Measurement of Higgs Branching Ratios at FCC-ee

HADRONIC FINAL STATES

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FUTURE CIRCULAR COLLIDER

Motivations

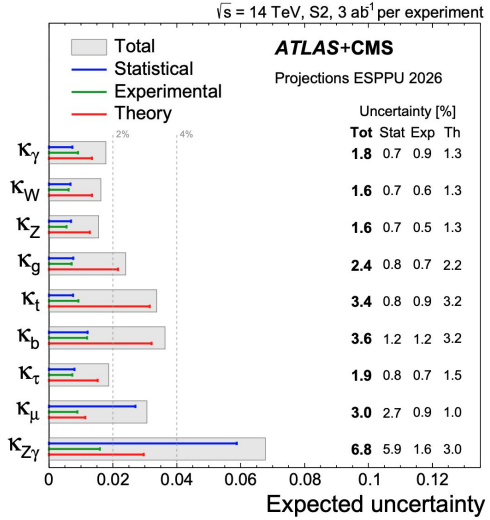
Yukawa coupling

$$m_f = v\frac{y_f}{\sqrt{2}}$$

Coupling-mass relation for fermions in the SM

- Precise measurements of Higgs couplings might yield to deviation from SM → Possible BSM physics

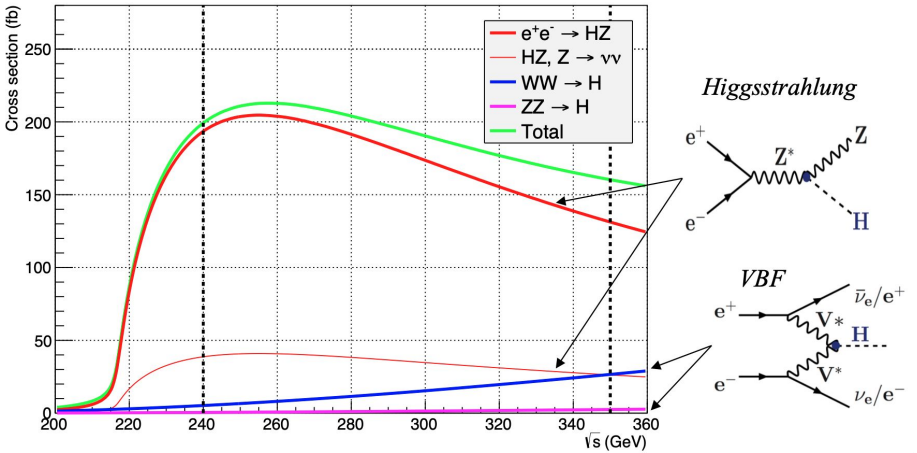
- FCC-ee allows precise, model-independent measurement of numerous couplings including some unobservable at the LHC
  - H→Hadrons = 80% of H decays and LHC only measures bottom Yukawa
  - H→gg is very sensitive to BSM



Mostly limited by stats. and th. unc.

4 interactions points

	$\sqrt{s}$ (GeV)	Luminosity (ab^{-1})	ZH Events	WW Fusion Events
3 years	240	10.8	2.2M	65k
5 years	365	3.12	0.37M	92k



Analysis Strategy

Z decay channels

Z→ll, l = e,μ

BR(Z→ll) ~ 6.7 %

Z→qq

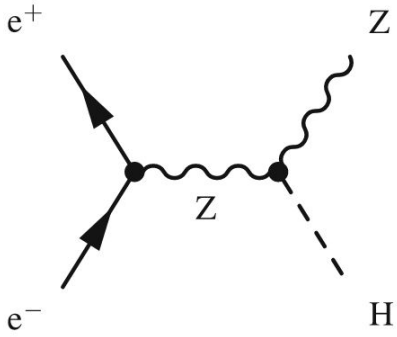
BR(Z→qq) ~ 67%

Limited by jet clustering

Z→$\nu\nu$

BR(Z→$\nu\nu$) ~ 20%

Requires a separation of ZH and VBF productions processes



Samples IDEA (Delphes fast sim)

signals ZH(+VBF)@240&365 - H→bb/cc/gg/ss/WW/ZZ/ττ

N = 2 exclusive kT clustering for Z(ll/$\nu\nu$)**, N = 4 for Z(qq)

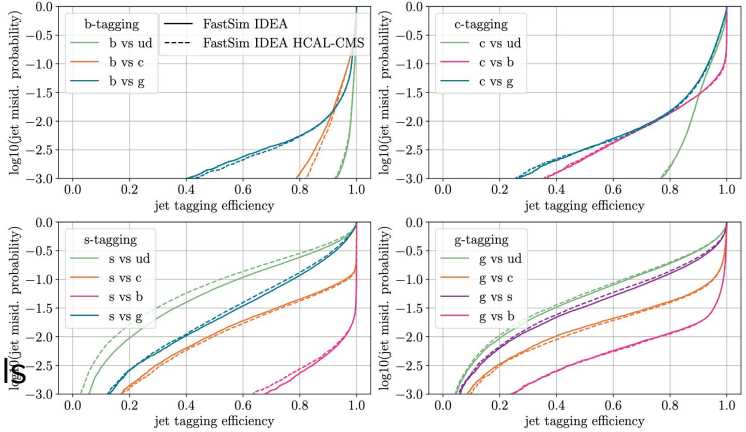
backgrounds WW, ZZ, Z/γ*, Zqq, ee, μμ, tt, $\nu\nu$Z, qqH

** We also force reconstruction of H(WW/ZZ) to be 2 jets (rather than the expected 4)

Analysis strategy

- **S/B optimization** with kinematic selection
- **Categorization** using ParticleNet tagger output

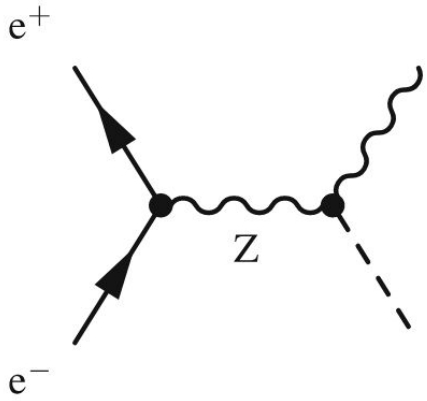
  (7 outputs (b,c,s,g,d,u,tau) for each jets)
- **Simultaneous fit** on all categories
- **Combination** of all Z decay channels



Michele Selvaggi & Loukas Gouskos

ZH⟶lljj

- 1D Study of the mass recoiling from the Z



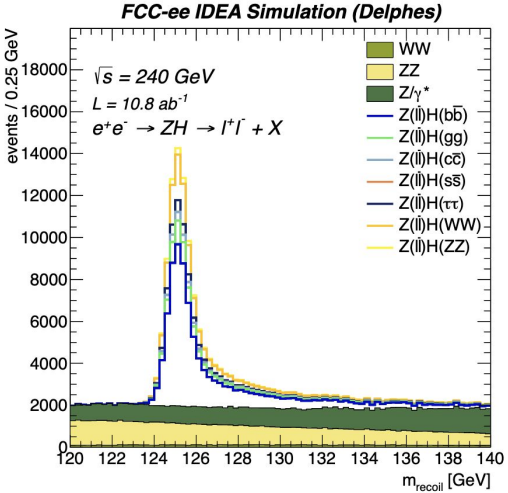
$$m^2_{\text{recoil}} = s + m_Z^2 - 2E_{\ell\ell}\sqrt{s}$$

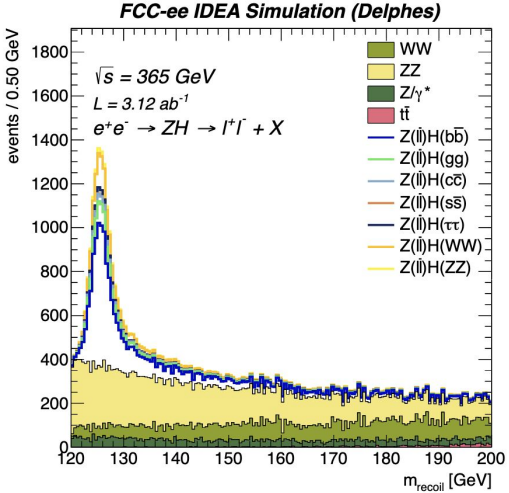
Selection:

- m_{ll} around Z mass (81-101 GeV), m_{recoil} around Higgs mass (120-140 GeV), no additional leptons with p > 25 GeV
- Elimination of non fully hadronic decays using veto on jet components kinematics

365 GeV:

- Additional *tt* bkg component and tuning of the selection criteria. Same strategy afterwards.
- Wider BES and high lepton momenta:
  - Wider signal distribution and longer tail





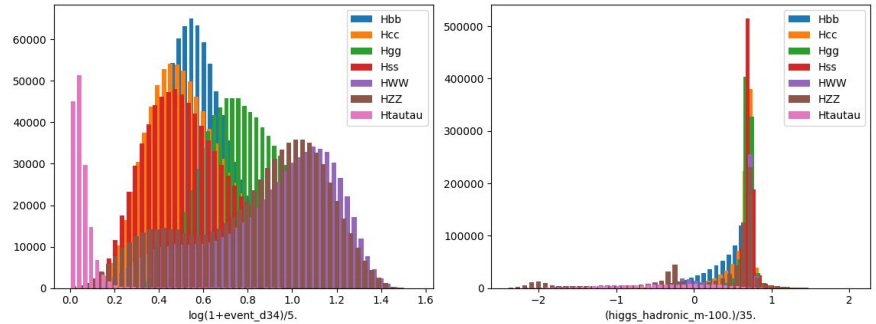
ZH⟶lljj categorization

We train a Neural Network to categorize the events in one of the **7 signal channels (7 Higgs decays)** or one of the **3 background channels**

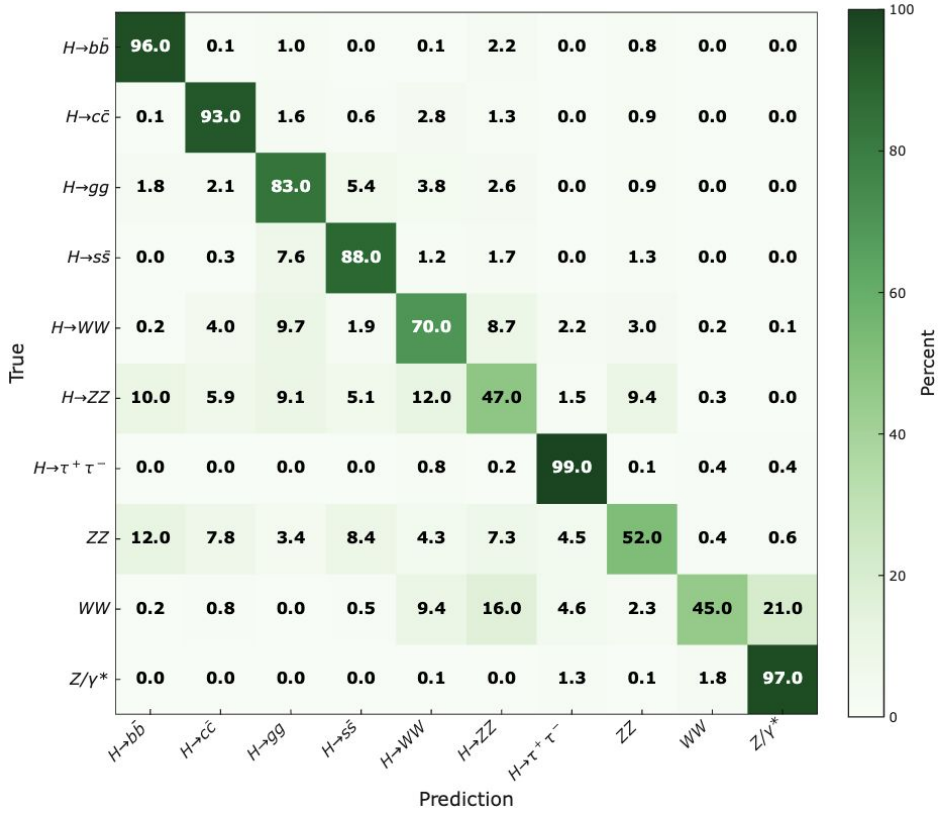
Training variables

```
"jet1_isB",
"jet2_isB",
"jet1_isC",
"jet2_isC",
"jet1_isG",
"jet2_isG",
"jet1_isU",
"jet2_isU",
"jet1_isD",
"jet2_isD",
etc...

angular distance between the
2nd and 3rd jet components

+ 'log_d23',
  'log_d34',
  'm_visible',
```

Training variables: ParticleNet jet tagger score, kinematic variables, Angular variables (from Z decay)



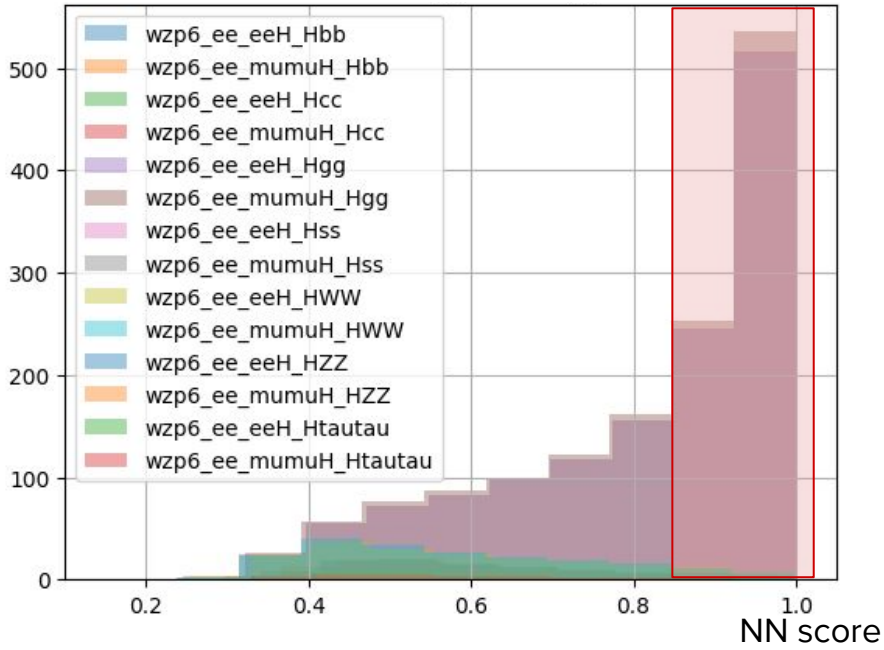
Categorisation confusion matrix (240 GeV)



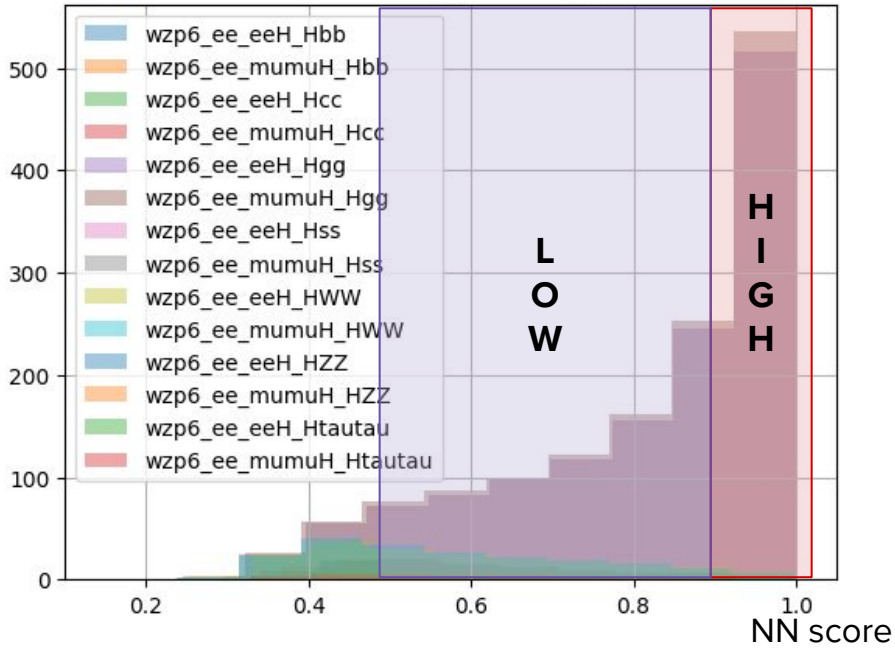
Purity categorization

Goal : increase analysis sensitivity by including purity categories in the samples (ie. include more events in the fit)

before



after



We considered a maximum of **3 purity categories (high, mid, low)**

$ZH \rightarrow \nu\nu jj$

- 2D Study of the mass recoiling from the H + visible mass from H decay

  $m_{miss} (= m_{\nu\nu}) = m_{recoil}$ $\qquad$ $m_{visible} = m_{jj}$

Selection:

- Cuts on kinematics

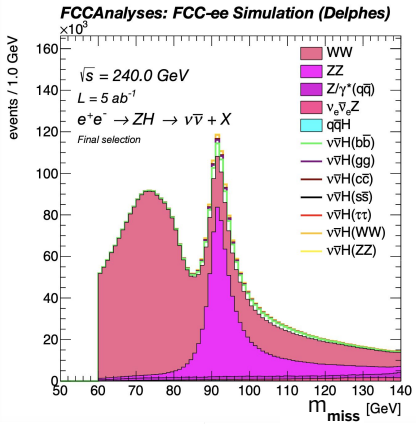
ZH/VBF Separation:

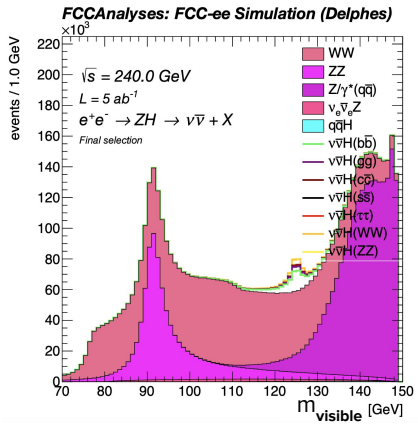
- Separate templates and signal strengths for ZH and VBF
  - ZH : $e^+e^- \rightarrow \nu_\mu \nu_\mu$ * 3
  - VBF : $e^+e^- \rightarrow \nu_e \nu_e$ - $e^+e^- \rightarrow \nu_\mu \nu_\mu$ (contains interference)

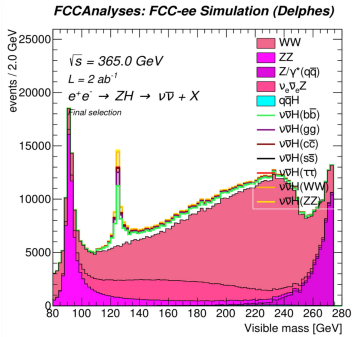
Categorisation:

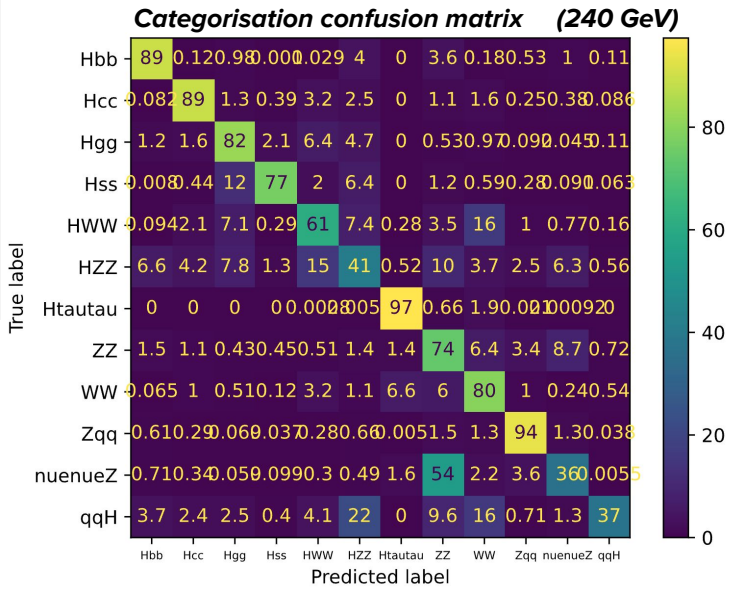
- We perform the same categorization than for $ZH \rightarrow lljj$

Same analysis for **365GeV** with some tuning









ZH⟶qqjj

Performed by George Iakovidis

Signals: Z(qq)H(bb/cc/gg/ss/WW/ZZ/ττ)

Backgrounds: WW, ZZ, Z/γ*, Zqq, $\nu\nu$Z

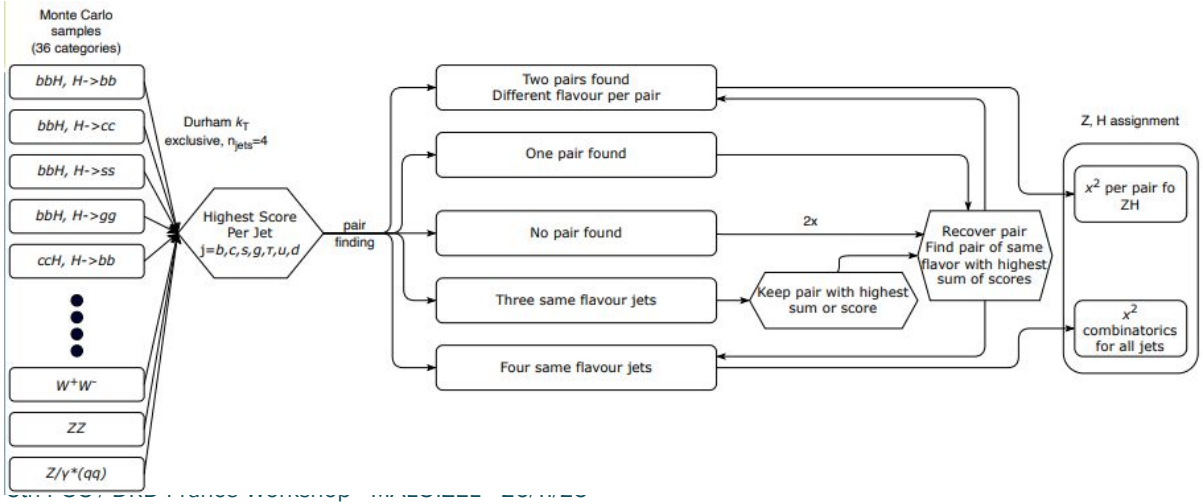
2D Study of the both hadronic masses from the **H** and **Z**

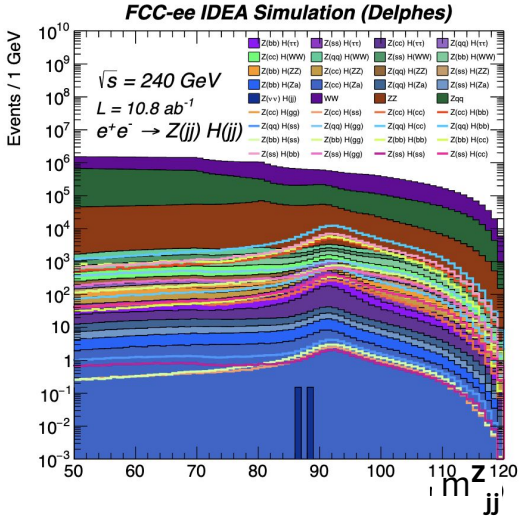
$m_H = m^H_{jj}$ $m_Z = m^Z_{jj}$

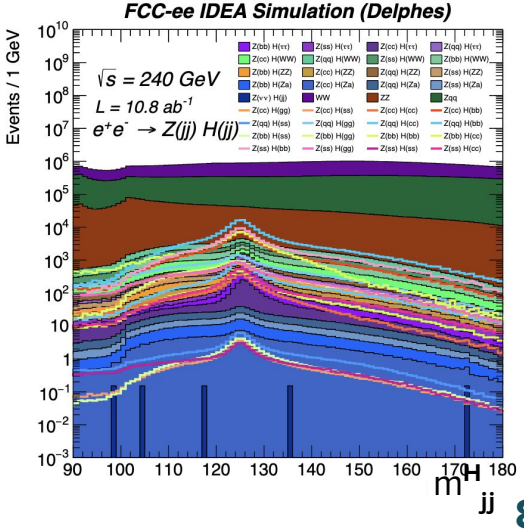
Events selection orthogonal to Z(ll)/Z($\nu\nu$) analysis

Jet Pairing based on tagger scores & combinatorics (see next)

Categorization of jets using the same ParticleNet jet tagger scores as previous analysis (different method)







Final results

- Simultaneous fit on all categories templates to extract **σ.BR**
- All signal and background parameters are let free. **Monte Carlo stats uncertainties included**
- Full combination of all channels, with ZH/VBF separation

Expected sensitivity (%) of σ.BR(H⟶jj) at 68% CL

Byproducts of the analysis

240 GeV L = 10.8ab^{-1}		H⟶bb	H⟶cc	H⟶gg	H⟶ss	H⟶ZZ	H⟶WW	H⟶ττ
Combined	**ZH**	0.21	1.75	0.85	110	6.9	1.08	2.53
	VBF	1.89	19.4	5.50	990	130	16	∞
365 GeV L = 3.12ab^{-1}		**H⟶bb**	**H⟶cc**	**H⟶gg**	**H⟶ss**	**H⟶ZZ**	**H⟶WW**	**H⟶ττ**
Combined	**ZH**	0.39	3.01	2.13	340	25	3.05	11.0
	VBF	0.64	3.36	2.56	280	36	5.15	23

Conclusion

- %-level and better precision achieved for several couplings
- Very promising in comparison to other proposed future experiments
- Summary presentation of other Higgs decay study available: **[FCC-Week25]** / **[EPS-HEP]**

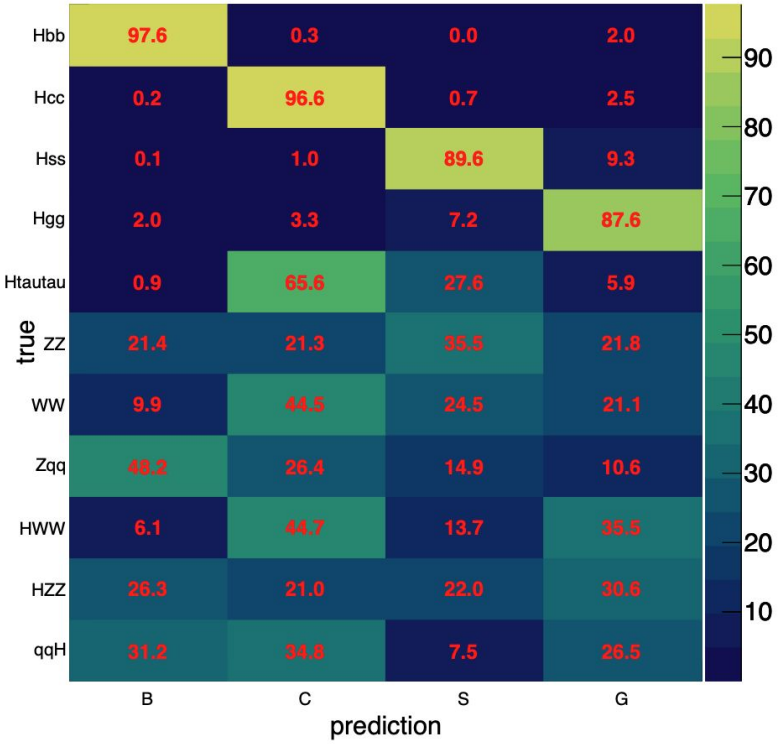
Thanks for your attention

Backup

ZH⟶qqjj Categorization

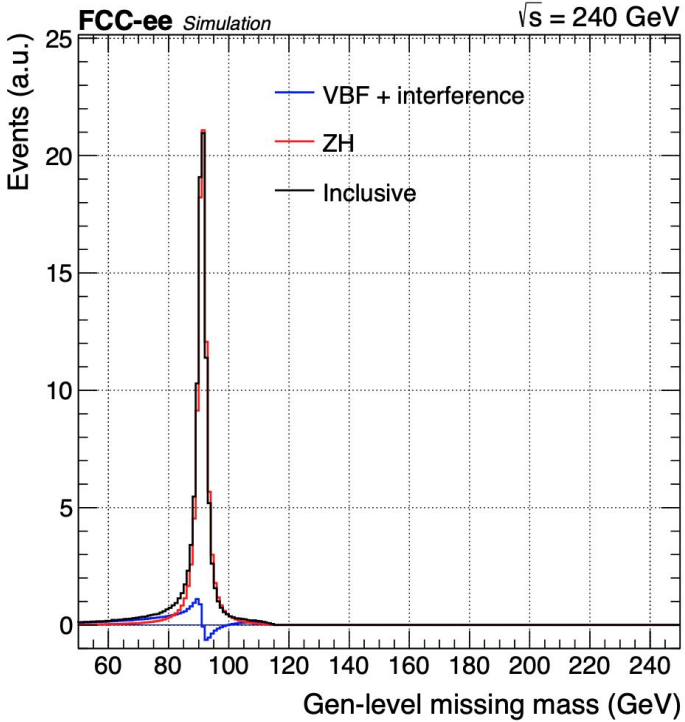
	B	C	S	G
L	< 1.1	< 1.0	< 1.1	< 1.2
M	$\in [1.1, 1.9]$	$\in [1.0, 1.8]$	$\in [1.1, 1.7]$	$\in [1.2, 1.5]$
H	> 1.9	> 1.8	> 1.7	> 1.5

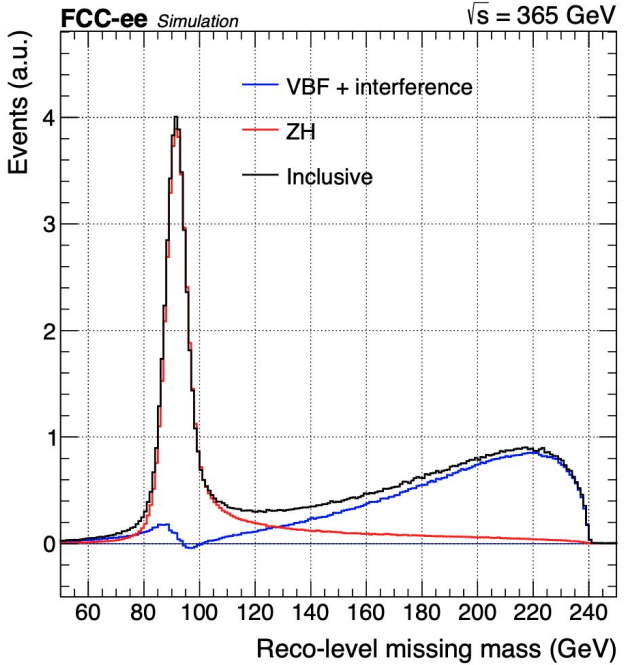
$$J_{12}^{score} = J_1^{score} + J_2^{score}, J = b, c, s, g, u, d, \tau,$$



ZH & VBF separation

- ZH : $e^+e^- \to \nu_\mu \nu_\mu$ * 3
- VBF : $e^+e^- \to \nu_e \nu_e$ - $e^+e^- \to \nu_\mu \nu_\mu$ (w/ interference)





Comparison with ILC

- Results rescaled to reach similar luminosity
- Additional scalings to remove impact of beam polarization
- **Results for ILC would correspond to a ~4x longer data taking period compared to FCC**

Collider	FCC CDR	FCC ESPPU	LCF ESPPU	LCF	LCF $\times\sqrt{1.2}$
Integrated luminosity	10.8 ab^{-1}	10.8 ab^{-1}	2.7 ab^{-1}	10.8 ab^{-1}	10.8 ab^{-1}
$H \to$ any	± 0.36	± 0.31	± 0.62	± 0.31	± 0.34
$H \to bb$	± 0.20	± 0.21	± 0.41	± 0.21	± 0.22
$H \to cc$	± 1.5	± 1.6	± 2.5	± 1.25	± 1.37
$H \to gg$	± 1.3	± 0.8	± 2.1	± 1.05	± 1.15