LES HOUCHES 2013
PHYSICS AT TEV COLLIDERS

SUMMARY OF
HIGGS WORKING GROUP

Conveners:

Roberto Contino (theory)

Filip Moortgat (experiment)

Projects underway for Les Houches

- Higgs Effective Lagrangian
- Double Higgs production
- Exotic Higgs Decays
- Theoretical and systematic uncertainties on the Higgs couplings
- HDECAY extensions

Higgs Effective Lagrangian

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i \equiv \mathcal{L}_{SM} + \Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{gauge} + \Delta\mathcal{L}_{CP} + \Delta\mathcal{L}_{F_1} + \Delta\mathcal{L}_{F_2} + \Delta\mathcal{L}_{4f}$$

see review arXiv:1303.3876
and references therein

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$$\begin{aligned}
\Delta\mathcal{L}_{SILH} =& \frac{\bar{c}_H}{2v^2}\, \partial^\mu\big(H^\dagger H\big)\, \partial_\mu\big(H^\dagger H\big) + \frac{\bar{c}_T}{2v^2}\, \Big(H^\dagger \overleftrightarrow{D^\mu} H\Big)\Big(H^\dagger \overleftrightarrow{D}_\mu H\Big) - \frac{\bar{c}_6\,\lambda}{v^2}\, \big(H^\dagger H\big)^3 \\
&+ \Big(\frac{\bar{c}_u}{v^2}\, y_u\, H^\dagger H\, \bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\, y_d\, H^\dagger H\, \bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\, y_l\, H^\dagger H\, \bar{L}_L H l_R + h.c.\Big) \\
&+ \frac{i\bar{c}_W\, g}{2m_W^2}\, \Big(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\Big)\, (D^\nu W_{\mu\nu})^i + \frac{i\bar{c}_B\, g'}{2m_W^2}\, \Big(H^\dagger \overleftrightarrow{D^\mu} H\Big)\, (\partial^\nu B_{\mu\nu}) \\
&+ \frac{i\bar{c}_{HW}\, g}{m_W^2}\, (D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\, g'}{m_W^2}\, (D^\mu H)^\dagger (D^\nu H) B_{\mu\nu} \\
&+ \frac{\bar{c}_\gamma\, {g'}^2}{m_W^2}\, H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\, g_S^2}{m_W^2}\, H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}\,,
\end{aligned}$$

$$\begin{aligned}
\Delta\mathcal{L}_{gauge} =& \frac{\bar{c}_{2W}}{m_W^2}\, (D^\mu W_{\mu\nu})^i\, (D_\rho W^{\rho\nu})^i + \frac{\bar{c}_{2B}}{m_W^2}\, (\partial^\mu B_{\mu\nu})\, (\partial_\rho B^{\rho\nu}) + \frac{\bar{c}_{2G}}{m_W^2}\, (D^\mu G_{\mu\nu})^a\, (D_\rho G^{\rho\nu})^a \\
&+ \frac{\bar{c}_{3W}\, g^3}{m_W^2}\, \epsilon^{ijk} W_\mu^{i\,\nu} W_\nu^{j\,\rho} W_\rho^{k\,\mu} + \frac{\bar{c}_{3G}\, g_S^3}{m_W^2}\, f^{abc} G_\mu^{a\,\nu} G_\nu^{b\,\rho} G_\rho^{c\,\mu}
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$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i \equiv \mathcal{L}_{SM} + \Delta\mathcal{L}_{SILH} + \Delta\mathcal{L}_{gauge} + \Delta\mathcal{L}_{CP} + \Delta\mathcal{L}_{F_1} + \Delta\mathcal{L}_{F_2} + \Delta\mathcal{L}_{4f}$$

universal shift

Higgs trilinear

$$\Delta\mathcal{L}_{SILH} = \frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3$$
$$+ \left(\frac{\bar{c}_u}{v^2}\,y_u\,H^\dagger H\,\bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\,y_d\,H^\dagger H\,\bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\,y_l\,H^\dagger H\,\bar{L}_L H l_R + h.c.\right)$$
$$+ \frac{i\bar{c}_W\,g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\,g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right)$$
$$+ \frac{i\bar{c}_{HW}\,g}{m_W^2}(D^\mu H)^\dagger \sigma^i (D^\nu H) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\,g'}{m_W^2}(D^\mu H)^\dagger (D^\nu H) B_{\mu\nu}$$
$$+ \frac{\bar{c}_\gamma\,g'^2}{m_W^2} H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\,g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu} G^{a\mu\nu},$$

htt coupling

contact ggh / gghh

Operators relevant for Double Higgs production ($gg \to hh$, $WW \to hh$)

$$\Delta\mathcal{L}_{gauge} = \frac{\bar{c}_{2W}}{m_W^2}\left(D^\mu W_{\mu\nu}\right)^i \left(D_\rho W^{\rho\nu}\right)^i + \frac{\bar{c}_{2B}}{m_W^2}\left(\partial^\mu B_{\mu\nu}\right)\left(\partial_\rho B^{\rho\nu}\right) + \frac{\bar{c}_{2G}}{m_W^2}\left(D^\mu G_{\mu\nu}\right)^a \left(D_\rho G^{\rho\nu}\right)^a$$
$$+ \frac{\bar{c}_{3W}\,g^3}{m_W^2}\,\epsilon^{ijk} W_\mu^{i\,\nu} W_\nu^{j\,\rho} W_\rho^{k\,\mu} + \frac{\bar{c}_{3G}\,g_S^3}{m_W^2}\,f^{abc} G_\mu^{a\,\nu} G_\nu^{b\,\rho} G_\rho^{c\,\mu}$$

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$$\begin{aligned}
\Delta\mathcal{L}_{SILH} = &\frac{\bar{c}_H}{2v^2}\,\partial^\mu\left(H^\dagger H\right)\partial_\mu\left(H^\dagger H\right) + \frac{\bar{c}_T}{2v^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(H^\dagger \overleftrightarrow{D}_\mu H\right) - \frac{\bar{c}_6\,\lambda}{v^2}\left(H^\dagger H\right)^3 \\
&+ \left(\frac{\bar{c}_u}{v^2}\, y_u\, H^\dagger H\, \bar{q}_L H^c u_R + \frac{\bar{c}_d}{v^2}\, y_d\, H^\dagger H\, \bar{q}_L H d_R + \frac{\bar{c}_l}{v^2}\, y_l\, H^\dagger H\, \bar{L}_L H l_R + h.c.\right) \\
&+ \frac{i\bar{c}_W\, g}{2m_W^2}\left(H^\dagger \sigma^i \overleftrightarrow{D^\mu} H\right)\left(D^\nu W_{\mu\nu}\right)^i + \frac{i\bar{c}_B\, g'}{2m_W^2}\left(H^\dagger \overleftrightarrow{D^\mu} H\right)\left(\partial^\nu B_{\mu\nu}\right) \\
&+ \frac{i\bar{c}_{HW}\, g}{m_W^2}\left(D^\mu H\right)^\dagger \sigma^i \left(D^\nu H\right) W^i_{\mu\nu} + \frac{i\bar{c}_{HB}\, g'}{m_W^2}\left(D^\mu H\right)^\dagger\left(D^\nu H\right) B_{\mu\nu} \\
&+ \frac{\bar{c}_\gamma\, g'^2}{m_W^2}\, H^\dagger H B_{\mu\nu} B^{\mu\nu} + \frac{\bar{c}_g\, g_S^2}{m_W^2}\, H^\dagger H G^a_{\mu\nu} G^{a\mu\nu}\,,
\end{aligned}$$

EW operators relevant for EWPT, TGC, *Vh*, *h*→*VV*

$$\begin{aligned}
\Delta\mathcal{L}_{gauge} = &\frac{\bar{c}_{2W}}{m_W^2}\left(D^\mu W_{\mu\nu}\right)^i \left(D_\rho W^{\rho\nu}\right)^i + \frac{\bar{c}_{2B}}{m_W^2}\left(\partial^\mu B_{\mu\nu}\right)\left(\partial_\rho B^{\rho\nu}\right) + \frac{\bar{c}_{2G}}{m_W^2}\left(D^\mu G_{\mu\nu}\right)^a \left(D_\rho G^{\rho\nu}\right)^a \\
&+ \frac{\bar{c}_{3W}\, g^3}{m_W^2}\,\epsilon^{ijk} W^{i\,\nu}_\mu W^{j\,\rho}_\nu W^{k\,\mu}_\rho + \frac{\bar{c}_{3G}\, g_S^3}{m_W^2}\, f^{abc} G^{a\,\nu}_\mu G^{b\,\rho}_\nu G^{c\,\mu}_\rho
\end{aligned}$$

see review arXiv:1303.3876 and references therein

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$$\begin{aligned}\Delta\mathcal{L}_{CP} = {} & \frac{i\tilde{c}_{HW}\, g}{m_W^2}\,(D^\mu H)^\dagger\sigma^i(D^\nu H)\tilde{W}^i_{\mu\nu} + \frac{i\tilde{c}_{HB}\, g'}{m_W^2}\,(D^\mu H)^\dagger(D^\nu H)\tilde{B}_{\mu\nu} \\ & + \frac{\tilde{c}_\gamma\, {g'}^2}{m_W^2}\, H^\dagger H B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{\tilde{c}_g\, g_S^2}{m_W^2}\, H^\dagger H G^a_{\mu\nu}\tilde{G}^{a\mu\nu} \\ & + \frac{\tilde{c}_{3W}\, g^3}{m_W^2}\,\epsilon^{ijk} W^{i\,\nu}_{\mu} W^{j\,\rho}_{\nu}\tilde{W}^{k\,\mu}_{\rho} + \frac{\tilde{c}_{3G}\, g_S^3}{m_W^2}\, f^{abc} G^{a\,\nu}_{\mu} G^{b\,\rho}_{\nu}\tilde{G}^{c\,\mu}_{\rho}\,,\end{aligned}$$

$$\begin{aligned}\Delta\mathcal{L}_{F_2} = {} & \frac{\bar{c}_{uB}\, g'}{m_W^2}\, y_u\,\bar{q}_L H^c\sigma^{\mu\nu}u_R\, B_{\mu\nu} + \frac{\bar{c}_{uW}\, g}{m_W^2}\, y_u\,\bar{q}_L\sigma^i H^c\sigma^{\mu\nu}u_R\, W^i_{\mu\nu} + \frac{\bar{c}_{uG}\, g_S}{m_W^2}\, y_u\,\bar{q}_L H^c\sigma^{\mu\nu}\lambda^a u_R\, G^a_{\mu\nu} \\ & + \frac{\bar{c}_{dB}\, g'}{m_W^2}\, y_d\,\bar{q}_L H\sigma^{\mu\nu}d_R\, B_{\mu\nu} + \frac{\bar{c}_{dW}\, g}{m_W^2}\, y_d\,\bar{q}_L\sigma^i H\sigma^{\mu\nu}d_R\, W^i_{\mu\nu} + \frac{\bar{c}_{dG}\, g_S}{m_W^2}\, y_d\,\bar{q}_L H\sigma^{\mu\nu}\lambda^a d_R\, G^a_{\mu\nu} \\ & + \frac{\bar{c}_{lB}\, g'}{m_W^2}\, y_l\,\bar{L}_L H\sigma^{\mu\nu}l_R\, B_{\mu\nu} + \frac{\bar{c}_{lW}\, g}{m_W^2}\, y_l\,\bar{L}_L\sigma^i H\sigma^{\mu\nu}l_R\, W^i_{\mu\nu} + h.c.\end{aligned}$$

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$$+ \frac{\tilde{c}_\gamma\, g'^2}{m_W^2} H^\dagger H B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{\tilde{c}_g\, g_S^2}{m_W^2} H^\dagger H G^a_{\mu\nu}\tilde{G}^{a\mu\nu}$$
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also relevant for EWPT, TGC, *Vh*, *h*→*VV* for a CP-violating Higgs

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\, g'}{m_W^2} y_u\, \bar{q}_L H^c \sigma^{\mu\nu} u_R\, B_{\mu\nu} + \frac{\bar{c}_{uW}\, g}{m_W^2} y_u\, \bar{q}_L \sigma^i H^c \sigma^{\mu\nu} u_R\, W^i_{\mu\nu} + \frac{\bar{c}_{uG}\, g_S}{m_W^2} y_u\, \bar{q}_L H^c \sigma^{\mu\nu}\lambda^a u_R\, G^a_{\mu\nu}$$
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Top quark dipole operators

$$\Delta\mathcal{L}_{F_2} = \frac{\bar{c}_{uB}\, g'}{m_W^2} y_u\, \bar{q}_L H^c \sigma^{\mu\nu} u_R\, B_{\mu\nu} + \frac{\bar{c}_{uW}\, g}{m_W^2} y_u\, \bar{q}_L \sigma^i H^c \sigma^{\mu\nu} u_R\, W^i_{\mu\nu} + \frac{\bar{c}_{uG}\, g_S}{m_W^2} y_u\, \bar{q}_L H^c \sigma^{\mu\nu} \lambda^a u_R\, G^a_{\mu\nu}$$
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TASKS FOR LES HOUCHES:

1. Map operators to experimental observables

[Contino, Boudjema, Falkowski, Moortgat, ...]

– *complete the translation of operators to unitary gauge*

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Ex: h→gg rate -- from eHDECAY, arXiv:1303.3876

$$\Gamma(gg)\big|_{SILH} = \frac{G_F \alpha_s^2 m_h^3}{4\sqrt{2}\pi^3}\Bigg[\frac{1}{9}\sum_{q,q'=t,b,c}(1-\bar{c}_H-\bar{c}_q-\bar{c}_{q'})\,A^*_{1/2}(\tau_{q'})\,A_{1/2}(\tau_q)\;c^2_{eff}\,\kappa_{soft}$$
$$+\,2\,\mathrm{Re}\left(\sum_{q=t,b,c}\frac{1}{3}A^*_{1/2}(\tau_q)\,\frac{16\pi\,\bar{c}_g}{\alpha_2}\right)c_{eff}\,\kappa_{soft}$$
$$+\left|\sum_{q=t,b,c}\frac{1}{3}A_{1/2}(\tau_q)\right|^2 c^2_{eff}\,\kappa_{ew}\,\kappa_{soft}$$
$$+\,\frac{1}{9}\sum_{q,q'=t,b}(1-\bar{c}_H-\bar{c}_q-\bar{c}_{q'})A^*_{1/2}(\tau_q)\,A_{1/2}(\tau_{q'})\,\kappa^{NLO}(\tau_q,\tau_{q'})\Bigg]\,.$$

$$\frac{\Gamma(h\to gg)}{\Gamma(h\to gg)_{SM}} \simeq 1-\bar{c}_H-2.12\,\bar{c}_t+0.024\,\bar{c}_c+0.1\,\bar{c}_b+22.2\,\bar{c}_g\,\frac{4\pi}{\alpha_2}\,.$$

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– *is the current presentation of experimental results sufficient ?*
(ex: kappa's in Higgs searches vs Effective Lagrangian coefficients)

2. Derive constraints on EW operators from LEP1&2 (incl. TGC) and LHC

[Belyaev, Falkowski, Fichet, Mohan, Rohini, Rosenfeld, Sanz, Son]

- *decays $h \to WW^*$, $h \to ZZ^*$*
- *single-Higgs production via VBF*
- *Higgs associated production hV*
- *Triple Gauge Couplings (TGC)*

Anomalous HVV

w/ Kirtimaan, Maggie, Minho and Rohini

process by process

limits on CP-violating

Within Eff theory:

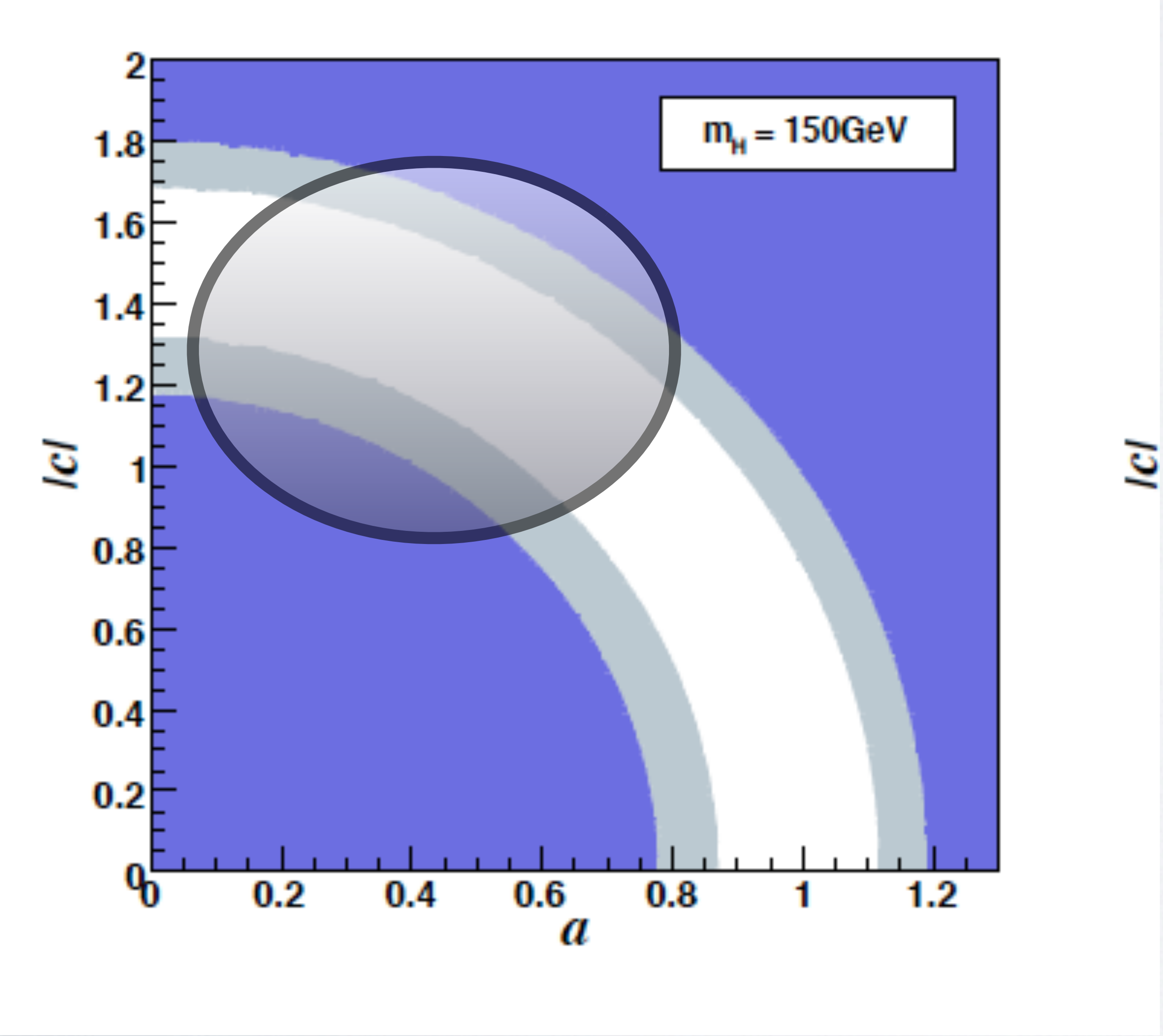
correlations & predictions

Angular distributions

H-> ZZ*

0708.0458

$$V^{\mu\nu}_{HZZ} = \frac{igm_Z}{\cos\theta_W}\left[a\, g_{\mu\nu} + b\,\frac{p_\mu p_\nu}{m_Z^2} + c\,\epsilon_{\mu\nu\alpha\beta}\frac{p^\alpha k^\beta}{m_Z^2}\right]$$



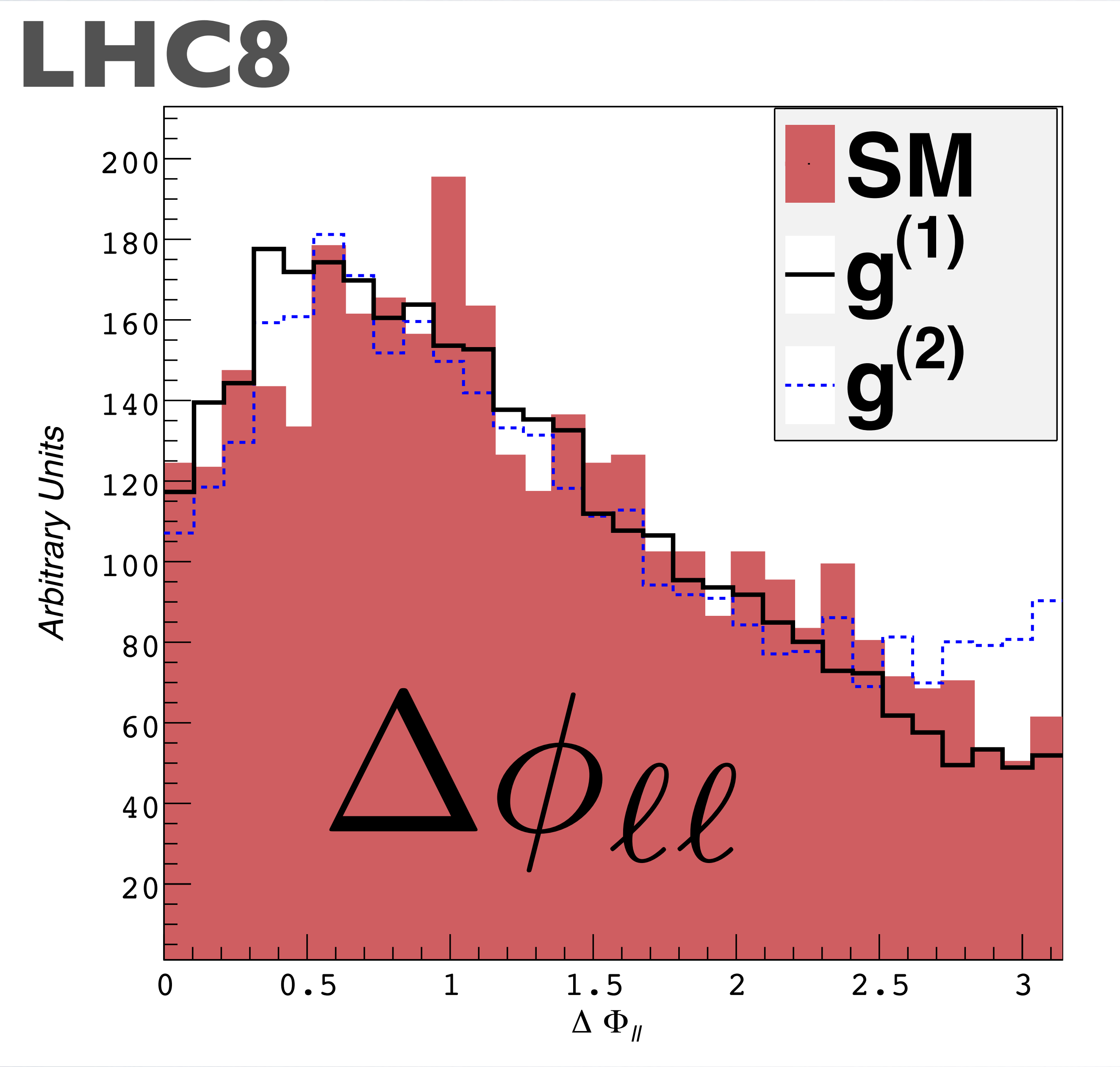
needs update

break degeneracies

H-> WW*

1211.1320

$$g^{(1)}_{HWW}\ \left(W^{+}_{\mu\nu}W^{-\mu}\partial^{\nu}H + \mathrm{h.c.}\right)\ +\ g^{(2)}_{HWW}\ W^{+}_{\mu\nu}W^{-\mu\nu}H$$



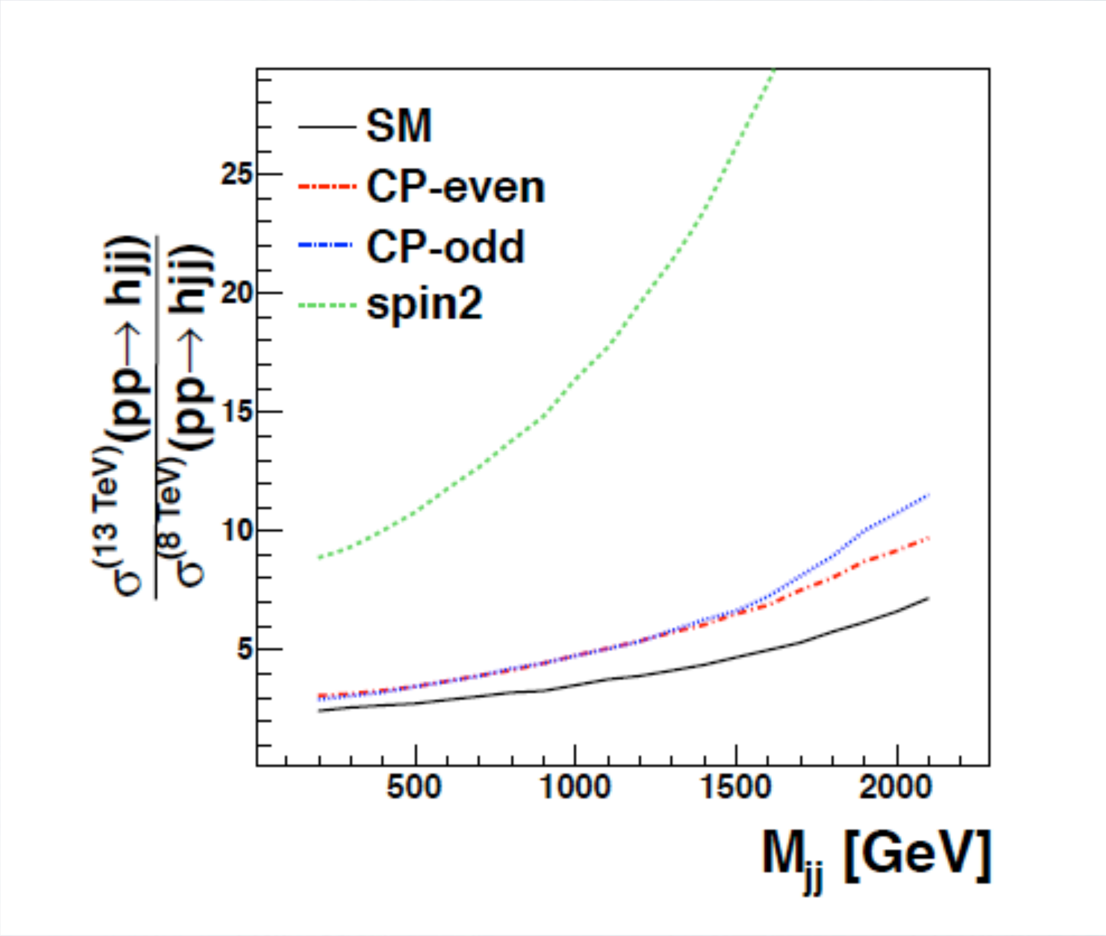
Fully leptonic, not very sensitive

Looking into semileptonic in assoc production (boosted V)

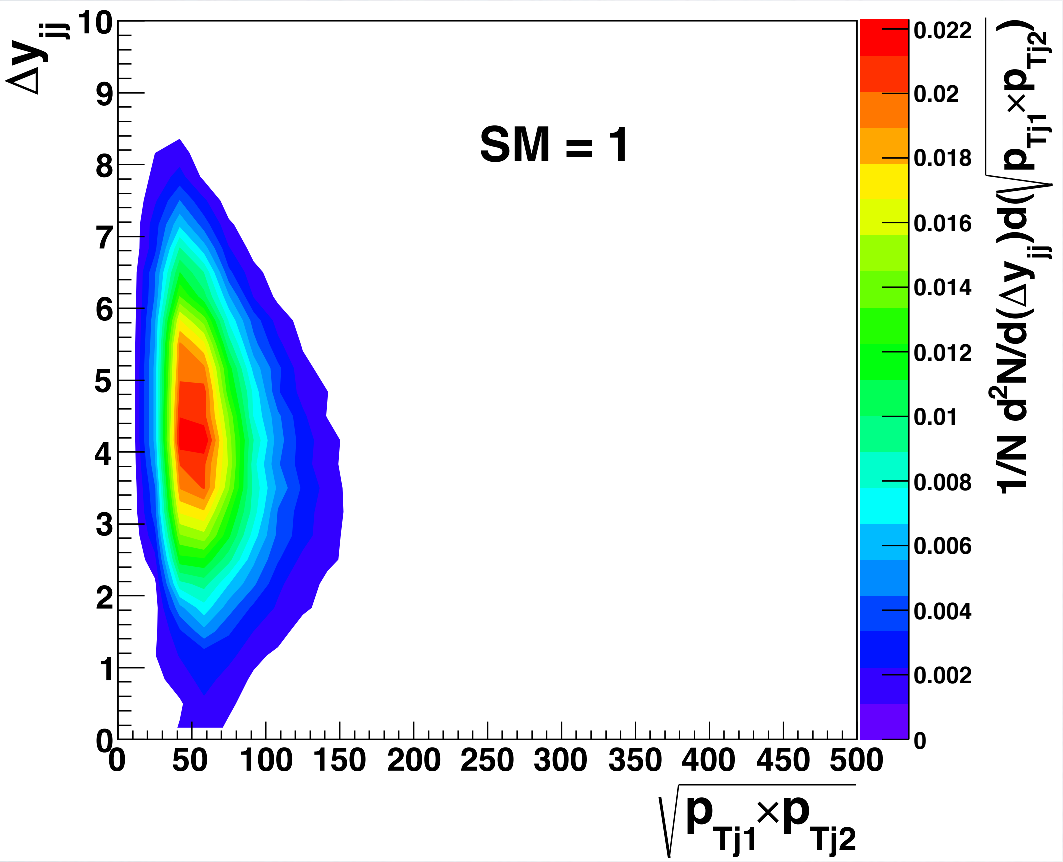
VBF

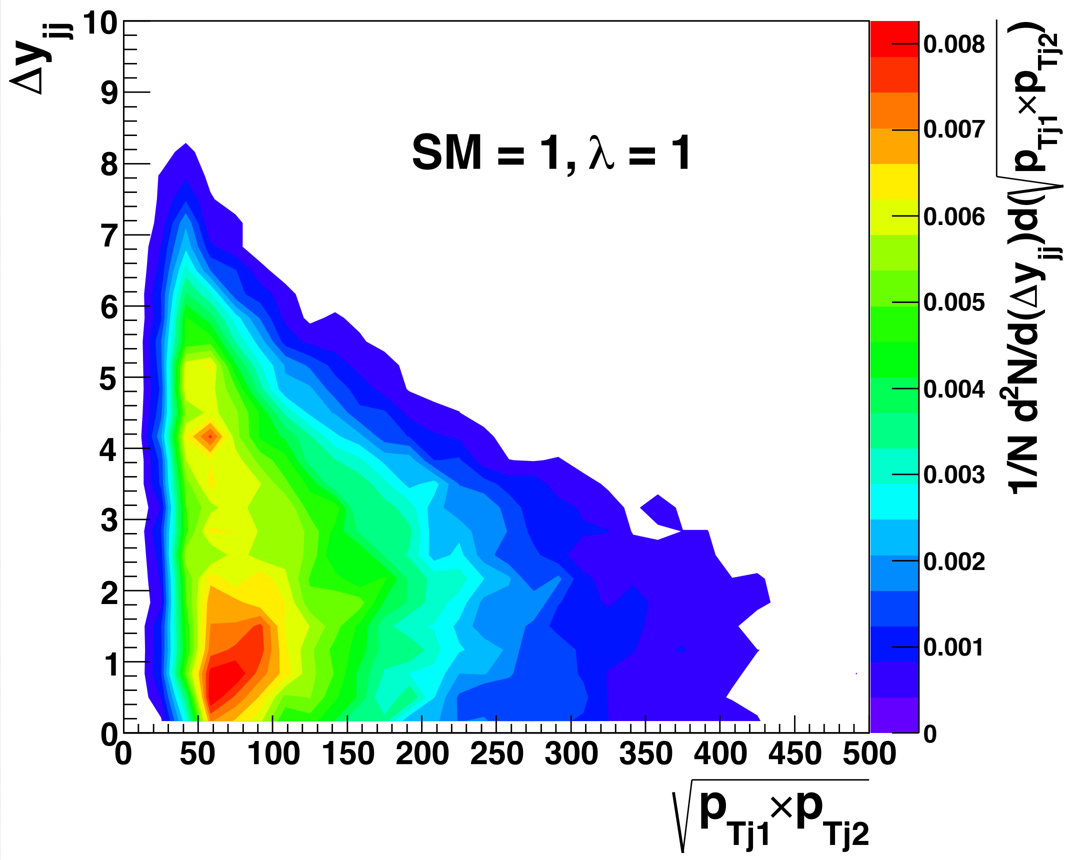
1301.4965

energy ratios



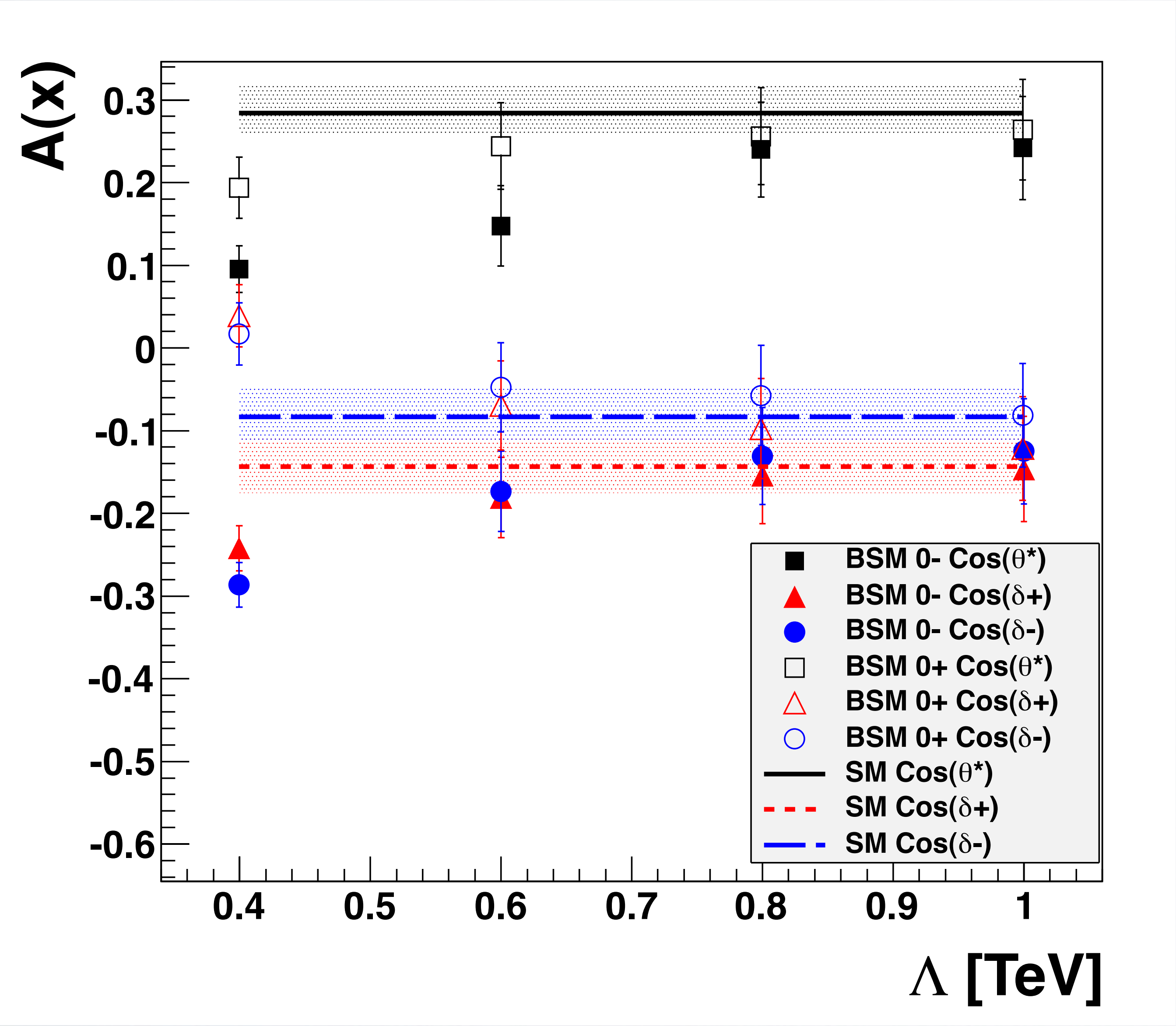
kinematics





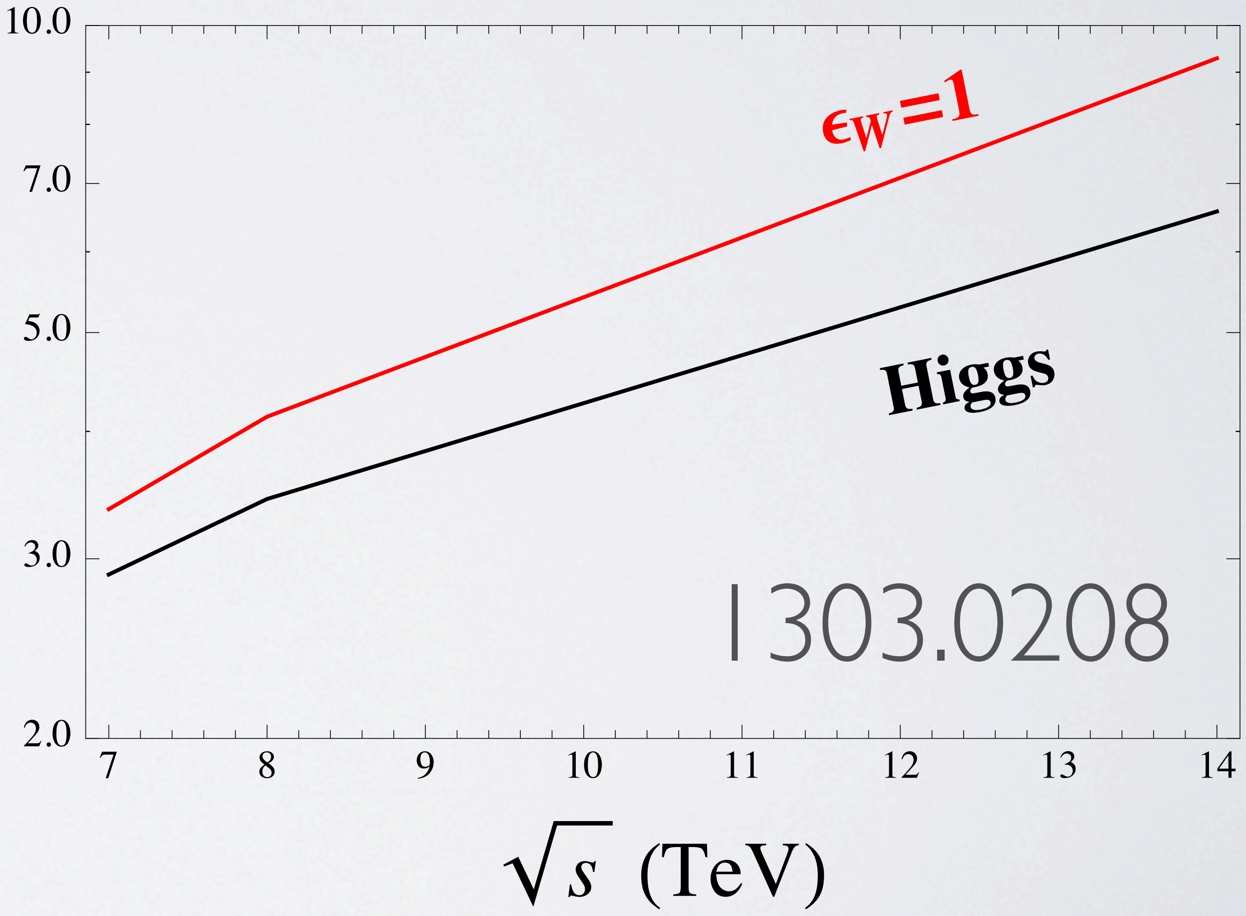
Associated production

1306.2573



energy dependence
8->13-> 14 TeV

$\frac{\sigma(E)}{\sigma_{\text{Tevatron}}}$ in 2l channel (incl. cuts)



Technicalities

FR implementation coming from Maltoni et al.
Contains just HVV anomalous couplings in mass basis
Need to
add translation to interaction basis
and all the terms
HH, LF1, LF2 and Wmunu^2

CalcHEP: Sasha and Rogerio, full Lagrangian in 1303.3876

Translation between different basis, checks

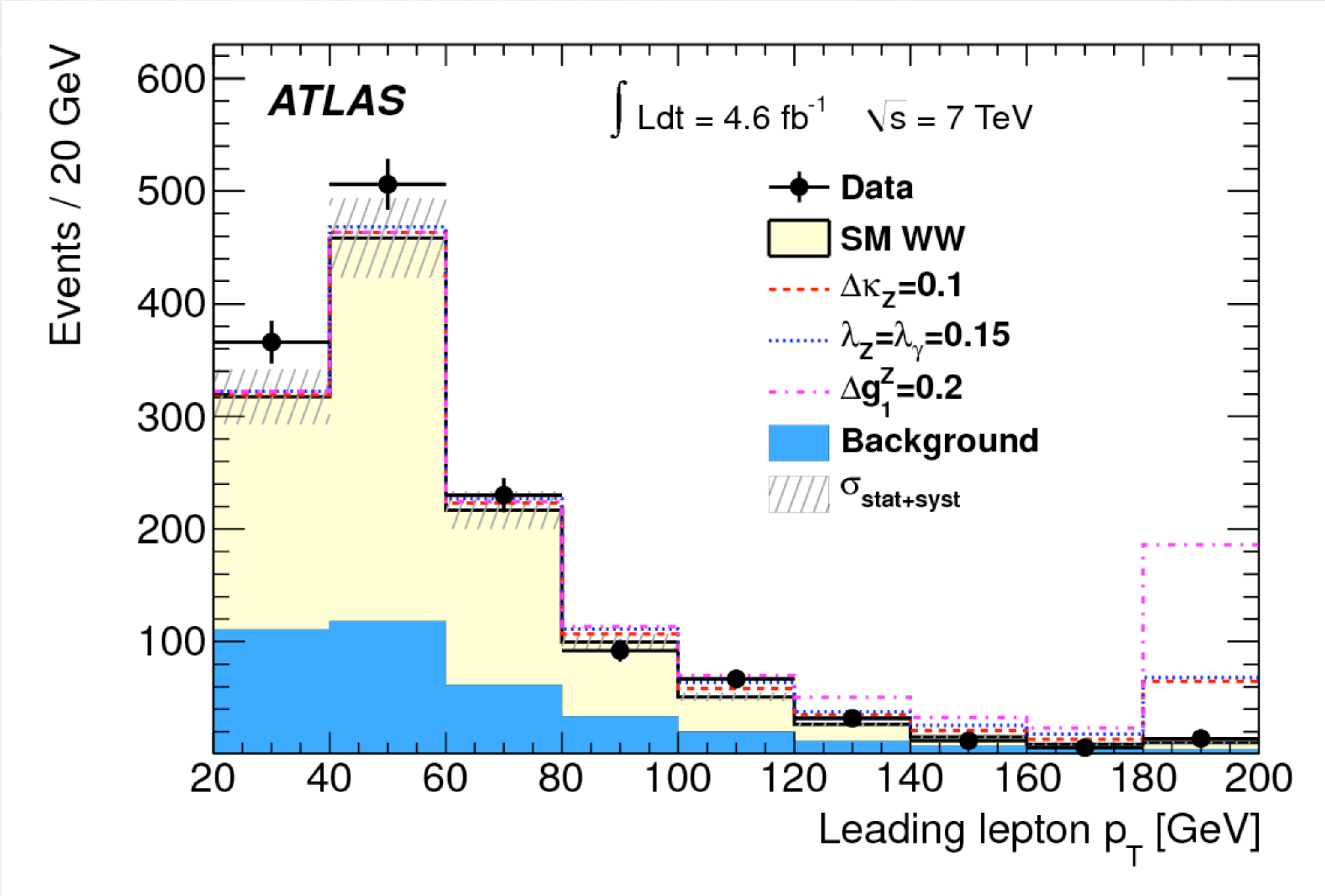
TGCs

w/ Adam, Kirtimaan, Minho & Sylvain

5 operators (including CP-odd ones) contribute to TGCs.

We will revisit LEP analysis to get correlations among the anomalous couplings.

Higgs couplings vs TGC couplings in the Eff thy framework



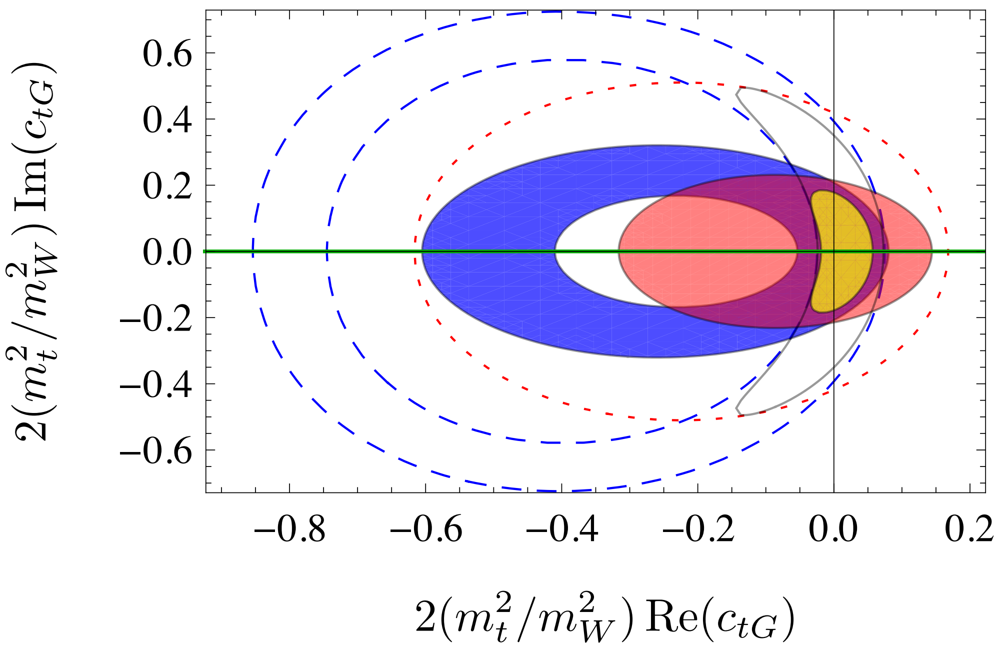
3. Probing top dipole operators

[Belyaev, Boos, Rosenfeld, Weiler, Spira, ...]

- *Constraints from ttbar differential cross sections (* $d\sigma/dp_T$ *,* $d\sigma/dm_{tt}$ *)*

  update to 8 TeV and extrapolate to 14 TeV

from arXiv:1107.3143



TASKS FOR LES HOUCHES:

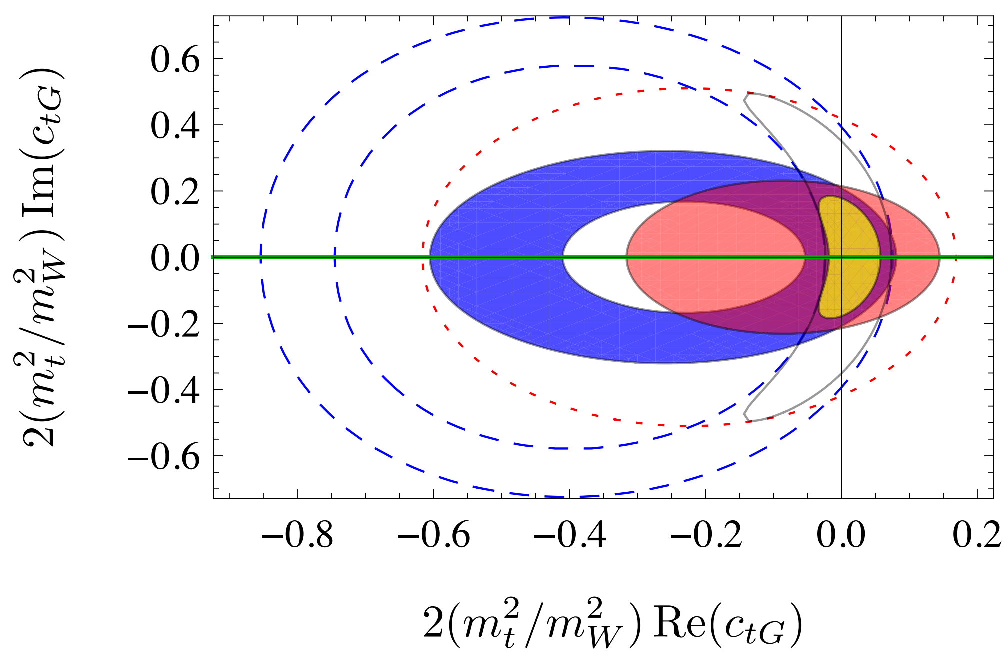
3. Probing top dipole operators

[Belyaev, Boos, Rosenfeld, Weiler, Spira, ...]

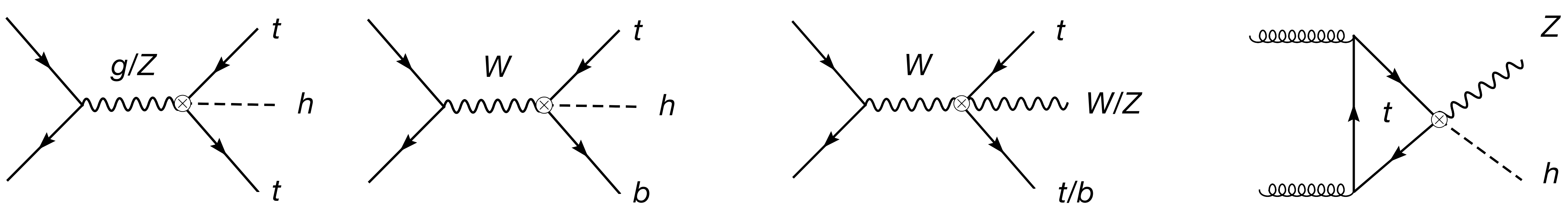
– *Constraints from ttbar differential cross sections* ($d\sigma/dp_T$, $d\sigma/dm_{tt}$)

update to 8 TeV and extrapolate to 14 TeV

from arXiv:1107.3143



– *study new processes ttW, Zh, tth, tWb*



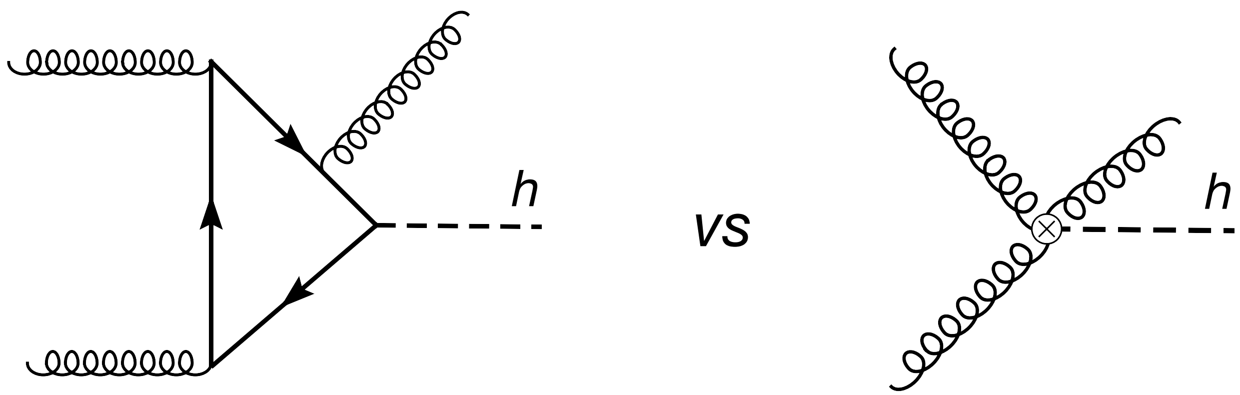
4. Implementation of Effective Lagrangian in Powheg for single-Higgs production

[Bondu, Contino, Massironi, Moortgat, Slavich, Vicini …]

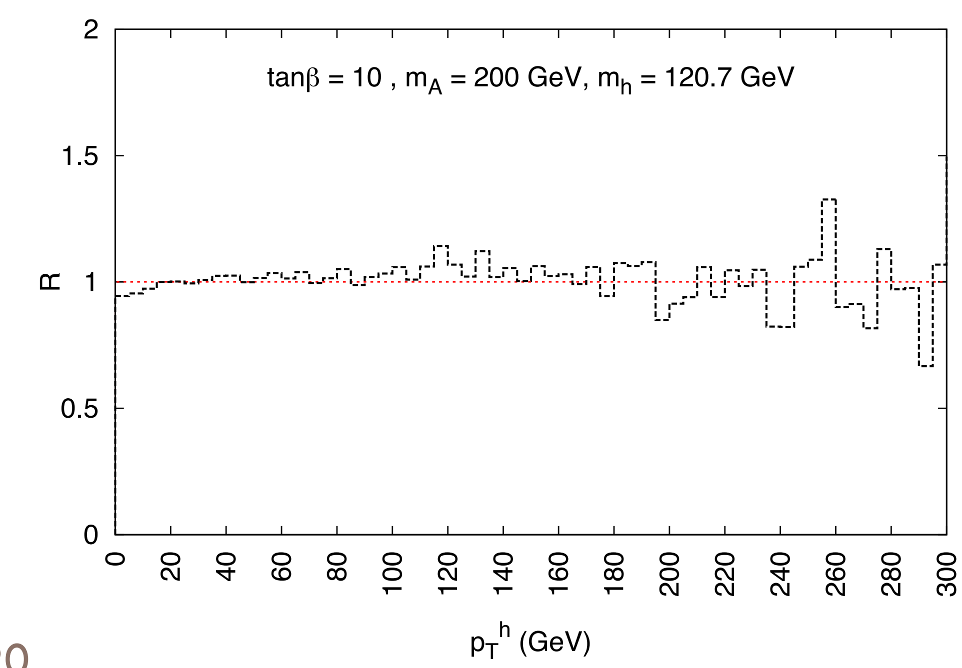
- *include GGh operator in Powheg*

- *study sensitivity on loop versus contact interactions using Higgs pT distribution*

Q: can we probe the SM top loop ?



from arXiv:1111.2854



First snapshot can be obtained from heavy-squark limit

Aim: sensitivity in (cg, ct) plane from pT distribution

Double Higgs production

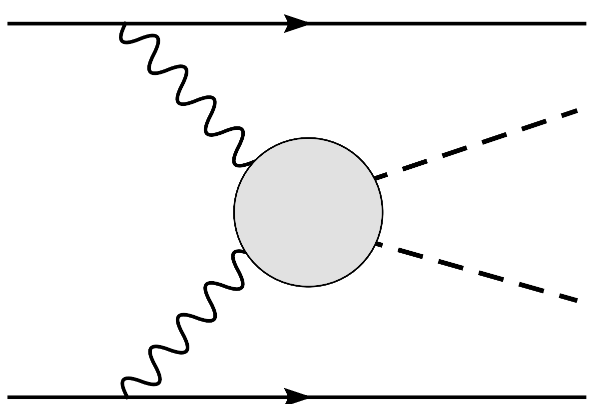
TASKS FOR LES HOUCHES:

1. Study feasibility of double Higgs production via VBF at the LHC

[Bondu, Brooijmans, Contino, Dolan, Englert, Jiang, Massironi, Moortgat, Spannowsky, Son, ...]

– *make table with figures of merit for signal and most relevant backgrounds in the following channels: $hh \to bbbb$, $bbWW$, $bb\tau\tau$*

– *which kind of future collider (ILC, CLIC, 100 TeV pp, …) would be sensitive?*

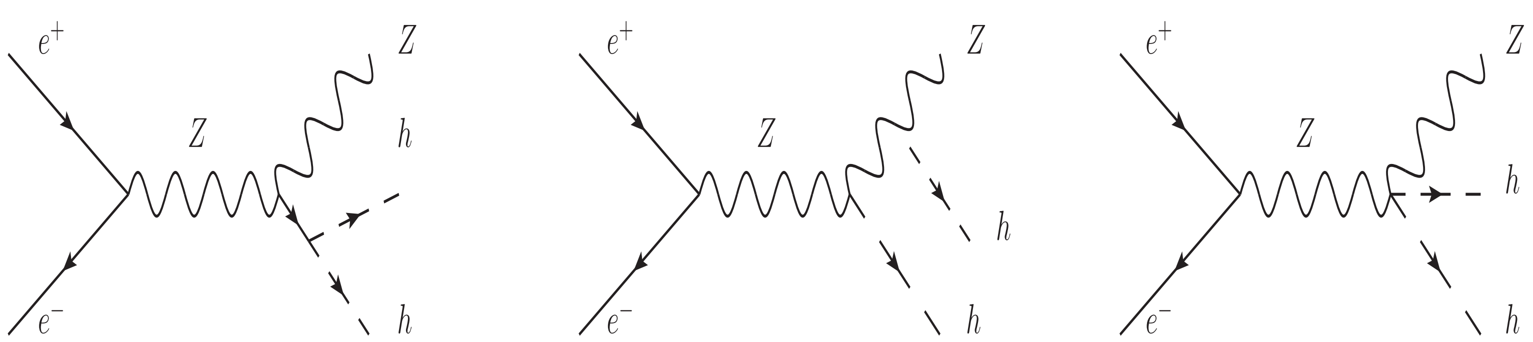


TASKS FOR LES HOUCHES:

2. Double Higgs-strahlung at the LC

DiHiggs[1]

- Linear Collider Study
- New Physics Effects in DiHiggs-Strahlung
- Loop Corrections



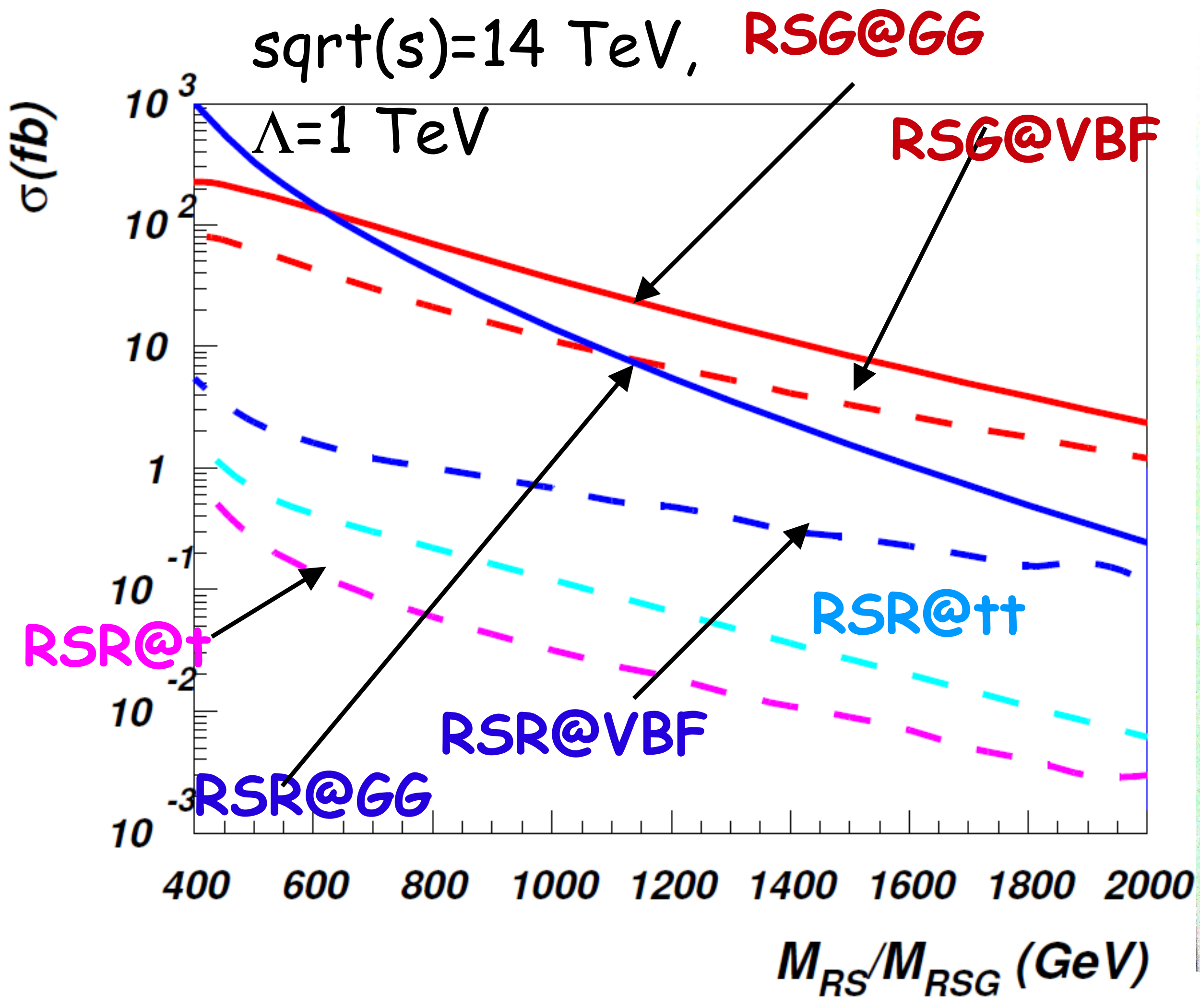
[1] Dolan,Englert,Muhlleitner,Spannowsky,???

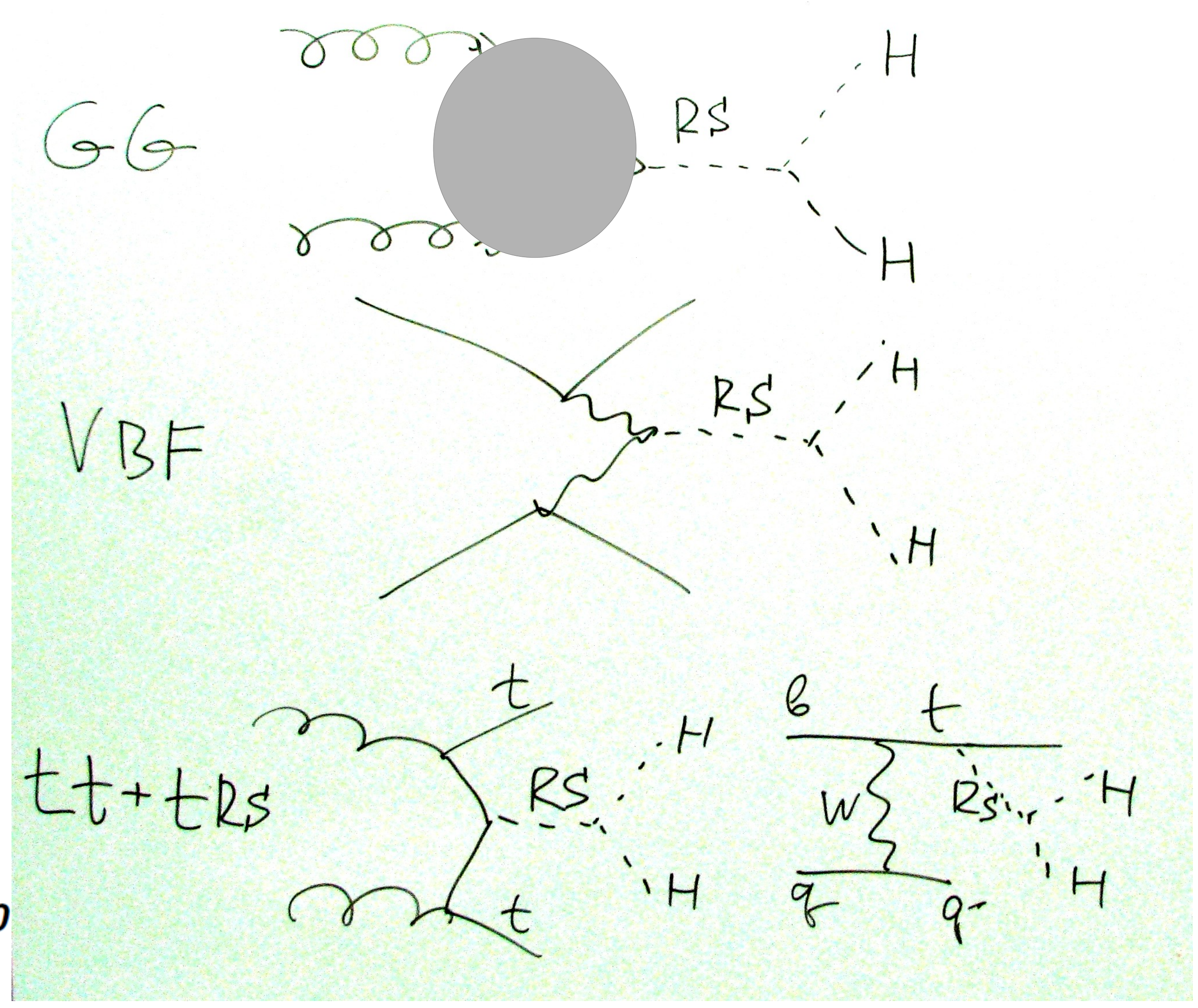
3. Higgs Pair Production in RS model

A.Belyaev, O.Bondu, A.Carvalho, M. Gouzevitch, A. Massironi, R.Rosenfeld, V.Sanz

The goal

* to study the Higgs pair production in the Randal Sundrum bulk model, combining GG,VBF and tt/t channels
* to develop methods for extracting the info about the nature of the resonance (Radion vs Graviton)
* work in progress!





Exotic Higgs Decays

Exotic Higgs Task Force

Roberto, Filip, Jack, Sabine, Grégory, Beranger, Kirtimaan, Jiang, Aoife, Andreas, Lorenzo, Nazila, Alex, ... , et moi

In the 1st approximation, Higgs is very standard

but a closer look may reveal something interesting

Exotic Higgs Decays - Why?

- Indirect constraints (via visible decays) allow for up to ~25% branching fraction into exotic states (if the Higgs production rate is as in the SM), or even up to ~50% with some conspiracy (if the Higgs production rate is enhanced). That means the LHC cross section for exotic Higgs decays could easily be order picobarn

- The SM Higgs width is just 4 MeV, so even weakly coupled new physics can lead to a significant branching fraction for exotic decays. E.g., a new scalar X coupled as $c|H|^2 |X|^2$ corresponds to BR $(h \to X^*X) = 10\%$ BR for $c \sim 0.01$.

- Thanks to the large Higgs cross section even tiny exotic branching fractions may possibly be probed, $O(10^{-4})$ now, and less in the future. [Note that the Higgs was first <u>discovered</u> in the diphoton (BR~10^{-3}) and 4-lepton (BR~10^{-4}) channels]

Exotic Higgs Decays - What?

One goal of this project is to compile a handbook of exotic Higgs decays for a reference for experimental collaborations.

- Classify exotic Higgs decays. One possible convenient classification is according to a number of on-shell visible SM particles in the final state.
- Check existing constraints on the couplings mediating the exotic decays, so as to see whether they leave room a non-negligible branching fraction. In many cases this step involves just compiling the available information from the literature, but in a few cases there's some work to do.
- Prompt experimental searches for the decays that are currently not being searched for at the LHC

Exotic Higgs Decays - Classification

The first pages of the handbook

0-particle

- Signature: $h \to$ invisible
- Models: $h \to \nu\nu$, Higgs portal dark matter: $h \to$ DM DM
- Searched for at the LHC in monojets, VBF, and Z/W associated production (public ATLAS results for the Zh channel)
- To do: apparently nothing

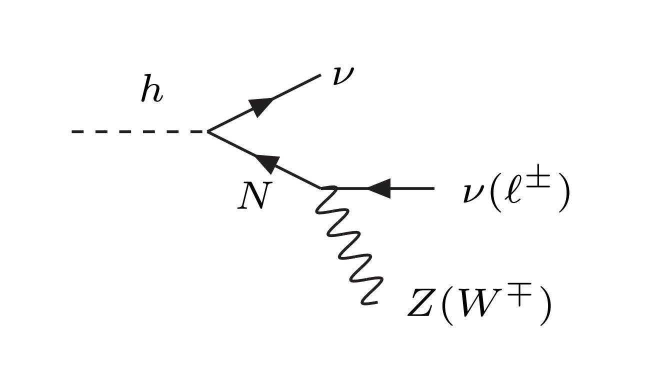
Exotic Higgs Decays - Classification

The first pages of the handbook

1-particle

- Signatures: $h \to \gamma$ + MET, $h \to Z$ + MET

- Models:
  - cascade decays $h \to V X \to V$ DM DM where X is dark vector boson coupled to SM via effective operator: c|H|^2/v^2 F_μν X_μν that decays to DM.
  - cascade decays via NLSP neutralinos in SUSY gauge mediation models: $h \to N G \to G G \gamma$, see 1203.4563
  - cascade decay via heavy neutrinos in inverse see-saw models: $h \to \nu N \to \nu \nu Z$



- To do: check constraints on effective operator, find the maximum allowed branching fraction, check whether some LHC searches (monophotons? mono-Z?) could pick up this decay, devise experimental strategy for different models

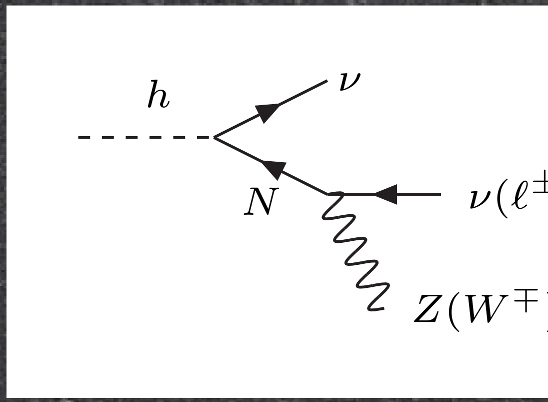
Exotic Higgs Decays - Classification

The first pages of the handbook

2-particle

Signatures:

- Flavor violating decays to quark, e.g. h→u cbar, probably hopeless given the constraints from flavor violation and difficult final state, see 1209.1397
- Lepton flavor violating decays, e.g. h→tau mu, more promising, see 1209.1397
- h → W+lepton+MET, e.g. via heavy neutrinos in inverse see-saw models: h → ν N → ν l W
- h → f+fbar+MET, e.g. as cascade decays h → hD hD → DM DM f fbar in Higgs portal models



To do: work out the last 2 cases in more detail (concrete models), recast existing constraints and devise experimental strategies

Exotic Higgs Decays - Classification

The first pages of the handbook

3-particle

of possibilities grows factorially, pick just 1 for this presentation:

$$h \to f1\ F^* \to f1\ f2\ Z/W$$

- Models: may occur in composite Higgs models, or more generally in models with vector-like quarks or leptons. Branching fraction may be significant if F is not much heavier than 100 GeV.

- To do: work out constraint on F from LHC searches and from single production at LEP, check if large enough branching fraction can be obtained, if yes, work out experimental strategies

- Sign up on the exotic wiki page http://phystev.in2p3.fr/wiki/2013:groups:higgs:ehd
- Project structured such that it can be inflated ad ∞
- A part of the project is just taxonomy and compiling existing literature, but also much original research to do

Uncertainties on Higgs couplings

Higgs Couplings and BSM Physics

Experimental accuracies, physics requirements, theory & parametric systematics

---

Systematic survey of sensitivity to new physics through precision determination of Higgs couplings (ff, VV, invisible, trilinear) and total width;

Models: MSSM (19-par pMSSM) with contributions from M_A and SUSY loops,

light DM with invisible Higgs decays

SILH models

Compare BSM physics effects to expected accuracy at
LHC (14 TeV 300 fb^{-1}, 14 TeV 3000 fb^{-1})
ILC (0.25+0.35 TeV 0.5 fb^{-1}, 0.5 TeV 0.5 fb-1, 1 TeV 1 fb^{-1})

and study effect of theory and parametric (m_b, m_c, α_s) uncertainties

---

Contributors:
A. Arbey, M. Battaglia, R. Contino, K. Desch, F. Mahmoudi, M. Mullheithner, M. Spira

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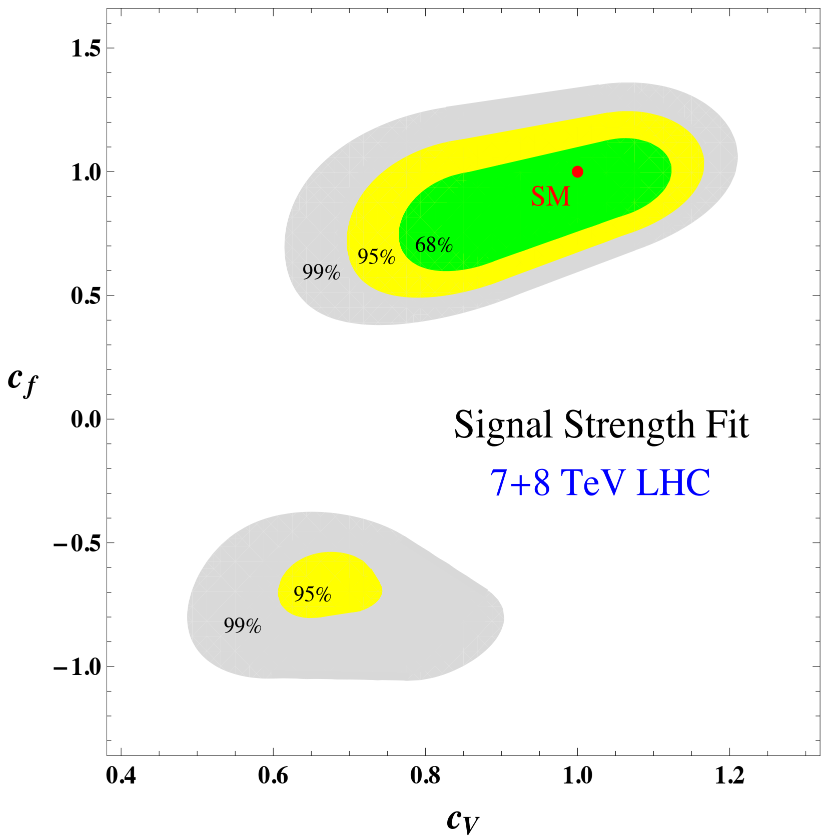
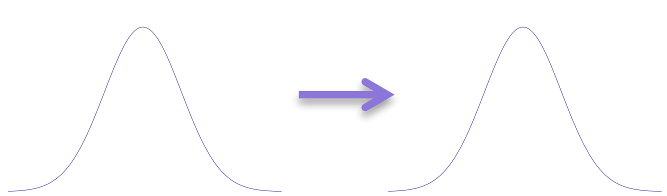
How to treat the theoretical (QCD) uncertainties in global Higgs fits ?

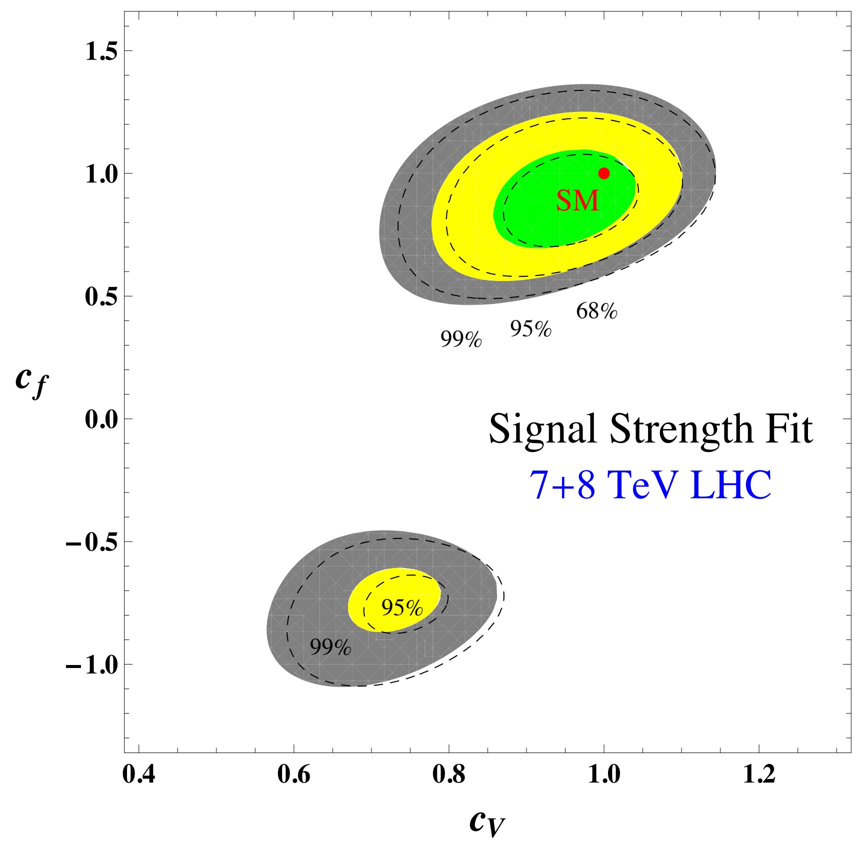
S. Fichet , G. Moreau

Th. error added in quadrature with the exp. one ☹

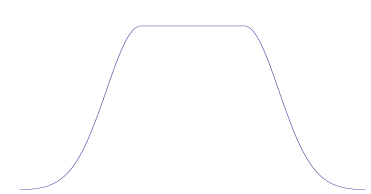


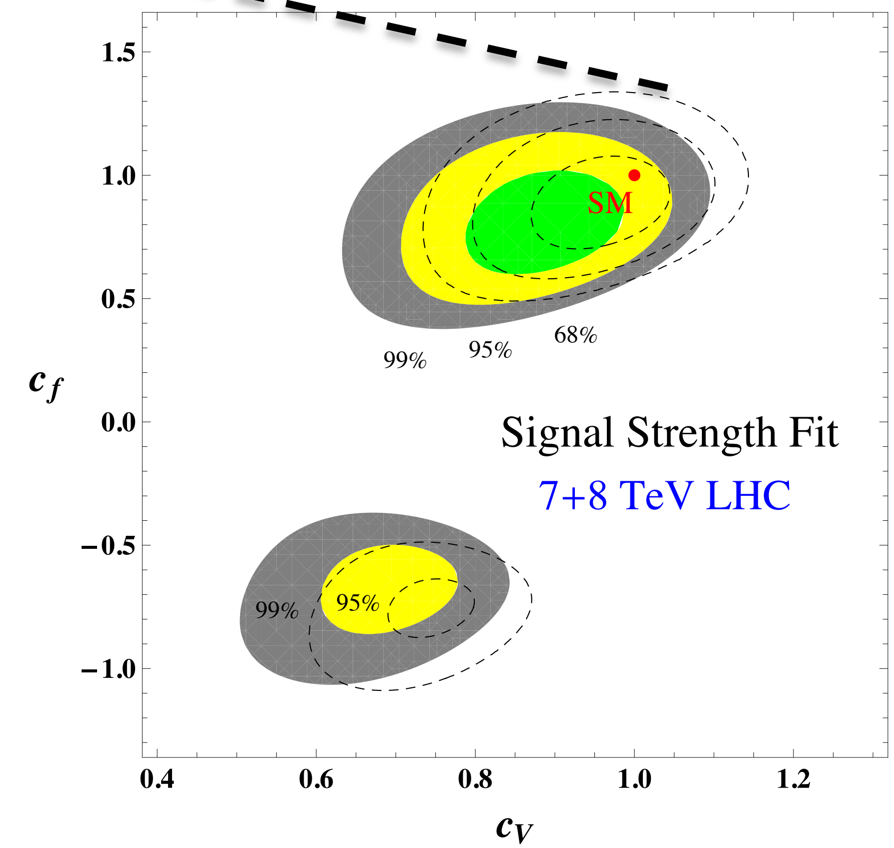
- Correlated th. errors
- *Frequentist bias*
- Shifted pdf central value :





- Decorrelated th. errors
- *Bayesian approach*
- Likelihood modified :





- Partly correlated th. errors
- *Bayesian approach*
- Nuisance param. / prior & pdf :

HDECAY extensions

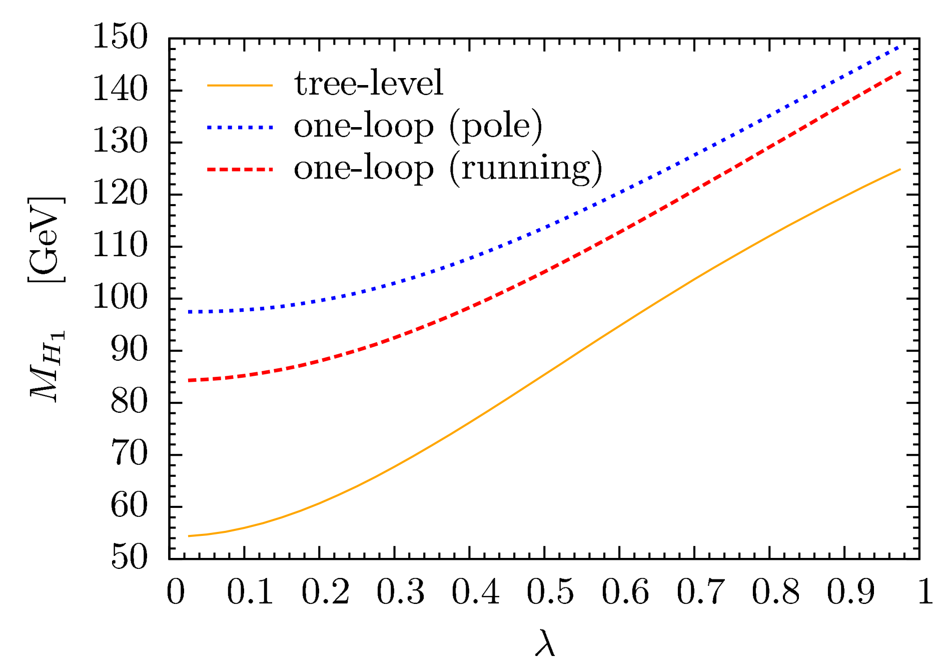
BMHDECAY (tentative name)

Fortran code for the

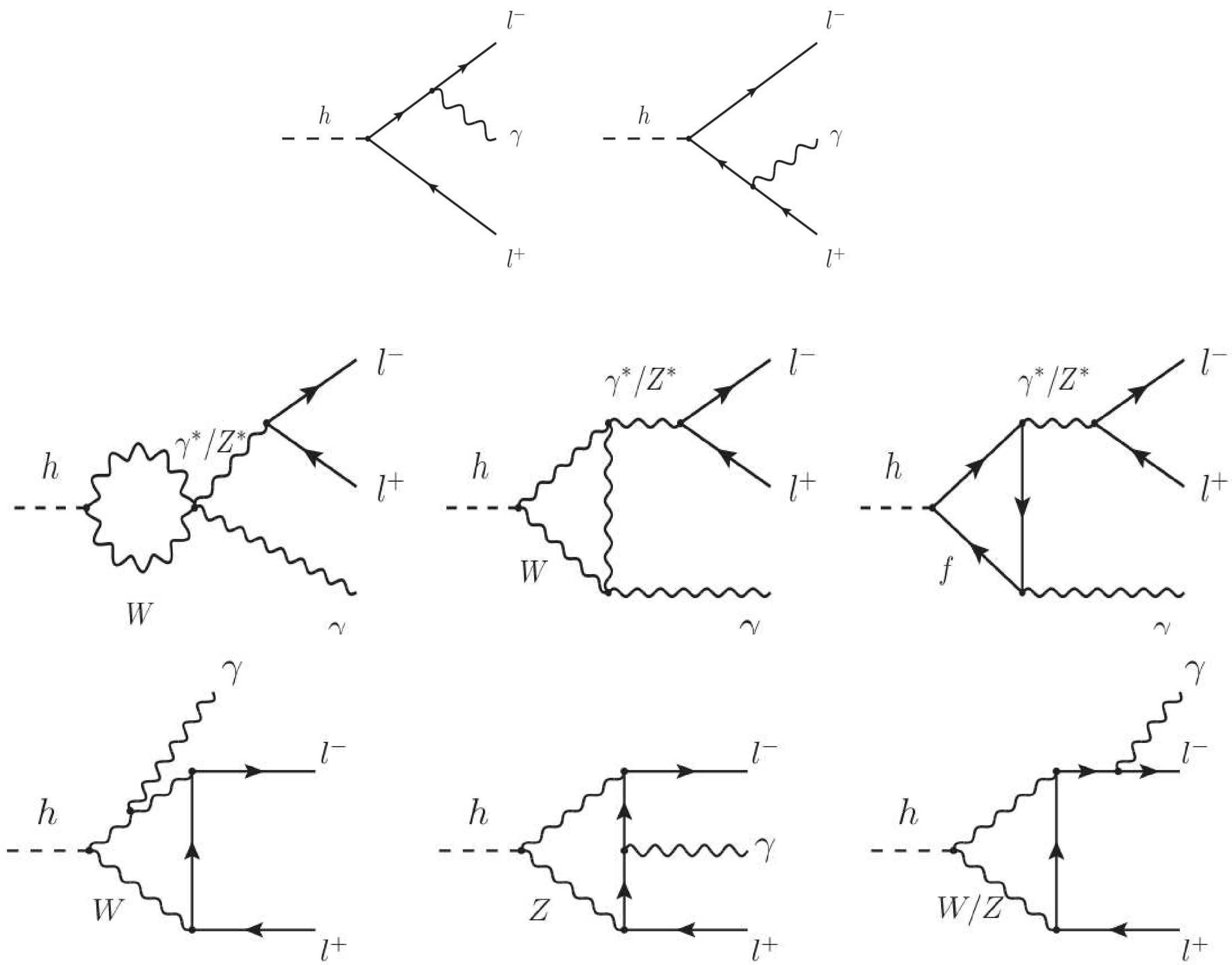
- Calculation of the loop-corrected NMSSM Higgs boson masses at 1-loop in a mixed $\overline{\text{DR}}$-on-shell and in the pure on-shell scheme. (2-loop later)
- Inclusion of the loop-corrected trilinear NMSSM Higgs self-couplings.
- Calculation of the NMSSM Higgs boson decays including the most important higher order corrections (extension of the code HDECAY).
- Input/output à la Les Houches Accord

Contributors: J. Baglio, R. Gröber, *M. Mühlleitner*, Dao Thi Nhung, H. Rzehak, *M. Spira*, J. Streicher, K. Walz

```
#         PDG            Width
DECAY        25     2.62257029E-05   # H1 decays
#          BR         NDA      ID1       ID2
     2.95014266E-01   2           5        -5   # BR(H1-> b       bb      )
     3.26600707E-02   2         -15        15   # BR(H1-> tau+    tau-    )
     1.15779144E-04   2         -13        13   # BR(H1-> mu+     mu-     )
     1.14731342E-04   2           3        -3   # BR(H1-> s       sb      )
     3.80058330E-01   2           4        -4   # BR(H1-> c       cb      )
     2.70599900E-01   2          21        21   # BR(H1-> g       g       )
     1.57344445E-02   2          22        22   # BR(H1-> gam     gam     )
     4.53226442E-03   2          24       -24   # BR(H1-> W+      W-      )
     1.17021310E-03   2          23        23   # BR(H1-> Z       Z       )
#
#         PDG            Width
DECAY        35     4.53057172E-03   # H2 decays
#          BR         NDA      ID1       ID2
     6.10914930E-01   2           5        -5   # BR(H2-> b       bb      )
     6.50482181E-02   2         -15        15   # BR(H2-> tau+    tau-    )
     2.30241528E-04   2         -13        13   # BR(H2-> mu+     mu-     )
     2.55637886E-04   2           3        -3   # BR(H2-> s       sb      )
     2.37863739E-02   2           4        -4   # BR(H2-> c       cb      )
     7.53952012E-02   2          21        21   # BR(H2-> g       g       )
     1.91593319E-03   2          22        22   # BR(H2-> gam     gam     )
     1.43002543E-03   2          23        22   # BR(H2-> Z       gam     )
     1.96035850E-01   2          24       -24   # BR(H2-> W+      W-      )
     2.49875885E-02   2          23        23   # BR(H2-> Z       Z       )
#
#         PDG            Width
DECAY        45     6.68787185E+00   # H3 decays
#          BR         NDA      ID1       ID2
     3.71354174E-03   2           5        -5   # BR(H3-> b       bb      )
     5.20563542E-04   2         -15        15   # BR(H3-> tau+    tau-    )
     1.84056057E-06   2         -13        13   # BR(H3-> mu+     mu-     )
```



Higgs Dalitz Decays → HDECAY



tree

off-shell

boxes

- important for $H \to Z\gamma$ search
- separation $H \to Z^{(*)}\gamma \quad \leftrightarrow \quad H \to \gamma^{(*)}\gamma$
- M. Mühlleitner, M. Spira, A. Djouadi, J. Kalinowski

Conclusions

- A lot of projects started, many interesting results expected !

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