Measuring Light Yukawa couplings and Flavour Changing Neutral Currents in Higgs hadronic decays at the FCC-ee

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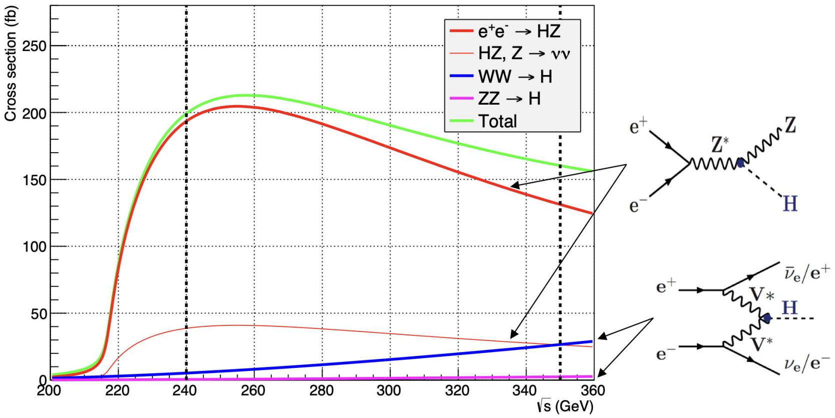
Intro

Physical Overview and Motivation



FCCee @ √s = 240 GeV → Higgs factory

Measure Higgs couplings

Sensitivity on coupling strength modifiers $\kappa_{b,c,s,g}$?

σ(vvH) = 46.2 fb (from Whizard, includes VBF and Z(vv)H)

BR(H→bb) = 0.582
BR(H→cc) = 0.0289
BR(H→ss) = 2.4e-04
BR(H→gg) = 0.819

BR(H→uu) = 1.2e-07
BR(H→dd) = 5.5e-07

BR(H→bs) = 8.9e-08
BR(H→bd) = 3.8e-09
BR(H→sd) = 1.9e-15
BR(H→cu) =2.7e-20

Current bounds on FCNCs

Michele Tammaro's talk at FCC pheno workshop based on [2306.17520]

Decay	SM prediction	exp. bound	indir. constr.
$\mathcal{B}(h \to bs)$	$(8.9 \pm 1.5) \cdot 10^{-8}$	0.16 ▲	2×10^{-3} ★
$\mathcal{B}(h \to bd)$	$(3.8 \pm 0.6) \cdot 10^{-9}$	0.16 ▲	10^{-3} ★
$\mathcal{B}(h \to cu)$	$(2.7 \pm 0.5) \cdot 10^{-20}$	0.16 ▲	2×10^{-2} ★
$\mathcal{B}(Z \to bs)$	$(4.2 \pm 0.7) \cdot 10^{-8}$	2.9×10^{-3} ■	6×10^{-8} ●
$\mathcal{B}(Z \to bd)$	$(1.8 \pm 0.3) \cdot 10^{-9}$	2.9×10^{-3} ■	6×10^{-8} ●
$\mathcal{B}(Z \to cu)$	$(1.4 \pm 0.2) \cdot 10^{-18}$	2.9×10^{-3} ■	4×10^{-7} ●

▲ $h \to$ BSM (CMS+ATLAS, 2207.00043)

★ Meson mixings

■ $\Gamma(Z \to \text{had})$ (hep-ex/0012018)

● Global fits (mostly semi-leptonic)

Outline

- quick recap
- impact of detector performance
- potential improvements

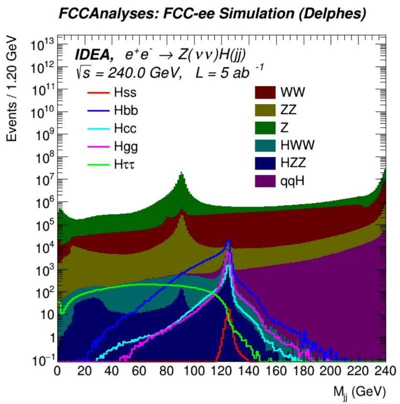
Analysis strategy in a nutshell for H→bb/cc/ss/gg

- Signal: H → jj (j = b, c, s, g, **τ**)
- Background:
  - WW/ZZ/Z, qqH, HWW, HZZ

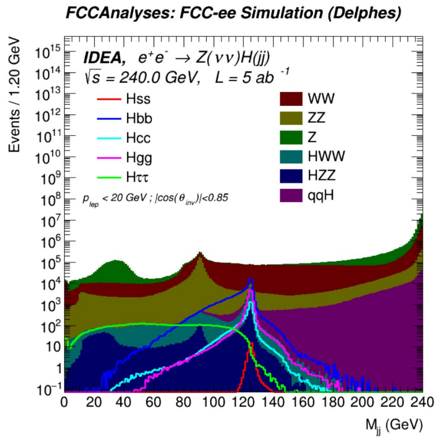
- Key ingredients:
  - Jets reconstruction
    - N = 2 Durham kt exclusive algorithm
  - ParticleNet jet tagger (4 categories: b, c, s, g)

- Analysis:
  1. Events pre-selection (lepton veto:orthogonalize with Z(ll)H analysis, cos theta),
  2. Categorization based on tagger scores
  3. Fit with floating 10% background normalisation uncertainty (to be constrained) and 4 signal strengths (Hbb, Hcc, Hss, Hbb)

Quick Recap:

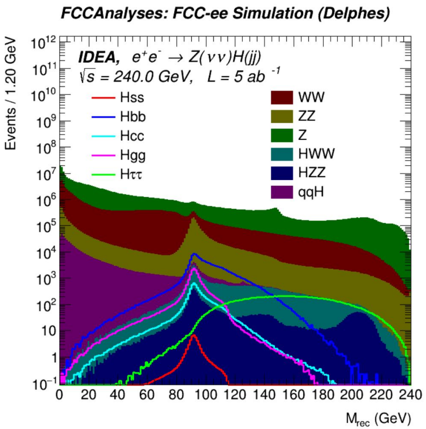


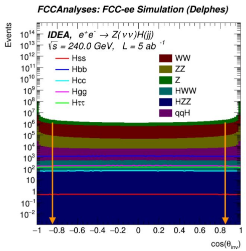
visible mass

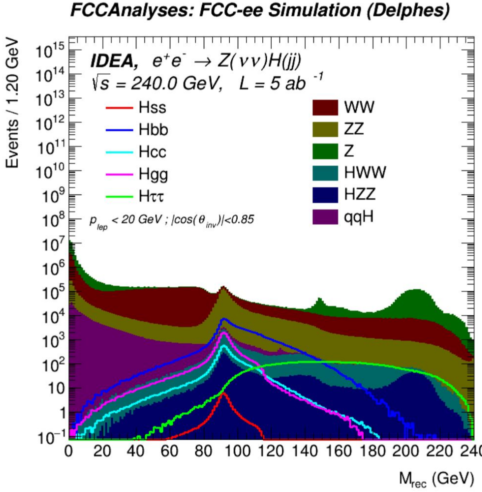


preselection

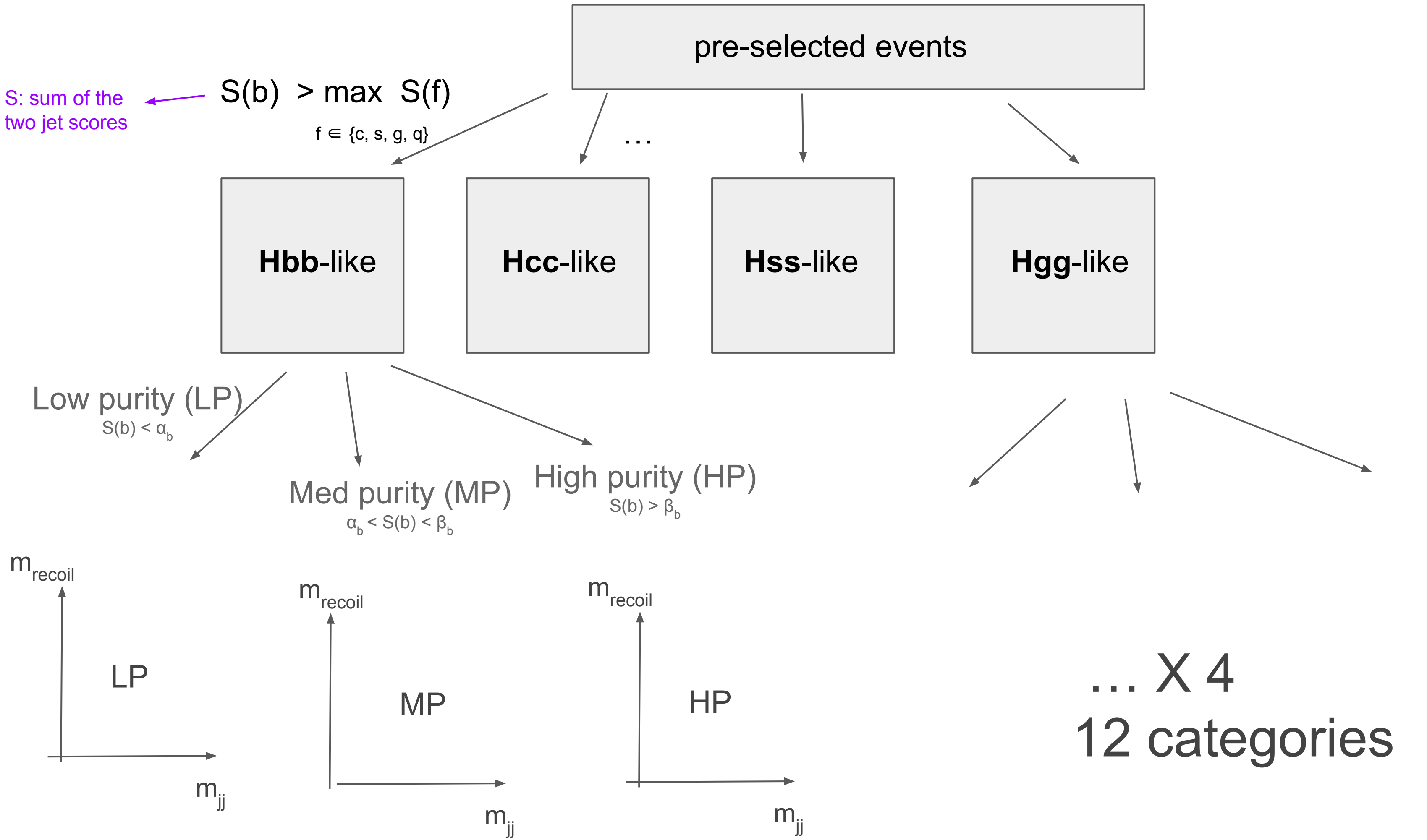
lepton veto
cosθ cut







recoil mass



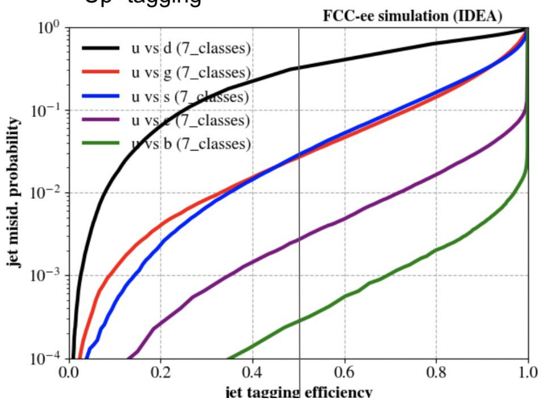
pre-selected events
S: sum of the two jet scores
S(b) > max S(f)
f ∈ {c, s, g, q}
…
Hbb-like
Hcc-like
Hss-like
Hgg-like
Low purity (LP)
S(b) < α_b
Med purity (MP)
α_b < S(b) < β_b
High purity (HP)
S(b) > β_b
m_recoil
LP
m_jj
m_recoil
MP
m_jj
m_recoil
HP
m_jj
… X 4
12 categories

Strategy update for Higgs FCNCs and light

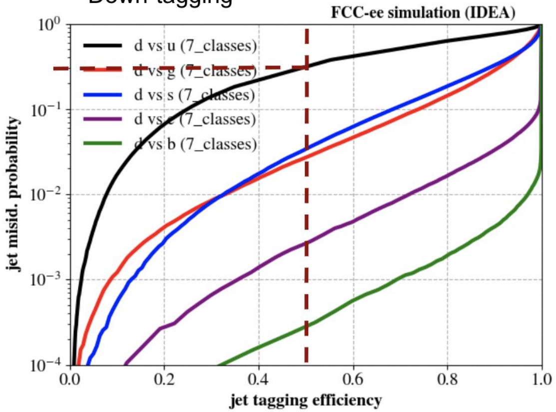
- We now have to fit 13 POI (instead of 4)
  - bb/cc/ss/gg
  - uu/dd/bs/bd/sd/cu
  - HWW/HZZ/Htautau (optional and unoptimised)

- Signal extraction strategy:
  - difficult to select signal regions with high purity using sum of jet scores
    - can be done but cumbersome.
  - Instead categorise simple to build a BDT using tagging scores (U,D,TAU, B, C, S, G) and jet substructure (dij clustering variables) -- mostly for HWW/HZZ/Htautau -- information
  - Construct L/M/H purity slices and fit (Mjj, Mrecoil) as previously

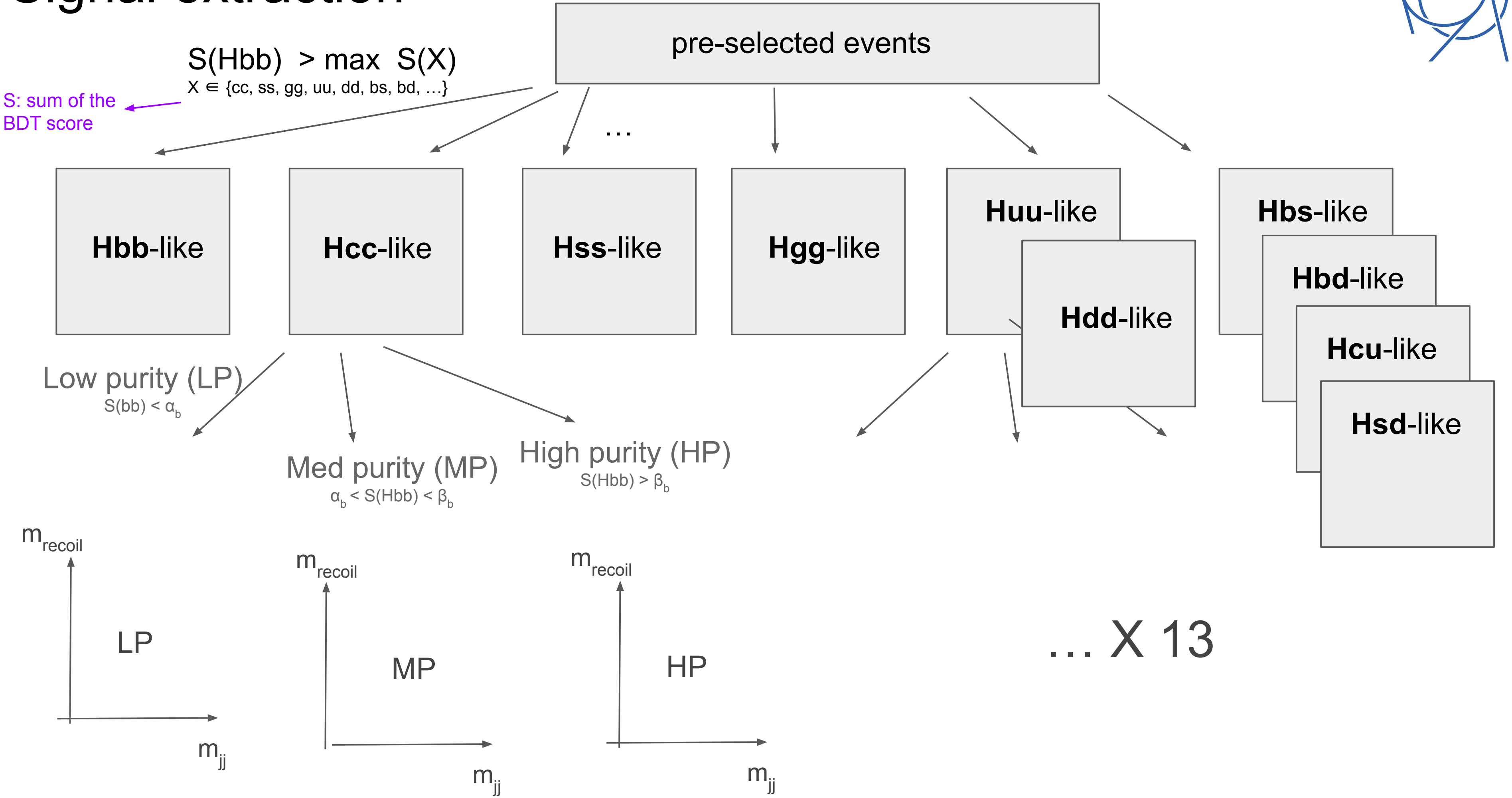
Up -tagging



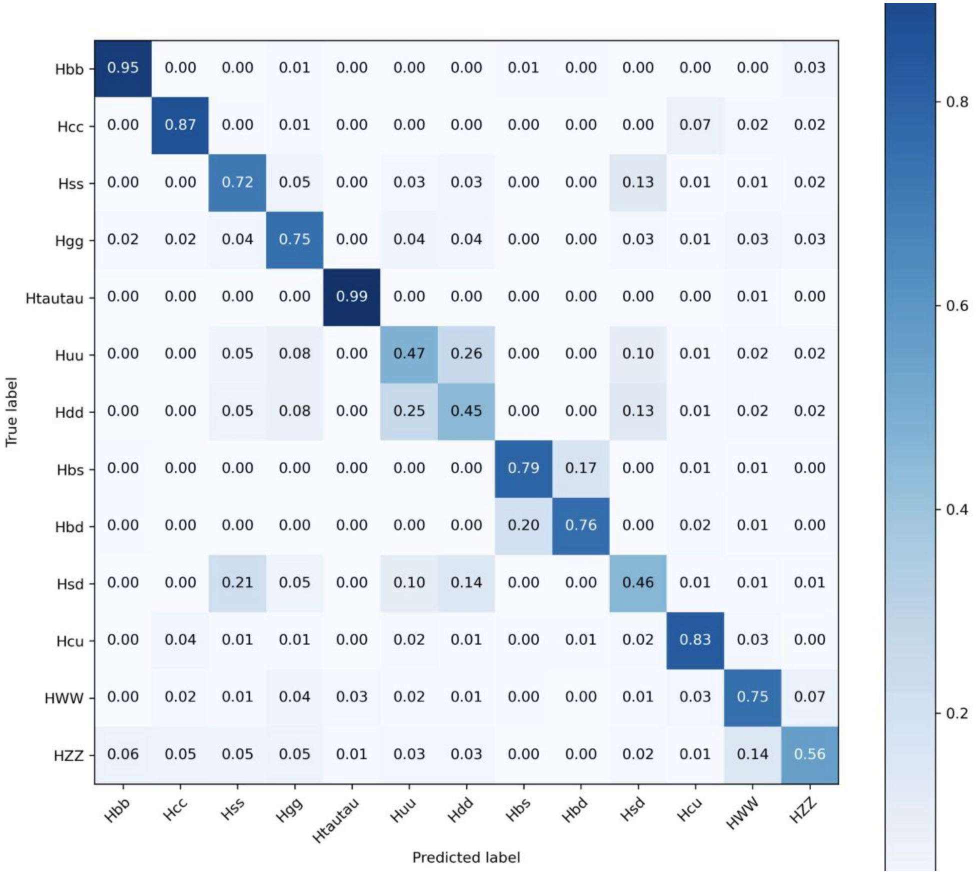
Down-tagging



Signal extraction



BDT training




```
training_vars = [
    "jet1_scoreU_{}".format(tag),
    "jet1_scoreD_{}".format(tag),
    "jet1_scoreB_{}".format(tag),
    "jet1_scoreC_{}".format(tag),
    "jet1_scoreS_{}".format(tag),
    "jet1_scoreG_{}".format(tag),
    "jet1_scoreTAU_{}".format(tag),
    "jet2_scoreU_{}".format(tag),
    "jet2_scoreD_{}".format(tag),
    "jet2_scoreB_{}".format(tag),
    "jet2_scoreC_{}".format(tag),
    "jet2_scoreS_{}".format(tag),
    "jet2_scoreG_{}".format(tag),
    "jet2_scoreTAU_{}".format(tag),
    "d_23_{}".format(tag),
    "d_34_{}".format(tag),
    "d_45_{}".format(tag),
    "d_56_{}".format(tag),
    "d_67_{}".format(tag),
    "d_78_{}".format(tag),
    "d_89_{}".format(tag),
]
```

Fit results

13x (Hbb, Hcc, Hss, Hgg, Huu, Hdd, Hbs, ..)
3x (LP/MP/HP)

= 39 categories (mjj, mrecoil) 2D fit

bin size:
1 GeV for m_{jj}
1 GeV for m_{recoil}

13 POIs signal strength freely floating

→ **Hbb**, **Hcc**, **Hss**, **Hgg**, **Huu**, **Hdd**, **Hbs**, **Hbd**, **Hsd**, **Hcu**, **HWW**, **HZZ**, **Htautau**

Uncertainties:

- each background 10% uncorrelated normalisation unc. across bins
  → constrained to sub % level
- MC stats uncertainties

FIT

simultaneous template fit of the 39 categories

with CMS “combine tool”

Expected precision (at 68% CL)

old result with 4 POI

Hgg : 1.1%
Hss : 146 %
Hcc : 2.7%
Hbb : 0.37%

new result with 13 POI

Hgg : 1.1%
Hss : 161 %
Hcc : 2.7%
Hbb : 0.42%

compatible!

Fit results (HWW/HZZ/Htautau)

HWW :	1.8%
HZZ :	13 %
Htautau :	11%

- H→WW/ZZ
    - lepton veto selects predominantly H→WW/ZZ→4j
    - indicative of expected performance in vv4j channel
        - dij in BDT encapsulates most information jet kinematics information (including masses)
        - but probably can be optimised further by explicitly reclustering N=2 to N=4 and using tagging information
- H→tau tau:
    - not competitive w.r.t to dedicated analysis (mjj, mrecoil not optimal here), see Maria Cepeda 's talk

Fit results (Huu/dd/bs/bd/sd/cu)

With 5 ab^{-1}

BR(Huu) < 1.8e-03 @95% CL
BR(Hdd) < 1.7e-03 @95% CL

BR(Hbs) < 4.5e-04 @95% CL
BR(Hbd) < 3.3e-04 @95% CL
BR(Hcu) < 3.0e-04 @95% CL
BR(Hsd) < 9.5e-04 @95% CL

- WARNING: crude estimate (2x 68% error)
- Results in the right ball park e.g. BR(Hss) < 6e-04
  - compatible with pheno study in 2306.17520
  - slightly better here, but expected since we use fully differential tagger information

FCC-ee seems to be able to beat indirect constraints from meson mixing

FCC-ee reach	Indirect constraints
$\mathcal{B}(h \to bs) \lesssim 9.6 \times 10^{-4}$	$\mathcal{B}(h \to bs) \lesssim 1.6 \times 10^{-3}$

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