Common SMEFT parameterisation of the STXS

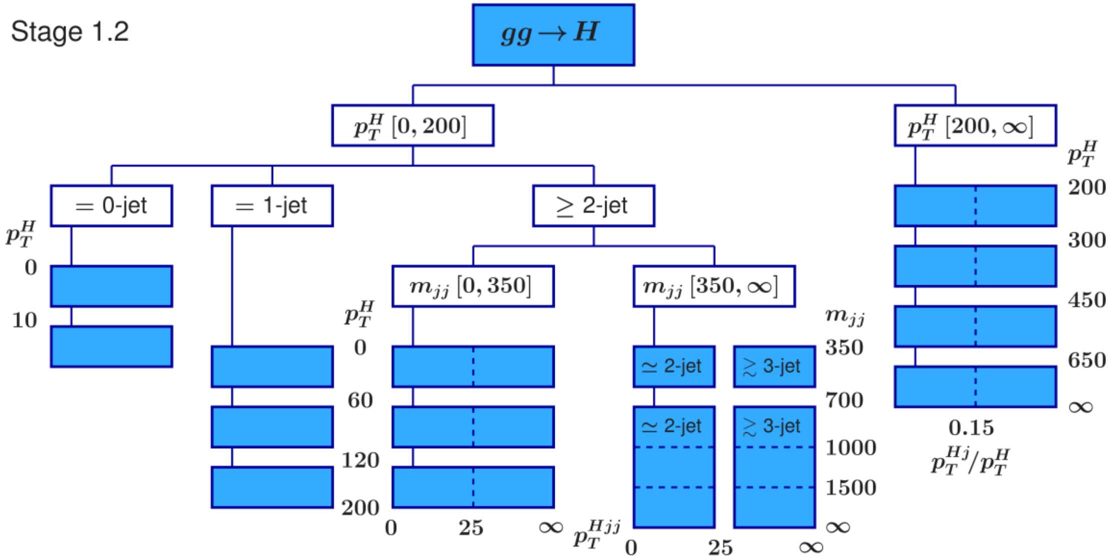
Ana Cueto and Matthew Knight

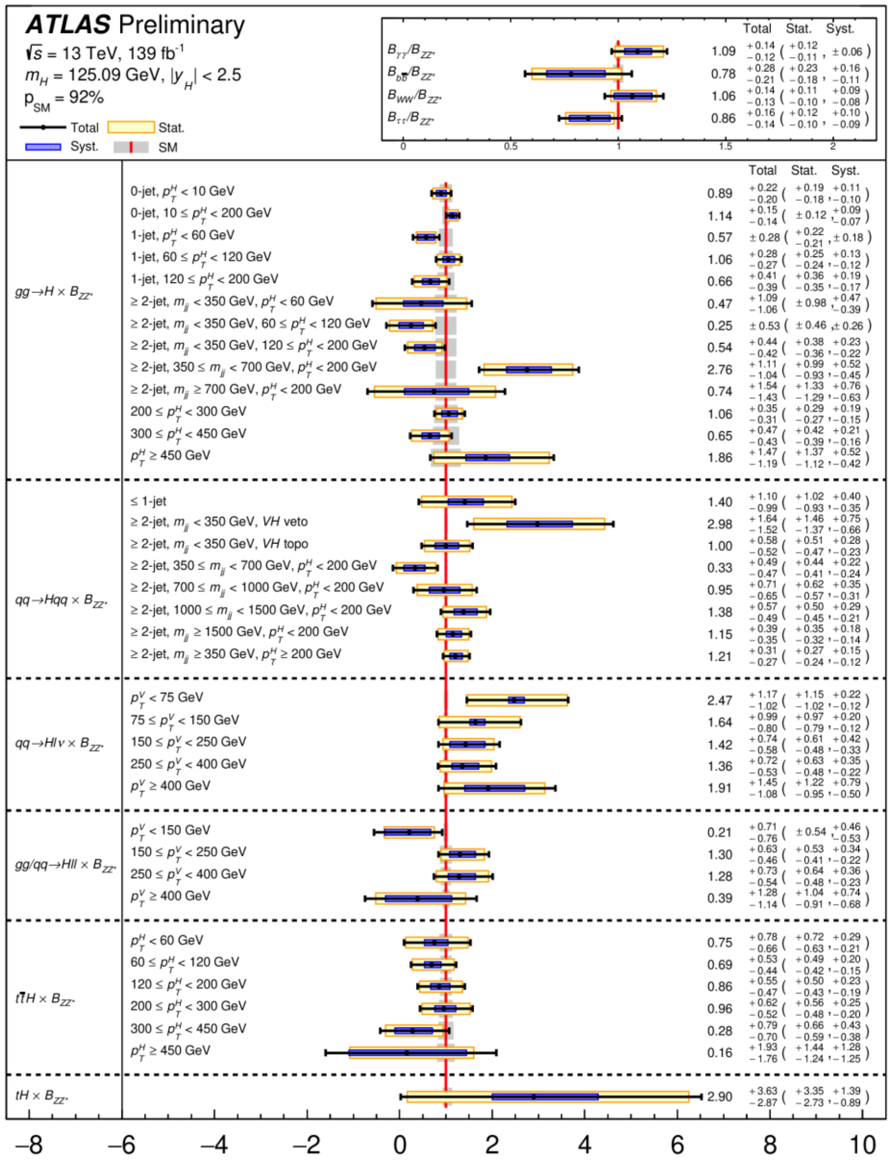
2nd December 2022

5th General Meeting of the LHC EFT Working Group

Simplified Template Cross Sections (STXS)

- Framework for Higgs boson measurements
- Template cross sections with binning motivated by
  - Sensitivity to NP
  - Avoidance of large theory uncertainties
  - Close matching to experimental selections
- Common production mode binning across decay channels
  - Provide $\sigma_i \times B_{ZZ}$ and ratios of branching ratios B_i/B_{ZZ}





ATLAS-CONF-2021-053

A common parameterisation

Idea: create a SMEFT parameterization of the STXS which is public and free to use by CMS, ATLAS and theorists

Motivation: efficiency and accuracy/validity

- CMS, ATLAS and theorists (> 1 group) derive their own SMEFT parameterisations
  - We are wasting time developing and using our separate tools which lead to the same results*
- Quite a bit of crosstalk between experiment and theory already, e.g. support for `SMEFT@NLO` and `SMEFTsim`
  - Theorists spend time telling both experiments how to do the same thing
- Encourages collaboration between experiment and theory $\rightarrow$ more accurate interpretations
  - From theory: newest models, analytical equations, checking input parameters, theoretical discussions such as linear vs quadratic order
  - From experiment: acceptance corrections, frameworks such as EFT2Obs (incl. matching & merging)

*repetition for validation's sake is not wasted time... we'll come back to this

How would this work?

More EFT2Obs details in backup

- Will use EFT2Obs to produce parameterisation
  - Best established tool available to us (please let us know if you know of another!)
  - Create a separate branch for every parameterisation we want to make
    - There will inevitably be new iterations for better models, new flavour schemes, new STXS binning etc.
  - Store the parameterisation in this branch
    - Exact format is still pending, e.g. json
  - In each branch have the cards, scripts, and instructions to reproduce the parameterisation
    - Easier for anyone to bring updates and create the latest iteration
    - Transparency should also make it easier for mistakes to get noticed

- Probably will be a join effort between LHC Higgs WG2 and LHC EFT WG
- Ultimately, parameterisation and tools will be published in some note
  - Include proposal for format of parameterisations moving forward
  - Details of publication plan have not been settled

Plan moving forward

- Presented at LHC Higgs WG general meeting
  - So far, only support and interest in the idea. No objections.

The following are not settled on, but I could see it playing it out like this:

- Given CMS's EFT2Obs expertise, they starts with EFT2Obs development:
  - Update to MG5 v2.9.9 (latest version validated within CMS)
  - Better handling of cases with big mismatches between EFT and SM phase space, e.g. $H \to 4f$ decay (backup)
  - Other nice-to-haves such as easy conversion between `SMEFT@NLO` and `SMEFTsim` notation
- Theorists prepare cards and other advice, e.g. what order(s) in the expansion are worth publishing
- Anyone should be able to run EFT2Obs at this point, but it'll probably be easier if it is CMS
- ATLAS use their own tools to validate the parameterisation from EFT2Obs

Discussion points

- Advantage of independent parameterisations is validation
  - I have noticed discrepancies between CMS, ATLAS and theory parameterisations

    → Mistakes are common and easy to make
  - A common parameterisation will no longer have constant validation/comparisons
  - But true 1-to-1 comparisons don't happen often anyway (different approaches and cards etc.)
  - Here, <u>there will be</u> a 1-to-1 comparison with ATLAS, at least initially
  - With the common parameterisation: many more eyes → greater scrutiny → less mistakes

- Handling acceptance corrections
  - Selection criteria differs between experiments → parameterisation will have to diverge at one point
  - We could have an approximate approach with Rivet routines
    - Anyone can reproduce but is simple
  - Also have more advanced approaches within experiments
    - Iteration is slower but is accurate
  - Still to be figured out, but should only affect a few equations → not a showstopper

Back-up Slides

EFT2Obs

"A tool to automatically parametrize the effect of EFT coefficients on arbitrary observables." EFT2Obs

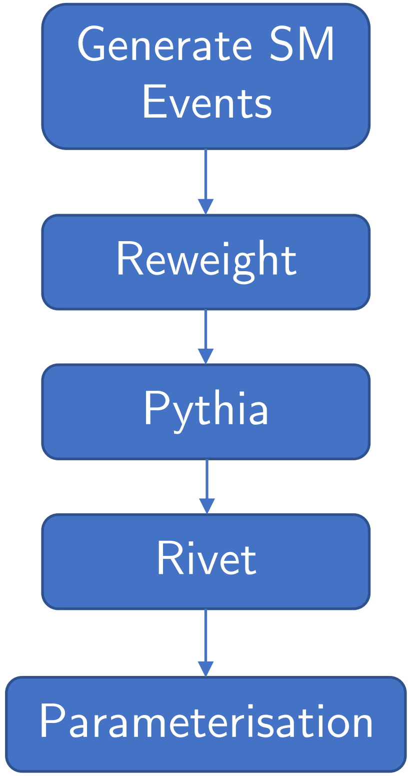
1. Generate events with MadGraph
2. Reweight those events during generation
   - $c_i = 0.5$ and 1.0 for each $c_i \rightarrow A_i$ and B_{ii} terms
   - $c_i = 1,\ c_j = 1$ for each combination of c_i and $c_j \rightarrow B_{ij}\ i \neq j$ terms
3. Events passed through Pythia
4. Classification into STXS performed by Rivet
5. Equations extracted from cross sections in each bin at each of the reweighting points

More details in the EFT2Obs README

$$\sigma_1 = \sigma\left(C = \frac{x}{2}\right) \qquad \mu_i = \frac{\sigma_i}{\sigma_{SM}} \qquad A = \frac{4\mu_1 - \mu_2 - 3}{x}$$

$$\sigma_2 = \sigma(C = x) \qquad \mu(C = x) = 1 + Ax + Bx^2 \qquad B = \frac{2(\mu_2 - 2\mu_1 + 1)}{x^2}$$

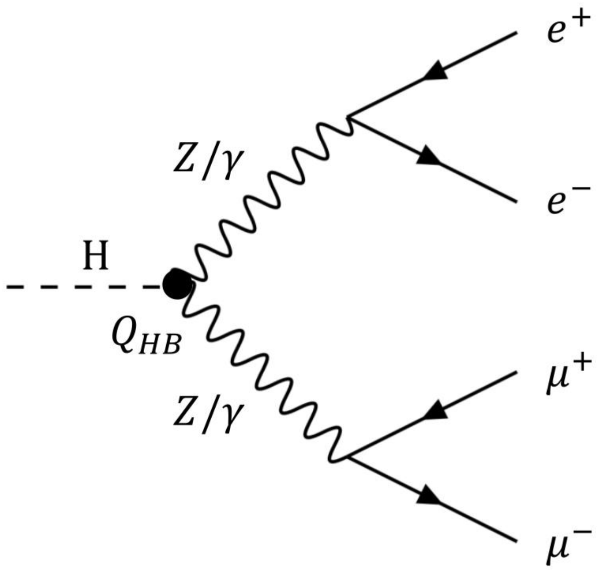
EFT2Obs Approach



Handling phase space mismatches

- Reweighting as a technique is ineffective if the EFT phase space is significantly different to the SM phase space
  - If generate at SM event, there are not enough statistics in EFT phase space to get EFT prediction with low uncertainty
- Example: $H \rightarrow 4f$ decay
  - Operators such as Q_{HB} introduce photon-mediated diagrams

  → large enhancement at low m_{ll} due to $\sim \frac{1}{m_{ll}}$ term in proagator



Solutions:

1. Dedicated generations (no reweighting involved)

   Can use MG5 syntax to isolate different EFT contributions →

2. Create multiple gridpacks at different c_i and reweight from there
3. Gridpacks for different phase space, e.g. one for $m_{ll} < 5$ and one for $m_{ll} > 5$ GeV

	σ_{SM}	σ_α	σ_β	$\sigma_{\alpha\alpha}$	$\sigma_{\beta\beta}$	$\sigma_{\alpha\beta}$
NP=0	✓					
NP<=1	✓	✓	✓	✓	✓	✓
NP==1				✓	✓	✓
NP<=1 NP^2<=1	✓	✓	✓			
NP<=1 NP^2==1		✓	✓			
NP<=1 NPc[a]^2<=1	✓	✓				✓
NP<=1 NPc[a]^2<=1 NPc[b]^2<=1	✓	✓	✓			✓
NP<=1 NPc[a]==1		✓		✓		
NP<=1 NPc[a]^2==1		✓				✓
NP<=1 NPc[a]^2==2				✓		
NP<=1 NP^2==1 NPc[a]^2==1		✓				
NP<=1 NP^2==2 NPc[a]^2==1						✓