Higgs Combination

The 3 analyses

Z(ll)H(XX): neural to categorize in H flavour decay modes; fit on recoil distribution
Z(vv)H(XX): neural to categorize in H flavour decay modes; 2D fit on visible and missing mass
Z(qq)H(qq): multi-jet environment – categorization in flavours, 2D fit on recoil and dijet system

Final state	**Z(ll)H(jj) [%]**	**Z(vv)H(jj) [%]**	**Z(jj)H(jj) [%]**	**Comb. [%]**
$H \rightarrow bb$	0.68	0.3	0.25	0.18
$H \rightarrow cc$	4.11	2.17	2.92	1.60
$H \rightarrow gg$	2.28	0.92	2.00	0.78
$H \rightarrow ss$	342	114	363	103

Previous results from Annecy, using 7.2 /ab

Combination = quadrature sum

What we need for the mid-term

We fit directly σ(ZH)*BR(H→jj) (assume Z branching ratios perfectly measured)

The minimal deliverables for the mid-term report are:

- Combination of the 3 analyses at 240
- Combination of the 3 analyses at 365

Knowing ZH couplings, we can directly fit the BR and/or kappa’s

- Combination of 240+365 GeV
- In first stage, combine assuming “absolute” ZH coupling known from Z(ll)H
- Afterwards, we can attempt for a simultaneously with the Z(ll)H analysis to extract the kappas:
  - At 240 GeV: σ(ZH) ~ 0.7%, at 365 GeV: σ(ZH) ~ 1.1%
  - Need to take into account possible correlations (some discussion needed)

- **It seems important to monitor the improvements due to better algorithms**
  - CDR (and MTR) precisions based on 2018 ILC efficiencies - see table below
    - Let’s see where we can do better and update the table accordingly

Table 1. From Ref. [4]: Relative uncertainty (in %) on $\sigma_{ZH} \times \mathcal{B}(H \to X\bar{X})$ and $\sigma_{\nu_e \bar{\nu}_e H} \times \mathcal{B}(H \to X\bar{X})$, as expected from the FCC-ee data at 240 and 365 GeV.

$\sqrt{s}$	240 GeV		365 GeV	
Integrated luminosity	5 ab^{-1}		1.5 ab^{-1}	
Channel	ZH	$\nu_e \bar{\nu}_e$ H	ZH	$\nu_e \bar{\nu}_e$ H
$H \to$ any	±0.5		±0.9	
$H \to b\bar{b}$	±0.3	±3.1	±0.5	±0.9
$H \to c\bar{c}$	±2.2		±6.5	±10
$H \to gg$	±1.9		±3.5	±4.5
$H \to W^+W^-$	±1.2		±2.6	±3.0
$H \to ZZ$	±4.4		±12	±10
$H \to \tau^+\tau^-$	±0.9		±1.8	±8
$H \to \gamma\gamma$	±9.0		±18	±22
$H \to \mu^+\mu^-$	±19		±40	
$H \to$ invisible	< 0.3		< 0.6	

More lumi

Table 3. From Ref. [4]: Relative uncertainty (in %) on $\sigma_{ZH} \times \mathcal{B}(H \to X\bar{X})$ and $\sigma_{\nu_e \bar{\nu}_e H} \times \mathcal{B}(H \to X\bar{X})$, as expected from the FCC-ee data at 240 and 365 GeV.

$\sqrt{s}$	240 GeV		365 GeV	
Integrated luminosity	10.8 ab^{-1}		3.0 ab^{-1}	
Channel	ZH	$\nu_e \bar{\nu}_e$ H	ZH	$\nu_e \bar{\nu}_e$ H
$H \to$ any	±0.36		±0.6	
$H \to b\bar{b}$	±0.20	±2.1	±0.35	±0.6
$H \to c\bar{c}$	±1.5	?	±4.4	±7.1
$H \to gg$	±1.3	?	±2.5	±3.2
$H \to W^+W^-$	±0.8	?	±1.8	±2.1
$H \to ZZ$	±3.0	?	±8.5	±7.1
$H \to \tau^+\tau^-$	±0.6	?	±1.3	±5.7
$H \to \gamma\gamma$	±6.1	?	±13	±16
$H \to Z\gamma$	??	??	??	??
$H \to \mu^+\mu^-$	±13	?	±28	
$H \to$ invisible	< 0.2	?	< 0.4	

Chap. 1.3:

https://link.springer.com/content/pdf/10.1140/epjst/e2019-900045-4.pdf

Combination strategy

Definition of signal processes:

- POIs and names
- H→(tautau, WW, ZZ) as auxiliary POIs

Definition of backgrounds

- Procs: WW, ZZ, Zgamma, rares?
- Constrained or unconstrained

Separation of Z(vv) and vvH

- Necessary for 365 GeV, but also at 240 (for the width measurement)
- Split on missing mass at RECO/GEN level

Fitting tools

All the fitting tools basically provide an implementation of the Poisson likelihood fit

- Combine (RooFit based)
- CombineTF (Tensorflow based)
- Custom RooFit

→ Combine and CombineTF are identical for binned fits

→ CombineTF does not support unbinned/analytic fits

→ Analytic fits should be identical to binned fits

Binning strategy

Need to synchronize on the binning strategy:

- Important, especially for sensitivity of the rare process $H \rightarrow ss$
- Extensive studies done with the hadronic analysis

Converged on:

- Start from uniform 1 GeV bins in recoil/mjj/etc. templates
- Rebin such that
  - At least one expected event in each bin (i.e. both signal and backgrounds)
  - Put 1e-4 event content in empty bins

MC statistical uncertainties

Monte Carlo statistical uncertainties important to consider

Combine and CombineTF have the Barlow-Beeston light algo implemented

- Used in all CMS analyses
- Effectively assigns an equivalent stat. uncertainty of all processes combined
- Should include the signal processes as well

Usage:

- Combine: in the cards using: `* autoMCStats 0 1`
- CombineTF: arumgent line: `--binByBinStat`

Obviously, need to enable TH1::Sumw2()

Systematic uncertainties

Currently only uncertainties on the background (normalization)

Repository/versioning/lumi

Will make a repository so we can track the versionings of the cards

Need to converge on the lumis (final numbers to be used)