MC for HH
Another summary on the Monte Carlo being used in ATLAS and CMS for the HH searches

Alexandra Carvalho
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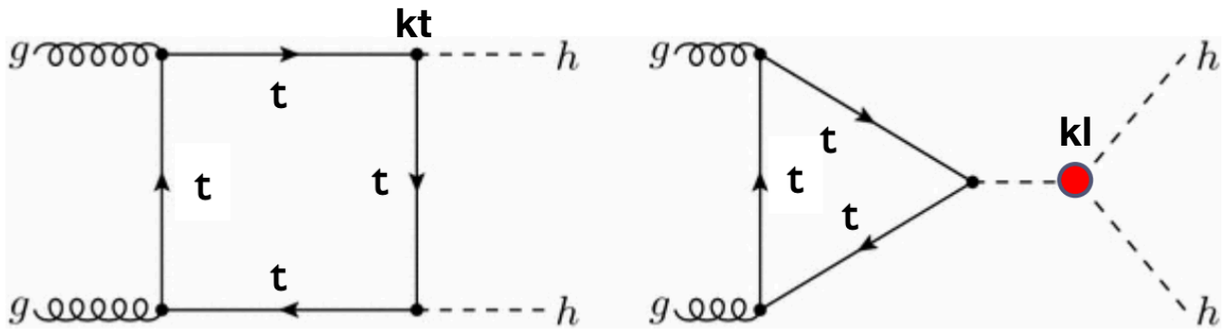
On behalf of ATLAS and CMS collaborations

Outline

- Non-resonant
  - Gluon fusion
    - kl-kt scan on NLO MC
      - Internal validations
    - Other anomalous couplings
    - Theory Uncertainties
  - VBF
- Resonances

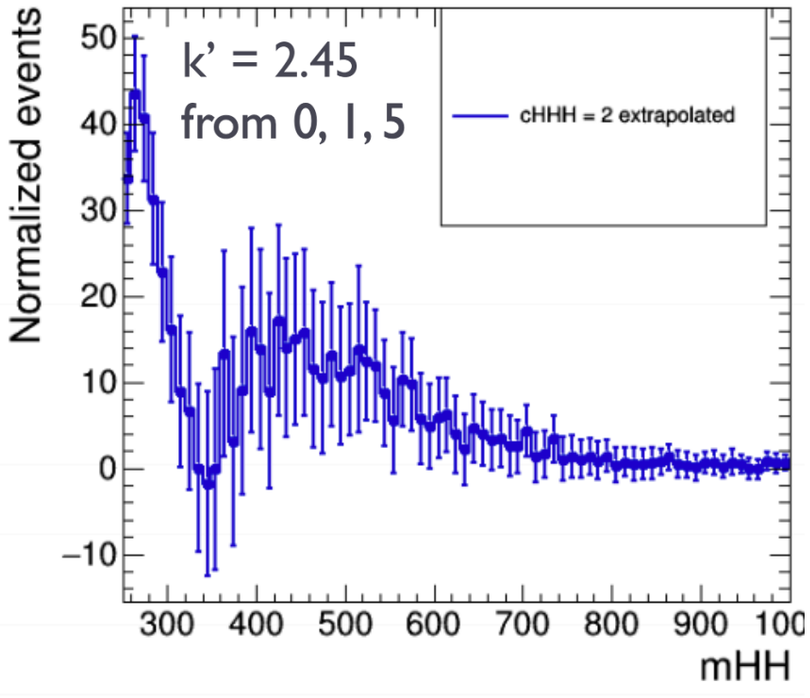
This is more a list of ongoing efforts than a talk

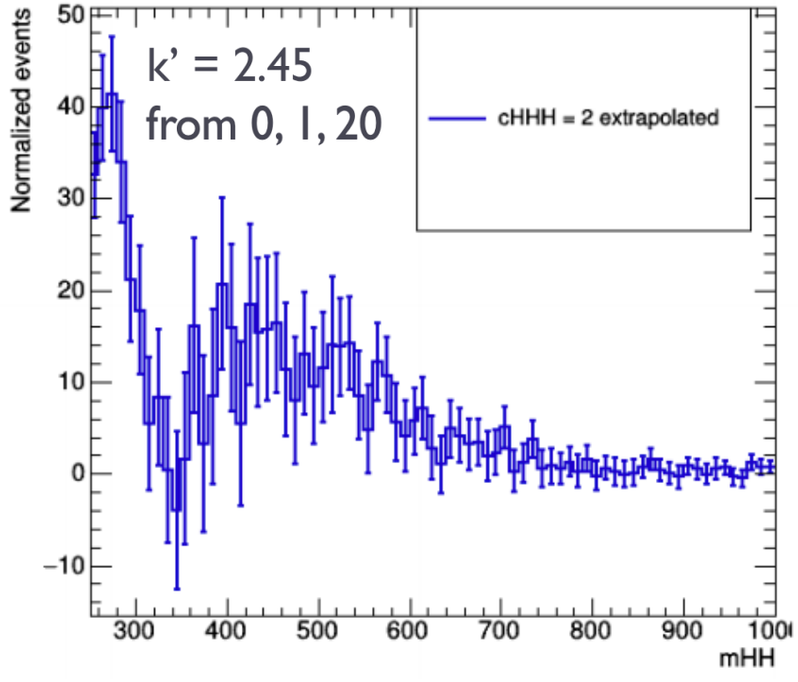
GGF non-resonant: kl-kt scan on NLO MC



- We can construct a shape for any combination of kt and kl with three samples
  - The choice of the input points is arbitrary, but can be made to maximize statistical power

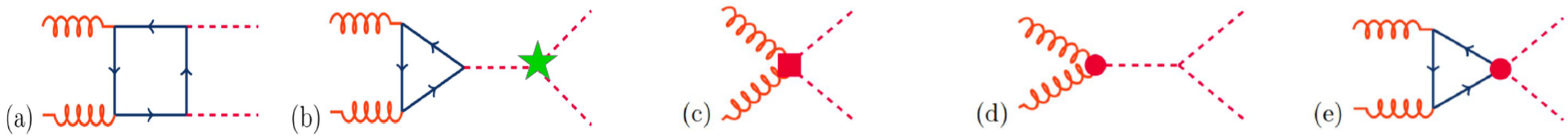
- the choice of k giving the maximal statistical power in modeling arbitrary k' is not the most signal-like (kl = 20) but the one with the most different, i.e. softest, m(HH) spectrum (kl = 5)
  - Tricky effects of the destructive interference:
  - e.g. maximal interference case (kl = 2.45)





- To have a better statistical power around this point another input combinations would be better
  - With the current sensitivity this optimization was not yet done
  - One idea would be to have two choices of input shape and use the statistical distance (the same used for the cluster analysis) to find point by point the best combination to construct the shape

GGF non-resonant: Other anomalous couplings



+ chromodynamic

- No clear idea of direct **interpretation** to be done (e.g. which scans/correlations would be nice to look at)
- Meanwhile:
  - CMS: We do explore the impact on sensitivity of the different searches in different kinematic regimes using the shape benchmarks as defined on [1]
  - ATLAS: under discussion
    - It would allow to compare results in different kinematic regimes between experiments and understand some features

- Recently that were an study validating the shape benchmark method at NLO [2] (see Gundrun talk)

[1] Higgs pair..With Cluster Analysis: JHEP 1604 (2016) 126 (A.C , T. Dorigo, M. Dall'Osso, F.Goertz, C. Gottardo,M. Tosi)
[2] Shape analysis in Higgs boson pair production (Matteo Capozi, Gudrun Heinrich)

GGF non-resonant: Theory uncertainties

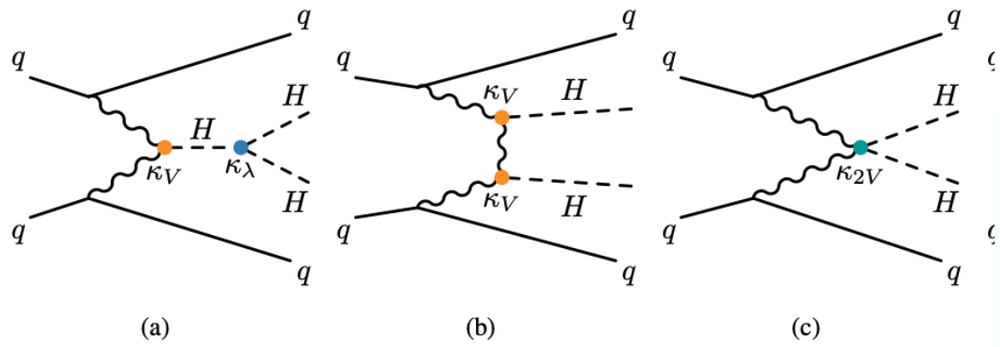
- Generators used:

  - MC
    - GGF NLO + FT (for kl-kt scans): Powheg-Box-V2
    - GGF LO (for other anomalous couplings): LO MG5_aMC@NLO

  - Showering CMS: Pythia8
  - Showering ATLAS: Herwig7

- We use different shower schemes, how is the best prescription to correlate (or not) the theory uncertainties on acceptance/shape?

VBF non-resonant



$\mathcal{A} =$ $c_V k_\lambda A$ + $c_V^2 B$ + $c_{2V} C$

- **Modeling of BSM**
  - Similar to the one already described for ggF HH (summing three components)

- **Studies of contamination from other processes**
  - First public result considering VBF HH is from ATLAS in the 4b final state [2]
    - A large contamination of the ggF HH process was found
      - For the moment, the NLO ggF HH nominal (no additional jet on the ME) samples are used for this estimation
    - To push the precision to a next level, one can test the NNLO ggF HH+jj
      - A NNLO model is ready from theorists, in Sherpa. https://gitlab.com/Lindert/hhjj.git
        - Efforts are needed to get hands on it from the experimental sides.

  - **Contraints in couplings:**
    - The [2] found a limits on k2V (ratio wrt SM) between [-0.56, 2.89] when all the other couplings are SM-like
      - A combination with ggF HH including at least (kt, kl) needs to be set up

- Generators used at the moment:
  - MC CMS: LO MG5_aMC@NLO (nothing public yet)
  - MC ATLAS: NLO Powheg-Box-V2
  - Showering: Pythia8 (dipole mode on)

[2] arXiv:2001.05178, it also contains a resonant study

Resonances

- Already settled:
  - GF/VBF X -> HH , with narrow width approximation
  - Both use LO MG5_aMC@NLO

- Setting up:
  - X -> SH and X -> SS
    - CMS: LO MG5_aMC@NLO , Model inherited from NMSSM
    - ATLAS, Pythia8 also to simulate the Matrix element part

  - Initial attempts to compare the two at fixed order were made last year, but stalled due to technical aspects (Pythia8 in ATLAS does not save LHE outputs ...)
    - This was not continued up to the present date

- Generators used:

  - MC:
  - Showering CMS: Pythia8
  - Showering ATLAS: Herwig7

Theory uncertainties on single H due heavy flavor radiation (Background)

- Single H processes are BKG to HH searches
  - In special, ggF single-Higgs + heavy-flavour modelling is background to bbXX

- Currently ATLAS treatment on the HF single Higgs is:
  - Assign 100% uncertainty to ggF, VBF and WH single Higgs, based on studies of HF quarks associated with tt [1304.6386] and W [1302.2929]
  - No uncertainty on ZH and ttH single Higgs, as the dominant heavy-flavour production is considered at LO

- ggF [1509.05843] and bbH can be generated in Powheg separately
  - Need to deal with the overlap between ggF (H+bjets) and bbH

- CMS is ignoring this uncertainty

It would be good to have estimate of the heavy flavour contribution directly from generators in the future.

Conclusions

- A summary of the MC methods used by ATLAS and CMS collaborations was presented
  - The intention was to be short an leave time for discussion