Shape analysis for HH(bbbaa) at FCC

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Shape and HH

Our goal is a 2D analysis, with limits set on signal strength \( r \) and trilinear coupling \( k_\Lambda \).

When studying \( hh \to aabb \) we can study 3 distributions:

- \( m_{aa} \), \( m_{bb} \), \( m_{hh} \)

\( m_{aa}, m_{bb} \) provide good S/B separation, increase sensitivity to yield variations.

\( k_\Lambda \) is known to have an effect on the distribution of \( m_{hh} \). We lose this information using only \( m_{aa}, m_{bb} \).

We can try to model the \( m_{hh} k_\Lambda \) dependence:

- Template morphing (see Michele’s talk at FCC week)
- Parametric functional form of the signal lineshape
Template morphing

Our first attempt was to use template morphing to model the shape variation from generated templates

Vertical interpolation of each bin in the template, correlated with yield variation $k_{\lambda}$.

Final result show “wiggles” in the final limit, especially when using $m_{hh}$. Sensitive to statistical fluctuations in the input templates, result not optimal.

Precision of about $\sim 6\%$ on $k_{\lambda}$, both when using $(m_{aa}, m_{hh})$ and $(m_{aa}, m_{bb})$.

- Why do we observe wiggles? Some problem with morphing procedure?
- Why don’t we see an improvement when using $m_{hh}$ instead of $m_{bb}$?
- What is the optima pair of variables?
MHH signal

The effect of $k_\lambda$ on the shape is small

Larger than statistical fluctuations only in the low mass region

For the morphing is very difficult to obtain reasonable interpolation in these conditions

$2D(m_{aa},m_{bb})$ fit might prove to be better as it provides higher S/B separation

We still want to investigate if we can extract the info from the $m_{hh}$ shape variation

$k_\lambda$ variation is always related to yield effects as well
Signal parametrisation

Landau + expo tail seems to be a good candidate for the signal shape

The shape parameters can be made \( k \) dependent to extract a bit more information from the fit

Need to be reevaluated for the boosted topology (similar, not identical)

A simple Gaussian is a good match for \( m_{aa} \). We can then incorporate resolution/smearing effects in the Gaussian width and vary them at will

Fit with parametric shape (or with constant shape/template) is more stable and reliable wrt to template morphing
Options and Plans

Structure of the analysis is rather flexible.

**We can do any combination of**

- fit dimensions: $1D(m_{aa}/m_{bb}/m_{hh})$, $2D(m_{aa}, m_{hh}/m_{aa}, m_{bb})$
- $m_{hh}$ parametrisation: parametric with parameters depending on $k_{\lambda}$, parametric with constant parameters, template, morphed template
- $m_{aa}$ parametrisation: Gaussian, template
- $m_{bb}$ parametrisation: only fixed template for now
- categories: resolved, boosted, combination of the two

For both $k_{\lambda}$ and signal strengths scans

**What we can vary/check at the moment**

- Background normalisation by any factor (we are doing 0.5/2 for now)
- fake rate on b-jets
- photon resolution by smearing Gaussian width
- Normalisation (lumi) uncertainties on signal and backgrounds processes
Results

Not many differences between parametric/templates
But param gives more flexibility for studies, so is probably the best option
2D(aa,bb) has slightly better sensitivity, default for our results
We might even think of a 3D($m_{aa}, m_{bb}, m_{hh}$) fit, but statistics is an issue

Sensitivity:
4% on coupling,
2.5% in signal strength
Results (some example of...)  

Boosted category: 
\( \sim 20\% \) precision on couplings, 10\% on \( r \)  
1D(\( m_{hh} \)) fit after cut on diphoton mass  
We can probably still gain something

Parametric shape for the boosted category is not ready yet

Maybe we can stay with templates here

The code can be found at [https://github.com/giacomoortona/PersonalStuff/tree/master/FCC](https://github.com/giacomoortona/PersonalStuff/tree/master/FCC)  
Not meant for a general analysis, but we can work on integrating it in the FCC repository
BACKUP
Remember: negative correlation between kl,r
This is not actually realistic as the shape varies wildly across this range
Maybe we can use the morphing here, or impose boundaries
maa scan

Sensitivity:

~4.5% on coupling,
3% in signal strength