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

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Supervised by Giovanni Marchiori

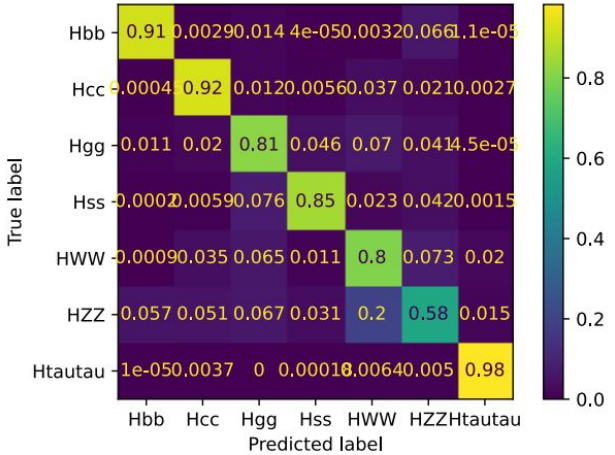
Introduction (1/2)

- Results from Giovanni's latest presentation (15/05/23: link) and mid-term report

Zll: 7 categories (WW/ZZ/tautau discriminated in the NN using d_merge, m_had and E_miss variables)

Cut	ZHbb Yield	Eff	ZHcc Yield	Eff	ZHgg Yield	Eff	ZHss Yield	Eff	ZHWW Yield	Eff	ZHZZ Yield	Eff	ZHtautau Yield	Eff	ZZ Yield	Eff	WW Yield	Eff	Zll Yield	Eff	Zqq Yield	Eff
No cuts	40355	-	2013	-	5700	-	17	-	14985	-	1838	-	4367	-	6794950	-	82192500	-	67965000	-	263269500	-
one Z->ll candidate	36448	90	1808	90	5119	90	15	90	13571	91	1664	91	3956	91	566449	8	772157	1	13389259	20	141045	0
m(ll) 81-101 GeV	32793	90	1627	90	4605	90	14	90	12151	90	1502	90	3547	90	363333	64	190171	25	5677860	42	7530	5
|cos(theta_ll)|<0.8	26694	81	1327	82	3746	81	11	81	9889	81	1223	81	2884	81	227312	63	145268	76	906114	16	5550	74
m(recoil) 120-140 GeV	25497	96	1268	96	3580	96	11	96	9408	95	1154	94	2743	95	32182	14	61912	43	206164	23	1079	19
max p(extra lep) < 25 GeV	24318	95	1256	99	3577	100	11	100	6912	73	1040	90	2031	74	28850	90	61825	100	206163	100	977	91
l=e	11950	-	616	-	1754	-	5	-	3386	-	510	-	998	-	14481	-	31880	-	171906	-	466	-
l=mu	12368	-	640	-	1823	-	5	-	3526	-	530	-	1033	-	14369	-	29945	-	34258	-	511	-

NN separation matrix



1D parametrical fit results :

```
Relative error on mu_bb: 0.82%
Relative error on mu_cc: 4.96%
Relative error on mu_gg: 2.70%
Relative error on mu_ss: 377.81%
Relative error on mu_WW: 2.00%
Relative error on mu_ZZ: 18.35%
Relative error on mu_tautau: 3.31%
```

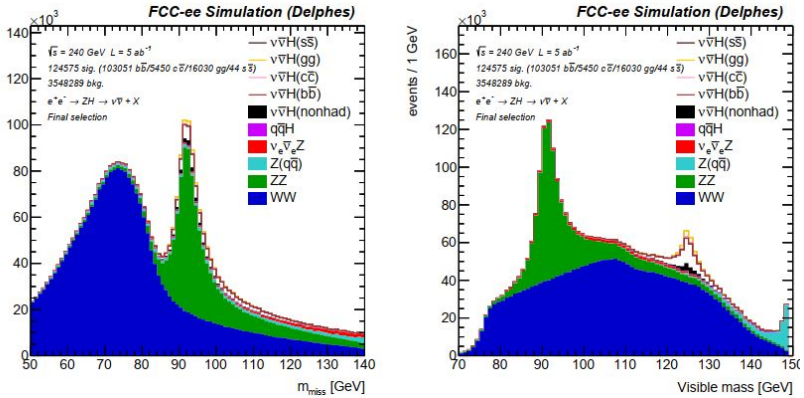
Introduction (2/2)

$Z\nu\nu$: 5 categories with bb/cc/gg/ss/nonhad

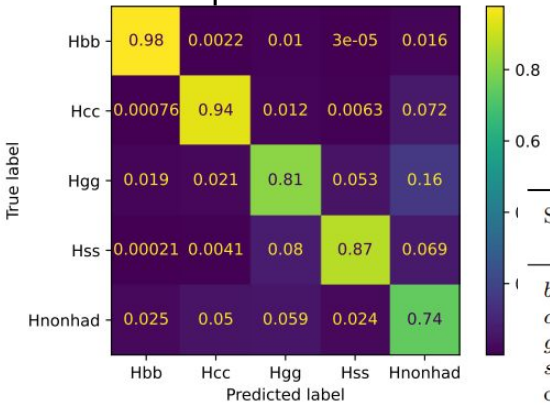
Table 5: Event cutflow for the $\nu\bar{\nu}H$ analysis, assuming an integrated luminosity $L = 5$ ab^{-1} of ee collisions at $\sqrt{s} = 240$ GeV.

Selection	$\nu\bar{\nu}H(b\bar{b})$		$\nu\bar{\nu}H(c\bar{c})$		$\nu\bar{\nu}H(gg)$		$\nu\bar{\nu}H(s\bar{s})$		$\nu\bar{\nu}H(other)$		$qqH(q=u,d,s,c,b)$		ZZ		WW		$Z/\gamma^*(q\bar{q})$		$\nu_e\bar{\nu}_eZ$	
	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)
No cuts	134500	-	6675	-	18910	-	55	-	70285	-	681520	-	6794950	-	82192500	-	263269500	-	166370	-
No lepton with $p > 20$ GeV	123364	92	6531	98	18877	100	55	100	49340	70	580210	85	5299230	78	49001192	60	254437693	97	152109	91
$45 < E_{j1} < 105$ GeV, $20 < E_{j2} < 70$ GeV	121338	98	6425	98	18521	98	54	98	37915	77	16957	3	1660546	31	6117861	12	99840730	39	139887	92
$n^{j1}_{\text{const}} > 10$, $n^{j2}_{\text{const}} > 6$	120775	100	6304	98	18480	100	51	93	32320	85	16522	97	1457666	88	5431194	89	93228121	93	101358	72
$\lvert\cos\theta_{jj}\rvert < 0.9$	109227	90	5701	90	16735	91	46	90	29248	90	14632	89	1114929	76	3869367	71	567057	1	81757	81
$\lvert\cos(\theta_{j1}+\theta_{j2})\rvert > 0.5$	108844	100	5683	100	16629	99	46	100	28522	98	14508	99	883038	79	3071403	79	549323	97	70911	87
$\lvert\cos(\phi_{j1}-\phi_{j2})\rvert < 0.999$	105409	97	5504	97	16145	97	44	97	27780	97	13959	96	866569	98	3006142	98	268455	49	69145	98
$70 < m_{\text{vis}} < 150$ GeV, $50 < m_{\text{miss}} < 140$ GeV	103051	98	5450	99	16030	99	44	99	25967	93	13386	96	830000	96	2532328	84	91053	34	55594	80

Histograms of interest, after selection



NN separation matrix



2D fit result

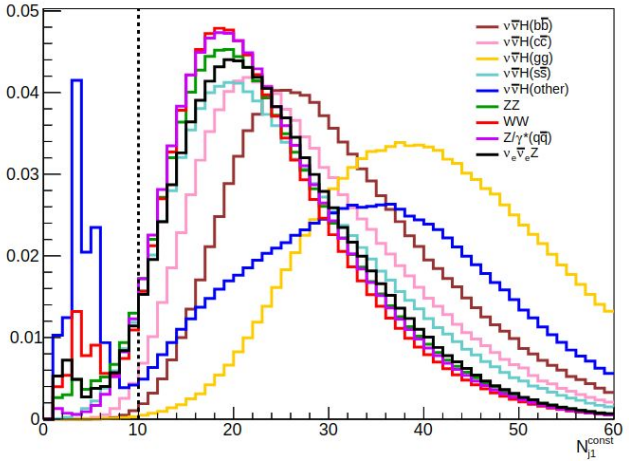
Signal strength	Uncertainty (%)			
	5 POIs	4 POIs	4 POIs	3 POIs
$b\bar{b}$	0.37	0.37	0.37	0.37
$c\bar{c}$	2.50	2.50	2.50	2.50
gg	1.25	1.24	1.25	1.24
$s\bar{s}$	160	160	-	-
other	1.46	-	1.46	-

Updated selection

- Used latest jet tagger version (addition of isU/D/tau scores)

  -> Removed former variables used to split WW/ZZ/tautau

- Removed cut on the N of constituants in the jets to avoid cutting $\nu\nu$Htautau events.



- Also updated cut on m_miss, and included it in the NN training

- Both Zll and Z$\nu\nu$ now are studied with **7 decay categories**

Cutflow updates - $Z\nu\nu$

Before

Table 5: Event cutflow for the $\nu\bar{\nu}H$ analysis, assuming an integrated luminosity $L = 5$ ab^{-1} of ee collisions at $\sqrt{s} = 240$ GeV.

Selection	$\nu\bar{\nu}H(b\bar{b})$		$\nu\bar{\nu}H(c\bar{c})$		$\nu\bar{\nu}H(gg)$		$\nu\bar{\nu}H(s\bar{s})$		$\nu\bar{\nu}H(other)$		$qqH(q=u,d,s,c,b)$		ZZ		WW		$Z/\gamma^*(q\bar{q})$		$\nu_e\bar{\nu}_eZ$	
	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)	Yield	ε (%)
No cuts	134500	-	6675	-	18910	-	55	-	70285	-	681520	-	6794950	-	82192500	-	263269500	-	166370	-
No lepton with $p > 20$ GeV	123364	92	6531	98	18877	100	55	100	49340	70	580210	85	5299230	78	49001192	60	254437693	97	152109	91
$45 < E_{j1} < 105$ GeV, $20 < E_{j2} < 70$ GeV	121338	98	6425	98	18521	98	54	98	37915	77	16957	3	1660546	31	6117861	12	99840730	39	139887	92
$n^{j1}_{\text{const}} > 10$, $n^{j2}_{\text{const}} > 6$	120775	100	6304	98	18480	100	51	93	32320	85	16522	97	1457666	88	5431194	89	93228121	93	101358	72
$\lvert\cos\theta_{jj}\rvert < 0.9$	109227	90	5701	90	16735	91	46	90	29248	90	14632	89	1114929	76	3869367	71	567057	1	81757	81
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$70 < m_{\text{vis}} < 150$ GeV, $50 < m_{\text{miss}} < 140$ GeV	103051	98	5450	99	16030	99	44	99	25967	93	13386	96	830000	96	2532328	84	91053	34	55594	80

After

Cut	vvHbb		vvHcc		vvHgg		vvHss		vvHWW		vvHZZ		vvHtautau	qqH		nuenueZ		Zqq		WW		ZZ	
	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Eff	Yield	Eff
No cuts	134500	-	6675	-	18910	-	55	-	49700	-	6100	-	14485	681520	-	166370	-	263269500	-	82192500	-	6794950	-
No leptons with p>20 GeV	123364	92	6531	98	18877	100	55	100	34142	69	5335	87	9824	580210	85	152109	91	254437693	97	49001192	60	5299230	78
15<E_j1<105, 10<E_j2<70 GeV	122075	99	6439	99	18501	98	54	98	32873	96	4922	92	7801	16777	3	147609	97	109466219	43	6515777	13	1811708	34
|cos(theta_jj)|<0.9	110401	90	5824	90	16754	91	49	90	29563	90	4226	86	6496	14859	89	92878	63	2556074	2	4698934	72	1312817	72
cos(th_j1+th_j2)>0.5	110014	100	5806	100	16648	99	49	100	28351	96	4025	95	6441	14725	99	80799	87	2508454	98	3787830	81	1035917	79
cos(phi_j1-phi_j2)<0.999	106539	97	5623	97	16165	97	48	97	27633	97	3919	97	6200	14169	96	78719	97	2045260	82	3698506	98	1014048	98
70<mvis<150, 60<mmiss<220 GeV	105661	99	5555	99	15955	99	47	99	27094	98	3792	97	6165	13083	92	77045	98	2039752	100	2846585	77	974735	96
d23>0, d34>0	105661	100	5555	100	15955	100	47	100	27078	100	3787	100	5896	13083	100	76961	100	2039516	100	2829867	99	973642	100
All cuts	105661	100	5555	100	15955	100	47	100	27078	100	3787	100	5896	13083	100	76961	100	2039516	100	2829867	100	973642	100

Efficiency (%)	vvHbb	vvHcc	vvHgg	vvHss	vvHWW	vvHZZ	vvHtautau	qqH	nuenueZ	Zqq	WW	ZZ
	78.56	83.23	84.38	84.52	54.48	62.09	40.70	1.92	46.26	0.77	3.44	14.33

Eff. in ZH(other) channels wrt had decays (%)	WW	ZZ	tautau
	83.65	82.51	77.83

Fitting with Combine

Cross-checking fitting results between previous code (HistFactory RooFit script) and Combine

Zll template fit	bb	cc	gg	ss	WW	ZZ	tautau
HistFactory	0.72	4.31	2.35	333.73	1.75	15.17	4.49
Combine	0.73	4.31	2.35	335	1.77	15.10	4.45
CombineTF	0.71	4.25	2.37	355	1.75	15.4	4.50

Systematics : MCstats + 5% bkg unc.

Similar cross-checking has been performed for analytical fit (between HF and combine)

Channel combination

- Channels combination results

	bb	cc	gg	ss	WW	ZZ	tautau
template comb.	0.33	2.16	1.10	134	1.56	11.5	4.00
analytic (Zll) + template (Znunu)	0.35	2.32	1.14	140	1.68	10.7	3.25

- Old results
  - Zll

```
Relative error on mu_bb: 0.82%
Relative error on mu_cc: 4.96%
Relative error on mu_gg: 2.70%
Relative error on mu_ss: 377.81%
Relative error on mu_WW: 2.00%
Relative error on mu_ZZ: 18.35%
Relative error on mu_tautau: 3.31%
```

$Z\nu\nu$

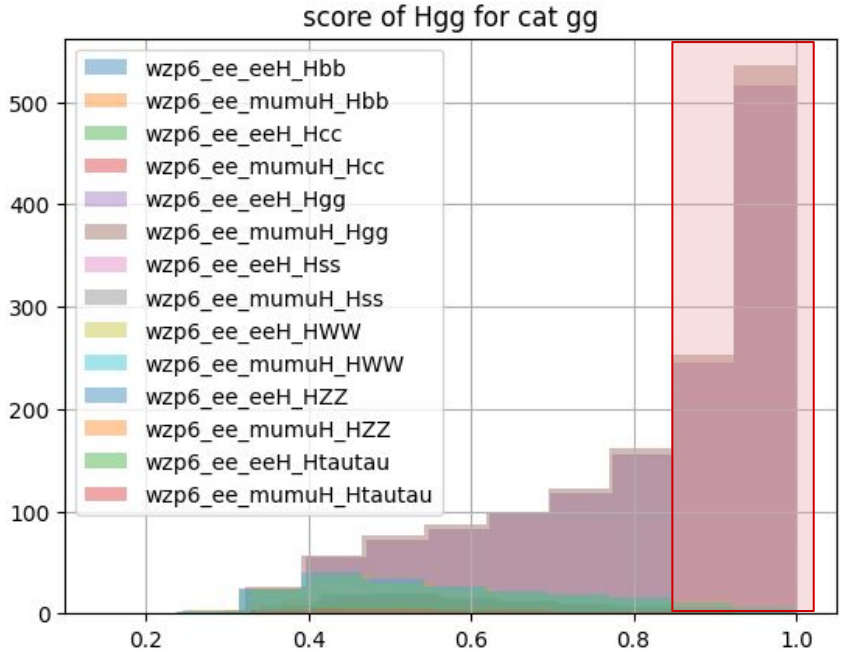
Signal strength	Uncertainty (%)			
	5 POIs	4 POIs	4 POIs	3 POIs
$b\bar{b}$	0.37	0.37	0.37	0.37
$c\bar{c}$	2.50	2.50	2.50	2.50
gg	1.25	1.24	1.25	1.24
$s\bar{s}$	160	160	-	-
other	1.46	-	1.46	-

- If the full hadronic decay channel workspace is available, it can be included to this combination

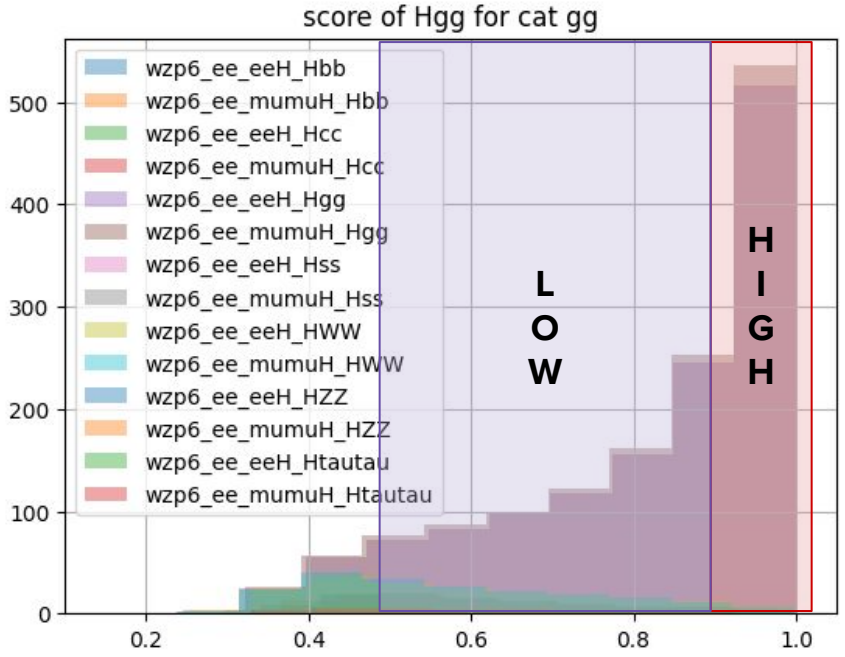
Purity categorization (1/2)

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

before



after

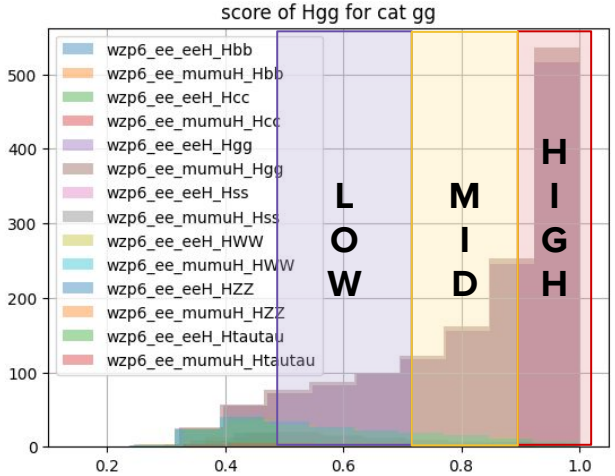


Purity categorization (2/2)

Zll:

	bb	cc	gg	ss	WW	ZZ	tautau
Zll	0.71	4.25	2.37	355	1.75	15.4	4.50
Zll with purity cat.	0.70	4.06	2.27	269	1.72	13.0	3.97

Categorization can still probably be slightly improved to win small .% in some categories



Including a 3rd category very slightly increases max significances but no specific improvement in precision

Same study for $Z\nu\nu$ is WIP

uu, dd and flavour violating samples (1/2)

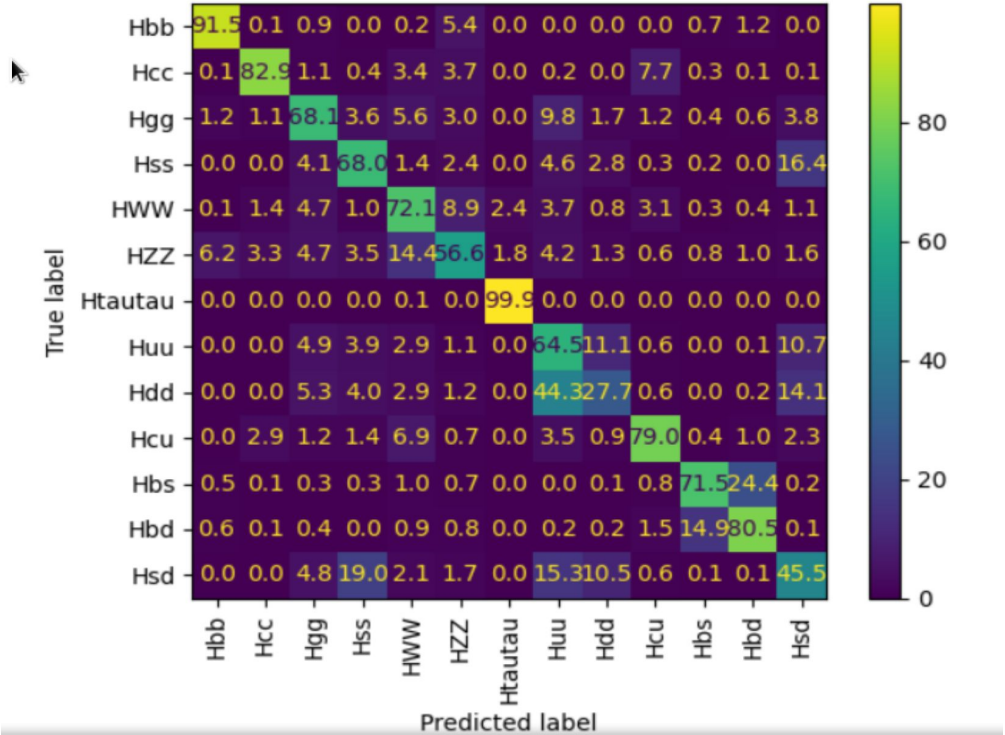
Generated H to **uu**, **dd**, and **cu**, **bs**, **bd**, **sd** samples (400k events each) and prepared analysis elements to be included in the analysis

Efficiency (%)	ZHbb	ZHcc	ZHgg	ZHss	ZHWW	ZHZZ	ZHtautau	ZHcu	ZHbd	ZHbs	ZHsd
	59.96	62.42	62.75	62.88	45.65	53.62	41.22	62.59	61.66	61.45	62.94
Eff. in e channel (%)	**ZHbb**	**ZHcc**	**ZHgg**	**ZHss**	**ZHWW**	**ZHZZ**	**ZHtautau**	**ZHcu**	**ZHbd**	**ZHbs**	**ZHsd**
	58.93	61.24	61.53	61.61	44.78	52.67	40.87	59.73	58.73	58.35	59.80
Eff. in mu channel (%)	**ZHbb**	**ZHcc**	**ZHgg**	**ZHss**	**ZHWW**	**ZHZZ**	**ZHtautau**	**ZHcu**	**ZHbd**	**ZHbs**	**ZHsd**
	60.99	63.59	63.97	64.14	46.53	54.56	41.57	65.45	64.59	64.54	66.08

Eff. in ZH(other) channels wrt had decays (%)	WW	ZZ	tautau
	62.89	58.88	55.93

uu, dd and flavour violating samples (2/2)

Generated H to **uu**, **dd**, and **cu**, **bs**, **bd**, **sd** samples (400k events each) and prepared analysis elements to be included in the analysis



Conclusion

- Included the 7 categories (bb/cc/gg/ss/WW/ZZ/tautau) in both Z(ll,$\nu\nu$) channels
- Updated selection and analysis lead to an upgrade in both channel and combination yielded first promising results
- Whole analysis was re-implemented by Giovanni in FCCAnalysis/FCCeePhysicsPerformance git forks
- WIP to improve Znunu channel (and combination) with purity
- WIP to include newly generated signal samples for Huu, Hdd, Hcu, Hbs, Hbd, Hsd in the analysis