Les Houches 2017
Summary of the BSM Higgs WG

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ETH Zurich

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CERN

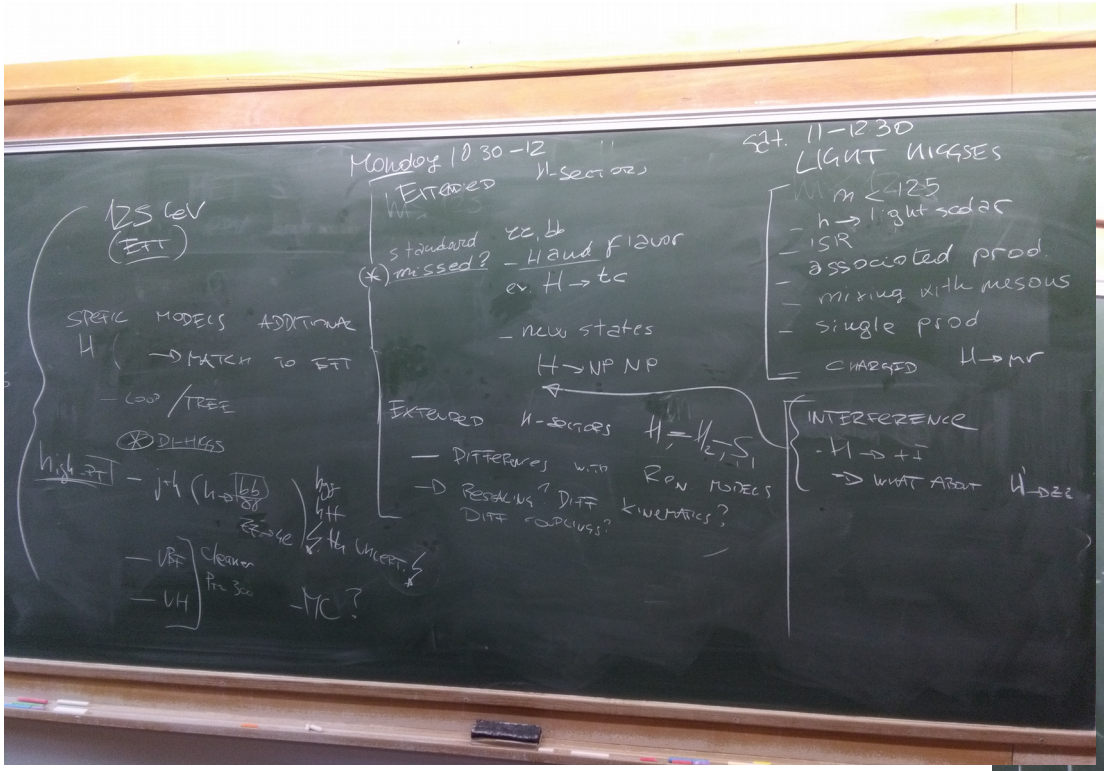
June 23rd 2017

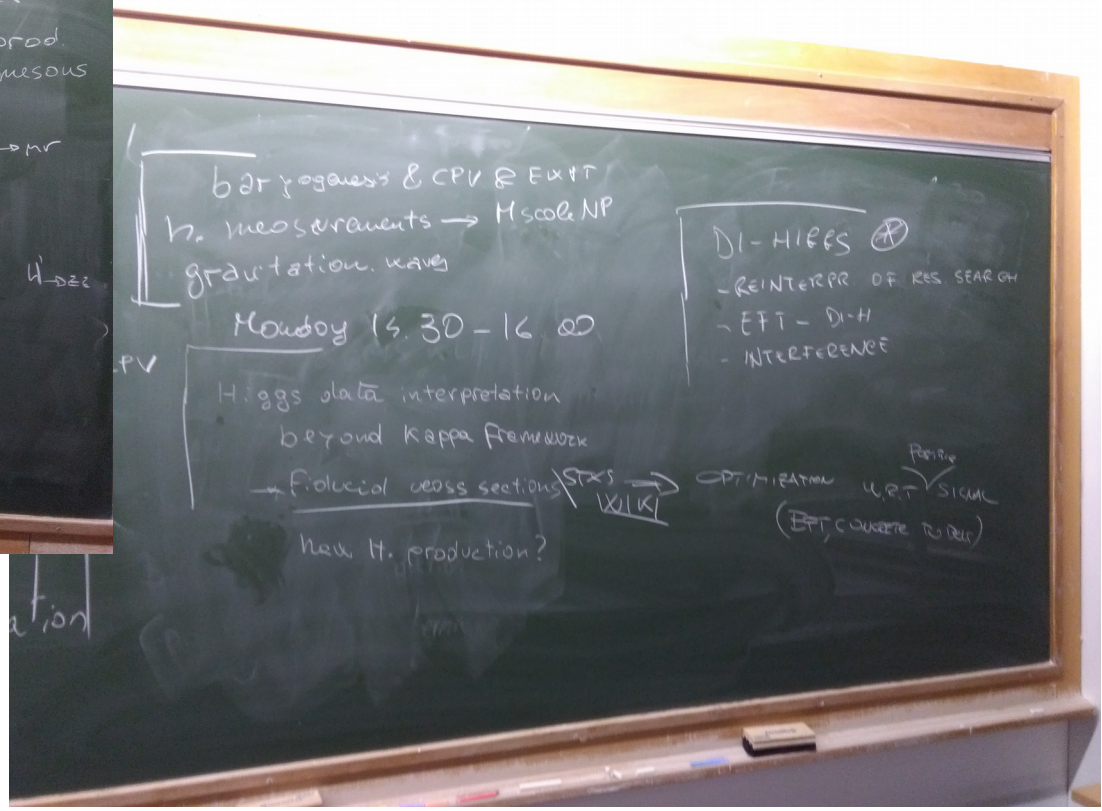
An exciting 10 days...

16 "official" discussions in the Wiki
52 participants (according to the Wiki)

Our first brainstorming session

(Thursday, June 15)





Three main topics

125 GeV
Higgs boson

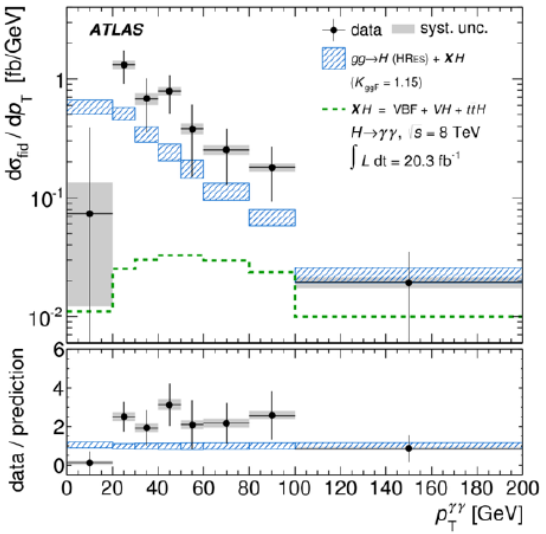
Higgs & EFT

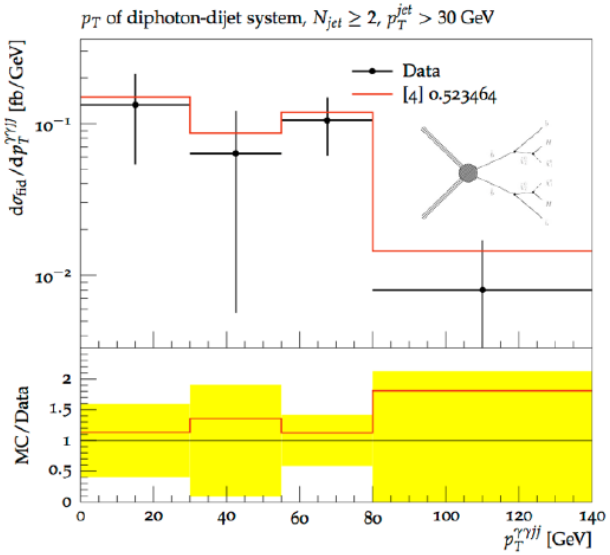
Additional
Higgs bosons

Using Higgs fiducial cross sections and differential distributions to constrain new physics

Benjamin, Fabio, Jérémie, Kentarou, Kristin, Sabine, Stefan, Stefania, Ursula, …
(Contact: Sabine)

- New production modes for the SM-like Higgs present in BSM, e.g. from decays of heavier states, can change the kinematic distributions of the Higgs signal at 125 GeV.
- This may be tested with fiducial cross sections and differential distributions already available from ATLAS and CMS. However, dedicated tools and explicit studies using the available measurements are still missing.
- Changes in kinematic distributions will affect the Higgs signal acceptance. If this effect is large, the usual signal strength constraints can't be used in the model at hand.





Plot by Ursula Laa

Tasks

- define benchmarks in concrete models, e.g. SUSY, 2HDM
- produce UFO file for generic "weird" Higgs production modes
- test predictions against data and quantify constraints
- make/include in public tools (Rivet, Contur?)

125 GeV Higgs boson

https://phystev.cnrs.fr/wiki/2017:groups:higgs:fxsnp

Using Higgs fiducial cross sections and differential distributions to constrain new physics

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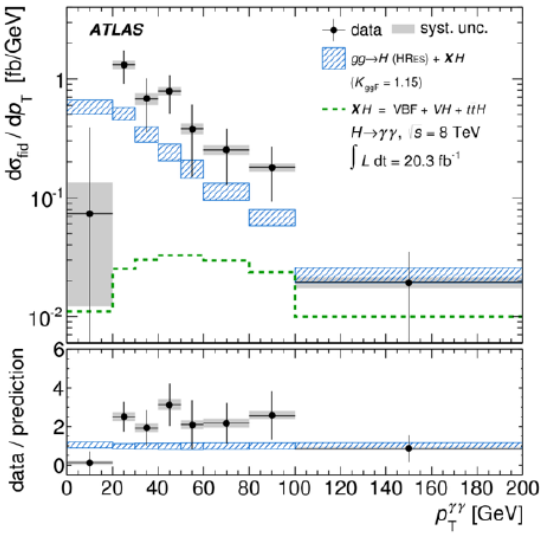

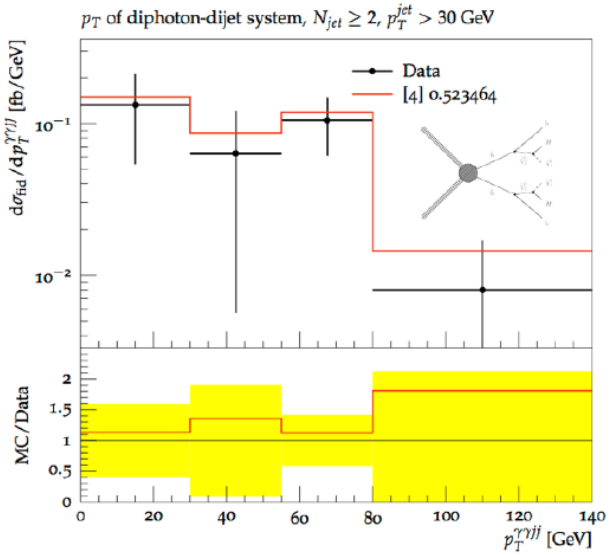

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125 GeV Higgs boson

https://phystev.cnrs.fr/wiki/2017:groups:higgs:fxsnp

UFO models for exotic production modes of the Higgs

T → t h (+t z, b w)
B → b h (+b z, t w)
Q → q h (+q z, q' w)

(SH → h LPS)
SQ → SQ' h → h + jets + LSP
SG → SQ q → h + jets + LSP
(SQ → jet/top +LSP)

L → l h (l z, v w)
Nu → nu h (nu z, l w)
Z → z/a h (+ z/a z , q q~ (universal))
W → w h (+w z, q q' (universal))

G → g h (?)

H → h h, h1 h, h z (+gg, q q' (MFV))
H+ → h w+ , q q' (MFV)

...

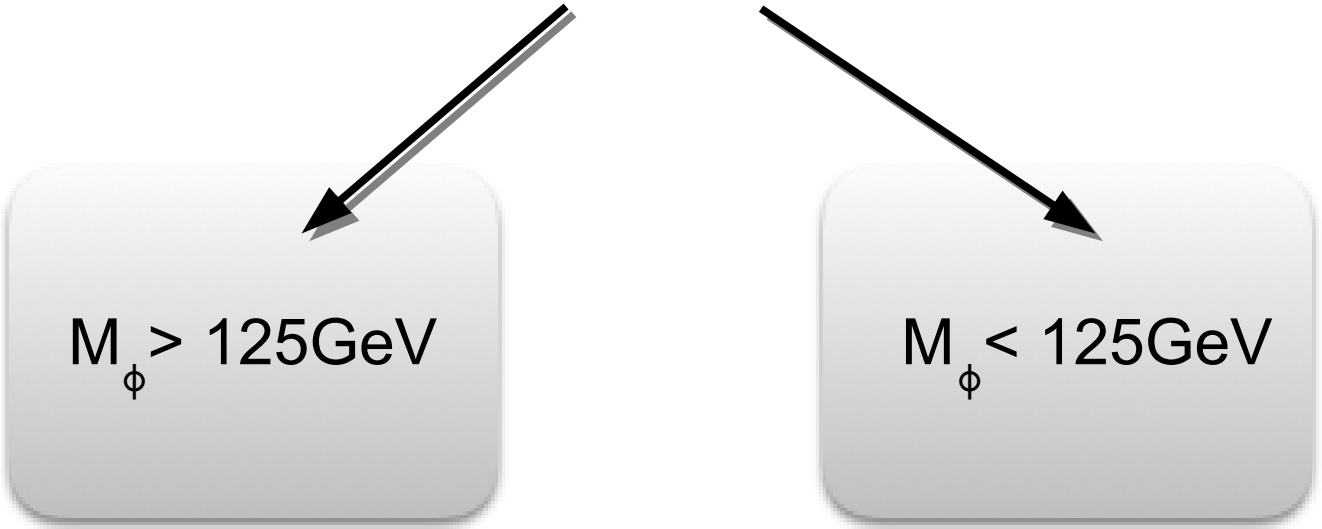
Contact people:

Benjamin Fuks
and Fabio Maltoni

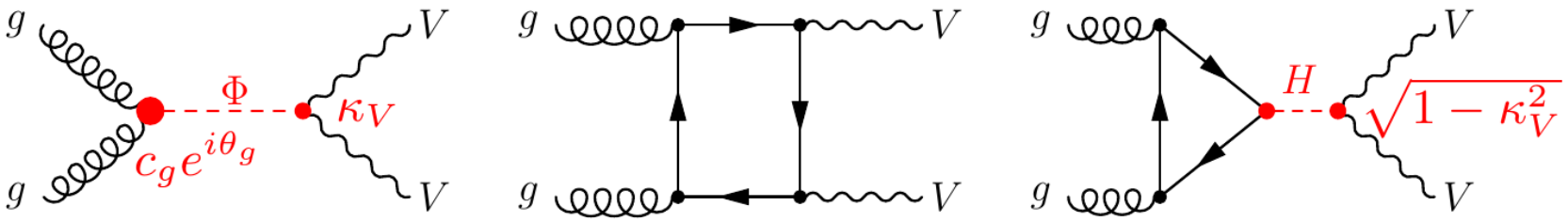
Additional Higgs bosons

Aim:

Broadening the search program for additional scalars/Higgs bosons (ϕ)



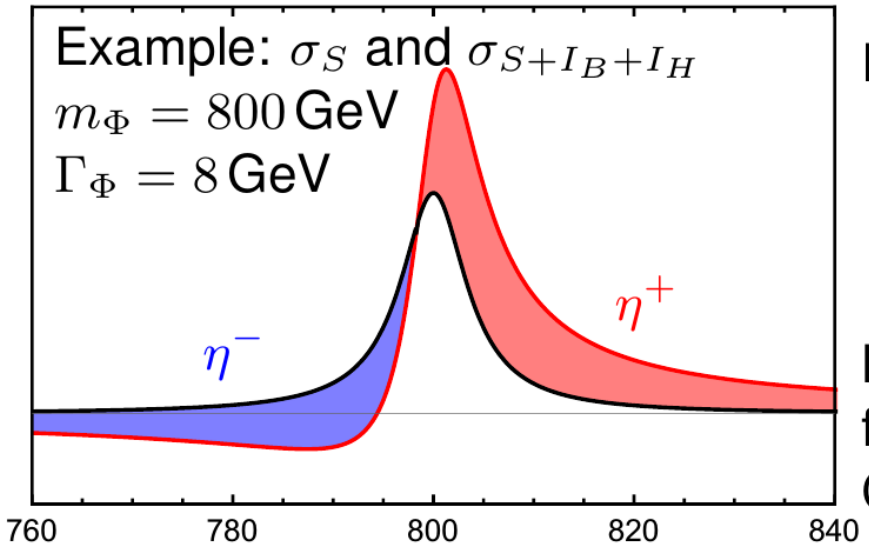
Idea: Classify relevance of interferences in the VV and HH final states:
Interferences among



Simplified approach with 5 parameters: $c_g e^{i\theta_g}, m_\Phi, \Gamma_\Phi, \kappa_V$
Similar for HH with $\lambda_{\Phi hh}$ and λ_{hhh} instead of κ_V
Quantify interference in terms of:

$M_\phi > 125\text{GeV}$

$$\eta = \sigma_{I_B+I_H}/\sigma_S \quad \text{with} \quad \sigma_X = \int_{m_\Phi-5\Gamma_\Phi}^{m_\Phi+5\Gamma_\Phi} dm_{VV} \frac{d\sigma^X}{dm_{VV}}$$



E.g. provide relative corrections:

$$\eta^\mp = \begin{pmatrix} \eta^- \\ \eta^+ \\ \eta \end{pmatrix} = \begin{pmatrix} -165\% \\ +160\% \\ +38\% \end{pmatrix}$$

Make tables, figures as a function of free parameters. Provide guidance.
Check quantity $\Gamma_\Phi/m_\Phi \cdot \sigma_S/\sigma_B$.

New Search Channels for Heavy Higgses:
$H \to A\,A \to 4b$

People: Caterina, Jose Miguel, Stefania, Ken, Daniele, Ramona, Stefan, Haiying, Jérémie, Alexandra, José

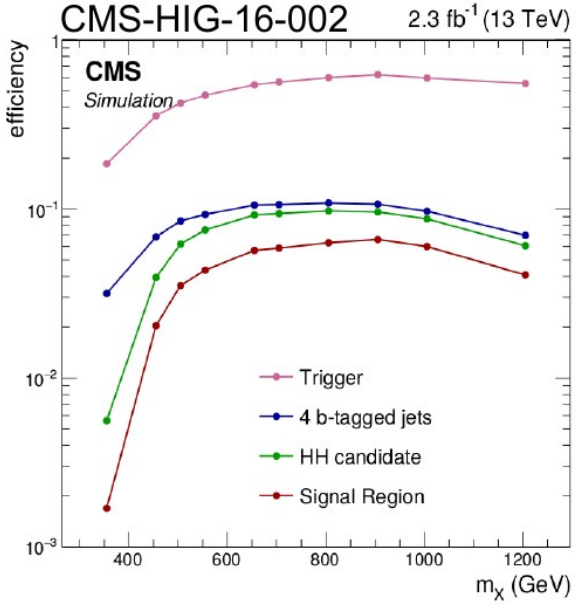
Aim: $H \to A\,A$: Potential Discovery Channel for H (and A) in extensions of SM Higgs Sector
Generalize $H \to h\,h$ searches to m_H - m_A plane. Feasibility Study, 4 b final State.

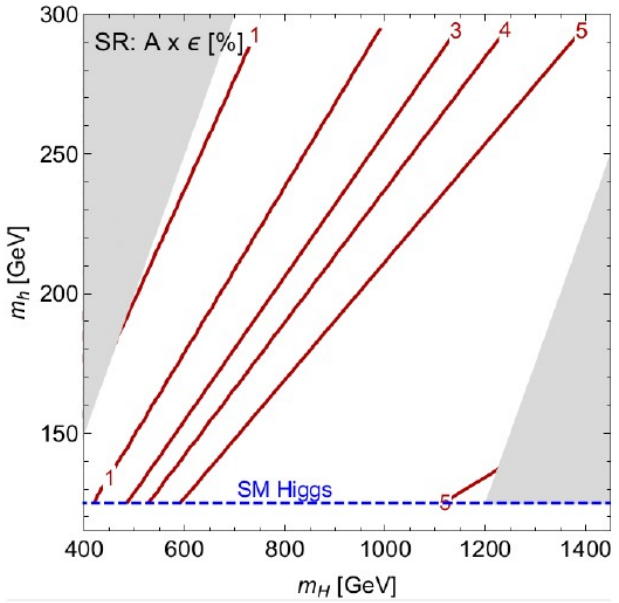
Low Mass Region (LMR)
Medium Mass Region (MMR)

Cutflow (MMR)

- Event Selection: 4 b-tagged Jets
- HH: $\Delta R(bb) < 1.5$ on H candidates
- Signal: *h* Invariant mass window

+ Shape analysis on m_{4b}





CMS 1D Signal Efficiency (~ only depends on m_H/m_h ratio) to 2D Mass plane
Validate efficiency map extrapolation with a couple of mass points
Background Publicly Available from CMS analysis

$M_\phi > 125GeV$

XS Sensitivity + Limits on Benchmarks: 2HDM , NMSSM (2HDM+Singlet)

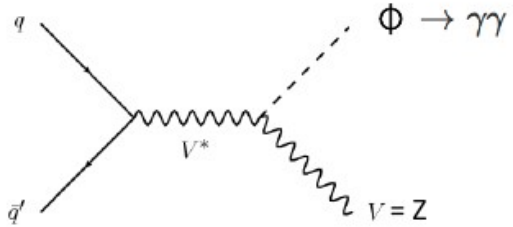
Further: Repeat procedure for bb ττ , bb γγ

$M_\phi < 125GeV$

Light (pseudo-) **scalars at LHC: the associated production (ϕZ)**

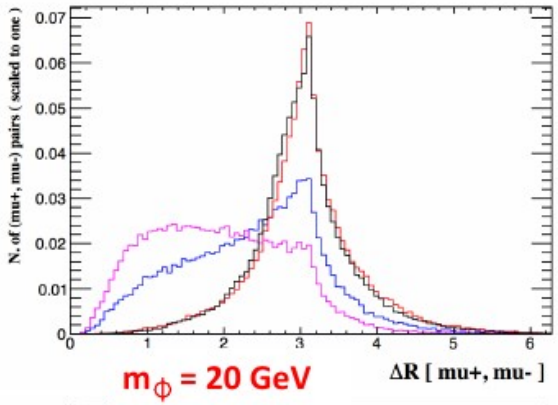
EXP: ***L. Finco, S. Gascon-Shotkin, S. Zhang***
TH: ***A. Angelescu, S. Fichet, G. Moreau***

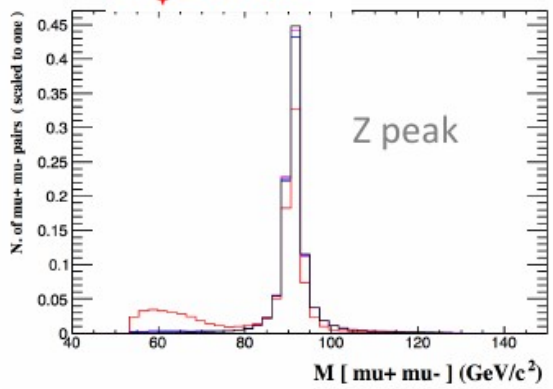
For (pseudo-) scalars below ~ 70-80GeV
⇒ decay: ZZ* kin. closed and $\gamma\gamma$ difficult (trigger)
⇒ ggFusion mechanism not promising
⇒ **take advantage of the $Z \to l^+l^-$** from $pp \to Z\phi$



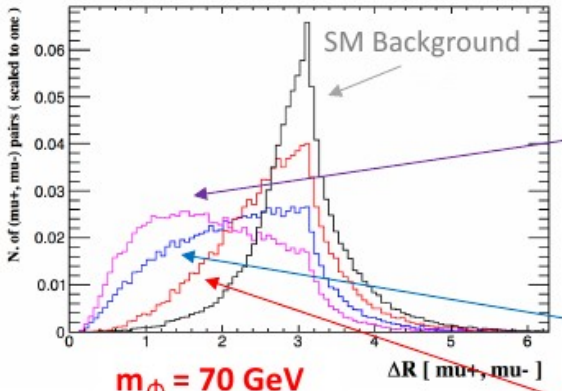
ϕ = light Higgs, radion, dilaton, axion…

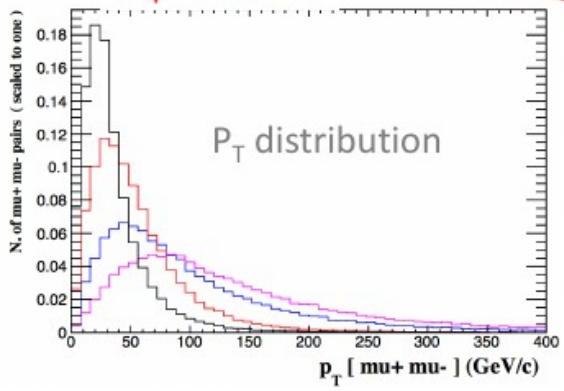
Using **generic** (EFT) parameters so that any BSM model can be constrained :





ΔR





CP odd ϕ

$$\frac{\phi}{\tilde{f}_Z} Tr[V_{\mu\nu}\tilde{V}^{\mu\nu}]$$

CP even ϕ

$$\frac{\phi}{f_Z} Tr[V_{\mu\nu}V^{\mu\nu}]$$

$$\frac{\phi}{f_H} |D_\mu H|^2$$

possible discrimination

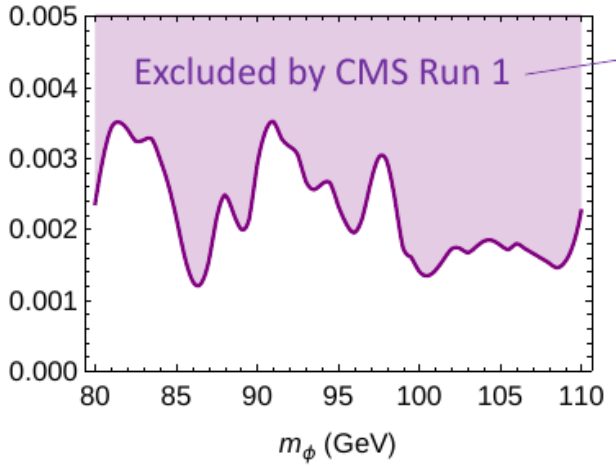
…towards a Run 2 reach plot…

$M_\phi < 125\text{GeV}$

BONUS: **above 80GeV** with pp→Zϕ + VBF (interesting e.g. for measuring the ZZϕ coupling)

$(f_Z[\text{TeV}])^{-2}\, B_{\phi\to\gamma\gamma}$

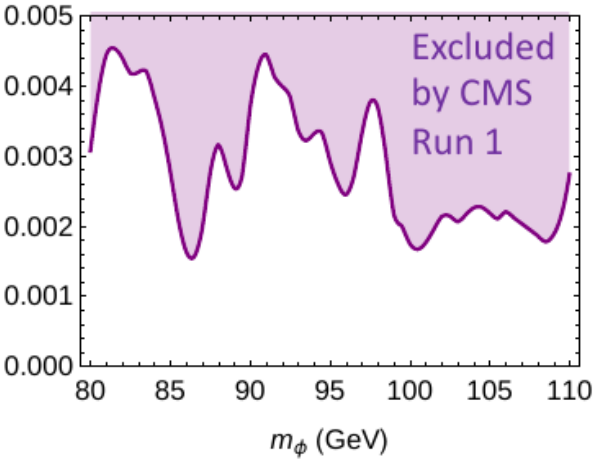
$$\frac{\phi}{f_Z} Tr[V_{\mu\nu} V^{\mu\nu}]$$



CMS-PAS-HIG-14-037
(low mass h → diphoton @ 8TeV)

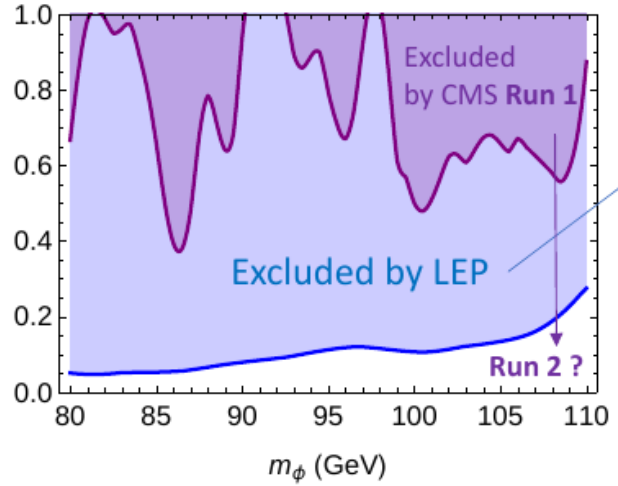
$(\tilde{f}_Z[\text{TeV}])^{-2}\, B_{\phi\to\gamma\gamma}$

$$\frac{\phi}{\tilde{f}_Z} Tr[V_{\mu\nu} \tilde{V}^{\mu\nu}]$$



$(f_H[\text{TeV}])^{-2}\, B_{\phi\to\gamma\gamma}$

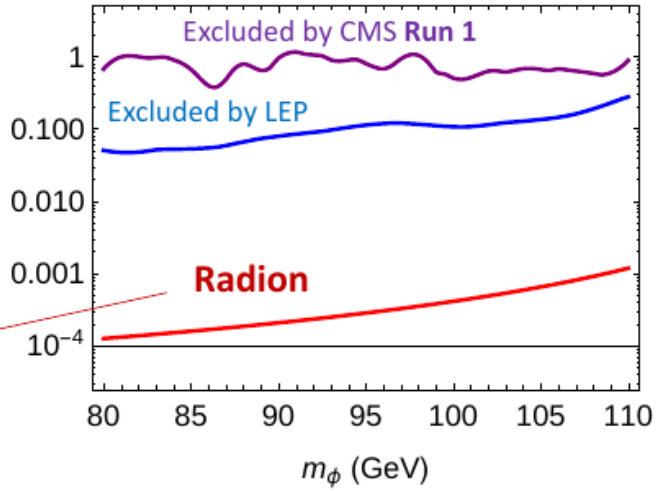
$$\frac{\phi}{f_H} |D_\mu H|^2$$



hep-ex/0212038
(ICHEP02)

1702.03984 [hep-ph]
($f_Z \to oo$, ξ =0.3, M_{KK}=4TeV)

$(f_H[\text{TeV}])^{-2}\, B_{\phi\to\gamma\gamma}$



...towards a Run 2 reach plot...

Additional discussions on

Contact people:
Stefania Gori,
Ken Mimasu,
Jose-Miguel No,
...

- (125 GeV) Higgs exotic decays, h→NP (SM)

- Signatures involving MET do not have a good coverage

Case study: h→Za, a→invisible

- Signatures involving photons

- Signatures involving LLPs in the Higgs decay (LHCb seminar by M.Borsato)

- Flavor violating heavy Higgs decays

- (Light) pseudoscalar mixing with the SM mesons & impact on the di-muon spectrum

...

Higgs & EFT

1) Non-interference in dimension 6 EFT: beyond LO & 2 to 2 processes

Francesco Riva, Ken Mimasu, Benjamin Fuks, Julia Harz, Kristin Lohwasser, Fabio Maltoni, Jorge de Blas, Daniele Barducci, Minho Son, Haiying Cai,…

Some operators don't interfere with the SM in certain processes.

Study e+e- —>WW(+gamma) to see how extra emission/finite mass effects/ loops can increase our sensitivity

2) Simplified Template Cross Sections (STXS) and EFT constraints

Francesco Riva, Ken Mimasu, Fabio Maltoni, Benjamin Fuks, Kristin Lohwasser, Jorge de Blas, Pasquale Musella,…

Are STXS optimized for expected signals?

In a specific scenario compare direct reach to EFT (via BDTs) with reach obtained through STXS.

3) Estimation of theoretical uncertainty in EFT

Olivier Mattelaer, Ken Mimasu, Kentarou Mawatari, Shankha Banerjee, Biplob Bhattacherjee, Francesco Riva, Benjamin Fuks, Ramona Groeber, Julia Harz, Jorge de Blas, Kristin Lohwasser, Alexandra Carvalho…

Are dimension-8 important?

A class of dimension-8 that arises when changing basis has coefficient related to dimension-6 coefficients… under what conditions can these effects be relevant?

Feel free to join, it's never too late! Add your name

Non-interference in D=6 SMEFT

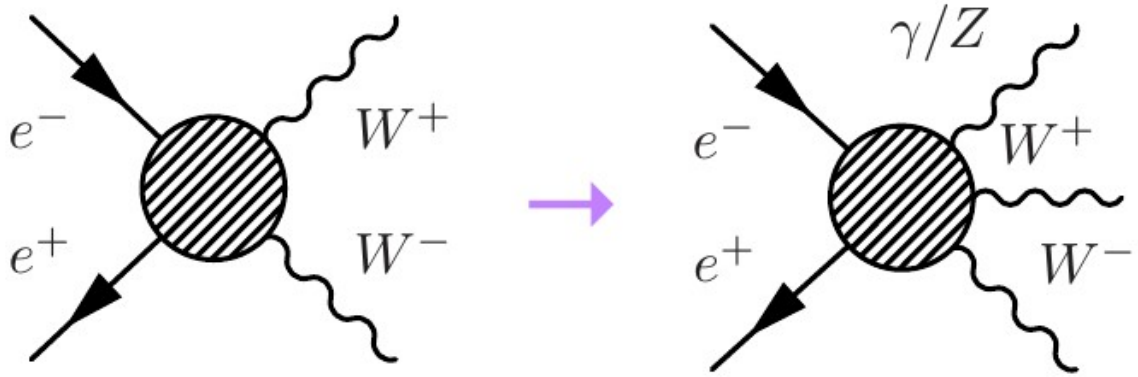
1)

Beyond LO and 2 →2 processes

D. Barducci, J. de Blas, H. Cai, B. Fuks, J. Harz, K. Lohwasser, F. Maltoni, O. Mattelaer, K. Mimasu, F. Riva, M. Son

- Many high energy 2→2 processes with one D=6 operator have been shown not to interfere in the high energy limit at LO due to helicity arguments
- Aim: investigate the impact of higher order corrections/additional radiation to such non-interference theorems

Concrete process: $e^+e^- \to W^+W^-(\gamma/Z)$ (at least one transverse)



$$\frac{1}{\Lambda^2} \propto \frac{m_W^2}{E^2} \qquad \frac{1}{\Lambda^2} \propto ?$$

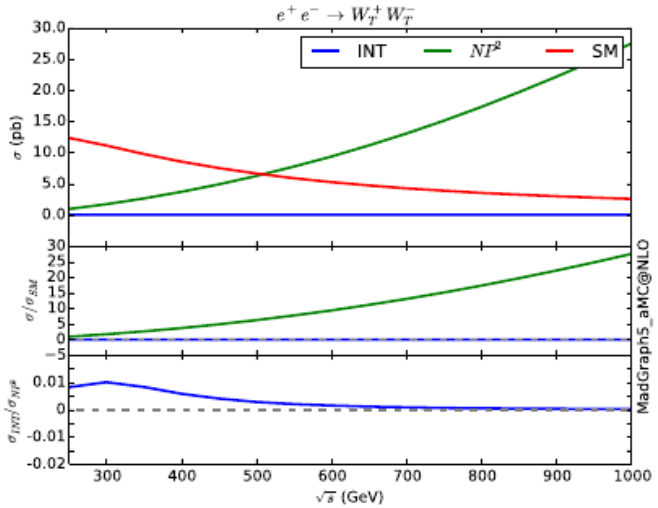
A_4	$\lvert h(A_4^{\rm SM})\rvert$	$\lvert h(A_4^{\rm BSM})\rvert$
$VVVV$	0	4,2
$VV\phi\phi$	0	2
$VV\psi\psi$	0	2
$V\psi\psi\phi$	0	2
$\psi\psi\psi\psi$	2,0	2,0
$\psi\psi\phi\phi$	0	0
$\phi\phi\phi\phi$	0	0

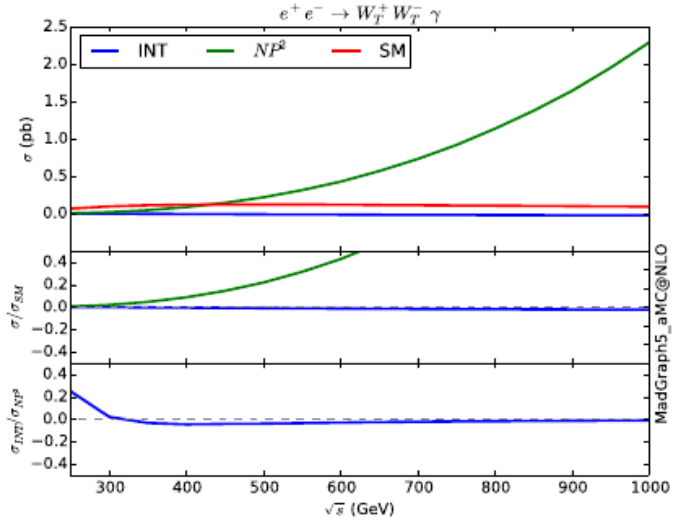
$$\mathcal{O}_{3W} = \varepsilon_{abc} W_\mu^{\nu,a} W_\nu^{\rho,b} W_\rho^{\mu,c}$$

Non-interference in D=6 SMEFT

1)

- 2→3 EFT amplitude should interfere with the SM, even for M=0
- Investigate/compare patterns of interference arising from the violation of the theorem due to:
  - Mass effects (relevant near threshold)
  - Extra radiation/higher order corrections (dominant at high energies)
- Aim to understand the phase space/polarisation dependence
- Construct optimal observables to consistently test the “leading” Dim=6 interactions w.r.t the EFT expansion
- Analytical and numerical approaches are under way (partial results)
- Applications to be tested in a phenomenological collider study (e.g. CLIC, ILC, FCC-ee)





TEMPLATE XS VS EFT

2)

FRANCESCO RIVA, KEN MIMASU, FABIO MALTONI, BENJAMIN FUKS, KRISTIN LOHWASSER, JORGE DE BLAS, PASQUALE MUSELLA, ALEXANDRA CARVALHO, CATERINA VERNIERI, BENJAMIN FREUND

MOTIVATION:

SIMPLIFIED TEMPLATE CROSS SECTIONS (STXS) ARE DIFFERENTIAL SIGNAL STRENGTH WITH PRE-DEFINED BINNING.
THEY BEING ADOPTED AS STANDARD REPRESENTATION FOR LHC HIGGS DATA. BINNING LEADS TO LOSS OF INFORMATION WHEN THE INFORMATION IS REUSED TO CONSTRAIN BSM EFFECTS.

GOAL:

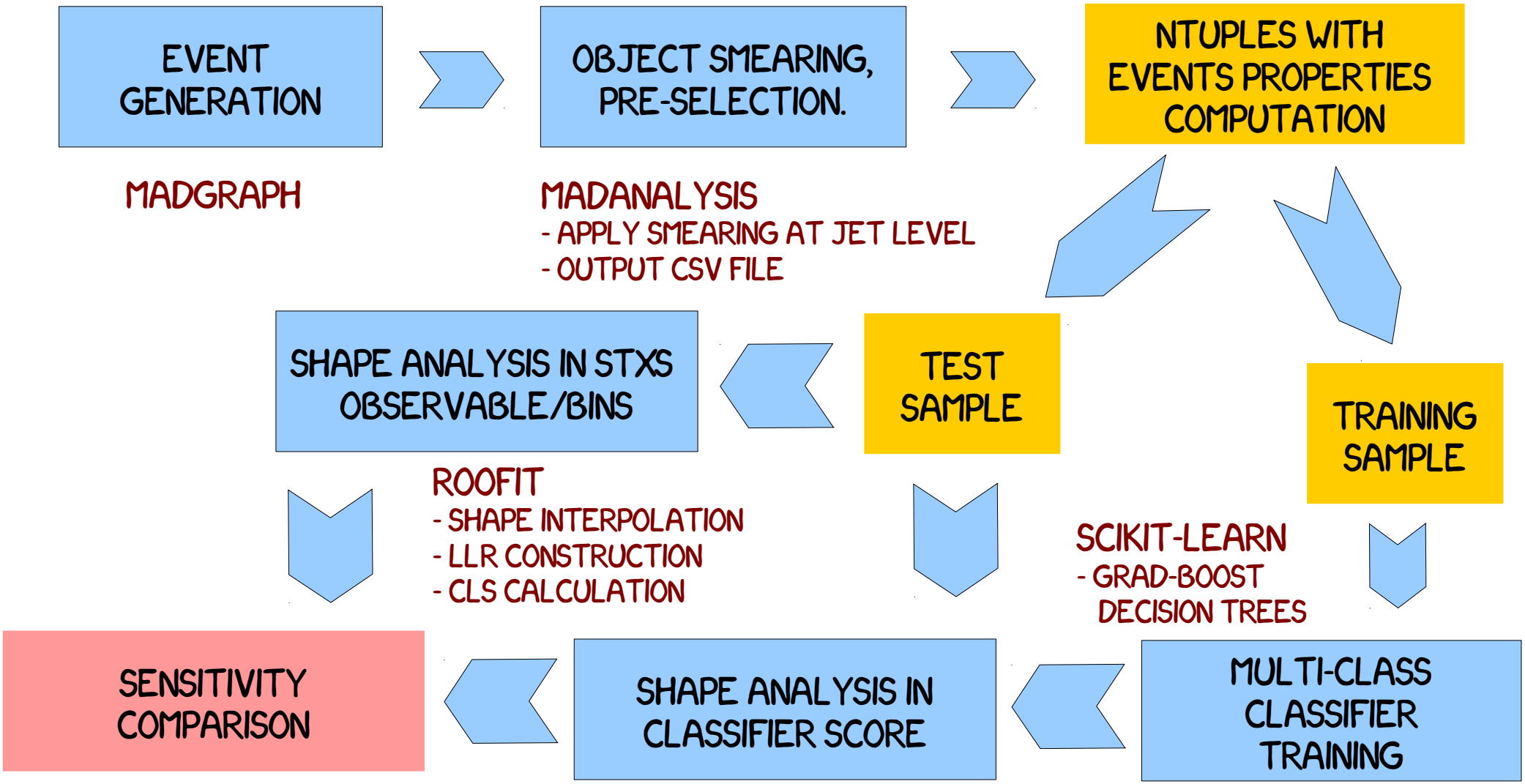
STUDY THE CONSTRAINING POWER ON EFT WILSON COEFFICIENTS FROM HIGGS DATA THROUGH STXS AND QUANTIFY POTENTIAL LOSSES.

METHOD:

COMPARE THE SENSITIVITY OF PERFORMING A FIT TO THE WILSON COEFFICIENTS OF INTEREST VIA THE STXS WITH A DIRECT FIT FROM LHC DATA AND QUANTIFY ANY LOSS OF INFORMATION INCURRED.

WORKFLOW

2)


EVENT GENERATION
MADGRAPH
OBJECT SMEARING, PRE-SELECTION.
MADANALYSIS
- APPLY SMEARING AT JET LEVEL
- OUTPUT CSV FILE
NTUPLES WITH EVENTS PROPERTIES COMPUTATION
TEST SAMPLE
TRAINING SAMPLE
SHAPE ANALYSIS IN STXS OBSERVABLE/BINS
ROOFIT
- SHAPE INTERPOLATION
- LLR CONSTRUCTION
- CLS CALCULATION
SCIKIT-LEARN
- GRAD-BOOST DECISION TREES
SENSITIVITY COMPARISON
SHAPE ANALYSIS IN CLASSIFIER SCORE
MULTI-CLASS CLASSIFIER TRAINING

EFT Uncertainties

3)

Starting Point

$$\mathcal{L} = \mathcal{L}_{\rm SM} + c^{(3)}_{\phi q}\mathcal{O}^{(3)}_{\phi q} \qquad \mathcal{O}^{(3)}_{\varphi q} = i\left(\varphi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)\left(\bar{q}\sigma_I\gamma^\mu q\right)$$

Field Redefinition/ Change of basis

$$W^I_\mu \to W^I_\mu + \frac{\tilde{c}}{\Lambda^2}\left(\varphi^\dagger \overleftrightarrow{D}^I_\mu \varphi\right)$$

$$\mathcal{L}_{\rm SM} \to \mathcal{L}_{\rm SM} + \tilde{c}'\mathcal{O}^{(3)}_{\phi q} + \sum_i \frac{1}{\Lambda^2}c^i\mathcal{O}^6_i + \sum_i \frac{1}{\Lambda^4}c^i\mathcal{O}^8_i,$$

$$\tilde{c}' \equiv -\,c^{(3)}_{\varphi q},$$

Final Lagrangian

$$\mathcal{L} \to \mathcal{L}_{\rm SM} + \sum_i \frac{1}{\Lambda^2}c^i\mathcal{O}^6_i + \sum_i \frac{1}{\Lambda^4}c^i\mathcal{O}^8_i$$

Typically throw away
Used here as th. error

Plan

- compute O8 analytically/numerically
- estimate impact on some observables (WH)
- compare to the amplitude squared term

EFT Uncertainties

3)

Plan continued

- Same idea for the EW Dim6 operators
  - directly used their equivalent in different basis
    - Use Rosetta for the translation

EW parameters

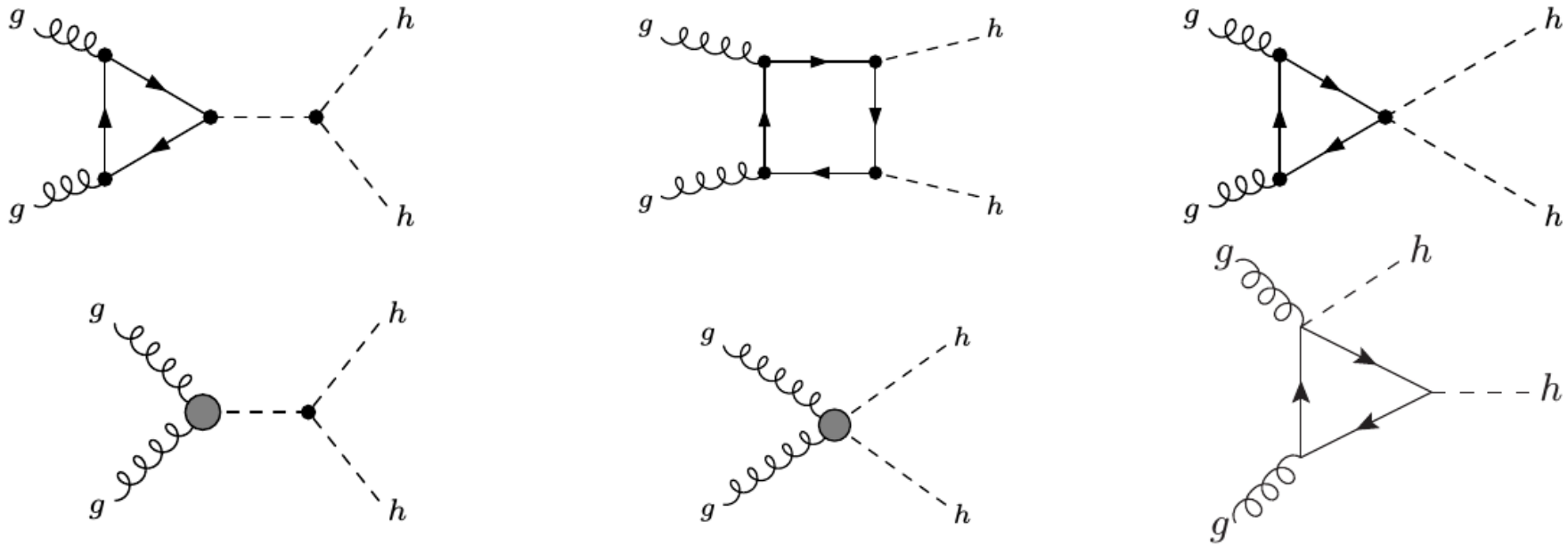
- The EFT have effects included in the definition of the dependent EW parameters

$$e \to e(1 + \frac{f(c_i)}{\Lambda^2})$$

- Amplitude can depend of the EW parameters multiple times
  - Expected to be VERY small -> we want to quantify

Additionally...

Di-Higgs: (Alexandra, Fabio, Jose, Minho, Pasquale, Ramona, …)



Our plan for the Proceeding:

Use all operators in linear EFT (including CP-violating and chromomagnetic operator) for a shape analysis

Further activity: interference effects in resonant HH production (together with interference group)

LH SMEFT roadmap: step 1

Fabio Maltoni

Motivation: Fiducial cross section measurements and STXS in Higgs physics are being developed and will provide non-maximally sensitive input to global SMEFT fits. Direct experimental top-down SMEFT interpretations of LHC SM measurements in Higgs and top physics have not yet taken off, due mostly to a difficulty of handling the richness of possible theoretical approaches together with many technical complications.

Aim: Stimulate the implementation and development of SMEFT measurements at the LHC by devising a multi-staged approach.

Proposal (**for stage 1)**: Provide the strongest (even MVA based) constrains from (one or more) processes/observables on **one operator at the time.**

Some advantages: 0) A necessary step before achieving a global fit, 1) way easier and feasible now, 2) (less than) linear scaling with the number of operators, 3) basis agnostic, 4) provides reference information to fits based on model independent approach (fiducial or simplified XS), 5) educational purposes, 6) clear benchmarking of sensitivities between different analyses and experiments, 7) interference vs squared and validity studies easy, 8) it can be automatised on the analysis level.

Project: Provide comprehensive list of operators (with simple normalisation) and a minimal list of recommendations (sanity checks, int vs square treatments, perturbative orders, EFT validity,…) and work out a few examples in Higgs, top and EW physics.

Thanks for all the present **and future** contributions!