Higgs → bb/cc/gg/ss/WW/ZZ/tautau with Z(ll,$\nu\nu$)H at √s=240/365 GeV

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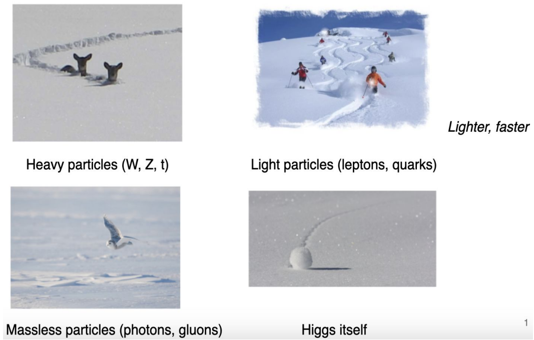
Supervised by Giovanni Marchiori

Studying the Higgs couplings

In the Standard Model (SM), fermions inherit their mass from their coupling with the Higgs Boson

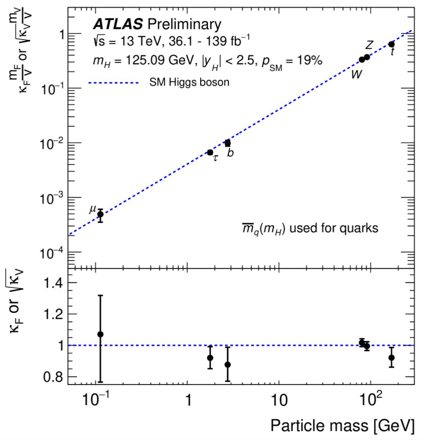


Our study aims at estimating the best precision with which we could measure these couplings

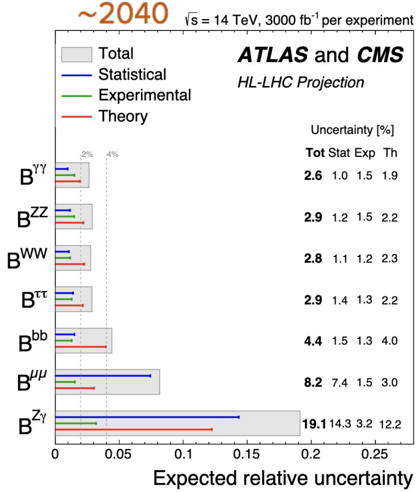
$$m_f = v \frac{y_f}{\sqrt{2}}$$

Any deviation from the expected value would indicate possible beyond SM processes

2022

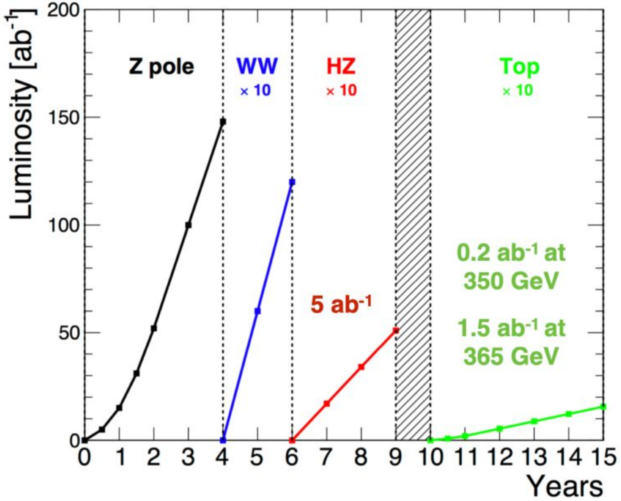


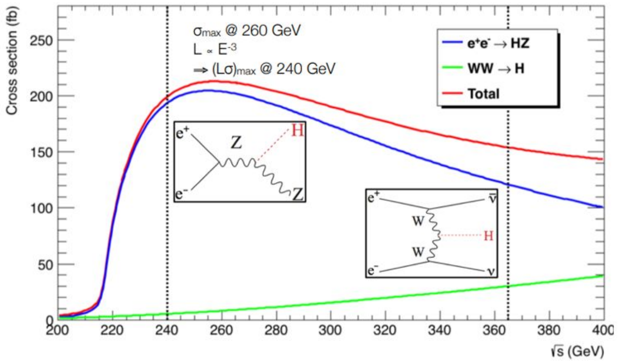
~2040



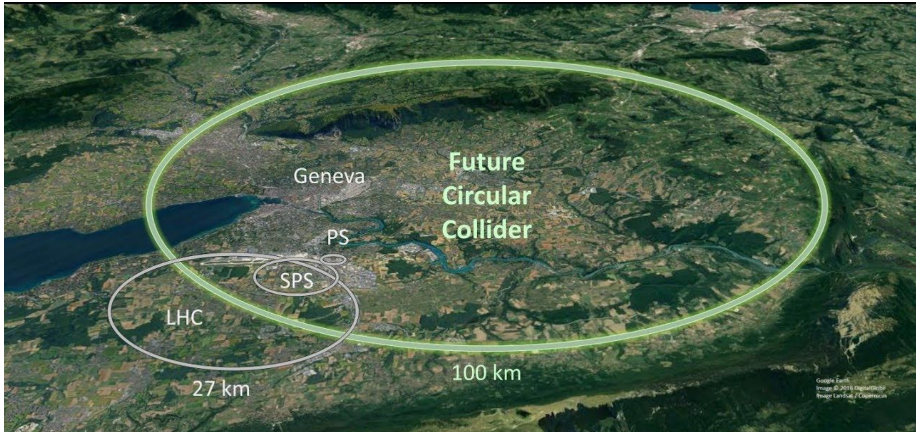
The FCC experiment - FCC-ee

FCC-ee functioning schedule





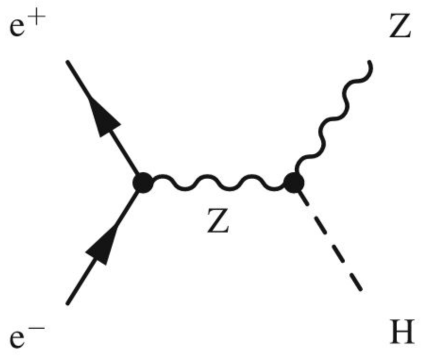
- **FCC** (Future Circular Collider)
  - ~90km circular collider project
  - Two periods on functioning : **FCC-ee** & FCC-hh



  - Great improvement on EW studies wrt **LEP**
  - Higgs factory
  - Great prospects for new physics (hh)

(ZH) Higgstrahlung process - Recoil Mass

- $e^+ + e^- \rightarrow Z + H$



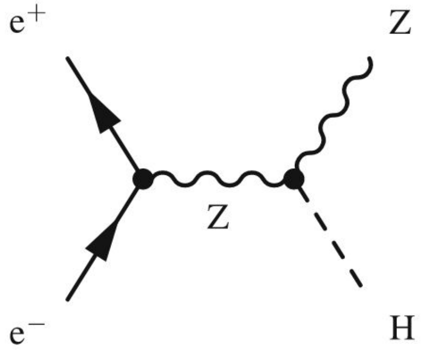
Recoil Mass :

$$(E_{ll} + E_H, \overrightarrow{p_{ll}} + \overrightarrow{p_H}) = (\sqrt{s}, \vec{0}) \Rightarrow M^2_{recoil} = s + m_Z^2 - 2E_{ll}\sqrt{s}$$

- Allows model independent measurement of the total Higgs Cross-section
- Unusable in the LHC due to the composite nature of protons

(ZH) Higgstrahlung process - Zll & Znunu at 240 GeV

- $e^+ + e^- \rightarrow Z + H$



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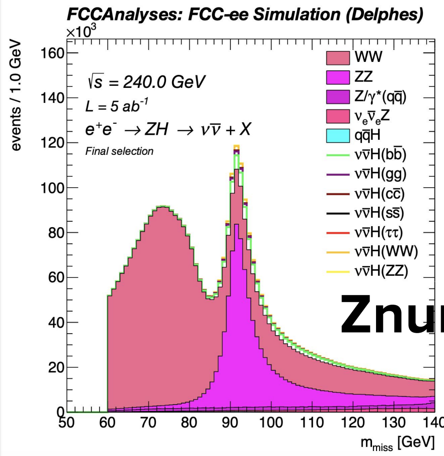
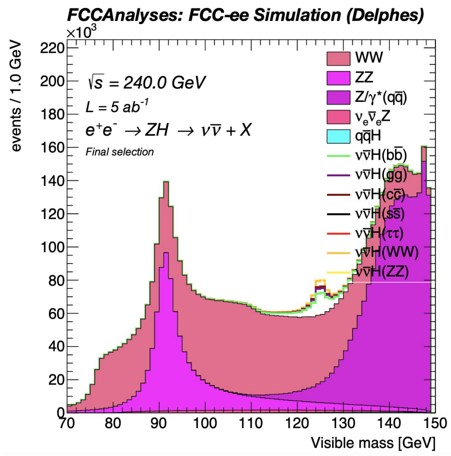
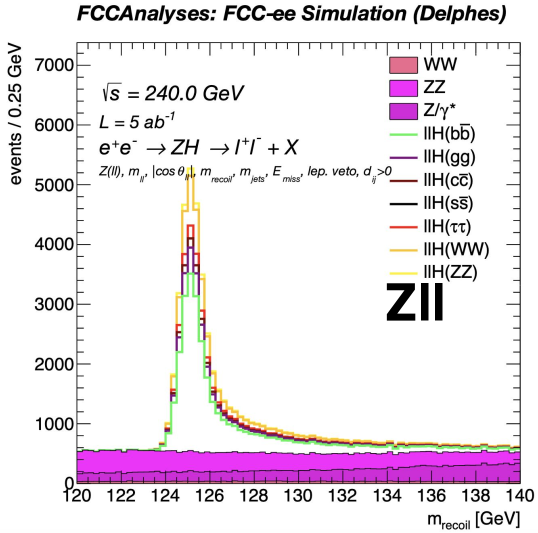
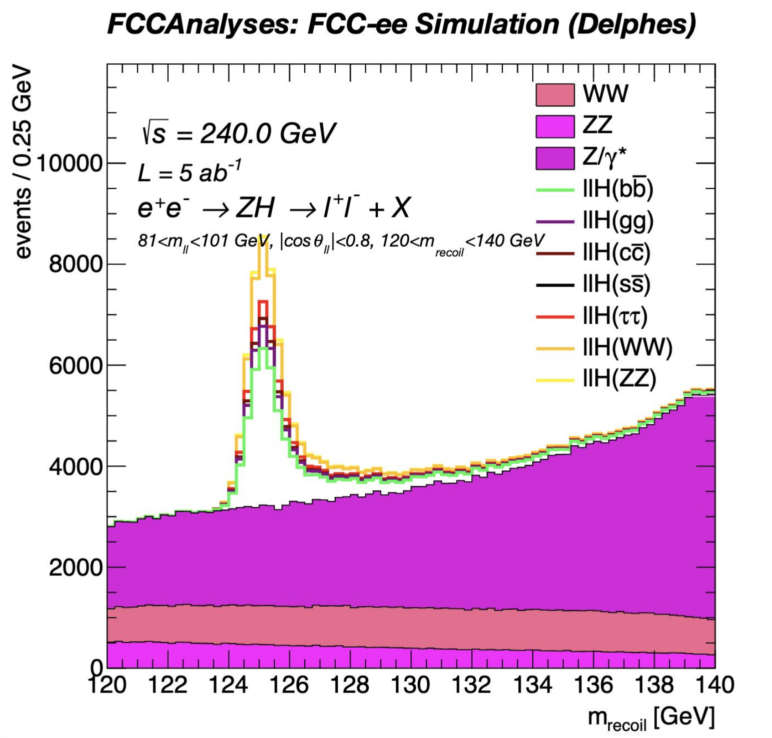


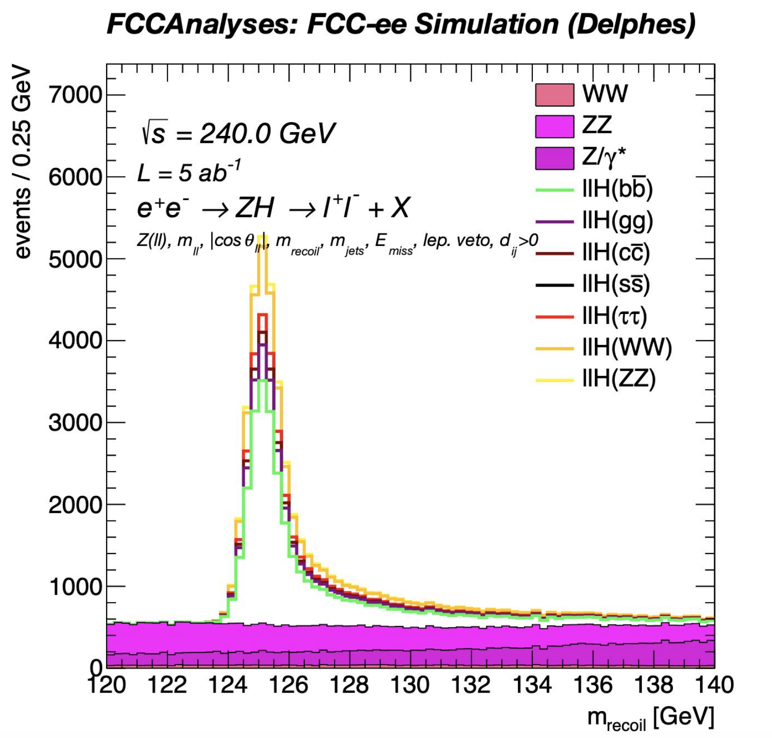




After H reco.

Events selection - Zll example at 240 GeV

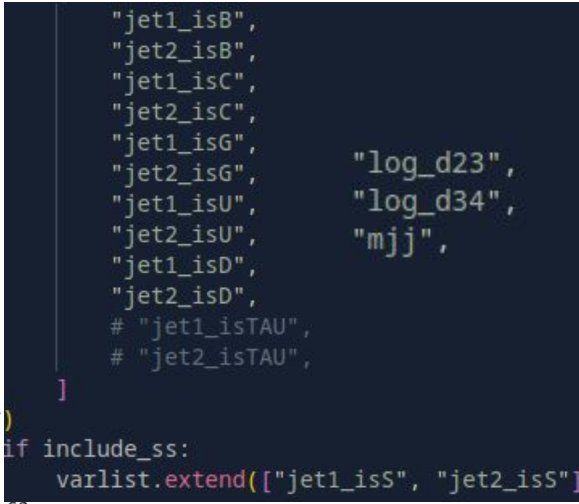




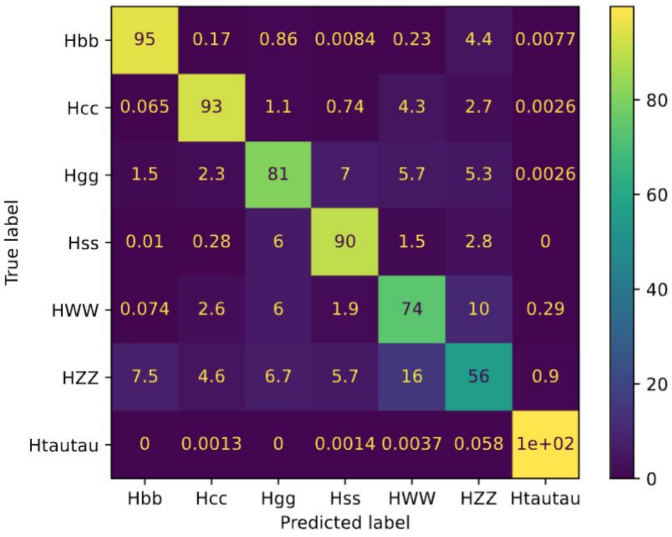
Events categorization

We train a Neural Network to categorize the events in one of the signal channels :

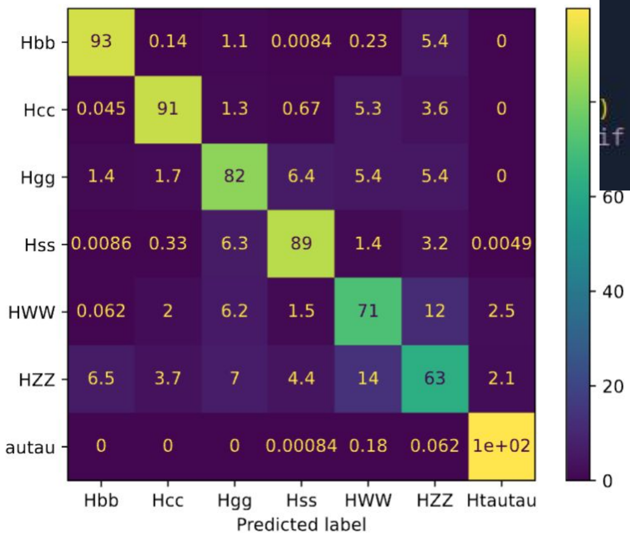
$H \rightarrow bb/cc/gg/ss/WW/ZZ/\tau\tau$



Znunu Confusion Matrix

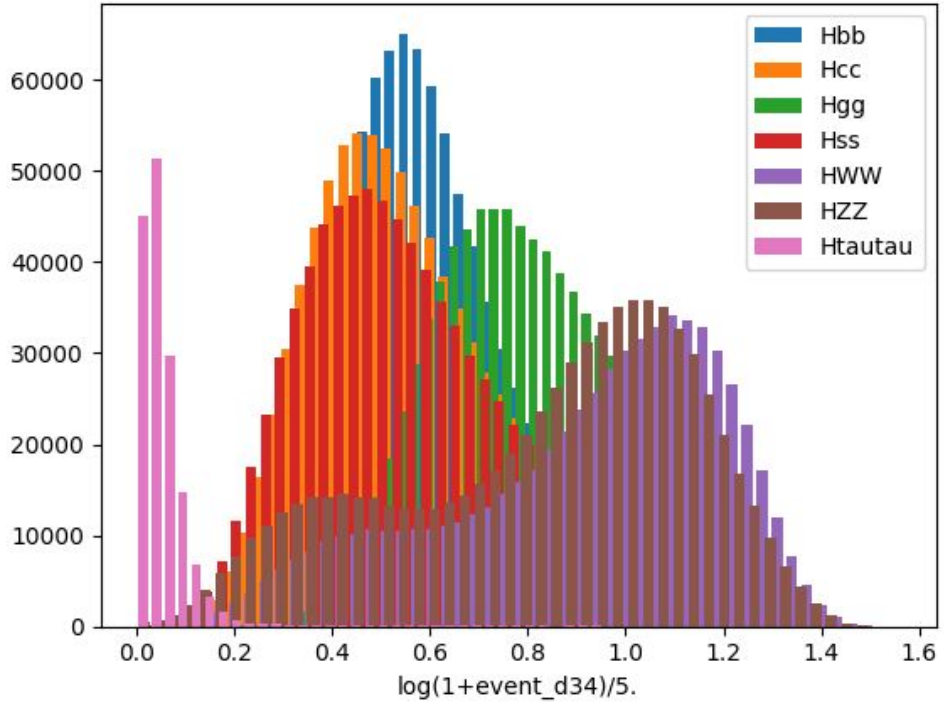


Zll Confusion Matrix

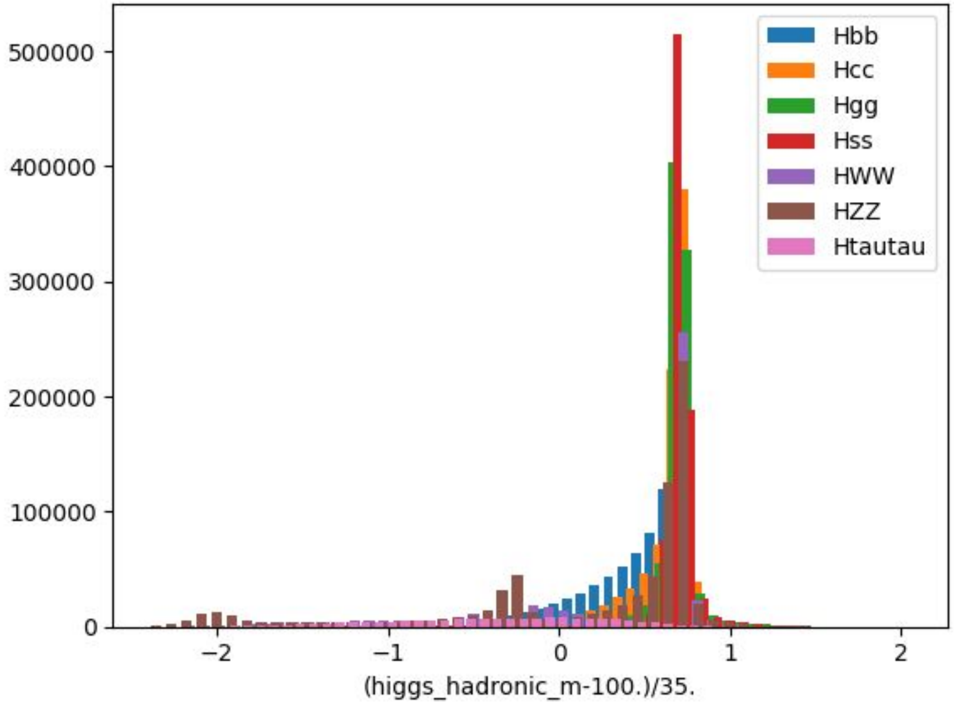


Training variables

Sufficient to get near perfect tautau labeling



Slightly improves performances in the ZZ cat.



365 GeV - introduction

Performed a "baseline" analysis of llH (l=e,mu) and $\nu\nu$H channels at 365 GeV, to establish reference sensitivity (for further optimisation later)

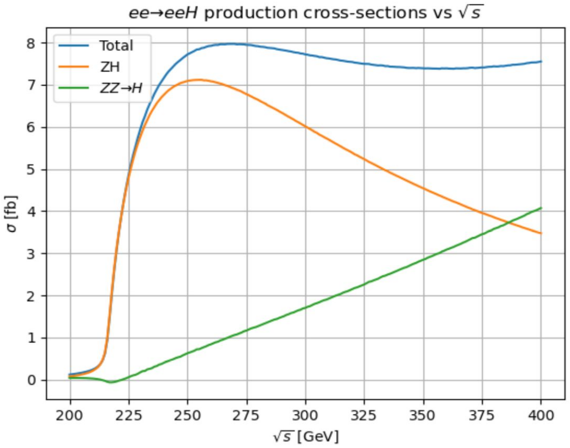
- Same variables used for event selection at 240 GeV, loosening inefficient cuts (e.g. lepton momentum and recoil mass in llH)
  - no attention paid so far to efficiently reconstruct ZZ fusion in eeH channel nor separate WW fusion in ν_e ν_e H channel
- Use isolation to make channels orthogonal and improve S/B (at least one isolated lepton with p > 40 GeV in llH, no isolated leptons with p>1 GeV in $\nu\nu$H)
- Assume L=2.3/ab
- Train MVA to discriminate among different Higgs decays
- Fit each channel and combination to extract the **σ.BR** of the various decays

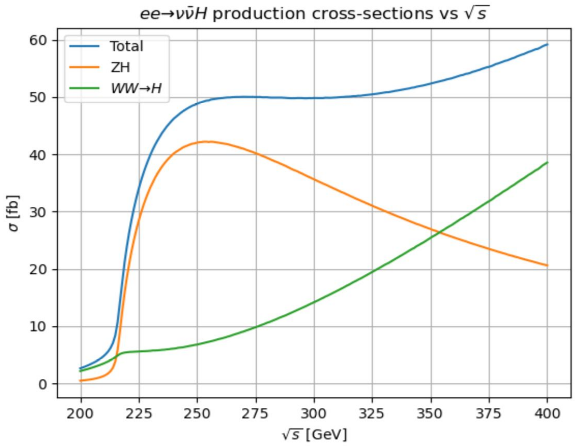
365 GeV - MC samples

Process	sigma [fb]	Ngen	Lgen [/fb]	Lgen/L
vvHbb	31.430000000	1200000	38180	16.600
vvHcc	1.560000000	1200000	769231	334.448
vvHss	0.010790000	1200000	111214087	48353.951
vvHgg	4.418000000	1200000	271616	118.094
vvHtautau	3.385000000	1200000	354505	154.133
vvHWW	11.610000000	900000	77519	33.704
vvHZZ	1.425000000	1200000	842105	366.133
eeHbb	4.303000000	1200000	278875	121.250
eeHcc	0.213600000	900000	4213483	1831.949
eeHss	0.001478000	1122800	759675237	330293.581
eeHgg	0.604900000	1200000	1983799	862.521
eeHtautau	0.463400000	1200000	2589555	1125.894
eeHWW	1.590000000	1100000	691824	300.793
eeHZZ	0.195100000	1200000	6150692	2674.214
mumuHbb	2.438000000	1000000	410172	178.336
mumuHcc	0.121000000	1100000	9090909	3952.569
mumuHss	0.000837100	1000000	1194600406	519391.481
mumuHgg	0.342600000	900000	2626970	1142.161
mumuHtautau	0.262500000	900000	3428571	1490.683
mumuHWW	0.900700000	1100000	1221272	530.988
mumuHZZ	0.110500000	800000	7239819	3147.747
qqHbb	19.220000000	1200000	62435	27.146
qqHcc	0.954000000	1100000	1153040	501.322
qqHss	0.006599000	1100000	166691923	72474.749
qqHgg	2.701000000	1100000	407257	177.068
qqHtautau	2.070000000	1200000	579710	252.048
qqHWW	7.101000000	1100000	154908	67.351
qqHZZ	0.871500000	1200000	1376936	598.668
ssHbb	10.800000000	1200000	111111	48.309
ssHcc	0.535900000	900000	1679418	730.182
ssHss	0.003708000	1200000	323624595	140706.346
ssHgg	1.518000000	1200000	790514	343.702
ssHtautau	1.163000000	1200000	1031814	448.615
ssHWW	3.989000000	1000000	250689	108.995
ssHZZ	0.489600000	1100000	2246732	976.840
ccHbb	8.407000000	900000	107054	46.545
ccHcc	0.417300000	1100000	2635993	1146.084
ccHss	0.002887000	1100000	381018358	165660.156
ccHgg	1.182000000	1200000	1015228	441.404
ccHtautau	0.905400000	1200000	1325381	576.253
ccHWW	3.107000000	1200000	386225	167.924
ccHZZ	0.381300000	1000000	2622607	1140.264
bbHbb	10.710000000	1200000	112045	48.715
bbHcc	0.531600000	1200000	2257336	981.451
bbHss	0.003678000	1200000	326264274	141854.032
bbHgg	1.506000000	1200000	796813	346.440
bbHtautau	1.153000000	1000000	867303	377.088
bbHWW	3.957000000	1200000	303260	131.852
bbHZZ	0.485700000	1000000	2058884	895.167
nuenueZ	126.240000000	1400000	11090	4.822
WW	10716.500000000	11754213	1097	0.477
ZZ	642.800000000	11470944	17845	7.759
Zqq	21414.900000000	6000000	280	0.122
Zee	1527.000000000	3000000	1965	0.854
Zmumu	2285.800000000	6600000	2887	1.255
ttbar	800.000000000	2700000	3375	1.467

eeH almost 2x larger than mumuH due to Z fusion contribution

$\nu\nu$H receives large contribution from WW fusion

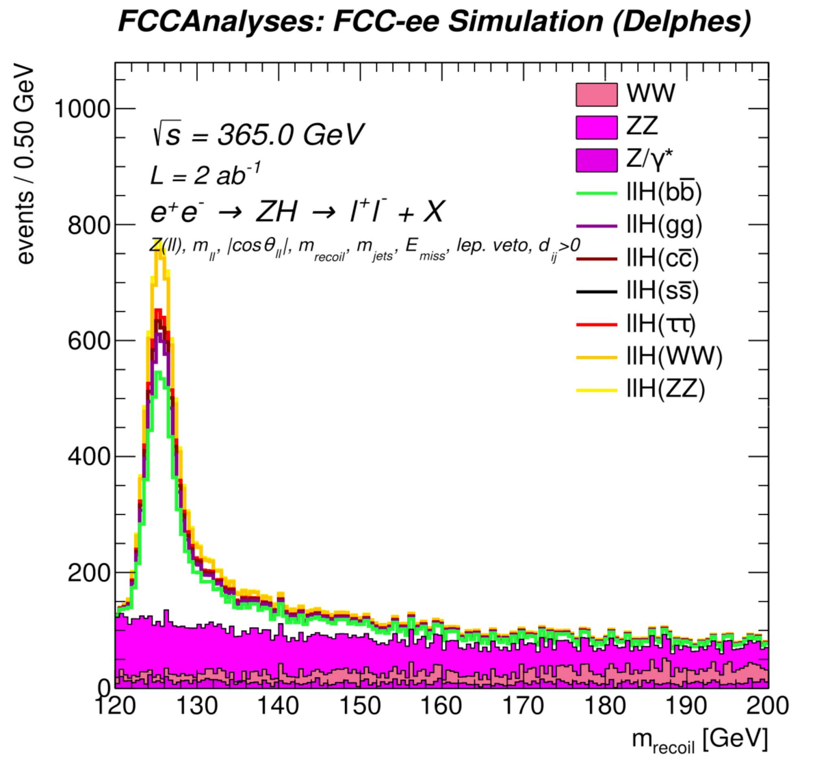




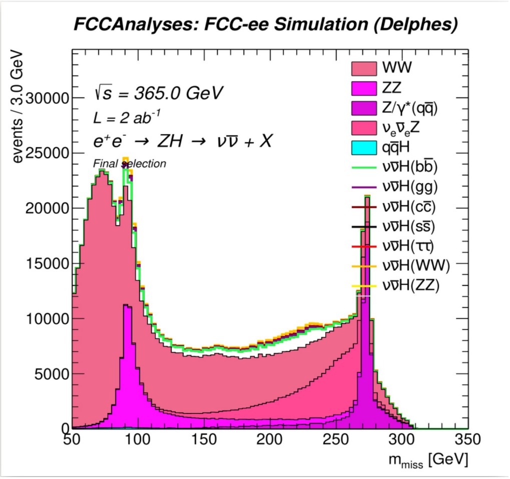
Cross sections predicted by Whizard

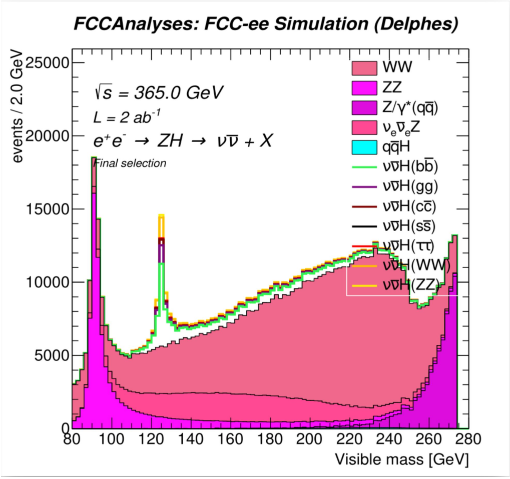
365 GeV - selection

llH



$\nu\nu$H

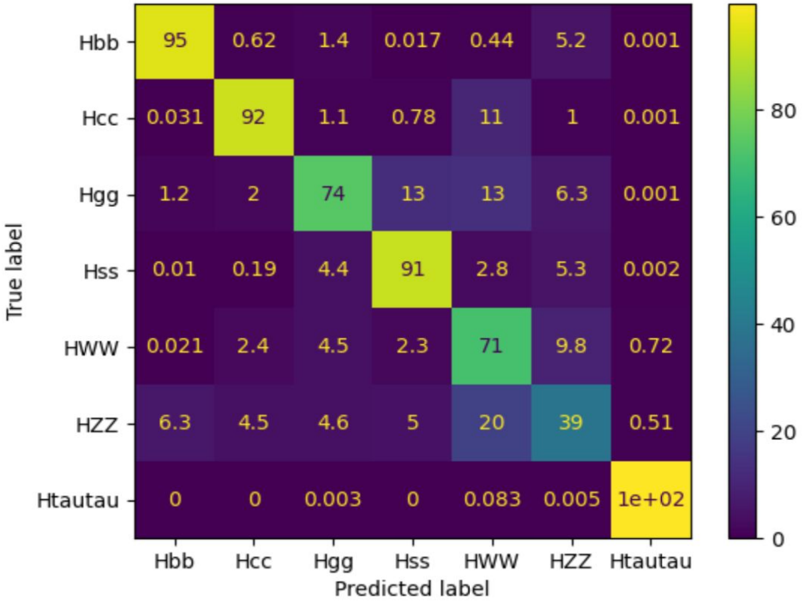




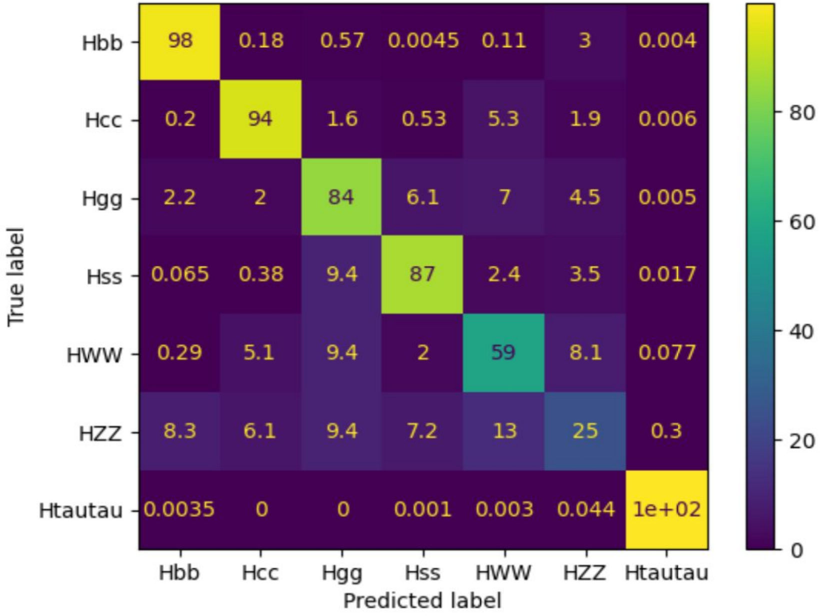
365 GeV - MVA training

- Use same variables as for 240 GeV analysis and same training setup

llH



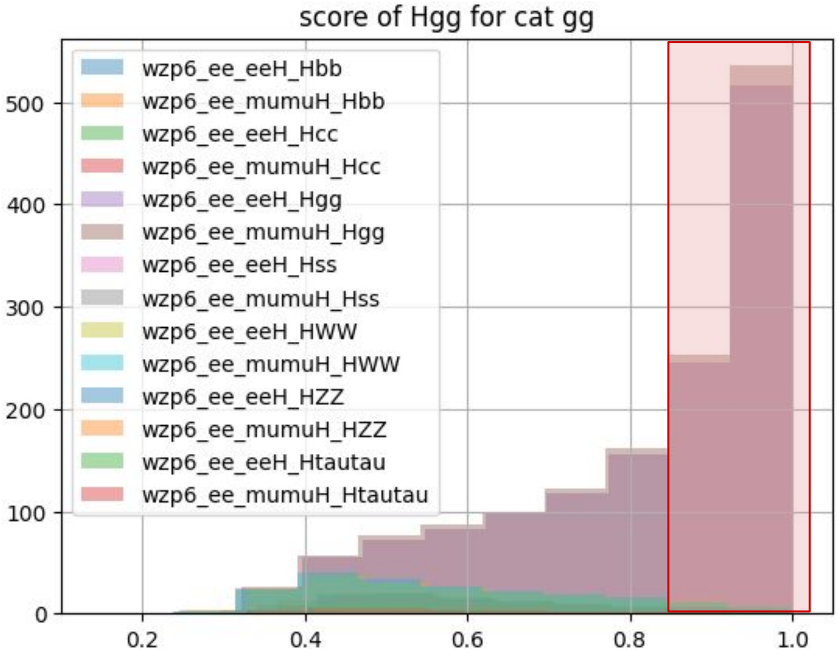
$\nu\nu$H



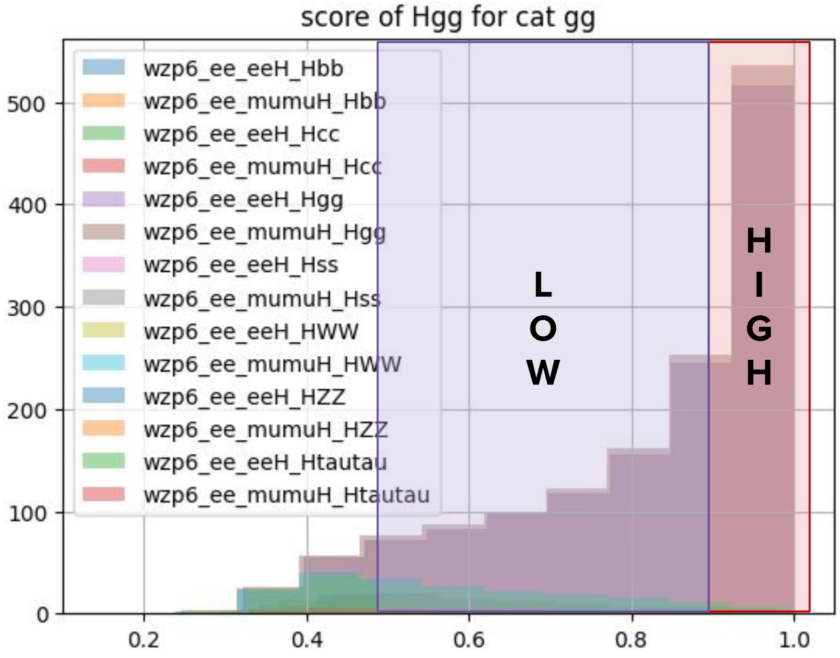
Purity categorization

Goal : increase analysis sensitivity by including purity categories in the samples

before



after



In our analysis we considered **3 purity categories**

Fit

We rebin all histograms to remove all empty bins in the fit to avoid non convergence

We use **Combine** to perform first Zll and Znunu fits independently

Systematics :

- MCstats
- 5% background norm.

Both channels are studied for a number of purity cats i = 1, 2, 3

We perform then the **combination** of the two channels

240 GeV = 7.2ab-1 || 365 GeV = 2.3ab-1

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H 240	0.83	4.84	2.65	287.06	2.08	16.03	4.93
Z(ll)H 365	1.97	12.76	6.49	1424.84	6.11	51.07	15.02
Z(ll)H 240+365	0.76	4.53	2.45	281.39	1.97	15.24	4.70
Z($\nu\nu$)H 240	0.35	2.15	0.97	155.64	1.42	13.01	8.19
Z($\nu\nu$)H 365	0.54	3.21	1.81	119.03	2.91	29.46	9.30
Z($\nu\nu$)H 240+365	0.29	1.80	0.85	75.09	1.27	11.49	6.16
Z(ll+$\nu\nu$)H 240	0.32	1.96	0.91	136.24	1.17	9.83	4.22
Z(ll+$\nu\nu$)H 365	0.51	3.16	1.69	85.58	2.56	22.52	7.95
Z(ll+$\nu\nu$)H 240+365	0.27	1.67	0.80	72.46	1.06	8.97	3.74

Results are WIP (especially for the ss cat that needs some possible correction)

Conclusion: next steps

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll+$\nu\nu$)H 240+365	0.27	1.67	0.80	72.46	1.06	8.97	3.74

- Combination with **Z(qq)H(qq)**
- Fix remaining issues with some channels
- Improve purity categorisation using another optimization
- Analysis including **FV-violating** samples and **uu/dd** is **WIP**
- Try to **disentangle VBF from ZH** - for couplings fit at 365 GeV