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

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Previous results

Last time :

No purity categories for **Z($\nu\nu$)**

Luminosity for 240 GeV was **5 ab-1**, now **7.2 ab-1**

No analysis at 365 GeV

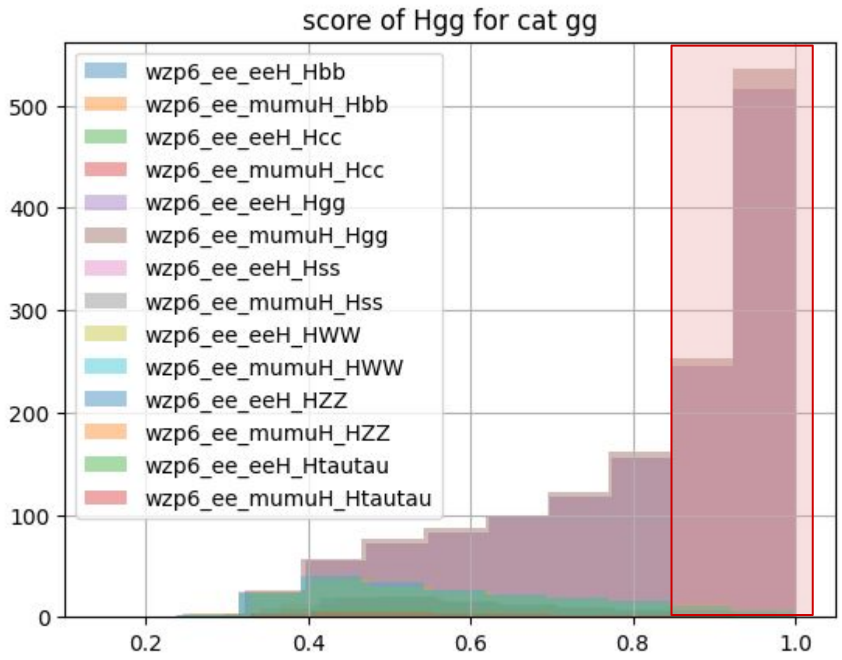
Old results :

Precision (%)	**bb**	**cc**	**gg**	**ss**	**WW**	**ZZ**	**ττ**
template comb.	0.33	2.16	1.10	134	1.56	11.5	4.00
analytic Z(ll)H + template Z(nunu)H	0.35	2.32	1.14	140	1.68	10.7	3.25

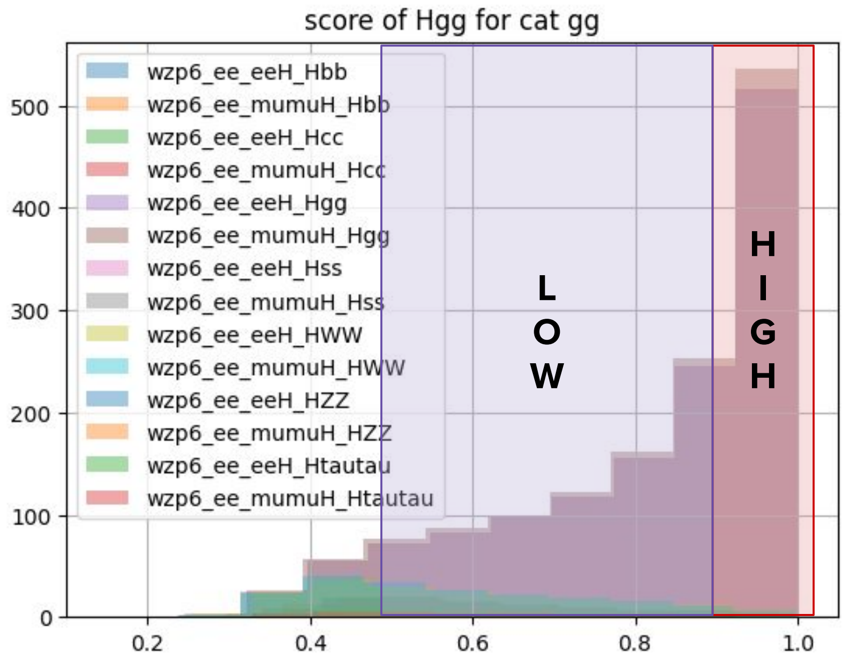
Purity categorization

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

before



after



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

240 GeV

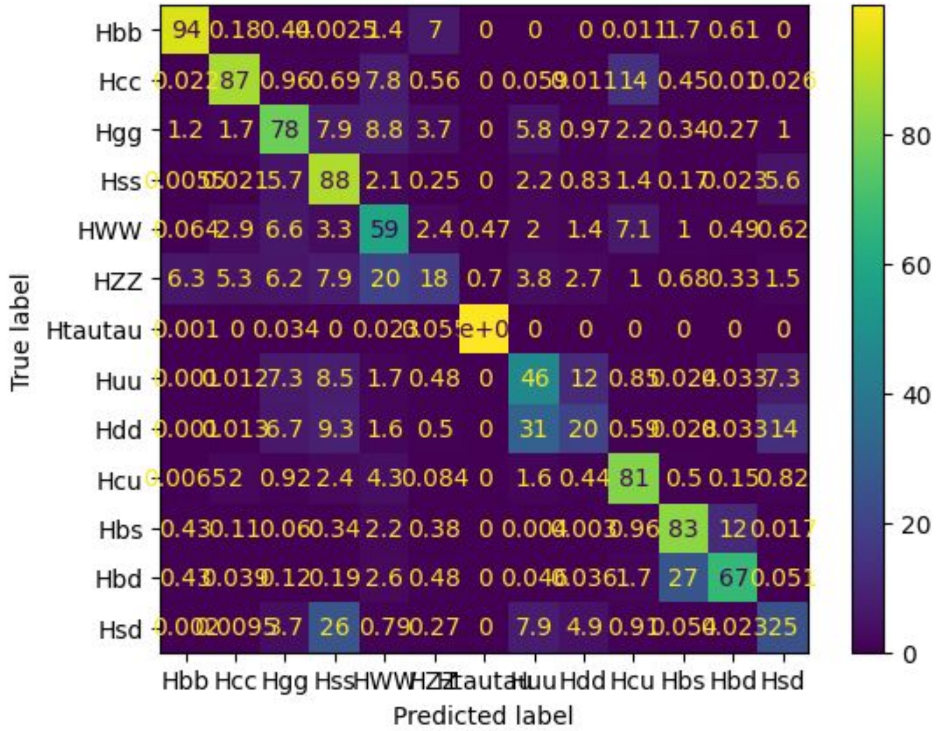
Training updates

Z(ll)H, Z($\nu\nu$)H and combination results

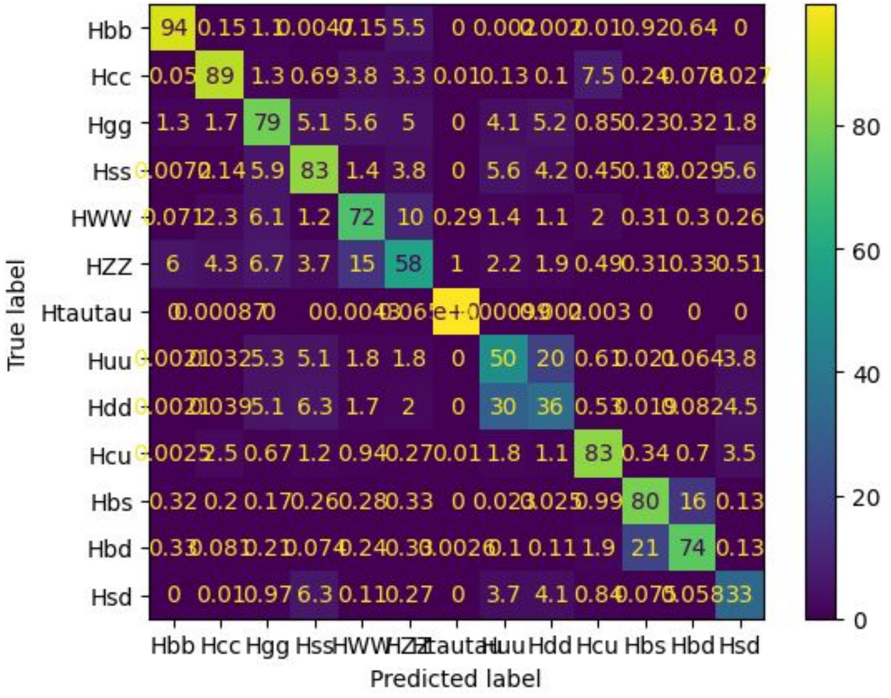
Update on the training

Before, training used only **~40%** of all samples in all categories. Now uses up to **~90%** (except **sd** to prioritize **ss** cat. in the training)

Z(νν)H before

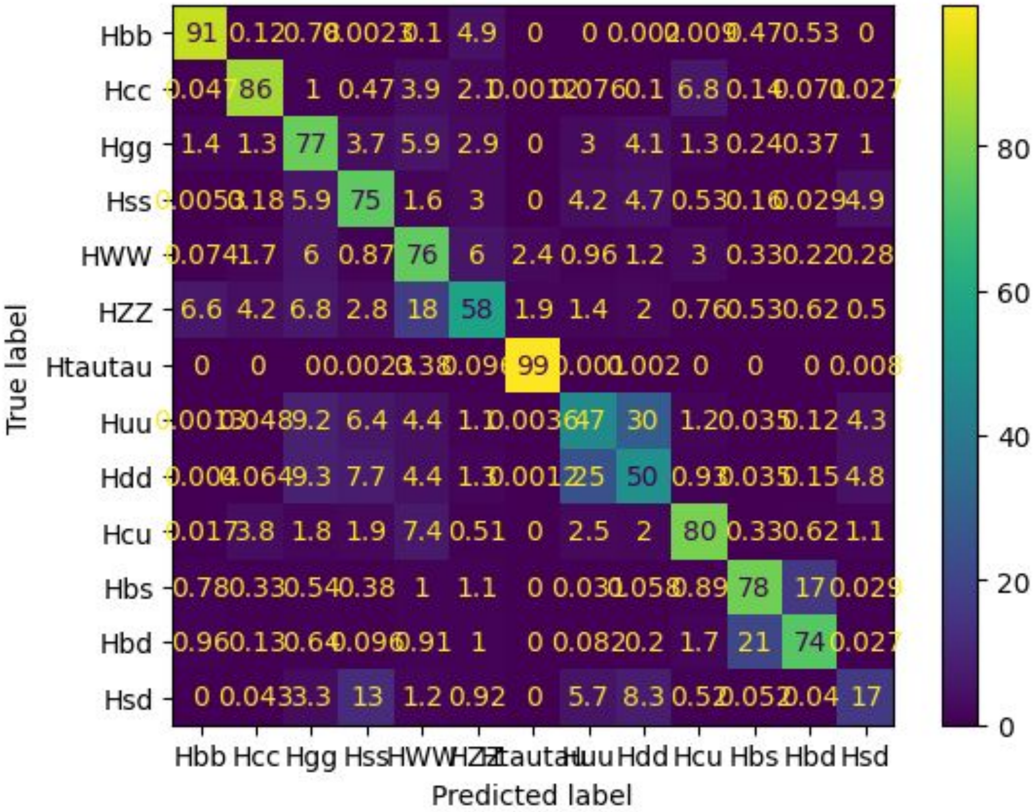


Z(νν)H now



Training parameters

Z(ll)H



Variables :

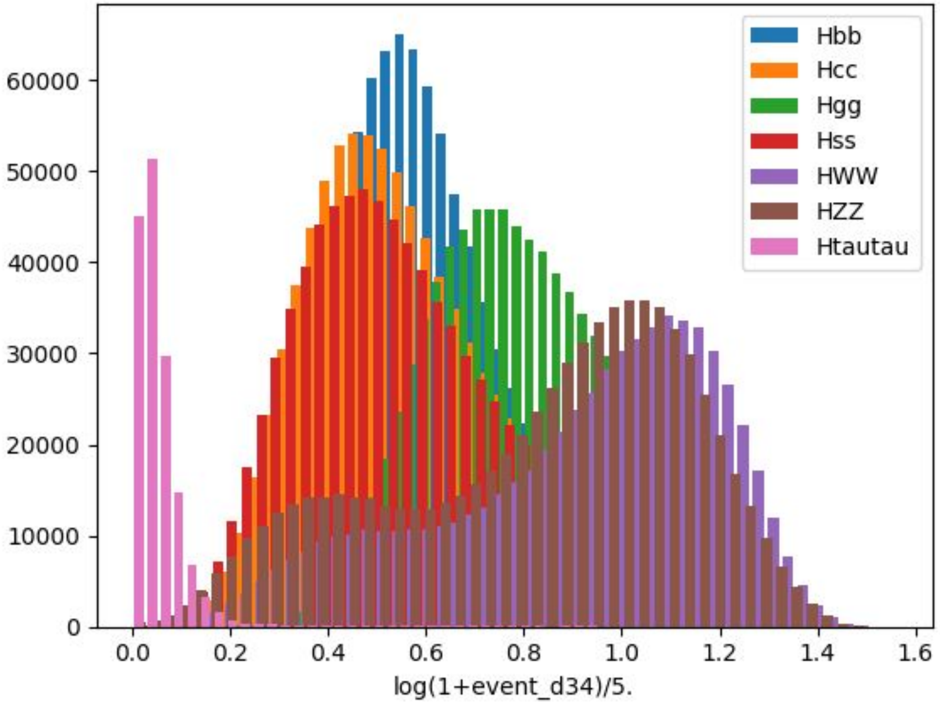
```
        "jet1_isB",
        "jet2_isB",          "log_d23",
        "jet1_isC",          "log_d34",
        "jet2_isC",          "mjj",
        "jet1_isG",
        "jet2_isG",
        "jet1_isU",
        "jet2_isU",
        "jet1_isD",
        "jet2_isD",
        # "jet1_isTAU",
        # "jet2_isTAU",
    ]
)
if include_ss:
    varlist.extend(["jet1_isS", "jet2_isS"])
```

Going beyond **d34** does not improve the performance

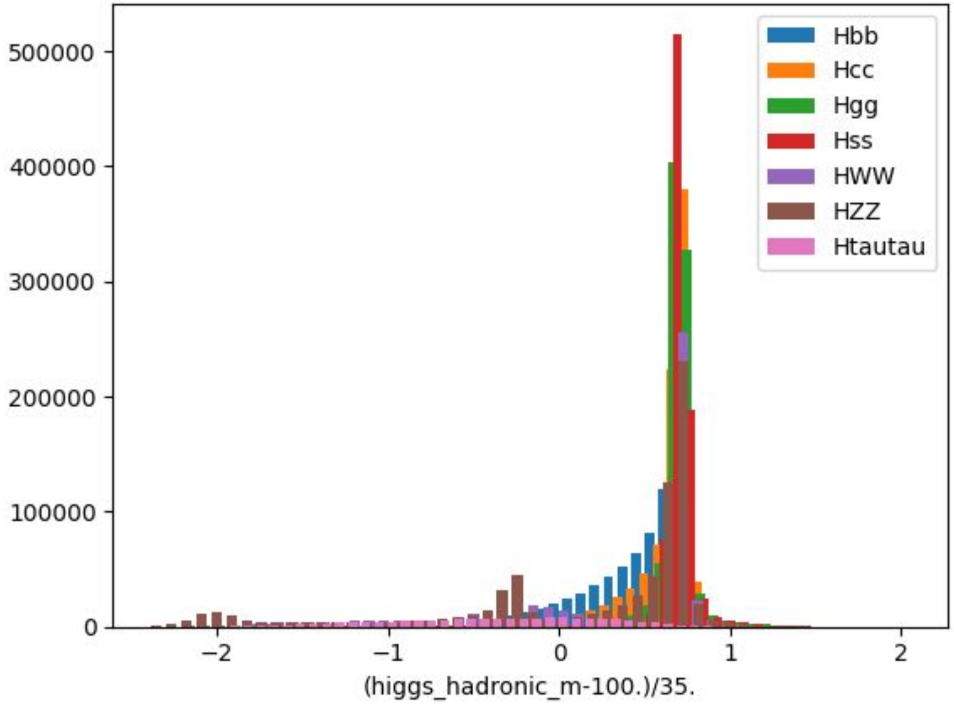
isTAU variable can be removed to ease the training

Training variables

Sufficient to get near perfect tautau labeling



Slightly improves performances in the ZZ cat.



240 GeV results for 7 categories

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H	0.59	3.36	1.88	258	1.44	11.4	3.34
Z(ll)H OLD	0.70	4.06	2.27	269	1.72	13.0	3.97
Z(νν)H	0.30	1.74	0.83	63.13	1.36	5.58	16.19
Z(νν)H OLD	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Z(ll,νν)H	0.26	1.54	0.76	61.24	0.97	4.94	3.27
Z(ll,νν)H OLD	0.33	2.16	1.10	134	1.56	11.5	4.00
(old-new)/old	22%	40%	30%	54%	38%	57%	18%

Systematics:

5% on bkg

MCstats

Conclusions:

Gain of sqrt(7.2/5.0) (20%) with scaling to 7.2ab-1

Improvement of ~15% with new MVA training

365 GeV

Event selection

Training

Z(ll)H, Z($\nu\nu$)H and combination

Combination with 240 GeV

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)

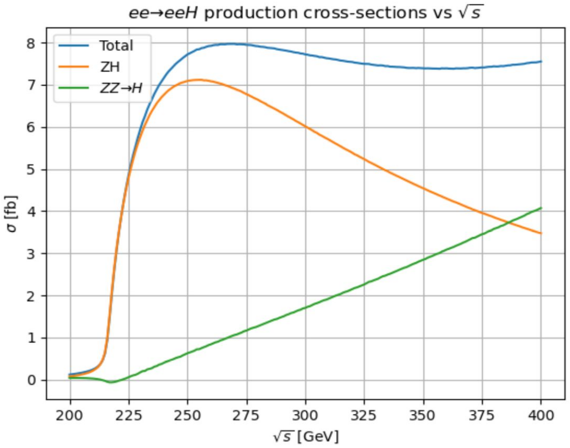
- Same variables used for event selection at 240 GeV, loosening inefficient cuts (e.g. lepton momentum and recoil mass in llH)
  - no attention paid so far to efficiently reconstruct ZZ fusion in eeH channel nor separate WW fusion in ν_e ν_e H channel
- Use isolation to make channels orthogonal and improve 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

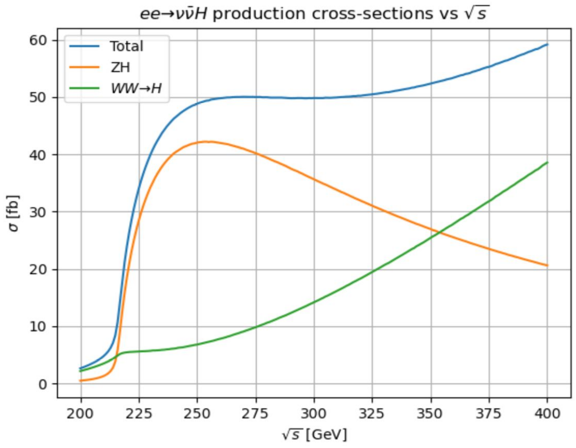
365 GeV - MC samples

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

Cut	ZHbb Yield	ZHbb Eff	ZHcc Yield	ZHcc Eff	ZHgg Yield	ZHgg Eff	ZHss Yield	ZHss Eff	ZHWW Yield	ZHWW Eff	ZHZZ Yield	ZHZZ Eff	ZHtautau Yield	ZHtautau Eff
No cuts	15504	-	770	-	2179	-	5	-	5729	-	703	-	1670	-
>0 iso-leptons with p>40 GeV	15267	98	758	98	2146	98	5	98	5656	99	693	99	1648	99
one Z->ll candidate	14194	93	702	93	1986	93	5	93	5275	93	647	93	1539	93
m(ll) 81-101 GeV	9421	66	464	66	1309	66	3	66	3507	66	438	68	1027	67
|cos(theta_ll)|<0.8	8028	85	397	86	1122	86	3	86	2981	85	373	85	871	85
m(recoil) 120-200 GeV	7276	91	362	91	1025	91	3	91	2688	90	328	88	783	90
E(j2)>15 GeV	7255	100	361	100	1025	100	3	100	2555	95	299	91	597	76
<=2 iso leptons	6685	92	357	99	1018	99	2	100	1618	63	244	82	307	51
d23>0, d34>0	6685	100	357	100	1018	100	2	100	1616	100	232	95	296	97
All cuts	6685	100	357	100	1018	100	2	100	1616	100	232	100	296	100
l=e	3289	-	176	-	501	-	1	-	795	-	114	-	146	-
l=mu	3396	-	182	-	518	-	1	-	821	-	118	-	150	-
H->had	6685	-	357	-	1018	-	2	-	1227	-	153	-	284	-
H->oth	0	-	0	-	0	-	0	-	388	-	79	-	12	-

Cut	ZZ Yield	ZZ Eff	WW Yield	WW Eff	tt Yield	tt Eff	Zll Yield	Zll Eff	Zqq Yield	Zqq Eff
No cuts	1478440	-	24647950	-	1840000	-	8769440	-	49254270	-
>0 iso-leptons with p>40 GeV	273844	19	9077163	37	467641	25	7187002	82	54598	0
one Z->ll candidate	200127	73	562743	6	69355	15	4590047	64	39609	73
m(ll) 81-101 GeV	123438	62	48867	9	9046	13	2165561	47	25	0
|cos(theta_ll)|<0.8	54684	44	26214	54	7292	81	245000	11	0	0
m(recoil) 120-200 GeV	13233	24	6635	25	323	4	33794	14	0	0
E(j2)>15 GeV	12496	94	6173	93	320	99	24013	71	0	0
<=2 iso leptons	11109	89	6138	99	297	93	24013	100	0	0
d23>0, d34>0	9126	82	2992	49	297	100	1597	7	0	0
All cuts	9126	100	2992	100	297	100	1597	100	0	0
l=e	4699	-	1564	-	150	-	1201	-	0	-
l=mu	4427	-	1428	-	147	-	396	-	0	-
H->had	9126	-	2992	-	297	-	1597	-	0	-
H->oth	0	-	0	-	0	-	0	-	0	-

	ZHbb	ZHcc	ZHgg	ZHss	ZHWW	ZHZZ	ZHtautau	ZZ	WW	tt	Zll	Zqq
Efficiency (%)	43.11	46.41	46.73	46.93	28.21	33.07	17.73	0.62	0.01	0.02	0.02	0.00
Eff. in e channel (%)	33.23	35.75	35.98	36.12	21.73	25.49	13.73	0.50	0.01	0.01	0.02	0.00
Eff. in mu channel (%)	60.56	65.22	65.70	66.02	39.64	46.46	24.78	0.83	0.02	0.02	0.01	0.00

Eff. in ZH(other) channels wrt had decays (%)	WW	ZZ	tautau
	47.25	44.66	40.61

- $\nu\nu$H

Cut	vvHbb Yield	vvHbb Eff	vvHcc Yield	vvHcc Eff	vvHgg Yield	vvHgg Eff	vvHss Yield	vvHss Eff	vvHWW Yield	vvHWW Eff	vvHZZ Yield	vvHZZ Eff	vvHtautau Yield	vvHtautau Eff
No cuts	72289	-	3588	-	10161	-	25	-	26703	-	3278	-	7786	-
No iso-leptons with p>1 GeV	65969	91	3542	99	10084	99	25	100	15832	59	2637	80	3529	45
15<E_j1<105, 10<E_j2<70 GeV	65513	99	3516	99	10022	99	25	99	15219	96	2203	84	2747	78
|cos(theta_jj)|<0.9	57369	88	3075	87	8763	87	21	87	13360	88	1833	83	2352	86
cos(th_j1+th_j2)>0.5	47080	82	2522	82	6987	80	18	82	10109	76	1418	77	1954	83
cos(phi_j1-phi_j2)<0.999	46134	98	2470	98	6849	98	17	98	9910	98	1390	98	1906	98
80<mvis<280, 50<mmiss<350 GeV	46072	100	2465	100	6831	100	17	100	9793	99	1368	98	1903	100
d23>0, d34>0	46072	100	2465	100	6831	100	17	100	9792	100	1368	100	1857	98
All cuts	46072	100	2465	100	6831	100	17	100	9792	100	1368	100	1857	100
H->had	46072	-	2465	-	6831	-	17	-	7817	-	992	-	1825	-
H->oth	0	-	0	-	0	-	0	-	1975	-	376	-	33	-

Cut	qqH Yield	qqH Eff	nuenueZ Yield	nuenueZ Eff	Zqq Yield	Zqq Eff	WW Yield	WW Eff	ZZ Yield	ZZ Eff	tt Yield	tt Eff
No cuts	193598	-	290352	-	49254270	-	24647950	-	1478440	-	1840000	-
No iso-leptons with p>1 GeV	157565	81	260263	90	49030812	100	14344054	58	1110069	75	1005183	55
15<E_j1<105, 10<E_j2<70 GeV	6062	4	252989	97	25162964	51	2071904	14	385816	35	59129	6
|cos(theta_jj)|<0.9	3228	53	153878	61	92360	0	764404	37	199914	52	53118	90
cos(th_j1+th_j2)>0.5	3026	94	115310	75	91375	99	642857	84	108146	54	51379	97
cos(phi_j1-phi_j2)<0.999	2696	89	112847	98	68069	74	611088	95	104804	97	49618	97
80<mvis<280, 50<mmiss<350 GeV	2507	93	112637	100	68028	100	545504	89	100107	96	47041	95
d23>0, d34>0	2507	100	112610	100	68012	100	543308	100	100054	100	47041	100
All cuts	2507	100	112610	100	68012	100	543308	100	100054	100	47041	100
H->had	853	-	112610	-	68012	-	543308	-	100054	-	47041	-
H->oth	1654	-	0	-	0	-	0	-	0	-	0	-

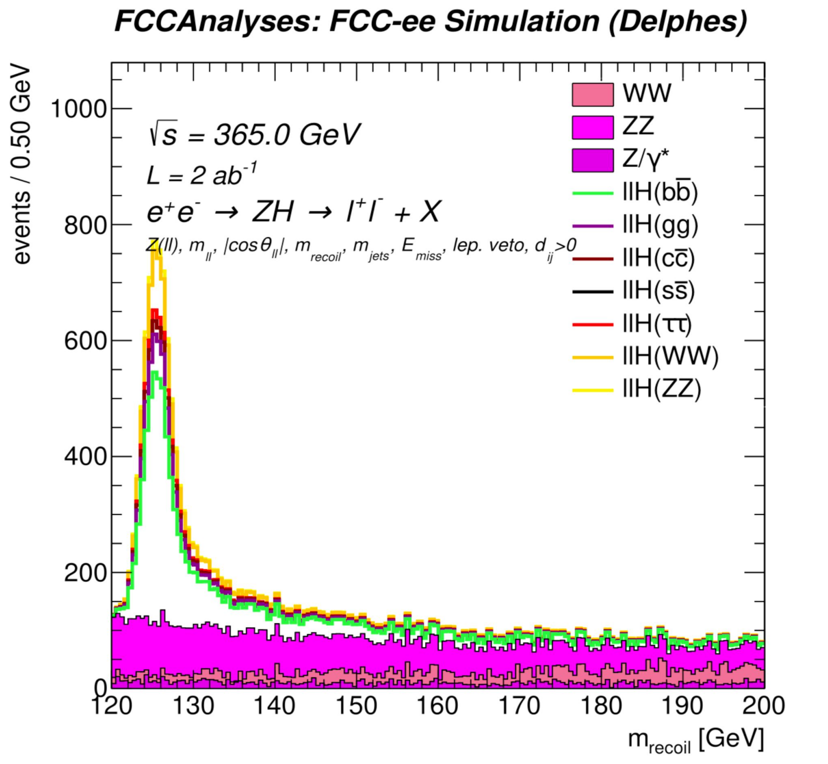
	vvHbb	vvHcc	vvHgg	vvHss	vvHWW	vvHZZ	vvHtautau	qqH	nuenueZ	Zqq	WW	ZZ	tt
Efficiency (%)	63.73	68.69	67.22	69.38	36.67	41.73	23.86	1.29	38.78	0.14	2.20	6.77	2.56

Eff. in ZH(other) channels wrt had decays (%)	WW	ZZ	tautau
	64.48	61.88	55.80

quite large bkg after selection - but with different mvis,mmiss distribution than signal. Anyway will check if sensitivity can be improved with extra selection

365 GeV - selection

llH



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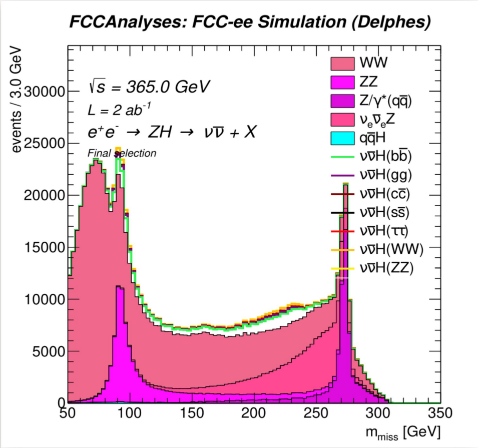
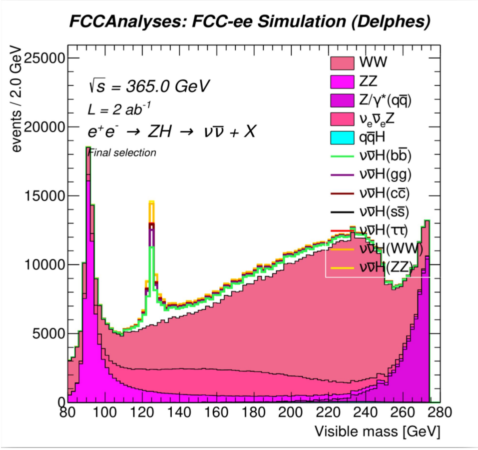
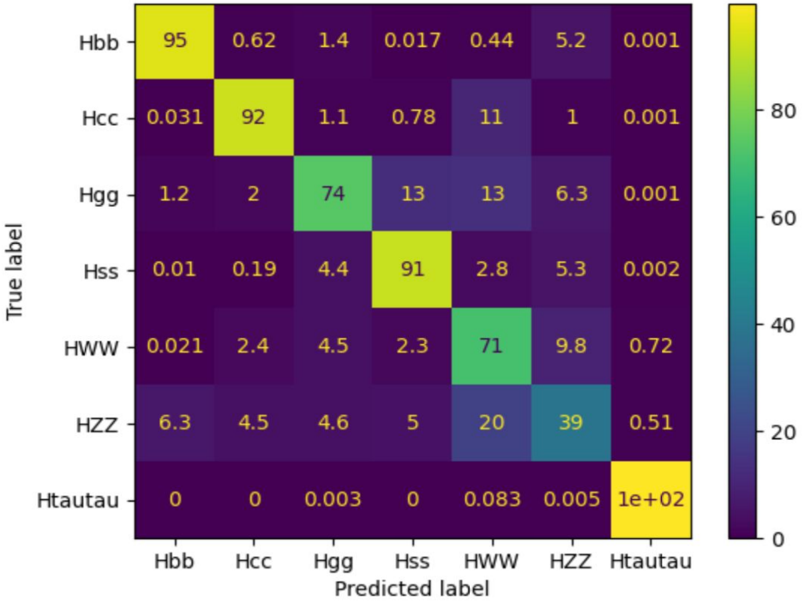




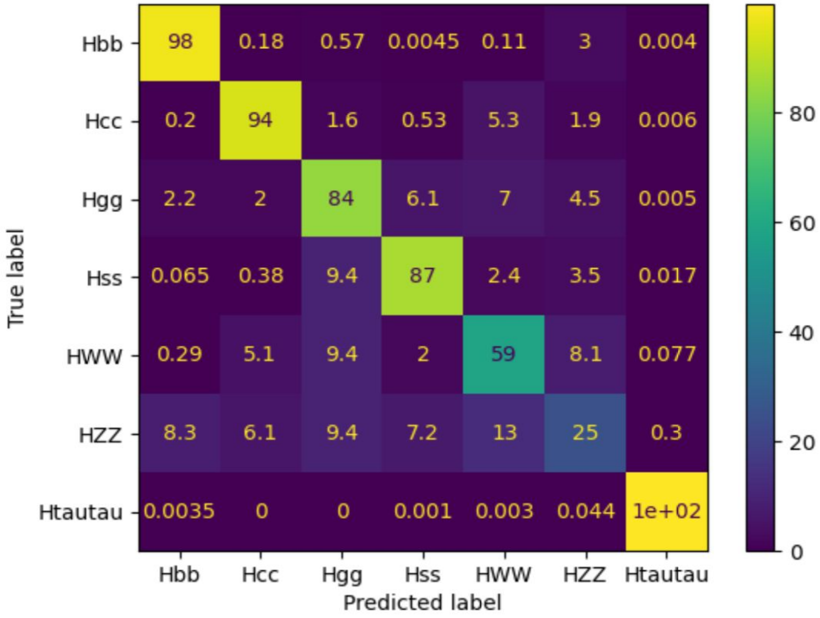
365 GeV - MVA training

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

llH



$\nu\nu$H



365+Comb. GeV results

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H 365	1.23	8.20	4.24	1153	4.16	50.8	10.17
Z(ll)H 240	0.59	3.36	1.88	258	1.44	11.4	3.34
Z(ll)H 240+365	0.53	3.11	1.71	252	1.35	11.1	3.18
Z($\nu\nu$)H 365	0.68	3.95	2.51	214	3.35	50.1	10.2
Z($\nu\nu$)H 240	0.30	1.74	0.83	63.13	1.36	5.58	16.19
Z($\nu\nu$)H 240+365	0.27	1.59	0.79	60.54	1.25	5.54	8.62
Z(ll+$\nu\nu$)H 240	0.26	1.54	0.76	61.24	0.97	4.94	3.27
Z(ll+$\nu\nu$)H 365	0.59	3.54	2.16	210	2.58	34.17	7.20
Z(ll+$\nu\nu$)H 240+365	0.24	1.41	0.72	58.78	0.91	4.88	2.98
old comb. (240)(5ab)	0.33	2.16	1.10	134	1.56	11.5	4.00

365+Comb. GeV results

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H 365	1.23	8.20	[illegible]	[illegible]	4.16	50.8	10.17
Z(ll)H 240	0.59	3.36	1.88	258	1.44	11.4	3.34
Z(ll)H 240+365	0.53	3.11	1.71	252	1.35	11.1	3.18
Z($\nu\nu$)H 365	0.68	3.95	2.51	214	3.35	50.1	10.2
Z($\nu\nu$)H 240	0.30	1.74	0.83	63.13	1.36	5.58	16.19
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.62
Z(ll+$\nu\nu$)H 240	0.26	1.54	0.76	61.24	0.97	4.94	3.27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.24	1.41	0.72	58.78	0.91	4.88	2.98
old comb. (240)(5ab)	0.33	2.16	1.10	134	1.56	11.5	4.00

240 GeV

Great improvement in the 240 GeV energy channel

20% from luminosity rescaling and +15% from improved NN training

Possible gain by choosing specific number of purity sub-samples for each fitting categories

365+Comb. GeV results

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H 365	1.23	8.20	4.24	1153	4.16	50.8	10.17
[redacted]							
Z($\nu\nu$)H 365	0.68	3.95	2.51	214	3.35	50.1	10.2
[redacted]							
Z(ll+$\nu\nu$)H 365	0.59	3.54	2.16	210	2.58	34.17	7.20
[redacted]							

365 GeV

Purity analysis WIP : significant gain possible in the channel + in the combination

Selection and NN training can be improved

Combine results for 365 GeV are coherent with parallel analytical fit

365 GeV+Comb. results

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ

[redacted]

Combination

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H 240+365	0.53	3.11	1.71	252	1.35	11.1	3.18

[redacted]

The inclusion of 365 GeV in the combination yields in a ~10% improvement in sensitivity

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z($\nu\nu$)H 240+365	0.27	1.59	0.79	60.54	1.25	5.54	8.62

[redacted]

Once again this is considering un-optimized selection and NN training

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll+$\nu\nu$)H 240+365	0.24	1.41	0.72	58.78	0.91	4.88	2.98
old comb. (240)(5ab)	0.33	2.16	1.10	134	1.56	11.5	4.00

Conclusion: next steps

Precision (%)	bb	cc	gg	ss	WW	ZZ	$\tau\tau$
Z(ll+$\nu\nu$)H 240+365	0.24	1.41	0.72	58.78	0.91	4.88	2.98

- Combination with **Z(qq)H(qq)**
- Optimise selection and implement **purity** categories for **365 GeV**
- Analysis including **FV-violating** samples and **uu/dd** is **WIP**
- Try to **disentangle VBF from ZH** - for couplings fit at 365 GeV

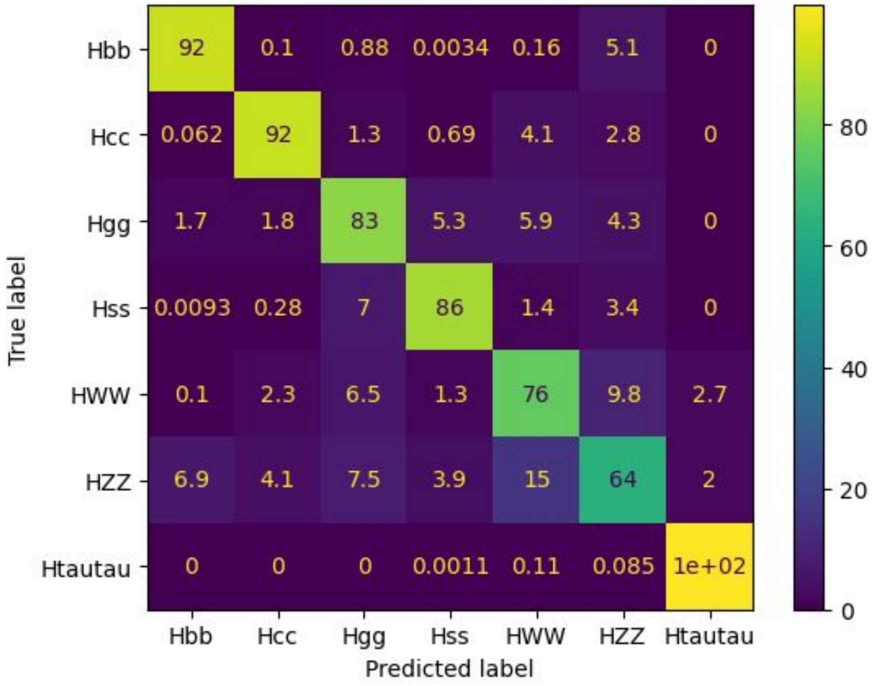
- StonyBrook colleagues interested to join effort

Backup

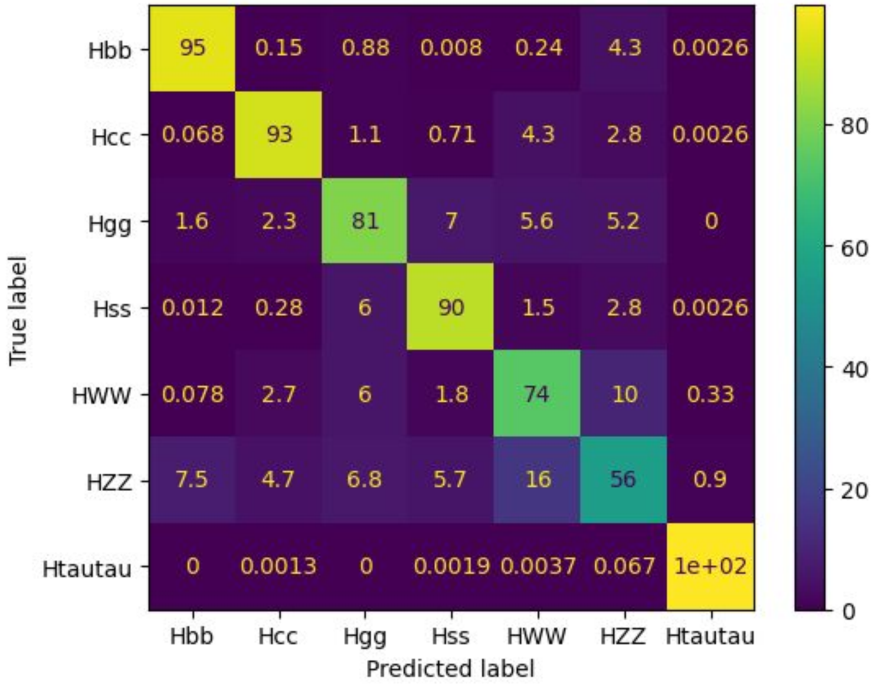
Thank you

7 categories training

Zll



Z$\nu\nu$



Results when fitting 7cat with the 13 cats training

Slightly better for ZZ only, worse for the rest

	bb	cc	gg	ss	WW	ZZ	tautau
Zll_purity_240	0.60	3.50	1.94	242.06	1.54	10.84	3.62
Zll_365	1.23	8.20	4.24	1153.85	4.16	50.77	10.17
Zll_purity_240and365	0.54	3.22	1.76	236.87	1.44	10.48	3.43
Znunu_purity_240	0.30	1.89	0.91	80.83	1.41	5.03	16.27
Znunu_365	0.68	3.95	2.51	214.49	3.35	50.09	10.19
Znunu_purity_240and365	0.27	1.70	0.86	75.62	1.29	5.00	8.63
ZllZnunu_purity_240	0.27	1.66	0.83	76.60	1.03	4.49	3.53
ZllZnunu_purity_365	0.59	3.54	2.16	210.42	2.58	34.17	7.20
ZllZnunu_purity_240and365	0.24	1.50	0.77	71.97	0.95	4.45	3.18

240 GeV for 13 categories

uu/dd scaled with **BR(uu) = 1.2e-07** and **BR(dd) = 5.5e-07**

Flavour violating samples are scale such that **σ.BR = 1**

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ	uu	dd	cu	bs	bd	sd
Z(ll)H	0.70	7.71	12.97	7e3	6.41	65.7	3.71	3e7	4e5	0.04	0.04	0.04	0.06
Z(ll)H no pur.	1.16	13.91	24.38	1e4	12.74	59.17	3.86	2e6	6e4	0.04	0.05	0.06	0.19
Z(νν)H	0.33	2.12	0.99	876.2	1.69	9.63	16.19	8e4	9e3	0.03	0.03	0.03	0.04
Z(ll,νν)H	0.30	2.05	0.98	867	1.64	9.52	3.57	7e4	9e3	0.02	0.03	0.03	0.03

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ
Z(ll)H	0.59	3.36	1.88	258	1.44	11.4	3.34
Z(νν)H	0.30	1.74	0.83	63.13	1.36	5.58	16.19
Z(ll,νν)H	0.26	1.54	0.76	61.24	0.97	4.94	3.27

7cat results for comparison : significant loss in 7 main categories

240 GeV for 13 categories

Precision (%)	bb	cc	gg	ss	WW	ZZ	ττ	uu	dd	cu	bs	bd	sd
Z(ll)H	0.70	7.71	12.97	7e3	6.41	65.7	3.71	3e7	4e5	0.04	0.04	0.04	0.06
Z(ll)H no pur.	1.16	13.91	24.38	1e4	12.74	59.17	3.86	2e6	6e4	0.04	0.05	0.06	0.19
Z($\nu\nu$)H	0.33	2.12	0.99	876.2	1.69	9.63	16.19	8e4	9e3	0.03	0.03	0.03	0.04
Z(ll,$\nu\nu$)H	0.30	2.05	0.98	867	9.52	3.57	3.57	7e4	9e3	0.02	0.03	0.03	0.03

uu/dd & Flavour violation results in term of BR limits

BR < x	uu	dd	cu	bs	bd	sd
Z(ll)H	7.2e-2	4e-3				
Z($\nu\nu$)H	5.8e-4	1e-4				
Z(ll,$\nu\nu$)H						

Previous results from here

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