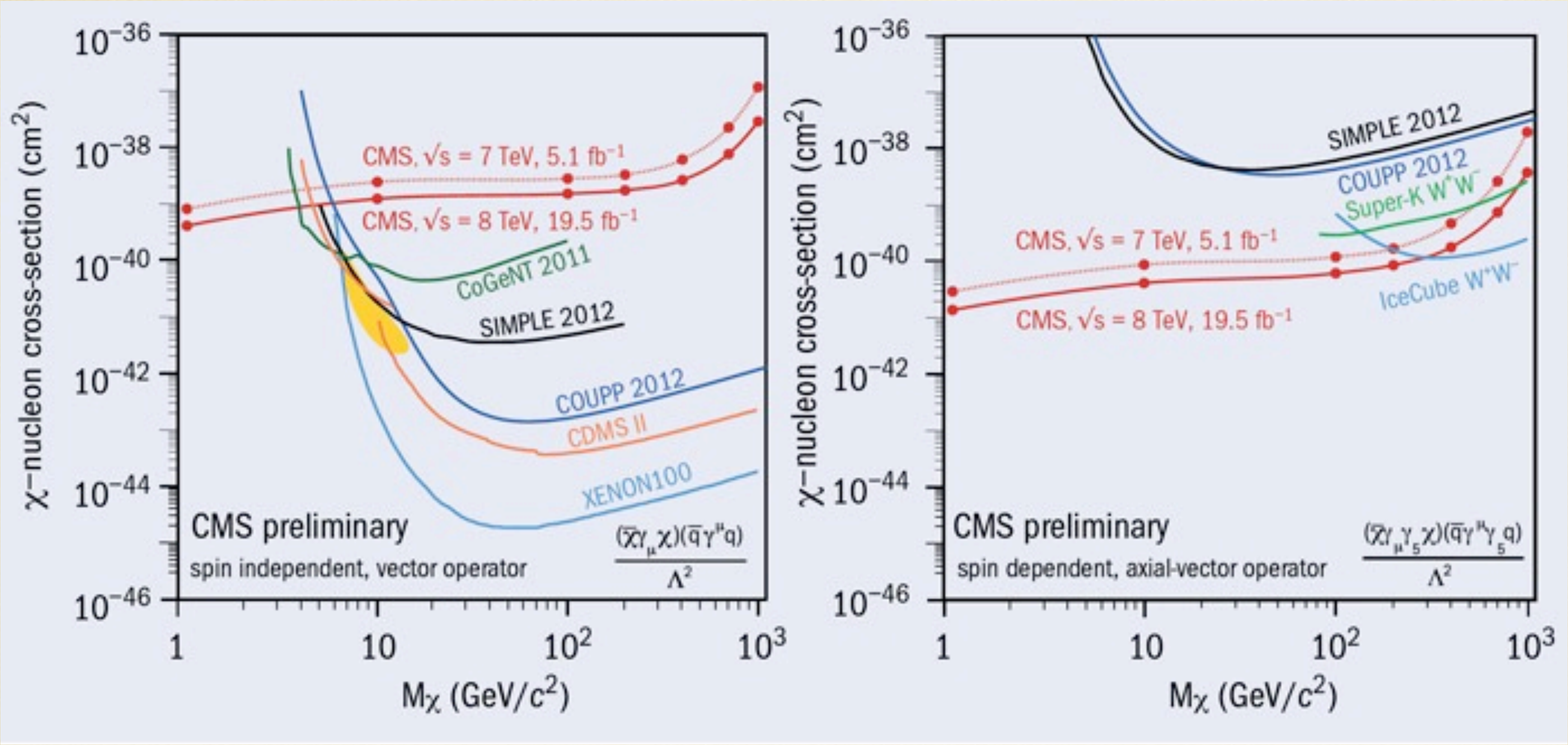
D Choice of basis

And, **finally**

Observables as a function of HDOs coefficients

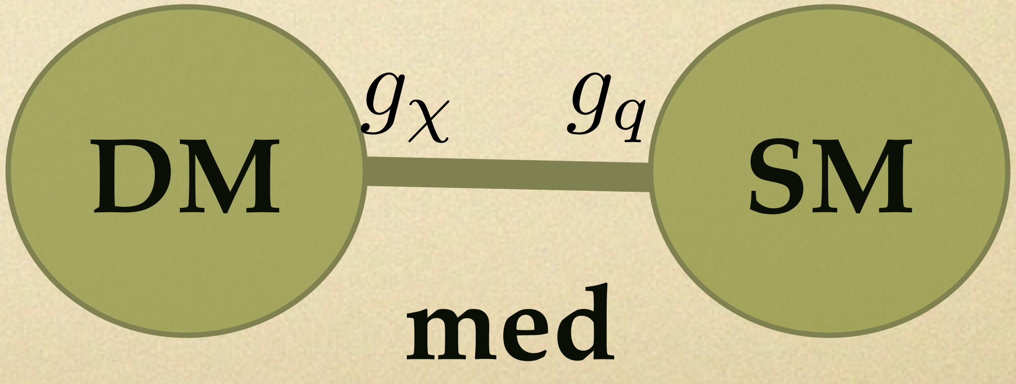
Beware of abusing the HDO framework

ex. Monojet searches as DM searches



HDO for DM

$$\frac{1}{\Lambda^2}\bar{\chi}\gamma_\mu\chi\bar{q}\gamma^\mu q$$



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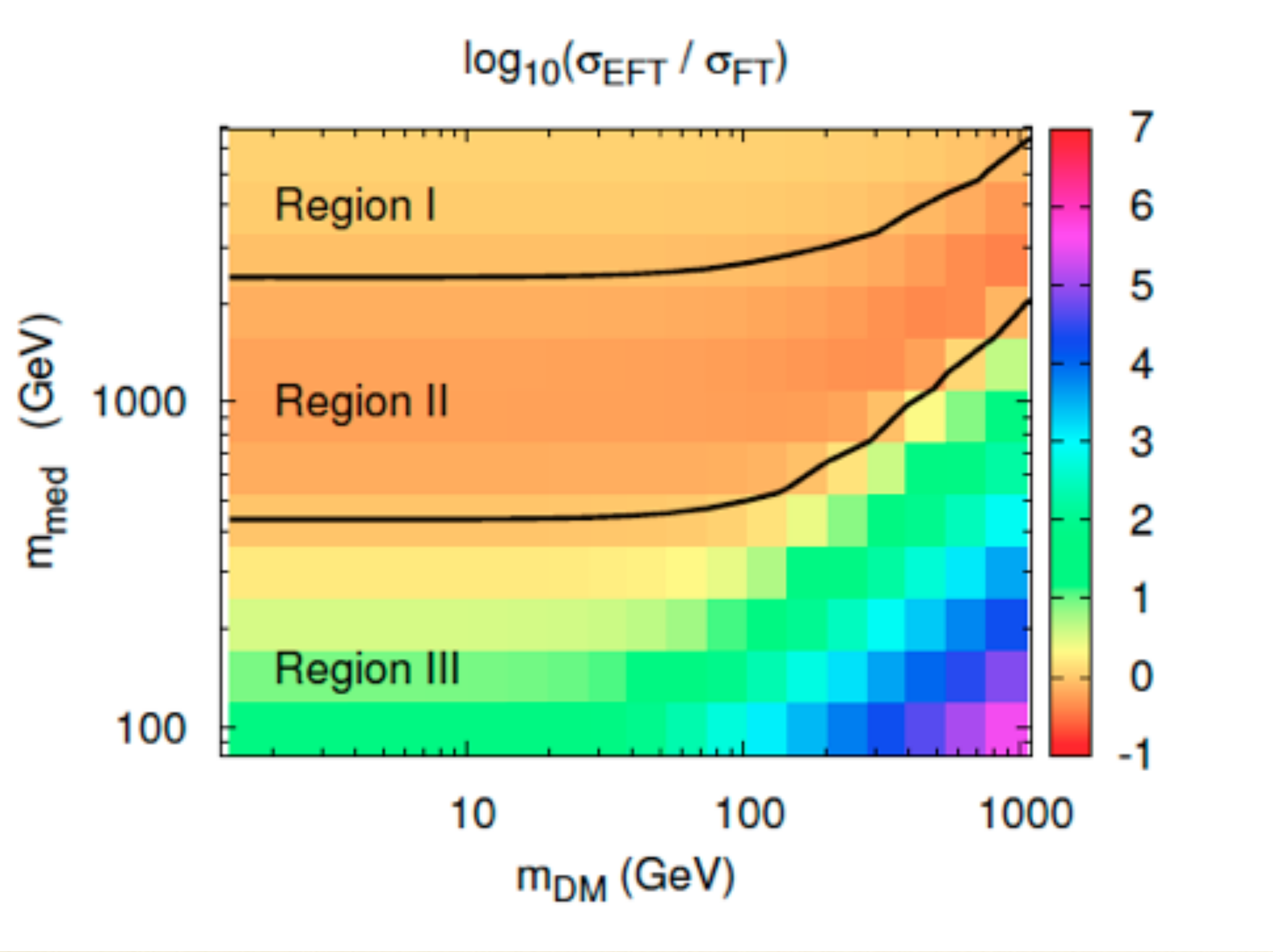
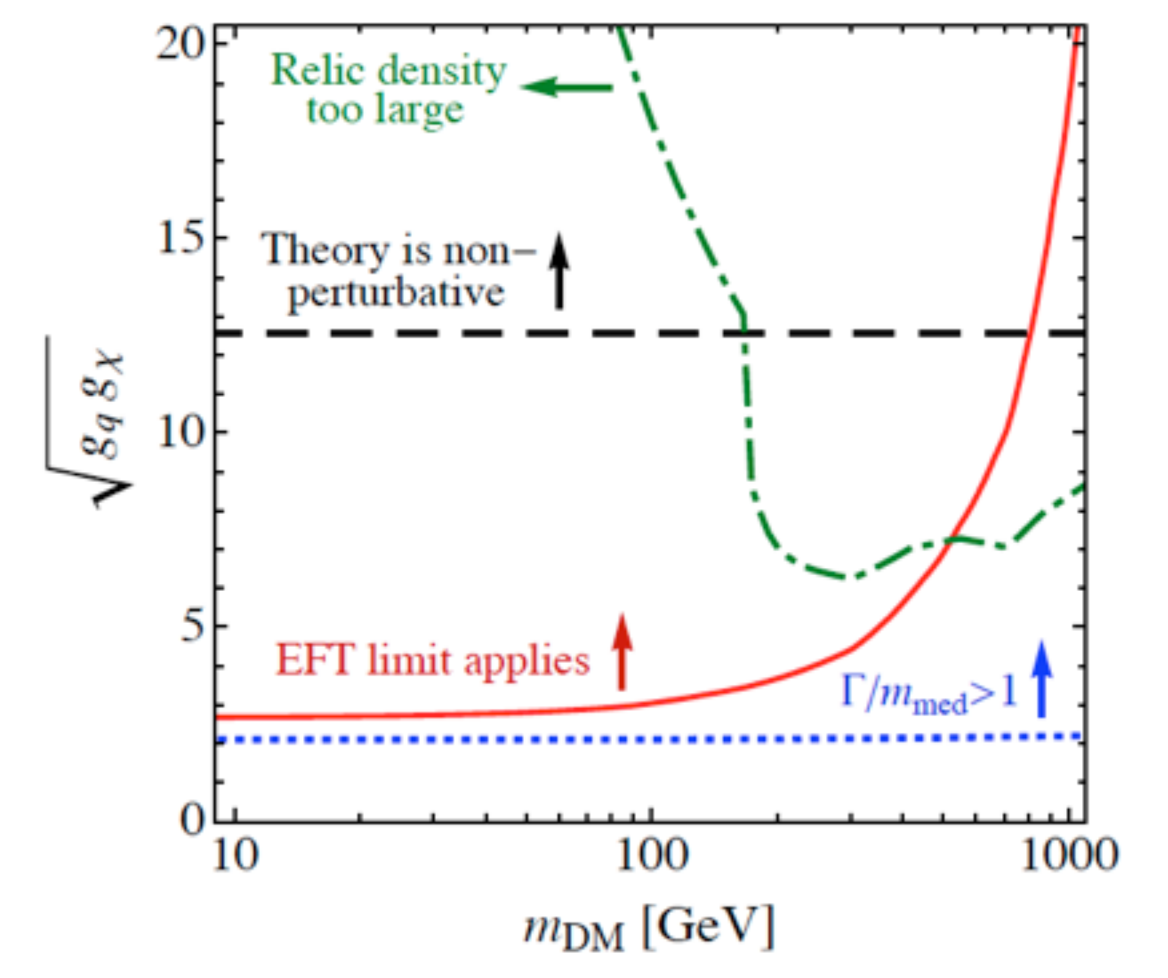




Buchmueller, Dolan and McCabe. 1308.6799

Limits valid to 20% if

$$m_{med} > \ 2.5 \text{ TeV}$$

$$\sqrt{g_\chi g_q} > 3 \qquad \Gamma/m_{med} > 1$$

Expansion may (non-trivially) *fail*

Some operators could have large coefficients

ex. $$\frac{c_6}{\Lambda^2}(D^\mu\Phi^\dagger)\hat{W}_{\mu\nu}(D^\nu\Phi)$$ could be loop-ind

$$\frac{c_8}{\Lambda^4}(D^\rho\Phi^\dagger)(D_\rho\Phi)\hat{W}_{\mu\nu}\hat{W}^{\mu\nu}$$ could dominate

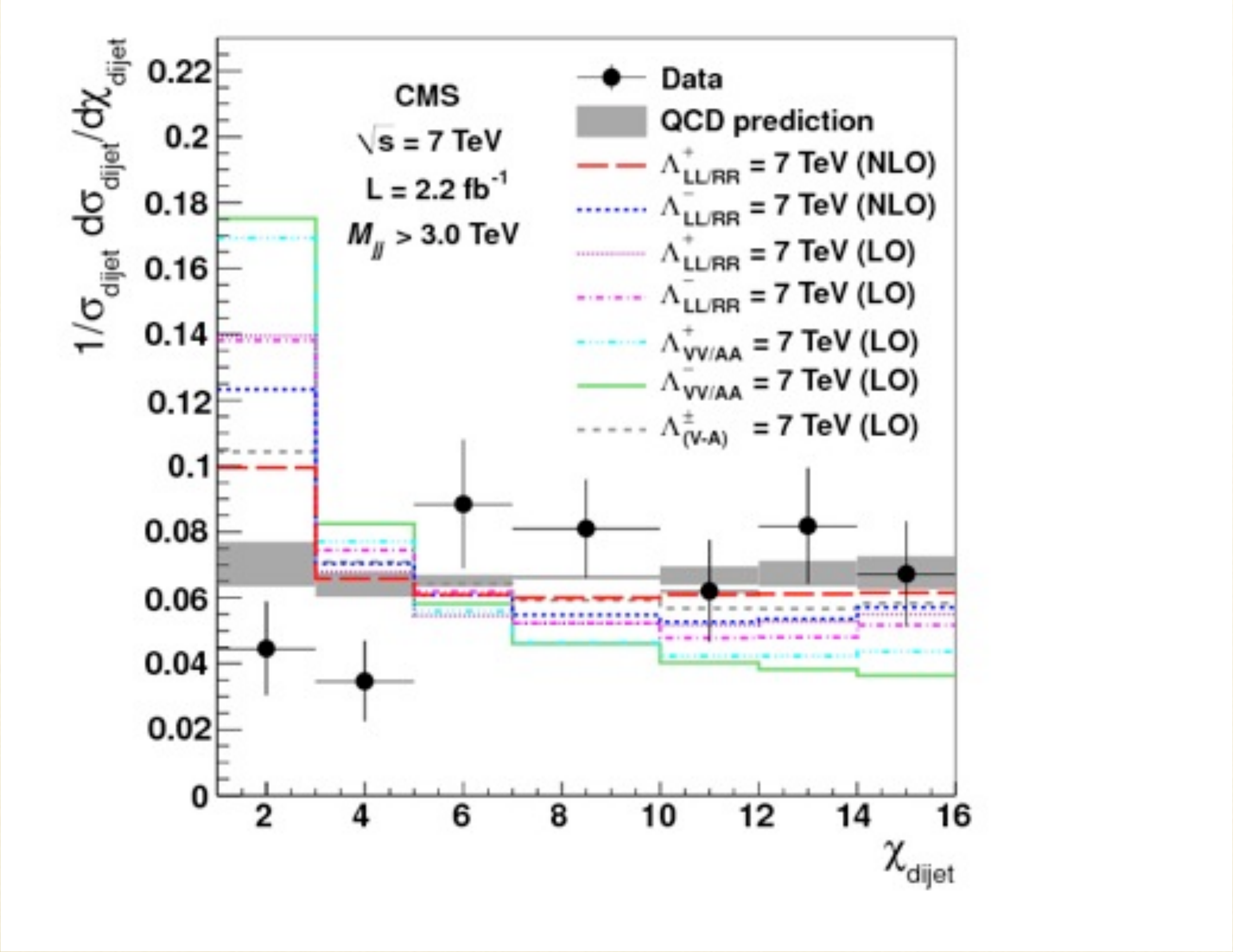
specially dangerous when

$$\Lambda \sim m_W \text{ and high-}p_T$$

How do we look for HDOs?

HDOs affect momentum dependence: angular, pT and inv mass distributions

Usual searches,



Dijet angular distribution

ex. dijet searches

HDOs affect momentum dependence: angular, pT and inv mass distributions

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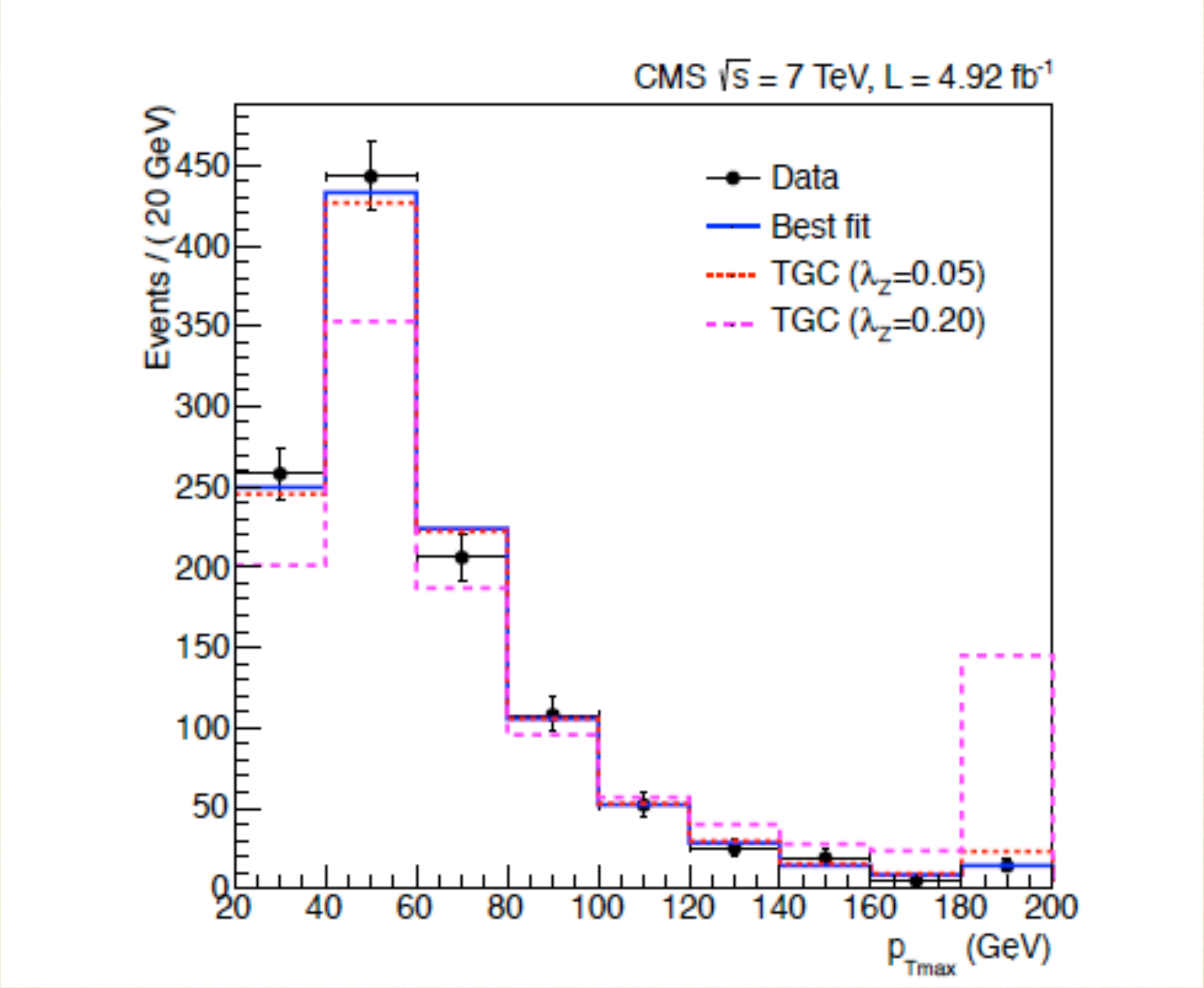

ex. TGCs

leading lepton pT

And what about the Higgs?

Higgs anomalous couplings

HDOs generate HVV interactions with more derivatives

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

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

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

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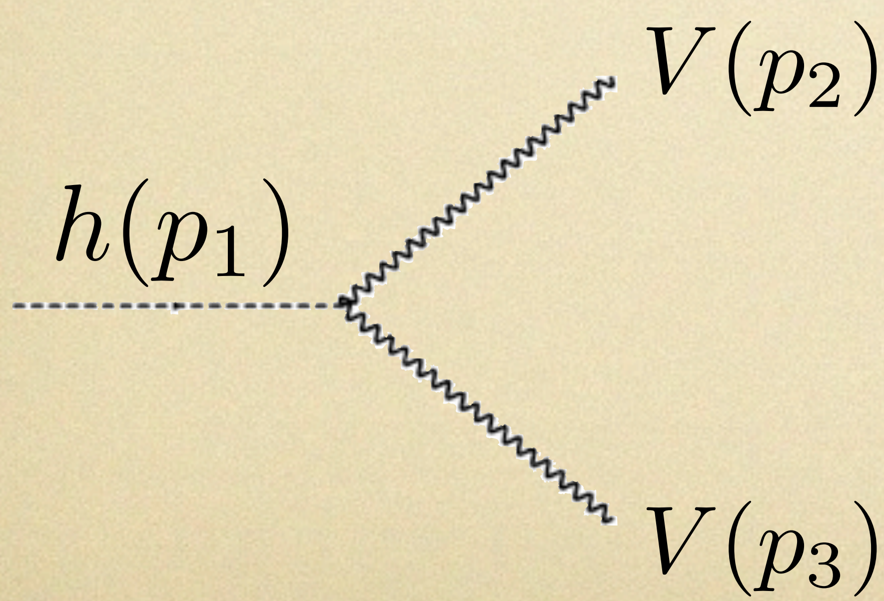
ex. Feynman rule if mh>2mV



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

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

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

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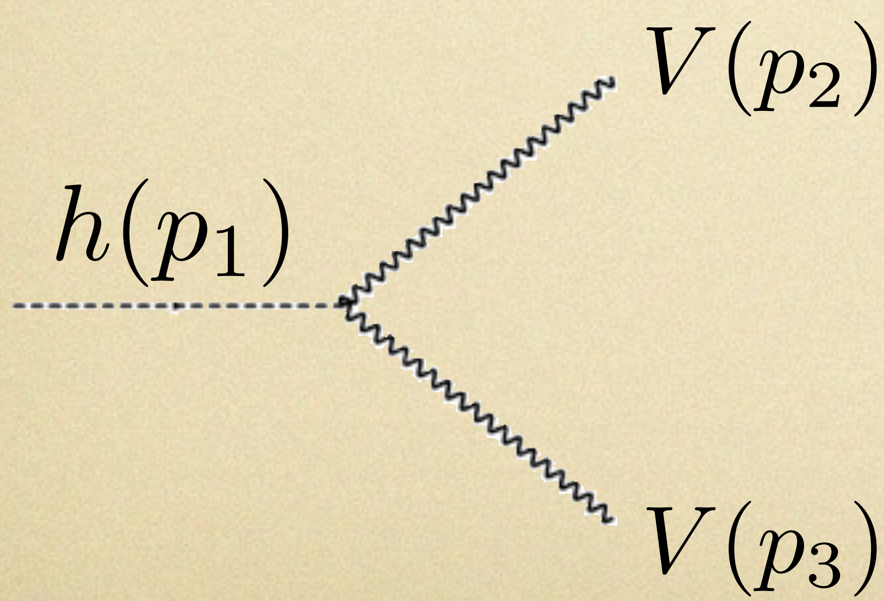

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total rates, COM, angular, inv mass and pT distributions

Framework for EFT studies

Higgs BRs

eHDECAY

Contino, Ghezzi, Grojean, Muhlleitner and Spira.
1303.3876

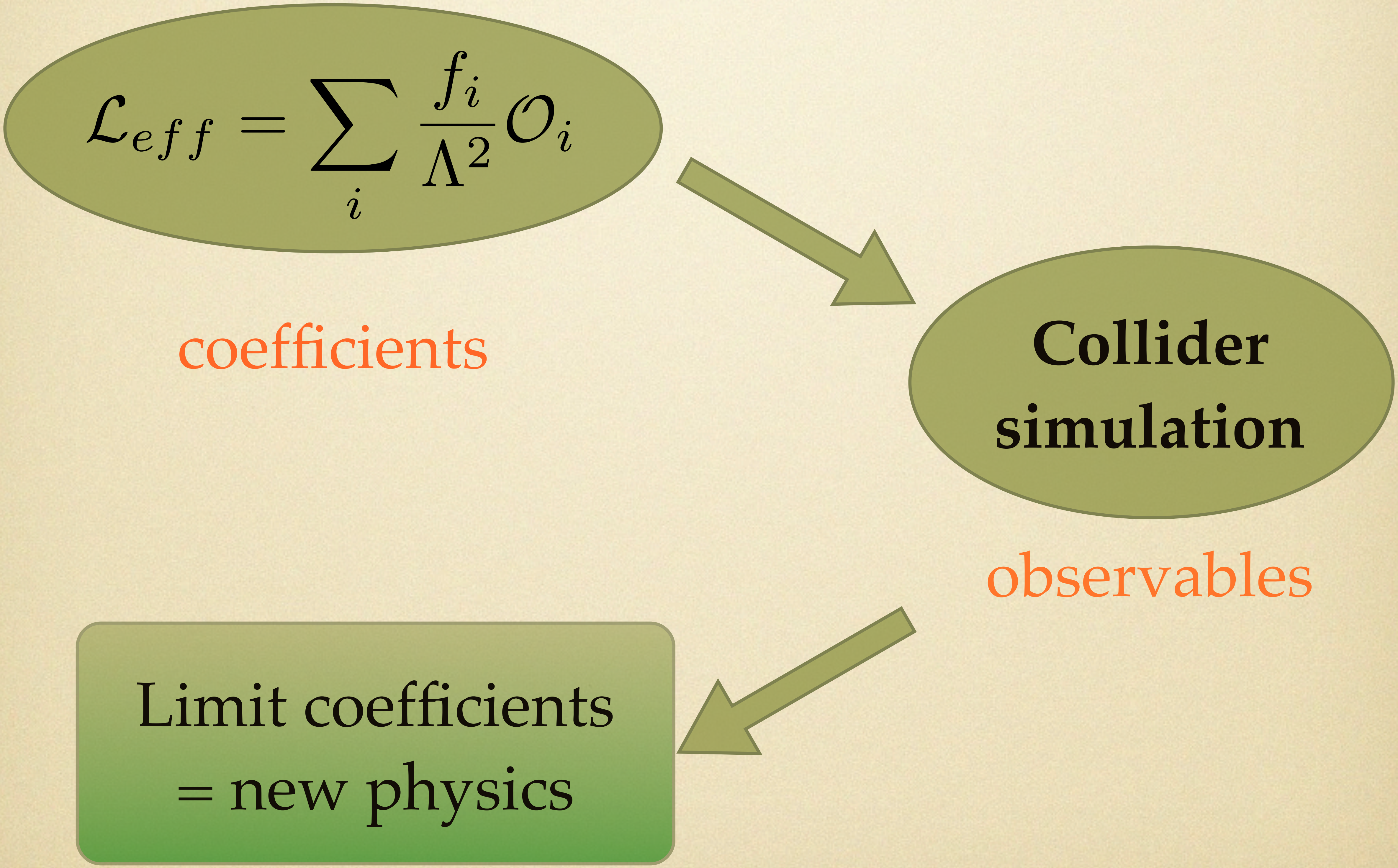
Production rates and kinematic distributions

depend on cuts

need radiation and detector effects

Simulation tools

We need a framework



A couple of tools

1. Feynrules HDOs involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

links to CalcHEP, LoopTools, Madgraph...

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

2.QCD NLO HDOs involving Higgs and TGCs

VS and Williams. In prep.

MCFM and POWHEG

Pythia, Herwig... -> FastSim / FullSim

Before we move onto Higgs physics

Reviewing LEP constraints

Three CP-conserving operators affect TGCs

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

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

dim-6 and TGCs

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

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

LEP fit to WW observables

Falkowski, Fichet, Mohan, Riva, VS.
Les Houches proceedings. To appear.

Total cross section and diff distributions from
ALEPH, DELPHI, L3, OPAL, LEP Electroweak Collaboration.
Phys.Rept. 532

SM NLO from RACOONWW

$$c_{WB} = -0.01 \pm 0.03, \qquad c_W = 1.18 \pm 0.56, \qquad c_{3W} = -0.30 \pm 0.16,$$

partial cancellation in the direction c3W+0.3 cW

due to polarization of main contribution to WW

the fit leads to no meaningful limits, strong sensitivity to quadratic terms (= higher-orders)

to compare with setting by hand c3W=0

$$c_{WB} = 0.03 \pm 0.02, \qquad c_W = 0.18 \pm 0.07,$$

Consequences:

1. TGCs at the LHC are terribly important (no cancellation there)

2. LEP TGCs do not constrain Higgs operators to the extent it was thought before by, e.g.

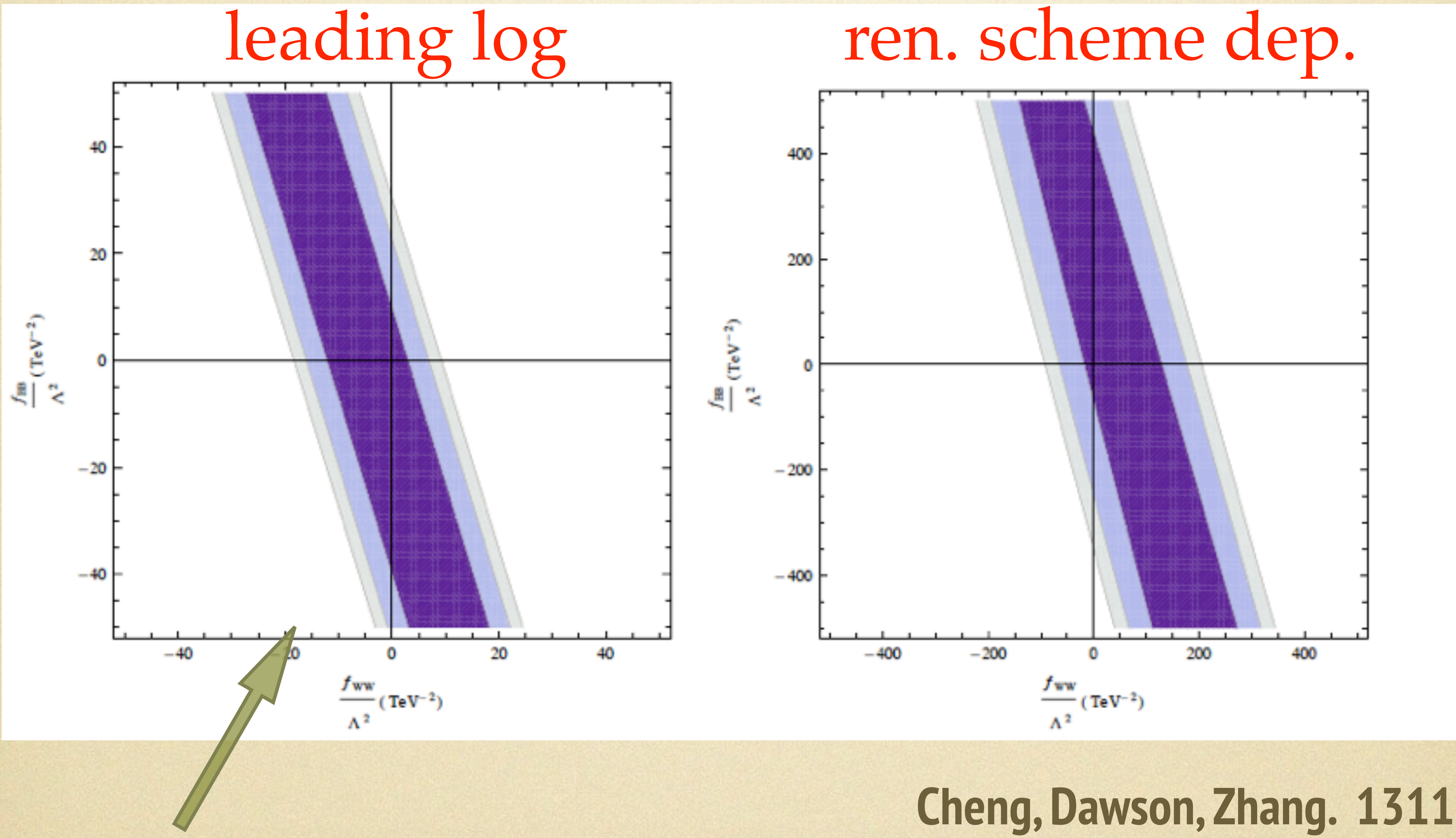
Pomarol and Riva. 1308.2803

Corbett et al. 1211.4580

Higgs data truly complementary to TGCs

Same goes for EWPTs

renormalization is important



Cheng, Dawson, Zhang. 1311.3107

results of
Masso, VS. 1211.1320

Higgs data is complementary to EWPT and TGCs

Complete analysis of dim-6 Higgs

Ellis, VS and You.

1404.3667

Number of independent operators in Higgs physics

CP-conserving

See Rohini's talk for CP-violating

In the SILH basis

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

(cB has been eliminated using S)

Other operators affect TGCs and EWPTs but not Higgs

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

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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and kinematic distributions

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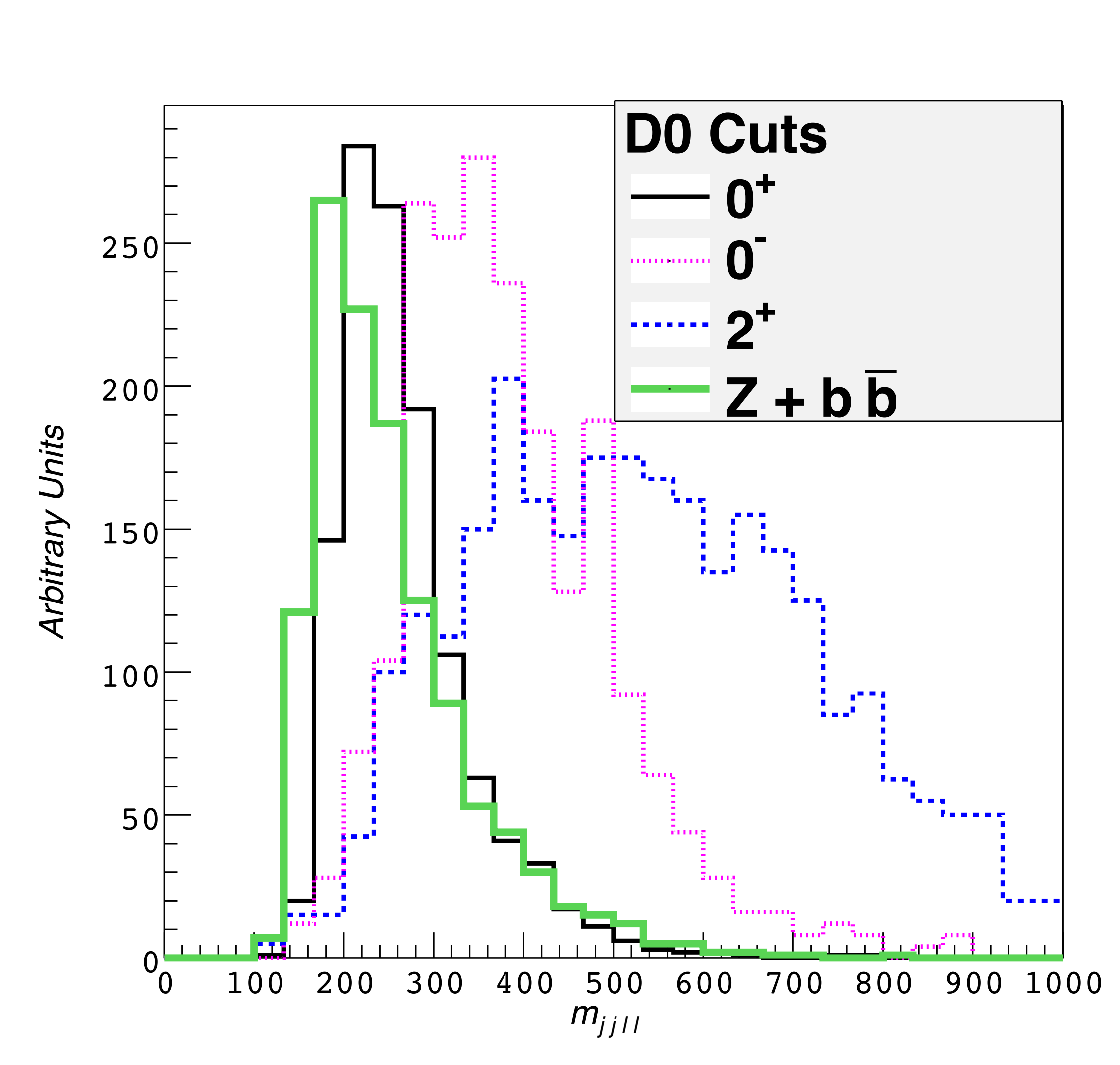
Kinematics of associated production

AP is very sensitive to the Lorentz structure of the vertex



Ellis, Hwang, VS, You. 1208.6002

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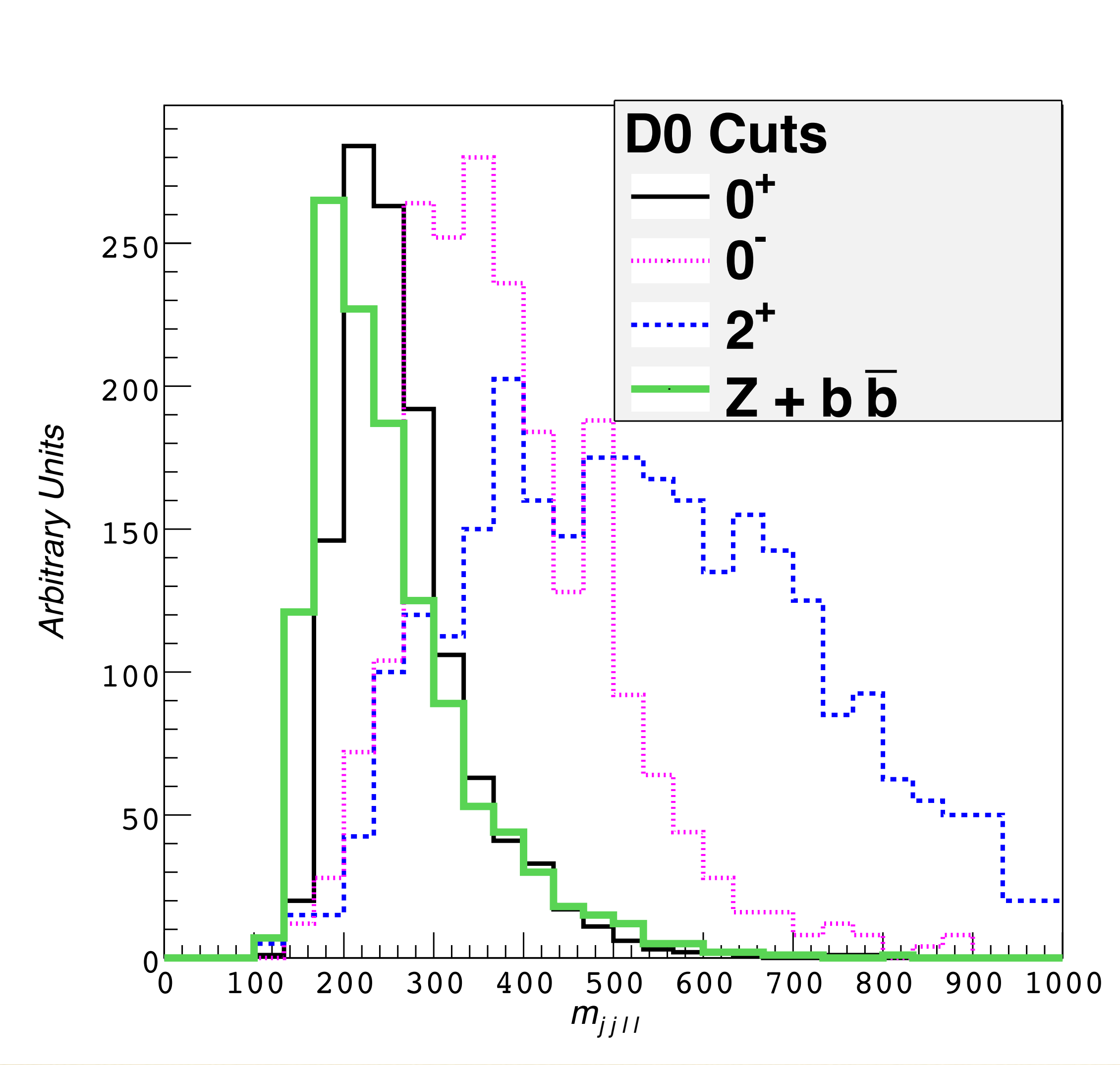

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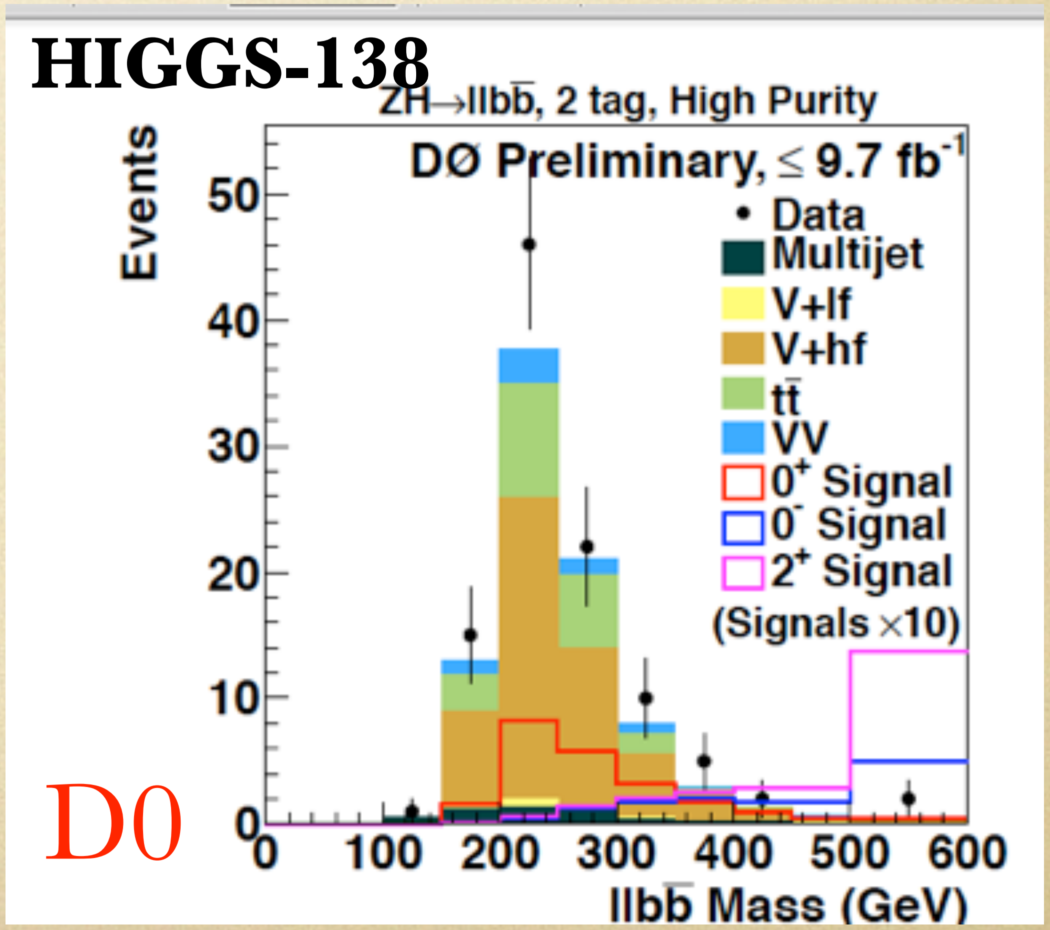
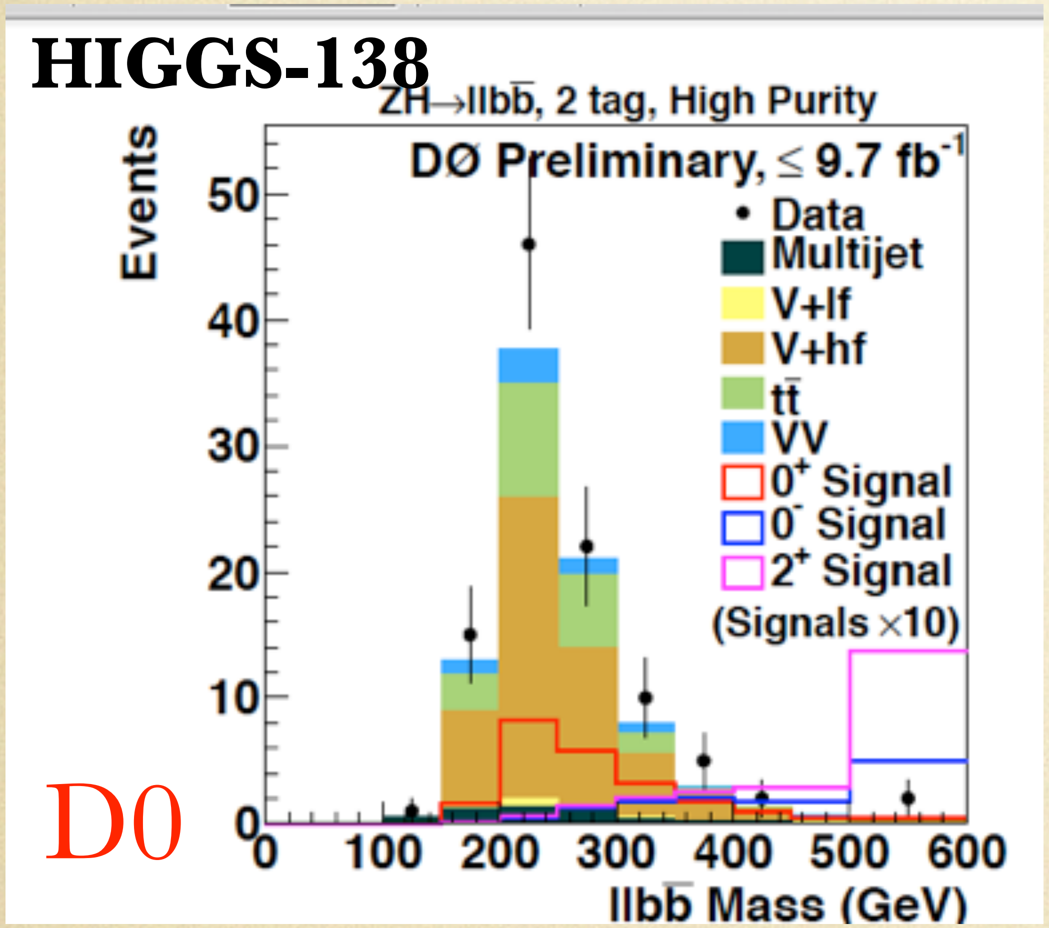
Test JCP of the Higgs

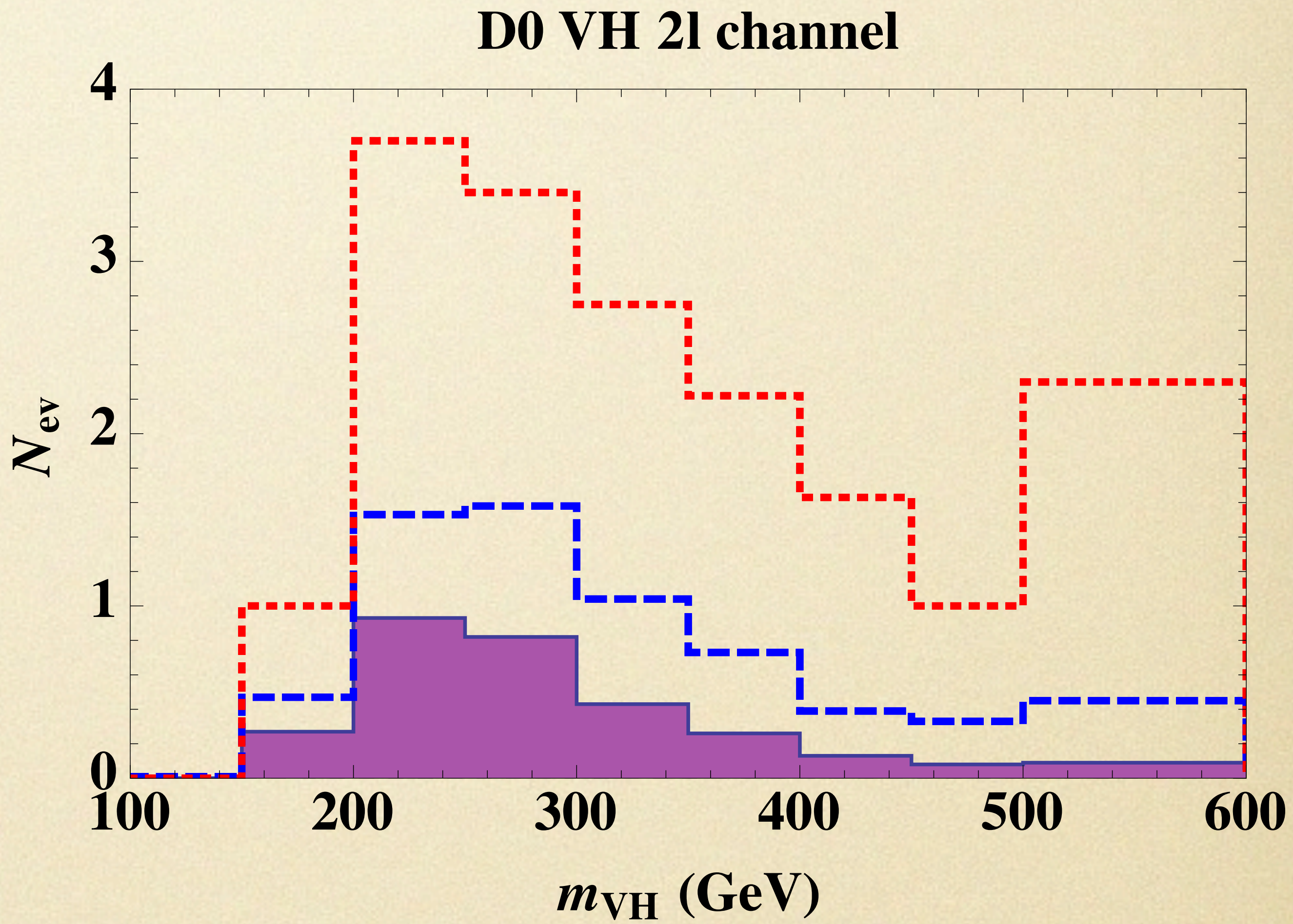
$$m_{Vh}$$



Kinematics of associated production

Higgs' HDOs also have a different Lorentz structure



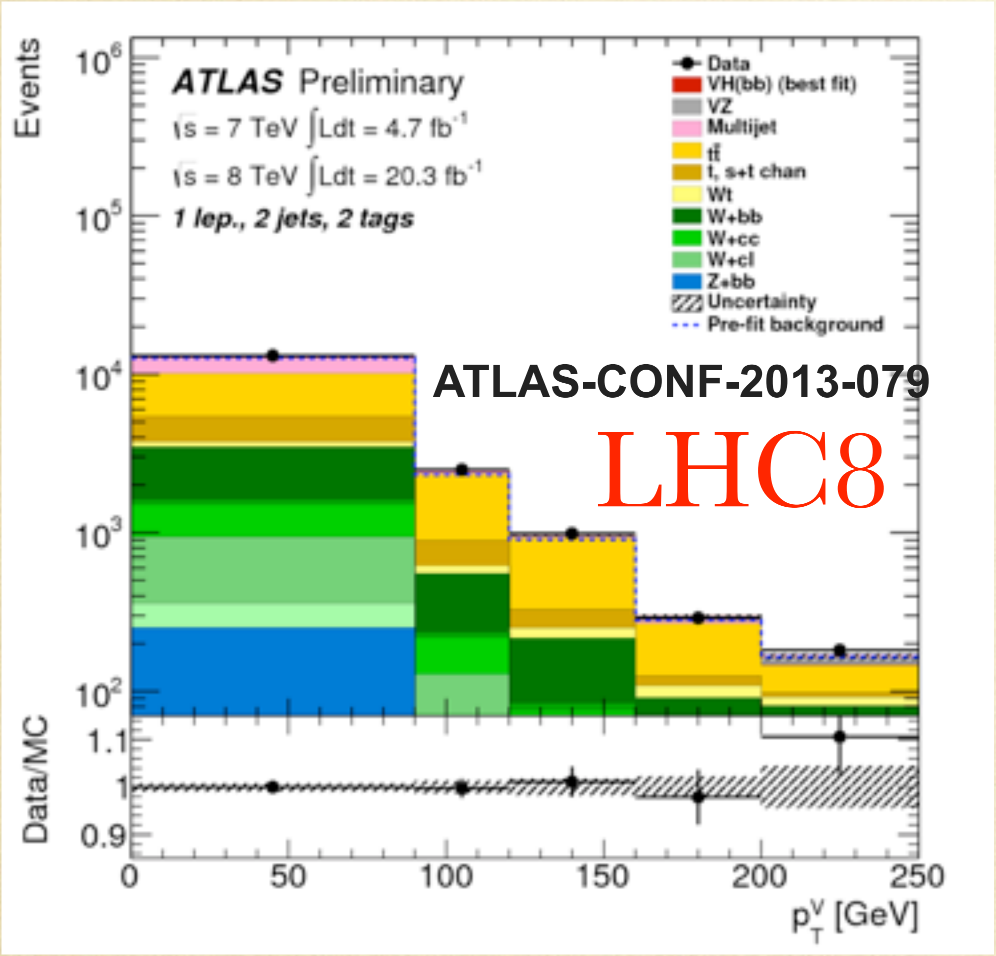


Feynrules -> MG5-> pythia->Delphes3
validate SM/BGs => expectation for HDOs

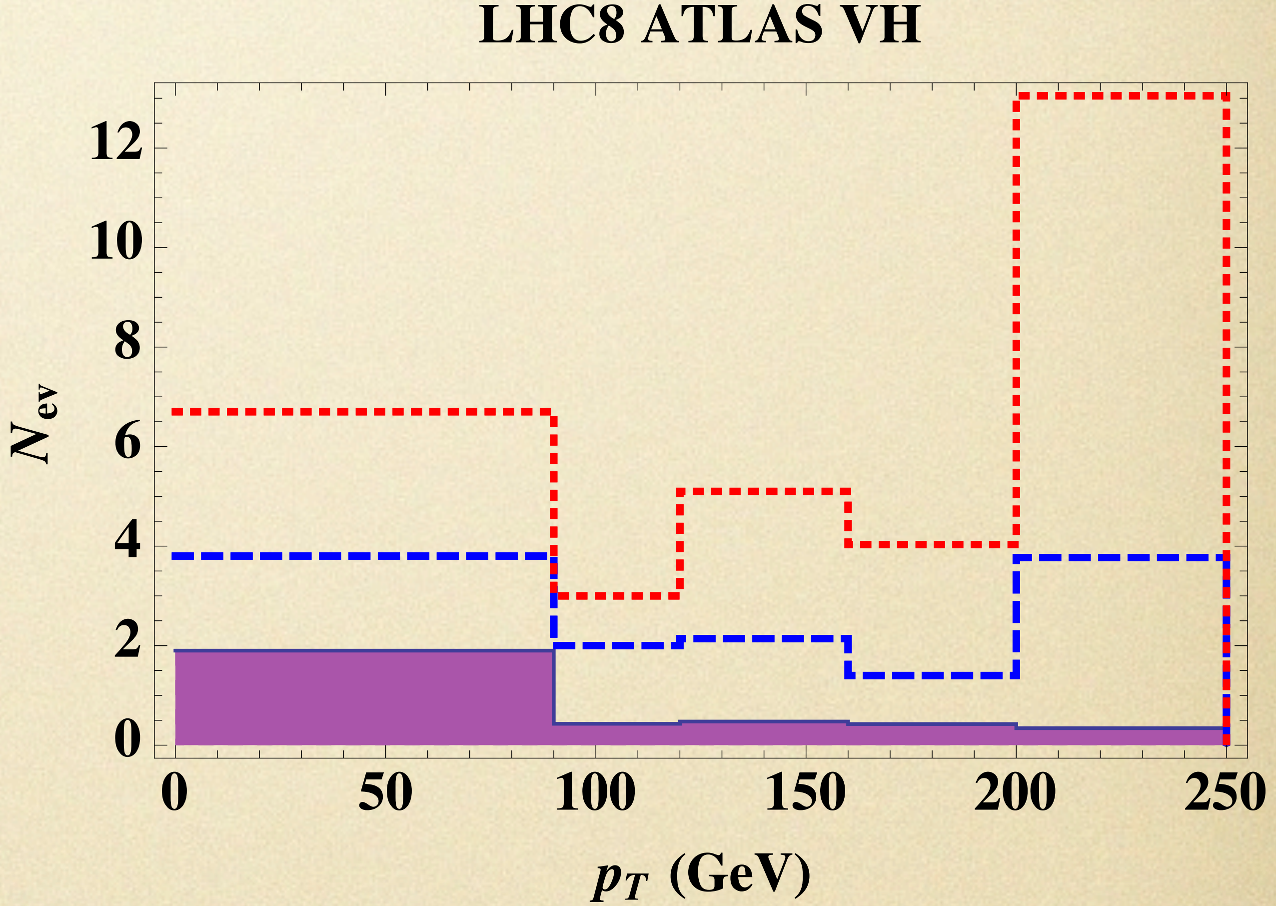
Last bin constraint better than D0 signal strength

Kinematics of associated production

LHC data should be even better



only p_T^V available



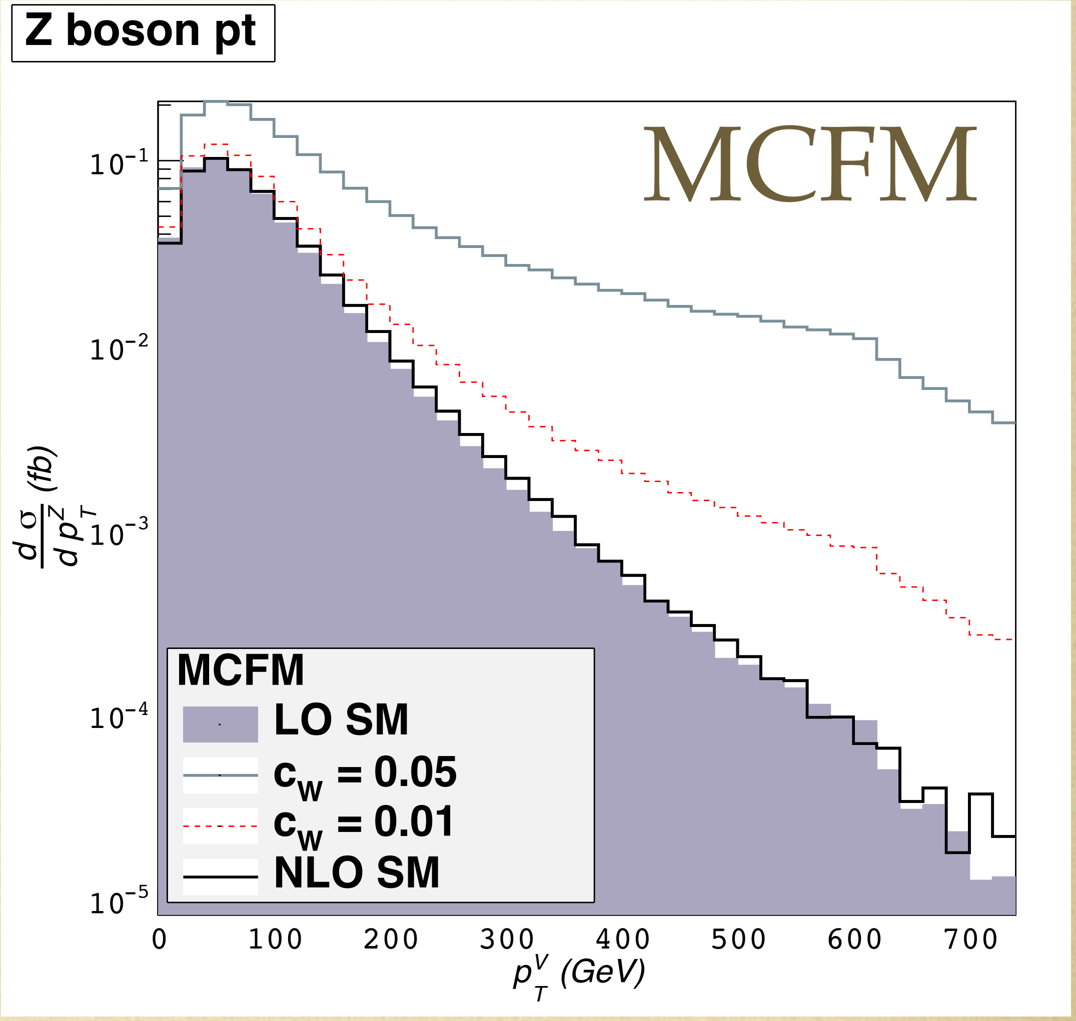
Feynrules -> MG5-> pythia->Delphes3

verified for SM/BGs => expectation for HDOs

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.

Global fit to signal strengths and kinematic distributions

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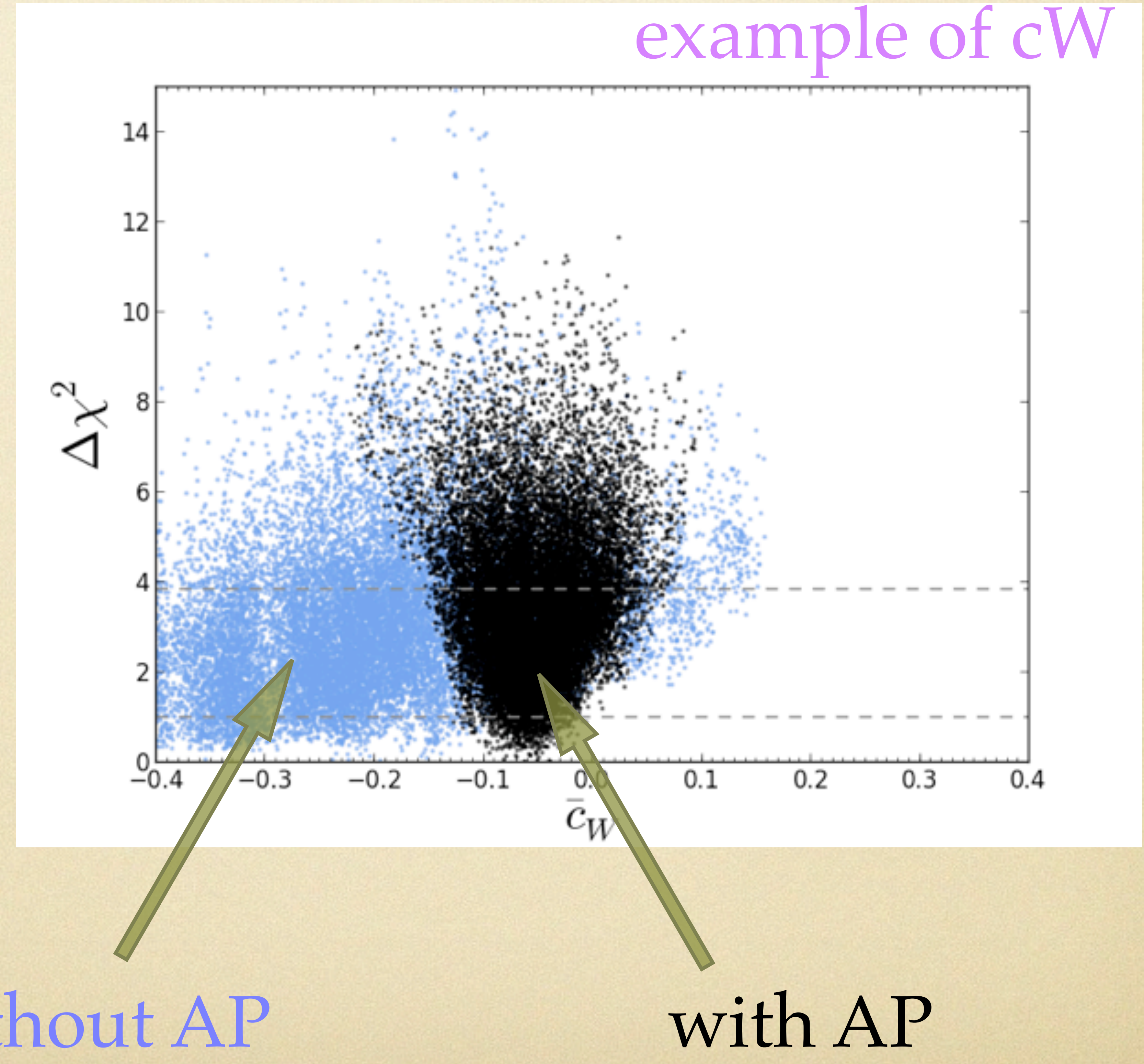
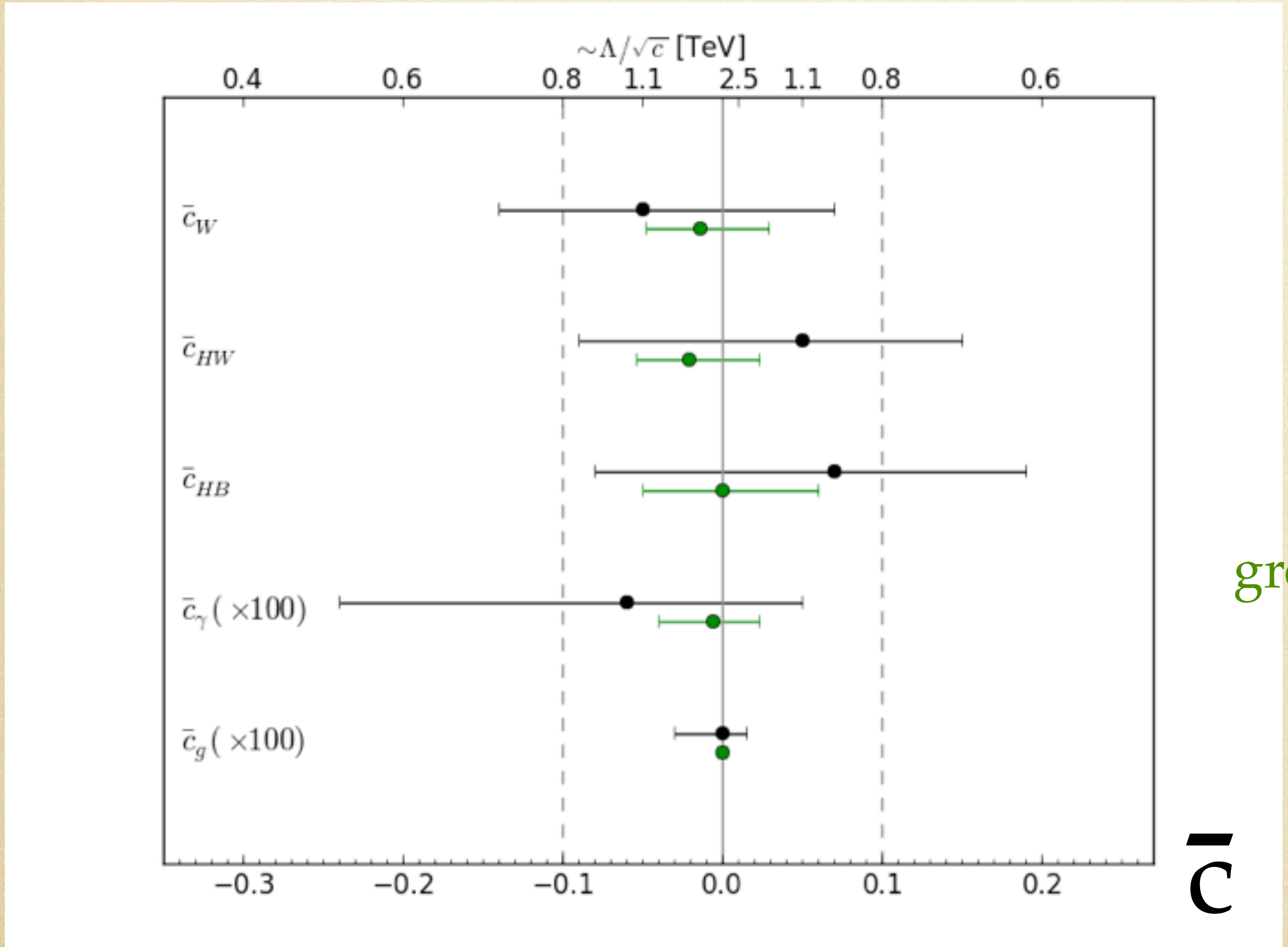
Global fit to 8 parameters



In summary



black global fit

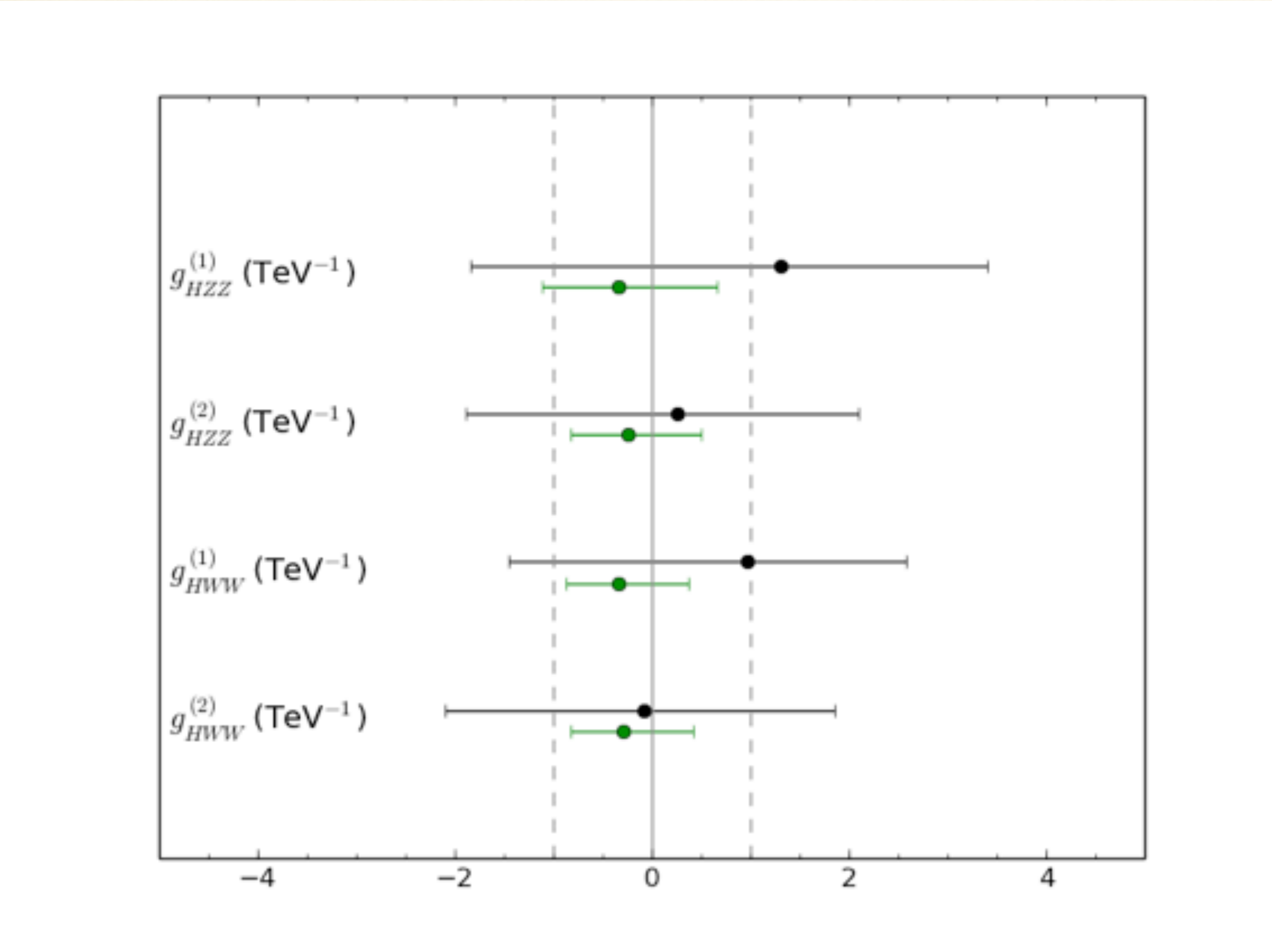
green one-by-one fit

ct,cd,cH: no meaningful constraints

In summary

In terms of Higgs' anomalous couplings

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



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Conclusions

Absence of hints in direct searches
EFT approach to Higgs physics
Systematic, model-independent

Handles at LHC and Tevatron
beyond signal strengths
COM dependence, angular, pT and inv mass

SM precision crucial: excess as genuine new physics

LEP constraints not as powerful as expected
Higgs physics is complementary

Complete global fit to Higgs physics
also, beyond signal strengths
Use of AP breaks degeneracy in fit, plus provides
stronger constraints through kinematics

Framework for HDO studies

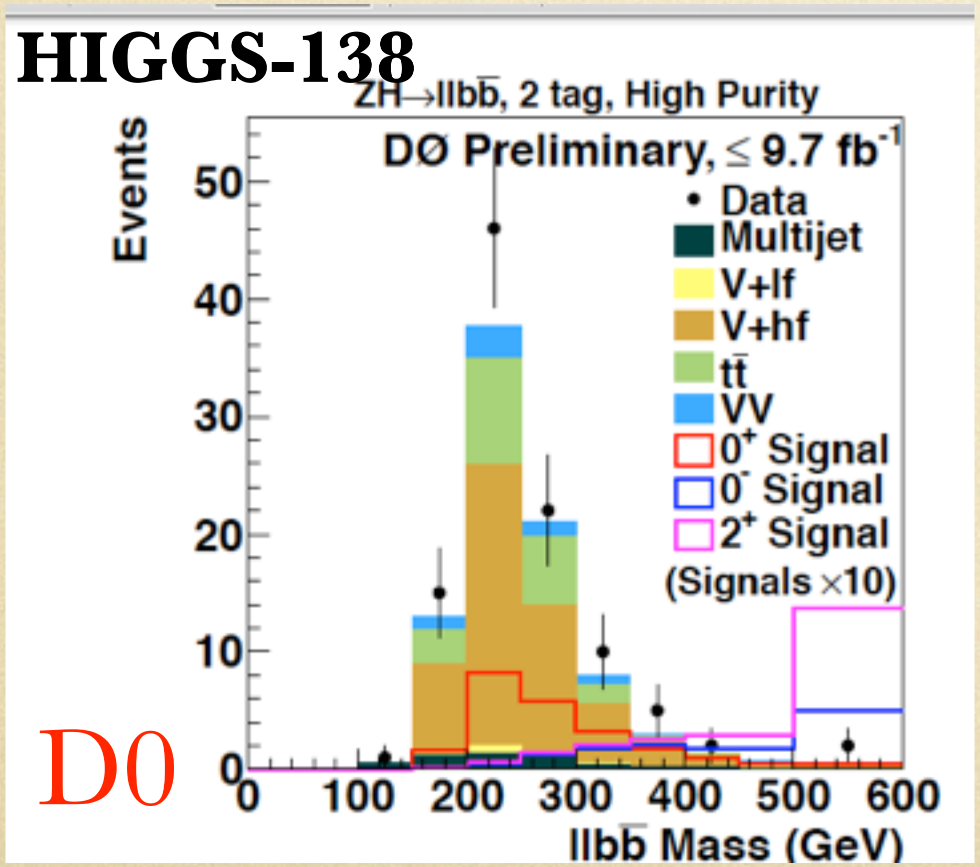
Feynrules HDOs involving Higgs and TGCs

Alloul, Fuks, VS. 1310.5150

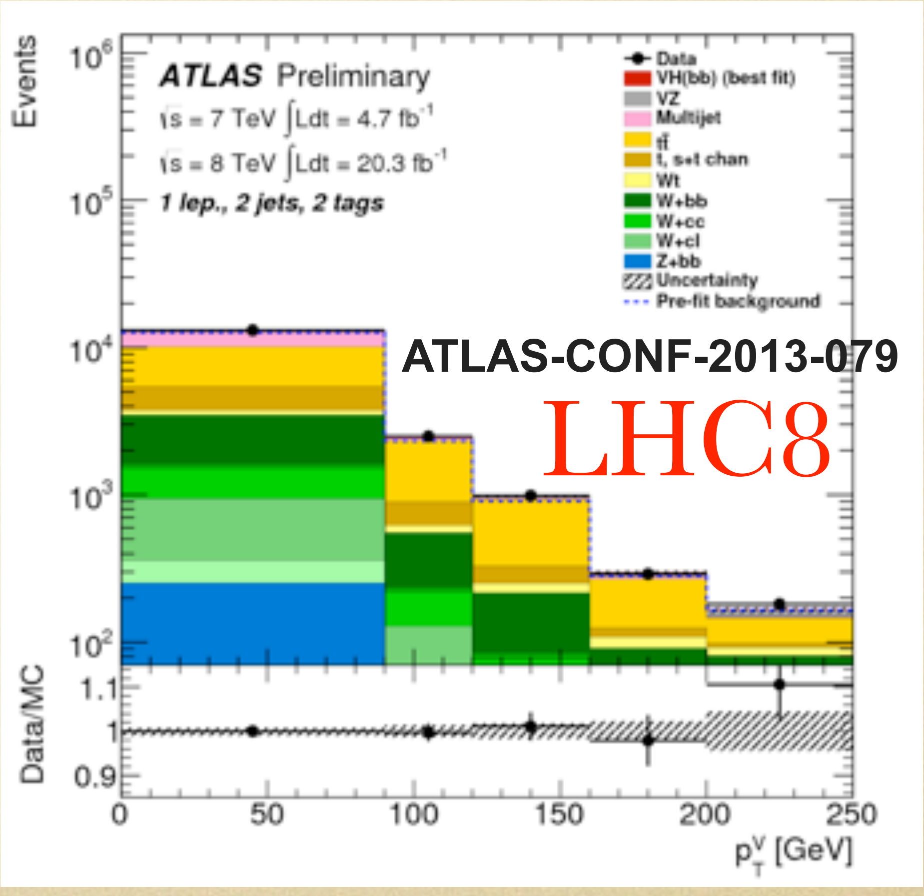
links to CalcHEP, LoopTools, Madgraph...

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

ex. Higgs in associated production



m_{Vh}



p_T^V

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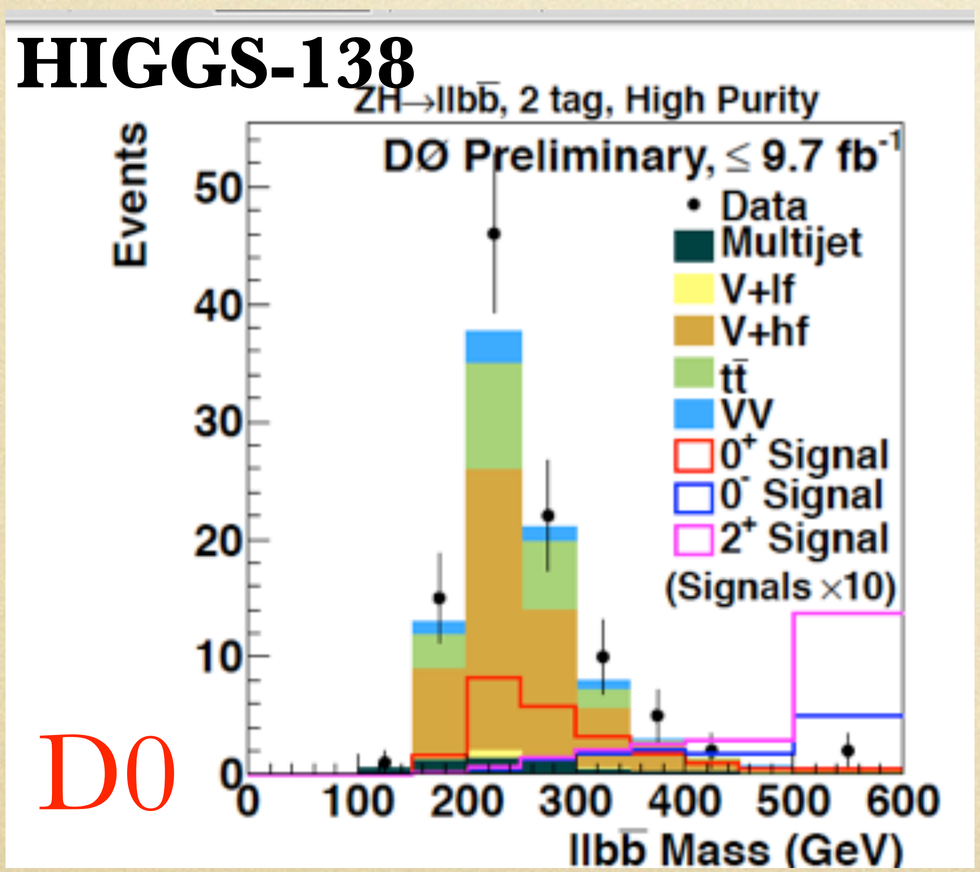
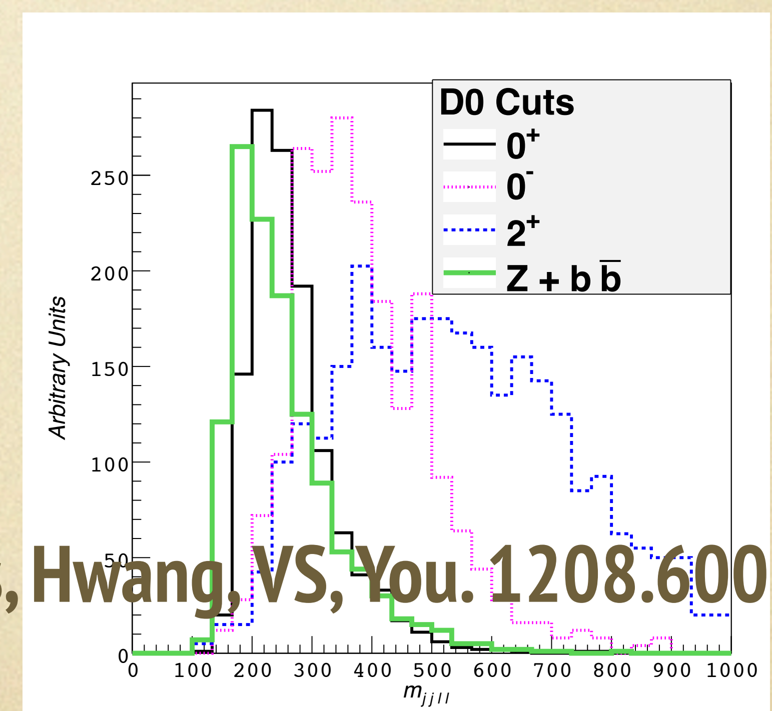


m_{Vh}

Test other JCP



Ellis, Hwang, VS, You. 1208.6002