Measurement of hadronic Higgs boson decays at FCC-ee

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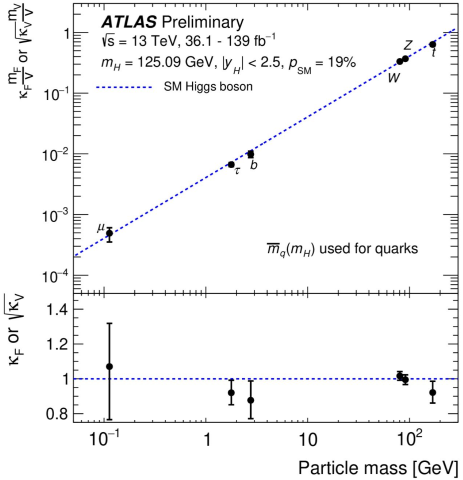
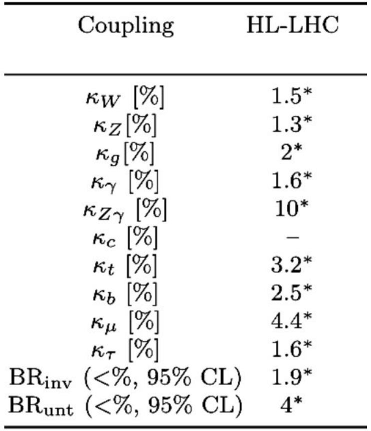
Motivations

Measurement of **Higgs couplings** to qu

2022 (LHC)



~2040 (HL-LHC)



Coupling	HL-LHC
κ_W [%]	1.5*
κ_Z [%]	1.3*
κ_g [%]	2*
κ_γ [%]	1.6*
$\kappa_{Z\gamma}$ [%]	10*
κ_c [%]	–
κ_t [%]	3.2*
κ_b [%]	2.5*
κ_μ [%]	4.4*
κ_τ [%]	1.6*
BR$_{\text{inv}}$ (<%, 95% CL)	1.9*
BR$_{\text{unt}}$ (<%, 95% CL)	4*

Yukawa coupling

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

Coupling-mass relation for fermions in the SM

Deviation from SM → Possible BSM physics

Fully hadronic represents 80% of the Higgs decays

Higgs decay	**H→bb**	**H→WW/ZZ**	**H→gg**	**H→cc**	**H→ss**	**(H→ττ)**
BR	57.7%	11%	8.6%	2.9%	0.024%	(6.2%)

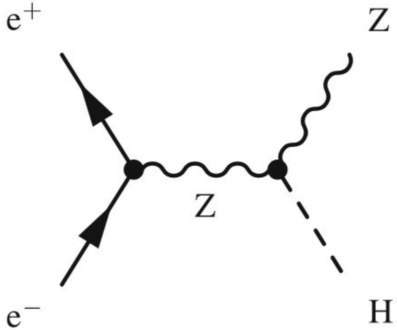
only one observed to this day

Observable at FCC-ee

Also possible future observation of **Flavour-violating** decays

Overview

ZH (Higgstrahlung)



Z decay channels

Z→ll,   l = e,μ
Z→qq
Z→$\nu\nu$

√S & Luminosities (full program)

240 GeV ➜ 10.8ab-1
365 GeV ➜ 3.0ab-1

Samples IDEA (Delphes fast sim)

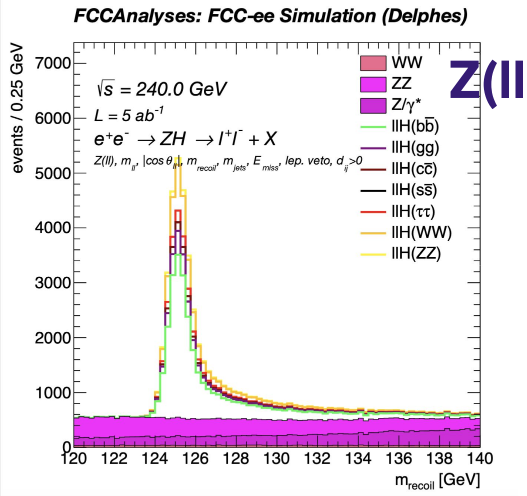
signals ZH@240 - H→bb/cc/gg/ss/WW/ZZ/ττ
ZH(+VBF)@365
N = 2 exclusive kT clustering for Z(ll/$\nu\nu$)**, N = 4 for Z(qq)

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

- **Orthogonal selection** to separate all **Z decay** channels (ll, qq, $\nu\nu$)
- S/B optimization with **cuts** on H dijets and Z decay pairs
  - cuts on E_{jets}, E_{miss}, $p_{leptons}$l, $m_{ll/qq}$, …
- **Categorization** of events in relation to their tagged Higgs decay *(b,c,g,s,W,Z,τ)*
  - categorization using Jet Tagger scores + jet properties
- **Simultaneous fit** on all categories assuming tagging efficiencies

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

ZH⟶lljj/$\nu\nu$jj at 240 GeV



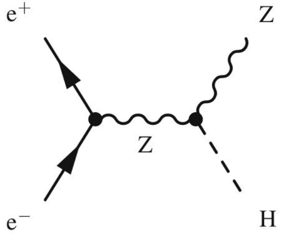
Z(ll)

Signals: Z(ll)H(bb/cc/gg/ss/WW/ZZ/ττ)

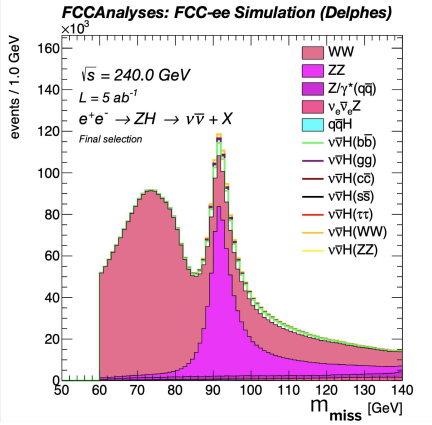
Backgrounds: WW, ZZ, Z/γ*, Zqq, ee, mumu

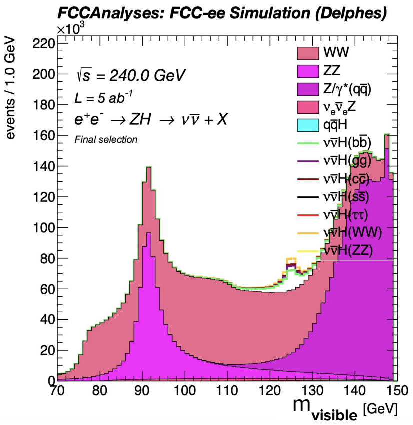
1D Study of the mass recoiling from the **Z**

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



Z($\nu\nu$)





Signals: Z($\nu\nu$)H(bb/cc/gg/ss/WW/ZZ/ττ)

Backgrounds: WW, ZZ, $\nu\nu$Z, Zqq, qqH

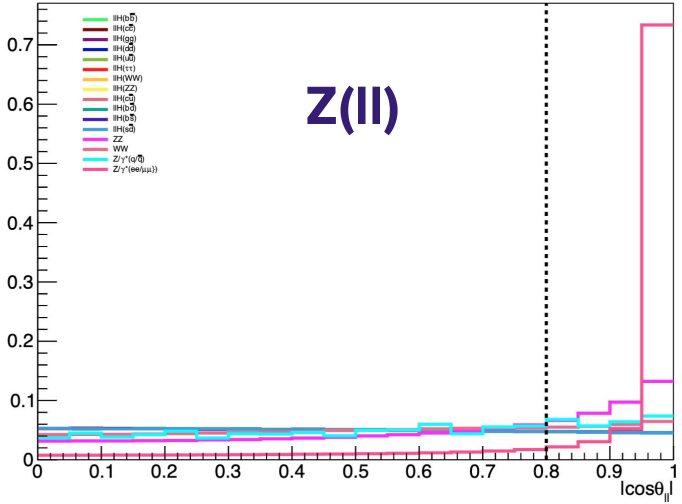
2D Study of the mass recoiling from the **H** + visible mass from **H decay**

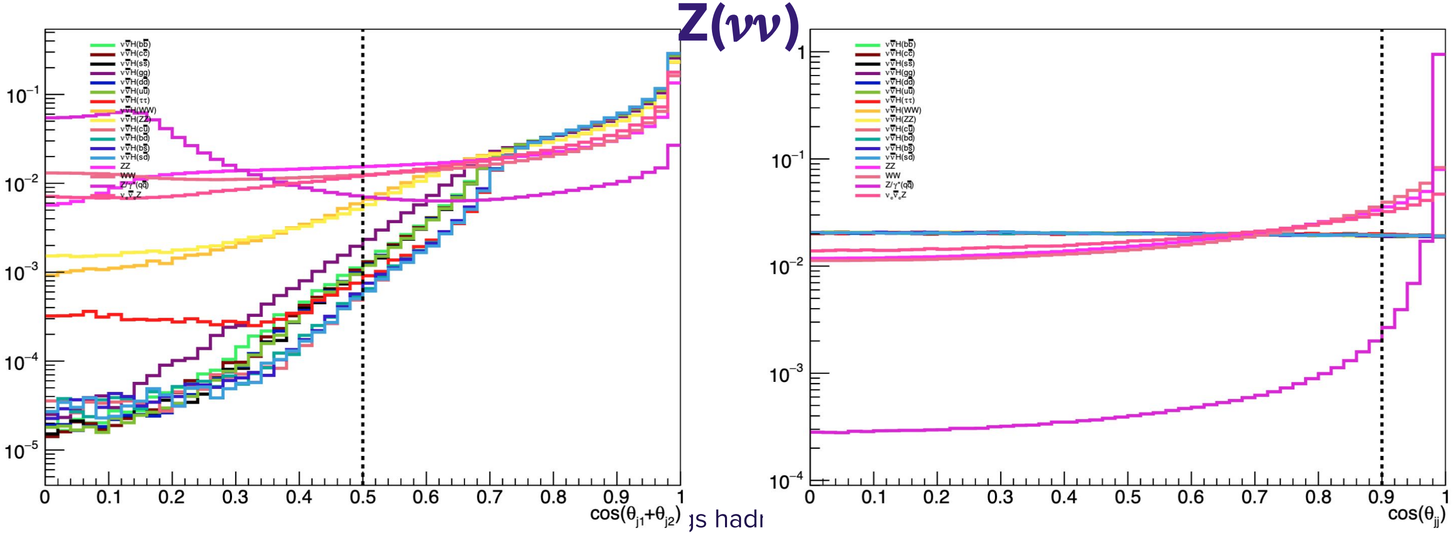
$m_{\mathbf{miss}} (= m_{\boldsymbol{\nu\nu}}) = m_{\mathbf{recoil}}$

$m_{\mathbf{visible}} = m_{\mathbf{jj}}$

Selection update at 240

- **Removed all cuts on angular variables**
  We include these variable in the NN categorization training

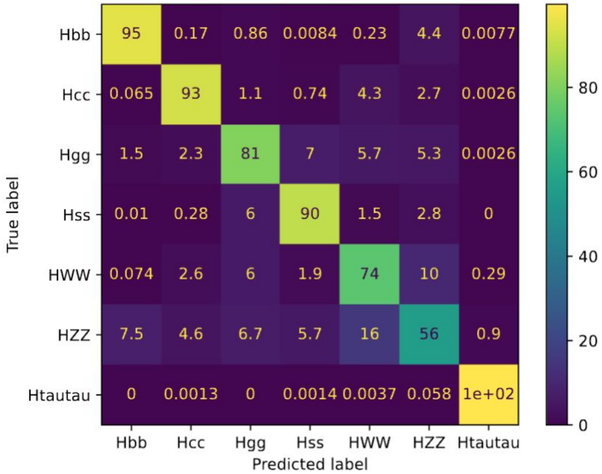




Events categorization

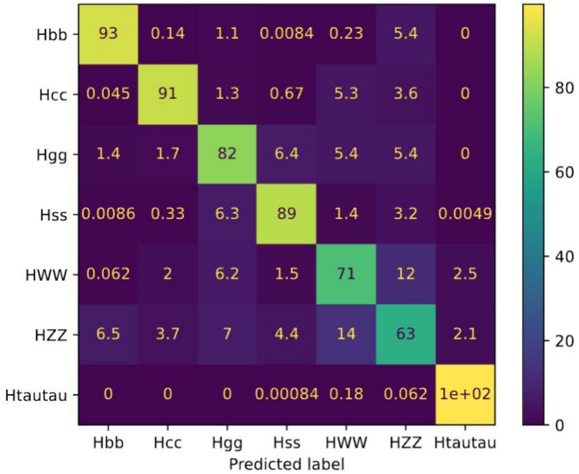
We train a Neural Network to categorize the events in each signal channels

$Z(\nu\nu)$ Confusion Matrix



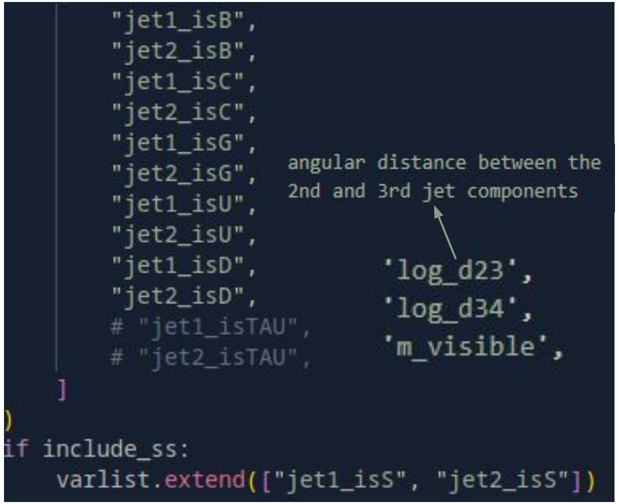
	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau
Hbb	95	0.17	0.86	0.0084	0.23	4.4	0.0077
Hcc	0.065	93	1.1	0.74	4.3	2.7	0.0026
Hgg	1.5	2.3	81	7	5.7	5.3	0.0026
Hss	0.01	0.28	6	90	1.5	2.8	0
HWW	0.074	2.6	6	1.9	74	10	0.29
HZZ	7.5	4.6	6.7	5.7	16	56	0.9
Htautau	0	0.0013	0	0.0014	0.0037	0.058	1e+02

Z(ll) Confusion Matrix



	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau
Hbb	93	0.14	1.1	0.0084	0.23	5.4	0
Hcc	0.045	91	1.3	0.67	5.3	3.6	0
Hgg	1.4	1.7	82	6.4	5.4	5.4	0
Hss	0.0086	0.33	6.3	89	1.4	3.2	0.0049
HWW	0.062	2	6.2	1.5	71	12	2.5
HZZ	6.5	3.7	7	4.4	14	63	2.1
Htautau	0	0	0	0.00084	0.18	0.062	1e+02

Training variables

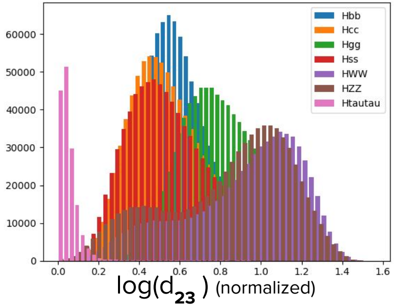


```
        "jet1_isB",
        "jet2_isB",
        "jet1_isC",
        "jet2_isC",
        "jet1_isG",
        "jet2_isG",
        "jet1_isU",
        "jet2_isU",
        "jet1_isD",
        "jet2_isD",
        # "jet1_isTAU",
        # "jet2_isTAU",
    ]
)
if include_ss:
    varlist.extend(["jet1_isS", "jet2_isS"])
```

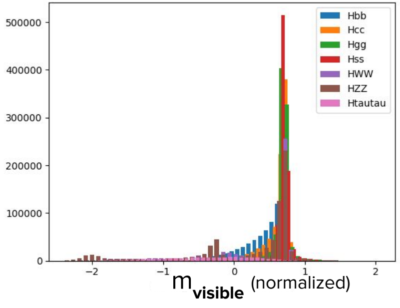
angular distance between the 2nd and 3rd jet components

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

Training variables consist of output scores of a ParticleNet jet tagger which runs after reconstruction + some additional kinematic variables improving sensitivity in some channels



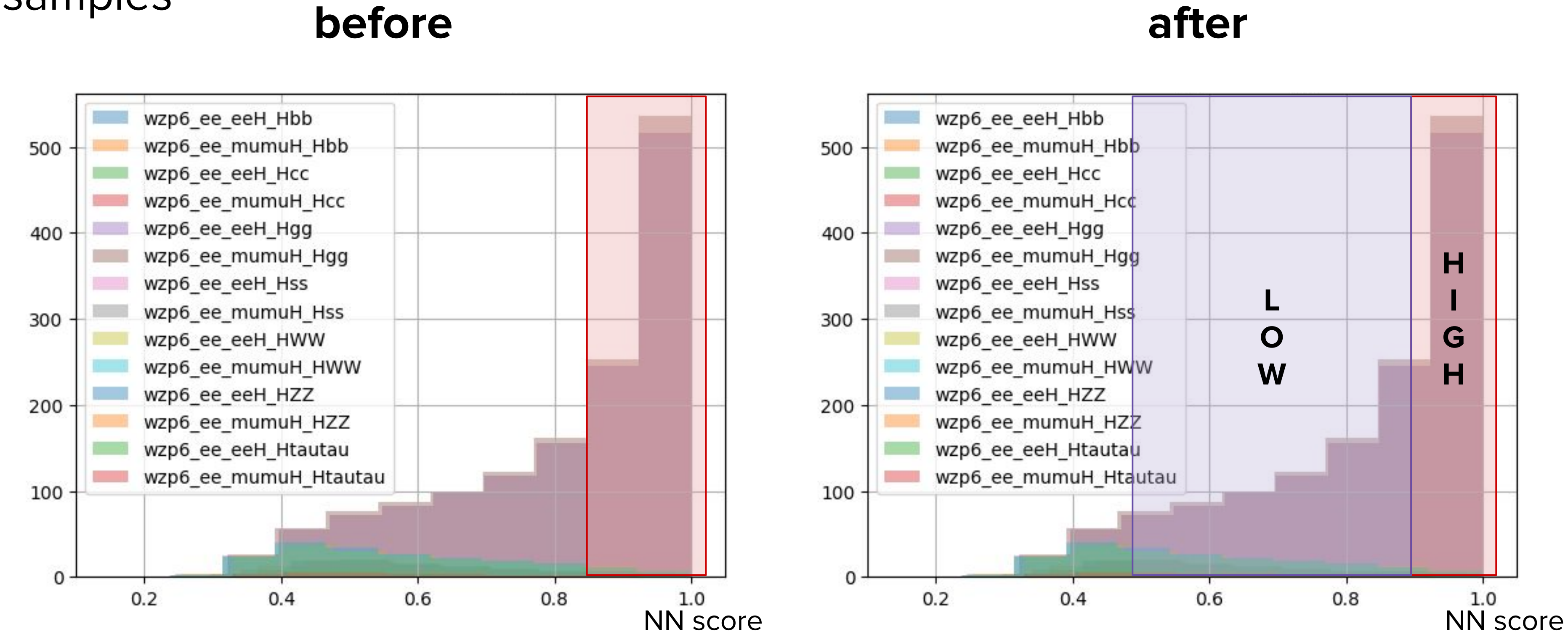
$\log(d_{23})$ (normalized)



$m_{visible}$ (normalized)

Purity categorization

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

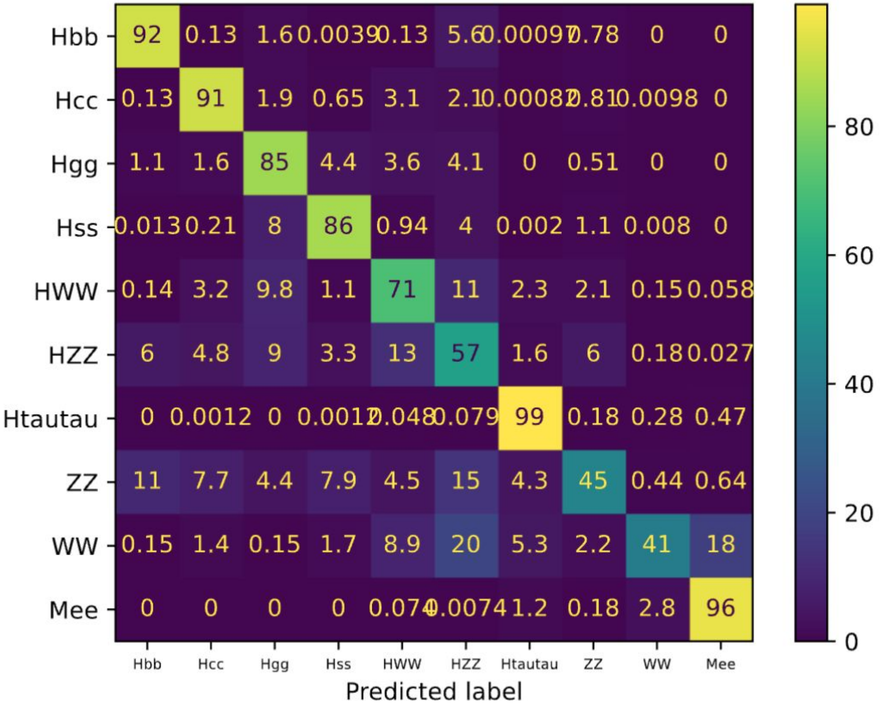


We considered a maximum of **3 purity categories (high, mid, low)**

Categorization update

We included **angular variables** to the training, and introduced new categories for the background

We tried including **recoil masses** to the training to fit the **NN score** directly



	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau	ZZ	WW	Mee
Hbb	92	0.13	1.6	0.0039	0.13	5.6	0.00097	0.78	0	0
Hcc	0.13	91	1.9	0.65	3.1	2.1	0.00082	0.81	0.0098	0
Hgg	1.1	1.6	85	4.4	3.6	4.1	0	0.51	0	0
Hss	0.013	0.21	8	86	0.94	4	0.002	1.1	0.008	0
HWW	0.14	3.2	9.8	1.1	71	11	2.3	2.1	0.15	0.058
HZZ	6	4.8	9	3.3	13	57	1.6	6	0.18	0.027
Htautau	0	0.0012	0	0.0012	0.048	0.079	99	0.18	0.28	0.47
ZZ	11	7.7	4.4	7.9	4.5	15	4.3	45	0.44	0.64
WW	0.15	1.4	0.15	1.7	8.9	20	5.3	2.2	41	18
Mee	0	0	0	0	0.074	0.0074	1.2	0.18	2.8	96

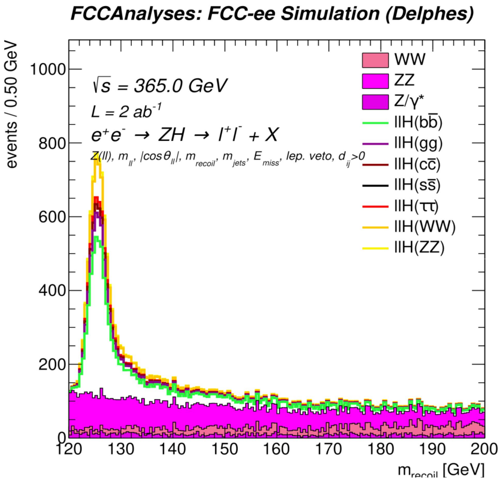
Example of an updated confusion matrix for **Z(ll)** at **240 GeV**

Optimal strategy seem to include the newly uncut **angular vars** but without **recoil which we fit** rather than the score

We keep the purity categorization

ZH⟶lljj at 365 GeV

changes compared to 240 GeV

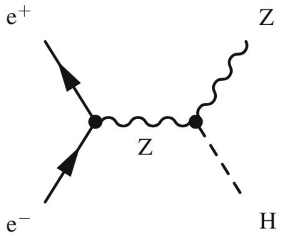


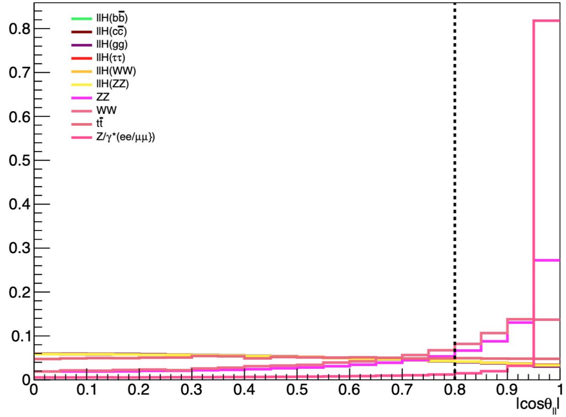
Signals: Z(ll)H(bb/cc/gg/ss/WW/ZZ/$\tau\tau$)

Backgrounds: WW, ZZ, Z/γ*, ~~Zqq~~, ee, mumu, tt

1D Study of the mass recoiling from the **Z**

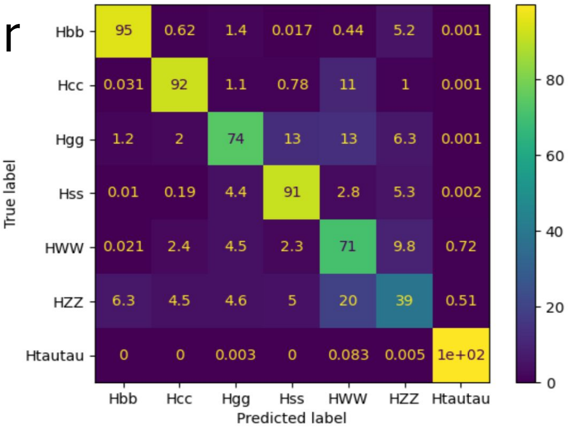
$$\left(E_{ll}+E_H,\overrightarrow{p_{ll}}+\overrightarrow{p_H}\right)=\left(\sqrt{s},\vec{0}\right)\Rightarrow M^2_{recoil}=s+m_Z^2-2E_{ll}\sqrt{s}$$





Same training variables and strategy as for 240GeV

Z(ll) Confusion Matrix



True label \ Predicted label	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau
Hbb	95	0.62	1.4	0.017	0.44	5.2	0.001
Hcc	0.031	92	1.1	0.78	11	1	0.001
Hgg	1.2	2	74	13	13	6.3	0.001
Hss	0.01	0.19	4.4	91	2.8	5.3	0.002
HWW	0.021	2.4	4.5	2.3	71	9.8	0.72
HZZ	6.3	4.5	4.6	5	20	39	0.51
Htautau	0	0	0.003	0	0.083	0.005	1e+02

Results - Combination at 240 GeV

Fitting using **CMS** tool **CombineTF** to extract σ.BR in each category

Monte Carlo stats uncertainties

Backgrounds are let fully floating

Yields available in the Backup

Results comparison

OLD

NEW

Expected sensitivity (%) of σ(ZH).BR(H⟶jj) at 68% CL L = 10.8ab-1

240 GeV	H⟶bb	H⟶cc	H⟶gg	H⟶ss	H⟶ZZ	H⟶WW	H⟶ττ
Z⟶ll	0.68	4.02	2.18	234	13.66	1.78	4.08
Z⟶ll	0.61	3.48	1.89	219	7.99	1.48	2.53
Z⟶νν (BNL)	0.33	2.27	0.94	137	19.84	1.89	21.76
Z⟶νν (APC)	0.36	2.18	1.10	151	15.29	1.51	11
Z⟶νν (APC)	0.34	1.98	0.99	90.95	10.40	1.33	9.65

365 GeV	H⟶bb	H⟶cc	H⟶gg	H⟶ss	H⟶ZZ	H⟶WW	H⟶ττ
Z⟶ll	1.74	11.29	5.74	1169	44	5.61	13.15
Z⟶ll	1.38	9.92	4.48	1082	21.76	3.48	6.43

Combination at 240 GeV

OLD

NEW

Expected sensitivity (%) of σ.BR(H⟶jj) at 68% CL L = 10.8ab-1

240 GeV	H⟶bb	H⟶cc	H⟶gg	H⟶ss	H⟶ZZ	H⟶WW	H⟶ττ
Combined (BNL)	0.21	1.66	0.8	104.99	10.07	1.16	3.97
Combined (APC)	0.22	1.65	0.93	121	9.56	1.11	3.79
Combined	0.21	1.53	0.84	82.54	6.23	0.97	2.44

Further optimization are being tested, as **combining background NN categories** or slight purity categories optimization for **Zll** at **240GeV**

Started producing samples to conduct a **ZH/VBF separation at 240GeV**

Working on some cross checks for results for **Z($\nu\nu$)** at **365GeV** (before implementing new optimizations)

Comparisons with ILC

Valentin Deumier

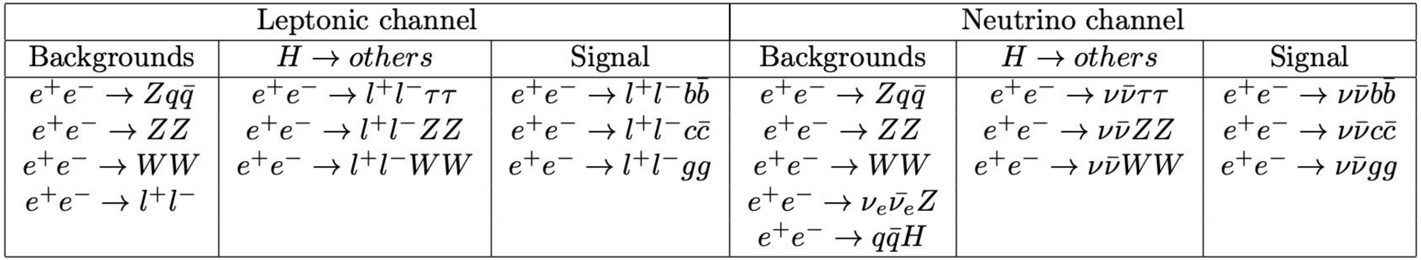
Main changes to compare with ILC

√S & Luminosities (full program)

240 GeV ➔ 375fb-1

All fits were performed on the **NN categorization score**

We consider only three Higgs decay as main categories and merge all the backgrounds



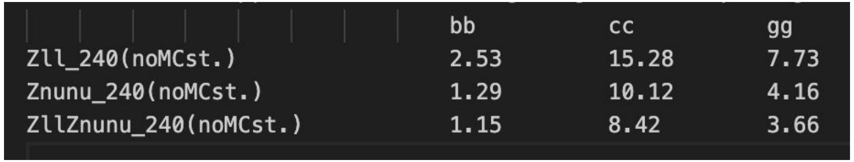
Leptonic channel			Neutrino channel		
Backgrounds	$H \rightarrow others$	Signal	Backgrounds	$H \rightarrow others$	Signal
$e^+e^- \rightarrow Zq\bar{q}$	$e^+e^- \rightarrow l^+l^-\tau\tau$	$e^+e^- \rightarrow l^+l^-b\bar{b}$	$e^+e^- \rightarrow Zq\bar{q}$	$e^+e^- \rightarrow \nu\bar{\nu}\tau\tau$	$e^+e^- \rightarrow \nu\bar{\nu}b\bar{b}$
$e^+e^- \rightarrow ZZ$	$e^+e^- \rightarrow l^+l^-ZZ$	$e^+e^- \rightarrow l^+l^-c\bar{c}$	$e^+e^- \rightarrow ZZ$	$e^+e^- \rightarrow \nu\bar{\nu}ZZ$	$e^+e^- \rightarrow \nu\bar{\nu}c\bar{c}$
$e^+e^- \rightarrow WW$	$e^+e^- \rightarrow l^+l^-WW$	$e^+e^- \rightarrow l^+l^-gg$	$e^+e^- \rightarrow WW$	$e^+e^- \rightarrow \nu\bar{\nu}WW$	$e^+e^- \rightarrow \nu\bar{\nu}gg$
$e^+e^- \rightarrow l^+l^-$			$e^+e^- \rightarrow \nu_e\bar{\nu}_eZ$		
			$e^+e^- \rightarrow q\bar{q}H$		

Table 4: Processes considered for each channel ($l = e, \mu$ and $q = b, c, u, d, s$)

No MCstats in the fit. Bkg and H(other) are floating

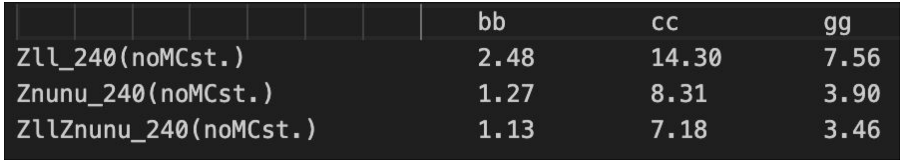
Optimization of the analysis

Initial fit of the score with 5 categories



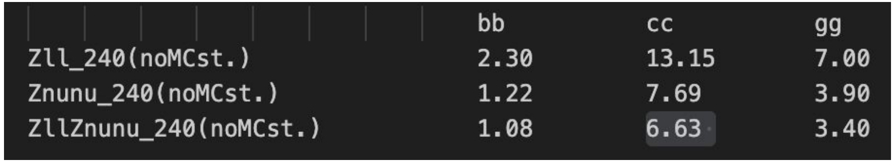
```
                              bb        cc        gg
Zll_240(noMCst.)              2.53      15.28     7.73
Znunu_240(noMCst.)            1.29      10.12     4.16
ZllZnunu_240(noMCst.)         1.15      8.42      3.66
```

Including recoil mass in training + optimizing NN score binning



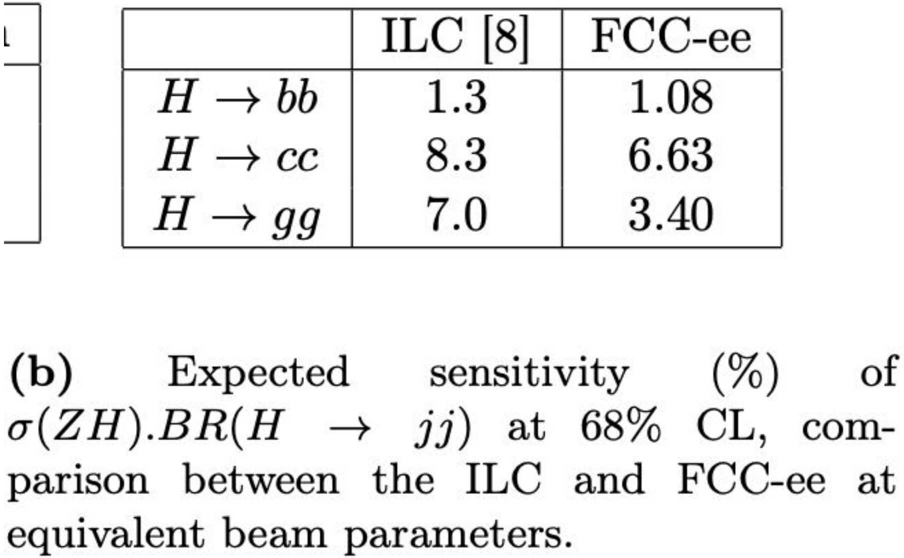
```
                              bb        cc        gg
Zll_240(noMCst.)              2.48      14.30     7.56
Znunu_240(noMCst.)            1.27      8.31      3.90
ZllZnunu_240(noMCst.)         1.13      7.18      3.46
```

Loosening angular variables cuts and including them in training



```
                              bb        cc        gg
Zll_240(noMCst.)              2.30      13.15     7.00
Znunu_240(noMCst.)            1.22      7.69      3.90
ZllZnunu_240(noMCst.)         1.08      6.63      3.40
```

Results comparison with ILC



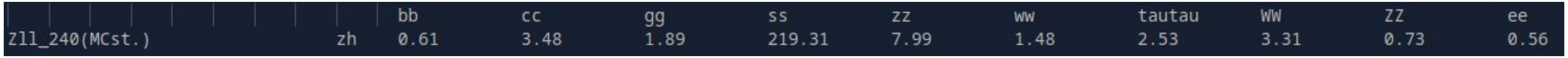
	ILC [8]	FCC-ee
$H \rightarrow bb$	1.3	1.08
$H \rightarrow cc$	8.3	6.63
$H \rightarrow gg$	7.0	3.40

(b) Expected sensitivity (%) of $\sigma(ZH).BR(H \rightarrow jj)$ at 68% CL, comparison between the ILC and FCC-ee at equivalent beam parameters.

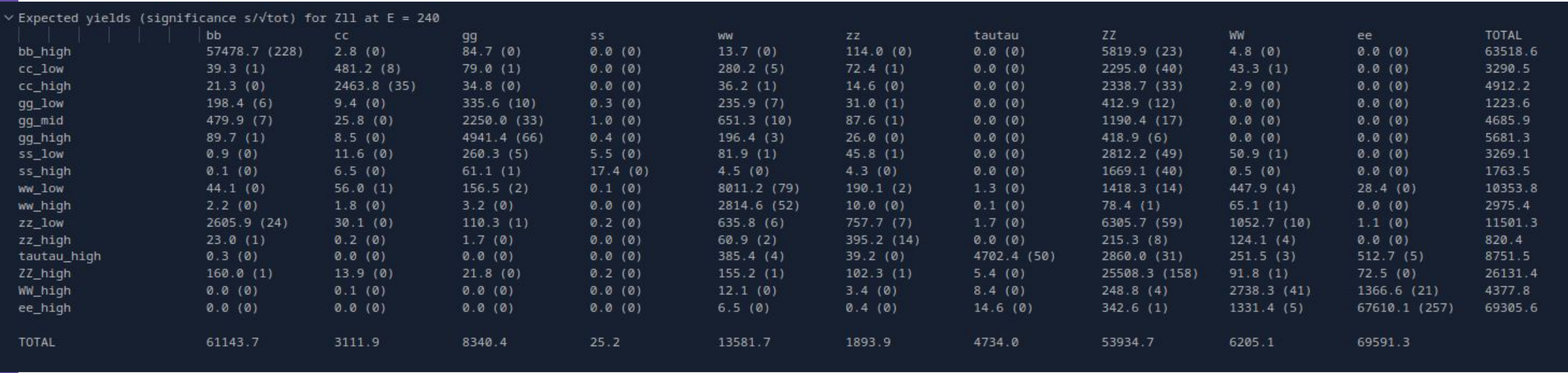
Thank you

Big thanks to : George Iakovidis
and Giovanni Marchiori, Jan Eysermans and Michele Selvaggi

Yields Z(ll) 240 GeV



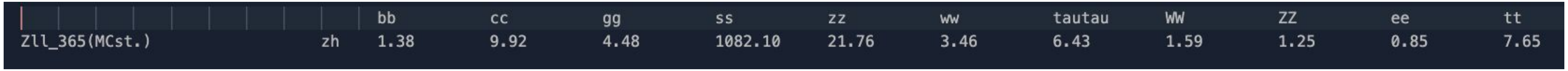
```
                                      bb          cc          gg          ss          zz          ww          tautau      WW          ZZ          ee
Zll_240(MCst.)                  zh    0.61        3.48        1.89        219.31      7.99        1.48        2.53        3.31        0.73        0.56
```



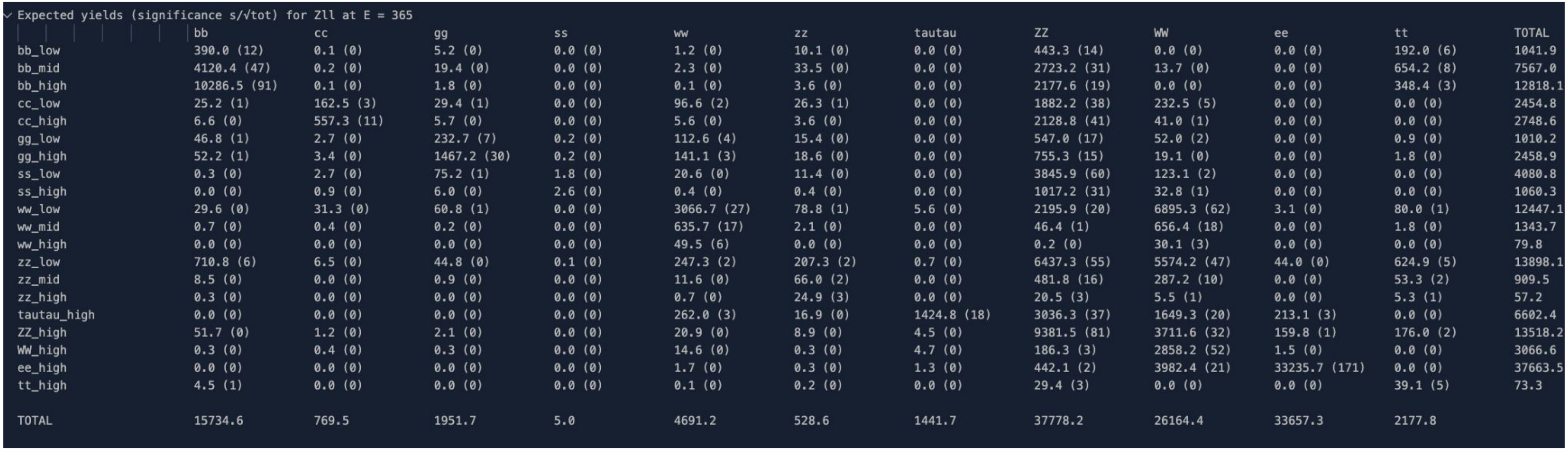
```
Expected yields (significance s/√tot) for Zll at E = 240
                         bb               cc               gg               ss               ww               zz               tautau           ZZ               WW               ee               TOTAL
bb_high                  57478.7 (228)    2.8 (0)          84.7 (0)         0.0 (0)          13.7 (0)         114.0 (0)        0.0 (0)          5819.9 (23)      4.8 (0)          0.0 (0)          63518.6
cc_low                   39.3 (1)         481.2 (8)        79.0 (1)         0.0 (0)          280.2 (5)        72.4 (1)         0.0 (0)          2295.0 (40)      43.3 (1)         0.0 (0)          3290.5
cc_high                  21.3 (0)         2463.8 (35)      34.8 (0)         0.0 (0)          36.2 (1)         14.6 (0)         0.0 (0)          2338.7 (33)      2.9 (0)          0.0 (0)          4912.2
gg_low                   198.4 (6)        9.4 (0)          335.6 (10)       0.3 (0)          235.9 (7)        31.0 (1)         0.0 (0)          412.9 (12)       0.0 (0)          0.0 (0)          1223.6
gg_mid                   479.9 (7)        25.8 (0)         2250.0 (33)      1.0 (0)          651.3 (10)       87.6 (1)         0.0 (0)          1190.4 (17)      0.0 (0)          0.0 (0)          4685.9
gg_high                  89.7 (1)         8.5 (0)          4941.4 (66)      0.4 (0)          196.4 (3)        26.0 (0)         0.0 (0)          418.9 (6)        0.0 (0)          0.0 (0)          5681.3
ss_low                   0.9 (0)          11.6 (0)         260.3 (5)        5.5 (0)          81.9 (1)         45.8 (1)         0.0 (0)          2812.2 (49)      50.9 (1)         0.0 (0)          3269.1
ss_high                  0.1 (0)          6.5 (0)          61.1 (1)         17.4 (0)         4.5 (0)          4.3 (0)          0.0 (0)          1669.1 (40)      0.5 (0)          0.0 (0)          1763.5
ww_low                   44.1 (0)         56.0 (1)         156.5 (2)        0.1 (0)          8011.2 (79)      190.1 (2)        1.3 (0)          1418.3 (14)      447.9 (4)        28.4 (0)         10353.8
ww_high                  2.2 (0)          1.8 (0)          3.2 (0)          0.0 (0)          2814.6 (52)      10.0 (0)         0.1 (0)          78.4 (1)         65.1 (1)         0.0 (0)          2975.4
zz_low                   2605.9 (24)      30.1 (0)         110.3 (1)        0.2 (0)          635.8 (6)        757.7 (7)        1.7 (0)          6305.7 (59)      1052.7 (10)      1.1 (0)          11501.3
zz_high                  23.0 (1)         0.2 (0)          1.7 (0)          0.0 (0)          60.9 (2)         395.2 (14)       0.0 (0)          215.3 (8)        124.1 (4)        0.0 (0)          820.4
tautau_high              0.3 (0)          0.0 (0)          0.0 (0)          0.0 (0)          385.4 (4)        39.2 (0)         4702.4 (50)      2860.0 (31)      251.5 (3)        512.7 (5)        8751.5
ZZ_high                  160.0 (1)        13.9 (0)         21.8 (0)         0.2 (0)          155.2 (1)        102.3 (1)        5.4 (0)          25508.3 (158)    91.8 (1)         72.5 (0)         26131.4
WW_high                  0.0 (0)          0.1 (0)          0.0 (0)          0.0 (0)          12.1 (0)         3.4 (0)          8.4 (0)          248.8 (4)        2738.3 (41)      1366.6 (21)      4377.8
ee_high                  0.0 (0)          0.0 (0)          0.0 (0)          0.0 (0)          6.5 (0)          0.4 (0)          14.6 (0)         342.6 (1)        1331.4 (5)       67610.1 (257)    69305.6

TOTAL                    61143.7          3111.9           8340.4           25.2             13581.7          1893.9           4734.0           53934.7          6205.1           69591.3
```

Yields Z(ll) 365 GeV



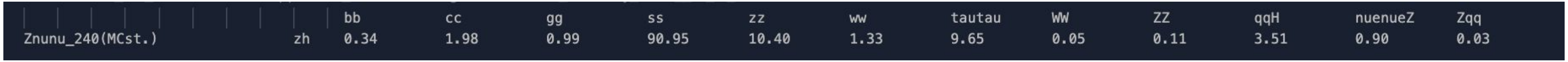
		bb	cc	gg	ss	zz	ww	tautau	WW	ZZ	ee	tt
Zll_365(MCst.)	zh	1.38	9.92	4.48	1082.10	21.76	3.46	6.43	1.59	1.25	0.85	7.65



Expected yields (significance s/√tot) for Zll at E = 365

	bb	cc	gg	ss	ww	zz	tautau	ZZ	WW	ee	tt	TOTAL
bb_low	390.0 (12)	0.1 (0)	5.2 (0)	0.0 (0)	1.2 (0)	10.1 (0)	0.0 (0)	443.3 (14)	0.0 (0)	0.0 (0)	192.0 (6)	1041.9
bb_mid	4120.4 (47)	0.2 (0)	19.4 (0)	0.0 (0)	2.3 (0)	33.5 (0)	0.0 (0)	2723.2 (31)	13.7 (0)	0.0 (0)	654.2 (8)	7567.0
bb_high	10286.5 (91)	0.1 (0)	1.8 (0)	0.0 (0)	0.1 (0)	3.6 (0)	0.0 (0)	2177.6 (19)	0.0 (0)	0.0 (0)	348.4 (3)	12818.1
cc_low	25.2 (1)	162.5 (3)	29.4 (1)	0.0 (0)	96.6 (2)	26.3 (1)	0.0 (0)	1882.2 (38)	232.5 (5)	0.0 (0)	0.0 (0)	2454.8
cc_high	6.6 (0)	557.3 (11)	5.7 (0)	0.0 (0)	5.6 (0)	3.6 (0)	0.0 (0)	2128.8 (41)	41.0 (1)	0.0 (0)	0.0 (0)	2748.6
gg_low	46.8 (1)	2.7 (0)	232.7 (7)	0.2 (0)	112.6 (4)	15.4 (0)	0.0 (0)	547.0 (17)	52.0 (2)	0.0 (0)	0.9 (0)	1010.2
gg_high	52.2 (1)	3.4 (0)	1467.2 (30)	0.2 (0)	141.1 (3)	18.6 (0)	0.0 (0)	755.3 (15)	19.1 (0)	0.0 (0)	1.8 (0)	2458.9
ss_low	0.3 (0)	2.7 (0)	75.2 (1)	1.8 (0)	20.6 (0)	11.4 (0)	0.0 (0)	3845.9 (60)	123.1 (2)	0.0 (0)	0.0 (0)	4080.8
ss_high	0.0 (0)	0.9 (0)	6.0 (0)	2.6 (0)	0.4 (0)	0.4 (0)	0.0 (0)	1017.2 (31)	32.8 (1)	0.0 (0)	0.0 (0)	1060.3
ww_low	29.6 (0)	31.3 (0)	60.8 (1)	0.0 (0)	3066.7 (27)	78.8 (1)	5.6 (0)	2195.9 (20)	6895.3 (62)	3.1 (0)	80.0 (1)	12447.1
ww_mid	0.7 (0)	0.4 (0)	0.2 (0)	0.0 (0)	635.7 (17)	2.1 (0)	0.0 (0)	46.4 (1)	656.4 (18)	0.0 (0)	1.8 (0)	1343.7
ww_high	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	49.5 (6)	0.0 (0)	0.0 (0)	0.2 (0)	30.1 (3)	0.0 (0)	0.0 (0)	79.8
zz_low	710.8 (6)	6.5 (0)	44.8 (0)	0.1 (0)	247.3 (2)	207.3 (2)	0.7 (0)	6437.3 (55)	5574.2 (47)	44.0 (0)	624.9 (5)	13898.1
zz_mid	8.5 (0)	0.0 (0)	0.9 (0)	0.0 (0)	11.6 (0)	66.0 (2)	0.0 (0)	481.8 (16)	287.2 (10)	0.0 (0)	53.3 (2)	909.5
zz_high	0.3 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.7 (0)	24.9 (3)	0.0 (0)	20.5 (3)	5.5 (1)	0.0 (0)	5.3 (1)	57.2
tautau_high	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	262.0 (3)	16.9 (0)	1424.8 (18)	3036.3 (37)	1649.3 (20)	213.1 (3)	0.0 (0)	6602.4
ZZ_high	51.7 (0)	1.2 (0)	2.1 (0)	0.0 (0)	20.9 (0)	8.9 (0)	4.5 (0)	9381.5 (81)	3711.6 (32)	159.8 (1)	176.0 (2)	13518.2
WW_high	0.3 (0)	0.4 (0)	0.3 (0)	0.0 (0)	14.6 (0)	0.3 (0)	4.7 (0)	186.3 (3)	2858.2 (52)	1.5 (0)	0.0 (0)	3066.6
ee_high	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	1.7 (0)	0.3 (0)	1.3 (0)	442.1 (2)	3982.4 (21)	33235.7 (171)	0.0 (0)	37663.5
tt_high	4.5 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (0)	0.2 (0)	0.0 (0)	29.4 (3)	0.0 (0)	0.0 (0)	39.1 (5)	73.3
TOTAL	15734.6	769.5	1951.7	5.0	4691.2	528.6	1441.7	37778.2	26164.4	33657.3	2177.8	

Yields Z($\nu\nu$) 240 GeV



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|   |   |   |   |   |   |   |   |   |  bb          cc          gg          ss          zz          ww          tautau      WW          ZZ          qqH         nuenueZ     Zqq
Znunu_240(MCst.)                zh     0.34        1.98        0.99        90.95       10.40       1.33        9.65        0.05        0.11        3.51        0.90        0.03
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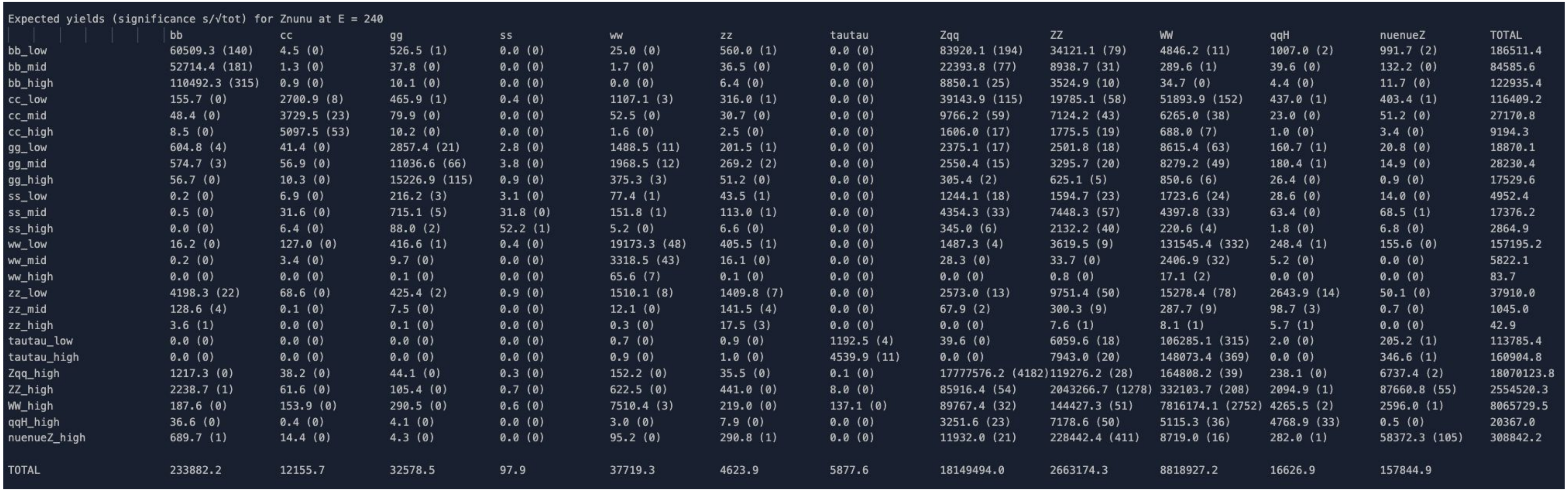

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Expected yields (significance s/√tot) for Znunu at E = 240
|   |   |   |   |   |   |bb               cc               gg               ss               ww               zz               tautau           Zqq              ZZ               WW               qqH              nuenueZ          TOTAL
bb_low                   60509.3 (140)    4.5 (0)          526.5 (1)        0.0 (0)          25.0 (0)         560.0 (1)        0.0 (0)          83920.1 (194)    34121.1 (79)     4846.2 (11)      1007.0 (2)       991.7 (2)        186511.4
bb_mid                   52714.4 (181)    1.3 (0)          37.8 (0)         0.0 (0)          1.7 (0)          36.5 (0)         0.0 (0)          22393.8 (77)     8938.7 (31)      289.6 (1)        39.6 (0)         132.2 (0)        84585.6
bb_high                  110492.3 (315)   0.9 (0)          10.1 (0)         0.0 (0)          0.0 (0)          6.4 (0)          0.0 (0)          8850.1 (25)      3524.9 (10)      34.7 (0)         4.4 (0)          11.7 (0)         122935.4
cc_low                   155.7 (0)        2700.9 (8)       465.9 (1)        0.4 (0)          1107.1 (3)       316.0 (1)        0.0 (0)          39143.9 (115)    19785.1 (58)     51893.9 (152)    437.0 (1)        403.4 (1)        116409.2
cc_mid                   48.4 (0)         3729.5 (23)      79.9 (0)         0.0 (0)          52.5 (0)         30.7 (0)         0.0 (0)          9766.2 (59)      7124.2 (43)      6265.0 (38)      23.0 (0)         51.2 (0)         27170.8
cc_high                  8.5 (0)          5097.5 (53)      10.2 (0)         0.0 (0)          1.6 (0)          2.5 (0)          0.0 (0)          1606.0 (17)      1775.5 (19)      688.0 (7)        1.0 (0)          3.4 (0)          9194.3
gg_low                   604.8 (4)        41.4 (0)         2857.4 (21)      2.8 (0)          1488.5 (11)      201.5 (1)        0.0 (0)          2375.1 (17)      2501.8 (18)      8615.4 (63)      160.7 (1)        20.8 (0)         18870.1
gg_mid                   574.7 (3)        56.9 (0)         11036.6 (66)     3.8 (0)          1968.5 (12)      269.2 (2)        0.0 (0)          2550.4 (15)      3295.7 (20)      8279.2 (49)      180.4 (1)        14.9 (0)         28230.4
gg_high                  56.7 (0)         10.3 (0)         15226.9 (115)    0.9 (0)          375.3 (3)        51.2 (0)         0.0 (0)          305.4 (2)        625.1 (5)        850.6 (6)        26.4 (0)         0.9 (0)          17529.6
ss_low                   0.2 (0)          6.9 (0)          216.2 (3)        3.1 (0)          77.4 (1)         43.5 (1)         0.0 (0)          1244.1 (18)      1594.7 (23)      1723.6 (24)      28.6 (0)         14.0 (0)         4952.4
ss_mid                   0.5 (0)          31.6 (0)         715.1 (5)        31.8 (0)         151.8 (1)        113.0 (1)        0.0 (0)          4354.3 (33)      7448.3 (57)      4397.8 (33)      63.4 (0)         68.5 (1)         17376.2
ss_high                  0.0 (0)          6.4 (0)          88.0 (2)         52.2 (1)         5.2 (0)          6.6 (0)          0.0 (0)          345.0 (6)        2132.2 (40)      220.6 (4)        1.8 (0)          6.8 (0)          2864.9
ww_low                   16.2 (0)         127.0 (0)        416.6 (1)        0.4 (0)          19173.3 (48)     405.5 (1)        0.0 (0)          1487.3 (4)       3619.5 (9)       131545.4 (332)   248.4 (1)        155.6 (0)        157195.2
ww_mid                   0.2 (0)          3.4 (0)          9.7 (0)          0.0 (0)          3318.5 (43)      16.1 (0)         0.0 (0)          28.3 (0)         33.7 (0)         2406.9 (32)      5.2 (0)          0.0 (0)          5822.1
ww_high                  0.0 (0)          0.0 (0)          0.1 (0)          0.0 (0)          65.6 (7)         0.1 (0)          0.0 (0)          0.0 (0)          0.8 (0)          17.1 (2)         0.0 (0)          0.0 (0)          83.7
zz_low                   4198.3 (22)      68.6 (0)         425.4 (2)        0.9 (0)          1510.1 (8)       1409.8 (7)       0.0 (0)          2573.0 (13)      9751.4 (50)      15278.4 (78)     2643.9 (14)      50.1 (0)         37910.0
zz_mid                   128.6 (4)        0.1 (0)          7.5 (0)          0.0 (0)          12.1 (0)         141.5 (4)        0.0 (0)          67.9 (2)         300.3 (9)        287.7 (9)        98.7 (3)         0.7 (0)          1045.0
zz_high                  3.6 (1)          0.0 (0)          0.1 (0)          0.0 (0)          0.3 (0)          17.5 (3)         0.0 (0)          0.0 (0)          7.6 (1)          8.1 (1)          5.7 (1)          0.0 (0)          42.9
tautau_low               0.0 (0)          0.0 (0)          0.0 (0)          0.0 (0)          0.7 (0)          0.9 (0)          1192.5 (4)       39.6 (0)         6059.6 (18)      106285.1 (315)   2.0 (0)          205.2 (1)        113785.4
tautau_high              0.0 (0)          0.0 (0)          0.0 (0)          0.0 (0)          0.9 (0)          1.0 (0)          4539.9 (11)      0.0 (0)          7943.0 (20)      148073.4 (369)   0.0 (0)          346.6 (1)        160904.8
Zqq_high                 1217.3 (0)       38.2 (0)         44.1 (0)         0.3 (0)          152.2 (0)        35.5 (0)         0.1 (0)          17777576.2 (4182)119276.2 (28)    164808.2 (39)    238.1 (0)        6737.4 (2)       18070123.8
ZZ_high                  2238.7 (1)       61.6 (0)         105.4 (0)        0.7 (0)          622.5 (0)        441.0 (0)        8.0 (0)          85916.4 (54)     2043266.7 (1278) 332103.7 (208)   2094.9 (1)       87660.8 (55)     2554520.3
WW_high                  187.6 (0)        153.9 (0)        290.5 (0)        0.6 (0)          7510.4 (3)       219.0 (0)        137.1 (0)        89767.4 (32)     144427.3 (51)    7816174.1 (2752) 4265.5 (2)       2596.0 (1)       8065729.5
qqH_high                 36.6 (0)         0.4 (0)          4.1 (0)          0.0 (0)          3.0 (0)          7.9 (0)          0.0 (0)          3251.6 (23)      7178.6 (50)      5115.3 (36)      4768.9 (33)      0.5 (0)          20367.0
nuenueZ_high             689.7 (1)        14.4 (0)         4.3 (0)          0.0 (0)          95.2 (0)         290.8 (1)        0.0 (0)          11932.0 (21)     228442.4 (411)   8719.0 (16)      282.0 (1)        58372.3 (105)    308842.2

TOTAL                    233882.2         12155.7          32578.5          97.9             37719.3          4623.9           5877.6           18149494.0       2663174.3        8818927.2        16626.9          157844.9
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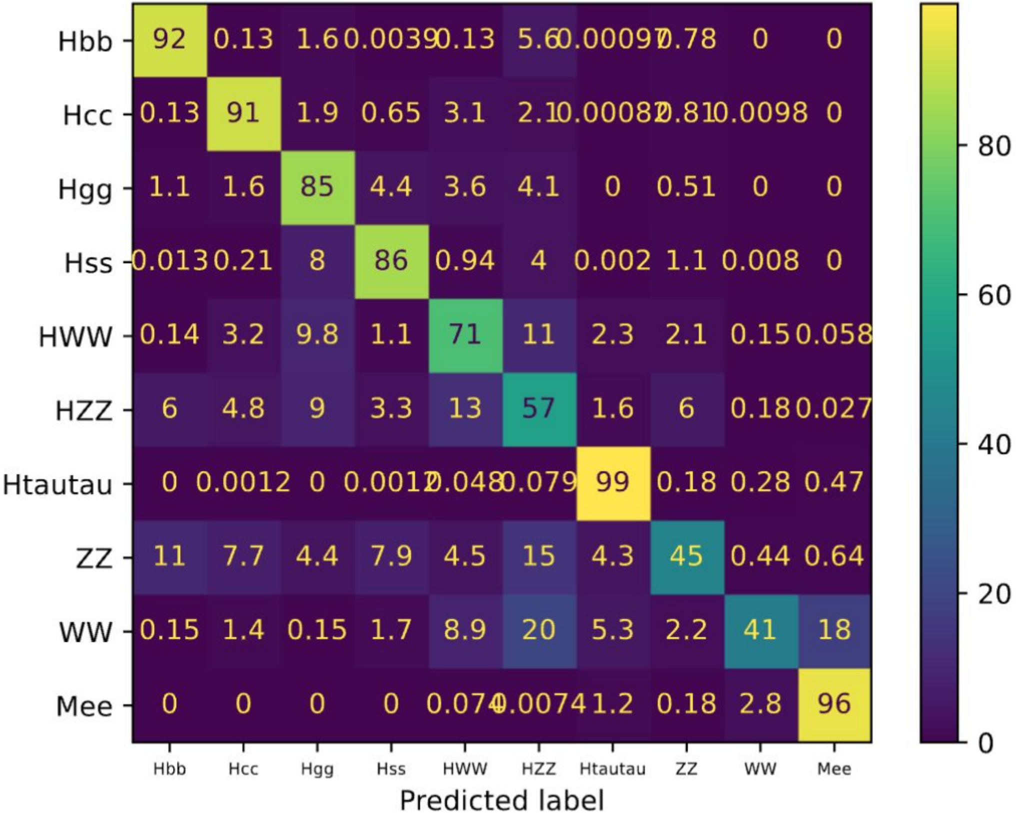
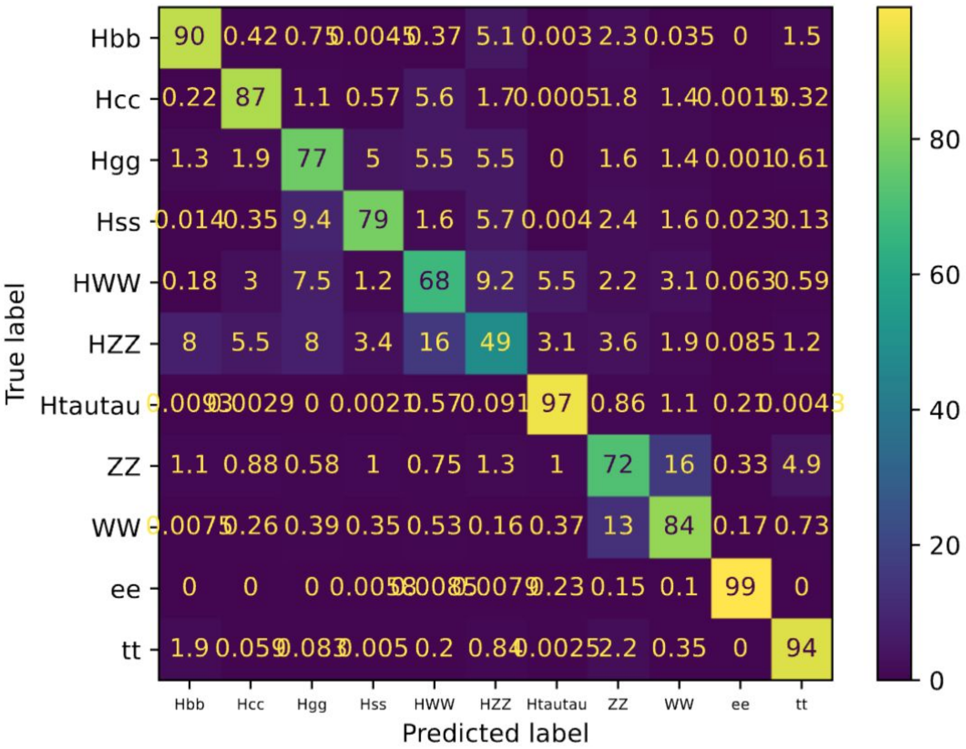
Categorization with background categories - Z(ll) 240



	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau	ZZ	WW	Mee
Hbb	92	0.13	1.6	0.0039	0.13	5.6	0.00097	0.78	0	0
Hcc	0.13	91	1.9	0.65	3.1	2.1	0.00082	0.81	0.0098	0
Hgg	1.1	1.6	85	4.4	3.6	4.1	0	0.51	0	0
Hss	0.013	0.21	8	86	0.94	4	0.002	1.1	0.008	0
HWW	0.14	3.2	9.8	1.1	71	11	2.3	2.1	0.15	0.058
HZZ	6	4.8	9	3.3	13	57	1.6	6	0.18	0.027
Htautau	0	0.0012	0	0.0012	0.048	0.079	99	0.18	0.28	0.47
ZZ	11	7.7	4.4	7.9	4.5	15	4.3	45	0.44	0.64
WW	0.15	1.4	0.15	1.7	8.9	20	5.3	2.2	41	18
Mee	0	0	0	0	0.074	0.0074	1.2	0.18	2.8	96

note : Mee = ee + mumu bkg

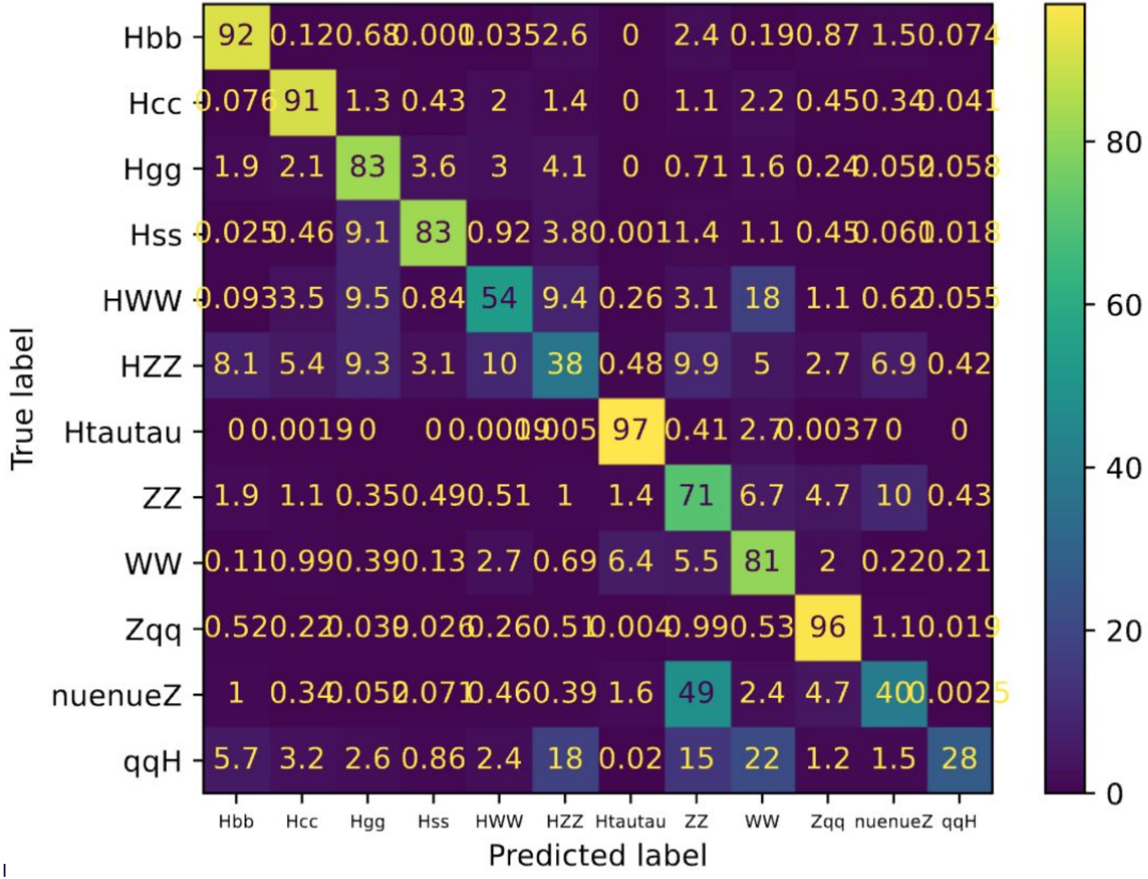
Categorization with background categories - Z(ll) 365



	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau	ZZ	WW	ee	tt
Hbb	90	0.42	0.75	0.0045	0.37	5.1	0.003	2.3	0.035	0	1.5
Hcc	0.22	87	1.1	0.57	5.6	1.7	0.0005	1.8	1.4	0.0015	0.32
Hgg	1.3	1.9	77	5	5.5	5.5	0	1.6	1.4	0.001	0.61
Hss	0.014	0.35	9.4	79	1.6	5.7	0.004	2.4	1.6	0.023	0.13
HWW	0.18	3	7.5	1.2	68	9.2	5.5	2.2	3.1	0.063	0.59
HZZ	8	5.5	8	3.4	16	49	3.1	3.6	1.9	0.085	1.2
Htautau	0.0093	0.0029	0	0.0021	0.57	0.091	97	0.86	1.1	0.21	0.0043
ZZ	1.1	0.88	0.58	1	0.75	1.3	1	72	16	0.33	4.9
WW	0.0075	0.26	0.39	0.35	0.53	0.16	0.37	13	84	0.17	0.73
ee	0	0	0	0.0058	0.0085	0.0079	0.23	0.15	0.1	99	0
tt	1.9	0.059	0.083	0.005	0.2	0.84	0.0025	2.2	0.35	0	94

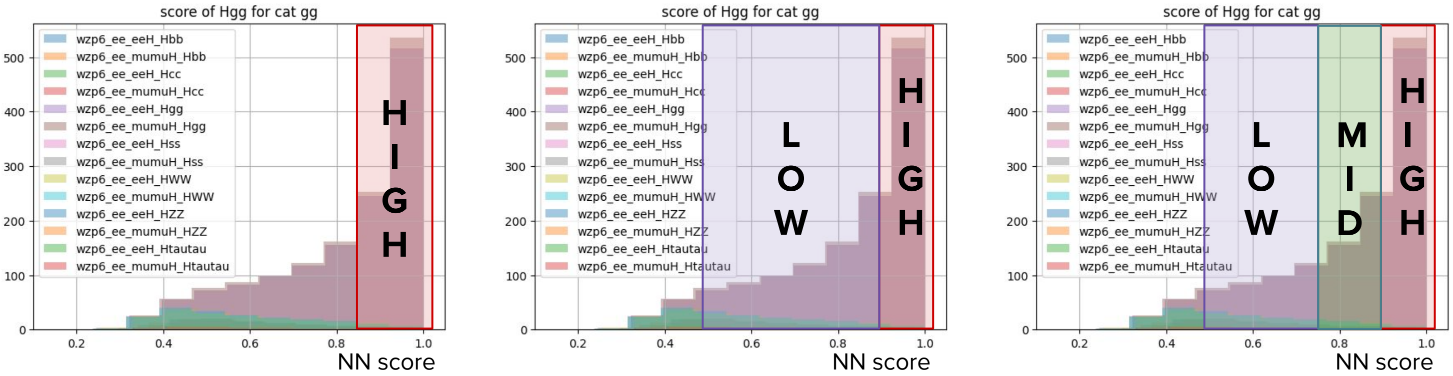
`note : Mee = ee + mumu bkg`

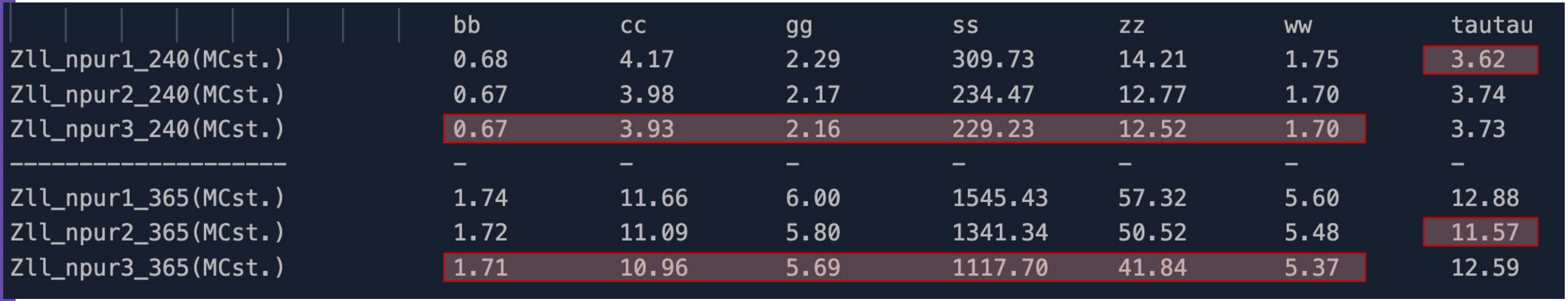
Categorization with background categories - Z($\nu\nu$) 240



	Hbb	Hcc	Hgg	Hss	HWW	HZZ	Htautau	ZZ	WW	Zqq	nuenueZ	qqH
Hbb	92	0.12	0.68	0.0001	0.035	2.6	0	2.4	0.19	0.87	1.5	0.074
Hcc	0.076	91	1.3	0.43	2	1.4	0	1.1	2.2	0.45	0.34	0.041
Hgg	1.9	2.1	83	3.6	3	4.1	0	0.71	1.6	0.24	0.05	0.058
Hss	0.025	0.46	9.1	83	0.92	3.8	0.001	1.4	1.1	0.45	0.06	0.018
HWW	0.093	3.5	9.5	0.84	54	9.4	0.26	3.1	18	1.1	0.62	0.055
HZZ	8.1	5.4	9.3	3.1	10	38	0.48	9.9	5	2.7	6.9	0.42
Htautau	0	0.0019	0	0	0.00019	0.0005	97	0.41	2.7	0.0037	0	0
ZZ	1.9	1.1	0.35	0.49	0.51	1	1.4	71	6.7	4.7	10	0.43
WW	0.11	0.99	0.39	0.13	2.7	0.69	6.4	5.5	81	2	0.22	0.21
Zqq	0.52	0.22	0.039	0.026	0.26	0.51	0.004	0.99	0.53	96	1.1	0.019
nuenueZ	1	0.34	0.052	0.071	0.46	0.39	1.6	49	2.4	4.7	40	0.0025
qqH	5.7	3.2	2.6	0.86	2.4	18	0.02	15	22	1.2	1.5	28

Backup - Purity categories





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| | | | | | | |            bb       cc       gg       ss         zz       ww       tautau
Zll_npur1_240(MCst.)      0.68     4.17     2.29     309.73     14.21    1.75     3.62
Zll_npur2_240(MCst.)      0.67     3.98     2.17     234.47     12.77    1.70     3.74
Zll_npur3_240(MCst.)      0.67     3.93     2.16     229.23     12.52    1.70     3.73
--------------------      -        -        -        -          -        -        -
Zll_npur1_365(MCst.)      1.74     11.66    6.00     1545.43    57.32    5.60     12.88
Zll_npur2_365(MCst.)      1.72     11.09    5.80     1341.34    50.52    5.48     11.57
Zll_npur3_365(MCst.)      1.71     10.96    5.69     1117.70    41.84    5.37     12.59
```

For Z$\nu\nu$, all categories yield the best precision with 3 purity categories

Fitting strategy for all channels

Fitting using **CMS** tool **CombineTF** to extract σ.BR in each category

7 POIs, Hbb, Hcc, Hss, Hgg, Hττ, HWW, HZZ (floating parameters)

Binning :

BNL : 1 GeV bin width (projected in 5 GeV for the recoil mass)

APC : custom binning *by-eye* (negligible/little improvement compared to 1 GeV width)

Empty categories removed from the fit

Rebinned such that :

There is at least one **expected** (sum of sig+bkg) event in each bin

Add 10-6 events in empty bins to help fit convergence, without implementing a bias

Monte Carlo stats uncertainties

No systematics on the backgrounds